EARTH SYSTEM SCIENCE
INTERDISCIPLINARY CENTE
(ESSIC)

Final Report

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Director

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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 CO2?

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 CO2 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?

In Figure 1, we categorize the funding on the agreement ($12.85M) in terms of the above themes.
ESSIC continues to grow, with the addition of 8 new employees co-located at Goddard. Brief biographies of scientists hired in the last year are provided.

The remainder of this report summarizes the contributions of almost 60 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.

With the acceptance of our follow-on proposal, we look forward to another 5 years of collaborative and productive research with Goddard Earth Science.
II. HIGHLIGHTS OF THIS YEAR’S RESEARCH

The ESA ENVISAT mission is providing new lake-level products for the USDA/FAS CropExplorer on-line database. These products are archival and currently available for ~80 lakes and reservoirs around the world.

Global Land Data Assimilation Systems (GLDAS) has been generating surface fluxes and states at global, high spatio-temporal resolution, supporting hydro-meteorological studies and applications. New updates, capabilities, and constraints are continuously added to derive more accurate land surface conditions.

There is ongoing testing/evaluating updated calibration approaches for collection 6 Level-1B Terra/Aqua MODIS data using NASA Goddard’s Deep Blue aerosol retrieval algorithm and investigating the optical properties and direct radiative effects of mineral dust aerosol.

In a study systematically analyzing NASA A-train satellite data, it was discovered that anthropogenic pollutants such as SO2 from China can frequently reach the other side of the Pacific ocean, and have much greater impact than previously suggested by aircraft measurements. It also highlights the importance of long-range transport in fall, which has been rarely studied.

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.

GRACE derived terrestrial water storage changes show great potentials in improving model estimated runoff and for agricultural and hydrological drought monitoring. Detailed benchmarking effort indicates there still exists considerable room for improving snow prediction using the current generation of LSMs and forcing data; assimilation of bias-corrected satellite SWE observations can lead to significant improvement in snow and streamflow predictions.

The incorporation of real-time analysis of atmospheric temperature, water vapor, and snow cover will significantly improve the ability of GPM to detect falling snow over a variety of surface types.

Meteorological model simulations and emissions input files for air quality model simulations covering the July 2011 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.

A sophisticated software implementation of a crop water stress model "WRSI" was overhauled for integration into NASA's Land Information System (LIS) for the USGS/NASA/UCSB FEWS-NET collaboration. Successful validation of the resulting software, FLDAS-WRSI, was presented in conference for its promising new drought prediction capabilities.

The cloud microphysical package of the WRF-SBM was updated by using a new module that includes explicit melting and snow-riming processes and conducted the simulations of particular precipitation events upon the C3VP, LPVEx and MC3E field campaigns. The simulation results
were archived in the CRM database and analyzed to investigate the distinctive cloud microphysical structures in the events though a comparison with ground validation data.

A large field campaign, **CBODAQ (Chesapeake Bay Oceanographic Campaign with Discover-AQ)**, was conducted in the Chesapeake Bay estuary during the summer of 2011, co-led by ESSIC and NASA/GSFC scientists Dr. Tzortziou and Dr. Mannino. Among the main objectives of the campaign was to obtain detailed atmospheric and oceanographic observations for characterizing short-term dynamics and spatio-temporal variability in atmospheric and coastal ecosystem processes. This information is critical to further develop measurement and instrument requirements for the ocean ecosystem portion of NASA's GEO-CAPE (Geostationary for Coastal and Air Pollution Events) Decadal Survey mission.

**GEOS-5** chemistry climate model development efforts are focused on implementing hydroxyl parameterization scheme and creating a coupled CH$_4$-CO-OH system to understand the sensitivity of methane growth rates to variability in meteorological and chemical parameters.

We are developing a new first-order scattering radiative transfer model to improve the accuracy and reliability of soil moisture retrievals in moderately to densely vegetated terrain using **L-band microwave radiometry**.

Mapping of forest biomass over large areas and in at higher accuracy becomes more and more important for studies of the global carbon cycle and related climate change impacts. The studies show that biomass estimation model from **lidar waveform data** can be developed at lidar footprint size (~20m) level, and then used as biomass samples to develop biomass maps using other imagery data such as synthetic aperture radar data. The models developed in a year can be applied to lidar waveform data acquired at different years to estimate the change of the biomass.

**EMPLOYEE AWARDS**

Ms. Hiroko Kato Beaudoing, Hydrospheric and Biospheric Sciences (HOBI) Annual Award for Scientific, Technical, and Outreach in recognition of her exceptional efforts

Dr. Qiang (Jack) Ji, Climate and Radiation Laboratory, best first-authored paper

Mr. Maksym Petrenko, Climate and Radiation Laboratory, Scientific Leadership Award

Dr. Takamichi Iguchi, Mesoscale Atmospheric Processes Laboratory, for outstanding scientific research in improving WRF simulations using spectral bin microphysics to support GPM and the GPM simulator

Dr. Richard Cullather, Global Modeling and Assimilation Office, performance award for thorough analysis of the high latitude climatology strengths and weaknesses in MERRA, leading to a better understanding of the reanalysis system and two published papers.

Dr. Andrea Molod, Global Modeling and Assimilation Office, performance award for the implementation of the COSP simulators to support the GEOS-5 submission to CFMIP.
NEW ESSIC EMPLOYEES

**Tzu-Chin Tsai** as a Research Assistant for ESSIC/NASA GSFC on July 1st, 2011, working with Dr. Wei-Kuo Tao on one new double-moment microphysical cloud scheme (CLR) in WRF model. Tzu-Chin Tsai received his MS degree in National Taiwan University during 2002-2004. Now he is one PhD student in National Taiwan University and his research interests are mainly focused on CLR double-moment cloud scheme in WRF model developing and applications at meso-scale weather systems. In order to improve the representation of cloud properties and understand the relationships between aerosol and convective system, Tsai is developing/implementing their CLR microphysical scheme into WRF model. The major feature of CLR scheme keeps track of the mixing ratios and number concentrations with respect to 5 hydrometeors (cloud, rain, ice, snow, and graupel), 3 groups of CCN (dry CCN, rain CCN, and cloud CCN), as well as a specified number of ice nuclei (IN) species. The explicit treatment the interaction between aerosol and cloud in CLR scheme will help to evaluate the impact of aerosol on convective system.

**Dr. Ling Tang** began as a Research Associate at ESSIC/NASA-GSFC on August 29th, 2011, working with Dr. Yudong Tian and Dr. Christa D. Peters-Lidard at GSFC Hydrological Sciences Laboratory. Her research work is focusing on estimating uncertainties of satellite-based precipitation sensors, and identifying error propagation of their systematic errors into merged multi-sensor high resolution precipitation measurements. This work will be critical in quantifying the uncertainties in NASA’s precipitation Earth science data records (ESDRs) by determining both the systematic and random errors, and in tracking down the error sources and their relative contributions. Dr. Ling Tang received her BS and MS Degree in 2003 and 2006 from Wuhan University, China, majored in Remote Sensing. Dr. Ling Tang received her PhD degree in 2011 from Department of Civil and Environmental Engineering at Tennessee Technological University. Her PhD research was focusing on transferring of uncertainty of satellite-based high resolution precipitation products at ungauged regions. This work was funded by NASA’s Earth System Science Fellowship from 2008-2011. Before the scheduled launch of Global Precipitation Measurement (GPM) Mission in 2013, it is essential for both data producers and hydrological users to know the extent to which the high resolution precipitation products could be used over ungauged regions.

**Jaehwa Lee** joined ESSIC/NASA GSFC as a Research Associate on February 1st, 2012, working with Dr. Christina Hsu on development of aerosol retrieval algorithms using EOS-era satellites. He received the MS and PhD degree in Atmospheric Sciences from Yonsei University, Korea in 2005 and 2011, respectively. His research interests are mainly focused on improving aerosol products from passive satellite sensors, such as VIIRS, MODIS, MISR, etc. and reducing uncertainties in radiative forcing of aerosols. Recently, he has been working on improving optical properties of various aerosol types throughout the globe as input data in the radiative transfer model simulations, thereby retrieving more accurate aerosol optical properties from satellites. By collaborating with colleagues at NASA Goddard, improvements of aerosol monitoring capability using EOS-era satellites are expected.

**Dr. Jian-Jian Wang** began as an Associate Research Scientist for ESSIC/NASA GSFC on January 1st, 2011, working with Dr. Robert Adler on the TRMM composite climatology of
tropical rainfall and its validation. Dr. Wang received his MS degree in Meteorology from Peking University, China in 1990 and PhD degree from University of Hawaii at Manoa in 1995. His research interests are mainly focused on creation, demonstration and validation of satellite and ground-based radar products. Dr. Wang has developed a technique to do a bulk adjustment of the TRMM Precipitation Radar (PR) data to account for the altitude boost of the satellite. In addition, he has carried out an analysis of TRMM precipitation estimates from various instruments and techniques that has led to development of a 13-year TRMM Composite Climatology (TCC). This approach provides a TRMM-based overview answer to questions as to rainfall climatology in the Tropics and an excellent product to compare with pre-TRMM climatologies. His more recent efforts include evaluating and validating the TCC surface rainfall by comparing to ground-based observations, and developing of monthly and anomaly precipitation maps from TRMM data.

Christopher P. Loughner began as a Research Associate for ESSIC/NASA GSFC on May 16, 2011, working with Drs. Ken Pickering and Maria Tzortziou on the following objectives: 1) investigating the role of the Chesapeake Bay breeze on air pollutant distribution; 2) determining the spatial and temporal variability of trace gas and aerosol concentrations and pollution deposition into the Chesapeake Bay watersheds; and 3) formulating relationships between column amounts of trace gases and aerosols and surface air quality. Dr. Loughner received his MS degree in Atmospheric Science from the University of Nevada, Reno in 2005 and PhD degree in Atmospheric and Oceanic Science in 2011 at the University of Maryland. His research interests are in investigating interactions between land cover change, weather, climate, and air and water quality. He participated in the Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) and the Geostationary Coastal and Air Pollution Events with Discover-AQ (GeoCAPE-CBODAQ) field campaigns during July 2011 by measuring air pollution over the Chesapeake Bay and producing meteorological and air quality forecasts for research flight planning assessments. He is now performing high resolution meteorological and air quality model simulations, which will be analyzed alongside observations obtained during the field experiment to achieve the above mentioned objectives.

Dr. Jordan Borak began as a Faculty Research Assistant for ESSIC/NASA GSFC on June 6, 2011. He works with Dr. Michael Jasinski of the GSFC Hydrological Sciences Laboratory on retrieval of meteorological variables from satellite data, as well as statistical analysis of model data for the NCA (National Climate Assessment). Dr. Borak also works with Dr. Gustavo Goncalves (formerly of ESSIC/NASA GSFC), helping to coordinate the LBA-DMIP (Large-Scale Biosphere-Atmosphere Experiment in Amazonia Data Model Intercomparison Project). Dr. Borak received his MA and PhD degrees in Geography from Boston University in 1996 and 2000, respectively. His primary research interests focus on remote sensing of vegetation, interannual variability and phenology, and their linkages to the hydrological cycle.

Dr. Lars Peter Riishojgaard is the Director of the NASA/NOAA/DoD Joint Center for Satellite Data Assimilation, and his primary interests are observing systems and data assimilation. Dr. Riishojgaard received his M.Sc. in geophysics from the University of Copenhagen in 1989 and a Ph.D. from the same institution in 1992. Until 1995 he was with the Danish Meteorological Institute in Copenhagen, after which he came to NASA’s Goddard Space Flight Center in to work on ozone and stratospheric dynamics. He took a position with EUMETSAT in Germany in 1999, and returned to Goddard in 2000 to lead the analysis development in the Data Assimilation Office. He was appointed JCSDA Director in 2007. Dr. Riishojgaard is chairing the Open Area Program...
Group for Integrated Observing Systems under the WMO Commission for Basic Systems, he is Co-Chair of the US Working Group on Space-based Wind Lidars and is a member of several other national and international committees on data assimilation and space-based remote sensing matters. Dr. Riishojgaard joined ESSIC in May 2011.

Elena Yegorova joined ESSIC in 2011 as a Research Associate and is working with Dr. Bryan Duncan on-site at the NASA’s Goddard Space Flight Center in the Atmospheric Chemistry and Dynamics Laboratory. Dr. Yegorova is studying the impact of varying oxidizing capacity of the atmosphere on future climate. She is implementing and testing the NASA Goddard Earth Observing System (GEOS-5) chemistry climate model with simplified hydroxyl radical-carbon monoxide-methane tropospheric chemistry for computationally efficient future climate sensitivity studies. Dr. Yegorova received double B.S. degrees in Computer Science and Physical Sciences (2004); M.S. degree in Meteorology (2006); and Ph.D. in Atmospheric and Oceanic Sciences (2011) from University of Maryland, College Park. Her research topics include greenhouse gas variability and global climate change; air quality; atmospheric chemistry and dynamics; satellite remote sensing techniques; regional and global chemical transport modeling.

We said farewell to:

John Strack, for the UDA ARS in Big Spring, TX
Chein-Jung Shiu for REC, Academia Sinica, Taiwan
III. Major Accomplishments—Research Progress and Plans

**Task 101: The Impact of using Lidar Network Data for a Summertime Cold Front Case Study: PI: S. Rabenhorst; Sponsor: D. Whiteman**

*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 1. 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.

Description of Scientific Program
The objective of our project is to use the NASA Goddard Earth Observing System version 5 (GEOS-4 and GEOS-5, respectively) atmospheric general circulation model (AGCM) and data assimilation system to understand the influence of the parameterization of dust emission on simulated dust distributions, particular, the effects of varying the source scheme, model resolution, and meteorology on emission and aerosol optical thickness (AOT) distributions. We employed several satellite and in situ observation datasets to understand the controls on an observed barrier to dust transport over the Caribbean.

Approach
- Improve the parameterization of the dust emission process in the NASA GEOS-4/5 AGCM through the use of the Mineral Dust Entrainment and Deposition (DEAD) dust emission scheme and sub-grid wind variability.
- Validate GEOS-5 vertical dust distributions by determining settling rates and optical properties using CALIOP extinction profiles.
- Investigate the effect of model resolution on dust sources and distributions.
- Use GEOS-5 to understand the controls on the observed Central American dust barrier

Accomplishments
To summarize the past efforts: The aerosol module in GEOS-4/5 is based on a version of the Goddard Chemistry, Aerosol, Radiation, and Transport (GOCART) model. We analyzed the effect of replacing the GOCART dust emission scheme based on Ginoux et al. [2001] with a more physically based scheme that is a version of the Dust Entrainment and Deposition (DEAD) model [Zender et al., 2003] and evaluated it during NASA African Monsoon Multidisciplinary Analyses (NAMMA) field experiment (August – September, 2006). Additionally, we have evaluated GEOS-5 simulated vertical distributions using observations from CALIOP. Then, we used GEOS-5 to understand the cause and controls on the observed Central American dust barrier during the NASA TC4 field campaign (July – August 2007). This work is complete and will be submitted to JGR-Atmospheres shortly.

Currently, we are working on understanding the role of model resolution, source scheme, and meteorology on simulated dust distributions by performing several sensitivity tests for April 2008. In the sensitivity tests, a high-resolution dust source function (0.25° x 0.25°) was used in a set of simulations run with the standard GOCART mobilization scheme, the DEAD mobilization scheme, and the GOCART mobilization scheme with the 10-meter wind speed replaced by the equivalent neutral 10-meter wind speed (GOCART-10N). The equivalent neutral 10-meter wind speed has a dependency on the surface wind stress, and provides a link to the surface in the GOCART scheme. A fourth sensitivity test was aimed at understanding the effect of source function resolution was performed using the standard GOCART mobilization scheme with a coarser (2° x 2.5°) source function (GOCART-B). To understand how the simulated dust distributions vary with spatial resolution, the sensitivity tests were
performed at 2°x2.5° (“B”), 1°x1.25° (“C”), and 0.5°x0.625° (“D”) resolution. Figure 1 shows the April 2008 African dust emissions and AOT for our sensitivity tests as a function of spatial resolution. For simulations using versions of the GOCART emission scheme, dust emissions increase with resolution. The GOCART and GOCART-10N simulations increase linearly with model resolution, while GOCART-B has a nonlinear dependence. The DEAD simulation exhibits a unique dependence on resolution over Africa. Emissions decrease from “B” to “C” resolution and then increase from “C” to “D” resolution. DEAD scheme emissions are more sensitive to soil moisture. Our “C” resolution simulation produces more precipitation than at “B” resolution and inhibits dust emission. However, at “D” resolution, we suspect that this effect is somewhat countered by the higher resolution of the driving winds.

![Graphs showing African April 2008 dust emissions and AOT for different resolutions: B, C, D.

Refereed Journal Publications


Conference Publications

Nowottnick, E. P., P. R. Colarco, A. da Silva, M. McGill, and D. Hlavka (2010), The Fate of Saharan Dust Across the Atlantic and Implications for a Caribbean Dust Barrier, NASA A-Train Symposium, New Orleans, LA.

Description of Scientific Problem
An accurate specification of anthropogenic and natural emissions is crucial for determining the impact of emission perturbations on air quality. However, when this project began, lightning-NO emissions, a substantial contributor to tropospheric NO2 columns over the United States during the summertime, were not included in the Community Multiscale Air Quality (CMAQ) model used by the Environmental Protection Agency. The first goal of this project was to add lightning-NO emissions to CMAQ. Simulations with lightning-NO emissions provide more accurate estimates of nitrogen deposition and are useful for top down estimates of anthropogenic emissions. The second goal of this project was to use tropospheric nitrogen dioxide (NO2) columns retrieved from the Ozone Monitoring Instrument (OMI) aboard NASA’s Aura satellite to refine emissions of nitric oxide (NO) by microbial activity in soils calculated by the Biogenic Emission Inventory System (BEIS) that is used within the EPA’s Community Multiscale Air Quality Model (CMAQ).

Lightning-NO emissions in the CMAQ model were parameterized using a previously developed method that utilizes the relationship between flash rate and convective precipitation rate. The resulting flash rate distributions were scaled so that monthly average model flash rates match observed monthly average flash rates where the “observed” flash rates were determined using National Lightning Detection Network (NLDN) cloud-to-ground (CG) flash rates for the months of interest and climatological IC (intracloud)/CG ratios. CMAQ simulations were run with the improved source distributions for lightning-NO. Results were evaluated and the resulting algorithm is included as an option in the most recent release of CMAQ.

In order to evaluate how well CMAQ captures changes in NO2 columns associated with soil-NO emissions from BEIS, we compared changes in modeled and OMI-retrieved columns following precipitation events. Our goal was to determine if changes in NO2 columns associated with soil-NO emissions were visible in the OMI data set and if the observed changes were consistent with what was modeled via simulations with CMAQ. In order to put bounds on the emissions, we also performed CMAQ simulations with no soil-NO emissions and with doubled soil-NO emissions.

Accomplishments
During the first two years of this project, lightning-NO emissions were prepared for use in CMAQ simulations designed to study the impact of lightning-NO production on tropospheric photochemistry, surface air quality, and nitrogen deposition during the summers of 2004 and 2006.

During the most recent year, we provided a final version of this algorithm to EPA. We worked with EPA personnel as they implemented this algorithm into CMAQ. It is available to the scientific community in the most recent release of CMAQ. In February 2012, a paper summarizing the results of this project appeared in the journal, Atmospheric Chemistry and Physics. As part of this article, we studied the impact of lightning-NO production on wet deposition of oxidized nitrogen (nitrate) over the eastern United States (longitudes east of 100°W). Figures 1a-d compare wet deposition rates from National Acid Deposition Program (NADP)
monitoring sites to modeled deposition rates for simulations without (left) and with (right) lightning-NO production and for simulations with unadjusted (top) and adjusted (bottom) precipitation rates. Model wet deposition of nitrate is 27.5% too low without lightning-NO production (Figure 1a). Adding lightning-NO production eliminates this low-bias (Figure 1b). However, the resulting fit shows considerable scatter (RMSc=0.13) and correlations between model and NADP deposition rates of nitrate are only moderate (R = 0.50). The scatter is reduced and correlations improve when adjustments are made for biases in modeled precipitation with respect to NADP-measured precipitation. When these adjustments are made, RMSc decreases to 0.10 and the correlation increases to 0.76 (Figure 1d).

Figure 1a-d. Scatterplot comparing modeled and measured wet deposition of oxygenated nitrogen (nitrate) at National Trends Network (NTN) sites in the eastern United States. a: top left) CMAQ simulation noL versus NADP sites, b: top right) CMAQ simulation LNOx versus NADP sites, c: bottom left) CMAQ simulation noL versus eastern United States NADP sites after adjusting for biases in model precipitation, and d: bottom right) CMAQ simulation LNOx versus eastern United States sites after adjusting for biases in model precipitation.

As the last part of the lightning-NO component of this project, we are providing monthly average estimates of cloud-to-ground and total flash rates over the United States to the CMAQ community for the 2002 to 2010 time period. These flash rates distributions will make it possible to use month specific lightning-NO emissions in CMAQ simulations of tropospheric photochemistry and air quality over the United States.
Figures 2a-d. Mean tropospheric NO$_2$ column for April to May 2006. a: top left) DOMINO product from OMI instrument on NASA Aura satellite, b: top right) column from CMAQ simulation without soil-NO emissions, c: bottom left) column from CMAQ simulation with soil-NO emissions from BEIS, d bottom right) column from CMAQ simulation with doubled soil-NO emissions from BEIS. Notes: Averaging kernel not applied to model results. CMAQ simulations do not include lightning-NO emissions.

As part of the soil-NO component of this project, we performed CMAQ simulations of spring 2006 using three different assumptions on soil-NO emissions (no emissions, standard BEIS emissions, and doubled BEIS emissions). The simulations suggested that soil-NO adds 8-22% to the tropospheric NO$_2$ column over the US (east of 110°W). The simulations also indicated that doubling the Yienger-Levy soil-NO source in BEIS decreased the bias between model and satellite retrieved NO$_2$ columns from -10% to -2%. (Figure 2). After examination of 16 precipitation events over the central Plains regions, we determined that model-calculated and satellite-retrieved increases in NO$_2$ columns associated with precipitation pulsing were also consistent with a doubled soil-NO source. However, the large uncertainty range on the satellite-retrieved changes makes it difficult to further refine the soil-NO source using satellite data.

**Conference Presentations**

Allen, D. J., L. Silverman, S. Ehrman, K. Pickering, H. Plata, and T. Pierce, Soil NO$_x$ model/satellite measurement intercomparisons, 2011 CMAS meeting, Chapel Hill, NC.
Allen, D. J., K. Pickering, R. Pinder, B. Henderson, K. W. Appel, and A. Prados, Impact of lightning-NO on eastern United States photochemistry during the summer of 2006 as determined using the CMAQ model, 2011 CMAS meeting, Chapel Hill, NC.

Allen, D. J., K. Pickering, R. Pinder, B. Henderson, W. Koshak, and T. Pierce, Impact of lightning-NO emissions on eastern United States photochemistry during the summer of 2006 as determined using the CMAQ model, 2011 AMS meeting, Seattle, WA.

Allen, D. J., K. Pickering, R. Pinder, B. Henderson, W. Koshak, and T. Pierce, Impact of lightning-NO emissions on eastern United States photochemistry during the summer of 2006 as determined using the CMAQ model, 2010 CMAS meeting, Chapel Hill, NC.

Allen, D. J., K. Pickering, R. Pinder, and T. Pierce, 2010: Impact of lightning-NO emissions on eastern United States photochemistry determined using the CMAQ model. 2010 AMS Meeting, Atlanta, GA.

Allen, D. J., K. Pickering, R. Pinder, and T. Pierce, 2009: Impact of lightning-NO emissions on eastern United States photochemistry during the summer of 2004 as determined using the CMAQ model. 2009 CMAS meeting, Chapel Hill, NC.

Publications
Task 114 and 142: Using a Cloud-resolving Model to Simulate Lightning NOx Production During the TC4 Experiment; PI: K. Cummins; Sponsor: K. Pickering

Description of Scientific Problem
Forecasting lightning flash rates based on model storm parameters is a useful way to simulate the electrical activity in a thunderstorm, as well as estimate the production of lightning-generated nitrogen oxides (LNOₓ). Six types of flash rate parameterization schemes (FRPS) were evaluated using the cloud-resolved WRF Aqueous Chemistry (WRF-AqChem) simulation of the 16 November 2005 Hector thunderstorm, which occurred over the Tiwi Islands during the Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere (SCOUT-O3) and Aerosol and Chemical Transport in Tropical Convection (ACTIVE) field campaign near Darwin, Australia, in 2005. We will test six FRPS, based on work by Barthe et al. (2010), in the Hector storm simulation to determine if there is a scheme(s) that best estimates the total flashes and resulting NOₓ production over the lifetime of the convective event. The FRPS will also be tested in two case studies, which investigate the influence of the El Niño Southern Oscillation (ENSO) on the lightning flash rate and resulting NOₓ production in Hector thunderstorms from an El Niño year (2002) and La Niña (1999) year during the month of November.

Approach
Our specific tasks:
- Test six FRPS based on the following model storm parameters: maximum vertical velocity, updraft volume, cloud top height, precipitation ice mass, ice mass flux product, and ice water path
- Compare the estimated total (intra-cloud and cloud-to-ground) flashes over the lifetime of the simulated 16 November 2005 Hector storm with the total flashes observed by the lightning detection network (LINET)
- Calculate scaling factors for each FRPS and select a scheme(s) to include in the WRF model that best represents the trend in total flashes
- Compare the resulting LNOₓ produced by the FRPS(s) against that produced by the simulated Hector storm when observed total flashes were used as model input
- Incorporate the FRPS(s) that best represent the 2005 Hector storm in the two ENSO case studies

Accomplishments
The two FRPSs that best represent the trend in total flashes observed by the LINET for the 16 November 2005 Hector thunderstorm are maximum vertical velocity and cloud top height (Figure 1). Both FRPS show a trend similar to the observed flash rates, with a large peak in flashes shortly after convection initiation, which is followed by a decreasing trend in flashes and a secondary peak in the second half of the storm’s life cycle. The magnitude of flashes per minute was also similar at both the primary and secondary peaks and the number of total flashes over the lifetime of the simulated Hector storm is similar to that of the observed flashes. These two schemes are currently being incorporated into the WRF-AqChem model for simulation of LNOₓ in the 2005 Hector thunderstorm. The resulting NOₓ production based on observed and parameterized lightning flash rates will be compared, and further adjustments will be made to the
FRPS equations if need be, before the FRPS are employed in the simulated Hector storms during the ENSO cases.

![Graph showing Instant 10min WRF output (Flashes/min) vs Instant 10min Obs (Flashes/min)](image)

**Figure 2.** Total (intra-cloud and cloud-to-ground) flashes based on LINET observations and FRPS over the lifetime of the simulated 16 November 2005 Hector thunderstorm. Flash rates are plotted every 10 minutes.

**Conference Presentations**
Task 115: The Global Reservoir and Lake Monitoring System: Enhancing the USDA/FAS DSS with NASA, NRL and ESA Satellite Radar Altimeter Data; PI: C. Birkett (ESSIC/UMD); 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 20years 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 (launch mid-2011) 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, 5-26398 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 that went out on-line at the USDA GRLM web site at the end of 2011. Currently ~80 ENVISAT targets are displayed there with the intention of adding several hundred more as 2012 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.
Journal Publications


Presentations
Birkett et al., IRSRE conference in Sydney, Australia, April 2011
Birkett et al., NASA/GSFC invited seminar in Maryland, May 2011
Birkett et al., NASA/CNES OSTM PI’s meeting in San Diego, October 2011
Gao H., D.P. Lettenmaier, and C.M. Birkett, Global Monitoring of large reservoir storage from satellite remote sensing, 2011, Fall AGU, H11K-07.

Figure Caption: Preliminary (ENV.1.4) ENVISAT lake level product for Lake Angostura. Graph shows raw (top) and smoothed (bottom) relative lake level variations for the 2002-2010 period derived from the ESA ENVISAT mission. This large reservoir produces hydroelectric power on the Grijalva River in Mexico.
Task 116: Automating Boundary Layer Detection for Aerosol Lidar; PI: Z. Li; Collaborator: V. Sawyer; Sponsors: J. Richards/J. Welton

Description of Scientific Problem
The planetary boundary layer (PBL) varies in depth on a time scale of minutes to hours, with implications for aerosol transport, surface air quality, and radiative forcing. Unfortunately the most direct method for observing the PBL top height, via thermodynamic profiles from radiosonde launches, is available only four times per day even during intensive campaigns and less frequently than that during normal operational use. The timing of the launches seldom corresponds to the extremes of the diurnal cycle. Because a higher temporal resolution for PBL measurements would be valuable to modeling efforts, remote sensing methods are an important potential source. In order to determine whether aerosol profiles detected by micropulse lidar can serve as effective proxies of the thermodynamic structure, PBL heights derived from them must be compared to PBL heights taken from radiosonde and other thermodynamic profiles, such as AERI retrievals. All three sets of measurements are available at the ARM SGP site; intensive collocated radiosonde and MPL data come from the ICEALOT research cruise of March-April 2008.

Approach
A wavelet covariance transform technique (Davis et al. 2000; Brooks 2003) is combined with a curve-fitting iterative process (Steyn et al. 1999, Hägeli et al. 2000) to detect the PBL top height in backscatter profiles from ground-based aerosol lidar such as those at ARM sites and in the MPLNET group. The resulting PBL heights were compared to PBL heights taken from Liu and Liang (2010), who analyzed the radiosonde record at the SGP site over several years’ worth of data. In addition, the algorithm has recently been adapted to work with AERI retrievals of virtual potential temperature. Some changes to the algorithm are needed to reduce errors and artifacts in the resulting PBL time series. The accuracy of the results will vary by time of day and the stability profile of the lower troposphere.

Accomplishments
The combined algorithm is more sensitive to small-scale changes in the PBL height over time, while less susceptible to errors caused by the extraneous backscatter signals of high clouds, elevated aerosol plumes, etc. than the wavelet covariance technique alone. It remains suitable for automated PBL detection, requiring little prior knowledge or computational resources. It can be shown that while Steyn et al. (1999) used the iterative method to find entrainment zone depth as well as PBL height, the drop in aerosol concentration at the boundary does not necessarily correspond to the depth of the temperature inversion found in thermodynamic profiles. A journal article is in the works.

Conference publications

Sawyer, V.R. and Z. Li, 2011. Boundary layer and entrainment zone observations using MPLNET lidar. ASR Science Team Meeting, Annapolis, MD.


**Figure 1.** Comparison between combined-algorithm lidar PBLs and those from Liu and Liang (2010), during the period 2003-2004 at the ARM SGP site. Cases are classified by the stability regime of the lower troposphere: stable PBLs often occur below the minimum range detectable by lidar, while neutral and convective conditions allow for more accurate results.
Task 121 & 139: 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
Develop and 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. Regional applications focus on East Africa through our participation in SERVIR-Africa. Our flood and landslide models are routinely running in real-time, with 3-hr updates, with graphic results appearing on the TRMM web site (trmm.gsfc.nasa.gov). Multi-satellite rain estimates are obtained from the TRMM/GPM Precipitation Processing System (PPS) and combined with the surface information (SRTM DEM, MODIS vegetation, etc.) and the models to produce the locations of probable flood and landslide activity.

Results from the project are being used by the International Red Cross and other national and international organizations to monitor global hazard events and plan mitigation strategies. This work is also part of the Societal Benefits efforts under the CEOS/GEO umbrella, with specific items in the international work plan for continuation and testing of the algorithms and transfer of the operational responsibility for the products.

A major accomplishment this year has been 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. Four methods were explored to define flood events from the model results, including three percentile-based statistic methods and a Log Pearson-III flood frequency curve method. The evaluation showed the GFMS detection performance improves with longer flood durations and larger affected areas. The impact of dams was detected in the validation statistics. The presence of dams tends to result in more false alarms and false alarm duration. The GFMS statistics for flood durations > 3 days and for areas without dams vary across the four identification methods, but center around a POD of ~ 0.70 and a FAR of ~ 0.65. When both flood events-based categorical verification metrics and flood duration metrics are considered, a method using the 95th percentile runoff depth plus two parameters related to variability and basin size (method 3) may be more suitable for application to our routine, real-time flood calculations. The evaluation showed the GFMS detection performance improves with longer flood durations and larger affected areas. The new GFMS (operationally available at http://trmm.gsfc.nasa.gov/) improved not only the flood detection performance, but also in the presentation of flood evolution (start, development and recession) in the drainage network. The new GFMS is further evaluated.
with more quantitative flood properties including flood peak timing, peak stage, peak volumes, and duration of flood flows at basins across USA, by comparing the simulated results to gauge based hydrograph. This model development and evaluation provide a pathway forward for continued improvement. The improvements brought by the new hydrological model encourage us to use more physically-based hydrological models to potentially achieve better flood forecasting capability and performance in future endeavor, though very likely with much higher computational cost. The gauge flow based evaluation clearly indicated the importance of snowmelt process in flood simulation which is lack in the CREST model current used in the GFMS.

To realize the potential of global flood monitoring systems, robust flow routing schemes that contain minimal calibration parameters wherever possible are needed, in addition to the a priori parameters. Therefore during this year, to improve the stream flow simulation accuracy, a new kinematic wave based routing scheme for large scale applications while taking into account subgrid stream routing at finer resolution has been developed and tested with a community hydrologic model –Variable Infiltration Capacity model (with snowmelt) using conventional meteorological forcing inputs. 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 like this study were developed by applying the hierarchical Dominant River Tracing (DRT) algorithm to the HydroSHEDS fine scale (1km) baseline hydrography inputs (Wu et al., 2011).

**Refereed Journal Publications**


Task 127: Validation and Calibration of Airborne Lidar Data Collected Using NASA’s Laser Vegetation Imaging Sensor in Support of the DESDynl Lidar Mission; PI: M. Hofton; Sponsor: S. B. Luthcke

Description of Scientific Problem
This project coordinates high-altitude airborne lidar data experiments in the Antarctic and Greenland to collect elevation and surface structure information in support of NASA’s Operation Ice Bridge. After processing and quality checking, data precision and accuracy are assessed using crossover analyses and comparison with available in situ data. Data are released publically. The study results in the collection, analysis and validation of the precision and accuracy of elevation and topographic structure products derived from the 25m-footprint, waveform LVIS lidar over ice targets.

Approach
Our specific objectives are:
- After liaison with Ice Bridge science team members, generate detailed flight plans and mission specific information that is used in the collection of medium-altitude, 25m wide footprint airborne lidar data during flights performed as part of NASA’s Operation Ice Bridge. Data are collected using NASA’s Land, Vegetation and Ice Sensor (LVIS).
- Process and validate precision of waveform lidar elevation, structure and height metrics and release data to investigators.
- Data mining of existing LVIS data for science team and other studies.

We are collecting, processing and distributing lidar data over sites in Greenland and Antarctica that have a variety of surface conditions (surface slope, dh/dt, flow) and where other data sets are available for comparison. Detailed analysis of data product precision and accuracy are possible as well as simulation of the measurements that future spaceborne lidars might make.

Accomplishments
LVIS data were collected at various sites in Greenland and Antarctica. The flight missions were undertaken in March-April, 2011 and October-November 2011. Data are processed and released via the LVIS and NSIDC web sites. Streamlining of the data processing flow as well as new data product development has taken place to improve data processing and release schedules.

Conference presentations
J. Blair and M Hofton, LVIS Precision and Accuracy, Ice Bridge Planning Meeting, UC Irvine, CA, June 14-16, 2011.


Task 128: Pilot Applications of the Chesapeake Bay Forecast System; PI: A. Busalacchi; Sponsor: J. Bryson

Description of Scientific Problem
A project aimed at demonstrating the value and utility of applications of the Chesapeake Bay Forecast System (CBFS), a prototype regional integrated Earth System Model being developed and implemented at the University of Maryland Earth System Science Interdisciplinary Center. This pilot effort will develop several Pilot User Collaborations aimed at identifying and testing methods for applying CBFS forecast products to sector-specific needs.

Approach
Rising temperatures have important implications for estuarine ecosystem structure and metabolism. Although elevated nutrient loadings are the dominant cause of eutrophication and hypoxia in coastal waters, rising temperatures can increase rates of oxygen consumption and further reduce the solubility of atmospheric oxygen in coastal waters, ultimately driving deoxygenation. Furthermore, global climate change may increase coastal stratification and inhibit vertical mixing, thereby reducing ventilation of subsurface coastal and ocean waters. The Chesapeake Bay is the largest estuary in the North American region and is facing severe summer hypoxia and anoxia problems. Moreover, changes in land-use and climate amplify the terrestrial nutrient loadings to the Bay that subsequently affects the water quality. The aim of this research is to understand the impacts of climate change induced rising temperatures on dissolved oxygen (DO) dynamics and to develop the ecosystem models to understand intricate interactions among various ecological processes and to predict DO in the Chesapeake Bay.

We collected the long term water temperature, dissolved oxygen and dissolved nutrients (nitrogen and phosphorus) data were collected from various stations of the Chesapeake Bay from the Chesapeake Bay Program. Each station is sampled once a month during the colder late fall and winter months and twice each month in the warmer months. At each station, a hydrographic profile is made and water samples for chemical analysis are collected at the surface and the bottom, and (for deeper stations) at two additional mid-water depths depending on the existence and location of the pycnocline. Long-term (1979-2009) air temperatures over the Chesapeake Bay were collected from the National Centers for Environmental Prediction (NCEP)-North American Regional Reanalysis (NARR) data. In this study, air temperatures for the central axis stations were computed by interpolating temperatures from the neighboring grid points, if the air temperature was not available for that particular station. The long-term trends in air- and water temperatures and DO were analyzed using SAS to depict the interactive control of rising temperatures on DO dynamics and depletion of DO in the Chesapeake Bay. Furthermore, the multivariate statistical model was developed using a set of environmental variable (water temperature, salinity, nitrogen and phosphorus). The developed model was validated for the operational prediction of DO in the Chesapeake Bay.

Earth’s surface temperatures are likely to increase by 1.1-6.4 °C by the end of the 21st century relative to the 1980-1990 base periods, with a best estimate of 1.8-4.0 °C for a wide range of greenhouse gas emission scenarios. An increase in air temperature will likely be reflected in higher water temperatures, which has implications for the structure and metabolism of coastal ecosystems. Statistically significant long-term trends in air temperatures were observed in CB
with a measured rate of warming of 0.05 °C yr⁻¹ (r = 0.63, p<0.05; Fig. 1). An increase in air temperature will likely be reflected in higher water temperatures, which impact estuarine ecological processes, water circulation and nutrient dynamics. Weak increasing trends in water temperatures (0.0145 °C/yr; p<0.47, see Fig. 1) are observed in CB, and the air- and water temperatures are also strongly correlated (Fig. 2). This clearly describes that the heat balance and distribution of heat in shallow estuaries are largely controlled by meteorological forcings at the air–water interface.

Figure 1: Long-term analysis of air- and water temperatures of the Chesapeake Bay (1985-2008).

Figure 2: Correlation between air- and water temperatures in Chesapeake Bay.

An important regulator of dissolved oxygen concentrations in coastal surface waters is its solubility, which decreases with increasing temperatures. Strong negative correlations between temperature (both air and water) and DO in both estuaries clearly demonstrate that climate induced variability in temperatures drives down the DO levels in coastal waters (Fig. 3). Moreover, distributions of oxygen levels in coastal and marine waters are also controlled by both rates of photosynthesis and heterotrophic respiration. Rising temperature could accelerate the metabolism of large quantities of terrestrial organic matter delivered to coastal waters from watersheds and have a profound effect on bacterial heterotrophic respiration and oxygen levels. In addition, sinking of organic matter due to eutrophication demands substantial oxygen levels for microbial
respiration in the bottom waters of CB that further exacerbate the bottom water hypoxia and anoxia, and these rates of respiration may also be influenced by temperature.

Figure 3 Dynamic interactions of dissolved oxygen with air- and water temperatures in Chesapeake Bay.

The spatially-explicit ecological model was developed for prediction of DO in the Chesapeake Bay using a suite of environmental variables like water temperature, salinity, nitrogen and phosphorus. The developed model was well validated with the observations (Fig. 4). The developed model is an effective ecological tool can be used to describe the response of ecosystem to changing environmental variables, like rise in temperature and salinity and increase in terrestrial nutrient loadings.

Figure 4: Correlation ($R^2$) between observed and predicted DO concentrations for both surface and bottom layers

Publications
**Task 131: Impact of Moisture Conditions on Twomey Effect; PI: Z. Li; Collaborator: Y. Ding; Sponsor: W. Tao**

**Description of Scientific Problem**
Generally, aerosols suppress shallow cloud development and precipitation process through Twomey effect and aerosol second indirect effect. However, it is not always the case if the meteorological variables change. Previous studies have shown the possibility of anti-Twomey effect. This study attempts to identify and evaluate the dependence of aerosol effects on meteorological variables using both RACORO (Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations) aircraft field campaign data, long-term GOES (Geostationary Operational Environmental Satellite) and surface observational data in ARM SGP site. During the RACORO campaign (January to June, 2009), 57 flights were taken, and half of them were inside the boundary layer clouds. The obtained long-term representative statistics of cloud microphysical and aerosol properties of the atmosphere make the statistical average methods possible. These data could also support model simulations of boundary layer clouds. Various factors such as cloud water mixing ratio, RH, and liquid water content (LWC) are investigated.

**Approach**
Making use of the aircraft data inside the boundary layer liquid-water cloud, we characterized the strength of Twomey effect by the slope of correlation between CCN and droplet effective radius (Re). Only the data collected in the core area of clouds were used because the droplets at the edge part suffer from the entrainment and evaporation. Cloud albedo and Re from satellite observation and aerosol concentration from ground observation are also used to provide long-term evidence. For the further study, model simulations are used to understand the cloud microphysical mechanism underlying the observed phenomenon and to examine these effects in other types of clouds with different LWC, RH and mixing ratio value.

**Accomplishments**
In the aircraft statistical averaging study, significant impacts of cloud water mixing ratio on Twomey effect were found, indicating that increasing total cloud water mixing ratio leads to a weaker Twomey effect while there is no clear trend for the LWC and RH impact. The weak competition among cloud droplets for water vapor in humid environment might be responsible to migrating effect of total cloud water mixing ratio. The long-term study also revealed that Re is larger in the humid half year than that in arid half year, and that cloud albedo slightly increases with aerosol concentration in the arid half year while decreases in the humid half year. Both the aircraft and satellite data analysis prove that Twomey effect is weaker in humid environment. Model simulation in the future could provide more evidence of our results.

**Refereed journal publications**

Conference publications
1. Poster titled by “Dependence of aerosol effect on meteorological variables” in ASR 2012 Science Team Meeting
2. Talk titled by “Dependence of aerosol effect on meteorological variables” in breakout session in ASR 2012 Science Team Meeting
**Task 132: Analysis and Evaluations of Passive Microwave Measurements; PI: Nai-Yu Wang; Sponsor: M. Schaller**

**Description of Scientific problem**
Measurements from polar orbiting satellites, in particular, microwave sensors, offer perhaps the most viable means to develop global precipitation retrievals. Measurements from the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Mission (GPM) will exploit such data to provide global, three-hourly precipitation monitoring. Much research and development needs to be done to prepare for the GPM core satellite launch in 2013. The next three years is the most critical time to develop and deliver the pre-launch algorithms. We’ll work closely with several Precipitation Measurement Missions (PMM) science team working groups (WGs) and team members to develop and deliver the baseline precipitation algorithms over land.

**Approach**
Development and evaluation of land surface emissivity estimates extracting from different methods (e.g., emissivity calculations from land surface emissivity model coupled with land surface model, or emissivity estimates from satellite observations) and its impact on the precipitation retrievals.

**Accomplishments**
An example of emissivity estimates over the Amazon (7S, 70W) from AMSR-E 19V, 37V and 85V measurements for the year of 2006 is shown in figure 1. Blue lines represent the calculated emissivity using AMSR-E brightness temperatures and the NCEP GDAS profiles of temperature, relative humidity and cloud mixing ratio. The red dots in the figure are calculated assuming clear sky (no clouds or precipitation in the vertical profile). Notice that the effect of clouds and precipitation on the brightness temperatures increases with frequency, which reflects on the highly varying 85V emissivity estimates.

**Conference Presentations**
Presented the status and plan for the surface characteristics working group in the Combined algorithm team meeting in May 2010 in College Park Maryland.
Task 133: Polar Climate System; PI: L. Boisvert; Sponsor: T. Markus

Description of Scientific problem
We want to calculate the moisture flux over the entire Arctic using satellite data on board NASA’s Aqua satellite daily from 2003-2009. We would like to study how the moisture flux has been changing in recent years with the dramatic changes in the Arctic sea ice pack thickness, compactness, and extent. We would like to compare these findings to recent studies dealing with Arctic cloud changes in recent years to see if they relate. We began with a small-scale study of the North Water polynya in order to test the accuracy of the satellite data before moving on to the entire Arctic sea ice pack.

Approach
Satellite data were applied to calculate the moisture flux from the North Water polynya during a series of events spanning 2003-2009. The fluxes were calculated using bulk aerodynamic formulas with the stability effects according to the Monin-Obukhov similarity theory. Input parameters were taken from three sources: air relative humidity, air temperature, and surface temperature from the Atmospheric Infrared Sounder (AIRS) onboard NASA’s Earth Observing System (EOS) Aqua satellite, sea ice concentration from the Advanced Microwave Scanning Radiometer (AMSR-E, also onboard Aqua), and wind speed from the ECMWF ERA-Interim reanalysis. Our results show the progression of the moisture fluxes from the polynya during each event, as well as their atmospheric effects after the polynya has closed up. These results were compared to results from studies on other polynyas, and fall within one standard deviation of the moisture flux estimates from these studies. Although the estimated moisture fluxes over the entire study region from AIRS are smaller in magnitude than ERA-Interim, they are more accurate due to improved temperature and relative humidity profiles and ice concentration estimates over the polynya. Error estimates were calculated to be $5.56 \times 10^{-3} \text{ g m}^{-2} \text{ s}^{-1}$, only 25% of the total moisture flux, thus suggesting that AIRS and AMSR-E can be used with confidence to study smaller scale features in the Arctic sea ice pack and can capture their atmospheric effects. These findings bode well for larger-scale studies of moisture fluxes over the entire Arctic Ocean and the thinning ice pack.

I am currently using the Monin-Obukov Similarity Theory and data from NASA’s Aqua satellite in order to compute the moisture flux over the entire Arctic sea ice pack daily from 2003-2009. I am looking at sea surface temperatures, air temperature profiles, relative humidity profiles, surface temperature, geopotential height and ice concentration from these sensors. I hope to be able to see changes and trends in the moisture flux on a yearly, seasonal and monthly basis and compare my results to recent studies done with changes in Arctic clouds. I also hope to make some changes to the Monin-Obukov Similarity Theory that better suit the conditions present in the Arctic to make more accurate moisture flux estimates and compare these to ECMWF Interim reanalysis data.

Accomplishments
In December I defended my thesis topic in front of my committee and it was accepted. I will also be receiving my Master’s degree in the UMD 2012 May Commencement. We have recently been accepted for publication in the Journal of Geophysical Research- Atmospheres on our work of the moisture flux from the North Water Polyanya 2003-2009.
**Figure.** Maps of daily ice concentration [IC] (%) (top row) and moisture flux [MF] (kg/m$^2$•day) (bottom row) for each polynya event. All maps cover the same region as the polynya map of Figure 1. Black is land.

**Refereed Journal Publications**

**Conference Publications**

Boisvert, L., and T. Markus, ‘Sea Surface Temperatures: High latitude SSTs and their Interaction with the Arctic Sea Ice Cover’, World Climate Research Program (WCRP) Conference, Denver, CO.
Task 134: Dynamic Downscaling and Urban Land Use; PI: R. Murtugudde; Collaborator: Bin Zhang; Sponsor: M. Imhoff

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 135: Improved Hypoxia Modeling for Nutrient Control Decisions in the Gulf of Mexico (Hypo-G); PI: J. Stehr; Sponsor: K. Pickering

Description of Scientific Problem
Every year, a large dead zone in the Gulf of Mexico emerges, fed by large inputs of nitrogen and other nutrients from the Mississippi river. The dead zone consists of an area of low dissolved oxygen the size of Massachusetts arising from algae blooms and subsequent die off of the algae. Once the algae die, they decay, consuming oxygen and depriving other species of the oxygen they need to live. The dead zone leads directly to fish kills and loss of habitat for less mobile organisms such as mussels and crabs. The goal of the overall project is to provide a scientific basis for addressing the Gulf of Mexico dead zone. In particular, we will use NASA satellite products to evaluate predictions from rain and snow simulations and to provide ocean color evaluations. The University of Maryland (UMD) portion of this project seeks to approach one aspect of the nutrient loading to the Gulf, namely deposition of nutrients from the atmosphere in rain and snowfall. As nitrogen-rich water and snow fall on the watershed of the entire Mississippi River system, a portion of that nitrogen makes its way to the Gulf of Mexico, producing the dead zone there. This project seeks to improve the understanding of these processes and to improve the ability of the models to treat these processes properly. It also responds to a plan put forward by the governors of Gulf of Mexico states, the Governors’ Action Plan for Healthy and Resilient Coasts.

Approach
NASA, EPA and the University of Maryland, along with other partners, have teamed up to address this problem. In particular, our partners are the EPA Gulf of Mexico Program office and the Gulf of Mexico Modeling and Monitoring project at the EPA Office of Research and Development and colleagues at NASA. We are teaming up to use NASA satellite products to help evaluate the outputs of their air and water quality models. The UMD aspect of this collaboration involves comparing NASA and NOAA precipitation satellite and ground-based products to the precipitation part of the Gulf modeling system. This modeling system necessarily includes a meteorological model that drives the air and water quality models. In consultation with leading experts in the field, we have begun using 4 km resolution monthly Parameter-elevation Regressions on Independent Slopes Model (PRISM) data to compare with monthly aggregated WRF precipitation fields. The results are good, but indicate that there is room for improvement. The PRISM model is a regression model that starts from the observational rain gauge data network, and performs an intelligent interpolation between monitoring stations to develop a better representation of precipitation. The dominant parameter is altitude, which is known to strongly affect precipitation, though other parameters are relevant as well.

Accomplishments
The first run of the meteorological, emissions and air quality modeling are complete. We have performed some quantitative evaluations of the meteorological model, as mentioned above, and found that the meteorological model performs well in simulating precipitation and somewhat poorer at simulating deposition on a monthly basis. We do not expect perfect performance on a short-term basis, as this requires the model to time precisely precipitation and its intersection with chemistry. We are currently ratioing the precipitation from the model to the PRISM data and will
use that to adjust the deposition accordingly. Latysh and Wetherbee (2012), used this approach to improve nitrogen deposition performance.

5 & 6. A conference presentation at the Chesapeake Modeling Symposium on evaluating and improving nitrogen deposition to watersheds is planned for later this spring.

**Reference**

*WRF outputs are shown in a)-c) for a) annual precipitation, b) January precipitation, and c) July precipitation. PRISM data are shown in panels d)-f) for the months corresponding to the WRF results to the left. Areas in WRF with precipitation significantly above that observed in PRISM are highlighted with large + signs; those with precipitation below PRISM observations with – signs. In January, a large area of increased precipitation in the lower Mississippi River Valley is displaced to the north and west of where it appears in the PRISM observations, as indicated by the orange arrow over Alabama and Georgia in the southeast. Overall, such features as the dry wintertime in Florida, the summer monsoon over Arizona, New Mexico and Colorado, and the broad area of summertime precipitation in the Ohio River and Northeast are well represented in the model.*
Task 136 and 137: Impact of satellite sensor calibration on the long-term trend of global aerosol products. PI: Z. Li; Collaborator: A. Jongeward; 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 understanding of the overall radiative forcing due to aerosols is further 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]. 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].

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/NASAs VIIRS instruments.

Approach:
The approach of assessing the impact of satellite sensor calibration on the long-term trend of global aerosol products consists of several steps:
- 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 from a variety of satellite reflectance data sets. 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 satellite input, thus eliminating signal variations influenced by the use of different aerosol and land properties.
- As mentioned above and in the previous section, a variety of satellite reflectance data sets will be utilized. Studies will be performed using current, sensor specific calibration, as well as a variety of inter-/cross- sensor and historic calibrations.
- A comparison between MODIS and VIIRS products will be of interest due to the similar onboard calibration capabilities of all channels of these two sensors. Similarly, a comparison of each with the AVHRR product will shed light on the importance of onboard
calibration capabilities. AVHRR sensors are only capable of onboard calibration of thermal channels, and aerosol products have been derived from visible channels.

- 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.

Accomplishments:
Work on the current study is in its infant stages. A review of relevant, peer-reviewed literature has been performed by A. Jongeward. Currently, A. Jongeward is reading documentation on and familiarizing himself with the AOT2 system. A conference presentation of current work and progress is expected during the current year.

References:
Task 138: Comparison of Air Quality Models with Satellite Observations for Improved Model Predictive Capabilities; PI: C. Flynn; Sponsor: 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. The hourly time series of column O3 and NO2 from the aircraft data, ground-based Pandora UV/Vis spectrometer data, CMAQ output, and OMI dataset were analyzed for each of six Maryland Department of the Environment (MDE) air quality monitoring sites involved in the deployment. 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. The column time series allow comparison of the column amounts obtained from the model, satellite, and in situ data. A correlation analysis was also performed between column amounts and surface mixing ratio data for O3 and NO2 for each surface site for the aircraft data, Pandora data, and CMAQ. The linear Pearson correlation coefficient (R) was computed for each site as a measure of the degree of fit of a linear relationship. Gao Chen (NASA/LaRC), Lok Lamsal (NASA/GSFC), and Jay Herman (NASA/GSFC) must be acknowledged for providing the aircraft, OMI, and Pandora column data, respectively.

Accomplishments
The hourly column time series presented the column amounts of O3 and NO2 from multiple perspectives. The time series revealed the variation in the CMAQ model bias compared to the aircraft, Pandora, and OMI columns. During the July 4th weekend getaway days, CMAQ demonstrated a low bias relative to the observed columns for O3 and NO2, indicating that NOx emissions may be too low in the model for these days. Later in July, CMAQ demonstrated
reasonable agreement with the observations during the late morning, but transitioned to a high bias by afternoon and evening. Mean ratios for July of the CMAQ column to the columns derived from the aircraft, Pandora, and OMI data demonstrated that for NO$_2$, CMAQ has a general high bias for more urban sites, such as Beltsville, near Washington, D.C., and a low bias for more rural sites, such as Fair Hill, in northeastern Maryland. Example time series are displayed in the top panel of Figure 1.

Large correlation was obtained for both the aircraft O$_3$ column$_{air}$ and column$_{ground}$. Moderate correlation was obtained for the aircraft NO$_2$ column$_{ground}$, while low correlation was obtained for NO$_2$ column$_{air}$. These initial results indicate that with sufficient sensitivity to the lower troposphere, satellite observations may be meaningful for surface air quality analysis. Example scatter plots for the aircraft data are displayed in the middle panel of Figure 1. Large correlation was obtained for O$_3$ in the CMAQ model, while moderate to large correlation was obtained for NO$_2$ in CMAQ. Example plots for CMAQ are displayed in the bottom panel. For both O$_3$ and NO$_2$, CMAQ demonstrated larger correlation between the column and the surface than was apparent in the aircraft data, indicating that the CMAQ surface is more connected to the overlying column than observations support. This indicates that the model underestimates the variability observed in the lower troposphere, and that the model boundary layer is too well-mixed.

![Column Abundances CMAQ vs. P3B Edgewood 201107C2](image1)

![Column Abundances CMAQ vs. P3B Edgewood 20110726](image2)

![O3 P3B-Surface Site Correlation Beltsville](image3)

![NO2 P3B-Surface Site Correlation Aldino](image4)
Figure 1: (top) Column time series for O₃ and NO₂ from the aircraft, CMAQ, Pandora, and OMI for July 2^{nd} and July 28^{th} at the Edgewood site. Column amount is plotted against hour of the day in UTC. (middle) Scatter plots of column vs. surface value for the aircraft at the Beltsville and Aldino sites for O₃ and NO₂. Correlation coefficients are displayed on each plot. Column amount is plotted against surface mixing ratio value. (bottom) Scatter plots of column vs. surface value from CMAQ for the Fair Hill and Padonia sites. Same as for the aircraft plots.

Conference Publications
Clare M. Flynn, Kenneth E. Pickering, Pius Lee, Youhua Tang, Andrew Weinheimer, Ronald Cohen, and James Szykman, “Correlation analysis of column-integrated P-3B data with surface mixing ratio for in situ observations and model for O₃ and NO₂”, 3^{rd} International Workshop on Air Quality Forecasting Research, Potomac, MD, November 29, 2011.
Description of the Scientific Problem

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, 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 feed back on the population.

Approach

We are developing a prototype Earth System Model (ESM) coupled with a Human model where all of the above-mentioned variables are fully coupled to each other. As a result, we do not need to import the values for any of the variables from external sources, e.g. United Nations population projections for the next 50 years. Instead, the model internally determines any of the variables, say population, in the coming decades based on the dynamical relations with the rest of the variables. When the prototype model is ready we will work with the Climate@Home team to post the model 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 a fundamental issue, and 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.

Accomplishments

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. 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 are currently preparing a manuscript of the results from HANDY for publication.

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, INCOWA (Intermediate-Complexity Water model). We also created a simplified version of INCOWA, called SIWA (Simple Water model). INCOWA 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 will be back in 2012 to continue her work with us on INCOWA.
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), currently under review.

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) in the North Africa region since his arrival in UMD in Aug 2011. He has also started development of a river-routing module to be coupled to the UMD-ICTP Earth System Model. He will complete this work and building and running the couple Human-Water-Climate model after finishing 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.

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 145: Model based study of DC-Baltimore Urban heat island; PI: R. Murtugudde; Collaborators: M. Ganeshan; Sponsor: M. Imhoff

Description of the 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 impact of Urbanization, land use, and heat island effects on weather and climate is being studied in a dynamic downscaling framework for Regional Earth System Prediction. Urban areas are known to alter local temperature and winds due to differences in surface roughness, albedo, and surface sensible and latent heat fluxes. As the human population continues to grow, we can also expect urban areas to expand and potentially affect weather and climate on a regional scale in some areas.

The Urban Heat Island (UHI) impact of DC-Baltimore on local precipitation is studied using WRF at 500m resolution. The various processes related to urban surfaces are simulated using an urban canopy model in combination with NOAH’s Land Surface Model. The heavy precipitation event that occurred on 13th-14th July 2010 in the DC-Baltimore area is analyzed.

Approach
We plan to run high resolution WRF simulations (2-km), using NARR as forcing, over the upcoming year with the goal of determining the extent of the Baltimore-Washington urban heat islands under different synoptic weather conditions. In addition, we will run simulations with the urban areas removed and expanded by arbitrary amounts for comparison with the present day condition. We will use the NOAH land surface model urban scheme along with MODIS land cover data. We had originally hoped to compare Terra/Aqua derived profiles of temperature and water vapor to the model output, however, the data lack sufficient vertical and temporal resolution for this purpose.

Accomplishments
The nocturnal UHI for DC and Baltimore appears to be stronger than the diurnal one. The model captures heavy precipitation in the vicinity of both cities during the 2-day rainfall event. In particular, it simulates a nocturnal storm that passes directly over DC on 13th July 2010 at around 11p.m. LT (Fig.1(a)).

Figure 1(b) shows the urban heat island simulated by the model one hour prior to the occurrence of the storm (10p.m. LT). The 2m air temperature over the core of DC is up to 3-4°K warmer than its surroundings. The temperature gradients between the capital city and its neighboring areas are strongest in the northern and western regions. In cities with a pronounced UHI, the warmer temperatures can often lead to local convergence and hence result in higher precipitation.

As the storm moves over DC, however, the maximum rainfall does not occur over the city itself. Instead the heaviest precipitation is predicted to occur to the west and northwest of DC (Fig.1(a)). It appears that this spatial pattern of heavy precipitation is a direct result of the strong temperature advection at the surface (Fig.1(b)). It is a well-known fact that both temperature and moisture advection can lead to local instabilities that produce precipitation. The downwind impact of UHI on precipitation has been well documented in previous studies. It is possible that the temperature...
or thickness advection due to strong gradients between the city and neighboring areas could play an important role in enhancing downwind precipitation.

Through our study, we seek to identify the dominant patterns of rainfall resulting from DC-Baltimore’s UHI. The role of thermal, moisture and other gradients will be investigated. The impact of replacing the urban cover with natural land cover will be studied. Also, we will examine possible plans for the future expansion of the city in order to identify land-use land-cover changes that have the least impacts on precipitation, temperature and other parameters.
Fig.1 (a) Rainfall (mm) at 11p.m. LT, and (b) 2m temperature (Kelvin) along with 2m wind contours (m/s) at 10p.m. LT on July 13th 2010.

A script was written to modify the extent of urban cover in the input surface files for WRF. Several sets of WRF runs have been made on a 500-m grid centered on the Washington DC – Baltimore area. The runs were done in pairs, one control run with current urban cover distribution as determined from MODIS, and one perturbation where the urban cover was replaced with deciduous forest. The urban heat island appears to be 1-4 C warmer than the surrounding area and is strongest in the night. Preliminary results suggest that the DC-Baltimore heat island may increase precipitation downwind of the cities by increasing 1000-500 mb advection.

Difference in precipitation (mm) between urban and urban removed case for August 22, 2009.
**Task 146: Analysis of OMI tropospheric NO2 data in relation to global lightning flash data; PI: K.Pickering; Collaborators: A. Ring; Sponsor: K. Pickering**

**Description of the Scientific Problem**
This effort will be aimed at estimating NO\(_x\) 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 matches between major lightning events and the Aura/OMI overpass. Mean NO\(_x\) 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 been plotted for years 2007 and 2008 to describe daily, monthly, and seasonally occurring flash rates. This coupled with flash rate information from Optical Transient Detector and Lightning Imaging Sensor (OTD/LIS) satellite instruments will provide an understanding of global flash rates for 2007 and 2008. Comparison of these two data sets will allow determination of detection efficiencies for WWLLN. The WWLLN data (adjusted for detection efficiency) will then be compared to the Aura/OMI satellite NO\(_x\) data, specifically for storm events. This comparison will help to quantify average NO\(_x\) production per lightning flash (LNO\(_x\) production). GMI simulations with and without lightning will be used to estimate background tropospheric NO\(_x\), determining scaling factors to ensure only LNO\(_x\) 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. Comparison between the OTD/LIS data and WWLLN data is progressing to determine flash detection efficiency. WWLLN data is also being compared to the National Lightning Detection Network (NLDN) data to further assess detection efficiency over the United States.
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.

Approach
The ultimate decisions about flight safety due to volcanic ash (VA) should be a collective responsibility of travelers, airlines, airports, and air navigation service providers (e.g., FAA). Such decisions have to be made well in advance, some a day prior, particularly forecasting future VA cloud position and properties which play a critical role in decision making process. The US volcanic hazard decision support systems (DSS's) processed and managed by NOAA and the USGS provide important safety information on VA clouds and warnings to the aviation community. The primary DSS are the VA Advisory Centers (VAACs) where satellite, model, and volcano monitoring data are ingested to disseminate VA Advisory Statements. Currently VAACs rely on excessive manual analysis that can be automated to produce products that can better support decision-makers. NASA’s contribution to this problem is maintaining near real-time (NRT) data flow from the Aura/OMI satellite data produces to NOAA, as shown in figure 1. These data present a marked improvement in global volcanic cloud detection by combining UV Aerosol Index (AI) and sulfur dioxide volcanic gas, SO2 as markers for ash: http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html.

Accomplishments
Task 1 Evaluation of baseline volcanic emissions in GEOS-5 Baseline sulfate cycle includes a database of volcanic SO2 emissions and injection heights. We will use OMI SO2 data to evaluate the GEOS-5 simulation of the SO2 volcanic clouds for selected eruptions in 2007-2009. Global model runs are available at 50km spatial resolution in 72 vertical layers. These will serve as baseline forecasts generated with simplified assumptions about volcanic emission parameters (emission height profile, rate and duration). The volcanic emission database will be evaluated, updated and documented (Figure 1).
Figure 1. Left: OMI observed Kasatochi volcanic SO2 cloud on August 11 2008 (note logarithmic scale). Maximum observed SO2 column density was 190 Dobson Units or 5.4 [g/m2] and total observed SO2 mass ~1.8 Tg [Krotkov et al., 2010; Yang et al, 2010]; Middle: Kasatochi SO2 column mass simulated in baseline GEOS-5 run without constrain by satellite SO2 data. Although SO2 cloud shape was accurately predicted, the column mass density is underestimated by factor 2-3, likely due to underestimation of initial volcanic source emission. The source term can be easily scaled to match OMI data (estimated initial emission ~2.2 Tg on Aug 8); Right: GEOS-5 vertical profiles (curtains) of SO2 mixing ratios [ppb] averaged from 50N to 70N as function of longitude. The contour lines are heights in km; therefore, plume is situated between 7 and 14km in agreement with trajectory height estimates and CALIPSO lidar vertical profiles [Krotkov et al., 2010].

Task 2 Evaluate impact of OMI SO2 assimilation for forecasting SO2 volcanic clouds
As it becomes available, we will assimilate both OMI SO2 column amounts and plume height and re-examine the same cases in Task 1, now starting from assimilated OMI SO2 retrievals. The expected result is that with a better initial condition the SO2 plume forecast will improve. We will also explore possibility including OMI AI (ash) observations into GEOS-5 model. The model has on-line aerosol module (GOCART, Colarco et al. 2010) and model AI simulator is currently under development. After initial demonstrating of GEOS-5 model SO2 forecasts, activities in stage 2 would include:

- automatic NRT acquisition of volcanic emission estimates (important for data assimilation);
- implement OMI SO2 assimilation in GEOS-5 in NRT
- implement OMI AI assimilation in GEOS-5 (important for VA forecasts)
- bring AIRS/IASI SO2 channels into GSI (atmospheric radiance assimilation), performing a joint SO2 analysis.

The anticipated results of our project will be demonstration of improved VA forecasts that are more accurate, have higher spatial and temporal resolution; describe cloud densities, and are more dynamic. This will be achieved by integrating the most advanced satellite sensor data with proven volcanic cloud forecasting models and automating the process by which improved forecasts are generated. The expedited integration of multiple satellite data streams in digital form into VA DSS at different agencies and delivering to the public via web interface will greatly advance current abilities of the VAACs in the detection, monitoring, analyzing and forecasting of VA and SO2 clouds.
Task 148: CloudSat-TRMM Intersection Processing; PI: Shen-Shyang Ho; Sponsor: David Starr

Description of Scientific Program
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 $= 70$ 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 (94 GHz) 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.

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.

Accomplishments
1. Implemented a brute force algorithm for verification. Completed.
2. Designed and implemented the intersect algorithm in Matlab. Completed.
3. Run the intersect algorithm on historical data. In Progress.
**Task 200: Global Land Data Assimilation System (GLDAS); PI: H. K. Beaudoing; 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 GLDAS products from NASA/GSFC's Data and Information Services Center (DISC). The products are updated every month to extend to delayed present. The GLDAS data is one of the top accessed datasets at GES DISC, making it into six categories of the NASA GES DISC 2011 Top 10 List (http://disc.sci.gsfc.nasa.gov/gesNews/nasa_ges_disc_top10_2011).

While we keep up with the monthly delivery of the GLDAS version 1 products, we are working on producing GLDAS version 2 dataset. The GLDAS2 is forced by a climatologically consistent meteorological dataset of Princeton University, with the updated versions of LSMS, and extended period from 1948 to present. The 1 degree NOAH model simulation from 1948 to 2008 has been published at the DISC. Due to an updates to the forcing dataset, the simulation was re-processed. The 0.25 degree NOAH simulation is in production. Catchment model simulation has been implemented, finished spin-up, and is in last stage of preparation before the production begins. Generation of the MODIS based 1 km parameter datasets for Community Land Model (CLM) is on the last item, the maximum fractional area, which is used for the runoff parameterization. MODW44 data is applied to all maps including the plant functional types, leaf area index and stem area index monthly climatology, land units (lake, wetland, and urban), and soil color to enforce a common land water mask.

With the numerous members of the NASA Energy and Water cycle Study (NEWS) climatology group, we are establishing the current “state of the global water/energy cycle”, by using modern, observation-integrating products and associated error-analyses. 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. An initial analysis revealed that the GLDAS precipitation using CMAP had low bias, so we reprocessed the four LSM simulations using the GPCP Daily precipitation data. Error analysis is carried out by using two different methods, namely, constrained optimization and Lagrange multiplier, in order to check that the budget can be balanced within the uncertainty bounds. Figure 1 shows current analysis of the global, mean annual water cycle.

![Figure 3 Global mean water fluxes (1,000 km²/yr) at the start of the 21st century. Best guesses based on observational products and data integrating models with error estimates (white). When water balance is enforced via optimization, uncertainty decreases (red). Trenberth et al. (2006) for comparison (yellow). Taken from Matt Rodell’s presentation at NEWS workshop in August, 2011.](image)

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 (http://droughtmonitor.unl.edu/) on a weekly basis. I received a Hydrospheric and Biospheric Sciences Annual Award for Scientific Support for the implementation of this automatic end-to-end process for the drought indicator generation.

**Refereed Journal Publications**


Conference Publications


Task 202: Ground-based Supersite/Network Measurements in Support of NASA/EOS Missions; PI: Q. Ji; Sponsor: S-C. Tsay

Description of Scientific Problem
According to NASA's Science Mission Directorate (SMD), "in order to study the Earth as a whole system and understand how it is changing, NASA develops and supports a large number of Earth observing missions. These missions provide Earth science researchers the necessary data to address key questions about global climate change." (http://science.nasa.gov/earth-science/missions). As a major component of the Earth Science Division of NASA/SMD, "the Earth Observing System (EOS) is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans." (http://eospso.gsfc.nasa.gov). As the EOS follow-on, "the Decadal Survey will generate consensus recommendations from the Earth and environmental science and the applications communities regarding a systems approach to space-based Earth Science observations." (http://decadal.gsfc.nasa.gov). However, satellite observations alone is not sufficient to provide a complete understanding of the complex earth-atmosphere system. Extensive ground-based measurements and comprehensive modeling analysis are also indispensable parts in this endeavor.

Approach
Satellite observations, modeling analysis, and ground-based measurements are complementary. They can be brought together through carefully designed field campaigns. The following sketch illustrates how the three components may support each other.

For understanding the earth-atmosphere system, a comprehensive strategy is needed to integrate the complementing activities to utilize their relative strengths. Field campaign provides a vehicle for achieving this goal.
Accomplishments
To support NASA/EOS missions, we built the GSFC/SMART-COMMIT-ACHIEVE ground-based mobile laboratories (http://smartlabs.gsfc.nasa.gov). These facilities host a broad range of passive and active instruments for measuring atmospheric solar and terrestrial radiations, for in-situ observations of the chemical, optical, and microphysical properties of aerosols and trace gases, and for probing water vapor and clouds.

During the past decade we have participated over a dozen international field campaigns. Our footprints are around the world associated with satellite retrieval/validation projects.

The Major field deployments participated by SMART-COMMIT are: PRIDE (Puerto Rico Dust Experiment, June-July 2000); SAFARI (Southern Africa Fire-Atmosphere Research Initiative, Aug-Sep 2000); ACE-Asia (Aerosol Characterization Experiment-Asia, March-May 2001); CRYSTAL-FACE (Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment, July 2002); DOE/ARM Aerosol IOP (ARM Aerosol Intensive Observing Period, May 2003); UAE² (United Arab Emirates Unified Aerosol Experiment, Aug-Sep 2004); EAST-AIRE (East Asian Study of Tropospheric Aerosols - International Regional Experiment, March-May 2005); BASE-ASIA (Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment, Feb-May 2006); NAMMA (NASA African Monsoon Multidisciplinary Activities, Aug-Sep 2006); CHINA²-AMY08 (Cloud, Humidity Interacting Natural/Anthropogenic Aerosols - Asian Monsoon Year-08, Apr-Sep 2008); RAJO-MEGHA (Radiation, Aerosol Joint

Normally we deploy our mobile laboratories as a supersite. To meet the dynamic mission requirements, since RAJO-MEGHA in 2009 we started to explore distributing our sensors in a network to gain more spatial information. The first step is to use pyranometers, which are relatively affordable and easier to handle. These instruments capture downward solar irradiance that is an essential driving force of climate. In order to guarantee and to enhance the data quality, we developed a new technique to measure the thermal-dome-effect (TDE) of a pyranometer (Ji & Tsay, 2010). We also demonstrated that if TDE is not accounted for, there will be an impact on climate studies (Ji et al., 2011).

Recently we used available NIST traceable light sources maintained in the Radiometric Calibration Laboratory at Goddard to calibration our improved pyranometers (Ji et al., 2011). For the first time, the historical pyranometer calibration equation ($I = c_h V$) has been significantly corrected. The new equation becomes

$$I = cV + f(T) = (T + a)^4 - T_d^4,$$

and account for the thermal effect. The photo below shows the setup of a pyranometer (PSP) in front of an integrating sphere (Grande).

![Pyranometer Setup](image)

*The two curves next to the photo are the radiance from the integrating sphere and the transmittance of a pyranometer's dome. The improvement of the new calibration over the traditional one can be clearly seen in the color plot on the right-hand side. While the outcomes of a historical calibration (red curves) drift and deviate from a known irradiance (black dotted curves) dramatically, the results using the new calibration equation (green curves) repeatedly track a standard accurately.*

**Award**

NASA/GSFC/Climate & Radiation Laboratory: For Best First-authored Paper (Citation: For your excellent and innovative investigation of solar irradiance measurement with pyranometers for improved accuracy.)

**Refereed Journal Publications**


**Task 203: Diurnal Variation of Tropospheric Trace Gas Amounts and Aerosol Optical Characteristics; PI: M. Tzortziou; Sponsor: J. Rodriguez**

**Description of Scientific Problem**

The project involves the development of a new ground-based network of highly accurate spectrometer systems (Pandora and Cleo instruments, Fig 1) and the development, optimization and validation of remote-sensing retrieval algorithms for obtaining new measurements of aerosol optical characteristics and tropospheric trace gas amounts and vertical distribution (NO₂, O₃, SO₂, H₂O, HCHO). The resulting data provide a unique dataset for bounding tropospheric photochemical models, and studying the evolution of tropospheric ozone, NO₂, other trace gases, and aerosols and their impacts on climate and air quality. Measurements are applied to improve interpretation of current satellite observations and assess more effective design and observing strategies for future NASA satellite missions.

**Approach**

Our specific objectives are:

- Characterize the spatial and temporal (diurnal and seasonal) variability of tropospheric trace gas amounts, and O₃ and NO₂ vertical distribution at both polluted and clean sites. This is essential for improvement of both satellite retrievals and photochemical model predictions.
- Determine the input of trace gas and aerosol pollutants into the atmosphere during extreme events (e.g. extensive forest fires, desert dust events).
- Determine aerosol optical characteristics (optical depth, single scattering albedo and particle size distribution) over UV and visible wavelengths.
- Apply results to improve satellite retrieval algorithms and interpretation of satellite observations to diagnose near-surface conditions relating to air quality.

We use the Multiple-Angle Spectrally Resolved method for measuring tropospheric O₃ and NO₂ total column amounts and vertical profiles. The measurements are obtained every 10 minutes using measured sky radiances from a small, highly accurate, spectrometer system, Pandora (280 – 525 nm with spectral resolution of 0.5 nm; high signal to noise ratio 1000:1). A new spectrometer version (300 nm to 800 nm; 1 nm resolution) of a shadowband-type instrument (Cleo) has also been developed for measurements of UV aerosol properties.

**Accomplishments**

A network of Pandora spectrometers (both direct and sky-radiance instruments) is currently operating successfully in the Washington-Baltimore metropolitan area. We have completed the development of a new modified Pandora instrument that can operate on coastal platforms and onboard ships, using feedback from a digital camera to the sun-tracker to keep Pandora pointing at the sun on a moving platform. This new instrument was deployed on a ship for the first time.
during the summer 2011 NASA-funded campaign CBODAQ (Chesapeake Bay Oceanographic campaign with Discover-AQ). Dr. Tzortziou co-led this campaign and was co-Chief Scientist on the NOAA vessel used for the shipboard air- and water-quality measurements. Among the unique aspects of this campaign was the combination of very detailed atmospheric and oceanographic observations for characterizing short-term dynamics and spatio-temporal variability in both atmospheric and coastal ecosystem processes. The deployment of the modified Pandora instruments resulted in the first ground-based measurements on total column NO2 and O3 spatio-temporal variability over this estuarine environment.

Measurements of total column NO2 have been validated using MFDOAS spectrometers and the Direct-Sun DOAS Technique. We have studied changes in the diurnal variability of total column NO2 with season and day of the week based on a 2-year time series at Goddard Space Flight Center. Results have been applied to OMI validation [Herman et al., 2009].

We have developed an algorithm for measuring total column ozone (TCO) amounts using direct-sun observations and an independently measured reference spectrum (Kurucz extraterrestrial spectrum, normalized to SUSIM, convoluted with the Pandora slit function). Pandora TCO retrievals were compared with accurate TCO measurements obtained by a modified, Brewer (#171) double monochromator and with OMI satellite total column ozone retrievals at several locations (Fig. 2) including NASA/GFSC in Maryland, NASA/Langley in Virginia, Cabauw in Netherlands, Helsinki in Finland and Fairbanks in Alaska. Measurements were found to be in close agreement throughout the day, including near sunrise and sunset conditions with solar zenith angles up to 80°. Sharp ozone gradients, as strong as 20 DU change within 2-h periods, have been observed in several cases at GSFC by both Pandora and Brewer, mostly associated with changes in stratospheric ozone amount due to weather systems. The observed short-term temporal changes in ozone cannot be captured by OMI or other satellite instruments in sun-synchronous orbits with 1 to 3 daily overpasses [Tzortziou et al., 2010; Tzortziou et al., Submitted].

We have participated in several air-quality field campaigns (e.g. Cabauw-Netherlands, in Summer 2009, Frostburg MD, in Fall 2010; DISCOVER-AQ and CBODAQ campaigns in Summer 2011) for integration of Pandora and Cleo.
measurements with other ground-based and aircraft observations. Measurements of trace gas variability from our network of Pandora spectrometers at 14 locations provide a unique dataset for testing and validating model photochemistry and satellite data, and capturing short-term, small-scale variability in atmospheric composition. These data are particularly useful for measuring satellite sub-pixel and pixel-to-pixel variability, and validating satellite data so that they can be used for monitoring the response of the ozone layer to atmospheric changes and studying impacts on climate and air quality.

**Future Plans**

We are currently developing a new software tool for deriving tropospheric O3 vertical distribution amounts using VLIDORT (Vector Linearized Discrete Ordinate Radiative Transfer) and our published O3 profile retrieval algorithm [Tzortziou et al., 2008]. Frequent measurements of tropospheric ozone concentrations and vertical distribution are essential for determining short time-scale changes in ozone amounts close to the ground, and quantifying the role of tropospheric ozone on local and regional environmental degradation, tropospheric chemistry, surface UV-B budgets, human health, radiative forcing and climate.

Results from our activities and participation in field campaigns, and comparisons with CMAQ and WRF-Chem model outputs, are currently being used to determine how often and by how much tropospheric column NO2 and O3 deviate from climatology in coastal areas. Information will be used to evaluate whether climatology or OMI data would be sufficient for accurate atmospheric correction of the high resolution ocean color measurements proposed for the NASA GeoCAPE (Geostationary Coastal and Air Pollution Events mission) ocean sensor. Results will be assessed in terms of the proposed characteristics of GeoCAPE and recommendations will be made to meet ocean retrieval requirements.

**Referred Journals Publications**


**Conference Presentations**


Dickerson, J W Hair, R Rogers, M D Obland, "Horizontal and vertical distribution of air pollution over Maryland and the Chesapeake Bay, 3rd International Workshop on Air Quality Forecasting Research, Potomac, MD, 29 November - 1 December 2011.


Task 204: GMAO Core MERRA Research & Evaluation of Global Water Cycle in Reanalyses; PI: J. Chen; Sponsor: M. G. Bosilovich

Description of Scientific Problem
The changes of observing system have significant impact on the temporal consistency of all reanalysis datasets. Especially when new observation types are introduced, the related discontinuities or jumps could be big obstacles for climate study.

MERRA is a global reanalysis dataset based on NASA GEOS5 data assimilation system. In 2011, we continued to investigate the impact of observing system changes on the MERRA dataset, especially the different characters of impact from individual observing system change events, namely the introduction of SSM/I in 1987 and NOAA15 ATOVS in 1998.

Approach
Based on two observing system experiments (OSE) withholding SSM/I and NOAA-15 ATOVS and data, we systematically analyzed the impacts of the introduction of SSM/I data in 1987 and ATOVS data in late 1998, respectively. An OSE withholding a new kind of observation is a natural continuation of MERRA at the time before the new observation data is added in the MERRA stream, except that the new observation data that comes along will not be assimilated. By comparing the OSE output with the original MERRA data, the impact of the new observation could be isolated. Each OSE covers two year period, so to get clear seasonal cycle.

Accomplishments
Based on the two OSEs, we found:
1. The impacts of both SSM/I and NOAA15 ATOVS on cloud, precipitation, TOA and Surface fluxes are tightly related.
2. The change in precipitation drives significant change in overturning circulation.
3. The impact of SSM/I is mainly over the tropical region, while the impact of NOAA15 ATOVS has significant signal in middle and high latitudes.
4. Associated with SSM/I, the changes in moisture and moisture increment have same sign, but the changes in temperature and temperature increment have opposite sign. Associated with NOAA15 ATOVS, the changes in state variables and corresponding increments have same sign. These facts imply different cause and effect relationships between the changes in state parameter and corresponding increment in different observing system.
5. SSM/I observation causes more moisture injected in the tropical middle and low troposphere, the additional moisture is depleted through convective precipitation in the tropics. The released latent heat from moisture process (convective precipitation) heats the tropics, especially the equatorial region, and the associated intensification of Hadley Circulation make adiabatic cooling in equatorial region and warming in subtropical region, the net effect of the moisture, dynamic and radiative processes is positive warming, and the temperature observation from other observation kinds (SSM/I contents little temperature infor) passively adjust the temperature increment negatively, so to offset the extra warming caused by SSM/I data.
The JJA zonal mean change in moisture increment (upper left), moisture (lower left), temperature increment (upper right) and temperature (lower right) because the introduction of SSM/I data in 1987.

The JJA zonal mean change in moisture increment (upper left), moisture (lower left), temperature increment (upper right) and temperature (lower right) because the introduction of NOAA15 ATOVS data in 1998.
Refereed Journal Publications:


Conference Presentations

Task 206 and 254: Vegetation 3D structural parameters from multi-sensor data: Biomass mapping and change analyses from LVIS data; PI: G. Sun; Sponsor: K. J. Ranson

Description of Scientific Problem
Lidar provides sample data for forest parameters mapping using other imagery data in a region. Most of previous studies on biomass estimation from lidar data produced satisfactory results at forest stand or plot levels, not in the lidar footprint level. To map biomass using remote sensing imagery data in large scale, the estimation of biomass at lidar waveform footprint needs to be investigated.

Approach
The models developed using field measurements at footprints were applied to all LVIS waveforms within the study sites. Plots at 0.25-ha, 0.5-ha and 1-ha were used to validate the biomass averaged from footprints measured in these plots. The effect of forest disturbances on lidar biomass prediction models was investigated too. The results show that: 1) the prediction accuracy of models at footprint-level was acceptable at various plot-levels. The results were the best at at 1-ha scale; 2) the differences between biomass prediction models for disturbed and non-disturbed forests were statistically significant; and 3) the footprint-level models developed using 2009 data could be applied to 2003 data for forest biomass change estimation.

Accomplishments
1. Eco-3D campaign and Collection of validation data in field
The test site is located in Maine, USA, in a transition region between boreal and broadleaf biomes. The ~20×100 km study area includes the Northern Experimental Forest (NEF) near Howland, ME (45.25°N, 68.75°W), and the Penobscot Experimental Forest (PEF) near Bradley, ME (44.8°N, 68.6°W). An airborne-field campaign Eco-3D funded by NASA was conducted in summer 2011. Digital Beam forming Synthetic Aperture Radar (DBSAR) and Slope Imaging Multi-polarization Photon-counting Lidar (SIMPL) of NASA GSFC acquired data at test site and forest data were collected in field.

2. Biomass estimation from LVIS data
2.1. biomass estimation model
The biomass prediction based on the single independent variable regression models were generated. The RH50 and RH75 metrics perform similarly in terms of R²(0.88), RMSE (28.9 Mg/ha and 29.7 Mg/ha) and RRE.(28%).

The best multi-regression model from step-wise regression (both directions) selected RH25 and RH75 with multiple R²: 0.90, RSE: 26.94 Mg/ha, F-statistic: 491.1 on 2 and 106 degrees of freedom, and a p-value < 2.2e-16. The performances of single-independent and multi-independent models are very close. Therefore we simply choose the single-variable model for biomass estimation.

2.2. Effect of Disturbance on biomass estimation model
A statistical test was employed by adding a dummy variable (0 for disturbed and 1 for undisturbed forest) in the regression model. For the model using RH50, the coefficient for the dummy variable (6.2) is not equal to zero, so we reject the H₀ hypothesis. Disturbance has a significant effect on
the biomass prediction model. Hence, footprint-level single-variable models were developed for undisturbed and disturbed forest with RH50 models (Table 1).

Table 1. Combined and disturbance-specific models at footprint-level

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Group</th>
<th>Intercept</th>
<th>Slope</th>
<th>R²</th>
<th>RMSE (Mg/ha)</th>
<th>RRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>RH50</td>
<td>combined</td>
<td>26.4</td>
<td>16.6</td>
<td>0.88</td>
<td>28.9</td>
<td>28%</td>
</tr>
<tr>
<td>1</td>
<td>RH50</td>
<td>undisturbed</td>
<td>23.3</td>
<td>18.1</td>
<td>0.93</td>
<td>27.1</td>
<td>24%</td>
</tr>
<tr>
<td>2</td>
<td>RH50</td>
<td>disturbed</td>
<td>39.7</td>
<td>11.9</td>
<td>0.80</td>
<td>22.3</td>
<td>25%</td>
</tr>
</tbody>
</table>

2.3. Validation of prediction model in 2009
The footprint-level RH50 model from the combined data (Biom = 26.4 + 16.6*RH50) was first applied to 2009 LVIS data and then was validated at three plot-levels: 1) 0.25-ha plot (50m x 50m), 2) 0.5-ha plot (50m x 100m), and 3) 1-ha plot (50m x 200m), respectively. Similar steps were applied to the disturbance-specific RH50 models. The validation plots were divided into two groups of disturbed and undisturbed plots using LTSS VCT and air photos. Values of RMSE were 23.7 Mg/ha and 25.0 Mg/ha for undisturbed and disturbed models, respectively. Both are lower than the combined RH50 model (30.1 Mg/ha) at 1-ha plot-level.

2.4. Validation of prediction model in 2003
The biomass estimation model developed using 2009 data were applied to 2003 LVIS data. The results were tested using field measurements collected in October 2003. The predicted model has acceptable performance in 2003 (R²=0.62; RSME=39.2; RRE=27%).

2.5. Biomass mapping from LVIS data
The above-ground biomass maps (Fig. 1) from LVIS data for year 2003 and 2009 were produced using the 1-ha RH50 regression model. The biomass was classified into 10 categories with an interval of 25 Mg/ha and a range to 275 Mg/ha.

![Fig. 1. Biomass Map in 2003 and 2009 for Howland](image)

2.6. Biomass change from 2003 to 2009
Fig. 2 shows the change of AGB from 2003 to 2009 at Howland (right) with corresponding reclassified disturbance map (left). It can be seen that the changes are consistent with the forest disturbance patterns detected from temporal LANDSAT images. Biomass changes in the old growth portion (highlighted by pink polygon in dotted line) were mostly positive (5 ~ 50 Mg/ha) or near neutral (-5 ~ 5 Mg/ha). The area surrounding the old growth forest showing strong
negative change (-25 ~ -50 Mg/ha) degraded forests from logging that occurred during 2003-2009. These sheltwood cuts removed large trees accounting for about 1/3 of the basal area. Several patches in the middle of Howland forest show an increasing in biomass during 2003 to 2009, due to the forest regrowth after cuts in the 1990s.

![Image of maps](https://example.com/image.png)

**Fig. 2.** Change of above-ground biomass from 2003 and 2009 at 1-ha level by uniform and disturbance-specific RH50 models

3. SAR data processing
The repeat orbit interferometry package (ROI_PAC) developed by NASA JPL was modified to process the calibrated PALSAR single look complex data (Level 1.1). Coherence images at different seasons and at various environmental conditions were generated along with the temporal radar backscattering coefficients. The data will be further analyzed to evaluate its usefulness in target classification and parameters retrieval. The coherence model upgraded from our former incoherent 3D radar backscatter model has been preliminary validated using SRTM and PALSAR data and will be further validated using UAVSAR PolInSAR data when it is available.

**Refereed Journal Publications**


**Conference Presentations**


Task 213: Applications, Evaluation, and Improvement of Goddard Multi-scale Modeling System; PI: B-W. Shen; Sponsor: W. Tao

Description of Scientific Problem:
To examine the impacts of resolved moist processes on the short-term and long-term climate simulations with the MMF.

Approach
During the execution of year 2011, two major tasks which were performed under the support of this master grant are (1) implementation of two-level parallelism in the fvMMF 2.0 on Pleiades supercomputer; (2) development of MJO analysis package for the verification of 30-day simulations of the selected MJO cases. We have finished the first task completely, and almost (above 90%) finished the second task. With additional support (~75% of PI’s time) from the AIST project (PI: Shen), we applied related tools to studying TC genesis that is associated with precipitation processes and tropical waves such as MJO, mixed Rossby gravity wave, equatorial Rossby wave or (African) easterly wave.

Accomplishments
• Research results in a series of papers by Bo-Wen Shen and his colleagues are featured in a recent President's Corner article of UCAR Magazine by Dr. Rick Anthes, which was published on May 6, 2011. This article entitled "Turning the Tables on Chaos: Is the atmosphere more predictable than we assume?"
• Invited project demonstration with the title of "Coupling Advanced Modeling and Visualization to Improve High-impact Tropical Weather Prediction" at the NASA Booth (schedule) at the 2011 AGU Fall Meeting. [http://www.nas.nasa.gov/assets/pdf/AGUprogram_final.pdf](http://www.nas.nasa.gov/assets/pdf/AGUprogram_final.pdf)
• The proposal, which is led by Bo-Wen Shen (ESSIC) with the title of "Integration of the NASA CAMVis and Multiscale Analysis Package (CAMVis-MAP) For Tropical Cyclone Climate Study,” has been selected by the NASA AIST (Advanced Information System Technology) program. A list of 18 selected proposals from 88 submitted proposals can be found: [http://esto.nasa.gov/files/solicitations/AIST_11/ROSES2011_AIST_A41_selections.html](http://esto.nasa.gov/files/solicitations/AIST_11/ROSES2011_AIST_A41_selections.html). The CAMVis-MAP project requested the total funding $1.16M over three years with the starting date of May 1, 2012.
• Published one journal article (IEEE CiSE)
• Submitted three journal articles (two to AGU-JGR, one to IEEE CiSE)
• For the computational tasks, we (1) finished scalable, two-level parallelism on Pleiades (distributed memory) supercomputer; (2) obtained a speedup of 79.8 by increasing the number of cores from 30 to 3335, which allows to finish a 30-day run within 41 minutes; (3) produced bit-by-bit results with different CPU configurations. All of these enable high-resolutions and higher-dimensions for Goddard Cumulus Ensemble (GCE) model in the fvMMF.
• For the MJO diagnostic package, related data (scripts) have been created (developed) and are saved under /nobackup2d/bshen/NCEP_ReAna/Daily/Y2008-2011 on lou.nas.nasa.gov. A brief note is as follows:
  1) pre-120d-ave: previous 120-day mean,
  2) daily-120d_mean: daily - 120d_mean (from the above)
3) lat-ave: average over (lat=-15, lat=15)
4) proj-rmm: project NCEP analyses into the EOF1 and EOF2
5) plot-RMM: map the above projected values into the lat-lon grid for plotting

**Journal Publications**

- Shen, Bo-Wen, 2012c: Nonlinear Feedback in a Generalized Lorenz Model. (submitted to AGU JGR [https://sites.google.com/site/bowenshen159/cv/docs/Shen-2012-GRL-draft.pdf](https://sites.google.com/site/bowenshen159/cv/docs/Shen-2012-GRL-draft.pdf))

**Conference presentations (13 presentations/reports in 2011)**

- [http://sites.google.com/site/bowenshen159/cv](http://sites.google.com/site/bowenshen159/cv)
**Task 221: Optical Properties Of Mineral Dust Aerosol; PI: R. Hansell; Sponsor: S. Tsay**

**Description of Scientific Problems**
To conduct testing of the MODIS Characterization Support Team's (MCST) updated calibration approaches for collection 6 Level-1B Terra/Aqua MODIS data using NASA Goddard’s Deep Blue aerosol retrieval algorithm. Also to investigate the optical properties of mineral dust aerosol between the near to thermal IR using global aerosol field measurements combined with analysis of model data to help advance ground and satellite-based remote sensing applications and column energetic studies.

**Approach**
Specific objectives were:
- To perform detailed testing of MCST’s updated calibration approaches for collection 6 Level-1B data for Terra and Aqua MODIS using the Deep Blue aerosol retrieval algorithm. The test domain was fixed over the Saharan Desert (Latitude 0°-35° N; Longitude 20°W - 60° E) for the years 2003, 2006, 2008, and 2010. The calibration approaches were evaluated by comparing Deep Blue’s retrieved aerosol optical depths with those from AERONET and MISR to help identify the optimal calibration approach used in the collection 6 Level-1B product. Additional comparisons were made using NASA Goddard's Ocean Biology Processing Group's (OBPG) calibration scheme.
- To apply spherical and non-spherical light scattering codes to calculate dust aerosol mass extinction and absorption efficiencies (MEE and MAE, respectively) at wavelengths commonly used in remote sensing, covering an extended range of dust physicochemical properties including particle chemistry, morphology, and size.
- To provide a reference to facilitate interpreting field measurements of dust aerosol.
- To identify spectral relationships in dust MEE values between the near and thermal IR useful for estimating thermal impacts on retrieved parameters such as SST and for identifying long wave radiative effects of dust aerosol.
- To provide constraints for modeling studies.
- To utilize hyperspectral radiances measurements from NASA Goddard’s ground-based Atmospheric Emitted Radiance Interferometer (AERI) to probe the longwave radiative impacts of dust aerosol near major source regions.
- To evaluate/compare direct aerosol radiative effects (DARE) of global dust over the column atmosphere.

**Accomplishments**
- After extensive testing using Deep Blue, the updated calibration method from MCST and that from OBPG for collection 6 Level-1B data were found to be relatively consistent and satisfactory for use in the collection 6 product. Further investigations may be required.
- Completed a detailed modeling study of the optical properties of dust aerosol between the near and thermal IR wavelengths which provides an envelope of expected MEE values corresponding to extreme cases in dust physicochemical properties.
- Completed study of the longwave DARE for dust aerosol during the Asian Monsoon Year (2008) field campaign using NASA Goddard’s ground-based facilities (SMART-
• COMMIT) in Zhangye China (manuscript in review).
• DARE results will later be compared with other important dust regions to evaluate differences and similarities in the radiative energetics.

**Refereed Journal Publications**


Calculated MEE of dust aerosol from the near to thermal IR over extended ranges of particle shape, size and composition. The values shown represent the maximum MEE for each channel investigated. Note the two dominant peaks at the near and thermal IR wavelengths, both associated with non-spherical particles.
**Task 224: Improving NOAA/NWS River Forecast Center Decision Support with NASA Satellite and Land Information System Products; PI: S. Yatheendradas; Sponsor: C. Peters-Lidard**

**Description of Scientific Problem**
The overarching goal was to demonstrate improved accuracy in runoff, stream flow, and flood monitoring and simulation that result from the combination of NASA infrastructure of snow data (MODIS) and model (LIS), with operational NOAA National Weather Service (NWS) River Forecast System (NWSRFS) Decision Support Tools (DST). The objectives were to engineer and integrate NASA satellite- and model-derived land surface products, through the Land Information System (LIS), into NWSRFS DST component models. The specific science question we investigated is whether adjusting modeled snow area with MODIS estimates improves modeled streamflow.

**Approach**
This work leveraged ongoing NASA/NOAA collaborative research toward the integration of LIS and NWSRFS components (called LIS-RFS), mainly the Sacramento Soil Moisture Accounting (SAC-SMA) and SNOW17 models. With inputs from NOAA/NWS/OHD, NASA/GSFC continuously evaluated the system at successive software integration levels and benchmarked the Distributed Model Intercomparison Project II (DMIP2) Western snow basins in a retrospective simulation mode focusing on the assimilation of NASA remotely sensed MODIS snow covered fraction product. We also introduced a snow masking effect under vegetation canopy present in almost any satellite snow product and also possibly to some extent in model analysis/reanalysis products like the Snow Data Assimilation System (SNODAS).

**Accomplishments**
The project work has finished up with the submission in August 2011 of a manuscript to WRR currently under review having the following abstract: " Snow extent affects snowmelt, soil moisture, evapotranspiration, and ultimately basin streamflow. For the Distributed Model Intercomparison Project - Phase 2 Western basins, we assimilate fractional snow extents from satellite (Moderate Resolution Imaging Spectroradiometer or MODIS) into the National Weather Service (NWS) SNOW-17 model. SNOW-17 is used with the NWS Sacramento Heat Transfer Model (SAC-HT) model after porting into the National Aeronautics and Space Administration's (NASA) Land Information System. SNOW-17 computes snow extents from snow water equivalents (SWEs) using areal depletion curves. Using a first-cut direct insertion, we assimilate snow extents in two fully distributed ways: either we continuously update the curve by preserving SWEs, or we reconstruct SWEs using the curve. The preceding are refinements of an existing simple and conceptually-guided NWS direct insertion algorithm. Satellite snow extent data over densely forested areas contain inaccuracies in below-canopy snow during melt conditions, leading to degraded streamflow simulations upon assimilation. As such, we cautiously implemented a below-canopy allowance during assimilation. Especially for streamflow volume for the uncalibrated basin runs, we obtain: [1] substantial to major improvements (64-81 %) as a percentage of the control run residuals (or distance from observations), and [2] minor improvements (18-22 %) as a percentage of observed values. This shows the potential relevance and value of the assimilation application to ungauged basins. We speculate that snow extent
assimilation results should improve further over hydrologically less complex basins, and suggest further improvements for mountainous forested basins in the areas of canopy treatment and snow optical radiative transfer." An example paper Figure is reproduced next, showing the effect of different MODIS snow extent assimilations (e.g., preserving SWE with and without undercanopy snow allowance, recreating SWE etc.) on uncalibrated runs over a Sierra Nevada basin. The comparison against calibrated control run highlights that assimilation could be as effective as calibration for ungaged basins.

![Example precipitation, SWE and streamflow plots](image)

**Figure**: Example precipitation, SWE and streamflow plots (a-c): uncalibrated Carson runs for May-July 2005 springtime melt season. Bottom plots d-f display corresponding monthly plots of mean of discharge residual improvement (by assimilation) against observed streamflow.

**Refereed Journal Publications**

**Task 224a: A Land Data Assimilation System for Famine Early Warning; PI: S. Yatheendradas; Sponsor: C. Peters-Lidard**

**Description of Scientific Problem**
The overarching goal was to demonstrate improved accuracy in runoff, stream flow, and flood monitoring and simulation that result from the combination of NASA infrastructure of snow data (MODIS) and model (LIS), with operational NOAA National Weather Service (NWS) River Forecast System (NWSRFS) Decision Support Tools (DST). The objectives were to engineer and integrate NASA satellite- and model-derived land surface products, through the Land Information System (LIS), into NWSRFS DST component models. The specific science question we investigated is whether adjusting modeled snow area with MODIS estimates improves modeled streamflow.

**Approach**
This work leveraged ongoing NASA/NOAA collaborative research toward the integration of LIS and NWSRFS components (called LIS-RFS), mainly the Sacramento Soil Moisture Accounting (SAC-SMA) and SNOW17 models. With inputs from NOAA/NWS/OHD, NASA/GSFC continuously evaluated the system at successive software integration levels and benchmarked the Distributed Model Intercomparison Project II (DMIP2) Western snow basins in a retrospective simulation mode focusing on the assimilation of NASA remotely sensed MODIS snow covered fraction product. We also introduced a snow masking effect under vegetation canopy present in almost any satellite snow product and also possibly to some extent in model analysis/reanalysis products like the *Snow Data Assimilation System (SNODAS)*.

**Accomplishments**
The project work has finished up with the submission in August 2011 of a manuscript to WRR currently under review having the following abstract: "Snow extent affects snowmelt, soil moisture, evapotranspiration, and ultimately basin streamflow. For the Distributed Model Intercomparison Project - Phase 2 Western basins, we assimilate fractional snow extents from satellite (Moderate Resolution Imaging Spectroradiometer or MODIS) into the National Weather Service (NWS) SNOW-17 model. SNOW-17 is used with the NWS Sacramento Heat Transfer Model (SAC-HT) model after porting into the National Aeronautics and Space Administration's (NASA) Land Information System. SNOW-17 computes snow extents from snow water equivalents (SWEs) using areal depletion curves. Using a first-cut direct insertion, we assimilate snow extents in two fully distributed ways: either we continuously update the curve by preserving SWEs, or we reconstruct SWEs using the curve. The preceding are refinements of an existing simple and conceptually-guided NWS direct insertion algorithm. Satellite snow extent data over densely forested areas contain inaccuracies in below-canopy snow during melt conditions, leading to degraded streamflow simulations upon assimilation. As such, we cautiously implemented a below-canopy allowance during assimilation. Especially for streamflow volume for the uncalibrated basin runs, we obtain: [1] substantial to major improvements (64-81 %) as a percentage of the control run residuals (or distance from observations), and [2] minor improvements (18-22 %) as a percentage of observed values. This shows the potential relevance and value of the assimilation application to ungauged basins. We speculate that snow extent assimilation results should improve further over hydrologically less complex basins, and suggest..."
further improvements for mountainous forested basins in the areas of canopy treatment and snow optical radiative transfer." An example paper Figure is reproduced next, showing the effect of different MODIS snow extent assimilations (e.g., preserving SWE with and without undercanopy snow allowance, recreating SWE etc.) on uncalibrated runs over a Sierra Nevada basin. The comparison against calibrated control run highlights that assimilation could be as effective as calibration for ungaged basins.

Figure: Example precipitation, SWE and streamflow plots (a-c): uncalibrated Carson runs for May-July 2005 springtime melt season. Bottom plots d-f display corresponding monthly plots of mean of discharge residual improvement (by assimilation) against observed streamflow.

Refereed Journal Publications

Task 226: 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, as land surface models predict key variables of the water cycle, including terrestrial water, energy, and biogeophysical states. This task involves adding functionality to LIS through the addition of advanced algorithms to maximize the utilization of available data and science. Recent extensions to LIS include a new optimization and uncertainty analysis subsystem (LIS-OPT/UE). The optimization and uncertainty modeling algorithms in LIS allow for use of satellite (and other) data for parameter estimation and probabilistic prediction. These new capabilities will improve land surface prediction and therefore global water cycle prediction.

Approach
Our specific objectives are:
- 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
- Further develop the LIS-OPT/UE framework to allow for the calibration and estimation of uncertainty for land surface-coupled models
- Implement and test the optimization and uncertainty algorithms

Accomplishments
The LIS-OPT/UE system was further extended to allow for the identification of major sources of uncertainty in land surface models and coupled models (emissivity models, landslide models, streamflow, etc.) and the estimation of coupled model parameters. In Figure 1, the benefit of the subsystem for data assimilation is shown. In the example, parameter estimation is shown to be an effective means of bias mitigation, on par with the conventional data assimilation approach, that of a priori scaling.
Background: DA success depends on unbiased model state predictions. The bias is often handled in DA by scaling observations to model climatology. Incorrect LSM parameter specification, however, is a known source of bias and can be minimized through calibration. Experiment: Evaluate skill improvement of scaling and LIS-OPT calibration for root zone soil moisture. Finding: Skill improvement from calibration is comparable with a priori scaling.
Refereed Journal Publications
**Task 227: Microphysical Processes of Atmospheric Convective Systems; PI: C.-J. Shiu; Sponsor: W-K. Tao**

**Description of Major Work**
We validate the hydrometeors simulated by Goddard Multi-scale Modeling Framework (MMF) through comprehensive comparisons with satellite and reanalysis data sets. Major parameters include total precipitable water, cloud liquid water, and cloud ice water as well as precipitation.

**Approach**
Simulations for 2005 and 2006 summer seasons (JJAS) are carried out via using the coupled fvGCM-GCE Multi-scale Modeling Framework (MMF) that replaces the sub-grid cloud parameterization with an explicit cloud-resolving models. General verifications of MMF results are investigated through comprehensive comparisons with reanalysis dataset e.g. NASA MERRA and other satellite datasets such as AIRS, GPCP, TRMM, MODIS, AMSR-E and so on. Different dynamical and microphysical parameters are examined to study their differences between 2005 and 2006 and the proficiency and deficiency of the MMF for further model improvements.

**Accomplishments**
Preliminary results show that most of the parameters are well simulated by MMF especially in terms of their spatial distributions. Total column cloud liquid water, cloud ice water and precipitation rate and spectrum simulated by MMF are even better than those of MERRA when compared to satellite retrievals. Figs 1 and 2 show the results for precipitation intensity spectrum and total column cloud ice, respectively.

**Conference Presentation**

**Paper in preparation**
Shiu, C.-J., Jiun-Dar Chern, Wei-Kuo Tao, Shaw Chen Liu (2012), Hydrometeors Simulated by a Superparameterization Model and Their Validations with Satellite and Reanalysis Data Sets (to be submitted to GRL)
Fig. 1 Compared to MERRA, precipitation intensity spectrum of MMF is closer to that of CMORPH. For MERRA, the contributions from heavy precipitation say intensity greater than 100 mm/day are smaller than those of other data sets. TRMM and CFSR results are more or less similar with CMOPRH. Among MMF and the two reanalyses, CFSR gives best results regarding land and ocean contrast when compared to observed results from CMOPRH.

Fig. 2 Over the tropical and subtropical regions, total column cloud ice water simulated by MMF is quite similar to that of MODIS. MERRA appears to have very low total column cloud ice water and also quite different in its spatial distributions compared to that of MMF and that of MODIS.
Task 229: Evaluation of mesoscale model (WRF) and LIS-WRF under for various thunderstorm cases across continents; PI: A. Kumar; Sponsor: C. Peters- Lidard

Description of Scientific Problem

Goals:
(a) To evaluate NASA developed Land Information System (LIS) in WRF (LIS coupled WRF) and also evaluate LIS spin-ups soil condition. First we have to run LIS spin-up for 10 years and evaluate simulated soil moisture, soil temperature at different soil depth, latent heat flux and sensible heat flux for over Southern Great Plains region, and compare with station flux site data for verification. In second step we ran NU-WRF coupled system and performed evaluation, our study objective is to understand the impact of different microphysics schemes on land-surface process (surface and soil parameters).

Approach

We made LIS spinups for period 01 Jan 2000 to June 2002 at two different domain resolution (6 and 2 km resolution). In second stage, NU-WRF coupled LIS is used for our case studied and conducted simulation in two-way nested run. Evaluation is done using domain averaged analysis software and also on individual flux tower sites. Our research paper is focusing on the impact of different microphysics schemes under NU-WRF-LIS coupled system. LIS verification tool kit (LVT) is used to evaluate surface soil parameters.

(b) Self-guided research on mesoscale model evaluation and analysis: This work mostly done in my free time (weekends) and carried out with two groups: University of Washington- Prof. Robert Houze and Purdue University- Prof. Dev Niyogi. With Houze group, we are evaluating current microphysics scheme used in WRF mesoscale model and evaluating for severe thunderstorms cases over South America and West Africa. With Niyogi group, understanding then impact of soil moisture, land-surface process in regional models.

Accomplishments

For Goal (a)
• LIS spinups are done for our domain cases study over SGP region, we ran LIS at two different resolutions i.e. 6 and 2km.
• NU-WRF coupled LIS model two-way nested simulations are done.
• LIS-WRF model evaluated using MET verification package and conduct domain average analysis (2m temperature, 2m- mixing ratio, vertical temperature and moisture profiles).
• LIS-WRF simulated surface fluxes are verified using IHOP-2002, Ameriflux, ARM’s flux sites.
• LVT is used for surface evaluation.

Refereed Journal Publications


Conference Presentations

Summary
The NU-WRF model is ran for 13 June 2002 IHOP-2002 case and tested six microphysics schemes available in NU-WRF model. The objective is to understand the land-surface process evaluation under different cloud schemes. We focused more on quantitative analysis so the statistical domain averaged bias analysis suggest that Goddard microphysics schemes perform better than other microphysics in NU-WRF model. The temperature and mixing ratio atmospheric statistics shows that Goddard scheme simulate better than other microphysics scheme (see below Figure 1- upper panel). The land-surface feedback in response to different microphysics scheme also resolved better surface condition (see below Figure 1 – lower panel). We evaluated all other surface parameters such as surface heat fluxes, surface wind speed, ground heat flux, net radiation and found good result from Goddard scheme. Currently we are evaluating soil temperature and soil moisture, model skill score etc. We plan to submit our manuscript in March 2012.
Figure 1. Temperature and mixing ratio bias analysis. Top panel shows spatial and temporal averaged domain statistics, top (left) shows temperature bias (in C) and top (right) shows mixing ratio bias (in g/Kg). Lower pane shows three hourly domain averaged bias in temperature (left) and mixing ratio (right) from different microphysics schemes.
Task 230: 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
We have analyzed the data from the deployment of the NASA GSFC SMARTLabs facility in Southeast Asia during spring 2006 (BASE-ASIA). Using the data set, we have characterized the chemical composition, optical and microphysical properties of aerosols in the region during the peak biomass burning season. We have also determined the source areas of aerosols in the region by combining measurements and trajectory modeling.

Another regional field experiment will be carried out in March-April, 2012, in northern Vietnam, to further enhance our understanding of the impact of forest fires on the regional climate.

We have also analyzed the data from the 7-SEAS/Dongsha field experiment, conducted in South China Sea in spring 2010, as a pilot study of 7-SEAS (Seven SouthEast Asian Studies). The rich data set of aerosol composition and properties have been used to characterize both maritime aerosols and as well as long-range transport from the Asian continent.

In addition to field experiments, we also continue to explore the applications of NASA EOS satellite data in understanding the sources, properties, and impacts of aerosols and precursor gases. We have experimented methods to combine field measurements, satellite retrievals, and atmospheric modeling to study regional aerosol transport events.

Accomplishments
Our analyses of the BASE-ASIA data indicate that aerosol pollution has developed into a regional problem for northern Indochina. Biomass burning, industrial pollution and long-range transport all contribute to the aerosol loading in the area. A paper reporting the results have been submitted to Atmospheric Environment, and is now under revision after the initial review.

We have explored the application of NASA satellite in monitoring and forecasting aerosol pollution in China and Southeast Asia. We established a new methodology combining the trajectory models and satellite data to provide 24-hr forecast of surface particulate matter. The method can be easily adapted for other areas. The results were published in Atmospheric Environment.

In another study we have systematically analyzed the rapid transpacific transport of Asian pollution. This study discovers that the anthropogenic pollutant such as SO2 from China can frequently reach the other side of the Pacific ocean. Their impact is much greater than previously suggested by aircraft measurements. It also highlights the importance of long-range transport in
fall, which has been rarely studied. The paper has been accepted by Journal of Geophysical Research and will appear soon.

Papers analyzing data from the RAGHO-MEGHA and 7-SEAS/Dongsha field experiment have been published.

**Referred Journal Publications**


**Awards**

*Best Research Faculty Paper Award*, Earth System Science Interdisciplinary Center, University of Maryland, December 15, 2011
Task 231: 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 plan to 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 (LPVEx) and Midlatitude Continental Convective Clouds Experiment (MC3E).

Accomplishments
During this term, we updated the cloud microphysical package of the WRF-SBM by using a new module that includes explicit melting and snow-riming processes. The updated model was employed for the simulations of the snowfall events during the C3VP, mixed-phase precipitation events during the LPVEx 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. Additional tests are performed using different planetary boundary layer (PBL) schemes and/or special microphysics treatments to investigate a sensitivity of the properties of the convective boundary layer (CBL) clouds to them. The tests reveal that PBL process has an influence not only on the macrostructure of the CBL clouds and precipitation but also on the cloud microphysical structure with riming process through changes in moisture supply and resultant supercooled water.

The update of WRF-SBM made possible to represent a radar blight band associated with a melting layer. However in the LPVEx 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 (Figure). 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 profile tends to be more scattered. This classification has also applied to the correlation plots between surface rain number concentration and rain rate derived from both the measurement and simulation.

Scatter plots between surface rain rate and bulk effective rain radius, comparing between the ground-based in-situ measurement (Parsivel) and the WRF-SBM model simulation.

**Conference Presentations**
**Task 233: Evaluation of the NASA GMAO Modern Era Retrospective-Analysis for Research and Applications (MERRA) in Polar Latitudes; PI: R. I. Cullather; Sponsor: M. Bosilovich**

**Description of Scientific Problem**

The work performed under this task relates to high latitude process modeling and analysis. MERRA is a state-of-the-art global numerical reanalyses that has recently been produced by the NASA GMAO, and covers the period from 1979 until 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. Additionally, work is to be performed with experts in ice sheet modeling along with the GEOS-5 model development team to integrate and evaluate a community ice sheet model within the GEOS-5 modeling framework. Analysis of GEOS-5 climate simulations and GEOS-5 products is also conducted to evaluate the representation of the water and energy cycle in the model and assimilation systems at high latitudes, and to contribute to better understanding the Earth system, models and reanalyses. To that end, both in situ and remote sensing observations will be considered along with MERRA and other existing reanalyses and the climate simulations. Topics of particular interest are ice sheet surface mass balance, precipitation processes and high latitude climate processes in general. The position is part of a team, and as such, the incumbent’s expertise may be useful to other activities, generally related to atmospheric reanalysis.

**Approach**

In the first stage of this work with MERRA, the focus has been on assessing components of the atmospheric energy and moisture balances with prior studies. To this end a combined approach has been used to compare fixed sub-regions with prior studies, and to make concurrent comparisons with in situ observations at point locations. The second stage is the application of MERRA for regional climate study. The approach used here is to take advantage of lessons learned from the budget assessments in order to understand the strengths and limitations of reanalyses. This work also makes use of other data products including those from the European Centre for Medium-Range Weather Forecasts (ECMWF) and the U.S. National Centers for Environmental Prediction (NCEP) in order to improve confidence in the conditions described by MERRA.

The goals of the ice sheet integration project are to fully couple a dynamical ice sheet model (ISM) to GEOS-5, improve the representation of critical processes in ISMs with initial focus on grounding line dynamics and melt-freeze parameterizations beneath ice shelves, and investigate the sensitivity and feedbacks of the atmosphere-ocean-cryosphere coupled system. The project seeks to improve the representation of the surface climate over polar ice sheets, adequately simulate energy and moisture fluxes between ice sheets and other model components, and support a prognostic capability for eustatic response to dynamically- and thermodynamically-induced ice sheet variations. ISMs may be thought of as self-contained dynamical representations of ice sheets, with surface mass balance (accumulation) and surface temperature as primary inputs. In two-way coupling, the exchange of fluxes may impact the GCM. As GEOS-5 currently does not run a snow hydrology model over ice sheets, the work plan of the first year has focused on establishing a snow model for the land ice surface category. Additionally the project has sought to identify strengths and weaknesses in prospective ISMs, develop downscaling methods for surface
mass balance, and use the developed snow model to estimate surface mass balance from MERRA. This will lead to one-way coupling of an ice sheet model in early 2012.

**Accomplishments**

Cullather and Bosilovich (2011, 2012) evaluates the polar atmospheric moisture and energy budgets in MERRA and have been published in special collections of the *Journal of Climate* on MERRA and on the U.S. CLIVAR/SeaFlux Workshop on Surface Fluxes: Challenges for High Latitudes. An analysis of variations in baroclinic instability in the summertime Arctic and its relation to sea ice cover was presented at the American Meteorological Society Polar Meteorology and Oceanography conference and at the World Climate Research Programme Open Science Conference, and results are being assembled for publication.

For the ice sheet model development, a pro-type snow hydrology model suitable glacial ice has been developed. The model utilizes the Stieglitz snow model, which currently runs on non-glacial land surfaces in GEOS-5. Over ice sheets, the primary difficulties in simulating snow hydrology are associated with initialization and a never-ending supply of snow accumulation which may destabilize the model. These issues have been finessed by applying a fixed snow depth, which is replenished at each time step at the bottom interface. Melt water is allowed to percolate through the snowpack to a critical snow density, and then refreezes or becomes runoff. The snowpack is initialized to the annual mean surface temperature. This configuration, which corresponds to a state-of-the-art surface mass balance model that is typically not found in a GCM, is undergoing testing. Cullather met with participants of the SeaRISE modeling workshop held at Goddard on 26-27 September 2011, and participated in the Ice Sheet System Model (ISSM) workshop, 12-13 December 2011 at NASA Jet Propulsion Laboratory. The ISSM and the Los Alamos/NCAR Community Ice Sheet Model (CISM) are prospective ISMs for coupling with GEOS-5. Methods for transitioning between the coarse-resolution surface mass balance of GEOS-5 to a higher spatial resolution suitable for ISMs have been investigated using synthetic downscaling of a high resolution data set. These results are being evaluated for publication. The ice sheet modeling investigation is in collaboration with NASA PI Sophie M.J. Nowicki. Additional evaluation of the GEOS-5 model performance in high latitudes is associated with decadal simulations produced for the IPCC. A preliminary assessment was presented at the WCRP Open Science Conference.

**Refereed Journal Publications**


**Conference Presentations**

Cullather, R.I., B. Zhao, and M.G. Bosilovich, 2011: The Twenty-First Century Arctic atmospheric energy budget from coupled model simulations and numerical reanalyses. *World Climate Research Programme Open Science Conference*, 24-28 October, Denver, CO.

Figure 1: Schematic diagram of changes to the GEOS-5 representation of glacial land ice surfaces. The existing configuration shown at left does not use a snow hydrology model, and determines the surface energy flux based on a fixed subsurface temperature. The configuration at right employs a significantly modified version of the Stieglitz snow model with additional parameterizations for glacial surfaces, and is currently undergoing testing.
Task 234: 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), MODIS (Moderate-resolution Imaging Spectroradiometer), MISR (Multi-angle Imaging Spectroradiometer), OMI (Ozone Monitoring Instrument), and CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) sensors.

Accomplishments
During the reporting period of March 1, 2011 – February 29, 2012, the MAPSS project has been expanded to include aerosol measurements from SeaWiFS (Sea-viewing Wide Field-of-view Sensor) spaceborne sensor and MAN (Maritime Aerosol Network) network of sensors deployed onboard ocean-bound ships. SeaWiFS provides one of the longest continuous aerosol datasets available, with an extensive coverage of deserts and other bright surfaces. On the other hand, MAN provides well-calibrated in-situ aerosol retrievals over ocean surfaces, complimenting the measurements from the network of ground-based AERONET sensors that are already supported in MAPSS. In this way, both datasets represent a valuable addition to the MAPSS framework, especially since these datasets provide aerosol measurements over regions, where retrievals from other sensors are either scarce, or uncertain.

In addition to supporting these two products, we updated MAPSS to support the recently released new version of the OMI aerosol product. We also collaborated with other research groups to adapt MAPSS for the validation of the novel aerosol products that are currently being developed by these groups. These include the new 3-km aerosol product from the MODIS sensors, aerosol product from the recently launched VIIRS (The Visible Infrared Imager Radiometer Suite) sensor...
onboard of the NPP satellite, and an experimental Absorption Aerosol Optical Depth and Single Scattering Albedo product from the MODIS sensors.

Furthermore, we continued improving and expanding the WEB interface for interactive plotting and retrieval of MAPSS data. During the reporting period, we have implemented support for interactive Quality Assurance (QA) screening of the data, and have introduced a support for online generation of customizable scatter plots (currently, available at http://giovanni.gsfc.nasa.gov/aerostat/). We have also greatly simplified the interface of the tool, in order to make it more accessible to novice users.

Based on the MAPSS data, we have conducted a series of initial studies into the issues of data quality and other sources of uncertainty in aerosol products retrieved by spaceborne sensors. The studies revealed important differences that exist in data quality handling approaches, supported in these products. We are working on a more detailed study that will further characterize these differences, enabling a synergetic use of the investigated products.

**Refereed Journal Publications**

**Conference Presentations**
Maksym Petrenko, Charles Ichoku, Gregory Leptoukh, Effects of Data Quality on the Characterization of Aerosol Properties from Multiple Sensors, 2011 AGU Fall Meeting, 5–9 December 2011, Moscone Convention Center, San Francisco, California, USA.


**Seminars**

**Awards**
**Task 235: Arctic and Southern Ocean Sea Ice; PI: S. L. Farrell; Sponsor: T. Markus**

**Description of Scientific Problem**
The work being conducted under this project is in support of NASA’s Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) scheduled for launch in 2016. ICESat-2 is a follow-on to the ICESat mission, which operated between 2003 and 2009. ICESat-2 will provide sustained monitoring of changes in ice-sheet mass balance, and Arctic and Southern Ocean sea ice volume. The goals under this ICESat-2 Science Definition Team (SDT) project are to derive the Level 1 and 2 sea ice science requirements and measurement accuracies, and to determine the optimum spatial sampling strategy for profiling the complex sea ice environment of the Arctic and Southern Oceans.

**Approach**
We aim to define the optimal footprint size, spacing, and ground-track configuration, for sea ice observations using satellite laser altimetry. The system is required to obtain representative elevation measurements over sea ice, and identify leads within the ice pack, so as to provide accurate measurements of sea surface height, sea ice freeboard, and ultimately sea ice thickness. The technical approach is to use airborne laser altimetry data to simulate ICESat-2-type data prior to launch. Analysis of airborne data gathered over Arctic sea ice is used to perform a trade study for the various multi-beam systems being considered for the ICESat-2 mission, as well as to identify possible sources of geophysical range error.

**Accomplishments**
The laser altimeter to be carried on ICESat-2 is the Advanced Topographic Laser Altimeter System (ATLAS), which will use a photon-counting, multi-beam system with variable beam energy and dense along-track sampling [Abdalati et al., 2010]. The proposed sampling approach should provide improved detection of leads in the ice pack, which are critical for estimating sea ice freeboard and deriving sea ice thickness [e.g. Farrell et al., 2011a]. ATLAS therefore represents a departure from the analogue laser techniques used on ICESat, so new algorithm development is critical for the identification of cryospheric features using photon-counting data.

The major accomplishment under this Task during the reporting year was a first assessment of airborne photon-counting data from the Multiple Altimeter Beam Experimental Lidar (MABEL) system, over a frozen lake surface, which acts as a sea ice analogue [Farrell et al., 2011c]. MABEL is a high-altitude airborne simulator intended to test the instrument theory of the ICESat-2 laser altimeter ATLAS. A number of MABEL test-flights were conducted in 2011 over land in the western United States. The main objective of our analysis was to take a first look at MABEL L2A data over the sea ice analogue to become familiar with reading and processing photon-counting data. We also conducted an initial analysis of surface elevation accuracy, as well as an assessment of pitch and roll corrections. A prior simulation study conducted by Farrell et al. [2011a] comparing the digital photon counting approach proposed for ICESat-2 with conventional analogue systems showed that simulated ICESat-2 data could offer considerable improvements over ICESat. In particular, the dense along-track sampling of the surface should allow flexibility in the algorithmic approaches taken to optimize the signal-to-noise ratio, for accurate freeboard retrieval. Figure 1 shows our preliminary analysis of photon-counting data collected over the
frozen surface of Lake Crowley, California. Each individual photon return is indicated by a blue dot. The highest photon density (darker blue line) originates from the surface return and demonstrates the surface-tracking capabilities of MABEL.

![Figure 1. (a) Airborne MABEL photon-counting data (blue dots) over Crowley Lake, CA (see Google Earth inset, bottom right). The highest photon density (darker blue line) originates from the lake surface. Lower photon counts at the lake edges indicate a darker surface such as open water adjacent to the lake coastlines. (b) A zoom of the lake surface within the green box shown in (a) indicates some surface elevation anomalies associated with residual errors in the aircraft pitch/roll corrections. These project results were reported via a presentation at the ICESat-2 science team meeting in La Jolla, CA, September 2011 [Farrell et al., 2011c].](image)

A secondary objective of work under this Task is to assist with defining the scientific goals of the ICESat-2 mission as they relate to the polar oceans and deriving the measurement requirements for observing the complex sea ice environment. During the reporting year we helped to develop a preliminary list of ICESat-2 data products associated with sea-ice including the definition of the basic Level 2 products such as sea surface and sea ice elevation, the derived Level 3 products such as sea ice freeboard and thickness, and the gridded Level 4 products such as monthly mean sea surface height and sea ice thickness distributions. We also provided guidance on MABEL test flights for the Spring 2012 Arctic campaign, particularly sea ice flight-line layout with the goal of optimizing links with IceBridge aircraft surveys and leveraging historical ICESat data.

Integral to the process of deriving sea ice freeboard (and thickness) is the accurate determination of sea surface height. Under one related research activity we constructed the highest resolution mean sea surface (MSS) mapping of the Arctic Ocean to date [Farrell et al., 2012]. Using a combination of ICESat-laser and Envisat-radar altimetry the new ICEn MSS contains details of the steepest sloping sea surface topography of the Arctic Ocean. Given that some short-wavelength error still exists in the best available Arctic geoids, the ICEn MSS can be used in place of a geoid to act as a reference surface for more accurate retrieval of sea ice freeboard. We
therefore plan to incorporate the ICEn MSS into the ICESat-2 pre-launch processing chain as required. Under a second, related research task, we assessed the lead mapping capabilities of the Digital Mapping System (DMS), a nadir-looking, high-resolution digital camera mounted on the aircraft associated with the NASA Operation IceBridge Mission [Farrell et al., 2011b; 2011d]. Discrimination of leads along-track is critical for deriving the elevation of open water within leads and defining sea surface height. The DMS digital imagery data were used to generate statistics on lead distribution and spacing, lead width, and areal coverage. Knowledge of such lead distribution statistics is used to assess the sampling geometries employed by current airborne and future satellite laser altimeters that map the complex sea ice environment, including the multi-beam photon-counting approach proposed for ICESat-2.

Dr. Farrell was recently selected to serve on the ICESat-2 Science Definition Team from January 2012 – 2015. As part of this project, the task lead will continue her work in support of the ICESat-2 mission in the run-up to launch, via investigation of airborne MABEL data over cryospheric targets such as sea ice/open ocean, to better quantify the extent of scattering issues and assist with algorithm development.

Refereed Journal Publications


Conference Presentations


Farrell, S., K. Brunt, T. Markus, and A. Neuenschwander, 2011c: A First Look at MABEL L2A Data over a Sea Ice Analogue, ICESat-2, SDT Meeting, Martin Johnson House (T-29), Scripps Institution of Oceanography, La Jolla, C.A., September 7-8, 2011.

Task 236: Hypo-G: Improved Hypoxia Modeling for Nutrient Control Decisions in the Gulf of Mexico; PI: M. Tzortziou; Sponsor: S. Habib

Description of Scientific Problem
The main objective of this project is to assess and transition the potential benefits of using NASA satellite data products within the EPA’s Gulf of Mexico Modeling Framework. The hypoxic zone in the Northern Gulf of Mexico forms each summer and can extend up to 80 miles offshore and stretch from the discharge of the Mississippi River westward to coastal waters of Texas. The size of the hypoxic zone varies considerably each year. In 2007, the size of the hypoxic zone was 20,500 km² approximately the size of Massachusetts. The direct effects of hypoxia include fish kills, depletion of fisheries, and loss of habitat for less mobile animals such as crabs and mussels. The purpose of the EPA Gulf of Mexico Modeling and Monitoring project is to provide the scientific basis to guide a reduction in the frequency, duration, size, and degree of oxygen depletion in the northern Gulf of Mexico as outlined in the recently released Hypoxia Action Plan. The Gulf of Mexico Modeling Framework is a suite of coupled EPA models linking the deposition and transport of sediment and nutrients to subsequent bio-geo chemical processes and concentrations of dissolved oxygen in the coastal of waters of Louisiana and Texas. Use of NASA’s Earth Observations can potentially improve the accuracy of these models by providing more accurate inputs, thus enabling determination of best practices and strategies for managing the Mississippi/Achafalaya river basin. More information about the project can be found on the project’s website at: http://oas.gsfc.nasa.gov/Gulf/index.html

Approach
Our approach to enhance the EPA’s Modeling Framework is divided into three components:
(a) Improvement of the precipitation input data, by using the NASA TRMM-based Multi-satellite Precipitation Analysis (TMPA) and the NOAA/National Weather Service Multi-sensor Precipitation Estimator (MPE) products;
(b) Improvement of atmospheric constituent concentrations in EPA’s air quality/deposition model, by using NASA MODIS, CALIPSO, and OMI data products;
(c) Improvement of the calculation of algal biomass, organic carbon and suspended solids within the water quality/eutrophication models, by using NASA MODIS and SeaWiFS ocean color data products.

The primary purpose of the EPA Gulf of Mexico Modeling Framework is to characterize the impacts of nutrient management actions, or proposed actions on the spatial and temporal characteristics of the Gulf hypoxic zone. The Modeling Framework is expected to play a significant role in determining best practices and improved strategies for incentivizing nutrient reduction strategies, including installation of on-farm structures to reduce sediment and nutrient runoff, use of cover crops and other agricultural practices, restoration of wetlands and riparian buffers, improved waste water treatment and decreased industrial nitrogen emissions. The use of NASA satellite data products in the models and for long term validation of the models has the potential to significantly increase the accuracy and therefore the utility of the model for the decision making described above.
**Accomplishments**

We evaluated the WRF (Weather and Research Forecasting) model precipitation estimates using gridded precipitation observation products from NOAA and NASA. Over the continental United States the NOAA/National Weather Service Multisensor Precipitation Estimator (MPE) product is used. MPE combines precipitation observations from over 6000 rain gauges, 160 Doppler radars, and multiple IR and microwave satellite sensors. MPE does not provide sufficient coverage over the Gulf of Mexico for the hypoxia project. Therefore, we also use the NASA TMPA product. While the primary data are from satellite microwave and infrared sensors, data from the TRMM precipitation radar and rain gauges are used for calibration. Validation results have shown good performance at monthly time scales and for detecting large daily events. TMPA has lower skill in specifying light rain events over short intervals.

We have also been using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) to evaluate meteorological outputs from WRF (Fig. 1). PRISM interpolates between station-based observations of precipitation and other meteorological variables using a digitized elevation model and assuming that local differences in precipitation and temperature are primarily driven by differences in elevation, but accounting for other factors. Results from our preliminary comparisons between WRF output and PRISM data are presented in Shahid et al. [2010]. Relatively good overall agreement was found for both magnitude and location of precipitation over the Gulf of Mexico watershed area. However, the model seems to overestimate precipitation over Louisiana and Mississippi during the summer month. Further comparisons with satellite data will be used to suggest improvements to the model, including changing convective parameterization or cloud/precipitation microphysical scheme.

![Figure 1: Model WRF estimates (left panels) and PRISM measurements (right panels) of precipitation over the US, for January (upper panels) and July (lower panels) of 2006 (from Habib et al., 2010).](image-url)
Because NO₂ is the critical species in determining the nitrogen deposition, we are evaluating the CMAQ column amounts of NO₂ using tropospheric column NO₂ observations from the OMI sensor on NASA’s Aura satellite. Sulfate ion is typically the largest contributor to acidity, and SO₂ gas is the precursor for sulfate. Thus, tropospheric column SO₂ amounts derived from CMAQ are also compared with those measured by OMI.

Satellite derived measurements of the amount of organic matter present as particulate organic carbon (POC), chlorophyll, dissolved organic carbon (DOC) and total suspended solids (TSS) in surface waters of the Gulf of Mexico are critical for remote sensing monitoring of hypoxic conditions. We have been comparing these satellite products with output from the EPA’s Water Quality Fate and Transport Model (WASP, CE-QUAL-ICM) to assess how well the model is performing and suggest areas of improvement. Level 1 SeaWiFS and MODIS sensor data have been processed to level 2 using up-to-date versions of SeaDAS and IDL along with all the required masking. Measurements are processed using existing algorithms for chlorophyll, distributed by the NASA Ocean Biology Processing Group (OBPG), and for POC. Field measurements (e.g. Chl-a, DOC, POC, TSS concentrations) collected in the Gulf of Mexico by the EPA Gulf Breeze Lab are currently being applied to the validation and refinement of MODIS and SeaWiFS algorithms for improved estimates of biogeochemical variables in the study region.

Satellite and ground-based data have been compared with the estimates provided by the EPA’s Models before and after model modification resulting from evaluation with satellite data. Performance is measured with regard to improvements in the model estimates of precipitation, trace gas and aerosol, and water quality, as compared to the satellite data.
**Task 237: Data Assimilation of AMSR-E Soil Moisture Retrievals and Analysis of Soil Moisture Spatial Variability; PI: B. Li; Sponsor: D. Toll**

**Description of scientific problem**
Terrestrial water storage (TWS), which includes soil moisture, groundwater, surface water and snow, is an important hydrological indicator and can be used to infer the potential for future hydrological stress (drought). The state of TWS is also directly linked to other aspects of the hydrological cycle such as infiltration rates and subsurface flow. Large uncertainty exists in model estimated TWS due to uncertainties in forcing, model parameters and inadequacies in model physics. The TWS variations as observed by the Gravity Recovery and Climate Experiment (GRACE) satellites, which is the only satellite mission that monitors the water storage changes in the Earth’s vertical profile, can be used to nudge model estimates towards the truth so that more objective estimates of TWS can be achieved.

**Approach**
Because of the coarser temporal and spatial scale of GRACE data, data assimilation is the ideal approach to seamlessly merge GRACE observations with high resolution model estimates. An ensemble Kalman smoother (EnKS) developed earlier in the NASA group led by M. Rodell was applied to the NASA Catchment model.

**Accomplishment**
The study was conducted in western and central Europe where diverse climate and hydrological conditions exist. An open loop (OL) and a GRACE data assimilation (DA) run were performed for the 2002-2009 period to demonstrate the effect GRACE data assimilation on modeled states and fluxes. Evaluation results show that GRACE data assimilation improved the runoff correlation in 17 out 18 hydrological basins (Figure 1), even in basins smaller than the effective resolution of GRACE, suggesting the successful downscaling of GRACE TWS. In addition to improving temporal correlations, GRACE data assimilation also reduced increasing trends in simulated monthly TWS and runoff associated with increasing rates of precipitation (Figure 2). Evaluation on soil moisture is less conclusive due to the shortness of in situ measurements. GRACE assimilated root zone soil moisture and TWS fields exhibited significant changes (Figure 3) in their dryness rankings relative to those without data assimilation, suggesting that GRACE data assimilation could have a substantial impact on drought monitoring.

A journal article submitted to J. of Hydrology was reviewed with request for moderate revisions. The results were also presented at 2011 AGU Fall meeting.
Figure 1. Correlation of model estimates runoff by the open loop (OL) and data assimilation (DA) run with GRDC stream flow data.
Figure 2. Slopes of trend for monthly runoff at GRDC stations. Trends with a 0.1 significance level are marked with bold symbols.
Figure 3. Dryness ranks of simulated root zone soil moisture and TWS for November 2007 in the 2002 to 2009 period.

Description of Scientific Problem
Recent evaluations of TRMM-era multi-sensor precipitation products have helped raise the priority of developing improved over-land retrieval algorithms in preparation for the GPM era. An example of recent work evaluating TRMM-era multi-sensor precipitation products (Tian and Peters-Lidard, 2007) has documented systematic biases in overland retrievals related to land surface states—in this case the presence of inland water bodies. Physical precipitation retrievals rely on accurate characterization of the microwave radiometric properties of the land surface. Therefore it is critical to understand how the land surface states can affect these properties, and how we can accurately model these properties, specifically, surface microwave emissivity at various frequencies.

Approach
Land surface emissivity is simulated with NASA’s Land Information System (LIS) coupled to various radiative transfer models, including the Community Radiative Transfer Model (CRTM, ver. 1 and ver. 2, Weng, et al. 2001) developed at the U.S. Joint Center for Satellite Data Assimilation, and the Community Microwave Emission Model (CMEM, ver. 3, Holmes et al. 2008) by ECMWF. LIS is run with various land surface models to generate a wide range of land surface variables, including soil moisture content, soil temperature, land surface temperature, and snow depth, that are used to drive CRTM or CMEM to produce land surface emissivity values at various frequencies.

Accomplishments
We performed extensive studies with NASA Land Information System (LIS) coupled with radiative transfer models (RTM) such as CRTM. Our results show that the interplay of soil moisture content (SMC) and leaf area index (LAI) is the most critical driver for the dynamics of land surface emissivity. We constructed an SMC-LAI regime diagram to depict the nonlinear dependencies of emissivity on these two land surface variables. Our model tests indicate SMC-LAI can capture most of the variability and serve as an accurate predictor of emissivity.

Specifically, our studies reached the following conclusions:
1) The integrated LIS/RTM framework can generate both realistic land surface hydrologic status and radiometric signatures.
2) Our modeling studies identified that SMC-LAI combined can serve as a good predictor for land surface emissivity.
3) The SMC-LAI regime diagram gives us a unified paradigm to understand the nonlinear interplay of soil and vegetation.
4) More reference data are needed to verify, validate and calibrate model results.
Figure 1: Average land surface emissivity as a function of soil moisture content (SMC) and leaf area index (LAI), produced by LIS-CRTM online runs for the Southern Great Plain (SGP) at 1x1-km resolution, for the 3-year period of Jul. 2004 – Jun. 2007. The combination of SMC and LAI represents well the nonlinear dependencies of emissivity on the two land surface variables, and captures most of the variability. Different geographic regions/climate regimes occupy different areas of the diagram.

Refereed Journal Publications

Conference Presentations
Task 239: HIMALA: Climate Impacts on Glaciers in the Himalayan Region; PI: M. Tzortziou; Sponsor: M. Brown

Description of Scientific Problem
Glaciers are the largest reservoir of freshwater on Earth supporting one third of the world’s population. Himalayas possess one of the largest resources of snow and ice, which act as a freshwater reservoir for more than 1.3 billion people. Monitoring glaciers is important to assess the overall health of this reservoir. Glaciers and snowfields also form potential hazards in the Himalayas, and in similarly glacierised regions of the world. Water resources will be affected by climate change as well as population growth, changing economic activity, land use change, rapid urbanization and inefficient water use. National governments have limited capacity to determine and accurately predict possible impacts to water resources due to scarcity of hydrometeorological data, limited technical capacity, and the transboundary nature of many major river systems. This has also led to recent controversies surrounding the fate of Himalayan glacier melt, which highlight the need for further glaciological and hydrological research in this region.

The HIMALA project aims at developing a system that will aid populations at risk on early warning of floods, droughts and other water and climate-induced natural hazards in the Himalayan region. Among the project's main goals are to: (i) introduce the use of NASA Earth Science products and models to the International Center for Integrated Mountain Development (ICIMOD) and its member countries, through collaboration with USAID (the United States Agency for International Development) and USGS (the U.S. Geological Survey), (ii) enhance the decision making capacity of ICIMOD and its member countries for management of water resources (floods, agricultural water) in the short (snow, rainfall) and the long-term (glaciers), and (iii) provide projections of climate change impacts on water resources through 2100 using the IPCC models.

Approach
To accomplish the HIMALA project goals, we focus on creating an end-to-end sub-basin prototype hydrological model which includes both snow and glacier melt that contributes to stream flow. Specific objectives include:

- Create a new, area-wide snow water equivalent and snow extent product that allows monitoring of melt water in the region on a daily basis;
- Build on existing regional modeling capacity to integrate snow and glaciers outflow to primary river basins (Ganges, Indus and Brahmaputra);
- Provide a methodology that allows the intersection snow extent with glacier area maps to determine water outflow from melting glaciers using mass balance equations;
- Engage ICIMOD national members in their efforts to monitor river flow using the GeoSFM hydrologic models, with new elements that incorporate melt water from the cryosphere into system;
- Enable ICIMOD members to interpret and use snow extent products and to map and monitor glaciers in their river basins.
- Establish capability at ICIMOD to effectively understand and monitor the impacts of short and long term climate variability on hydrological resources.
**Accomplishments**

The first phase of the project focuses on the development, testing and evaluation of the prototype modeling framework in three pilot river-basins. Jhelum river, in the Indus River Basin, Koshi river, in the Ganges River Basin, and Manas river, a tributary of the Brahmaputra River Basin, have been selected as our pilot basins for initial development of the modeling framework (Figure 1). The sites were selected based on the climatic and geographic diversity of the Hindu Kush-Himalayan (HKH) region, and also due to availability of observations and strong interest by partners in each country who will be willing to participate in the demonstration project.

Existing data on snow and glaciers were identified for use in the UEB model. In collaboration with ICIMOD we acquired the available in-situ data for the project and also acquired relevant satellite images and other regional / global data products (e.g. MODIS snow cover, AMSR-E based SWE, NOAA-Snow cover). New collaborations have been initiated with the Department of Hydrology and Meteorology (DHM) (Ministry of Environment) in Nepal, which will allow access to additional in-situ measurements of hydrological and meteorological parameters in the study region. Activities in the area of data identification, acquisition and initial processing have included: (i) development of broad-band albedo from ASTER imagery for the Langtang basin, using various algorithms developed in other parts of the world; ii) basin delineation in Langtang and Imja using SRTM DEM (Shuttle Radar Topography Mission -Digital Elevation Model) and hydrologic functions, and comparison with previous delineations; iii) compilation of meteorological and hydrologic stations for Langtang basin from DHM data, in collaboration with ICIMOD, and selection of stations from which we need to acquire complete data; iv) delineation of glacier outlines from multi-temporal Landsat satellite imagery, in collaboration with ICIMOD; v) thorough search and scene selection of high resolution imagery (QuickBird, Ikonos and World View) for the Langtang and Khumbu regions; these images will be used for two purposes: validation of debris covered algorithms, and glacier delineation; vi) initial parameterization of various components in the UEB model, using data from existing literature.

We are developing a portable code for the snow and ice melt component of the hydrologic model. Several components of the graphical user interface (GUI) of the model have been developed in Perl programming language. Completed components of the GUI include: (a) element to create UEB directory tree for data downloads and processing, and (b) module to extract archive files or download current precipitation datasets either from for the NOAA’s rainfall estimates (RFE, at ftp.cpc.ncep.noaa.gov) product for preset windows or the NASA’s TRMM 3B42RT product globally.

**Future Plans**

After completing testing and evaluation in the pilot basins, the new modeling framework will be upscaled to other basins in the Himalayan region. Climate data from the IPCC AR4 model scenarios will be incorporated into the analysis. These studies will enable long term estimates of...
the impact of precipitation dynamics on long term river flow in the region.

**Manuscripts and other Publications**

**Conference Presentations**
Task 240: Aerosol Characterization and Radiative Forcing Assessment Using Satellite Data and Models; PI: H. Yu; Sponsor: M. Chin/L. Remer

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) examining daytime variations of aerosols over Americas using AERONET measurements in supporting GEO-CAPE science definition; (2) exploring the estimate of above-cloud aerosol by integrating complementary measurements from multiple A-Train sensors; and (3) assessing climate impacts of anthropogenic aerosol intercontinental transport using source-receptor relationship simulations from multiple chemical transport models.

Accomplishments
1. **Daytime variations of aerosols in the Americas.** We analyze the daytime variation of aerosol with seasonal distinction by using multiyear measurements from 54 of AERONET sites over the Americas. The analysis shows a wide range of daily variability of aerosol optical depth (AOD) and Ångström exponent depending on location and season (Zhang et al., 2012). Possible reasons for daytime variations are given. The largest AOD daytime variation range at 440 nm, up to 75%, occurs in Mexico City, with maximum AOD in the afternoon. Large AOD daily variations are also observed in the polluted mid-Atlantic United States and West Coast with maximum AOD occurring in the afternoon in the mid-Atlantic United States, but in the morning in the West Coast. In South American sites during the biomass burning season, maximum AOD generally occurs in the afternoon. But the daytime variation becomes smaller when sites are influenced more by long-range transported smoke than by local burning. The diverse patterns of aerosol daytime variation suggest that geostationary satellite measurements would be invaluable for characterizing aerosol temporal variations on regional and continental scales. In particular, simultaneous measurements of aerosols and aerosol precursors from a geostationary satellite would greatly aid in understanding the evolution of aerosol as determined by emissions, chemical transformations, and transport processes.

2. **Estimate of above-cloud aerosol from an integration of A-Train measurements.** We conduct an integrated analysis of aerosols above clouds by using multi-sensor A-Train
measurements, including CALIOP, OMI, and MODIS (Yu et al., 2012). The analysis of Saharan dust outflow and Southwest African smoke outflow regions shows that the CALIOP above-cloud AOD correlates positively with OMI aerosol index (AI) (a qualitative measure of aerosol loading) in an approximately linear manner, and that the AOD/AI ratio decreases with increasing cloud optical depth (COD). The COD-dependence of AOD/AI ratio doesn’t depend on aerosol type when potential biases in the CALIOP AOD measurements are empirically accounted for. Our results may 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 CALIOP measurements, which needs to be further explored in the future.

3. Climate impacts of anthropogenic aerosol intercontinental transport. We assess changes of AOD and direct radiative forcing (DRF) in response to the reduction of anthropogenic emissions in four major pollution regions in the northern hemisphere by using results from 9 global chemical transport models. The impacts of the regional emission reductions on AOD and DRF are extended well beyond the source regions because of the aerosol intercontinental transport. On annual basis, the relative contribution of aerosol transport accounts for 10-30% of the overall impacts by both the domestic emissions and intercontinental transport, depending on regions and species. While South Asia is most influenced by import of sulfate aerosol from Europe, North America is most influenced by import of black carbon from East Asia. It is found that the model simulations show large spread, highlighting a need of improving aerosol processes in models and evaluating and constraining models with observations. Some of the analysis has contributed to the HTAP 2010 Assessment report (West et al., 2011) and a more complete analysis will soon be submitted to a scientific journal.

Other achievements include: (a) contributing a set of aerosol direct forcing calculations to the AeroCom experiments; (b) detecting modifications of cloud properties by aerosols from A-Train satellite measurements (Yuan et al., 2011a; Yuan et al., 2011b); and (c) deriving the optical properties for “pure” dust by analyzing long-term AERONET measurements.

Refereed Journal Publications


**Conference Publications**


**Task 241: 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**
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 (NUWRF) model, and Goddard Multi-Scale Modeling Framework (G-MMF). 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 several tasks in this year relating to the NUWRF. First, we finally finished the first fully coupled version of the NUWRF, which features

- Externally coupled Modeling Systems to support observation-driven model framework: a) GSFC Land Information System (LIS) that includes various land-surface models, physical boundary conditions, data assimilation, and model evaluations, and b) the G-SDSU that allows the NUWRF simulation to be evaluated against satellite L1B observations.
- Lateral and initial boundary conditions: In addition to the traditional NCEP global and regional models, the NU-WRF can be driven by the NASA GEOS-5 global forecasting simulations or the MERRA reanalysis, and the global GOCART simulations for atmospheric aerosols. Various physics modules, external modeling framework, and boundary conditions have been integrated and hardwired to simulate fully coupled aerosol-cloud-precipitation-land surface processes at the satellite-resolvable scales through the effort across NASA’s laboratories.

The fully coupled NUWRF simulation was conducted for the event of Mesoscale Convective System (MCS) over the West Africa associated with dust aerosols plume. This simulation is also coincided for African Monsoon Multidisciplinary Analyses (AMMA) experiments. The NUWRF simulations are conducted with two domains; horizontal grid spacings of mother and nested
domains are 6km and 2km, respectively. Simulation runs with same physics configuration: Goddard semi-two-moment microphysics 2011, Goddard shortwave/longwave radiation, MYJ boundary layer scheme, and NOAH land-surface model, and GOCART scheme for aerosols. Boundary and initial conditions are derived from NCEP GFS forecasting models.

The NUWRF simulation was used to generate satellite observable radiance and backscattering through the G-SDSU with respect to the NASA A-Train satellites: Aqua MODIS infrared (IR) brightness temperature (Tb$_{11\mu m}$), Aqua AMSR-E microwave brightness temperature at 89GHz(V) (Tb$_{89GHZ}$). By comparing with the corresponding satellite L1B observations, it reveals the performance of the cloud-precipitation processes in the NUWRF simulations. The NUWRF simulation overestimates non-raining high clouds (~30% of domain), while it underestimates the non-raining low clouds (~30% of domain). In terms of convective-stratiform separation in raining cloud, the NUWRF simulation produced ~96% of stratiform rain, which is quite close to the observation (~98%). Thus, the G-SDSU makes the NUWRF as the “observation-driven” modeling framework.

Refereed Journal Publications


Seminars and Presentations

Figure 1. Simulated MODIS $T_{B_{11 \mu m}}$ (<273K, gray shaded) and AMSR E $T_{B_{89GHZ}}$ (<270K, color shaded) from satellite observations (top, left) and the NUWRF simulations (top, right) at 01Z, Aug 6, 2006. Bottom panel shows the joint $T_{B_{11 \mu m}}$-$T_{B_{89GHZ}}$ diagram that reveals the new classification of cloud types including raining/non-raining and high/mid/low clouds. Convective and stratiform ratio can be estimated from the frequency of RH (raining high clouds) and CC (convective core) types.
**Task 243: Development of a holistic statistical framework for precipitation estimation; PI: C. Kidd; Sponsor: A. Hou**

**Description of Scientific Problem**

The objective is to develop and test techniques for the amalgamation of multi-sensor (satellite and surface) observations to improve global precipitation estimates.

**Approach**

The project will exploit the wealth of satellite and surface data sets to provide a holistic statistical framework of precipitation estimation. Surface data sets will be sourced from gauge and radar products, and combined with satellite estimates sourced from multi-platforms observations. Results will be inter-compared with current state-of-the-art techniques to assess improvements and application potential. The project involves collaboration with colleagues at ESSIC, at Goddard Space Flight Center and major international partners.

**Accomplishments**

The initial phase of this project has been to investigate the individual precipitation products that will eventually go into the multi-sensor precipitation product. Since it is envisaged that this will involve multi-satellite, surface radar and gauge observations it is deemed important to characterize the individual components to ensure that their combination is expedited in appropriate and efficient manner.

Therefore, two main objectives during the past year were realized:  
- inter-comparison of existing satellite and surface data sets to assess relative performance of currently available data products, and;  
- establishing and understanding characteristics and relationships in component data sets.

A test region was selected over northwest European as an initial test region which encompasses a number of countries including the United Kingdom, France, Germany and the Netherlands. The region was chosen due to the large scale coverage by an integrated surface radar network, together with dense gauge observations and temporal and spatial scales appropriate to this study. A study period from 2005 through to 2011 was selected to permit six years of data to be processed. Gauge data from hourly gauges was collected via the British Atmospheric Data Centre and from the GPCC. Radar data was obtained from the UK Meteorological Office, while satellite products (PERSIANN, CMORPH, 3B42RT, CPC merged microwave and NRL-blended) were obtained from their respective providers. In addition, precipitation generated by the operational ECMWF forecast model was obtained via Peter Bauer at the ECMWF. All the data sets were processed to permit comparison of the data sets at a 3-hourly, 0.25 degree resolution, resulting in about 17000 observations for each grid point.

Results from this analysis are summarized below:  
- satellite precipitation underestimate precipitation over this region;  
- correlations of satellite vs. surface precipitation are generally poor during the cold season, but improve during the warm season;  
- conversely, correlations of model vs. surface precipitation are greater during the cold season than the warm season, particularly over continental Europe.
- overall, the operation forecast model precipitation proved to be more consistent than the satellite observed precipitation.

However, further analysis of the data showed that the performance of the ECMWF operational forecast model varied diurnally (see figure below). While satellite products, although having an overall lower level of performance, had little discernible variation across the diurnal cycle, the ECMWF model product showed a significant variation in the false-alarm ratio and the probability of detection.

![Plot of precipitation product performance over the UK (left) and over Germany (right), illustrating the diurnal variability in the performance of the ECMWF product.](image)

A time series analysis of the performance of the different products provided some interesting insights into the different data products. It was clear that at monthly timescales the relative performance of individual gauge:radar pixels was consistent, indicating that the errors between different precipitation products (at least for surface data sets) could be defined and mapped. These errors are most likely to result from the retrieval ability of the radar system (e.g. elevation angle/range effect) and local topographical effects influencing the gauge observations. At finer time scales the consistency between the different data locations became more disparate, indicating that the temporal/spatial consistency of the precipitation fields breaks down and errors become increasingly related to the characteristics of the weather system, rather than the retrieved products.

**Future Plans**

The next stage in this project is to derive relative error maps of individual precipitation products (satellite and surface) to enable a scheme to usefully combined the different estimates. For surface radar, this error map will largely be dominated by range and anaprop errors which in the first instance can be defined through comparison between ‘simple’ satellite techniques (e.g. cloud thresholds vs radar); these can be further refined through iterative calculations to optimize the error boundaries. Within the satellite products, a first-guess error product will be generated through the comparison of the different products, highlighting discrepancies between the different data products.
Additional regional data sets from different parts of the globe will be sourced to test the technique and evaluate its’ performance in these regions. In particular, data sets from the US, Australia and Japan will be obtained and processed.

**Associated Accomplishments**

In addition to the above tasks, the PI has undertaken a work associated with a number of ground validation campaigns, notably the GPM Light Precipitation Experiment (LPVEx) and the GPM Cold-season Precipitation Experiment (GCPEX). Both these campaigns focused on mid- to high-latitude, light, mixed-phased precipitation regimes that will prove a challenging environment for retrievals from the upcoming Global Precipitation Measurement (GPM) mission. These field campaigns collected extremely useful information on cloud and precipitation that will help our understanding of the processes operating in these regions, and will help improve the satellite precipitation retrievals over these areas.

*Precipitation identified by a micro rain radar at Jarvenpaa, Finland on 20 September 2010 during the LPVEx campaign: note the longevity of precipitation < 1 mmh⁻¹.*

**Referred Journal Publications**


**Seminars and Presentations**

- Kidd, C. and Hou, A. 2011. Advancing the next generation of global precipitation measurements. European Geophysical Union General Assembly, Vienna, Vienna Centre, Austria. 3-8 April 2011
- Kidd, C. and Hou, A. 2011: Global Precipitation Measurements European Geophysical Union General Assembly, Vienna, Vienna Centre, Austria. 3-8 April 2011
- Huffman, G.J., Bolvin, D.T., Braithwaite, D., Hsu, K-L., Joyce, R., Kidd, C., Sorooshian, S., Xie, P. and Yoo, S-H. 2011: The day-1 GPM combined precipitation algorithm IMERG. American Geophysical Union, San Francisco. 5-9 December 2011.
Web Highlights
IPWG European Product Comparisons

GPM Cold-season Precipitation Experiment blogs:
http://pmm.nasa.gov/mission-updates/gcpex-blog/snow-must-be-saturday
http://pmm.nasa.gov/mission-updates/gcpex-blog/snow-ground-satellites-overhead
http://pmm.nasa.gov/mission-updates/gcpex-blog/more-snow-photos
Task 245: Develop Satellite Snow Data Assimilation Capabilities into the NASA Land Information System (LIS) to Support NWS Hydrologic Applications; 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 due to poor model physics in representing the snow processes and other sources of uncertainties such as inaccurate model forcing. Satellite-derived snow products, albeit subject to errors themselves, hold great potential for improving model snow predictions if properly assimilated into the models. This project represents a collaborative effort between NASA GSFC and the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the National Weather Service, which aims to develop snow data assimilation (DA) capabilities into the NASA Land Information System (LIS) to integrate satellite-based SWE and snow cover fraction (SCF) products into several land surface models to improve snow prediction over the Alaska domain. The developed snow DA capability will be transferred to NOHRSC to support their hydrologic forecasting in Alaska and other research domains such as Afghanistan.

Approach
Our approach consists of two major steps: 1) conduct comprehensive benchmarking efforts to understand and analyze the primary uncertainty sources in the model snow predictions, such as model forcing (e.g., precipitation and temperature) and model physics, by using multiple land surface models and multiple forcing sources; 2) based on the uncertainty analysis in step 1), conduct ensemble-based assimilation (e.g., using ensemble Kalman Filtering) of satellite-based SWE and SCF products from AMSR-E and MODIS into the land surface models, and evaluate the performance gain (in any) 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 (Fig. 1 and Fig. 2) indicate that a large portion of the uncertainty in snow prediction comes from precipitation, while there also exists considerable uncertainty in model physics and other forcing terms such as radiation and temperature.

For the data assimilation efforts, the error-prone SWE observations from AMSR-E were first bias-corrected using in-situ snow observation from NWS COOP and other stations, prior to being assimilated into the models using an EnKF based technique. As expected, this has led to considerable improvement in snow predictions as compared to in-situ snow observations. For independent verification of the data assimilation results, we compared the monthly discharged computed by the models (with and without SWE assimilation) with USGS streamflow observations at 12 selected gages (Fig. 3) and conclude that, while SWE assimilation has little or no effect on streamflow prediction at some gages, it does lead to significant improvement at most gage locations with snow-dominant flow regimes. More investigation with SCF assimilation is
underway, but we expect to see less improvement compared to SWE assimilation as already demonstrated in some previous studies.

The snow DA capability will be completed in the next couple of months and will be delivered to the NOHRSC. Two manuscripts (focusing on benchmarking and data assimilation, respectively) are being prepared and will be submitted to appropriate journals in the next few months. Other related publications and conference presentations are given below.

**Journal Publications**


evaluation, Geosci. Model Dev. Discuss., 5, 229-276, doi:10.5194/gmdd-5-229-2012 (published as a discussion paper).


**Conference Presentations**


![Figure 3](image)

*Figure 3. Comparison of simulated monthly discharge (black: control run; blue: with SWE assimilation) to streamflow observations (red) at 12 selected streamflow gages in Alaska. Blue axes indicated gages with improvement in discharge simulation from SWE assimilation.*
Task 246: GEOS-5 atmospheric modeling and diagnostics; P.I.: A. Molod; Sponsor: M. Rienecker

Description of scientific problem
An overarching goal of the GMAO atmospheric modeling effort is to develop a single atmospheric general circulation model (GCM) suitable for data assimilation, weather forecasting and climate simulation. Climate simulation includes atmosphere only, coupled ocean atmosphere, and coupled chemistry-climate modes. The model’s collection of physical parameterizations is of central importance to the success of the GMAO’s modeling effort.

Part of this year’s effort was focused on the final model changes that led to improvements in data assimilation mode at higher resolution, and resulted in the release of the model to be used for decadal climate prediction.

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 explain 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
The Fortuna 2_5 version of the GEOS-5 GCM was released, for use in the GMAO’s Coupled Model Intercomparison Project -5 (CMIP5) coupled and atmosphere only simulations and for use in the GMAO assimilation system used for mission support during the Discover AQ mission. Fortuna-2_5 was also released for public use through the GMAO web server. Results of coupled atmosphere-ocean climate simulations and of atmosphere only climate simulations are comparable in accuracy to other state of the art GCMs.

A series of 3-year simulations were performed with the Fortuna-2_5 version of the GEOS-5 GCM, aimed at a comprehensive validation and documentation of many aspects of the simulations. A series of experiments was also designed and performed to carefully attribute the differences between Fortuna-2_5 and MERRA AGCM simulations to specific changes in model parameterizations. The behavior of the mean climate as compared to reanalyses and to satellite-based observational estimates of many facets of the simulation are documented in a NASA technical memorandum. The technical memorandum also includes the documentation of the model changes implemented to improve the simulations.

Objectives for next year
The development effort for the GEOS GCMs physical parameterizations during the coming year will focus primarily on the identification and removal of model behavior which is discontinuous in nature. Analysis of GCM and single column simulations has pointed to errors specifically connected to the discontinuities in the behavior of the turbulence and moist parameterizations. The aspects of the parameterizations that will be specifically addressed include the assumption of a ‘top-hat’-shaped sub-grid scale distribution of water vapor and sudden onset of phase changes in the prognostic cloud scheme, and an abrupt end to buoyant ascent in both the convective and
turbulence parameterizations. The model parameterizations will also be examined to remove behavior that is inherently dependent on vertical resolution. Removal of these discontinuities is anticipated to reduce model error and enable a more continuous response to parameter changes during model tuning endeavors. In addition to the correction of these known errors, development during the coming year will include the replacement of the current version of the cumulus parameterization with the more modern RAS-2, which includes the simulation of a cumulus downdraft and a modified mass flux entrainment profile for shallow convection.

In addition to the model development effort, the coming year will be focused on the completion of technical memoranda, and journal papers presently in the review process. These publications include a technical memorandum documenting the changes in parameterizations and the connections to the improved climate simulation. A journal paper will follow, focused on explaining the improvements in tropical precipitation and global stationary wave pattern in the context of existing theory about tropical organization and teleconnections. A journal paper reporting on the study of model subgrid scale variability of total water and the connection to the parameterization of critical relative humidity will also be completed and submitted.

**Presentations**


**Task 247: 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**
In support of the GPM Microwave Imager (GMI) algorithm, the capability of GMI to detect precipitation (both liquid and frozen) over a variety of surface types, including (but not limited to) water, bare land, snow-covered land was assessed. In order to replicate GMI observations as closely as possible, existing sensors (SSMIS, AMSR-E, AMSU-B, and MHS) were used. Ground truth for precipitation detection comes from active sensors such as the NOAA National Mosaic and QPE (NMQ) product over the continuous US and CloudSat globally. The essence of the approach is to evaluate a set of GMI-equivalent brightness temperatures for consistency with a non-precipitating atmosphere. This requires a priori knowledge of the means and covariances of surface emissivity (we use a physical model over ocean and the TELSEM climatology over land) and atmosphere (climatology from MERRA re-analysis) parameters combined with a radiative transfer model. This approach has the advantage of not requiring a database of precipitation profiles as in Bayesian algorithm; these databases are still under development for GPM and provides for an evaluation of the improvement from real-time vs. ancillary data sources (such as NWP data vs. climatology for atmospheric parameters).

In support of the GPM combined radar-radiometer algorithm development, the focus is on the sensitivity of algorithm output (primarily rain rate, although secondary parameters are also examined) to the initial assumptions. Because a GPM-like platform does not yet exist on a satellite, data from GRIP, MC3E, and GCPEX field campaigns, all of which contain co-located Ku/Ka band radar data and at least a partial set of GMI channels, will be used to mimic observations. In-situ observations from these campaigns will also be used to construct optimal parameterizations of hydrometeor size distributions and cloud vertical profiles.

**Accomplishments**
The ability of the AMSU-B/MHS to identify precipitation over various surfaces is illustrated in Figure 1. The metric used to evaluate skill is the Heidke Skill Score (HSS). Best detection occurs over the ice-free where physical emissivity models are relatively mature. Over more complex surfaces, detection is limited to heavier precipitation and skill is generally lower. In particular, there is no skill over the ice sheets although this may also be due to a lack of sufficiently heavy precipitation in these regions to produce a detectable signal.
Figure 1: Heidke Skill Score of precipitation detection as a function of vertical average CloudSat Reflectivity (x-axis) and non-scattering radiative transfer model error (y-axis) for various surface types.

We have also evaluated the improvement in skill that comes from the use of a real-time (vs. climatological) atmospheric state and use of a snow emissivity database in place of TELSEM when snow is analyzed on the ground (Figure 2). The addition of MERRA greatly improves the skill for instruments with sounder channels (GMI and SND), whereas the conditional snow emissivity database provides the best improvement for instruments with surface-sensitive channels (TMI and GMI).
Figure 2: Skill score of detecting snow falling on snow-covered surfaces as a function of precipitation rate for SSMIS in three configurations (TMI, GMI, and Sounder), using climatology/TELSEM (solid), MERRA reanalysis/TELSEM (dashed), and MERRA reanalysis/conditional snow emissivity as the base atmosphere and surface emissivity state.

As a side product of this analysis, a high-frequency (>100 GHz) emissivity database was developed in order to complement the TELSEM (Tool to Estimate Land Surface Emissivity in the Microwave) database, which is a 10+ year climatology of land surface emissivity from SSM/I. High-frequency emissivities are particularly important in cold and dry environments, where water vapor emission does not entirely obscure the surface. These have been used by various members of the GPM passive microwave algorithm team in developing model-based Bayesian databases for GMI. Another side product being used by the GPM radiometer algorithm team is a Bayesian database of SSMIS brightness temperatures and co-located NMQ precipitation rate.

The combined algorithm information content analysis has been performed with data from GRIP and MC3E thus far. As an example the sensitivity of the retrieved median raindrop diameter to initial assumptions is shown in Figure 3. Three regimes are apparent below the melting layer:

1. Very light rainfall (leading edge of storm; < 1 mm/hr). Here D₀ is poorly constrained because Ka and Ku bands wavelengths do not contain independent information.
2. Light-moderate rainfall (1 mm/hr < R < 25 mm/hr). Here D₀ is well constrained (white region in lower panel indicates no sensitivity to initial assumption).
3. Heavy rainfall (R > 25 mm/hr). Here the dual-wavelength retrieval algorithm becomes numerically unstable. Alternate approaches (bottom-up Hitschfeld-Bordan) are being pursued to mitigate this problem.
Figure 3: Retrieval of \( D_m \) (top) and sensitivity to initial assumption (bottom) using data from the APR2 instrument from the GRIP field experiment.

**Conference Presentations**


Task 248: Modified Tau-Omega Model for Moderately to Densely Vegetated Landscapes; PI: M. Kurum; Sponsor: P. O’Neill

Description of Scientific Problem
Soil moisture (SM) is recognized as an important component of the water, energy, and carbon cycles at the interface between the Earth's surface and atmosphere, yet it is difficult to measure globally using traditional in situ techniques. Several planned microwave space missions, most notably ESA's Soil Moisture Ocean Salinity (SMOS) mission (launched November 2009) and NASA's Soil Moisture Active Passive (SMAP) mission (to be launched 2014/2015), are focusing on obtaining accurate SM information over as much of the Earth's land surface as possible. However, current baseline retrieval algorithms for SMOS and candidate retrieval algorithms for SMAP are based on an easily implemented but theoretically simple zero-order radiative transfer (RT) approach which includes components from the soil and vegetation, but ignores vegetation scattering except for the effect of the scatterers in the attenuation of the emission through the vegetation canopy. This approach essentially places a limit on the density of the vegetation through which SM can be accurately retrieved. Our proposed work involves the development of a new SM retrieval model which could potentially overcome this limitation and thus could be used with SMAP and SMOS data to increase the accuracy and reliability of SM products over moderately to densely vegetated landscapes.

Both SMOS and SMAP have mission requirements to retrieve SM to an accuracy of 0.04 cm$^3$/cm$^3$ through vegetation water content (VWC) of 5 kg/m$^2$. These missions are expected to meet their requirement for SM retrieval accuracy using the heritage tau-omega model (zero-order RT solution) approach over approximately 65% of the Earth's land surface where the VWC does not exceed 5 kg/m$^2$. As the density of vegetation increases, sensitivity to the underlying SM begins to degrade significantly and errors in the retrieved SM increase accordingly. Thus, knowledge of L-band vegetation features appears to be of great importance when the tau-omega approach is applied to dense vegetation (i.e. forest, mature corn, etc.) where scattering from branches and trunks (or stalks in the case of corn) is likely to be very important.

Our proposed new model is a first-order scattering RT model for microwave radiometry of vegetation at L-band. The model is based on an iterative solution (successive order of scattering) of the RT equations up to the first-order. This formulation adds a new scattering term to the tau-omega model. The additional term represents emission by particles in the vegetation layer and emission by the ground that is scattered once by particles in the layer. The resulting model represents an improvement over the standard zero-order solution since it accounts for the scattered vegetation and ground radiation that can have a pronounced effect on the observed emissivity and subsequent SM retrieval. Although the new approach would add another parameter to the list of unknowns in the inversion procedure to retrieve SM from microwave measurements, it has the advantage that the formula relating SM is physically-based, and as a result, should be more robust under varying conditions.

Approach
Global measurements and interpretation of SM products might be best accomplished by a combination of ground-based and spaceborne techniques. The first stage of our research will be to focus on the ground-based ComRAD radiometer data because of the extensive heritage that this type of observation has in SM applications. Building on our SM investigations using ComRAD
observations, we will evaluate how the proposed new algorithm could be applied to spaceborne data for densely vegetated areas which are normally beyond the baseline SM retrieval range of such space missions. To test the performance of the new model against the candidate SMAP algorithms in the years prior to the SMAP launch, we plan to use SMOS data as proxy SMAP data.

In the proposed research, a first-order RT model will be developed to investigate the relationship between scattering mechanisms within vegetation canopies (with large scatterers) and the microwave brightness temperature. The model will then be used to perform a physical analysis of the scattered and emitted radiation from vegetated terrain. The main goal of the proposed work is to more accurately account for vegetation canopy scattering by modifying the basic tau-omega model to include the first-order scattering term, and then to assess the performance and operational usefulness of both versions of the tau-omega model in retrieving SM. Specifically, the proposed work involves the following approaches:

- To determine the impact of scattering at L-band on the microwave retrieval of SM under vegetation using existing ground-based measured field data,
- To obtain some insights into the first-order scattering solution regarding possible emission/scattering mechanisms,
- To assess whether modifications are necessary to the tau-omega model in terms of form or quantification of parameters,
- To determine appropriate values for vegetation parameters which produce the most accurate SM retrievals under moderately and densely vegetated terrain,
- To implement and to assess the usefulness of the new modeling approach to improve the accuracy of large scale SM retrievals through different types of vegetated landscapes, where the VWC exceeds 5 kg/m².

**Accomplishments**

- A first-order radiative transfer model was developed to more accurately account for vegetation canopy scattering by modifying the basic zero-order RT (tau–omega) model, which is used in soil moisture retrieval algorithms.
- Effective tree scattering and opacity parameters were evaluated with theoretical definitions of these parameters for forest canopies and a new effective scattering albedo formulation is developed for soil moisture retrievals.
- Antenna illumination effects such as platform height on the measurements of the backscattering coefficient by a ground-based scatterometer (which plays an important role in development and validation of soil moisture products) were demonstrated.

**Refereed Journal Publications**


Conference publications

Task 250: Integration of FEWS-NET into the Land Information System; PI: B. Wind; Sponsor: C. Peters-Lidard

Description of Scientific Problem
A USGS famine early warning system (FEWS-NET) drought model, Water Requirement Satisfaction Index (WRSI), stood to benefit from being integrated into NASA (Code 614.3)'s Land Information System (LIS), which is a software framework for high performance land surface modeling and data assimilation. LIS brings to bear a host of flexible modeling and computing capabilities for those models privileged enough to be integrated into the LIS framework. However, LIS is a general-purpose Fortran (LINUX/UNIX) batch-queue submission shell executable. Whereas, USGS's most up-to-the-minute implementation of WRSI was a custom Visual Basic .Net (Windows) graphical user interactive (GUI) application. A phased conversion and integration process was required.

Approach
Implementation and integration of WRSI into LIS was to constitute a system called FLDAS-WRSI. 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 concomitant testing to ensure against lossy or inaccurate translation. In Phase 2 the fortran physics is being integrated with the Land Information System.

Accomplishments
Phase 1 of the Task was completed from the ground up. All salient WRSI model code features of the 20,000 line Visual Basic .Net code were re-written as half as many lines of fortran90. Testing was designed and conducted to ensure that original and converted codes produced the same output. This work was first performed locally on an x86 32bit host, where for this project all of the development tools had also to be installed from scratch. These installations were Visual Studio 10 in the Windows environment for the Visual Basic work; and gfortran, vi, and svn on Redhat5 through VMWarePlayer for the Fortran conversion.

A sophisticated Start of Season (WRSI parameter) calculation of several additional thousand lines of code was required in addition to the core WRSI algorithm. An SOS algorithm was translated from the Visual Basic equivalent.

For Phase 2, development moved to NASA Center for Climate Simulation’s 14,400-processor Dell PowerEdge C6100 cluster “discover” running the ifort compiler. ESRI’s binary-interleaved (.bil) format was the data file format used by the USGS WRSI model. The first step to enable running of the full WRSI model, beyond the single point calculation, on discover was to create a brand new file I/O library. This several thousand line Fortran (LINUX) library was functionality extracted and translated from a 40,000 line custom Windows library written in Visual Basic. File reading and writing, including grid interpolation for aligning in a consistent fashion data and model run domain resolutions, of the new “bil” library was tested extensively for the many relevant uses, data sources and types, and domain setup scenarios present in the WRSI model.

The WRSI standalone fortran point calculation created during Phase 1 was integrated into LIS. Massive reorganization of the standalone code into LIS structures and several libraries was done.
Handling of the model’s precipitation and potential evapotranspiration atmospheric forcing data was integrated into LIS as a new specialized supplemental forcing module. Testing validated.

Features of the USGS WRSI model were ported and expanded further going from the point calculation to that of a full spatial grid. The USGS WRSI model implementation was a highly interactive graphical analysis tool concerned with narrowly-defined local crop growing conditions, whereas LIS was a generic batch calculator of evolving hydrology over an arbitrary spatial domain. The USGS WRSI model was only capable of running one growing season of one crop in one administrative growing region. To run in LIS, the new model needed to be able to run multiple growing seasons, and for multiple crops in multiple administrative growing regions, simultaneously. These new features, and a few of those ported over such as controlled substitution of climatological data for current data and the use of idiosyncratic dekad time steps, required brand new subsystems within and outside of LIS to support FLDAS-WRSI including a parameter management subsystem and multiple time handling tables. The SOS algorithm, meanwhile, was evolved to work seamlessly within LIS as an independent mode of running the same WRSI model. SOS is a parameter to WRSI. Therefore the official LIS post-processor “LVT” was augmented to enable reorganizing by season and reformatting into bil the output of the SOS mode runs for use in the WRSI run mode.

FLDAS-WRSI operation was validated extensively using the 2003-2004 maize season in Malawi by comparing FLDAS-WRSI SOS and WRSI output against the equivalent USGS model outputs. Results were shown to match identically both in memory on discover and on firn.umd.edu, a Dell x86_64 LINUX machine managed at ESSIC and installed with a slightly newer version of ifort, as well as through the use of extensive GrADS visualization techniques. Results, including the figure that follows, were presented at PECORA in November 2011.

Thorough documentation and training of co-workers on building, setup, and running the FLDAS-WRSI model was completed.

Integration of WRSI proceeds to make the FLDAS-WRSI implementation more in the mold of other land surface models in LIS. WRSI will thereby have accessible to it all of the advanced features of LIS available to other fully-integrated models. Meanwhile requirements are being gathered for publication worthy studies and potential operational assimilation of the NASA LIS system, and specifically FLDAS-WRSI, into Earth Resources Observation and Science (EROS) – like prominence within the broader FEWS NET Mission.
WRSI Implementation Benchmark - Spatial

GEO- WRSI  

FLDAS-WRSI  

Difference

eosWRSI

eosSumET

Pg. 6
**Task 251: NASA GEOS-5 Chemistry Climate Model (CCM); 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**
*Methane-Only Option of CCM:* A tagged methane option was implemented and evaluated in the CCM. Tracers are carried for each methane source (e.g., wetlands, termites, etc.) and loss is linearly proportional to archived monthly OH fields. This option allows us to track the contribution of various methane sources to total methane at any given location in the model. A limitation of this option is that nonlinear feedbacks of the CH₄-CO-OH cycle are not captured (Prather, 1994). Nevertheless, this model option is a useful diagnostic tool that allows investigation of the behavior of methane in a computationally expedient way. The simulation shown in the plot uses climatological methane emissions and calculates methane loss using one year of monthly-averaged OH from a full chemistry run. **Completed**

*CH₄-CO-OH Option of the CCM:* We are currently implementing/evaluating an option in the CCM that captures the nonlinear feedbacks of the CH₄-CO-OH system in a computationally-efficient way. The coupled methane-CO-OH cycle is important to simulate because of the nonlinear feedbacks. The oxidation of CO by OH represents nearly 100% of the sink for CO and about 60% for OH. Methane oxidation represents about a third of the total CO source and about 10% of the total sink of OH. Both methane and CO are tagged as functions of their sources or regions. A parameterization of OH (Duncan et al., 2000) calculates the 24-average concentration of OH as a function of meteorological variables, solar irradiance variables and chemical variables,
including CO and methane. The parameterization accurately represents OH predicted by a full chemical mechanism (see figures below). The methane-only and CH₄-CO-OH options are important for studies of methane, which has an atmospheric lifetime of about 9 years. We can do many decade-long simulations, which is not feasible with the full chemistry option of the CCM. Therefore, these options are considered “reduced-chemistry” options of the CCM.

**Figure 1.** Zonal OH (10⁵ molec/cm³) from the OH parameterization for January using GEOS-5 CCM meteorological fields as input.

**Figure 2.** Zonal OH from Spivakovsky et al. (2000) for comparison.
Task 252: Improving AOD retrieval over ocean from MODIS; PI: Jaehwa Lee; Sponsor: N. Christina Hsu

Description of Scientific Problem
Aerosols exert a significant impact on climate change and air quality. These small airborne particles regulate the radiation budget through their direct and indirect effects (IPCC, 2007), or more specifically, by scattering and absorbing radiation and by modifying the microphysics of clouds. In the sense that aerosol shows highly variable spatial and temporal properties, the observations made from satellite, such as Moderate Resolution Spectroradiometer (MODIS) aboard the Terra and Aqua satellites, provide an unprecedented opportunity to investigate aerosol properties (AOP). However, a recent validation by Remer et al. (2008) showed underestimation of aerosol optical depth (AOD) over the ocean from Aqua-MODIS for high AOD case in particular. To resolve this issue, this study aims to improve AOD accuracy using new aerosol models archived by integrating Aerosol Robotic Network (AERONET) inversion data (Dubovik and King, 2000; Dubovik et al., 2006) and a tri-axial ellipsoidal dust database data (Meng et al., 2010).

Approach
Simulation of satellite-observed top-of-atmosphere (TOA) reflectance using a radiative transfer model (RTM) requires aerosol characteristics such as spectral refractive indices, size distribution, and nonsphericity when resolving nonspherical particles. Otherwise, spectral AOD, SSA, and phase function, which are derived from the aforementioned aerosol properties, are required instead. Thus, long-term AERONET inversion data that provides the aforementioned AOP for the globe can be used to simulate the satellite signal for various aerosol types. To create improved aerosol model based on AERONET retrievals, the aerosol models are first classified using fine-mode fraction (FMF) and single scattering albedo (SSA). Then, each aerosol model is further categorized as a function of AOD. Since the AERONET inversion data provide AOP for wavelengths ranging from 440 nm to 1020 nm, while the MODIS observations cover the wavelengths from 470 nm to 2120 nm, the wavelength range is extended using the tri-axial ellipsoidal dust database data.

Accomplishments
The new aerosol models improve correlation between AERONET-observed AOD and MODIS-retrieved AOD compared to the MODIS Collection 5 products with a Pearson coefficient of 0.93 and a regression slope of 0.99 compared to 0.92 and 0.85, respectively, for the MODIS operational algorithm. Moreover, use of the new algorithms increases the percentage of data within an expected error of ±(0.03 + 0.05 × AOD) from 62% to 64% overall and from 39% to 51% for AOD > 0.3.
Comparison of AOD between AERONET and MODIS over the global ocean for a period from 2003 to 2010. The MODIS AODs are from the C005 algorithm (left) and the test-bed algorithm using new aerosol models (right). The collocation criteria of ±30 minutes in time and 25 km in space were used. The gray dots represent all data points, whereas black dots with one-standard deviation interval represent mean AODs in 20 equal-number-of-data bins with respect to the AERONET data. The solid line is from the regression equation, while the dotted and dashed lines are the one-to-one line and the MODIS expected error (EE) line showing ±(0.03 + 0.05 × AOD), respectively. Only data points overlapped between the two algorithms are compared. Originally, the number of data points was 3106 for the C005 algorithm and 3578 for the test-bed algorithm. The statistics shown are the Pearson coefficient (R), root mean squared error (RMSE), mean bias (MB), and the number of data points (N).
Task 253: Summary of Tropical Rainfall Measuring Mission (TRMM) Accomplishments to Date: PI: Jian-Jian Wang; Sponsor: Scott Braun

Description
The Tropical Rainfall Measuring Mission (TRMM) is a joint project between NASA and the Japanese space agency, JAXA. It was launched on November 27, 1997 and continues to provide the research and operational communities unique precipitation information from space well into 2011. The first-time use of both active and passive microwave instruments and the precessing, low inclination orbit (35°) make TRMM the world’s foremost satellite for the study of precipitation and associated storms and climate processes in the tropics. To prepare for the TRMM Senior Review Proposal 2011, a thorough review of scientific accomplishment by TRMM is required.

Accomplishment
TRMM products are used extensively by the research and applications communities. One measure of TRMM’s contribution is the large number of refereed publications that mention TRMM in 2009 and 2010. The TRMM launch triggered a virtual flood of research that has led to significant improvements in our understanding of the hydrologic cycle, of the climate system, and of tropical weather systems and their prediction.

The main effort of this task is to summarize TRMM’s scientific contributions in various categories, with an emphasis on findings from the past two years. In brief, a literature review of more than 1200 TRMM related papers published by American Meteorological Society (AMS), American Geophysical Union (AGU), Meteorological Society of Japan (MSJ), Royal Meteorological Society (RMS), and Springer-Link journals, have been made. The recent scientific progresses made by TRMM scientists have covered many areas including rainfall and lightning climatology and diurnal cycle, profiles of latent heating, tropical dynamics, impact of humans on rainfall, convective systems characteristics, tropical cyclones, improvement of algorithms, multi-satellite analyses, data assimilation, model improvements and evaluations, hydrological/land surface applications, and fire detection and monitoring.
Task 254: 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. Model simulations covering this field campaign are currently underway to help interpret the observations and achieve the above mentioned goals. In addition, the observations and model simulations will be used to evaluate the models and determine 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:

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

**Accomplishments**

Steps 1-4 described above have been completed. WRF-Chem model setup and code bug fixes have been applied by other scientists at the NASA GSFC following my instructions. CMAQ Version 5.0 was released in late February 2011. I am currently testing the CMAQ code and a simulation covering the 2011 DISCOVER-AQ field campaign will be underway in the near future.

A preliminary analysis of the vertical variability of air pollution was conducted over the Chesapeake Bay using in-situ ship and aircraft based observations alongside the NOAA-NMM-CMAQ modeling system, which is run at a horizontal resolution of 12 km. It was found that this model does not have a large enough vertical gradient compared with observations in the stable marine boundary layer. In addition, the model does not simulate elevated ozone aloft at around 950 mb, which the observations show. This suggests the model is not transporting pollution vertically associated with a bay breeze circulation. Model simulations at 12 km or coarser are not expected to capture local scale circulations, like a bay breeze, but they should be captured with resolutions at 1.3 and 4 km.

**Conference presentations**


*Description of Scientific Problem*
Ozone (O3) and sulfur dioxide (SO2) are trace gases that have important effects on climate and air quality. The spatiotemporal distributions of these trace gases, which can be measured by space-borne ultraviolet (UV) instruments, provide essential information needed to monitor their changes over time and space, estimate their climate and pollution impacts, and understand the chemical and physical processes in the atmosphere. SO2 is also a unique marker of explosively injected volcanic plumes, which pose a significant threat to aircraft. Tracking volcanic plumes in near-real-time provides critical information for aviation hazard mitigation.

*Approach*
The ESSIC investigator has developed and implemented a number of techniques for accurate retrievals of O3 and SO2 from UV measurements simultaneously and for near-real-time mapping and tracking of volcanic eruption clouds. The main objective of this research is to improve O3 and SO2 retrievals by taking full advantage of hyper-spectral backscattered UV radiance measurements.

*Accomplishments*
In this year, considerable efforts are invested in the improvement and maintenance of the OMI data products. Specifically we have developed and implemented common approaches that can be applied to different OMI retrievals, including OMI ozone profiles and the direct spectral fitting (DSF) OMI SO2 product.

The first approach is the accurate accounting of the instrument degradation over time. Many OMI products, such as the ozone profile and the DSF SO2, are derived using a composite solar irradiance based on the OMI solar measurements in the first year of OMI operation. Doing so neglects the instrument degradation over time, resulting in bias in the products. To remove this bias, we have conducted a thorough analysis of the all the daily OMI measured irradiance since the start of its operation, and have derived the instrument degradation over time for all the wavelengths and all the cross-track positions.

The second approach to improve OMI product quality is the implementation of new Ring effect correction scheme based on Dr. Spurr’s LIDORT-RRS radiative transfer computation. Specifically using LIDORT-RRS, we have built a set of master tables and developed a set of Fortran 90 codes to efficiently use them to correct the Ring contributions to the measured radiance data from BUV instruments, such as OMI and OMPS. This approach can account for the Ring contributions more accurately under a diverse range conditions including variations in ozone amount, surface pressure, surface albedo, and viewing and illumination angles, leading to higher quality ozone and SO2 products.
**Task 256: Development and Analysis of Satellite-Based Aerodynamic Roughness Fields For Regional And Global Modeling Applications Using MODIS Data; PI: J. Borak (ESSIC/UMD); 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.

**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). In addition to the roughness research, the PI works with the GSFC sponsor on a statistical analysis of modeled snow water equivalent (SWE) 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. The sponsor and PI are currently participating in the NCA effort by planning how they will analyze the modeled SWE data – once they have become available – including performing some proof-of-concept type research with remotely sensed estimates of SWE.

**Accomplishments**
The key accomplishment for this task during the reporting period is the generation of a preliminary global roughness time series dataset. Some issues remain, so the data are still unreleased, but the initial goal of producing global databases of a) zero-plane displacement height ($d_0$) and b) roughness length ($z_0$) has been achieved. Each field is mapped to a 1-km grid, on an 8-day time step. The current version of the product covers the ten-year period from 2001-2010, and it is expected that additional temporal coverage will be added in the near future. Other anticipated enhancements include improved vegetation canopy height information available from recently published datasets.

**Conference Presentations**
Task 258: The impacts of aerosol on convective system with WRF; PI: Tzuchin Tsai; Sponsor: W. Tao

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 301: Joint Center for Satellite Data Assimilation; P.I.: Lars Peter Riishojgaard; Sponsor: Jack Richards

Description of Scientific Problem
The Joint 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 2011 budget of the Center amounted to ~$20M.

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 improved use of radiances from hyperspectral IR sensors such as AIRS and IASI and 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.

Accomplishments
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 9th Annual Science Workshop at the University of Maryland College Park on May 24-25. The Workshop drew its highest attendance number ever with over 160 participants well gathering to present, review and discuss progress and plans for Joint Center research and development. Very good progress was noted for several areas including atmospheric composition and land data assimilation.

Data assimilation systems are extremely valuable tools also for developers of observing systems, since the use if these systems in the so-called Observing System Simulation Experiments (OSSE) methodology allows us to simulate the impact on forecast skill of new, hypothetical observing...
systems before even making the decision whether to fund the development and deployment. JCSDA has built up a successful OSSE capability and has demonstrated its use via a series of impact experiments for NASA’s GWOS concept, a wind lidar demonstration mission developed in response to the NRC Decadal Survey. The OSSE facility is now used also to study various potential scenarios for DoD’s future operational polar meteorological satellite system.

Outside the main task of leading the Joint Center, the JCSDA Director continues to be active 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 also very active in WMO and is currently chairing the Open Program Area Group on Integrated Observing Systems under the WMO Commission for Basic Systems and is involved in the implementation of WIGOS, the WMO Integrated Observing Systems.
Appendix A: Papers published in 2011


Fishman J.; J Al-Saadi; P Bontempi; K Chance; F Chavez; M Chin; P Coble; C Davis; P DiGiacomo; D Edwards; J Goes; J Herman; C Hu; Laura T Iraci; D Jacob; C Jordan; S R Kawa; R Key; X Liu; S Lohrenz; A Mannino; V Natraj; D Neil; J Neu; M Newchurch; K Pickering; J Salisbury; H Sosik; M Tzortziou; J Wang; M Wang, 2012, Progress Report on NASA’s GEO-CAPE Mission: Fulfilling the Mandate and Meeting the Challenges of the


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.


