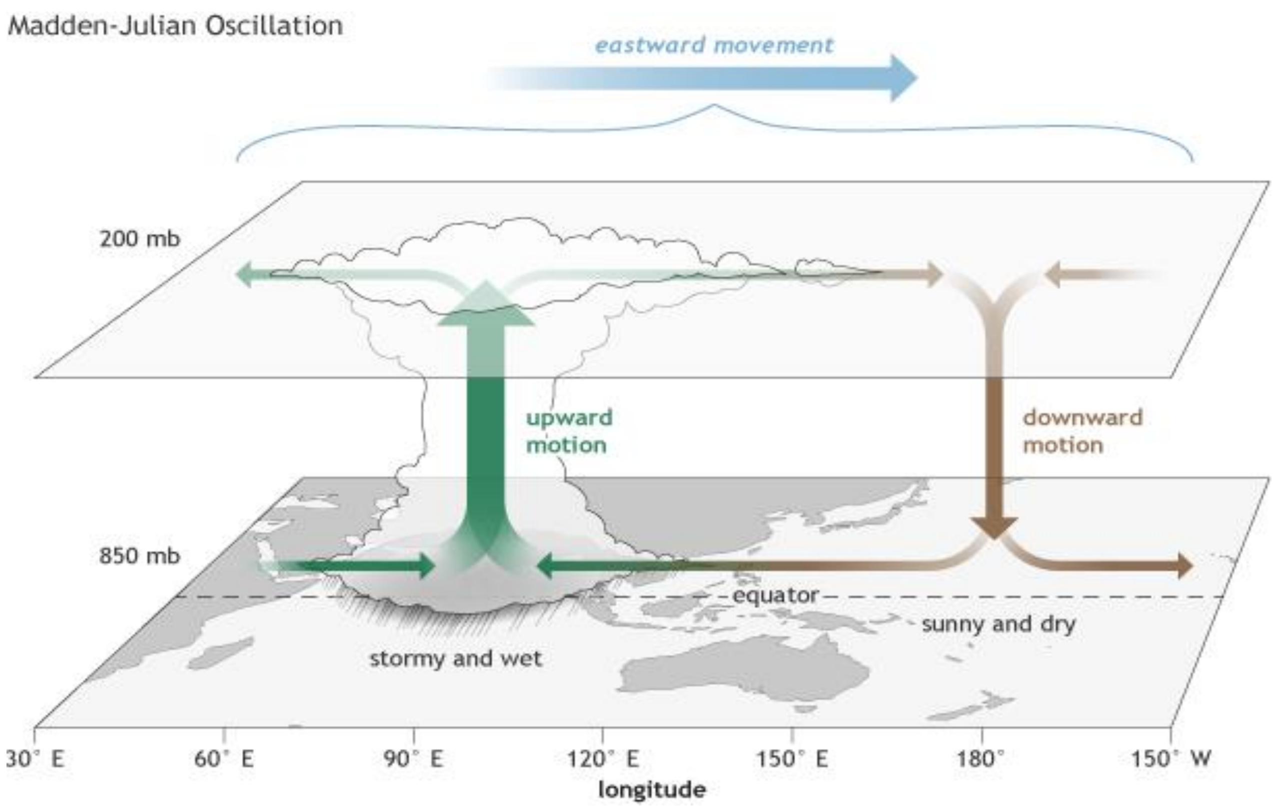
The Madden-Julian Oscillation

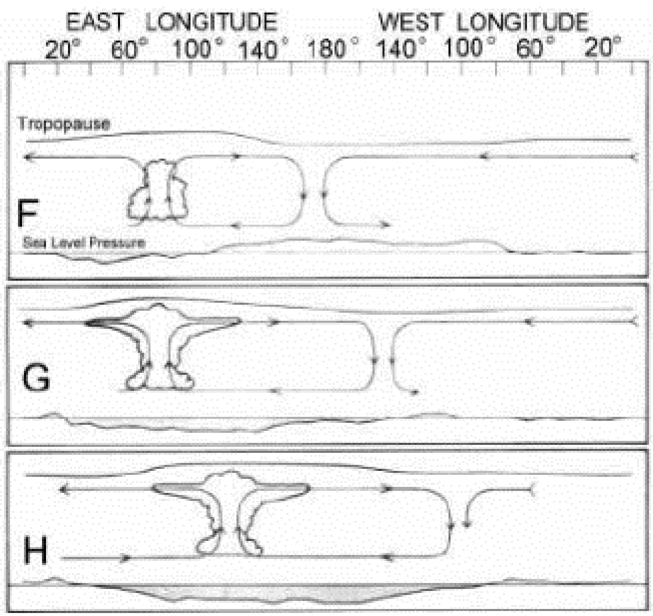


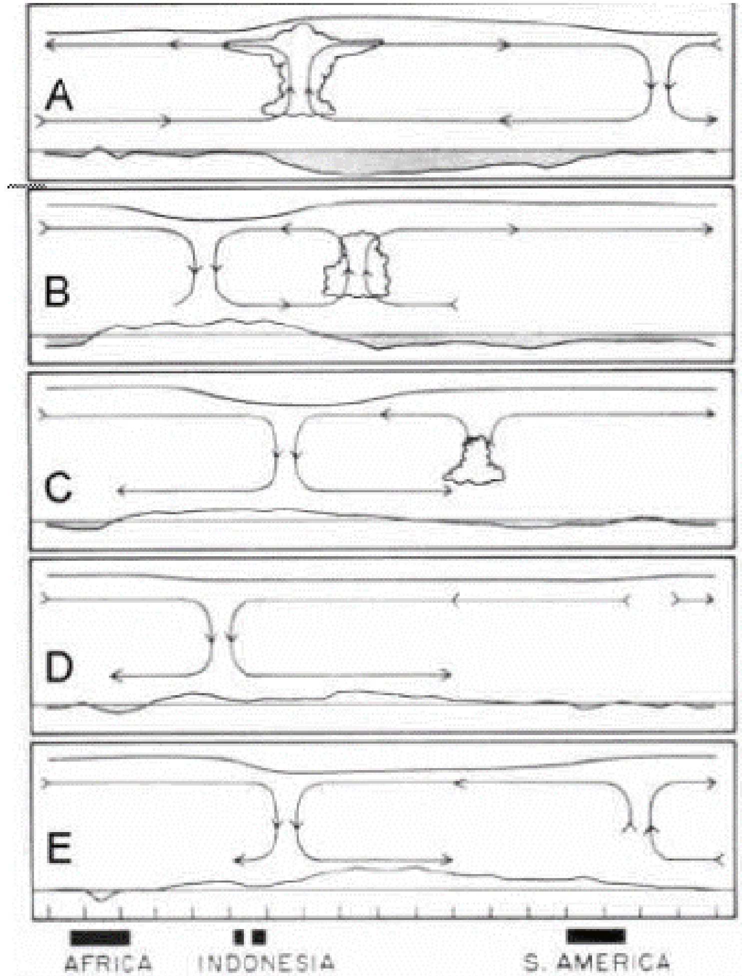
Gottschalk et al, 2014

Frédéric Vitart

European Centre for Medium-Range Weather Forecasts

The Madden-Julian Oscillation (MJO)

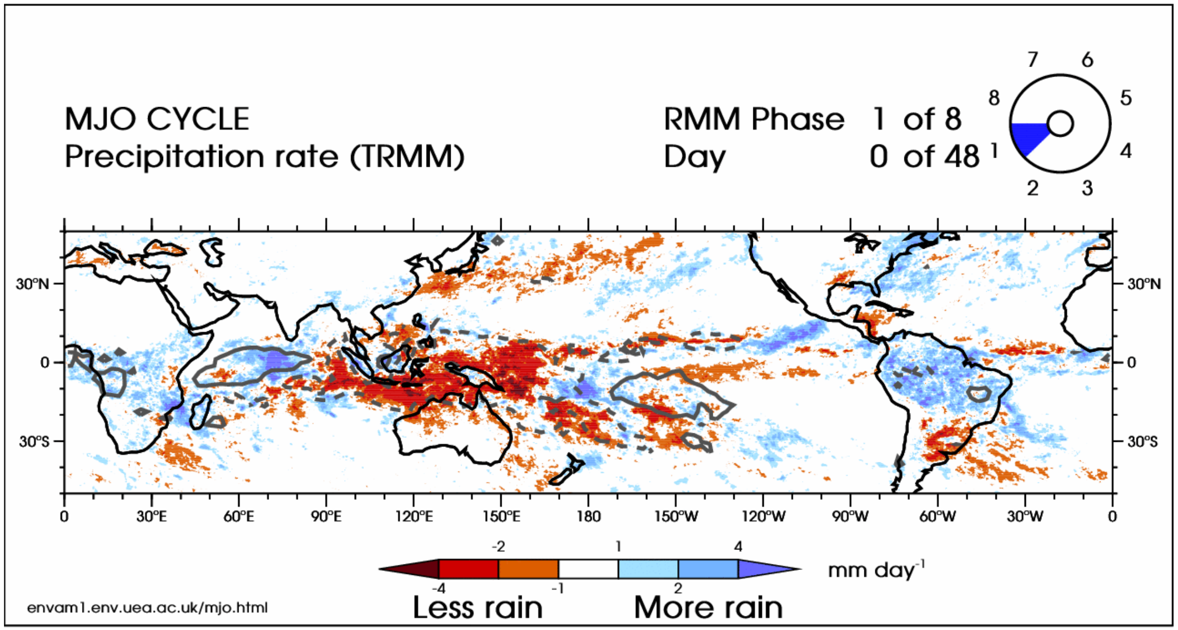


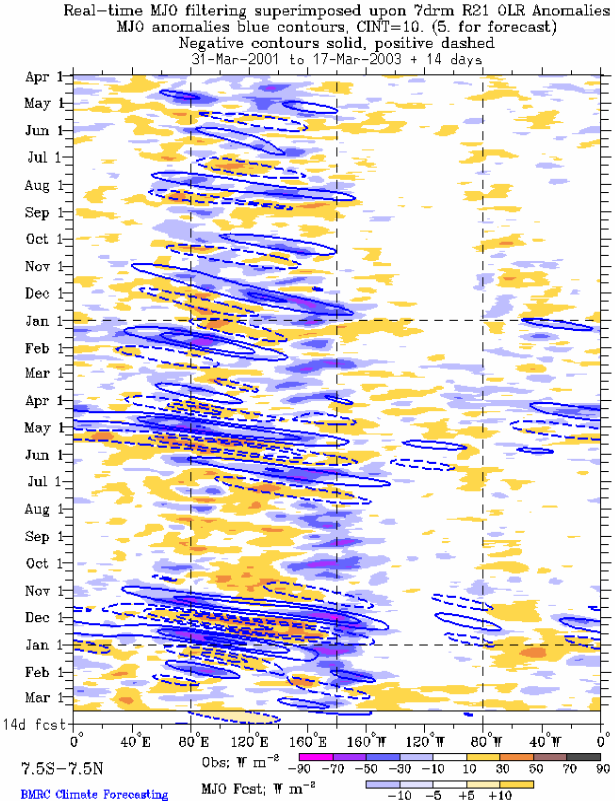


From Madden and Julian (1972)

What is the MJO?

MJO life cycle





From http://envam1.env.uea.ac.uk/mjo.htm

From http://www.bom.gov.au/bmrc/clf

What is the MJO?

- The MJO is a 40-50-day oscillation

- The MJO is a near-global scale, quasi-periodic eastward moving disturbance in the surface pressure, tropospheric temperature and zonal winds over the equatorial belt (4 to 8 m/s). Propagation speed is too slow for the MJO to be a Kelvin wave.

- The Madden-Julian Oscillation (MJO) is the dominant mode of variability in the tropics in time scales in excess of 1 week but less than 1 season.

- The MJO has its peak activity during Northern winter and spring.

Theories for the onset of an MJO event

- **Local recharge/discharge processes** (e.g. Hendon 1988, Blade and Hartmann 1993, Hu and Randall 1994…)

- **Upstream effects of circumnavigating waves** (e.g. Knutson et al 1986, Knutson and Weickmann 1987, Lau and Peng 1987)

- **Stochastic forcing** (Wilson and Mak 1984, Neelin and Yu 1994, Yu and Neelin 1994)

- **Extratropical influences** (e.g. Lau and Peng 1987, Hsu et al 1990, Lin et al 2007, Ray et al 2010, Wedi and Smolarkiewicz 2010..)

The Madden Julian Oscillation (MJO)

Why is the MJO so important?

- Impact on the Indian and Australian summer monsoons (Yasunari 1979), Hendon and Liebman (1990)

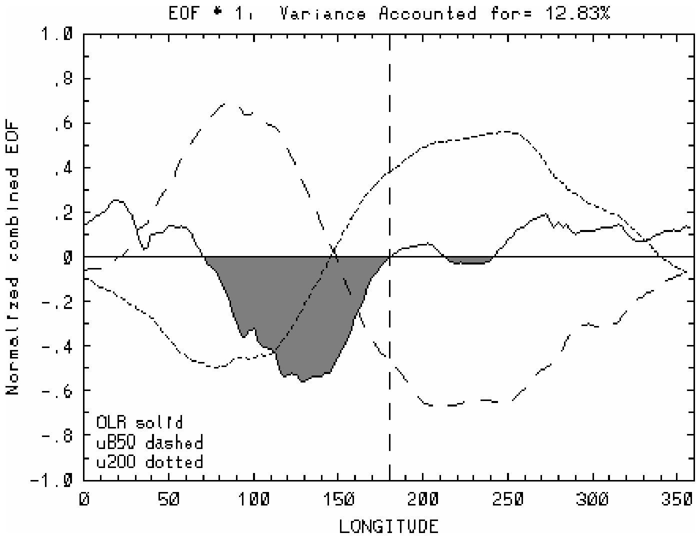
- Impact on ENSO. Westerly wind bursts produce equatorial trapped Kelvin waves, which have a significant impact on the onset and development of an El-Niňo event. Kessler and McPhaden (1995)

- Impact on tropical storms (Maloney et al, 2000; Mo, 2000)

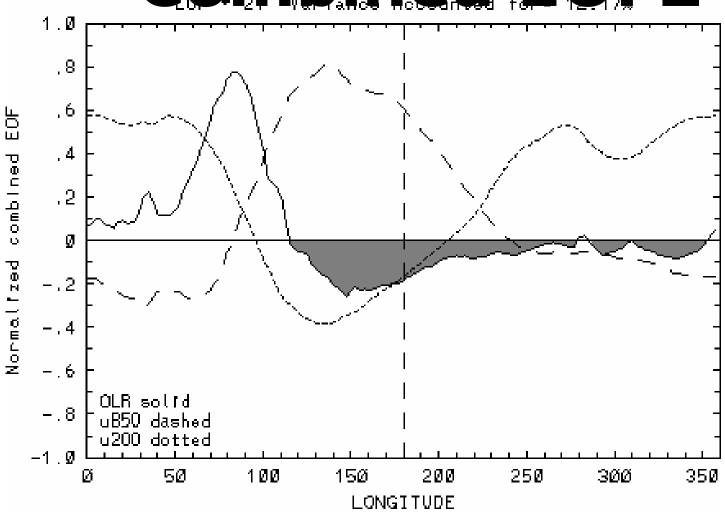
- Impact on Northern Hemisphere weather

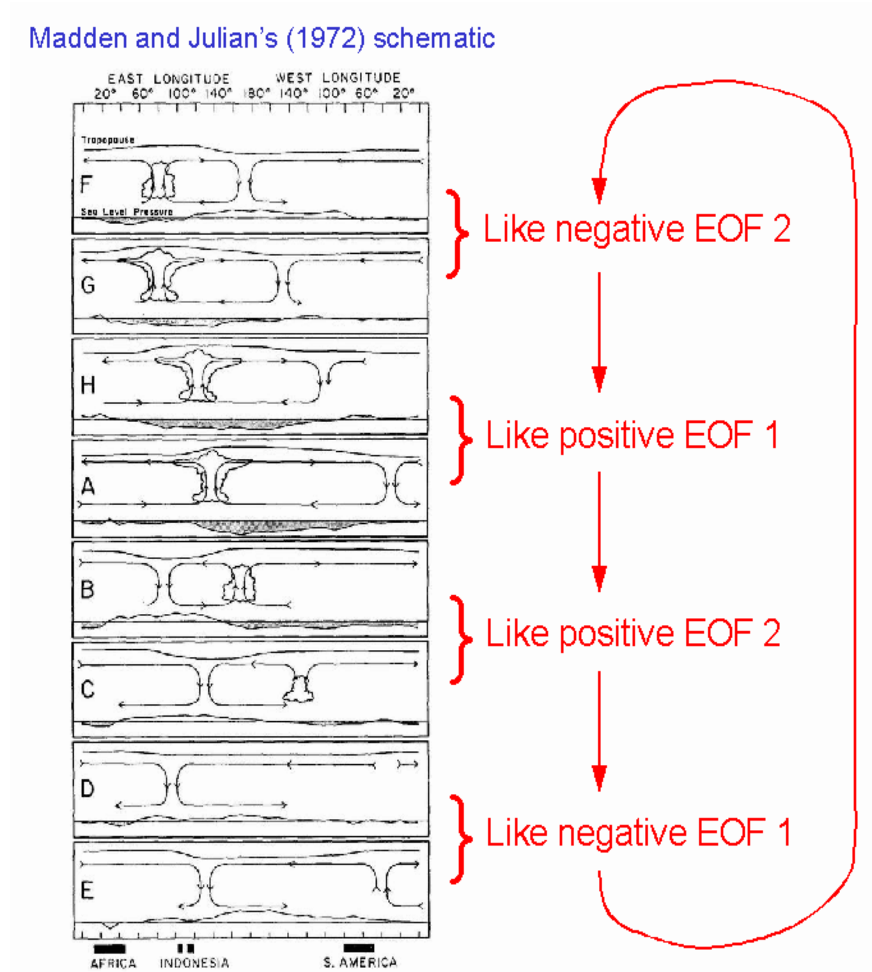
MJO Index

Combined EOF1



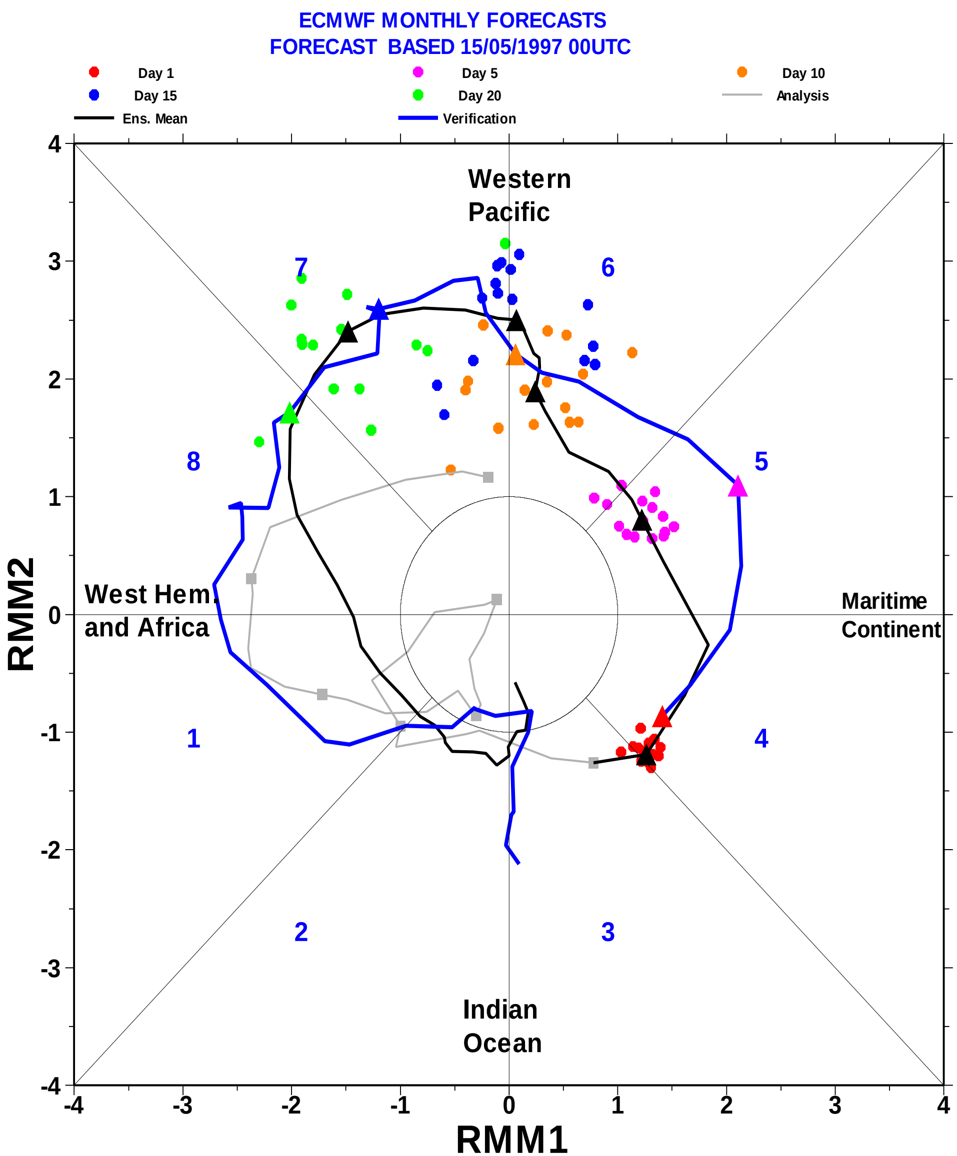
Combined EOF2



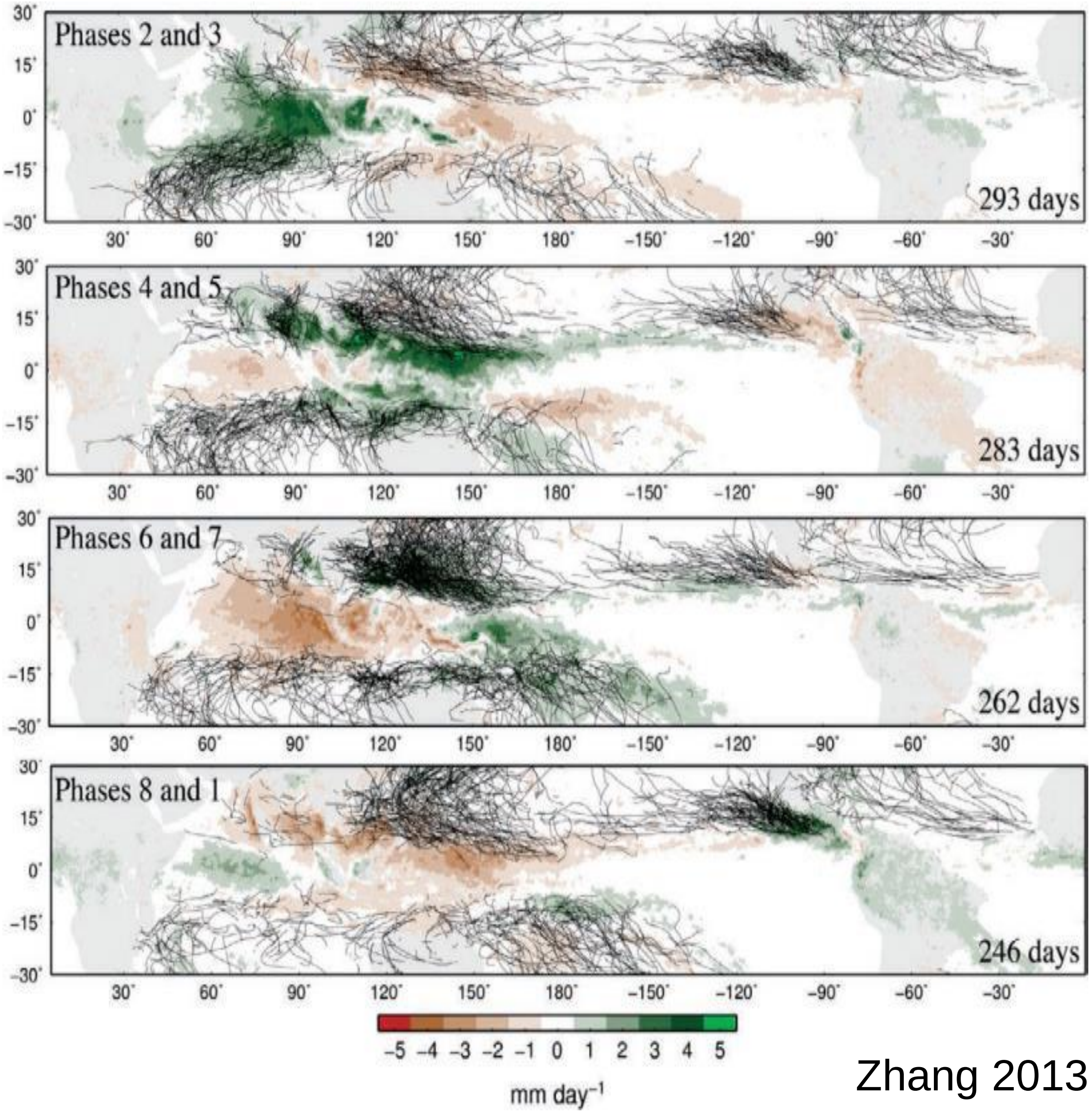


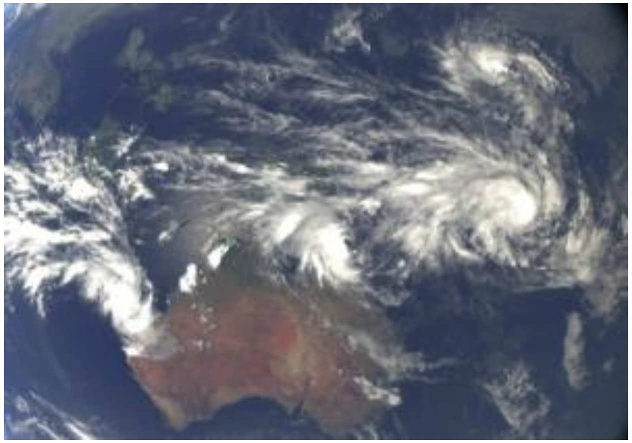
From Wheeler and Hendon, BMRC

MJO prediction



Impact of MJO on tropical cyclones

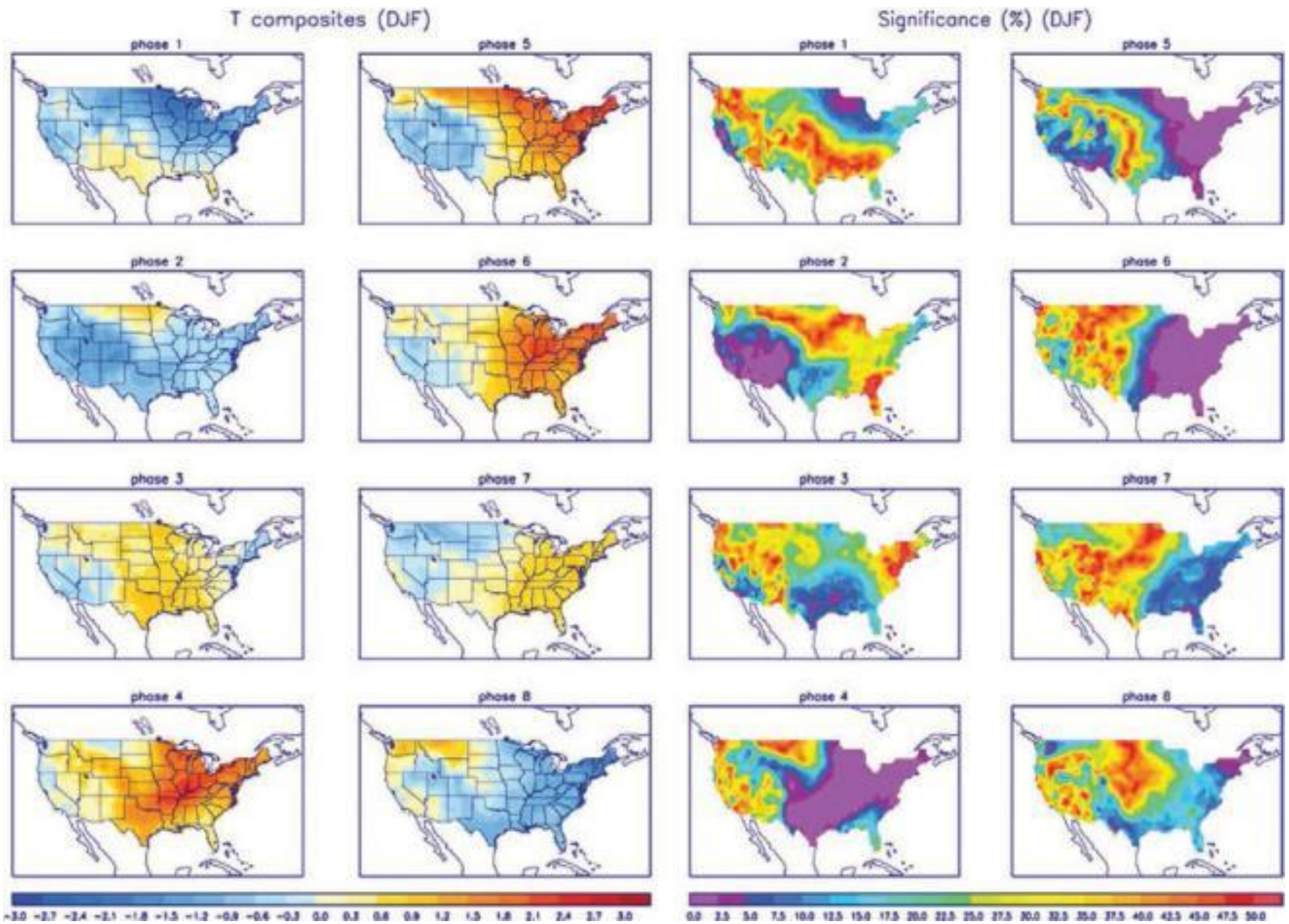




Zhang 2013

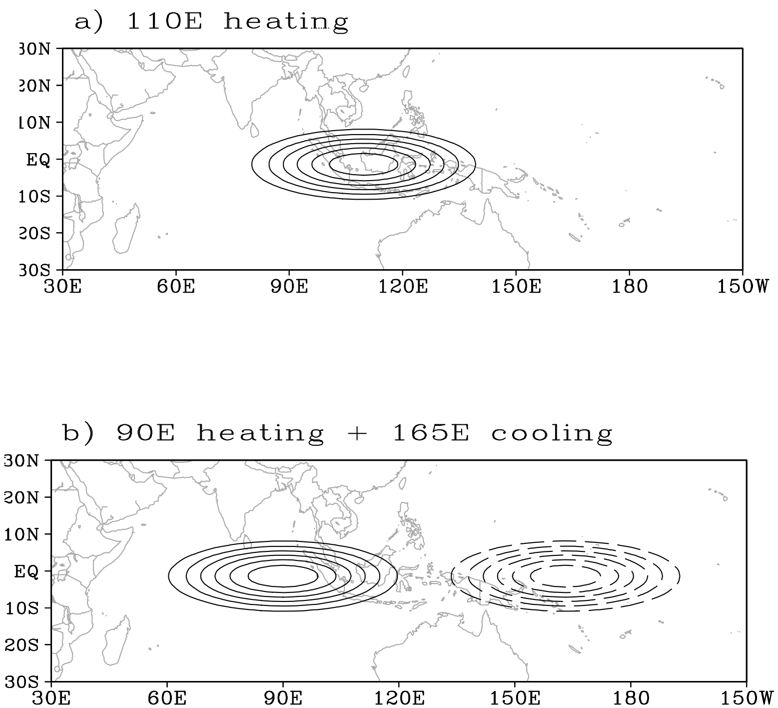
Impact of MJO on Extratropics

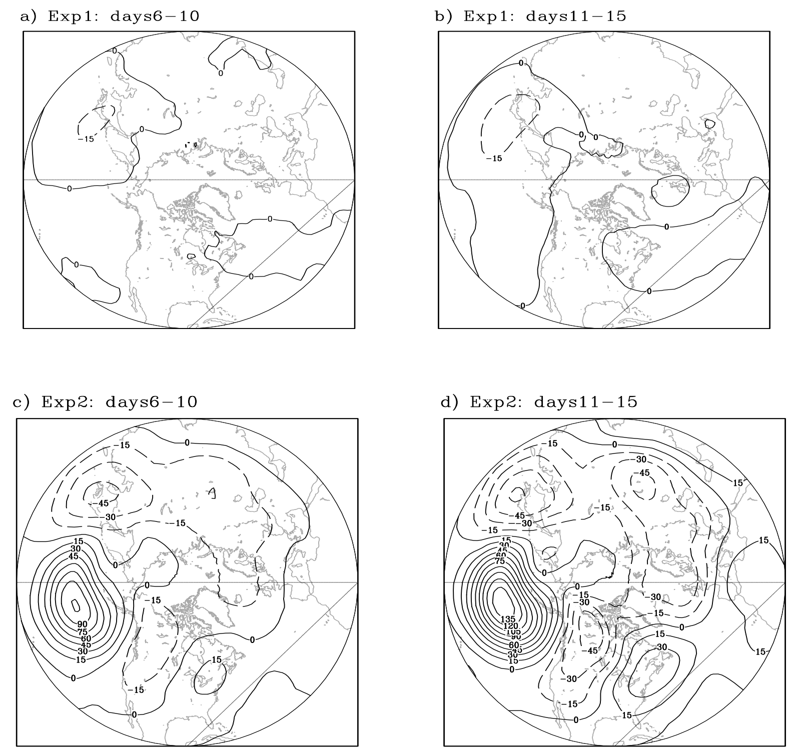
MJO influences on wintertime (December–February) surface air temperature over the United States



Zhang 2013

Impact of MJO on Extratropics





Lin et al, MWR 2010

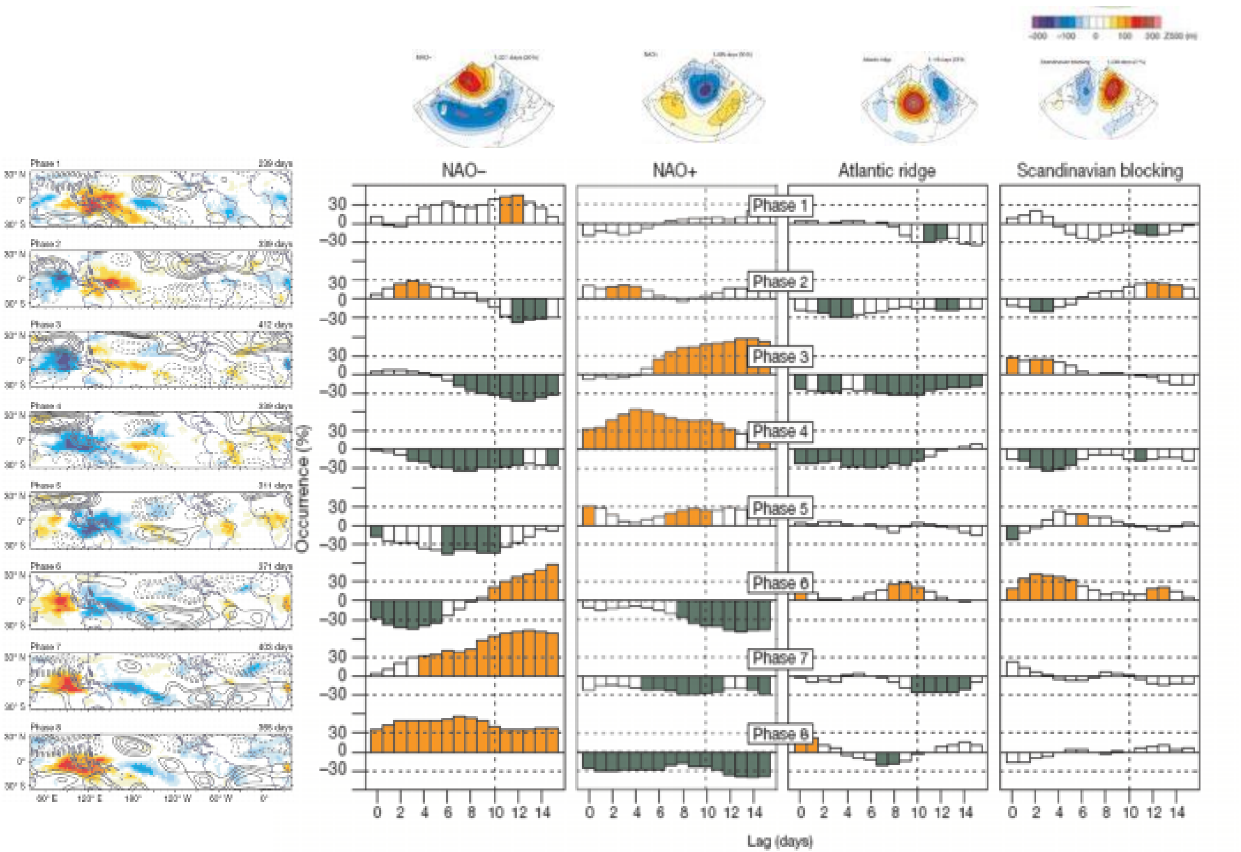
See also

Simmons et al JAS 1983

Ting and Sardeshmukh JAS 1993

Impact of the MJO on Euro-Atlantic weather regimes

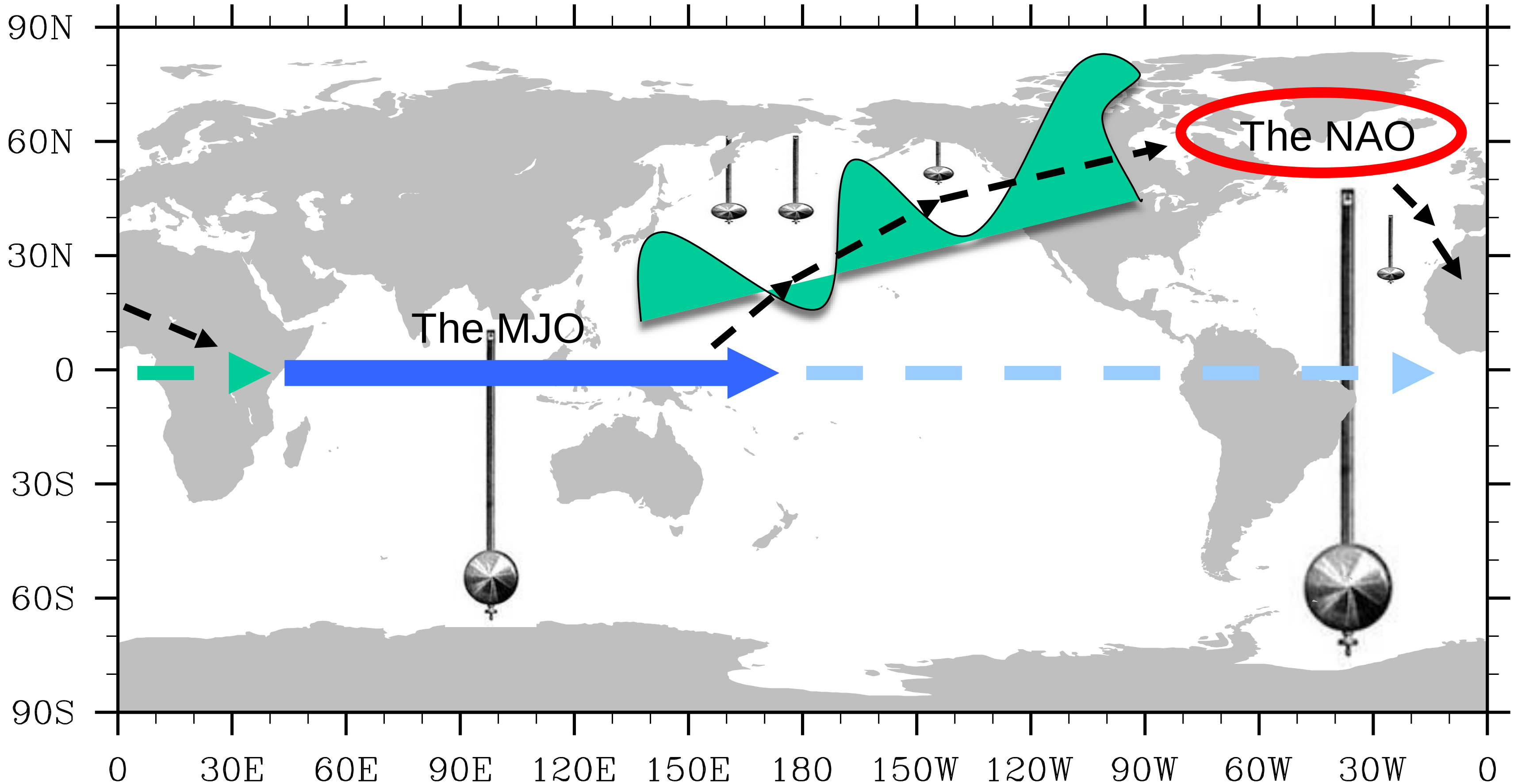
- *Simmons et al JAS 1983*
- *Ferranti et al. JAS 1990*
- *Ting and Sardeshmukh JAS 1993*
- *Lin et al, MWR 2010*



Cassou C,2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. *Nature*, **455**, 523-527.

Increased probability of NAO+ (NAO-) following an active phase of the MJO over the Indian Ocean (West Pacific)

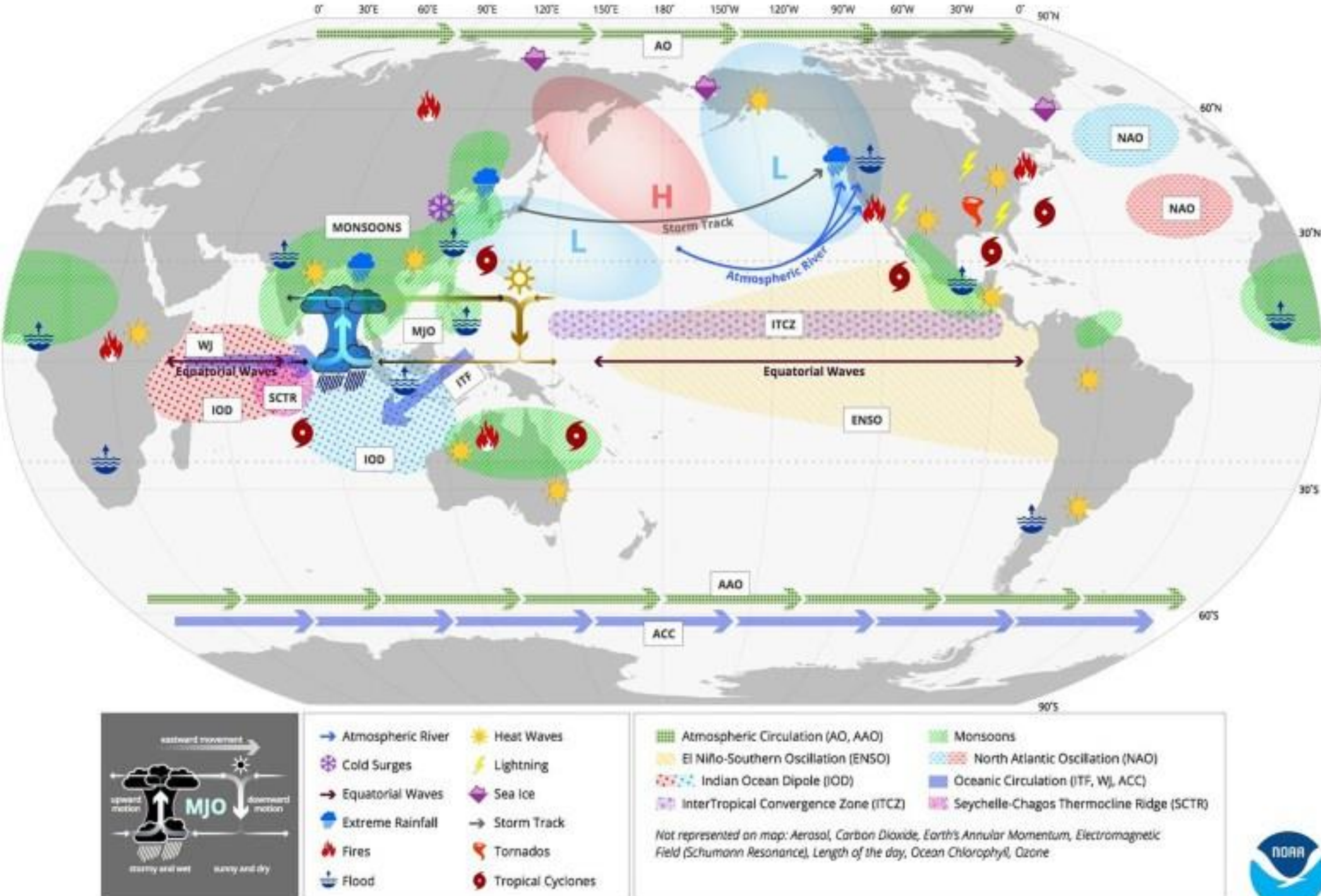
The multi-scale organisation of tropical convection and its two-way interaction with the global circulation.



large scale oscillations interact?

From Brunet, 2015

MADDEN-JULIAN OSCILLATION (MJO): GLOBAL IMPACTS

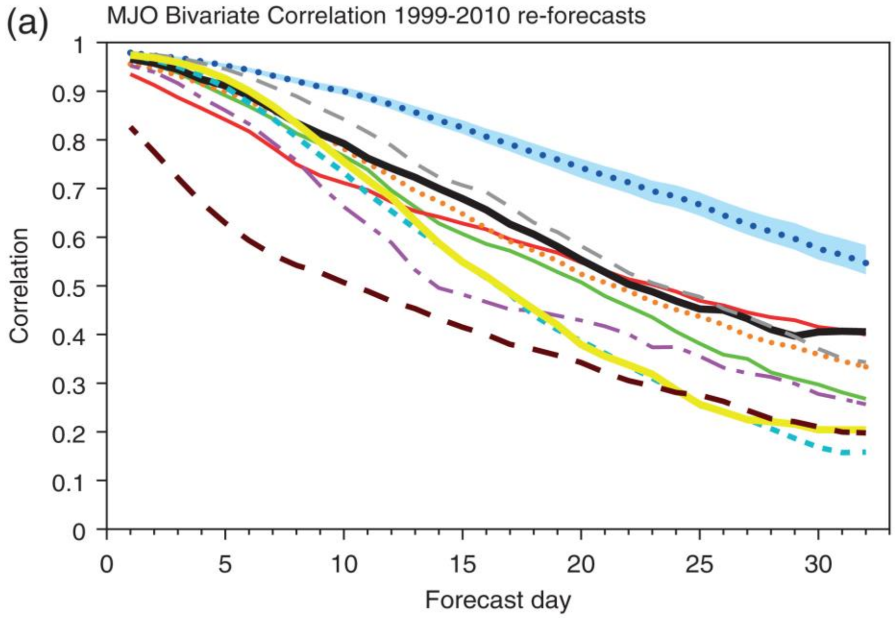


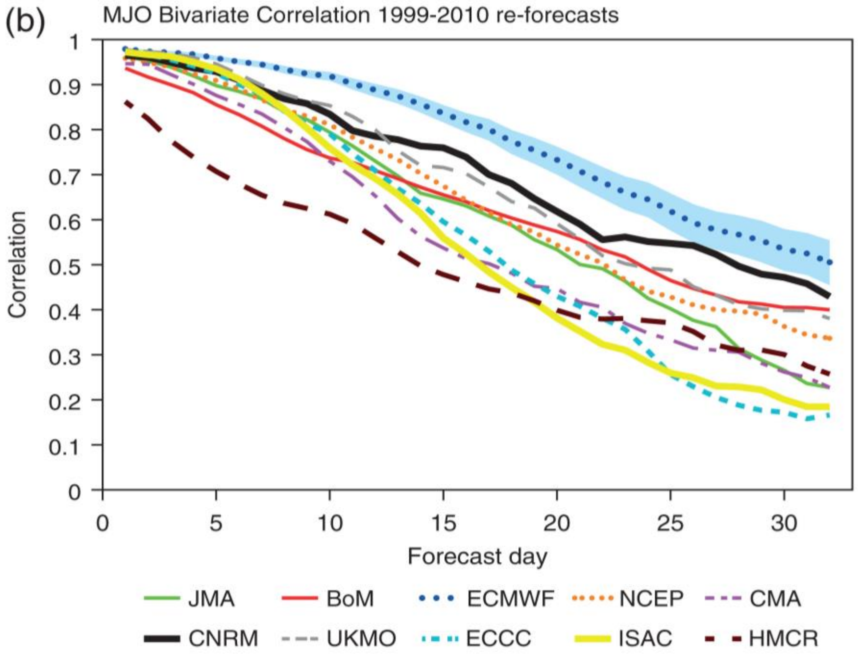
MJO Prediction

MJO forecast skill scores 1999-2010

All Year

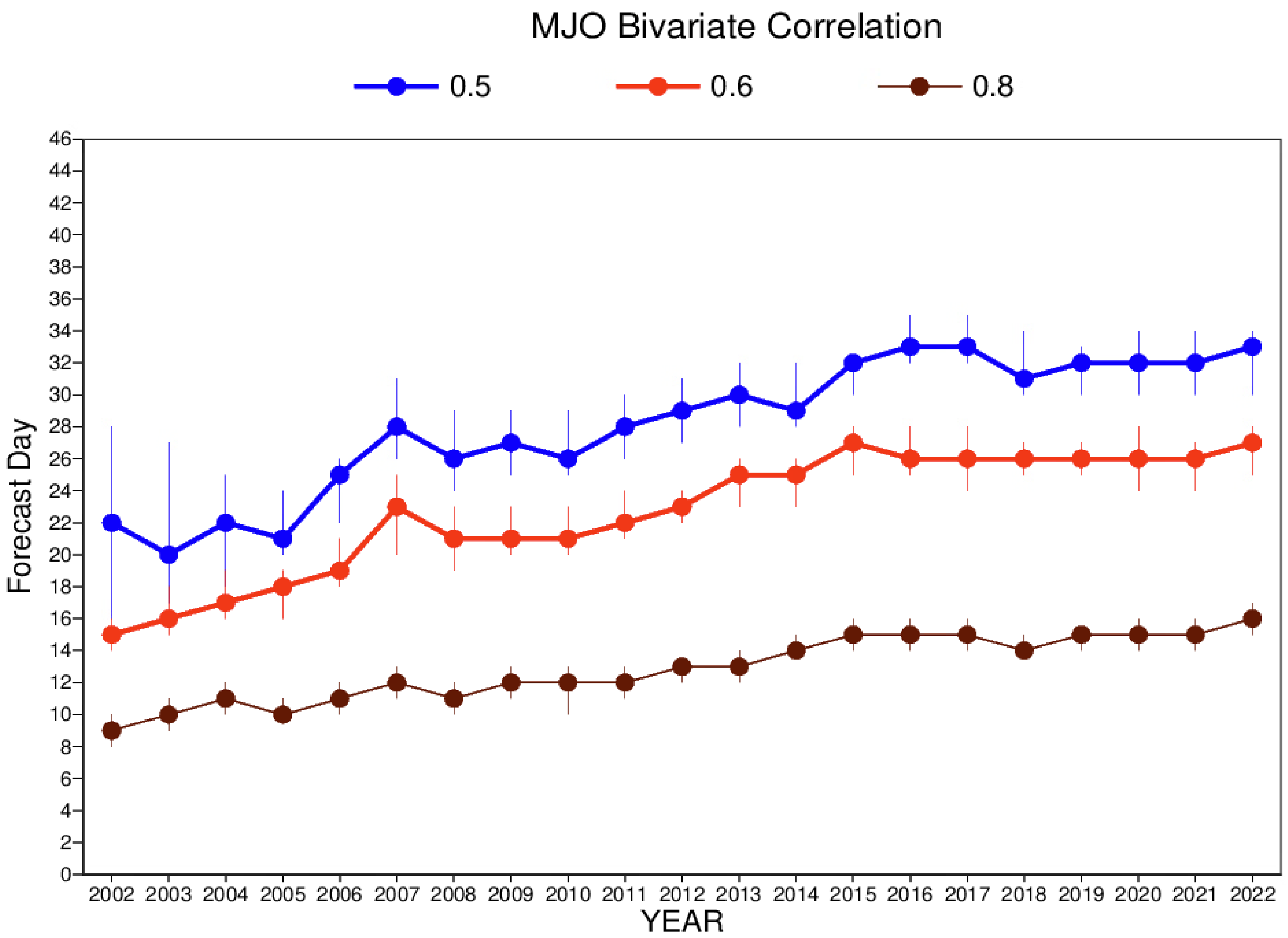
Dec-Marc



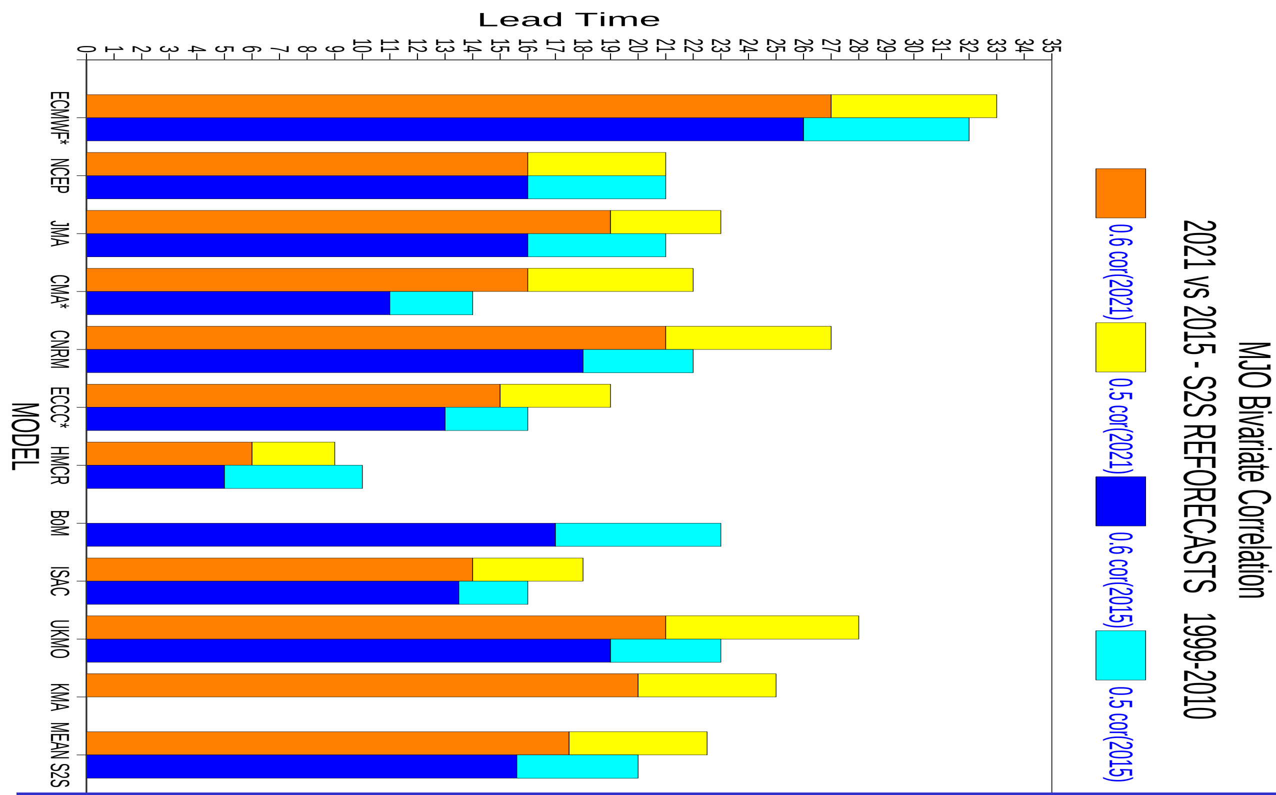


MJO forecast skill horizon up to 4 weeks

MJO skill scores



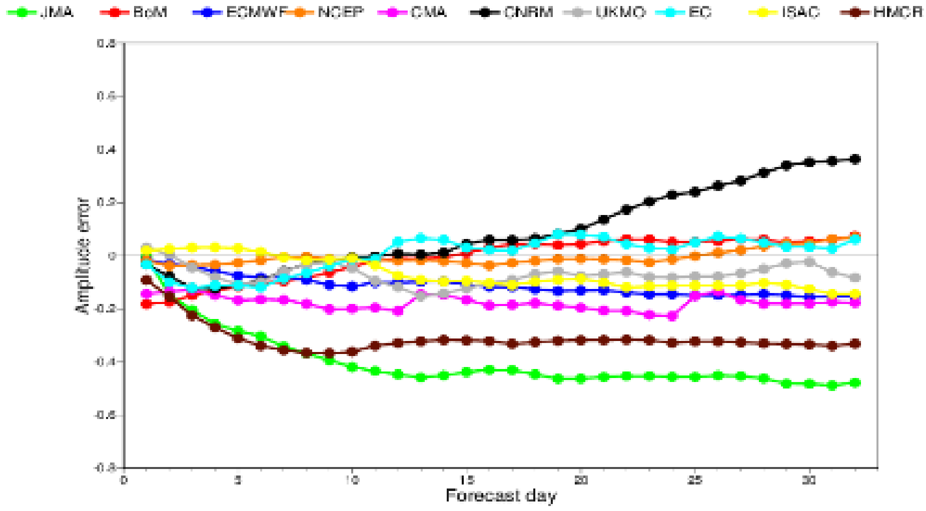
Evolution of MJO forecast skill scores



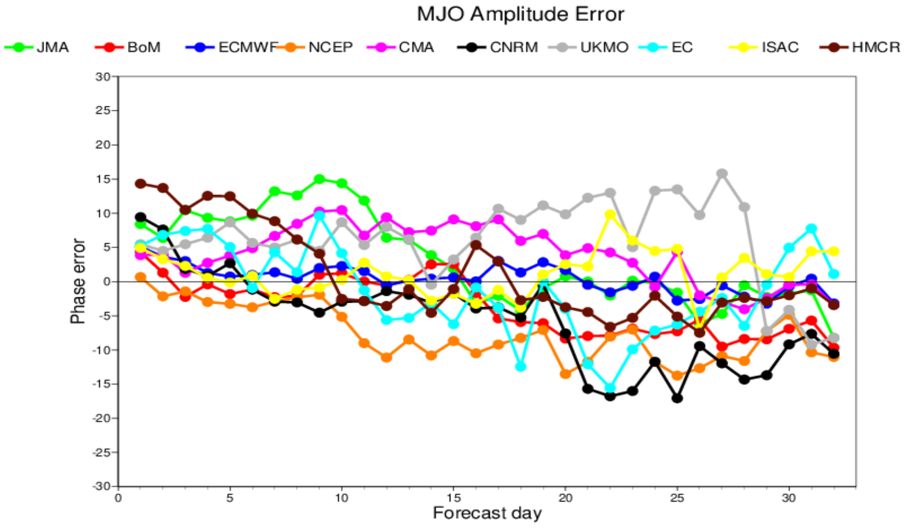
The MJO prediction skill of the models from the S2S database has increased since 2015.

Errors in the Representation of the MJO in S2S models

MJO Amplitude error relative to ERA Interim

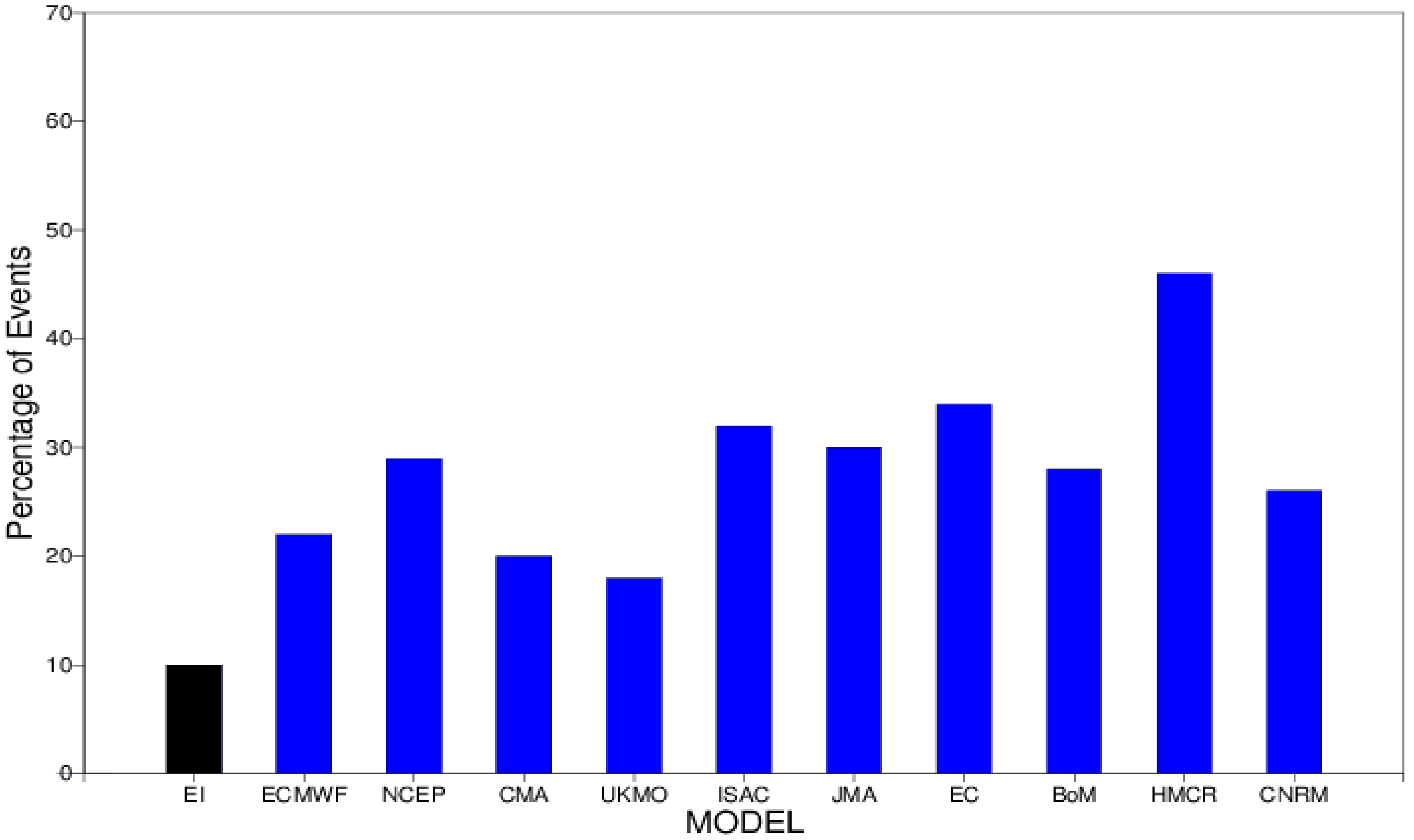


MJO Phase error relative to ERA Interim

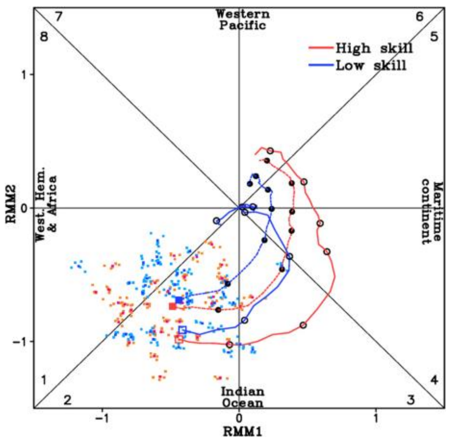


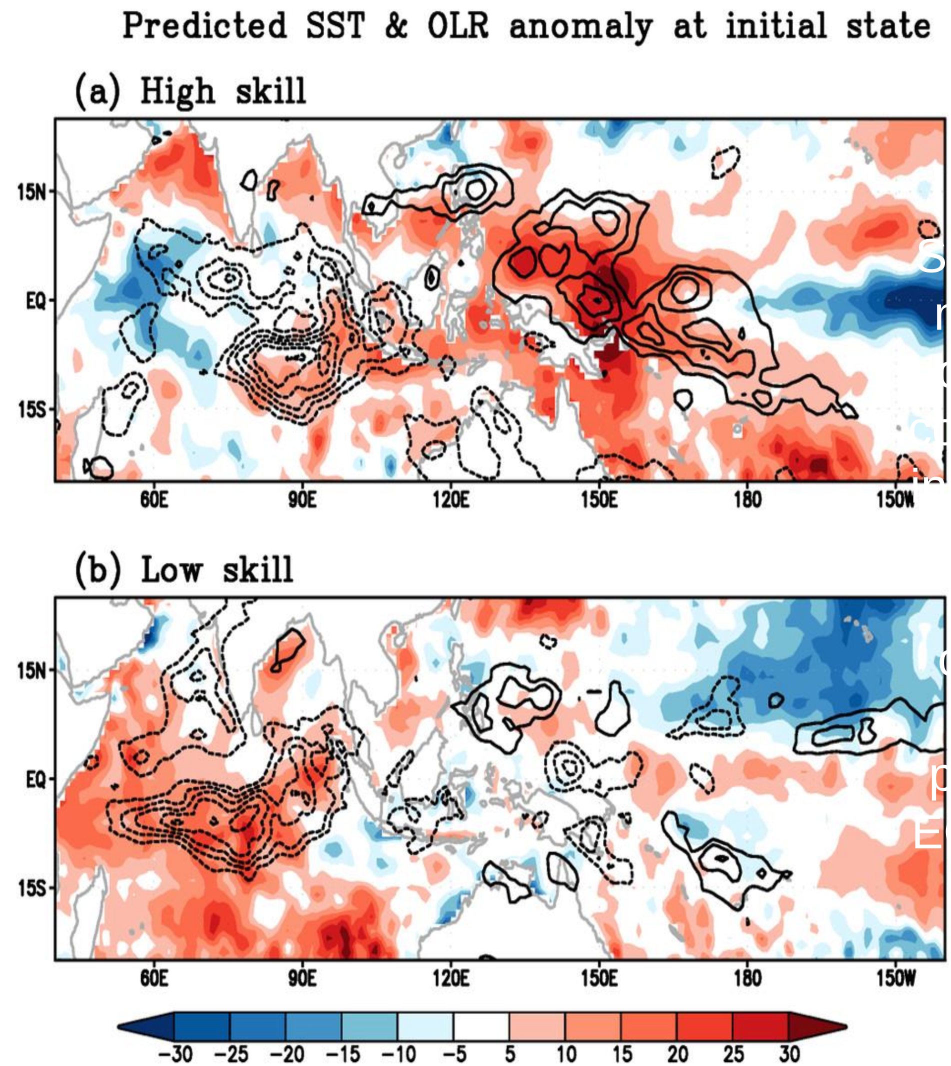
Vitart, 2017

Maritime Continent Barrier



Maritime Continent barrier

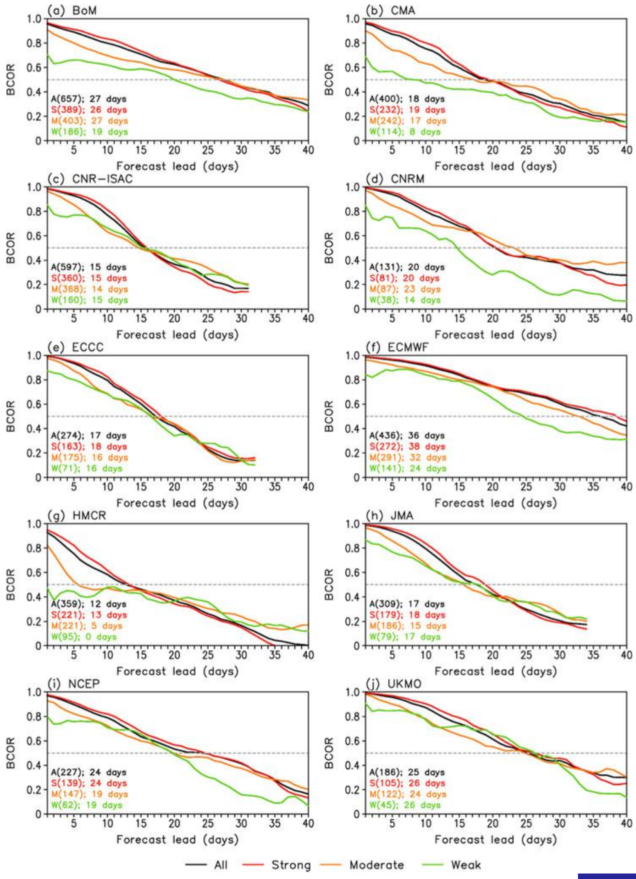


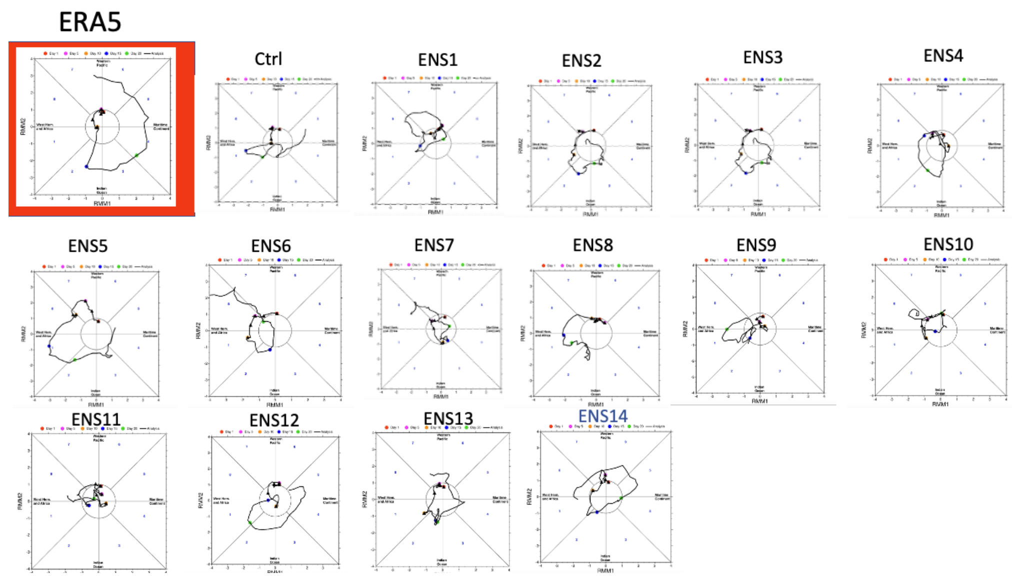


Kim et al, 2016

Predicting the Onset of the MJO

Example: MJO event mid April 2019.
Forecasts starting 10days before onset

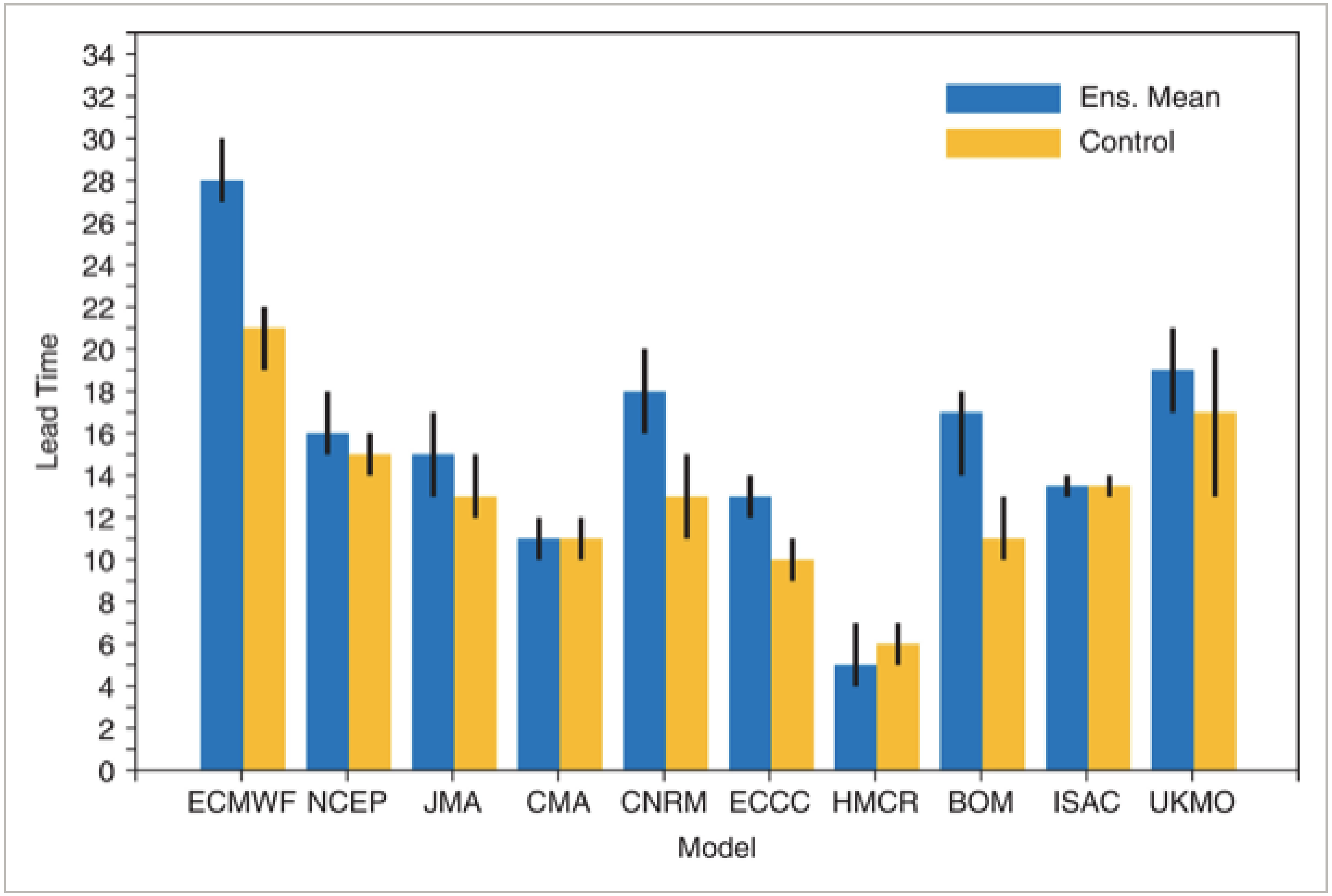




Lim et al, 2018

Forecasts with weak MJOs in initial conditions are less skillful

Impact of ensemble generation

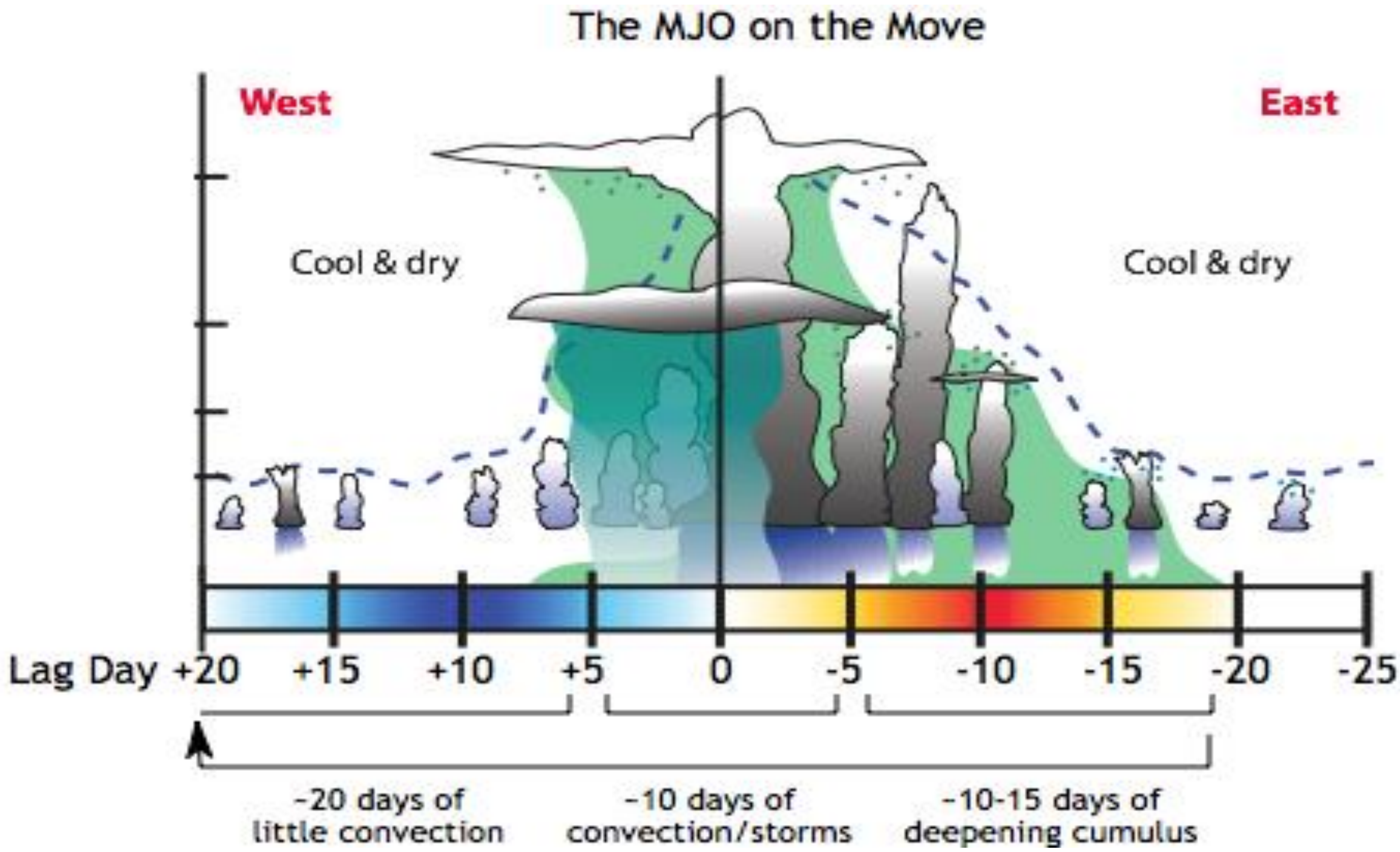


Ensemble forecasts of the MJO are more skillful than an individual ensemble member

Simulation of the MJO in climate models

- Horizontal resolution: not important
- Vertical resolution: positive impact
- Air-sea coupling: Positive impact but not crucial
- Convection scheme: crucial

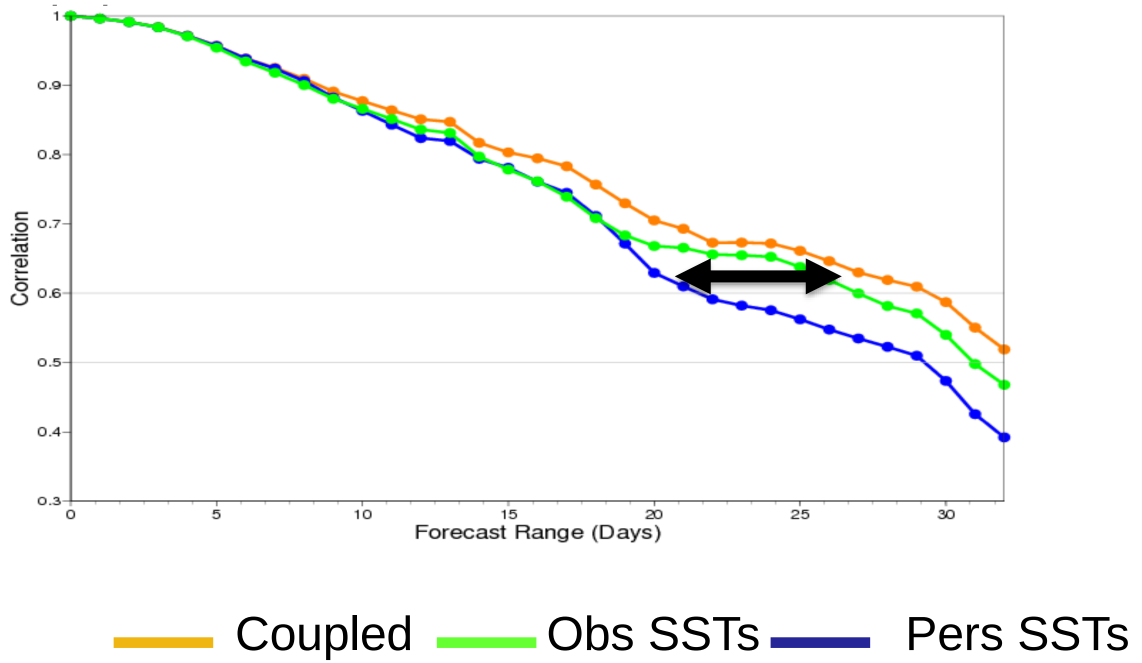
Air-sea Interaction



Impact of ocean/atmosphere coupling

- Uncoupled model has skill in predicting the evolution of the MJO
- Ocean-atmosphere increases significantly the MJO forecasting skill horizon
- Coupled model displays higher skill than atmospheric model forced by observed SSTs

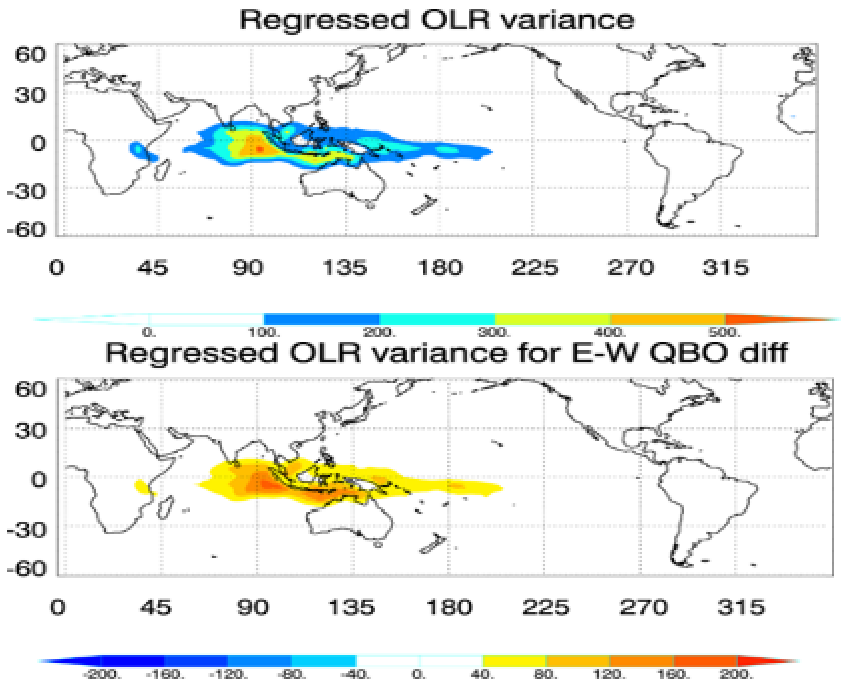
MJO Bivariate Co



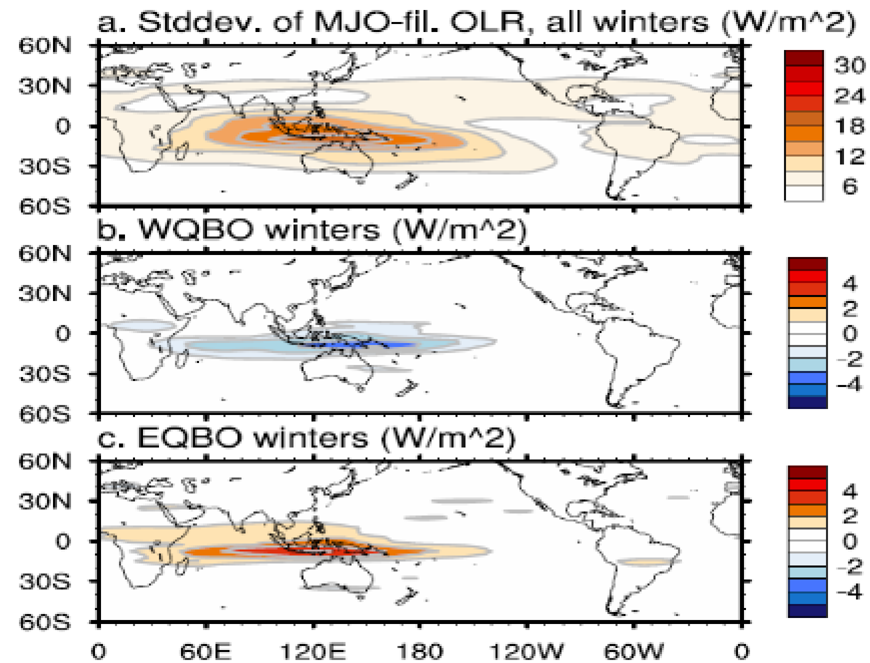
80 cases, starting on 1st Feb/May/Aug/Nov 1989-2008

Impact of the QBO?

MJO OLR Variance (DJF) from reconstruction onto RMM



East waves 1-5 periods 30-80 days

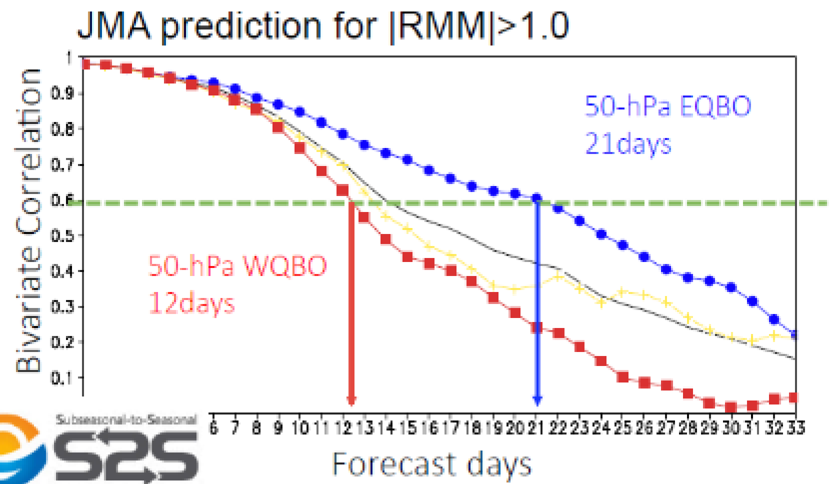


Yoo and Son 2016

2 proposed mechanisms for impact on tropical convection

1**) Changes in static stability at tropopause**: more stable and lower tropopause in west phase> convection lower (and maybe less top heavy heating profile based on Nie and Sobel 2015)
2) **Changes in vertical shear of zonal wind at tropopause**: less shear at tropopause over equatorial IO/West Pac in easterly phase, favors increased convection in easterly phase?

Impact of the QBO?



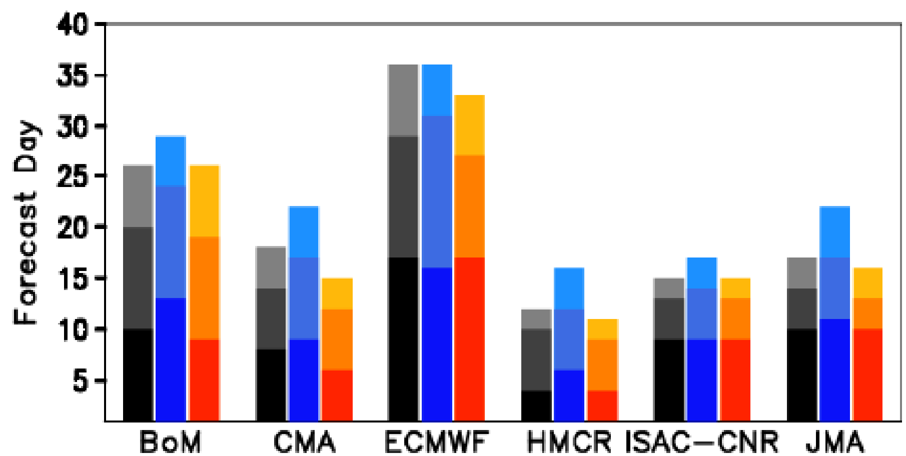


Figure 4. MJO prediction skill for six models. Light, medium, and Dark bars indicate respectively day when the MJO bivariate correlation reaches 0.5, 0.6, and 0.8

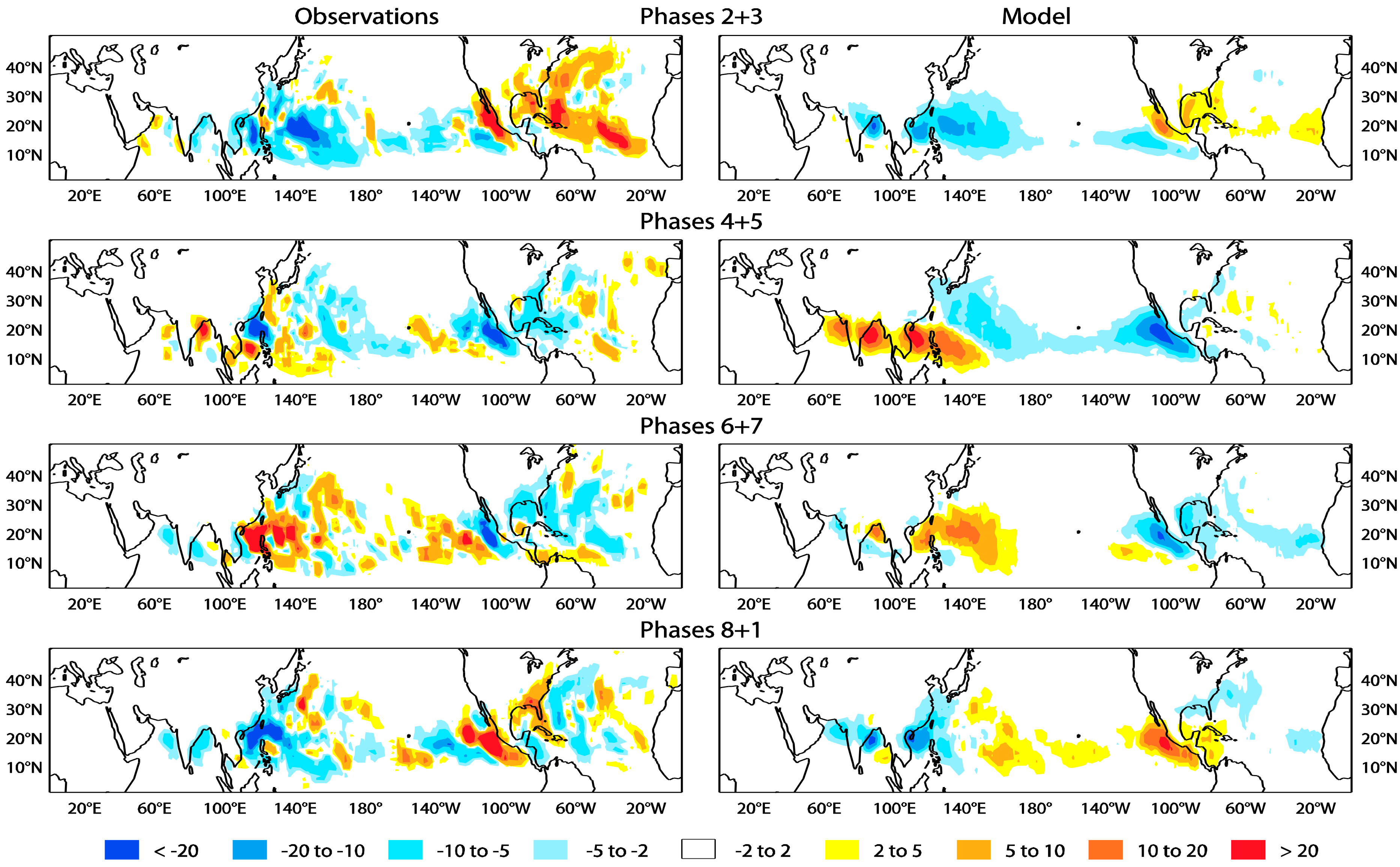
Yoo and Son 2016

S2S models display higher forecast skill during Easterly QBOs than during Westerly QBOs

MJO teleconnections in S2S models

(

Impact on Tropical Cyclone Density (Summer)

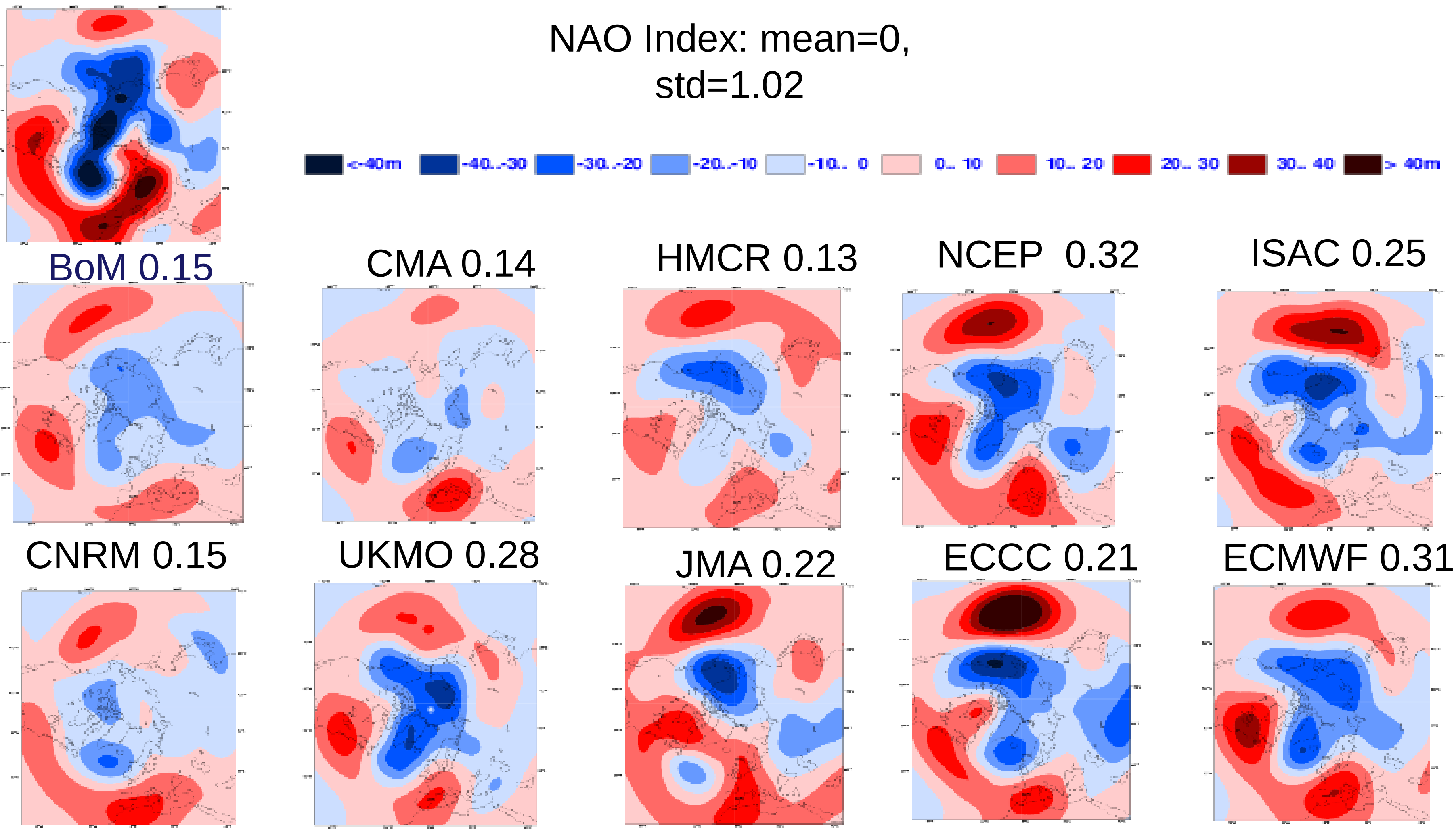


Vitart, GRL 2009

Impact of the MJO on the N. Extratropics

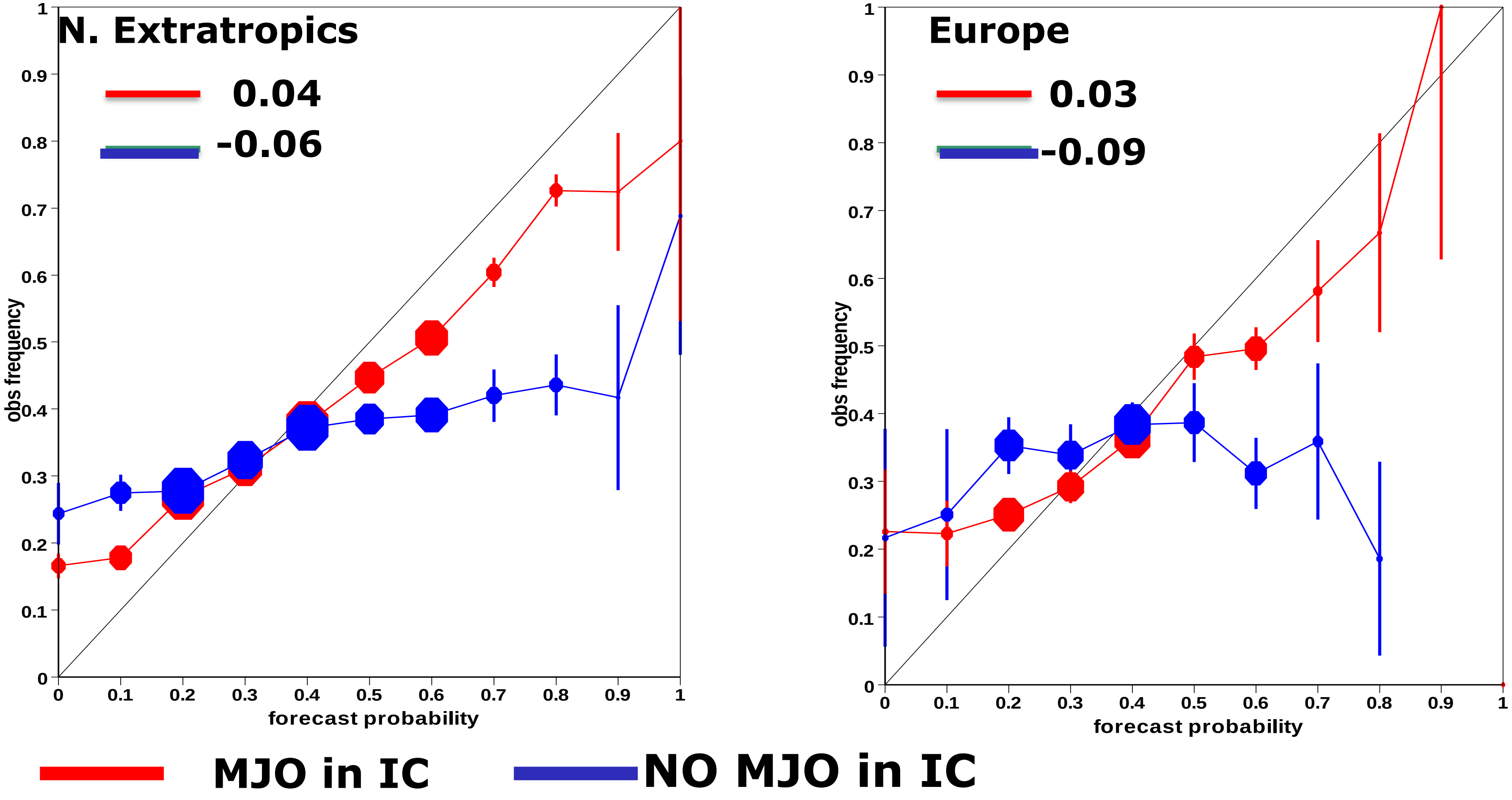
3 pentads after MJO in phase 3

EI 0.48



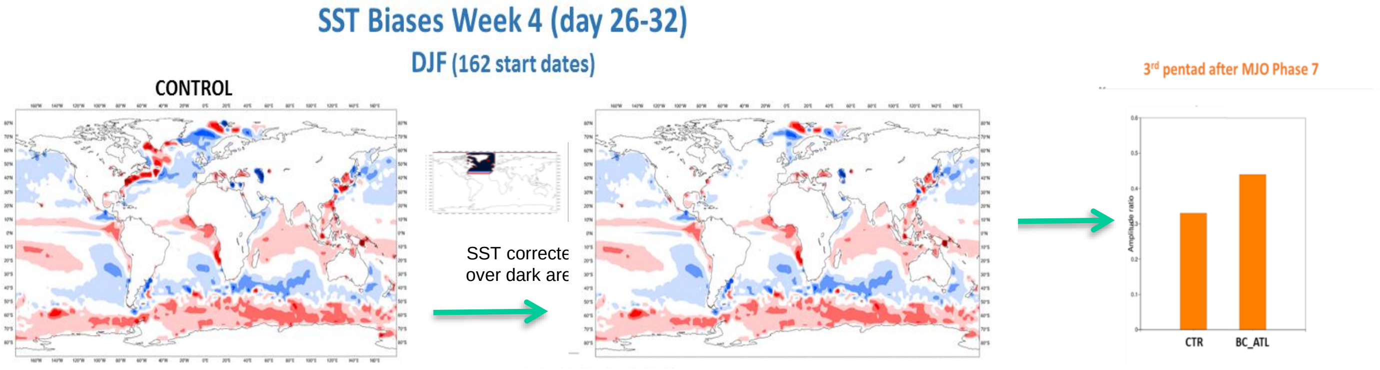
Impact of the MJO on the NAO

Reliability Diagram – NDJFMA 1989-2008
Probability of 2-m temperature in the upper tercile
Day 19-25



Issues with Ocean Coupling

Non linear interactions: North Atlantic SST mean errors impact subseasonal forecast skill



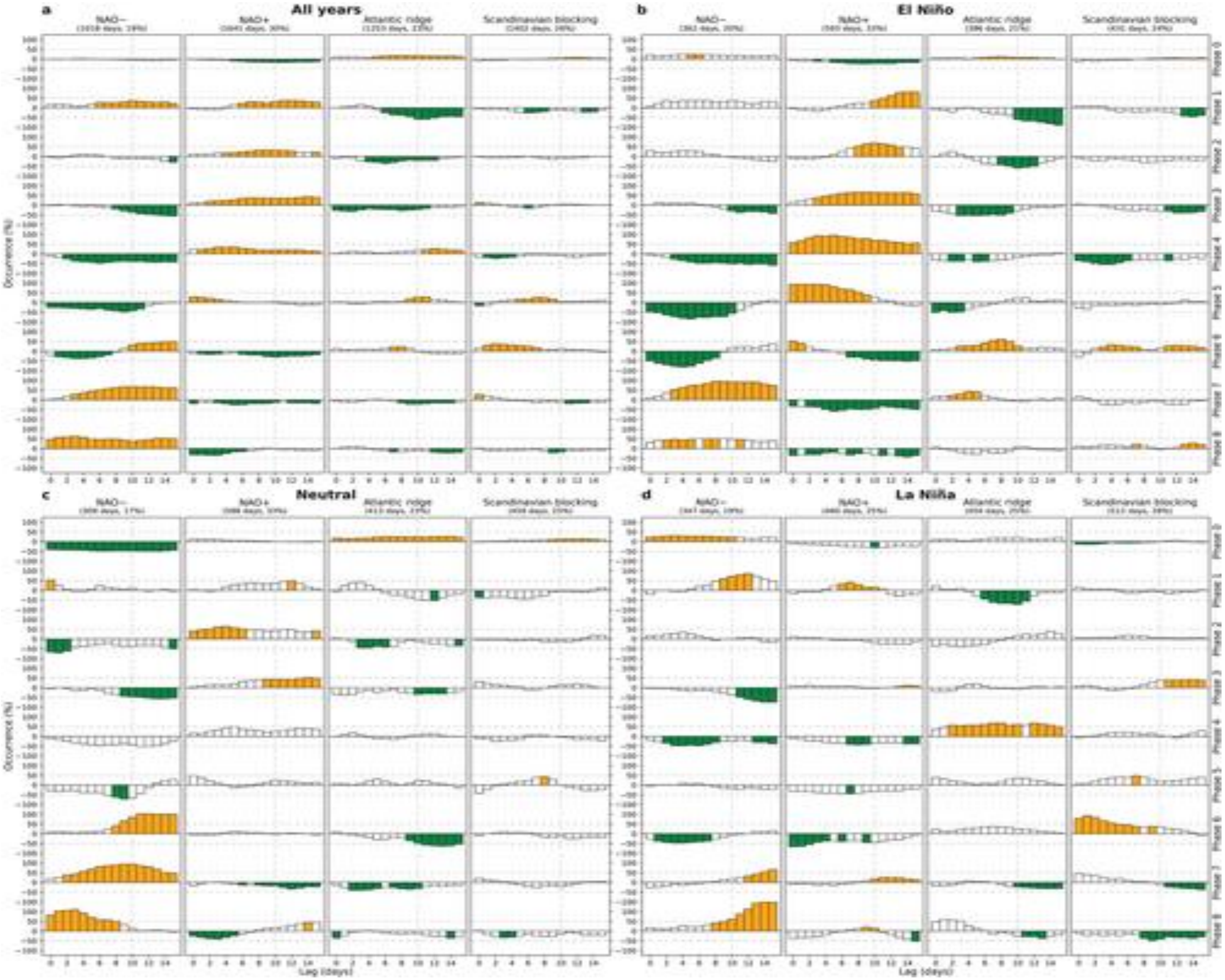
Correcting bias on SST over North Atlantic impacts the skill over Europe by improving MJO/ NAO teleconnections

From Vitart and Balmaseda 2018

SST biases in western Atlantic can affect MJO teleconnection pathway

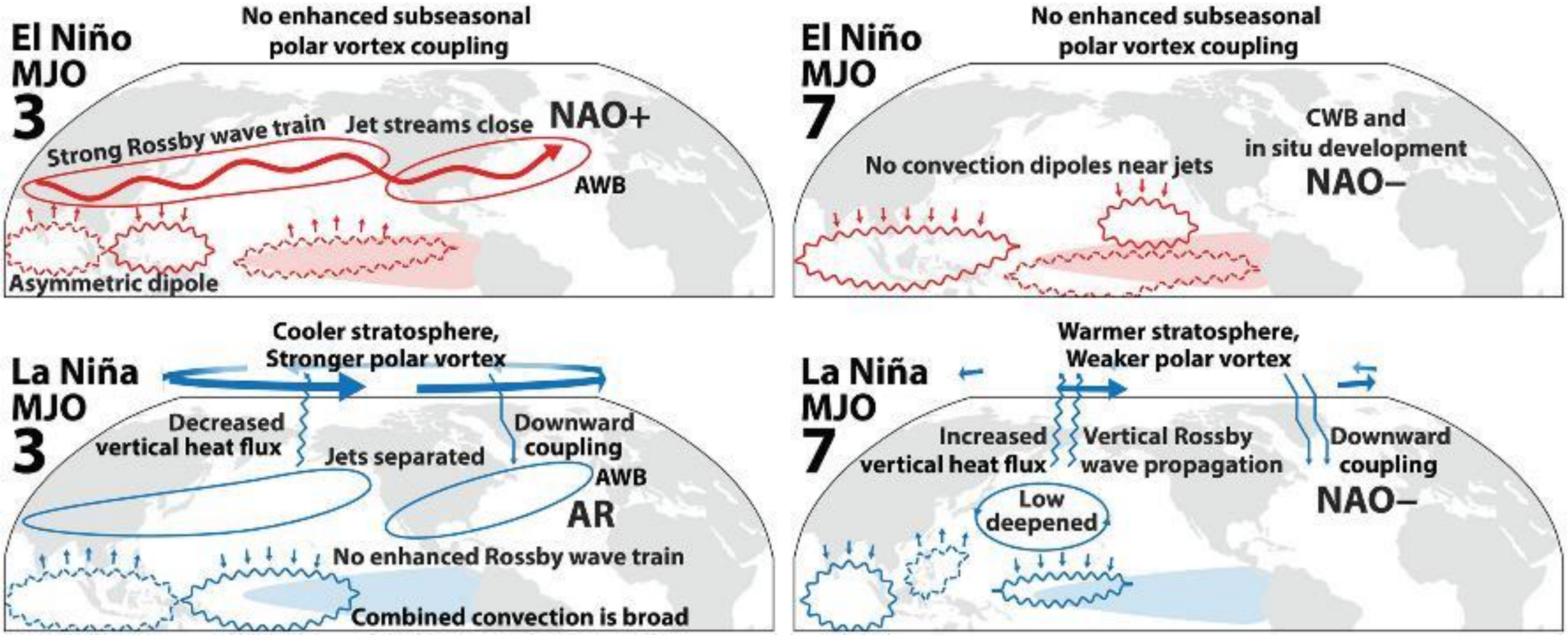
ECMWF

ENSO Modulation of MJO teleconnections



Lee et al. 2019

ENSO Modulation of MJO teleconnections



Lee et al. 2019

MJO modulation by ENSO

Forecasts underestimate the ENSO modulation of MJO-regime interactions

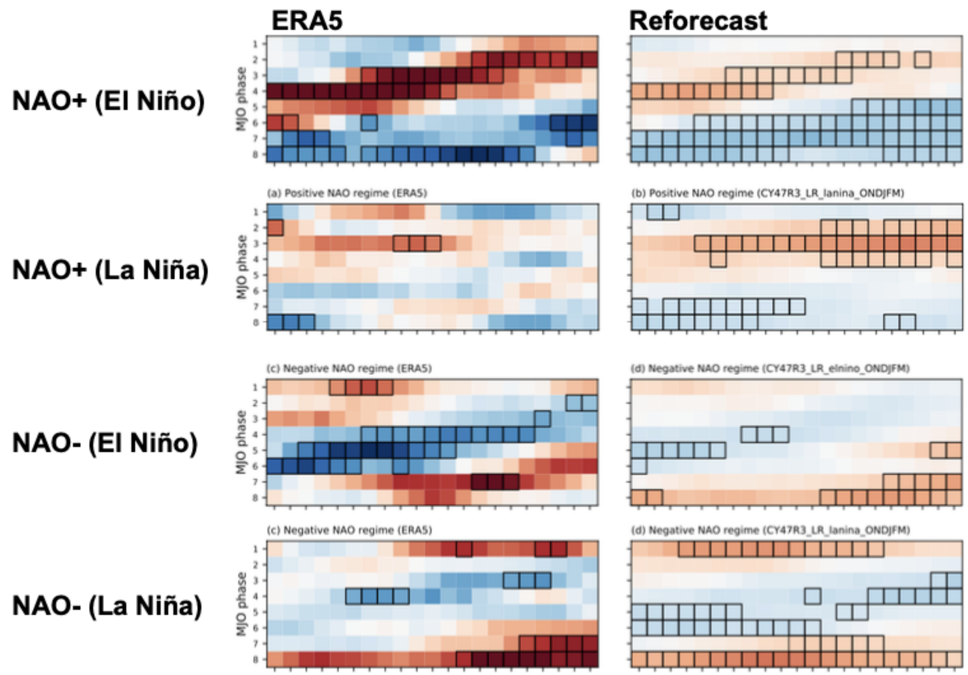
Regime frequency conditioned on ENSO and the phase of the MJO at different lags (1980-2020)

Lee et al. (2019) demonstrated that MJO-regime teleconnections depend on the ENSO background state.

1. Tropospheric teleconnection associated with increased NAO+ frequency following MJO phase 3/4 is stronger during El Niño years but suppressed during La Nina.

2. NAO- events following MJO phase 7/8 occurs later in the MJO phase cycle during La Niña years due to an enhanced stratospheric teleconnection pathway mediated by variations in the strength of the polar vortex.

3. Reforecasts do not reproduce this modulation.



Roberts et al. 2023

Conclusions

- MJO is the main source of tropical variability between a week and a season
- Global Impact of the MJO including over Europe. Main source of sub-seasonal predictability.
- MJO prediction: success story – Significant improvement in the prediction of MJO over the past decade. Operational systems show predictive skill up to week 4
- Importance of SST coupling, although not crucial
- Extratropics can also impact MJO
- MJO activity is modulated by ENSO and QBO

Future Perspectives

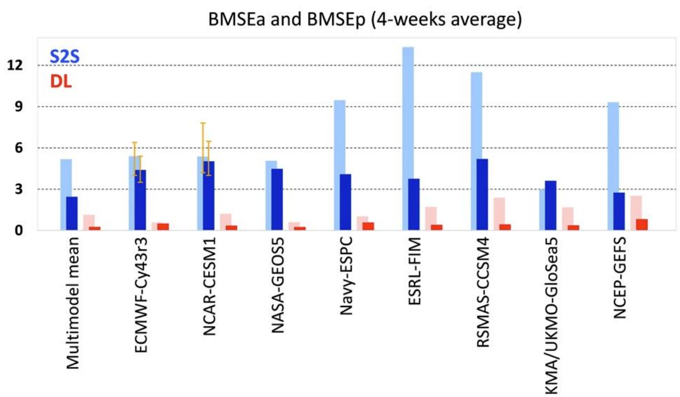
- Coupled data assimilation might help improve MJO initialization

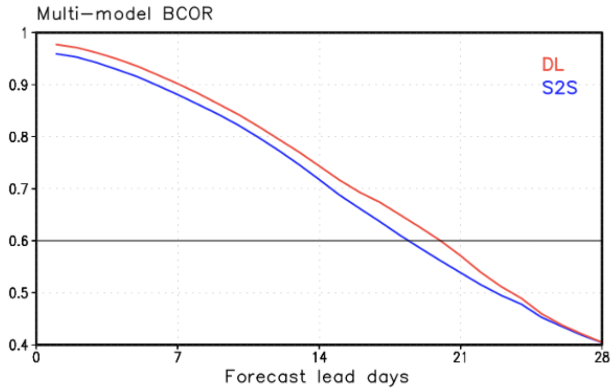
- Km-scale resolutions might be an opportunity to improve MJO prediction by removing some errors associated with convective parameterization.

- Machine learning brings opportunities to reduce model errors in the representation of the MJO and possibly produce more skillful MJO forecasts.

Machine Learning for MJO prediction

1. Deep learning methods to correct model outputs (e.g. Kim et al., 2021 Nature Communications).





ML methods replacing GCMs
(e.g. Silini et al., 2021)

Use of two artificial neural networks (ANNs) to predict the MJO