Earth's Weather and Climate

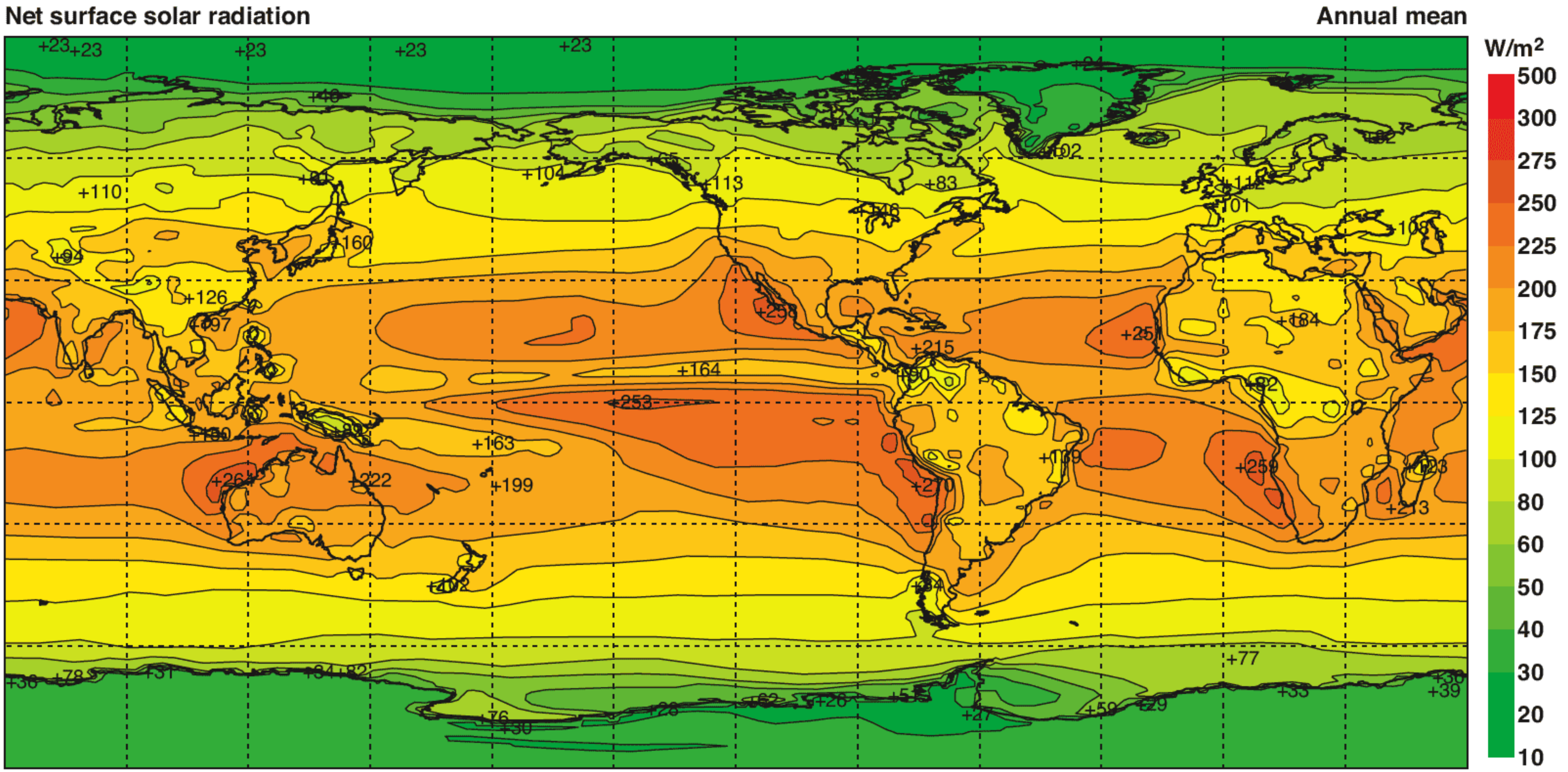
Fundamental controls and processes

GEOL-412 – Climate Change

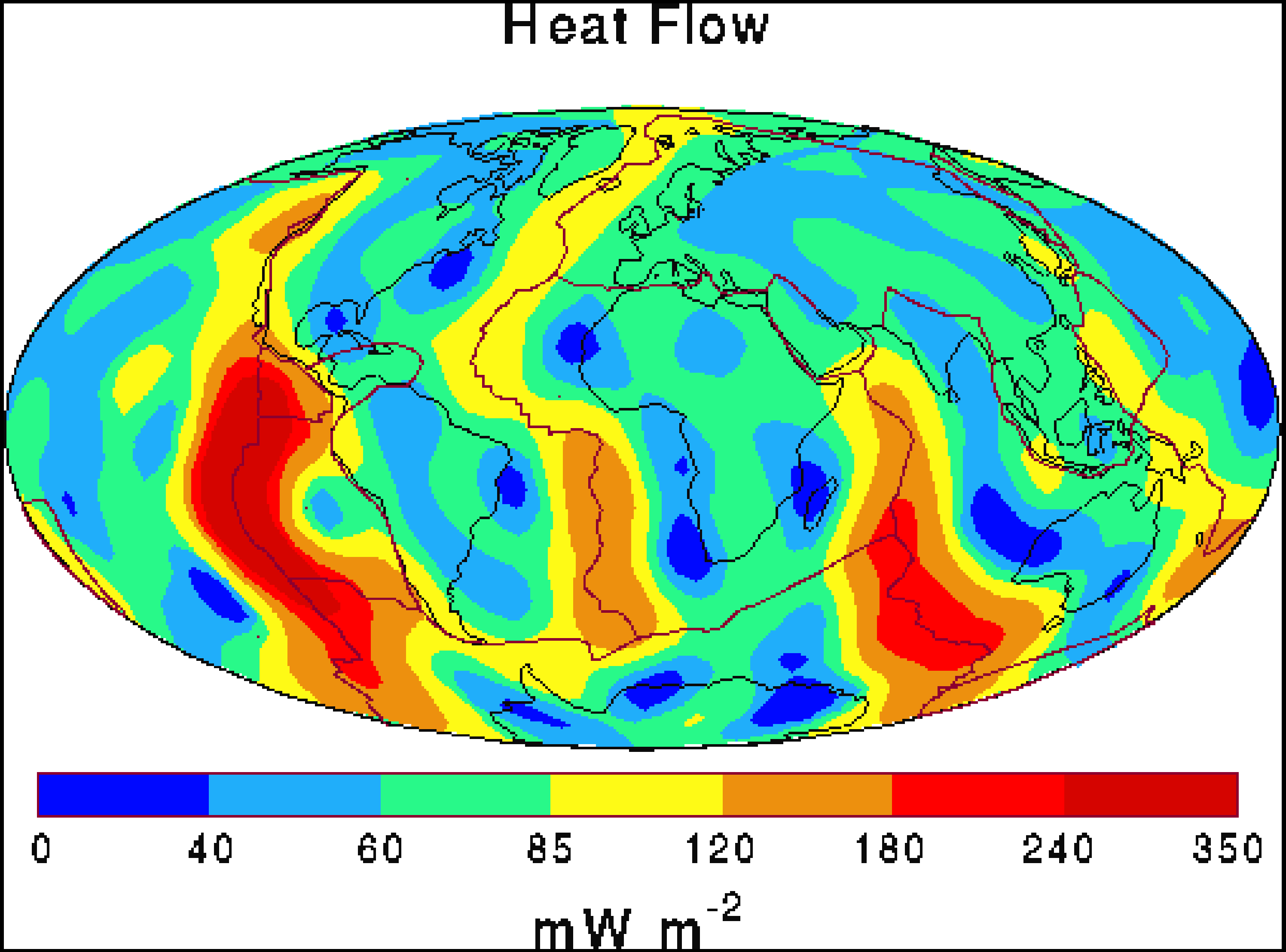
Important factors controlling the Earth's Weather and Climate

- Solar radiation
- Characteristics of the atmosphere
- Differential heating between tropical and temperate regions
- Convection systems in the atmosphere
- Jet streams
- Albedo and heat capacity
- Monsoons
- Ocean currents
- Thermohaline circulation
- ENSO and PDO
- Greenhouse effect

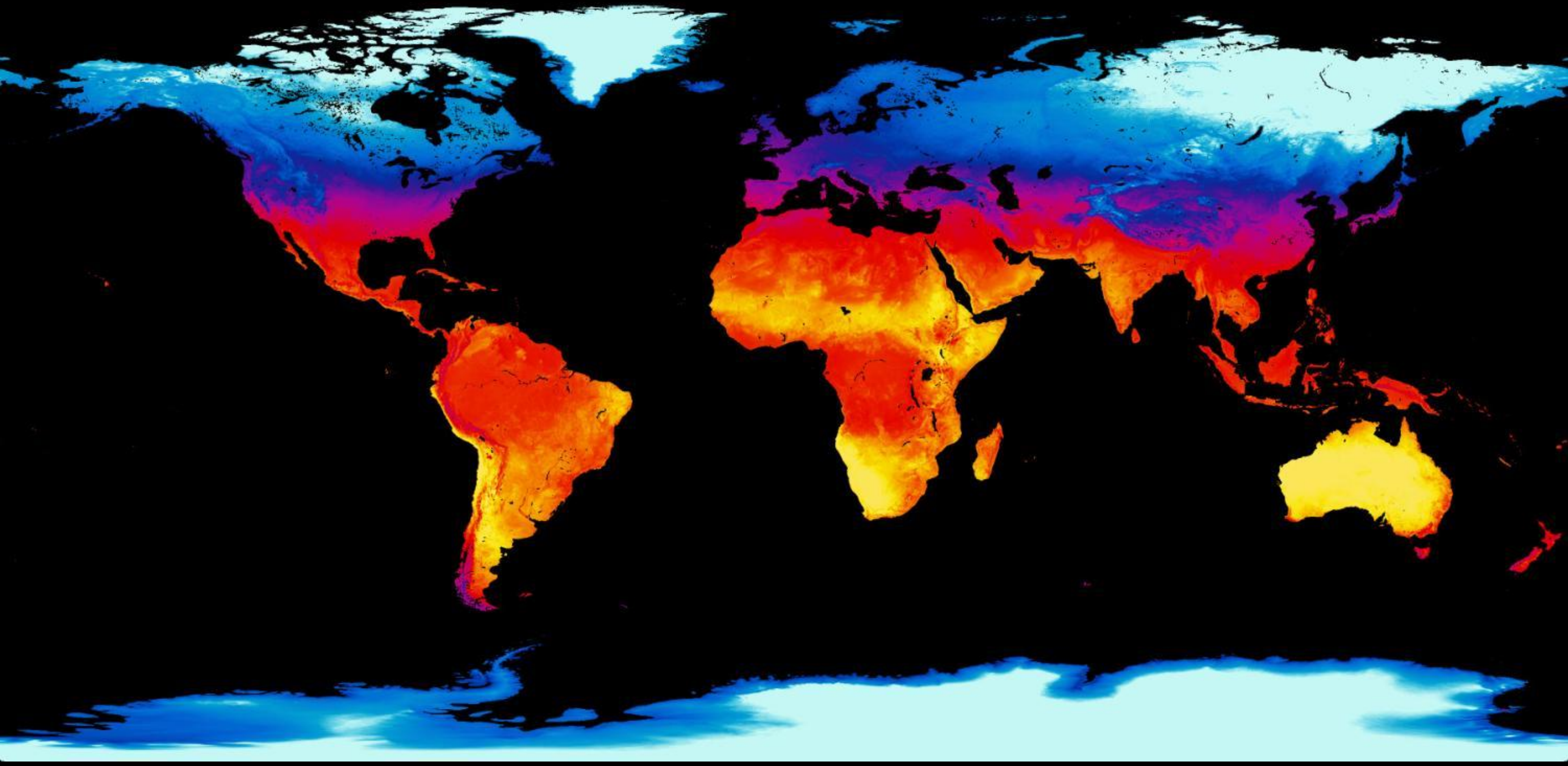
Net solar radiation at surface (W/m^2)



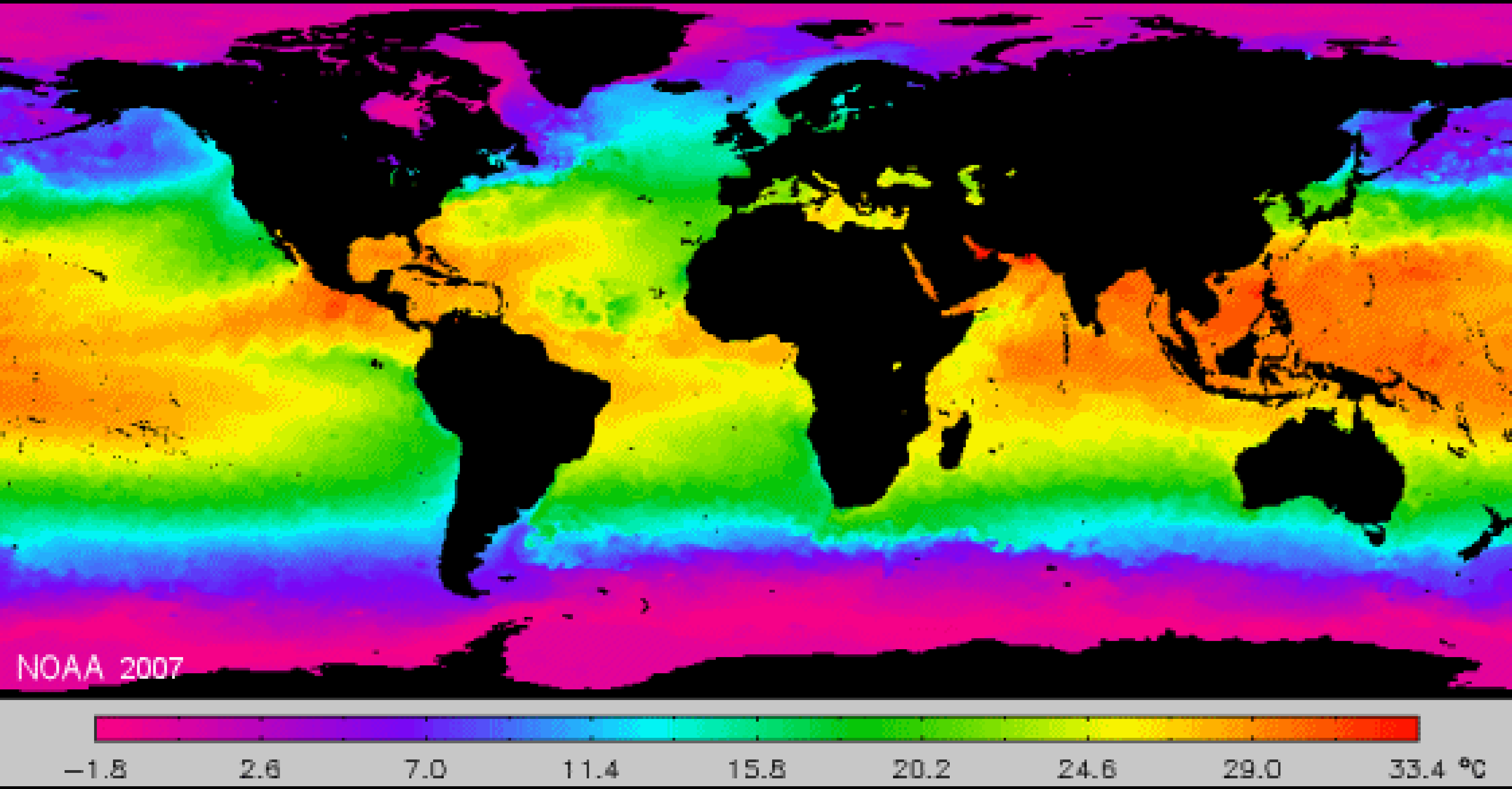
Net geothermal heat flow at surface (mW/m^2)



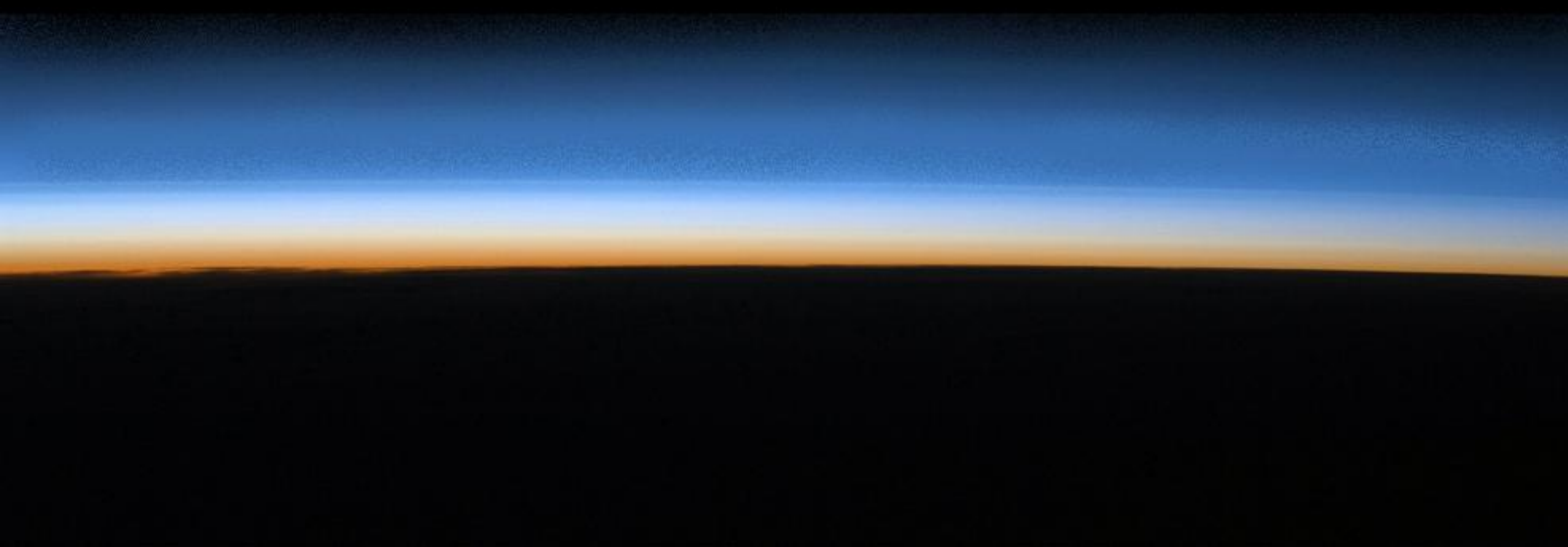
Land-surface temperatures

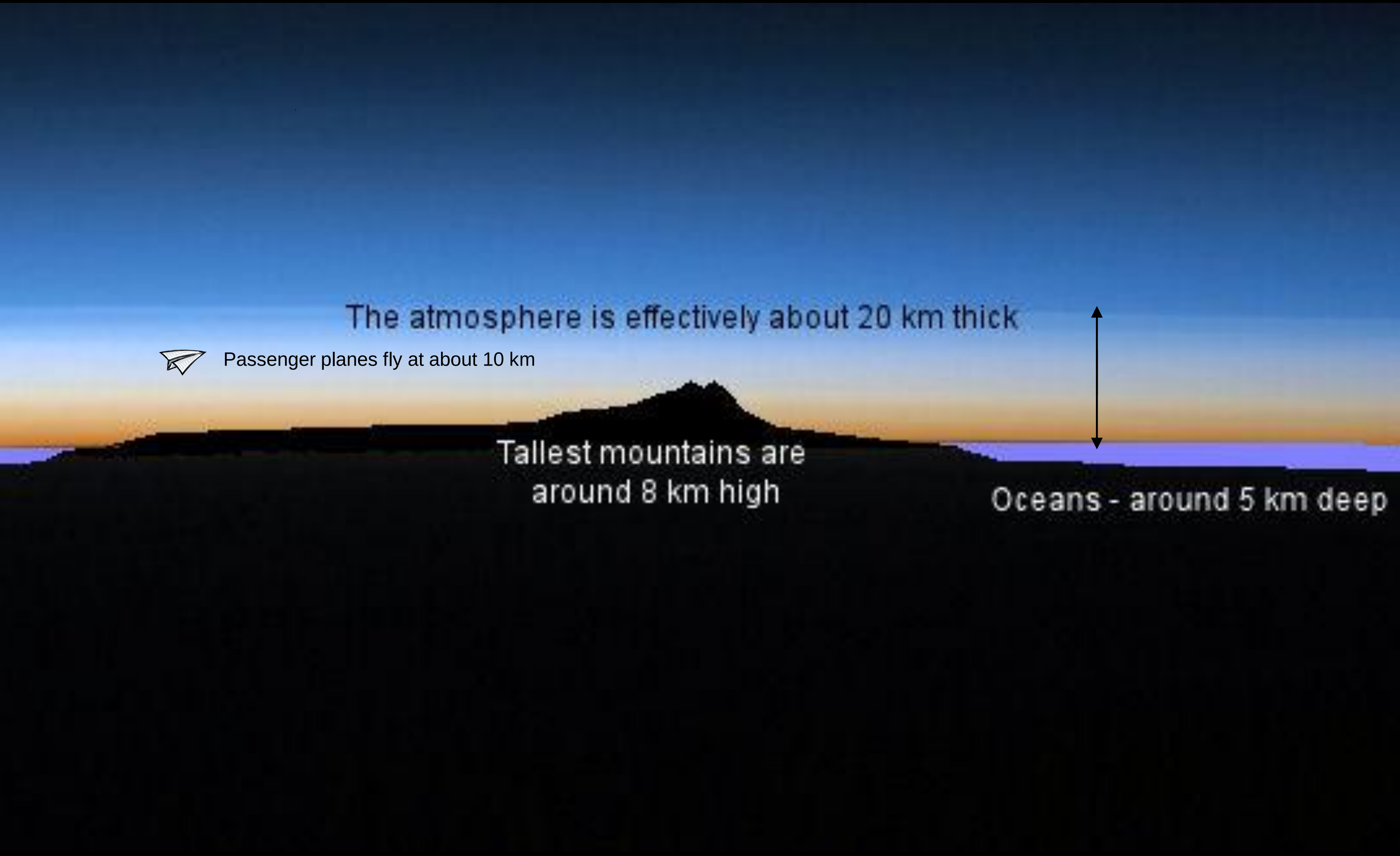


Sea-surface temperatures (SSTs)

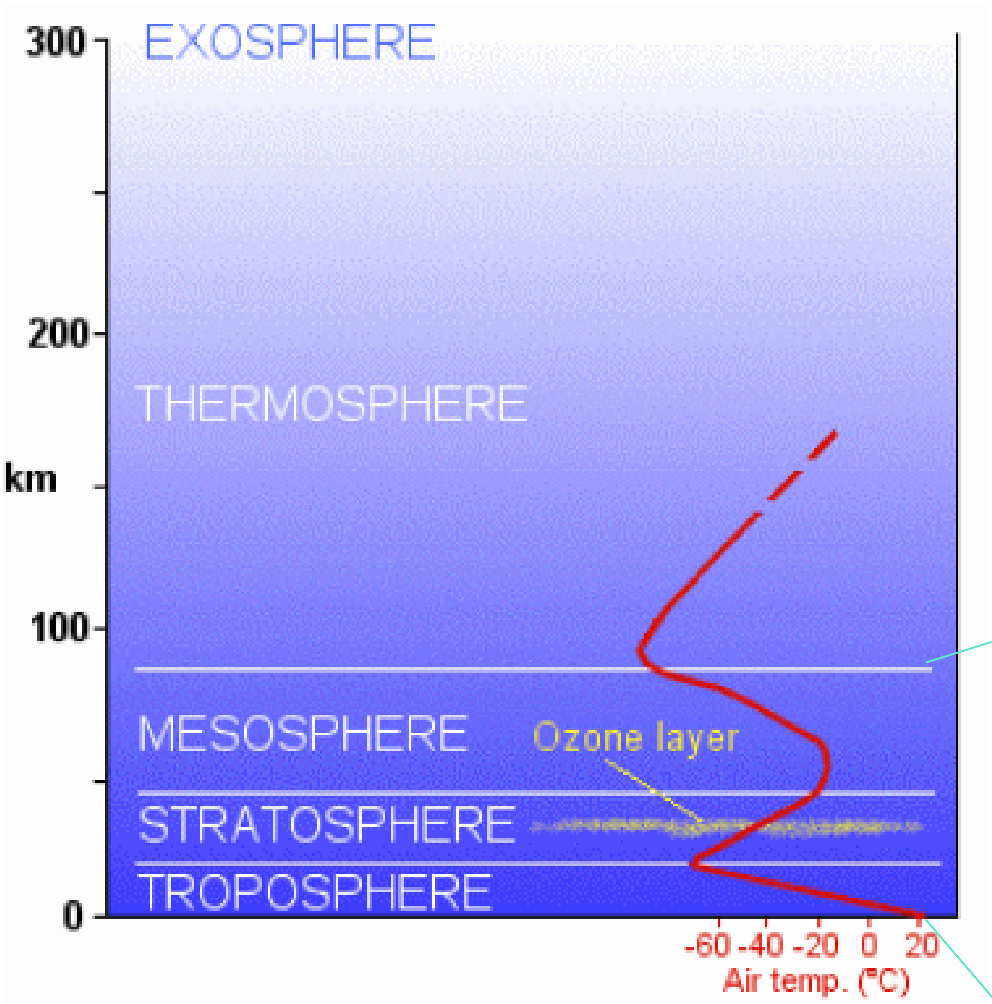


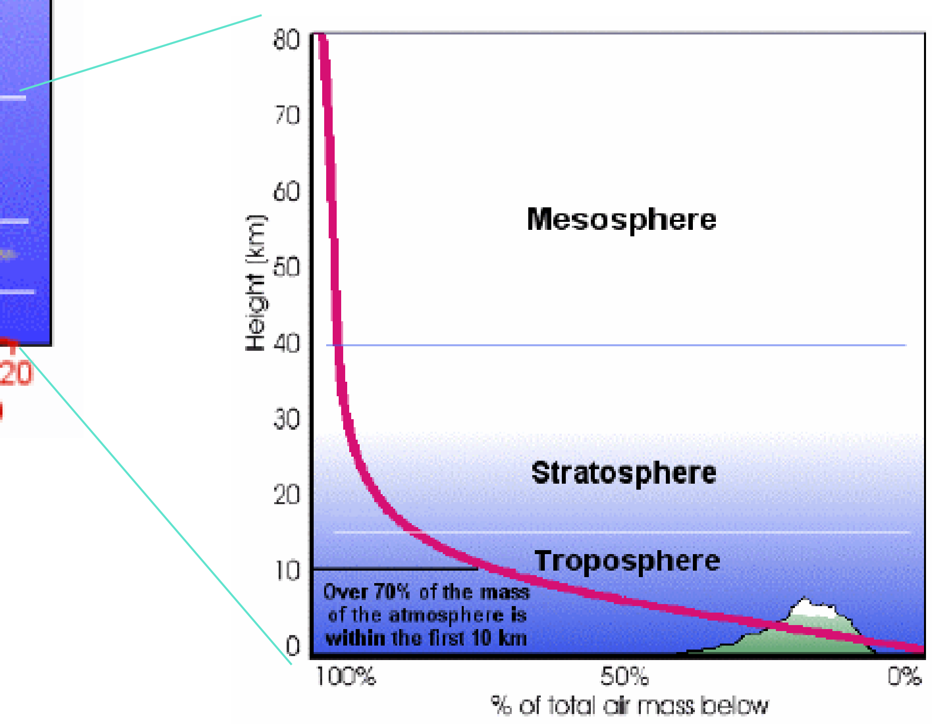
Significance of the atmosphere



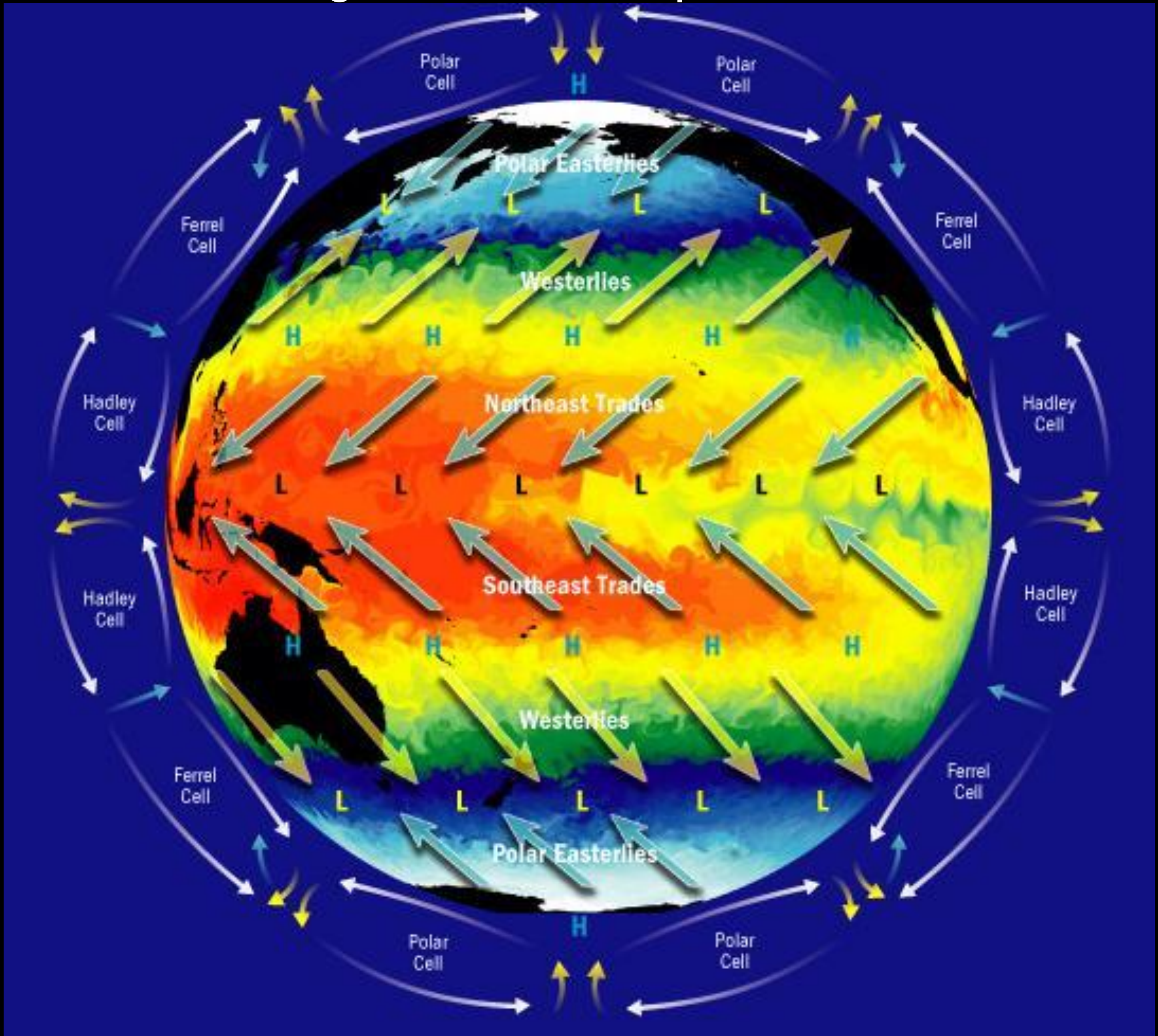

The atmosphere is effectively about 20 km thick
Passenger planes fly at about 10 km
Tallest mountains are
around 8 km high
Oceans - around 5 km deep

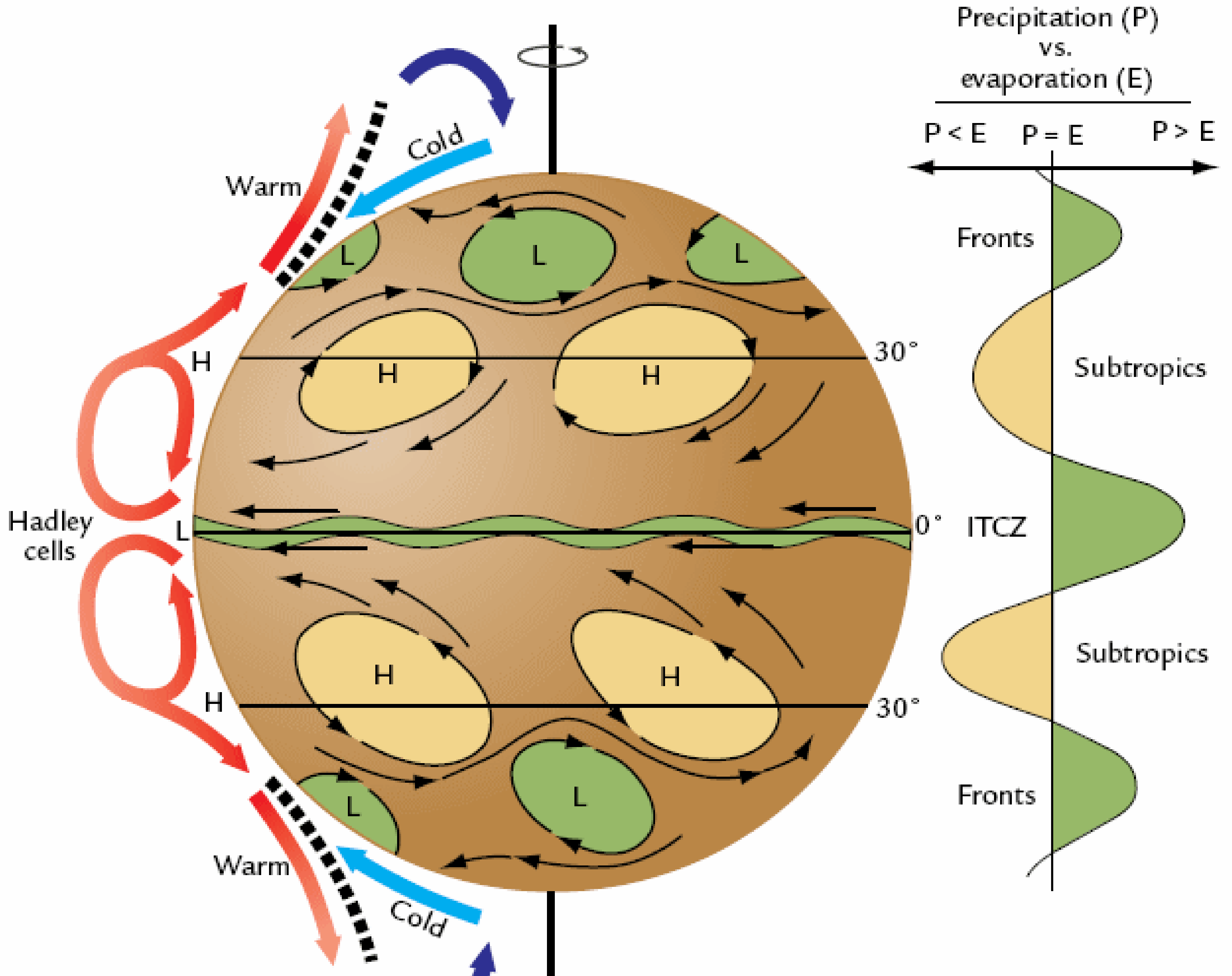
Layers of the atmosphere



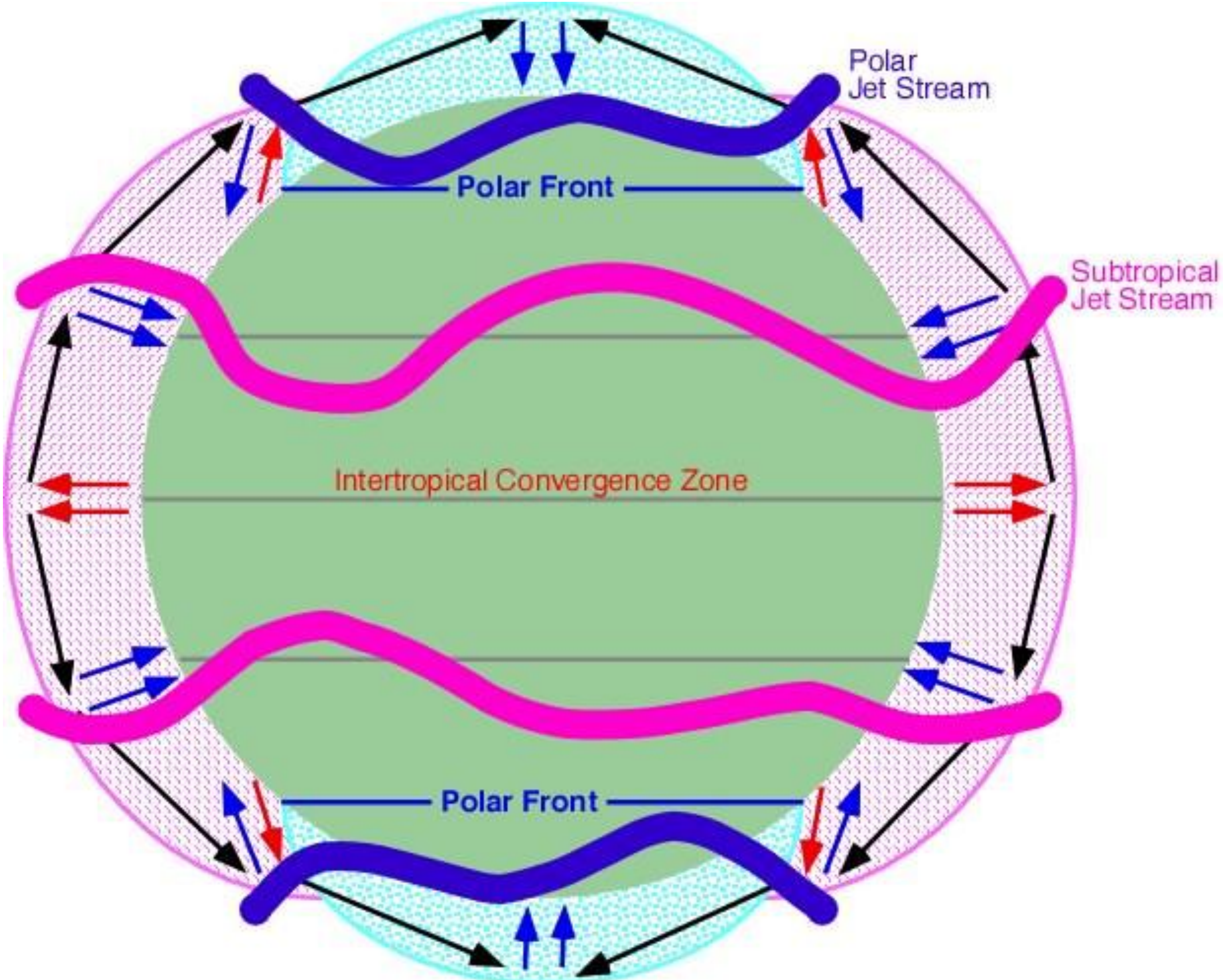


Differential heating of tropical versus temperate regions leads to large-scale atmospheric convection



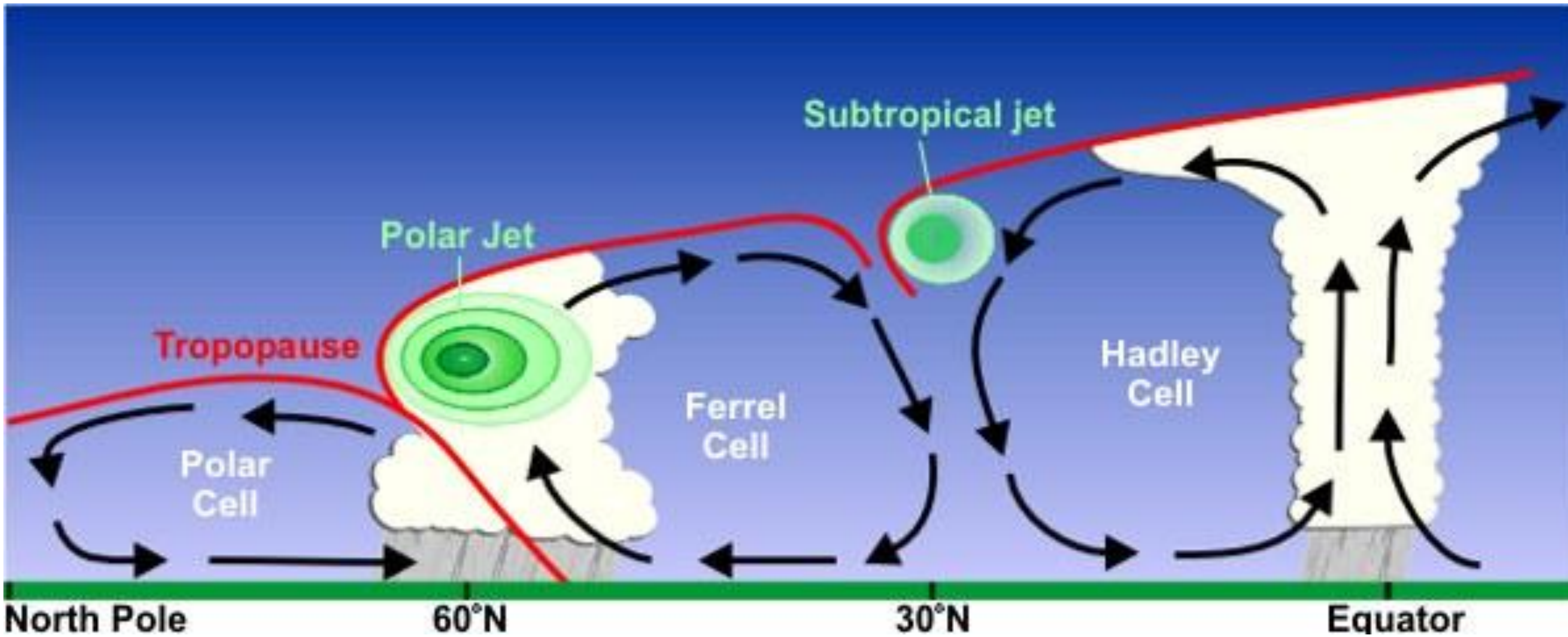


Ruddiman, 1st Ed.



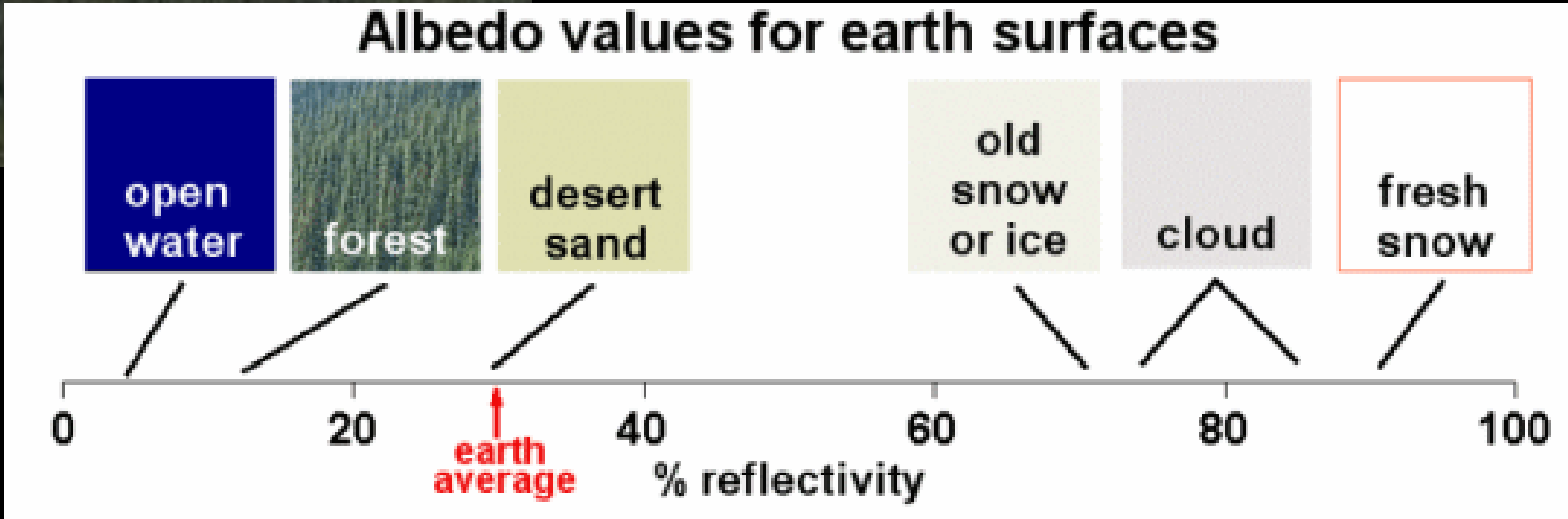
M. Pidwirny, UBC-O

Jet Streams



NOAA

Albedo – the reflectivity of a surface



Heat capacity

Can also be expressed in calories per gram per degree –

cal/g/˚C or cal g^{-1} $˚C^{-1}$

Substance	Heat capacity ($J\ g^{-1}\ K^{-1}$)	Substance	Heat capacity ($J\ g^{-1}\ K^{-1}$)
Water	4.18	Granite	0.79

Substance	Heat capacity ($cal\ g^{-1}\ ˚C^{-1}$)	Substance	Heat capacity ($cal\ g^{-1}\ ˚C^{-1}$)
Water	1.00	Granite	0.19

Heat capacity

$$q = m\, C\, \Delta T$$

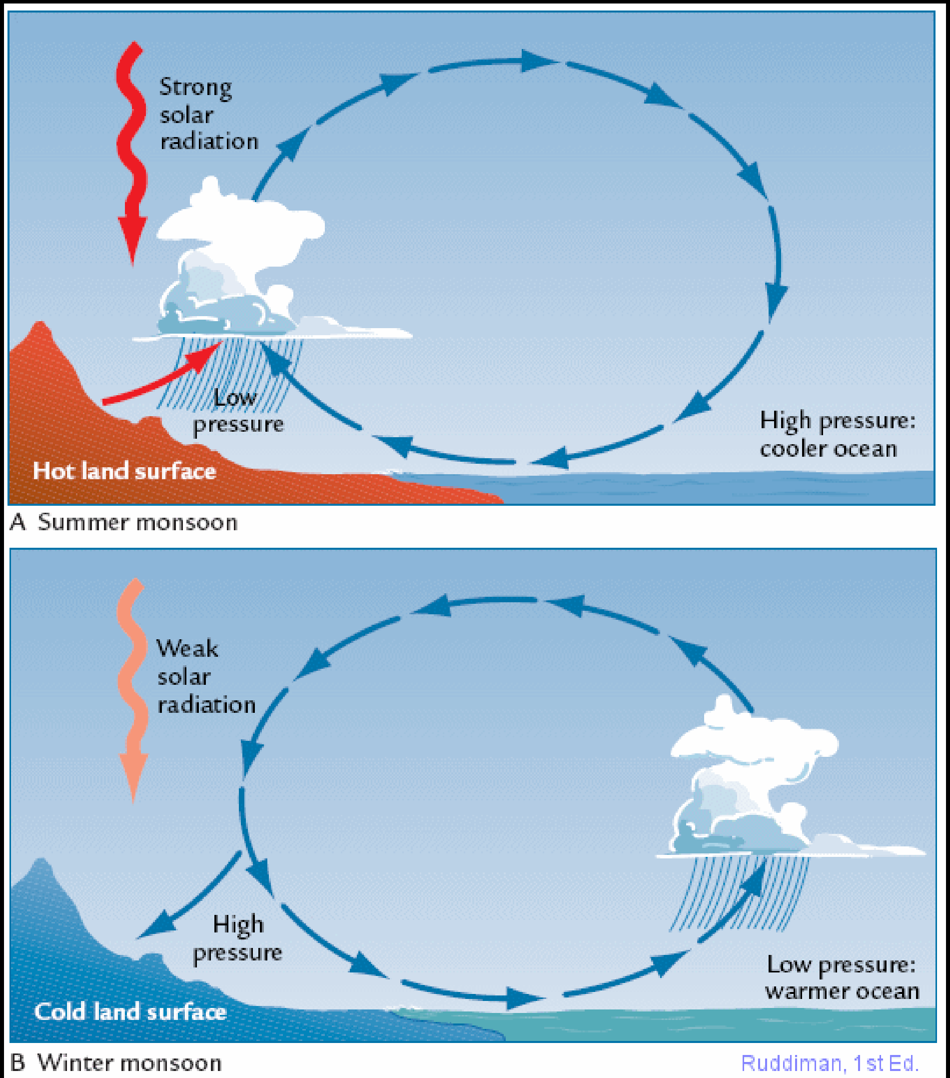
or

$$\Delta T = q/(m\, C)$$

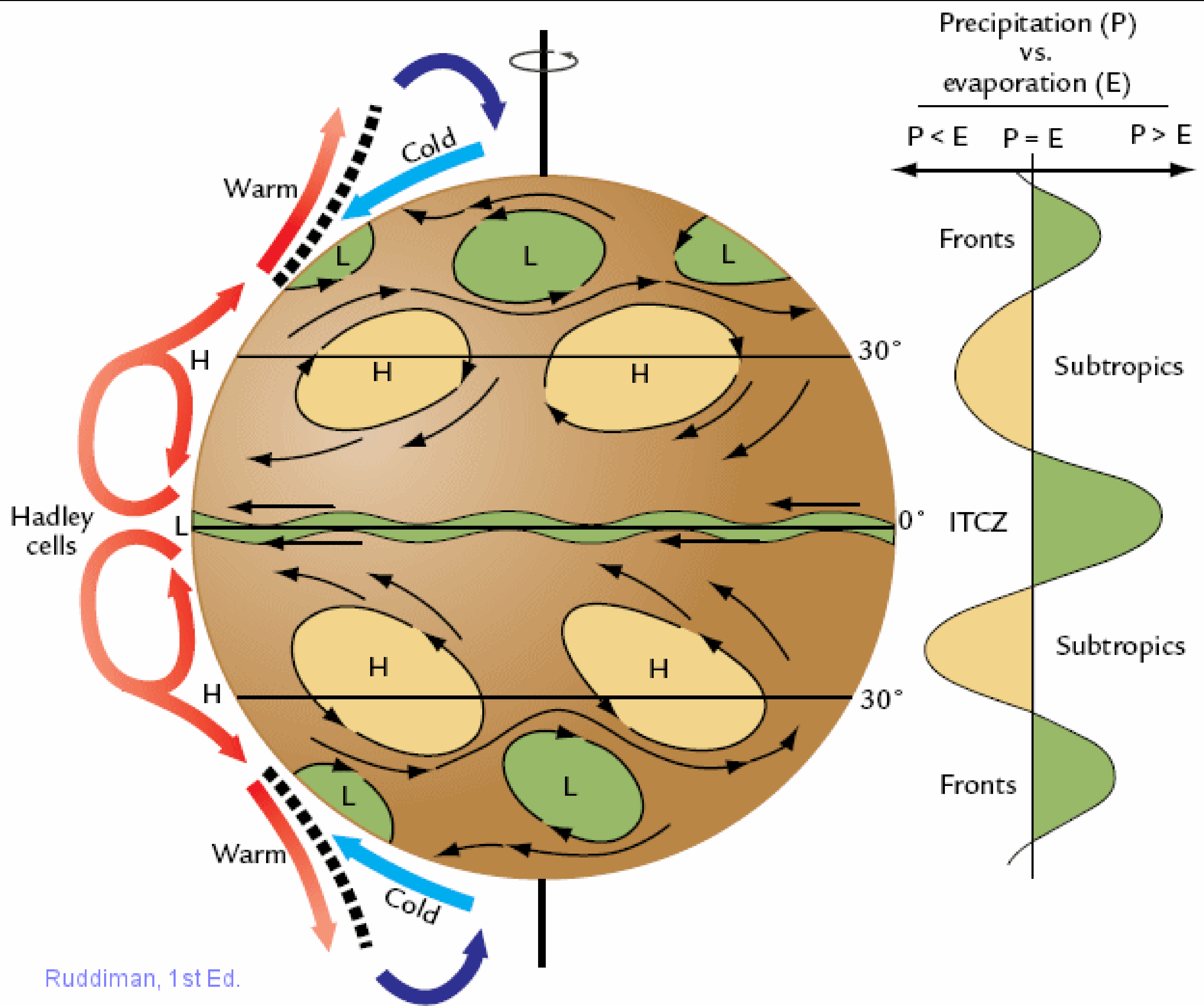
where q is the heat energy (cal), m is the mass (g), C is the heat capacity (cal g^{-1} C^{-1}) and ΔT is the change in temperature (ºC)

Substance	Heat capacity (cal g^{-1} C^{-1})	ΔT (ºC) with addition of 1000 calories	q (energy, cal) required to increase T by 2º C
Water (1000 g)	1.00	1	2000
Granite (1000 g)	0.19	5.26	380
Air (1000 g)	0.24	4.17	520

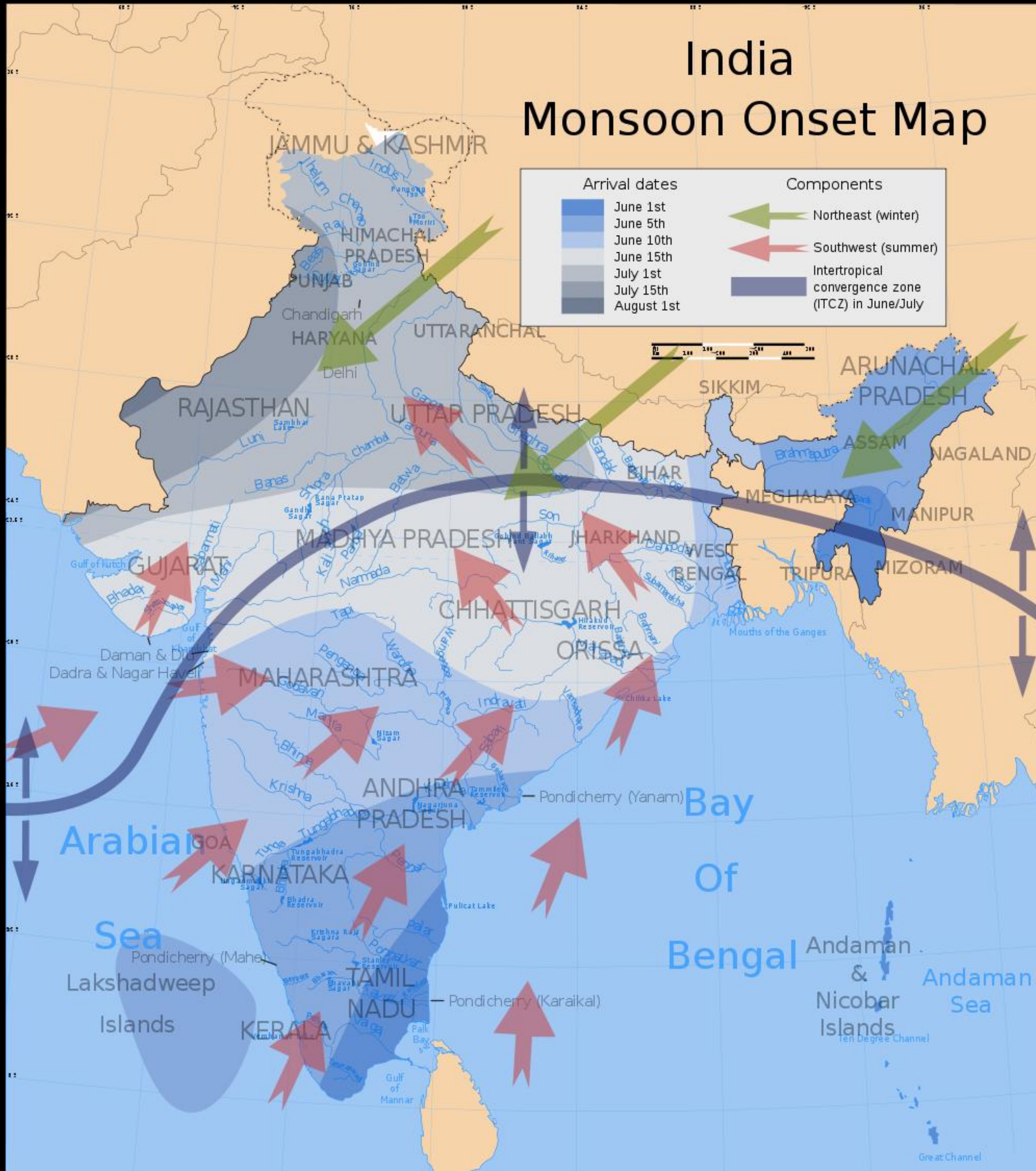
Monsoons



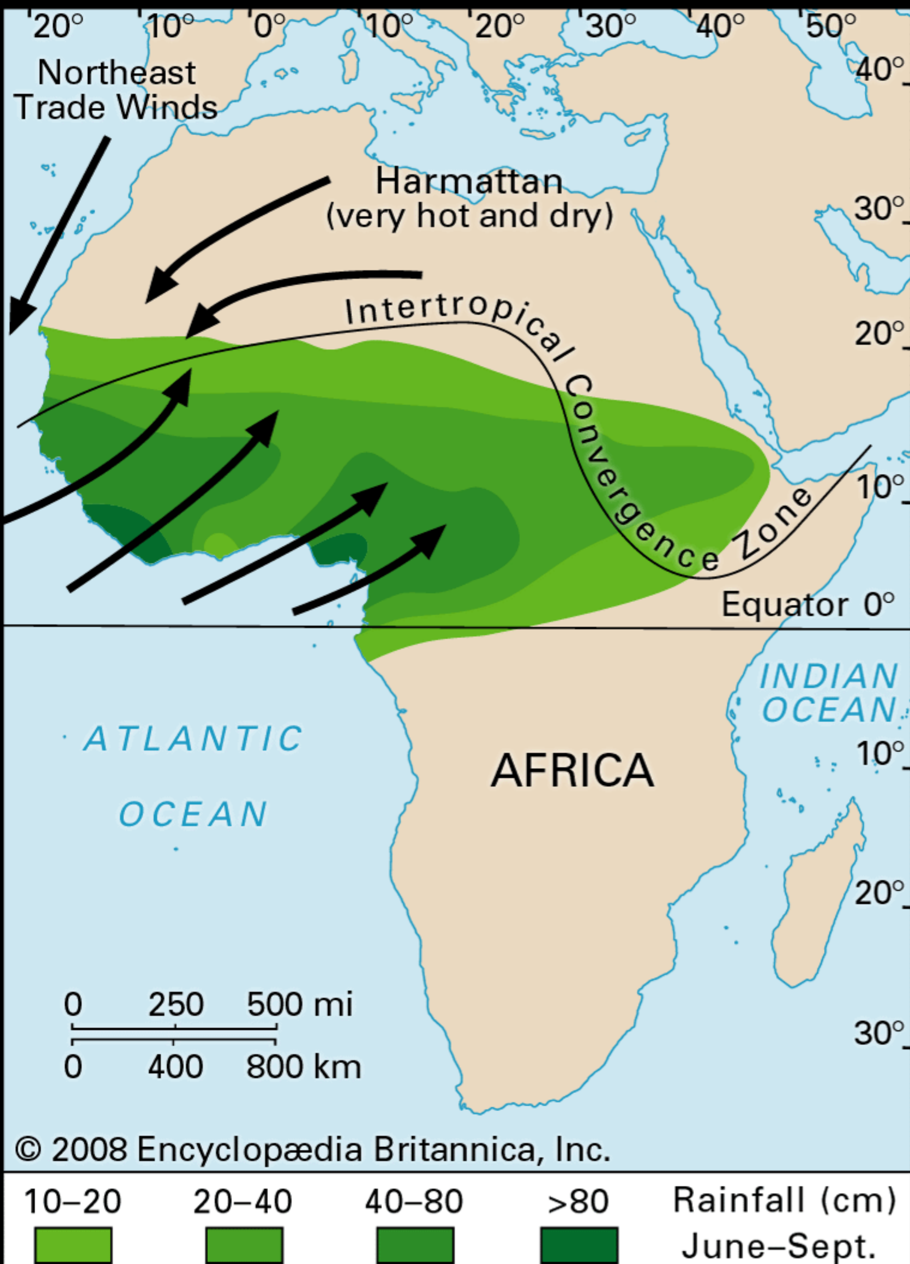
(see pages 138/9 in Ruddiman for more on monsoons)

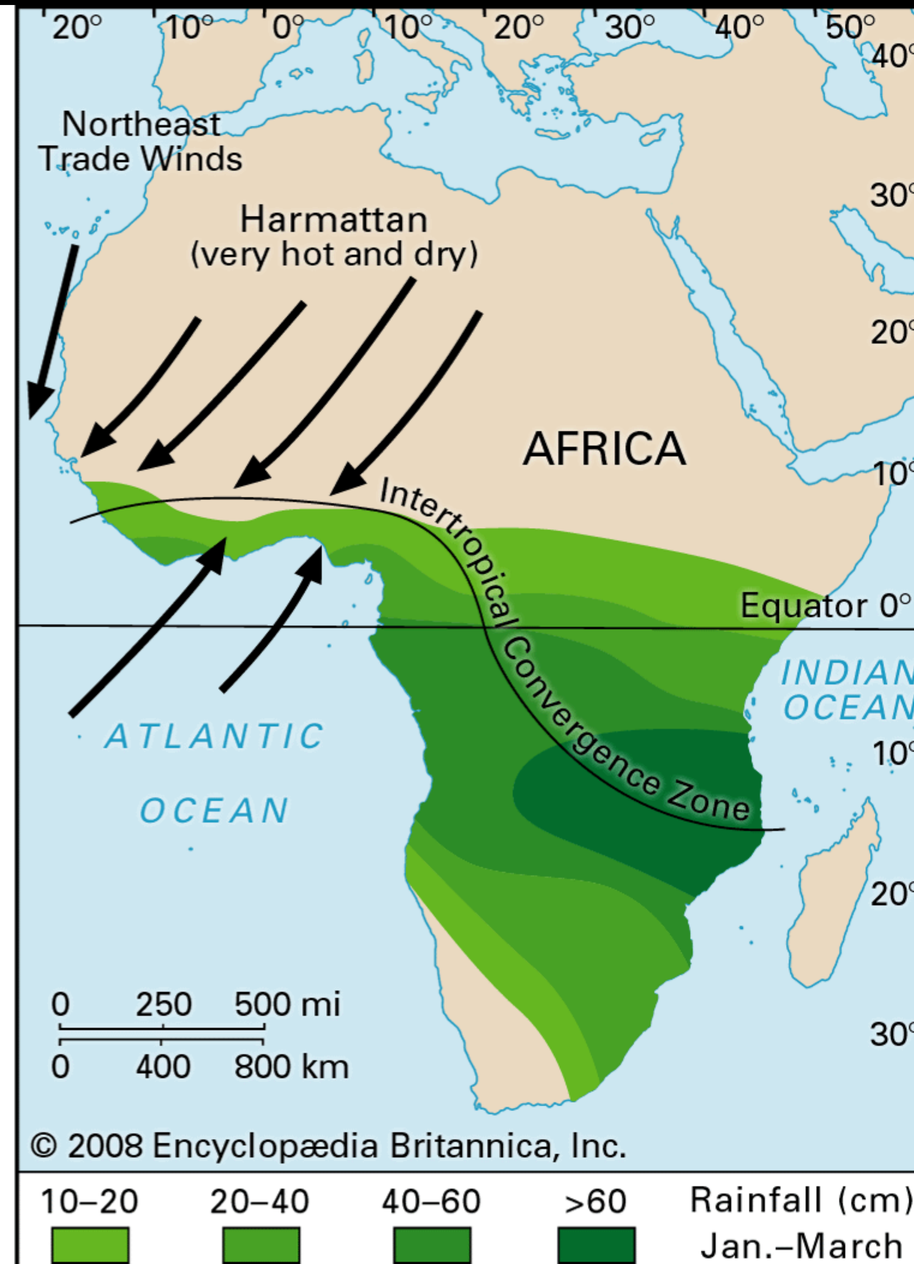


Precipitation (P) vs. evaporation (E)
P < E
P = E
P > E
Fronts
Subtropics
ITCZ
Subtropics
Fronts
Warm
Cold
Warm
Cold
Hadley cells
H
L
H
L
L
L
H
H
30°
0°
H
H
30°
L
L
H
Ruddiman, 1st Ed.


India
Monsoon Onset Map
Arrival dates
June 1st
June 5th
June 10th
June 15th
July 1st
July 15th
August 1st
Components
Northeast (winter)
Southwest (summer)
Intertropical convergence zone (ITCZ) in June/July
JAMMU & KASHMIR
HIMACHAL PRADESH
PUNJAB
Chandigarh
HARYANA
Delhi
UTTARANCHAL
RAJASTHAN
UTTAR PRADESH
SIKKIM
ARUNACHAL PRADESH
ASSAM
NAGALAND
BIHAR
MEGHALAYA
MANIPUR
MADHYA PRADESH
JHARKHAND
WEST BENGAL
TRIPURA
MIZORAM
GUJARAT
CHHATTISGARH
ORISSA
Daman & Diu
Dadra & Nagar Haveli
MAHARASHTRA
ANDHRA PRADESH
Pondicherry (Yanam)
Bay Of Bengal
Arabian Sea
GOA
KARNATAKA
Pondicherry (Mahe)
Lakshadweep Islands
TAMIL NADU
Pondicherry (Karaikal)
KERALA
Andaman & Nicobar Islands
Andaman Sea

Pakistan floods, 2010


20° 10° 0° 10° 20° 30° 40° 50°
40°
30°
20°
10°
Equator 0°
10°
20°
30°
Northeast
Trade Winds
Harmattan
(very hot and dry)
Intertropical Convergence Zone
INDIAN
OCEAN
ATLANTIC
OCEAN
AFRICA
0 250 500 mi
0 400 800 km
© 2008 Encyclopædia Britannica, Inc.
10–20 20–40 40–80 >80
Rainfall (cm)
June–Sept.


20° 10° 0° 10° 20° 30° 40° 50°
40°
30°
20°
10°
Equator 0°
10°
20°
30°
Northeast
Trade Winds
Harmattan
(very hot and dry)
AFRICA
Intertropical Convergence Zone
INDIAN
OCEAN
ATLANTIC
OCEAN
0 250 500 mi
0 400 800 km
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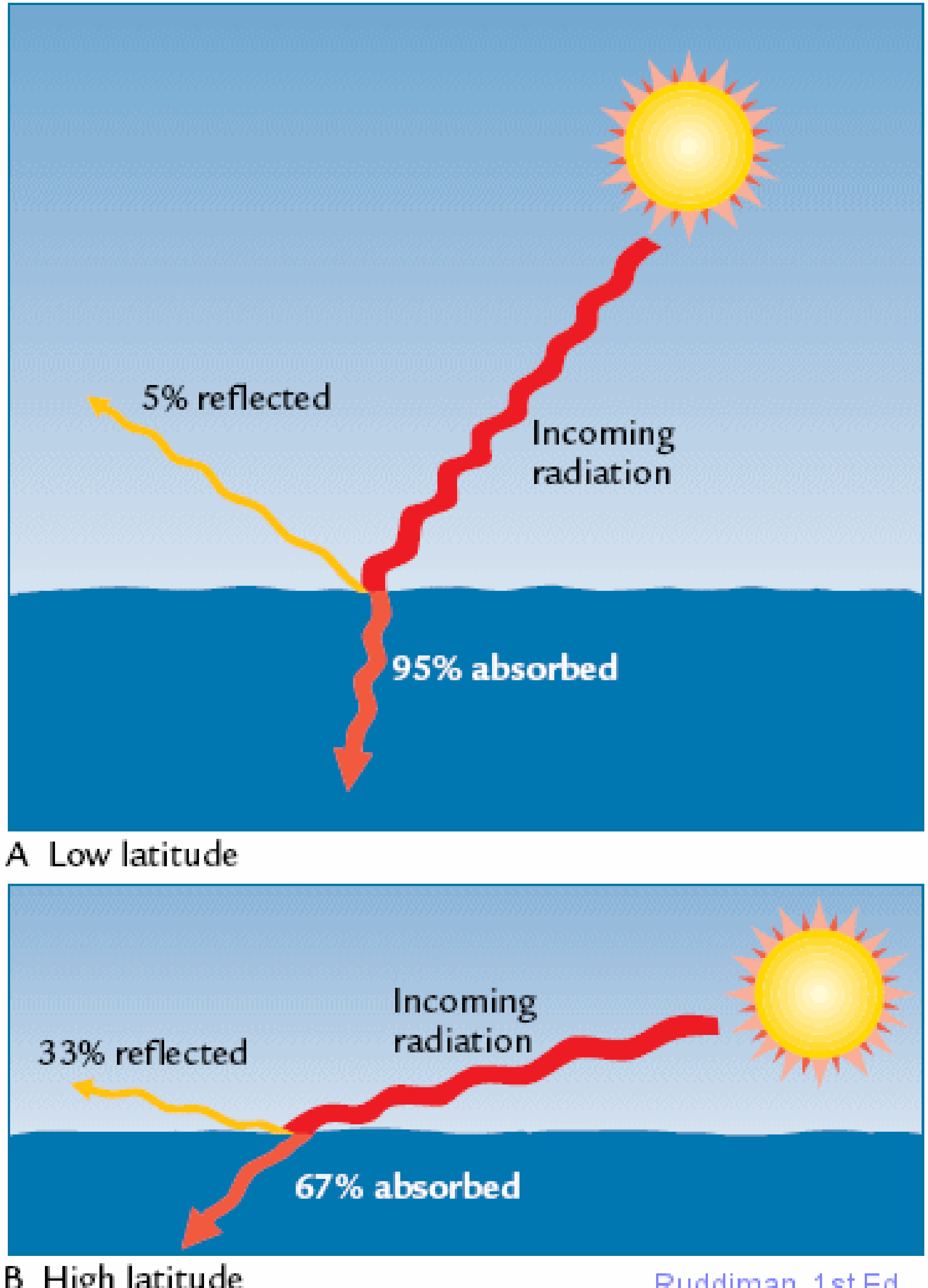
10–20 20–40 40–60 >60
Rainfall (cm)
Jan.–March

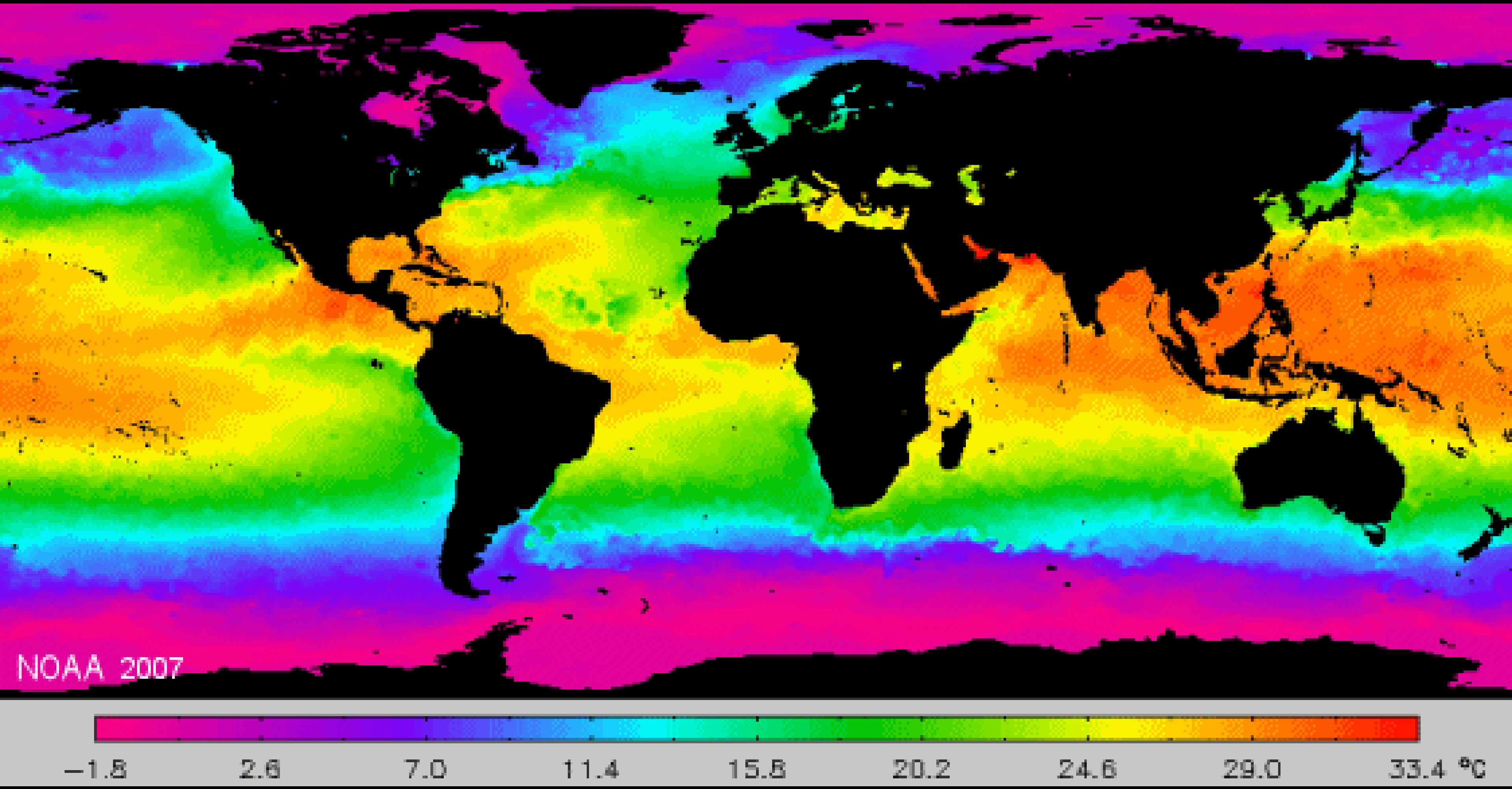
The importance of ocean currents in the global thermal energy budget



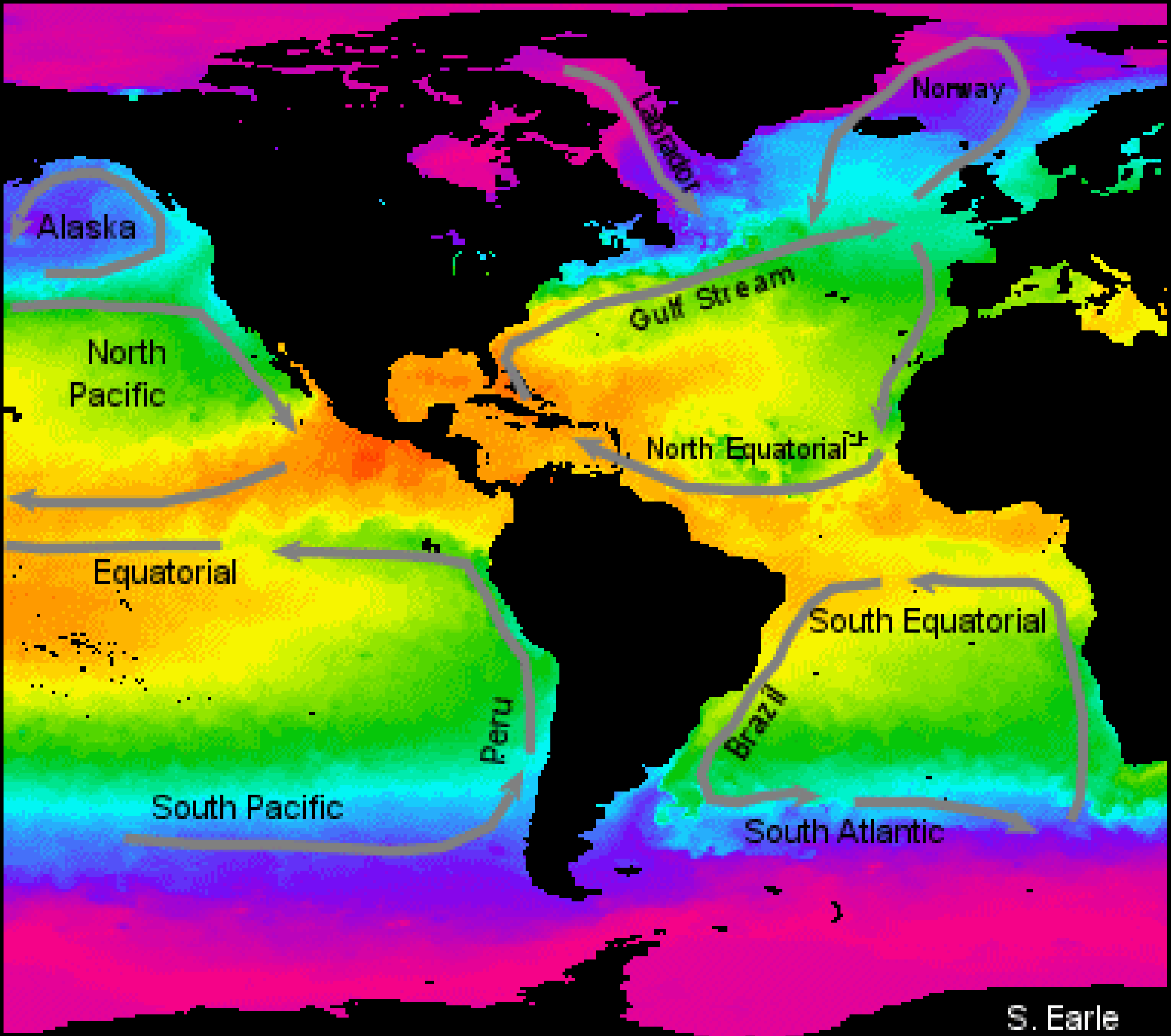
Ruddiman, 1st Ed.

But even at high latitudes water absorbs a lot more radiant energy than other surfaces. This radiant energy is converted into heat.

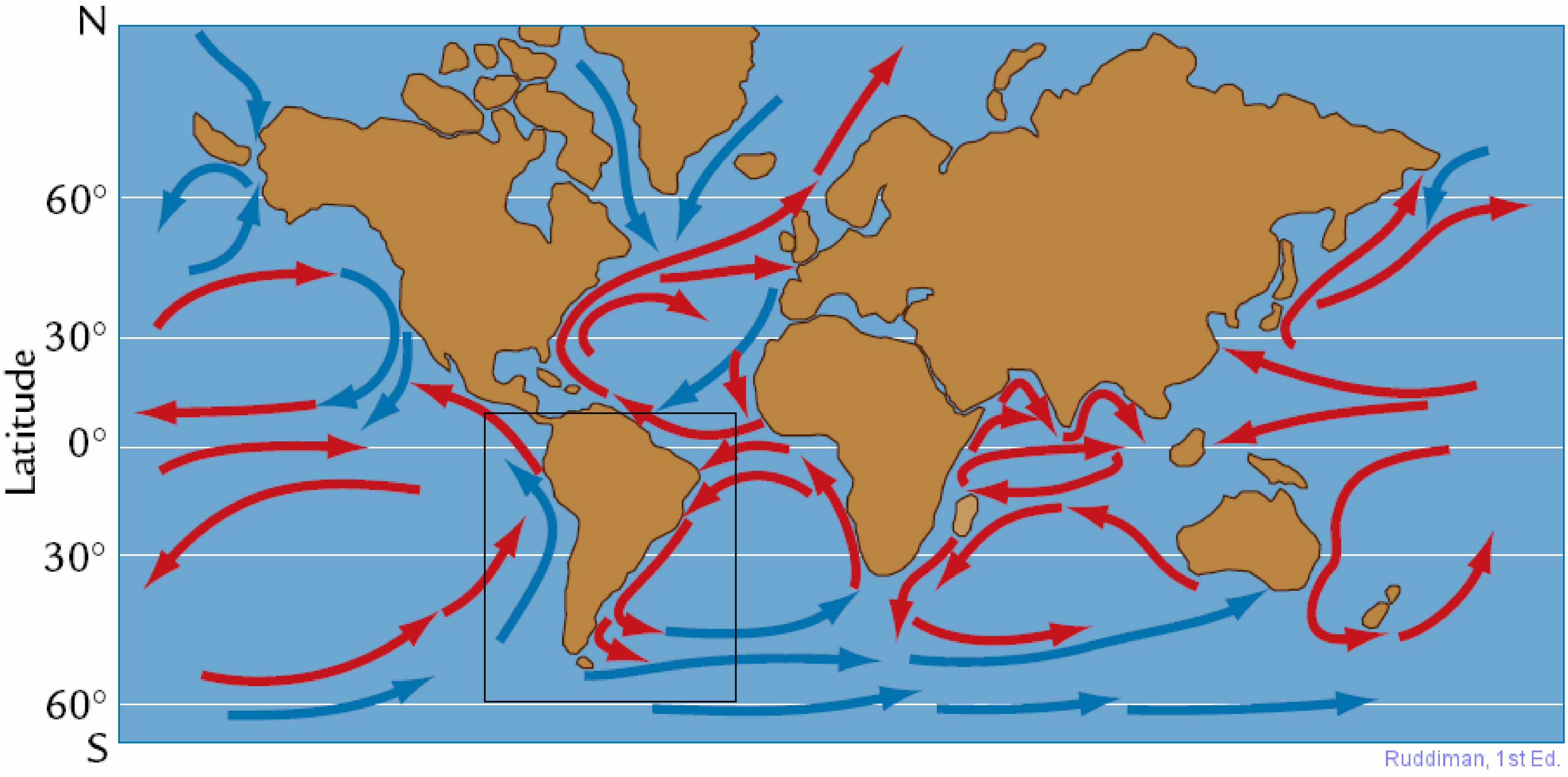
Sea-surface temperatures (SSTs)



Major ocean currents



Major ocean currents



The effect of opposing current directions

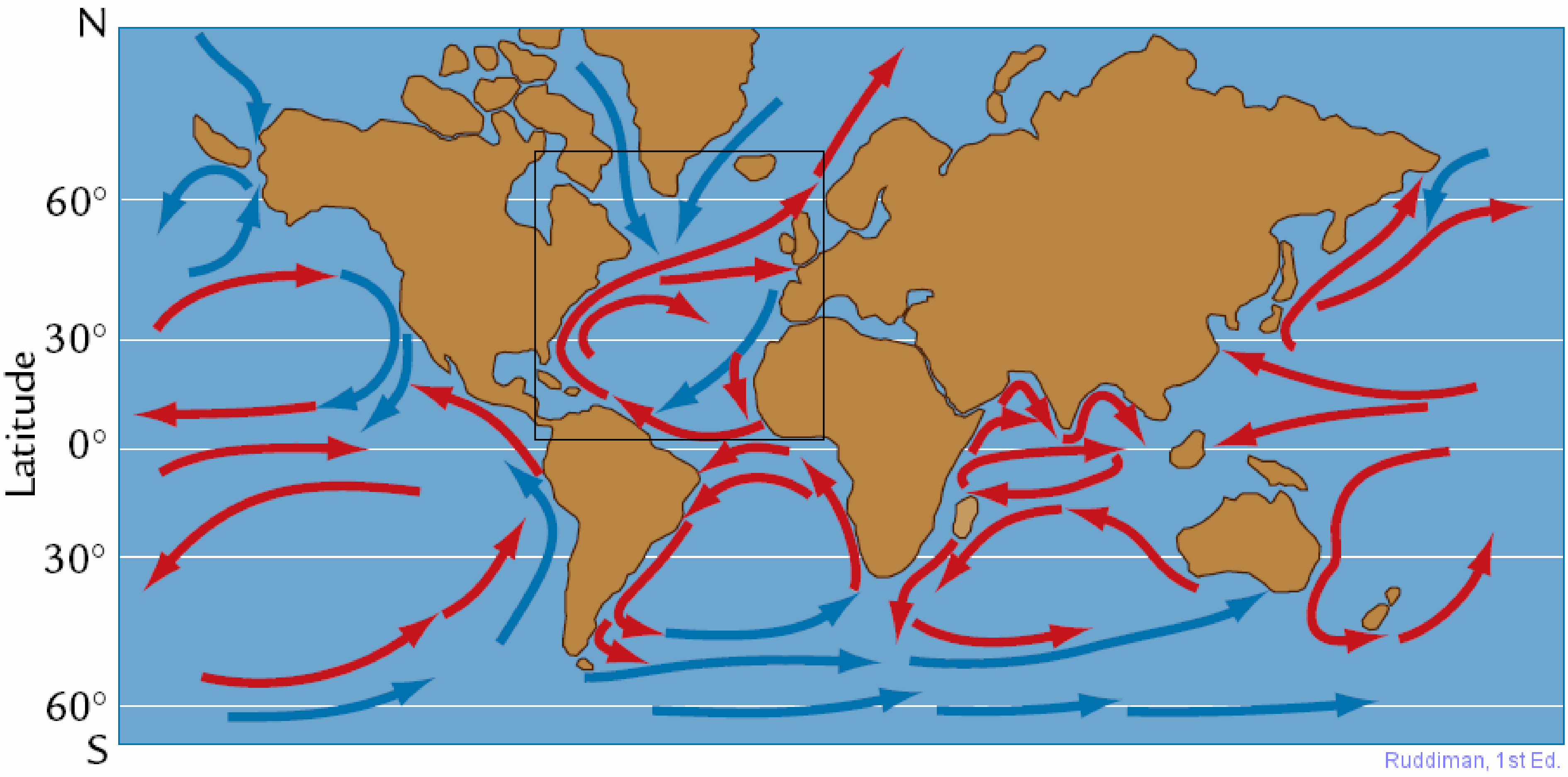
Lima, Peru

Month	Average Sunlight (hours)	Temperature Average Min	Temperature Average Max	Temperature Record Min	Temperature Record Max	Discomfort from heat and humidity	Relative humidity am	Relative humidity pm	Average Precipitation (mm)	Wet Days (+0.25 mm)
Jan	6	19	28	15	32	Medium	93	69	3	0.5
Feb	7	19	28	15	33	Medium	92	66	0	0.1
March	7	19	28	16	33	Medium	92	64	0	0.1
April	7	17	27	13	34	Medium	93	66	0	0.2
May	4	16	23	11	29	Moderate	95	76	5	0.8
June	1	14	20	9	27	-	95	80	5	1
July	1	14	19	9	27	-	94	77	8	1
Aug	1	13	19	10	27	-	95	78	8	2
Sept	1	14	20	11	26	-	94	76	8	1
Oct	3	14	22	12	26	-	94	72	3	0.2
Nov	4	16	23	11	29	Moderate	93	71	3	0.2
Dec	5	17	26	13	31	Medium	93	70	0	0.1

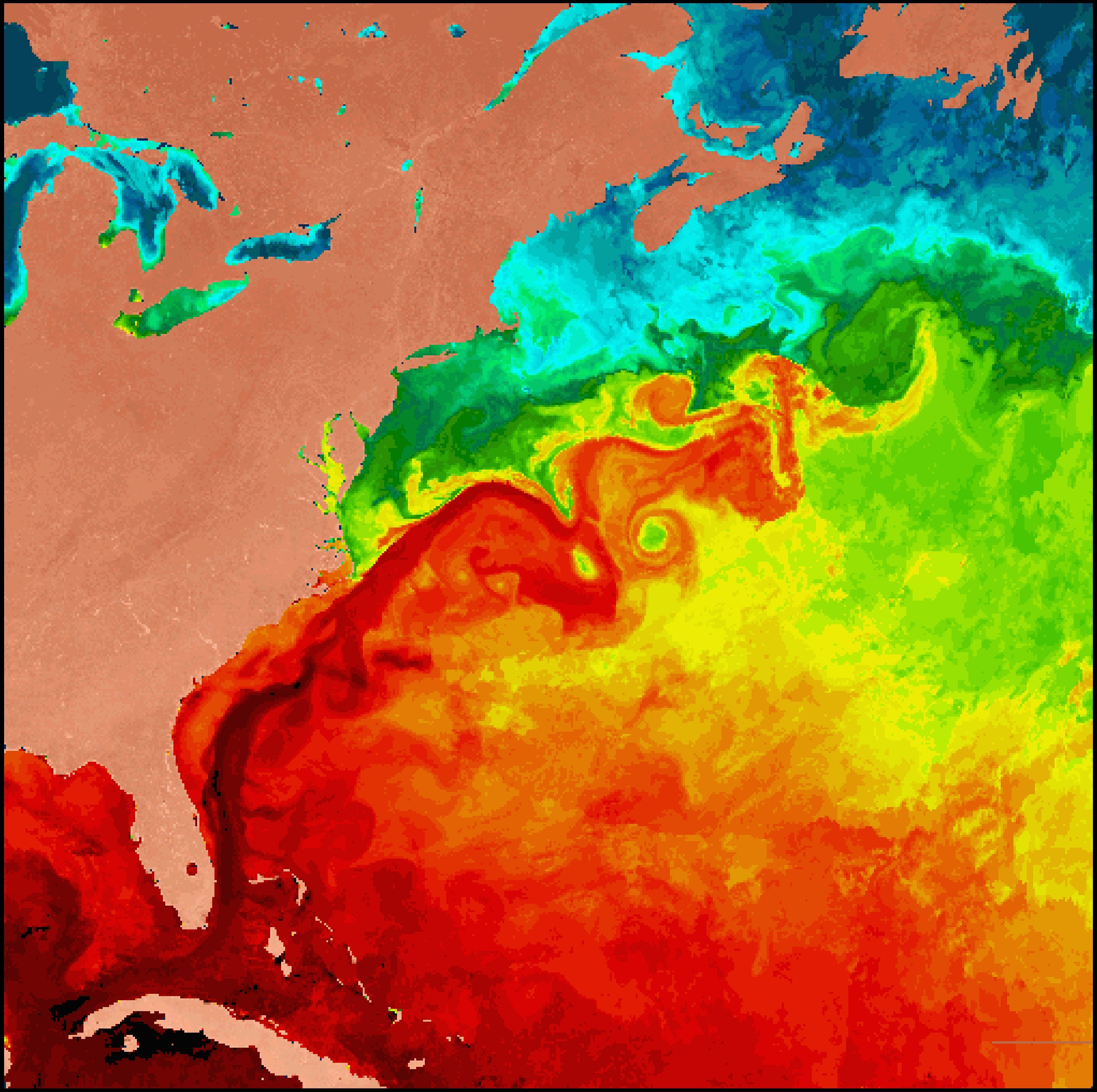
Recife, Brazil

Month	Average Sunlight (hours)	Temperature Average Min	Temperature Average Max	Temperature Record Min	Temperature Record Max	Discomfort from heat and humidity	Relative humidity am	Relative humidity pm	Average Precipitation (mm)	Wet Days (+0.25 mm)
Jan	7	25	30	22	34	High	77	69	53	10
Feb	7	25	30	21	34	High	81	70	84	12
March	8	24	30	21	34	High	81	71	160	14
April	8	24	29	21	34	High	83	73	221	17
May	7	23	28	21	32	Medium	84	74	267	21
June	5	23	28	19	32	Medium	84	75	277	21
July	6	22	27	18	31	Medium	83	75	254	22
Aug	7	22	27	18	31	Medium	82	73	152	19
Sept	7	23	28	19	32	Medium	78	70	64	11
Oct	9	24	29	20	33	Medium	75	67	25	8
Nov	9	24	29	21	33	Medium	74	68	25	7
Dec	8	25	29	21	33	Medium	76	67	28	6

Major ocean currents

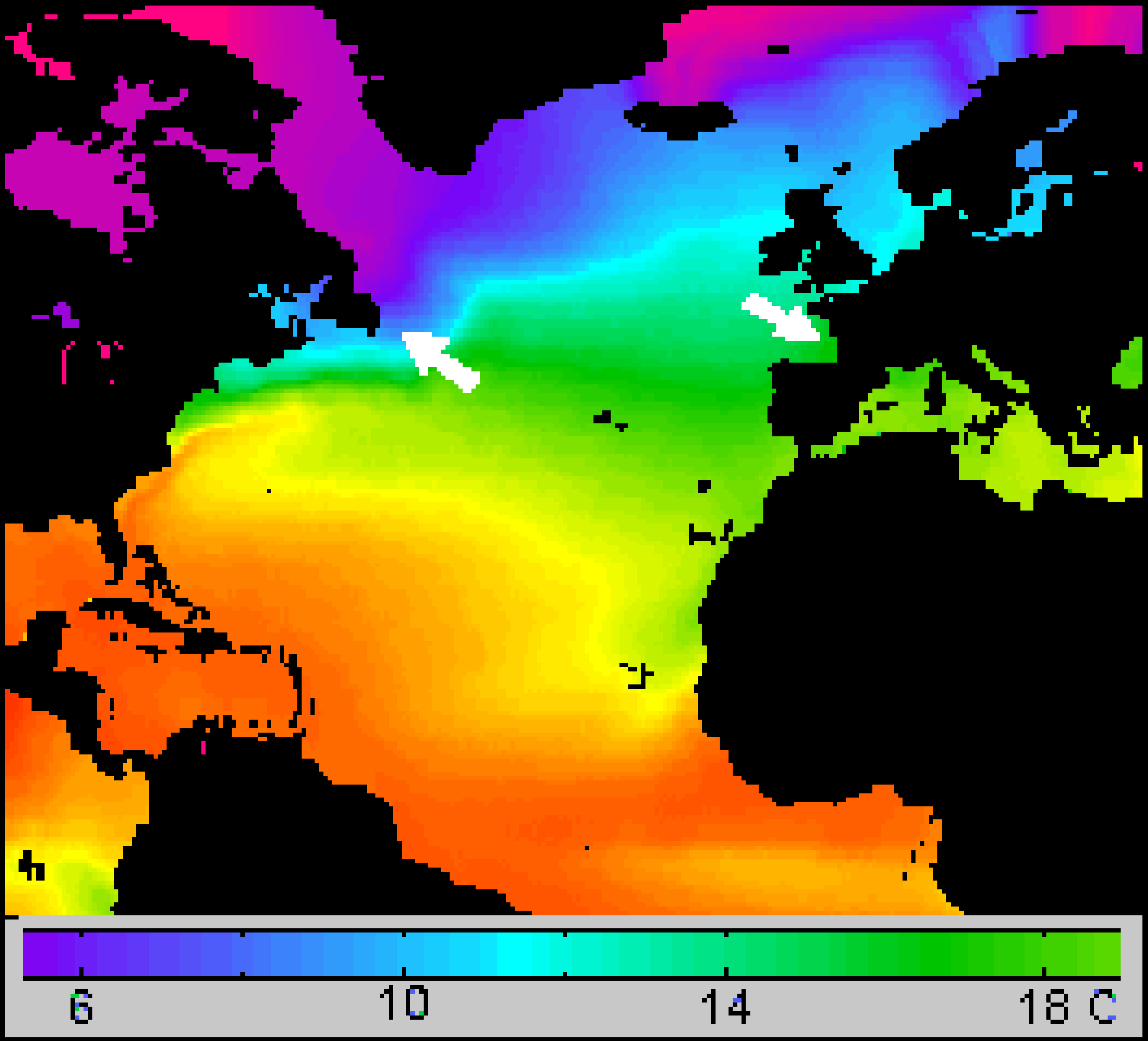


The Gulf Stream

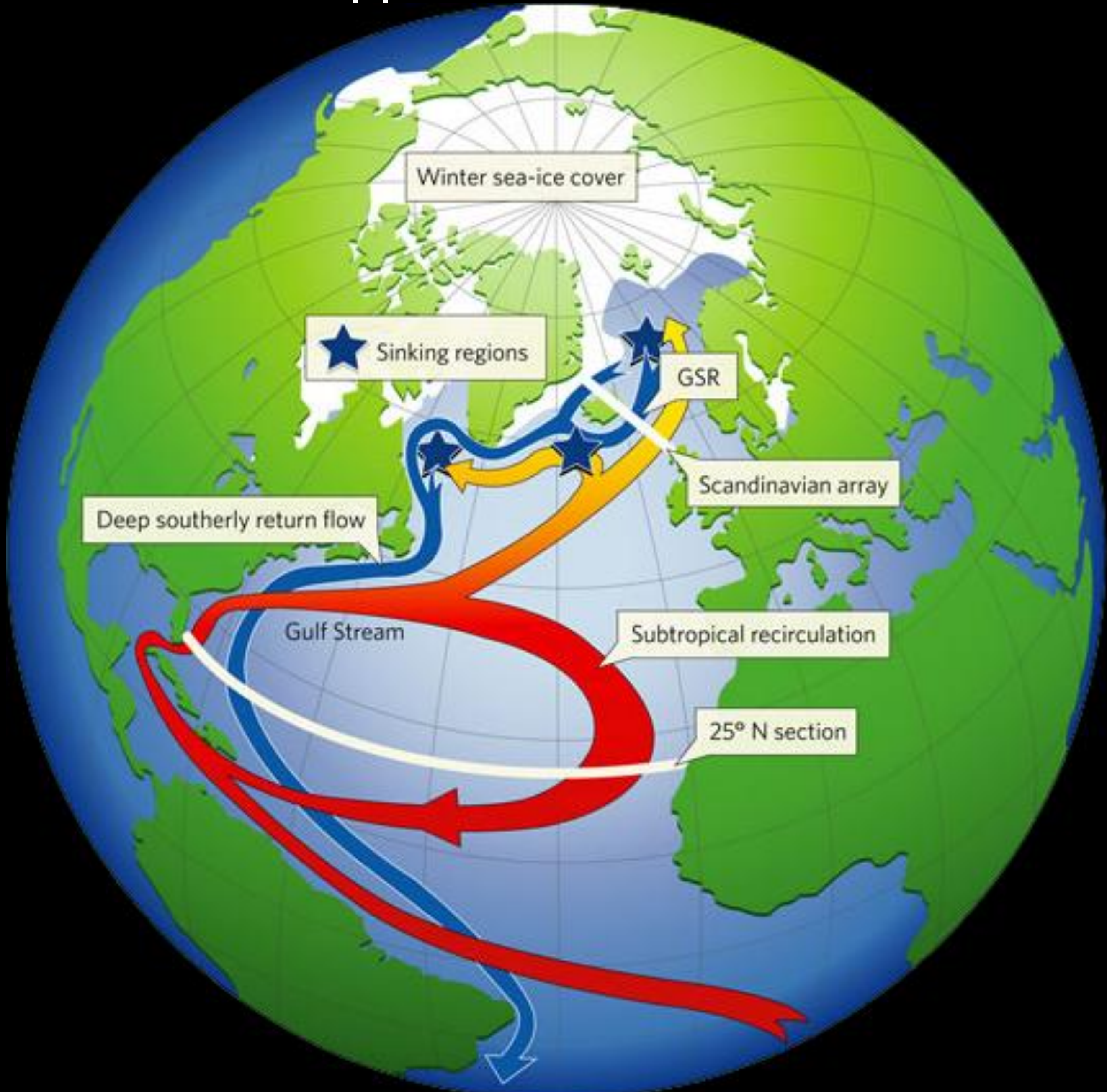


http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/eastcoast.gif

Compare the climates of Newfoundland and southern France – both at the same latitude

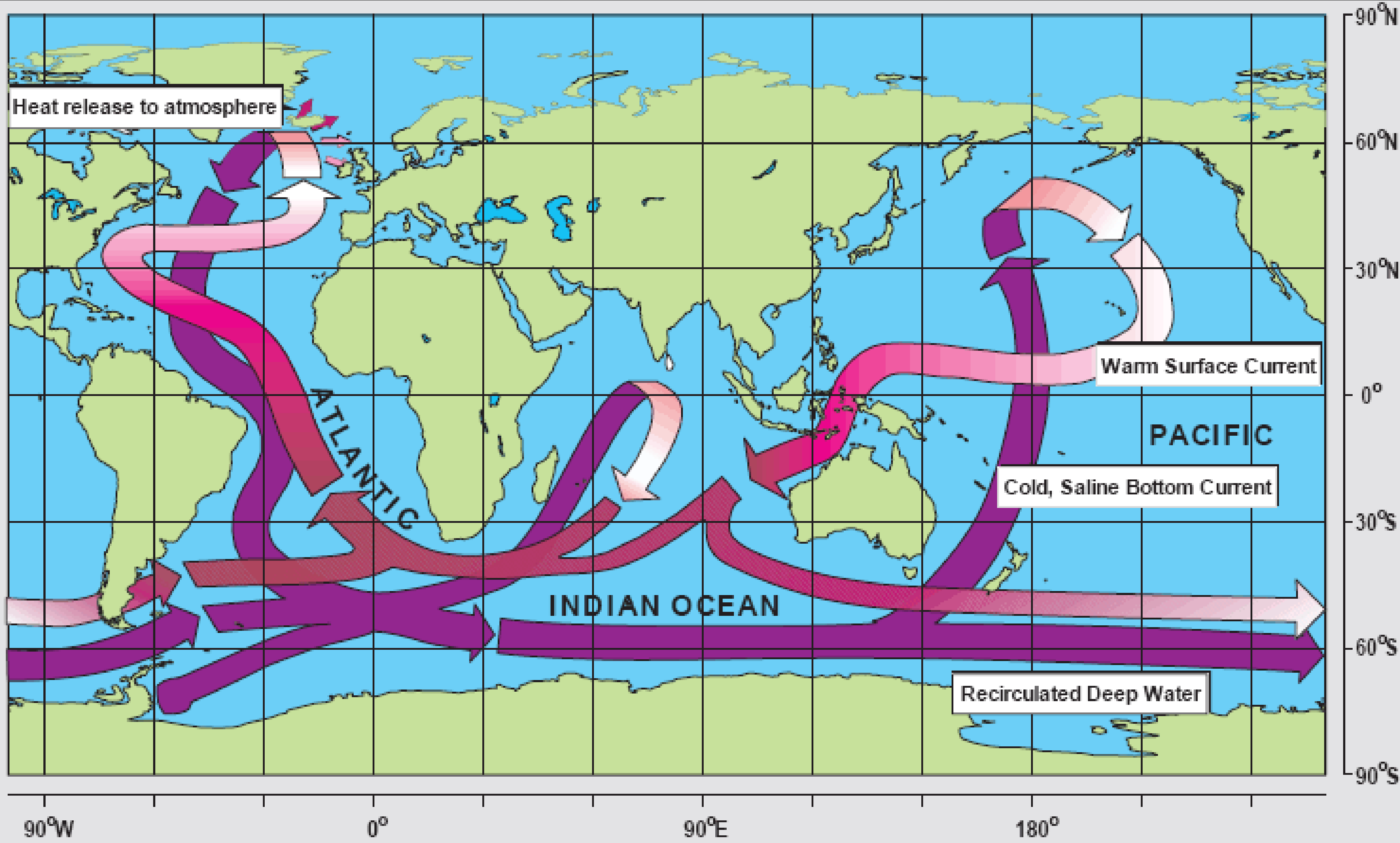


What happens to the Gulf Stream?

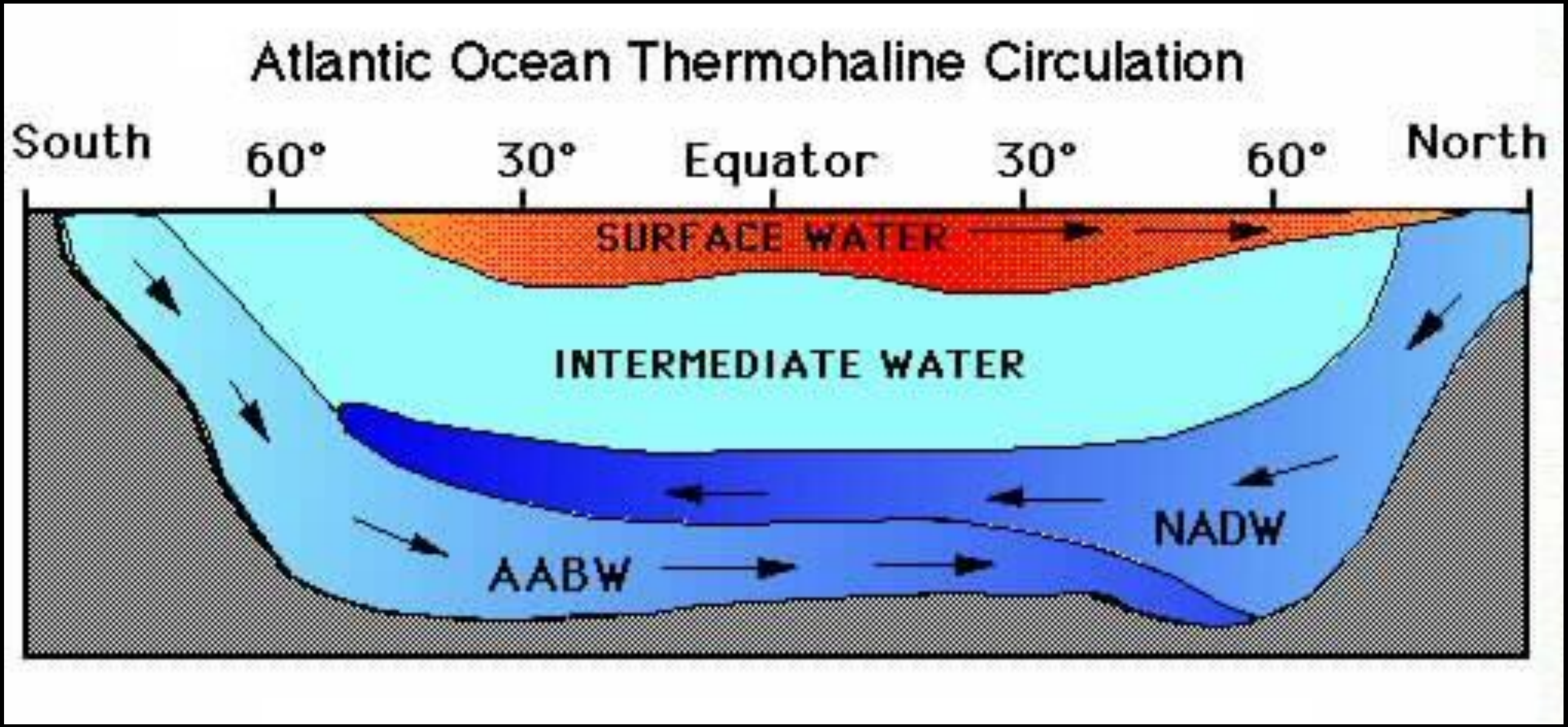


nature.com

Thermohaline circulation

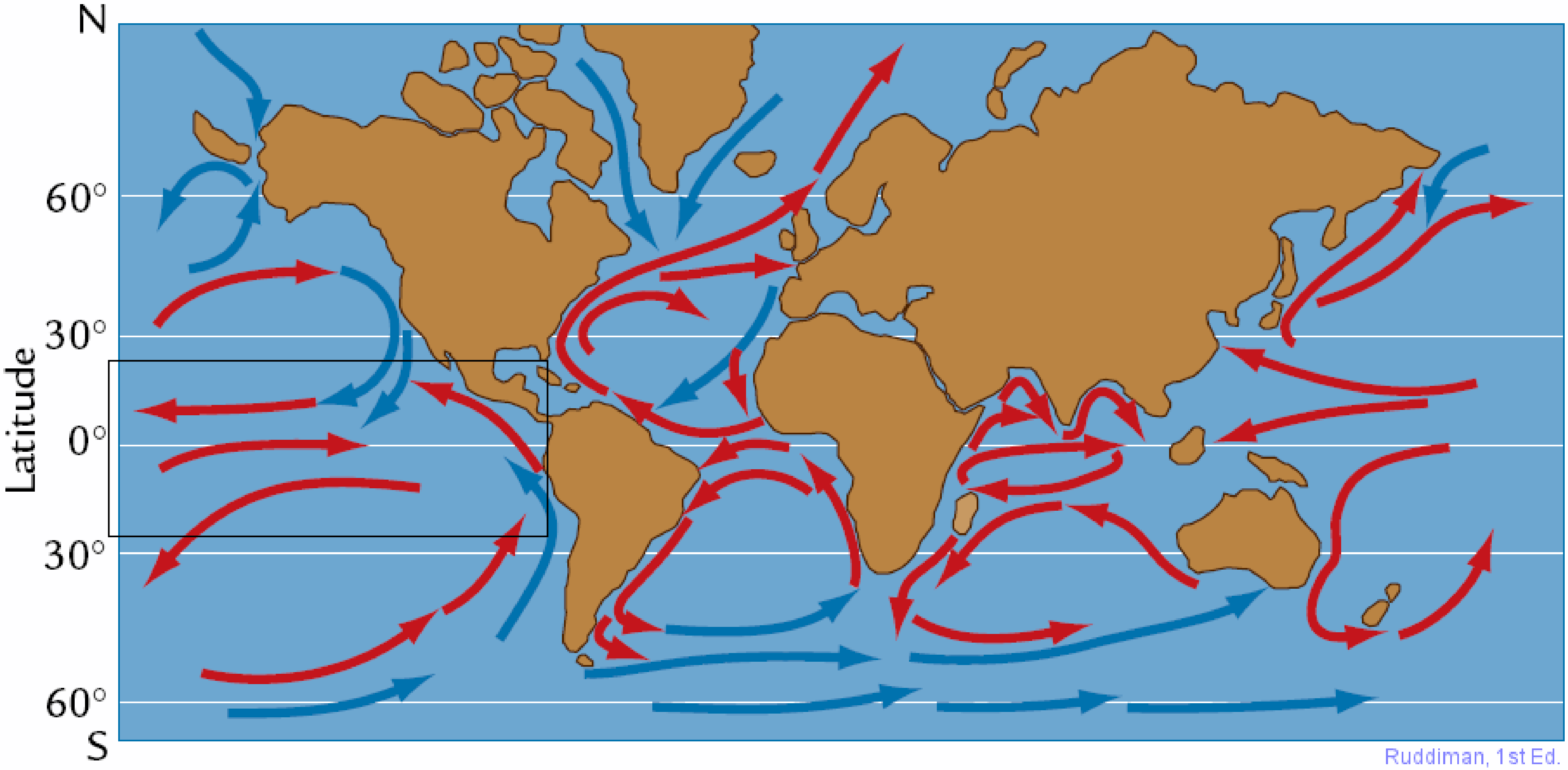


Credit: Image courtesy CLIVAR (after W. Broecker, modified by E. Maier-Reimer)

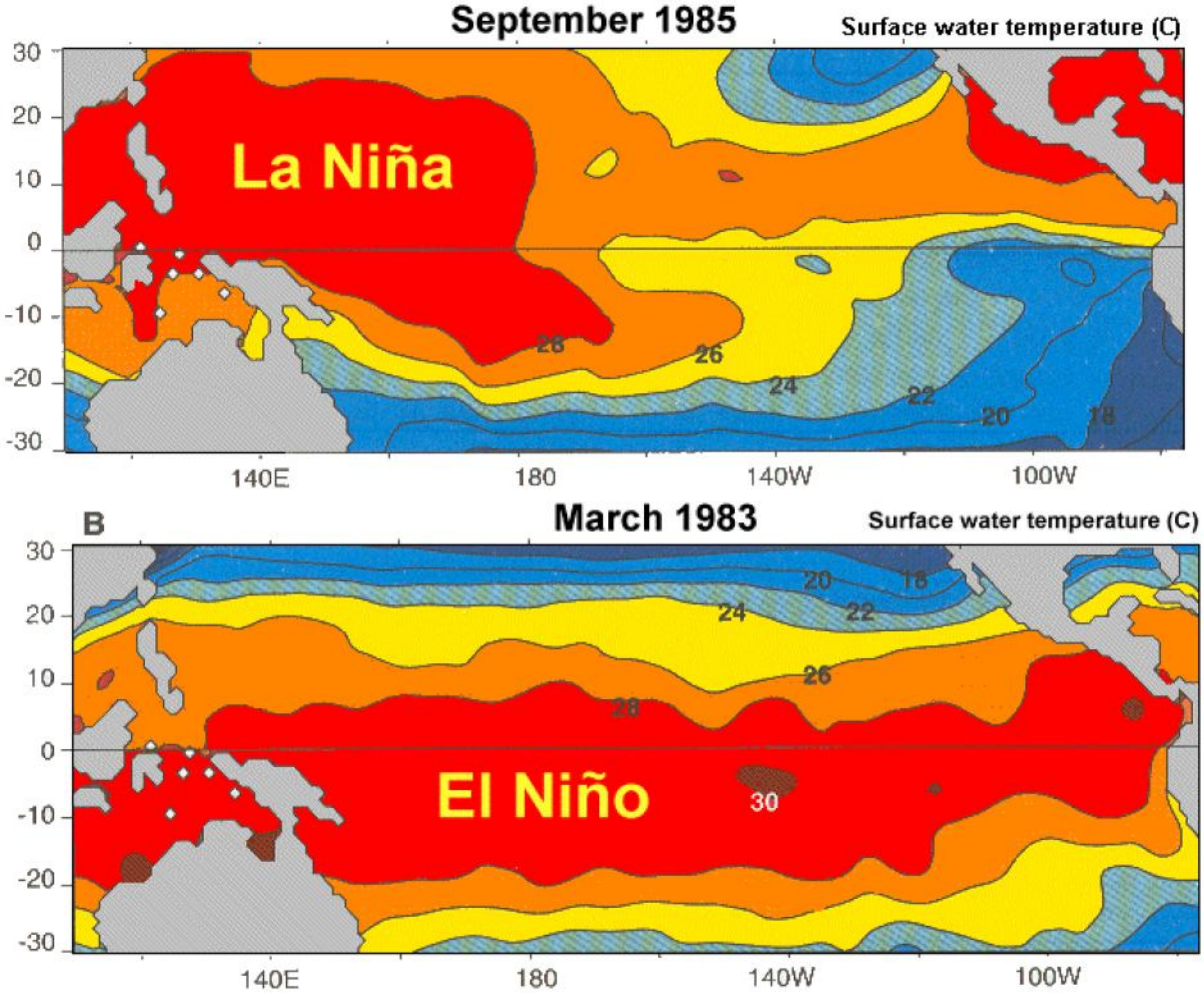


NADW = North Atlantic deep water
AABW = Antarctic bottom water

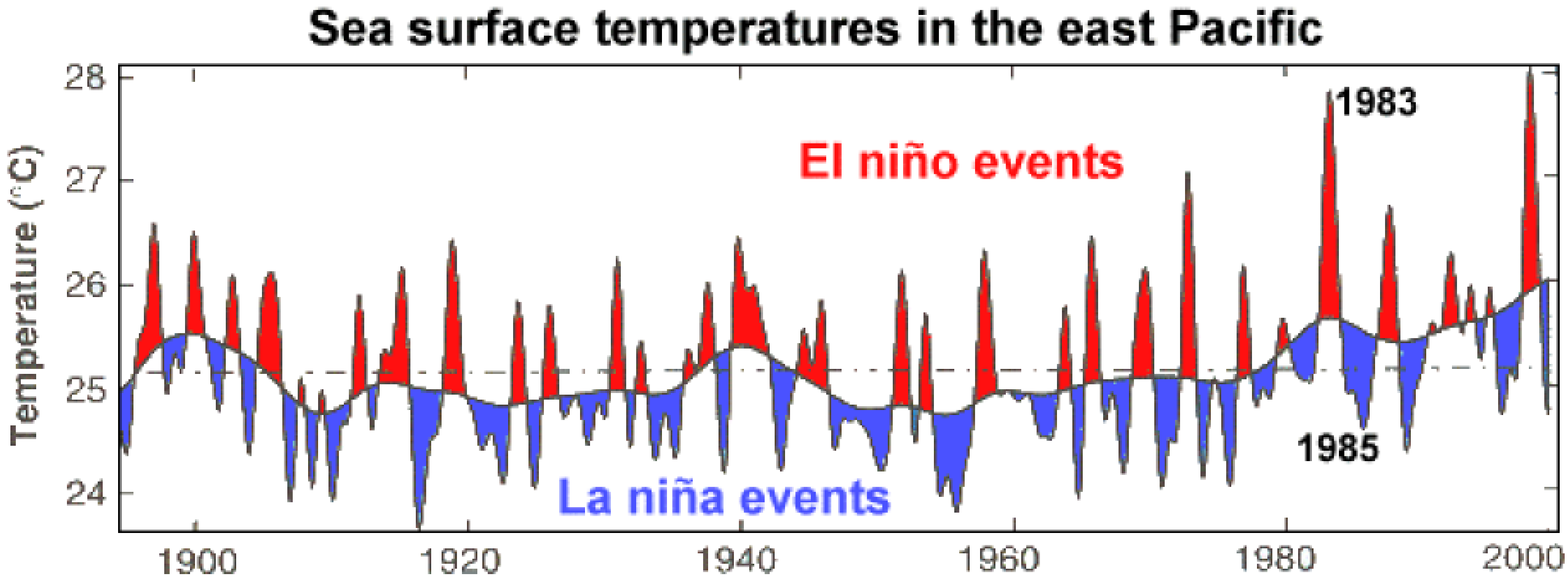
Major ocean currents

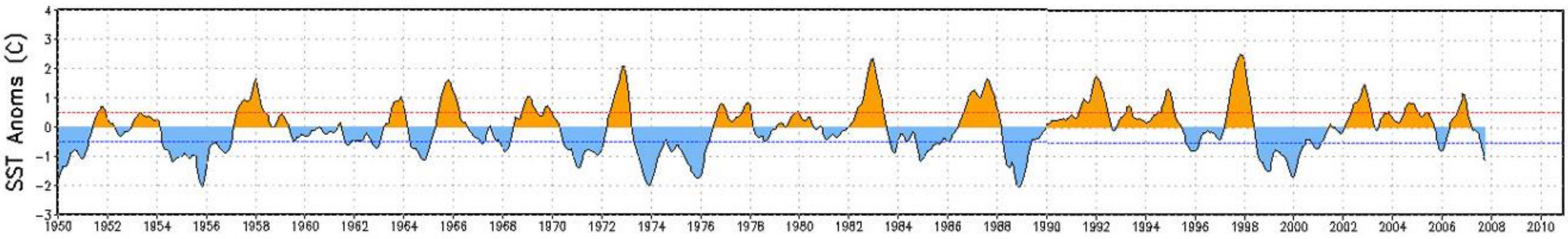


La Nina and El Nino



El Nino over the past century

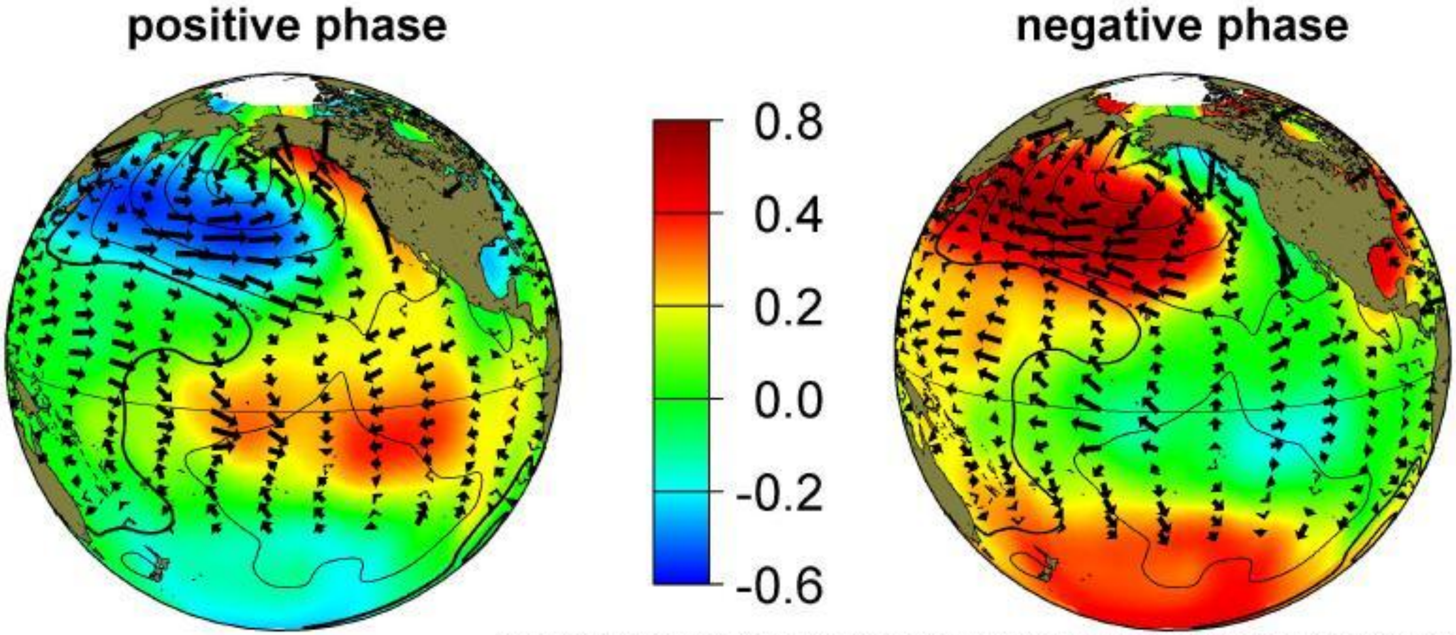




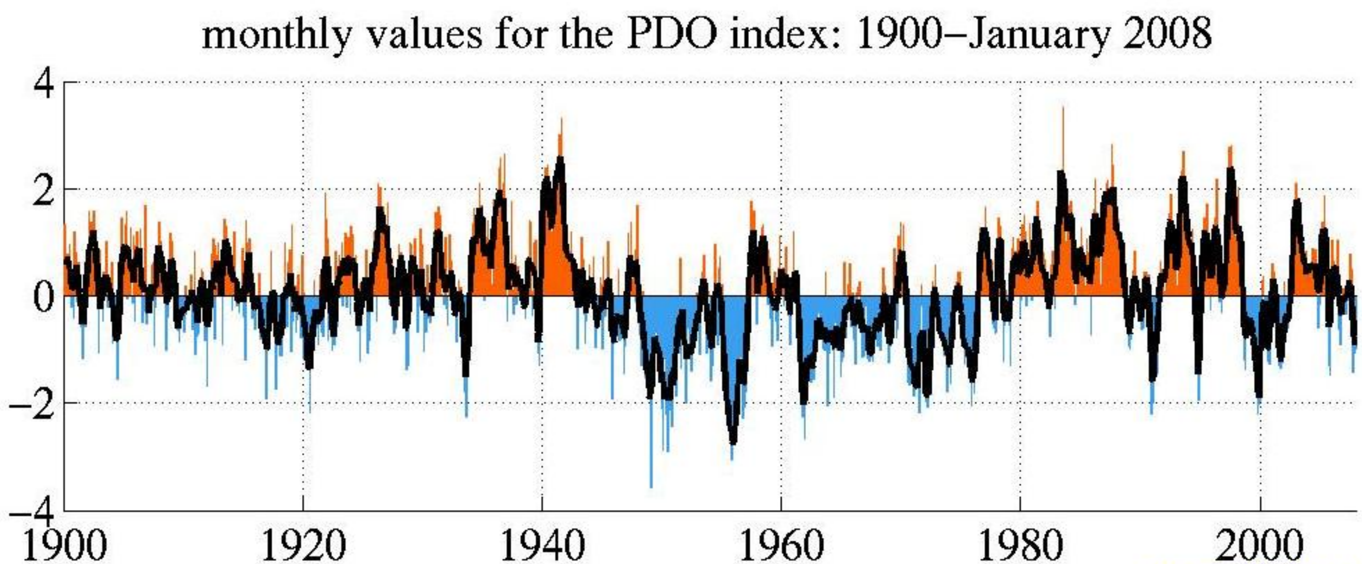
El Nino – Southern Oscillation (a.k.a. ENSO) has climate impacts in many parts of the world, including western Canada.

Pacific Decadal Oscillation

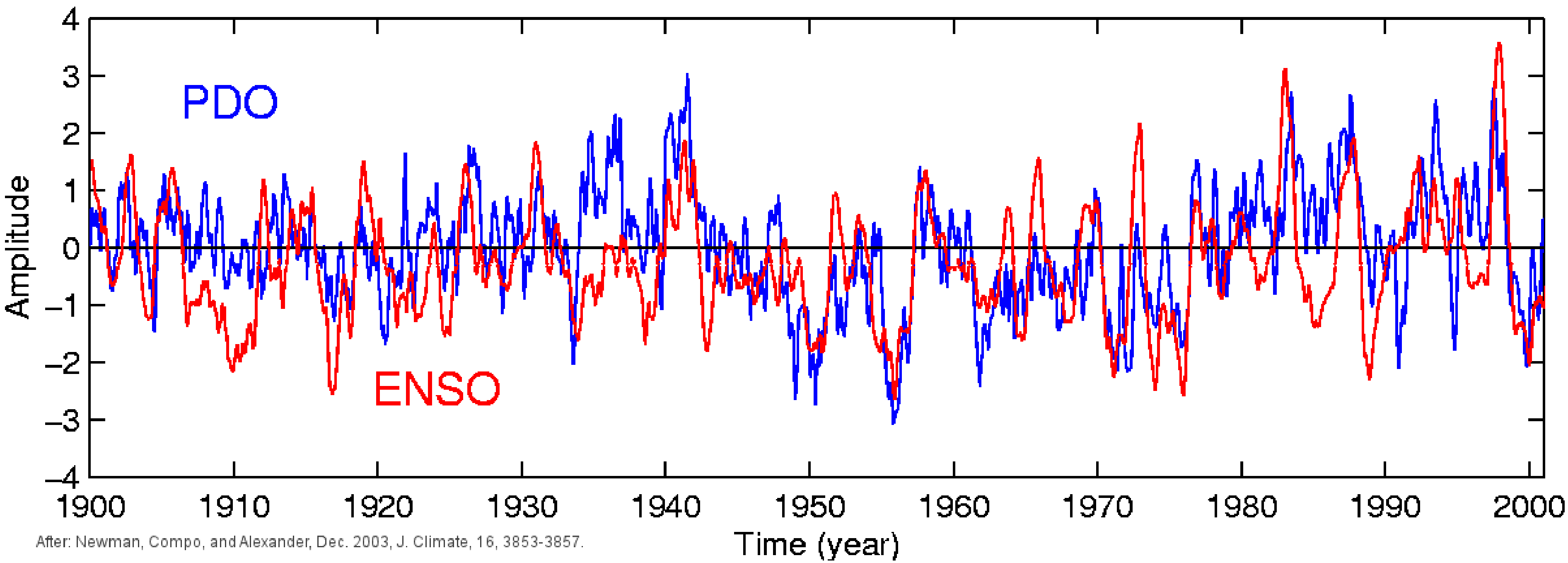
Sea surface temperature anomalies and wind trends



From Joint Inst. for the Study of the Atmos. and Oceans (U. Wash.) - http://jisao.washington.edu/

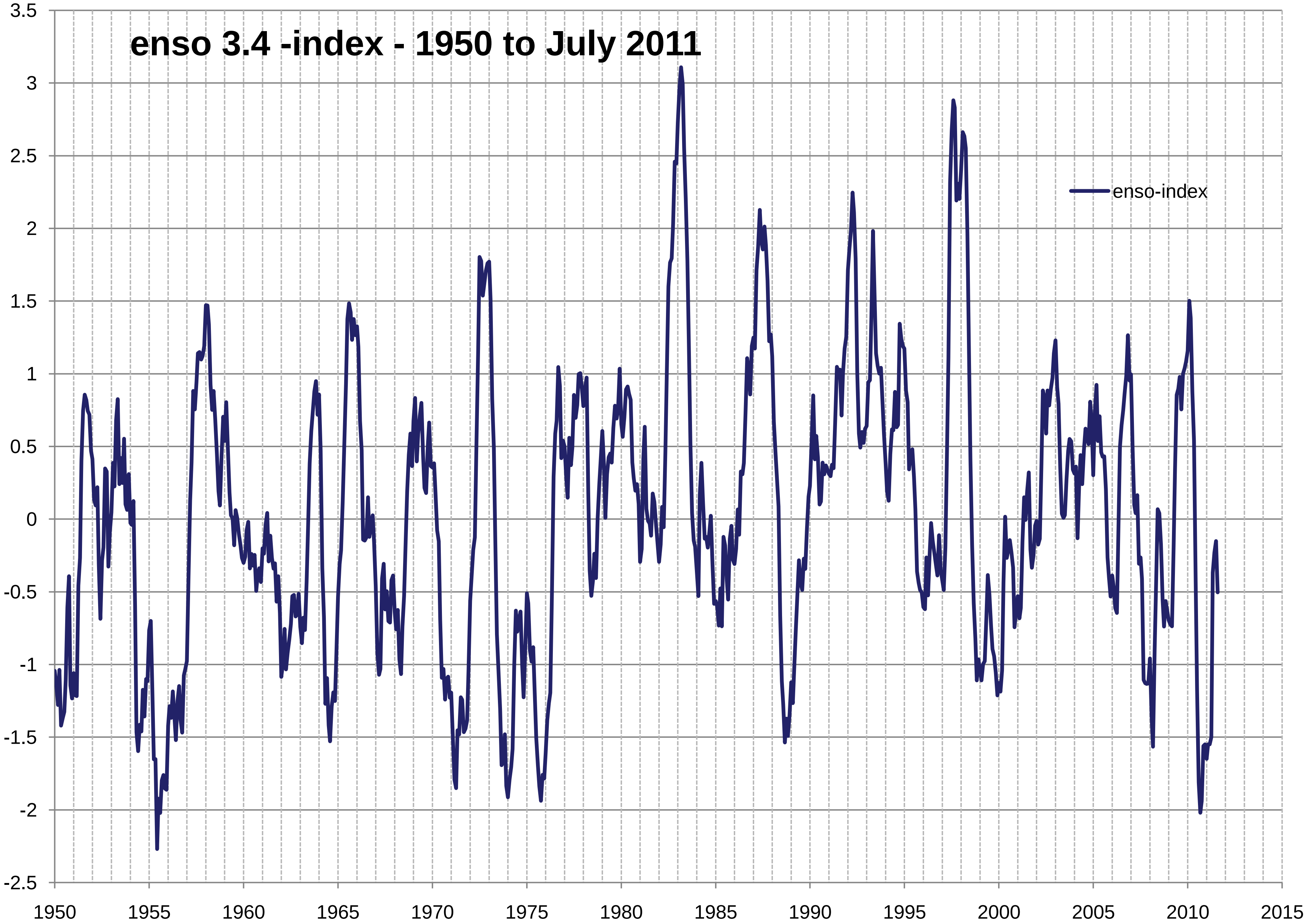


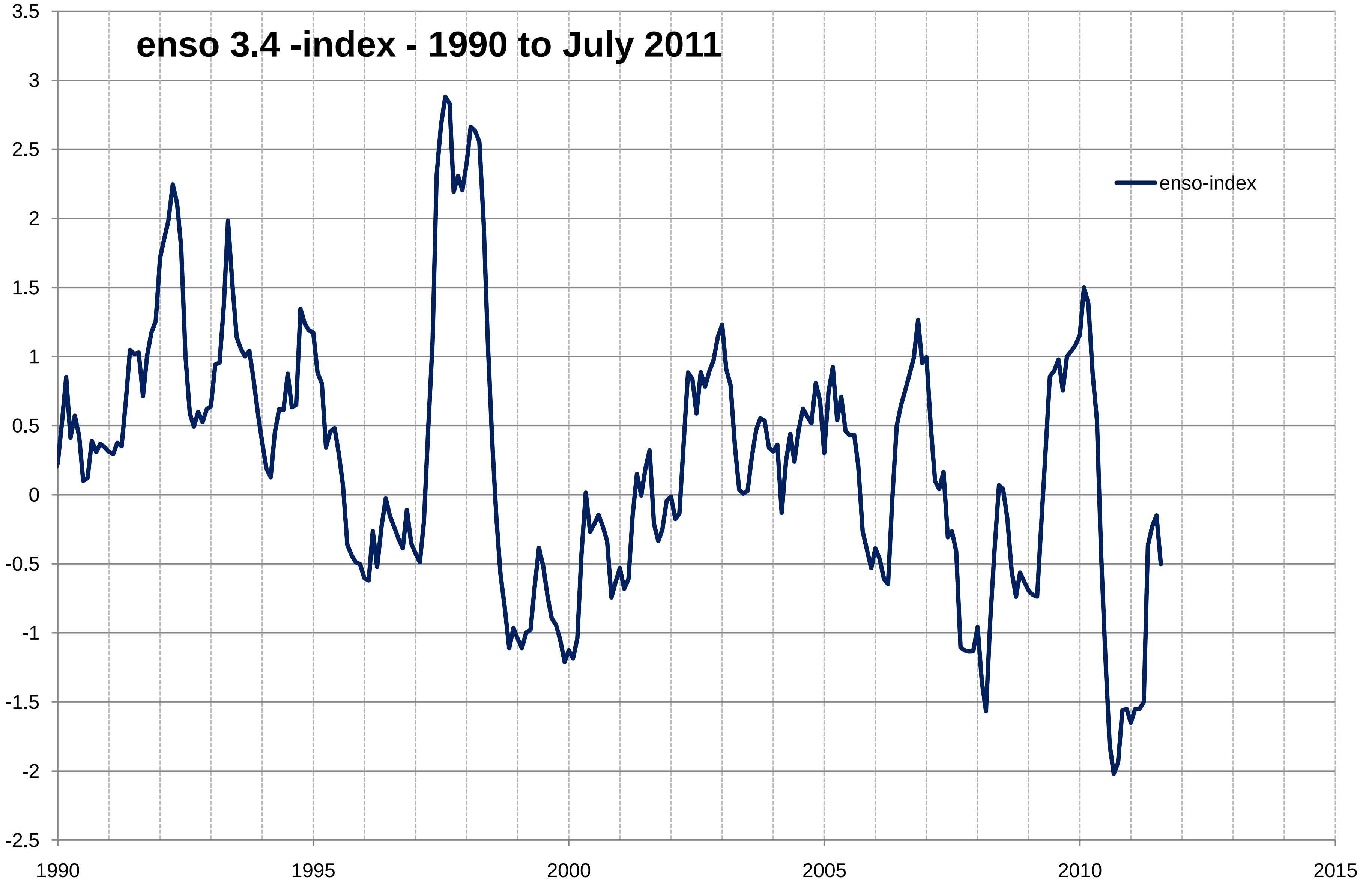
From Joint Inst. for the Study of the Atmos. and Oceans (U. Wash.) - http://jisao.washington.edu/



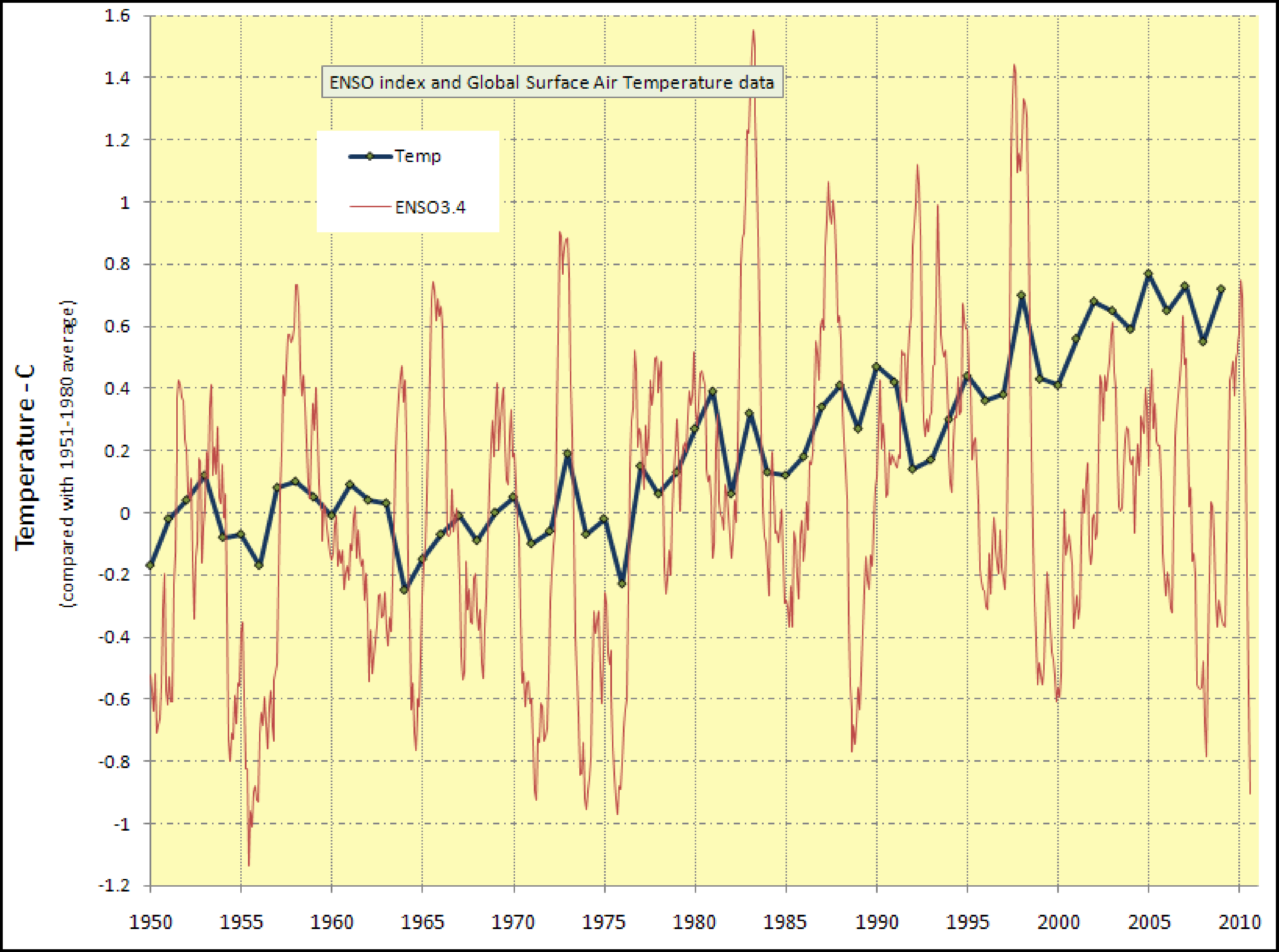
Numerous studies have attempted to determine the effect of the PDO and ENSO on each other. The results have been largely inconclusive and/or contradictory. However, a study by Gershunov and Barnett (1998) shows that the PDO has a modulating effect on the climate patterns resulting from ENSO. The climate signal of El Nino is likely to be stronger when the PDO is highly positive; conversely the climate signal of La Nina will be stronger when the PDO is highly negative. This does not mean that the PDO physically controls ENSO, but rather that the resulting climate patterns interact with each other.

http://ffden-2.phys.uaf.edu/645fall2003_web.dir/Jason_Amundson/enso.htm


enso 3.4 -index - 1950 to July 2011
enso-index
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

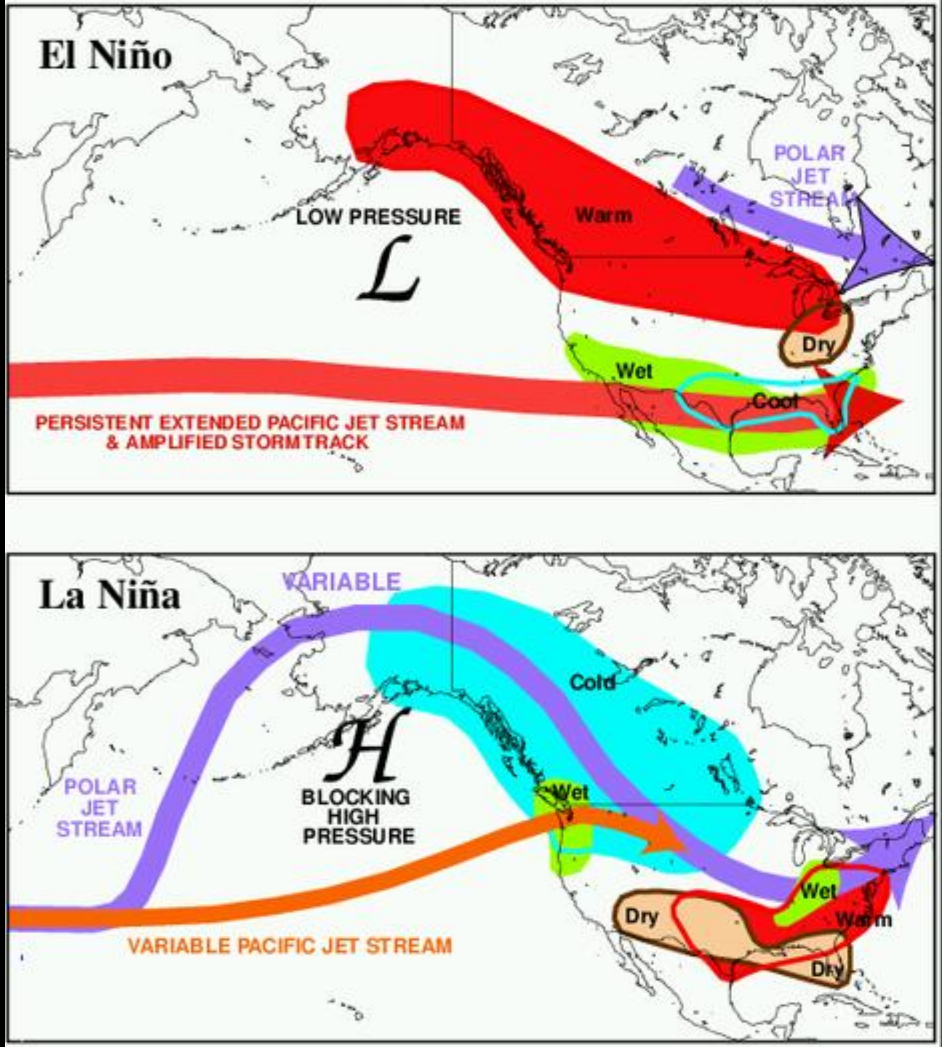


enso 3.4 -index - 1990 to July 2011
enso-index
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1990
1995
2000
2005
2010
2015



ENSO index and Global Surface Air Temperature data
Temp
ENSO3.4
Temperature - C
(compared with 1951-1980 average)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

TYPICAL JANUARY-MARCH WEATHER ANOMALIES
AND ATMOSPHERIC CIRCULATION
DURING MODERATE TO STRONG
EL NIÑO & LA NIÑA

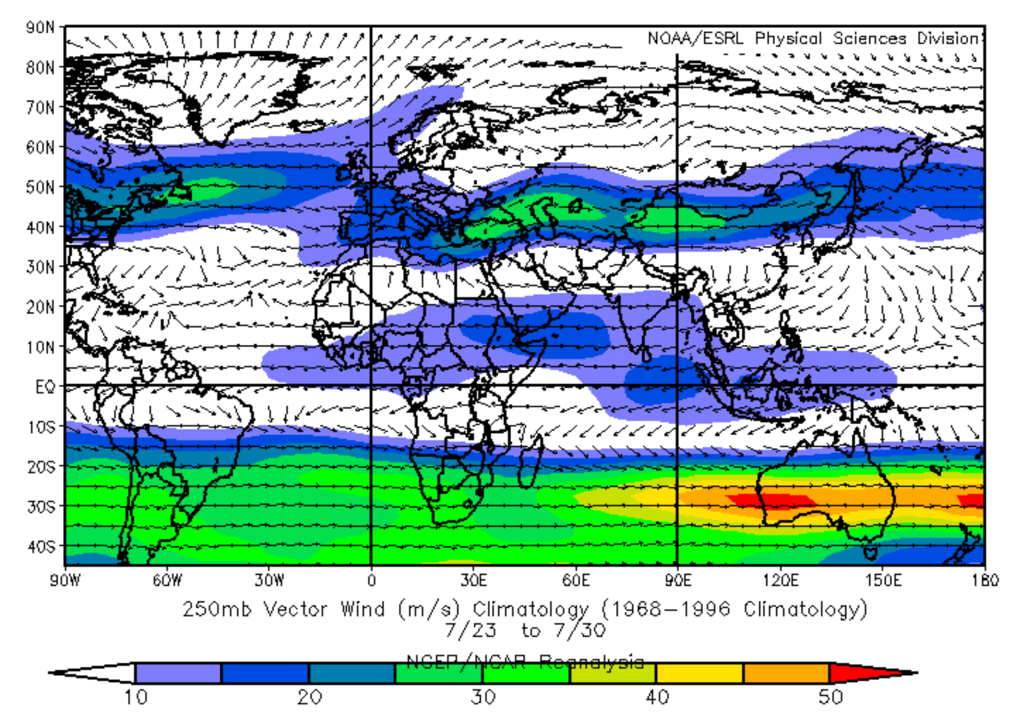


Pakistan floods, 2010

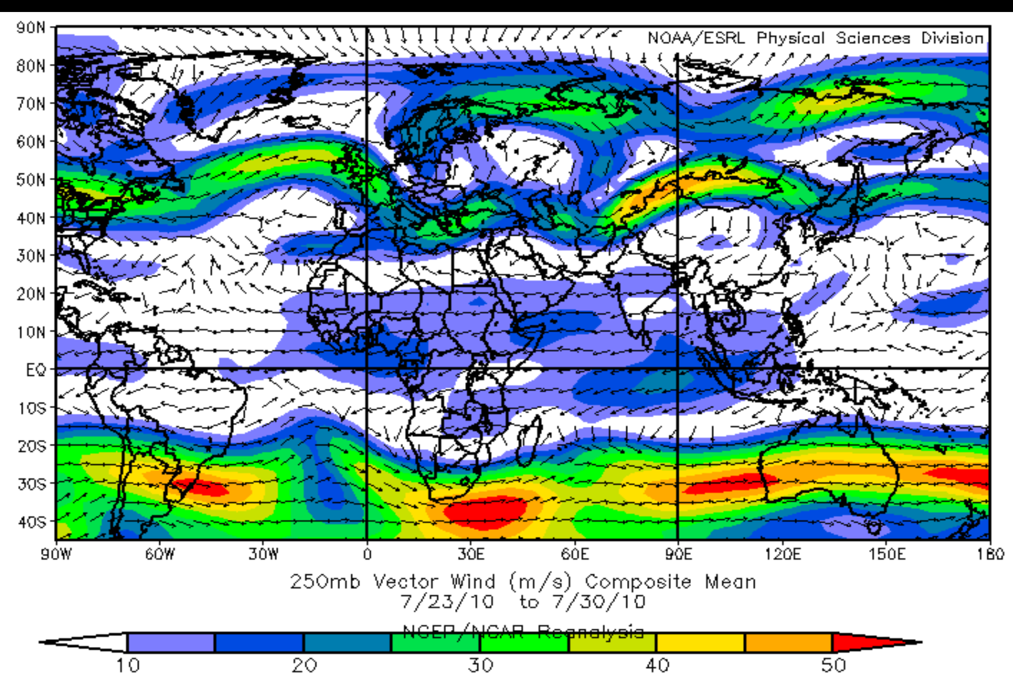
Pakistan typically receives about half its annual rainfall of 250–500 mm during July and August.

In 2010 between 200 and 415 mm fell over a 3-day period in late July. Heavy rain continued through the first half of August.

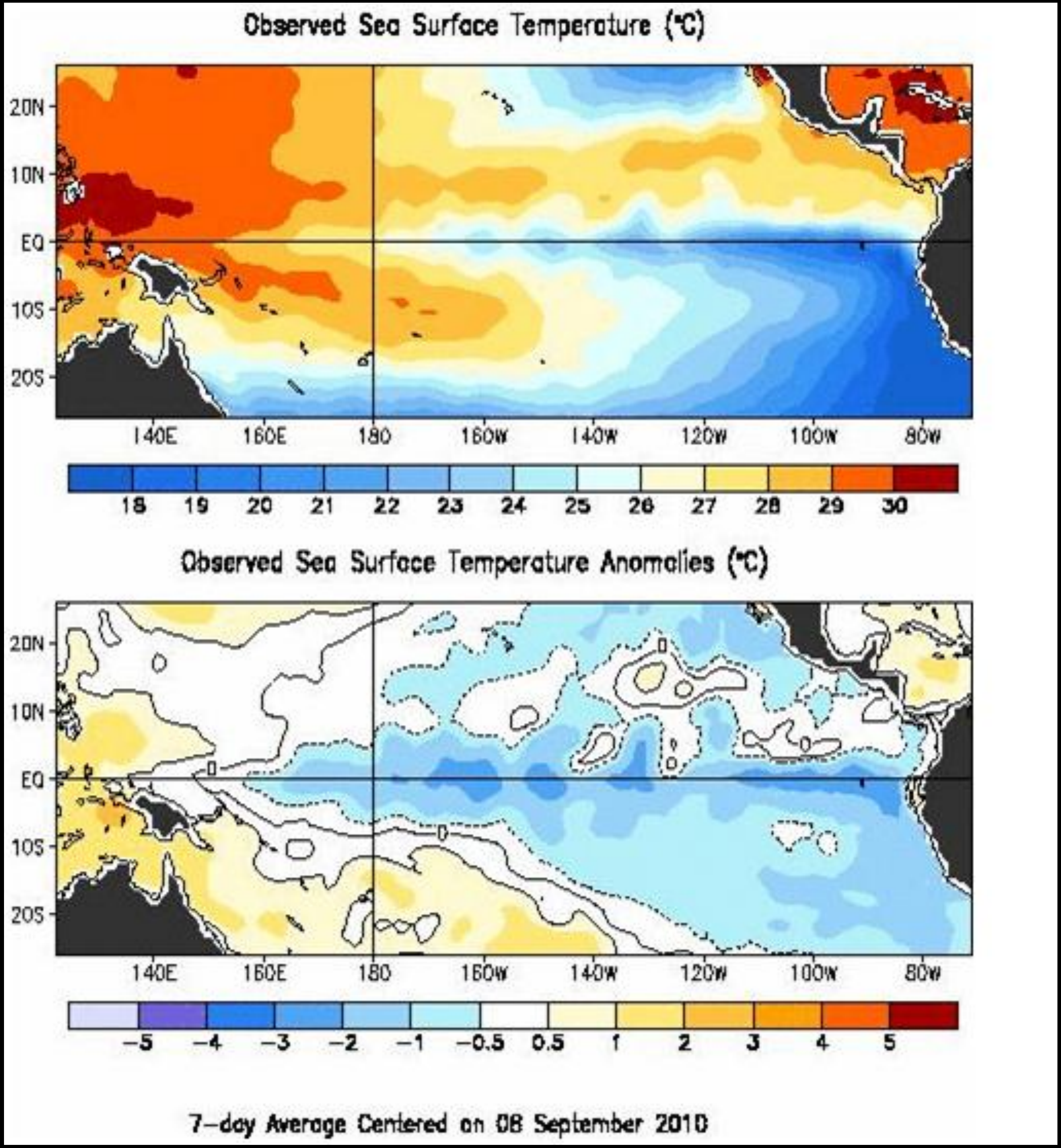
The July rainfall in the Northwest Frontier Province was 1.8 times normal.



Normal summertime jet stream



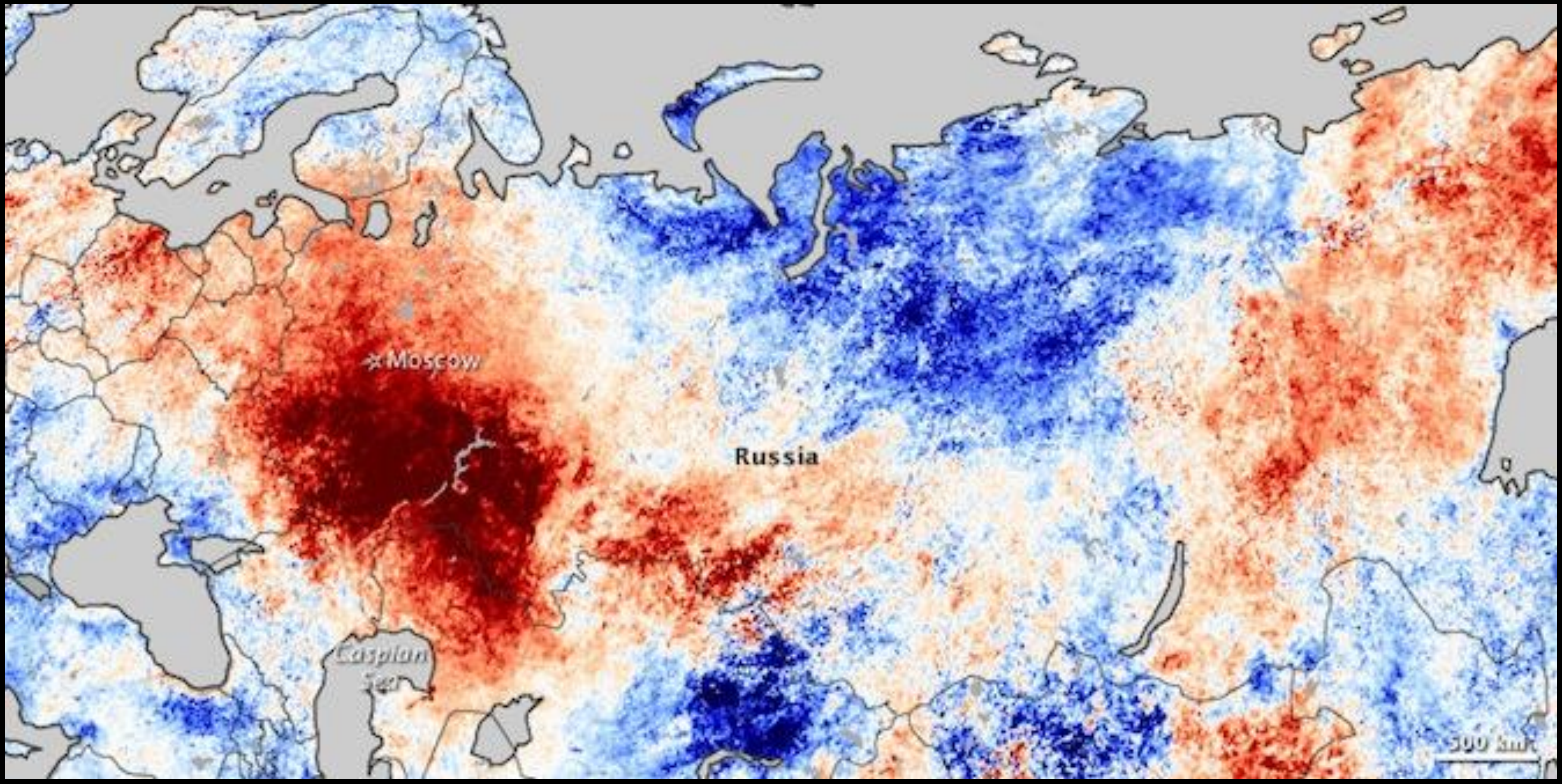
2010 summertime jet stream



Observed Sea Surface Temperature (°C)
20N
10N
EQ
10S
20S
140E
160E
180
160W
140W
120W
100W
80W
18
19
20
21
22
23
24
25
26
27
28
29
30
Observed Sea Surface Temperature Anomalies (°C)
20N
10N
EQ
10S
20S
140E
160E
180
160W
140W
120W
100W
80W
−5
−4
−3
−2
−1
−0.5
0.5
1
2
3
4
5
7−day Average Centered on 08 September 2010

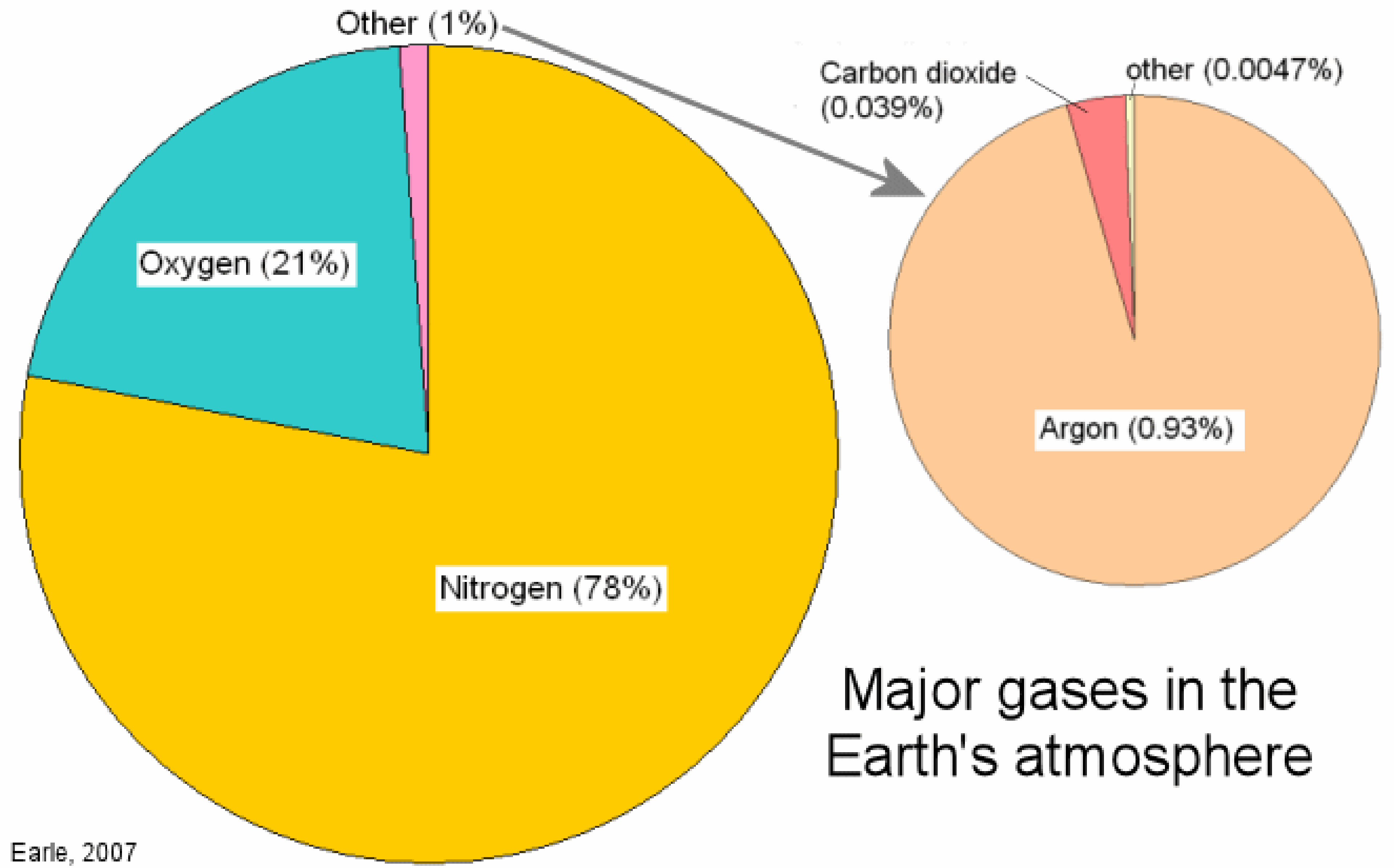
2010 La Nina

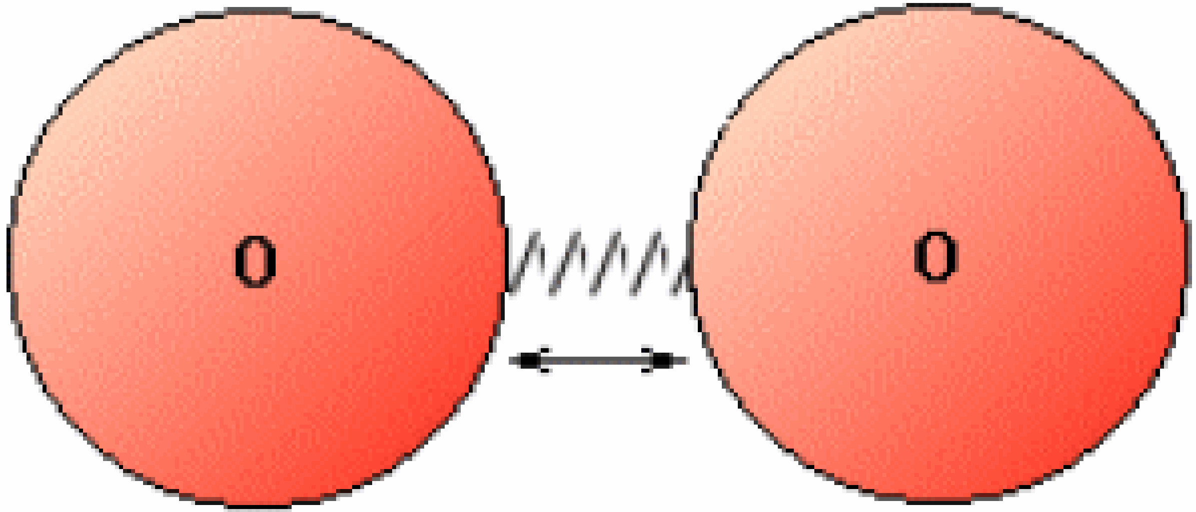
Summer heat wave in Russia and other parts of Asia



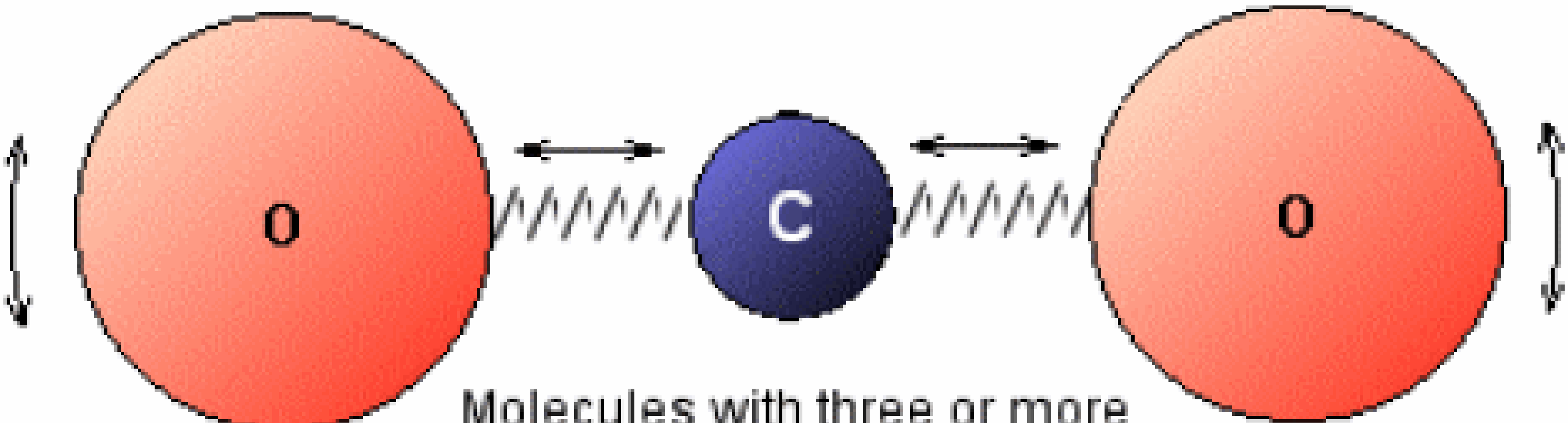
2011 - Bummer Summer?

The Greenhouse Effect

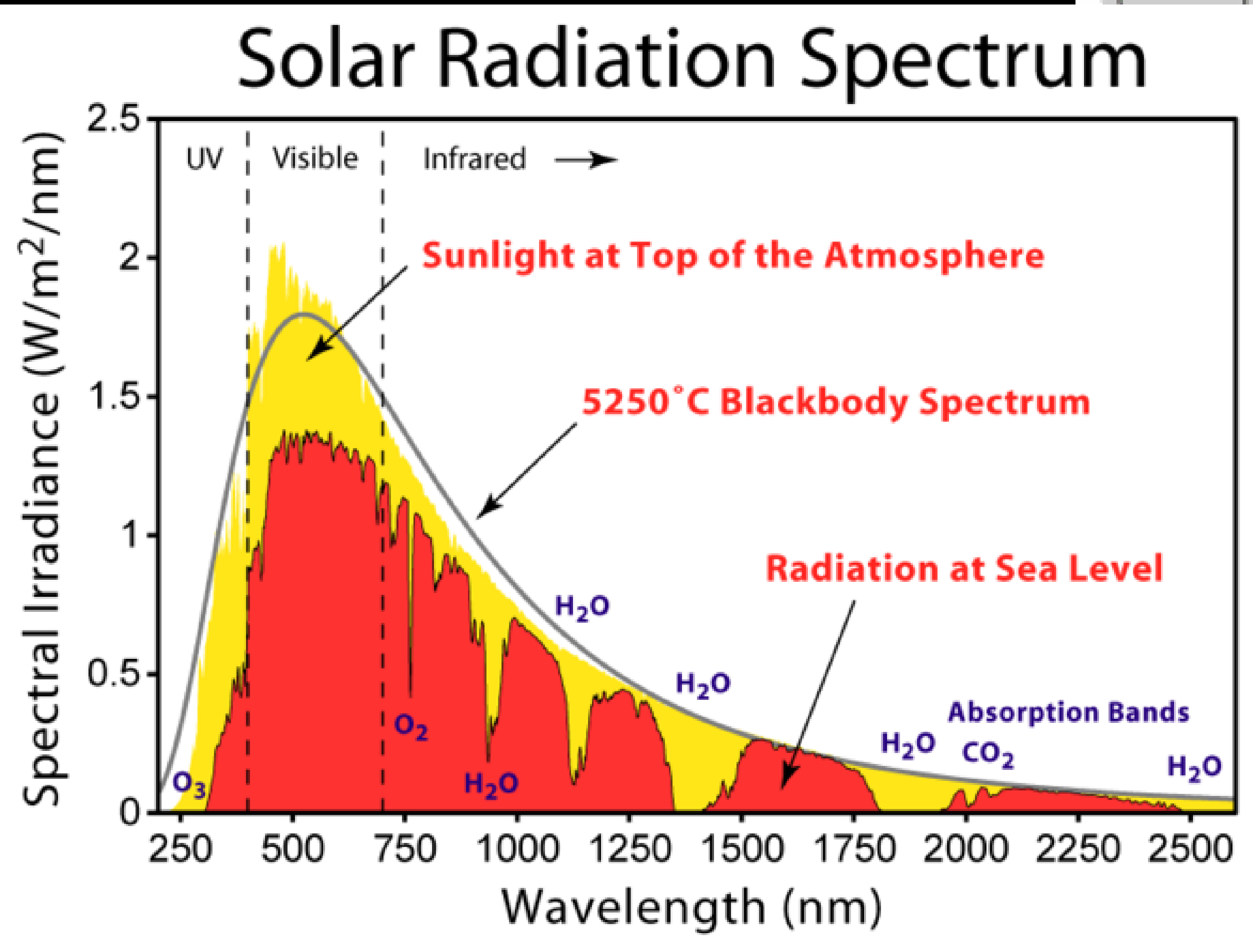

Other (1%)
Oxygen (21%)
Nitrogen (78%)
Carbon dioxide
(0.039%)
other (0.0047%)
Argon (0.93%)
Major gases in the
Earth's atmosphere
Earle, 2007

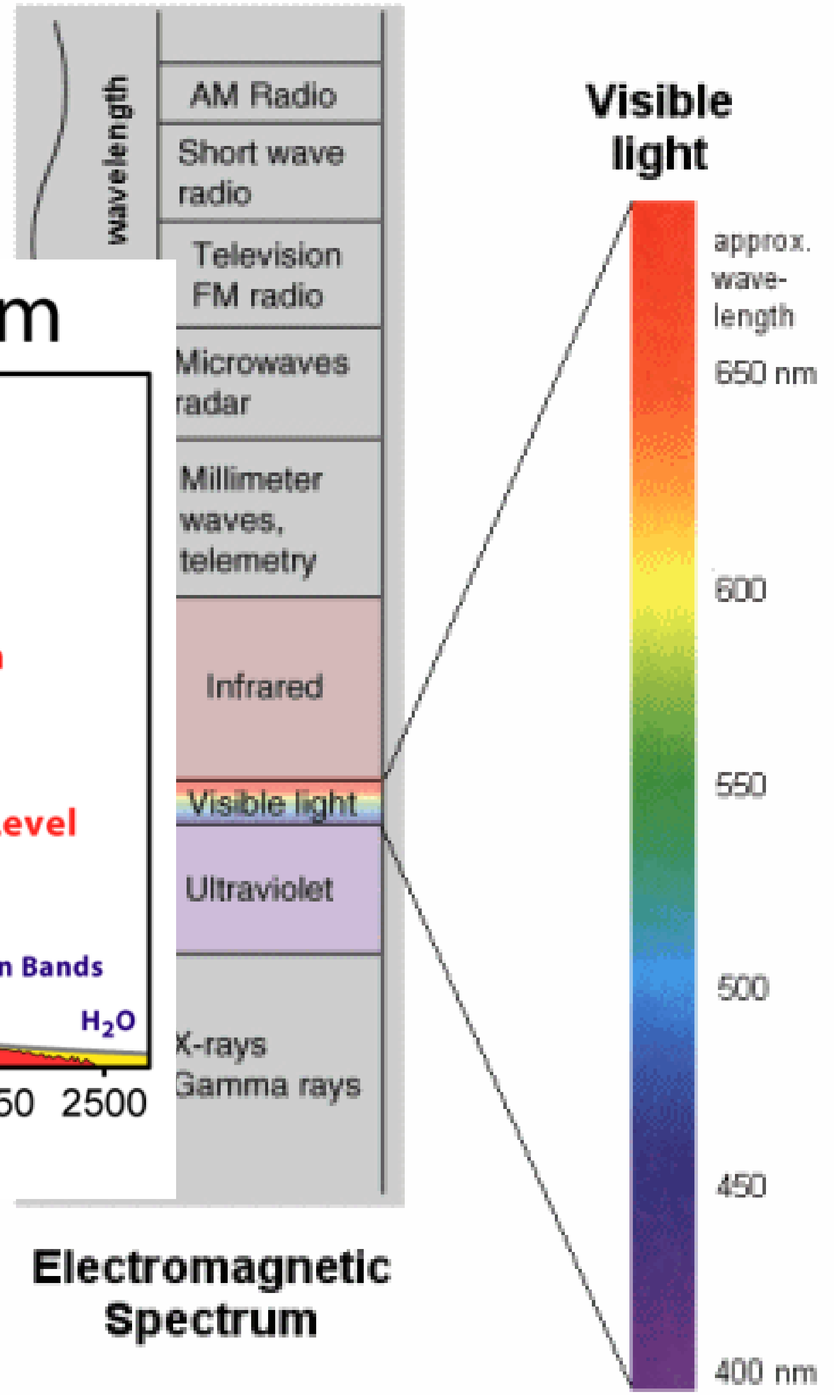


Molecules with two atoms can only vibrate back and forth



Molecules with three or more
atoms can vibrate back and forth and rotationally


Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
H₂O
H₂O
O₂
H₂O
H₂O
Absorption Bands
CO₂
H₂O
O₃
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)


wavelength
AM Radio
Short wave radio
Television FM radio
Microwaves radar
Millimeter waves, telemetry
Infrared
Visible light
Ultraviolet
X-rays
Gamma rays
Electromagnetic Spectrum
Visible light
approx. wave-length
650 nm
600
550
500
450
400 nm

Black body radiation