Atmospheric Modelling

GEOG/ENST 3331 – Lecture 9

Ahrens: Chapter 13; A&B: Chapters 12 and 13

Agenda for February 3

- Assignment 3: Due on Friday

Lecture Outline

- Numerical modelling
- Long-range forecasts
- Oscillations

Discussion of A1 and A2

Numerical weather forecasting

Requirements:

- Conceptual framework - set of mathematical equations to predict temperature, pressure (height), moisture, wind
- Initialization data
- Fast computers

Four step process

Step 1: Data acquisition

Synoptic Data Sources

- Radiosondes
- Dropsondes
- Met stations
- Ships

Broad scale and simultaneous

Asynoptic Data Sources

- Radar
- Satellites
- Aircraft
- Drifting buoys

- Localized and/or infrequent

Step 2: Computer analysis

- Check for accuracy and consistency
- data onto a grid – points in space where each variable has a distinct value
- Calculate a grid of atmospheric variables
  - Pressure, temperature, humidity, wind velocity
- Produce a chart (map) for a given instant in time
  - 00 UT, 06 UT, 12 UT
  - Data onto a grid – points in space where each variable has a distinct value

Step 3: Computer forecast

- Rapidly resolve physical equations
- Model the flows of mass and heat to predict changes in the grid over time
  - Produce charts of the future
- Requires robust theories about atmospheric phenomena

(b)

A&B: Figure 13-1

Step 4: Forecast dissemination

- Regional centres interpret and disseminate forecast discussion to local weather offices
- Science and art in weather forecasts

- An upper level trough will continue moving from the Prairies through Ontario. Likely clearing trend from west to east … cold air advection behind the front will help maintain/develop low level stratus. Flurries are possible …

Computational power

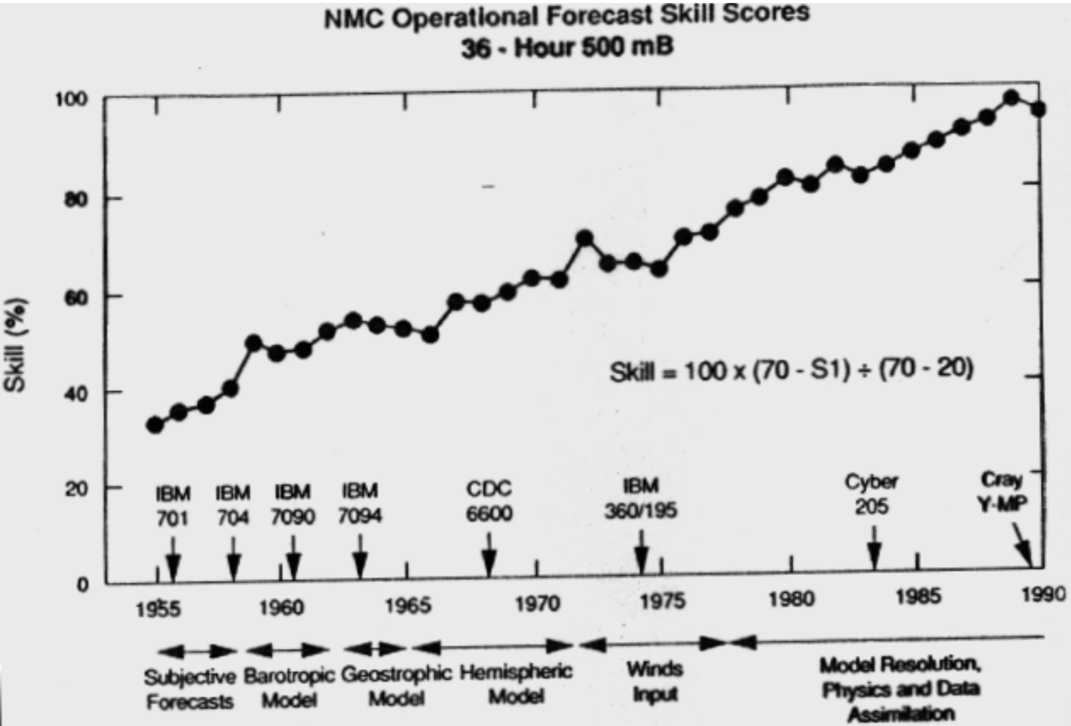


Fig. 9.2 36 hour 500 mb forecast skill over North America at the National Meteorological Center (after Kálnay et al., 1991).

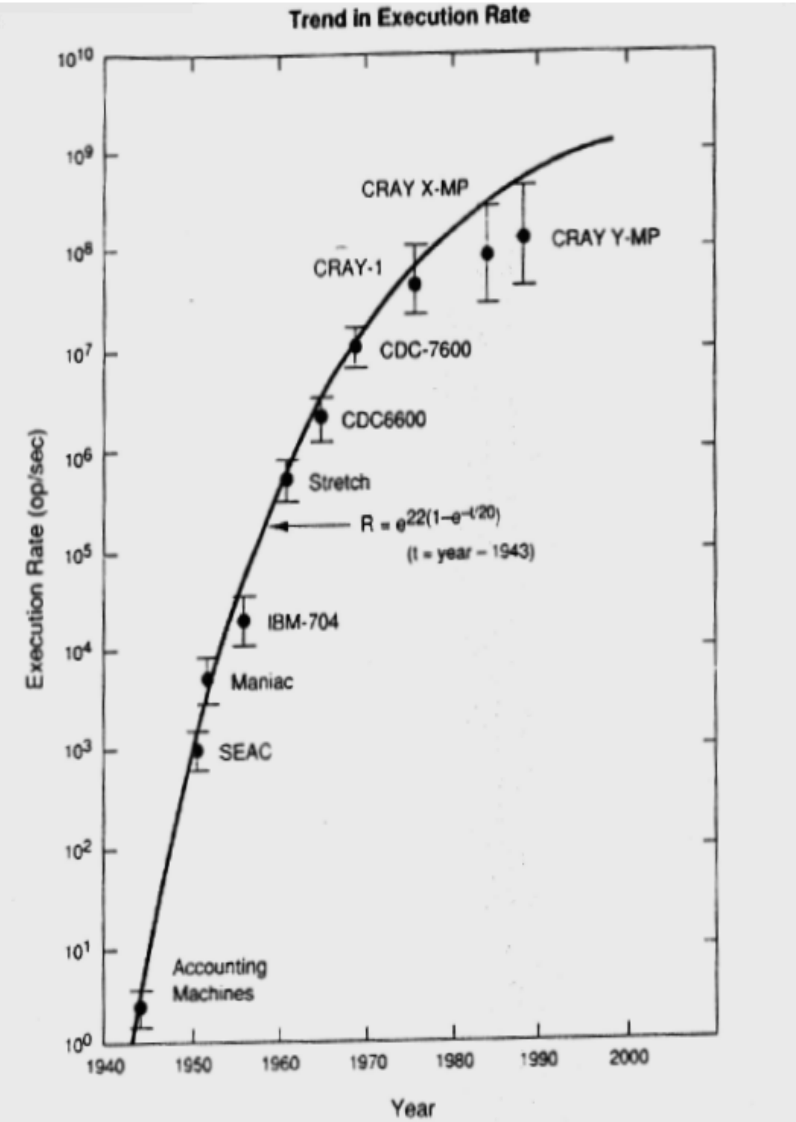


Fig. 9.1 Trend in single processor computational performance (after Worlton, 1987 [perso communication]).

Limits to Numerical Forecasting

- Low resolution – e.g. Great Lakes poorly resolved
  - Sometimes 100 km grids

- Modelling of physical processes – e.g. clouds, ocean eddies

- Inaccuracy and sparseness of initialization data

- Intrinsic non-linearity and chaotic behaviour – *theoretical limit to this approach is 2 weeks*

Long range forecasting

- 1960s Edward Lorentz
  - Chaos theory
  - Placed a limit of 2 weeks on weather forecasting

- "The butterfly effect"
  - Small changes in initial conditions lead to a very different end state

Double compound pendulum

Long range forecasting

Climatology

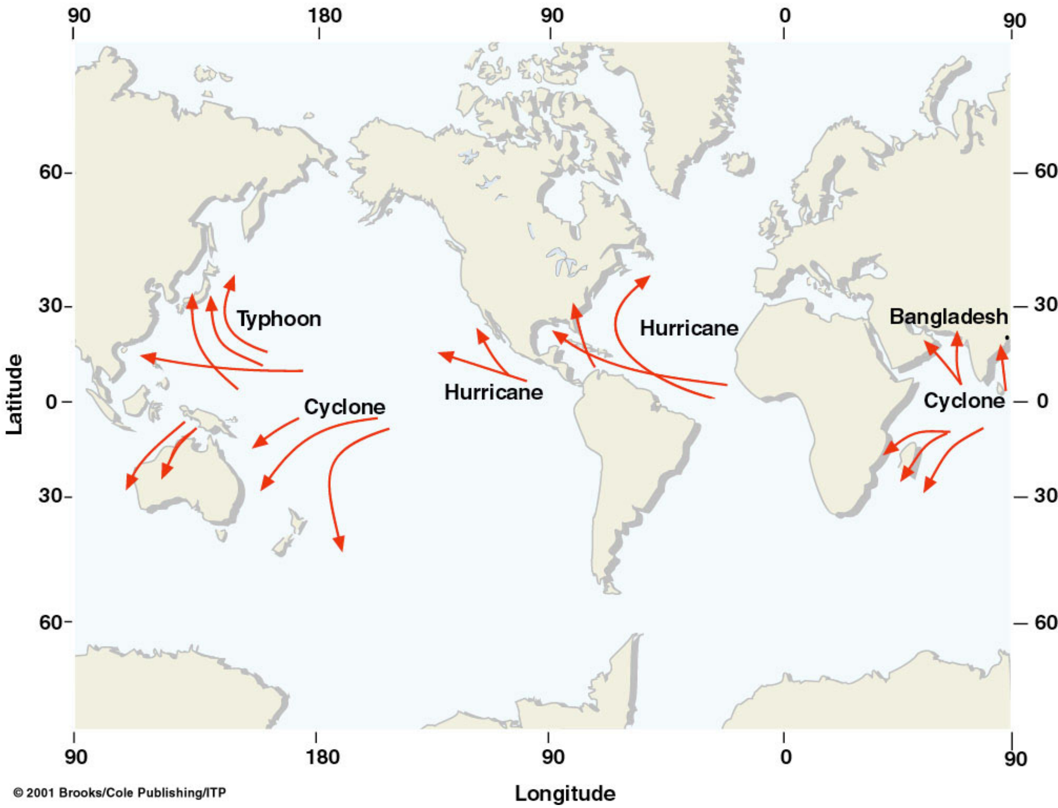
Memory

Low frequency variations:

- El Niño/Southern Oscillation (ENSO)
- North Atlantic Oscillation (NAO)
- Pacific Decadal Oscillation (PDO)

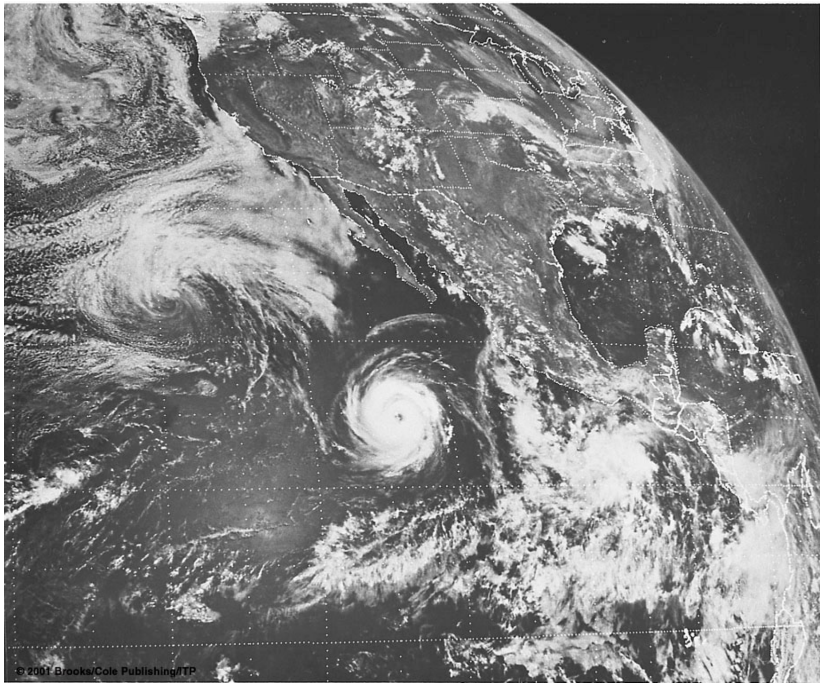
Example: Tropical cyclones

- Hurricane
  - North American term (Atlantic hurricanes, Eastern Pacific hurricanes)
- Typhoon
  - term used in Western Pacific
- Cyclone
  - Term used in Australia and in the Indian Ocean



Dynamics

- How do hurricanes form?
  - Tropical storms fueled by sea surface temperatures and latent heat release
  - Observationally it has been noted that 26.5°C (80°F) is the threshold for tropical storm formation
  - This is a necessary but not sufficient condition for tropical storms to form



Tropical cyclone lifespan

- SSTs
  - Warmer the surface provides more moisture and energy
- Upper wind structure
  - ENSO – enhances hurricanes in the Eastern Pacific while suppressing them in the Atlantic
  - QBO – quasi-biennial oscillation of the winds in the stratosphere
- Landfall
  - Cuts off cyclone from both sources of energy (SSTs and water vapour)
  - Increases surface roughness

Forecasting Hurricanes

- Colorado State University (CSU)
- University College London (UCL)
- National Oceanic and Atmospheric Administration (NOAA)

- Factors affecting hurricanes
  - ENSO (El Nino Southern Oscillation)
  - QBO (Quasi-biennial Oscillation)
  - SSTs (sea surface temperatures)
  - Sahel rainfall

Dr. William Gray

Hurricane Forecasting

- Statistical methods employed
- Predicts the number of tropical storms for the next season
    - No details on location or precise timing
- Where is the memory located?
    - Ocean – ENSO, SST
    - Atmosphere – QBO (upper troposphere)
- Let's see how well it works

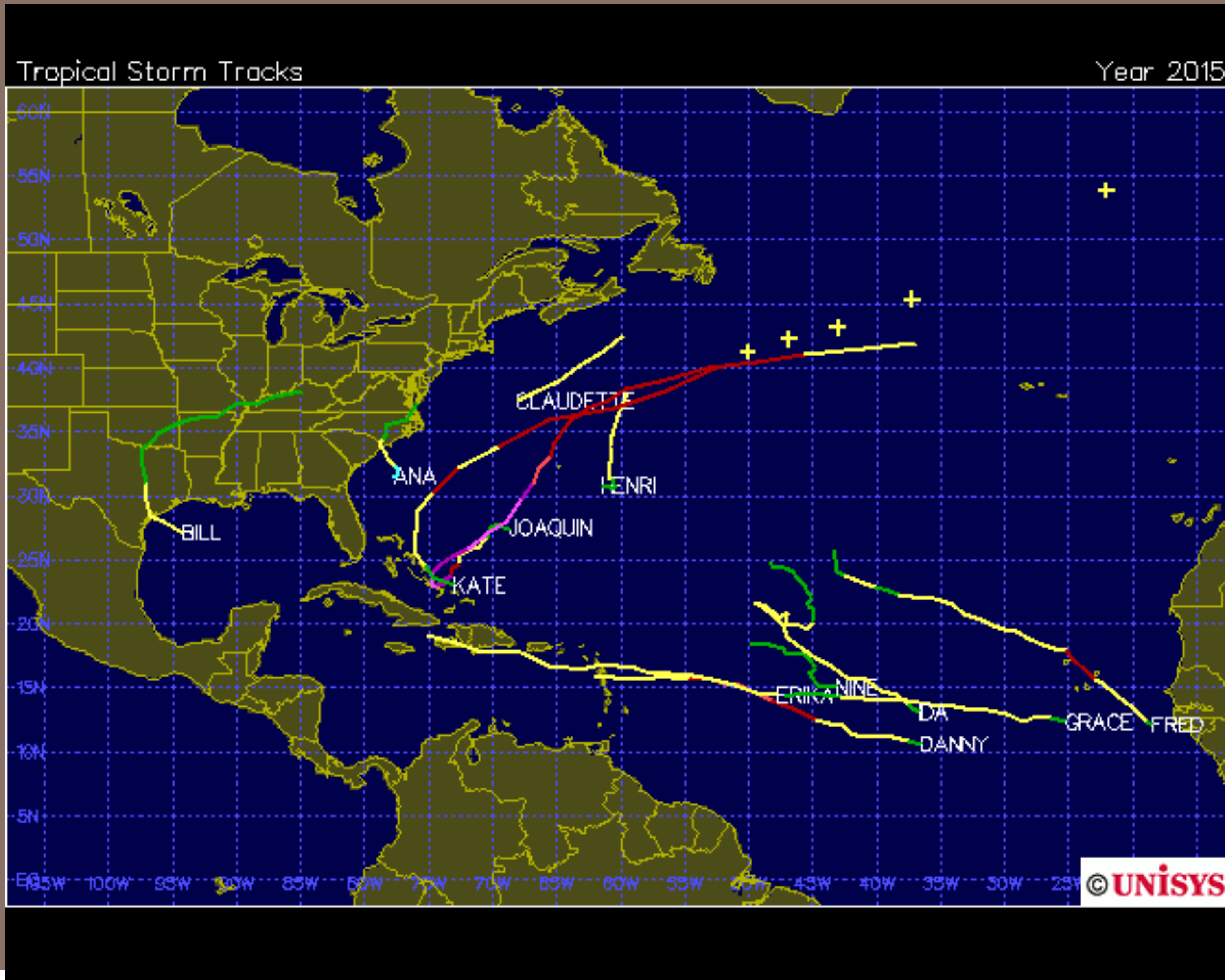
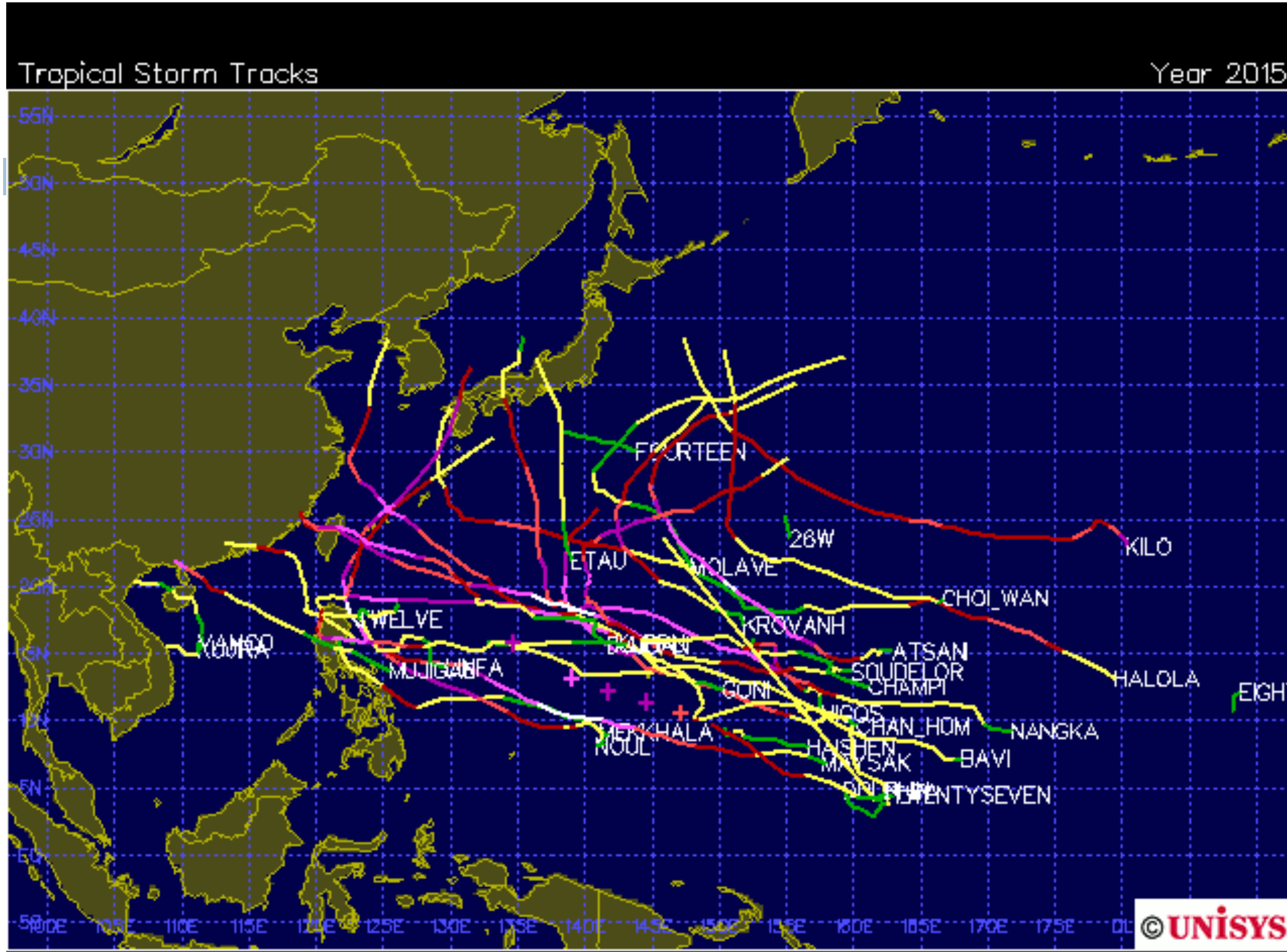


Figure above Atlantic Hurricanes: 2015



Western Pacific Typhoons: 2015

Hurricane Sandy

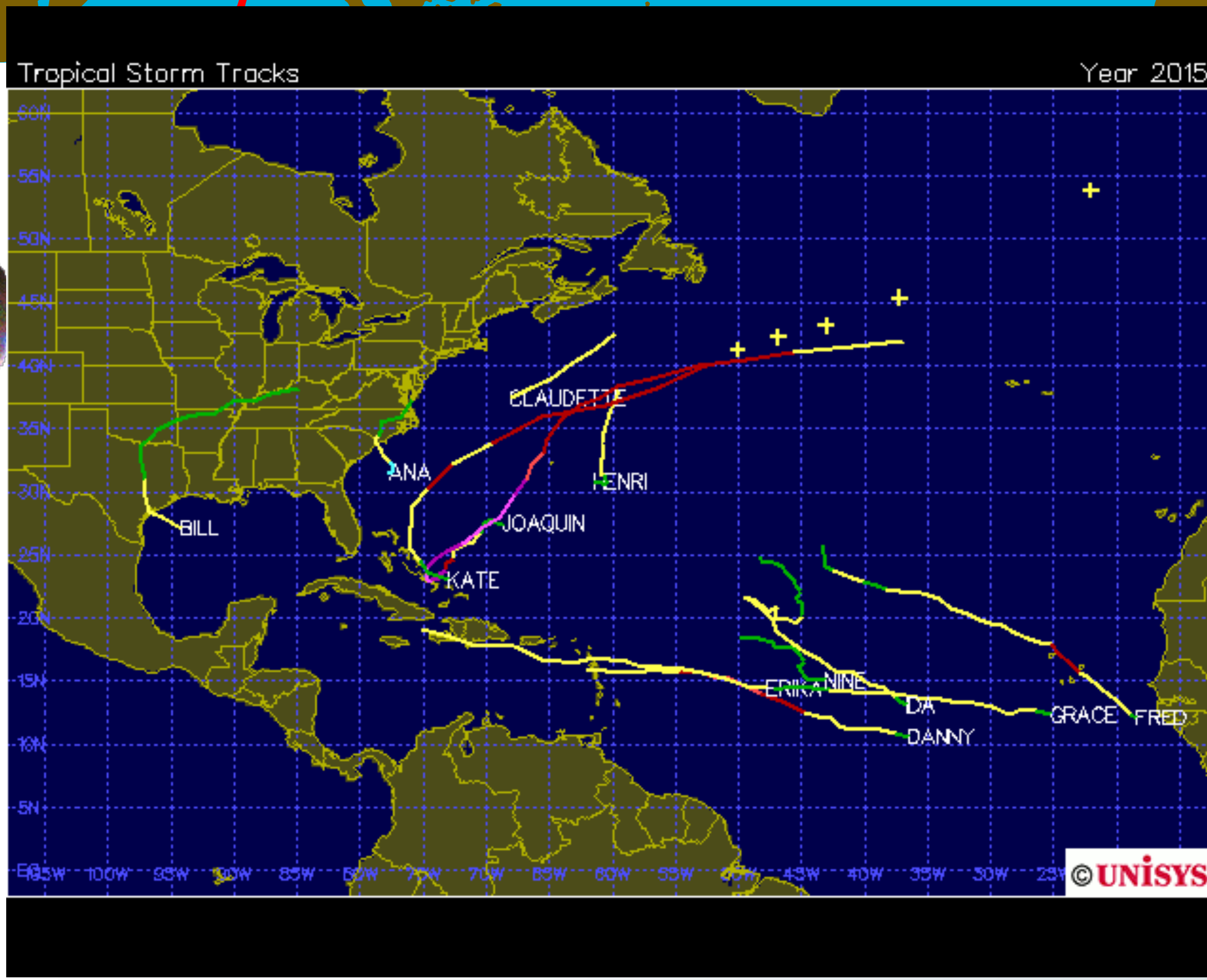
- October 25, 2013
  - Sandy peaks at Category 3
  - Landfall in Cuba
- October 30
  - Tropical storm
  - Landfall in New Jersey

Hurricane Sandy

European Centre for Medium-Range Weather Forecasts

- Independent intergovernmental organisation
- Supported by 21 European Member States
- World's largest archive of numerical weather prediction data
- Global weather forecasts to 15 days and seasonal forecasts to 12 months
- prediction of Hurricane Sandy in October 2012 making landfall on the East Coast of the United States seven days before it happened

Tropical Storm tracks 2015

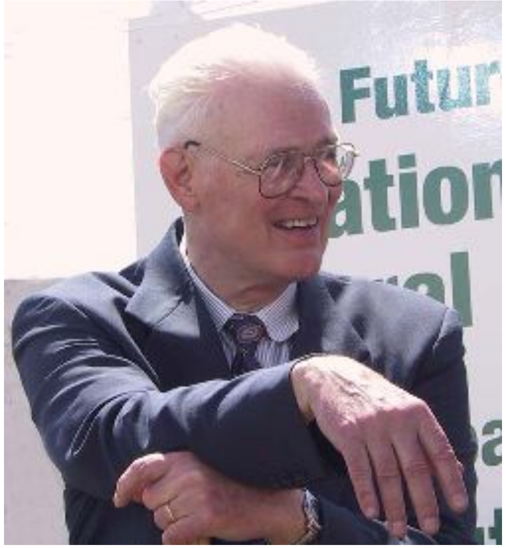


Hurricane-strength storms: 2015 compared to average

Basin	1 an 2	3 to 5	Total	Average
Atlantic	2	2	4	5.9
NH East Pacific*	7	11	18	9.0
NH West Pacific*	5	21	26	16.9
NH Indian	0	2	2	2.2
SH Indian	3	2	5	10.3
SH West Pacific	3	2	5	4.8
* **Active TS** **Global**	**20**	**40**	**60**	**48.3**

Scientific Community divided

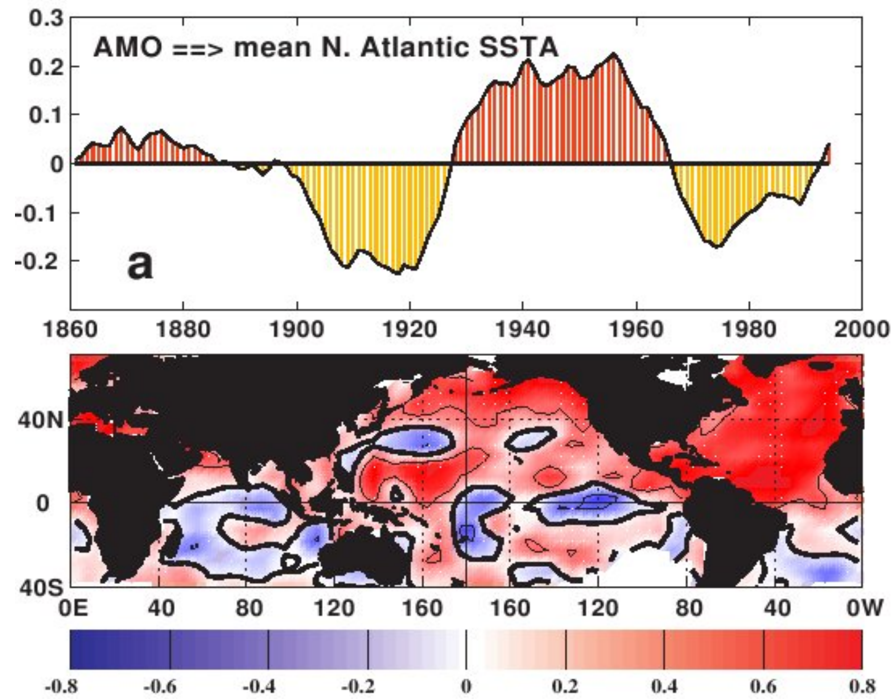
- William Gray
- Atlantic Multidecadal Oscillation (AMO)



- Kerry Emanuel
- Global Warming

What is AMO?

- Not well understood
- Variation in the three dimensional circulation of the Atlantic Ocean
  - Leads to changes in heat transport
- Warm temperatures in 1940s and 1950s correlated with more frequent hurricanes



Impacts

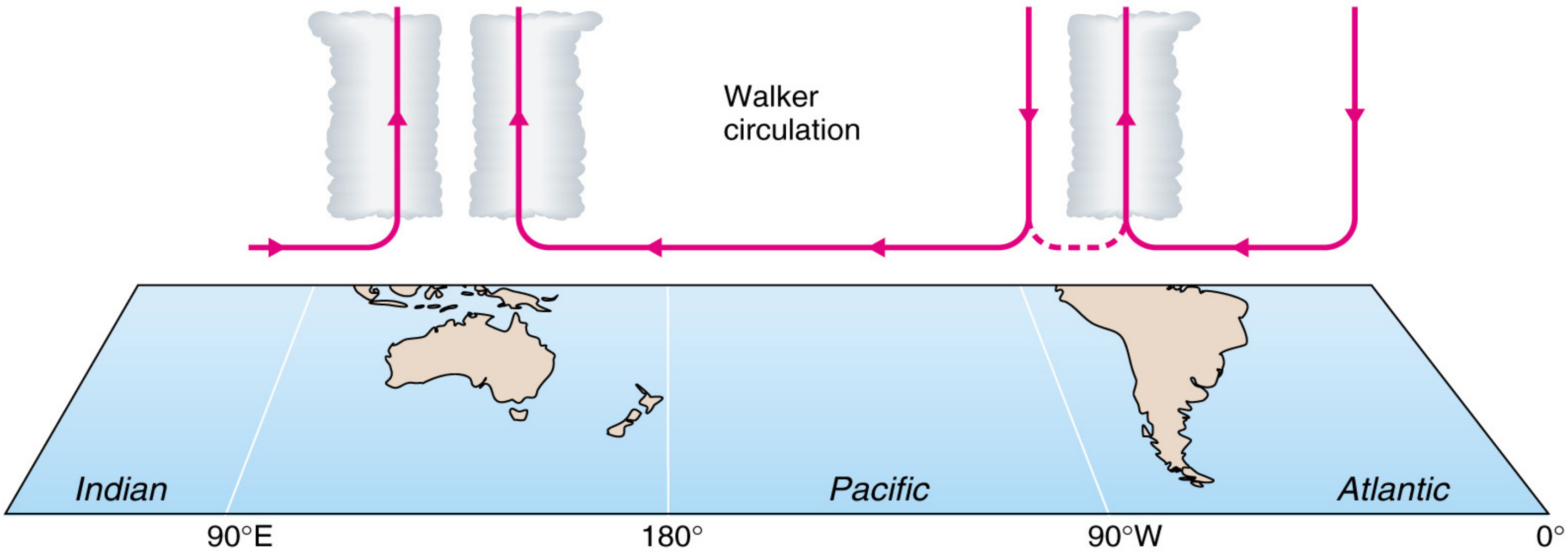
- Whether the culprit is the AMO or global warming (or both) the hurricane driver is warmer SSTs
- Increases the frequency in which minor hurricanes develop into major ones

ENSO

El Niño / Southern Oscillation

- 4 to 7 year oscillation in tropical Pacific Ocean temperatures and associated changes in atmospheric circulation
- Cause is unknown, although it is linked to changes in the Asian monsoon season

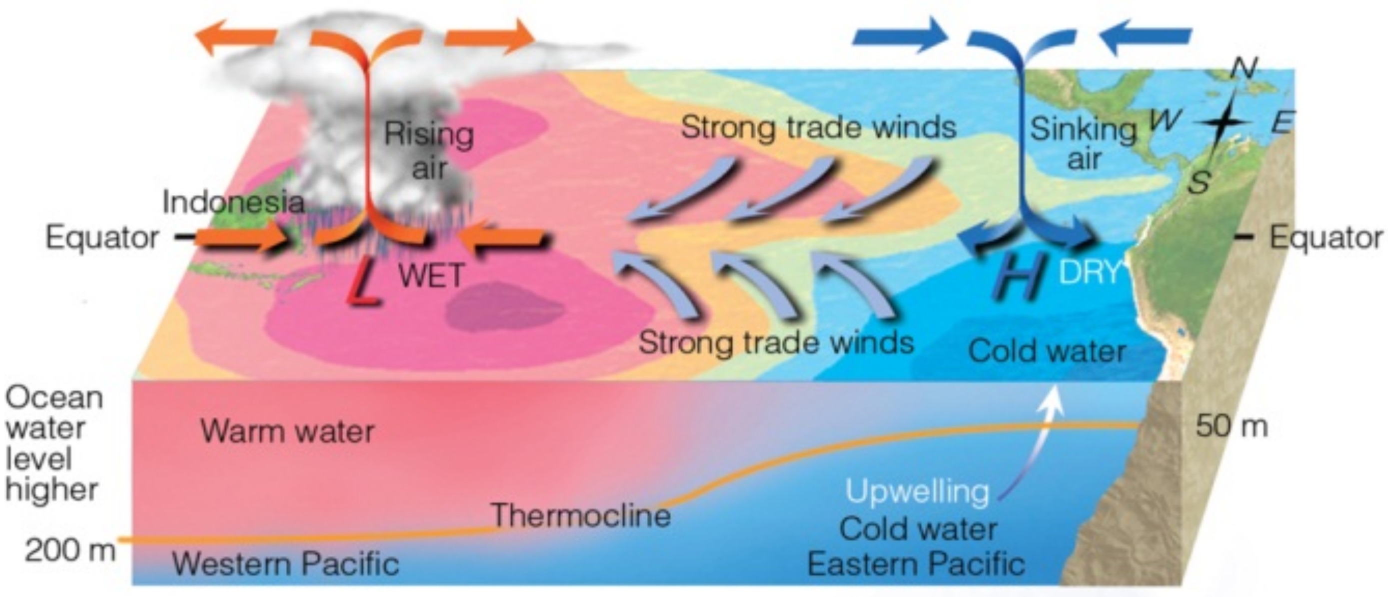
The "Normal" Walker Circulation



A&B: Figure 8-27

Walker Circulation

- Easterly trade winds
- Low pressure, rising air and heavy rain over western Pacific
- Winds push surface water away from SA, causing cold water to well up from below
- **Particularly intense years are called La Niña**



Ahrens: Fig. 10.19

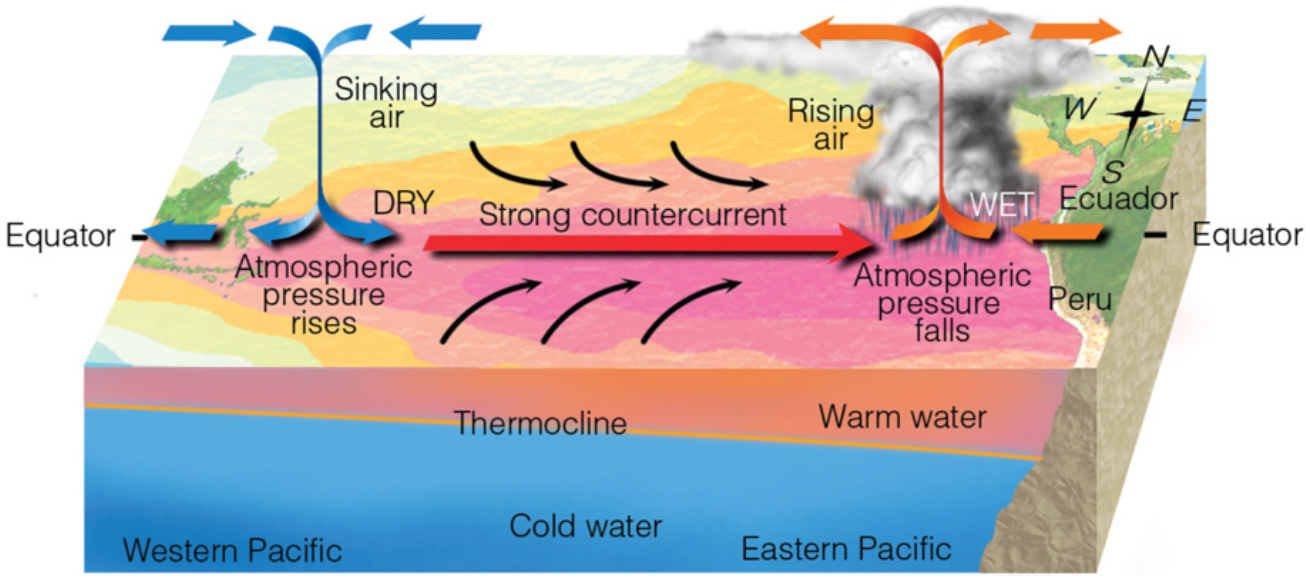
ENSO

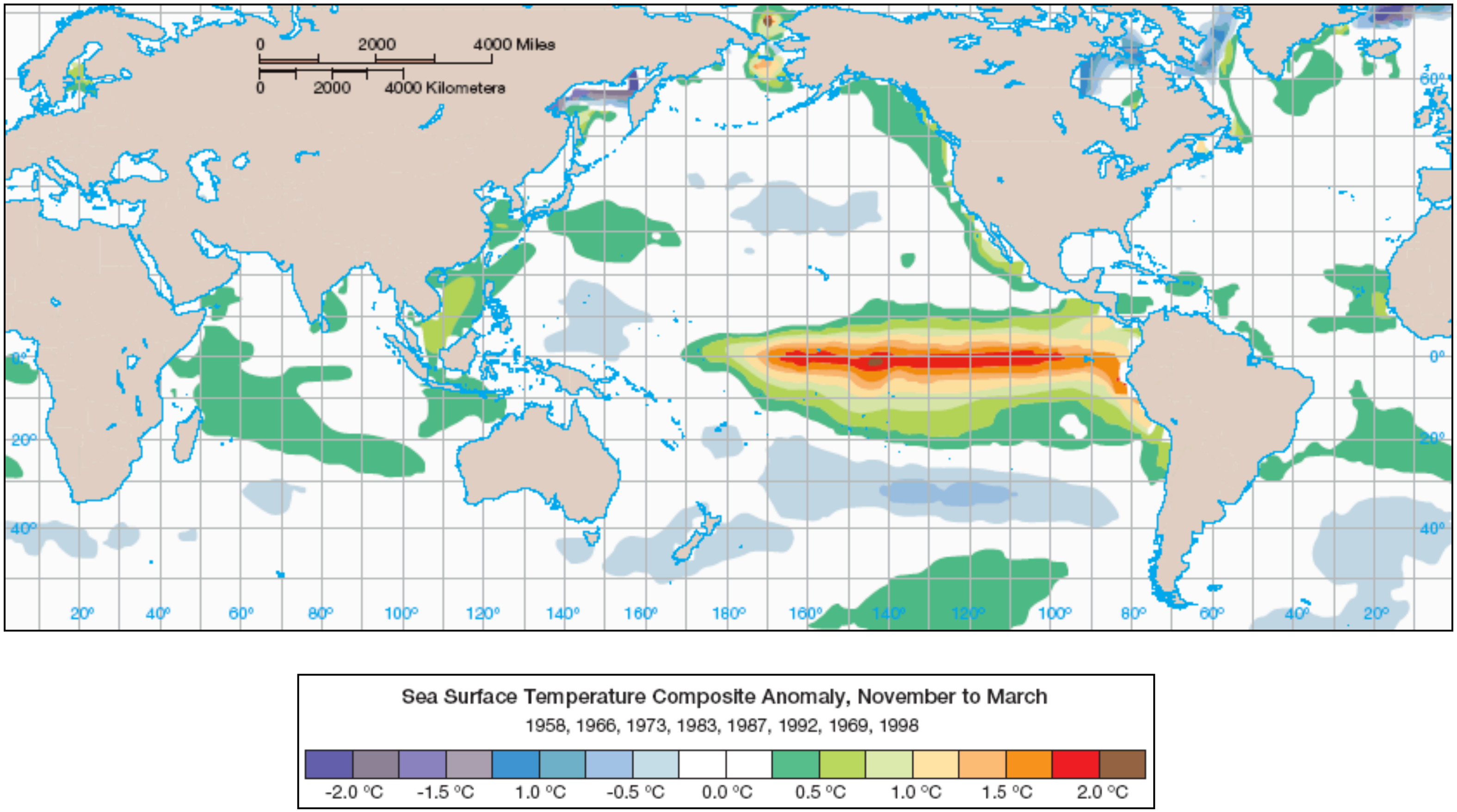
Southern Oscillation

- Winds weaken or reverse
- High pressure, subsiding air, drought over western Pacific

El Niño

- Upwelling in eastern Pacific stops, surface temperatures rise





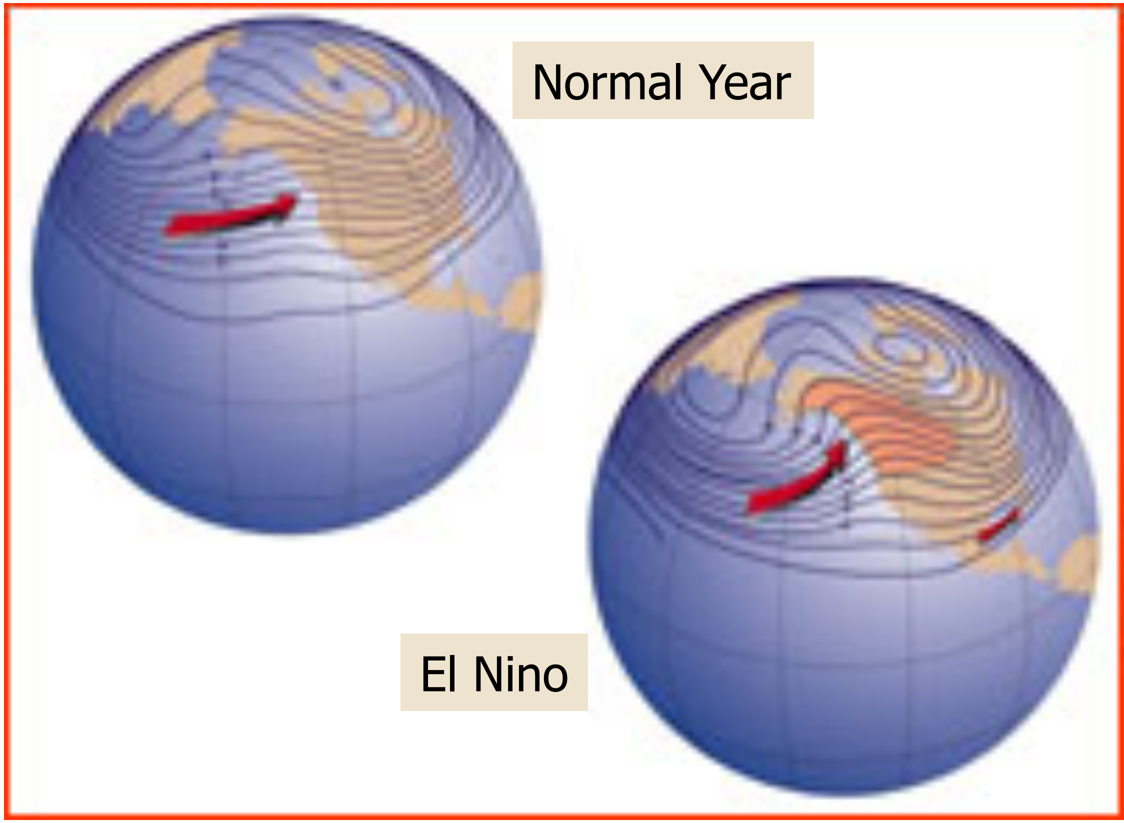
Average sea surface temperature differences from normal during the November through March period for eight El Niño episodes.
A&B: Figure 8-29

Impacts of ENSO

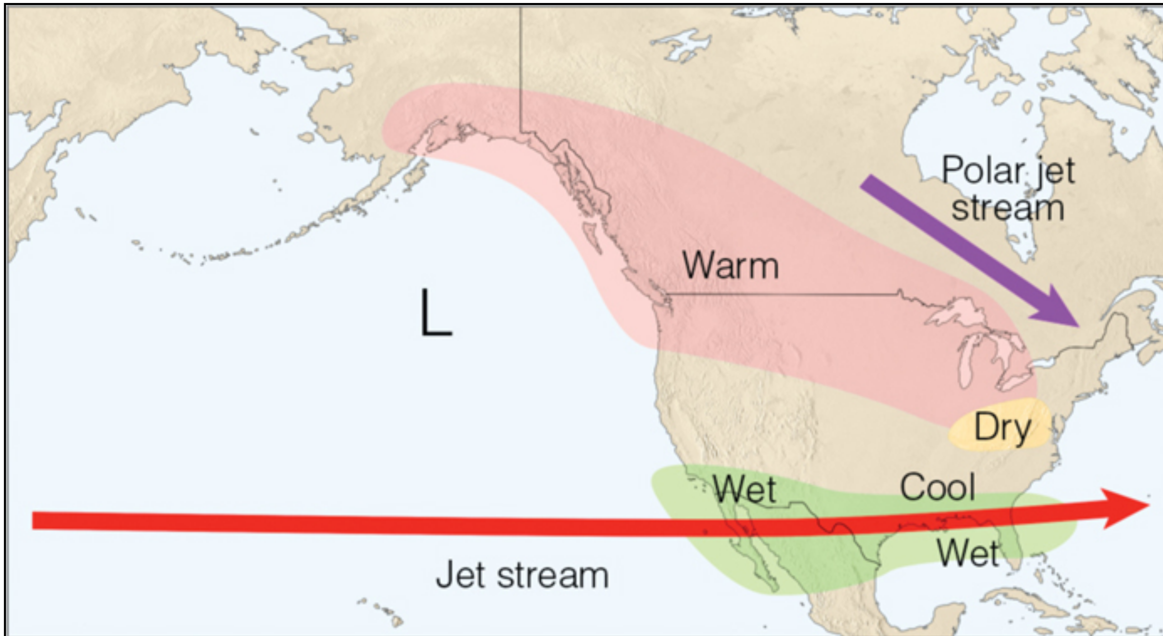
Teleconnections:

Interactions between weather patterns in different parts of the world

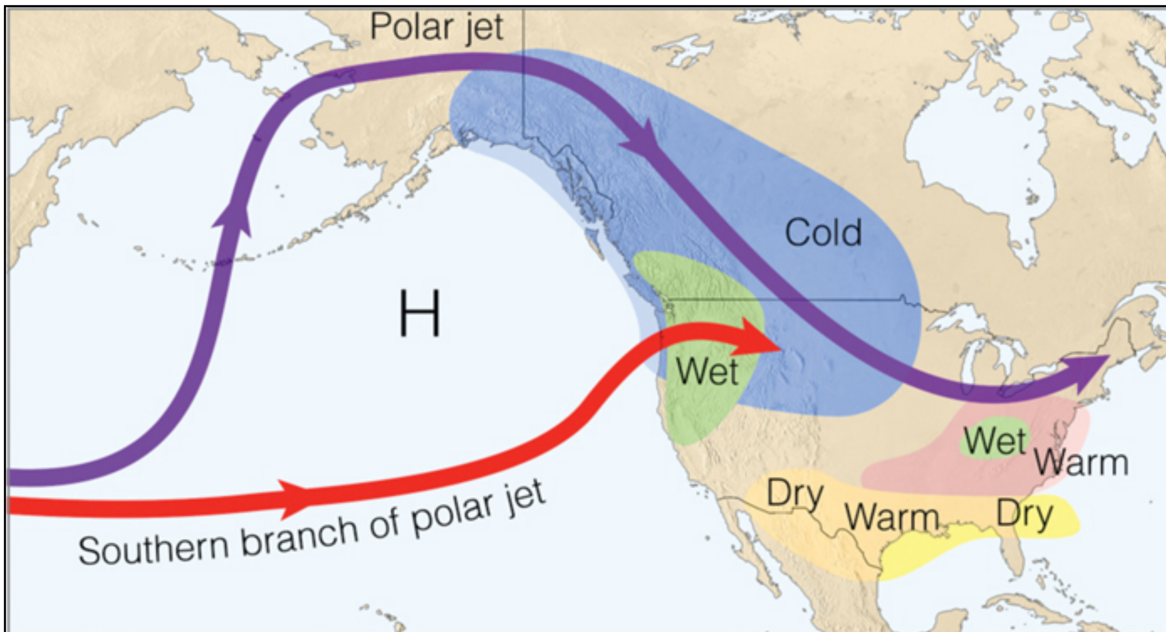
- Jet streams
  - Pushed further north over the Pacific
- Weather in Canada
  - More warm air masses



Teleconnections



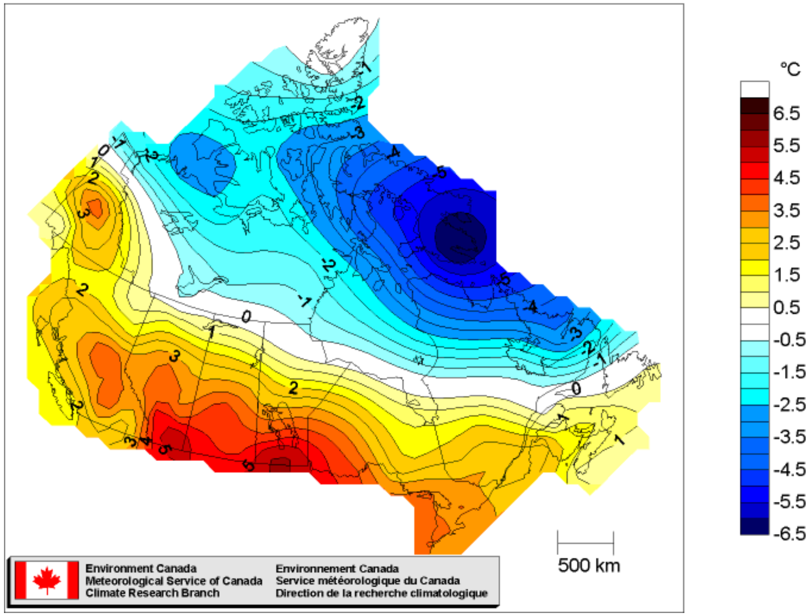
(a) El Niño winter conditions



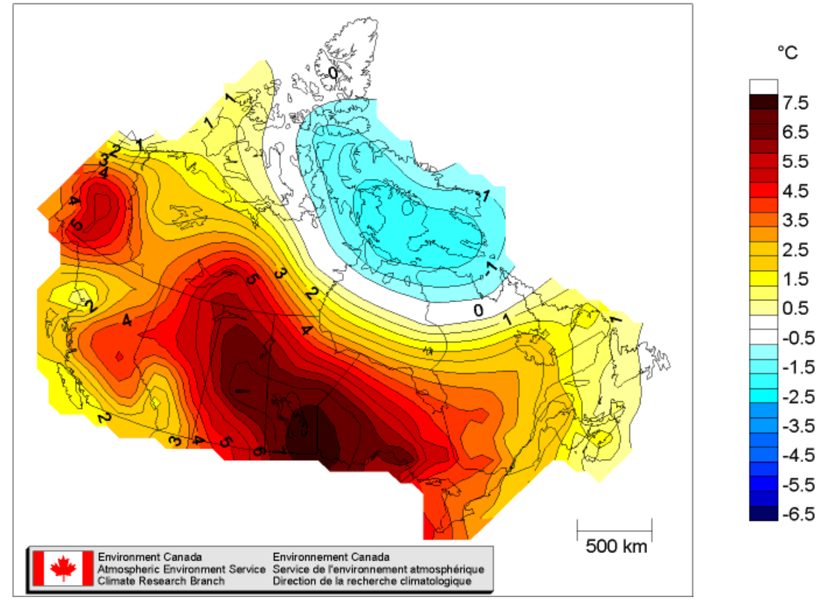
(b) La Niña winter conditions

Ahrens: Fig. 10.23

TEMPERATURE DEPARTURES FROM NORMAL
ANOMALIES DE LA TEMPERATURE PAR RAPPORT A LA NORMALE
Winter/Hiver (Dec-Jan-Feb) 1982/83



TEMPERATURE DEPARTURES FROM NORMAL
ANOMALIES DE LA TEMPERATURE PAR RAPPORT A LA NORMALE
Winter/Hiver 1998



PRECIPITATION DEPARTURES FROM NORMAL
ANOMALIES DES PRECIPITATIONS PAR RAPPORT A LA NORMALE
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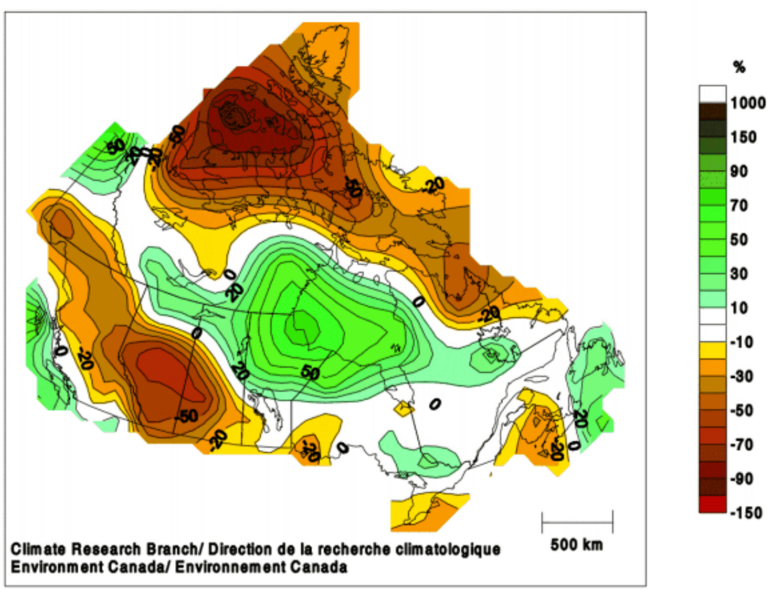

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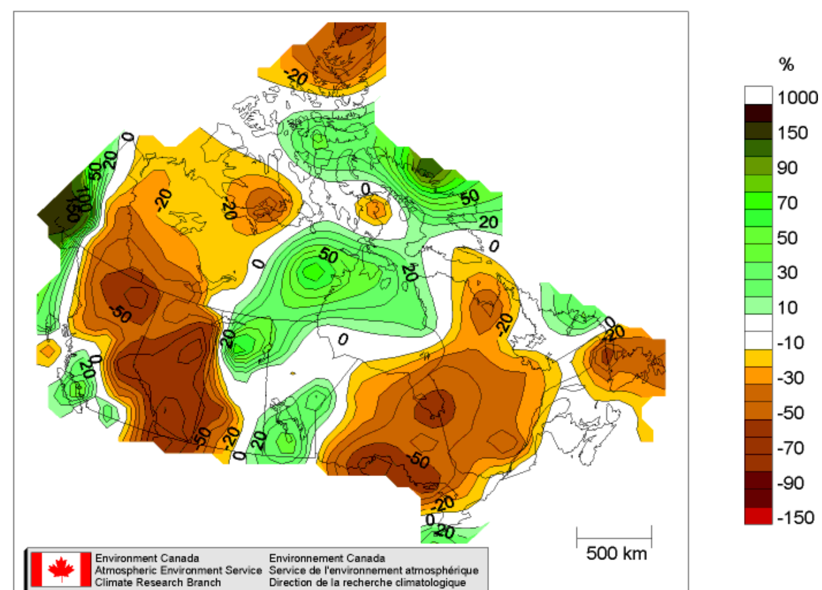
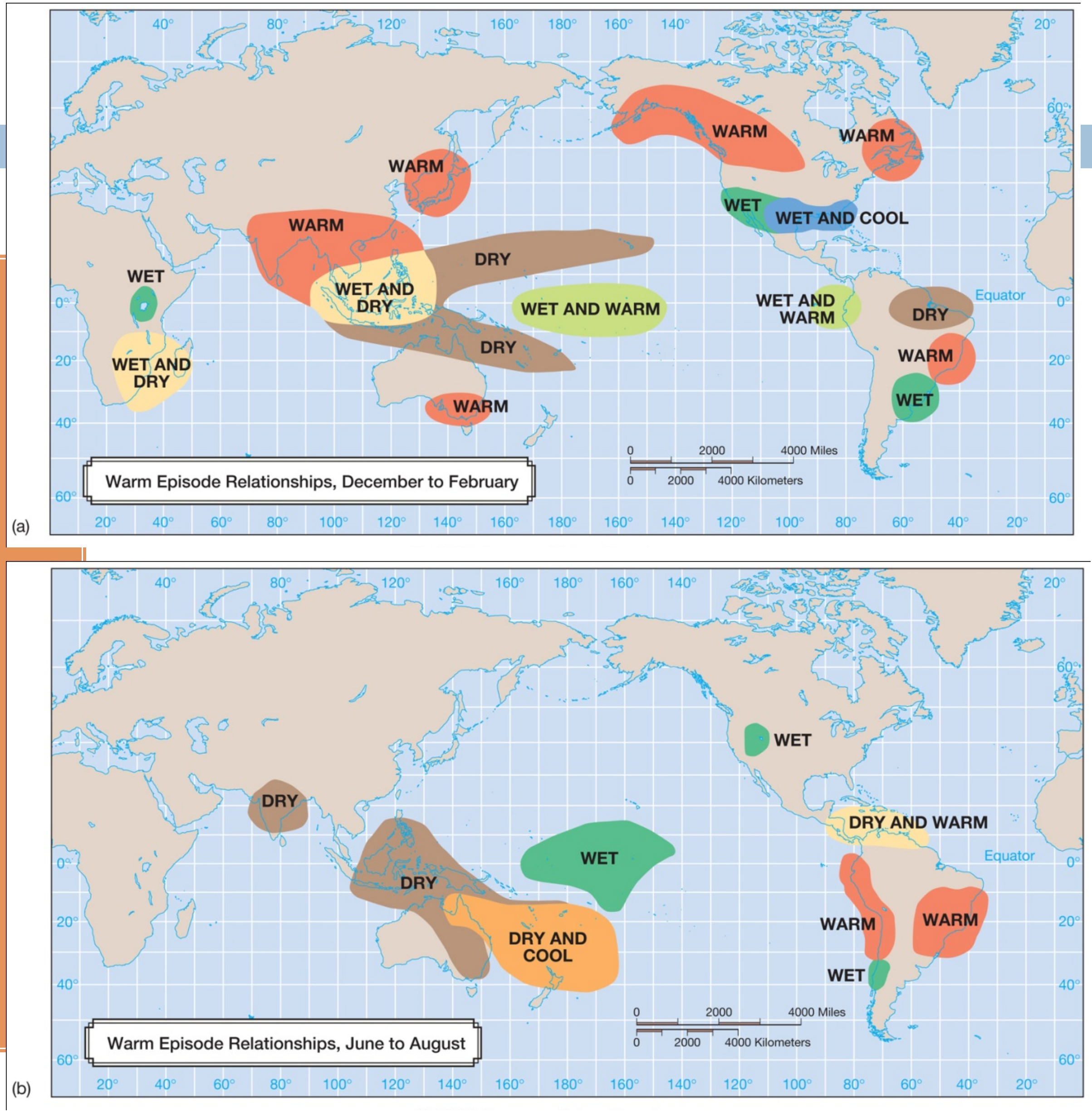
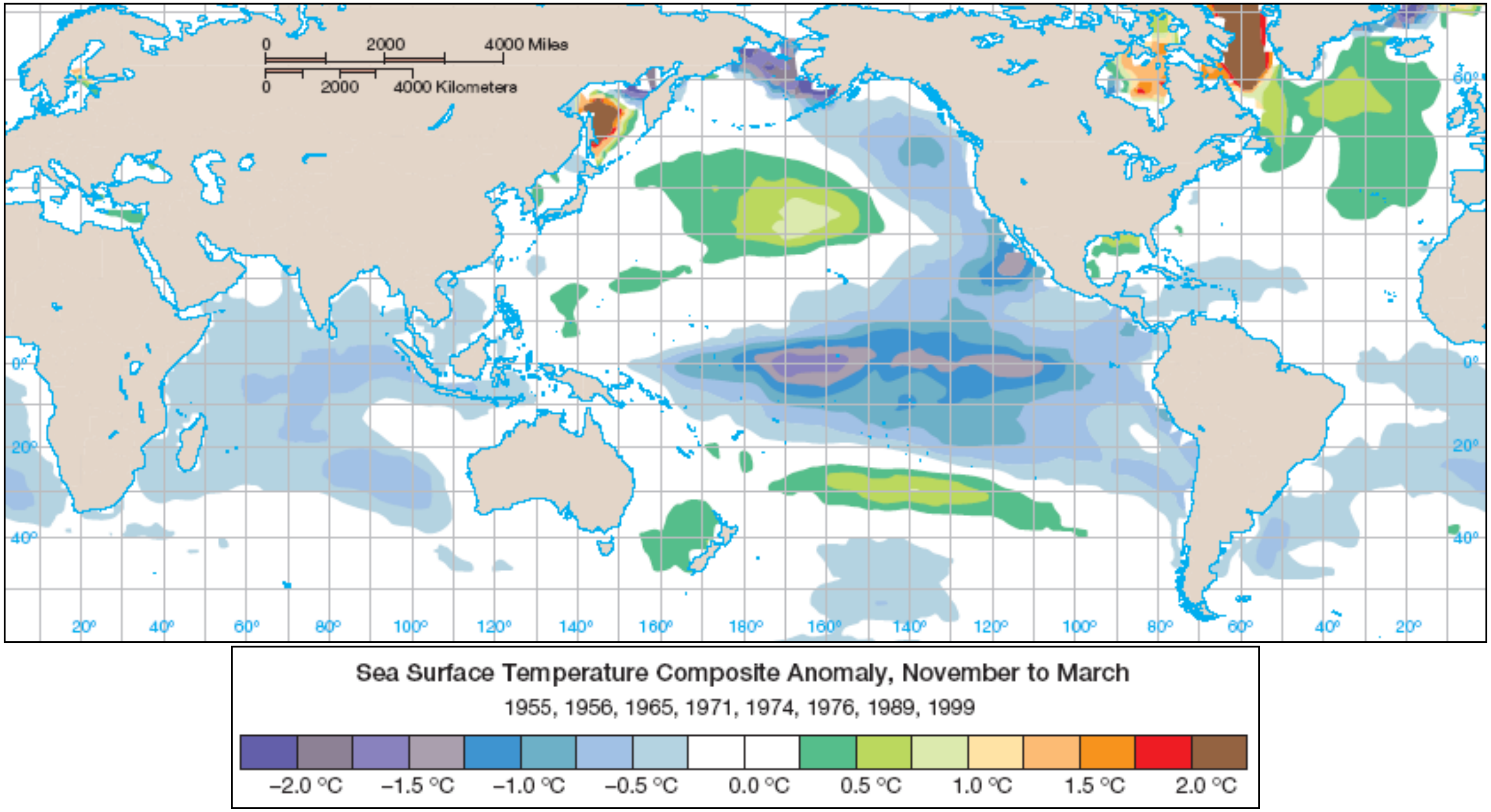


Impacts of El Niño

A&B: Figure 8-35

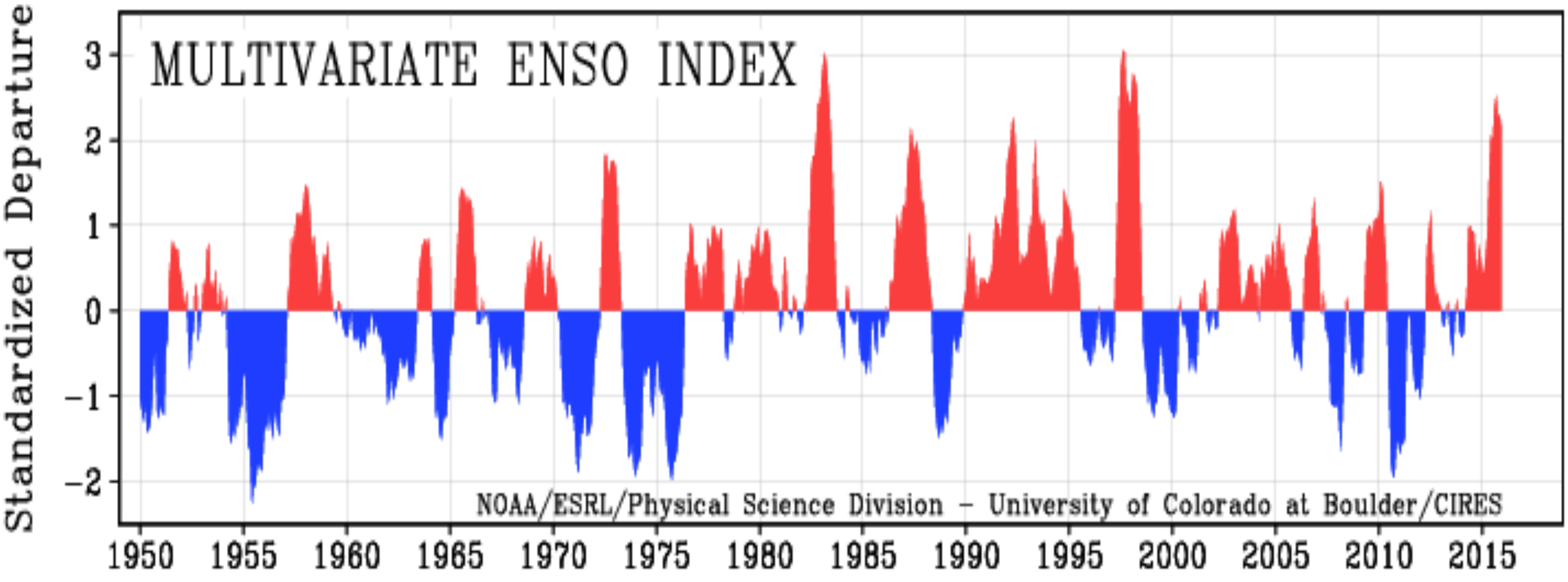




Average sea surface temperature differences from normal during the November through March period for eight La Niña episodes.
A&B: Figure 8-31

ENSO Index

- Strong positives are El Niño
- Strong negatives are La Niña



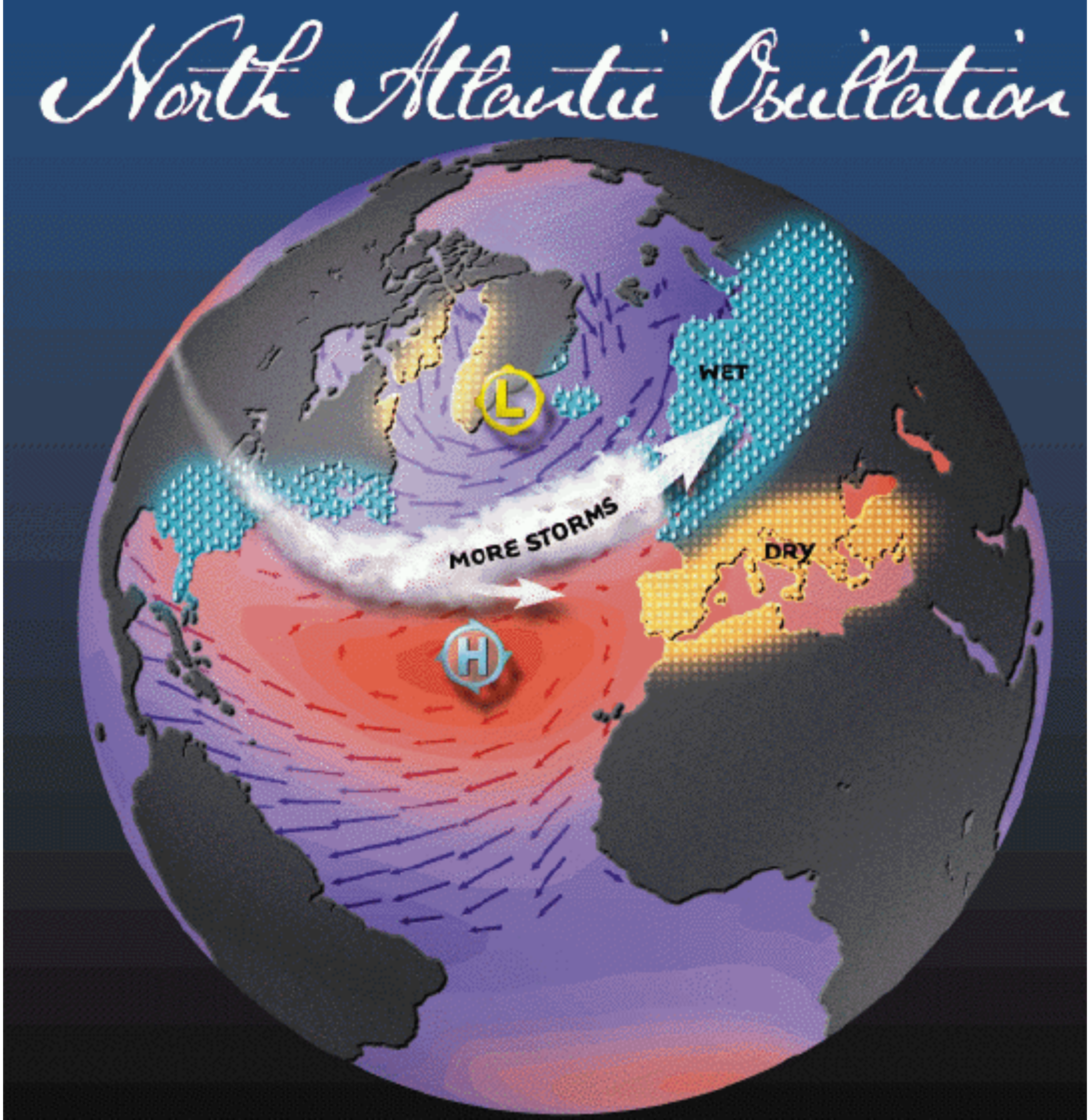
Source: NOAA

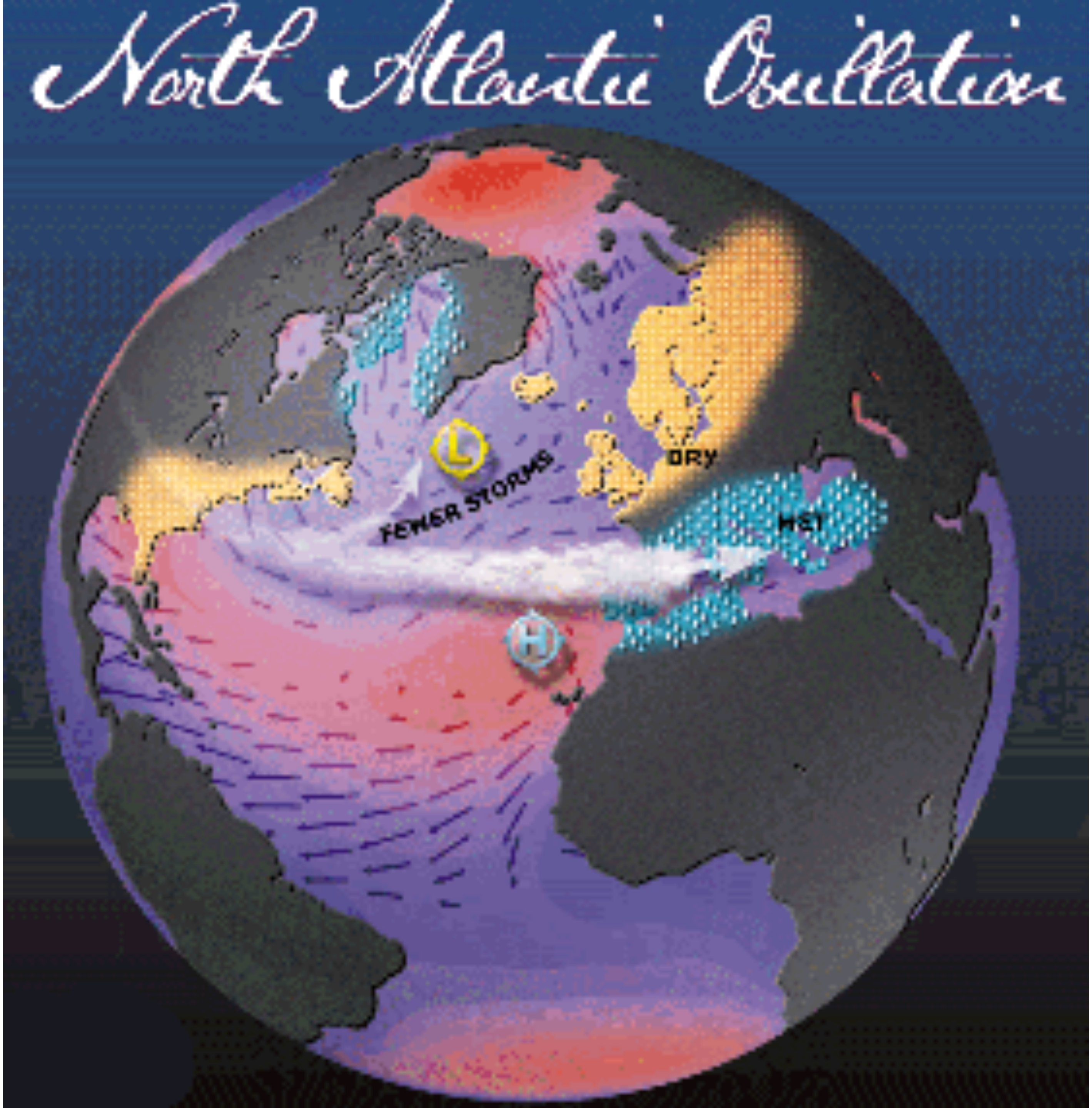
North Atlantic Oscillation

Pressure variations in the North Atlantic

Typified by difference in Icelandic low and Azores high

Affects precipitation over Eastern Canada and Western Europe

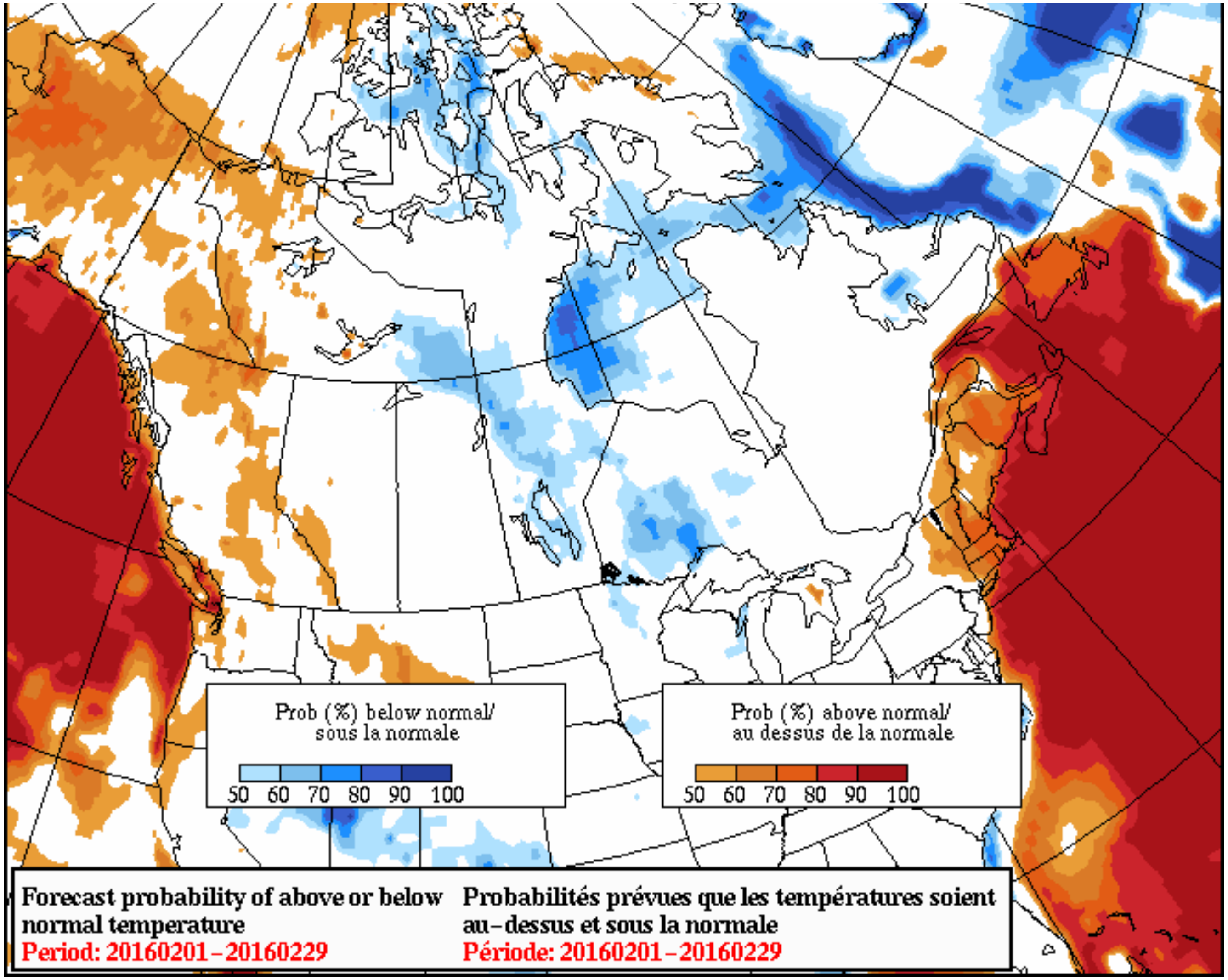

North Atlantic Oscillation
L
WET
MORE STORMS
DRY
H


North Atlantic Oscillation
L
FEWER STORMS
DRY
WET
H

Long range forecasting

- Memory:
  - ENSO
  - NAO
  - SST
  - Ice cover
- Routinely produced by Environment Canada using canonical correlation analysis (CCA)
- http://weatheroffice.ec.gc.ca/saisons/index_e.html

February temperature forecast



Coming up

- Global biogeochemic
  How chemical transport
  is controlled by climate