Land Surface Processes

Global Systems Division (GSD)
Tanya Smirnova (+John Brown, Stan Benjamin)

ESRL Theme Team Presentation, 10 May 2007
Atmospheric models coupled to Land-Surface Models (LSM)

NOAA weather prediction models:

- **GFS**  »  Noah LSM (GFS version)
- **NAM**  »  Noah LSM (NAM version)
- **RUC**  »  RUC LSM
- **WRF**  »  “simple” LSM
  - Noah LSM
  - RUC LSM

Other Land Surface Models:
- SSiB, VIC, CLM, CROCUS, ISBA ….
Linkage between Atmospheric Models (RUC model as example) and LSM

RUC or Rapid Refresh (RR) - hourly assimilation/forecast cycle

RUC/RR hourly forcing for LSM - precipitation, surface fields, snow....

Feedback to atmosphere through surface fluxes - improved PBL structure

LSM - evolution of soil temperature, moisture, snow depth, snow temperature
Blame game -
Complicated interaction of physical parameterizations and initial conditions in model
Land Surface Model validation

• Project for the Intercomparison of Land-Surface Paramaterization Schemes (PILPS), coordinated by Global Land Atmosphere System Study (GLASS)

- 21 models participated (including RUC LSM, Noah)

- 27 models participated (including RUC LSM, Noah)

Goal – controlled comparisons of LSM and snow models of different complexity
SnowMIP, an intercomparison of snow models: first results - P. Etchevers, E. Martin, R. Brown et al.
ISSW meeting, August 2002

Figure 1: RMS of the simulated SWE for each model on the different sites (PF indicates that the model has run with a prescribed soil flux, ES that the exchanges between the soil and the snowpack have been explicitly simulated).

SWE - snow water equivalent
Schematic presentation of processes included into RUC-LSM

- more accurate lower boundary for weather prediction in RUC (aviation/severe weather)

- 10-year long record of surface grids provided to GCIP/GAPP community for climate studies

*Cycling* of soil moisture, soil temperature, snow cover, depth, and temperature in RUC 1h cycle since 1997
Impact of *Frozen* Soil Physics in RUC LSM

**1975 - 1976**

**Precipitation forcing**
- OBS
- No frozen soil
- w/ frozen soil

**Snow water equivalent**
- OBS
- No frozen soil
- w/ frozen soil

**Total runoff**

**Soil moisture content**
Snow model in RUC-LSM

1. One- or two-layer snow model (threshold – 7.5 cm)
2. Changing snow density depending on snow depth temperature, compaction parameter
3. Snow can be melted from the top and bottom of snow pack
4. Prescribed amount of liquid water (13%) from melting can stay inside the snow pack
5. Melted water infiltrates into soil and forms surface runoff

Falling snow can be intercepted by the vegetation canopy until the holding capacity is exceeded.
Cycled field of snow depth from operational RUC20 at NCEP

- Cycled snow matches NESDIS
- Rapid surface changes from snow melting/accumulation

Valid at 2100 UTC 8 January 2003
Large variation of soil moisture / snow cover within short time scale (~6h) is commonplace.

Soil moisture content in the top 2.5 cm

Snow water depth

Precipitation forcing

72-h forecast loop from 13-km development RUC

http://ruc.noaa.gov

1200 UTC 4 May - 1200 UTC 7 May 2007
Goals:
Hourly NWP update including
- Alaska
- Canada

Rapid Refresh
- replace RUC – 2009
- 13km resolution
- use WRF model
  (RUC LSM - possible physics option)
Challenges and future plans for ESRL in Rapid Refresh

- LSM validation/development for polar application in Canada and Alaska including extended permafrost tundra zones
- Improvements in hydrometeor initialization for better 1-h precipitation forecast to minimize possible model drift in soil moisture field
- Assimilation of satellite/in-situ data for snow depth, soil moisture, skin temperature
- Use of real time greenness fraction rather than climatology
- More accurate specification of surface characteristics, inclusion of sub-grid scale variability (e.g., tiling)
Challenges and future plans for ESRL in Rapid Refresh, other model applications

• LSM validation/development for polar application in Canada and Alaska including extended permafrost tundra zones
• Improvements in hydrometeor initialization for better 1-h precipitation forecast to minimize possible model drift in soil moisture field
• Assimilation of satellite/in-situ data for snow depth, soil moisture, skin temperature
• Inclusion of sub-grid scale variability of surface characteristics (e.g., tiling)
• Increase in LSM sophistication in transition to higher resolutions, especially for application in climate models, air quality models....
72-h forecast loop from 13-km development RUC

2-m relative humidity

2-m temperature

http://ruc.noaa.gov

1200 UTC 4 May - 1200 UTC 7 May 2007
Aspects of RUC LSM that differ from Noah LSM:

- **Surface layer**
  - layer approach to energy and moisture budget
  - implicit solution of energy and moisture budgets
  - bare soil evaporation
  - transpiration (simpler, less sensitivity to parameters)

- **Soil model**
  - soil moisture variable - $(\theta - \theta_r)$
  - 2nd order numerical approximation
    for hydraulic conductivity
  - larger number of levels, thinner top layers

- **2-layer Snow model versus bulk snow layer**
  - treatment of mixed phase precipitation

- **Frozen soil physics algorithm**
Simulations of a Boreal Grassland Hydrology at Valdai, Russia: PILPS Phase 2(d)

C. Adam Schlosser, Andrew G. Slater, Alan Robock, Andrew J. Pitman, Konstantin Ya. Vinnikov, Ann Henderson-Sellers, Nina A. Speranskaya, Ken Mitchell, and The PILPS 2(d) Contributors

Seasonal Cycles (1966–1983)

- **a) Root-Zone Total Soil Moisture**
- **b) Total Runoff**
- **c) Evapotranspiration**
- **e) Water Equivalent Snow Depth**

End of Snow Melt

Frozen Soil Physics in RUC LSM

\[ C_a \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \nu_f \frac{\partial T}{\partial z}, \]  

(8)

where \( C_a \) is called the apparent heat capacity and is equal to

\[ C_a = C + \rho_l L_f \frac{\partial \eta_i}{\partial T}. \]  

(9)

The slope of the soil-freezing characteristic curve \( \partial \eta_i/\partial T \) with zero solute concentration in the soil solution can be obtained from [Cary and Mayland, 1972; Flerchinger and Saxton, 1989]

\[ \eta_i = \eta_s \left[ \frac{L_f (T - 273.15)}{g T \Psi_s} \right]^{-1/b}, \]  

(10)

where \( \eta_s \) is the volumetric moisture content at saturation, \( \Psi_s \) is the moisture potential for saturated soil.

The heat capacity of the soil is calculated according to the weighted contribution of the dry soil, liquid water, and ice:

\[ C = (1 - \eta_s)C_s + \eta_l C_l + \eta_i C_i. \]  

(11)
Motivation – correct excessively cold temperatures at night (with clear skies, low winds) over thin snow layer; improve estimation of the snow melting rate.

Modifications to the snow model –

- changed vertical structure of the snow model
- snow albedo reduction for thin snow layer
Surface temperature comparison between operational RUC and experimental RUC (with changed vertical structure of snow model)

Valid 1200 UTC 5 March 2002

Control (21-h fcst)
Experimental (21-h fcst)

Experimental - Control
~1 inch of snow

Contr.       - 19 C
Exper.       - 10 C
Obs.         - 11 C
(12 F)
RUC performance for surface:

- **Precipitation**
  Spatial patterns and magnitude of 0-1h RUC precipitation agrees relatively well with observed – prerequisite for realistic soil moisture field in RUC cycle – more improvement needed

- **Snow**
  Cycled snow-water equivalent depth is in good agreement with NESDIS (sat obs) areas of snow cover
  RUC cycled snow-water depth appears very reasonable

- **Soil**
  Soil temperature/moisture variation in RUC w/ ongoing cycle in good general agreement with in situ soil observations
  - dependent on likeness of soil type between site and model, and 1-h model precipitation
Snow water depth
30 January 2003
RUC to Rapid Refresh

- CONUS domain (13km) → North American domain (13km)
- RUC model → WRF model (ARW very likely)
- RUC 3DVAR → GSI (Gridpoint Statistical Interpolation)
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Skin temperature difference between 24-h forecasts from RUC control and RUC experimental (improved snow model and reduced albedo over shallow snow).

Valid 2100 UTC 4 April 2002

Control Experimental

Contr.  -12 C
Exper.  - 4 C
Obs.  - 3.8 C
(25 F)

Observations:

Obs.  5 C (41 F)
Contr.  9 C
Exper.  6 C
Soil types in 13-km RUC (16 classes)

Files obtained from WRF Standard Initialization (WRF SI)

Vegetation types in 13-km RUC (24 USGS classes)

Topography in 13-km
Improvement of frozen soil physics algorithm

- needed when both soil moisture and soil temperature increase – *typical situation* for the snow melting season.
  - Tested in 1-D for Valdai, Russia

![Graph showing daily averaged skin temperature (C), April-May 1980](image)

- Tested in Experimental RUC at FSL
RUC CDAS is a four-dimensional system which:

- Uses a forward full-physics model
- Cycles surface/soil fields depending on the RUC atmospheric forcing
- Cycles 5 hydrometeor species: cloud, ice, rain, snow, and graupel. Cloud clearing/building based on GOES data

new compared to RUC Control:

- Adjusts cycled cloud and precipitation fields using NEXRAD radar reflectivity observations (Kim and Benjamin 2002, 15th NWP)

Main Goal:
- to improve 1-h precipitation forcing and the land surface model climate
2-m temperature valid at 2100 UTC 24 June 2005
RUC CDAS hypothesis -

• Mesoscale model forecast of precipitation and precipitation type may be better than analyses from observations in some situations:
  - orographic precipitation, especially in cold season
  - data void area

• Assimilation of radar reflectivity allows use of beam-blockage information
Maximum reflectivity (dBZ) from RUC hydrometeor fields

First guess

Adjusted

3-h Accumulated precipitation

RUC Control

RUC CDAS

1500 UTC
3 May 2002
24-hour precipitation accumulation ending at 1200 UTC 6 May 2003
Spatial Correlation fields of 24-h Accumulated Precipitation ending at 1200 UTC 6 May 2003

(Dongsoo Kim)
Diurnal cycle of biases from RUC control and RUC CDAS averaged for the period 1 December – 1 March 2003

2-m dew point

2-m temperature
RUC CDAS runs at FSL as a continuous cycle since 1800 UTC 17 April 2002

Snow cover with surface observations overlaid

First-order stations
- non-zero snow depth
- no snow reported

Cooperative stations
- non-zero snow depth
- no snow reported

Non-zero snow reported by surface stations

Valid 1800 UTC
22 April 2002