Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

Seasonal Prediction: An Introduction

Bill Merryfield

Canadian Centre for Climate Modelling and Analysis (CCCma)

CITES-2019 International Young Scientists School, 27 May 2019

Topics covered

- Basis for seasonal forecasting
- How seasonal forecasts are produced
- Deterministic vs probabilistic forecasts
- Forecast skill
- ENSO
- Multi-model ensembles

Basis for seasonal forecasting

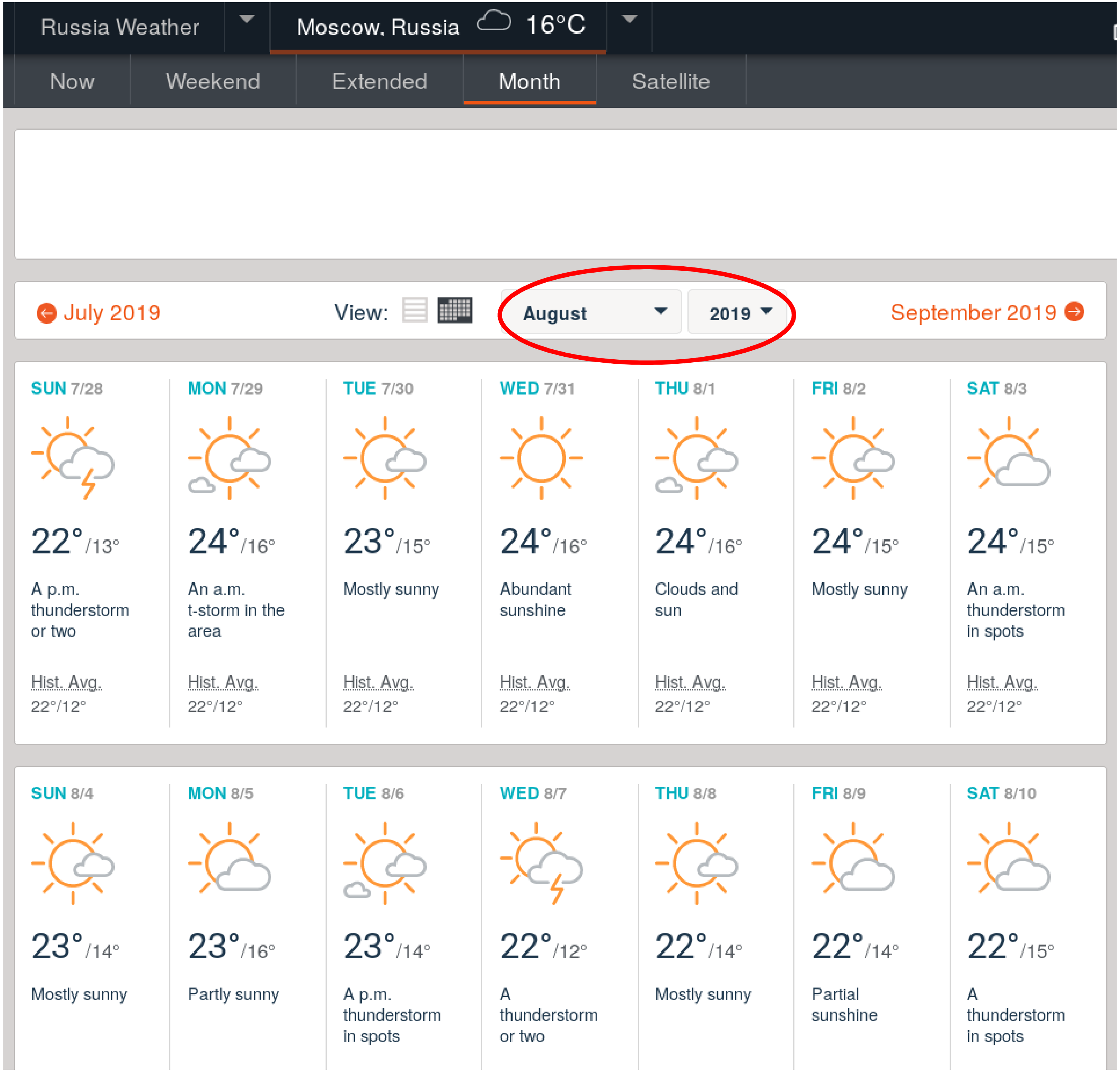
Russia Weather | Moscow, Russia 16°C

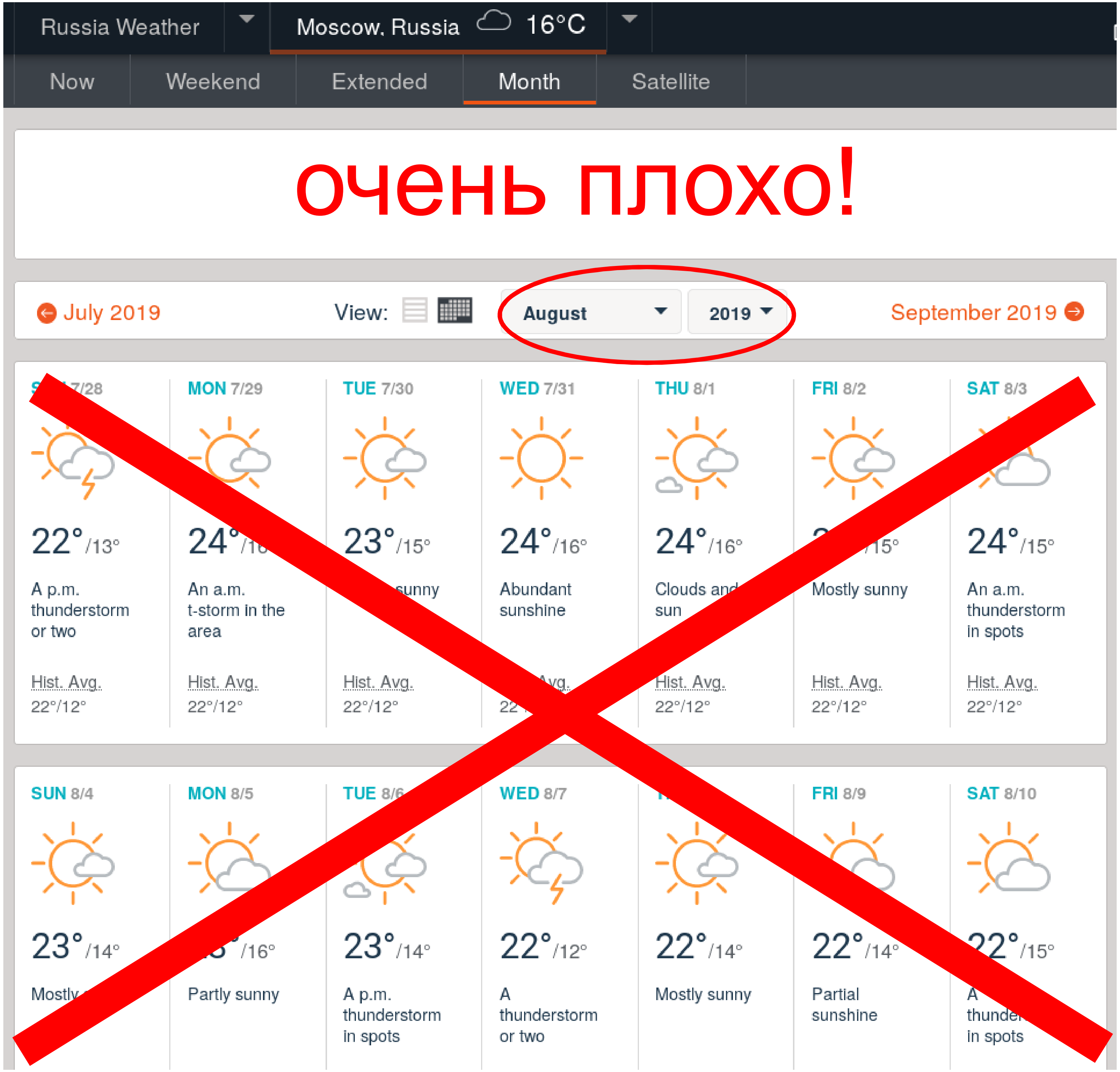
Now | Weekend | Extended | Month | Satellite

July 2019 View: August 2019 September 2019

SUN 7/28	MON 7/29	TUE 7/30	WED 7/31	THU 8/1	FRI 8/2	SAT 8/3
22°/13°	24°/16°	23°/15°	24°/16°	24°/16°	24°/15°	24°/15°
A p.m. thunderstorm or two	An a.m. t-storm in the area	Mostly sunny	Abundant sunshine	Clouds and sun	Mostly sunny	An a.m. thunderstorm in spots
Hist. Avg. 22°/12°	Hist. Avg. 22°/12°	Hist. Avg. 22°/12°	Hist. Avg. 22°/12°	Hist. Avg. 22°/12°	Hist. Avg. 22°/12°	Hist. Avg. 22°/12°

SUN 8/4	MON 8/5	TUE 8/6	WED 8/7	THU 8/8	FRI 8/9	SAT 8/10
23°/14°	23°/16°	23°/14°	22°/12°	22°/14°	22°/14°	22°/15°
Mostly sunny	Partly sunny	A p.m. thunderstorm in spots	A thunderstorm or two	Mostly sunny	Partial sunshine	A thunderstorm in spots

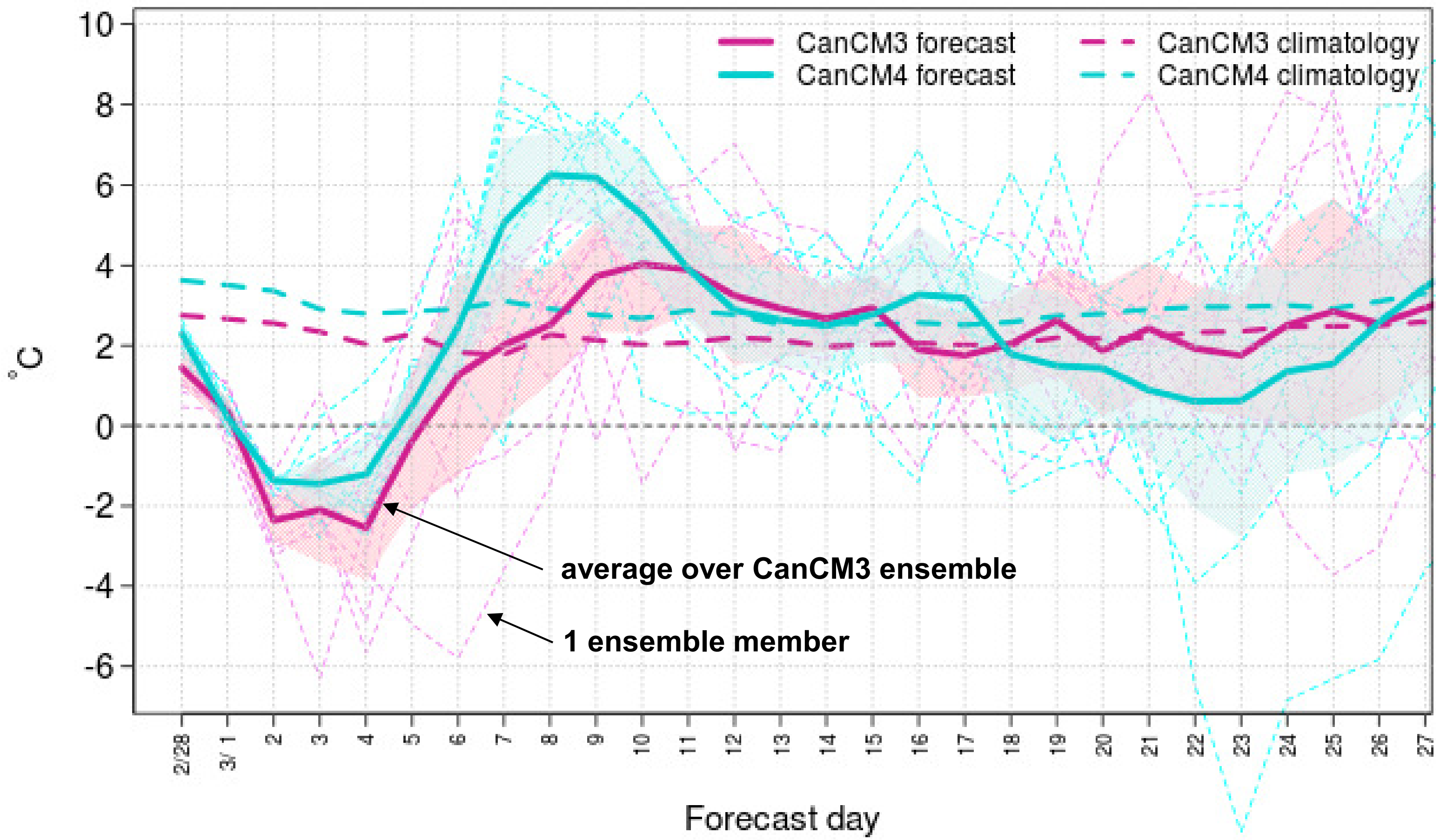

Russia Weather
Moscow, Russia 16°C
Now
Weekend
Extended
Month
Satellite
July 2019
View:
August
2019
September 2019
SUN 7/28
22° /13°
A p.m. thunderstorm or two
Hist. Avg. 22°/12°
MON 7/29
24° /16°
An a.m. t-storm in the area
Hist. Avg. 22°/12°
TUE 7/30
23° /15°
Mostly sunny
Hist. Avg. 22°/12°
WED 7/31
24° /16°
Abundant sunshine
Hist. Avg. 22°/12°
THU 8/1
24° /16°
Clouds and sun
Hist. Avg. 22°/12°
FRI 8/2
24° /15°
Mostly sunny
Hist. Avg. 22°/12°
SAT 8/3
24° /15°
An a.m. thunderstorm in spots
Hist. Avg. 22°/12°
SUN 8/4
23° /14°
Mostly sunny
MON 8/5
23° /16°
Partly sunny
TUE 8/6
23° /14°
A p.m. thunderstorm in spots
WED 8/7
22° /12°
A thunderstorm or two
THU 8/8
22° /14°
Mostly sunny
FRI 8/9
22° /14°
Partial sunshine
SAT 8/10
22° /15°
A thunderstorm in spots


очень плохо!
Russia Weather
Moscow, Russia 16°C
Now
Weekend
Extended
Month
Satellite
July 2019
View:
August
2019
September 2019
MON 7/29
TUE 7/30
WED 7/31
THU 8/1
FRI 8/2
SAT 8/3
22° /13°
A p.m. thunderstorm or two
An a.m. t-storm in the area
23° /15°
24° /16°
Abundant sunshine
24° /16°
Clouds and sun
Mostly sunny
24° /15°
An a.m. thunderstorm in spots
Hist. Avg. 22°/12°
SUN 8/4
MON 8/5
TUE 8/6
WED 8/7
FRI 8/9
SAT 8/10
23° /14°
Partly sunny
23° /14°
A p.m. thunderstorm in spots
22° /12°
A thunderstorm or two
22° /14°
Mostly sunny
22° /14°
Partial sunshine
22° /15°

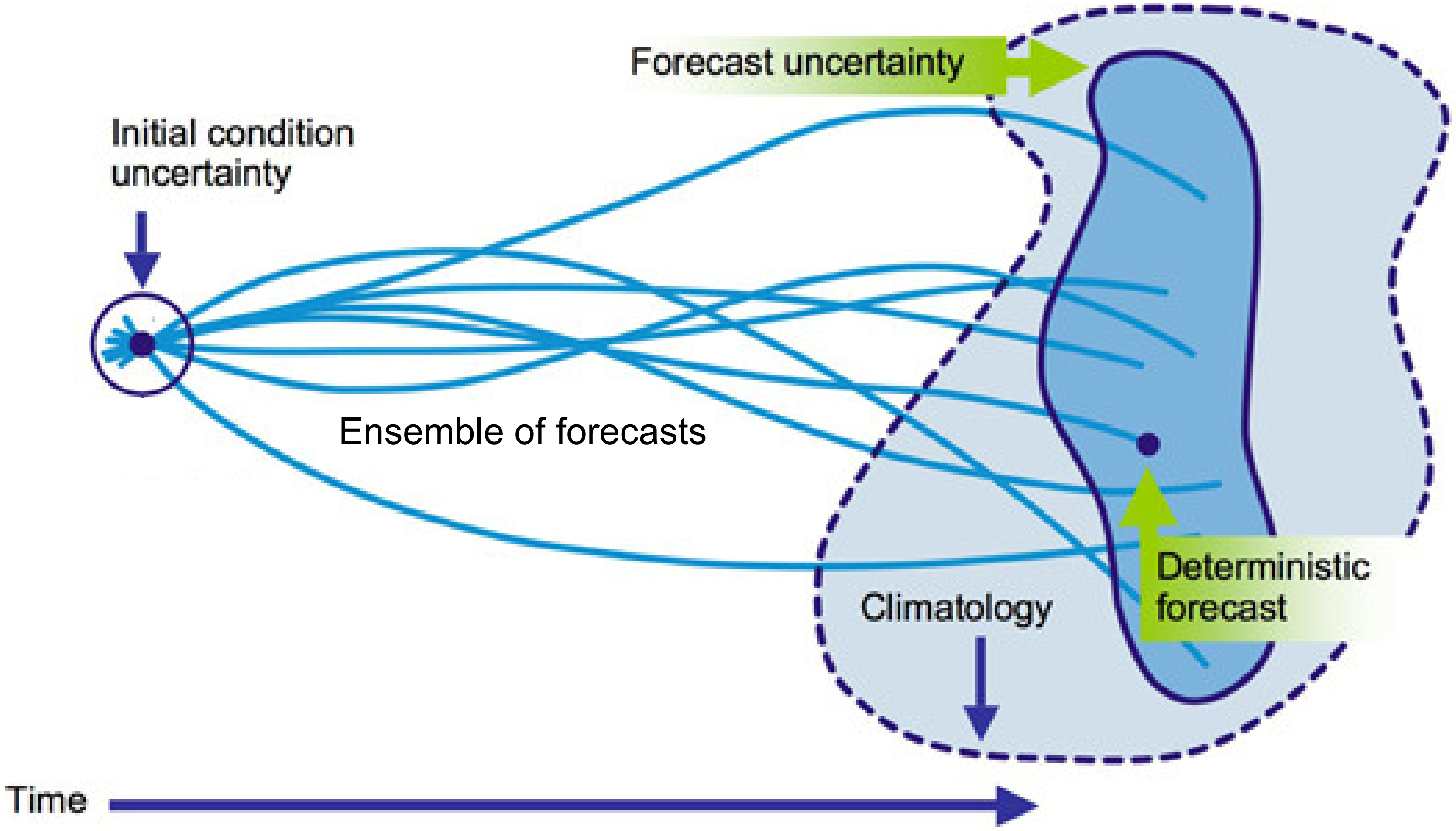
Fundamental importance of uncertainty

Daily temperature forecast for Victoria, Canada starting February 28

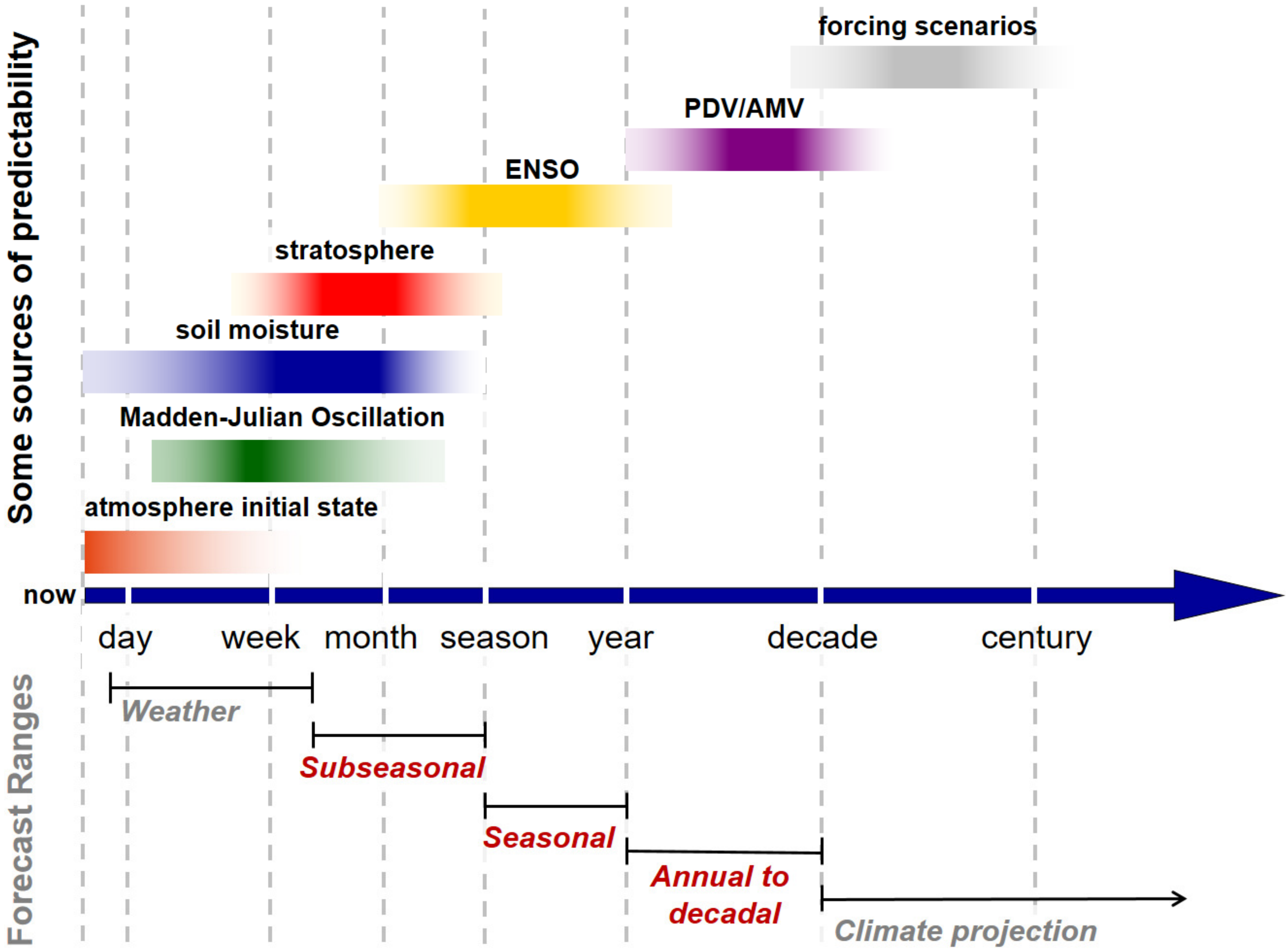
2 models, 10 forecasts from each starting from slightly different initial conditions



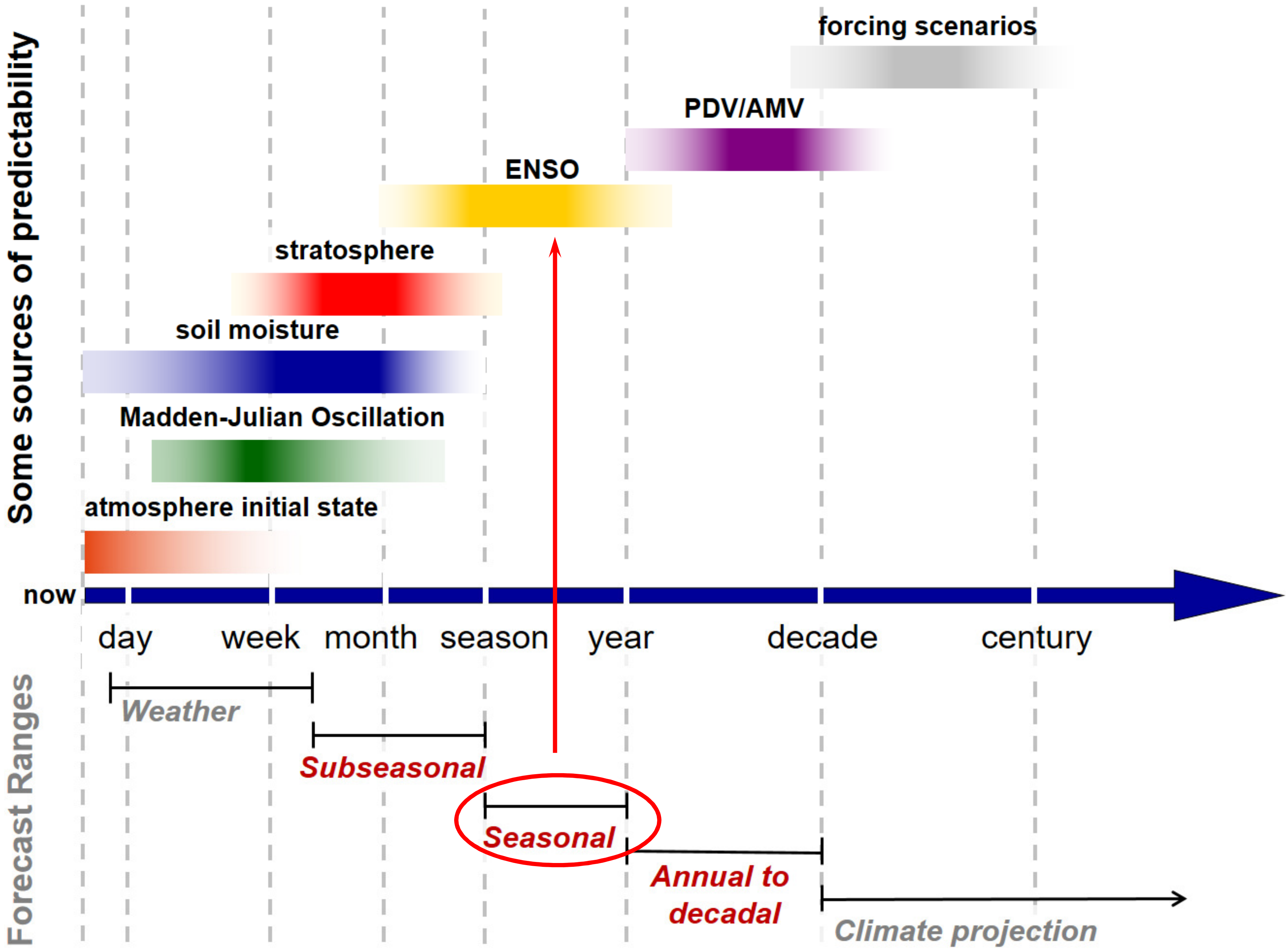
Initial condition uncertainty leads to forecast uncertainty!



When uncertainties are large, a single forecast tells us very little $\rightarrow$ need an *ensemble* of forecasts to estimate the probabilities of different outcomes



Some sources of predictability
forcing scenarios
PDV/AMV
ENSO
stratosphere
soil moisture
Madden-Julian Oscillation
atmosphere initial state
now
day
week
month
season
year
decade
century
Forecast Ranges
Weather
Subseasonal
Seasonal
Annual to decadal
Climate projection


Some sources of predictability
forcing scenarios
PDV/AMV
ENSO
stratosphere
soil moisture
Madden-Julian Oscillation
atmosphere initial state
now
day
week
month
season
year
decade
century
Forecast Ranges
Weather
Subseasonal
Seasonal
Annual to decadal
Climate projection

Necessary conditions for useful climate predictions

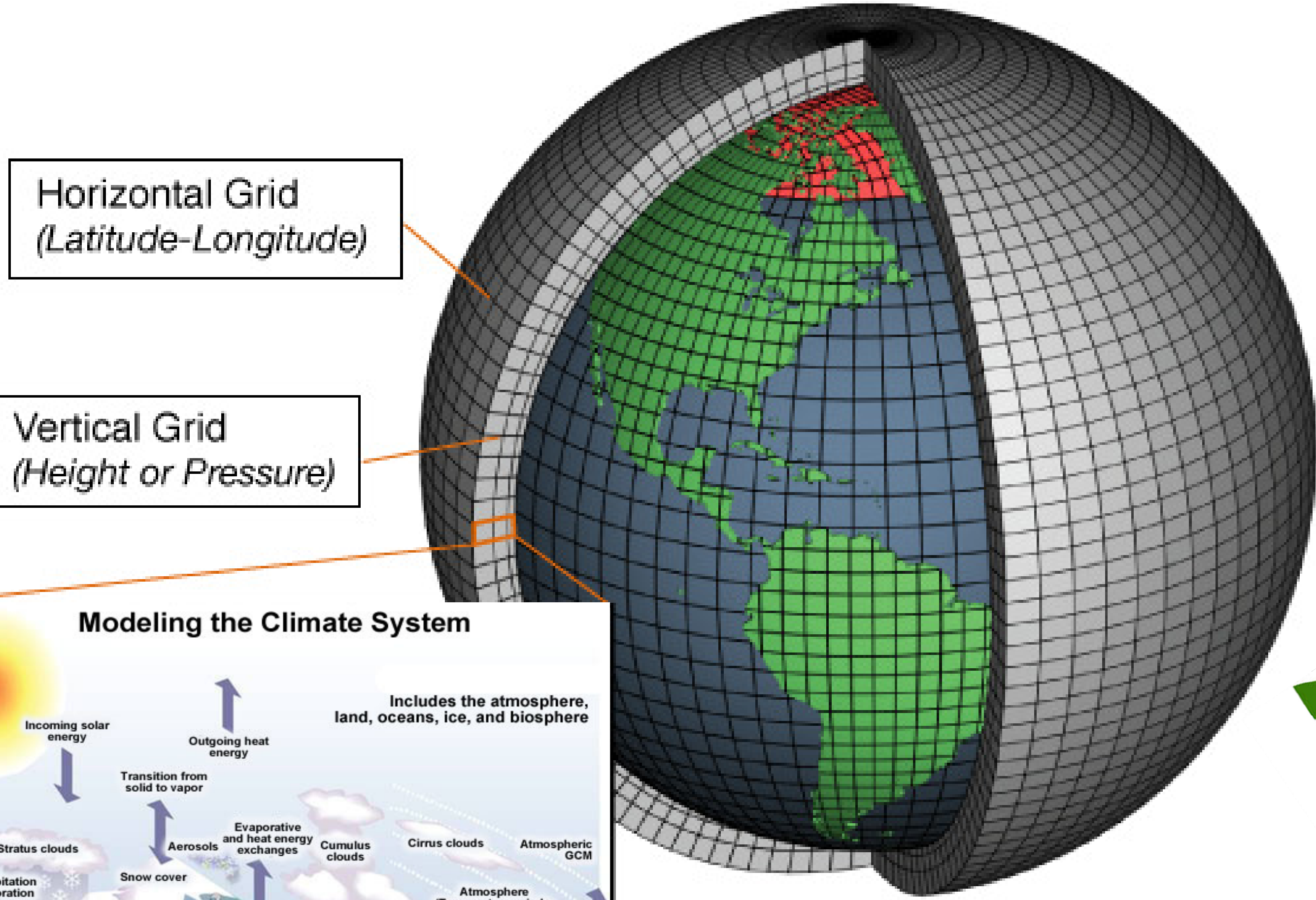
1) The phenomenon being forecast must be *predictable*

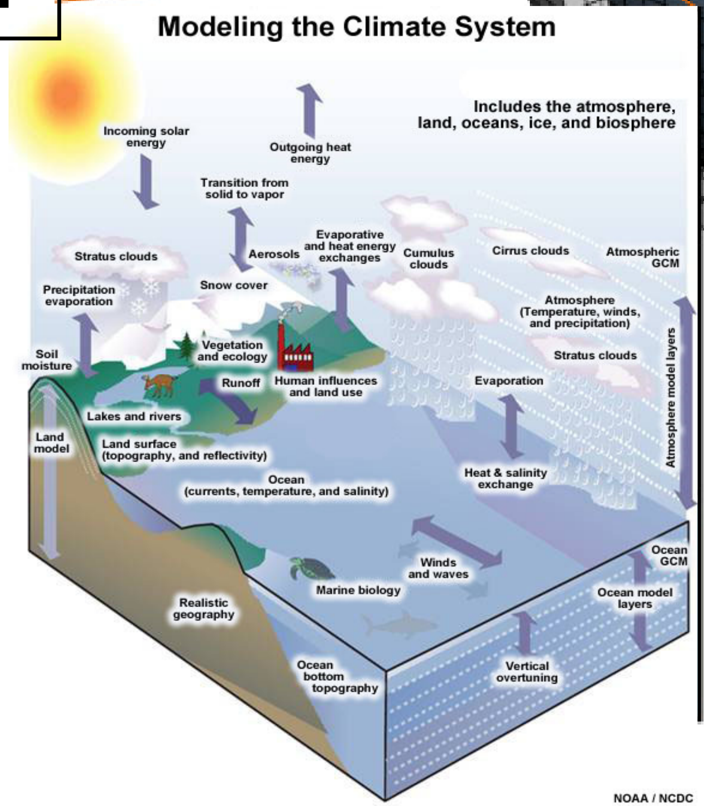
2) Prediction method must have ability to capitalize on natural predictability

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

How seasonal forecasts are produced

Computer models of the Earth's climate:
tools for assess-ment and prediction





What are seasonal forecasts?

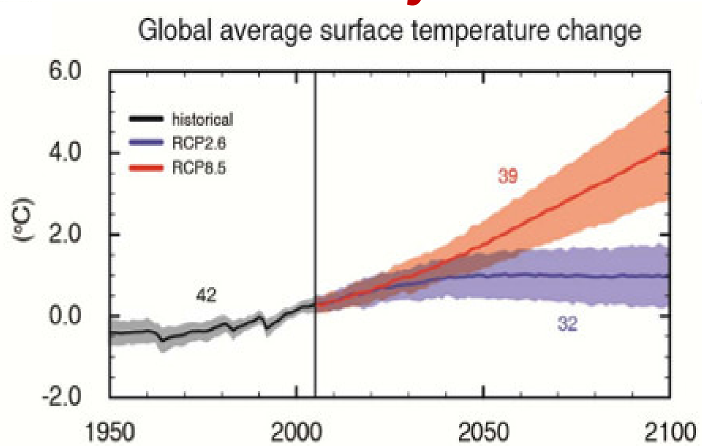
Weather forecast

1-10 days

- Weather prediction model
- Current global observations used to initialize model

Climate projection

10-100 years



- Climate model (atmosphere /ocean/land/sea ice)
- Initial conditions not critical

What are seasonal forecasts?

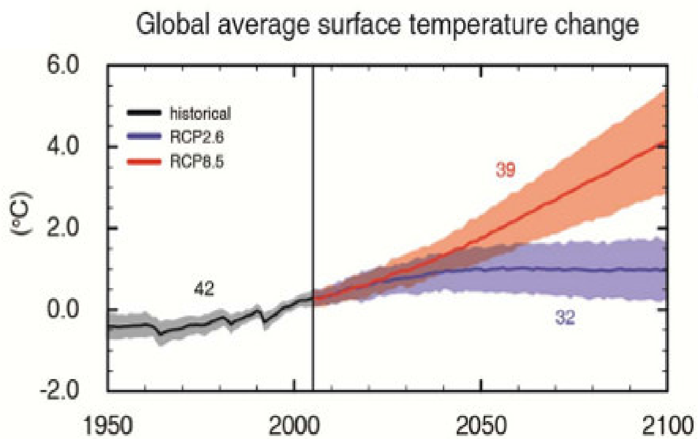
Weather forecast

1-10 days

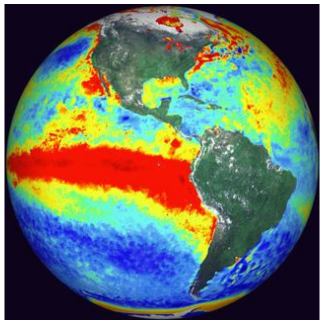
- Weather prediction model
- Current global observations used to initialize model

Climate projection

10-100 years

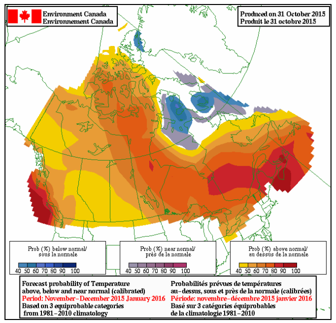


- Climate model (atmosphere /ocean/land/sea ice)
- Initial conditions not critical



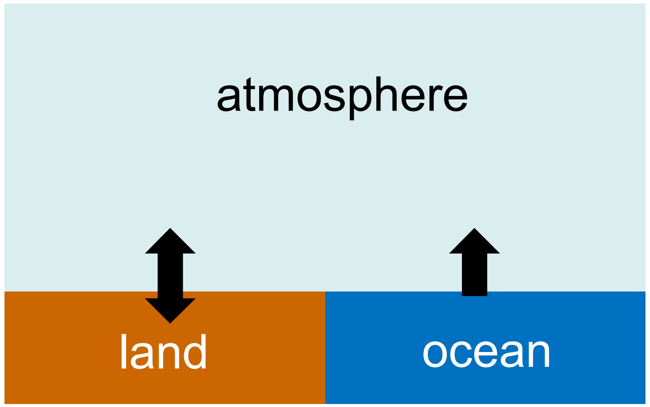
Seasonal forecast

1-12 months



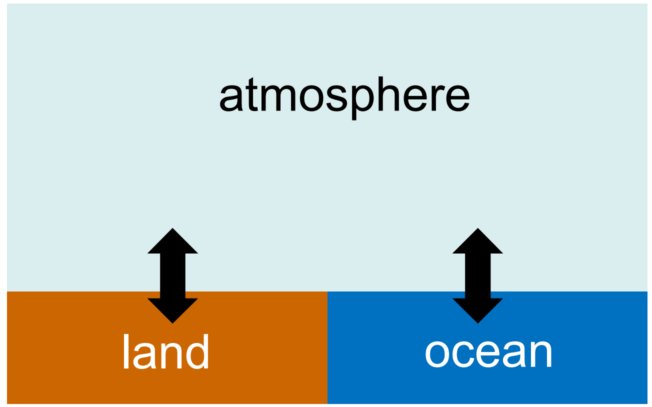
1 tier (coupled) vs 2 tier forecasts

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*

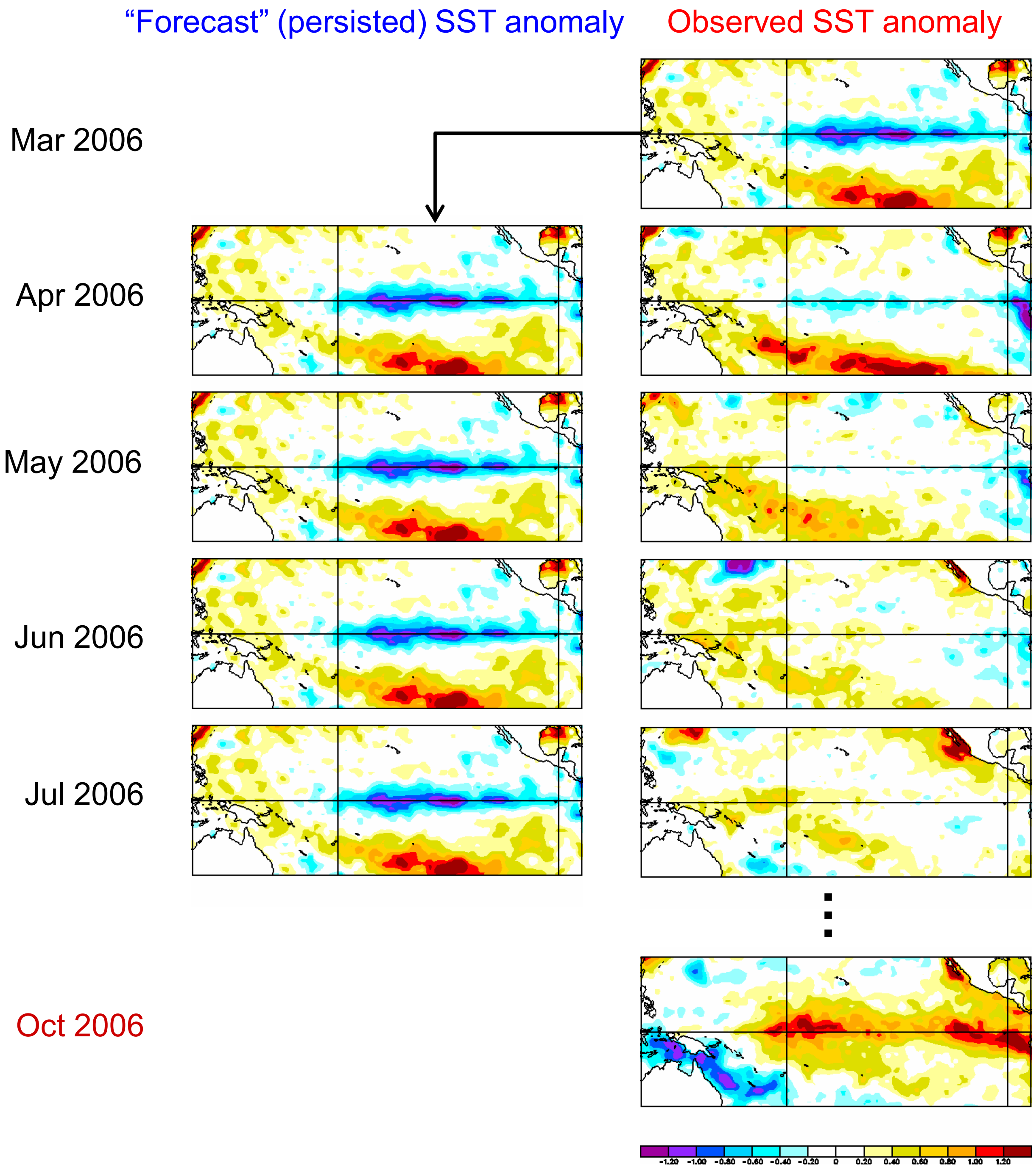
2 tier forecast



- 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

Motivation for coupled vs 2-tier system

<u>Example</u>: consider 2-tier forecast (persisted SSTA) from 1 April 2006



→ 2-tier system with persisted SSTA *<u>cannot predict an El Niño or La Niña</u>*

Steps for producing seasonal forecasts

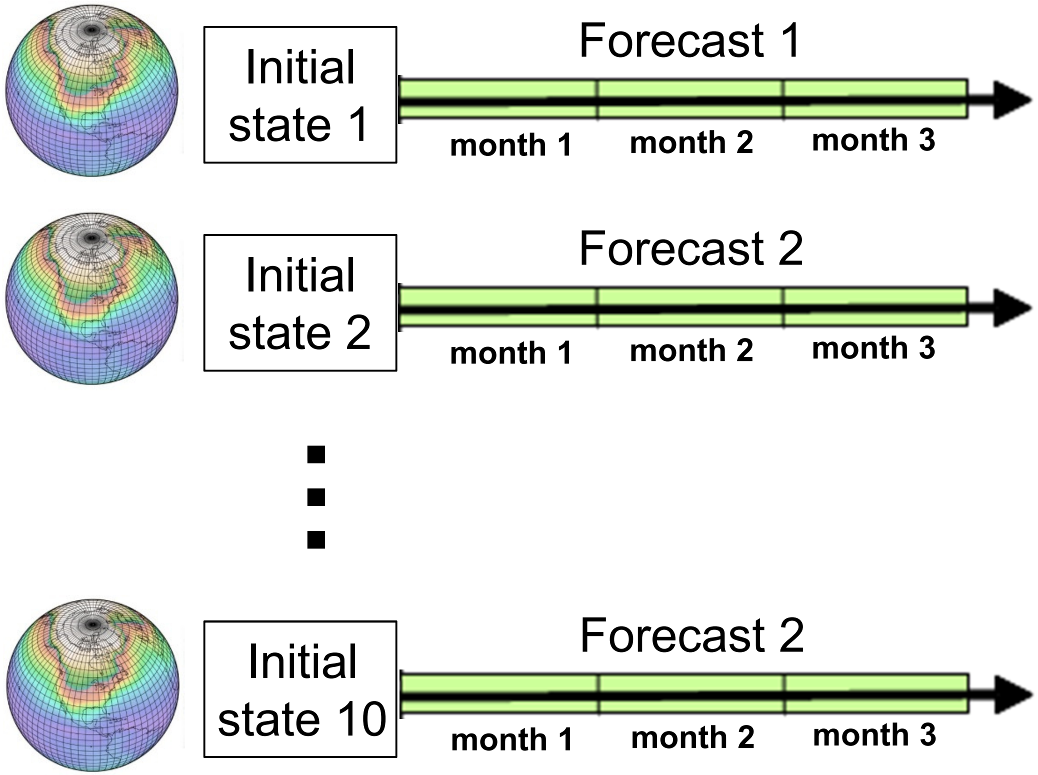
- Run **ensemble** of forecasts from slightly different initial conditions

- Correct for biases in forecasts using hindcasts → anomalies

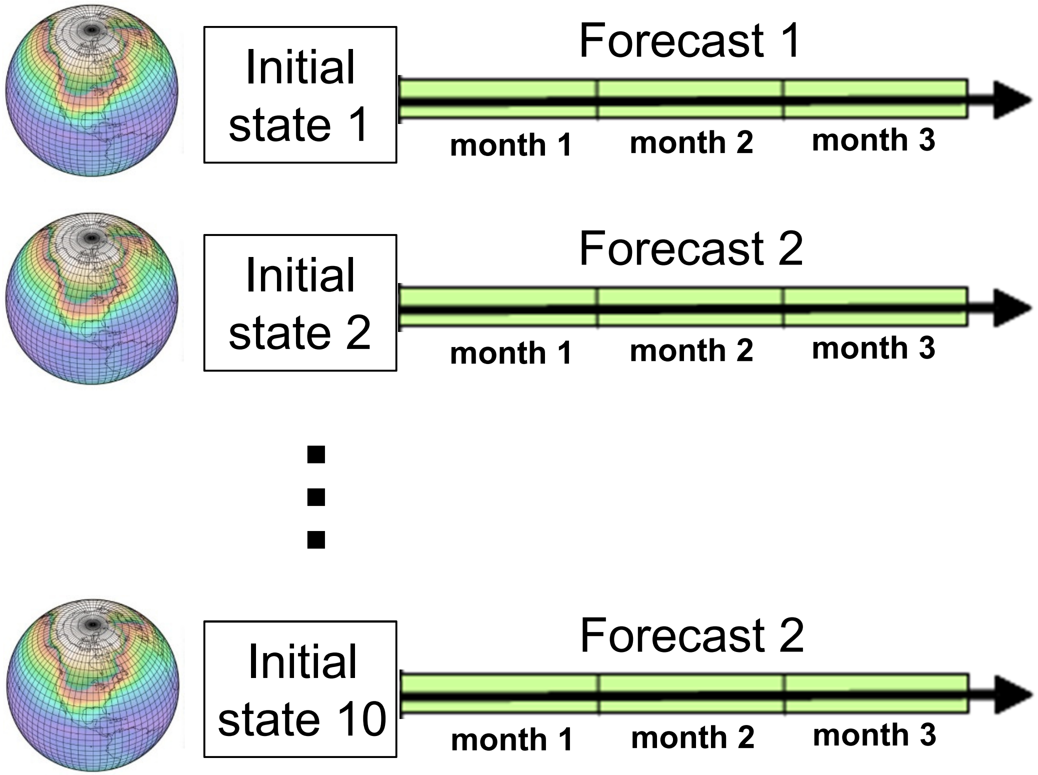
- Process information into deterministic or probabilistic forecast

- Include skill evaluation with forecast

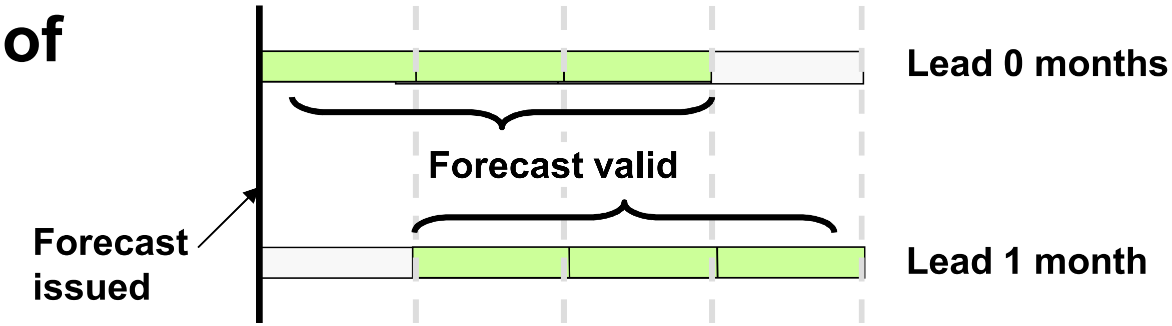
Ensemble forecast



Ensemble forecast

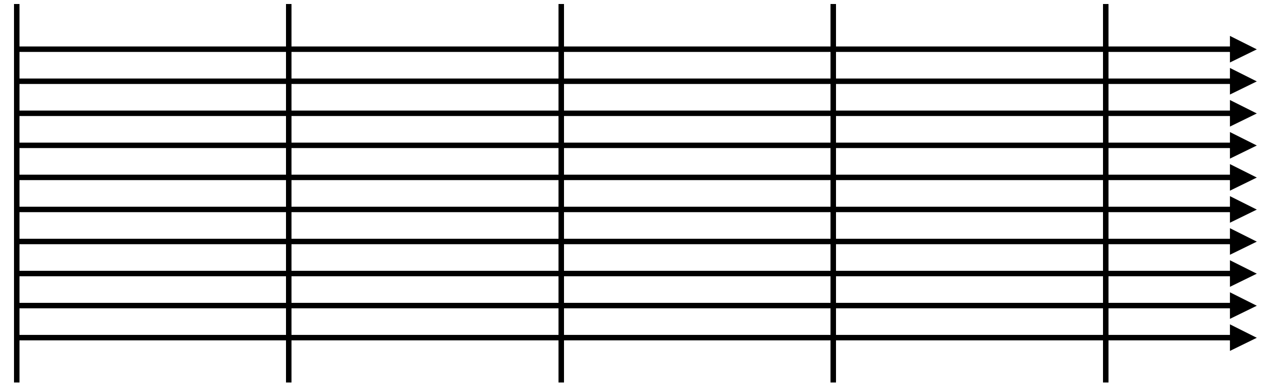


Definition of lead time



Burst vs lagged initialization

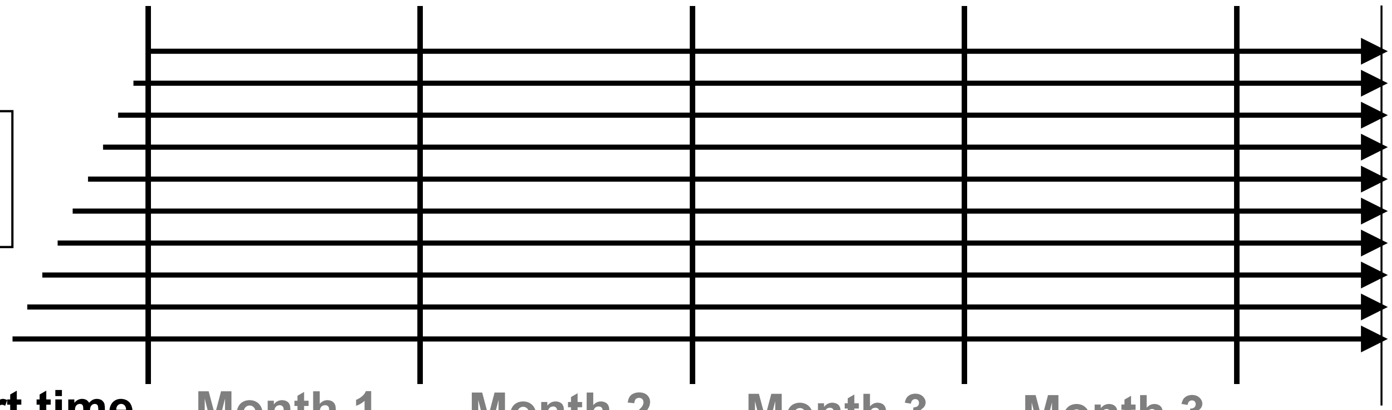
Burst initialization



Advantages of burst initialization

- Shortest lead time, statistically homogeneous sample
- Anomalies, hindcast climatologies etc. easy to compute

Lagged initialization



Advantages of lagged initialization

- Computational load spread out in time → can have more ensemble members, more expensive model

Purposes of hindcasts

Hindcasts (or reforecasts or historical forecasts) are "forecasts" of the past

<u>Hindcasts enable us to</u>…

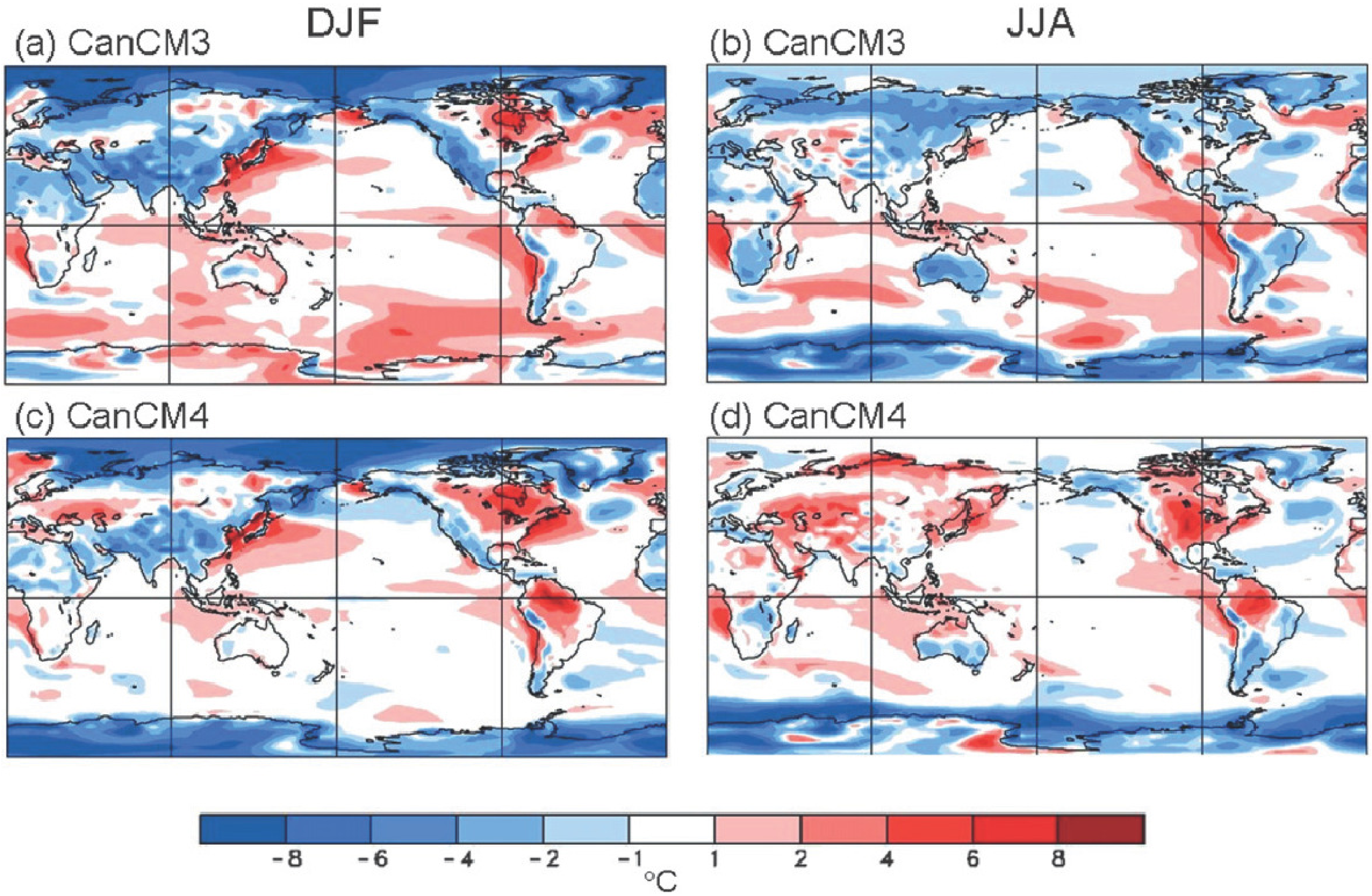
- Estimate lead-time dependent model biases ("drift") so that they can be corrected for – more in lab session
- Estimate historical skill
- Calibrate probabilistic forecasts

<u>Notes</u>:

- When estimating in-sample corrections and skill, cross validation should be applied to avoid inflated estimates of skill
- WMO currently recommends 1981-2010 as hindcast base period
- 30 years $\times$ 12 initialization months $\times$ 10 ensemble members = 3600 years of model integration per hindcast ! (assuming 12 mon range)

CanCM3/4 model temperature biases

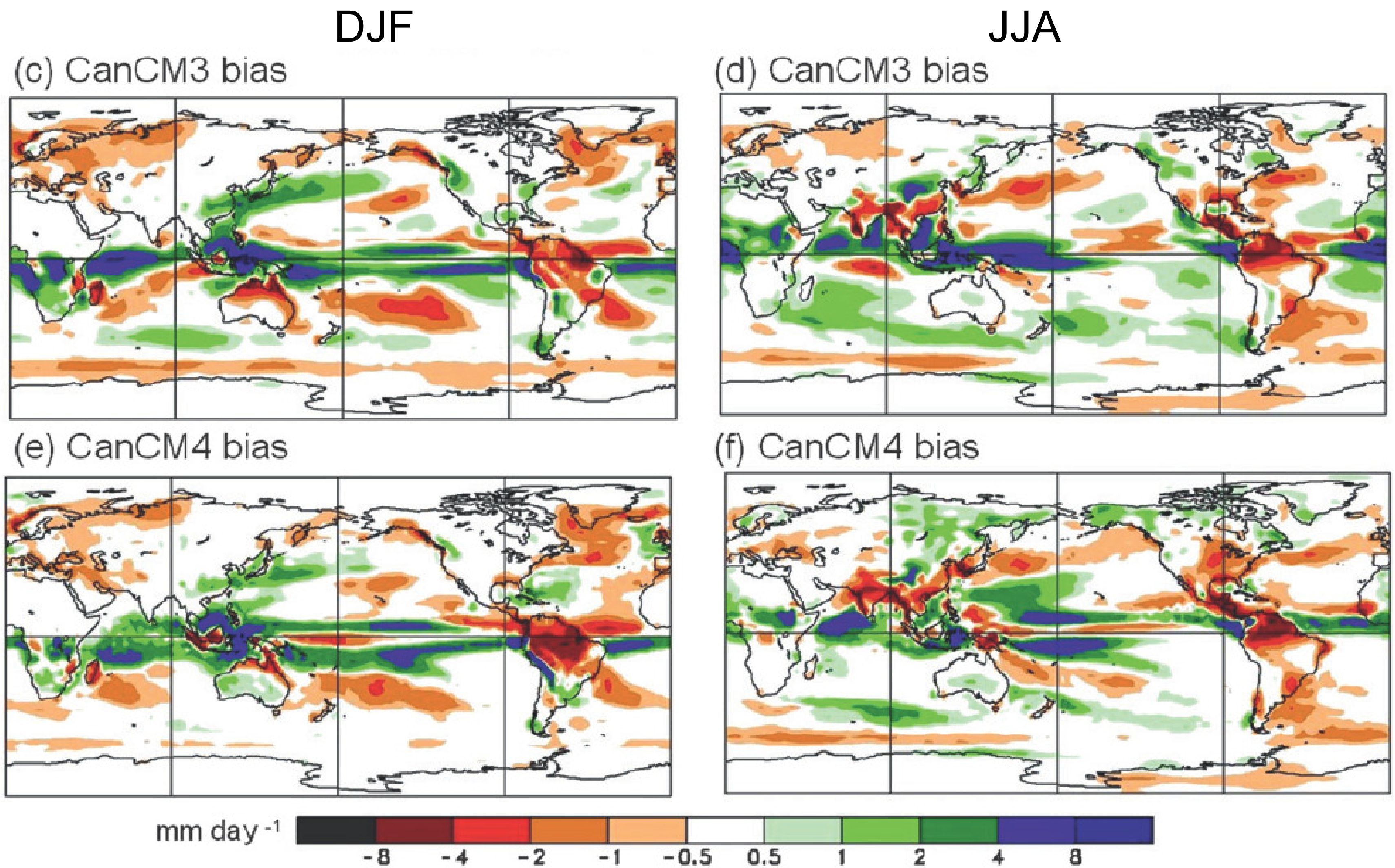
Relative to ERA-Interim reanalysis 1981-2010



Merryfield et al. (MWR 2013)

CanCM3/4 model precipitation biases

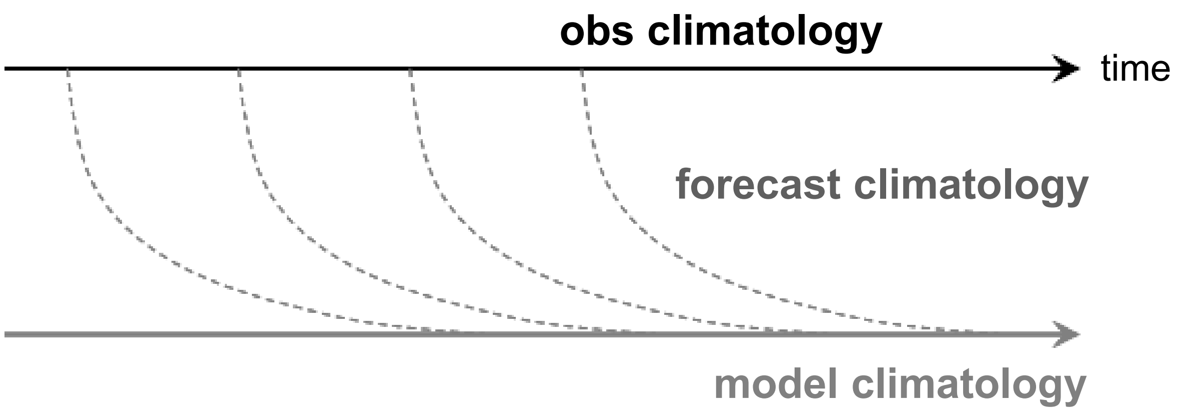
Relative to GPCP2.1 1981-2010



Merryfield et al. (MWR 2013)

Correction for model biases

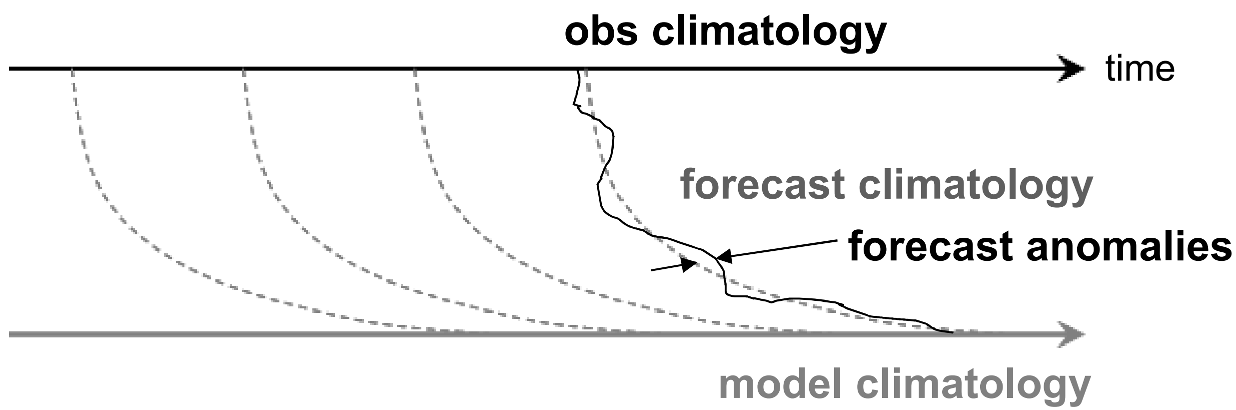
- Because climate models are imperfect, each model has its own climate that differs from that of the real world
- Thus, models initialized near observed climate state will progressively *drift* towards biased model climate:



- These biases can be removed by computing *anomalies* with respect to forecast climatology that is a function of forecast time and lead time, & comparing with observed anomalies

Correction for model biases

- Because climate models are imperfect, each model has its own climate that differs from that of the real world
- Thus, models initialized near observed climate state will progressively *drift* towards biased model climate:



- These biases can be removed by computing *anomalies* with respect to forecast climatology that is a function of forecast time and lead time, & comparing with observed anomalies

Calculation of bias correction

- Forecast anomalies:

$$F'_{k,l} = F_{k,l} - < F_{k,l} >$$

where k = predicted season, l = lead time,

< > indicates averaging over some standard set

of years (e.g. 1981-2010)

- Bias corrected forecast:

$$(F_{k,l})_{corr} = F'_{k,l} + < O_k > = F_{k,l} + < O_k > - < F_{k,l} >$$

where $< O_k >$ = average of observations (climatology)

Deterministic vs probabilistic forecasts

Ensemble deterministic forecasts

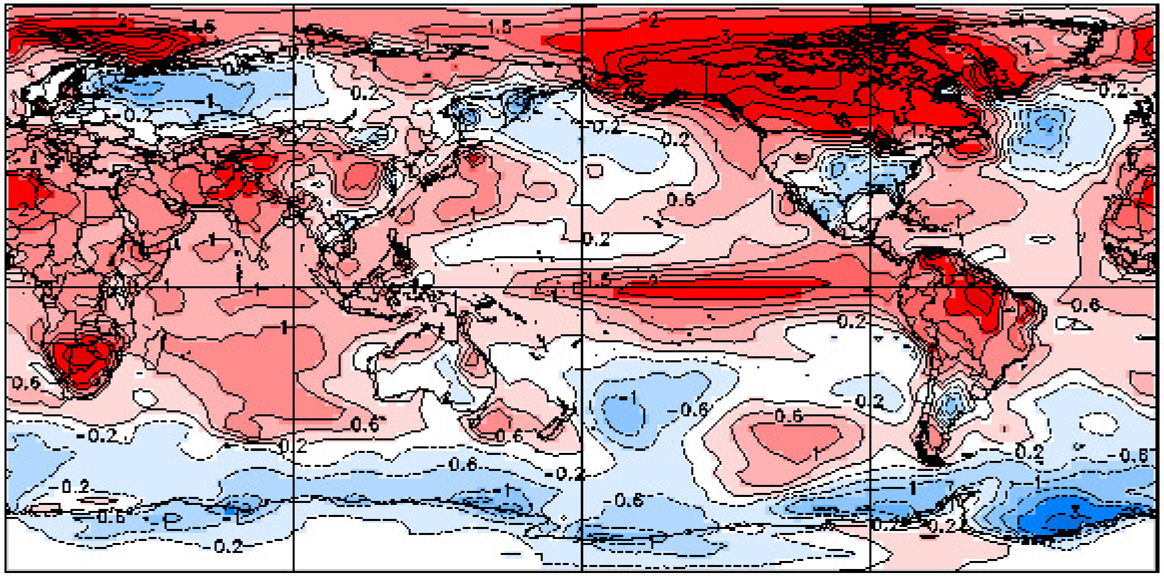
Example: Seasonal mean temperature for JFM 2016

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

2-m Temperature, Anomaly Forecast
year=2016, JFM, 0-month lead



Uncalibrated ensemble mean anomaly forecast.

<u>However, these products contain no indication of uncertainty</u>

Representing forecast uncertainty

Example: forecast of Victoria average temperature

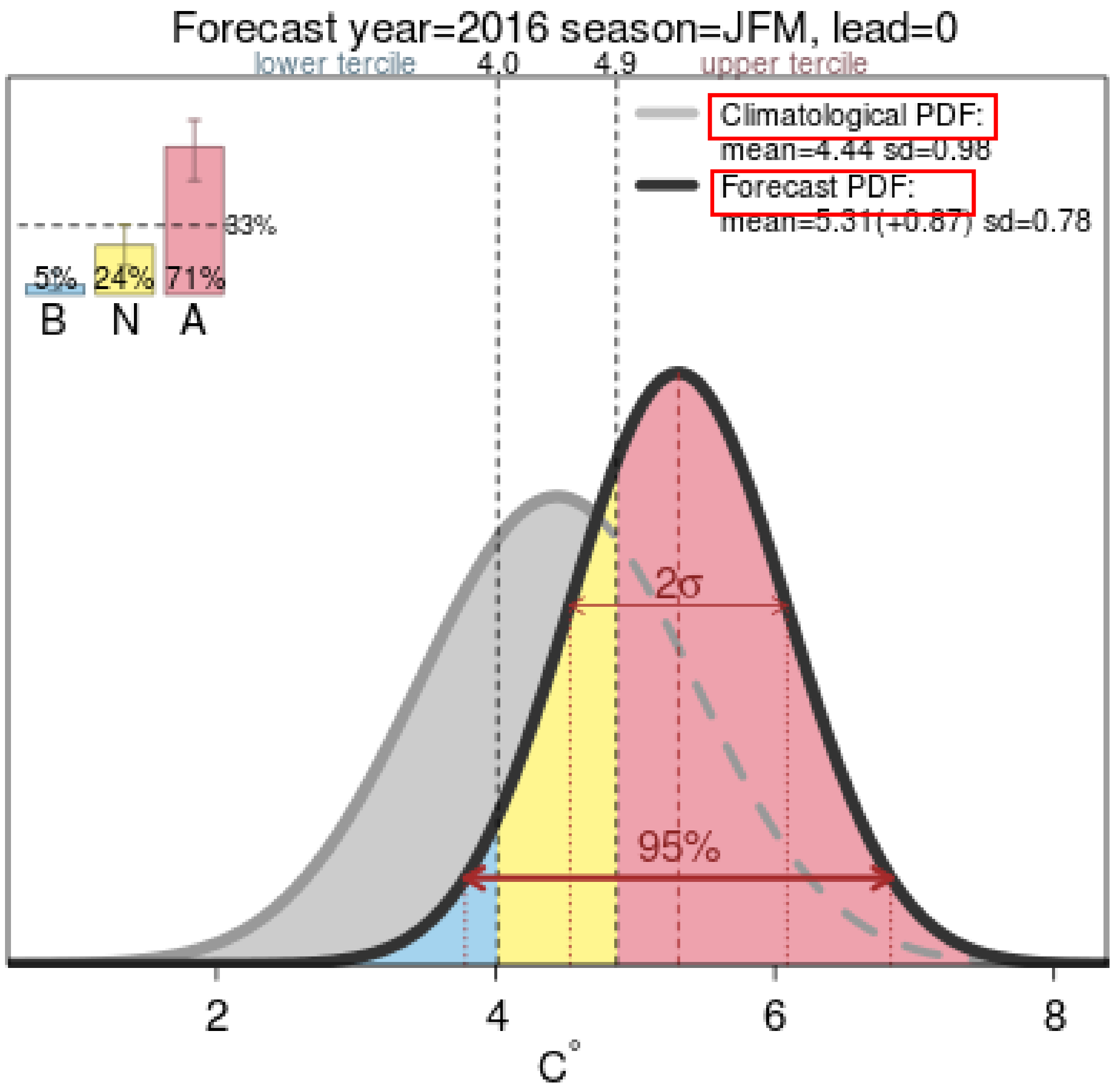
(departure from normal in °C for winters starting in Dec of indicated year)

Consider 30 recent winters (1981-2010)

Divide into 10 coldest, 10 middle, 10 warmest:

below normal					near normal					above normal				
1984 -2.07	1988 -1.54	1981 -1.12	1996 -0.78	2010 -0.39	1995 -0.37	1985 -0.17	1999 -0.11	2000 0.00	2006 0.28	1997 0.54	1993 0.77	1982 0.88	1986 0.99	2002 1.55
1992 -1.95	2008 -1.49	1990 -1.06	1983 -0.55	2007 -0.37	1998 -0.19	1987 -0.13	1989 -0.06	2001 0.12	1994 0.49	2004 0.57	2003 0.78	2009 0.96	2005 1.12	1991 1.71

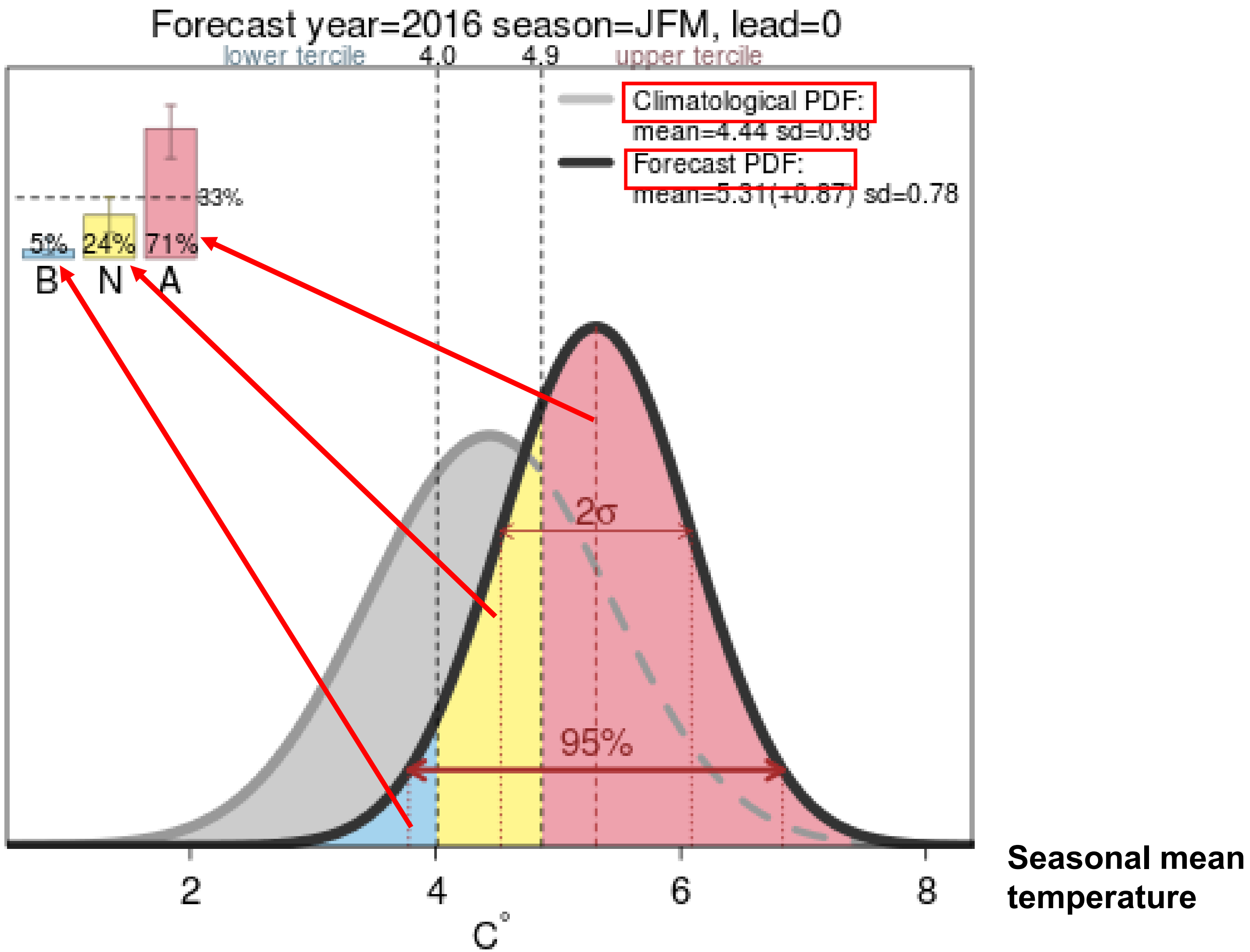
Probabilistic forecast (single location)



Seasonal mean temperature

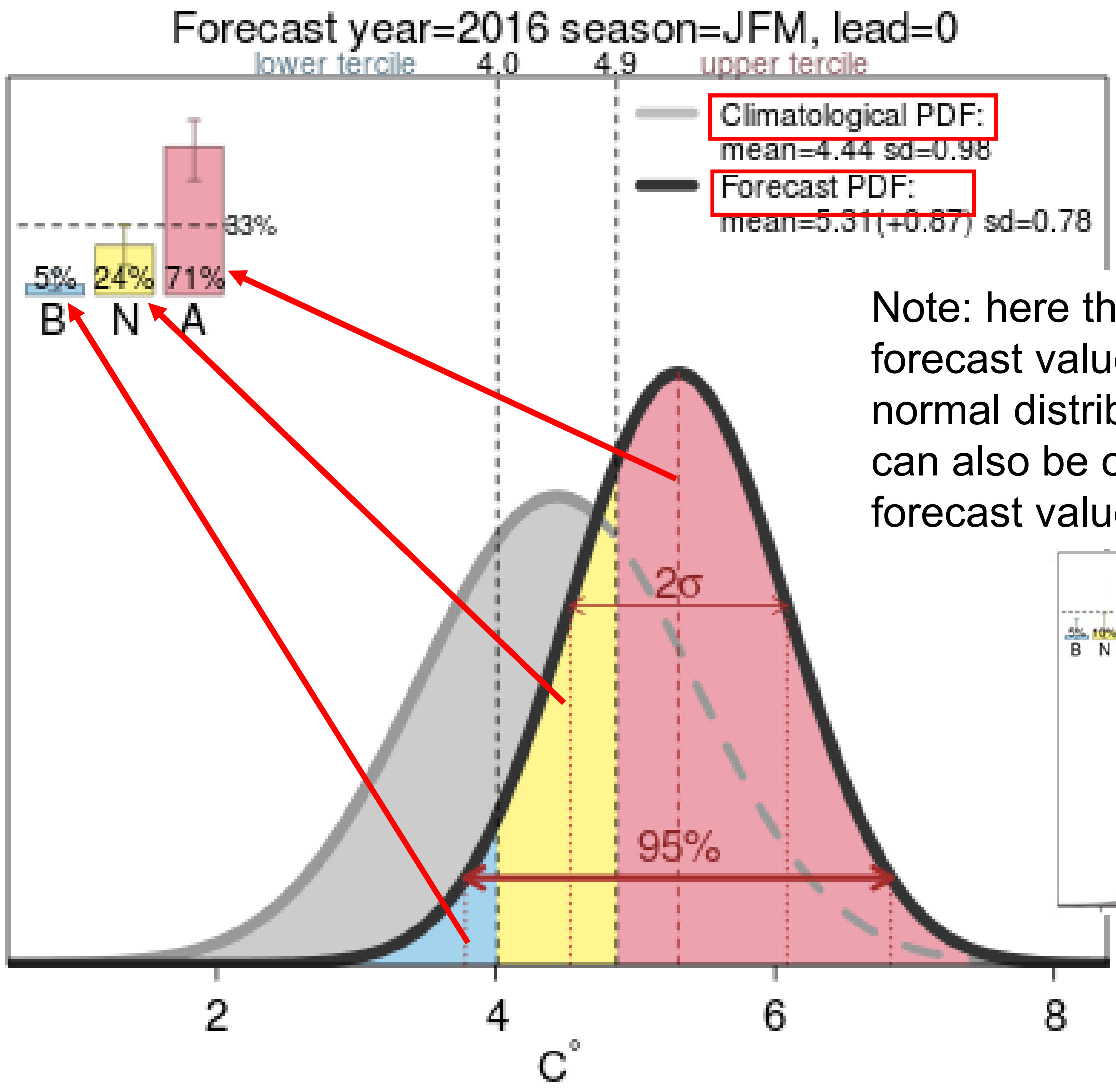
Here the forecast probability distribution or PDF is described in terms of probabilities that forecast seasonal mean temperature will fall into climatologically equi-probable tercile categories: **below normal** **near normal** **above normal**

Probabilistic forecast (single location)

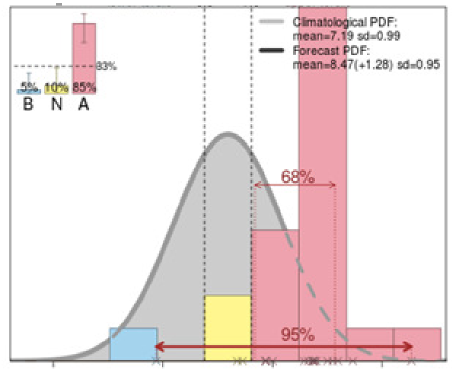


Here the forecast probability distribution or PDF is described in terms of probabilities that forecast seasonal mean temperature will fall into climatologically equi-probable tercile categories: **below normal** **near normal** **above normal**

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 ↓



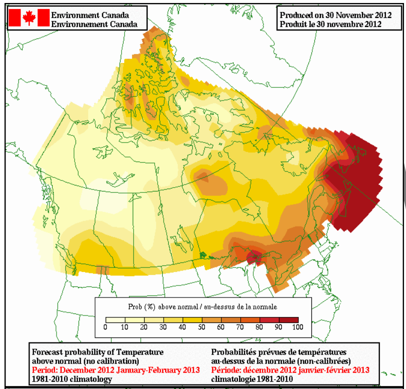
Seasonal mean temperature

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**

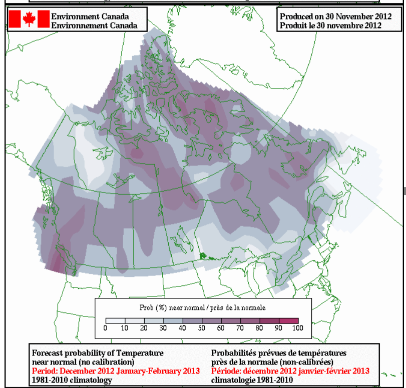
Probabilistic forecast maps

Probabilities in each category

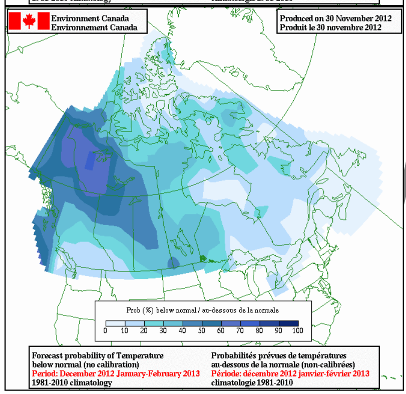
Above Normal



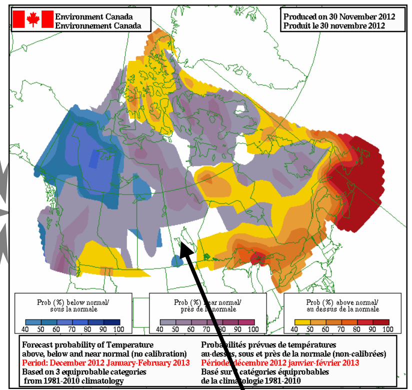
Near Normal



Below Normal



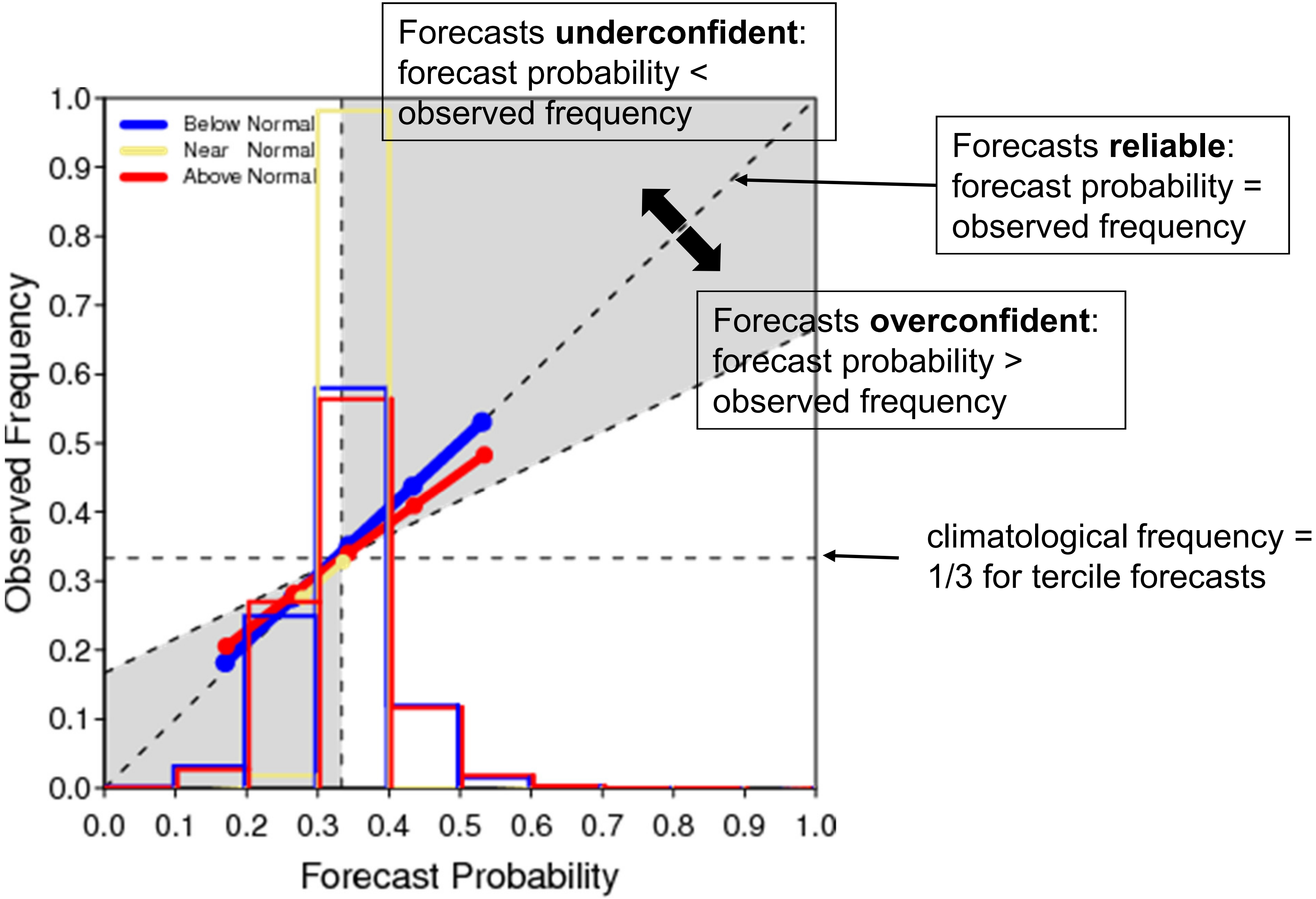
Highest probability at each location



White = 'equal chance' (no category > 40%)

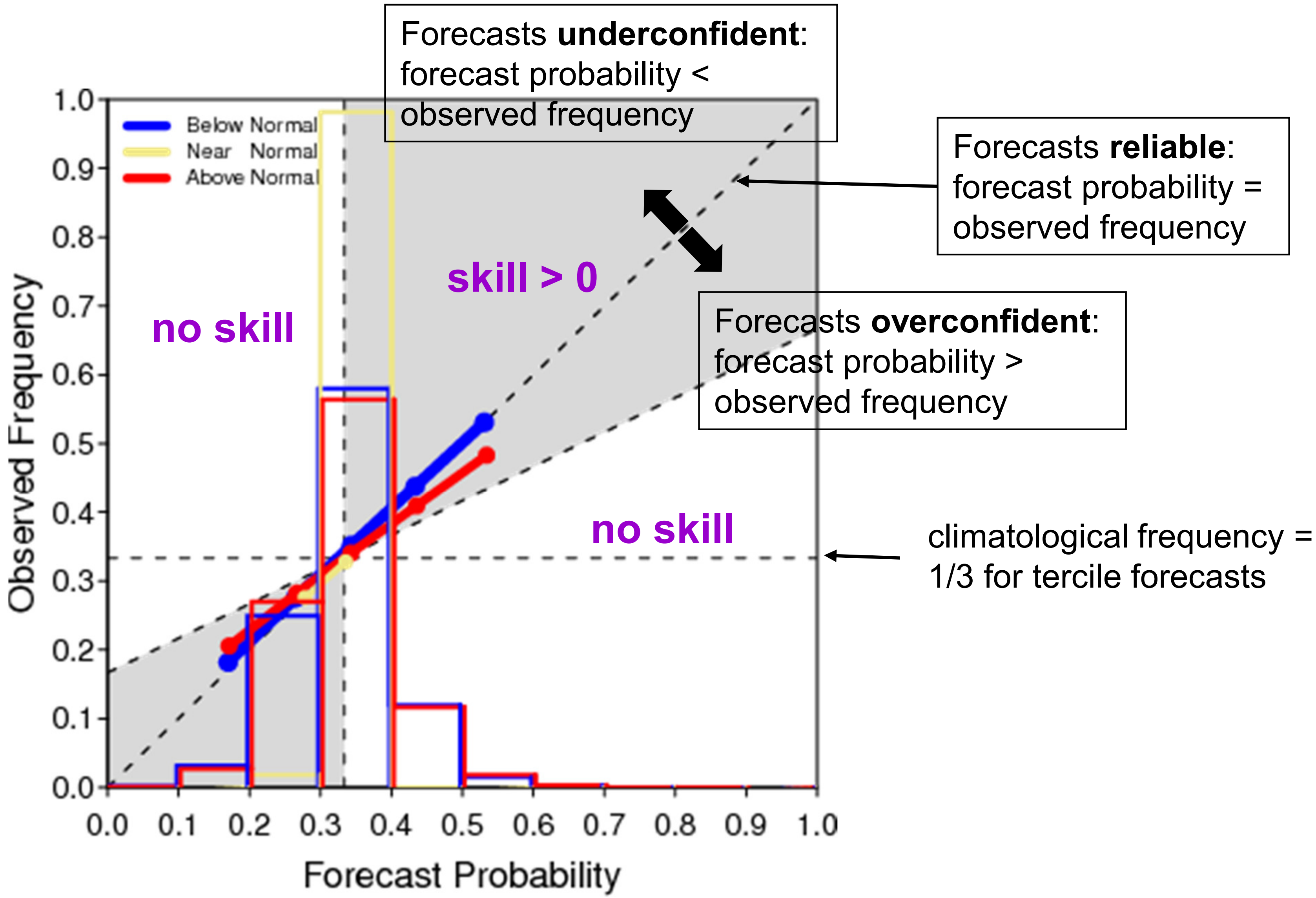
Reliability of probabilistic forecasts

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



Reliability of probabilistic forecasts

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



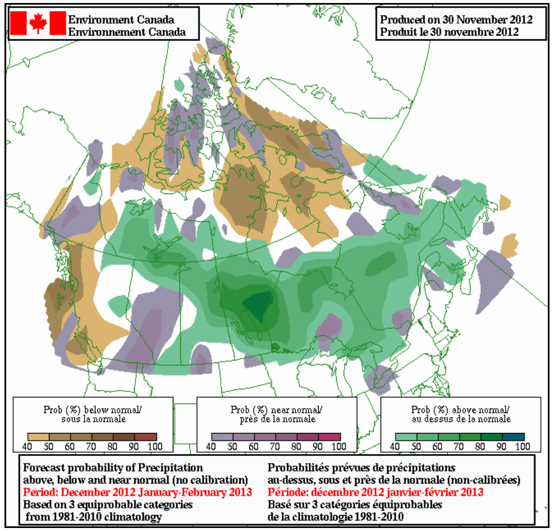
Advantages of calibrated probability forecasts

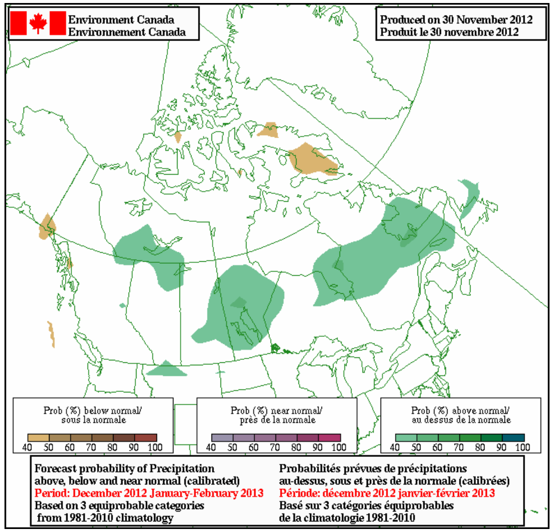
Seasonal precipitation forecast

- **uncalibrated** probabilities:
  - high probabilities predicted far more frequently than observed
  - **overconfident**, especially for precipitation and near-normal category
  - near-normal grossly overpredicted

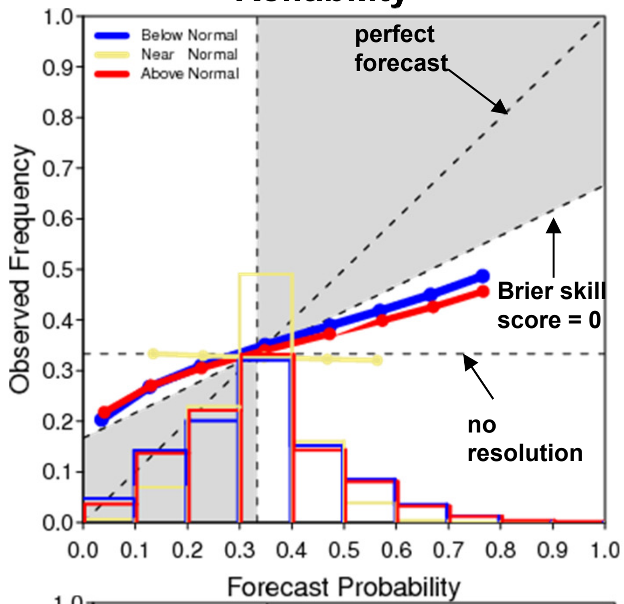
- **calibrated** probabilities:
  - much more **reliable** (forecast probability ≈ observed frequency)
  - **less overconfident**
  - near-normal less overpredicted

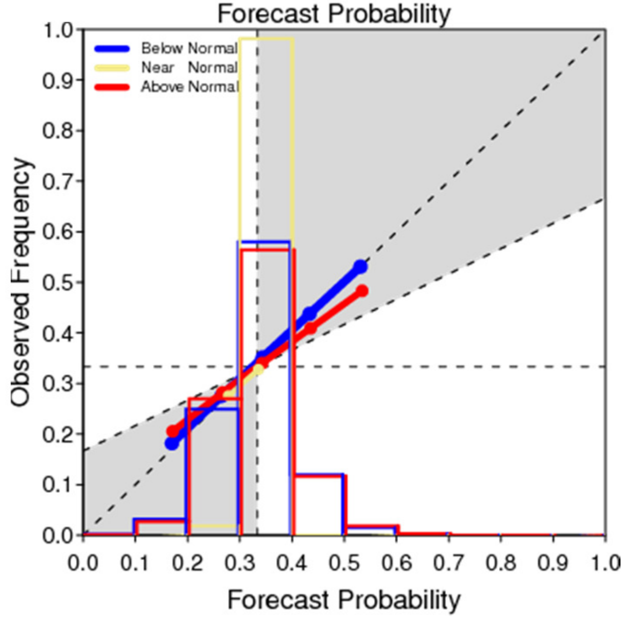
Forecast





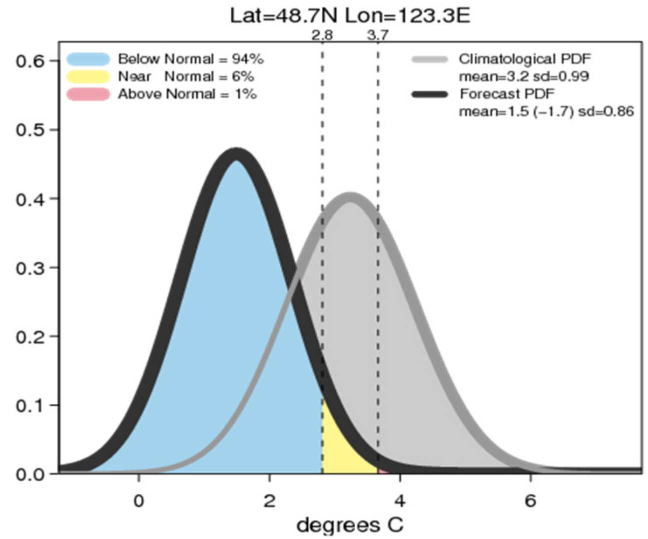
Reliability



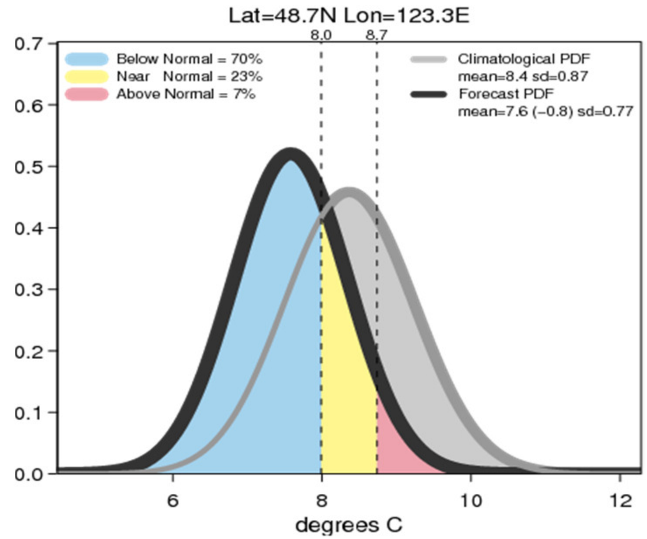


Growth of uncertainty with increasing lead

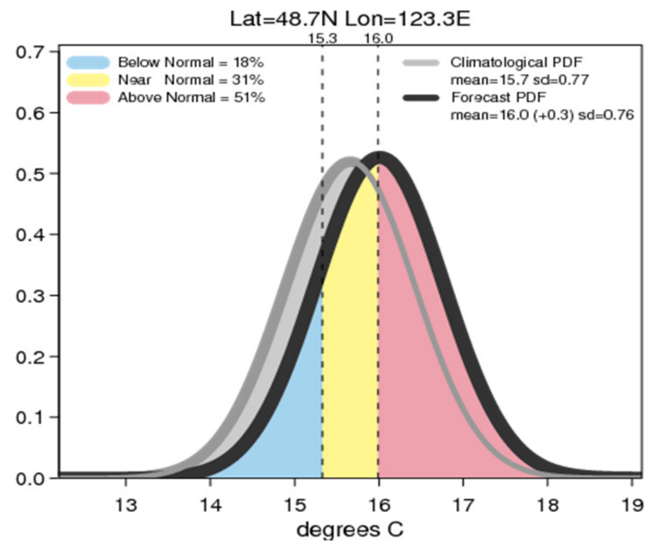
Lead 0 months



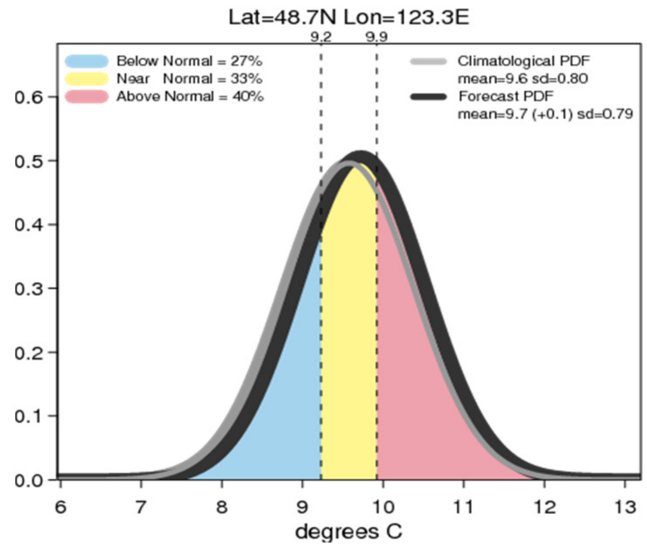
Lead 3 months



Lead 6 months



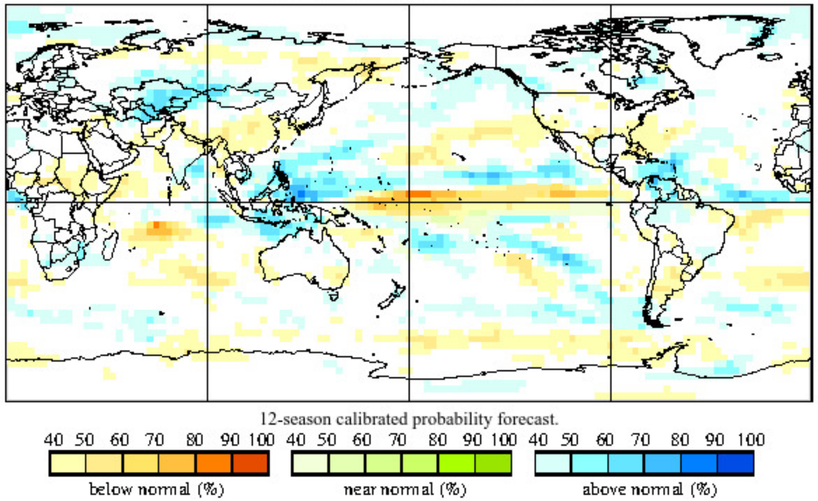
Lead 9 months



Growth of uncertainty with increasing lead

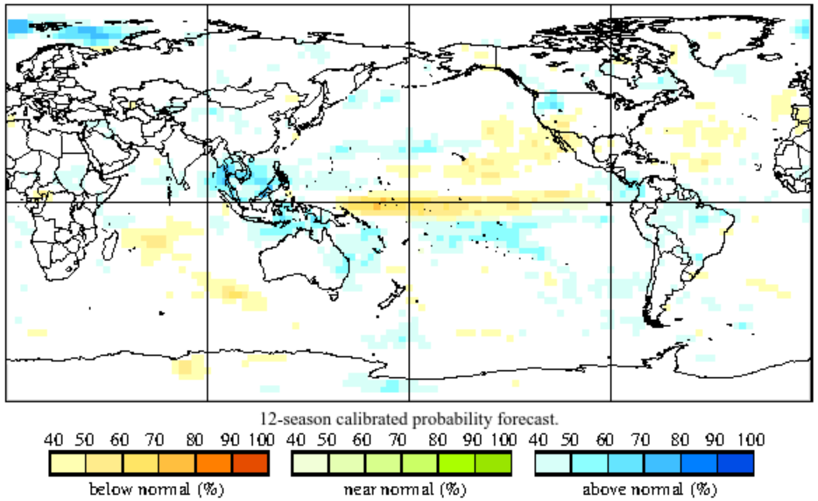
Lead 0 months

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



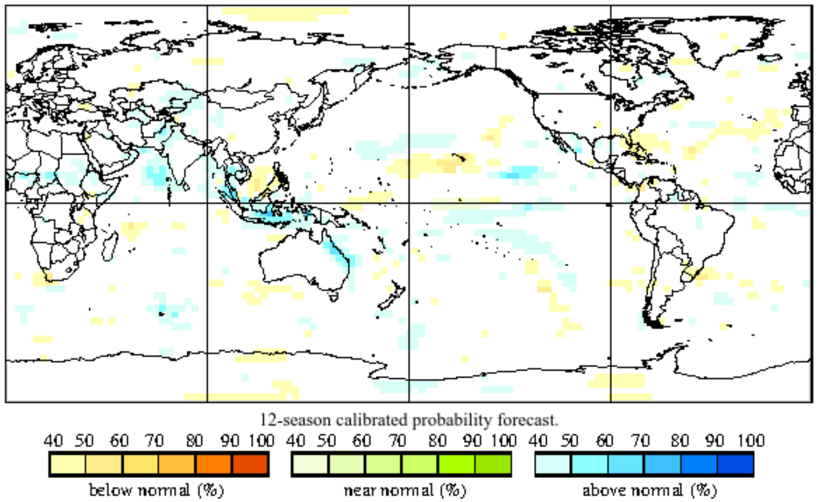
Lead 3 months

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



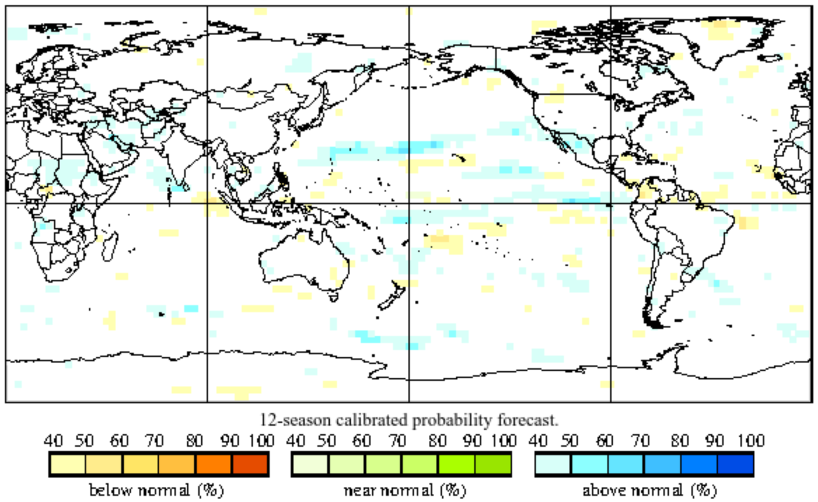
Lead 6 months

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

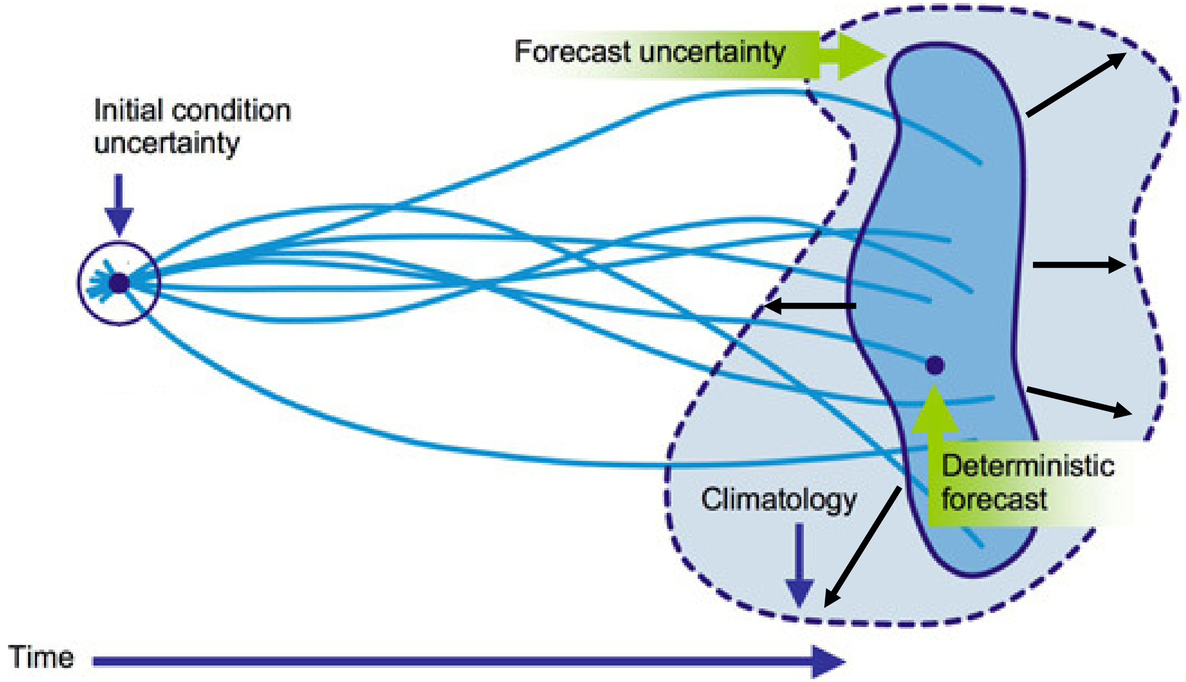


Lead 9 months

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

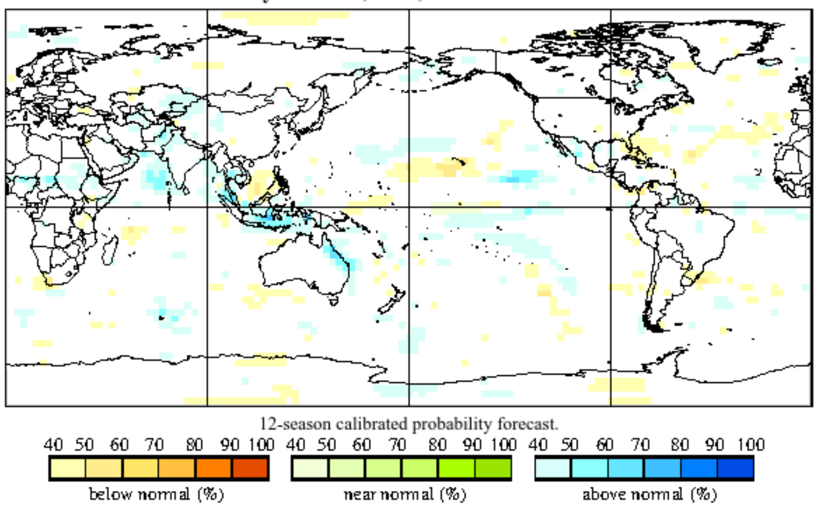


Growth of uncertainty with increasing lead



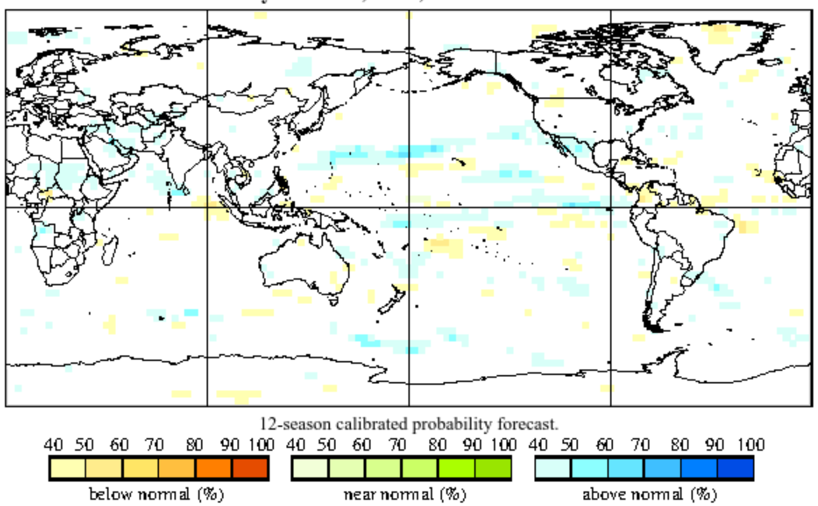
Lead 6 months

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



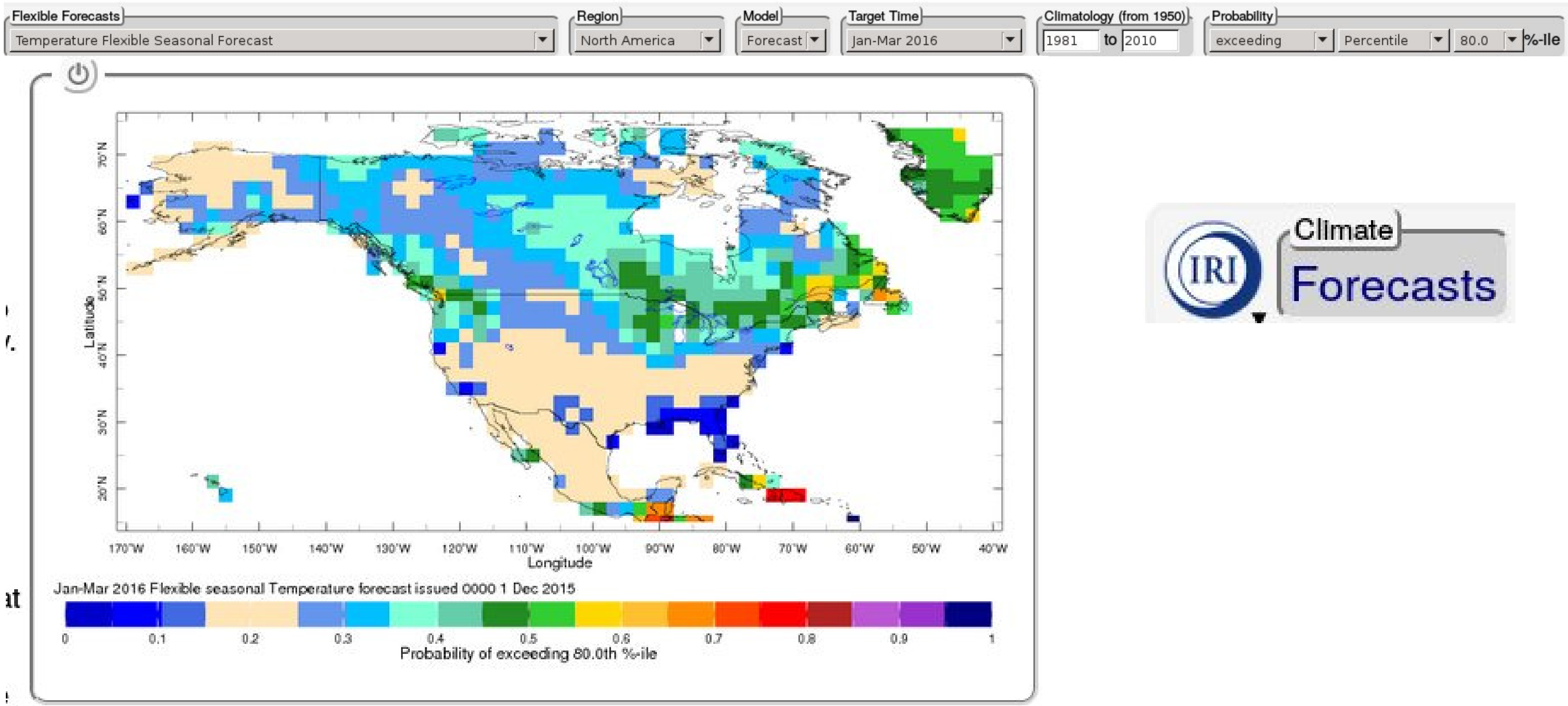
Lead 9 months

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



Probability of exceedance 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)



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

Forecast skill

Skill scores

Example: Anomaly correlation

$$AC = \frac{\overline{f' \cdot o'}}{\sigma(f')\,\sigma(o')}$$

1 *Perfect*

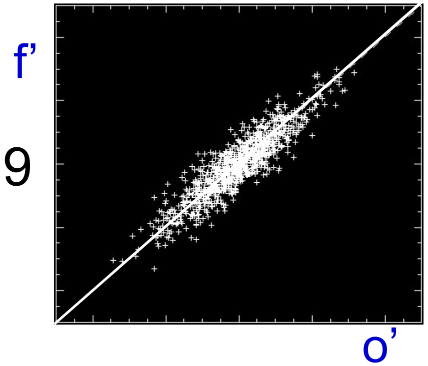
0 *No skill*

-1 (?)

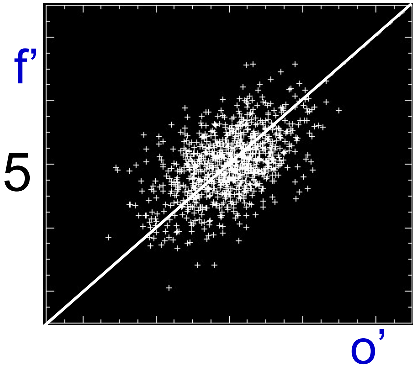
f'= forecast anomaly

o'= observed anomaly

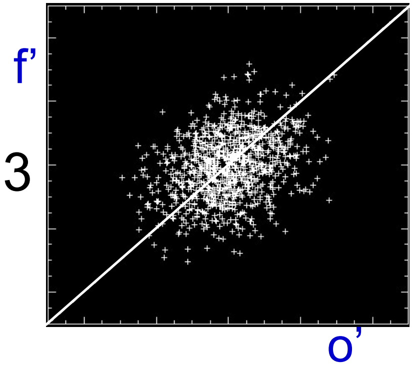
AC=0.9



AC=0.5



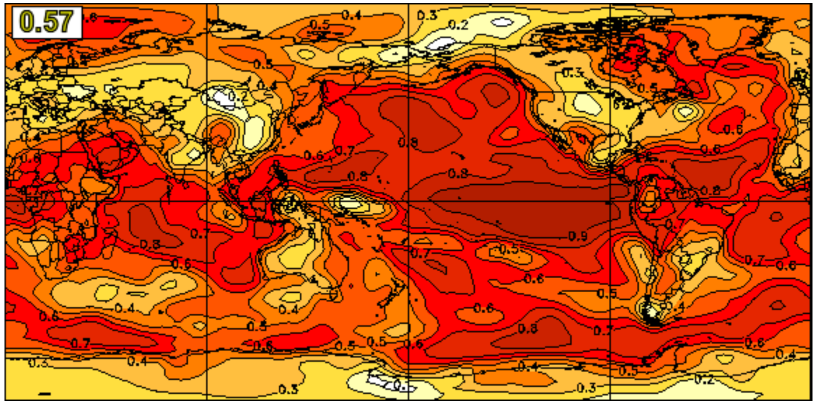
AC=0.3

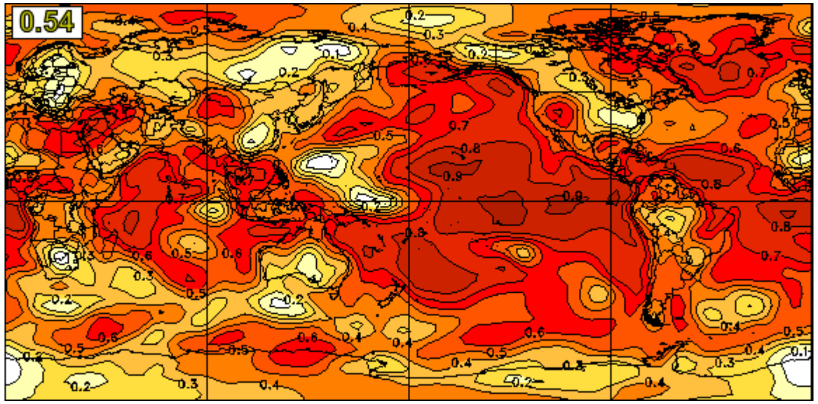


Global anomaly correlation skills

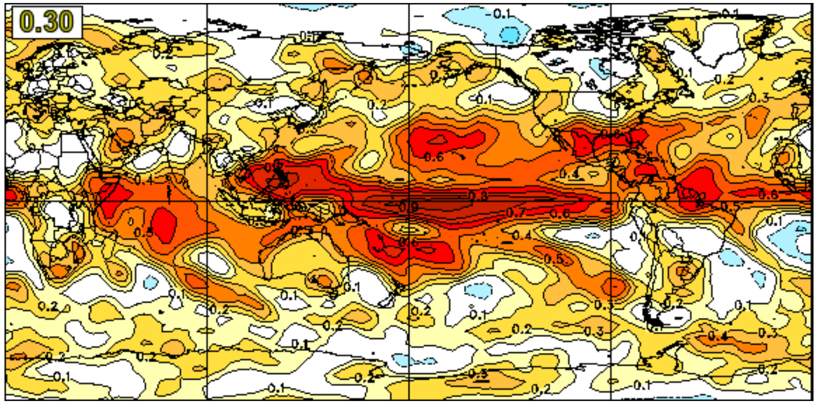
DJF (Lead 0 months) **JJA (Lead 0 months)**

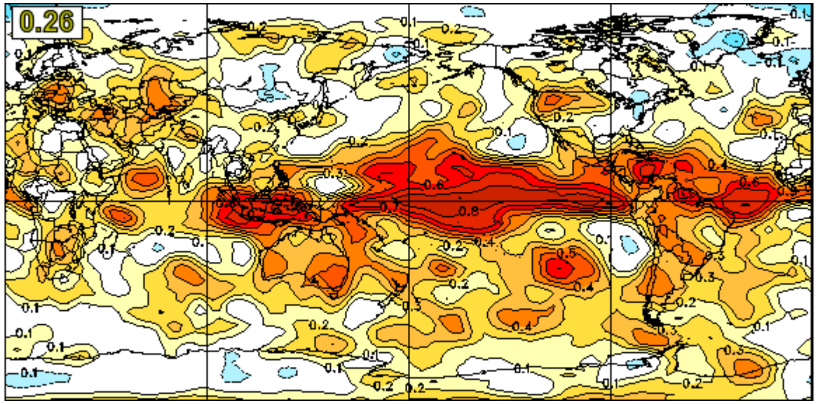
Near-surface temperature





Precipitation





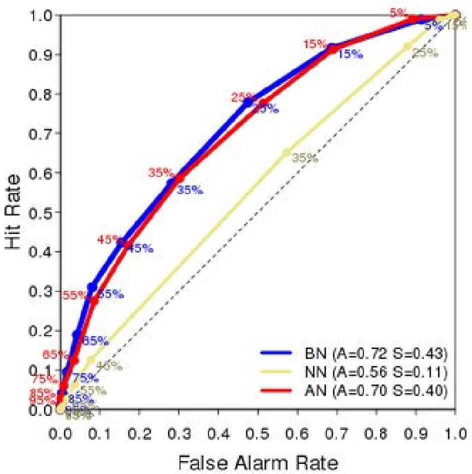
Rules of thumb

- Lower in extratropics than in tropics
- Lower over land than oceans
- Lower in winter than summer
- (Much) lower for precip then temp

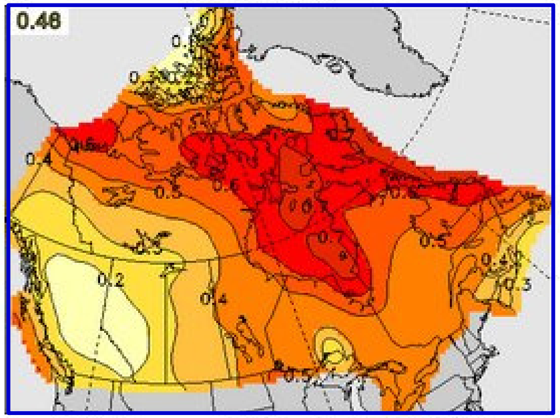
Additional **deterministic** and **probabilistic** skill scores

SON temperature (lead 0 months)

Relative Operating Characteristic

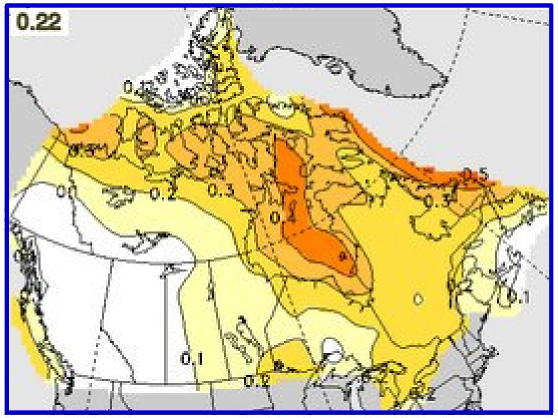


Correlation



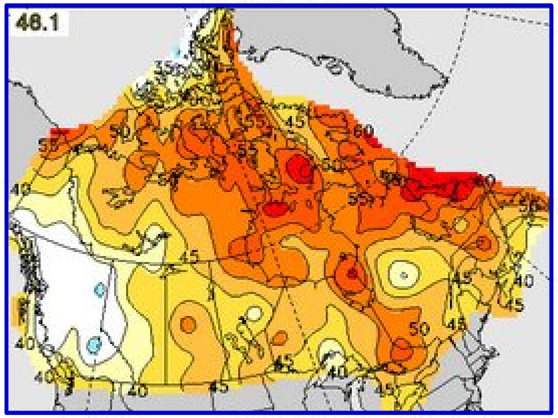
Correlation skill score of the ensemble mean forecast.

MSSS



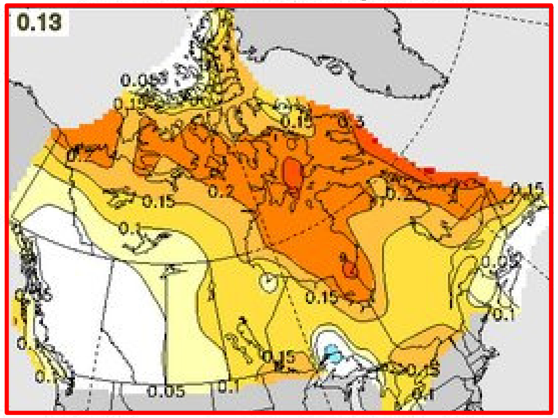
Mean square skill score of the linearly rescaled ensemble mean forecast.

Percent Correct



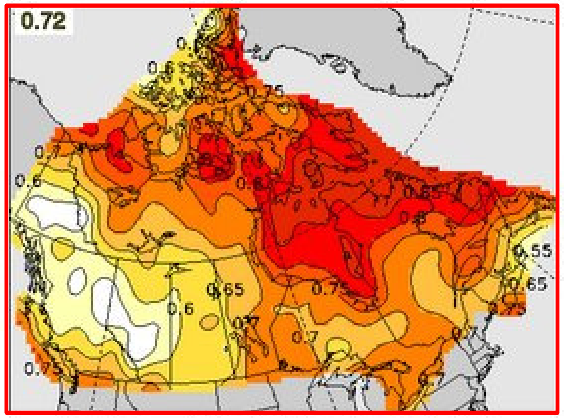
The percent correct score is the percentage of correctly predicted categories.
The percent correct of skillful forecasts is greater than 33.3%.

Continuous Ranked Probability Skill Score



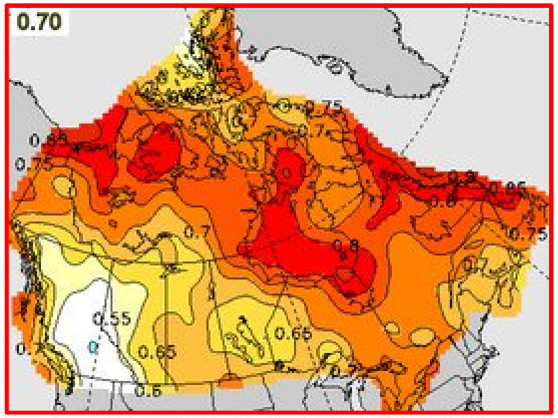
Continuous ranked probability skill score (CRPSS).
CRPSS measures differences between the forecast and observed distributions.

ROC, below normal



ROC score for the lower tercile.
Skillful forecasts have ROC scores greater than 0.5.

ROC, above normal

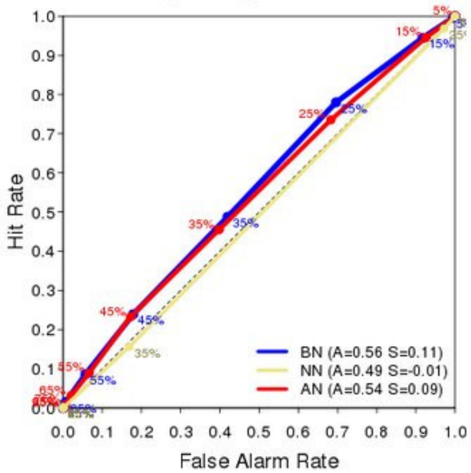


ROC score for the upper tercile.
Skillful forecasts have ROC scores greater than 0.5.

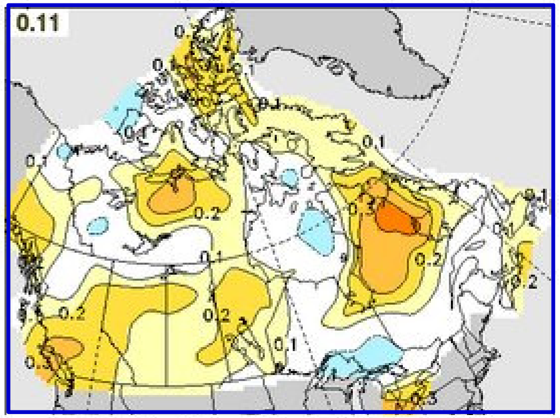
Additional deterministic and probabilistic skill scores

SON precipitation (lead 0 months)

Relative Operating Characteristic

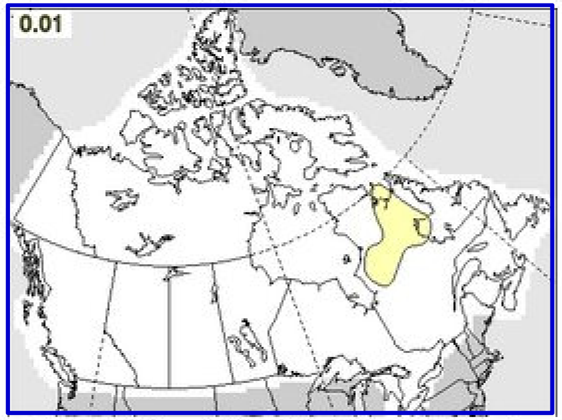


Correlation



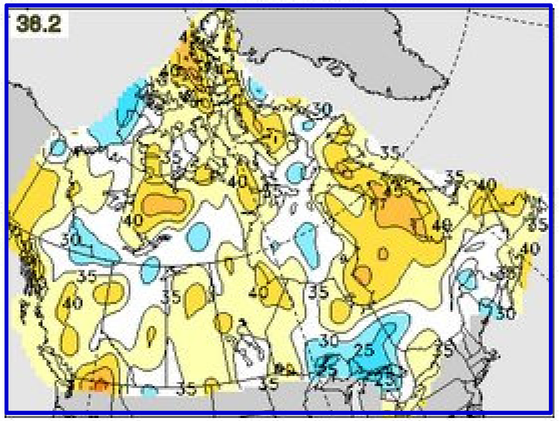
Correlation skill score of the ensemble mean forecast.

MSSS



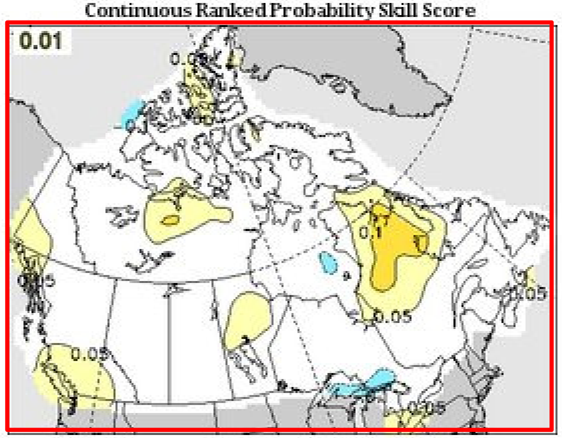
Mean square skill score of the linearly rescaled ensemble mean forecast.

Percent Correct



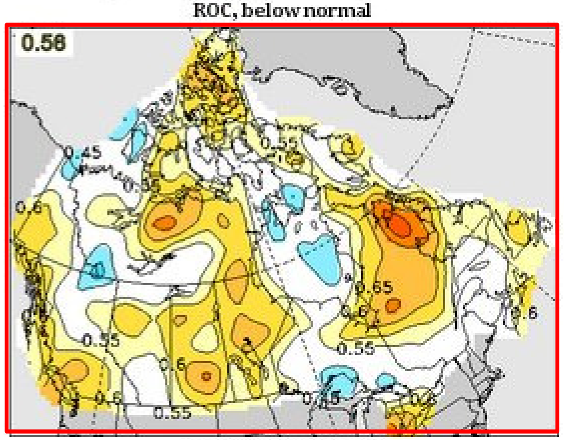
The percent correct score is the percentage of correctly predicted categories.
The percent correct of skillful forecasts is greater than 33.3%.

Continuous Ranked Probability Skill Score



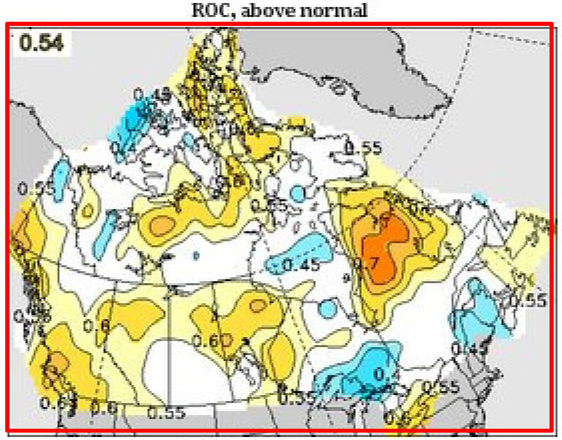
Continuous ranked probability skill score (CRPSS).
CRPSS measures differences between the forecast and observed distributions.

ROC, below normal



ROC score for the lower tercile.
Skillful forecasts have ROC scores greater than 0.5.

ROC, above normal

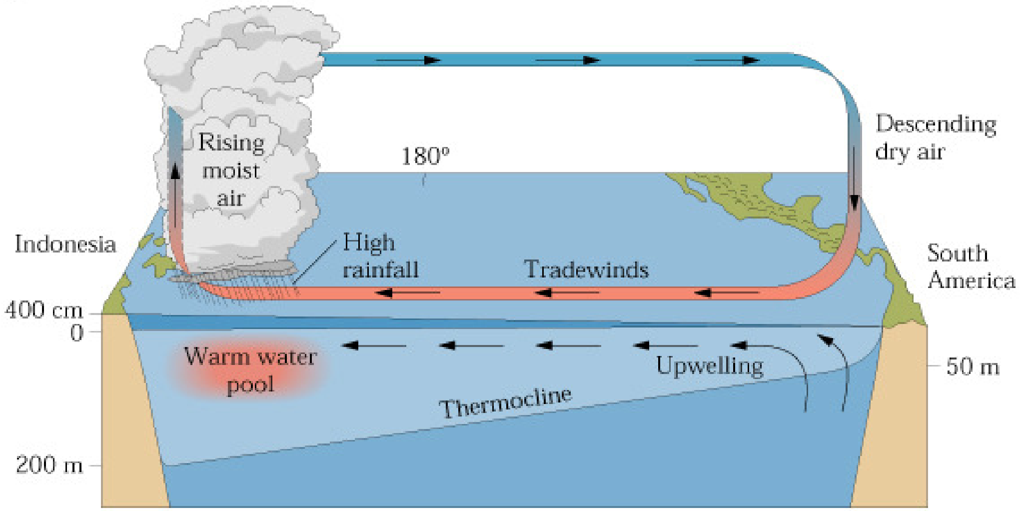


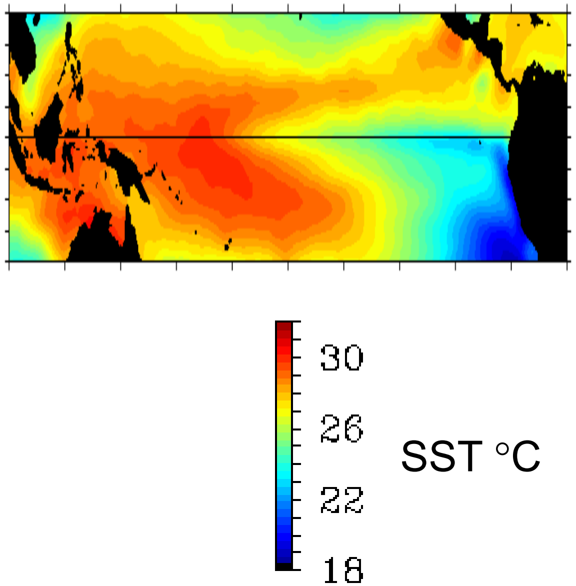
ROC score for the upper tercile.
Skillful forecasts have ROC scores greater than 0.5.

ENSO

Equatorial Pacific climate

Normal

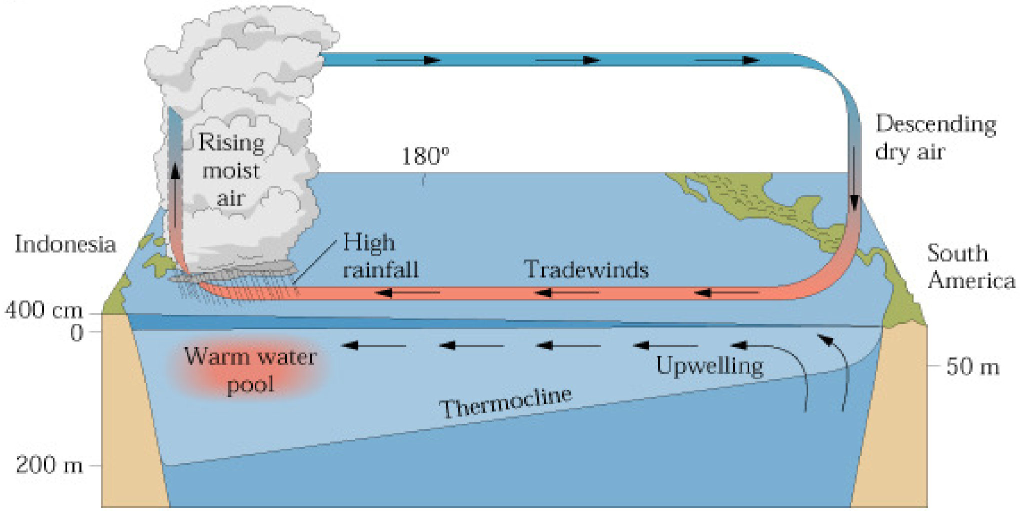


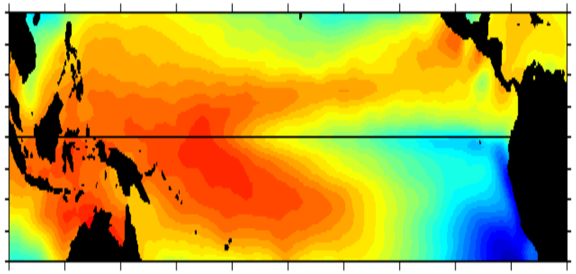


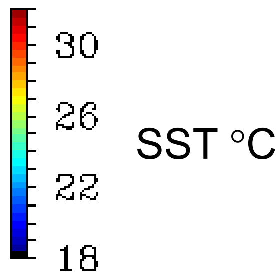
Copyright 1999 John Wiley and Sons, Inc. All rights reserved.

Equatorial Pacific climate

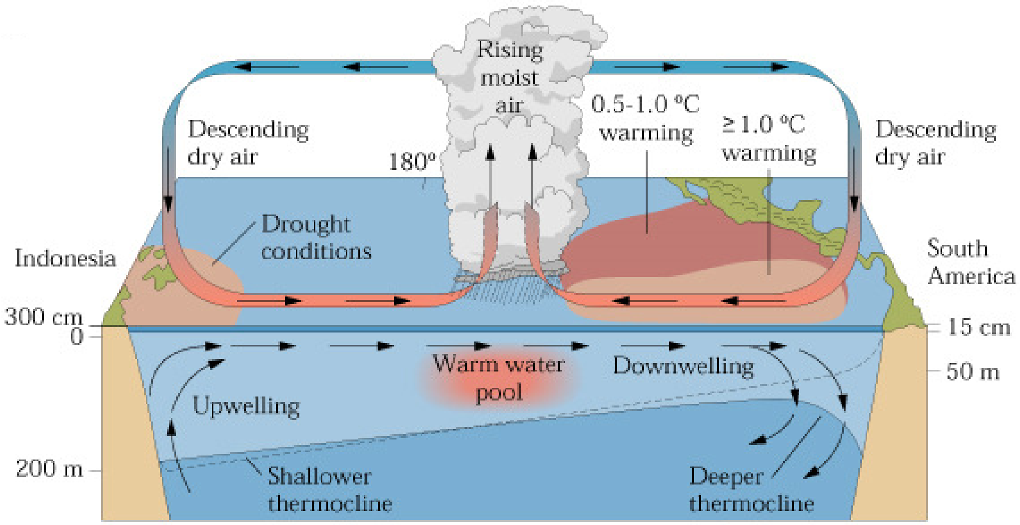
Normal

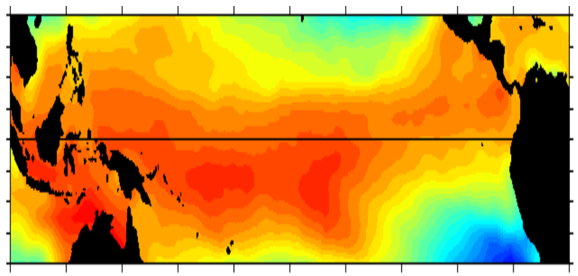






El Niño

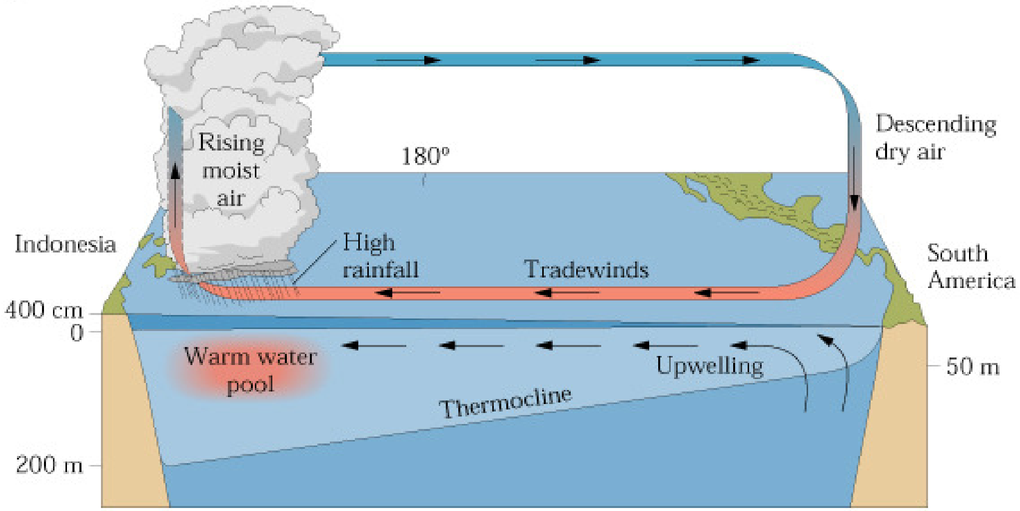


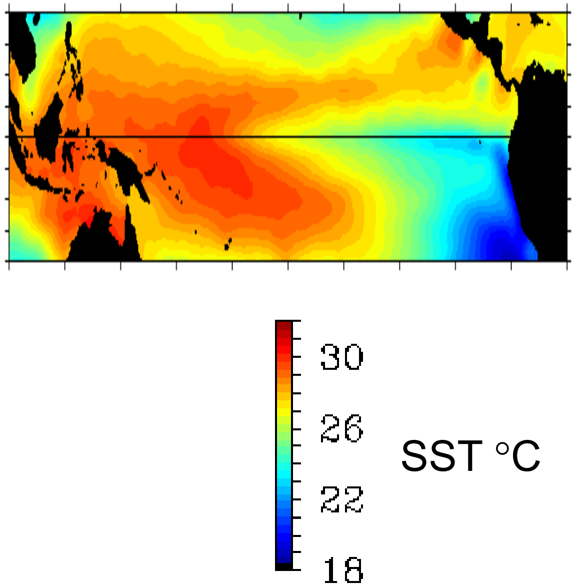


Copyright 1999 John Wiley and Sons, Inc. All rights reserved.

Equatorial Pacific climate

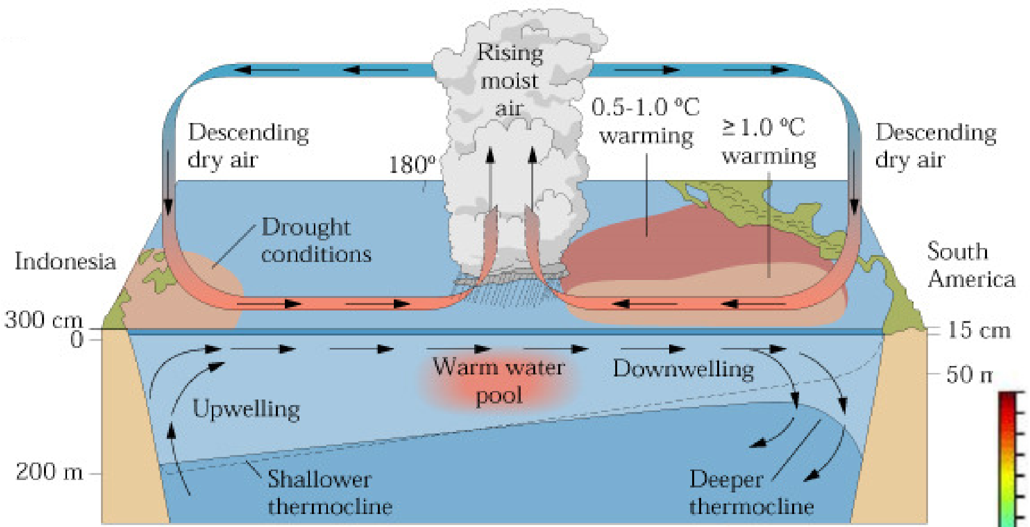
Normal



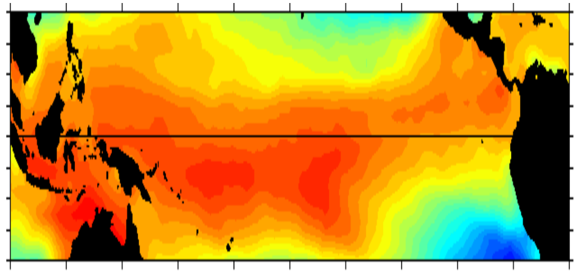


SST °C

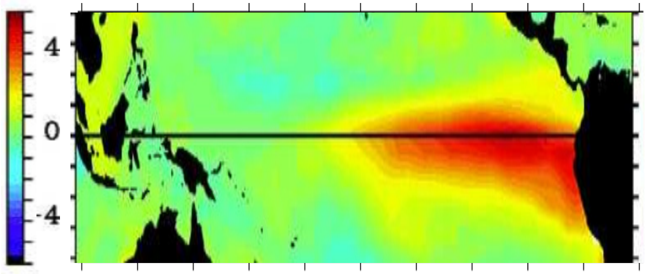
El Niño



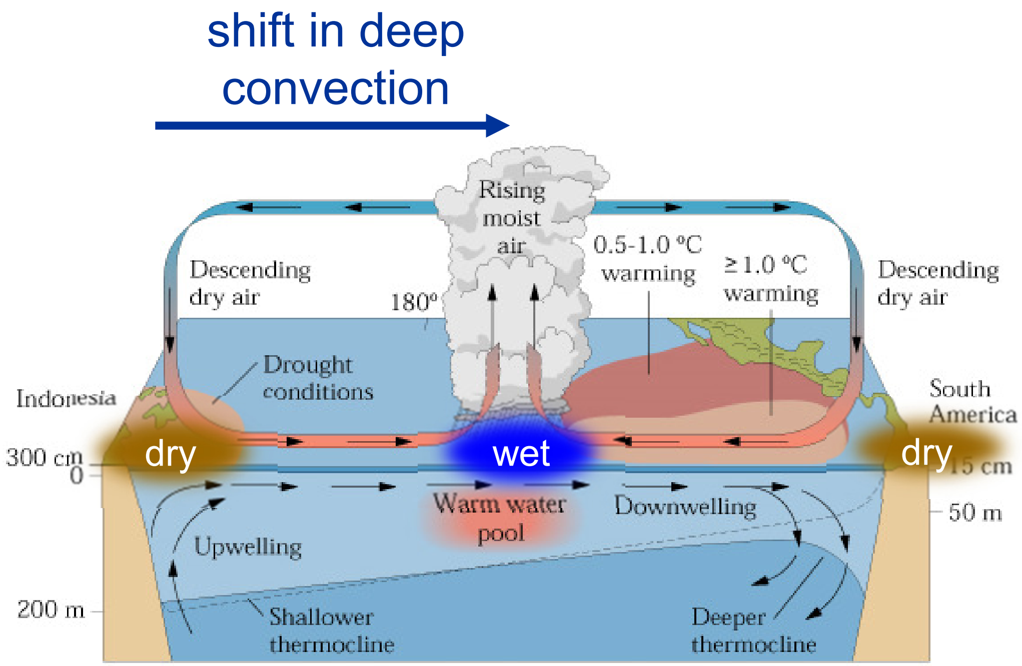
Copyright 1999 John Wiley and Sons, Inc. All rights reserved.



SST anomaly °C



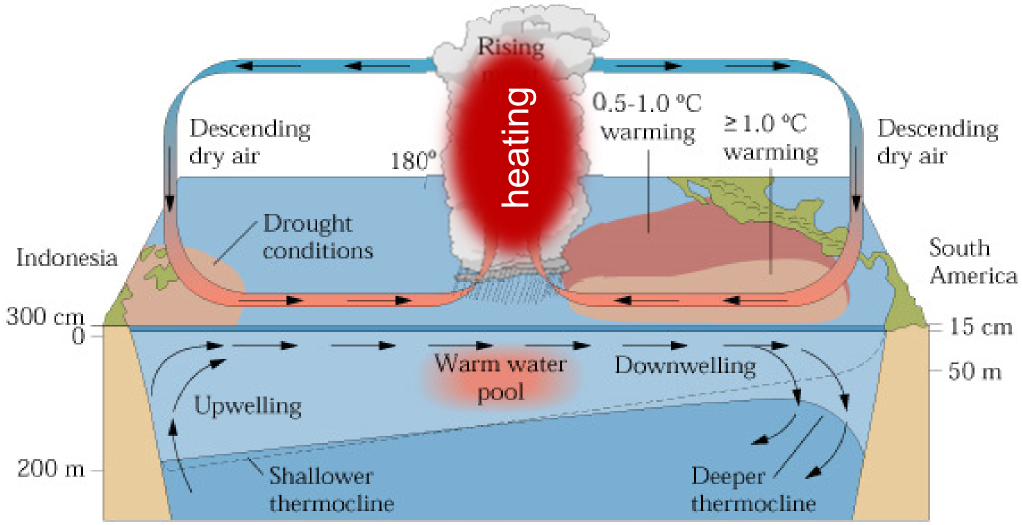
El Niño direct impacts



El Niño conditions in the tropical Pacific

Copyright 1999 John Wiley and Sons, Inc. All rights reserved.

El Niño teleconnections

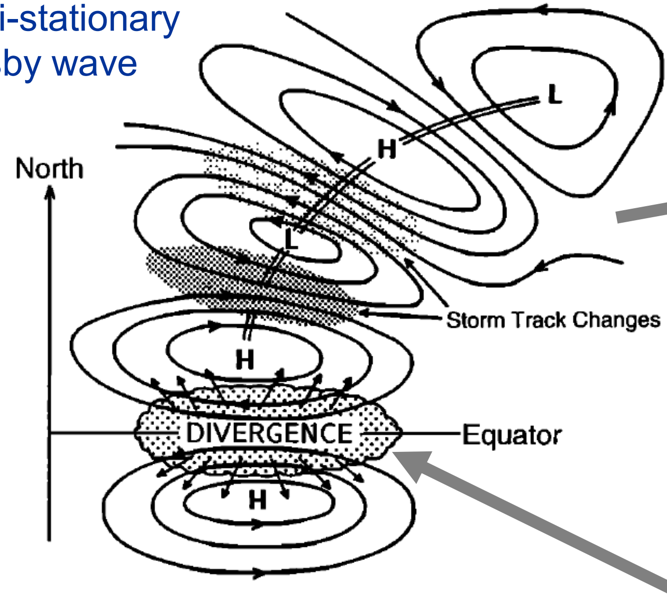


El Niño conditions in the tropical Pacific

Copyright 1999 John Wiley and Sons, Inc. All rights reserved.

El Niño teleconnections

upper tropospheric response:
quasi-stationary
Rossby wave

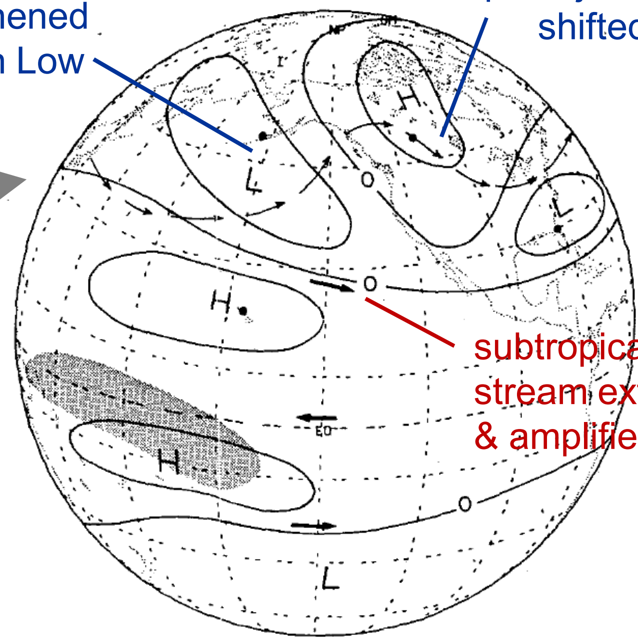


Trenberth et al., *JGR* (1998)

Northern winter

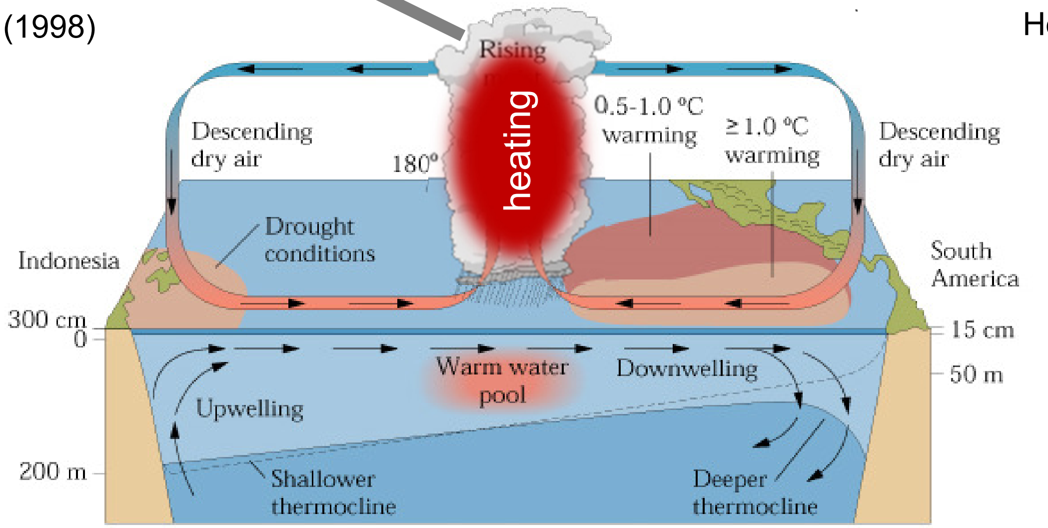
strengthened
Aleutian Low

polar jet stream
shifted north



subtropical jet
stream extended
& amplified

Horel & Wallace, *MWR* (1981)

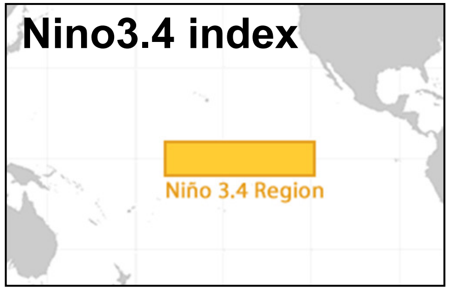


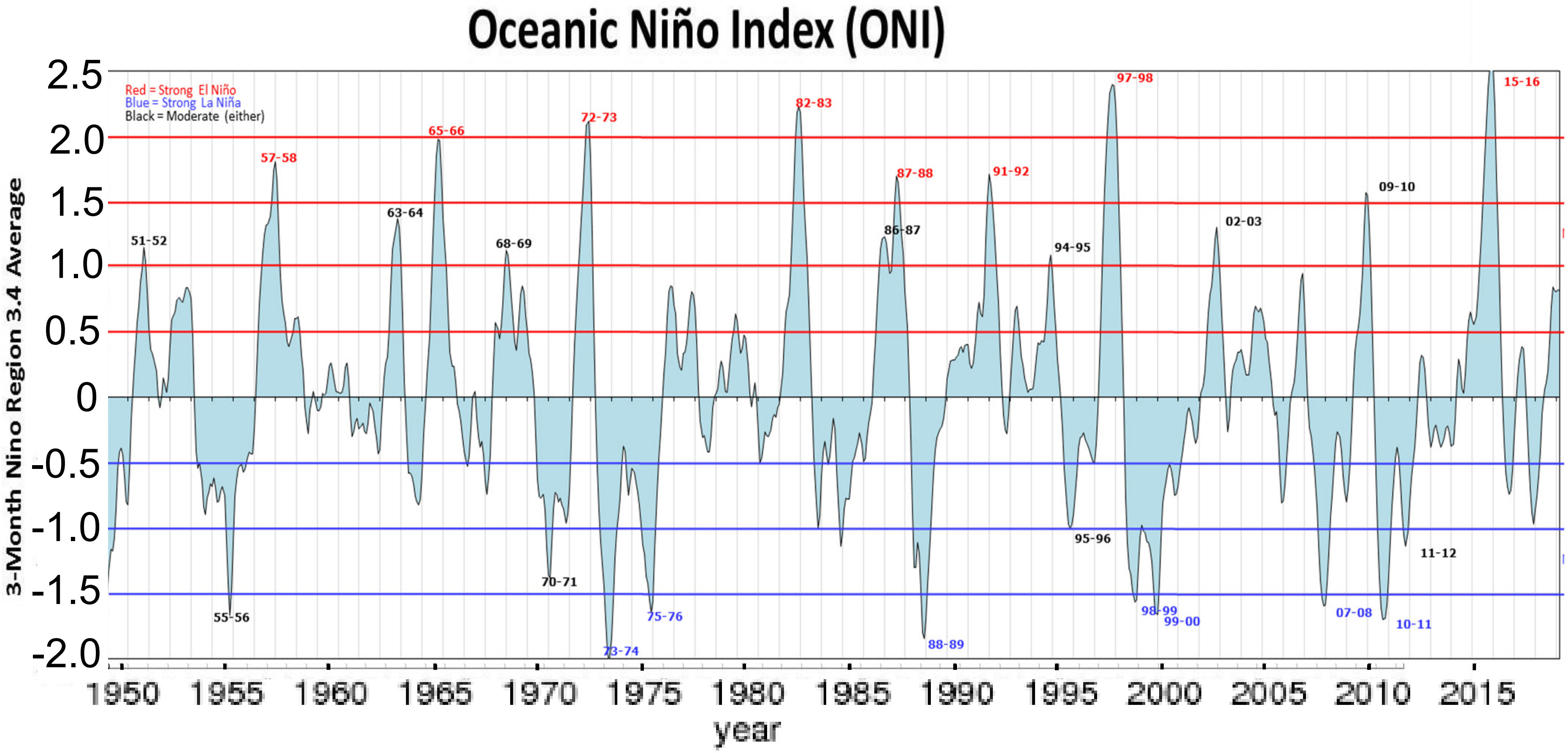
El Niño conditions in the tropical Pacific

Copyright 1999 John Wiley and Sons, Inc. All rights reserved.

Historical El Niño/La Niña variability

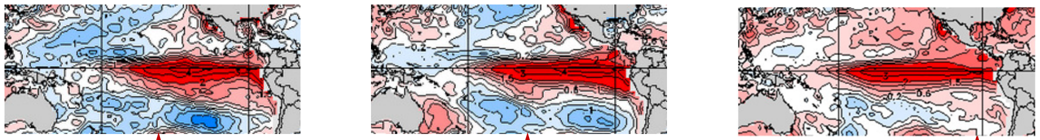
- A widely used indicator of El Niño/La Niña activity is Nino3.4 = mean SST anomaly in 5N-5S, 120W-170W
- The Oceanic Nino Index (ONI) consists of a 3-month rolling average of Nino3.4



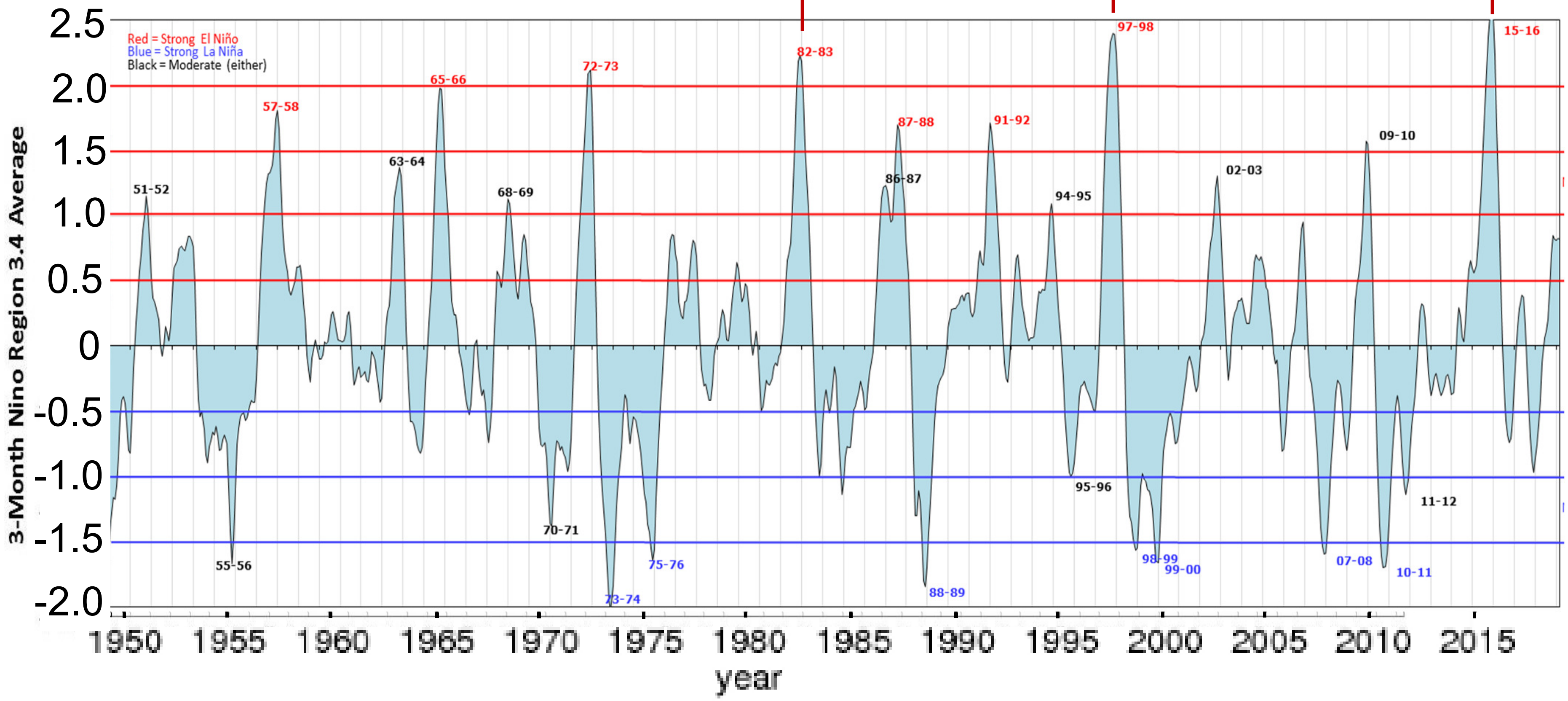


Historical El Niño/La Niña variability

Very strong El Niños



DJF-averaged SST anomalies from NCEP/OISST

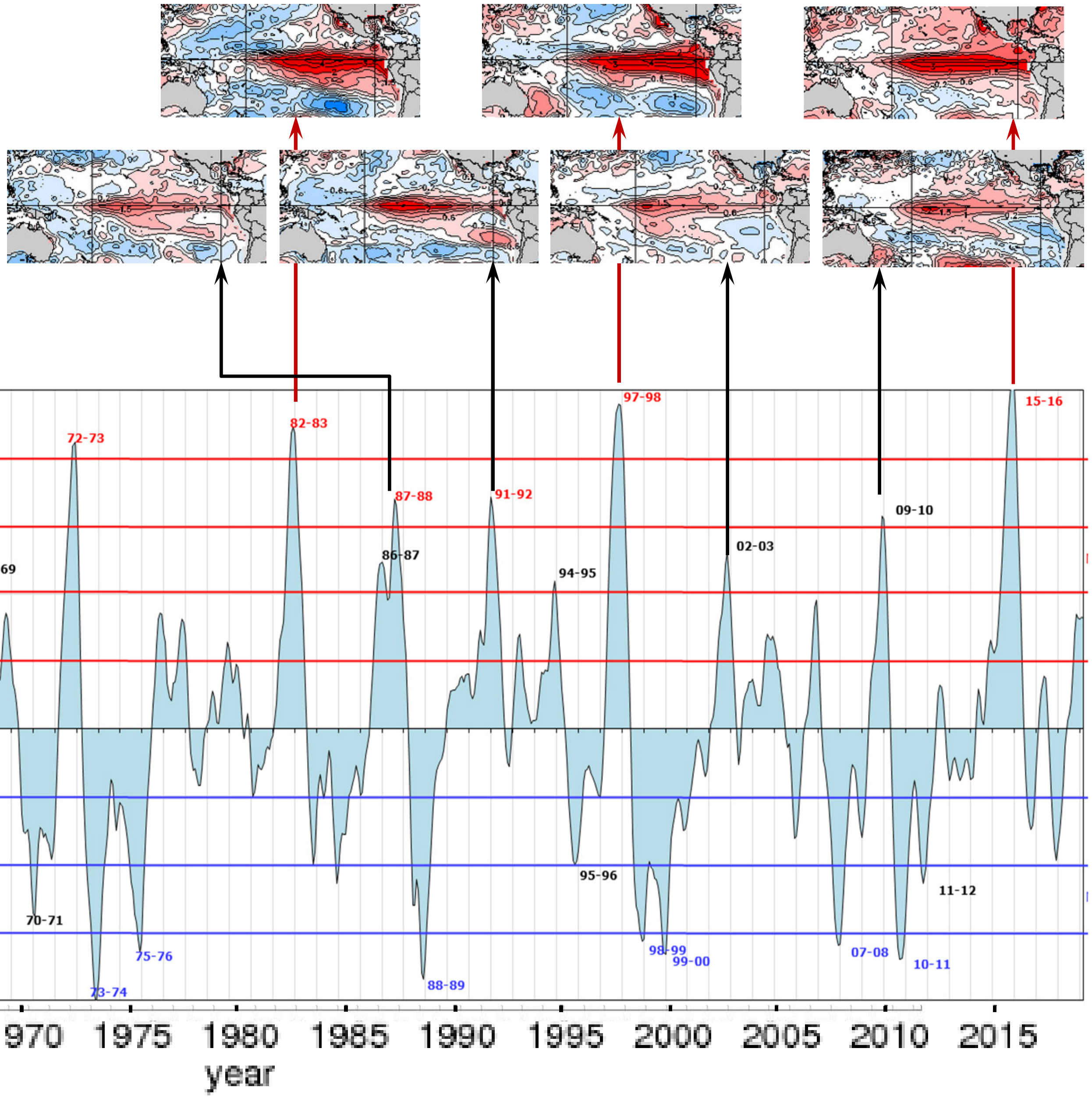


Historical El Niño/La Niña variability

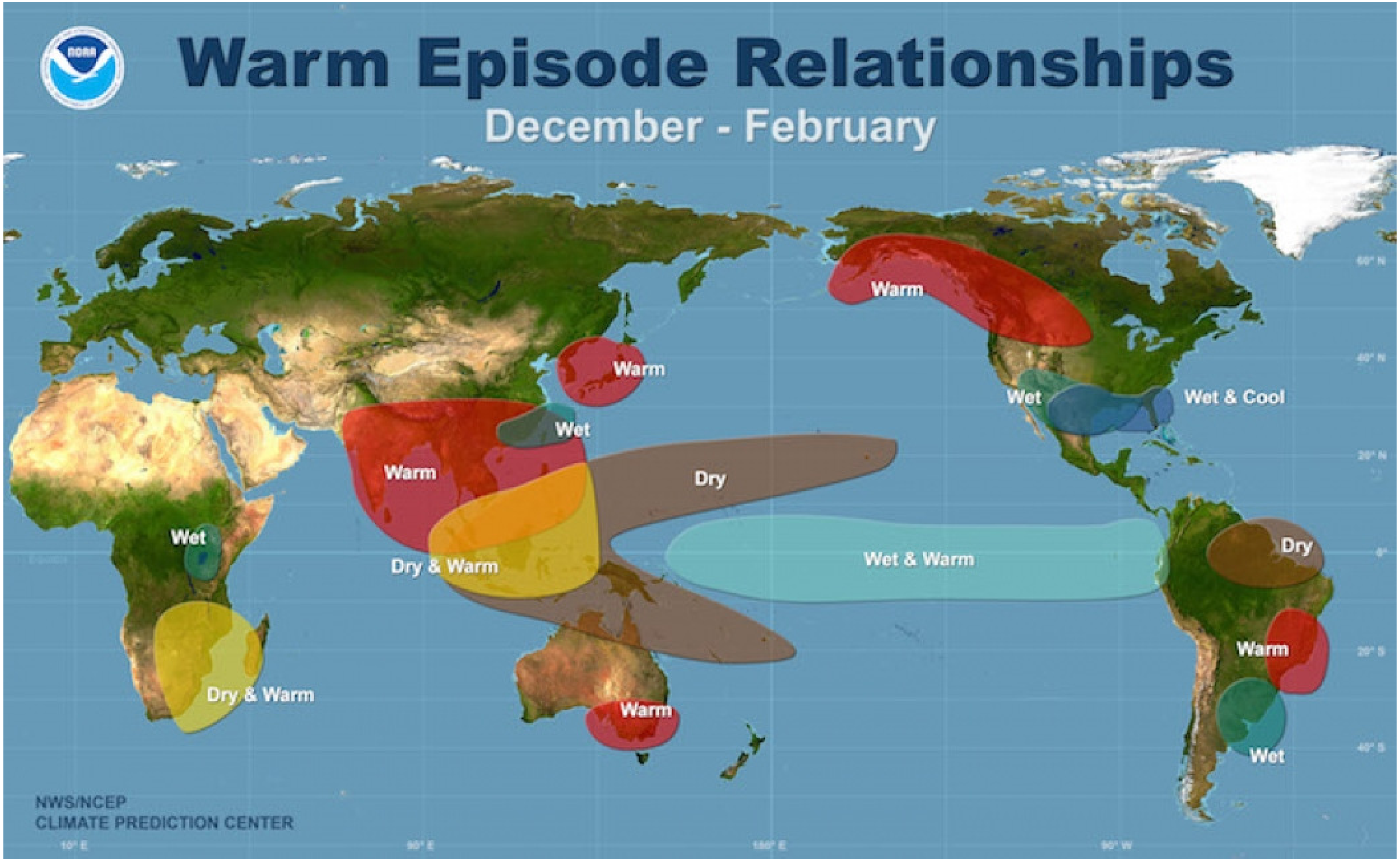
Very strong El Niños
"Eastern Pacific"

Moderate El Niños
"Central Pacific" or "Modoki"

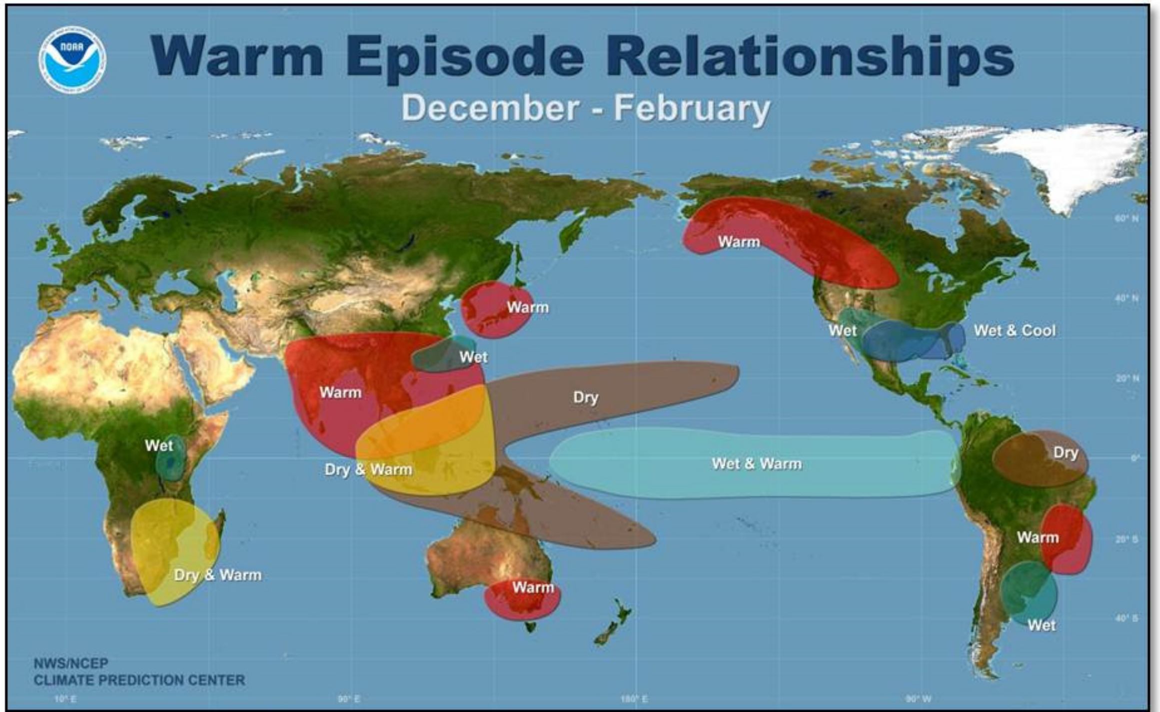
DJF-averaged SST anomalies from NCEP/OISST

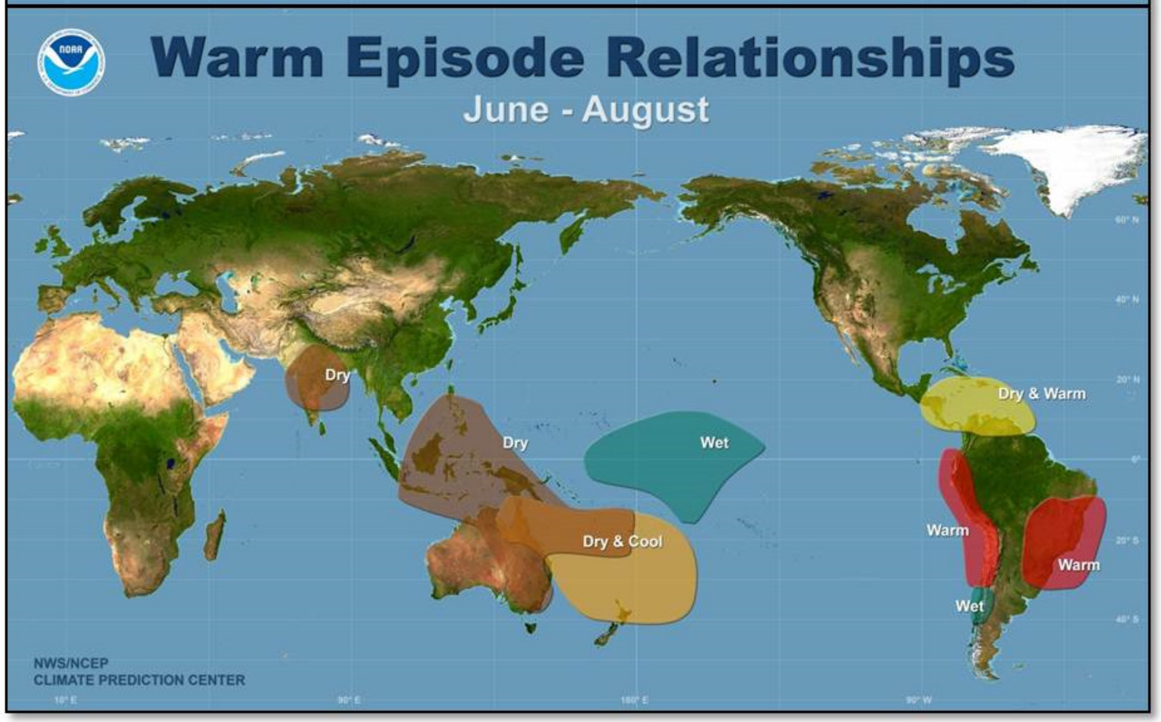


Global El Niño impacts

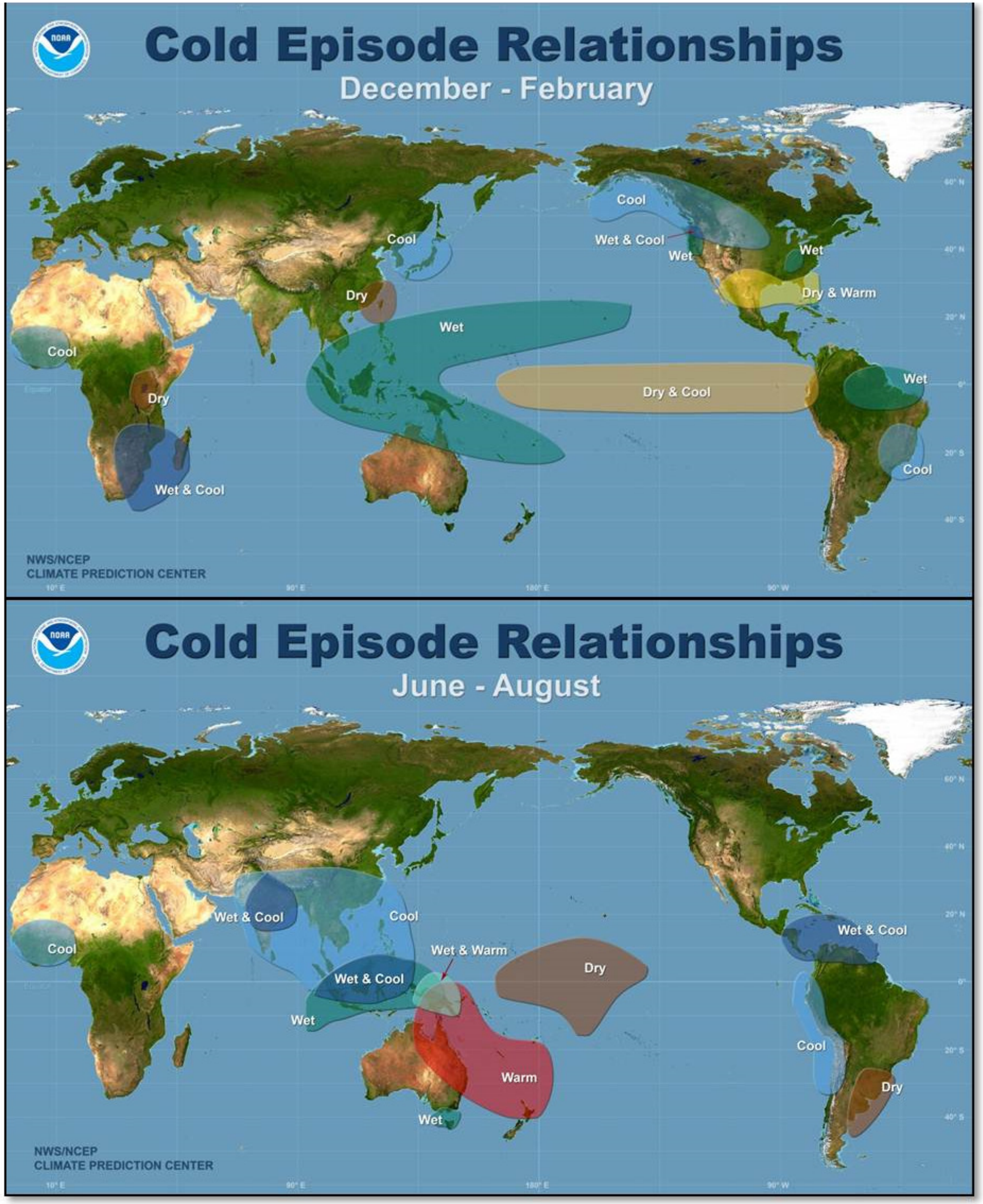


Global El Niño impacts





Global La Niña impacts



Example: ENSO impacts on Victoria

Example: forecast of Victoria average temperature

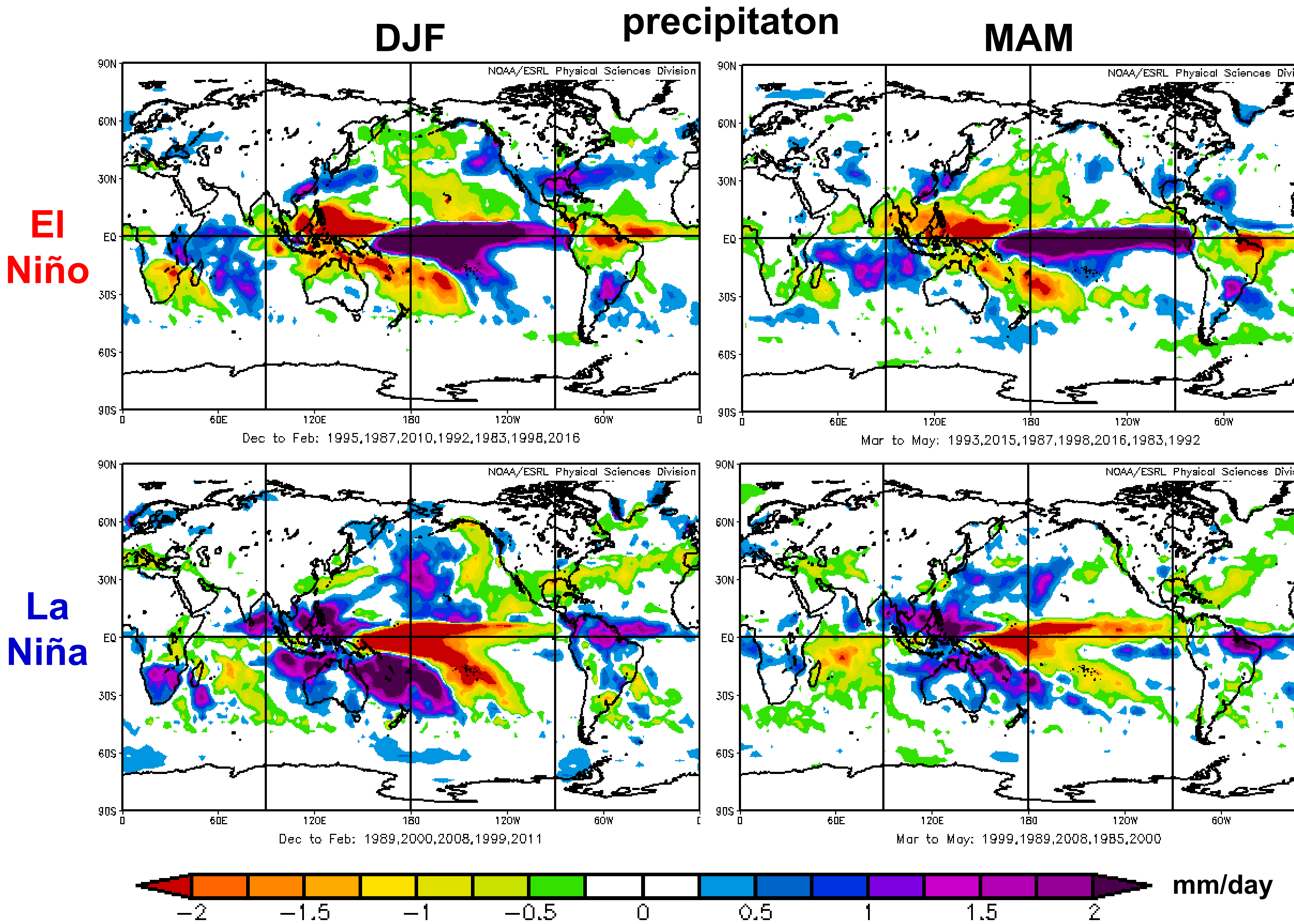
(departure from normal in °C for winters starting in Dec of indicated year)

Consider 30 recent winters (1981-2010)

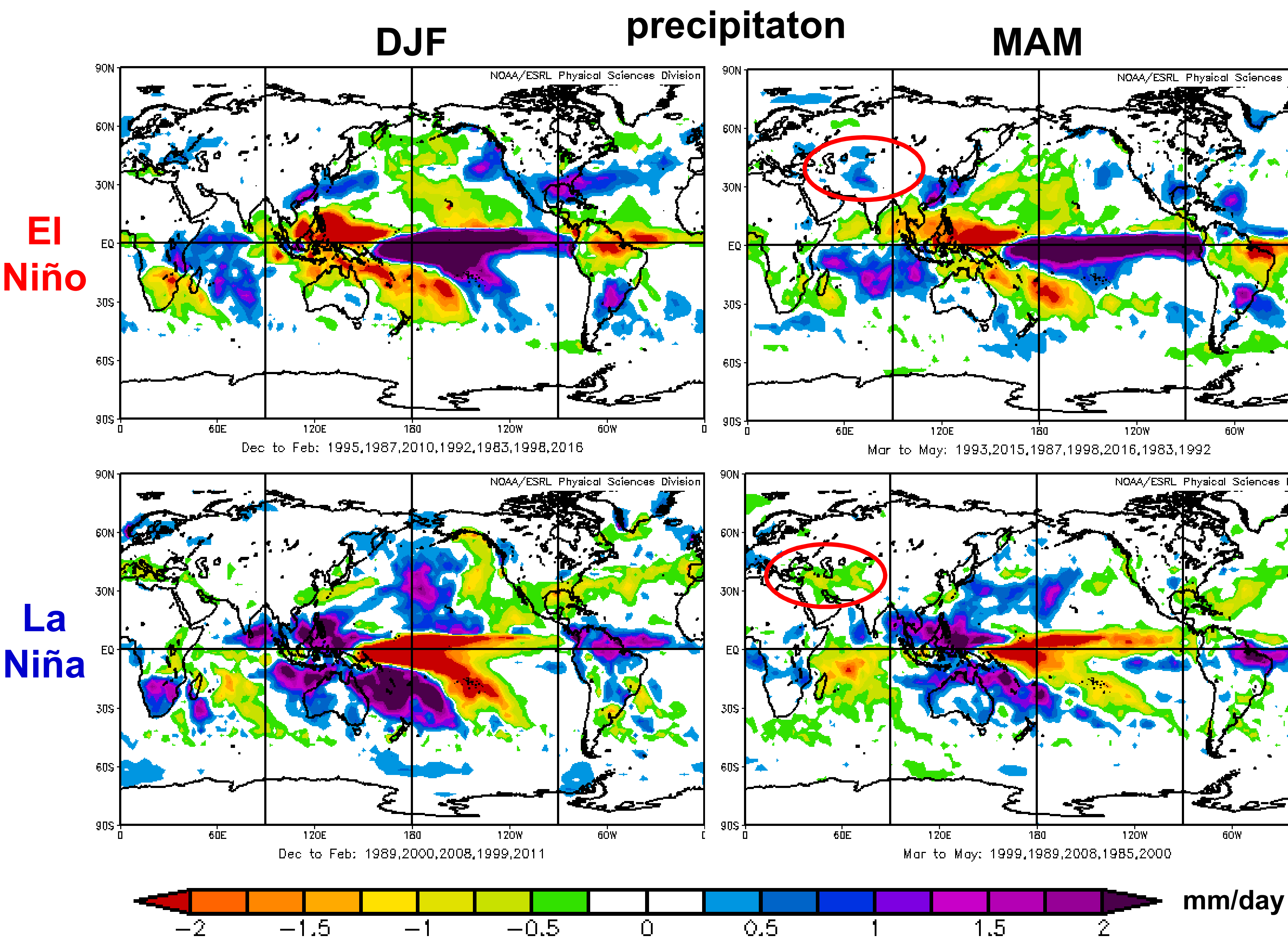
Divide into 10 coldest, 10 middle, 10 warmest:

below normal					near normal					above normal				
La Niña	La Niña			La Niña	La Niña		La Niña	La Niña	El Niño	El Niño		El Niño	El Niño	El Niño
1984 -2.07	1988 -1.54	1981 -1.12	1996 -0.78	2010 -0.39	1995 -0.37	1985 -0.17	1999 -0.11	2000 0.00	2006 0.28	1997 0.54	1993 0.77	1982 0.88	1986 0.99	2002 1.55
1992 -1.95	2008 -1.49	1990 -1.06	1983 -0.55	2007 -0.37	1998 -0.19	1987 -0.13	1989 -0.06	2001 0.12	1994 0.49	2004 0.57	2003 0.78	2009 0.96	2005 1.12	1991 1.71
				La Niña	La Niña	El Niño			El Niño	El Niño		El Niño		El Niño

Composites of strongest El Niño/La Niña events since 1981

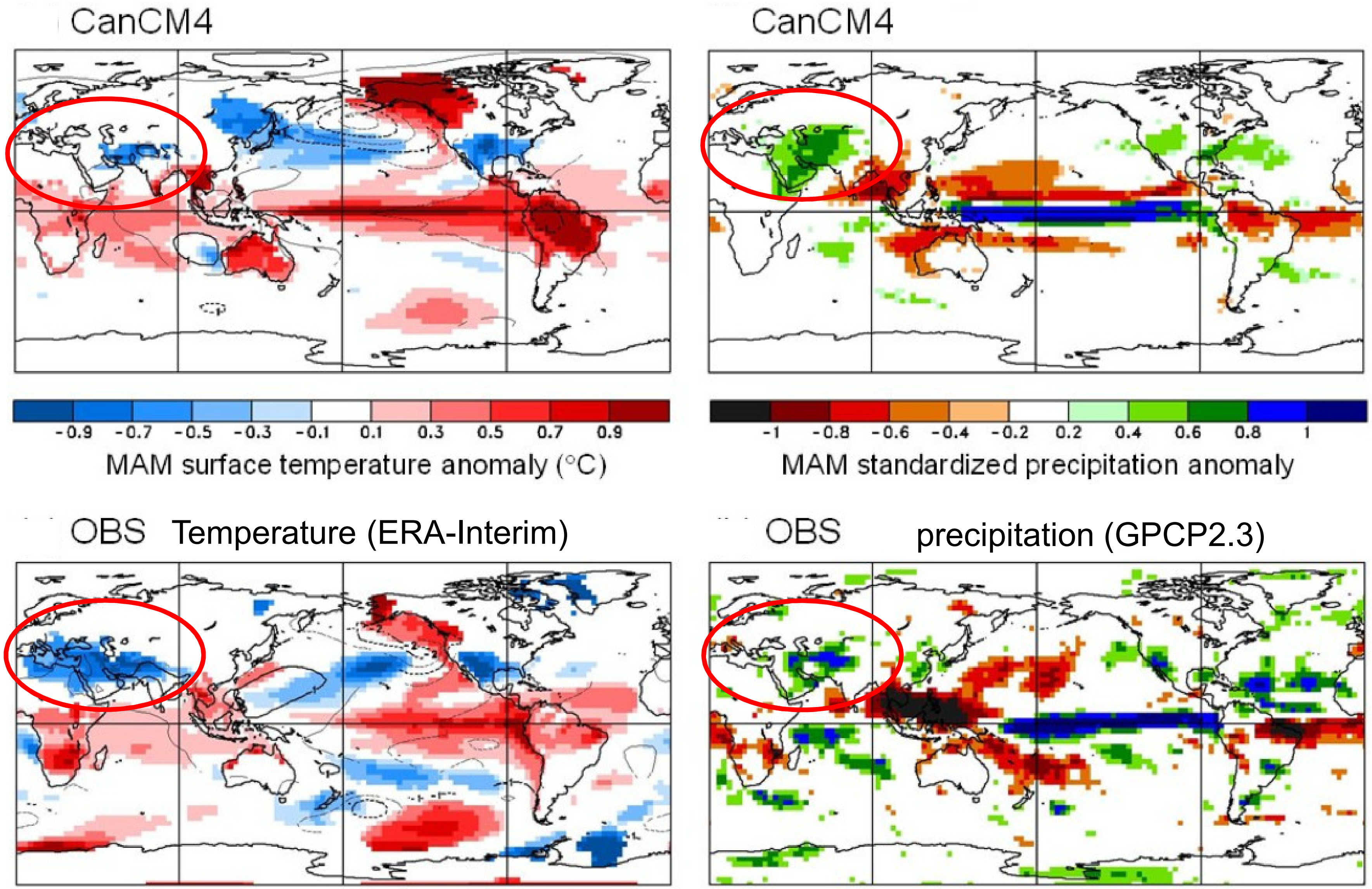


Composites of strongest El Niño/La Niña events since 1981



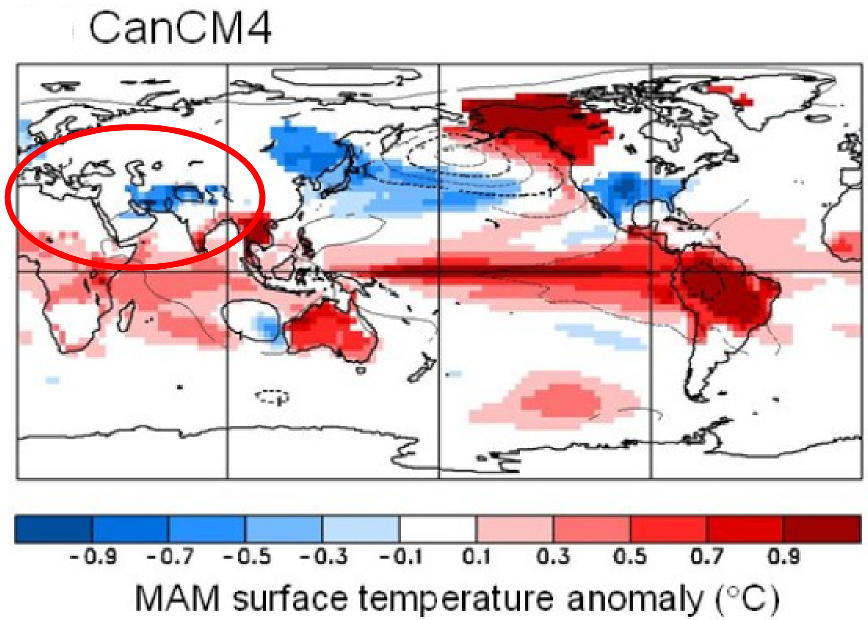
ENSO teleconnection to SW Asia in Spring

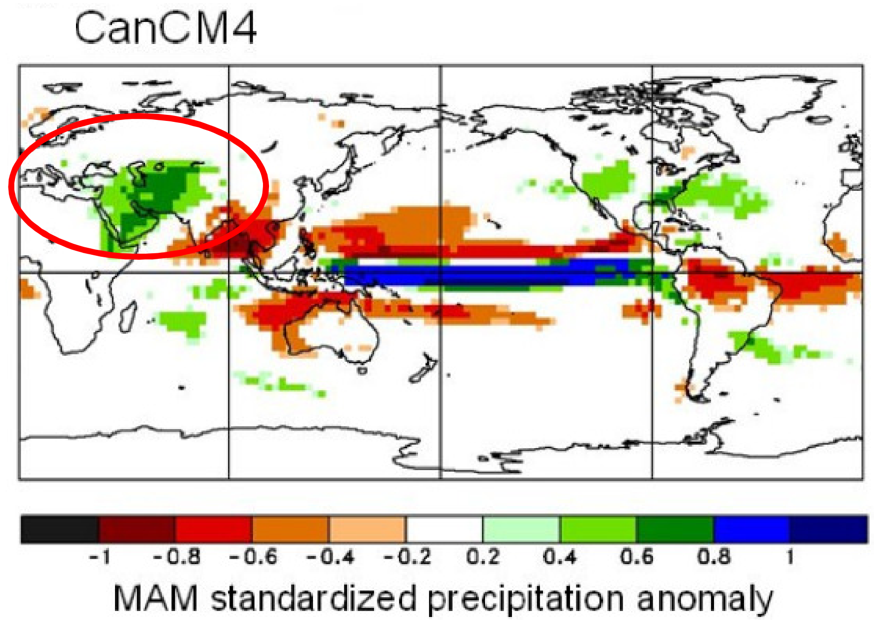
Regressions of MAM temperature and precipitation on Nino3.4 index (1981-2010, plotted where correlation>0.3)



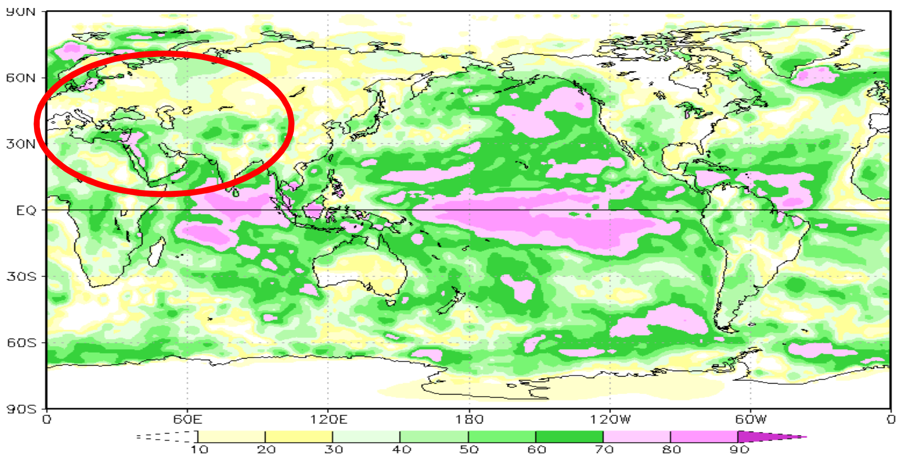
ENSO teleconnection to SW Asia in Spring

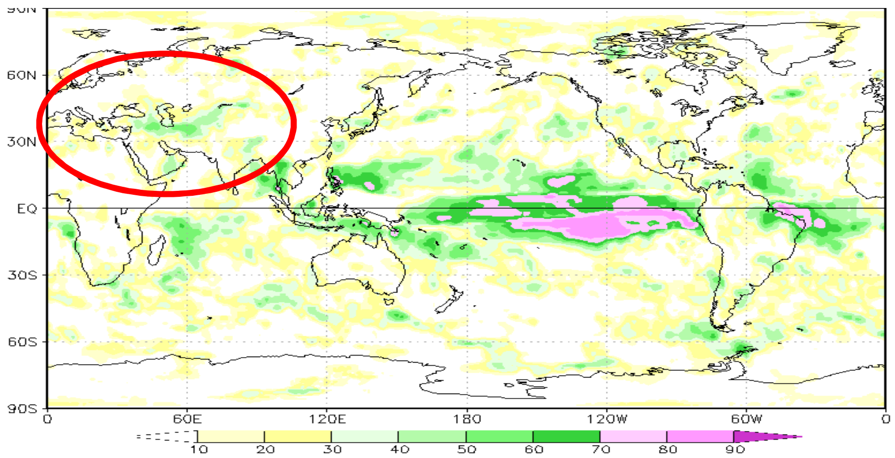
Regressions of MAM temperature and precipitation on Nino3.4 index (1981-2010, plotted where correlation>0.3)





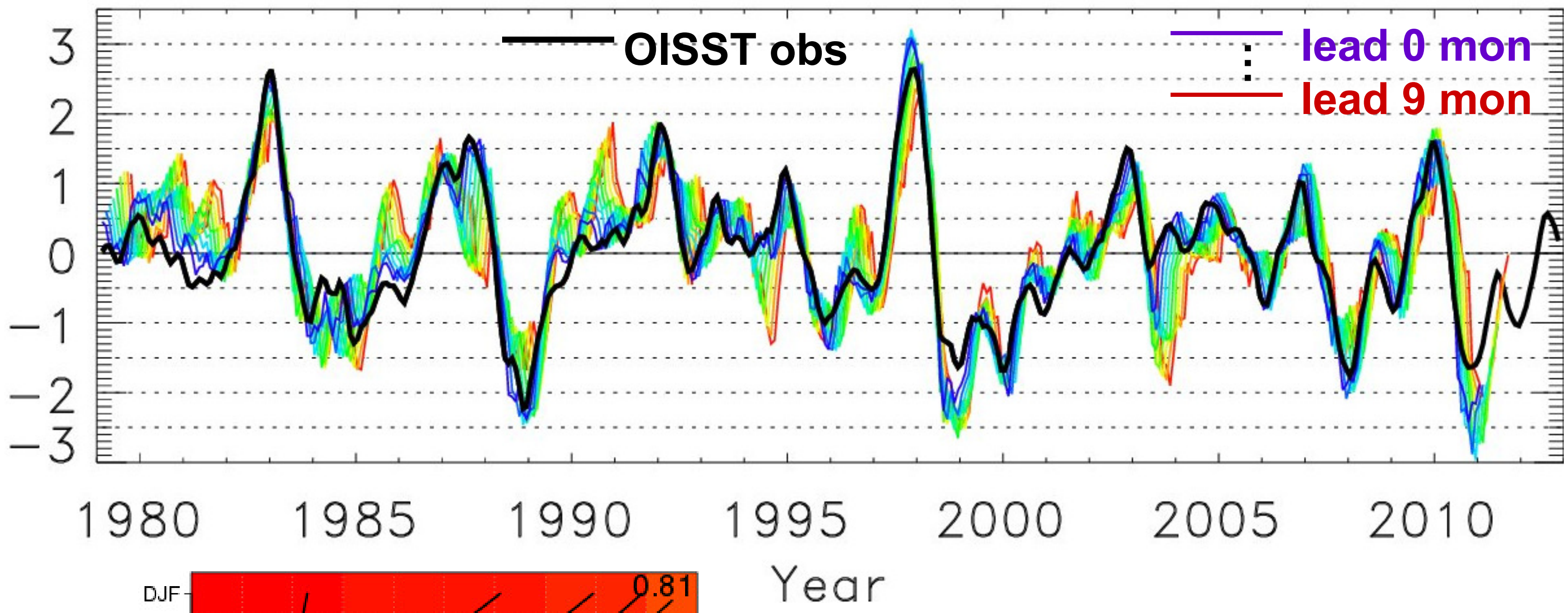
CanCM4 skill

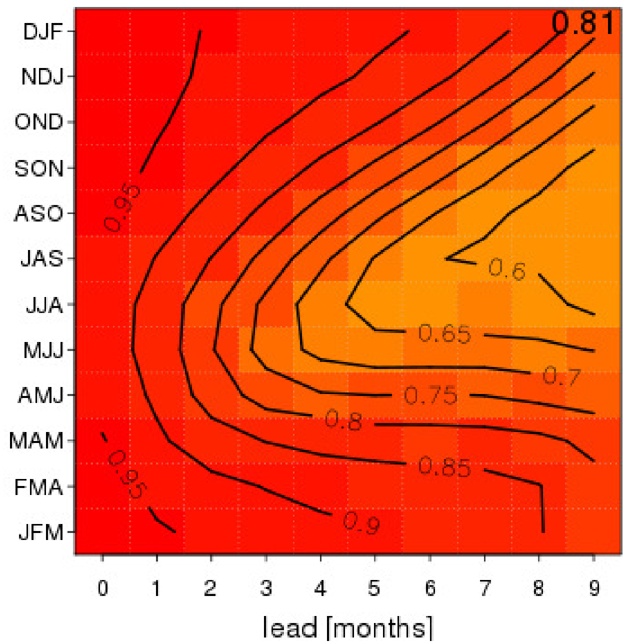




Historical CanCM3/4 ENSO predictions

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

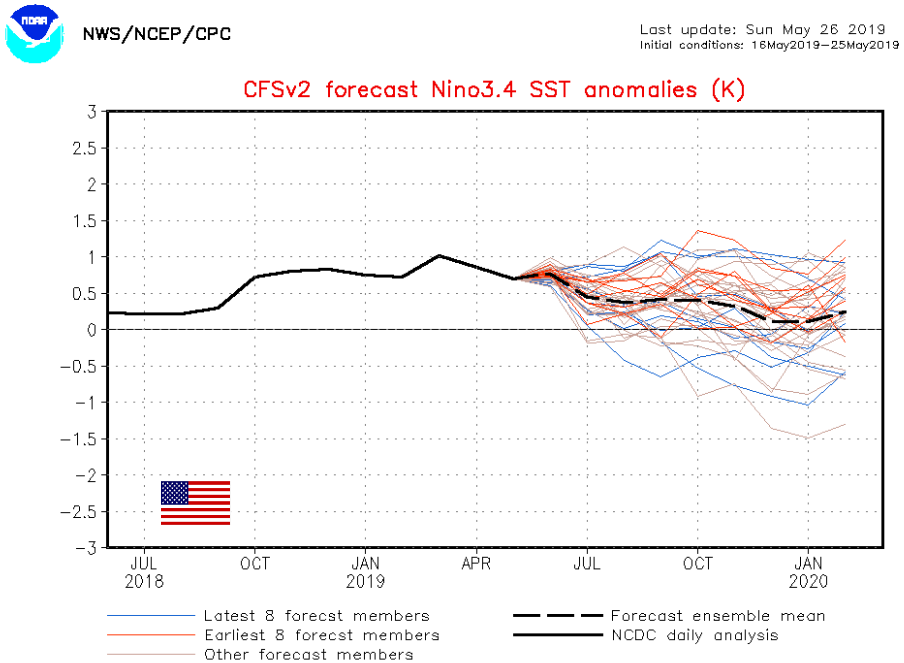


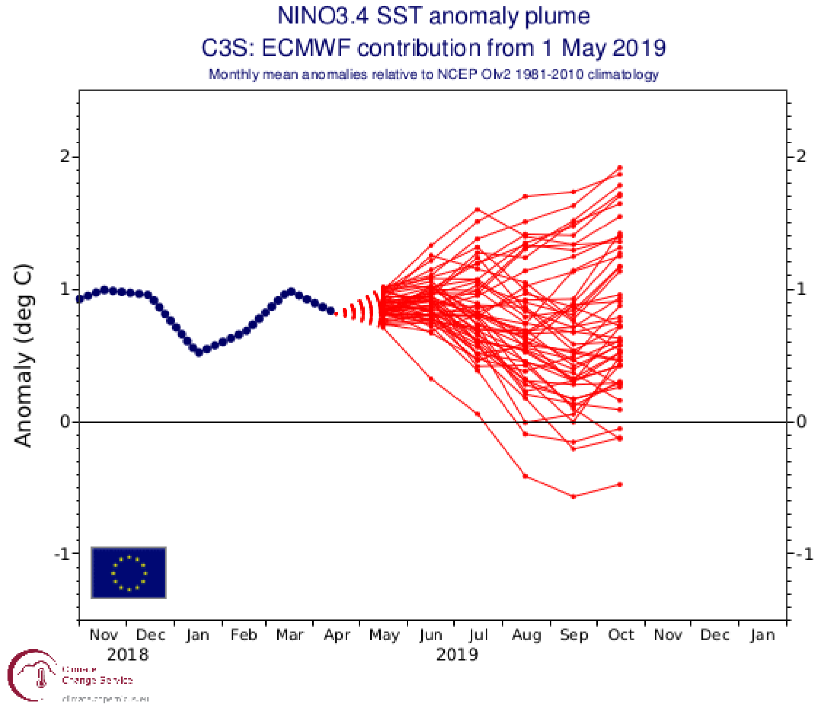


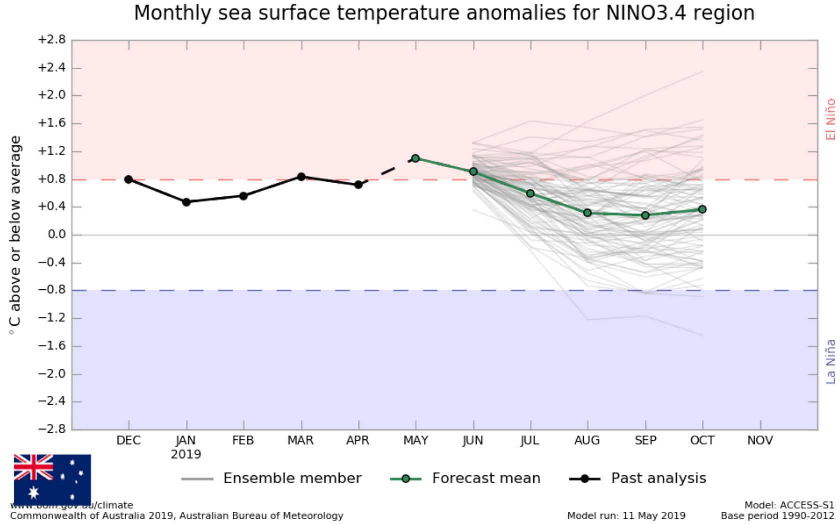
Nino3.4 anomaly correlation skill

- **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

Nino3.4 ensemble plumes from May 2019







→ similar message: weak El Niño trending toward ENSO-neutral, with some chance of persisting

Multi-model ensembles

Why multi-model ensembles?

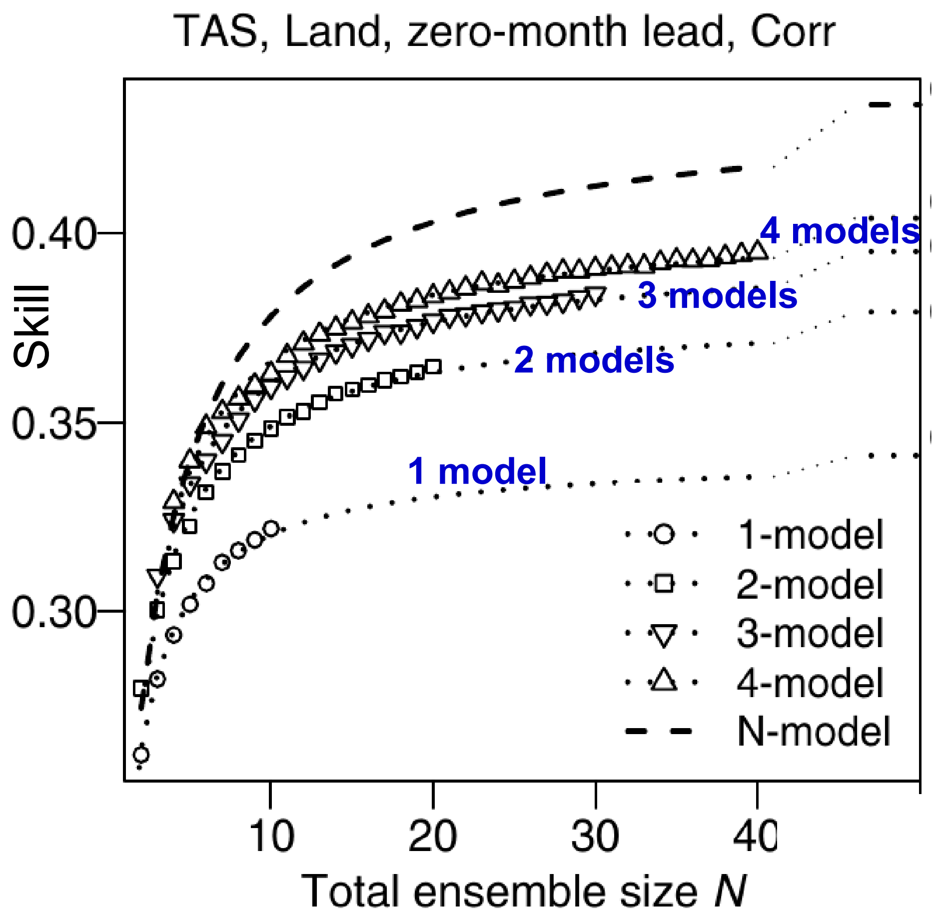
1) Different models have different strengths and weaknesses

   - *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*

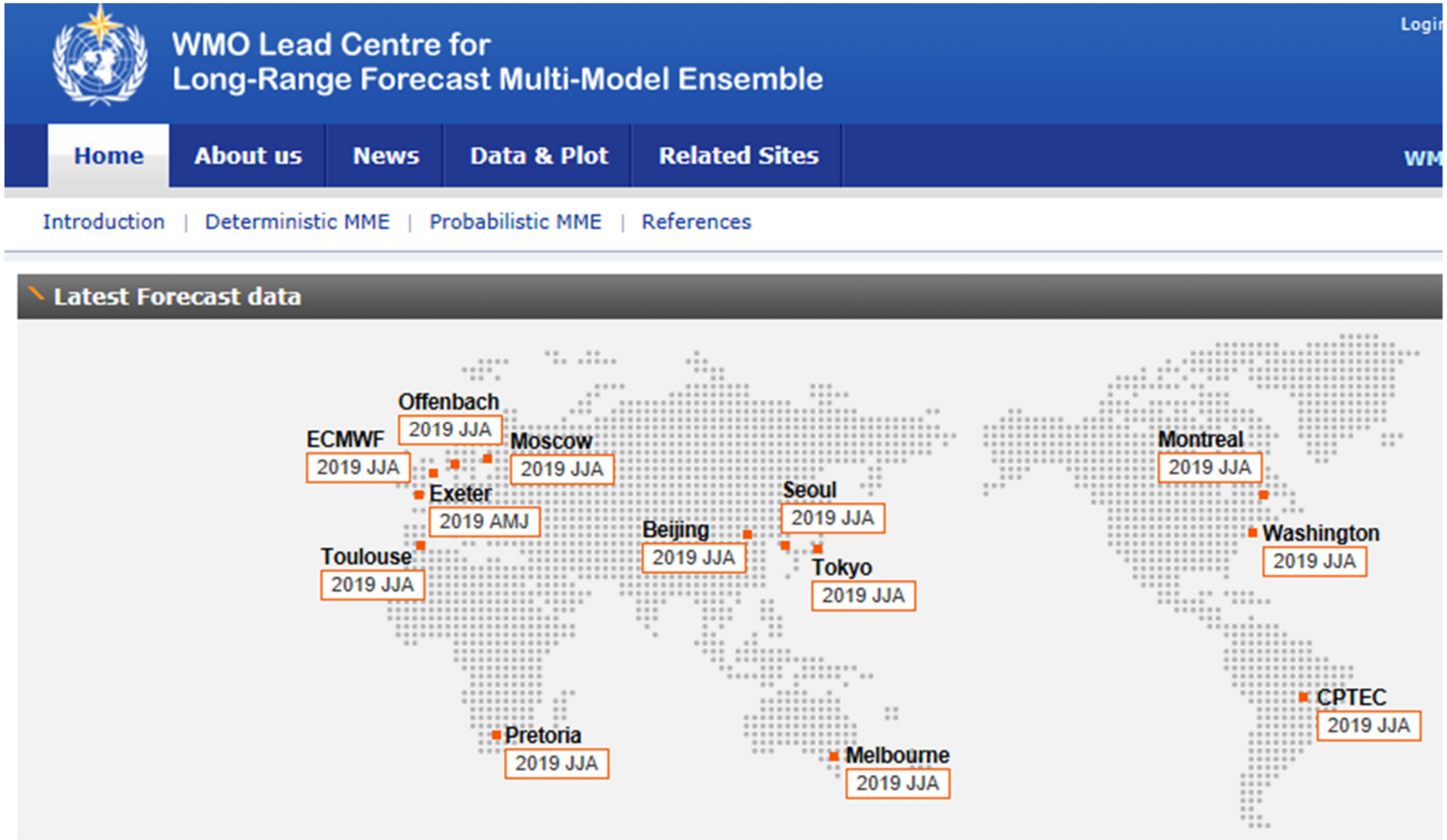
2) More ensemble members available by combining models than from individual models



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

WMO multi-model ensemble

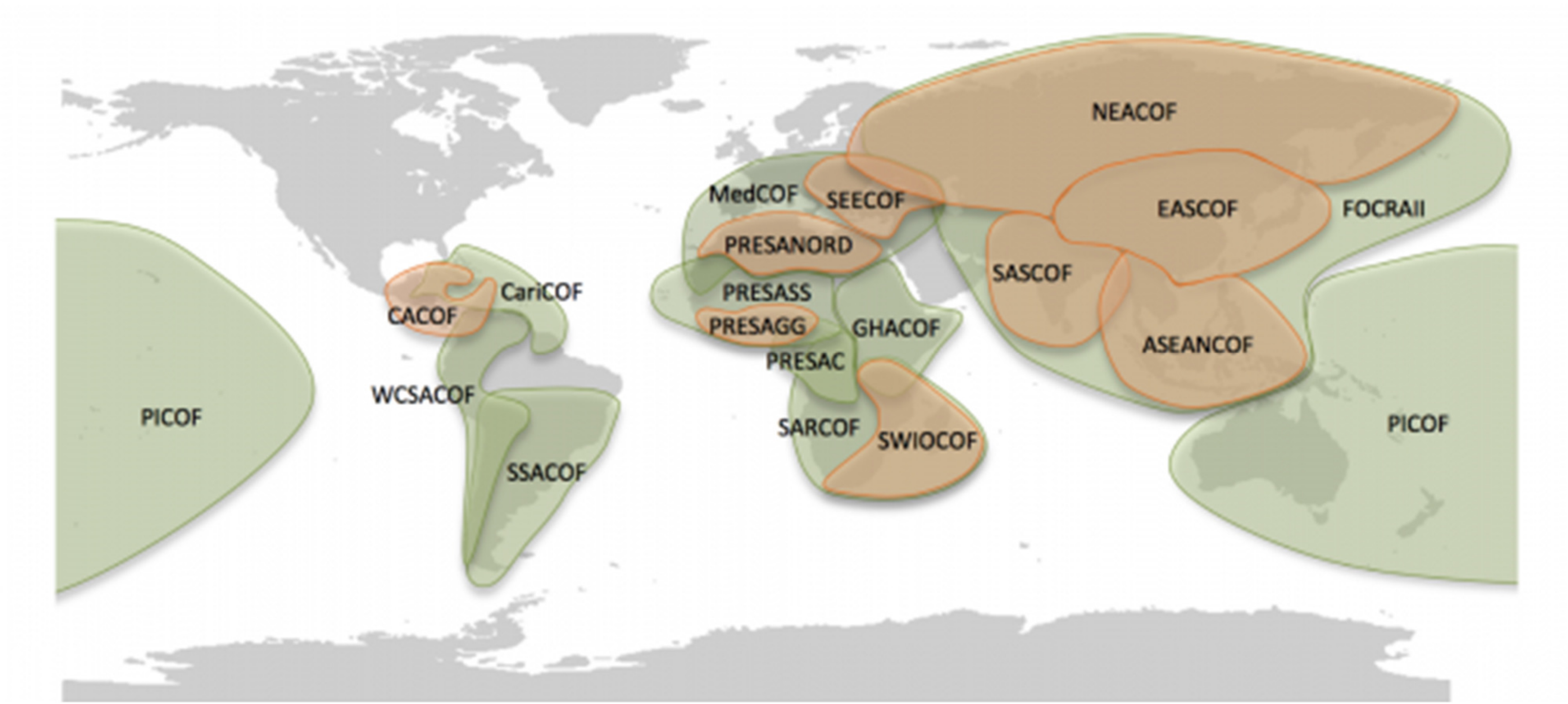
https://www.wmolc.org/



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

WMO multi-model ensemble

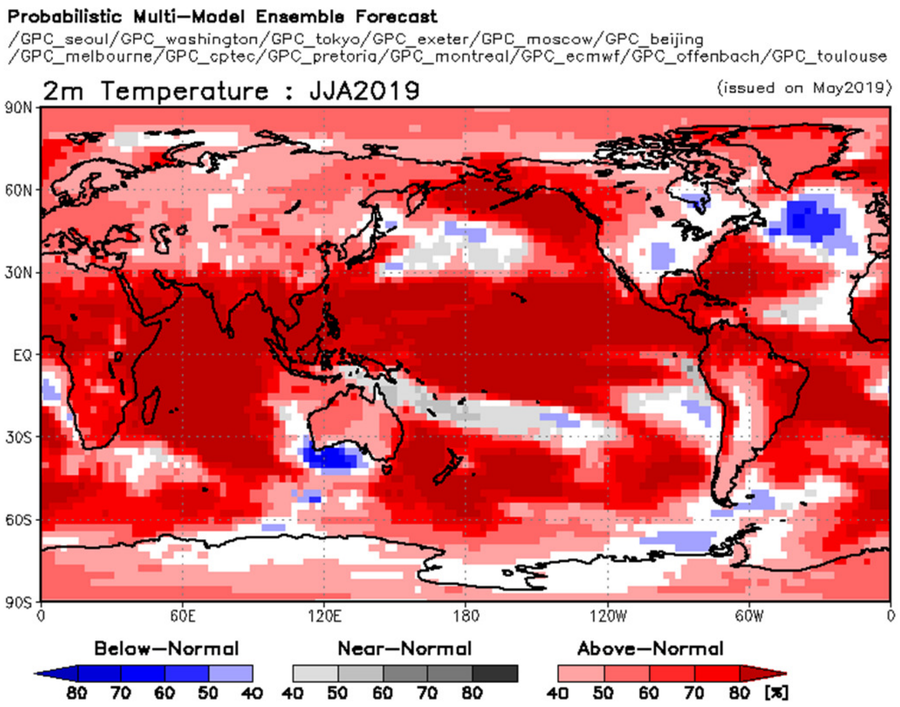
https://www.wmolc.org/

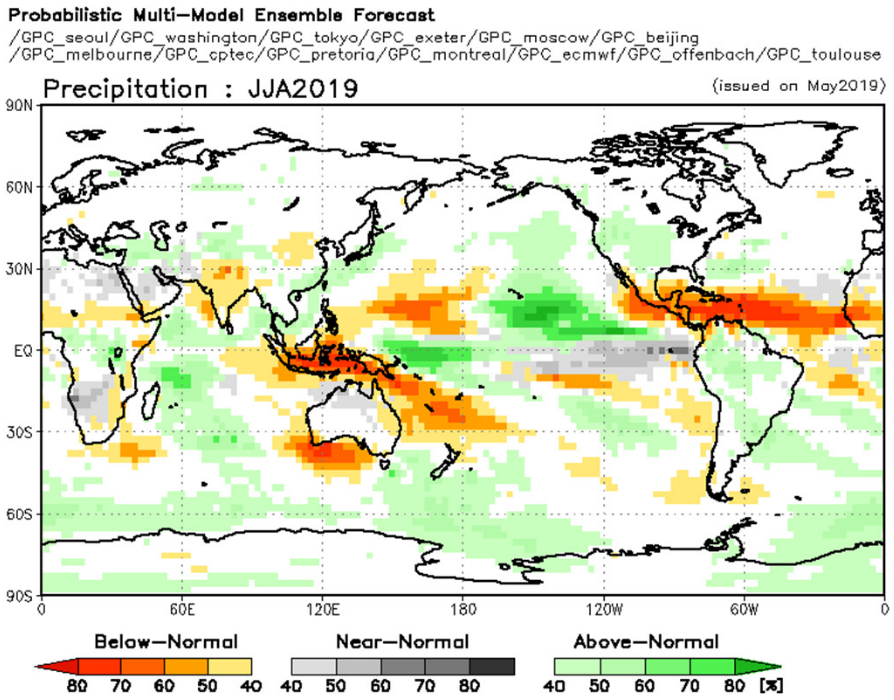


- 13 Global Producing Centres (GPCs) representing different meteorological services
- Forecast information provided to Regional Climate Centres (RCCs) and Regional Climate Outlook Forums (RCOFs)
- Maps publicly available, data password protected

WMO multi-model ensemble

https://www.wmolc.org/





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

APCC multi-model ensemble

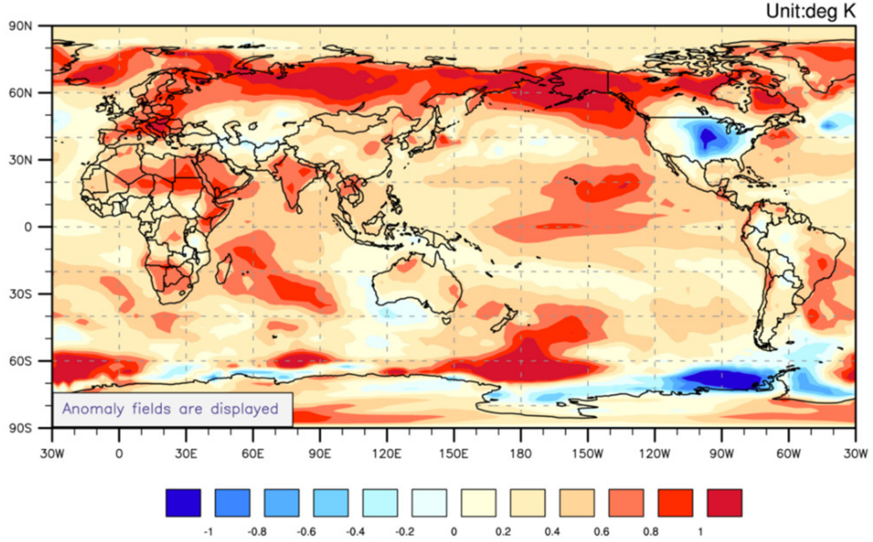
APCC
APEC CLIMATE CENTER

http://www.apcc21.org/ser/outlook.do

Climate Outlook for June - November 2019

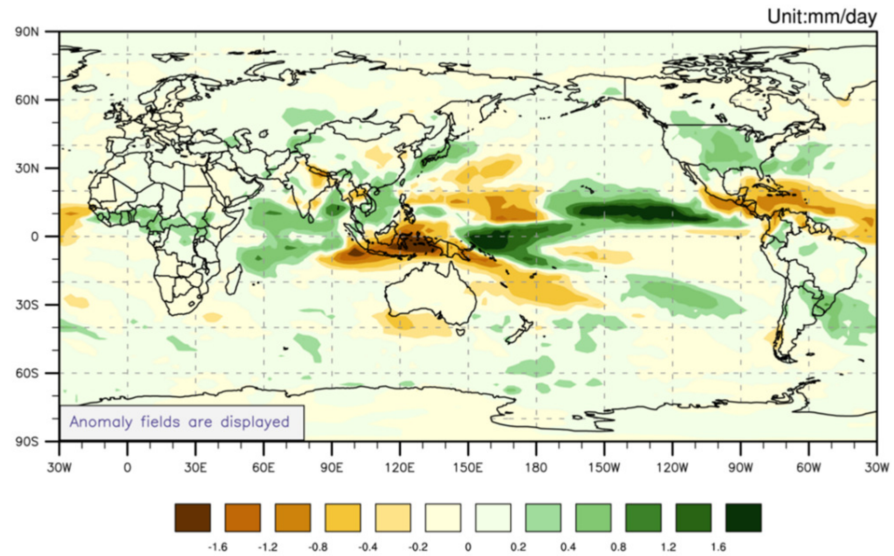
- During April 2019, El Niño conditions persisted with positive sea surface temperature anomalies across the equatorial Pacific Ocean.
- The latest APCC ENSO outlook suggests about a 35% probability for weak El Niño conditions during June – August 2019 and the conditions are likely to persist through September – November 2019.

Temperature at 2m for June-August 2019



Issued: 25 May, 2019 © APEC Climate Center

Precipitation for June-August 2019



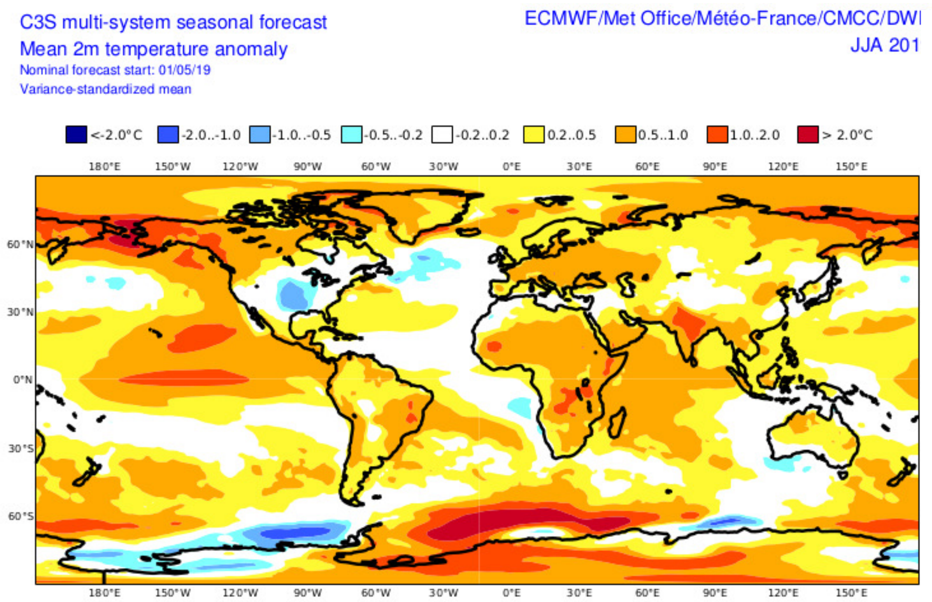
Issued: 25 May, 2019 © APEC Climate Center

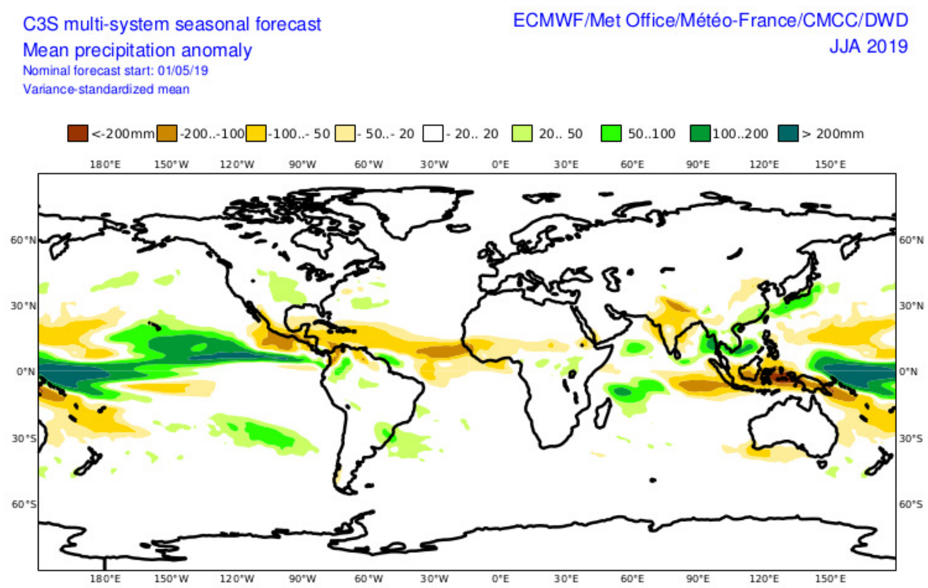
- Includes models USA, Canada, Australia, Korea, …
- Month 1-3 and 4-6 probabilistic & deterministic forecast maps publicly available

Copernicus multi-model ensemble

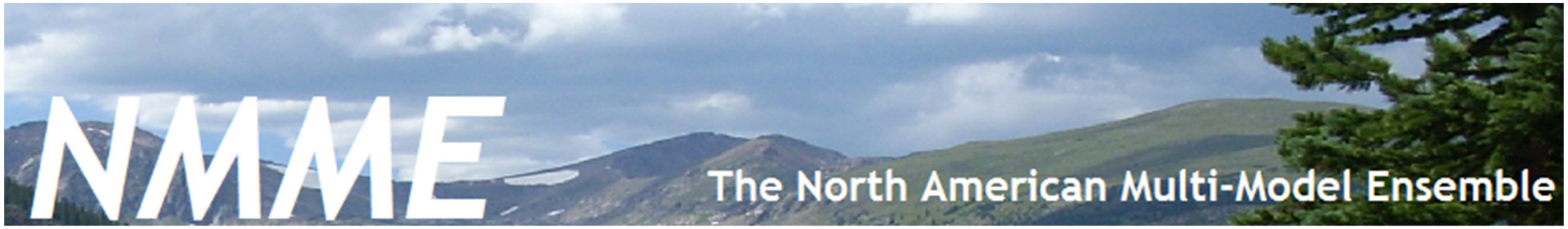
Climate Change Service

https://climate.copernicus.eu/seasonal-forecasts

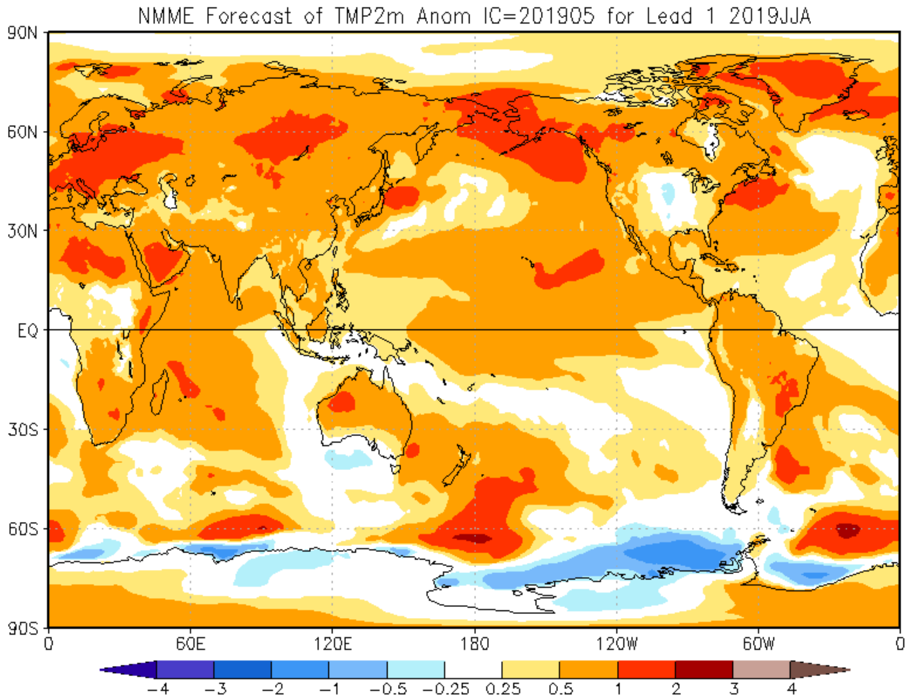


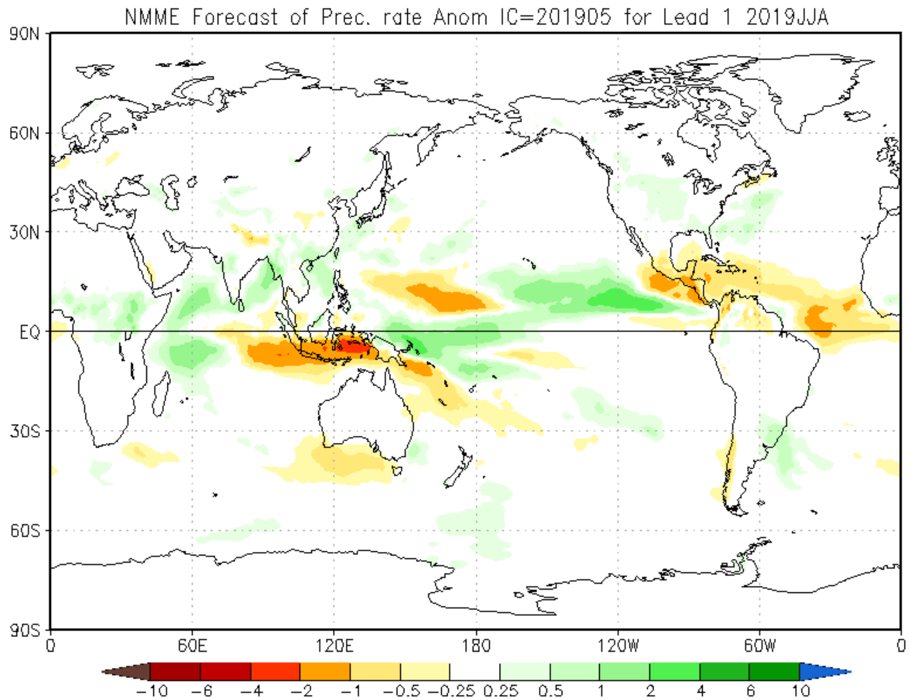


- Currently models include ECMWF, UK Met Office, Météo-France, CMCC, DWI
- Numerical data publicly available
- More models to be added



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



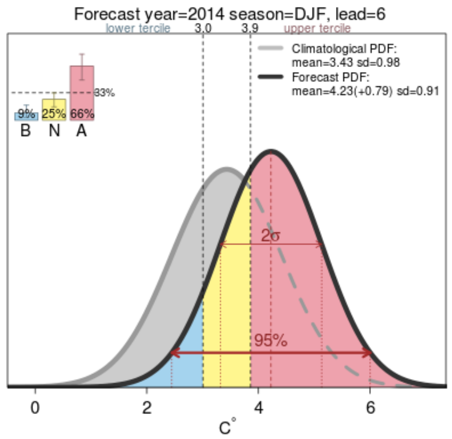


- Currently 7 models from US, Canada
- Numerical data publicly available
- More in tomorrow’s lecture

Summary

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

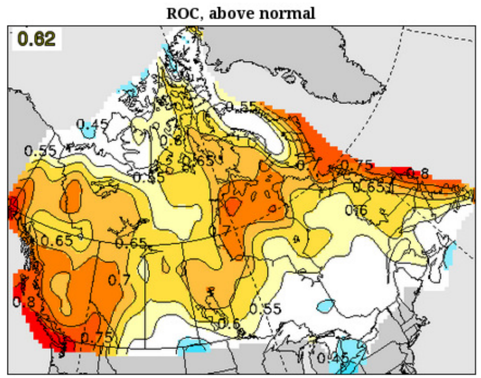
1) Forecasts must communicate uncertainty



Probabilities

→ *ensemble forecasts*

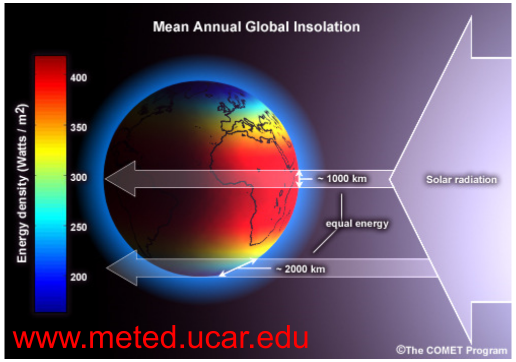
2) Forecasts should be interpreted in the context of past performance (skill)

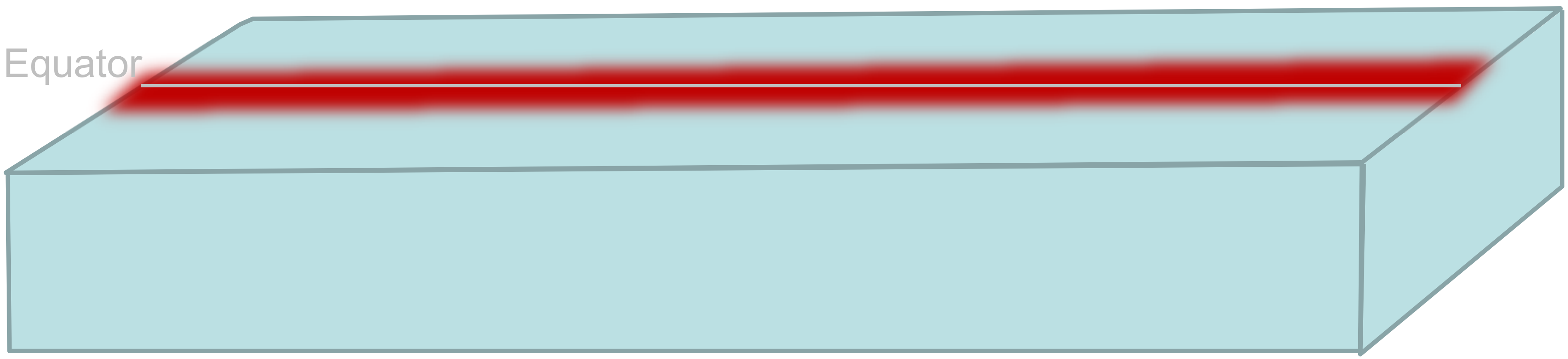


→ many years of *hindcasts*

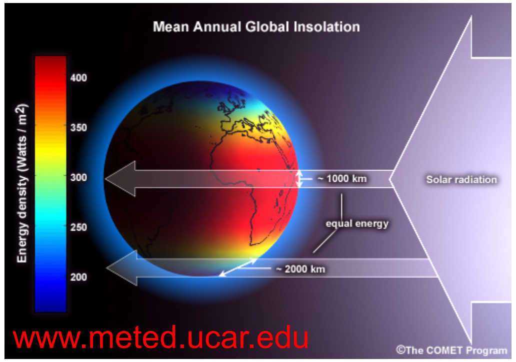
Extra slides

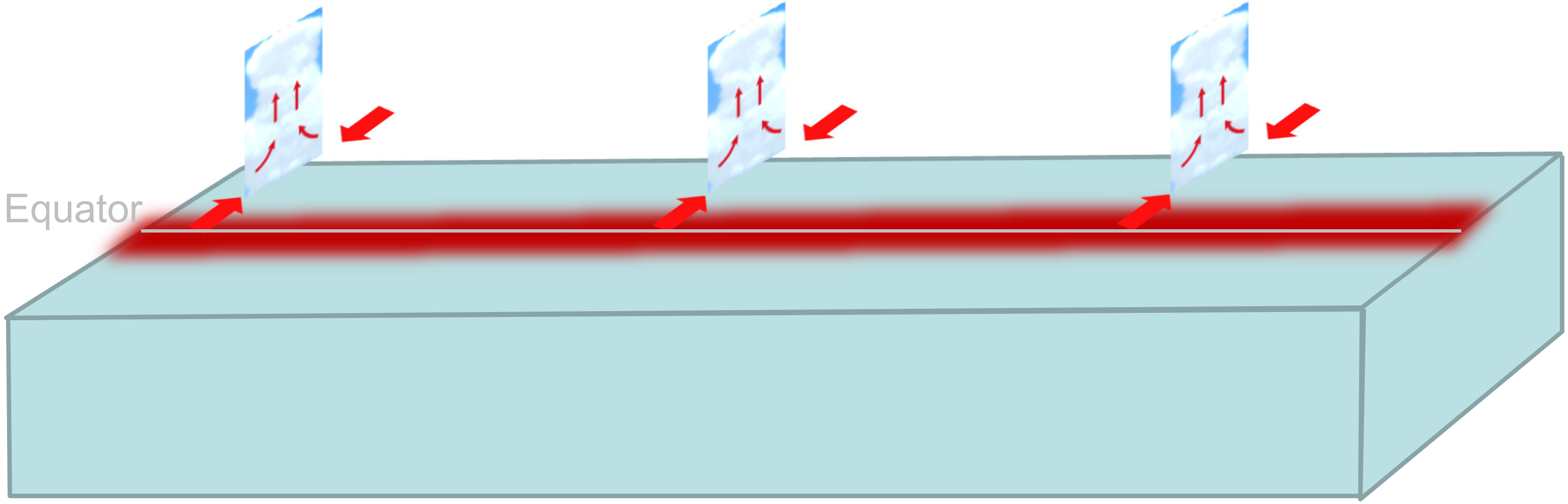
Equatorial atmosphere/ocean



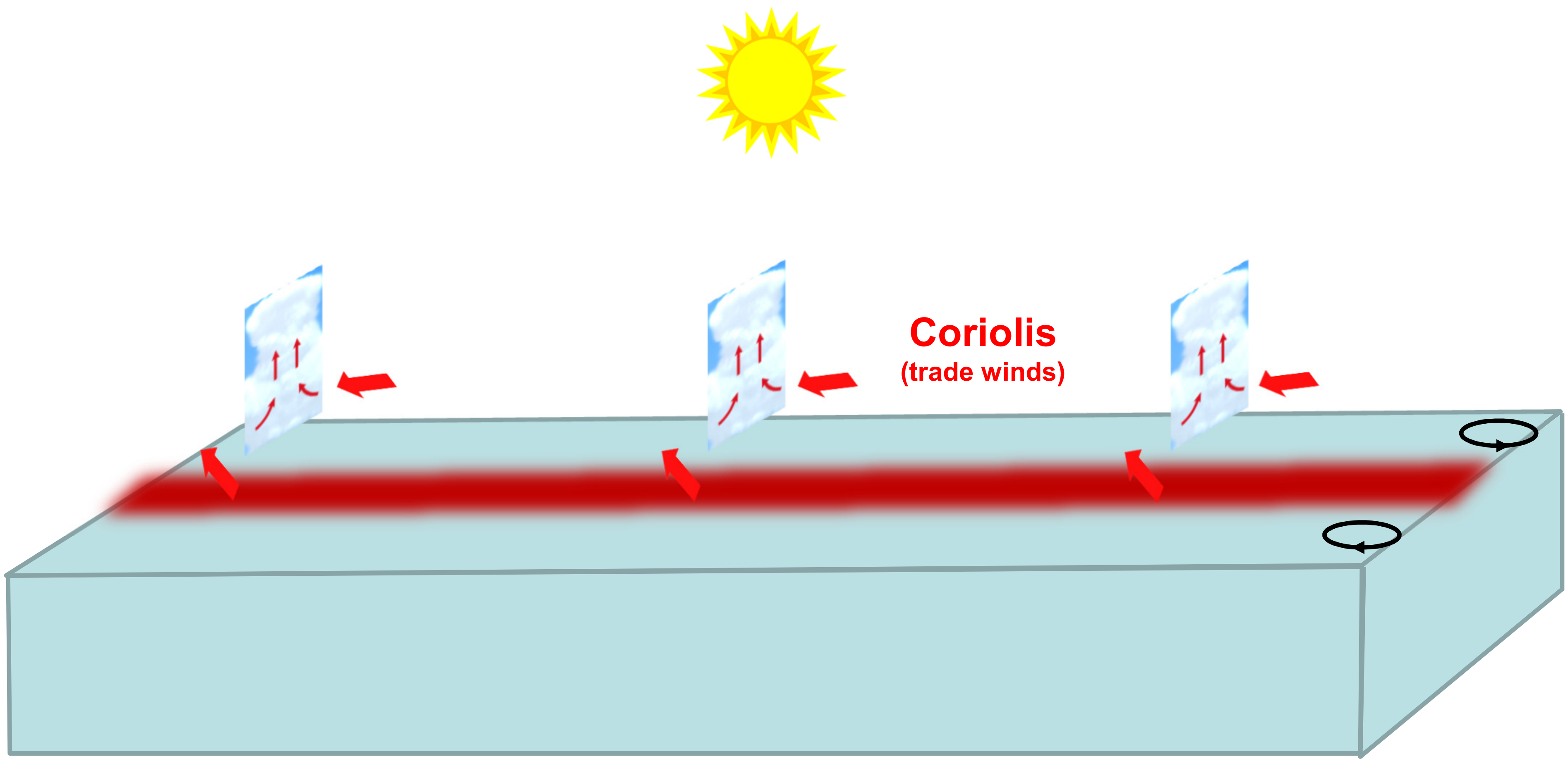


Equatorial atmosphere/ocean

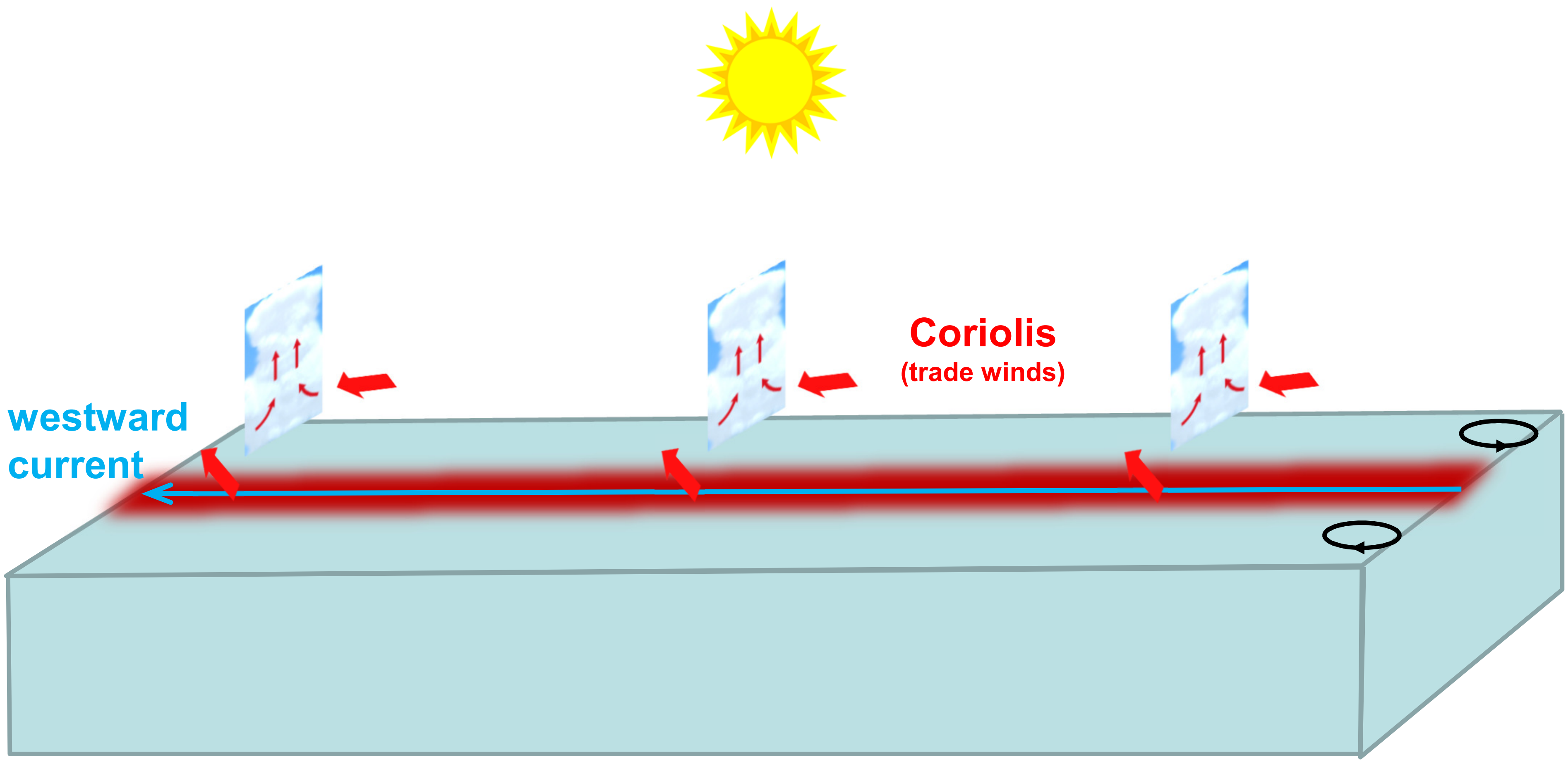




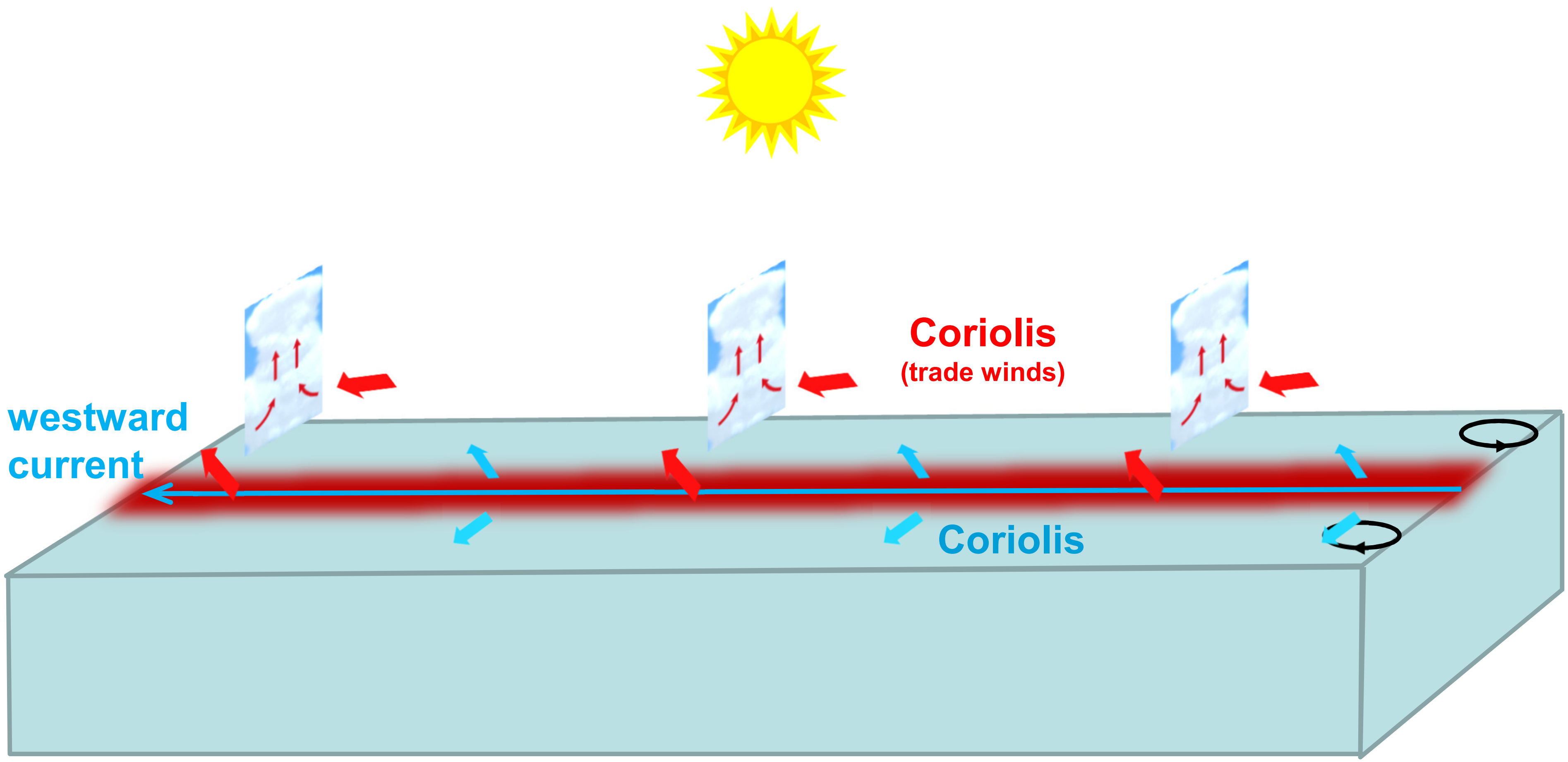
Equatorial atmosphere/ocean



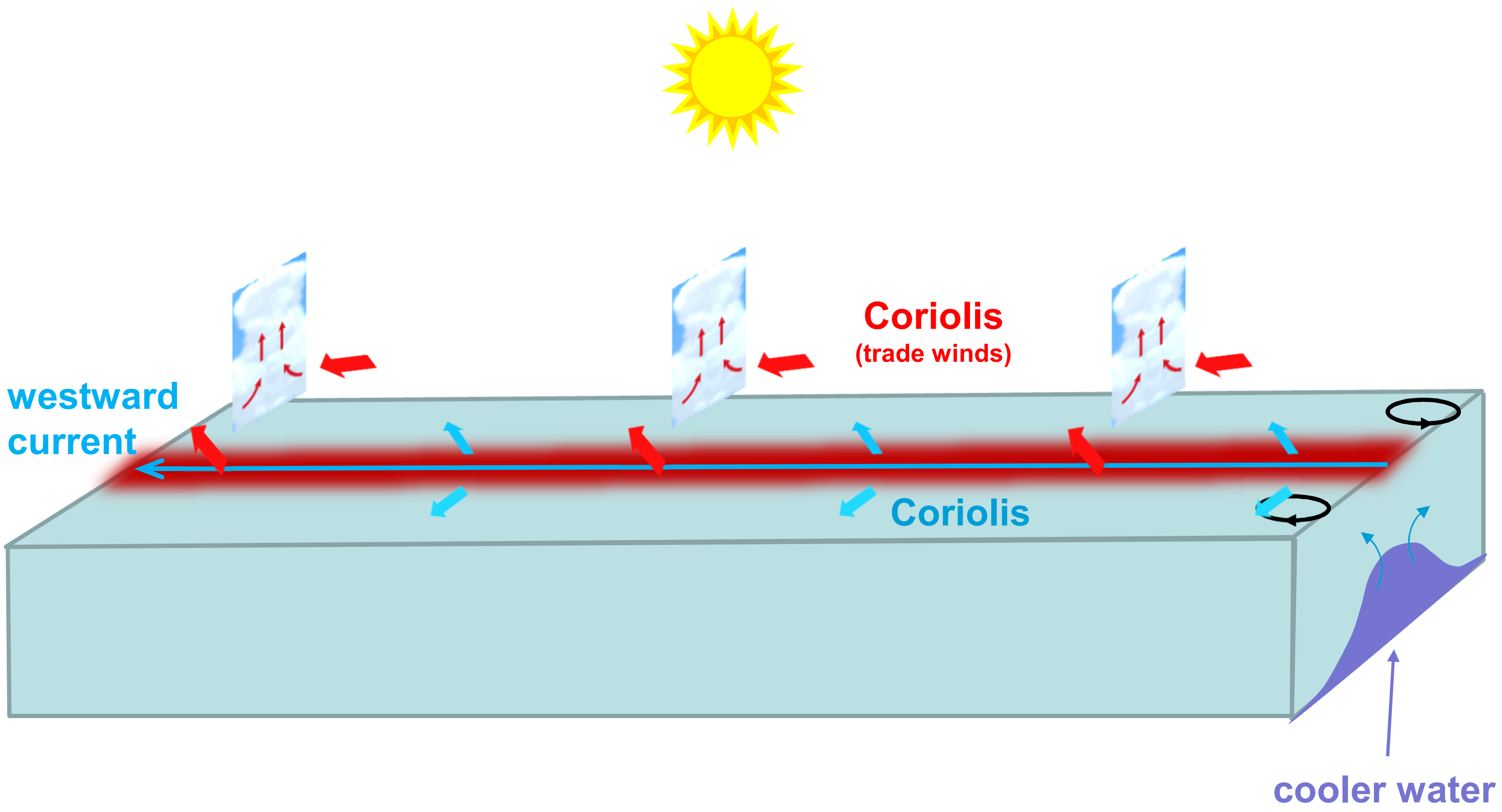
Equatorial atmosphere/ocean



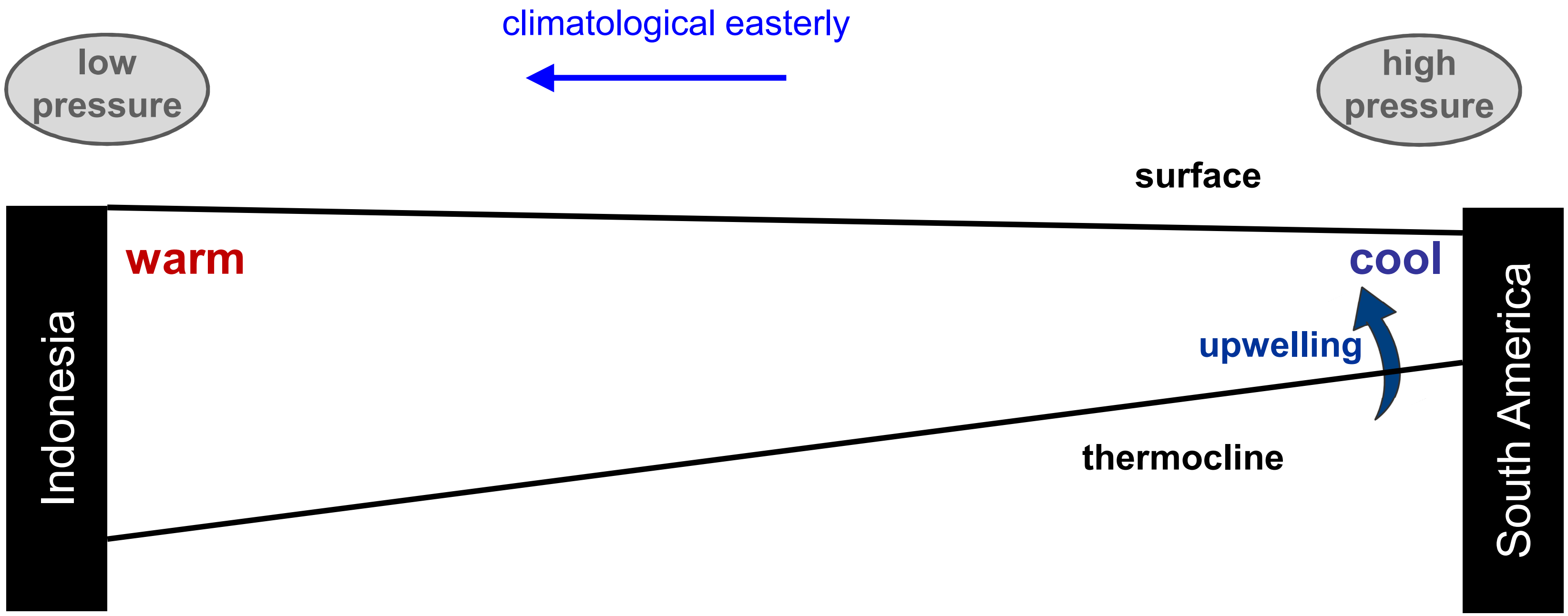
Equatorial atmosphere/ocean



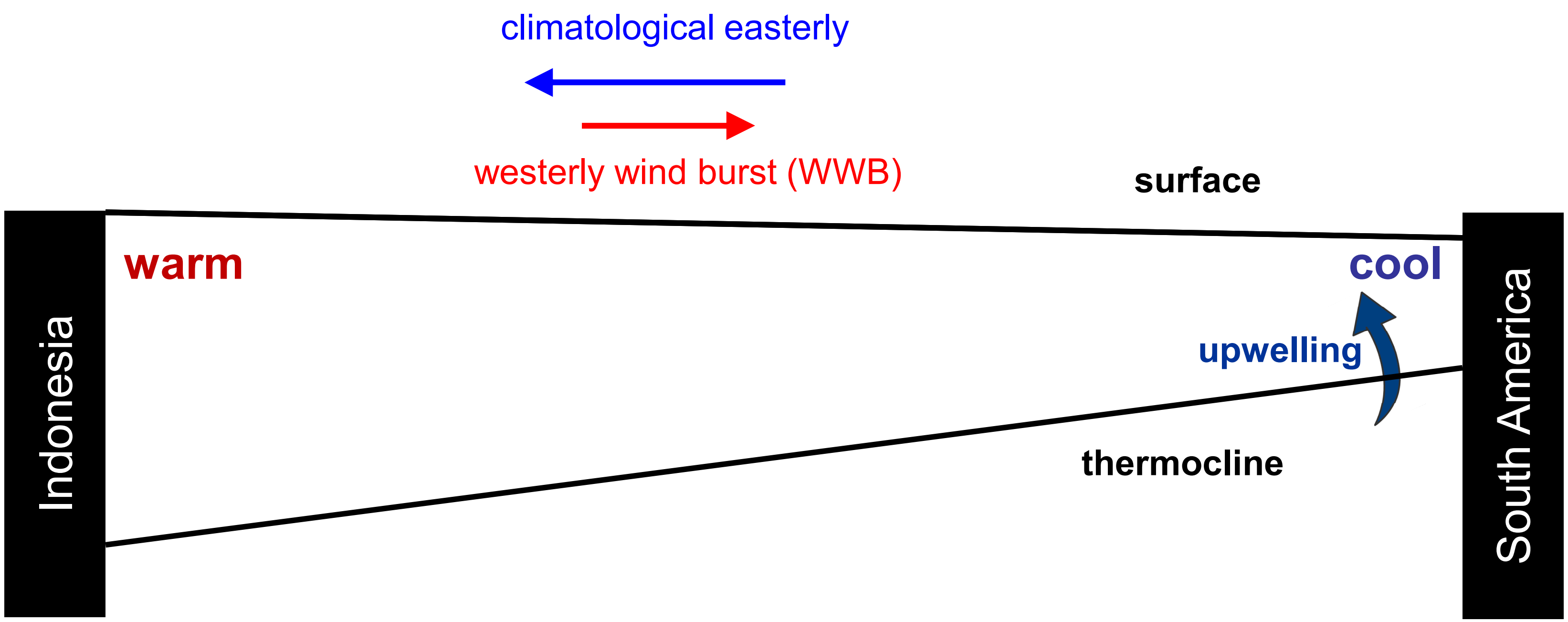
Equatorial atmosphere/ocean



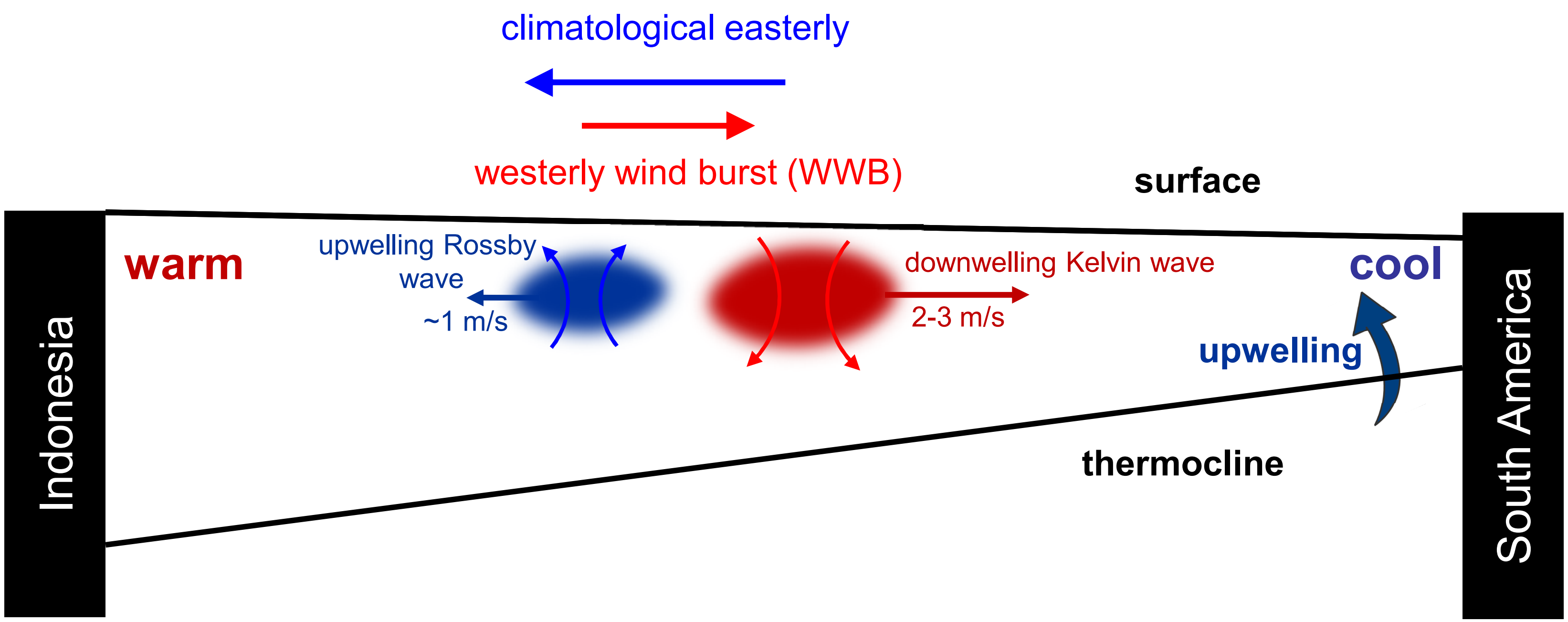
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



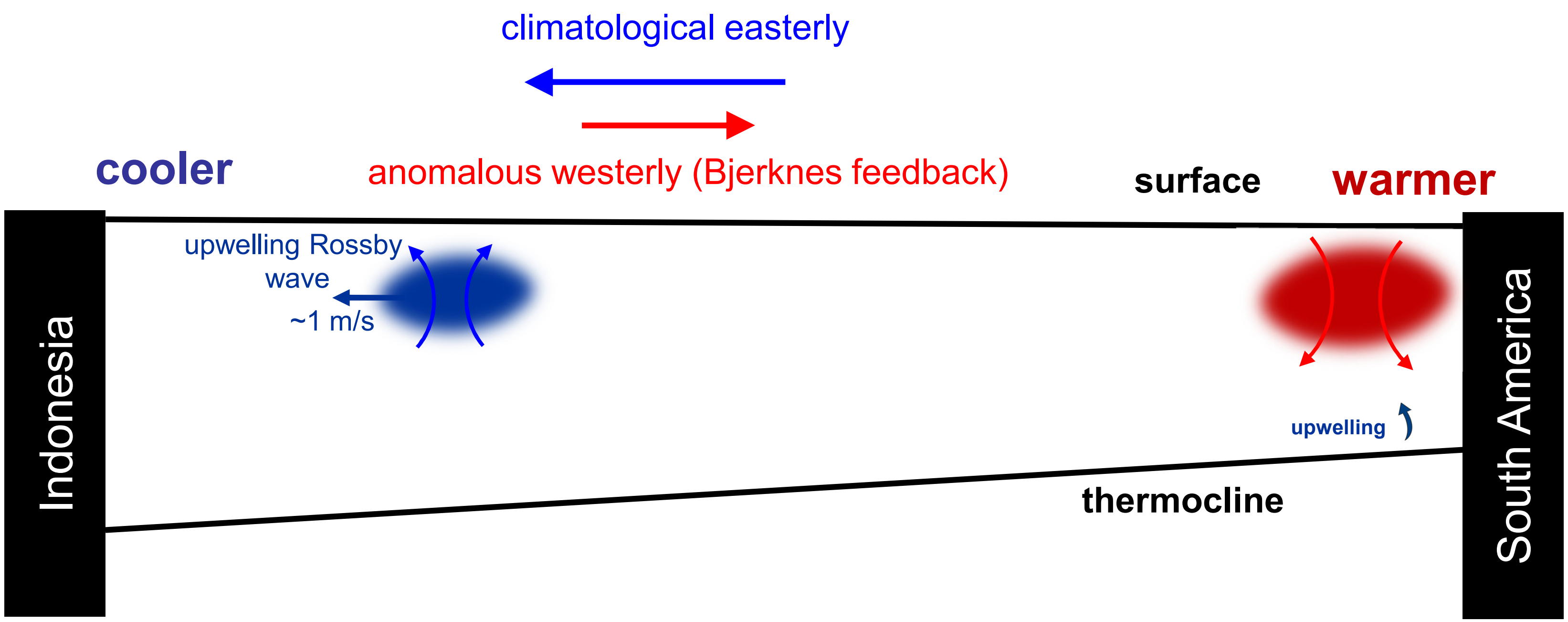
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



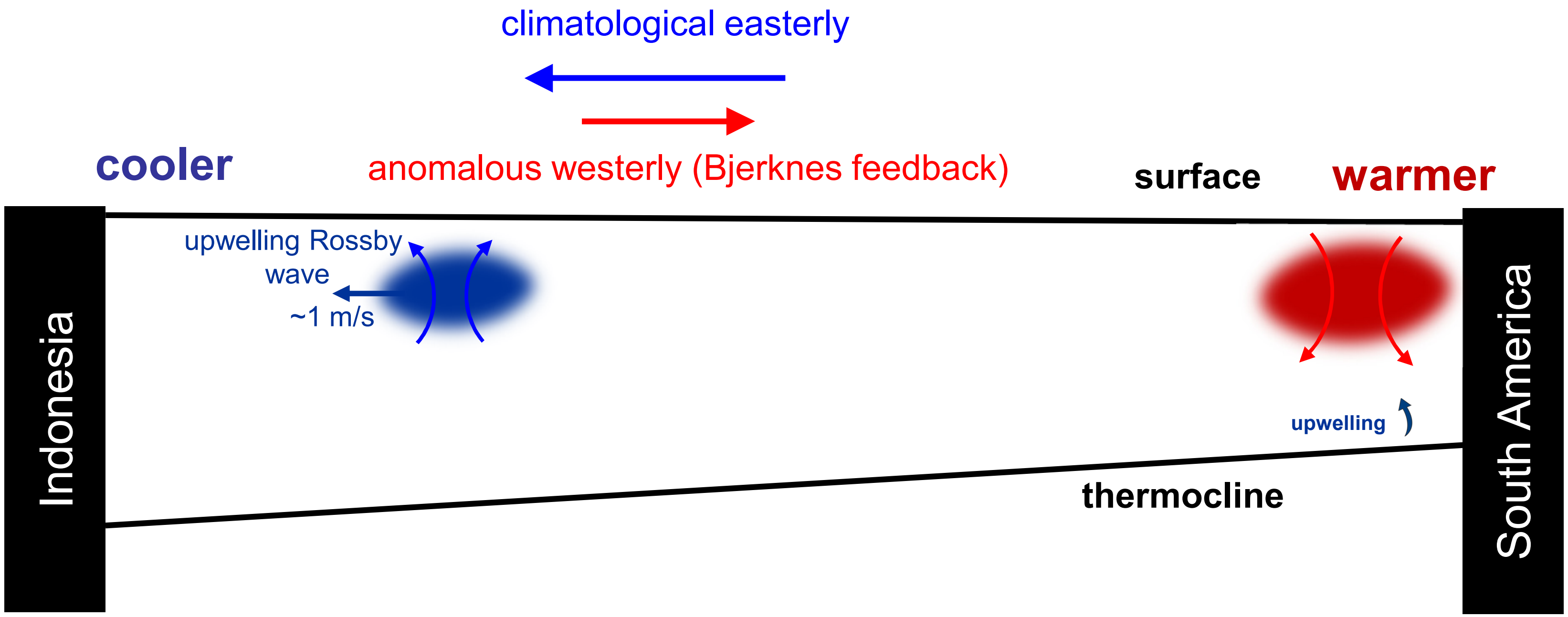
Typical buildup of a strong El Niño: the role of westerly wind bursts (WWB)



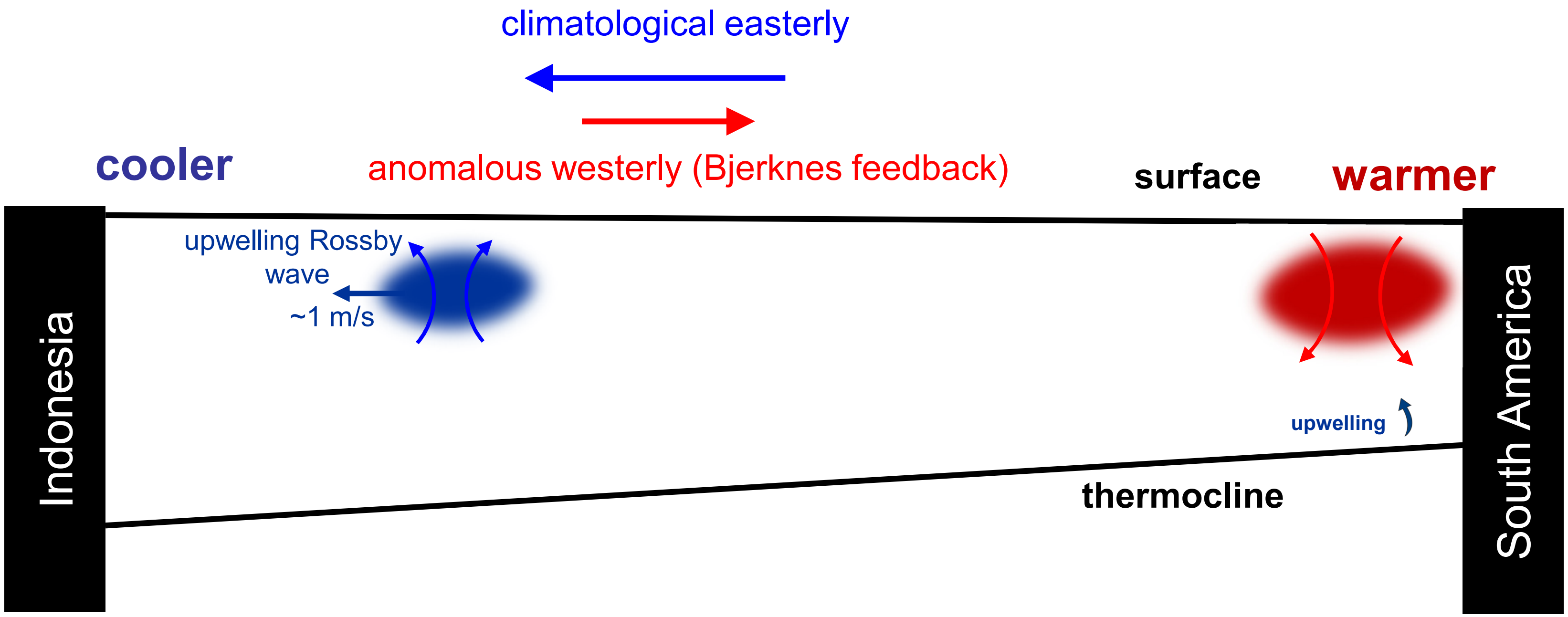
2-3 months later



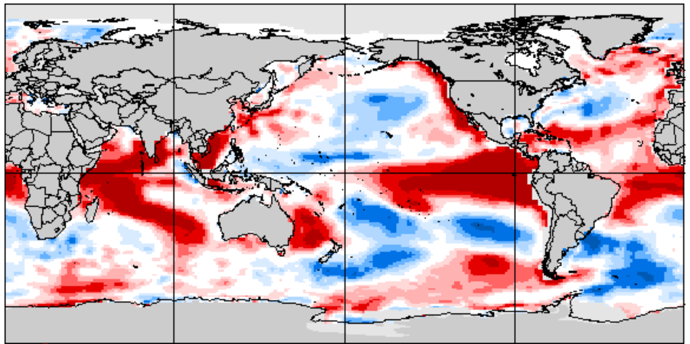
2-3 months later



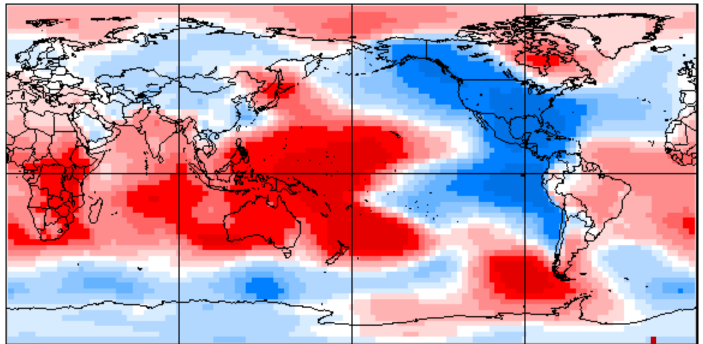
2-3 months later



SST anomaly - "El Niño"



SLP anomaly - "Southern Oscillation"

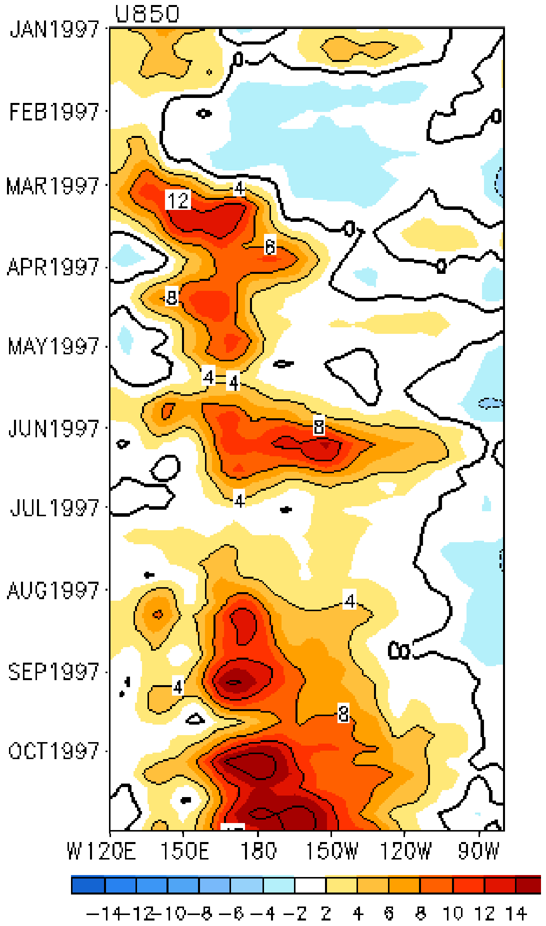


El Niño Southern Oscillation (ENSO)

Example: 1997

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

Low-level zonal wind anomalies

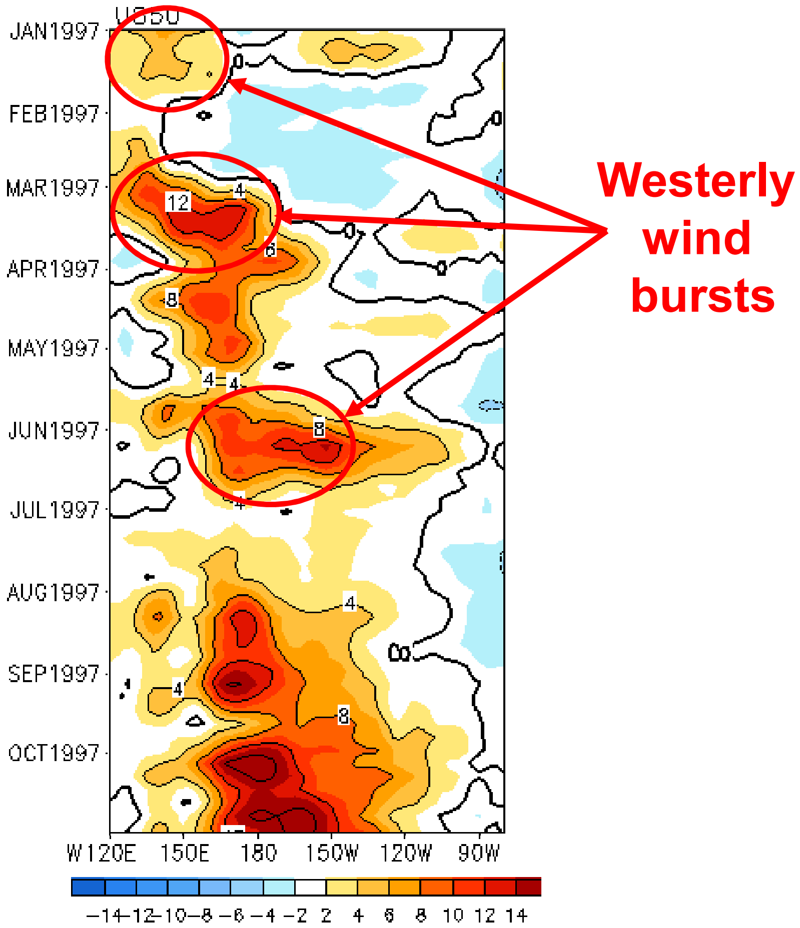


NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997

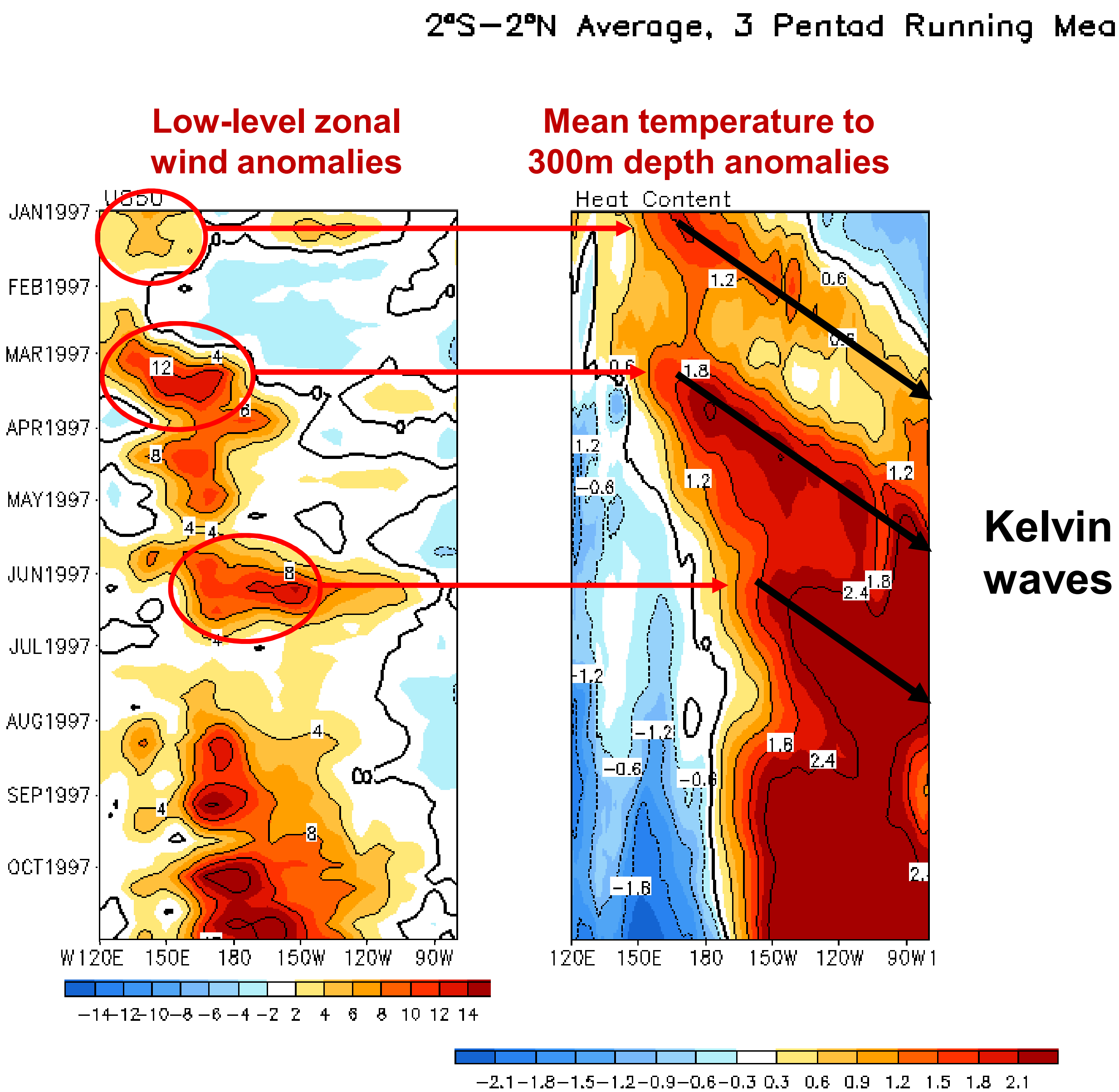
2°S–2°N Average, 3 Pentad Running Mean

Low-level zonal wind anomalies



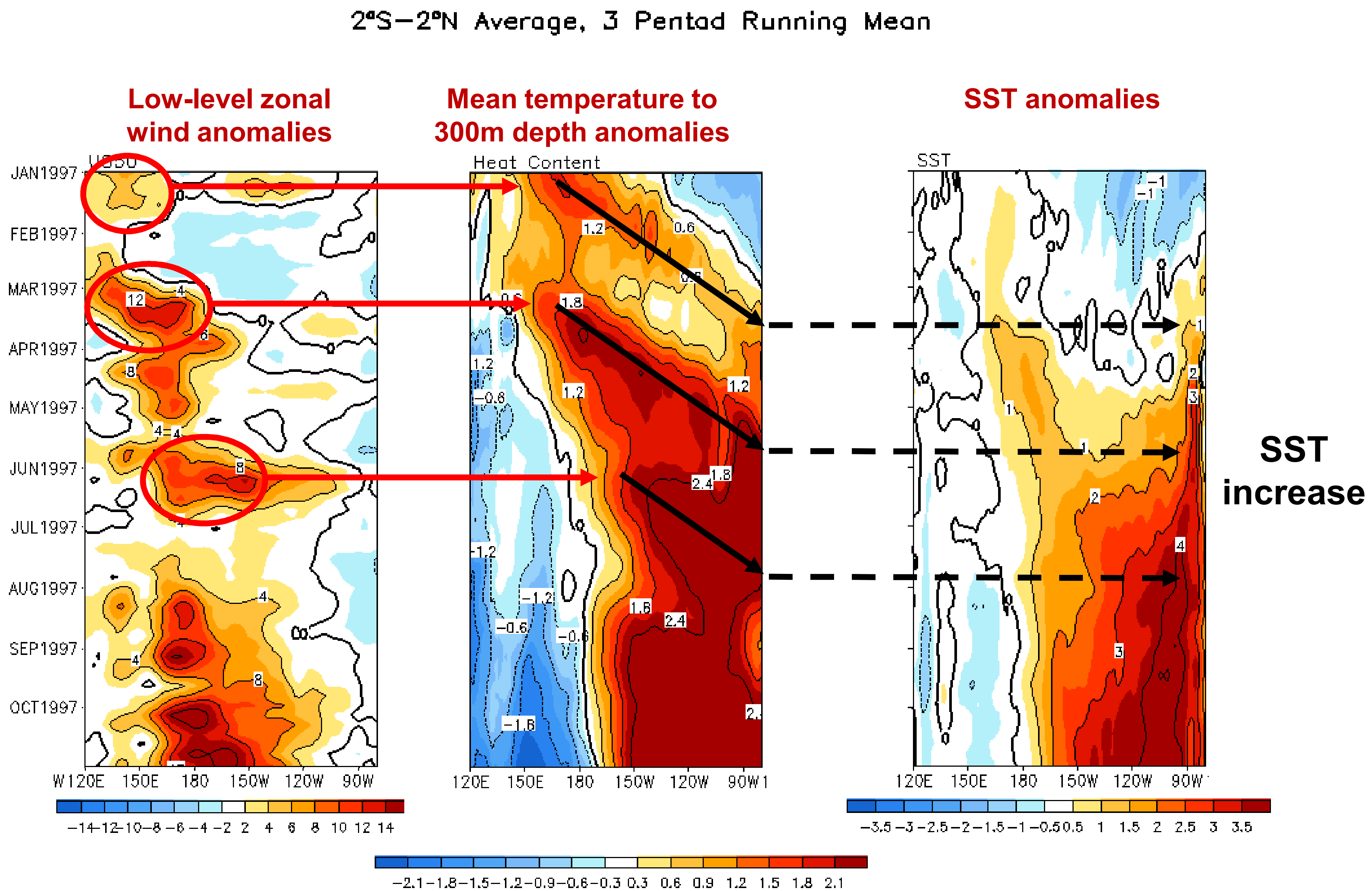
NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

Example: 1997



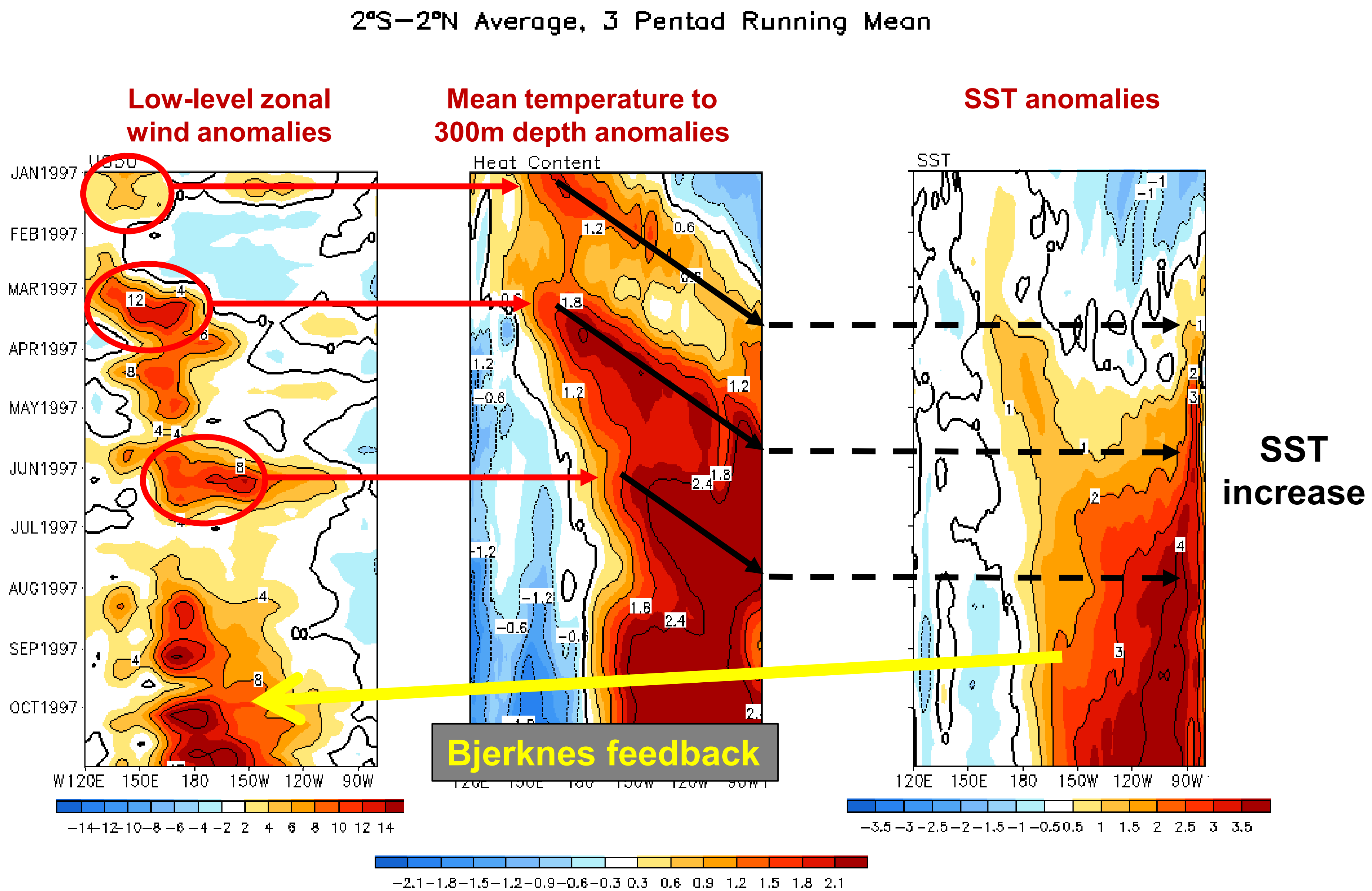
NOAA/NCEP/CPC Monthly Ocean Briefing
http://www.cpc.ncep.noaa.gov/products/GODAS/

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/