Examples of Spatiotemporal Climate Variability:

Maritime vs. Continental Climate & El Nino

Baylor Fox-Kemper
University of Colorado, Boulder

ICEE Workshop
Monday June 14, 2:20-3:20

What is Climate?

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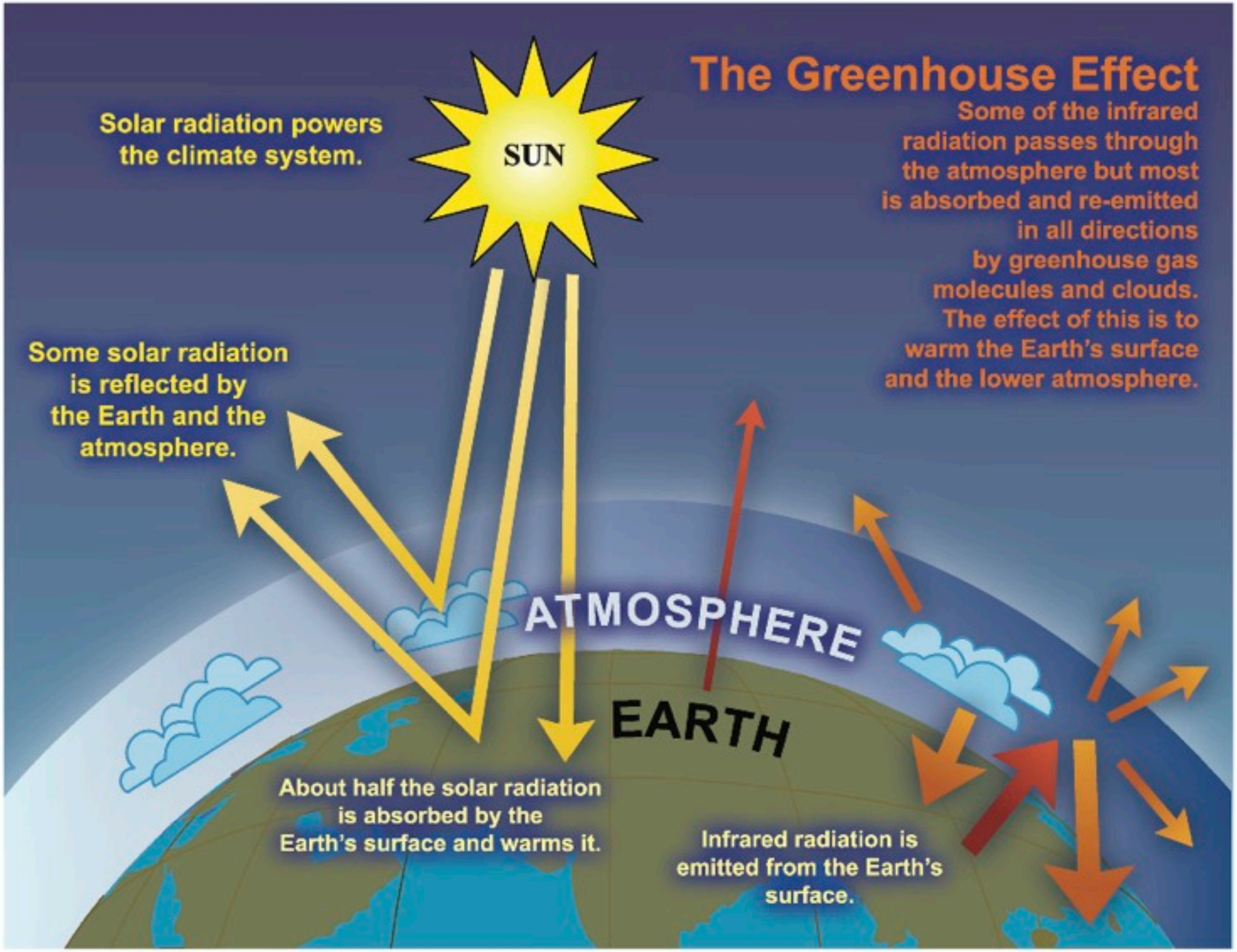
- Does climate variability affect the system's and our response to climate change?
  - Yes!

The Forcing of Climate

(image: IPCC AR4 FAQ, 2007)



FAQ 1.3, Figure 1. *An idealised model of the natural greenhouse effect. See text for explanation.*

Without Atmosphere Ocean & Ice and GHG, the Earth's Temp would be -184C to 100C (as on moon)

instead it's -90C to 58C

Who? Before the IPCC

- The Charney et al. 1979 National Academy Assessment warned of a 1.5K to 4.5K warming with doubled CO_2
- This range essentially came from two modeling groups
  - Jim Hansen's group at NASA Goddard
  - Suki Manabe's group at Princeton
- One group estimated 1.5K, the other 4.5K
- Charney worked on the first numerical weather models (1952)
- In 1906, Svante Arrhenius estimated that doubling CO_2 would raise temps by 5-6K, and halving would decrease by 4-5K
- These estimates are similar to present estimates,
  - But a lot more is known now about uncertainties, consequences, and regional effects

Images from Wikipedia, unescso.org

IPCC: Why do we know more now?

The basic climate has been clear for 100yr,
the details are being worked out now

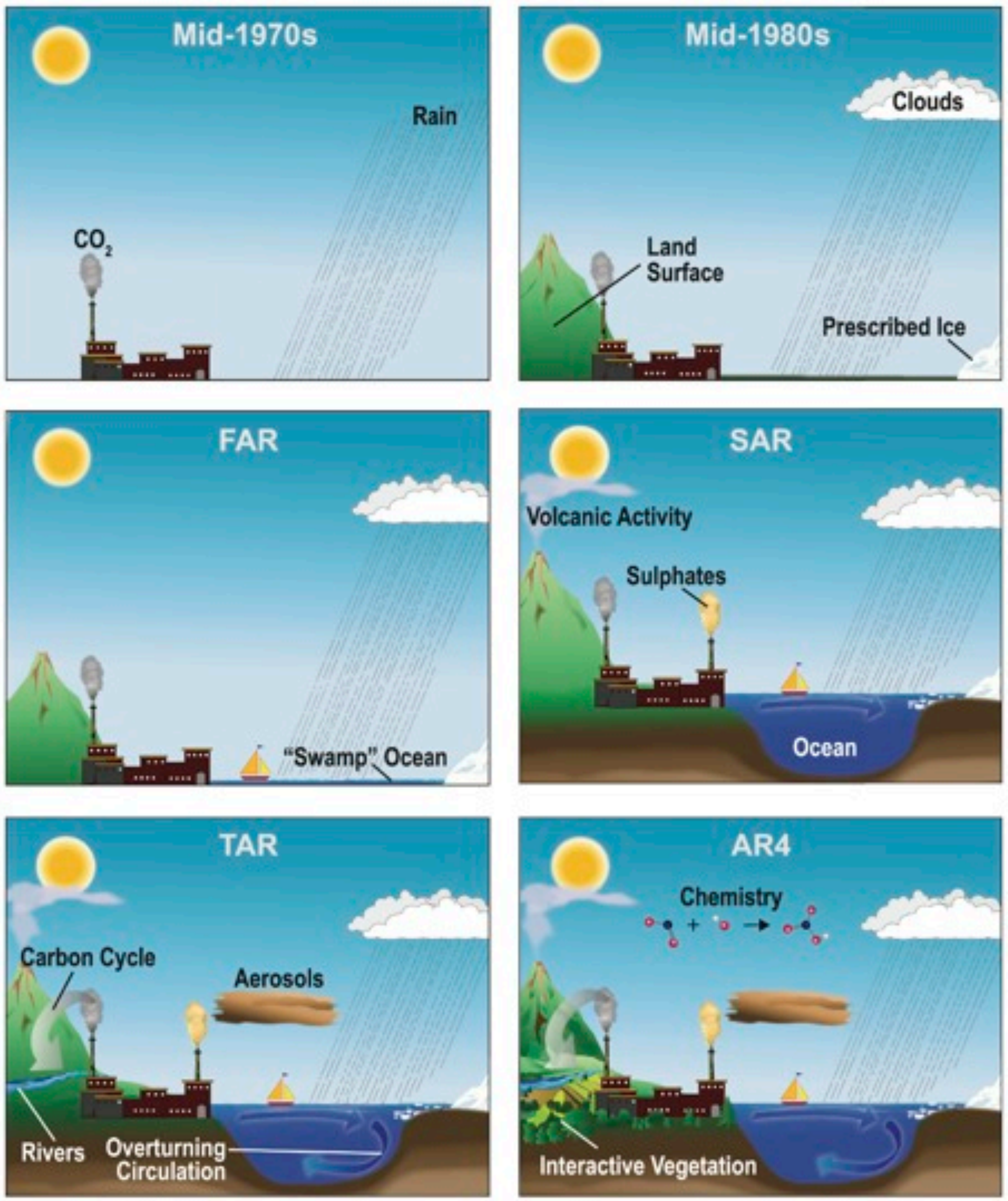


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*

images IPCC, AR4 2007

AR5:
Submesoscale Eddies!
(Fox-Kemper et al.)

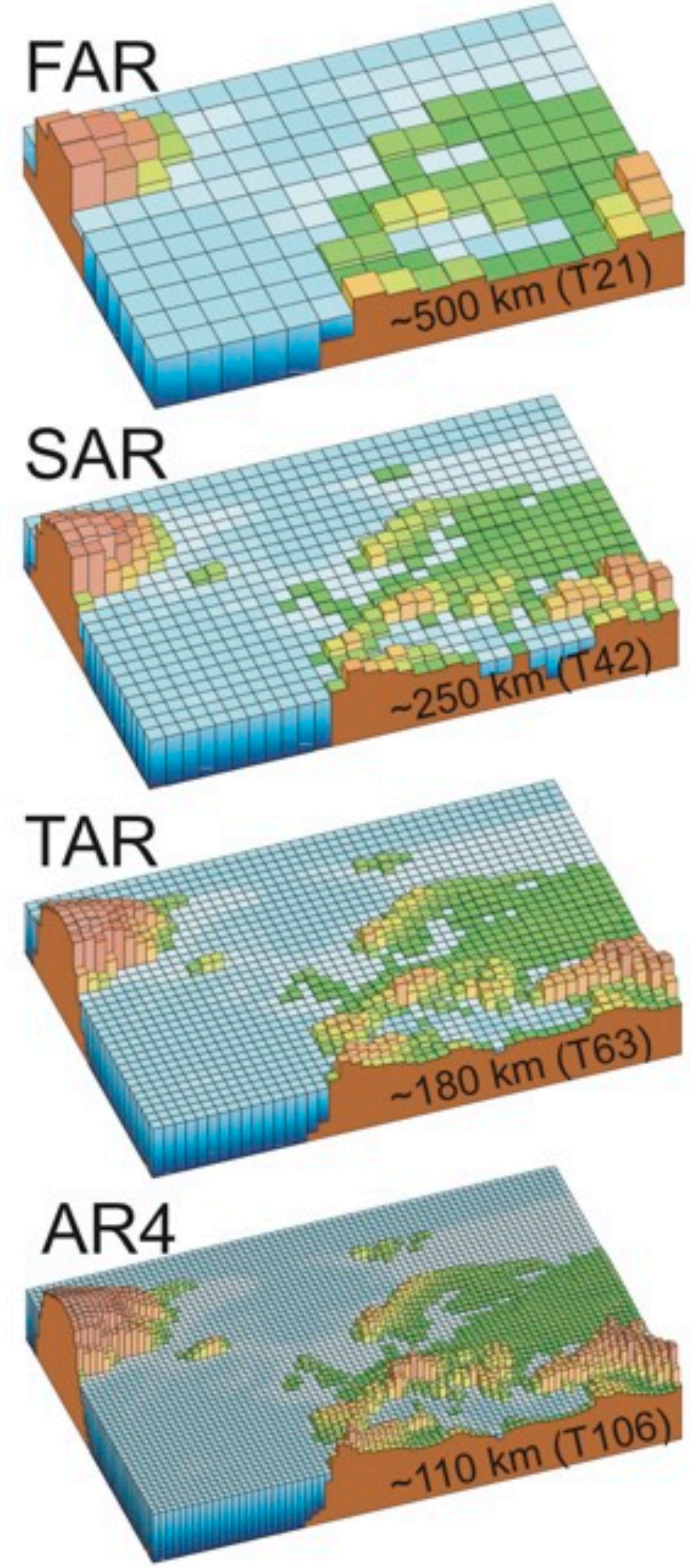


Figure 1.4. *Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe. These illustrations are representative of the most detailed horizontal resolution used for short-term climate simulations. The century-long simulations cited in IPCC Assessment Reports after the FAR were typically run with the previous generation's resolution. Vertical resolution in both atmosphere and ocean models is not shown, but it has increased comparably with the horizontal resolution, beginning typically with a single-layer slab ocean and ten atmospheric layers in the FAR and progressing to about thirty levels in both atmosphere and ocean.*

Maritime vs. Continental Climate

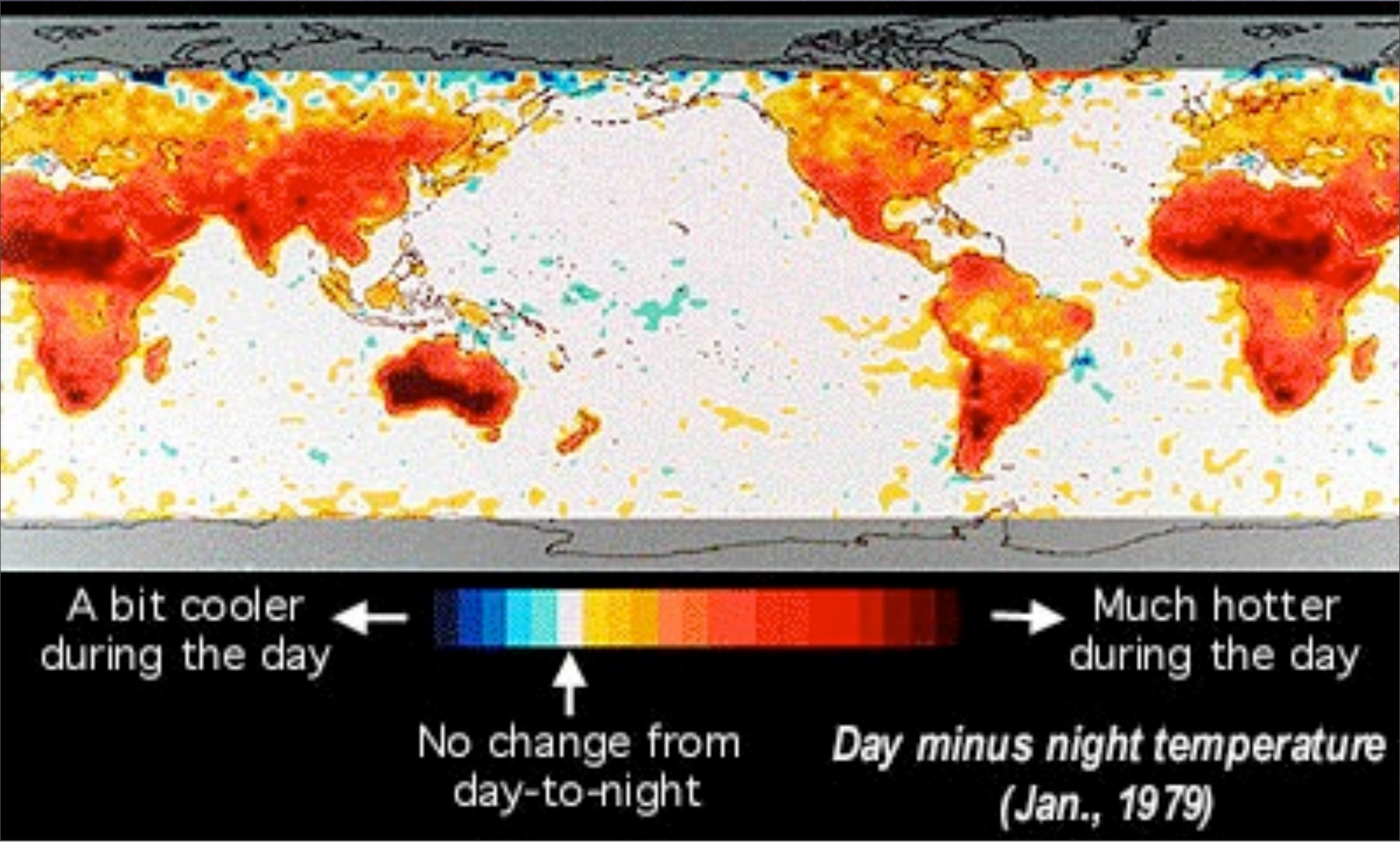
- Key Idea: Large Heat Capacity of Water & the Ocean
  - Maritime vs. Continental
  - Related:
    - Land-Sea Breezes
    - Monsoon

- Heat Capacity==Change of Temperature with Energy
  - Liquid Water (1 cal/g/°C) vs. Dry Air (0.24 cal/g/°C)

Day – night air temperature change

Land: up to 30°C Ocean: ~1°C

slide credit: Tom Marchitto



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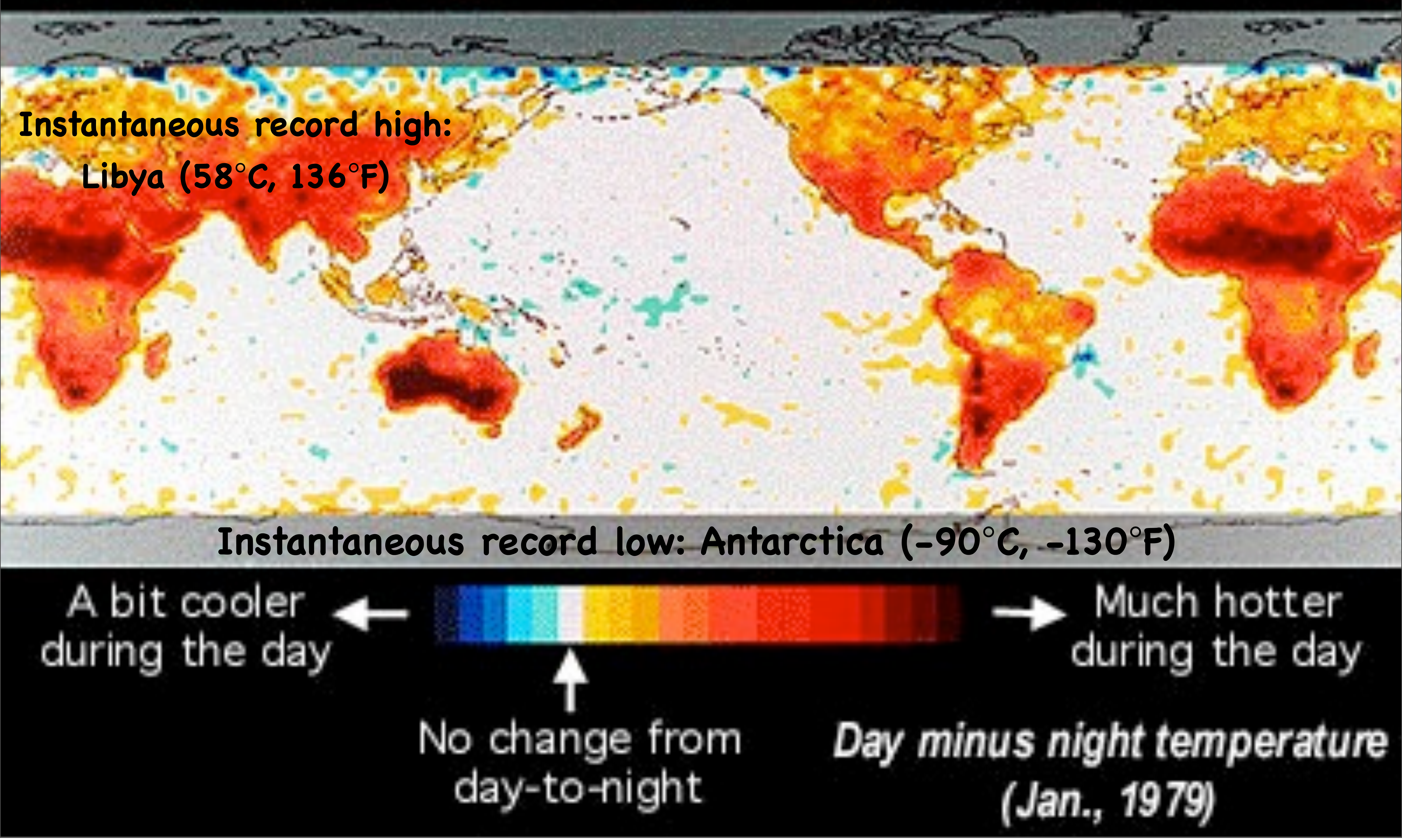

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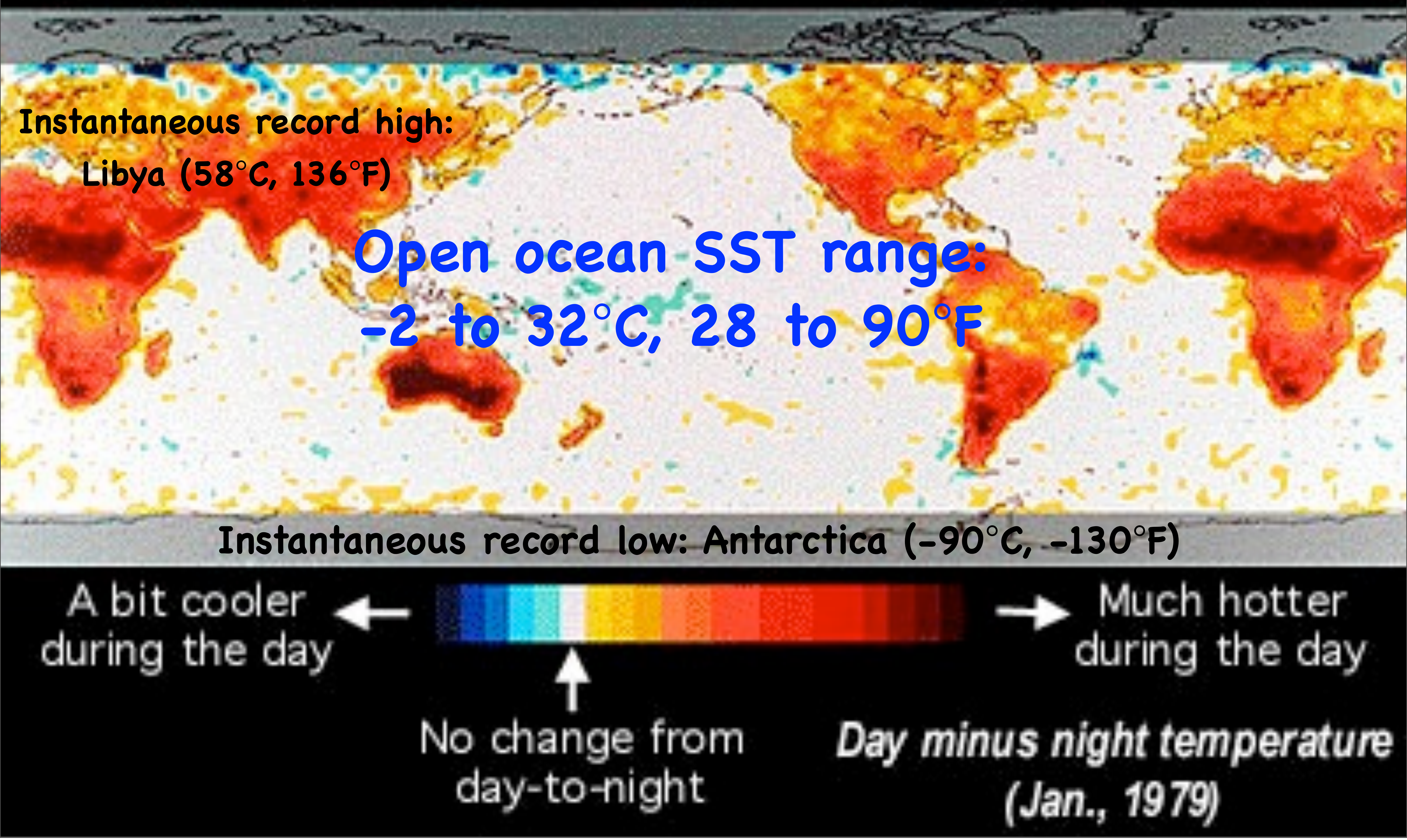
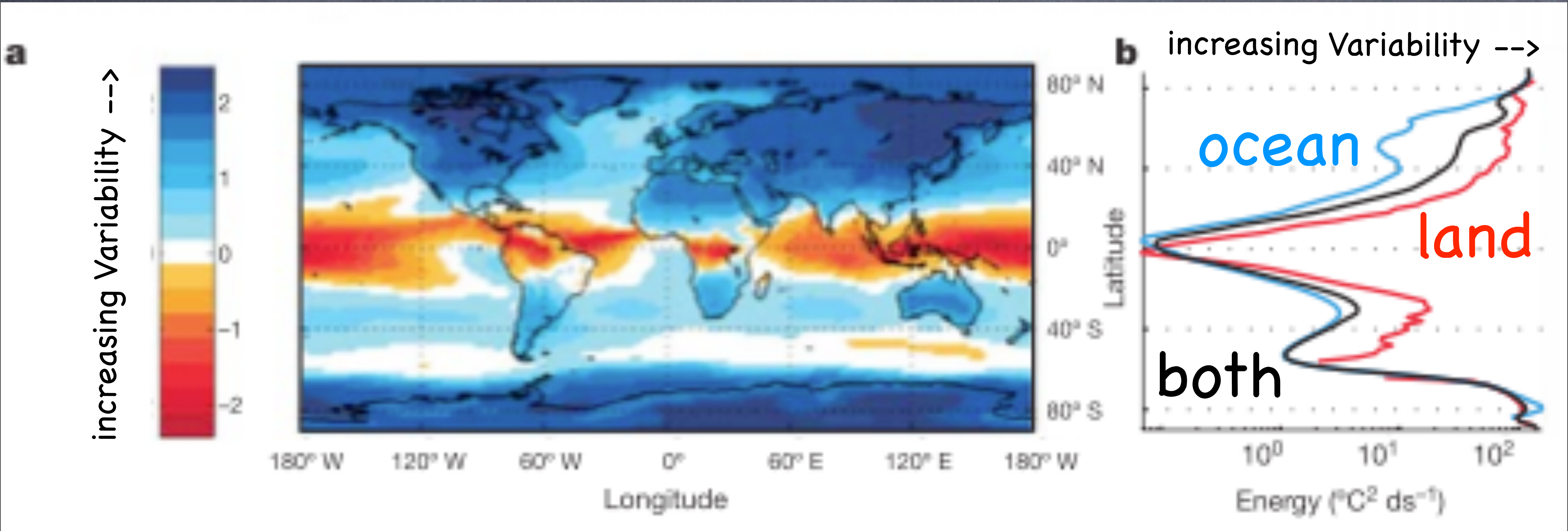
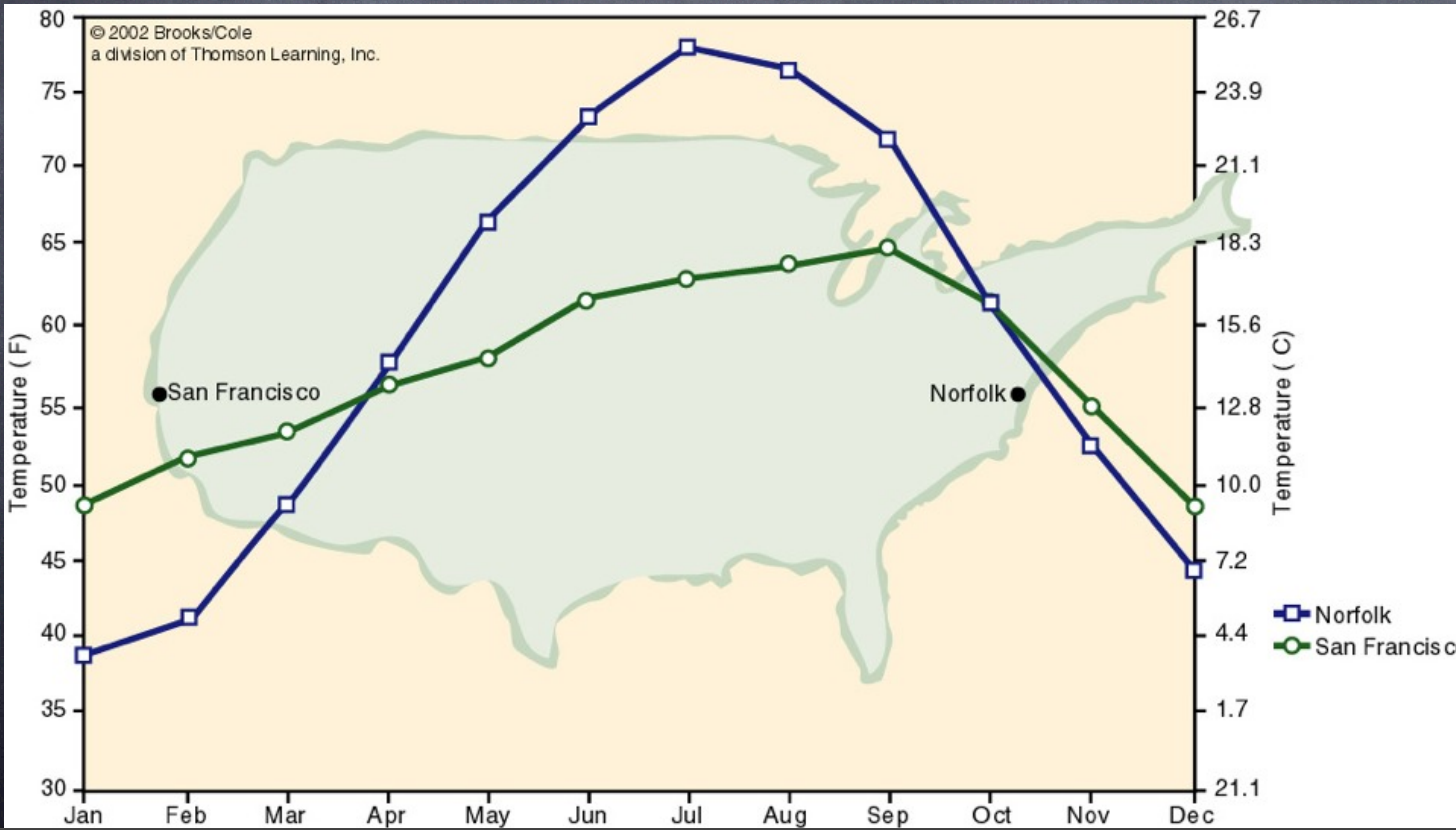


Seasonal Temperature Variability



- Similar patterns show the degree of Summer to Winter Temperature difference. (Huybers & Curry, 2006)



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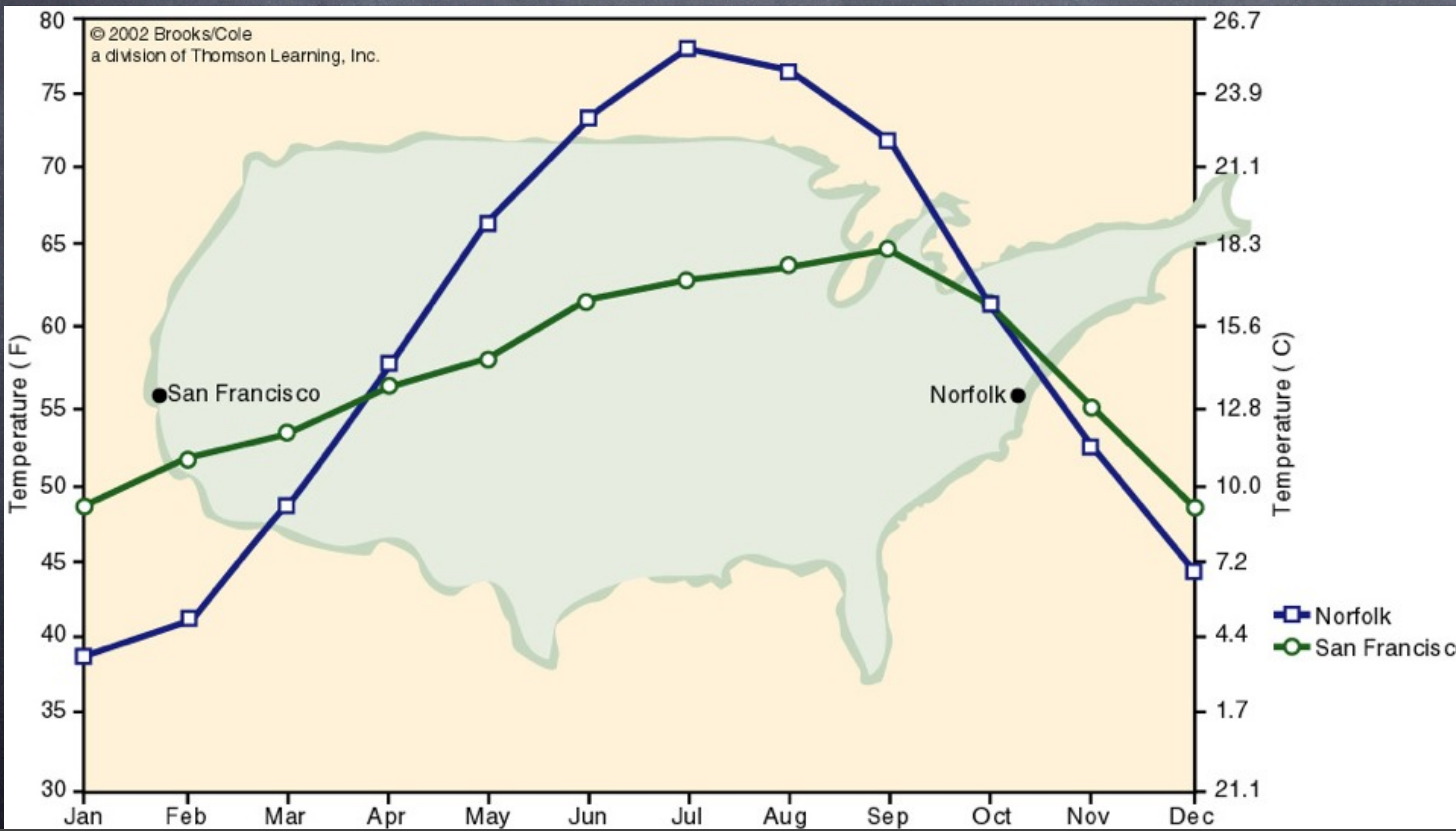
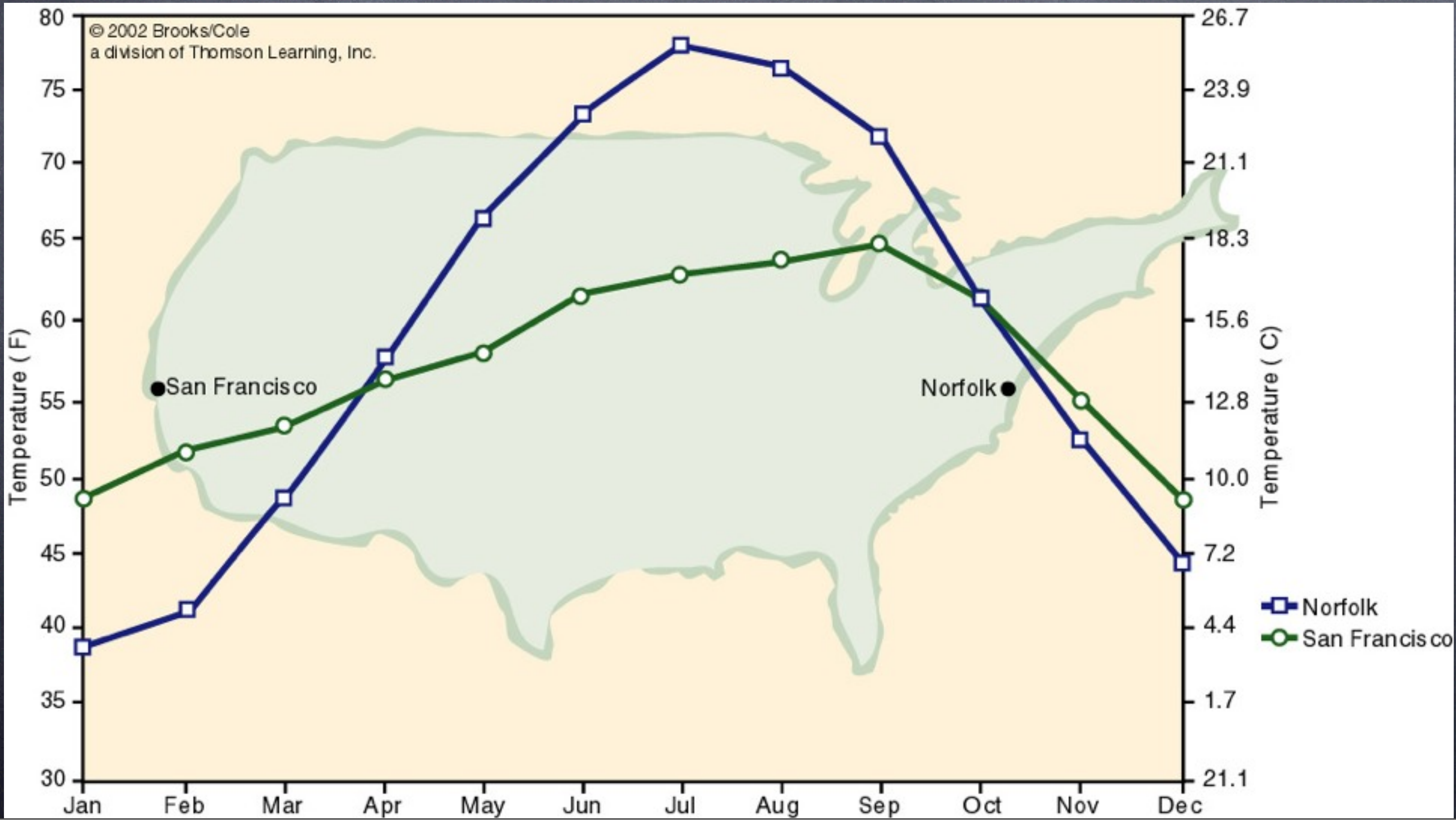
Temperature (F)
Temperature (C)
80
75
70
65
60
55
50
45
40
35
30
26.7
23.9
21.1
18.3
15.6
12.8
10.0
7.2
4.4
1.7
21.1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
San Francisco
Norfolk
Norfolk
San Francisco

Thermal inertia—Ocean Heat Capacity



Thermal inertia—Ocean Heat Capacity

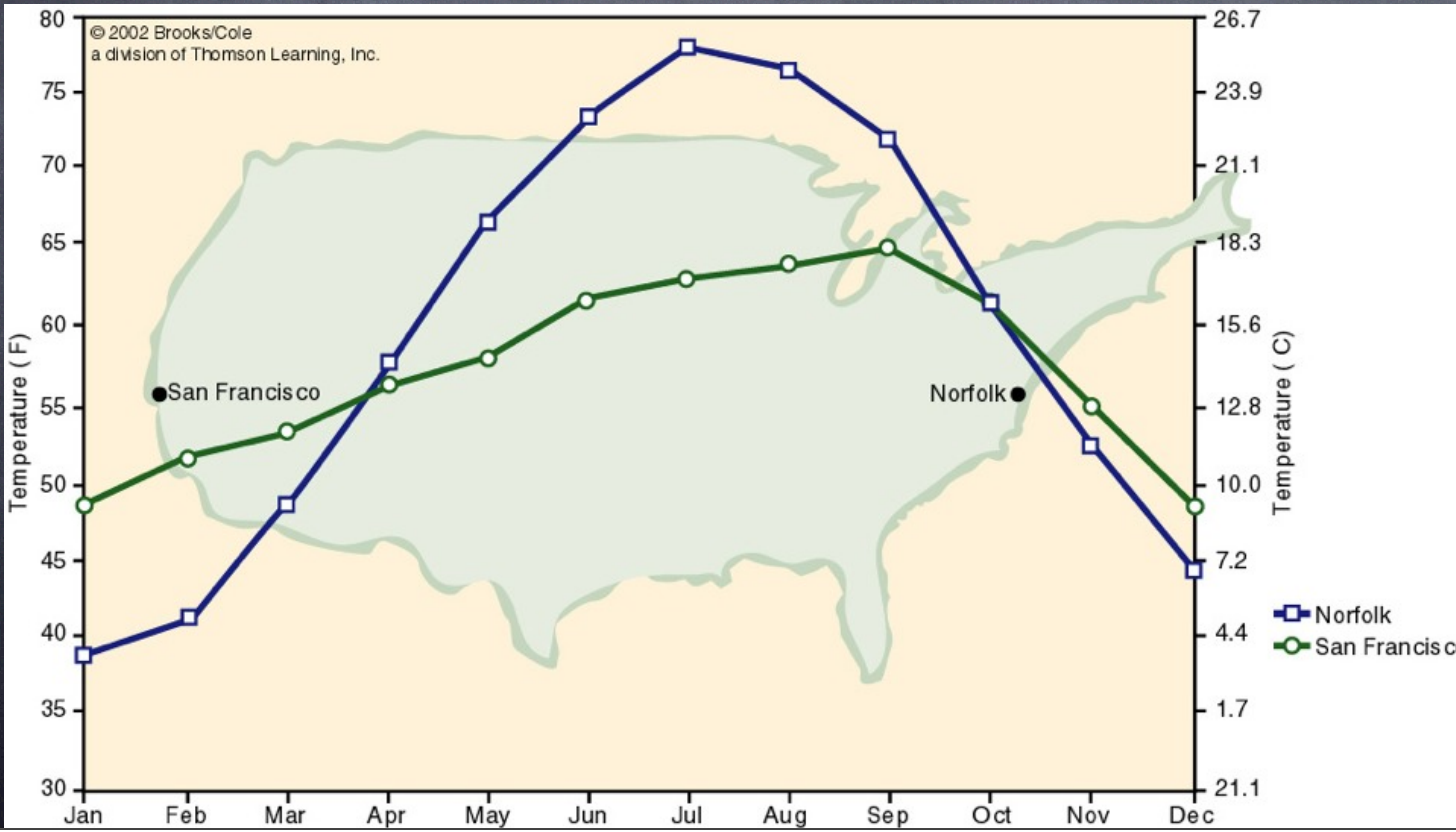
- tendency to remain at same temperature



Monday, June 7, 2010

Thermal inertia—Ocean Heat Capacity

- tendency to remain at same temperature
- San Francisco: high inertia (marine climate)



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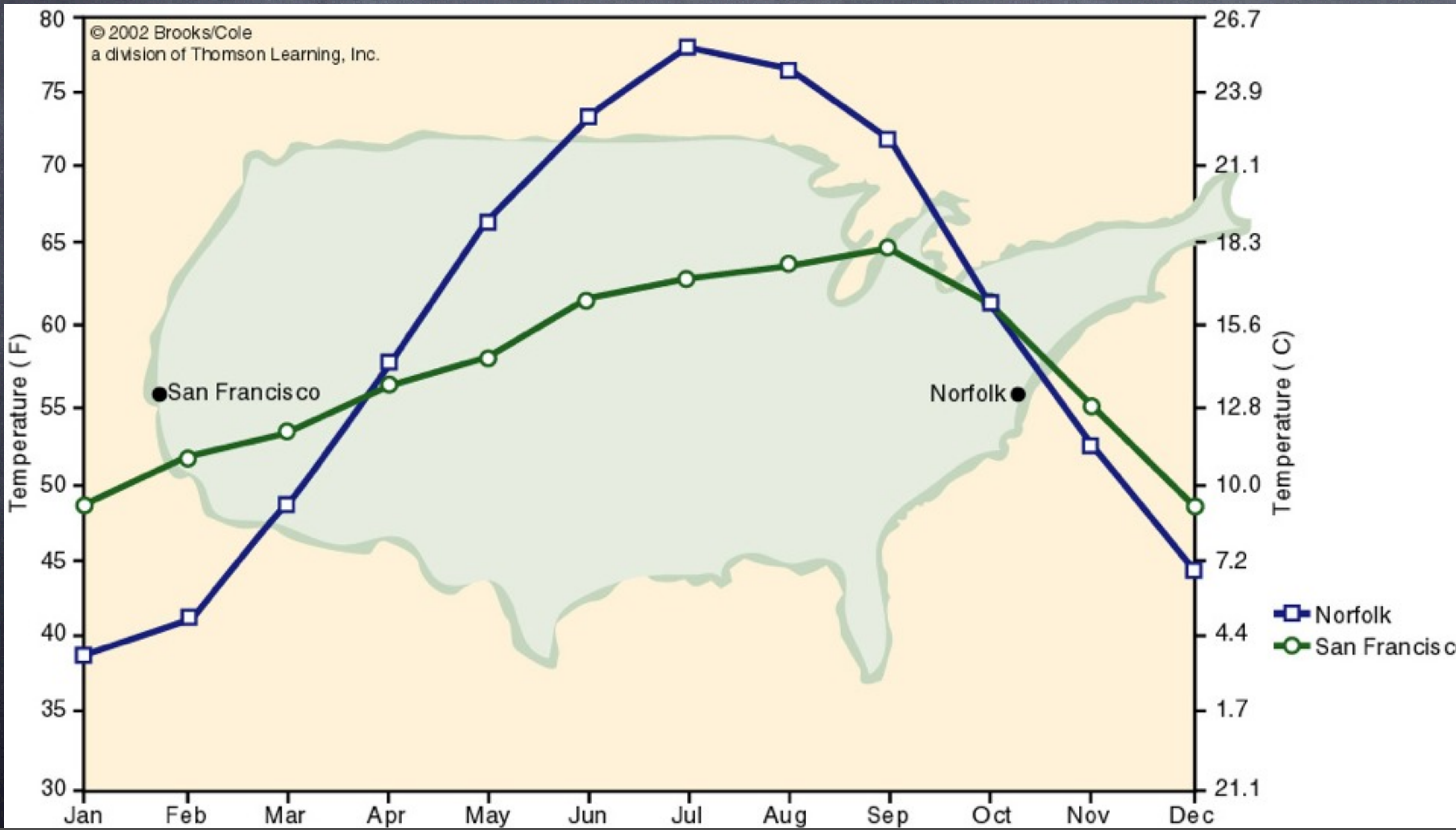

Question: Thermal inertia

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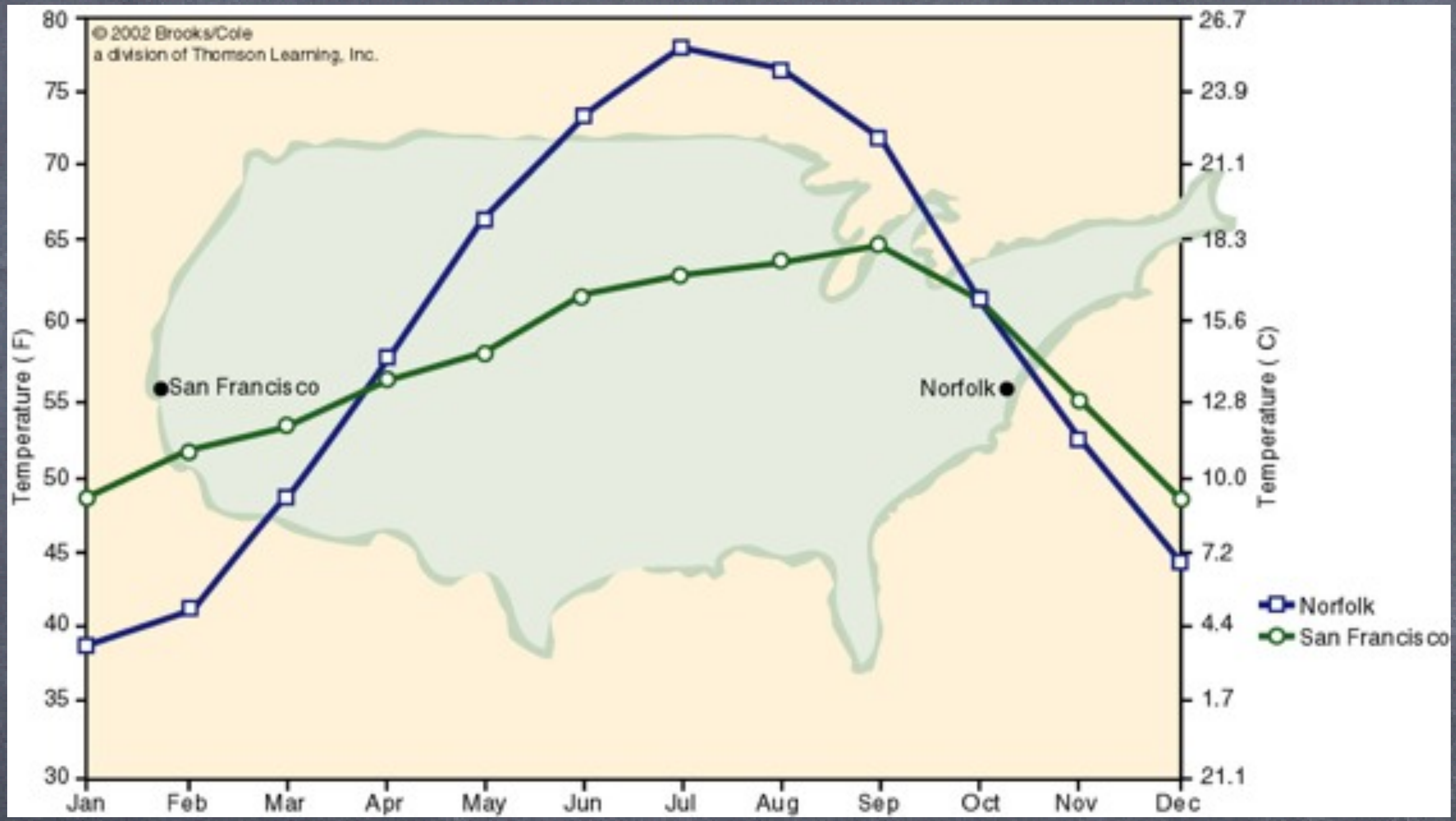

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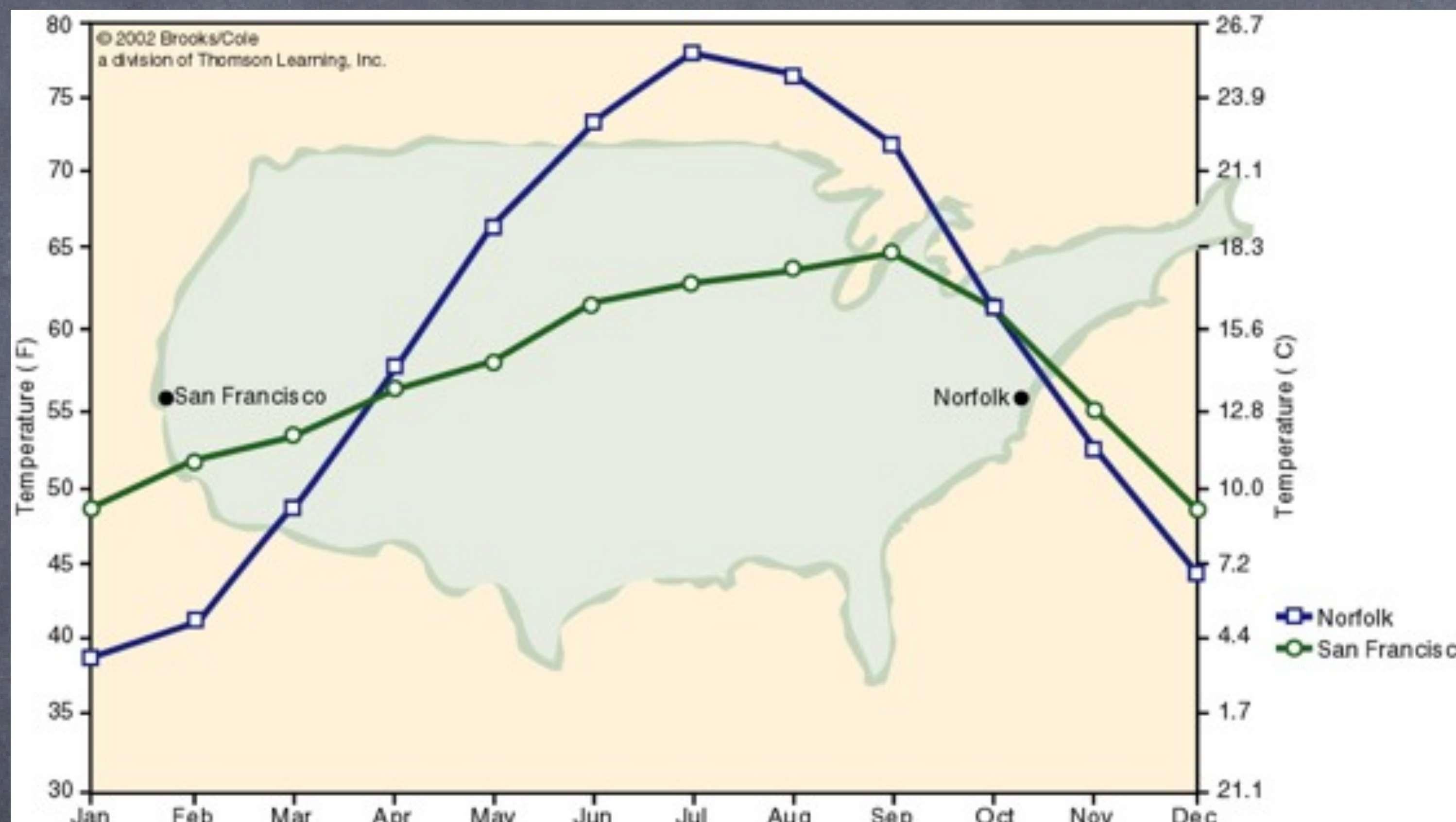


- WHICH WAY DOES THE WIND OVER THE US TEND TO
- BLOW?
- A) West to East B) East to West

Earth's Solar Heating is uneven... and SEASONAL

The why? of climate variation is redistributing this heating. The how? are climate processes.

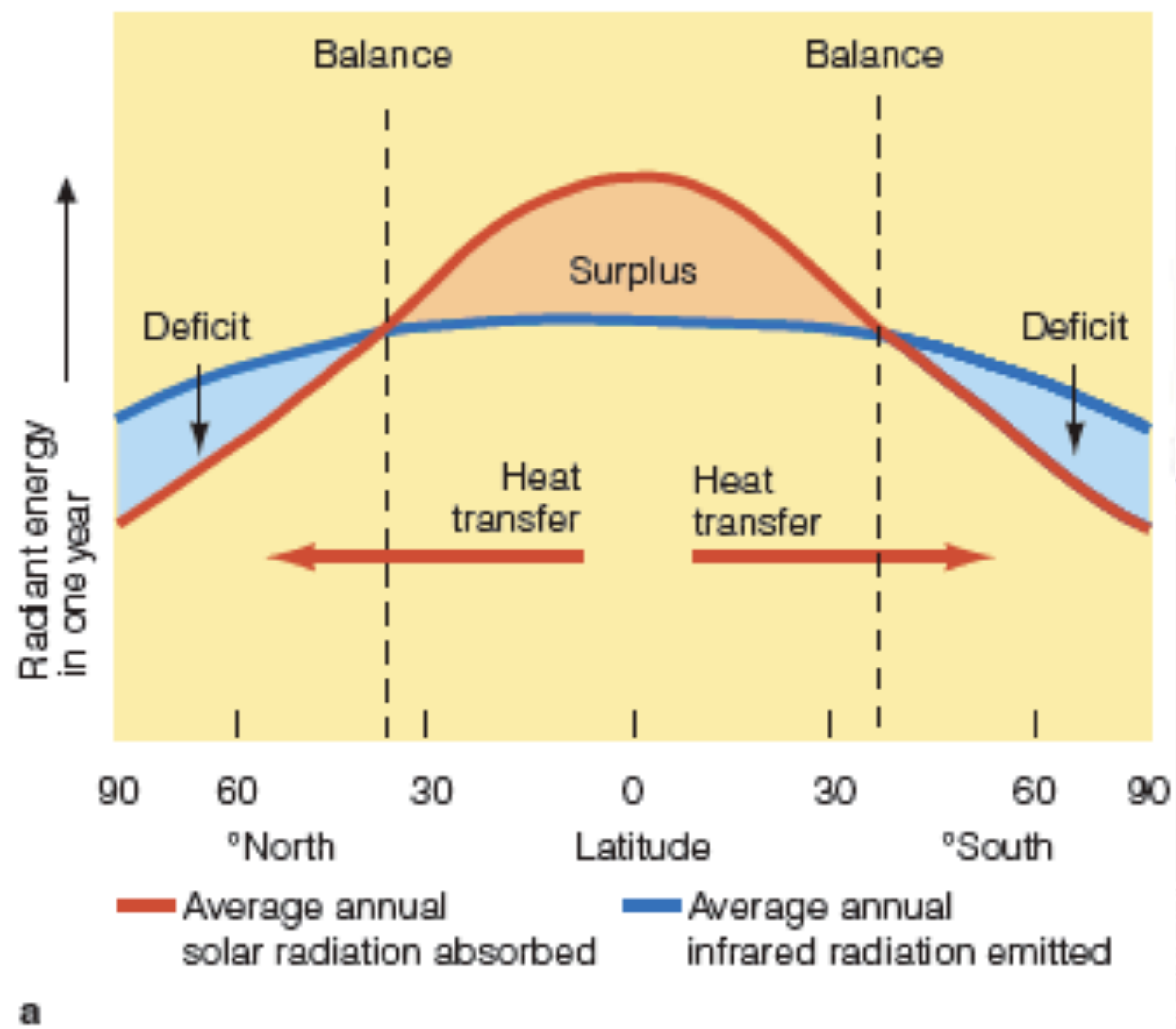
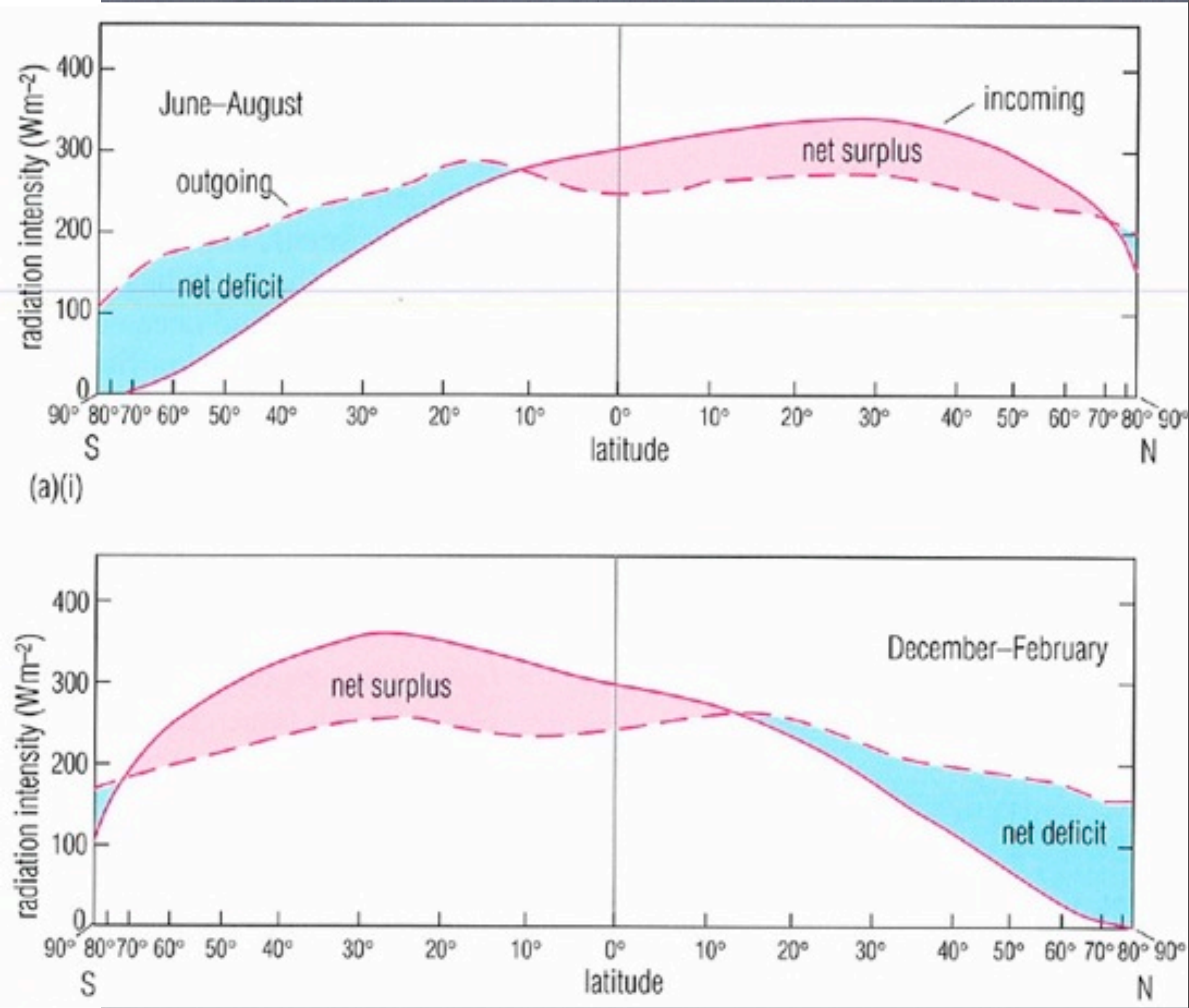


Figure 8.5 Areas of heat gain and loss on Earth's surface. **(a)** T average annual incoming solar radiation (red line) *absorbed* by Ea is shown along with the average annual infrared radiation (blue line) *emitted* by Earth. Note that polar latitudes lose more heat to space than they gain, and tropical latitudes gain more heat than they lose. Only at about 38°N and 38°S latitudes does the amount



Figures: Garrison (left); Colling, Ocean Circulation (right)

Other Regional Variations:

- Monsoons--Seasonal reversal of winds due to interhemispheric heating, changes precip.
- Orographic Effects--Upslope vs. Downslope winds strongly affect precipitation
- Land Use--Plant transpiration, soil type affects radiation & humidity; City Heat Islands from A/C & Pavement
- Ice Albedo--Sea ice is much more reflective of sun than open ocean--Same for snow vs. grassland

- Why does climate vary regionally?
  - Different components
    - Ocean
    - Ice
    - Mountains
  - Different forcing
    - By latitude
    - By season

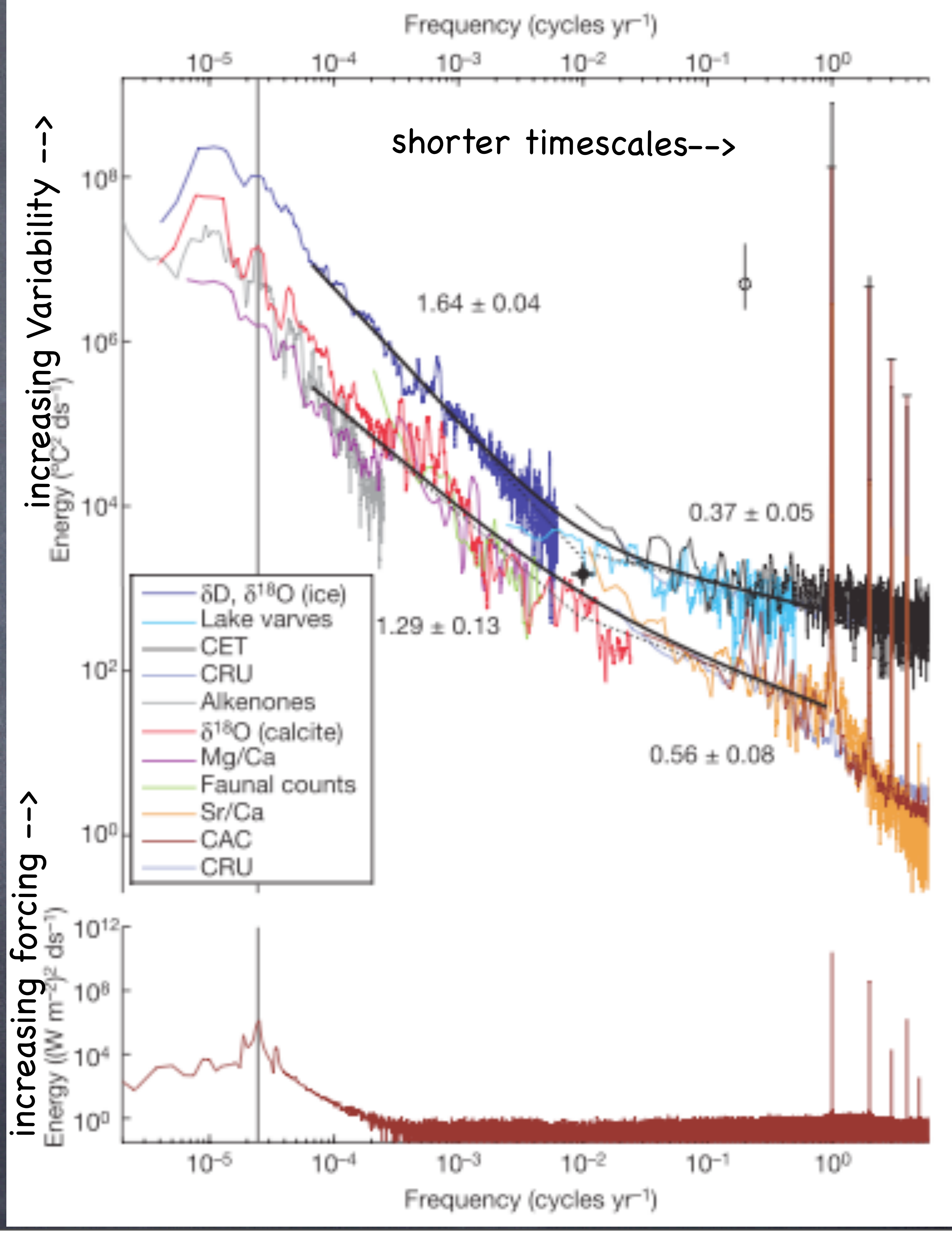
Temporal Variations of the Climate

- Why does climate vary temporally?
  - Changes in forcing
  - Slow oscillations of components
  - Chaotic nonlinear interactions

Earth System response by frequency at 65N

To:

Changing Forcing (65N Insolation, not including GHG)



Changing Forcing not enough: Underlying Resonant Oscillators?

Resonance: Strong response to forcing results from matching forcing timescales to natural system timescales

- Atmosphere is fast (<2 weeks)--No Climate Resonance
- Ocean has many climate-period oscillations
  - Tropical Waves (4yr): ENSO=El Nino/Southern Oscillation
  - Gyres (10s of yrs): NAO, PDO
  - Meridional Overturning (1000s of yrs): D-O, Ice Ages?
- Cryosphere has many climate-period oscillations (100s-10,000yr): Ice Ages

ENSO Phases (Tropical Pacific)

Warm Pool energizes convection

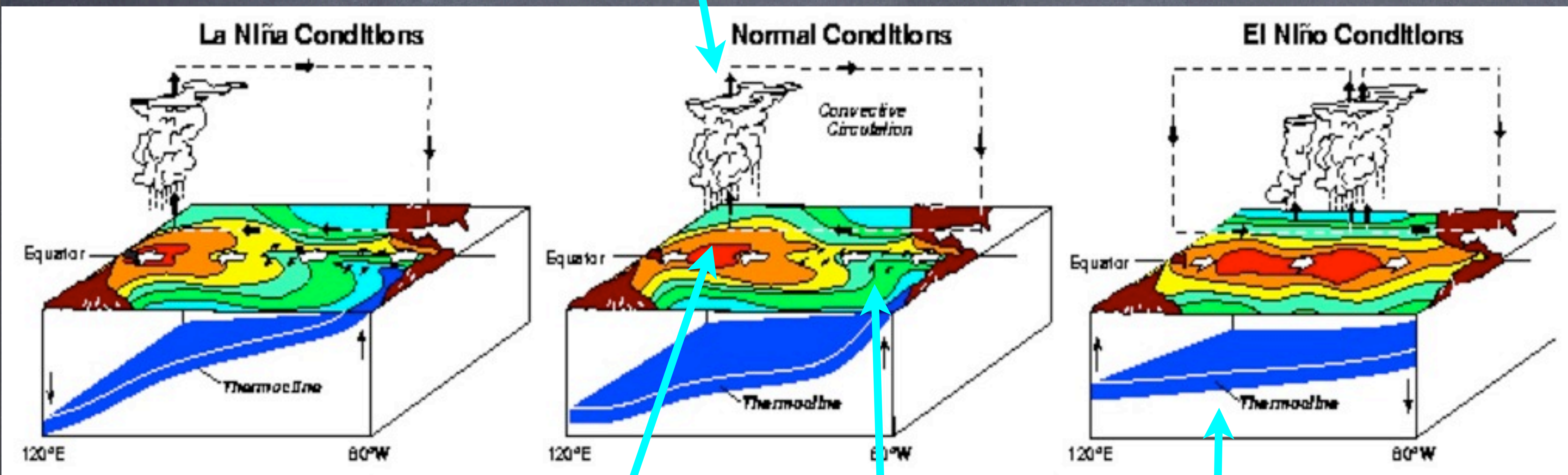


image: NOAA/PMEL

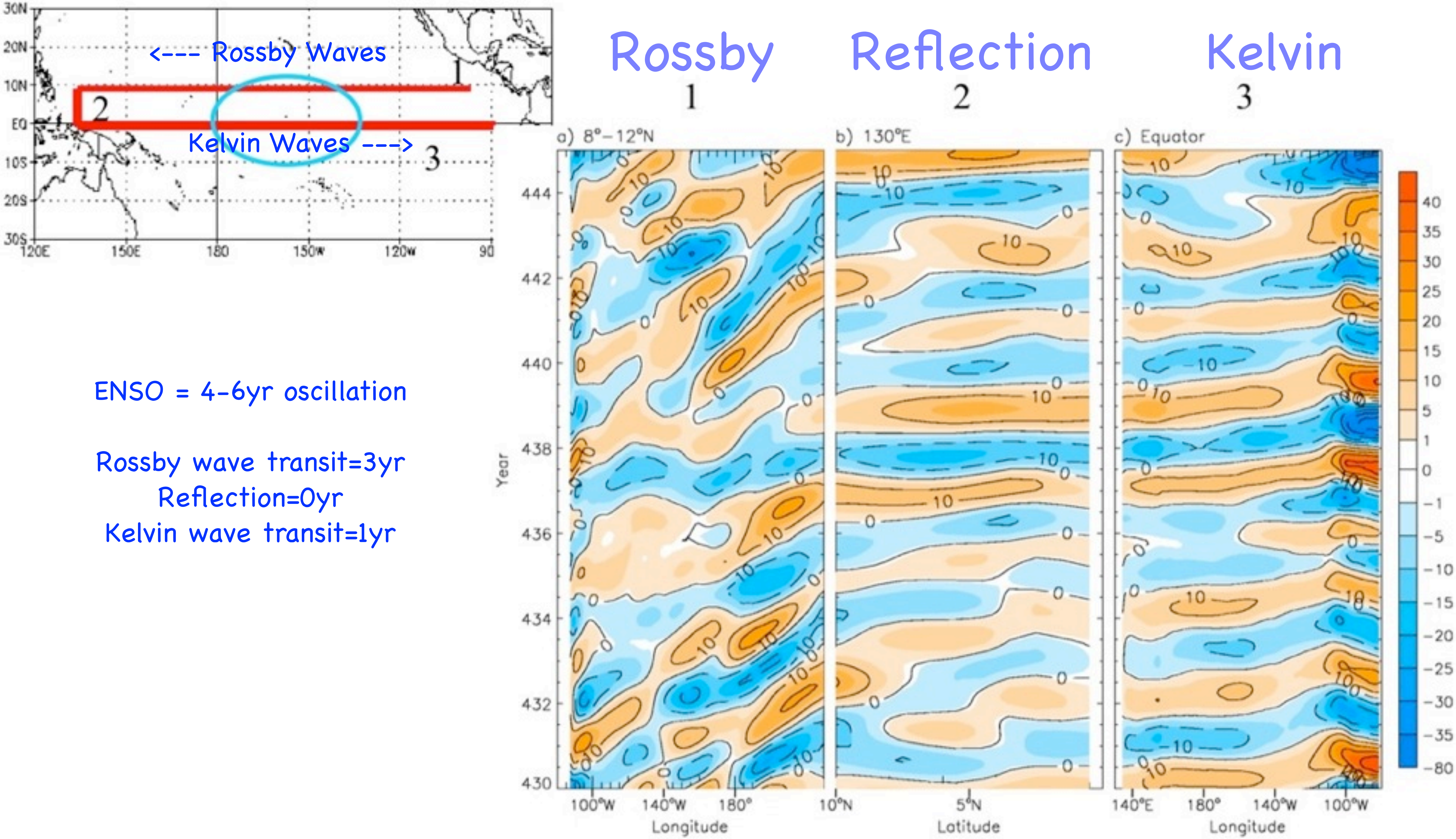
Warm Pool

Cold Tongue

Bjerknes Feedback: Wind->Tilt, Tilt->Wind

ENSO=El Nino/Southern Oscillation

The "delayed oscillator" paradigm
The role of off-equatorial waves



ENSO = 4-6yr oscillation

Rossby wave transit=3yr
Reflection=0yr
Kelvin wave transit=1yr

Image: Capotondi

Credit: NASA/JPL Air-Sea Connections

Satellites: the 1997-1998 El Nino

Winds

Sea Surface Height (Anomaly)

Sea Surface Temp.

Credit: NASA/JPL Air-Sea Connections

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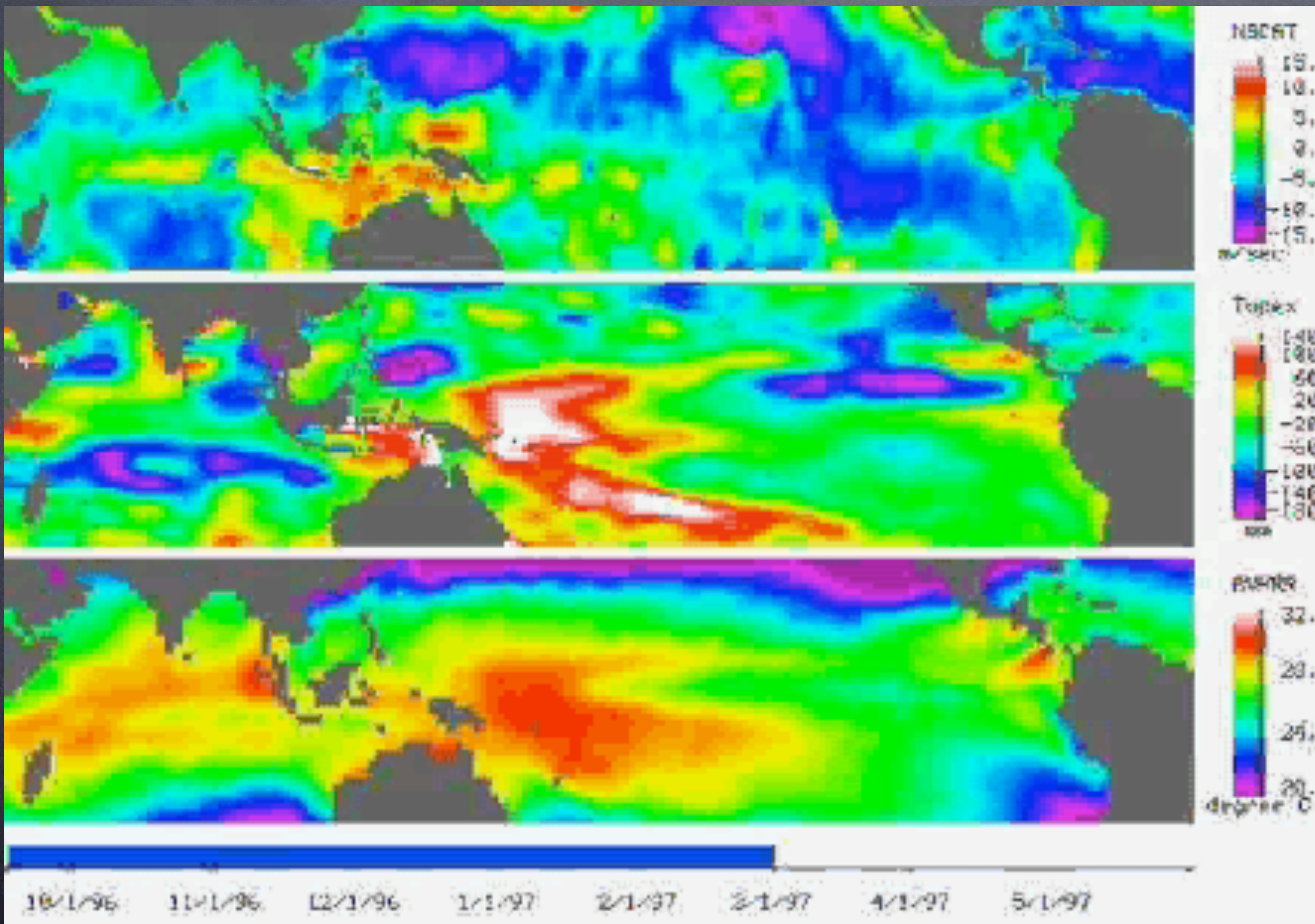

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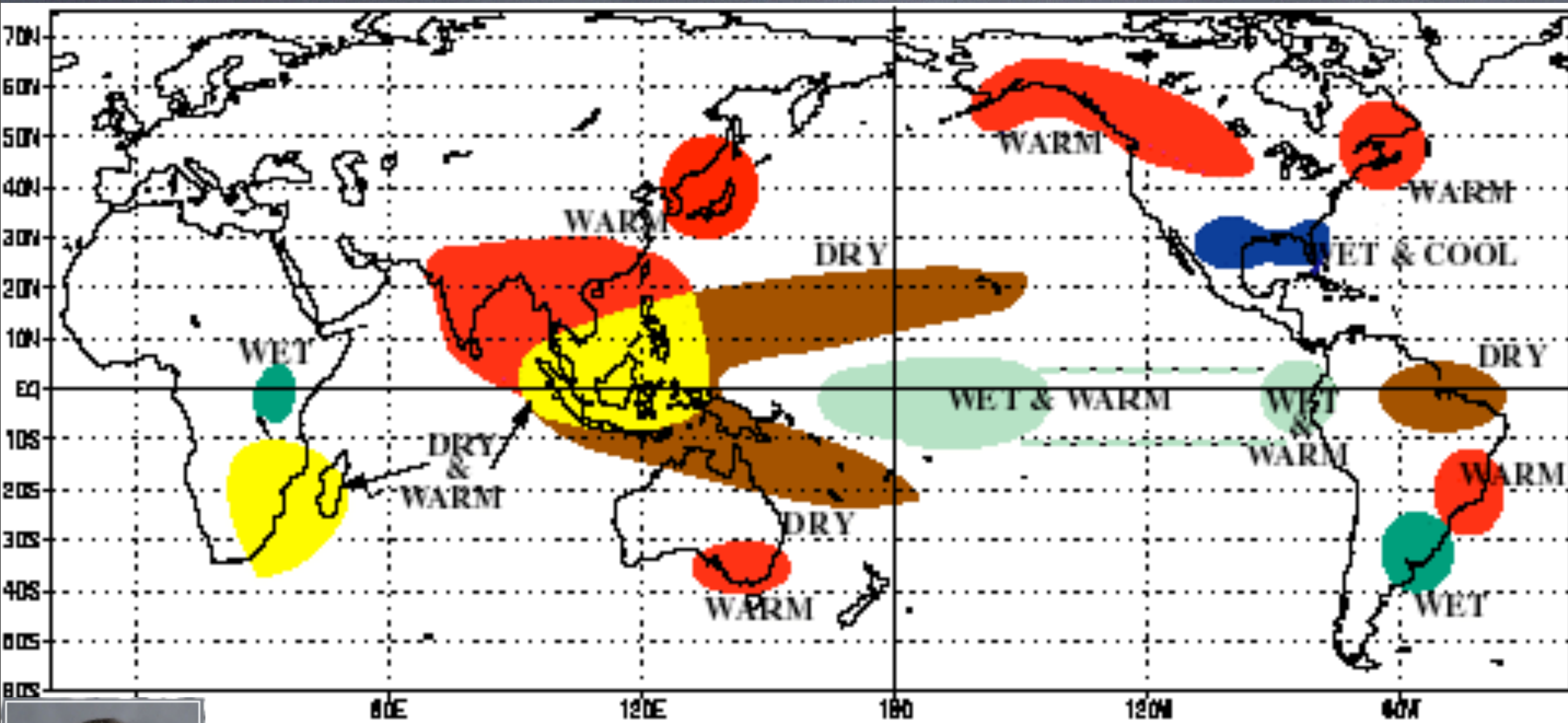
Surface
Height
(Anomaly)

Sea
Surface
Temp.

ENSO Teleconnections



Effect of ENSO is global, not only tropical

Eli Tziperman

http://www.seas.harvard.edu/climate/eli

Colorado Snow and El Nino? Depends! (www.snowforecast.com)

EL NINO YEAR SNOWFALL COMPARISON
FOR CLIMAX, CO, near Leadville at 11,500'* (PLEASE READ COMMENTS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	TOTAL
EL NINO SEASON	--	--	--	--	--	--	--	--
1965-1966	7.5	40.0	17.6	15.4	19.4	11.7	32.0	143.6
1969-1970	63.9	28.2	53.6	50.0	27.4	32.7	39.0	294.8
1972-1973	2.2	28.8	30.4	9.3	13.7	35.9	42.2	162.5
1976-1977	12.2	20.8	15.3	19.3	26.5	23.8	33.5	151.4
1982-1983	28.2	28.2	24.6	24.7	37.6	56.9	38.7	238.9
1986-1987	19.6	30.5	15.7	31.3	22.0	38.5	20.0	177.6
1991-1992	27.0	48.7	5.7	19.4	25.6	49.2	29.0	204.6
1994-1995	38.5	14.4	41.5	70.1	44.4	67.0	57.5	333.4
1997-1998	26.6	42.2	15.1	57.2	32.2	48.2	33.3	254.8
EL NINO YEAR AVERAGE SNOWFALL	25.1	31.3	24.4	33.0	27.6	40.4	36.1	217.9
"NORMAL" YEAR AVERAGE	17.7	32.3	37.7	41.0	35.3	39.5	39.5	243.0
EL NINO YEAR % OF NORMAL	142	97	65	80	78	105	91	90

*The averages above are from Climax, and are not representative of any certain resort. This is for comparative purposes only, as we also have provided a percentage of "normal".

* Based on the above, El Nino seasons do not seem to help with snowfall any, however the most recent 2 were nice, especially 1994-1995 with 333" of snow (137% of normal). Lets hope the 2002-2003' El Nino episode is similar to 1994-1995!

See also http://www.esrl.noaa.gov/psd/boulder/boulder.elnino.html

For example, for January Boulder precipitation, the average during El Niño is .45 inches; during La Niña years it is .72 inches and the total mean is .68 inches. Of the 11 El Niño years, 8 had below normal precipitation and 3 had above normal. For La Niña, 5 were below normal and 6 were above.

2010-2011 Forecast CLIMATE PREDICTION CENTER/ NCEP/NWS 3 June 2010

- ENSO Alert System Status: La Niña Watch / Final El Niño Advisory
- Synopsis: Conditions are favorable for a transition to La Niña conditions during June - August 2010.

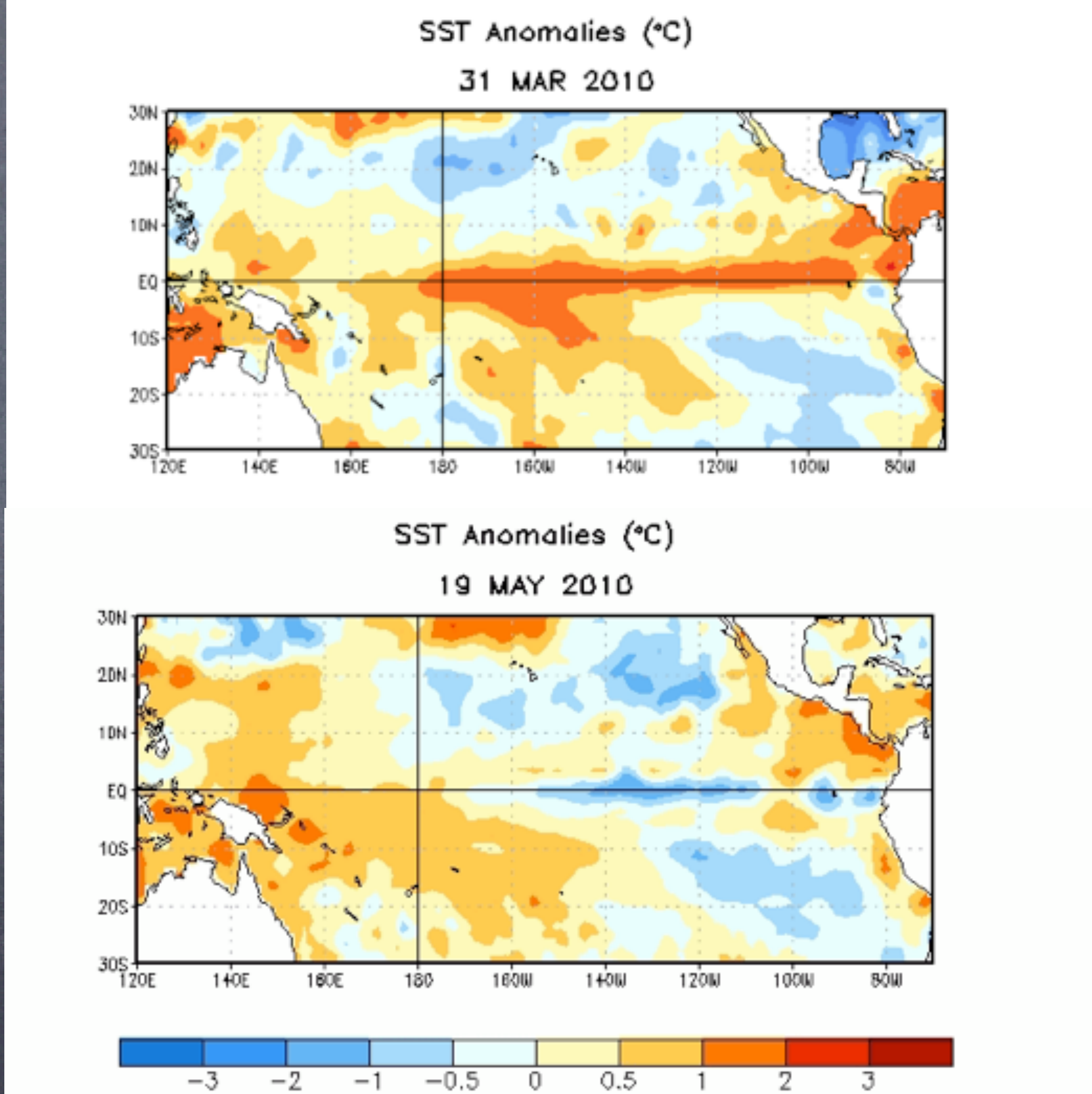


Figure 1. Average sea surface temperature (SST) anomalies (°C) for the week centered on 19 May 2010. Anomalies are computed with respect to the 1971-2000 base period weekly means (Xue et al. 2003, *J. Climate*, **16**, 1601-1612).

Chaos & Nonlinearity

- Unlike most linear systems, nonlinear systems can share energy among different frequencies
- Chaos is complex behavior arising from simple (nonlinear) governing equations
- Thus, the forcing frequency and response frequency can be non-trivially related in a chaotic system
- For example, ENSO models are usually chaotic
- Chaos & nonlinearity make climate math fun!

Conclusions

- Basic forcing of the climate is well understood, but spatiotemporal detail not so much
- Water's heat capacity plays a large role--as humidity and oceans tend to stabilize temps.
- This, and other variations in the relative roles of different climate system components, lead to large regional and temporal variability of climate
- The complexity of the system is enormous, but we are gaining understanding as observations and modeling begin to 'resolve' regional effects

Future?
Our choices are bigger than the model differences

Effects not just a few degrees C regionally & temporally

Projected changes in extremes