EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER (ESSIC)

1st Annual Report

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Director

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EXECUTIVE SUMMARY

This year marks the 14th anniversary of the collaboration between the University of Maryland Earth System Science Interdisciplinary Center (UMD/ESSIC) and Goddard Earth Sciences. It is the 1st year under the current cooperative agreement. The cooperative agreement continues to grow, with the addition of 8 new employees (7 co-located at Goddard). These researchers are representative of the spectrum of collaborative research between ESSIC and Goddard.

Dr. Hongbin Yu received a NASA/GSFC Laboratory for Atmospheres Contractor Award for Best Senior Author publication in recognition of his innovative use of satellite data to quantify the transport of dust and pollution aerosols across the Pacific Ocean and to estimate the impact of such transport on North America's climate and air quality.

Dr. Can Li received the ESSIC best paper award for his publication in Geophysical Research Letters entitled, “Recent large reduction in sulfur dioxide emissions from Chinese power plants observed by the Ozone Monitoring Instrument”.

ESSIC’s Wilfrid Schroeder processed the first satellite images of fire produced as a part of NASA’s Suomi National Polar-orbiting Partnership (NPP) and Earth Observing System (EOS). The images were acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS), an instrument attached to the NPP spacecraft launched in October 2011.

Our current scientific staff under this agreement includes 36 scientists, 33 employed by ESSIC, 1 by the department of Atmospheric and Oceanic Sciences (AOSC) and 2 by the department of Geography (GEOG) and 15 graduate students (13 AOSC, 1 GEOG, and 1 UMIACS).

A study conducted by ESSIC Associate Research Scientist Dr. Hongbin Yu and a team of scientist that assesses the contributions of cross-ocean aerosol transport to North America was published in Science Magazine.

Data show that Arctic ice is melting at an increasing rate, a rate that NASA wants to more clearly define through airborne observation. ESSIC Assistant Research Scientist Sinead Farrell has worked with NASA to help accomplish that goal. Farrell is a member of NASA’s Operation IceBridge science team.

Despite less than desirable weather, many people still turned out for Maryland Day, a campus wide open house event to promote the departments, organizations and activities around campus. ESSIC’s display this year was situated on “Science and Tech Way,” with other science and math displays. ESSIC had 25 volunteers helping out throughout the day, and there was constant action at the Magic Planet, an interactive globe that displays NASA satellite data.
I. INTRODUCTION

The Earth System Science Interdisciplinary Center (ESSIC) is a joint center of the University of Maryland Departments of Atmospheric and Oceanic Science, Geology, and Geography and the Earth Sciences Division of the National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (GSFC). ESSIC was formally established in September 1999 via a Memorandum of Agreement (MOA) between the University and Goddard. ESSIC seeks to better understand how the atmosphere-ocean-land-biosphere components of Earth interact as a coupled system and how human activities influence this system. To accomplish this, ESSIC studies the interaction between the physical climate system (e.g., El Niño) and biogeochemical cycles (e.g., greenhouse gases, changes in land use and cover).

The Center concentrates on four major research areas:

- Climate Variability and Change
- Atmospheric Composition and Processes
- Global Carbon Cycle (including terrestrial and marine ecosystems/land use/cover change)
- Global Water Cycle

Research is conducted through in situ and remotely sensed observations, together with component and coupled ocean-atmosphere-land modeling. This multi-pronged approach provides a foundation for understanding and forecasting changes in the global environment and regional implications. Data assimilation and regional downscaling are used to link the observations and models, enabling us to study the interactions between the physical climate system and biogeochemical cycles from global to regional scales.

Climate Variability and Change. Societies around the world expect, and depend upon, a stable, though seasonally variable, climate. Climatic events such as the El Niño/Southern Oscillation (ENSO) disrupt the normal seasonal cycle, heightening awareness that, in reality, climate can vary dramatically from year to year and significantly affect society. Over the past two decades, research has demonstrated that ENSO is an intrinsic oscillation of the coupled ocean-atmosphere system. Other, more sustained, climatic variability’s are known but not well understood, such as the changes in annual rainfall in the African Sahel on decadal and longer time scales; lengthy droughts in the Nordeste region of Brazil; and the 1930s dust bowl in the United States. The rise in atmospheric concentration of greenhouse gases and predictions of global warming and regional climate change are also relevant to studies of climate variability. Taken together, these examples demonstrate the need for better understanding of the coupled climate system, its natural variability, and its susceptibility to human influences, such as increases in radiatively active gases and atmospheric aerosols.

ESSIC’s research is oriented toward understanding, monitoring, and predicting the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial time scales. Key components of the research strategy include:
Focusing on the role of the coupled ocean and atmosphere within the overall climate system (with emphasis on ocean variability) on seasonal to centennial time scales;
Developing data assimilation methods to merge remotely sensed and in situ observations with models of the climate system;
Developing and applying regional and global models of the coupled climate system;
Analyzing remotely sensed, instrumental, and quality-controlled paleoclimatic data sets;
Studying the response of the climate system to increases in radiatively active gases and aerosols, and to changes in land surface;
Exploring the predictability of climate variability and climate change, and improving predictions using existing, re-analyzed, and new global observations, enhanced coupled ocean-atmosphere-land-ice-ecosystem models, and paleoclimate records.

Atmospheric Composition and Processes. The atmosphere links the components of the Earth System, including the oceans, geosphere, terrestrial and marine biospheres, and cryosphere. As a result, the atmosphere is the conduit for change on a local, regional and global scale. Natural events and human activities can change atmospheric composition, which in turn alters Earth’s radiative balance. Subsequent responses by the climate system and the stratospheric ozone layer can influence both natural systems and the biosphere. The atmosphere represents the fast response of the coupled Earth System. Given the rapid and often global dispersal of chemical emissions into the atmosphere, the importance of atmospheric observation as an indicator of global change is evident.

ESSIC’s research is oriented toward understanding, monitoring, and predicting the interrelationships of changes in atmospheric composition, climate, ozone-layer depletion, and surface-level chemical and radiative exposure. Key questions involving Earth System interactions include:

- How do atmospheric composition changes alter the radiative balance of the climate system (and vice versa)?
- What are the interactions between the climate system and the ozone layer?
- What are the effects of regional pollution on the global atmosphere, and the effects of global climate and chemical change on regional air quality?
- What effect do human activities and natural ecosystems have on atmospheric composition and, in turn, how are human activities and natural ecosystems affected by changes in atmospheric composition caused by alteration of global and regional climate, ozone-layer/ultraviolet radiation, and pollutant exposures?

Global Carbon Cycle (terrestrial and marine ecosystems; land use/cover change). Recent developments in science, resource management, and public policy have intensified interest in the global carbon cycle. Carbon is important as the basis for the food that sustains human populations, and as the primary energy source that fuels human economies. It also significantly contributes to the planetary greenhouse effect and the potential for climate change. Fossil fuel consumption and land clearing over the past 150 years have caused atmospheric CO₂ and CH₄ concentrations to increase to a level higher than it has ever been in over 400,000 years. Changes in land management practices and CO₂ and nutrient additions can also significantly enhance carbon “sinks.”
ESSIC’s research is oriented toward understanding, monitoring, and predicting the global carbon cycle, including the role and variability of terrestrial and marine ecosystems, land use, and land cover. Key questions involving Earth System interactions include:

- What are the dynamic storages, transfers, and pathways of carbon within the Earth System, and how will this carbon cycling change in the future?
- On longer time scales, what exchanges exist with the lithosphere?
- How do various processes in the ocean and on the land determine the interannual growth rate in atmospheric CO$_2$?
- What are the global patterns of land cover and land use, and how do land management practices affect carbon storage and release?
- What interactions and feedbacks with the physical climate system are induced by changes in terrestrial and marine ecosystems, land use, and land cover?

**Global Water Cycle.** The behavior of water in the Earth System is central to nearly every aspect of the global climate and crucial to human welfare. Interannual changes in precipitation and evaporation are associated with droughts and floods that threaten the lives and livelihood of millions of people. Evidence indicates that the global hydrological cycle is accelerating, resulting in an increasing number of extreme precipitation events. Improving our understanding of the ways that water influences, and is influenced by, the integrated Earth System is a critical component of our ongoing effort to predict climate variations and anticipate global climate change.

ESSIC’s research is oriented toward understanding, monitoring and predicting the global water cycle, including precipitation, evaporation, storage and transport, on time scales from weeks to centuries. Key questions involving Earth System interactions include:

- What are the dynamic pathways, storages, transfers and transformations of water within the Earth System, and how do they change in association with seasonal to interannual climate variability?
- What are the interactions and feedbacks among terrestrial and marine ecosystems, land use and land cover, and the global water and carbon cycles, and how will these evolve as atmospheric CO$_2$ increases?
- How do regional changes in air pollution affect the local and global behavior of the water cycle?
- What is our ability to reproduce/assimilate, simulate and/or predict the water cycle and/or its components at global and regional scales using the state-of-the-art models and data assimilation systems?
- What new observations are needed to improve our understanding of the water cycle?
- How will the humidity of the stratosphere and upper troposphere change in response to anthropogenic CO2 emissions, and how will these changes influence other aspects of global change?
- How will global climate change and human activities on land affect the ocean-continental margins, biogeochemistry, ecosystems, and fisheries?
What are the connections between land-ocean interactions and human health, and how will they be influenced by global climate change?

**Demographics**

In the following figures we show the distribution (by Goddard Laboratory) of UMD research scientists and graduate students supporting the cooperative agreement. There are 36 scientists, 33 employed by ESSIC, 1 by the department of Atmospheric and Oceanic Sciences (AOSC) and 2 by the department of Geography (GEOG) and 15 graduate students (13 AOSC, 1 GEOG, and 1 UMIACS). Distribution by UMD title is also displayed.

**Distribution of Scientists by GSFC Unit**

- Hydro: 9
- Meso: 6
- Chem: 7
- Clim & Rad: 3
- GMAO: 3
- Bio: 4
- App. Sci: 1
- JCSDA: 1
- Laser: 1

**Distribution of Students by GSFC Unit**

- Chem: 7
- Meso: 3
- Bio: 3
- Clim & Rad: 1
- Cryo: 1

**Key to GSFC Laboratories**
- **Hydro**: Hydrological Sciences
- **Meso**: Mesoscale Atmospheric Processes
- **Clim & Rad**: Climate & Radiation
- **Chem**: Atmospheric Chemistry & Dynamics
- **GMAO**: Global Modeling and Assimilation Office
- **Bio**: Biological Sciences
- **App. Sci**: Office of Applied Sciences
- **JCSDA**: Joint Center for Satellite Data Assimilation
- **Cryo**: Cryospheric Sciences
- **Laser**: Laser Remote Sensing
Distribution of Scientists (36) by UMD title

- Research Associate, 12
- Research Professor, 1
- Associate Research Scientist, 9
- Assistant Research Scientist, 8
- Faculty Research Assistant, 3
- Senior Research Scientist, 1
- Assistant Research Engineer, 2

Total: 36 scientists
Funding History

The figure below shows the funding history of the cooperative agreement. Funding tends to spike in the initial year of a new (but continuing) agreement (e.g. 2007, 2012).

The remainder of this report summarizes the contributions of over 50 research scientists, post-docs and graduate students working both at Goddard and at UMCP, towards the scientific goals of the Earth Sciences Division. Highlights of ESSIC's research in these areas, as well as ESSIC's achievements in academia and publishing, are described in the pages that follow. Appendix A contains papers published in the previous year. Appendix B contains a detailed list of ESSIC tasks.
II. HIGHLIGHTS OF THIS YEAR’S RESEARCH

Data show that Arctic ice is melting at an increasing rate, a rate that NASA wants to more clearly define through airborne observation. ESSIC Assistant Research Scientist Sinead Farrell has worked with NASA to help accomplish that goal. Farrell is a member of NASA’s Operation IceBridge science team – she is one of 5 or 6 sea ice scientists on a science team of more than 15 people – that surveyed land and sea ice in the Arctic Ocean from aircraft equipped with a range of instruments, including radars, lasers, digital cameras, surface temperature instruments and a gravimeter, in order to measure changes in ice thickness.

A study conducted by ESSIC Associate Research Scientist Dr. Hongbin Yu and a team of scientist that assesses the contributions of cross-ocean aerosol transport to North America was published in Science Magazine. In the study, titled "Aerosols from Overseas Rival Domestic Emissions over North America", the team estimates, from NASA satellite observations, that the mass of aerosols arriving at North American shores from overseas is comparable to the total mass of particulates emitted domestically.

Uncertainty can be a dangerous force of doubt when dealing with research data. Dr. Yudong Tian, an associate research scientist at ESSIC, is nearing the end of the first phase of a project to address this issue by developing a way to accurately predict uncertainties in satellite precipitation measurements.

The MAPSS project is aimed at facilitating the integrated analysis, inter-comparison and validation of aerosol products from multiple sensors, in order to advance the harmonization of these measurements, and improve our knowledge of aerosol properties and impacts on the air quality, hydrological cycle, and climate.

The European Space agency (ESA) ENVISAT mission is providing new water-level products for the US Department of Agriculture USDA Foreign Agricultural Service (USDA/FAS) CropExplorer on-line database. These products are archival and currently available for ~150 lakes and reservoirs around the world.

Meteorological model simulations and emissions input files for air quality model simulations covering the DISCOVER-AQ field campaign have been completed. Air quality model simulations are underway to aid in determining how current and future satellite observations can more effectively diagnose ground level air pollution.

The Joint Center for Satellite Data Assimilation (JCSDA) supercomputer operated by the Goddard Space Flight Center for the Joint Center was intended to facilitate the testing of new data and algorithms in the context of operational data assimilation systems, and critical NOAA weather prediction systems have been ported onto the machine and their performance has been validated against their operational counterparts.

Goddard Earth Observing System Model Version 5 (GEOS-5) chemistry climate model...
development efforts are focused on implementing a hydroxyl parameterization scheme and creating a coupled CH₄-CO-OH system to understand the sensitivity of methane growth rates to variability in meteorological and chemical parameters. An initial evaluation of the GEOS-5 model’s ability to accurately simulate volcanic SO₂ emissions has been conducted and the results are positive.

An on-going activity is to adapt, improve, validate, and transfer a global flood and landslide technique to an operational entity so that it will be available for decision-making in support of disaster risk reduction activities around the globe.

Model and observations are now being used together to investigate how the Chesapeake Bay breeze impacts surface air pollution levels, pollutant transport between the boundary layer and free troposphere, and the spatial and temporal variability of air pollution concentrations, column content, and deposition over the Chesapeake Bay watershed.

ESSIC’s Wilfrid Schroeder processed the first satellite images of fire produced as a part of NASA’s Suomi National Polar-orbiting Partnership (NPP) and Earth Observing System (EOS). The images were acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS), an instrument attached to the NPP spacecraft launched in October 2011. The VIIRS is one of five key instruments on the spacecraft that measure atmospheric and sea surface temperatures, humidity sounding, land and ocean biological productivity and cloud and aerosol properties that can then be distributed to meteorology and climate change researchers and scientists around the world.

**EMPLOYEE AWARDS**

Dr. Hongbin Yu received a NASA/GSFC Laboratory for Atmospheres Contractor Award for Best Senior Author publication in recognition of his innovative use of satellite data to quantify the transport of dust and pollution aerosols across the Pacific Ocean and to estimate the impact of such transport on North America's climate and air quality.

Dr. Can Li received the ESSIC best paper award for his publication in Geophysical Research Letters entitled, “Recent large reduction in sulfur dioxide emissions from Chinese power plants observed by the Ozone Monitoring Instrument”.

**NEW ESSIC EMPLOYEES**

**Dr. Steve Guimond** received his B.S. in atmospheric science from Iowa State University and his M.S. and Ph.D. in atmospheric science from Florida State University. After graduation, he was a NASA Postdoctoral Fellow at NASA/GSFC in the Mesoscale Atmospheric Processes Laboratory between 2010 - 2012 working on airborne radar and hurricane dynamics. In the fall of 2012, he joined ESSIC to continue working at GSFC. Steve's research interests are broad and include radar algorithms and data analysis, hurricane dynamics and numerical modeling with a current focus on dynamic cores. Collaboration on these topics with groups at Goddard Space Flight
Center, NOAA's Hurricane Research Division and Los Alamos National Laboratory have proved fruitful and will continue to bring cutting-edge ideas to the understanding of the Earth system.

**Dr. Kwo-Sen Kuo** received his MS in Meteorology (1987) from South Dakota School of Mines and Technology, Rapid City, SD, and PhD in Atmospheric Science (1995) from Colorado State University, Fort Collins, CO. He joined ESSIC in 2012 as a visiting research associate. Dr. Kuo is specialized in atmospheric radiation, with PhD dissertation on three-dimensional radiative transfer. He applies this expertise to remote sensing with an emphasis on spaceborne instruments, including visible, infrared, and microwave radiometers, as well as spaceborne radars. His recent contribution is primarily in obtaining and characterizing the scattering properties of irregularly shaped ice particles. Dr. Kuo is also well-versed in information technology (IT), with a passion in employing IT to boost scientific endeavors.

**Dr. Xin Lin** joined ESSIC/NASA as an Associate Research Scientist on May 2nd, 2012, working on uncertainty characterization of satellite rainfall retrievals. He received the MS and PhD degree in Atmospheric Sciences from Colorado State University in 1992 and 1997, respectively. His research interests are mainly focused on mesoscale and large-scale observations and model diagnostics, data assimilation of satellite radiance/rainfall retrievals, convection/cloud parameterization, satellite retrieval evaluations.

**Dr. Jianping Mao** received a MS (1992) and a Ph.D. (1995) in Meteorology from the University of Maryland at College Park, MD. His Ph.D. thesis is on climate signal analysis in the global surface air temperature climate records. He worked for two years as a Postdoctoral Research Associate in the same university where he expanded his work on atmospheric radiation and remote sensing. After that he participated in the development of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) ranging from system configurations to data retrieval algorithms. He started his research on CO2 remote sensing in 2001. In Oct. 2012, he joined the ESSIC/UMD as a member of research faculty. His main research interest is in the mission concepts, feasibility and sensitivity studies and performance analysis for new measurements about Earth and other planets. His current goal is to support NASA's carbon missions with his expertise and experience in atmospheric radiation, remote sensing and climate change studies.

**Dr. Wenjian Ni** received the B.Eng. degree in surveying and mapping from Shandong University of Technology, Zibo, China, in 2004 and the Ph.D. in cartography and geography information system from the Graduate University of Chinese Academy of Sciences, Beijing, China, in 2009. He is doing postdoctoral research at University of Maryland at College Park from July 2010. His research interests include measuring and modeling the radar backscattering of vegetated surface, description of 3D forest scene using terrestrial, airborne or spaceborne laser scanner data, algorithm exploration for the mapping of forest aboveground biomass at regional scale using multiple remote sensing data.

**Dr. Ryan Walker** joined ESSIC/NASA GSFC as an Assistant Research Scientist on August 12, 2012 after four years with the Penn State Ice and Climate research group, and is working with Dr. Sophie Nowicki to couple an ice sheet model with NASA's GEOS-5 climate model. He received the PhD degree in Atmosphere Ocean Science and Mathematics from the Courant Institute of New York University in 2006. His research interests are polar oceanography and
glaciology, with an emphasis on the interaction between oceans and ice shelves and its effect on ice sheet stability. He is a member of the SeaRISE community modeling effort to place upper bounds on the contribution of ice sheets to sea level in the next few centuries.

**Dr. Clark Weaver** received his Ph.D. in Atmospheric Science from Colorado State University in 1987. After which he joined the Graduate School of Oceanography at University of Rhode Island and studied the transport of mineral dust to ocean drilling sites using paleoclimate models. Clark has most recently been communicating climate science to staff members on Capitol Hill as a representative for the American Geophysical Union (AGU). He has been working at NASA Goddard’s Atmospheric Chemistry and Dynamics Branch since 1991. Clark is currently developing a retrieval algorithm for an airborne laser sounder that measures CO2. He has developed an algorithm to retrieve CO2 and O2 from GOSAT radiances and developed an algorithm to measure aerosol absorption from ground-based AERONET radiances. During the summers of 2011 and 2012 he was a visiting scientist at the Deutsches Zentrum für Luft- und Raumfahrt (DLR), Oberpfaffenhofen Germany.
III. RESEARCH TASKS—PROGRESS AND PLANS


Note: This task was cancelled before funding. No funds have been expended on this task.
Task 602: Global Land Data Assimilation System (GLDAS); PI: H. K. Beaudoin; Sponsor: M. Rodell

Description of Scientific Problem
Land surface states and fluxes influence the weather and climate through exchanges of energy, water, and momentum between land and atmosphere. The energy and water stored in land present persistence on diurnal, seasonal, and inter-annual time scales. Because these conditions (e.g. soil moisture, temperature, and snow) are integrated states, biases in forcing data (i.e. meteorological and land characteristics) and parameterizations (i.e. models) lead to incorrect estimates. We are working on deriving accurate surface conditions at global, high spatio-temporal resolutions, and near-real time to help improve weather forecast and prediction skills, water and energy budget studies, and water resource management applications.

Approach
We work with offline land surface model (LSM) simulations (uncoupled to atmosphere) using the observation based input that are ground-based, remote sensing, and/or reanalysis/analysis fields data. By using such data, we constrain the model states in two ways; one is through realistic forcing fields and the other is through data assimilation. One of the primary objectives was to develop a modeling framework that allows users to run multiple LSMs using various combination of forcing and land characteristic datasets. We do not develop the LSMs ourselves, but rather, we focus on optimizing the configuration (e.g. merge and refine input data) and developing supplemental capabilities (e.g. irrigation, data assimilation).

Accomplishments
We continue to serve the GLDAS products from NASA/GSFC's Data and Information Services Center (DISC). We had some intermissions and delays this year but the products are updated to delayed present. The GLDAS data was accessed by up to 1134 distinct users monthly during FY2012.

Substantial data processing was performed and ongoing this year. The GLDAS version 2 dataset that was first released last year has been reprocessed with multiple updates including the forcing dataset, land surface model version upgrade, and switch to MODIS based land surface parameter datasets. The GLDAS 2.0 NOAH at 1 degree product now extends from 1948 to 2010 and will be published at the DISC within a week or so. The 0.25 degree NOAH simulation is in the production. The catchment model simulation has completed but an analysis depicted a problem in the evapotranspiration over the tropics, thus it is under debugging. The latest Community Land Model (CLM) code was ported and tested on the NASA computer system by our colleague who works in a separate project in our group, and we are working on preprocessing the input datasets and configuration for additional GLDAS2 simulation. Also work in progress is the near real-time product, GLDAS version 2.1, which covers 2001 onward forced with a combination of NCEP’s GDAS meteorological data, CPC’s CMAP precipitation, and U.S. Air Force’s AGRMET radiation datasets. We found a problem in the real-time pentad CMAP precipitation that is used in the current GLDAS version 1 product due to a change in the gauge inputs. We will use the post processed CMAP precipitation dataset and are currently working on disaggregating the pentad data to spatially and temporally higher resolution. In the meantime, GLDAS1 products are updated monthly until GLDAS2.1 becomes operational. The AGRMET
radiation dataset used to be provided by our NCEP colleague, but we are taking it over and processing it in house by directory receiving the data from AFWA.

We continued on establishing the current “state of the global water/energy cycle” with the numerous members of the NASA Energy and Water cycle Study (NEWS) climatology group. We integrated ‘best-estimates’ for water and energy cycle components from the team members and developed annual and monthly climatology of water and energy budget and associated uncertainties for each continental/oceanic regions and globe. Progress was made in refining the error analysis using a constrained optimization. For annual scale, the water and energy budget components are coupled via evapotranspiration and optimized over the 6 continents and global ocean simultaneously. At monthly scale, only water budget components are optimized due to a lack of observed heat transport. Subsequently, the monthly fluxes are adjusted to obtain consistency with the annual mean flux using variance weighting. Figure 1 shows current analysis of mean monthly water cycle for global land and ocean.

![Global Land](image1.png) ![Global Ocean](image2.png)

Figure 1 Global land and ocean monthly mean water fluxes (1,000 km³/yr) at the start of the 21st century. “Best guesses” estimates based on observational products and data integrating models.

On a separate project, we are generating drought indicators by assimilating the Gravity Recovery and Climate Experiment (GRACE) data into the catchment land surface model. The indicator is produced and disseminated to the U.S. Drought Monitor community for the operational drought monitor assessment weekly on a semi-operational mode (http://drought.unl.edu/MonitoringTools/NASAGRACEDataAssimilation.aspx). The GRACE drought monitor product was featured as “Image of the Day” at the NASA Earth Observatory on September 19th (http://earthobservatory.nasa.gov/Features/GRACEGroundwater/page4.php).

**Conference Publications**

Toure A. M., M. Rodell, and H. K. Beaudoin, 2012: Evaluation of snow cover fraction estimates from CLM v.4.0 using MODIS observations, MODIS Science Team meeting, Silver Spring, MD, May 7-9, poster presentation

Rui, H., H. K. Beaudoin, W. L. Teng, B. E. Vollmer, M. Rodell, and G. Lei, 2012: New and Improved GLDAS data sets and data services at NASA GES DISC. 4th WCRP Meeting, Silver Spring, MD, May 7-11, poster presentation

Toure A. M., M. Rodell, and H. K. Beaudoin, 2012: Evaluation of snow cover fraction estimates from CLM v.4.0 using MODIS observations, CESM Annual Workshop, Breckenridge CO, June 18 - 21, poster presentation
Task 603: Forcing bias correction and model output scaling for drought monitoring; PI: B. Li; Sponsor: M. Rodell

Description of scientific problem
Due to lack of networks of in situ measurements at continental scales, drought monitoring has increasingly relied on land surface models, in conjunction with meteorological forcing fields, to obtain states such as soil moisture and groundwater storage in past and current time. Droughts are detected when current conditions reach to certain low thresholds determined from past conditions (climatology). To obtain a climatology that consists of historical drought events, land models have to be driven with forcing data spanning over several decades. As is often the case, such long retrospective forcing data may not have data for recent years and therefore, a second forcing data set with the latest meteorological conditions has to be employed to extend model simulation to present time. Bias as well as differences in temporal variability between the two forcing data sets may lead to systematic deviations in modeled states that may hinder their comparison with the climatology and directly affect accurate evaluation of drought severity.

Approach
In this study, the Princeton forcing data available for 1948 to 2008, was used to drive the NASA Catchment model to obtain the climatology of modeled states and the North America Land Data Assimilation (NLDAS) forcing was used to drive the model from 2002 to present time. Two approaches, bias correction on forcing fields and linear scaling on modeled states, were used to enforce that estimates derived from NLDAS are comparable with the climatology. Bias correction and output scaling factors were derived from a 7-year period (2002-2008) when both forcing data sets were available.

Accomplishment
We found that forcing bias correction on NLDAS in conjunction with output scaling provided more consistent soil moisture and groundwater estimates with the Princeton estimates in the same period than output scaling alone. Output scaling alone is especially less effective for scaling groundwater estimates in certain areas because they often lack of seasonal cycles and are more sensitive to forcing bias and its accumulated effects. Figure 1 shows the drought indicator map produced by the Nation Drought Mitigation Center (NDMC), percentile maps of groundwater storage from Princeton forcing, NLDAS and bias-corrected NLDAS forcing. Percentile maps of soil moisture and groundwater storage generated using the combined scaling scheme are sent to and analyzed regularly by NDMC for producing current US drought indicators. A journal article is in preparation and the results of this study will be presented at American Geophysical Union Fall Meeting 2012.
Figure 1: Drought percentile map produced by NDMC (upper left), groundwater storage percentile map using Catchment estimates based on Princeton (lower left), NLDAS (upper right) and bias-corrected NLDAS (lower right) forcing. All the maps are for August 19, 2008.
Task 604: Joint Center for Satellite Data Assimilation; P.I.: Lars Peter Riishojgaard; Sponsor: Jack Richards

Description of Scientific Problem
The Join Center for Satellite Data Assimilation is a US interagency distributed center charged with coordinating satellite data assimilation activities for environmental prediction applications between NASA, NOAA and the Department of Defense. The Director reports to a Management Oversight Board that consists of representatives from the three partner agencies, and he is responsible for the strategic direction and the daily execution of the research and development work undertaken by the Center as well as for representing the Center in national and international scientific contexts. The Fiscal Year 2012 budget of the Center amounted to ~$21M.

Approach
JCSDA funds a number of external and internal research activities aimed at increasing both the amount of satellite data used in operational prediction systems in the US and the overall impact on performance of these data. The center also funds and coordinates activities aimed at preparing for assimilation of data from new satellite systems well in advance of the launch of these systems. This is important in order to improve the return on the very substantial investment of the US federal government and other entities in satellite systems. Highlights of the activities of the past year include preparatory work for the assimilation of data from NASA’s NPP mission, a precursor to the next generation of polar orbiting operational meteorological satellites, which was launched in October 2011, and a broad assessment of the contribution to forecast skill of all major observing systems.

Accomplishments
One of the main limiting factors for progress in data assimilation and forecast skill of operational prediction system is the transfer of new research ideas, algorithm and data into operations. The JCSDA supercomputer operated by the Goddard Space Flight Center for the Joint Center was intended to facilitate the testing of new data and algorithms in the context of operational data assimilation systems, and critical NOAA weather prediction systems have been ported onto the machine and their performance has been validated against their operational counterparts. This environment was used to successfully complete preoperational testing of radiance data from the Advanced Technology Microwave Sounder (ATMS) flying on NASA’s Suomi-NPP mission launched in October 2011. As a result NOAA/NCEP was able to implement ATMS data in operational data assimilation on May 22 2012, less than seven months after launch and before the satellite itself had been declared operational.

In addition to its use for preoperational testing, the Goddard computer is used extensively for impact experiments aimed at assessing the respective contributions to forecast skill of various parts of the Global Observing System and for simulated impact studies for potential future observing systems (“Observing System Simulation Experiments” or OSSE’s, discussed below). The machine is also used to support external researchers for activities such as improved use of satellite winds, improved use of hyperspectral infrared radiances, and candidate methodologies for assimilation of lightning imager data.
As part of the monitoring effort for its various activities and in order to foster cross-pollination between the projects funded by it, the Joint Center hosted its 10th Annual Science Workshop in the new NOAA Center for Weather and Climate Prediction in College Park on October 10-12. The Workshop was attended by around 100 participants who presented, reviewed and discussed progress and plans for Joint Center research and development. The six sessions followed the six Science Priority Areas, which are 1. Radiative Transfer Modeling, 2. Preparation for assimilation of data from new sensors, 3. Clouds and Precip, 4. Land Surface DA, 5. Ocean DA, and 6. Atmospheric Composition.

The JCSDA OSSE capability, which demonstrated its use via a recently completed series of impact experiments for NASA’s GWOS concept, has now become the focal point for a series of projects concerning projected forecast impacts of future space systems. These include 1. Various options for early morning orbit satellite sounding, 2. Hyperspectral infrared sounding from geostationary orbit, and 3. Alternative wind lidar technologies.

Outside the main task of leading the Joint Center, the JCSDA Director continues to be engaged in space system development. He is a member of the Mission Advisory Group of ESA’s ADM/Aeolus Wind Lidar Mission, of the International Users and Science Team of the Canadian PCW mission, and he is a Co-Chair of the US Working Group of Space-Based Wind Lidars.

The JCSDA Director is very active in WMO and is currently chairing the Open Program Area Group on Integrated Observing Systems under the WMO Commission for Basic Systems. In this capacity, he chaired the local organizing committee for the “Fifth WMO Workshop on the Impact of Various Observing Systems on NWP” which was hosted by the Joint Center for WMO in Sedona AZ May 22-25 2012.
Task 605: GPM Algorithm Development; PI: J. Munchak; Sponsor: A. Hou

Description of Scientific Problem
The general objective is to develop a general framework and state-of-the-art algorithms to advance precipitation observations from space using information from active and passive microwave sensors. In particular, two areas of investigation have been selected: 1) Support of the falling snow portion of the GPM passive radiometer algorithm; and 2) assessing the information content of combined dual-frequency radar and multichannel radiometer measurements of clouds and precipitation.

Approach
The at-launch GPM radiometer algorithm, to be used on the core satellite and constellation radiometers, will be a Bayesian approach and as such requires a priori databases of precipitation and associated microwave radiances. While the ultimate goal is to construct this database from the combined radar-radiometer retrievals from the GPM core satellite’s microwave imager (GMI) and dual-frequency precipitation radar (DPR) instruments, these will not be available and mature until 1-2 years after launch. The database currently in use and derived by TRMM does not sample the mid- and high-latitude environments that GPM will encounter nor does it include the high-frequency (166 and 183 GHz) channels that will be present on GMI. The approach being used to augment the TRMM-derived database involves the merging of several data sources (CloudSat, AMSR-E, MHS, and cloud resolving models) to extend it to higher latitudes.

Activities related to the combined GMI-DPR algorithm include testing the at-launch code and research activities that will benefit future versions of the algorithm. Testing activities include running retrievals on TRMM orbits with simulated DPR measurements and evaluating the impact of assumptions regarding the raindrop size distribution and other parameters. Research activities are currently focused on examining the relationship between radar surface backscatter and microwave surface emissivity, in order to ensure consistency between the two parameters in the combined retrieval.

Accomplishments
Dr. Munchak has been collaborating with Dr. Mark Kulie (University of Wisconsin) in specific steps of this process, including land surface classification and development of a principal-component based method to efficiently match model-derived and observed CloudSat reflectivity profiles. These databases were delivered to Prof. Chris Kummerow and Dr. Dave Randal (Colorado State University) in early November 2012. Using a similar proxy database (this time based upon the US-based NMQ radar product and SSMIS), Dr. Munchak evaluated the ability of different sensors that will be in the GMI constellation to detect precipitation over different surface types. These findings are currently in publication (Munchak and Skofronick-Jackson, 2012; Skofronick-Jackson et al., 2012). Key findings include:

- Up to 90% of precipitation over water and 80% over land can be detected reliably with GMI.
- Ancillary data concerning atmospheric state and surface condition (snow/no snow) significantly improve precipitation detection, particularly in cold environments.
Dr. Munchak has been collaborating with Drs. William Olson, Mircea Grecu, and Ziad Haddad to test the at-launch code GPM algorithm testing. One area of focus for this testing has been to evaluate the ability of the algorithm to retrieve rainfall rate, liquid water path (LWP), and median raindrop size (D0) using synthetic data. Synthetic data is DPM-like data generated from TRMM, using an assumption about the raindrop size distribution to generate Ka-band reflectivities. Then, the retrieval is run using the synthetic Ka-band data, but without any DSD assumptions to estimate the error that results from these assumptions that must be made in the algorithm. Rainrate errors are generally 8%, higher than LWP (5%) but lower than D0 (13%) due to the more direct physical connection between radiance measurements and LWP than rain or D0.

Another activity that is in the early stages of research, but has already produced fruitful results, is the investigation of the relationship between microwave surface emissivity and radar backscatter cross section. The variability in the surface cross section has been a limitation for radar algorithms, because it represents an uncertainty in the estimate of path-integrated attenuation (PIA) that algorithms rely upon to constrain rain rate estimates. Similarly, emissivity has long been a source of uncertainty for combined radar-radiometer and radiometer-only algorithms. These uncertainty sources have been treated independently by existing TRMM and GPM algorithms, but have physical basis in common parameters such as wind-induced roughness (over water) and soil moisture (over land). An empirical study of these correlations is consistent with these physical explanations (Figure 1). Work will continue to be done to assess the feasibility of including these relationships in future GPM algorithms.

**Conference Presentations**


Cross Section Derived from 15 years of TRMM PR and TMI Data. 4th TRMM and GPM International Science Conference, Tokyo, Japan, November 13-16, 2012.

Peer-Reviewed Publications

V. N. Bringi, Gwo-Jong Huang, S. Joseph Munchak, Christian D. Kummerow, David A. Marks, David B. Wolff, 2012. Comparison of Drop Size Distribution Parameter (D₀) and Rain Rate from S-Band Dual-Polarized Ground Radar, TRMM-Precipitation Radar (PR) and Combined PR/TMI: Two events from Kwajalein Atoll. *J. Atmos. Oceanic Technol.*, http://dx.doi.org/10.1175/JTECH-D-11-00153.1
Task 606: DART-LiDAR Model Simulations of Full Waveform and Photon Counting Instruments; PI: J. Rubio; Sponsor: B. Cook

Description of Scientific Problem
NASA has developed and deployed a broad range of airborne and space-based LiDAR instruments for remote sensing of the Earth’s surface. Instruments on ICESat and ICESat-2 use two fundamentally different LiDAR technologies, full-waveform and photon-counting, yet the comparability of measurements from these instruments has not been assessed. The goal of this project is to develop a theoretical basis using the Discrete Anisotropic Radiative Transfer (DART) model for evaluating and comparing measurements of Earth surface properties from full-waveform and photon-counting LiDAR technologies.

Approach
A LiDAR module was recently developed for the Discrete Anisotropic Radiative Transfer (DART) model. DART provides an ideal foundation for LiDAR modelling, because the architecture supports Monte Carlo and ray tracing methods to simulate radiative transfer in complex 3D scenes, thereby enabling realistic simulations of spaceborne systems. We aim at building a robust and validated physically based radiative transfer module to simulate both full waveform and photon counting instruments. Field measurements from a stem mapped study site in Howland Forest, Maine, USA, have been used as input to the model. Model performance was verified and validated with independent airborne observations from NASA’s Laser Vegetation Imaging Sensor (LVIS). A sampling approach for simulating photon counting data was also developed based on instrument specifications for the ICESat-2 mission.

Accomplishments
The major accomplishments under this Task during this 1st year are the validation of a full Waveform LiDAR module and the development of a photon counting module.

The full waveform module was tested and a sensitivity analysis was performed with the model to evaluate instrument characteristics (e.g., laser wavelength, detector response), canopy and ground surface properties (e.g., LAI leaf angle distribution, reflectance), and site conditions (e.g., presence of snow, wet/dry litter, and terrain slope) on the ability to characterize vegetation structure.

The photon counting module was developed [Rubio et al., 2012] and an atmospheric component has been incorporated into the model. We aim at validating the photon counting module using ICESat-2 simulator MABEL (Multiple Altimeter Beam Experimental LiDAR). A number of MABEL data were acquired in September 2012 over the mid-Atlantic region where extensive field and airborne data is available.

Conference and other Presentations
Tasks 607, 609, 644, 645 and 662: Lidar and radar collaboration; PI: Guoqing Sun; Sponsors: R. Nelson (607), B. Cook (609), T. Fatoyinbo Agueh (644, 645, 662)

Description of Tasks

Task 607
On this task I am responsible for downloading and post-processing space lidar and radar data in order to estimate the forest biomass of the continental US and Mexico. He will access, download, and compute forest canopy height and density metrics from two space data sources, i.e., the ICESat/GLAS waveform lidar and the ALOS-PALSAR L-band radar.

Task 609
I work on the NASA Remote Sensing Theory project, “DART-LiDAR: A Coupled Atmosphere-Vegetation Model for Simulating Full-Waveform and Photon-Counting LiDAR” to provide guidance and support for 1) developing a full-waveform and photon-counting LiDAR modules DART; and 2) validating and comparing full-waveform and photon-counting model results at field study sites.

Task 644
As a Co-I on the IIP- ECOSAR project I am responsible for helping define the science requirements for the ECOSAR instrument, and working with Dr. Lola Fatoyinbo and Dr. Rafael Rincon on deriving Polarimetric InSAR processing algorithms, biomass estimation algorithms and ECOSAR validation efforts.

Task 645
As a Co-I on the TERRAQUA project, I lead the development of the radar portion of BioPHYS MFM and its implementation on GSFC computer facilities.

Task 662
I provide scientific support for projects that are assessing forest biomass and ecosystem structure using remote sensing. Support is required in the area of SAR and Lidar data processing and analysis, SAR and LIDAR forest canopy modeling, field measurements and other experiment support.

Accomplishments

1) Data acquisition and processing for task 607 (20%)
   Land surface altimeter data (GLA14) and altimeter Data (GLA01) from Geoscience Laser Altimeter System (GLAS) on board ICESat acquired from 2004 to 2006 (L3A, L3C, L3D, L3F and L3G) were downloaded for entire North America, Alaska and Mexico. For each footprint of the GLAS data, the information from GLA14 data (such as lat/lon of the footprint center, waveform starting and ending points, fitted Gaussian peaks, location of the waveform centroid, etc.) and the waveform and associated information from GLA01 data were processed to generate various “waveform indices” for estimation of forest structural parameters (canopy height and above-ground biomass). The processed data is also screened using thresholds of maximum waveform length, maximum top canopy height, etc. to remove bad data points.

2) Lidar data modeling for task 609 (10%)
DART model, which is a 3D optical radiative transfer model, is being modified to simulate photon-counting lidar data from vegetated targets. The model has been modified but needs to be validated using field-measured vegetation data and lidar data. Data from SERC, MD and Howland, MN are being used to build 3D forest scenes for input to the model. At the same time we are getting familiar with the photon-counting lidar data, preparing to process the data acquired by MABEL (http://cpl.gsfc.nasa.gov/MABEL/mabel10/mabel10.htm).

3) DBSAR and EcoSAR – task 644 (20%)
EcoSAR is an advanced airborne polarimetric and "single pass" interferometric P-band SAR instrument in development at NASA/Goddard Space Flight Center through NASA’s Instrument Incubator Program (IIP). The EcoSAR design leverages the L-band Digital beam forming SAR (DBSAR) architecture which demonstrated advanced digital beam forming SAR techniques for surface imaging and biomass applications. While I attend group meetings and providing scientific advice on the EcoSAR system, I spent rest of my time working with Dr. Ni on the processing DBSAR data. To provide the SAR data from DBSAR and EcoSAR, various steps needed to calibrate the data radiometrically and geometrically. Preliminary results (relations between DBSAR backscattering and forest biomass; single-pass InSAR data processing) have been achieved from DBSAR data. A plan for systematic processing GSFC SAR data is being formed now, which will include 1) SAR raw data focusing, motion compensation, polarimetric calibration, and geo-rectification (ortho-rectification).

4) Radar backscatter simulation for task 645 (20%)
A forest growth model was used to simulate forest growth. Forest stands of ages from 5 to 500 years were simulated. The output from the growth model is a list of trees (dbh, species, height and LAI) growing in a 30m by 30m area at certain ages. These data was used to build a 3D scene for the input to our 3D radar backscatter model. Radar backscattering of PALSAR FBD data (L band, 34 incidence angle, HH and HV polarizations) of these forest stands were simulated. The forest parameters calculated from the input tree data and the simulated radar backscattering signature form a look-up table. It will be combined with a look-up table at optical region (LANDSAT multi-spectral) for forest physical parameters retrieval.

5) Field work in Siberia and biomass mapping of Northern forests – task 662 (10%)
From 8-22, July, 2012, I joined the field work along Tembichi river (65N, 99.2E) and Kochechum (64.4N, 100.3E) river, Tura, Russia. Six of us (Drs. Ranson, Nelson and me from US and three Russian colleagues) traveled on river using rubber boats and visited GLAS footprints at both sides of the river, camped on river beaches. More than 100 GLAS footprints were measured. In addition some sampling plots were located and measured for flying GSFC GLight (combination of laser scanner and hyperspectral radiometer) next year.

Publications

Task 608: Optical Closure Studies and the Direct Radiative Effects of Mineral Dust Aerosol; PI: R. Hansell; Sponsor: S.C. Tsay

Description of Scientific Problems
The research was comprised of two main areas of study. First, detailed investigations were performed of the scattering and absorption properties of a variety of aerosols associated with different air mass regimes during a pre-7-SEAS experiment in the northern South China Sea at Dongsha Island. Second, the longwave direct aerosol radiative effects (DARE) of mineral dust were examined using surface data at Zhangye China during the Asian Monsoon Years (AMY) field campaign in 2008, followed by comparisons of the radiative parameters from a previous study of Saharan desert dust at Cape Verde Islands.

Approach
Specific objectives were:

- To systematically cross-check the consistency of aerosol microphysical and chemistry data collected during the 7-SEAS Dongsha experiment in 2010 using in-situ measurements from NASA Goddard’s COMMIT laboratory (SMARTLabs- http://smartlabs.gsfc.nasa.gov/). An optical model constrained by particle size and mass measurements combined with aerosol composition information from a collocated IMPROVE chemical sampler was used to predict the scattering and absorption coefficients ($\lambda=0.55 \mu m$) for a variety of aerosols corresponding to variable air mass regimes. Comparisons of modeled and measured optical properties were made to assess the consistency in the measurements and to attempt, what appears to be the first time for this region, optical closure in this aerosol-rich environment.
  - Constraints to the model included combined SMPS and APS number concentration data for a continuum of fine and coarse-mode particle sizes up to PM$_{2.5}$
  - Aerosol composition and mass portioning of key elemental species included sea-salt, particulate organic matter, soil, non-sea-salt sulphate, nitrate, and elemental carbon
- To employ a deterministic 1-D radiative transfer model constrained by local field measurements, including spectral photometry/interferometry, lidar, and aerosol physicochemical properties, to assess the longwave behavior in the direct aerosol radiative effects (DARE) of Asian dust and to evaluate its significance relative to that in the shortwave.
  - This effort also involved constructing a regional aerosol optical model by combining SMARTLabs microphysical measurements with compositional information obtained from previous research.
  - The current endeavor is part of an on-going research study to perform a large-scale assessment of DARE near key dust source regions worldwide to better understand the longwave component.
- To compare the DARE of Saharan and Asian dust using field measurements obtained from NASA SMARTLabs during the NAMMA and AMY field campaigns, respectively.
Accomplishments

- Results of the optical closure study (recently published in a special issue of the Journal of Atmospheric Environment on the “Observation, Modeling and Impact Studies of Biomass Burning and Pollution in the SE Asian Environment”) revealed that observed aerosol scattering and absorption for diverse air masses were reasonably captured by the model (Figure 1). Peak aerosol events and transitions between key aerosols types were evident (e.g., heavy polluted aerosol composed mostly of ammonium and non-sea-salt sulphate mixed with some dust with transitions to background sea-salt conditions were apparent in the absorption data).
  - The 7-SEAS/Dongsha study experimentally confirmed the consistency in the aerosol in-situ measurements and enabled a first time attempt in achieving shortwave optical closure for the aerosol-rich environment at Dongsha.
  - The study also revealed that full closure is hampered by limitations in accounting for the role of water vapor in the system, instrumental uncertainties, and the need for further knowledge in the source apportionment of the model’s major chemical components.
- The DARE study of dust at Zhangye during AMY-2008 revealed that the longwave radiative component can be significant and can compensate for at least one-half of the shortwave cooling effect at the surface. This has important implications for better understanding regional changes in surface temperatures and moisture budgets.
  - DARE at Zhangye was found to be a factor of two larger than that at Cape Verde, owing to differences in the dust absorbing properties and proximity to the major desert source regions (Figure 2).
  - This work was recently featured in a NASA cover story on October 31 2012 (http://www.nasa.gov/topics/earth/features/dust-warming.html)

Refereed Journal Publications


*corresponding author

Presentations


Presentation at NASA GSFC’s lecture series (Laboratory for Atmospheres) entitled “Dust Aerosols: A Longwave Perspective of Their Radiative Effects”, June 6 2012
Figure 1 Comparison of modeled versus measured absorption (top panels) and scattering (bottom panels) coefficients from the 7-SEAS/Dongsha Experiment.

Figure 2 Comparison of longwave surface DARE at Zhangye (blue markers) versus Cape Verde (red markers). Individual points represent instantaneous DARE while slopes of fitted curves denote the DARE efficiency.
**Task 610: Aerosol Remote Sensing; PI: M. Petrenko, Sponsor: C. Ichoku**

**Description of Scientific Problem**
The effects of atmospheric aerosols on the air quality, the hydrological cycle, and climate are still poorly understood. During the past decade, there have been increased efforts to employ satellite remote-sensing approaches in measuring aerosols in order to complement measurements from ground-based systems. However, because of the differences in the sensor measurement characteristics and algorithms used for aerosol retrievals, the products are often inconsistent, making it difficult to derive objective measures of aerosol amounts and properties. Therefore, it has become necessary to conduct integrated analysis of aerosol measurements acquired with different types of instrumentation, in order to narrow down the uncertainties that delay improvements in the knowledge of the different aerosol impacts. The purpose of this project is to provide an approach and a unified framework for inter-comparison and validation of aerosol measurements from different sensors and instruments, including ground-based, airborne, and spaceborne, obtained at different locations and time around the globe.

**Approach**
A Multi-sensor Aerosol Products Sampling System (MAPSS) software and supporting database have been established as a consensus data framework for multi-sensor aerosol validation, inter-comparison, and joint-analysis. A simple web-based service was developed for rapid and efficient access to the database. In addition, a web portal was established to provide for a fast and convenient access to the database, as well as for a customized on-demand retrieval of the data from this database (http://giovanni.gsfc.nasa.gov/mapss/). As of the beginning of the reported phase of the project, MAPSS supported data derived from the AERONET (Aerosol Robotic Network), MAN (Maritime Aerosol Network), MODIS (Moderate-resolution Imaging Spectroradiometer), MISR (Multi-angle Imaging Spectroradiometer), OMI (Ozone Monitoring Instrument), CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), and SeaWiFS (Sea-viewing Wide Field-of-view Sensor) sensors.

**Accomplishments**
During the reporting period of March 1, 2012 – February 29, 2013, the multi-sensor data prepared using the MAPSS system during the previous reporting periods was analyzed to identify the regions of the best and the worst performance for each of the supported aerosol products. Based on the outcomes of this analysis, the methodology was designed for a further in-depth analysis of the data and its associated uncertainties.

To facilitate sharing and discussion of these initial results with the members of the aerosol community, we have designed and performed the visualization of the data analysis statistics and created a prototype of an interactive WEB-based tool that would allow exploring these results in details, see the figure below. Furthermore, the results are currently being summarized in a draft of a journal paper, to be submitted for a peer review later this year.

We collaborated with the University of Nebraska-Lincoln to perform a MAPSS-based analysis of the coastal MODIS aerosol data to identify possible sources of errors and uncertainties in these data. Based on this study, we have submitted a manuscript to AMT; the manuscript is currently...
being revised based on the first stage of the peer reviews. During the reporting period, we also continued collaborating with other research groups that use MAPSS for the validation of novel aerosol products, especially as these products approach the stage of release. These include the new 3-km aerosol product from MODIS and the aerosol product from the recently launched VIIRS (The Visible Infrared Imager Radiometer Suite) sensor onboard the NPP satellite.

We continued improving and expanding the Giovanni WEB interface for interactive plotting and retrieval of the MAPSS data. Particularly, we implemented a procedure for bias analysis and adjustment in MODIS and MISR aerosol data products based on the MAPSS data within the framework of AeroStat (http://giovanni.gsfc.nasa.gov/aerostat/). We also made a number of improvements to the interfaces of both MAPSS and AeroStat systems in Giovanni, based on the feedback from the early users of the systems.

Web interface developed for the uncertainty analysis of aerosol products from multiple satellite sensors over AERONET and other ground stations. All ground sites are displayed on a Google map, and by clicking a given site, a panel pops up, showing the values of an uncertainty parameter (e.g. $r^2$, slope, offset, mean negative and positive deviations, and root mean square error) for all sensors compared to AERONET, in different seasons, with or without QA filtering, and including or excluding distinct outliers. In this example a circular shows coefficients of determination ($r^2$) of the linear least squares regression fits of each sensor AOD against that of the GSFC AERONET station. Colors and symbols are explained below the map, whereas the bottom right circular chart shows the average $r^2$ values based on all AERONET stations globally. This tool is still being evaluated before release, which is planned for earlier next year.

**Refereed Journal Publications**


Conference Presentations

Charles Ichoku, Maksym Petrenko, “Asian Aerosols and Their Impacts on Regional and Global Climate”, AOGS-AGU (WPGM) Joint Assembly, 13-17 August 2012, Singapore.
**Task 611: Correction for cirrus signals in aerosol optical properties retrieved from MODIS; PI: Jaehwa Lee; Sponsor: N. Christina Hsu**

**Description of Scientific Program**
Aerosol retrievals from TOA reflectance data observed from passive satellite sensors have been limited to cloud-free areas due to strong signals of clouds. However, thin cirrus clouds which are sufficiently transparent can be corrected out by using correlation between TOA reflectances at 1.38 μm and aerosol bands. In this study, using Moderate Resolution Imaging Spectroradiometer (MODIS) correction for cirrus signal in TOA reflectances at aerosol bands is conducted by using the correlation method, and cirrus-corrected aerosol optical properties are retrieved over cirrus-contaminated areas by using the cirrus-corrected TOA reflectance data.

**Approach**
1) To correct for cirrus signals regression equations and correlation coefficients between TOA reflectances at 1.38 μm and minimum values at aerosol bands are calculated over each section which is divided into 9 from the whole granule. The reason to use minimum values at aerosol bands is that there exist other signals, such as surface, aerosol, and air molecules, than cirrus at those bands, whereas only cirrus signal exists at 1.38 μm in the case of sufficient water vapor.
2) The cirrus signals in the TOA reflectances at the aerosol bands are removed out by using regression equation between the two bands and TOA reflectance at 1.38 μm when the reflectance values between two bands are highly correlated.
3) The cirrus-corrected aerosol optical properties are retrieved by inputting the cirrus-corrected TOA reflectance data into aerosol retrieval algorithm.

**Accomplishments**
The cirrus-corrected aerosol optical properties are retrieved over various regions, and differences in AOD and fine-mode fraction (FMF) between cirrus-contaminated and cirrus-corrected cases are analyzed. The cirrus correction results in decrease in high AOD and low FMF in the frequency distribution because of reduced TOA reflectance and large particle size of cirrus clouds. A case scene shows that the method results in reasonable spatial homogeneity in AOD correction, representing negligible artificial errors in the cirrus-corrected AOD.

![Frequency distribution of AOD (left) and FMF (right) before and after correction for cirrus signal for a case granule on February 1, 2007.](image-url)
A case granule for cirrus correction in AOD retrieved from MODIS. Each panel shows MODIS RGB image (upper left), TOA reflectance at 1.38 μm (upper right), cirrus-contaminated AOD (lower left), and AOD difference between cirrus-contaminated and cirrus-corrected cases (lower right).

**Refereed Journal Publications**
Lee, J., J. Kim, P. Yang, and N. C. Hsu, 2012: Improvement of aerosol optical depth retrieval from MODIS spectral reflectance over the global ocean using new aerosol models archived from AERONET inversion data and tri-axial ellipsoidal dust database, *Atmos. Chem. Phys.*, 12, 7087-7102, doi:10.5194/acp-12-7087-2012.

**Conference Presentations**


**Task 612: Effective Microwave Albedo of Vegetated Landscapes; PI: M. Kurum; Sponsor: P. O’Neill**

**Description of Scientific Problem**

Monitoring the hydrological state of the land surface by measuring soil moisture (SM) is of value primarily in improved understanding of the physical processes linking the water, energy, and carbon cycles. Availability of SM information at a global scale will lead to improved numerical weather and climate prediction, flood and drought monitoring, forecasts of agricultural productivity, and to many other applications of societal benefit. Microwave observations at low frequencies, such as L-band (1–2 GHz), have a great potential to sense surface SM spatially and temporally at large scales due to high sensitivity to dielectric properties of the surface, deeper penetration into vegetation, and all-weather, and day and night observing capability (almost transparent to the atmosphere and clouds, and independent of solar radiation). Currently, one combined active/passive L-band microwave mission called SMAP is being prepared for launch by NASA, and one passive-only mission, SMOS, was launched in November 2009 by ESA. These missions are focusing on obtaining accurate SM information over as much of the Earth’s land surface as possible. The main difficulty in the estimation of SM arises from the presence of vegetation which covers a large fraction of the Earth’s land surface. Microwave emission from soil is attenuated and scattered by the vegetation while the vegetation contributes its own emission. Accurately correcting for the effects of vegetation scattering and absorption over a wide range of vegetation canopies remains one of the ongoing challenges in the microwave estimation of SM.

There are a number of approaches that can be used to retrieve SM from low frequency passive microwave observations over vegetation-covered regions. They all use slightly different approaches to describe the soil and vegetation characteristics. Almost all of these are, nonetheless, founded on the same zero-order radiative (RT) solution due to its simple and intuitive nature. The retrieval model is usually referred to as the \(\tau-\omega\) (tau-omega) model. This model has extensive heritage and has been effectively used over generally light to moderate vegetated soils during SM field campaigns that cover mostly grasslands and agricultural crops under a variety of conditions. The current baseline SM retrieval algorithms for SMOS and the candidate algorithms for the SMAP radiometer are also based on this model.

The \(\tau-\omega\) model represents a zero-order RT solution that links terrain geophysical variables to the observed brightness temperature through microwave reflectivity and two vegetation parameters, the optical depth and the single-scattering albedo. The surface reflectivity is related to SM, surface roughness, and soil texture. The optical depth describes propagation within vegetation and it is related to vegetation water content (VWC) and canopy architecture. The single-scattering albedo is defined as the fractional power scattered within the vegetation layer and it also depends on vegetation properties such as plant architecture and VWC. There are several empirical and theoretical approaches available in the literature to calculate surface reflectivity and vegetation opacity for different surface and vegetation types. On the other hand, values for single-scattering albedo found in the literature are often limited to agricultural crop data, are not consistent with each other, and are difficult to compare due to varying assumptions and simplifications with respect to absorption and scattering within the canopy. Moreover, the theoretical formulation for single-scattering albedo is rarely used in all its complexity in the SM estimation algorithms.
retrieval studies. In general, the albedo is assumed to be zero or independent of time, polarization, and incident angle, and used as a fitting parameter.

This study aims (1) to provide a theoretical/physical framework to quantify the vegetation scattering effects on radiometric measurements of SM, (2) to provide a better understanding of the scattering albedo in the retrieval algorithms as applied to denser vegetation, and thus (3) to extend the usefulness of the $\tau$-$\omega$ model to a wider range of vegetation conditions.

**Approach**

In this study, the $\tau$-$\omega$ model is modified to more accurately account for vegetation canopy scattering, including multiple-scattering effects. The modified model, called the $\tau$-$\bar{\omega}$ (tau-omega bar) is developed. This model explicitly incorporates multiple-scattering effects into the effective albedo and differs from the original model only in terms of the form of the albedo used. An explicit expression is obtained for an effective albedo of vegetated terrain from the zero- and multiple-order RT solutions. The formulation establishes a direct physical link between the effective vegetation parameterization and the theoretical description of absorption and scattering within the canopy. While the single-scattering albedo represents single-scattering properties of vegetation elements only, the effective albedo takes into account all of the processes taking place within the canopy, including multiple scattering. In addition, the modified model has the same vegetation opacity as in the original model. This implies that the tau values in the $\tau$-$\bar{\omega}$ model preserve the physical description, thus leading to direct comparability with the values used in radar scattering models. This approach has important implications for microwave retrievals, particularly for NASA’s L-band SMAP mission, which will attempt to exploit combined active/passive observations for Earth applications.

To demonstrate usefulness of the new approach, the models are first tested against the Huntsville field experiment corn data set which represents stem-dominated vegetation. The investigation includes

- demonstration of the effect of the single-scattering albedo and multiple-scattering on the simulated microwave emission,
- comparison of the single-scattering and effective albedo formulation as function of angle of observation over wide range of angle at both polarizations,
- quantifying the effects of SM and VWC on the effective albedo.

The effective albedo formulation is also simulated for a soybean canopy (leaf dominated vegetation) which has a low scattering albedo (<0.1).

**Accomplishments**

- A theoretical/physical framework was developed to quantify the vegetation scattering effects on radiometric microwave measurements of soil moisture.
- Limitations of the existing tau-omega model with respect to vegetation scattering was assessed
- Effective albedo was related to single-scattering albedo explicitly.
- Soil moisture dependence of effective albedo was demonstrated.
Refereed Journal Publications

Conference publication/presentation


Task 613: Development of a holistic statistical framework for precipitation estimation; PI: C. Kidd; Sponsor: A. Hou

Description of scientific problem
i) improved multi-satellite/multi-sensor retrieval schemes
ii) precipitation errors and uncertainties – comparison with surface reference data sets – quantification of errors from surface reference data sets (NMQ & European)

Approach
Current work has concentrated upon two main aspects of the problem: i) the development of retrievals from the microwave sounding instruments to enable their contribution to a multi-satellite/multi-sensor precipitation retrieval scheme, and ii) an evaluation of surface reference data errors.

Cross-track sensor retrievals
The first aspect is currently being pursued through the incorporation of the passive microwave sounders into the new Goddard-Profiling (GPROF) retrieval scheme. The current scheme has two processing streams, one that utilizes an observational database based upon ‘historical’ matchups between the Precipitation Radar (PR) on the Tropical Rainfall Measuring Mission (TRMM) and the Advanced Microwave Sounding Unit-B (AMSU-B) and Microwave Humidity Sounder (MHS) on the National Oceanographic and Atmospheric Administration (NOAA) and the European Meteorological Operational satellites (MetOp) (developed in collaboration with Joe Turk, NASA/JPL) and the other using a database based upon the MMF model (developed by Toshi Matsui, UMD/ESSIC).

Through a series of collaborative meetings held at Colorado State University an initial working version of the retrieval scheme has been developed and run. This scheme is currently under evaluation; the retrievals are being evaluated against surface reference data sets. In particular, the representativeness of the MFF model-generated database is being evaluated. The plot below shows the mean brightness temperature (Tb) for a range of rainrates; the modeled database does not generate higher precipitation intensities identified in the TRMM-PR/MHS data base, and also under-represents the scattering signal generated by the hydrometeors.
Precipitation errors and uncertainties

This aspect of the work has focused on the errors and uncertainties within surface reference data sets, and in particular those inherent within surface radar network data sets. A study was carried out comparing the US-based NMQ surface radar data with the TRMM-based Precipitation Radar (PR). Although the TRMM-PR has a low-rain intensity sensitivity issue (the lowest reliably retrievable rain rate is about 0.7 mmh⁻¹), its great advantage is the consistency of its measurements. All surface radar data suffers from a number of issues, including a range dependency where the transmitted beam increases in altitude with range, leading to an underestimation at range. By mapping coincident PR and surface radar a comparison between the two can be made. In particular, the regions of disagreement can be examined; the figure below shows where the surface radar underestimates and overestimates relative to the TRMM-PR. These areas agree well with known surface radar retrieval quality; the PR identifies the underestimation of precipitation at the greater ranges of the radar coverage, while conversely, the PR indentifies regions of overestimation (lower figure) close to the radar locations and due to anaprop errors (such as backscatter from terrain or buildings). The color figure shows the Heidke skill scores for the PR-NMQ comparison; such comparisons will form the basis of combining multi-sensor (including satellites and surface data) into a ‘best available’ product.
Comparison of co-incident TRMM-PR and NMQ surface radar precipitation estimates over the southern United States. The top figure shows regions where the surface radar underestimates (with respect to the TRMM PR), the center figure shows where the surface radar overestimates (with respect to the TRMM PR), while the bottom figure shows the Heidke skill scores of co-incident TRMM-PR and NMQ surface radar precipitation estimates.

**Publications**


**Presentations**


Kidd, C. 2012: Validation of Surface Reference Data Sets using Satellite and Model Information. 6th IPWG meeting, Sao Jose Dos Campos, Brazil. 15-19 October 2012
Task 614: CloudSat-TRMM Intersection Processing; Graduate Student: Khoa Doan; PI: S. Ho; Sponsor: D. Starr

Description of Scientific Problem
Before the launch of CloudSat in April 2006, the Ku-band (13.8 GHz) Precipitation Radar, PR, aboard the Tropical Rainfall Measurement Mission (TRMM) was the only spaceborne radar capable of making rainfall measurements. The TRMM PR is designed for precipitation measurements over the tropics and is capable of measuring most rain rates greater than 0.7 mm/h with its $\approx 70$ dB dynamic range. However, its 17 dB sensitivity effectively makes the PR unable to measure light rains with rain rates less than or equal 0.7 mm/h. Although the W-band (94GHz) Cloud Profiling Radar, CPR, flown on CloudSat is designed for observing the vertical structure of clouds it is also capable of measuring light rains. The CPR’s light rain capability naturally complements the PR. In addition, the CloudSat CPR offers information about the cloud structure above the rain which is useful in providing better attenuation estimate for the PR.

The synergy of these two spaceborne radars possesses such a potential for benefiting the researches of cloud precipitation systems that it is only logical to pursue a combined product of the two. In this project, the main objective is the design and implementation of efficient and effective algorithm to extract the 2D-CloudSat-TRMM intersection data product. In addition to CloudSat and TRMM data, we also want to include data from Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), which is swath and whose orbits are similar to CloudSat, and from Tropical Microwave Imager Instruments (TMI), which are also swath and whose orbits are similar to TRMM, at the intersections of CloudSat and TRMM.

Approach
Develop an intersect algorithm to find the intersections of CloudSat and TRMM orbits, given a time precision for their intersections. The algorithm can be optimized based on the facts that CloudSat is sun-synchronous. Thus, regions that do not make a specific angle with the sun rays can be ignored.

AMSR-E data and TMI data are extracted by finding their intersection, which is a set of 4 points on the intersections of the outermost rays of each satellite’s swath. This set of 4 points can be optimally computed by using the CloudSat-TRMM intersection since AMSR-E has similar temporal orbits as CloudSat and TMI has similar temporal orbits as TRMM.

Accomplishments
We have successfully implemented our algorithm to extract TRMM-CloudSat data. We also finish implementation of AMSR-E and TMI data import into our final products. Our final step is to create a monthly processing job of this algorithm.
Task 615 - Real-time volcanic cloud products for Aviation Alerts; P.I.: Eric Hughes; Collaborator: Kai Yang; Sponsor: N. Krotkov

Description of the Scientific Problem
Volcanic eruptions can inject significant amounts of sulfur dioxide (SO2) and particulate matter (ash) into the atmosphere, posing a substantial risk to aviation safety. Ingesting near-real time (NRT) satellite volcanic cloud data is vital for improving reliability of volcanic ash forecasts and mitigating effects of volcanic eruptions on aviation and the economy. NASA volcanic NRT products from the Aura/OMI UV sensor can be currently accessed through a NOAA operational volcanic SO2/ash web site. We continue collaboration with NOAA and other partner organizations (USGS) to fully utilize and disseminate NASA SO2 and ash volcanic data to further improve their Decision Support System (DSS) for early warning. The satellite products will be enhanced with Aqua/AIRS data and continued using new SO2 and ash data from the next generation operational NPP/JPSS sensors.

Accomplishments
An initial evaluation of the GEOS-5 model’s ability to accurately simulate volcanic SO2 emissions has been conducted and the results are positive. An archive of GEOS-5 simulations of volcanic eruptions (SO2 only) has previously been generated, where crucial simulation parameters like SO2 injection altitude and amount had been estimated. The ability of the model to correctly simulate the dispersal of SO2 from eruptions was evaluated through a comparison with observed SO2 amounts following a few large eruptions. When the background sources of SO2 were removed from the simulation data, the simulated dispersal of SO2 closely agreed to the observed dispersal rates. This demonstrates that even with limited information about the initial eruption parameters, GEOS-5 can reasonably simulate the dispersion of SO2 from volcanic eruptions.

Figure 1. A comparison of SO2 dispersion following the eruptions of Okmok in 2008 (left), Kasatochi in 2008 (center), and Soufriere Hills in 2006 (right). The GEOS-5 simulations are shown in red, and the orange points show the same simulation data, but with non-eruption SO2 sources removed. OMI observations are shown as blue points.
There are a few cases that show a large difference between the simulated and observed dispersal rates. It is suspected that this stems from an incorrect model initialized SO$_2$ altitude, but further studies are needed.

Much time was spent on the development of a near-realtime (NRT) SO$_2$ retrieval algorithm for the NPP/OMPS instrument. This algorithm has been adapted from the NRT retrieval algorithm developed for the Aura/OMI instrument. The data being produced from this algorithm has undergone initial testing and is currently being adapted for operational implementation. This algorithm is expected to be running operationally by the end of the year, 2012.

![Figure 2. Column SO$_2$ observations from the NPP/OMPS instrument. These results were generated using the OMPS NRT SO$_2$ retrieval algorithm, adapted from the OMI NRT SO$_2$ algorithm (OMSO2).](image)

**Conference Presentations:**


Publications:
Task 616: GEOS-5 chemistry climate model development; PI: Elena Yegorova; Sponsor: Bryan Duncan

Description of Scientific Program
Methane’s concentration has more than doubled since pre-industrial times, but its observed growth rate has declined since 1980 and has remained near zero during much of the 2000s. The causes of the observed growth rate are not well understood. It is important to improve understanding of methane’s behavior because a) methane is the third most important greenhouse gas after water vapor and CO₂, with 25 times more global warming potential than CO₂ on a 100 year time scale, b) methane contributes to the formation of tropospheric ozone, which is harmful to human health, and c) methane is part of the nonlinear methane (CH₄)-carbon monoxide (CO)-hydroxyl radial (OH) system which largely controls the oxidizing capacity of the atmosphere. I am working on improving understanding of the observed variability of methane since 1980, using a computationally-efficient version of the NASA GEOS chemistry-climate model (GEOS CCM). The model accounts for the non-linear response to perturbations of the CH₄-CO-OH system.

The objective of this project is to understand the 1) sensitivity of methane to variations in OH and emissions and 2) causes of variability in observed methane, so as to lend confidence to projections of future methane growth.

Approach
1) Implement an existing parameterization of OH (Duncan et al., 2000) within the simple CO and simple CH₄ modules of the GEOS-5 CCM and allow for feedbacks between CH₄, CO, and OH in the model environment.
2) Perform idealized experiments of the coupled CH₄-CO-OH system to understand the sensitivity of methane growth rates to i) perturbations of variables used in the parameterization of OH (i.e. meteorological variables and chemical variables, including CO and methane) and to ii) CH₄ emissions.

Accomplishments and Achievements
I have implemented a parameterization of OH (Duncan et al., 2000; Duncan et al., 2007a) that accurately represents OH predicted by a chemical mechanism with a full representation of O₃-NOₓ-VOC chemistry as a set of high-order polynomials in meteorological variables (i.e., pressure, temperature, cloud albedo, water vapor), solar irradiance variables (i.e., ozone column, surface albedo, declination angle, latitude) and chemical variables (i.e., nitrogen oxides (as a family), ozone, and various VOCs), including CO and methane. That is, the 24-hour average OH is calculated interactively in the model and responds to changes in the concentrations of trace gases and meteorology.

Both methane and CO are tagged as functions of their sources and/or regions; in addition to the methane tracers from the CH₄-only option. The methane, CO, and OH tracers are not allowed to influence the dynamics of the AGCM directly or indirectly through radiative forcing; they are radiatively inactive. The same meteorology is used in all simulations so as to more cleanly isolate the impact of the causal factors on methane, CO, and OH.

I adjust the OH calculated by the parameterization to account for updates in kinetic and photolytic information since the parameterization was first developed. The primary production of OH occurs via the photolysis of ozone (J_{O(1D)}: O₃ + hv → O(¹D)), followed by quenching of
O(1D) by water vapor (k1: O(1D) + H2O → 2 OH). Competing reactions include quenching of O(1D) by N2 (k2) and O2 (k3). Therefore, the rate of OH production is represented by J_{O(1D)} * [O3] * 2*k_{1}[H_{2}O]/(k_{1}[H_{2}O] + k_{2} [N_{2}] + k_{3}[O_{2}]). To apply this correction, I multiply the OH from the parameterization by the rate of OH production using newer rate information divided by the rate of OH production using older rate information when the parameterization of OH was developed. Typically, this adjustment decreases OH by 10-30%, depending on altitude and season.

Figure 1 shows a comparison of zonal mean OH from two simulations: 1) an AGCM run with the CH4-CO-OH option and sea surface temperature (SST) boundary conditions for 2011, and 2) a NASA Global Modeling Initiative (GMI) Chemical Transport Model (CTM) run, which carries a full representation of O3-NOx-VOC chemistry and uses NASA Modern-Era Retrospective Analysis (MERRA) reanalyses for 2006 that were generated with the GEOS-5 AGCM and data assimilation system (Rienecker et al., 2011). The chemical variables required as input to the parameterization of OH were taken from the GMI CTM run. The meteorology used in these two simulations are not identical, which causes differences in clouds, the locations of NO emissions from lightning, etc. Nevertheless, the OH fields between the two runs are consistent, including in horizontal distribution at various pressure levels (not shown), illustrating that the parameterization of OH reasonably reproduces OH from a run with a full representation of O3-NOx-VOC chemistry.

![Figure 1. Comparison of OH from the AGCM run using the methane-CO-OH option (left) and a NASA GMI CTM run using MERRA reanalysis (right).](image)

I am implementing a computationally-efficient wetlands regression model (Walter et al., 2001; Shindell et al., 2004) into the AGCM to simulate this source of methane as a function of model precipitation and soil temperature; the regression model assumes a fixed distribution of wetlands, which is a reasonable assumption for our study period.
**Tasks 617 & 618: Global Floods and Landslides; PI's: R. Adler, H. Wu; Sponsor: F. Policelli**

**Description of Scientific Problem**
The objective is to develop, test and apply a global system for estimating floods and landslides using satellite precipitation information, other satellite data and hydrological models.

**Approach**
Lead effort to test hydrological models with satellite precipitation data and evaluate results in terms of floods and landslides with calculations made in real-time. This work is accomplished with colleagues at ESSIC and at Goddard Space Flight Center.

**Accomplishments**
The primary goal of this on-going activity is to adapt, improve, validate, and transfer a global flood and landslide technique to an operational entity so that it will be available for decision-making in support of disaster risk reduction activities around the globe. Our flood and landslide models are routinely running in real-time, with 3-hr updates, with graphic results appearing on the global flood website (http://oas.gsfc.nasa.gov/globalflood/) and landslide results on the TRMM web site (http://trmm.gsfc.nasa.gov).

Results from the project are being used by the DoD-sponsored University of Hawaii’s Pacific Disaster Center (PDC), providing a key link to the international disaster management community, International Red Cross and other national and international organizations to monitor global hazard events and plan mitigation strategies. A publication was produced on the further quantitative evaluation of the real-time global flood monitoring system (GFMS) in terms of flood event detection during the TRMM era (1998-2010) using a global retrospective simulation (3-hourly and 1/8 degree spatial resolution) with the TMPA 3B42V6 rainfall (Wu et al., 2012). According to the evaluation, we began to develop a new generation of the Global Flood Monitoring System (GFMS).

A major accomplishment this year has been the further development, test and integration of the new generation of the GFMS into the operational systems for evaluation and use by a wide array of users. We have examined and modified the Variable Infiltration Capacity (VIC) Model, which has been widely used to simulate spatially-distributed total runoff (quick and slow-response runoff) over global land areas at various spatial resolutions (e.g. 1/16th degree to 2 degrees). The VIC model also includes a snowmelt and soil frost module, which will also benefit the GFMS in forecasting spring streamflow and snowmelt related floods. To use the VIC model for real-time runoff prediction, we have adapted the VIC model from its original individual grid cell based running mode to a mode that is able to simulate spatially distributed runoff at each time step, i.e., running all the grids at each time step.

The user community needs high-resolution (~ 1 km) information for many applications of the flood information and the river routing module is the key to obtaining that information. We developed and justified an efficient, accurate and high-resolution river routing module-the hierarchical Dominant River Tracing-based Routing (DRTR) model and coupled it with the adapted VIC model for runoff calculation and routing to derive streamflow for each grid cell at each time step at variable spatial resolutions. The DRTR model outputs additional flood information such as flood magnitude, timing, flood wave celerity, river depth, potential inundation extent and depth etc. Together with the routing scheme developing, an upscaled
global hydrography dataset (including flow direction, river network, drainage area, river length, channel slope, overland slope etc.) which are critical inputs for macroscale hydrologic modeling in this study were developed and published by applying the hierarchical Dominant River Tracing (DRT) algorithm to the HydroSHEDS fine scale (1km) baseline hydrography inputs (Wu et al., 2011, Wu et al., 2012).

Refereed Journal Publications
Task 619: Impact of satellite sensor calibration on the long-term trend of global aerosol products; Graduate student: A. Jongeward; PI: Z. Li; Sponsor: X. Xiong

Description of the Scientific Problem:
Aerosols influence both the transfer of short- and long-wave radiation through the processes of scattering and absorption; this is known as the aerosol direct effect. Accurate understand of the overall radiative forcing due to aerosols is compounded due to their high spatiotemporal variability. Satellite observations on multiple platforms have been made since the late 1970s to measure aerosol loading and optical properties and have been used to constrain various types of models as well as in atmospheric reanalyses. However, inconsistencies exist between different satellite derived aerosol products which can result in discrepancies of up to 50% in aerosol optical depth (AOD), for example [Li et al. 2009].

Li et al. [2009] found that differences in satellite calibrations lead to the largest discrepancies in AOD, with cloud screening, aerosol model selection, and surface effects also contributing, albeit to lesser extents. Halthore et al. [2008] note that, due to sensor performance degradation following launch, prelaunch calibrations are generally not valid. This is further confirmed by Xiong et al. [2010]. Due to the weak radiometric signal of aerosols, high calibration accuracy and precision are needed as well as consistency across sensors in order to produce an accurate long-term aerosol climate data record time series [Li et al. 2009; Cao et al. 2008]. For example, a linear change of -0.01/decade in aerosol optical thickness (AOT) is reported from nearly 25 years of global and monthly mean AVHRR aerosol observations [Zhao et al. 2008]. Zhao et al. [2008] also showed that, given the same input radiances from AVHRR, differences in the calibration and retrieval algorithms can potentially double the long-term trend in AOT. Finally, Jeong et al. [2005] showed that the monthly mean AOD from AVHRR is globally lower than that of MODIS, with some regions having differences >0.5.

In the current study, the impact of satellite sensor calibration on the long-term trend of global aerosol products will be assessed, with a specific focus on NASA’s MODIS instruments. Other sensors of interest to this study are NOAA’s AVHRR and NOAA/NASA’s VIIRS instruments. The goal of this study is to improve the calibration of AVHRR radiances by utilizing MODIS and the long-term aerosol accuracy, ultimately providing a coherent and consistent method for the cross-calibration and normalization of polar orbiting satellites so as to continue the climatic record begun with the AVHRR observations over 30 years ago.

Approach:
The general approach for this study will be to determine a consistent calibration methodology for calibrating Channels 1 and 2 (solar channels) on all AVHRRs that have flown using the on-board, high accuracy calibration capabilities of MODIS. When first designed, AVHRR instruments were designed only to have on-board calibration capabilities for the thermal channels [NOAA KLM]. With the launches of two MODIS instruments and the newly launched VIIRS instruments, the historic AVHRR record can be continued thanks to the design similarities of the newer instruments. Precluding such a continuation is the calibration and validation of the entire AVHRR record to one calibration standard (MODIS) normalized across all sensors. Once accomplished, aerosol retrievals can be performed.
More specifically, the approach of assessing the impact of satellite sensor calibration on the long-term trend of global aerosol products consists of several steps:

- First, the entire AVHRR record must be calibrated, normalized, and validated. This will be accomplished by first calibrating recent AVHRRs using MODIS, then proceeding backward in time to calibrate and normalize older AVHRRs to the MODIS standard.

- It is anticipated that there will be several hurdles during the study. Known now are: spectral response function differences, orbital drifts, differences in digitization of the radiance signal, the dual gain nature of AVHRR/3 channels, and, most problematic, water vapor absorption in AVHRR Channel 2. There will also be unforeseen hurdles.

- Once calibration has been standardized among AVHRRs and AVHRR and MODIS, aerosol retrievals can then be performed using the AOT2 System (version 2.2), An Aerosol Retrieval System for Multi-Channel Radiometers, a universal aerosol retrieval system developed by Dr. X.-P. Zhao at NOAA, will be utilized to produce aerosol products. The advantage of using the AOT2 system stems from its consistent treatment of aerosol microphysical and land surface properties in the generation of aerosol products unique to each sensor, thus eliminating signal variations influenced by the use of different aerosol and land properties.

- A comparison between old and new AVHRR, MODIS, and VIIRS products will be of interest due to the similar onboard calibration capabilities of all channels of the latter two sensors and can shed light on the importance of onboard calibration capabilities.

- After aerosol products have been derived using the AOT2 System, a comparison with AERONET ground stations and other field campaigns will provide a ground truth to which the various satellite derived aerosol products can be compared.

- Finally, efforts will be made through the research process to ensure that such an in depth and comprehensive calibration and normalization project can easily be continued in the future to include other current sensors with similar characteristics, to include future sensors, and also for the update of the calibration standard, should a better, more accurate one become available or shown to be better.

**Accomplishments:**
In continuing with reviews of peer-reviewed literature, techniques have been found that will be incorporated into the current study, specifically those of the efforts from the ISCCP and PATMOS-x teams and their calibrations. Additionally, it has been found that AVHRR Channel 2 exists in a water vapor absorption band, and recent efforts by the authors have been looking into methods to mitigate such effects. Work on the current study has progressed to the point where the student, A. Jongeward, is currently writing a prospectus for his Ph.D. research at UMD. A conference presentation of current work and progress is expected during the current year.

**References:**


Task 621: Dynamic Downscaling and Urban Land Use; PI: R. Murtugudde; Collaborator: Bin Zhang; Sponsor: M. Imhoff

Note: Dr. Bin Zhang has left ESSIC as of 4/20/12. Dr. Marc Imhoff retired 10/1/12. The report that follows is from the previous cooperative agreement.

Description of Scientific Problem
This task provides additional support to look at the use of Terra and other data sets in the application of urban related impacts to the Chesapeake Bay environment within the context of the on-going CBFS. The Chesapeake Bay land use has been under great pressure due to population growth and sea level rise. Including the interaction among the atmosphere, ocean, land under a Regional Earth System Prediction Framework is important to study the impact of urban land use on the long term climate and short term weather and ocean forecasting.

Approach:
We will set up a coupled model to study the interaction of atmosphere and ocean over the Chesapeake Bay region. A Coupled-Ocean-Atmosphere-Wave- Sediment Transport Modeling System (COAWST) model has been used to couple the atmosphere/ocean/wave models for air-sea interaction studies in coastal ocean by coupling the Weather Research and Forecast Model (WRF), Regional Ocean Modeling System (ROMS) and wave models (SWAN) together. Here we use the interface of COAWST to study the simple coupling effects over Chesapeake Bay by coupling the WRF and ROMS together. We will apply this coupling system to the 14 days forecasting via downscaling ensemble NOAA GFS and seasonal forecasting via downscaling ensemble seasonal outlooks from the ECHAM4.5 of IRI at Columbia University. We will also use this coupling system to study the urban heat effects with a high resolution model a 2 km WRF model with couple ocean model.

Accomplishments:
Besides of our ongoing 14 days and seasonal forecasting of CBFS, a coupled ocean/atmosphere model over Chesapeake has been set up using ROMS3.2 and WRF3.1 over Chesapeake Bay. A simple comparison of the model results are shown in the figure. The transferring of ROMS SST to WRF has been successfully captured. Clearly, the wind patterns in WRF are different in a short time with/without coupling and so does the ROMS simulated SST.
Task 622: The Influence of the Urban Heat Island on daytime and nocturnal precipitation during the warm season; Graduate Student: M. Ganeshan; PI: R. Murtugudde; Sponsor: L. Bounoua

Description of the Problem
Several studies have highlighted the role of the Urban Heat Island (UHI) or the “thermal effect” in producing anomalous increases in warm season precipitation over and downwind of urban areas. Observational and model diagnostic analyses have typically pointed to the UHI-induced perturbed boundary layer circulation as the primary mechanism for urban rainfall enhancement. In this study, observations indicate the presence of a nocturnal downwind anomaly, which is comparable to the daytime peak in urban-enhanced precipitation. This suggests that the well-known UHI-circulation, which peaks during the day, is not the only leading mechanism to explain the rainfall increase in an urban environment. The role of thermodynamic instability, which is often considered secondary to the dynamically induced disturbance within the urban atmosphere, is investigated. The results indicate that urban areas can sustain increased thermodynamic instability during nighttime (higher equivalent potential temperature) that appears to play a significant role in enhancing downwind rainfall. This may place more stringent requirements on observations and models to resolve the UHI. Further investigation of this urban-enhanced nocturnal precipitation using modeling studies is underway.

Approach
The 30 m resolution National Land Cover Dataset (NLCD 2006) is used to identify urban regions over the continental US based on Impervious Surface Area (ISA) classification. Meteorological parameters such as temperature, cloud cover, relative humidity, obtained from NCEP’s Real-Time Mesoscale Analysis (RTMA) dataset (available at 5km resolution) are used to identify cities with a well-defined UHI. After carefully eliminating urban areas where UHI-impacts may be masked due to the diverse surrounding topography and water body effects, the precipitation patterns are analyzed for the cities of Minneapolis, Washington D.C., Houston and Dallas. NCEP’s Stage IV precipitation dataset, available at 4.7 km resolution, is used.

Accomplishments
Minneapolis and Washington D.C. receive most of their warm season rainfall through weak frontal systems or propagating storms. Each individual storm during June-August (2007-2008) is tracked and the associated urban and downwind rainfall anomalies are computed with respect to the upwind observations (see Fig.1). The anomalous increase in urban and downwind rainfall associated with propagating storms is observed to peak during nighttime and briefly during afternoon hours. Figure 2 shows the anomalous rainfall increase for storms passing through Minneapolis. The urban-enhanced precipitation during the afternoon may be associated with the well-known UHI-circulation. However, the nocturnal increase in precipitation appears to be related to the enhanced advection of equivalent potential temperature (θ_e). The top panel of Figure 3 shows the diurnal cycle of θ_e for Minneapolis during June-August (2007-2008) suggesting that the nighttime urban environment is thermodynamically unstable compared to its rural counterpart. The bottom panel shows a significant correlation between θ_e-advection and downwind maximum rainfall anomaly for nocturnal events.
Fig. 1 Schematic representing the urban, upwind and downwind impact regions defined based on the storm propagation axis for each individual storm.

Fig. 2 The mean and maximum rainfall anomalies for various propagating storms, calculated as the percentage change with respect to upwind values, for (a) urban region and (b) downwind region of Minneapolis. The blue asterisks and red circles indicate (a) the urban anomaly for maximum and mean rainfall, and (b) the downwind anomaly for maximum and mean rainfall, respectively. Shading indicates the diurnal period when precipitation increase associated with storms is maximum.
Fig. 3(a) The diurnal cycle of $\theta_e$-difference between Minneapolis (urban) and surrounding rural regions plotted for a period of 181 days (JJA, 2007-2008), and (b) the relation between downwind maximum rainfall anomaly and $\theta_e$-advection (for nocturnal storms), derived using the least squares method for curve-fitting. $R^2$ value represents the coefficient of multiple determination for the observed relationship. No such relation is observed for daytime storms.
**Task 623: Human appropriated net primary production study and biophysical modeling in global irrigation water project; PI: Zhengpeng Li; Sponsor: L. Bounoua**

**Description of Scientific Problem:**
Human demand for agricultural and forestry products greatly influences the carbon and water cycle in the terrestrial ecosystem. The main purpose of the research is to support the NASA’s research on estimating the ability of terrestrial ecosystem to support human demand in carbon and water. There are two research questions we focused this year: How much net primary production (NPP) from the terrestrial ecosystem is required for human consumption? How much water will be used on cropland in the world for irrigation to fulfill the demand of human food consumption?

**Approach**

**Human Appropriated Net Primary Production (HANPP)**
We used the United Nations Food and Agriculture (FAOSTATS) data to support the research in human appropriation of net primary production (NPP). We used a social-economic model, the Global Change Assessment Model (GCAM) developed by the Joint Global Change Research Institute in University of Maryland, to predict the human demand of NPP changes in the future. We developed algorithms to convert the output of the GCAM model to HANPP so it is comparable with the ecosystem NPP estimates from satellite. This research is completed because the NASA sponsor changed research priority.

**Biophysical modeling in global irrigation water project**
The simple biosphere model version 2 (SIB2) is used to estimate the irrigation water amount on the cropland in different part of the world. We will develop an algorithm to use SIB2 with remote sensing input data from MODIS. This algorithm is based on a published algorithm by Dr. Bounoua in NASA but needs further development. We will perform the test of this algorithm at multiple field sites, with calibration and validation of the model parameters. The developed algorithm will be applied with remote sensing data to estimate the water demand for irrigation globally.

**Accomplishments**
For the HANPP project, we updated the parameters in previous HANPP calculation based on new research results through the literature review. We also developed an algorithm to convert the GCAM model outputs to HANPP. We compared the NPP between the terrestrial ecosystem NPP estimated from remote sensing data and the NPP estimated from GCAM model outputs from 2005 to 2095 in the GCAM base scenario (Figure 1). The deficiency of the ecosystem was calculated at each region by subtracting the current ecosystem NPP estimated from MODIS from simulated HANPP from the GCAM outputs. Positive value of the deficiency means the NPP estimated from remote sensing is lower than the NPP required from human usage. The Africa, Mideast and Southeast Asia showed increasing deficiency from 2005 to 2050. This indicated that the terrestrial ecosystem productions in these regions are not sufficient to support the growing human demand for food and wood products. Australia and New Zealand, Canada, Former Soviet Union, Latin America, and Europe (eastern and western) all have sufficient ecosystem production from 2005 to 2050 which indicated that these regions have enough NPP to fulfill the
future demand of local human society and have the potential to export food and wood products to the other regions. This work is completed because the NASA sponsor changed the research direction.

Figure 1. Deficiency of the ecosystem production as predicted by the base scenarios in Global Change Assessment Model (GCAM)

In the global irrigation water project, the research focused on the processing input data for the biophysical model in this year. We have compared the precipitation and temperature data in 2001 from Modern-Era Retrospective analysis for Research and Applications (MERRA) project with Global Air Temperature and Precipitation (GATP) climatology data set to provide two files with correction ratios for MERRA 2001 temperature and precipitation. The comparison of monthly temperature showed very high correlation ($R^2 > 0.96$) between MERRA 2001 and GATP data. The monthly precipitation showed lower but still significant correlations ($0.84 > R > 0.74$). The two files containing correction ratios will be used in SIB2 simulation. We also processed the input short wave radiation data from MERRA and separated it into 4 fractions: beam visible (radvbc), diffuse visible (radvdc), beam near infrared red (radnbc), diffuse infrared red (radnde) for the global land pixels.

Figure 2. SIB2 calculated FPAR from AVHRR NDVI percentile and MODIS NDVI percentile for tall vegetation (evergreen broadleaf, deciduous broadleaf, mixed forest, evergreen needle,
deciduous needle) and short vegetation (cropland, grassland, shrub land and other non-forest land cover) using 2001 global MODIS NDVI

The original parameters used in SIB2 were developed with NDVI data from AVHRR. Since we will use MODIS data as input in the project, we need to generate a new set of the model parameters. We processed the MODIS NDVI to generate NDVI histogram for each land cover class. Then we used the published SIB2 algorithm to generate a new set of model parameters based on the 98% and 5% value of MODIS NDVI. We compared the results of calculated fraction of photosynthetically active radiation (FPAR) between two parameter sets (Figure 2). We found out using the original parameter set from AVHRR NDVI percentile obvious overestimate the FPAR for all the land covers. The new parameter data set is used to generate the biophysical drivers for model simulation. We have successfully run the program to generate the biophysical drivers globally at 0.25 degree with 2001 MODIS NDVI. We will run the program to generate the biophysical drivers at 5km spatial resolution in the USA in 2001. We are working on to publish the biophysical datasets of USA on the Journal of Dataset Papers in Geosciences.
**Task 624: Polar Climate System; Graduate Student: L. Boisvert; PI: J. Carton; Sponsor: T. Markus**

**Description of Scientific Problem**
In recent years the Arctic sea ice pack has become more vulnerable, thinner and less compact due to increased ablation in the summer months, warmer sea surface temperatures and air temperatures. The sea ice pack acts as an insulator between the surface and the lower atmosphere in the Arctic and since the ice pack is less compact and there is more open ocean present than ever before, there must be an elevated exchange of moisture between the ocean and the atmosphere. A larger flux of moisture in the Arctic can potentially lead to warmer temperatures in the winter months because water vapor is a greenhouse gas and it is thought that the excess moisture can lead to the creation of low-level clouds. Low-level clouds were found to trap outgoing longwave radiation, thus warming the Arctic. Warmer Arctic winters can lead to an earlier melt onset thus making the sea ice even more vulnerable.

**Approach**
Data sets from NASA’s Aqua satellite were used to calculate the moisture flux over the Entire Arctic from 2003-2009 using the Monin-Obukhov similarity theory. Use of multiple data sets from one platform is important because data are retrieved at the same time, which leads to better estimates. Monthly trends in the moisture flux over the Entire Arctic and in specific areas are being looked into for statistical significance. Trends in the moisture flux are also being compared with the Arctic ice concentration in order to determine if changes in the moisture flux are due to geophysical changes or changes in the ice compactness. Moisture fluxes will also be compared to the melt and freeze onset data sets to see if when the ice melts and freezes impacts the flux of moisture into the atmosphere.

Monthly moisture flux anomalies will be compared with MODIS (also on Aqua) cloud fraction anomalies to determine if increased moisture fluxes actually produce more clouds.

I am also working on estimates of ice accretion in the Arctic using datasets from the Aqua satellite in order to study changes in heavy ice accretion potential. This is important because as more ice melts away in the summer shipping routes will open, but if there is more moisture in the lower atmosphere from an increased moisture flux then there could be larger potential for ice accretion on ships making travel hazardous.

**Accomplishments**
I am currently on track to finish my thesis in February of 2013 and will hopefully have two more papers in press by then as well.
**Task 625: NASA MAP convection and NASA Aura analysis; PI: D. Allen; Sponsor: K. Pickering**

**Description of Scientific Problem**
Deep convection affects atmospheric chemistry in many ways. Three of the most important effects are transport of boundary layer trace gases and aerosols to the upper troposphere, wet removal of soluble species, and production of NO in electrically charged deep convection via the Zeldovich mechanism. The GEOS-5 Chemistry and Climate Model (CCM) and the offline Global Modeling Initiative (GMI) chemical transport model (CTM) are tools that can be used to study the impact of these sub-grid processes on ozone production, radiative forcing, and global climate.

As part of this project, we will use the GEOS-5 GCM as a tool to examine the sensitivity of trace gas distributions to details in the deep convective parameterization. Case studies will be performed for various field campaigns. In order to better constrain the LNO_x source, we will derive LNO_x production per flash estimates from a combination of Aura/Ozone Monitoring Instrument (OMI) observations, lightning flash rate observations, and output from NASA’s GMI CTM. Flash count estimates will be derived from the World Wide Lightning Location Network (WWLLN) data and scaled using detection efficiencies estimated through comparisons with flash data from the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS). OMI LNO_x will be retrieved downwind of the flash rate observations and production per flash will be estimated using data from the 2007-2008 time period.

**Accomplishments**
During the past year, I participated in three sub-tasks related to this project. These sub-tasks were: (1) participation in the Deep Convective Clouds and Chemistry Project (DC3) field campaign, (2) development of an algorithm for estimating total flash rates from WWLLN data, and (3) analysis of output from GEOS-5 CCM simulations with standard and perturbed parameterizations of deep convective mixing. A brief description of accomplishments in each of these sub-tasks is now provided.

The DC3 field campaign investigated the impact of deep convection including its dynamical, physical, and lightning processes, on upper tropospheric composition and chemistry. The field campaign was held over the central USA during May and June 2012 and included extensive measurements by three research aircraft including the National Science Foundation / National Center for Atmospheric Research Gulfstream V (NSF/NCAR GV) and the NASA DC-8. As part of this mission, I spent 14 days at the mission center in Salina, KS. I filled three roles while in Salina. In the early morning, I prepared and delivered a large-scale chemical weather forecast briefing. As part of this discussion, I summarized the contribution of biomass burning, stratosphere-troposphere exchange, urban pollution, and other factors to tropospheric atmospheric composition over three regions of interest: Colorado, Alabama, and Oklahoma. The summary was one tool of several used to determine where to fly that day and on following days. For flight planning purposes, I also used satellite data (e.g., NO_2 columns from GOME-2) and HYSPLIT trajectories to forecast the location of outflow from “yesterday’s” storms. Finally, in the afternoon (on flight days) I served as a mission coordinator for the DC-8 and was a link between the chief scientist in Salina and the chief scientist on the DC-8 plane. As part of my
duties, I monitored the location of the research plane with respect to the deep convection and communicated flight path change suggestions to the DC-8 crew. The suggestions were based on on-ground scientists’ analyses of real-time plots of meteorological observations and atmospheric composition.

In preparation for using WWLLN data to estimate lightning-NO emissions, WWLLN data for 2007-2008 were read in and gridded hourly as a function of local and universal time on a 2° x 2.5° grid. WWLLN detection efficiencies were then estimated by comparing WWLLN flash rates with flash rates from the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS). The resulting detection efficiencies for the 2007 to 2008 time period are shown in Figure 1.

In general, detection efficiencies of 2-8% are common over land and 5-20% are common over water. Uncertainties are relatively large because the number of sensors in the network increased during this time period. In order to determine how well this detection-efficiency adjustment worked, we compared detection-efficiency adjusted WWLLN flash rates over the United States with National Lightning Detection Network (NLDN)-based estimates of total flash rates (Figure 2). While differences at some locations during some months were large, the WWLLN network with detection efficiencies of only 4-8% over the USA produces a distribution that is similar to one produced by the NLDN network, which has cloud-to-ground detection efficiencies exceeding 90%. Therefore, with further refinement of the detection efficiency, WWLLN flash rates will provide useful flash rate information (especially at marine locations) that can be used to estimate LNOX production per flash.
Figure 2. Mean monthly averaged flash rates (flashes per 2°x2.5° grid box per minute) for May (top plot), June, July, and August (bottom plot) 2008 are shown. Left column shows NLDN-based estimate of total flash rate while right column shows detection-efficiency adjusted flash rates from WWLLN. Total flash rate (flashes per second) over model domain is shown in upper right caption of each plot.

Finally, as the third part of this project, trace gas profiles from CCM simulations with perturbed and standard deep convection were compared to each other and to profiles from the INTEX-A field campaign. Overall, the simulations showed that increasing the intensity of deep convection led to an increase in vertical mixing but also wet scavenging. Therefore upper tropospheric concentrations of soluble species were decreased considerably when the intensity of convection was increased. Figure 3 shows an example for HNO₃.

Figure 3. Mean CCM HNO₃ profiles during the INTEX-A field campaign from simulations with maximum, standard, and minimum deep convection are compared to the statistical distribution of INTEX-A HNO₃ measurements.

Conference Presentations
Task 626: Comparison of Air Quality Models with Satellite Observations for Improved Model Predictive Capabilities; Graduate Student: C. Flynn; Sponsor and PI: K. Pickering

Description of Scientific Problem
Satellite observations provide several important benefits to air quality, including improved forecasting ability for air quality models, assessment of air quality for attribution to specific sources, and improved estimation of source emissions. However, many challenging problems remain for the use of satellite observations in diagnosing near-surface air pollution. The column-integrated quantities retrieved from satellite instruments for key trace gases and aerosols must be interpreted correctly to derive information about near-surface conditions. Despite these challenges, a major scientific goal remains the use of satellite observations to improve and validate current air quality models for more accurate predictive capability. The DISCOVER-AQ field project provides surface, in-situ aircraft, and remote sensing data that will aid in the interpretation of satellite data for air quality. This project was conducted in support of this overall goal, by comparing satellite observations, aircraft measurements, and surface air quality datasets with air quality model output. Such a comparison may lead to better understanding of the factors affecting the correlation of satellite observations with current models.

Approach
The first deployment of the Earth Venture-1 DISCOVER-AQ project was conducted during July 2011 in the Baltimore-Washington region. The DISCOVER-AQ datasets, model output from the Community Multiscale Air Quality (CMAQ) model, and data from the Ozone Monitoring Instrument (OMI) onboard NASA’s Aura satellite were used in this analysis. Two different column amounts for O₃ and NO₂ were computed from the aircraft data. Column_air was computed through integration of the trace gas profile after extension of the lowest aircraft mixing ratio value to the surface, while column_ground was computed in the same manner but after extension of the surface mixing ratio value to the profile, if available. Model column amounts for O₃ and NO₂ were computed through integration of the model profile from the model surface through the depth of the aircraft profiles.

Correlation analyses were performed for O₃ and NO₂ for each of six Maryland Department of the Environment (MDE) air quality monitoring sites involved in the deployment, using the aircraft data, Pandora data, and CMAQ output. These correlations were performed for several different conditions, including separation of the column and surface data by the time of day, separation by height of the planetary boundary layer (PBLH, with thresholds of 1000m and 1300m), after normalization of the column amount by the concurrent PBLH, separation into background flow regimes, separation into temperature/humidity regimes, and separation into surface pollution regimes. The linear Pearson correlation coefficient (R) was computed for each correlation as a measure of the degree of fit of a linear relationship. This analysis investigated the impact that the preceding conditions may have on the column-surface correlation. A simple linear regression analysis was also performed for O₃ and NO₂ for each of the six surface sites and for an aggregate of data over all sites for the aircraft data; a simple linear regression was performed for NO₂ for all six sites for the Pandora data. The observed column abundance was used to predict the concurrent surface mixing ratio value, and errors relative to the observed mixing ratios were assessed.
Gao Chen (NASA/LaRC), Lok Lamsal (GESTAR/NASA/GSFC), and Jay Herman (JCET/NASA/GSFC) must be acknowledged for providing the aircraft, OMI, and Pandora column data, respectively.

**Accomplishments**

The correlation analyses indicate factors that may be important influences on the column-surface correlation. The aircraft data indicated that, for O$_3$, PBLH, background flow/transport, and surface pollution levels all had significant influence on the correlations. For PBLH, 5 of 6 surface sites increased in correlation from the Low PBLH group to the High PBLH group for both threshold values. For background flow/transport all 6 sites demonstrated increased correlation for the less polluted background flow regime than for the more polluted flow regime. For surface pollution levels 5 of 6 sites demonstrated the largest correlation for the cleanest surface pollution regime. The observational data do not indicate influences for NO$_2$ that are as strong as for O$_3$; however, normalization of the column by PBLH resulted in a moderately strong pattern of improved correlation over the original, full data set correlations for the aircraft and Pandora data sets. CMAQ indicated that the time of day influences the correlations, with increased correlation from morning to afternoon at all six sites for O$_3$ and NO$_2$. The CMAQ results further indicate that PBLH and mixing may be important influences for O$_3$, as the correlation increased as PBLH increased, consistent with the aircraft results. Background flow emerged as an important influence for O$_3$ within CMAQ, though correlation was larger at all sites for the more polluted flow regime unlike the aircraft results; the correlation also increased between the less and more polluted flow regimes at all six sites for NO$_2$, again unlike the aircraft results.

The simple linear regression analyses for O$_3$ demonstrated similar results for the slope, intercept, and value of the coefficient of determination ($R^2$) between surface mixing ratio and column_air and column_ground at each site and for the aggregate. All regressions were significant, with values of $R^2$ between approximately 60-90% for the individual sites; the values of $R^2$ for the aggregate were approximately 25%, indicating that information is lost when individual site data are combined. However, the results for column_air and column_ground NO$_2$ were often very different, with some non-significant column_air regressions. Values of $R^2$ for column_air NO$_2$ also remained below 15% (with the exception of Fair Hill at 41.5%), while the values for column_ground were much larger, between approximately 40-90%; the values for Pandora NO$_2$ remained generally below 35%. The values for the aggregate analyses were again smaller than for most of the individual sites, indicating a loss of information. The average percentage error of the regression relative to the observed surface data also varied among sites, but in general aircraft O$_3$ demonstrated smaller average errors than aircraft and Pandora NO$_2$, and aircraft NO$_2$ demonstrated less error than Pandora NO$_2$. These linear regressions results suggest that future satellite instruments with sufficient sensitivity to the lower tropospheric ozone can be meaningful for surface air quality analysis.
Figure 1: (top left) Scatter plots of column vs. surface value for the aircraft at Aldino for O₃. Column_air and column_ground data separated into the Low PBL group, data occurring for a PBLH at or below 1000m, and the High PBL group for data occurring at a PBLH greater than
1000m. (top right) Scatter plots of column vs. surface value for the aircraft at Essex for O₃. Column_air and column_ground data separated into flow regimes; Flow 1 for less polluted background flow and Flow 2 for more polluted background flow. (bottom left) Scatter plots of column vs. surface value for CMAQ at Beltsville for NO₂. Data separated into morning (before 12pm LST) and afternoon (after 12pm LST) groups. (bottom right) Scatter plots of column vs. surface value for CMAQ at Essex for NO₂. Data separated into flow regimes; Flow 1 for less polluted background flow and Flow 2 for more polluted background flow. Correlation coefficients are displayed on each plot. Column amount is plotted against surface mixing ratio value.

**Conference Publications**


**Task 627: Regional model simulations of meteorology and chemistry for the period covering the NASA DISCOVER-AQ field experiment; PI: C. P. Loughner; Sponsor: K. E. Pickering**

**Description of Scientific Problem**
It is difficult to interpret what satellite observations of air pollutants throughout the entire vertical column of the atmosphere means in terms of what pollutants people breathe at Earth’s surface. DISCOVER-AQ aims to close this gap by forming relationships between column content and surface concentrations. In addition, DISCOVER-AQ aspires to further improve how satellite observations are interpreted when large spatial and/or temporal variability of pollution is present. These goals will be achieved by using observations of air pollution and meteorological variables from satellite, aircraft, sondes, tethered balloons, ground, and ship based observations as well as meteorological and air quality model simulations to determine how current and future satellite observations can more effectively diagnose ground level air pollution. Observations were collected during the first of four field campaigns during July 2011 in the Washington, DC and Baltimore, MD metropolitan areas. Meteorological and air quality model simulations for this field campaign were performed and evaluated with observations and are now being analyzed to help interpret the observations and achieve the above mentioned goals. In addition, the observations and model simulations are being used to determine how Chesapeake Bay breezes impact air pollution levels, pollutant transport between the boundary layer and free troposphere, and the spatial and temporal variability of air pollution deposition.

**Approach**
Meteorological and air quality model simulations are being performed to achieve the above mentioned objectives by following these steps:

1) Simulate the meteorology for the DISCOVER-AQ field campaign with the Weather Research and Forecasting (WRF) model. Four modeling domains are used at horizontal resolutions of 36, 12, 4, and 1.3 km. The finest domain is centered over the Washington, DC and Baltimore, MD metropolitan areas and the Chesapeake Bay.

2) Prepare emissions input files for the Community Multi-scale Air Quality (CMAQ) model for the 36, 12, 4, and 1.3 km horizontal resolution modeling domains and the WRF model coupled with Chemistry (WRF-Chem) for the 36, 12, and 4 km modeling domains. Meteorological model output from the WRF model simulation is required as input for creating emissions input files for the CMAQ and WRF-Chem models. Anthropogenic emissions input files are created by processing projected 2012 emissions from the 2005 National Emissions Inventory with the Sparse Matrix Operator Kernel Emissions (SMOKE) model, biogenic emissions are created with the Model of Emissions of Gases and Aerosols from Nature (MEGAN), and biomass burning emissions are from the Fire Inventory from NCAR (FINN). WRF-Chem emissions input files are passed on to other scientists to perform WRF-Chem and NASA Unified-WRF (NU-WRF) model simulations.

3) De-bug the WRF-Chem model and pass on the model fixes to other scientists for them to incorporate into their versions of the WRF-Chem and NU-WRF model codes.

4) Prepare chemical initial and boundary conditions for the CMAQ model with output from the Model for Ozone and Related Chemical Tracers chemical transport model (MOZART CTM).
5) Run the CMAQ model for the 36, 12, 4, and 1.3 km horizontal resolution domains and make the model output available for other scientists to perform their own analyses.

6) Analyze the CMAQ model output alongside observations to evaluate the model simulation and investigate the role of the Chesapeake Bay breeze on air quality, vertical transport, and the spatial and temporal variability of air pollution concentrations, column content, and deposition over and near the Chesapeake Bay.

**Accomplishments**

Steps 1-5 described above have been completed. The meteorological and air quality model simulations have been evaluated with observations provided from the National Weather Service, EPA, and the DISCOVER-AQ field campaign. The model and observations are now being used together to investigate how the Chesapeake Bay breeze impacts surface air pollution levels, pollutant transport between the boundary layer and free troposphere, and the spatial and temporal variability of air pollution concentrations, column content, and deposition over the Chesapeake Bay watershed.

Observations and model results reveal that the bay breeze can exasperate surface air pollution levels at the bay breeze convergence zone and export a significant amount of air pollution out of the boundary layer into the free troposphere where it is susceptible to long range transport (Figure 1). This is significant, in that transporting pollutants from the boundary layer to the free troposphere impact climate and air quality far downwind. Once in the free troposphere, pollutants have longer lifetimes and are susceptible to long range transport. Pollutants have a larger impact on climate in the free troposphere than in the boundary layer due to their longer lifetime and greater impact on the radiative budget. Greenhouse gases, such as tropospheric ozone and water vapor, have a larger impact on climate in the free troposphere than in the boundary layer due to their ability to absorb outgoing longwave radiation from the surface and then re-emit the energy as a function of temperature. Since the temperature is cooler in the free troposphere, ozone will emit less radiation away from Earth’s surface in the free troposphere than in the boundary layer and so contribute to net heating.

**Conference presentations**


over Maryland and the Chesapeake Bay, DISCOVER-AQ Data Workshop, Newport News, VA.


**Figure 1:** CMAQ simulated (background) and observed (overlay) ozone concentrations along a flight track on 11 July 2011. The white line shows the location of the top of the boundary layer as calculated by the WRF model. The model was run with a horizontal resolution of 1.33 km. The highest surface concentrations on this day were located at Beltsville and Padonia, shown with the white letters “Be” and “Pa” in the figure, respectively. The aircraft spiraled over Beltsville at approximately 2:10 and 4:30 pm EDT and spiraled over Padonia at 2:30 pm and 4:50 pm EDT. The bay breeze convergence zone was located near Padonia. At this location, air pollutants were lofted upward and then were transported downwind aloft where they detrained out of the boundary layer into the free troposphere. High ozone concentrations are shown in the free troposphere downwind of the bay breeze convergence zone over Fair Hill, Aldino, Edgewood, and Essex, denoted by the white letters “Fa”, “Al”, “Ed”, and “Es”.

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Task 628: Using a Cloud-Resolved Model to Investigate the Redistribution of Trace Gases by Convection in the Atmosphere; Graduate Student: T. V. Lyons III; PI and Sponsor: K. Pickering

Description of the Scientific Problem
Convection plays a major role in transporting trace gases from the boundary layer to the free troposphere, particularly the upper troposphere. Whereas in the boundary layer these trace gases are short-lived and transported slowly, in the upper troposphere the trace gases have longer lifetimes and are transported rapidly over great distances. How these trace gases are transported is of great interest because some, such as ozone and water vapor, are important radiatively while others, such as carbon monoxide and methyl iodide, are relatively inert and useful for diagnosing vertical motion both in situ and in weather/climate models.

Measurements of these trace gases is done primarily in field campaigns. The data we have used comes from three field campaigns: the Tropical Composition, Convection and Climate (TC4) mission, which took place in July & August of 2007 in Central America; the African Monsoon Multidisciplinary Analysis, which took place throughout 2006 in West Africa; and the Deep Convection, Clouds, and Chemistry campaign which took place this year in the Central US, from May through June of 2012, which I personally participated in.

Approach
Our approach has been consistent throughout this investigation. We initially constructed a 'clear air' profile of each of the three trace gases (ozone, methyl iodide (where available) and carbon monoxide) from the aircraft. Every effort was made to ensure these 'clear air' profiles were unperturbed by recent convection. Then we inserted these tracer profiles into the WRF-ARW model, running each flight day three times, using different initial/boundary conditions (GFS, ECMWF, MERRA) We implement radiative and microphysical modules for the WRF model from NASA Goddard. The WRF simulations were two-way nested runs, with the inner domain having a cloud-resolving resolution of 3 km with explicit convection.

Our work in the DC3 campaign had a similar setup, but this modeling was done in real time in support of the campaign. Drs. Mary Barth at UCAR and Ken Pickering (among many others) ran WRF simulations for each day of the campaign. Instead of modeling these tracers, these simulations used lightning NOx and a generic boundary layer tracer to track the influence of convection (among other processes). Our task was to use the model output, which was produced every 12 hours throughout the campaign, to guide the flight missions towards fresh and aged convective outflow composed of LNOx and boundary layer air.

Accomplishments
Our simulations have continued to show skill in simulating well organized systems for the AMMA and TC4 campaigns. Trace gas profiles have shown clear influences of convection in the simulations, and also within the flight data as well. Less organized systems in both campaigns have been less successfully modeled, and we continue our work to understand what elements of the simulation (module choices, initial conditions, resolution, etc.) could improve these
simulations. Another continuing challenge is evaluating *post hoc* whether sampled parcels were or were not under convective influence.

Here our work during the DC3 campaign will provide a significant boon to improving TC4 and AMMA analysis. Throughout the DC3 campaign, it was necessary to provide decision making in real-time as to where to direct the flight sampling. To that end, we used the FLEXPART (courtesy of Jerome Brioude) and HYSPLIT (courtesy of NOAA) to back trace the origin of parcels in the upper troposphere. Real-time results from the DC3 campaign showed great success in using these tools. The DC3 campaign also showed encouraging results for using the WRF model at cloud resolving resolutions for decision making. Despite largely different regimes in the regions of focus, results were extremely promising. We will use our experience in this campaign to enhance our work going forward.
**Task 629: NOx production from lightning through analysis of Aura/OMI; Graduate Student: Allison Ring; Sponsor and PI: K. Pickering**

**Description of the Scientific Problem**
This effort is aimed at estimating NOx production from lightning through analysis of Aura/OMI tropospheric NO2 data. The second major data set to be utilized will be the World Wide Lightning Location Network (WWLLN) flash data. The OMI data (which have been retrieved especially for quantifying the lightning impact) and the WWLLN data will be allocated to the NASA Global Modeling Initiative (GMI) global grid. Analysis will be conducted on this grid to identify correspondence between major lightning events and the Aura/OMI overpass. Mean NOx production per flash will be computed for each grid cell.

**Approach**
The lightning data gathered from the World Wide Lightning Location Network (WWLLN) will be plotted for years 2007 and 2008 to describe daily, monthly, and seasonally occurring raw flash rates. This, coupled with flash rate information from Optical Transient Detector and Lightning Imaging Sensor (OTD/LIS) satellite instruments will provide an estimation of the WWLLN detection efficiency from which adjusted WWLLN global flash rates for 2007 and 2008 can be computed. Detection efficiencies for WWLLN derived from OTD/LIS and from the National Lightning Detection Network (NLDN) over the US will be compared in an effort to accurately determine the lightning detection efficiency, which is needed before quantifying NOx. Looking specifically at storm events, comparison of flash rate data to the Aura/OMI satellite NOx data, will help to quantify average NOx production per lightning flash (LNOx production). GMI simulations with and without lightning will be used to estimate background tropospheric NOx, determining scaling factors to ensure only LNOx is accounted for in the OMI data sets.

**Accomplishments**
To date, the daily, monthly, and seasonally occurring flash rates taken from the raw WWLLN data have been plotted on a global map. Plotting of the overpass files from the GMI model for 2007 has begun, comparing NO and NO2 at various times of the day, and for various altitudes (see attached figure). Further work has been done to develop an algorithm for retrieving LNOx from OMI data. This will be used to quantify NO2 production from lightning, with a lag time incorporated for atmospheric movement.
This figure shows the NO and NOx concentrations for July 5, 2007 at ~400 hPa. Overpass 1 occurs from 10:00-11:00 local time, overpass 2 from 13:00-14:00 local time, and overpass 3 from 21:00 to 24:00 local time.
Task 630: Development and Analysis Of Satellite-Based Aerodynamic Roughness Fields For Regional And Global Modeling Applications Using MODIS Data; PI: J. Borak; Sponsor: M. Jasinski

Description of Scientific Problem
The primary purpose of this task is to develop aerodynamic roughness fields at regional to global scales from MODIS data for improving models of land-atmosphere exchanges. The theory and algorithms have been developed by the task sponsor, Michael Jasinski, while the PI is primarily responsible for application of the algorithms. The sponsor and PI intend to develop and analyze other large modeled data fields from remote sensing products in the near future. In addition to the roughness research, the PI works with the GSFC sponsor on a statistical analysis of hydrological data as part of the sponsor’s involvement with the collaborative National Climate Assessment (NCA) project being carried out within the Hydrological Sciences Laboratory at NASA/GSFC.

Approach
The sponsor has expanded on earlier aerodynamic momentum roughness theory of M. Raupach, and extended it to produce parameters that are specific to vegetation type. The PI then employs these parameterizations with MODIS data products to generate a global time series of 1-km roughness fields. Also, the PI performs ongoing data reconnaissance in order to acquire validation data, as well as ancillary information about vegetation canopy height (e.g., from ICESat). The sponsor and PI are currently participating in the NCA effort by analyzing long-term records of snow water equivalent (SWE) derived from a) passive microwave remote sensing instruments; b) ground station measurements and c) land surface model output. In addition to SWE, they are also beginning to look at stream flow data. Over the past few months, the NCA work has become the primary focus of this task on a temporary basis.

Accomplishments
The key accomplishment for this task during the reporting period is the assembly of various analysis data sets for the NCA effort. Significant effort has been expended to acquire and process the disparate data into intercomparable forms. This is expected to continue as the sponsor and PI expand their analysis to include different hydrological basins and sub-basins. The actual analysis is still in a preliminary phase in a sense because the associated hydrological climate indicators will ultimately be derived from model output that has not yet been generated by other members of the NCA project. Once that output becomes available, the NCA work’s focus will shift to working with this modeled output.
Task 631: Microphysical Processes of Atmospheric Convective Systems; PI: T. Iguchi; Sponsor: W-K. Tao

Description of Scientific Problem
Cloud microphysics focuses on the physical processes on the scale from μm to cm orders in clouds. Not only it decides features of precipitation from clouds attributed to convective systems, but also it has a large impact on the overall structure of the system through heating or cooling by the water phase conversion and radiation process. Exact representation of cloud microphysics is thus an important subject of numerical studies for cloud and convective systems. We propose the development of the numerical model package to investigate a role of the cloud microphysics for the atmospheric convective systems.

Approach
We develop The Weather Research and Forecasting model coupled with Spectral Bin Microphysics for cloud (WRF-SBM), which can simulate a detailed structure of cloud microphysics in the particulate forms in idealized or real-case simulations. The development of the model is proceeded with collaborating on the project of the synthetic Global Precipitation Measurement (GPM) simulator. The coupling between the model and the Goddard Satellite Data Simulation Unit (SDSU) is aimed at providing Virtual Cloud Library (VCL) to support the development of the satellite retrieval algorithm in the GPM mission. The VCL is composed of ground validation (GV)-constrained 3D database of cloud resolving model (CRM) output and simulated GPM L1 product. The satellite retrieval algorithm can be cross-checked through a physical-based approach using the VCL as a priori database in the ground validation. We have three stages for the experiments: the Canadian CloudSAT/CALIPSO Validation Project (C3VP), Light Precipitation Validation Experiment (LPVEEx) and Midlatitude Continental Convective Clouds Experiment (MC3E).

Accomplishments
During this term, the WRF-SBM model was employed for simulations of the snowfall events during the C3VP, mixed-phase precipitation events during the LPVEEx campaign and continental convective precipitation events upon the MC3E campaign. The results of the simulations were archived in the VCL database of the preliminary validation stage and analyzed by comparing with observational data for the validation. In the analysis for the C3VP case, the WRF-SBM simulation has reproduced the distinct microphysical structures of the events characterized by presence or absence of riming process through an interaction with supercooled water. The VCL database is prepared to be opened in the Cloud Library website (http://portal.nccs.nasa.gov/cloudlibrary/)

The update of WRF-SBM made possible to represent a radar blight band associated with a melting layer. However, in the LPVEEx analysis, the WRF-SBM tends to overestimate the thickness of the bright bands as compared with the ground-based radar measurement. A modification for the calculation of melting process is now being developed. In the MC3E analysis, the WRF-SBM simulation successfully reproduced a classification of precipitation type observed in the ground-based instrument measurement (Fig. 1). The surface precipitation sampled by the ground in-situ instrument was divided into two distinct types: relatively large particle size with a proportionate increase in rain rate (convective) and small particle size less
correlated with rain rate (stratiform). The corresponding derivative simulated using the WRF-SBM result shows the similar characteristics, though the pattern tends to be more scattered.

Fig. 1. Two distinct modes (deep convective and shallow stratiform) of rainfall structure observed and numerically simulated around the ARM SGP site on 25 April 2011.

**Referred Journal Publications**

**Conference Presentations**
Iguchi T., T. Matsui, W.-K. Tao, 2012: WRF-SBM simulation upon C3VP field campaign for development of the synthetic GPM simulator, 5th international workshop for GPM ground validation, Toronto, Canada, July 10-12, 2012.
Task 632: Interactive processes between cloud-precipitation, land-surface, radiation, and aerosol processes; PI: T. Matsui; Sponsor: W-K. Tao

Description of Scientific Problem
Aerosols, cloud, and precipitation processes play major roles in describing earth’s energy and water budget and cycle. Thus, understanding of these processes and interactions via in-situ observations, satellite remote sensing, and state-of-art numerical modeling is essential for atmospheric scientists. However, links between satellite observations and modeling have been always untied, because assumptions in geophysical parameters are usually different between them. Thus, a new tool must be developed to overcome such issue, and facilitate modeling development using satellite observations.

Approach
The Goddard Satellite Data Simulator Unit (G-SDSU) is the comprehensive satellite simulator that can reproduce L1 signals of different instruments of NASA’s satellites from high-resolution aerosol-cloud-precipitation model simulations, including Goddard Cumulus Ensemble (GCE) model, NASA-Unified Weather Research and Forecasting (NU-WRF) model, Goddard Multi-Scale Modeling Framework (G-MMF), and WRF with Spectra Bin Microphysics (WRF-SBM). In this way, the performance of these modeling systems can be evaluated against the satellite L1 signals. This new evaluation is superior to the traditional evaluation using satellite L2 data, because satellite data and model has identical physical assumptions. The detailed and comprehensive evaluation guides us to a better direction in model improvements. Eventually, the realistic model simulations and simulated satellite signals can also support satellite missions by serving as satellite algorithm testbed.

Accomplishments
Dr. Matsui accomplished a new benchmark for supporting algorithm development of the upcoming NASA’s Global Precipitation Measurement (GPM) mission. It is the Synthetic GPM Simulator, which is the integrated framework to support the next-generation GPM satellites. It is not merely a satellite simulator. It is a combination of measurements from field campaigns, advanced regional storm model (WRF-SBM), and noble GPM satellite simulators. Essentially, in-situ observations from various field campaigns [GPM Ground Validation (GV) sites] were compiled to characterize precipitation systems; WRF-SBM-simulated precipitation systems are evaluated and constrained by the in-situ observations; and, finally, GPM-observable signals are simulated from the WRF-SBM-simulated geophysical parameters through the unified satellite simulators (the G-SDSU). In this way, this process conducts bottom-up approach that re-scales the in-situ scale (point), to the CSRM scale (1km), to the sensor footprint scales (5~30km), and eventually to the satellite swath scales (125km~ 1500km).

Simulated Orbital GPM Testbeds were generated from sets of 24-hr WRF-SBM simulations in various GV cases (Table 1). International Cloud Experiment (TWP-ICE) cases at Darwin Island, Australia (Li et al. 2012). Thus, total 240 (24hr×2golden cases×5sites) scenes of the GPM Microwave Imager (GMI) Level 1B and the Dual-Frequency Precipitation Radar (DPR) Level 2 orbital data are generated for supporting the GPM pre-launch algorithm developments (Figure 1). Uniqueness of this simulated orbital data is the inclusion of the detailed
L1B data as well as retrieval-like geophysical parameters derived from the WRF-SBM, such as rainfall rate, column water vapor, surface skin temperature, moments of precipitation PSDs. These geophysical parameters are also processed with the same antenna convolution method in the GPM instrument. So the satellite sensor-observable signals and algorithm-retrievable geophysical parameters are sampled in identical footprints, allowing algorithm scientists to quickly evaluate their algorithms.

For more convenient, the NASA Precipitation Processing System (PPS) team converts the data format identical to the GPM official HDF format. The initial version (V1) of the synthetic orbital databases becomes available at the NASA PPS ftp site (ftp://trmmopen.gsfc.nasa.gov/pub/simulatedData/). HDF product can be readily visualized and checked by new GPM-era free viewer THOR (the Tool for High-resolution Observation Review).

**Refereed Journal Publications**


Han M., S. A. Braun, **T. Matsui**, C. R. Williams (2012), Impact of cloud microphysics schemes in WRF model on the simulation of a winter storm as compared to radar and radiometer measurements. *Journal of Geophysical Research* (revised)


**Matsui, T.** and et al. (2012), GPM satellite simulator over ground validation sites, *BAMS*, (submitted).

**Seminars and Presentations**

**Matsui, T.**, T. Iguchi, X. Li, and W.-K. Tao (2012), Overview of the Synthetic GPM Simulator upon the high-latitude GV program (Invited), 5th International Workshop for GPM Ground
Validation, 10-12, June, 2012, Toronto, Ontario, Canada.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Location</th>
<th>Date</th>
<th>Details of Precipitation Systems</th>
</tr>
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<tbody>
<tr>
<td>C3VP (Canadian CloudSat/CALIPSO Validation Project)</td>
<td>Ontario Canada</td>
<td>1/19/2007</td>
<td>Lake-effect snow breeze. Narrow and shallow, but robust snow band.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1/21/2007</td>
<td>Large-scale homogeneous storm event.</td>
</tr>
<tr>
<td>LPVEx (Light Precipitation Validation Experiment)</td>
<td>Helsinki Finland</td>
<td>9/21/2010</td>
<td>Large-scale mixed-phase stratiform rain with relatively high (~2400m) altitude of melting band.</td>
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<tr>
<td></td>
<td></td>
<td>10/20/2010</td>
<td>Large-scale mixed-phase stratiform rain with low (~1000m) altitude of melting band.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5/20/2011</td>
<td>Severe convection and extensive stratiform rain.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2/05/2006</td>
<td>Isolated cumulus congestus.</td>
</tr>
<tr>
<td>HMT (Hydrometeorology Testbed)</td>
<td>California, USA</td>
<td>12/30/2005</td>
<td>Frontal orogenic mixed-phased rainfall (phase in).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12/31/2005</td>
<td>Frontal orogenic mixed-phased rainfall (phase out).</td>
</tr>
</tbody>
</table>

Table 1. Description of GPM Ground Validation (GV) sites and additional support sites, locations, golden cases, and precipitation systems.

Figure 1. Three dimensional view of the simulated GPM orbital data over TWP-ICE case. Bottom color-shaded terrain represents 15dBZ echo-top height of the DPR Ku band, and above horizontal slices represent microwave brightness temperature of the GMI 37GHz (V) and 166GHz(V) channels.
**Task 633: The impacts of aerosol on convective system with WRF; PI: Tzuchin Tsai; Sponsor: W. Tao**

*Note: Dr. Tsai left ESSIC on 4/30/12. The report that follows is from the previous cooperative agreement.*

**Description of Scientific Problem**
To evaluate the impacts of aerosol on convective system with WRF double-moment microphysical scheme

**Approach**
Aerosol can serve as cloud condensation nuclei (CCN) to initial cloud drops and regulate drop number and size, thus affecting precipitation development. But so far most microphysical schemes in the Weather Research and Forecasting (WRF) model crudely set cloud drop number as a constant. The CLR double-moment microphysical scheme based on Chen and Liu (2004), Reisner et al. (1998), and Cheng et al. (2010) keeps track of the mixing ratios and number concentrations with respect to five hydrometeors (cloud, rain, ice, snow, and graupel), 3 groups of CCN (dry or interstitial CCN, rain CCN, and cloud CCN), as well as a specified number of ice nuclei (IN) species. The information in rain and cloud CCN allows aerosol recycling from drop evaporations. In CLR scheme, condensation nuclei (CN) are assumed to compose of ammonium sulfate with a tri-modal lognormal size distribution. Cutoffsize CN to be activated into cloud drops depending on supersaturation according to Köhler equation.

**Accomplishments**
Now, CLR scheme has been implemented into the newly released WRF model version 3.3.1 to evaluate aerosol impact on cloud and precipitation. The Tropical Warm Pool—International Cloud Experiment (TWP-ICE) that took place over Australia (May et al., 2008) is selected for simulation. Comparison of the simulation results with observation and other double-moment schemes like Morrison scheme is analyzing.

**Conference publications**
Task 634: Applications, Evaluation, and Improvement of Goddard Multi-scale Modeling System; PI: B-W. Shen; Sponsor: W. Tao

Note: No funds have been expended on this task
**Task 635: Aerosol Characterization and Radiative Forcing Assessment Using Satellite Data and Models; PI: Hongbin Yu; Sponsor: Mian Chin**

**Description of Scientific Problem**
Aerosols affect the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei and, thereby, affecting cloud properties. Aerosols can be transported thousands of miles downwind, thereby having important implications for climate change and air quality on a wide range of scales. Enhanced new satellite passive sensors introduced in the last decade, the emerging measurements of aerosol vertical distributions from space-borne lidars provided the opportunity to attempt measurement-based characterization of aerosol and assessment of aerosol radiative forcing. Such satellite-based methods can play a role in extending temporal and spatial scale of field campaigns and evaluating and constraining model simulations. On the other hand, model simulations and measurements from field campaigns can provide essential parameters that satellites don’t observe. The overall goal of this research is to characterize aerosol distributions and assess the aerosol radiative forcing through an integration of multiple satellite observations and model simulations.

**Approach**
We address the scientific problems by integrating surface and satellite remote sensing measurements and model simulations. During the past year, we conducted three major tasks: (1) quantifying trans-Pacific dust transport and assessing contributions of intercontinental transport to aerosols in North America; (2) exploring the estimate of above-cloud aerosol by integrating complementary measurements from multiple A-Train sensors; and (3) assessing aerosol direct effects on radiation and climate.

**Accomplishments**
1. **Quantifying trans-Pacific dust transport and assessing contributions of intercontinental transport to aerosols in North America:** We published a study in Science (Yu et al., 2012a) that integrate satellite measurements from the Moderate resolution Imaging Spectroradiometer (MODIS) and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) to characterize the three-dimensional distributions of trans-Pacific dust transport and calculate mass fluxes of trans-Pacific dust. We found that on an annual basis, 140 Tg (1 Tg = 10^6 tons) of dust is exported from East Asia. After the trans-Pacific transport, 56 Tg of dust reaches the west coast of North America.

The work offers first satellite perspective of the contribution of foreign sources through intercontinental transport to the aerosol loading over North America, as shown in Figure 1. The total annual import of aerosols amounts to 64 Tg, including 56 Tg of dust via trans-Pacific transport, 4 Tg of combustion aerosols also via trans-Pacific transport and an additional 4 Tg of Saharan dust via trans-Atlantic transport (north of 20°N). The total import is nearly equivalent to the estimated total (69 Tg) of domestic emissions and production of particulate matter in North America. Collectively the imported pollution and dust introduces a reduction of cloud-free net
solar radiation of -1.7 and -3.0 Wm\textsuperscript{-2} at top-of-atmosphere and surface, respectively, which represents 31\% and 37\% of the total aerosol direct radiative effect over North America.


![Figure 1. Satellite-based estimate of annual dust mass flux in East Asia outflow and North America inflow (A). The import of aerosols to North America is 64 Tg/a (B), including trans-Pacific dust and pollution aerosols and trans-Atlantic dust, is comparable to the annual emissions and productions of aerosols of 69 Tg/a from major domestic sources in North America (C). Primary PM emissions include only anthropogenic sources (excluding prescribed fires).](image)

2. **Exploring the estimate of above-cloud aerosol from an integration of A-Train measurements.** Yu et al. (2012b) conducted an integrated analysis of aerosols above clouds by using multi-sensor A-Train measurements, including above-cloud aerosol optical depth at 532 nm (AOD\textsubscript{532}) from CALIPSO lidar, the UV aerosol index (AI) from OMI, and cloud fraction and cloud optical depth (COD) from MODIS. The analysis of Saharan dust outflow and Southwest
African smoke outflow regions shows that the above-cloud AOD correlates positively with AI in an approximately linear manner, and that the AOD\textsubscript{532}/AI ratio decreases with increasing COD. The dependence of AOD\textsubscript{532}/AI ratio on COD doesn’t depend on aerosol type when potential biases in the CALIOP AOD measurements are empirically accounted for. Our results suggest the potential of combining OMI AI and MODIS cloud measurements to empirically derive above-cloud AOD with a spatial coverage much more extensive than CALIPSO measurements, which needs to be further explored in the future.

3. **Assessing aerosol direct effects on radiation and climate.** Aerosol diurnal variation and its influence on aerosol direct radiative effect estimate have been studied with AERONET measurements over North and South America (Zhang et al., 2012). We have collaborated with scientists around the world in estimating aerosol direct radiative forcing by anthropogenic aerosols (Myhre et al., 2012) and identifying host model uncertainties including cloud fields, surface albedo, and radiative transfer scheme (Stier et al., 2012; Zhu et al., 2012). Most of the work in this area has been performed under the framework of the Aerosol Comparisons between Observations and Models (AeroCom). The AeroCom project is an open international initiative of scientists interested in the advancement of the understanding of the global aerosol and its impact on climate. In Collins et al. (2012), we assessed global and regional temperature-change potentials for aerosol direct radiative forcing based on ensemble model simulations of the Hemispheric Transport of Air Pollution (HTAP).

**Refereed Journal Publications**


Task 636: GEOS-5 atmospheric modeling and diagnostics; PI: A. Molod; Sponsor: M. Rienecker

Description of scientific problem
The GEOS-5 Atmospheric General Circulation Model (AGCM) has been developed for use in a wide range of applications, including data assimilation, weather forecasting and climate simulations at a wide range of resolutions. The climate simulations include atmosphere only, coupled atmosphere-ocean, and coupled chemistry-climate experiments. The model’s collection of physical parameterizations is of central importance to the success of the GMAO’s modeling effort. The last year’s effort was focused on the documenting the developments that lead to the current model, and beginning the development that will constitute the foundation for the next generation AGCM.

Approach
The basic approach is through multiple simulations in climate, weather forecasting and assimilation modes, analysis of model results based on comparison with observations, and new experiments based on hypotheses to ameliorate model-validation inconsistencies. This includes the development of innovative ways in which to compare model and observations, and innovative ways to inform the model’s parameterizations using observations.

Accomplishments
Lead authorship was taken on a NASA technical memorandum based on series of 30-year simulations at several resolutions that were performed with the Fortuna-2_5 version of the GEOS-5 AGCM. The report summarizes a comprehensive validation and documentation of many aspects of the simulations and included a description of the behavior of the mean climate as compared to different reanalyses and to satellite-based observational estimates of many facets of the simulation. The technical memorandum also includes the documentation of the model changes implemented to improve the simulations. In addition, the report shows the results of a series of experiments designed and performed to carefully attribute the differences between Fortuna-2_5 and MERRA AGCM simulations to specific changes in model parameterizations. Two peer-reviewed manuscripts were also written to describe two different aspects of the developments that lead to the Fortuna-2_5 AGCM, one in press and one in review.

The highest priority development that lays the foundation for the next generation AGCM is the ability to vary the vertical resolution of the model as well as the horizontal resolution. Previous AGCM development has focused on seamless simulations across changes in horizontal resolution, and the current development is focused on extending this “seamless” behavior to include changes in vertical resolution as well. Based on a single climate length atmosphere only simulation using 91 levels rather than the 72 currently in use for all simulations, the issues that result in a fundamental degradation in simulated mean climate were identified. Modifications to the moist processes in the AGCM are under way which will result in a description of each process that independent of vertical resolution. In addition, modifications have begun to be made to moist and cloud-radiative processes which exhibited abrupt threshold behavior, including the top-hat shaped subgrid scale probability distribution function for total moisture and the assumed size distribution of condensate. These abrupt behaviors exacerbate the changes in simulated climate at different vertical resolutions.
Objectives for next year

The development effort for the GEOS GCMs physical parameterizations during the coming year will begin with the completion of the algorithm changes needed to accommodate variations in vertical resolution. The next year’s effort will also include the initial exploration of fundamental changes in the cumulus and turbulence parameterizations. The increased horizontal resolution of the next generation AGCM necessitates a more accurate parameterization of shallow convection and balance between shallow and deep convection, and the increased vertical resolution necessitates a more accurate scheme for stable boundary layers. Ongoing efforts will also continue to correct long existing model biases, such as the underestimate of precipitation in the central U.S. in summertime, and the boreal summer tropical bias in precipitation.

Presentations


Molod, A. (2012), Constraints on the Width of GCM Total Water PDF from AIRS and High Resolution Modeling. CESM Atmospheric Modeling Working Group meeting, Boulder, CO.


Publications (lead authorship)


Proposal Submitted:

The Use of Observational Estimates of Planetary Boundary Layer Height to Evaluate and Improve the Simulation of Turbulent Processes in the GEOS AGCM. Submitted in response to NASA NNH12ZDA001N-MAP.
Task 637: Evaluation of NASA GMAO Models and Analyses in Polar Latitudes; PI: R. I. Cullather; Sponsor: M. Rienecker

Description of Scientific Problem
The work performed under this task relates to the modeling and analysis of high latitude processes in four specific areas which include (1.) MERRA appraisal in high latitudes, (2.) assessment of GEOS-5 model integrations, (3.) the adaptation of snow and sea ice parameterizations for GEOS-5, and (4.) sensitivity experiments using a dynamical ice sheet model (ISM) for use in coupling to GEOS-5. MERRA is a state-of-the-art global numerical reanalyses produced by the NASA GMAO for the period 1979 to the present. The work associated with MERRA seeks to characterize its performance over polar regions including the Arctic Ocean and continental ice sheets and, where appropriate, apply MERRA for the purpose of regional climate study. GEOS-5 is a finite-volume atmospheric general circulation model (GCM) that is used as the background model for MERRA and for decadal prognostic simulations. Understanding the performance of GEOS-5 in polar regions is important for improving model forecasts and future reanalysis products, and for improving our understanding of physical processes in high latitudes. Coupled to sea ice and ocean components, GEOS-5 participated in the recent Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) under a new category of initialized decadal prognostic simulations. As polar regions— and the Arctic in particular— are associated with recent, dramatic changes in the regional climate including a significant loss of perennial sea ice and significant glacier melt, a predictive capability on decadal time scales is of interest. Climate modeling remains a challenge in these areas due to sparse observations and the variety of physical processes that are encountered, which are associated with the various phases of water matter affecting clouds, precipitation, and surface characteristics. Two model deficiencies previously identified and addressed in the present work are the sea ice albedo and the surface representation over glaciated land areas. The representation of Greenland and Antarctica surface albedo and snow hydrology are of interest to a joint project with the NASA Cryospheric Sciences Laboratory for the coupling of an ISM to GEOS-5. In preparation for this work, an understanding of ISM performance characteristics is also desirable.

Approach
For MERRA, an assessment was conducted of the atmospheric moisture transport into the north polar cap (70°N–90°N). In contrast to prognostic surface fluxes from reanalyses, atmospheric moisture transport and convergence are generally considered to be more stable variables, and are a more direct product of data assimilation. Additionally, moisture transport provides additional information that relates the surface flux to atmospheric circulation. A comparison of reanalysis moisture transport and convergence fields over the north polar cap (70°N – 90°N) was made using MERRA, the interim re-analysis of the European Centre for Medium-Range Weather Forecasts (ECMWF; ERA-I), and the NOAA Climate Forecast System Reanalysis (CFSR). The comparison was conducted over the period 1989-2009. The monthly-averaged total transport is a pre-computed quantity in MERRA. The NCAR Climate Analysis Section has computed the total transports for ERA-I and CFSR.

An assessment of AR5 decadal forecasts with GEOS-5 focused on the predictability of Arctic sea ice cover in comparison to contemporary model forecasts. In earlier assessments of MERRA and
the GEOS-5 atmospheric model, it was noted that sea ice albedo is a fixed value \(a = 0.6\) and that this leads to a significant underestimate of the reflected shortwave radiative flux in the Arctic spring. The resulting erroneous surface energy balance produces an overestimate in surface temperature of several degrees. To address the problem, the ECMWF solution of utilizing a seasonally-varying albedo climatology has been applied to GEOS-5, and sensitivity experiments have been conducted to assess the improvement in model performance. A second issue related to the surface energy balance is associated with the surface representation over ice sheets. Currently, GEOS-5 uses a fixed subsurface temperature, and snow hydrology is not represented. This produces an annual mean net cooling of the atmosphere by glacier surfaces. Additionally, there is no melt runoff, and therefore no surface mass balance field is produced. Competing surface redesigns have been tested with the goal of having a unified snow model in GEOS-5. These configurations differ in the representation of the snow-ice interface. In the first, snow depth is a fixed value over glaciers, and snow is allowed to compact to the approximate density of ice. In the second, snow and ice are separately represented, and snow is allowed to accumulate to a maximum depth or melt to a bare ice surface. These configurations have been evaluated over the Greenland Ice Sheet (GIS).

Mass balance and temperature produced from the surface representation in GEOS-5 will be the primary input fields to be passed to the ISM in coupling. The ISM determines overall changes in glacier volume resulting from the dynamical flow of ice. In two-way coupling over land, the ISM would return ice sheet topography which, in turn, may feedback on temperature and surface mass balance. GCMs are typically run at grid spacings of tens to hundreds of km, while ISMs require a refined mesh spacing that may be less than 1 km in locations of high flow velocities. To understand the effects of this spatial discontinuity, a series of surface mass balance and temperature fields have been filtered at incrementally coarsened resolutions for the GIS domain. These fields have been used as input for the NASA JPL ISM. Additionally, the ISM has been forced with GEOS-5 output using the developed snow hydrology representation to simulate surface mass balance at 2° and ½° resolution.

**Accomplishments**

1. The meridional atmospheric moisture transport across 70°N has been evaluated in comparison to contemporary reanalyses and previous study. The zonal distribution of MERRA and ERA-I are in close agreement while CFSR differs in sign for the Barents Sea region. For ERA-I and MERRA, anomalous high-pressure patterns in spring and summer have resulted in decreased atmospheric moisture convergence in more recent years. Small but robust increases in October are associated with the presence of more open water at the onset of colder temperatures. These results were presented at the WCRP Reanalysis Conference in Silver Spring, Md.

2. Initialized simulations of Northern Hemisphere sea ice extent in GEOS-5 for the IPCC AR5 were evaluated in comparison to the NOAA GFDL CM2.1, the Max Planck Institute ESM-LR model, and observation. In a series of ensemble experiments with successively increasing greenhouse gas concentrations, it is expected that the simulated perennial sea ice as measured in the September ice extent will decrease with successive forecasts. Some skill is imparted to the early period of the forecast which, due to chaos in the climate system, is gradually reduced until the forecast eventually becomes out of phase with the observed variability. In the correlations with observed ice extent (Fig. 1), we see a marked decrease in the coefficient for two models: after forecast-year two in the MPI-ESM-LR, and after forecast-year three in GEOS-5. We interpret
this drop as the point at which the skill derived from the initialization has effectively eroded. In
the later period of the forecasts, the model is farther removed from the chaos of the climate
system resulting from initial conditions, and is more exclusively responding to the trend in
greenhouse gases. In this later period of the simulation, the correlation with observation
increases with forecast time. No change in skill is apparent in the GFDL CM2.1. Here, it is
suggested the model may have rapidly lost the skill provided by the initialization within year
one. The high correlation for the CM2.1 is then due to its ability to represent the forced response.
These results are being assembled for publication.

3. Model experiments have shown that an explicit representation of snow and ice separately
provides a better representation in comparison to observation. A review of the snow model
implementation is being assembled for publication. The snow model and sea ice albedo are
undergoing final testing for incorporation into GEOS-5 for use in the MERRA-2 reanalysis.

4. One hundred year ISM integrations are performed using specified input fields. In preliminary
results using the MacAyeal ice flow approximation, the coarsening of both input fields to 205km
resolution results in a GIS volume discrepancy that is equivalent to 5 times the standard
deviation of the ice volume over the length of the integration. Simulated total volume is more
sensitive to the resolution of SMB than surface temperature. At higher spatial scales, differences
in ice thickness and velocity vary over the ice sheet. These results are being presented at AGU.

Conference Presentations
Cullather, R.I., S.M.J. Nowicki, B. Zhao, and M.J. Austerberry. Sensitivity of a dynamical ice
sheet model to the spatial resolution of boundary conditions. *American Geophysical
Union Fall Meeting*, 3-7 December, San Francisco, Calif.

Cullather, R., and M. Bosilovich. A comparison of atmospheric moisture transports from
reanalyses for the north polar cap. *4th World Climate Research Programme International
Conference on Reanalyses*, 7-11 May, Silver Spring, Md.

Cullather, R.I., B. Zhao, S.M.J. Nowicki, and M. Suarez. Greenland surface mass balance from a
reanalysis-forced surface model. *IPY2012 From Knowledge to Action Conference*,
22-27 April, Montréal, Canada.
Figure 1: The correlation of ensemble mean decadal forecasts with observed sea ice extent values by forecast time for 1960-2010. All forecasts are initialized in January, so forecast month 24 corresponds to December of year 2 of the forecast, for example.
Task 638: GMAO Core MERRA Research & Evaluation of Global Water Cycle in Reanalyses; PI: J. Chen; Sponsor: M. G. Bosilovich

Note: No funds have been expended on this task.
Task 639: Integration of FEWS-NET into the Land Information System; PI: B. Wind; Sponsor: C. Peters-Lidard

Description of Scientific Problem
NASA's Land Information System (LIS) is a software framework for high performance land surface modeling and data assimilation. LIS has a host of flexible modeling and computing capabilities for land surface models (LSMs) in its framework. The USGS famine early warning system (FEWS-NET) stands to benefit from integration of its agricultural drought model, Water Requirement Satisfaction Index (WRSI), into LIS to form a customized FEWS-NET Land data Assimilation System (FLDAS). However, LIS is a general-purpose Fortran (LINUX/UNIX) code with C components in the core. But USGS's implementation of WRSI is a custom Visual Basic .Net (Windows) graphical user interactive (GUI) application. Hence, a phased conversion and integration process was required.

Approach
The approach to creating FLDAS-WRSI was as follows: Phase 1 required first the identification and conversion of core physics from the 20,000-line USGS visual basic code into a standalone fortran executable, and associated testing and debugging to ensure against lossy or inaccurate translation. In Phase 2 the fortran physics is being integrated with the Land Information System.

Accomplishments
After the last Master Grant Report update for this task early this year, this task has ended in May. Phase 2 benchmarking results were presented at USGS/EROS in Sioux Falls. Aside, most of B. Wind’s remaining time was spent in technology transfer to other project personnel. Specifically:

- Comparisons of spatial and temporal variations (for example dry & wet pixels) of drought indices and actual/potential evapotranspiration outputs for 2 sample months were done of the FLDAS-WRSI against FLDAS-Noah3.2, i.e., a ‘standard’ LSM inside LIS (see Figures 1 & 2). These results were presented at a project meeting held at USGS/EROS in Sioux Falls.
The executable files for conversion of GeoWRSI BIL binary files containing signed and unsigned data to GrADS-readable binary format was provided to other personnel on the project. This facilitates direct comparison of GeoWRSI and LIS outputs.

The RGB color palettes (and associated GrADS scripts) created and used for FLDAS-WRSI output (e.g., Figures 1 & 2 above) so that it closely mimicked the GeoWRSI screen output visual display, were provided to other personnel on the project. This enabled a later refining of these palettes to perfectly match the original GeoWRSI screen visuals (see Figure 2 for report on Task 643a in this Master Grant report).

Experimental work and testing was done for being able to use multiple standard (hourly, daily etc.) and non-standard (e.g., decadal, pentadal) time steps.

Together with S. Yatheendradas (Task 643a in this Master Grant Report), a bug in the FLDAS-WRSI code was corrected so that seasons that do not wrap around at the end of the year use the correct ending dekad and year of the season.

This is the final report for this task 639.

**Conference and other presentations**

**Task 640: Land Surface Emissivity Characterization and Dynamic Modeling to Support GPM; PI: Yudong Tian; Sponsor: C. Peters-Lidard**

**Description of Scientific Problem**
Land surface emissivity at microwave frequencies contains a wealth of information on the physical, biological and hydrological processes of the Earth’s surface. This forms the basis for remote sensing of a wide range of land surface states and processes such as soil moisture, vegetation characteristics and land cover dynamics. In addition, land surface emissivity acts as the background noise for the retrieval of atmospheric variables, such as rainfall and snowfall, and therefore greatly affects the accuracy and uncertainty in such measurements. Therefore better understanding and modeling of land surface emissivities will benefit remote sensing of both terrestrial and atmospheric processes.

**Approach**
We used seven years (from 2004 through 2010) of measurements by the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) onboard the Aqua satellite for our study. This selection is based on AMSR-E’s wide frequency range with dual polarizations and long-term coverage. AMSR-E is a conical-scan passive-microwave radiometer with a nominal incidence angle of 55°. It measures microwave emission for both horizontal and vertical polarizations at six frequencies (6.9, 10.65, 18.7, 23.8, 36.5 and 89.0 GHz).

The brightness temperature (Tb) measurements by AMSR-E are used to form two indices: one is the vertically polarized Tb at 36.5 GHz, which has been shown to be well-correlated with surface temperature; the other index is the microwave polarization difference index (MPDI) at 10.65 GHz, which is intimately related to a host of radiometric processes on the land surface but insensitive to the atmosphere.

Two microwave emissivity models were tested. One is NOAA’s Community Radiative Transfer Model (CRTM), and the other is the ECMWF’s Community Microwave Emission Model (CMEM).

**Accomplishments**
1. **Modeling dynamic emissivity with coupled land surface--radiative transfer models.** We have integrated both CRTM and CMEM into NASA’s Land Information System (LIS). We have extensively studied their sensitivities to various parameters and evaluated their performances over selected LSWG sites.
2. **Quantification of uncertainties in current microwave emissivity retrievals.** Using rainforest and desert as simple validation targets, we analyzed several emissivity data products and determined both random errors and systematic differences.
3. **Sensitivity studies and the regime diagram.** Despite the complexity in the full-scale models, our studies found that over snow-free land surfaces, the microwave emissivity variation can be primarily represented in a two-dimensional parameter-space with soil water content (SWC) and leaf area index (LAI). This regime diagram not only provides a more intuitive understanding of the surface emissivity dynamics, but also enables one to effectively predict the emissivity values.
4. *Dynamic regimes of microwave emission from various types of land surfaces.* We found over many types of land surfaces other than the ideal vegetation-soil complex, the microwave emission can exhibit qualitative different behaviors. This will be demonstrated and we are exploring ways to extend the RTMs to account for these complexities (e.g., rugged terrain, frozen soil and snow cover, etc.).

**Figure 1:** Dynamical regimes in the MPDI-Tb36V phase space for 12 diverse land surface sites, from the 7-year AMSR-E descending-pass (nighttime) observations. Ascending-pass (daytime) data produced similar results but with slightly higher Tb36V values.

**Figure 2:** Comparison of models and AMSR-E. Top: in the soil moisture-LAI regime space. Bottom: in the MPDI-Tb36V phase space.

**Refereed Journal Publications**


Conference Presentations

**Task 641: Quantitative Verification and Flash Flood case study using NASA Unified WRF (NU-WRF) Model and Land Information System (LIS); PI: Anil Kumar; Sponsor: Christa Peter Lidard**

**Description of Scientific problem**
From an energy and water cycle perspective, land-atmosphere interactions play a very crucial role in extreme weather events that can lead to drought or flash flood situation. To this end, the National Aeronautics and Space Administration (NASA) Unified Weather Research Forecasting (WRF) model (NU-WRF) coupled to Land Information System (LIS) (NU-WRF; [https://modelingguru.nasa.gov/community/atmospheric/nuwrf](https://modelingguru.nasa.gov/community/atmospheric/nuwrf)) modeling system at NASA's Goddard Space Flight Center (GSFC) has been developed with the goal to integrate satellite- and ground-based observational data products and advanced land surface modeling techniques to produce optimal fields of land surface states and fluxes. The atmospheric and hydrologic components of NU-WRF model is verified against surface and remote sensed data and used to understand the flash flood case study that was favored by the occurrence of unusual heavy rainfall over Leh city in India is a meteorological events coinciding temporally and spatially with favorable hydrologic conditions.

Secondly, we are also evaluating different microphysics scheme within NU-WRF model in high resolution model simulations.

**Approach**
(a) We made LIS spinups for period 01 Jan 2005 to September 2010 for multiple nested domains (12,3, and 1-km resolution). From the LIS based simulation we investigated hydrological parameters and found significantly high precipitation and high surface runoff over Leh during flash flood. The precipitation and soil moisture is unusual high during this event when compared on longer time scales.
(b) In second stage, NU-WRF coupled LIS and conducted high resolution simulation and investigated surface land-atmosphere and atmospheric interactions at mesoscale.
(c) Self-guided research on hurricane modeling, land-surface interactions: This work is mostly done in my own time frame (weekends).

**Accomplishments**
- Flash flood simulation using LIS and NU-WRF coupled LIS is conducted and investigated, this flood event is a combination of hydrological and Atmospheric processes. The journal paper is submitted and under review in JHM.
- NU-WRF model’s microphysics evaluation is underway as another paper and this paper is also a part of NU-WRF project.
- Modeling Evapotranspiration using two canopy resistance approaches. This work is in-press.

**Refereed Journal Publications**
Conference Presentation
Krishna K. Osuri1, U. C. Mohanty, Dev Niyogi, A. Kumar and A. Routray, Role of Land Surface Parameters on eye characteristics of cyclone Aila during landfall. Second WMO International Conference on Indian Ocean Tropical Cyclones and Climate Change, 14 - 17 February 2012 New Delhi – India.

Summary

- A coupled NU-WRF coupled land-surface and atmospheric model simulation validates this hypothesized storm scenario, with the model storm taking the form of a traveling mesoscale squall line with a leading convective line, trailing stratiform region, and midlevel inflow jet. In this region, development of a mesoscale storm over high terrain is highly unusual, especially one in the form of a propagating squall-line system. This unusual storm occurrence and behavior could serve as a warning sign in flash flood prediction. The atmospheric and hydrologic models together showed that the excessive runoff leading to the flood and landslide were favored by the occurrence of this unusual meteorological event coinciding temporally and spatially with favorable hydrologic conditions (see Figure 1 and Figure 2).
- On land-surface model development, LSM development work is required for better understanding of physical processes from leaf-level to the PBL scale. However, results continue to show that LSM components and coupling are very important in all aspects of weather and climate modeling systems, and are critical to explaining the role of carbon and biogenic emission on weather and climate. Our results also show that only with more sophisticated coupled Earth system models (e.g. atmospheric and hydrological)
components will we be able to predict extreme conditions provide detailed assessments of hydrological aspects such as precipitation amount and surface runoff (Figure 1).

Figure 1. LIS based hydrological parameters from May to August 2010 over Leh showing the following: (a) top soil layer (at 5 cm soil depth) soil moisture (m$^3$ m$^{-3}$), (b) hourly rainrate (mm hr$^{-1}$), and (c) surface runoff (mm hr$^{-1}$).

Figure 2. Total precipitation occurring between 0600 UTC 5 August 2010 to 0600 UTC 6 August 2010 from: (a) the bias corrected CMORPH merged with gauge analysis on a 0.25° latitude-longitude grid; (b) TRMM product 3B42; and (c) the NU-WRF model simulated precipitation from 3-km resolution domain. Leh is indicated on panels (b) and (c) with a black circle.
**Task 642: Development of the Land Information System (LIS) Framework; PI: K. Harrison; Sponsor: C. Peters–Lidard**

**Description of Scientific Problem**
NASA’s Land Information System (LIS) is a high performance land surface modeling and data assimilation system. LIS supports global water cycle research by predicting key variables of the water cycle, including terrestrial water, energy, and biogeochemical states. This task involves adding functionality to LIS through the addition of advanced algorithms to maximize the utilization of available data and science. These new capabilities will improve prediction of land surface and related states, and therefore global water cycle prediction.

**Approach**
Our specific objectives are:

7) Support of the Precipitation Measurement Mission (PMM) Land Surface Characterization Working Group (LSWG) by using physically-based models to estimate the dynamics of microwave land emissivity

8) Evaluate the uncertainty of land surface model predictions

9) Develop a new platform for conducting observing system simulation experiments (OSSEs), the goal of which is to evaluate the impact of remote sensing data on the quality of model predictions

**Accomplishments**
Accomplishments this year include adding the capability to directly assimilate satellite-observed radiances into the land models, further application of remote sensing data to address model bias in land surface models through parameter estimation, and evaluation of the uncertainties in land surface model predictions globally. Importantly, the capability for applying the underlying algorithms has been extended to allow for its application to land-coupled models such as the coupling of land surface models and radiative transfer models. Finally, a LIS platform for conducting OSSEs is under development. In Figure 1, an example OSSE result from initial testing of the OSSE platform is shown for an important question regarding the impact of a soil moisture satellite’s revisit time on the estimation of soil moisture.
Figure: The simulated impact of less frequent L-band observations on soil moisture estimation accuracy, as measured by the change in root mean square error (RMSE). Darker blue means a greater reduction in soil moisture estimation error; darker red means greater degradation. A more frequent satellite revisit time yields considerably greater improvement to a larger portion of the country.

Refereed Journal Publications
Task 643: A Land Data Assimilation System for Famine Early Warning; PI: S. Yatheendradas; Sponsor: C. Peters-Lidard

Description of Scientific Problem
This project proposes to enhance the operations of the Famine Early Warning Systems Network (FEWS NET), the US Agency for International Development’s (USAID) decision support system for high priority international food aid programs that safeguard the lives and livelihoods of tens of millions of the world’s poorest and most vulnerable people. Such enhancement will be through a unified land modeling and assimilation solution-based integration of a custom instance of NASA's Land Information System (LIS), specifically for the domains, data streams, and monitoring/forecast requirements associated with food security assessment in data-sparse, developing country settings. Increased specificity and confidence in FEWS NET weekly hazard assessments and seasonal food security outlooks will also be achieved. The science hypothesis interspersed with the human food security dimension is then that the higher quality hydroclimatic modeling made possible by FLDAS will lead directly to more accurate food security outlook (FSO) Integrated Phase Classification (IPC) maps of food security and humanitarian action officials.

Approach
The technical approach is composed of three components:
1. Implementation of a FEWS NET Land Data Assimilation System (FLDAS) from LIS, including addition or enhancement of multiple Land Surface Models (LSMs) like Noah and VIC (Variable Infiltration Capacity) besides the existing WRSI model used by USGS FEWS NET.
2. Application of FLDAS with seasonal climate and/or ensemble forcing forecasts to model outcomes for rain fed agricultural and pastoralist livelihood systems in the Greater Horn of Africa
3. Production of food security outlook (FSO) IPC maps based on the results of (2). Skill scores will be computed for the outlooks by comparison with actual outcomes to determine skill improvement after implementation of FLDAS.

Accomplishments
- In addition to the earlier LIS-incorporated rainfall reader of the original daily CPC/NCEP RFE 2.0 unprojected version (ftp://ftp.cpc.ncep.noaa.gov/fews/newalgo_est/) used in FEWS NET, a reader for this rainfall disaggregated to subdaily time steps using other data sources like GDAS has been written in collaboration with Clement Alo formerly at Johns Hopkins. This subdaily time stepping is relevant to running many LSMS.
- Incorporating crop types into LSMS like Noah need consideration of time-varying rooting depth and finer soil layer depth discretization etc. We implemented the former during our presentation at the NASA Drought Workshop in 2011.
- Some experimental corrections and numerical enhancement were done for the FEWS NET Water Requirement Satisfaction Index (WRSI) soil water balance model for crops, including a required but missing dynamic depth store following the crop dynamic rooting depth. These enhancements better represent the temporal variation in soil moisture and evapotranspiration, especially during the crop’s initial and developmental stages. The corrections are expected to improve predictions in subhumid regions. Recent work by the hydrological community has highlighted that explicit numerical formulation with operator splitting, such as that in the original WRSI water stores, can lead to model infidelity through loss of accuracy, stability
and reliability. At the recent 2011 Pecora symposium, it was shown for an example time step that this infidelity could be critical for the detection of drought in WRSI model based on the FAO-56 model, particularly in stressed conditions (Figure 1).

Figure 1: Effects of numeric correction on ET for different combinations of soil water holding capacity, time initial soil moistures and rains. The sharpening ET differences directly cause sharpening differences in agricultural drought index values basically calculated as the ET divided by PET.

- Benchmarking comparisons done of the FL DAS WRSI model against the FEWS-NET archive and GeoWRSI (Figures 2 & 3).

Figure 2: 2009 Oct-Feb end-of-season WRSI drought index from LIS-WRSI model (upper panels) and FEWS-NET archive and GeoWRSI (lower panels). LIS-WRSI is based on GeoWRSI. FEWS-NET archive and GeoWRSI crop start option differences reflect in differences in "No Start" areas.
• Figure 3 shows multi-model comparisons for the end-of-season drought indices. The VIC ET is based on standard land cover maps. Noah and VIC are drier as compared to the WRSI model. Noah and VIC were run assuming arbitrary “crop” parameters, with pre-defined seasonal cycle starts of vegetation greenness (GVF in Noah) or leaf area (LAI in VIC), in addition to fixed rooting depths and soil parameters. Such parameters need further improvement for East Africa Maize crops, e.g., rain-dependent crop cycle starts.

Figure 3: 2009 Oct-Feb end-of-season WRSI drought index (upper panels) and soil moisture (lower panels) from WRSI, Noah3.2 and VIC models in LIS.

Conference and other presentations
• S. Yatheendradas and A. McNally (2012), Land surface modeling in Africa with LIS, Oral presentation at the USGS FEWS NET Science Meeting on Agricultural Drought: New Directions in Risk Assessment, Monitoring, and Forecasting, UCSB, Santa Barbara, Calif., 2-3 Oct.
Task 646: Diurnal Variation of Tropospheric Trace Gas Amounts and Aerosol Optical Characteristics; PI: M. Tzortziou; Sponsor: J. Rodriguez

No funds have been expended on this task.
Task 647: Toward Thermally and Spectrally Controlled NIST-traceable Calibrations of Shortwave Radiometers; PI: Q. Ji; Sponsors: James J. Butler and Si-Chee Tsay

Description

A new calibration system has been developed in the NASA GSFC Calibration Development Laboratory consisting of a customized clean-room compatible thermal environmental chamber capable of calibrating irradiance sensors under the range of thermal environmental conditions typically experienced in the field.

Figure 1 shows a setup of the new calibration system. Figure 2 is an example demonstrating that even in a dramatically varying thermal environment the true irradiance can be correctly measured once the thermal effect is accounted for. This task contributed to our goal of reducing the uncertainty of pyranometer measurements of solar irradiance from 3% (hourly average) and 2% (daily average) to less than 1% (instantaneous).

Approach

Figure 1. This photo shows the pyranometer mounted on the dual rotation stage inside the stray-light control chamber (SLCC) in the thermal environment chamber (TEC). The front, top, and back panels of the SLCC have been removed for this photo. Light from the integrating sphere source enters the SLCC from the left through the TEC port window and a black baffled tube and illuminates the pyranometer. In this photo, the incident light angle on the pyranometer is about 45°.

Accomplishments
Figure 2. a. Pyranometer irradiance measurements as a function of time (light incident angle) and environmental temperature as temperature is increased; b. Pyranometer dome and case temperatures measured during thermal environment chamber heating; c. The temperature difference between the pyranometer dome and case during heating.
**Task 648: Joint Aerosol-Monsoon Experiment; PI: C. Li; Sponsor: S.-C. Tsay**

**Description of Scientific Problem**
Atmospheric aerosols, through interaction with clouds and alteration of the radiation, may influence the Asian Monsoon system, a critical component in the water cycle for this most populated continent of the world. Climate modeling studies of the aerosol-cloud-water cycle require detailed information about aerosol distribution and properties, which are highly variable and necessitate intense field deployments.

**Approach**
A regional field experiment was carried out in March-April, 2012 in Son La, northern Vietnam. Before the campaign, a suite of newly-acquired aerosol and trace gas instruments were integrated into the NASA/GSFC SMARTLabs COMMIT mobile laboratory. These included two BAM-1020 beta ray attenuation PM monitors, a custom modified NOx-NOy monitor (TECO 42c), three PMex aerosol extinction monitors, and a TSI 3-wavelength nephelometer. These instruments were selected to improve COMMIT’s capacity in measuring aerosol properties, in anticipation of the humid environment during the experiment. As a pilot study of 7-SEAS (Seven SouthEast Asian Studies), the field experiment was also participated by a team of scientists from Taiwan, who brought a number of aerosol and other pollutant samplers to be co-located with COMMIT.

During the 1-month field experiment, COMMIT was deployed at a hill-top site near the west edge of Son La, a town of about 50,000. Pollutant gases (CO, NOx/NOy, and O3), aerosol mass concentration, and aerosol scattering and absorption coefficients were measured throughout the experiment. The data set collected during the seasonal peak of biomass burning in Indochina will be used to characterize both local pollution sources and also long-range transported smoke aerosols from the west (northern Thailand and Myanmar). Our collaborators from both Taiwanese and Vietnamese institutions also showed great interests in the COMMIT laboratory and tours of the facility were provided at their request.

**Accomplishments**
A comprehensive data set was collected during the 2012 field deployment and has been archived by the SMARTLabs team at GSFC. Initial inspection and analysis of the data set indicate that it is of good quality and should be useful for studies concerning the climate impact of biomass burning aerosols from Indochina, a region with substantial aerosol sources but to this day is still largely understudied.

The paper presenting our analyses of the BASE-ASIA data, which presented the first comprehensive characterization of aerosol composition and optical/microphysical properties in Indochina, has been accepted by Atmospheric Environment after revision. It will appear along with a few other co-authored papers in an Atmospheric Environment 7SEAS special issue.

The study on the rapid transpacific transport of Asian pollution has been published in Journal of Geophysical Research - Atmospheres. This study discusses a new method combing A-train satellite data and trajectory modeling to systematically investigate the potential effect of Asian anthropogenic emissions on North America.
**Referred Journal Publications**


Description of the Scientific Problem

The first decade of the twenty-first century has been characterized by an increased awareness of global challenges for humanity and for our planet. On the human side, our world is facing serious social and economic problems. Increasing social inequality appears to exacerbate existing conditions of poverty, hunger, and unrest in many countries. Rising energy prices have resulted in increased food prices, a major topic of discussion during meetings of world leaders, e.g., the 2008 G8 Summit in Tokyo and the upcoming Rio+20 conference in Brazil. Long-lasting droughts in northeast Africa have caused a humanitarian crisis in Somalia; sudden drought conditions in Latin America (most notably Mexico in 2011 and Argentina in 2008) have yielded significant economic impacts due to losses in agricultural productivity. Rapidly growing population and high fertility rates is a major factor behind youth unemployment, which is as high as 30% in some Middle Eastern and African countries. Even the United States and the European Union struggle with unemployment and other symptoms of long-lasting financial and economic critical conditions.

Overall, drought, famine, poverty, terrorism, disease, conflict, social unrest, and economic state failure are just a few of these challenges, which we must overcome as regions around the world are constrained by factors such as availability of natural resources, a changing climate and population growth. Over-exploitation of natural resources, mostly non-renewable or very slowly renewable, has become a critical problem. Climate change has increased both frequency and severity of extreme weather events, including floods, droughts, and storm surges. Many of these challenges and driving factors are often intertwined, and understanding their coupling and dynamics is limited to commonly-used cause-effect analyses, which are insufficient. This will continue to be the case until transformative approaches are developed and implemented to positively affect stable and secure social, economic and political environments internationally. This proposal embodies such an approach.

Various governments, research institutes and international organizations have attempted to address several of the abovementioned challenges over the past decades. However, a case can be made that not only they are not being solved, but that many of them have actually worsened. We hypothesize that this overall outcome is due to the fact that past solution attempts have relied on approaches developed and implemented in isolated silos. For the most part, solution approaches in academia and research institutes have been discipline-oriented, i.e., with primary emphasis placed on only one aspect of the larger problem, e.g., policy, science, engineering, economics, etc. Governments and international organizations, i.e., development banks, think tanks, and NGOs tend to focus on a particular socioeconomic “sector” such as water, energy, agriculture,
and biodiversity, often ignoring the shared commonalities and connections (resources and constraints) between such sectors. Therefore, improved approaches and innovative methods are needed to tackle these global challenges. It is imperative to realize that finding solutions for these challenges that are actionable and sustainable requires a new paradigm that considers apparent and hidden connections between the natural and human systems.

Human population and consumption has grown significantly over the past few decades. The Earth’s natural resources were assumed to be practically infinite for the whole length of the history, but we are now realizing that they may be scarce. This has rung a bell for the policy makers, scientists, economists, and all other conscious individuals. Economic growth has reached an “uneconomic growth” phase. To cope with such issues, new fields of study like “ecological economics” are born. Several research groups around the globe have developed (mathematical) models to predict the future of human population and nature. Such models have helped scholars to understand and investigate possible scenarios for the future of life on our planet more thoroughly.

The most complete versions of such models incorporate population, climate, energy, water, and agriculture as main variables. However, some of these variables, like population, are taken as exogenous variables and therefore, the coupling between the variables is uni-directional. This means that, for example, increased population can affect climate by creating more pollution, but the climate change does not feedback on the population.

**Approach**

We will study the interactive dynamics of the five key sub-systems of the human-nature system: population, climate, water, energy/resources, food/agriculture. The last three subsystems will include an input/output economic module. This will be done through integrative activities that combine data acquisition (field-based and remotely sensed), analysis techniques, modeling, and data assimilation. We will propose, explore, analyze, and optimize measures and policies that can be implemented in practice for use in early detection of critical and/or collapsing conditions. We also aim to recognize parameters and externalities (such as inadequate measures or policies) that can play a significant role in occurrence of catastrophes and collapses. By adjusting the values of those parameters found to be influential through numerical experiments and simulations, we will generate short-term and long-term policy recommendations that can keep values of the system variables within a range that achieves sustainable development targets (e.g., millennium development goals or OECD targets).

When the prototype model is ready, we will work with the Climate@Home team to post the model on the web and allow many members of the public to test the impact of the model assumptions and parameters on the model behavior. Calibration of models is also a fundamental issue. We plan to apply the powerful tool of Local Ensemble Transform Kalman Filter (LETKF)
to calibrate the parameters of the model to the past 40 years or so of observed data.

**Current Stage of the project**

During the first three months of the project (Jan-Mar 2011), we developed a basic toy version of our model, with two variables, population and nature. Nature represents an aggregate of physical and natural resources. Although we could observe scenarios showing periods of growth and decay using that model, we were not content with the structure and possible outcomes. Kalnay and Motesharrei, together with Jorge Rivas (external collaborator from University of Minnesota), continued developing several versions of the model until Nov 2011. This latest version of the model, called HANDY (Human And Nature DYnamics), has population separated into two variables, Rich and Poor, as well as an additional variable, Wealth, which represents the accumulated physical wealth, i.e. consumable goods and products. Production is done by the Poor. Although the Rich does not work, it controls the Wealth.

We observed several interesting output scenarios of this minimal 4-variable model: steady-state equilibrium, overshoot followed by oscillatory approach to the carrying capacity, severe overshoot resulting in full collapse, and collapse after a long period of equilibrium. In Dec 2011, Motesharrei presented the above results for the first time at the AGU annual meeting in San Francisco, CA. He also presented the results at the Dynamics Days 2012 conference in Baltimore, MD, in Jan 2012.

In late Jan 2012, we also observed scenarios that explains the direct effect of high productivity per capita (long work hours) on unemployment. This result is also confirmed by the recent work of Knight, Rosa, and Schor. Knight et al. [2012] show, through a panel analysis of data for 29 high-income OECD countries from 1970 to 2010, that reducing work hours can contribute to sustainability by reducing ecological strain. Motesharrei presented this new result together with the earlier results at the Weather and Chaos Group semester kick-off seminar on Feb 6, 2012, at the University of Maryland, College Park, MD. Kalnay also presented these results on Feb 14, 2012, at the Jet Propulsion Laboratory (JPL) in Pasadena, CA.

We continued our experiments in spring and summer of 2012 with HANDY and discovered many implications of the model for two new types of societies. The original experiments were carried out for an unequal society. We performed new experiments for equitable and egalitarian societies. We found out that it is possible to attain equilibrium in such societies if the depletion rate is kept within a certain range. We also discovered possibility of reaching equilibrium in an unequal society, a result that we could not achieve earlier. Motesharrei was invited to give a lecture on HANDY at the Symposium of the Canon Institute for Global Studies in Washington, D.C., on May 10, 2012. Full results of the project are written in a somewhat long paper and submitted to the journal Ecological Economics. The paper is currently under review.
In summer of 2011, together with Jorge Rivas, Fernando Miralles (FIU), and Cortney Gustafson (visiting graduate student of Miralles from FIU), we developed a Human-Water model, COWA (Coupled Water model). We also created a simplified version of COWA, called SIWA (Simple Water model). COWA still needs further development. However, we were able to obtain some preliminary results from SIWA. We simulated effects of three different factors: pipeline leaks, water dispensing technology, and recycling capacity on sustaining the freshwater sources and supplies. We observed that there is a critical value for each parameter (interdependent with the value of the other two parameters) below which the lifetime of the supply can become very short. We are planning to present these results at the upcoming conferences and develop them for publication.

We also employed SIWA to study the causes of Famine in the country of Somalia. Gustafson represented results of that study at the AGU annual meeting in San Francisco, CA, in Dec 2011. Gustafson came back in Maryland in summer 2012 to continue her work with us on COWA.

We added a new source of water to SIWA, rooftop rain water, and did detailed experiments to obtain fixed-depletion-time curves in the parameter space of the model. Motesharreii gave an oral presentation of the results from the water project at the Chesapeake Modeling Symposium on May 21-22 in Annapolis, MD. The talk was very well accepted by the audience, consisting of both academics and practitioners.

In the current version of SIWA, water availability is primarily determined by precipitation and evaporation. Water from net river flow (river inflow minus river outflow) is assumed to be constant. We aim to improve the model by developing a river routing module that uses the runoff information from our Earth System Model. This module calculates runoff rates into and out of different regions using flow direction, distance, and slope data. This tool enables us to determine a realistic time series for river inflow and outflow rates in any region.

In summer 2012, Zhao wrote the Fortran code for the river routing scheme described in Miller (1994). Our external collaborator, Dr. Huan Wu of ESSIC/NASA GSFC, kindly provided us the recently compiled global Dominant River Tracing (DRT) based hydrography datasets, which contain high quality flow direction, distance, and slope data. After a long debugging process, Zhao successfully produced a rather realistic global picture of river flow rates by the end of September.

Zhao later examined the mean river flow at the mouths of eight major rivers over different regions of the world, and compared them against observed river discharge data. It is quite encouraging that the simulated river flow rates are quite close to the observations, although the values are consistently higher than observed river discharge. This is expected, as the simple
routing module has not taken into account the effect of dams/reservoirs, or human withdrawing water from river for irrigation and other uses. Zhao plans to improve the module by parameterizing these anthropogenic influences and applying LETKF data assimilation techniques. With the availability of time-series form the river routing module, we now have the capacity to simulate regional water availability under different climate scenarios in future.

Over past several months, we have submitted several proposals to various institutions and agencies. We have followed two major themes in these proposals:

1. Further development of HANDY by adding a population distribution and separating Nature into Renewable and Non-Renewable Sources. Kalnay and Motesharrei will be collaborating with Jorge Rivas, Victor Yakovenko (UMD, Physics Dept), and Matthias Ruth (UMD, Public Policy) for this project. A proposal was submitted to INET (The Institute for New Economic Thinking) which made it to the final round of the selection process, but did not win. A second proposal was submitted to SeSynC (Socio-Environmental Synthesis Center).

2. Coupling the water model to a climate model and a river-routing module, and adding an economic module to the water model. Kalnay, Motesharrei, and Zhao will collaborate with Ning Zeng (UMD, AOSC), Rivas, Miralles, Gustafson, and Toon Haer (visiting Masters student from the Netherlands) in this project. Zhao has worked on running the UMD-ICTP Global Climate Model (GCM) since his arrival in UMD in Aug 2011. He developed a river-routing module to be coupled to the UMD-ICTP Earth System Model. He also successfully passed his qualifying courses and exams in June 2012.

We submitted a proposal to the Maryland Water Resources Research Center which was not awarded a grant. However, the Director of the center, Prof. Kaye Brubaker, supported redeveloping the proposal for a major grant application to USGS. Our final proposal was submitted on Mar 8, 2012. This proposal received “outstanding” review from two of the reviewers, although the third reviewer did not support the project. We have joined Klaus Hubacek and Kuishuang Feng from the department of geography and are working on a grand proposal to NSF CNH program based on the USGS proposal.

While we are working on the already existing Population, Climate, and Water modules of our future Human-Earth-System model, we are planning to at least get started with the Food/Agriculture and Energy modules in the upcoming year. This NASA grant is an essential support for this pioneering work. In addition to the support from NASA and submitted proposals, we involve student interns (e.g., Gustafson and Haer) and external collaborators (e.g. Rivas) in this project. Although they are not supported by this grant, they make significant contributions to this pioneering interdisciplinary project. We will offer all of our models and results for potential integration into the Climate@Home project.
Task 650: Develop Satellite Snow Data Assimilation Capabilities into the NASA Land Information System (LIS) to Support NWS Hydrologic Applications in Alaska; PI: Y. Liu; Sponsor: C. Peters-Lidard

Description of Scientific Problem
Accurate snow prediction during snow accumulation and melting periods is essential for various hydrologic and water resources applications in snow-impacted regions. However, estimates of snow water equivalent (SWE) from current land surface models typically contain significant errors. Satellite-derived snow products, albeit subject to errors themselves, hold great potential for improving model snow predictions if properly processed and assimilated into the models. This project represents a collaborative effort between NASA GSFC and the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the NWS, which aims to develop reliable snow data assimilation (DA) capabilities in the NASA Land Information System (LIS) to support snow prediction in Alaska.

Approach
Our approach consists of three major steps: 1) conduct comprehensive benchmarking efforts to understand and analyze the primary uncertainty sources in the model snow predictions, by using multiple land surface models and multiple forcing sources; 2) adjust satellite observations of snow depth from AMSR-E against in-situ observations from NWS COOP stations and NRCS SNOTEL stations; and 3) develop reliable data assimilation approaches to assimilate the bias-adjusted AMSR-E SWE estimates and MODIS-based SCF products into the land surface model, and evaluate the performance gain from data assimilation.

Accomplishments
For the benchmarking effort, 10-year (10/1/2000-9/30/2010) high-resolution (0.01 degree, hourly) retrospective simulations were conducted with LIS 6.1 using three land surface models (i.e., CLM2, Noah 2.7.1, and Noah3.2) and three different precipitation forcing sources (i.e., GDAS, CMAP, and station precipitation). Our results indicate that a large portion of the uncertainty in snow prediction comes from precipitation and Noah3.2 performs better than the other two models. Hence, it was chosen for use in the data assimilation experiments.

Several snow products are assimilated into Noah3.2 using the LIS infrastructure. These include the standard 500-m SCF product (MOD10A1) from the MODIS, and the 5-km SCF estimates and snow depth (SD) estimates from a blended snow product derived based on data from the MODIS and AMSR-E, using the Air Force Weather Agency (AFWA)/NASA Snow Algorithm (ANSA). Compared to MOD10A1, the ANSA SCF product has reduced data gaps due to cloud cover, by blending information from MODIS and AMSR-E. The ANSA SD estimates are adjusted against in situ observations via statistical interpolation to reduce the potentially large biases in the dataset prior to the assimilation. An EnKF-based approach is used to assimilate SD, while a customized, rule-based direct insertion approach is developed to assimilate SCF estimates. Our results indicate that the largest improvements on snow prediction are achieved via SD assimilation, while SCF assimilation results in the best improvement on streamflow prediction (Figs. 1&2). When SCF and SD data are assimilated jointly, SD assimilation tends to have the dominant influences on the results. The results also shows that filling gaps in the MODIS SCF dataset caused by cloud cover with AMSR-E data can significantly increase the...
information content of the SCF data, resulting in substantial improvements on snow and streamflow predictions (Figs. 1 & 2).

The snow bias correction and assimilation capabilities developed as a results of this research is being transferred to other regions such the contiguous US and will be delivered to our users including the NWS. An LIS DA tutorial will be offered on November 27-29, 2012 to assist the users in using the new snow DA and other assimilation capabilities in LIS.

Figure 1. The mean difference in RMSE between the open loop (no DA) and assimilation runs over the study domain for December, May and March. MODIS_DA: assimilating the standard the MODIS SCF product; SCF_DA: assimilating the ANSA SCF product with reduced cloud coverage from combining MODIS and AMSR-E; SD_DA: assimilating the bias-corrected AMSR-E SD estimates; SCF+SD_DA: assimilating simultaneously both ANSA SCF and AMSR-E SD. Overall, assimilating SD results in best performance in snow prediction; and assimilating ANSA SCF leads to better results than assimilating the standard MODIS SCF due to reduced cloud coverage in the former product.

Journal Publications


**Conference Presentations**


**Task 651: The Impact of using Lidar Network Data for a Summertime Cold Front Case Study: Graduate Student: S. Rabenhorst; PI: D. Zhang; Sponsor: D. Whiteman**

*Note: Dr. Scott Rabenhorst received his PhD and departed. The report that follows is from the previous cooperative agreement.*

**Description of Scientific problem**
Observation acquired during the Water Vapor Variability – Satellite/Sondes (WAVES) 2006 field campaign, centered at Beltsville, MD, provided a unique contiguous five-day period of concentrated high temporal and vertical resolution observations to examine fine-scale detail of a weather regime typical of the summertime Midatlantic area. The observations captured several interesting meteorological phenomenon that could not be explained from observations alone. Therefore, a modeling study was conducted to investigate these peculiarities. The Weather Research and Forecasting (WRF) model was used for detailed simulation of the 1-5 August 2006 events.

**Approach**
Prior to an in-depth analysis of the August 1-5 2006 case study, studies were conducted in four areas assumed to be most sensitive to the model: (1) initial condition data set, (2) cumulus parameterization, (3) planetary boundary layer parameterization (PBL), and (4) initialization time. WRF verification was performed using the Model Evaluation Tools package using the WRF post processing software. Several observation sources were used in the verification process. Field measurements from Beltsville were used, including local radiosondes, lidar measurements, 31-m flux tower measurements, and surface measurements. More broadly, the National Oceanic and Atmospheric Administration Meteorological Assimilation Data Ingest System (MADIS) data was used. Lastly, National Center for Environmental Prediction Stage IV data was used for precipitation comparisons. Several sensitivity runs were conducted and findings analyzed to determine appropriate model optimization for the case study. Following this, several high resolution model runs were conducted to explore the spatio-temporal evolution of the atmosphere during this case study.

**Accomplishments**
The model sensitivity studies were done using 54-hour forecasts with an 8 km grid over the eastern US. For the initial condition sensitivity tests, verifications were performed using runs initialized with North American Regional Reanalysis (NARR), North American Mesoscale, and Rapid Update Cycle analysis data. Cumulus sensitivity was done using four runs parameterized with: Kain-Fritsch, Betts-Miller-Janjic, Grell-Devenyi, and Grell-3D schemes. A fifth control run did not use any cumulus scheme. The PBL testing was done comparing the following parameterizations: Asymmetric Convective Model, Bougeault-Lacarrère, Medium Range Forecast, Mellor-Yamada-Janjic (MYJ), Mellor-Yamada Nakanishi and Niño Level 2.5 and 3, Quasi-Normal Scale Elimination, and Yonsei University. Lastly, initialization time sensitivity tests used five runs starting every three hours throughout the convective afternoon period. The sensitivity study indicated the optimized results for this East Coast case study were found using the NARR data for initial and boundary conditions, no cumulus scheme, MYJ PBL parameterization, and a 12Z initialization time.
Precipitation forecasts were challenging under this weather pattern. Most cumulus parameterizations were found to overestimate precipitation across widespread areas. Optimal spin up time was found to be 5-6 hours. Less time led to premature precipitation. More time led to significant forecast divergence from observations. Prognostic turbulent kinetic energy (TKE) schemes performed best even in convective regions. Even PBL profiles using TKE local closure schemes were over smoothed and over mixed. Overall, it is believed these parameters best represent Midatlantic, and more generally, east coast observations during summertime stable subsidence weather regimes.

High resolution modeling corroborated field observations. Two significant events were simulated: a nocturnal low-level jet (NLLJ) and a cold front passage. A prominent diurnal cycle was revealed that could be categorized into three stages: (1) daytime PBL growth through convection, characterized by increasingly calm southwesterly wind, (2) flow intensification after dusk, with conditions favorable for NLLJ development, and (3) interruption by downslope gravity winds (DGW) after midnight. The third stage is perhaps most interesting owing to the lack of literature documenting similar DGW occurrences in the Midatlantic. The DGW event was confirmed to be the overt but previously inexplicable signature in Beltsville field observations. More interestingly, the DGW event has a diminishing effect on the Midatlantic NLLJ that suppresses reaching mature development. Perhaps air quality forecasts are most affected by this nocturnal phenomenon.

Figure 2. This plot shows wind direction at 500 m above sea level. The Midatlantic nighttime DGW event resembles a cold front within the lowest kilometer of the atmosphere and displaces the NLLJ regime, clearing out summertime air pollution overnight.
Task 653: NASA In Situ Airborne Formaldehyde Measurements during DC3 and SEAC4RS Field Campaigns; Graduate Student: Heather Arkinson; PI: R. Dickerson; Sponsor: T. Hanisco

Description of Scientific Problem
Formaldehyde (HCHO) is a highly reactive and ubiquitous compound in the atmosphere that originates from primary emissions and secondary formation by photochemical oxidation of volatile organic compounds. HCHO is an important precursor to the formation of ozone and an ideal tracer for the transport of boundary layer pollutants to higher altitudes. In situ measurements of HCHO are needed to improve understanding of convective transport mechanisms and the effects of lofted pollutants on ozone production and cloud microphysics in the upper troposphere. The Deep Convective Clouds and Chemistry Project (DC3) field campaign was designed to address the effects of deep, midlatitude continental convective clouds on the upper troposphere by examining vertical transport of fresh emissions and water aloft and by characterizing subsequent changes in composition and chemistry. In situ observations targeting convective storms were made over Colorado, Alabama, Texas, and Oklahoma from the NASA DC-8 Airborne Science Laboratory during the DC3 campaign in May and June 2012. The Southeast Asia Composition Cloud Climate Coupling Regional Study (SEAC4RS) was designed to investigate the effects of Asian emissions on clouds, climate, and air quality, focusing on the influence of the Asian monsoon circulation and convective redistribution on upper atmospheric composition and chemistry. SEAC4RS was originally scheduled to be performed from a base located in U-Tapao, Thailand during August and September 2012, but the campaign was canceled due to the absence of necessary approvals from regional authorities.

Approach
Under this task, graduate student Heather Arkinson participated in the DC3 field campaign and was slated to participate in the SEAC4RS field campaign. Key tasks included operation of the In Situ Airborne Formaldehyde (ISAF) instrument on the DC-8 during field measurements and maintenance and calibration of the instrument during laboratory experiments performed before and after field deployment. The ISAF instrument detects HCHO via laser induced fluorescence (LIF). This method provides the fast time response and sensitivity required to detect HCHO in the finely structured outflow of convective storms and in the upper troposphere and lower stratosphere where mixing ratios are on the order of 10 parts per trillion (ppt). Measurements of HCHO from the DC3 and SEAC4RS campaigns were intended to elucidate mechanisms and consequences of convective transport and to quantify effects of boundary layer pollutants on photochemistry and microphysics in the upper atmosphere.

Accomplishments
Heather Arkinson successfully fulfilled the responsibilities necessary for running the ISAF instrument on the DC-8 for Science Operations during DC3. This required detailed knowledge on the theory, operation, calibration, and maintenance of the instrument. Additionally, Heather became proficient in working with the LabVIEW software and MATLAB programs utilized to interface with the ISAF instrument and to post process the HCHO data. To obtain the requisite knowledge and skills for operation of the instrument during DC3, Heather spent time at the NASA Goddard Space Flight Center laboratory where the instrument is under development, and
she participated in preliminary ground based field testing of the instrument on the University of Maryland campus during February 2012. Heather has analyzed and continues to develop data collected during laboratory experiments, instrument testing, and field campaigns. Preliminary results from DC3 indicate that the ISAF is able to resolve concentrations ranging from under 35 ppt to over 35 ppb, spanning three orders of magnitude in a few minutes time, as shown in Figure 1. Frequent, abrupt changes in HCHO captured by the ISAF are corroborated by similar patterns observed by simultaneous trace gas and aerosol measurements. Primary HCHO emissions are apparent in cases when the DC-8 flew over combustion sources or biomass burning, and secondary HCHO formation is suggested by observations of enhanced HCHO concurrent with other elevated hydrocarbons. Vertical transport of HCHO is indicated by measurements of over 6 ppb from outflow in the upper troposphere. Initial results from DC3 illustrate the efficacy of the instrument in detecting HCHO to elucidate convective transport of boundary layer pollutants and effects in the upper troposphere. 

Figure 1. Time series plot of HCHO and altitude data collected during one of the DC3 science flights conducted over northeastern Colorado to capture convection and biomass burning events on June 22, 2012.

Conference Poster Presentation
Task 654: Collaboration with ESDIS, ACE, and PMM projects; PI: K.-S. Kuo; Sponsor: D. Starr

Description of Scientific Problems

This task is composed of three (3) subtasks:

1. Collaboration with NASA Earth Science Data Information System (ESDIS) project to provide recommendations for improvements in EOSDIS to help meet Vision 2015 objectives set by the EOSDIS Evolution Study in 2005,
2. Science management support of Aerosol, Cloud and Ecosystem (ACE) mission pre-formulation, and
3. Investigation of the physical and radiative (scattering) properties of precipitating frozen precipitation particles in support of GPM algorithm development.

They will be reported under the headings of ESDIS, ACE, and PMM, respectively, in the following subsections.

Approaches

ESDIS
In order to arrive at practicable recommendations, the following steps are followed

1. Draw from personal experience of using data from the ESDIS data centers for scientific investigations,
2. Interview and study fellow scientists’ usage of data, and
3. Analyze “pain points”, derive insights, and explore potential solutions.

Most importantly, these steps are performed cognizant of the current developments and trends of data and information technologies, including database management technologies, data analytics technologies for massive data volumes, high-end computing technologies, and computer network technologies.

ACE
The approach for this subtask is a simple one: follow directions given by the sponsor and provide management support.

PMM
Accurate retrievals of hydrometeors require precise knowledge concerning the single-scattering properties of these particles, which, in turn, depends on the fidelity of the particle shape models used for their depictions. The uncertainties associated with solid-phase precipitation retrievals from space have always been the lack of accurate single-scattering properties, primarily due to the crude approximations to the shapes of the particles involved. Therefore, the approach taken for this subtask is to

1. Simulate realistic pristine ice particles with a numerical growth model, Snowfake (Gravner and Griffeth 2009),
2. Construct realistic aggregate particles, which are the major type of solid precipitating particles, using the pristine particles “grown” by Snowfake, and
3. Calculate the single scattering properties of pristine and aggregate ice particles using open-source DDSCAT code based on the discrete dipole approximation.

Accomplishments

ESDIS
My analysis recognizes that, among the academic and governmental agencies of the world, the services provided by the data centers of NASA ESDIS project undoubtedly rank near the top. However, this relative excellence does not eclipse the fact that using NASA Earth science data still requires disproportional effort from the researchers and that it is still far from the ideal that could have been achieved with current information technologies. The situation is difficult to improve with its current mode of operation, i.e. providing “packaged” data granules in the form of HDF files, which generally requires users of the data to download these files (or more commonly a subset of them) to local storage devices in order to perform analysis. This results in crowding network bandwidth and wasteful redundant storage. Although measures have been taken to address this inefficiency, they are beset by the intrinsic limitations of current architecture. The impact of these limitations is certainly going to grow more acute as the data volume increases. It is thus recommended that ESDIS data centers should transition to a share-nothing architecture with distributed parallel processing capability to enable server-side analyses as services, in addition to data distribution.

ACE
I assisted in the reviews of five (5) ACE study proposals, as well as in the technical review of Howard University’s Beltsville Center for Climate System Observation and the composition of its report.

PMM
A total of 2200+ realistic pristine ice crystals have been “grown” using a parallelized version of the Snowflake model of Gravner and Griffeth (2009) and 7000+ mono-habit ice aggregate particles have been constructed using the pristine ice crystals. Figure 3 provides a sample gallery of the aggregate particles (columns 3-5 from left) constructed for this subtask, with their corresponding pristine component particles (column 2 from left). The mass-dimension relations exhibited by these synthetic ice aggregate particles are

Figure 3 Sample particle images. Columns from left to right: 1 – corresponding colors used in later plots, 2 – pristine ice crystals, and 3-5 – sample aggregates constructed using the pristine ice crystals.
consistent with those observed. Scattering properties of these particles, both pristine and aggregate, are subsequently obtained at thirteen (13) microwave frequencies, covering the most common radar and radiometer bands used for satellite precipitation remote sensing. Using the scattering properties of these aggregate particles obtained from DDSCAT in an experiment of radar-radiometer combined retrieval shows that much better consistency is achieved for high-frequency (89 and 166 GHz) radiometer brightness temperatures than using those derived from various “fluffy sphere” approximations and obtained with Mie calculations.

**Refereed Journal Publications**

**Conference and Other Presentations**
Kuo, K.-S.: Introduction-Potential metamorphosis of the data archive centers (DACs). IGARSS 2012, Munich, Germany, 22-27 July 2012. (Oral presentation)

Description of Scientific Problems
Current satellite rainfall products have some well-known concerns: e.g., (1) there is no error information attached to each individual product; (2) very limited error information is used to construct merged rainfall products from different retrievals; (3) without careful calibrations, it is not suitable to directly use the merged product to study short- and long-term climate trend on rain amount, let alone important statistics of frequency of rain occurrence, rain intensity, and rain event duration. The next-generation rainfall product is expected to alleviate these concerns by optimally merging rainfall estimations from different platforms.

Approach
The objective of this work is to develop uncertainty variance databases on the global scale using space-borne precipitation radar and high-resolution NEXRAD data as references. For each individual satellite data, a rain uncertainty database will be constructed as a function of rain intensity, geo-location, and season. The resulting database will be used for the development of advanced statistical methods to merge precipitation data from multiple observation platforms.

Accomplishments
The initial step is to use the high-resolution NMQ Q2 surface radar data (5-minute, 1km x 1km) over the continental United States as the reference, and to evaluate satellite rain retrievals at individual rain pixel levels. We have obtained 3 years of NMQ Q2 rainfall data from NOAA National Severe Storm Laboratory (01/2009 to 10/2011) and archived them on NASA Center for Climate Simulation Mass Storage. Preliminary calibrations of the reference data have been conducted by adjusting Q2 data against the hourly Stage IV surface radar-gauge analysis. We are also collaborating with colleagues at ESSIC and at Goddard Space Flight Center to inter-compare existing satellite datasets and surface data to assess the reliability of the reference data, and to understand their characteristics in different seasons and under different topography and land surface types.

A preliminary framework has been developed to characterize land rain retrieval uncertainties for existing microwave rain retrievals. Specifically, we have co-located NMQ Q2 data with PR, TMI, and AMSR-E at their individual pixel levels, and have constructed the uncertainty covariance databases as a function of rain intensity, geo-location and season. Additional information on elevation (height and surface roughness) and land cover from AQUA ASTER and MODIS is also included. This uncertainty information has been used in a number of testing cases to optimally merge satellite retrievals.

We will continue to apply the methodology to other PWM retrievals from SSMI, SSMIS, Megha-Tropique, NPP, METOP, etc. We hope that for any satellite rain retrieval pixels over CONUS, given the rain intensity, geo-location, and season, uncertainty estimations can be provided statistically. Wherever and whenever there are high-resolution ground validation data (Europe, Asia, or small field campaigns), we will integrate them into this ground-based statistical database.
A second step is to use TRMM PR as another reference to mimic the GPM DPR in calibrating PMW retrievals as well as surface measurements. We have analyzed all the PR, TMI and AMSRE data and an error model is being considered in order to extrapolate error statistics to areas where there are no reference data.

**Associated Accomplishments**

In addition to the above work, the PI (1) has developed a data stream system for merging satellite rainfall retrievals; (2) has involved in examining the performance of advanced merging algorithm; (3) has evaluated the impact of assimilating rain-sensitive radiance on cloud and precipitation within a WRF-based ensemble data assimilation system.

![Figure 1: Jointed histograms of 85 GHz radiances (K): (a) TMI; (b) First-guess (FGS); (c) Analysis (ANL); (d) Analysis minus First-guess, vs. Stage IV rain rate (mm/hr.) over regions where observations indicate non-zero rain rates. The dashed line indicates the largest gradient between TMI 85 GHz radiance and observed surface rain rate.](image)

**Referred Journal Publications**


Conference and Other Presentations:
Task 656: Instrument for measuring atmospheric trace gases. PI: Elena Spinei; Sponsor: K. Pickering

**Description of Scientific problem**
1) Developing and building ground-based instruments for measuring atmospheric trace gas amounts from observations of the sun and sky, develop algorithms for retrieving trace gas and aerosol properties, and analyzing the data from such instrumentation.
2) Data analysis and retrieval algorithms for satellite instruments and related validation instruments. This may include algorithms for SBUV or OMPS instruments as well as work with data from the Goddard Brewer.

**Accomplishments**
1) Laboratory calibrated and characterized 8 new Pandora instruments needed for the upcoming Discover-AQ campaign
2) Developed a profiling algorithm for the Pandoras to enable us to retrieve ozone profiles throughout the day. Based on this work, we won a proposal to make these measurements over the next 4 years.
3) Set up the MFDOAS instrument at Goddard that was used as a calibration standard for ground-based trace gas measurements.
4) Developed a method for retrieving ground level concentrations of trace gases (NO2, HCHO, etc.) using the Pandora or MFDOAS systems. This method will be applied during the Discover-AQ campaigns.
5) Developed software based on Labview that simplifies data processing methods for the user.
Task 657: The processing of PolInSAR data from Digital Beamforming SAR and EcoSAR and its application on the estimation of forest structure parameters. PI: Wenjian Ni; Sponsor: J. Ranson

Description of Scientific problem
The regional estimation of forest structure parameters is important for the research on the global carbon cycle and forest resources management. Synthetic aperture radar (SAR) is believed to be the best dataset for the estimation of forest structure parameters because of its penetration ability. Most of current research mainly focused on the application of backscattering coefficients from SAR data. It is limited by the influence of soil parameters such as soil moisture and roughness. Polarimetric SAR Interferometry (PolInSAR) is found to be the promising technique for the estimation of forest structure parameters. However its data source is limited. NASA Goddard has developed new SAR equipment-Digital Beamforming Radar (DBSAR) and EcoSAR. They are designed specifically for the forest structure observation using PolInSAR technique. We mainly responsible for the processing of DBSAR and EcoSAR and the forest structure parameter estimation.

Approach
Our main tasks include:

- Polarimetric SAR calibration, remove the cross talk and channel imbalance to recover the data polarimetric signature.
- Single-pass InSAR data processing to derive the height of scattering phase center.
- SAR data geocoding, to project the SAR observations from slant range coordinate to ground surface.
- Motion compensation for SAR image focusing and repeat-pass Interferometry.
- The estimation of forest structure parameters using PolInSAR technique.

Accomplishments
Geocoding is a common part of all SAR processing. It is the basis for the estimation of biogeophysical parameters. Besides, there are some critical parameters cannot be calibrated. Geocoding results can provide us a guess of these parameters. Before geocoding, it is necessary to get the backscattering coefficients. First thing needs to do is the antenna pattern removal. Fig.1-a shows the original backscattering images. Fig.1-b is the results of after antenna pattern correction. It can be seen that the bright-dark pattern from left to right caused by antenna pattern has been removed. The first step of geocoding is the transform from slant range coordinate to ground range coordinate. The value of pixels in ground range image is obtained by interpolation. The results are shown in Fig.1-c. The next step it to do geocoding. The origin of the coordinate system for each line is the position of flight; the x axis is in the slant range direction while Y axis is in the flight direction. Supposing its UTM coordinate is $[x_0, y_0]^T$. The heading angle $\varphi$ (i.e. flight direction) is provided by flight data. Therefore the coordinates of the pixel under UTM projection can be calculated as
\[
\begin{bmatrix}
  x \\
  y
\end{bmatrix} = \begin{bmatrix}
  \cos \phi & \sin \phi \\
  -\sin \phi & \cos \phi
\end{bmatrix} \begin{bmatrix}
  \dot{x} \\
  \dot{y}
\end{bmatrix} + \begin{bmatrix}
  x_0 \\
  y_0
\end{bmatrix}
\]

The result is shown in Fig.1-f.

For single-pass InSAR data processing, it include: phase unwrapping, removal of flat earth phase and transforming phase to height. As shown in Fig.1-d, the blue line is the InSAR phase from interferogram. Three points were selected from the three cycles and unwrapped these three points first. The quadratic fitting was made using these three points. Quadratic fitting gives us an approximate of the unwrapped phase. By comparing them with InSAR phase, the phase of the pixel should be unwrapped. The unwrapped phase is shown as red line in Fig.1-d. In traditional method, the cycle boundary needs to be detected firstly by tracing the change of pixel value from PI to -PI. It is always affected by phase noise. The method we developed here can avoid this problem. Fig.1-e shows the total InSAR phase and the flat earth phase. Fig.1-g is the geocoded elevation map.
Figure 1 The results of DBSAR data processing. (a) The focused radar image; (b) the removal of radar antenna pattern; (c) Transformation from slant range to ground range; (d) phase unwrapping of single-pass InSAR data; (e) The removal of flight earth phase; (f) the geocoded backscattering coefficients; (g) The geocoded elevation of scattering phase center.
Task 658: Development of the dynamic ice sheet component to the NASA GOES-5 climate model; PI: R. Walker; Sponsor: S. Nowicki

Description of Scientific Problem
In its Fourth Assessment Report (2007), the Intergovernmental Panel on Climate Change provided predictions of sea-level rise with the critical caveat that “future rapid dynamical changes in ice flow” had not been included. This report also warned that “flow rates could increase or decrease in the future,” that “larger values [of discharge] cannot be excluded,” and that “understanding of these [dynamic] effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.” Among the more significant effects referred to in the last statement is the accelerated discharge of ice into the ocean resulting from warmer waters melting the floating ice shelves that restrain the seaward flow of grounded ice. Ice shelf-ocean interaction is an inherently interdisciplinary problem that requires coupled models in order to make accurate predictions of ice-sheet margin behavior; however, development of such models is still in its infancy.

Approach
We plan to couple the Ice Sheet System Model (ISSM) developed at the Jet Propulsion Laboratory with the Goddard Earth Observing System model, version 5 (GEOS-5). These models are a natural match, as both have extensive data assimilation capabilities and are well suited for predictions on decadal time scales. In addition, ISSM offers the higher-order ice physics required to accurately simulate fast-flowing ice streams and transitions between grounded and floating ice.

In order to maintain a clean interface with the existing ocean components of GEOS-5, the sub-ice shelf circulation (and resulting melting) will be determined by a separate sub-component rather than by extension of the full ocean model into the complex and changing sub-ice shelf cavity. The cavity sub-component must be capable of handling evolving ice-shelf geometry while efficiently dealing with the widely disparate space and time scales of ocean and ice dynamics. For these reasons, we are considering simplified models, including those that focus on the buoyant, meltwater-driven plumes that form at ice-shelf bases.

Accomplishments
Current research using a one-dimensional ocean plume model, both alone and fully coupled with a higher-order ice flowline model, shows that differences in the complexity of the thermodynamical equations used to calculate melting are less important than differences in the parameterization of vertical mixing at the upper and lower plume boundaries. Enhanced vertical mixing allows greater heat flux from the deep ocean through the plume into the ice shelf, resulting in increased melting. In the coupled model, varying the relevant coefficient across a range of reasonable values can lead to very different system responses to identical ocean conditions, sometimes determining whether an ice shelf can reach a stable steady state (Figure 1). Coupled experiments also demonstrate feedback between ice-shelf basal slope and melting, with steep slopes and high melt rates driving each other until coming into equilibrium with ice flux. Accurately tracking the transition between grounded and floating ice as it retreats can be challenging; even in a simplified coupled model, high spatial and temporal resolution and carefully chosen coupling intervals are required to capture the dynamics correctly. Lessons
learned from this preliminary study are expected to inform our efforts to develop an ocean cavity sub-model suitable for coupling with both GEOS-5 and ISSM.

Figure 1: Higher values of the drag coefficient $C_d$ produce increased vertical mixing and higher melt rates at the ice-shelf base, resulting in farther retreat of the transition between grounded and floating ice (i.e., the grounding line). Initial configuration includes a 100 km long grounded ice stream, so that red and green curves represent experiments ending with flotation of all ice in domain.
**Task 659: Development of the radar portion of BioPHYS MFM; Graduate Student: Wenli Huang; PI: G. Sun; Sponsor: T. Fatoyinbo**

**Description of scientific problem**

Multi-sensor physically-based data fusion is promising to produce terrestrial carbon product in terms of biomass, biomass changes and 3-D vegetation structure. Radar provides the ability to create a spatial and temporal continues map of forest biomass from SAR backscattering coefficient and InSAR scatter phase center. Lidar metrics at fine resolution provides as sample and validation data.

**Approach**

As a graduate research assistant on the project, I work on the radar image processing and forest growth modeling. The task is towards deriving maps of forest biomass at our test site Howland, Maine, USA from 1989 to 2009 with a 5 year interval. These involve three main aspects: 1) Process and calibrate the backscatter from multi-sensor radar data in different years; 2) Build up and apply biomass prediction models from field data in corresponding year for multi-sensor data; and 3) Evaluate the model predictions from field data and lidar-derived maps.

**Accomplishment**

Multi-sensor SAR data were prepared for the study site, as shown in Table 1. For data from the same sensor such as AIRSAR, the calibrations were included during the preprocessing, thus no additional works required. For data form different sensors, cross-sensor calibration/normalization is needed.

Table 1. List of data for mapping of forest biomass at Howland site

<table>
<thead>
<tr>
<th>Year</th>
<th>Data</th>
<th>Index for biomass retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>AIRSAR</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td>1994</td>
<td>AIRSAR</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td>1994</td>
<td>SIRC</td>
<td>InSAR scatter phase center, coherence</td>
</tr>
<tr>
<td>1995</td>
<td>JERS-1</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td>1998</td>
<td>JERS-1</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td>2003</td>
<td>LVIS</td>
<td>Waveform relative height metrics</td>
</tr>
<tr>
<td>2004</td>
<td>RadarSAT-1</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td>2007</td>
<td>PALSAR</td>
<td>InSAR scatter phase center, coherence</td>
</tr>
<tr>
<td>2009</td>
<td>LVIS</td>
<td>Waveform relative height metrics</td>
</tr>
<tr>
<td>2009</td>
<td>UAVSAR</td>
<td>SAR backscattering coefficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>InSAR scatter phase center, coherence</td>
</tr>
</tbody>
</table>

Validation data from field and lidar were prepared, and a corresponding paper was submitted to remote sensing of environment. Forest biomass was mapped from PALSAR InSAR data and ASTER GDEM, and the corresponding paper was prepared and submitted to remote sensing of environment.
A new version of forest ecosystem dynamic model (ZELIG v24, from Prof. Hank Shugart at University of Virginia) was adopted, which can simulate the forest stands with different management practices through thinning function. This model has successfully used for simulating the managed forest in Canada. After adapting site-dependent parameters in this model for our test sites, forest stands will be generated as inputs for radar and lidar signal simulation.

Refereed Journal Publications

Conference Presentations
**Task 660: Remote Sensing of Sulfur Dioxide from Space; PI: C. Li; Sponsor: N. Krotkov**

**Description of Scientific Problem**
Sulfur dioxide (SO₂) is an important pollutant gas emitted from both volcanic eruptions and combustion of fossil fuels. A regulated air pollutant in itself, SO₂ can also form sulfate aerosols in the atmosphere, which may influence visibility, air quality, and also the weather and climate through their direct and indirect effects. Satellite retrieval of anthropogenic SO₂ has always been challenging, due to its weak signal compared to volcanic sources, low surface albedo in UV and ozone interference. The current generation of spaceborne UV spectrometers, for example the Ozone Monitoring Instrument (OMI) aboard the NASA/Aura satellite, allows strong anthropogenic SO₂ pollution near point sources (e.g., coal power plants) to be monitored globally. But further improvement in the products is still needed before the satellite-retrieved SO₂ data can be used more quantitatively by the climate and air quality research communities. The main objective of this task is to help develop and evaluate new retrieval algorithms that would lead to significant improvements in the SO₂ data products.

**Approach**
A new direct spectral fitting (OMSO2SF) retrieval algorithm has been developed to take full advantage of the available hype-spectral measurements in the spectral range of 310-360 nm from the OMI instrument. Compared to the current operational algorithm, the OMSO2SF algorithm can extract more accurate and greater information contained in the radiance measurements. Forward radiative transfer calculations are compared to measurements, and the difference between the two is minimized by iteratively adjusting retrieval parameters: O₃, SO₂, cloud pressure and fraction.

Careful evaluation of the OMSO2SF algorithm against known emission sources, ground-based and aircraft measurements, as well as existing products from OMI and other satellite sensors is necessary before it can be employed in the operational production. The algorithm will continue to be refined as the evaluation is done on the test data.

**Accomplishments**
Test runs utilizing the OMSO2SF algorithm have been conducted to generate test data sets covering different parts of the Earth during selected periods of the OMI mission. Evaluation of these test data indicates that the algorithm significantly reduces noise compared to the operational standard algorithm, but there is still room for improvement to reduce the cross-track bias. A few different improvements involving the selected spectral fitting window, soft-calibration techniques and climatological profiles of O₃ and SO₂ have been recommended to be implemented in the algorithm. Next the setup of the OMSO2SF algorithm will be implemented in the operational environment and finalized before the operational data production and more thorough evaluation take place.

**Conference and Other Presentations**
**Task 661: Automated Event Service; Graduate Student: Khoa Doan; PI: S. Ho; Sponsor: T. Clune**

*Description of Scientific Problem*
A large portion of Earth Science investigations is phenomenon- or event-based, such as the studies of Rossby waves, mesoscale convective systems, and tropical cyclones. However, except for a few high-impact phenomena, e.g., tropical cyclones, comprehensive records are absent for the occurrences or events of these phenomena. Phenomenon-based studies therefore often focus on a few prominent cases while the lesser ones are overlooked. Without an automated means to gather the events, comprehensive investigation of a phenomenon is at least time-consuming if not impossible.

*Approach*
The proposed Automated Event Service (AES) is a system that methodically mines custom-defined events in the reanalysis data sets of atmospheric general circulation models. Our AES will enable researchers to specify their custom, numeric event criteria using a user-friendly web interface to search the reanalysis data sets. Searches can also be performed using our Event Specification Language (ESL) to afford more flexibility and versatility. Investigators will be able to subscribe to event searches and get notified of new results when data sets are updated with the latest additions.

*Accomplishments*
We have not worked on any application of machine learning on AES since we have just started from the ground up. We are getting ourselves familiar with the technologies behind AES, especially SciDB, which is our primary data store.
Task 663: Wind Algorithms and Data Analysis for the HIWRAP Airborne Doppler Radar; PI: S. Guimond; Sponsor: G. Heymsfield

Description of Scientific Problem
NASA’s new HIWRAP airborne Doppler radar flying aboard the unmanned Global Hawk aircraft presents unique challenges for retrieving the three-dimensional wind field of precipitating systems such as hurricanes. HIWRAP has two incidence angles (30 and 40 degrees) with each beam functioning at Ku- and Ka-band. In addition to volume scattering from precipitation, HIWRAP’s frequencies are capable of retrieving ocean surface winds through scatterometry techniques. The main focus of this work is designing wind algorithms for a better understanding of hurricane physics particularly in the genesis and intensification stages of the storms. Data from a previous field experiment, the Genesis and Rapid Intensification Processes (GRIP), and an ongoing one, the Hurricane and Severe Storm Sentinel (HS3), will provide real data to test the wind algorithms and understand hurricanes better.

Approach
Several methods are being evaluated for the wind retrievals: (1) nadir method, which solves for the winds using an exact solution at nadir, (2) direct swath method, which solves for the winds over the entire HIWRAP swath using linear algebra and (3) iterative swath method, which solves for the winds over the entire HIWRAP swath using a variational minimization approach. Numerically simulated and analytical wind fields are being used to document the error characteristics.

Accomplishments
Initial testing of the algorithms shows excellent results with all methods. There are, however, positives and negatives of all methods. The nadir method gives very accurate results at high resolution, but only for two components of the wind in a two-dimensional plane. The direct swath method is fast and efficient with good accuracy in the middle of the swath, but errors were found on the swath boundaries due to small azimuth diversity (points are nearly co-linear) that will limit the spatial extent of useful information from HIWRAP. The iterative swath method gives similar results to the direct method, but has the advantage of constraining the wind field to some chosen dynamic balance. This evaluation of this feature is ongoing.

Analysis of Tropical Storm Matthew (2010) during GRIP with the direct swath method revealed a circulation center not found by the National Hurricane Center (NHC); see Fig. 1. The NHC was off on their center position of this storm at this time by a significant amount (over 100 km). This result highlights the unique ability of HIWRAP to provide essential information on hurricanes to the community.
Figure 4. Left, HIWRAP wind retrievals in Tropical Storm Matthew (2010) at 3 km height. Right, GOES infrared imagery of Matthew near the center time of the HIWRAP composite. The GOES imagery is annotated with the center positions of Matthew from the NHC (NOAA) and from HIWRAP.

Conference Presentations
Task 664: Spectral absorption properties of aerosols in the UV wavelengths; Graduate student: J. Mok; PI: Z. Li; Sponsors: N. Krotkov/O. Torres

Description of Scientific Program
Quantifying spectral dependence of aerosol absorption at UV and visible wavelengths is critical for the accurate air pollution characterization using current (e.g., Aura/OMI) and future (e.g., GEOCape) satellite measurements. Measurements of column atmospheric absorption and its spectral dependence remain the most difficult part of atmospheric radiation measurements. Currently available ground measurements of spectral absorption optical thickness (or column effective single scattering albedo, SSA) are limited to the few discrete wavelength bands in the visible spectral region by AERONET almucantar inversions and at 7 UV wavelength bands by UV-MFRSR shadowband instruments. We have developed a new technique to derive column aerosol absorption in the UV wavelengths by combining co-located measurements by AERONET CIMEL and modified UV Multifilter Rotating Shadowband Radiometer (UV-MFRSR) instruments. We have also developed instrumentation and techniques to quantify and correct for gaseous interferences due to ozone and NO₂. This research is focused on application of our instrumentation and techniques for measuring column spectral aerosol absorption in the near UV and blue wavelengths at different locations. The goal is to demonstrate clear-sky spectral surface radiation closure with radiative transfer models and to quantify enhanced column UV aerosol absorption. These measurements are essential to answer key science questions of the atmospheric composition focus area and improve data products from the Aura OMI.

Approach
To address the lack of spectral aerosol and gaseous absorption measurements in UV, a suite of complementary ground-based instruments was established during 2005-2012 and is currently in use at Goddard Space Flight Center in Greenbelt, Maryland. The primary data set consists of 1-minute measurements of diffuse and total irradiance collected with the UV Multifilter Rotating Shadowband Radiometer UV-MFRSR instrument (Yankee Env.) part of UVB Monitoring and Research Network, UVMRP. A single measurement cycle consisted of measuring total horizontal irradiance (no sun blocking) following by 3 irradiance measurements with different positions of the shadow band blocking the sun and aureole. All spectral channels were measured within one second by 7 separate solid-state detectors with interference filters sharing a common Teflon diffuser. The complete shadowing cycle takes ~10sec and was repeated every minute throughout the day without averaging of the data. The raw data (voltages) were automatically transmitted every night (via dedicated telephone modem) to the UVMRP processing center at the Colorado State University (Fort Collins, CO) for voltage corrections and further processing. The standard UVMRP calibration procedure differs from that used in our measurements, where we used only cosine corrected voltages calibrated on-site against co-located reference AERONET sunphotometers (data available at http://aeronet.gsfc.nasa.gov). The AERONET automatic tracking Sun and sky scanning radiometers made direct Sun measurements with a 1.2° full field of view every 15 minutes at 340, 380, 440, 500, 675, 870, 940, and 1020 nm (accuracy typically ~0.003 to 0.01 in the visible with larger errors in the UV). The version 2 level 1.5 AOT at 340nm, 380nm 440nm and 500nm were interpolated in time and wavelength and compared with the UV-MFRSR measurements of cosine corrected direct-normal voltages to derive a more accurate daily \( V_o \) calibration than provided in the standard UVMRP data set.
This calibration method yields more accurate measurements of aerosol extinction optical thickness AOT and diffuse and direct atmospheric transmittances [Krotkov et al., 2005a].

Accomplishments

Task 1 Characterizing Long-term calibration changes

Comparisons of MFRSR and AERONET AOT allowed tracking of the UV-MFRSR calibration changes. It was found that the UV-MFRSR had relatively good day to day calibration reproducibility (+/-1% in daily average extraterrestrial voltage \( <V_o> \)), but larger than expected \( <V_o> \) changes were observed on a seasonal time scales (Figure 1). After a first week at GSFC in July 2005 the \( <V_o> \) stared to decline in all channels for more than 10 months and the minimal \( V_o \) value (\( \ln(r^2V_o) \approx 8.00 \) at 440nm ) was reached in summer 2006. The initial downward trend in \( <V_o> \), was attributed to observed changes in the throughput of the UV-MFRSR instrument, likely due to diffuser soiling [Krotkov et al., 2009]. Quartz dome was later installed atop the diffuser, which stabilized long-term throughput (Figure 1). Since spring 2007 the modified UV-MFRSR was continuously operated with dome at NASA/GSFC site, except during several field campaigns. We have also replaced 300nm filter with 440nm filter used in AERONET network.

Task 2 Aerosol absorption measurements

After accounting for calibration changes, the AOT and single scattering albedo (SSA) at 440nm and at UV wavelengths were inferred by fitting the measurements of global and diffuse atmospheric transmittances with the forward RT model at each UV-MFRSR spectral channel [Krotkov et al., 2005b]. The SSA retrievals are performed for cloud-free periods. The SSA were corrected for ozone and NO2 interference [Krotkov et al., 2005c] using co-located direct sun measurements and OMI overpass data and compared with co-located AERONET almucantar retrievals at 440nm. All available UV-MFRSR data (every 1 minute) within time interval \( \pm 30 \)min of each AERONET almucantar measurement were analyzed. We used AERONET aerosol size distribution, surface albedo and real part of refractive index at 440nm within each
30-minute time slot, but allowed for AOT and solar zenith angle ($\theta_o$) changes consistent with UV-MFRSR measurements. To compare only high quality SSA retrievals only the inversions with AOT440 >0.2 and $\theta_o$>45° (required for good AERONET inversions) and $\theta_o$<65° (required for good UV-MFRSR calibrations) were selected. Figure 2 shows average retrieved SSA by both instruments. The two methods of estimating SSA show good agreement at the common wavelength 440nm.

Apart from more frequent MFRSR SSA retrievals, the two methods are complementary in that the AERONET retrievals require large solar angles, while UV-MFRSR data are more reliable at low solar zenith angles. Currently, no AERONET SSA retrievals are available in the UV. Aerosol absorption increased in the UV and longer visible wavelengths (670nm and longer). The enhanced column UV absorption (small SSA values) is commonly attributed to the organic aerosol component (OC) that absorbs predominantly in UV, explaining much stronger wavelength dependence ($\sim \lambda^{-3}$) than a purely black carbon (BC) model would suggest ($\sim \lambda^{-1}$) [Kirchstetter et al., 2004]. The finding suggests critical importance of UV spectral range for quantifying OC/BC fraction. We note that simply extrapolating AERONET SSA retrievals at 670nm and 440nm into UV spectral region results in highly overestimated SSA (dashed line) and underestimated absorption optical thickness (AAOT).

**Figure 2.** Combined SSA and AOT spectral dependence in UV and visible wavelengths as measured by co-located UV/VIS MFRSR and AERONET CIMEL instruments at NASA GSFC site in Greenbelt, Maryland in 2005-2012. Both measurements agree well at common wavelength 440nm, where aerosol absorption is minimal (largest SSA). Larger absorption (smaller SSA) is measured by AERONET at longer visible and near IR wavelengths (<1020nm), and larger UV absorption is measured by MFRSR.
Task 665: Landslide monitoring and early warning using remote sensing: Application over Mesoamerica and Bridging between empirical and physical approaches; PI: S. Yatheendradas; Sponsor: D. Kirschbaum

Description of Scientific Problem
Quantifying both where and when landslides may impact an area is challenging due to limitations in detailed surface data (e.g. soils, soil moisture, topography, lithology), sparse landslide inventory information and limitations in accurately estimating triggers like rainfall. Recent examinations of rainfall-induced landslides have increased our understanding of the triggering mechanisms and surface conditions underlying slope instability; however, investigations remain largely site-specific or too general to be incorporated into hazard forecasting, land-use planning or policy making.

The SERVIR-Mesoamerica zone has had a significant number of episodic and often damaging landslides and associated fatalities. This is due to its location within an active tectonic and geomorphic setting and its exposure to extreme tropical rainfall and landfalling hurricanes every year. Though a better scientific foundation has been provided by recent evaluation of landslide susceptibility and triggering over this region, there still lacks a consistent, near real-time system to dynamically identify landslide prone areas and forecast future activity.

The modeling and monitoring basis of landslide processes has traditionally been either physically-based at local (or hillslope) scales having ample in situ data, or empirically-based at the global scale. The complex and coupled hydromechanical soil processes in hillslope-scale physical models make their extension to regional and global scales difficult. This difficulty can be overcome by considering the dominant factors that drive the most variability in landslide triggering predictions. However, no formal sensitivity analyses have been performed to identify such factors, and no methodology exists for operationally relevant probabilistic realization of these factors at the scale of available remote sensing products.

Approach
One goal is to develop a robust landslide hazard assessment system for SERVIR-Mesoamerica that effectively applies remote sensing information within a probabilistic landslide model. This will provide straightforward, easily-interpreted set of landslide hazard assessment and forecasting products in near-real time. Figure 1 illustrates the workflow towards this goal, the primary steps towards which are to:
(i) Perform probabilistic landslide susceptibility, exposure and hazard assessments for Mesoamerica using NASA and other remotely sensed data and in situ surface information,
(ii) Apply a regional numerical weather prediction system to enable short-range forecasting of potentially impacted landslide areas,
(iii) Develop a suite of landslide hazard assessment and forecasting tools within Mesoamerica, working with regional and country-level emergency managers and decision makers to identify a set of the most effective landslide hazard assessment products for their activities, and
(iv) Create a methodology for assessing landslide hazards that can be transferable to the SERVIR-Himalaya node, focusing on the application and communication of satellite imagery and estimation of landslides probabilities within affected landslide hazard areas.
Another goal is to bridge empirical and physical approaches by conducting sensitivity and uncertainty analyses of a hillslope-scale landslide triggering model in order to apply it in a landslide modeling and prediction framework over larger spatial scales. This will effectively exploit remote sensing products to better constrain the uncertainties inherent in both of these approaches. The primary steps towards this goal are to:

(i) develop model parameter representation to apply over larger spatial scales by identifying the key physical parameters and/or state variables that trigger rainfall-induced landslides,
(ii) use uncertainty analysis tools to probabilistically forecast landslide occurrences within an ensemble framework using remotely sensed products,
(iii) evaluate new physically-based multivariable triggering relationships over regional to global scales in order to probabilistically represent landslide triggering relationships using near real-time satellite data.

**Accomplishments**

This task is just beginning.
Task 666: Global Atmospheric CO2 Measurements; PI: Jianping Mao; Sponsors: Joanna Joiner and James Abshire

Description of Scientific Problem
Global high spatial and temporal resolution remote sensing of atmospheric CO2 concentration is greatly desired for global and regional carbon cycle sciences. The biggest challenge for CO2 remote sensing is to achieve the high-precision science measurement requirement (~1 ppmv or 0.3% on regional scales) so that such measurement will be valuable to reduce uncertainties about carbon sources and sinks. Other major challenges to obtaining high-precision CO2 measurement in the passive approach using reflected sunlight in these bands are the contamination of aerosol and/or cirrus cloud scattering in the sunlight path and poor sampling over oceans, snow/ice cover, high latitudes and wintertime.

Approach
NASA Goddard Space Flight Center is developing an active laser approach to measure atmospheric CO2 from space as a candidate for NASA’s future carbon mission ASCENDS - the Active Sensing of CO2 Emissions over Nights, Days, and Seasons, which is currently scheduled for launch in 2020. This mission was recommended in 2007 by the National Research Council of the U.S. National Academies in its Decadal Survey Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond and aims “to produce global atmospheric column CO2 measurements without seasonal, latitudinal, or diurnal bias using simultaneous laser remote sensing of CO2 and O2.” This approach uses two pulsed lasers to simultaneously measure both CO2 and O2 absorption at a number of wavelengths across an optimal CO2 line at 1572 nm and an optimal O2 line at 764 nm for estimating CO2 concentration with regard to dry air. This pulsed laser approach provides several advantages with respect to passive approaches and other laser techniques toward high-precision measurement of CO2 from space. Meanwhile, the retrieval algorithm with passive carbon satellites, GOSAT and OCO-2, needs improvements for better data quality and data spatial and temporal coverage (e.g., above clouds) and extension of data applications.

Accomplishments
In the past three year (2009-2011), the Goddard CO2/O2 laser sounders conducted science flight campaign each summer, flying together with other NASA’s ASCENDS candidates. These spiral and step-up/down flights during the campaigns allow to assess the information content of both CO2 and dry air vertical profiles from each flight altitude up to 13-km and at each measurement wavelength. The flights demonstrated the consistent performance of instruments for all surface types, flight altitudes, ground elevations and atmospheric states. The measurement results well agreed with in-situ measurements and calculations with the Line-By-Line Radiative Transfer Model (LBLRTM) using the HIgh-resolution TRANsmission molecular absorption (HITRAN) database. The analysis results will provide guidance for measurement wavelength selection, retrieval algorithm development and ASCENDS mission simulation studies for carbon cycle sciences.
Task 667: Development of an irrigation algorithm; PI: TBD; Sponsor: L. Bounoua

No funds have been expended on this task. No PI has been identified.
**Task 668: The Global Reservoir and Lake Monitoring System: Enhancing the USDA/FAS DSS with NASA, NRL and ESA Satellite Radar Altimeter Data; PI’s: C. Birkett; Sponsor: C. Peters-Lidard**

**Description of Scientific Problem**
This program aims to enhance and expand a satellite-based, near-real time, reservoir and lake water-level monitoring system. This system is on-line, operational, existing within the US Department of Agriculture (USDA) decision support system (DSS) through the cooperative USDA/NASA Global Agricultural Monitoring (GLAM) program. Current lake level products stem from the NASA/CNES TOPEX/Poseidon (archival 1992-2002), Jason-1 (post 2002 and near real time), Jason-2/OSTM (post 2008) missions, the US Naval Research Lab’s GFO (post 2000) mission, and the current ESA ENVISAT (post 2002) mission. The primary user is the Office of Global Analysis (OGA) within the USDA Foreign Agricultural Service (FAS). The FAS utilize the products for irrigation potential considerations and as general indicators of drought and high-water conditions. The monitoring system thus has relevance to water resources management and agriculture efficiency applications at both the national and international level.

**Approach**
Our specific objectives are:
- To improve the quality and quantity of the historical water level products.
- To extend the period of observations to 20 years or greater, with near real time products derived from the NASA/CNES Jason-2/OSTM mission.
- To increase, by at least a factor of 5, the number of targets in the current system via the inclusion of ESA ERS-1, ERS-2 (1994-2002), and ENVISAT (post 2002) data. This greatly enhances the DSS, in particular by the inclusion of a large number of smaller reservoirs (100-300km²), and additionally provides a means to validate the current NASA/NRL products in regions where ground-based gauge data cannot be acquired.
- With combined NASA/USDA support, continue the operational system with both NASA/CNES Jason-2 and ISRO/CNES SARAL near real time products.
- To provide an updated systems engineering report, which includes both an evaluation study and the results of the verification and validation exercises. The system is being benchmarked, where the overall value of the enhanced and expanded products to the USDA/FAS are recorded. An outline of the technical issues will be given and system requirements re-examined.

This project utilizes NASA Earth Science products in a USDA decision support tool that primarily supports agricultural efficiency. The program is a collaborative effort between the USDA, ESSIC/University of Maryland, NASA/GSFC and SGT inc. and runs parallel with a project running under a NASA grant award to UMD/ESSIC (NNX08AM72G, 5-26728 PI: Birkett). The accomplishments listed here are combined results.

**Accomplishments and Significance/Implications**
Accomplishments this past year have included the creation of preliminary ENVISAT lake level products. Currently ~150 ENVISAT targets are displayed there with the intention of adding several hundred more as 2013 progresses. The new products are significant in that they increase the water resources database the USDA Foreign Resource Analysts utilize in their irrigation planning and crop management. Near real time products derived from the NASA/CNES Jason-2/OSTM mission continue,
but the near real time products from SARAL could not proceed as the ISRO delayed the launch of their satellite – projected date is now January 2013.

**Journal Publications**

**Presentations**
Birkett et al., NASA HQ and PI’s meeting at NASA/Ames, September 2012
Birkett et al., NASA/CNES OSTM PI’s meeting in Florence, Italy, September 2012

![Graph showing raw and smoothed relative lake level variations for the Guri Reservoir.](image)

**Figure Caption:** Preliminary (ENV.1.4) ENVISAT lake level product for the Guri Reservoir. Graph shows raw (top) and smoothed (bottom) relative lake level variations for the 2002-2010 period derived from the ESA ENVISAT mission. This reservoir produces large amounts of hydroelectric power in Venezuela but due to drought in 2010, production almost came to a standstill.
Task 669,670 and 672: Laser measurements of total column methane; PL: C. Weaver; Sponsor: H. Riris, J. Joiner, K. Pickering

Description of Scientific Problem
Laser instruments designed to measure methane from air- and space-borne platforms are being developed at NASA (GSFC Methane Sounder) and DLR (Deutsches Zentrum fur Luft- und Raumfahrt, MERLIN). Designing these instruments with sufficient accuracy to advance our understanding of emission source strengths and locations is crucial to mission success.

Approach
We are developing a model to simulate total column methane to test the potential of laser measurements to improve methane source/sink estimates. Our approach uses the FLEXPART Lagrangian particle transport model, a global chemistry transport model, and hourly methane measurements from ground-based stations in Europe. We retrieve slowly varying (15 days) source strengths from European wetlands and anthropogenic emission regions. A by-product of our model is tropospheric methane column amounts, which can be displayed in a movie format as methane weather. We can examine the seasonal horizontal spatial variability in the methane fields and compare with the current proposed accuracy and precision specifications of the laser instrument design. Currently, we have run the model for 2010. A snapshot of the total column methane (minus the background value, 1861.8 ppb) on July, 19 2010 is shown below. If the instrument wanted to detect the plumes on this day it would need to be sensitive to changes in total column methane of 10 to 20 ppb.

Accomplishments
An abstract pertaining to this work has been accepted for the Fall Meeting of the American Geophysical Union.
Task 671: Laser measurements of total column methane; PI: Graduate student: X. Huang; PI and Sponsor: K. Pickering

Description of Scientific Problem
The graduate research assistant will run models such as WRF, WRF-Chem, and CMAQ for simulations of periods of intensive observations ranging from those of convective storms to regional air quality episodes. These cloud-resolved or regional simulations will be compared with output from larger-scale models such as NASA GEOS-5 or the NASA Global Modeling Initiative Chemical Transport Model.

Accomplishments
Xinzhou Huang is a new grad student at UMD who just started in September. She is being oriented toward some research activities.
Appendix A : Papers published in 2012


Bringi, V.N., Gwo-Jong Huang, S. Joseph Munchak, Christian D. Kummerow, David A. Marks, David B. Wolff, 2012. Comparison of Drop Size Distribution Parameter (D₀) and Rain Rate from S-Band Dual-Polarized Ground Radar, TRMM-Precipitation Radar (PR) and Combined PR/TMI: Two events from Kwajalein Atoll. J. Atmos. Oceanic Technol., http://dx.doi.org/10.1175/JTECH-D-11-00153.1


Han M., S. A. Braun, T. Matsui, C. R. Williams (2012), Impact of cloud microphysics schemes in WRF model on the simulation of a winter storm as compared to radar and radiometer measurements. *Journal of Geophysical Research (revised)*


Lee, J., J. Kim, P. Yang, and N. C. Hsu, 2012: Improvement of aerosol optical depth retrieval from MODIS spectral reflectance over the global ocean using new aerosol models archived from AERONET inversion data and tri-axial ellipsoidal dust database, Atmos. Chem. Phys., 12, 7087-7102, doi:10.5194/acp-12-7087-2012.


Tzortziou M., Herman J.R., Cede A., Abuhassan N., 2012: High Precision, Absolute Total Column Ozone Measurements from the Pandora Spectrometer: Comparisons with Data from a Brewer Double Monochromator and Aura OMI, JGR-Atmospheres.


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