Improvements in RUC Snow Model for Implementation in Rapid Refresh FV3 Standalone (RRFS) operational model

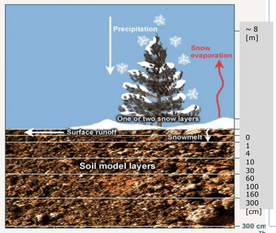
Tatiana G. Smirnova [1,2], Anton Kliewer[1,3], Siwei He[1,2],Stan G. Benjamin[1,2]

[1] NOAA Global Systems Laboratory, Boulder, CO; [2] CIRES, University of Colorado at Boulder, CO; [3] CIRA, Colorado State University, CO

RRFS - UFS-based regional weather prediction model

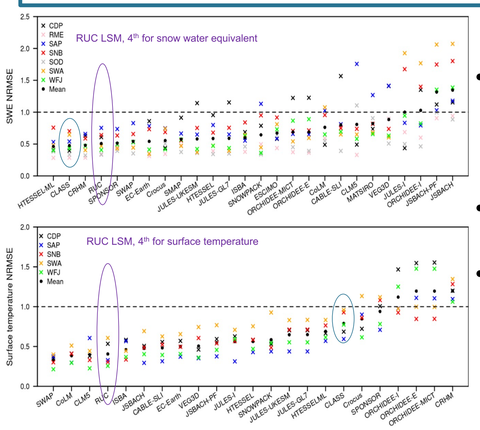
- *Hourly cycles* on 3-km CONUS and North America domains;
- Gridpoint Statistical Interpolation *(GSI)* analysis system;
- Finite-Volume Cubed-Sphere *(FV3)* dynamical core;
- Common Community Physics package – *FV3_HRRR suite*;
  - version 1 of RRFS uses *RUC LSM*
- Soil/snow states are initialized hourly from the previous cycle with updating soil/snow temperature and soil moisture using *Moderately Coupled Land Data Assimilation System* (MCLDA) in GSI;
- Snow cover on the ground is updated daily from 4-km Multisensor Snow and Ice Mapping System *(IMS)*

RUC LSM snow model



- *2-layer* snow model;
  - when SWE < 16 kg/m^2 – snow layer is combined with top soil layer;
- *"mosaic" approach for fractional snow cover* (SWE < 32 kg/m^2):
- *iterative* snow melting algorithm;
- *Snow albedo* – a function of temperature and snow fraction;
- *Snow interception by canopy* – a function of vegetation fraction and Leaf Area Index (LAI);
- *Density of snow on the ground* evolves as a function of compaction parameter, snow depth, snow temperature;
- *Density* of frozen phase precipitation is an empirical function of surface temperature.

Off-line testing of RUC snow model in ESM-SnowMIP



- Multi-year simulations for 10 sites in different climatological zones of the world;
- Observed atmospheric forcing;
- RUC LSM received a high ranking on the 4th place among 26 participating models for both snow water equivalent and surface temperature variables.

Figure 1: Model ranking as a function of normalised root mean square error of snow water equivalent and surface temperature.

Menard et al. 2020, "Scientific and Human Errors in a Snow Model Intercomparison", BAMS. https://doi.org/10.1175/BAMS-D-19-0329.1

Modifications to RUC snow model in RRFS

➢ Snow cover fraction (SCF)

- *Control (isncovr_opt = 1) -* threshold approach
- *Test (isncovr_opt = 3)* - based on Niu,G.-Y.,and Yang,Z.-L., 2007, JGR with modifications

$$SCF = \tanh\left(h_{sn}/(facsnf(i) * (\rho_{sn}/\rho_{new})^{**} m(i)\right),$$

where *facsnf(i)* and *m(i)* are *scale−aware parameters* dependent on vegetation type *i*

h_{sn} - snow depth on the ground

ρ_{sn} - density of snow on the ground

ρ_{new} - density of new snowfall

➢ Snow thermal conductivity

- *Control (isncond_opt=1)* – constant value

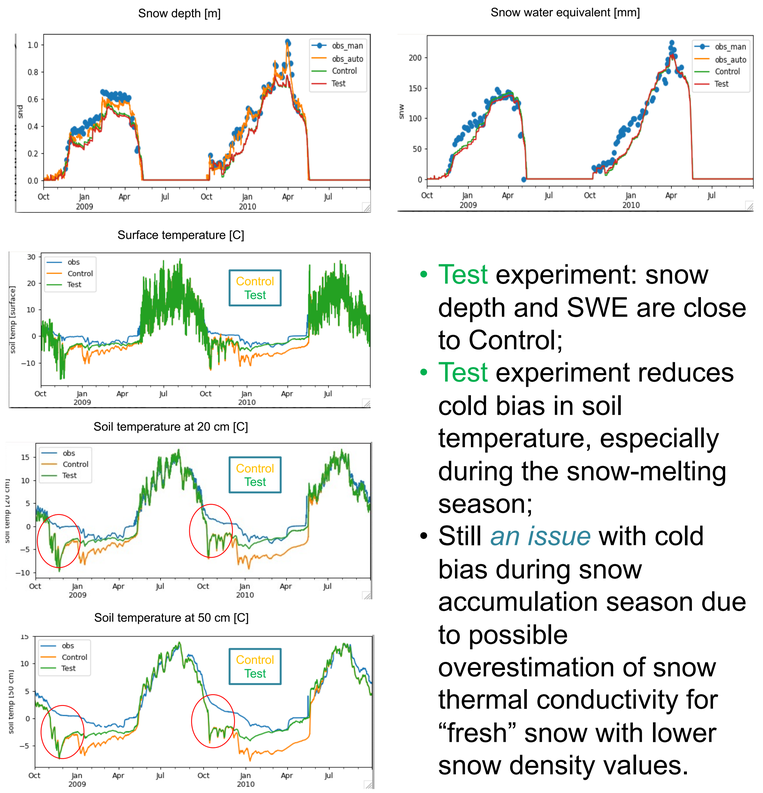
$$k_{eff} = 0.265\ W\ m^{-1}K^{-1},$$

- *Test (isncond_opt=2)* - empirical formulation of seasonal snow (Sturm et al., 1997)

$$k_{eff} = 0.138 - 1.01\rho_{sn} + 3.233\rho_{sn}^2, \quad (0.156 < \rho_{sn} < 0.6\ g/cm^3)$$

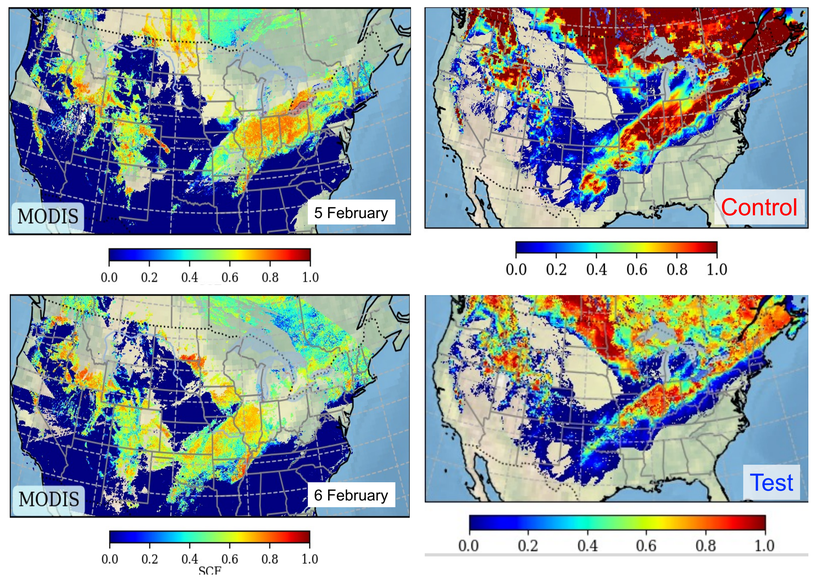
$$k_{eff} = 0.023 + 0.234\rho_{sn}\ , \ (\rho_{sn} < 0.156\ g/cm^3)$$

Testing of new options in RUC snow model in ESM_SnowMIP

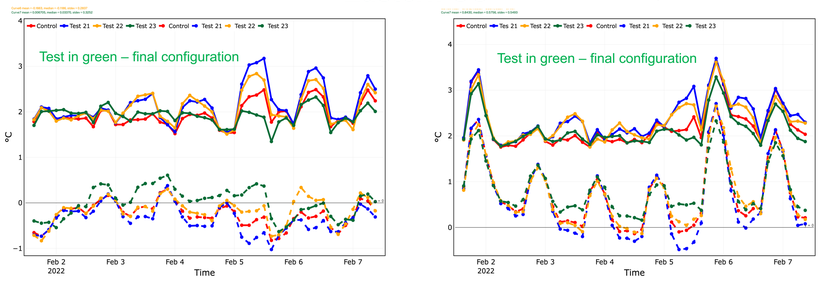


- Test experiment: snow depth and SWE are close to Control;
- Test experiment reduces cold bias in soil temperature, especially during the snow-melting season;
- Still *an issue* with cold bias during snow accumulation season due to possible overestimation of snow thermal conductivity for "fresh" snow with lower snow density values.

RRFS snow cover fraction, 5 February 2022



Surface verification for RRFS 6-h forecast, 1-8 February 2022, Eastern US



Summary:

- *Snow "mosaic"* approach in RUC snow model elevates the importance of snow cover fraction (SCF) computation;
- *New options* to compute snow cover fraction have been tested off-line and have improved surface temperature simulation;
- *New snow options* have been tested in the UFS-based RRFS for 1-8 February 2022:
  1. RRFS *Control* overestimates areas with full snow cover;
  2. RRFS with *new snow options* has reduced areas with full snow cover, and SCF better matches the MODIS snow cover information;
  3. *New snow options* reduce the space-averaged cold bias in 2-m temperature and improve RMS errors for both 2-m temperature and dewpoint;
- Modifications to RUC snow model will be used in the operational at NCEP RRFSv1 model.