Tropical Diagnostics for NWP

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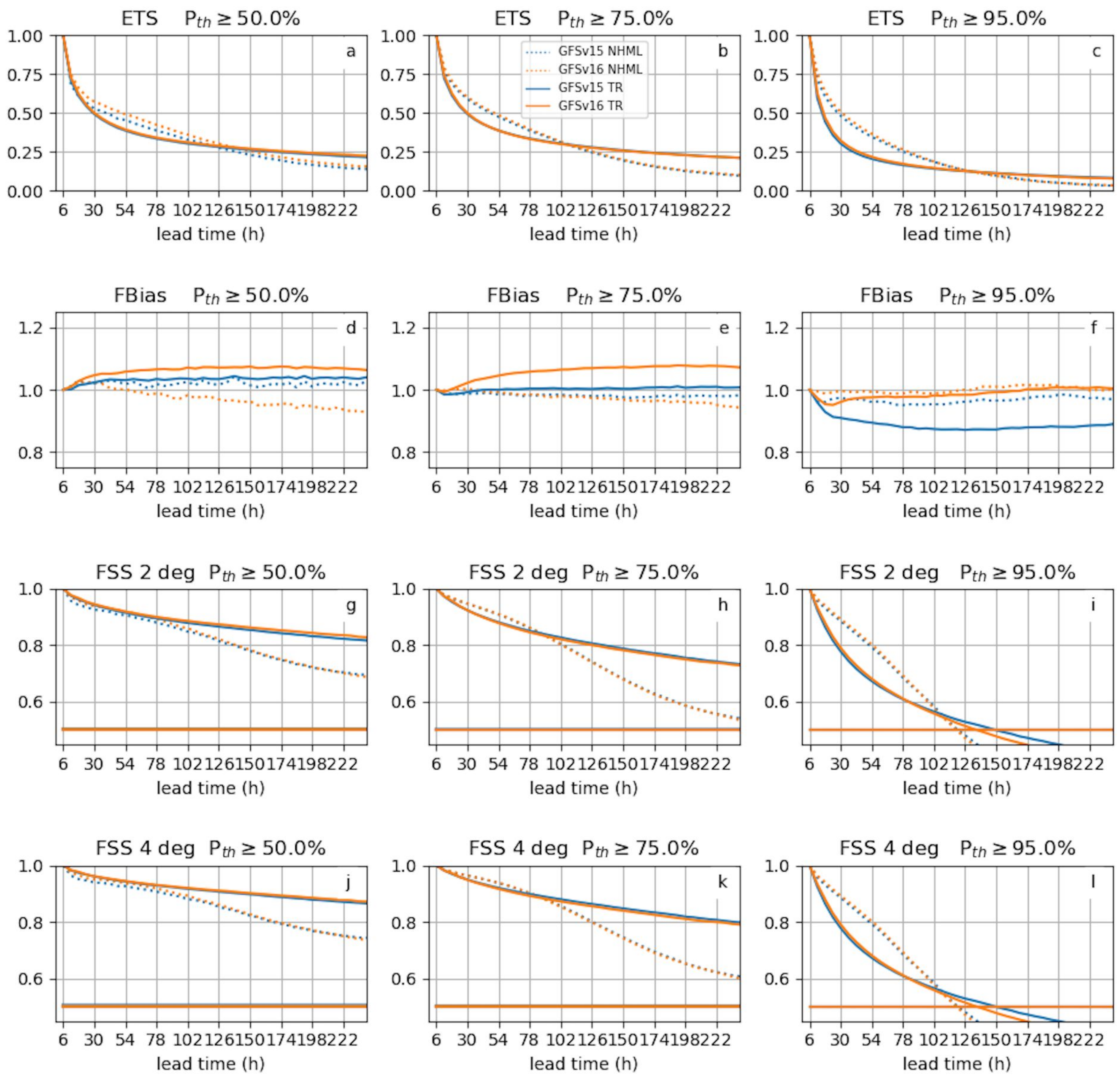


NWP models tend to perform better in mid-latitudes than in the Tropics for lead times <4 days.

- The underlying dynamics are different in the Tropics and mid-latitudes.
- Convection is main driver of precipitation in the Tropics.
- Convective parameterization has a larger impact on precipitation in the Tropics.

There is evidence that better forecast skill in the Tropics can lead to improved forecasts in mid-latitudes.

Tropical Diagnostics for NWP

It is not very well understood which processes in the Tropics are most important to mid-latitude forecast skill. There are well-known sources of predictability beyond a few days in the tropical atmosphere such as the MJO and CCEWs.

Introduce metrics and diagnostics for NWP in the Tropics.

- Better understanding of NWP model behavior with respect to tropical convection.
- Identify forecast error sources in the Tropics related to moisture-convection coupling, CCEWs and the MJO.

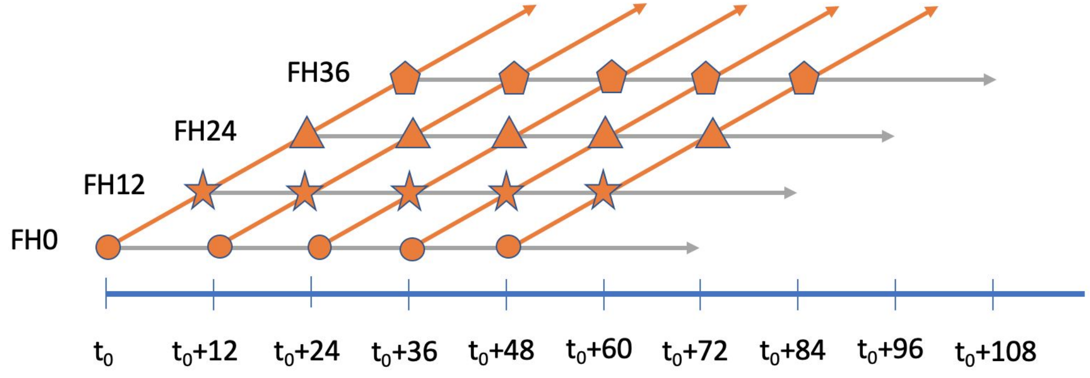
NWP evaluation presents different challenges than climate model evaluation.

- Forecasts are shorter: days-weeks.
- Model versions change frequently.
- It is rare to have long (multi-year) time series of operational model runs.

Consider diagnostics as a function of lead time.

If certain phenomena are initialized correctly, how long is the model able to keep that information?

Diagnostics



Hovmoeller diagrams and pattern correlation
(zonal propagation)

Space-time coherence spectra
(scales of coupling to moisture)

Vertical structure of coherence between precipitation and dynamical fields
(vertical structure and phase relationship within CCEWs)

Convectively coupled wave activity and skill
(CCEW propagation)

Moisture - convection coupling
(coevolution of precipitation and column saturation fraction)

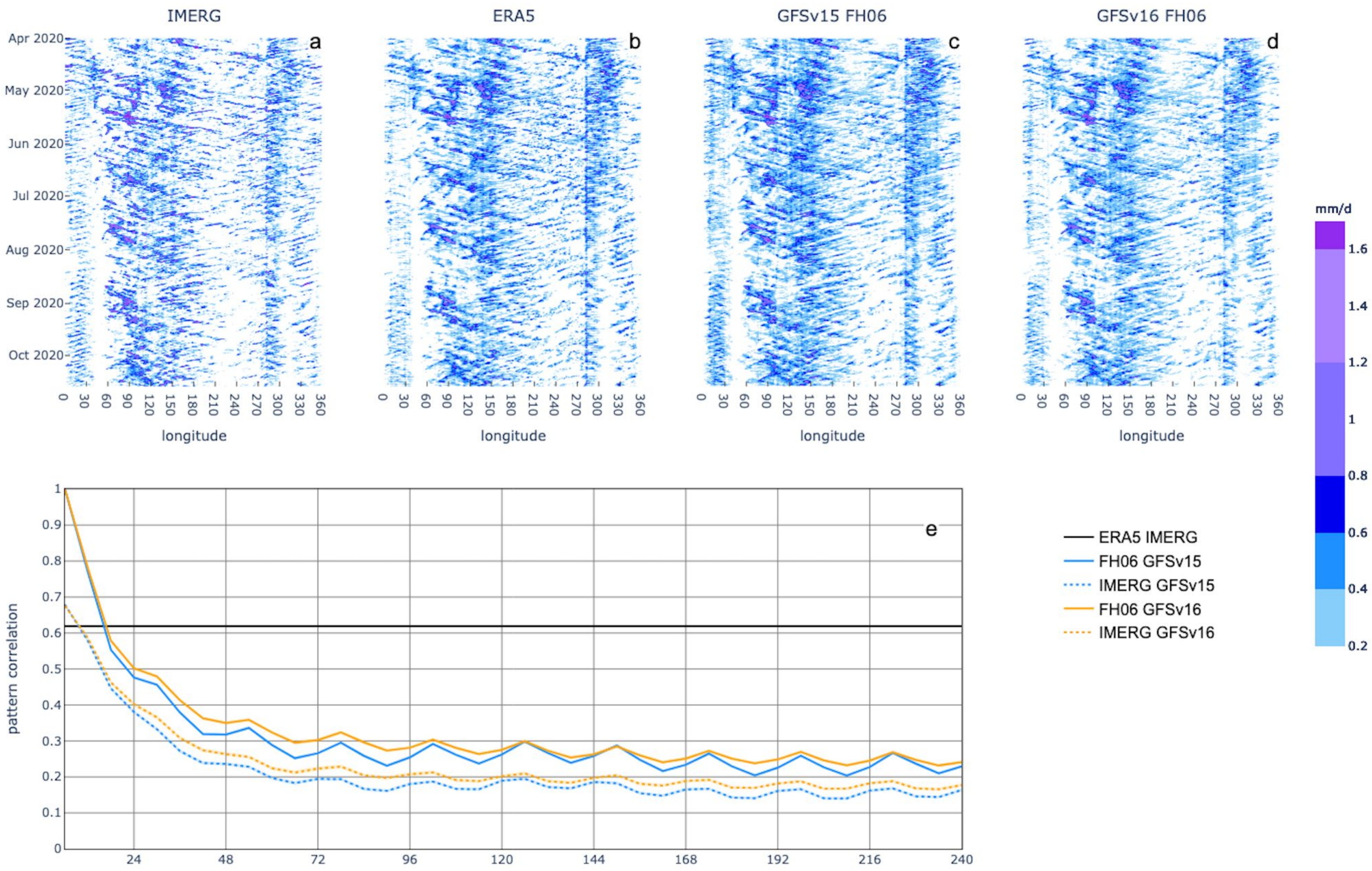
Development of diagnostics are focused on FV3GFS operational V15 and retrospective V16 model versions together with ERA5 and observed precipitation data sets.

Model output needed:

- gridded 2D fields of precipitation, surface pressure, land-sea mask
- gridded 3D fields of temperature, specific humidity, winds

Consider FV3GFS V15 operational vs FV3GFS V16 parllel runs that are initialized 6 hourly from April through October 2020 and run out to lead time 240h.

Hovmoeller diagrams and pattern correlation

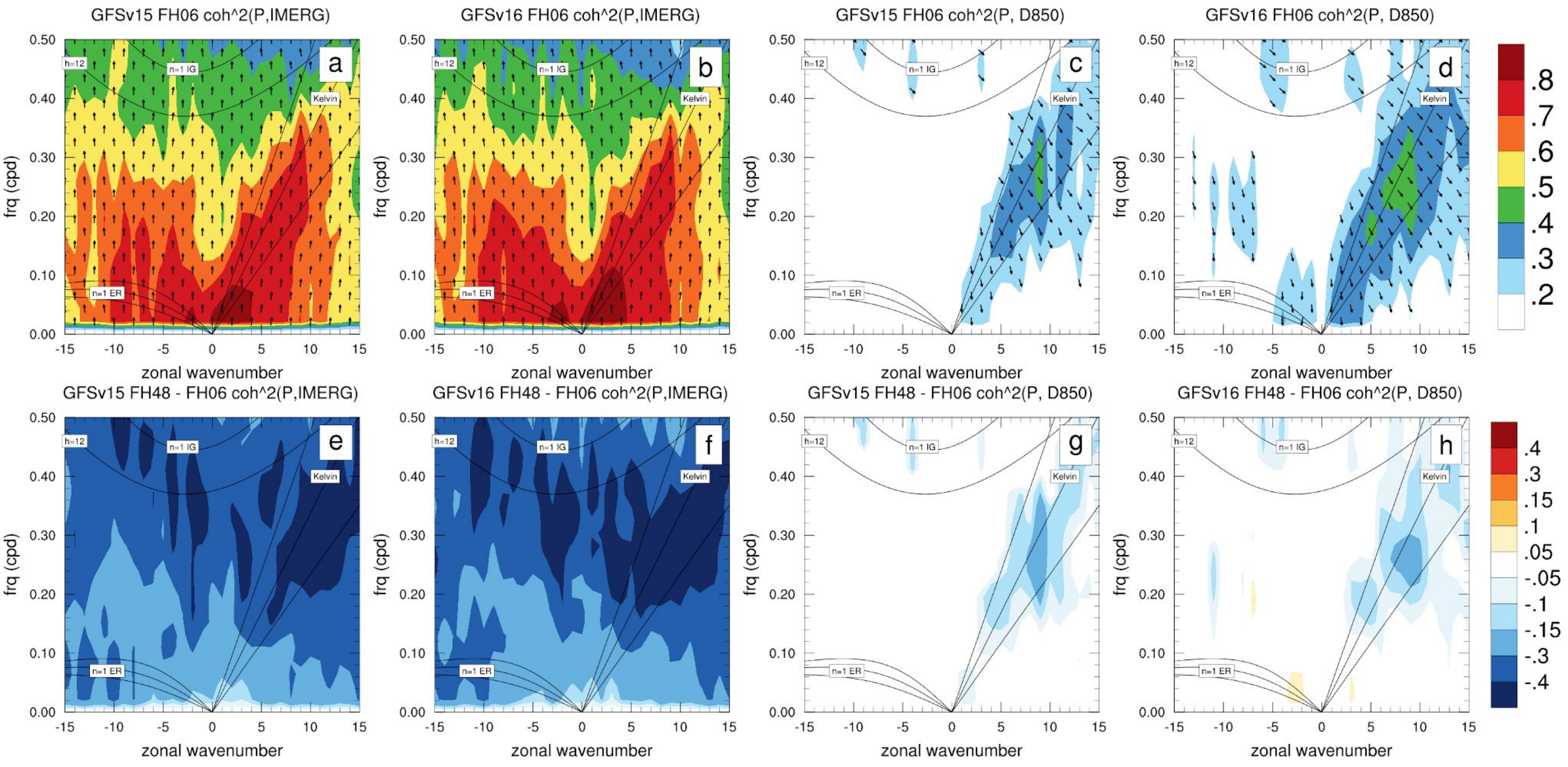


Assess the zonal propagation of convective features.

Pattern correlation between forecast and 'truth' can be used as a skill score.

- GFSv15 operational vs GFSv16 parallel shows only minor differences with GFSv16 slightly outperforming GFSv15.
- Correlation with IMERG is higher initially (<FH12) than correlation between IMERG and ERA5.
- Much potential skill in precipitation forecasts is already lost during the first few hours after initialization.

Space-time coherence spectra

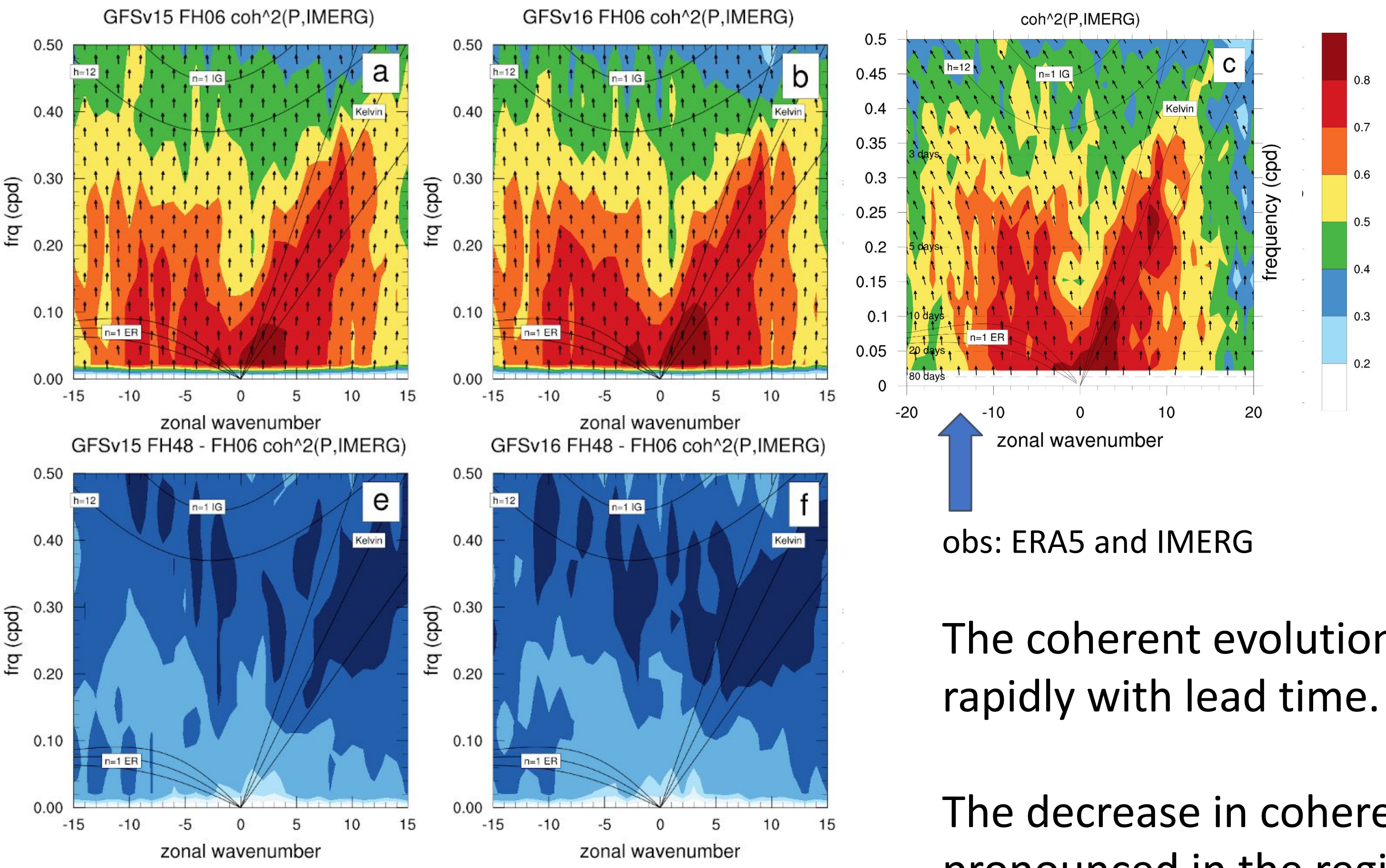


- How well do models initialize and propagate CCEWs?
- Coherence spectra show space-time regions of tropical variability without having to estimate a background.

Evaluate the consistency in variability between modeled and observed precipitation at a range of spatial and temporal scales.

It is possible to evaluate precipitation – dynamics relationship strength and how it changes with lead time.

Space-time coherence spectra



Initially larger coherence values tend to be located near CCEW dispersion curves and at lower frequencies and larger spatial scales.

Precipitation in both GFSv15 and GFSv16 in the first 12 - 24h past initialization is largely able to initialize and maintain large scale CCEW events

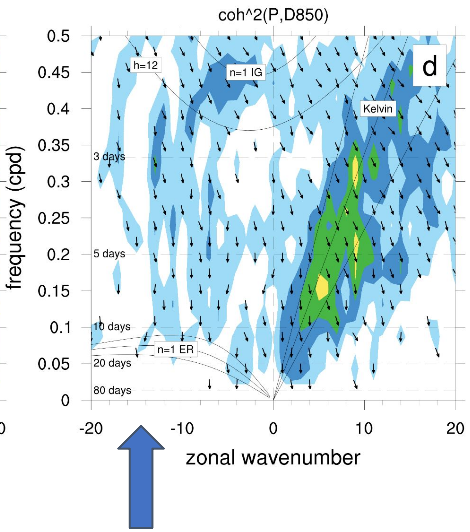
The model tends to have peaks at slightly higher frequencies than the reanalysis and observations

The coherent evolution of observed and modeled precipitation decreases rapidly with lead time.

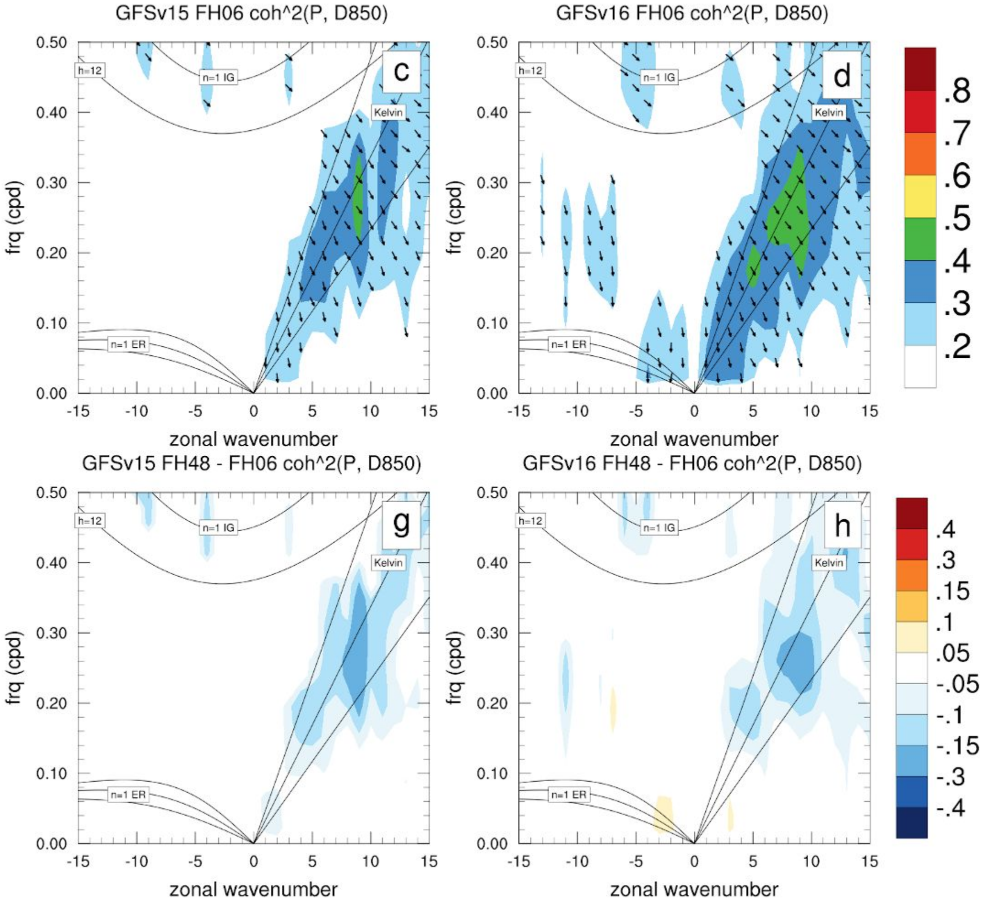
The decrease in coherence squared from 6h to 48h lead time is most pronounced in the regions of CCEW dispersion curves and higher frequencies and wavenumbers.

The coherence decay rate is related to the wave lifecycle and the model is able to propagate waves present in the IC, but spontaneous initialization of CCEWs is much harder.

Space-time coherence spectra



obs: ERA5 and IMERG



There are distinct peaks in coherence along CCEW dispersion curves, but overall the model coherence tends to be lower than observed.

By 48h lead time GFSv15 shows decreased coherence between precipitation and 850 hPa divergence and the two distinct peaks in the Kelvin wave band have decreased by 50-75%.

Model version GFSv16 initially has stronger coherence between precipitation and 850 hPa divergence and is still able to represent at least the lower frequency portion of the Kelvin wave peak at 48h lead time.

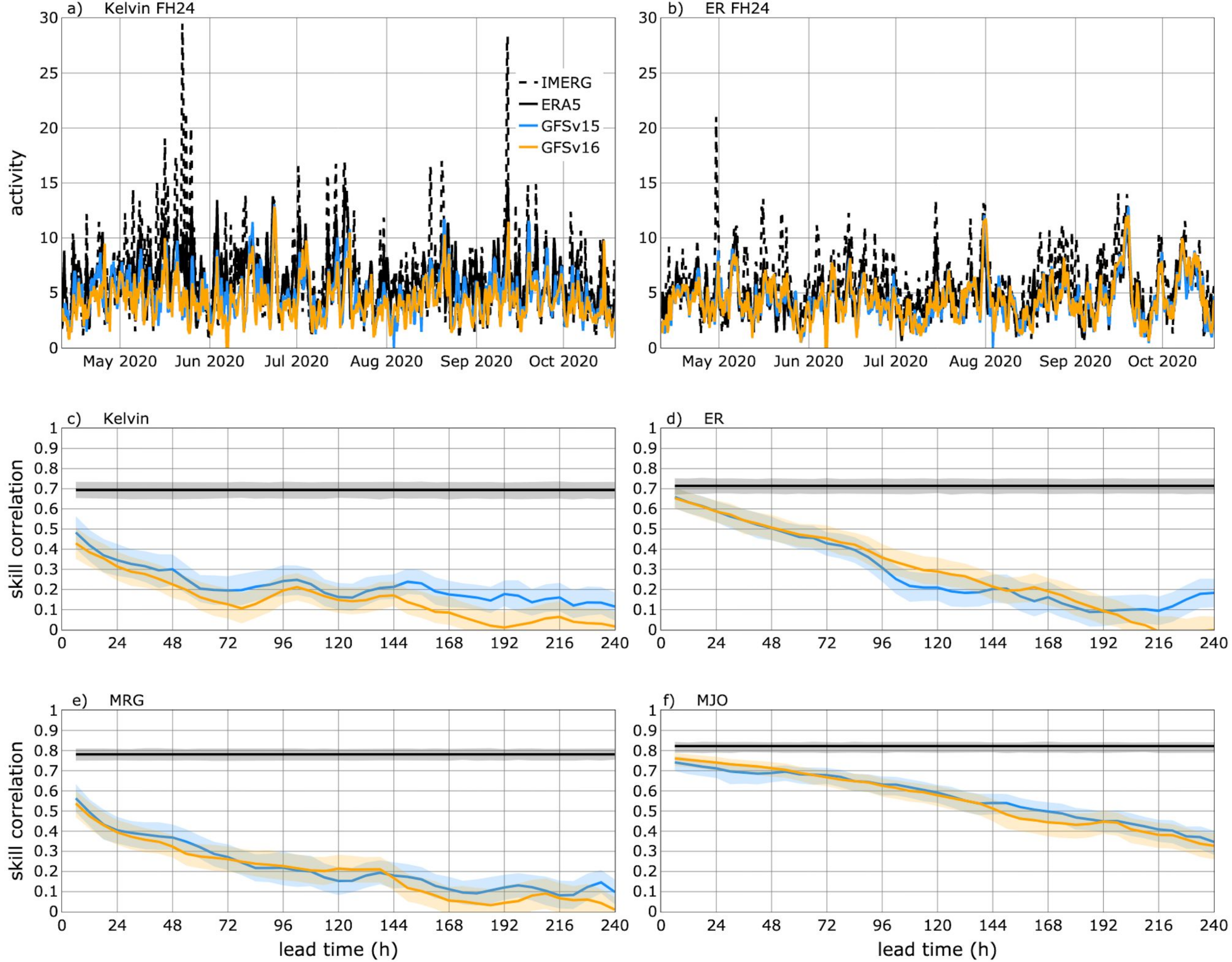
Both model versions are able to initialize CCEWs, the coupling between moisture and dynamics is too weak even at initial time.
At longer lead time precipitation is not coupled strongly to the near-surface dynamics, although this is improved in GFSv16.
There is almost no coherence at very high frequencies.

Variability at higher frequencies and wavenumbers does not contribute much to S2S predictability although this activity could still be a source of feedback to the larger scales.

CCEW activity

How long and how well can the model predict CCEWs?

1. Use long time series (30+ years) of observed filtered precipitation to compute EOFs describing CCEW signal.
2. Project the model precipitation at each forecast hour onto these EOF patterns and compute a CCEW activity index.
3. Compute anomaly correlation between the observed and model index.



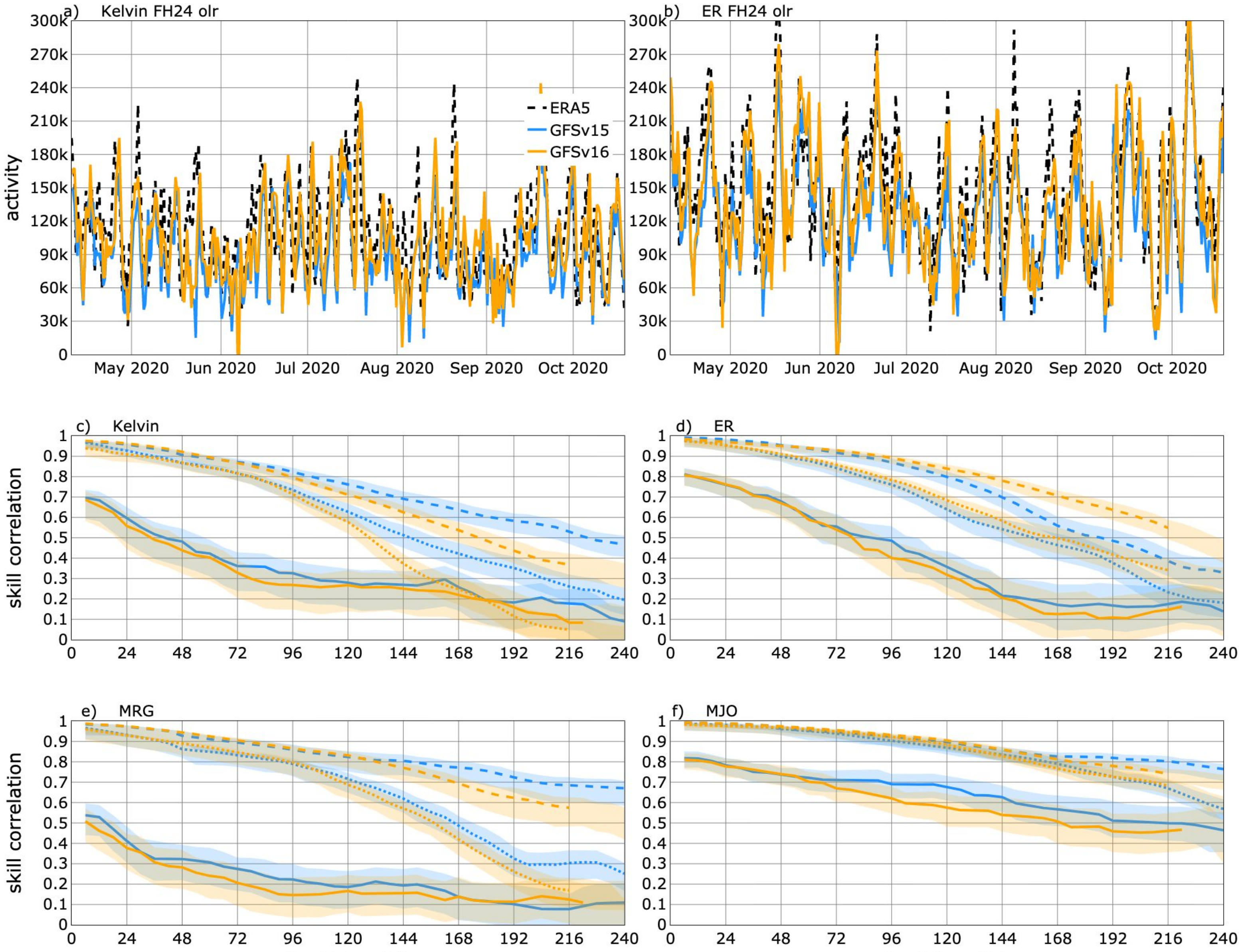
Performance of GFSv16 is slightly improved over GFSv15 for ER and MJO in this diagnostic during the first 48h of the forecast.
Model skill correlation for Kelvin waves drops below 0.5 by 12h lead time, while MJO skill stays above 0.5 past 5 days lead time

CCEW activity

Regress OLR and winds on precipitation PCs to find EOFs.

Skill for OLR is higher than precipitation for Kelvin (by 0.2) and ER (by 0.15) and comparable for MRG and MJO.

Wind skill is much higher than OLR or precipitation skill.



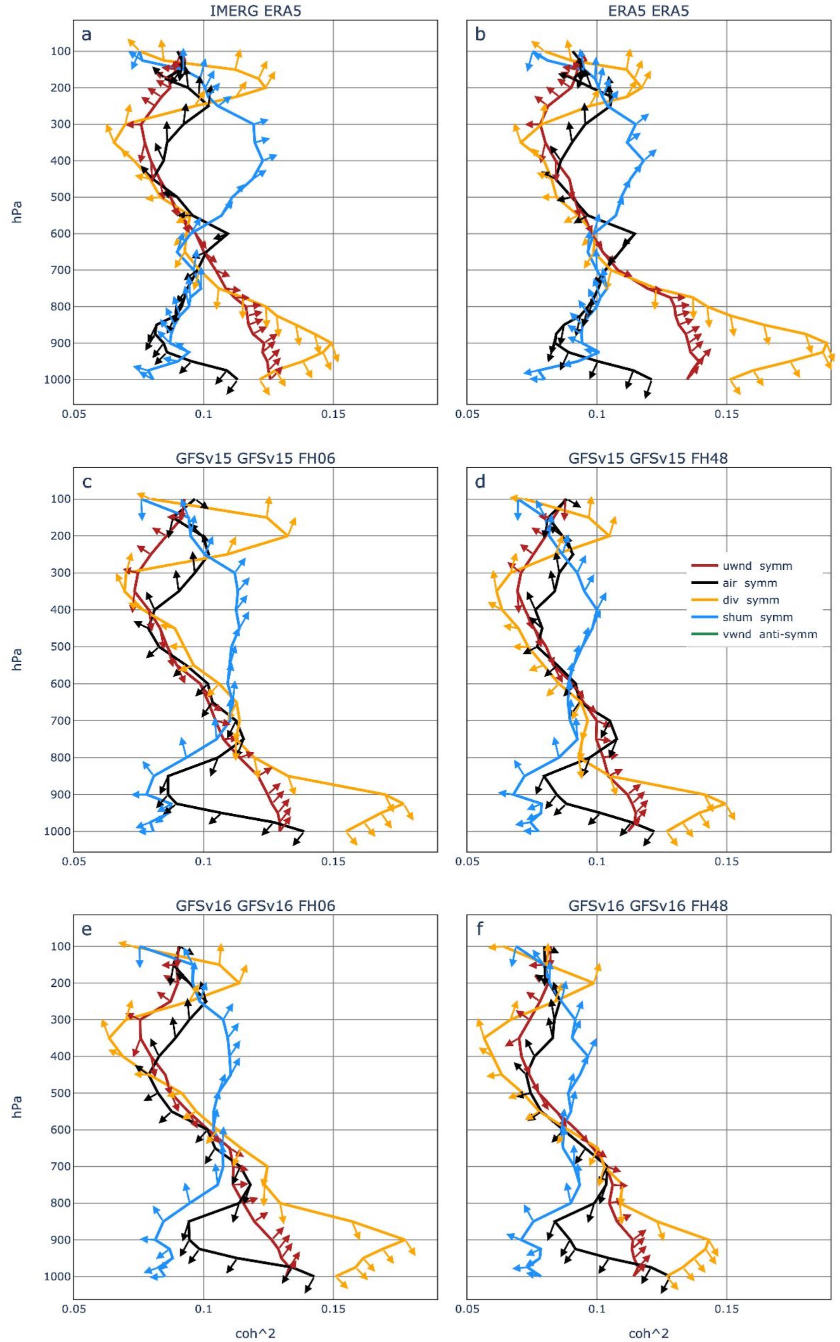
Vertical structure of coherence

- Proxy for vertical profile of latent heating associated with deep convection.
- Filtered P is used to compute coherence with dynamical variables at all vertical levels.

Results point to several issues in the coupling between large-scale dynamics and convection.

The low-level divergence coherence peak appears too weak and at slightly lower levels than observed and decreases with lead-time.
Mid-level peak in temperature coherence-squared is lower in GFSv15 and GFSv16.
Coherence with specific humidity does not show a well defined peak between 550 and 250 hPa in either model version.

Coherence weakens with lead time at all levels.

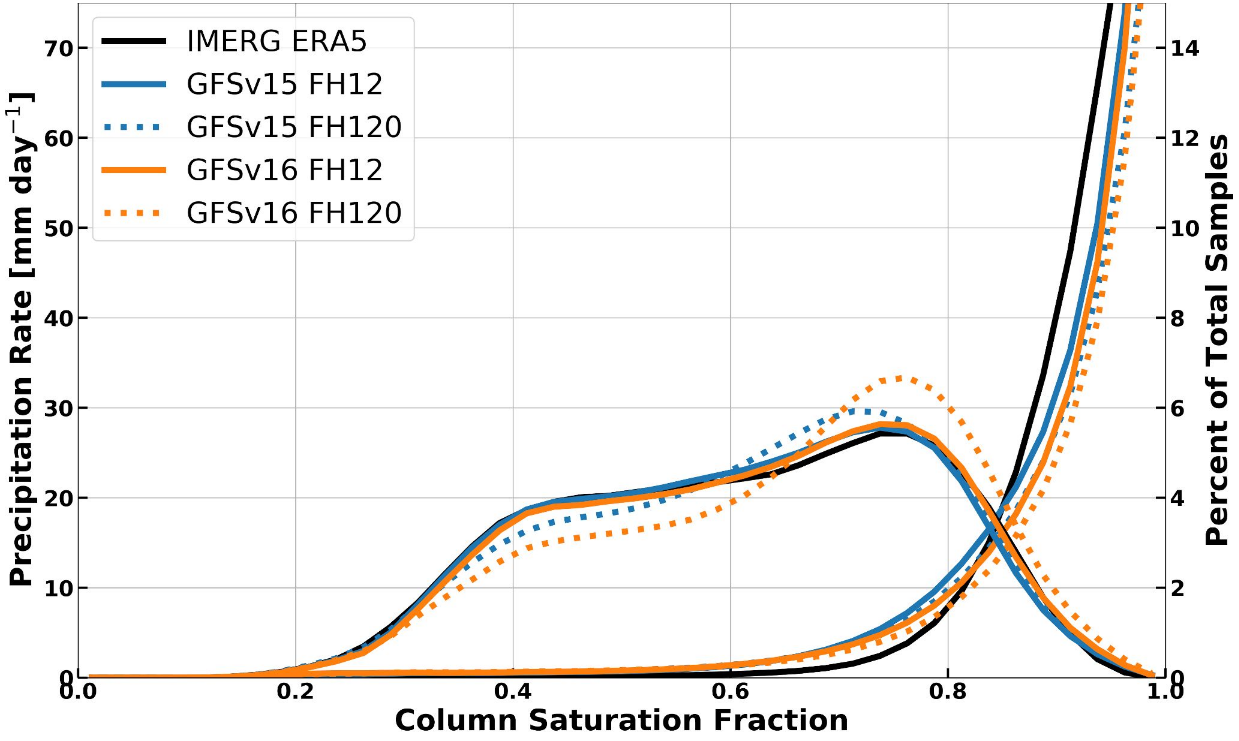


Moisture convection coupling

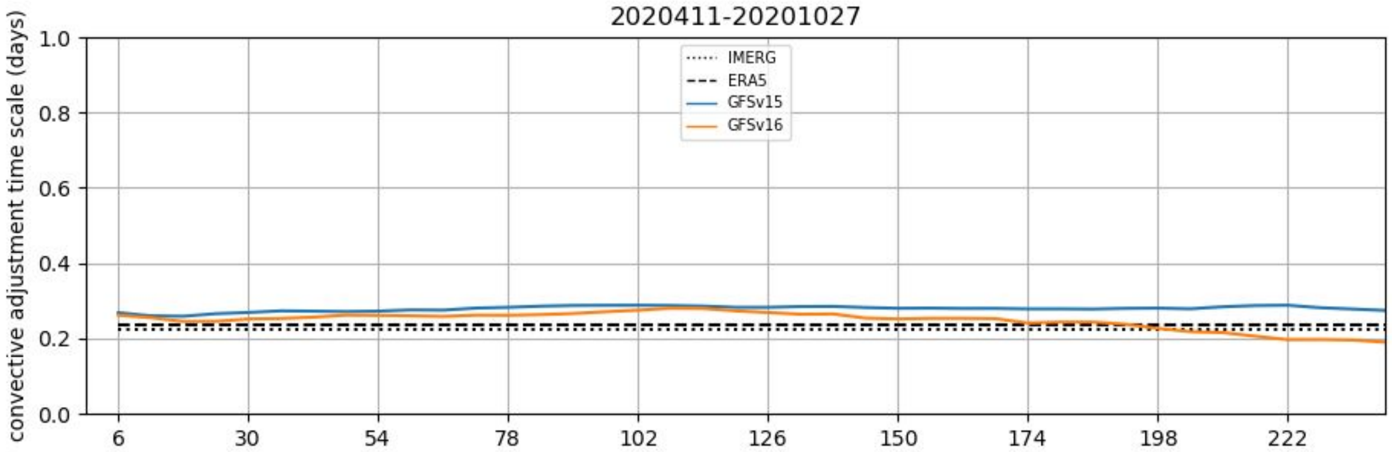
Column saturation fraction (CSF) distribution and precipitation rate conditioned on CSF. IMERG/ERA5 shows exponential pick-up of precipitation rate with CSF.

GFSv16 shows slight improvement over GFSv15 in the precipitation pick-up. This is sustained with lead time.

GFSv16 has larger shift in CSF distribution with lead time toward an increase in the occurrence of larger CSF values.



Convective adjustment time is slightly longer for both GFSv15 and GFSv16 than IMERG and ERA5. Shorter convective adjustment time indicates increased sensitivity of precipitation to atmospheric moisture.
Drift with lead time for GFSv16 convective adjustment time scale?



Moisture convection coupling

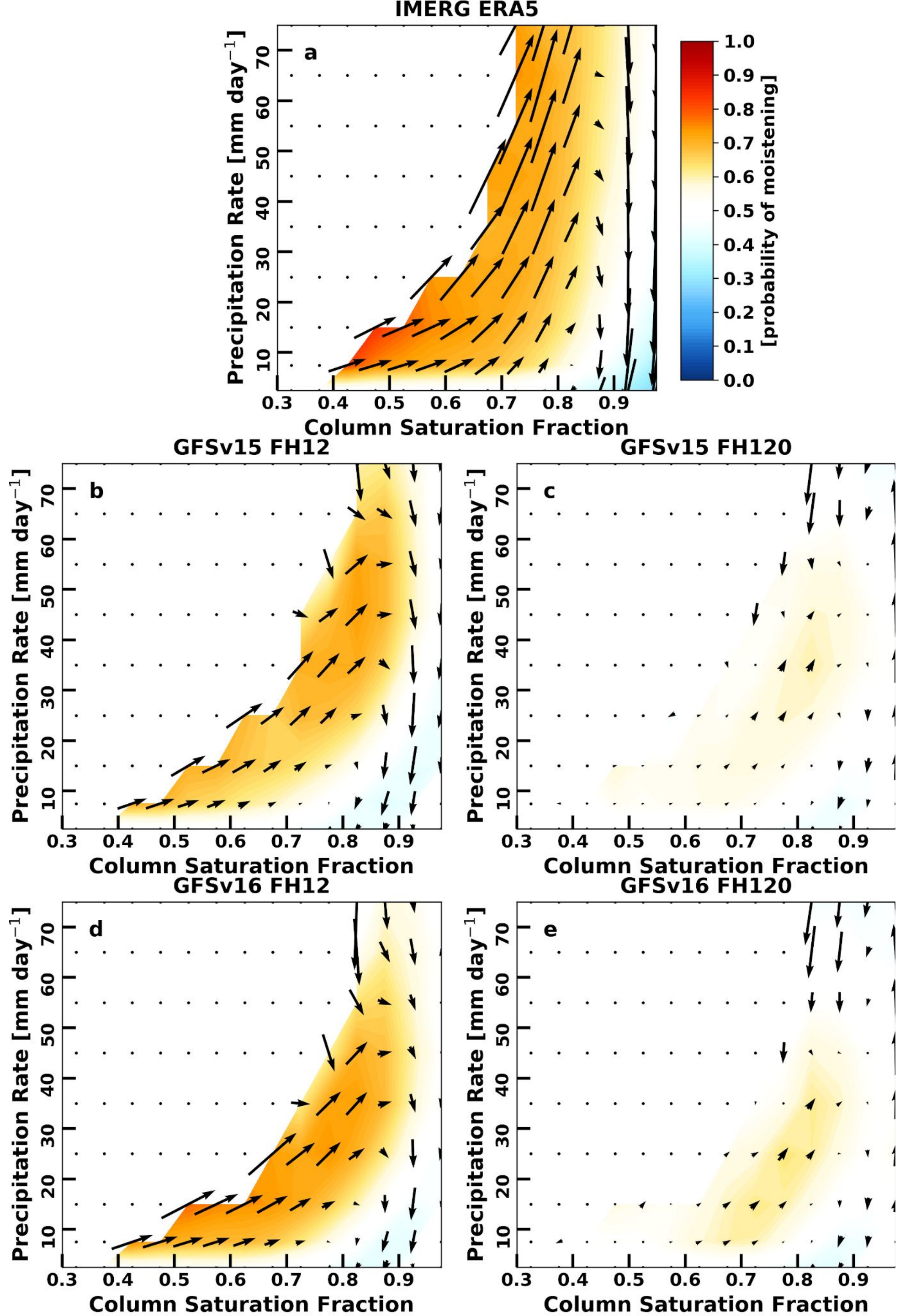
Coevolution of precipitation and column saturation fraction (CSF).

IMERG-ERA5 coevolution shows gradual moistening and increasing precipitation for intermediate precipitation rates. At very high CSF precipitation drops off and drying occurs.

At FH 12 GFSv15 shows similar evolution to IMERG-ERA5 although weaker moistening and less vigorous coevolution.

GFSv16 has slightly stronger moistening compared to GFSv15 at FH12.

In both model versions the coevolution weakens with lead time. By FH120 there is only a hint of the original coevolution left.



Caveat: ERA5 may also not be showing the “real” evolution as there are differences between reanalyses and radiosonde data. This is being investigated in more detail at the moment.

Summary

- Diagnostics for NWP are intended to help identify forecast error sources in the Tropics related to moisture-convection coupling, CCEWs and the MJO.
- Results show that the GFSv16 forecasts are slightly more realistic than GFSv15 in their coherence between precipitation and model dynamics at synoptic to planetary scales scales, with modest improvements in moisture convection coupling.
- However, this slightly improved performance does not necessarily translate to improvements in traditional precipitation skill scores.
- Have also evaluated UFS coupled prototypes P5 and P7 (P5 has strong unrealistic initial precipitation adjustment, P7 shows improved CCEW forecasts) using these diagnostics and are planning to evaluate P8 once it becomes available.

- The results highlight the utility of these diagnostics in the pursuit of better understanding of NWP model performance in the tropics, while also demonstrating the challenges in translating model advancements into improved skill.
- METplus is going to be the evaluation tool for the UFS. Adding these diagnostics to METplus will facilitate easy access of model developers.

Summary

- A stand-alone python GitHub repo for these diagnostics exists (tropical_diagnostics) and a release is public for testing.
- Several of these diagnostics were included in the November beta release of METplotpy and METcalcpy of METplus. A recording of the presentation on METplus Use Cases for UFS P5 and P7 output can be found here (https://dtcenter.org/events/2022/2022-dtc-metplus-workshop/agenda-recordings)
- Planning on adding these capabilities to the Model Diagnostics Task Force (MDTF) diagnostics package over the next few months.

More details can be found in:

Gehne M., B. Wolding, J. Dias and G. N. Kiladis (accepted). Diagnostics of Tropical Variability for Numerical Weather Forecasts, *Weather and Forecasting*
Wolding, B., Powell, S. W., Ahmed, F., Dias, J., Gehne, M., Kiladis, G., & Neelin, J. D. (2022). Tropical Thermodynamic-Convection Coupling in Observations and Reanalyses, *Journal of the Atmospheric Sciences*