Coupled Land-Atmosphere Data Assimilation (DA) in the NOAA Operational Weather Prediction Models – Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR)

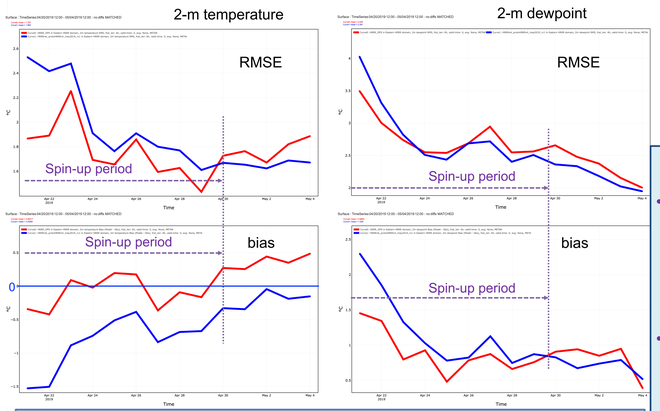
Tatiana G. Smirnova [1,2], Stanley G. Benjamin[1], Eric P. James[1,2], Brian Jamison[1,3], Ming Hu [1,2]

1. NOAA/ESRL/GSD, Boulder, CO; 2. CIRES, University of Colorado at Boulder, CO; 3. CIRA, Colorado State University.

Overview of Strongly Coupled DA (SCDA) approach in RAP and HRRR

- Cycling of soil temperature/moisture, lake temperature and snow temperature/depth for consistent coupled background state - unique in RAP and HRRR.
- DA in GSI is performed for the entire coupled earth system (for RAP/HRRR): Increment produced for soil/snow temp, soil moisture from atmospheric surface analysis increments using empirical 1-d covariances *(Benjamin et al 2016, MWR, App. A – pp.1689-1690)*
- Updating snow cover from 4-km NESDIS Snow and Ice Analysis once per day - trim or build cycled snow if necessary.

Spin-up period needed with inconsistencies in the initial coupled atmosphere/land state.



Red – HRRR oper
Blue – experimental HRRRv4 with introduced changes in soil properties.

6-h forecast valid at 00 UTC, 20 April – 4 May 2019

Conclusions:

- Spin-up in the first 7-10 days of cycling: larger RMSE and bias in 2-m T and dewpoint in HRRRv4
- Improved HRRRv4 performance when consistent coupled state is achieved in the coupled DA

Empirical 1-d covariances used in RAP coupled DA for soil temperature and moisture adjustment

- Soil temperature adjustment is based on the 2-m air temperature increment:

  $\Delta T_s(k)=\alpha(k)\cdot\Delta T_a$

  ΔT_a - the atmosphere temperature analysis increment;

  $\alpha(k)$ - the adjustment ratio for k^{th} soil level: 0.6, …., 0.2

  Cooling up to $\Delta T_s(k)=-2.0\times(1.+\min(1.5,\max(0.,(T-283.0)/15.0)))\times 0.6$

  Warming up to $\Delta T_s(k)= 1.5$ K

- Soil moisture adjustment is based on 2-m relative humidity increment and applied if daytime and no snow on the ground:

  $\Delta\eta_s(k)=\alpha(k)\cdot\Delta RH_a$

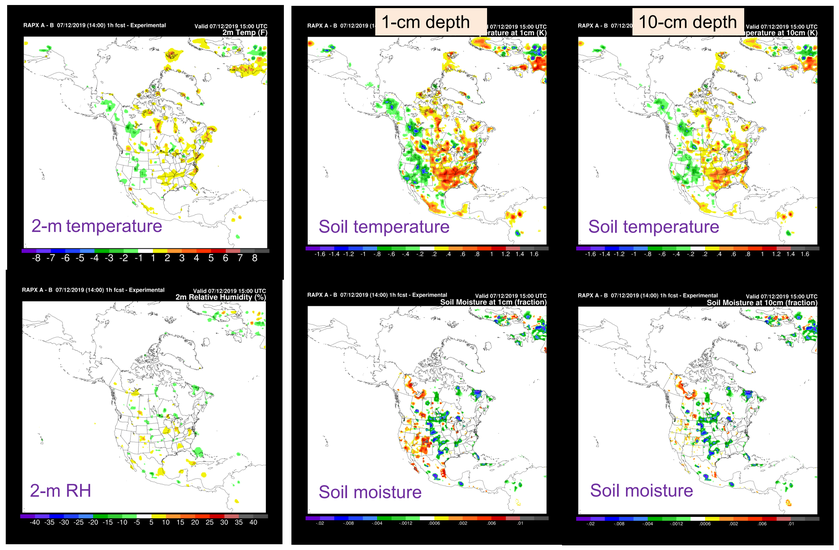
  ΔRH_a - the analysis increment of RH at the lowest model level;

  $\Delta\eta_s(k)$ - the soil volumetric water content increment $(-0.03<\Delta\eta_s(k)<0.03)$;

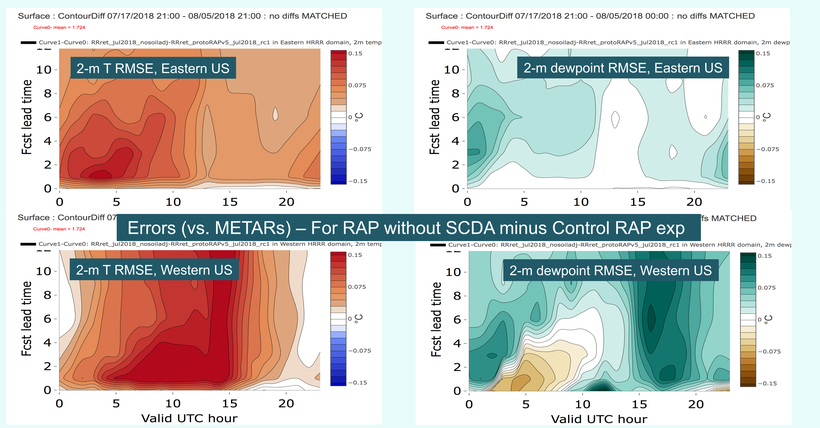
  $\alpha(k)$ - the adjustment ratio for k^{th} soil level: 0.2…. 0,.1.

  - *Soil moistening is applied when* $\Delta T_a < T_{crit}$ *where* $T_{crit} = -0.15$ K
  - *Soil drying is applied when* $\Delta T_a > T_{crit}$ *, where* $T_{crit} = 0.15$ K

RAP soil temperature and moisture increments from SCDA -- valid at 1500 UTC 12 July 2019



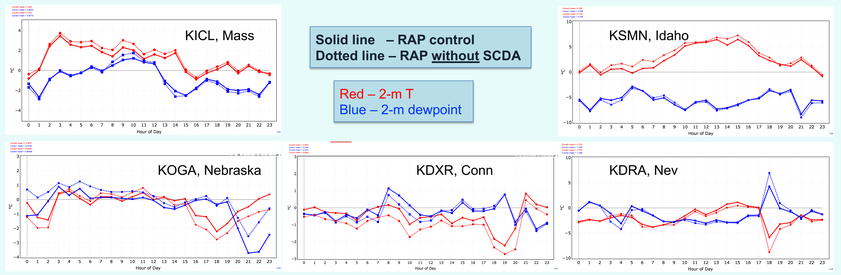
Effect from SCDA on RAP surface prediction
Warm season: 17 July – 5 August 2018



Errors (vs. METARs) – For RAP without SCDA minus Control RAP exp

- Overall soil adjustment has positive impact on surface (2-m) prediction;
- For 2-m dewpoint, soil adjustment has larger impact in Western US with dry soil conditions;
- 2-m temperature RMS errors without soil adjustment are the largest in daytime and early night hours in Eastern US, and during night and early morning hours in Western US.

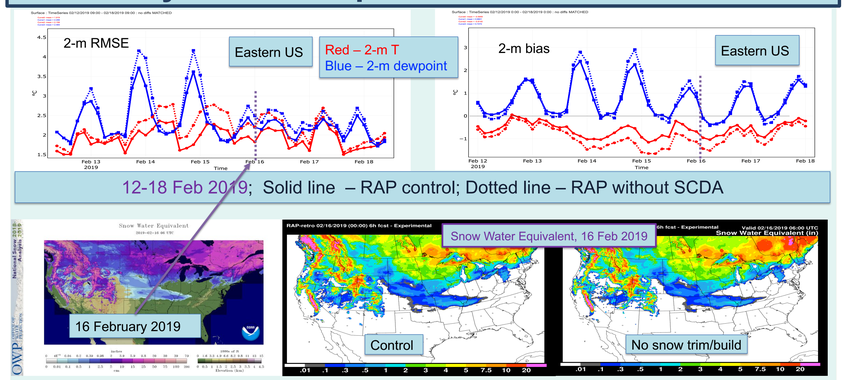
Diurnal cycle of 2-m temperature and dewpoint for selected stations
6-h forecast averaged over 1–5 August 2018.



Solid line – RAP control
Dotted line – RAP without SCDA

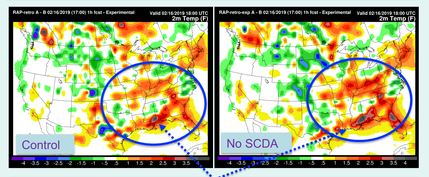
Red – 2-m T
Blue – 2-m dewpoint

Effect from SCDA on RAP snow cover and the accuracy of surface prediction in the cold season



12-18 Feb 2019; Solid line – RAP control; Dotted line – RAP without SCDA

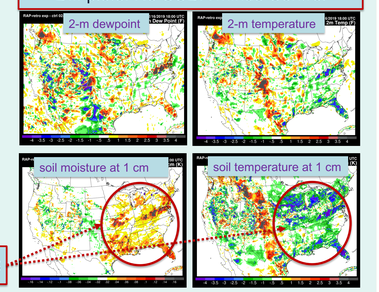
2-m temperature: analysis minus background



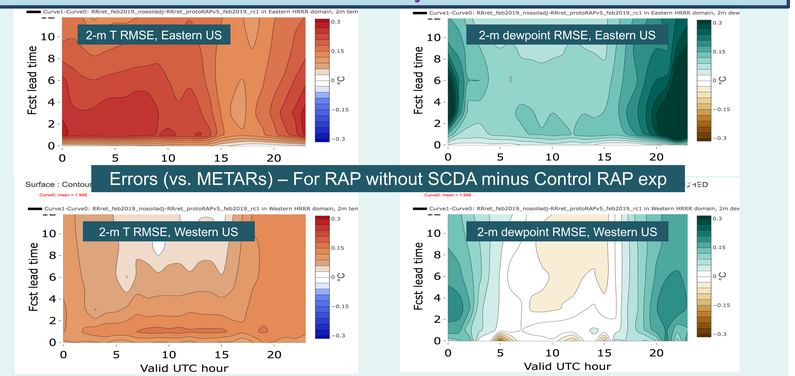
Larger 2-m T increments without SCDA

Soil in no SCDA run is too moist and cold in Eastern US

Diff plots: No SCDA minus Control



2-m temperature and dewpoint RMS errors with/without SCDA
Cold season: 9 February – 2 March 2019



Errors (vs. METARs) – For RAP without SCDA minus Control RAP exp

Conclusions and future plans

- Coupled DA is needed to avoid initial shock to system and ensure accurate fluxes across atmosphere/land interface especially in initial forecast hours;
- Positive impact of SCDA in RAP evident in both summer and winter experiments. More pronounced in cold season when possible errors in prediction of location and amounts of snow precipitation can substantially affect surface properties;
- Future work: Replace empirical covariances in SCDA with cross-domain error covariances for entire Earth system (atmos/land/snow) in which obs for one component can increment state of another;
- Assimilate soil moisture retrievals (SMOP, SMAS) in GSI SCDA.