Land DA for NOAA's Global NWP

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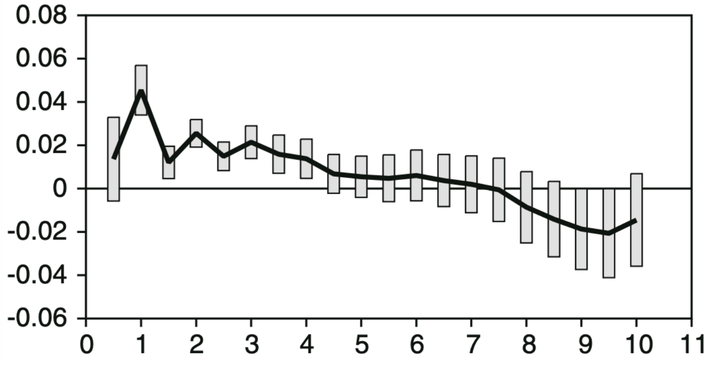
2. NOAA EMC, College Park, MD.
3. Lynker at NOAA EMC.

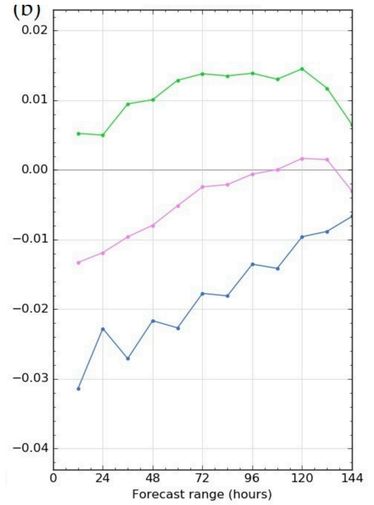
UIFCW25, Boulder, September, 2025.

Land DA in NWP

- All major international NWP centers use land DA to improve initialization of their land states
  - Demonstrated to lead to improved NWP forecasts
- For global NWP, NOAA's land DA is very far behind international practice
- Other centers use land DA to constrain the model:
  - Soil moisture (from T2m, q2m, and satellites)
  - Soil temperature (from T2m, q2m)
  - Snow amount (from station and satellite obs)



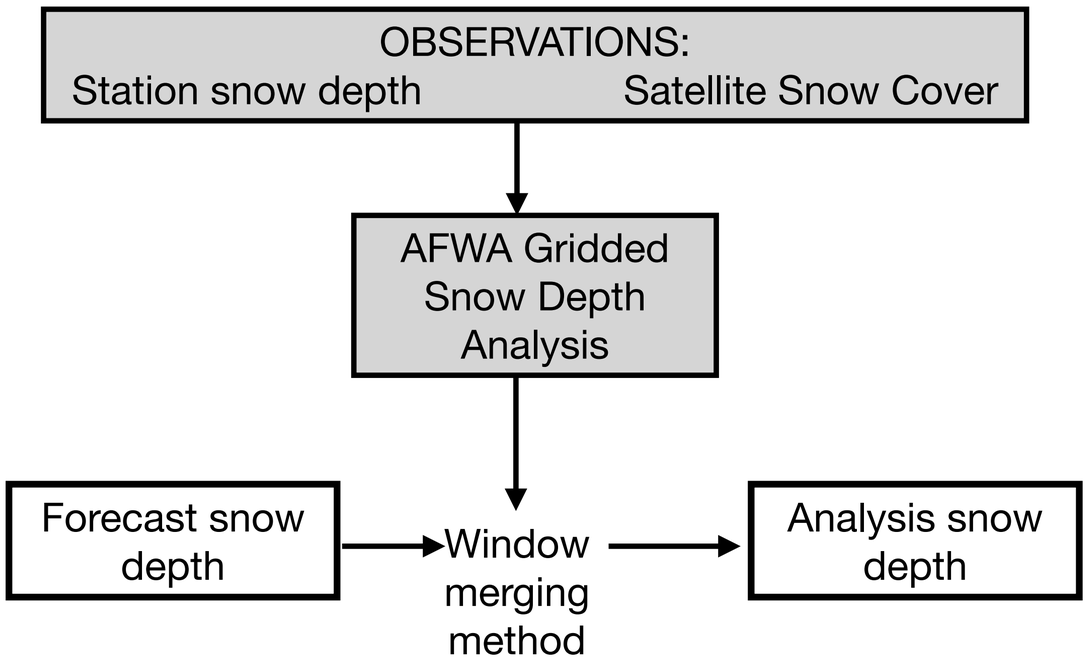
Improvement in normalized root mean square forecast 1000 hPa geopotential error [-] at ECMWF, from updating the snow depth analysis (de Rosnay et al, 2014).

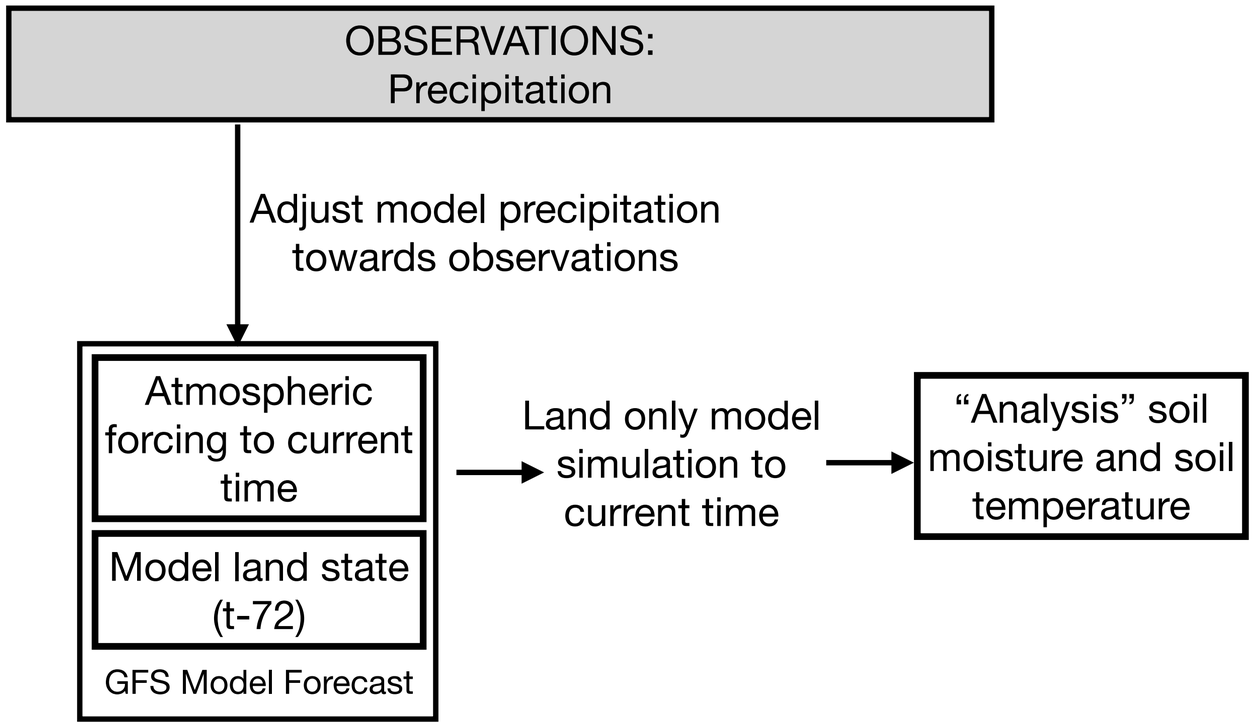


Change in forecast T2m RMSE [K] at UKMO due to the SEKF soil moisture analysis (three different versions shown; Gomez et al, 2020).

Land DA in NOAA's GFSv16

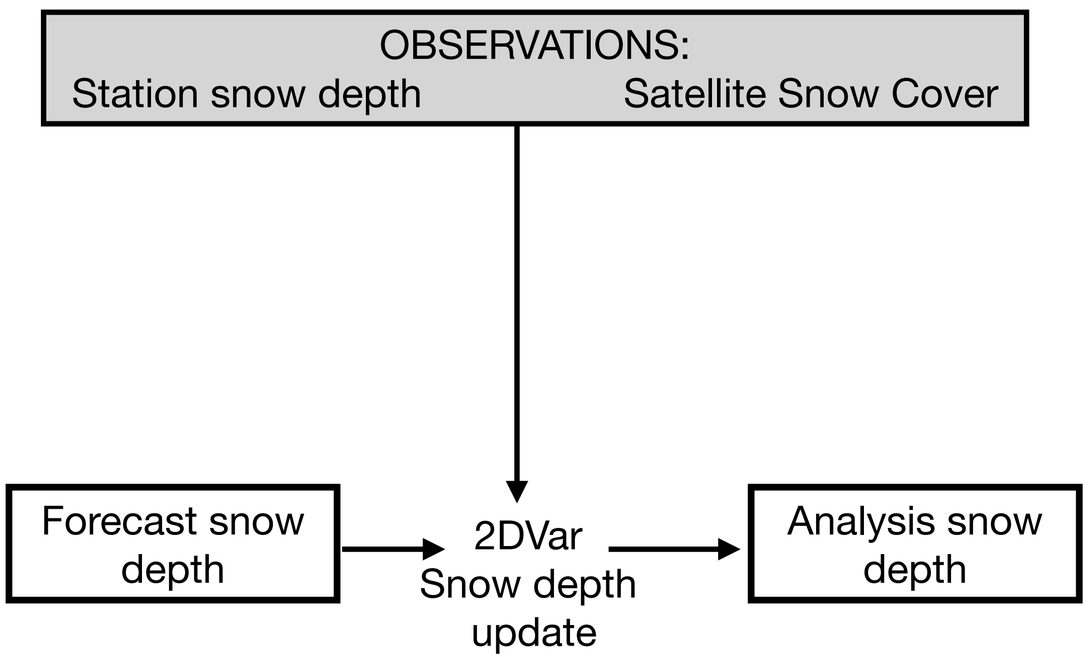
- Simple snow depth analysis
- No soil moisture or soil temperature analysis (instead retrospective correction with observed precipitation)

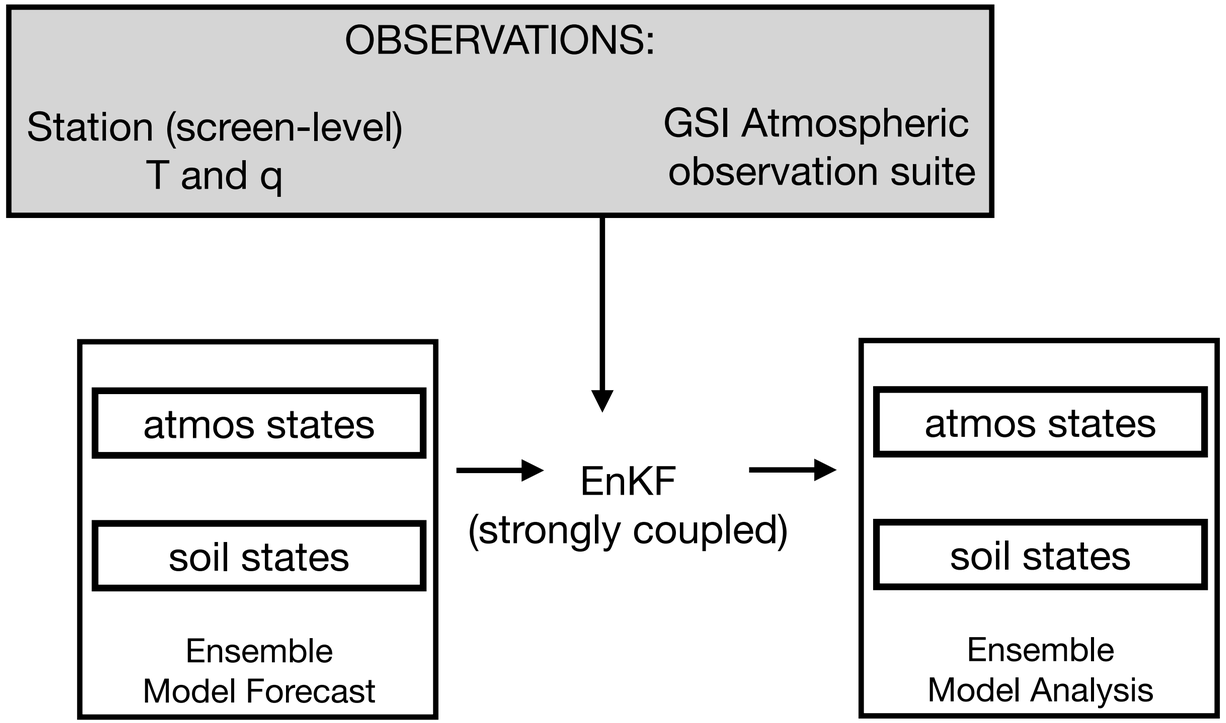




Land DA in NOAA's GFSv17 (sched. 2026)

- GFSv17 will include a major upgrade to our land DA
  - Upgrade snow DA to directly assimilate observations and use JEDI
  - Introduce first soil moisture and soil temperature analysis

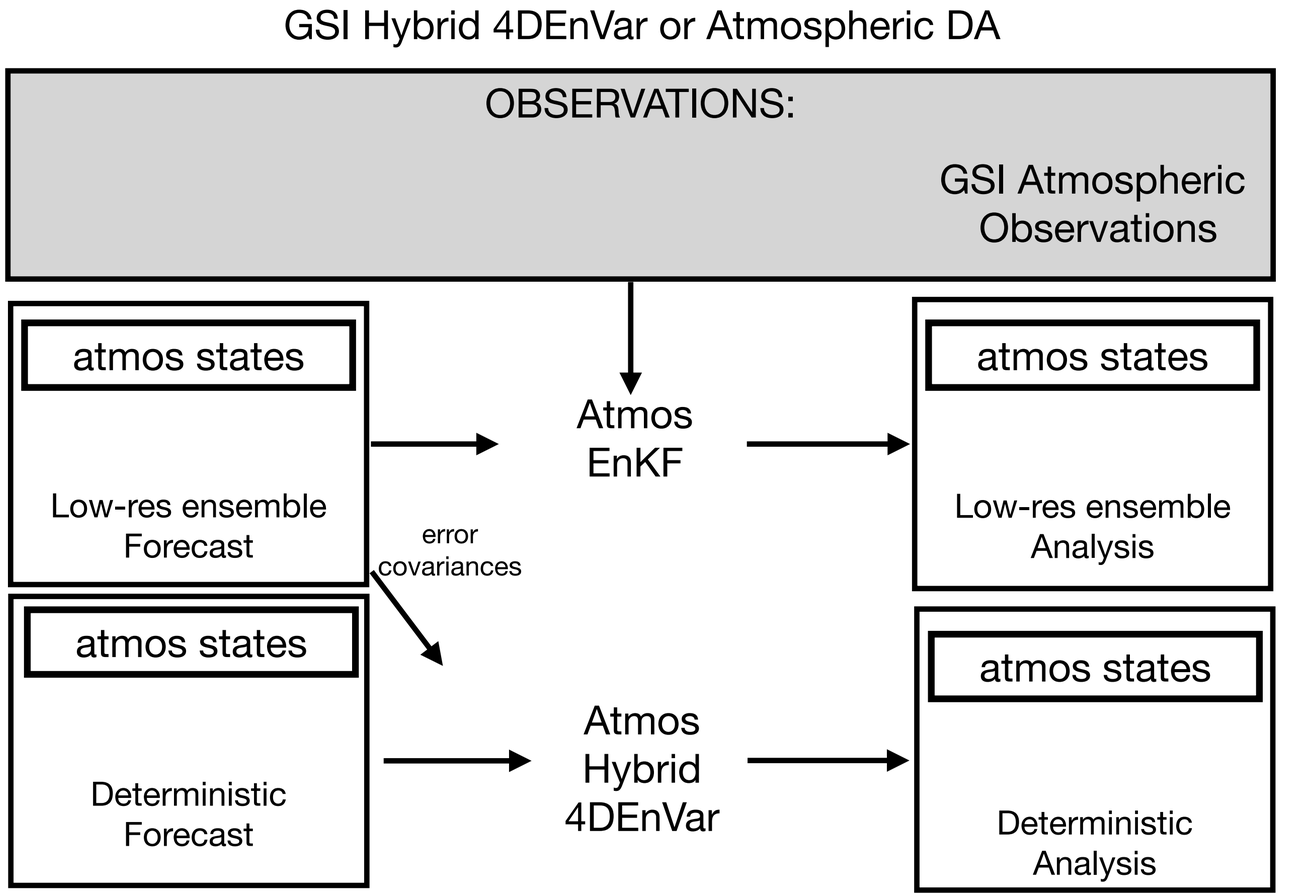




GFSv17 Soil Moisture and Soil Temperature Analysis

GFSv17 Soil Moisture and Soil Temperature Analysis

- At other NWP centers, the soil analysis is done with different DA methods to the atmospheric analysis
  - Relatively simple DA methods (SEKF, OI)
  - Initial soil analysis schemes were all based on assimilation of screen-level T and q
  - Some centers later added satellite soil moisture information
- We instead opted to use the more advanced DA method that are being applied to the atmosphere for the new soil analysis
  - Initially, using the EnKF component only for the soil moisture and soil temperature analysis
  - Also adding assimilation of screen-level T and q observations (not currently used in the GFS)



GFSv17 Soil Moisture and Soil Temperature Analysis

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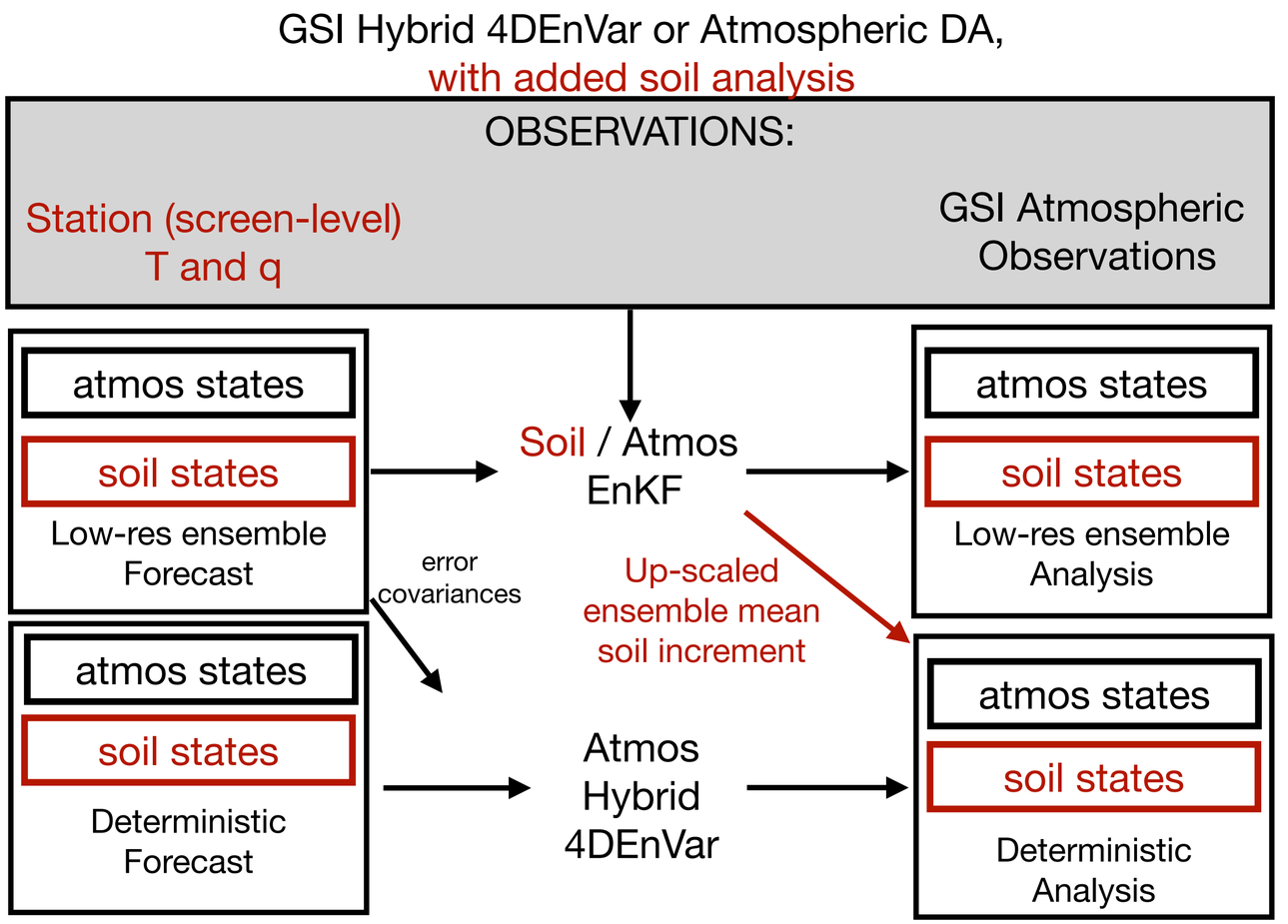
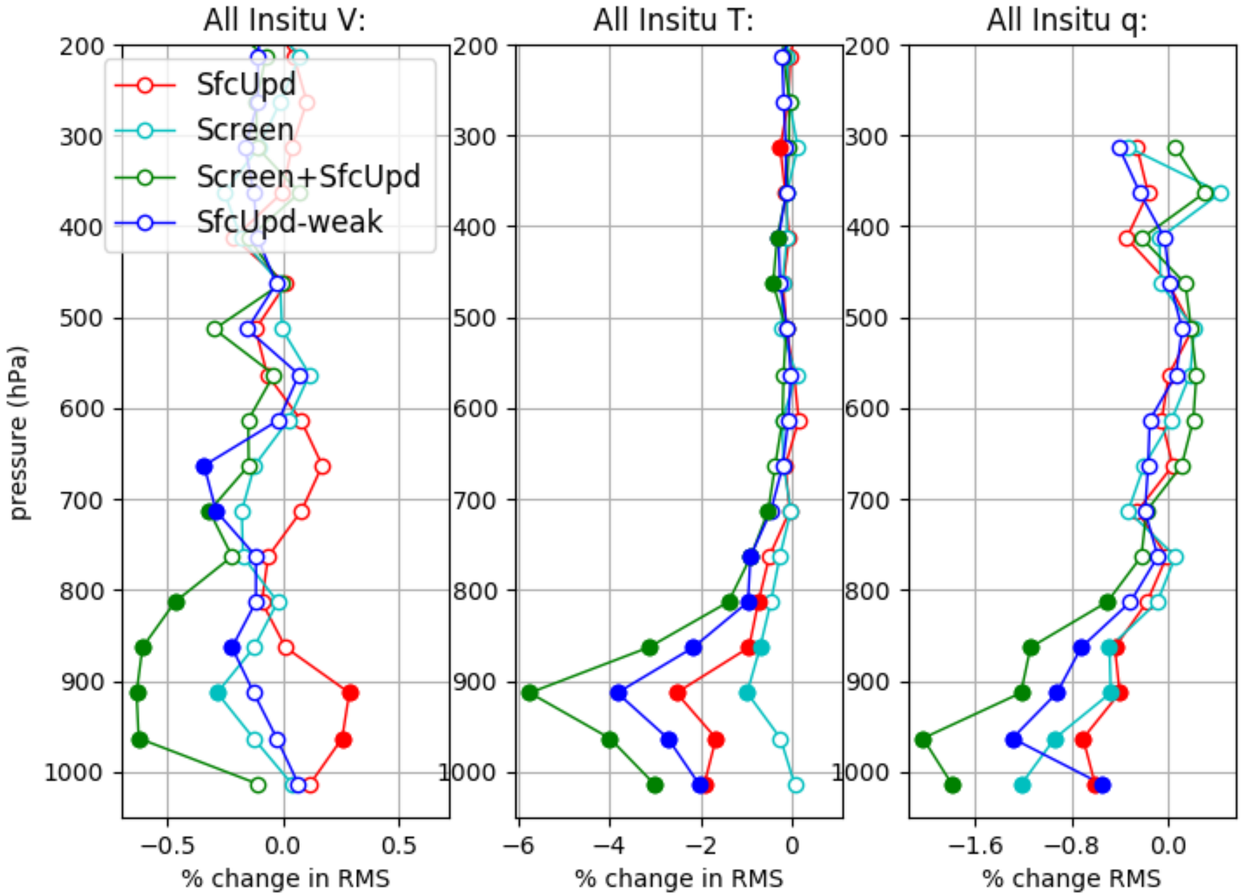
- We instead opted to use the more advanced DA method that are being applied to the atmosphere for the new soil analysis
  - Initially, using the only the EnKF component of the GSI Hybrid 4DEnVar for the soil moisture and soil temperature analysis
  - Add mean ensemble increment to the deterministic member
  - Also adding assimilation of screen-level T and q observations (not currently used in the GFS)



Coupled EnKF Soil Analysis Experiments

- Early experiments with the GSI atmospheric EnKF (no deterministic member, of Var update) show improvement in low-level O-F from adding the new soil analysis:
  - **Red**: Improvement from assimilating screen-level T and q observations into the atmosphere
  - **Aqua**: Improvements from including the soil states in the analysis
  - **Green**: Largest improvements from doing both (strongly coupled land/ atmos EnKF, with addition of screen-level obs) - selected option for GFSv17

Percentage change in RMS O-F from different coupling options for the atmos and soil EnKF

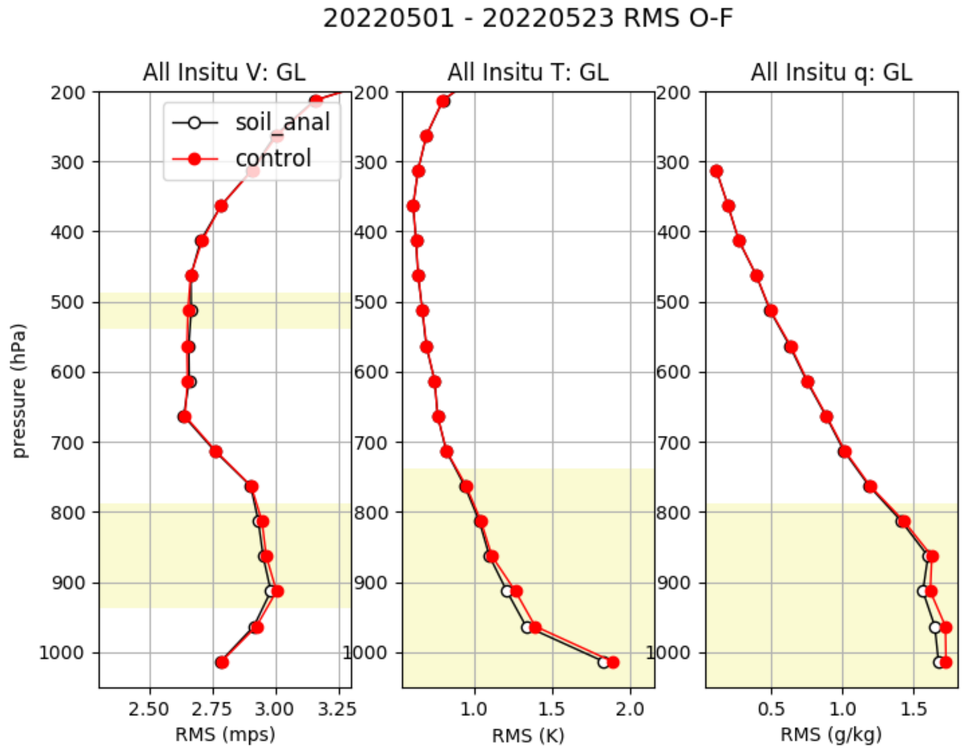


Full circle = significant difference from Control

Draper et al. QJRMS (2025)

GFSv17 Soil Analysis

- Recall: atmos DA is Hybrid 4DEnVar
  - Variational/hybrid methods not well established for land DA, but are theoretically quite attractive
  - For GFSv17 using interim solution of adding the mean EnKF increment to the deterministic member while we develop a hybrid/variational soil analysis
- Currently testing forecast impact of above design in a prototype version of GFSv17
  - C384/C192 (~12 km)
  - May 2022 -> October 2022
  - 10 day forecasts launched every 5 days



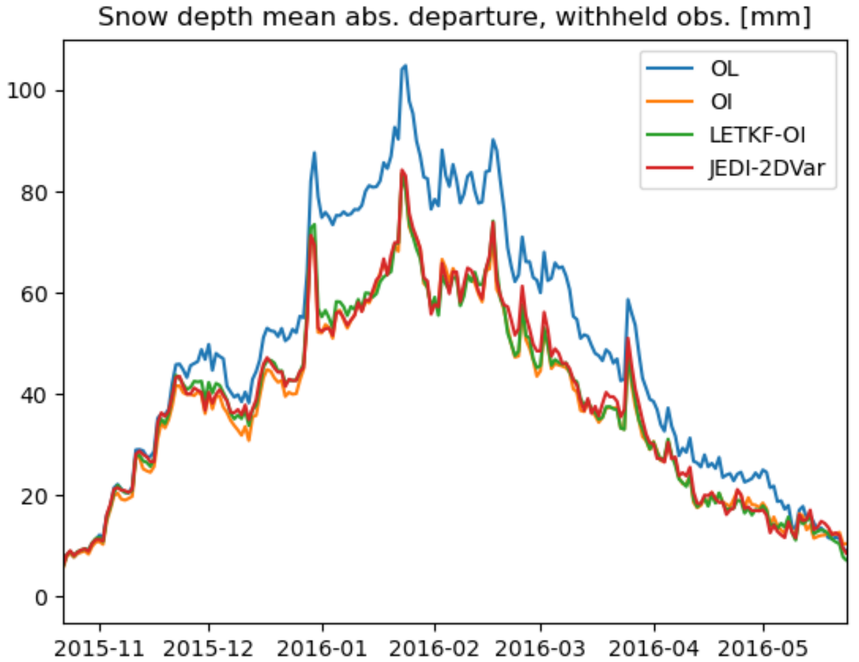
Above: first month of the soil analysis experiments, show significant improvement in low-level T and q O-F at analysis time

Experiments run by Tseganeh Gichamo

GFSv17 Snow Depth Analysis

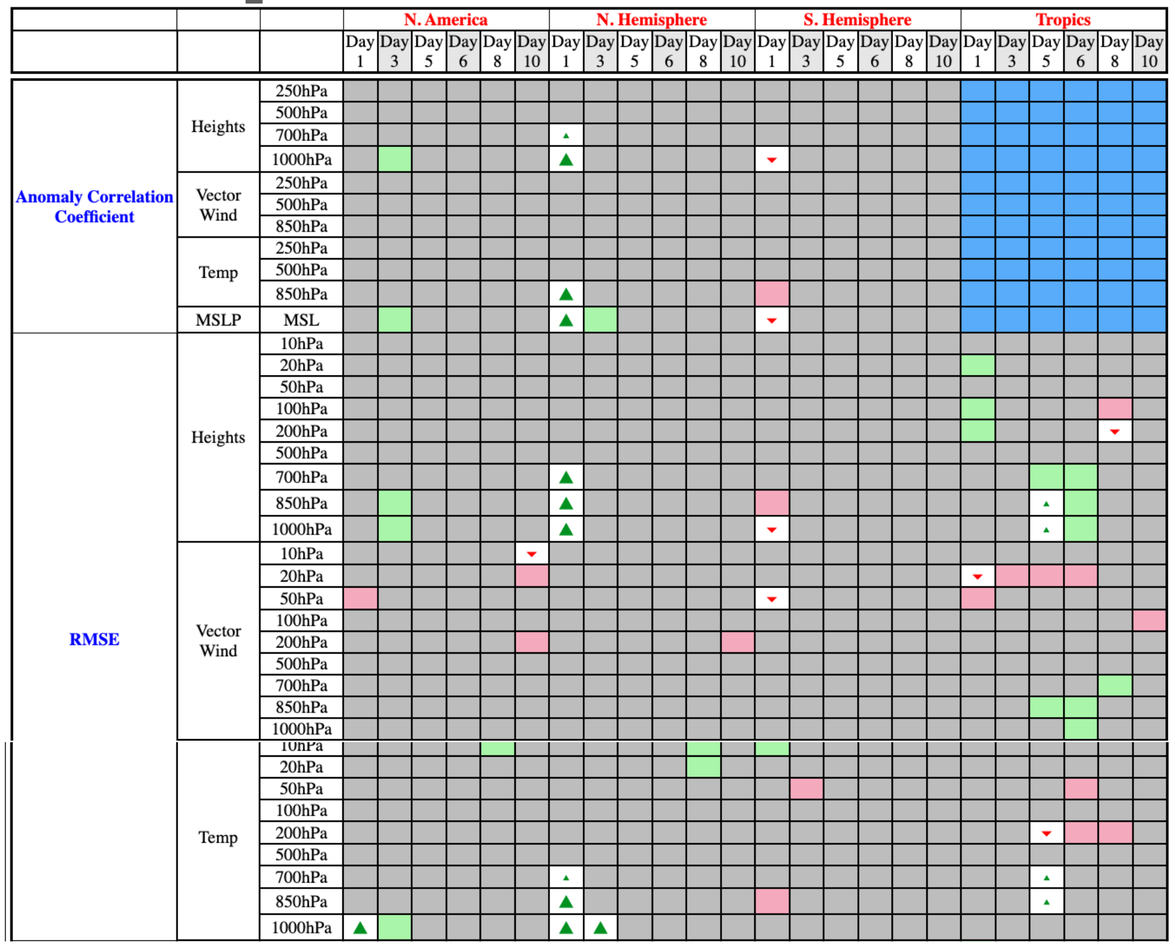
2DVar Snow Depth Analysis

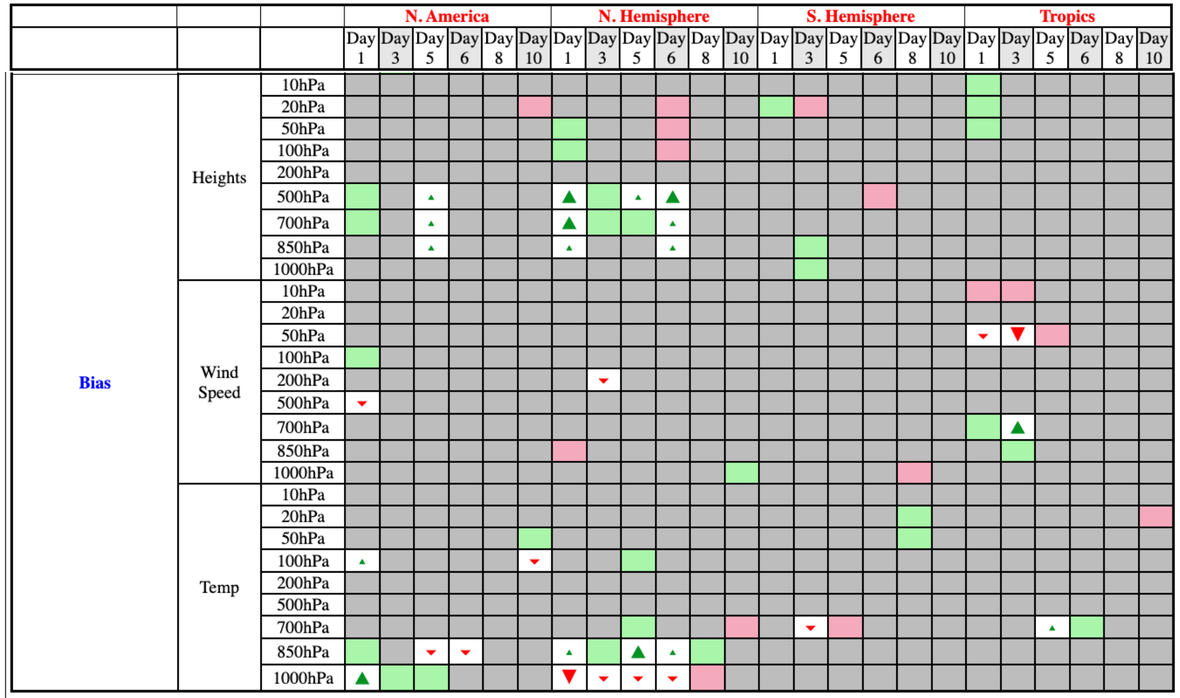
- Using 2DVar to update model snow depth from station snow depth and satellite snow cover observations
  - Implemented in JEDI
  - B matrix covariances calculated from variation (horizontal, vertical) in model surface terrain
    - Based on optimal interpolation schemes used elsewhere
  - In GFSv17, 2DVar is applied separately to the deterministic member, and to the ensemble mean



Above: 2DVar snow DA (red) improves the model snow depth compared to no snow DA (blue).

Improved NWP Forecasts from Snow DA





Scorecard Symbol Legend

C384mx025_2dvar_gfs is better than C384mx025_control_gfs at the 99.9% significance level	C384mx025_2dvar_gfs is worse than C384mx025_control_gfs at the 99.9% significance level
C384mx025_2dvar_gfs is better than C384mx025_control_gfs at the 99% significance level	C384mx025_2dvar_gfs is worse than C384mx025_control_gfs at the 99% significance level
C384mx025_2dvar_gfs is better than C384mx025_control_gfs at the 95% significance level	C384mx025_2dvar_gfs is worse than C384mx025_control_gfs at the 95% significance level
No statistically significant difference between C384mx025_2dvar_gfs and C384mx025_control_gfs	Not statistically relevant

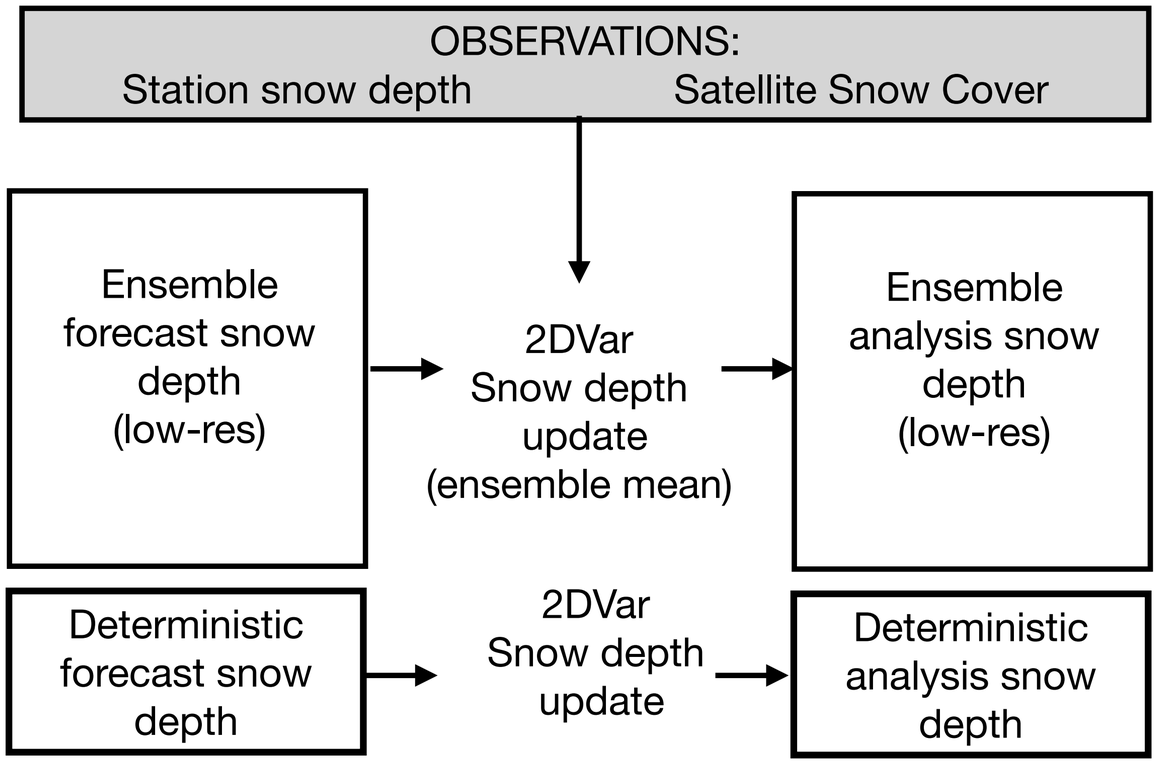
Dates: 20241025-20250513

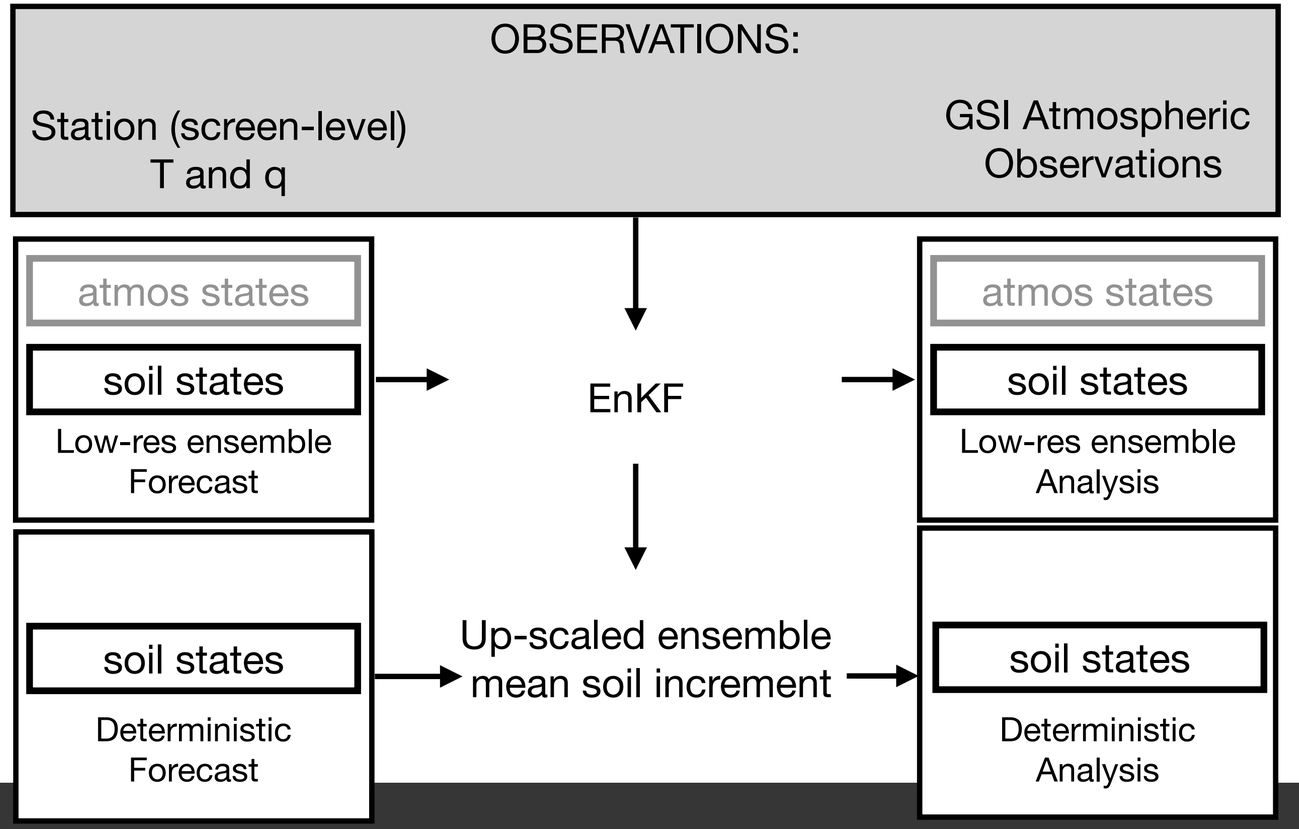
- Forecast impact experiment shows generally positive impact of the 2DVar snow analysis
  - ~12 km, 3DVar for atmosphere
  - Sep 1 2024 -> May 31 2025
  - 10 day forecasts, launched every 5 days

Experiments / figures by Jiarui Dong & Cory Martin

Summary / Land DA for GFSv17

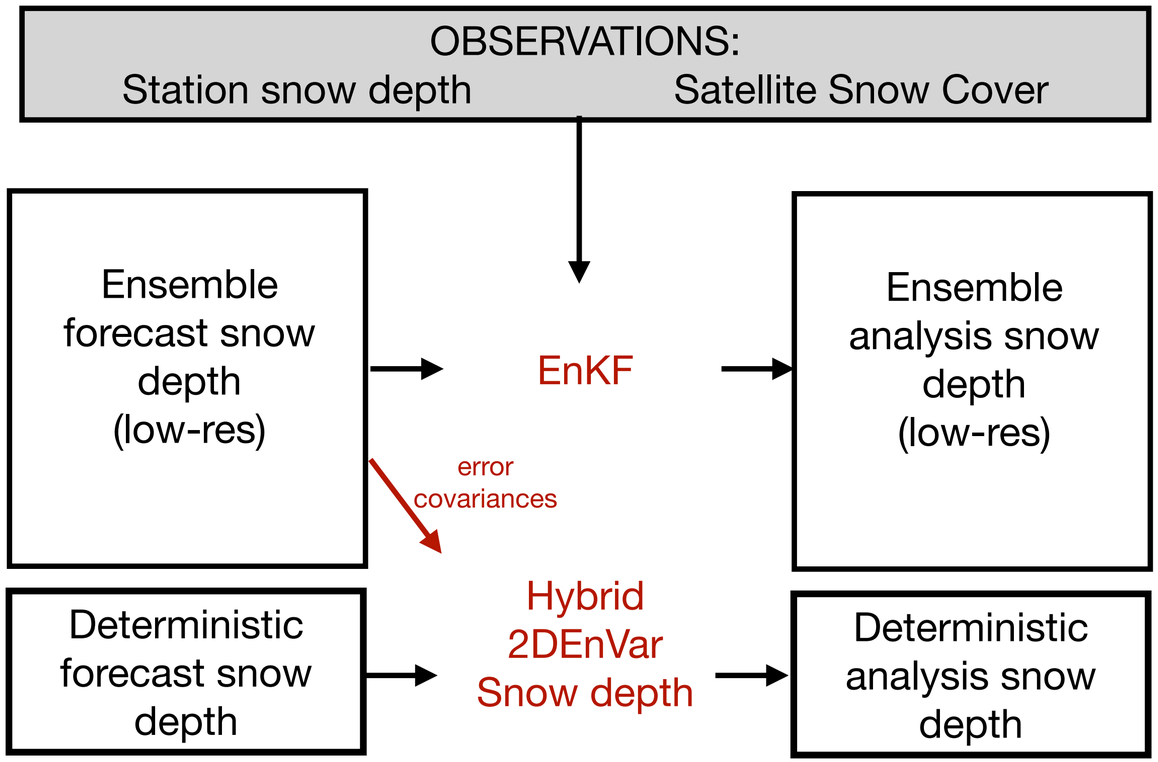
- GFSv17 planned to include a major upgrade to our land DA
  - Introduce strongly coupled EnKF soil moisture and soil temperature analysis (pending successful forecast impact experiments with GFSv17 prototype)
  - Upgrade snow DA to directly assimilate observations with a JEDI-based 2DVar
- These updates will bring NOAA's land DA up to (ahead of?) international standards
- Experiments to date show significantly improvements to land and atmospheric states from the upgraded land DA

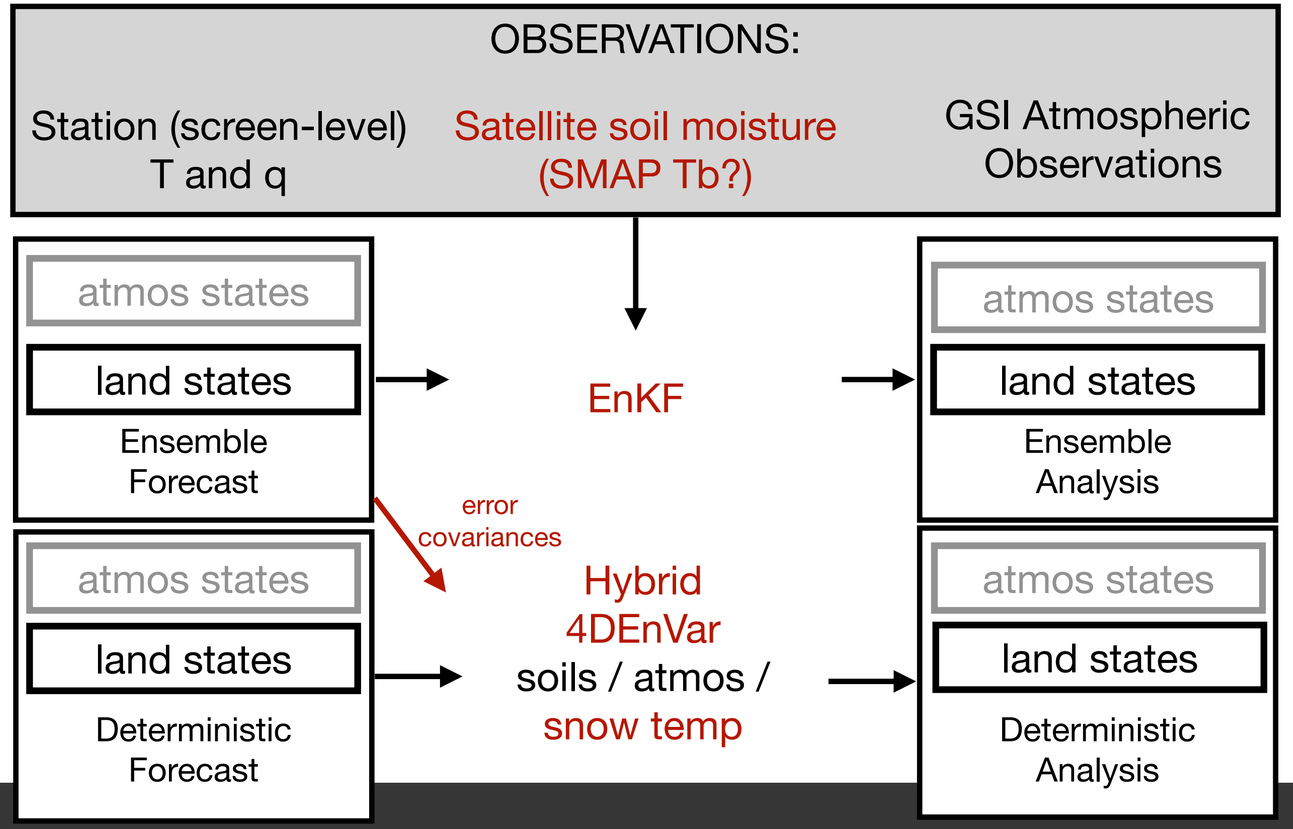




Next Steps / Land DA beyond GFSv17

- Exploring implementing hybrid EnVar for soils and snow
  - Snow: Tseganeh Gichamo (Lynker at EMC) Compared 2DVar, EnKF, and Hybrid 2DEnVar for assimilation of station snow depth in JEDI in land-only experiments; improved performance from hybrid (and EnKF)
  - Soils: Yanjun Gan (CIRES, at PSL) to implement a 3DVar soil moisture analysis in JEDI (SFS, Year 3 project)
- Addition of new obs (satellite soil moisture info, LST), and new control variables (snow temperature; see Yanjun Gan's poster)





Thanks for Listening

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Snow DA Beyond GFSv17

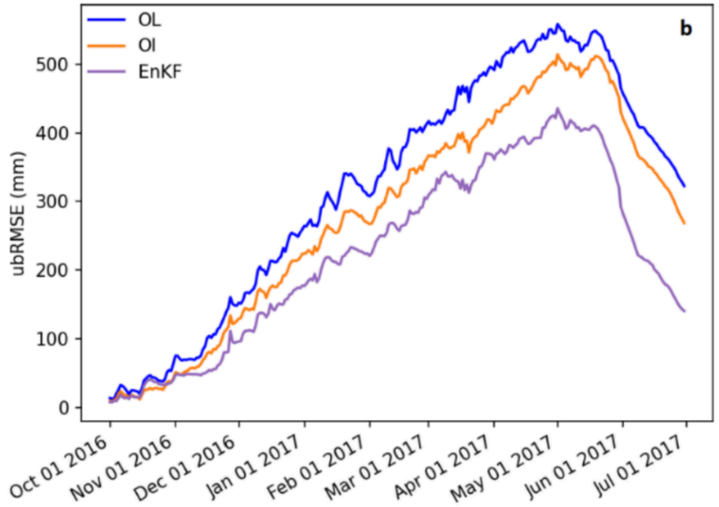
With Tseganeh Gichamo (Lynker at EMC):

- For assimilation of snow depth observations, the EnKF out-performs the 2DVar
  - Snow depth errors vary enormously in space and time
- For assimilation of snow cover, EnKF can struggle to add missing snow
- Early experiments using Hybrid 2DEnVar (in JEDI) show similar performance to EnKF, for assimilation of snow depth observations
  - Can we improve snow cover assimilation with hybrid DA?
  - Hybrid approach also more in-line with atmospheric DA

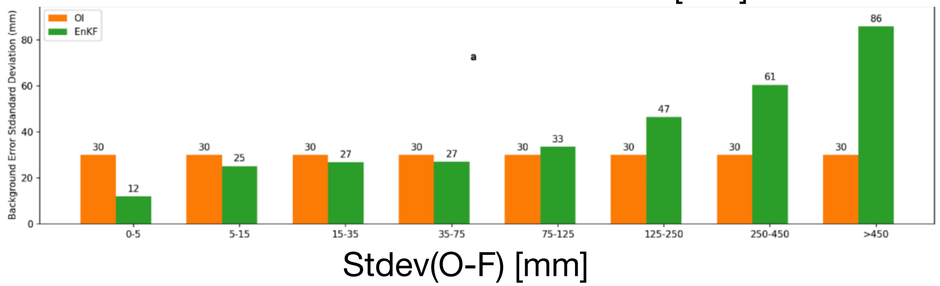
With Yanjun Gan (PSL, CIRES):

- Developing an EnKF snow temperature analysis (see today's poster)

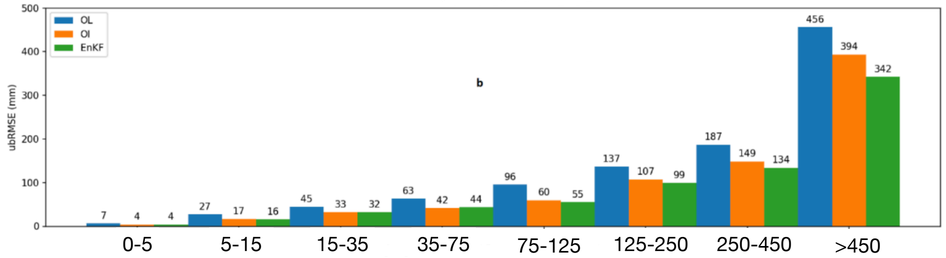
Snow Depth Error Stdev
against withheld observations [mm]



Model Error Stdev assumed in DA [mm]



Stdev(O-F) [mm]



Average grid-cell snow depth [mm]

Gichamo, et al, J Hydro (2025)