Soil Moisture and Runoff Forecasts
From the Climate Forecast System
Version 2

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Climate Forecast System (CFS)

- Climate Forecast System (CFS) is a global, coupled atmosphere-ocean-land-sea ice dynamical model used for operational intraseasonal-to-interannual prediction at NOAA/NCEP.
- The development cycle for CFSv2 included a new reanalysis (CFSR) of the 1979-2010 period to provide ICs for hindcasts. Information about CFSR is available at http://cfs.ncep.noaa.gov/cfsr.
## Climate Forecast System (CFS)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>CFS v1 (Operational Configuration)</th>
<th>CFS v2 (Q2FY11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis Resolution</td>
<td>200 km (T62)</td>
<td>38 km (T382)</td>
</tr>
<tr>
<td>Atmosphere model</td>
<td>1995: 200 km/28 levels</td>
<td>100 km(T126)/64 levels</td>
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<tr>
<td></td>
<td>Humidity based clouds</td>
<td>Variable CO2</td>
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<td></td>
<td></td>
<td>AER SW &amp; LW radiation</td>
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<td></td>
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<td>Prognostic clouds &amp; liquid water</td>
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<td></td>
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<td>Retuned mountain blocking</td>
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<td>Convective gravity wave drag</td>
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<tr>
<td>Ocean model</td>
<td>MOM-3: 60N-65S</td>
<td>MOM-4 fully global</td>
</tr>
<tr>
<td></td>
<td>1/3 x 1 deg.</td>
<td>1/4 x 1/2 deg.</td>
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<tr>
<td></td>
<td>Assim depth 750 m</td>
<td>Assim depth 4737 m</td>
</tr>
<tr>
<td>Land surface model (LSM) and assimilation</td>
<td>2-level LSM</td>
<td>4 level Noah model</td>
</tr>
<tr>
<td></td>
<td>No separate land data assim</td>
<td>GLDAS driven by obs precip</td>
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<tr>
<td>Sea ice</td>
<td>Climatology</td>
<td>Daily analysis and Prognostic sea ice</td>
</tr>
<tr>
<td>Coupling</td>
<td>Daily</td>
<td>30 minutes</td>
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<tr>
<td>Data assimilation</td>
<td>Retrieved soundings, 1995 analysis, uncoupled background</td>
<td>Radiances assimilated, 2008 GSI, coupled background</td>
</tr>
<tr>
<td>Reforecasts</td>
<td>15/month seasonal output</td>
<td>25/month (seasonal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>124/month (week 3-6)</td>
</tr>
</tbody>
</table>
Objectives

• To conduct an assessment of the soil moisture and runoff forecasts from CFSv2 using its retrospective forecasts from 1982 to 2009 to evaluate their usefulness for drought prediction.

• Climatological analysis: monthly mean runoff and soil moisture reforecasts from CFSv2 are evaluated against those from the North American Land Data Assimilation System (NLDAS).

• Forecast skill of soil moisture anomaly from direct CFSv2 forecasts and those obtained from a land surface model driven by daily P, T, and Wind forecasts from CFSv2 (hydroclimate forecast) are compared with forecasts based on persistence and the ensemble streamflow prediction (ESP) technique.
Hindcast Configuration for CFSv2 (T126L64)

- 9-month hindcasts initiated from every 5th day and run from all 4 cycles of that day, beginning from Jan. 1 of each year, over a 28-year period from 1982-2009.
- 8-member ensemble: 4 members with IC from the beginning of the month and 4 members with IC at the end of the previous month.
- For Feb, 8-member ensemble contains 4 members hindcasts with IC of Feb. 5 and 4 members hindcasts with IC of Jan. 31. The one-month lead reforecasts are verified against Feb. mean.
North American Land Data Assimilation System (NLDAS)

- Because long-term, in-situ measurements of soil moisture and runoff are not available, we use NLDAS as a proxy for observations.

- Forcing: CPC precipitation analysis and atmospheric forcing from NCEP *North American Regional Reanalysis* (NARR).

- Land surface models: *Noah*, SAC, VIC, and Mosaic (run uncoupled).

- Outputs: land & soil states, surface fluxes, runoff & streamflow etc.

- Anomalies are used for drought monitoring; support *National Integrated Drought Information System* (NIDIS).
Differences between CFSR and NLDAS
Winter (DJF), 1979-2008, Noah model
Runoff differences between CFSR and NLDAS (1979-2008, Noah Model)
Differences between CFSRR and NLDAS
Summer (JJA), 1982-2009, month-1 forecasts

**SM**
CFSRR-NLDAS_Noah

**R**
CFSRR-NLDAS_Noah

**SM**
CFSRR-NLDAS_ens

**R**
CFSRR-NLDAS_ens

Average 
CFSRR-NLDAS_Noah

R
CFSRR-NLDAS_Noah

(100*mm)

(mm/day)
Evaluation of Forecast Skill

- Compare seasonal soil moisture (SM) forecasts from 4 methods.
- Study area: contiguous United States (CONUS).
- Forecast methods:
  - Persistence based on NLDAS multi-model ensemble
  - Direct forecasts from CFSv2 (CFSRR)
  - Unconditional Ensemble Streamflow Prediction (ESP) technique
  - Hydroclimate forecasts (with and without P, T corrections)
- All SM forecasts are bias corrected and spatial downscaled (BCSD) to 0.5-degree grids covering the CONUS.
- Forecasts are verified against historical VIC simulations obtained from the Land Surface Hydrology Group at the University of Washington.
- Skill is measured by the RMSE of SM anomaly/STD.
Ensemble Streamflow Prediction (ESP)

- ESP uses historical weather traces (for the same calendar period of the forecast, but from past years) as meteorological inputs (forcing) to drive a land surface model.
- The forecasts are initialized using current hydrologic states, hence the results merge persistence in the anomalies of these states with climatological uncertainty about future weather.
- Originally developed to predict streamflow, but also can be applied to soil moisture forecasts.
- ESP has realistic ICs, but no information on forcing.
- ESP forecasts:
  - Model: the Variable Infiltration Capacity (VIC 4.0.6) macroscale hydrologic model developed by the University of Washington.
  - ICs: historical VIC simulation with NLDAS forcing.
  - Forcing: randomly resample from past NLDAS forcing for the forecast period.
Hydroclimate Forecast

- Use daily P, T, and wind forecasts from CFSv2 to drive a land surface model (8-member ensemble).
- Model: VIC 4.0.6
- ICs: historical VIC simulation driven by NLDAS forcing.
- Two sets of runs: one without P, T corrections; the other with P, T corrections.
- P, T corrections: daily forecasts of P and T are corrected, so the monthly mean of the corrected daily forecasts is the same as the BCSD corrected monthly mean.
The Effects of P, T Corrections
(RMSE for month-1 hydroclimate forecast)

With P, T corrections

Without P, T corrections

Feb

May

0.2 0.4 0.8 1 1.2 1.6
Forecast Skill (RMSE for month-1 forecasts)

Persistence

ESP

CFSRR

Hydroclimate

Feb

May

Aug

Nov
Forecast Skill (RMSE for month-2 forecasts)

Persistence  ESP  CFSRR  Hydroclimate

Feb

May

Aug

Nov
Forecast Skill (RMSE for month-3 forecasts)

Persistence

ESP

CFSRR

Hydroclimate

Feb

May

Aug

Nov
Comparison of Forecast Methods
(RMSE for Feb month-1 forecasts)

Persistence

CFSRR

ESP

Hydroclimate

0.2 0.4 0.8 1 1.2 1.6
Comparison of Forecast Methods
(RMSE for May month-1 forecasts)

Persistence

CFSRR

ESP

Hydroclimate

Legend:

0.2 0.4 0.8 1 1.2 1.6
Anomaly Correlation of P Hindcasts

- Averaged over the CONUS.
- Skill is seasonally dependent.
- Skill drops quickly after the first month.
- Skill is higher for winter and lower for summer.
- For the one-month lead, CFSv2 is more skillful than CFSv1, and the 8 youngest members has the best skill.
- After that, the 16-member ensemble performs better, and the skill for CFSv1 and CFSv2 is comparable.
Persistence vs. CFSRR (R for month-1 forecasts)

• $R = \frac{\text{RMSE(pers)}}{\text{RMSE(cfsrr)}}$
• $R < 1$ persistence has higher skill.
• $R > 1$ CFSRR has higher skill.
• RMSE indicated that for month-1, persistence has higher skill over the western interior region, in comparison to the SM forecasts from CFSv2.
Anomaly Correlation for Hydroclimate Forecasts

- Forecast skill is seasonally and regionally dependent.
- For one-month lead, forecasts are skillful.
- For Feb, forecasts over the western region are skillful out to 3 months.
- When P forecasts from CFSv2 is relatively skillful during winter, hydroclimate forecasts have good skill.
ESP vs. Hydroclimate (Rs for month-1 & month-3 forecasts)

- Count the number of years (N) that the ensemble mean difference is statistically significant at the 5% level.
- \( Rs = \frac{N}{28} \) (areas that Rs greater than 0.4 are shaded).
- For month-1 forecasts, the differences between the ESP and hydroclimate forecasts are not statistically significant.
- The only month that the differences are meaningful is May.
- Rs for lead 3 is larger because the impact of ICs decreases, but at that time forecast skill is too low, so it does not make a difference.
Summary and Conclusions

- Monthly mean runoff estimates from CFSv2 and CFSR are generally smaller than those from NLDAS.
- The partition between runoff, soil moisture, and evaporation in Noah model needs improvement.
- CFSR is used as ICs for CFSv2 forecasts and ICs play an important role in SM forecasts. Improving CFSR would improve forecasts.
- Forecast skill of SM anomalies is seasonally and regionally dependent.
- In winter, SM forecasts over the western region are skillful out to 3 months for all methods.
- For all lead months, forecast skill from CFSRR is lower than that based on persistence, suggesting that direct SM forecasts from CFSv2 may have limited use for drought prediction.
Summary and Conclusions

• For hydroclimate forecasts, the differences between the forecasts with and without P, T corrections are small. P, T corrections only improve the forecasts slightly.

• The skill of hydroclimate forecasts depends on the skill of CFSv2 forecasts.

• In winter season when P forecast skill from CFSv2 is high, hydroclimate forecasts outperform the other three forecast methods and can be used as a tool for drought prediction.
Thank you and Questions

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