Complexity in sub-seasonal prediction

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European Centre for Medium-Range Weather Forecasts

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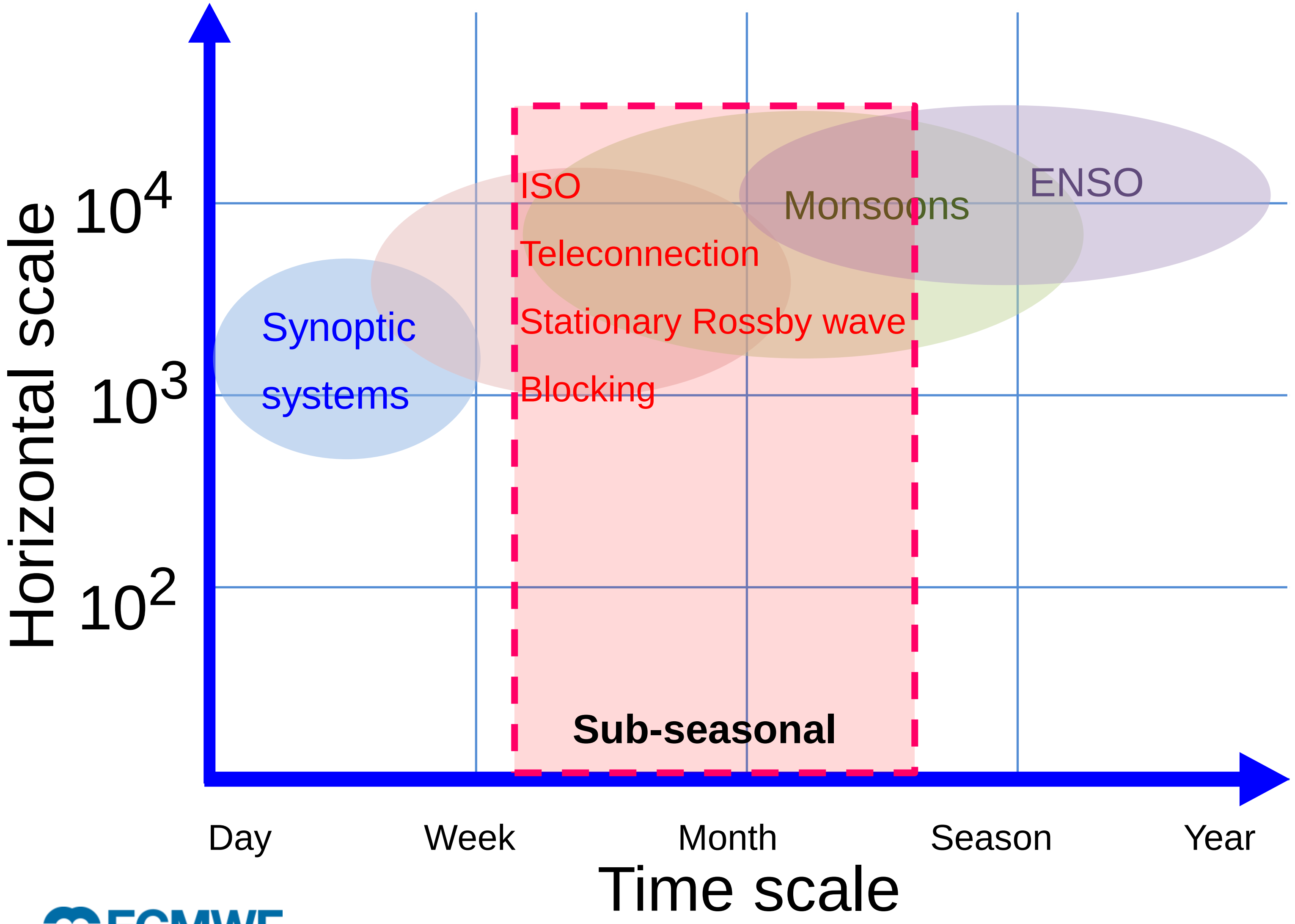
Sub-seasonal time range



ECMWF

Sub-seasonal prediction

- Bridges the gap between weather and climate forecasting.

- First attempts of sub-seasonal forecasting started in the 1980s (Miyakoda, Molteni..)

- A particularly difficult time range:

Is it an **atmospheric initial condition problem** as medium-range forecasting or is it a **boundary condition problem** as seasonal forecasting? Is it a “Predictability Desert” ?

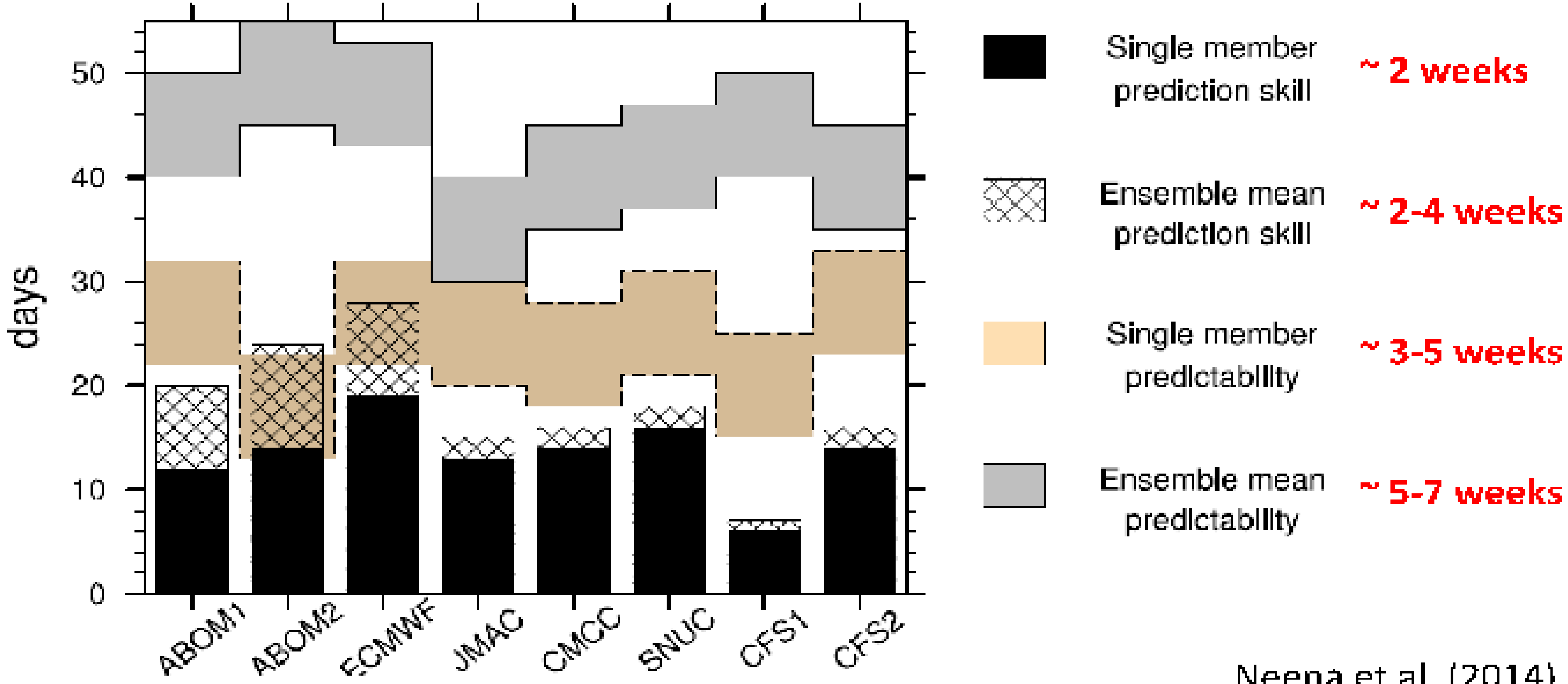
Sources of sub-seasonal predictability

- Madden-Julian Oscillation
- Extra-tropical modes (weather regimes: blockings, NAO, PNA, SAM..)
- Sudden Stratospheric Warming
- Quasi-Biennal Oscillation
- ENSO
- Slowing varying processes: Soil moisture/vegetation, snow, sea ice, ocean SSTs/heat content
- Chemistry: Ozone, aerorols…
- Others?

Sub-seasonal skill is strongly flow-dependent

1st Challenge: Predicting the predictors

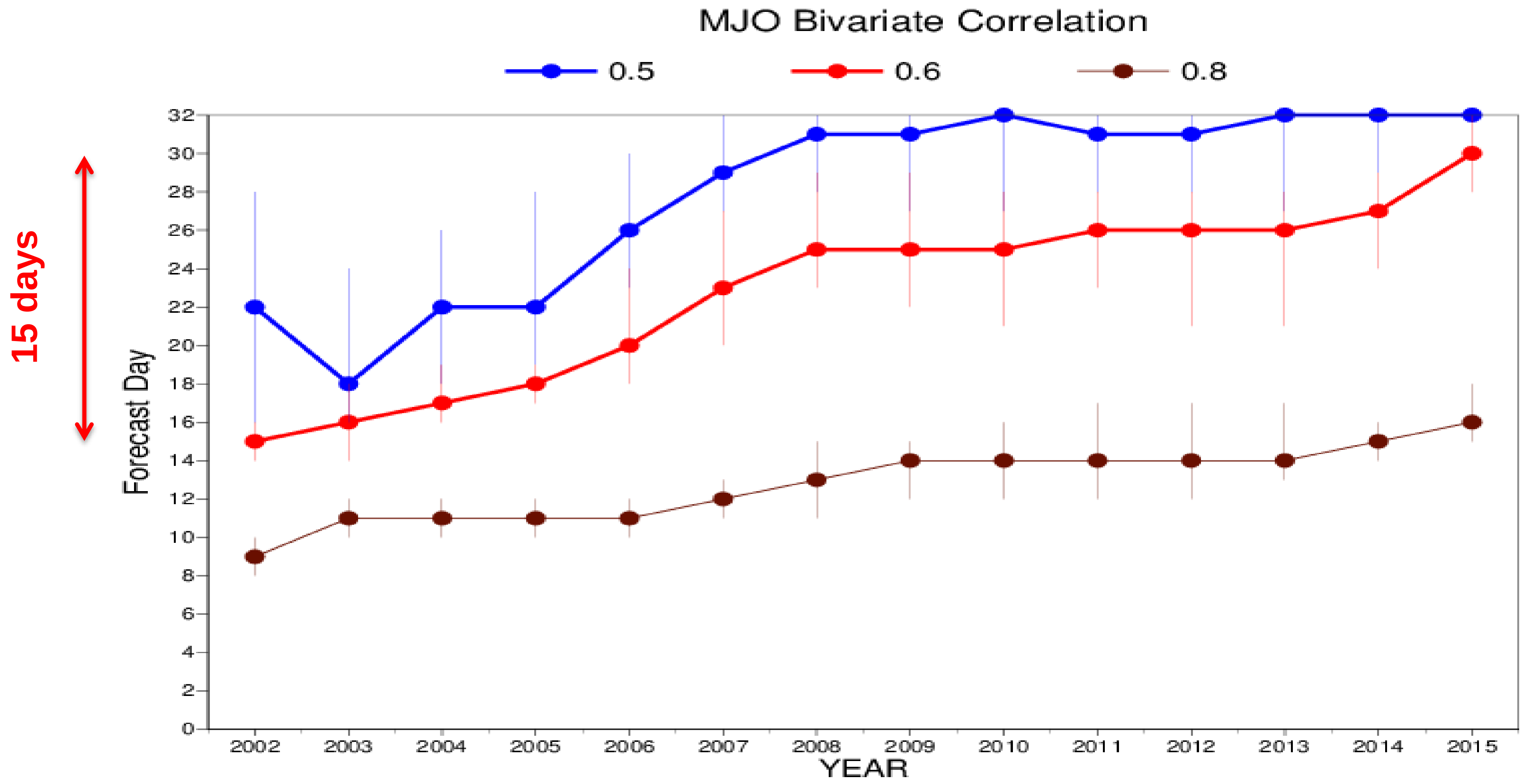
Capability of MJO forecast



Neena et al. (2014)

* ISVHE (Intraseasonal Variability Hindcast Experiment)

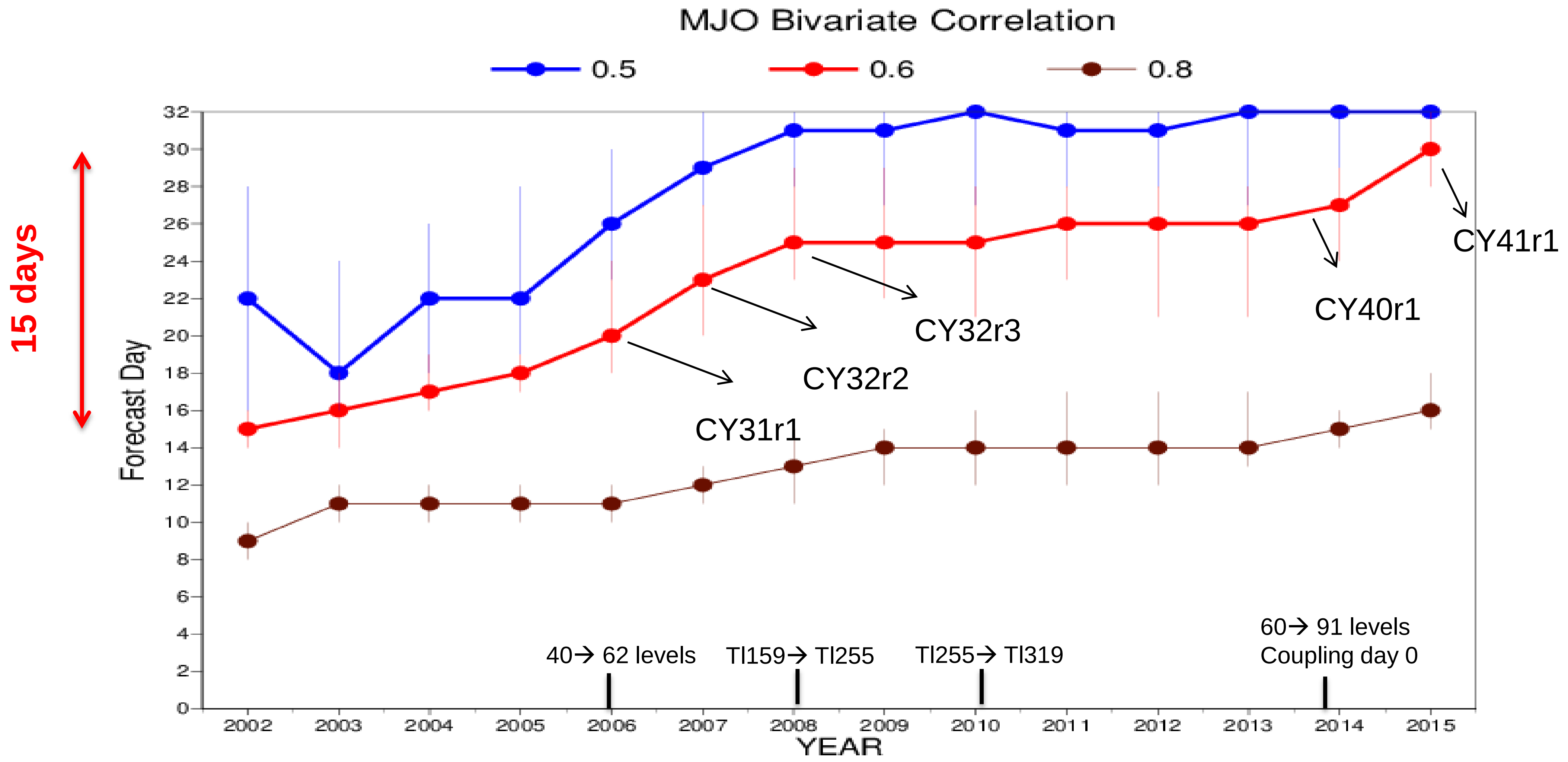
Madden Julian Oscillation prediction at ECMWF



Wheeler and Hendon (2003) Index

Re-forecast period 1995-2001

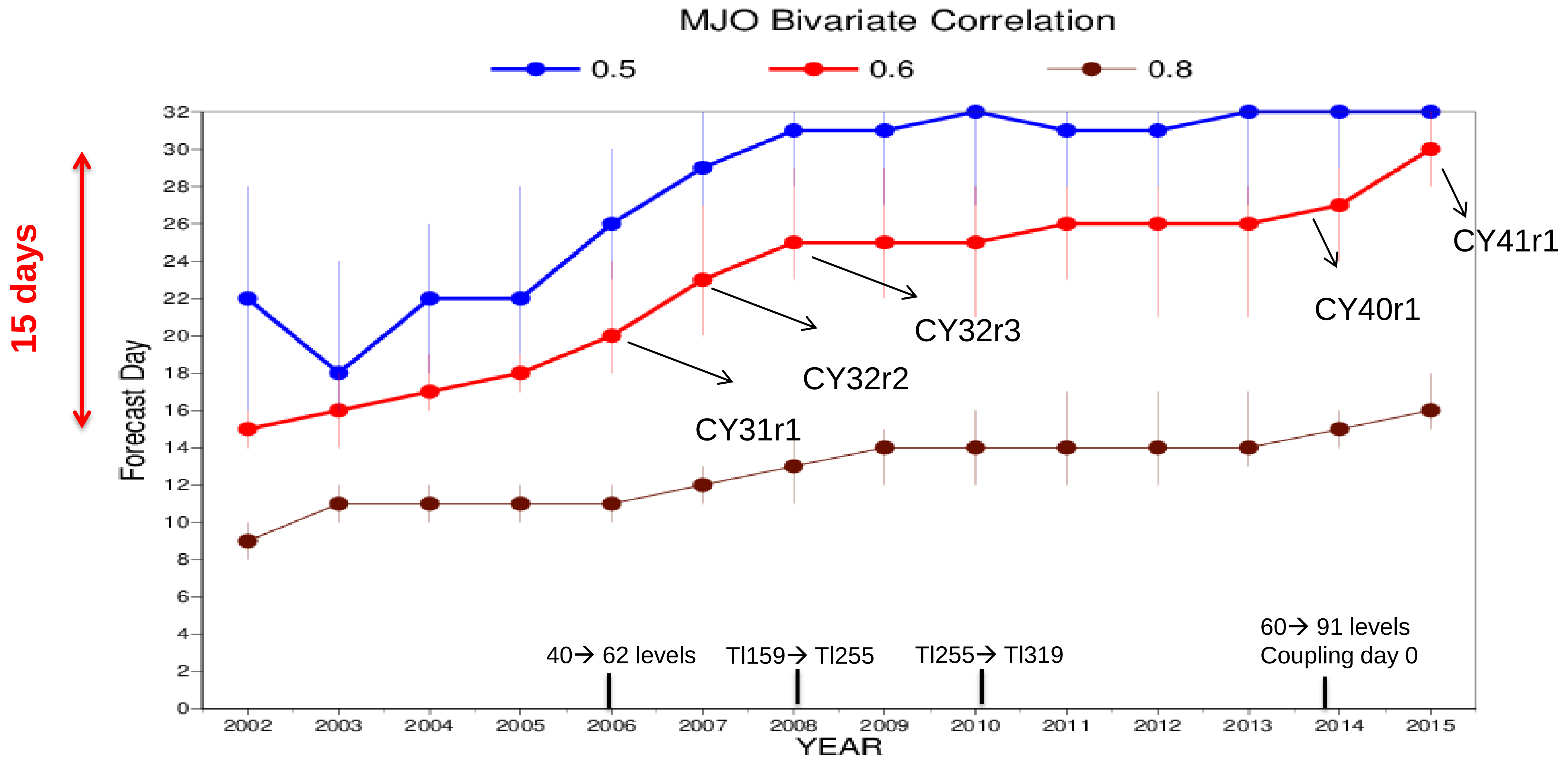
Madden Julian Oscillation prediction at ECMWF



Wheeler and Hendon (2003) Index

CY31R1: Parameterisation of ice supersaturation
CY32R2: McRAD (radiation scheme)
CY32R3: Changes in convective scheme (Bechtold at al. 2008)
CY40R1: Improved diurnal cycle of precipitation
CY41R1: revised organized convective detrainment and the revised convective momentum transport. …

Madden Julian Oscillation prediction at ECMWF



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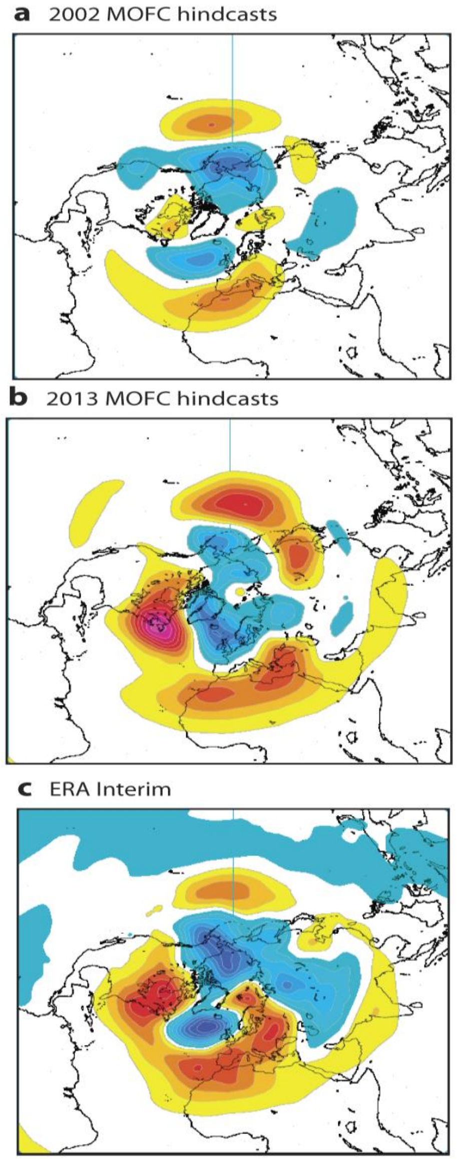
Wheeler and Hendon (2003) Index

Improvements in MJO Prediction mostly due to changes in convective parameterization

2nd Challenge: Predict the impact of predictors

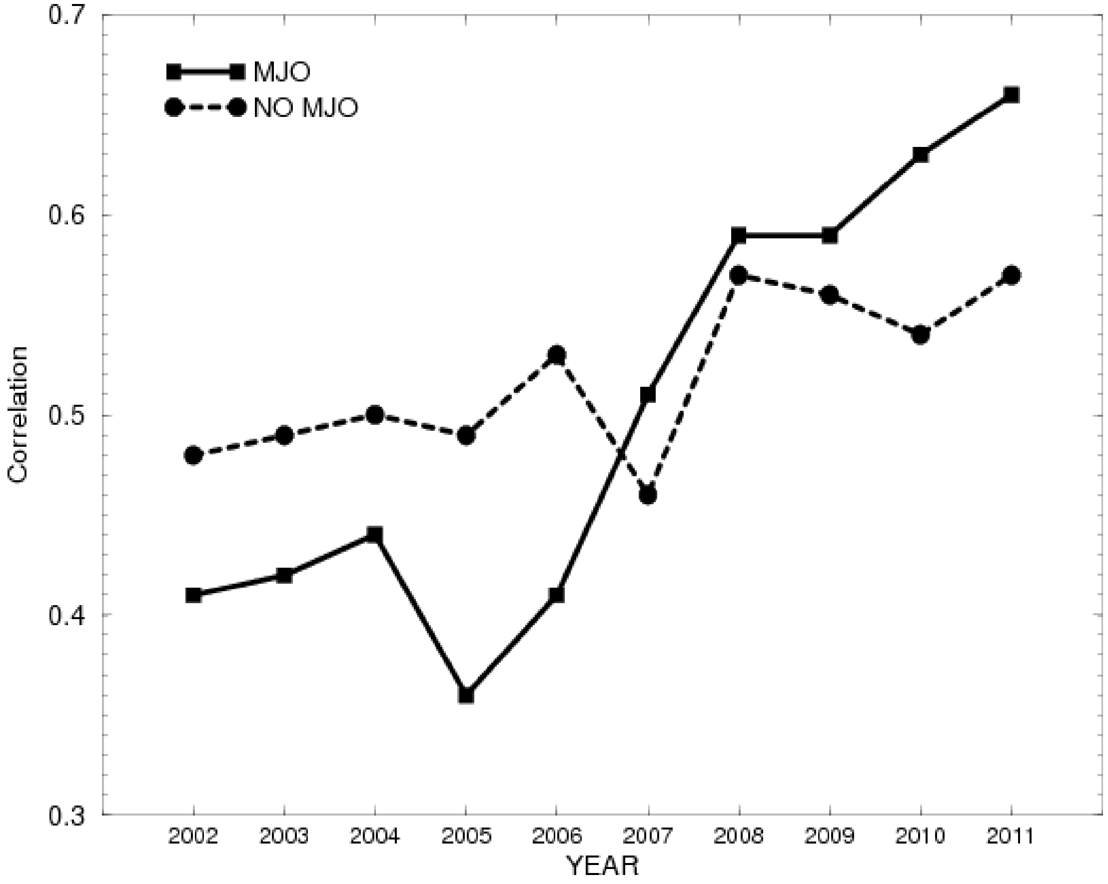
Z500 anomalies
10 days after an MJO in Phase 3



MJO teleconnections

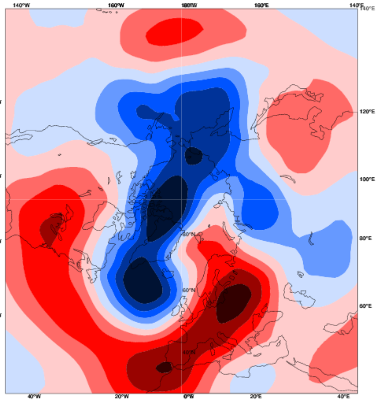
Evolution of NAO skill scores-Day 19-25

NAO Index: projection of Z500 on pre-computed EOF



Vitart, 2014

EI 0.48



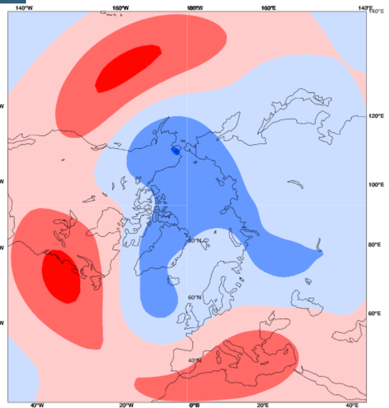
MJO Teleconnections (S2S re-forecasts)

Subseasonal-to-Seasonal S2S Prediction Project

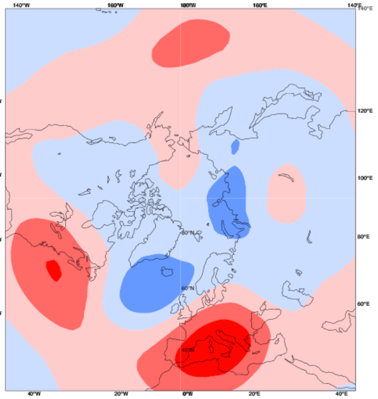
Phase 3 + 3 pentads NDJFM

<-40m | -40..-30 | -30..-20 | -20..-10 | -10.. 0 | 0.. 10 | 10.. 20 | 20.. 30 | 30.. 40 | > 40m

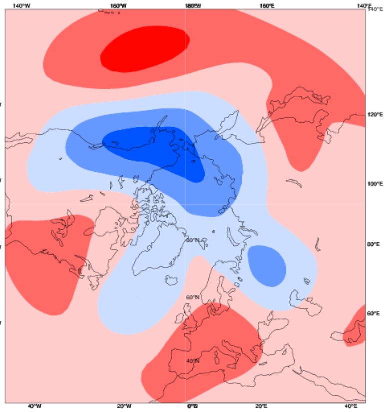
BoM 0.15



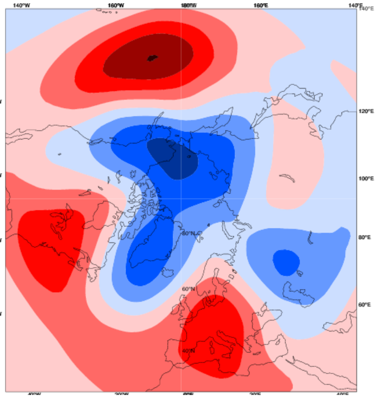
CMA 0.14



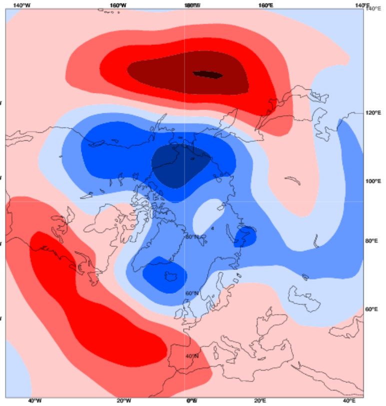
HMCR 0.13



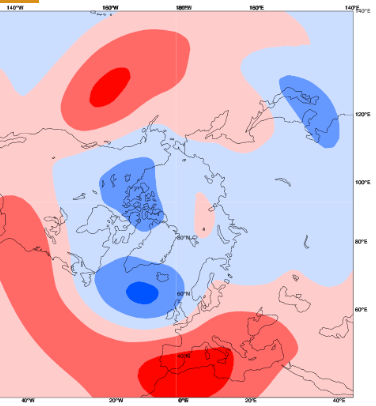
NCEP 0.32



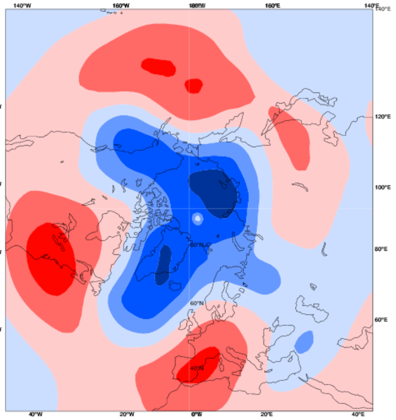
ISAC 0.25



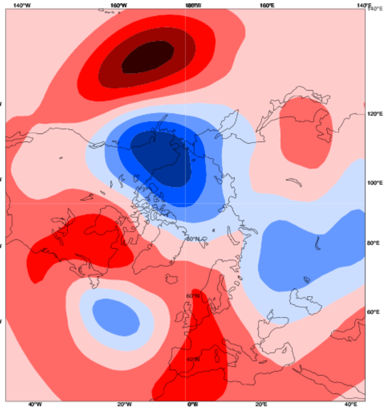
CNRM 0.15



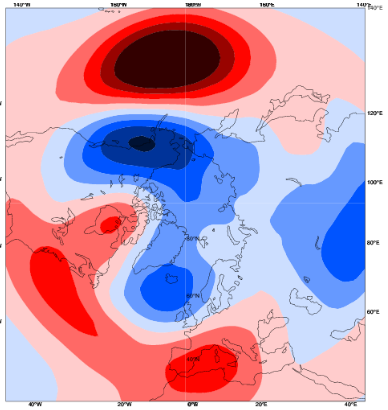
UKMO 0.28



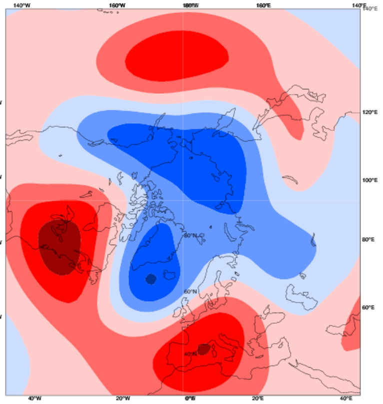
JMA 0.22



ECCC 0.21



ECMWF 0.31



Adding complexity improves sub-seasonal skill scores?

- Could add new sources of predictability

- Could impact sources of predictability and/or their teleconnections

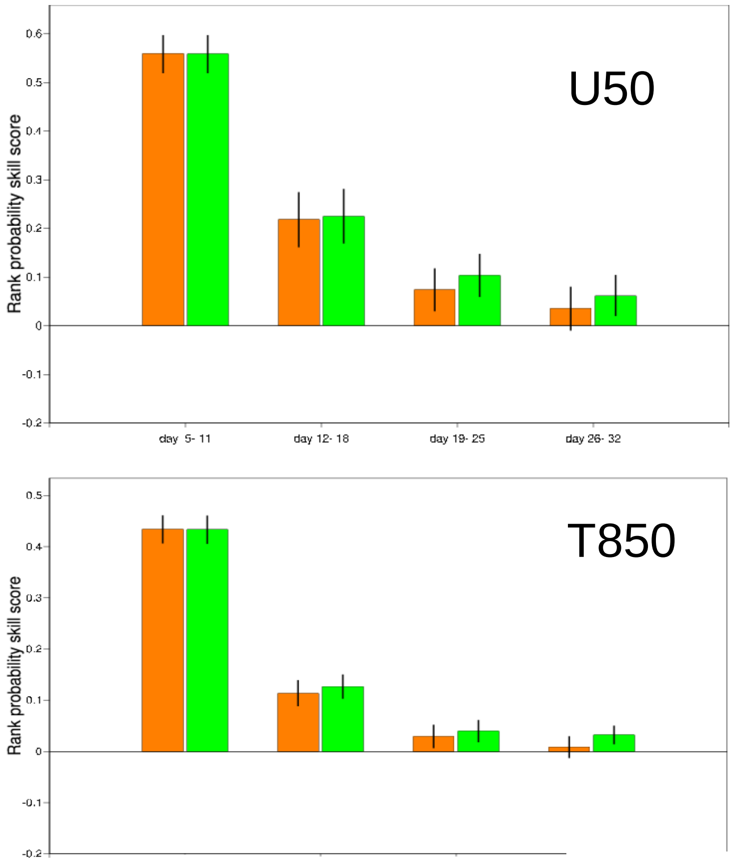
Ocean Model

Complexity in WWRP/WCRP S2S database models

Models	Time-range	Freq.	Resolution	Vert levels.	Ocean coupling	Active Sea Ice
ECMWF	D 0-46	2/week	0.3/0.3	91	**YES**	**Planned**
UKMO	D 0-60	daily	0.5/0.5	85	**YES**	**YES**
NCEP	D 0-44	4/daily	1/1	64	**YES**	**YES**
ECCC	D 0-35	weekly	0.45/0.45	40	NO	NO
BoM	D 0-60	2/weekly	2/2	17	**YES**	**Planned**
JMA	D 0-34	weekly	0.5/0.5	60	NO	NO
KMA	D 0-60	daily	0.5/0.5	85	**YES**	**YES**
CMA	D 0-45	daily	1/1	40	**YES**	**YES**
CNRM	D 0-60	weekly	0.7/0.7	91	**YES**	**YES**
ISA-CNR	D 0-32	weekly	0.8/0.6	54	**YES**	NO
HMCR	D 0-63	weekly	1.1/1.4	28	NO	NO

Impact of ocean/atmosphere coupling

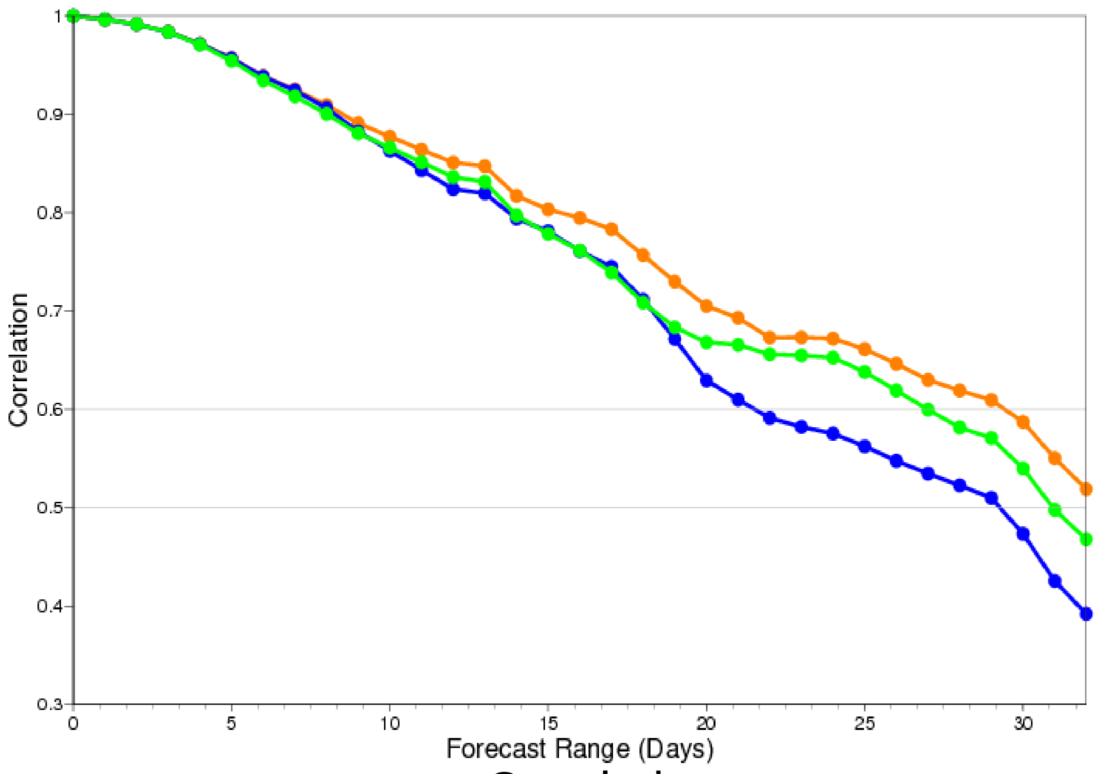
RPSS over NH



WEEK1 WEEK2 WEEK3 WEEK4

Obs SSTs Coupled

MJO Bivariate Correlation



Coupled

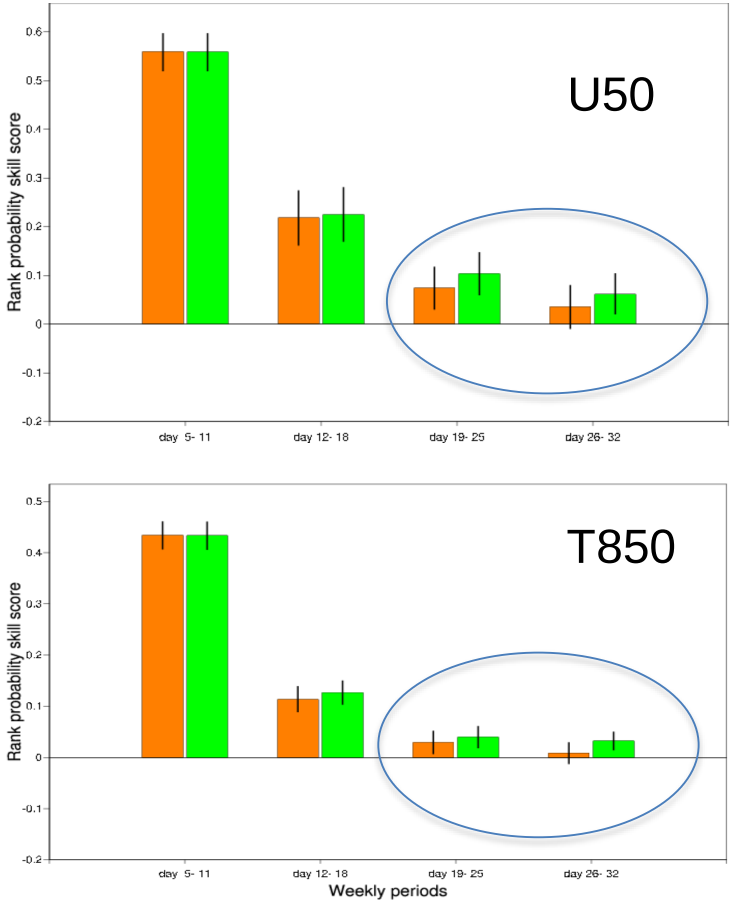
Obs SSTs

Pers SSTs

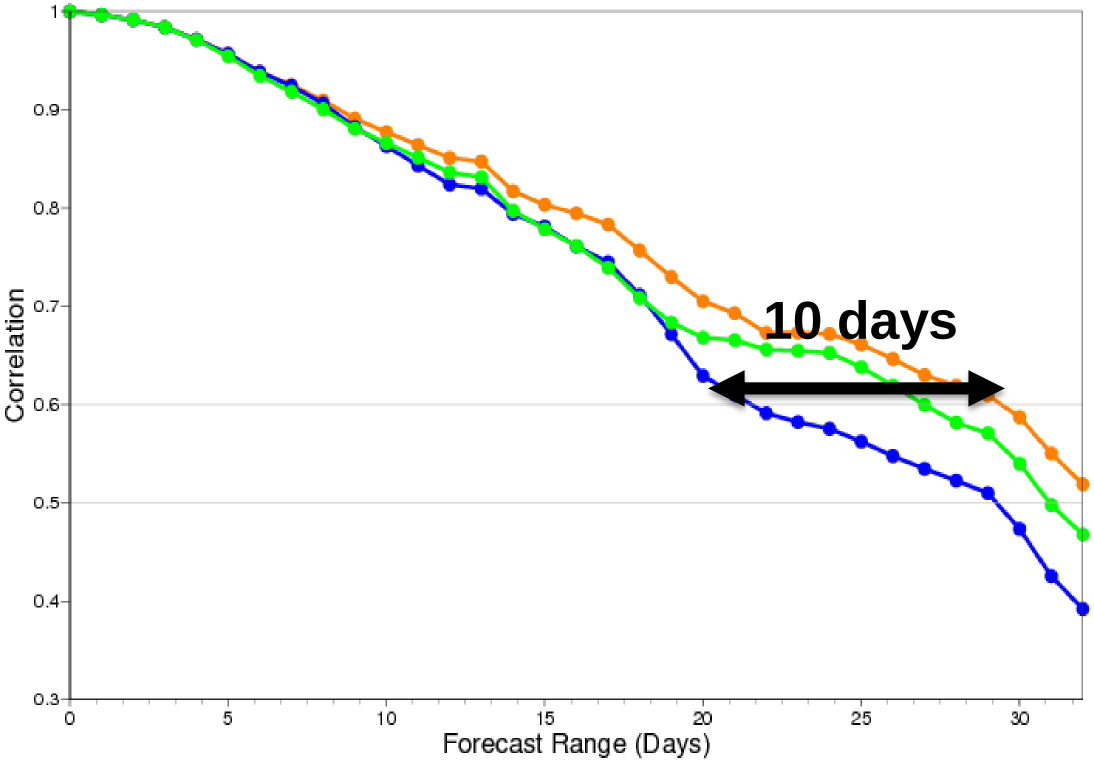
80 case, starting on 1st Feb/May/Aug/Nov 1989-2008

Impact of ocean/atmosphere coupling

RPSS over NH



MJO Bivariate Correlation



Coupled

Obs SSTs

Pers SSTs

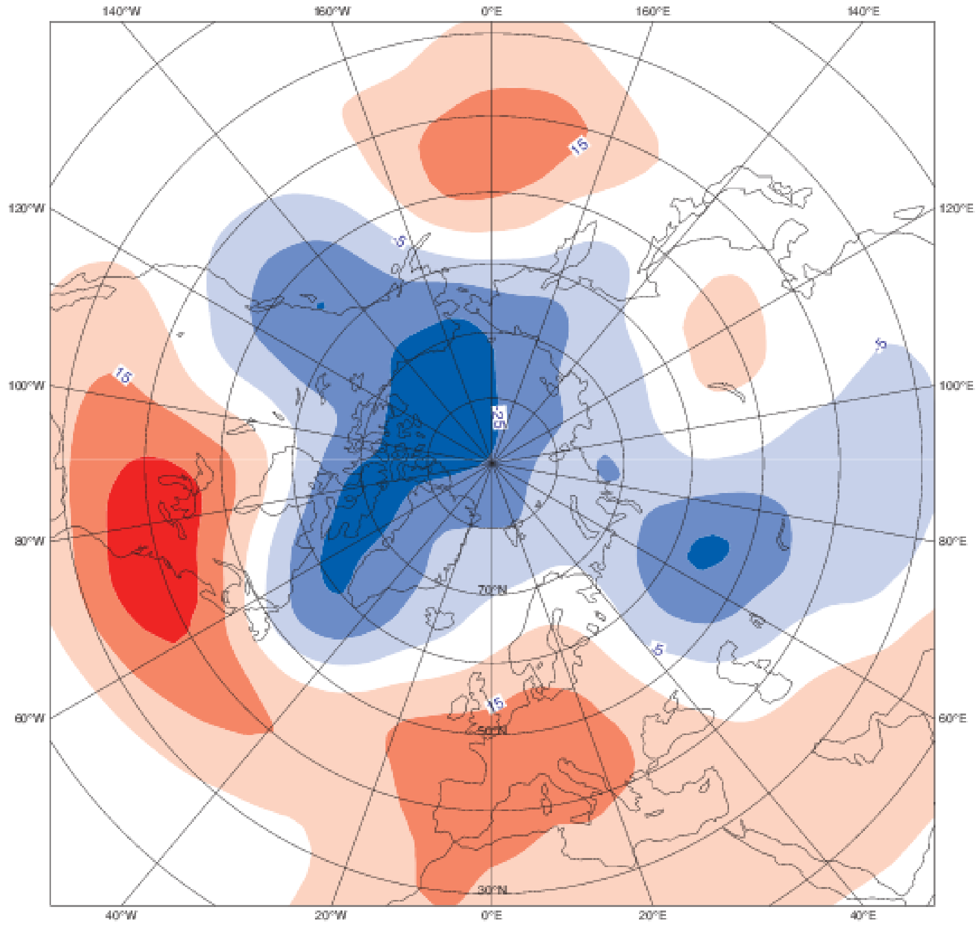
WEEK1 WEEK2 WEEK3 WEEK4

Obs SSTs Coupled

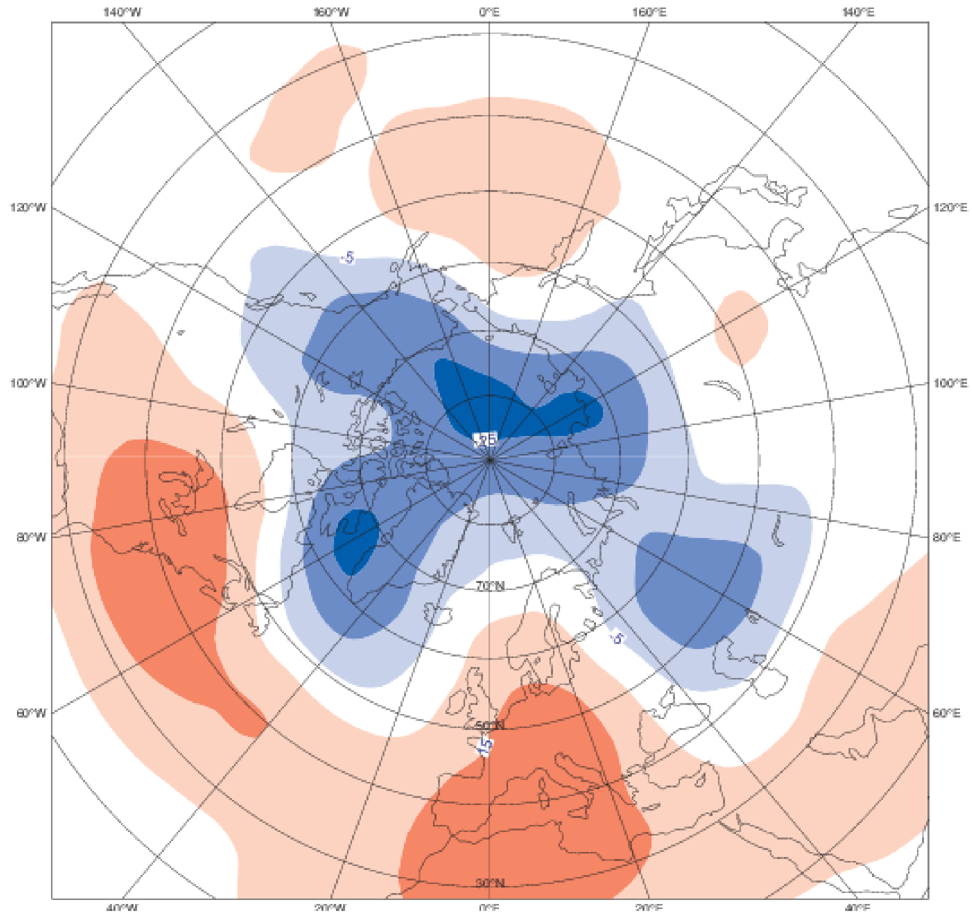
80 case, starting on 1st Feb/May/Aug/Nov 1989-2008

Z500 Composites 3rd pentad after an MJO in phase 3

Persisted SSTs



Coupled

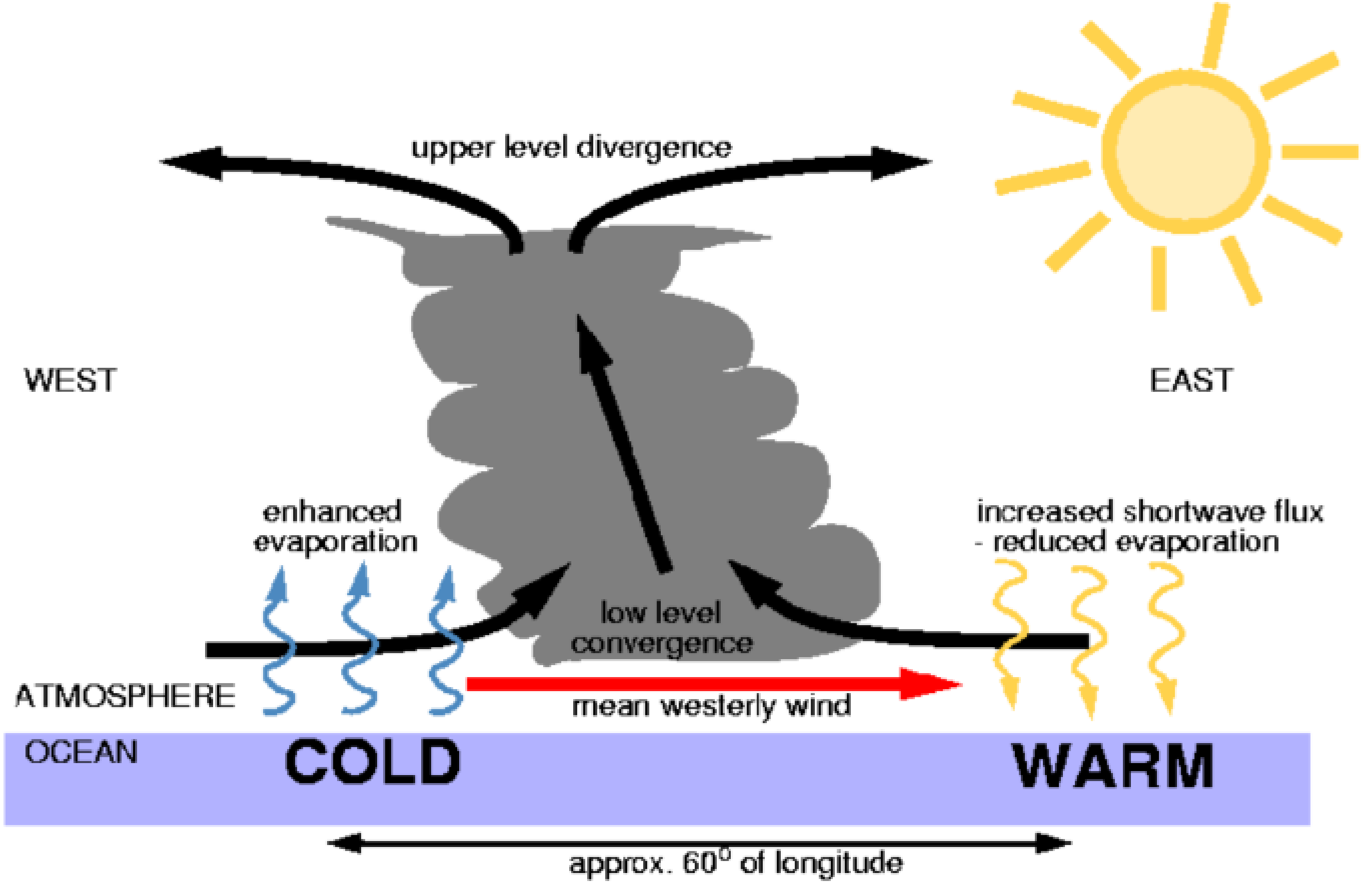


Which ocean configuration is needed?

- 1D mixed layer model or 3D OGCM?
- Which ocean vertical resolution is needed?
- Which ocean horizontal resolution?

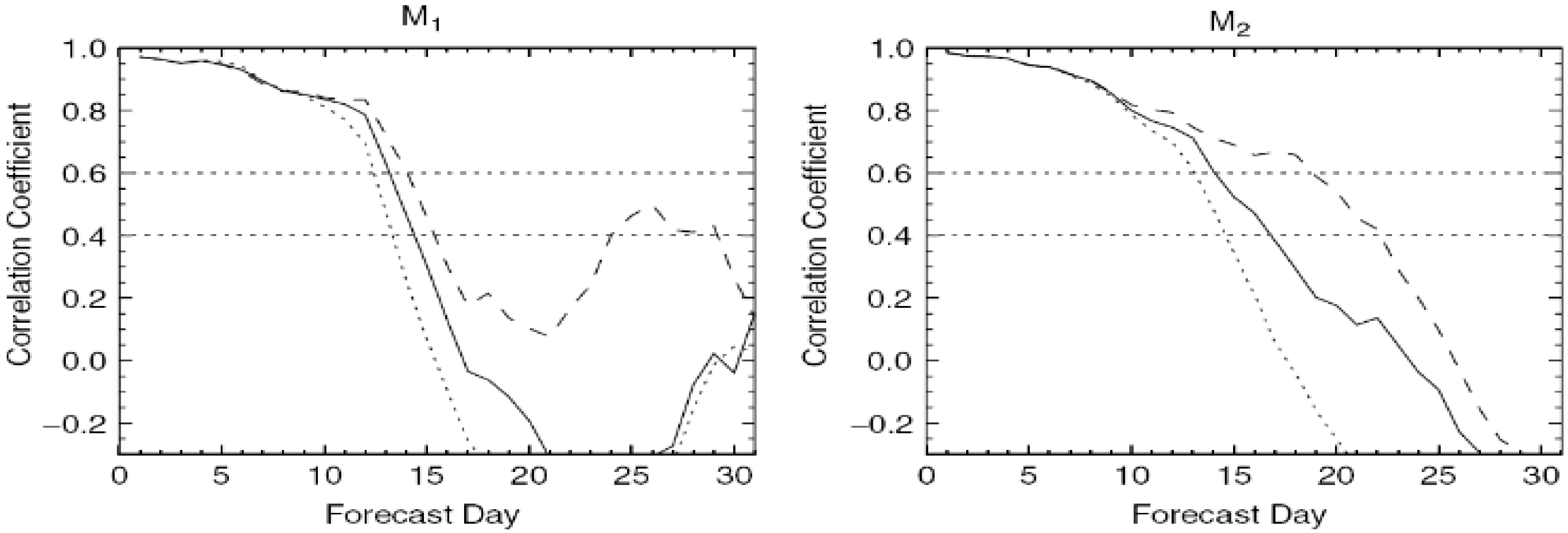
Air-sea Interaction

Air-sea interaction and the MJO



Courtesy: Pete Inness

Improvement of MJO Skill with Ocean Coupling



CONT : solid line
ML : dashed line
PERS : dotted line

Woolnough et al. (2007,QJRMS)

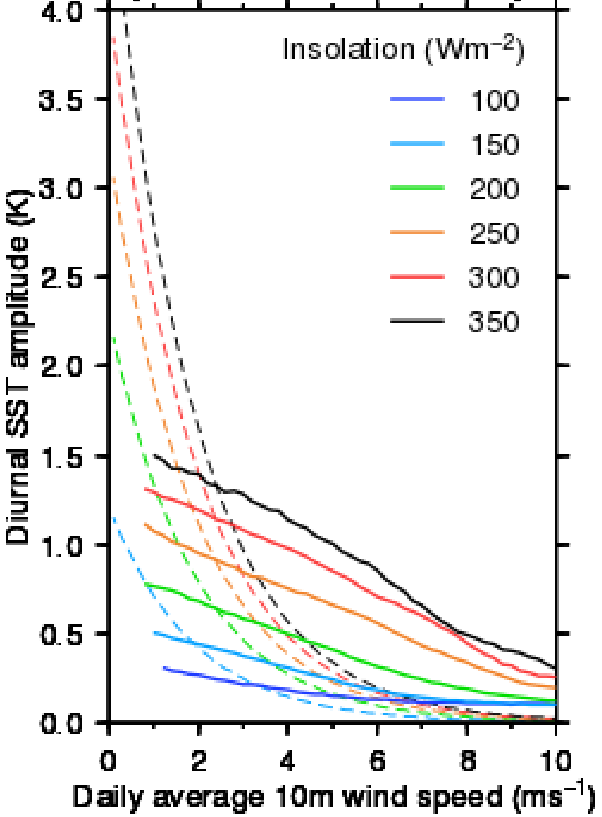
- Stronger impact with KPP model (1 metre vertical resolution) than with OGCM (10m) because of stronger and more realistic diurnal cycle of SSTs (Woolnough et al. 2007)
- The same experiment was repeated a few years later by E. De Boisseson. There was no significant difference in MJO skill scores between the KPP and OGCM coupling

Skin SST Scheme
(Zheng and Beljaars, 2005, modified Takaya et al. 2010)

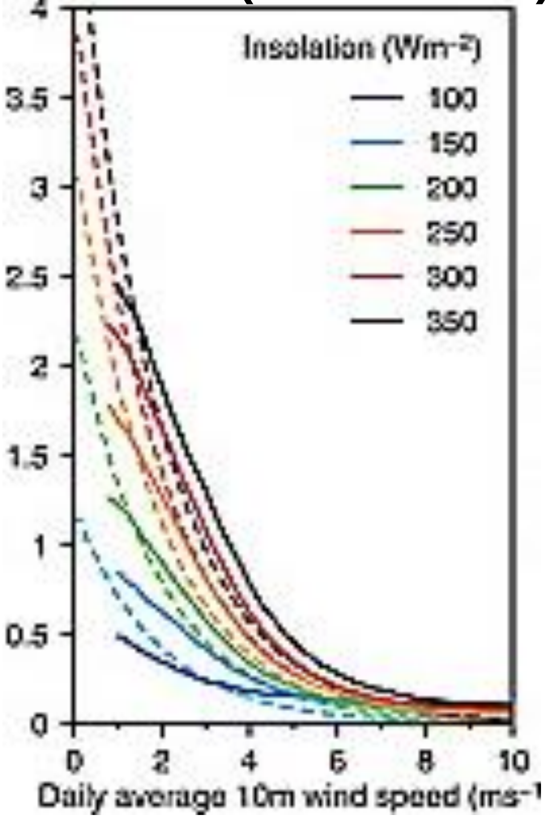
- **solves the one-dimensional heat transfer equation in the near-surface layer.**

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_w \frac{\partial T}{\partial z}\right) + \frac{1}{\rho_w c_w}\frac{\partial R}{\partial z},$$

Mixed-layer model
(1-metre vert. ers)



Skin SST scheme
+ OGCM (10m vert res)

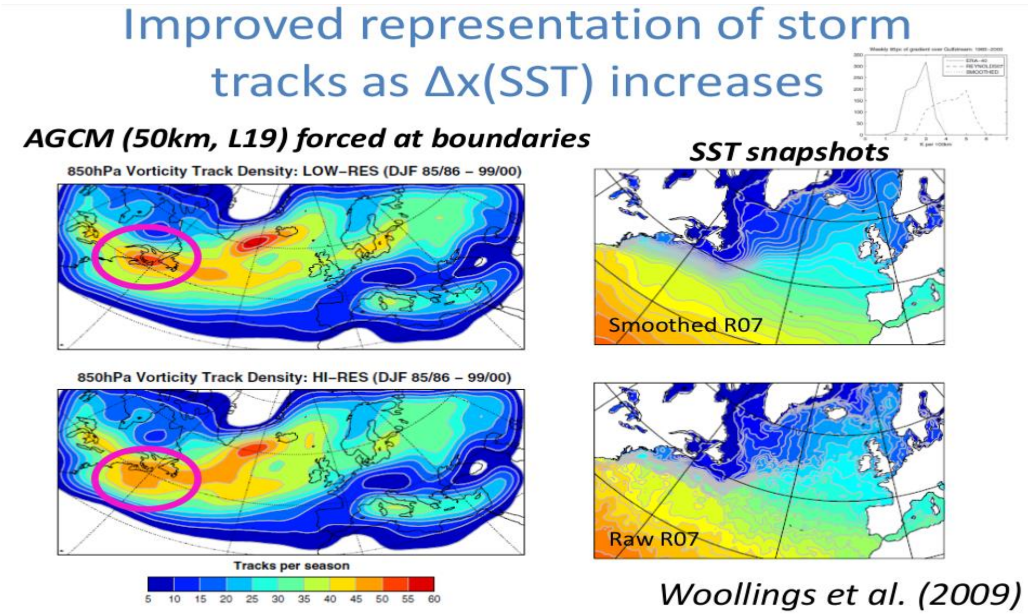


Dotted lines: Satellite estimates from Gentemann et al., 2003

Overestimation of diurnal cycle when introducing ORAC025 with 1 metre resolution?

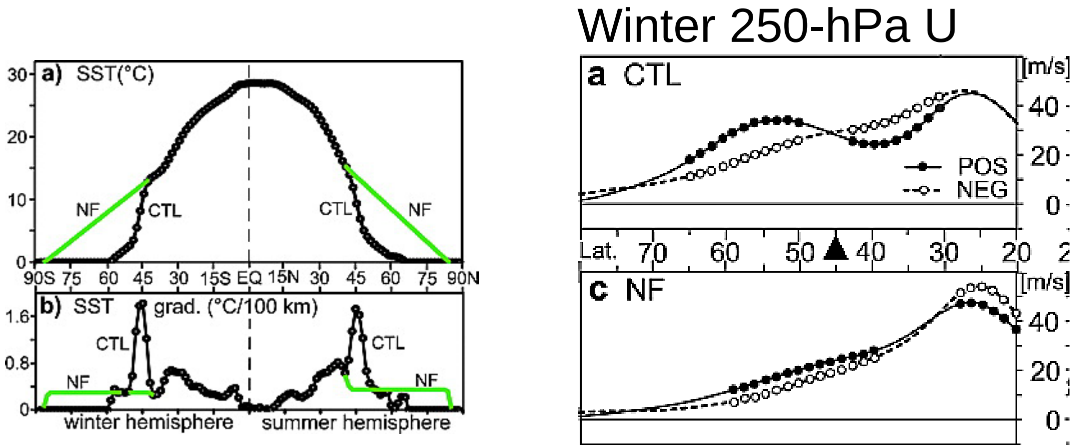
Takaya et al., 2010

Impact of increasing ocean horizontal resolution



- Impact of storm track – Possible impact on teleconnections
- SST gradient: Ocean resolution of ¼ degree sufficient?
- Problem of Gulf stream separation: Coupled model tend to move the front too much to the North. Issue with ocean parameterization or resolution?
- Publications have so far shown importance of Gulf stream separation for seasonal/climate integrations. We need to explore the impact for sub-seasonal forecasts.

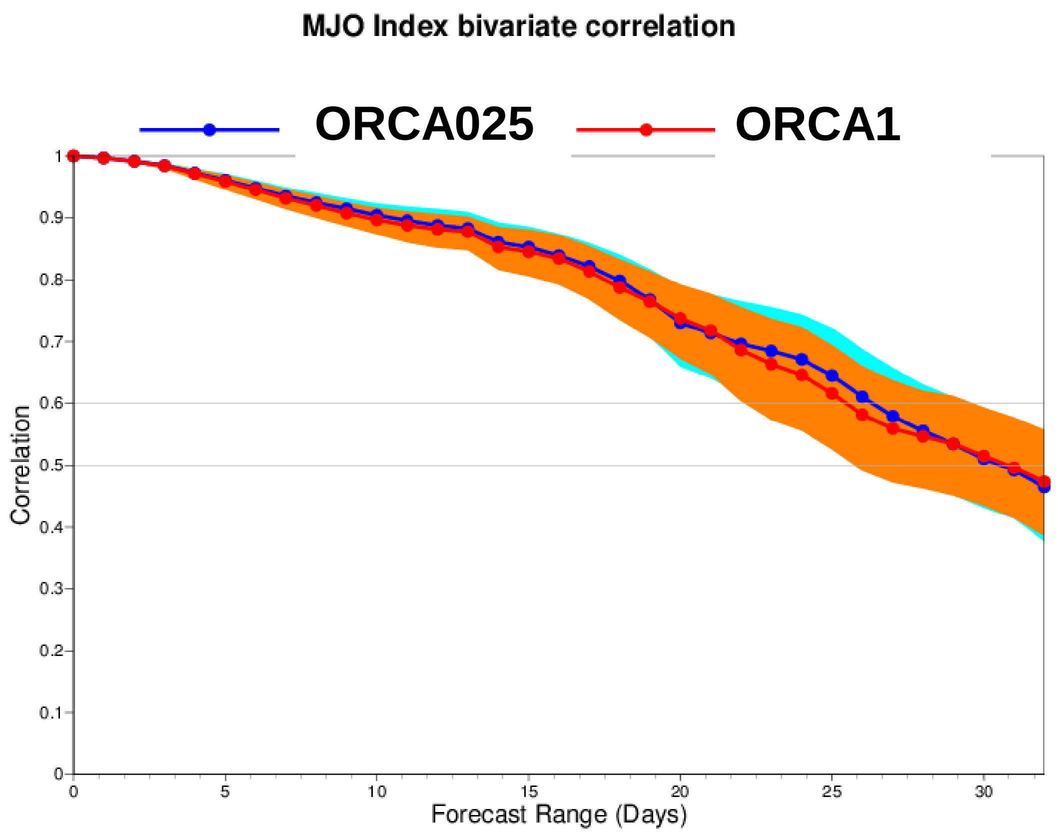
Importance of oceanic mid-latitude fronts

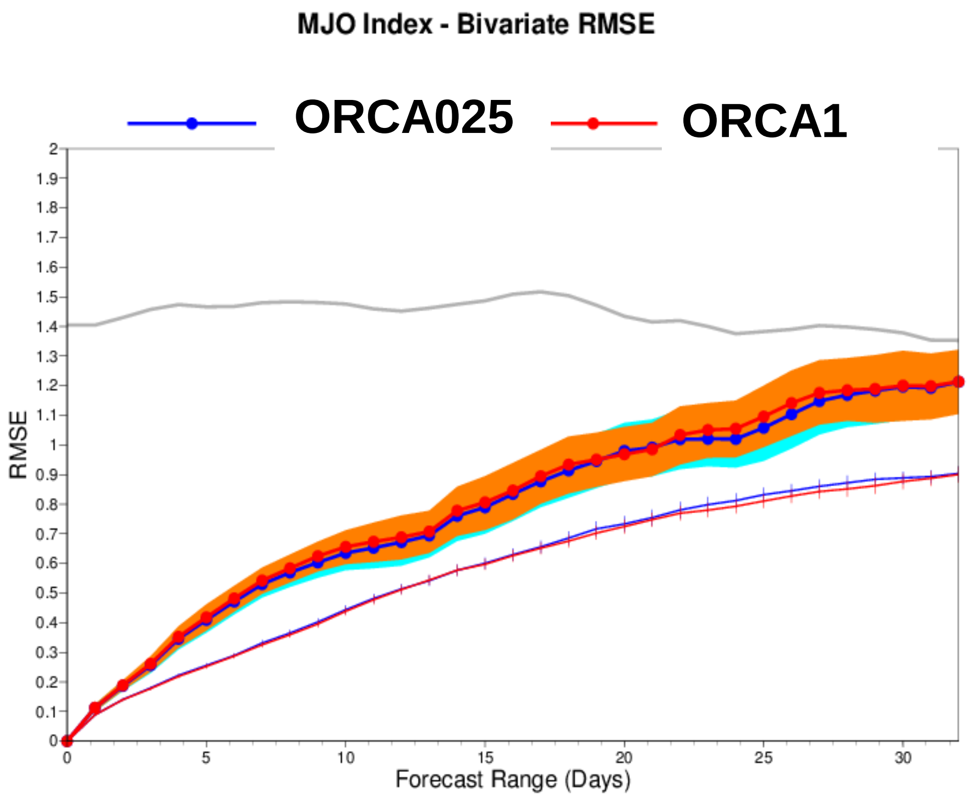


Nakamura et al. 2008

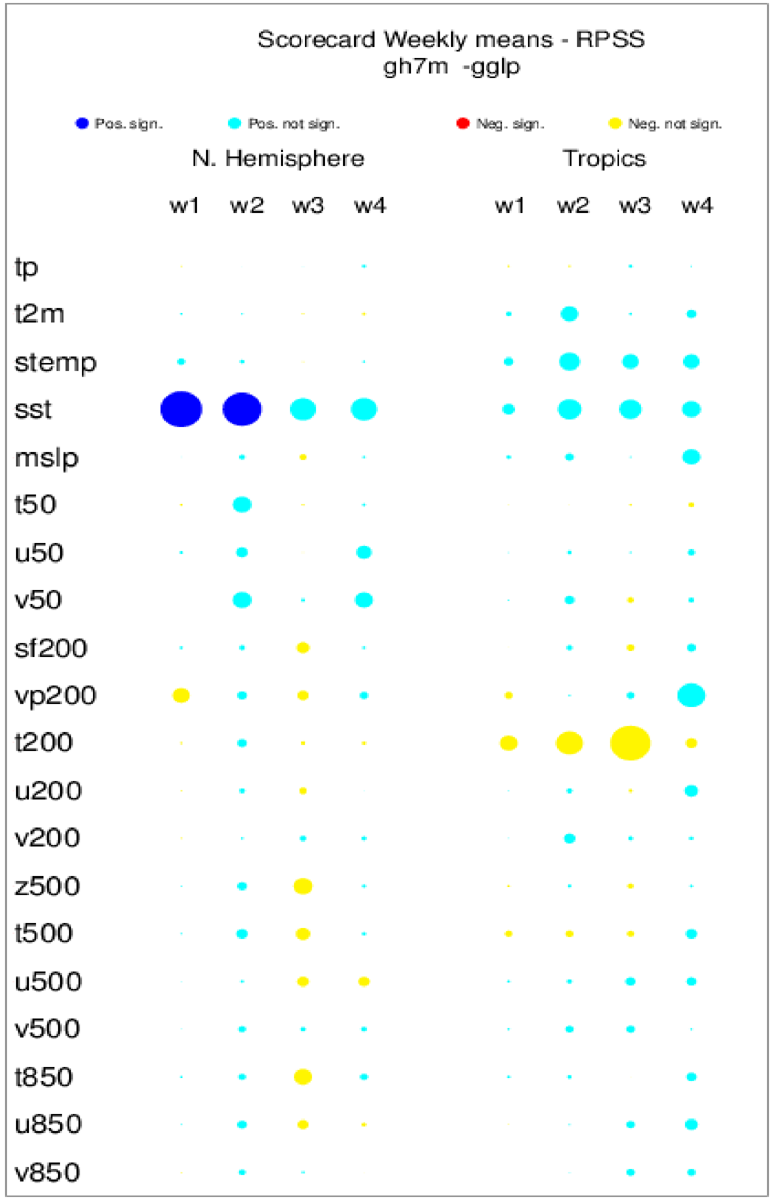
Impact of increasing ocean horizontal and vertical resolution

Impact of ¼ degree Ocean (ORCA025)





¼ degree no sea ice model – 1 degree no sea ice model (CY42R1)



Performance of increase ocean resolution.

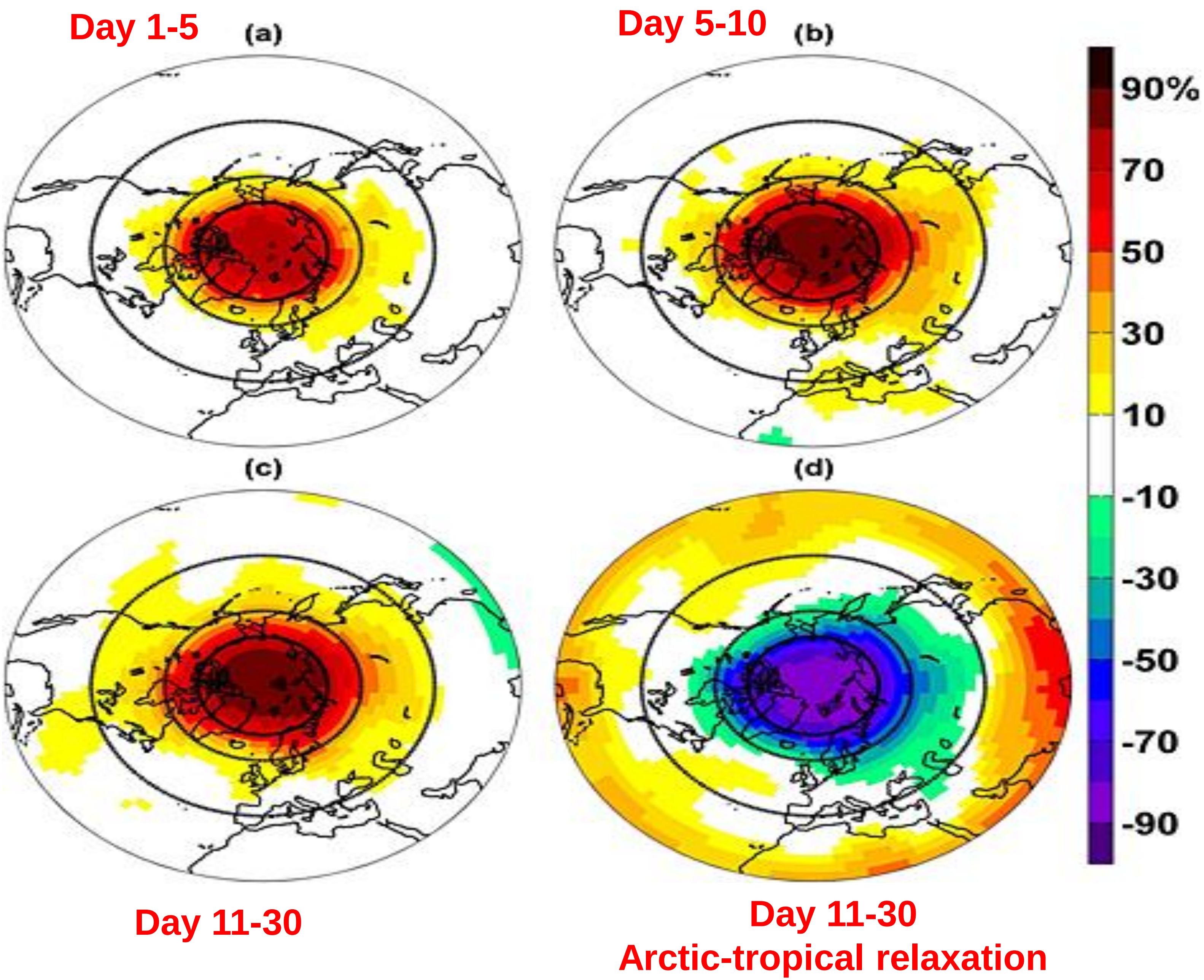
- *Blue circles indicate positive impact*
- *Dark blue circles indicate significant impact*

Results obtained show:

- Improved prediction of SSTs particularly in the N. Extratropics medium-range forecasts
- Degradation of skill scores at 200 hPa in the Tropics
- No significant impact on N. Hemisphere tropospheric skill scores.

Sea Ice

Impact of Arctic relaxation (north of 70N) on sub-seasonal RMS error



Reduction of Z500 RMS error Wintertime

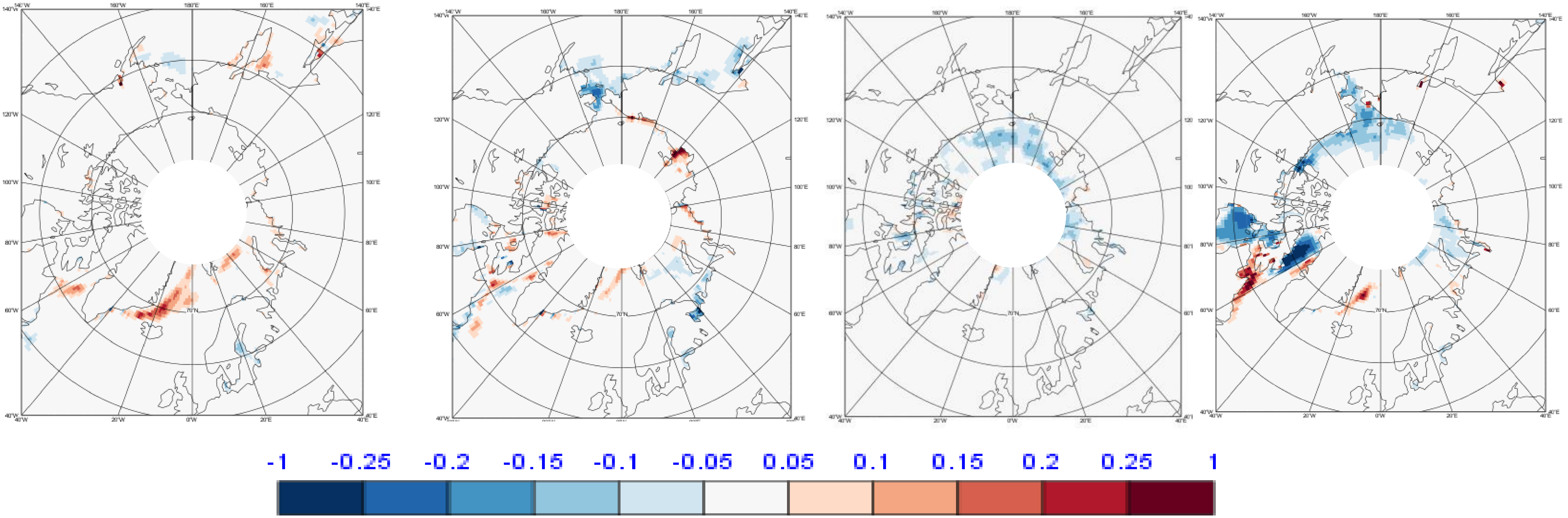
Jung et al., 2014

Sea Ice prediction at ECMWF

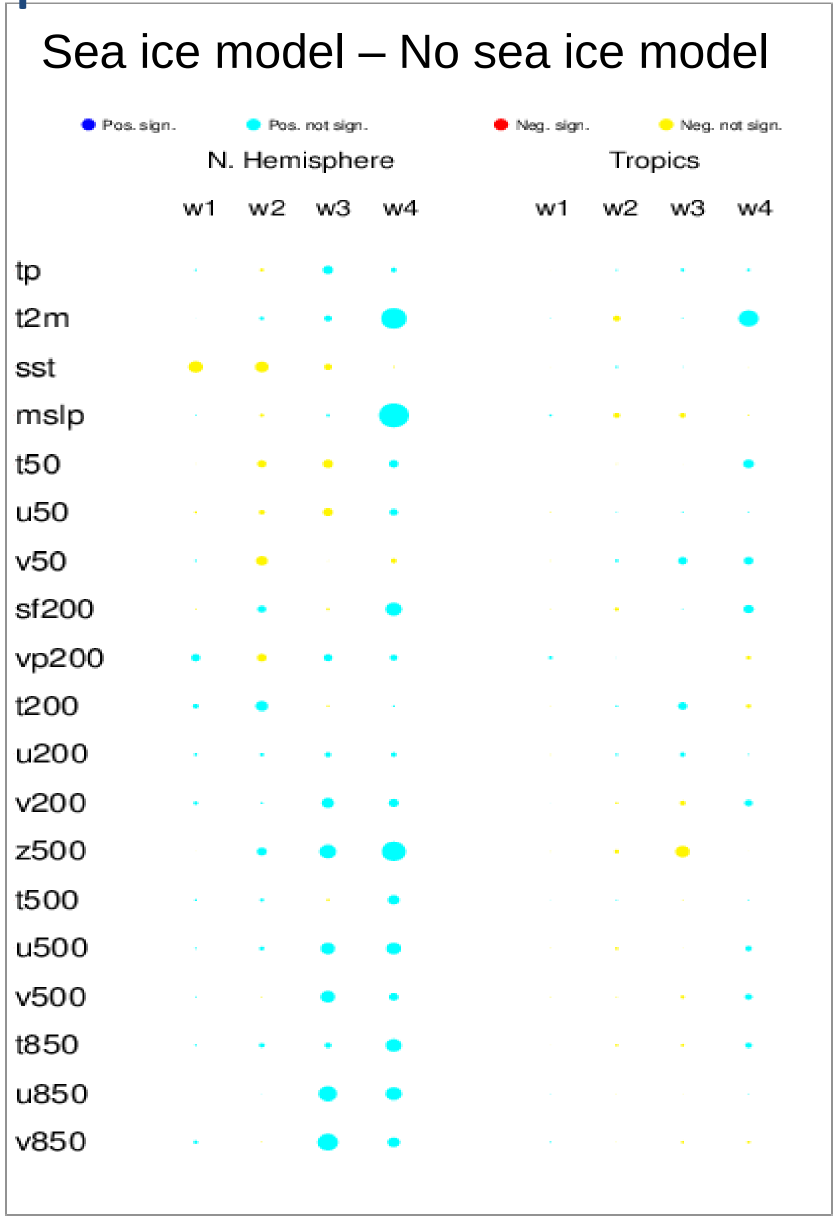
32-day ensemble re-forecast experiments (1989 to 2014)

RMS error of sea-ice concentration: Active sea ice (LIM2) - Persistence/climatology
Verification against ERA Interim
Step 720

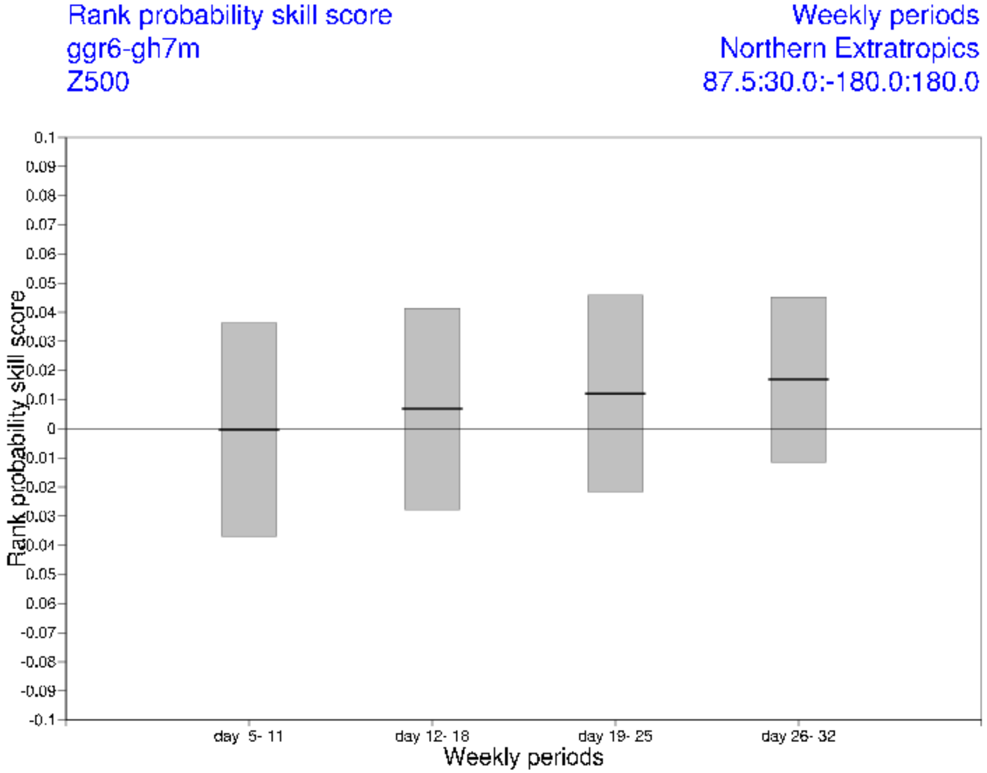
1st Feb start | 1st May start | 1st August | 1st Nov start



Impact of active sea-ice model on forecast skill scores



Z500 RPSS
Sea ice – no sea ice

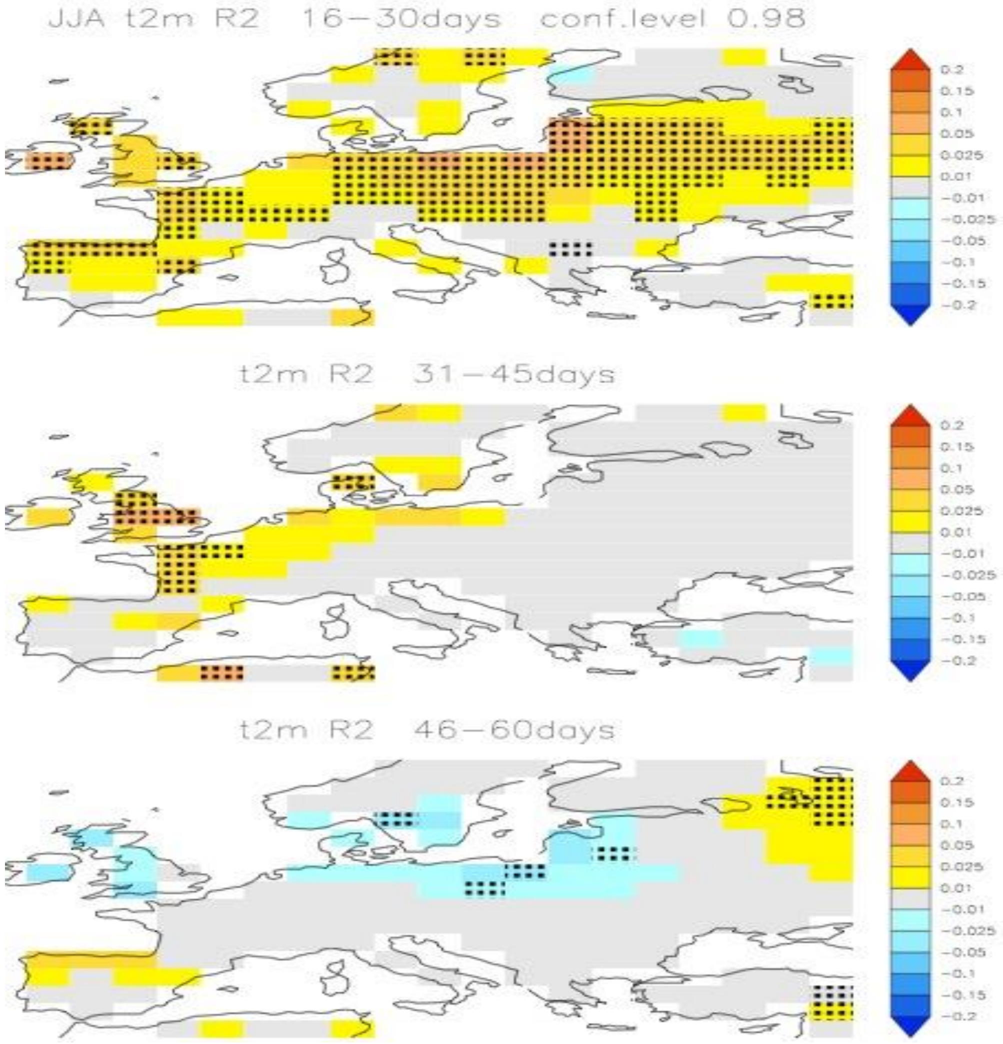


Blue/cyan (red/orange) circles indicate positive (negative) impact
Blue/red circles indicate significant impact

Land Surface

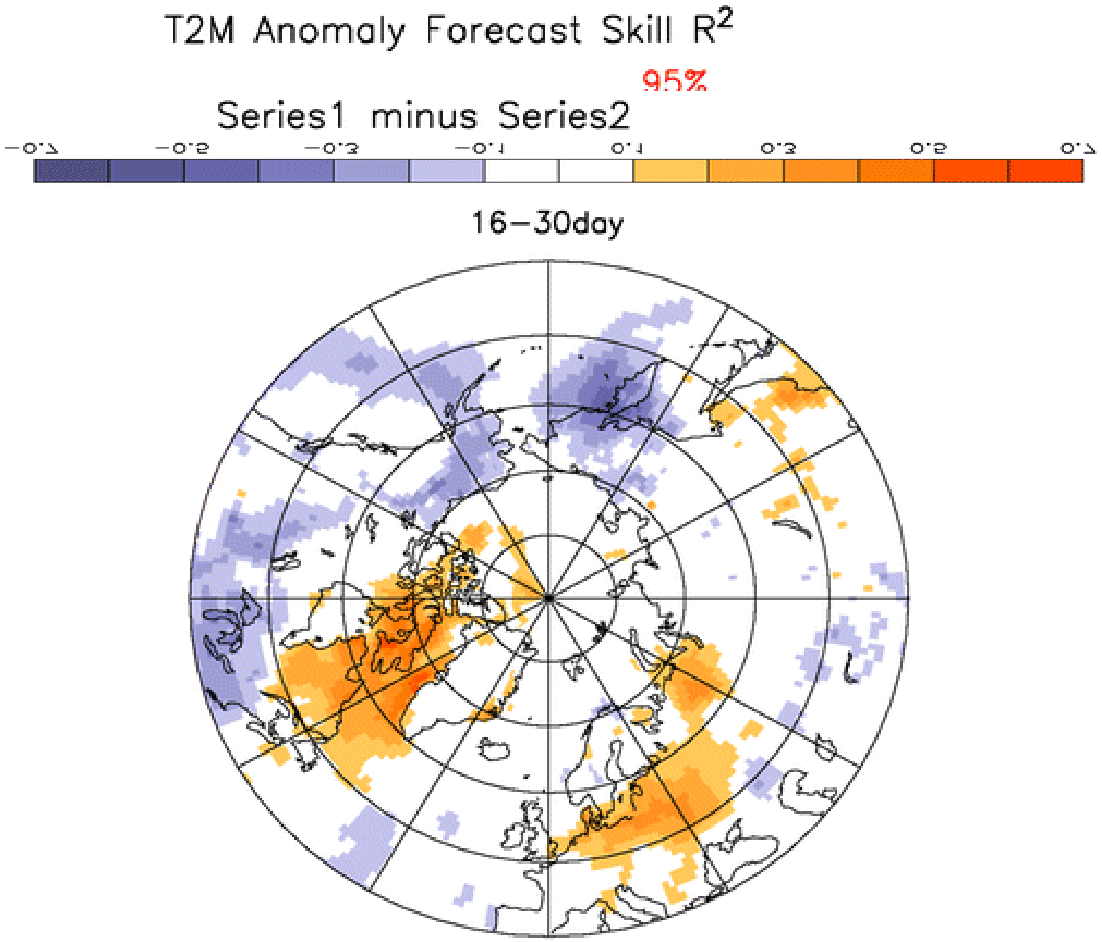
Soil Initial Conditions

GLACE2 experiments (Koster et al., 2011)



Van Den Hurk at al. (2012)

Snow Initial Conditions

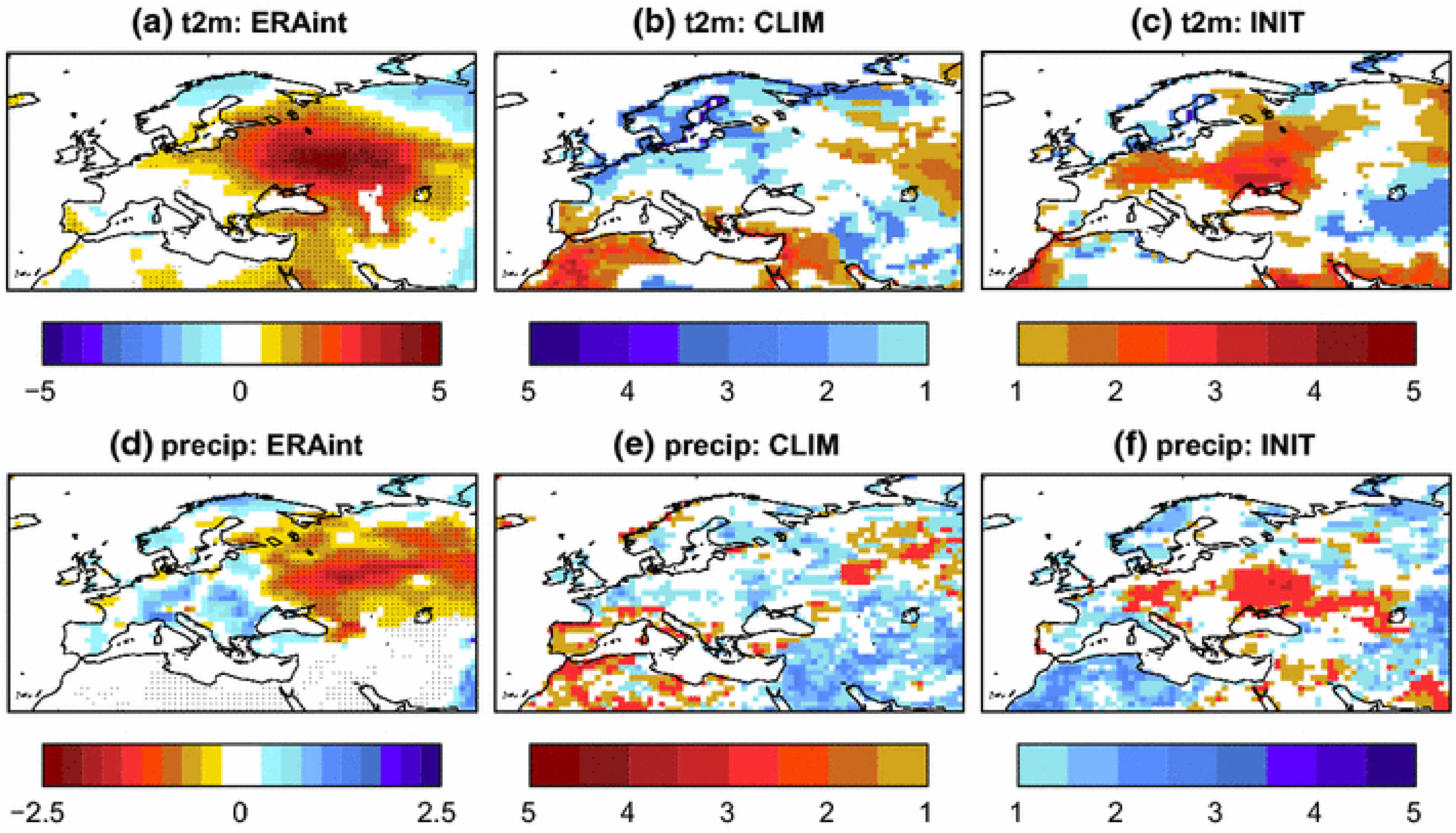


Orsolini et al. (2014)

GLACE experiments: strong perturbations in initial conditions

Importance of land-surface initial conditions for heat waves prediction

2010 summer heat wave



Prodhomme et al, 2015

See also Ferranti and Viterbo, 2006 for the 2003 European Heat wave

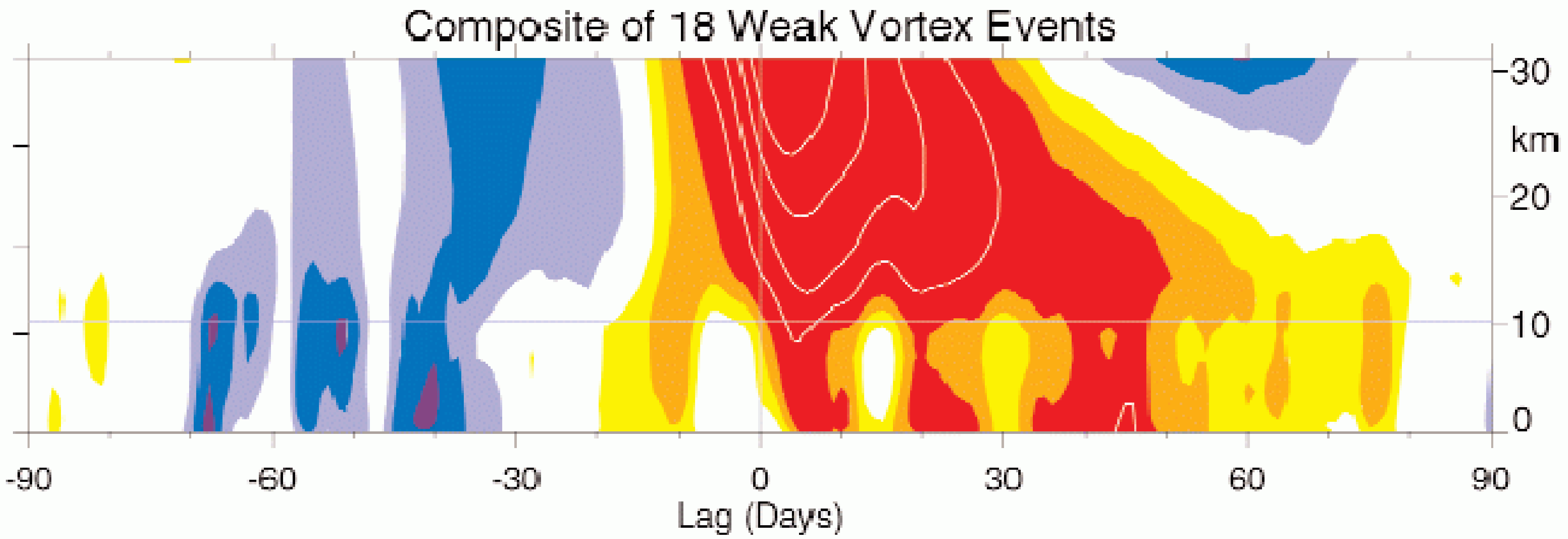
Land Surface for sub-seasonal prediction

- Land surface temperature/humidity: difficult to beat persistence for sub-seasonal time range. Complexity in land surface models still gives predictability thanks mostly to improved initial conditions.
- Importance of good quality initial conditions for extreme events
- Snow: Important to predict snow accumulation/melting

Stratosphere

Sudden Stratospheric Warming

Stratospheric influence on the troposphere?

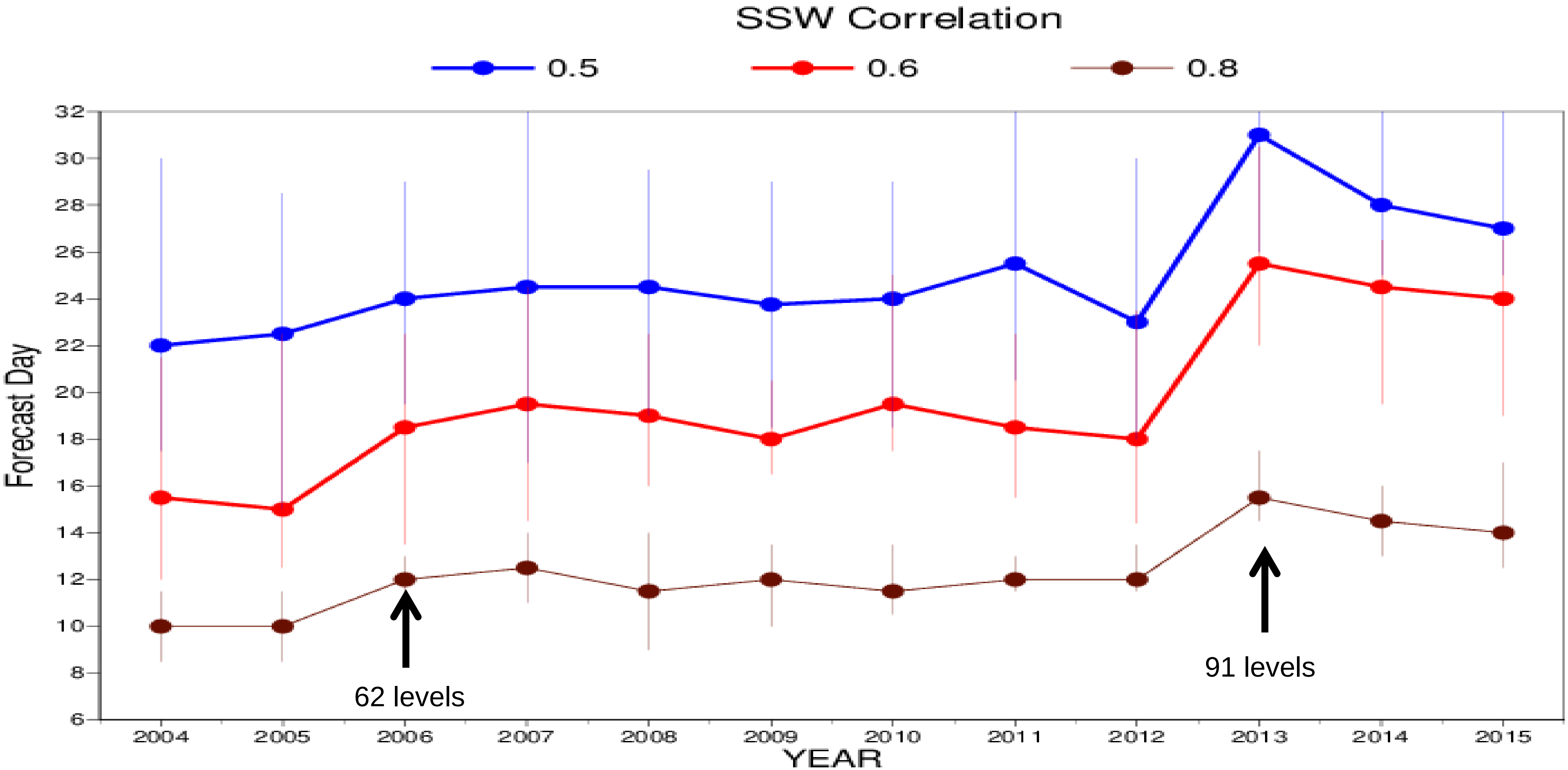


Weather from above. A weakening stratospheric vortex (red) can alter circulation down to the surface, bringing storms and cold weather farther south than usual.

Baldwin and Dunkerton, 2001

ECMWF

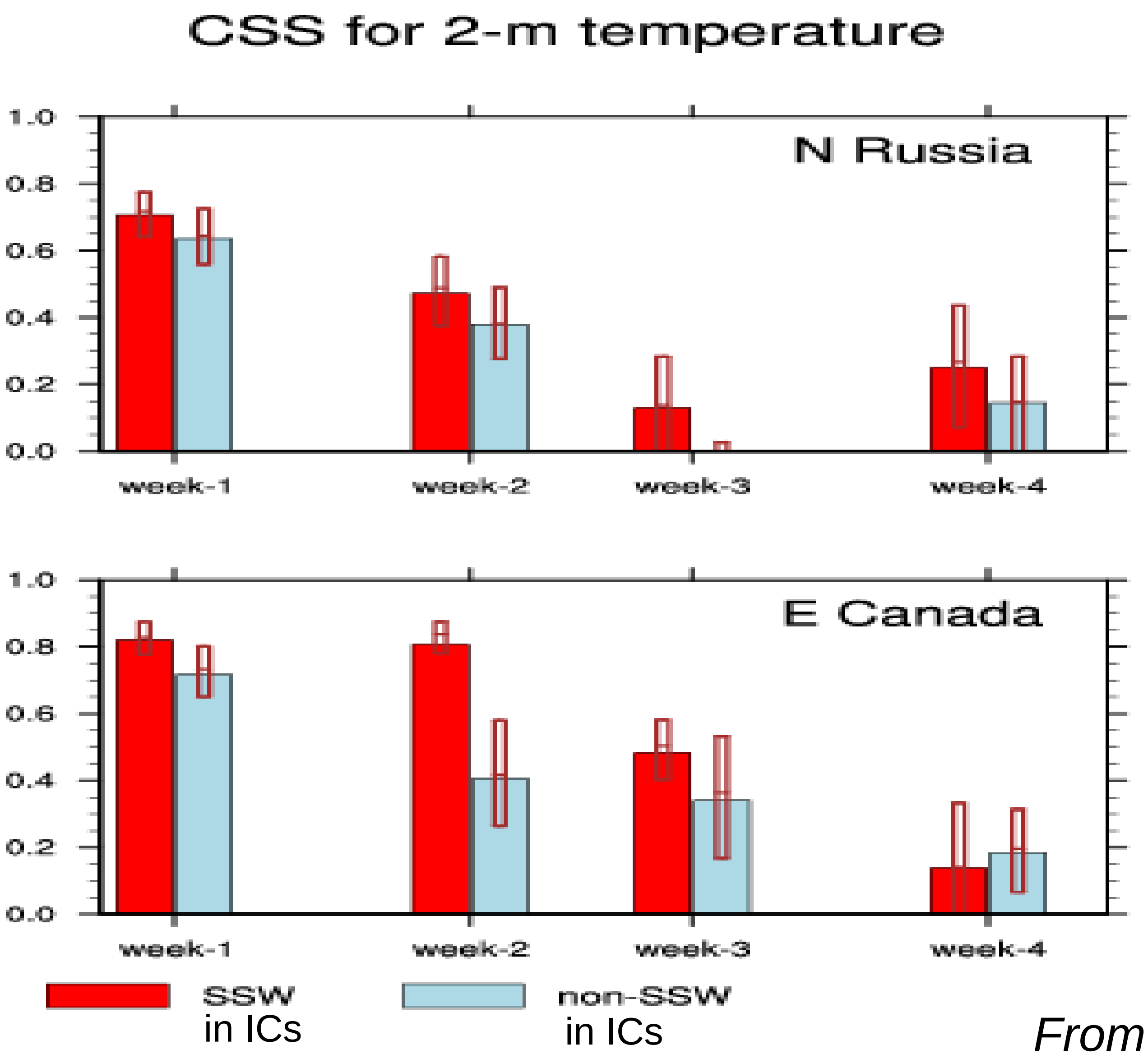
Prediction of Sudden Stratospheric Warming Index



SSW index: Difference of temperature at 50hPa between 90N and 60N averaged over all the longitudes

Improvements in SSW Prediction mostly due to changes in stratospheric resolution

Impact of SSWs on skill scores



This plot shows that over some regions, SSWs can have a significant impact on the monthly forecast skill scores.

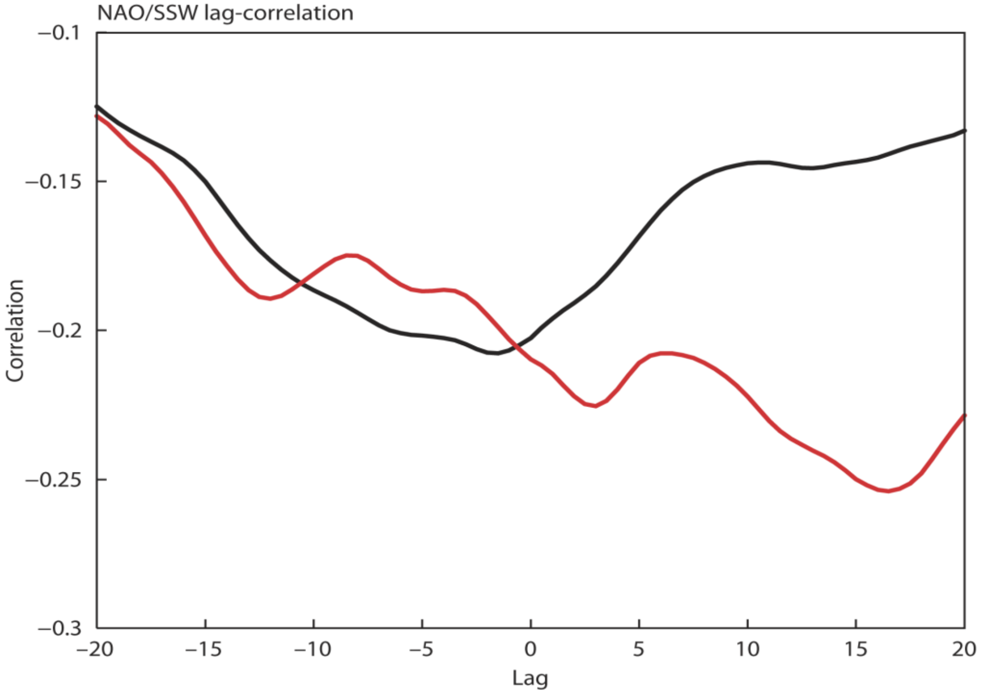
From Tripathi et al. (2015)

ECMWF

Sudden Stratospheric Warming

SSW: Downward propagation
too weak in the model?

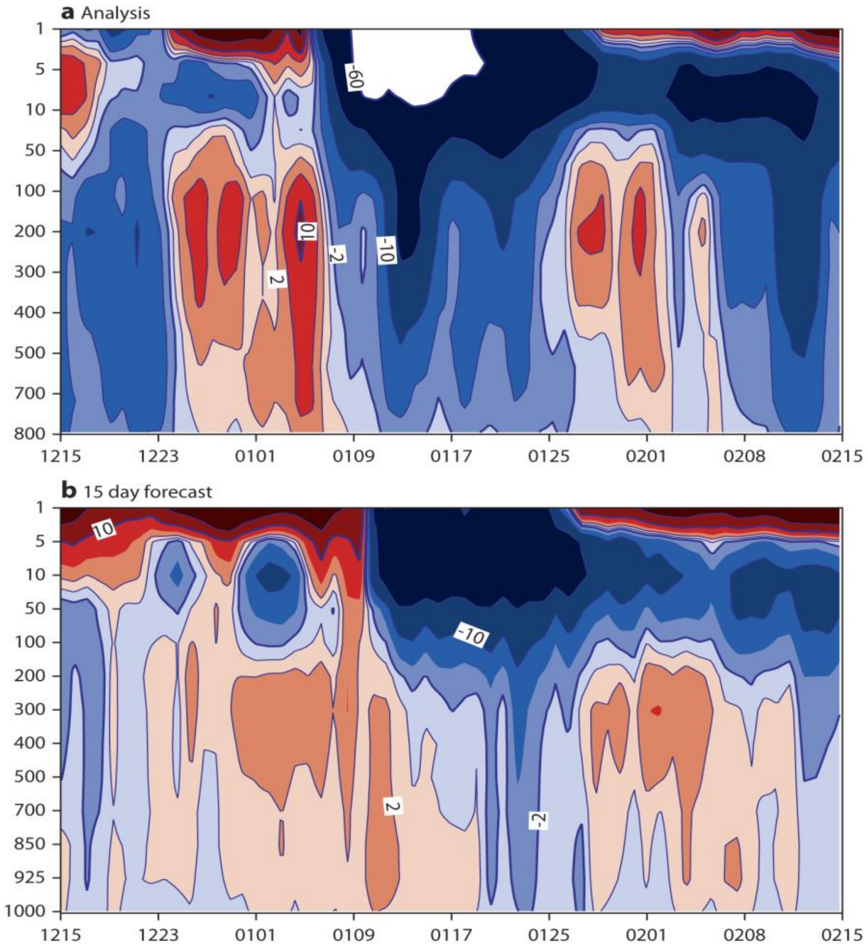
NAO/SSW lag correlation



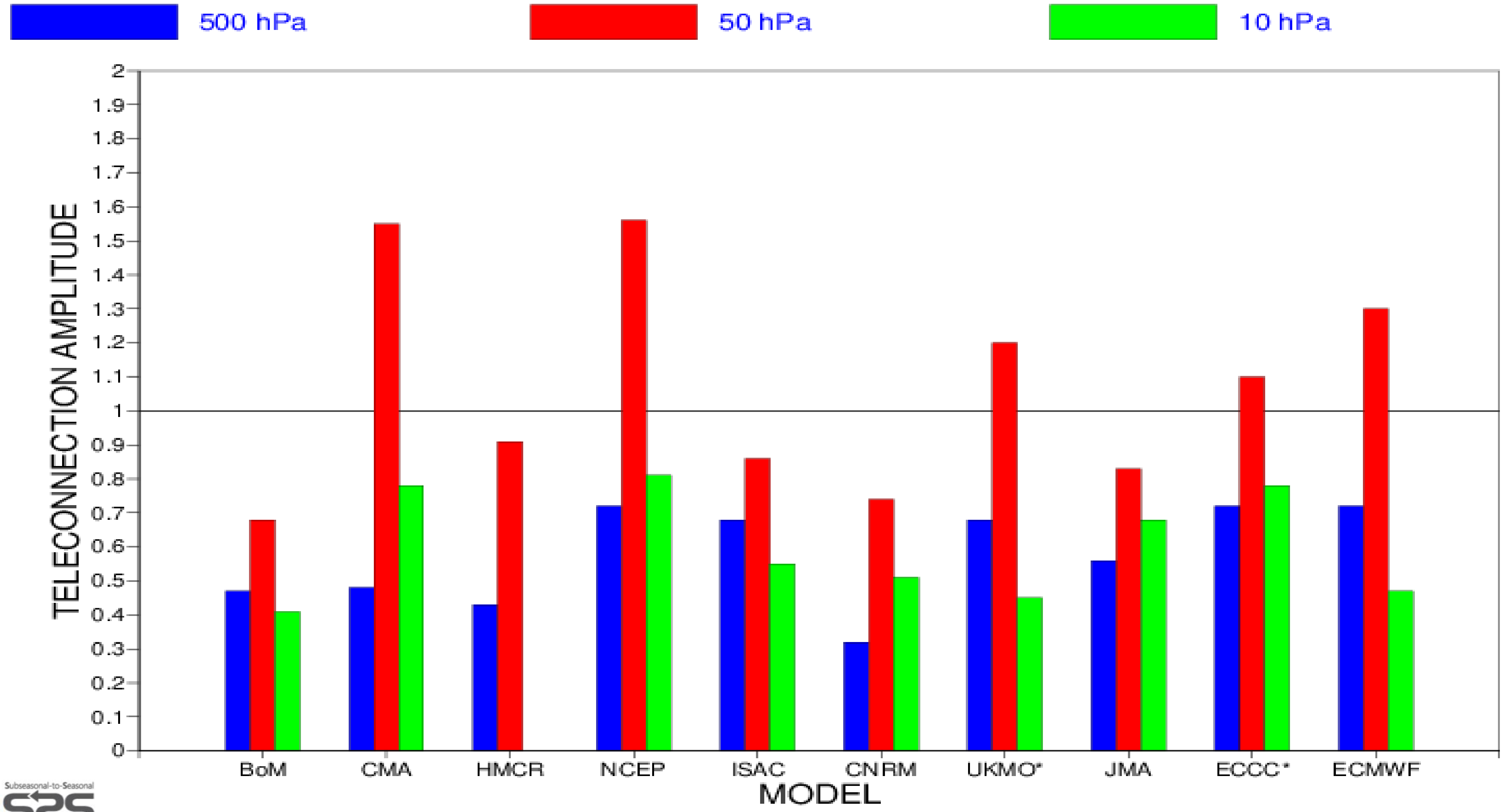
Sub-seasonal Forecasts

ERA Interim

Zonal Wind Anomaly at 60N
over Europe (15 Dec 2012-15 Feb 2013)

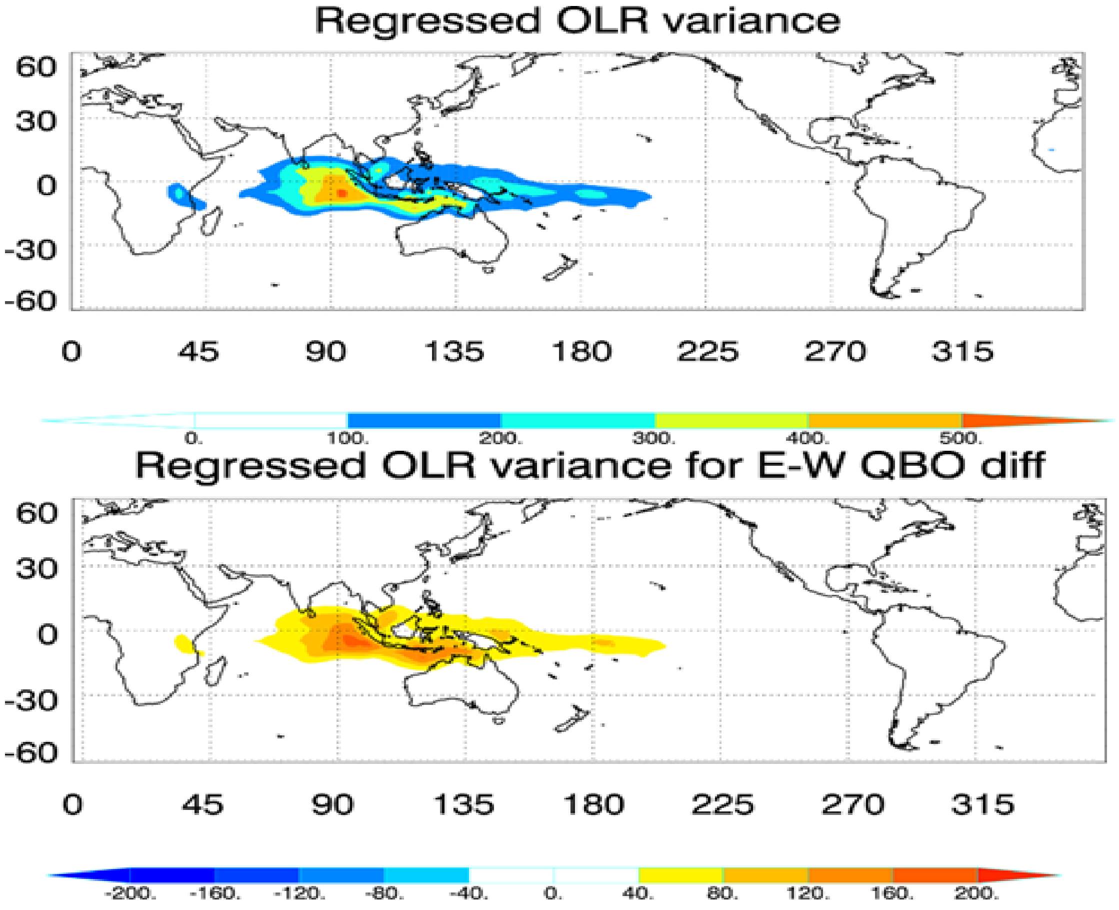


Amplitude MJO Teleconnections 3rd pentad after an MJO in Phase 3

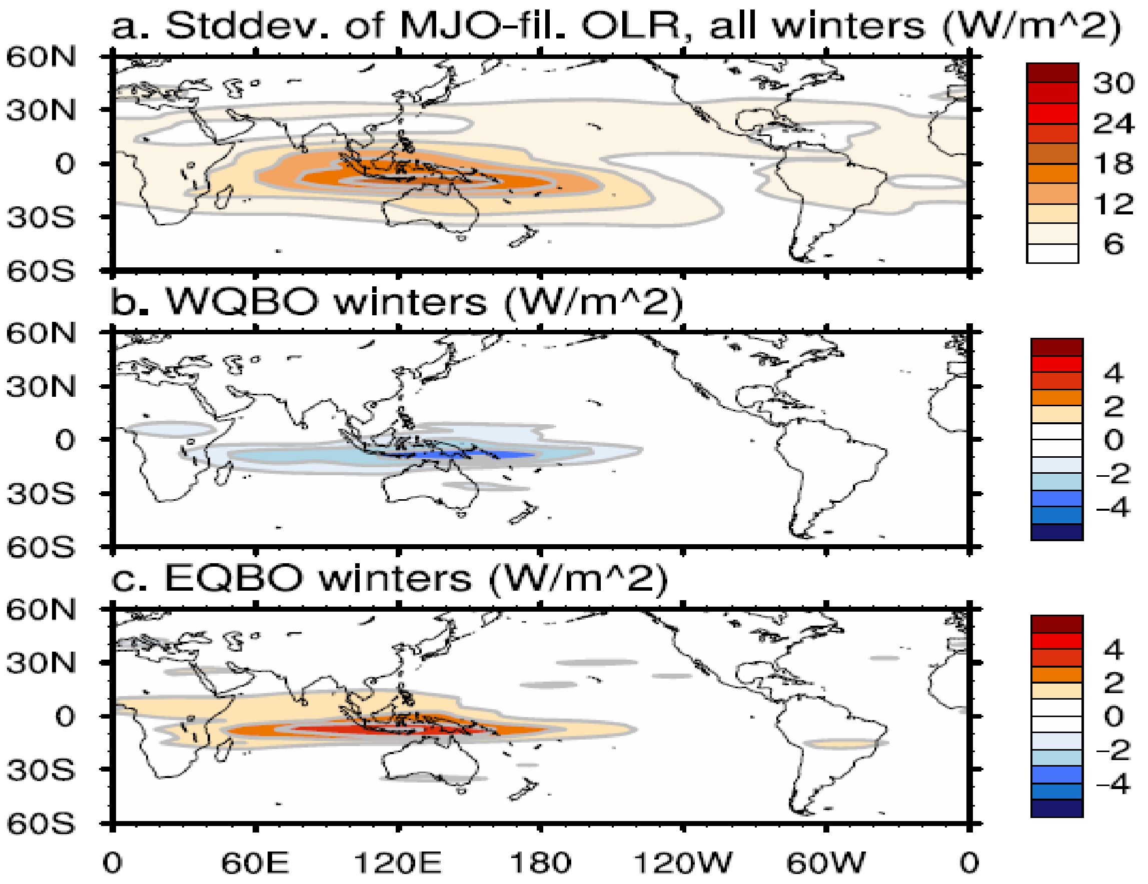


Impact of the QBO?

MJO OLR Variance (DJF) from reconstruction onto RMM



East waves 1-5 periods 30-80 days



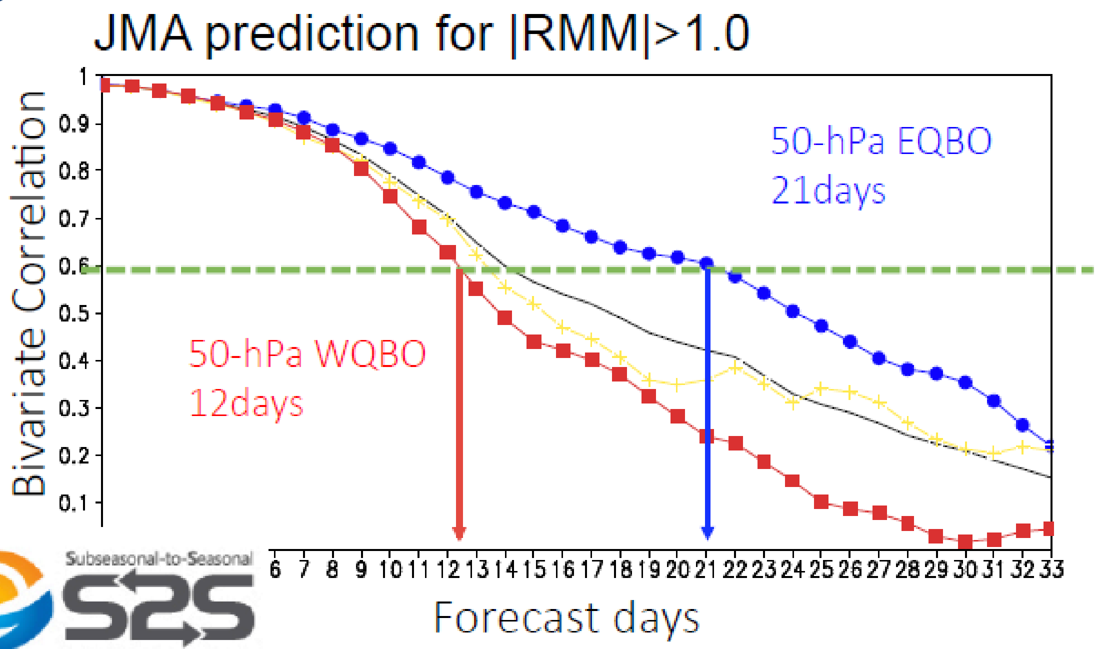
Yoo and Son 2016

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?



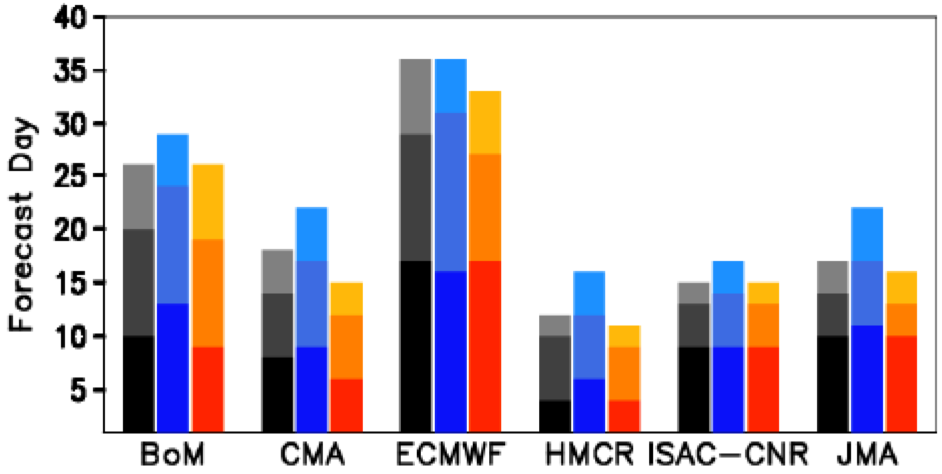


Figure 4. MJO prediction skill for six models. Light, medium, and Dark bars indicate respectively day when the MJO bivariate correlation reaches 0.5, 0.6, and 0.8

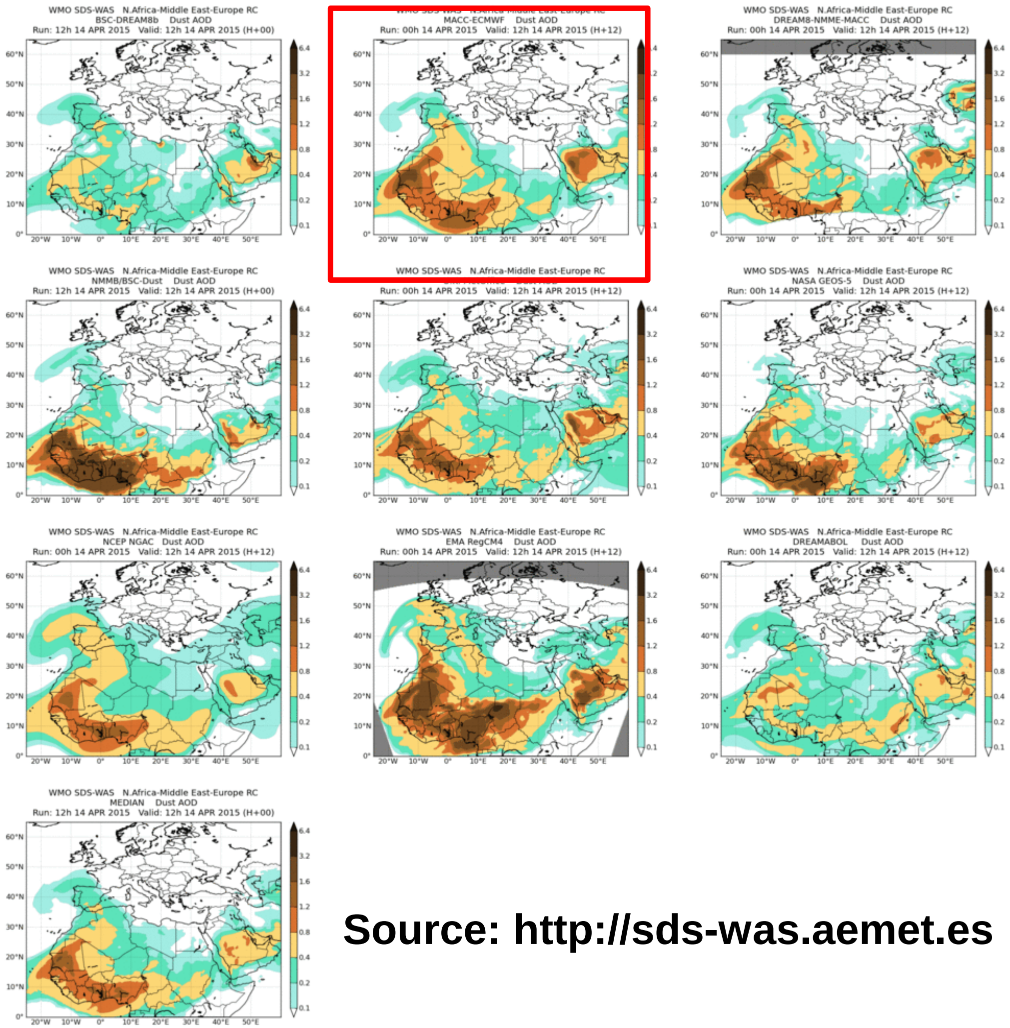
From available S2S forecasts

Yoo and Son 2016

Aerosols

CAMS aerosol forecasts

- Built on the ECMWF NWP system with additional prognostic aerosol variables (sea salt, desert dust, organic matter, black carbon, sulphates)
- Aerosol data used as input in the aerosol analysis:
  - NASA/MODIS Terra and Aqua Aerosol Optical Depth at 550 nm
  - NASA/CALIOP CALIPSO Aerosol Backscatter (experimental)
  - AATSR, PMAP, SEVIRI, VIIRS (experimental)
- Verification based on AERONET Aerosol Optical Depth (and now also Angstrom exponent)
- Part of multi-model ensemble efforts such as the International Cooperative for Aerosol Prediction (ICAP) and the WMO Sand and Dust Storm Warning and Assessment System (SDS-WAS) North-African-Middle-East-Europe and Asian nodes.



Source: http://sds-was.aemet.es

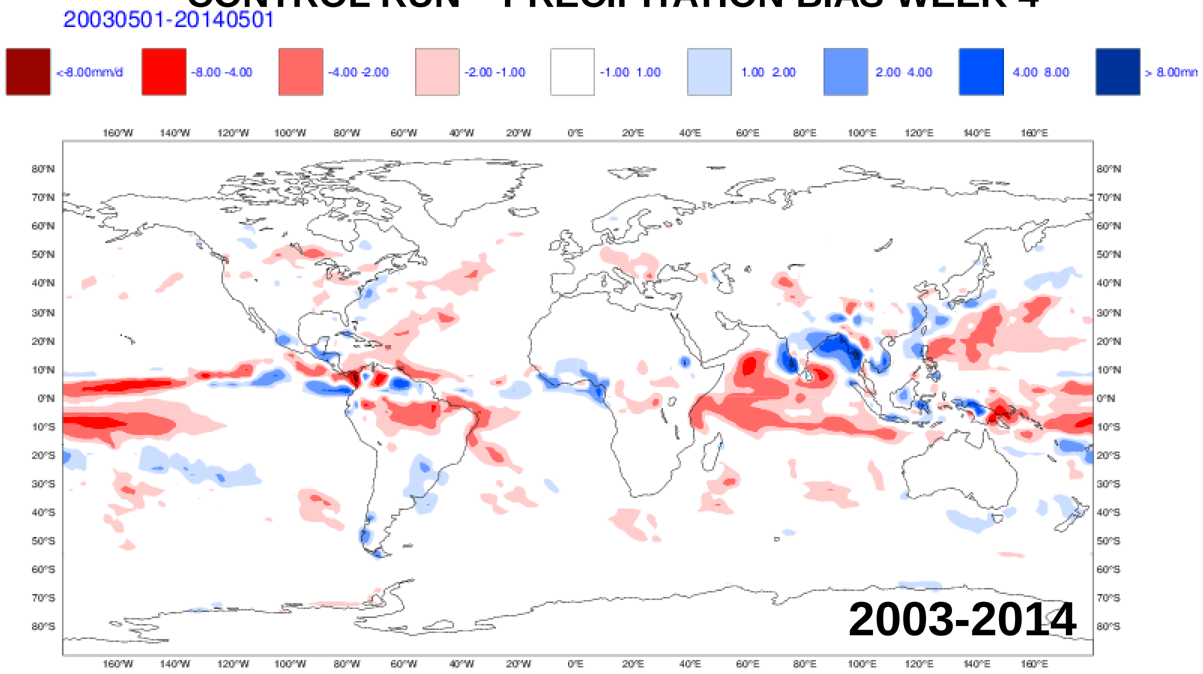
Monthly EPS coupled runs

- Control run for the period 2003-2015 uses standard Tegen et al 1997 climatology
- Interactive aerosol run covers the same period and uses fully prognostic aerosols in the radiation scheme
- Ensemble size is 11 members
- 5 different start dates around May 1 (65 cases in total)

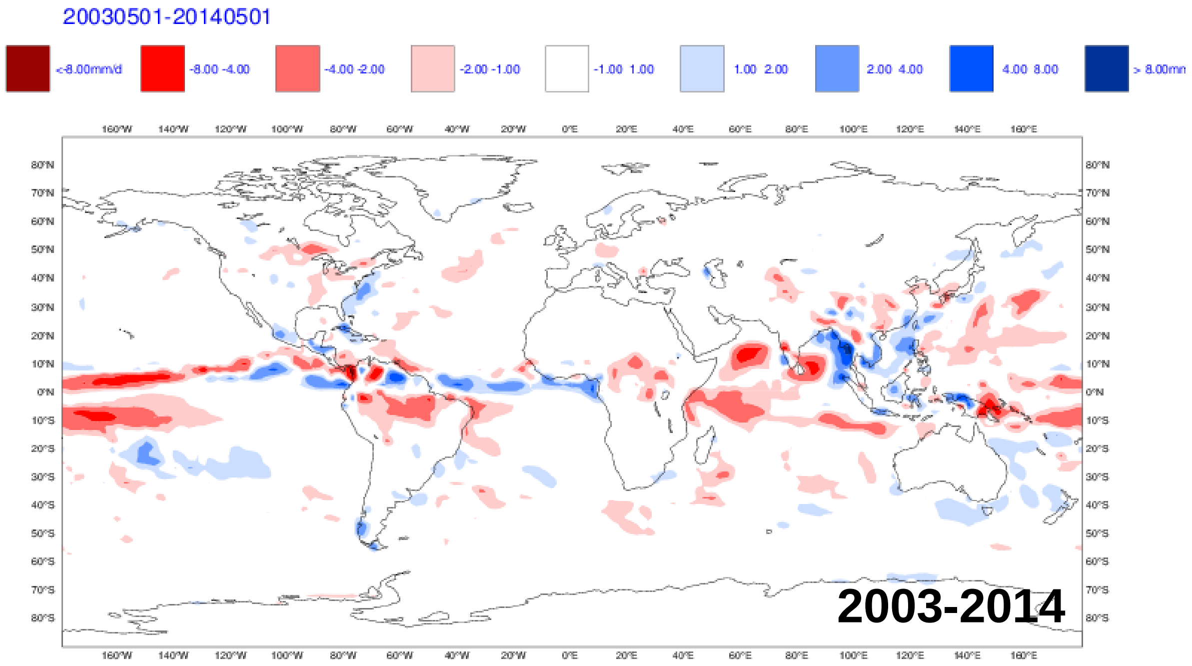
Aerosol impacts on monthly forecasts (I)

- Preliminary results confirm the positive impact (reduction in bias) of the interactive aerosols on meteorological fields (winds and precipitation)
- More prominent (positive) impact over the Indian Ocean and to a lesser extent in other areas
- Aerosol fields will be evaluated too by comparing with the MACC/CAMS reanalysis

CONTROL RUN – PRECIPITATION BIAS WEEK 4



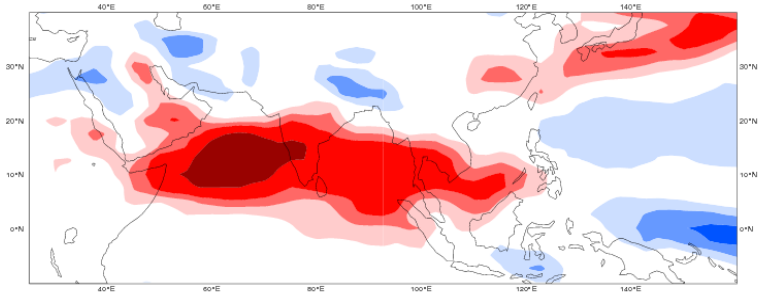
INTERACTIVE AEROSOL RUN – PRECIPITATION BIAS WEEK 4



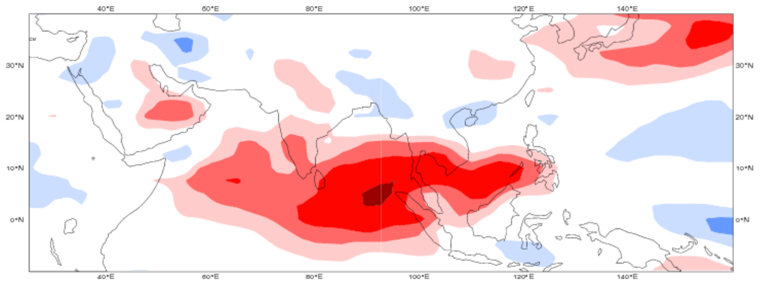
ECMWF

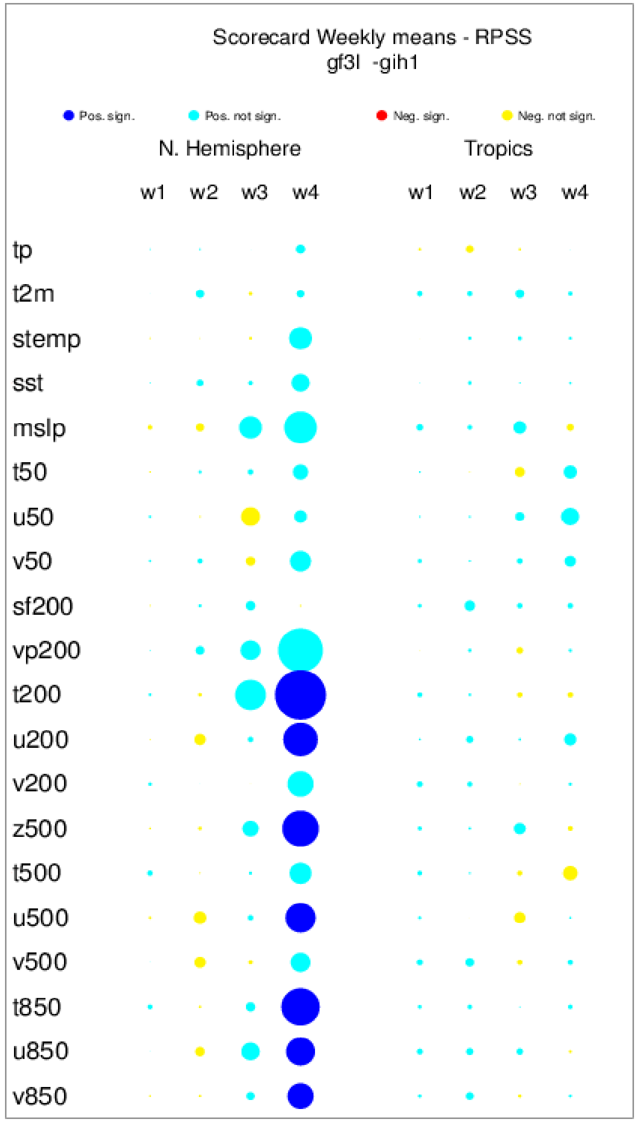
Aerosol impacts on monthly forecasts (II)

CONTROL RUN – 850 hPa U WIND BIAS WEEK 4



INTERACTIVE AEROSOL RUN – U WIND BIAS WEEK 4



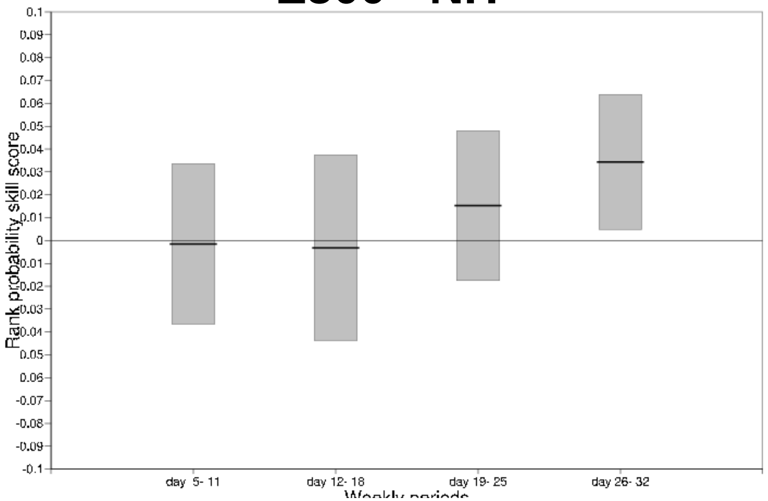


Performance of interactive aerosol experiment with respect to a control run for several parameters.

- Blue circles indicate positive impact
- Dark blue circles indicate significant impact

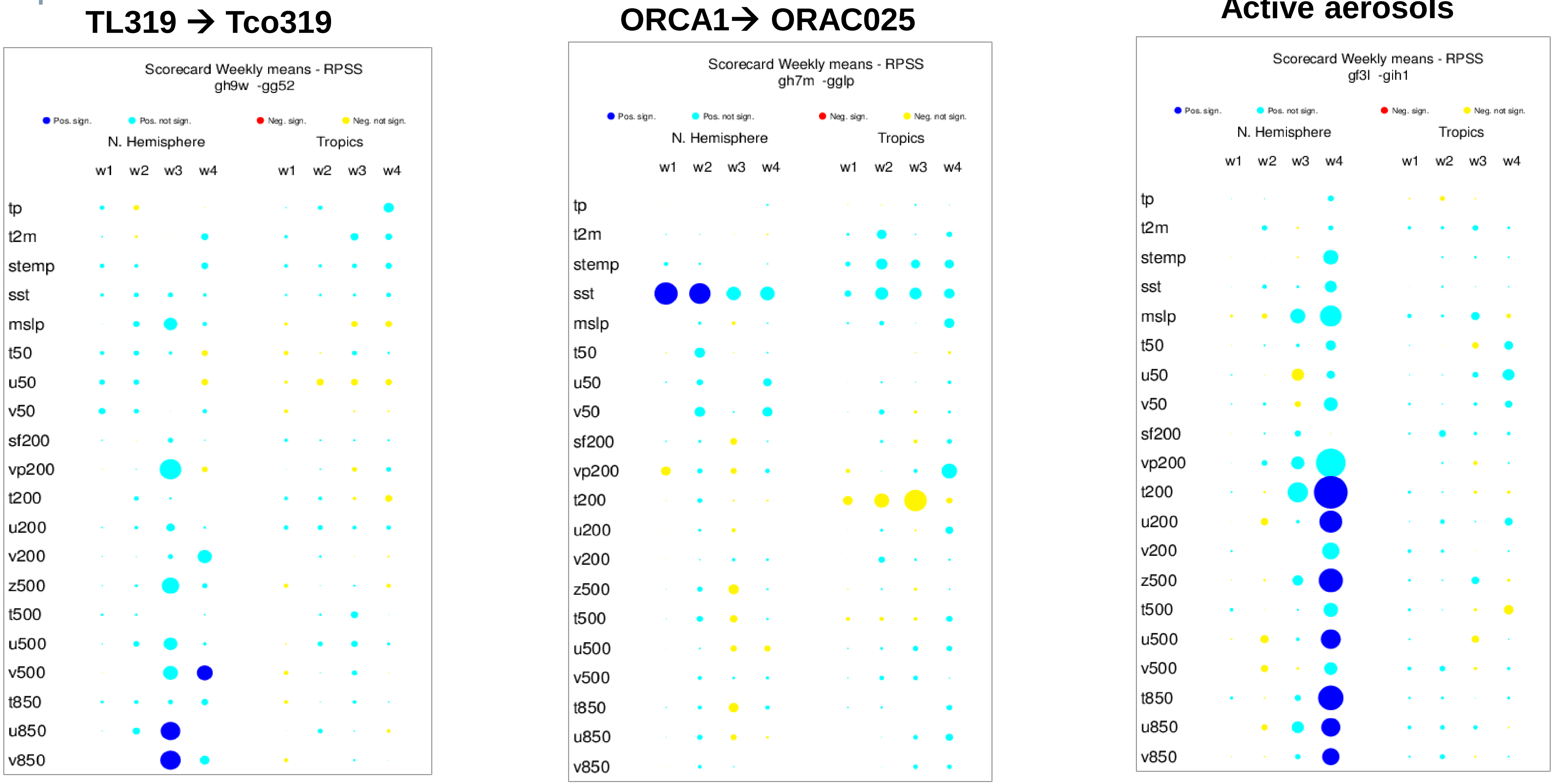
(Sores are applied to bias corrected fields)

Z500 - NH



Are the improvements due to aerosol climatology or variability?
Work in progress to better understand the impact of aerosols on sub-seasonal forecasts

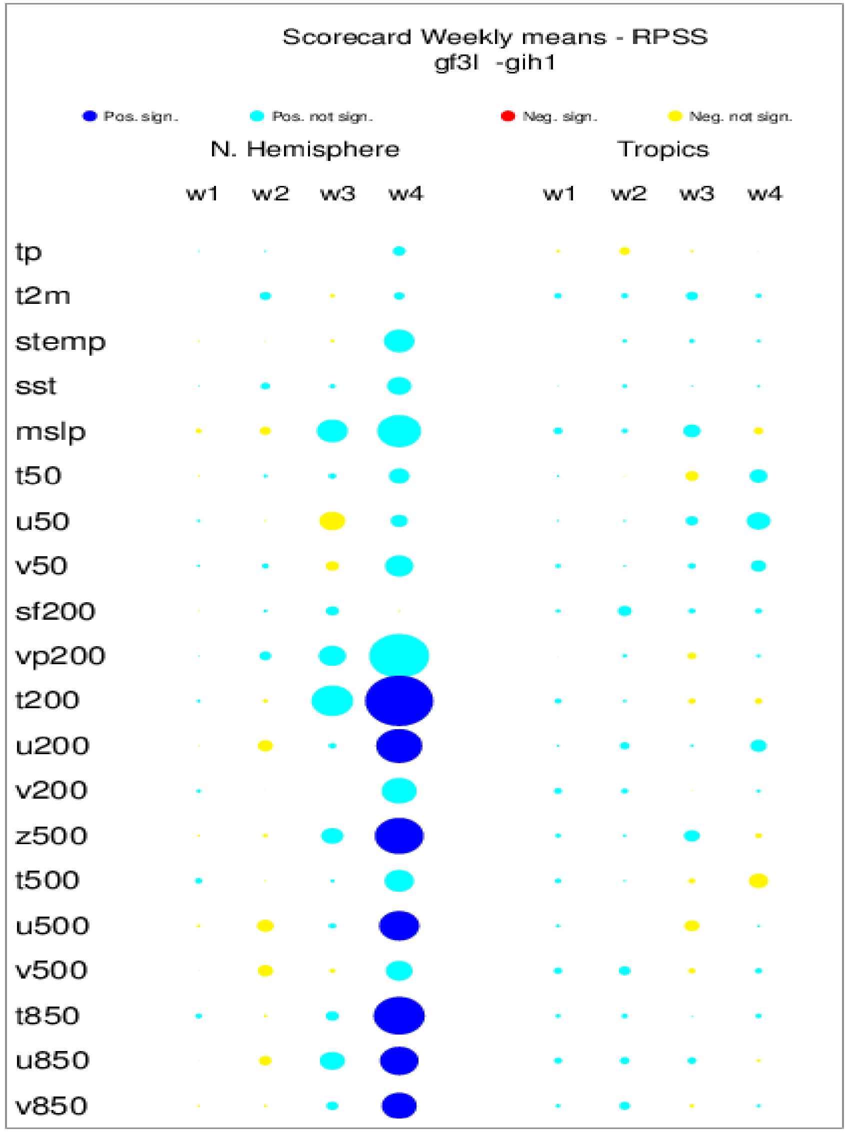
Improvements to sub-seasonal skill scores



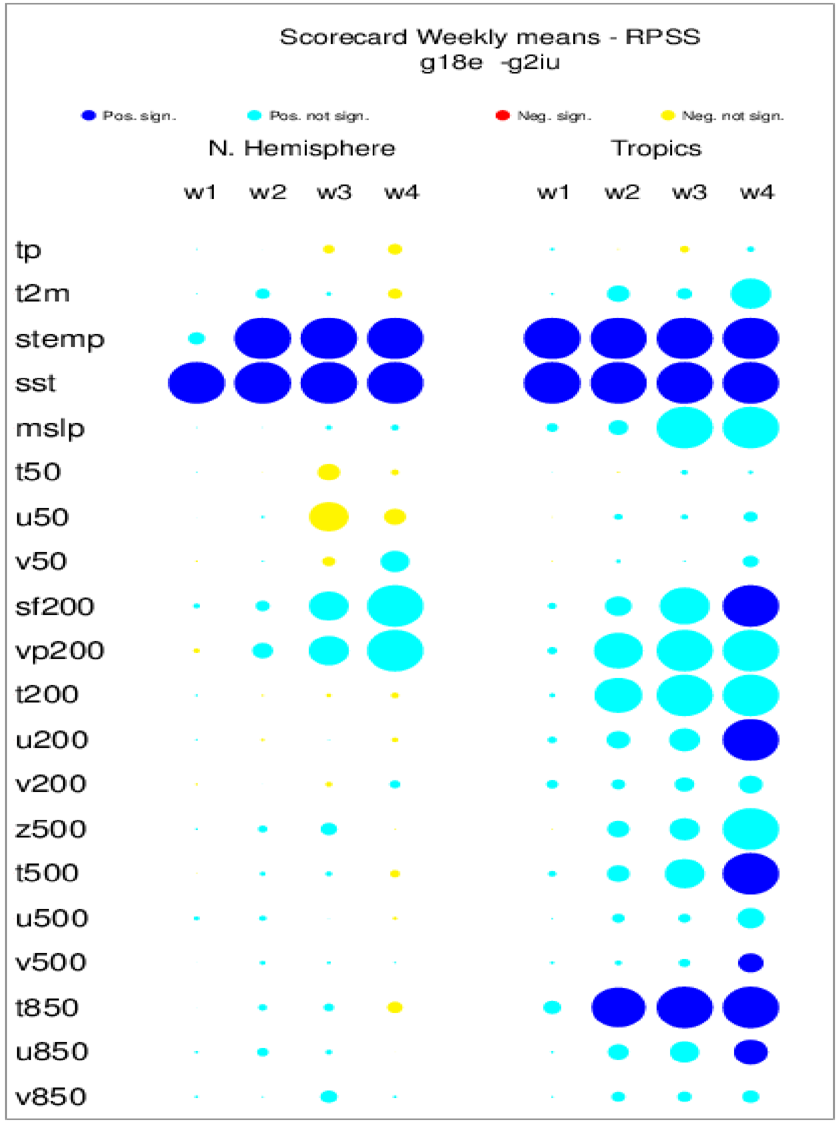
Caveat: May start dates only
2003-2015 period
Observed Fire emission

Improvements to sub-seasonal skill scores

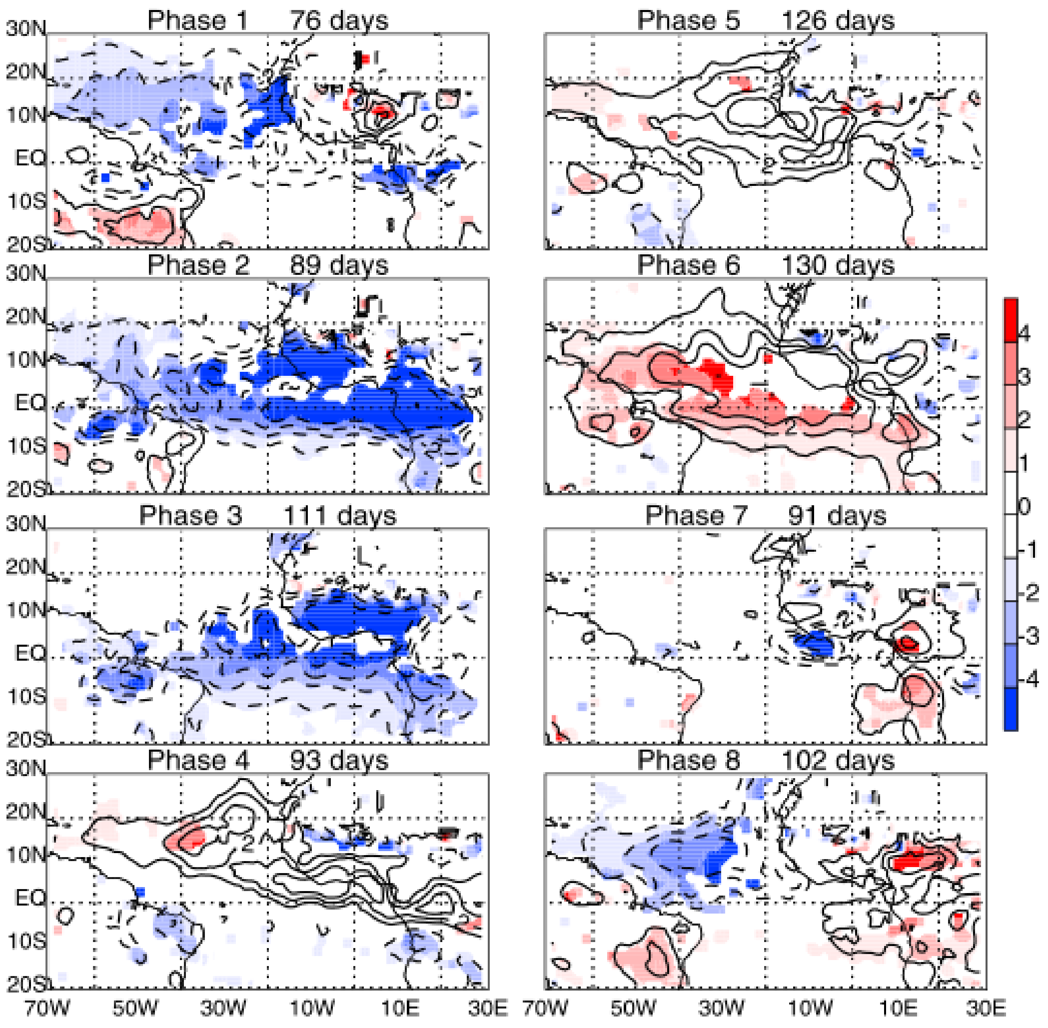
Active aerosols



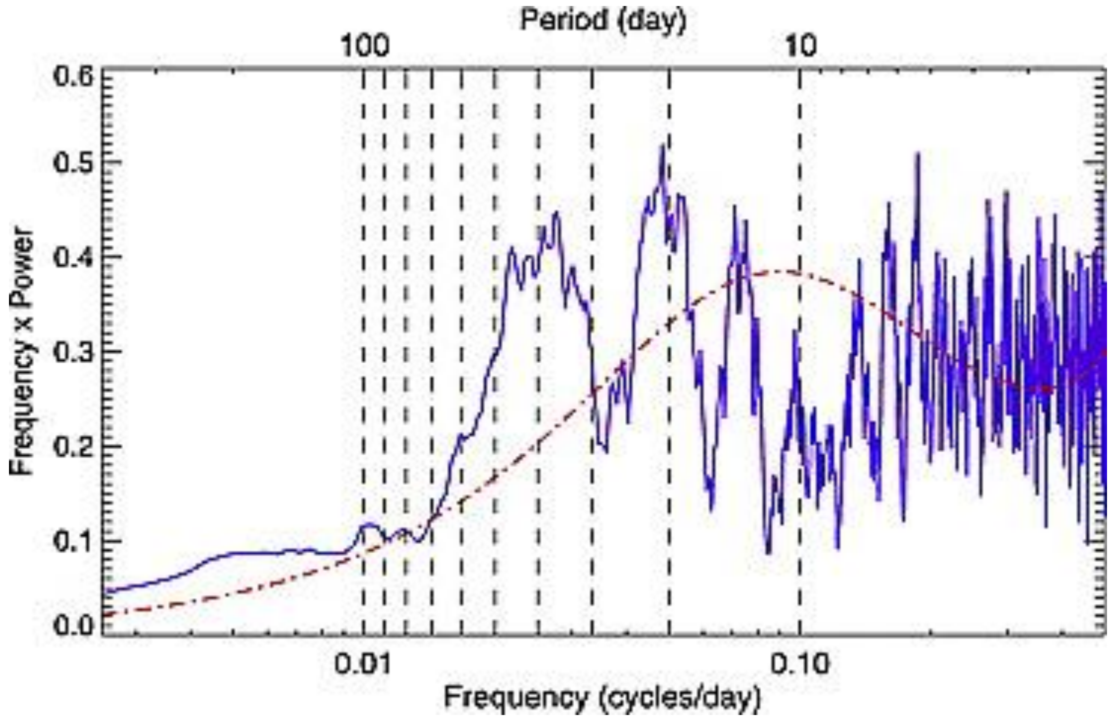
Coupled vs pers SST



Sub-seasonal variability of aerosols



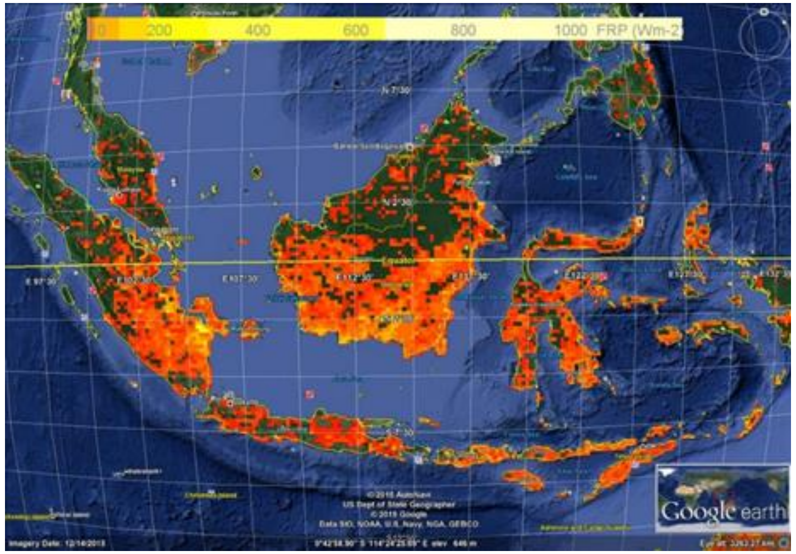
Time series spectrum of unfiltered MODIS AOT anomalies over the Atlantic



B. Tian et al, 2011

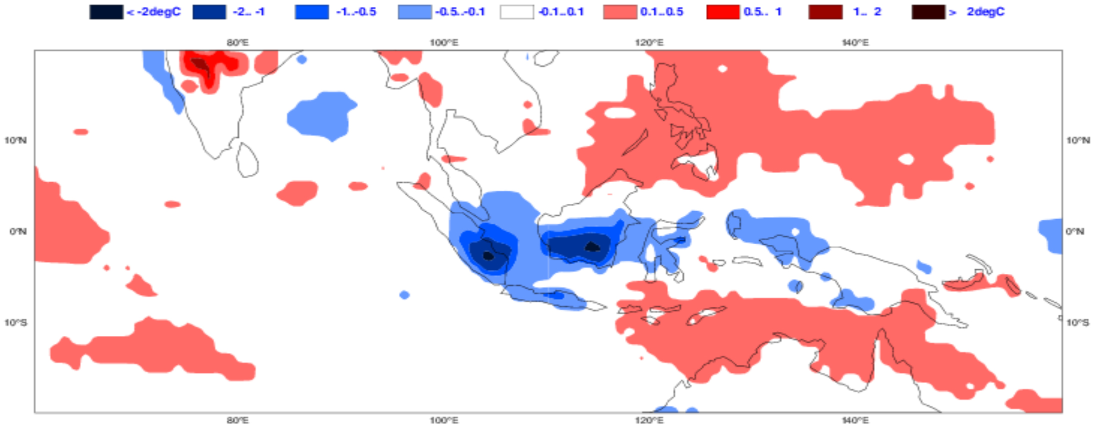
Intra-seasonal variance of AOT= ¼ of total variance of AOT

INDONESIAN FIRES (Aug-OCT 2015)

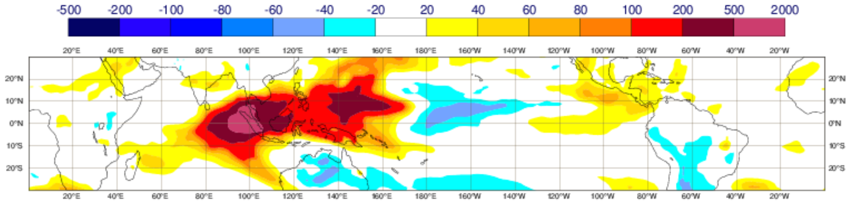


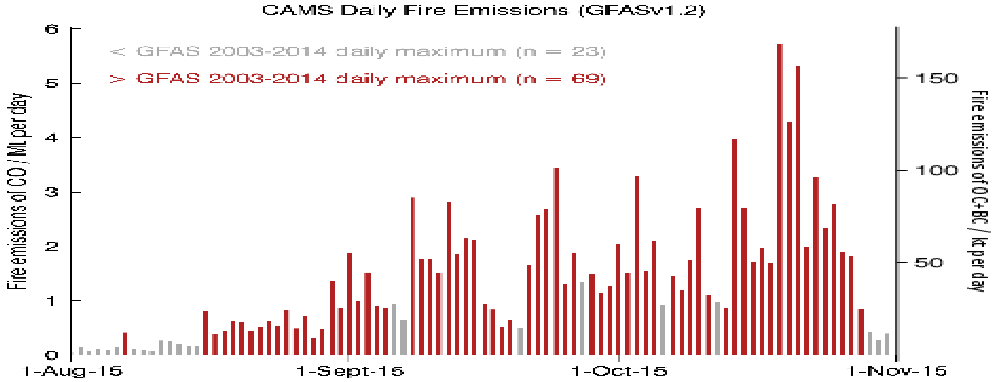
Fire radiative power Aug-Oct 2015

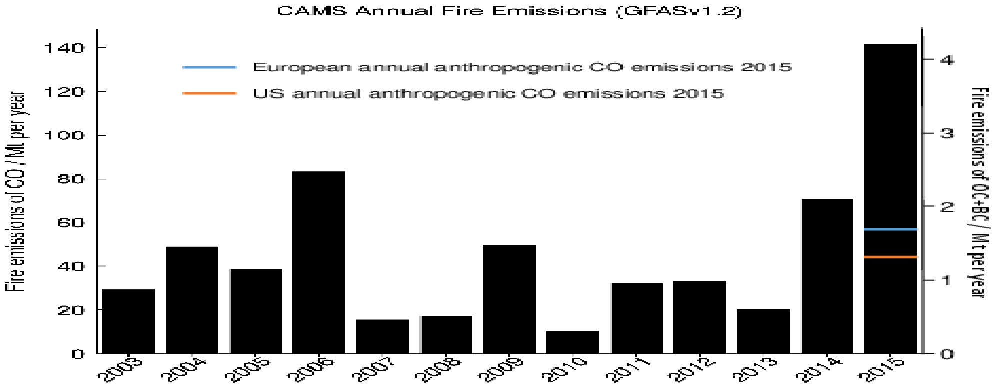
2m-tm anomaly Oct 2015 - Forecast starting 1st May



Biomass burning AOD anomaly: up to 2000%







Benedetti et al, to appear in State of Climate 2016, BAMS.
Credits: Antje Inness, Mark Parrington (ECMWF), Gerry Ziemke (NASA)

Need for fire prediction! (under development)

opernicus
Europe's eyes on Earth

More complexity for sub-seasonal forecasting?

Pros:

- Can improve skill scores (ocean, sea-ice, aerosols..)
- Can lead to new products:
  - **Active aerosols:** prediction of dust storm useful for Meningitis prediction
  - **Sea-ice model:** Extended-range sea-ice forecasts for ship routing in the Arctic in Summer.

Cons:

- Can be very expensive (e.g. active aerosols = 50% increase in cost)

Resources could be allocated to improve tropospheric models, through, for instance, increased resolution, more frequent call to radiative transfer, increased ensemble size, more frequent forecasts (daily instead of twice weekly)

- Makes system more complex to understand and maintain
- **Can increase systematic errors particularly in short/medium-range forecasts and possibly affect teleconnections**

Impact of atmospheric resolution

Impact of Resolution - Tropical cyclone PAM - 9-15 March 2015

Probability of a TC strike within 300 km

Day 12-18 | Day 19-25

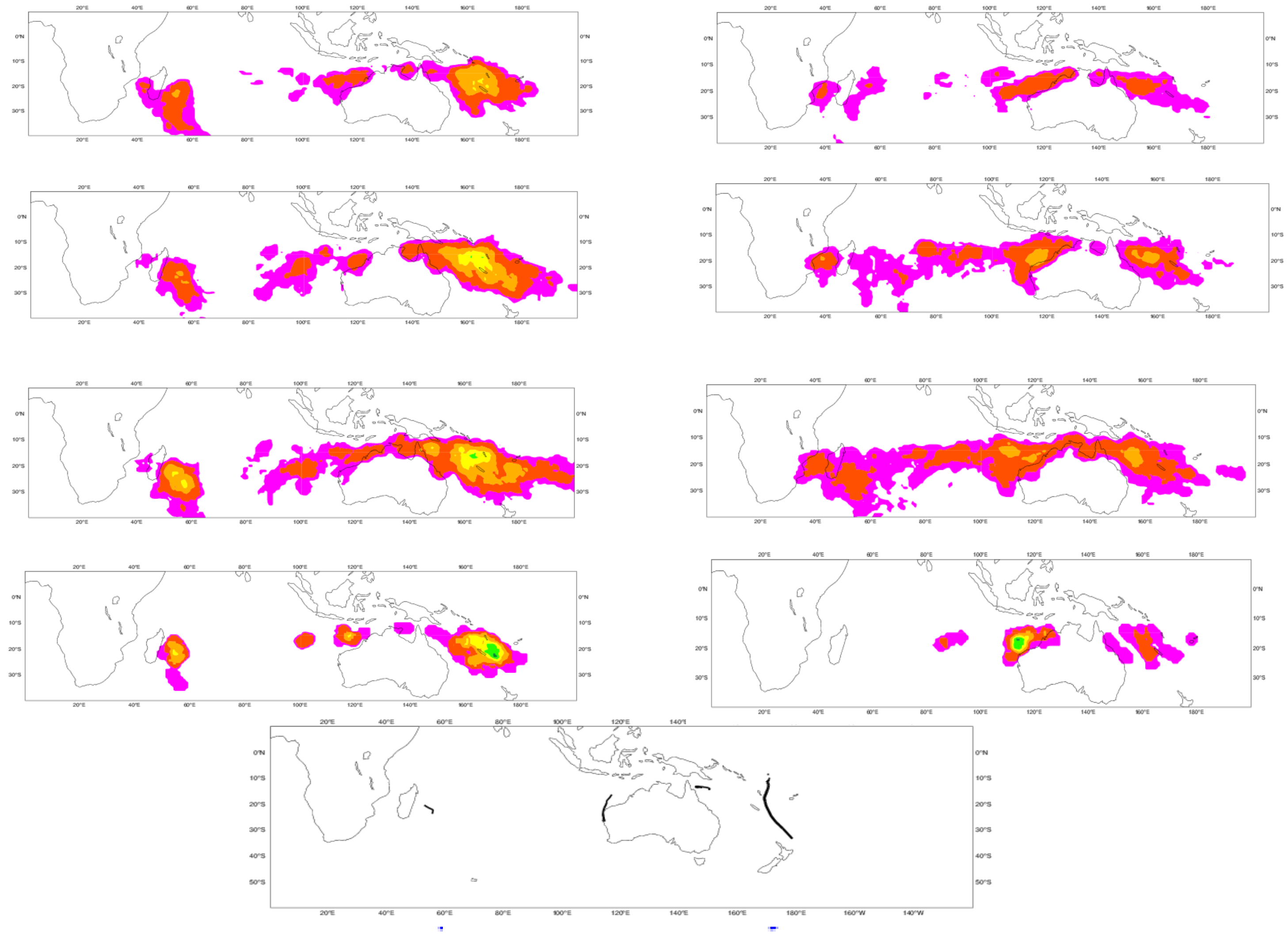
Oper (32/64km)

16/32km

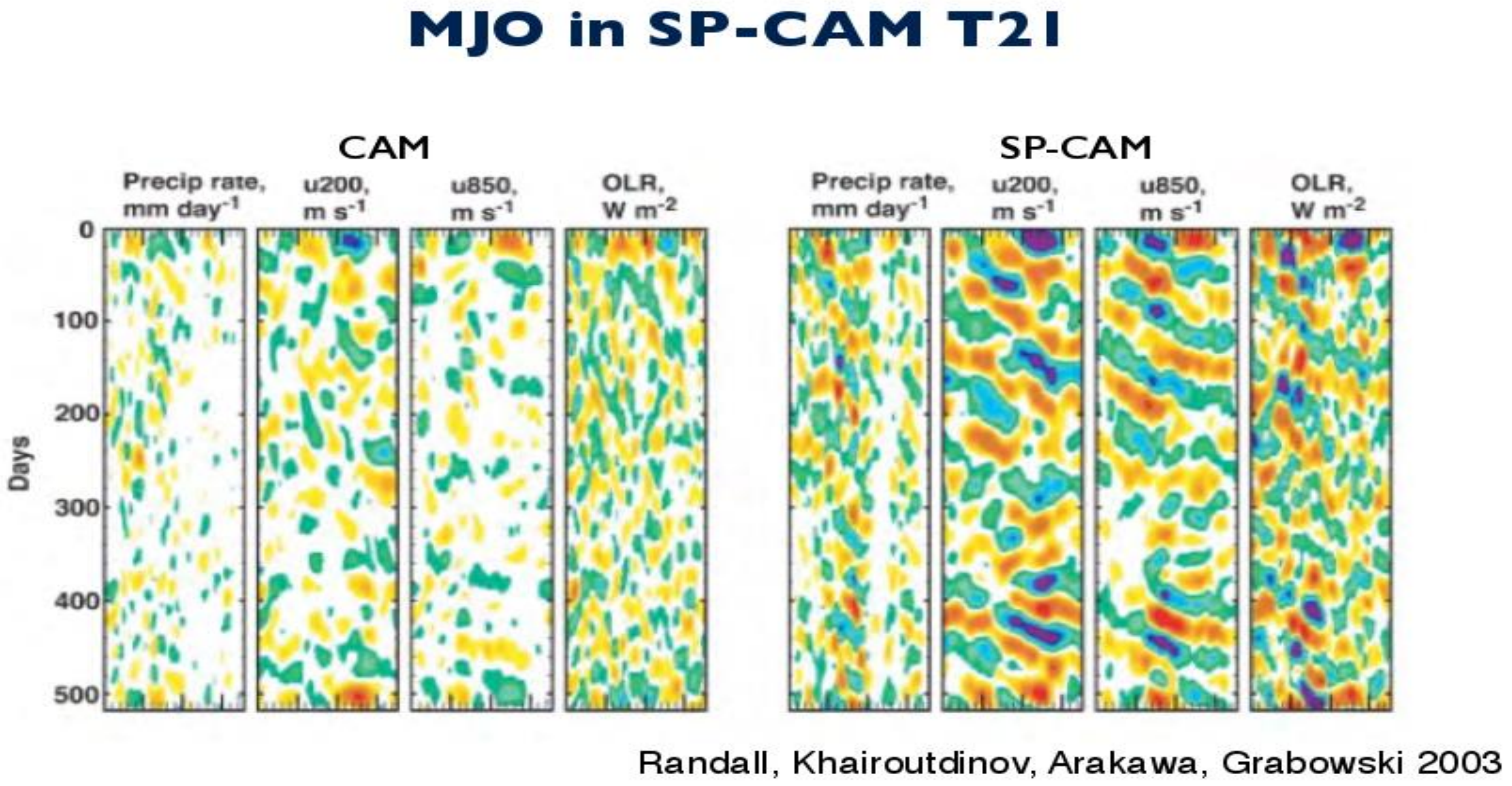
16km

110km+SP

VERIF



Impact of Increased resolution



Ongoing work by A. Subramanian (Oxford U.) to assess impact of Super-parameterization on sub-seasonal forecasts at ECMWF

Conclusions for a coupled ocean-atmosphere system

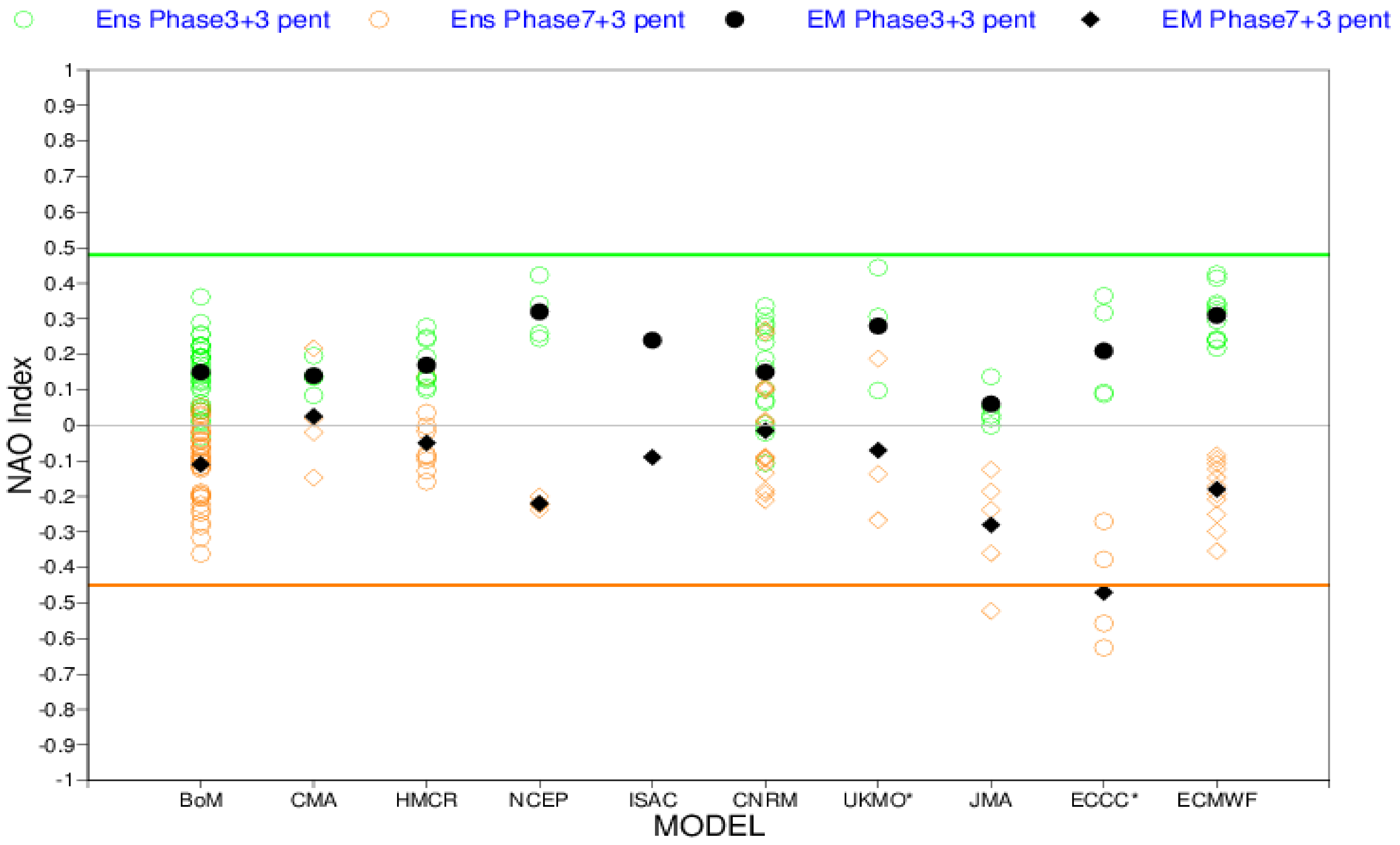
- Over the past decade, extended-range forecasts at ECMWF have significantly improved thanks mostly to improvements in the convective parameterization and possibly initial conditions (not discussed in this talk). It is likely to continue to be the case in the next years.

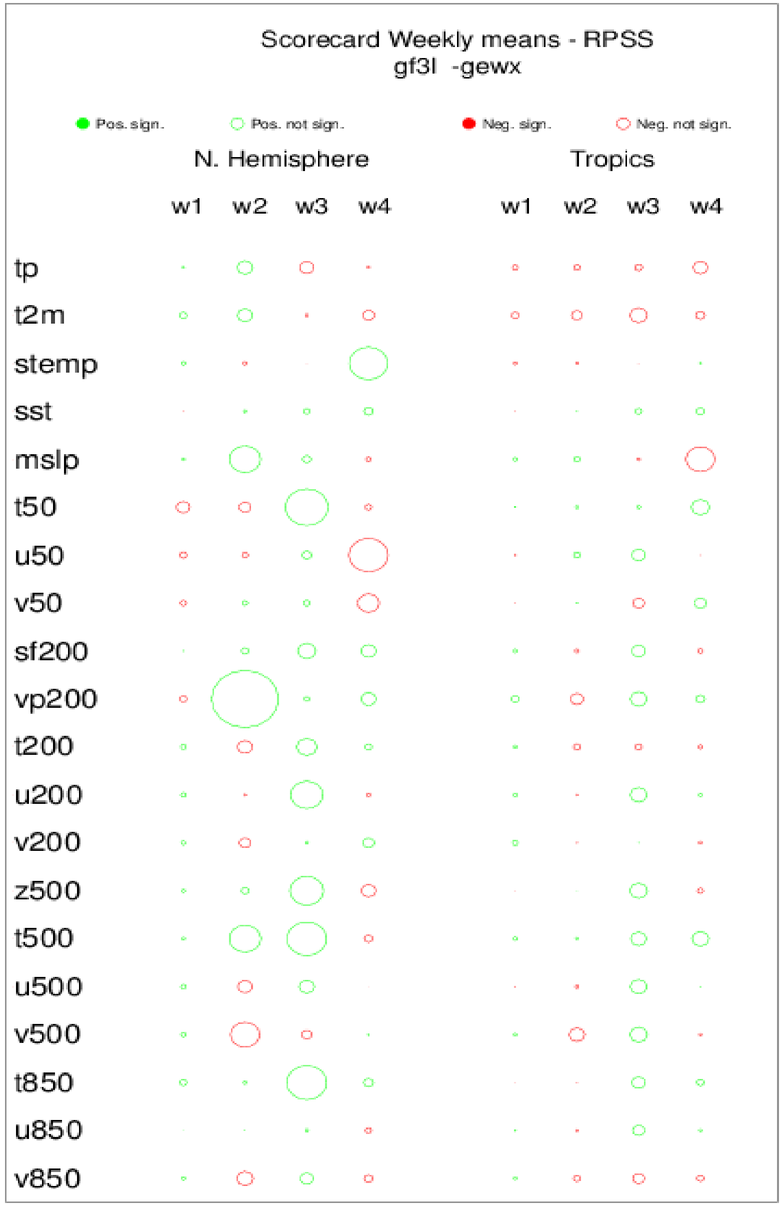
- There is room for improvement in many of the earth-system components which would produce incremental improvements in skill and also allow new sub-seasonal forecast products

- Of all the earth system components evaluated, the introduction of active aerosols seems particularly promising for sub-seasonal prediction.

- Resolution vs more complex systems: Not clear that resolution is the only way to go.

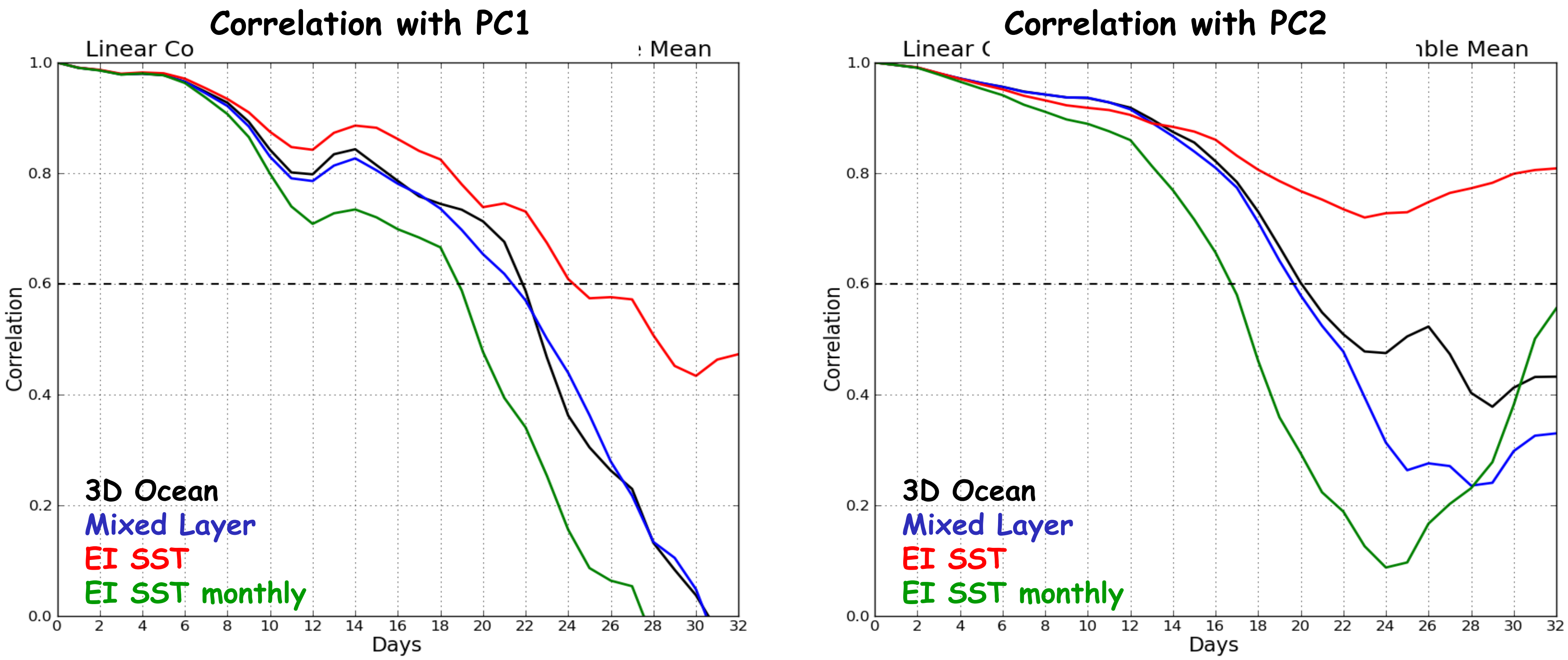
NAO Index
S2S REFORECASTS 1999-2010




Scorecard Weekly means - RPSS
gf3l -gewx
Pos. sign.
Pos. not sign.
Neg. sign.
Neg. not sign.
N. Hemisphere
Tropics
w1 w2 w3 w4
w1 w2 w3 w4
tp
t2m
stemp
sst
mslp
t50
u50
v50
sf200
vp200
t200
u200
v200
z500
t500
u500
v500
t850
u850
v850

Improvement of MJO Skill with Ocean Coupling

MJO scores: 1992-1993 case

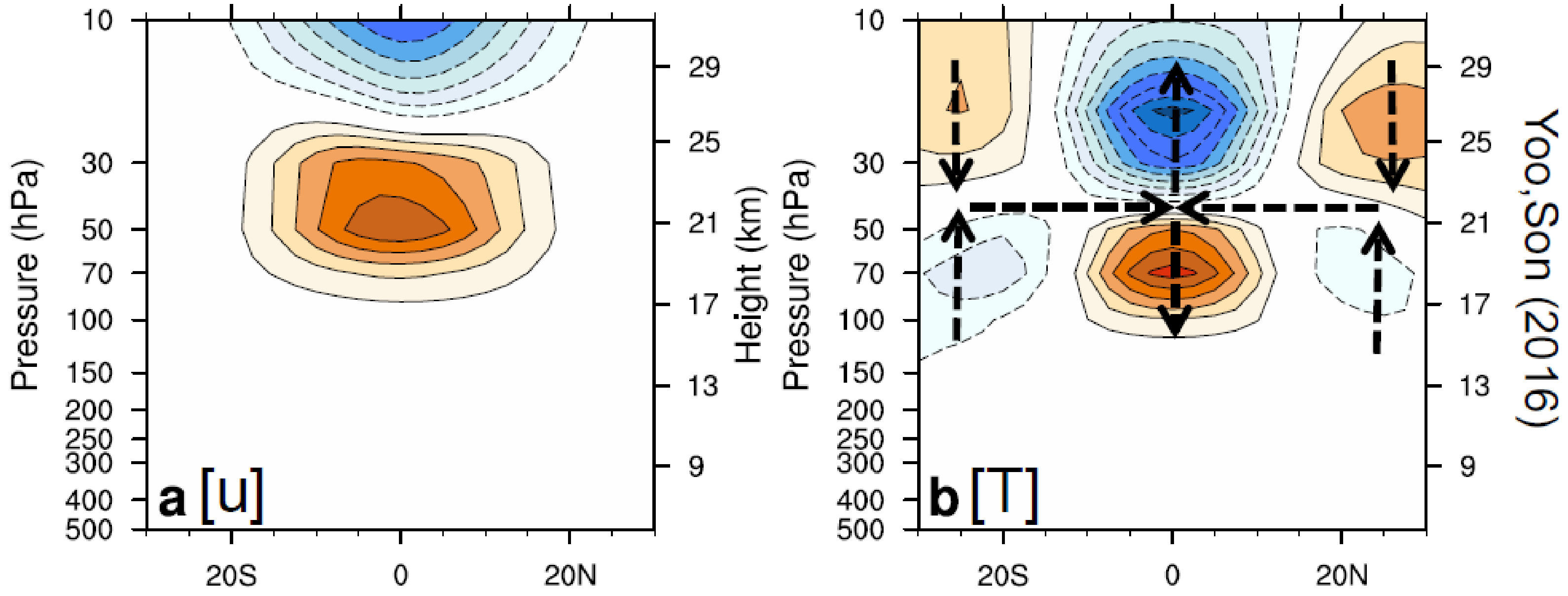


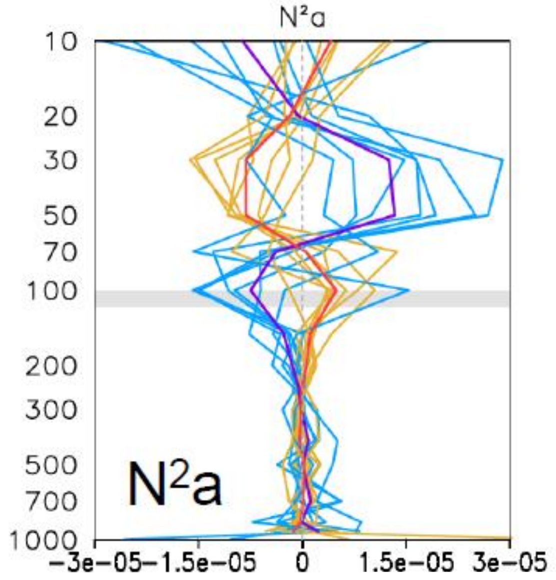
- No more gain for ML compared to 3D ocean

Courtesy E. De Boisseson

Impact of the QBO?

West minus East QBO Composite





EQBO
WQBO

Westerly at 50 hPa is associated with warm anomaly at 70 hPa through secondary circulation.

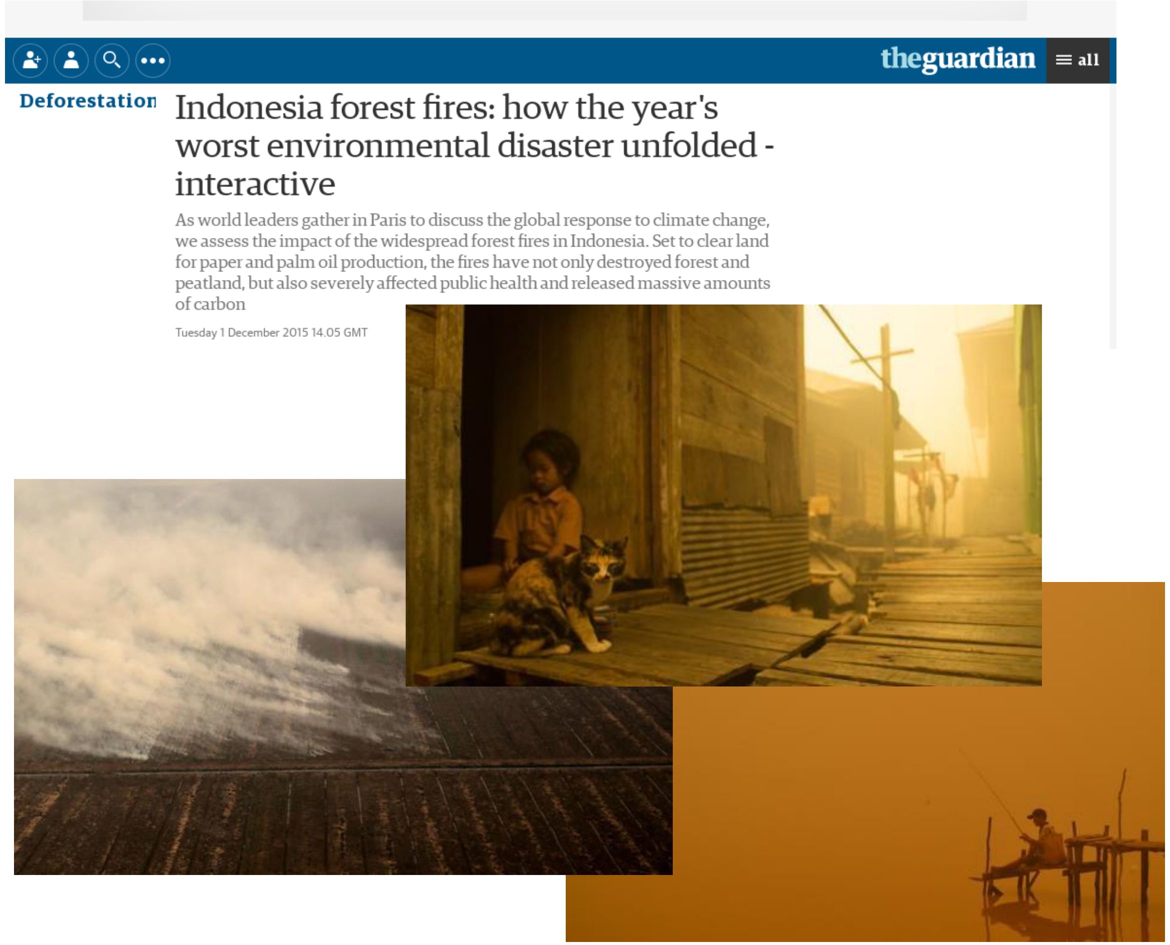
Yoo et al. 2015

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?

INDONESIAN FIRES (AUG-OCT 2015)



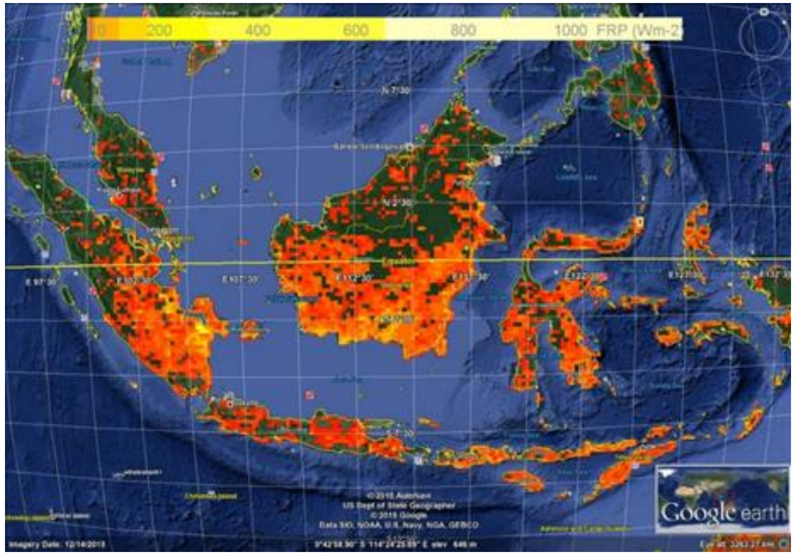
theguardian all

Deforestation

Indonesia forest fires: how the year's worst environmental disaster unfolded - interactive

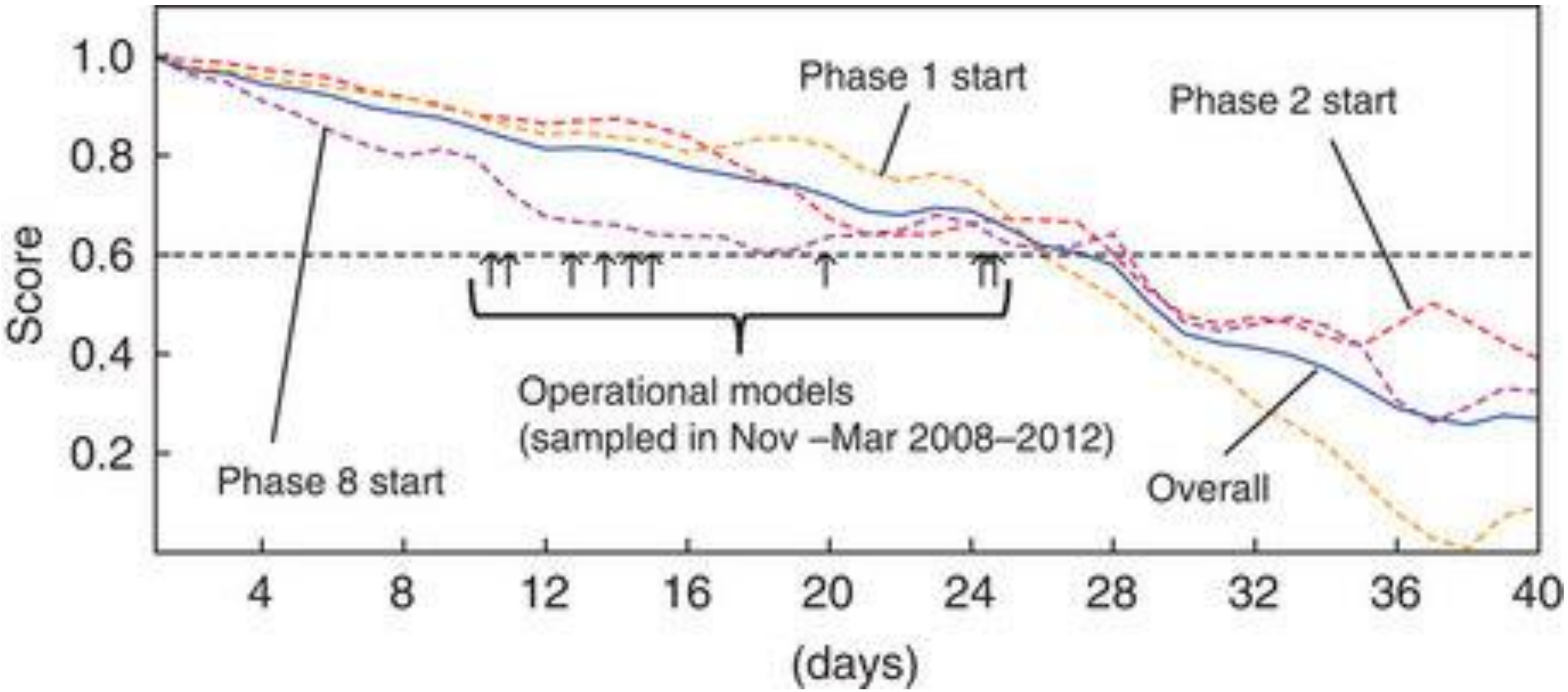
As world leaders gather in Paris to discuss the global response to climate change, we assess the impact of the widespread forest fires in Indonesia. Set to clear land for paper and palm oil production, the fires have not only destroyed forest and peatland, but also severely affected public health and released massive amounts of carbon

Tuesday 1 December 2015 14.05 GMT



Fire Radiative Power (W/m2) accumulated over Indonesia during the 2015 fire season (Aug-Oct). Credits: Francesca Di Giuseppe

Towards cloud-resolving models

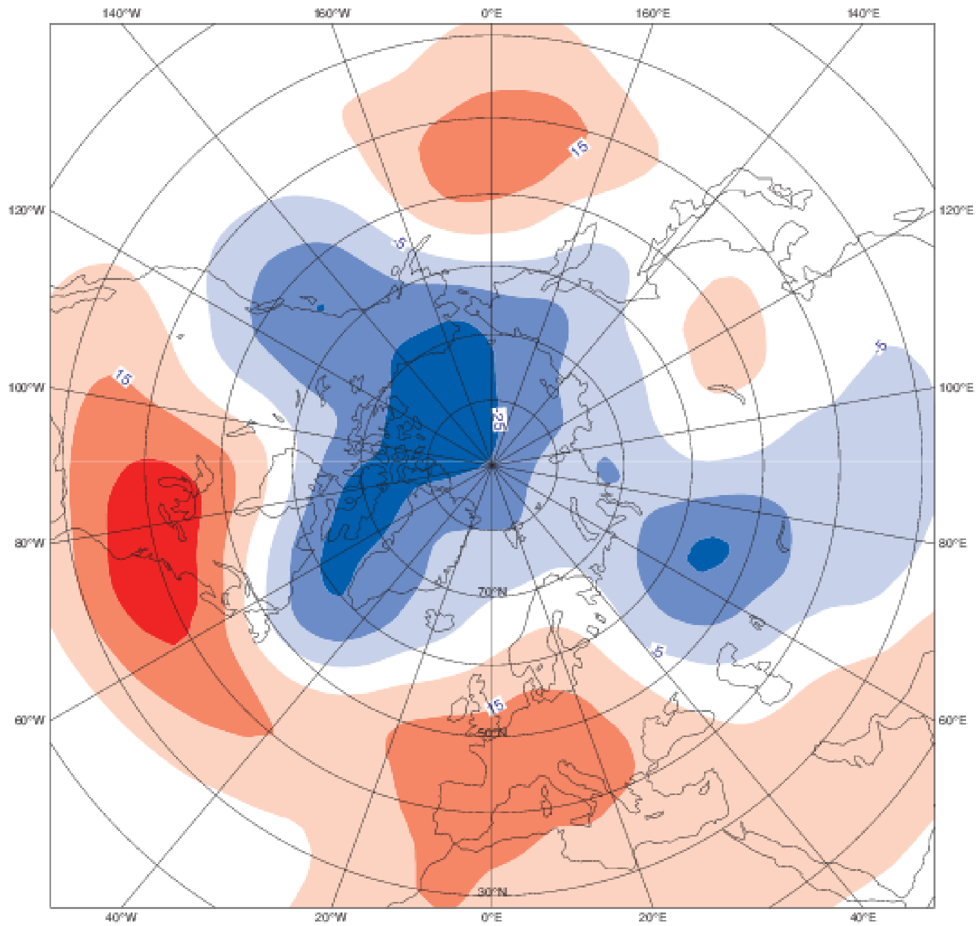


Nicam,14 km resolution

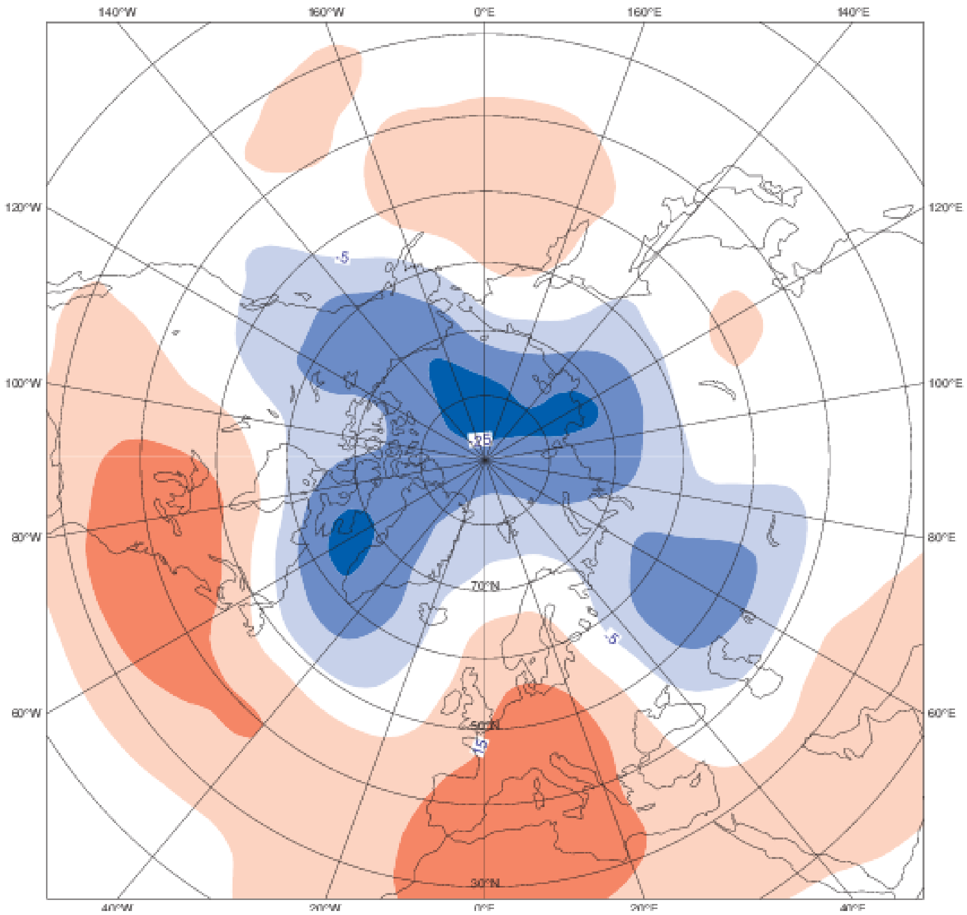
Miyakawa et al, Nature, 2014

Z500 Composites 3rd pentad after an MJO in phase 3

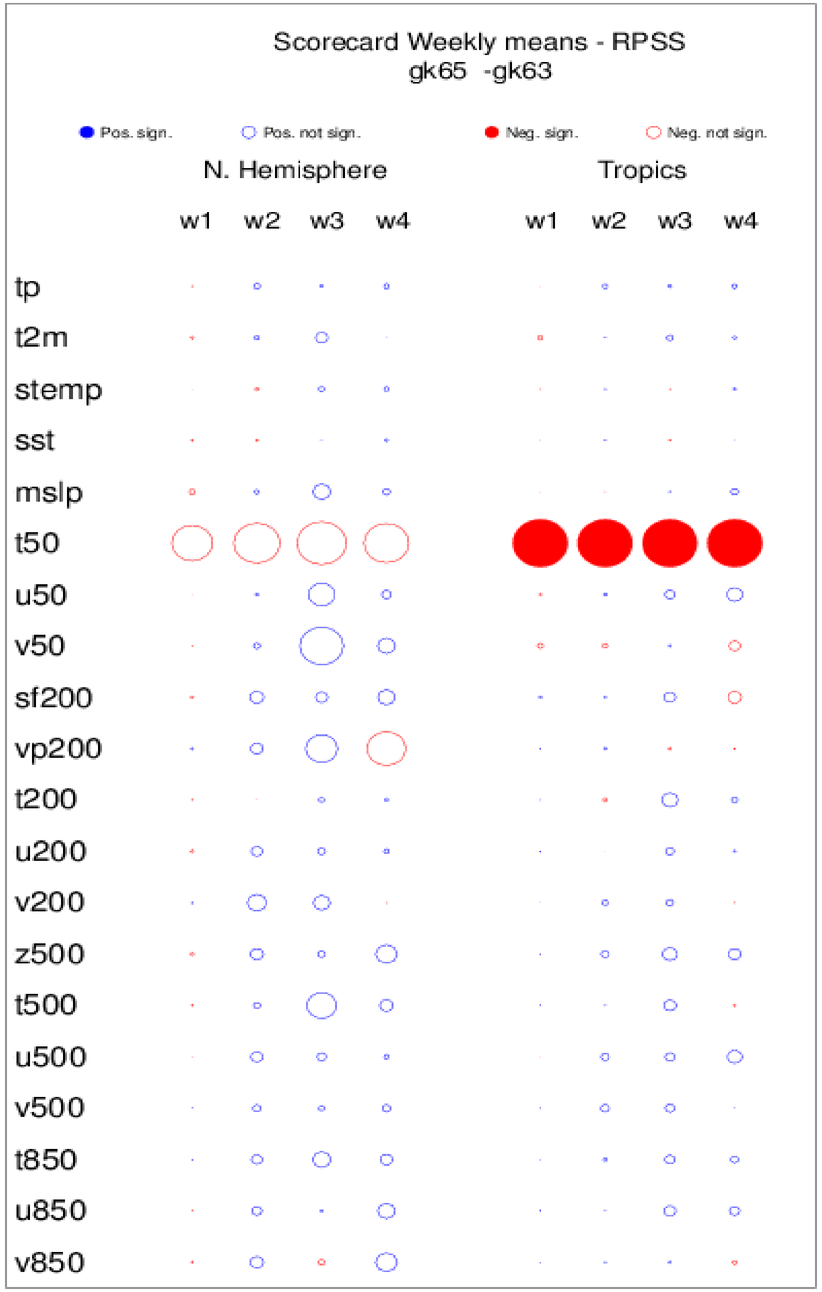
Persisted SSTs



Coupled

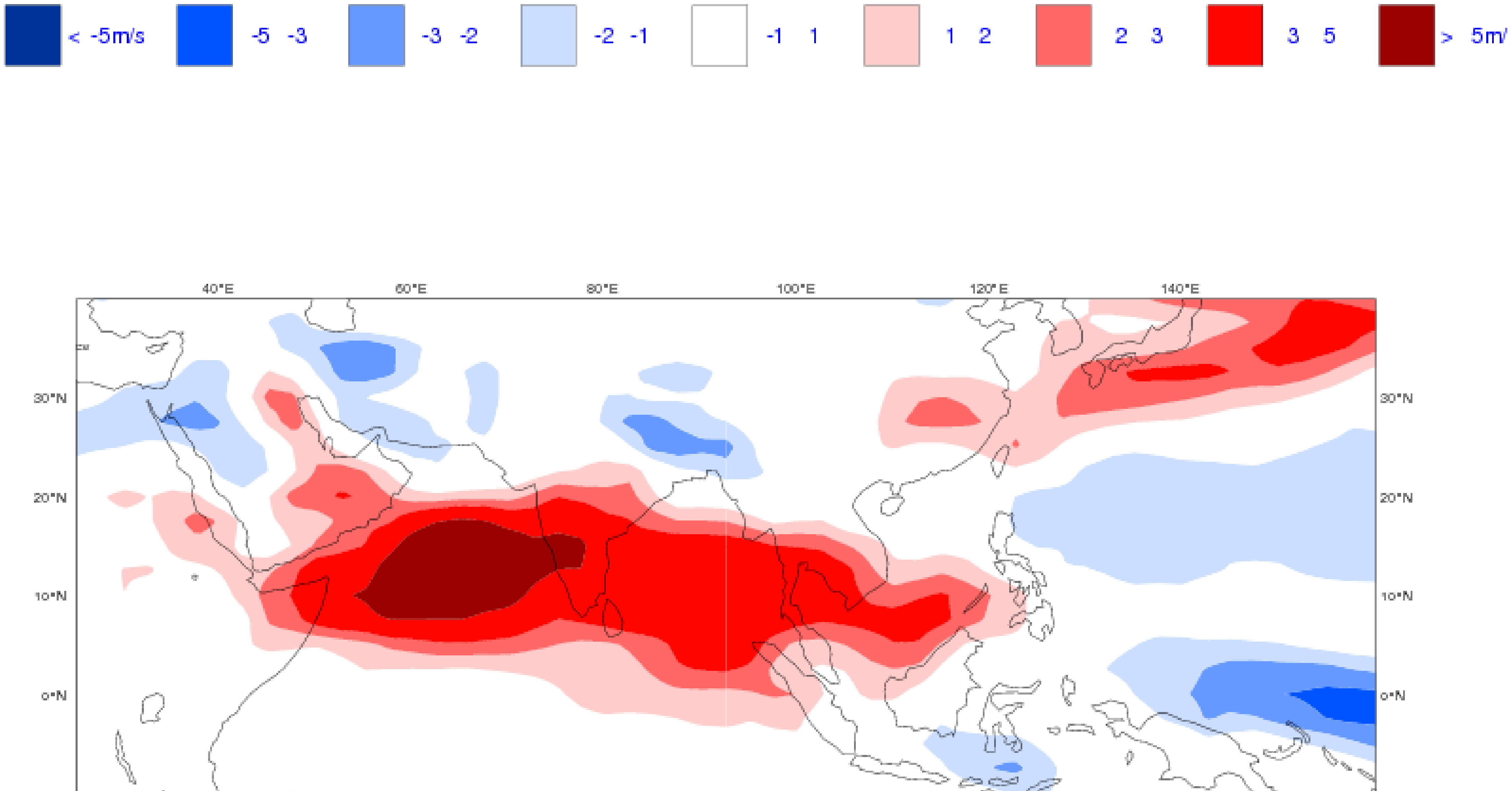


Impact of Active Ozone



gih1
850hPa Zonal Wind Bias
20030501-20140501

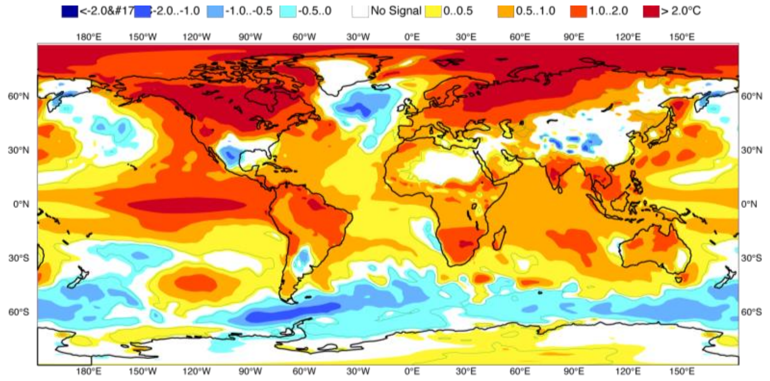
PERIOD:600-768



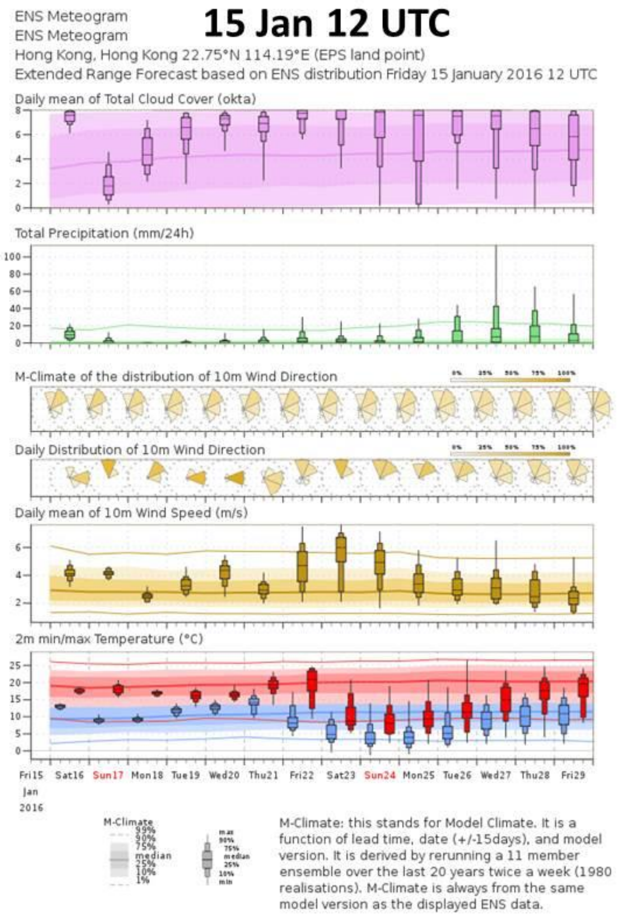
From medium-range to seasonal to extended range

Seasonal Forecast

DJF 2015/16



Medium-range



Extended-range