# The Cryosphere

## ES 383

Colby at Bigelow, September 2018

Bigelow | Laboratory for Ocean Sciences

# Three components

- Sea ice = frozen seawater.
- Ice sheets, only two exist today in the modern world: Greenland and Antarctica.
- Glaciers, both coming down from ice sheets and from mountain glaciers => Ice shelves, icebergs, and permanent and seasonal snowfields.

Sea ice

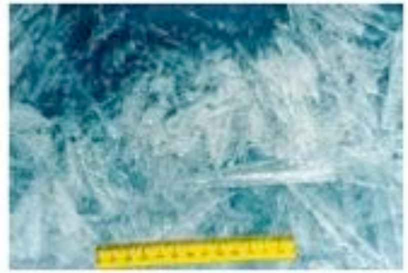
- Frozen sea water
- Forms, grows, melts in the ocean
- Grows in winter, melts in summer, can survive multiple years
- Typical thickness:
  - first year ice <= ~1.8m
  - 2-3 year old 2–3m,
  - 10 year old ~ 5 – 6 m

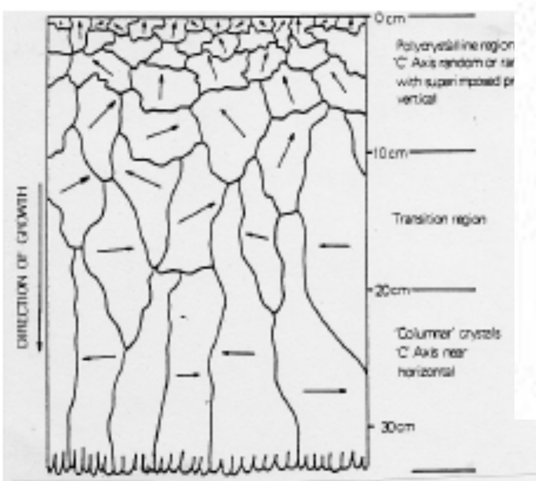
# Sea ice formation


First-year ice
30-150 cm thick, typically snow covered

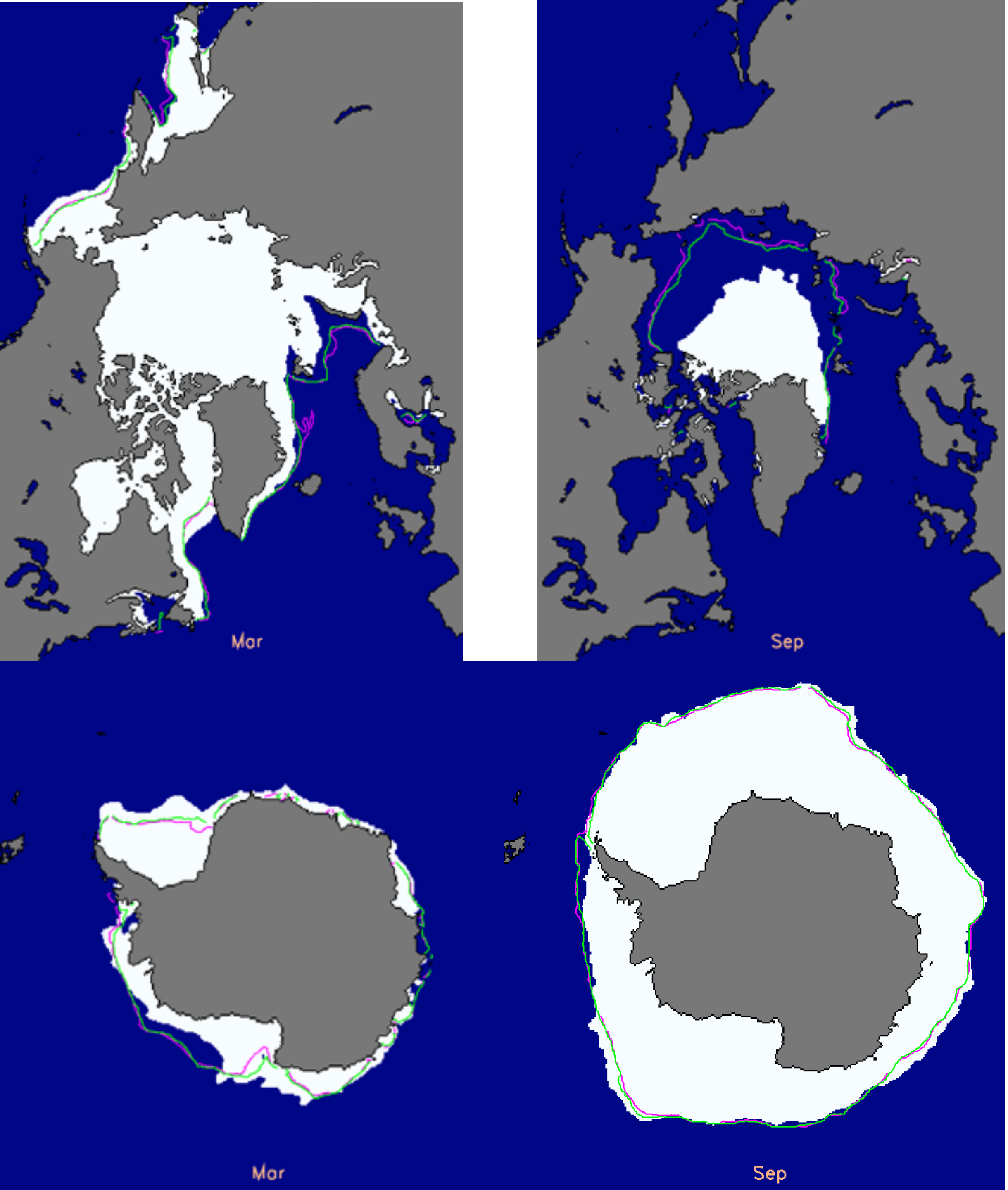


http://nsidc.org/cryosphere



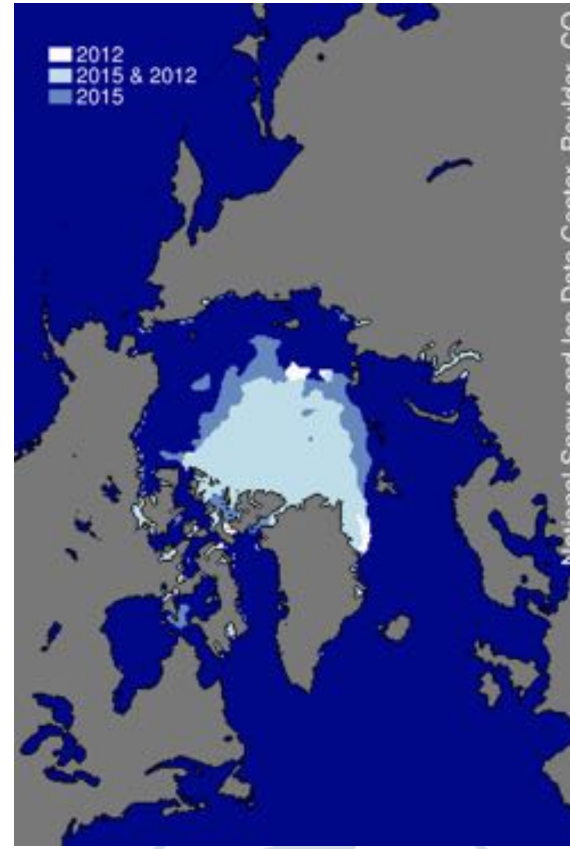

0 cm
Polycrystalline region
'C' Axis random or ra
with superimposed pr
vertical
10 cm
Transition region
20 cm
'Columnar' crystals
'C' Axis near
horizontal
30 cm
DIRECTION OF GROWTH

Bigelo




2012

Arctic Ocean




http://nsidc.org/cryosphere/sotc/sea_ice_animation_ant.html

# Arctic sea ice extent

min = https://www.youtube.com/watch?v=HgyQyyqa4tM
max = https://www.youtube.com/watch?v=RTslvm60aI4
https://www.youtube.com/watch?v=c6jX9URzZWg

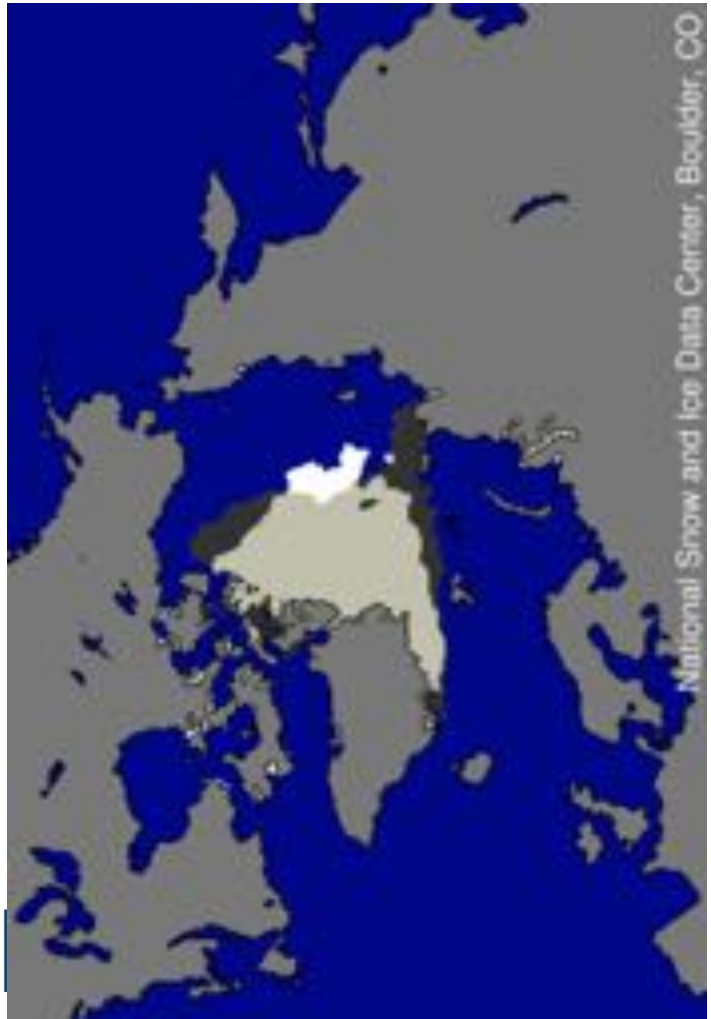
2007 vs. 2012

SEPT. ICE EXTENT

Dark gray = 2007 only;

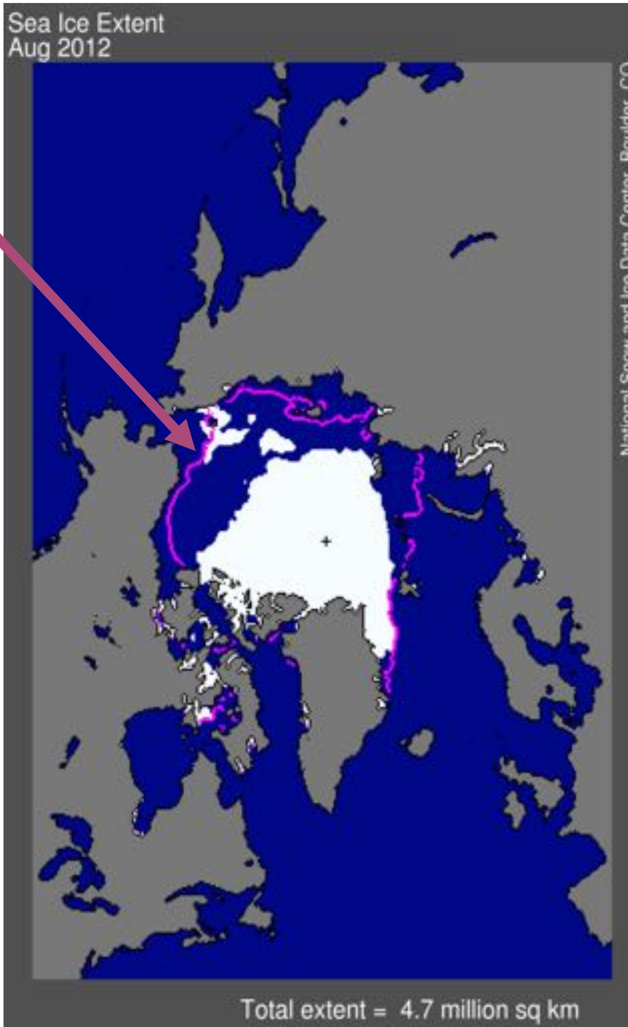
white = 2012 only;

light gray = both 2007 and 2012.

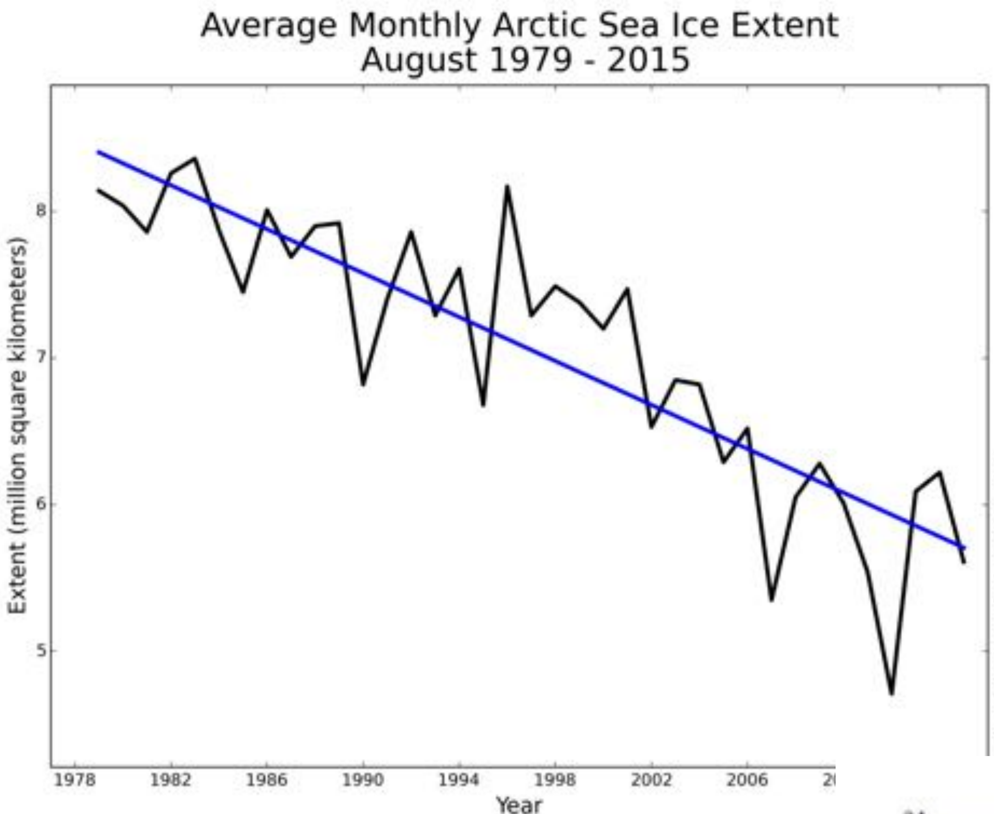


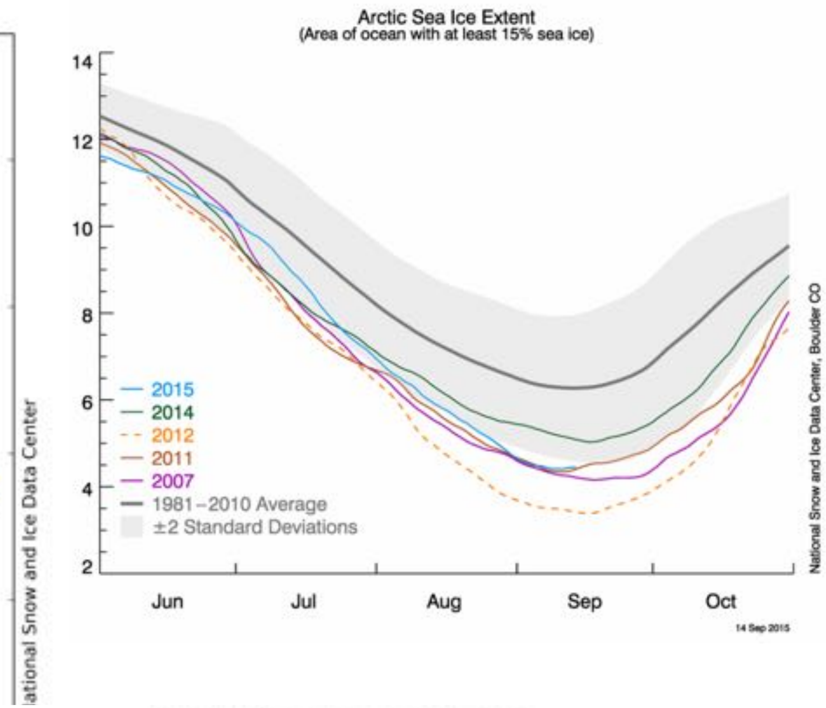

Aug 2012 vs. 21-yr mean

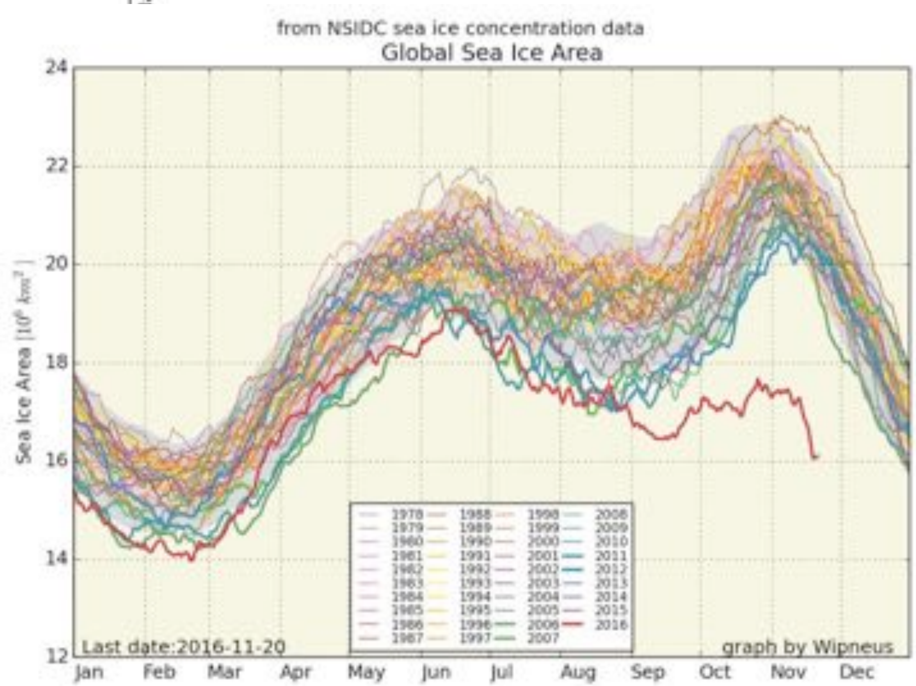
1979-2000 sea ice mean




Bigelow



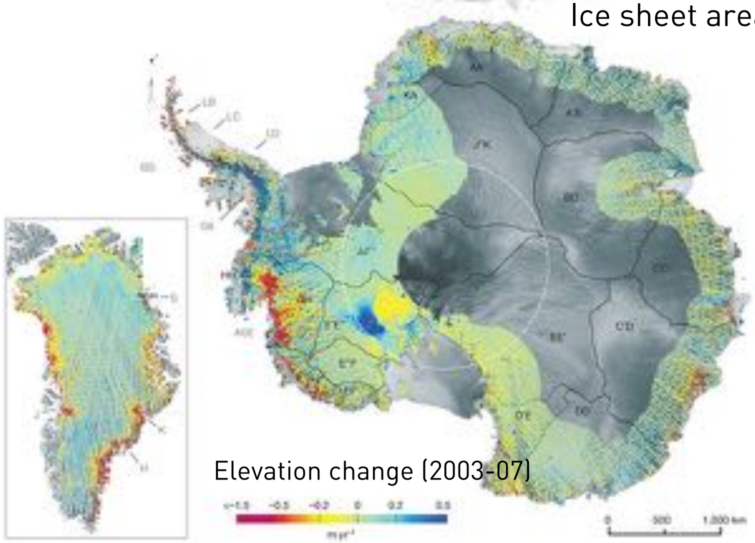




Bigelow | Laboratory for Ocean Sciences

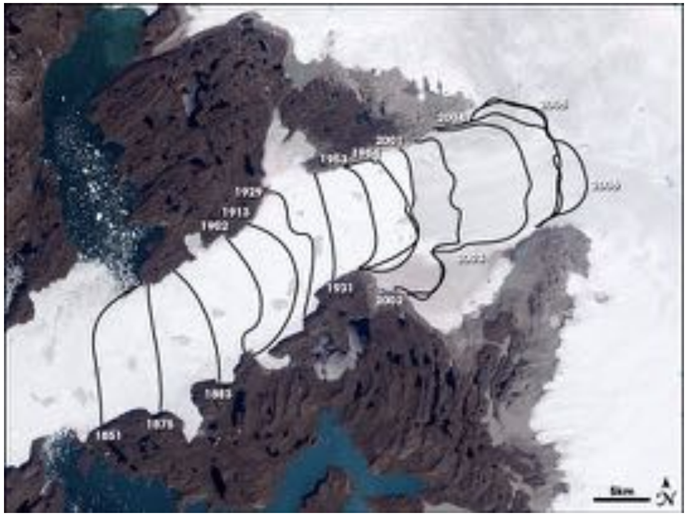
# Ice sheets, shelves and glaciers: calving, retreat, disintegration


Antarctic major ice shelf areas

Ice sheet areas



Elevation change (2003-07)



Greenland's Jacobshavn Glacier retreat


July 22, 2008

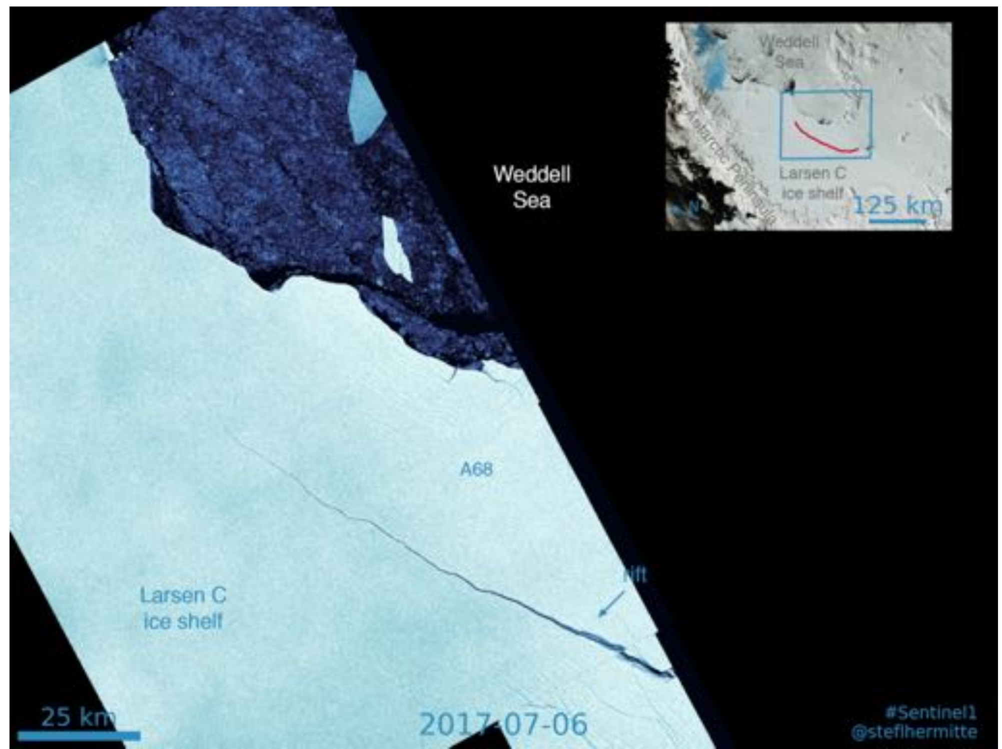
August 29, 2008

**Ice Shelf Retreat along the Ellesmere Coast:** Between 22 July (top) and 29 August (bottom) 2008, the five ice shelves remaining in the Canadian Arctic experienced major losses. By late August, Ellesmere ice shelves had lost a total of 214 km$^2$ (83 mi$^2$).

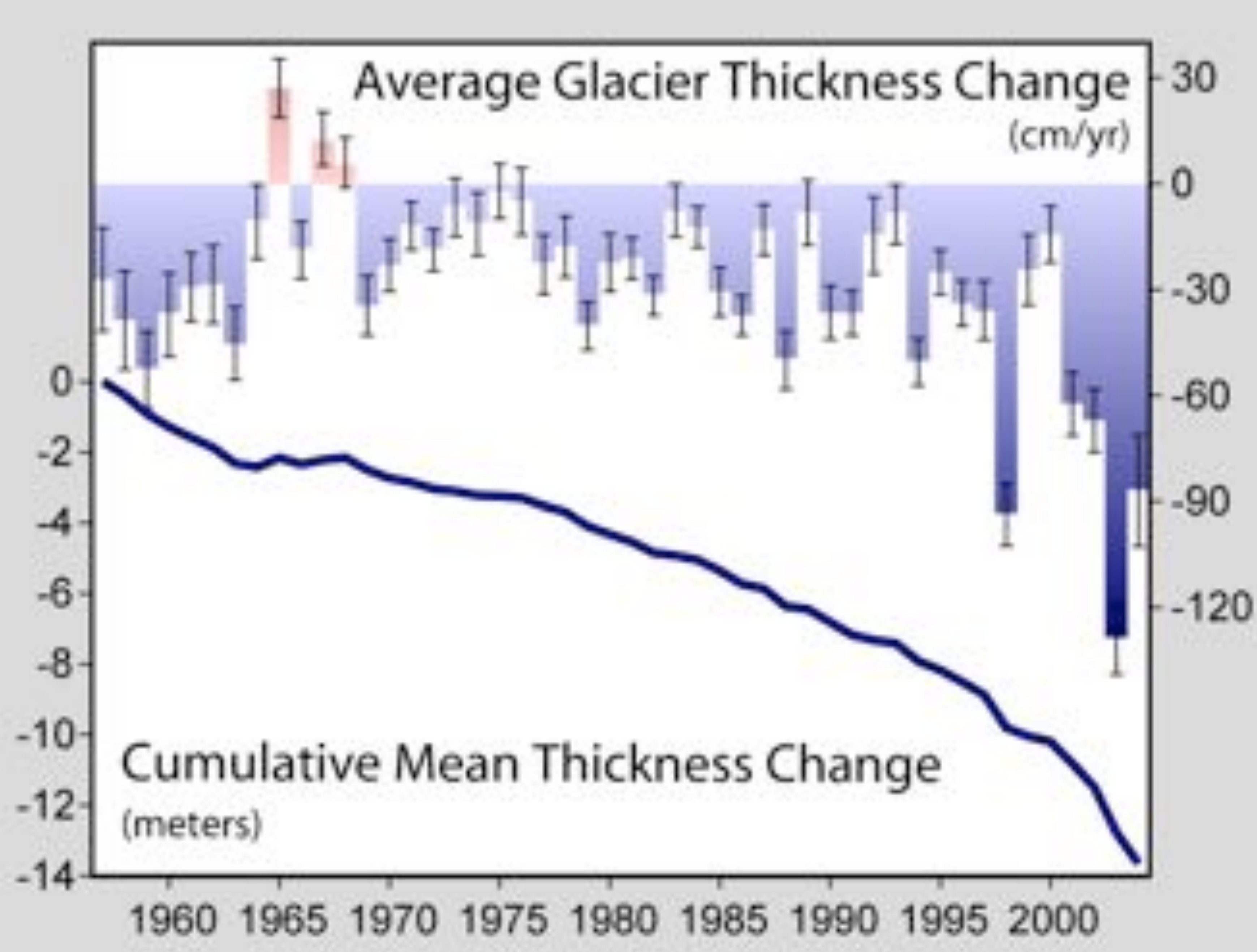
http://nsidc.org/cryosphere

Muir Glacier, Alaska

Larsen C Iceberg
(size of Delaware)

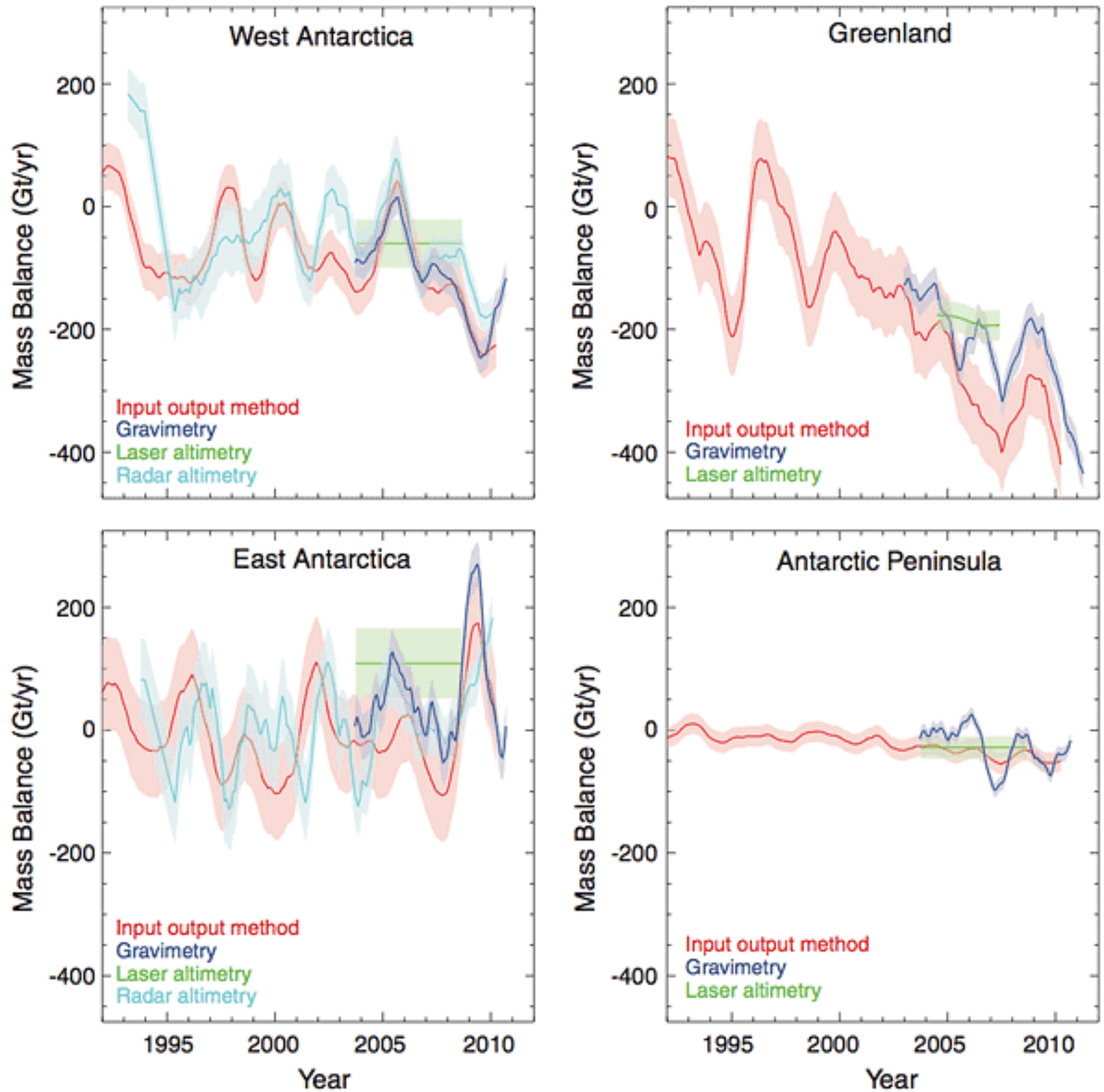



Bigelow | Laboratory for Ocean Sciences




Bigelow | Laboratory for Ocean Sciences

Changes in ice sheet mass (1992-2012)




Bigelow | Laboratory for Ocean Sciences

http://nsidc.org/cryosphere

# Why is sea ice important?

**1. Affects polar ecosystem, wildlife**

- Important habitat for algae, seals, bears, walrus
- Ice algae contributes 10 – 20% to Arctic primary production
- Effect of reduced ice cover uncertain

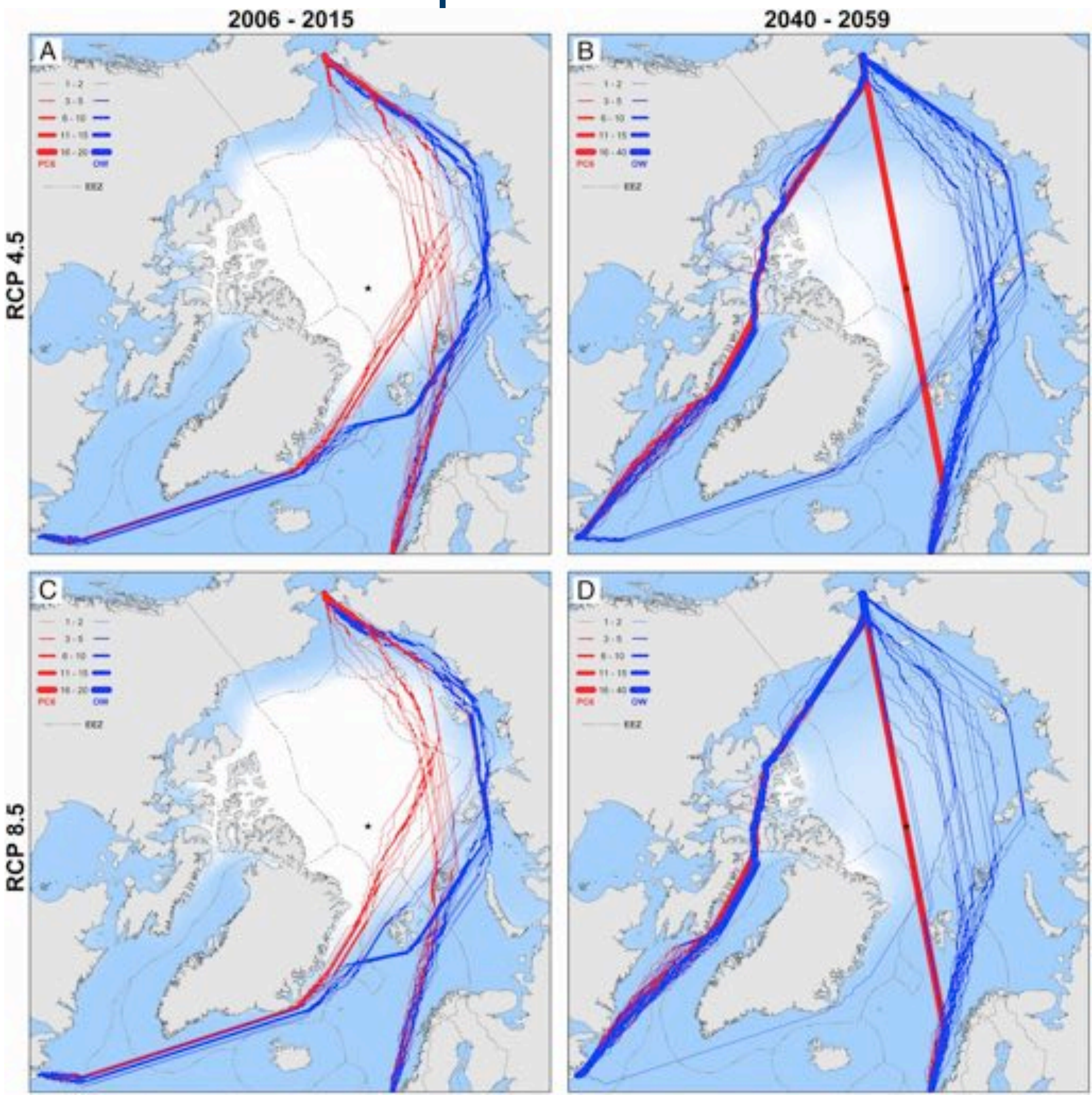
Bigelow | Laboratory for Ocean Sciences

# Why is sea ice important?

**2. Affects people who live in polar regions (subsistence hunting, travel)**

2007: Northwest passage open for first time in human memory

2008: Both Northern Sea Route and Northwest passage open for 1 week




Bigelow | Laboratory for Ocean Sciences

# Why is sea ice important?

**3. Influence on global climate**

- Bright surface (**albedo**) ⇒ good reflector of sunlight (important spring and summer)
- Ice covered areas absorb little solar energy and insulate warm ocean from cold air
- Ice free areas absorb much solar energy, allow heat transfer between ocean and air
- Sea ice covers 2/3 (by area) of the Earth's permanent ice cover, **but only 0.1% of its volume**!
- Small changes in climate can produce large changes in ice thickness and coverage
- Changes in ice extent
  - ⇒ changes in atmospheric circulation
  - ⇒ changes in ocean circulation: deep water formation in Greenland Sea and Antarctic polynyas

POSITIVE FEEDBACK:
Change in climate → change in ice
Change in ice → change in climate

# Sea ice: More than frozen water

1. Thermal: Conductivity; slows heat transfer,
   Implications for weather, climate

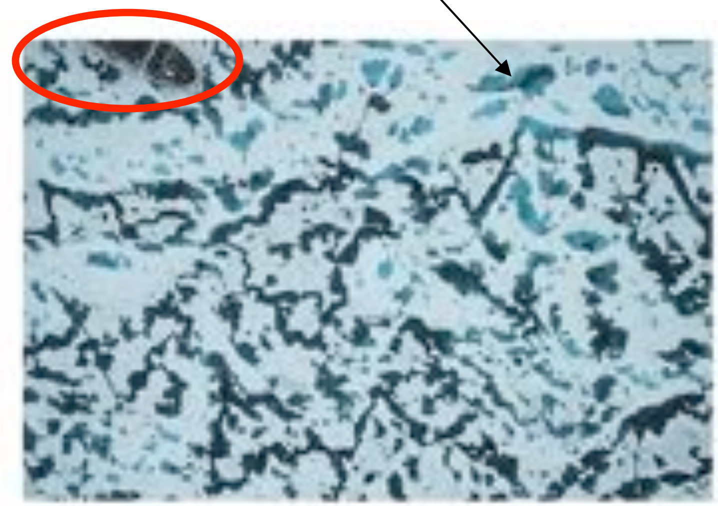
2. Mechanical: Porosity, compression
   Implications for movement

3. Electromagnetic: Heat balance, albedo; melt ponds; light penetration
   a) Optical
   b) Infrared
   c) microwave

   Remote sensing; infrared and visible limited by clouds, darkness; ice emits in µwave range => monitoring of snow, ice, melt ponds, water fraction

I. LARGE scale = Almost constant motion: Beaufort Gyre, Transpolar Drift through Fram Strait (10% export)

II. SMALL scale = leads & polynyas; rafting & pressure ridges => ice thickness

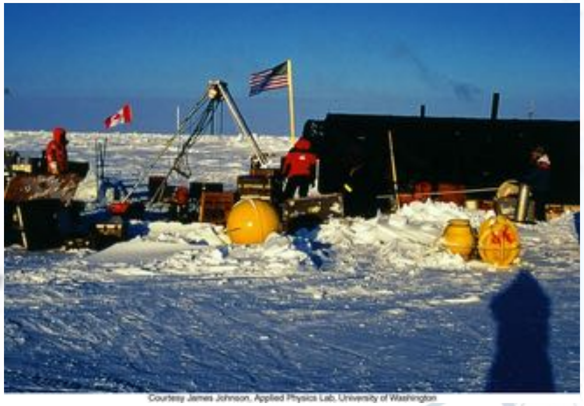


Bigelow | Laboratory for Ocean Sciences

## Studying sea ice: Remote locations and extreme conditions

Courtesy of Sandra Hines, University of Washington

Ice camps



Courtesy James Johnson, Applied Physics Lab, University of Washington

Hovercrafts "SABVABAA"
See www.polarhovercraft.no

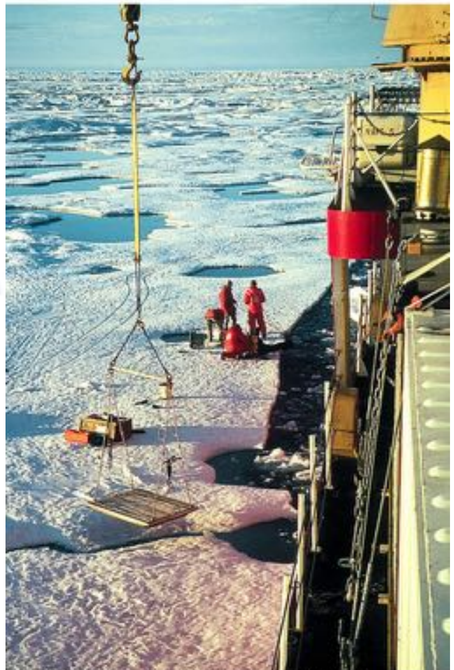
http://www.youtube.com/watch?v=lBJWBA2TAnY&feature=player_embedded

Bigelow | Laboratory for Ocean Sciences

# Studying sea ice: Remote locations and extreme conditions

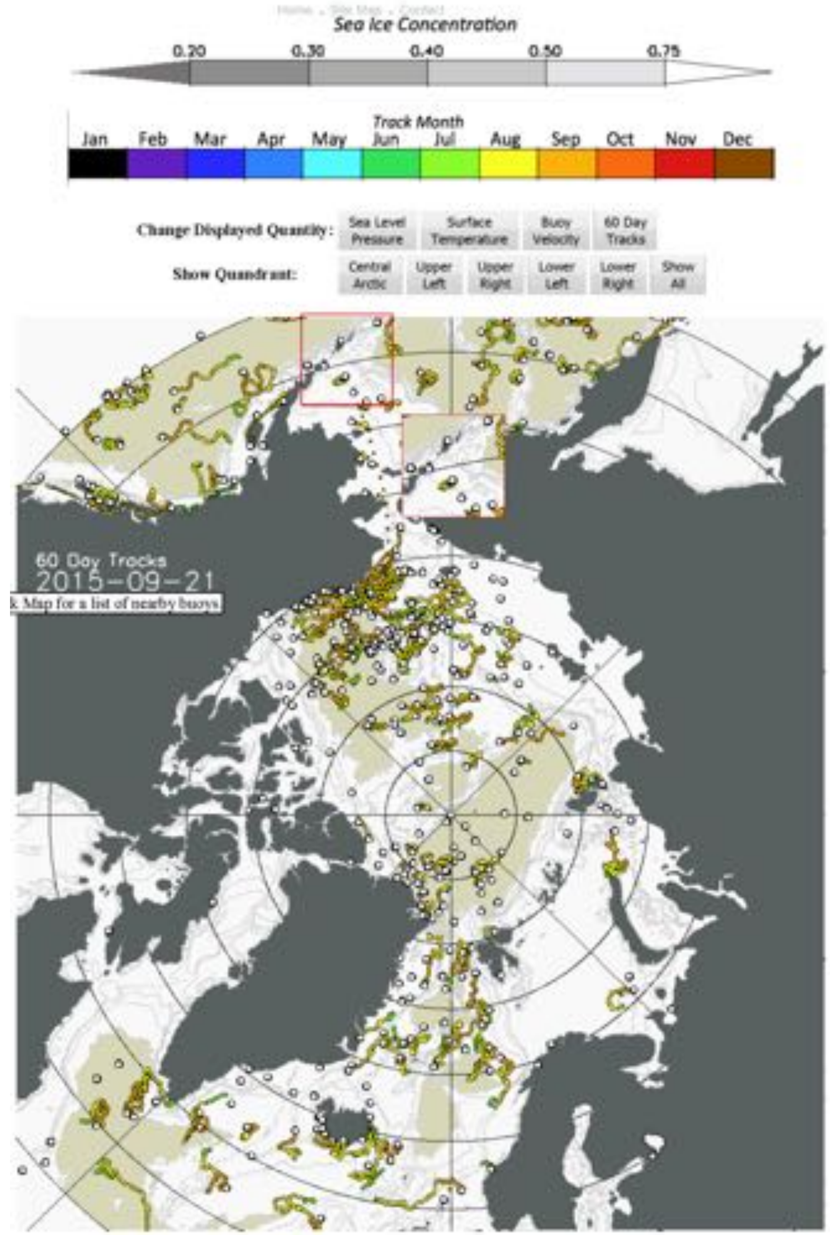
U.S.S. Pogy (SSN 647) surfaces through Arctic ice 05 November 1996, during a 45-day research mission to the North Pole.





Courtesy of Captain Lawson W. Brigham, retired, USCG

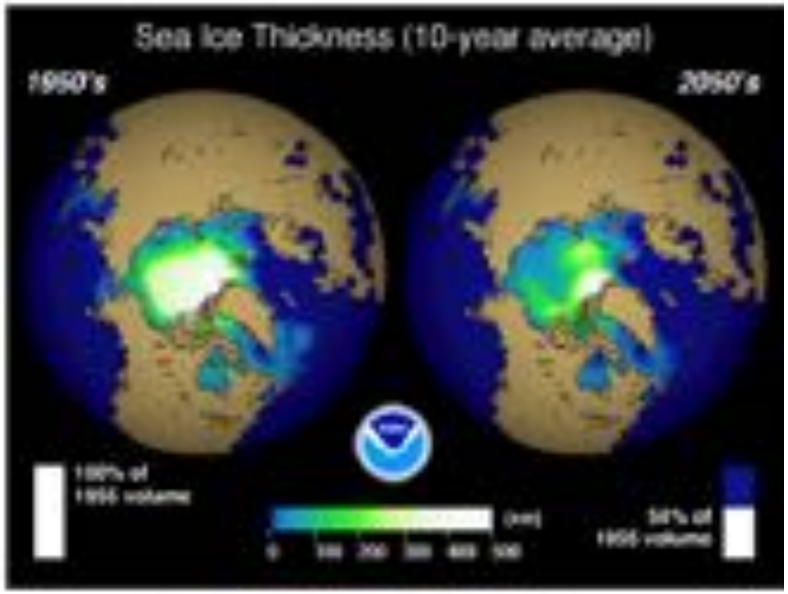
O-Buoy, CCG L St Laurent



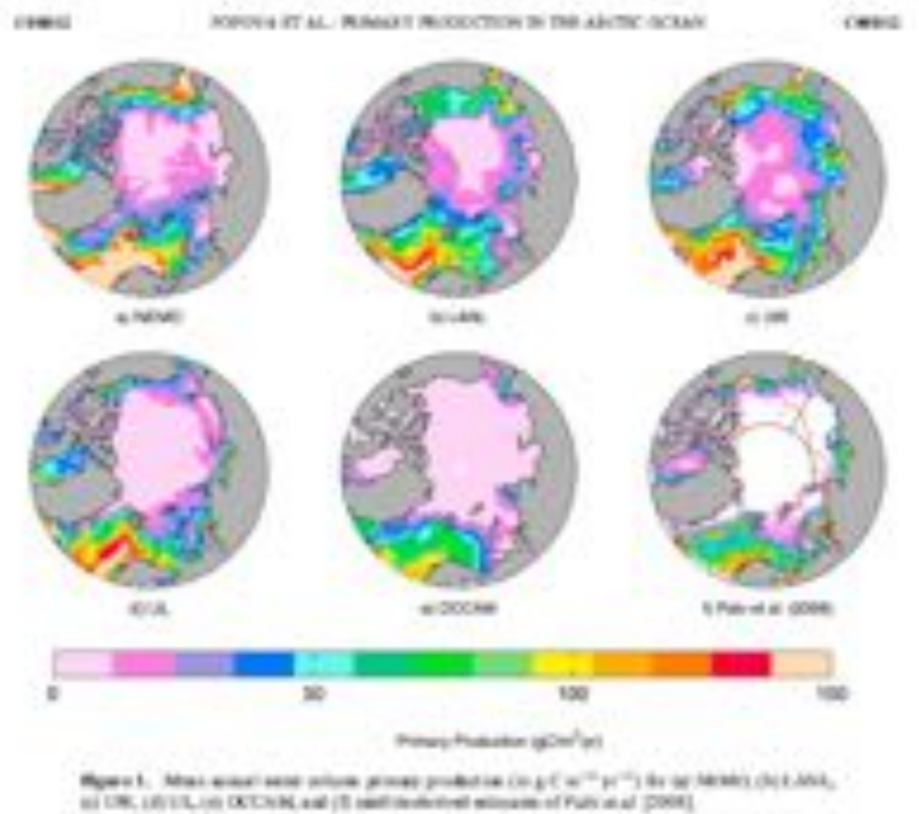

http://iabp.apl.washington.edu/

Bigelow | Laborator
Ocean Sci

# MODELS




Sea ice projections with global warming
(GFDL coupled climate GCM)



AOMIP [http://www.whoi.edu/page.do?pid=29836](http://www.whoi.edu/page.do?pid=29836)
FAMOS http://www.whoi.edu/projects/famos/

Goals:

1) Understanding and relative importance of processes (known and unknown)

2) Projections (hind- and fore-casts)

Bigelow | Laboratory for Ocean Sciences

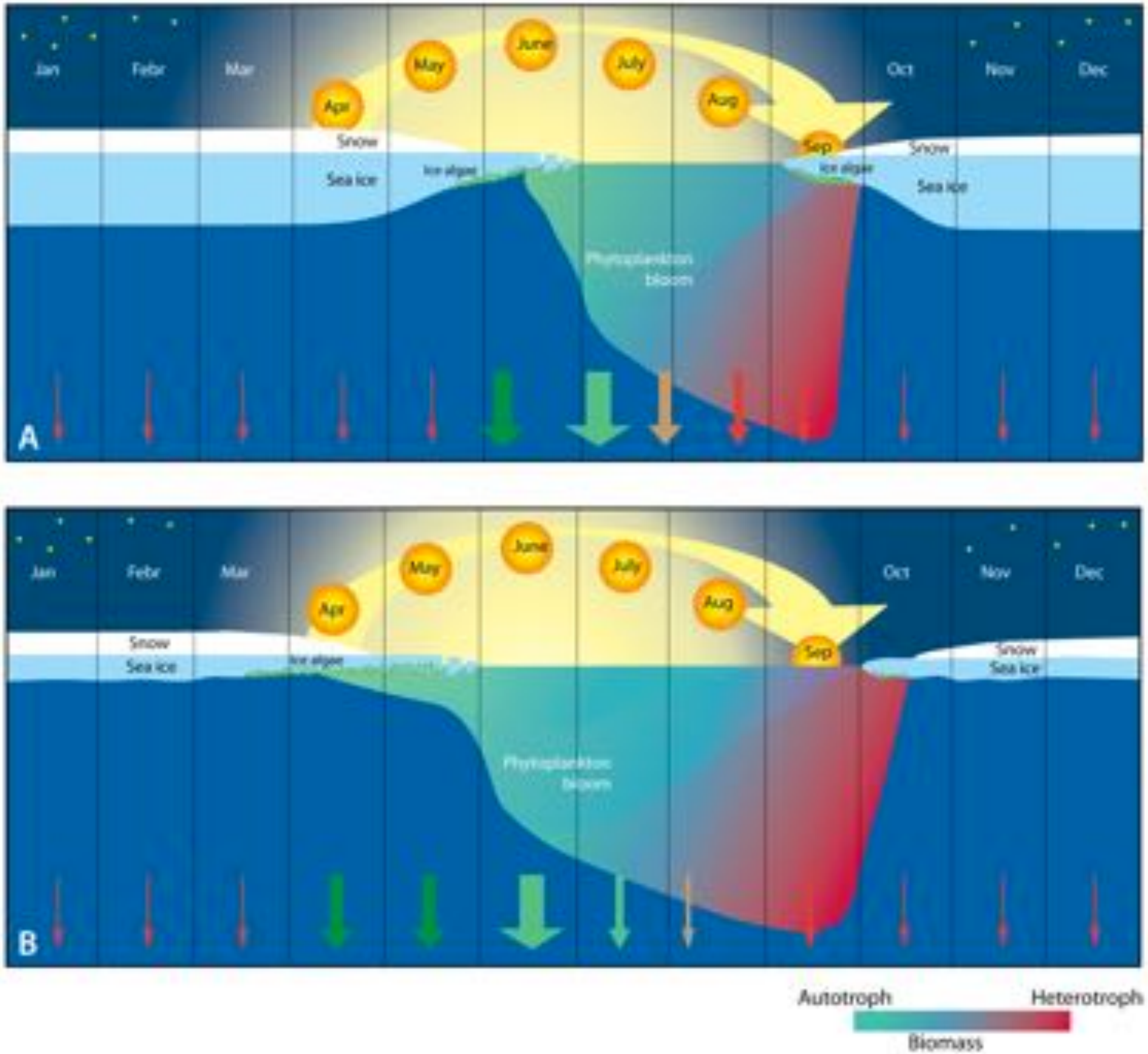



Figure 2. Seasonality in bloom development and in downward carbon export in present-day climate and ice conditions (A), and a future warmer climate with thinner ice in winter and more melting of summer ice, causing a widening of the seasonal ice zone (B). The green-to-red gradient indicates the balance of suspended biomass from autotrophic to heterotrophic sources. The new and export production in both scenarios is similar because stratification limits nutrient availability. The width and color of the vertical arrows illustrate the semi-quantitative magnitude and key composition of vertically exported organic matter. Dark green = ice algae-derived carbon. Light green = phytoplankton-derived carbon. Orange and red arrows = increasing degree of detritus (nonliving particulate organic material). *Modified from Wassmann (2011)*

Bigelow | Laboratory for Ocean Sciences

Wassmann & Reigstad 2011 Oceanography

# Upper trophic ecology

ARCTIC

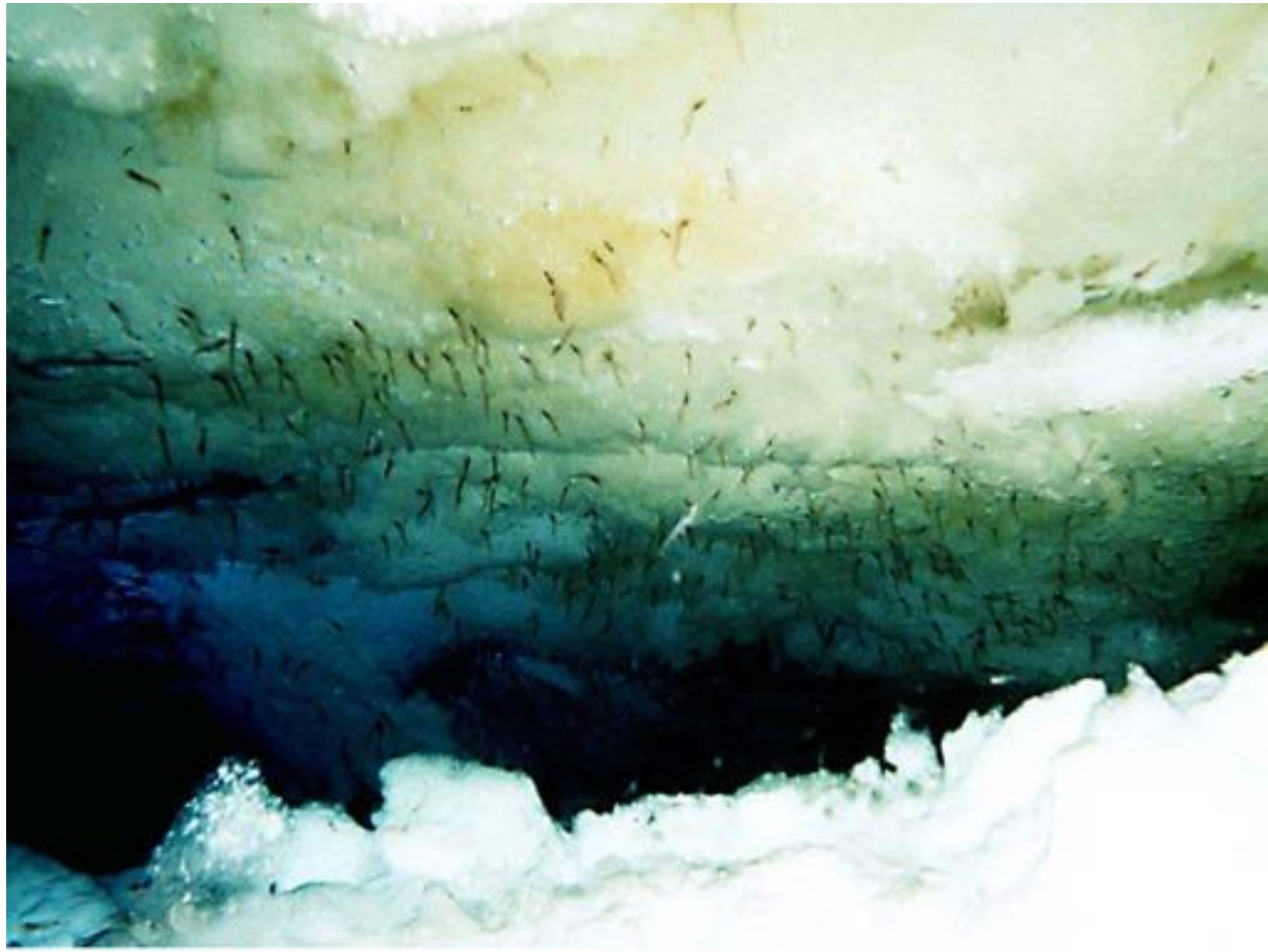
**Copepods**

- *Calanus glacialis, Calanus hyperboreus*
- Lipid sac for hibernation
- Creates a fatty prey resource for predators for long periods of time despite low productive periods

# Upper trophic ecology

ANTARCTIC

**Krill**
- *Euphausia superba*
- Feeds on ice algae
- Possibly largest biomass of a single species
- Supports penguins, whales, etc.



# Upper trophic ecology


**<u>Polynyas</u>** – open water surrounded by ice, important for marine mammals.

Algae-rich water frozen in ice

Bigelow | Laboratory for Ocean Sciences

Bigelow

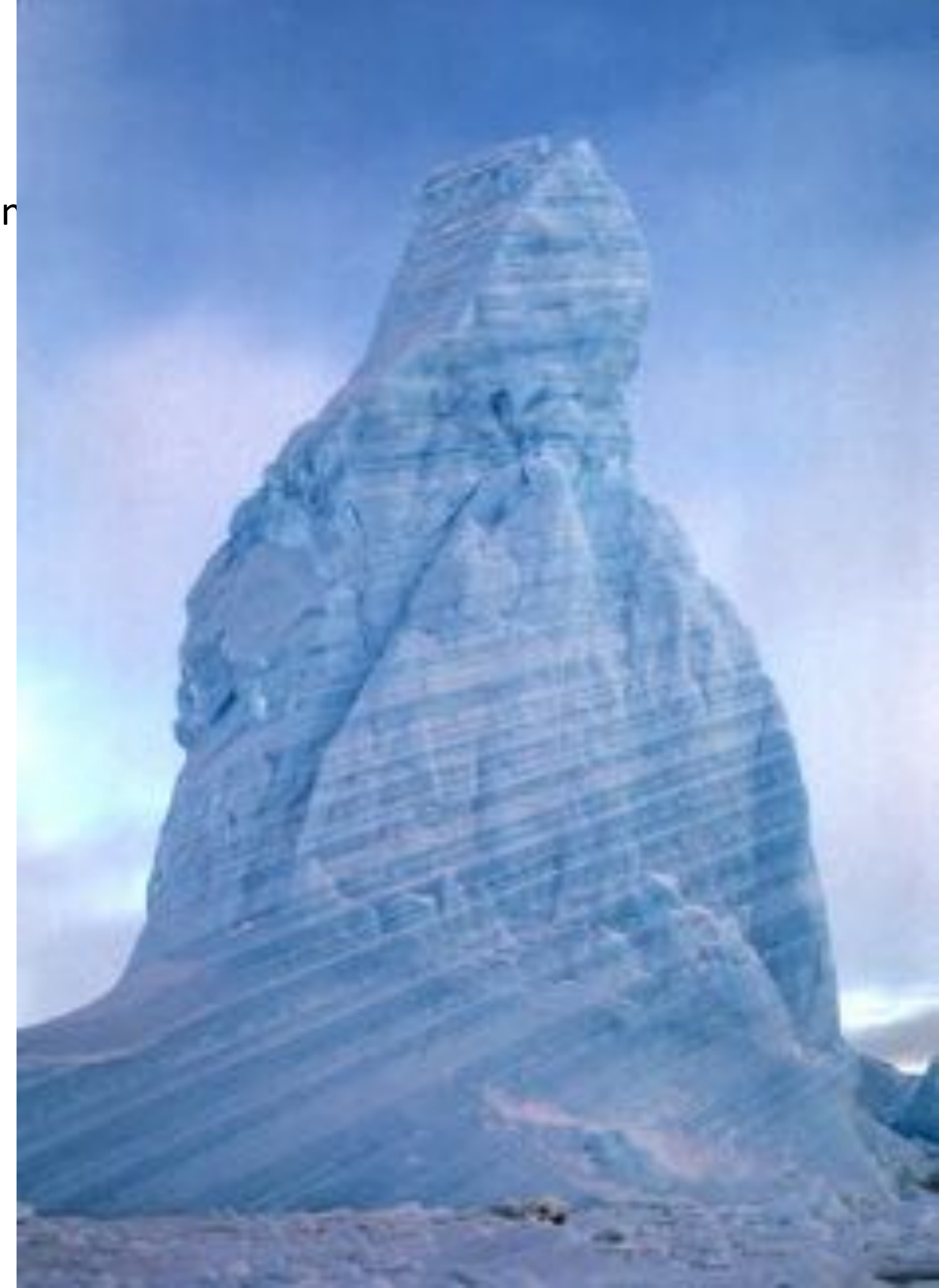
**Blueline Bergs**: freshwater filling cracks and freezing quickly

**Blueline Bergs**

## Blueline Bergs

**Blueline Bergs**

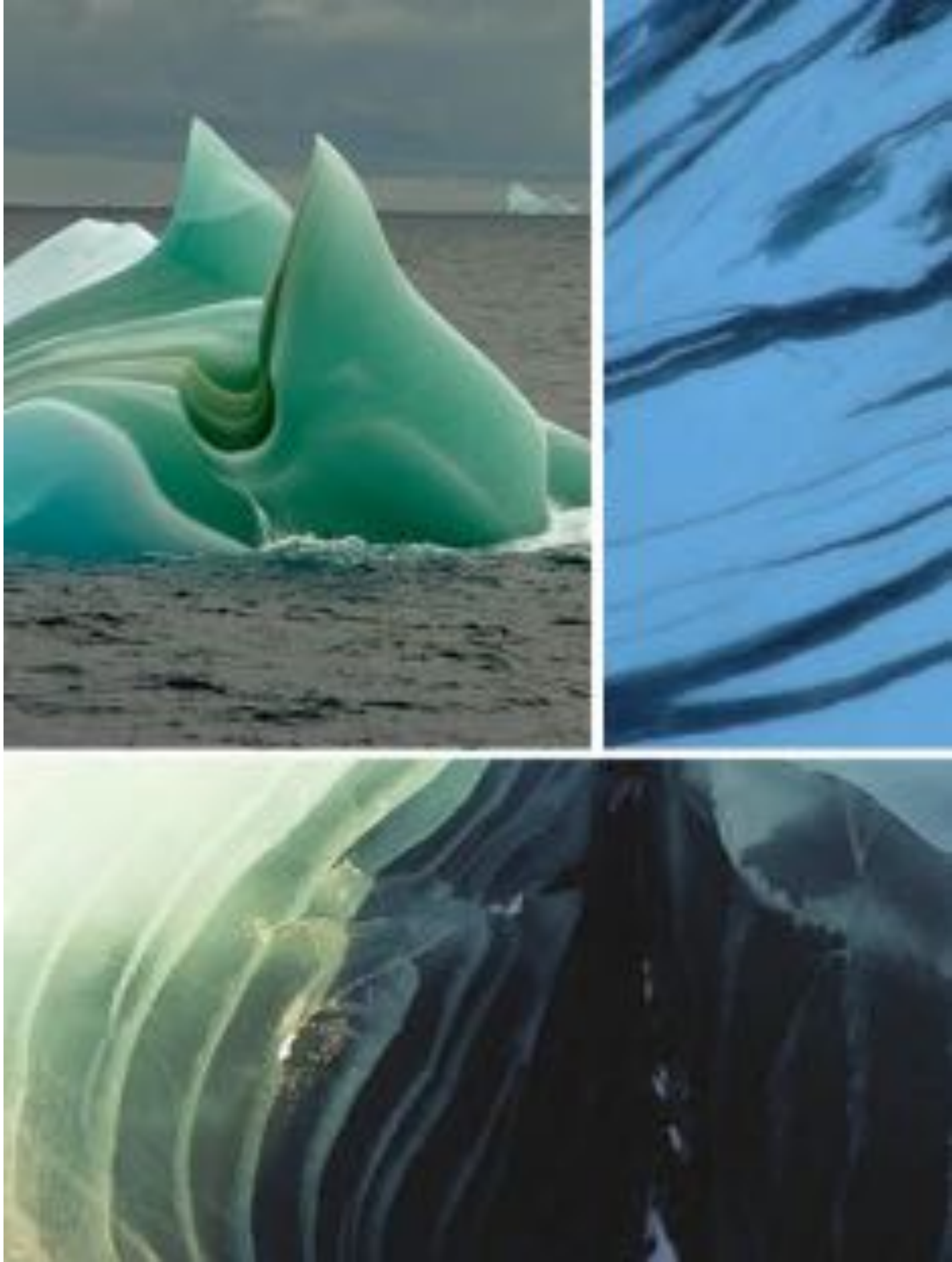
- not well understood
- might represent seasonal rain



Bigelow | Laboratory for Ocean Sciences

**Jade Bergs**

- when seawater freezes in cracks



Bigelow | Laboratory for Ocean Sciences

Bi

**Embryonic Striped Bergs**
- look like “frozen tidal waves”
- freezing/thawing + glacial pressure
→ cracks and transparency

Bigelow | Laboratory for Ocean Sciences

**Embryonic Striped Bergs**

- when they break off and reach the sea, they can become jade bergs

Bigelow

Bi

Bigelow | Lab Oce

# The Atmosphere

**To understand the motion of the atmosphere, use fluid dynamics:**

## <u>Navier-Stokes equations</u>

$$
\begin{aligned}
&\frac{dv}{dt} = -(1/\rho)\nabla p - g(r/r) + (1/\rho)\left[\nabla \cdot (\mu \nabla v) + \nabla(\lambda \nabla \cdot v)\right] \\
&c_v \frac{dT}{dt} + p\frac{d\alpha}{dt} = q + f \\
&\frac{d\rho}{dt} + \rho \nabla \cdot v = 0 \\
&p = \rho R T.
\end{aligned}
$$

# To understand the motion of the atmosphere, use fluid dynamics:

## <u>Navier-Stokes equations</u>

**Equations are chaotic, which limits prediction time frame**

**Turbulence is approximated**

**The main variables are pressure, density, temperature, and velocity**

- Reference pressure = sea level = 1 atm = 1013 mbars = 760 mm Hg
  - air density < average ➔ low pressure, hence rises
  - air density > average ➔ high pressure, hence sinks

# Atmospheric circulation: Begin with non-rotating earth

Energy is spread unevenly on a sphere

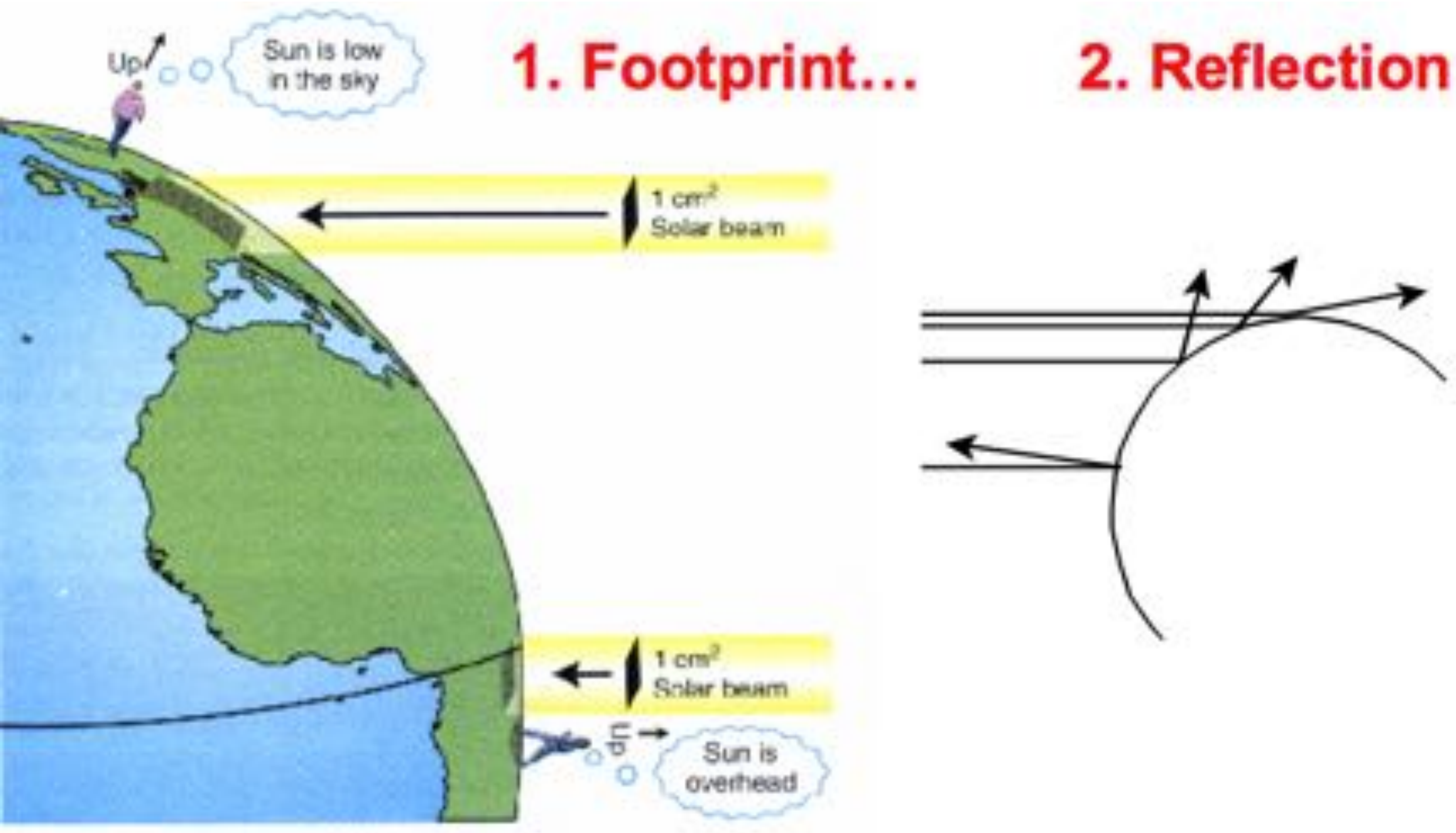
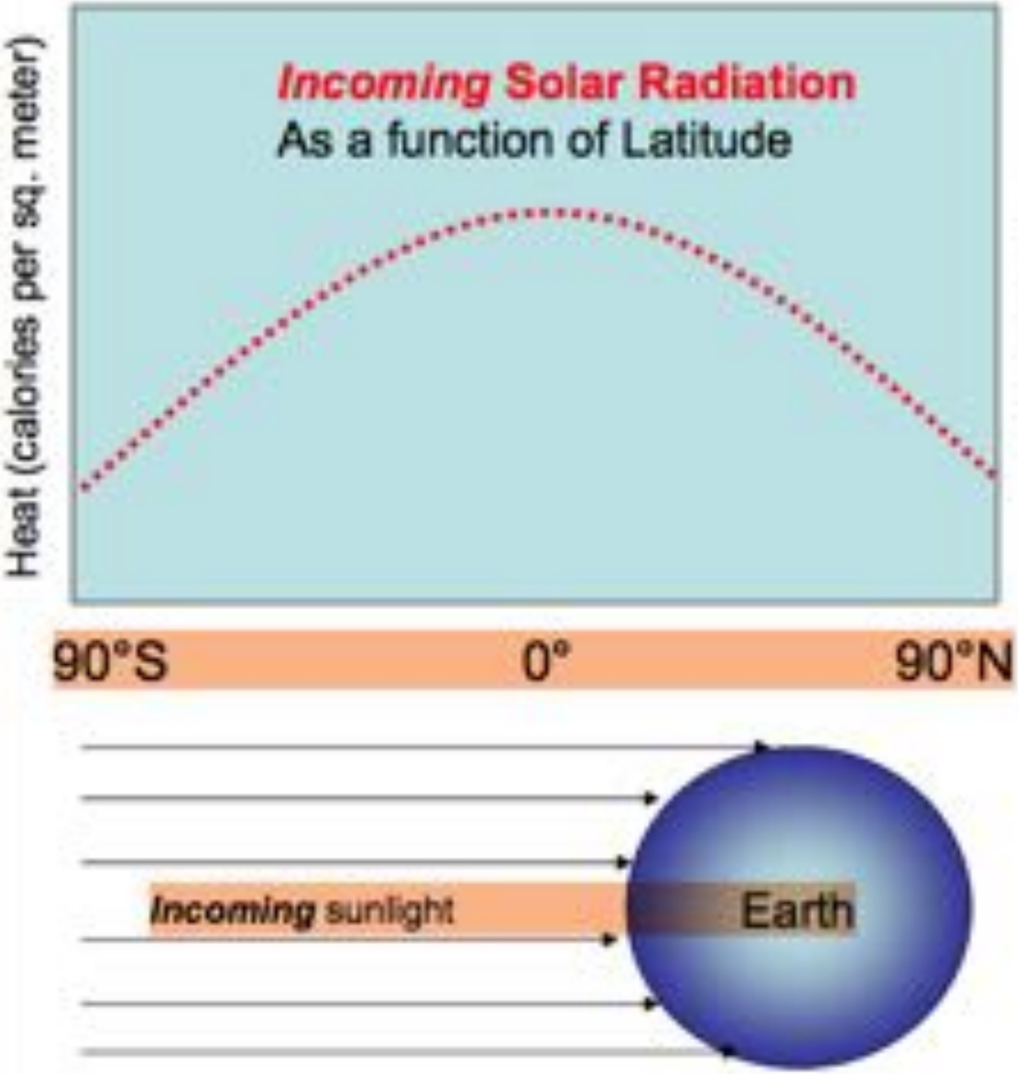
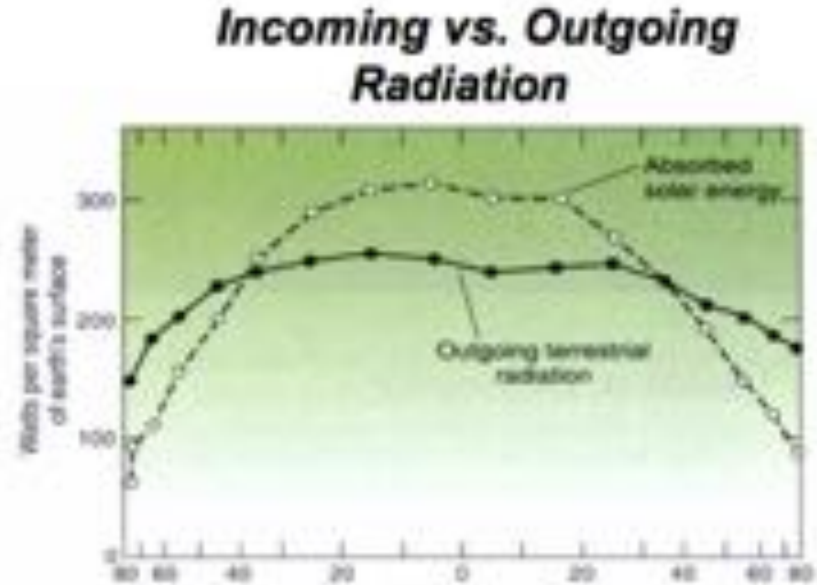
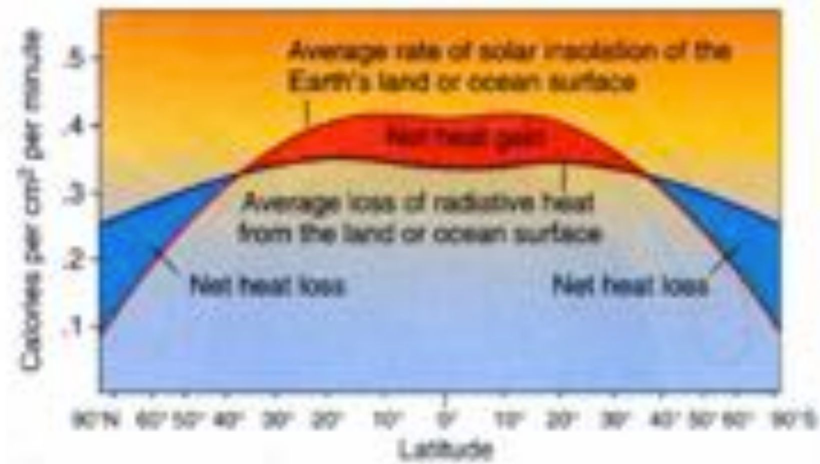



Image: David Townsend




**? How can more heat be lost at poles than received? …**

# Net Energy Transport Systems:

= Latitudinal Heat Pump

1. Atmospheric Circulation
2. Ocean Currents.

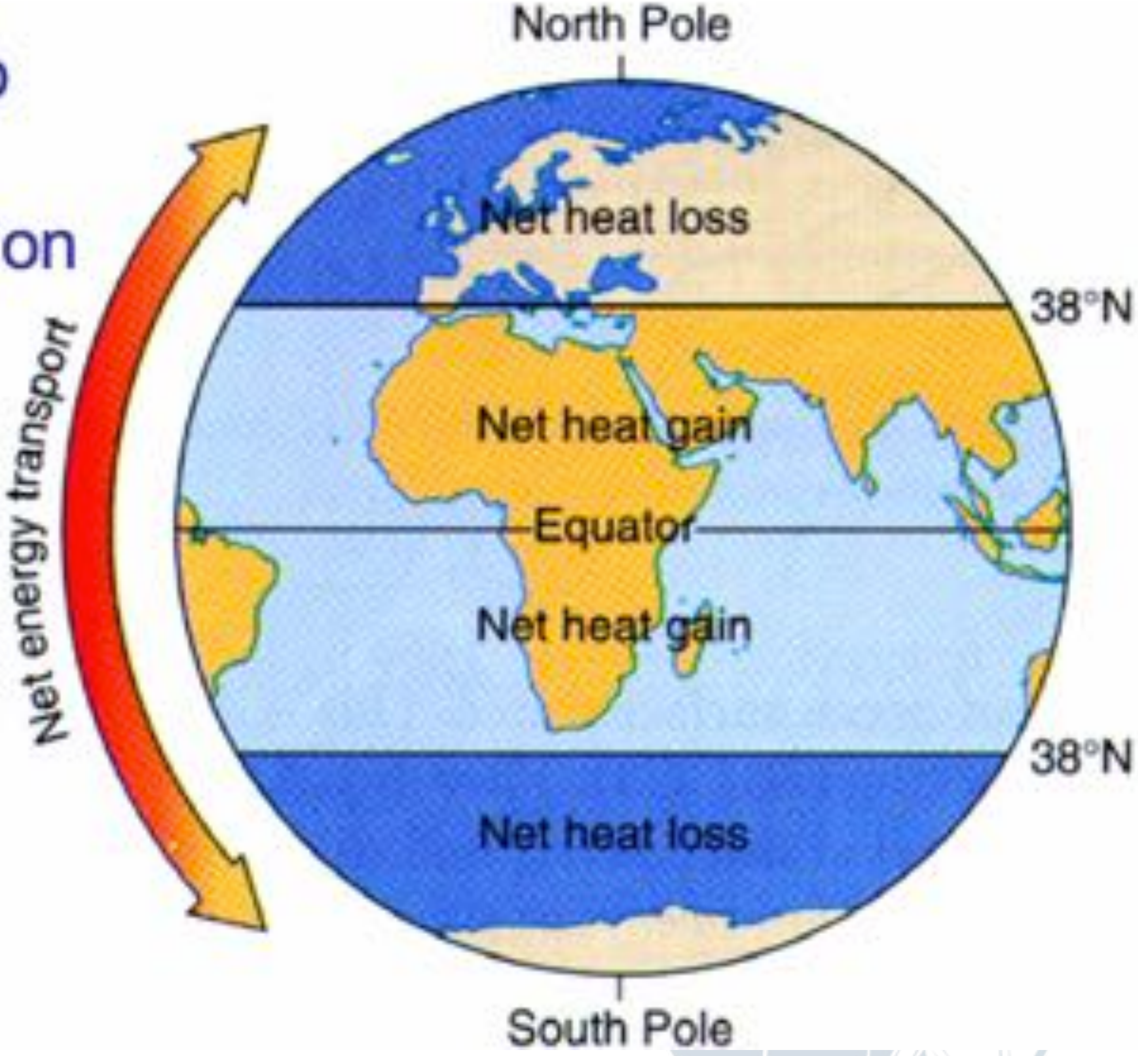



Image: David Townsend

# Basic Principle of an Atmospheric Convection Cell

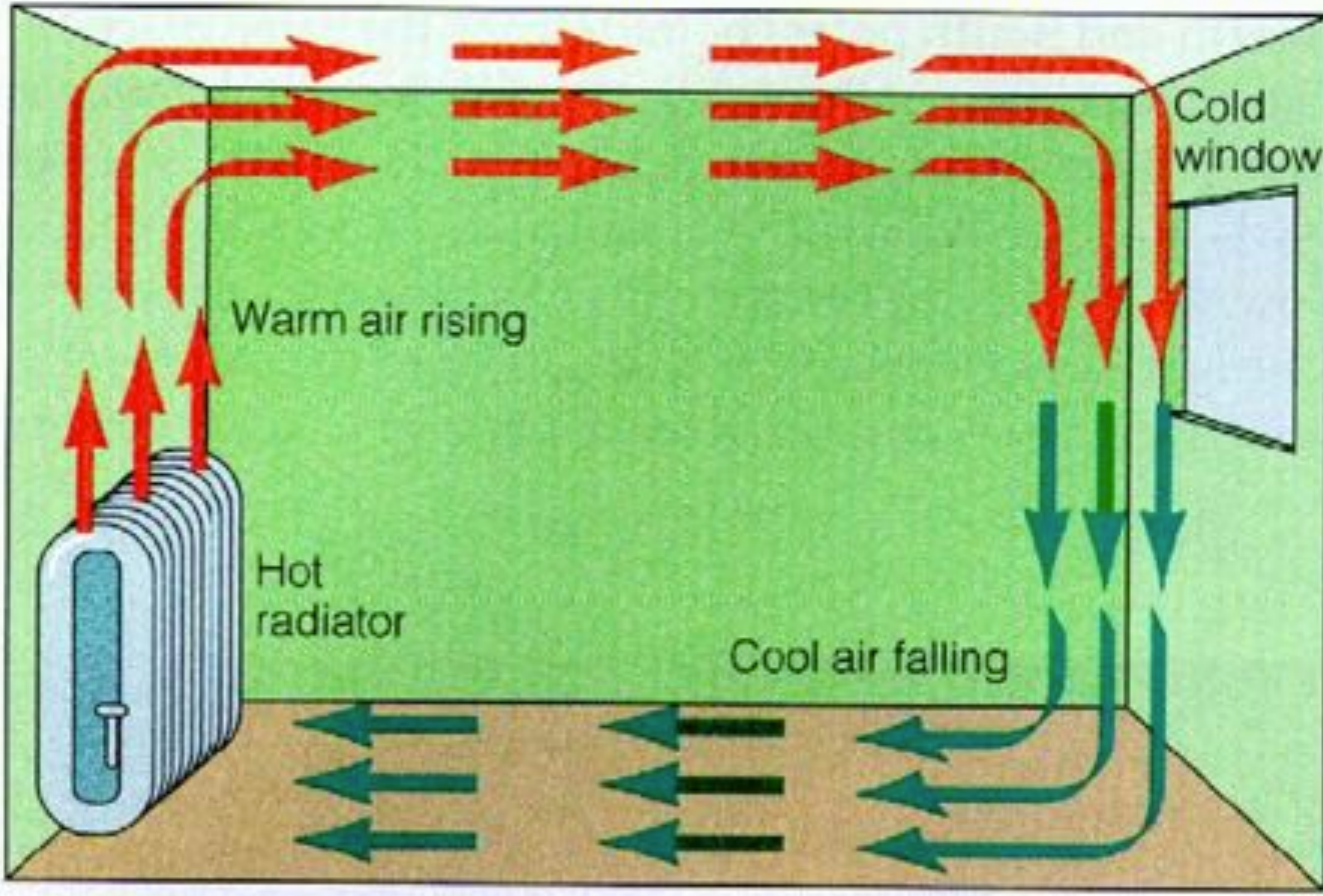



Image: David Townsend

Convection happens in the atmosphere because air masses acquire properties of land or ocean beneath them (e.g. temperature, moisture), ***altering their densities.***

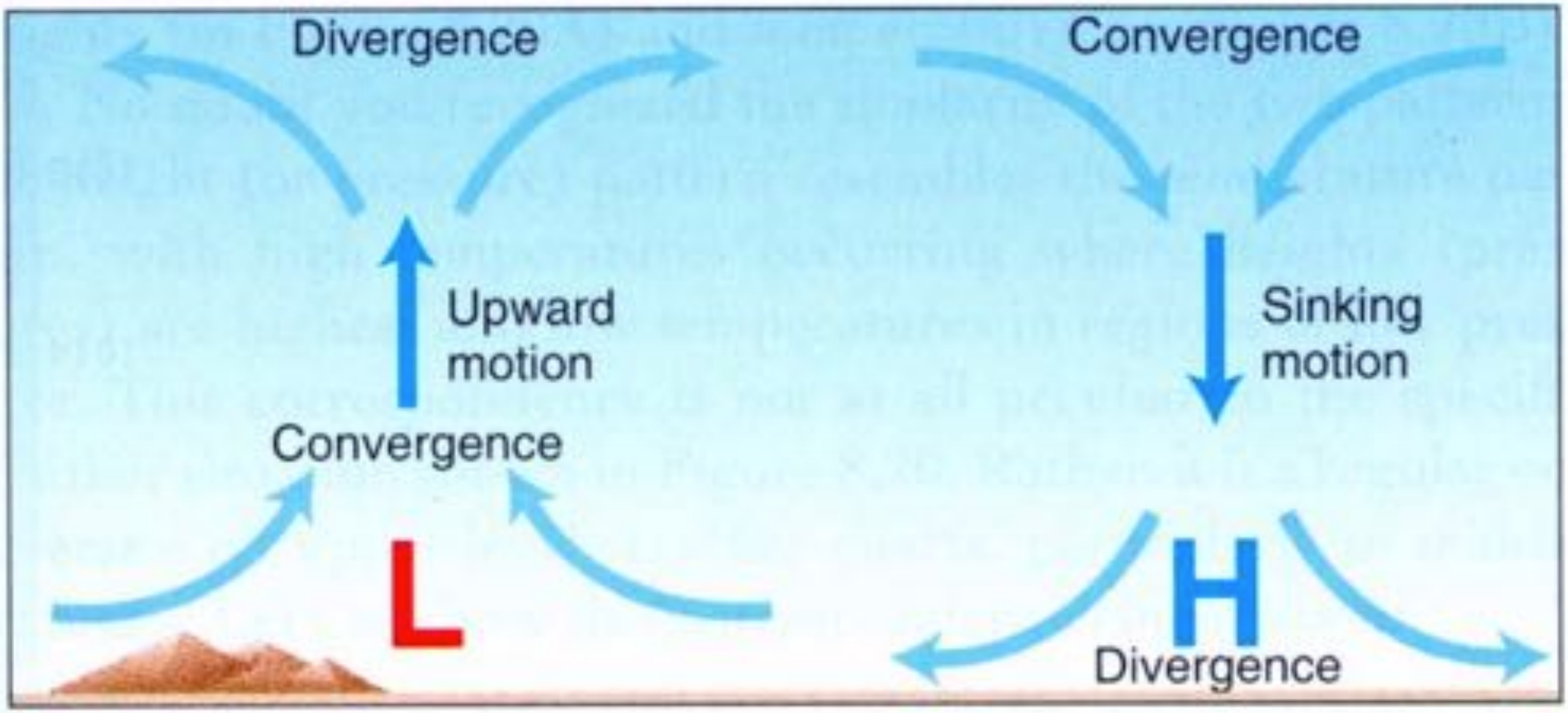
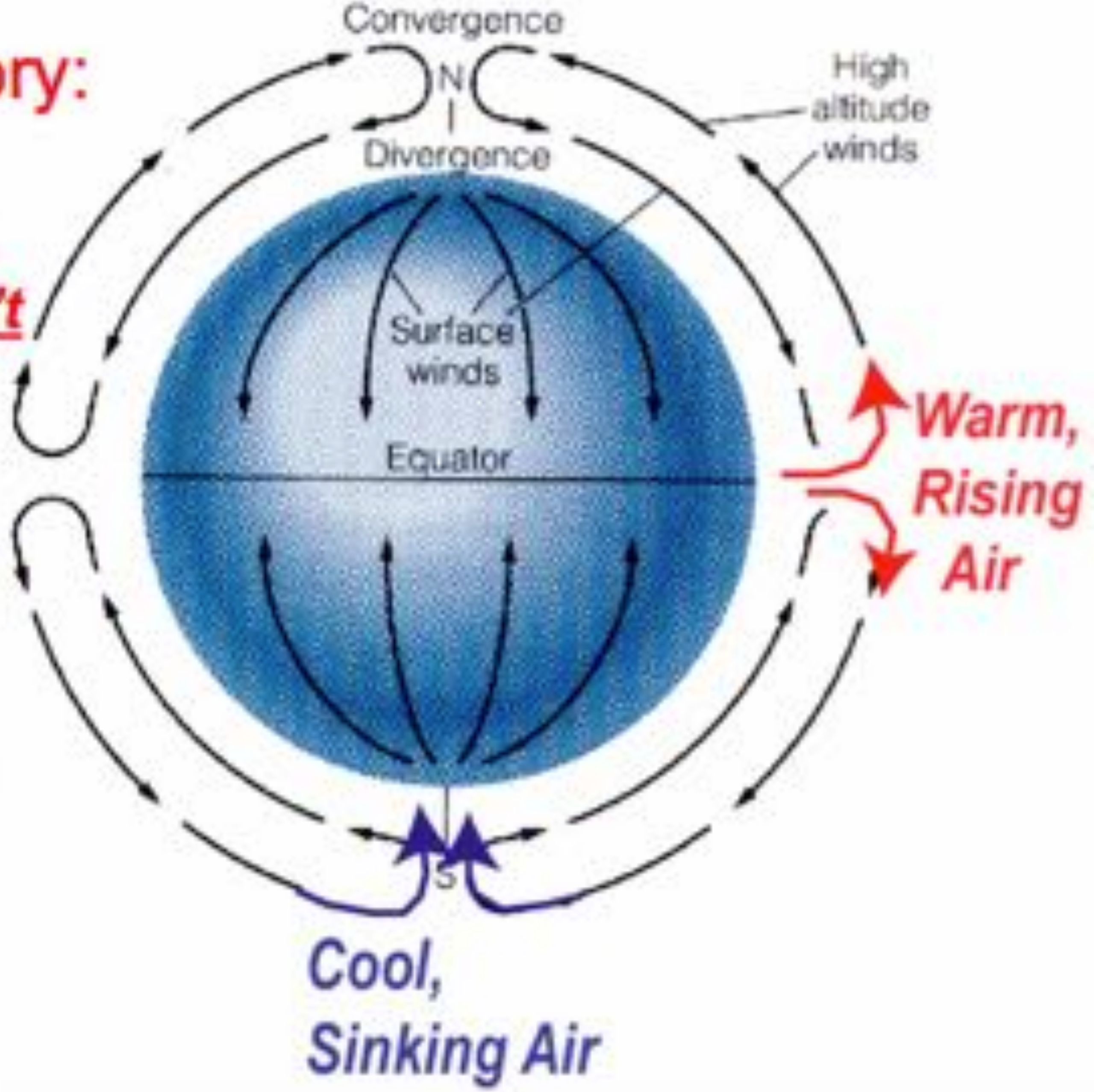



Image: David Townsend

# Simplified Theory:

Pattern of winds on
***an "Earth" that isn't Rotating…***

- The Result of Differential Heating



**Now add rotation**

**Coriolis**
In reality, the earth rotates

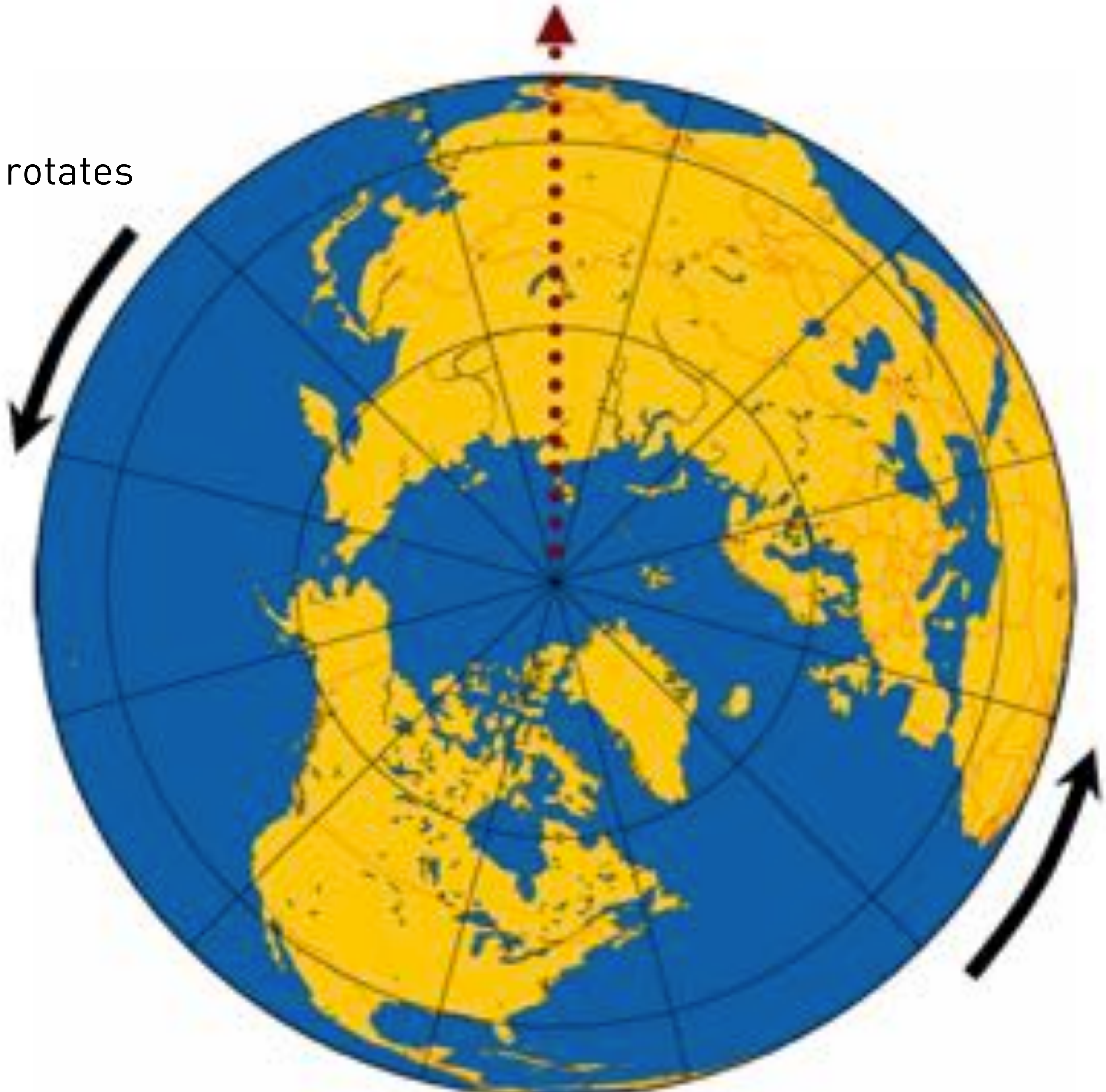
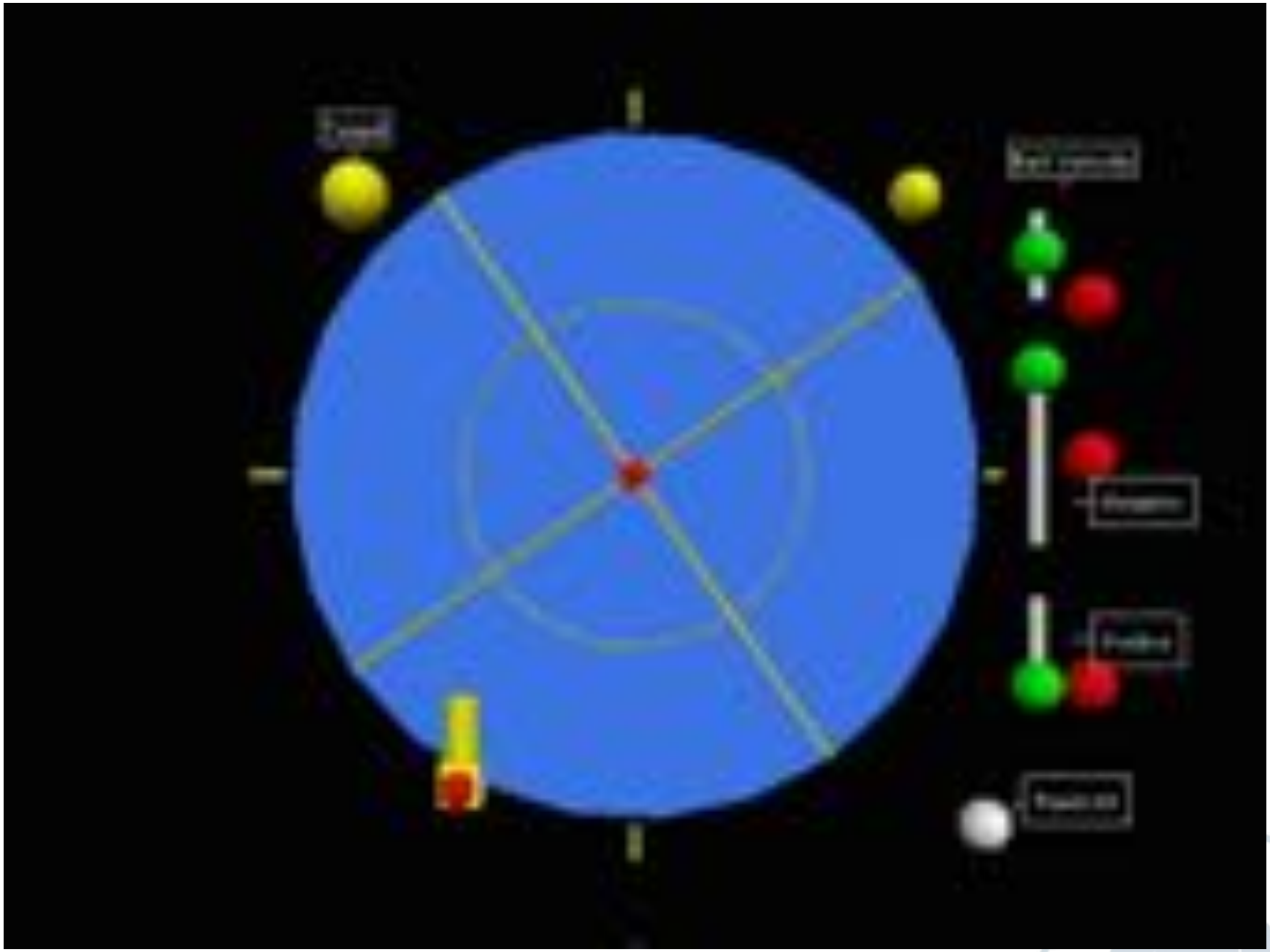
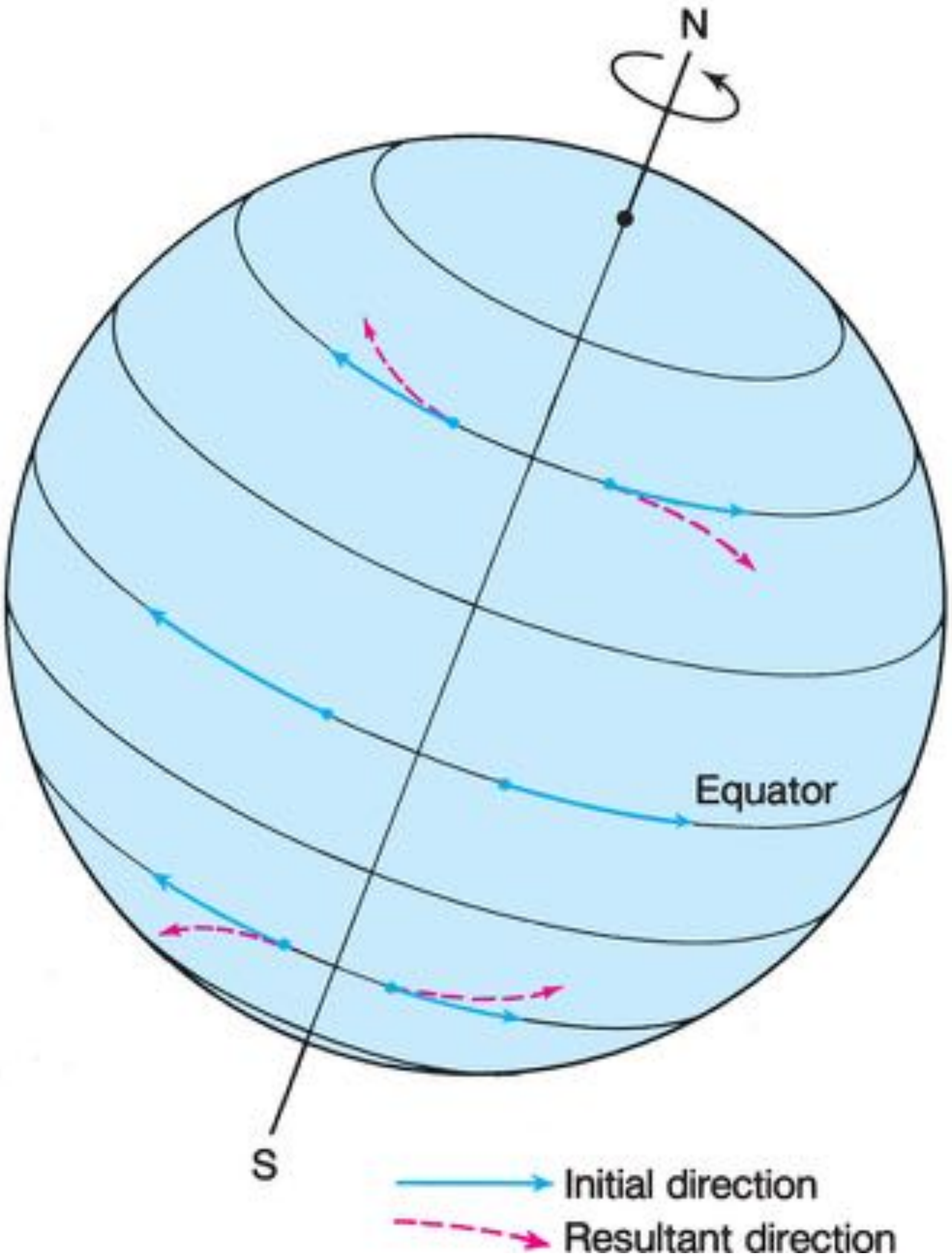


Image: David Townsend



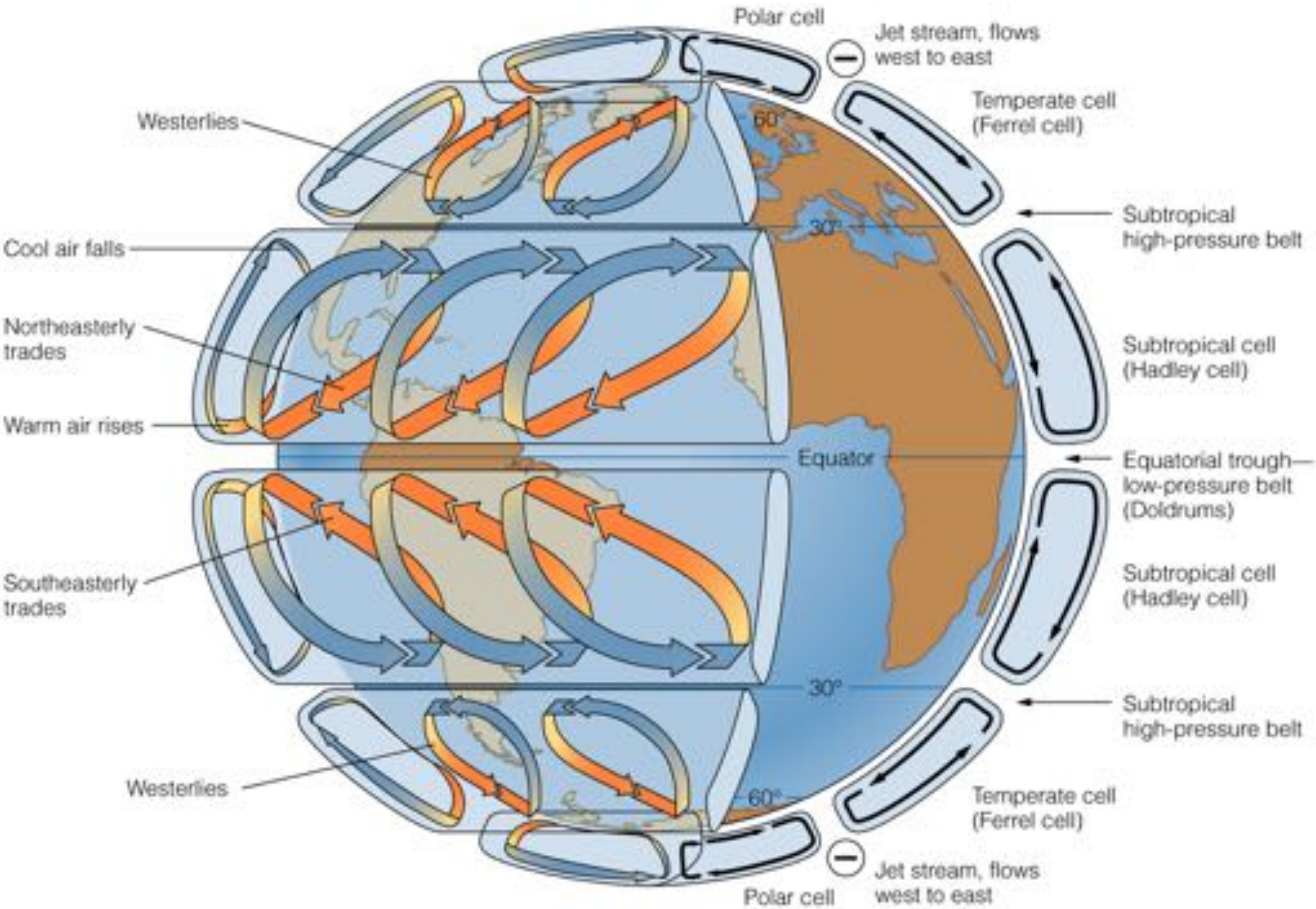
**Example** http://www.youtube.com/watch?v=_36MiCUS1ro

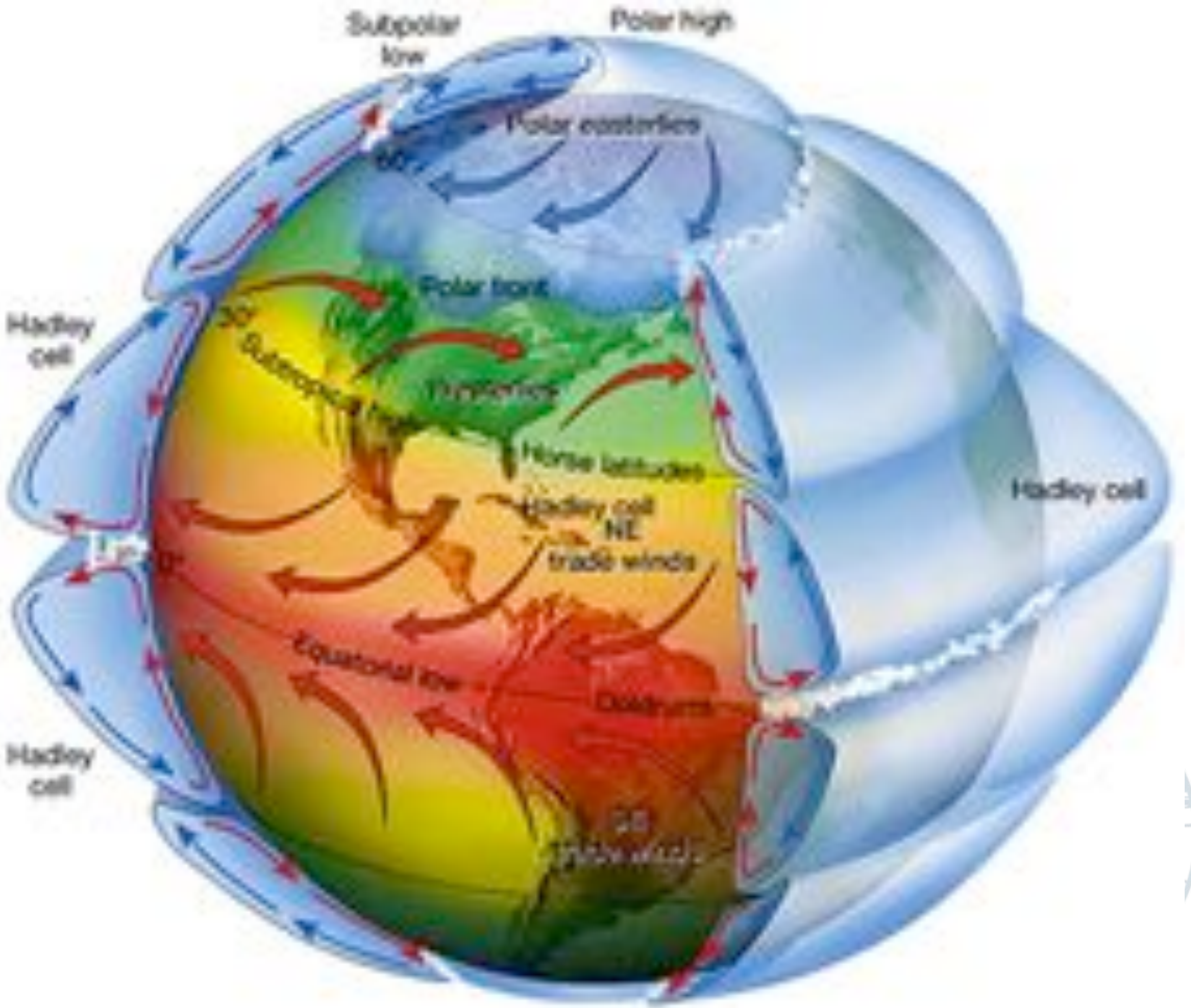



E-W movement

Bigelo

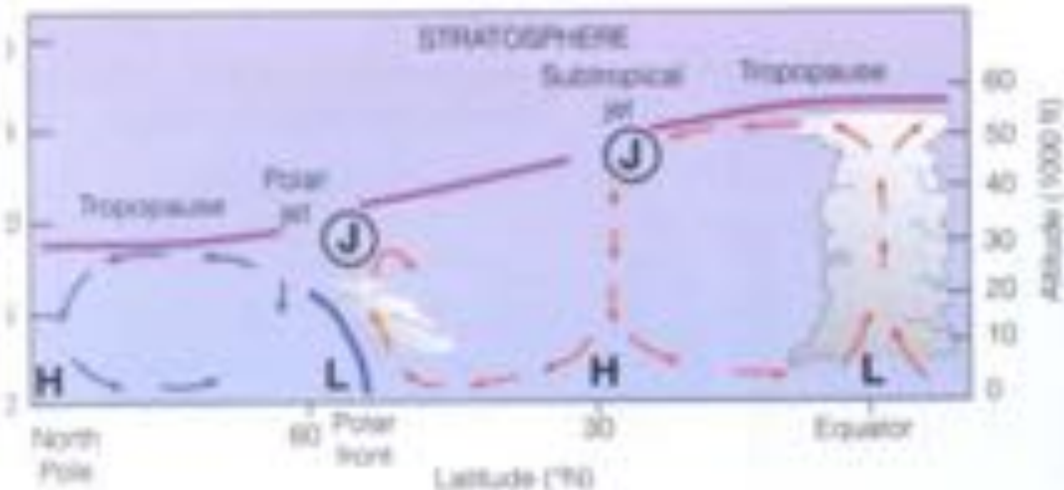
# Coriolis effect on convection cells: Hadley Cells





Subpolar low
Polar high
Polar easterlies
60°
Polar front
Hadley cell
30° Subtropical high
Horse latitudes
Hadley cell
NE trade winds
Equatorial low
Doldrums
Hadley cell
Hadley cell


Bi




# A Cross-Section…

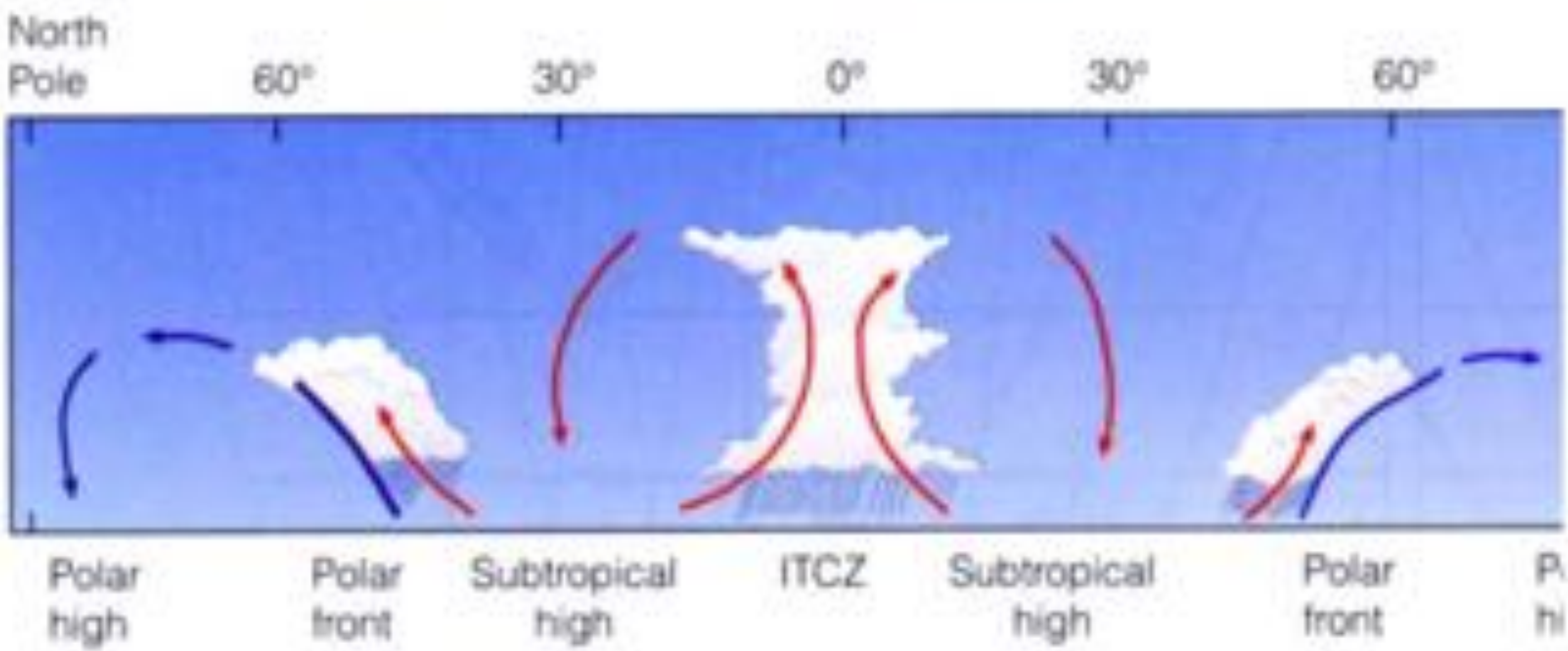
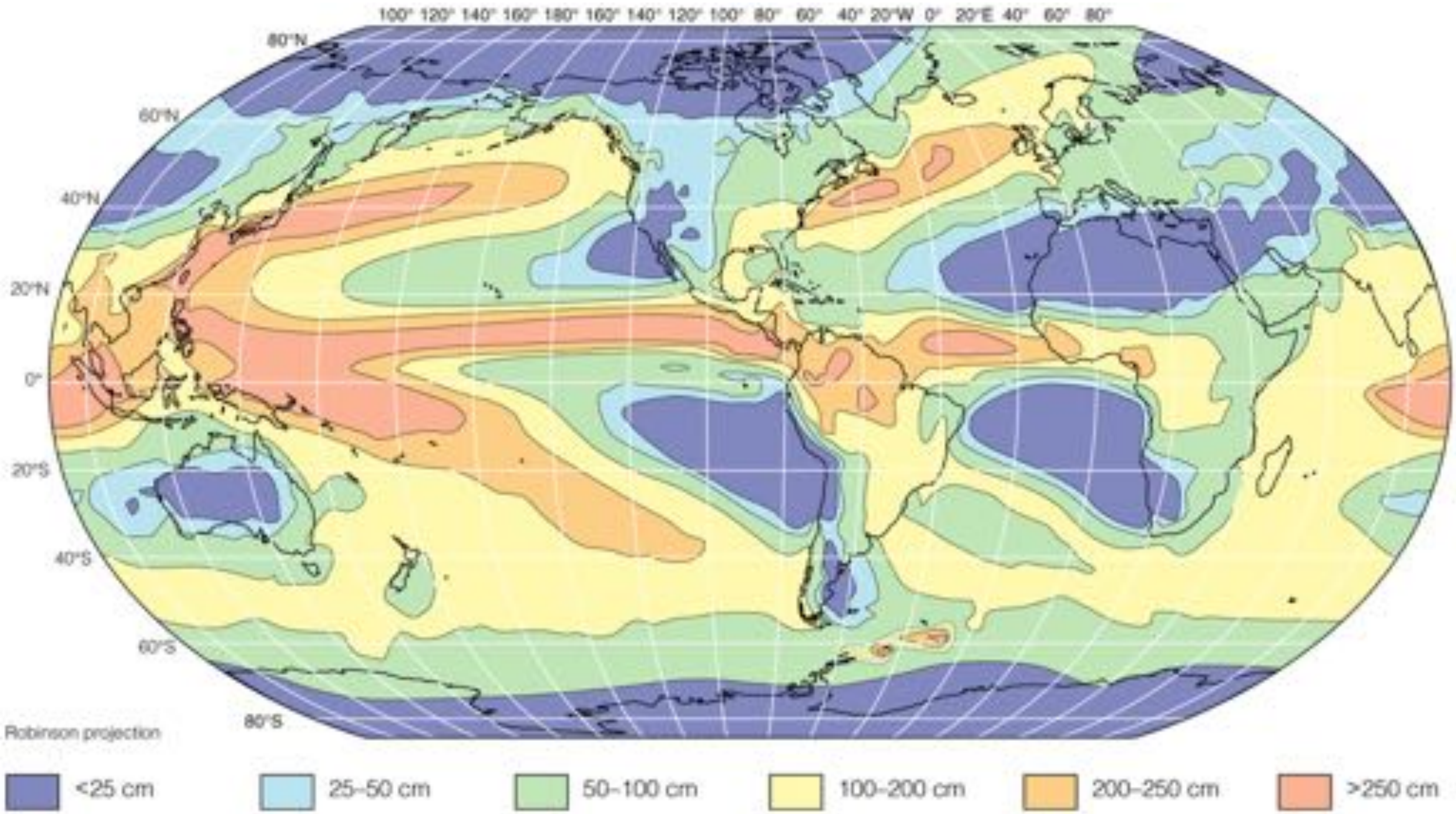



Image: David Townsend

Precipitation (annual)

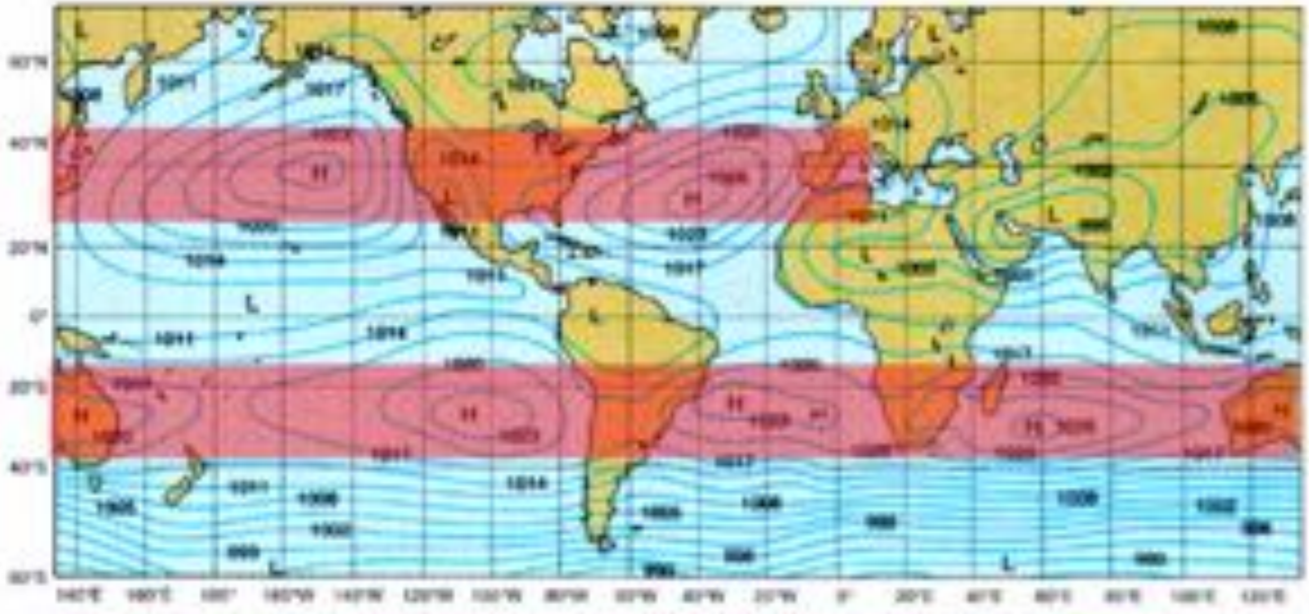



Bi

High & Low atmospheric pressure bands <u>are actually present</u>

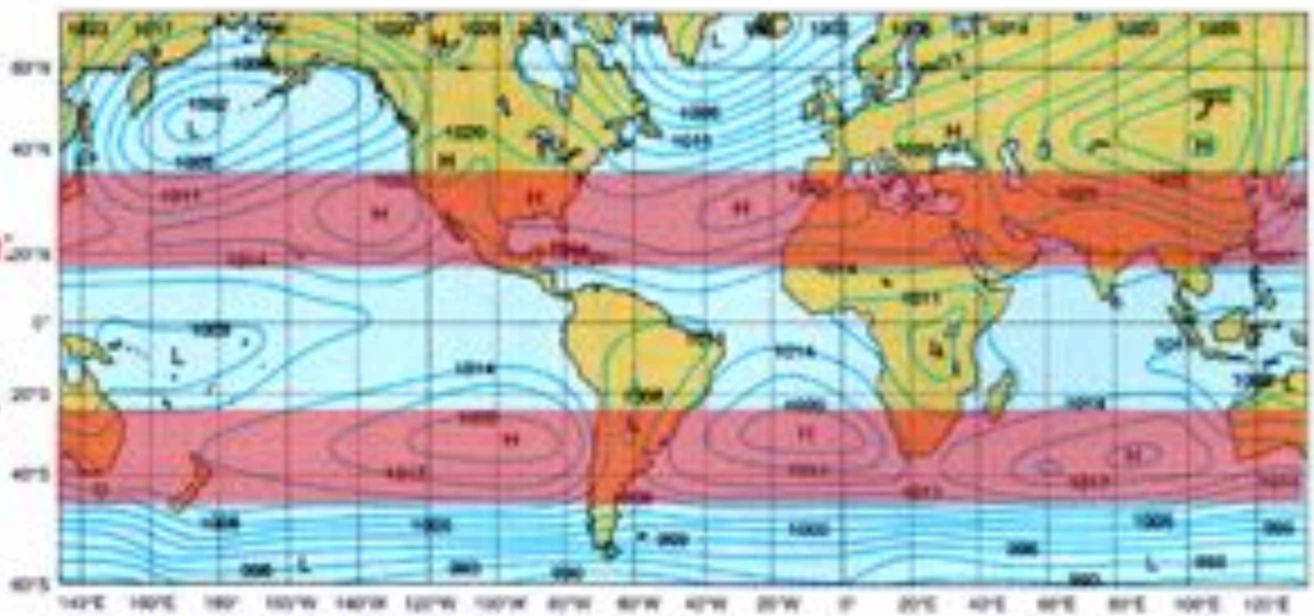
*-- but in Cells*

**Summer**



(a) July

**Winter**



(b) January

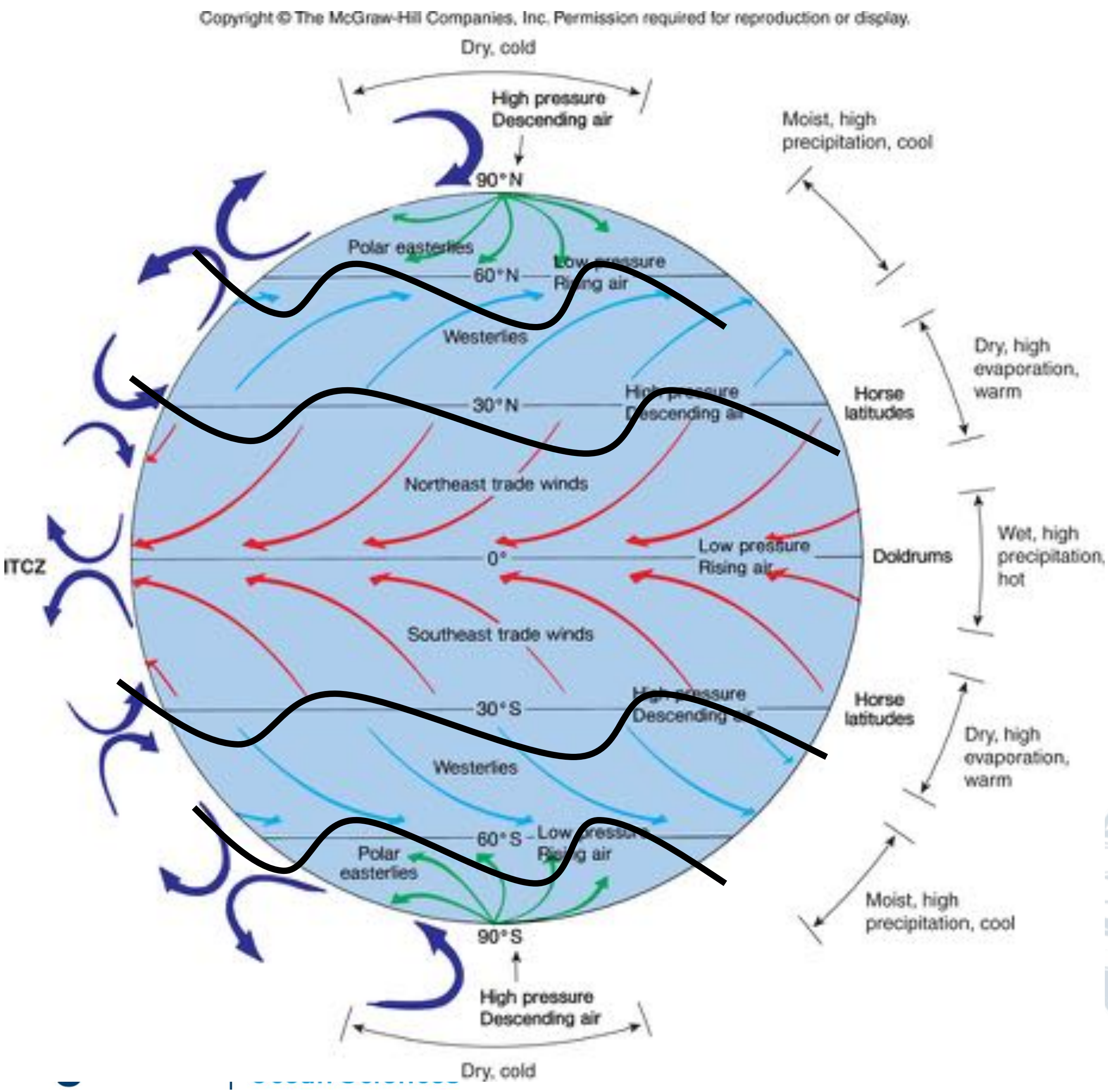
Cells result because:

- Land heats up faster than oceans, and cools off faster

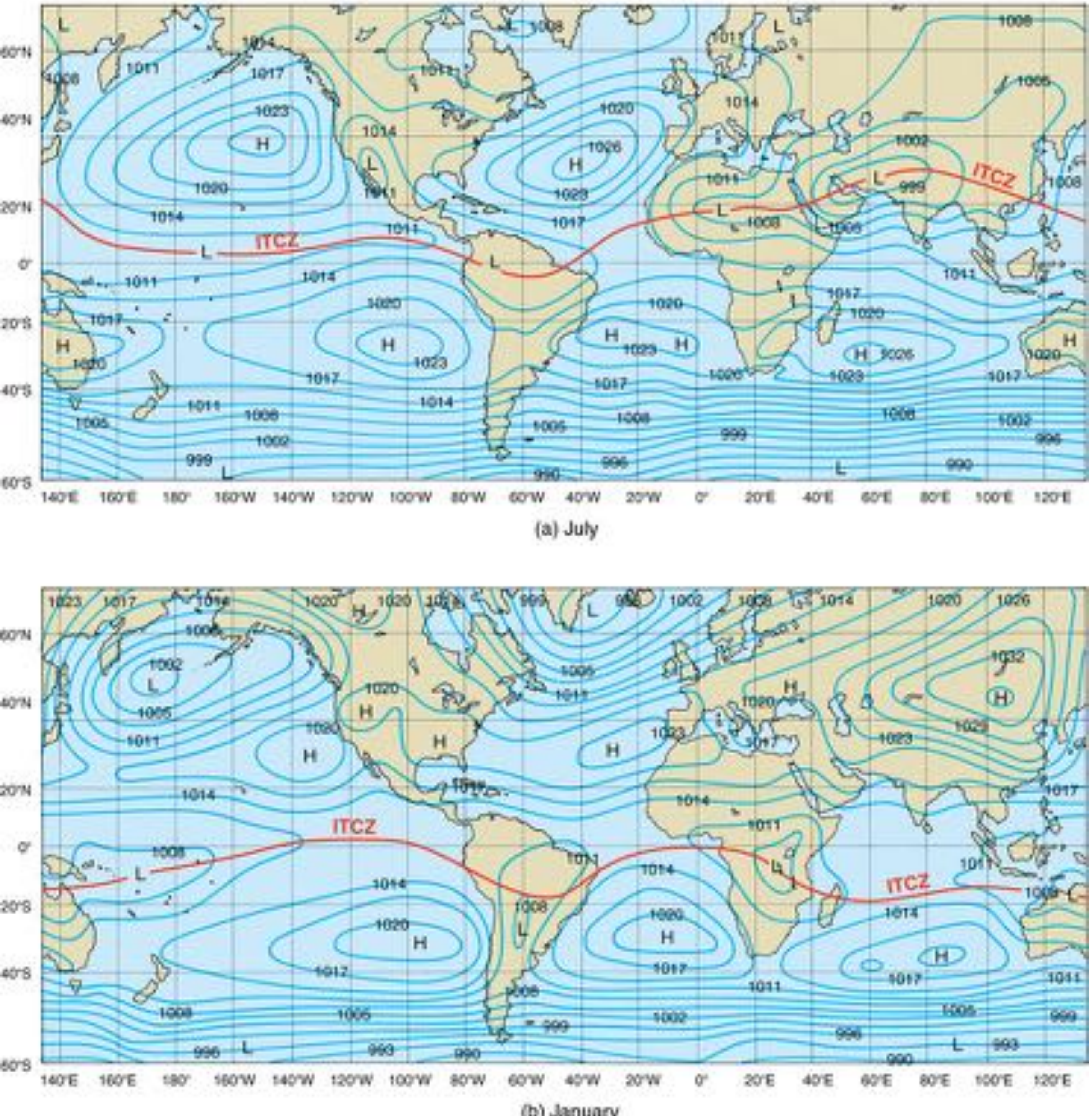
Image: David Townsend

CORIOLIS EFFECT

- increases with latitude
- Increases with speed of moving air parcel
- Depends on rate of rotation of earth
- NH: deflection to the right
- SH: deflection to the left
    - Air/water moving equatorward, deflects to the W
    - Air/water moving poleward, deflects to the E




Jet stream at 60°N&S, 30oN&S in upper troposphere




Seasonal changes in atmospheric pressure

Isobars; the closer the lines, the stronger the winds

Air motion around pressure cells:

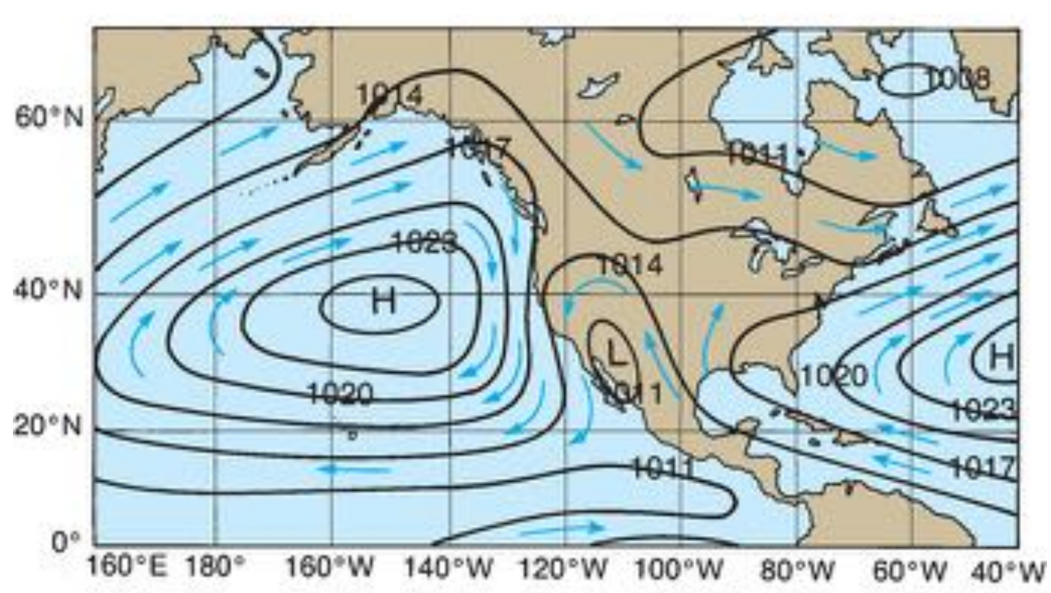
clockwise around high

Counter clockwise around low

** Opposite in Southern Hemisphere

**Geostrophy:** Why weather maps show pressure isobars






(a) July


(b) January

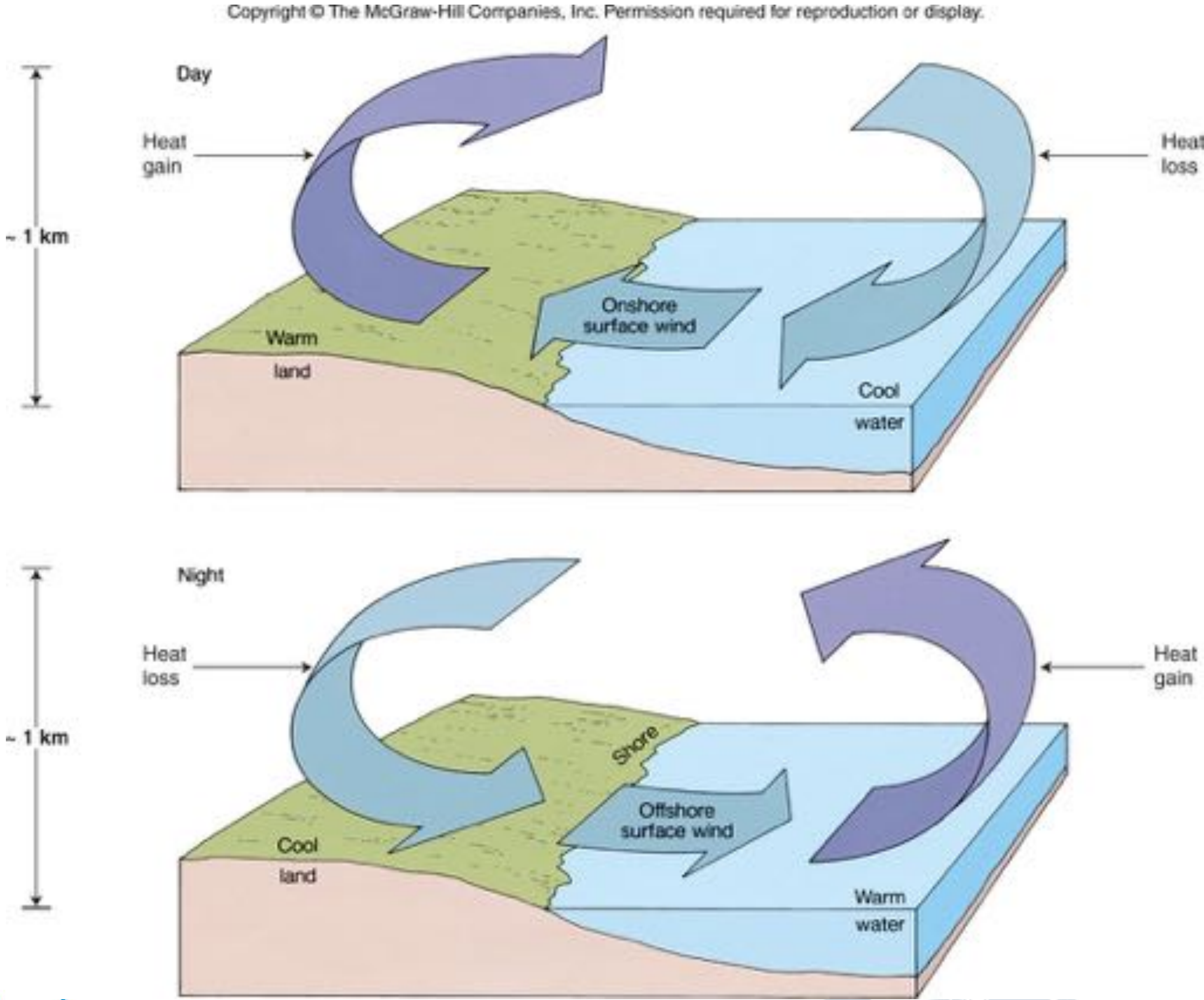
Bigelow | Laboratory for Ocean Sciences

## Local Processes

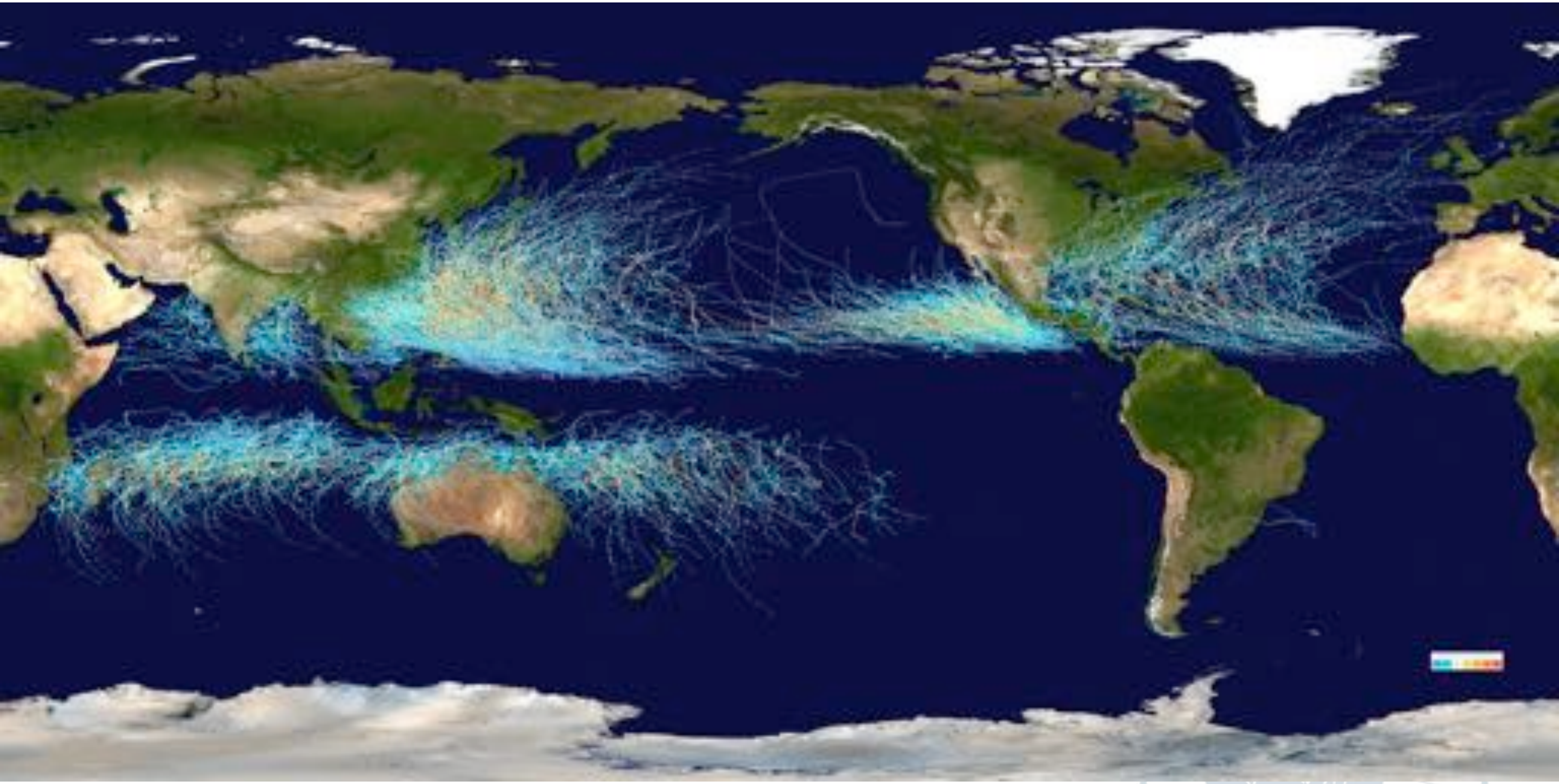
Sea breeze

(local, daily scale)

Same process drives monsoons at a seasonal scale




Bigelow | Laboratory for Ocean Sciences



Bigelow | Laboratory for Ocean Sciences