ESRL/PSD's planned research in support of improved sub-seasonal precipitation forecasts for California DWR

Tom Hamill, on behalf of

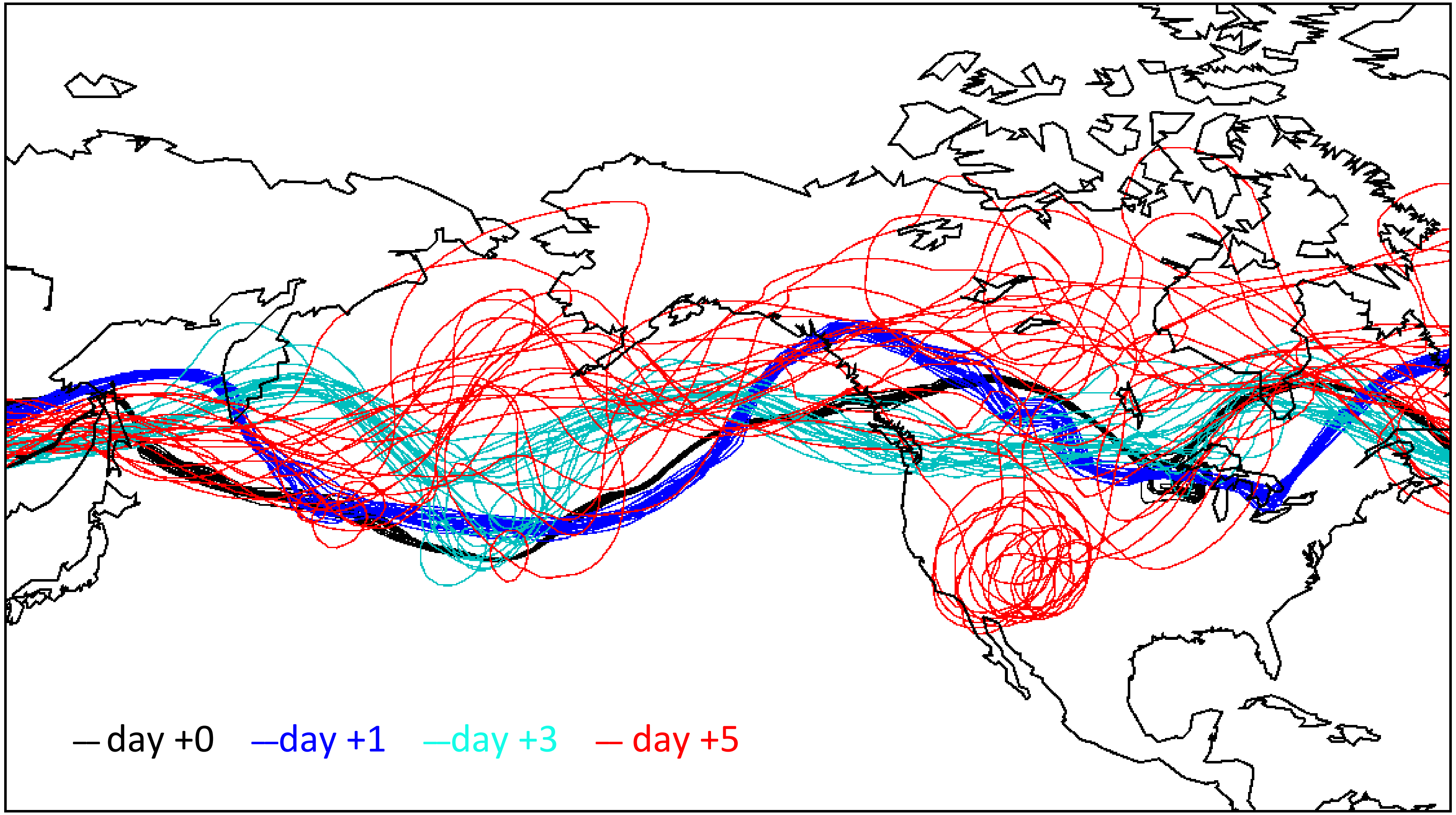
Michael Scheuerer, Lisa Bengtsson, and Juliana Dias

(also: Jian-Wen Bao, George Kiladis, Stefan Tulich)

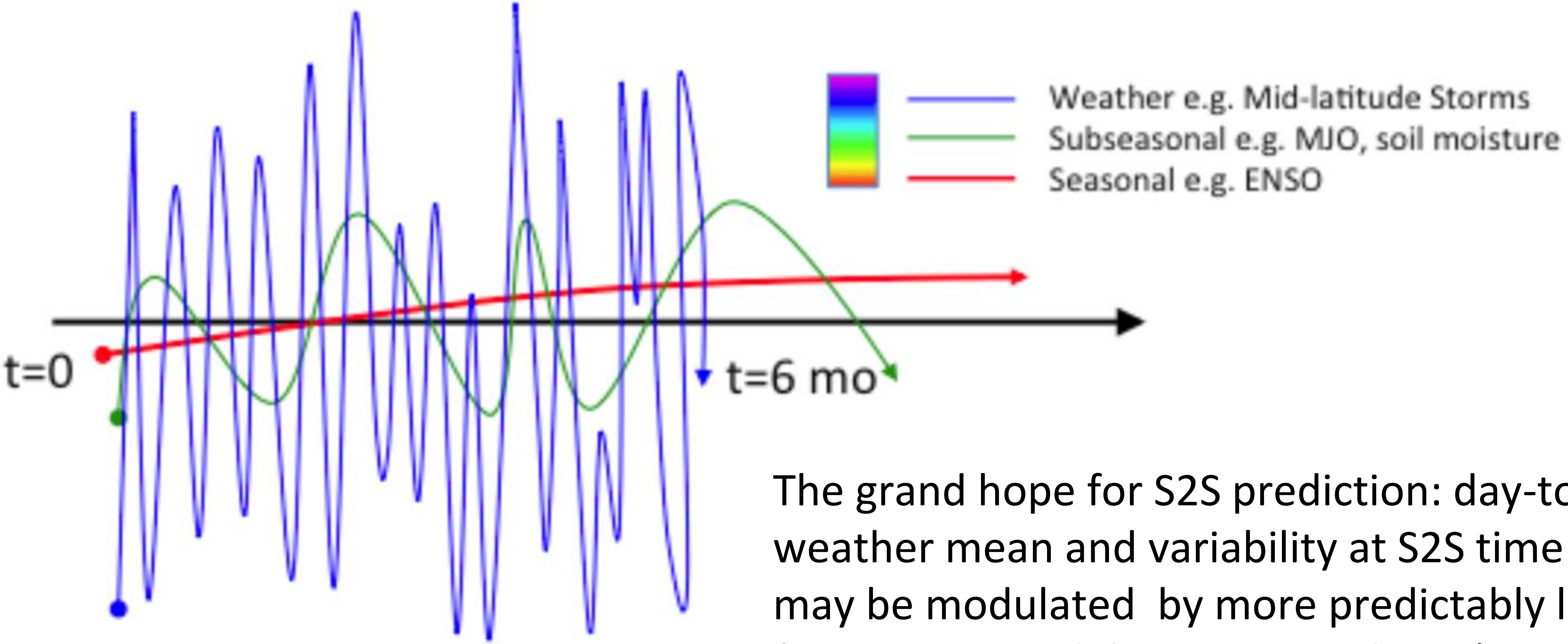
presentation to S2S precipitation forecasting workshop, Western States Water Council and Cali DWR, 15 May 2018

Chaos, one limiting factor in successful S2S predictions.

500 hPa Geopotential Height Spaghetti Plot for ECMWF, 00Z 24 Oct 2009 IC



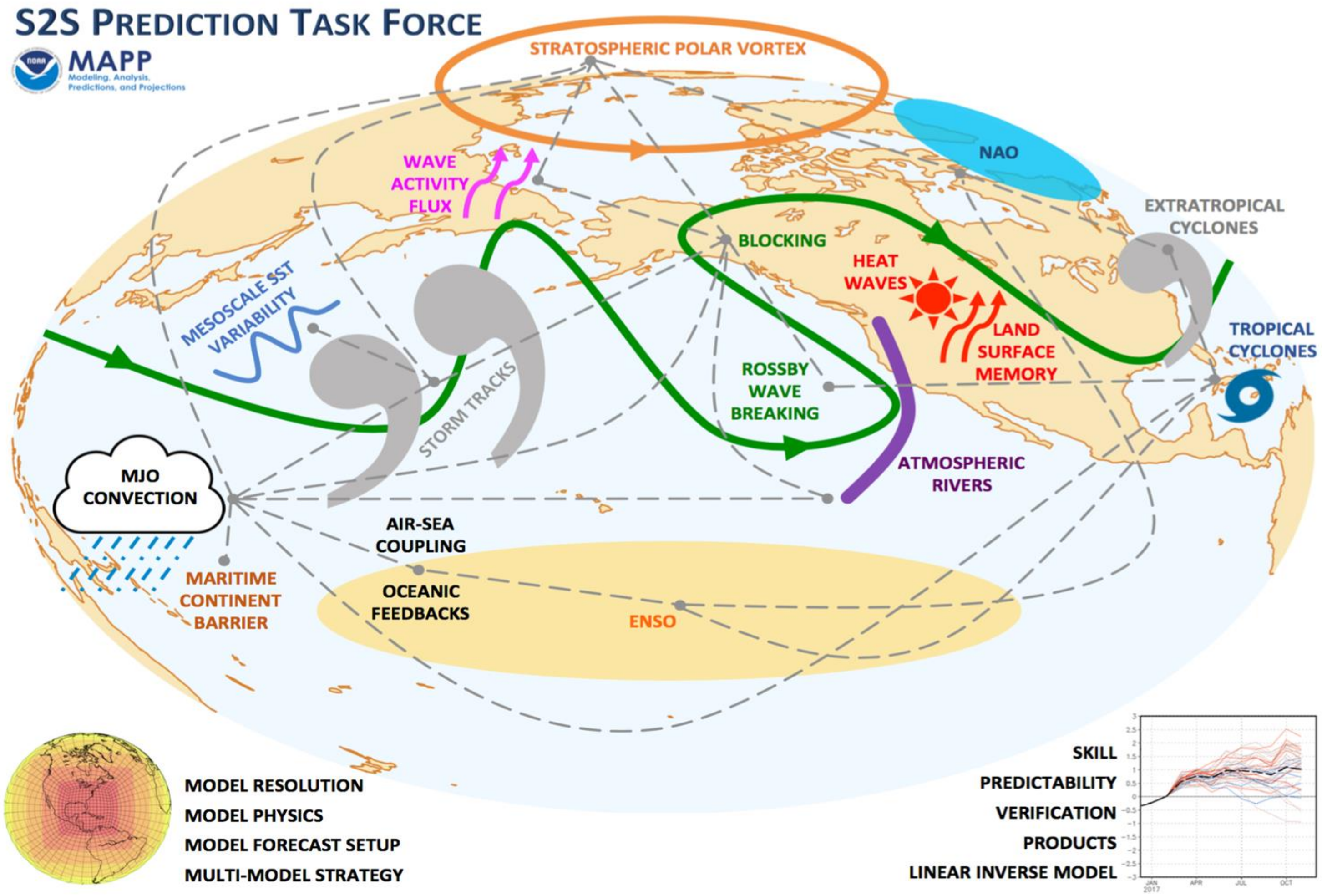
Weather, sub-seasonal, and seasonal variations.



The grand hope for S2S prediction: day-to-day weather mean and variability at S2S time scales may be modulated by more predictably low-frequency variability in atmosphere (MJO) and boundary forcings such as ocean surface temperature and soil moisture.

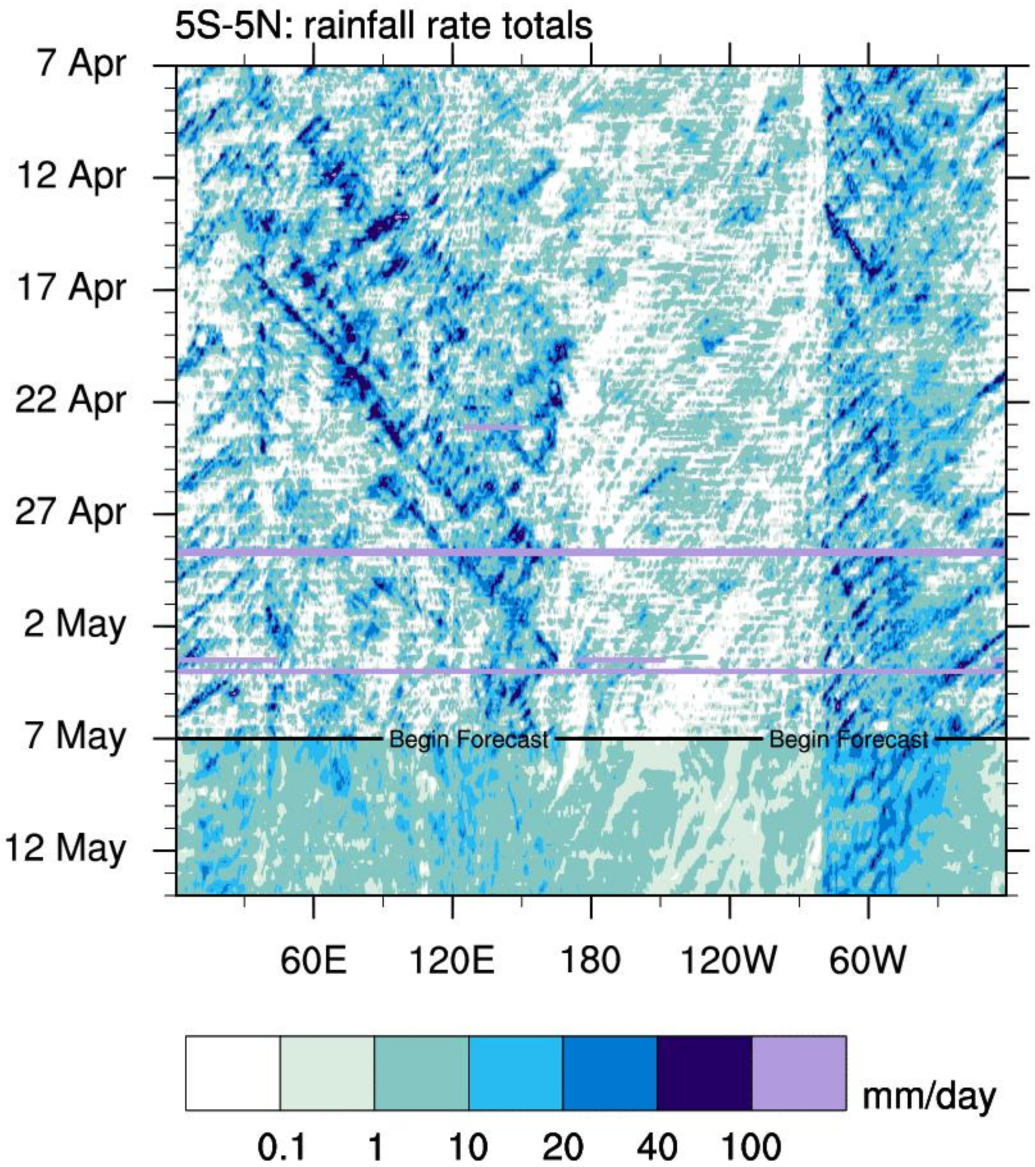
from 2016 NAS report on S2S improvement, [here.]

Inter-connected sources of skill for S2S forecasts, and research challenges in modeling them correctly.



- Madden-Julian Oscillation
- Polar stratospheric anomalies & NAO
- Blocking
- Sea-surface temperature anomalies, especially El Nino/La Nina
- Land-surface state anomalies
- Snow anomalies
- Sea-ice anomalies
- and more

Systematic model error: the other S2S dragon to slay.



Comparing rainfall observations to GFS forecasts, it is clear that the GFS produces excessive light rain rates, a weak diurnal cycle, and has trouble propagating disturbances (not only the MJO, but also smaller-scale waves)

Figure: Time–longitude plots of rainfall rates (3 hourly, 0.5°x 0.5°) averaged over 5°S-5°N. Observations from TMPA/TRMM 3B42RT for the last 30 days and GFS forecast for the next 7 days. From Michael Ventrice's Hovmollers Page.

NGGPS and S2S programs

2014 2018 2022

Next-Generation Global Prediction System

Atmospheric dycore selection (FV3)

Coupling component systems via NEMS →

Parameterization development & more →

GEFS reanalysis, reforecast data sets

Deploy community system

Implement GFS to +10 days

Implement GEFS to +35 days

etc.

- NOAA will expect its funded S2S R&D development to leverage NGGPS community system and to improve NGGPS, not other systems.
- Follow the ECMWF paradigm; concentrate resources to develop one great system. Multi-model internationally, perhaps not nationally.
- S2S: build out from week +3 to week +4 to month to season to inter-annual.
- **Still some areas under-resourced; we picked three that relate to S2S precipitation forecasts in California.**

Upcoming S2S project

Prediction system improvements related to S2S; others will still be handled through NGGPS.

Three areas of S2S western US precipitation improvement lacking in current NGGPS & S2S portfolios.

- **Statistical postprocessing**: while a dramatically improved S2S prediction system is being developed, statistically adjust the real-time forecast guidance to correct for systematic errors, statistically downscale, filter out the noise.
- **Better diagnoses** of what's wrong with tropical thunderstorms and the Madden-Julian Oscillation that modulate land-falling storms on the US West Coast.
  - Must understand what needs fixing before targeting model improvements.
- **Improve the representation of those tropical thunderstorms**.

Leaders of the planned research for California DWR

Michael Scheuerer
Statistical postprocessing of sub-seasonal precipitation forecasts

Lisa Bengtsson
Improving the modeling of thunderstorms and their variability in ensemble prediction systems.

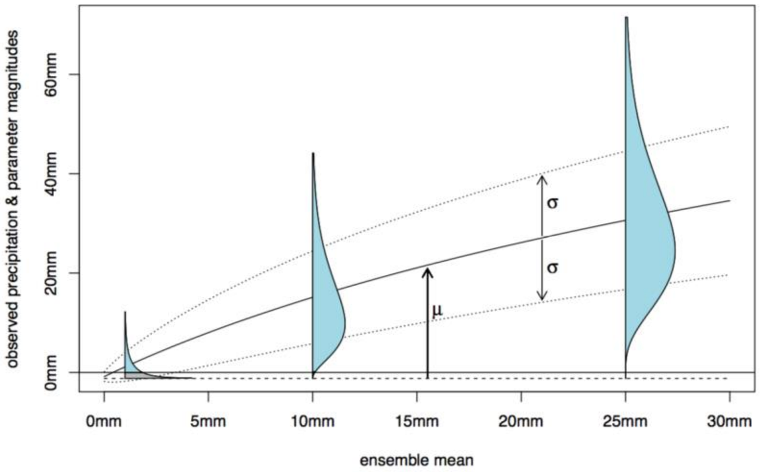
Juliana Dias
Diagnosing problems with thunderstorms in numerical weather and climate prediction systems.

Each of these scientists are 5-10 years past the Ph.D. and emerging leaders in their disciplines.
Expect to see them in future visits.

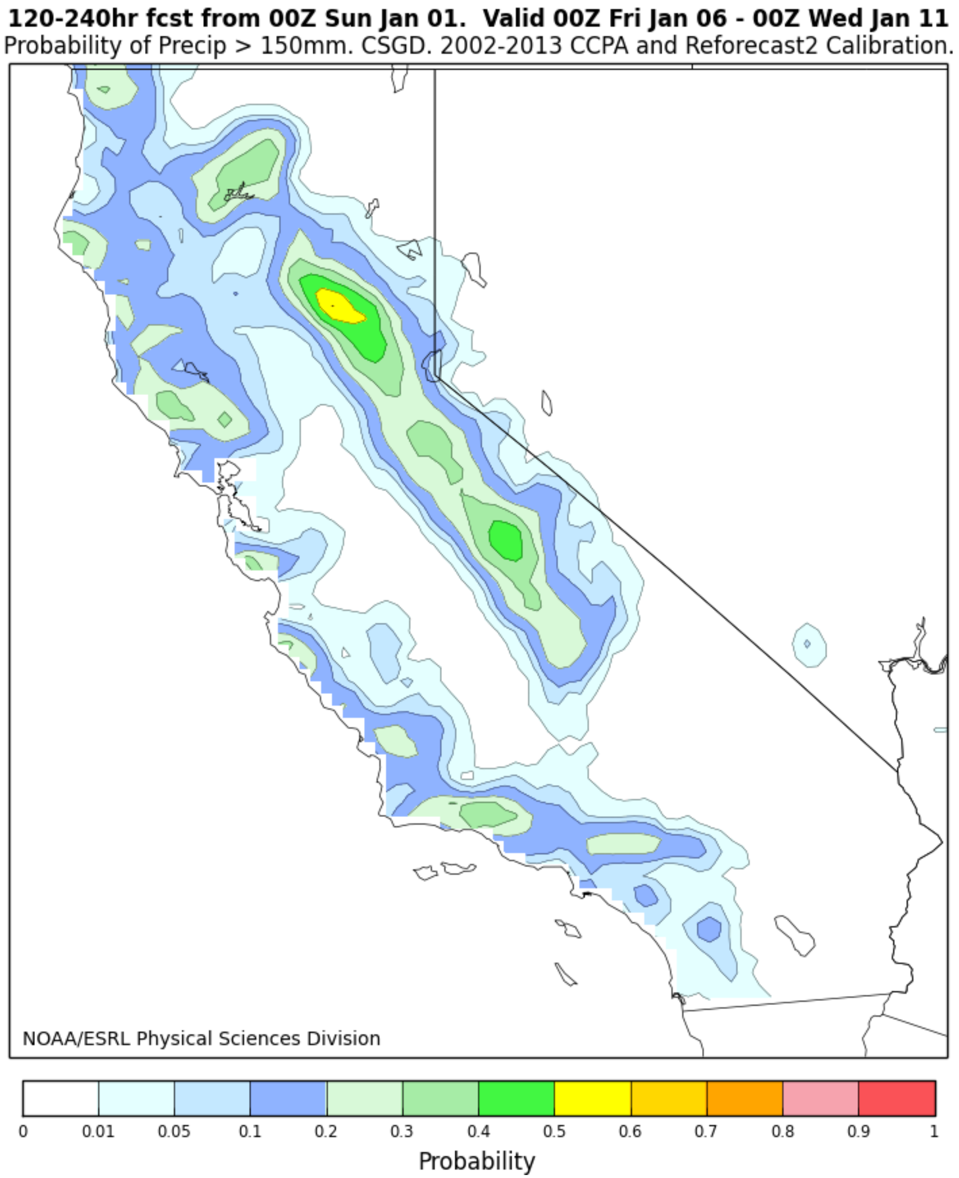
Statistical postprocessing

ESRL/PSD has extensive experience in the development and evaluation of advanced statistical postprocessing methodologies, especially for precipitation.

We are contributing to the development of NOAA's National Blend of Models (NBM), and we have developed several experimental forecast web products including one that provides medium-range probabilistic forecast guidance for extreme precipitation over California based on the algorithm proposed by Scheuerer and Hamill (2015).



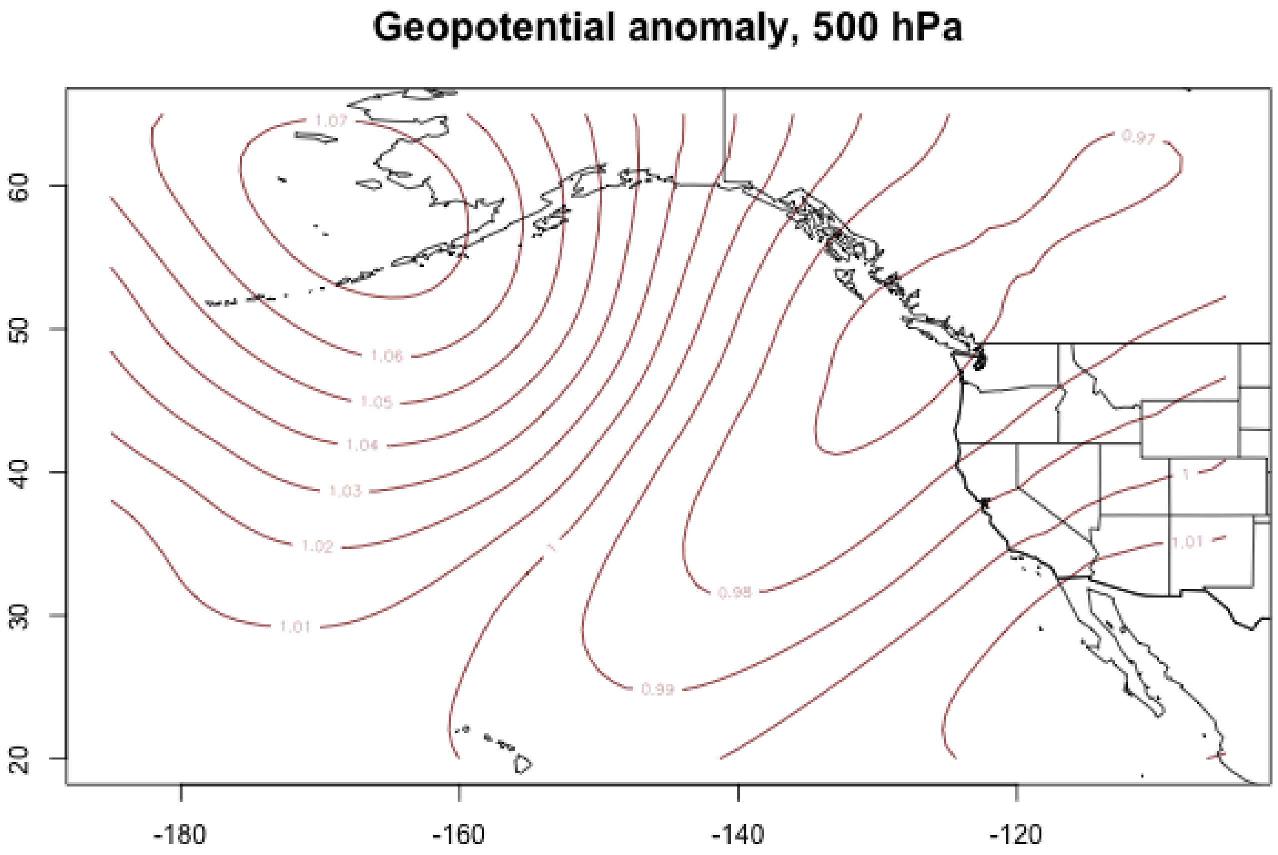
Heteroscedastic regression approach based on censored shifted gamma distributions proposed by Scheuerer and Hamill (2015).



https://www.esrl.noaa.gov/psd/forecasts/reforecast2/calif-csgd/index.html

Statistical postprocessing

The postprocessing methods developed in our group have been successfully used to provide probabilistic guidance for lead times up to 15 days. Ensemble precipitation forecasts by the current version of the GEFS show little skill for lead times beyond that.



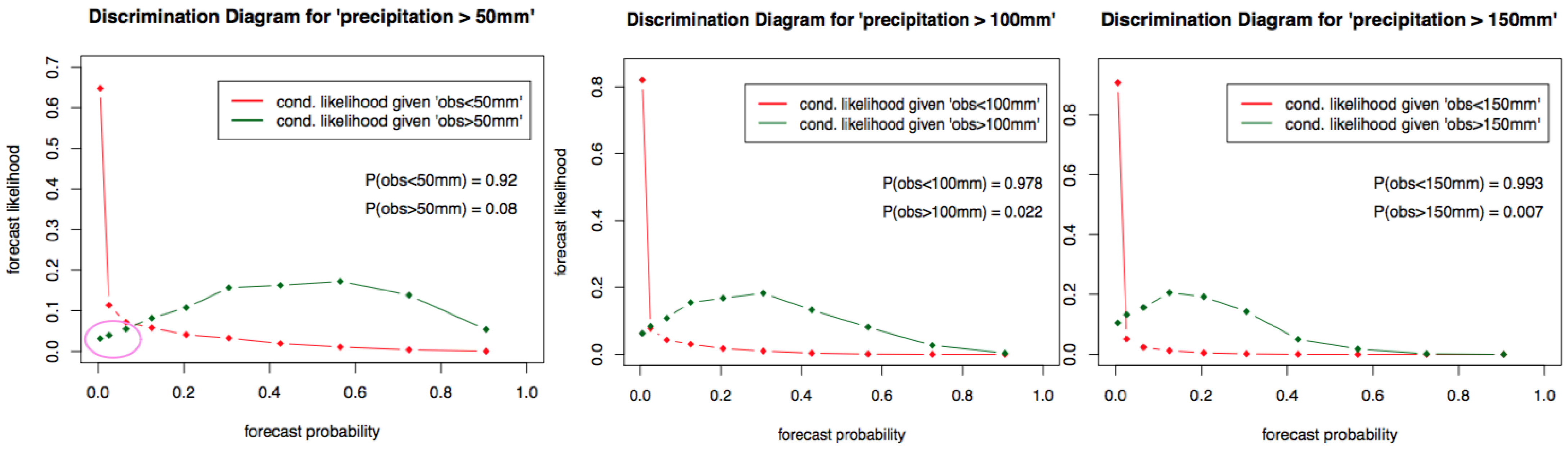
However, there might be some skill in GEFS forecasts of geopotential anomaly patters or large scale moisture transport.

We will develop new postprocessing methodology that links precipitation over California to these large scale predictors and thus generates reliable probabilistic guidance for precipitation accumulations with up to 3/4 weeks of lead time.

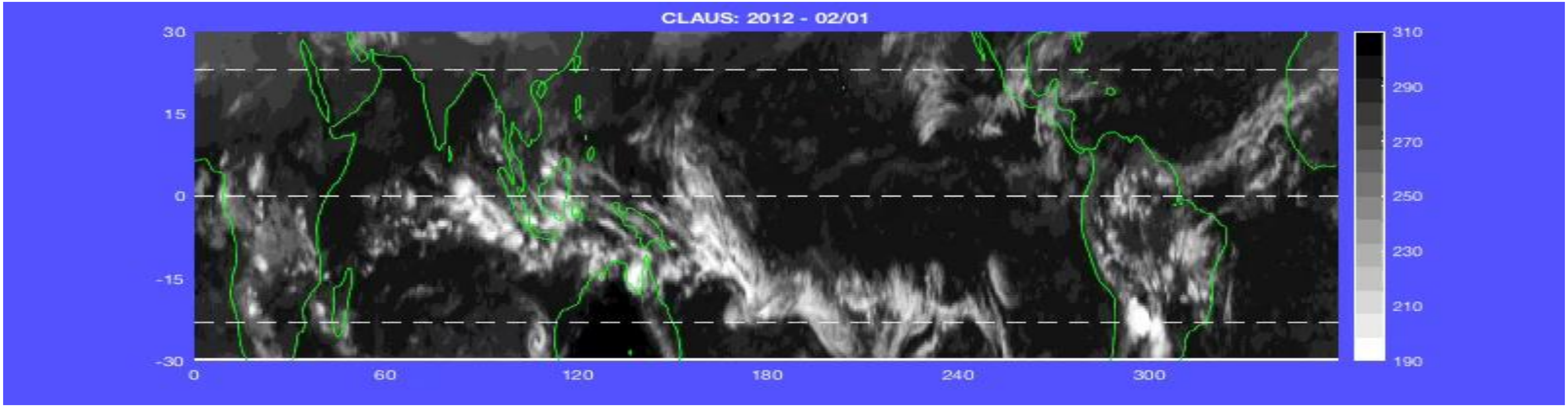
Statistical postprocessing

The postprocessing methods mentioned above are optimized for good overall performance. For water management in California, however, it is particularly important to *not miss an event*.

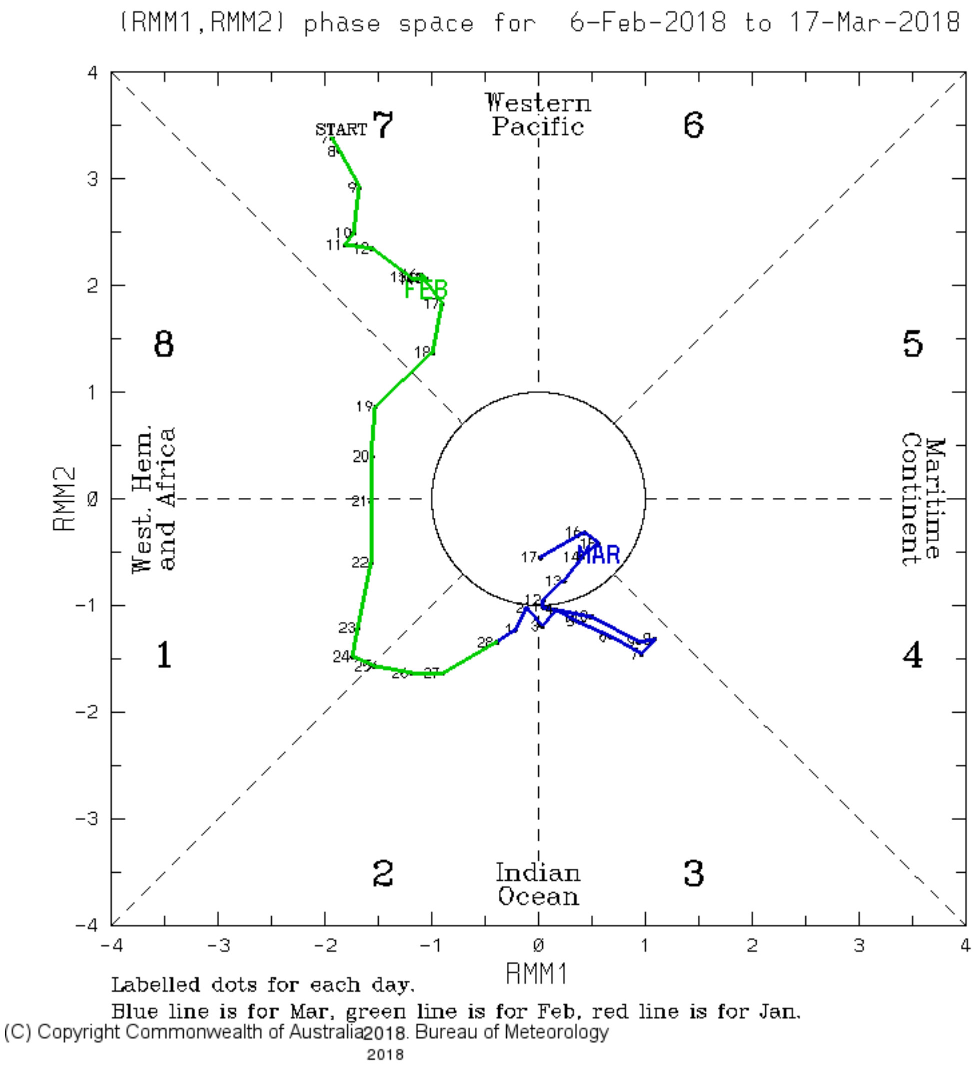
We will study alternative methods, including machine learning techniques, that are optimized to *predicting the non-occurrence of an event* and identify predictors that might not necessarily be useful for predicting the exact precipitation amount but allow one to rule out the possibility of heavy precipitation with high confidence.

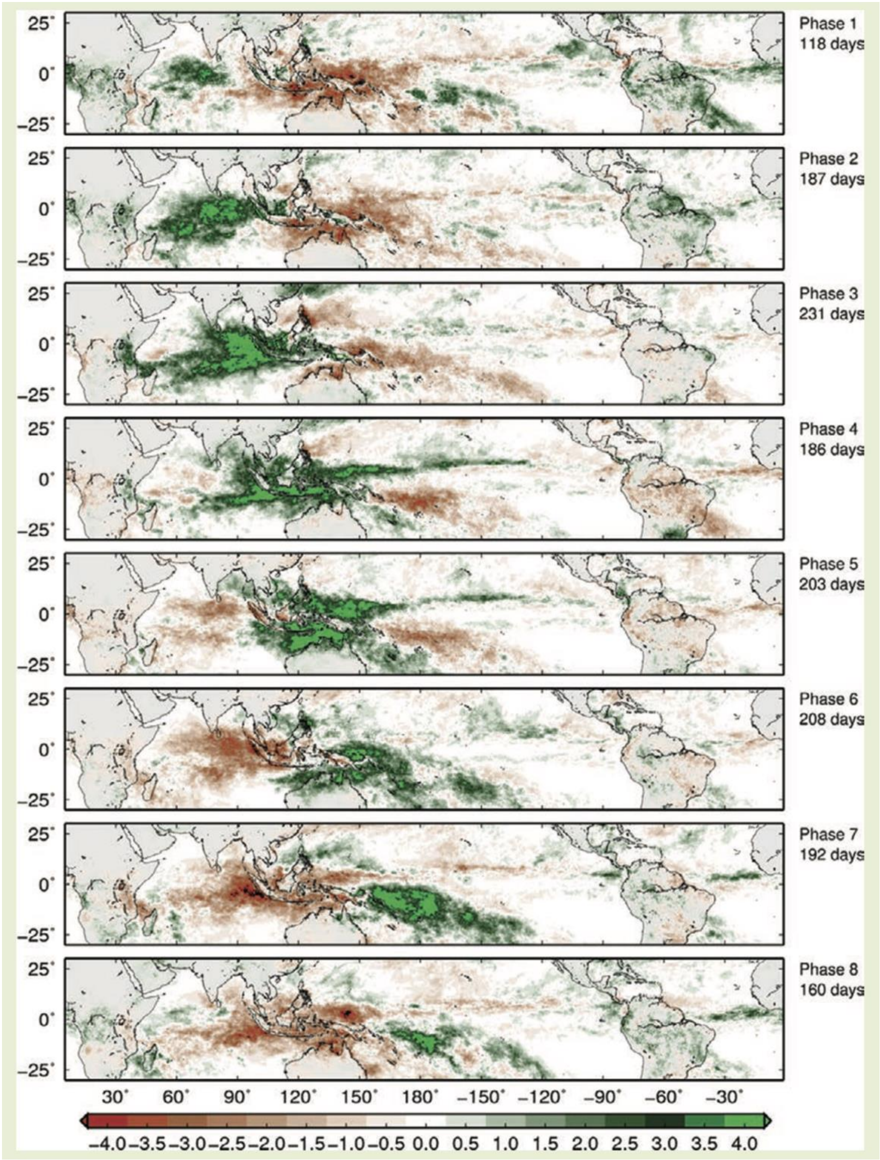


The Madden-Julian Oscillation and improved diagnostics of sources of tropical thunderstorm forecast error.



RMM1 and RMM2, the leading EOFs of MJO variability.



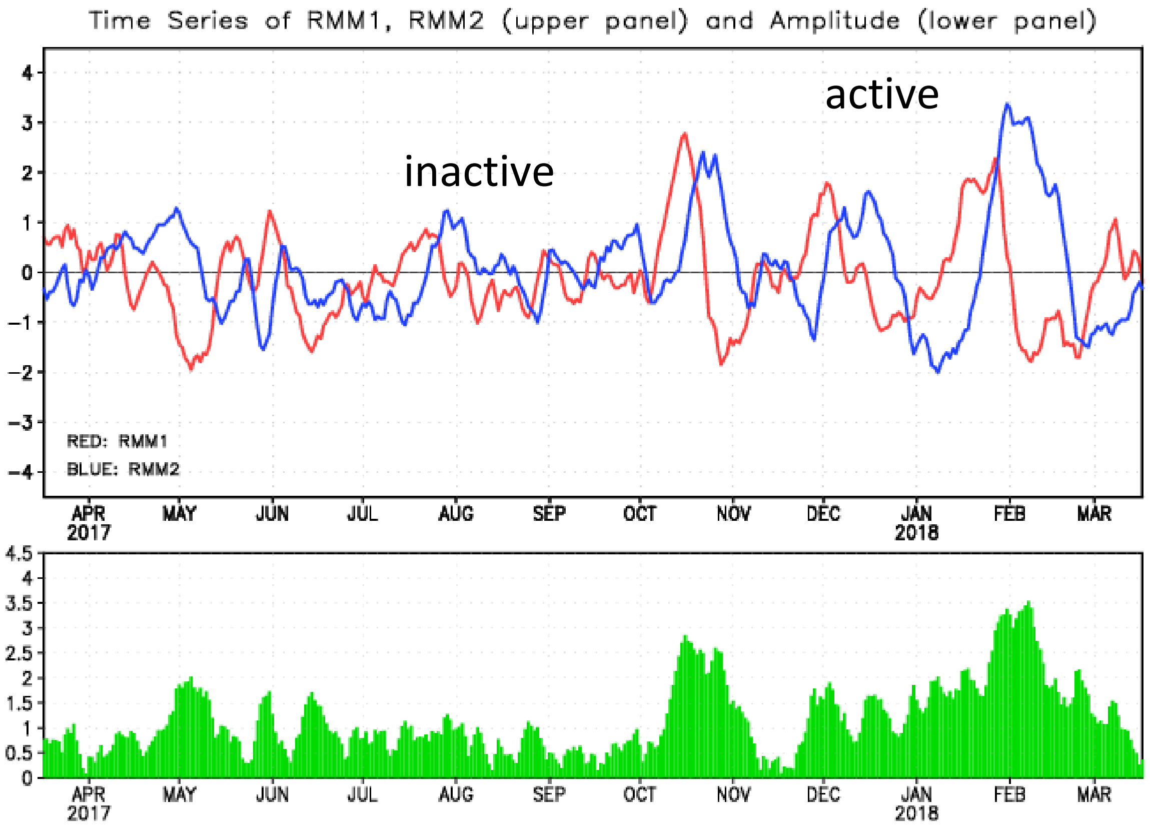


tropical precipitation anomalies associated with MJO phases.

from Zhang 2013 BAMS, here.

More on the MJO

- It’s intermittently active (more in winter; left).
- Modulates weather even far from the tropical Pacific, as the organized tropical convection forces mid-latitude Rossby wave train (right).



from https://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/rmm.html

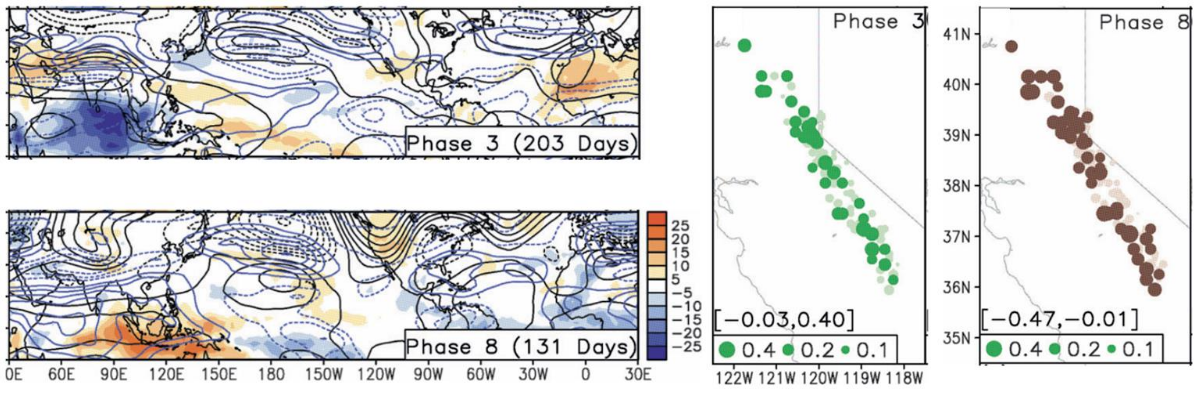
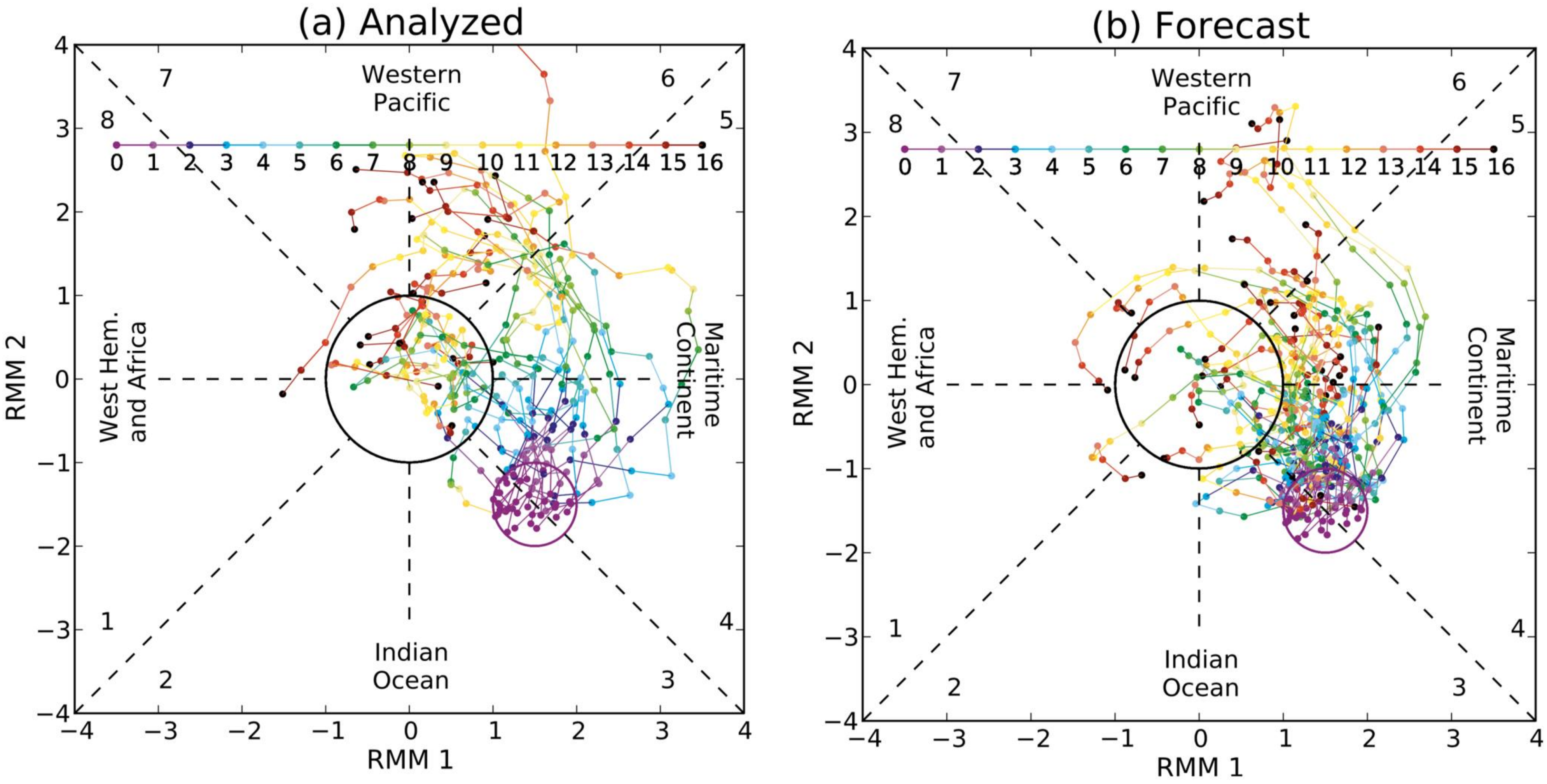


Illustration of the impact of the phase of the MJO and the rate of snow accumulation in the Sierras, adapted from Guan et al. (2012). The two left panels show outgoing longwave radiation anomalies relative to average conditions for phases 3 and 8 of the MJO. Blue colors indicate enhanced thunderstorm activity, orange colors indicate suppressed activity. The two right-hand panels show the contemporaneous changes in snow accumulation associated with Phases 3 and 8, illustrating how the MJO can modulate precipitation in California.

MJO intensity and propagation speed not well modeled in recent NCEP GEFS system.



Circa 2012 version of GEFS tends to decrease amplitude of MJO and propagate too slowly.

Probably several causes, including convective parameterization, lack of proper stochastic physics, modeling of SST response to MJO thunderstorms, & more.

The current poor prediction and its effect on US S2S forecasts make this a key area of R&D.

Ref: Hamill and Kiladis MWR 2014, here.

MJO performance depends on metric used

Circulation (RMM) versus Convection (ROMI) based MJO indices

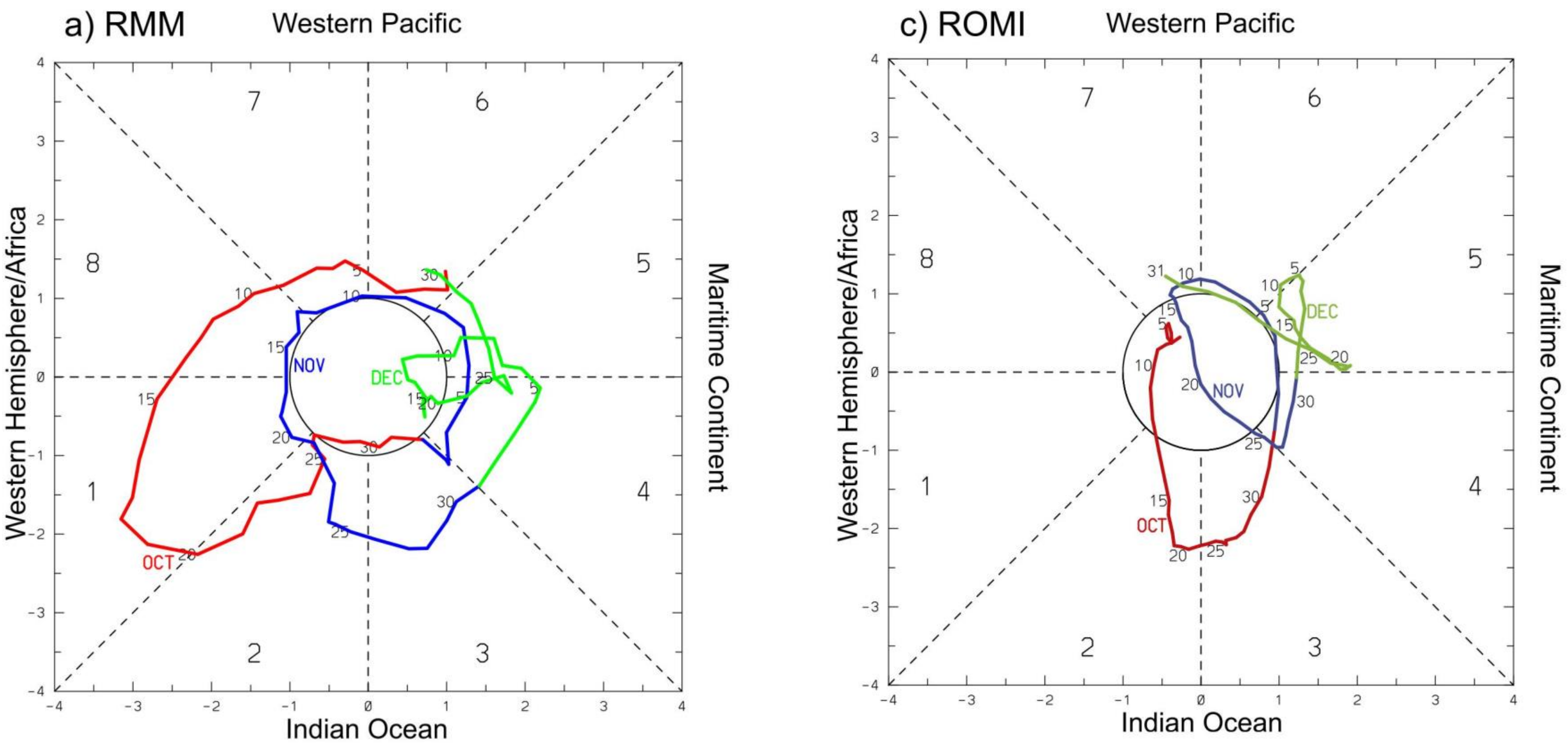
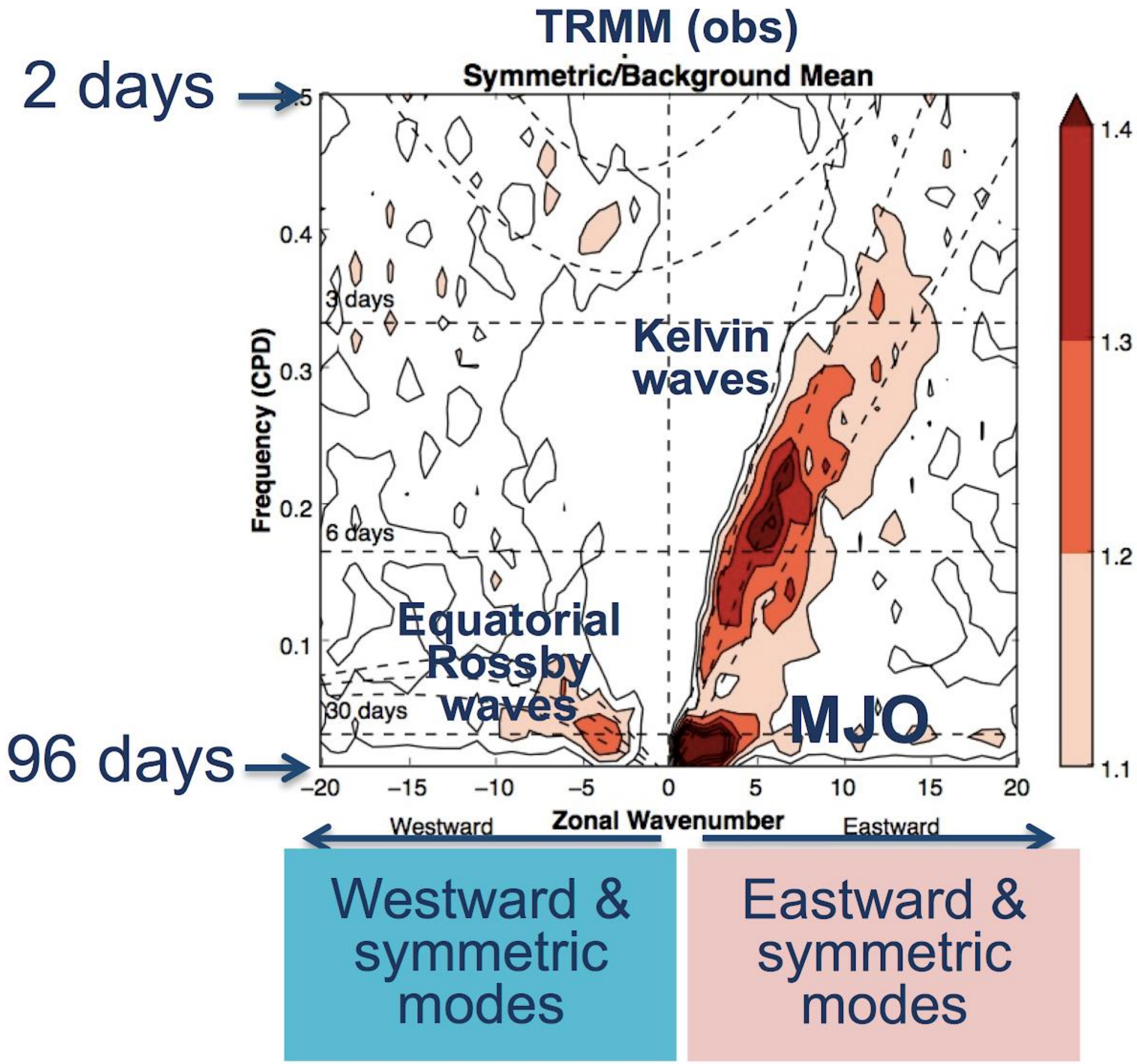


Figure: MJO phase diagram from October-December 2011. Figure from Kiladis et al 2014, MWR.

MJO propagation and amplitude depends on whether its circulation or convective signal is tracked

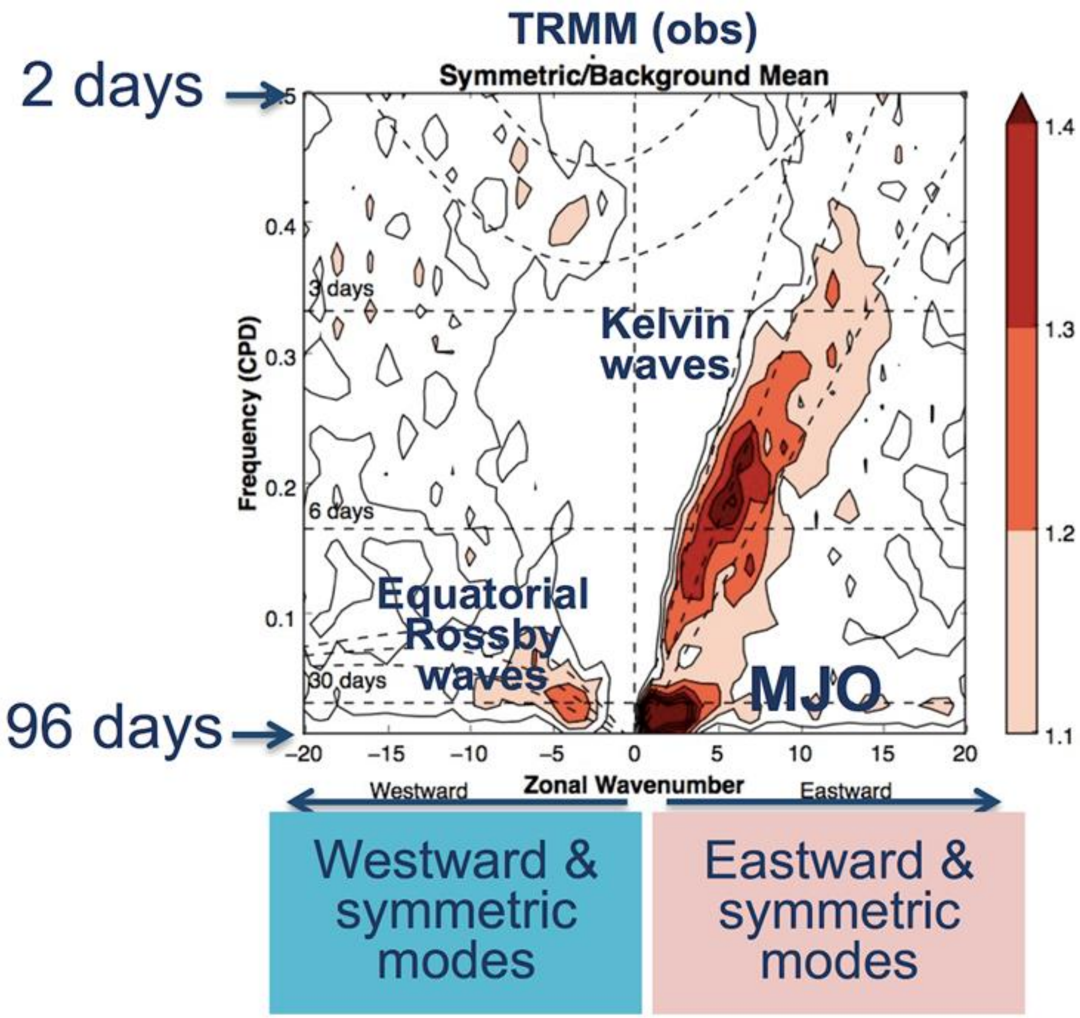
Verification of MJO inferred from convection based indices is a harder test for models.

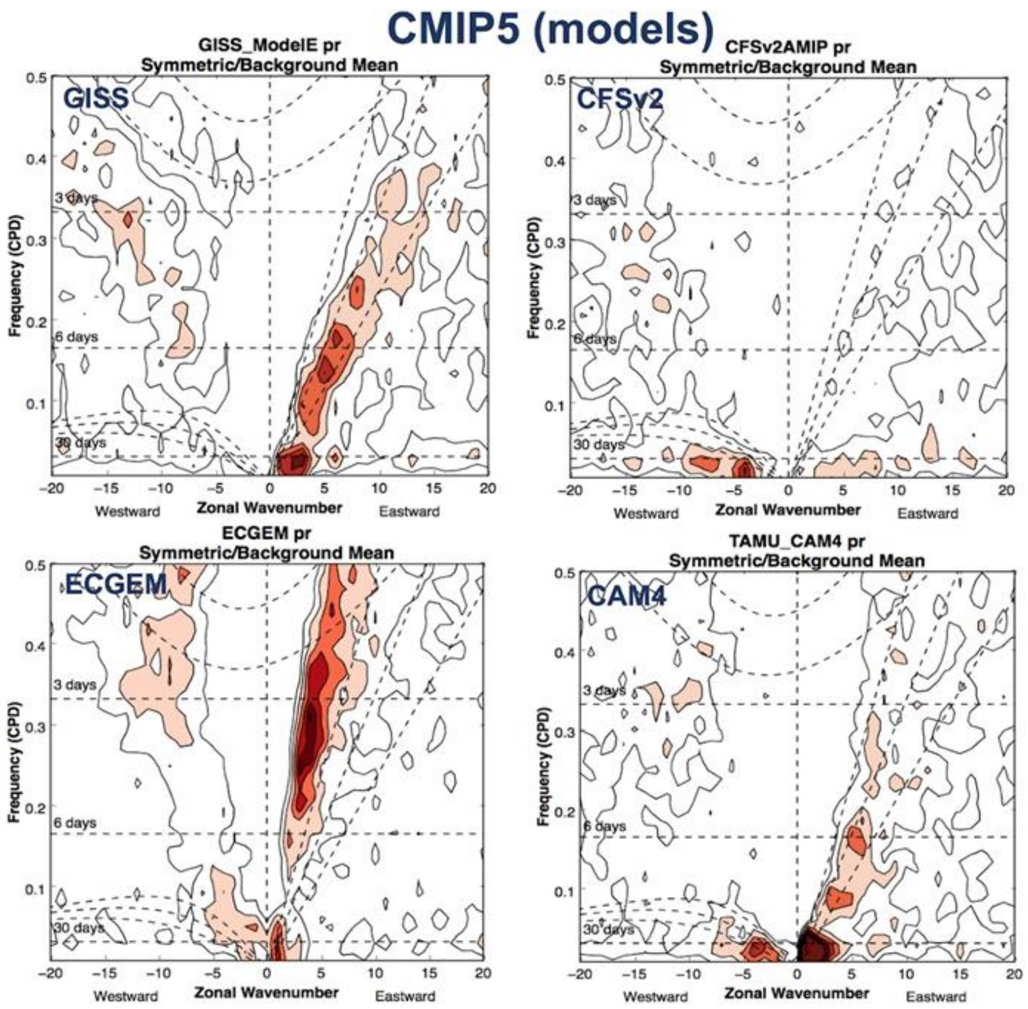
Model performance deficiencies extend beyond the MJO to higher-frequency tropical waves



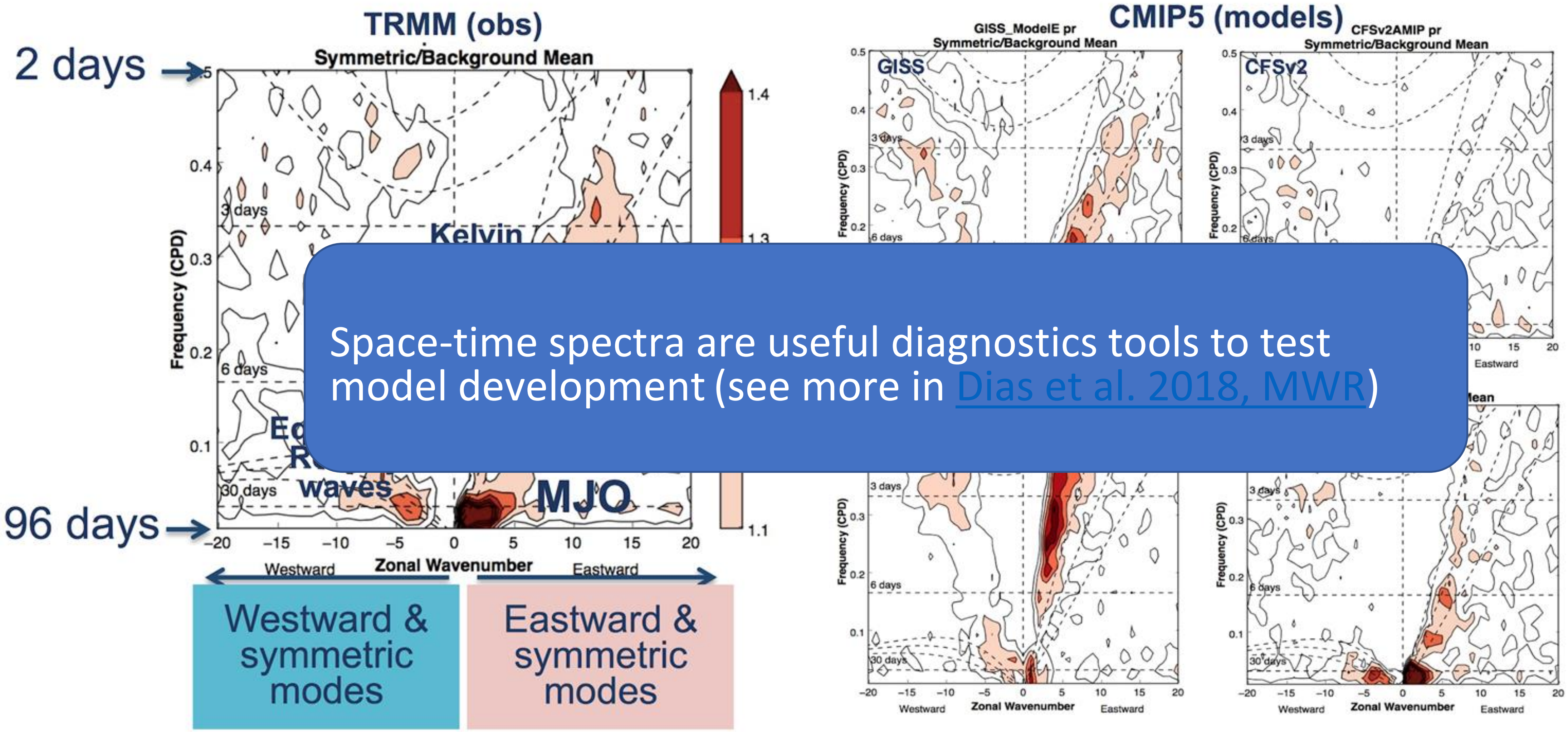
- The greatest power is low-frequency variability with a zonal wavenumber of 1. This is the MJO, the Madden-Julian Oscillation.
- Ref: Wheeler and Kiladis 1999 JAS, here.
- **Not modeled well in most current prediction systems.**

Model performance deficiencies extend beyond the MJO to higher-frequency tropical waves



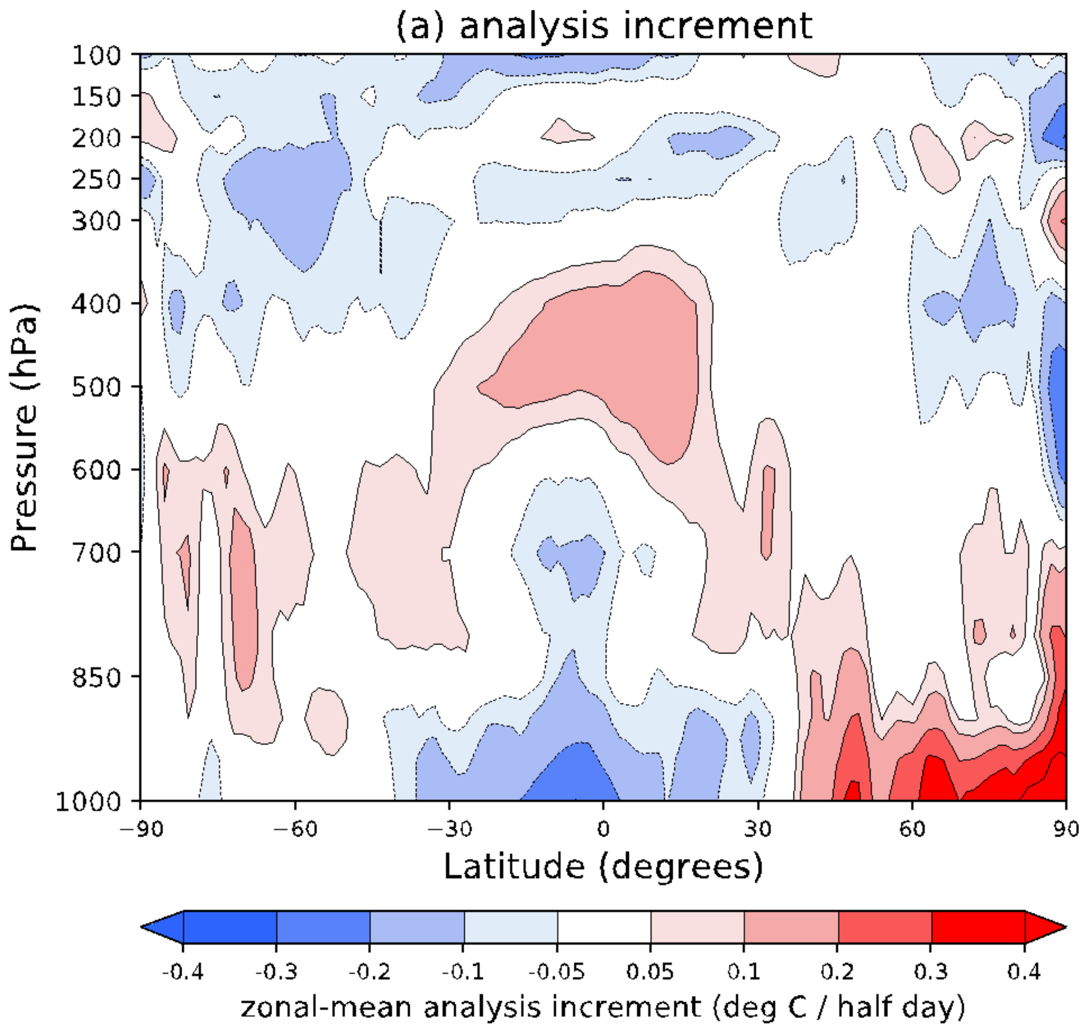


Model performance deficiencies extend beyond the MJO to higher-frequency tropical waves



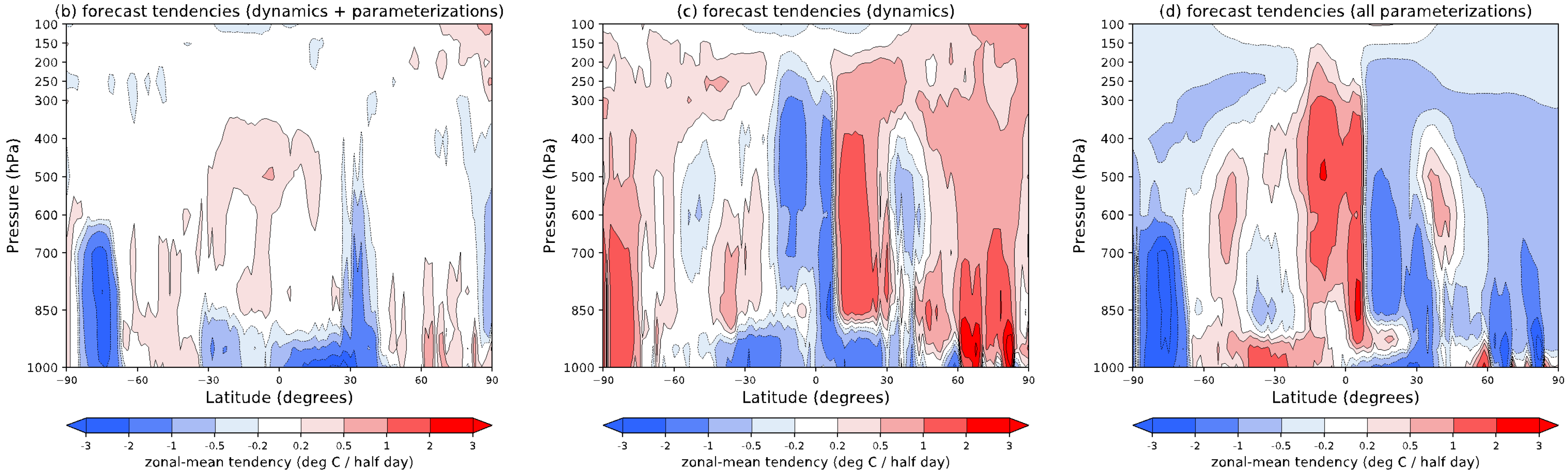
Space-time spectra are useful diagnostics tools to test model development (see more in Dias et al. 2018, MWR)

Time average of analysis increments (analysis minus forecast) January 2010, ECMWF



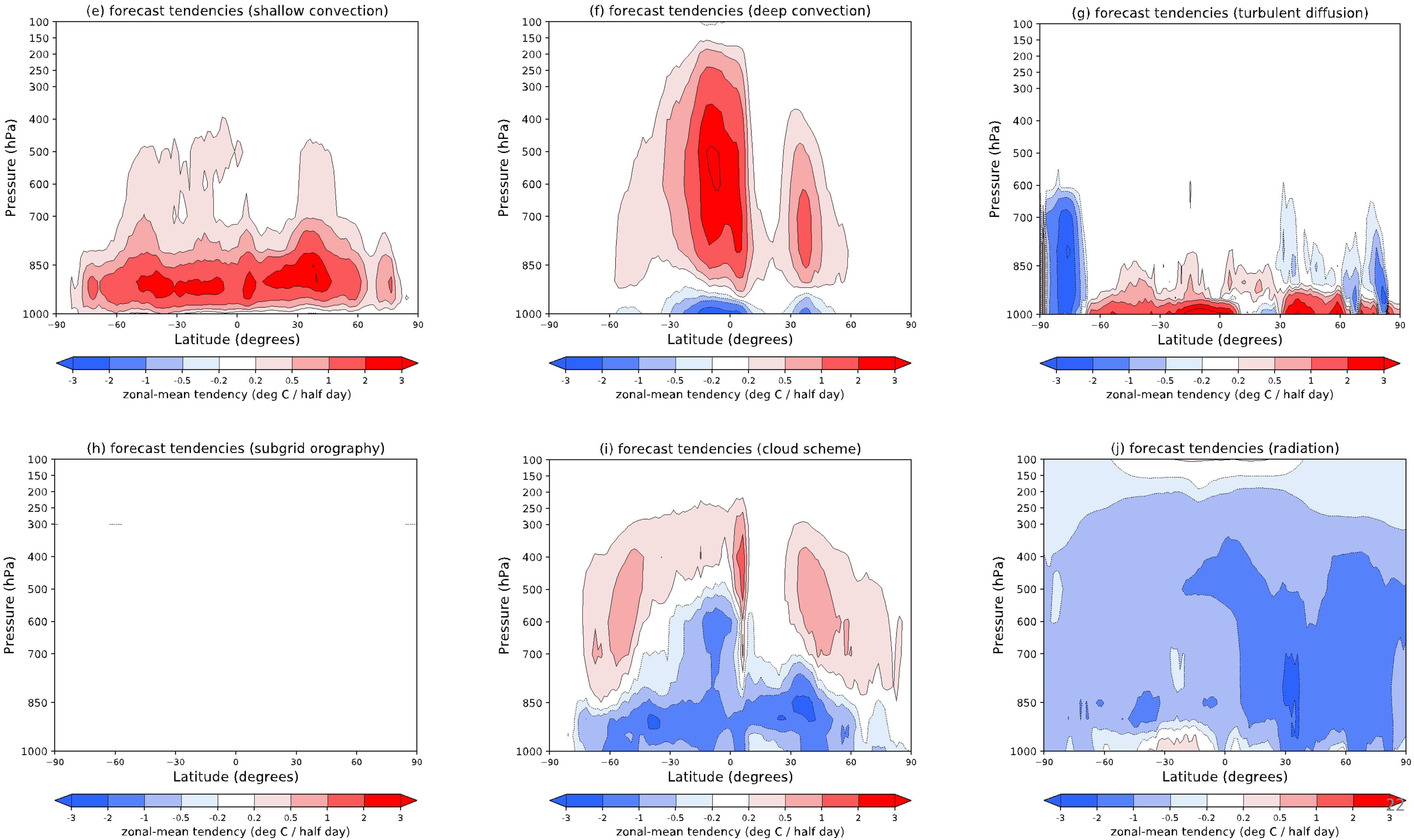
- In data assimilation, background forecasts should be unbiased, so corrections should be random and near zero.
- “YOTC” data set provides analysis, forecast, time tendency data to creatively explore potential sources of forecast error.
- ECMWF’s Jan 2010 biases in tropical upper troposphere are probably representative of current NCEP models.
- Errors in this area with thunderstorms are ones we’d like to tamp down.

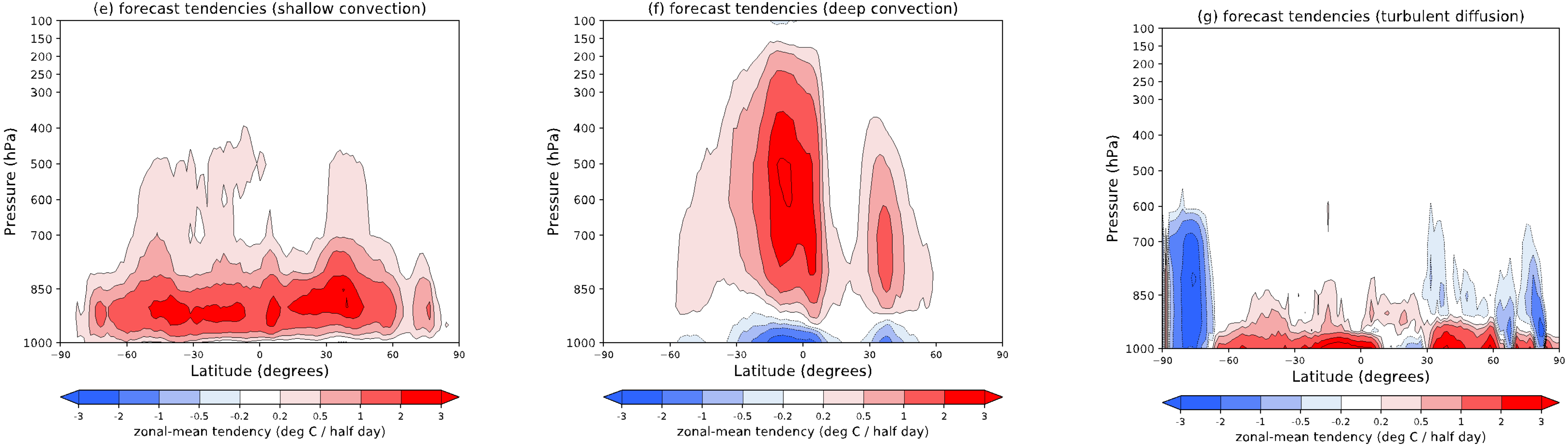
Forecast tendency = large-scale dynamics + sub-gridscale parameterizations.



A general anti-correlation between dynamics and physics tendency.

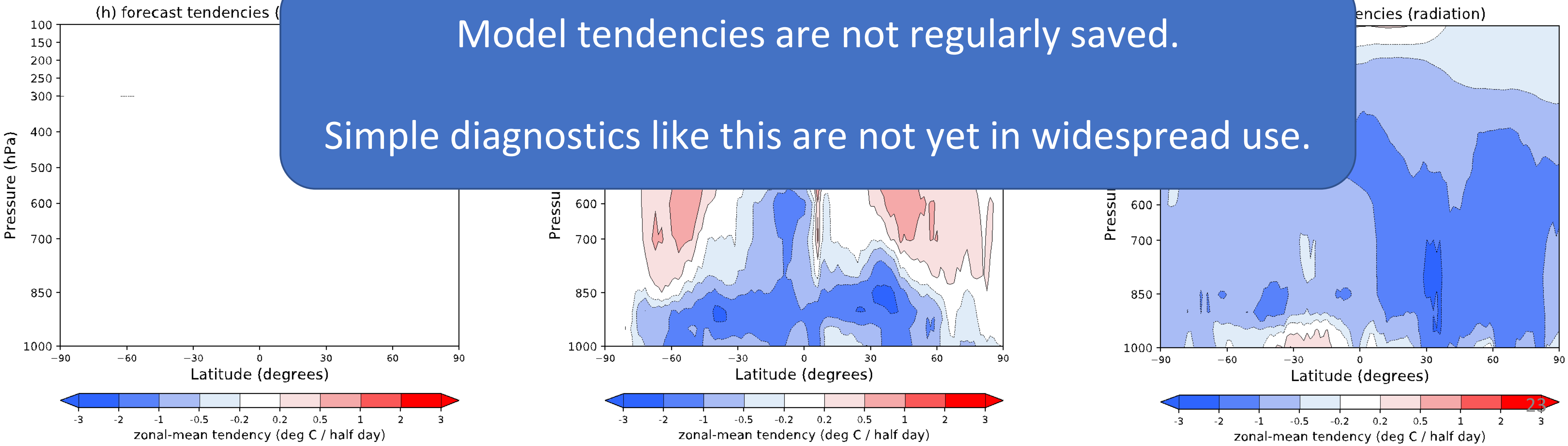
Example: large-scale upward motion induces cooling. Parameterizations of cloud latent heating introduce some compensating warming.


(e) forecast tendencies (shallow convection)
(f) forecast tendencies (deep convection)
(g) forecast tendencies (turbulent diffusion)
(h) forecast tendencies (subgrid orography)
(i) forecast tendencies (cloud scheme)
(j) forecast tendencies (radiation)
Pressure (hPa)
100 150 200 250 300 400 500 600 700 850 1000
Latitude (degrees)
−90 −60 −30 0 30 60 90
-3 -2 -1 -0.5 -0.2 0.2 0.5 1 2 3
zonal-mean tendency (deg C / half day)



Model tendencies are not regularly saved.

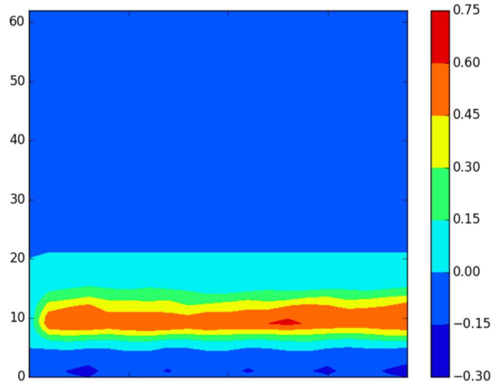
Simple diagnostics like this are not yet in widespread use.



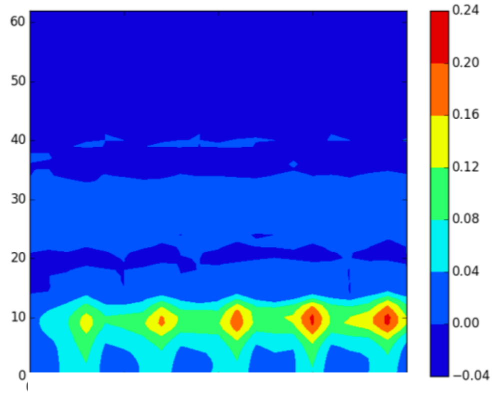
Improvement of the deep convective parameterization.

What can we learn from other state-of-the-art convection parameterizations?

Shallow convective heating tendency. SAS scheme.



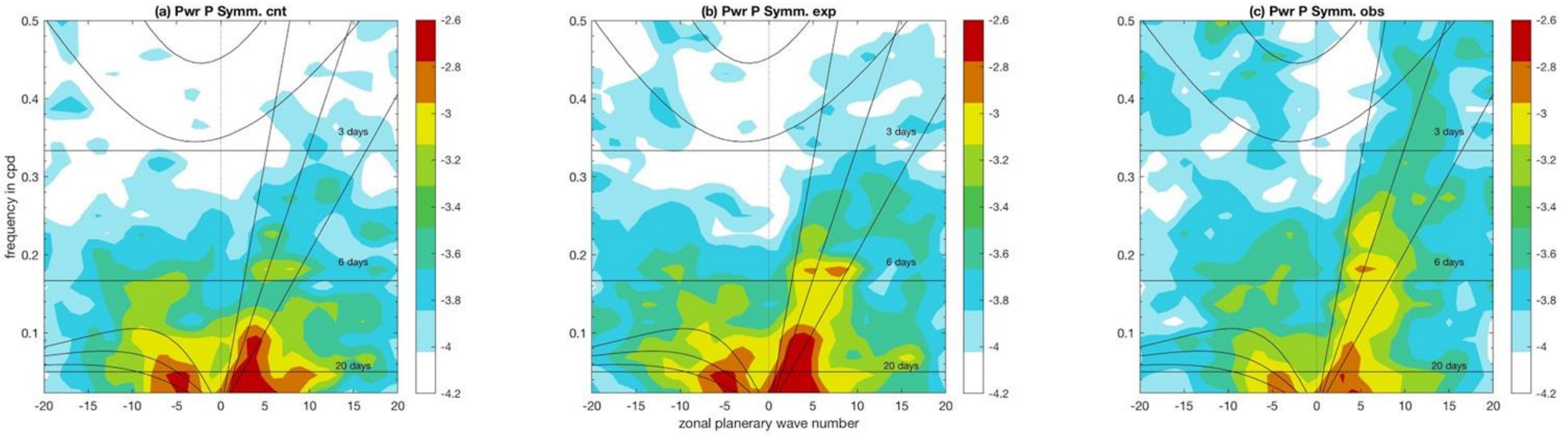
Shallow convective heating tendency. IFS scheme.



FV3 GFS v0

FV3 GFS w IFS conv

observed

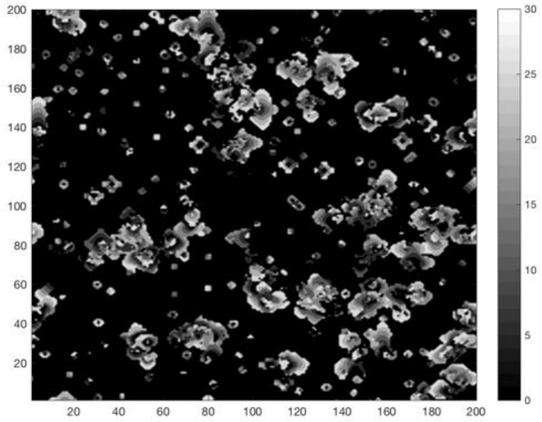


Example with the ECMWF's IFS convection scheme in FV3GFS. More power in the Kelvin mode (too much in low frequencies).

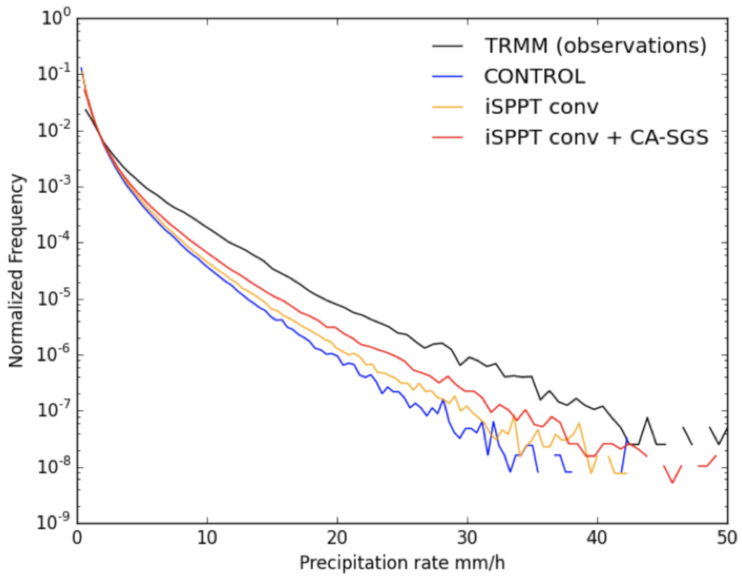
Better realism in diurnal cycle of shallow convection.

Improvement of the deep convective parameterization.

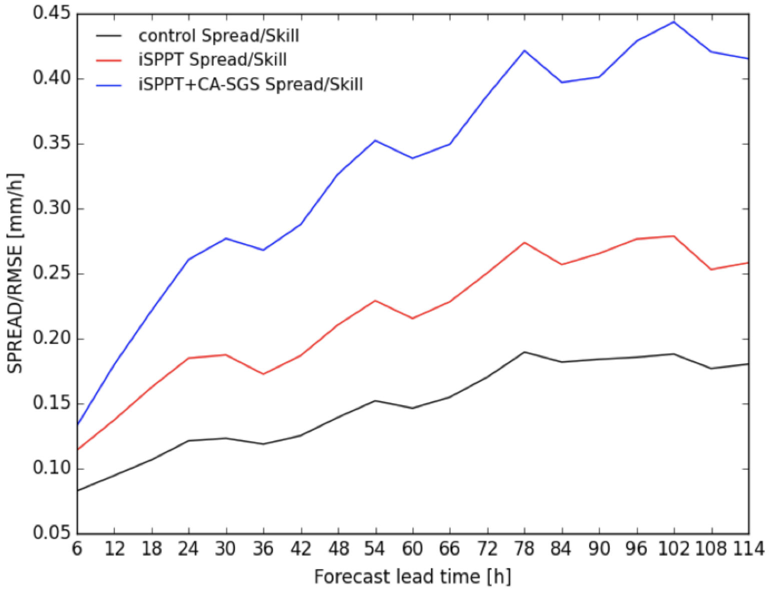
Stochastic deep convection parameterization can help improve the variability of convection and the frequency distribution of surface precipitation, and yield more reliable uncertainty estimates in an ensemble.



Use cellular automata to model sub-grid scale organization and stochastic plume-number distribution



6 h avg surface precip rate frequency distribution. (**Single forecast**).



Ensemble spread/skill ratio of 6 h avg surface precipitation.

Improvement of the deep convective parameterization.

Tasks include:

- Understand features of other successful (convective) parameterizations to improve FV3GFS schemes.
- Introduce convective organization, stochasticity and memory important for interaction with tropical wave dynamics through:
  - Lateral communication by cellular automata
  - Prognostic cloud life-cycle (memory from previous time-step, and ability to represent several stages of the convection)
  - Representation of sub-grid scale variability of cloud number modeled by stochastic processes.
- Improve variability of precipitation by including process-level physically based stochastic perturbations.
- Super-parameterization to inform sub-grid variability

Conclusions

We appreciate the support of California DWR to improve aspects of modeling related to medium-range and sub-seasonal precipitation prediction.

We have chosen 3 subject areas: (a) statistical postprocessing; (b) improved diagnostics to facilitate detection and correction of tropical thunderstorm errors; and (c) improved modeling of those thunderstorms.

We are at an early stage, and welcome constructive feedback, and can modify plans if needed.