Land Surface Model and Data Assimilation in NCEP FV3GFS

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Outline

• Role of Land Surface Model and Requirements
• Land Surface Physics – Noah Land Surface Model
• Land Data Sets
• Land Initialization
• Land Data Assimilation System
• Model Testing and Verification
• Current Development
• Summary
Role of Land Surface Model and Requirements

- Land Surface Models (LSMs) provide surface flux boundary conditions for **heat**, **moisture**, and **momentum** to the atmosphere for NCEP weather and seasonal prediction systems.
- Land models close surface energy and water budgets.
- **Land Model Requirements:**
  - **Physics:** appropriate to represent land surface processes (for relevant time/spatial scales) and associated LSM parameters.
  - **Atmospheric forcing:** drive LSM.
  - **Land data sets:** land use/land cover (vegetation type), soil type, surface albedo, surface roughness, etc.
  - **Land initial states:** compared to atmosphere, land states carry more memory (especially deep soil moisture), similar to the role of SSTs and ocean temperatures.
  - **Land Data Assimilation:** some of the state quantities may be assimilated, e.g. snow depth and cover, soil moisture.
  - **Land Data Assimilation System (LDAS):** provide optimal land initial states for NCEP prediction systems.
“Famous” figure from Koster et al. (2004, *Science*) which has become widely used to justify the role of land surface in weather and climate.

Land-Atmosphere coupling “hot spots” emerged in transition zones between arid and humid climate regions.

Land Surface Model is critical in weather and climate prediction.
Land Surface Energy and Water Budgets

Energy

INCOMING SOLAR RADIATION
absorbed by clouds
 reflected by clouds
 reflected by surface
back-scatter by air
absorbed by atmosphere

REFLECTED SOLAR RADIATION
sensible heat flux
latent heat flux
soil heat flux

OUTGOING LONGWAVE RADIATION
longwave emission by atmosphere
longwave absorption by clouds

R_n = H + LE + G + SPC

Water

precipitation
infiltration
percolation

evaporation
runoff
groundwater flow
to water bodies

ΔS = P − R − E

evapotranspiration
unsaturated zone
saturated zone
groundwater

water table

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Role of Land Surface Model in FV3GFS

Energy

- Incoming solar radiation
- Reflected solar radiation
- Outgoing longwave radiation
- Longwave absorption by atmosphere
- Longwave emission by clouds

Water

- Precipitation
- Evapotranspiration
- Infiltration
- Evaporation

Land Surface Model driven by the Atmospheric Model forcing

- Surface downward shortwave radiation
- Surface downward longwave radiation
- Precipitation (rain and snow)
- Surface pressure, air temperature, humidity, wind speed
Land Surface Model provides the Atmospheric Model

- Surface upward (reflected) shortwave radiation (surface albedo, including snow effects)
- Surface latent heat flux and Evapotranspiration
- Surface sensible heat flux
- Surface upward longwave radiation (skin temperature and surface emissivity)
- Surface momentum flux
**Land Surface Model Physics**

**Unified NCEP-NCAR Noah LSM**

- **Surface energy and water budget equations**

- **2-meters 4 soil layers soil** (10, 30, 60, 100 cm thick)

- **Land data sets:**
  - soil type
  - vegetation type
  - green vegetation fraction
  - snow-free albedo
  - maximum snow albedo

- **Land states:**
  - skin temperature, soil temperature*, soil moisture*, soil liquid moisture*, snow water equivalent*, snow depth*, canopy water*
  - *prognostic

- **Land fluxes:** \( SW, LW, LH, SH, G, ET, R \)
Land Surface Model Physics

Unified NCEP-NCAR Noah LSM

- Surface momentum roughness dependent on vegetation/land-use type.
- Surface thermal roughness dependent on green vegetation fraction.
- Stomatal control dependent on vegetation type, direct effect on transpiration.
- Depth of snow (snow water equivalent) for deep snow and assumption of maximum snow albedo is a function of vegetation type.
- Heat transfer through vegetation and the soil as function of green vegetation fraction (coverage) and leaf area index (density).
- Soil thermal and hydraulic processes dependent on soil type.
Land Data Sets used in FV3GFS

- **Green Vegetation Fraction (GVF)**
  - Monthly, 1/8-deg, NESDIS/AVHRR
  - Climatology: fixed/annual, monthly, weekly.
  - Near real-time observations, e.g. GVF becoming a land state (DA).

- **Soil Type**
  - 1-km, STATSGO-FAO

- **Max.-Snow Albedo**
  - 1-km, UAZ-MODIS
  - January and July maps provided.
Valid land states initial conditions are necessary for NWP and climate models, and must be consistent with the land surface model used in a given NWP or climate model, i.e. from same LSM cycling/spin-up with same land data sets.

Land Initial States for FV3GFS/Noah

- soil total moisture (4)
- soil liquid moisture (4)
- soil temperature (4)
- surface skin temperature
- snow water equivalent
- snow depth
- canopy water

Land IC given in the FV3GFS sfc restart file.
Soil moisture is highly dependent on soil and vegetation types. Since soil and vegetation types are updated in FV3GFS, soil moisture climatology is also updated for consistency.
Monthly 4-layer soil moisture climatology of FV3GFS is generated from a 30-year offline spin-up run of Noah LSM with updated soil and vegetation types.
Soil Parameters Refinement

Reduce **bare soil** resistance of **top soil layer** (0-10cm) to allow more evaporation from the **top layer**, potentially dryer and cooler top layer in the dry season, less impact on deep soil.

Soil Moisture differences

Soil Temperature differences

FV3 minus GFS

May 2018
NCEP Global Land Data Assimilation System (GLDAS)  
Operational since 01 April 2011

• Noah LSM runs in semi-coupled mode with Climate Data Assimilation System version (CDASv2); daily update provides initial land states to operational Climate Forecast System version 2 (CFSv2).

• Forcing: CDASv2 atmospheric output, & “blended” precipitation, snow.

• Blended Precipitation: CPC satellite (heaviest weight in tropics); CPC gauge (heaviest mid-latitudes); model CDASv2 (high latitude).

• Snow: IMS cover & AFWA depth, cycled if within 0.5-2.0x “envelope”.

• 30+ year global land surface climatology.

• Research/partners supported by the NOAA Climate Program Office, Modeling, Analysis, Predictions, and Projections (MAPP) program.
Model Testing and Verification

FV3 vs GFS
20180301-20180602

T SFC, Northern Great Plains, 00Z cycle, 20180301-00180602 Mean

Difference w.r.t. obs

CONUS Precip Skill Scores, 024-448, 01mar2016-02feb2016 12Z Cycle

NCEP/EMC FV3GFS Training
June 12-14, 2018

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Low-level biases in winds, temperature, and humidity are influenced in part by the land surface via biases in surface fluxes exchanged with the atmospheric model (radiation, precipitation, etc).

Improving the proper partition of surface energy budget between sensible, latent, soil heat fluxes and outgoing longwave radiation in FV3GFS/Noah requires:

• Improve atmospheric forcing for the land model, especially precipitation and downward radiation; enhanced downscaling techniques.
• Data assimilation of near-realtime snow, soil moisture, GVF.
• Improve snow physics (multi-layers, melt/freeze, densification).
• Improve vegetation parameters to calculate transpiration.
• Near-realtime vegetation greenness to improve Bowen ratio.
• Improve specification and representation of surface heterogeneity.
Summary

• **Noah Land Surface Model** and **land data sets** are updated and coupled to **FV3GFS** to enhance the representation of land processes and land-atmosphere coupling, toward improving NCEP operational predictions.

• Further developments for **NCEP Land Surface Model** and **Land Data Assimilation Systems** in fully-coupled Earth System Model and Data Assimilation (atmosphere-ocean-land-ice-waves-aerosols) with connections between **Weather and Climate**, **Hydrology**, **Ecosystems and Biogeochemical cycles** (carbon), and **Air Quality**, models and communities, e.g., community model development of **FV3GFS**.
Land Data Assimilation development

• Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for testing both GLDAS, NLDAS.
• LIS EnKF-based Land Data Assimilation tool used to assimilate:
  • **Snow depth** (SNODEP) from AFWA and **Snow cover area** (SCA) from operational NESDIS Interactive Multi-sensor Snow and Ice Mapping System (IMS).
  • **Soil moisture** from the NESDIS global Soil Moisture Operational Product System (SMOPS).

1. Build NCEP’s FV3GFS/LDAS by incorporating the NASA Land Information System (LIS) into NCEP’s FV3GFS.
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS.
3. Coupled land data assimilation tests and evaluation against the operational system.

**Land Data Assimilation Development**

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- CMAP precip
- SMOPS Soil Moisture
- IMS snow cover
- AFWA SNODEP
FV3GFS/GLDAS Initial States Testing and Verification 20181207-20171231

[Map showing surface accum. snow in kg/m²]

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FV3GFS/GLDAS Initial States Testing and Verification

20181207-20171231

T SFC, Northwest Coast, 00Z Cycle, 20171207-20171231 Mean

T SFC, Northern Mountain Region, 00Z Cycle, 20171207-20171231 Mean

Difference w.r.t. obs

Differences outside of outline bars are significant at the 90% confidence level.
Model Physics Improvement: 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.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover algorithm.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.

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Noah-MP references: Niu et al., 2011, Yang et al., 2011. JGR

Noah-MP development via CPO/MAPP
Model Improvement: Freshwater Lakes

- **Thousands** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake “**FLake**” model *(Dmitrii Mironov, DWD)*.
  - Two-layer.
  - Atmospheric forcing inputs.
  - Temperature & energy budget.
  - Mixed-layer and thermocline.
  - Snow-ice module
  - Specified depth/turbidity.
  - Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.
Model Improvement: River Routing

Atmospheric Forcing

Ensemble mean daily streamflow anomaly (NLDAS)

- Hurricane Irene and Tropical Storm Lee, 20 August – 17 September 2011
- Superstorm Sandy, 29 October – 04 November 2012
- Colorado Front Range Flooding, September 2013

Collaboration with National Water Center

Groundwater

Surface flow

Saturated subsurface flow