Snow Depth and New Winter Weather Diagnostics for UFS

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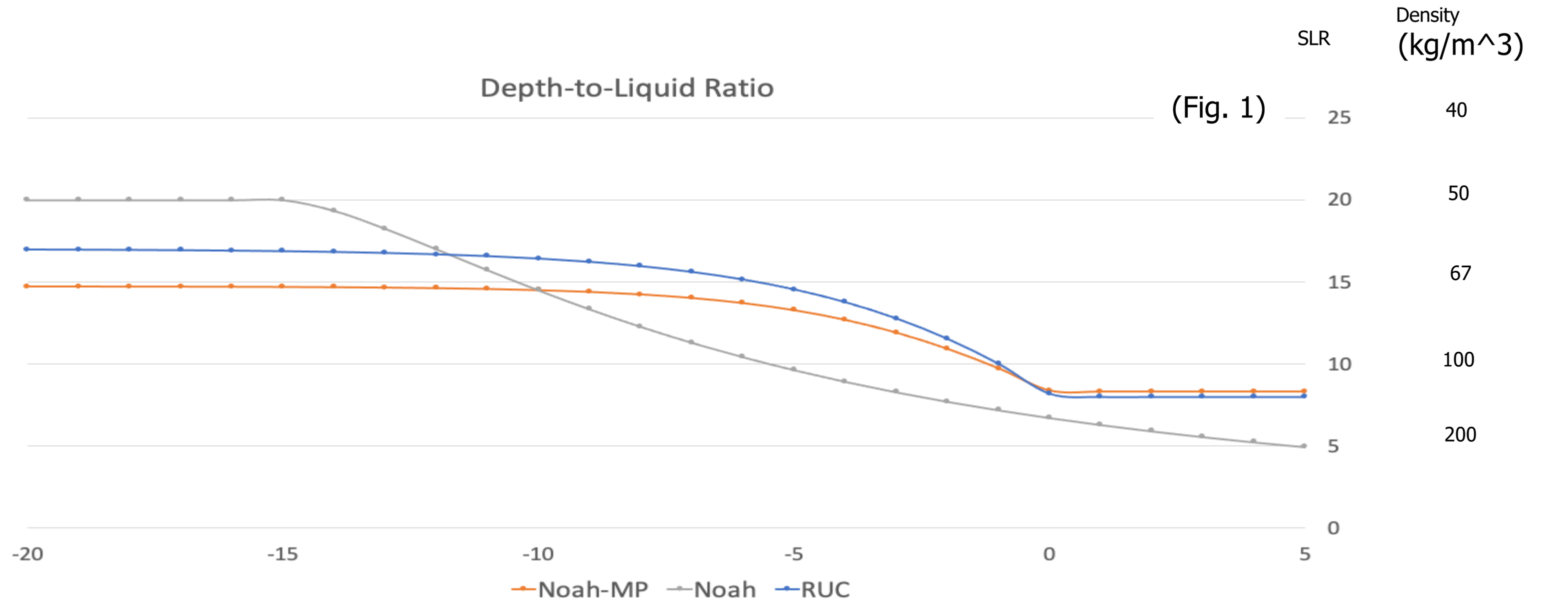
1. Introduction

Six new winter weather diagnostics were added to the Unified Forecast System (UFS), and will be part of future 3-km FV3 Rapid Refresh Forecast System (RRFS) and GFS implementations. They include the run-time accumulated (continuous) and bucket fields of surface snowfall, freezing rain and sleet/graupel. Table 1 indicates the field names as they would appear to the user.

GRIB2 Parameter Names

Precipitation Category	Snowfall (mm)	Freezing Rain (mm)	Sleet/Graupel (mm)
Bucket	TSNOWPB	FRZRB	FROZRB
Continuous	TSNOWP	FRZR	FROZR

A variable precipitation ice density used in the operational RUC/RAP/HRRR system is made as an option in the user namelist of the RRFS and GFS systems for NOAH and NOAH-MP LSMs. See Fig. 1 for the precipitation ice density and snow-liquid-equivalent (SLR) for all three LSMs as a function of temperature. The largest difference in SLR between the NOAH LSM and RUC LSM is for near surface temperatures around -5°C.



(Fig. 1)

2. Precipitation Ice Density

ORIGINAL NOAH LSM DENSITY

$$\rho_{totice} = \begin{cases} 0.05, & T \leq -15 \\ 0.05 + 0.0017(T+15)^{1.5}, & T > 15 \end{cases} \quad (1)$$

In (1), ρ_{totice} is the precipitation ice density and T is the near surface temperature in °C.

ORIGINAL NOAH-MP LSM DENSITY

$$\rho_{snow} = \min\left(120., 67.92 + 51.25e^{\left(\frac{T}{2.59}\right)}\right) \quad (2)$$

$$prcpfrozen = prcpsnow + prcpgrpl + prcphail \quad (3)$$

$$\rho_{totice} = \rho_{snow} * \left(\frac{prcpsnow}{prcpfrozen}\right) + \rho_{graupel} * \left(\frac{prcpgrpl}{prcpfrozen}\right) + \rho_{hail} * \left(\frac{prcphail}{prcpfrozen}\right) \quad (4)$$

In (2)-(4), ρ_{snow} is the snow density, $\rho_{graupel}$ is graupel density assumed to be 500 kg m^{-3}, and ρ_{hail} is the hail density assumed to be 917 kg m^{-3}. The precipitation amounts of snow, graupel and hail are represented as *prcpsnow, prcpgrpl* and *prcphail* , respectively.

***NEW* PRECIP ICE DENSITY**

Current Approach in RUC LSM

$$\rho_{snow} = \min(125, \frac{\rho_l}{\max\left(8, \left(17 * \tanh\left((276.65 - T) * 0.15\right)\right)\right)}) \quad (5)$$

$$\rho_{graupel} = \min(500, \frac{\rho_l}{\max\left(2, \left(3.5 * \tanh\left((274.15 - T) * 0.3333\right)\right)\right)}) \quad (6)$$

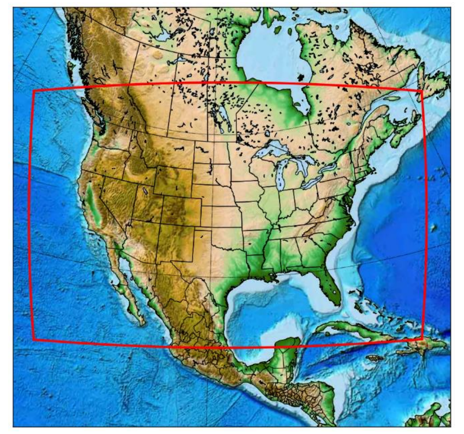
$$\rho_{cloudice} = \rho_{snow}$$

$$\rho_{totice} = \min(500, \max(58.8, (\rho_{snow} * \left(\frac{prcpsnow}{prcpfrozen}\right) + \rho_{graupel} * \left(\frac{prcpgrpl}{prcpfrozen}\right) + \rho_{cloudice} * \left(\frac{prcpcloudice}{prcpfrozen}\right) \quad (7)$$

In (5)-(7), ρ_l, is the density of water and $\rho_{cloudice}$ is the density of cloud ice. Note the ρ_{totice} calculation was moved out of the RUC LSM and to the end of the model time step in order to make it available to all LSMs.

3. RRFS Configuration

- FV3 dynamical core using the **L**imited **A**rea **M**odel (LAM) capability (Fig 2).
- Black et al. (*JAMES*, 2021)
- 65 vertical layers.
- Lowest model level at ~ 8 m

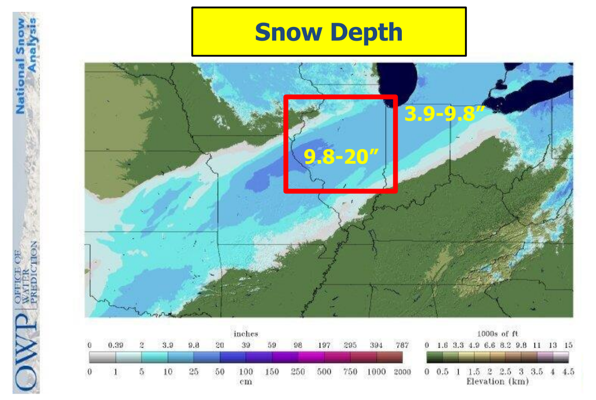


(Fig. 2)

- Dt=36s
- Aerosol-aware Thompson microphysics.
- MYNN PBL+ MYNN surface Layer.
- RRTMG radiation.
- **Case: 31 January 2022**

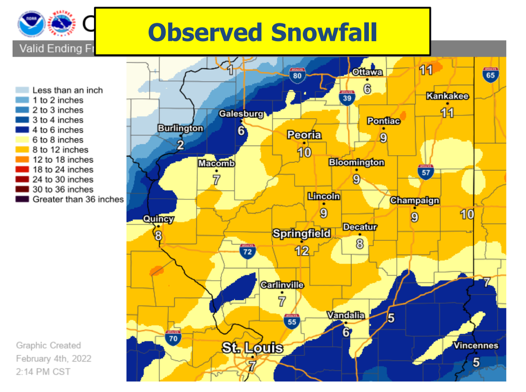
3a. Observations

Snow Depth



(Fig. 3a)

Observed Snowfall

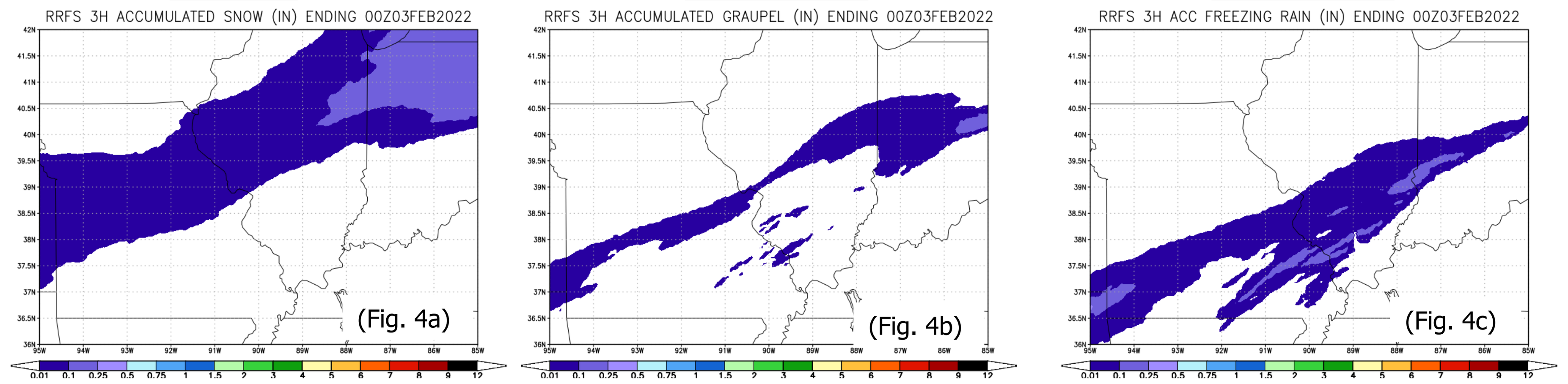


(Fig. 3b)

Figure 3a illustrates the snow depth at 06 UTC/03 Feb 2022 with generally > 10" of snow in IL/MO in the region of interest marked by the red box. Figure 3b illustrates observed snowfall associated with the same event.

3b. Results

Snowfall | Graupel/Sleet | Freezing Rain



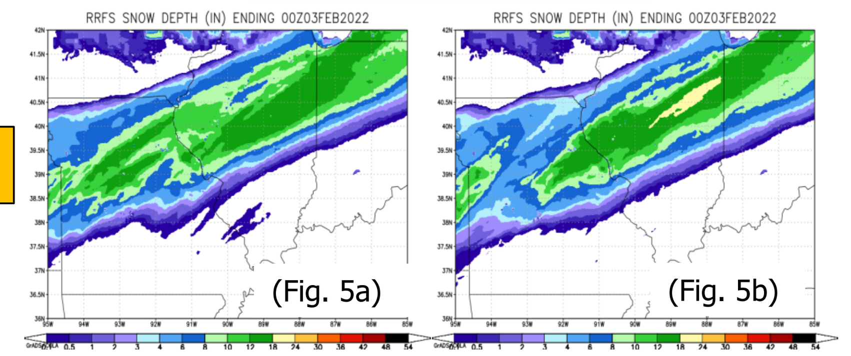
(Fig. 4a) (Fig. 4b) (Fig. 4c)

The three hour accumulations of surface snowfall, graupel/sleet, and freezing rain are shown in Figs. 4a-c ending on 00 UTC/03 February 2022 from a 3-km FV3 RRFS run using the RUC LSM. Note the water equivalent values are shown for snowfall as well as graupel/sleet.

Moving the ρ_{totice} calculation to the end of the model time step and out of the RUC LSM did result in a different forecast as expected with the total 60-h snow depth (inches) from the original approach shown in Fig. 5a and the snow depth with the new approach illustrated in Fig. 5b.

0-60h Snow Depth (inches)

ρ_{totice} computed inside the RUC LSM



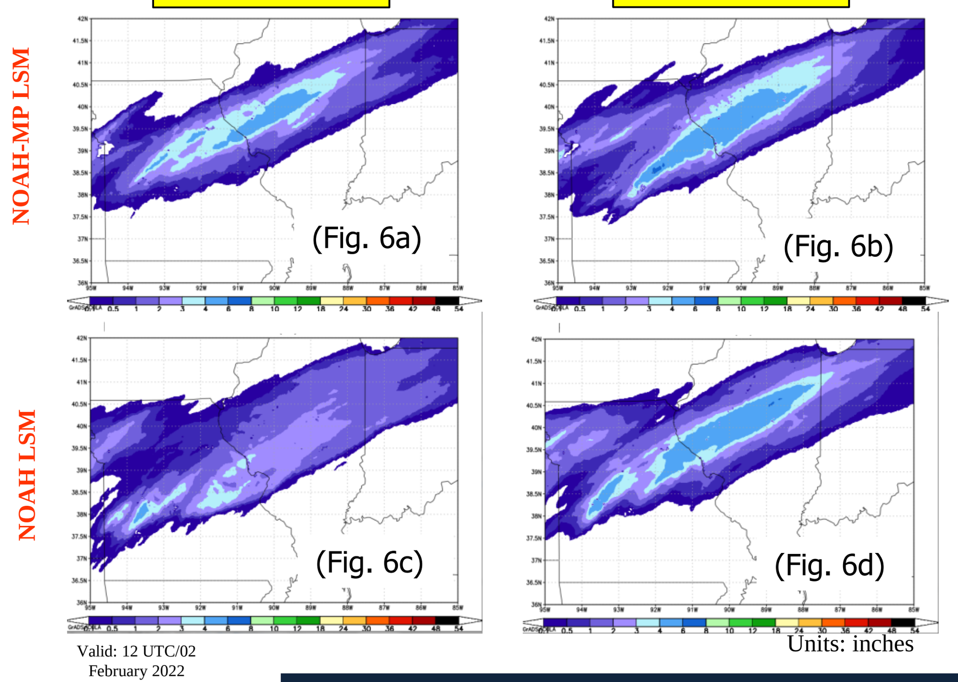
(Fig. 5a) (Fig. 5b)

ρ_{totice} computed outside the RUC LSM

An increase in snow depth can be seen in both the NOAH-MP and NOAH LSMs with the new ρ_{totice}(Figs. 6a-d). There was a larger density gradient across the area of precip as well as lower densities that allowed for higher SLRs (Figs. 7a-d).

3-h Snow Depth

Original Density | New Density

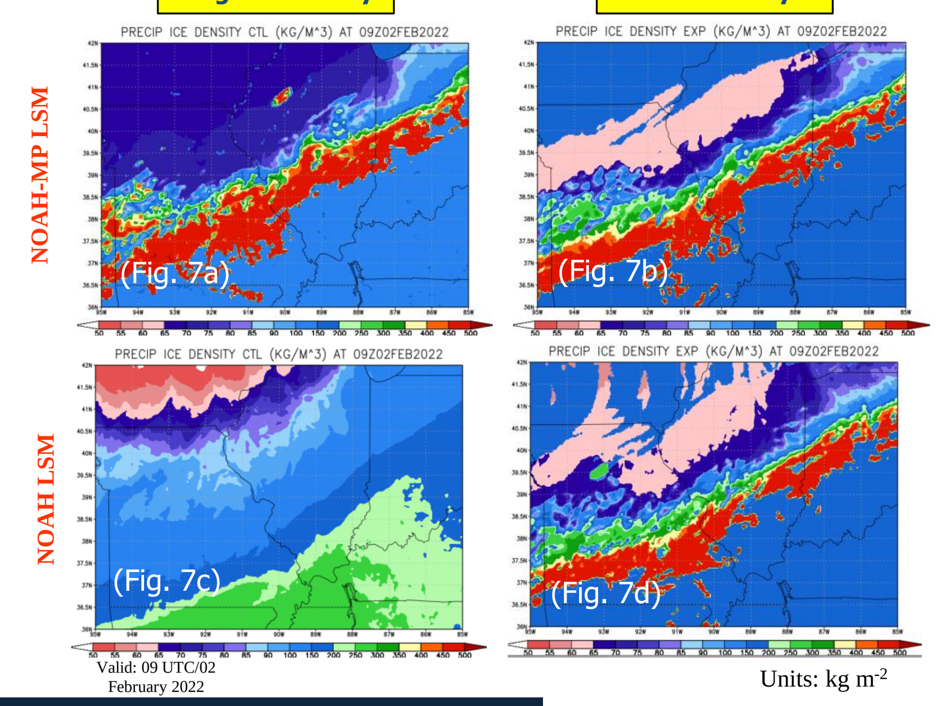


(Fig. 6a) (Fig. 6b) (Fig. 6c) (Fig. 6d)

Units: inches

Precipitation Ice Density (ρ_{totice})

Original Density | New Density



(Fig. 7a) (Fig. 7b) (Fig. 7c) (Fig. 7d)

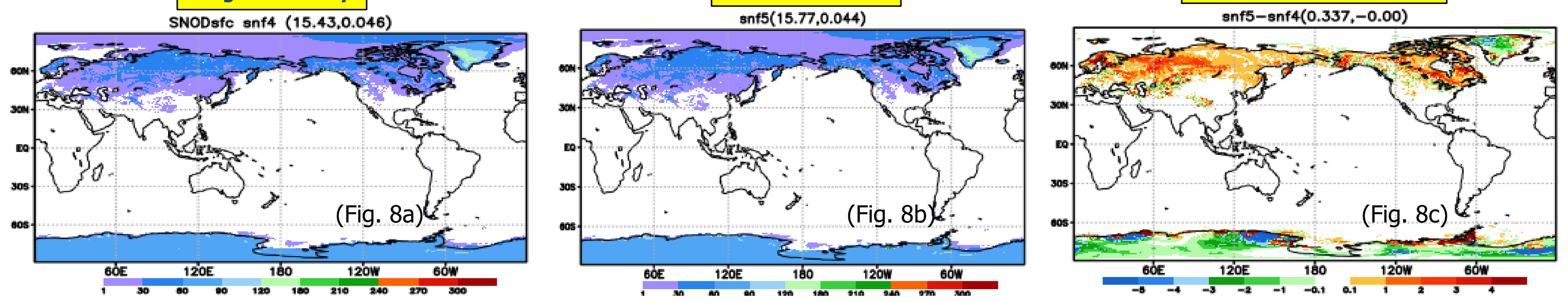
Units: kg m^{-3}

4. GFS Results

Global experimental runs (gfsv18p8) were initialized at 00 UTC/17 Jan 2021. Snow depth was evaluated in runs using the NOAH MP LSM with the original ρ_{totice} formulation (Fig. 8a) and the new formulation (Fig. 8b) at 120-h . Snow depth increased in the northern latitudes and mostly decreased in southern latitudes with the new ρ_{totice} formulation (Fig. 8c).

120-h Snow Depth

Original Density | New Density | New – Original Density



(Fig. 8a) (Fig. 8b) (Fig. 8c)

Units: inches

5. Summary

- Six new winter weather diagnostics have been added to all UFS applications including the RRFS and GFS with both the runtime-accumulated and bucket amounts of surface snowfall, sleet/graupel and freezing rain available to users.
- A variable precipitation ice density that takes into account information from the microphysics that is currently used in the operational RAP/HRRR (RUC LSM) to provide snow depth can now be used with the NOAH and NOAH-MP LSMs via a namelist option.
- In RRFS runs, the new precipitation ice density generally increased snow depth, while in preliminary results of global runs, there was an increase in snow depth in high latitudes and a decrease snow depth in low latitudes.
- **Future work** will evaluate the new precipitation ice density in NOAH MP in both RRFS and GFS applications.