Convectively Coupled Equatorial Waves in the Unified Forecast System

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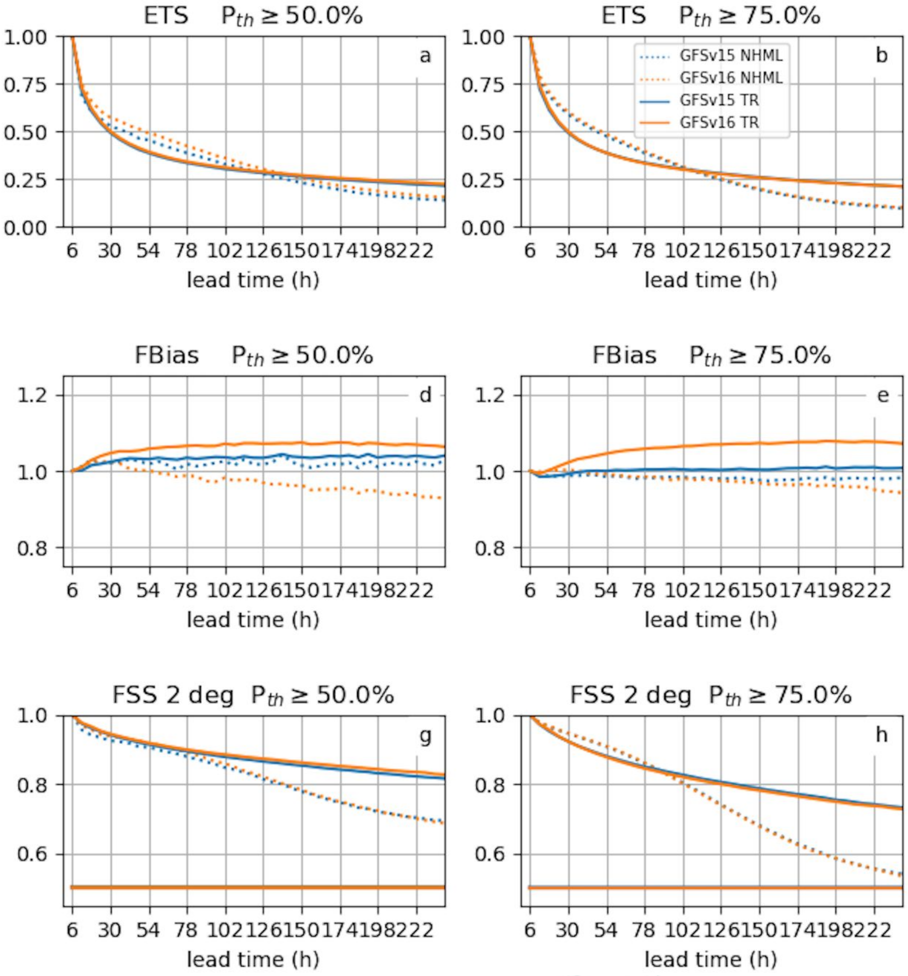


NWP models tend to perform better in mid-latitudes than in the Tropics for lead times <4 days.

- 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.

Evaluating tropical convection in NWP

It is not very well understood which processes in the Tropics are most important to mid-latitude forecast skill.

There are, however, well-known sources of predictability beyond a few days in the tropical atmosphere such as the MJO and Convectively Coupled Equatorial Waves (CCEWs).

Consider metrics and diagnostics specifically 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.
- We will look at variability and not biases in this presentation, although biases can be substantial at later lead times.

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?

Model runs

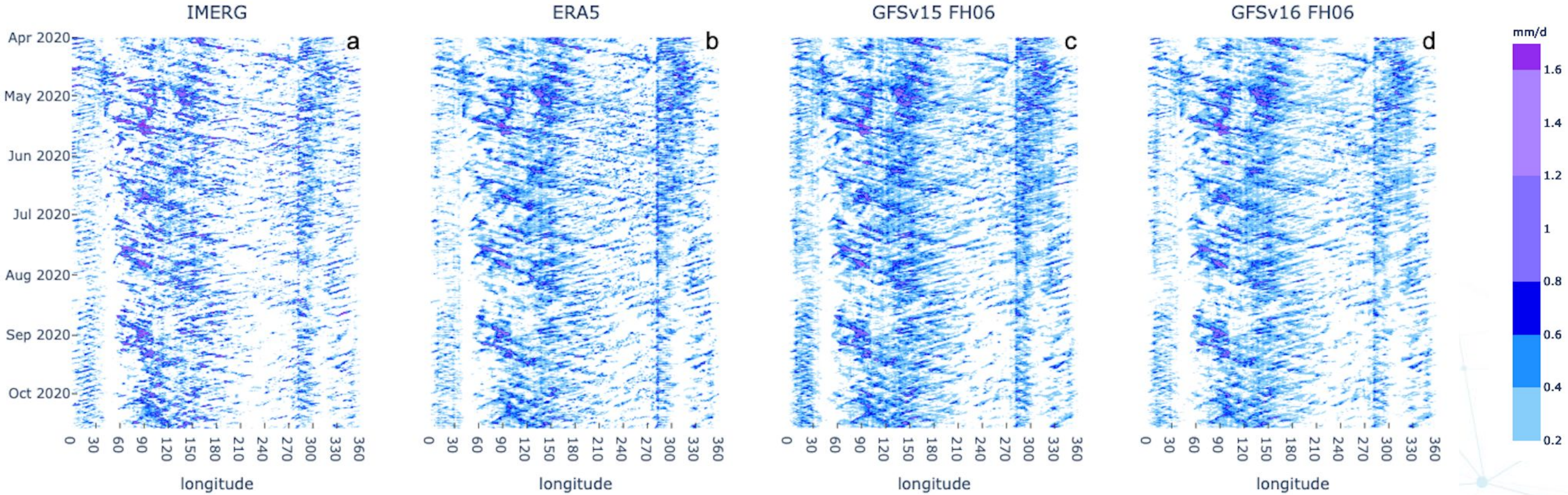
- FV3GFS V15 operational (GFSv15) and FV3GFS V16 parallel (GFSv16) runs initialized 6 hourly from April through October 2020 and run out to lead time 240h.
- These are uncoupled forecasts.

UFS coupled prototype (P5,7,8) runs - 168 initializations, every 1st and 15th of the month between 20110401 and 20180315.

ECMWF S2S (2021 model version) (EC2021) database runs - only initializations within +-2 days of the UFS initializations.

More details on the GFS v15 and v16: https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs.php
More details on the UFS prototypes: https://registry.opendata.aws/noaa-ufs-s2s/#:~:text=The%20UFS%20prototypes%20are%20the,weather%20prediction%20system%20from%20NWS.
More details on the ECMFS S2S: https://confluence.ecmwf.int/display/S2S/ECMWF+model+description

Hovmoeller and Pattern Correlation



Assess the **zonal** propagation of convective features.

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

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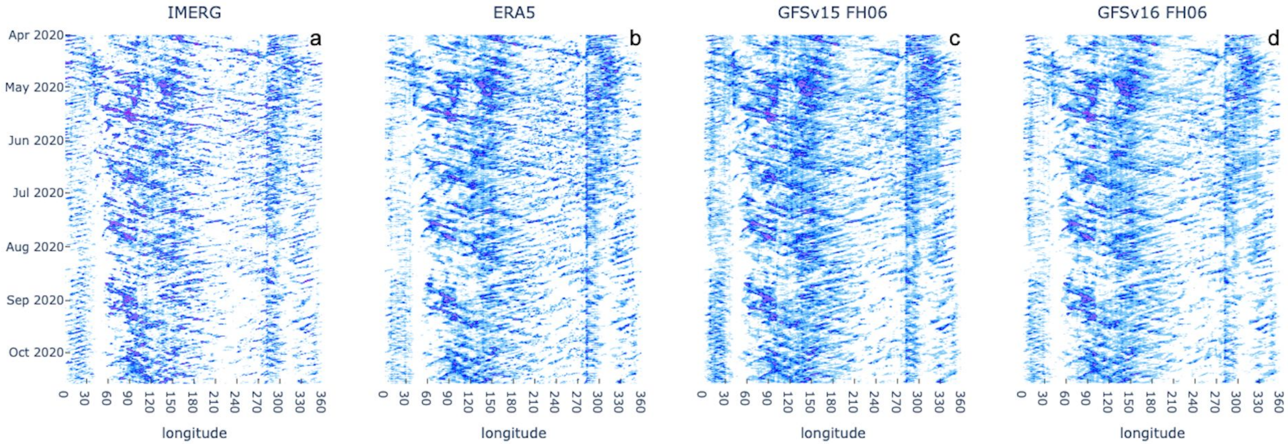
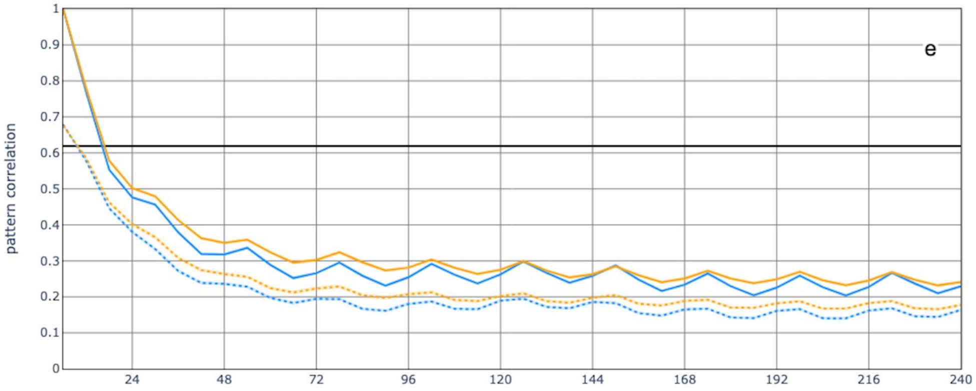
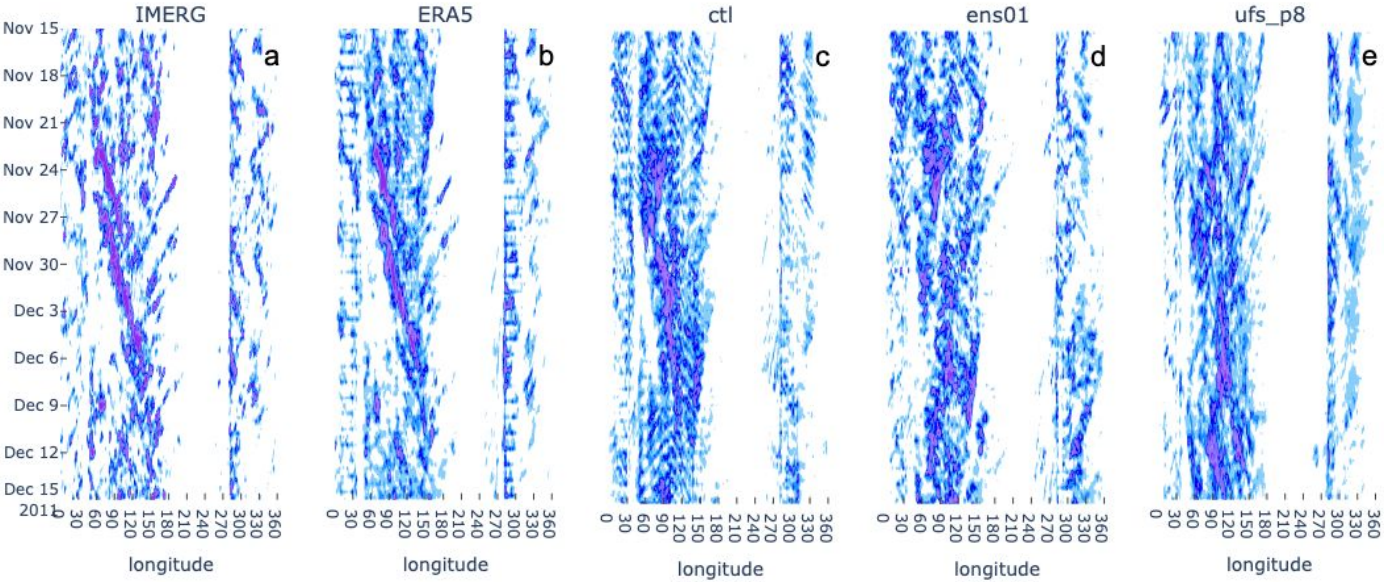
Hovmoeller and Pattern Correlation





- 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.

Hovmoeller and Pattern Correlation



30 day period in November - December 2011

IMERG and ERA5 show the MJO event observed during DYNAMO starting around 11/22.

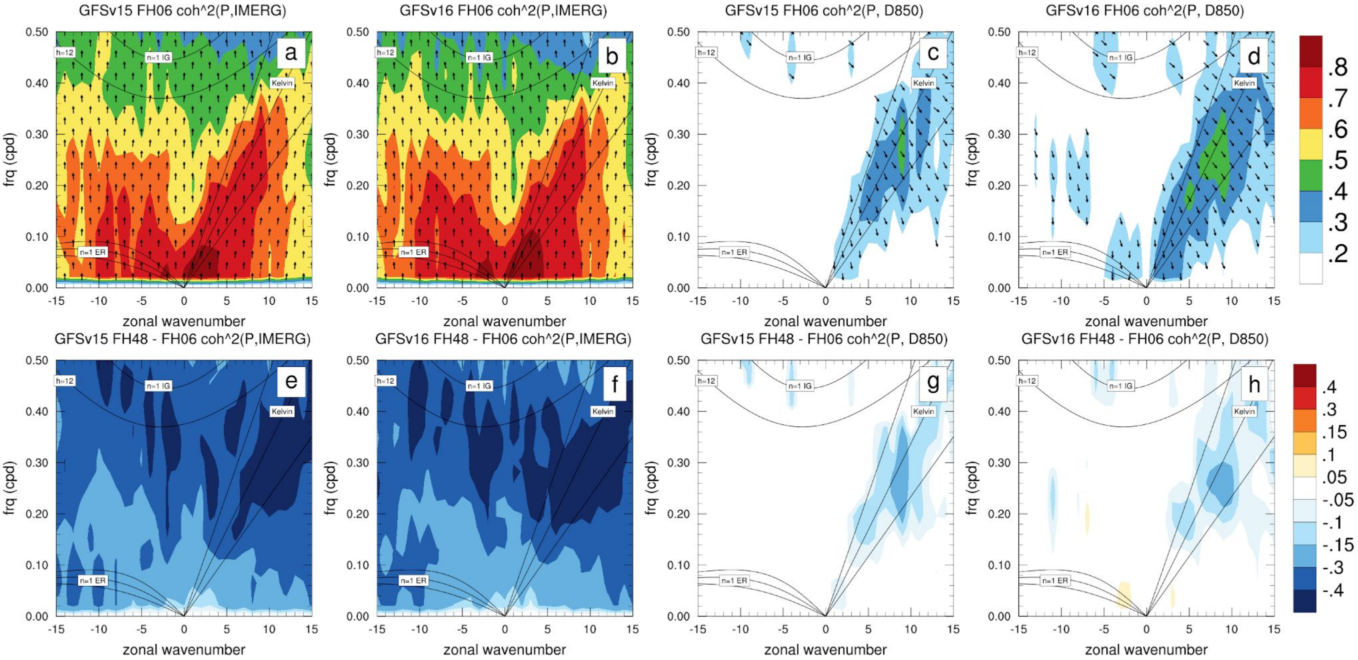
Model precipitation is plotted along the forecast instead of at a single lead time.

lead time increases

Model forecasts vary widely between models and ensemble members after a few days.

Some forecasts have an indication of enhanced convection during the observed MJO period and others don’t.

Space-time Coherence-squared 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.

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

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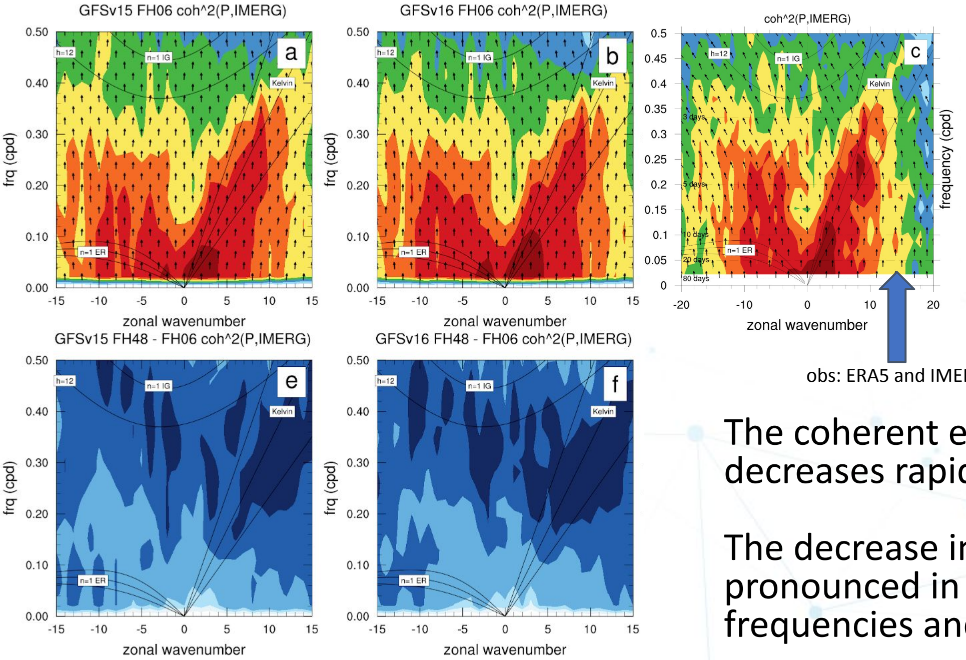
Space-time Coherence-squared Spectra



obs: ERA5 and IMERG

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 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.

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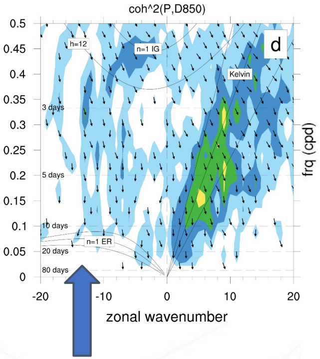
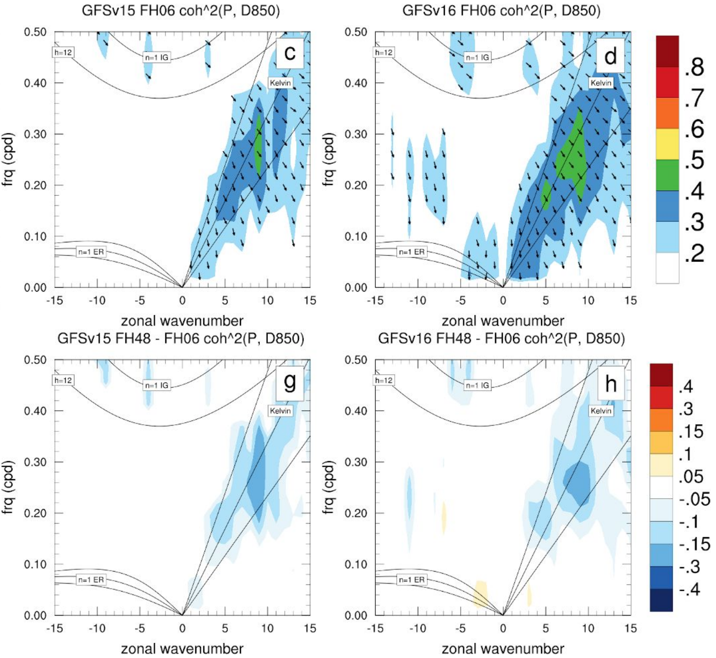


obs: ERA5 and IMERG



There are distinct peaks in coherence along CCEW dispersion curves, but overall the model coherence tends to be lower than observed. Models tend to have peaks at slightly higher frequencies than the reanalysis and observations

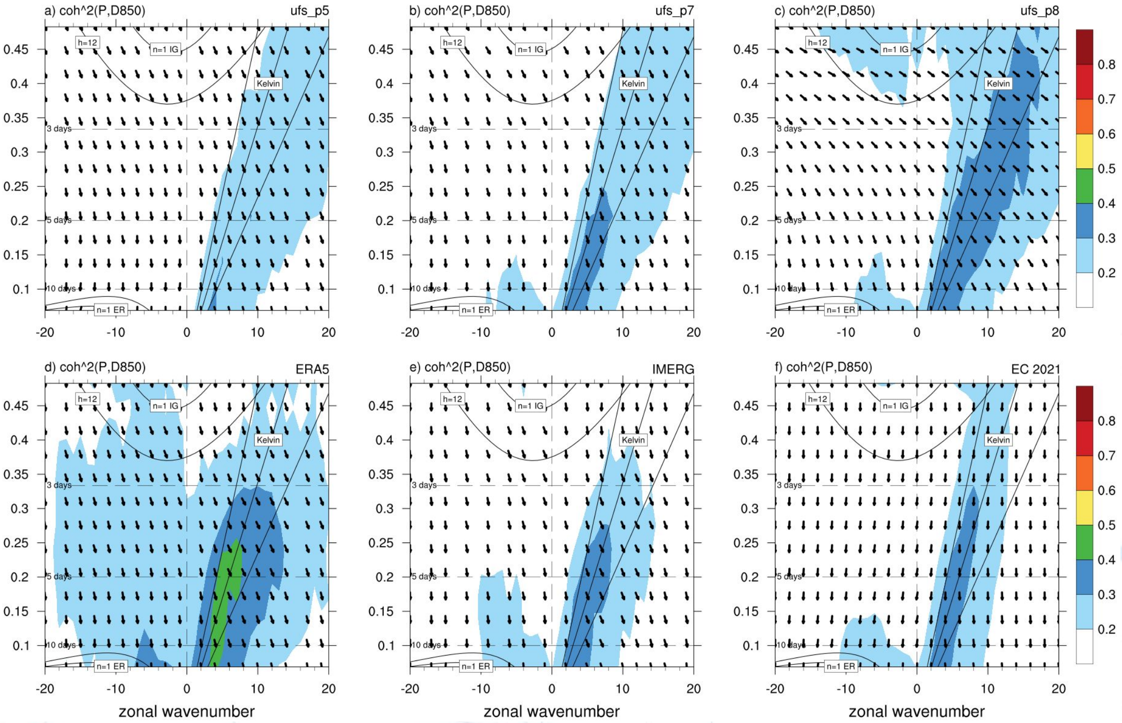
By 48h lead time coherence between precipitation and 850 hPa divergence at the peaks in the Kelvin wave band has decreased by 50-75% (GFSv15) and 30-50% (GFSv16).

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.

Space-time Coherence-squared Spectra

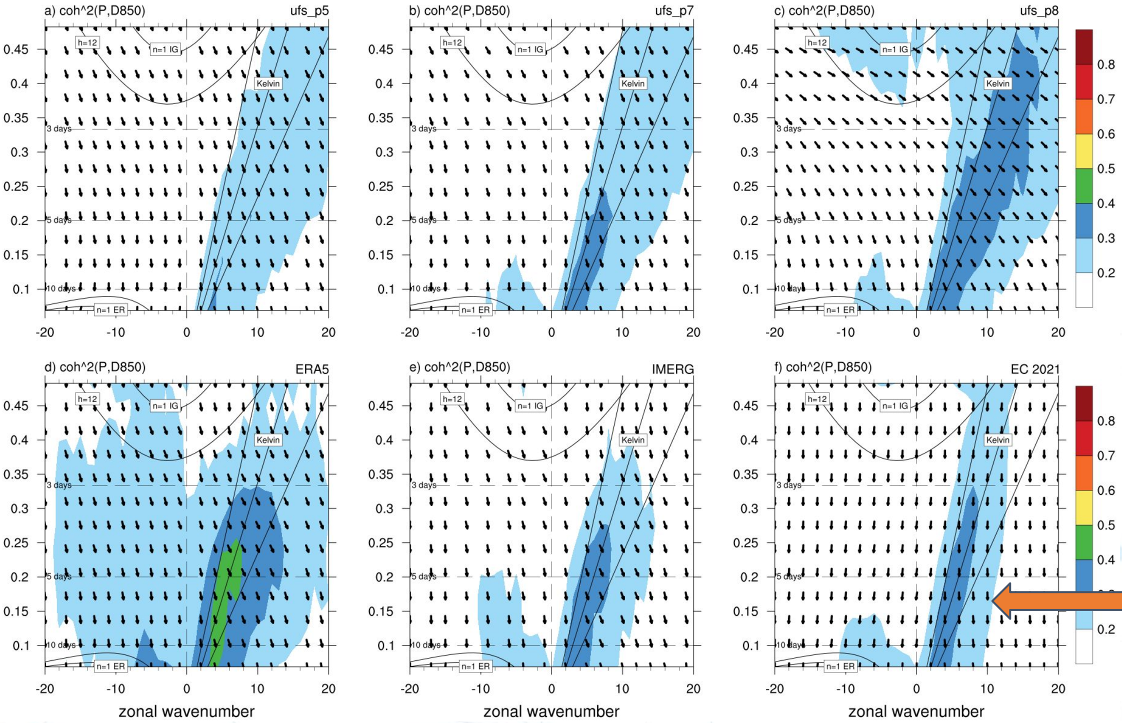


Coherence and phase spectra for precipitation and D850 from different sources for lead time 1- 30 days.

Coherence between low level convergence and precipitation for P7 is more confined.

P8 has stronger coherence and stronger dispersion. Maybe too much coherence at higher frequencies?

Space-time Coherence-squared Spectra



too narrow band of coherence

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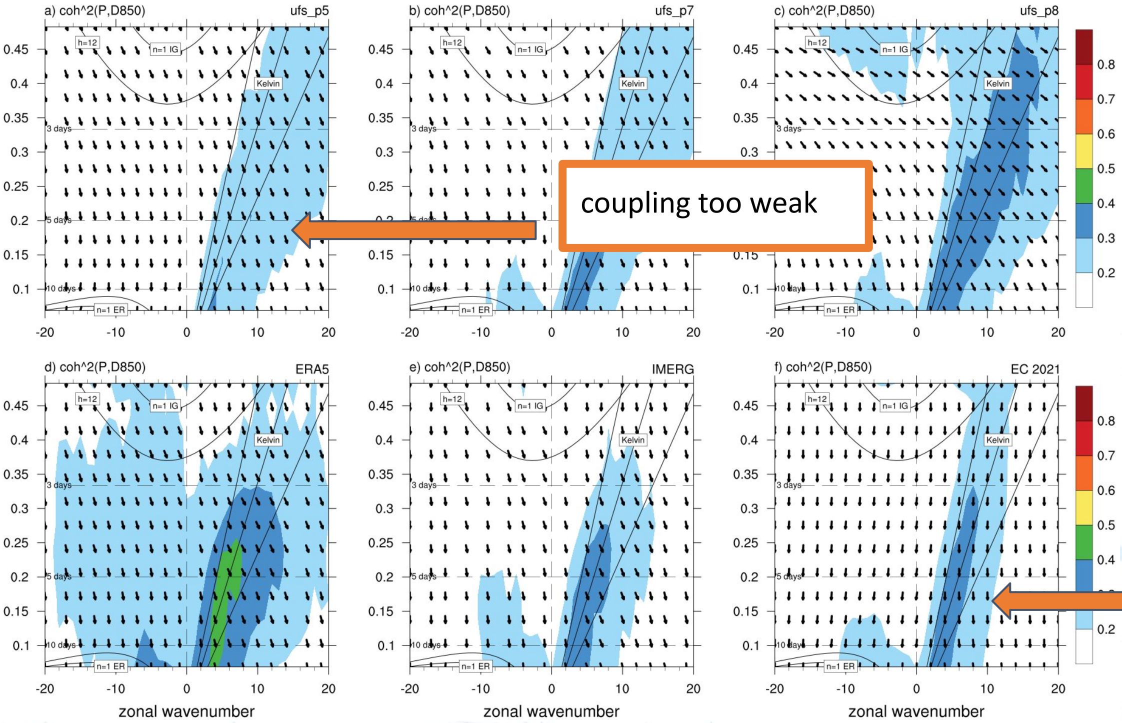

coupling too weak

too narrow band of coherence

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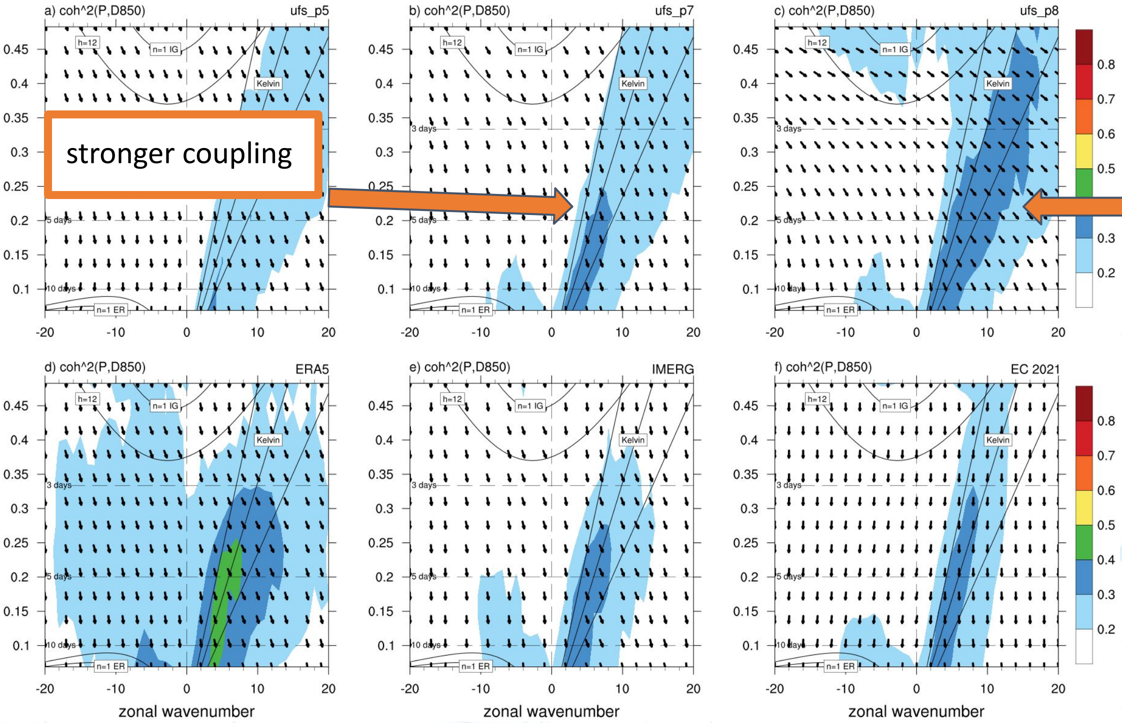

stronger coupling

More dispersion and stronger coupling

Coherence and phase spectra for precipitation and D850 from different sources for lead time 1- 30 days.
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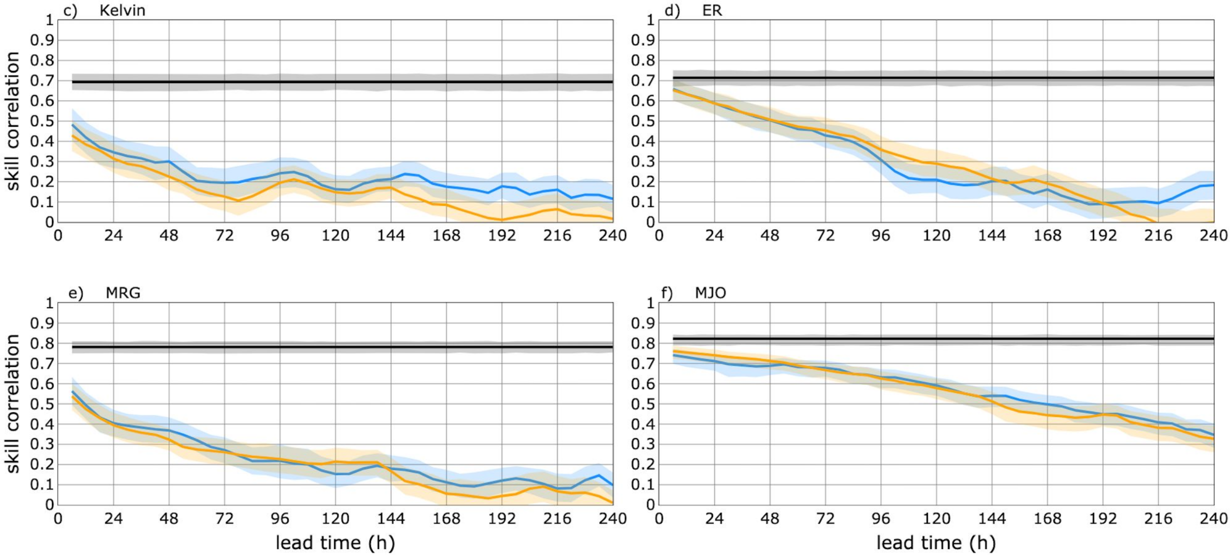
CCEW activity skill in the FV3GFS

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

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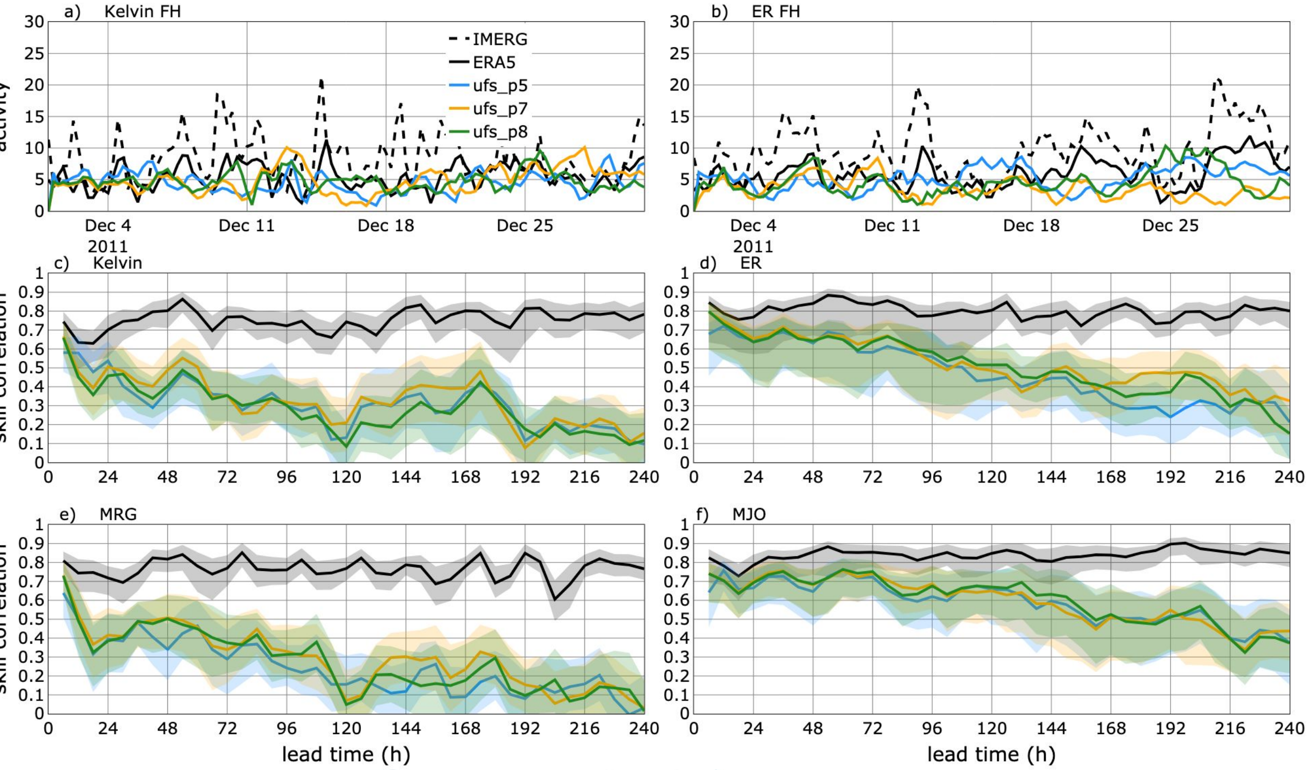
CCEW activity skill in the UFS



Similar results for the coupled forecasts, more noise because of smaller sample size.

ER skill is retained for longer in the coupled forecasts, but not for Kelvin, MRG or the MJO.

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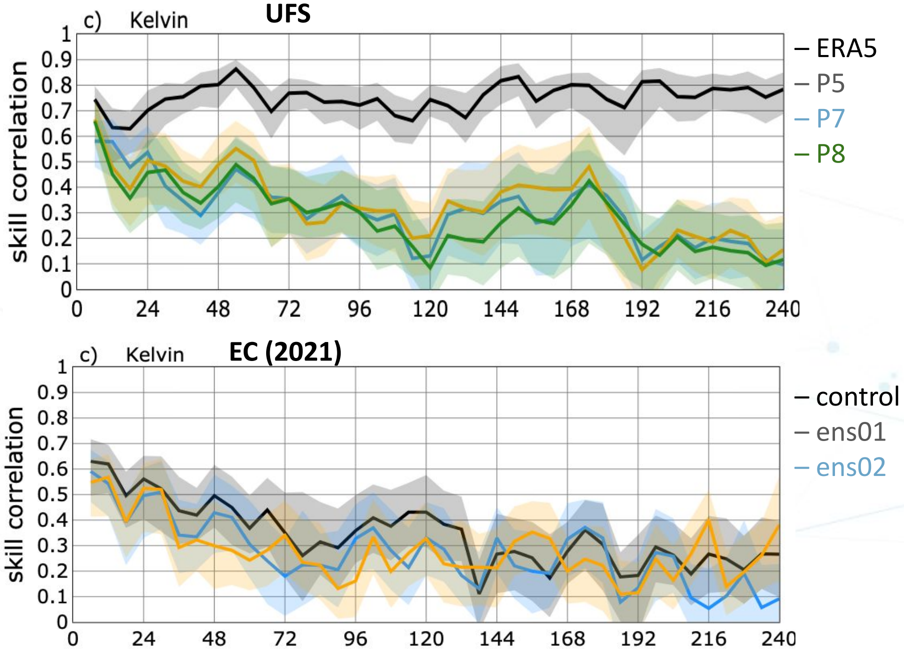
CCEW activity skill comparison to EC 2021



In general, UFS prototypes have comparable skill to the EC S2S ensemble.

UFS initial (at 6h lead time) Kelvin skill for P7 and P8 is slightly higher than in the EC, although difference is not significant.

EC skill at 12h lead time is still above 0.5 correlation while P7 and P8 have dropped below the 0.5 threshold.

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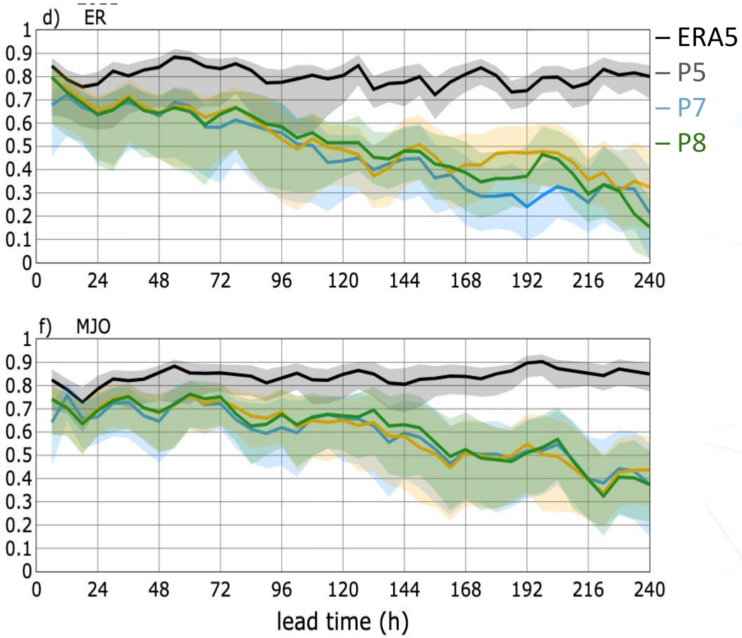
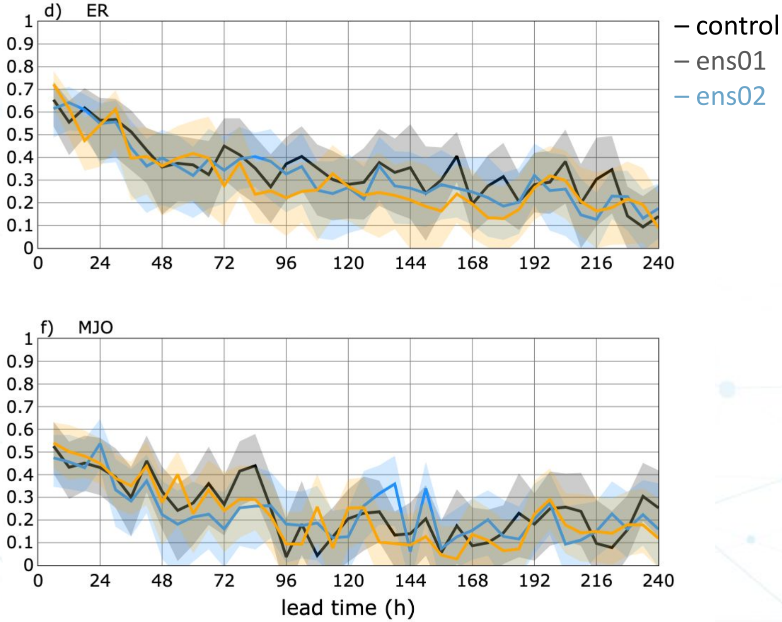
CCEW activity skill comparison to EC 2021





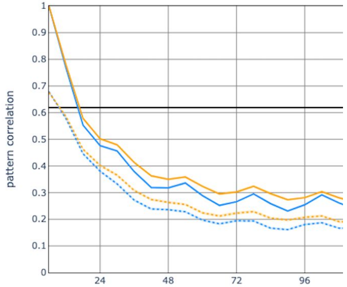
Initial ER skill is comparable between UFS prototypes and EC ensemble forecasts.

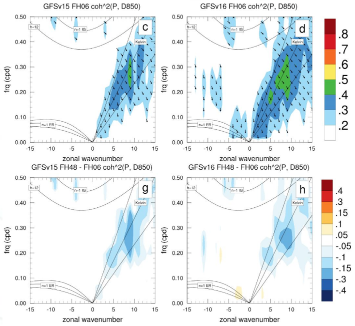
UFS prototypes have ER skill correlation above 0.5 until 96h lead time, while the EC skill correlation drops below 0.5 before 48h lead time.

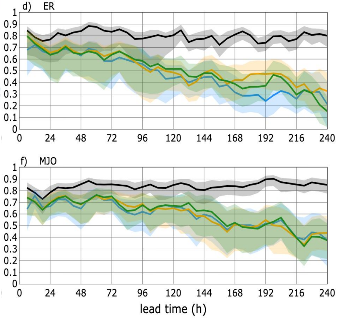
Initial MJO skill is significantly higher in P7 and P8 then the EC forecasts.

EC MJO skill drops below 0.5 in the first 24h, while the UFS MJO skill stays above 0.5 correlation until 144h lead time.

Summary







- Consider skill metrics for tropical convection and in particular for CCEWs.
- Much precipitation skill is lost in the hours immediately following initialization.
- Coupling between convection and the circulation is improved (in terms of scales and strength) in the UFS coupled prototypes, but decreases rapidly with lead time.
- The UFS coupled prototypes show skill at longer lead times for ERs and the MJO in a precipitation based metric.
- Further investigation of the ER/ MJO skill in the UFS is currently underway.

Summary

- A stand-alone python **GitHub** repo for these diagnostics (and more) 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)

More details on the diagnostics can be found in:

Gehne M., B. Wolding, J. Dias and G. N. Kiladis (2022). Diagnostics of Tropical Variability for Numerical Weather Forecasts, *Weather and Forecasting* (https://doi.org/10.1175/WAF-D-21-0204.1)

METplus GitHub