Seasonal forecasting with the NMME with a focus on Africa

Bill Merryfield

Canadian Centre for Climate Modelling and Analysis (CCCma)
Victoria, BC Canada

School on Climate System Prediction and Regional Climate Information
Dakar, 21-25 Nov 2016

Topics covered

- Fundamentals of seasonal forecasting
  - Deterministic vs probabilistic ensemble forecasts
  - Forecast skill
  - How seasonal forecasts are produced
  - El Niño impacts
  - ENSO prediction
- Multi-model ensembles (MMEs)
- North American Multi-Model Ensemble (NMME)

Fundamentals of seasonal forecasting

Necessary conditions for useful climate predictions

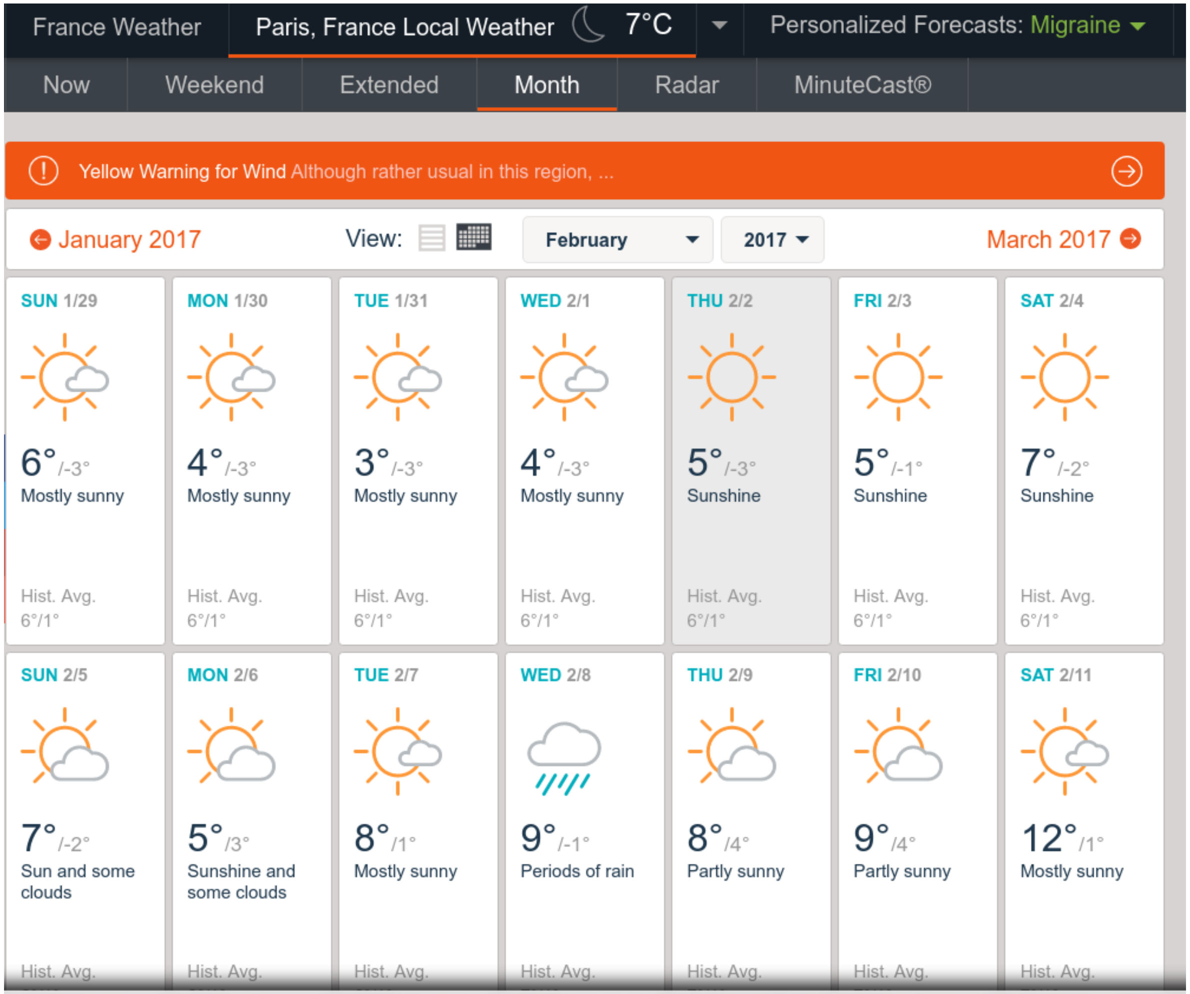
1) The phenomenon being forecast must be *predictable*

2) Prediction method must have ability to capitalize on natural predictability

→ *If these two conditions are met then there is potential for skillful predictions*

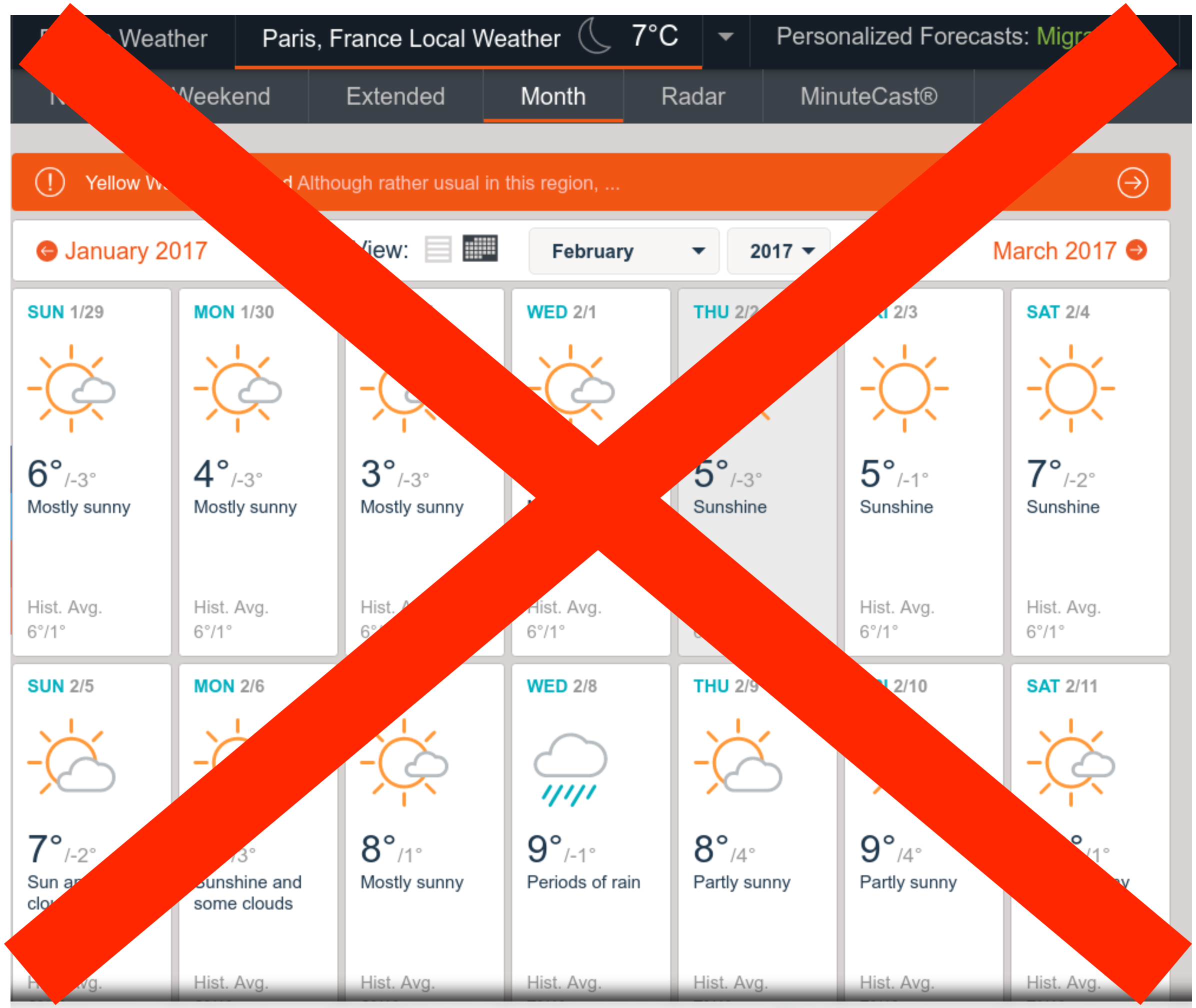
Daily weather is not very predictable after 7-10 days

Example: Daily weather predictions for Paris in February 2017, retrieved on 20 November 2016!



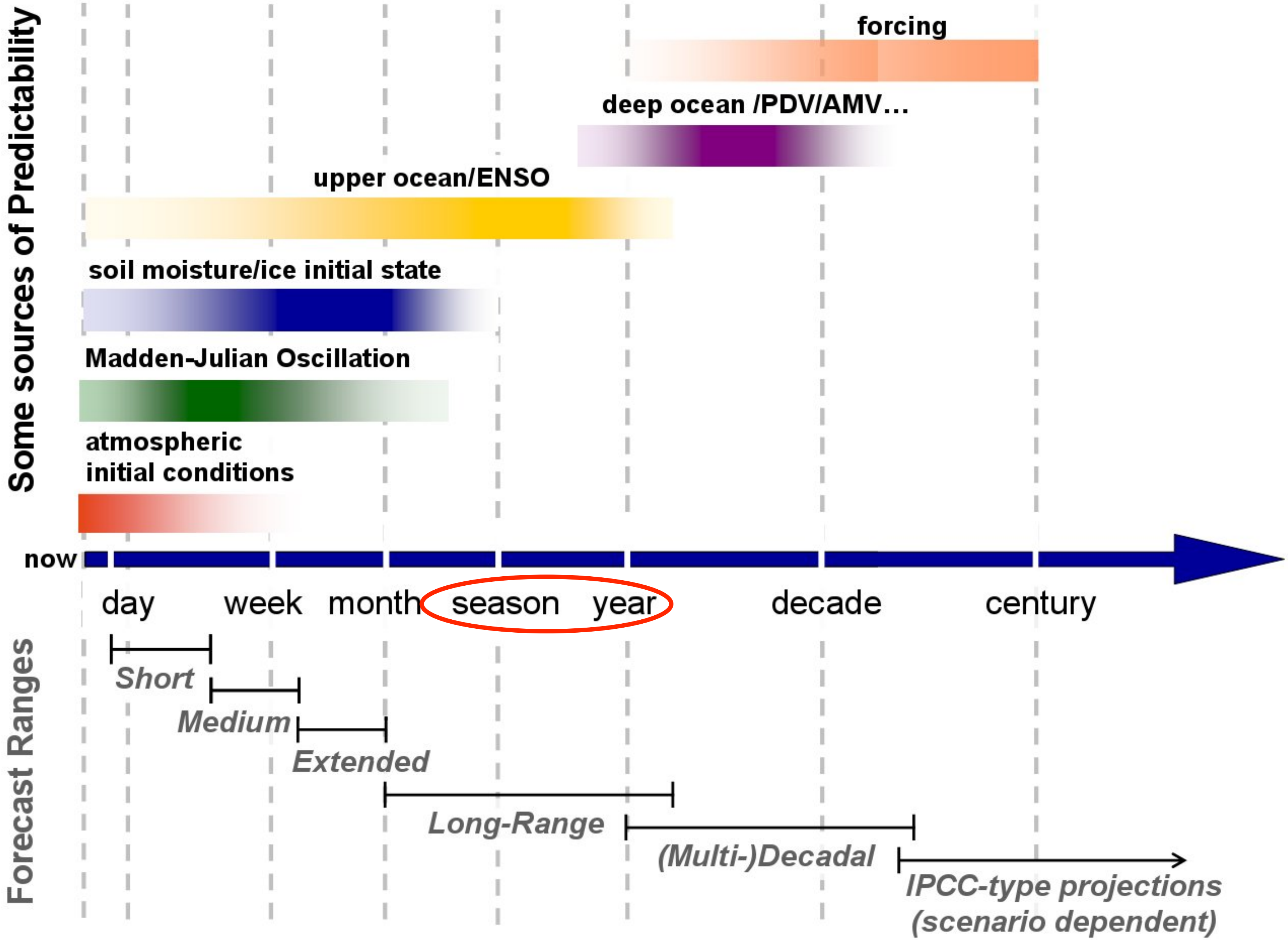
Daily weather is not very predictable after 7-10 days

Example: Daily weather predictions for Paris in February 2017, retrieved on 20 November 2016!

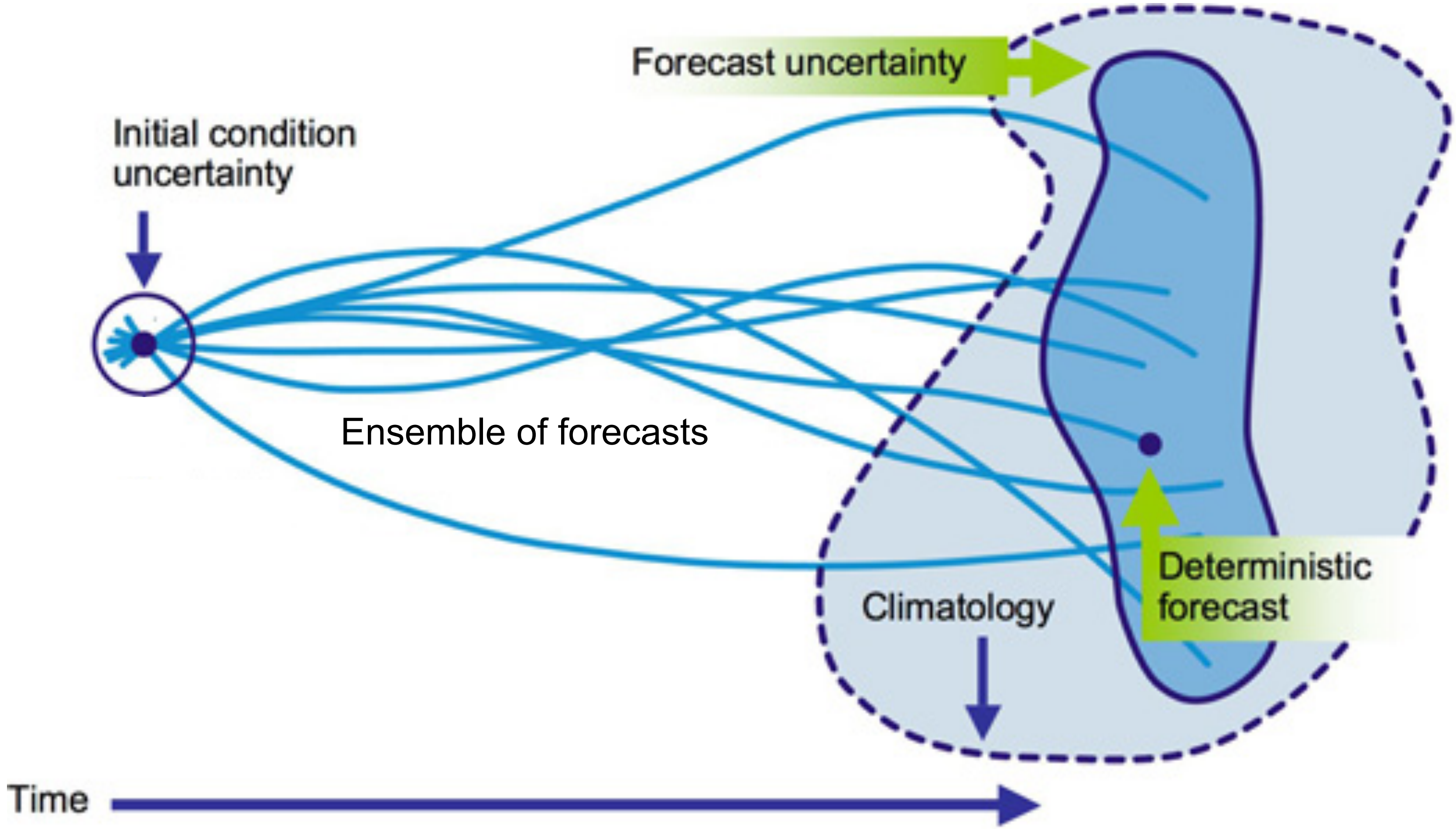


However, longer term averages over a week, month or season may be predictable depending on location, lead time, etc.

Predictability and Prediction



Probabilities based on an ensemble of forecasts



- When uncertainties are large, a single deterministic forecast tells us very little → need an *ensemble* of forecasts to estimate the probabilities of different outcomes
- **Ensemble average** provides a **deterministic forecast** for the ***average* outcome**
- Better are **probabilistic forecasts** describing the **likelihood of different outcomes**

Deterministic vs probabilistic ensemble forecasts

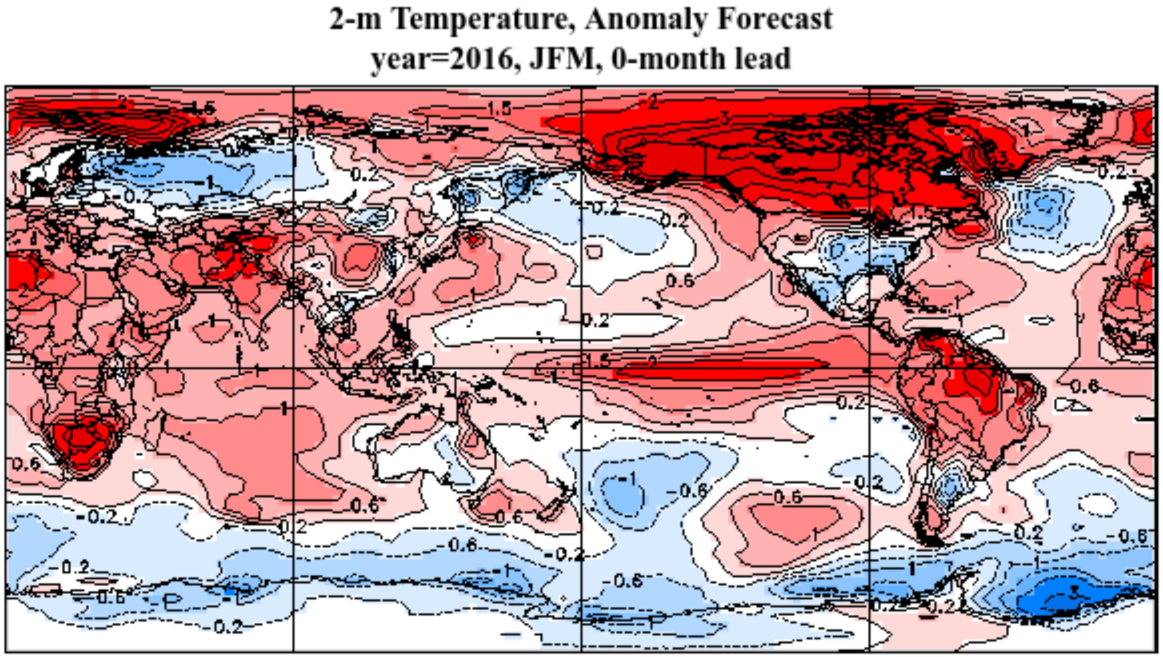
Ensemble deterministic forecasts

Example: Seasonal mean temperature for JFM 2016

Deterministic forecast (single location)

"The average temperature in Victoria, Canada during JFM 2016 will be 0.85°C above normal relative to the average of all years in 1981-2010."

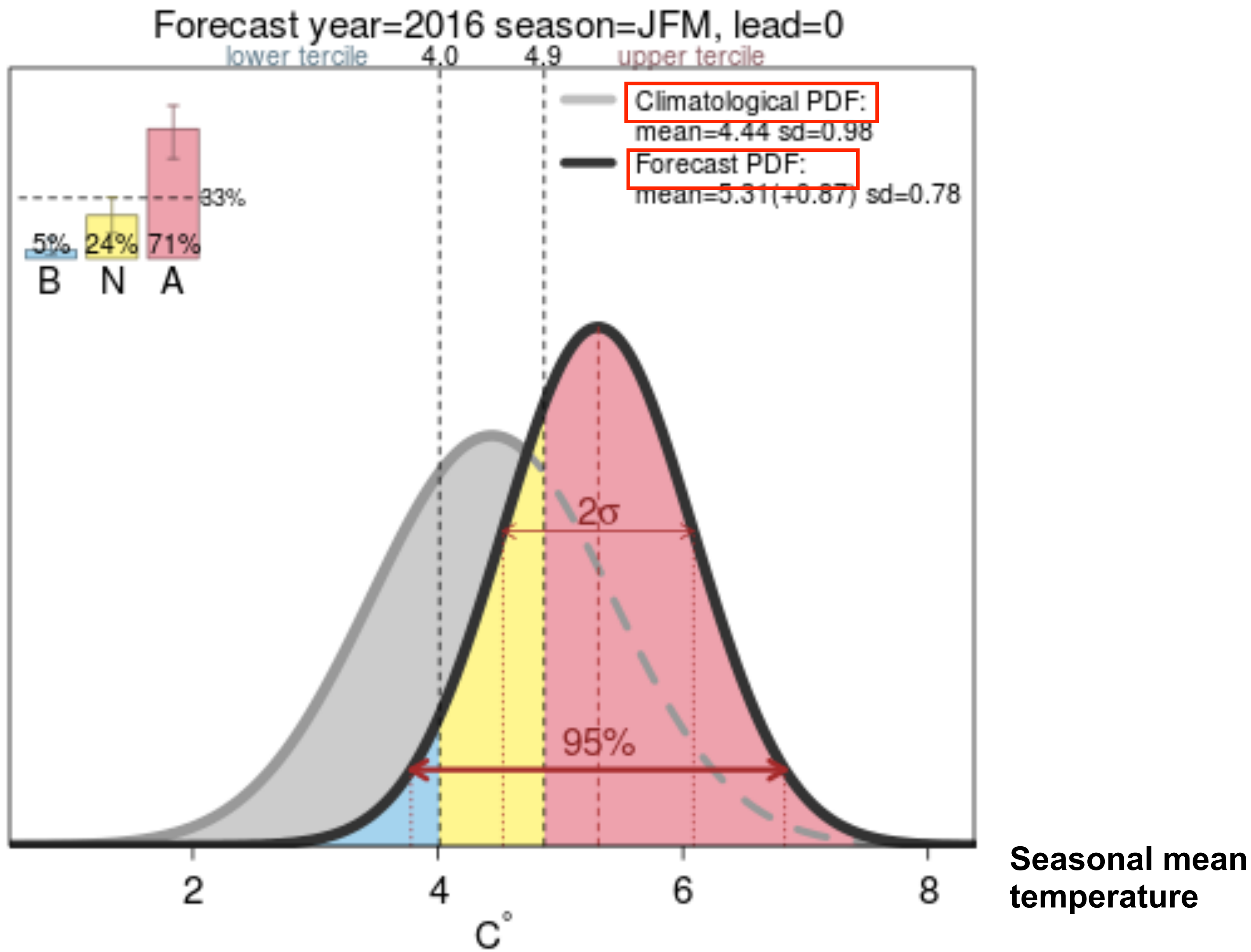
Deterministic forecast map



Uncalibrated ensemble mean anomaly forecast.

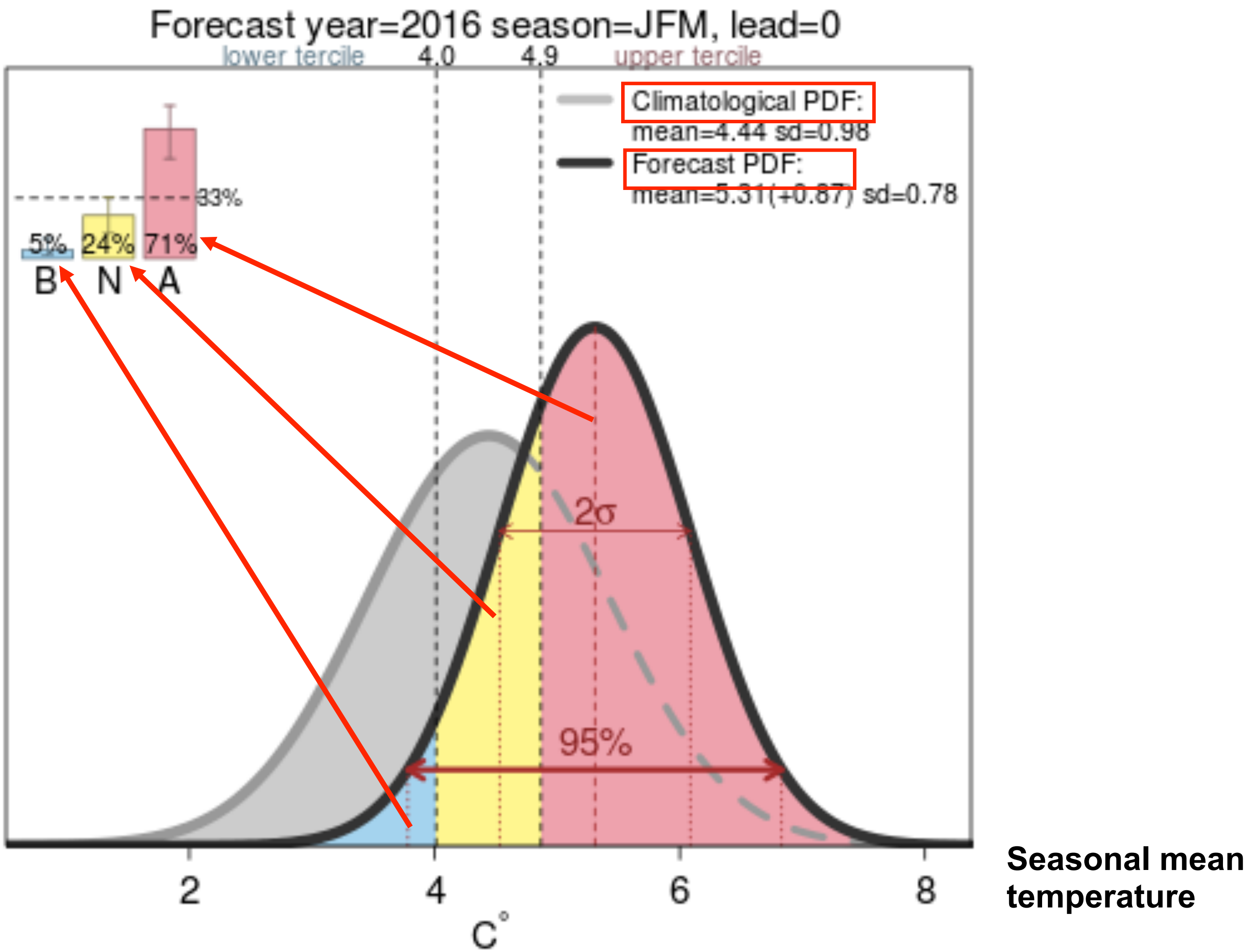
However, these products contain no indication of uncertainty

Probabilistic forecast (single location)



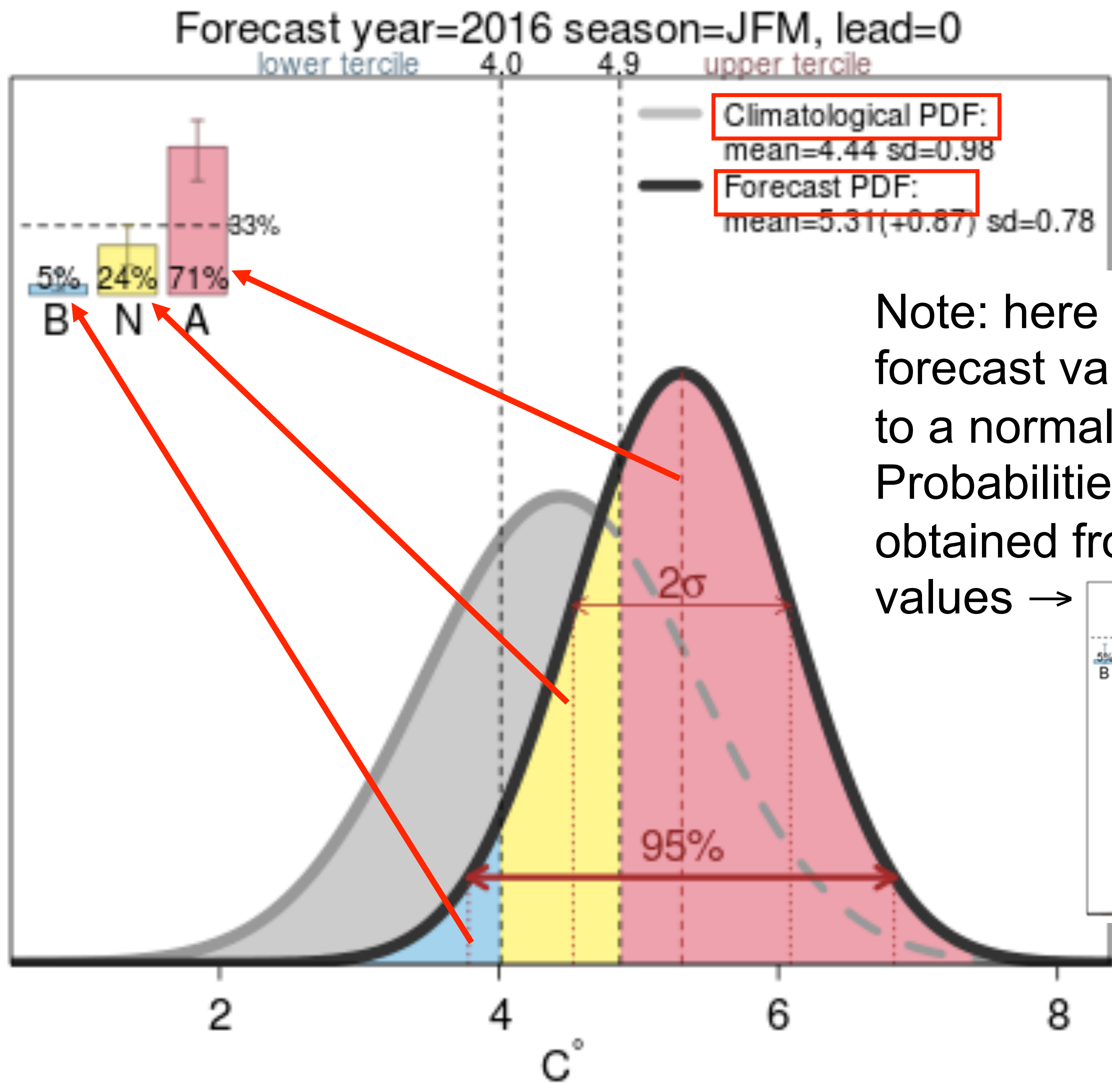
Here the forecast probability distribution or PDF is described in terms of probabilities that forecast seasonal mean temperature will fall into climatologically equi-probable tercile categories: **below normal** **near normal** **above normal**

Probabilistic forecast (single location)

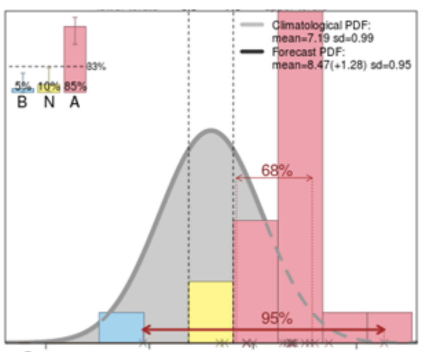


Here the forecast probability distribution or PDF is described in terms of probabilities that forecast seasonal mean temperature will fall into climatologically equi-probable tercile categories: **below normal** **near normal** **above normal**

Probabilistic forecast (single location)



Note: here the ensemble of forecast values has been fit to a normal distribution. Probabilities can also be obtained from raw forecast values →



Seasonal mean temperature

Here the forecast probability distribution or PDF is described in terms of probabilities that forecast seasonal mean temperature will fall into climatologically equi-probable tercile categories: **below normal** **near normal** **above normal**

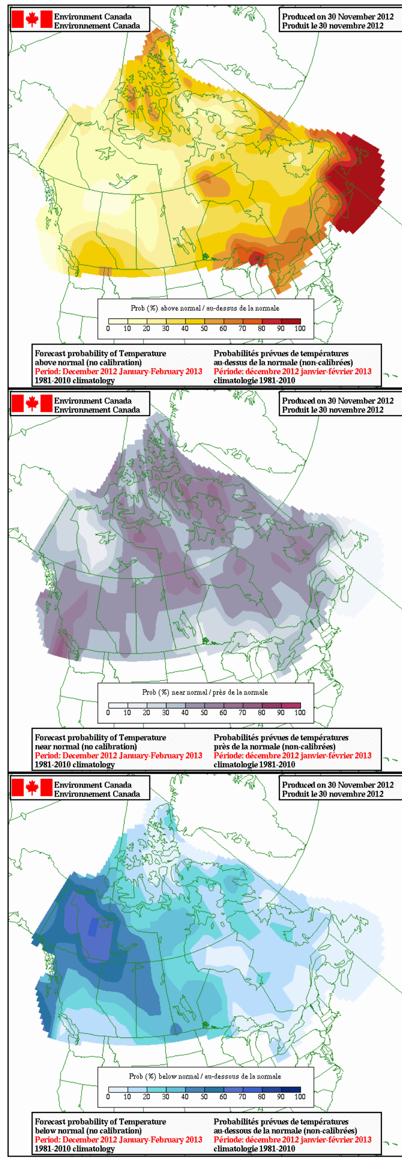
Probabilistic forecast maps

Probabilities in each category

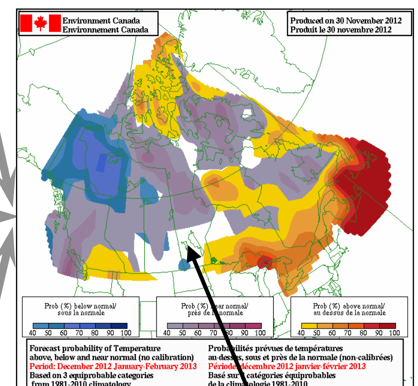
Above Normal

Near Normal

Below Normal



Highest probability at each location



White = ‘equal chance’ (no category > 40%)

Reliability of probabilistic forecasts

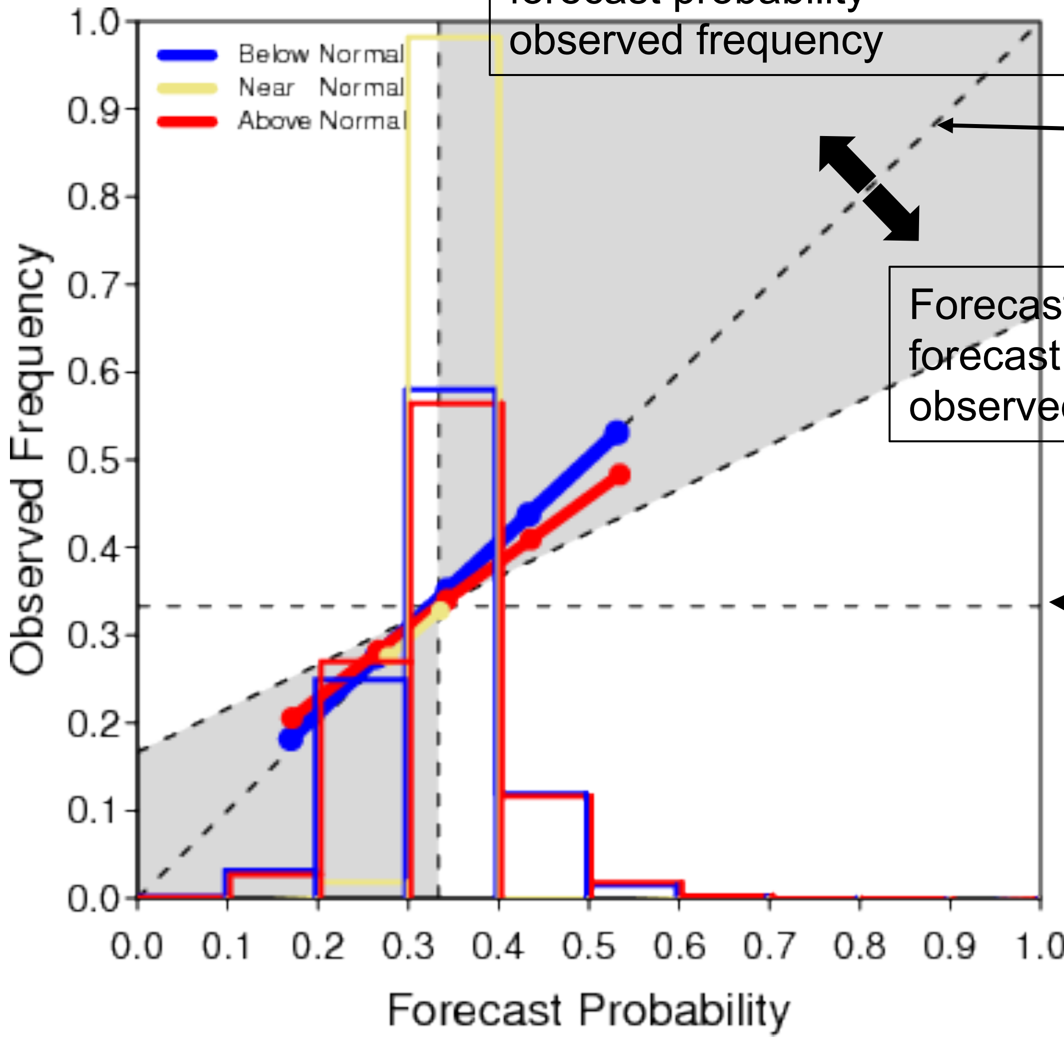
- Consider *many* probabilistic forecasts from different times, locations
- Compare **forecast probabilites** with **observed frequencies**

Forecasts **underconfident**: forecast probability < observed frequency

Forecasts **reliable**: forecast probability = observed frequency

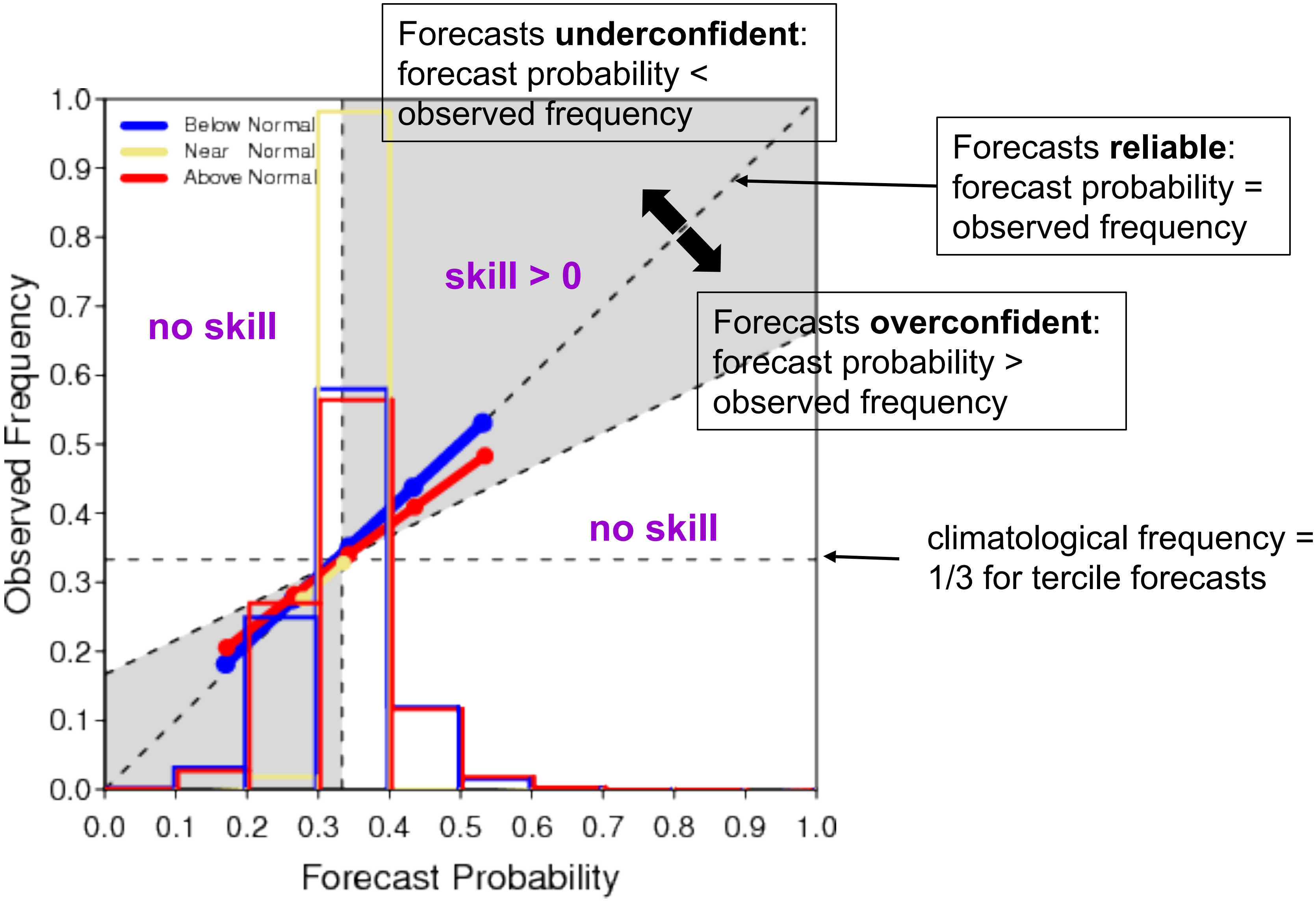
Forecasts **overconfident**: forecast probability > observed frequency

climatological frequency = 1/3 for tercile forecasts



Reliability of probabilistic forecasts

- Consider *many* probabilistic forecasts from different times, locations
- Compare **forecast probabilites** with **observed frequencies**



Advantages of calibrated probability forecasts

• **uncalibrated** probabilities:

- high probabilities predicted far more frequently than observed

- **overconfident**, especially for precipitation and near-normal category

- near-normal grossly overpredicted

• **calibrated** probabilities:

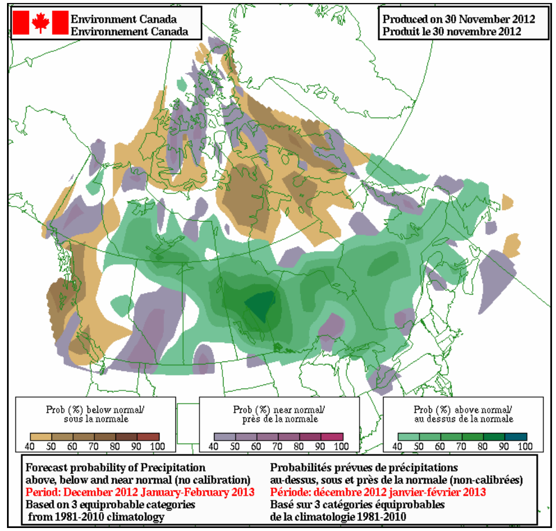
- much more **reliable** (forecast probability ≈ observed frequency)

- **less overconfident**

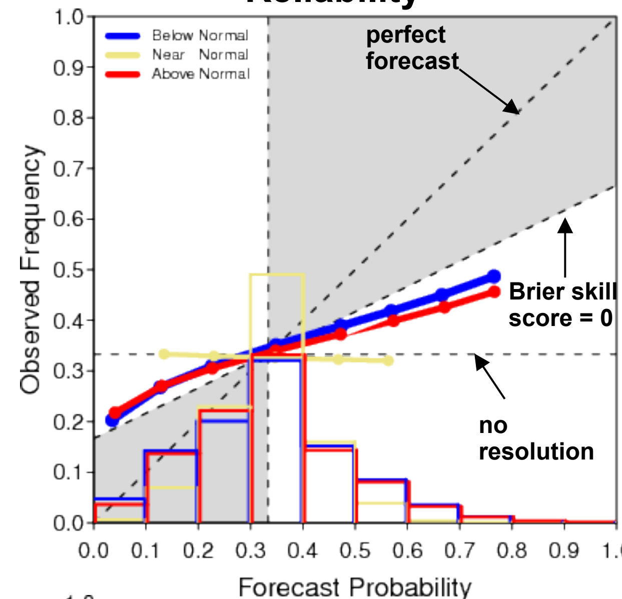
- near-normal less overpredicted

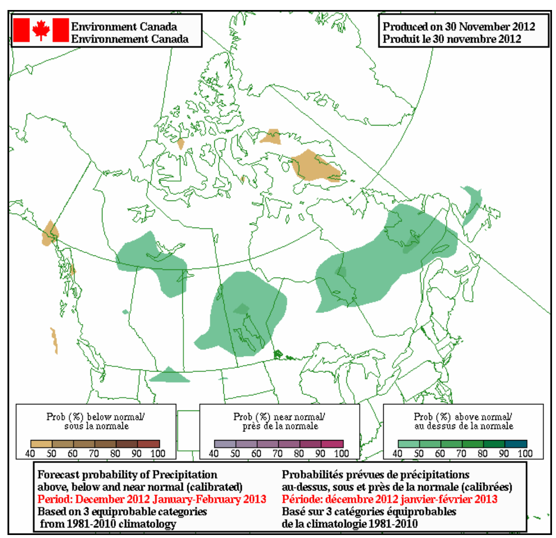
Seasonal precipitation forecast

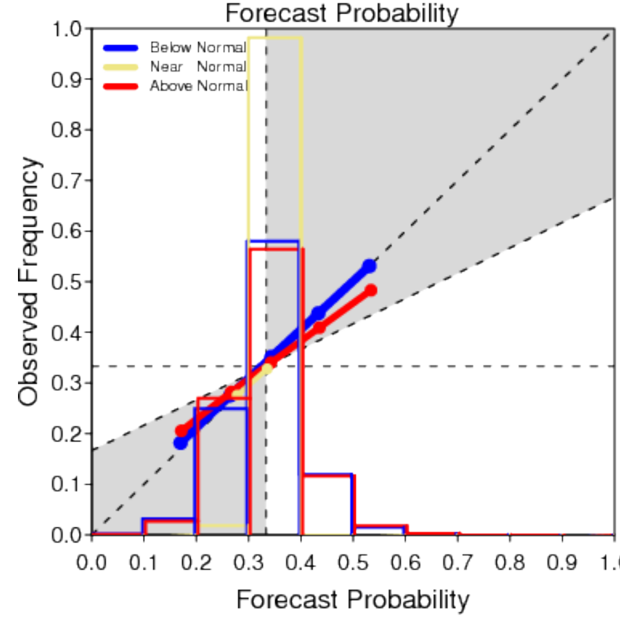
Forecast



Reliability

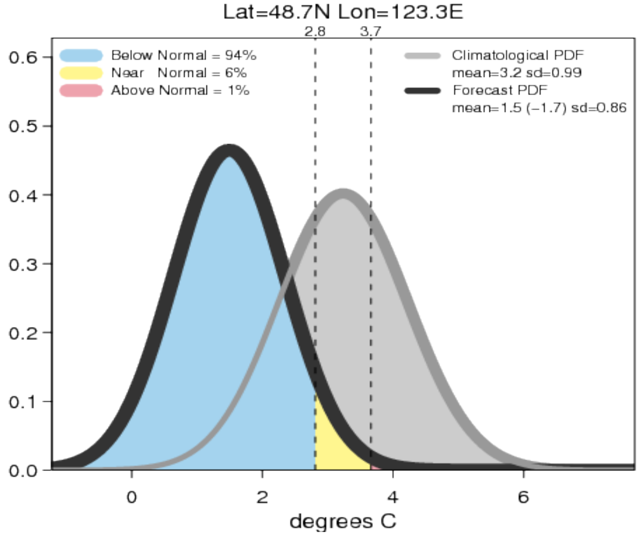




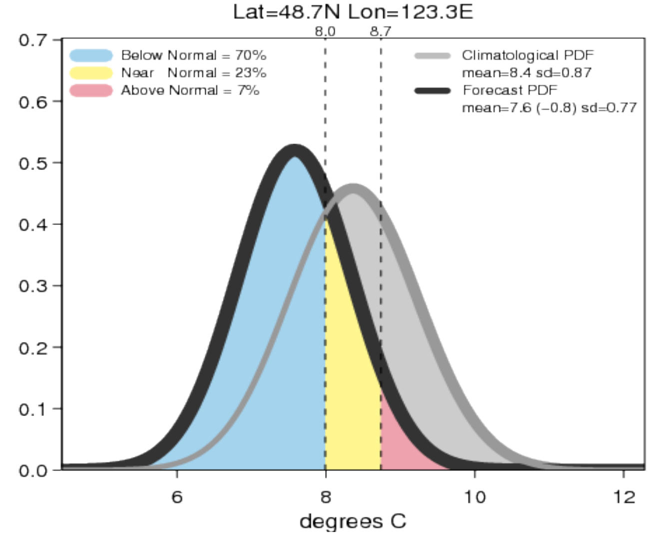


Growth of uncertainty with increasing lead

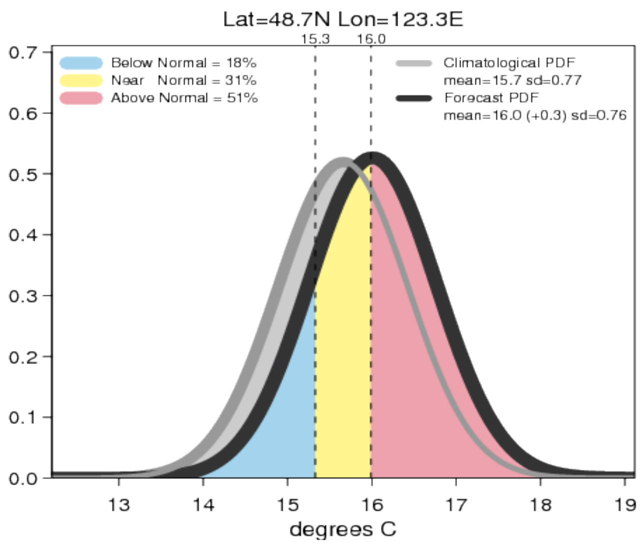
Lead 0 months



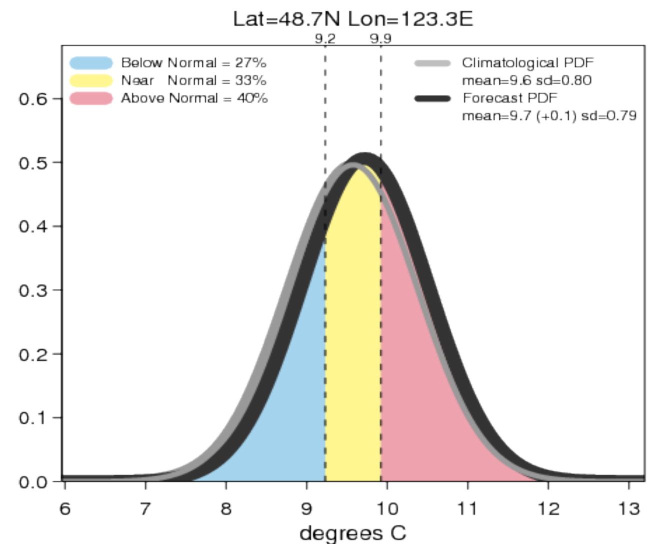
Lead 3 months



Lead 6 months



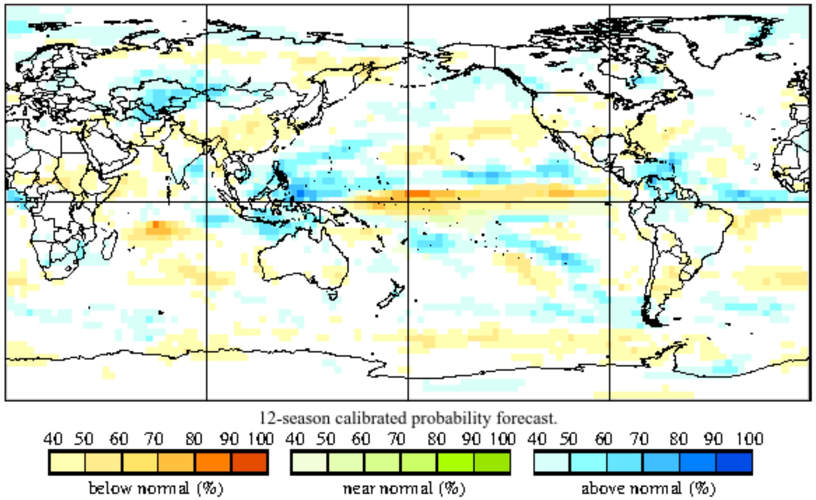
Lead 9 months



Growth of uncertainty with increasing lead

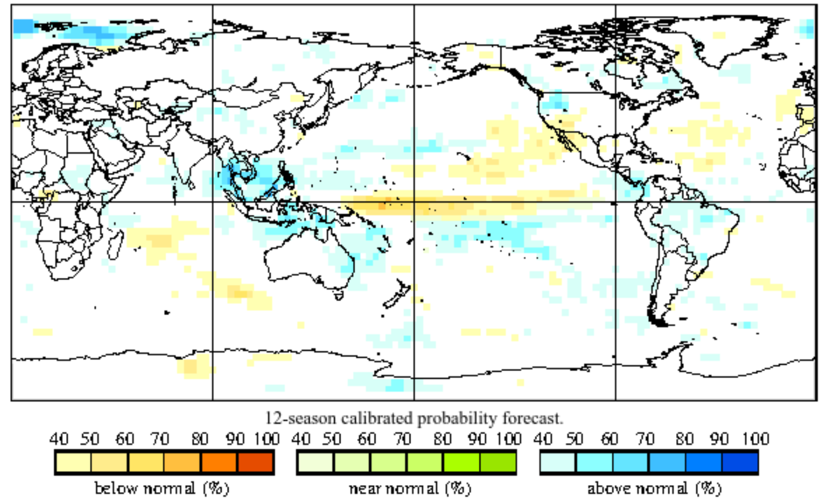
Lead 0 months

Precip.(gamma), 3-category Probabilistic Forecast
year=2016, NDJ, 0-month lead



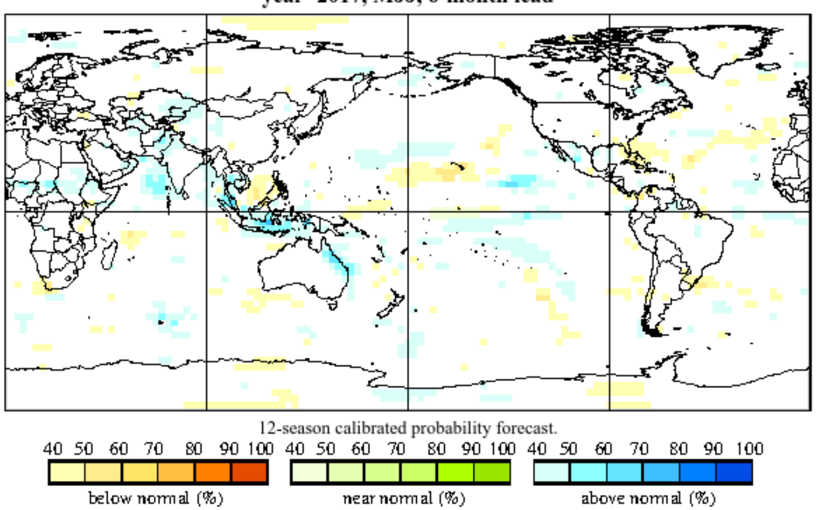
Lead 3 months

Precip.(gamma), 3-category Probabilistic Forecast
year=2017, FMA, 3-month lead



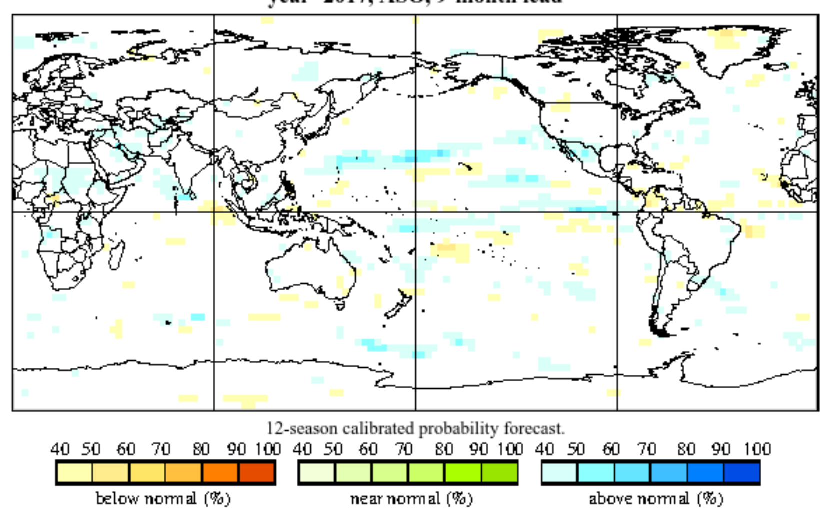
Lead 6 months

Precip.(gamma), 3-category Probabilistic Forecast
year=2017, MJJ, 6-month lead



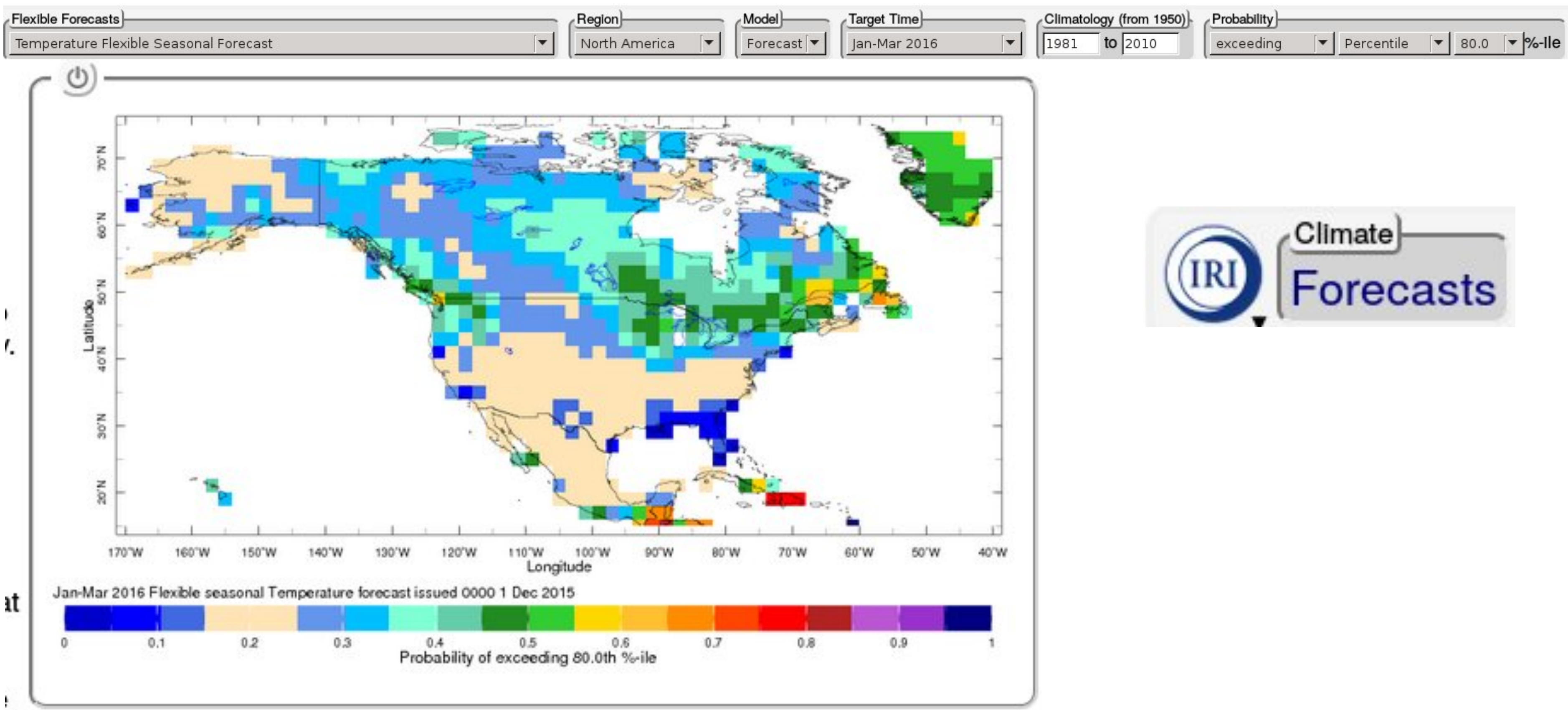
Lead 9 months

Precip.(gamma), 3-category Probabilistic Forecast
year=2017, ASO, 9-month lead



Flexible probabilistic forecasts from IRI

- Useful if tercile below/near/above normal probabilities are not specific enough
- Example: probability that JFM 2016 mean temperature will exceed 80th percentile relative to 1981-2010 (Options are 10, 15,…85, 90 percentiles)



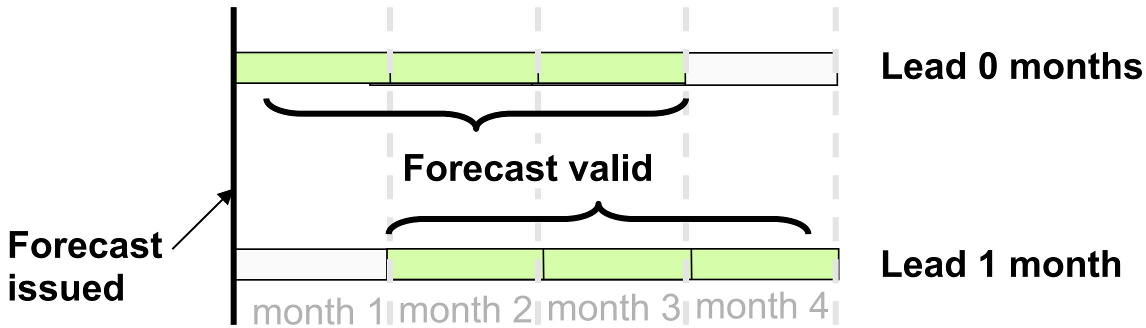
Climate Forecasts

http://iridl.ldeo.columbia.edu/maproom/Global/Forecasts/Flexible_Forecasts/temperature.html

Forecast skill

Some terminology

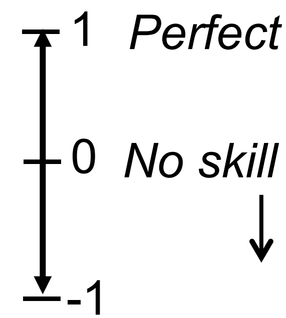
- <u>Forecast lead time</u>



- <u>Skill scores</u>

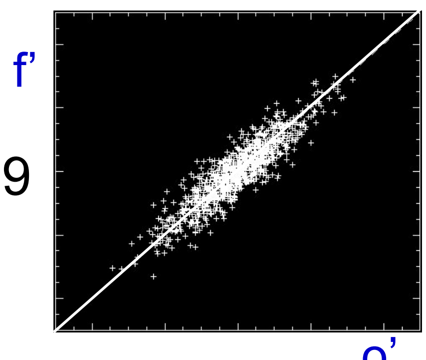
Example: Anomaly correlation

$$AC = \frac{\langle F' \cdot O' \rangle}{\sigma(F')\,\sigma(O')}$$

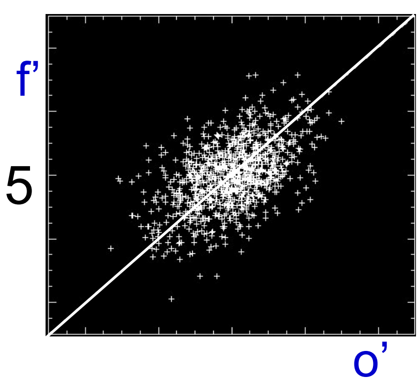


F'= forecast anomaly
O'= observed anomaly

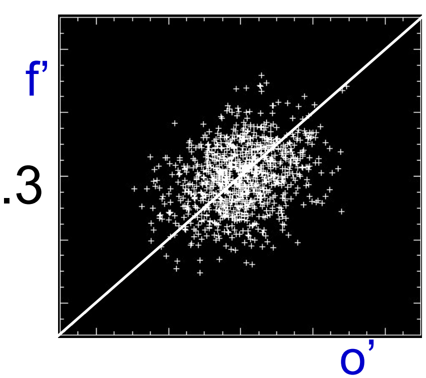
AC=0.9



AC=0.5



AC=0.3

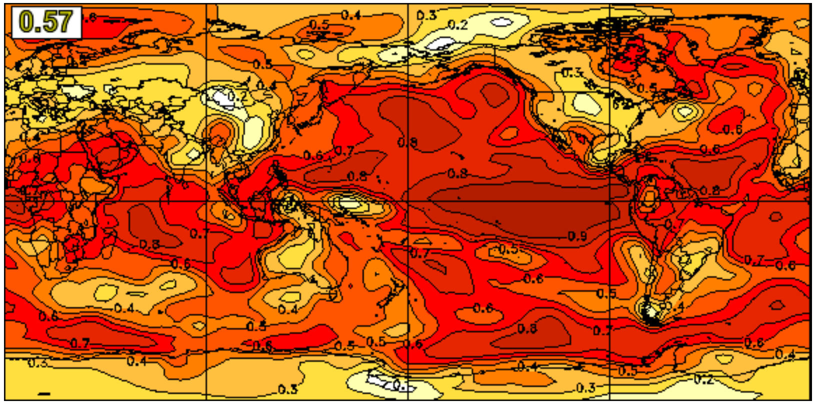


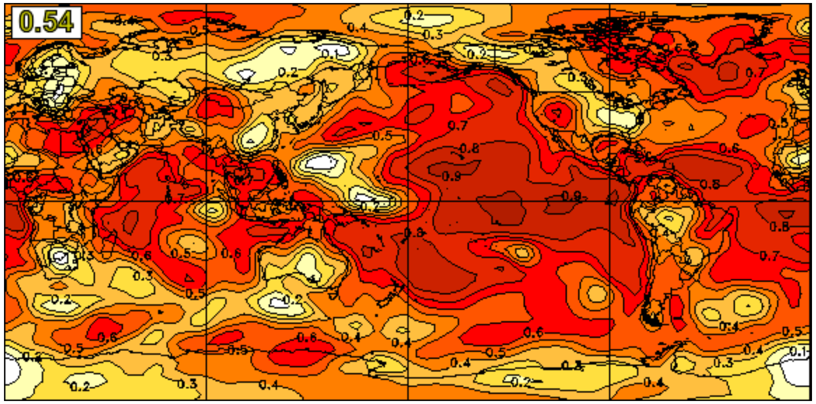
Global anomaly correlation skills

(from Canadian Seasonal to Interannual Prediction System)

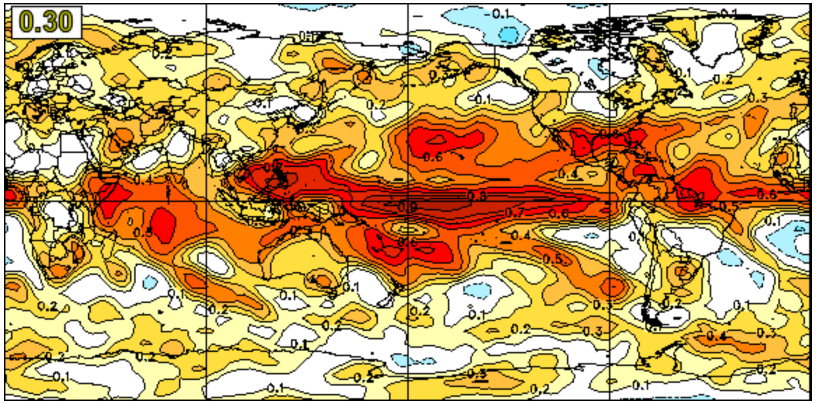
DJF (Lead 0 months) **JJA (Lead 0 months)**

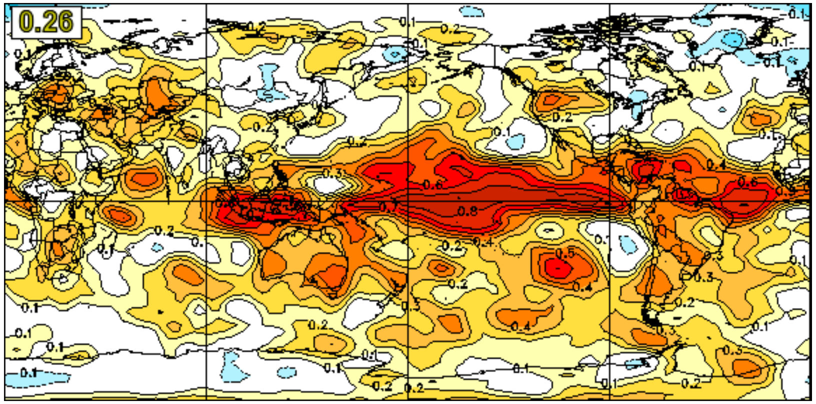
Near-surface temperature





Precipitation





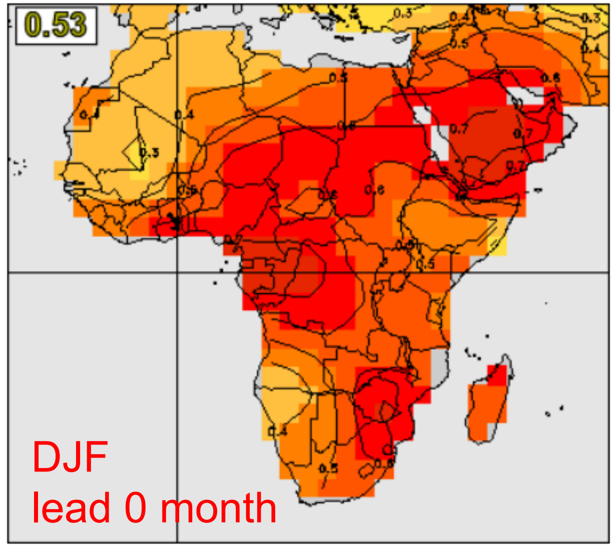
<u>*General behavior*</u>

- Higher in tropics than extratropics
- Higher over oceans than land
- Higher in winter than summer
- *Much* lower for precipitation then temp

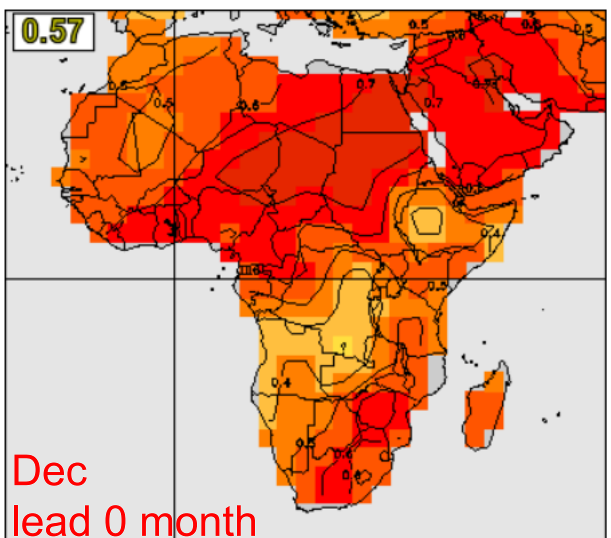
Skill dependence on lead time and averaging period

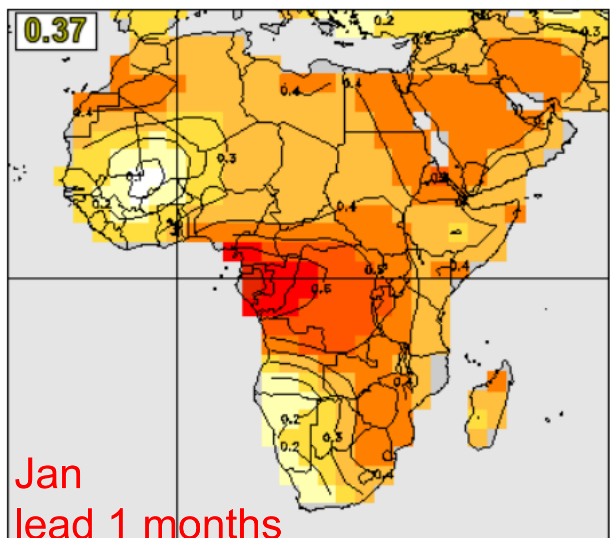
(from Canadian Seasonal to Interannual Prediction System)

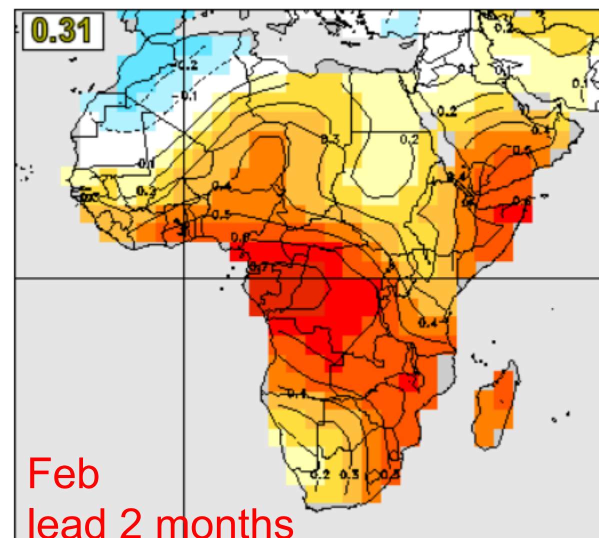
Example: Anomaly correlation for near-surface temperature from Dec



- lead 0 monthly skill > lead 0 seasonal skill
- atmospheric initial conditions contribute to skill in first month
- skill decreases (usually) as lead time increases



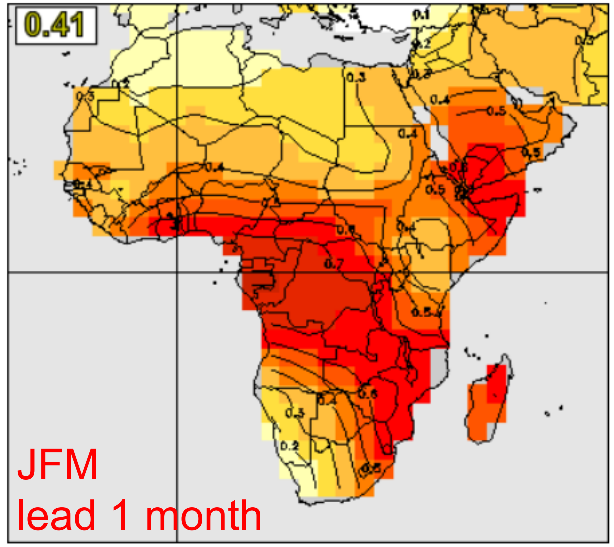




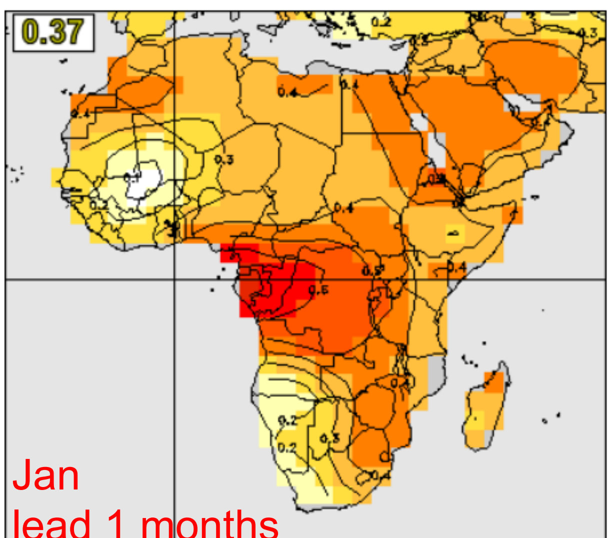
Skill dependence on lead time and averaging period

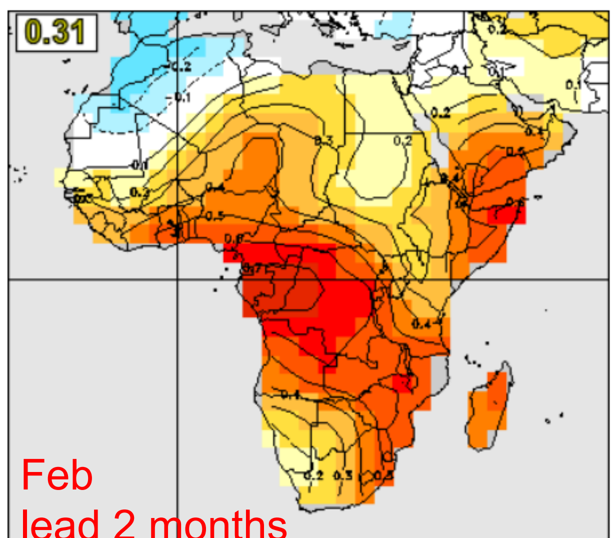
(from Canadian Seasonal to Interannual Prediction System)

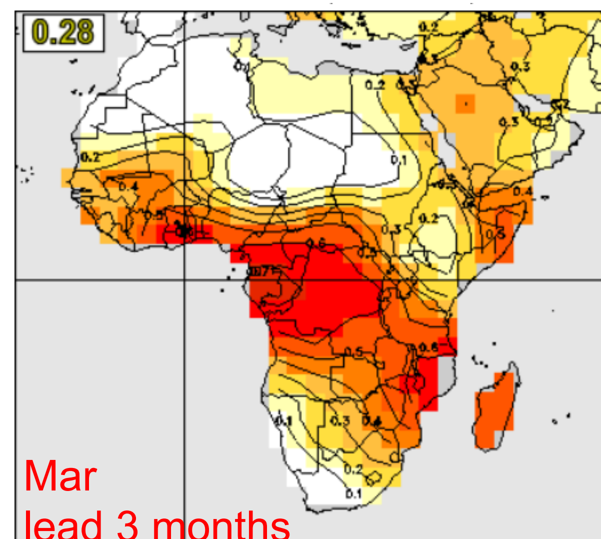
Example: Anomaly correlation for near-surface temperature from Dec



- lead 1 seasonal skill > lead 1,2,3 monthly skill
- seasonal averaging improves skill after lead 0 when atmospheric initial conditions are “forgotten”

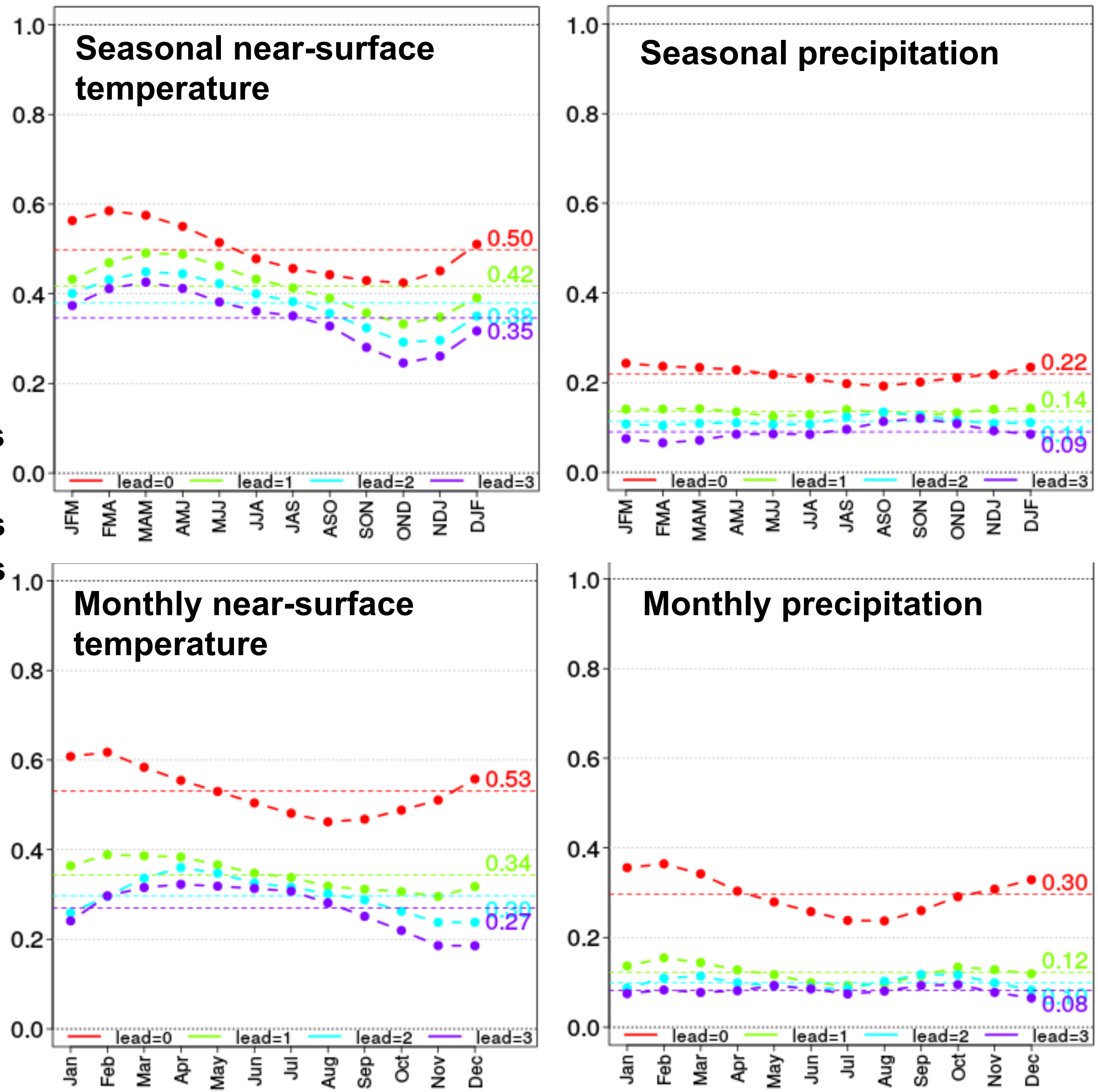






Anomaly correlations averaged over Africa vs predicted season & lead

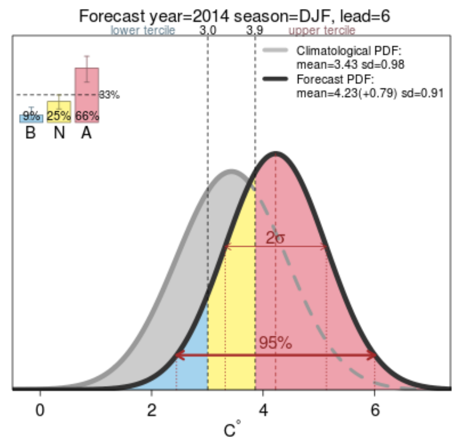
- lead 0 months
- lead 1 month
- lead 2 months
- lead 3 months



There are lots of other skill scores including prob-abilistic, not enough time to cover here,

Guiding principles of climate (e.g. seasonal) forecasting

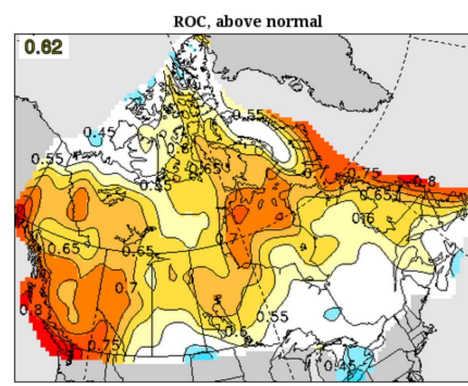
1) Forecasts should communicate uncertainty



Probabilities

→ ***ensemble forecasts***

2) Forecasts should be interpreted in the context of past performance (skill)



→ **need many years of *hindcasts* to calculate skill**

Purposes of hindcasts

Hindcasts enable us to…

- Estimate lead-time dependent model biases ("drift") so that they can be corrected for – more in lab session
- Estimate historical skill
- Calibrate probabilistic forecasts

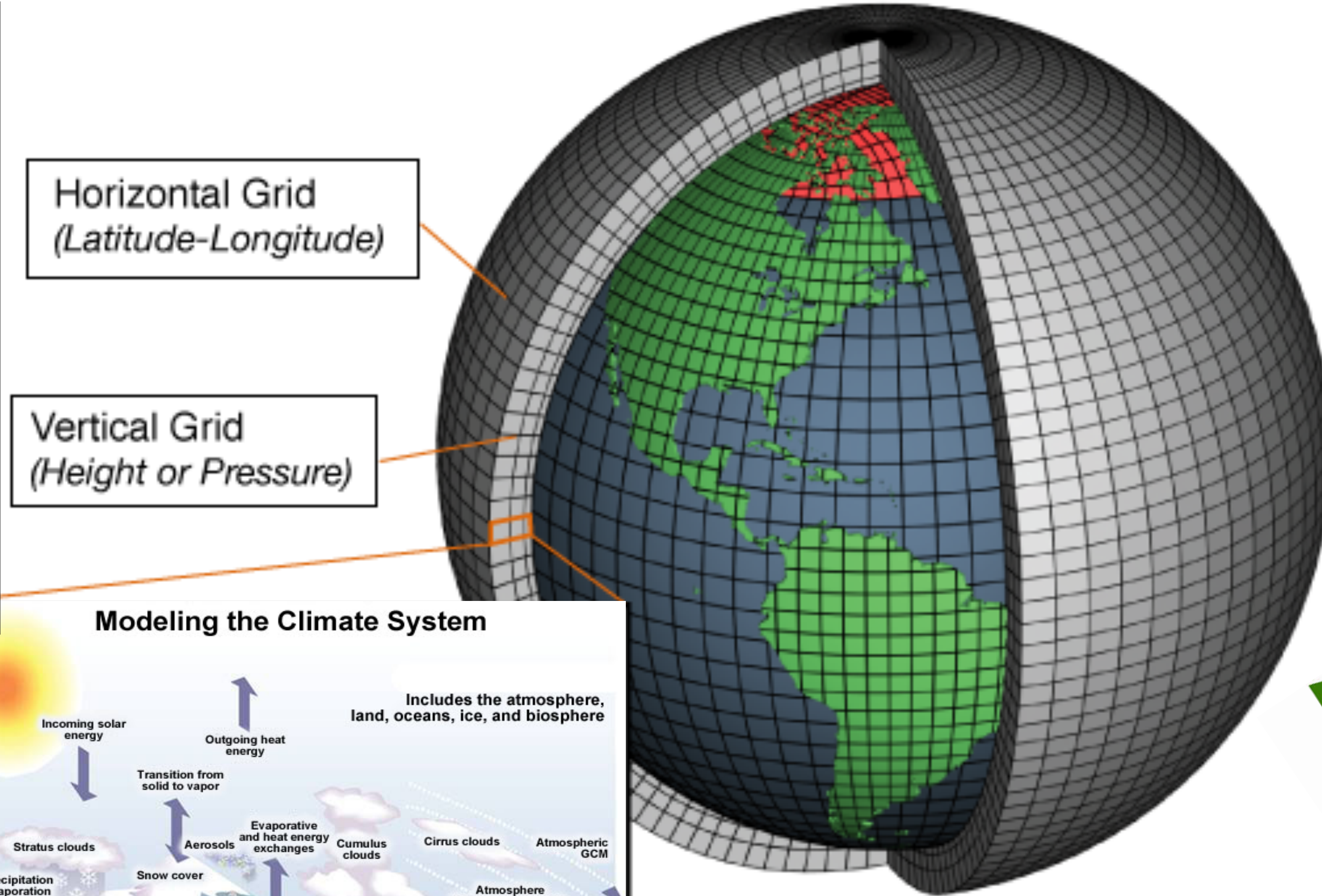
<u>Notes</u>:

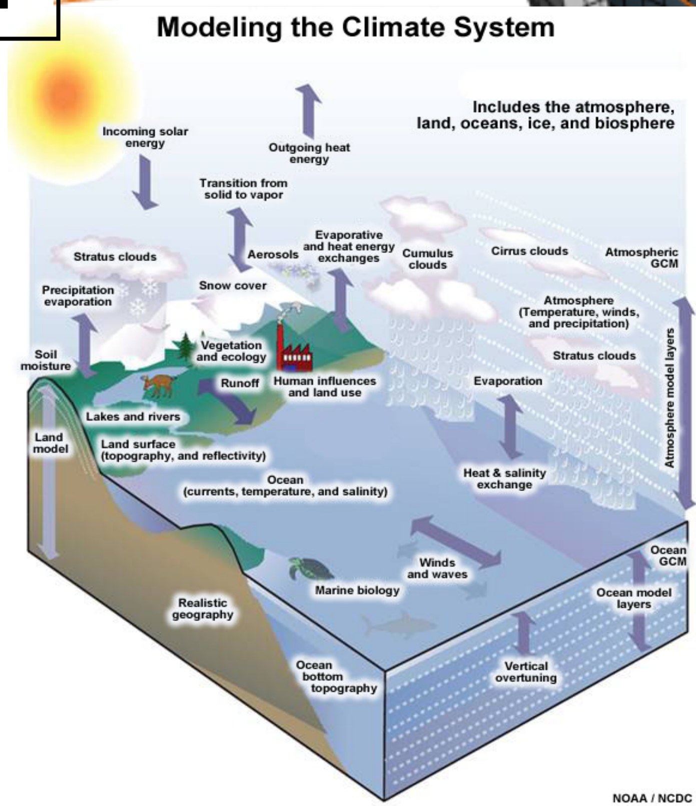
- When estimating in-sample corrections and skill, cross validation should be applied to avoid inflated estimates of skill (won't worry about it in the lab, unless you want to)
- WMO currently recommends 1981-2010 as hindcast base period
- 30 years × 12 initialization months × 10 ensemble members = 3600 years of model integration per hindcast ! (assuming 12 mon range)

How seasonal forecasts are produced

Computer models of the Earth's climate:

tools for assess-ment and prediction





How dynamical seasonal forecasts are made

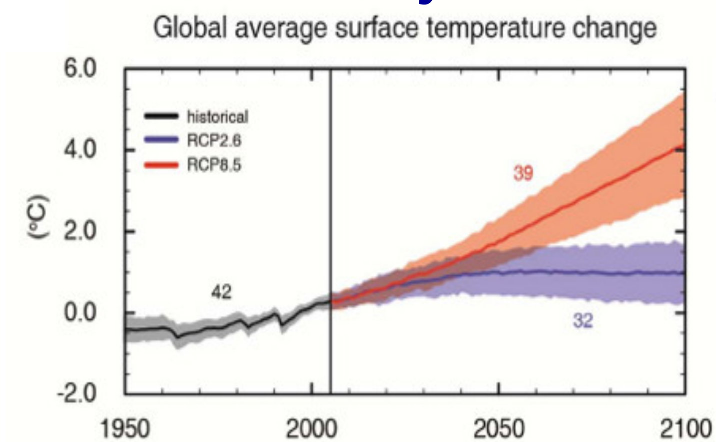
Weather forecast

1-10 days

- Atmosphere/land models
- Observations of current global conditions used to **initialize** model

Climate projection

10-100 years



- Atmosphere/ocean/ landsea ice models
- Initial conditions not crucial

How dynamical seasonal forecasts are made

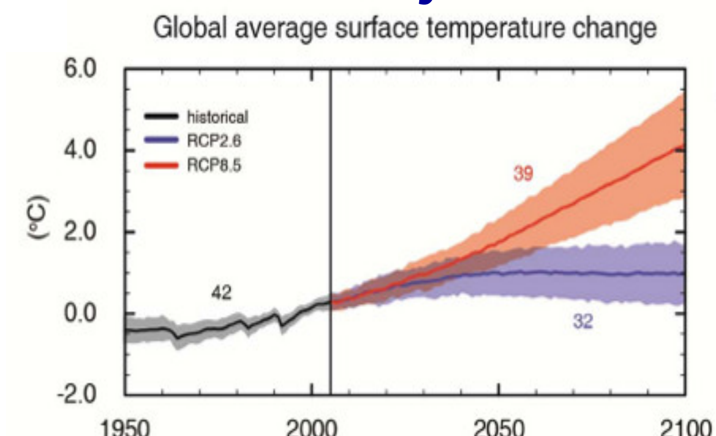
Weather forecast

1-10 days

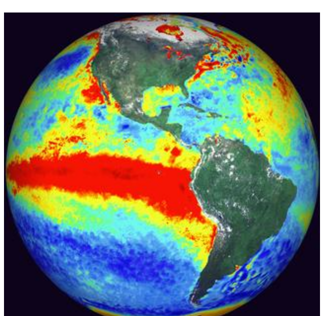
- Atmosphere/land models
- Observations of current global conditions used to **initialize** model

Climate projection

10-100 years

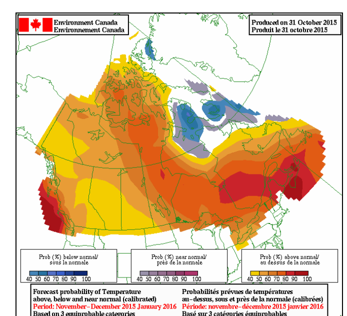


- Atmosphere/ocean/ landsea ice models
- Initial conditions not crucial



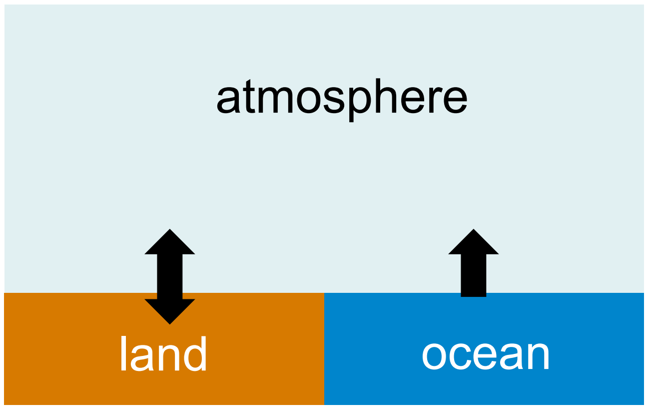
Seasonal forecast

1-12 months



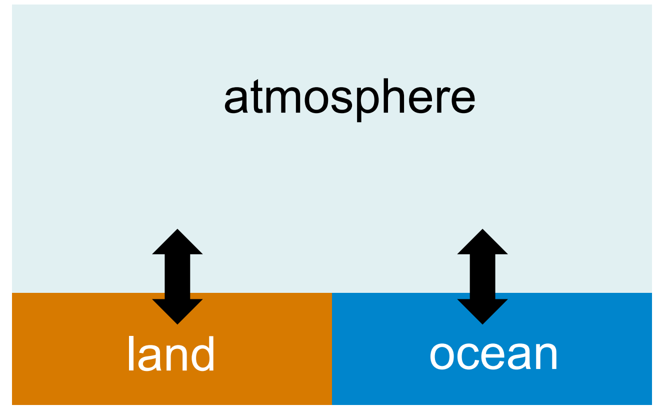
1 tier (coupled) vs 2 tier forecasts

1 tier forecast



- atmosphere interacts with land
- SSTs *specified* (no ocean model)
- For example, some systems simply persist the SST anomaly present before the forecast
- *1 tier systems cannot forecast El Niño/La Niña*

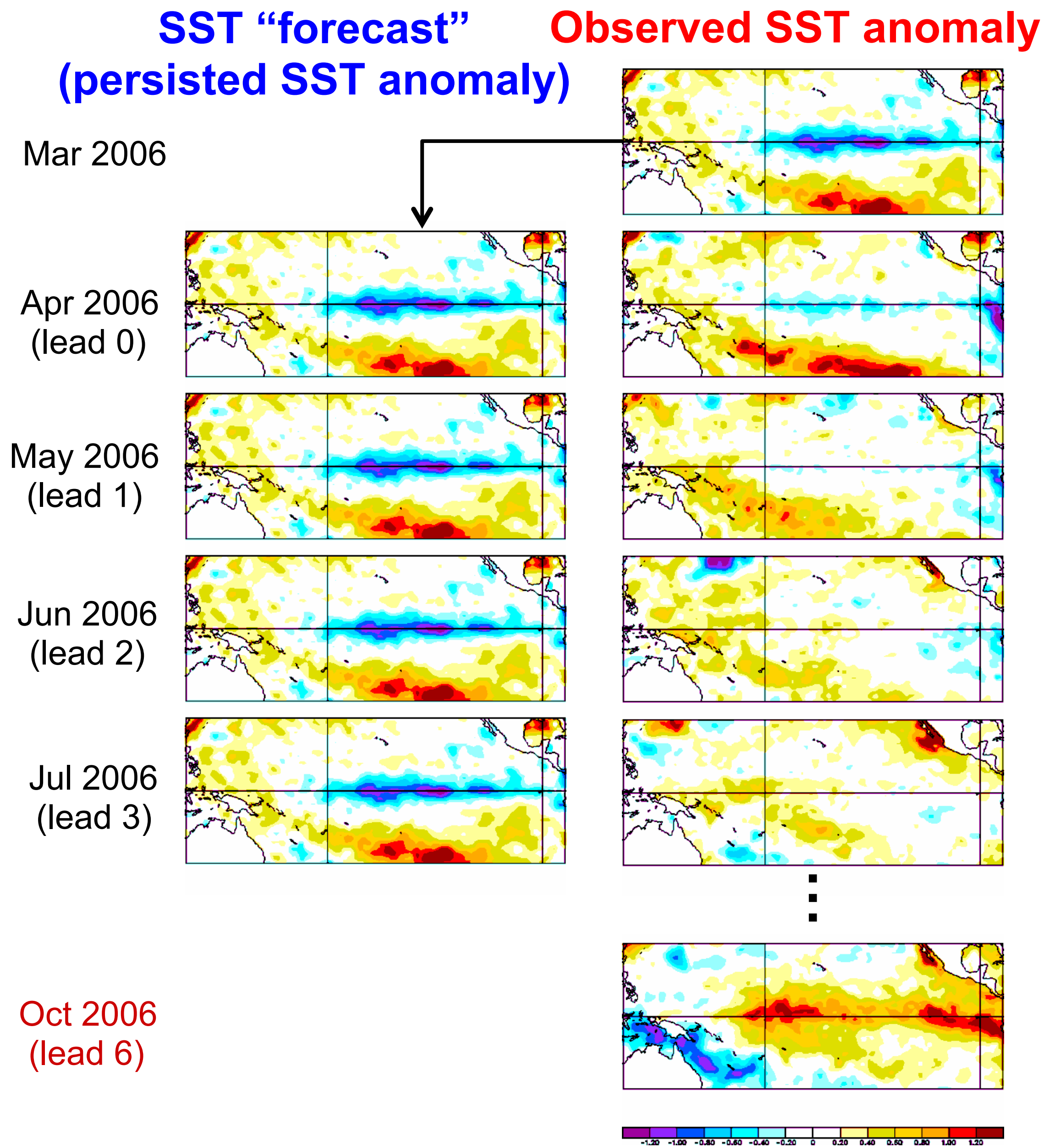
2 tier forecast



- atmosphere interacts with land *and* ocean
- coupled climate model includes ocean component
- future SSTs are forecast by model
- 2 tier systems potentially can predict El Niño/La Niña (and often do)

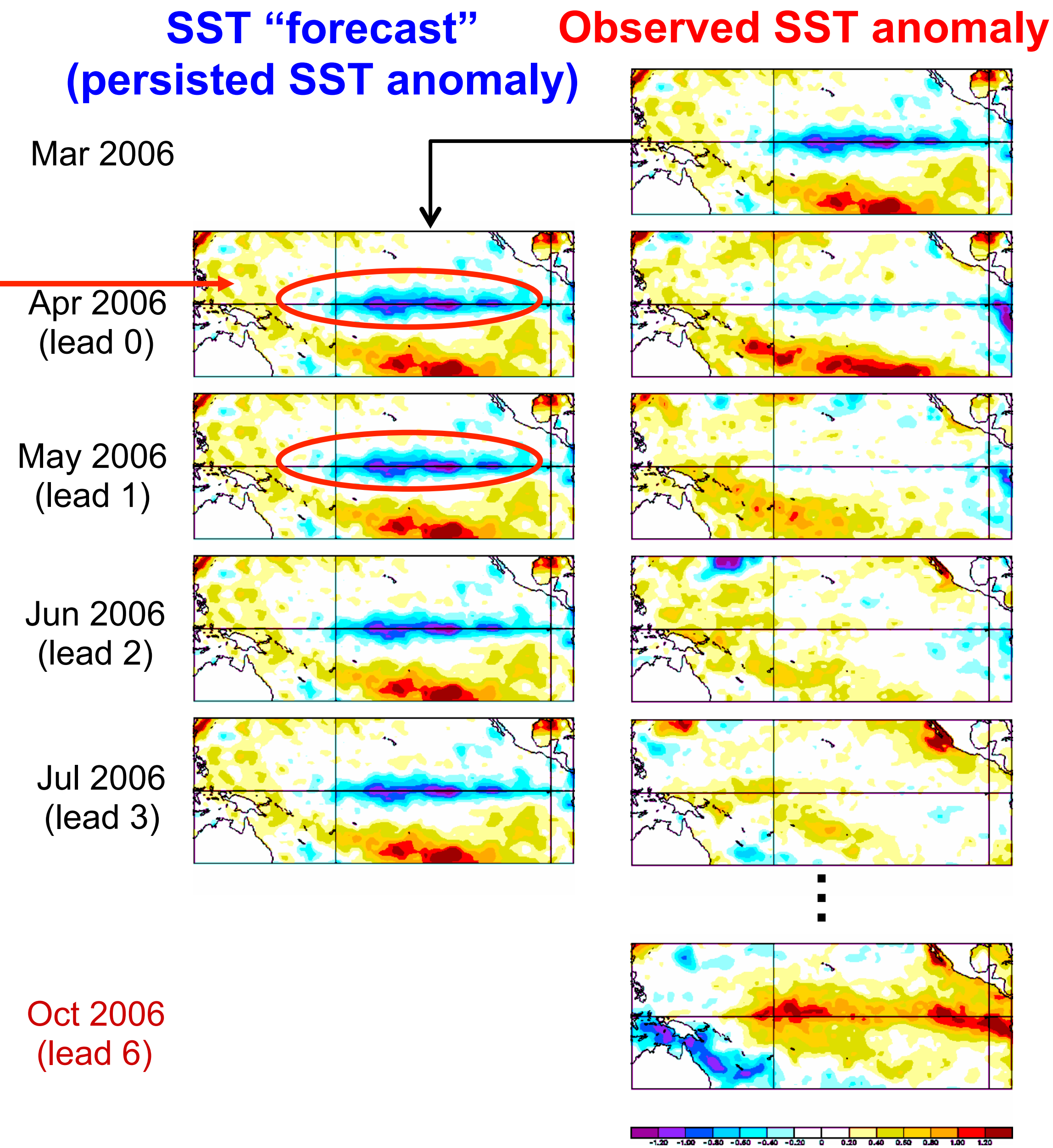
Problem with 1 tier forecasts

- Consider 2-tier forecast (persisted SSTA) from 1 April 2006



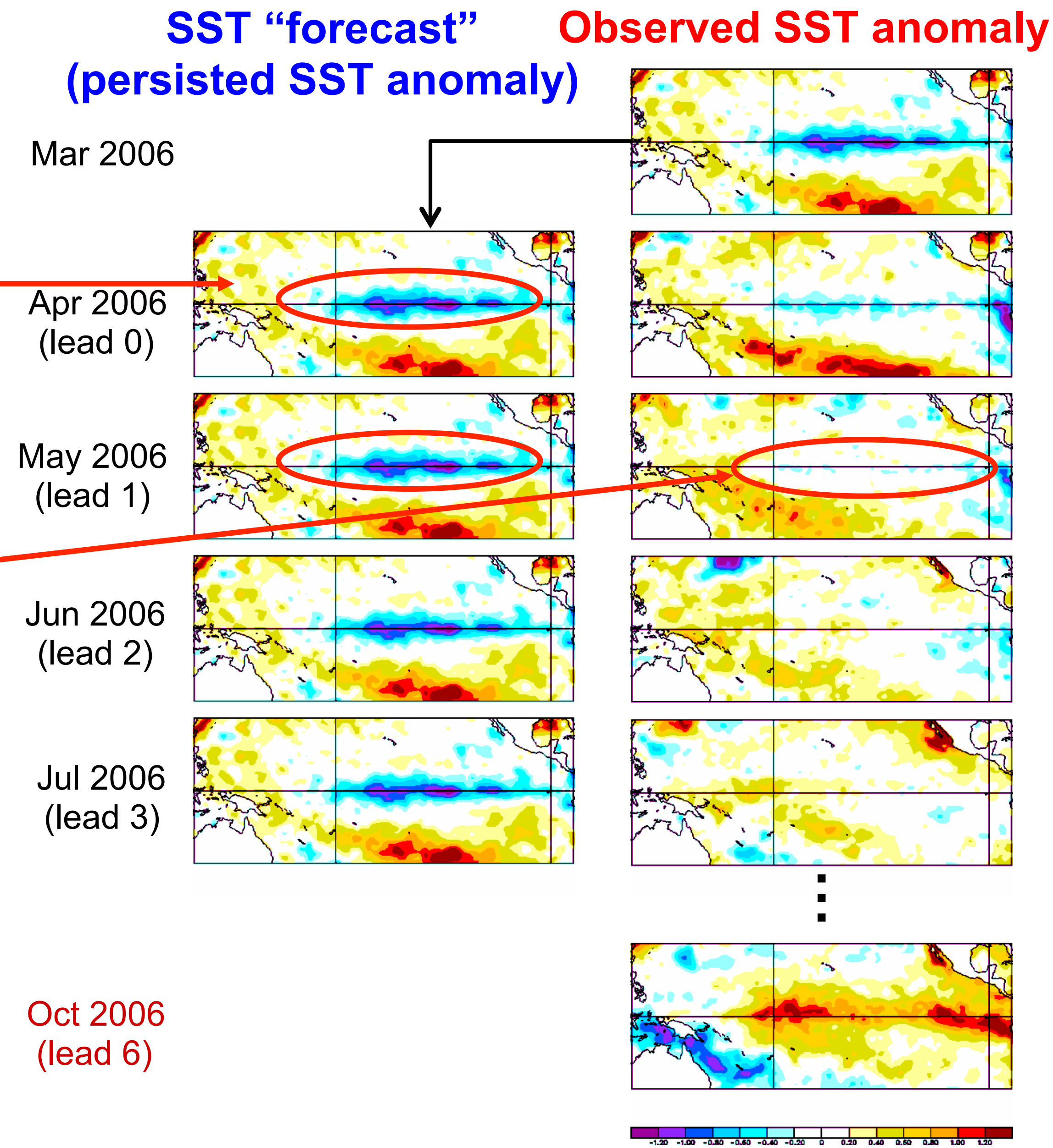
Problem with 1 tier forecasts

- Consider 2-tier forecast (persisted SSTA) from 1 April 2006
- The 1 tier forecast persists the La Niña present before the start of the forecast



Problem with 1 tier forecasts

- Consider 2-tier forecast (persisted SSTA) from 1 April 2006
- The 1 tier forecast persists the La Niña present before the start of the forecast
- But the La Niña soon disappears!



Steps for producing seasonal forecasts

- Run ensemble of forecasts from slightly different initial conditions

- Subtract the *hindcast climatology* to obtain anomalies, from the climatological mean and correct for model biases and drift

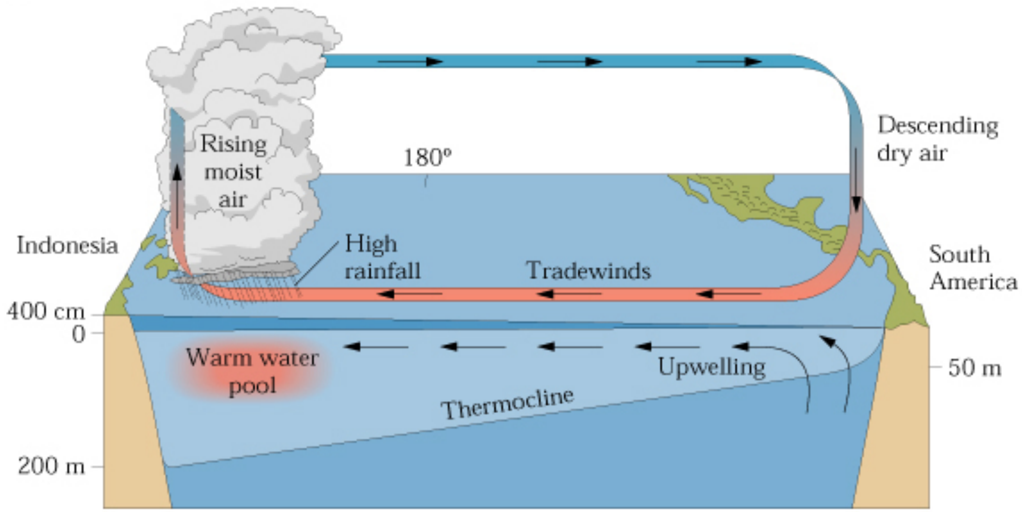
- Deterministic forecast = ensemble mean anomaly

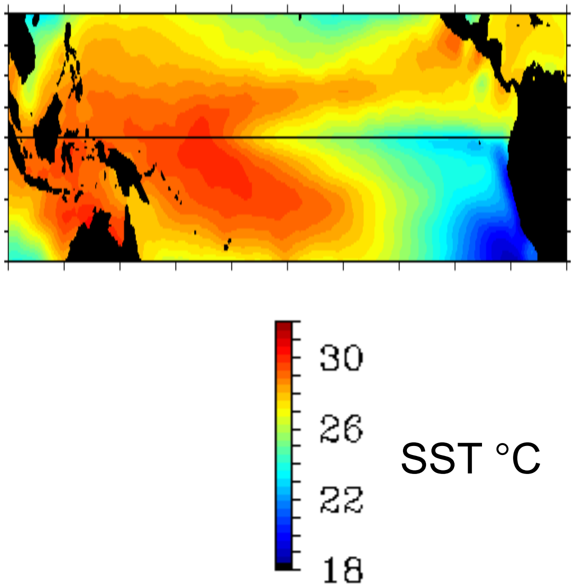
- To construct probabilistic forecast, must
  - count ensemble members in each tercile of observed climatology, or
  - fit ensemble values to a distribution (better), or
  - calibrate the forecast distribution to produce a more reliable forecast (best)

El Niño impacts

Equatorial Pacific climate

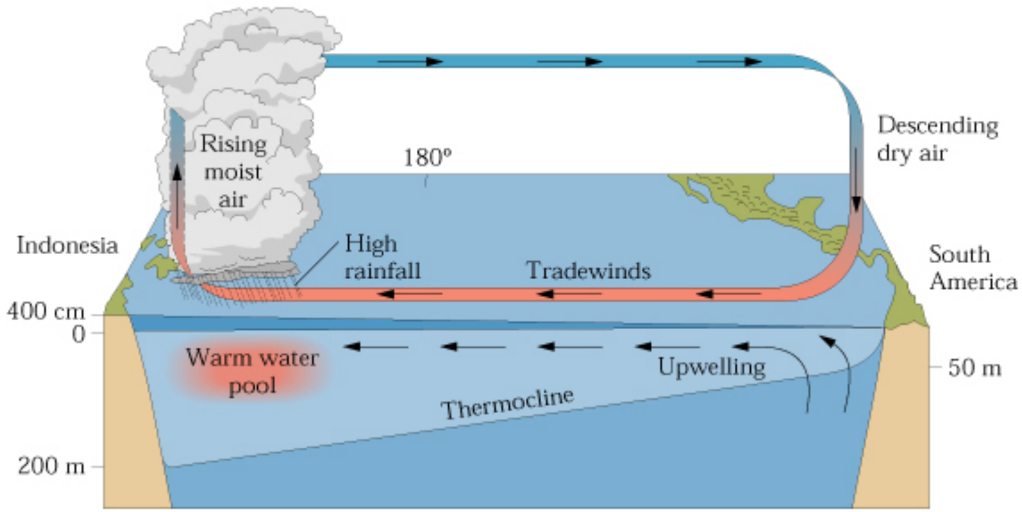
Normal

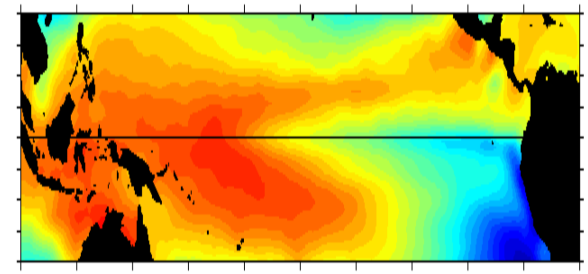


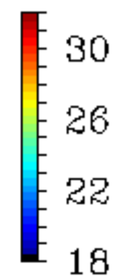


Equatorial Pacific climate

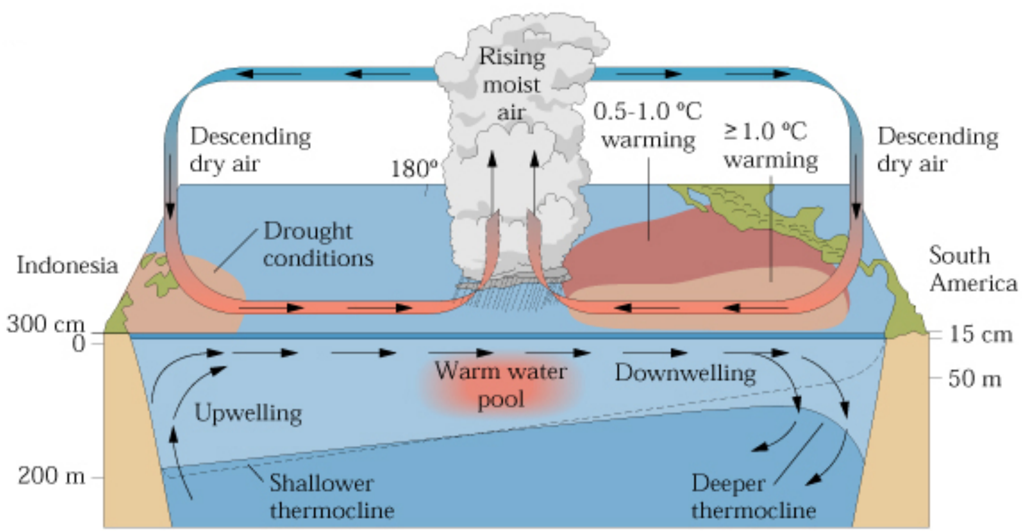
Normal

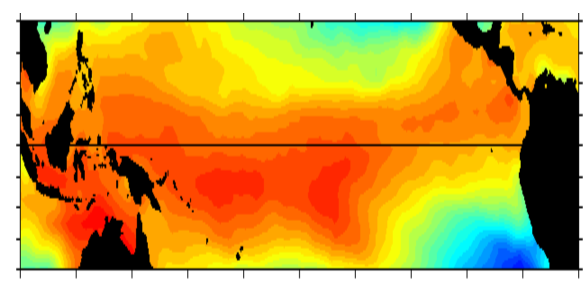






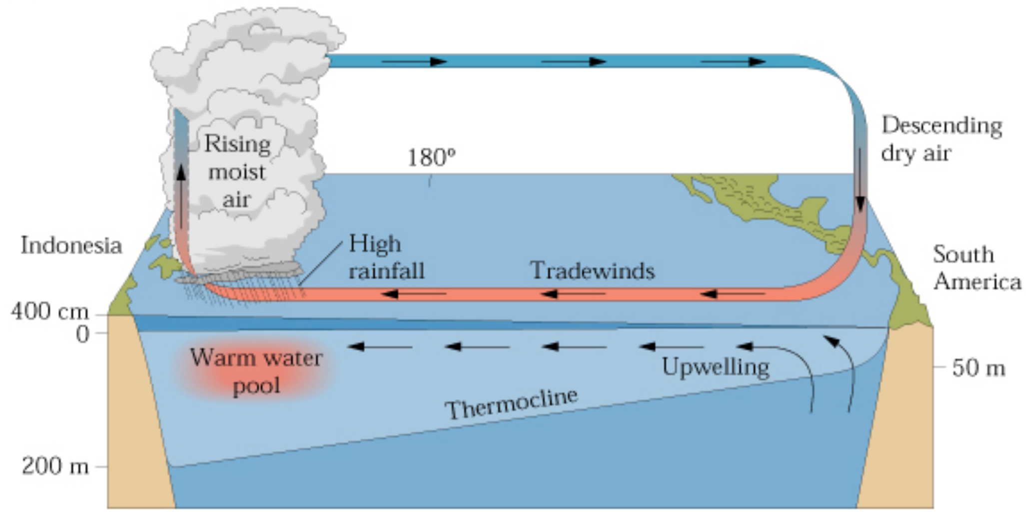
El Niño

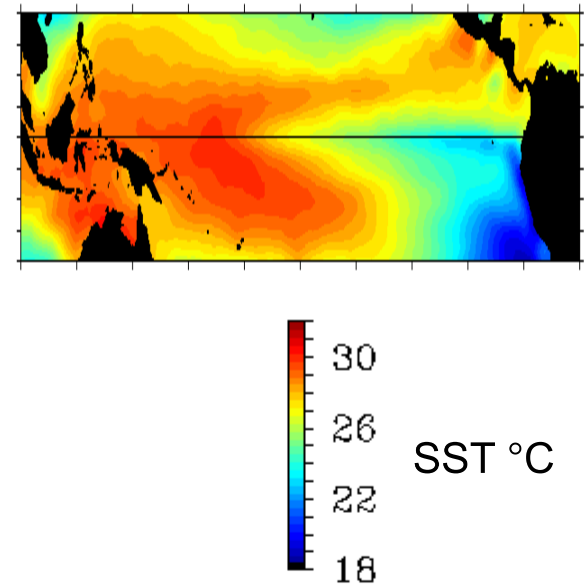




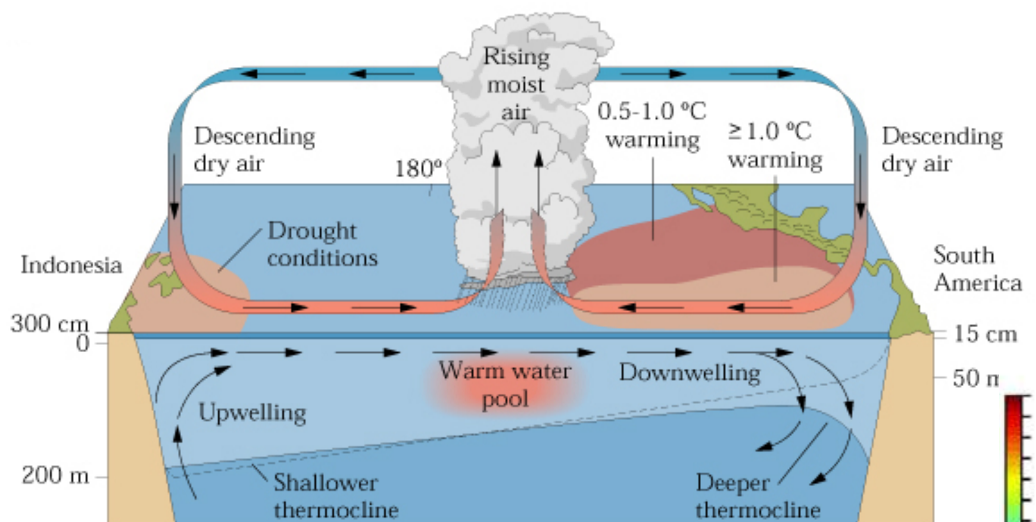
Equatorial Pacific climate

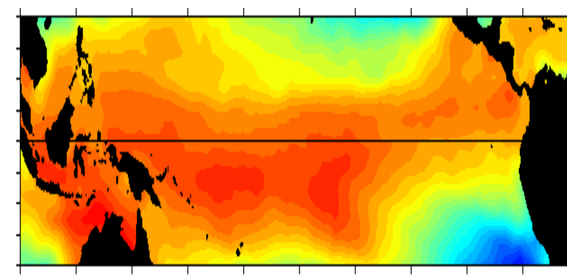
Normal

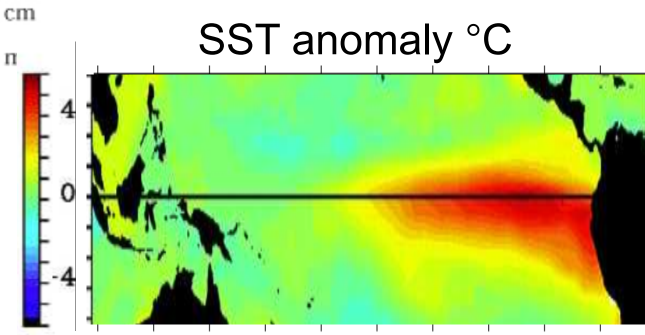




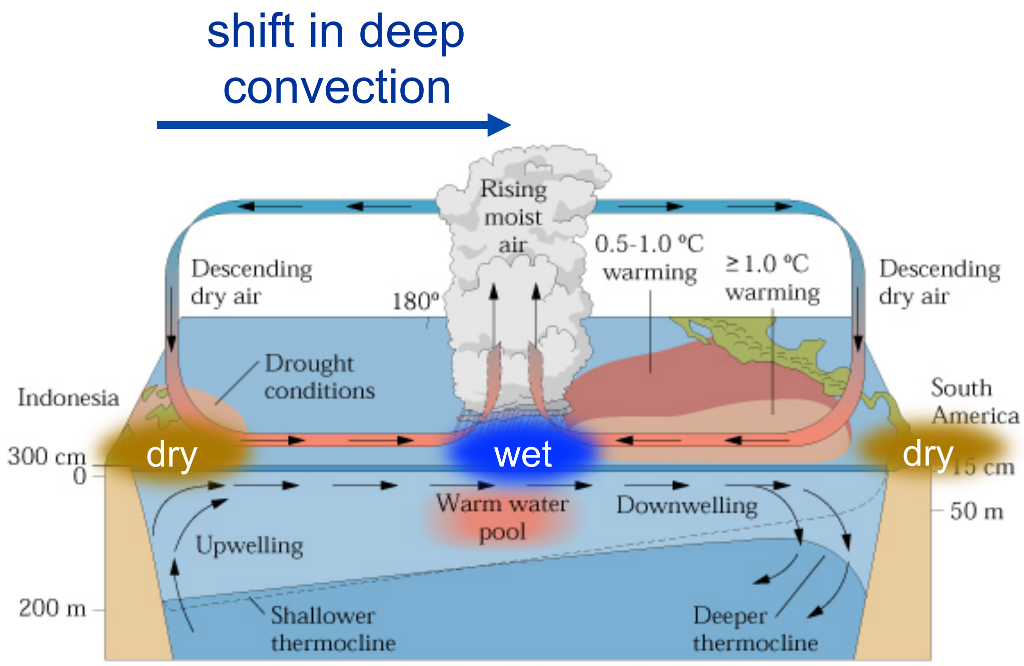
El Niño





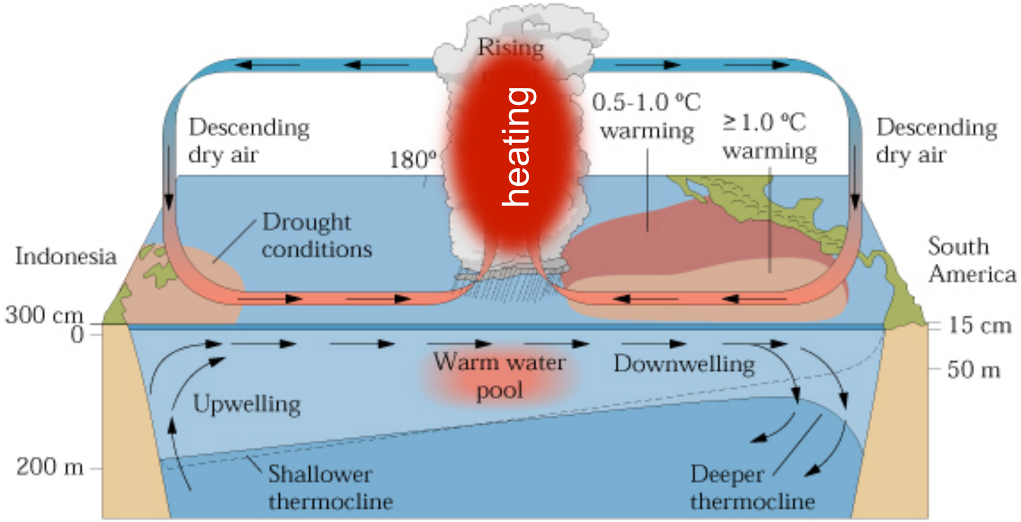


El Niño direct impacts



El Niño conditions in the tropical Pacific

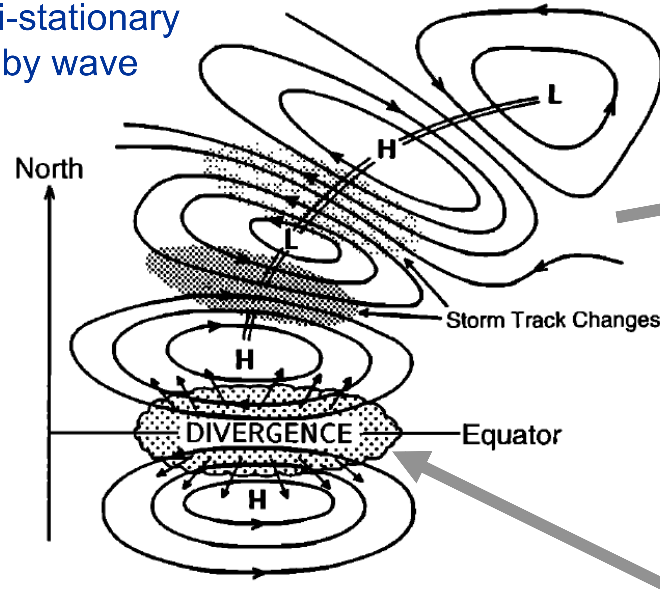
El Niño teleconnections



El Niño conditions in the tropical Pacific

El Niño teleconnections

upper tropospheric response:
quasi-stationary
Rossby wave

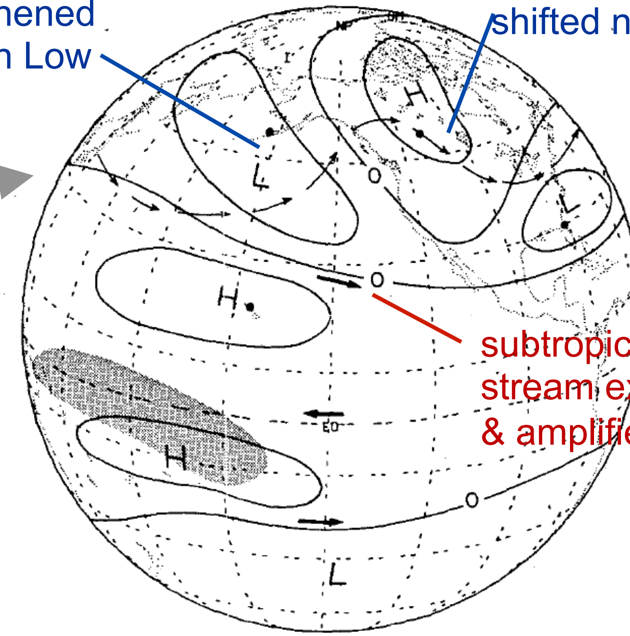


Trenberth et al., *JGR* (1998)

Northern winter

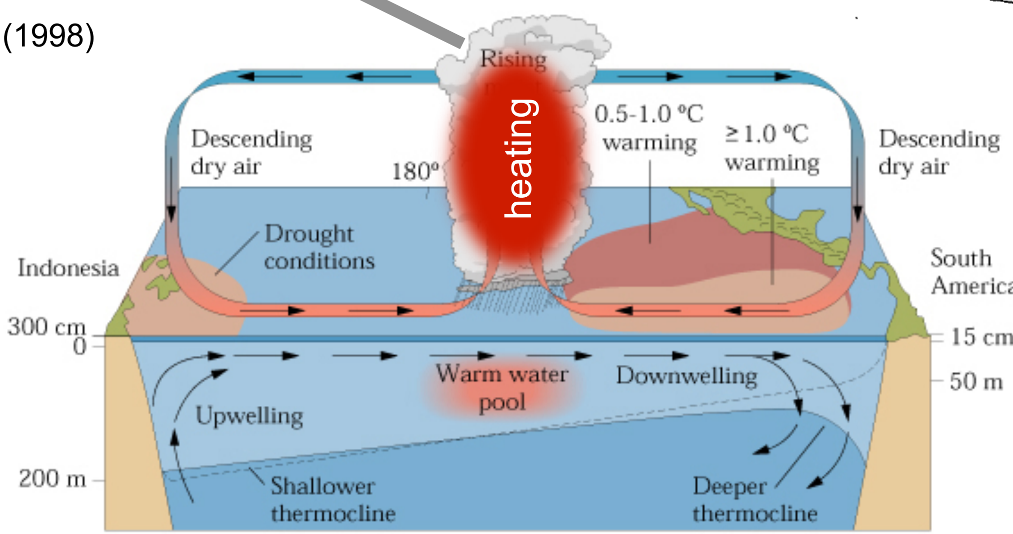
strengthened
Aleutian Low

polar jet stream
shifted north



subtropical jet
stream extended
& amplified

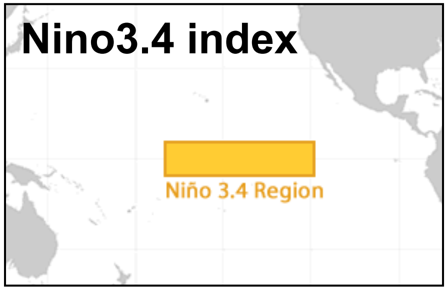
Horel & Wallace, *MWR* (1981)

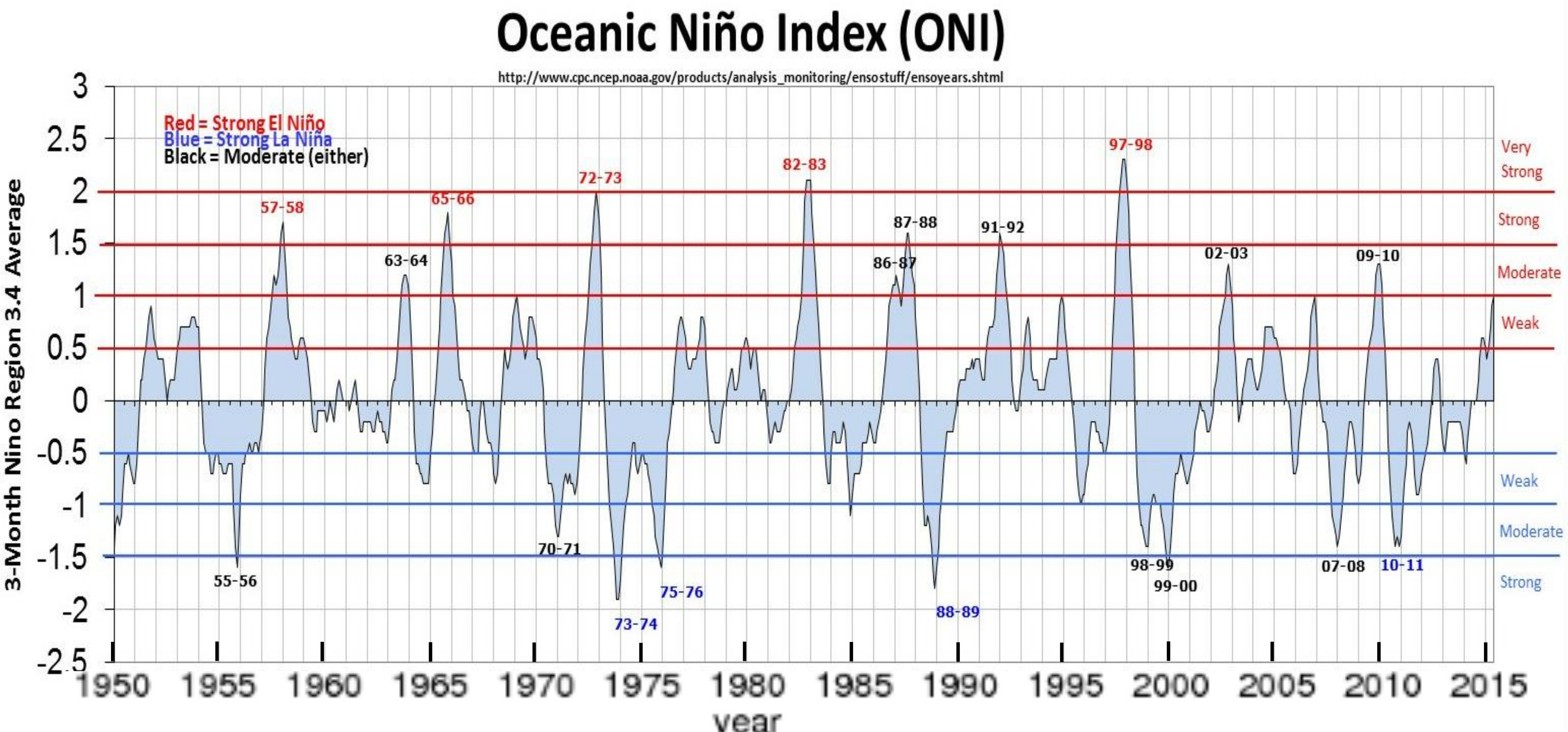


El Niño conditions in the tropical Pacific

Historical El Niño/La Niña variability

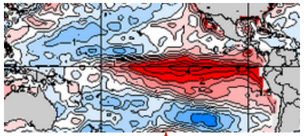
- A widely used indicator of El Niño/La Niña activity is Nino3.4 = mean SST anomaly in 5N-5S, 120W-170W
- The Oceanic Nino Index (ONI) consists of a 3-month rolling average of Nino3.4

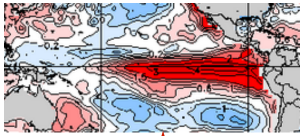




Historical El Niño/La Niña variability

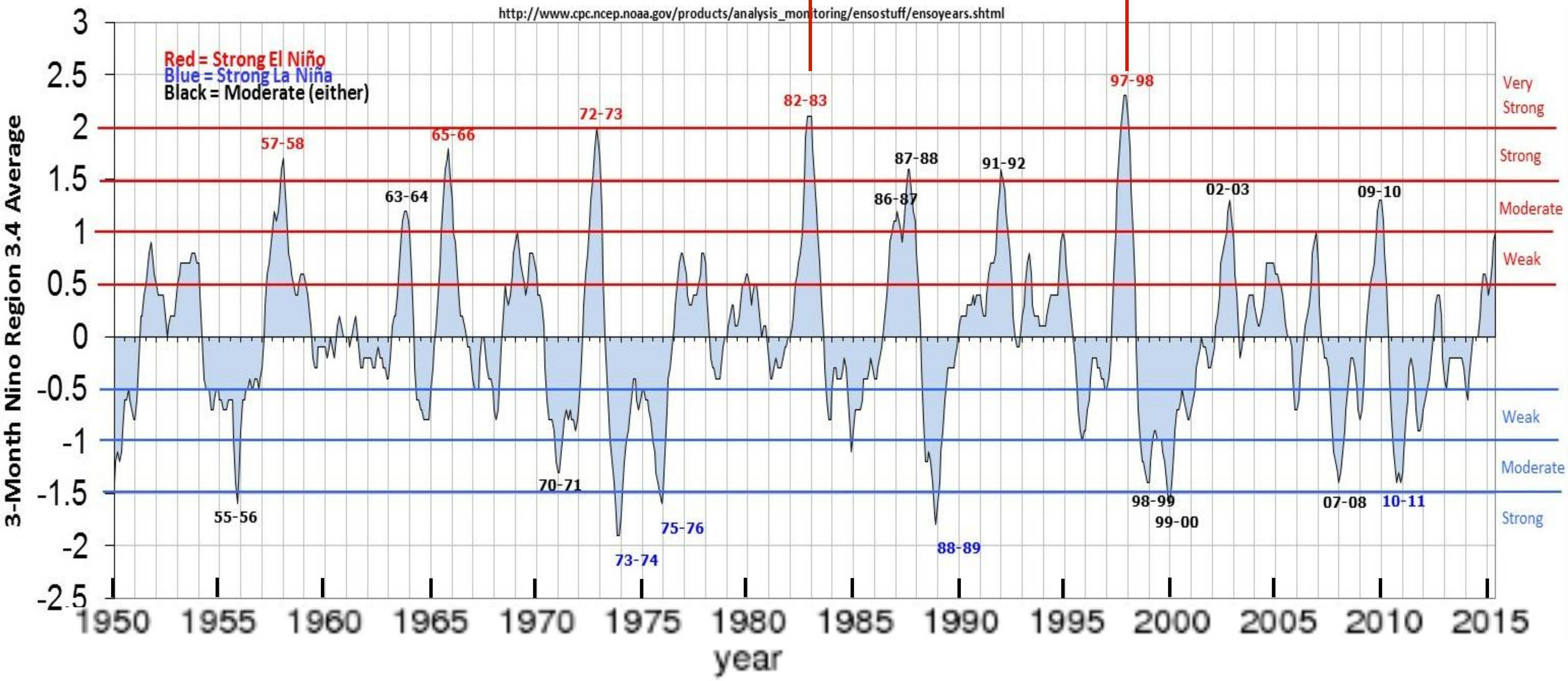
Very strong El Niños





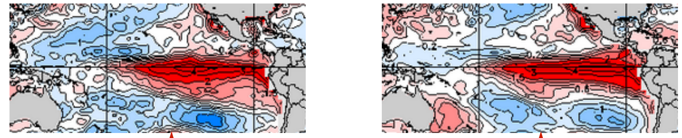
+ 2015

DJF-averaged SST anomalies from NCEP/OISST



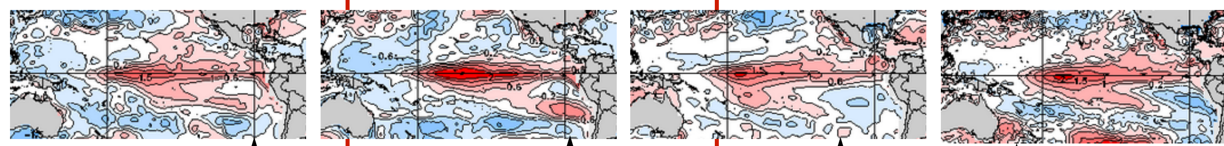
Historical El Niño/La Niña variability

Very strong El Niños
"Eastern Pacific"

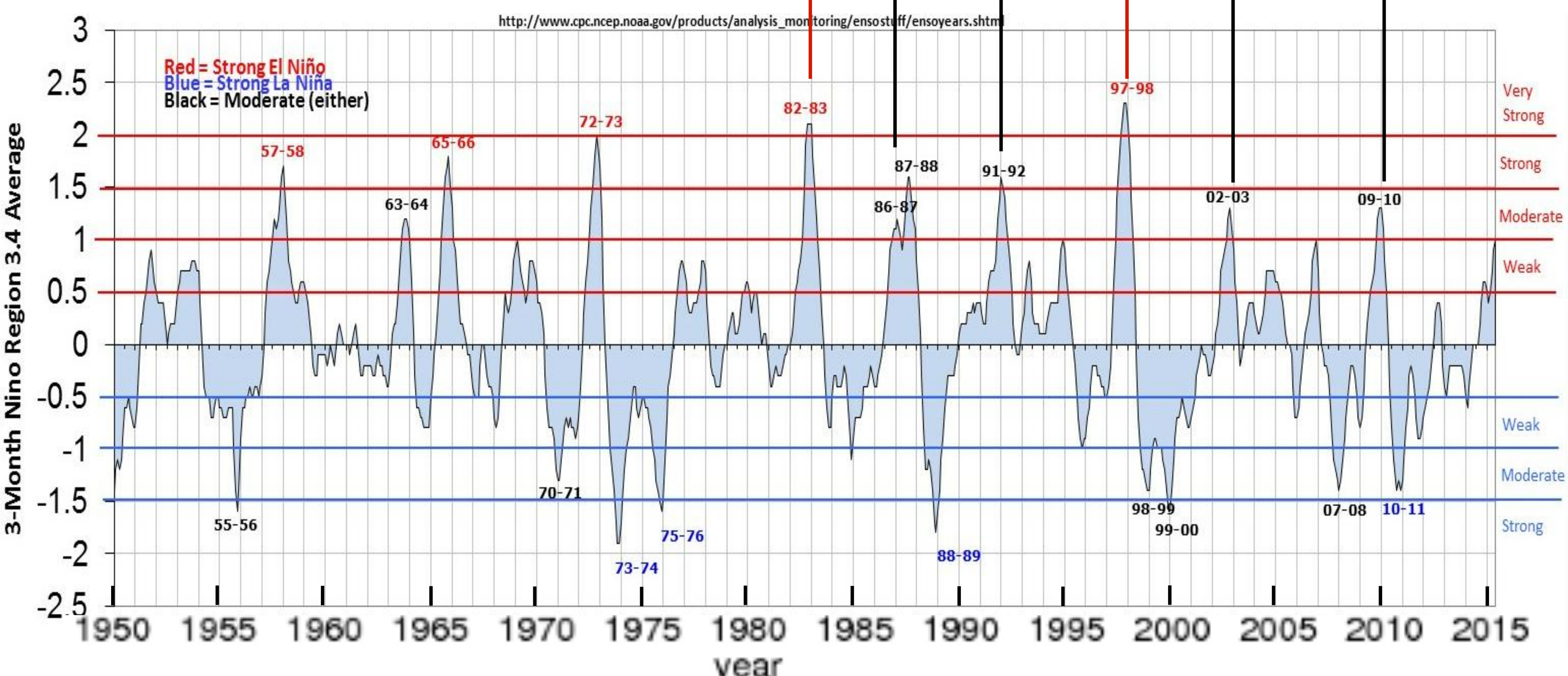


+ 2015

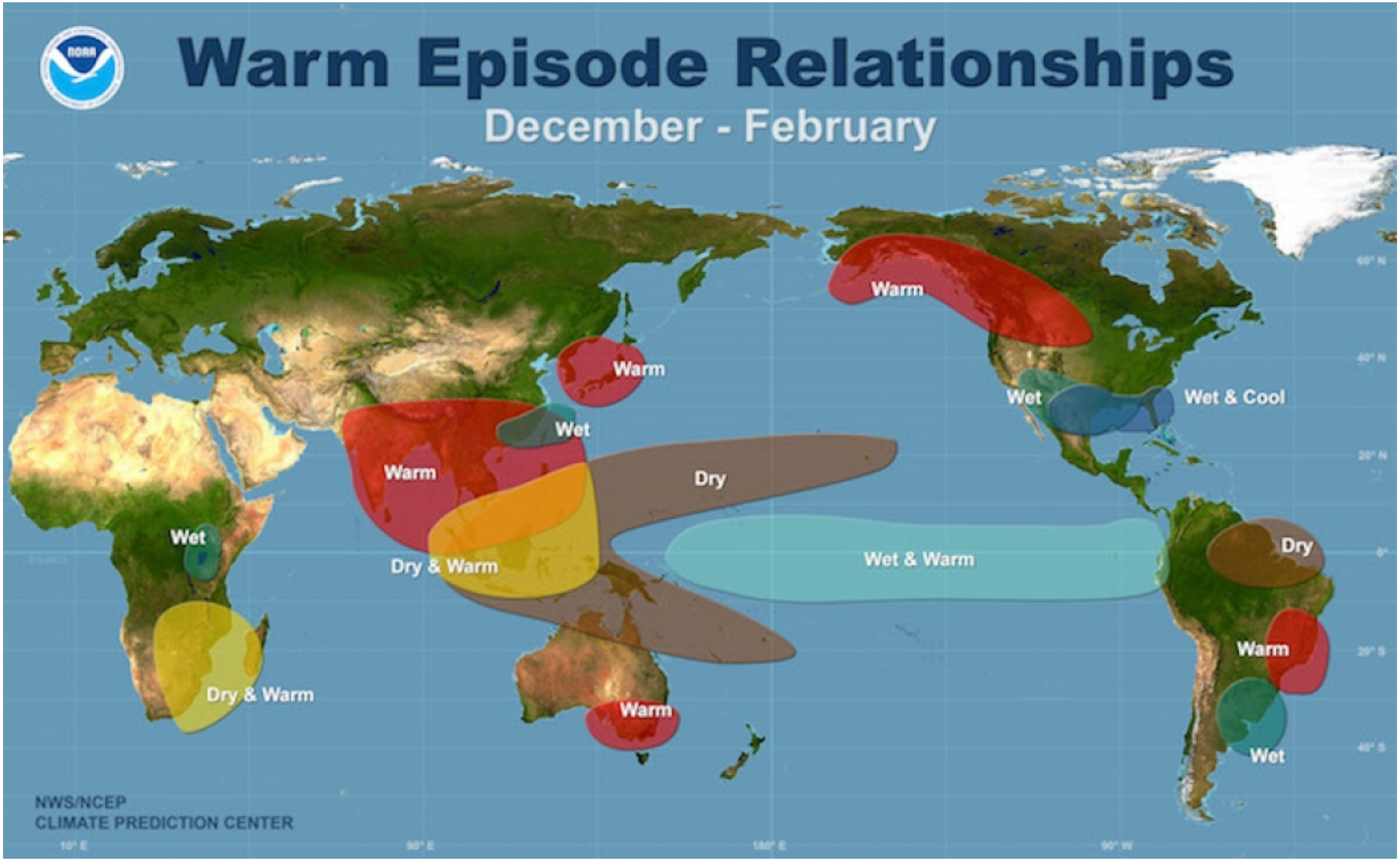
Moderate El Niños
"Central Pacific" or "Modoki"



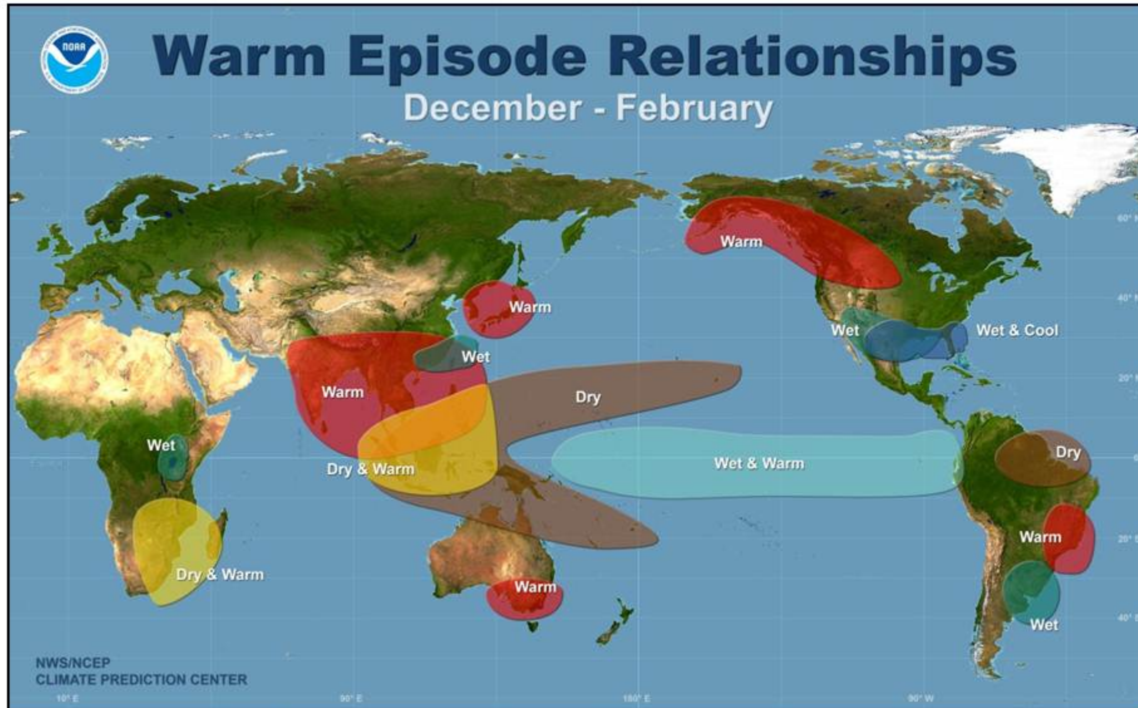
DJF-averaged SST anomalies from NCEP/OISST

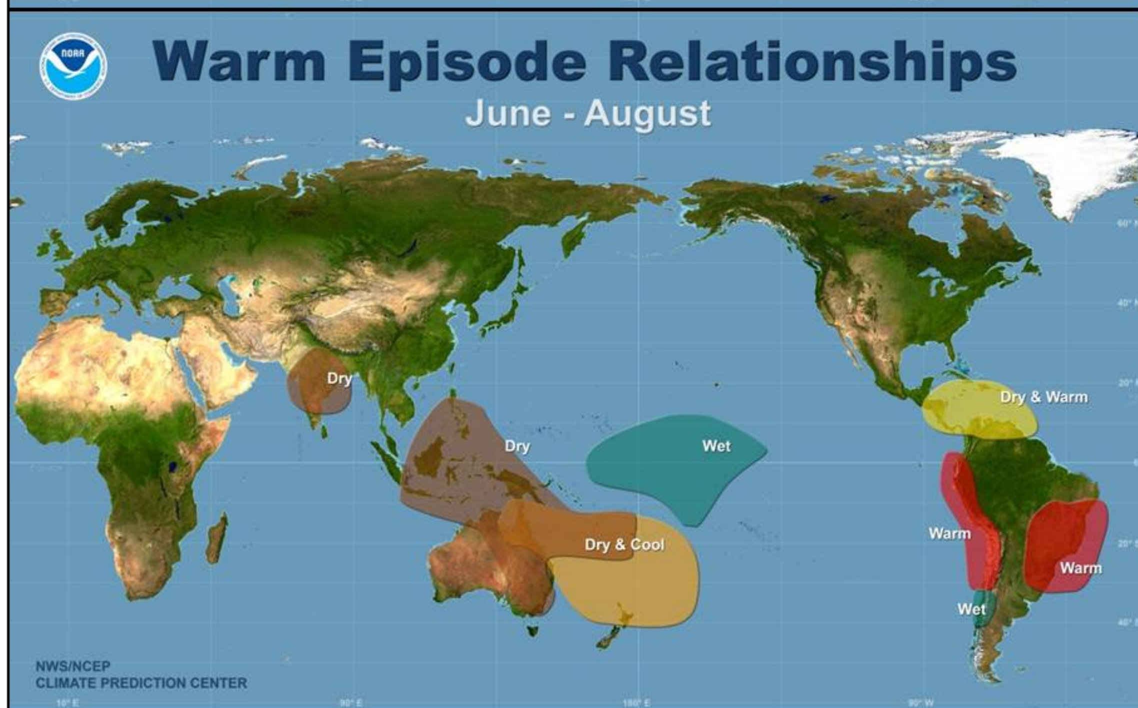


Global El Niño impacts

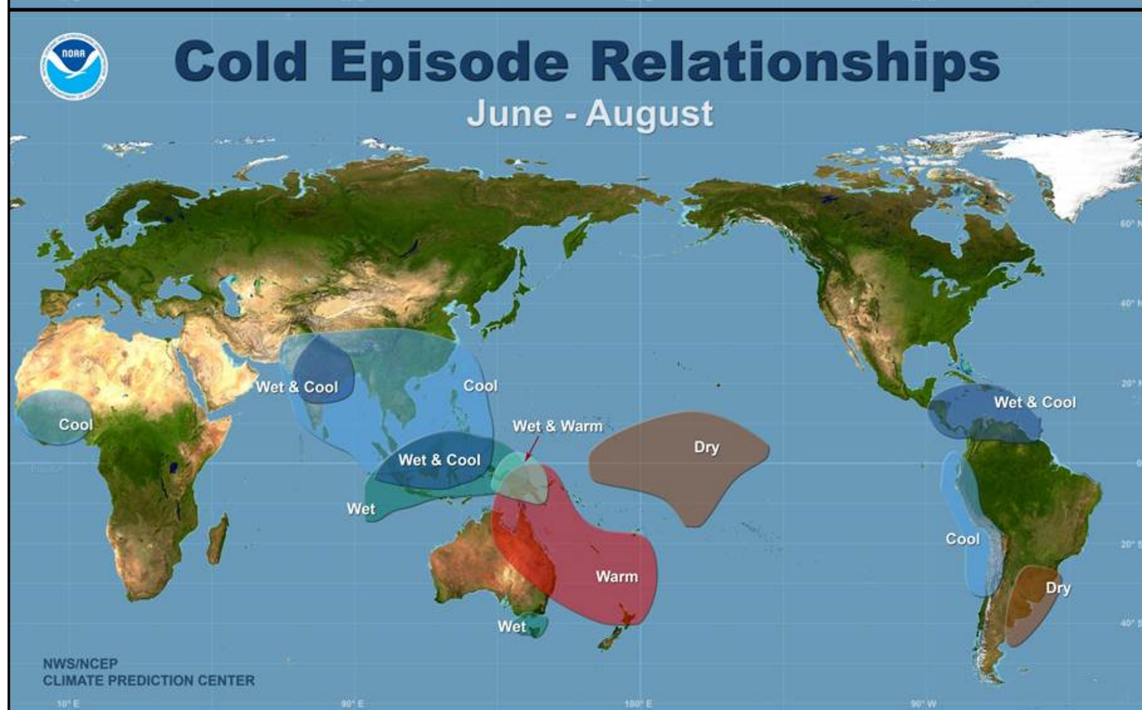


Global El Niño impacts



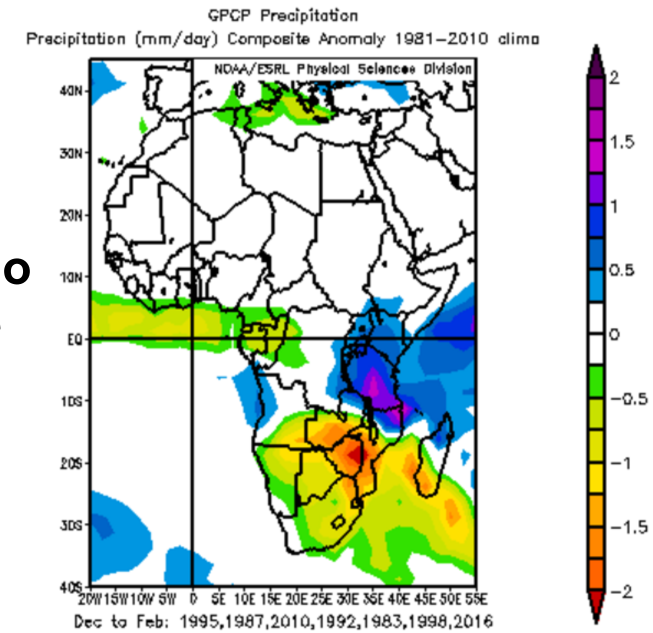


Global La Niña impacts

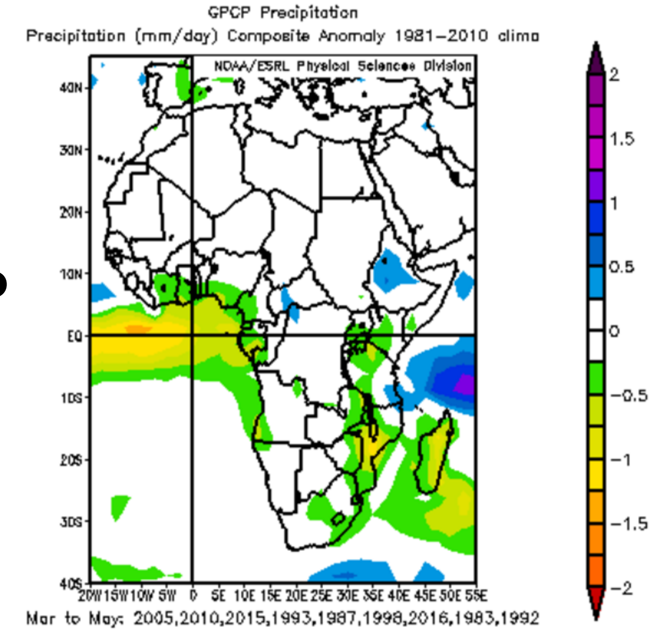


ENSO impacts on Africa precipitation

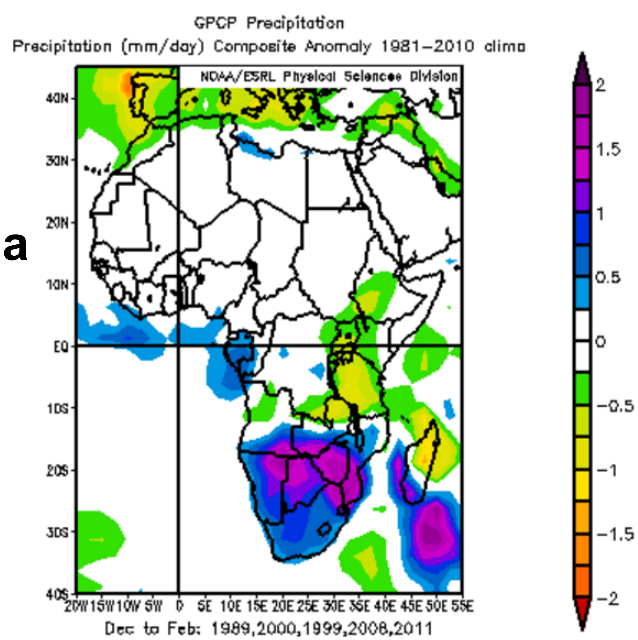
DJF El Niño composite



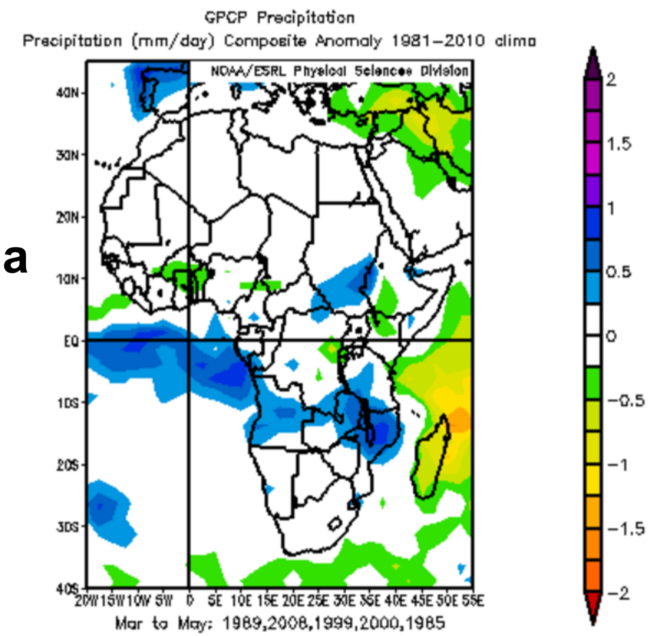
MAM El Niño composite



DJF La Niña composite

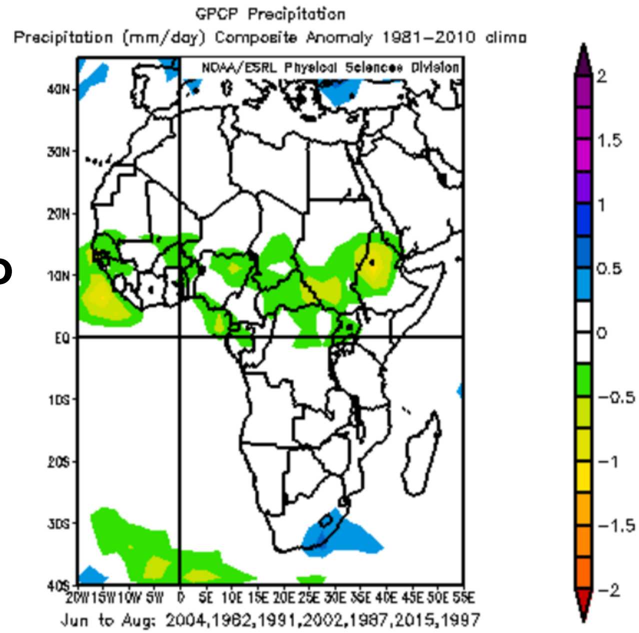


MAM La Niña composite

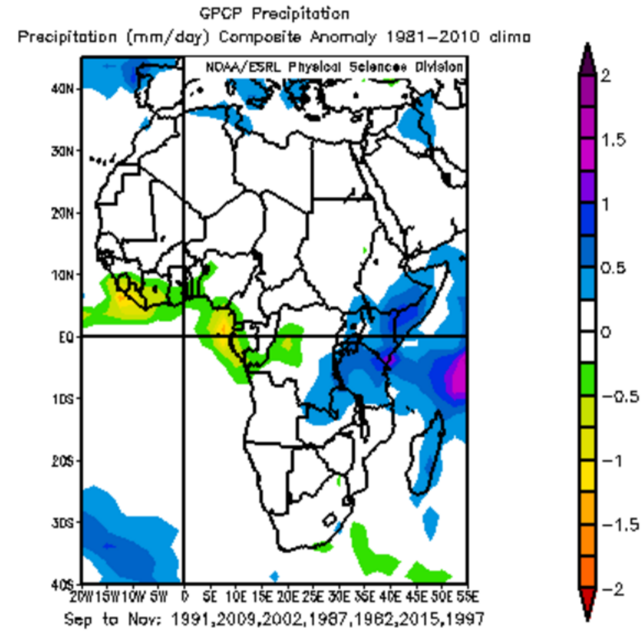


ENSO impacts on Africa precipitation

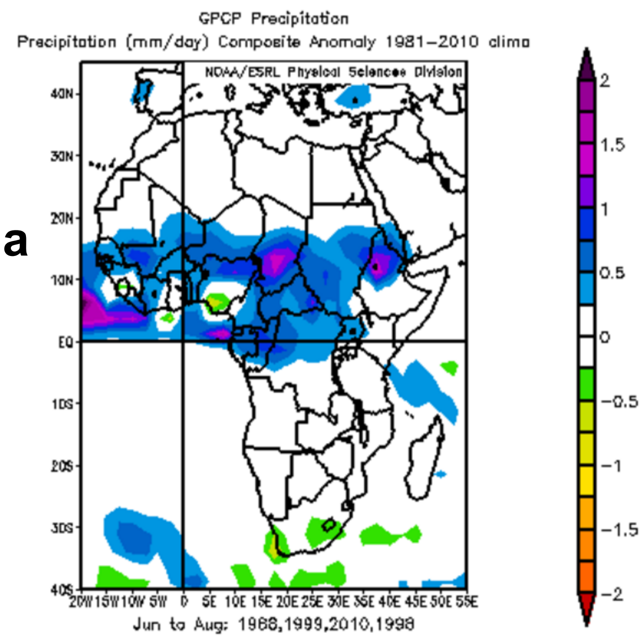
JJA El Niño composite



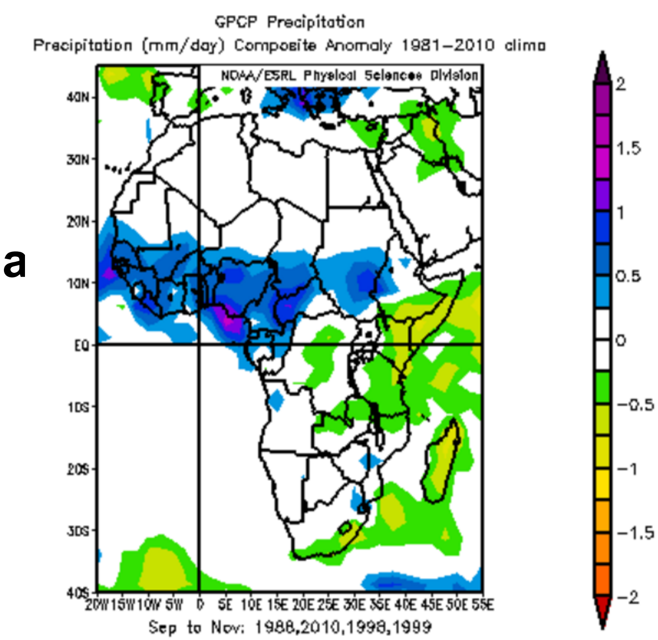
SON El Niño composite



JJA La Niña composite

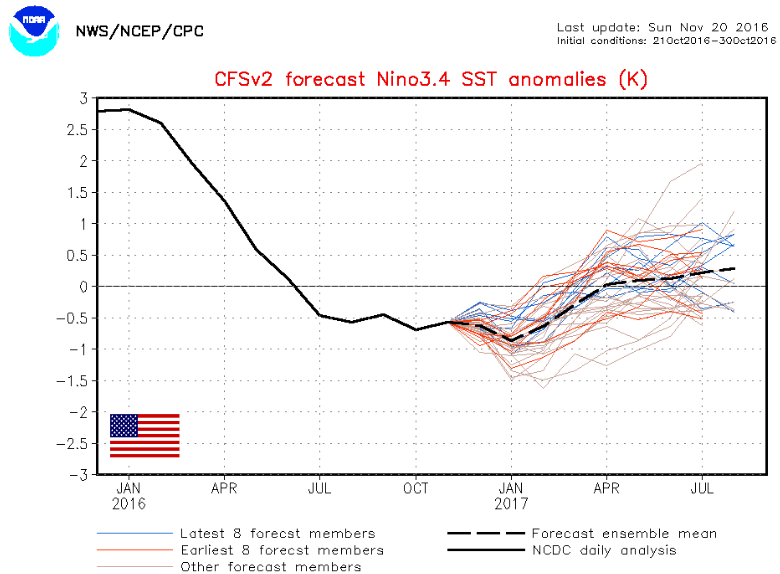


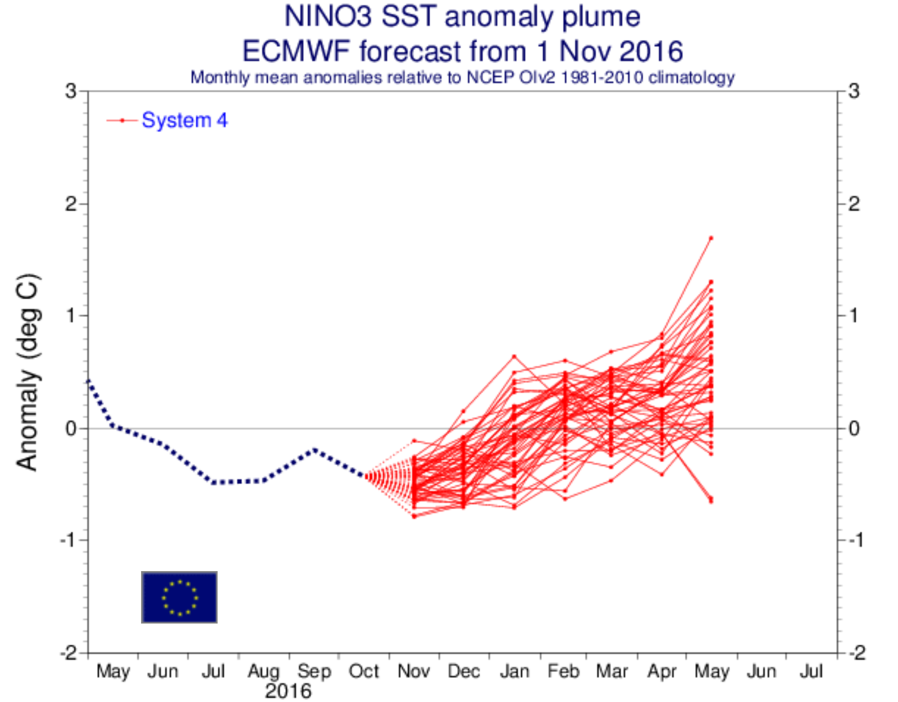
SON La Niña composite

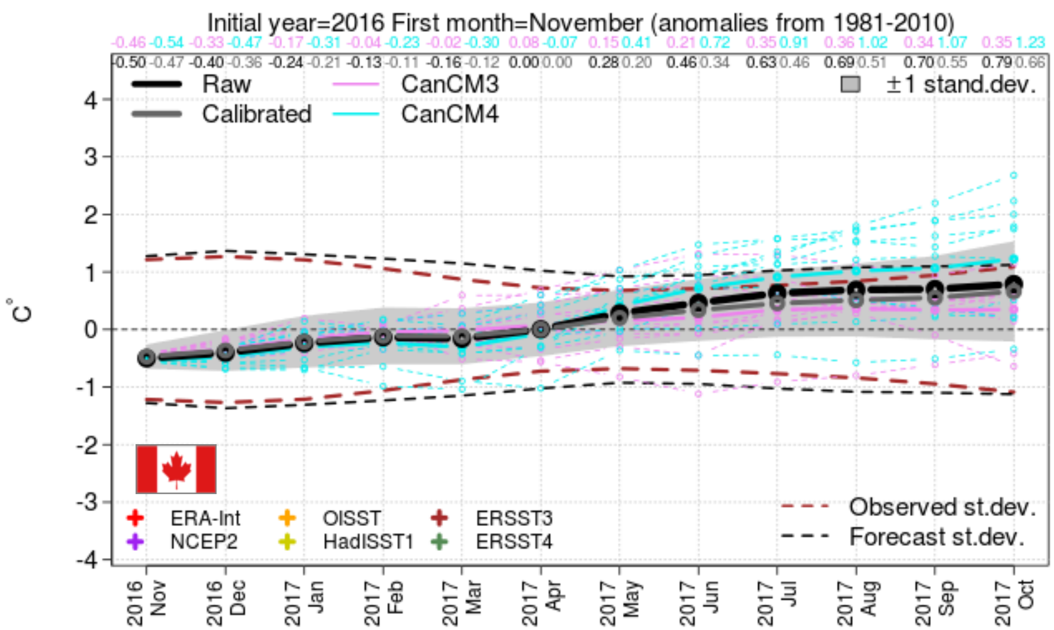


ENSO Prediction

Nino3.4 ensemble plumes from Nov 2016



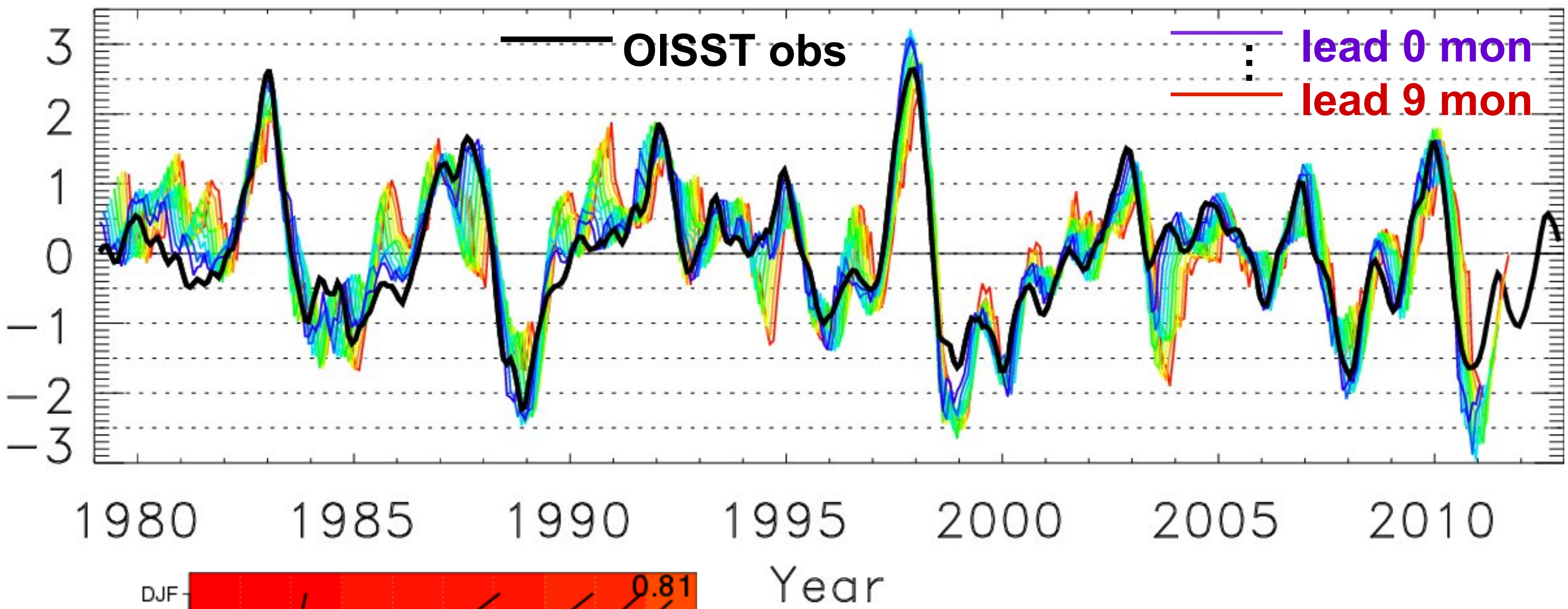


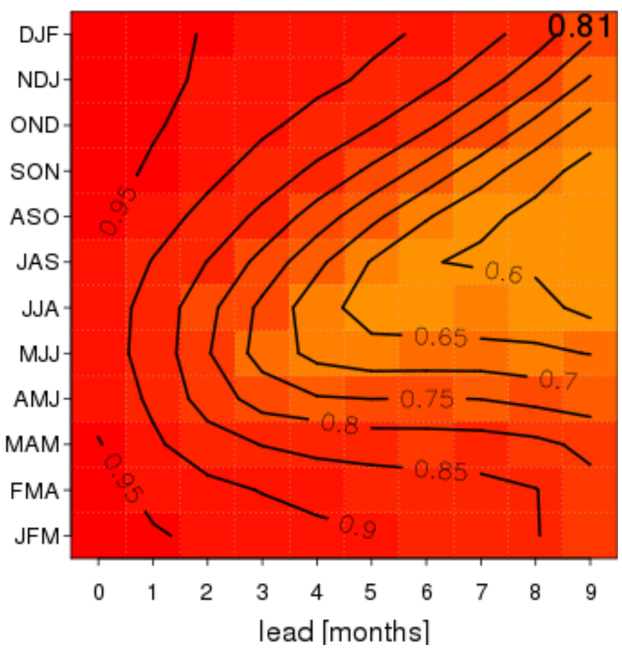


→ similar message: weak La Niña transitioning to possible weak to moderate El Niño by Summer 2017

Historical CanSIPS ENSO predictions

Seasonal mean Nino3.4 index: observed vs 0-9 month lead times





← **Nino3.4 anomaly correlation skill**

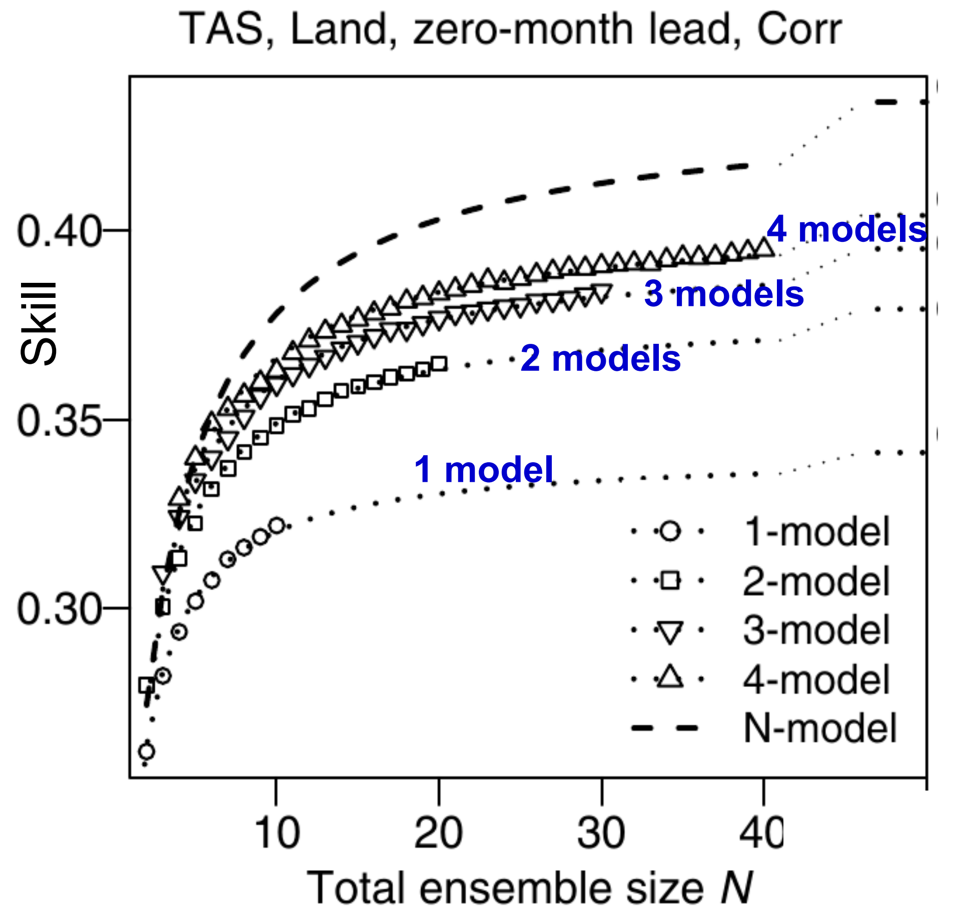
- **Some false alarms**, such as 1990-91 and 2003-2004
- However, **no misses** for El Niño/La Niña events exceeding ±1.5°C, except for unusual summer-peaked 1987 El Niño

Multi-model ensembles (MMEs)

Why multi-model ensembles?

1) Different models have different strengths and weaknesses

- *model errors will tend to cancel each other out*
- *higher skill for multi models than for single model, for a given ensemble size N*
- *this example considers 4 models with 10 ensemble members each*

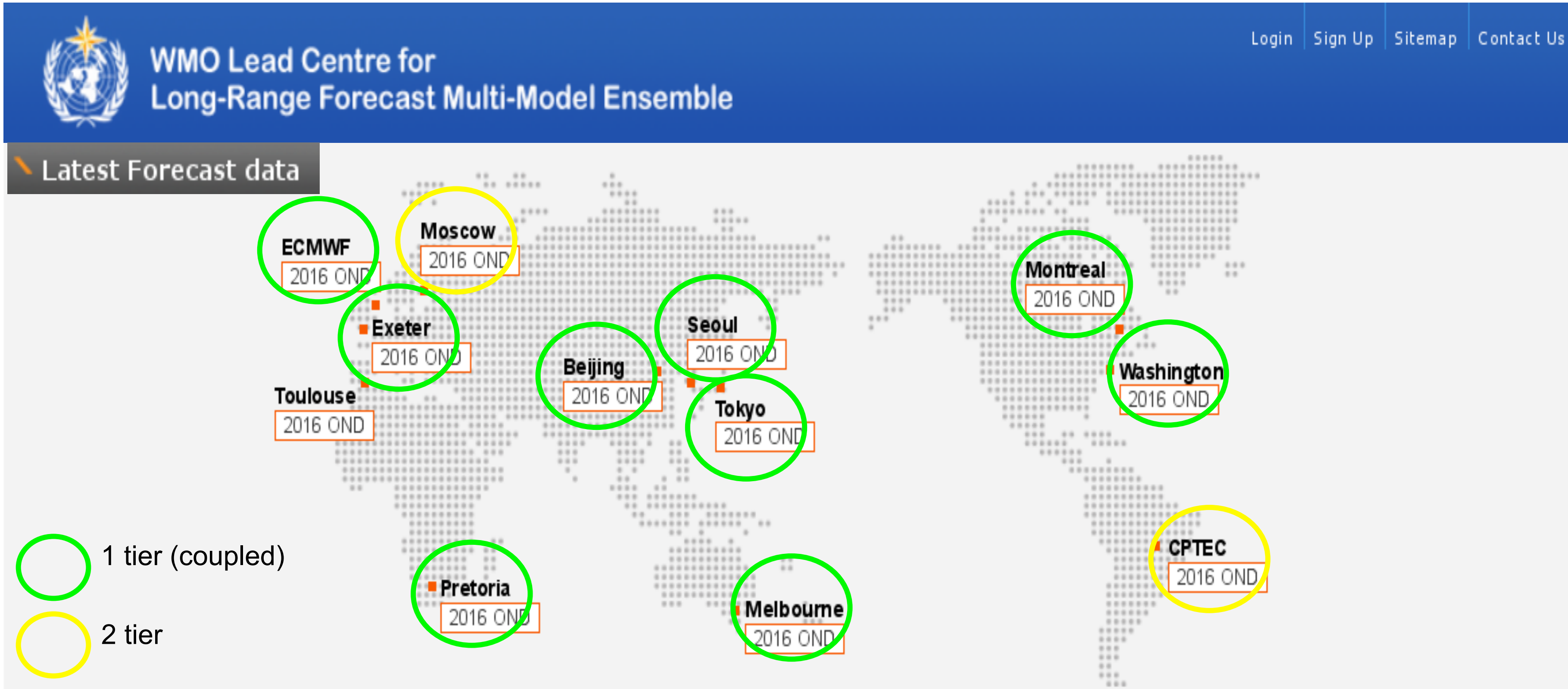


Kharin et al., Atm.-Ocn. (2009)

2) More ensemble members available by combining models than from individual models

WMO multi-model ensemble

https://www.wmolc.org/



- 12 Global Producing Centres (GPCs) representing different meteorological services
- Forecast information provided to Regional Climate Centres (RCCs) and Climate Outlook Forums (COFs)
- Maps and data password protected

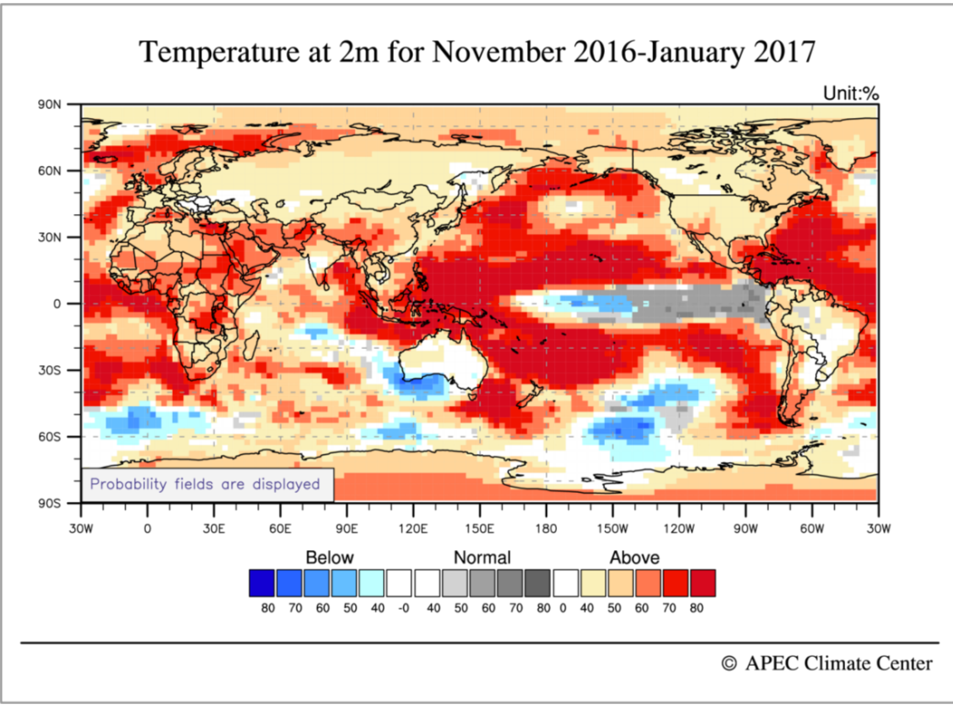
APCC multi-model ensemble

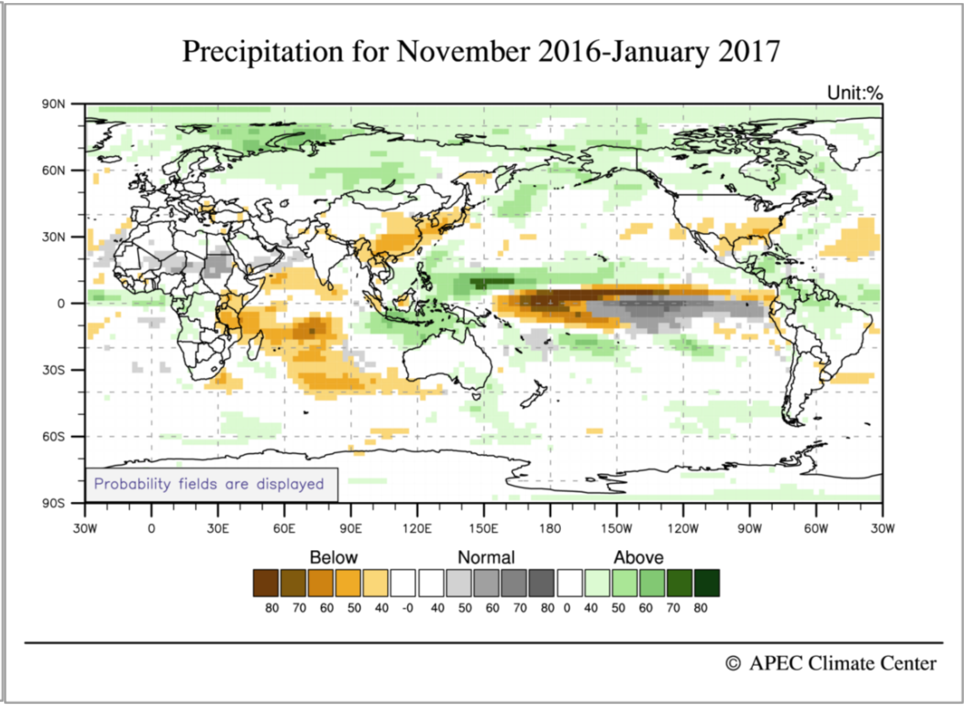
APEC CLIMATE CENTER

http://www.apcc21.net

Climate Outlook for November 2016 - April 2017

BUSAN, 25 October 2016 – Synthesis of the latest model forecasts for November 2016 to April 2017 (NDJFMA) at the APEC Climate Center (APCC), located in Busan, Korea, indicates the ENSO state to be neutral. The positive temperature anomalies are most likely to prevail over the globe. Highly probable above normal rainfalls over the maritime continent are predicted for NDJ.

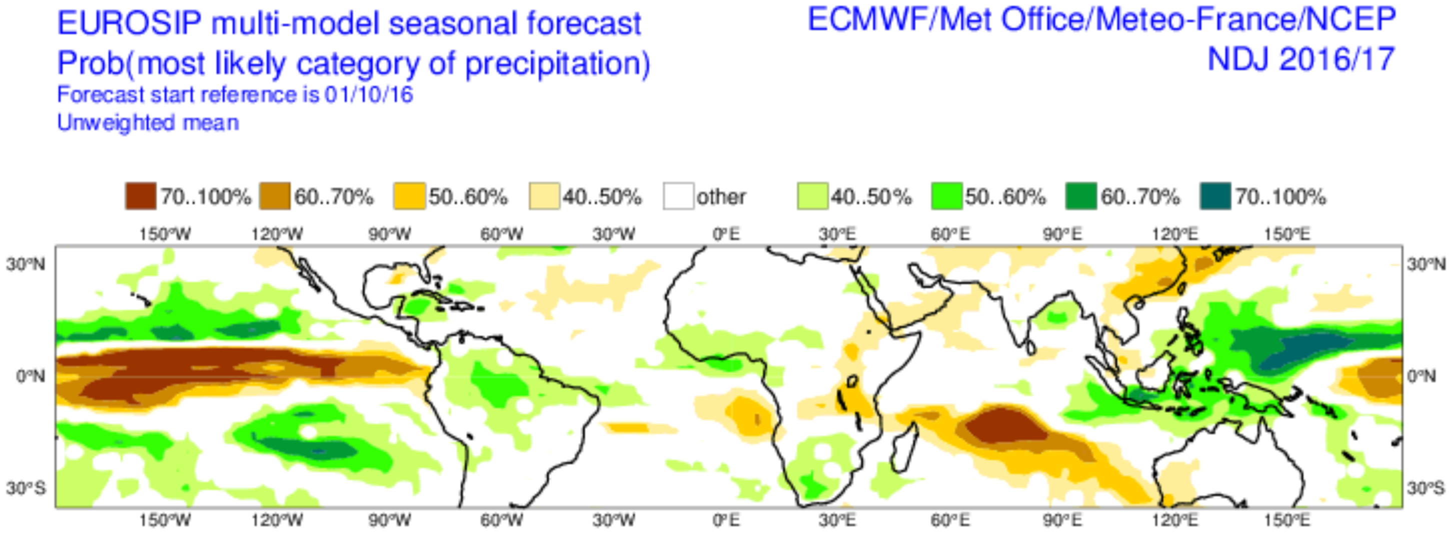




- Models include CMCC, CanCM3, CanCM4, NASA, NCEP, PMU, POAMA
- Month 1-3 and 4-6 probabilistic & deterministic forecast maps publicly available
- Data password protected

EUROSIP multi-model ensemble

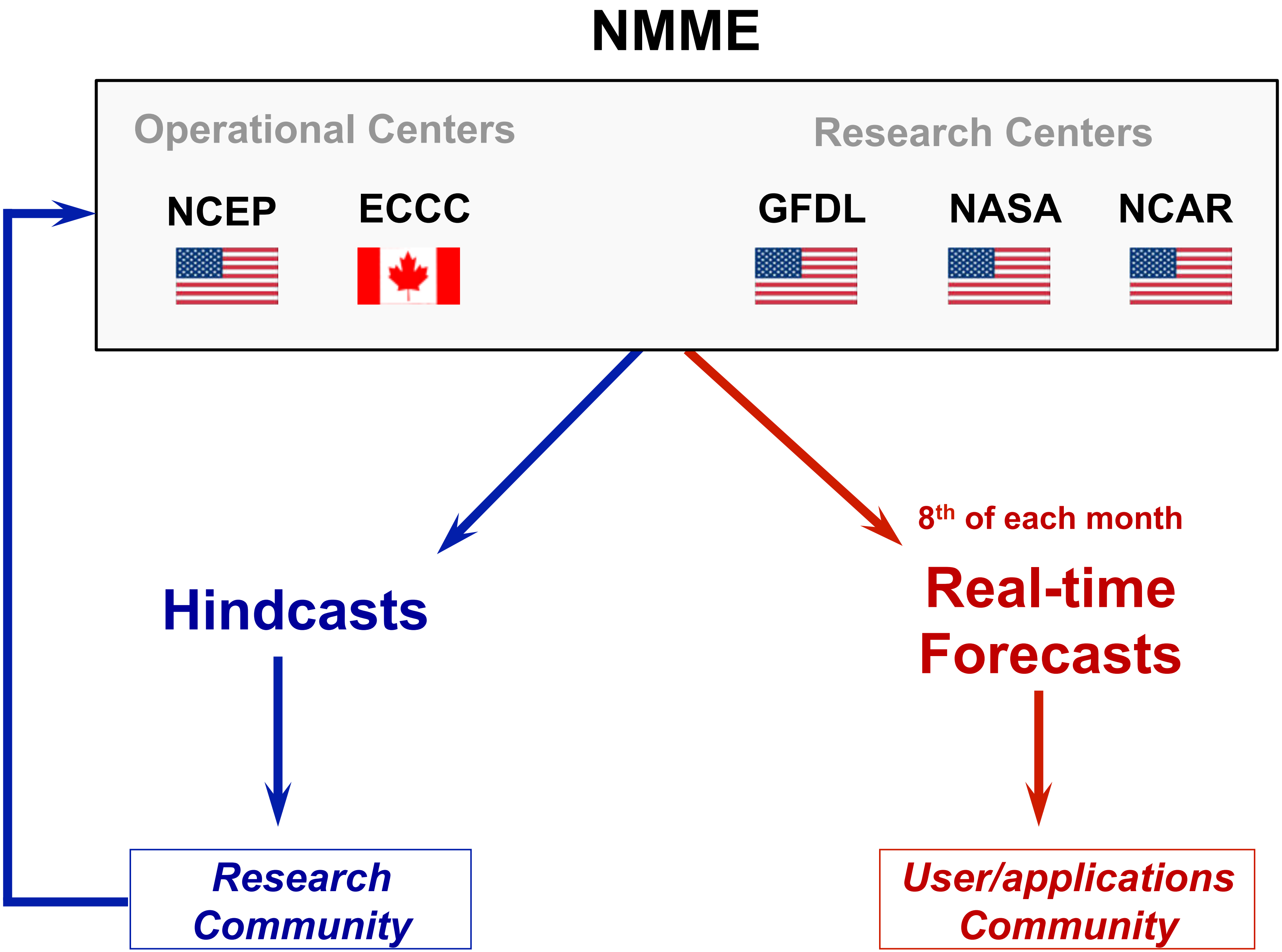
- Four models at ECMWF:
  - ECMWF System 4
  - Met Office – HADGEM model, Met Office ocean analyses
  - Météo-France – Météo-France model, Mercator ocean analyses
  - NCEP – CFSv2
- Common operational schedule (products released at 12Z on 15th)
- Some charts (ENSO plumes, tropics) publicly available at http://www.ecmwf.int/en/forecasts/charts/seasonal/



North American Multi-Model Ensemble (NMME)

What is the NMME?

- Ensemble of opportunity: US, Canadian operational forecast systems + US research systems
- Hindcasts *and* real time forecasts
- Real time forecasting since Aug 2011
- All data openly accessible
- Requirements for inclusion
  - ensemble system, range ≥ 9 months
  - must provide hindcast data for 1982-2010
  - commitment to provide real time forecasts by 8th of each month (CPC operational schedule)


NMME
Operational Centers
Research Centers
NCEP
ECCC
GFDL
NASA
NCAR
8th of each month
Hindcasts
Real-time Forecasts
Research Community
User/applications Community

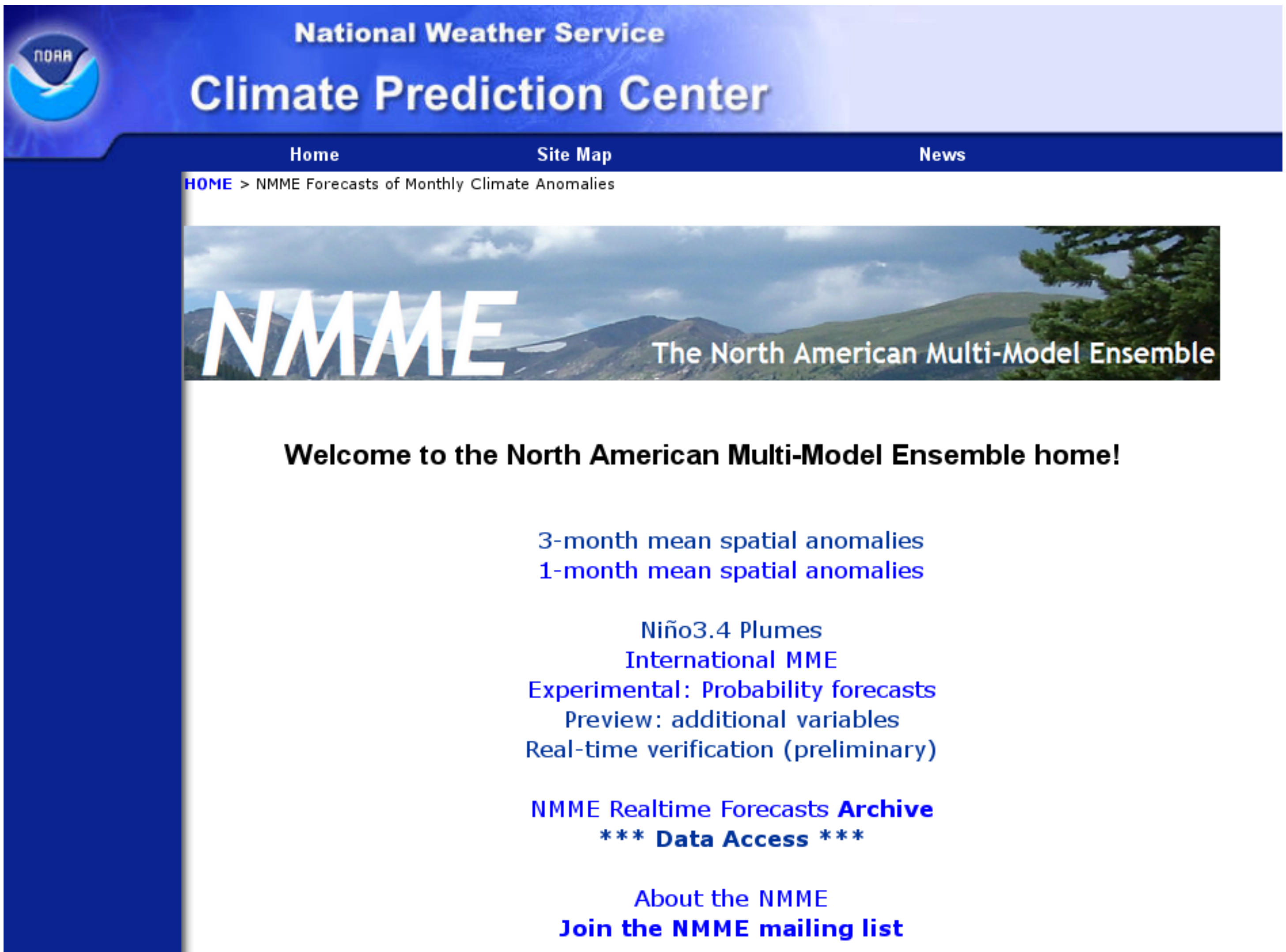
Currently contributing models

Model	Center	Ensemble size
CFSv2	NCEP	24 (28)
CanCM3	EC/CMC	10
CanCM4	EC/CMC	10
FLOR	GFDL	24
CM2.1	GFDL	10
CCSM4	NCAR	10
GEOS-5	NASA	11
CESM1	NCAR	10
Total ensemble size		109 (113)

NMME home page

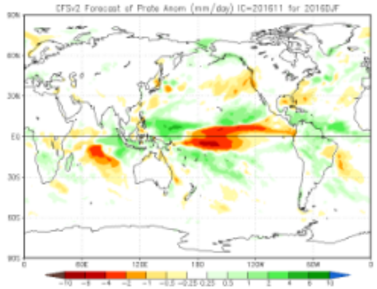
http://www.cpc.ncep.noaa.gov/products/NMME/

(web search “nmme”)

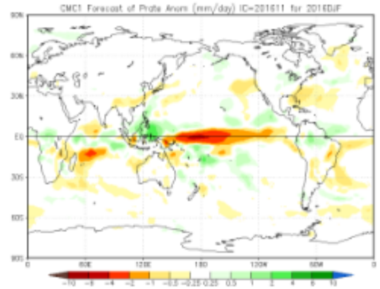


Individual model forecasts

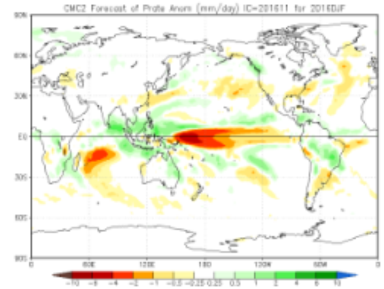
NCEP_CFSv2



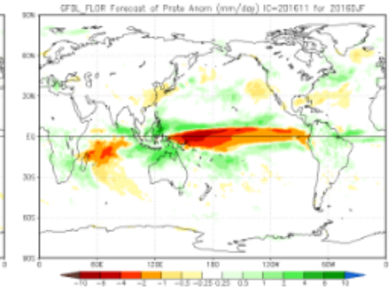
CMC1_CanCM3



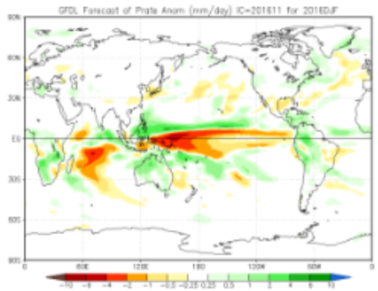
CMC2_CanCM4



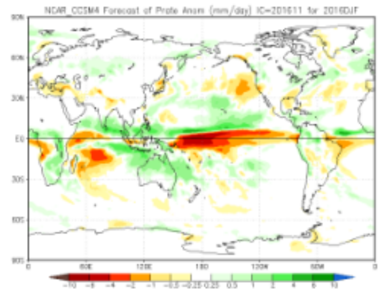
GFDL_FLOR



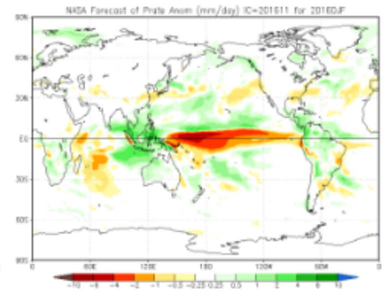
GFDL_CM2.1



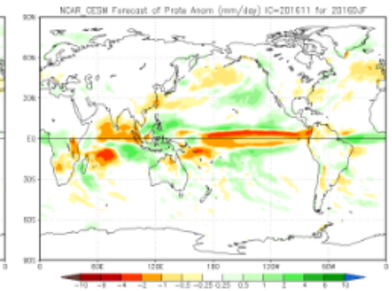
NCAR_CCSM4



NASA_GEOS5

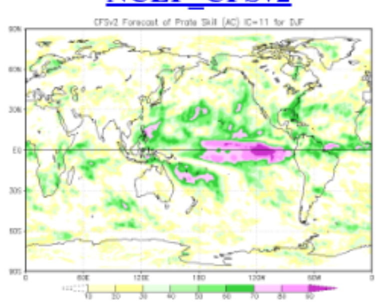


NCAR_CESM

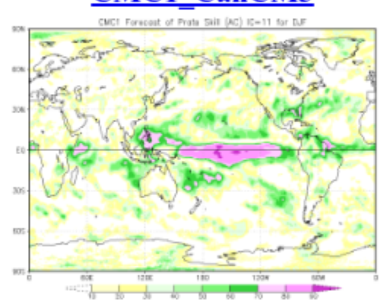


Individual model skills

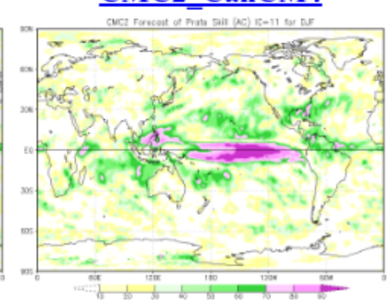
NCEP_CFSv2



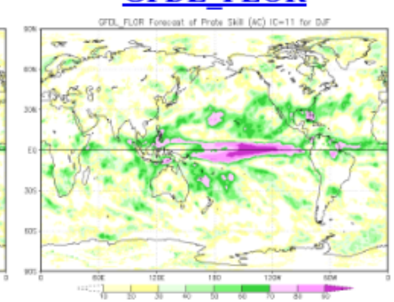
CMC1_CanCM3



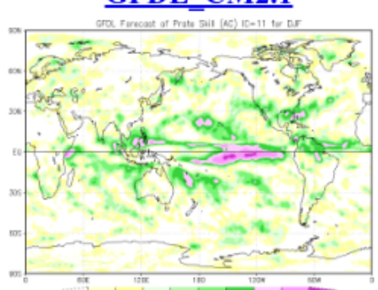
CMC2_CanCM4



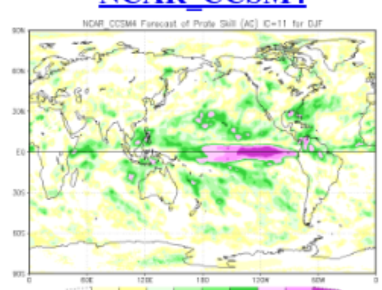
GFDL_FLOR



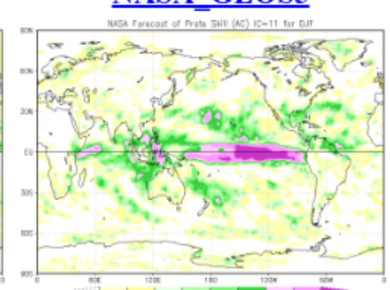
GFDL_CM2.1



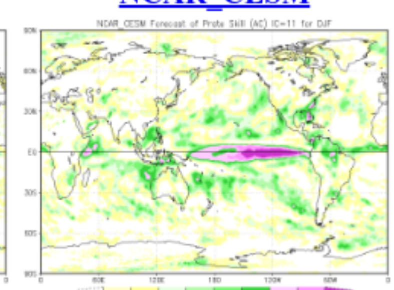
NCAR_CCSM4



NASA_GEOS5

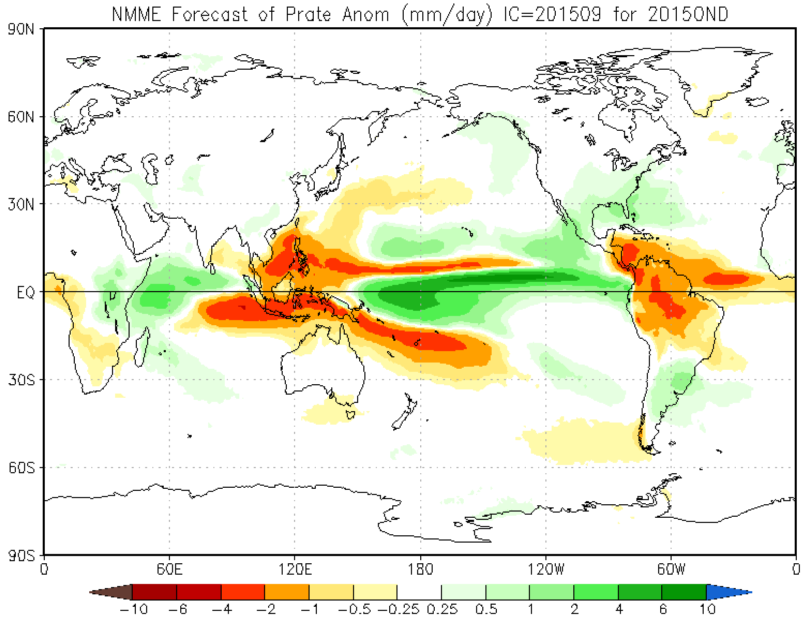


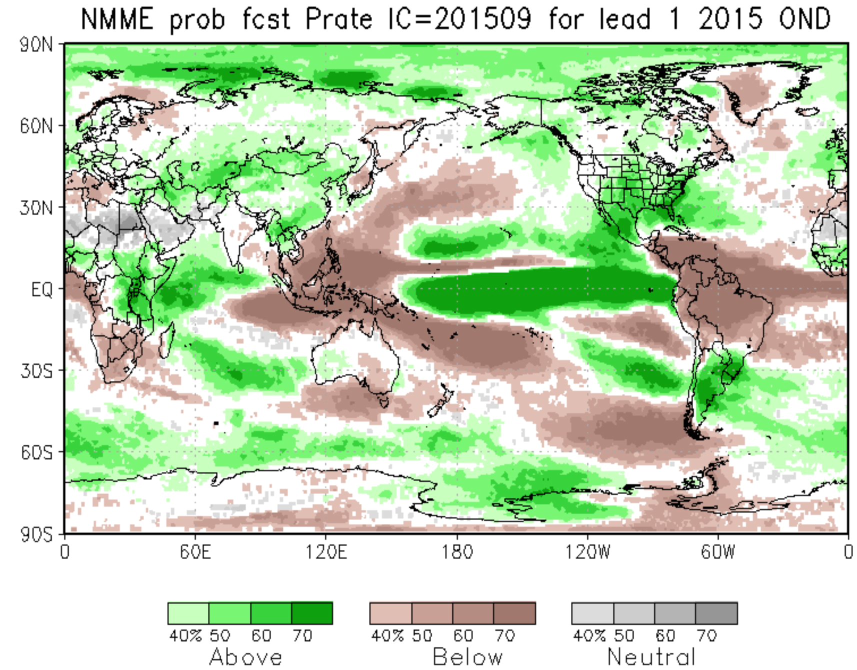
NCAR_CESM



Deterministic and probabilistic forecasts

Prate 2015 OND from 201509





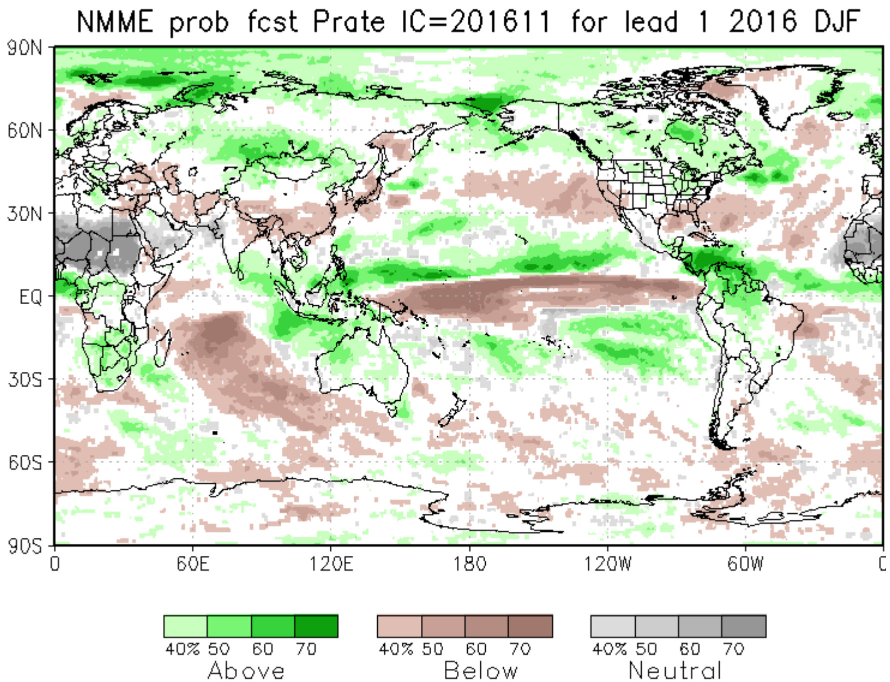
Deterministic
Models weighted equally

Probabilistic
*Ensemble members weighted equally**

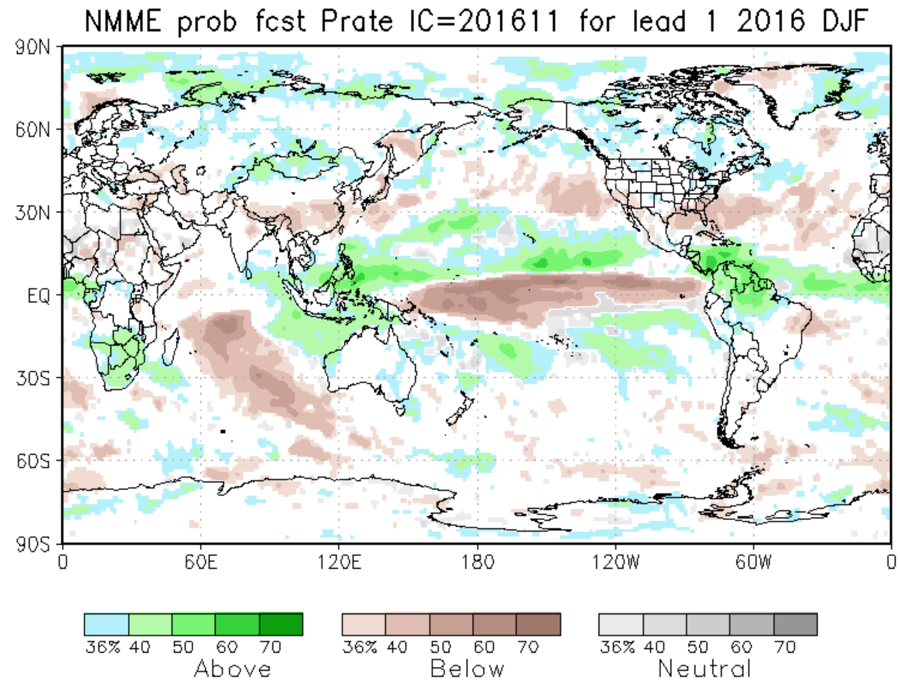
*Anomalies and tercile boundaries computed separately for each model

Raw and calibrated probabilistic forecasts

Prate 2016 DJF from 201511



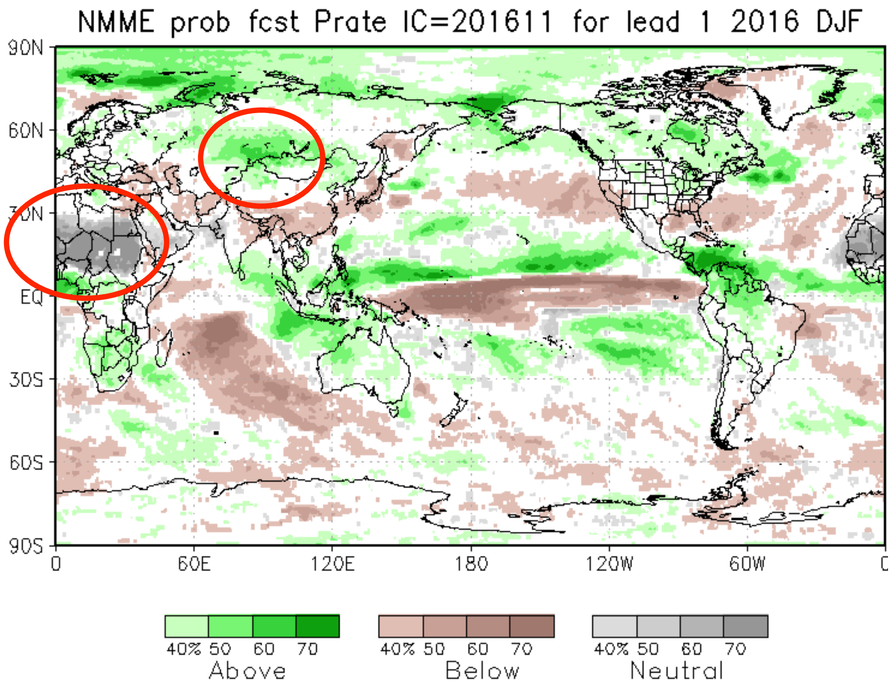
Raw probabilistic
(overconfident)



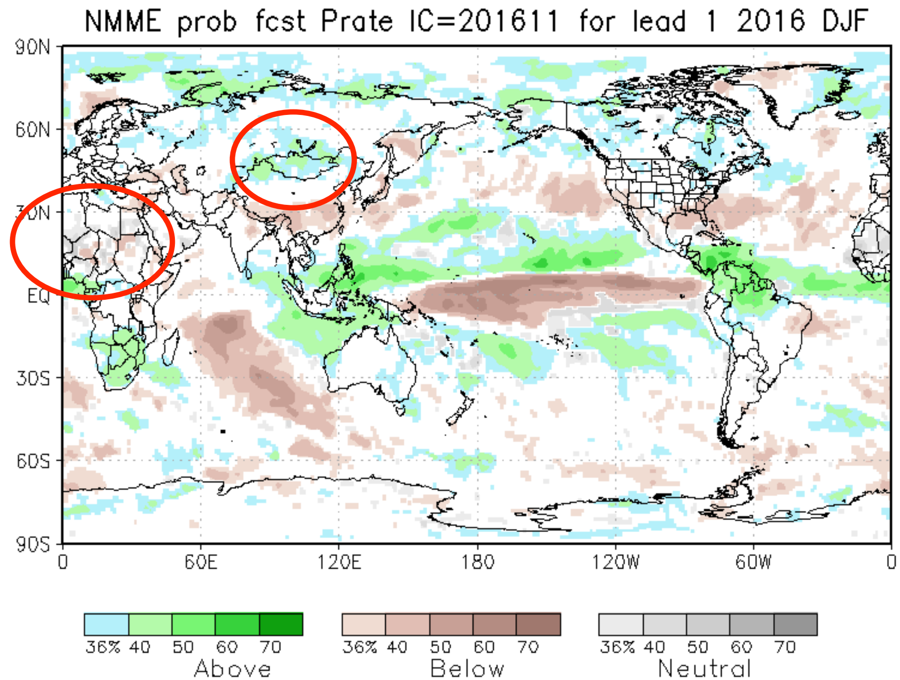
Calibrated probabilistic
(more reliable)

Raw and calibrated probabilistic forecasts

Prate 2016 DJF from 201511



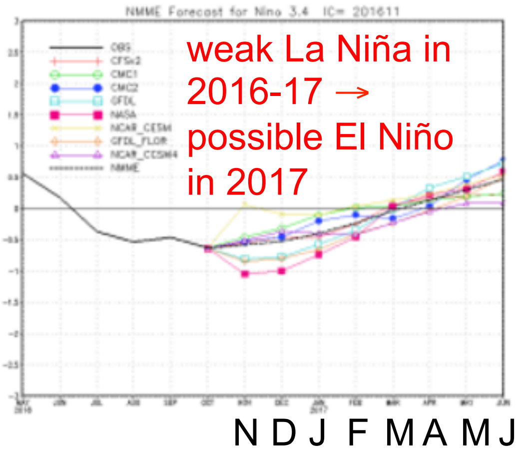
Raw probabilistic
(overconfident)



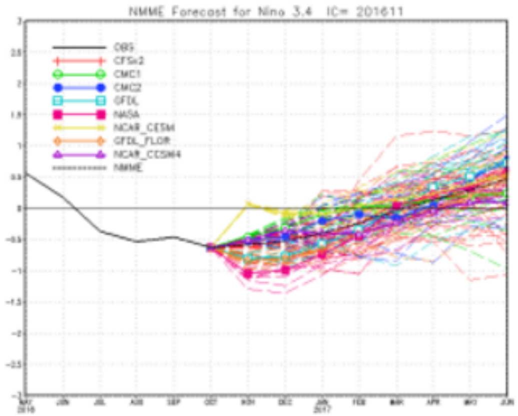
Calibrated probabilistic
(more reliable)

NMME Nino3.4 plumes

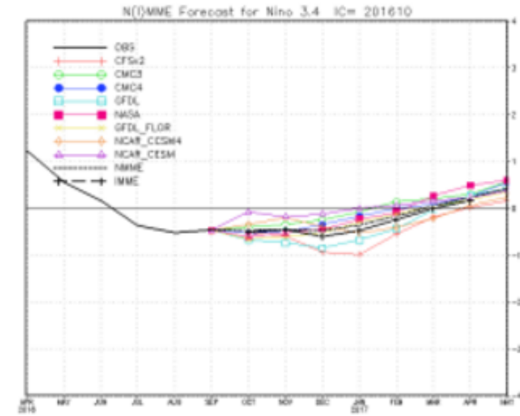
Ensemble Mean



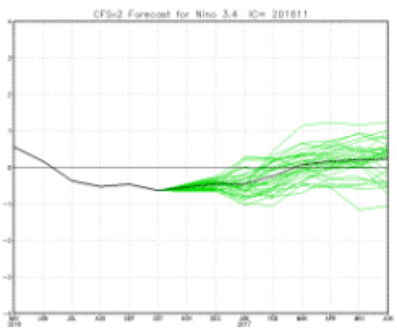
All Members



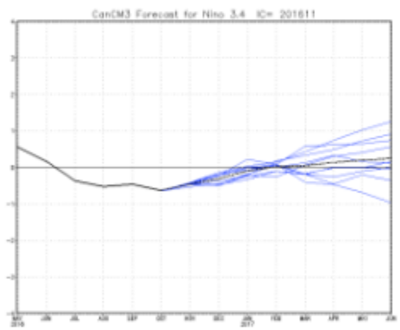
Ens Mean + IMME



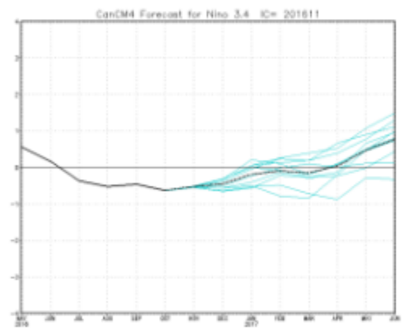
CFSv2_CFSv2



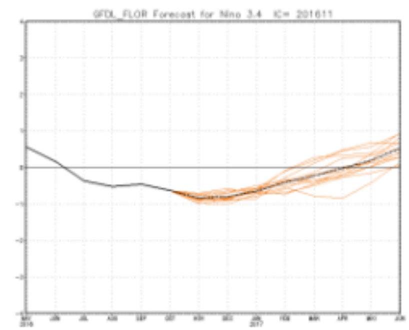
CMC1_CanCM3



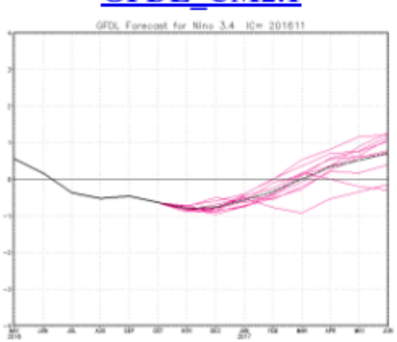
CMC2_CanCM4



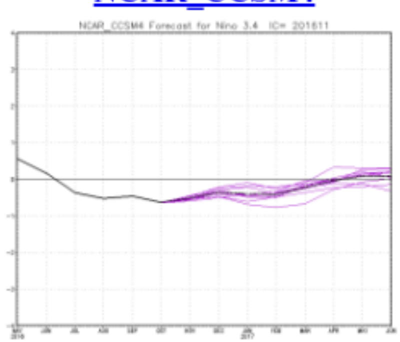
GFDL_FLOR



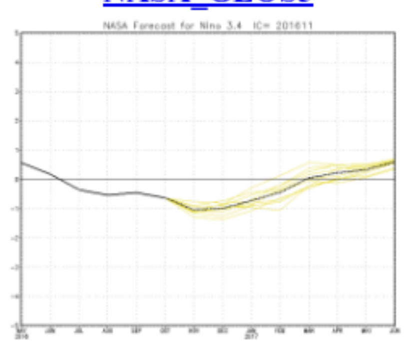
GFDL_CM2.1



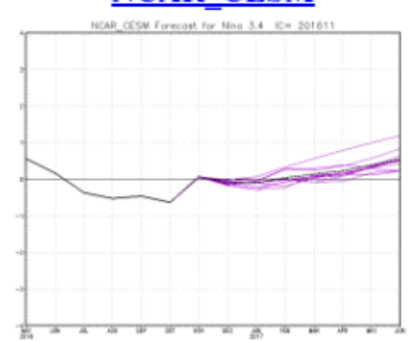
NCAR_CCSM4



NASA_GEOS5



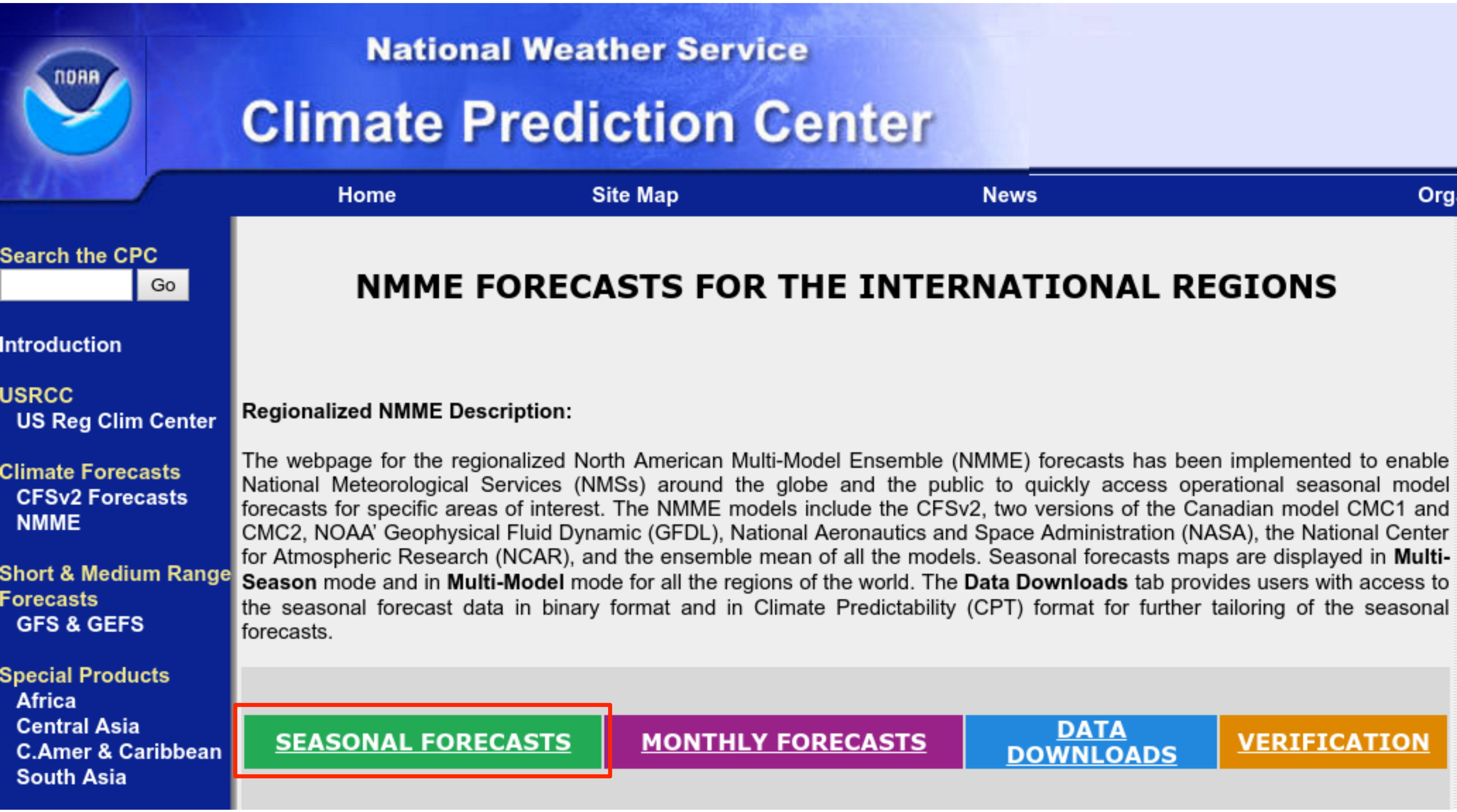
NCAR_CESM



NMME for International Regions

http://www.cpc.ncep.noaa.gov/products/international/nmme/nmme.shtml

(web search "nmme international")



NMME SEASONAL FORECASTS FOR INTERNATIONAL REGIONS

SEA SURFACE TEMPERATURE

Region | Model	Anomalies	StdAnom	Masked StdAnom	SkillMaps	ProbAnom	3Category Prob
Global	●	●	●	●	●	●
Pacific	●	●	●	●	●	●
Atlantic	●	●	●	●	●	●
Indian Ocean	●	●	●	●	●	●
Atlantic&Indian	●	●	●	●	●	●

PRECIPITATION

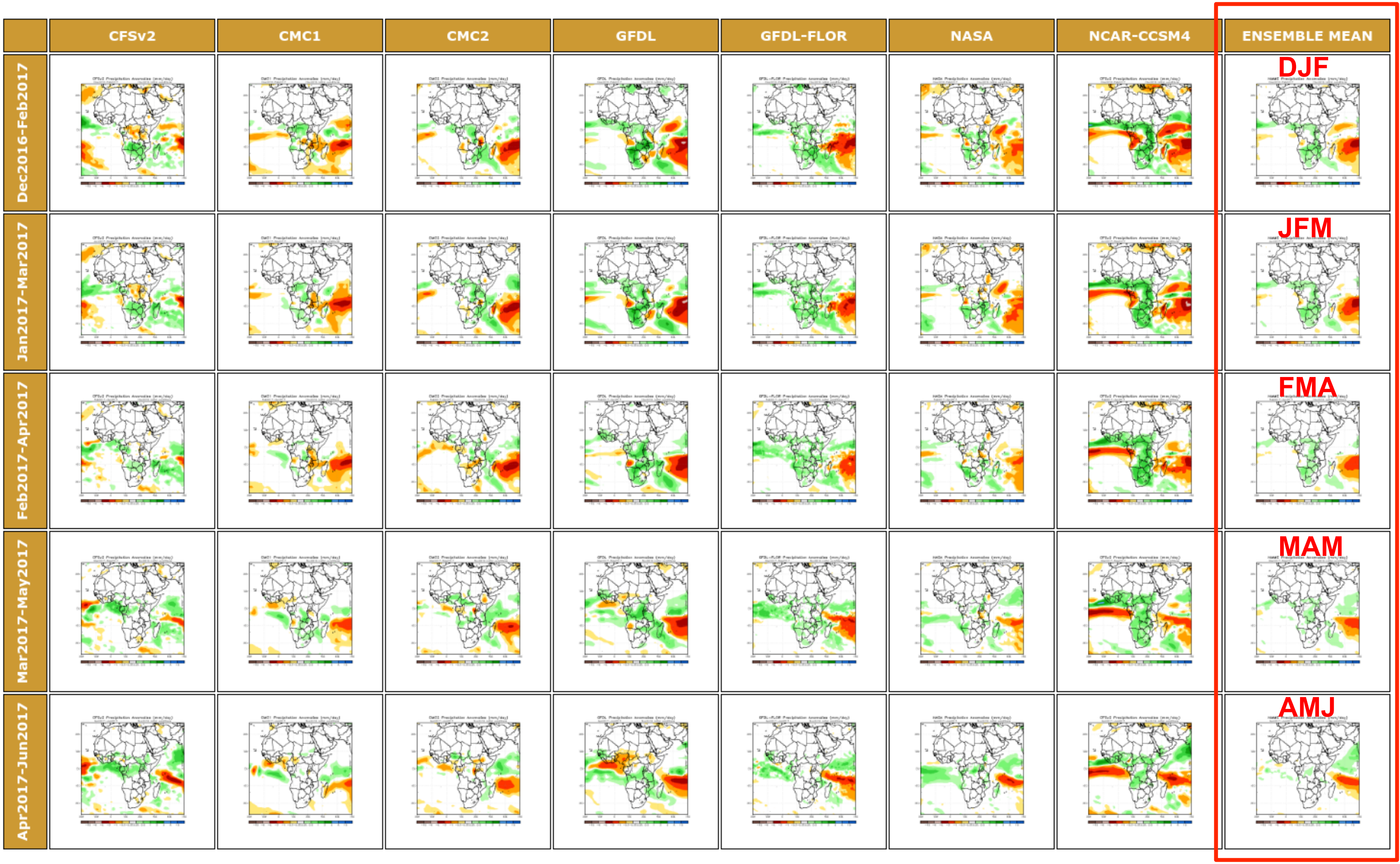
Region | Model	Anomalies	StdAnom	Masked StdAnom	SkillMaps	ProbAnom	3Category Prob
Global	●	●	●	●	●	●
Africa	●	●	●	●	●	●
CAM&Caribbean	●	●	●	●	●	●
Maritime-CONT	●	●	●	●	●	●
Central Asia	●	●	●	●	●	●
East Asia	●	●	●	●	●	●
South Asia	●	●	●	●	●	●
South America	●	●	●	●	●	●

2-METER AIR TEMPERATURE

Region | Model	Anomalies	StdAnom	Masked StdAnom	SkillMaps	ProbAnom	3Category Prob
Global	●	●	●	●	●	●
Africa	●	●	●	●	●	●
CAM&Caribbean	●	●	●	●	●	●
Maritime-CONT	●	●	●	●	●	●
Central Asia	●	●	●	●	●	●
East Asia	●	●	●	●	●	●
South Asia	●	●	●	●	●	●
South America	●	●	●	●	●	●

Precipitation forecasts from Nov 2016

AFRICA NMME SEASONAL PRECIPITATION ANOMALIES   November2016 INITIAL CONDITIONS



NMME International Data

http://ftp.cpc.ncep.noaa.gov/International/nmme/

Index of /International/nmme

Name	Last modified	Size
Parent Directory		-
binary_monthly/	09-Nov-2016 17:23	-
binary_seasonal/	09-Nov-2016 17:22	-
monthly_nmme_forecast_in_cpt_format/	09-Nov-2016 18:28	-
monthly_nmme_hindcast_in_cpt_format/	09-Nov-2016 18:34	-
readme	16-Oct-2015 17:29	823
seasonal_nmme_forecast_in_cpt_format/	09-Nov-2016 18:02	-
seasonal_nmme_hindcast_in_cpt_format/	09-Nov-2016 18:08	-

Data is freely accessible!

NMME Data at IRI

Hindcasts + real time forecasts

Real-Time Monthly fields (8)

- 2m T daily max
- 2m T daily min
- 2m temperature
- 200 mb Geopotential
- Total precipitation
- Total soil moisture
- Surface temperature (SST+land)
- Surface runoff

Data is freely accessible!

Models NMME options | Help | Expert Mode

SOURCES | Models | NMME

Data Library
Finding Data
Tutorial
Questions and Answers
Function Documentation
help

Models NMME

Models NMME from SOURCES: the IRI/LDEO collection of climate data.

Documents

overview	an outline showing sub-datasets of this dataset
CTB home	Climate Test Bed
NMME Home	Information about the NMME project

Semantic Documents

auxinfo.owl

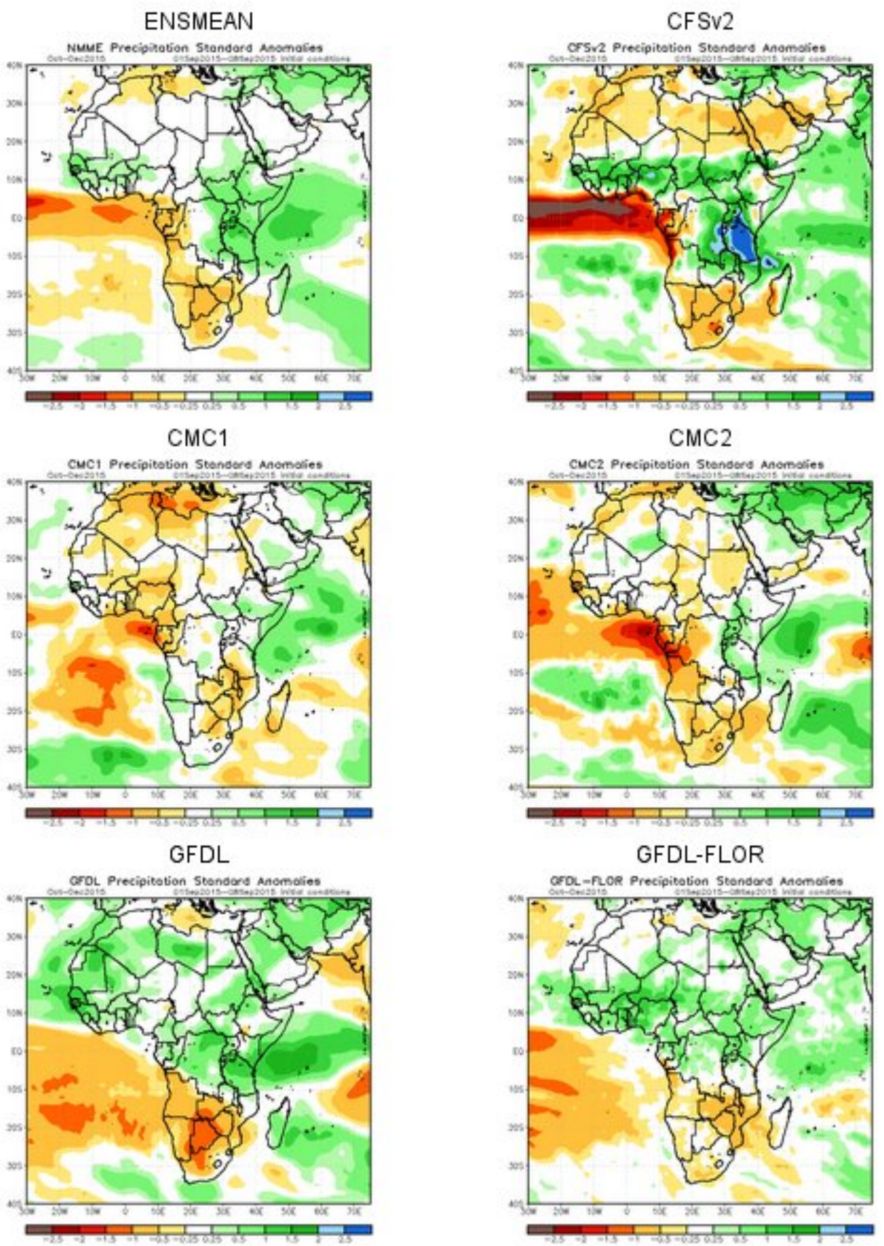
Datasets and variables

CMC1-CanCM3	Models NMME CMC1-CanCM3 [**FORECAST HINDCAST**]
CMC2-CanCM4	Models NMME CMC2-CanCM4 [**FORECAST HINDCAST**]
COLA-RSMAS-CCSM3	Models NMME COLA-RSMAS-CCSM3 [**MONTHLY**]
CPC-CMAP	Models NMME CPC-CMAP [**prate**]
CPC-PRECIP	Models NMME CPC-PRECIP [**prate**]
GFDL-CM2p1	Models NMME GFDL-CM2p1 [**MONTHLY**]
GFDL-CM2p1-aer04	Models NMME GFDL-CM2p1-aer04 [**MONTHLY**]
GFDL-CM2p5-FLOR-A06	Models NMME GFDL-CM2p5-FLOR-A06 [**MONTHLY**]
GFDL-CM2p5-FLOR-B01	Models NMME GFDL-CM2p5-FLOR-B01 [**MONTHLY**]
GHCN_CAMS	Models NMME GHCN_CAMS [**temp**]
IRI-ECHAM4p5-AnomalyCoupled	Models NMME IRI-ECHAM4p5-AnomalyCoupled [**MONTHLY**]
IRI-ECHAM4p5-DirectCoupled	Models NMME IRI-ECHAM4p5-DirectCoupled [**MONTHLY**]
LSMASK	Models NMME LSMASK [**land**]
NASA-GMAO	Models NMME NASA-GMAO [**MONTHLY**]
NASA-GMAO-062012	Models NMME NASA-GMAO-062012 [**MONTHLY**]
NCDC-OISST	Models NMME NCDC-OISST [**sst**]
NCEP-CFSv1	Models NMME NCEP-CFSv1 [**MONTHLY**]
NCEP-CFSv2	Models NMME NCEP-CFSv2 [**MONTHLY**]

http://iridl.ldeo.columbia.edu/SOURCES/.Models/.NMME

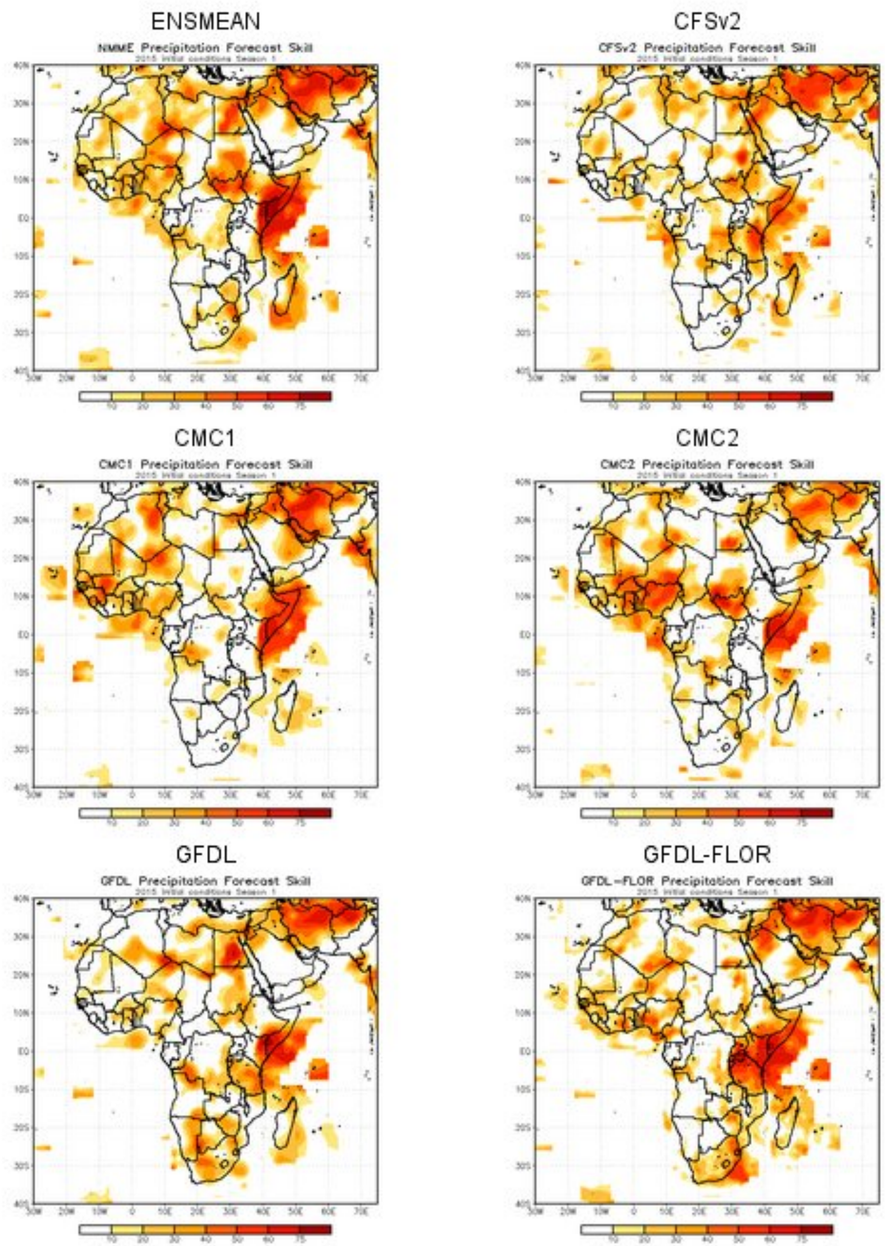
NMME PRECIPITATION SEASON1 Standard Anomalies

Initial Conditions: 01Sep2015-08Sep2015 Oct-Dec2015 Forecast



NMME PRECIPITATION SEASON1 Skill Maps

Initial Conditions: 01Sep2015-08Sep2015 Oct-Dec2015 Forecast



CanSIPS Explorer

- Developed and maintained at CCCma by Slava Kharin
- Displays all monthly, seasonal hind/forecasts + verifications 1979-present + skills
- Probabilistic/deterministic forecasts (maps & local PDFs) for many variables, regions (**including Africa**), indices

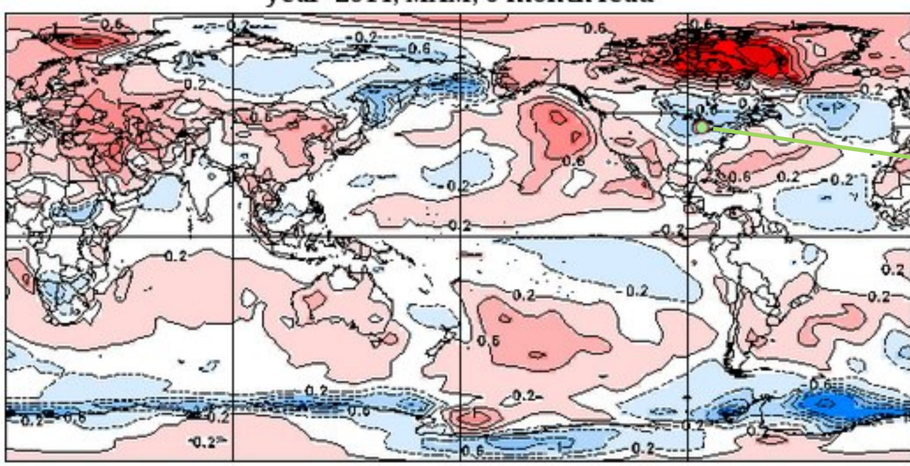
CMC/CCCma (Environment Canada) CanSIPS Experimental 12-month Forecasts issued monthly

[related: CanSIPS 3-month forecasts issued daily] [contact: slava.kharin@ec.gc.ca]

Variable	Time avg.	Time lead	Prev./Next		First year/month		Version
Temperature	Seasonal	0-month	<<	>>	2014	Mar	cmc(d+e)

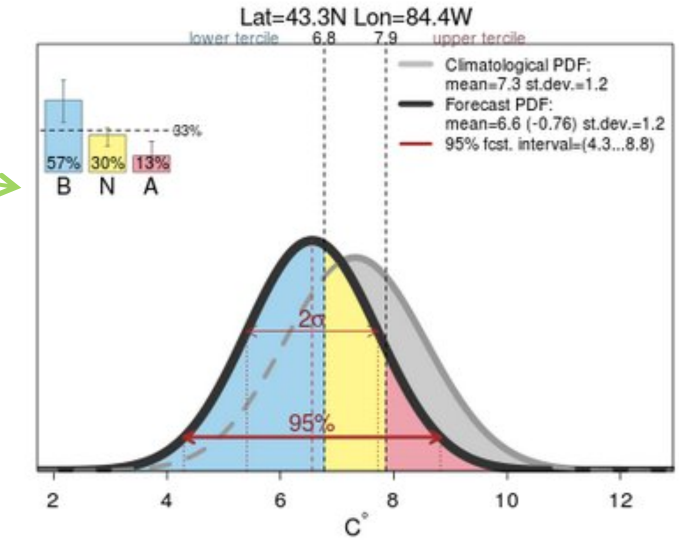
Region	Forecast Type	Observ. Type	Show PDF/Obs.	Calibration/Observations	
Globe(0..360)	Anomaly	N/A	Show PDF	Calibrated(constant)	eraint

Temperature, Anomaly Forecast
year=2014, MAM, 0-month lead



12-season calibrated ensemble mean anomaly forecast.

Local probability forecast



http://www.cccma.ec.gc.ca/cgi-bin/data/seasonal_forecast/sf2 ← *Monthly* to 12 mon

" " **sf2_daily**

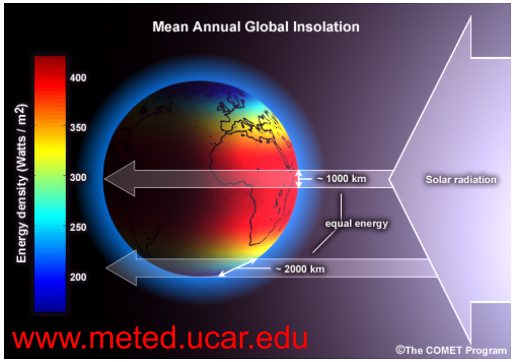
↑

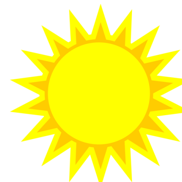
Daily N-day, monthly & seasonal forecasts

username: cccmasf
password: seasforum

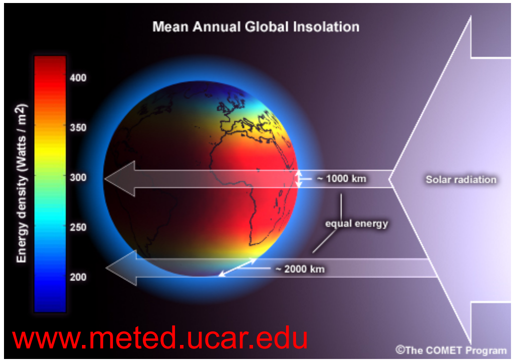
What is El Niño?

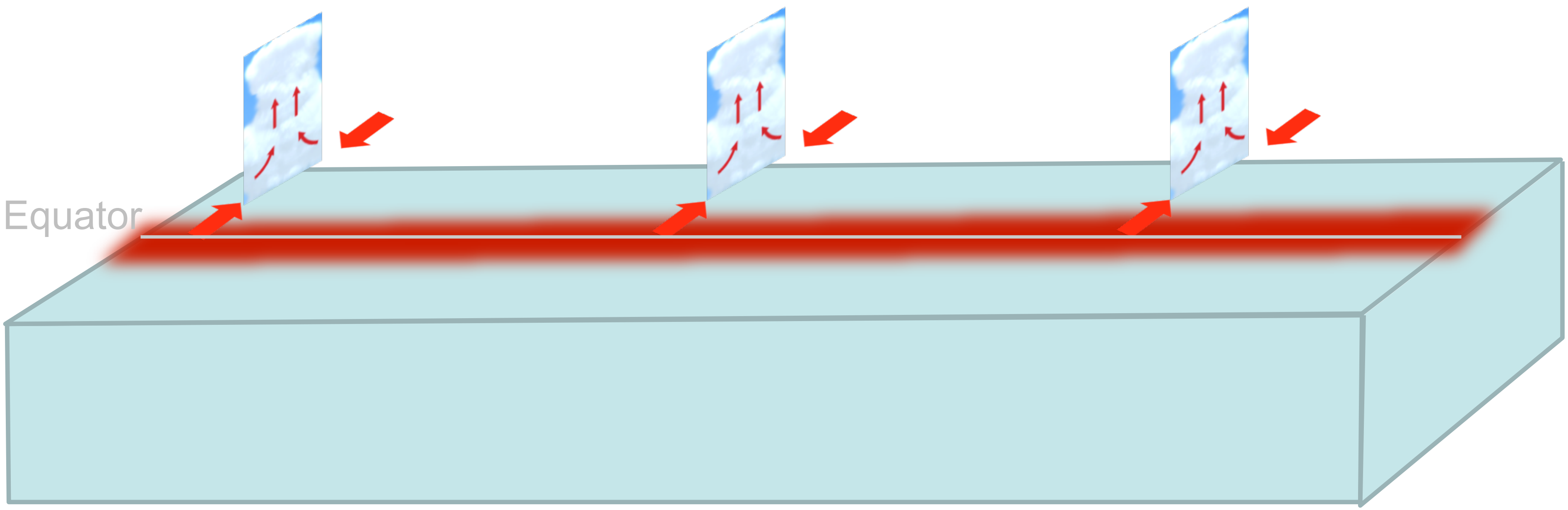
Equatorial atmosphere/ocean



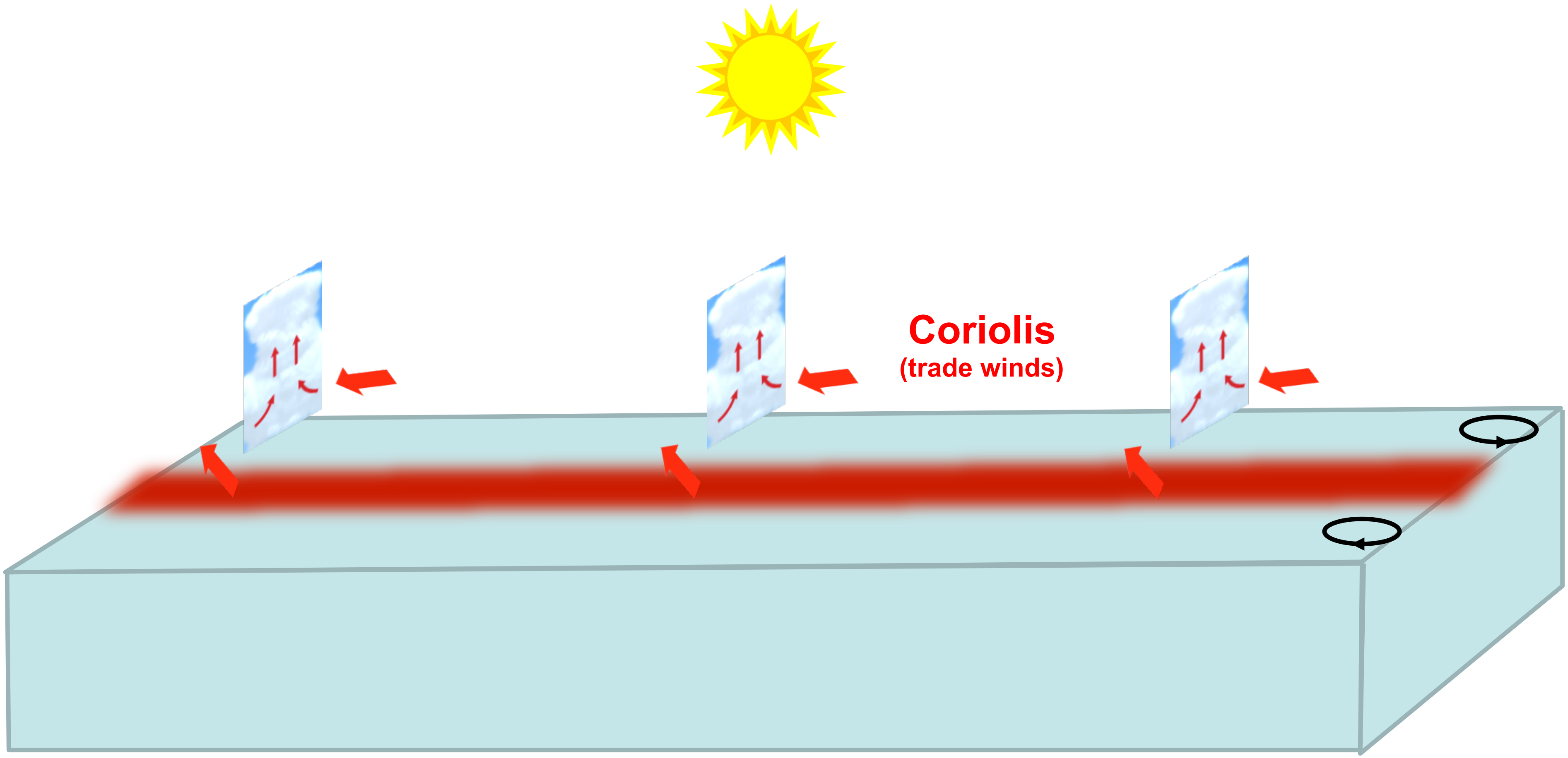


Equatorial atmosphere/ocean

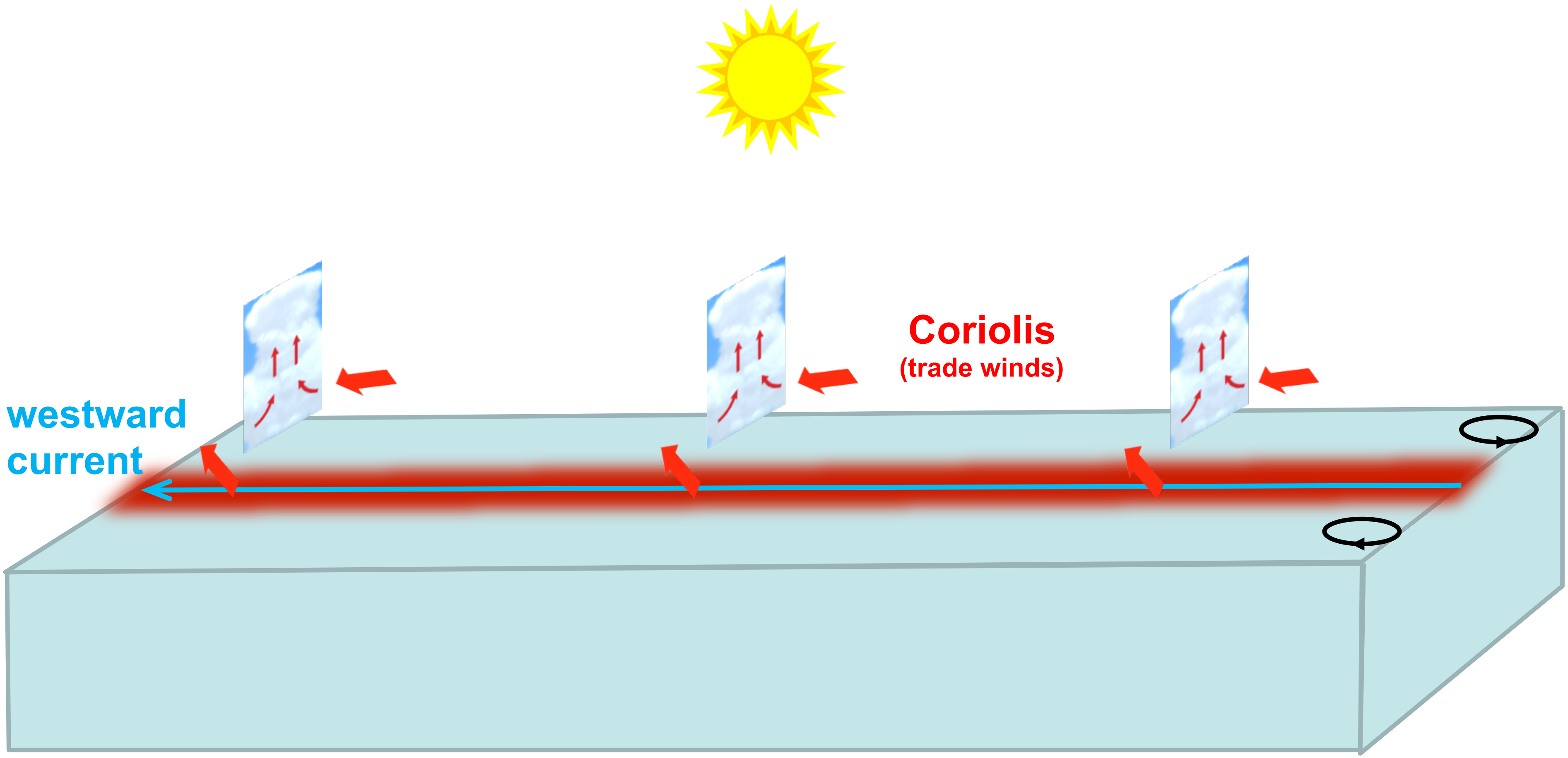




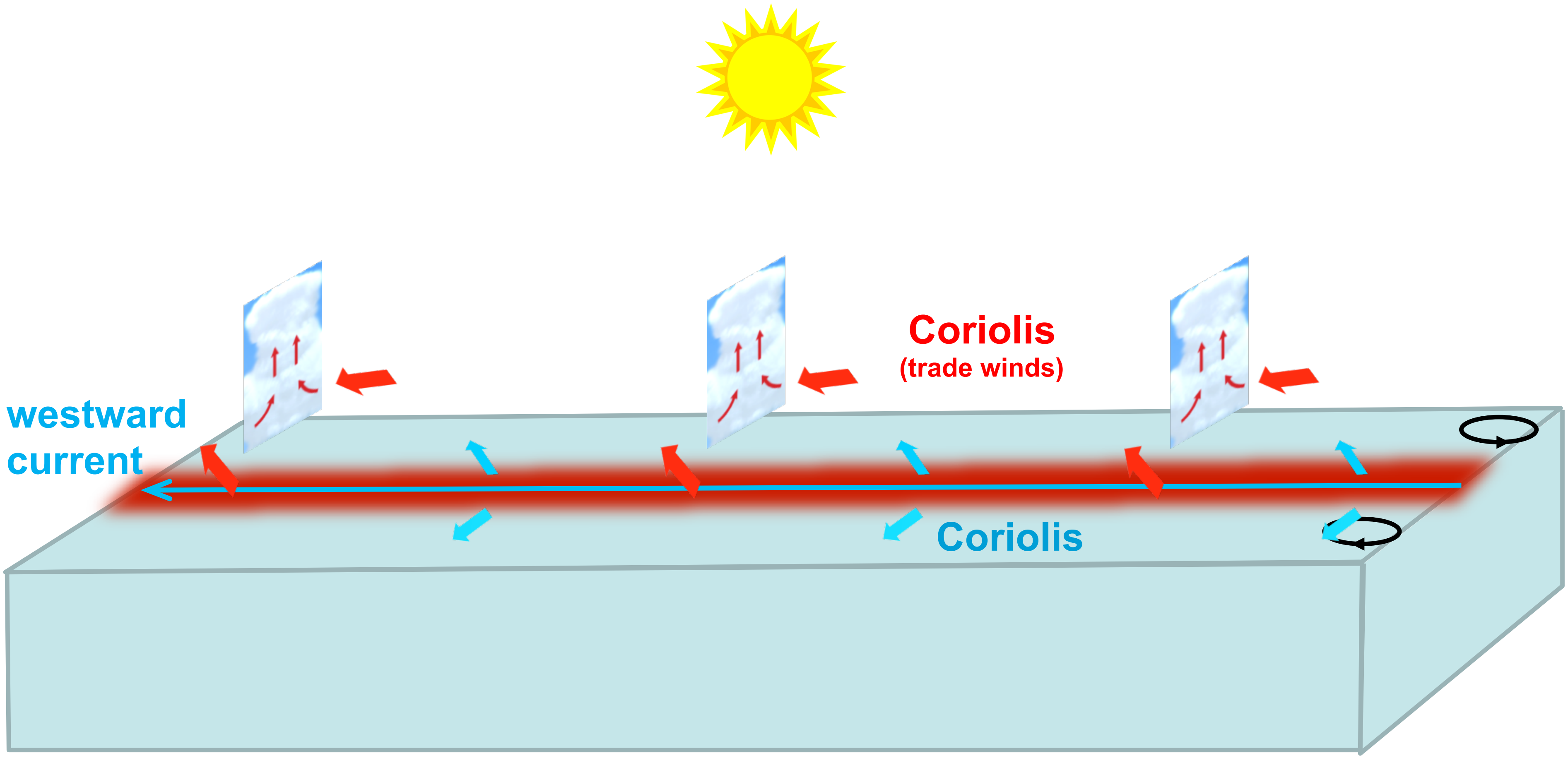
Equatorial atmosphere/ocean



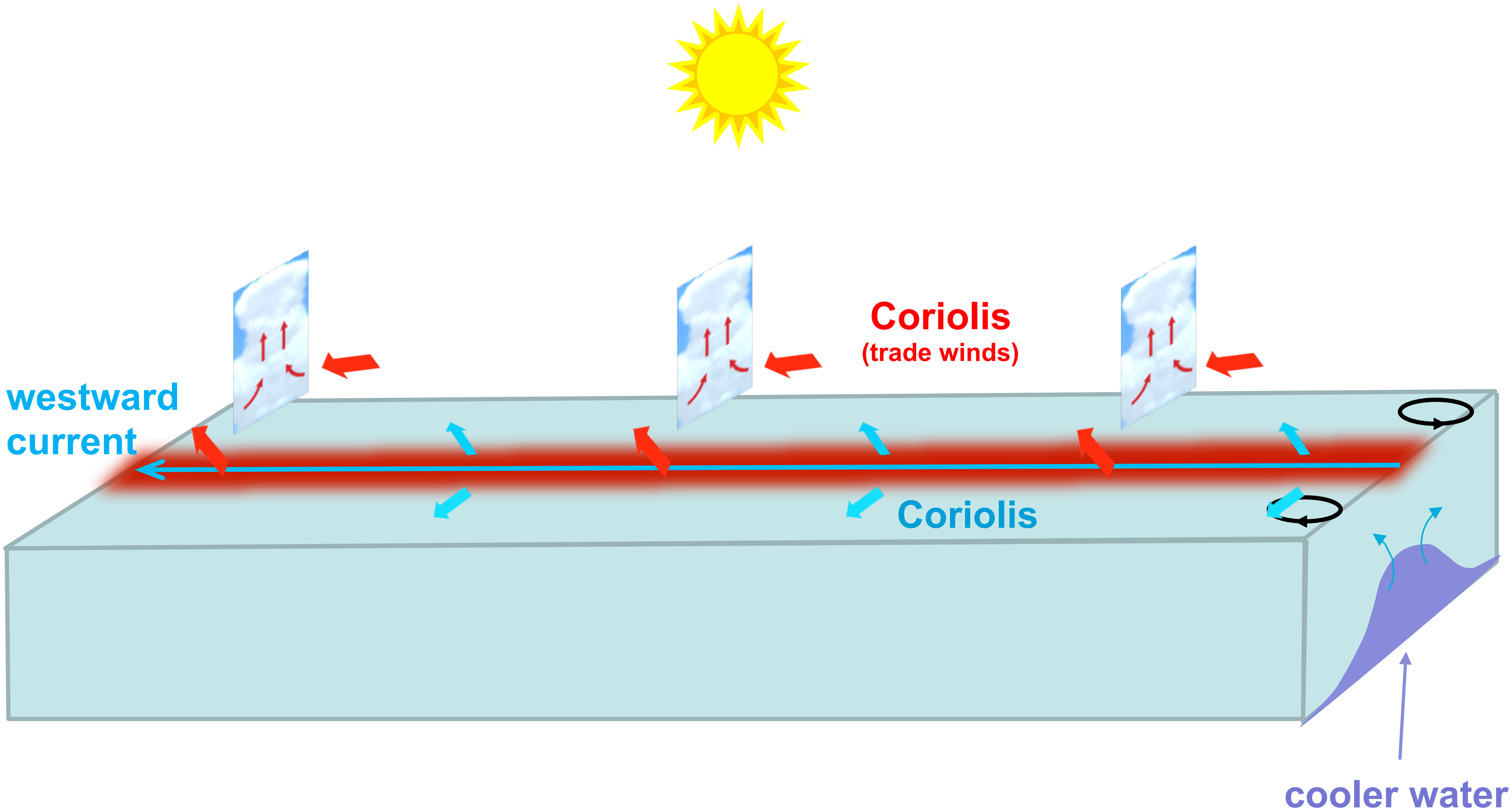
Equatorial atmosphere/ocean



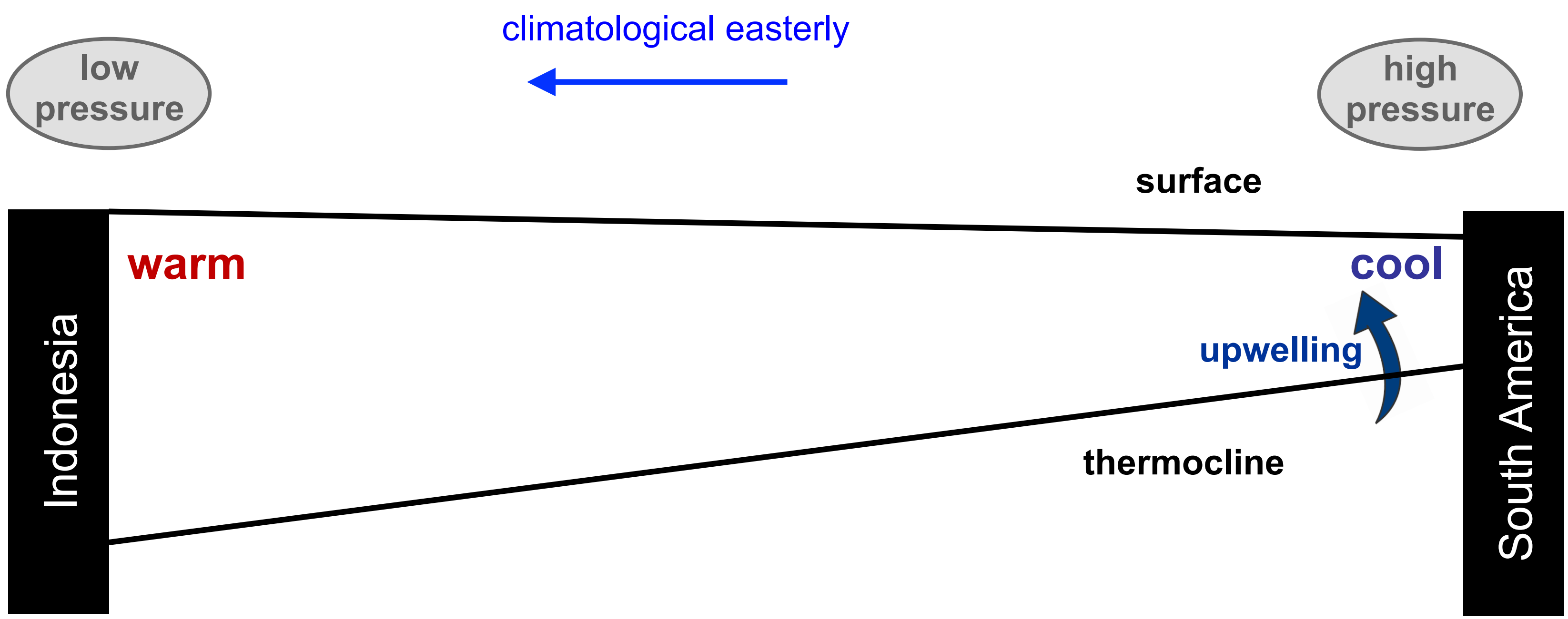
Equatorial atmosphere/ocean



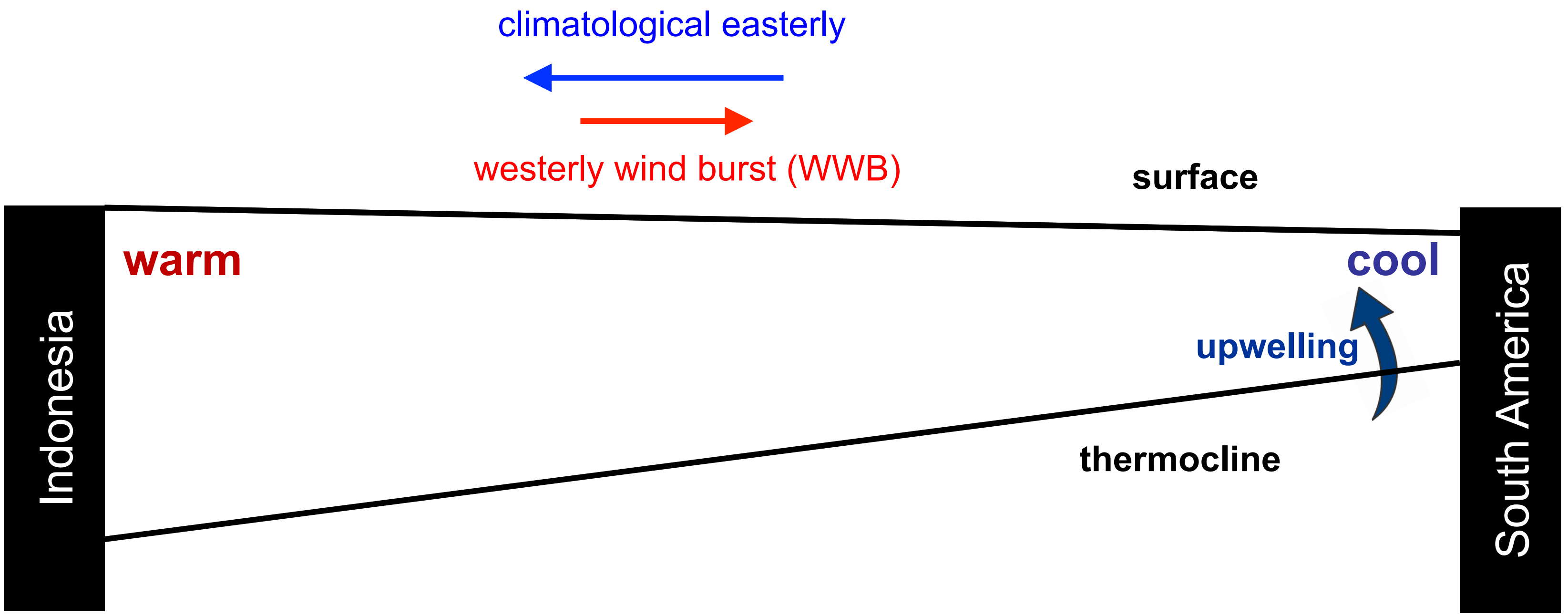
Equatorial atmosphere/ocean



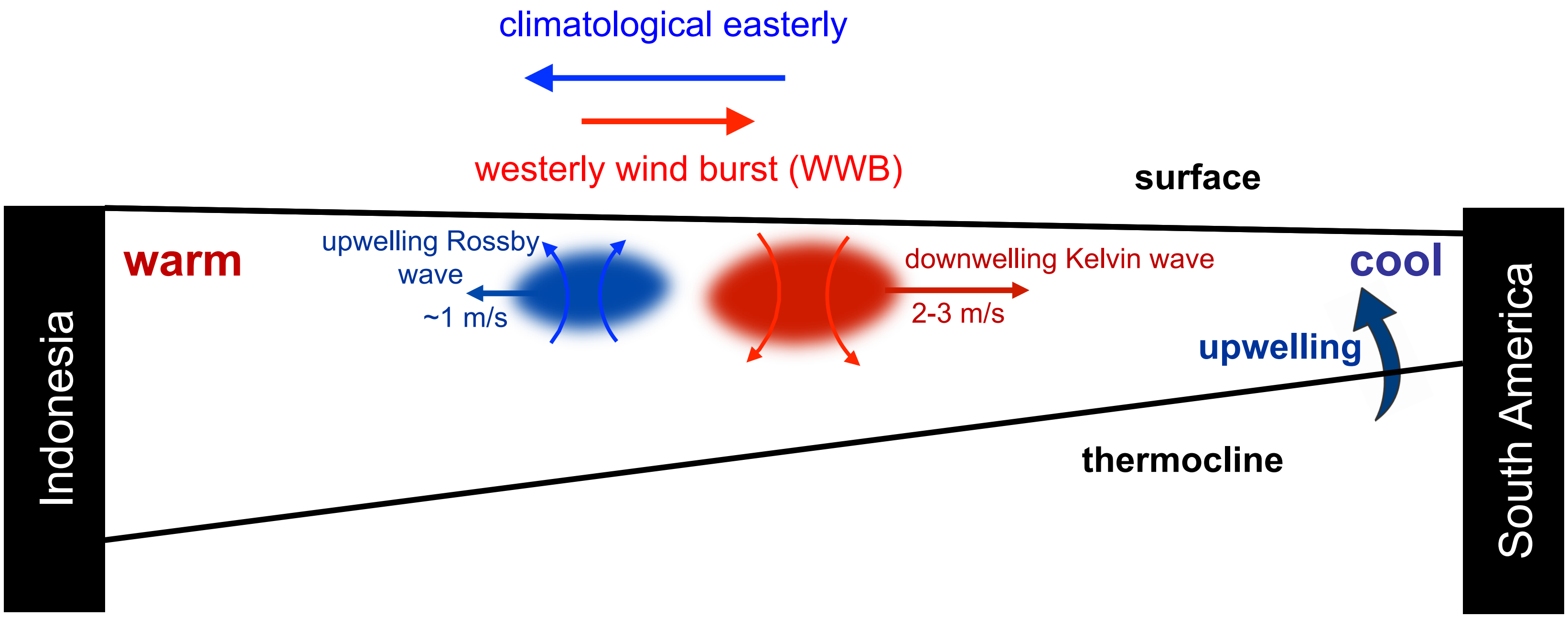
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



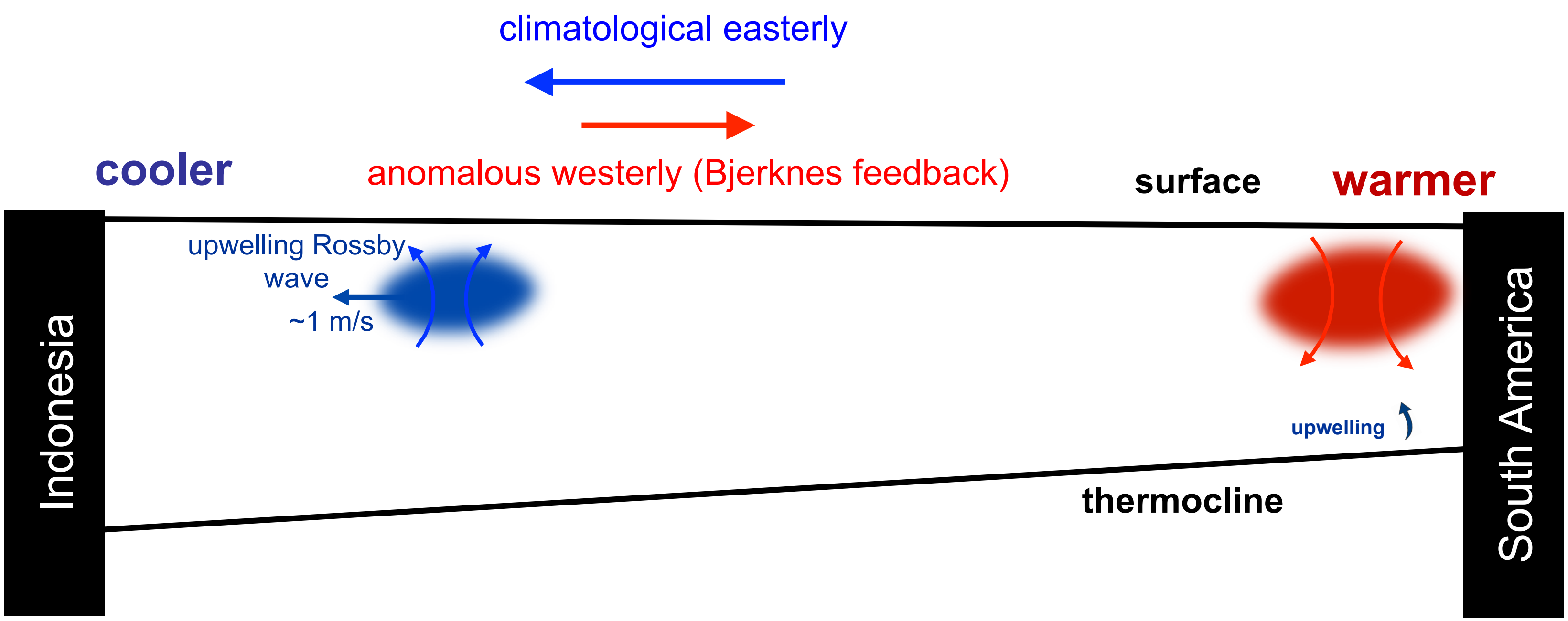
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



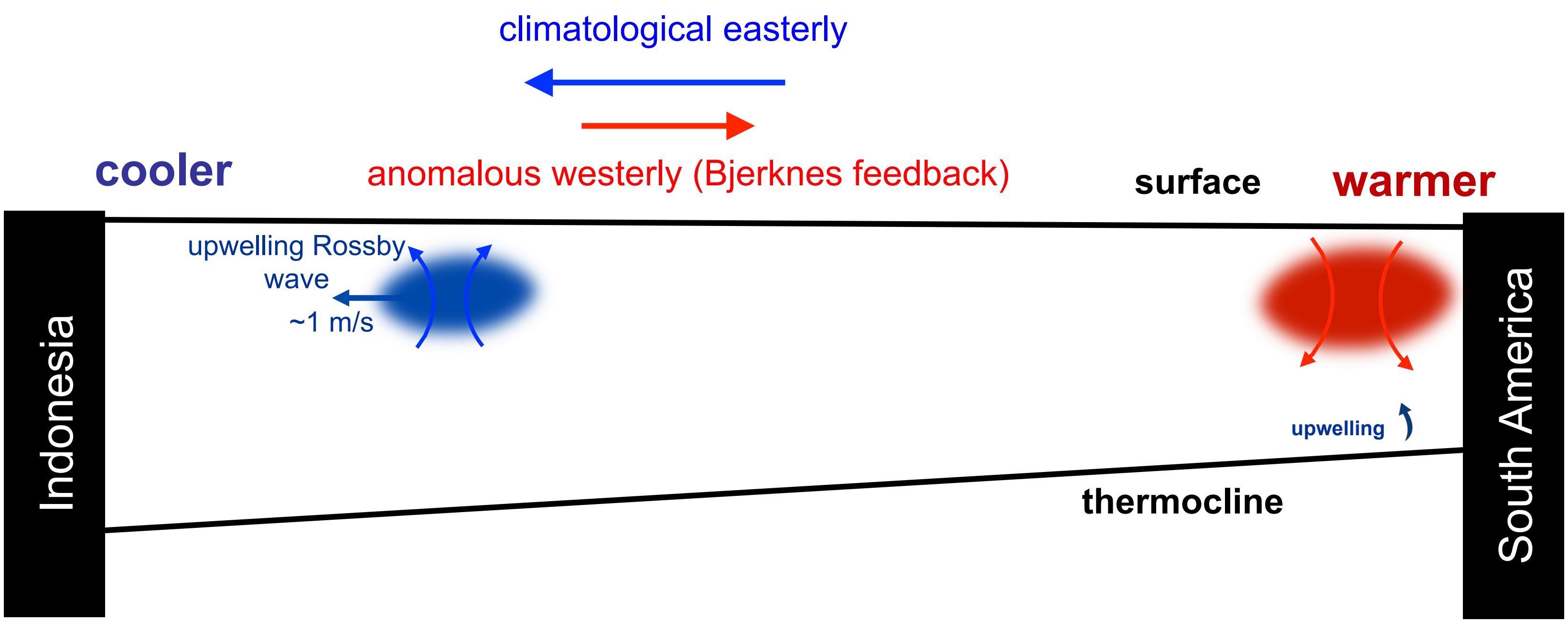
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



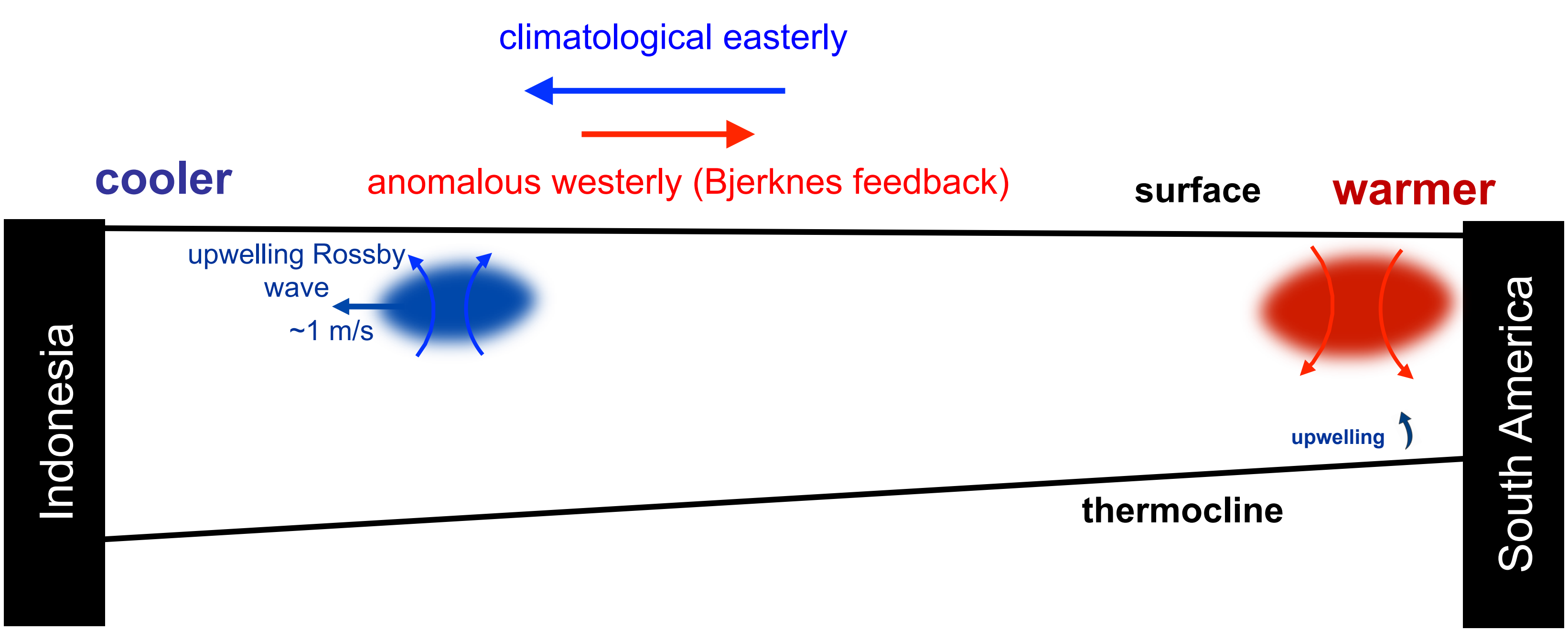
2-3 months later



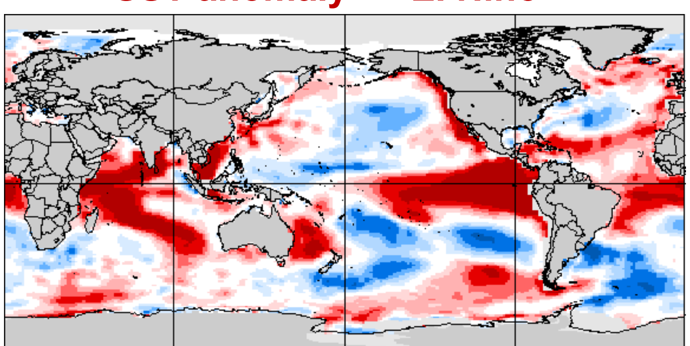
2-3 months later



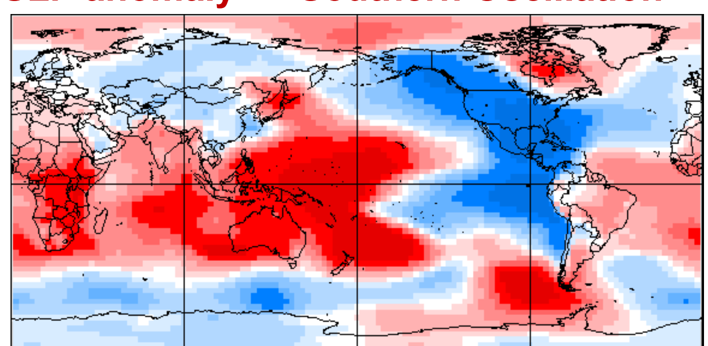
2-3 months later



SST anomaly - "El Niño"



SLP anomaly - "Southern Oscillation"

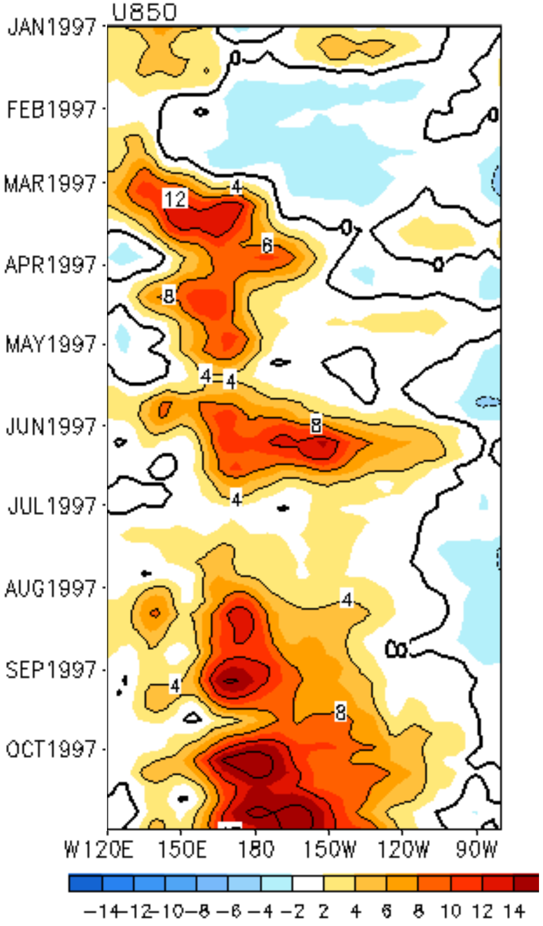


El Niño Southern Oscillation (ENSO)

Example: 1997

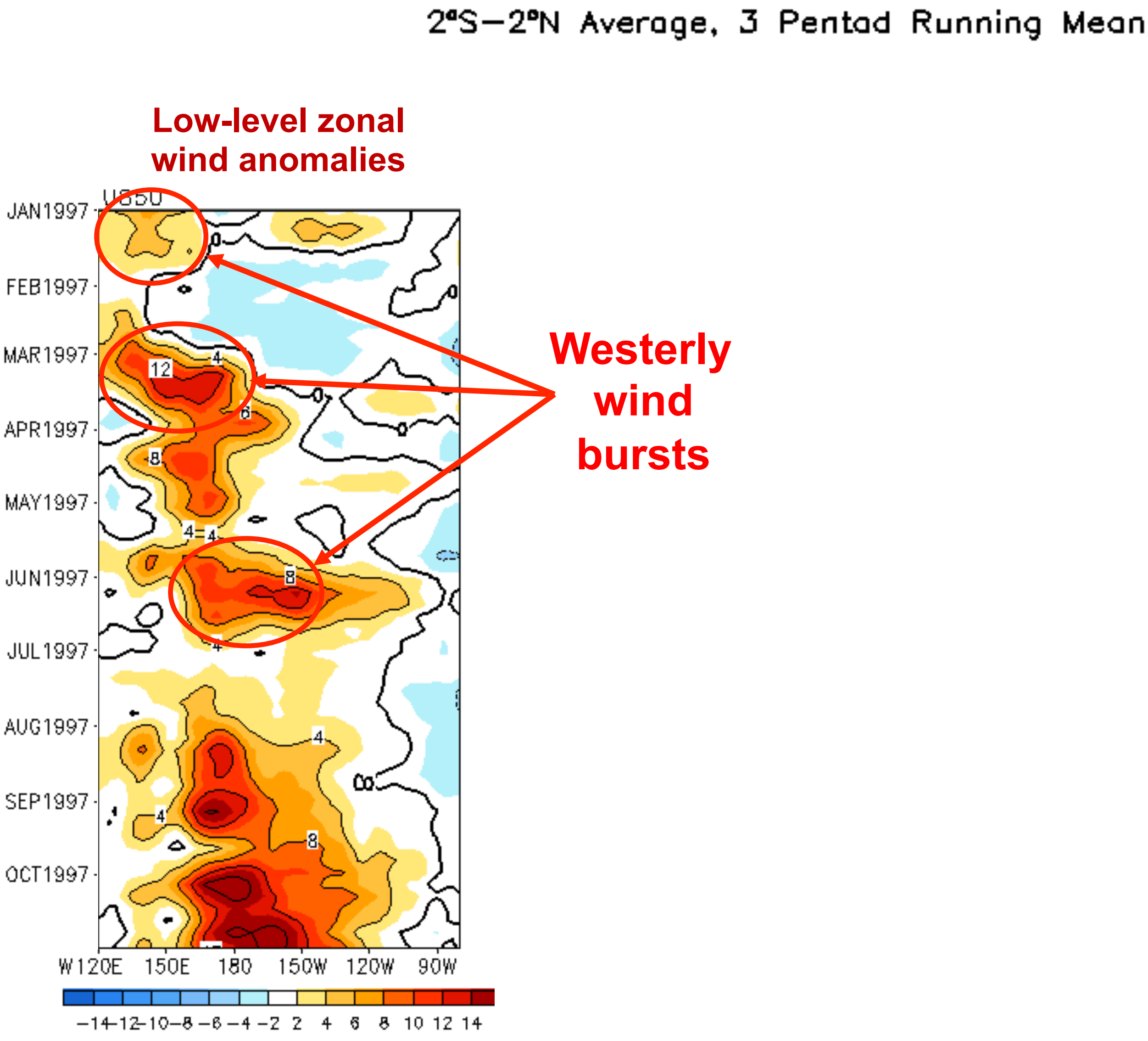
2°S–2°N Average, 3 Pentad Running Mean

Low-level zonal wind anomalies



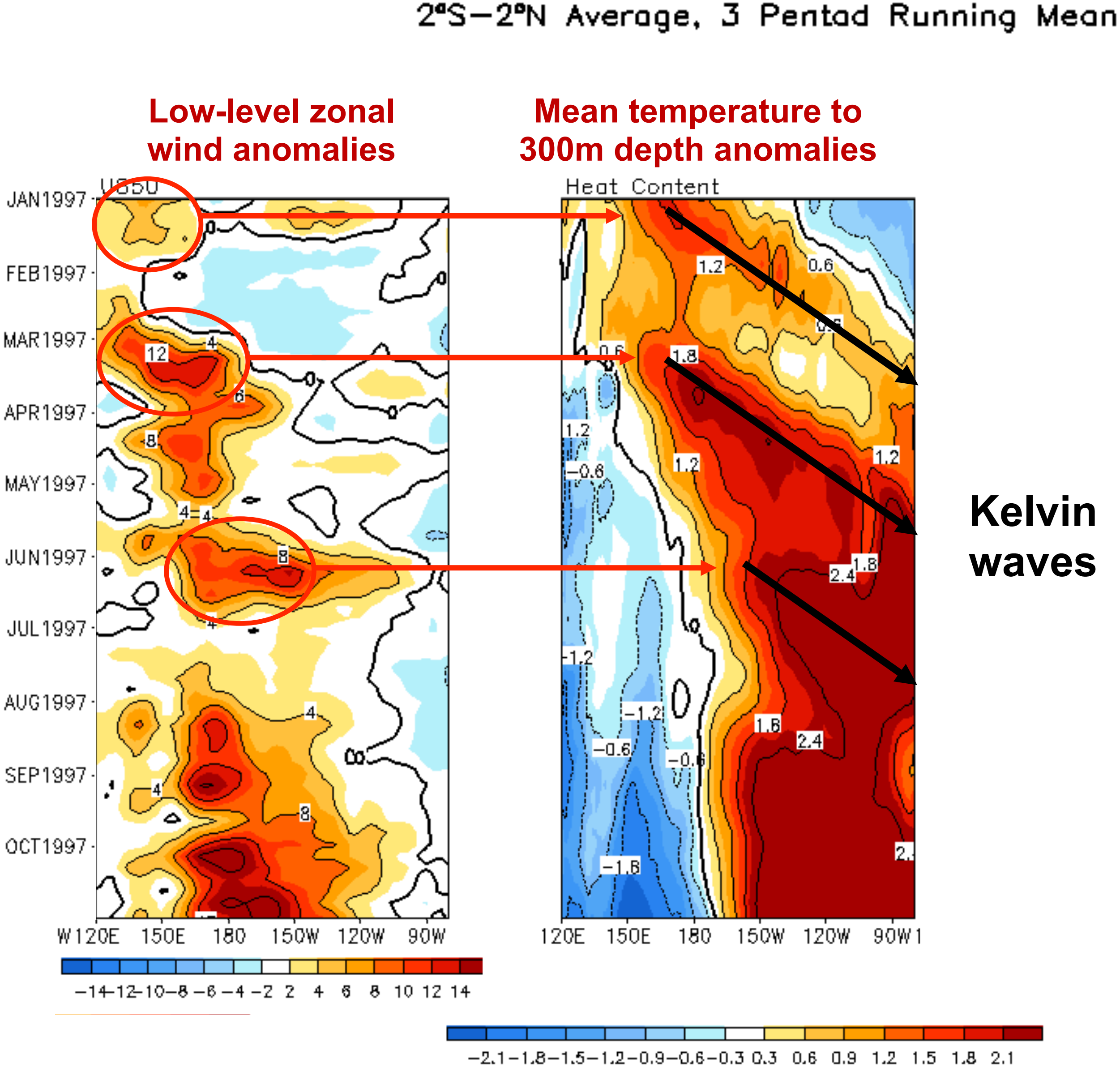
NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997



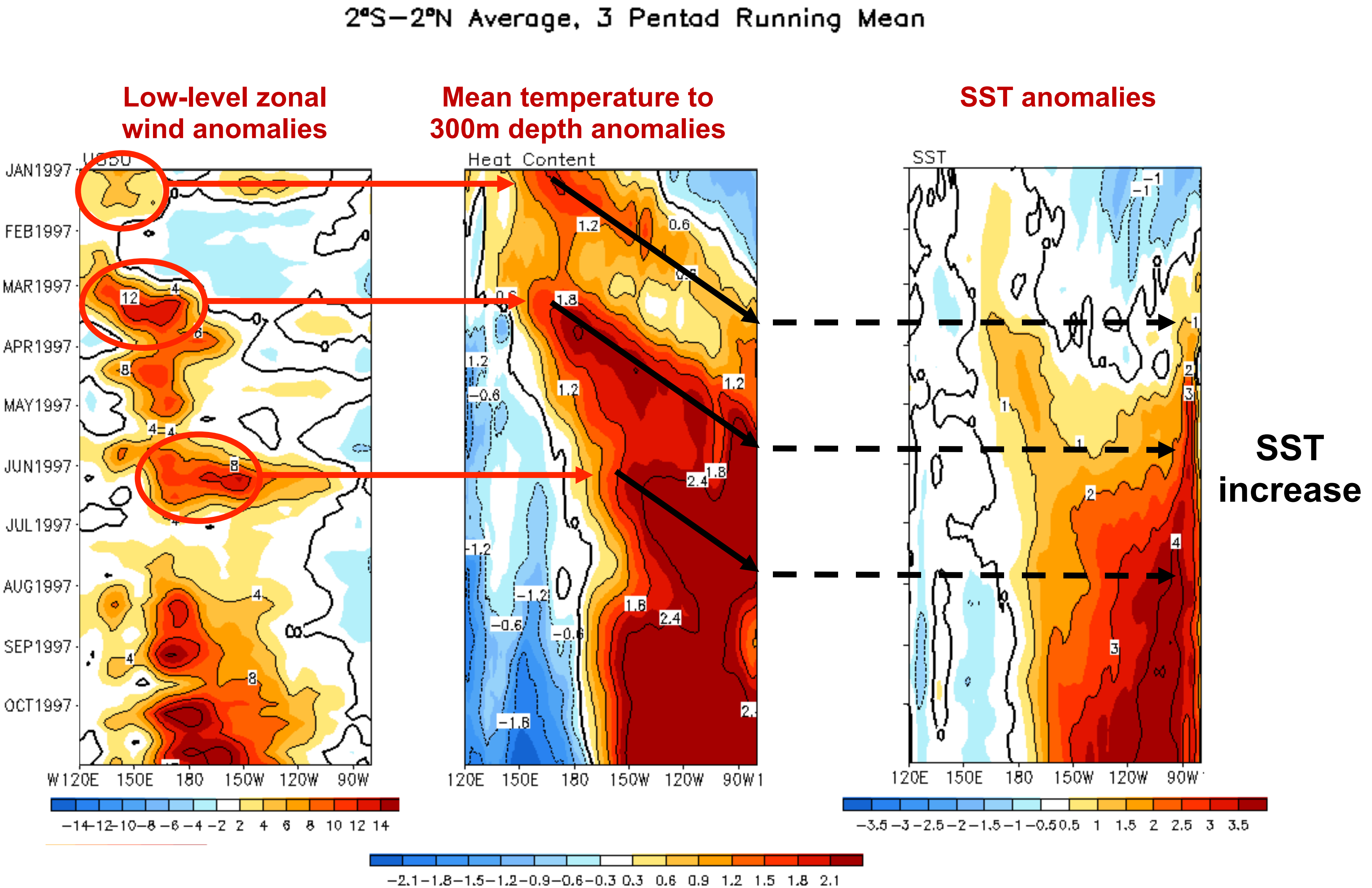
NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997



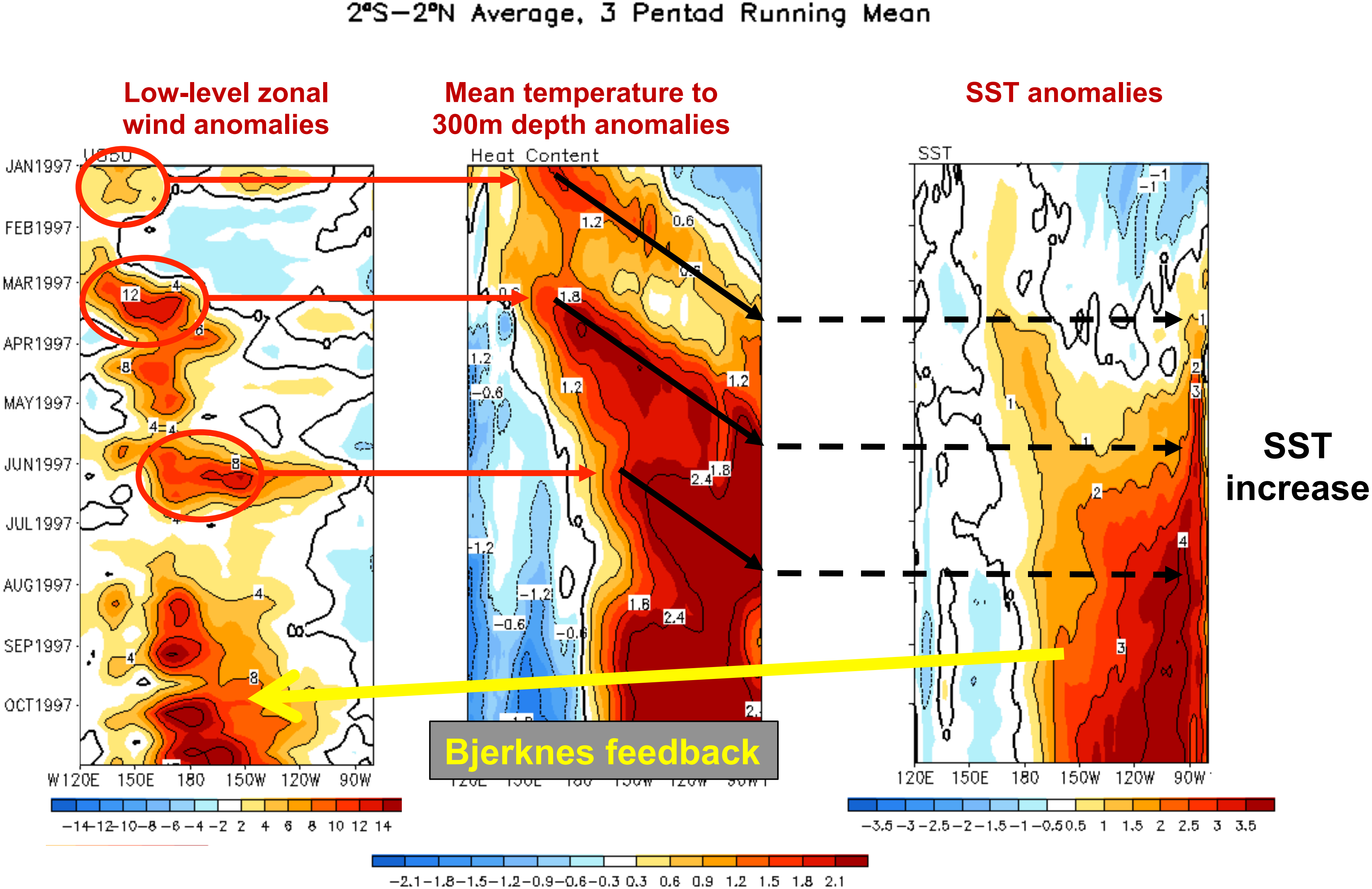
NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997



NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997



NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/