Sub-seasonal to Seasonal Prediction Project

"Bridging the gap between weather and climate"

나카자와 테츠오

WMO S2S ICO

NIMS/KMA

S2S Homepage at www://s2sprediction.net

THORPEX

A World Weather Research Programme

Accelerating improvements in the accuracy
of one-day to two weeks high-impact weather forecasts
for the benefit of society, economy and environment

2005

2014...

A photographic collage depicting the societal, economic and ecological impacts of severe weather associated with four Rossby wave-trains that encircled the globe during November 2002.

WMO
OMM

THORPEX

THORPEX
A World Weather Research Programme

- **Eight Core Research Objectives**
  - Increase knowledge of global-to-regional influences on the initiation, evolution and predictability of high-impact weather.
  - Contribute to the design and demonstration of interactive forecasting systems
  - Contribute to the development of advanced data assimilation and ensemble prediction systems.
  - Develop and apply new methods that enhance the utility and value of weather forecasts to society, economies and environment stewardship.
  - Carry out THORPEX Observing-System Tests and THORPEX Regional field Campaigns.
  - Demonstrate all aspects of THORPEX interactive forecasting systems, over the globe for a season to one year, to assess the utility of improved weather forecasts and user products.
  - Coordinate THORPEX research with the World Climate Research Programme Coordinated Observation and Prediction of the Earth System (WCRP/COPES) and the mesoscale/microscale community to address the observational and modeling requirements for the prediction of weather and climate for two weeks and beyond.
  - Facilitate the transfer of the results of THORPEX weather prediction research and its operational applications to developing countries through the WMO

WMO
OMM

Achievements of THORPEX

A World Weather Research Programme

- Increased knowledge of processes and predictability associated with High Impact Weather Events
- Improved forecasts for such events on synoptic scales from days to about two weeks
- Advanced research on global observing and data assimilation systems and of adaptive observations (Campaigns, DTS)
- Fostered research on EPS and their usage
- Enhanced cooperation between operational and academic research communities
- First attempt to socio-economic research applications (SERA)

THORPEX

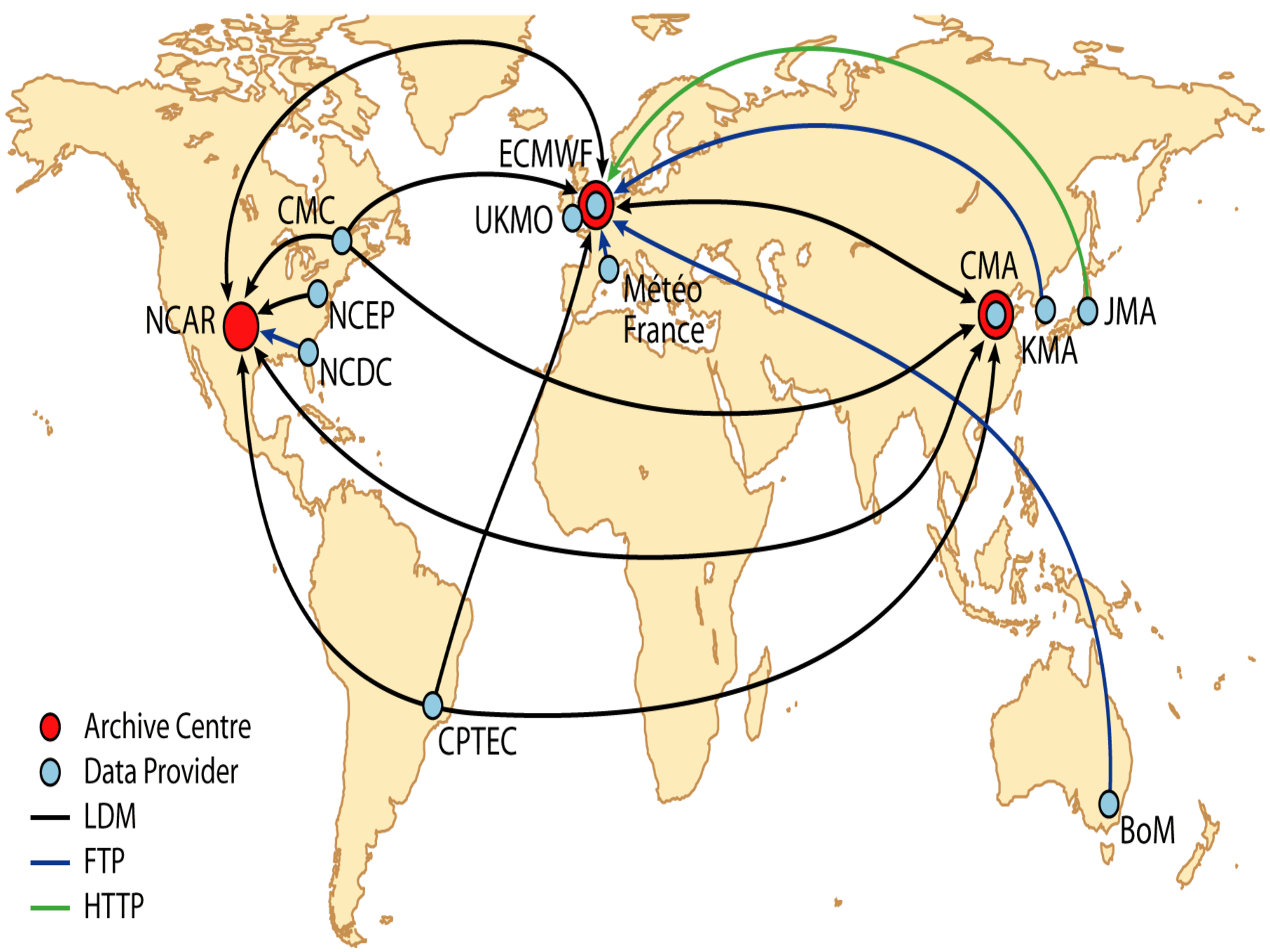
TIGGE

THORPEX Interactive Grand Global Ensemble

- A major component of THORPEX: a World Weather Research Programme to accelerate the improvements in the accuracy of 1-day to 2-week high-impact weather forecasts
- Over 500 GB data flow a day from 10 Operation Centers

Objectives:

- Enhance collaboration on ensemble prediction, both internationally and between operational centres & universities.
- Facilitate research on ensemble prediction methods, especially methods to combine ensembles and to correct systematic errors
- Enable evolution towards a prototype operational system, the "Global Interactive Forecast System"



WMO OMM

Achievements of THORPEX

A World Weather Research Programme

- Major International Field Programs
  (ATReC&E-TReC;T-PARC&TCS08; link to HyMEX; IPY; T-NAWDEX-Falcon)

- TIGGE: Operational EPS data used by research community

- Year of Tropical Convection (YOTC; link to MJO & WCRP)

- Dedicated funding obtained for THORPEX research
  (DIAMET, GEOWOW, PANDOWAE, PREVIEW, **PREVASSEMBLE, T-PARC, IPY-Cluster**)

THORPEX

THORPEX A World Weather Research Programme did not

- address longer time- and space scales important for climate and weather interface
- investigate model errors and non-linear error growth
- focus on verification
- consider how to meet requirements for applications
- investigate how to cover future needs of WMO members under a climate change condition

WMO OMM

Subseasonal-to-Seasonal
S2S
Prediction Project

Objectives

- "To improve forecast skill and understanding on the subseasonal to seasonal timescale with special emphasis on high-impact weather events"

- "To promote the initiative's uptake by operational centres and exploitation by the applications community"

- "To capitalize on the expertise of the weather and climate research communities to address issues of importance to the Global Framework for Climate Services"

Project timescale and scope

- This project focuses on the time range between two weeks and a season (e.g. 15-60 days). This time range bridges the gap between weather and climate forecasting.

- This project includes:

➢ Setting up a TIGGE-like database for sub-seasonal to seasonal prediction

➢ Demonstration projects

➢ Research activities as defined by the objectives

S2S History

Mar 2012	S2S Planning Group meeting in Geneva
Jun 2012	WMO 64th Session of Executive Council - Establishment of S2S and PPP Projects
Feb 2013	S2S Planning Group meeting in Exeter
May 2013	MoU on S2S ICO between WMO and KMA at WMO Executive Council
Nov 2013	S2S ICO Opening Ceremony and S2S Workshop in Jeju Transform of the Planning Group to the Steering Group
Feb 2014	S2S Workshop and S2S SG meeting in College Park
Aug 2014	World Weather Open Science Conference - Special Session on S2S and PPP
May 2015	Monsoon Workshop in Jeju
Apr 2016	Maritime Continent-MJO Workshop in Singapore

S2S History

Feb 2014	S2S Workshop and S2S SG meeting in College Park
Aug 2014	World Weather Open Science Conference - Special Session on S2S and PPP
Fall 2014	THORPEX ICSC-12 and WWRP JSC-7
Dec 2014	International Workshop on Tropical Cyclone in Jeju Closure of the THORPEX Programme
Jan 2015	Two new WGs under WWRP - WG on Predictability, Dynamics and Ensemble Forecast - WG on Data Assimilation and Observation Systems

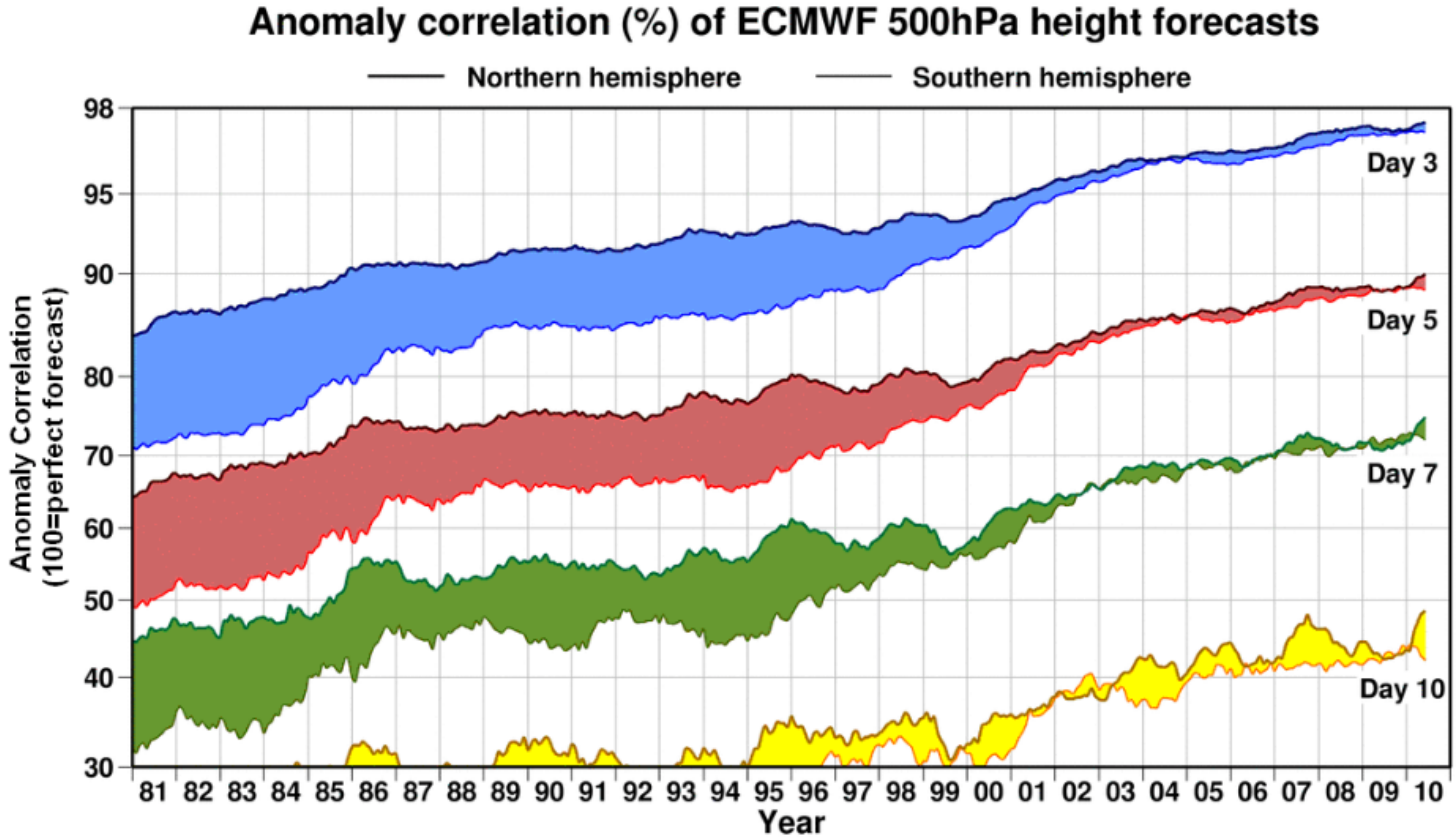


FIGURE 2.1. Evolution of ECMWF forecast skill for varying lead times (3 days in blue; 5 days in red; 7 days in green; 10 days in yellow) as measured by 500-hPa height anomaly correlation. Top line corresponds to the Northern Hemisphere; bottom line corresponds to the Southern hemisphere. Large improvements have been made, including a reduction in the gap in accuracy between the hemispheres. SOURCE: courtesy of ECMWF, adapted from Simmons and Hollingsworth (2002).

Source: NAS Report (2010)

Predictability Beyond the Deterministic Limit
(by Brian Hoskins, 2012)

The traditional idea of a deterministic limit is questioned by considering the possibility of some predictive skill on all time-scales from hours to decades. The discussion is framed in terms of the seamless weather-climate prediction problem.

- Contradiction between the fact that predictions are increasingly being attempted for months, seasons and longer and the idea that the atmosphere is essentially unpredictable beyond about two weeks from the work of Lorenz (1969)

- In most recent years there has been a realisation that forecasts on all scales should be probabilistic.

- The behavior of the atmosphere can often seem like noise, but we are looking for the patterns of behavior: the music.

- Understanding, and improved simulation and prediction at one scale, can provide valuable support for prediction on longer time-scales (ex. improvement in the forecasting of individual blocking events should help in improvement of the simulation over 20th century by climate models and more confidence in projections for changes in blocking at the end of the 21st century).

Maturity of Operational Numerical Weather Prediction: Medium Range

(by Eugenia Kalnay, S. J. Lord, and R. D. McPerson, BAMS, 1998)

- In 1960's Lorenz discovered that the chaotic nature of the atmosphere imposes a finite limit of about two weeks to weather predictability. At that time this fundamental discovery was "only of academic interest" and not really relevant to operational weather forecasting, since at that time the accuracy of even a 2-day forecast was rather poor. Since then, however, computer-based forecasts have improved so much that Lorenz's limit of predictability is starting to become attainable in practice, especially with ensemble forecasting, and the predictability of longer-lasting phenomena such as El Niño is beginning to be successfully exploited.

- The skill of operational weather forecasts has at least doubled over the last two decades. This improvement has taken place relatively steadily, driven by a large number of scientific and computational developments, especially in the area of NWP. It has taken place in all the operational NWP centers, as friendly competition and information sharing make scientific improvements take place faster than they would in a single center. Because the improvements have occurred steadily, rather than suddenly, the overall increase in forecast skill due to NWP has not been clearly recognized by the media and the public despite the impact that improved forecasts have on the national economy and on the lives of every American.

Maturity of Operational Numerical Weather Prediction: Medium Range

(by Eugenia Kalnay, S. J. Lord, and R. D. McPerson, BAMS, 1998)

- The authors discuss new approaches in the use of observation (variational assimilation of remote observations) and of numerical weather prediction guidance (ensemble forecasting) that have allowed the recent extension of operational predictions into longer ranges and the possibility of adaptive observing systems.

- **Ensemble forecasting provides the basic tool to extend forecasts beyond Lorenz's 2-week limit of weather predictability.** Slowly varying surface forcing, especially from the tropical ocean and from land surface anomalies, can produce atmospheric anomalies that are longer lasting and more predictable than individual weather patterns. **The most notable of these is the ENSO** produced by unstable oscillations of the coupled ocean-atmosphere system with a frequency of 3-7 yr.

Some S2S Modeling issues

- **Initial conditions:** The approach for medium-range forecasting has been to use the most accurate initial conditions possible for the atmosphere and to largely ignore the more slowly varying ocean conditions. For seasonal prediction, the initial conditions of the coupled system are important, particularly the upper ocean, and the rapidly varying components of the atmosphere are often less well predicted and initialised. The solution for the sub-seasonal timescale probably lies somewhere in-between.

- **Ensemble generation:** Should the focus be on optimal methods of perturbing the initial conditions, e.g. breeding methods that capture the leading modes of coupled model error growth, or should the focus be on perturbing the slow modes of the coupled system, e.g. the MJO and annular modes? Which is better: a lagged ensemble or a "burst" ensemble?

- **Ocean-atmosphere coupling:** The time scale of sub-seasonal prediction is such that the influence of initial conditions on the predictability is on the wane while the contribution from slowly evolving oceanic conditions may be on the rise.

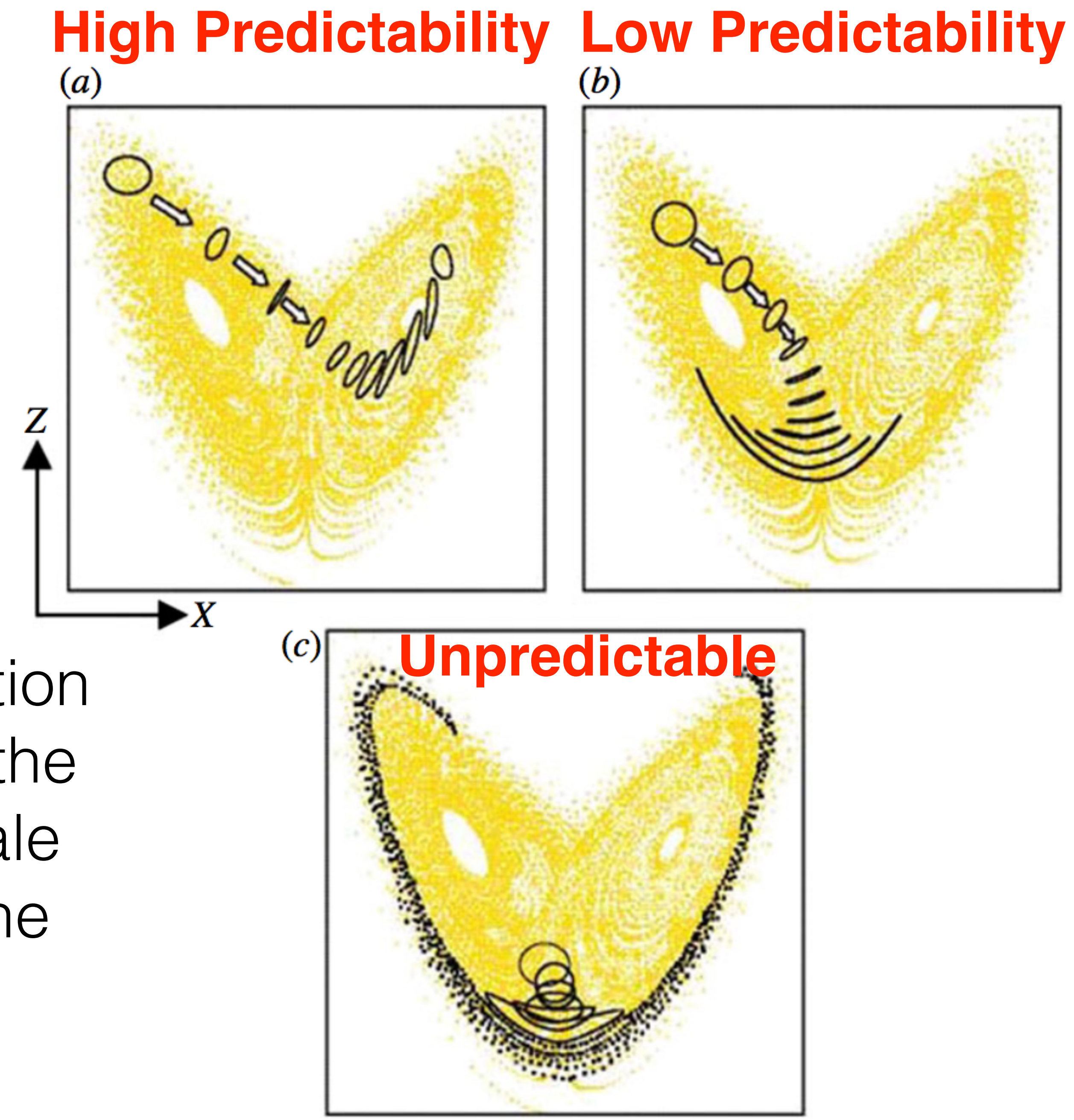
- **Resolution:** What processes are improved by increasing model resolution? What is the role of resolution in reducing mean biases? How are reductions in mean biases related to improved physical processes? Is there consistency across models; following the example below, do models with a high resolution ocean have a better representation of blocking?

Courtesy: A. Robertson

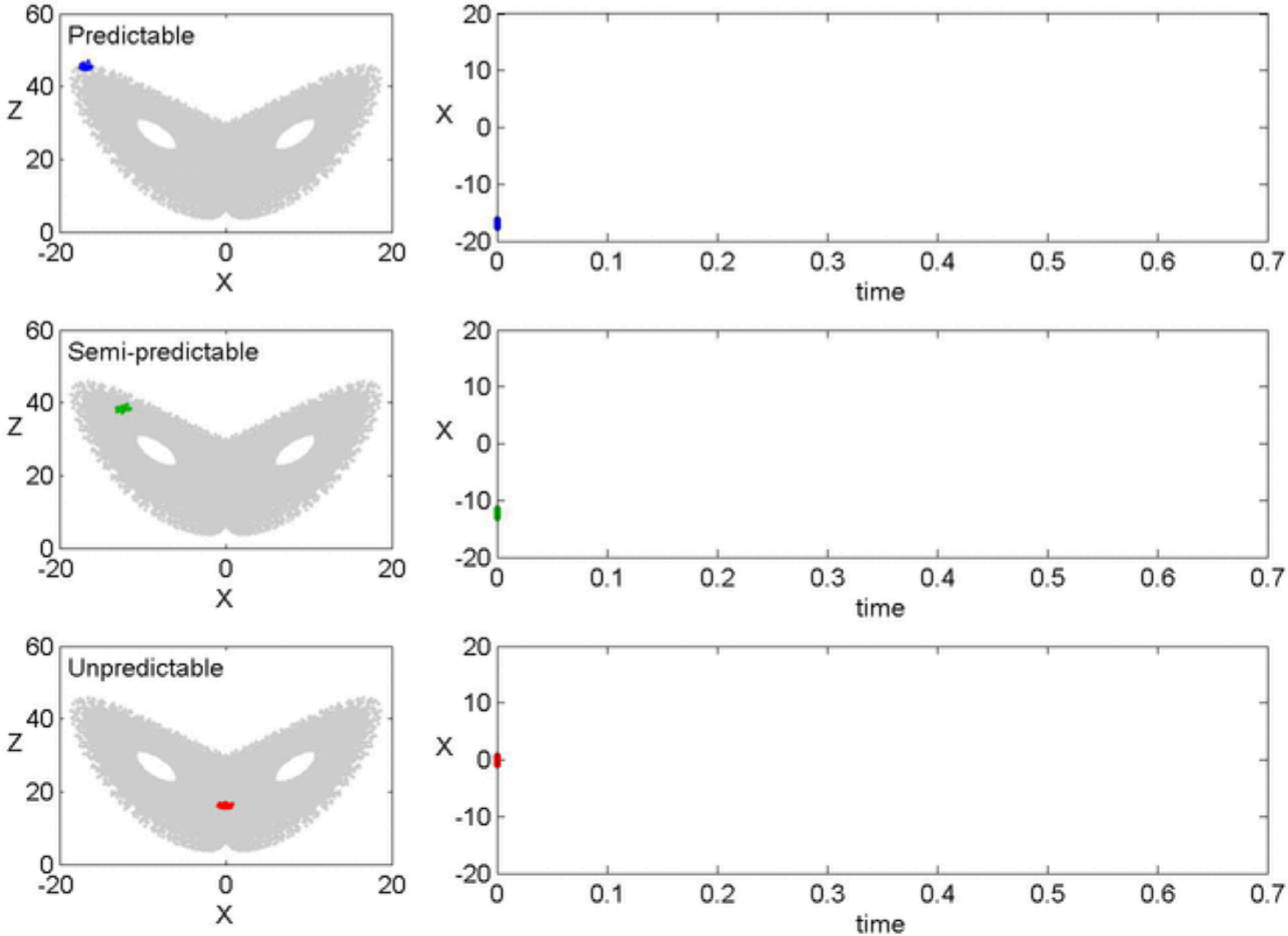
Uncertainty in weather and climate prediction
(by Julia Slingo and Tim Palmer, 2011)

The Lorenz model indicates that the predictability of a chaotic system is flow dependent; while <u>some weather patterns or regimes may be highly unpredictable, others may contain substantial predictability; in other words, the predictability is itself both variable and predictable.</u>

Lorenz also showed that **errors at the cumulus scale can invade the errors at the synoptic scale in two days and infect the very largest scales in two weeks.** Thirty years later, the relevance of this study has been realized in the development of stochastic approaches to represent cumulus convection and its upscale energy transports, and in the emerging efforts to resolve these multi-scale processes in atmospheric simulations at the cloud system-resolving scale.



How is the predictability of a chaotic system "flow dependent"?



https://www2.physics.ox.ac.uk/research/predictability-of-weather-and-climate

Sources of S2S Predictability

Inertia slowly changing

soil moisture, upper ocean heat content, snow cover, vegetation, water table variations, land heat content, polar sea ice

Patterns of variability quicker changing, than “Inertia”

convectively-coupled equatorial waves, MJO, SST, annular modes, Stratosphere-Troposphere Interaction, QBO, tropical instability waves, ENSO, Indian Dipole Mode, blocking high

External forcing

Greenhouse gases, anthropogenic aerosols, land use change, solar insolation, volcanoes

Source: NAS Report (2010)

Sources of S2S Predictability

Inertia

soil moisture, upper ocean heat content, snow cover, vegetation, water table variations, land heat content, polar sea ice

Patterns of variability

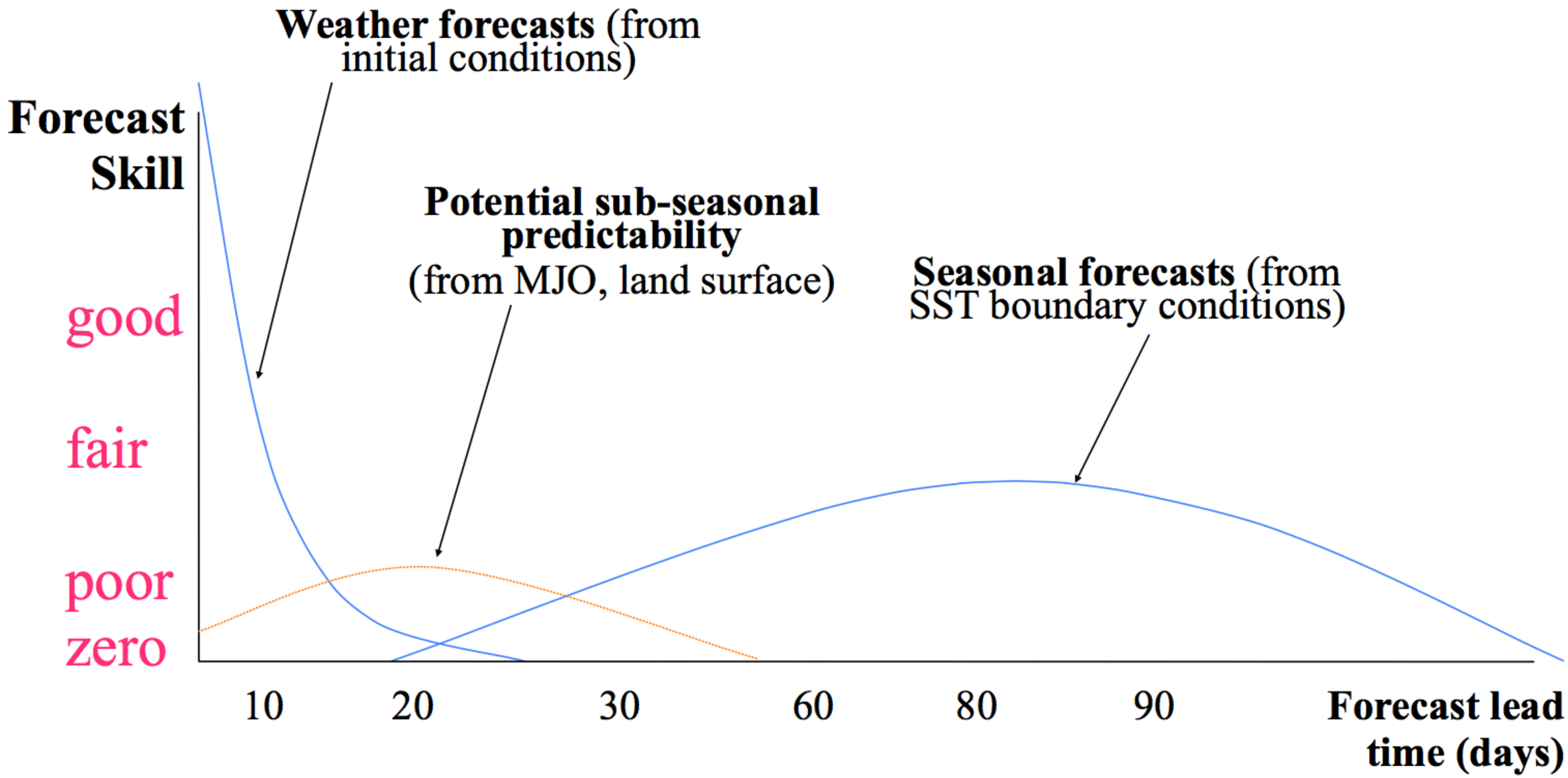
convectively-coupled equatorial waves, **MJO**, SST, annular modes, Stratosphere-Troposphere Interaction, QBO, tropical instability waves, **ENSO**, Indian Dipole Mode, blocking high

External forcing

Greenhouse gases, anthropogenic aerosols, land use change, solar insolation, volcanoes

There is a chance to extend the predictability by increasing our understanding of each source.

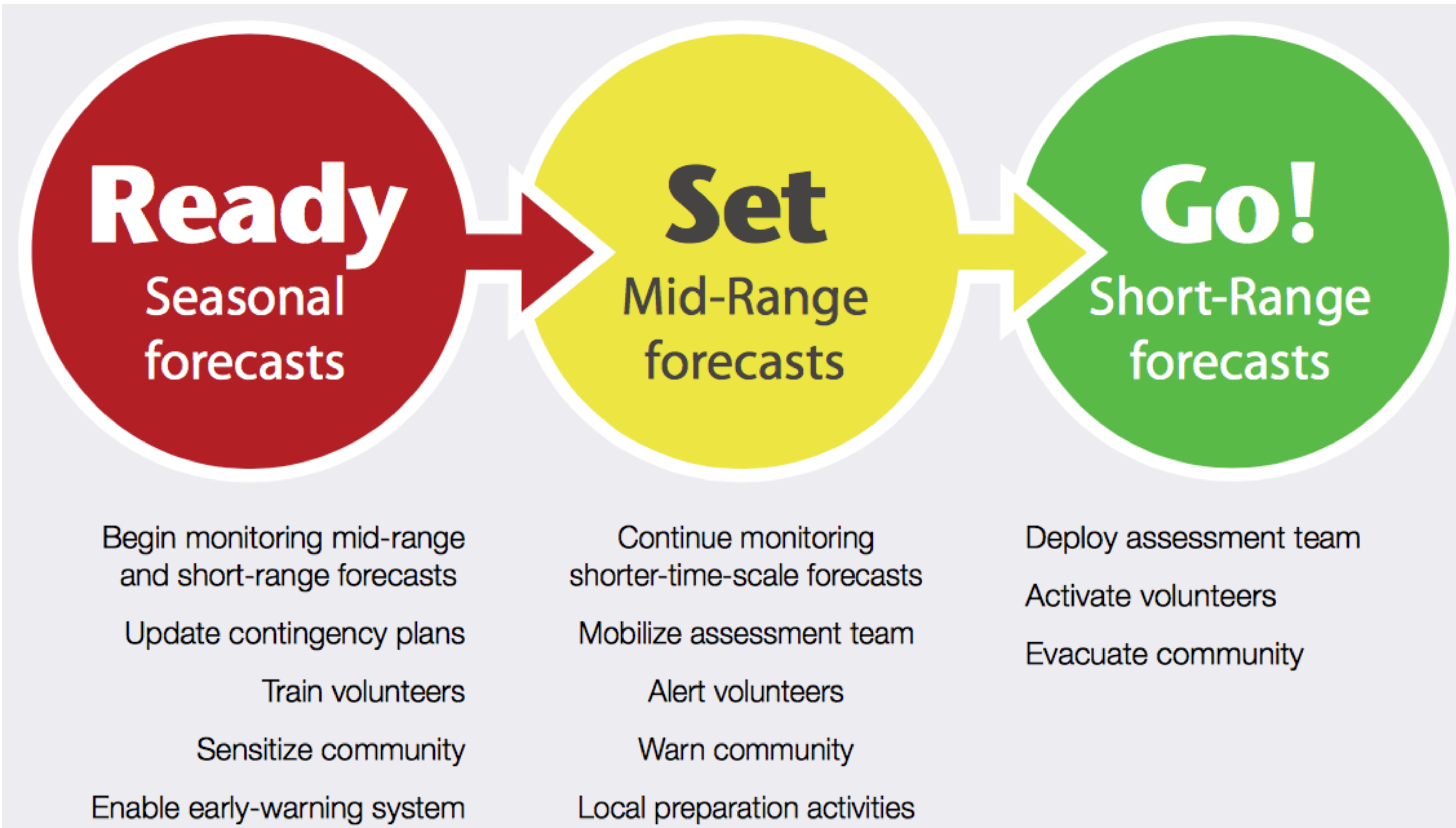
Source: NAS Report (2010)



S2S: where predictability in atmospheric state has been lost, but impact of SST boundaries is yet to be felt

Courtesy: A. Robertson/T. Barnston

Opportunity to use information on *multiple* time scales



Red Cross - IRI example

Courtesy IRI

ENSO

High Predictability

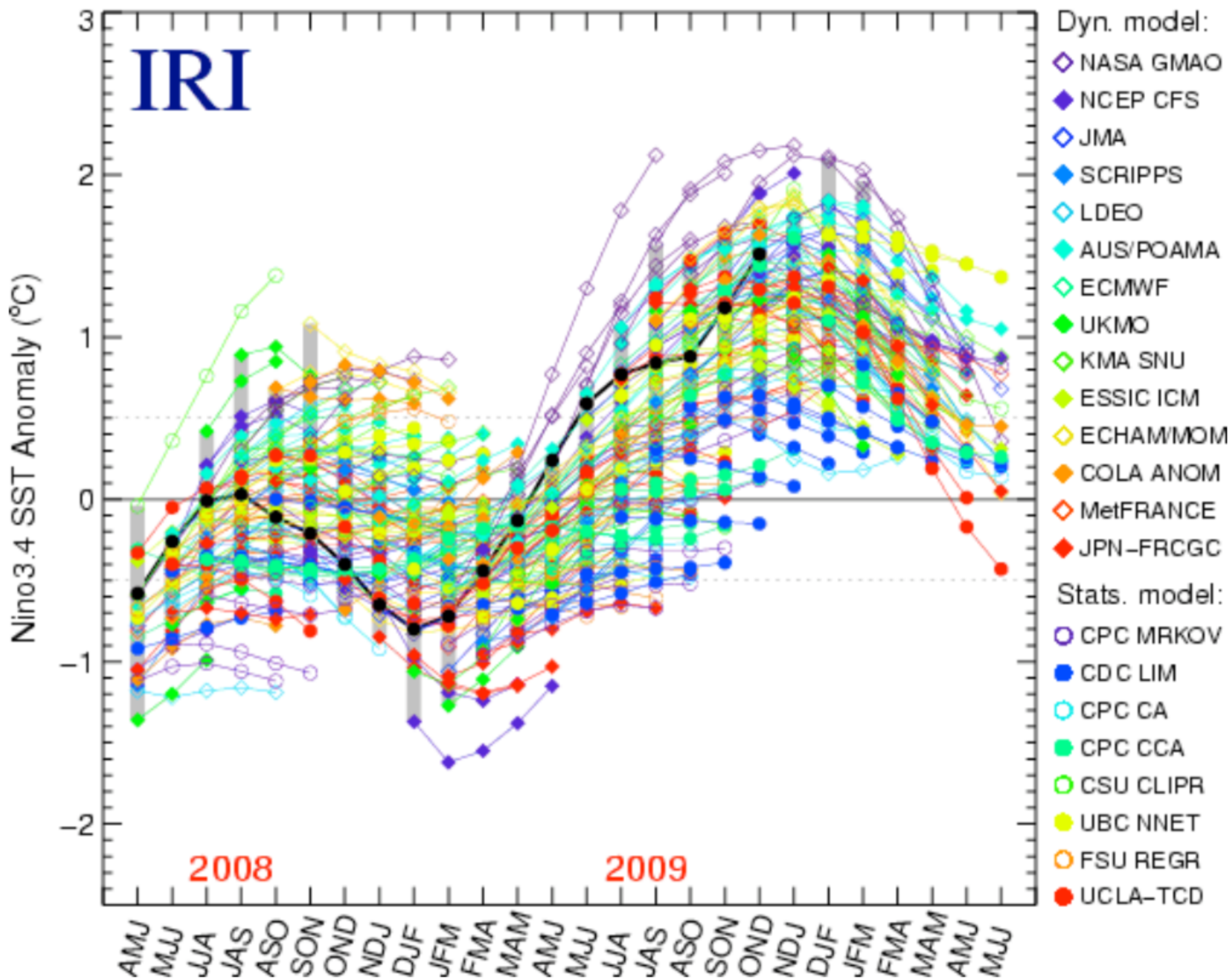


FIGURE 1.4 Predictions from various statistical (colored circles) and dynamical (colored diamonds) models along with observations (black circles) for SST anomalies in the equatorial Pacific Ocean. Many of the model predictions track the evolution of the anomalies, but the spread among the models is still rather large. The starting points of the models vary, and each prediction extends for approximately 5 months, since the predictions tend to diverge significantly after this period. SOURCE: International Research Institute for Climate and Society (IRI).

Courtesy: A. Robertson

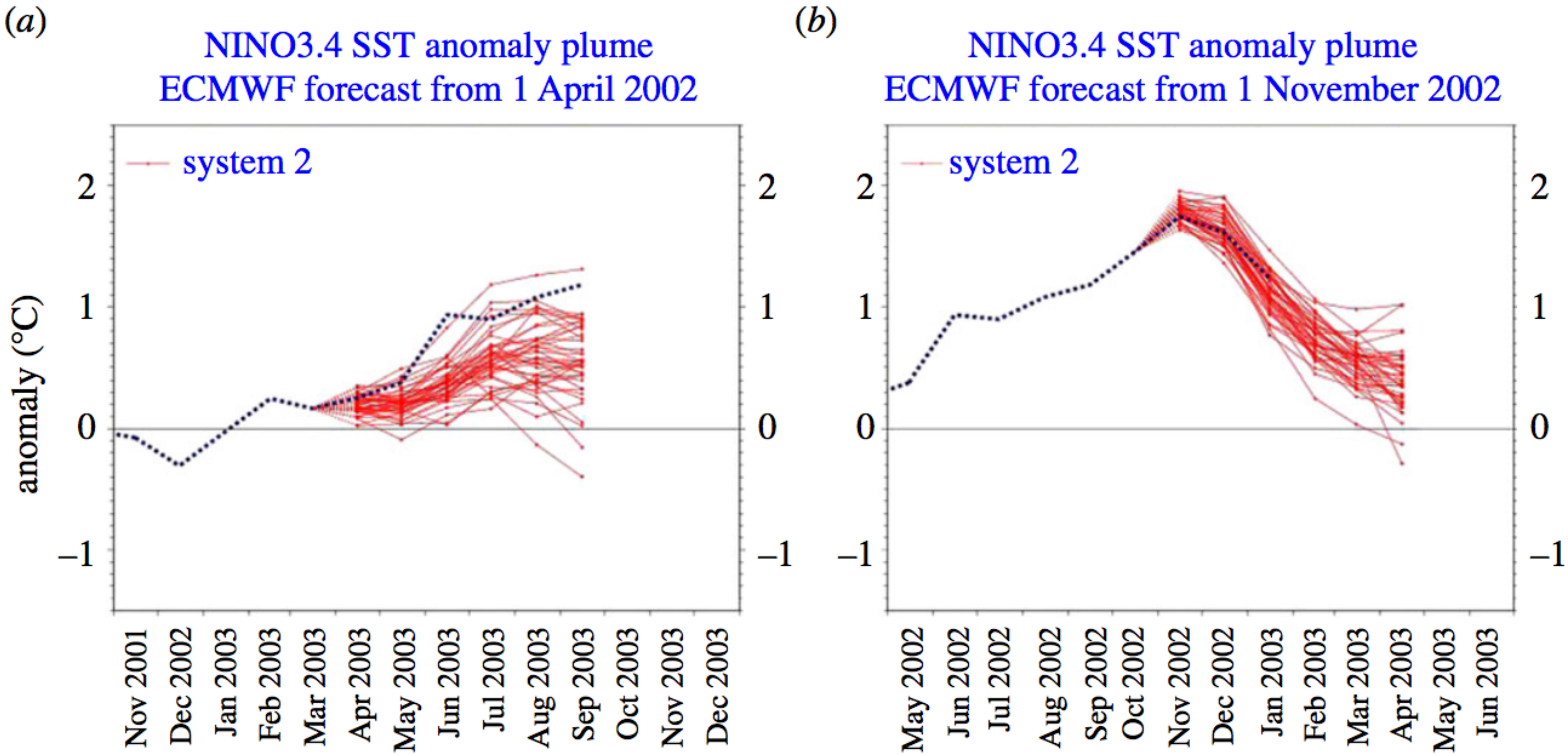
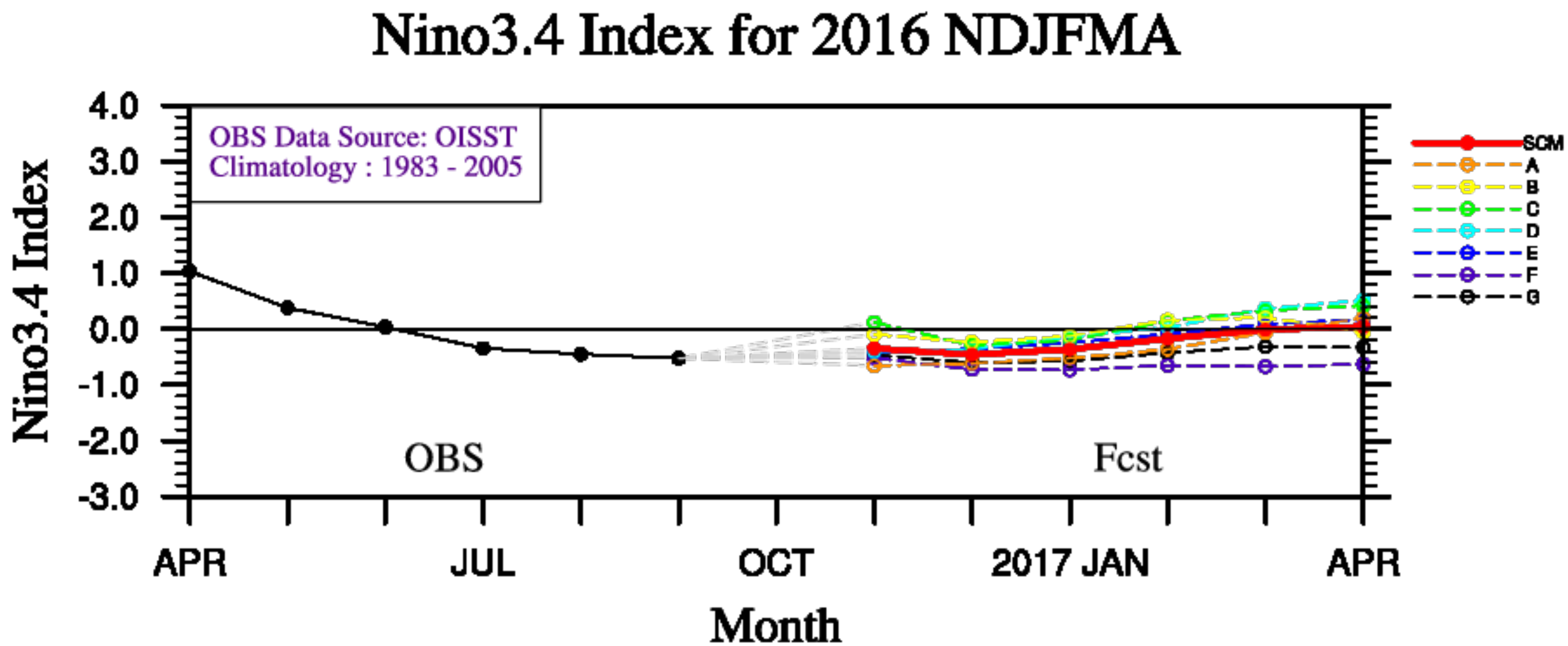
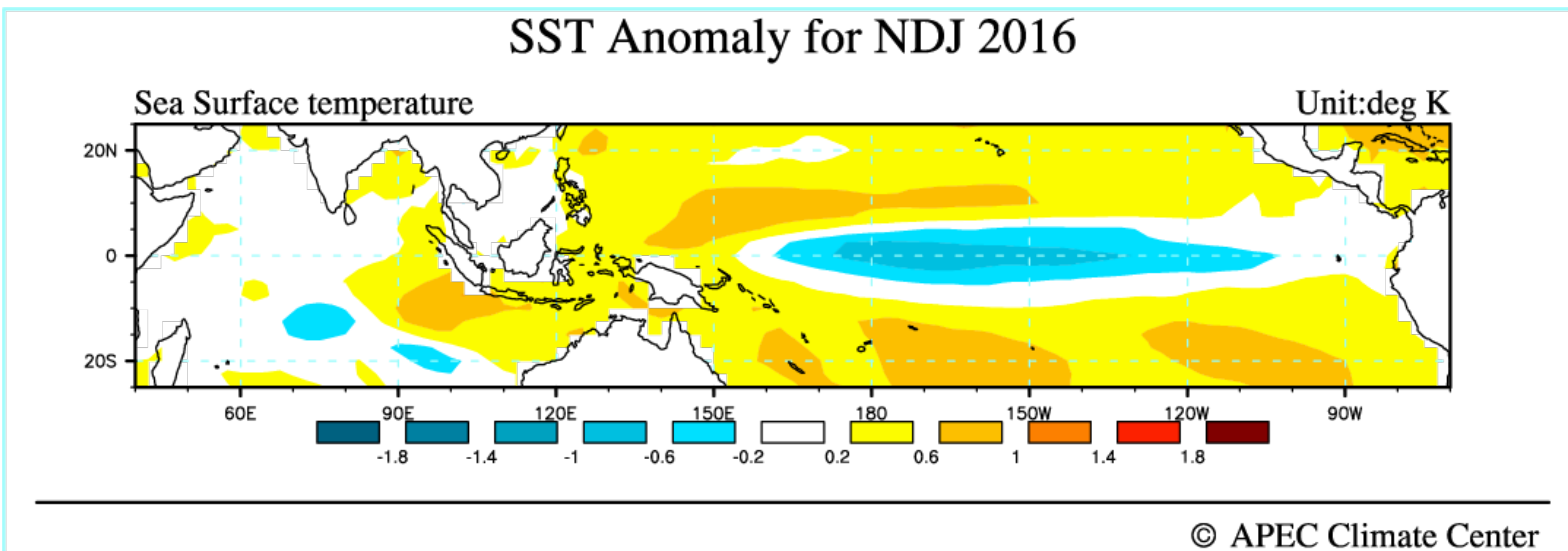


Figure 7. Two contrasting ensemble seasonal forecasts from the European Centre for Medium-range Weather Forecasts (ECMWF) for the evolution of El Nino. (*a*) The initiation of El Nino is difficult to forecast owing to stochastic forcing from the atmosphere, e.g. westerly wind events. (*b*) Decay of an El Nino is more predictable owing to the role of equatorial ocean dynamics.

(by Julia Slingo and Tim Palmer, 2011)

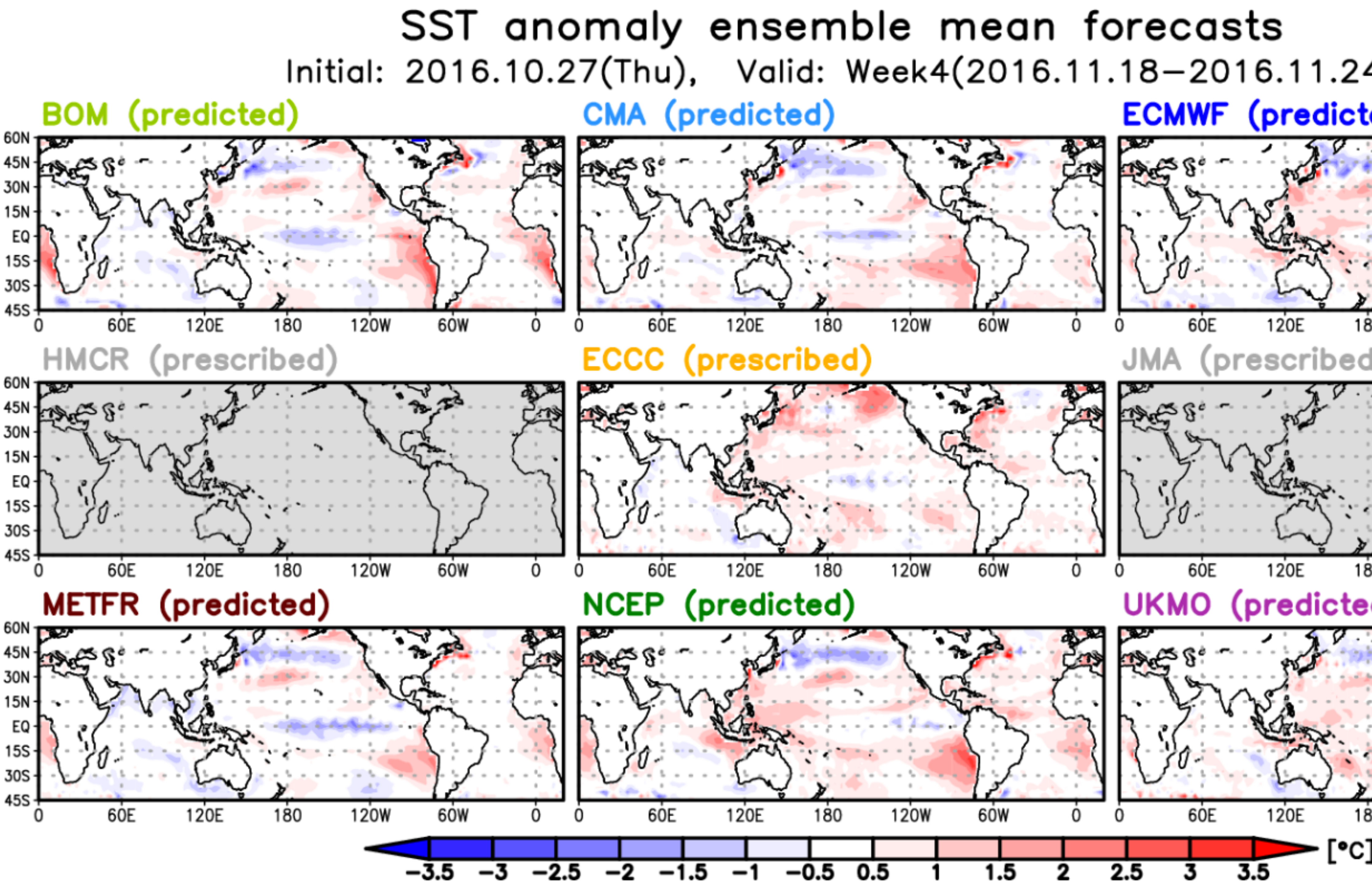
Seasonal ENSO Forecast at APCC





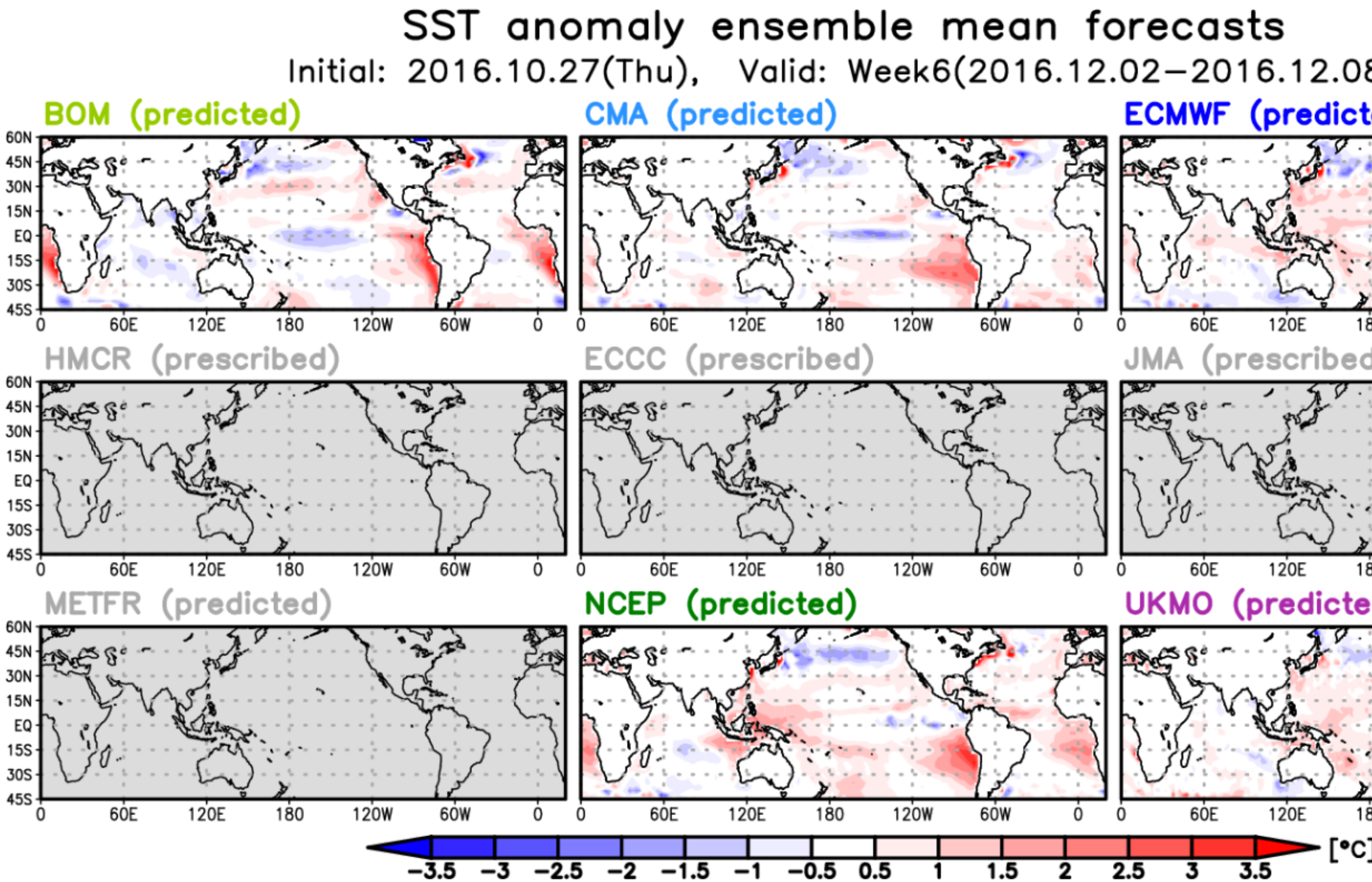
http://www.apcc21.net/ser/enso.do?lang=en

SST Forecasts (Week 4) at S2S Museum



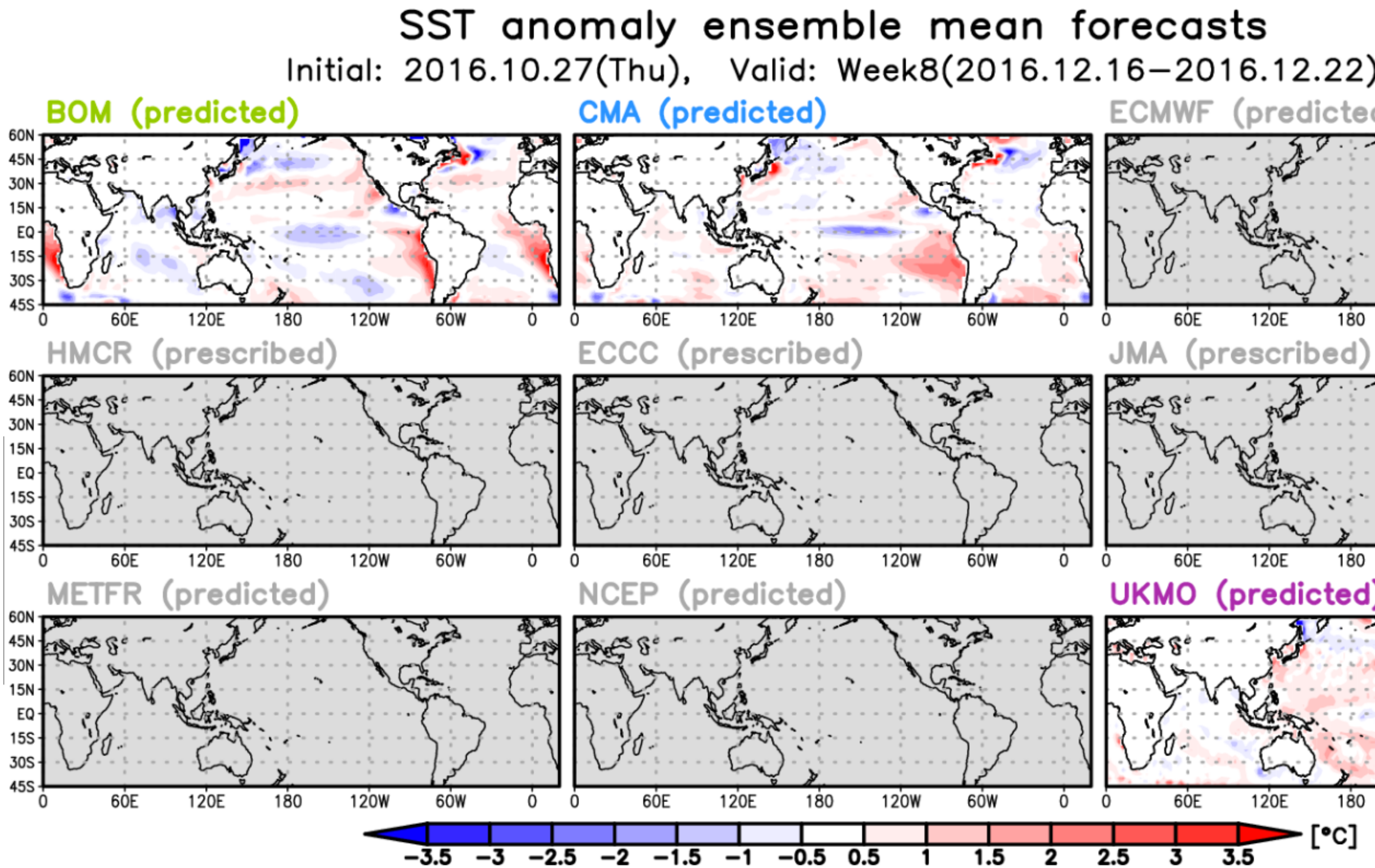
http://gpvjma.ccs.hpcc.jp/S2S/S2S_SSTmap.html

SST Forecasts (Week 6) at S2S Museum



http://gpvjma.ccs.hpcc.jp/S2S/S2S_SSTmap.html

SST Forecasts (Week 8) at S2S Museum

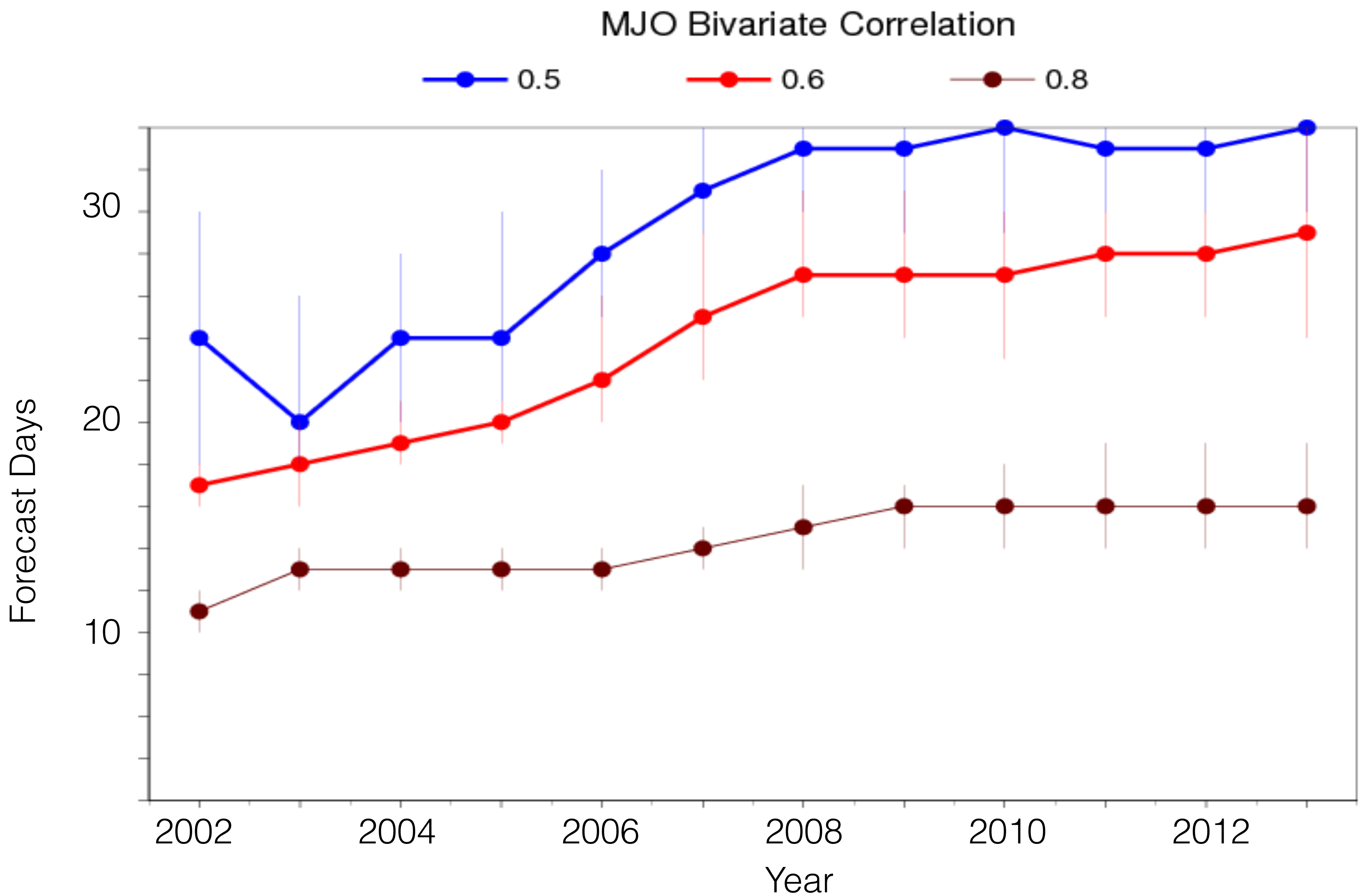


http://gpvjma.ccs.hpcc.jp/S2S/S2S_SSTmap.html

MJO

Progress in Predictability

MJO skill scores in ECMWF

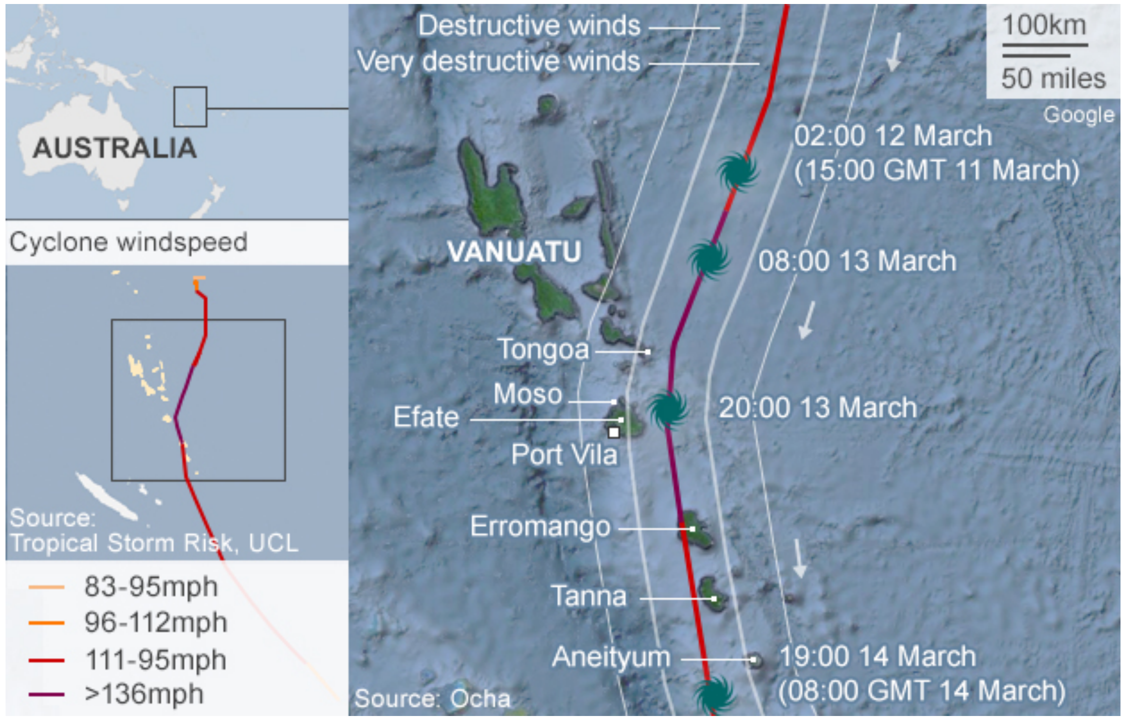


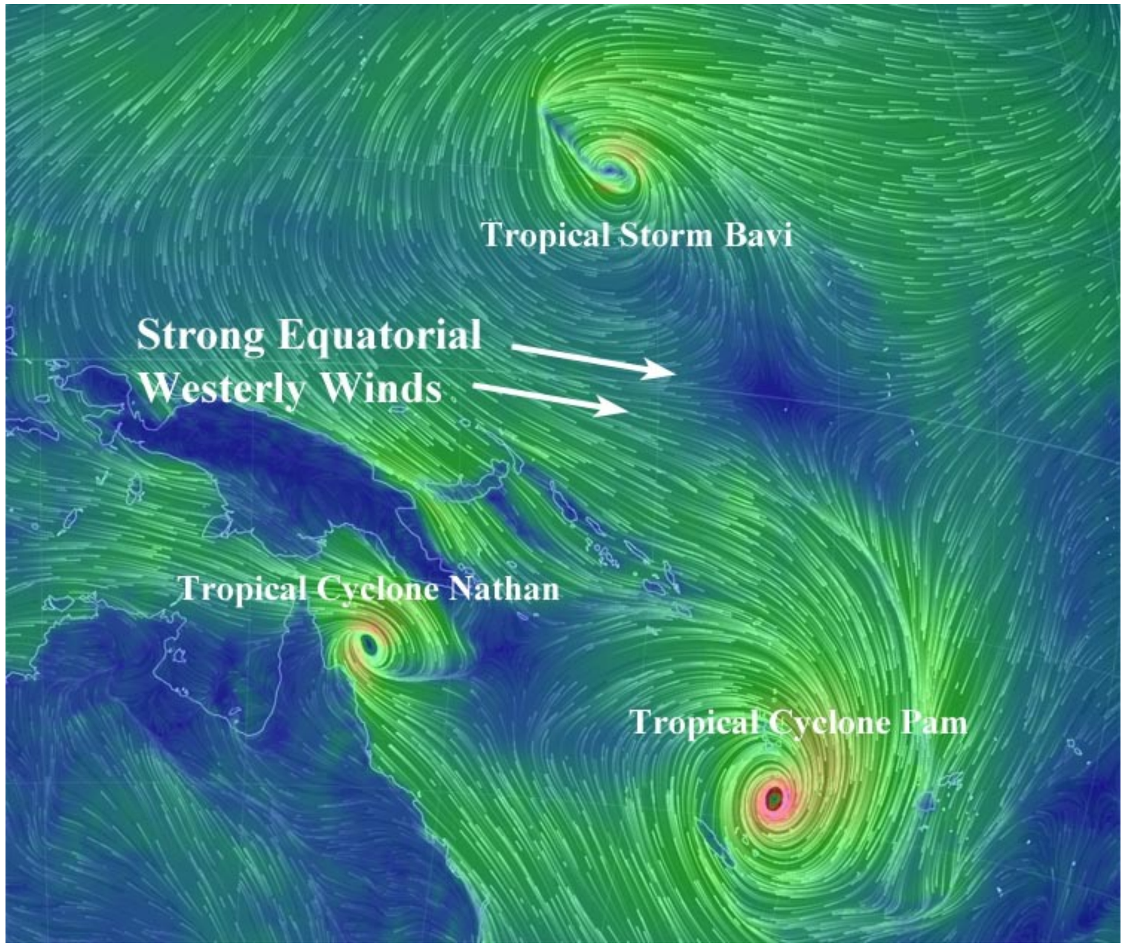
ECMWF has produced monthly forecasts routinely since March 2002. This figure shows the evolution of MJO skill scores since 2002. The MJO skill scores (bivariate correlations) have been computed on the model hindcasts produced during a complete year. For instance, 2002 indicates the hindcasts that were produced from March 2002 until March 2003. 2011 corresponds to the hindcasts produced from March 2011 until March 2012. The blue line indicates the day when the MJO bivariate correlation reaches 0.5. The red line indicates the day when the MJO bivariate correlation reaches 0.6 and the brown line indicates the day when the MJO bivariate correlation reaches 0.8. This suggests that the MJO skill scores have significantly improved over the past 10 years. If we consider the 0.6 correlation as a measure of MJO predictability, then the gain is of about 9 days of predictability.

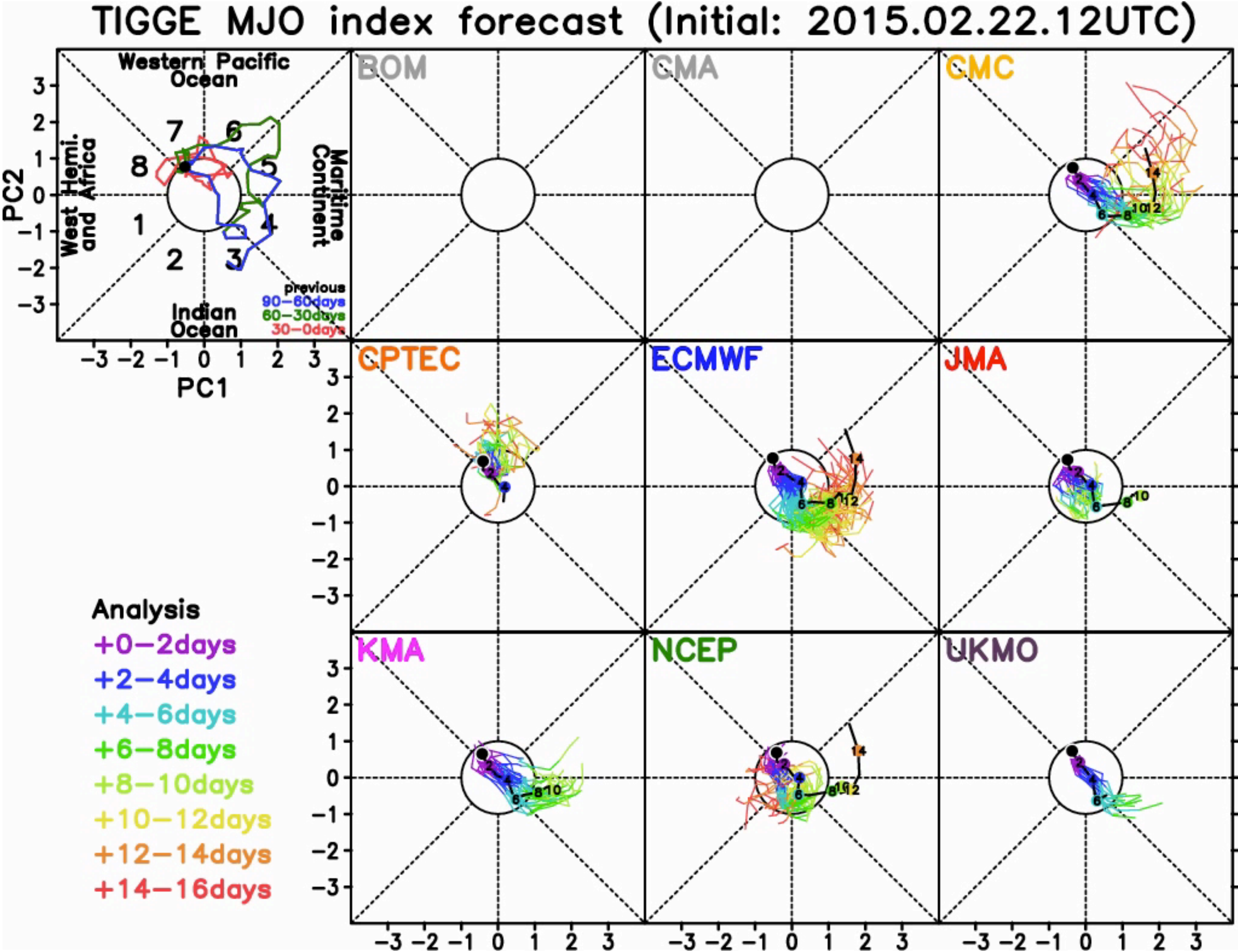
Courtesy: F. Vitart

Twin Cyclones: Pam and Bavi

13 Mar 2015

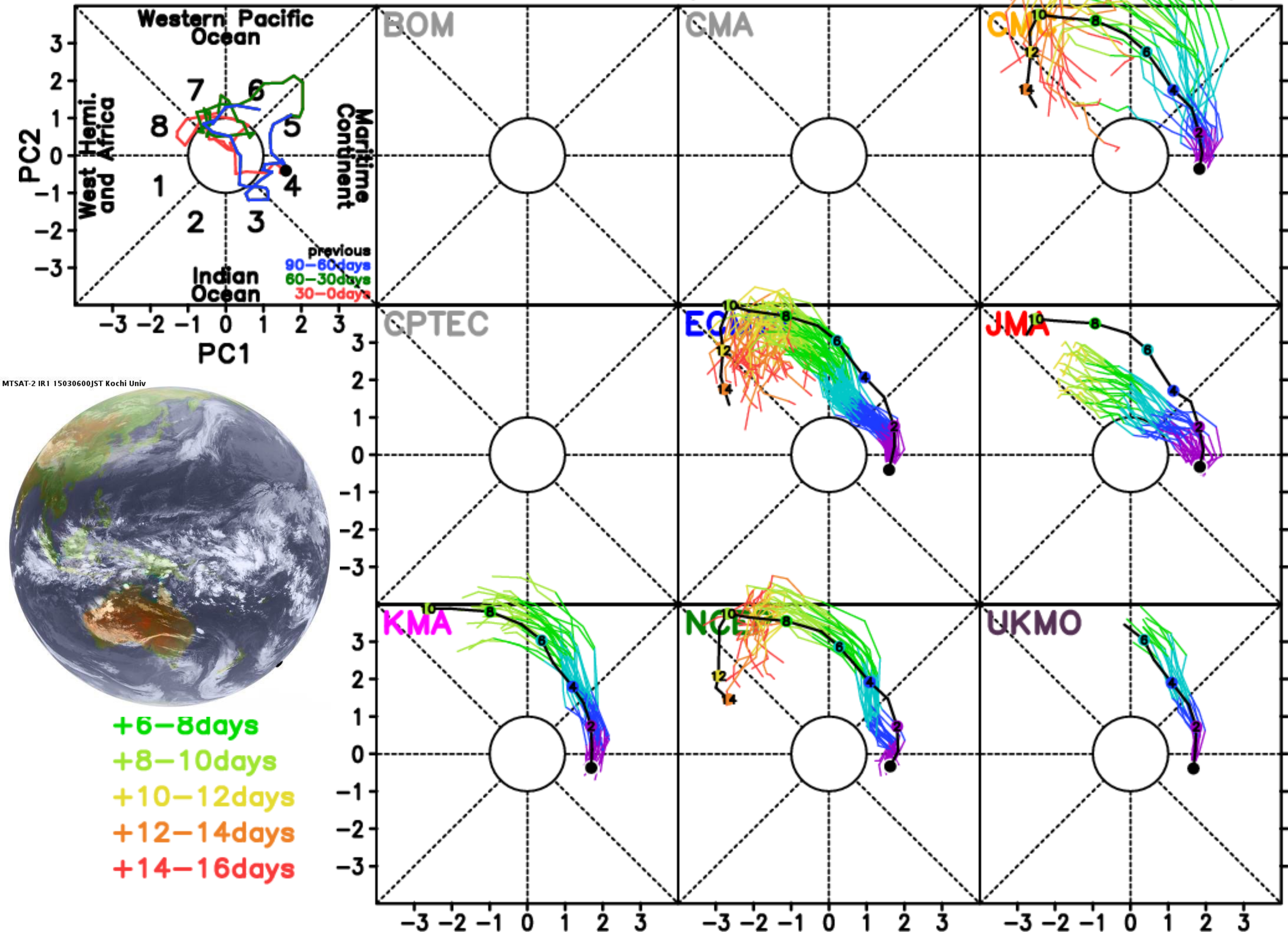




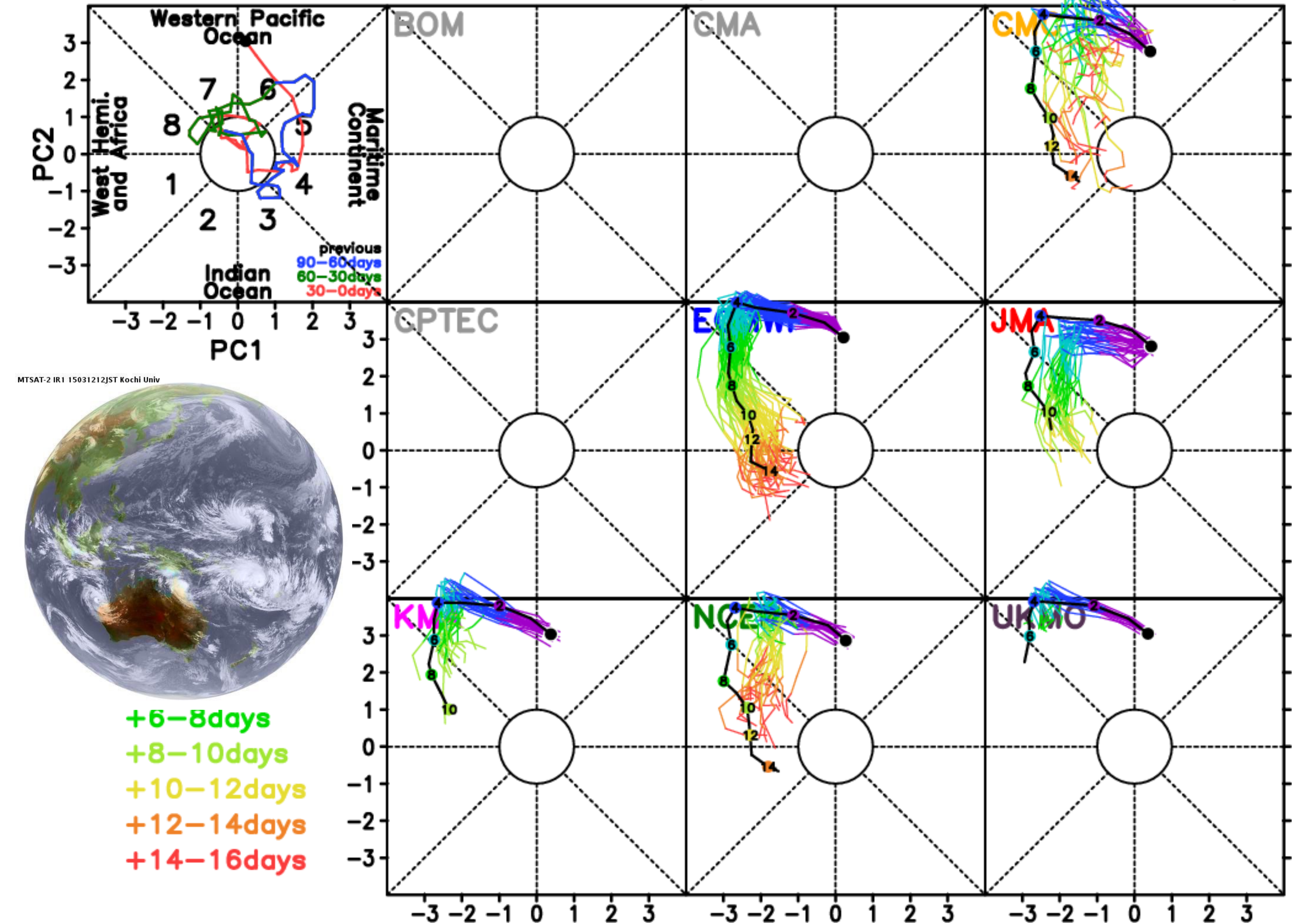


TIGGE MJO index forecast (Initial: 2015.02.22.12UTC)
Western Pacific Ocean
West Hemi. and Africa
Maritime Continent
Indian Ocean
previous
90–60days
60–30days
30–0days
PC1
PC2
BOM
CMA
CMC
CPTEC
ECMWF
JMA
KMA
NCEP
UKMO
Analysis
+0–2days
+2–4days
+4–6days
+6–8days
+8–10days
+10–12days
+12–14days
+14–16days

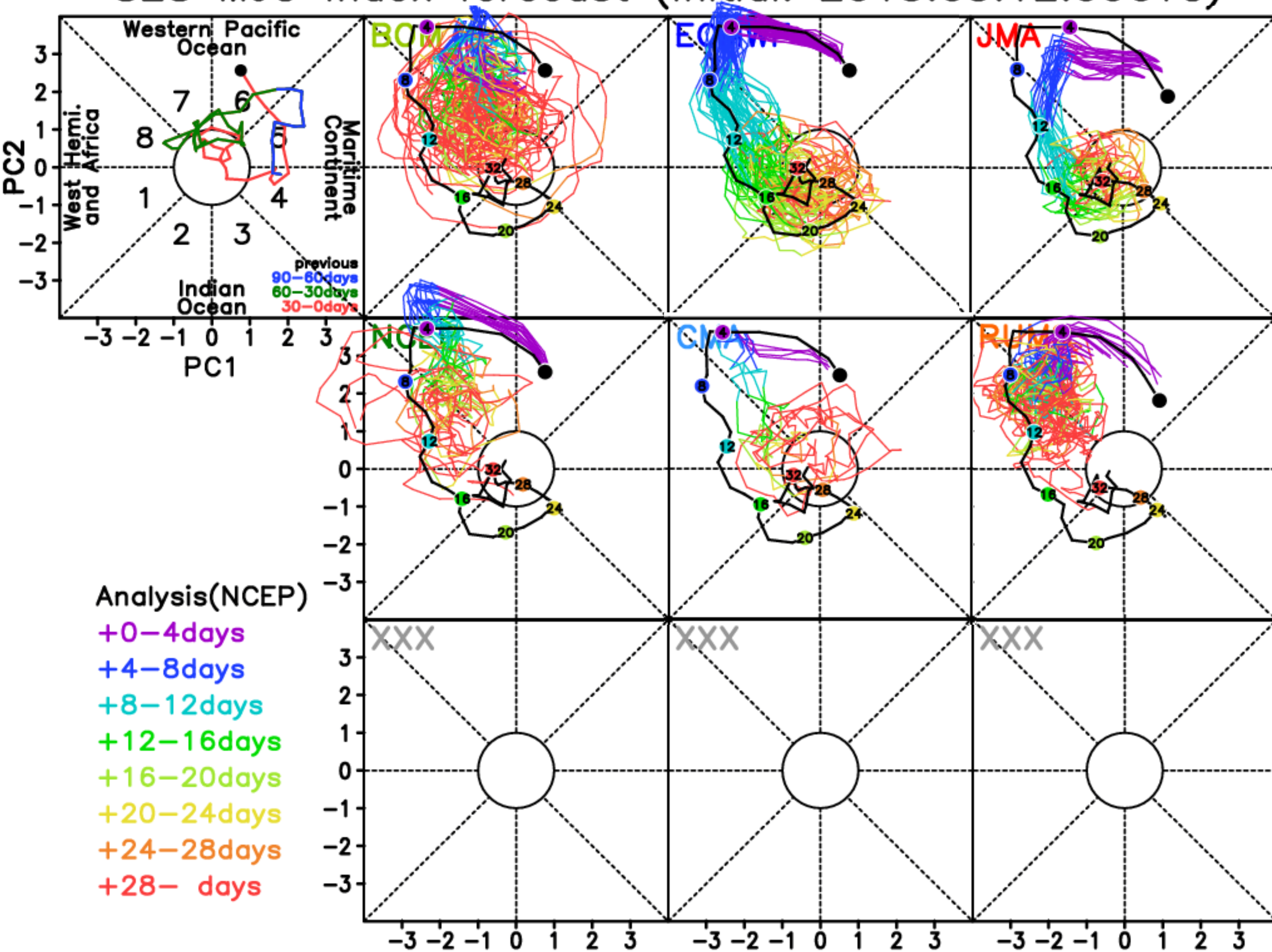
TIGGE MJO index forecast (Initial: 2015.03.06.12UTC)



TIGGE MJO index forecast (Initial: 2015.03.12 12UTC)



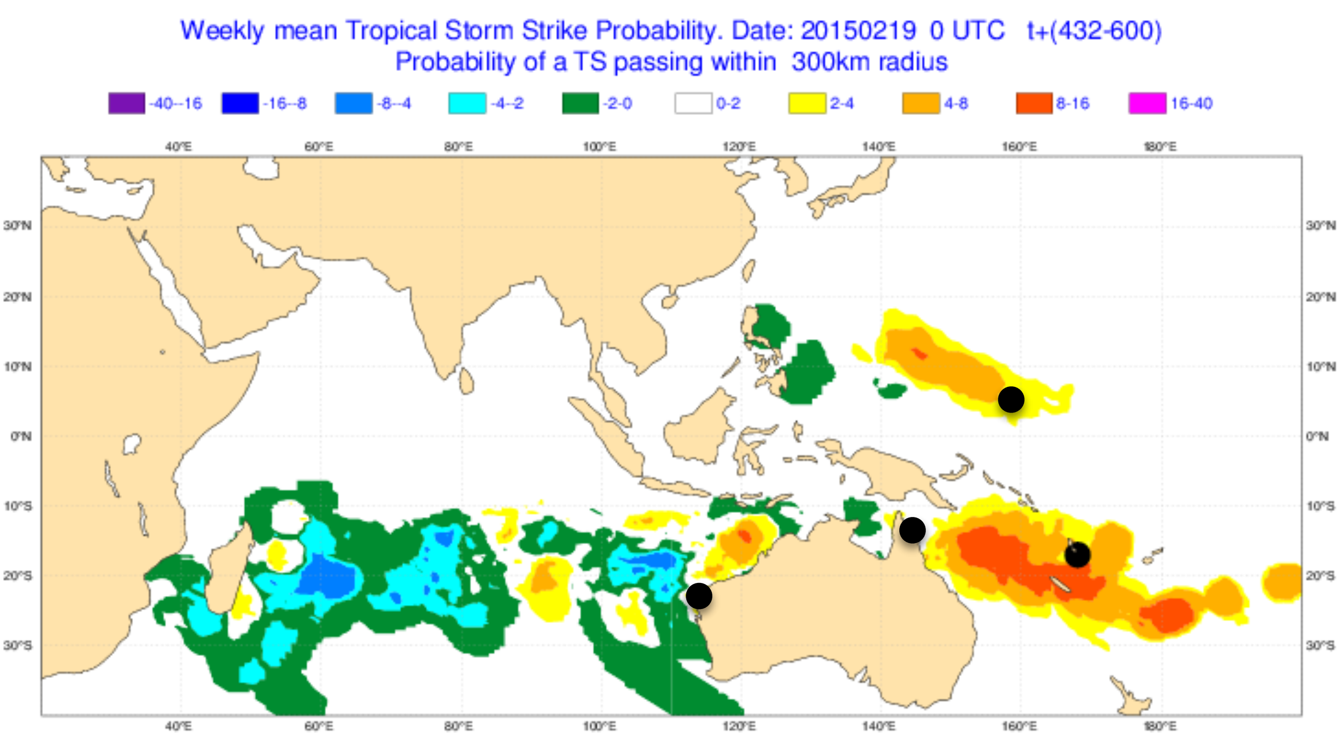
S2S MJO index forecast (Initial: 2015.03.12.00UTC)



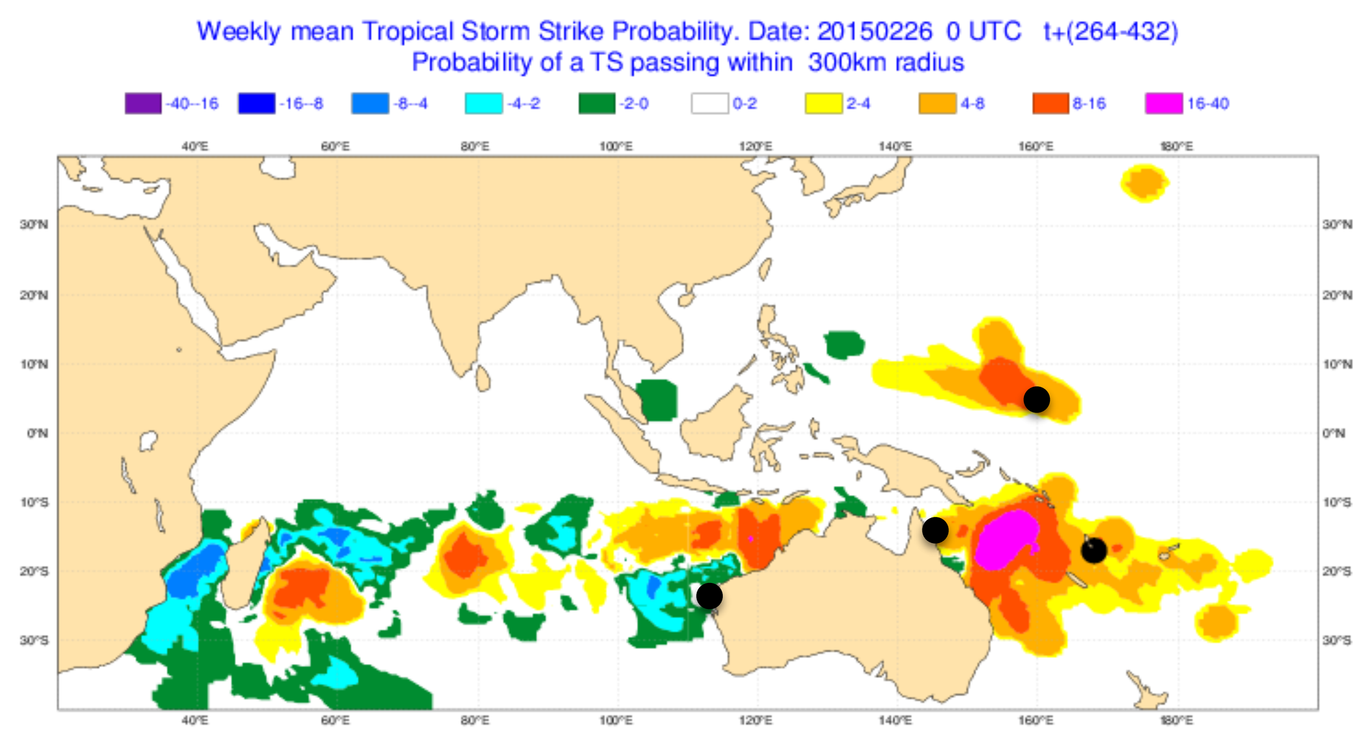
Tropical Cyclone Pam case study

Multi-model prediction of TC strike probability anomalies- 9-15 March 2015 (NCEP/ECMWF/BoM/JMA/CMA)

2015/02/19 day 19-25

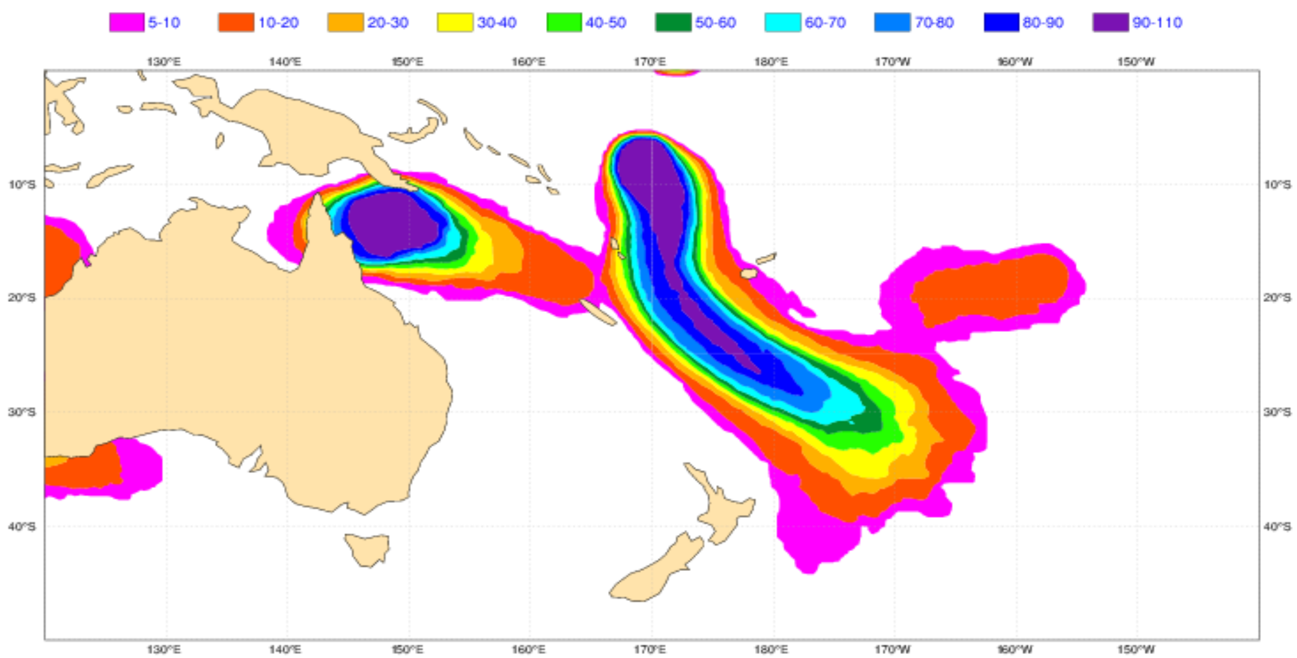


2015/02/26 day 12-18

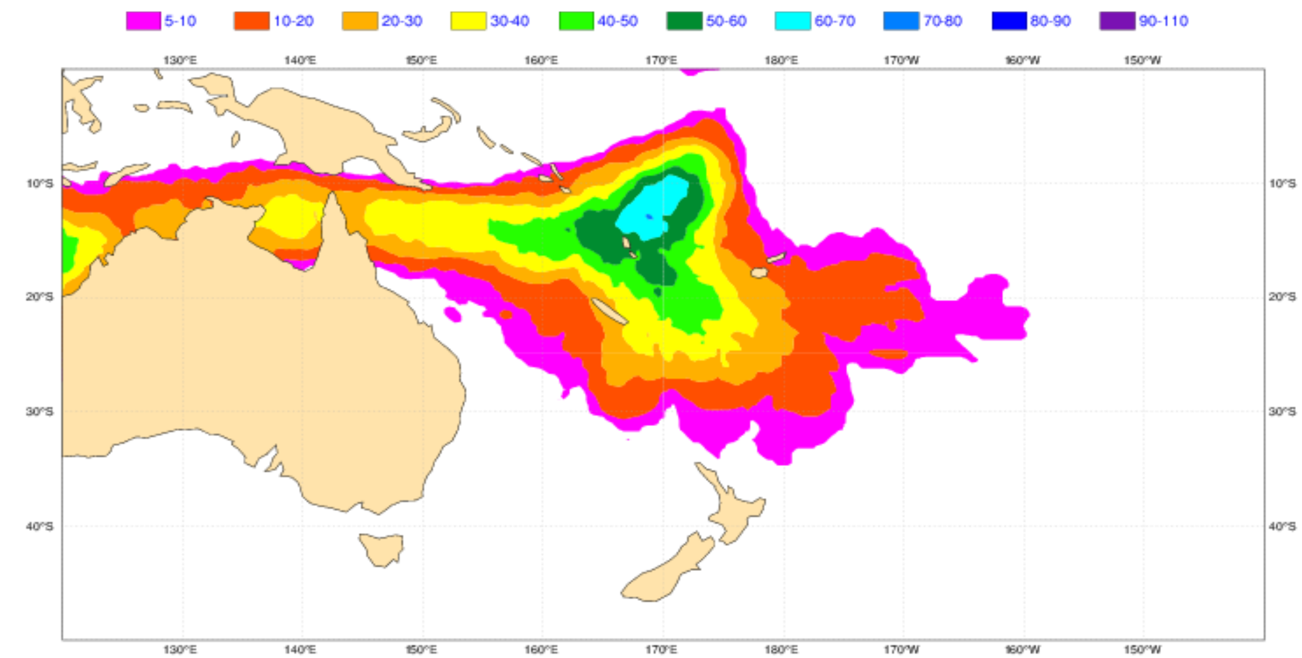


Prediction from ECMWF
Probability of a TC strike within 300 km

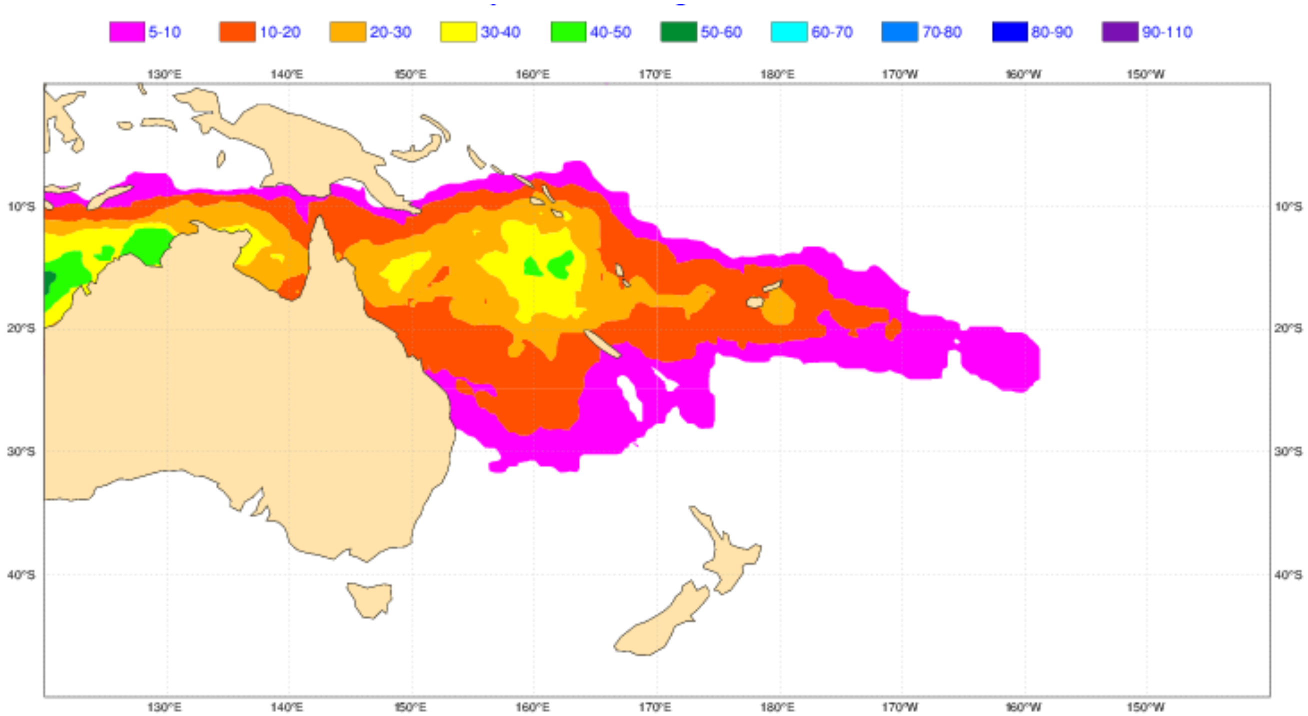
09 March 2015 Day 1-7



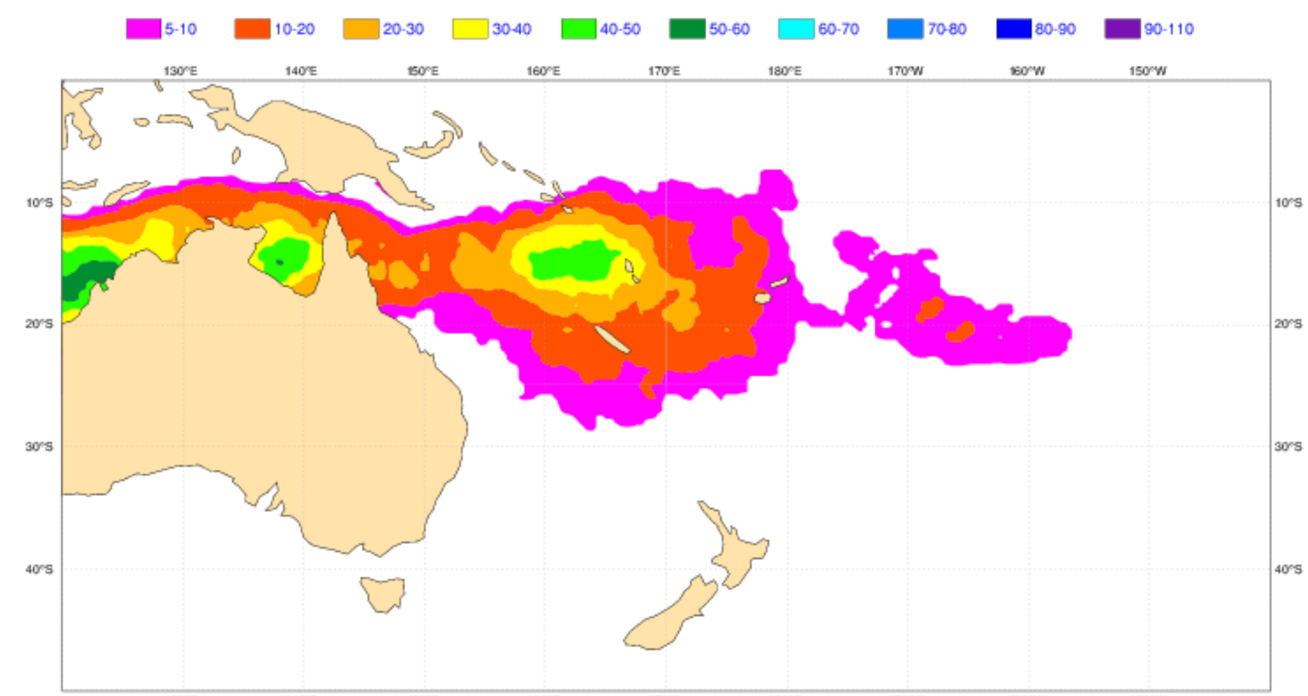
02 March 2015 Day 8-14



23 February 2015 Day 15-21

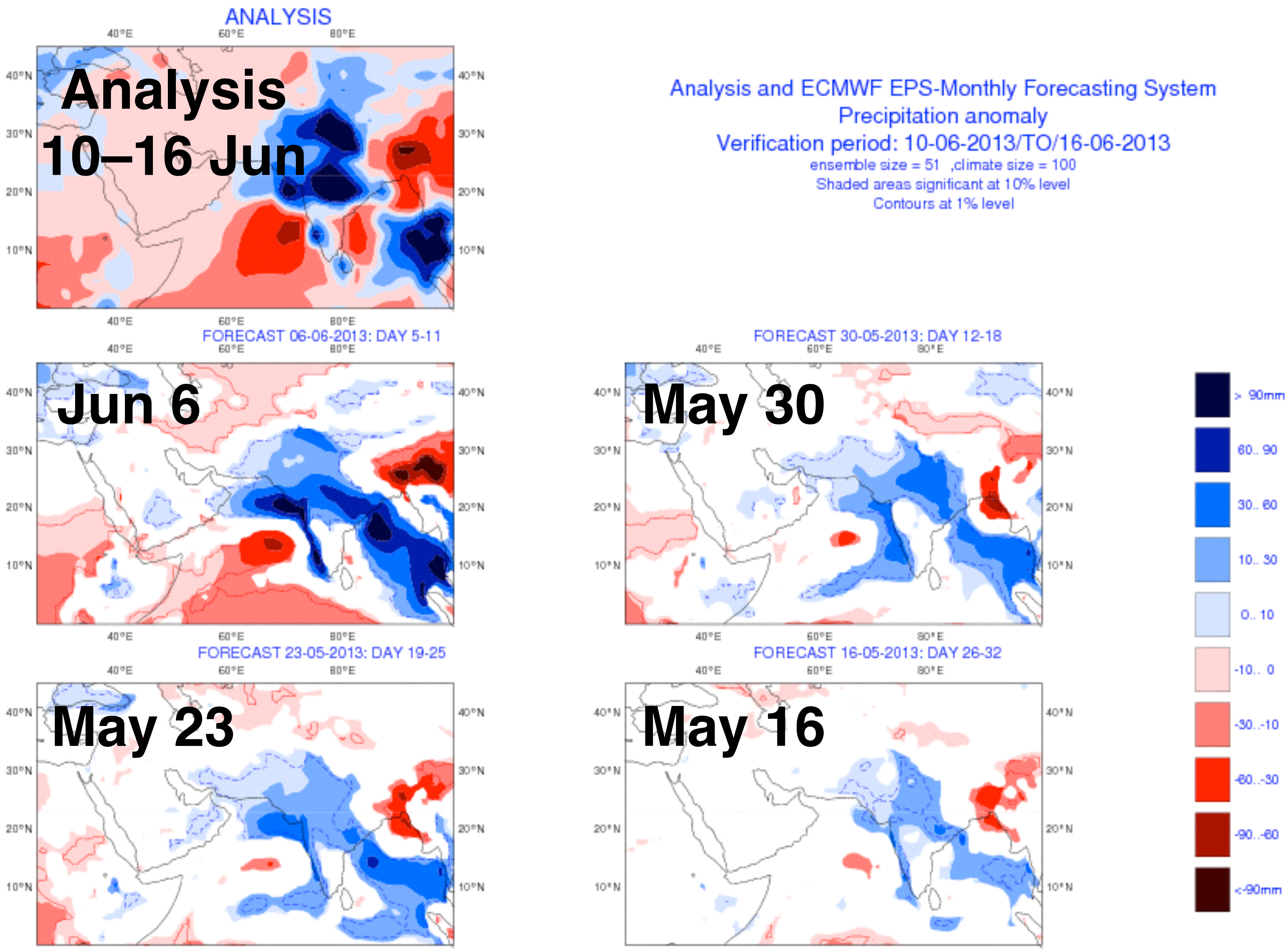


16 February 2015 Day 22-28



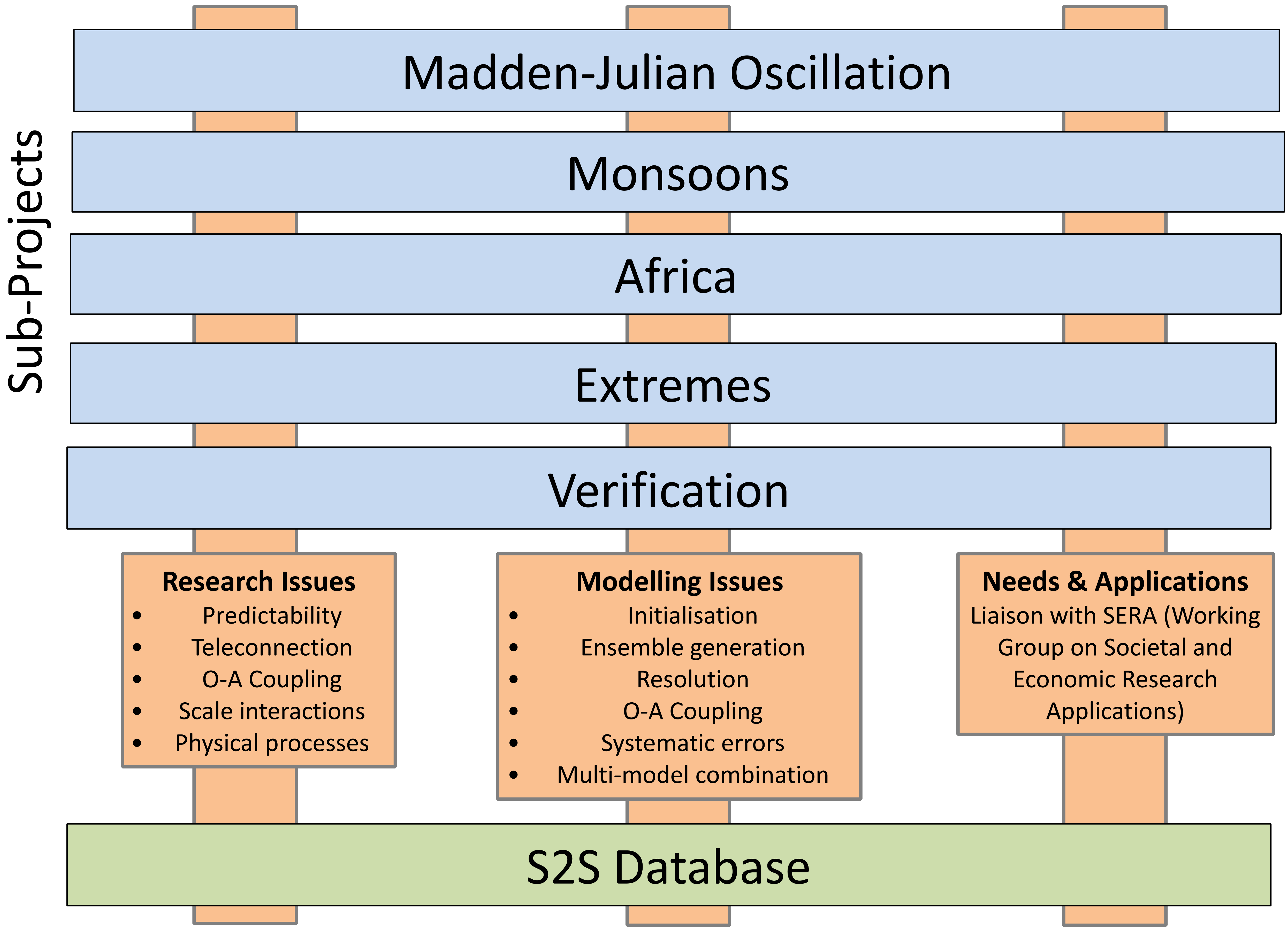

North India Floods
June 2013

Precipitation Anomaly Forecasts

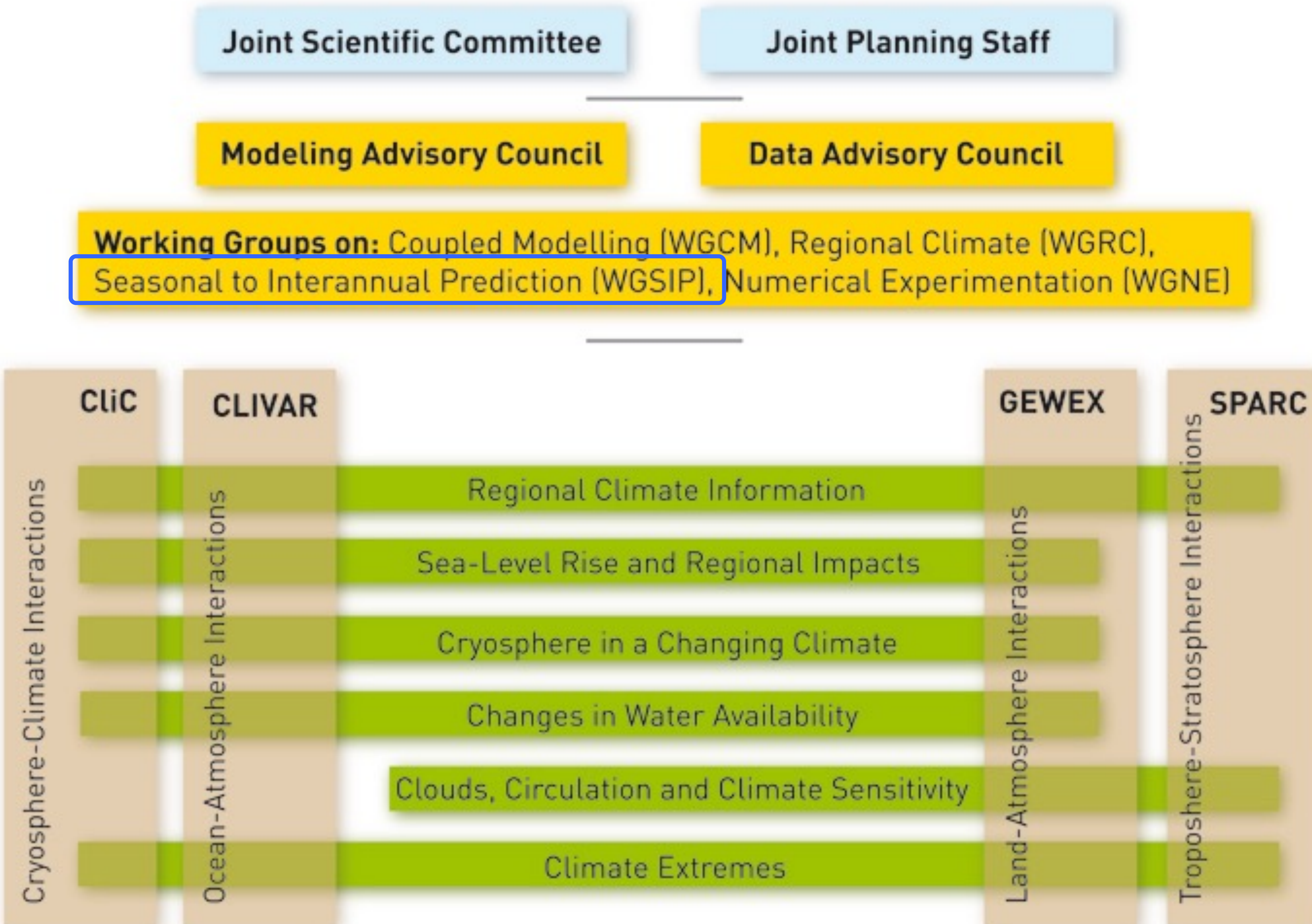


ECMWF

Sub-seasonal to Seasonal (S2S) Prediction Project



WCRP Organization



S2S Database

- Use TIGGE protocol (GRIB2) for archiving the data. The data should also be available in **NetCDF** for the Climate (WCRP) community.
- Archive daily means of real-time forecasts + **hindcasts**.
  - Real-time forecasts **3 weeks behind** real-time
  - Hindcasts depending on Centre (nonuniform)
  - Common **1.5 x 1.5 degree** grid
- Update frequency depending on centre
- Variables: most of TIGGE variables + mean variables and stratospheric levels + soil moisture/temperature + ocean/sea ice
- **ECMWF** and **CMA** are the archiving centres.

Sub-seasonal Ensemble Forecasts

Status on 10th March 2016	Time range	Resolution	Ens. Size	Frequency	Re-forecasts	Rfc length	Rfc frequency	Rfc size	Volume of real-time forecast per cycle	Volume of reforecast per update
BoM (ammc)	d 0-62	T47L17	33	2/week	fix	1981-2013	6/month	33		6 TB
CMA (babj)	d 0-60	T106L40	4	daily	fix	1994-2014	daily	4		
CNR-ISAC (isac)	d 0-31	0.75x0.56 L54	41	weekly	fix	1981-2010	every 5 days	1		
CNRM (lfpw)	d 0-32	T255L91	51	weekly	fix	1993-2014	2/monthly	15		6.75 GB/start date
ECCC (cwao)	d 0-32	0.45x0.45 L40	21	weekly	on the fly	1995-2014	weekly	4		
ECMWF (ecmf)	d 0-46	Tco639/319 L91	51	2/week	on the fly	past 20 years	2/week	11		
HMCR (rums)	d 0-61	1.1x1.4 L28	20	weekly	on the fly	1985-2010	weekly	10		
JMA (rjtd)	d 0-33	T319L60	25	2/week	fix	1981-2010	3/month	5	3.8 GB	900 GB
KMA (rksl)	d 0-60	N216L85	4	daily	on the fly	1991-2010	every 8 days	3		
NCEP (kwbc)	d 0-44	T126L64	16	daily	fix	1999-2010	day	4		
UKMO (egrr)	d 0-60	N216L85	4	daily	on the fly	1993-2015	4/month	3		

Parameters (bold in TIGGE)

Geopotential hight	Snow density*1	Sea ice cover*1	**Convective precipitation*2**
Temperature++*	**Snow fall water equiv. *2**	**Surface pressure***	Northward turbulent surface stress*2
U-velocity++*	Snow albedo*1	Time-integrated top net thermal rad. *2	Eastward turbulent surface stress*2
V-velocity++*	**Soil moisture top 20 cm*1**	Time-integrated surface lat. heat flux *2	Mean sea-level pressure*
Specific humidity+*	Soil moisture top 100 cm*1	Time-integrated surface net. solar rad. *2	Water runoff and drainage
Vertical velocity*	Soil T top 20 cm*1	Time-integrated surface net. thermal rad. *2	Surface water runoff
PV at 320 K*	Soil T top 100 cm*1	Time-integrated surface sensible. heat flux *2	**Land sea mask***
10 meter u-velocity*	**Surface air max. T*3**	Time-integrated surface. solar rad. downwards *2	**Orography***
10 meter v-velocity*	**Surface air min. T*3**	Time-integrated surface. thermal rad. downwards *2	Soil type*
CAPE*1	**Surface air T*1**	**Total cloud cover*1**	
Skin temperature*1	Surface air dew T*1	**Total Column Water*1**	
Snow depth water equiv.*1	Sea Surface T*1	**Total precipitation*4**	

* 00Z only *1 Daily averaged *2 Accumulated, daily *3 6-hourly *4 Accumulated, 6-hourly
+(+) at 1000, 925, 850, 700, 500, 300, 200, (100, 50 and 10 hPa)

Sub-seasonal to Seasonal Forecast at ECMWF

ECMWF EFI

- Research homepage
- Data Assimilation
- Modelling and prediction
- Climate reanalysis
- Projects
- Publications
- Special projects

Filters

Show All

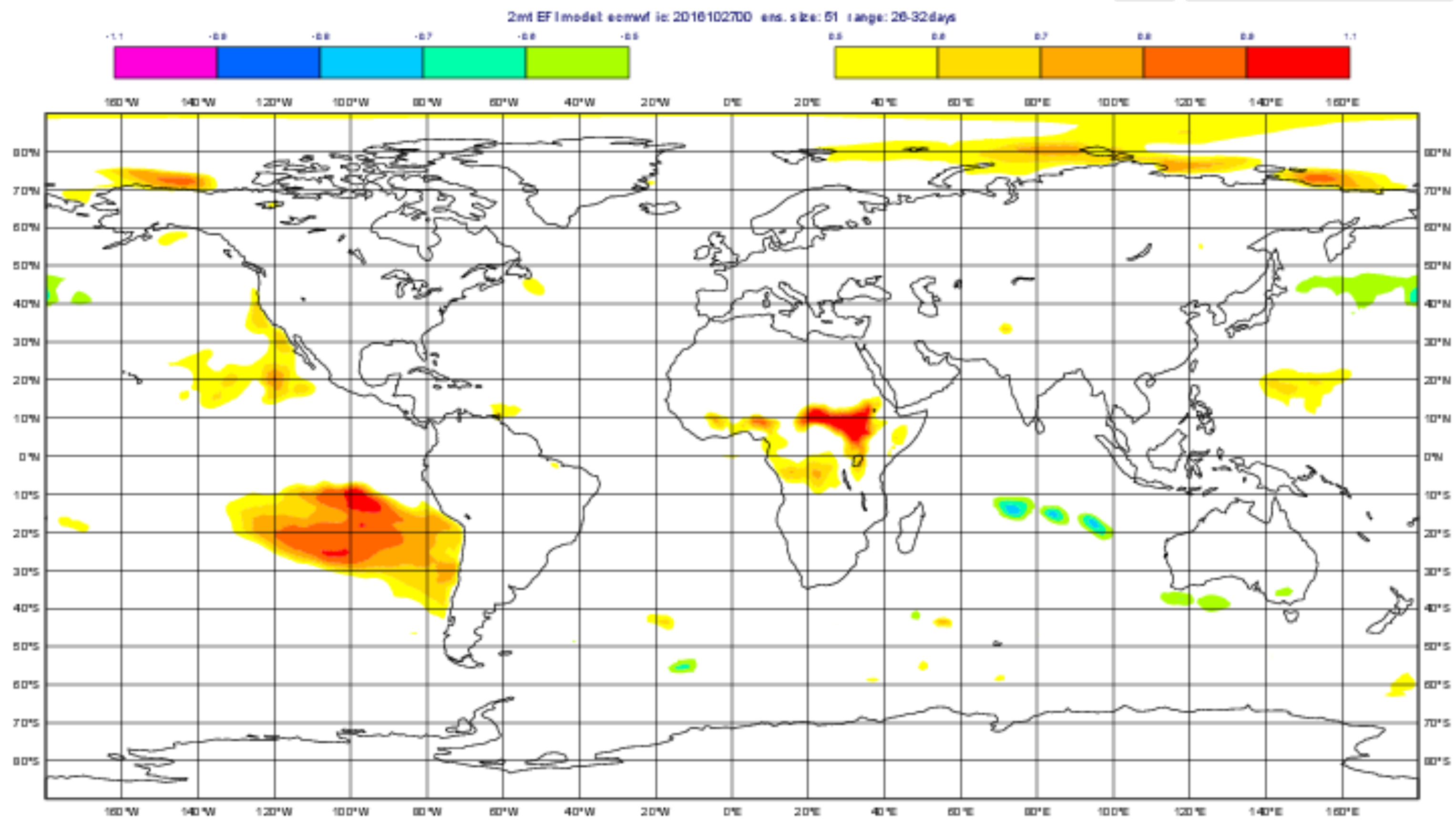
Product

- [ ] Anomaly (0/18)
- [x] EFI (6)
- [ ] Hovmoller (0/18)
- [ ] Madden-Julian Oscillation(MJO) (0/6

Centre

- [ ] BoM (1)
- [ ] CMA (1)
- [ ] ECMWF (1)
- [ ] JMA (1)
- [ ] NCEP (1)
- [ ] UKMO (1)

Base time ▾ ← Product results ▾



VT: Mon 14 Mon 21

EFI for weekly means:
The Extreme Forecast Index (EFI) is an integral measure of the difference between the ensemble forecast distribution and the model climate distribution. This allows the abnormality of the forecast weather situation to be assessed without defining specific (space- and time-dependant) thresholds. The EFI takes values from -1 to +1. If all the ENS members forecast values above the model climate maximum, EFI = +1; if they all forecast values below the model climate minimum, EFI = -1. Experience suggests that EFI magnitudes of 0.5 - 0.8 (irrespective of sign) can be generally regarded as signifying that "unusual" weather is likely whilst magnitudes above 0.8 usually signify that "very unusual" or extreme weather is likely. Although larger EFI values indicate that an extreme event is more likely, the values do not represent probabilities as such. Model climate is estimated by using the corresponding re-forecasts but, in order to allow comparisong among EFI from different S2S models, only the common period of 12 years (1999-2010) or 11 years (1999-2009) in case of the ukmo model is used. Note that the relatively short sample of re-forecasts, used to estimate the model climate, is not sufficient to satisfactory reduce sampling errors.

http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/

Welcome to the S2S Museum

@University of Tsukuba, Japan

The Subseasonal to Seasonal Prediction (S2S) Project is a proposed WWRP/THORPEX/ WCRP joint research project.

The main goal of the S2S project is to improve forecast skill and understanding on the subseasonal to seasonal timescale, and promote its uptake by operational centres and exploitation by the applications community. Specific attention will be paid to the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation.

The S2S data portals provide the S2S data freely with a 3-week delay only for research and education purposes. For details, visit the WMO S2S website or the ECMWF S2S website.

The S2S Museum is operated for a promotion of utilization of the S2S data by Dr. Mio Matsueda (University of Tsukuba and University of Oxford), with support from the ArCS (Arctic Challenge for Sustainability) Project of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

Arctic Challenge for Sustainability

Forecast products in the S2S Museum are updated everyday, with a 3-week delay, and are available for non-commercial use.

S2S Museum (Prof. Matsueda's Website)

S2S products Updated every day with a 21-day delay!

- Ensemble forecasts for specific atmospheric phenomena
  - AO/AAO (Arctic/Antarctic Oscillations) index [definition of AO/AAO (pdf)]
  - SLP anomaly
  - NAO (North Atlantic Oscillation) index [definition of NAO (pdf)]
  - Teleconnection indices (EA, PNA, WA, WP, and EU) [definition: Wallace and Gutzler(1981)]
  - Z500 anomaly
  - Wave Activity Flux at 200 hPa [definition of Wave Activity Flux: Takaya and Nakamura(2001)]
  - SSW (Sudden Stratospheric Warming) (only November-April)
  - Temperature at 10 hPa
  - MJO (Madden-Julian Oscillation)
  - SST (Sea Surface Temperature, 60S-60N)
  - Sea-ice cover

http://gpvjma.ccs.hpcc.jp/S2S/

The S2S Membership

Steering Group

- Frederic Vitart (co-chair)
- Andrew Robertson (co-chair)
- Arun Kumar
- Harry Hendon
- Duane Waliser
- Yuhei Takaya
- Hai Lin
- Anca Brookshaw
- Cristiana Stan
- Williem Landman
- Tongwen Wu

Liaison Group

- In-Sik Kang (WCRP JSC)
- Richard Graham (CBS)
- Oscar Alves (WG PDEF)
- Daryl D. Kleist (WG DAOS)
- Jean-Pierre Ceron (CCL)
- Caio Coelho (JWGFVR)
- Steve Woolnough (GEWEX/GASS)
- Paul Dirmeyer (GEWEX/GLASS)
- Joanne Robbins (SERA)

Summary

- S2S : to fill the gap between weather forecasts and climate prediction, to be critical place in weather and climate services
- Sources of S2S Predictability: MJO(shorter range)-ENSO(climate scale). Skill is gradually emerging.
- S2S Database Ready: Forecasts up to 60 days and Reforecasts
- S2S for the Society : Seamless Information from months to weeks

감사합니다!