Welcome to GOTHAM
- The Summer School -

Organizers:

Dim Coumou, Reik Donner, Efi Rousi
Chiranjit Mitra, Catrin Kirsch
Brigitta Krukenberg, Gabriele Pilz, Romy v Veelen
+
All Gotham Partners

GOTHAM

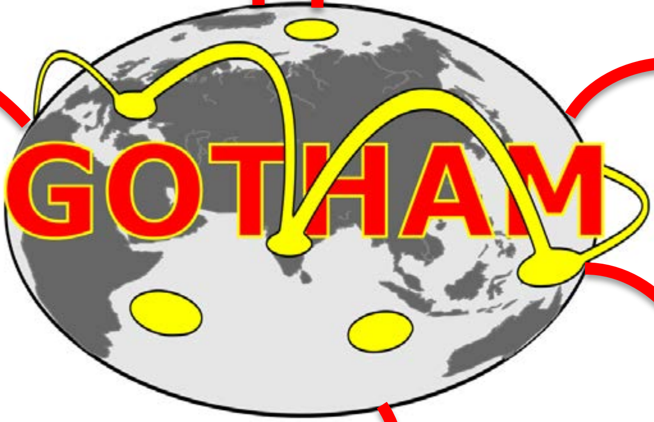
POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH

Globally Observed Teleconnections in a Hierarchy of Atmosphere Models

Lesley Gray, Scott Osprey
David Wallom, Sarah Sparrow

Francois Lott
Eric Guilyardi

Dim Coumou
Reik Donner

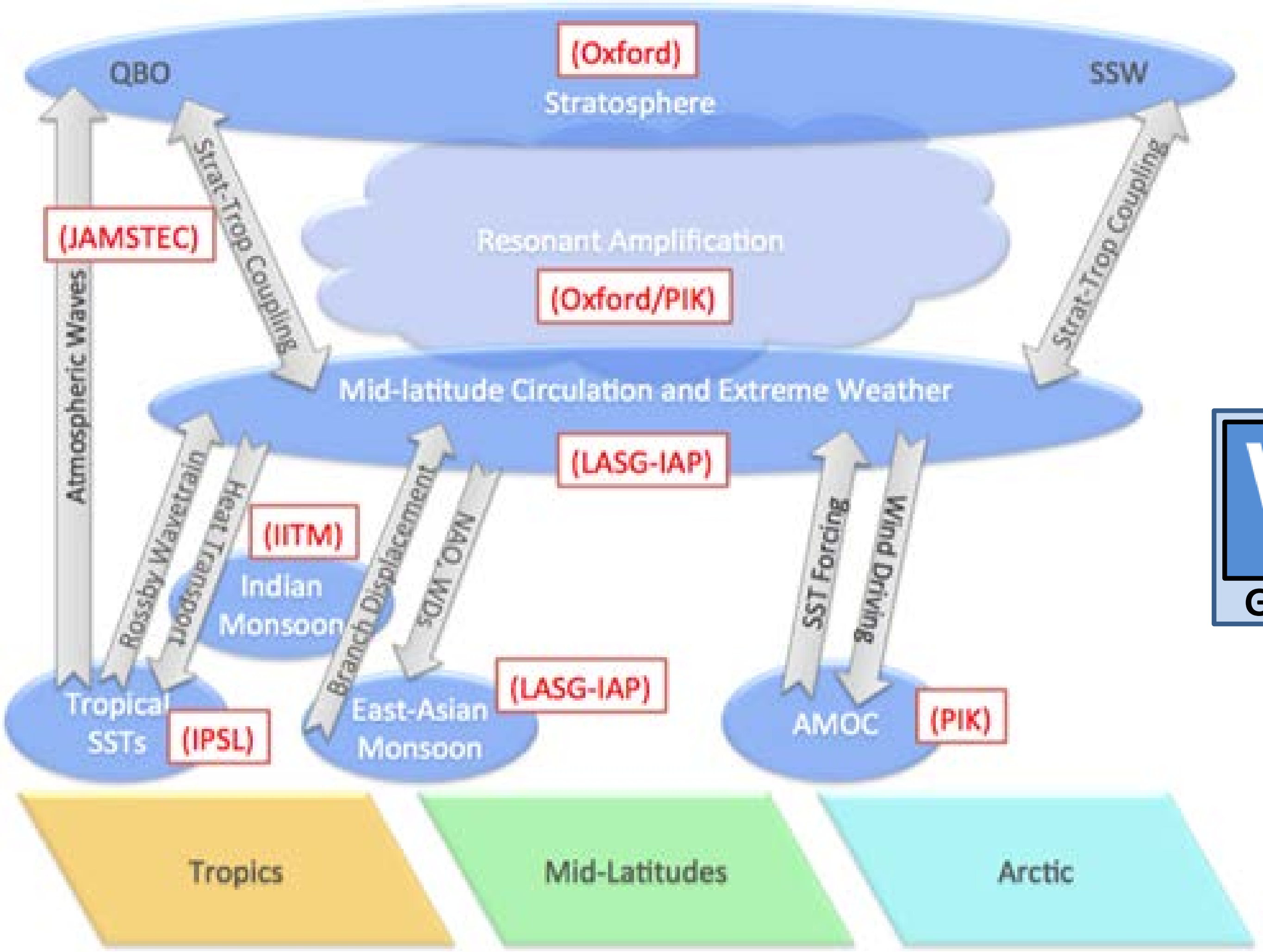


Shingo Watanabe

Bo Wu

Ramesh,
Krishnan

Connecting scientists from different fields



WCRP
World Climate Research Programme
Grand Challenge: Extremes

Extremes often happen when multiple drivers combine

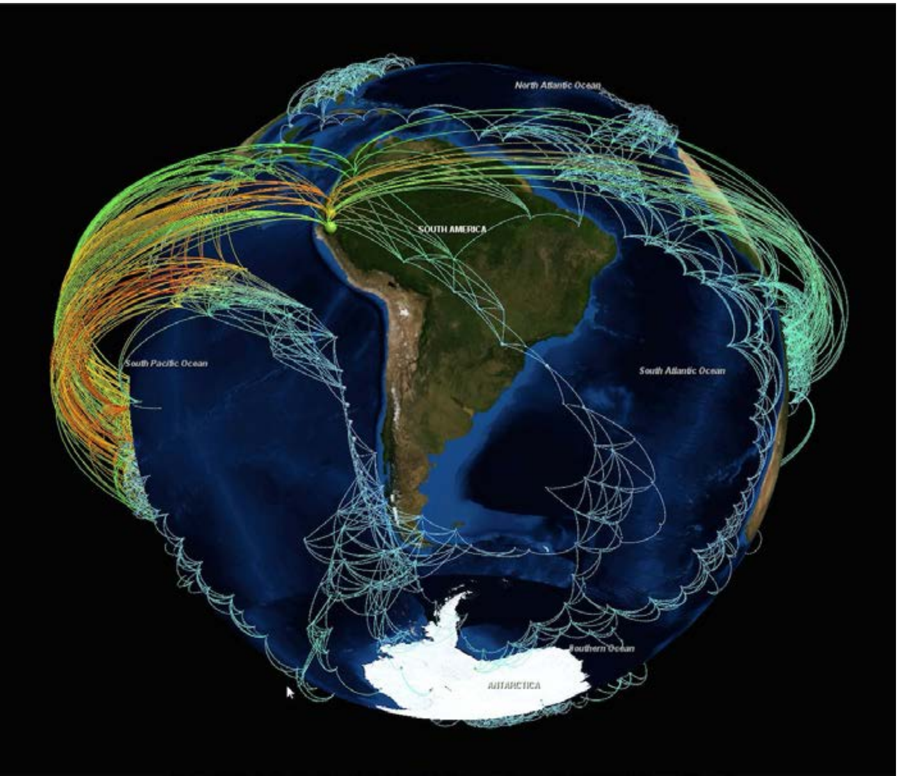
Use same state-of-the-art tools

Massive ensemble simulations using home computers of thousands of volunteers worldwide

(David Wallom, Sarah Sparrow)

climate*prediction*.net

the world's largest climate modelling experiment for the 21st century



Complex Network Analyses
(Reik Donner et al.)

GOTHAM Summer school

- Lectures on key dynamical aspects of the climate system
  - ENSO dynamics
  - Mid-latitude circulation
  - Stratospheric teleconnections
  - Indian Monsoon
- Invited lectures: Overarching themes, seasonal predictability, etc
- Practical Training: CPDN / pyunicorn / tigramite

GOTHAM

Midlatitude Circulation
Quasi-stationary waves and extreme weather in winter & summer

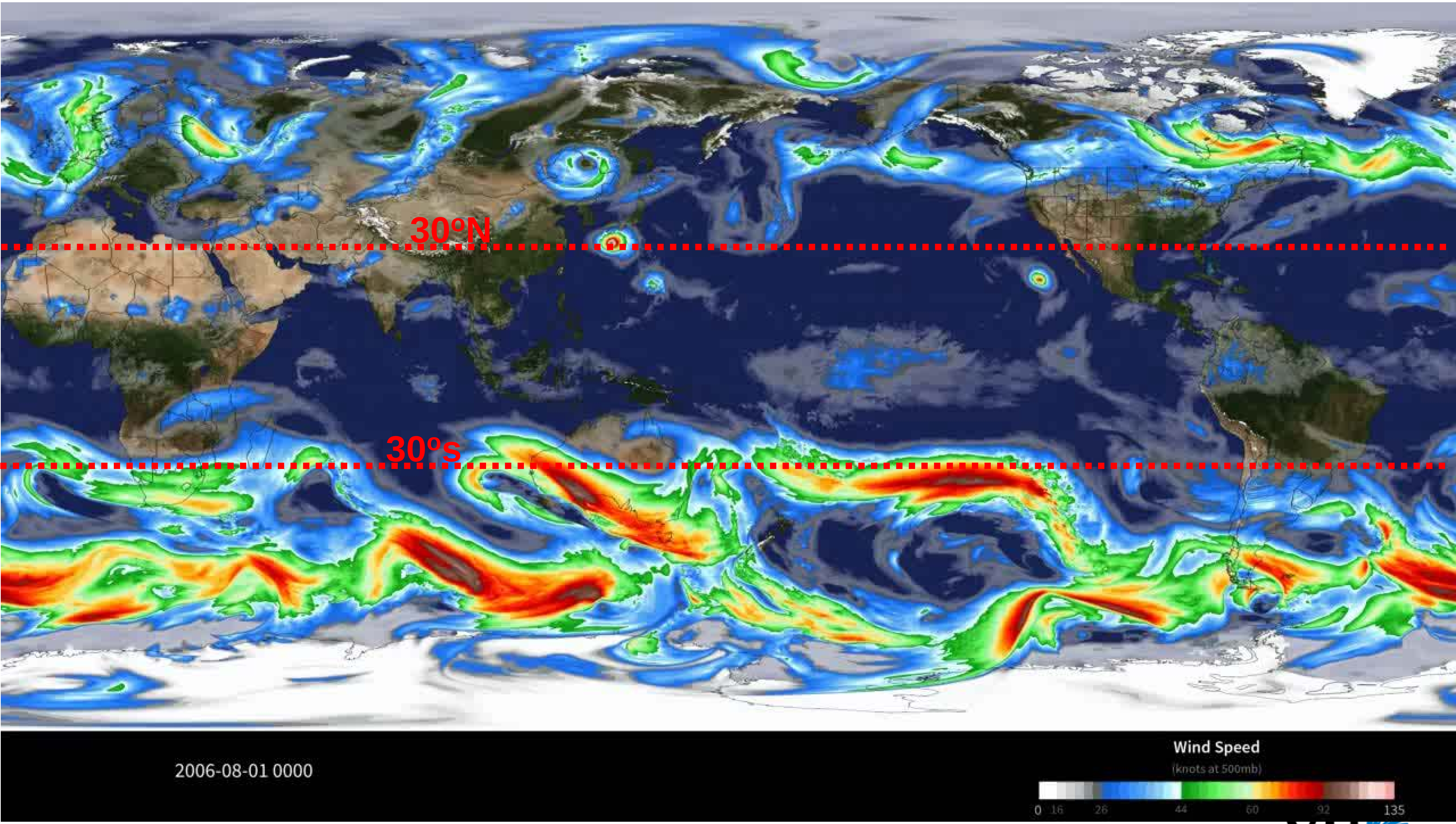
Dim Coumou

Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

VU UNIVERSITY AMSTERDAM

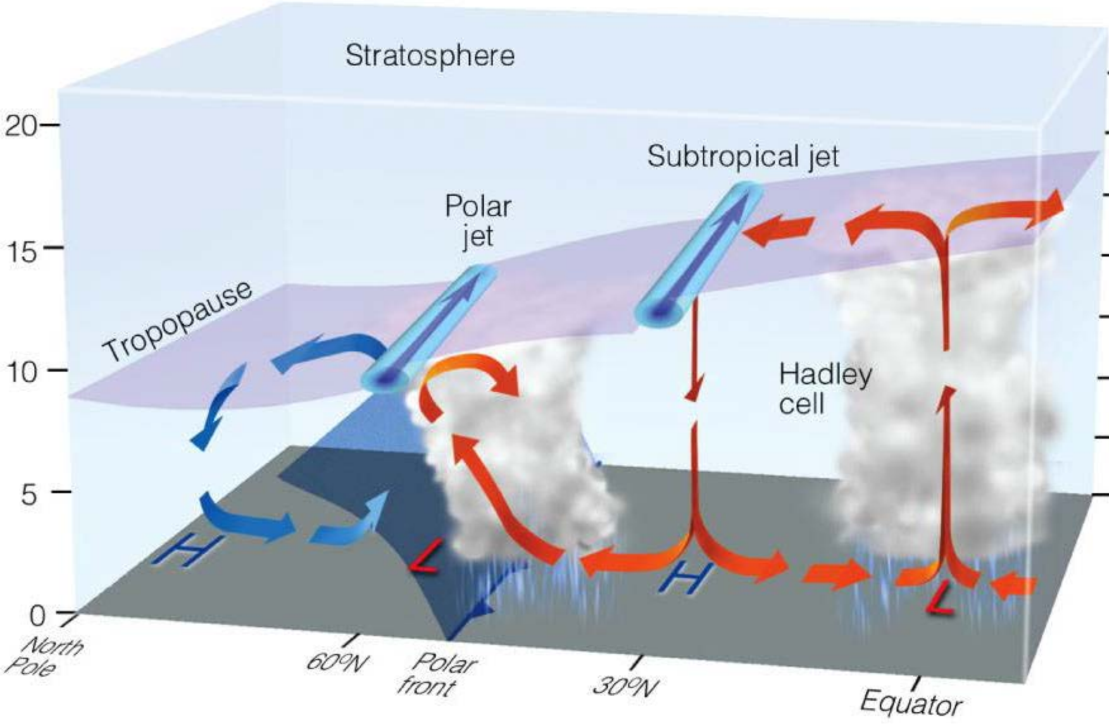
POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH

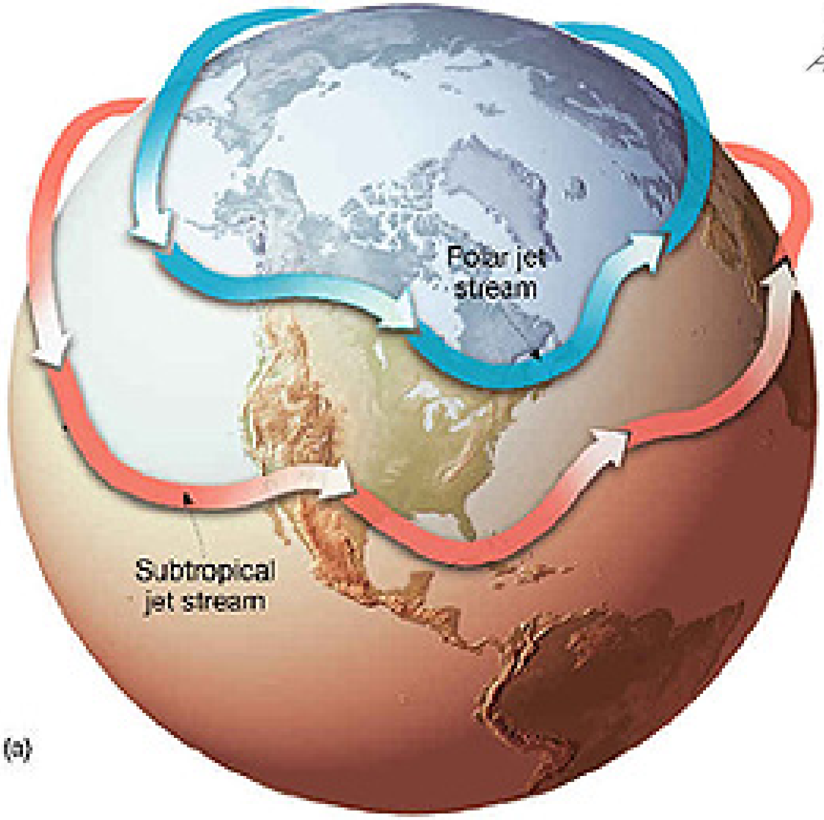
THE GENERAL CIRCULATION OF THE ATMOSPHERE



IDEALIZED STRUCTURE

- 3 Cell Model
- Sub-tropical & polar jet





- Explains patterns of surface winds: Tropical easterlies & mid-latitude westerlies
- 2-way momentum exchange between Earth & Atmosphere: Tropics extract angular momentum from the Earth, mid-latitudes return angular momentum

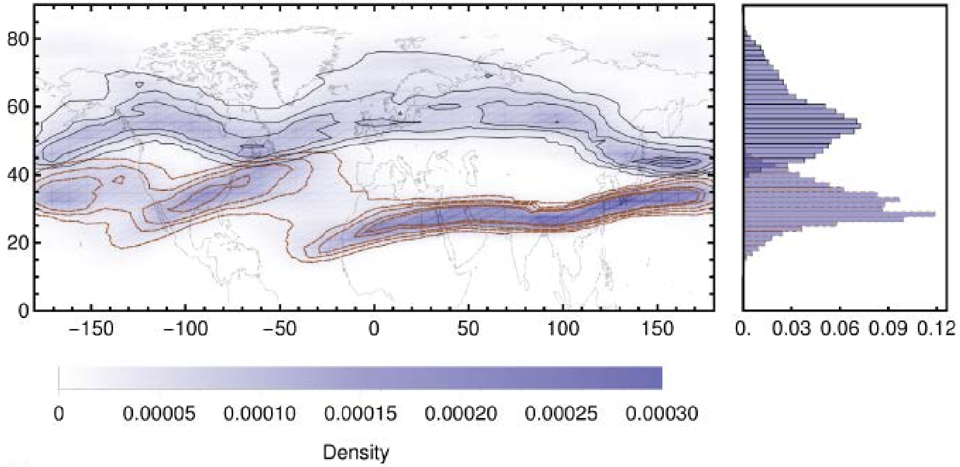
WINTER

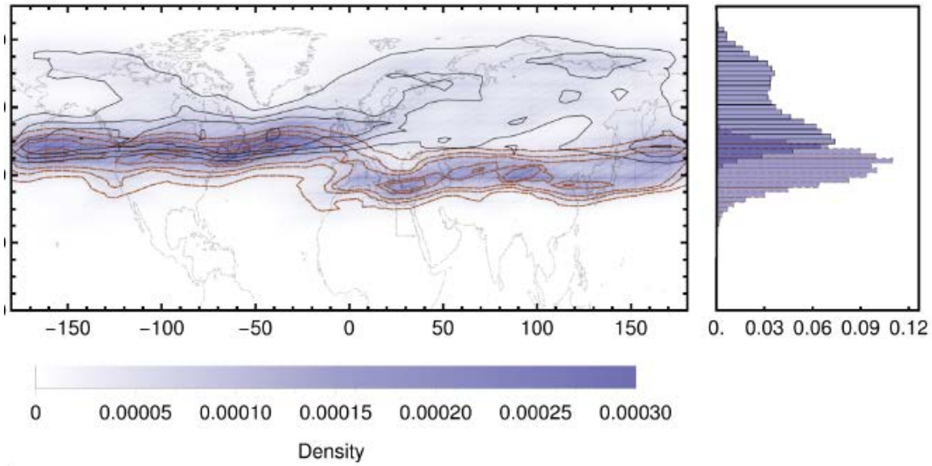
- Stronger westerlies.
- Sub-tropical jet further south
- Jets mostly separated

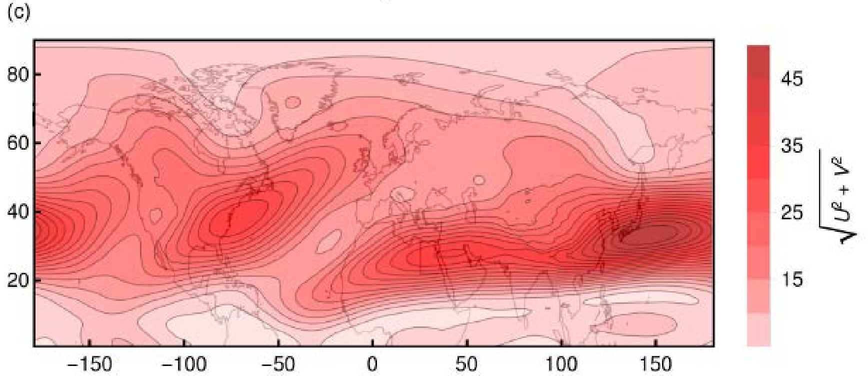
SUMMER

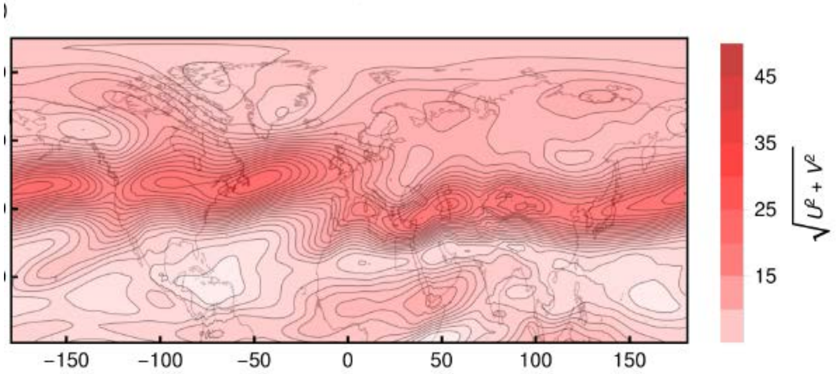
- Weaker westerlies.
- Sub-tropical jet further north
- Jets tend to merge
- 2nd peak at 70N: Arctic front jet

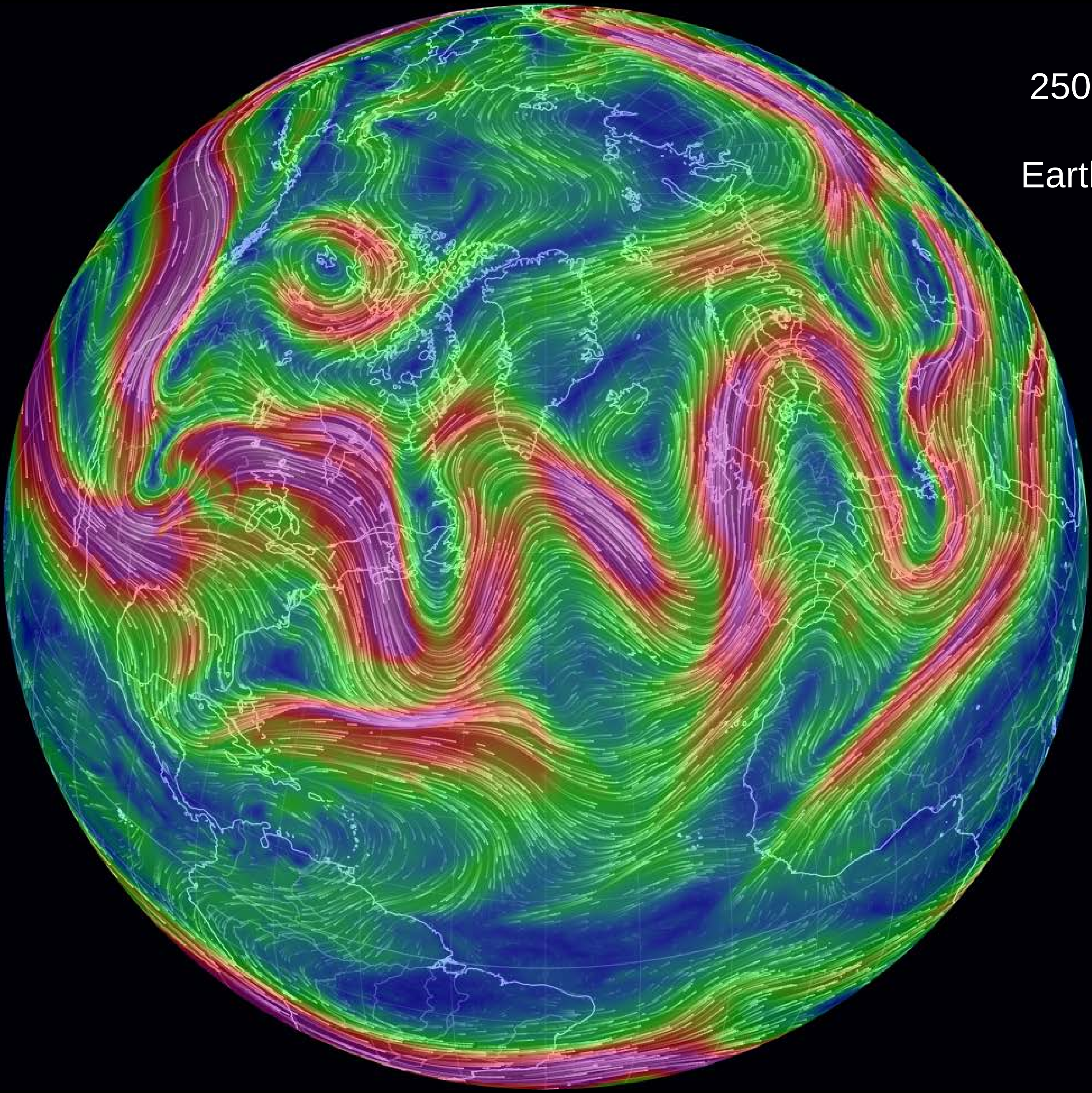
Molnos et al, 2016





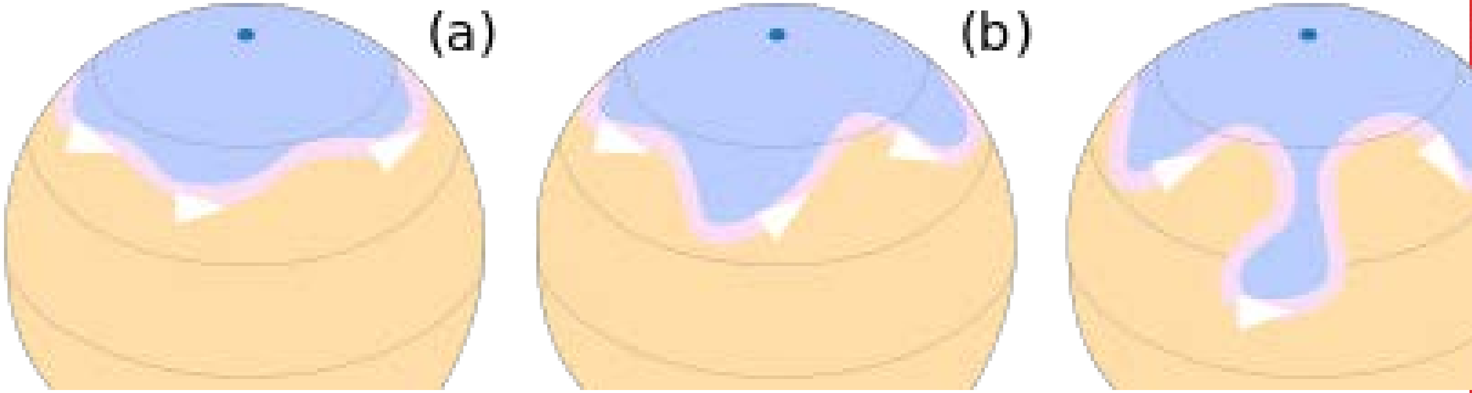


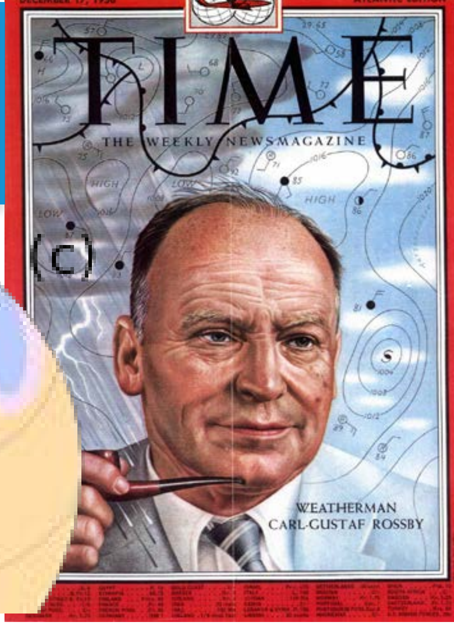




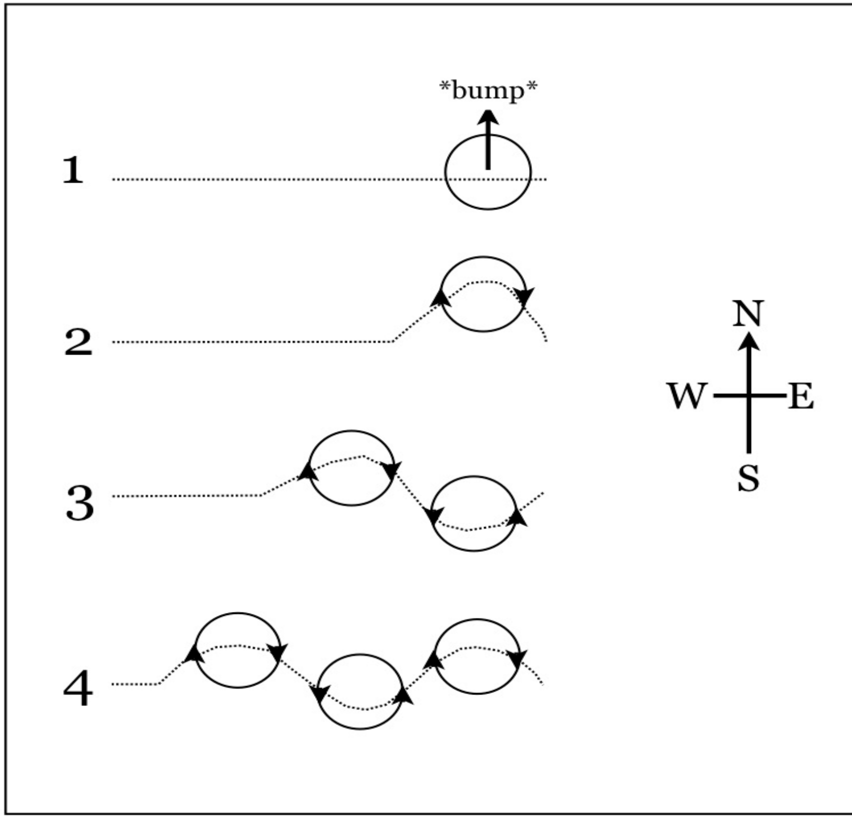
250mb windfield
17-05-2017
Earth NullSchool

FREE ROSSBY WAVES



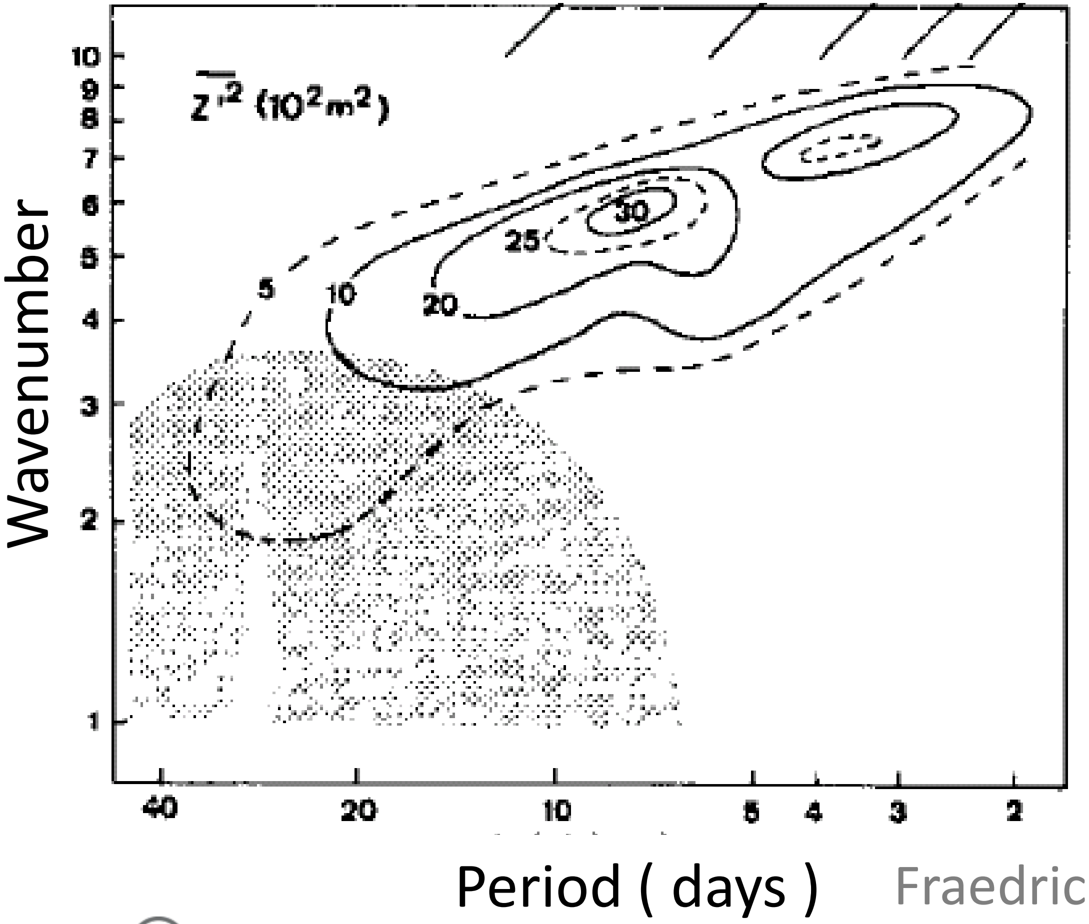


- Due to the variation in the Coriolis effect with latitude. Air parcel moving north is deflected creating wave-like behavior
- Rossby parameter: $\beta = \dfrac{\partial f}{\partial y} = \dfrac{2\Omega}{a}\cos\phi$
- Phasespeed: $c = U - \dfrac{\beta}{k^2}$
- Low wavenumbers (1-3): westwards
- High wavenumbers (>6): eastwards



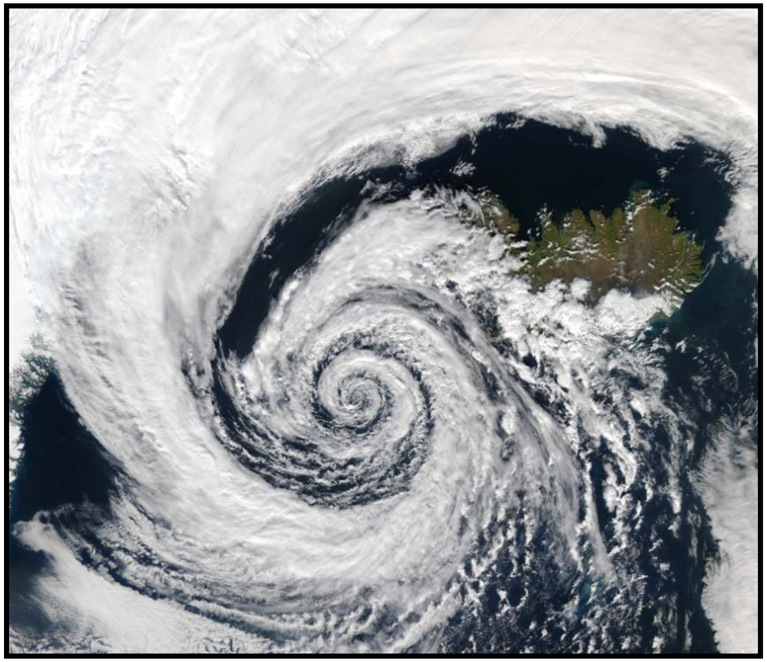
Wavenumber regimes

Atmospheric Power spectrum



Synoptic eddy

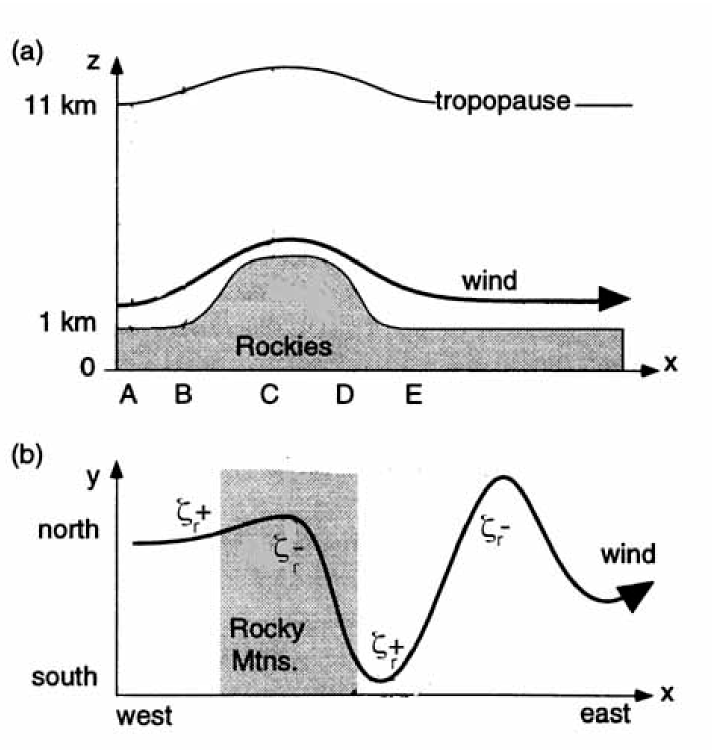
~25^o, ~ 3000km, k > 7

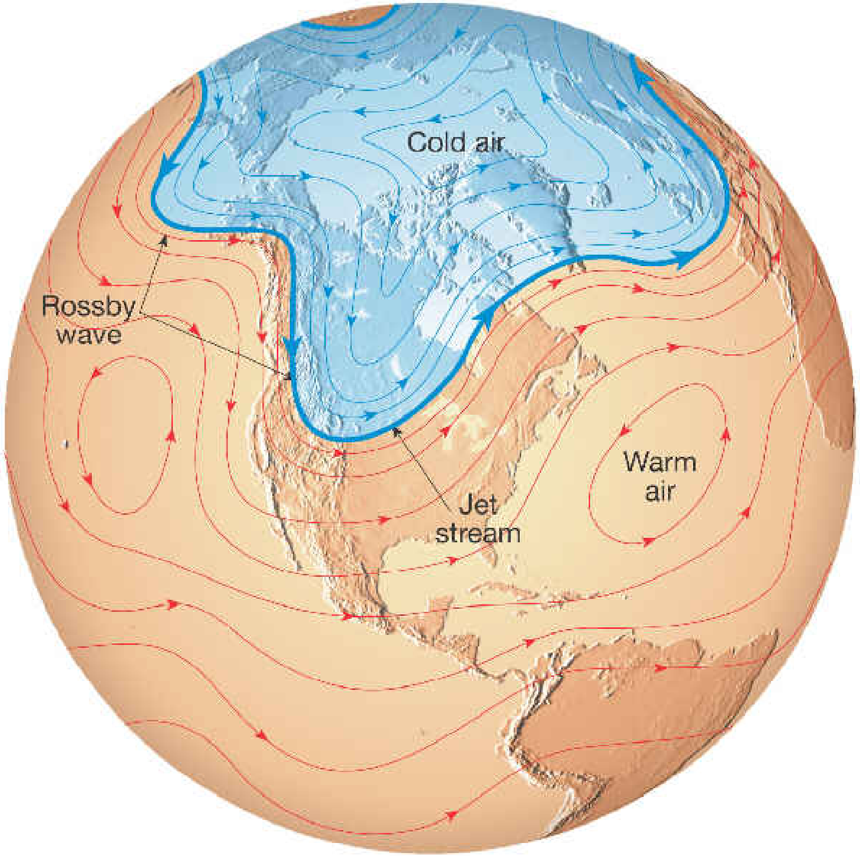


Fraedrich & Bottger, 1977

ROSSBY WAVES – OROGRAPHIC FORCING

Mountains disturb the flow and creating quasi-stationary Rossby waves



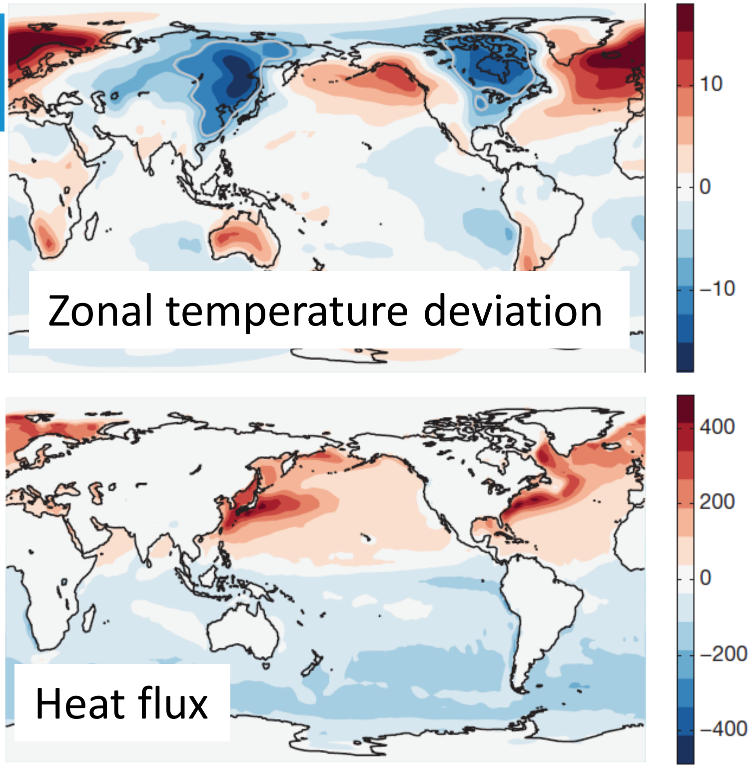


ROSSBY WAVES – THERMAL FORCIN
COLD EASTERN CONTINENTS

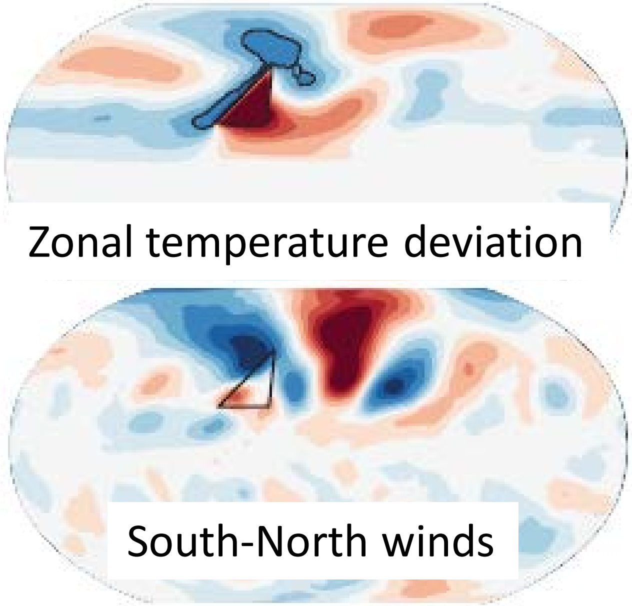
- Quasi-stationary Rossby waves partly responsible for cold eastern continents
- Eastern parts of continents much colder than west at the same latitude
- Warm oceanic western boundary currents release heat into atmosphere
- This creates a quasi-stationary Rossby wave with northerly flow over the continent, bringing cold Arctic air southwards.

Kaspi & Schneider, 2011

OBSERVATIONS



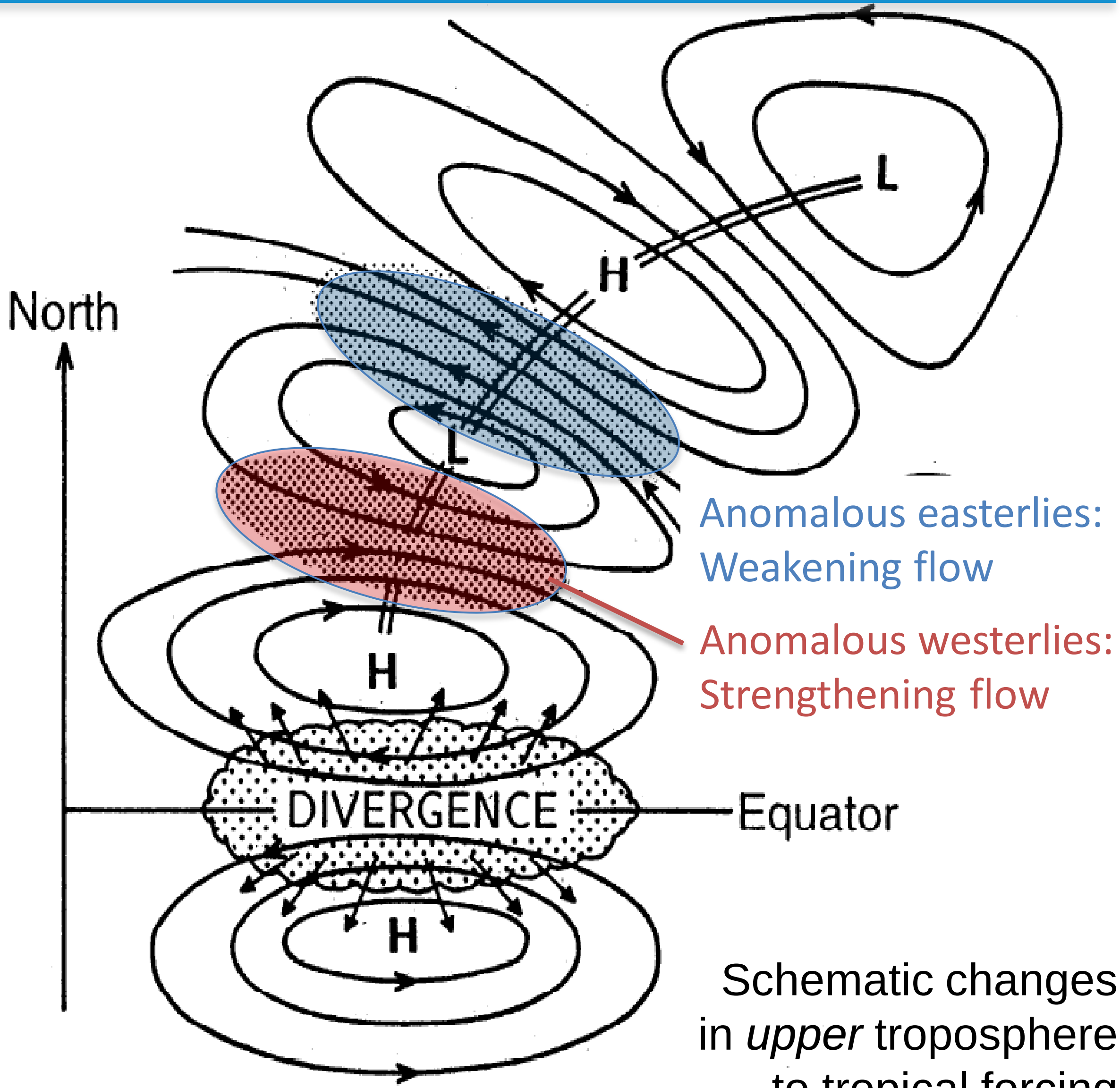
MODEL EXPERIMENT



ROSSBY WAVES EMANATING FROM TROPICS

Tropical thunderstorms and associated latent heat release are prominent sources of Rossby waves

Prime mechanism how El Nino's can influence the mid-latitudes



Anomalous easterlies: Weakening flow

Anomalous westerlies: Strengthening flow

Schematic changes in *upper* troposphere to tropical forcing

Trenberth et al, 1998

MORE-EXOTIC PHENOMENA

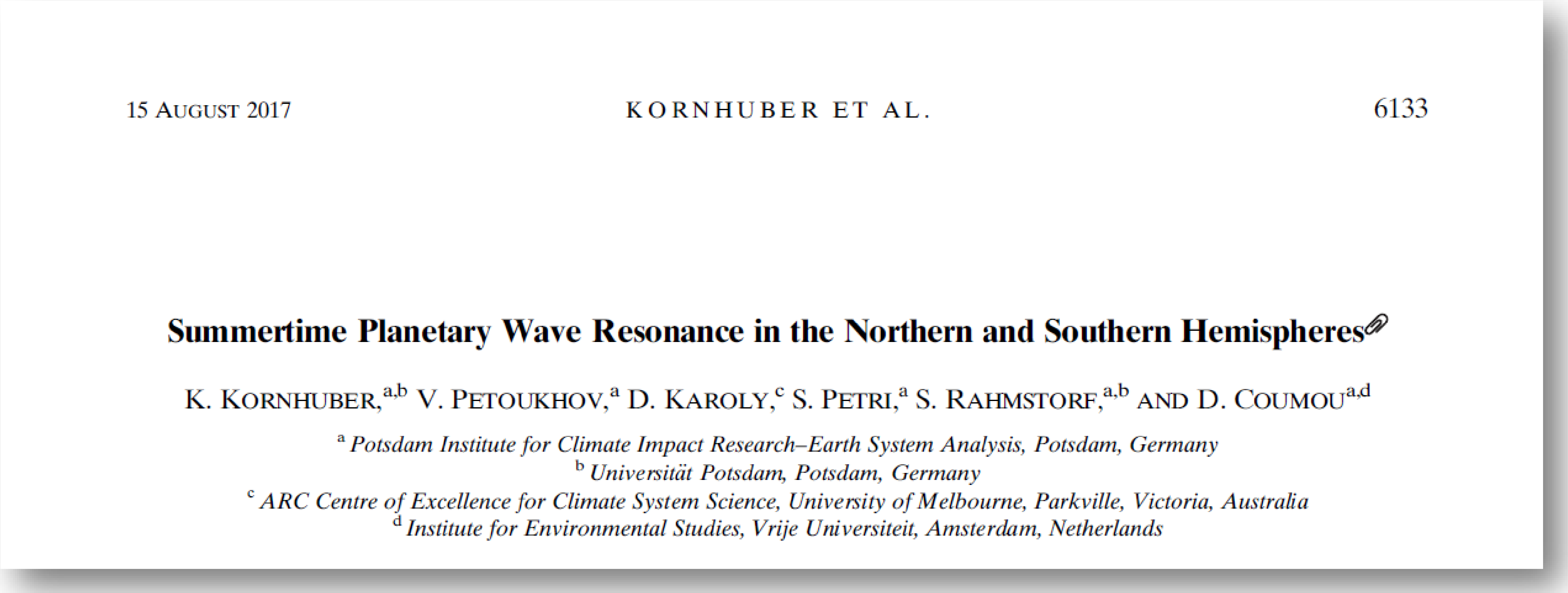
Mid-latitudes exercise 1

Summer: Wave-resonance effects leading to persistent extremes

Mid-latitudes exercise 2

Winter: Stratosphere-Troposphere interactions related to cold-spells

EXERCISE 1: SUMMER CIRCULATION OF 2010



15 AUGUST 2017 KORNHUBER ET AL. 6133

Summertime Planetary Wave Resonance in the Northern and Southern Hemispheres

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[b] *Universität Potsdam, Potsdam, Germany*
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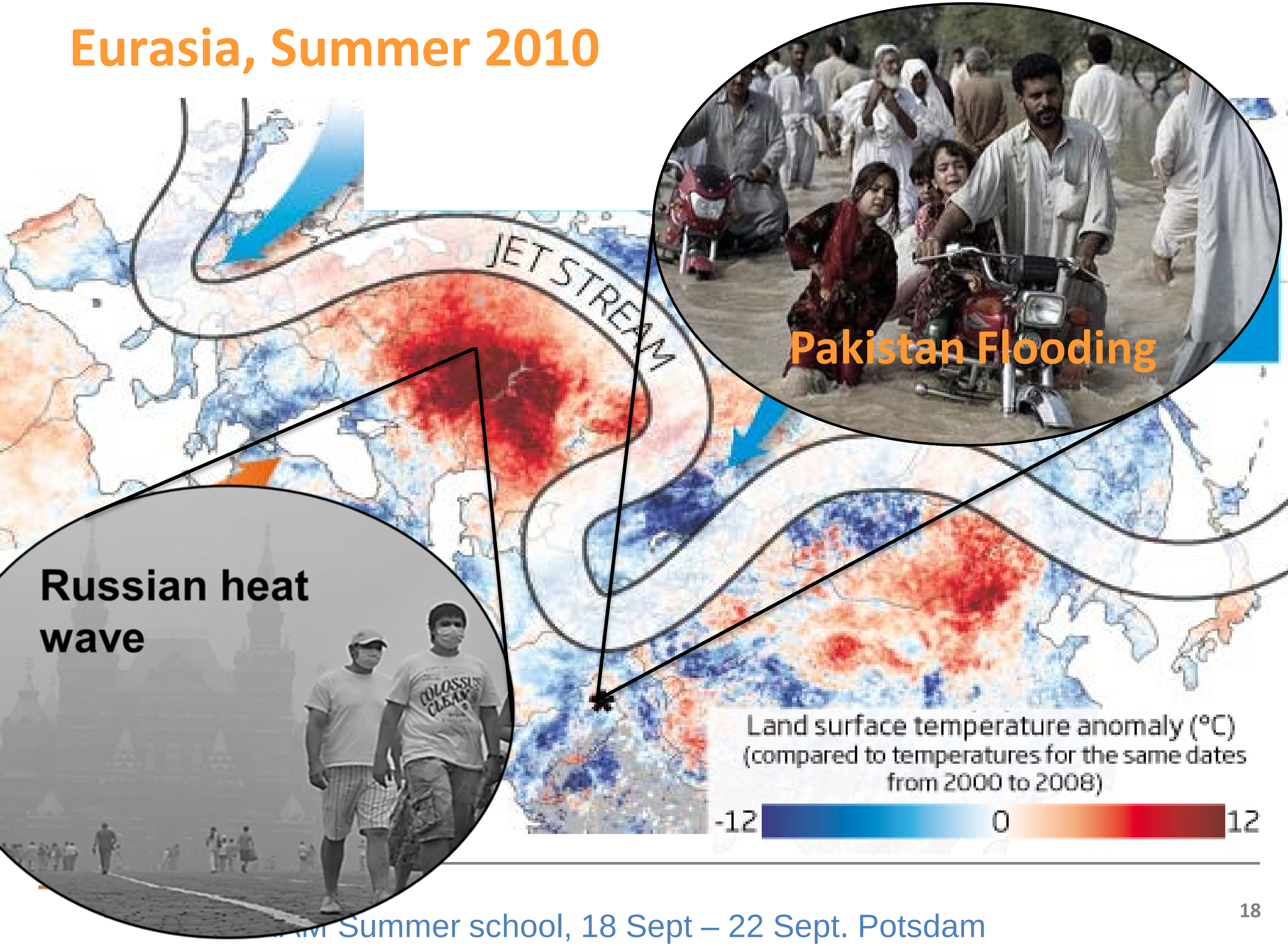
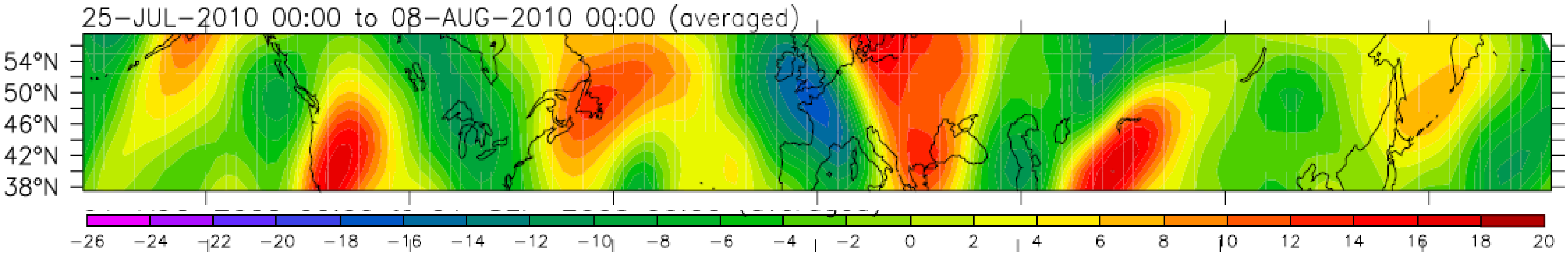
[d] *Institute for Environmental Studies, Vrije Universiteit, Amsterdam, Netherlands*

Eurasia, Summer 2010



Summer 2010: Wave resonance event

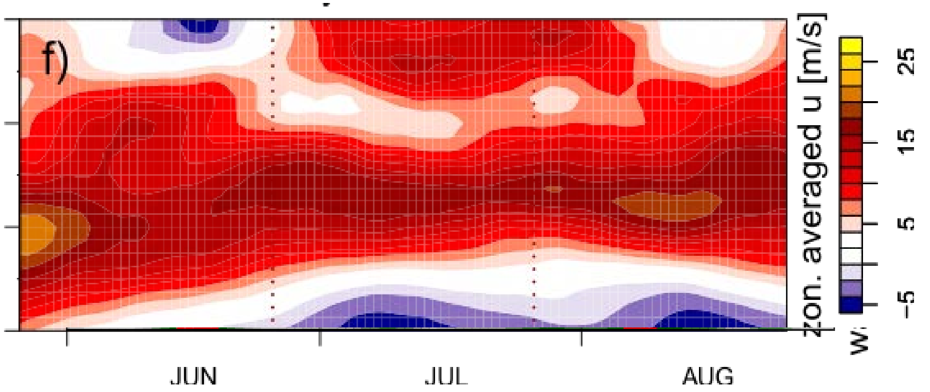


Meridional wind speed [m/s]

Resonance:

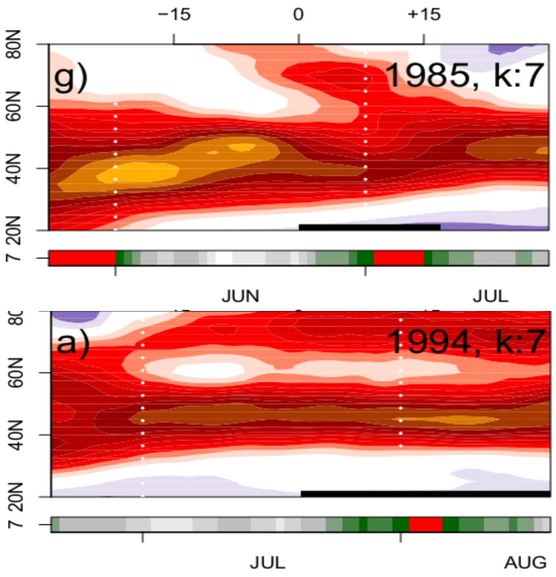
- Waves with wavenumber 6-8 get trapped in waveguide
- Resonance between free & forced component of trapped wave can create amplified quasi-stationary waves
- Associated with ‘double-jets’

Petoukhov et al.(2013)
Coumou et al.(2014)
Kornhuber et al. (2016, 2017)

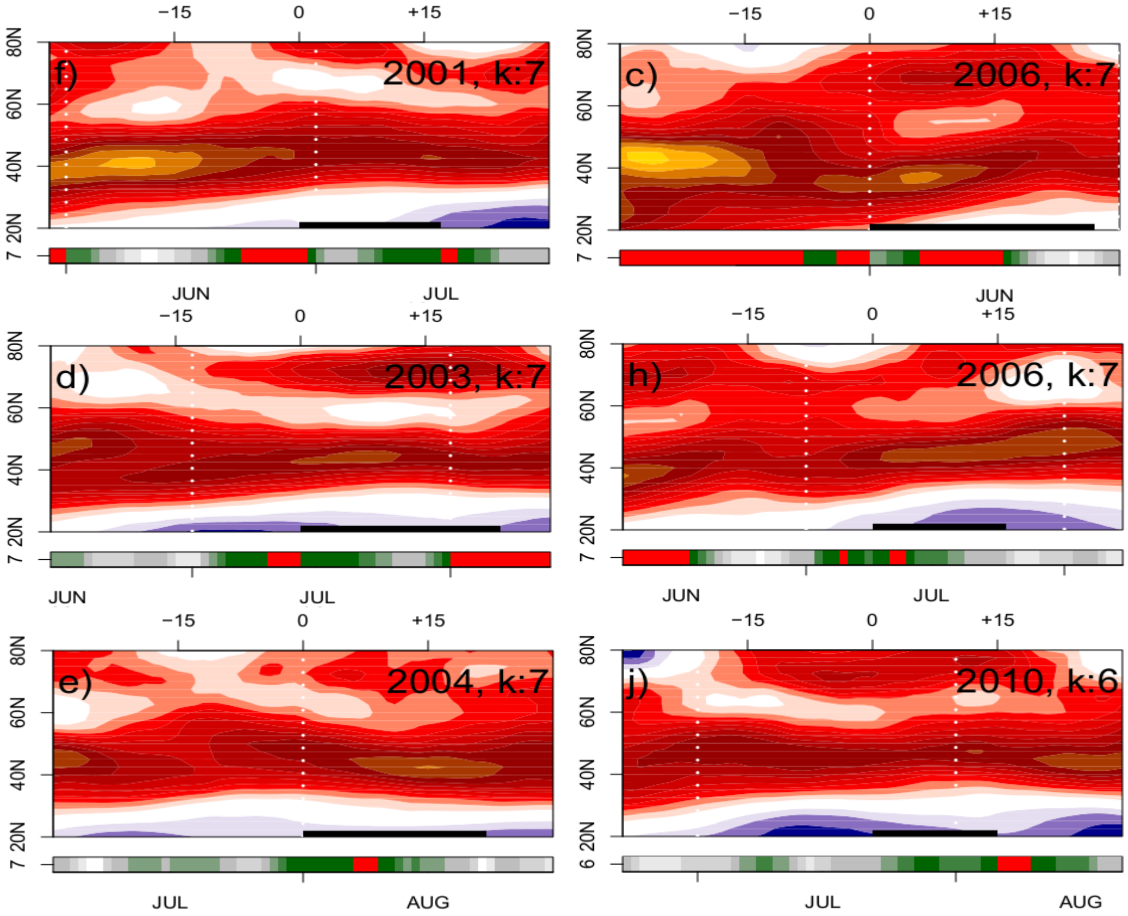


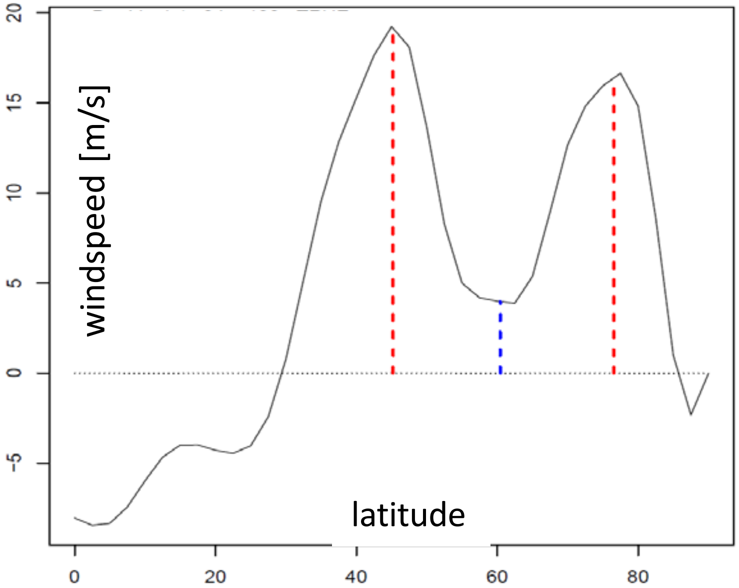
Prolonged Wave-Resonance Events

2 during 1979-1999



6 during 2000-2014





- Double jets + High-amplitude waves
- Especially wave 7 appears important
- Recent cluster of prolonged resonance events

Kornhuber et al. (2016)

EXERCISE 1: SUMMER CIRCULATION OF 2010

Data: CPDN simulations for summer 2010

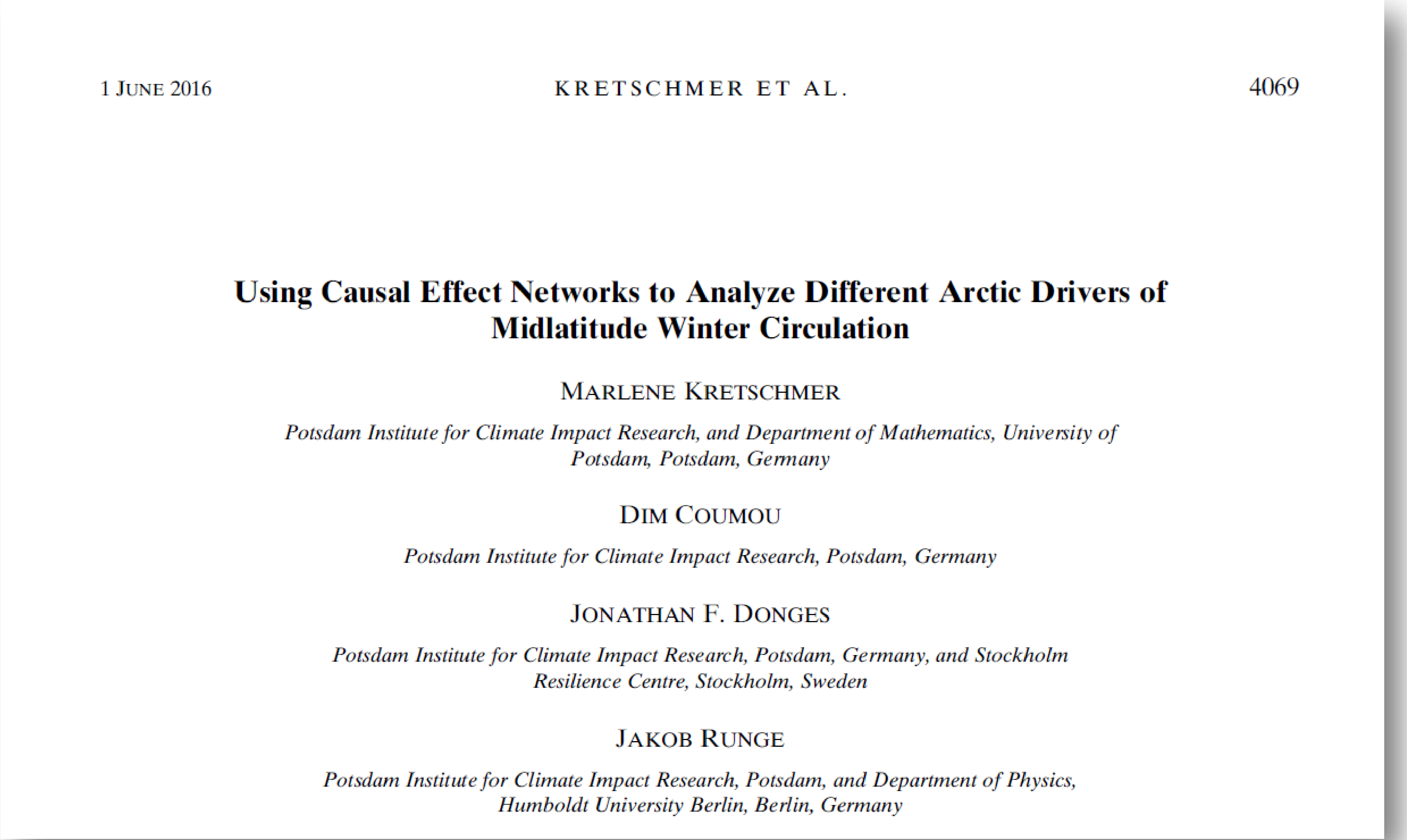
with clear *fingerprint* (i.e. ‘double jet’) and without (*control*)

Tool: *pyunicorn*

Exercise: Create networks for *fingerprint* and *control*

Compare their topology, connectivity, etc

EXERCISE 2: MIDLATITUDE WINTER CIRCULATION



Using Causal Effect Networks to Analyze Different Arctic Drivers of Midlatitude Winter Circulation

Marlene Kretschmer

Potsdam Institute for Climate Impact Research, and Department of Mathematics, University of Potsdam, Potsdam, Germany

Dim Coumou

Potsdam Institute for Climate Impact Research, Potsdam, Germany

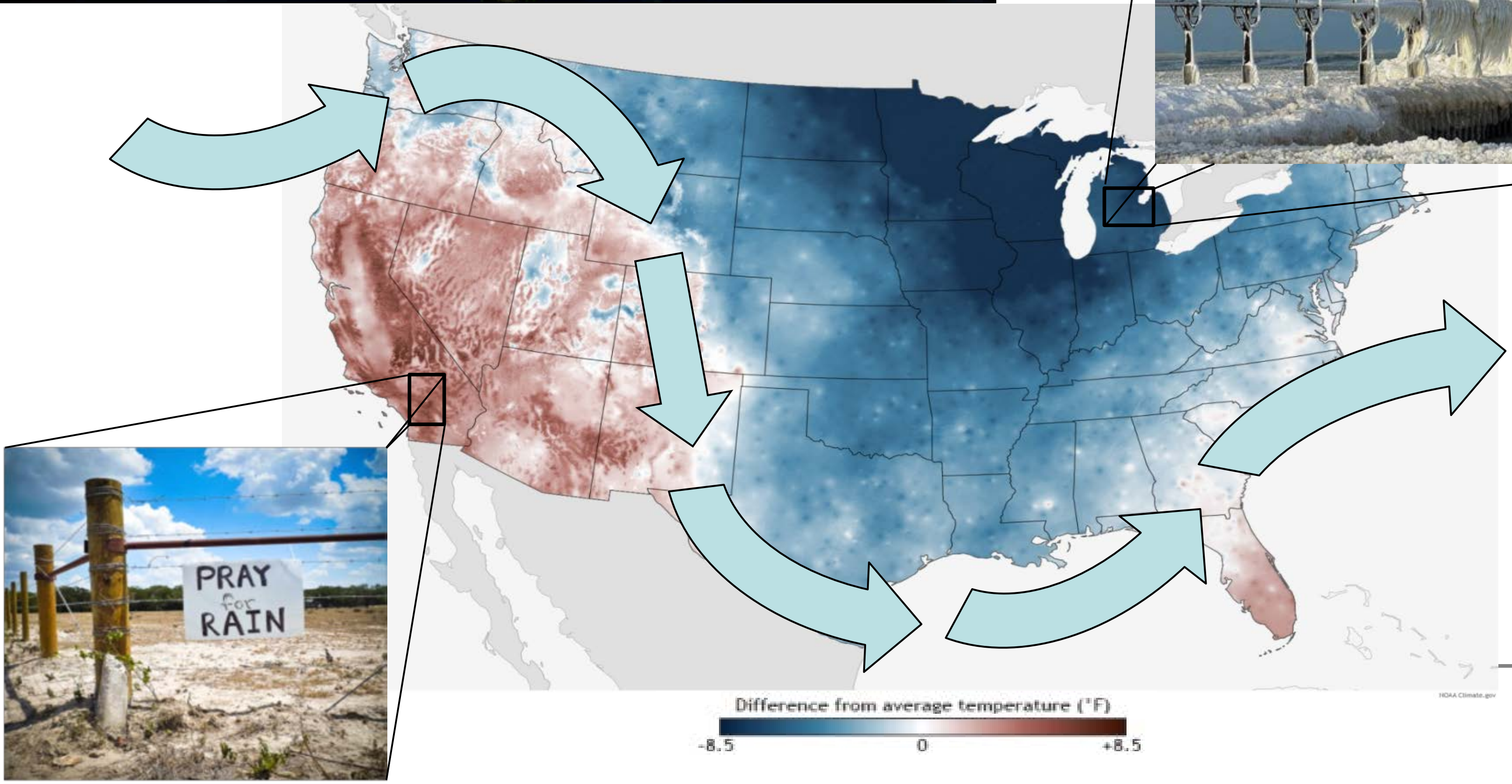
Jonathan F. Donges

Potsdam Institute for Climate Impact Research, Potsdam, Germany, and Stockholm Resilience Centre, Stockholm, Sweden

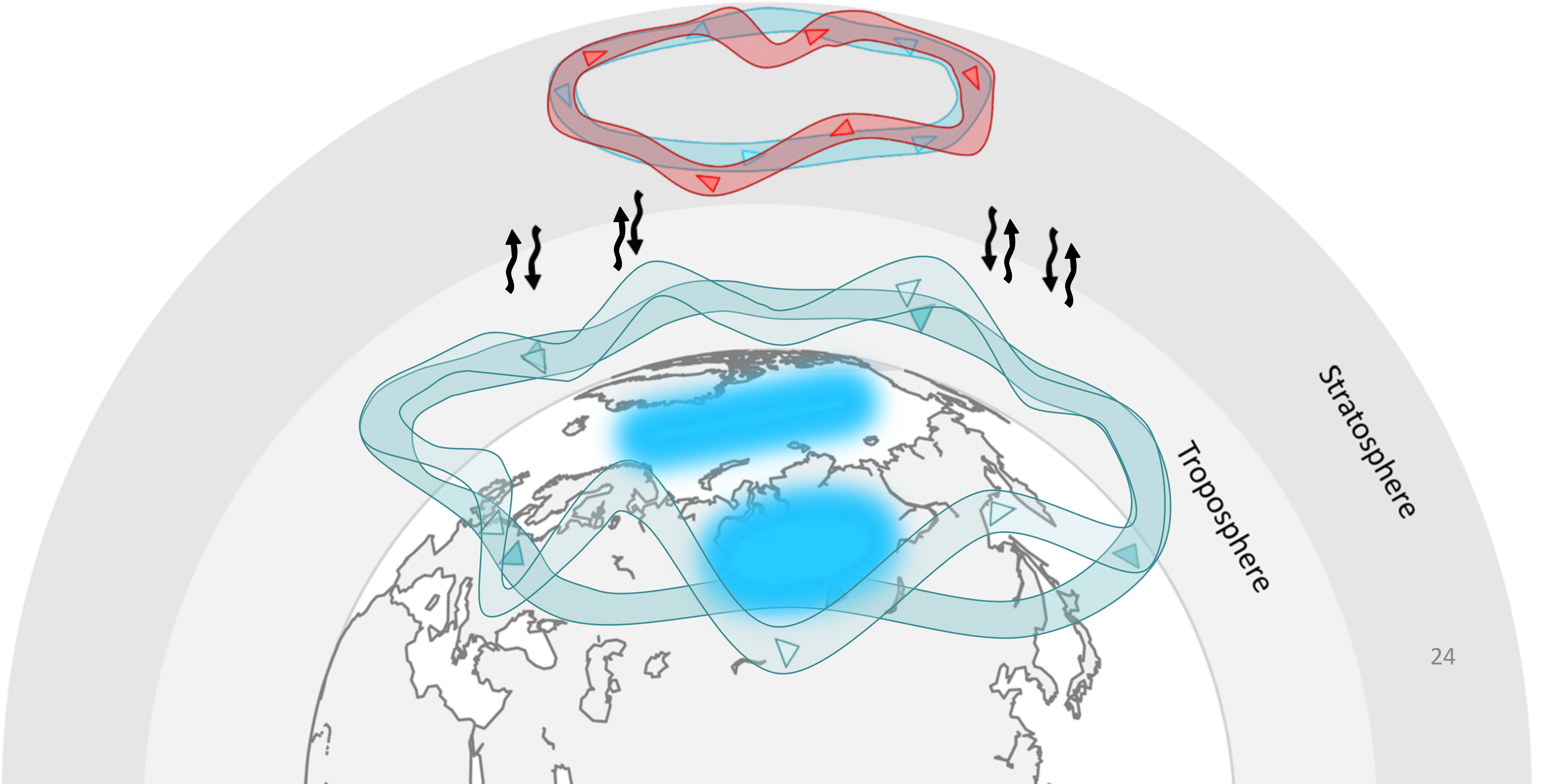
Jakob Runge

Potsdam Institute for Climate Impact Research, Potsdam, and Department of Physics, Humboldt University Berlin, Berlin, Germany

Recent Cold Spells
Polar Vortex Breakdown

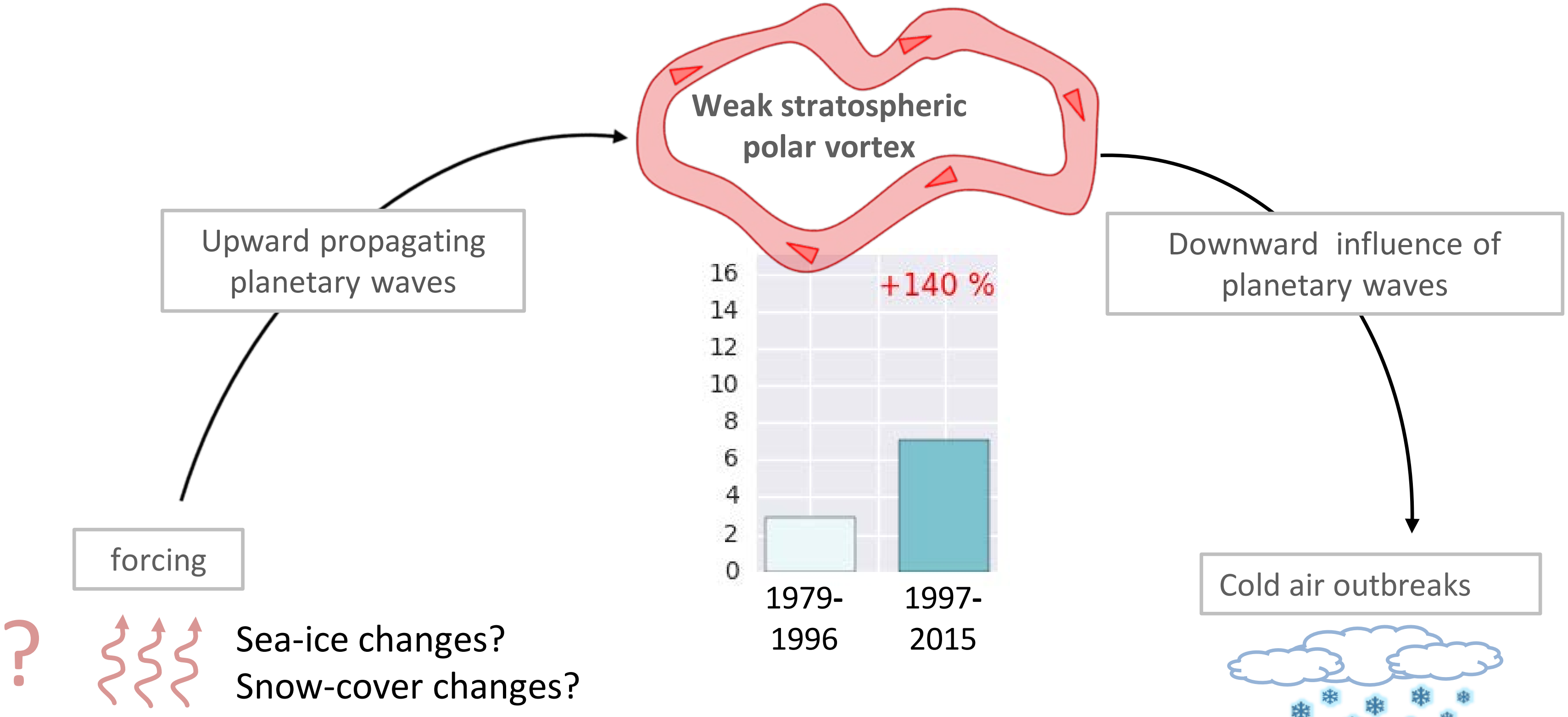


The Stratospheric Polar Vortex



Troposphere - Stratosphere - Troposphere Coupling

Autumn - - - - - - - - - - - - -> Winter



Weak stratospheric polar vortex

Upward propagating planetary waves

Downward influence of planetary waves

forcing

Sea-ice changes?
Snow-cover changes?

Troposphere

Cold air outbreaks

Troposphere

Kretschmer et al,*BAMS* (in press)

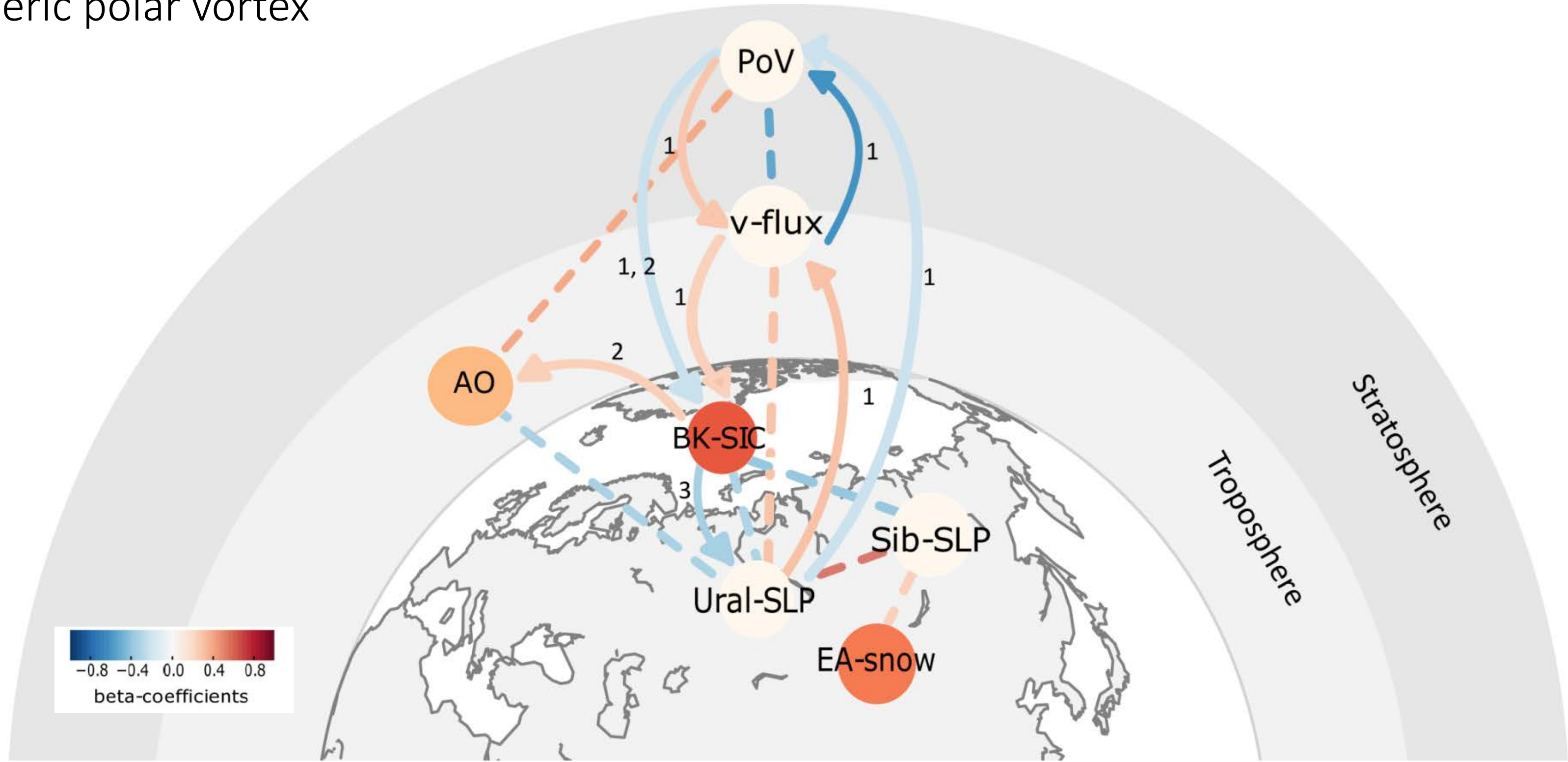
NOTE: talk by Dorthe Handorf

Causal Effect Network

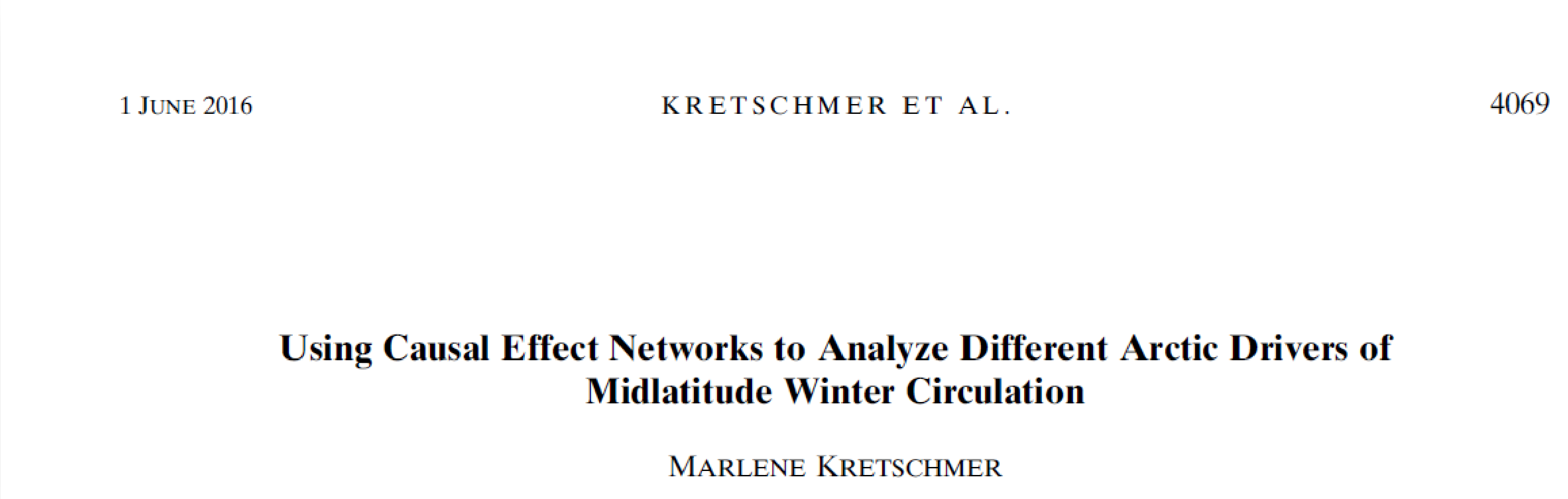
- CEN constructed for winter (DJF)
- Troposphere-Stratosphere coupling robustly found
- Low sea-ice conditions in fall can weaken polar vortex in winter
- Snow cover is *not* a driver of the stratospheric polar vortex

NOTE: talks by Jakob Runge & Marlene Kretschmer

Kretschmer et al, *J. Clim* (2016)



EXERCISE 2: MIDLATITUDE WINTER CIRCULATION



1 JUNE 2016 KRETSCHMER ET AL. 4069

Using Causal Effect Networks to Analyze Different Arctic Drivers of Midlatitude Winter Circulation

MARLENE KRETSCHMER

Reproduce these findings for CPDN model simulations

& compare with reanalysis CEN

PIK / SacreX / Climate Media Factory

Wave-Resonance:

Dynamical Mechanism to create High-Amp Quasi-Stationary Waves in Summer

Waveguide:

Trapping of synoptic-scale wave in mid-lats

+

Right forcing:

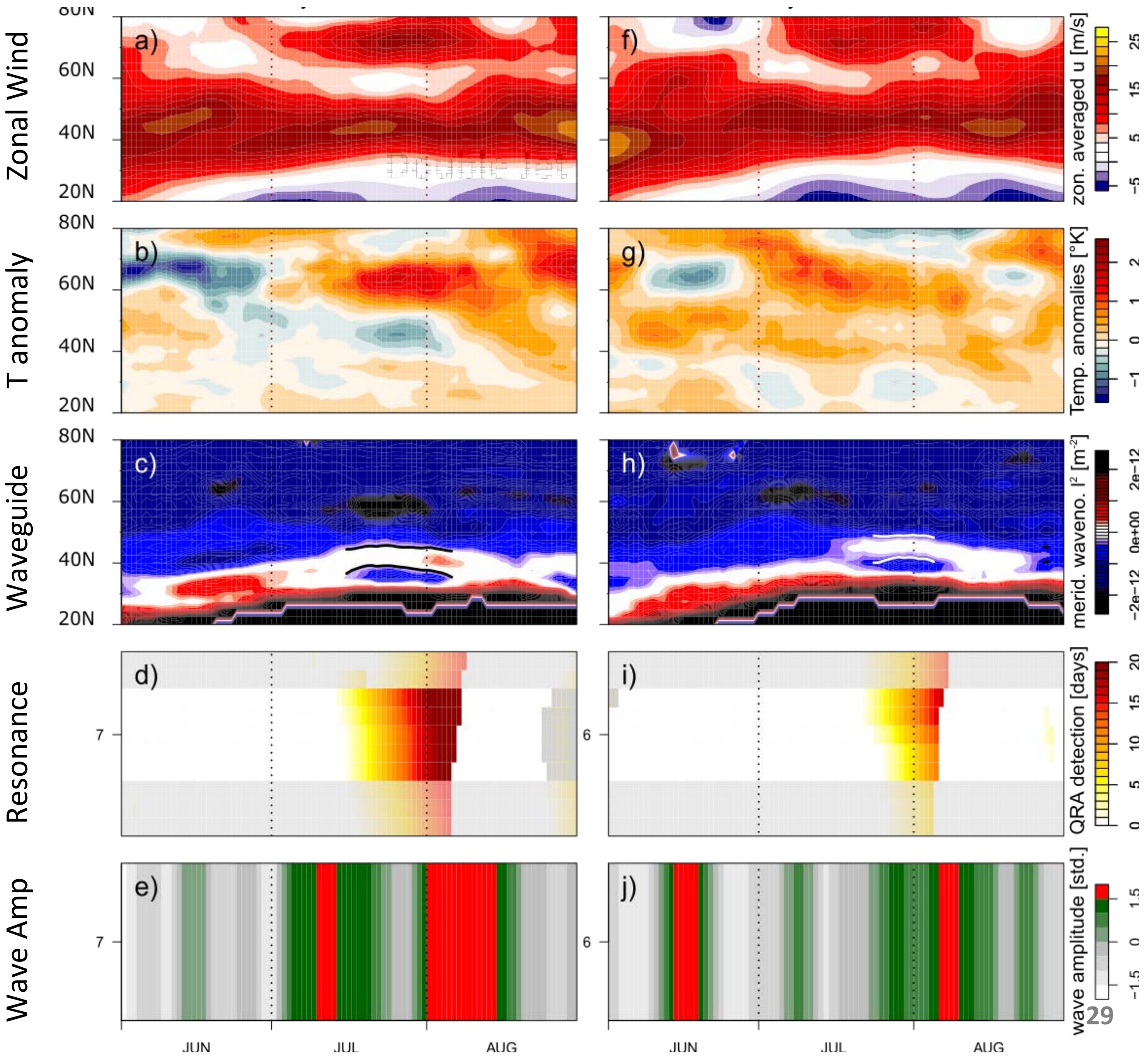
High-amp, quasi-stationary waves (6, 7 or 8).

Often associated with summer extremes

Petoukhov et al.(2013)
Coumou et al.(2014)
Kornhuber et al. (2016, 2017)

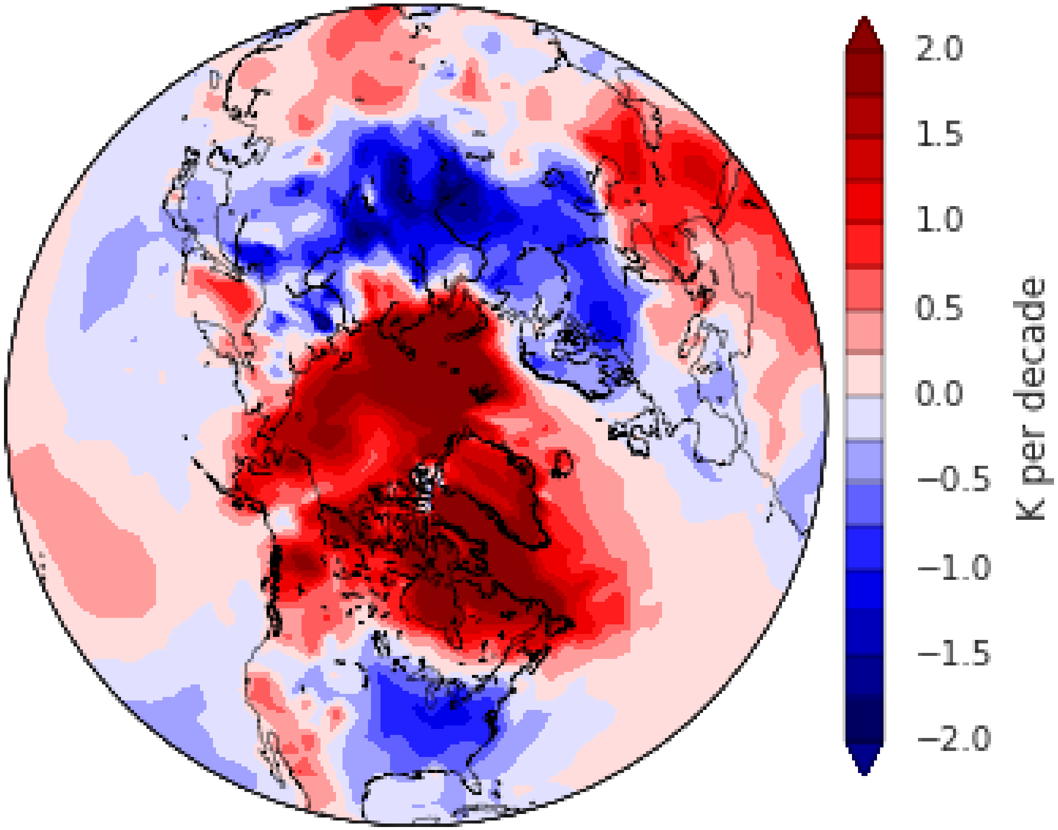
Zonal-mean Hovmöller diagrams

Summer 2003 **Summer 2010**



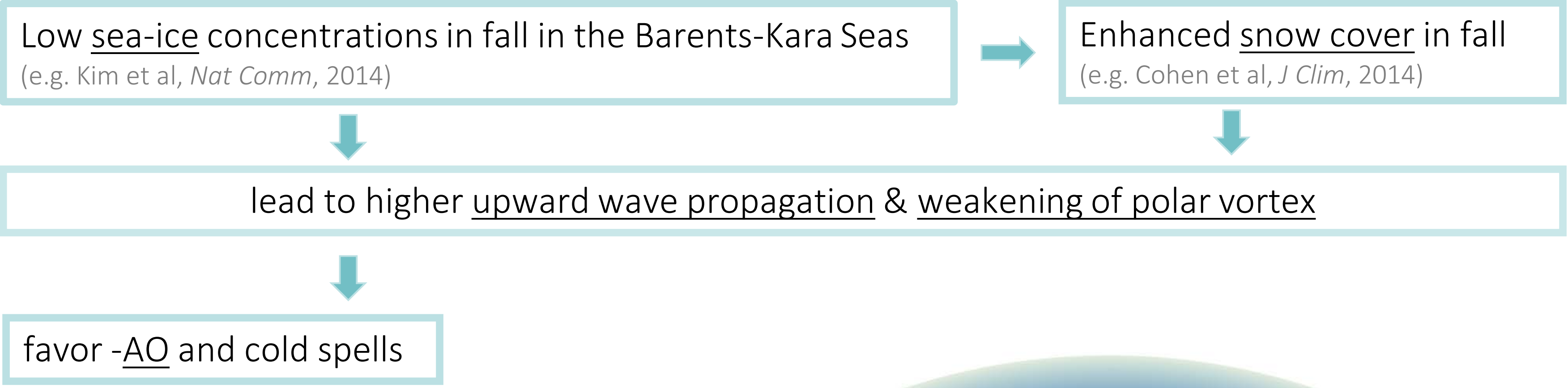
Warm-Arctic Cold-Continent pattern:
Some long-term cooling trends over continents observed

Linear trend 1990-2016 (DJF)



Kretschmer et al, *in press*

Hypothesis: Arctic drivers of Polar vortex variability?



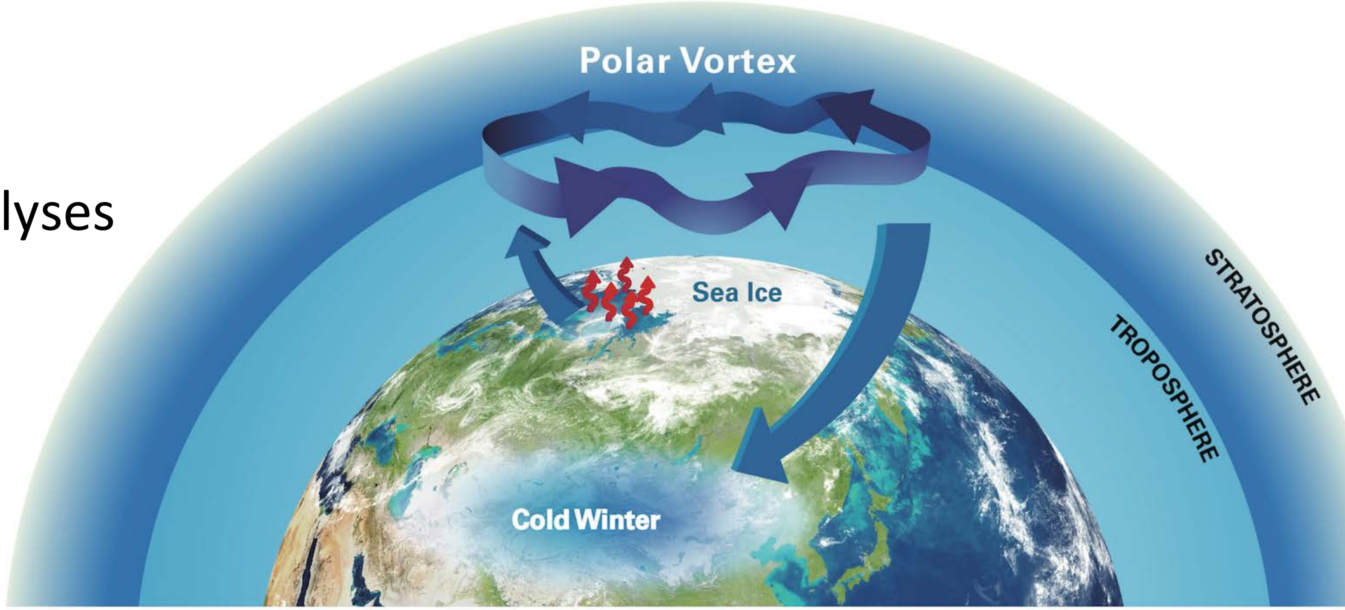
Low sea-ice concentrations in fall in the Barents-Kara Seas
(e.g. Kim et al, *Nat Comm*, 2014)

Enhanced snow cover in fall
(e.g. Cohen et al, *J Clim*, 2014)

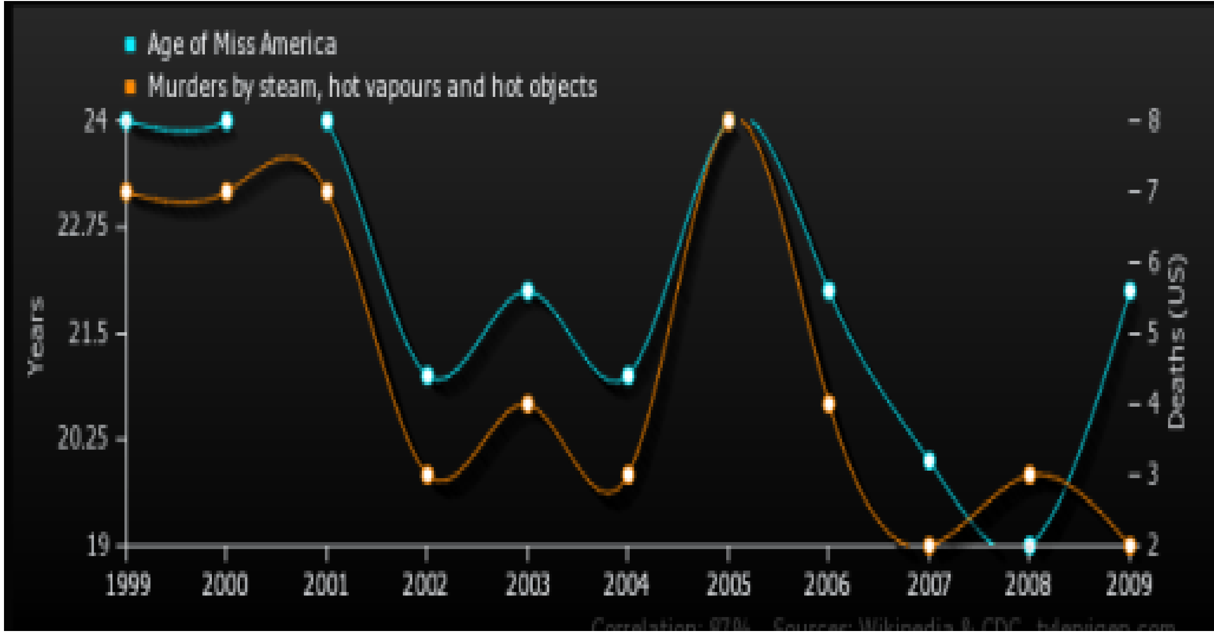
lead to higher upward wave propagation & weakening of polar vortex

favor -AO and cold spells

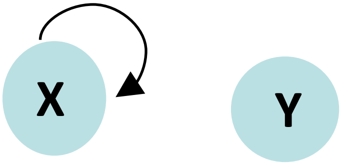
BUT: These were *correlation-based* analyses



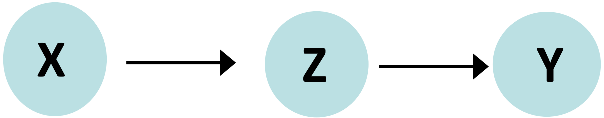
Problems with Cross-Correlation….

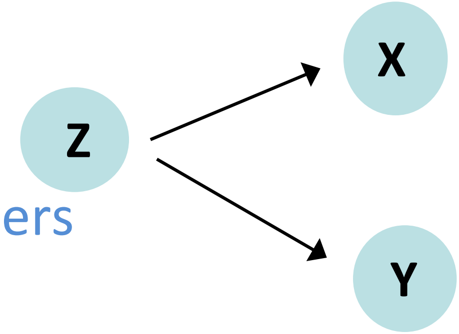


… auto-correlation



… indirect links



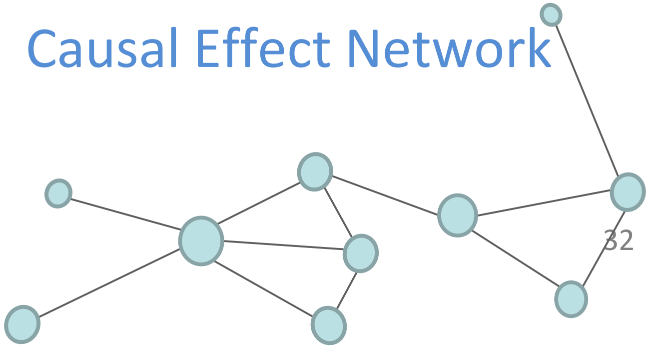


… common drivers

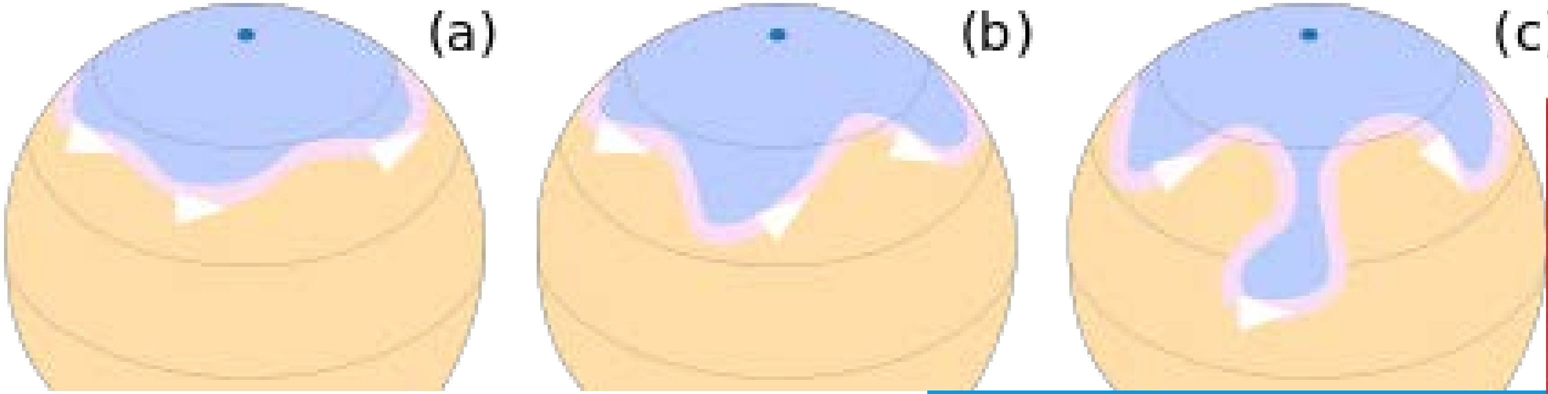
Causal Discovery Algorithm

Iteratively loop over *all possible* links and check if a correlation between two variables is explained by any of these three. If so the link is *non-causal* and thus removed from the network

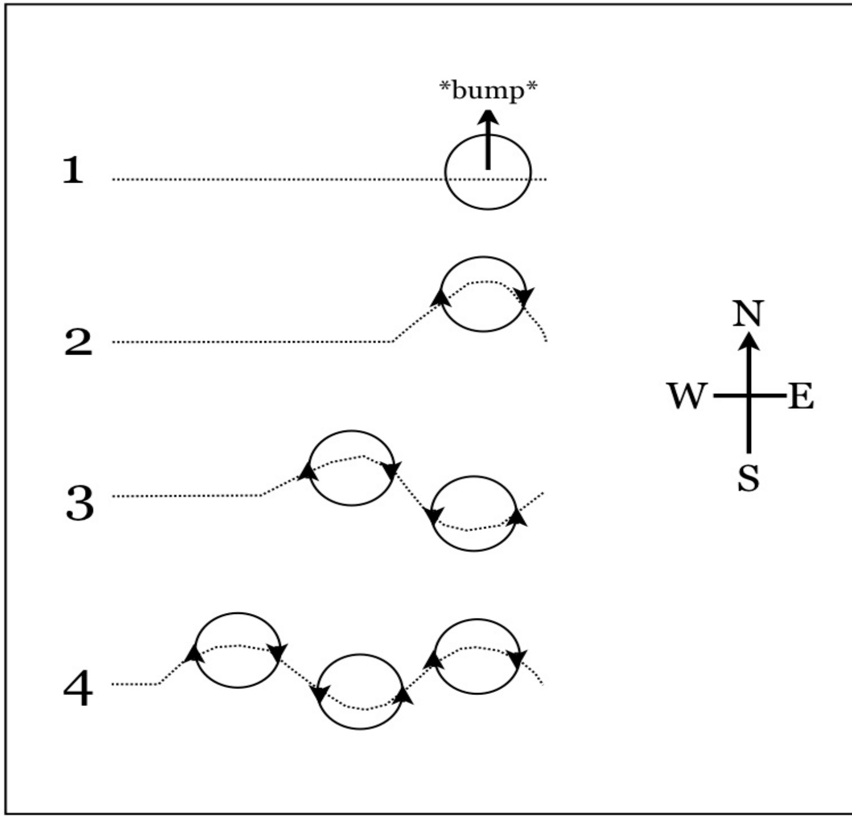
Causal Effect Network



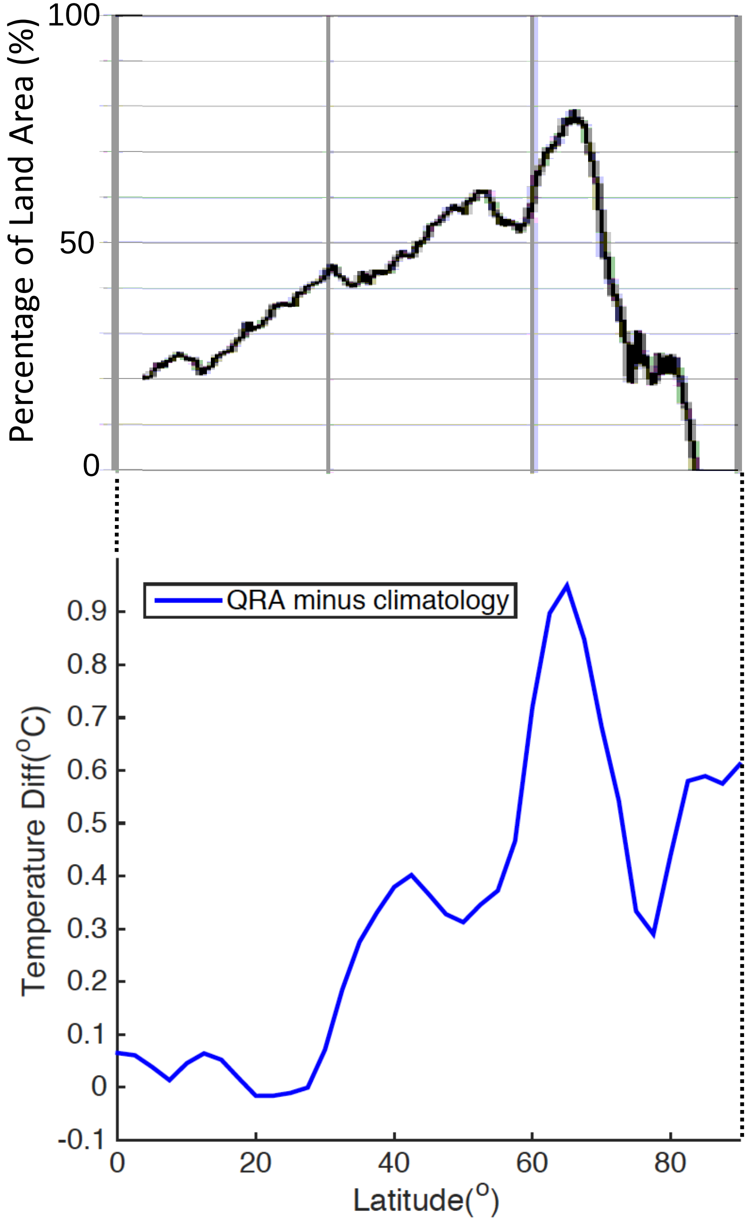
FREE ROSSBY WAVES



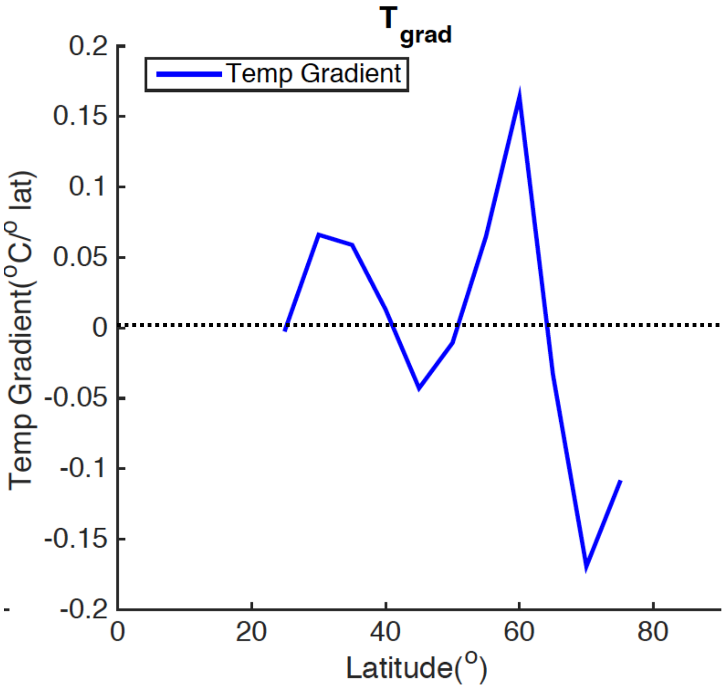
- Due to the variation in the Coriolis effect with latitude. Air parcel moving north is deflected creating wave-like behavior
- Rossby parameter: $\beta = \frac{\partial f}{\partial y} = \frac{2\Omega}{a} \cos \phi$
- If $\beta = 0$: No Rossby waves. Note equatorial waves possible
- Large meanders of the jet stream (usually wave 4-6)
- When deviations become very pronounced, masses of cold or warm air detach, and become (anti) cyclones



Fingerprint analyses

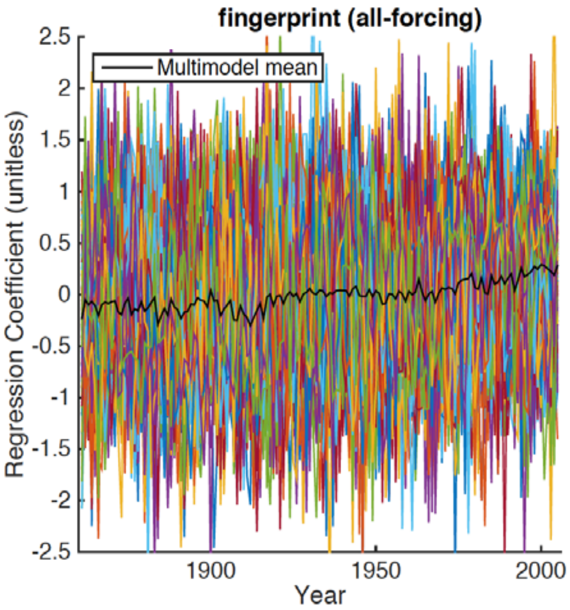


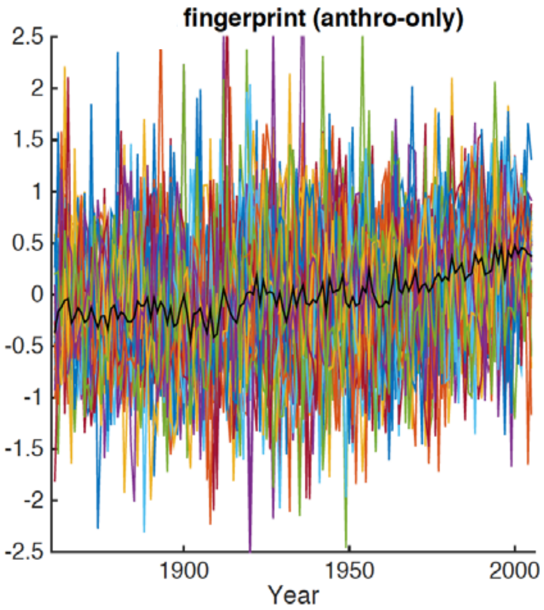
Surface temperature during resonance characterized by enhanced high-latitude warming and *enhanced land warming*



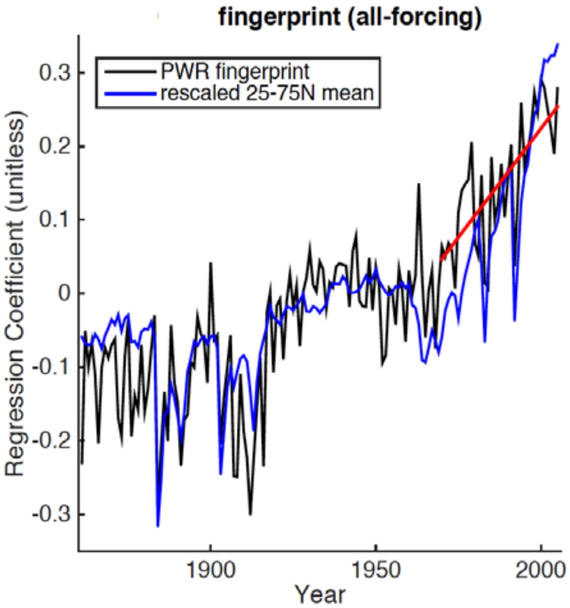
Mann et al. (in review)

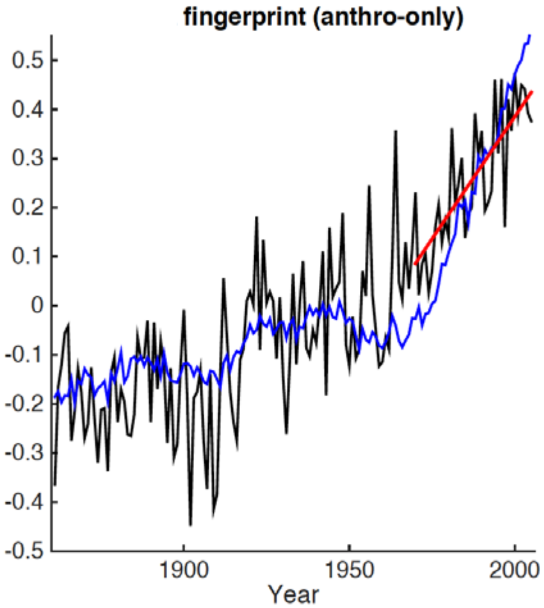
Resonance Fingerprint in Historic CMIP5 simulations

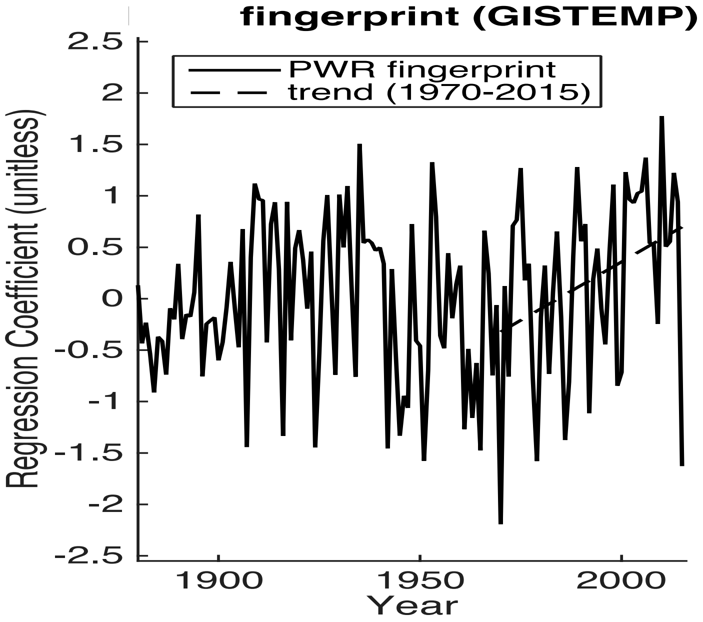




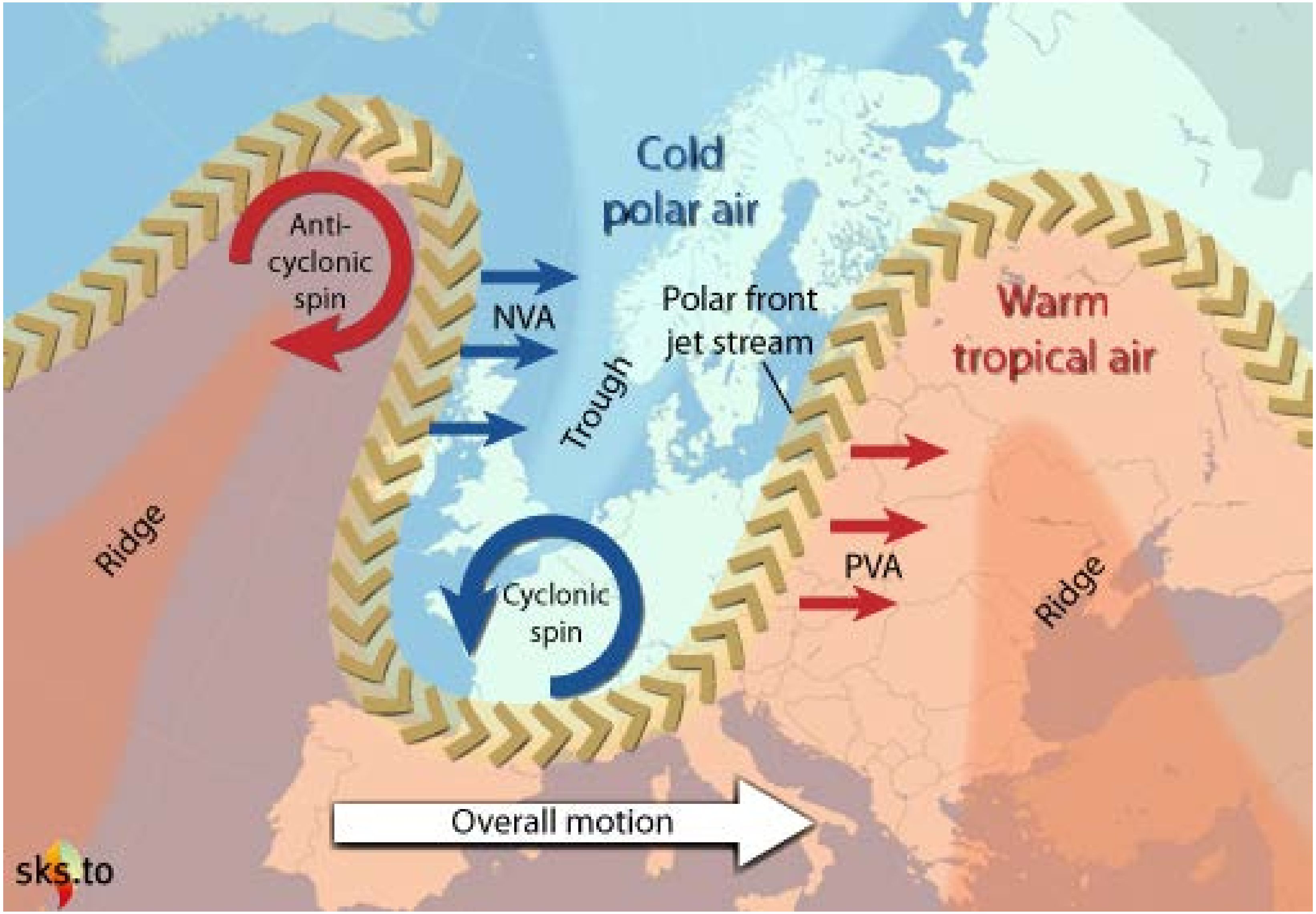
- Individual runs show large variability
- 68% of all-forcing and 88% of anthro-only runs have significant post-1970 trend
- Ensemble-mean clearly upward





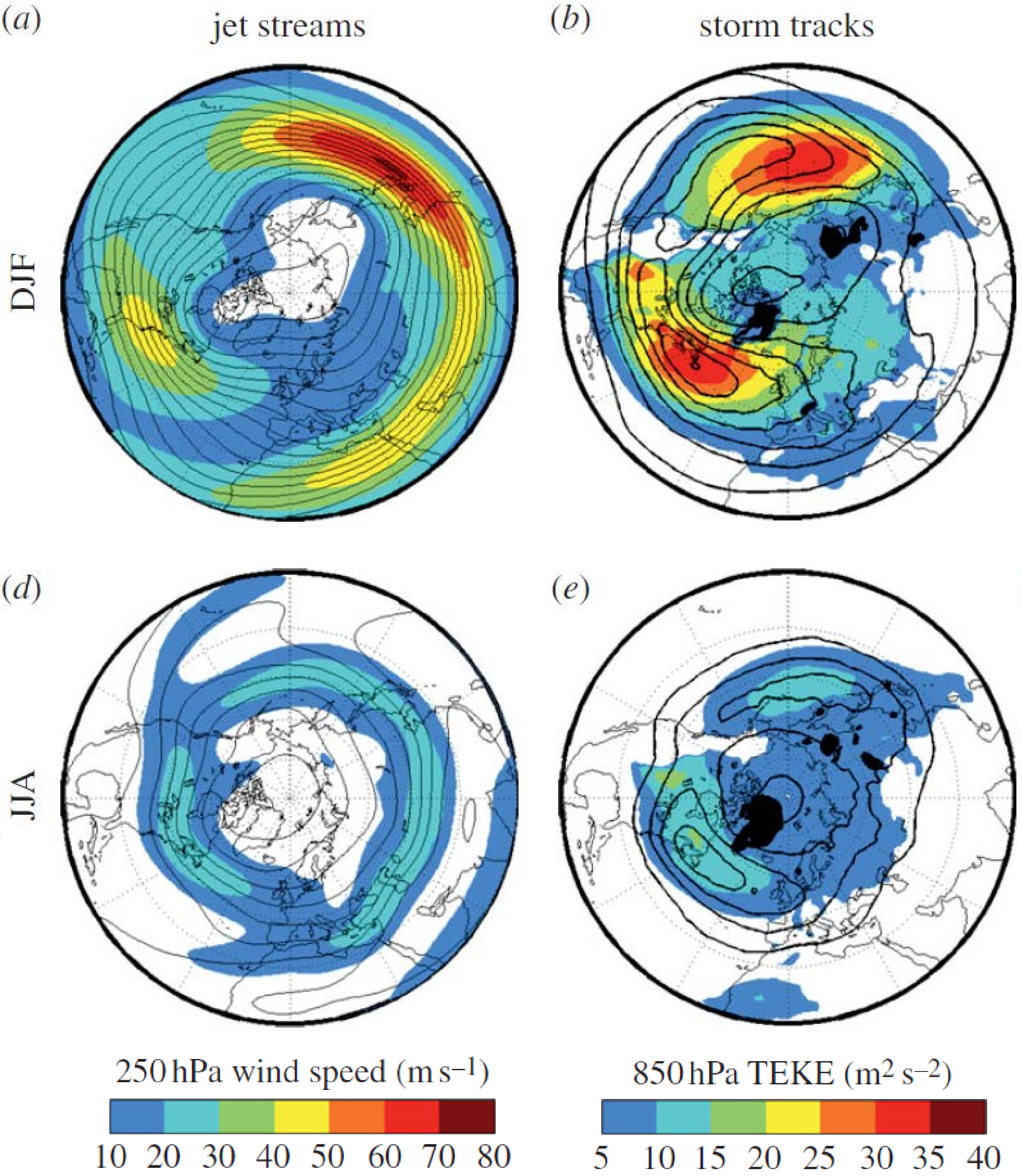


ROSSBY WAVES



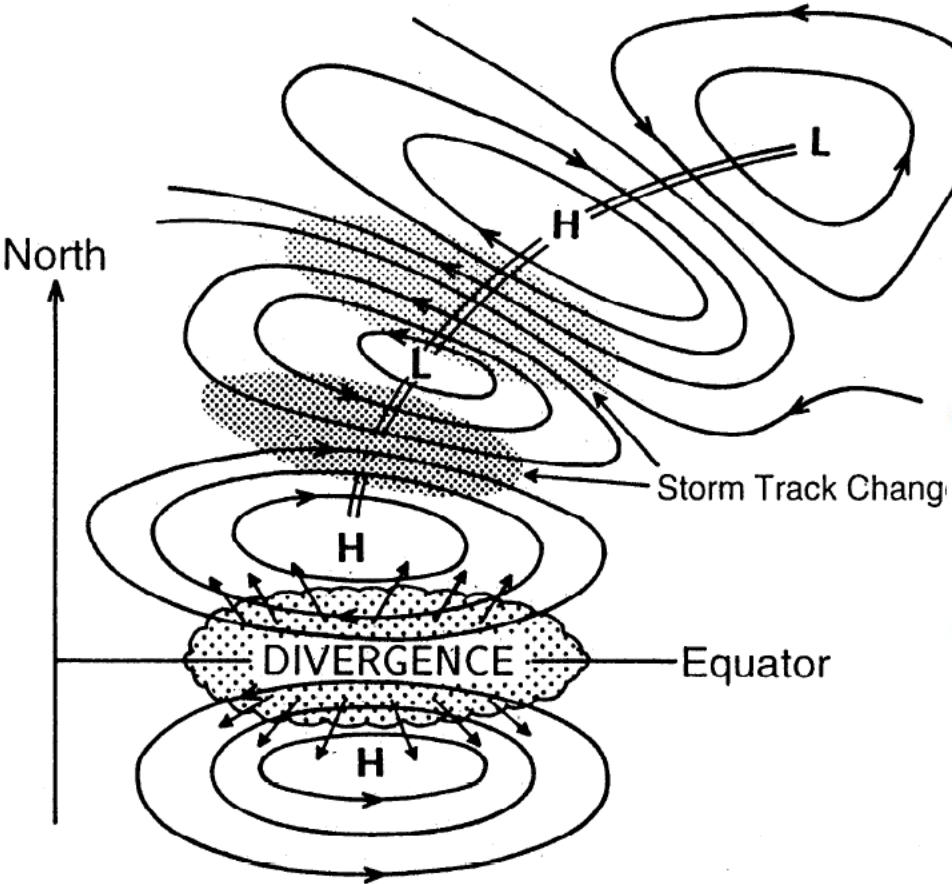
POLAR JET STREAM CLIMATOLOGY

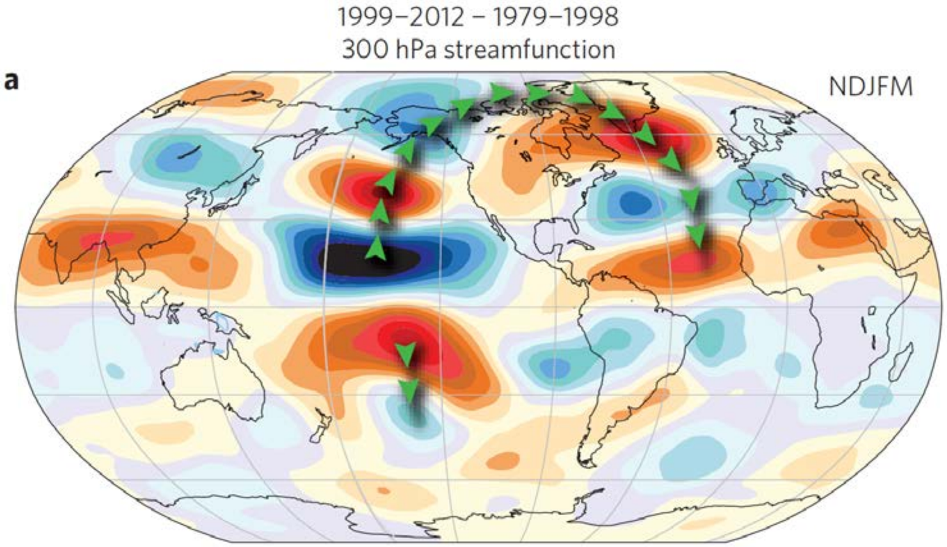
- Strong upper-level winds create shear, both in vertical and horizontal directions
- Shear creates instability, causing storms (or “eddies”)
- This preferably occurs at eastern coasts of continents (“Storm genesis regions”) where atmosphere is most instable
- Storms travel as low-pressure cyclones eastwards on top of background flow (“storm tracks”)
- Strong seasonal cycle



ROSSBY WAVES EMANATING FROM TROPICS

- Tropical thunderstorms and associated latent heat release are prominent sources of Rossby waves
- Prime mechanism how El Nino’s can influence the mid-latitudes

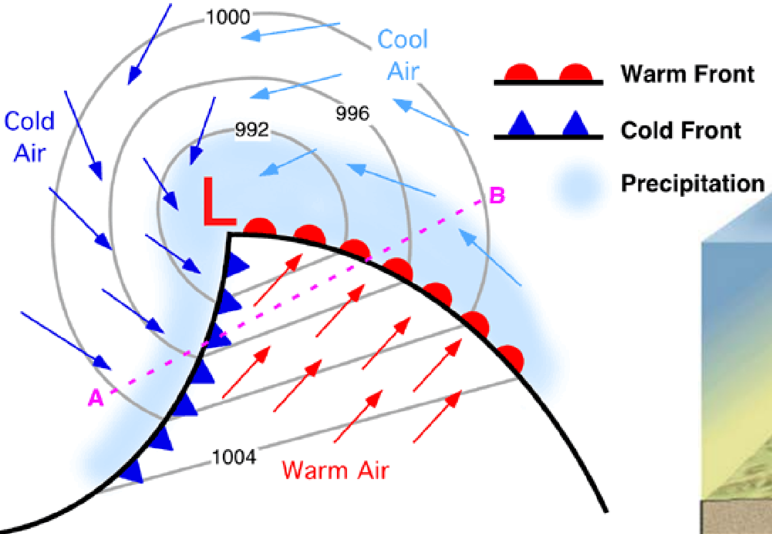


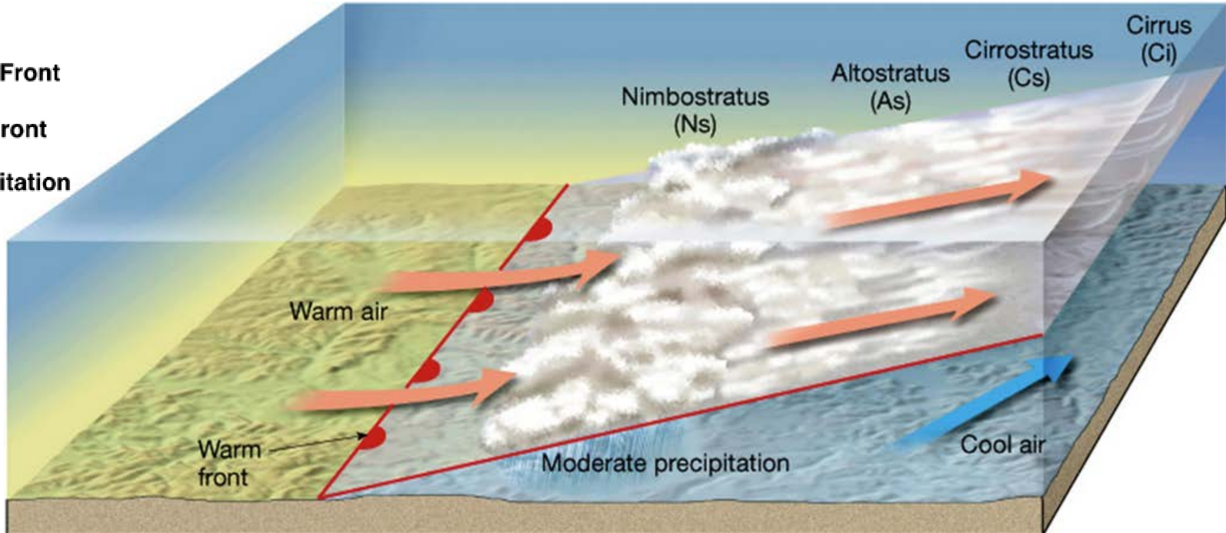


STORM TRACK REGIONS: SYNOPTIC-SCALE CYCLONES

Frontal precipitation: warm front (important for winter rainfall)

- Warm air moves to displace cold air
- Non-steep front slope: 1m / 80m to 1m / 200m
- Broad, pre-frontal strati-form cloud systems
- Steady, light to moderate precipitation lasting for a relatively long time

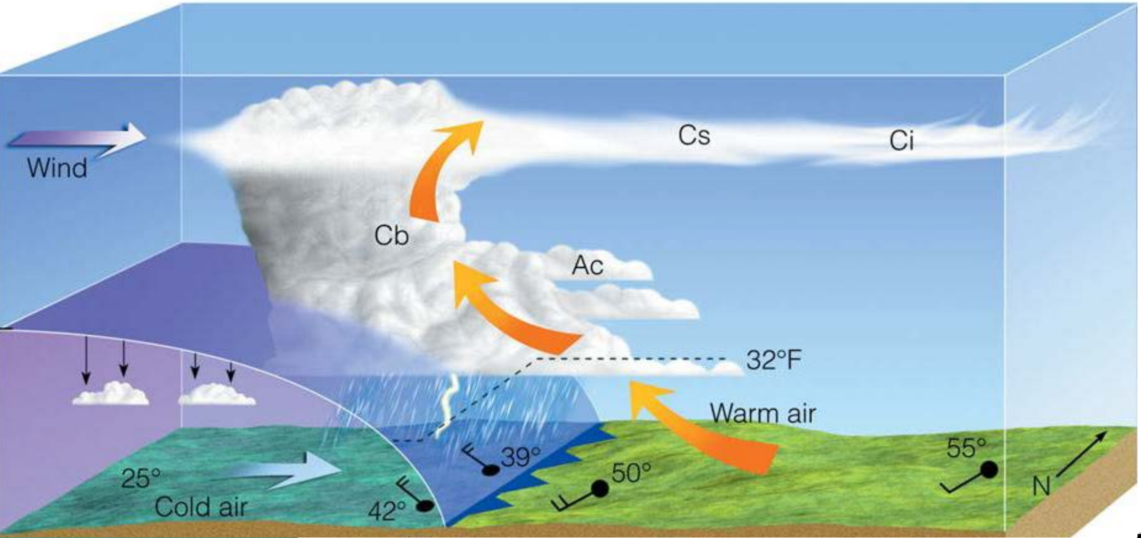


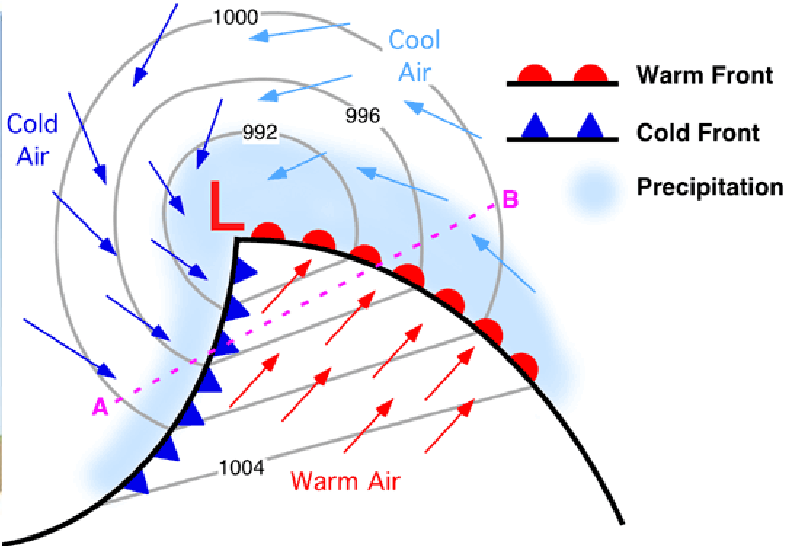


STORM TRACK REGIONS: SYNOPTIC-SCALE CYCLONE

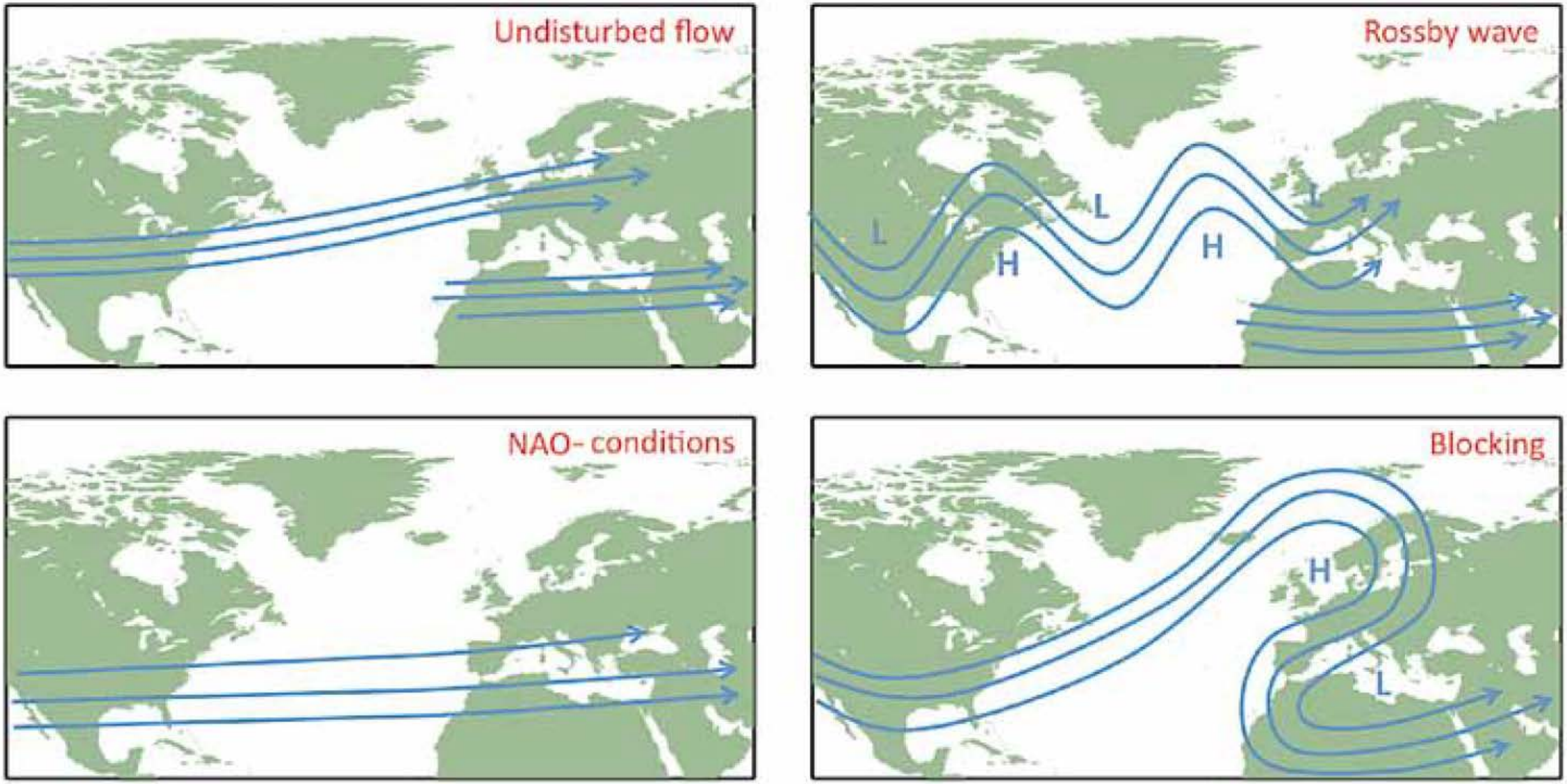
Frontal precipitation: cold front (important for winter rainfall)

- Cold air moves to displace warm air
- Steep slope: 1m / 40m to 1m / 80m
- Colder denser air tends to “under-run” warm air causing rapid uplift of warm air. Deep, narrow cloud systems extending from the surface front to 300-500 km behind it.
- Stormy, intense precipitation (thunderstorms) of much shorter duration than for warm fronts





NORTH-ATLANTIC JET STREAM REGIMES



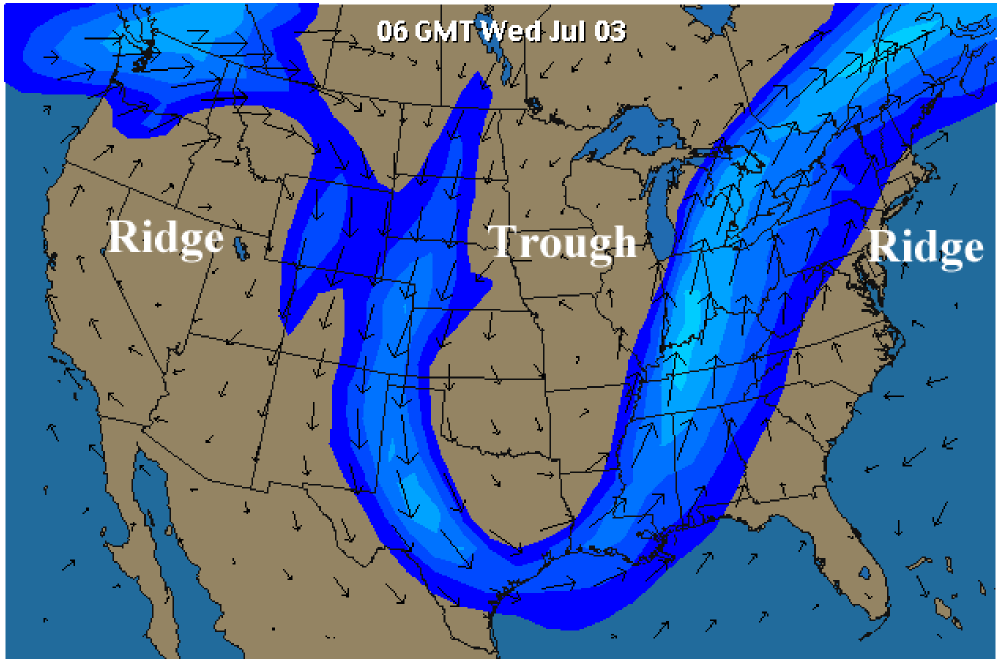
ROSSBY WAVES: IMPORTANT FOR EXTREME WEATHER

Example: U.S. July 2013

Death Valley:

129°F / 54°C

Highest temperature measured in a century



www.wunderground.com

Waco, Texas:

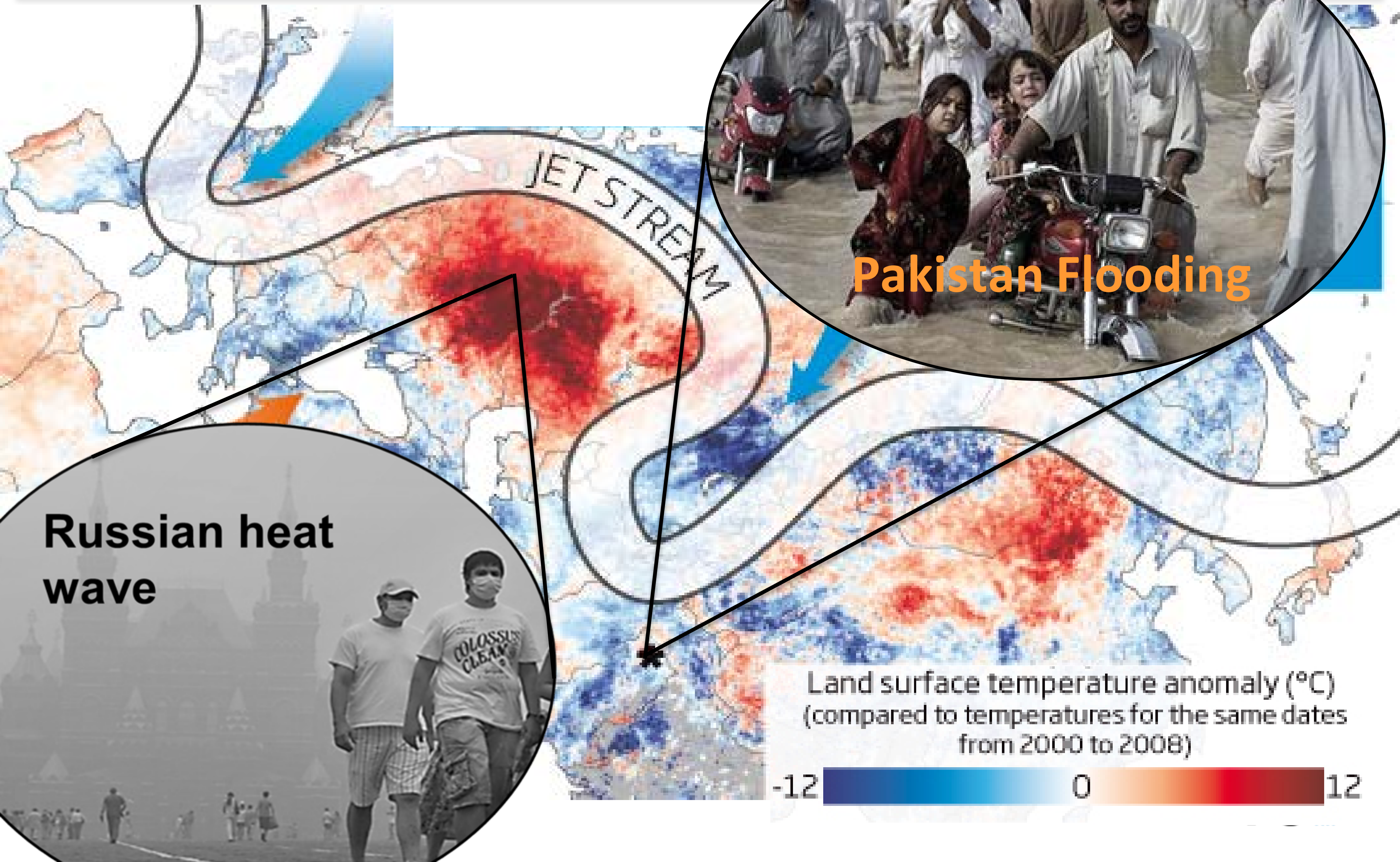
58°F / 14°C

Coldest temperature ever measured in July

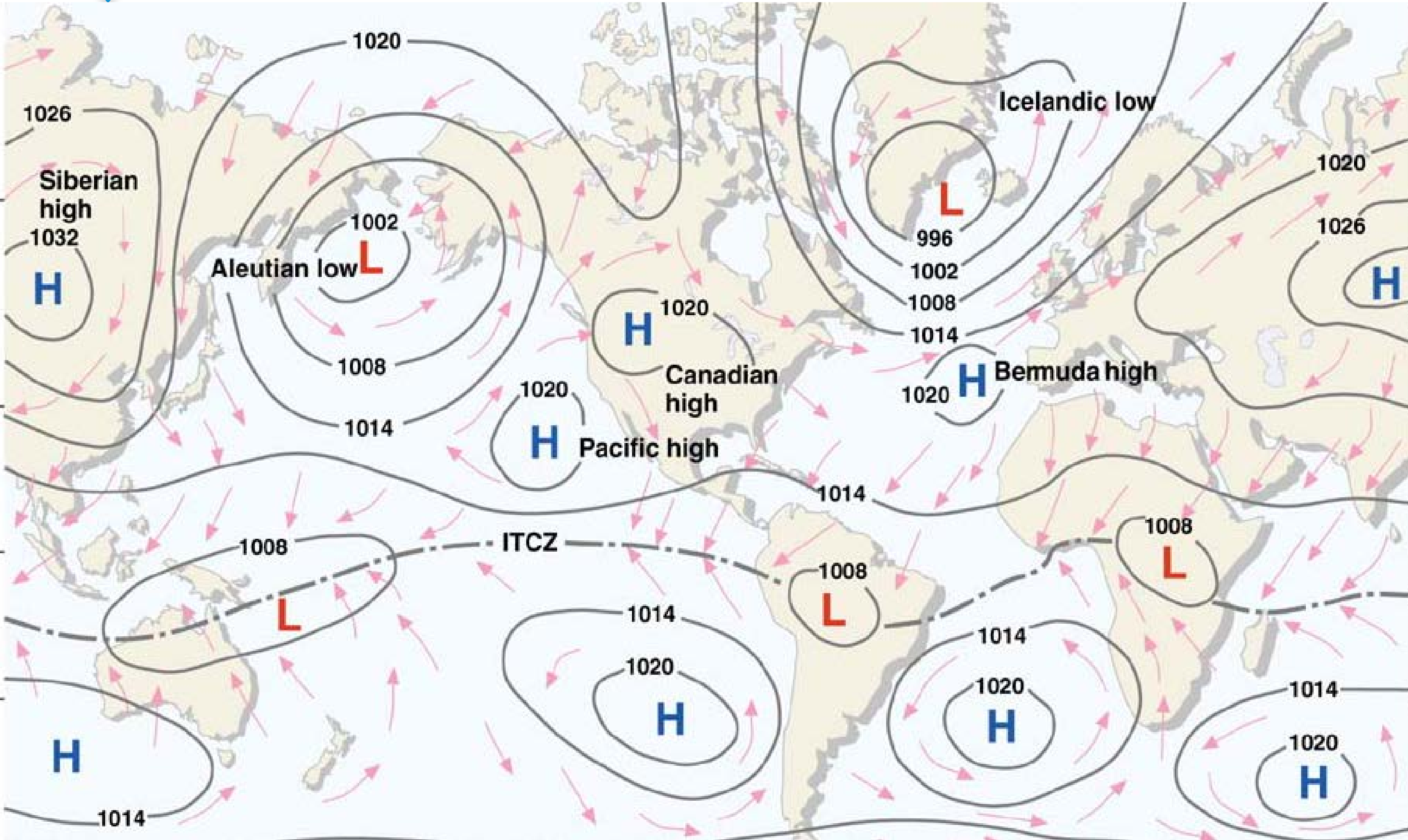
Other recent examples:

- Russian Heat Wave / Pakistan Flooding 2010 (Lau & Kim, 2012)
- European Heat Wave 2003 (e.g. Black et al, 2004)

ROSSBY WAVES: IMPORTANT FOR EXTREME WEATHER

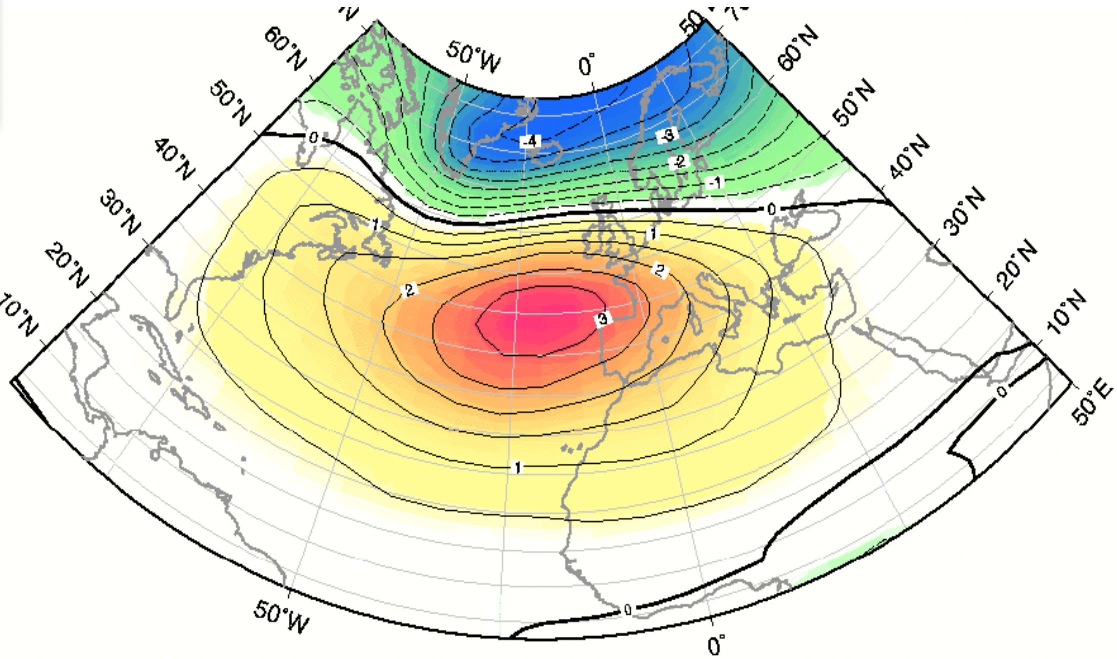


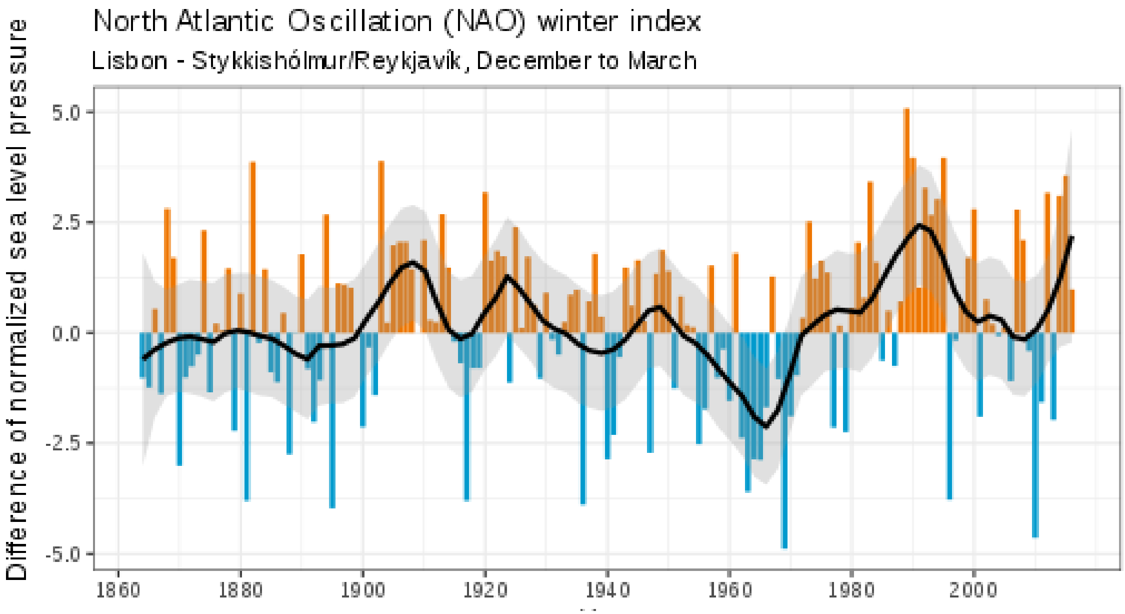
NORTH ATLANTIC OSCILLATION (NAO): PRESSURE DIFFERENCE BETWEEN SUBTROPICS AND SUBPOLAR LATITUDES



NORTH ATLANTIC OSCILLATION (NAO)

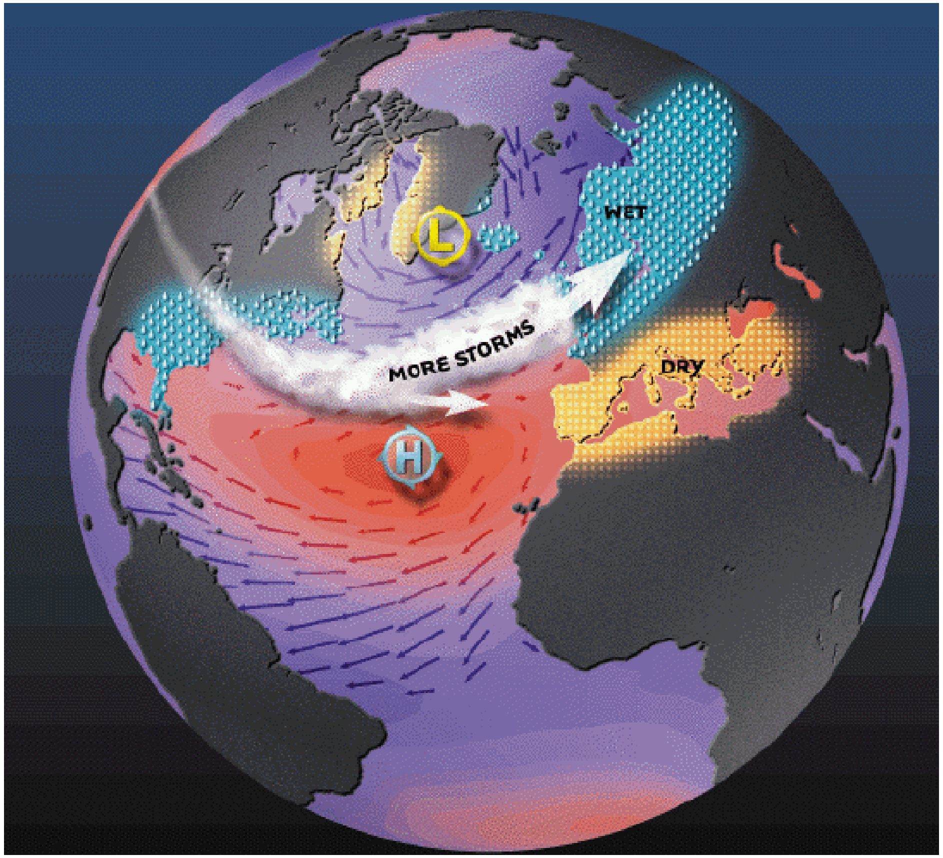
- Most important mode of atmospheric variability over the North Atlantic Ocean, but with hemispheric impact
- Historically defined as pressure difference between Iceland and Azores
- Measure of the strength of the westerly winds (think geostrophic wind)





NAO+

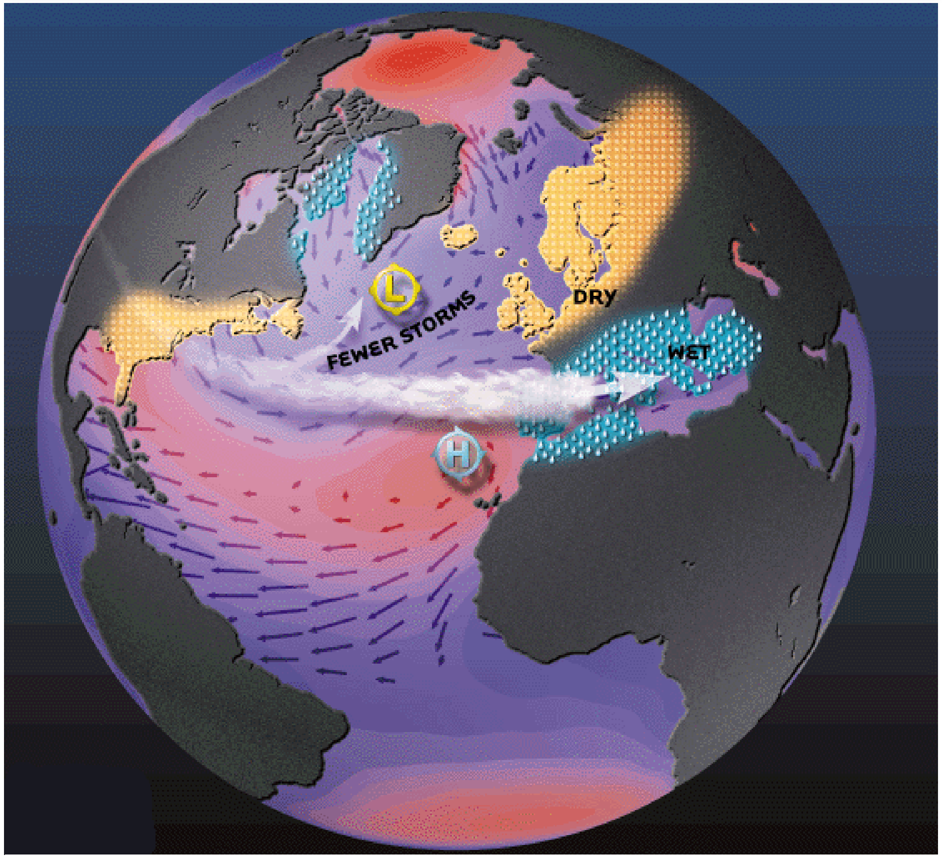
STRONG PRESSURE DIFFERENCE



- Strong westerlies
- Mild and wet conditions in central & northern Europe
- Dry Mediterranean

NAO-

SMALL PRESSURE DIFFERENCE

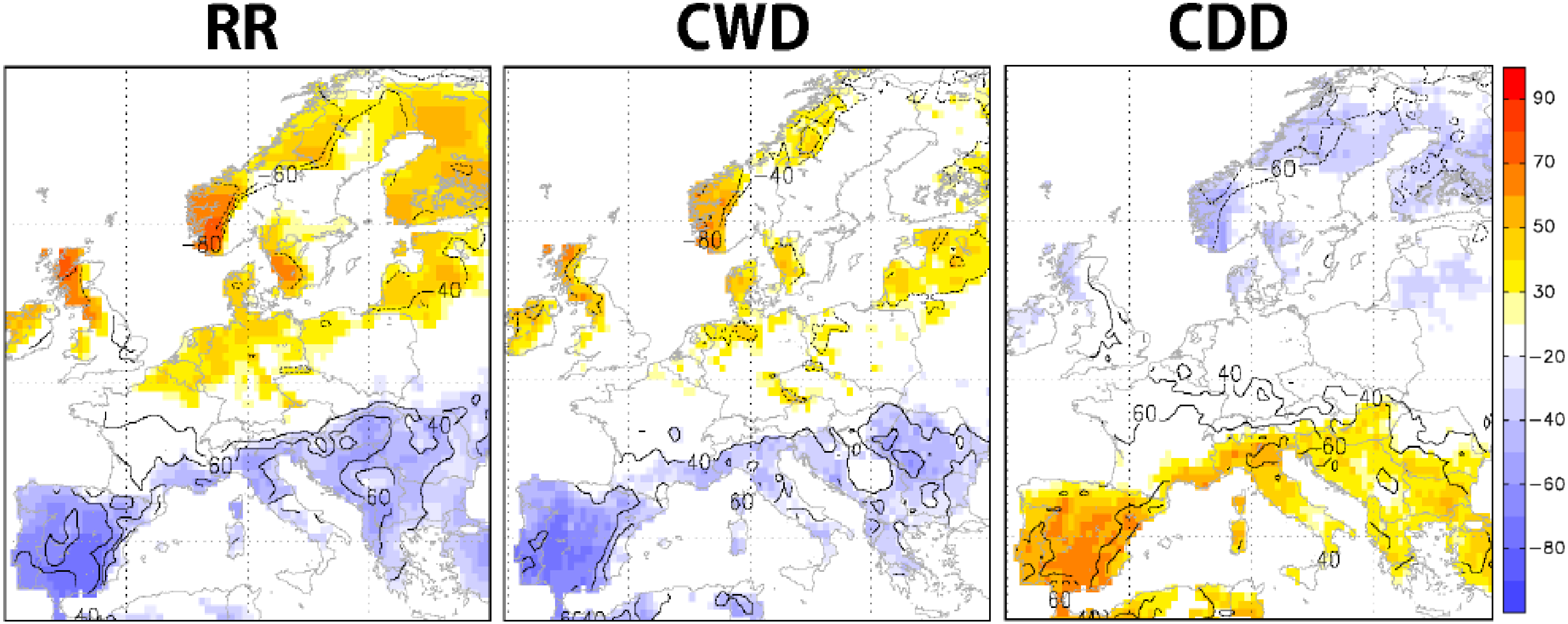


- Weaker westerlies
- Dry and cold conditions in central & northern Europe
- Wet Mediterranean

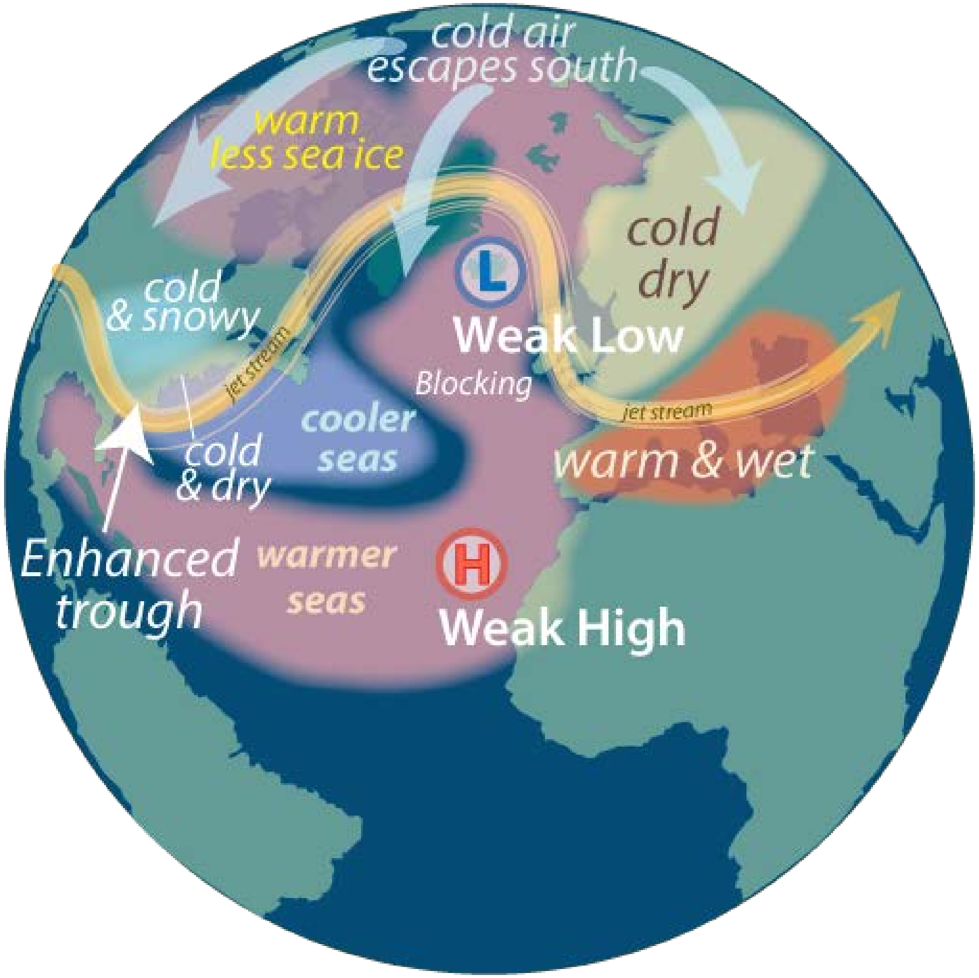
NAO INFLUENCE ON EUROPEAN WINTER PRECIPITATION

Regression between NAO index and rain (RR), consecutive wet days (CWD) and consecutive dry days (CDD).

NAO very important for rainfall and rainfall extremes



NEGATIVE NAO: ARCTIC AIR SPILLS SOUTHWARDS



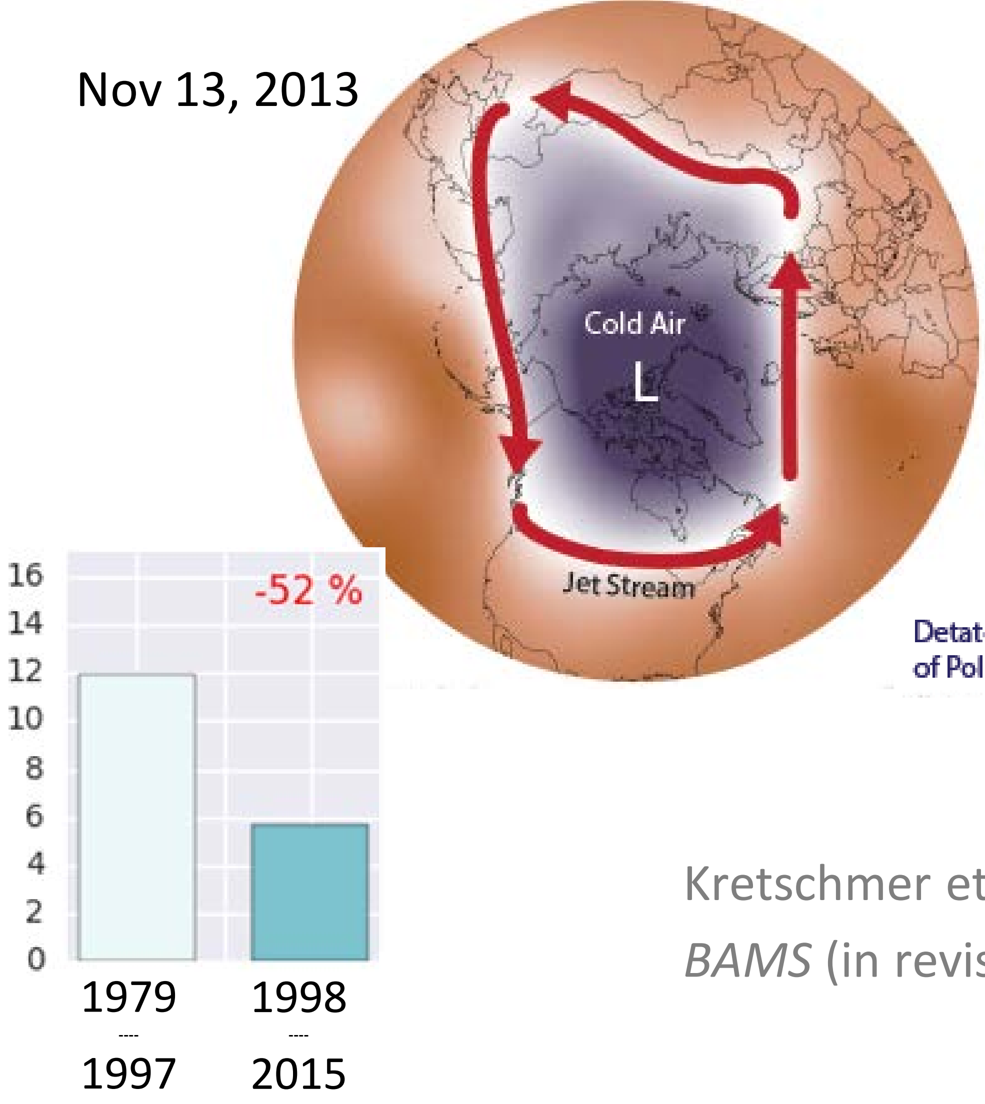
<u>Warming Arctic might play a role:</u>

- Reduced poleward temperature gradient
- Reduced pressure gradient
- Weakening westerlies
- Might favor the negative NAO

Strongly disputed (!)

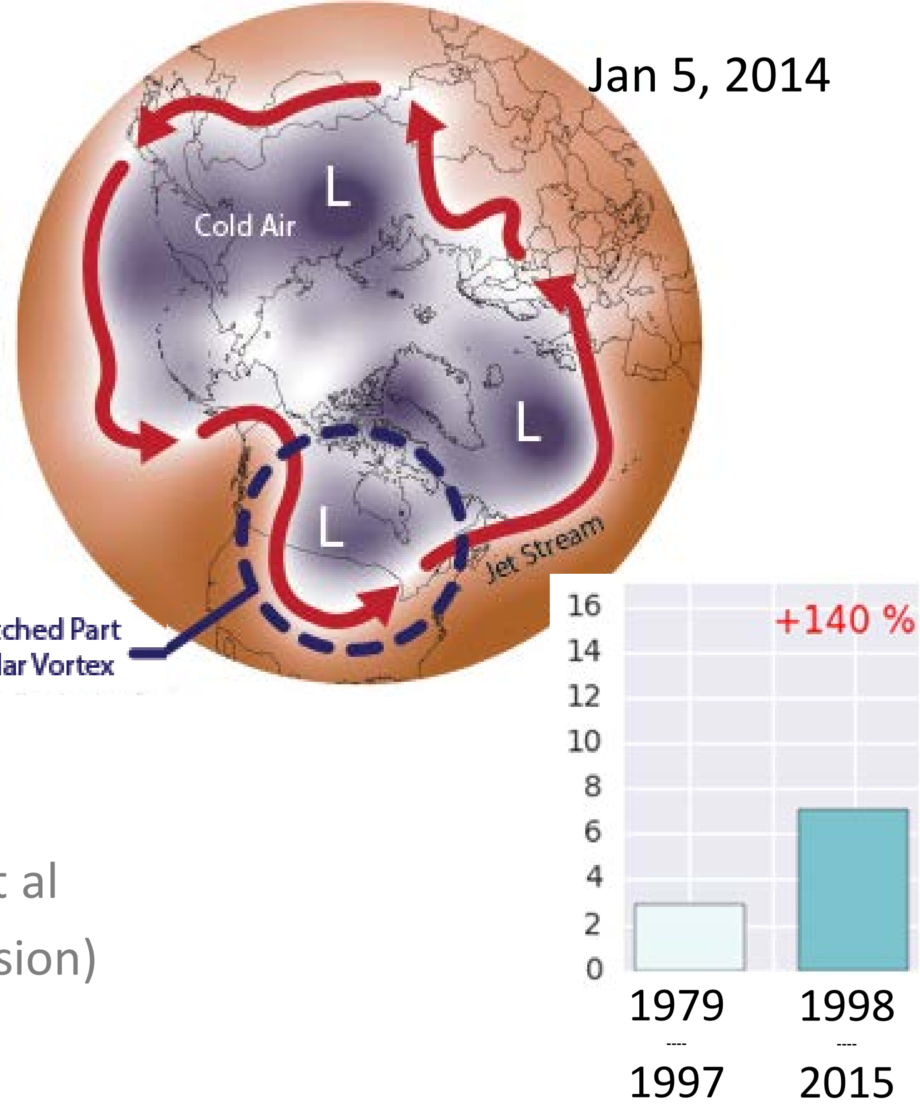
MORE FREQUENT WEAK POLAR VORTEX STATES LINKED TO COLD SPELLS

Strong Polar Vortex



Nov 13, 2013

Weak Polar Vortex



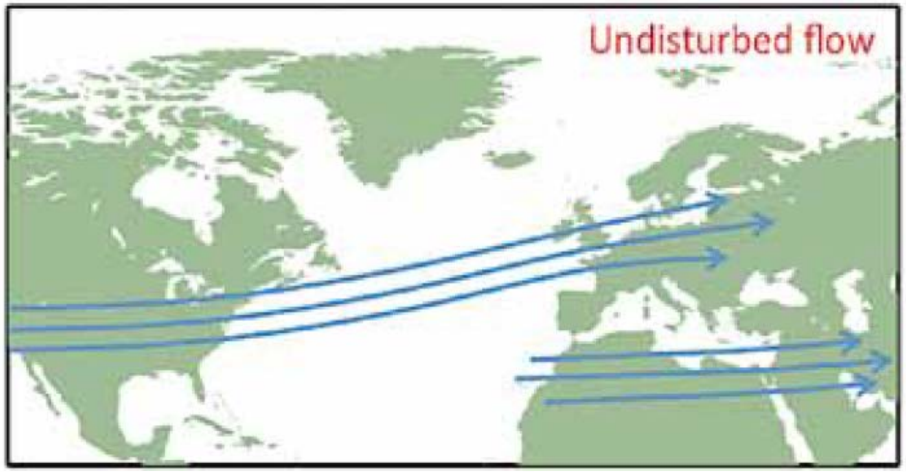
Jan 5, 2014

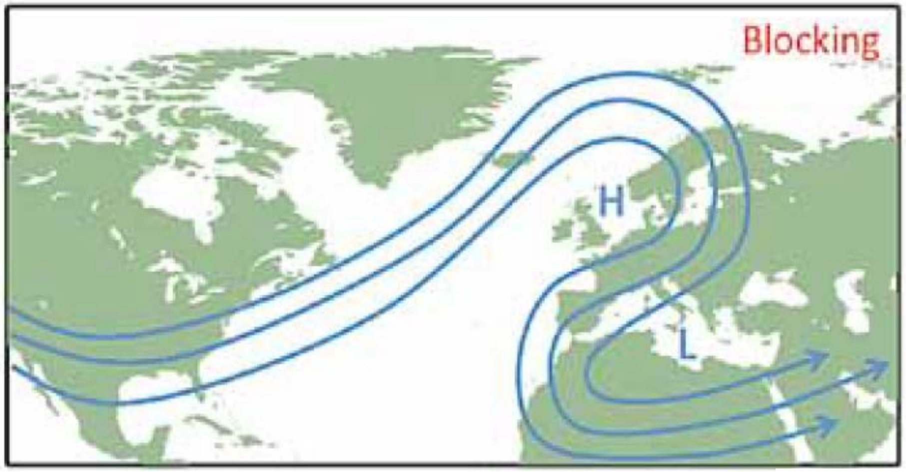
Kretschmer et al

BAMS (in revision)

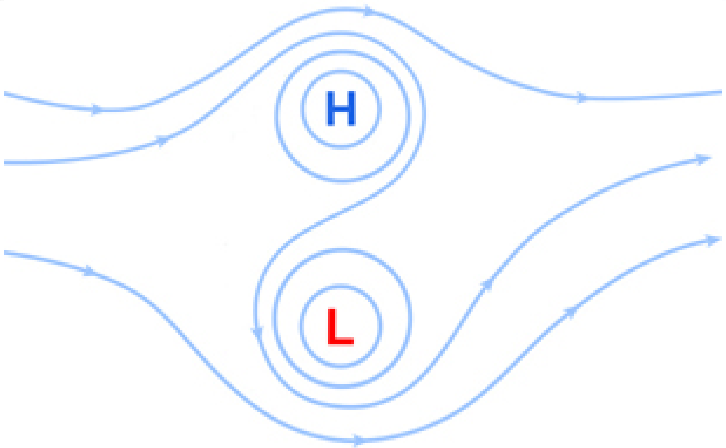
Courtesy: NASA

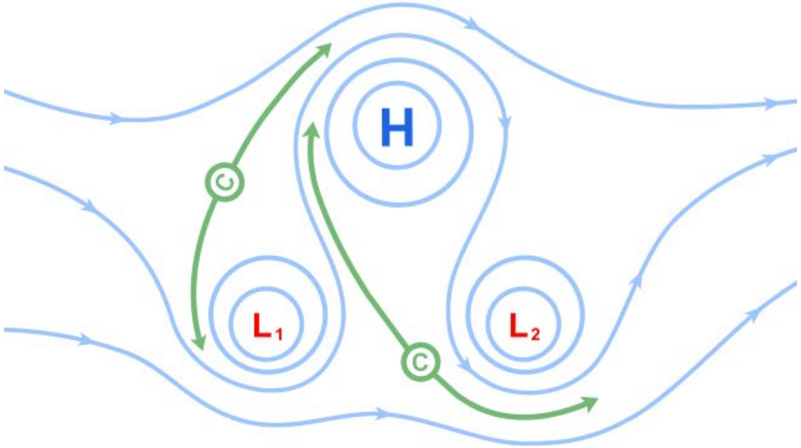
ATMOSPHERIC BLOCKING



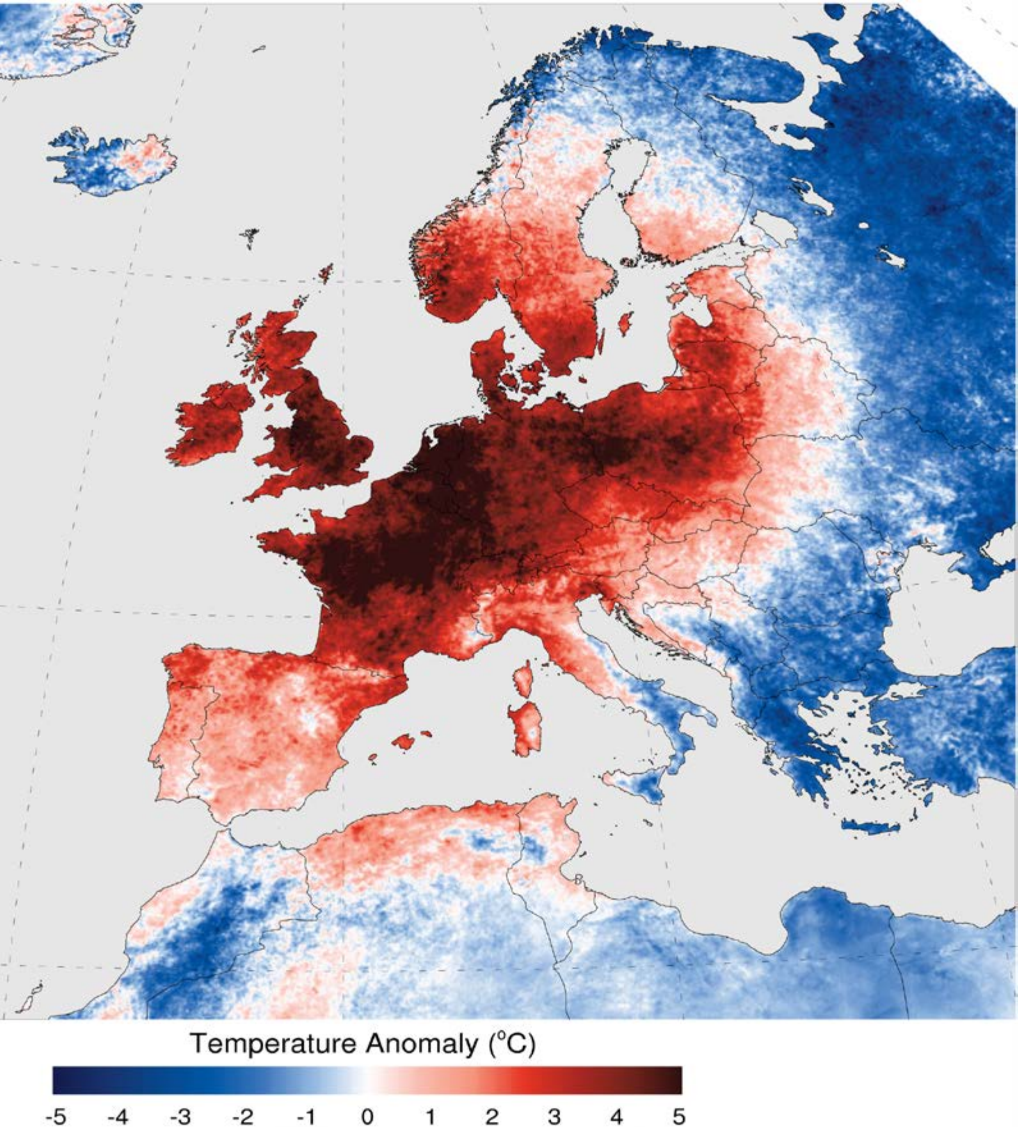


- Nearly stationary high-pressure systems that effectively block or redirect migratory cyclones
- Can remain in place for several days to weeks
- Causing same kind of weather in areas affected by them for extended period





EUROPEAN HEATWAVE 2003

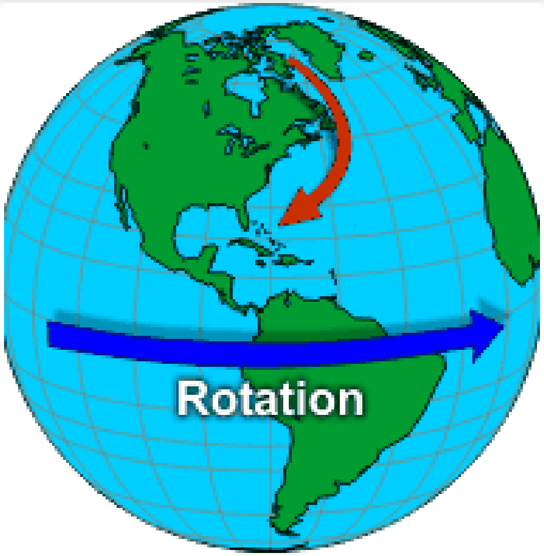


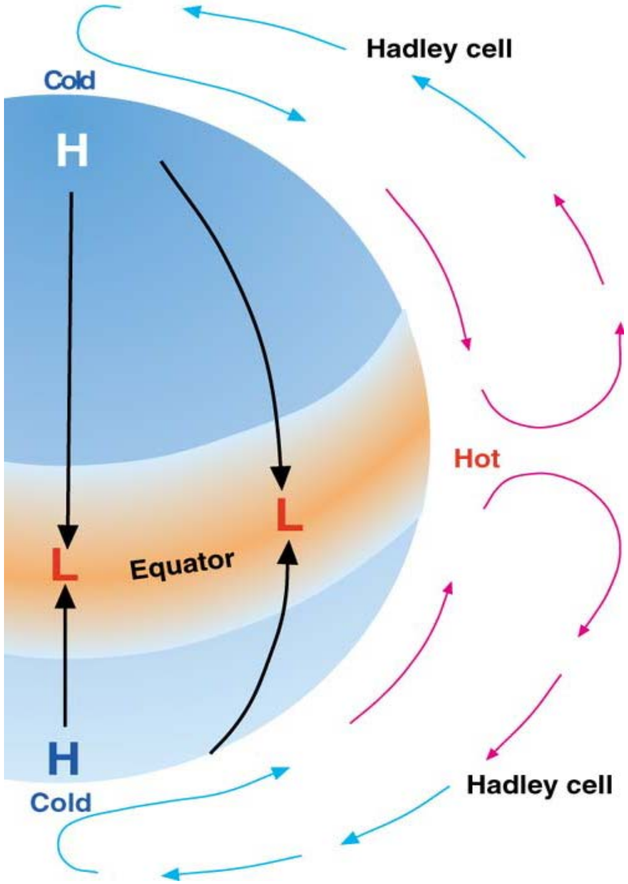
- Hottest summer in at least 500 years
- Blocking high pressure, lasting nearly full summer
- Low soil moisture concentrations important too
- Brought temperatures up to xxC
- An estimated 70.000 (!) heat-related deaths. Elderly and young kids
- Massive forest fires
- Agricultural production down by xx %

1735: GEORGE HADLEY`S SINGLE CELL MODEL

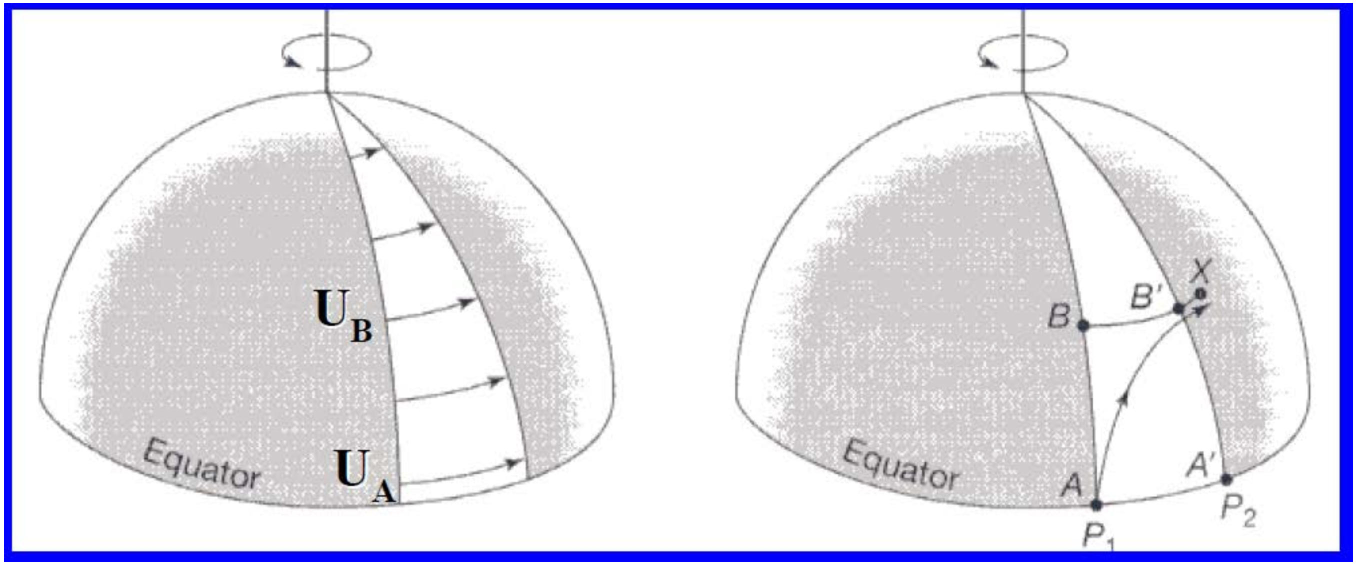
- Thermally driven convection cell

  Coriolis effect makes wind turn *right* in the NH and *left* in the SH





CORIOLIS EFFECT: ANGULAR MOMENTUM CONSERVATION OF NORTH-SOUTH TRAVELING WIND



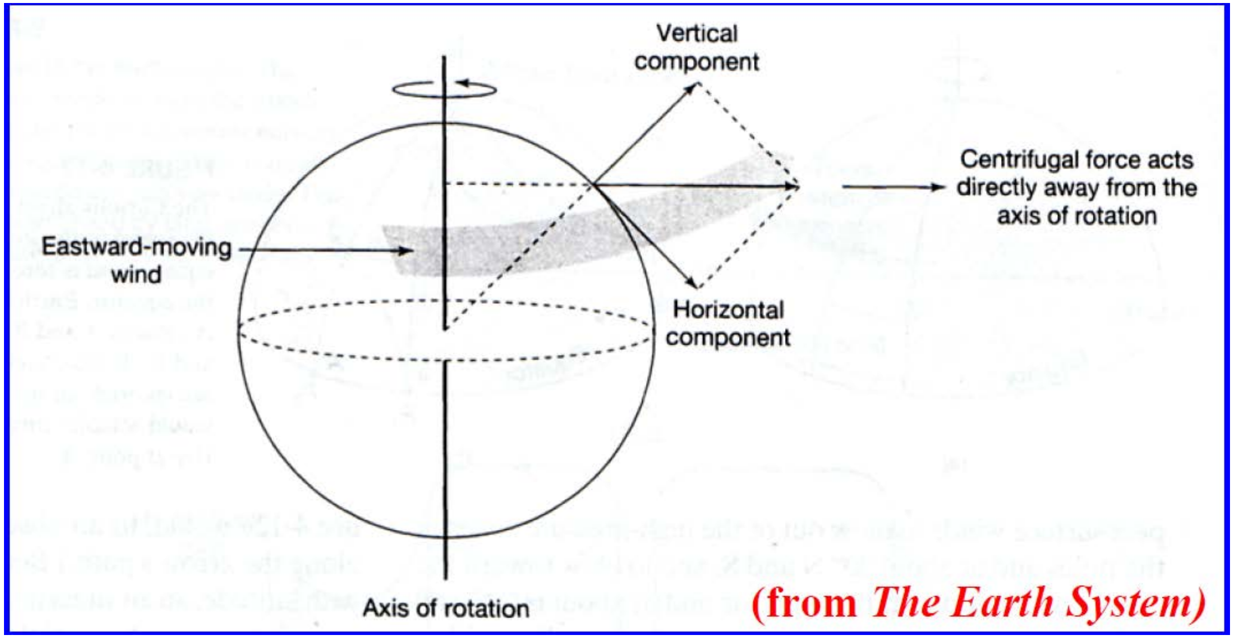
If the Coriolis parameter is large, the effect of the Earth's rotation on the body is large (outside tropics)

- A rotates faster than B
- Northward motion starting at A will arrive to the east of B because the air conserves its angular momentum
- (Apparent) Coriolis force: $fV = 2\Omega \sin\phi$

$$f = \text{Coriolis parameter} = 2\Omega \sin\phi$$

ϕ = latitude, Ω = angular momentum

CORIOLIS EFFECT: DEFLECTION OF EAST-WEST WINDS BY CENTRIFUGAL FORCE



(from *The Earth System*)

If the Coriolis parameter is large, the effect of the Earth's rotation on the body is large (outside tropics)

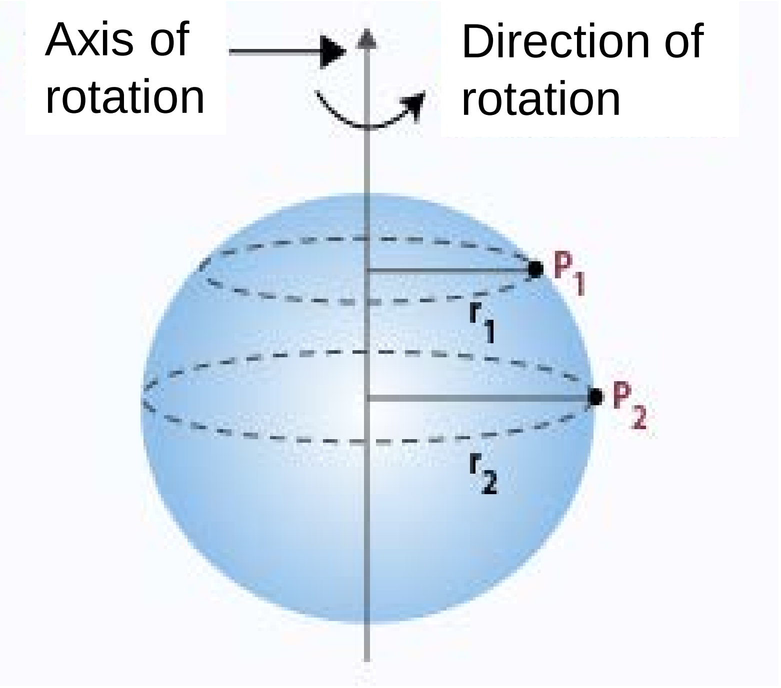
- Likewise directly related to Earth’s rotation
- Deflection of North-South and East-West motions are thus different, but mathematical notation is the same
- (Apparent) Coriolis force:

$$fV = 2\Omega \sin \phi$$

$$f = \text{Coriolis parameter} = 2\Omega \sin \phi$$

ϕ = latitude, Ω = angular momentum

CORIOLIS EFFECT

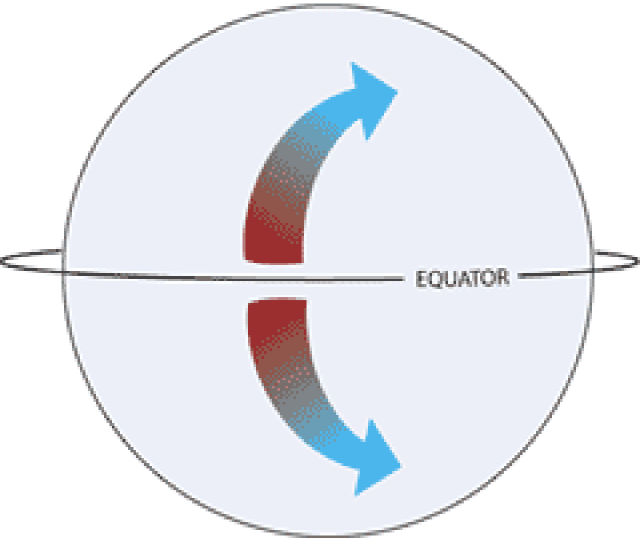


- Deflecting to the right in NH and to the left in SH
- Scales with distance to axis of rotation
- Coriolis parameter:

$$f = 2\Omega \sin \phi$$

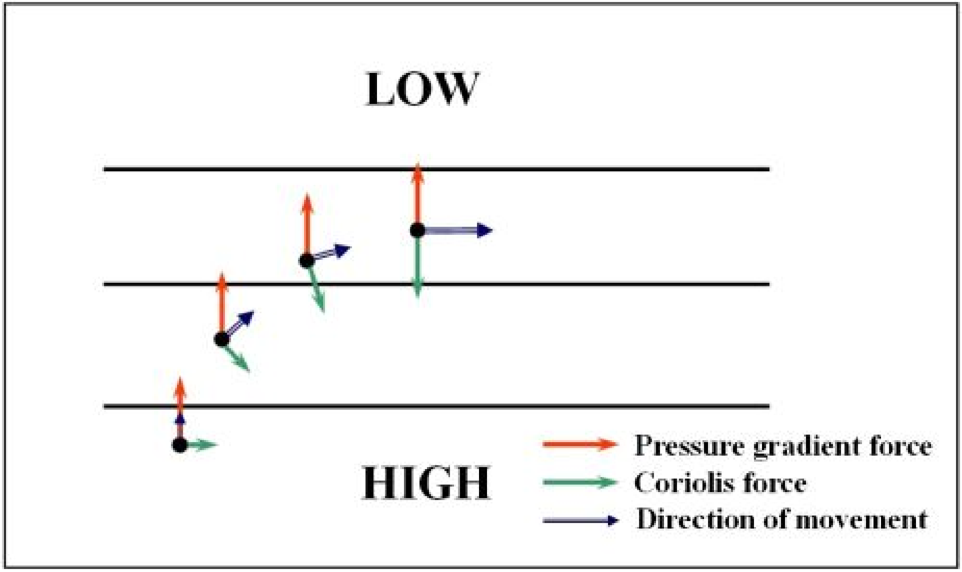
ϕ = latitude

Ω = angular momentum



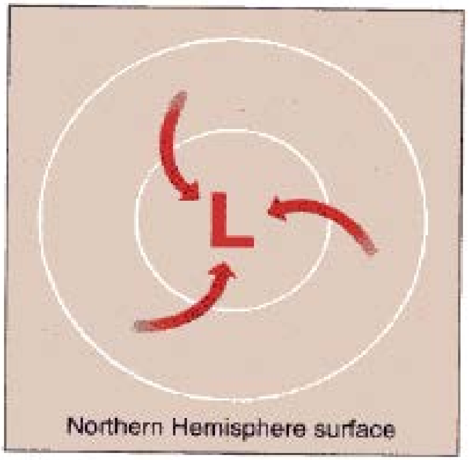
- If the Coriolis parameter is large, the effect of the earth's rotation on the body is significant (outside the tropics)
- If the Coriolis parameter is small, the effect of the earth's rotation is small (tropics)

GEOSTROPHIC WIND

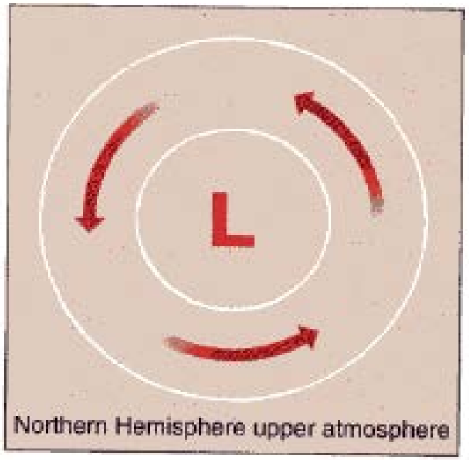


- Hypothetic wind speed assuming that pressure gradient force and coriolis "force" are in balance
- Pressure gradient force: $f_p = -\frac{1}{\rho}\nabla P$
- Friction force causes real wind to deviate from geostrophic wind

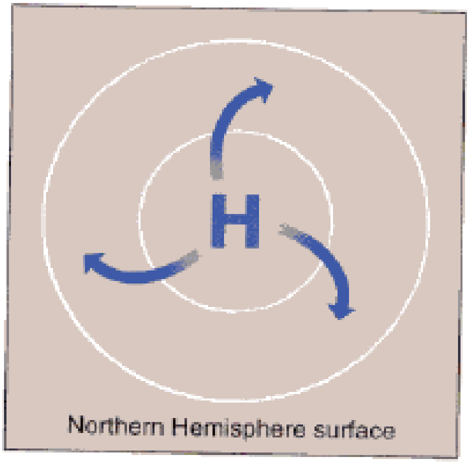
Surface



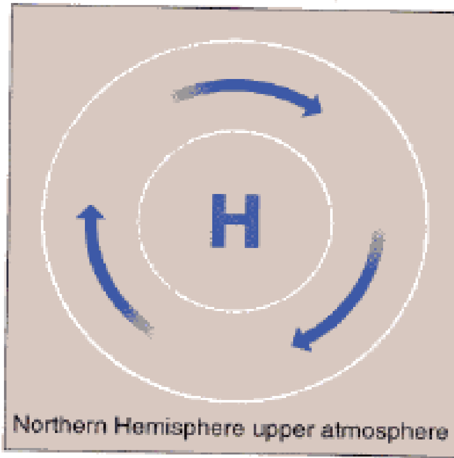
High up



Surface



High up



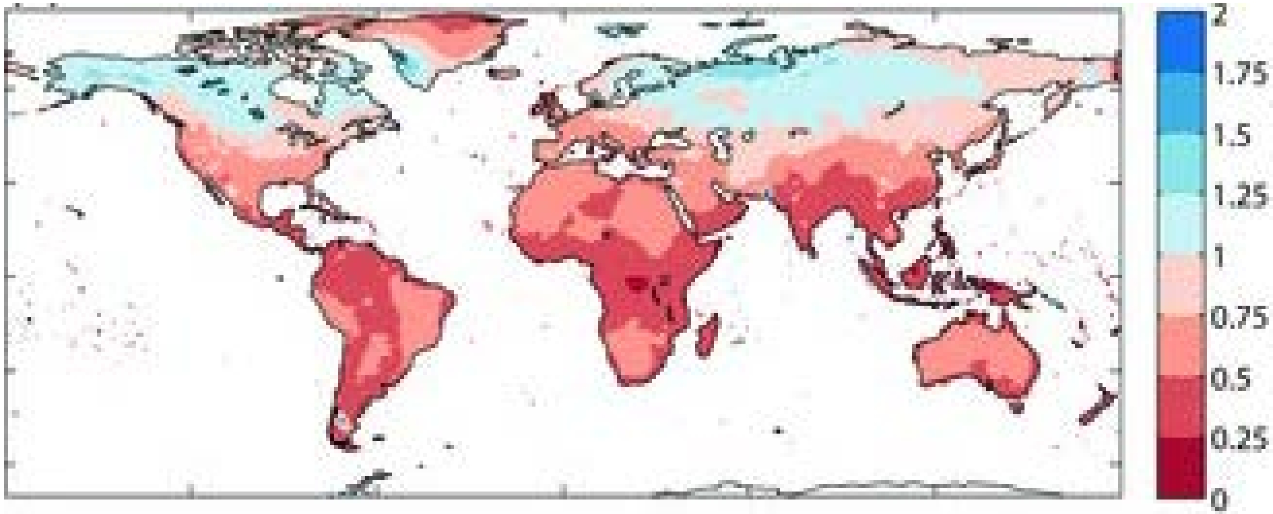
TROPICS VS EXTRA-TROPICS

Tropics:

- Coriolis parameter is small. Winds are far from geostrophic and thus blow from H to L pressure. For example: monsoons
- Temperature differences are quickly equalized

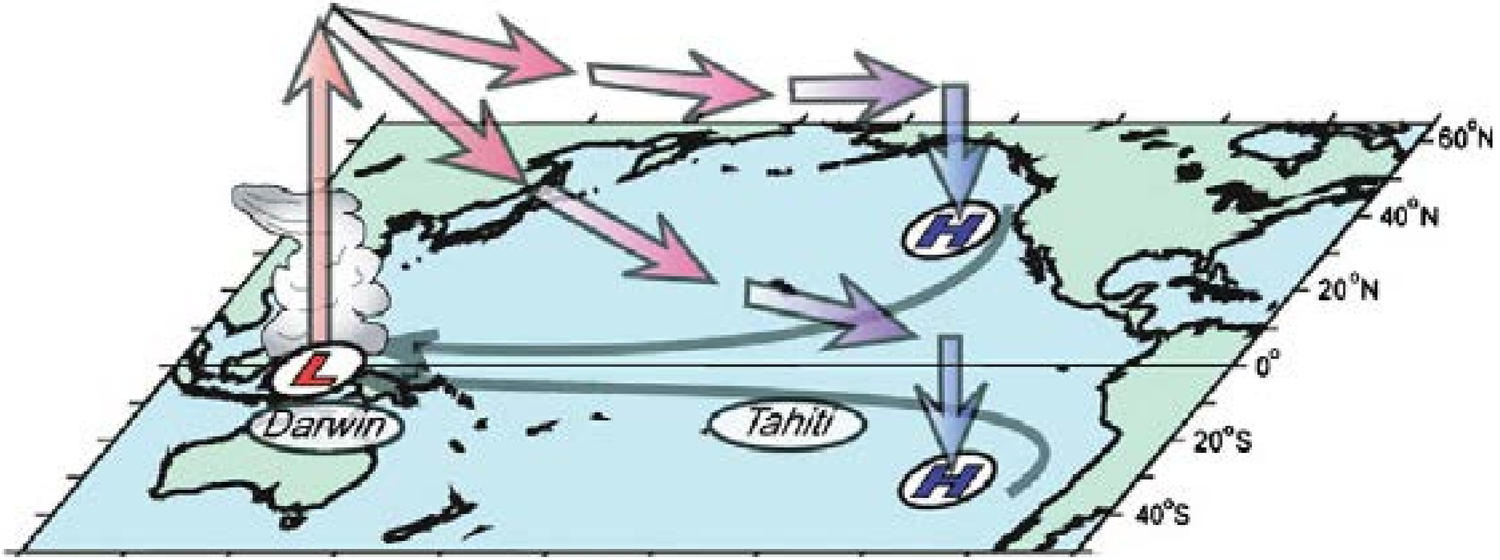
Extra-tropics:

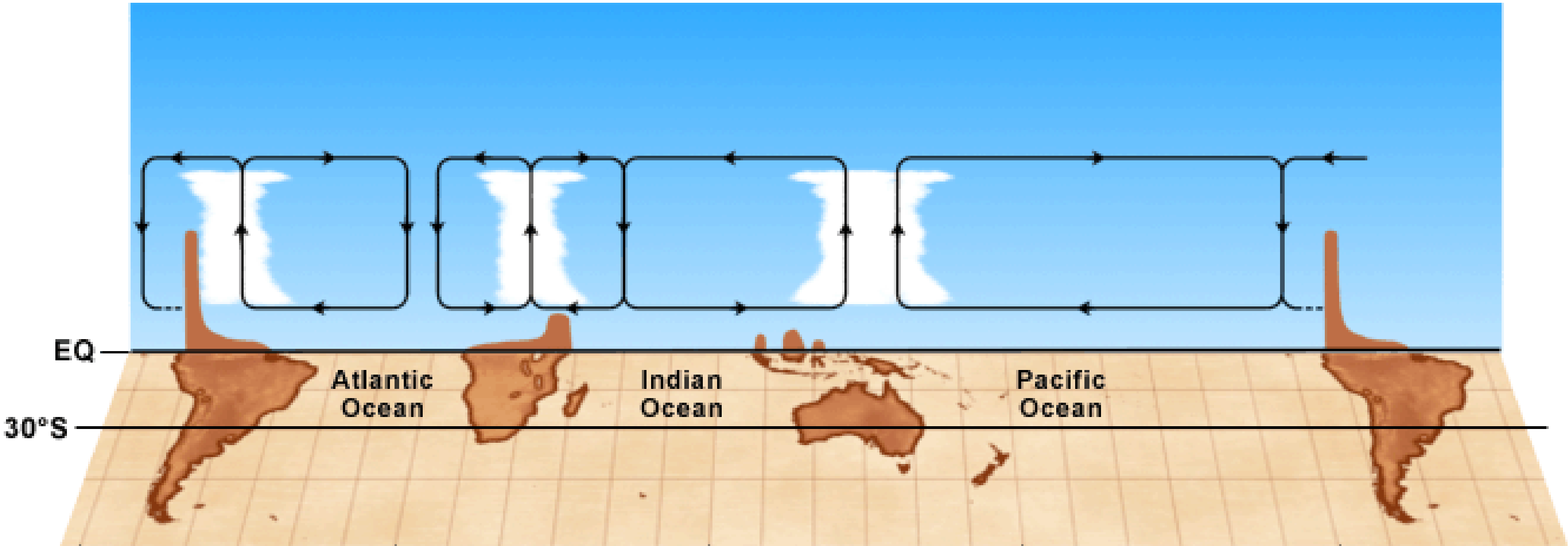
- Strong Coriolis parameter. Winds are close to geostrophic and thus blow along the isobars
- Temperature differences not easily equalized. Mid-latitudes characterized by strong temperature gradients



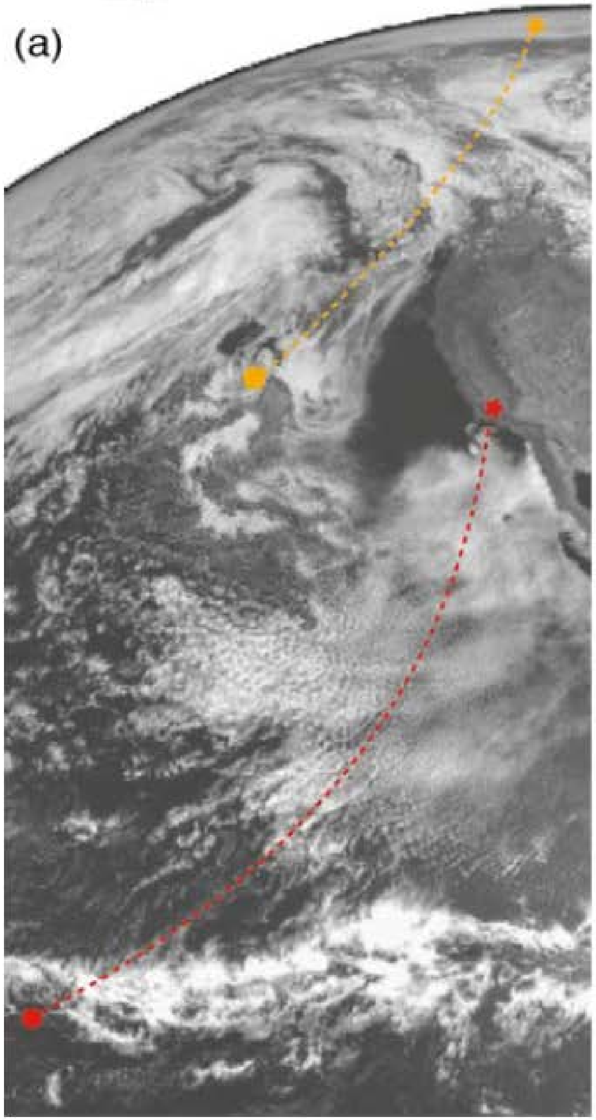
Interannual variability in the mean temperature (a, standard deviation in °C)

HADLEY-WALKER CIRCULATION

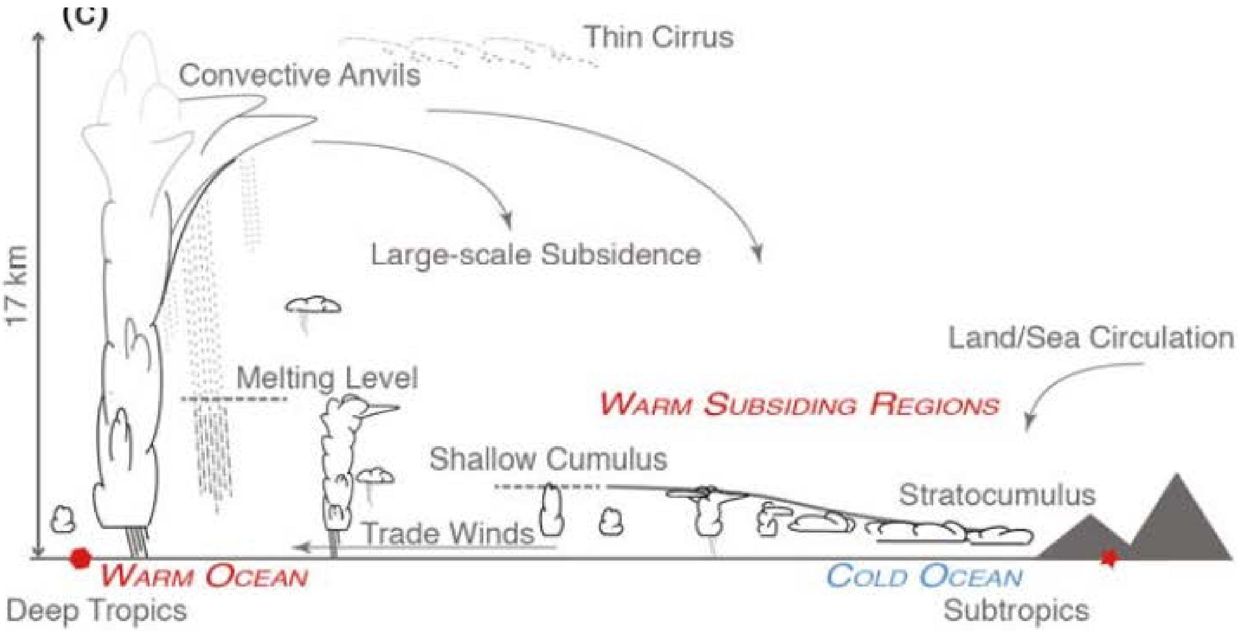




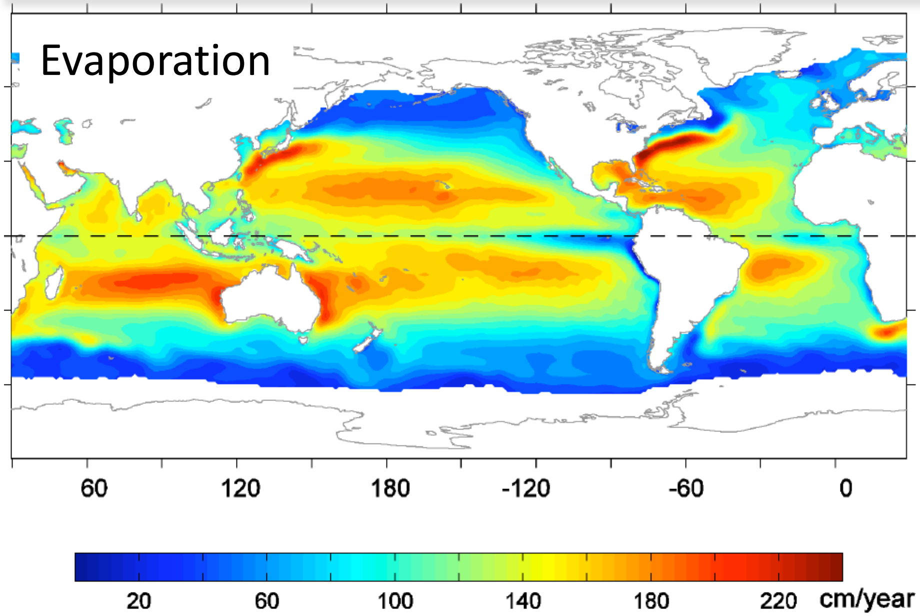
HADLEY-WALKER CIRCULATION: CLOUDS

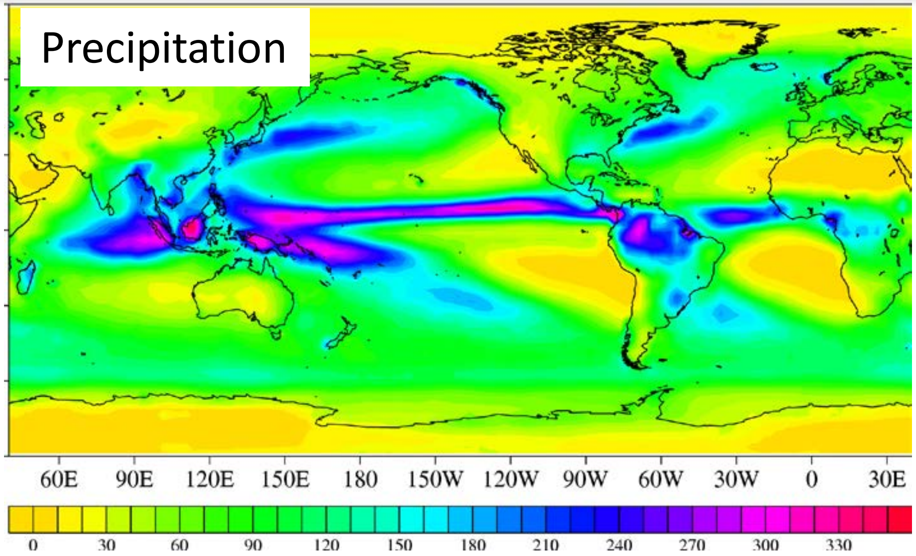


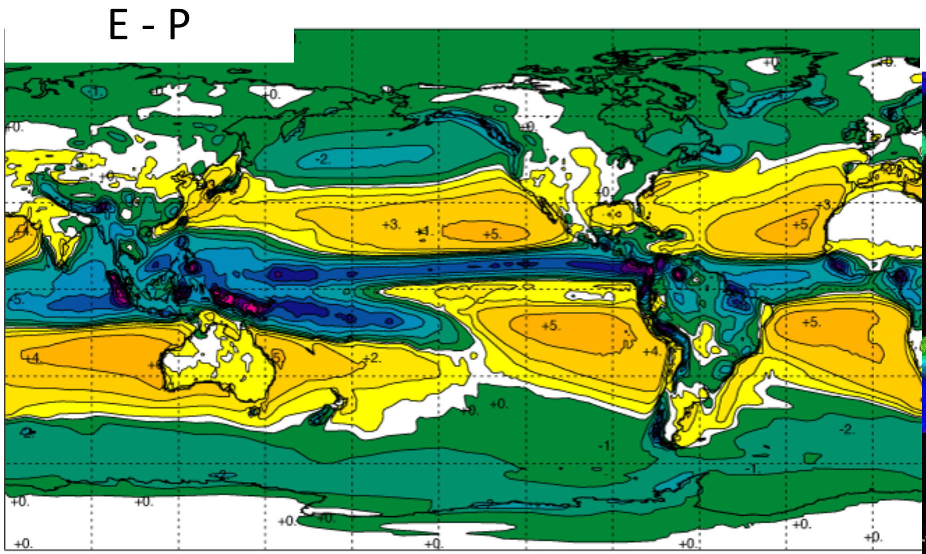
- Above “warm pool”: Deep convection made possible by latent heat release form ITCZ
- In “cold pool”: low-level stratus clouds form because water vapor evaporated from ocean is trapped in thin surface layer
- Clouds amplify both local warming and local cooling
- Reliable trade winds favorable for evaporation providing moist air to ITCZ.

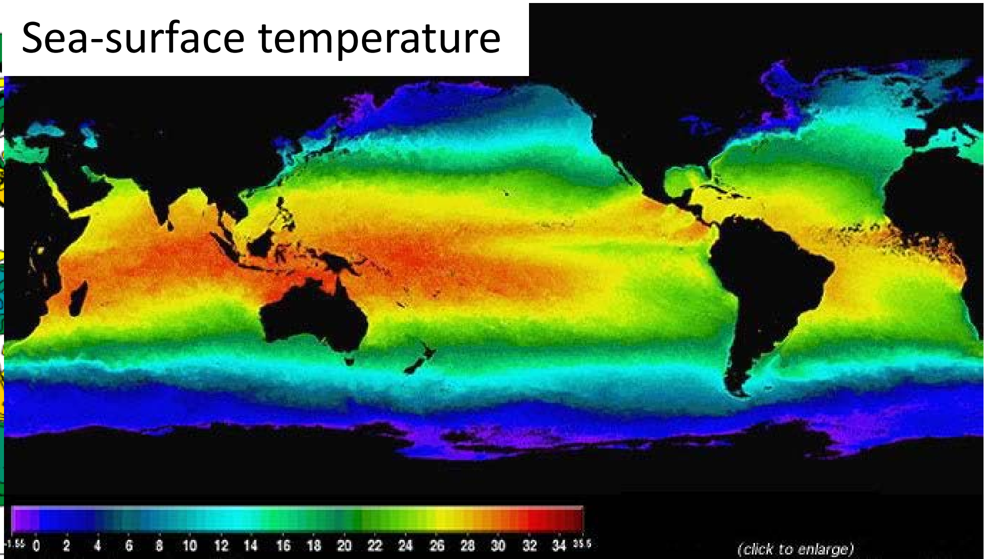


HADLEY-WALKER CIRCULATION: MOIST CONVERGENCE



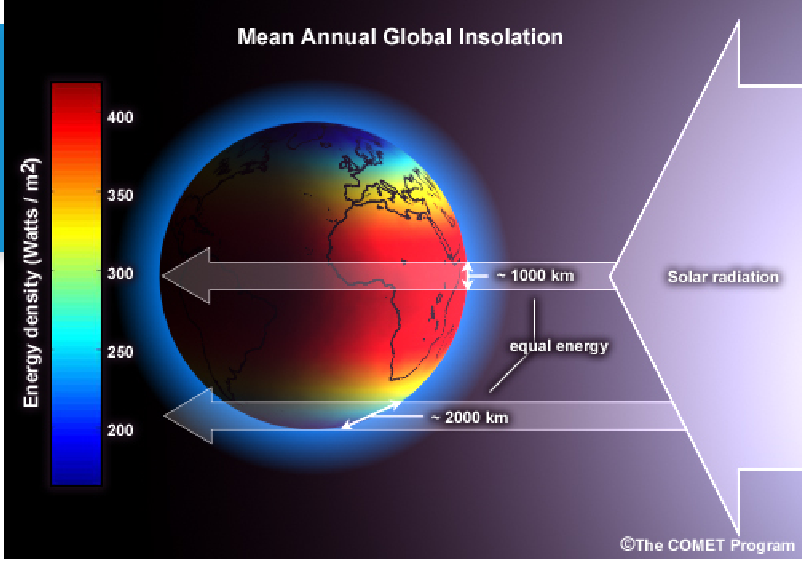






LATENT HEAT FLUX

- In the mid-latitudes nearly half of the energy flux is via latent heat
- In the tropics latent heat flux is *towards equator* (moist convergence)



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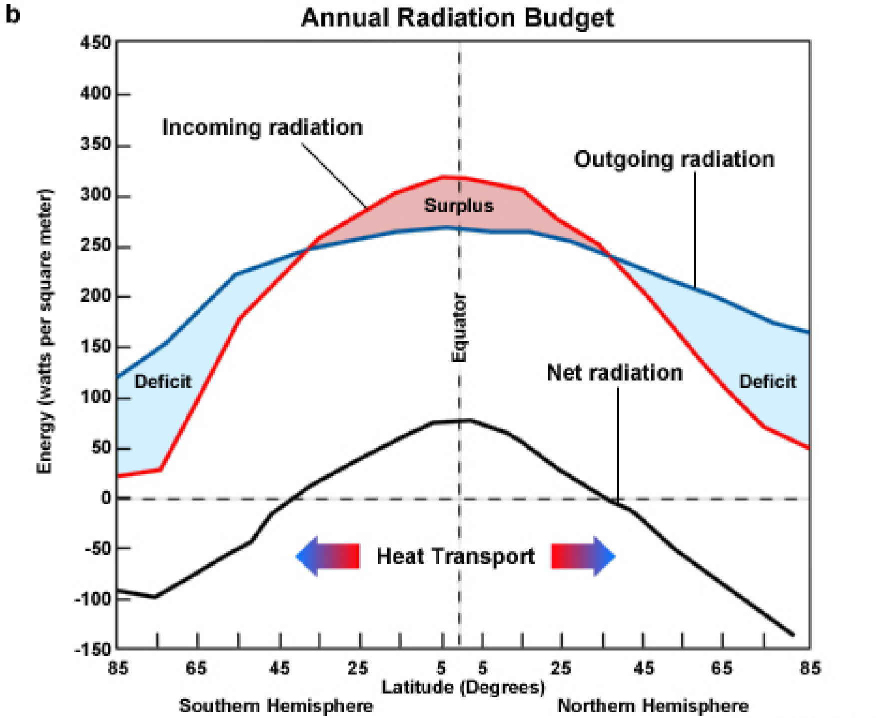

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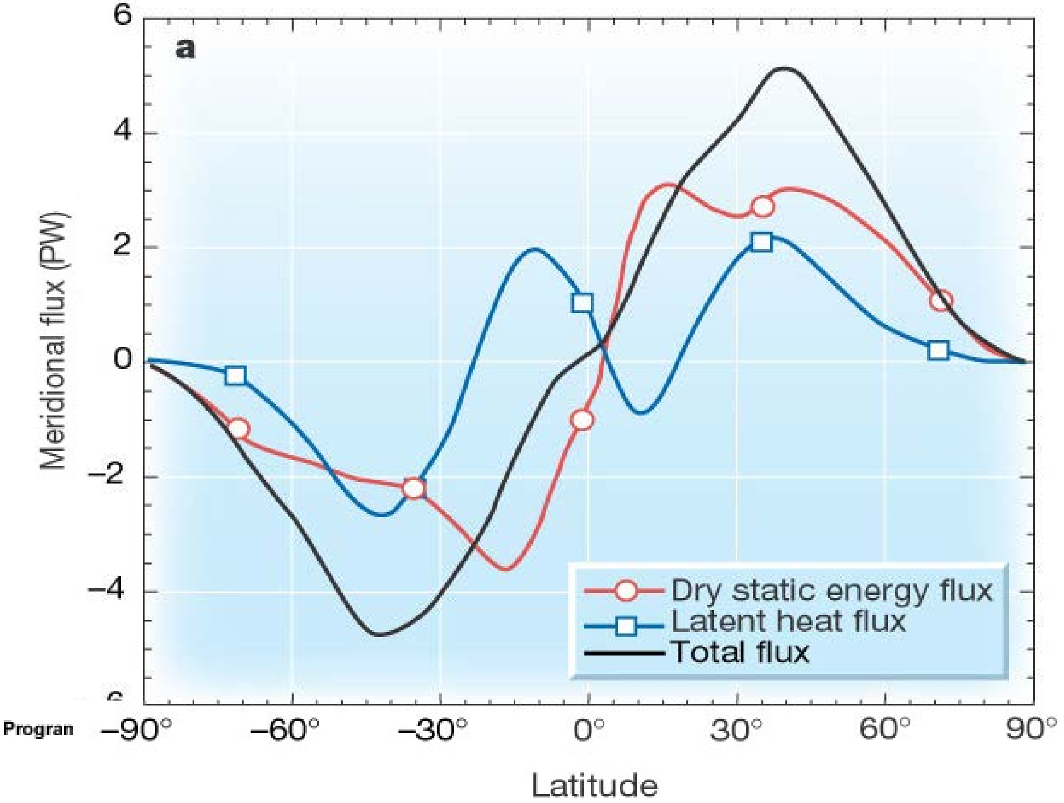
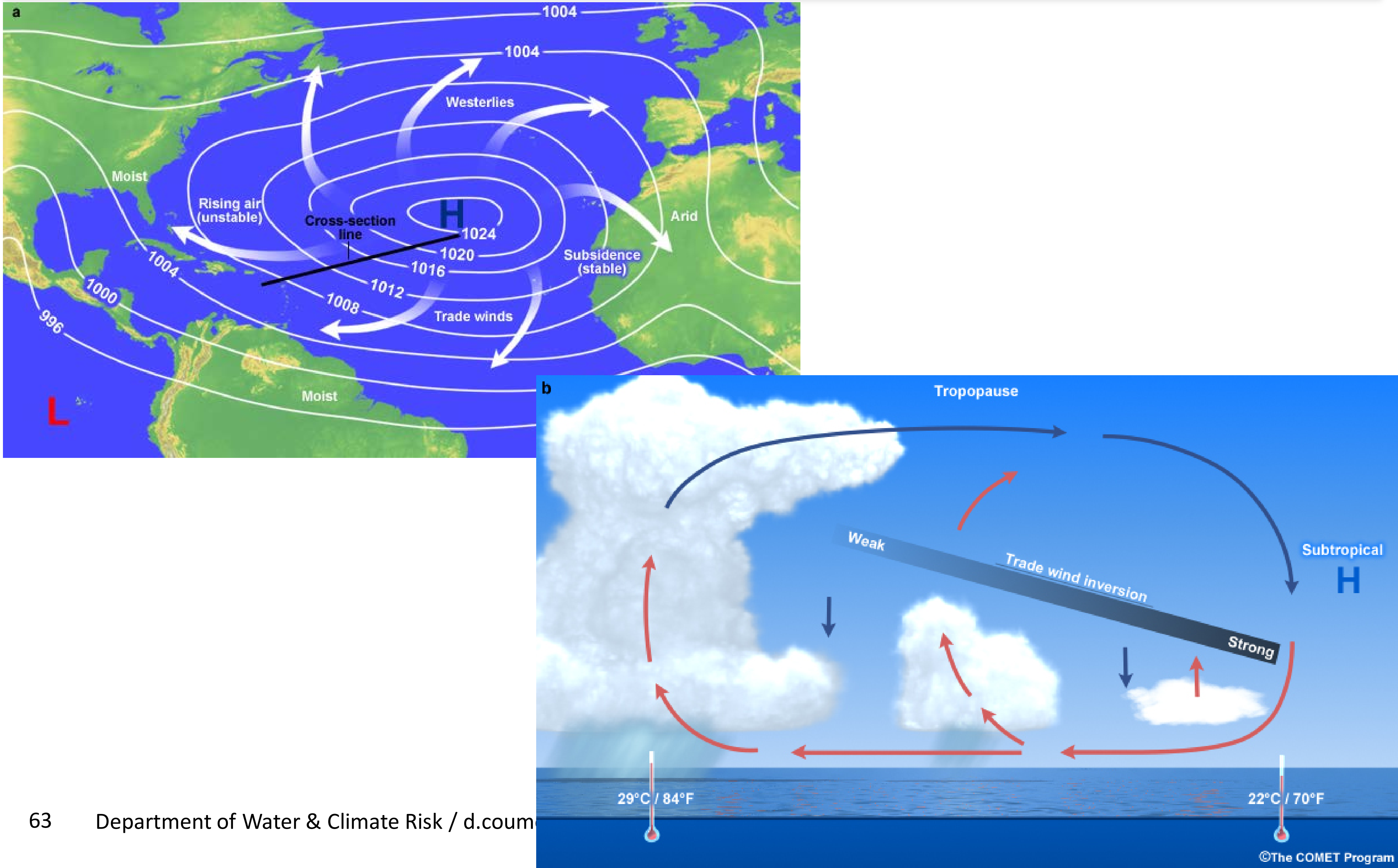


HADLEY-WALKER CIRCULATION - ATLANTIC



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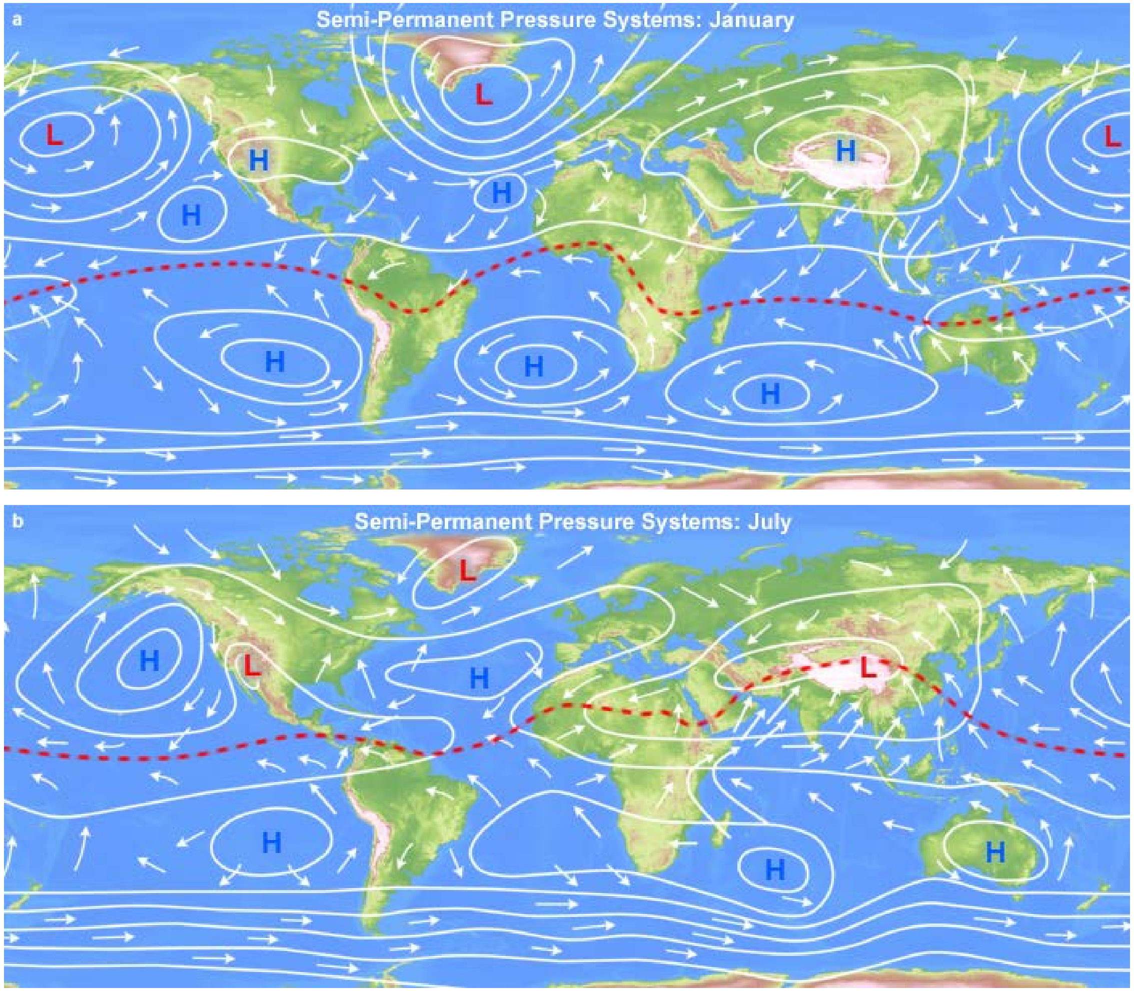
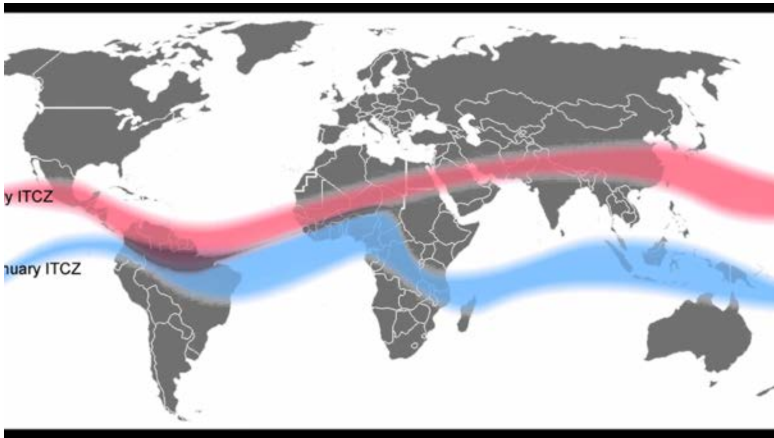
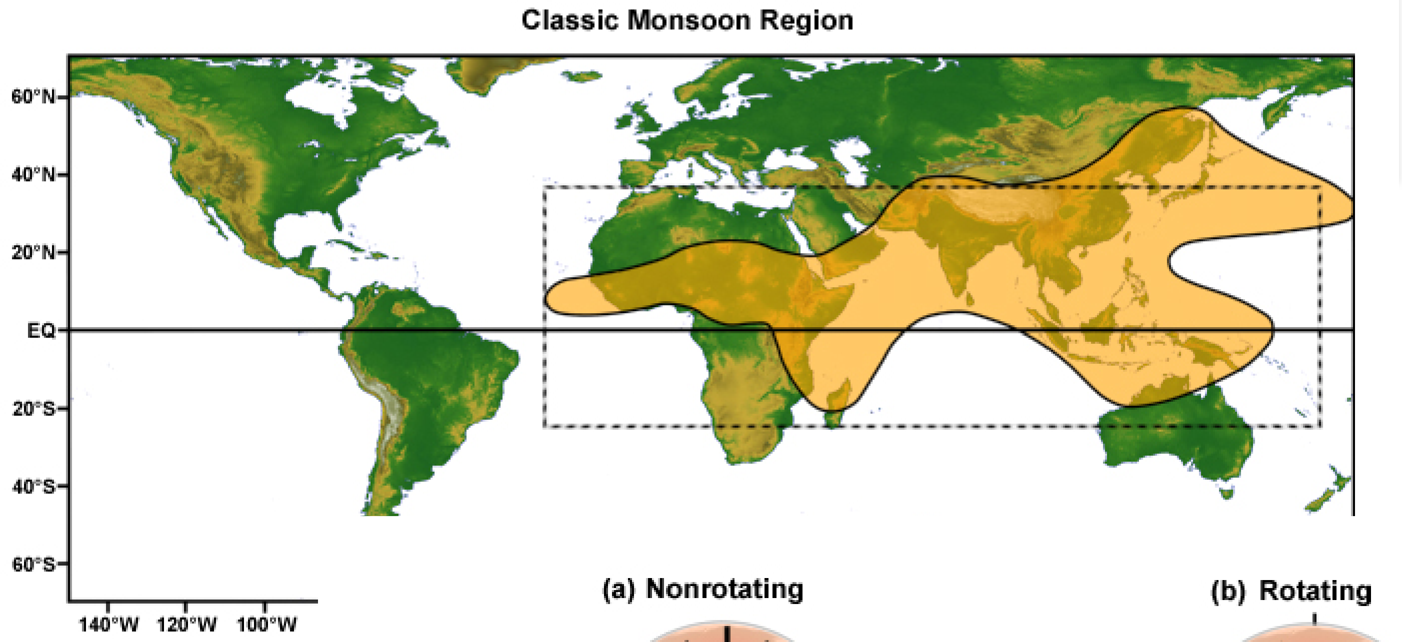
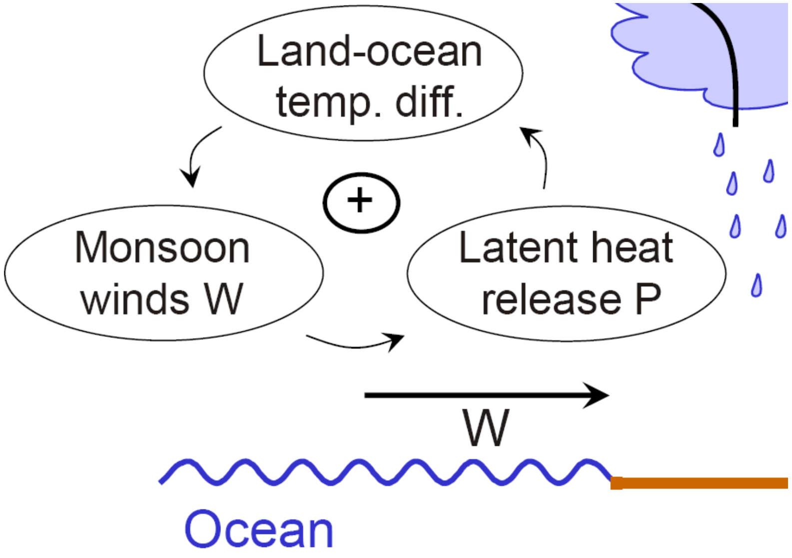
CLIMATOLOGICAL SEALEVEL PRESSURE & ITCZ

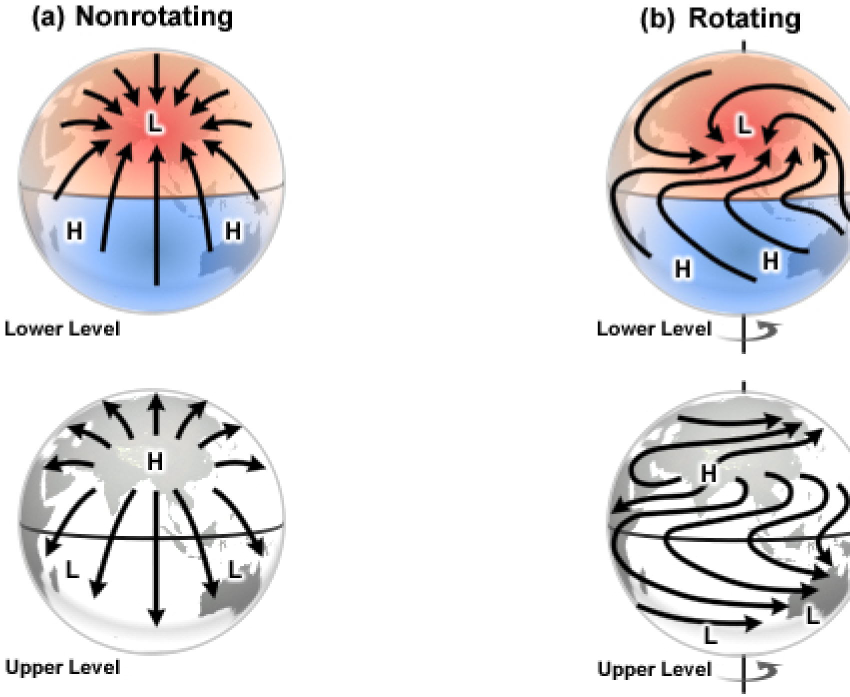




MONSOON


Classic Monsoon Region
60°N
40°N
20°N
EQ
20°S
40°S
60°S
140°W
120°W
100°W


Land-ocean temp. diff.
+
Monsoon winds W
Latent heat release P
W
Ocean


(a) Nonrotating
L
H
H
Lower Level
H
L
L
Upper Level
(b) Rotating
L
H
H
Lower Level
H
L
L
Upper Level

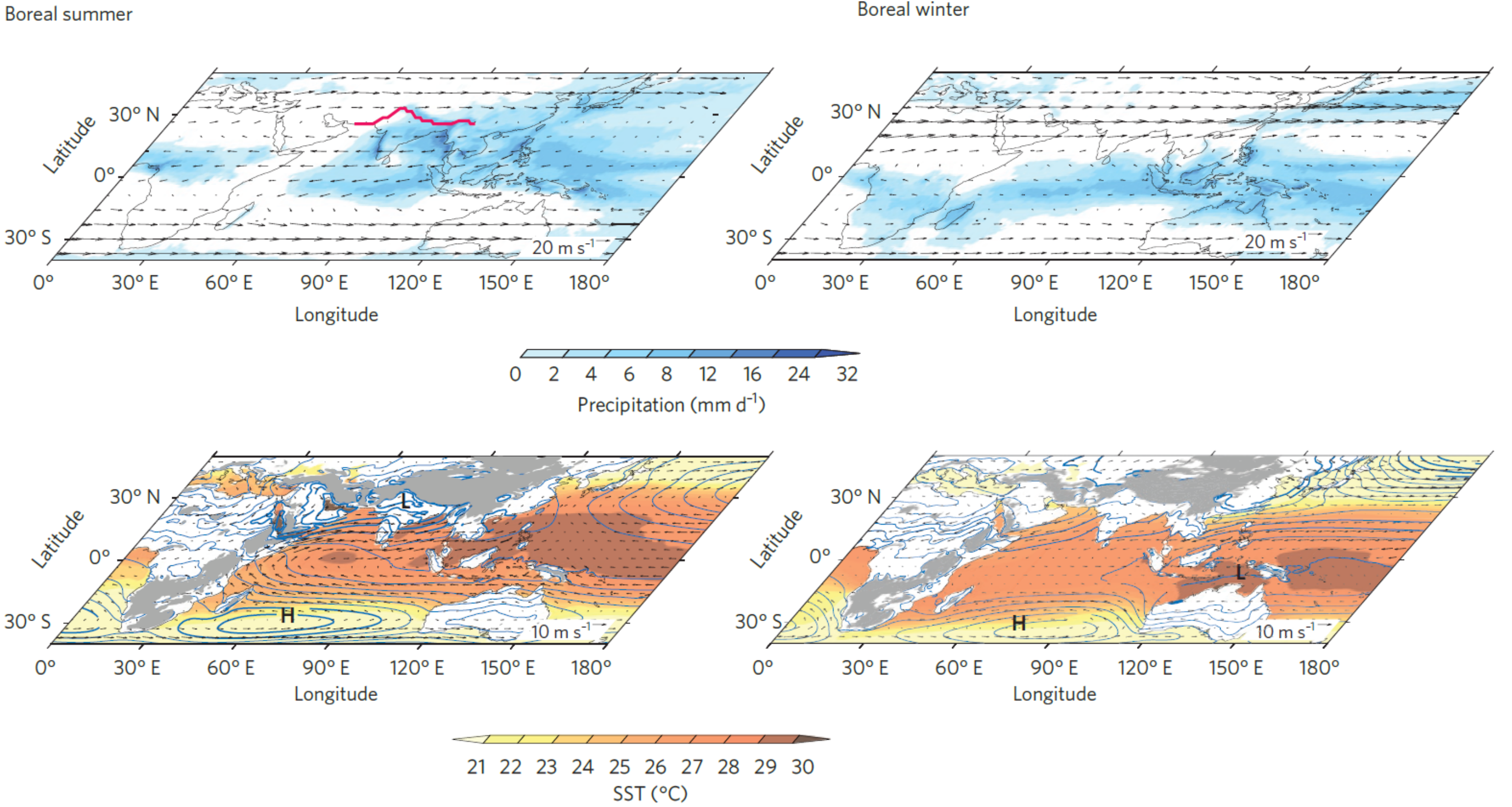
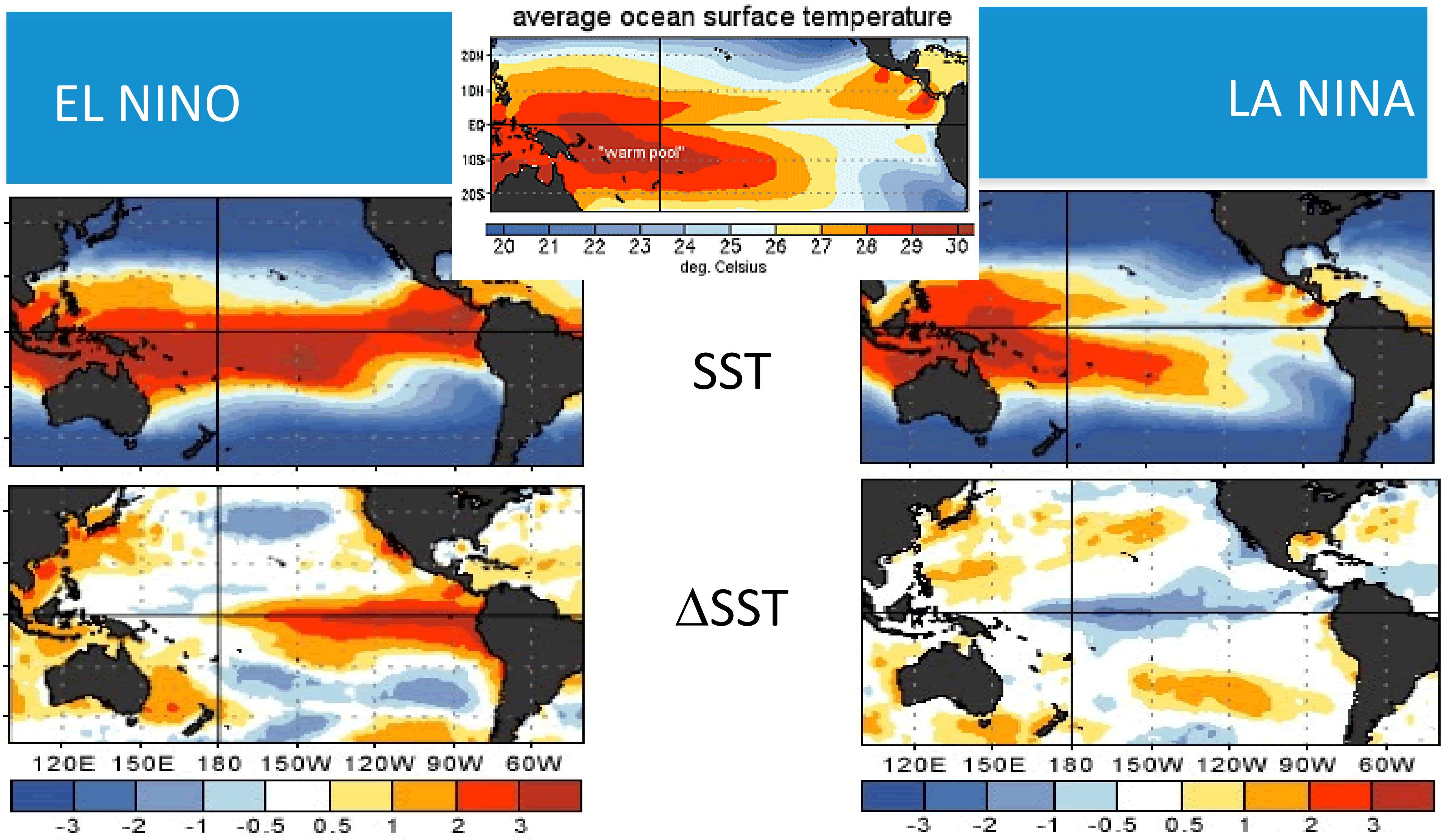


Figure 1 | Schematic of summer and winter climate in the South Asian monsoon region. Schematic of boreal summer (June–September) and winter (December–February) atmospheric conditions in the South Asian monsoon region. The summer and winter panels depict the Asian and Australian monsoons, respectively. In each case, the lower panels show: orography (>1,000 m, shaded grey); SSTs from the Hadley Centre Sea Ice and Sea Surface Temperature[91] data set for 1979–2010 (shaded yellow/orange); sea-level pressure for 1979–2010 (blue contours, interval 2 hPa) and lower tropospheric (850 hPa) winds from the European Centre for Medium Range Weather Forecasts Interim Reanalysis[92]. 'H' and 'L' refer to the monsoon highs and lows, respectively, in the both summer and winter. In summer, the high reaches around 1,024 hPa, whereas the low is approximately 1,000 hPa. The upper panels show upper tropospheric (200 hPa) wind vectors and Tropical Rainfall Measuring Mission 3B43 monthly rainfall[93] for 1998–2010 (shaded blue). The seasonal cycle of solar insolation leads to temperature gradients at the surface. In summer, this leads to a cross-equatorial pressure gradient from the Mascarene High in the southern Indian Ocean to the monsoon trough over northern India. Orography helps to both steer the cross-equatorial flow back towards India and isolate South Asia from dry air to the north: the summer diagram shows a line (in red) representing the location of maximum vertically integrated MSE, bounding the northward extent of the monsoon Hadley-type circulation. Over the ocean, rainfall locates over the warmest SST, whereas maxima over India occur near the Western Ghats and Himalaya, and near the Burmese mountains. During summer, the upper-level jet structure moves north, yielding the South Asia High over the Tibetan Plateau. This leads to upper-level easterly flow over South Asia, indeed the strength of the vertical shear at Indian latitudes has been shown to relate to the intensity of the Asian summer monsoon[94].

EL NINO

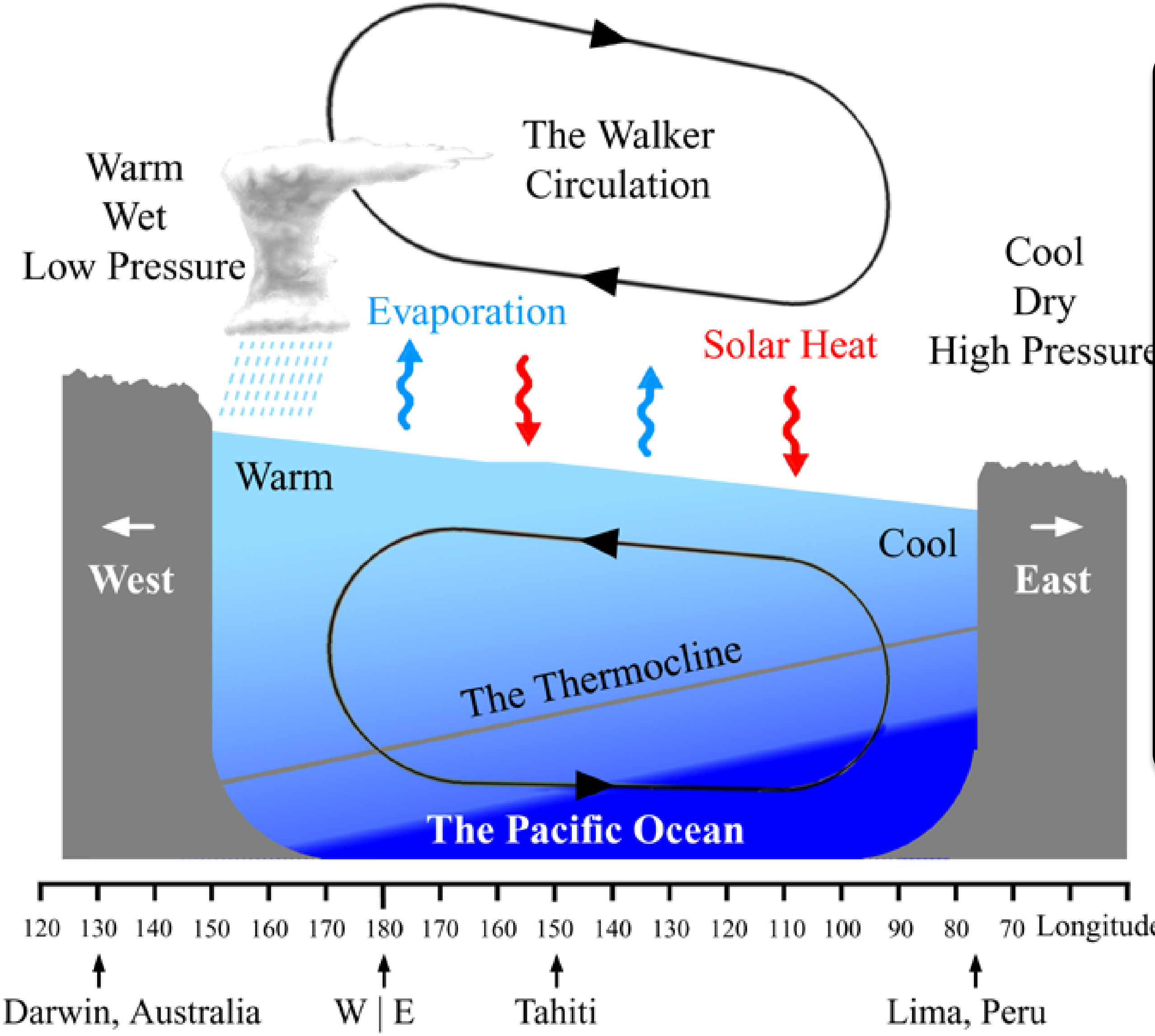
LA NINA

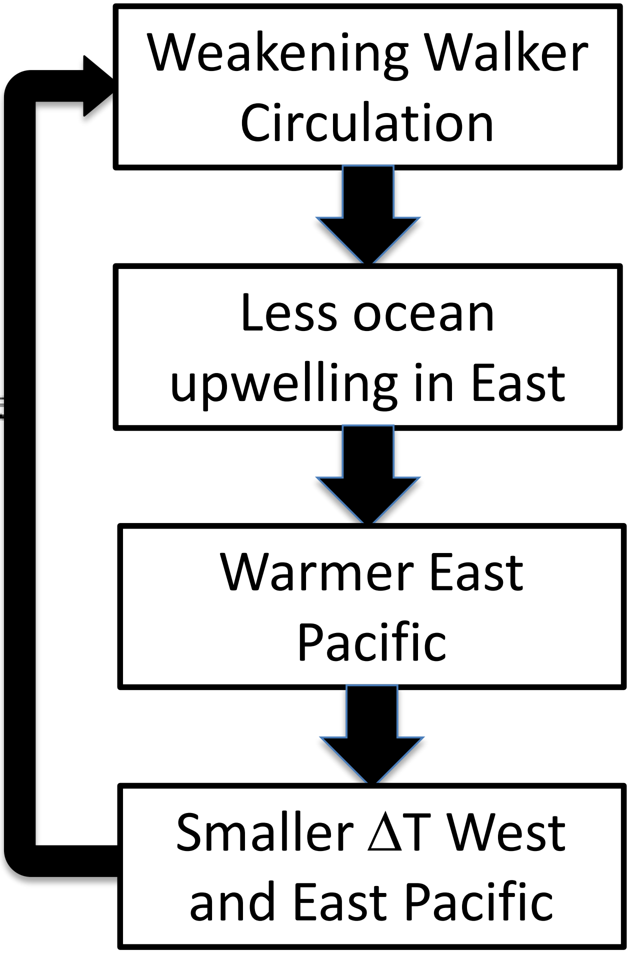


- Temperature variations in tropical Pacific Ocean and associated pressure/wind changes
- Globally dominant mode of variability: Easily seen in global-mean temperature

ENSO:
EL NINO – SOUTHERN OSCILLATION

ATMOSPHERE-OCEAN AMPLIFYING MECHANISM





Weakening Walker Circulation

Less ocean upwelling in East

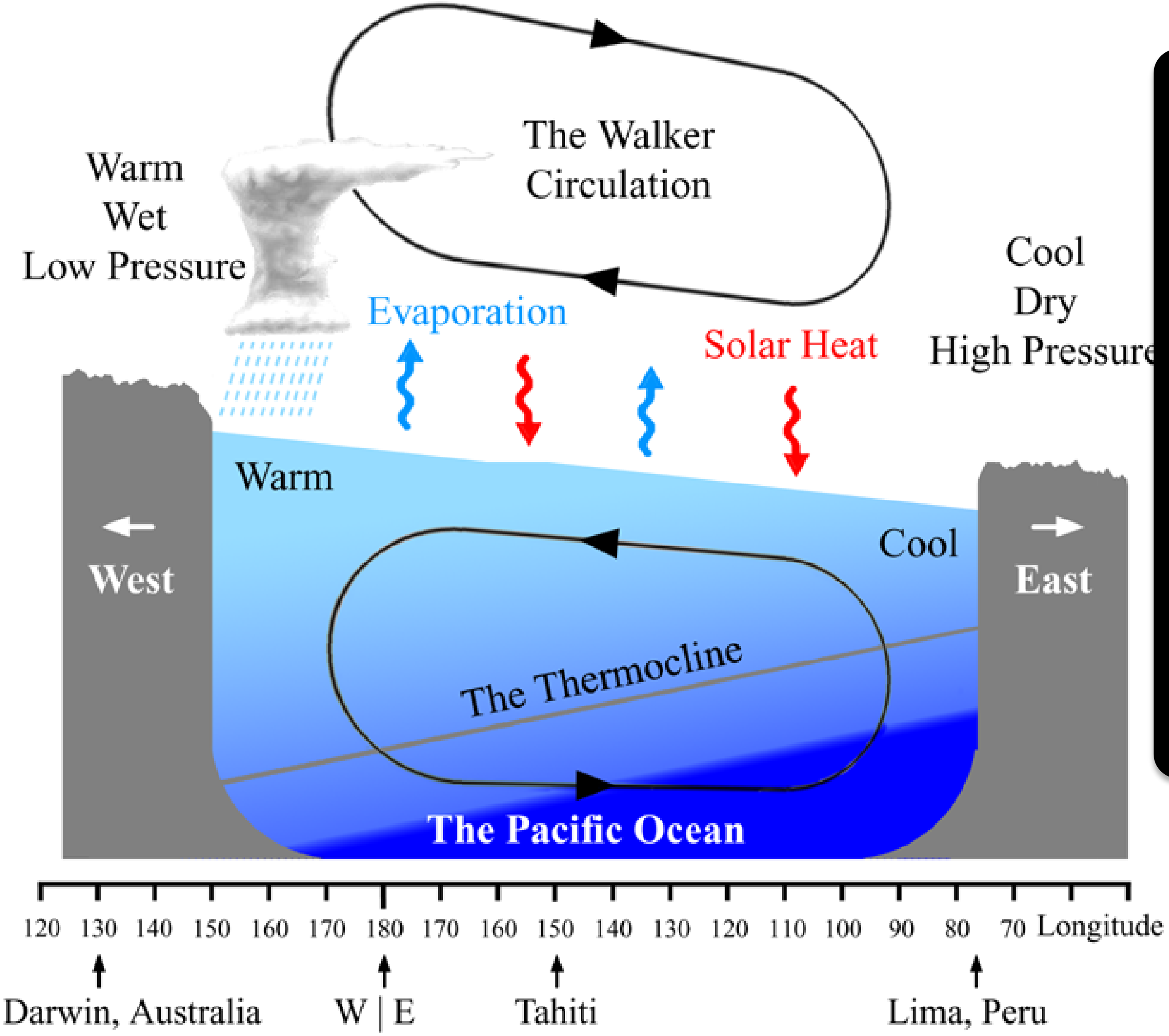
Warmer East Pacific

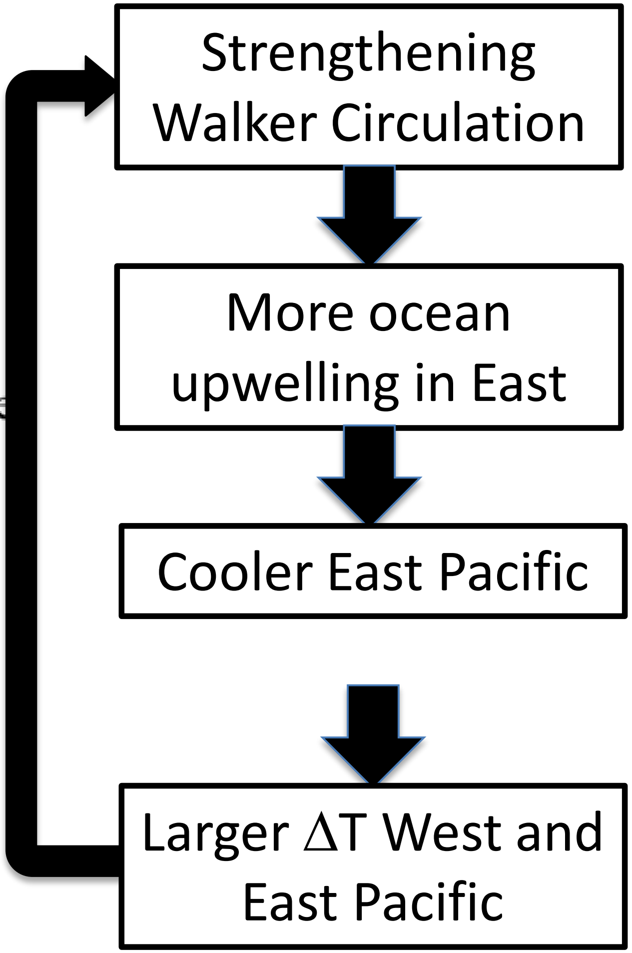
Smaller ΔT West and East Pacific

El Nino

ENSO:
EL NINO – SOUTHERN OSCILLATION

ATMOSPHERE-OCEAN AMPLIFYING MECHANISM





Strengthening Walker Circulation

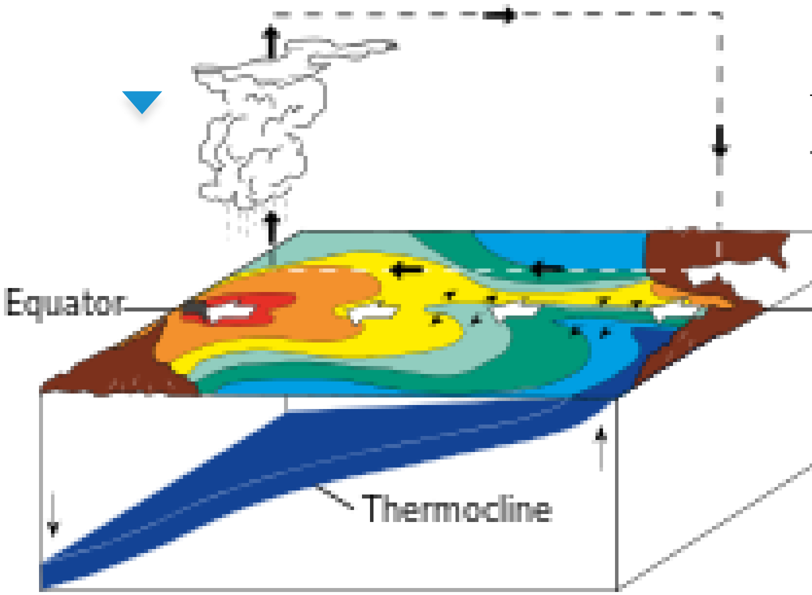
More ocean upwelling in East

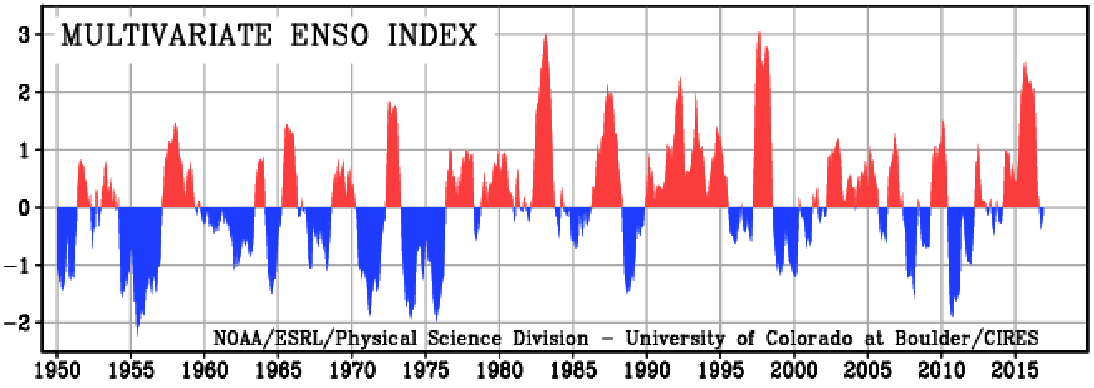
Cooler East Pacific

Larger ΔT West and East Pacific

La Nina

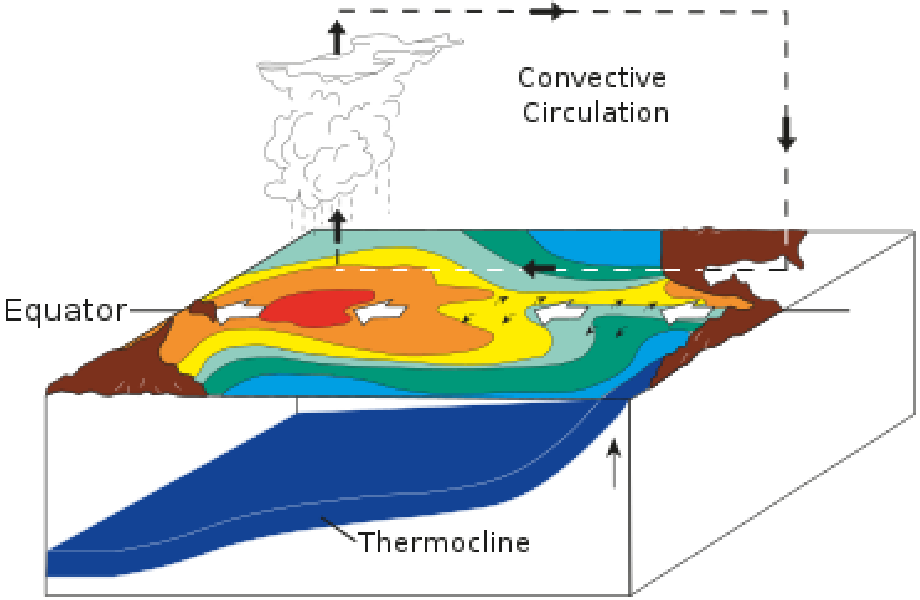
La Niña Conditions



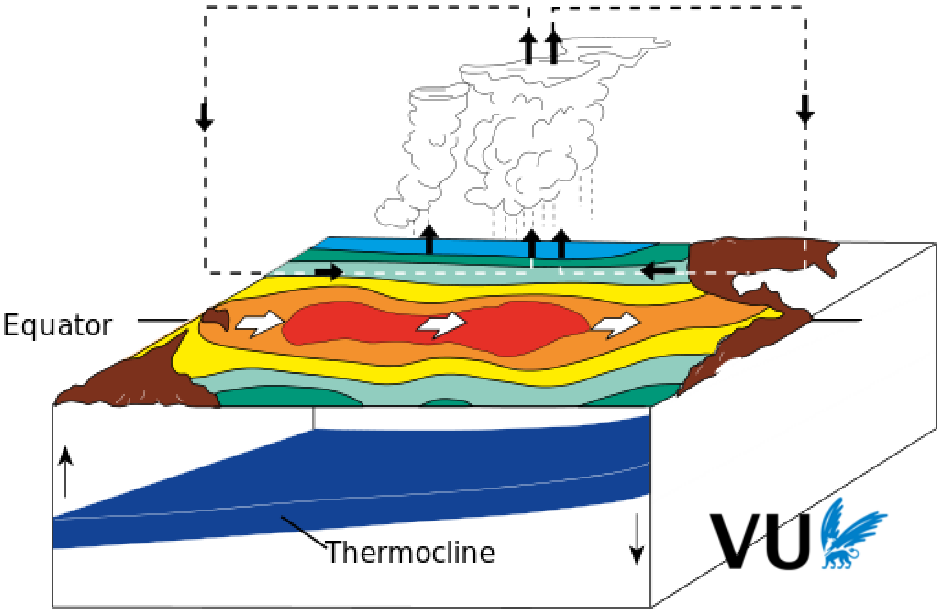


- 3 Phases lasting several months each
- Period of full cycle: 2 to 3 years

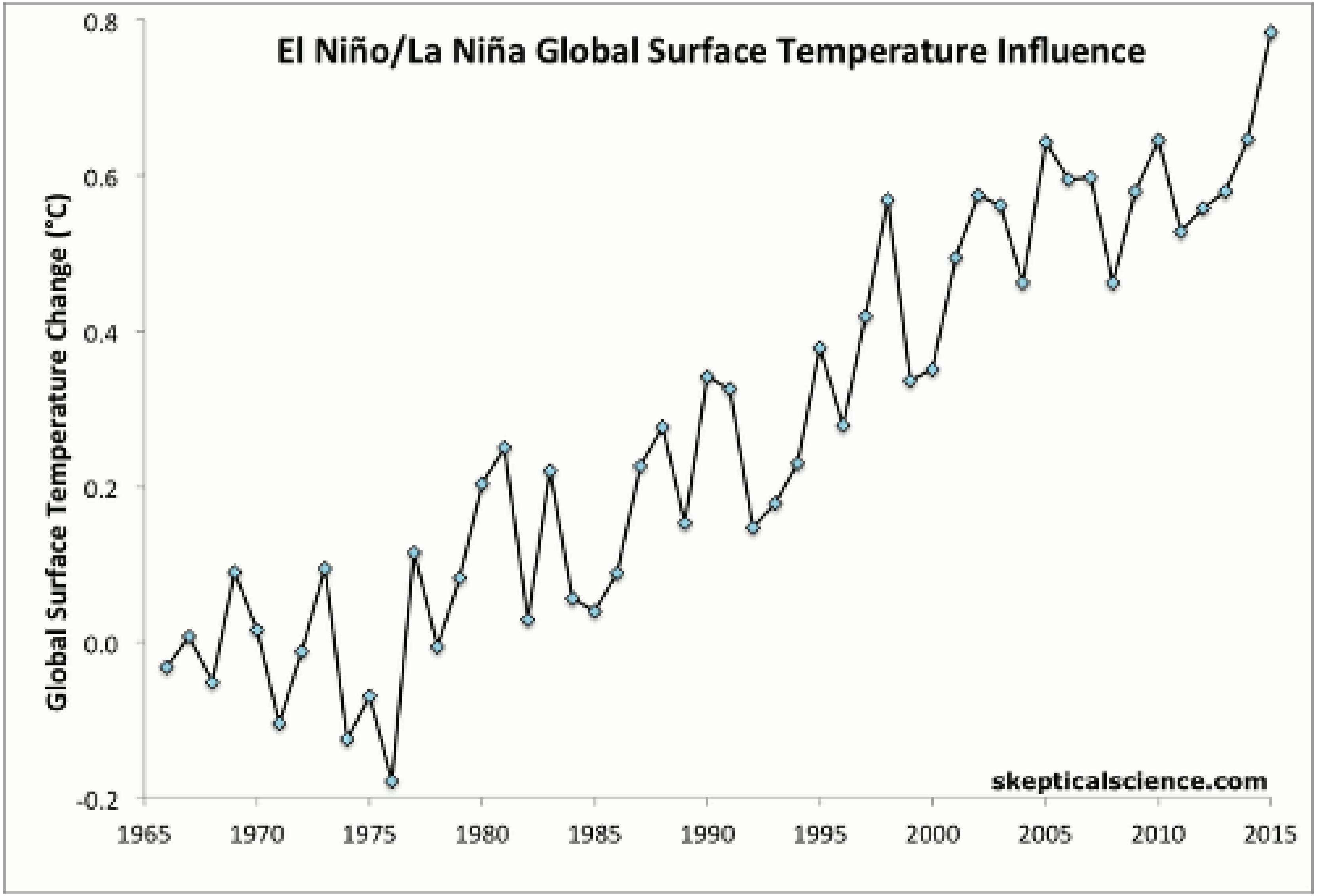
Normal Conditions



El Niño Conditions

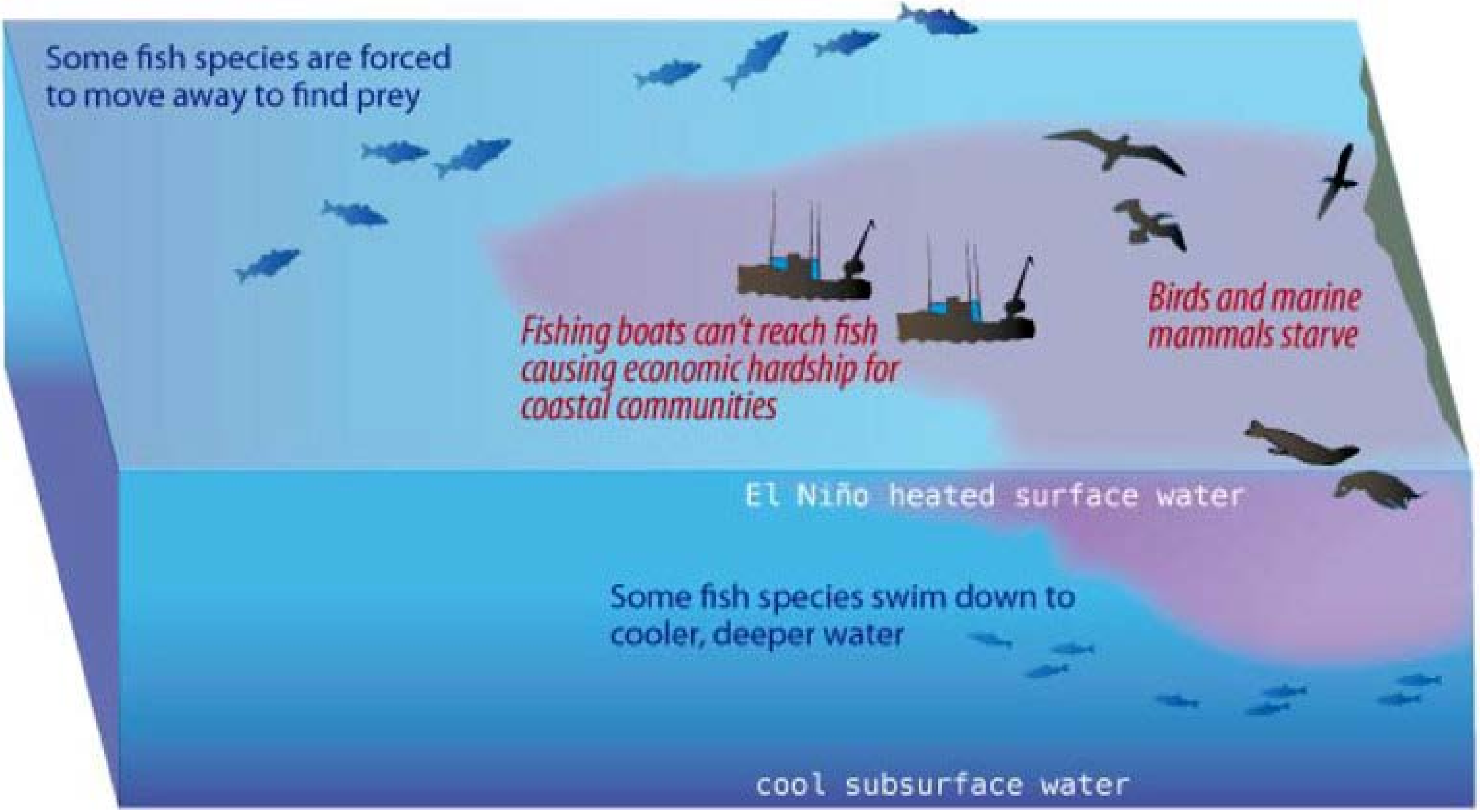


ENSO – INFLUENCE ON GLOBAL MEAN TEMPERATURE



ENSO – IMPACTS: REGIONAL FISH CATCH

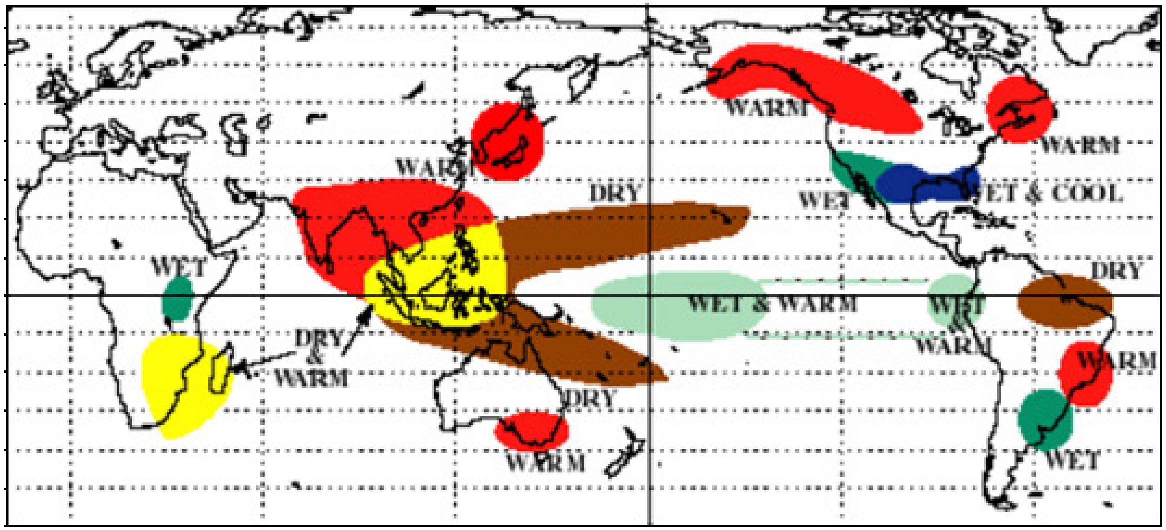
- El Nino very bad for Peruvian fishermen who named it after the Christ child as usually the warming starts around Christmas.



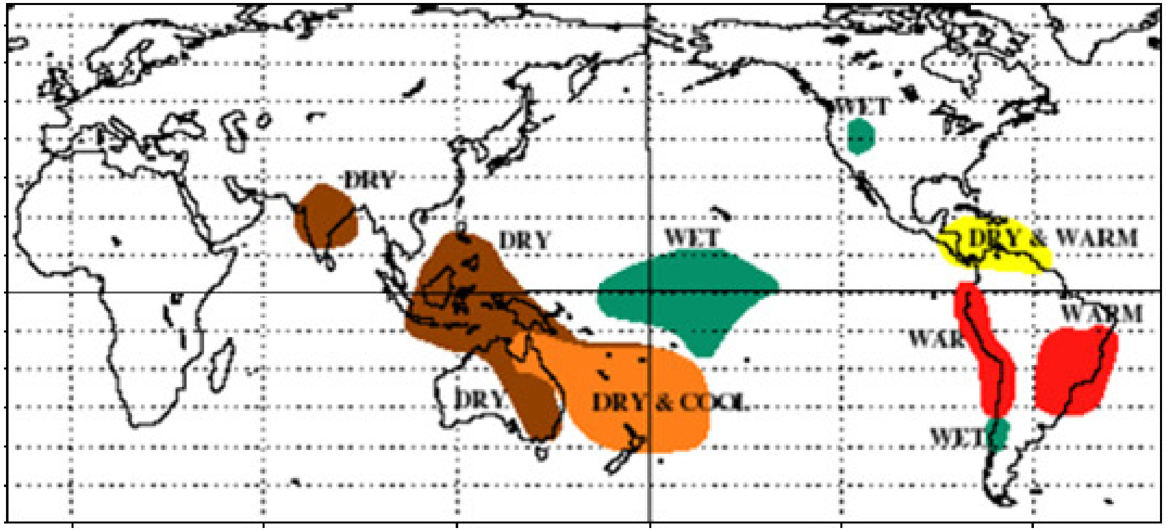
EL NINO
GLOBAL IMPACTS

- Global mean warmer
- Dry warm pool & wet cold pool (regions of thunderstorms migrate)
- In JJA mostly limited to tropical Pacific region
- In DJF stronger impacts, further away: Africa, US
- Very important for rainfall in Africa and California

Boreal winter (DJF)



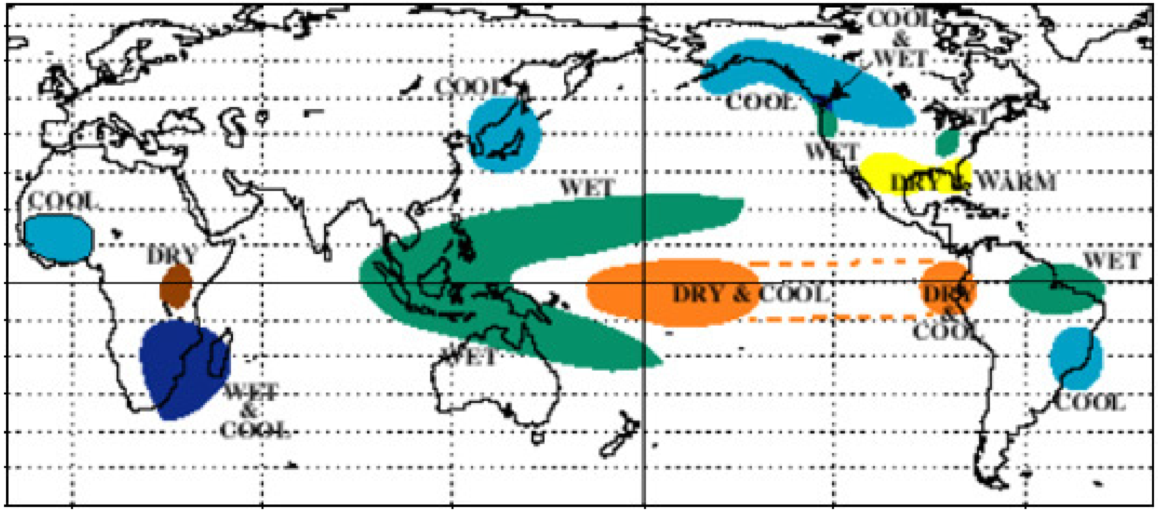
Boreal summer (JJA)



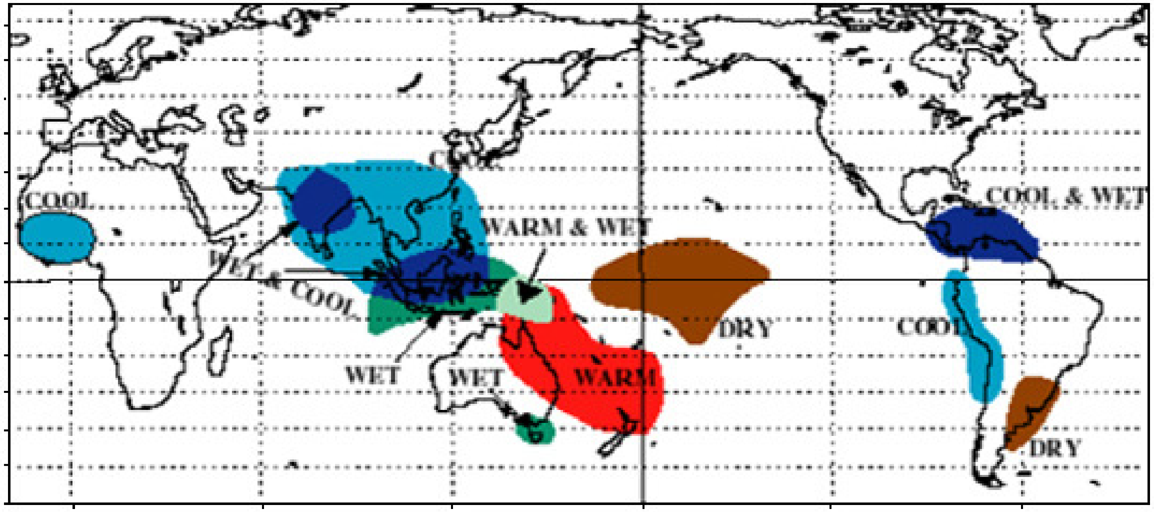
LA NINA
GLOBAL IMPACTS

- Wet warm pool & dry cold pool (regions of thunderstorms migrate)
- In JJA mostly limited to tropical Pacific region
- In DJF stronger impacts, further away: Africa, US
- Very important for rainfall in Africa and California

Boreal winter (DJF)

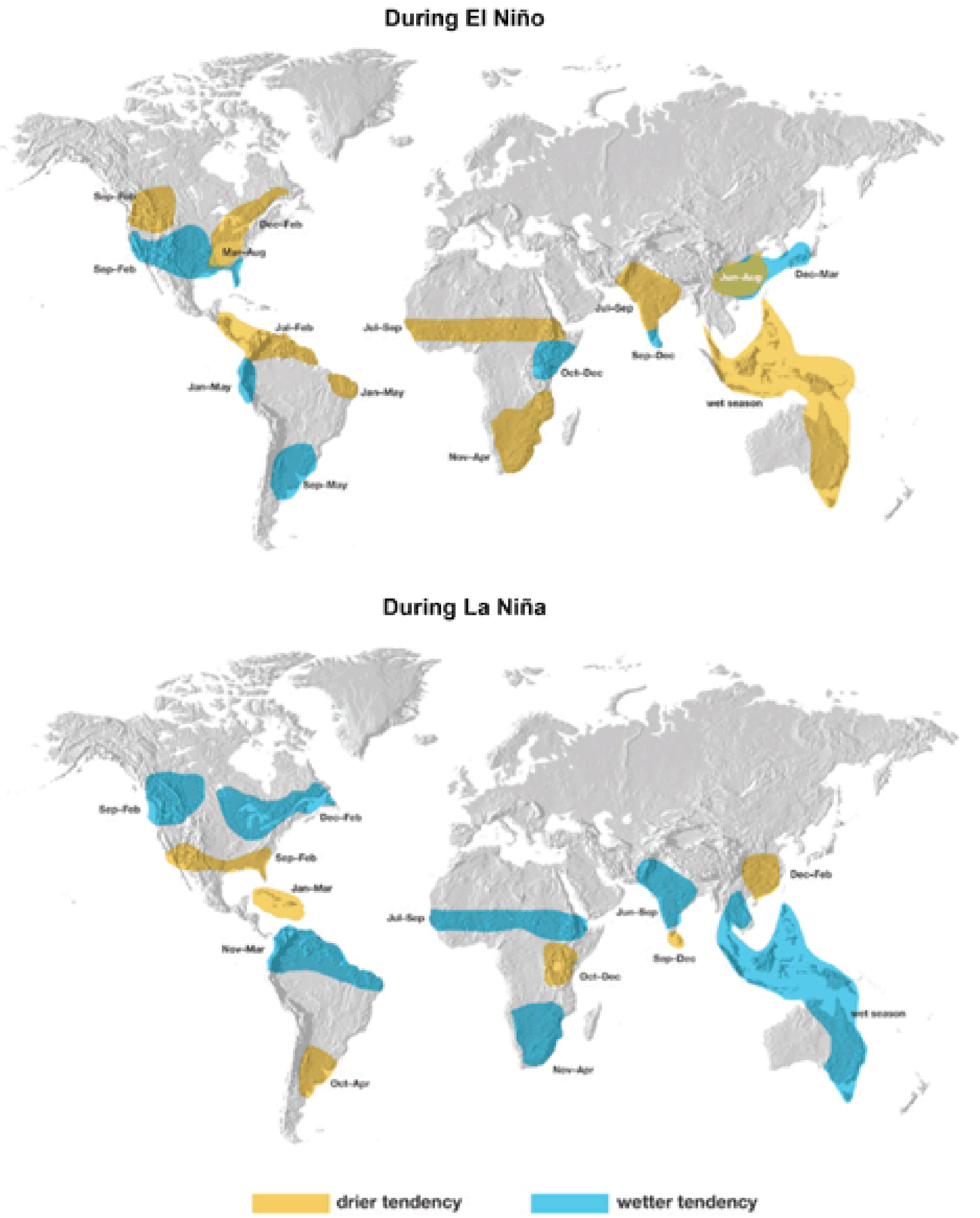


Boreal summer (JJA)



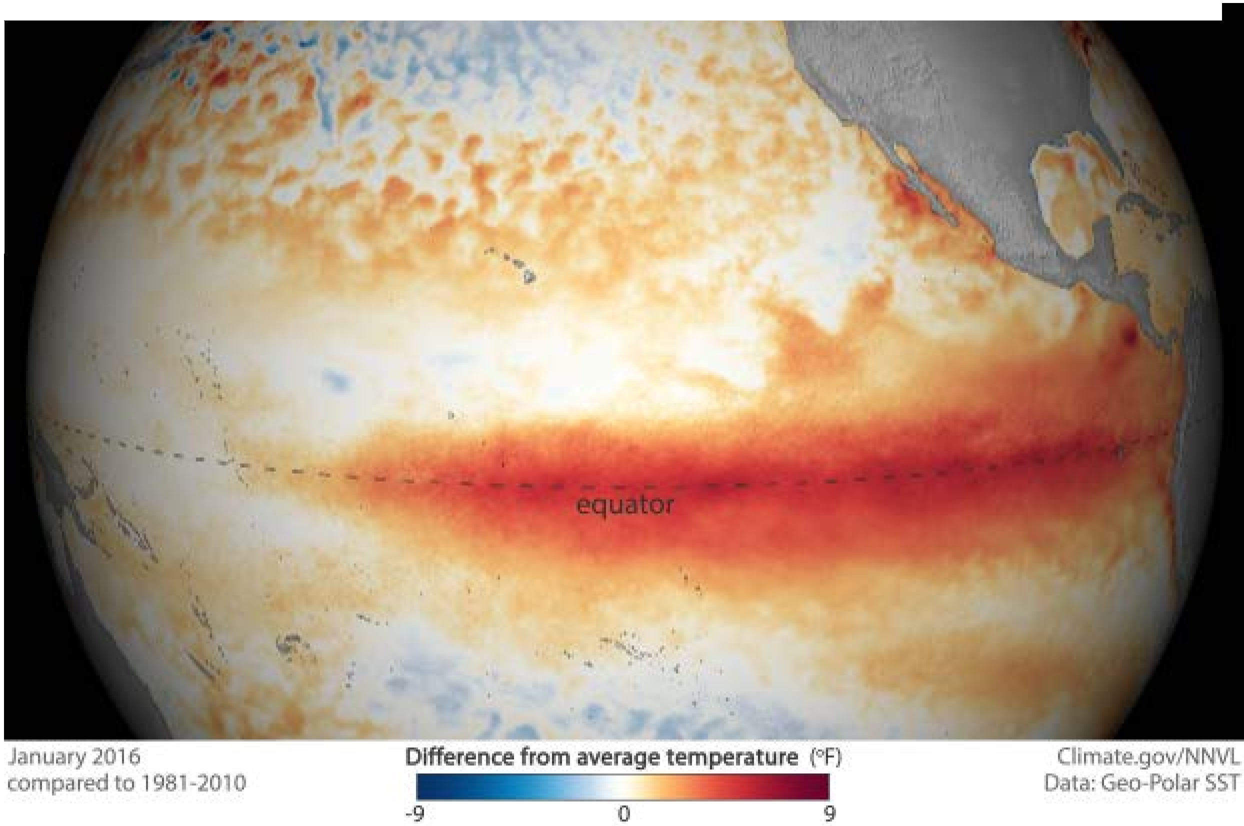
ENSO & RAINFALL

- More wet regions during La Nina. Thus, La Nina years tend to be wet years (global-land-mean)
- More dry regions during El Nino years. Exceptions:
  - Peru / Ecuador
  - California
  - Horn of Africa

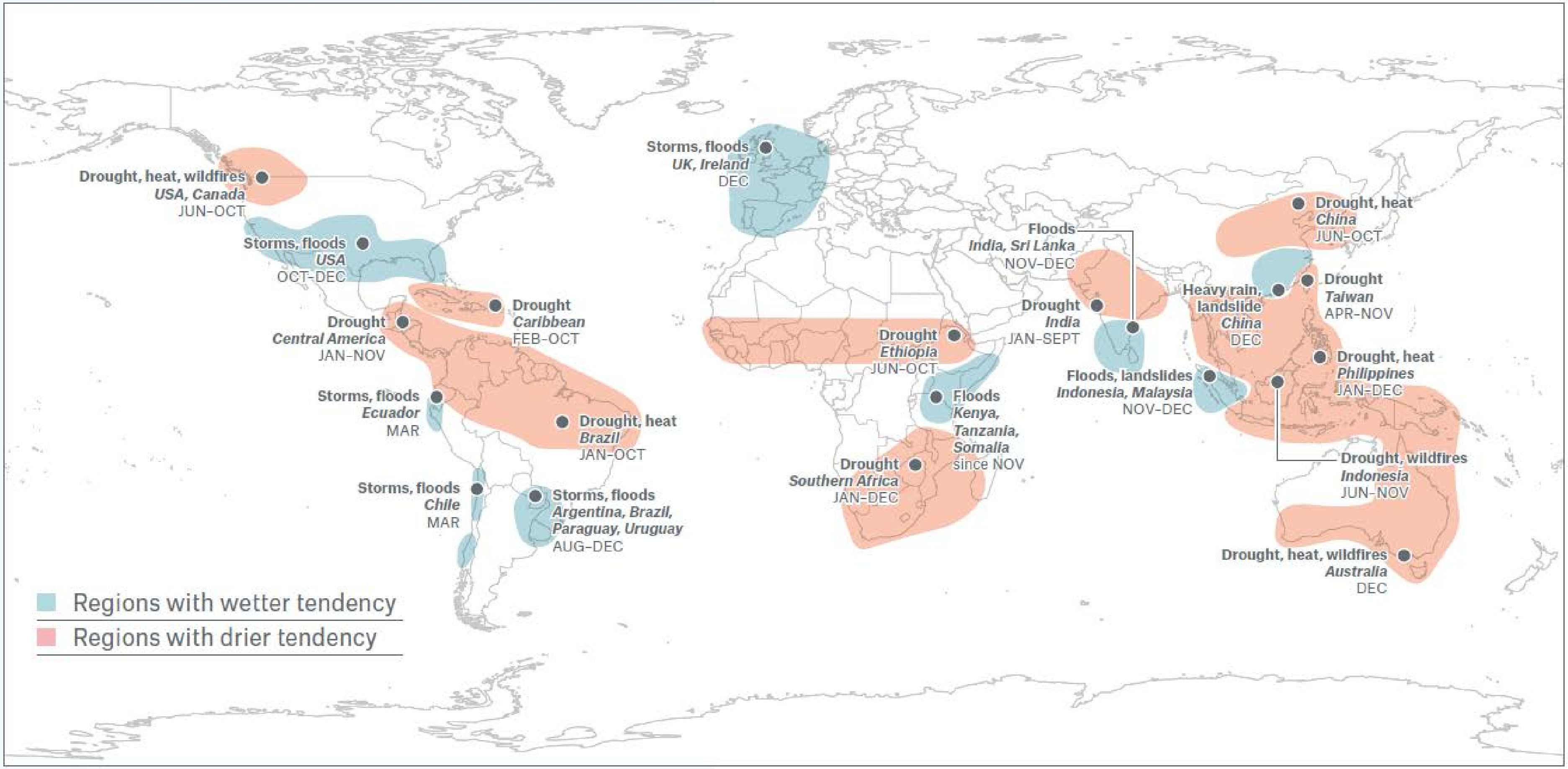


EL NINO 2015/2016

- Contributed to new global mean temperature record (third in a row), though long-term anthropogenic warming as important (!)
- Affecting millions of people world wide: Flooding in Peru, drought in Africa, peat fires in Indonesia
- Successfully forecasted up to 1 year ahead: Early warning possible

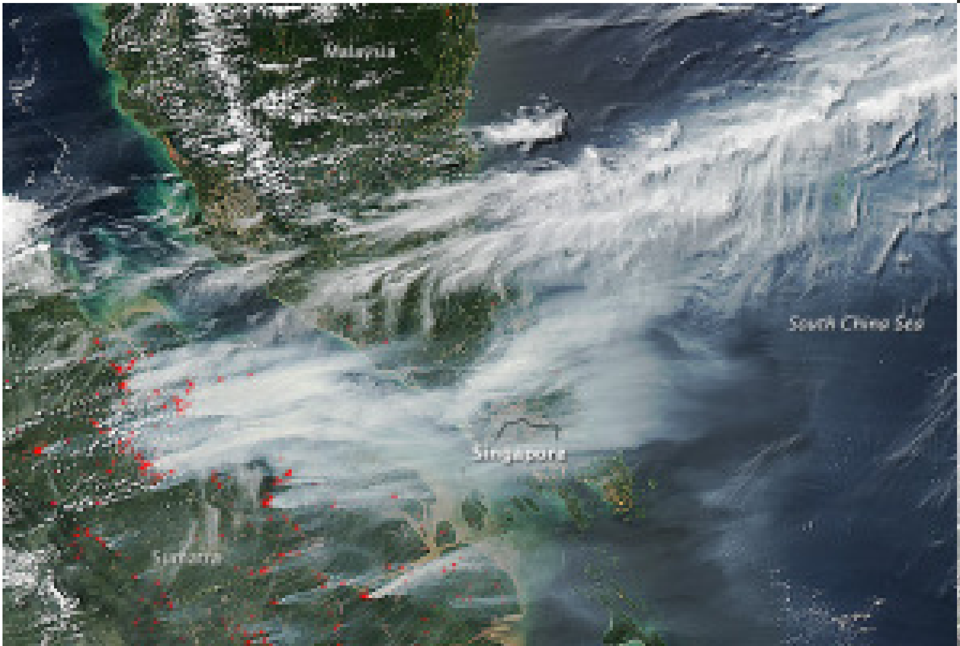


EL NINO 2015/2016: IMPACTS (MUNICH RE)



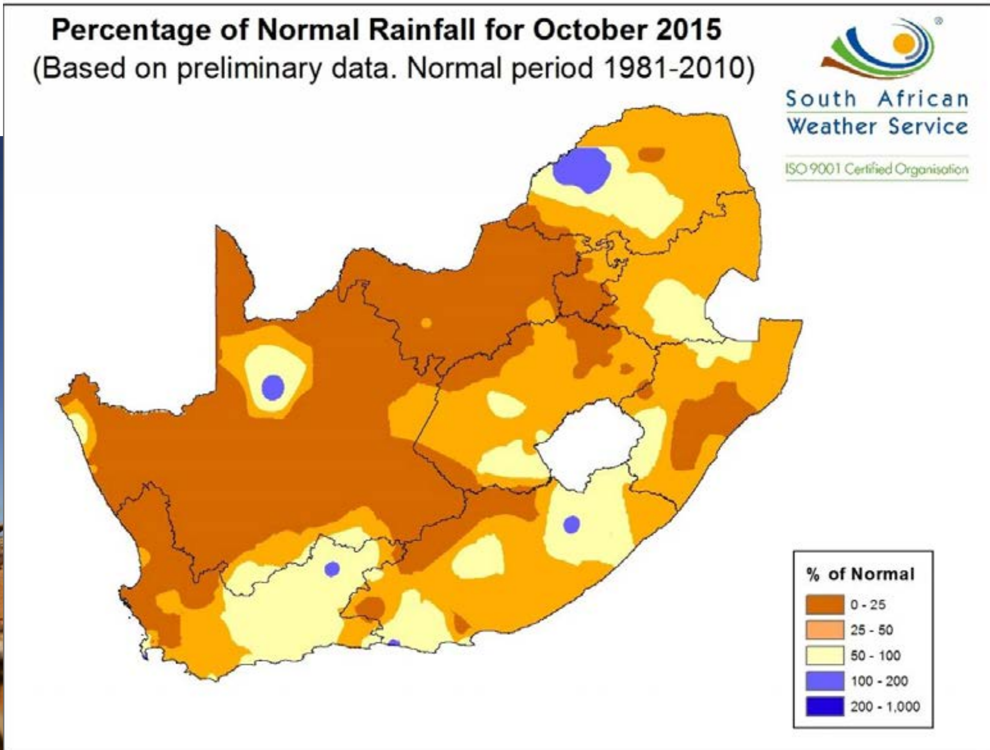
EL NINO 2015/2016:
INDONESIAN PEAT FIRES

- Peat fires can smolder underground for years: very difficult to extinguish
- Store lots of Carbon. Recent fires estimated to release more CO2 daily than entire US economy.
- Smog



EL NINO 2015/2016: AFRICAN DROUGHT

- Worst drought in decades in eastern and southern Africa
- 36M people in immediate danger of hunger
- Drought exacerbated by long-term global warming which heats and thereby dries the soils

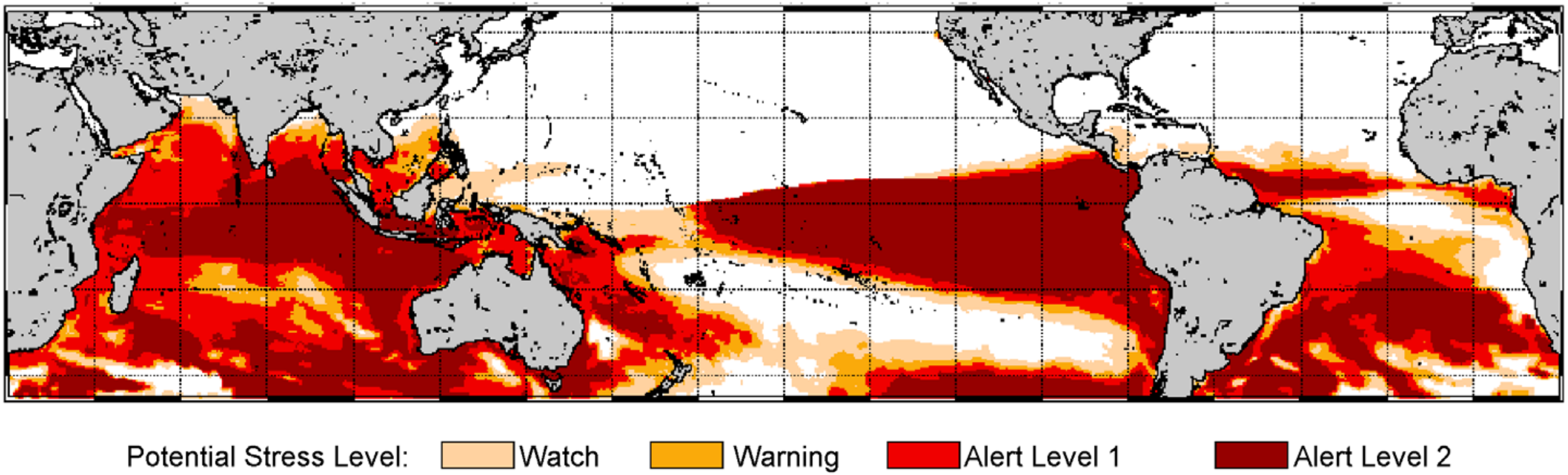


Percentage of Normal Rainfall for October 2015
(Based on preliminary data. Normal period 1981-2010)

EL NINO 2015/2016: CORAL BLEACHING

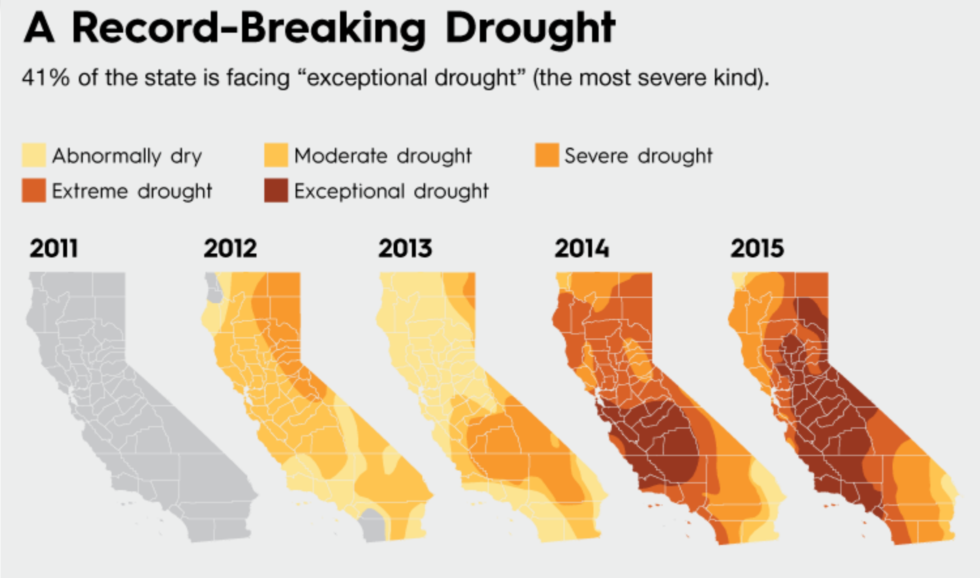
- Corals very sensitive to SST warming
- 2015-2016: 95% of reefs affected
- Long-term warming of course important too

2015 Oct 6 NOAA Coral Reef Watch 60% Probability Coral Bleaching Thermal Stress for Feb-May 2016



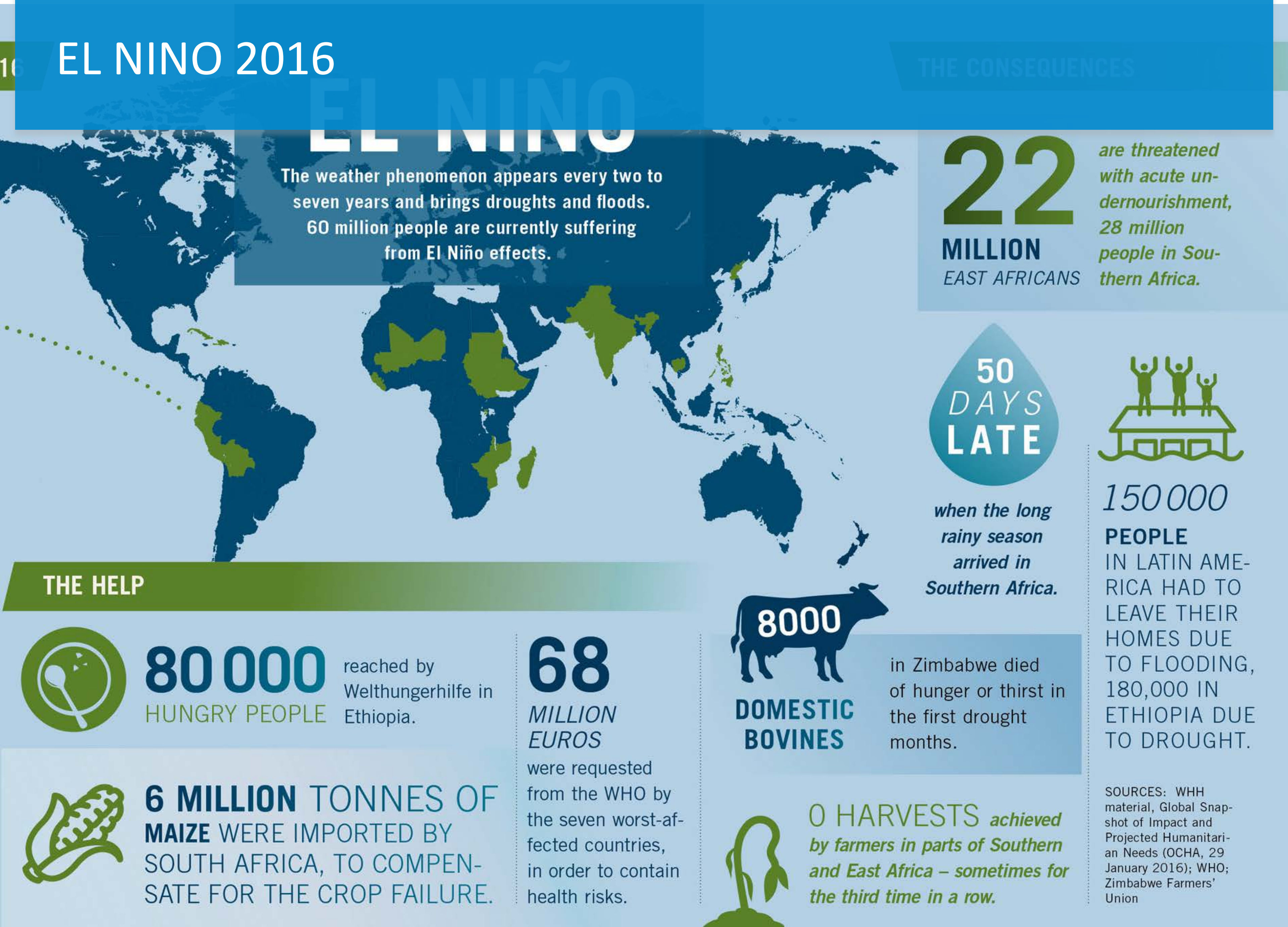
EL NINO 2015/2016: SOME RELIEF FOR CALIFORNIA …BUT RAIN-BRINGING STORMS NOT ENOUGH TO END DROUGHT

- El Nino brought some rains to California which suffered from multi-year drought, but less than expected (hoped for)
- Long-term warming (drying soils and melting snowcaps) also plays a role in Californian drought


A Record-Breaking Drought

41% of the state is facing “exceptional drought” (the most severe kind).

EL NINO 2016



EL NIÑO

The weather phenomenon appears every two to seven years and brings droughts and floods. 60 million people are currently suffering from El Niño effects.

THE CONSEQUENCES

22 MILLION *EAST AFRICANS* *are threatened with acute undernourishment, 28 million people in Southern Africa.*

50 *DAYS* **LATE** *when the long rainy season arrived in Southern Africa.*

150 000 **PEOPLE** IN LATIN AMERICA HAD TO LEAVE THEIR HOMES DUE TO FLOODING, 180,000 IN ETHIOPIA DUE TO DROUGHT.

8000 DOMESTIC BOVINES in Zimbabwe died of hunger or thirst in the first drought months.

0 HARVESTS *achieved by farmers in parts of Southern and East Africa – sometimes for the third time in a row.*

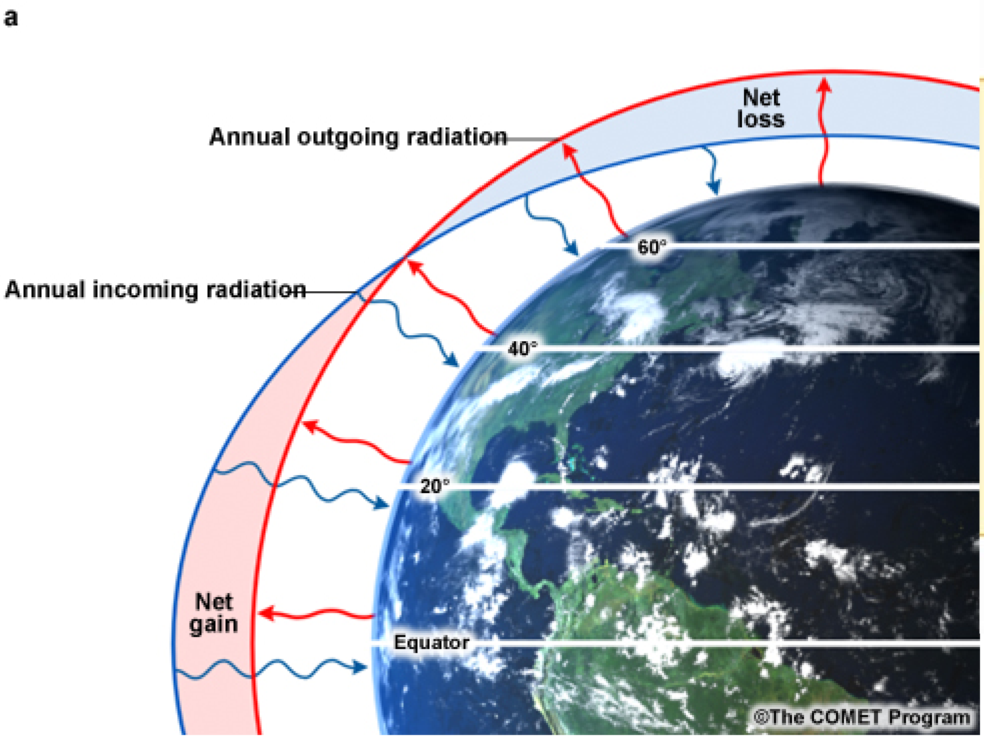
THE HELP

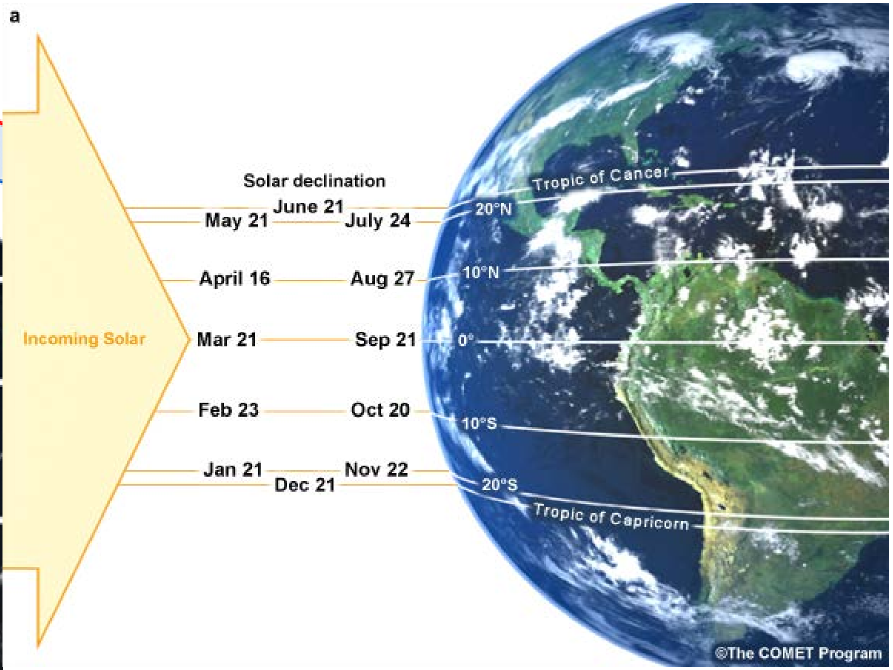
80 000 HUNGRY PEOPLE reached by Welthungerhilfe in Ethiopia.

6 MILLION TONNES OF **MAIZE** WERE IMPORTED BY SOUTH AFRICA, TO COMPENSATE FOR THE CROP FAILURE.

68 *MILLION EUROS* were requested from the WHO by the seven worst-affected countries, in order to contain health risks.

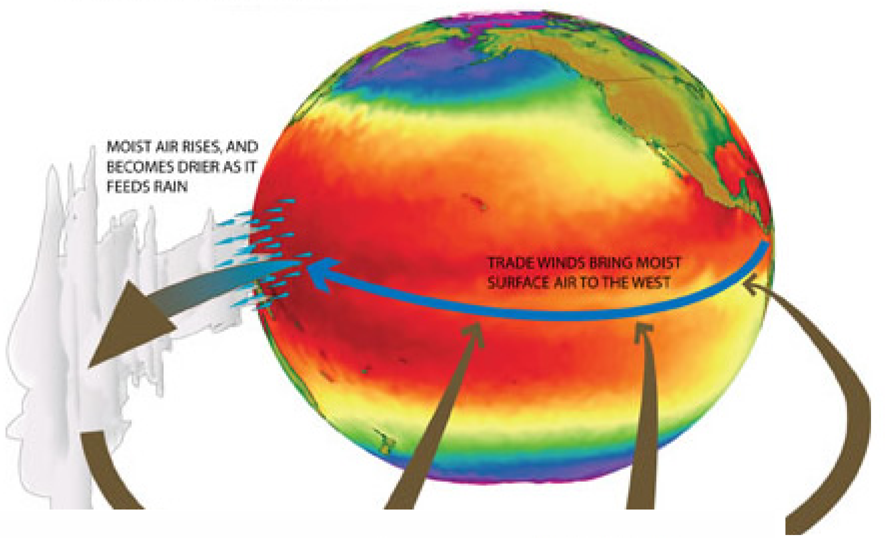
SOURCES: WHH material, Global Snapshot of Impact and Projected Humanitarian Needs (OCHA, 29 January 2016); WHO; Zimbabwe Farmers' Union

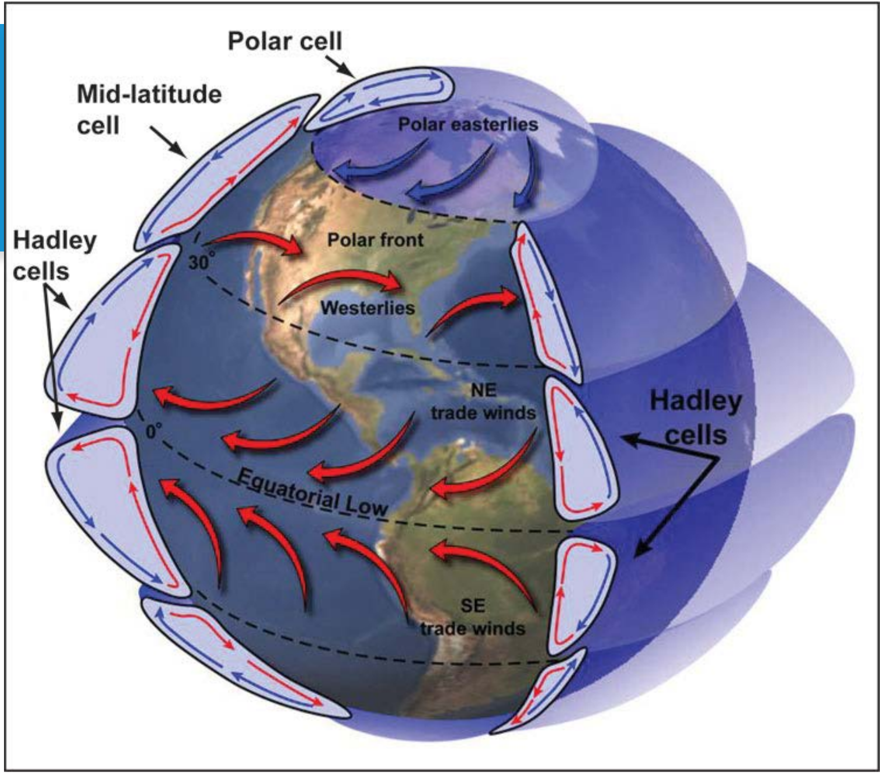

a
Annual outgoing radiation
Net loss
Annual incoming radiation
60°
40°
20°
Equator
Net gain
©The COMET Program

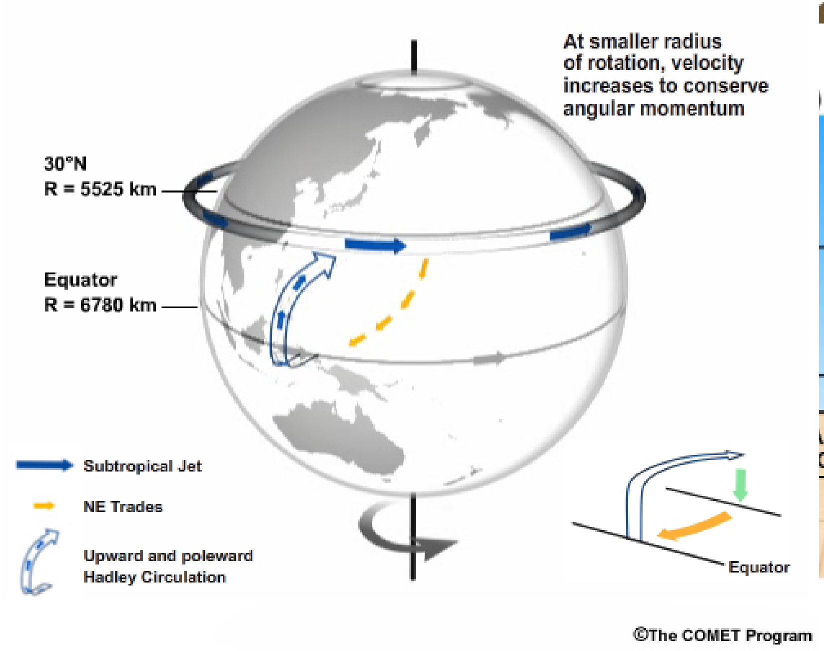

a
Incoming Solar
Solar declination
June 21
May 21
July 24
April 16
Aug 27
Mar 21
Sep 21
Feb 23
Oct 20
Jan 21
Nov 22
Dec 21
Tropic of Cancer
20°N
10°N
0°
10°S
20°S
Tropic of Capricorn
©The COMET Program

HADLEY-WALKER CIRCULATION

Pacific Walker Circulation







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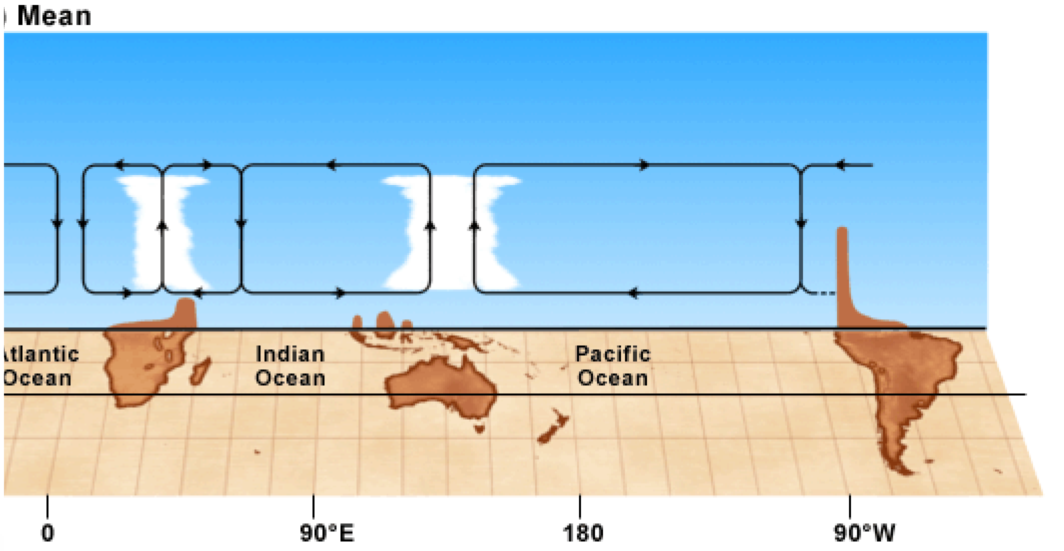
Global Walker Circulation



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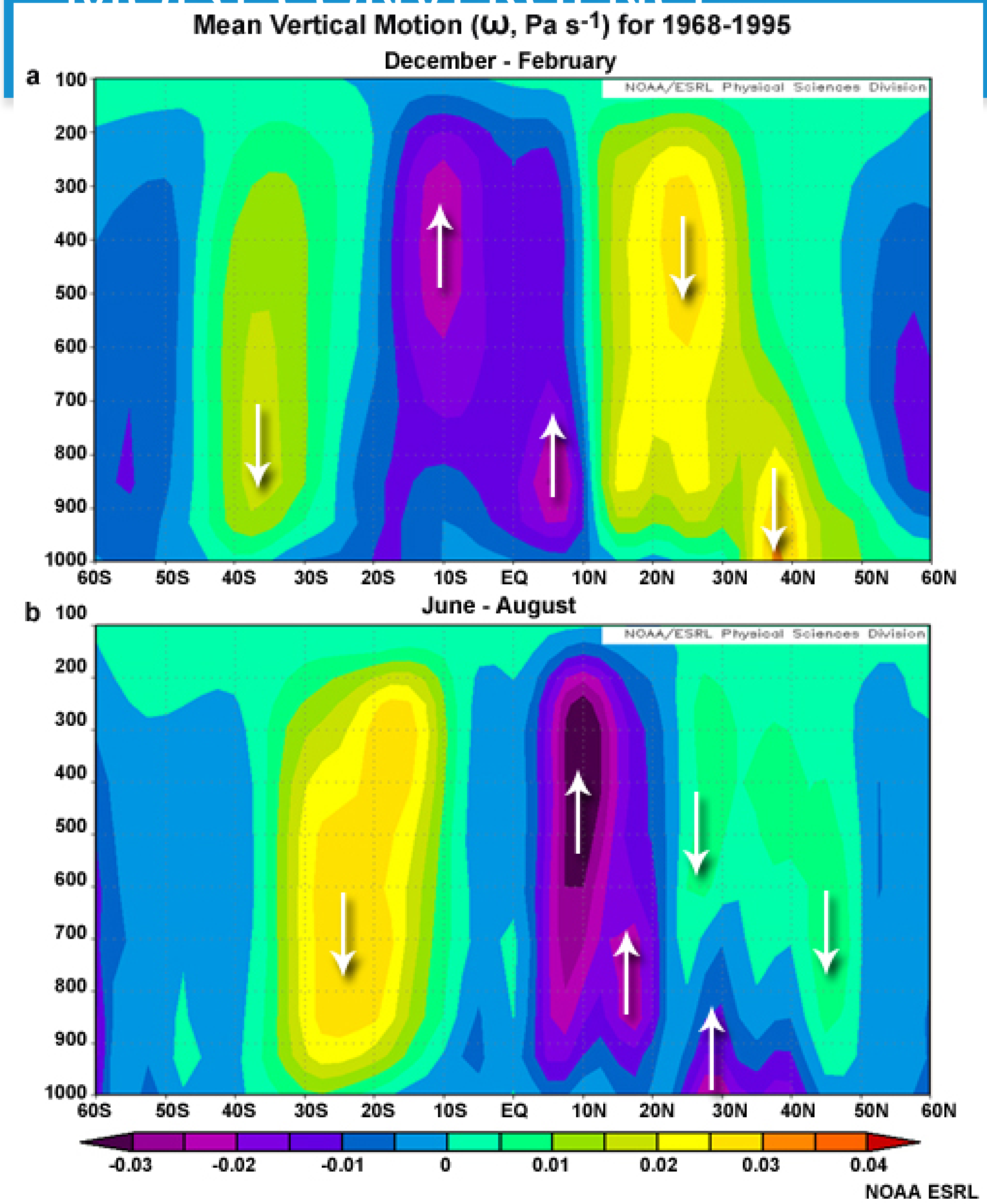
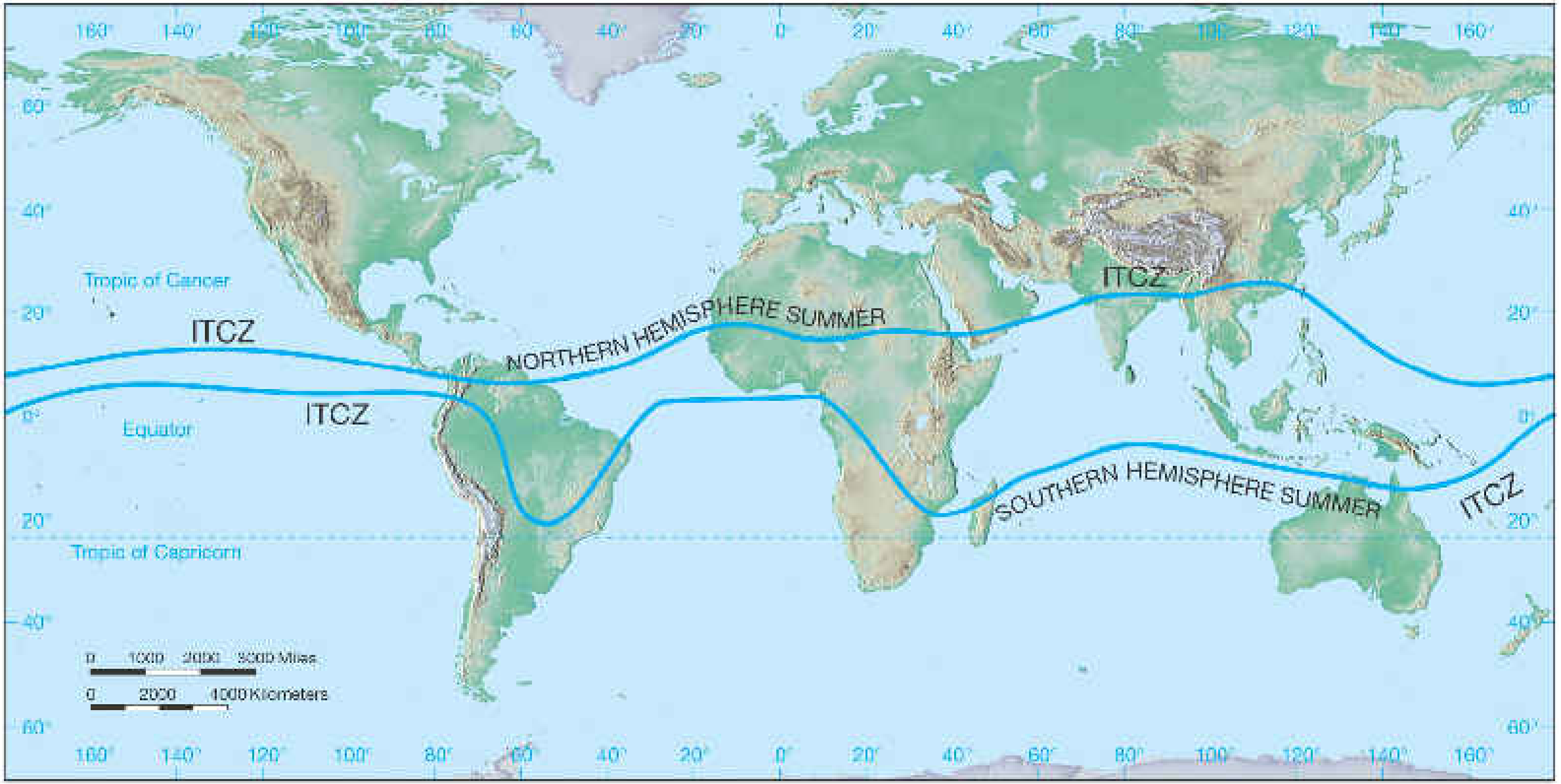
MOIST CONVERGENCE

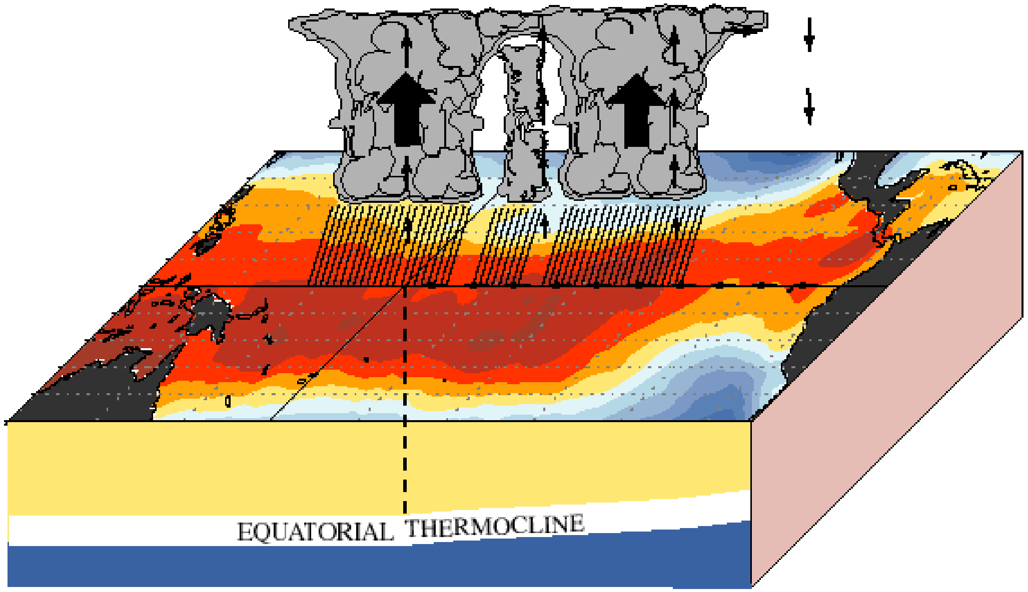


ITCZ

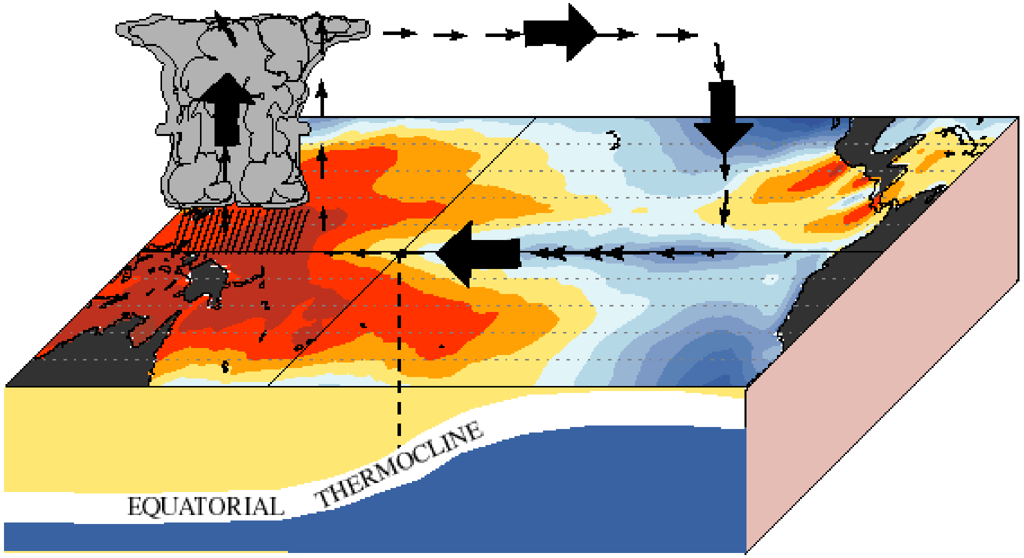

Tropic of Cancer
Equator
Tropic of Capricorn
ITCZ
NORTHERN HEMISPHERE SUMMER
SOUTHERN HEMISPHERE SUMMER
ITCZ
ITCZ
ITCZ
0 1000 2000 3000 Miles
0 2000 4000 Kilometers
160° 140° 120° 100° 80° 60° 40° 20° 0° 20° 40° 60° 80° 100° 120° 140° 160°
60° 40° 20° 0° 20° 40° 60°

EL NINO – LA NINA

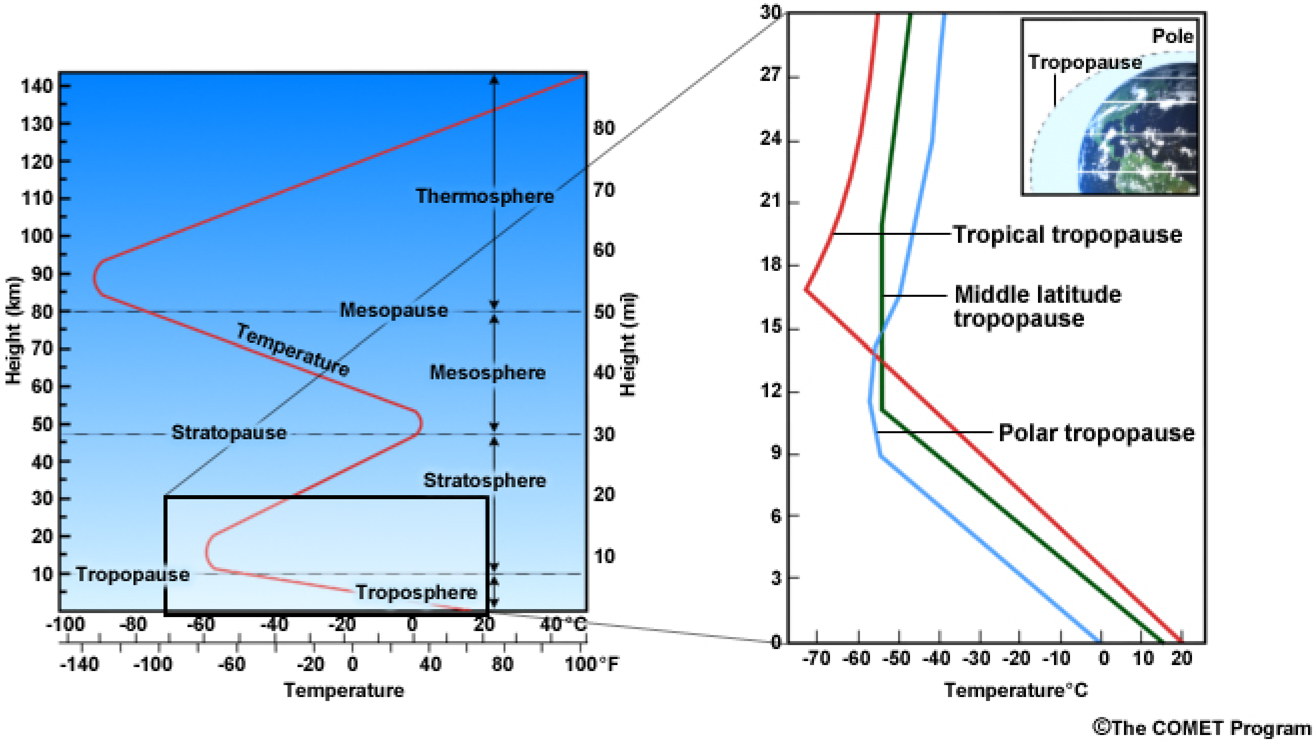
December - February El Niño Conditions



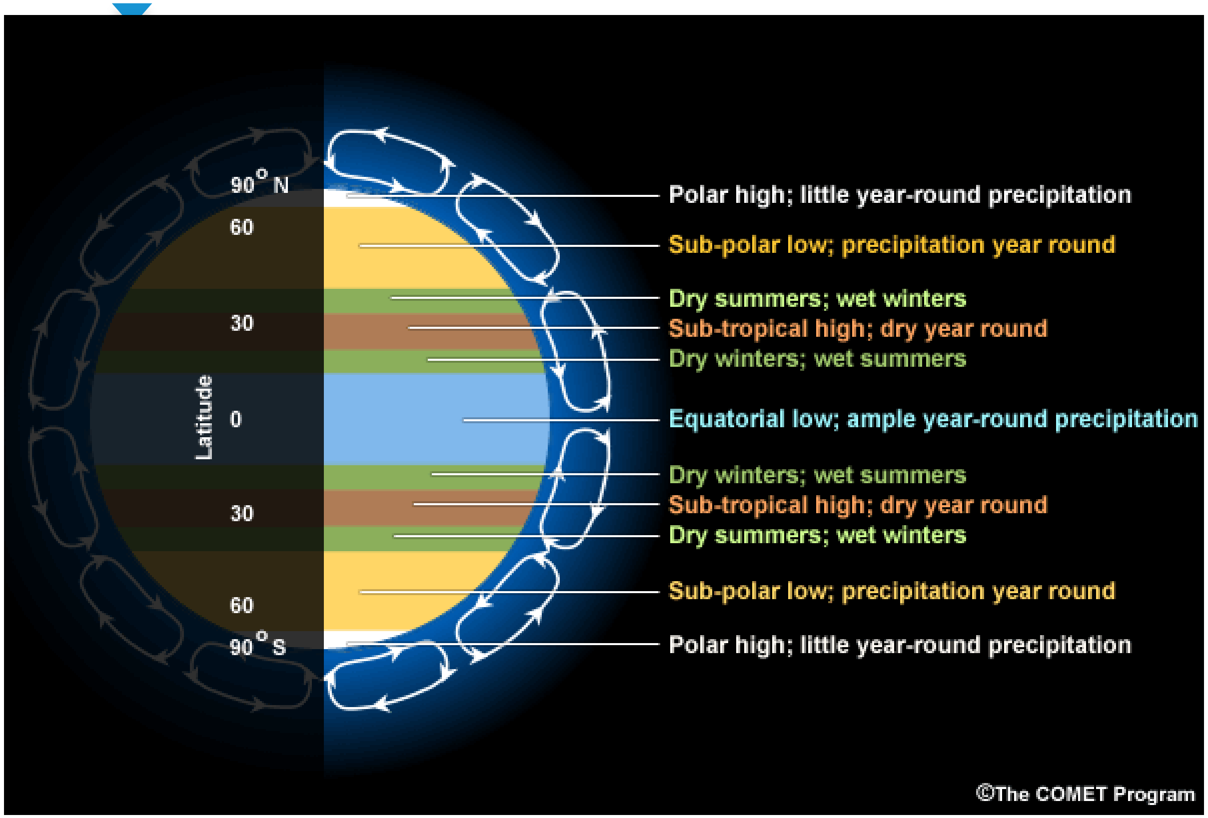
December - February La Niña Conditions



VERTICAL STRUCTURE



THE GENERAL CIRCULATION OF THE ATMOSPHERE



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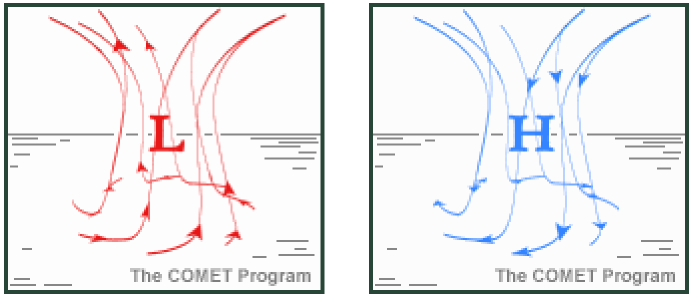
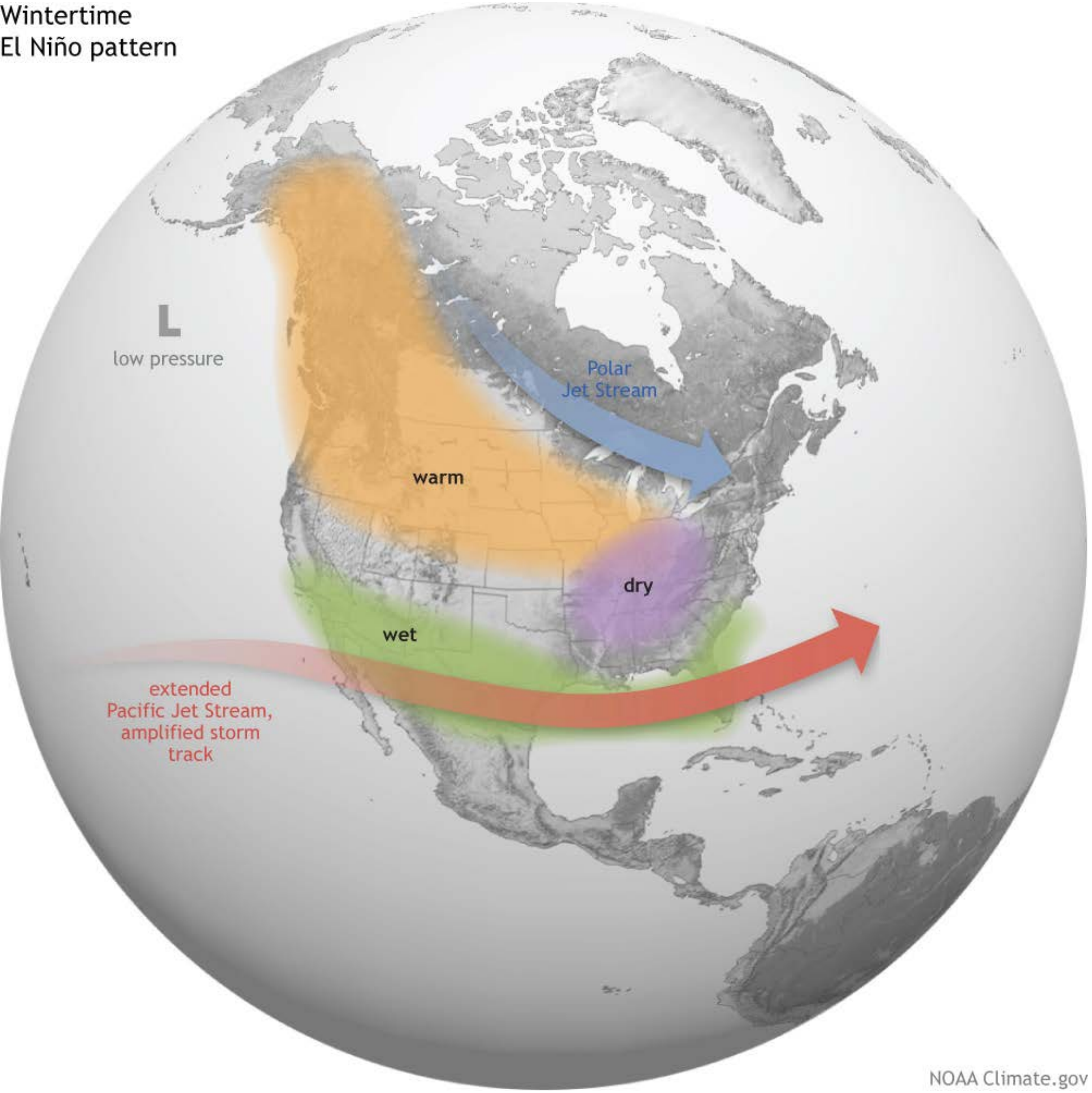
THE GENERAL CIRCULATION OF THE ATMOSPHERE

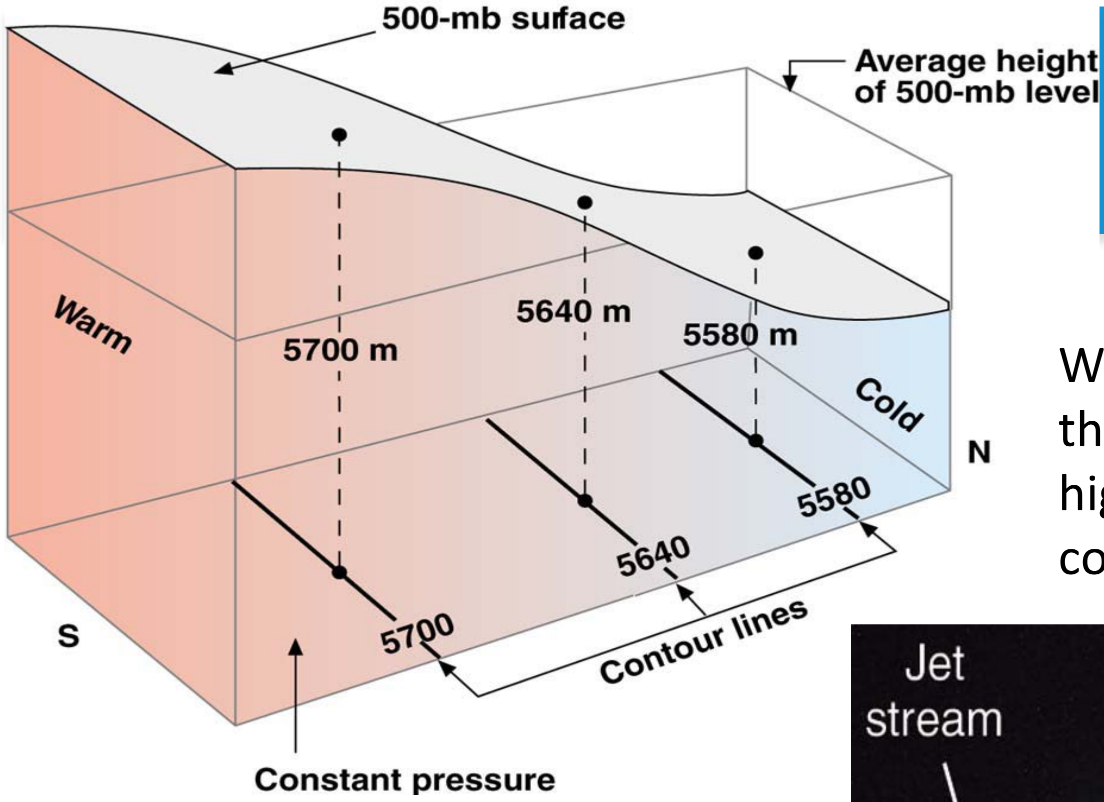


Schematic of 3-D flow in low and high pressure systems in the Northern Hemisphere

THE GENERAL CIRCULATION OF THE ATMOSPHERE



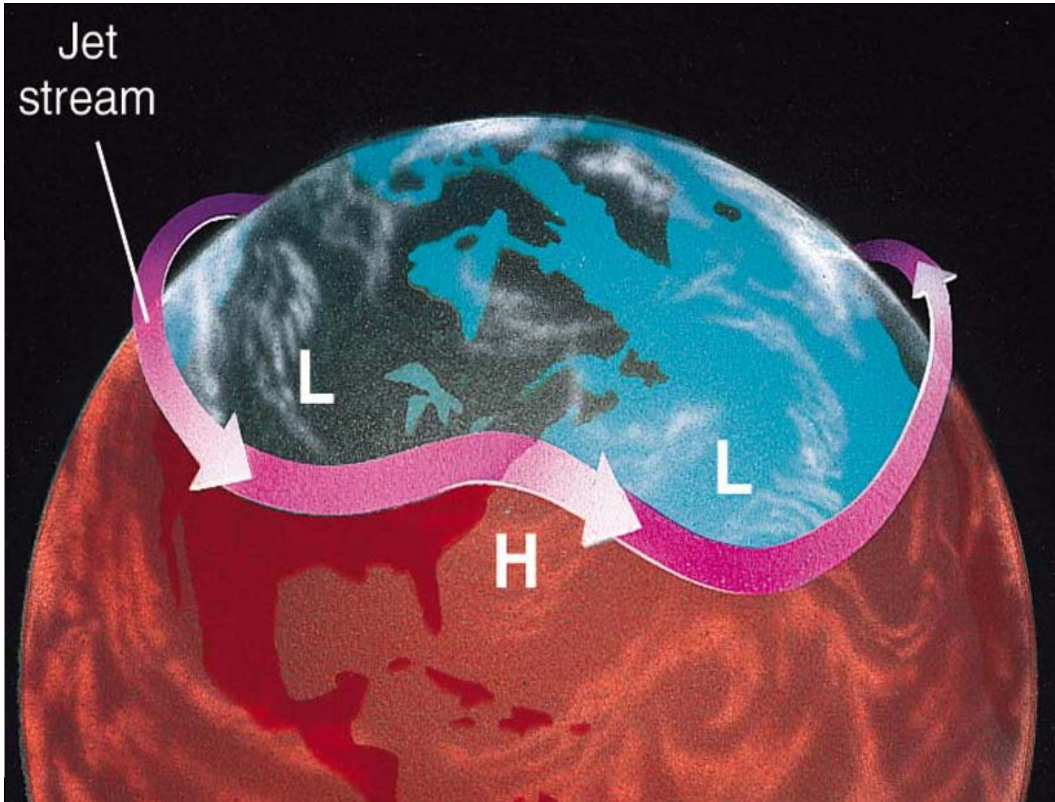
UPPER TROPOSPHERE: WESTERLIES



Warmer tropical air expands and thus the same pressure level is found at higher altitudes in the tropics compared to poles

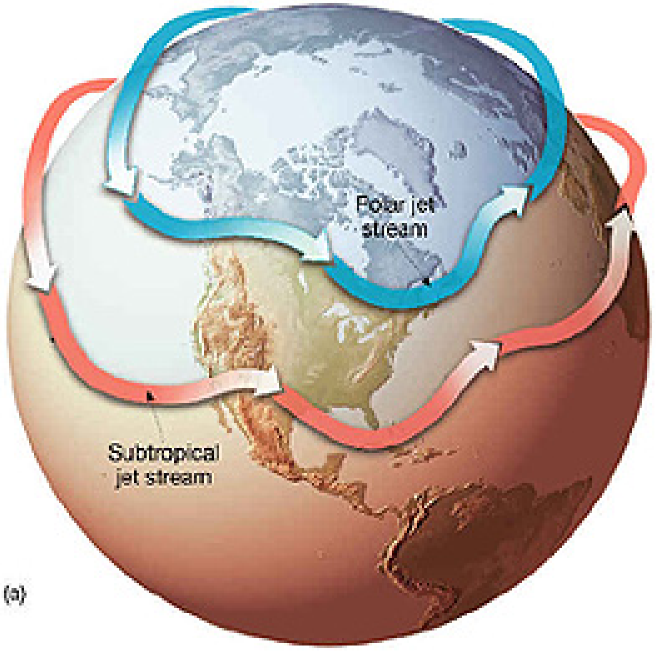
This pressure gradient drives winds which become westerlies due to Coriolis effect

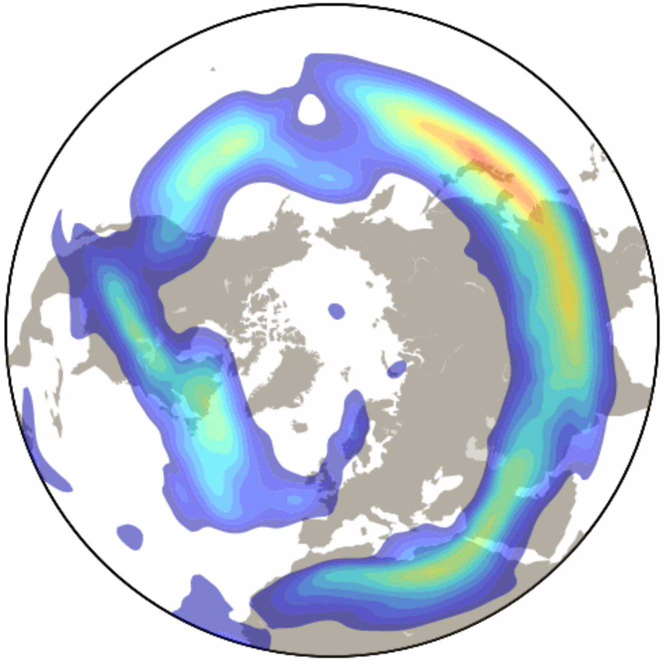
Strongest winds form at strong pressure gradients, and thus strong temperature gradients
→ Jet streams



THERMAL & EDDY-DRIVEN JETS

- Sub-tropical jet: Thermally driven / momentum conservation of Hadley circulation
- Polar jet: Eddy momentum fluxes strengthen jet. Strong 2-way interaction between jet and storm track
- Idealized! Jets merge and separate continuously

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