Assimilation of Satellite Snow Products into NCEP Operational CFS/GFS System

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STAR JPSS Science Team Meeting
August 17, 2017, NCWCP, College Park MD
Outline

1. NCEP Land Data Assimilation Systems
2. NASA Land Information System Applications
3. Land Data Assimilation Experiments
4. Summary
Noah Land Model Connections in NOAA’s NWS Model Production Suite

Global Data Assimilation

Regional Data Assimilation

Global Forecast System

Climate
CFS
MOM3

Hurricane
GFDL
HWRF

Regional NAM
WRF NMM
(including NARR)

Short-Range
Ensemble Forecast
WRF: ARW, NMM, ETA, RSM

Uncoupled “NLDAS”
(drought)

Oceans
HYCOM
WaveWatch III

Dispersion
ARL/HYSPLIT

Severe Weather
WRF NMM/ARW Workstation WRF

Air Quality
NAM/CMAQ

Rapid Update for Aviation (ARW-based)

North American Ensemble Forecast System
GFS, Canadian Global Model

NOAH Land Surface Model

3.5B Obs/Day
Satellites 99.9%
radar?

NCEP,
NCAR,
UT-Austin,
U. Ariz.,
& others
Unified NCEP-NCAR Noah Land Model

- Four soil layers (shallower near-surface).
- Numerically efficient surface energy budget.
- Jarvis-Stewart “big-leaf” canopy conductance with associated veg parameters.
- Canopy interception.
- Direct soil evaporation.
- Soil hydraulics and soil parameters.
- Vegetation-reduced soil thermal conductivity.
- Patchy/fractional snow cover effect on sfc fluxes.
- Snowpack density and snow water equivalent.
- Freeze/thaw soil physics.

Noah coupled with NCEP model systems: short-range NAM, medium-range GFS, seasonal CFS, HWRF, uncoupled NLDAS, GLDAS.
Noah Multi-Physics (Noah-MP)

Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- Canopy radiative transfer with shading geometry.
- Separate vegetation canopy layer.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.

Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)

Noah-MP references: Niu et al., 2011, Yang et al., 2011. JGR
Global Land Data Assimilation System (GLDAS)

- Snow cycled if snow from Noah land model within a 0.5x/2.0x envelope of observed value (IMS snow cover, AFWA depth).
- GDIS: GLDAS soil moisture climatology from 30-year runs provides anomalies for drought monitoring.
- GLDAS land “re-runs”, with updated forcing, physics, etc.
Satellite-based Land Data Assimilation in NWS GFS/CFS Operational Systems

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for both GFS and CFS.
- LIS EnKF-based Land Data Assimilation tool used to assimilate soil moisture from the NESDIS global Soil Moisture Operational Product System (SMOPS), snow cover area (SCA) from operational NESDIS Interactive Multisensor Snow and Ice Mapping System (IMS) and AFWA snow depth (SNODEP) products.

NGGPS Project: Land Data Assimilation

Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)
Christa Peters-Lidard, Sujay Kumar (NASA/GSFC)

1. Build NCEP’s GFS/CFS-LDAS by incorporating the NASA Land Information System (LIS) into NCEP’s GFS/CFS (left figure)
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS/CFS.
3. Coupled land data assimilation tests and evaluation against the operational system.
LIS is a flexible land-surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observed data products with land-surface models. 

Data Assimilation of: Soil Moisture, SWE, SCF, TWS
NCEP/EMC Land Team and DA Partners

NCEP/EMC Land Team: Michael Ek, Jiarui Dong, Weizhong Zheng, Helin Wei, Jesse Meng, Youlong Xia, Rongqian Yang, Yihua Wu, Anil Kumar, Roshan Shresth, working with:

Land Data Assimilation Algorithm:
• NASA/GSFC: Christa Peters-Lidard, Sujay Kumar et al. (LIS)
• NASA/GMAO: Rolf Rechelie et al. (EnKF)
• University of Maryland: Ning Zeng, Steve Penny (LETKF)
• NESDIS/STAR: Xiwu Zhan et al. (EnKF)
• Monash University, Australia: Jeffrey Walker (EKF)

Remotely-sensed Land Data Sets:
• NESDIS/STAR land group: Ivan Csiszar, Xiwu Zhan (soil moisture), Bob Yu (Tskin), Marco Vargas (vegetation) et al.
• NESDIS/OSPO: Sean Helfrich (IMS snow cover)
• 557th Weather Wing: Jeffrey Cetola (snow depth)
• NASA/GSFC: Dorothy Hall (MODIS snow cover), James Foster (SWE)

Verification:
• GEWEX/GLASS, GASS projects: Land model benchmarking, land-atmosphere interaction exp. with international partners.
Snow Products Received at NCEP

The **Air Force 557th Weather Wing (557WW)** snow depth is estimated daily by merging satellite-derived snow cover data with daily snow depth reports from ground stations.

Snow depth reports are updated by additional snowfall data or decreased by calculated snowmelt.

The **Interactive Multisensor Snow and Ice Mapping System (IMS)** snow cover product is a snow cover analysis at 4-km resolution manually created by looking at all available satellite imagery, several automated snow mapping algorithms, and other ancillary data.

Regions covered by cloud during the 24-hour analysis period take lower resolution passive microwave data and surface observations into account where possible. There are no missing values over the mapped region.
1. Forcing:

- **Spinup run**: three times over GFS forcing from 01/01/2009 to 12/31/2011

- **Control Run**: Starting at 00Z 01/01/2012 with initial condition from spinup run

- **Direct Replacement**: Starting at 01/01/2014 with the initial condition from the Control Run.

- **EnKF**: With 20 ensemble members starting at 01/01/2014 with the initial condition from the Control Run.

2. Initial conditions:

   - **Spinup run** three times over GFS forcing from 01/01/2009 to 12/31/2011

   - **Control Run**: Starting at 00Z 01/01/2012 with initial condition from spinup run

   - **Direct Replacement**: Starting at 01/01/2014 with the initial condition from the Control Run.

   - **EnKF**: With 20 ensemble members starting at 01/01/2014 with the initial condition from the Control Run.

3. Model configuration:

   Model is configured at T1534 (3072 by 1536) globally
**Verification Data and Method**

*POD*$_{S}$ measures the fraction of observed snow cover presence that were correctly detected in AFWA/IMS/GFS

*POD*$_{N}$ measures the fraction of observed snow-free land that were correctly detected in AFWA/IMS/GFS

*FAR* measures the fraction of observed snow-free land that were incorrectly detected as snow cover in AFWA/IMS/GFS

\[
POD_{S} = \frac{SS}{NS + SS}
\]

\[
POD_{N} = \frac{NN}{NN + NS}
\]

\[
FAR = \frac{SN}{SN + NN}
\]

*POD*: Probability of Detection

*FAR*: False Alarm Ratio

10,179 stations with at least one-year data records from year 2012 are selected.
Statistics of Snow Cover Mapping

POD and FAR statistics of IMS SCA, AFWA snow depth and GFS snow depth

\[ POD_s = \frac{SS}{NS + SS} \]
\[ FAR = \frac{SN}{SN + NN} \]

GFS/GDAS Product: Higher POD (98%) everywhere, but larger FAR (14%) in Canada, Mountains in the US and Europe.

Satellite Products: Lower POD in the southern U. S. and larger FAR in mountains of the US and in Norway.
$POD_{afwa} - POD_{ims}$

IMS snow cover product shows higher accuracy in snow cover detection than AFWA/SNODEP, especially over CONUS. Assimilation of IMS snow cover will be helpful in the regions with fast snow phase changes.
GFS demonstrates a strong ability to simulate the presence of snow cover (98%) comparing to IMS (94%) and AFWA SNODEP (87%).

However, GFS shows larger false snow cover detection (>40%) in winter months than IMS and AFWA (<30%).

LIS/Noah Cycle with GFS forcing shows even higher POD in snow detection (99%), but false alarm ratio is as higher as 80% during winter months.

\[
POD_S = \frac{SS}{NS + SS} \\
POD_N = \frac{NN}{NN + NS}
\]
### Snow Cover Mapping

<table>
<thead>
<tr>
<th></th>
<th>POD$_S$</th>
<th>FAR</th>
<th>Accuracy POD$_{S+N}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMS</td>
<td>93.85</td>
<td>8.29</td>
<td>91.91</td>
</tr>
<tr>
<td>AFWA</td>
<td>87.46</td>
<td>8.80</td>
<td>90.85</td>
</tr>
<tr>
<td>GFS/GDAS</td>
<td>98.35</td>
<td>14.47</td>
<td>86.69</td>
</tr>
<tr>
<td>Noah.3.3</td>
<td>99.50</td>
<td>32.10</td>
<td>71.01</td>
</tr>
<tr>
<td>Noah-MP3.6</td>
<td>93.71</td>
<td>9.03</td>
<td>91.24</td>
</tr>
</tbody>
</table>

\[
POD_S = \frac{SS}{NS + SS} \quad FAR = \frac{SN}{SN + NN} \quad POD_{S+N} = \frac{SS + NN}{NS + SS + SN + NN}
\]

Noah.3.3 cycled with GFS forcing shows higher POD of snow (99.5%), but with large FAR (32%).
The general accuracy of POD of snow and land (POD$_{S+N}$) is higher from IMS, AFWA and Noah-MP cycle.
Demonstration of LIS land data assimilation of AFWA Snow Depth

EnKF

- 01/01/2014 00Z
- 04/01/2014 00Z
- 07/01/2014 00Z
- 10/01/2014 00Z

Direct Insertion

Model Cycling

GFS/GDAS

Legend:
- Land
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.8
- 0.9
- 1.0
- 1.1
- 1.2
- 1.3
- m
Temporally, **AFWA/SNODEP** shows positive bias, and **GFS/GDAS** shows negative bias. **DI** (ingest AFWA/SNODEP into Noah) shows improved estimates in snowdepth with less bias and RMS errors. **EnKF** DA results are much better than all the other products with bias and RMS significantly reduced.
AFWA SNODEP and DI

Statistics over January 2014 to December 2016

AFWA SNODEP is better in Canada and Europe, and DI Assimilation shows improvements in these regions.
AFWA SNODEP is worse over CONUS, while DI Assimilation of AFWA SNODEP shows improvements over CONUS.
High quality satellite data will be required to improve surface snow depth estimates.
LIS EnKF DA results are better than all the other products including model cycling, AFWA/SNODEP, GFS/GDAS, and DI. Again, high quality satellite data result in big improvement in snow depth estimates.
Summary

- For NWP and seasonal forecasting, assimilation of AFWA SNODEP snowdepth demonstrated the improved estimates of surface states.

- Noah-MP is improved with explicit canopy, CO$_2$-based photosynthesis, dynamic vegetation, groundwater, multi-layer snowpack, and refined soil processes. Noah-MP is good at mapping snow.

- Large errors of snow depth modeling result from forcing including cold bias and overestimates of snowfall. EnKF is working relatively well with considering the errors from forcing fields.
THANK YOU!