An evaluation of CFSv2 tropical convection

GEWEX Convection-Permitting Climate Modeling Workshop

University of Washington
Atmospheric Sciences

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Question: Is poor simulation of convection in the tropics undermining NWP on all timescales?

Convection in the tropics significantly impacts global weather on numerous timescales through atmospheric teleconnections.

Examples include ENSO and the MJO.

Thus, poorly simulated tropical convection could reduce NWP skill on many temporal/spatial scales.

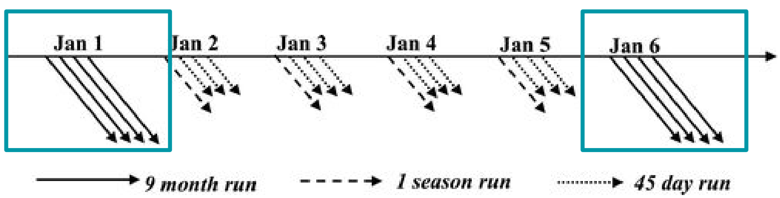
Motivating questions

- How does global model skill degrade with lead time?
- How does the representation of tropical convection change with lead time?
- Can some of the skill decline be explained by poor simulation of tropical convection?

Verification methodology

Forecasts used:

- 4-member CFSv2 reforecast ensemble mean
- 9-month forecasts
- Initialized every 5 days during 1982-2008



Verification dataset:

- GDAS analyses

Temporal timescales:

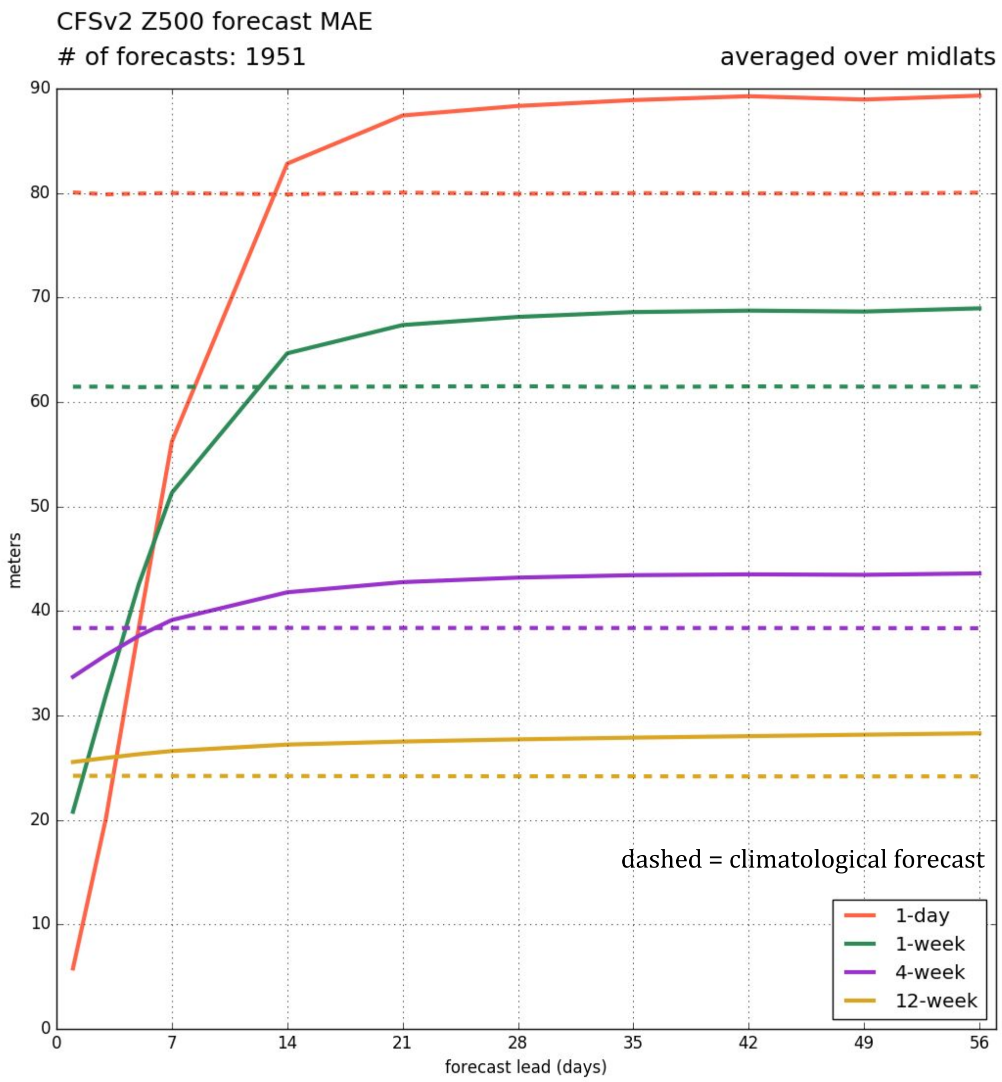
- Ranging from daily to seasonal
- Weekly-average forecasts primarily used here

Diagram from Saha et al. 2014

CFSv2 skill vs lead time

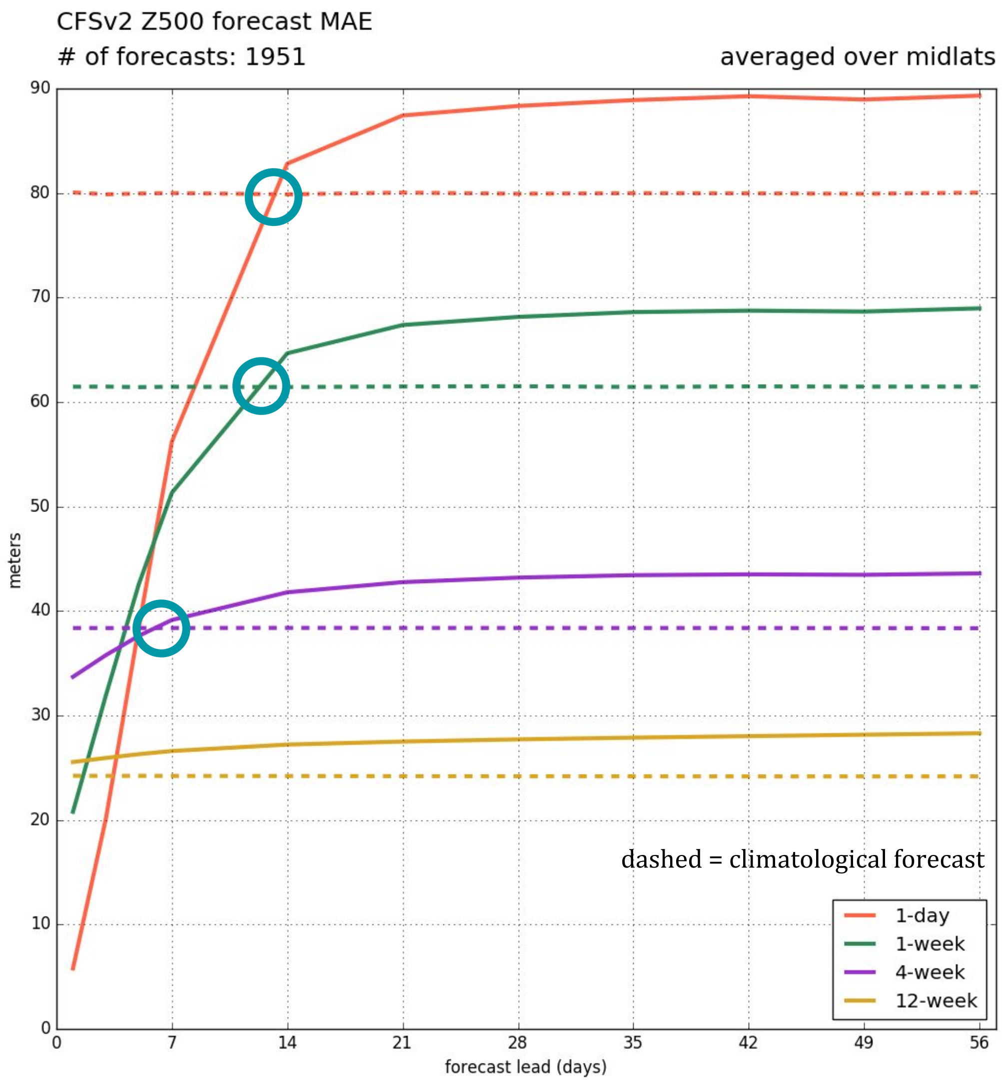
Z500 MAE vs lead time

- MAE averaged from 30N to 70N
- Errors saturate by week 3 for all averaging periods



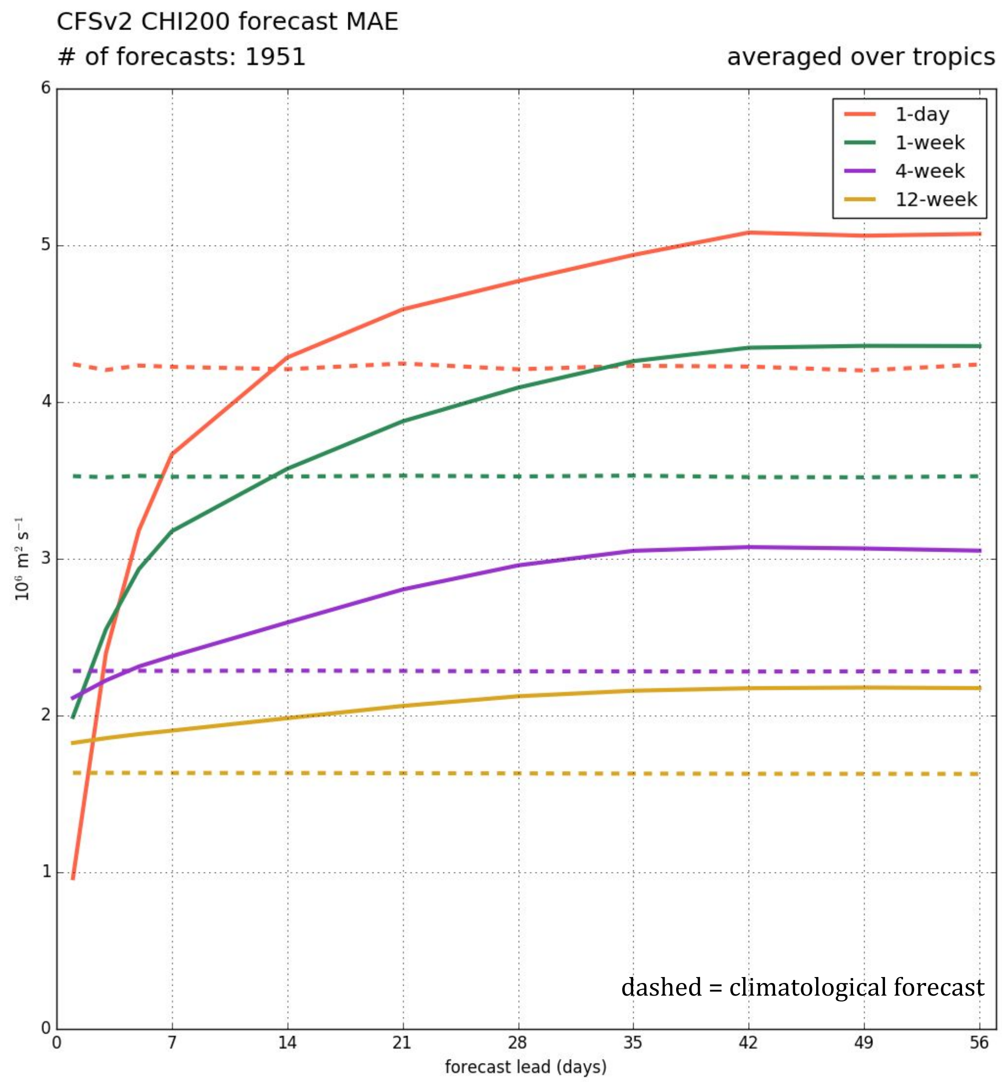
Z500 MAE vs lead time

- MAE averaged from 30N to 70N
- Errors saturate by week 3 for all averaging periods
- Skill over climatology fades in the first 2 weeks of the forecast



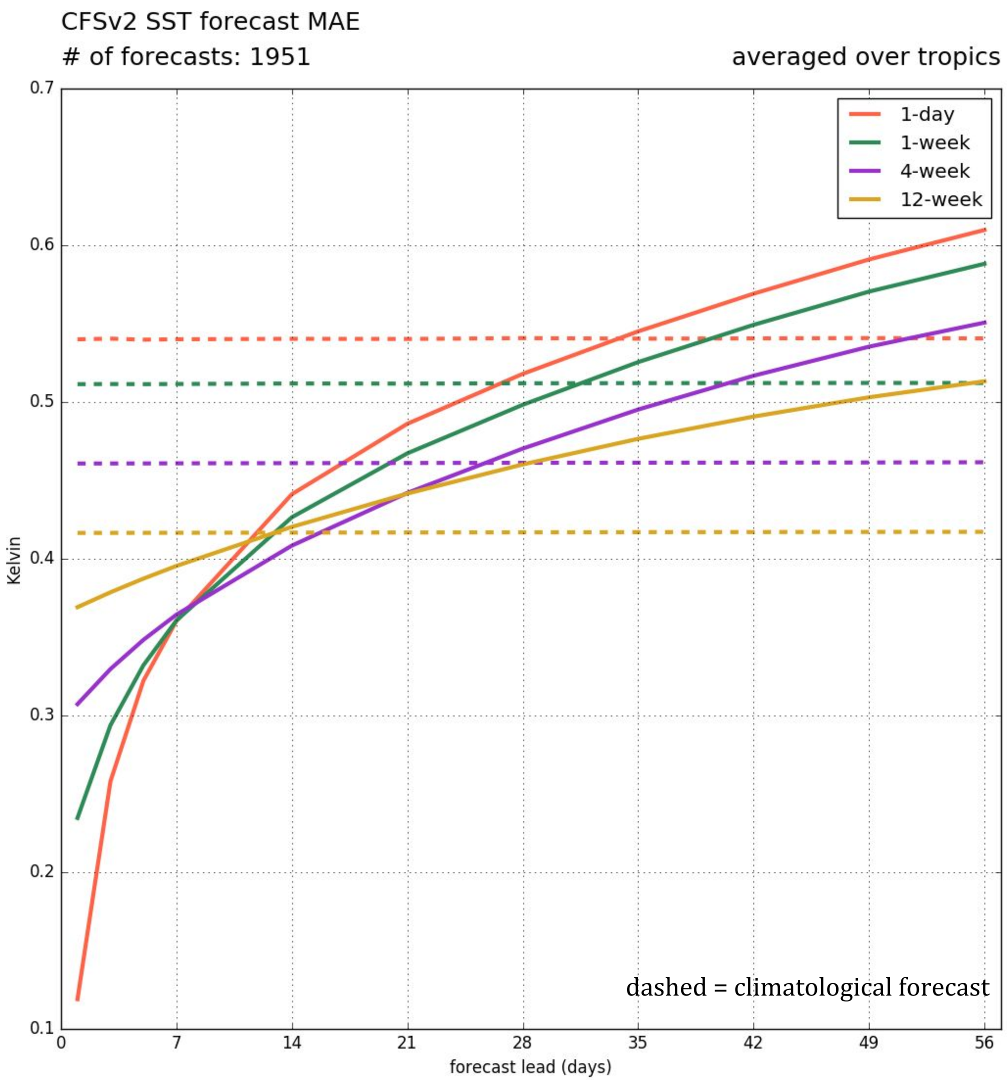
CHI200 MAE vs lead time

- CHI200 - analog for tropical convection
- MAE averaged from 10S to 10N
- Skill over climatology is similar to Z500, though errors saturate later in the forecast

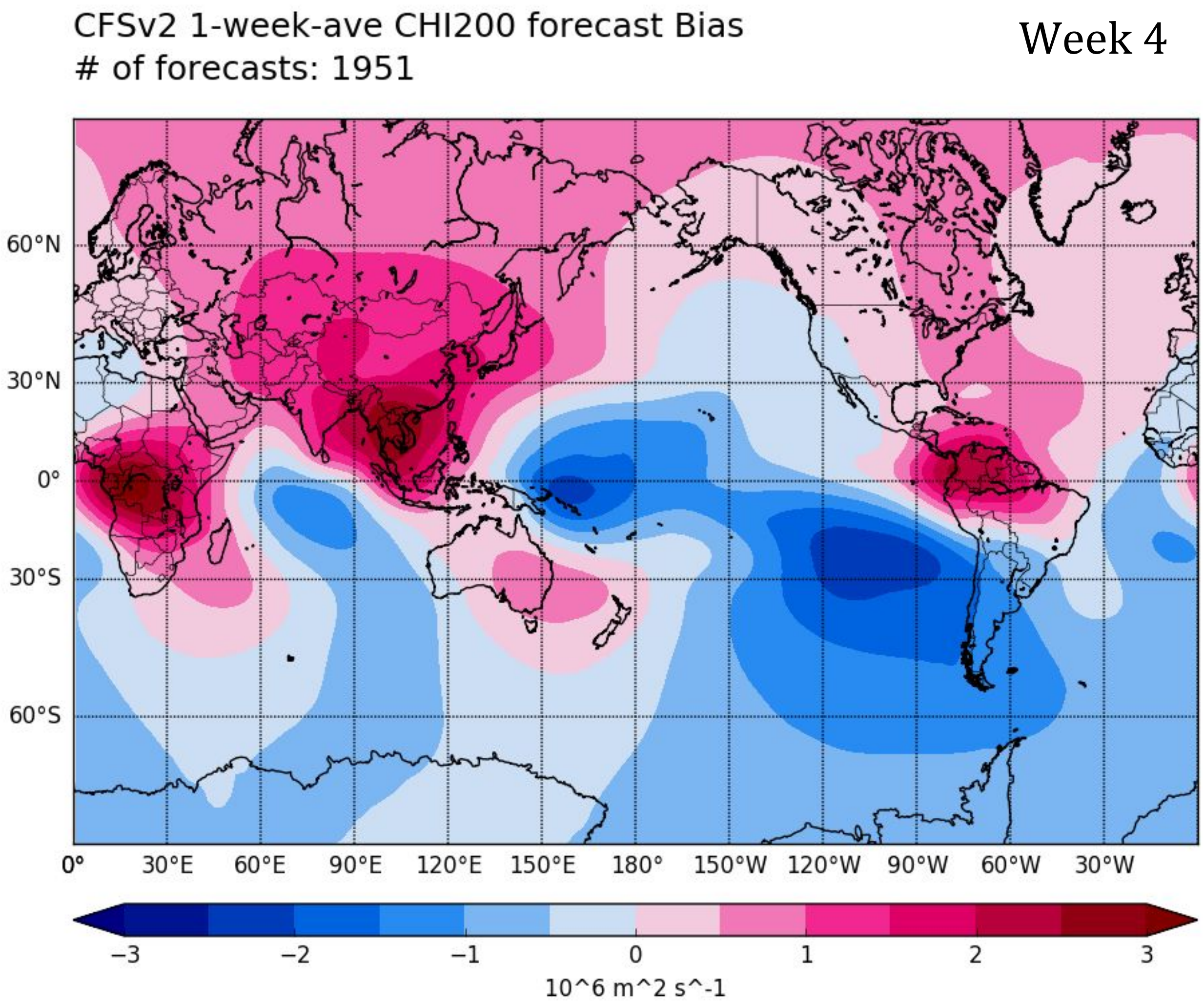


SST MAE vs lead time

- MAE averaged from 10S to 10N
- Errors do not saturate in the first ~2 months
- Skill over climatology extends much further in time than with Z500 and CHI200

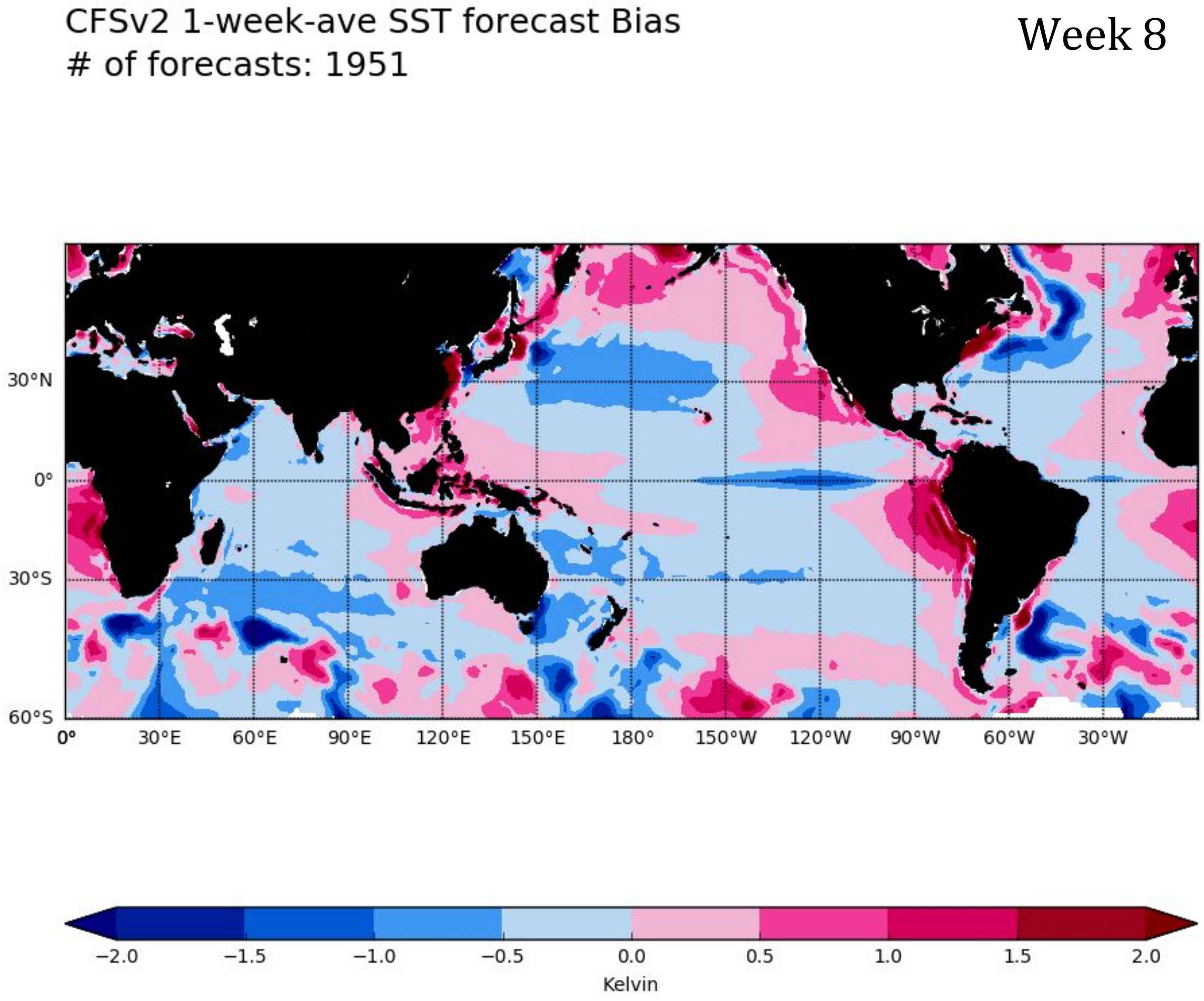


CHI200 annual bias



- Too little convection over tropical land
- Too much convection over Indian Ocean, equatorial West Pacific, and Southeast Pacific

SST annual bias



- Warm bias in subtropical stratocumulus environments
- Misplaced boundary currents
- Too cold in equatorial East Pacific (El Niño region)

Initial questions/observations

- Why does extended SST skill not project onto the atmosphere, e.g. CHI200 and Z500?

- How do the mean state biases impact simulated tropical convection?

- The mean state biases in SST and CHI200 do not seem to correlate with one another

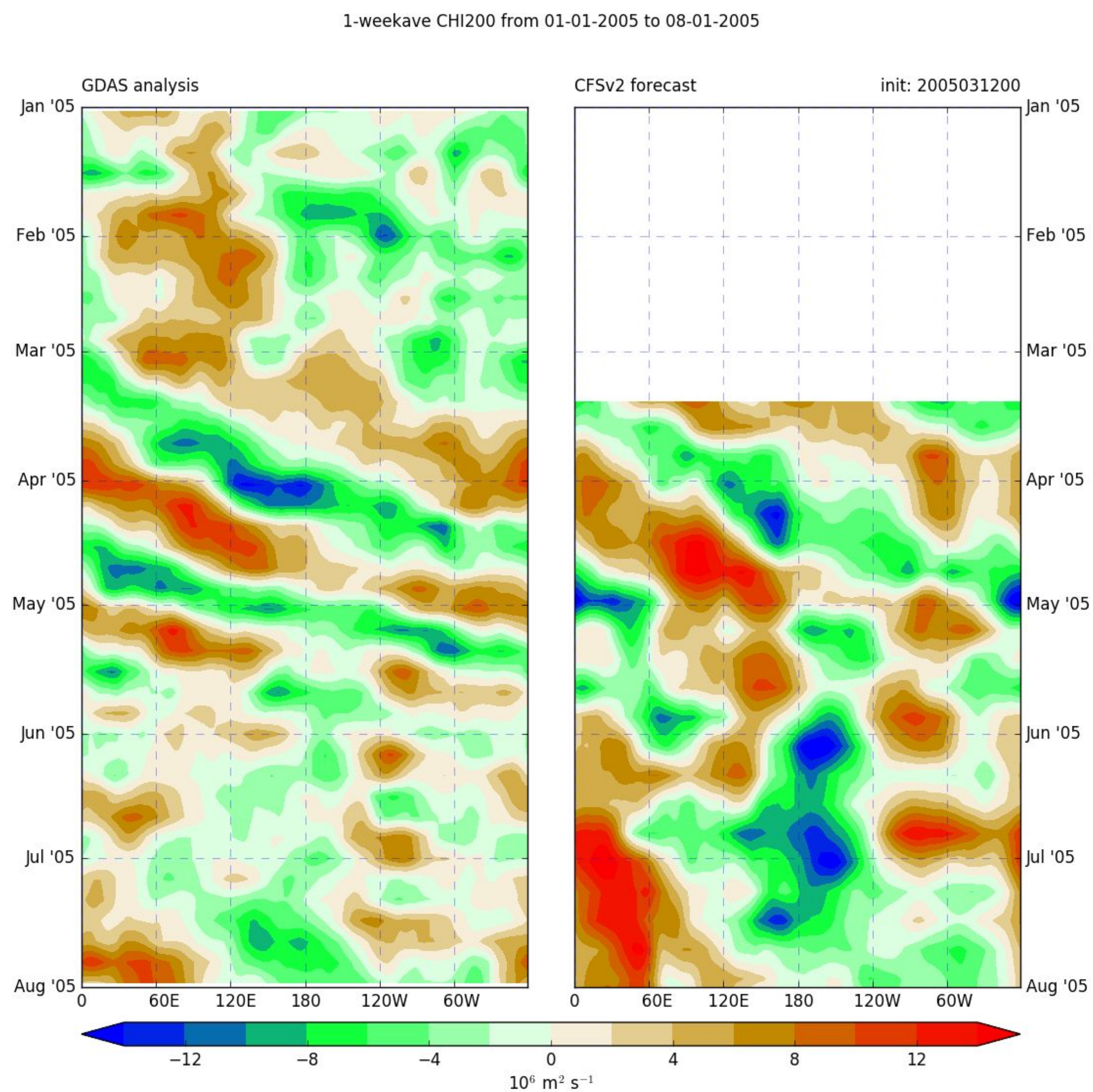
How tropical convection forecasts change with lead time

A) Hovmöller comparison: analyses vs a single CFSv2 forecast

CHI200 Hovmöller: analyses vs single forecast

Time period:
Spring/summer 2005

Forecast initialization:
March 12, 2005



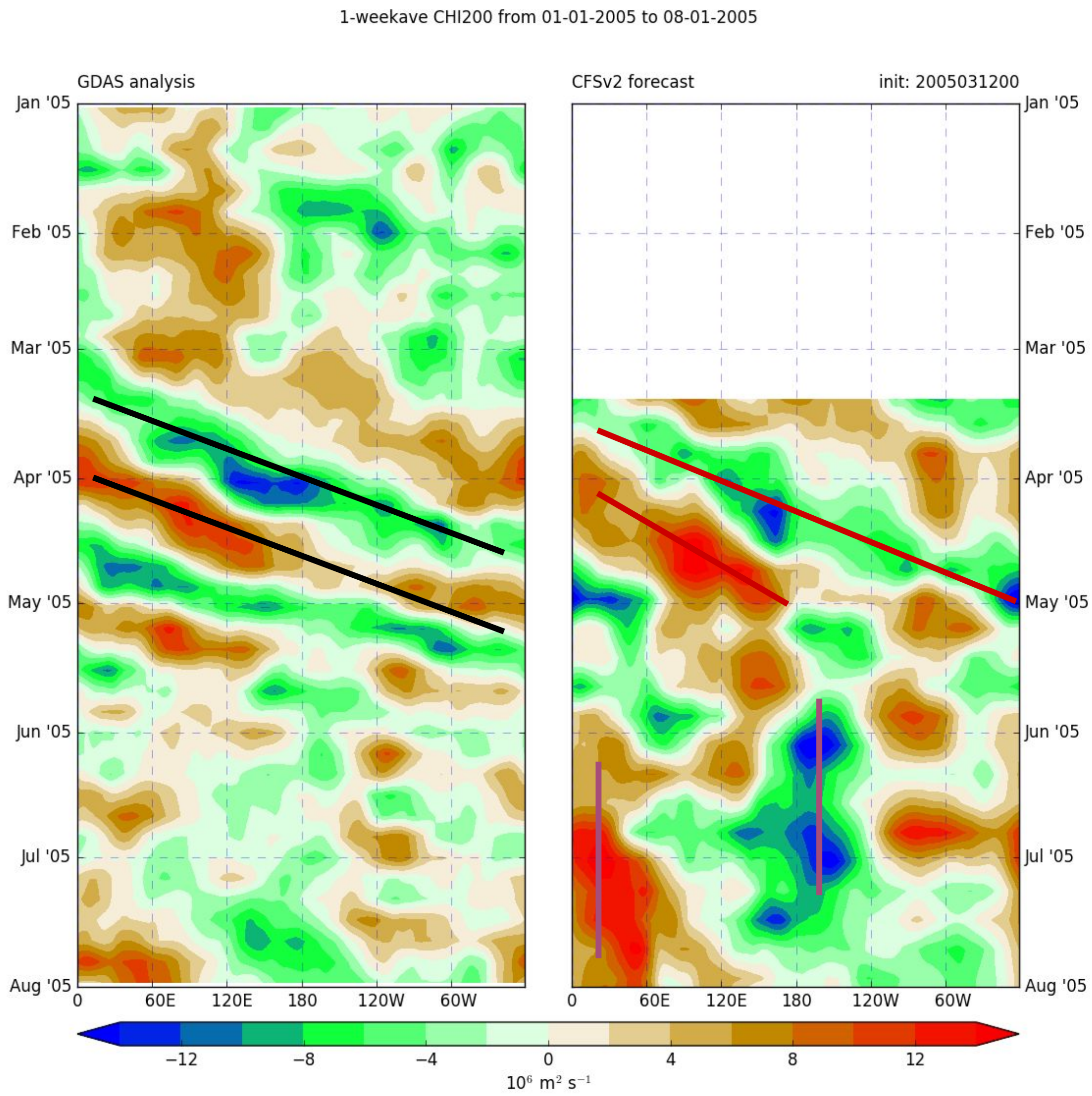
CHI200 Hovmöller: analyses vs single forecast

Time period:
Spring/summer 2005

Forecast initialization:
March 12, 2005

Short leads:
Clear propagating features (albeit with slower phase speed)

Long leads:
Non-propagating anomalies

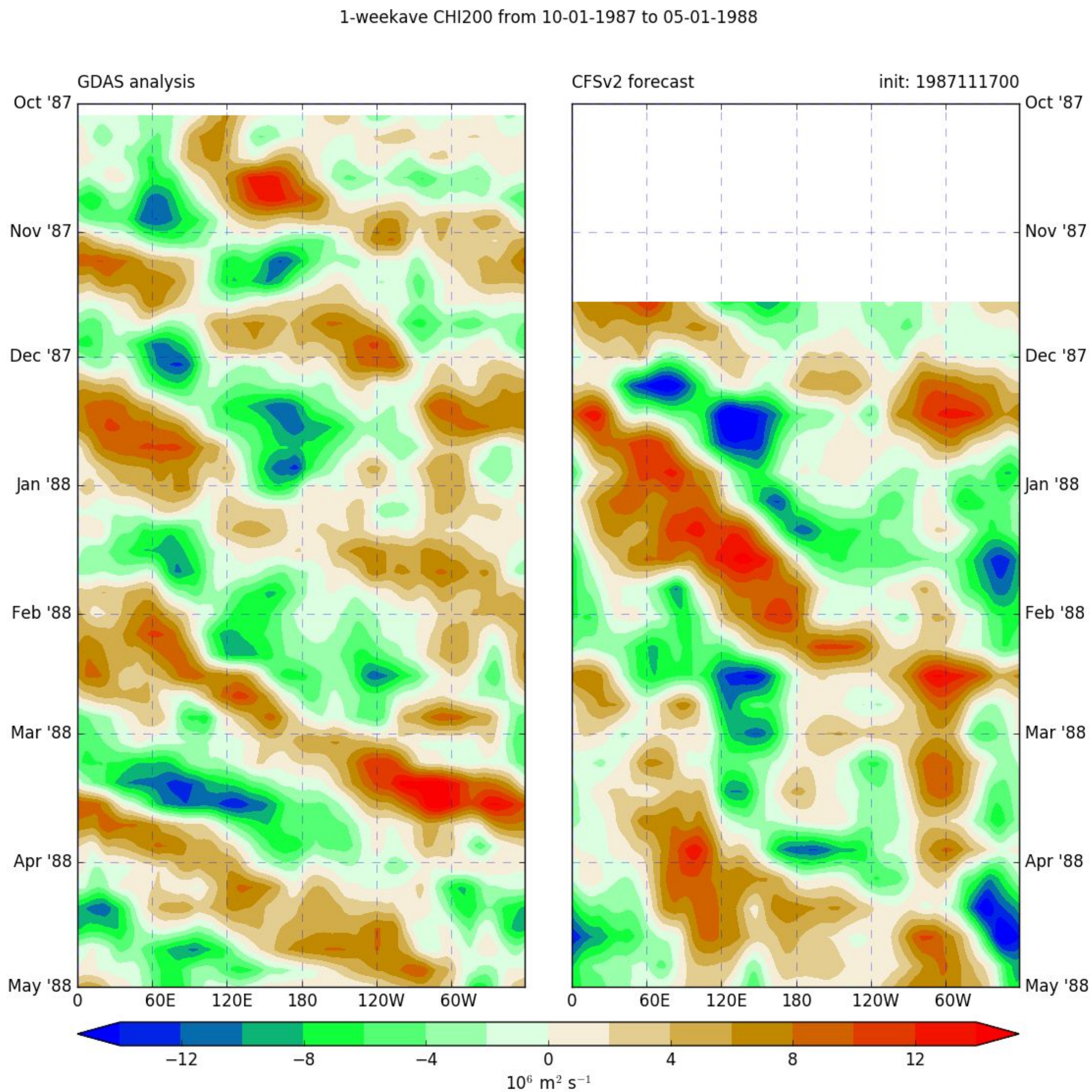


CHI200 Hovmöller: analyses vs single forecast

MORE EXAMPLES

Time period:
Winter/spring 1987-1988

Forecast initialization:
November 17, 1987

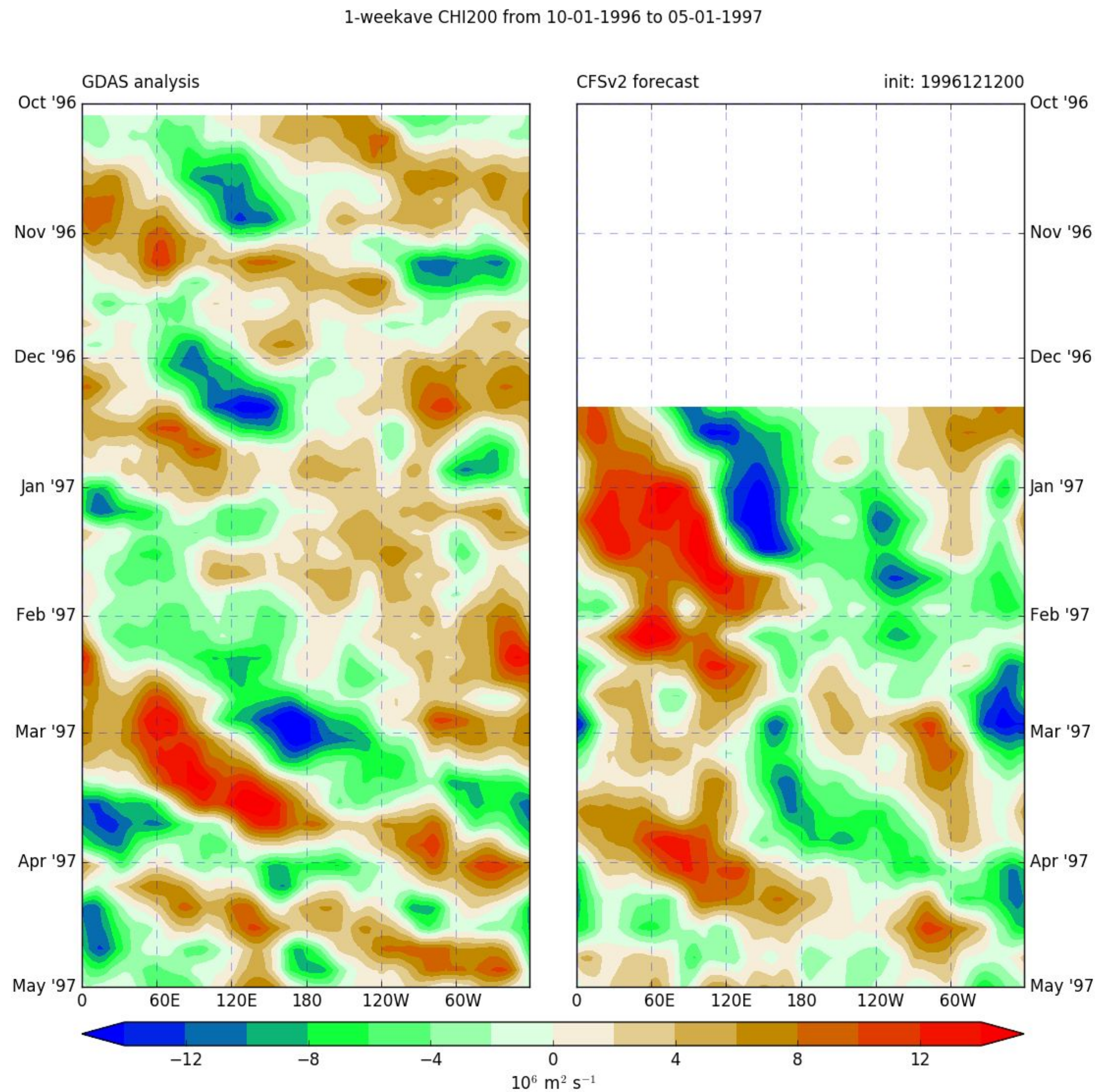


CHI200 Hovmöller: analyses vs single forecast

MORE EXAMPLES

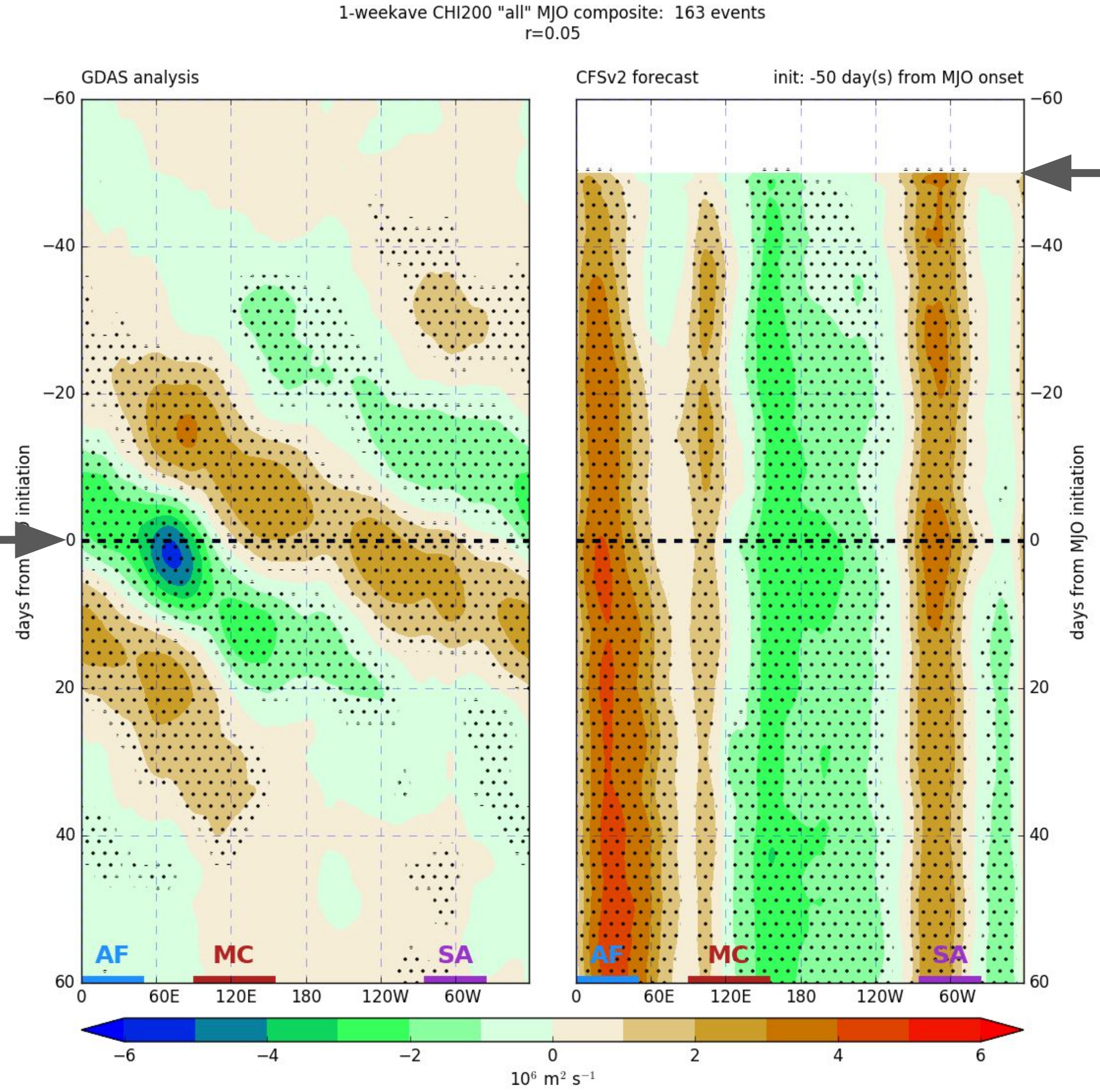
Time period:
Winter/spring 1996-1997

Forecast initialization:
December 12, 1996



B) MJO Hovmöller composites

CHI200 Hovmöller composites



MJO initiation (as determined by an Indian Ocean convection index)

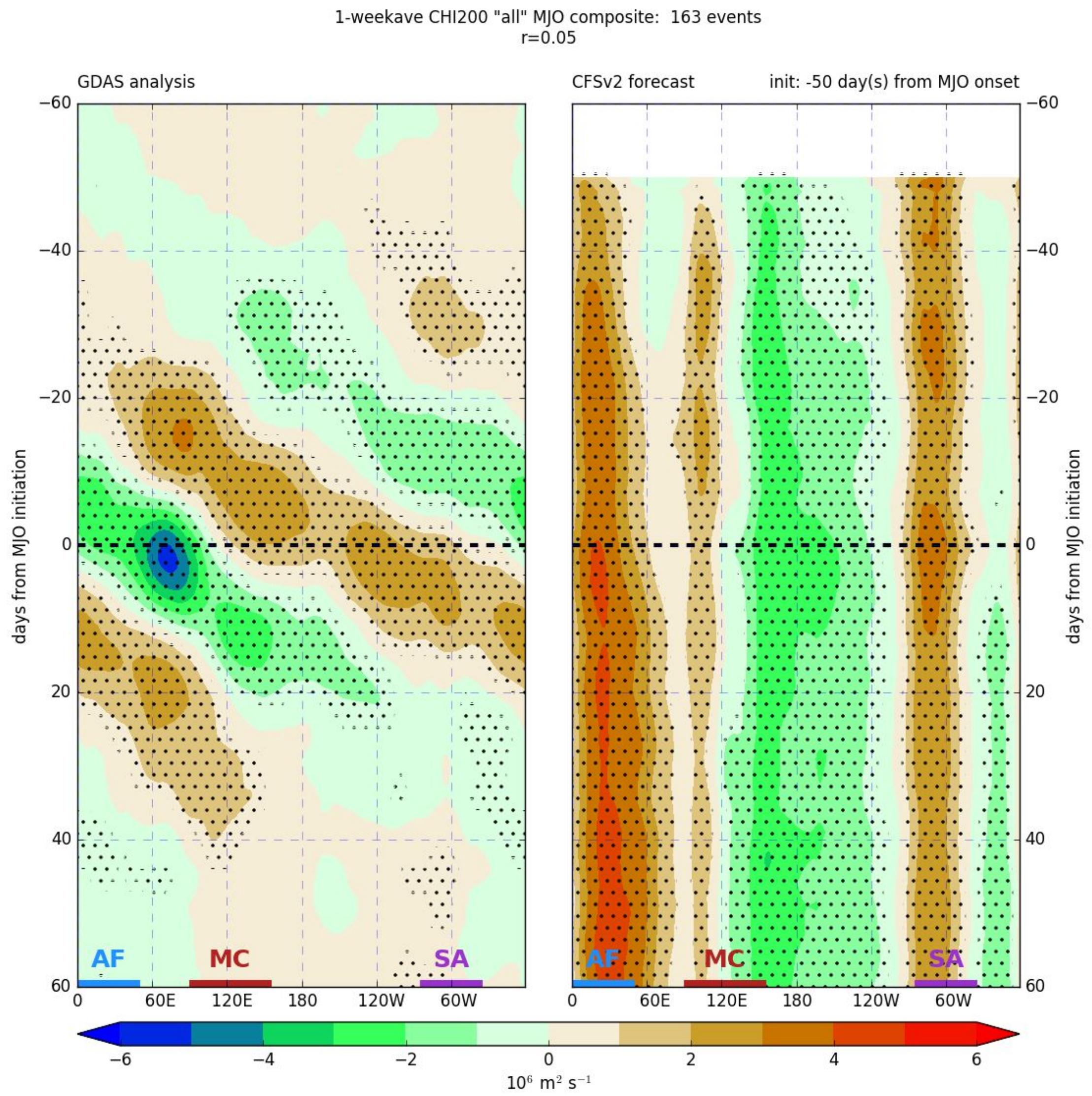
Forecasts initialized

Stippling = 95% sig.

CHI200 Hovmöller composites

Long leads:
No MJO signal.

Model biases dominate, e.g. dry equatorial land and wet West Pacific



CHI200 Hovmöller composites

<u>Long leads</u>:
No MJO signal.

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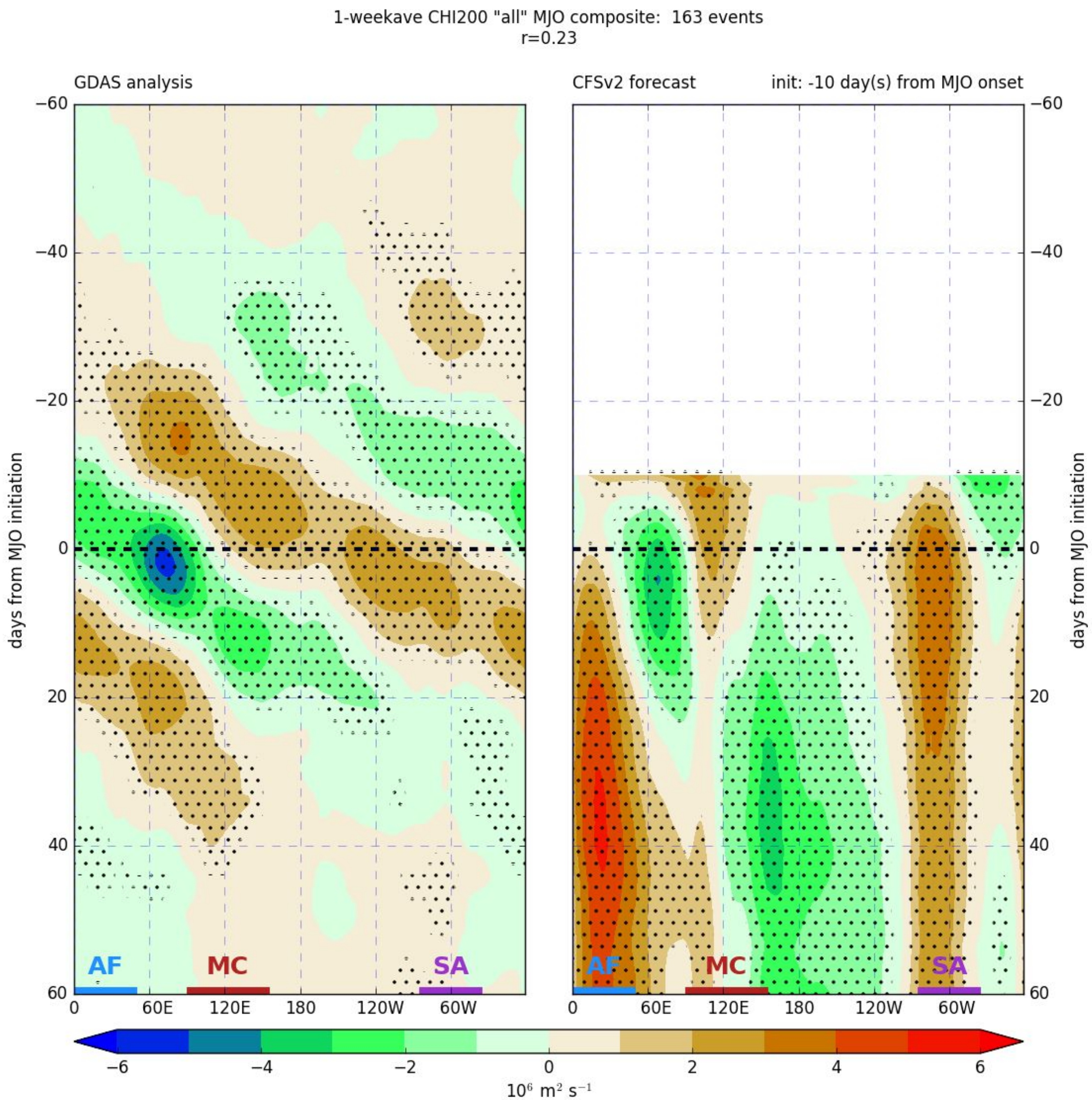
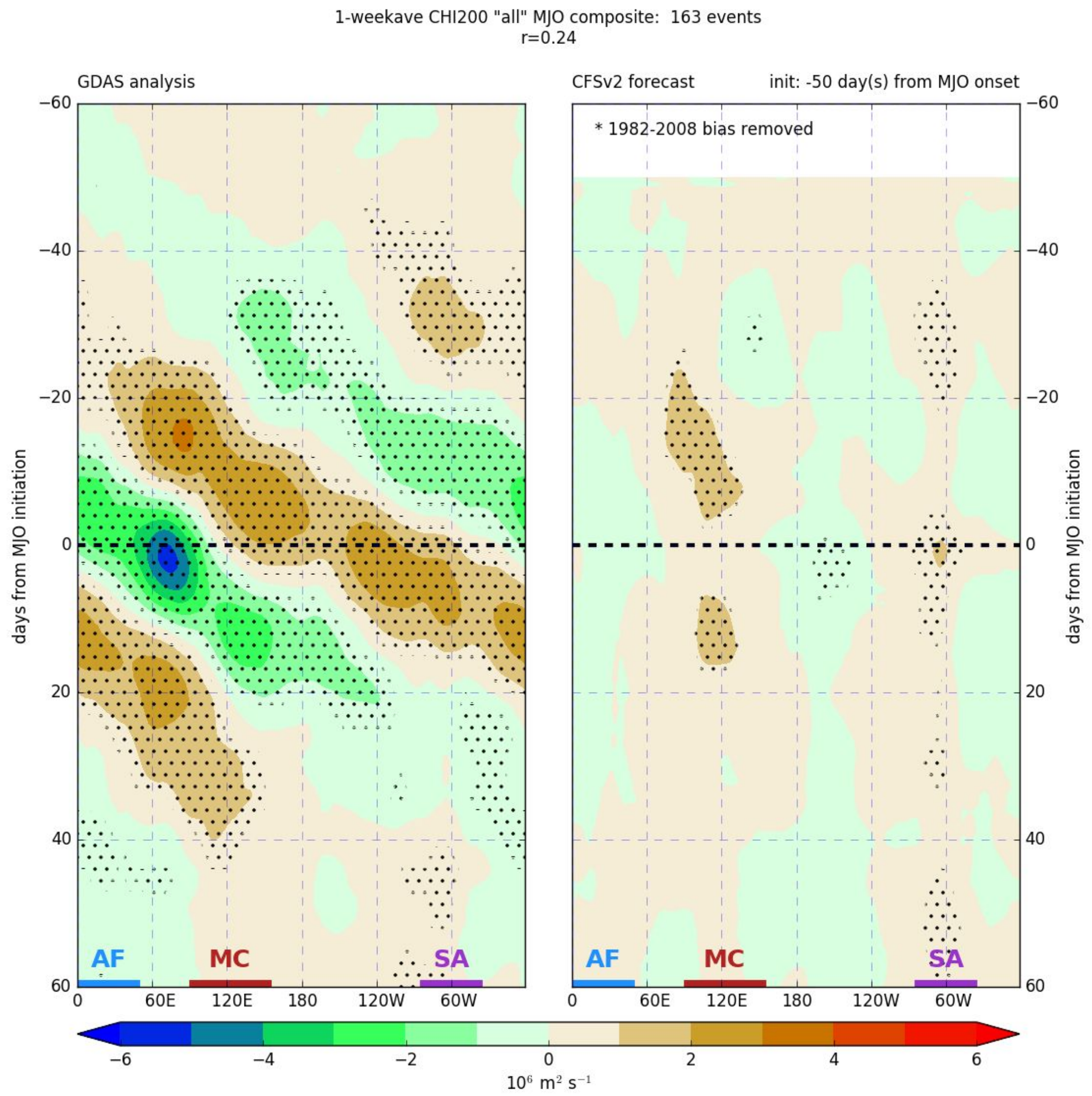


<u>Shorter leads</u>:
Weak MJO signal.

Model biases take over ~2 weeks into the forecast

CHI200 Hovmöller composites

*** Lead-dependent 1982-2008 bias removed from forecasts**



CHI200 Hovmöller composites

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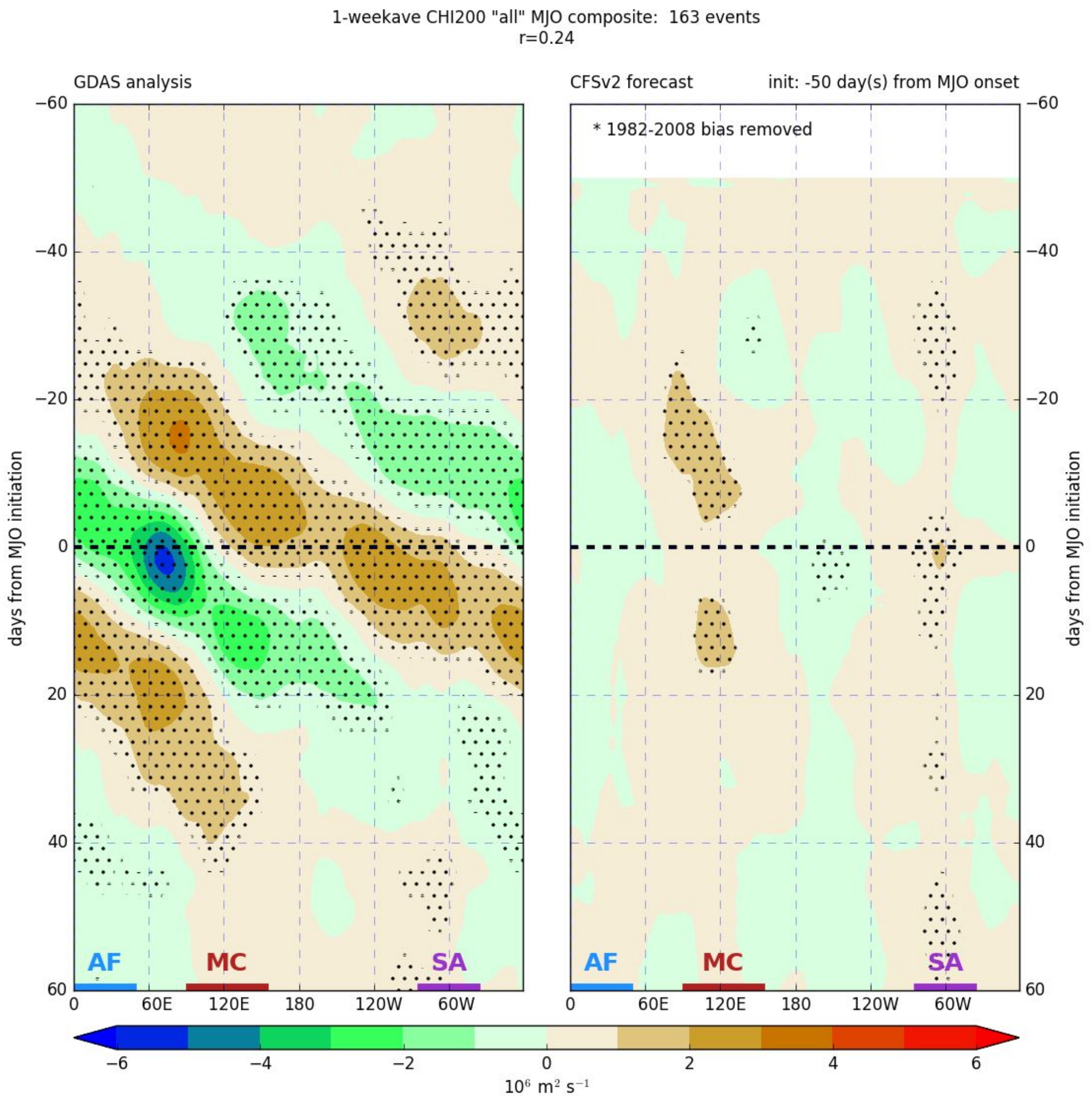

Long leads:
No MJO signal

CHI200 Hovmöller composites

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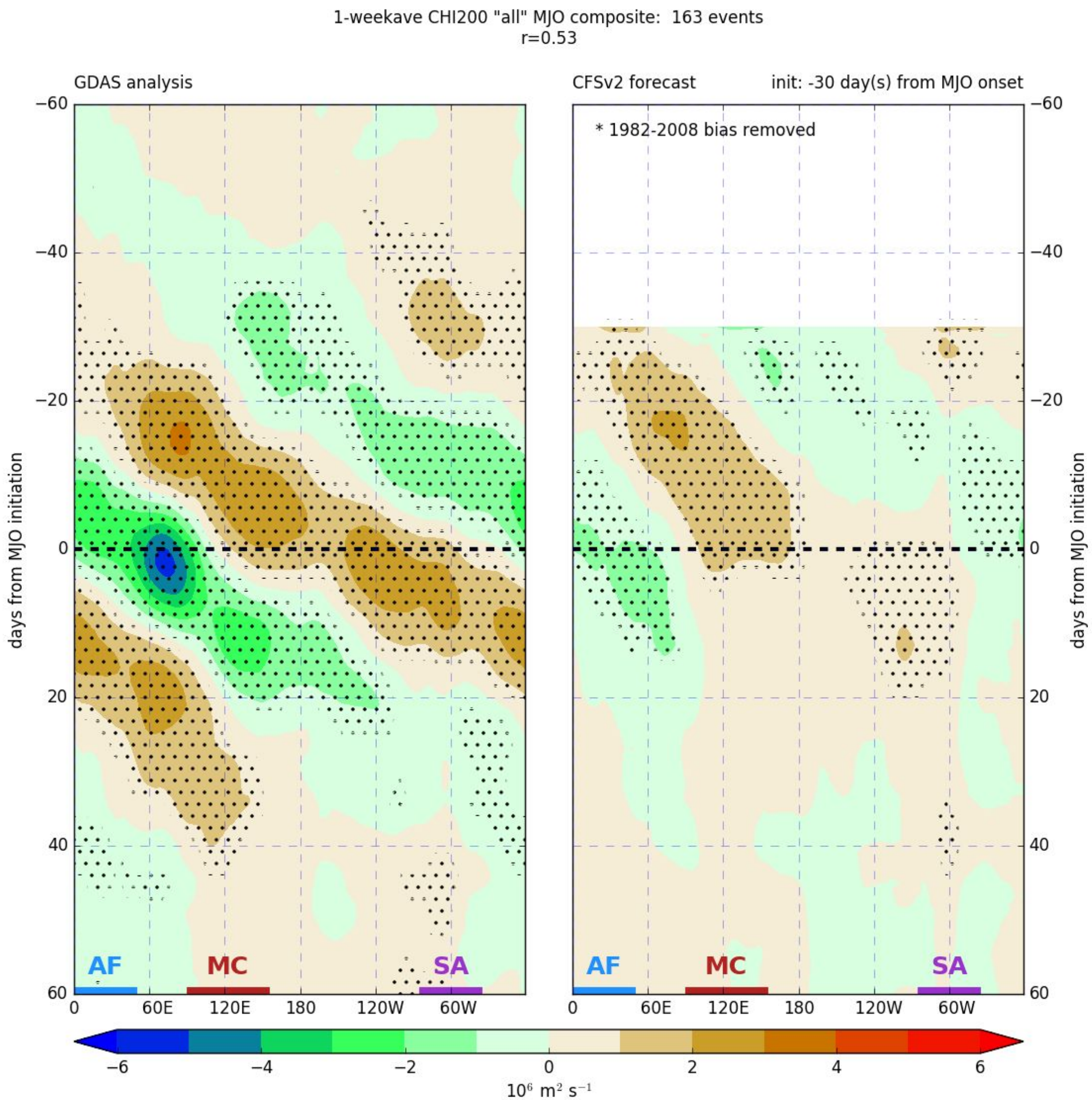

<u>Long leads</u>:
No MJO signal

<u>~30-day lead</u>:
Weak/slow MJO

CHI200 Hovmöller composites

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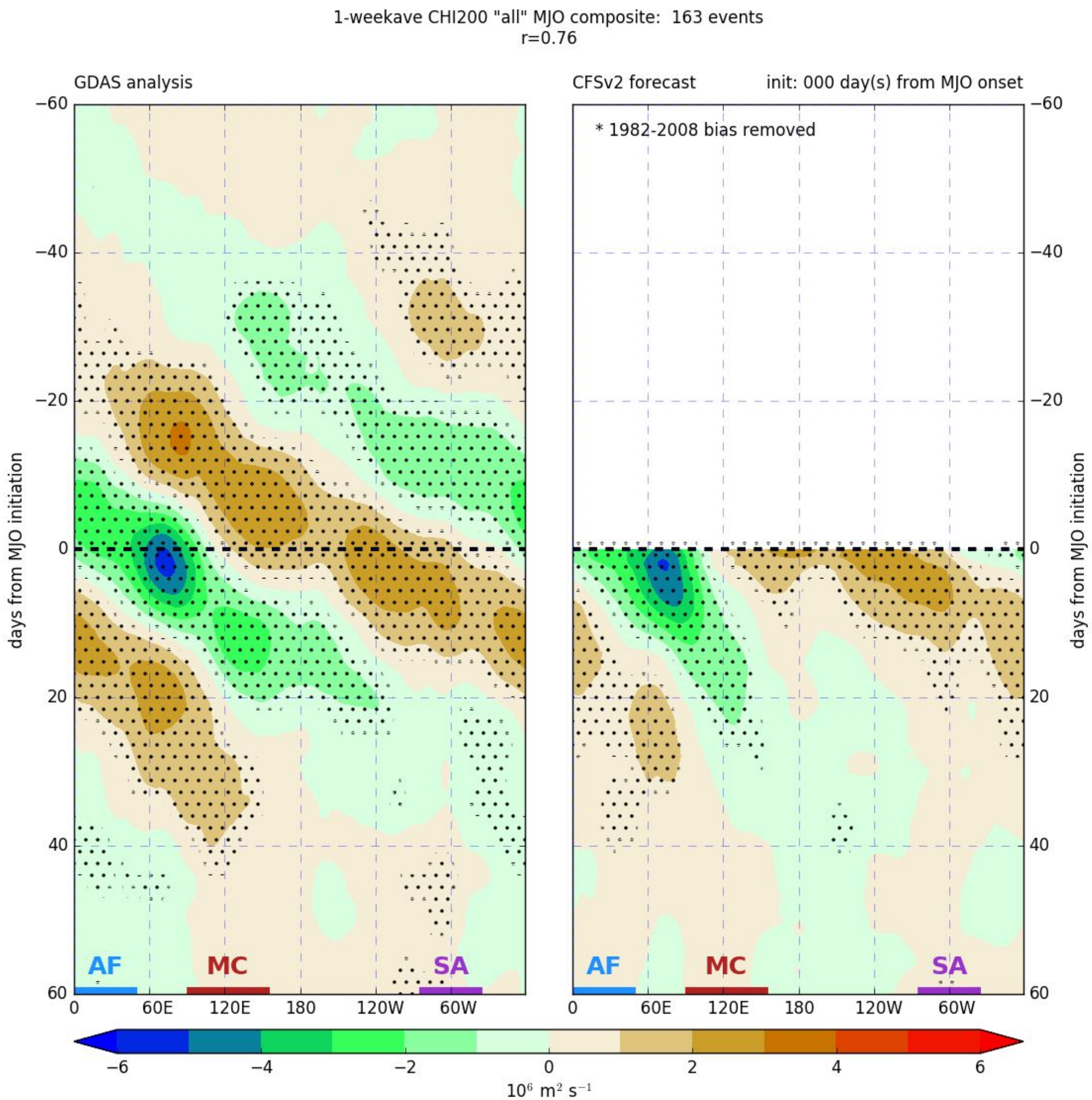


Long leads:
No MJO signal

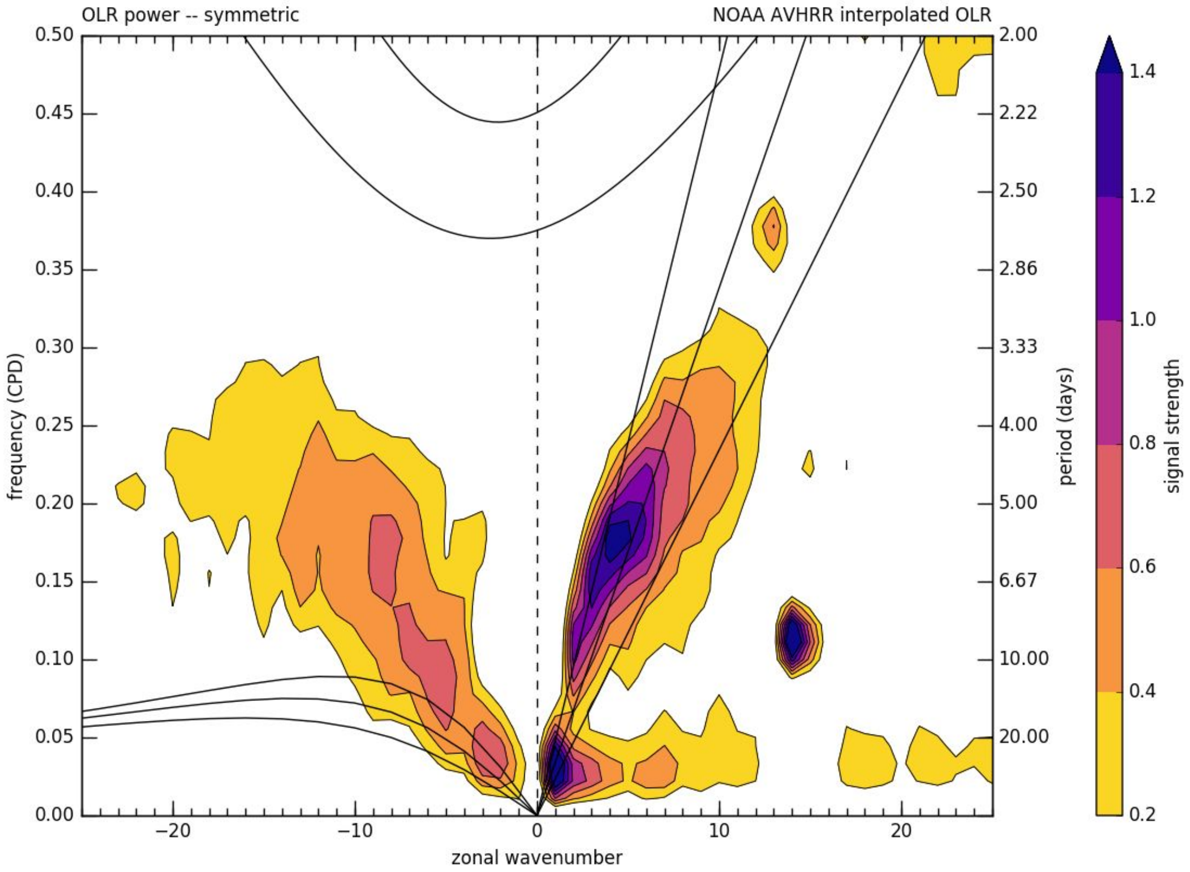
~30-day lead:
Weak/slow MJO

Shorter leads:
MJO intensity improves,
Phase speed still too slow,
M.C. Barrier

C) Wavenumber- frequency power spectra

Space-time power spectrum - satellite obs

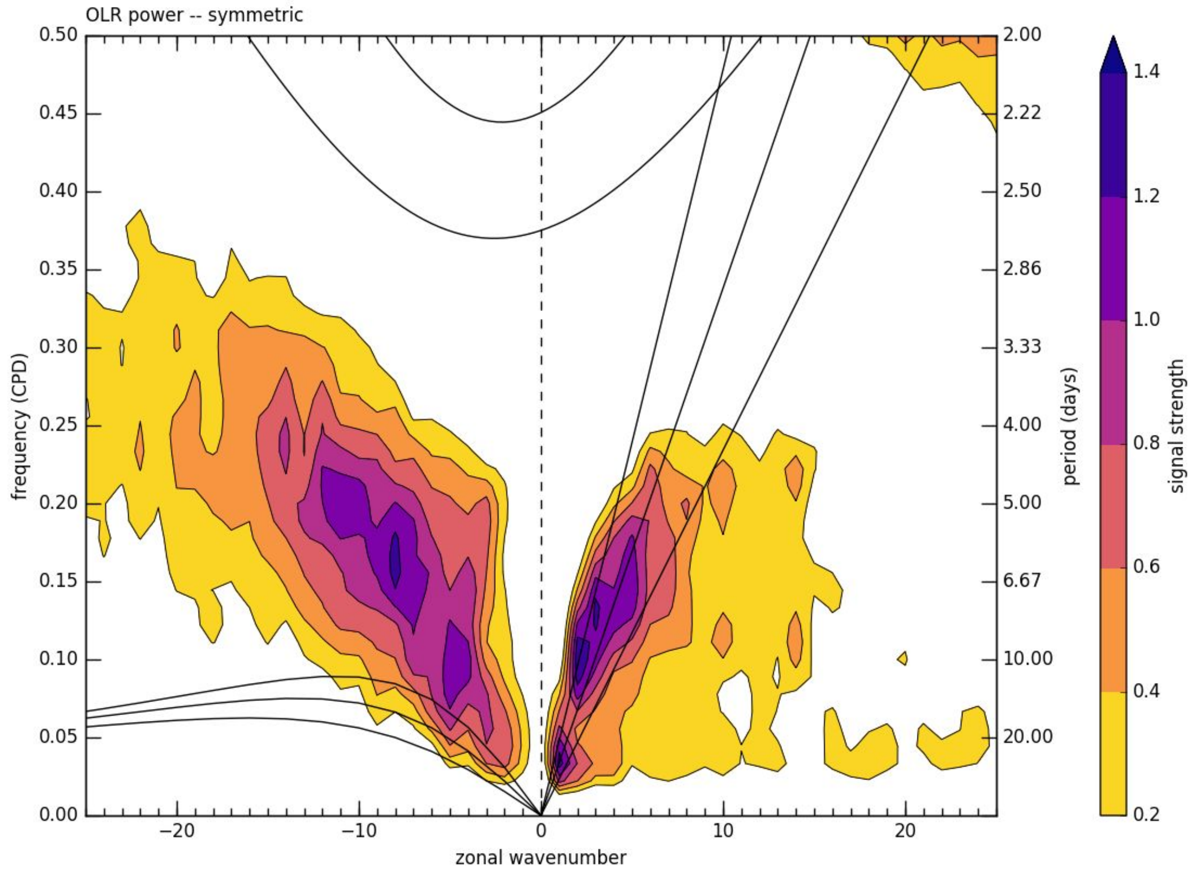
- Computed with daily, latitude-averaged (15S to 15N) data (here, AVHRR OLR)
- Amount of variance at different k, omega
- Shown as ratio between the power and the background "red" spectrum
- Black lines are the dispersion curves for Kelvin, Rossby, and inertia-gravity waves



See Wheeler and Kiladis (1999) for more details

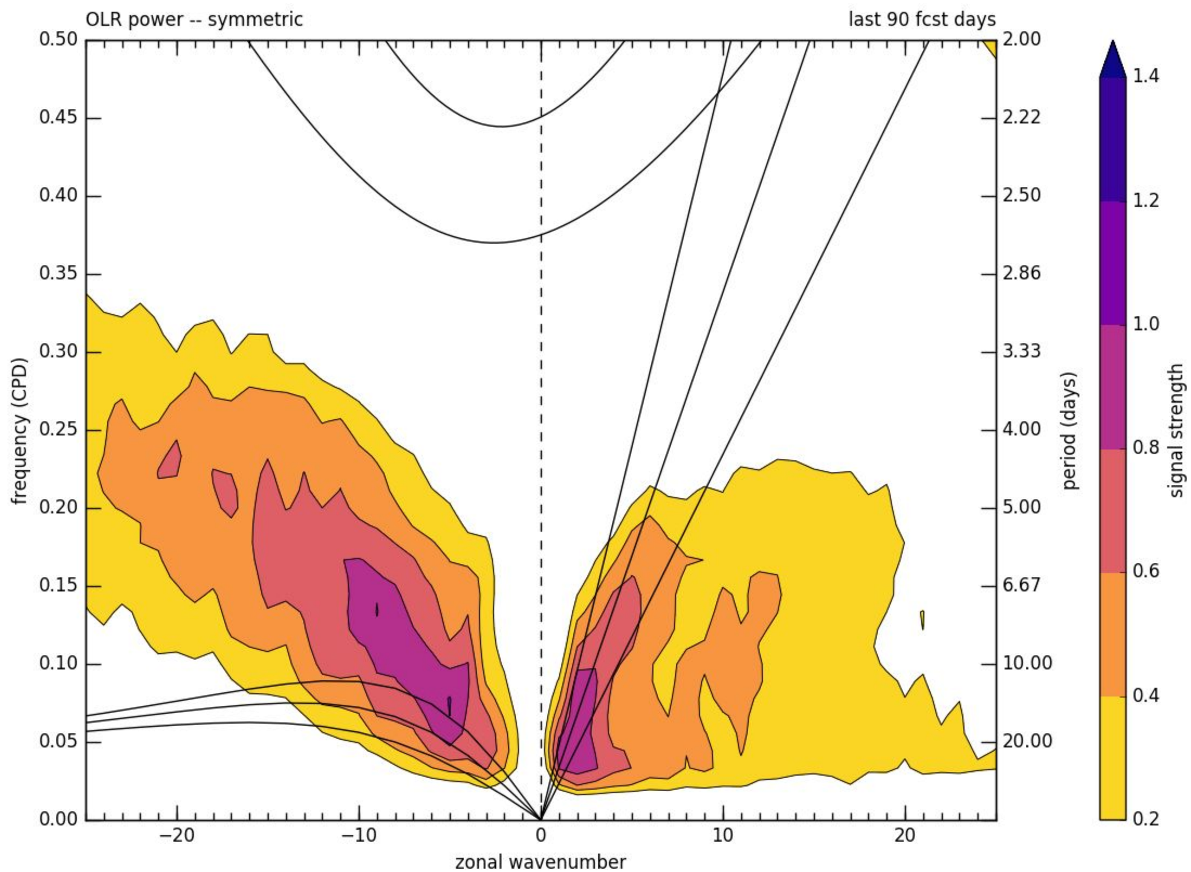
Space-time power spectrum - analyses

- MJO and Kelvin waves are the prominent eastward-propagating features
- More westward-propagating power than in the observations



Space-time power spectrum - CFSv2 forecasts

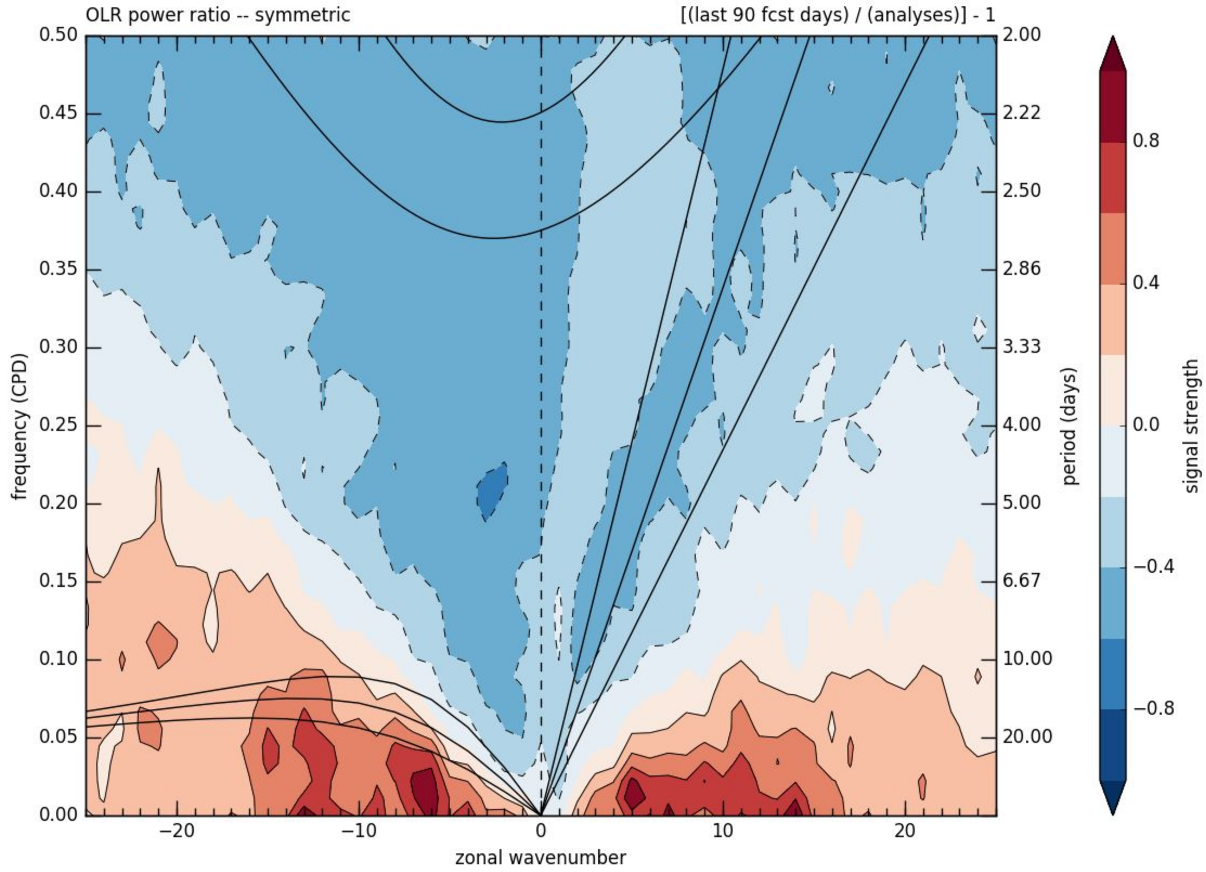
- *Last 90 days* of CFSv2 9-month forecasts
- MJO and Kelvin waves are less distinguished from each other and from the background spectrum
- Power over a wider range of wavenumbers and frequencies



Raw power ratio: CFSv2 vs analyses

$$\frac{\text{(raw power: forecasts)}}{\text{(raw power: analyses)}} - 1$$

- Long-lead forecasts tend to have:
  - Higher power at lower frequencies
  - Lower power at high frequencies



Conclusions so far

- CFSv2 tropical convective skill does not permeate far into the subseasonal time range (only the first few weeks of a forecast)

- Robust biases in the model's tropical convection and moisture fields may inhibit the formation of realistically propagating convective features like the MJO
  - The wet bias in the west Pacific likely acts to inhibit MJO propagation (Kim et al. 2014)

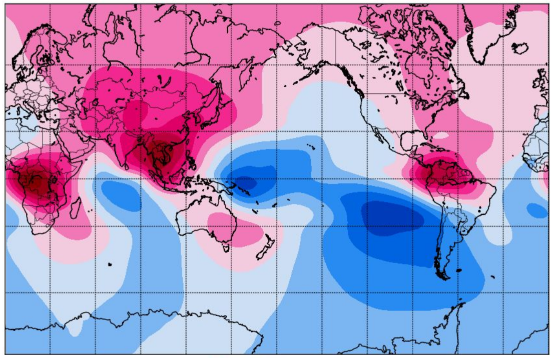
- The lack of coherence between the SST biases and CHI200 biases, *and* the extended SST forecast skill, suggests that the issue lies in the atmospheric model, rather than the ocean

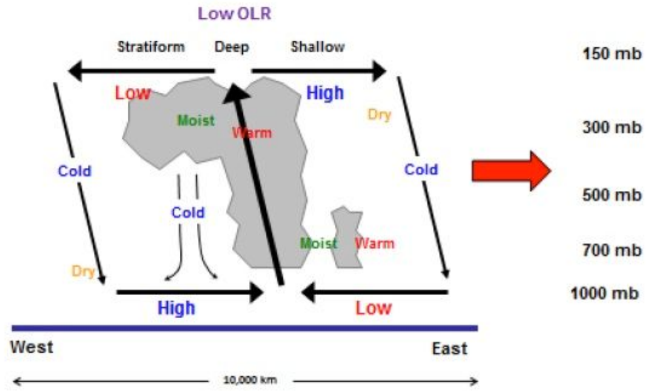
Some thoughts on parameterized convection

- Convective parameterizations can affect propagating convection in two ways:
  1. <u>Indirect effect</u>: Changing the mean state in the model, which has a huge impact on features like the MJO
  2. <u>Direct effect</u>: Altering the simulated convectively-coupled waves themselves by poorly representing the interactions between clouds and dynamics

- We should **<u>test</u>** to see how propagating convection might improve with explicit convection in the tropics

CHI200 bias





Schematic from wunderground.com

Convection-permitting models are able to...

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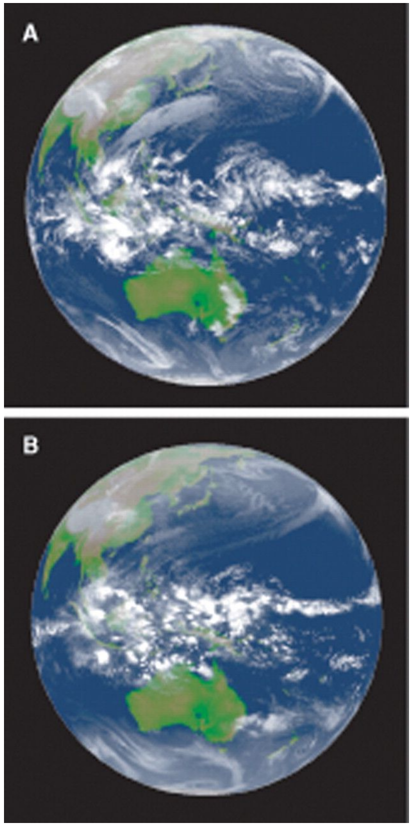
- Realistically simulate MJO events (e.g., Miura et al. 2007)

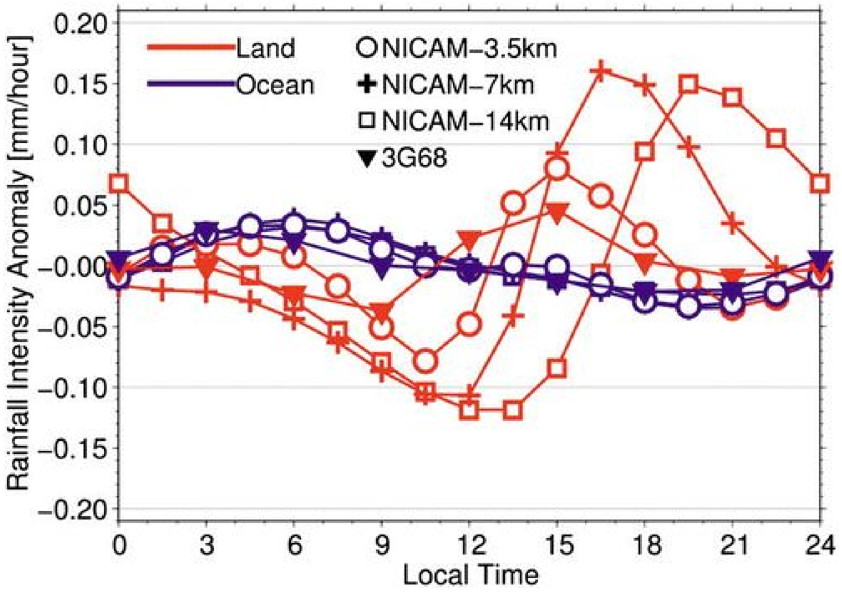


MTSAT-1R

NICAM 3.5km

Convection-permitting models are able to...

- Realistically simulate MJO events (e.g., Miura et al. 2007)
- More accurately reproduce the rainfall diurnal cycle (Sato et al. 2009)



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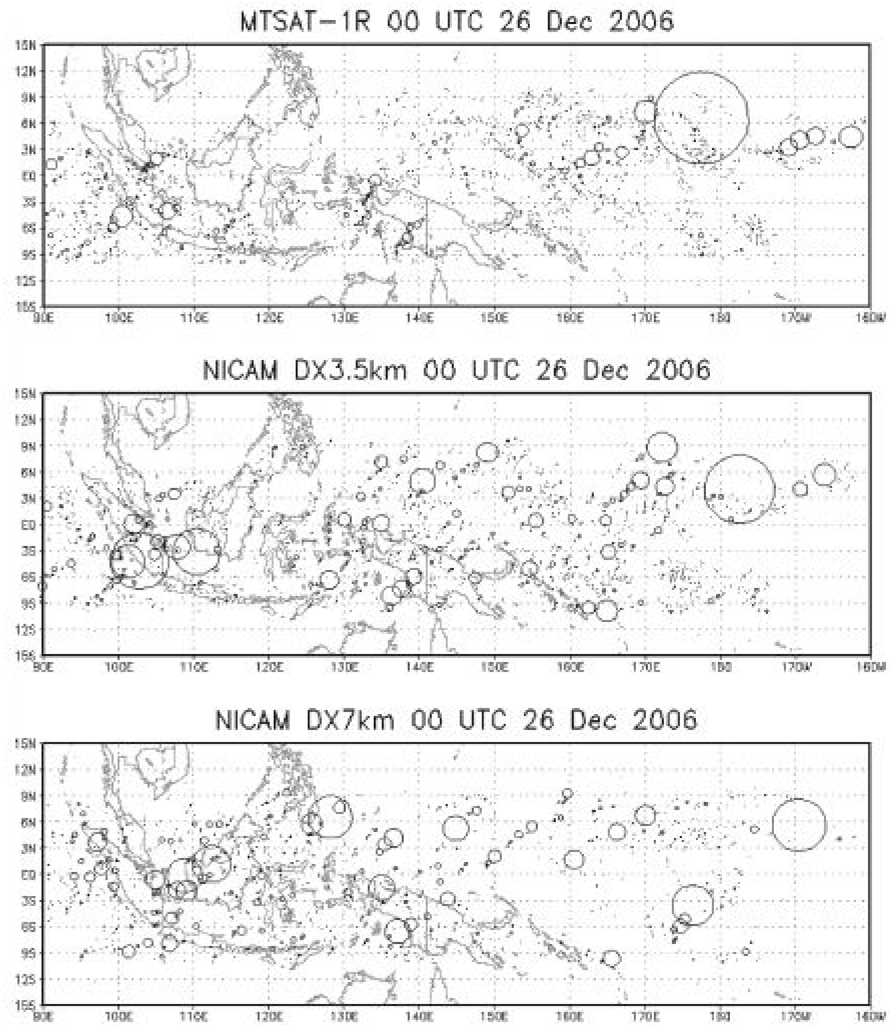
- Improve the distribution and characteristics of deep convection in the tropics (Inoue et al. 2008)



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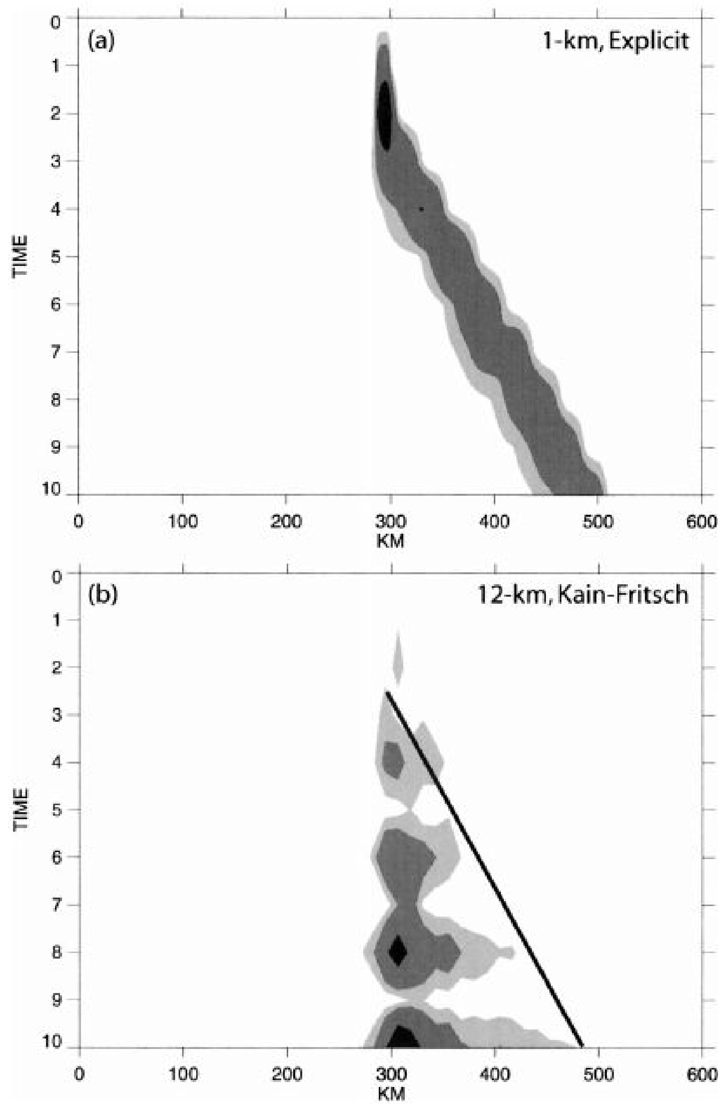
- Improve the propagation characteristics of convection
  - In the midlatitudes (Davis et al. 2003)



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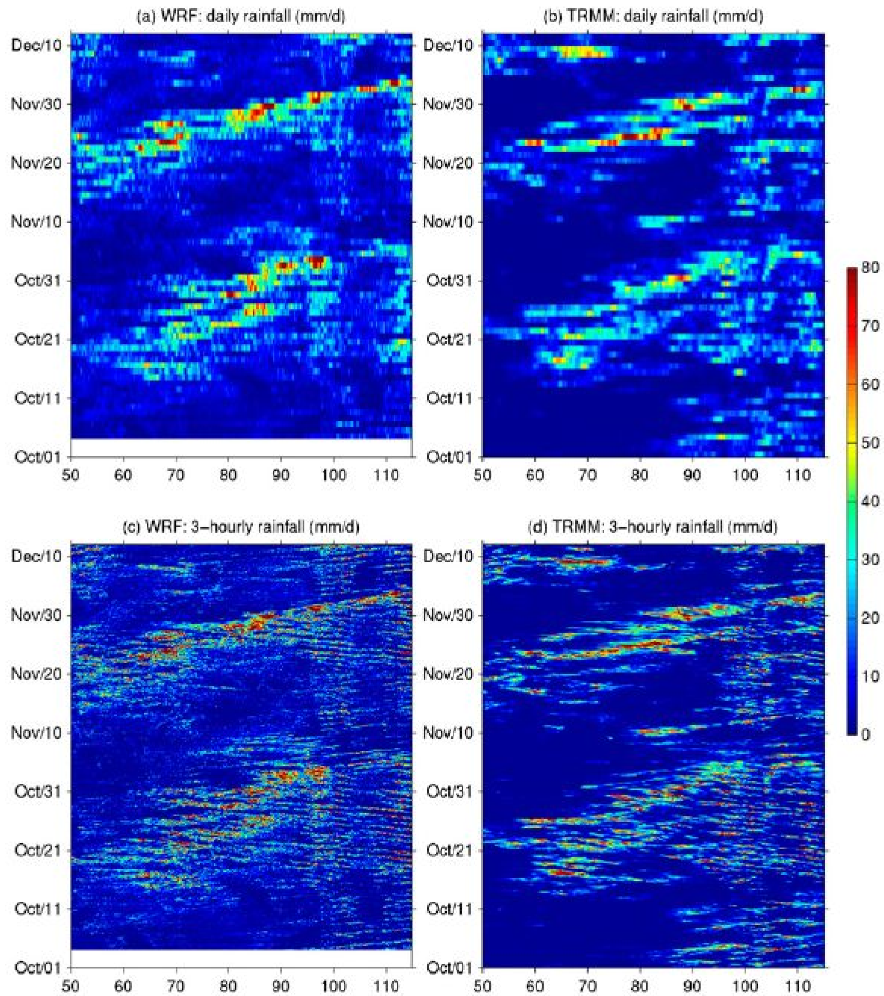
  - In the midlatitudes (Davis et al. 2003)
  - *And* in the tropics (Wang et al. 2015)



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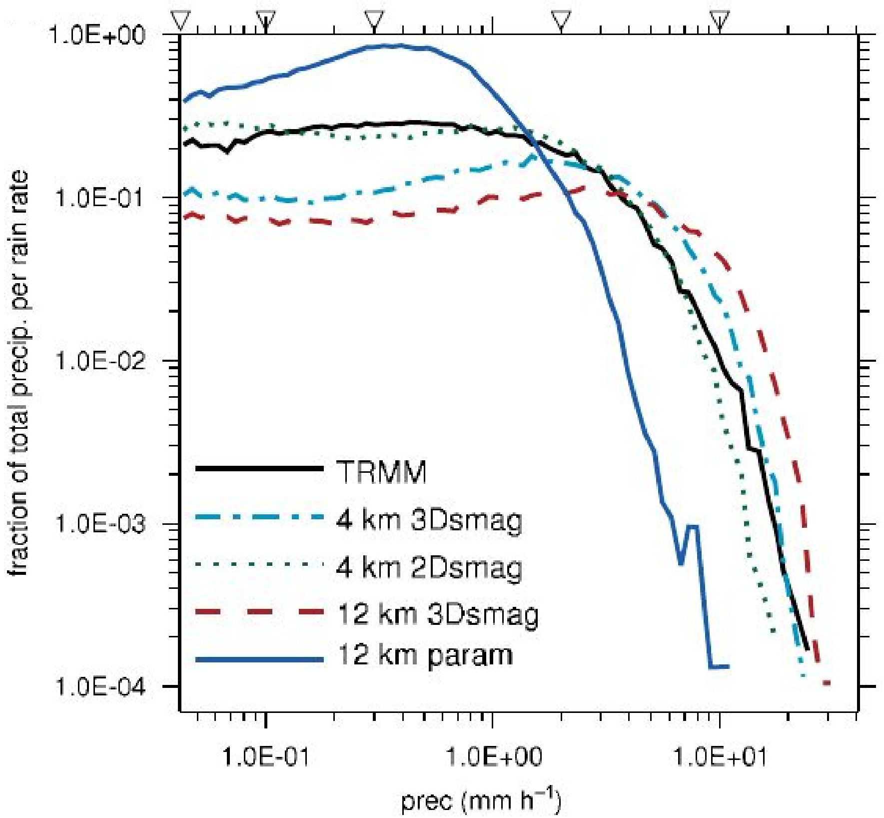
- Realistically simulate MJO events (e.g., Miura et al. 2007)
- More accurately reproduce the rainfall diurnal cycle (Sato et al. 2009)
- Improve the distribution and characteristics of deep convection in the tropics (Inoue et al. 2008)
- Improve the propagation characteristics of convection
  - In the midlatitudes (Davis et al. 2003)
  - *And* in the tropics (Wang et al. 2015)
- Mitigate the issue of "too much light rain" in many models (Holloway et al. 2012)



Moving forward: a grand experiment

The plan: Test a convection-allowing subseasonal forecast framework

a. Use a variable-resolution model, such as MPAS
b. 1-2 month integrations
c. High-resolution mesh (2-4 km) over the global tropics to allow explicit convection

MPAS
Model for Prediction Across Scales

Questions that will be addressed:

1. How will explicit convection in the tropics change the mean state (i.e., the biases) in the model?

2. Does explicit convection produce more realistic propagating convection, like the MJO?

3. Will the improved tropical convection, and the associated midlatitude teleconnections, improve the fidelity of global subseasonal prediction?


Thank you

References

Davis, C. A., K. W. Manning, R. E. Carbone, S. B. Trier, and J. D. Tuttle, 2003. Coherence of warm-season continental rainfall in numerical weather prediction models. *Mon. Wea. Rev.*, **131**, 2667-2679.

Holloway, C. E., S. J. Woolnough, and G. M. S. Lister, 2012. Precipitation distributions for explicit versus parametrized convection in a large-domain high-resolution tropical case study. *Q. J. R. Meteorol. Soc.*, **138**, 1692-1708.

Inoue, T., M. Satoh, H. Miura, and B. Mapes, 2008. Characteristics of cloud size of deep convection simulated by a global cloud resolving model over the western tropical Pacific. *J. Meteor. Soc. Japan*, **86A**, 1-15.

Kim, D., J.-S. Kug, and A. H. Sobel, 2014. Propagating versus nonpropagating Madden-Julian Oscillation events. *J. Climate*, **27**, 111-125.

Miura, H., M. Satoh, T. Nasuno, A. Noda, and K. Oouchi, 2007. A Madden-Julian Oscillation event realistically simulated by a global cloud-resolving model. *Science*, **318**, 1763-1765.

Saha, S and Coauthors, 2014. The NCEP Climate Forecast System version 2. *J. Climate*, **27**, 2185-2208.

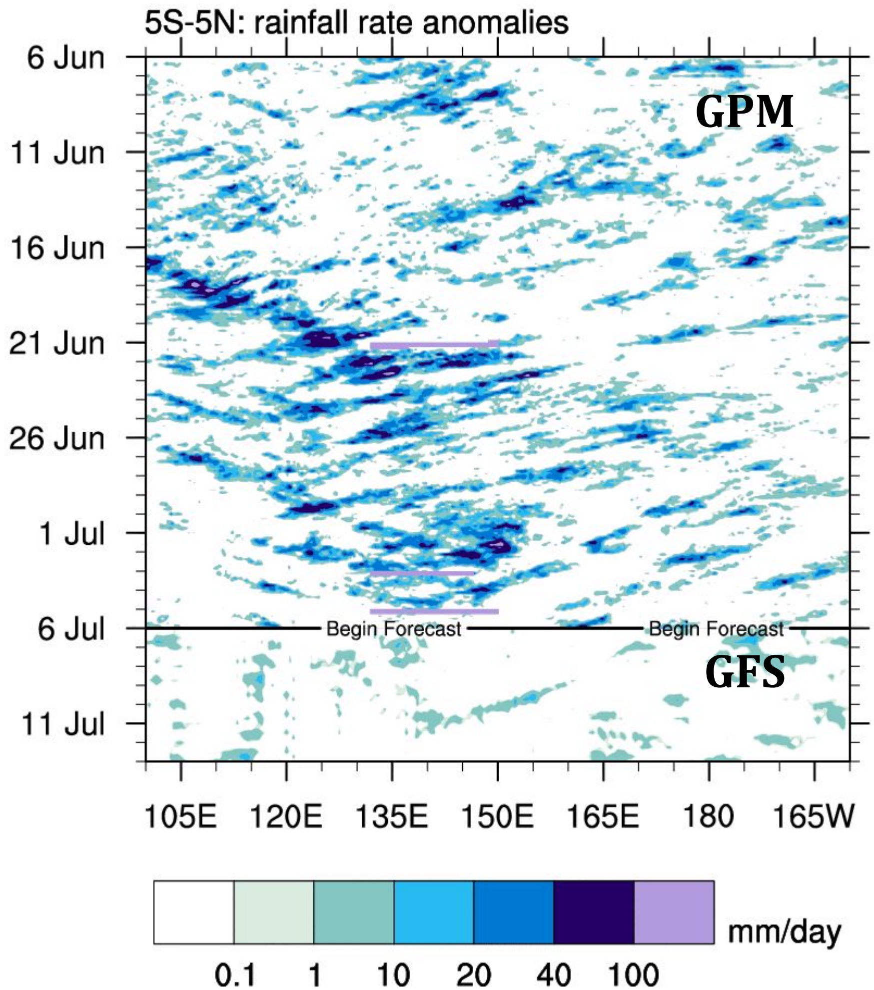
Sato, T., H. Miura, M. Satoh, Y. N. Takayabu, and Y. Wang, 2009. Diurnal cycle of precipitation in the tropics simulated in a global cloud-resolving model. *J. Climate*, **22**, 4809-4826.

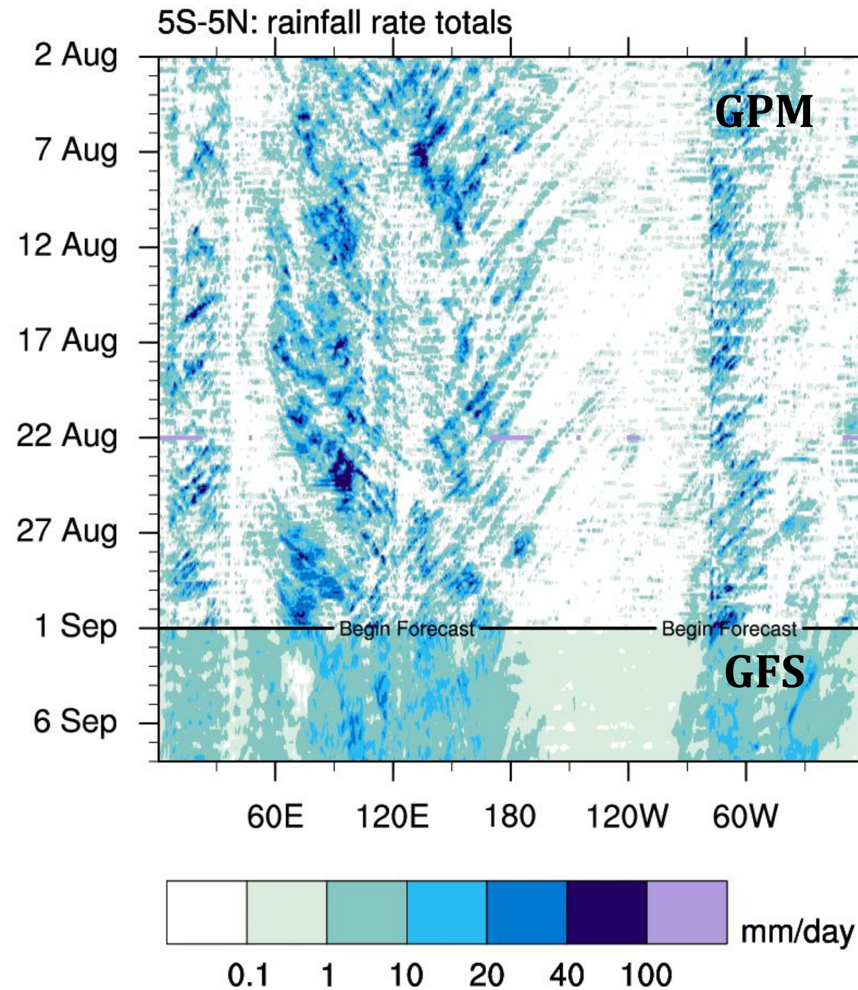
Wang, S., and Coauthors, 2015. Regional simulation of the October and November MJO events observed during the CINDY/DYNAMO field campaign at gray zone resolution. *J. Climate*, **28**, 2097-2119.

Wheeler, M. and G. N. Kiladis, 1999. Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain. *J. Atmos. Sci.*, **56**, 374-399.

Extra slide(s)

GFS tropical convection



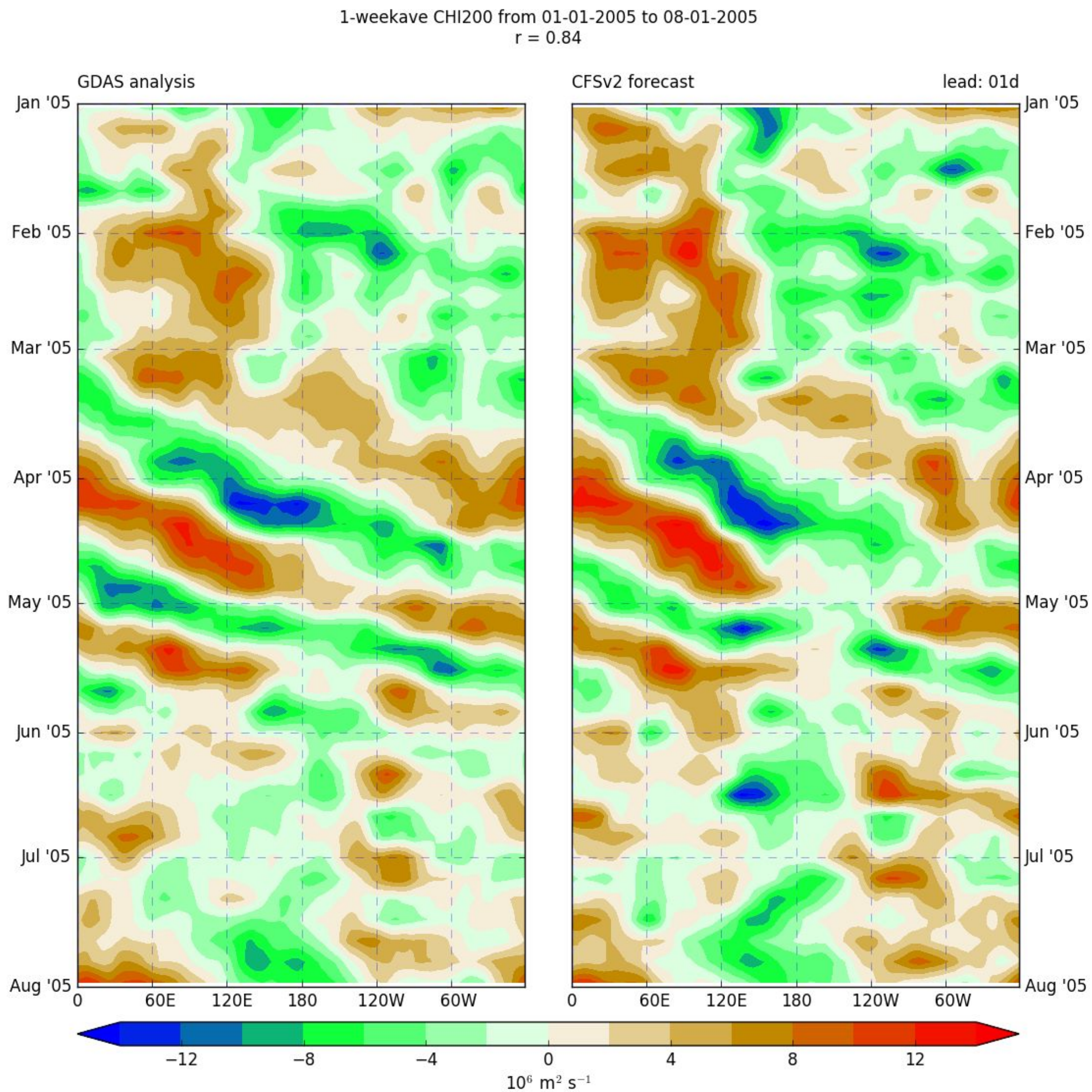


Figures from http://mikeventrice.weebly.com/hovmollers.html

CHI200 Hovmöller: analyses vs week-1 forecasts

<u>Time period</u>:
Spring/summer 2005

* CHI200 averaged from 5S to 5N



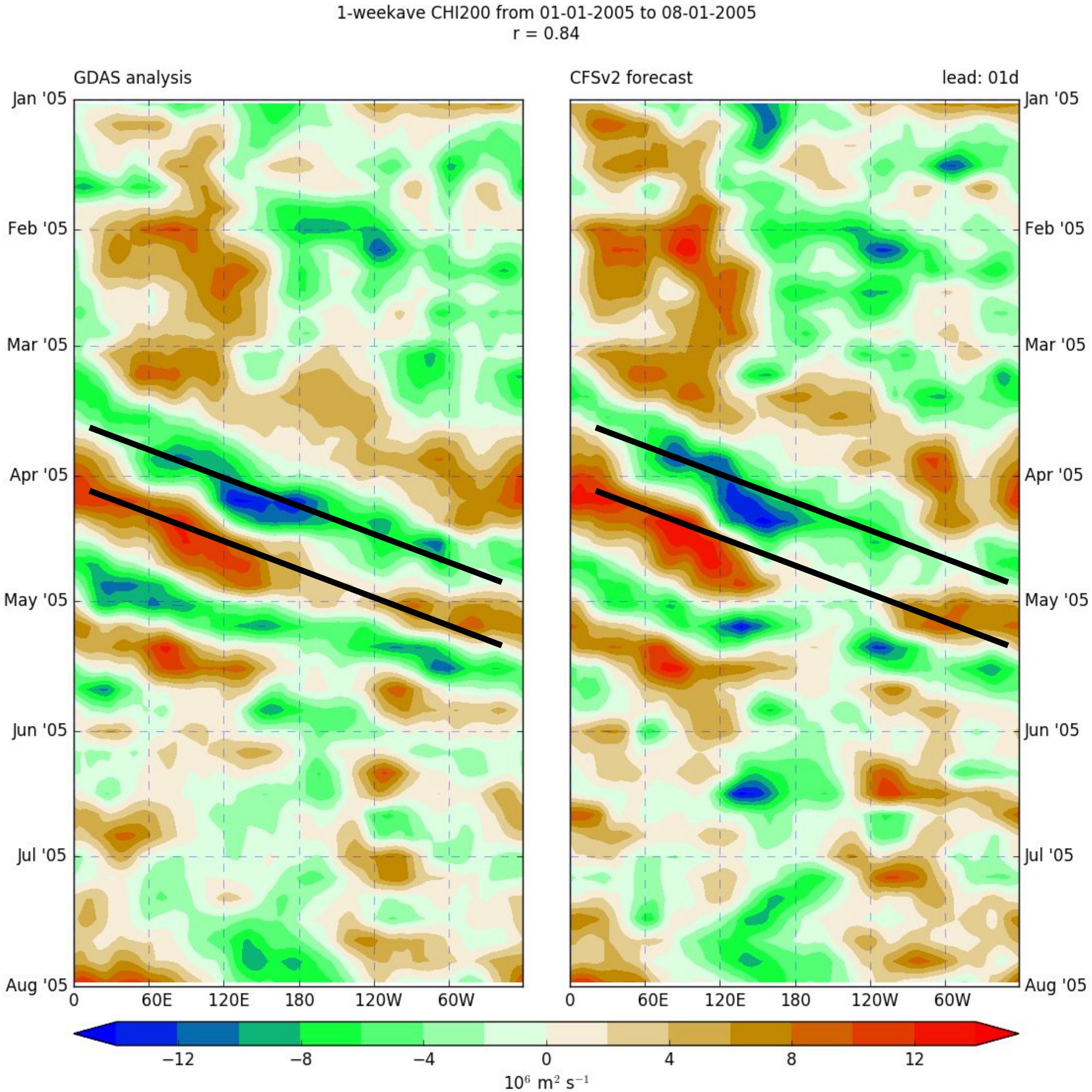
CHI200 Hovmöller: analyses vs week-1 forecasts

<u>Time period</u>:

Spring/summer 2005

<u>Short leads</u>:

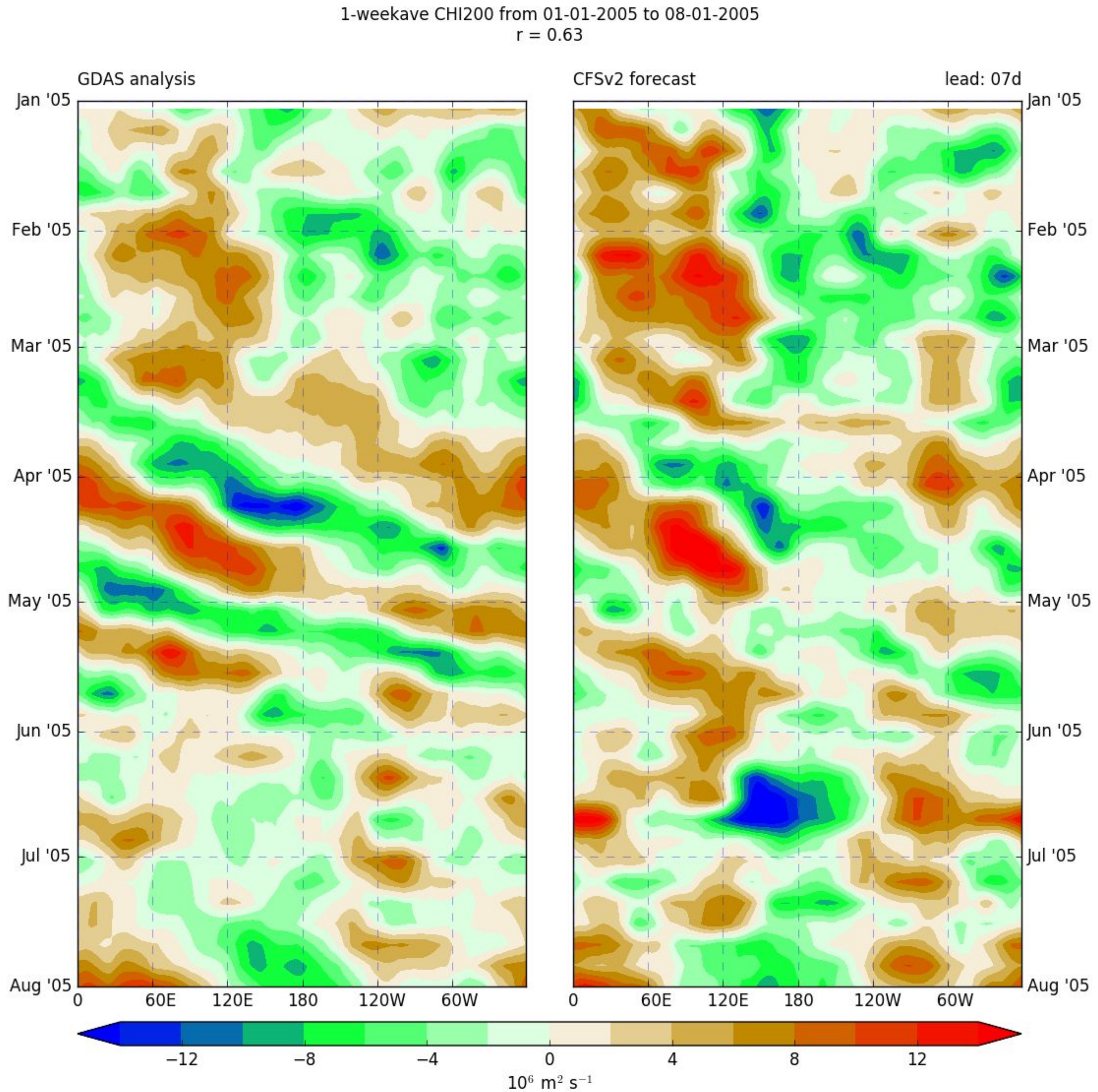
Clear propagating features in both the analyses and forecasts



CHI200 Hovmöller: analyses vs week-2 forecasts

<u>Time period</u>:
Spring/summer 2005

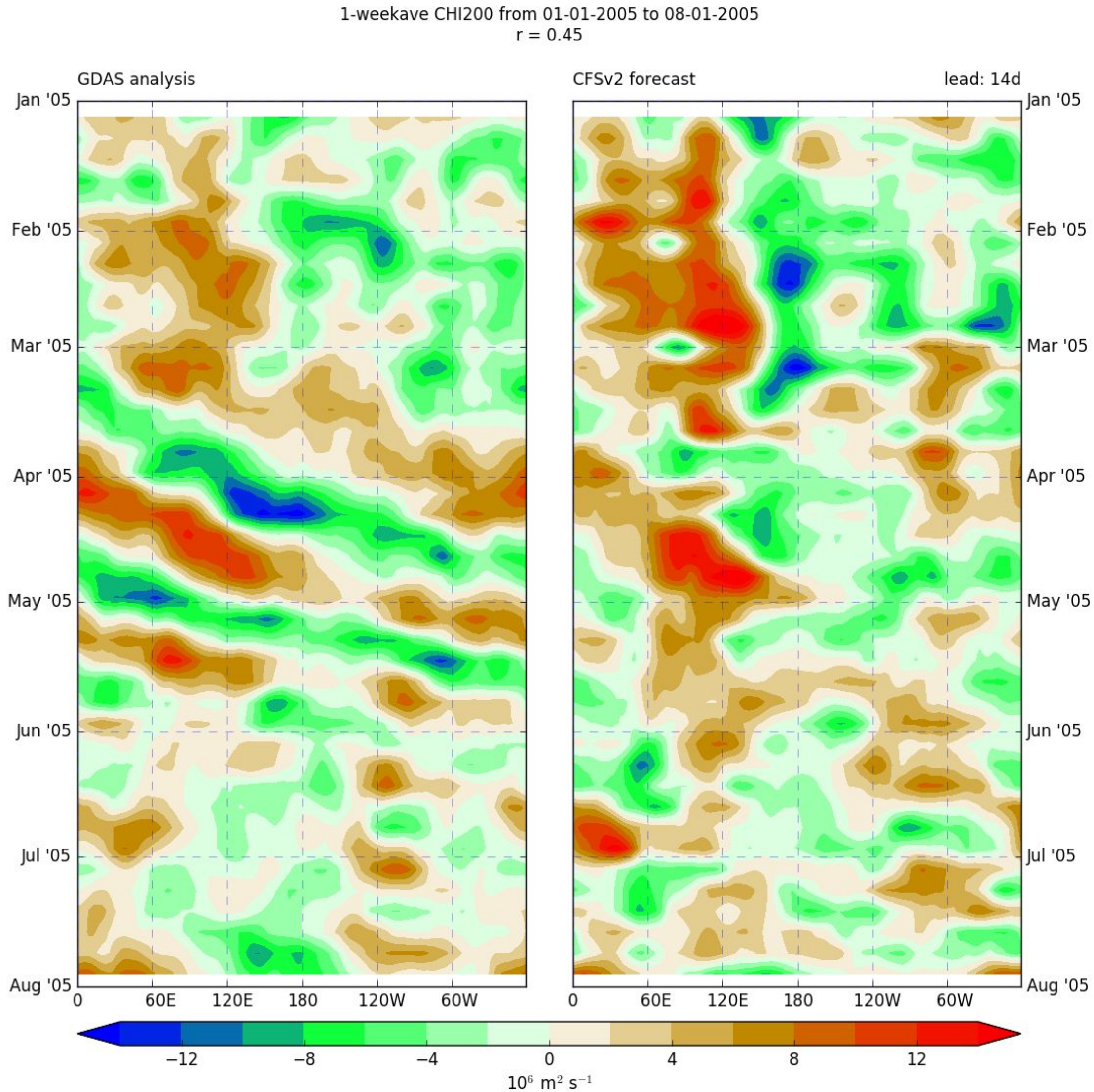
<u>Short leads</u>:
Clear propagating features in both the analyses and forecasts



CHI200 Hovmöller: analyses vs week-3 forecasts

Time period:
Spring/summer 2005

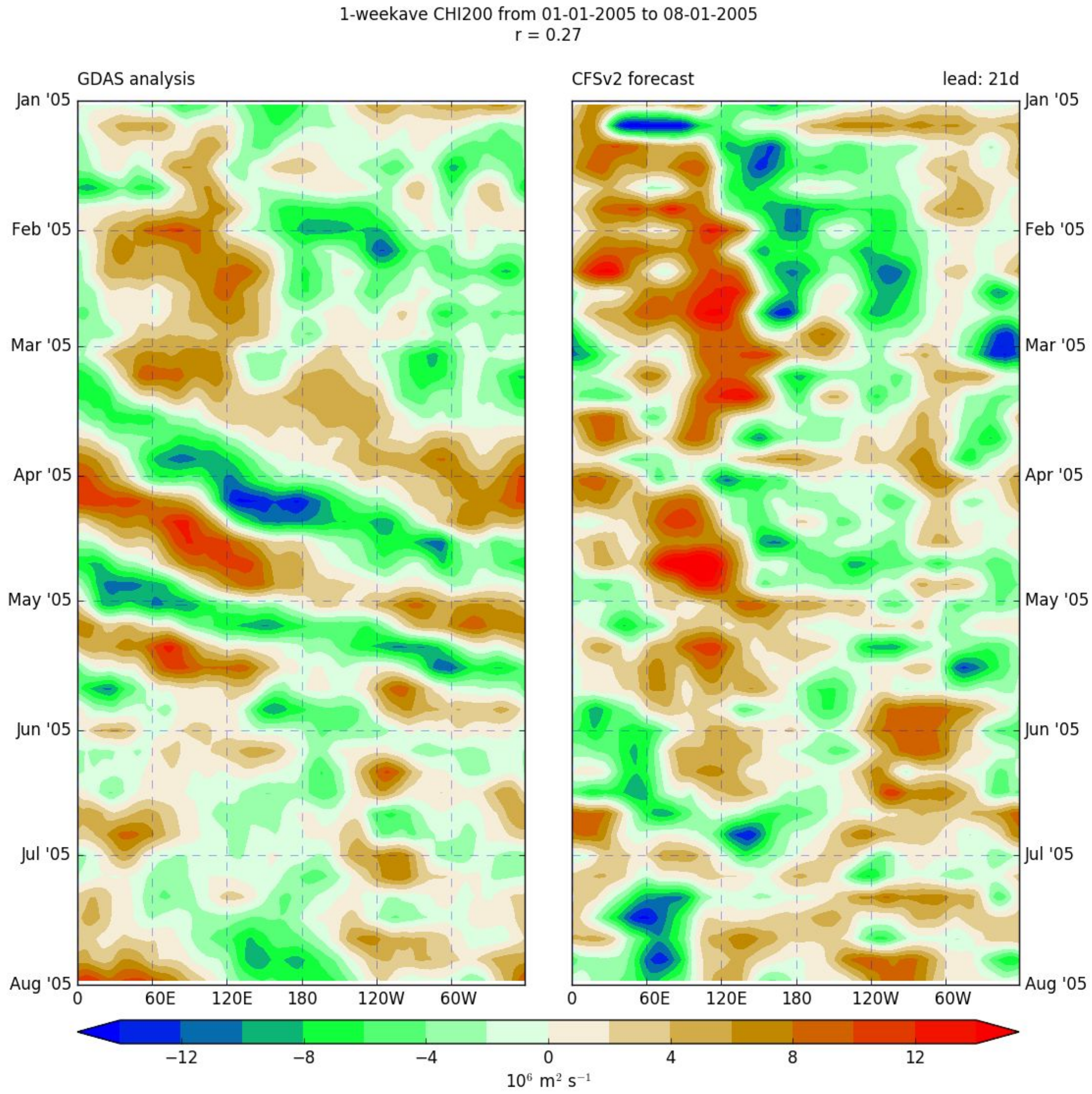
Short leads:
Clear propagating features in both the analyses and forecasts



CHI200 Hovmöller: analyses vs week-4 forecasts

<u>Time period</u>:
Spring/summer 2005

<u>Short leads</u>:
Clear propagating features in both the analyses and forecasts



CHI200 Hovmöller: analyses vs week-5 forecasts

Time period:
Spring/summer 2005

Short leads:
Clear propagating features in both the analyses and forecasts

Long leads:
Coherent propagating structures are lost, while more stationary patterns develop