Australian Government
Bureau of Meteorology

# Subseasonal to seasonal prediction of the climate system

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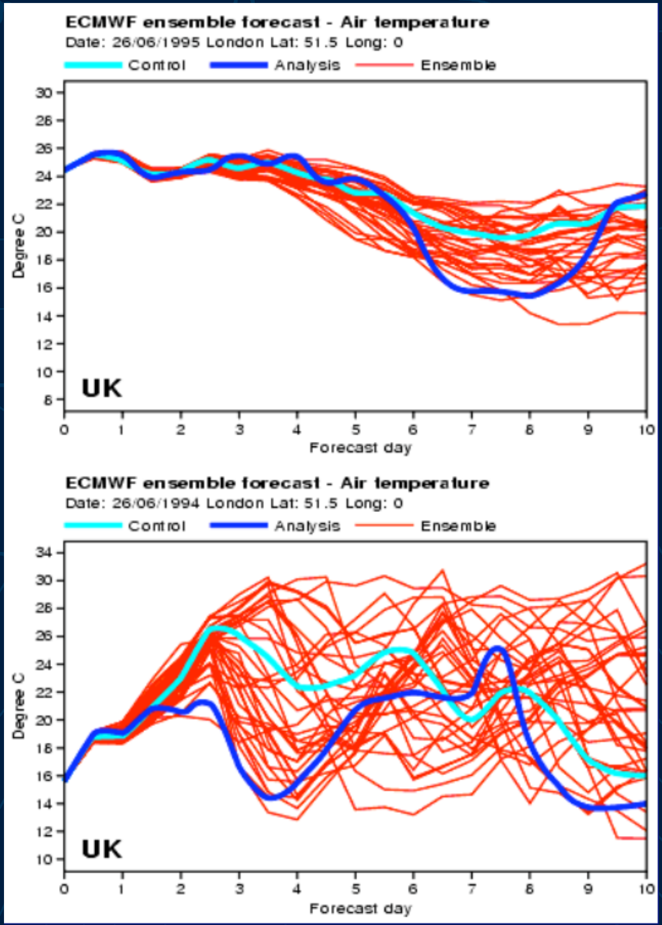
*With contributions from the Climate Processes and Coupled Modelling teams*

# Weather versus climate?

Lorenz's butterflies sets a limit to day-to-day weather prediction of 1-2 weeks.

Example of chaos limiting the prediction of London air temperature in 2008 version of ECMWF numerical weather prediction model.




**So why do we think we can predict climate?**

# Climate prediction possible because of the existence of climate modes and oscillations, persistence, and trends.

El Nino-Southern Oscillation (ENSO)

Indian Ocean Dipole (IOD)

Madden-Julian Oscillation (MJO)

Southern Annular Model (SAM)

Interdecadal Pacific Oscillation (IPO)

Quasi-Biennial Oscillation (QBO)

Northern Annular Mode (NAM)

Atlantic Multi-decadal Oscillation (AMO)

Ocean memory

SST-circulation feedback

Soil moisture feedback

Global warming trend

Ozone trends

Aerosol trends

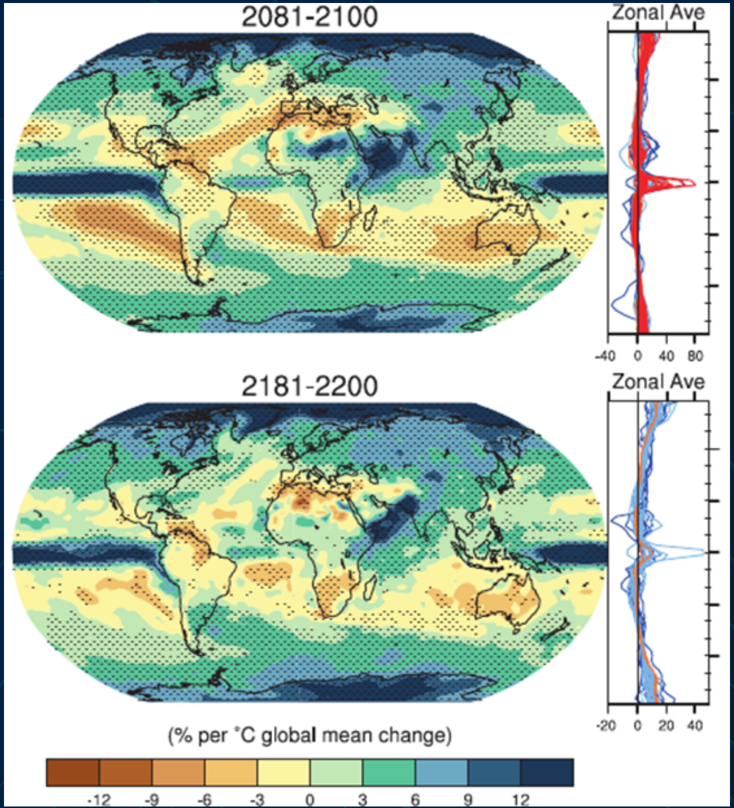
External forcing

# Climate prediction versus climate projection

Prediction takes into account the initial condition (IC) of the climate system, and may also take into account the "external forcing".

Projection only considers the "external forcing".

A climate change "projection" from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report . Precipitation change relative to 1986-2005.



# History of climate prediction in Australia

**1920s** Discovery of the Southern Oscillation and possibility of seasonal prediction using Darwin pressures was proposed (Quayle 1929).

**1970s-80s** Nicholls, McBride, and colleagues confirm the stability of the relationship between Australian seasonal rainfall and ENSO.

**1989** BoM begins issuing statistical predictions of Australian seasonal rainfall.

**1990s** The effects of the Indian Ocean were incorporated into the statistical predictions.

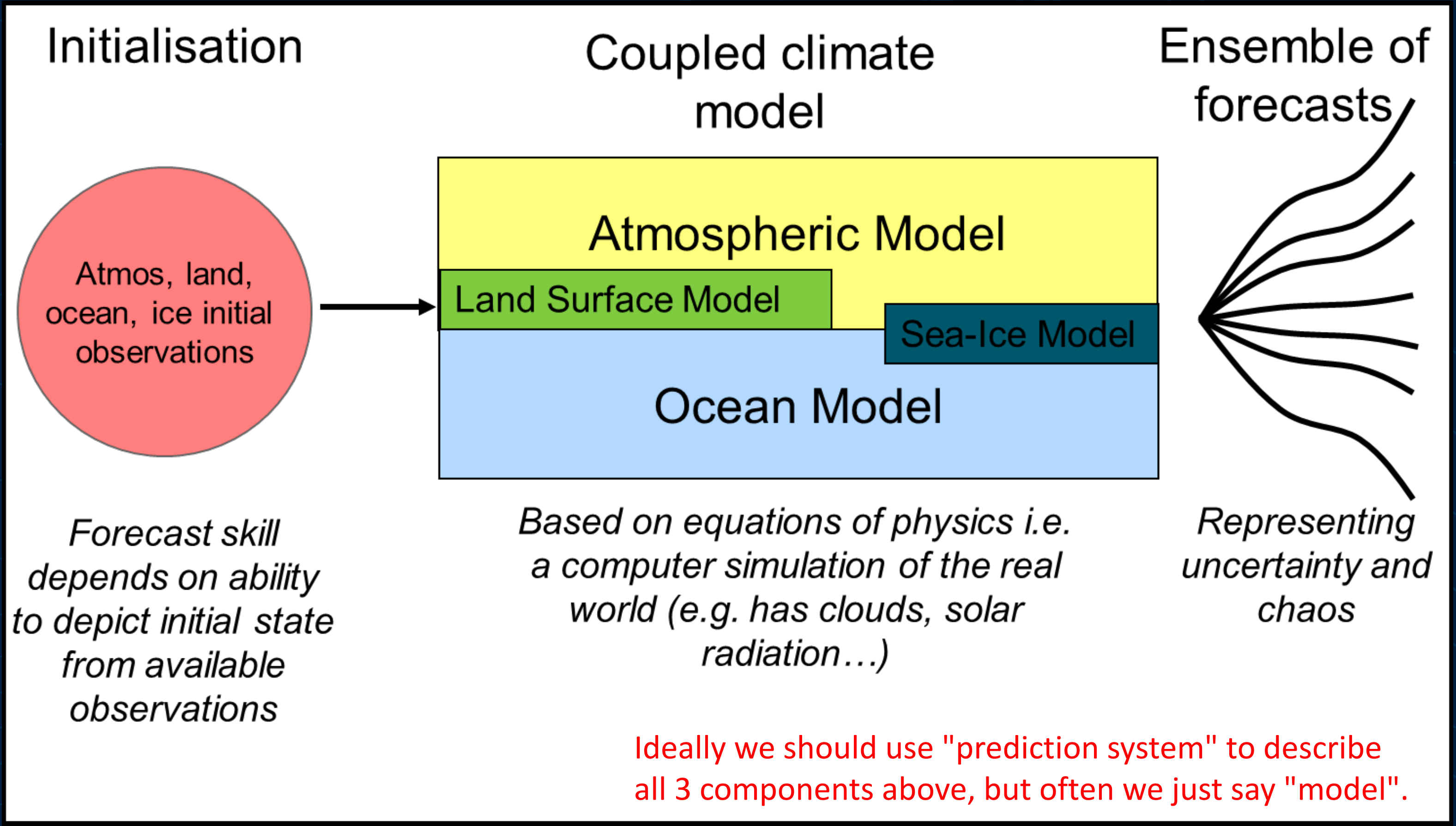
**2002** Prediction with a dynamical ocean-atmosphere model (POAMA-1) begins, but initially only used for forecasts of Pacific SSTs (i.e. ENSO).

**2013** POAMA-2 becomes operational and for the first time the BoM issues seasonal outlooks for Australian rainfall and temperature with a dynamical model.

**2018** ACCESS-S1 replaces POAMA-2M and monthly outlooks begin. Weekly outlooks to begin in late 2019.

**2017** CSIRO begins research project on decadal climate prediction.

# Dynamical Seasonal Prediction System

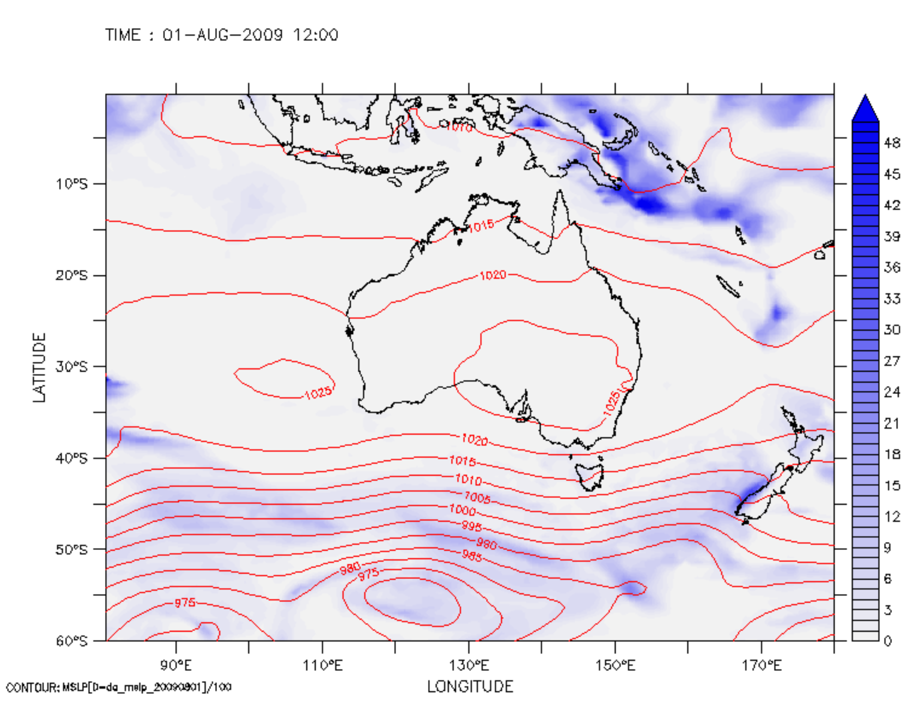


# The ACCESS-S1 model produces realistic weather and ocean eddies

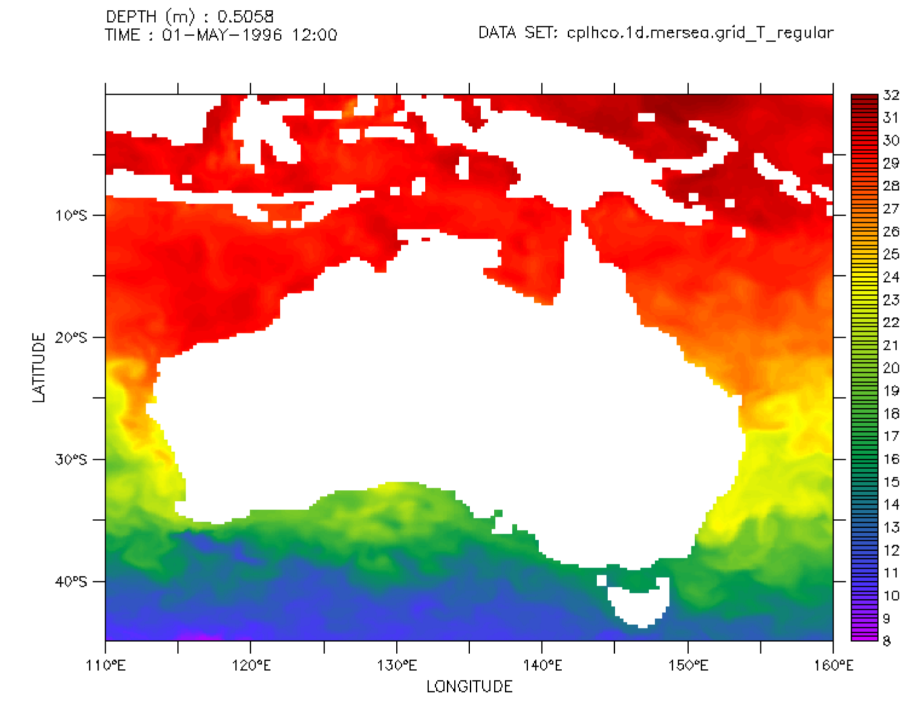
Atmosphere has 60km horizontal resolution with 85 vertical levels.

Ocean has 25km horizontal resolution with 75 vertical levels.

A global model is required



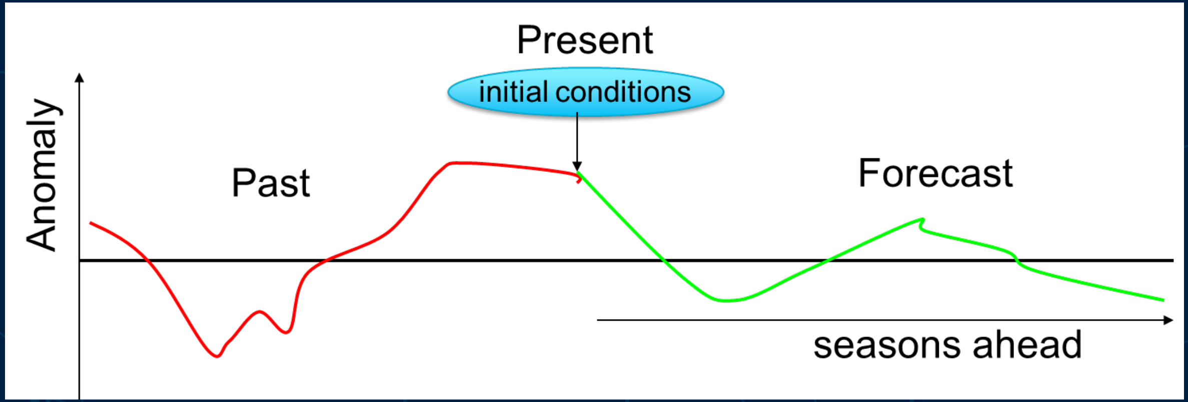

precipitation (mm/day) and MSLP (mb)




Ocean Temperature (degC)

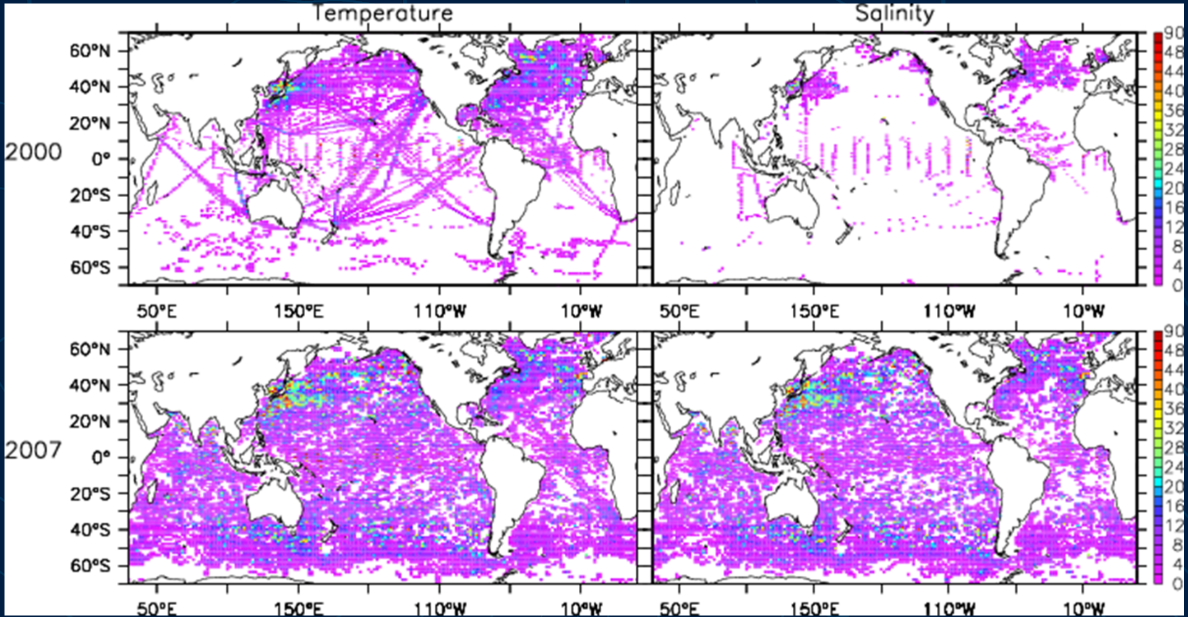
# Model Initialisation

The model needs to have accurate observations of the globe provided to it every day – "initial conditions".




Good observations of the past are also required for making hindcasts, which are essential for verification and correcting for model bias.

For ACCESS-S1 we use past observations to run hindcasts for 1990-2012.



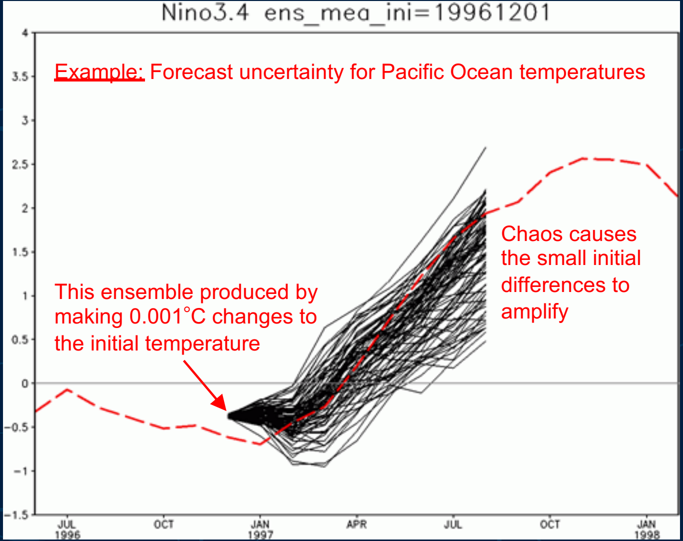

Locations of ocean observations in 2007 compared to 2000.

# Ensembles and probabilities

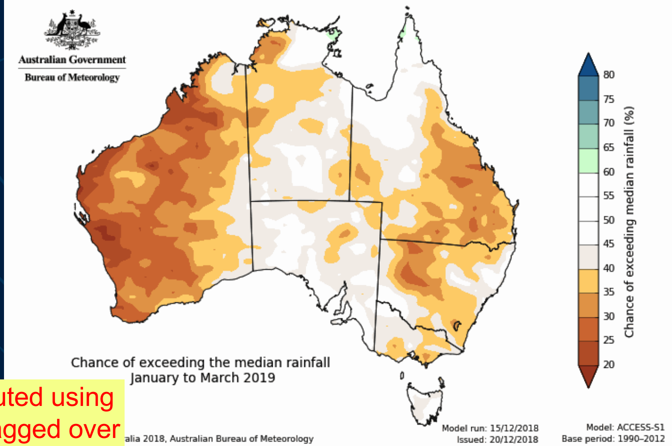
We currently run 33 ensemble members per day.

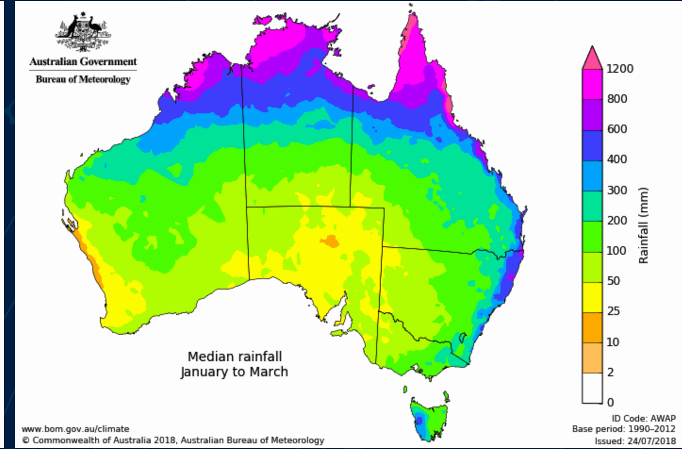
Each ensemble member is started with slightly different initial conditions.

We do this so that we can quantify our forecast uncertainty and provide forecast probabilities.




Probability forecast issued on 20th December for January-March 2019. →

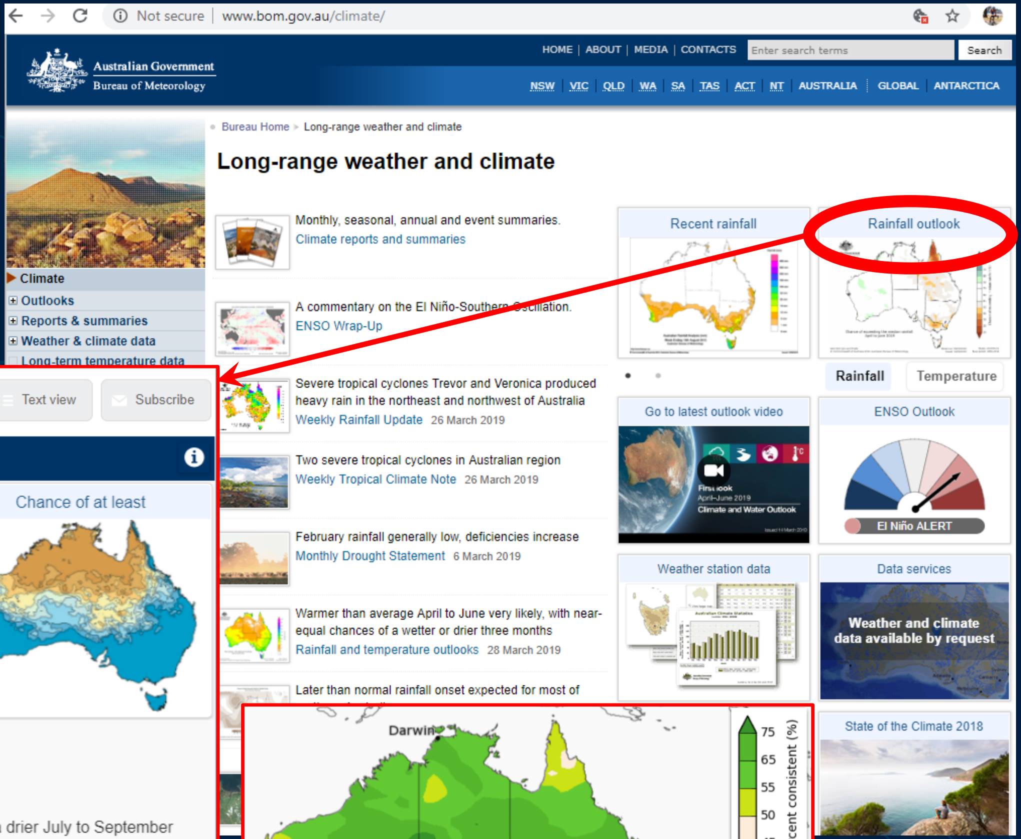


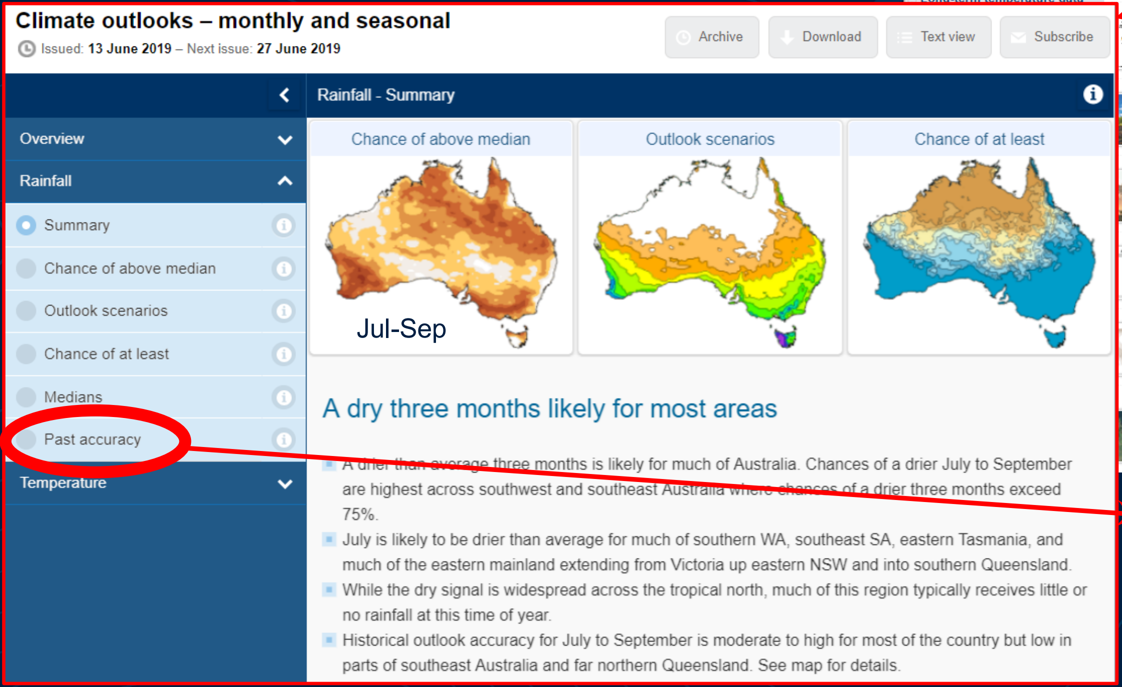



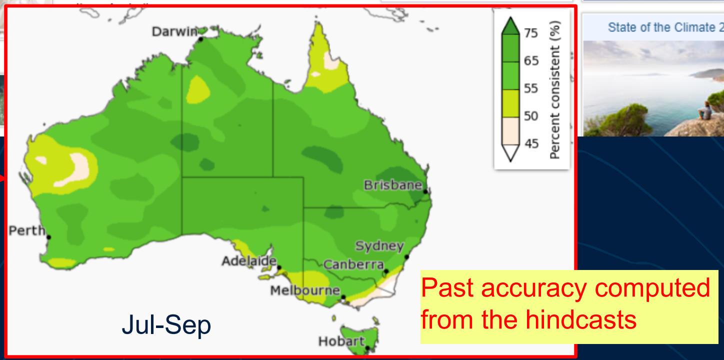

Normally, the chance of exceeding the median rainfall is 50% everywhere, but for this forecast we had many more of the ensemble members getting less than median rainfall.

Actually computed using 99 members lagged over several days

# Where to get your monthly to seasonal climate forecasts

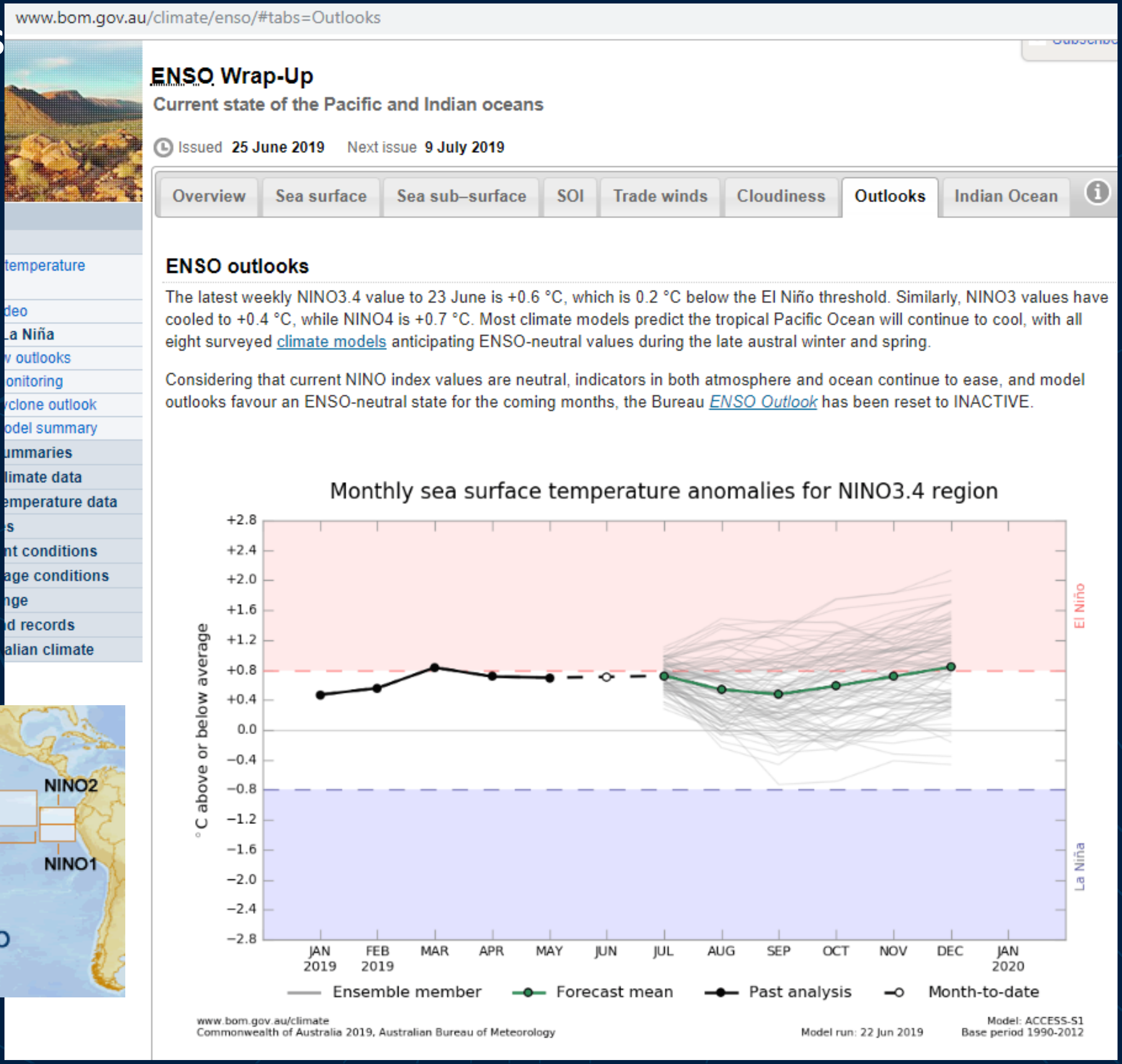


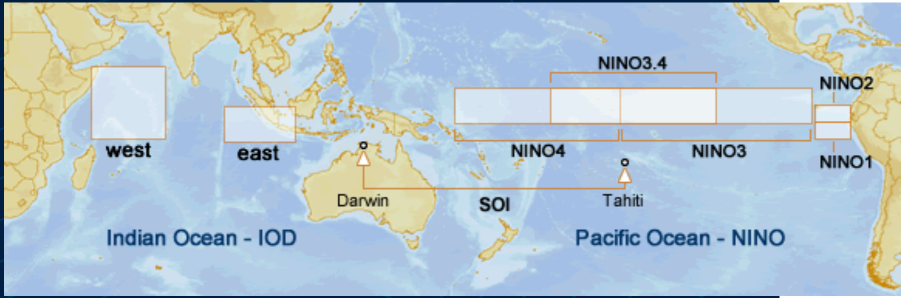



# The Bureau also currently provides predictions of ENSO and the IOD from ACCESS-S1

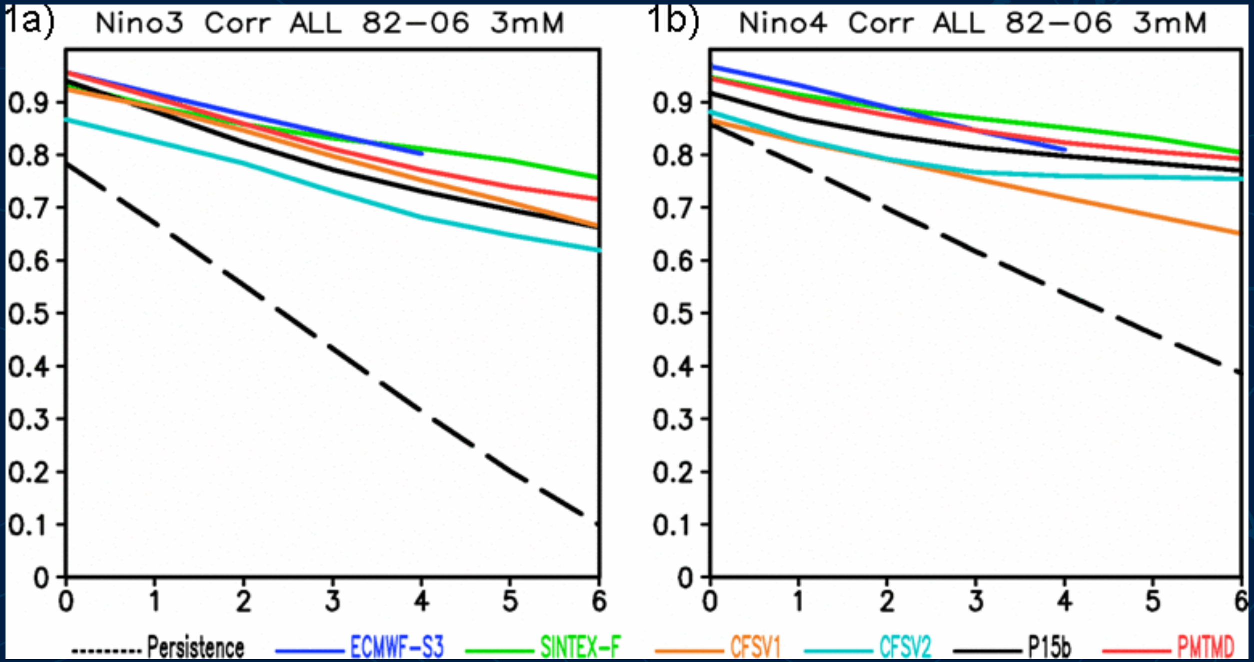
Nino 3, 3.4, or 4 are the main indices for ENSO

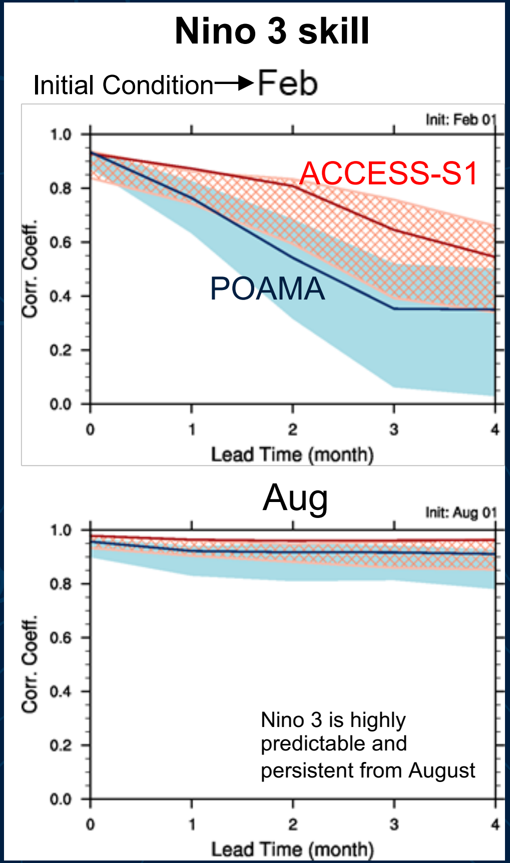


# Nino SSTs have long been the gold standard for predicting climate on seasonal time scales

Correlation skill of dynamical model forecasts of SST anomalies in Nino3 and Nino4

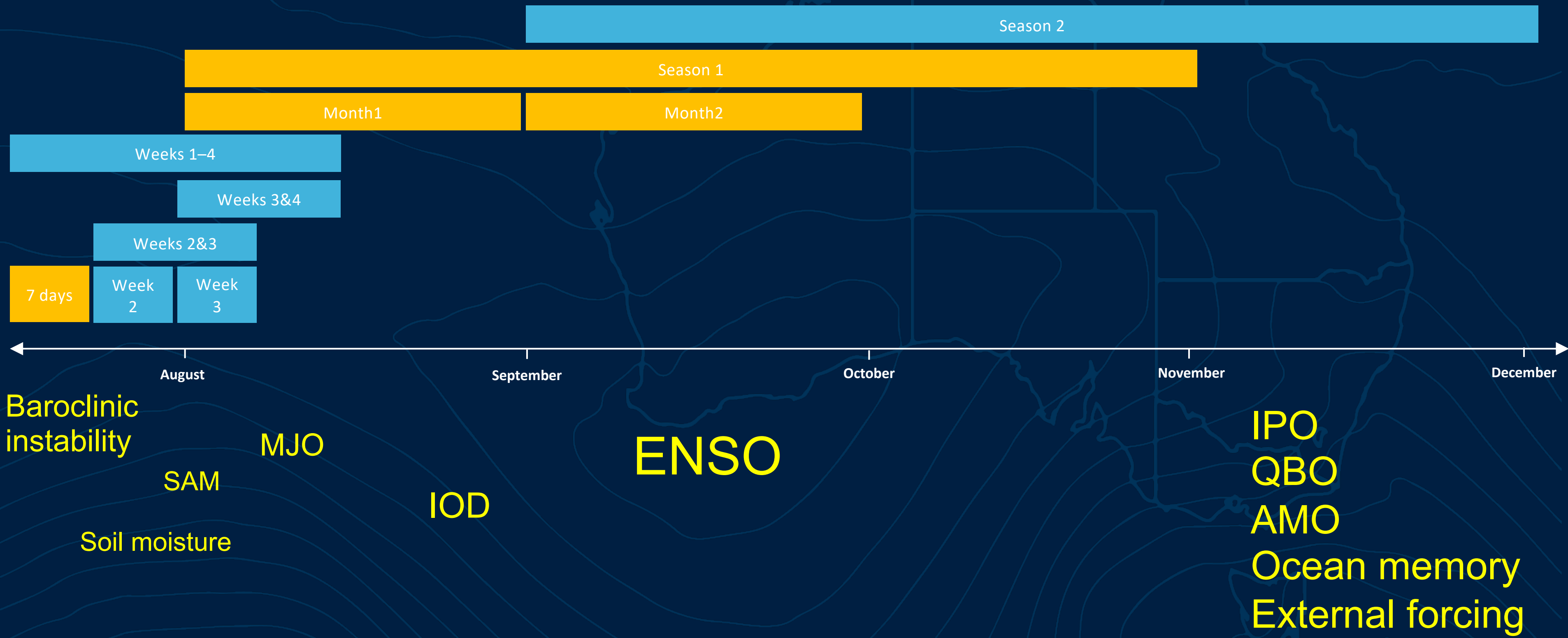


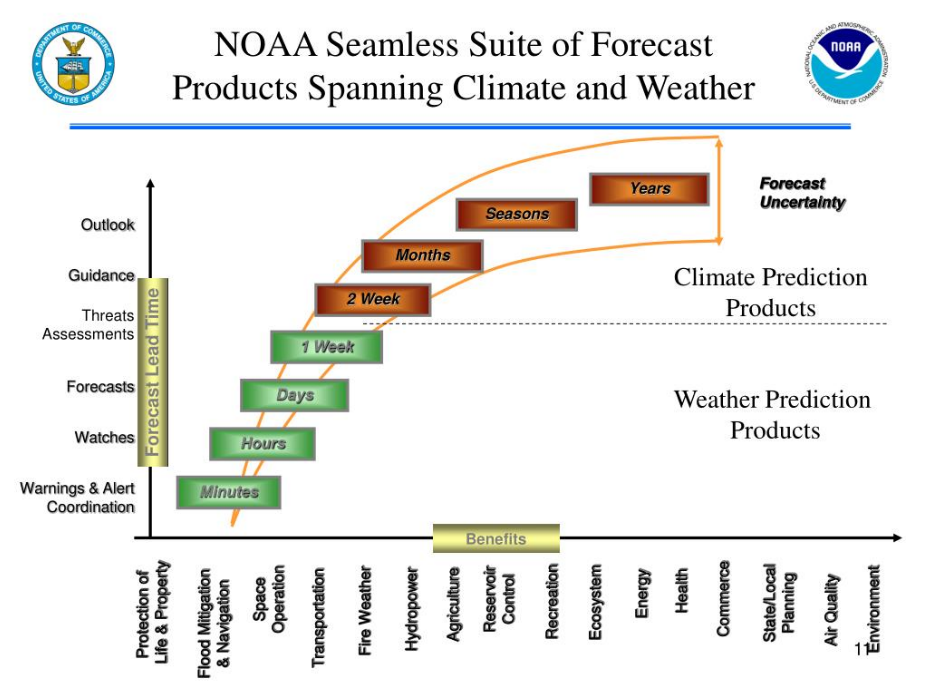

Nino 3 or 4 are usually the first variables to look at because:

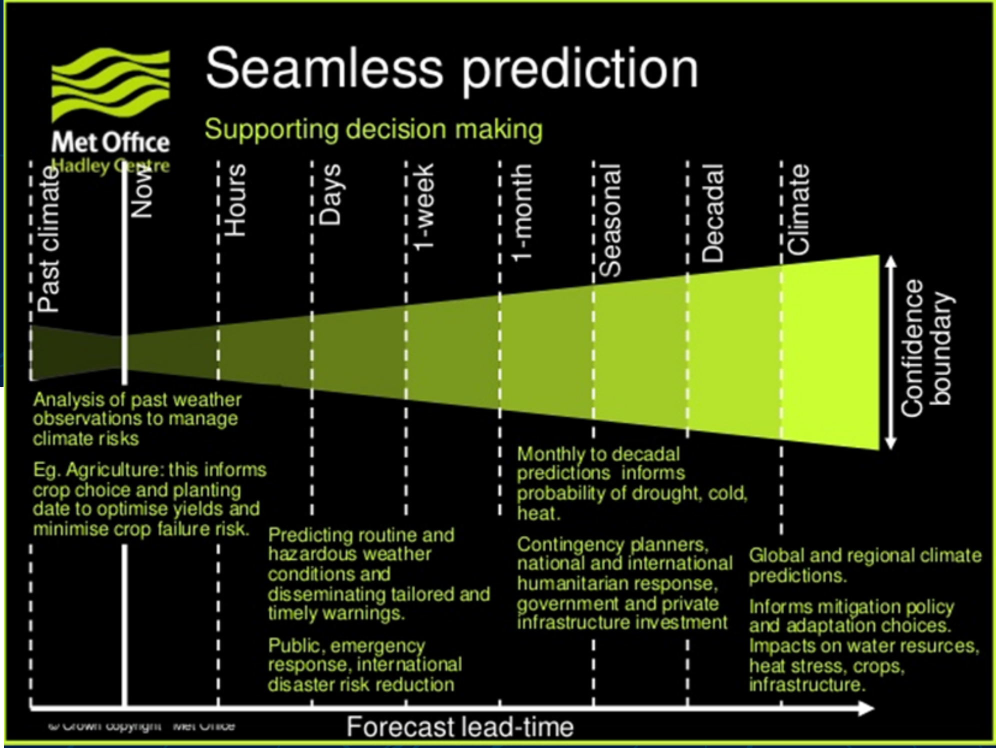
1) Importance of ENSO for driving global climate variability
2) These indices should be more predictable than most other variables

# Increasingly our users want more than just a seasonal prediction. They want all time scales.



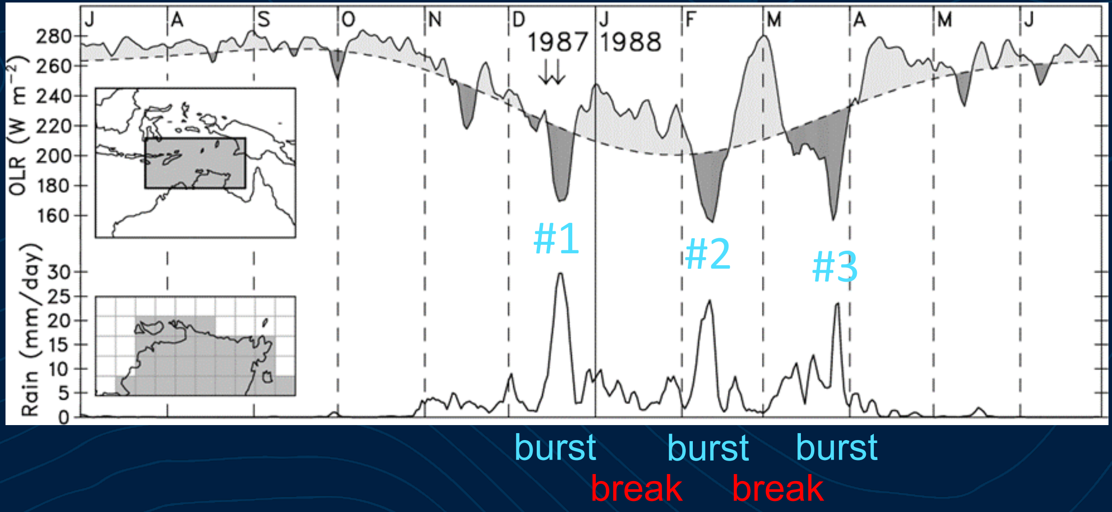
"Seamless prediction" is the new buzz phrase, and the distinction between weather and climate is becoming less meaningful.

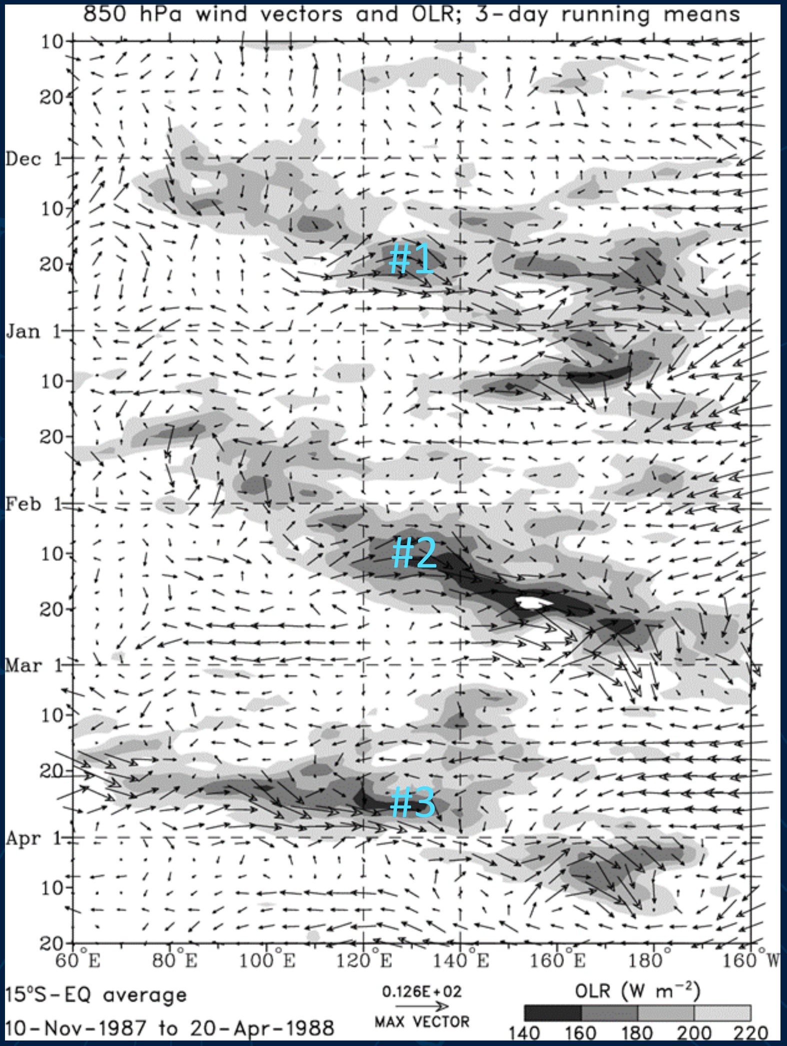


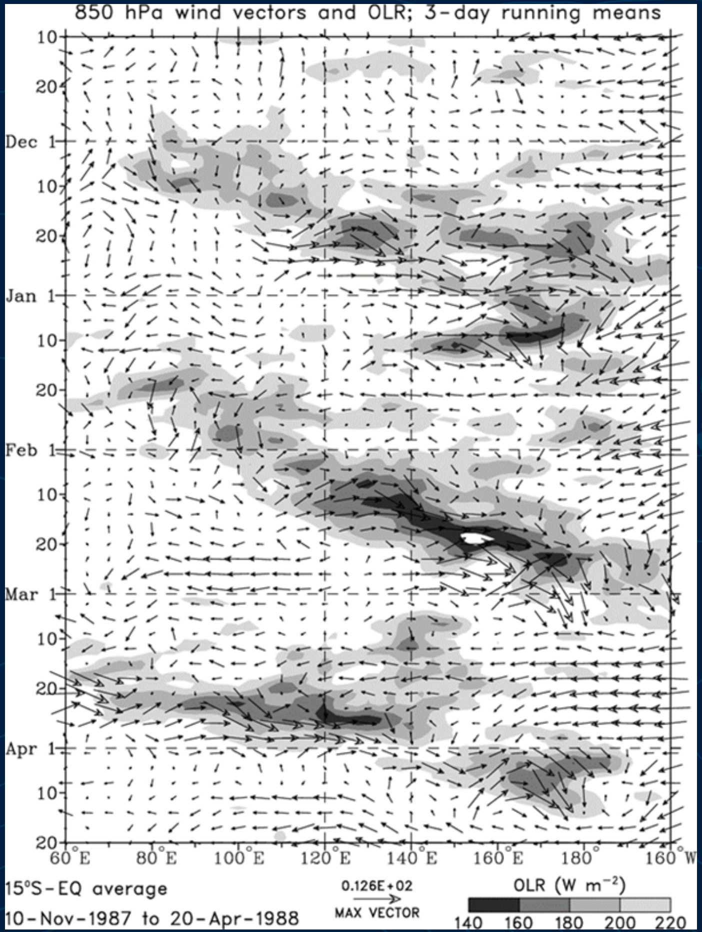
# The **MJO** as an example of a phenomenon we are now exploiting for prediction

The MJO is observed to often have a large impact on the Australian monsoon



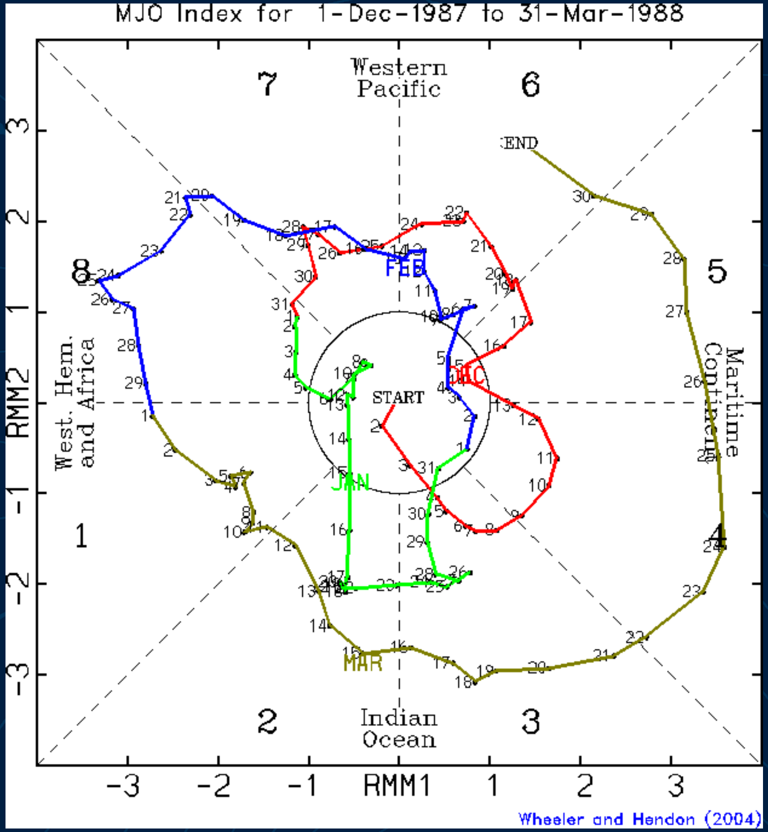



# We (at the Bureau) developed an index for monitoring the MJO




Using maths and decades of observations

EOFs of the combined fields of OLR, u850, u200

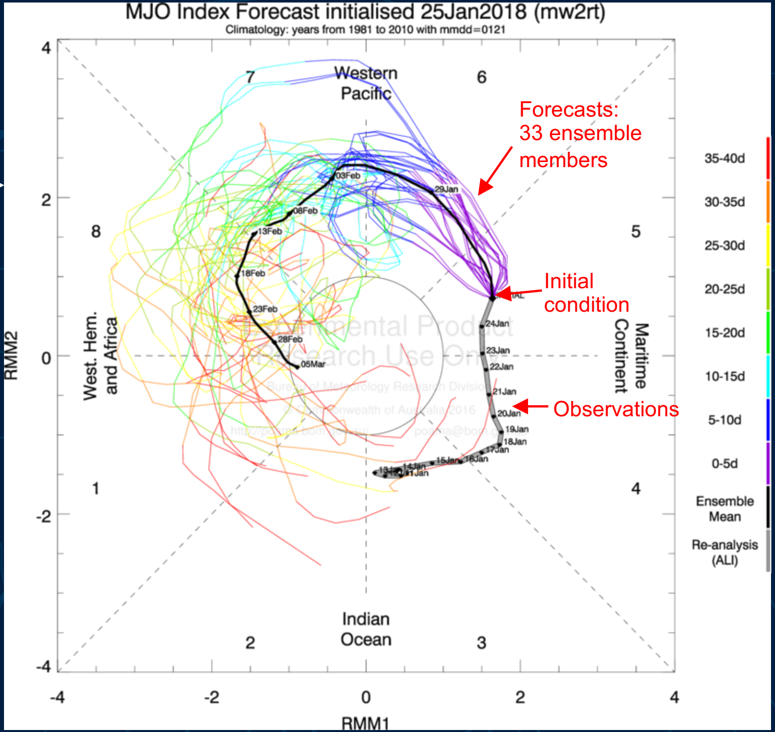



MJO Phases 1-8 track the propagation of clouds and wind anomalies eastward along the equator.

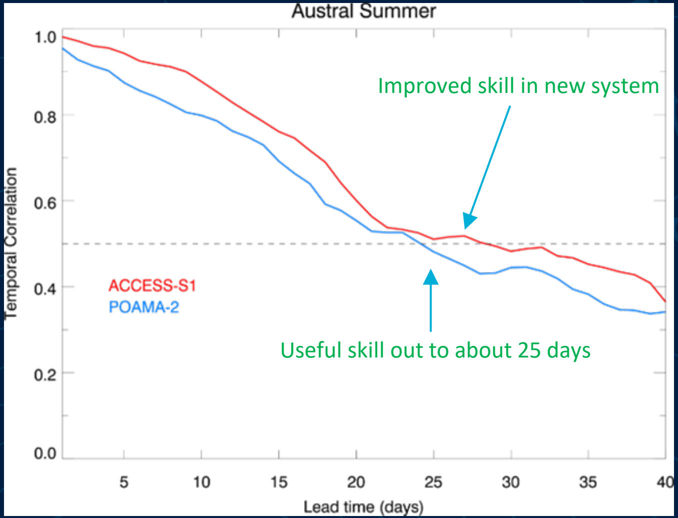
# MJO prediction and prediction skill

The MJO can be predicted out to about 20-30 days.

An example MJO index forecast from our old POAMA model →

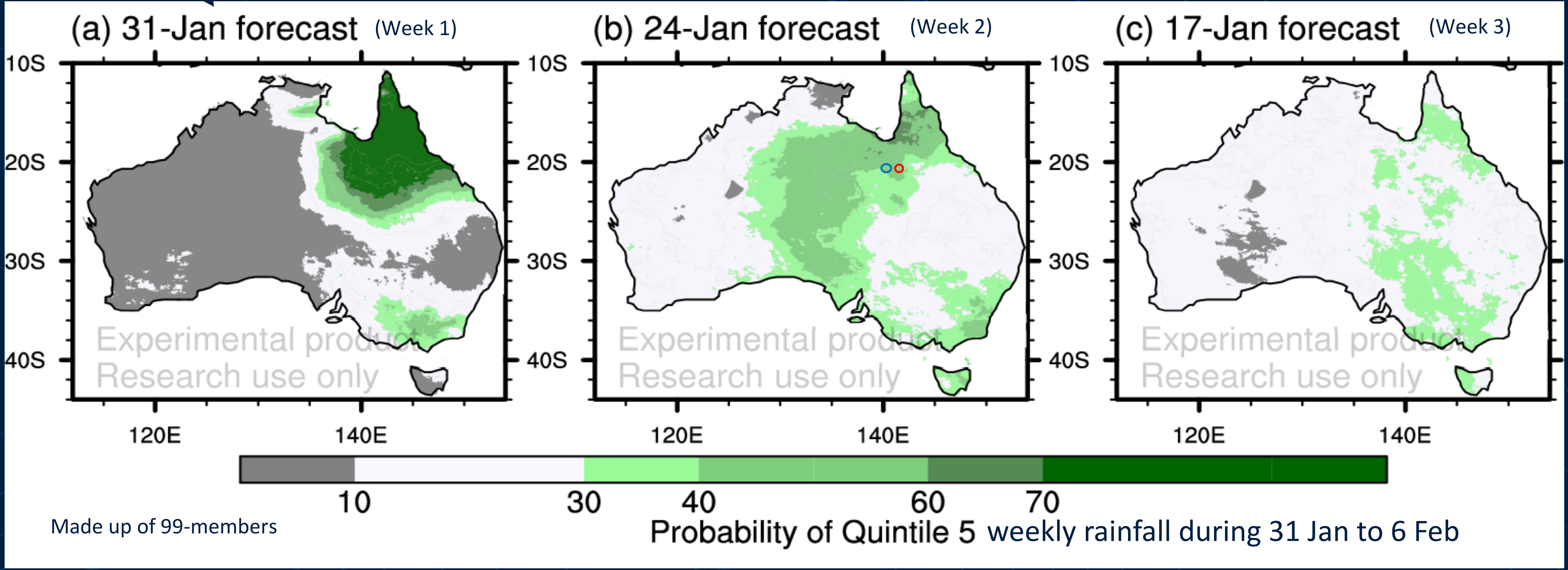



Our dynamical models are getting better at predicting it.



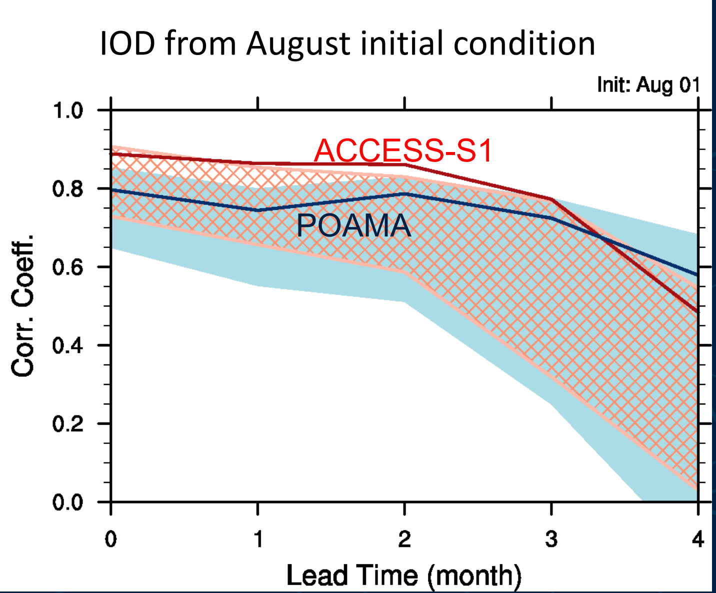

← Correlation skill for predicting the MJO index in our old (POAMA) and new (ACCESS-S1) seasonal prediction systems.

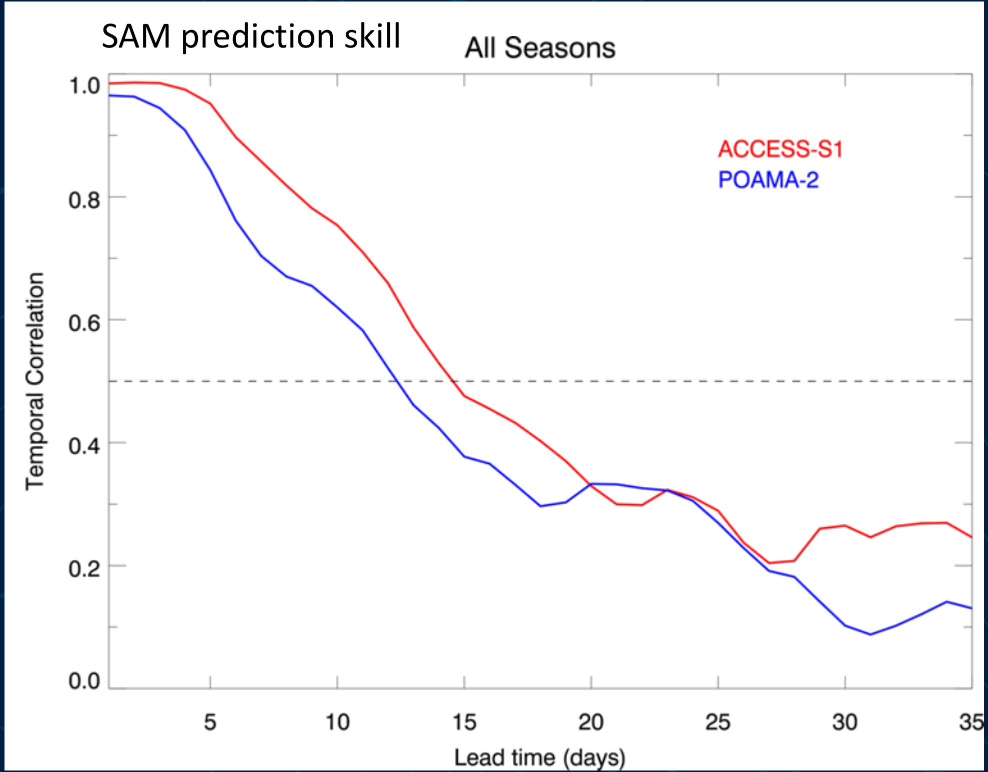
# QLD February floods: An example of the MJO driving the weather/climate and providing week 2 predictability




The flood/cold event was well-captured by ACCESS-S1 in weeks 1 and 2, but not in week 3 or the officially-released monthly outlook for February.

# Hudson et al. (2017) covers the skill of predicting all of the important drivers of Australian weather and climate



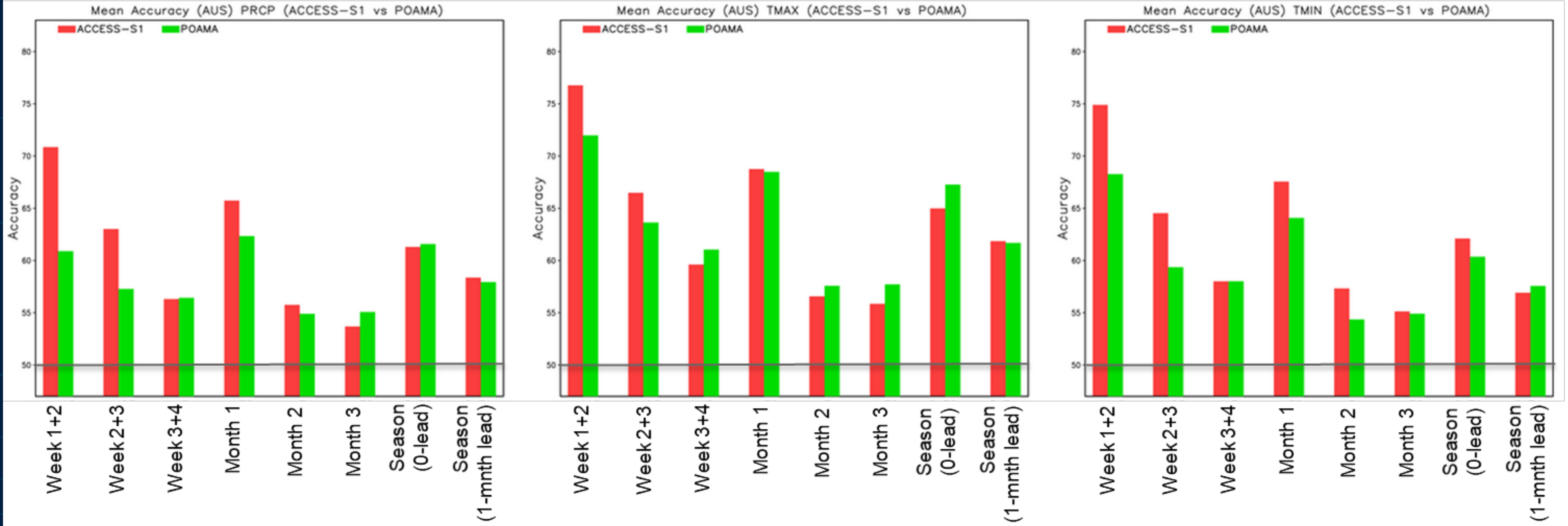



# Average accuracy for all AUS and all times of year

(For forecasts started on the 1st of every month in 1990-2012; n=276 i.e. 12 start_dates * 23yrs)

## Forecasts of probability of above median

Rainfall TMAX TMIN




Hudson et al. (2017)

ACCESS-S1 POAMA

# Exploring the global skill distribution of these prediction systems is also very instructive.

POAMA is ideal for this because of its very large hindcast size.

**Seamless Precipitation Prediction Skill in the Tropics and Extratropics from a Global Model**

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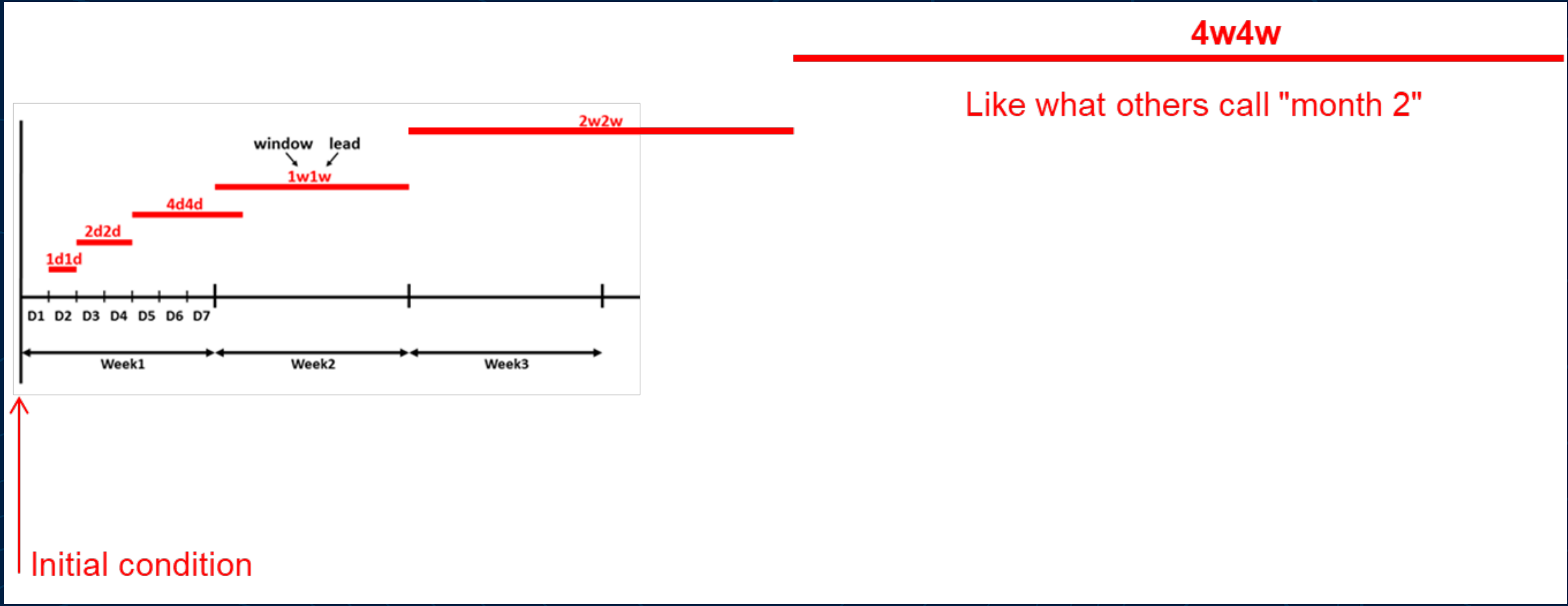
Zhu et al. (Mon. Wea. Rev., 2014)

# The essence of our approach is:

- Compute prediction skill **globally** for a large **range of lead times**.
- As we increase the lead time, we also increase the time-averaging window for a **seamless** transition from weather to climate.



# Data and Method

## a. POAMA-2 ensemble prediction system

T47L17 **atmosphere**; 0.5-2º L25 **ocean**; and **land**.

Initialized with realistic atmospheric, land, and ocean initial conditions.

Coupled breeding scheme to produce a burst ensemble of 11 members.

3 versions of the model to provide in total 33 members.

Hindcasts from the 1$^{st}$, 11$^{th}$, and 21$^{st}$ of each month (out to 120 days).

## b. Observations

GPCP daily precipitation (blended station and satellite).

1º grid converted to POAMA grid.

We use **1996 to 2009** for this work.

## *c. Measure of prediction skill*

We tried different verification measures (ROC score, Brier score, correlation skill).

In the end we chose the simplest: the **correlation of the ensemble mean**.

Here I present results for:

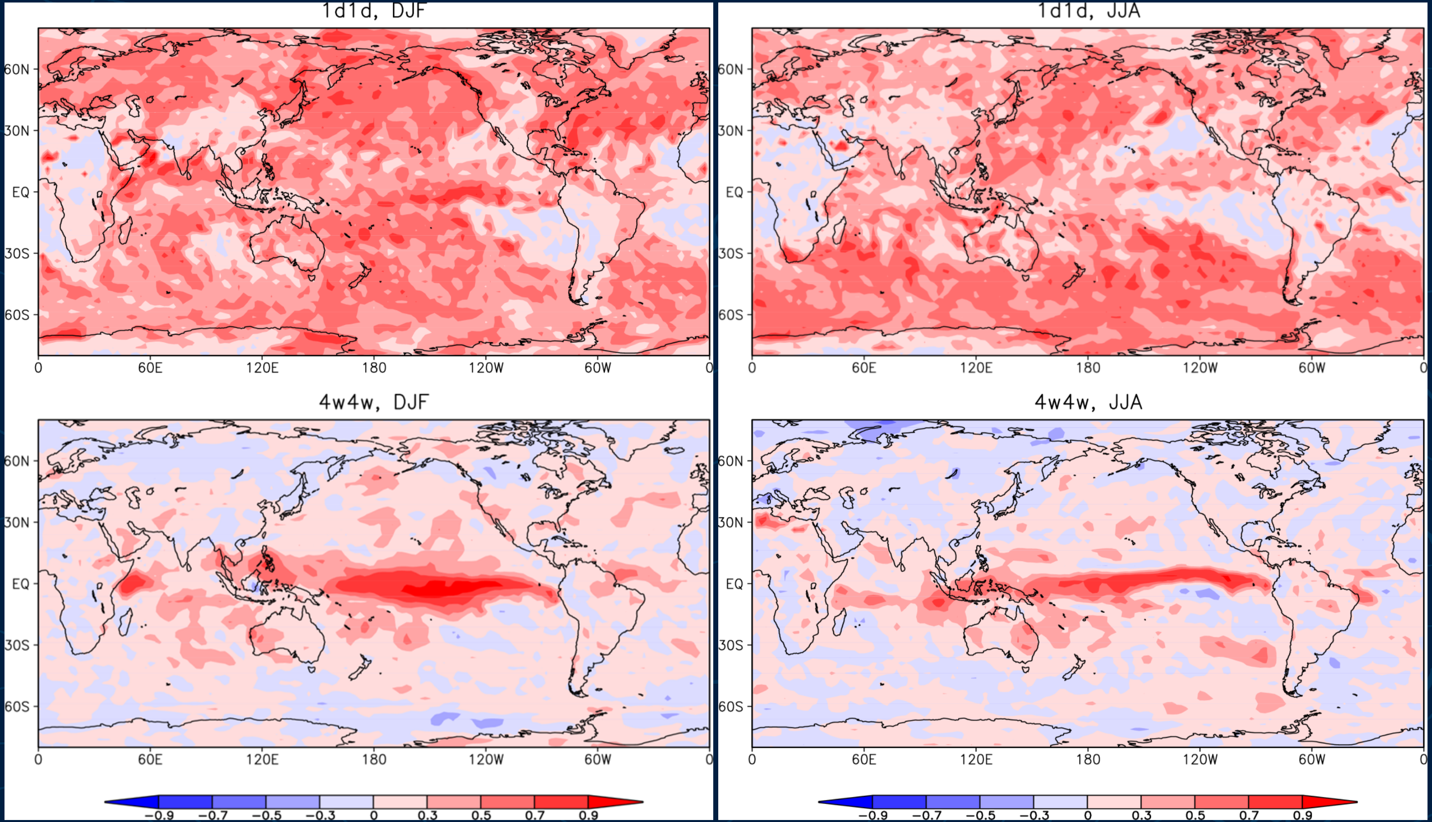
CORa - using **anomalies** with respect to separate climatologies for the hindcasts and observations.

The correlations are computed over time using data from multiple verification times.

Separately for each lead time and each grid point.

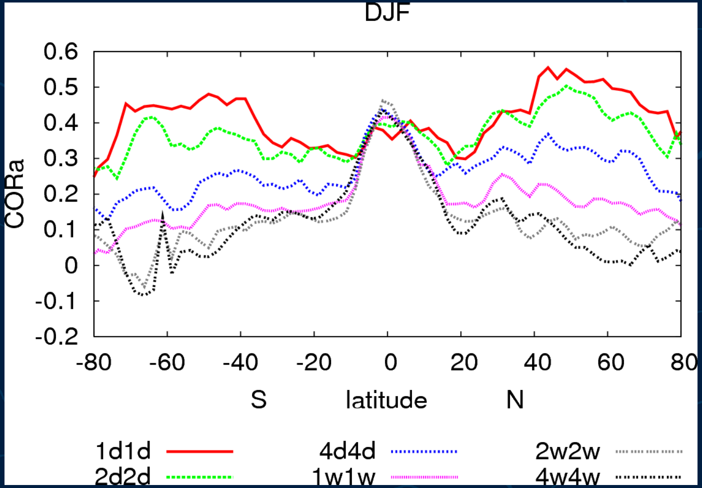
Separately for DJF (n=117) and JJA (n=108).

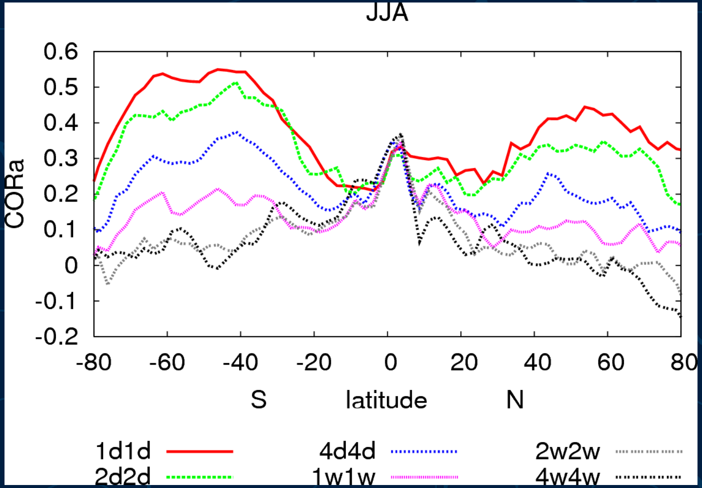
# CORa



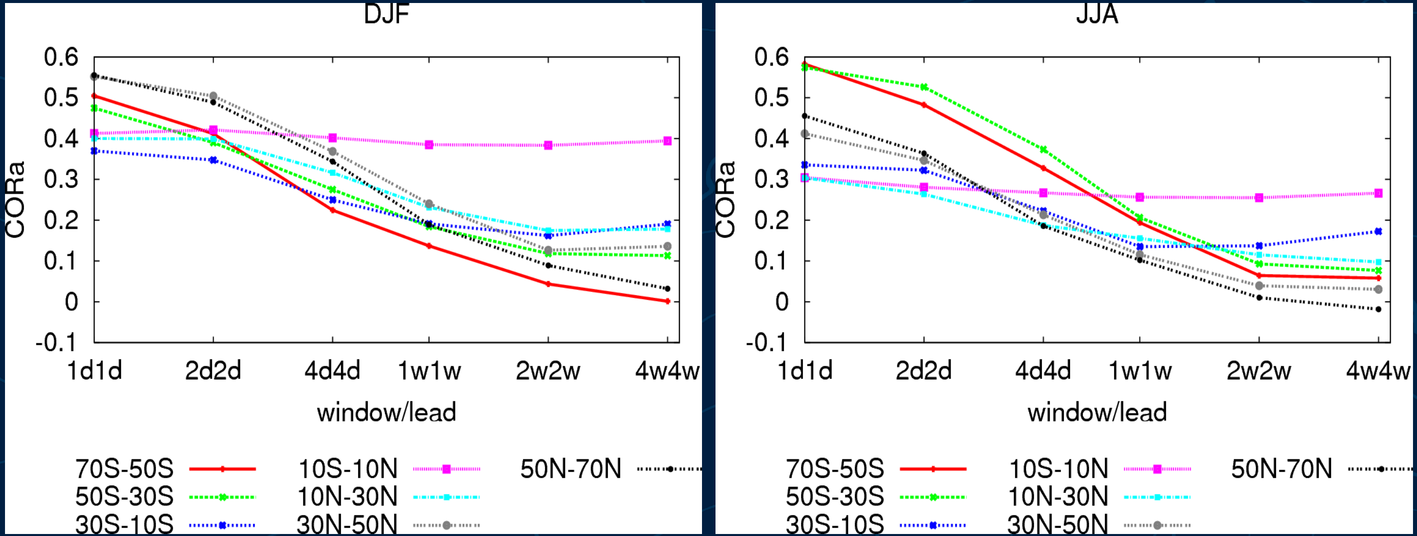

1d1d: Extratropics better than tropics; winter extratropics better than summer.
4w4w: ENSO dominates.

# Zonally-averaged CORa




The peak in skill at the equator is apparent at all lead times.
Extratropical skill drops rapidly from 1d1d to 1w1w and then levels-off.




Skill in tropics (10ºS-10ºN) overtakes skill in extratropics for 4d4d in DJF and 1w1w in JJA.

That's interesting, but what does it look like in a higher resolution model?

What about potential (perfect model) skill?

# Seamless precipitation prediction skill comparison between two global models

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[b]*Department of Applied Physics and Applied Mathematics, Lamont-Doherty Earth Observatory, Columbia University, New York, NY, USA*
[c]*European Centre for Medium-Range Weather Forecasts, Reading, UK*

Wheeler et al. (QJRMS, 2017)

**ECMWF monthly system**, cycle 36R4, as was operational in 2011

T639 L62 atmosphere uncoupled to day 10

T319 L62 atmosphere coupled to ~1° L29 ocean after day 10

15 ensemble members

4 hindcast start dates per year (1 Feb, 1 May, 1 Aug, 1 Nov)

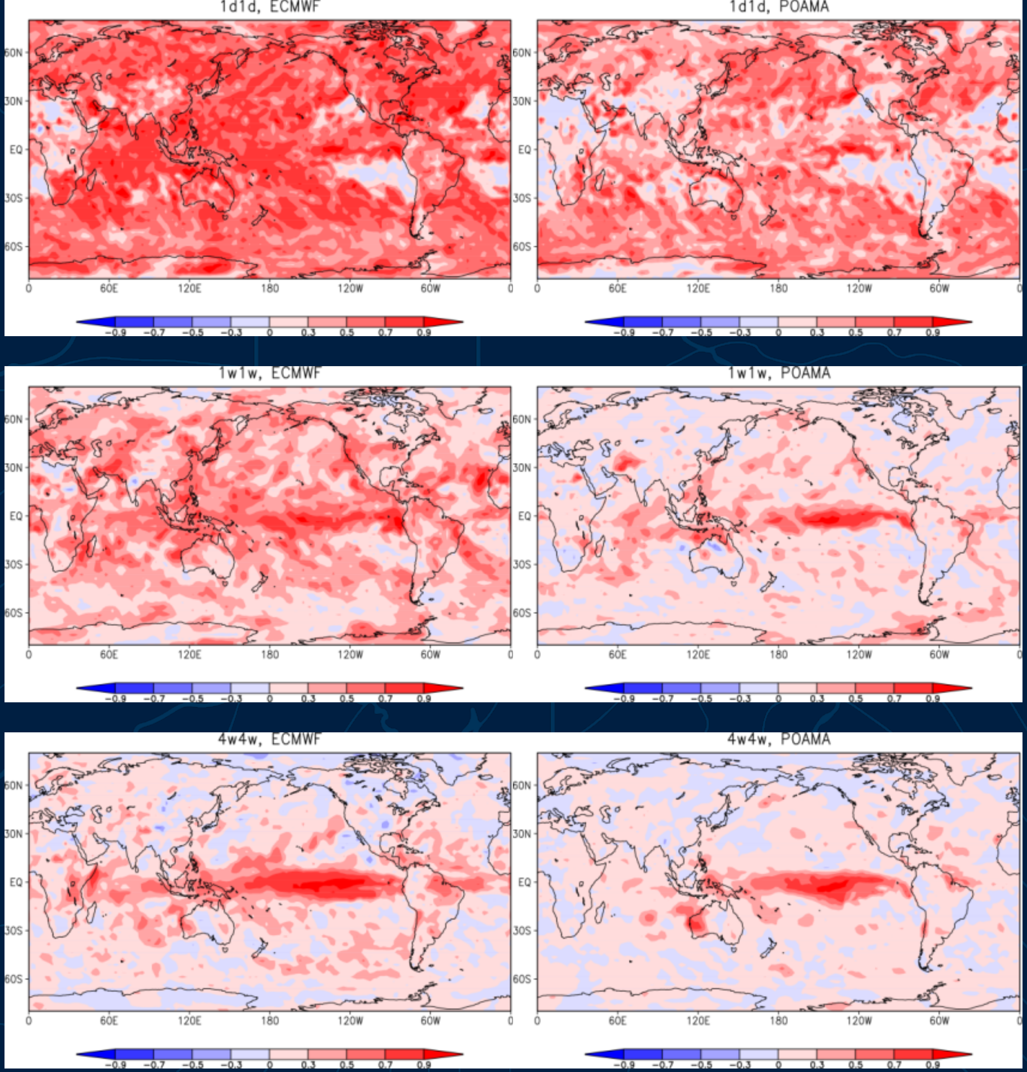
**POAMA** as before, except using the same start dates as ECMWF

**Observations** are GPCP as before, 1997-2008

12 years × 4 start dates = **48 values** in each grid-point correlation (not much)

Convert everything to POAMA's **~2.5° grid**.

# Actual skill - CORa

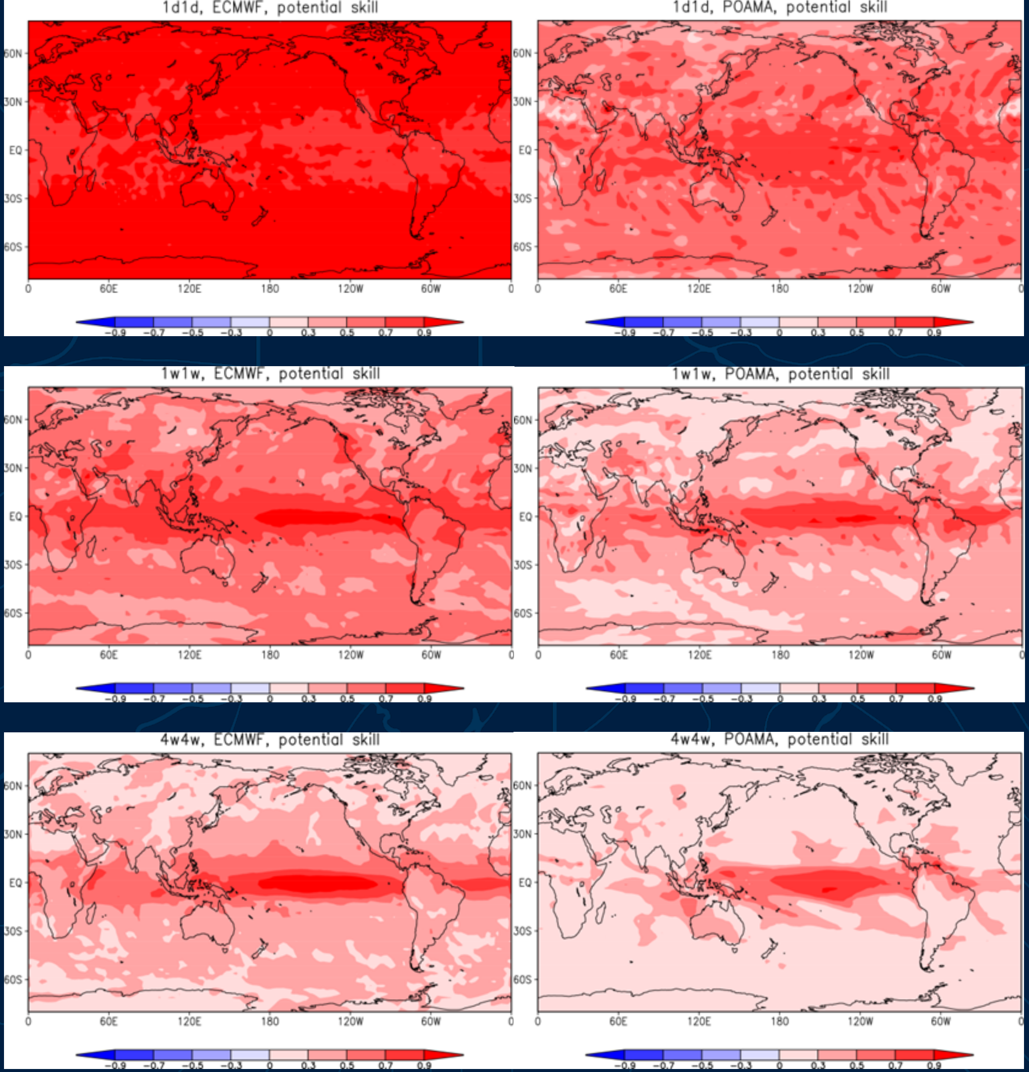



ECMWF better than POAMA almost everywhere, as expected.

But the spatial patterns remain similar across the time scales, indicating similar sources of skill.

# Potential (or Perfect) Skill:

## Using the assumption that one ensemble member is truth




As expected, almost everywhere higher than actual skill.

1w1w and 4w4w plots have similar shape to those for actual skill, with highest values in the central Pacific.

But the 1d1d plots are quite different for ECMWF vs. POAMA, and also very different to 1d1d actual skill.

# What does a difference between potential and actual skill mean?

*Possible interpretations:*

1. *Room for improvement in actual skill*
2. *Too little ensemble spread resulting in too high potential skill*
3. *Errors in the verifying observations which artificially reduce actual skill*

# The (near) future of climate prediction at the Bureau

## ACCESS-S1

Operational early 2018

- UKMO global coupled model (GC2)
- Uses UKMO initialisation
- BoM-developed ensemble generation (appropriate for mutli-week)
- Larger ensemble size than UKMO
- Forecasts out to 6-months lead time
- 23 years hindcasts

## ACCESS-S2

Operational end 2019

- UKMO global coupled model (GC2)
- BoM-developed ocean assimilation/initialisation
- Soil moisture initialisation
- 30+ years of hindcasts with more ensemble members

## ACCESS-S3

Operational in 2022+

- Improved global coupled model (GC4/5)
- Weakly-coupled assimilation/initialisation
- Model improvements from projects

# Key messages for climate prediction

- Good initial conditions, a coupled model, and appropriate ensemble perturbations are needed.
- Many hindcasts required, for verification and bias removal.
- The lack of good ocean observations in the past limits the hindcast length.
- Lots of computing required.
- The distinction between weather and climate is becoming less meaningful, both for users and our modelling strategies.
- You must know the limits to predictability.

# THE END