The GEFS v12 reanalyses and reforecasts

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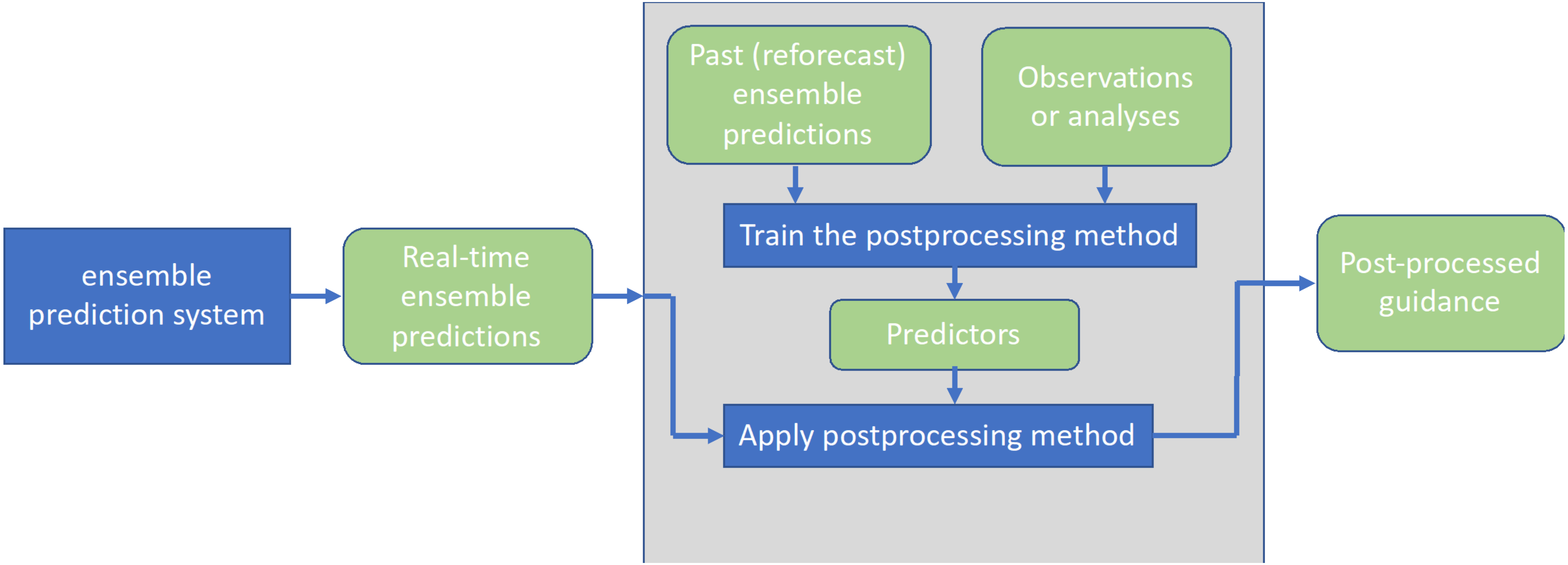
Outline

- Brief review of major changes with GEFS v12.
- Why do reforecasts? Why a new reanalysis this time, too?
- Reanalysis characteristics relative to previous generation Climate Forecast System Reanalysis:
  - Fits to observations.
  - Skills of GFS-FV3 forecasts from the two reanalyses.
- Looking to the future: GEFS v13 and beyond

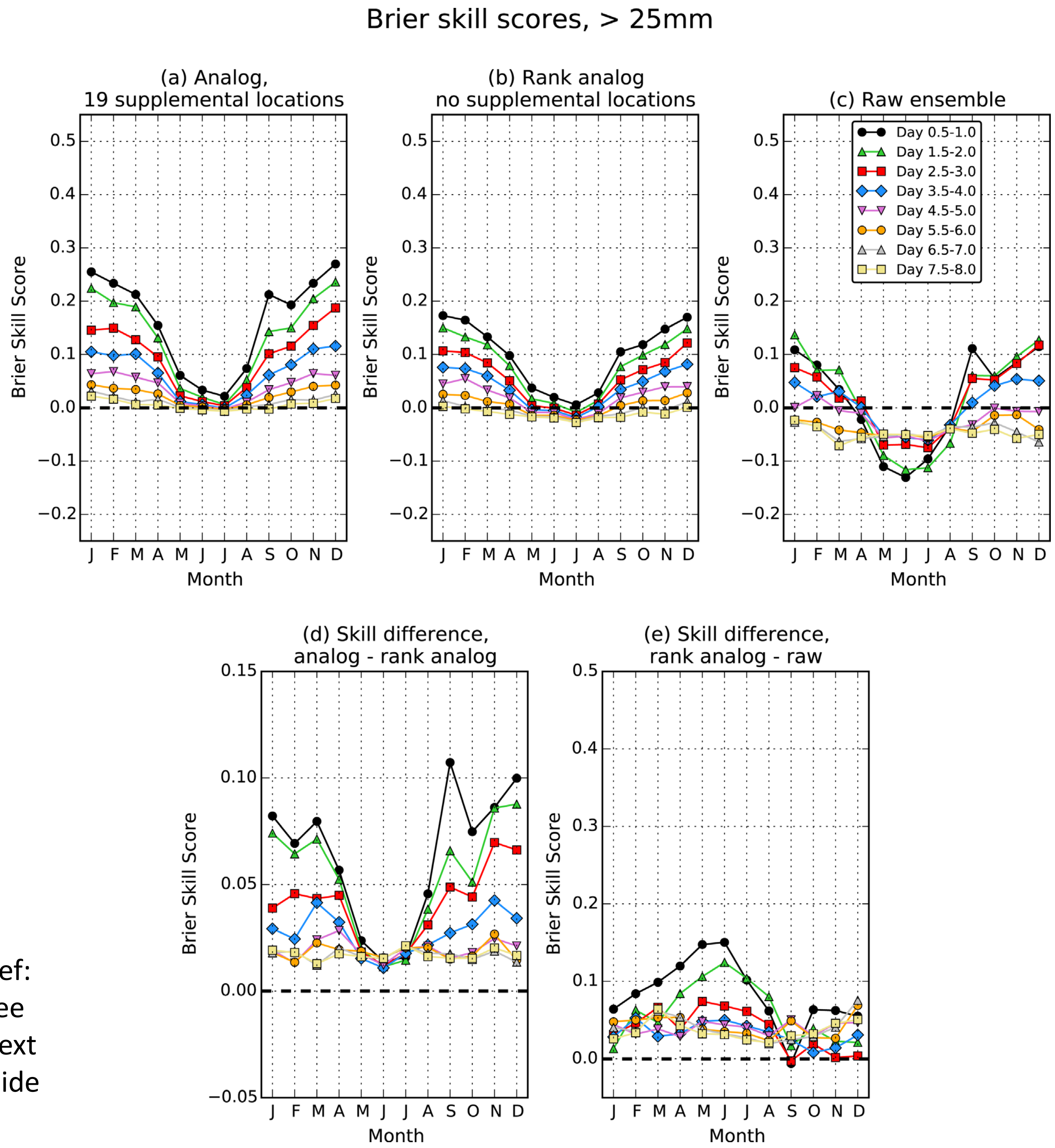
GEFS v12 implementation slated for 9 Sep 2020 (subject to modification by NCEP Central Operations)

- Per recent UFS webinar presentation by Vijay Tallapragada, EMC, GEFSv12 will provide a substantial improvement to the global ensembles. Key changes:
  - New FV3 dynamical core, applied in GEFSv12 at C384 (~ 25 km grid spacing). Key for ensembles is more small-scale variability.
  - Forecasts 4x daily, 31 members, to + 16 days lead.
  - Forecasts 1x daily, 31 members, to + 35 days lead.
  - New suite of stochastic physics, following best practices at ECMWF (SPPT and SKEB) provides much more realistic estimates of uncertainty.
  - SST evolution via transplantation of anomalies from older CFSR system.
  - The result are improved forecasts across many key variables, from hurricanes to precipitation to MJO, and more.
- GEFSv12 is accompanied by a new 20 year reanalysis and reforecast.
  - Reforecasts go back prior to 1999, but focus here is on 2000-current, as older ones initialized off CFSR.

Reanalysis and reforecasting as part of an integrated UFS prediction system.



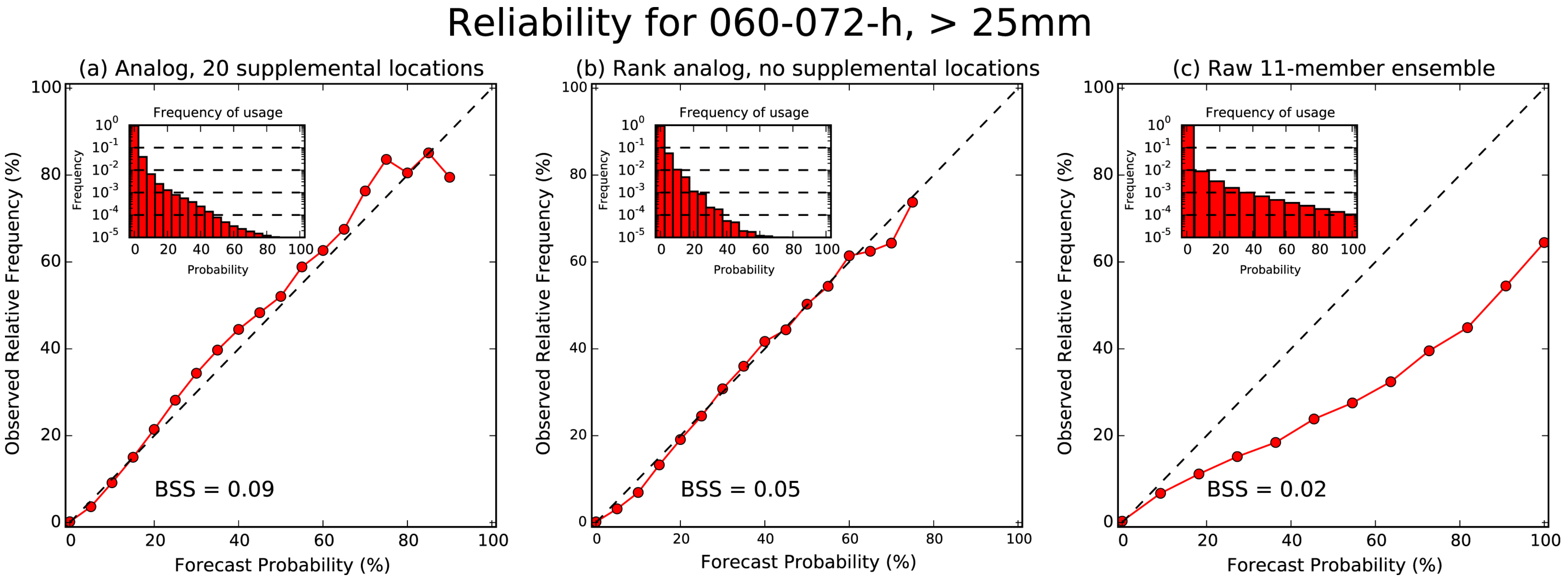
Example: precipitation forecast improvement with reforecast-based postprocessing.



Two slightly different methods for postprocessing of precipitation are compared against the skill of the raw ensemble with GEFS v10 for forecasts from days 0-8. Much improvement in these heavy precipitation forecasts. Yet more may be possible with improved GEFSv12 and more sophisticated machine-learning procedures.

Ref: see next slide

Reliability of post-processed forecasts

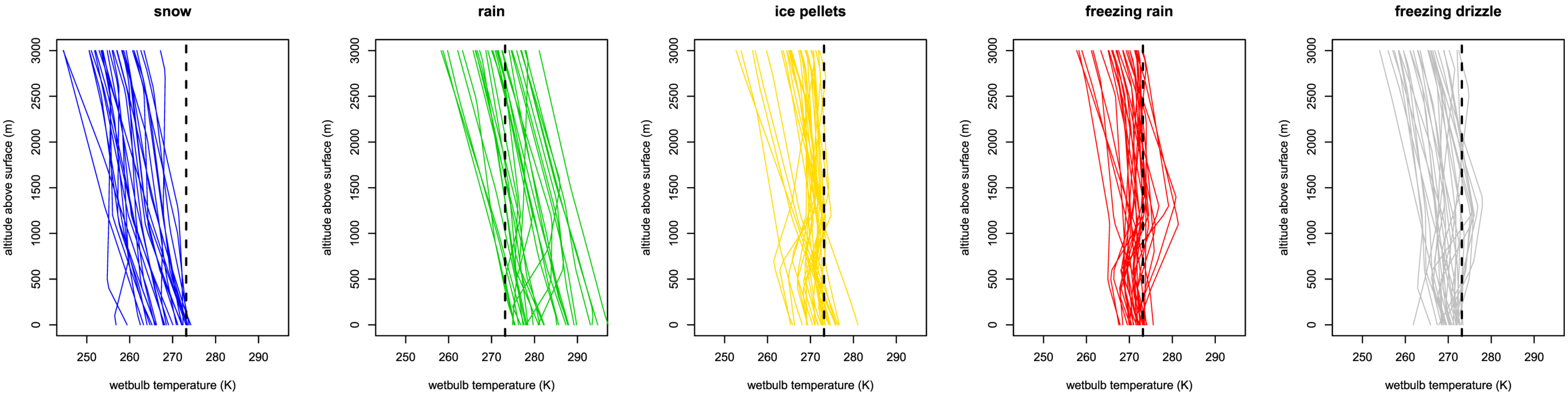


The reliability is also improved, and so customers can achieve improved decision support. With postprocessing when we say 20% probability, that event can be expected to happen 20% of the time.

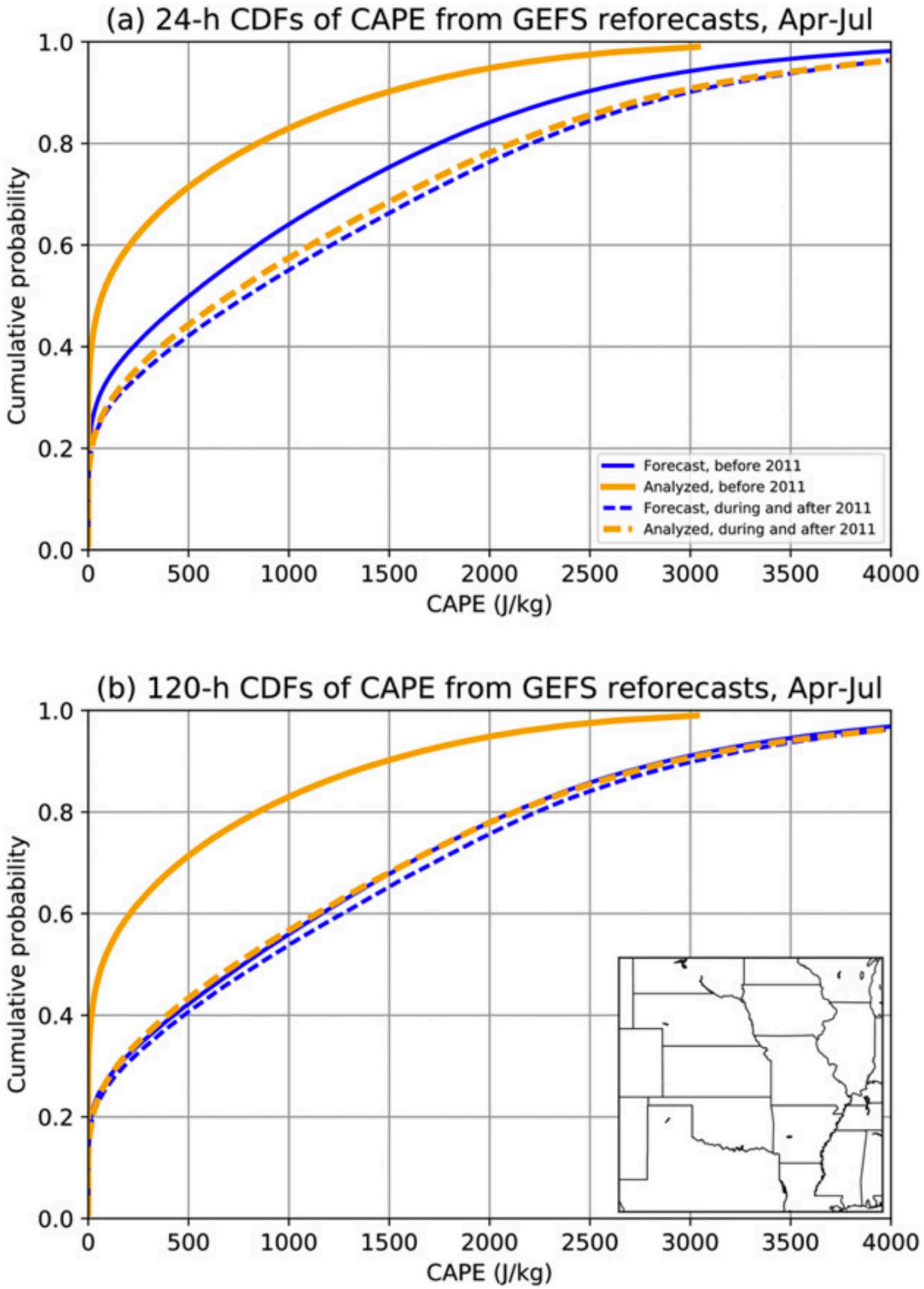
Ref: Hamill, T. M., M. Scheuerer, and G. T. Bates, 2015: Analog probabilistic precipitation forecasts using GEFS Reforecasts and Climatology-Calibrated Precipitation Analyses. *Mon. Wea. Rev.*, **143**, 3300-3309. Also: online appendix A and appendix B.

More challenging postprocessing applications will benefit from the additional data saved with GEFSv12

- Lower-tropospheric high vertical resolution GEFSv12 data will be available over a 20-year period for improved precipitation type forecasts, for example.



Ref: Scheuerer, M., S. Gregory, T. M. Hamill, and P. E. Shafer, 2016: [Probabilistic precipitation type forecasting based on GEFS ensemble forecasts of vertical temperature profiles.] *Mon. Wea. Rev.*, **145**, 1401-1412.



Modern reanalyses are expensive and difficult to produce. Why should we regularly perform them?

FIG. 1. Changes in the cumulative distribution function of analyses and forecasts of convectively available potential energy (CAPE) from GEFS reforecast initialization prior to vs during/after 2011. Data composited over April–June data for the region shown in the inset box. Red lines denote analyses, and blue lines denote reforecasts. Solid lines indicate data from before 2011, and dashed lines for data during and after 2011. Forecast CAPE at the (a) 24-h lead and (b) 120-h forecast lead. Inset box shows the domain where CDFs were calculated in the U.S. Great Plains.

Reanalyses commonly exhibit the systematic errors of the background forecasts. Until systematic errors in the analyses are reduced to a negligible level and don't change from one system version to the next, the reanalyses used to initialize the reforecasts will be a source of inconsistency between the reforecast and the real-time forecast, especially at early forecast leads. This degrades statistical postproc'ing.

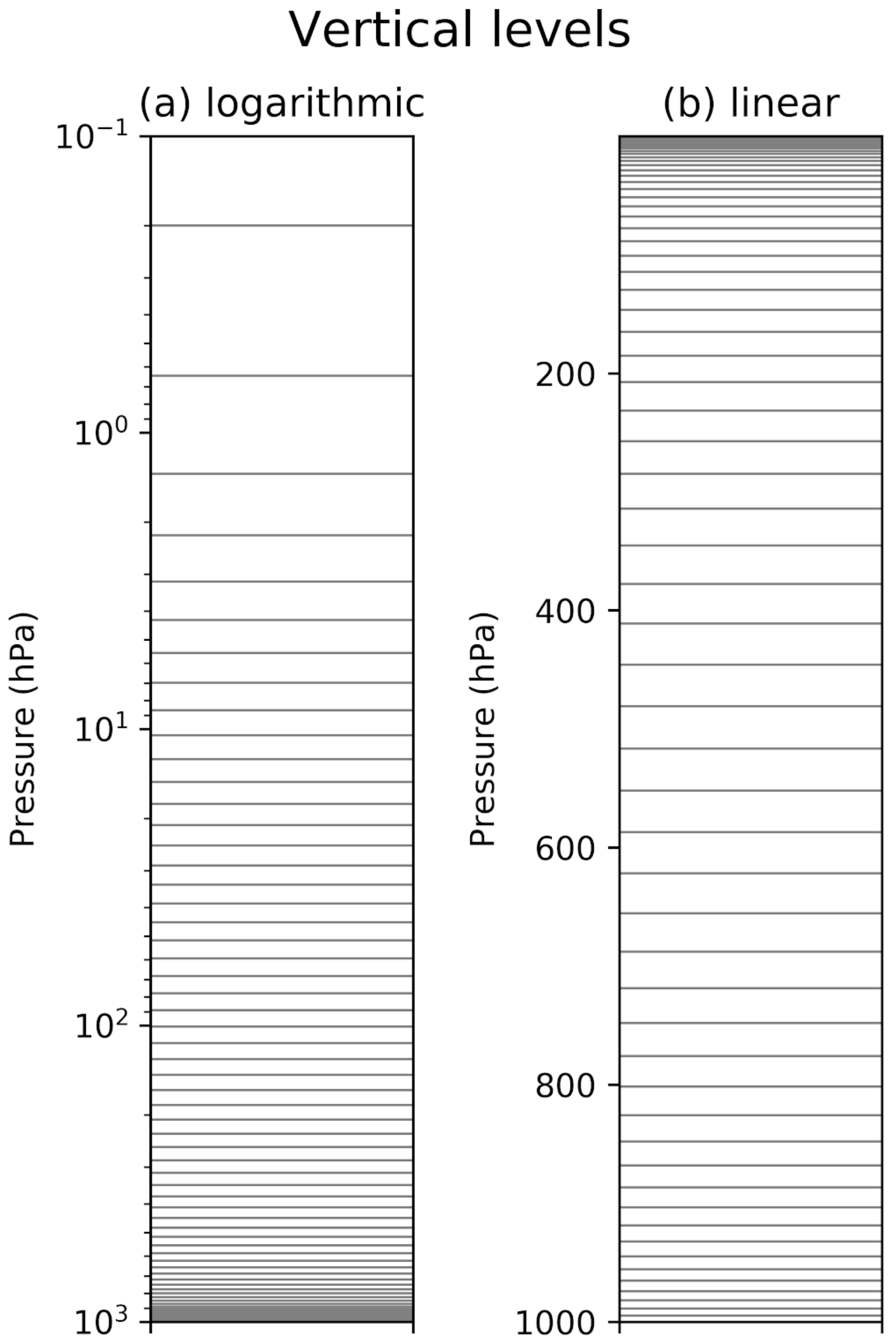
Hamill, T. M., 2017: [Changes in the systematic errors of global reforecasts due to an evolving data assimilation system.](#) *Mon. Wea. Rev.*, **145**, 2479-2485.

This reanalysis was optimized for *reforecast initialization.*

- The goal was not to produce a reanalysis that was tuned to be optimally accurate in its own right, but to *produce a reanalysis that was as consistent as practical with the eventual operational analysis system used with GEFSv12*. Consistency > absolute accuracy, bias.
- If you seek reanalysis data for model verification, climate variability analysis, and other applications, ECMWF/Copernicus ERA5 is probably a better choice.
- In the future, with decreases in UFS systematic and better coupling of analyses between state components, one NOAA reanalysis may serve multiple purposes.

Major differences, GEFS v12 vs. previous-generation CFSR reanalysis

Aspect changed	CFSR configuration	GEFS v12 configuration
Period of record	1978-current	2000 - 2020
Atmospheric dynamical core and control forecast grid spacing	Spectral, T382L64 (~ 38 km grid)	FV3 (Lin 2004, Putman and Lin 2007), C384L64 (~ 25 km grid)
Microphysical parameterization	Zhao-Carr (Zhao and Carr 1997)	GFDL (Phillips and Donner 2006, Zhou et al. 2019)
Other parameterizations	Saha et al. (2010)	GFSv15 (2020)
Atmospheric data assimilation methodology	3D-Var through 2011 (Parrish and Derber 1992, Kleist et al. 2009)	Hybrid En-Var
Ensemble usage in data assimilation	None through 2011, then following operations	80-member EnKF at C128L64 (~ 75 km) to provide background- error covariances
Ensemble stochastic physics	None (single control member for data assimilation)	Stochastically perturbed physical tendencies (SPPT), stochastic boundary-layer relative humidity (SHUM), and stochastic kinetic-energy backsctatter (SKEB) [this paper]
Snow updates	SNODEP (Kiess and Kopp, 1997) before 1997, NESDIS IMS (Helfrich et al. 2007) thereafter. Updated 4x daily.	NESDIS IMS (Helfrich et al. 2007). Updated only at 00 UTC, otherwise climatology for other 3 cycles (a bug).
Land-surface analysis	Separate land-surface analysis with analyzed forcings (Saha et al. 2010)	Land-surface forcings directly from short-term forecasts.
Ocean analysis	SST via OI (Reynolds et al. 2007); rest of ocean state with 3D-Var using MOM4 ocean and weak coupling	SST via OI (Reynolds et al. 2007). No weak coupling in cycled DA, no full ocean analysis.
Tropical cyclone processing	Vortex relocation to observed position (Liu et al. 1999)	Direct assimilation of central pressure, no relocation



64 vertical levels. Depending on how you look at it, there's either many vertical levels in the upper stratosphere, or perhaps not quite enough.

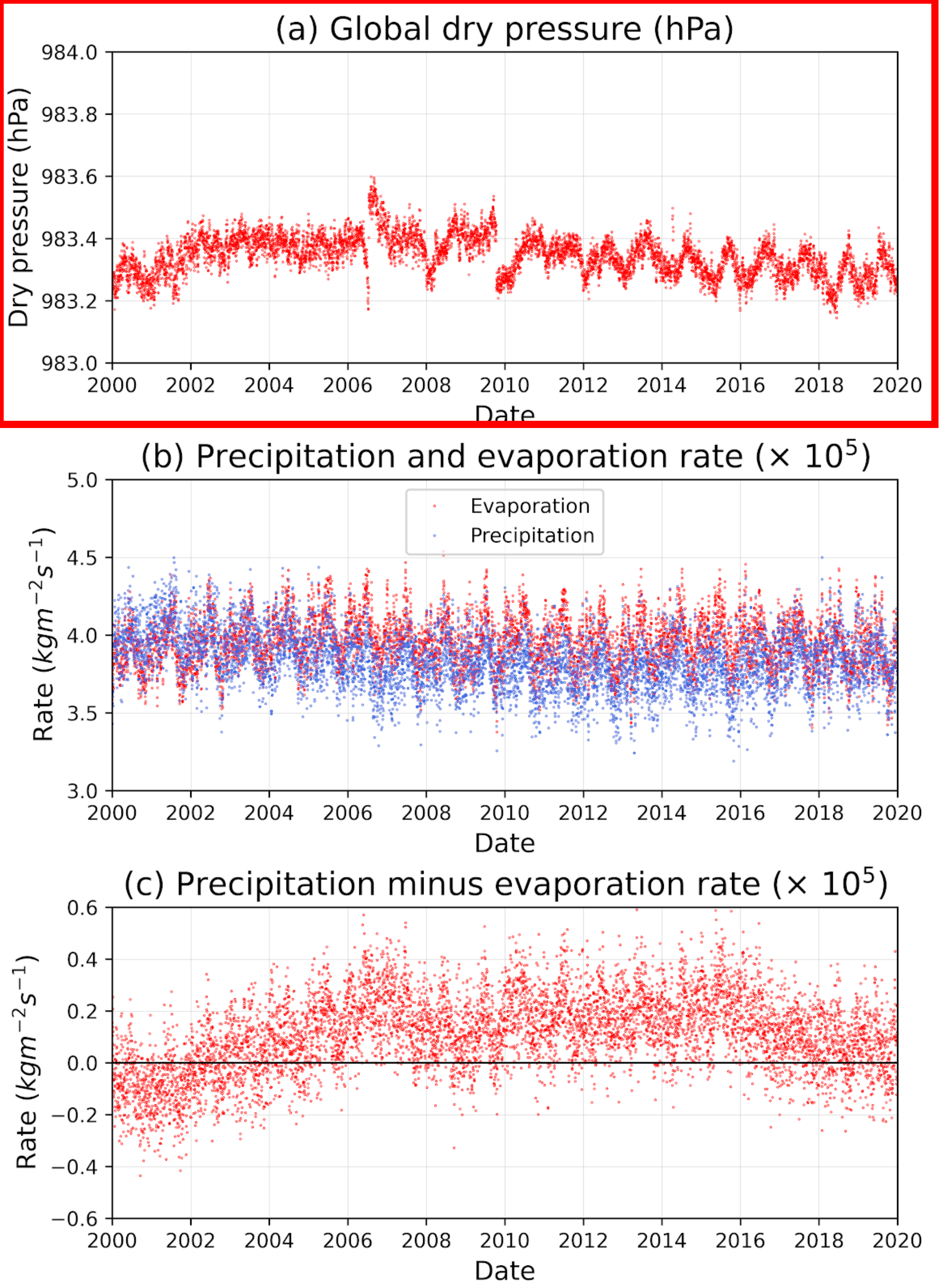
These levels are often critical, for example for gravity-wave momentum deposition, and as a source of extended-range predictability (QBO, Arctic Oscillation, sudden stratospheric warmings).

Major differences between the eventual real-time operational analysis and the reanalysis, + known bugs

- **Analysis resolution**: ½ of operations because of computational expense.
- **SST**: OI in reanalysis vs. NSST in real-time (NSST had large biases in data-sparse cloudy regions early in reanalysis period).
- **Snow initialization**: only refreshed once per day, 00 UTC in reanalysis, while refreshed 4x/day in operations. Addressed somewhat through a "replay" process.
- Some velocity-azimuth-display (VAD) winds snuck in with QC problems during bird migration. Turned VAD off when discovered.
- There are possibilities of finding more issues as more users look through the data.
- A few others (pressure jumps) discussed in subsequent slides.

Evaluation of the GEFSv12 reanalyses

- Fit of short-term (background) forecasts to newly available observations as a metric for system improvement.
- Deterministic “scout” runs with FV3 GFS from CFSR and GEFS v12 initial conditions, verified against independent (ECMWF) reanalyses.
- Other various diagnostics (QBO, checking expected conservation properties).
- Incomplete: comparisons of skill during overlap period of GEFSv12 reforecast and GEFS retro.

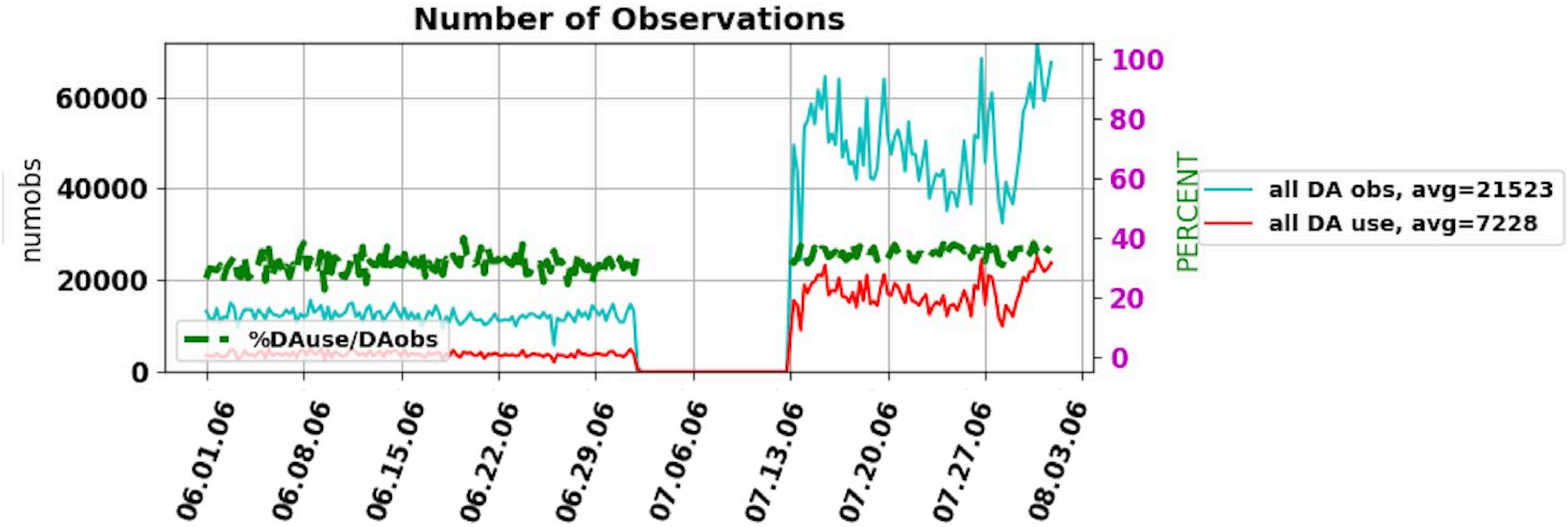


"Analysis" time series with dry pressure jumps.

Dry pressure jumps ~ July 13-15 2006 and Oct 11-13 2009. The first is understood (next few slides), the second not yet.

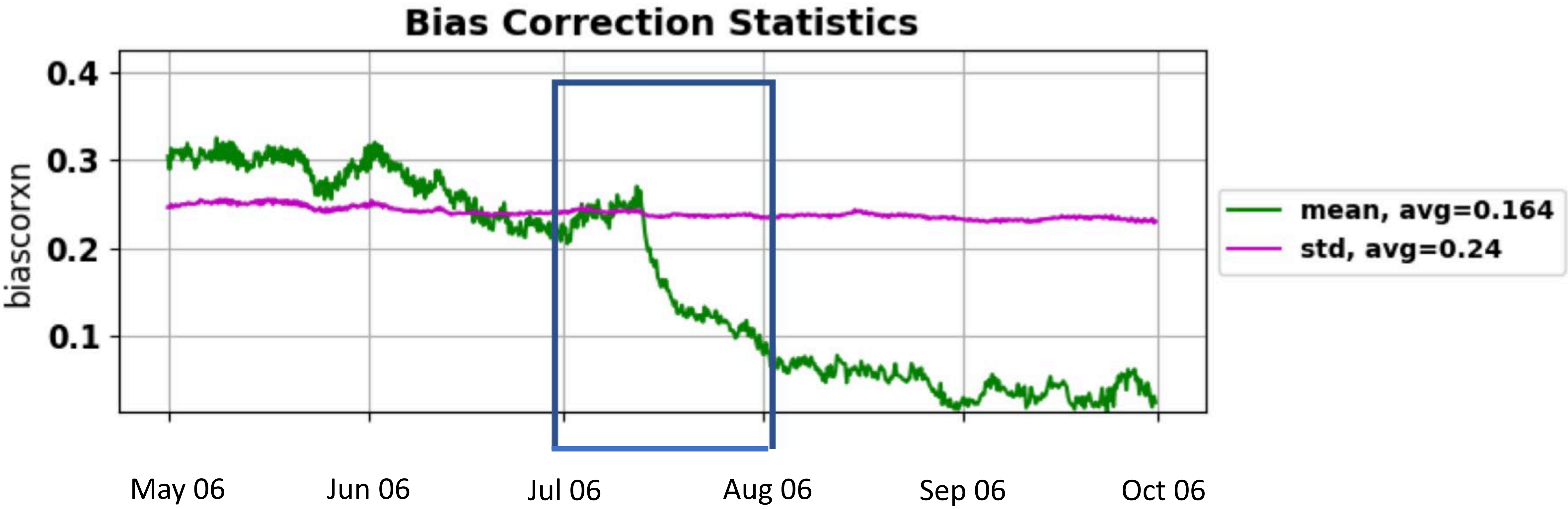
(this data is actually calculated with 6-hour forecasts; the eventual figure for the journal article will be based on analysis data)

GPS radio occultations observation count during pressure 2006 jump.

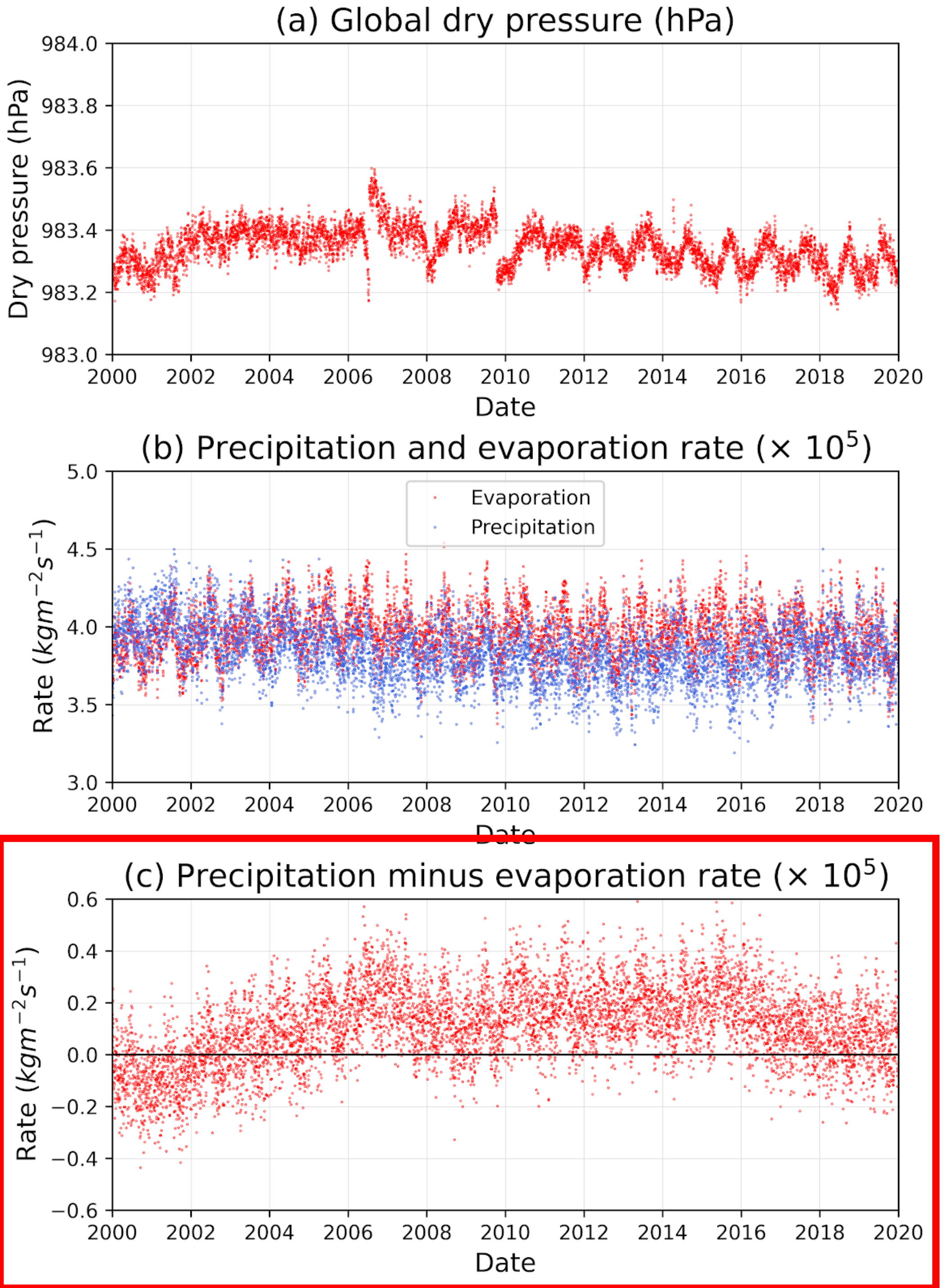


The sudden advent of the assimilation of many more GPSRO observations during this period suggests that these observations both directly affected the thermodynamic characteristics of the atmosphere (its integral reflected in the surface pressure) and indirectly, by anchoring the satellite radiances (next slide).

NOAA-15 AMSU-A channel 7 bias corrections

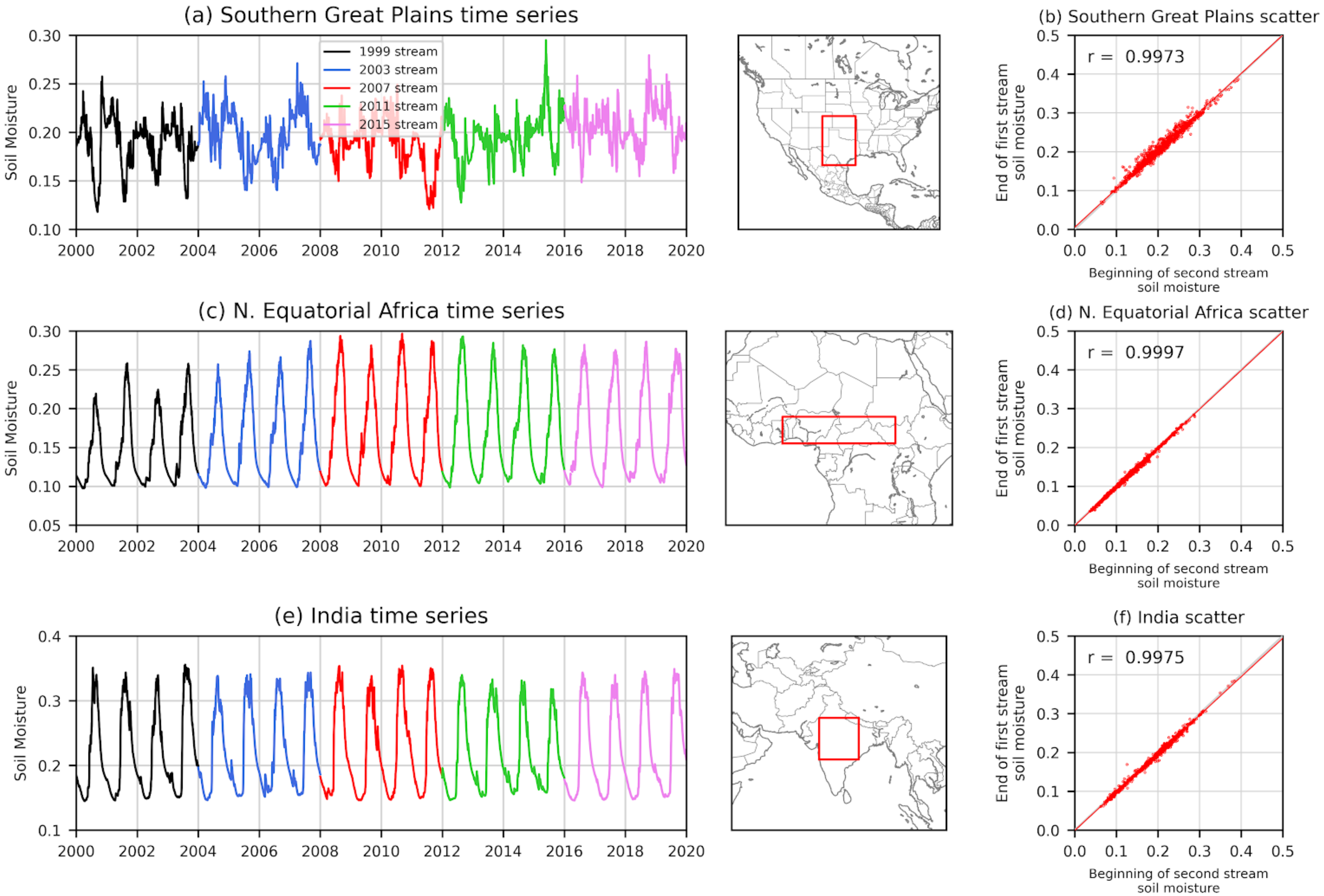


When (unbiased) GPSRO observations became much more plentiful, it was possible to more effectively bias correct the AMSU-A satellite data. Temperature corrections then caused the pressure jump.



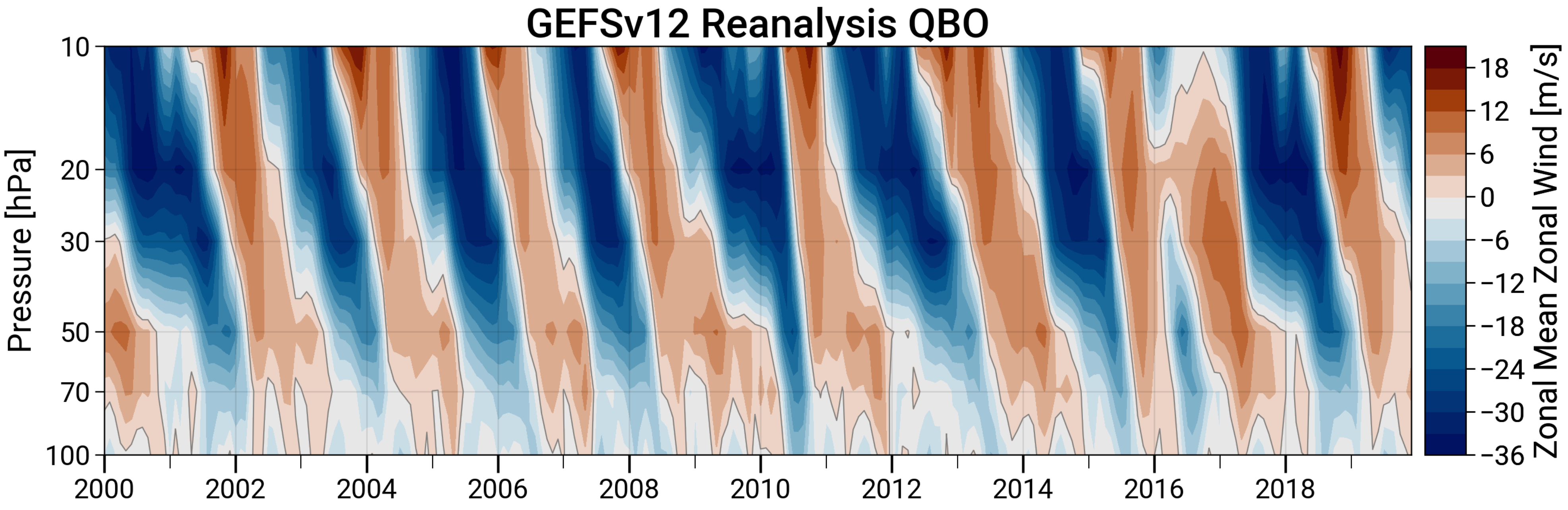
Precipitation minus evaporation

P - E here clearly not = 0. This reanalysis did not have the advanced procedures of NASA's MERRA-2 to close the water cycle.

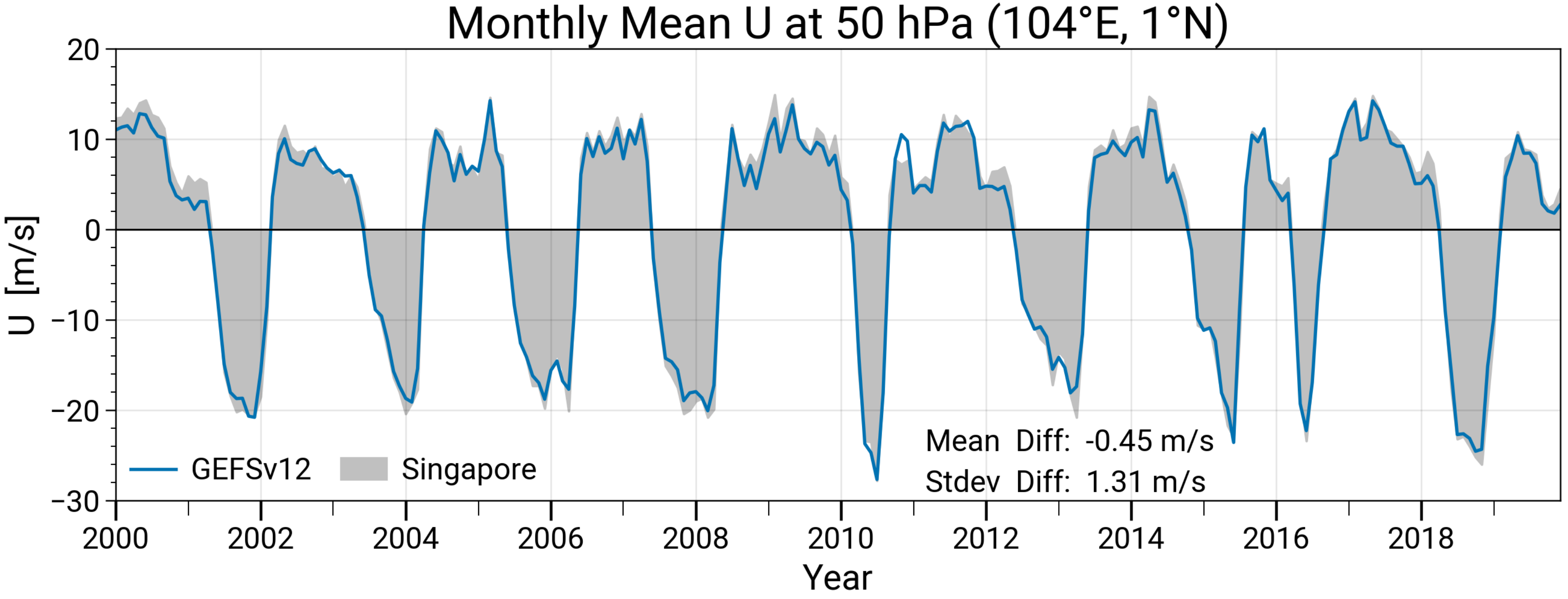


Problems with soil moisture at stream boundaries?

Illustration of 4-10 cm layer soil moisture for three regions with strong land-atmosphere coupling, following Koster el al. 2006. No sign of problem at stream boundaries.

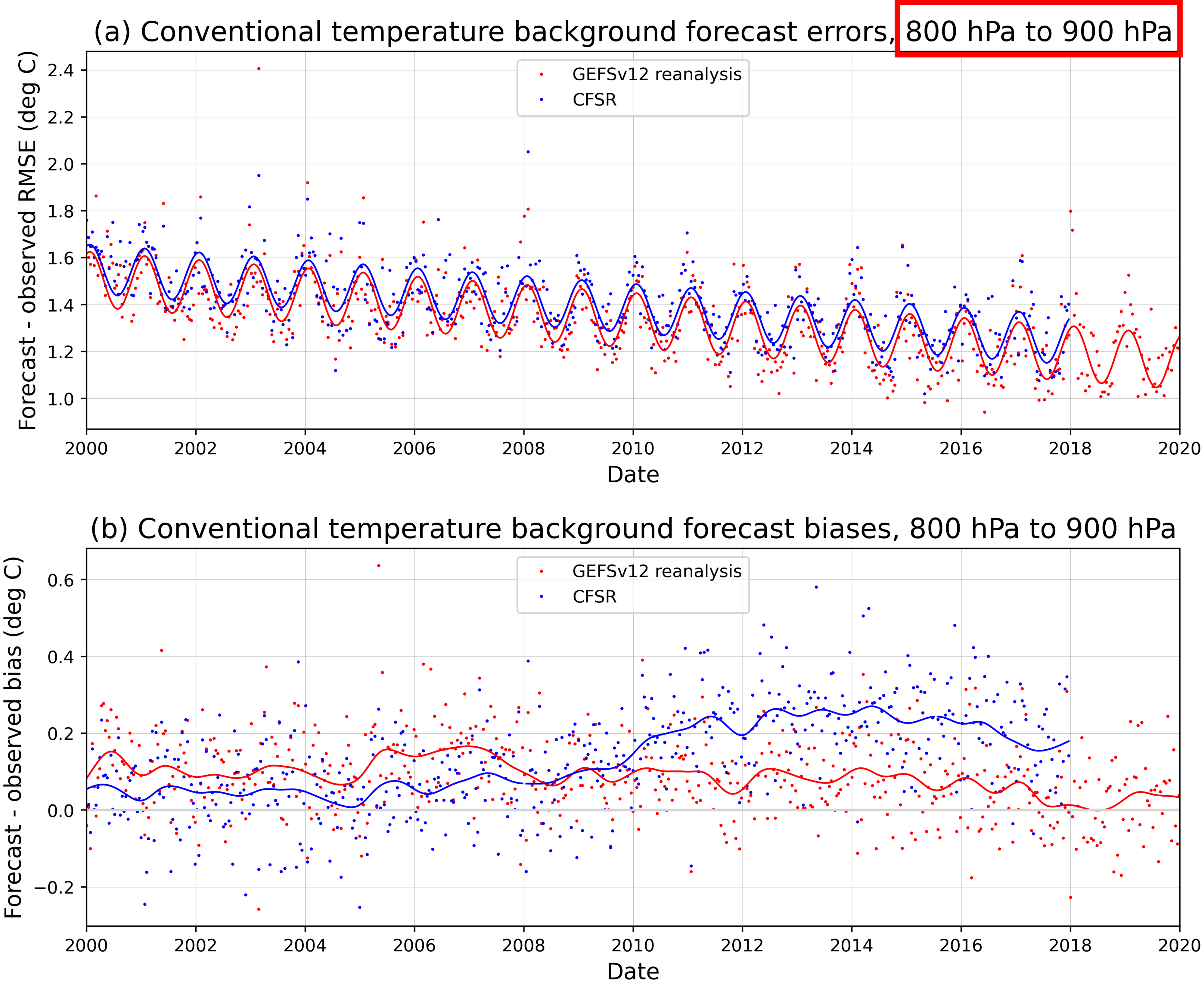


QBO in this reanalysis



No smoking-gun problems.

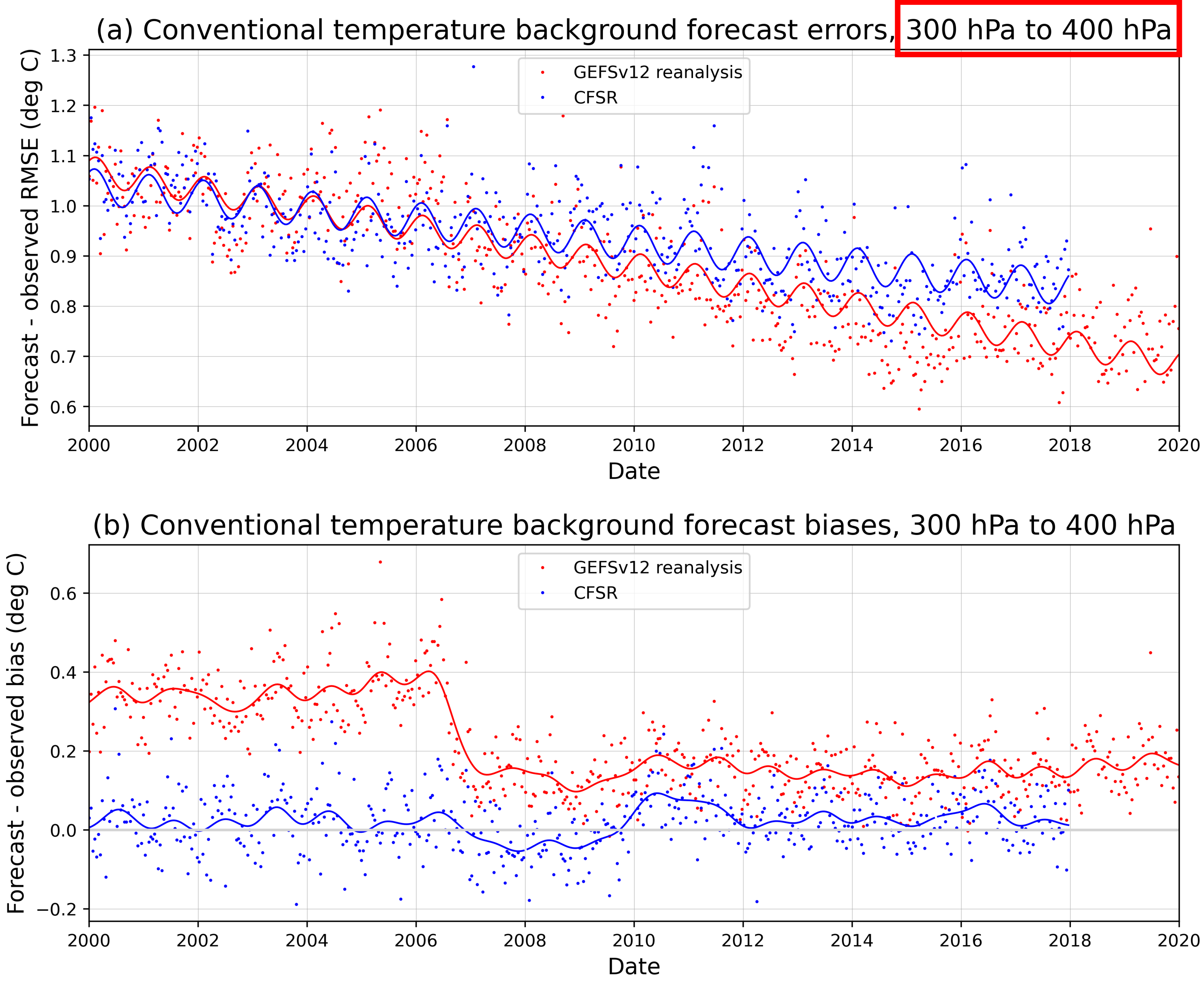
figure c/o Zac Lawrence, CIRES and PSL



Conventional data fit to observations

Improvement with GEFSv12 reanalysis in the fits to conventional observations is apparent here.

Top uses regression fit including an annual cycle. Bottom is a Gaussian kernel smoother with a 20-week smoothing timescale.

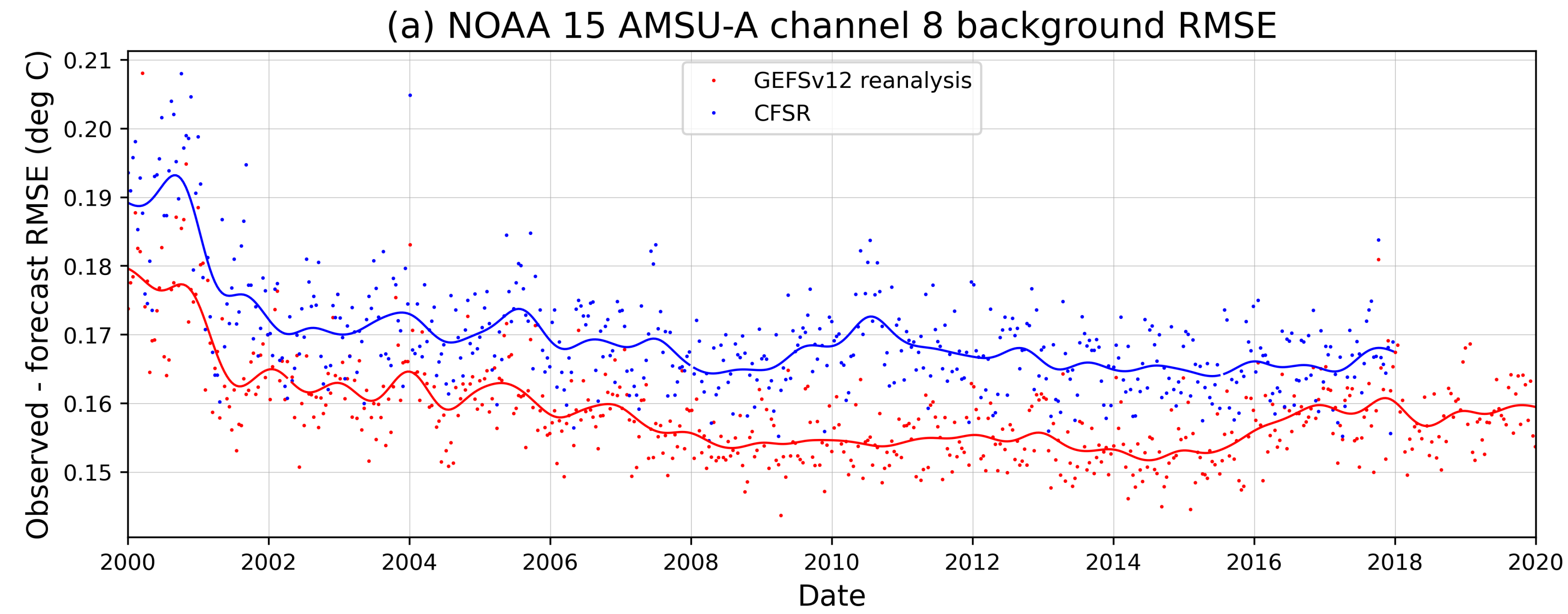


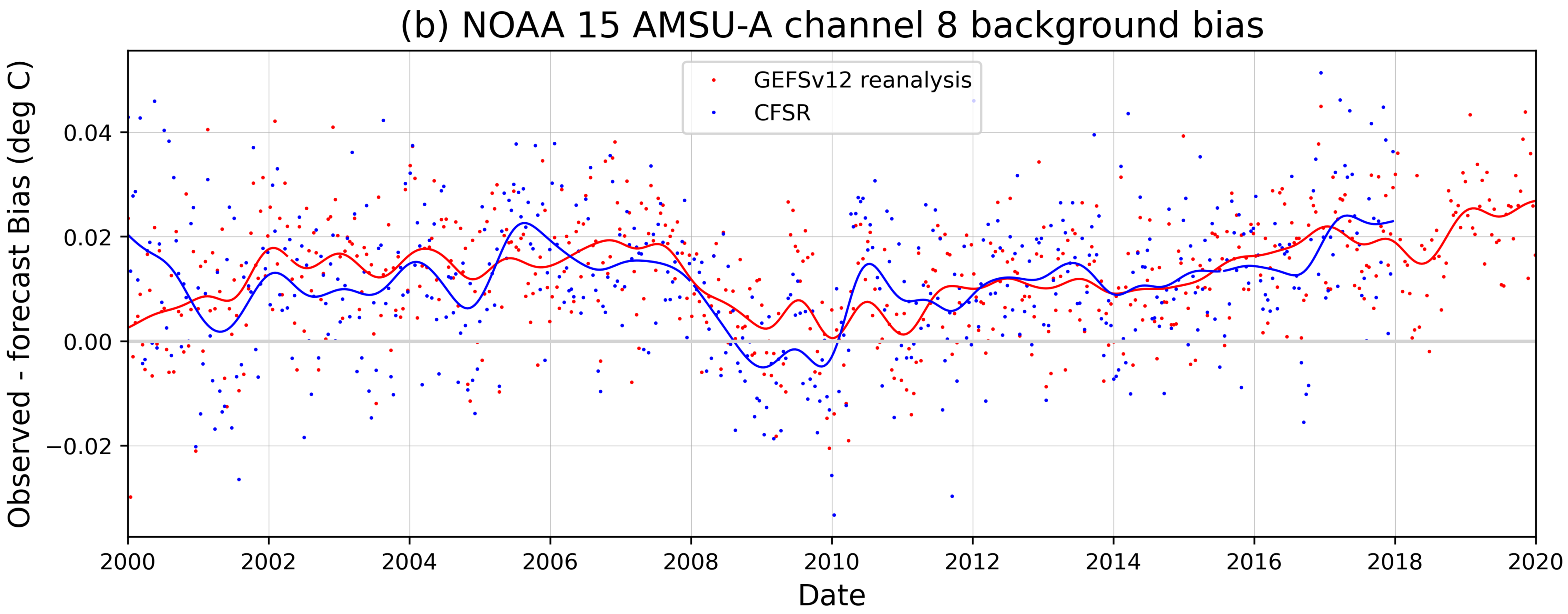
Conventional data fit to observations

Improvement with GEFSv12 reanalysis in the fits to conventional observations is apparent here.

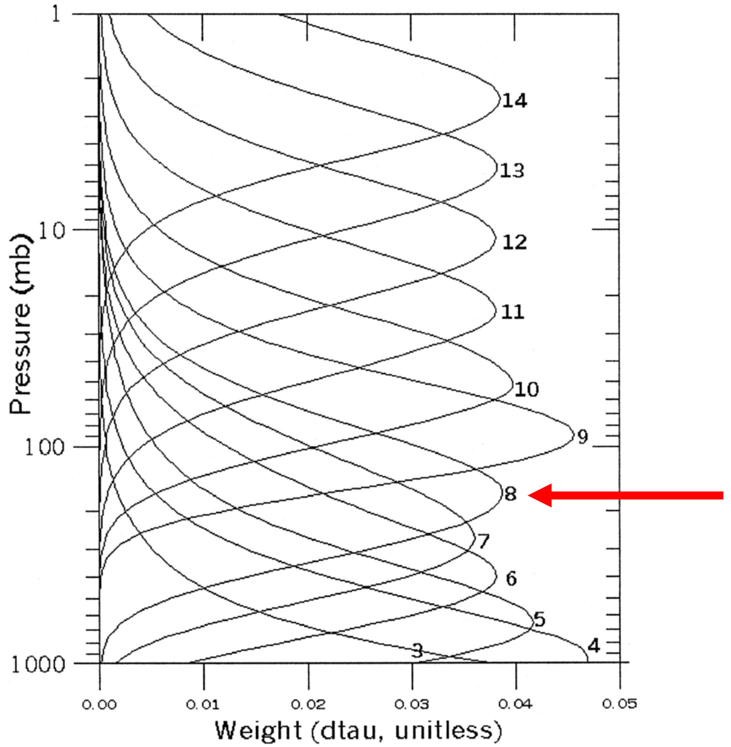
Improvement in bias roughly coincides with period when GPSRO data became widely available (launch 15 April 2006, data came online slowly thereafter), so likely that helped anchor other observations and reduce bias.

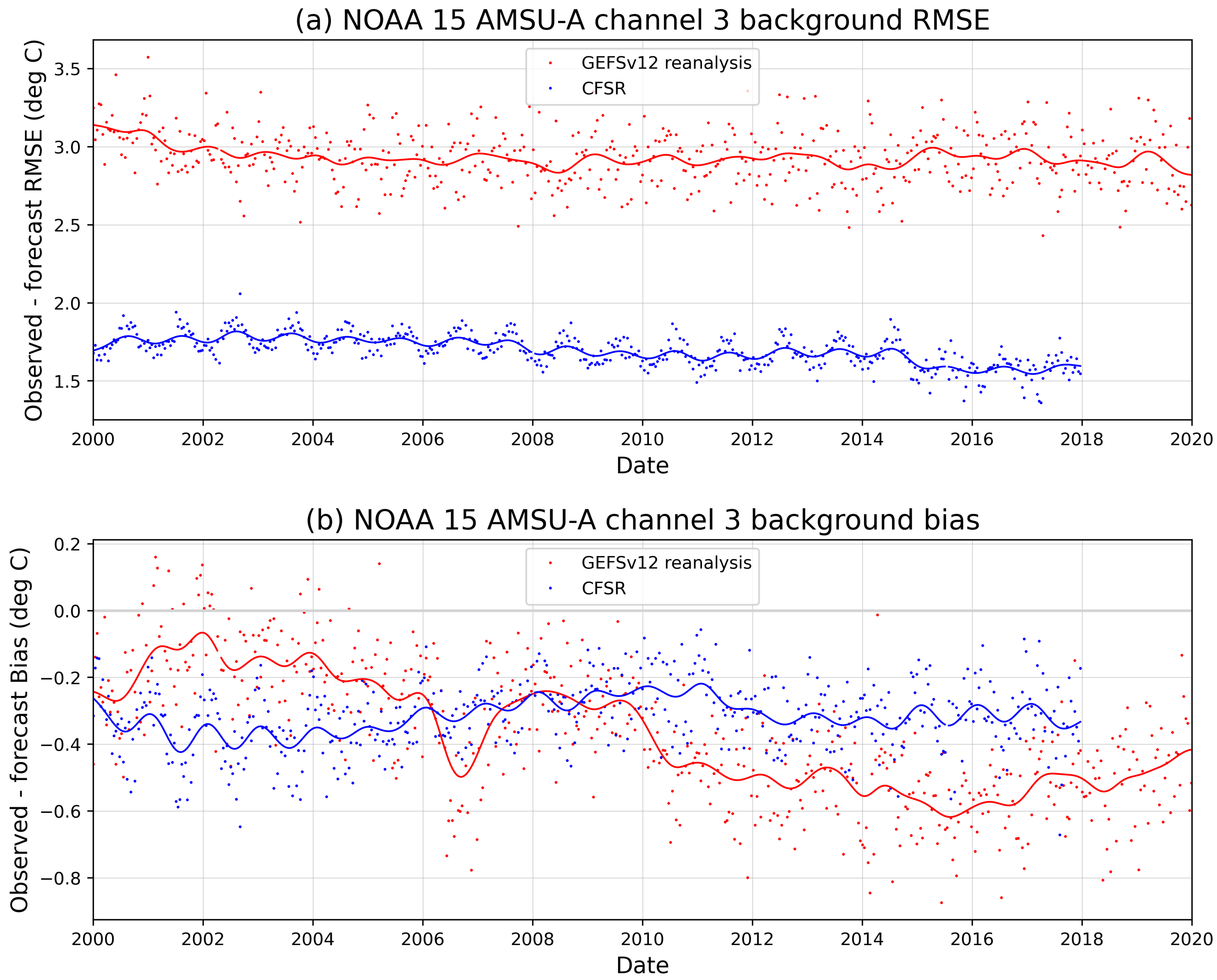
Satellite radiance fit of background to observations



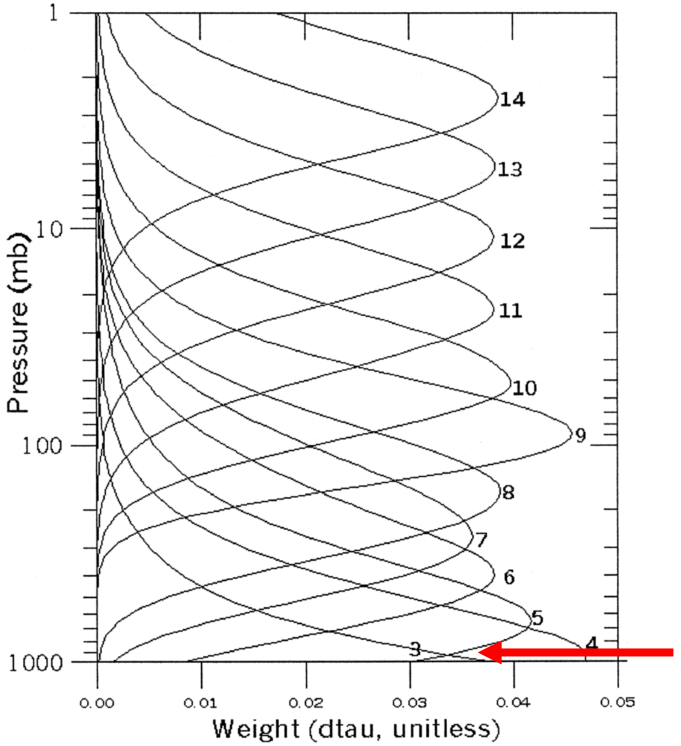


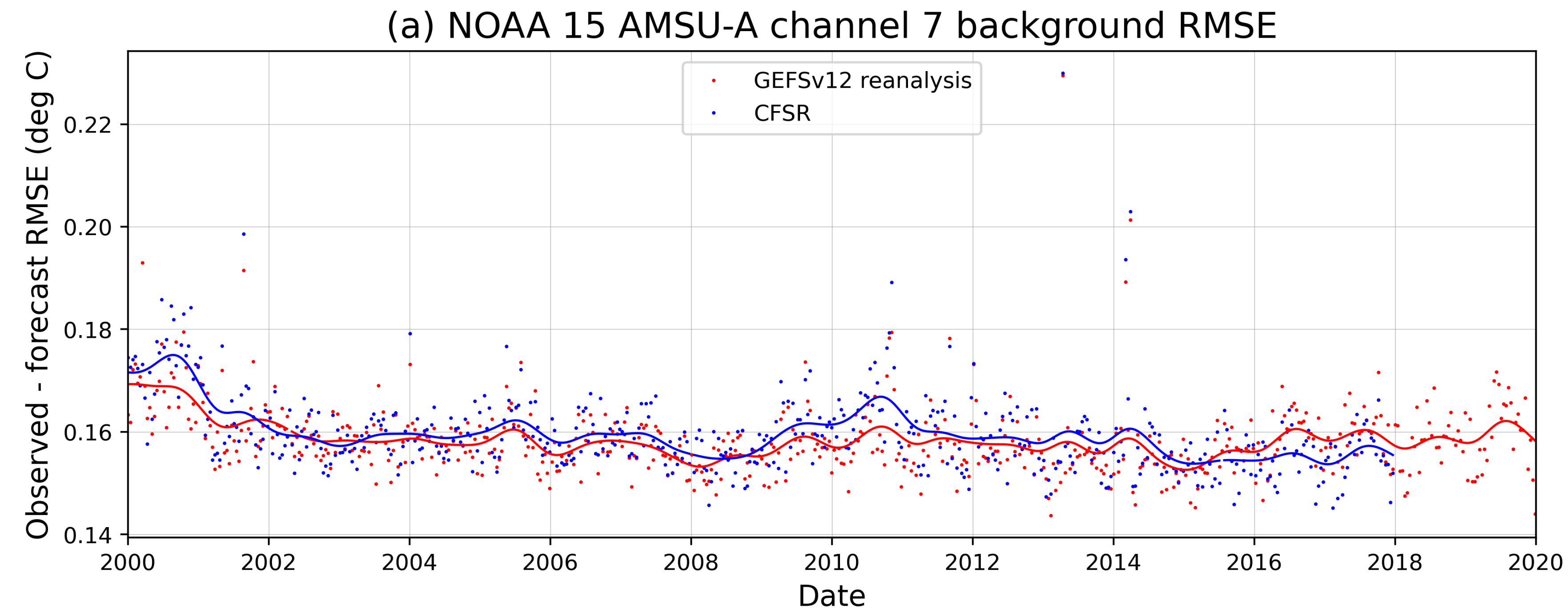
AMSU-A channel 8 peaks around 180 hPa.





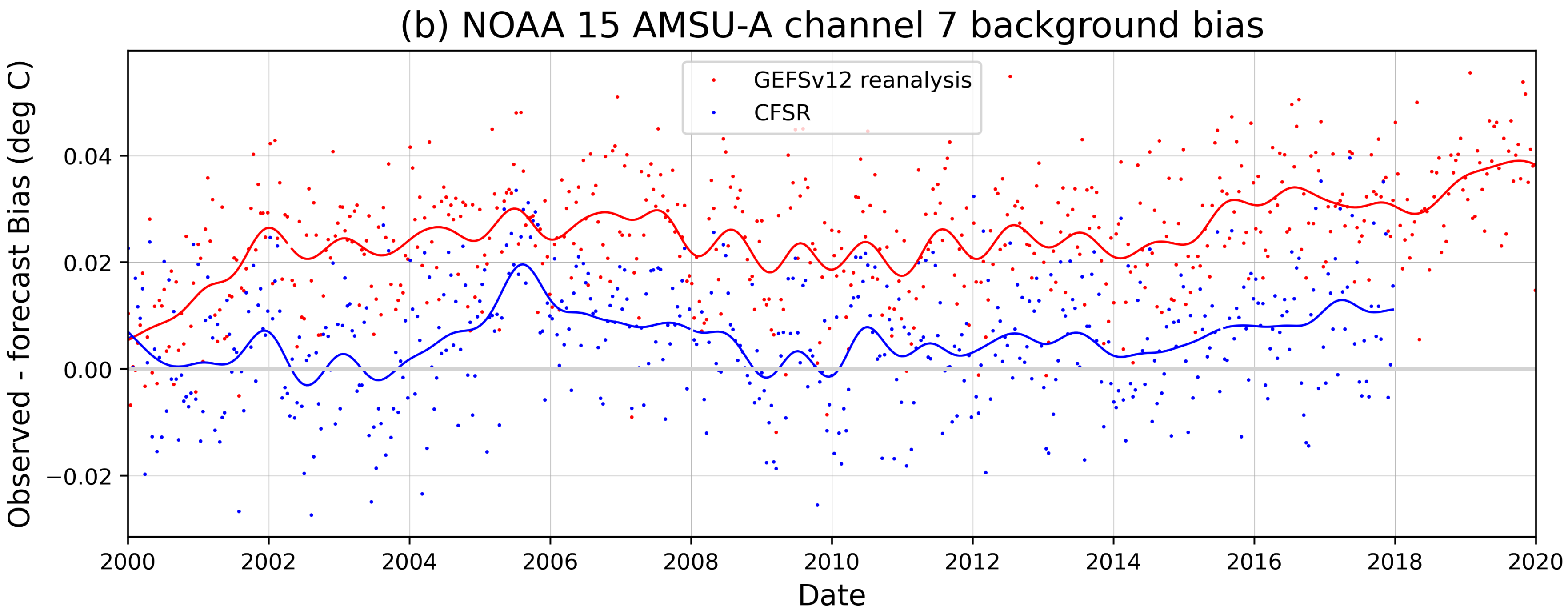
For channel 3 and some others, a direct comparison is not possible, in that GEFS v12 assimilated cloudy radiances, but CFSR did not.

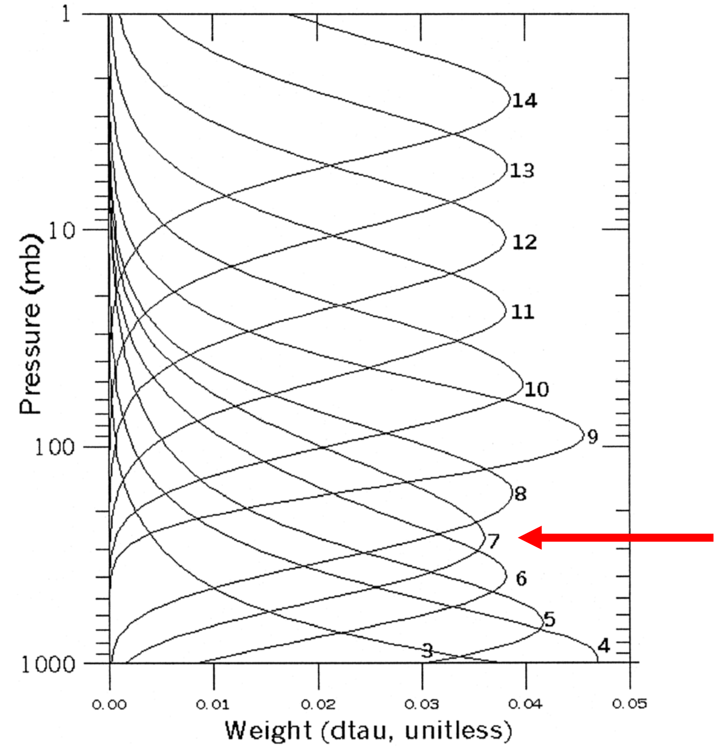




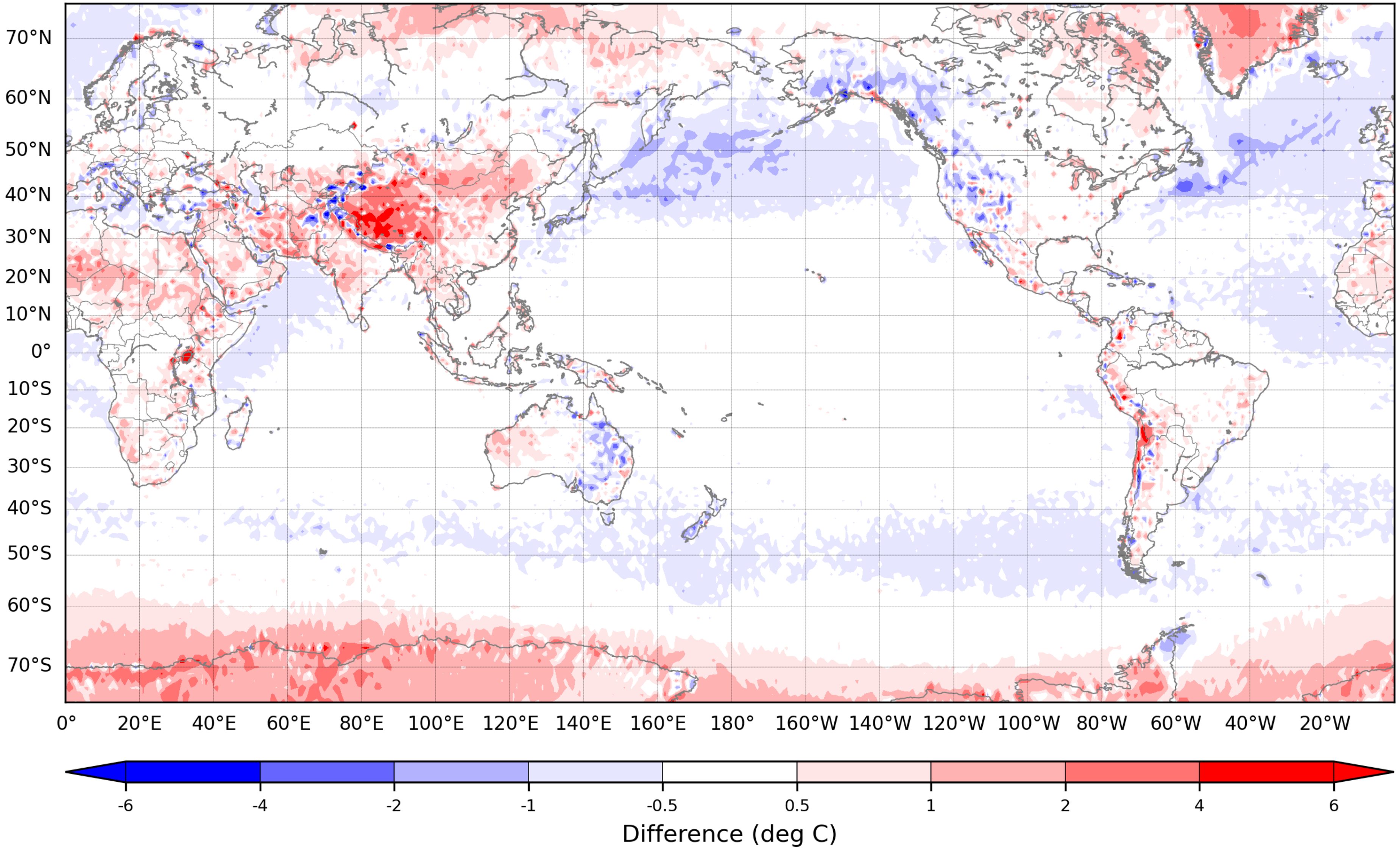
Channel 7 weighting function peaks around 300 hPa.

Why the larger bias in the new reanalysis?





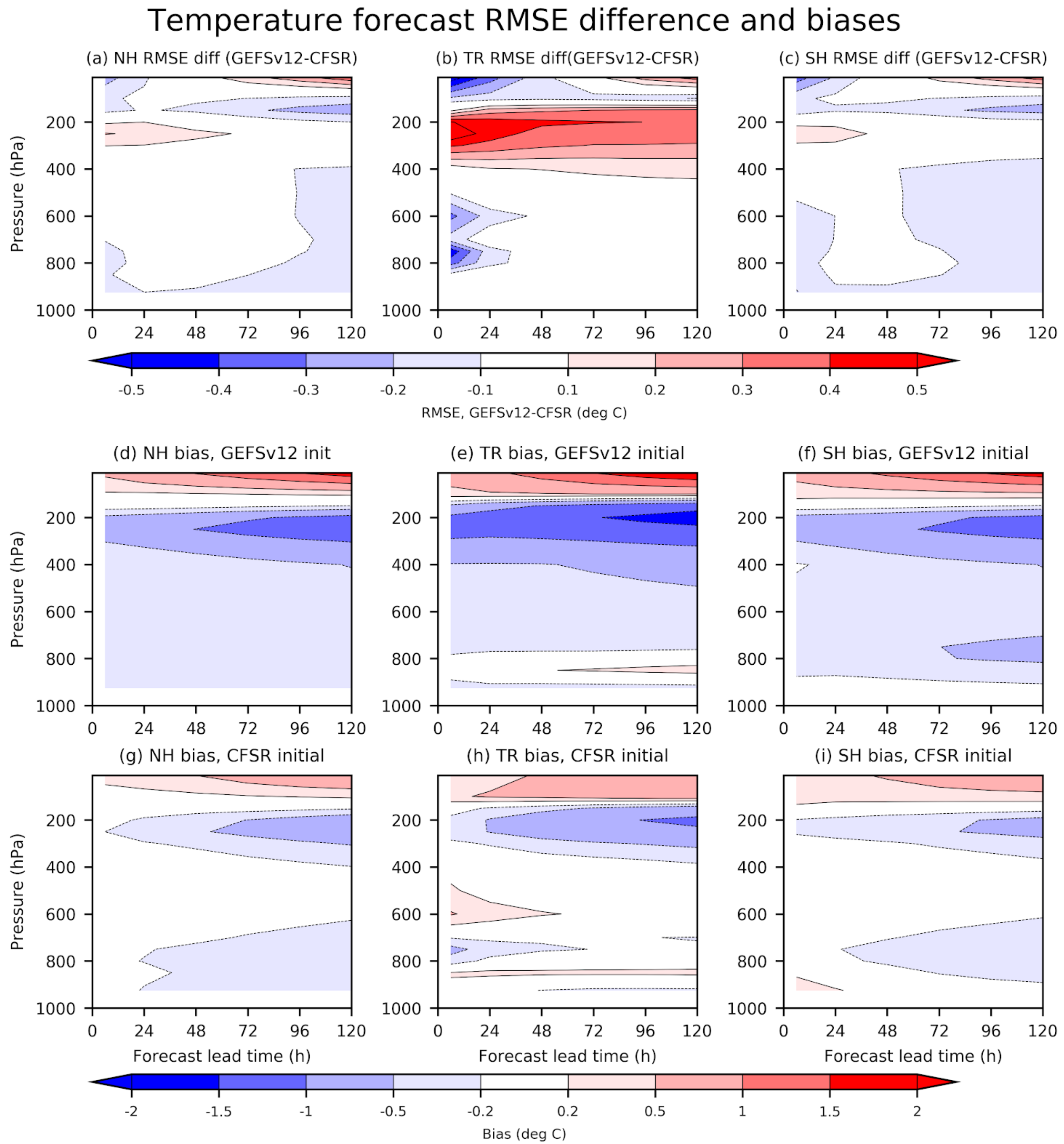
00 UTC global skin temperature differences, pre-production parallel minus reanalysis, 1 Dec 2017 to 30 Nov 2019



Does skin temperature (effectively SST over the ocean) differ substantially with use of "NSST" in operations vs. "OI" SST in the reanalysis?

Do skin temperatures over land differ systematically, with GLDAS used in operations and not in reanalysis? Also perhaps snow analysis deficiency introduces reanalysis issues.

While there are differences (skin temperature is a very sensitive variable) I don't see differences that raise major concerns,



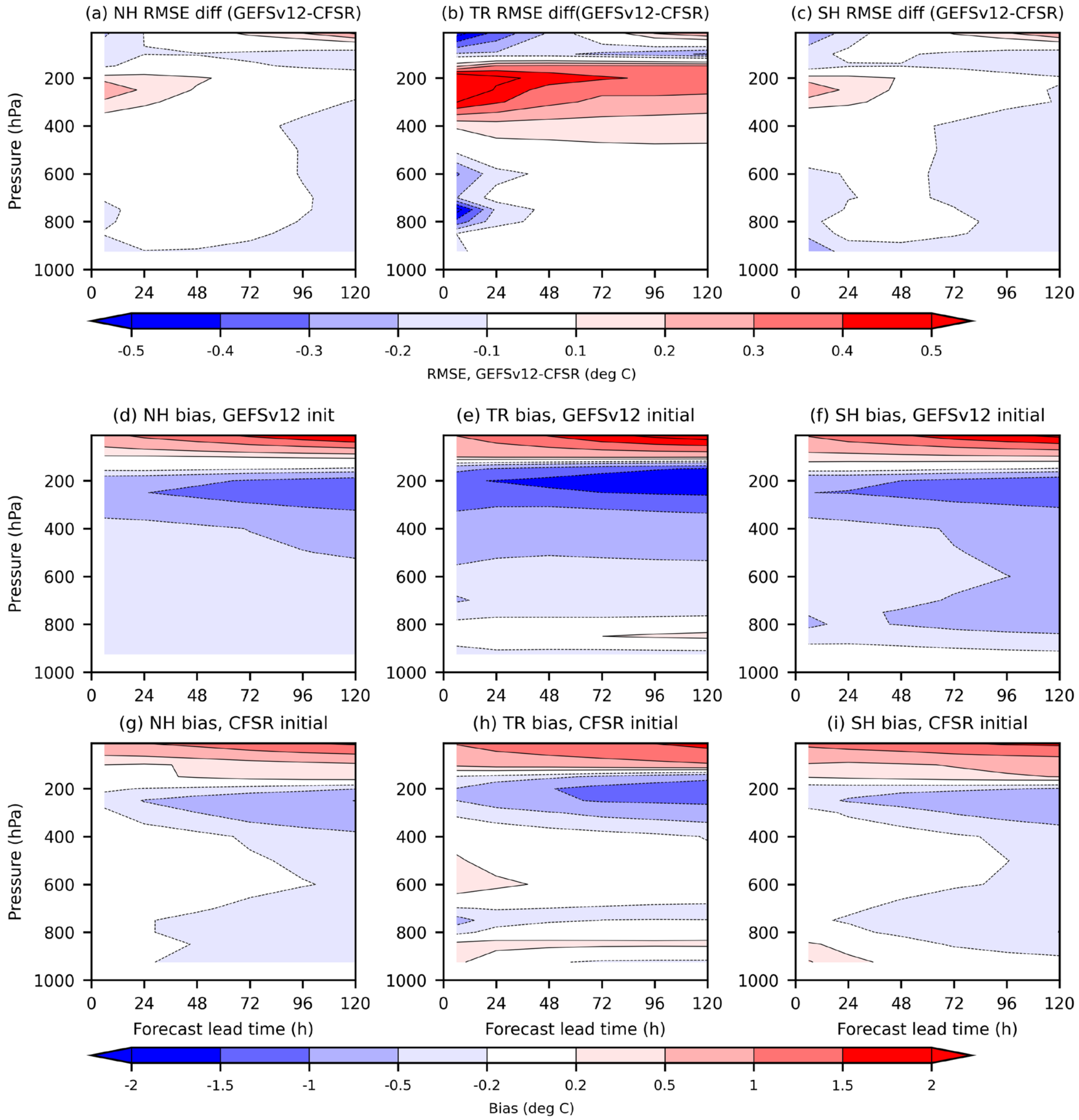
The larger bias around 300 hPa is also seen in this comparison of relative RMSE and bias for GEFSv12 and CFSR compared to ERA-Interim.

(we are working to re-do this comparison with ERA-5 as a replacement for the verification data)

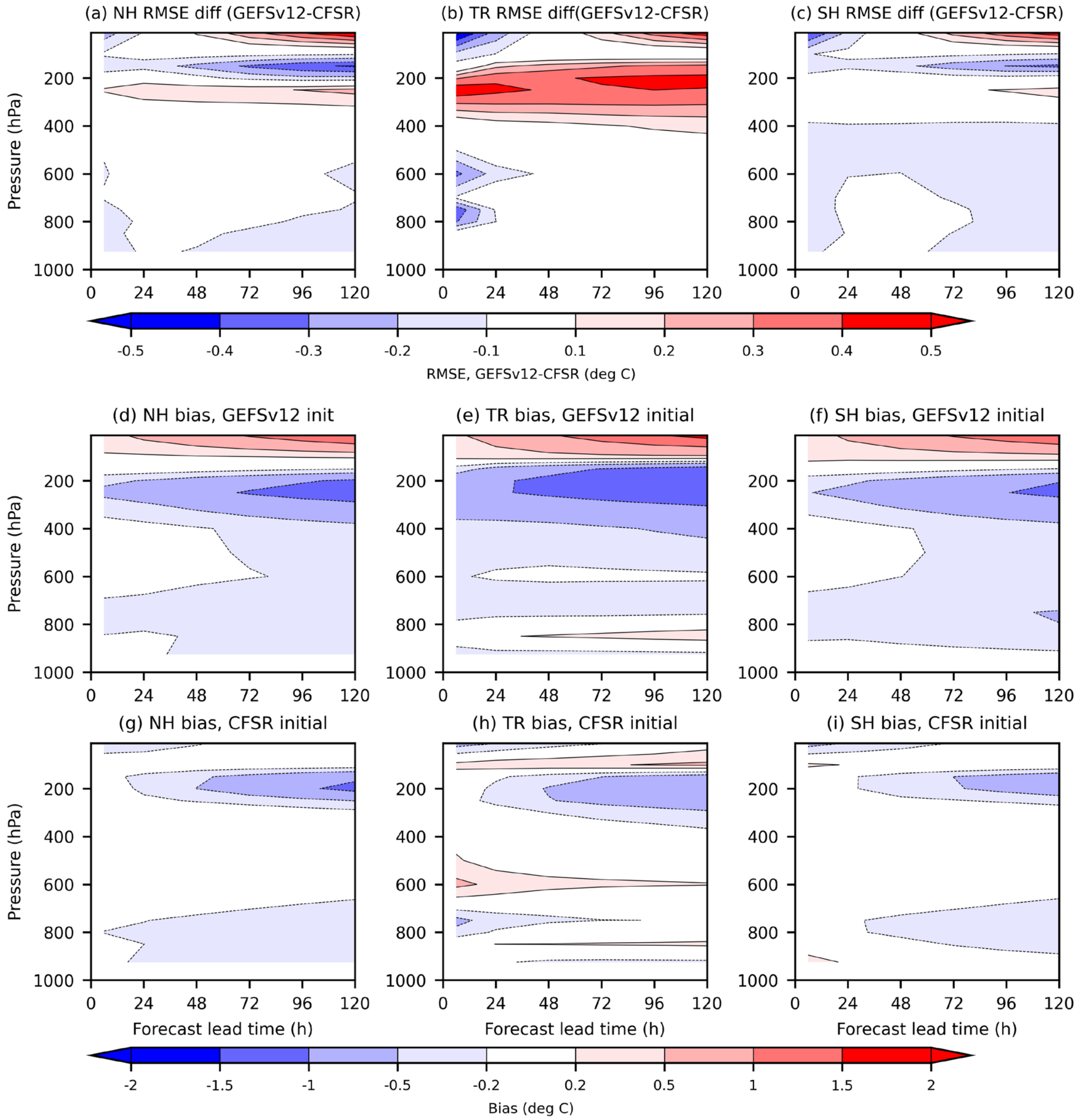
Consistently, NH, TR, SH shows greater bias around 250 hPa in GEFS v12. Major changes that could possibly affect this include FV3 dycore and microphysics (Zhao-Carr → GFDL). An issue for UFS physics team?

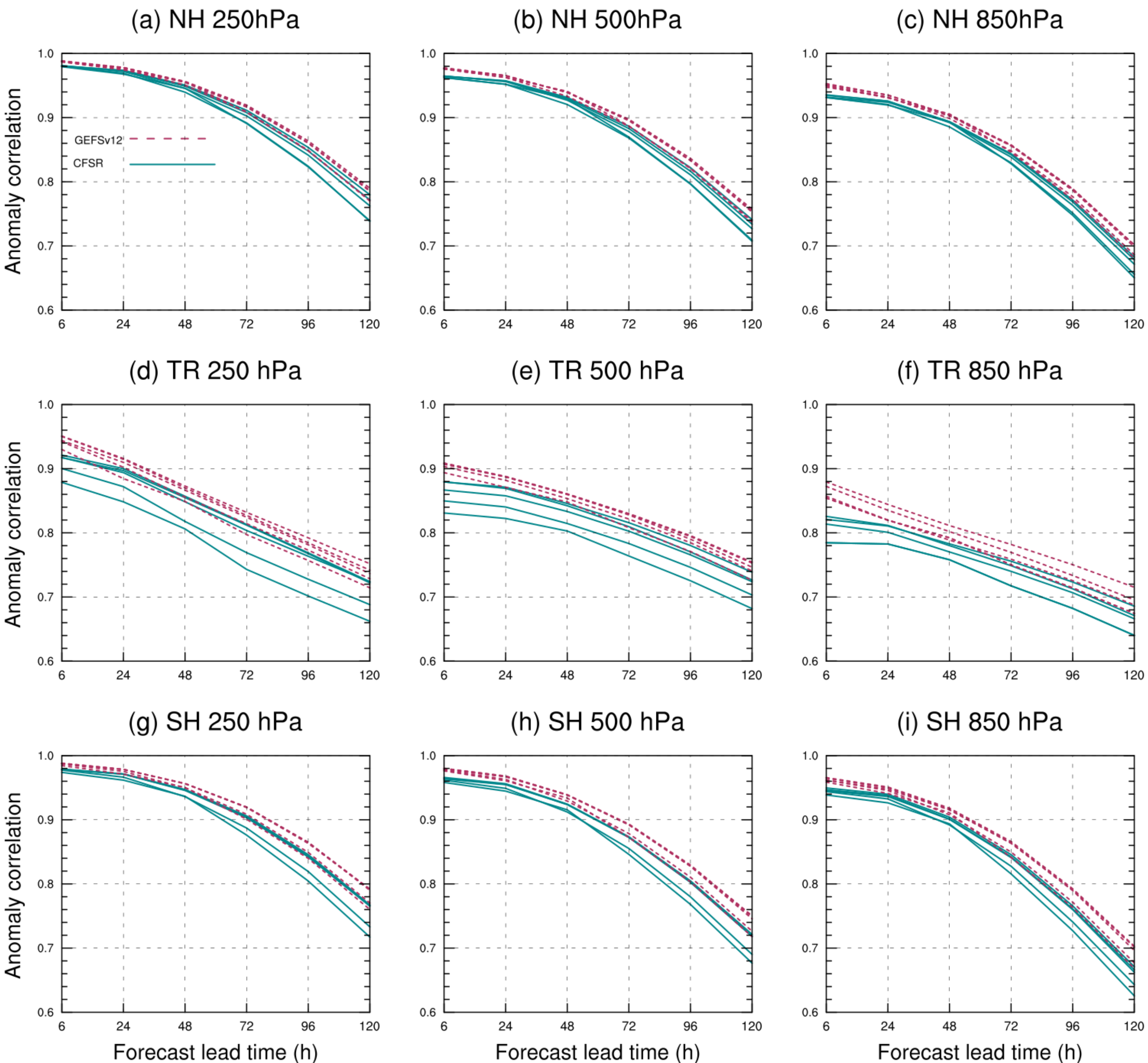
Before vs. after GPSRO assimilated; some effect on upper-tropospheric bias.

2000-2006 Temperature forecast RMSE difference and biases



2007-2019 Temperature forecast RMSE difference and biases





AC “dieoff” curves of u-wind component.

Different curves for each of the different streams to illustrate temporal variability.

The improvement to forecast skill from use of the new reanalysis is evident everywhere, especially in the tropics.

AC dieoff curves, operational initialization vs. reforecast initialization

- regrettably, not ready at the time of this seminar, but forthcoming.

R/R storage update, AWS and NOAA.

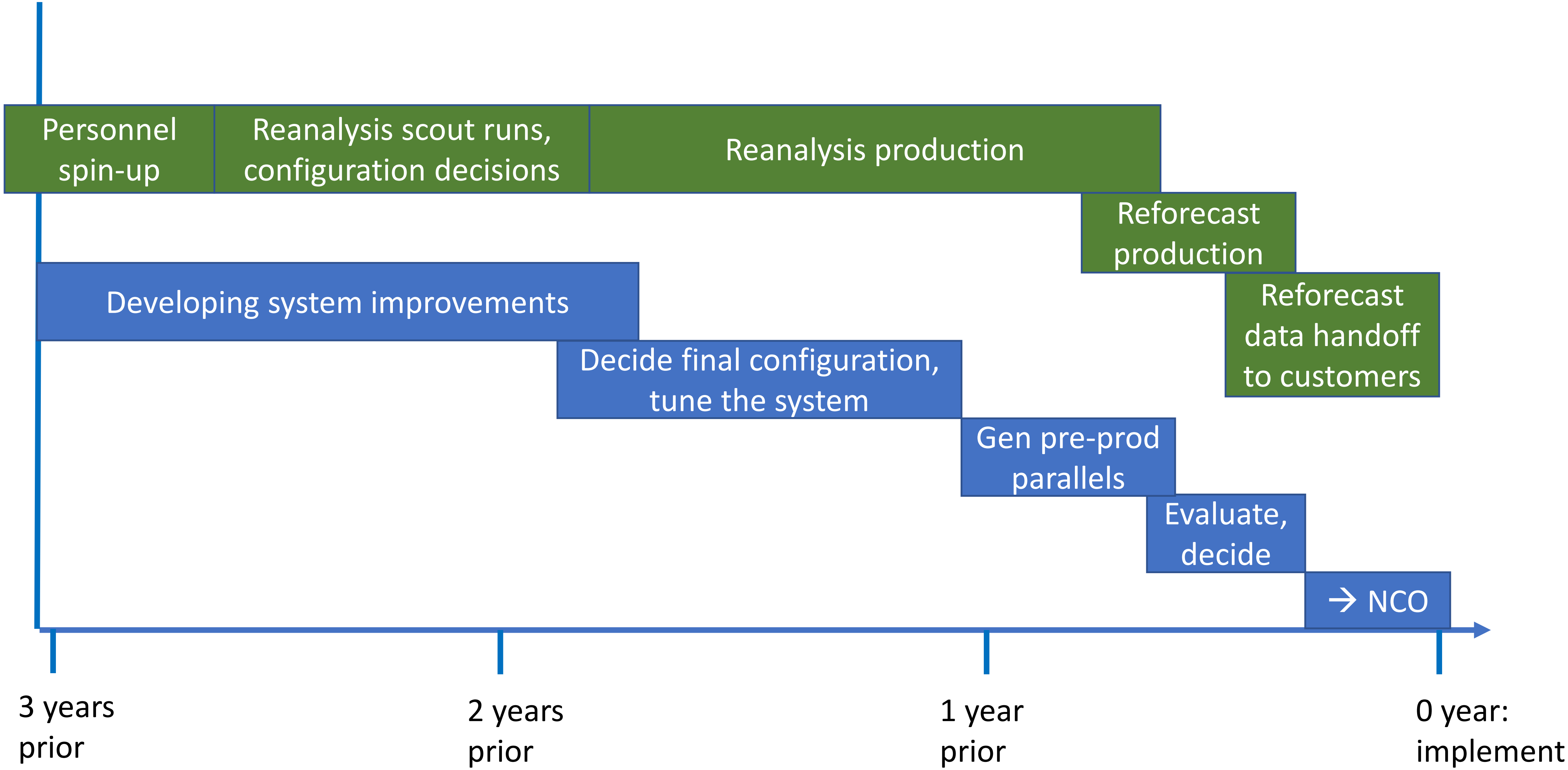
- Under the "Big Data" project, ~200 reforecast fields will be stored from the 2000-current reforecast in the AWS cloud. We are finishing this up, addressing minor issue with precipitation and related fields at the earliest leads.

- Reforecast (and control from reanalysis, + spread) are also being stored on NOAA-owned disk, attached to the "rzdm" computer in College Park, MD. In near future we will make this data available for ftp, web-interface access. Expect to finish copying this data in O(1 month).

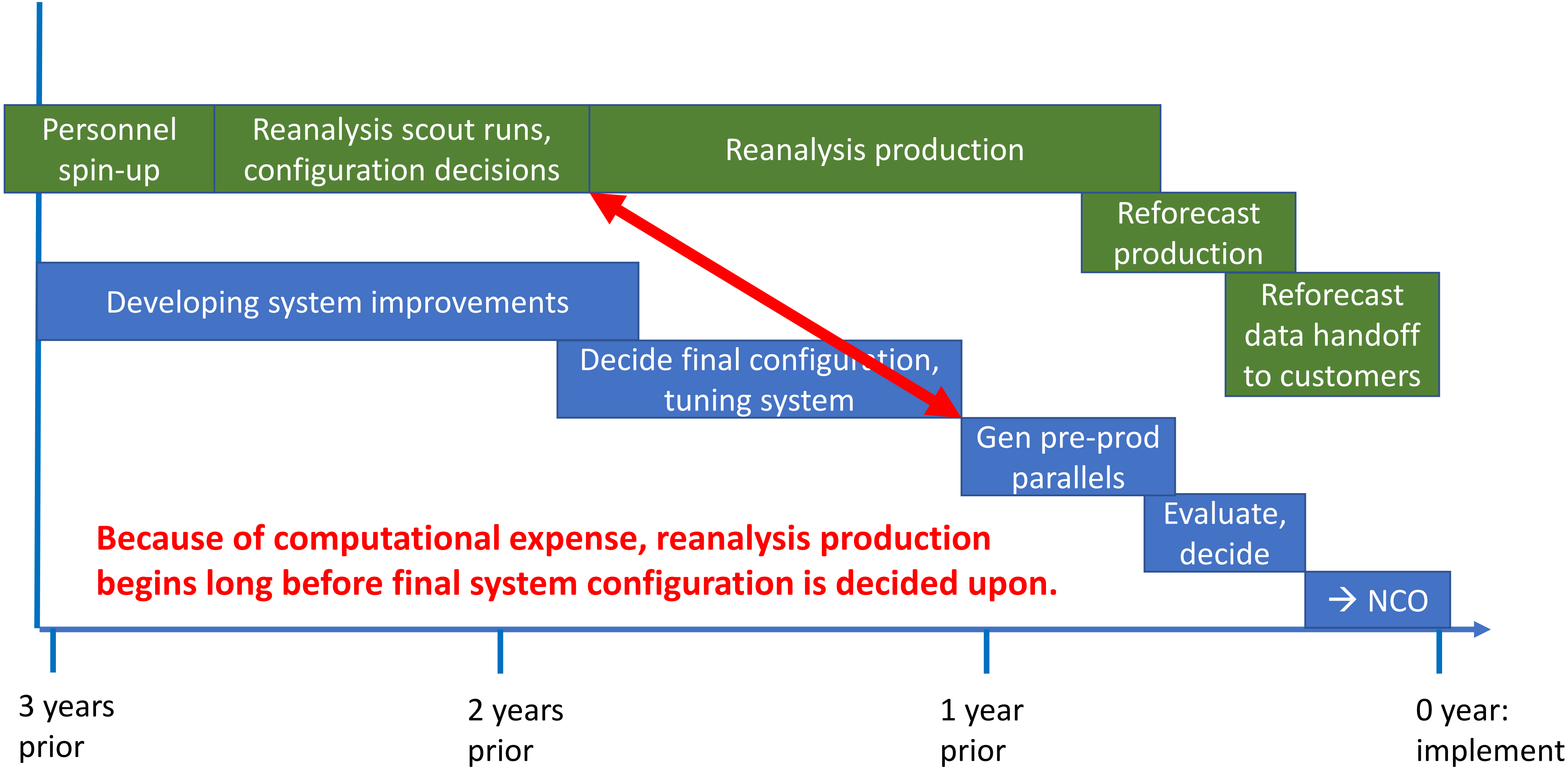
We expect to do reanalyses again to remain consistent with major system changes.

- *Statistical characteristics of the (re-)analyses are likely to change significantly with increased coupling*.
- GEFSv12 is **uncoupled**.
  - Forecast: Ocean-state anomalies from climatology transplanted from CFSR.
  - Atmosphere analyses: Hybrid 4D-En-Var; control SST background via NSST (diurnal variability)
  - Ocean analysis: NSST, GODAS.
- GEFSv13 likely to be **weakly coupled.**
  - Forecast: coupled GFS / MOM6.
  - Atmosphere to use ocean forecast background(s) in its DA.
  - Ocean to use atmospheric forecast background(s) in its DA.
- GEFSv14 likely to be **strongly coupled**.
  - Forecast: coupled GFS / MOM6.
  - Coupled DA utilizing cross covariances between state components; ocean obs make increments to atmosphere, atmospheric observations make increments to ocean.

A challenge with GEFSv12 reanalysis: the sequencing of reanalysis production with the operational upgrade schedule.

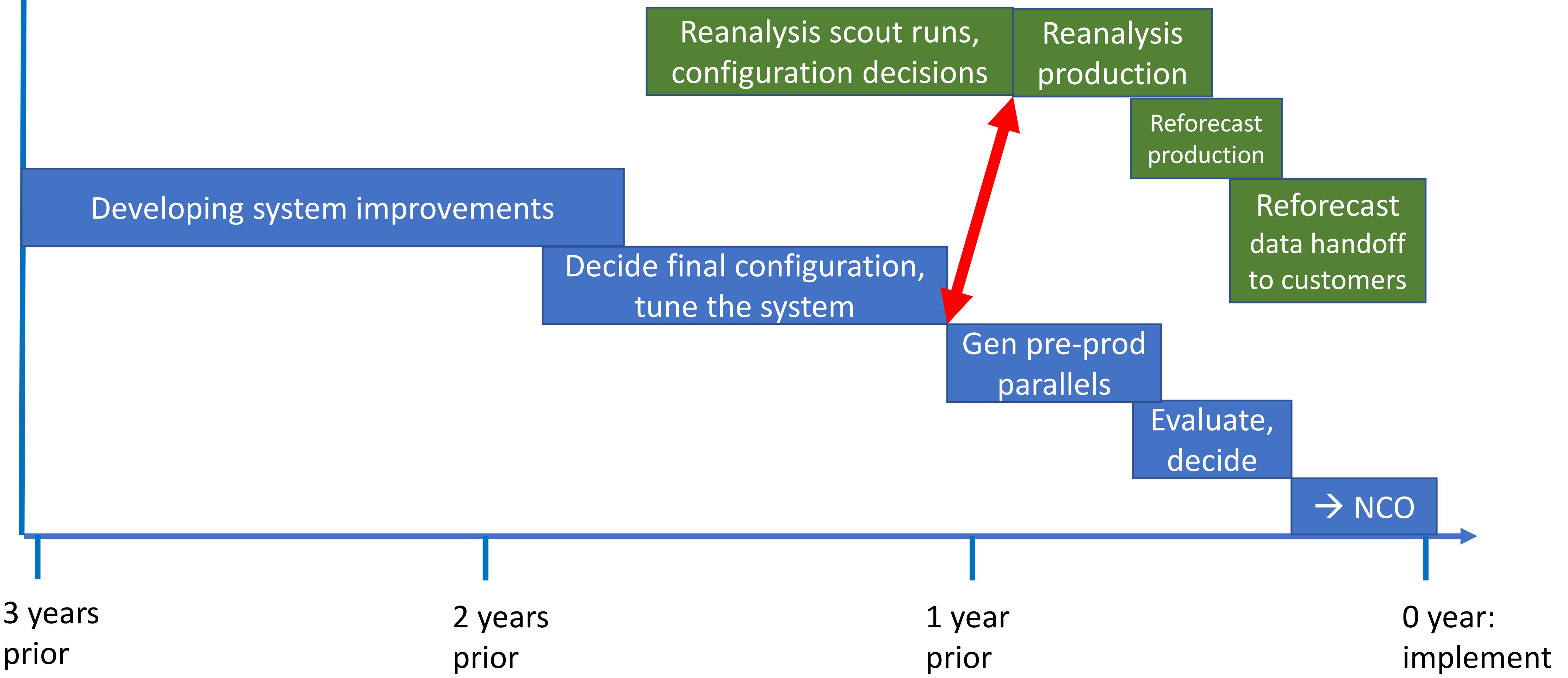


A challenge with GEFSv12 reanalysis: the sequencing of reanalysis production with the operational upgrade schedule.



Surging reanalysis/reforecast in the cloud.

- Potentially leveraging a cloud surge, we can wait to produce reanalyses till after next-gen configuration is more settled.



Conclusions

- For the first time, an update of the GEFS system (here, version 12) is accompanied by the provision of new reanalysis and reforecast data.
- While the GEFSv12 system will provide radically improved forecasts, from previous results, we expect that the statistical postprocessing leveraging the reforecasts will greatly improve the ultimate product quality.
  - CPC is readying new 6-10, 8-14, and hazards products based on the reforecasts.
  - Office of Water Prediction is updating their hydrologic ensemble forecast system to leverage the new GEFSv12 data.
  - PSL has a project to incorporate reforecast-based postprocessing into the "National Blend of Models."
- We hope and expect the wider enterprise will use these extensive reforecasts for many creative applications.

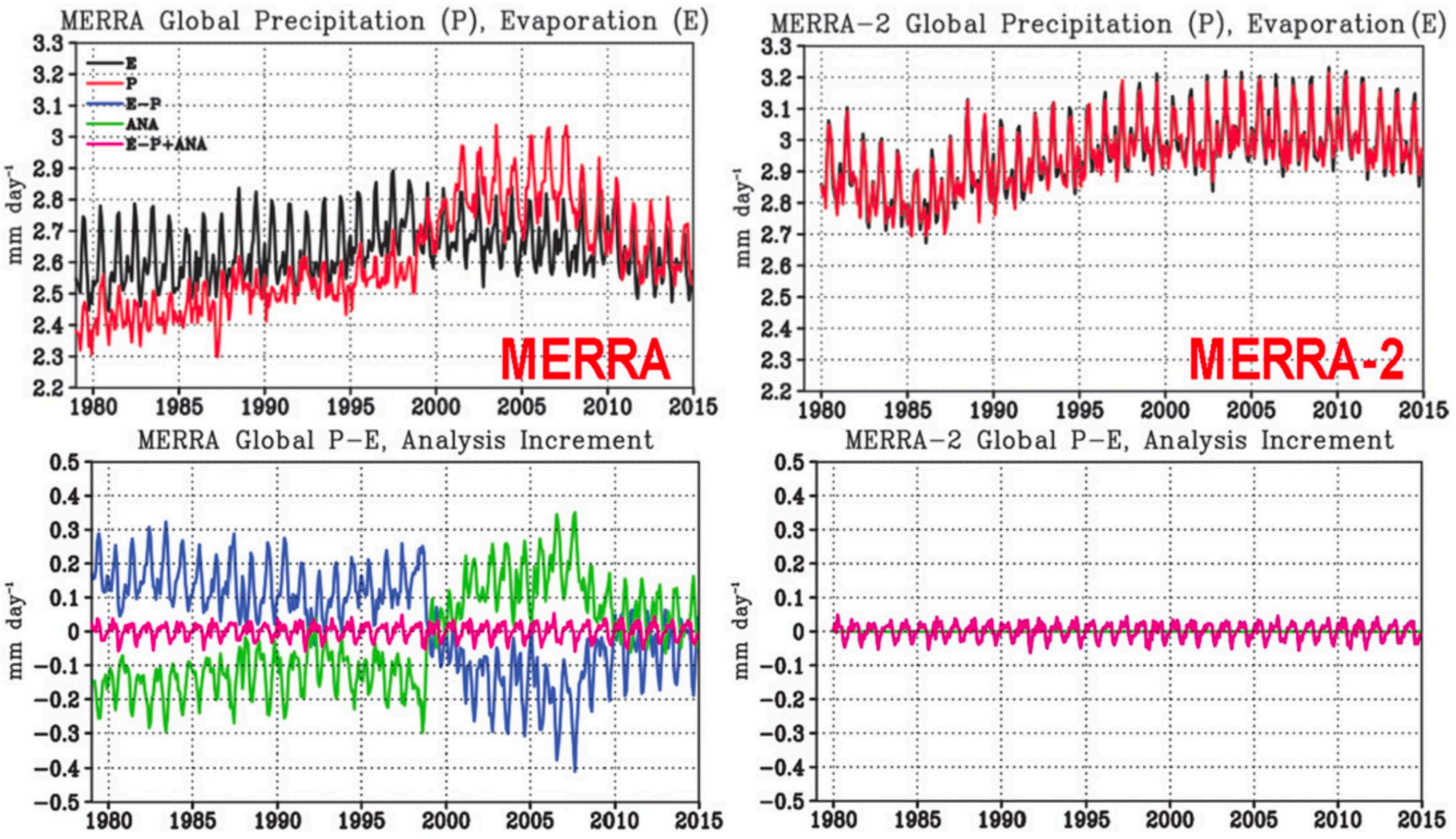


FIG. 1. Global time series of monthly mean water cycle terms (mm day^{-1}) for (left) MERRA and (right) MERRA-2: (top) global precipitation (P, red) and evaporation (E, black) and (bottom) the global $E - P$ increment (blue), the analysis increment (ANA, green), and the $E - P +$ ANA (pink). The MERRA-2 analysis increment is plotted but is near zero by design as described in the text. The $E - P +$ ANA represents the total time rate of change of total water.

Similar figure from MERRA-2 [article]