Wednesday October 25, 2017
Lecture #24

Review

Finish Atmosphere Circulation: Hadley cell, Walker Cell,

Ocean Basics...

- **How is the ocean different from the atmosphere?**

ATM and OCN differences

- **source of lots of moisture**
- **larger heat capacity**
- **nearly incompressible**
- **longer time scale, adds inertia to climate system**
- **smaller temperature variations than air**
- **separate basins (not continuous) with complex topography!**

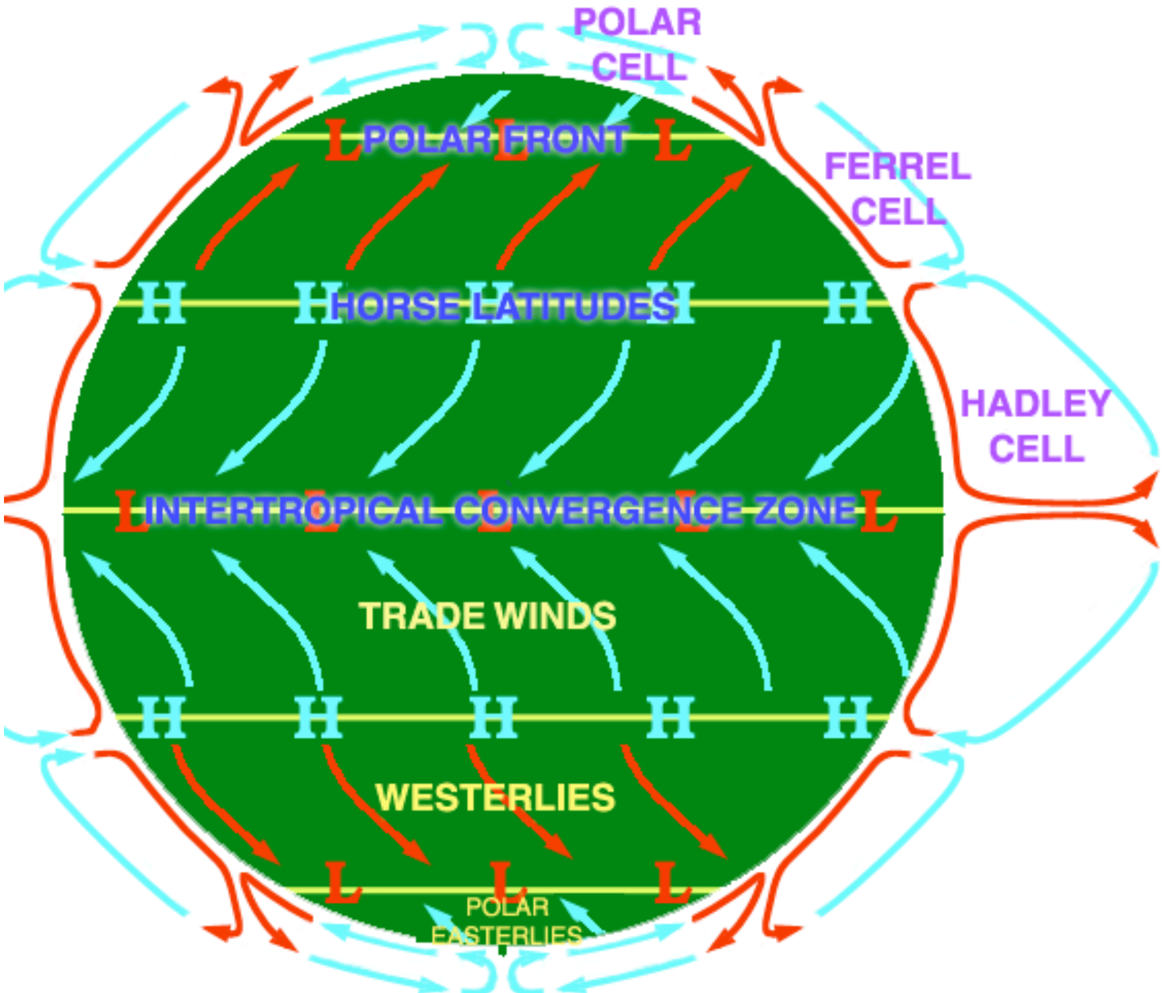
Review

- What is the SPCZ?
- Freshwater, how much of total global water?
- What is P-E? Why is P-E important to the ocean?
- What is evapotranspiration?
- What are the 3 ‘forces’ that impact winds?
- What is the circulation around a low pressure? high pressure?

Earth's circulation Cells (IDEALIZED)

- **General circulation (global circulation, planetary circulation)** of the atmosphere. Description of atmospheric motions over the Earth that results from uneven heating.
- Statistical Description
- Modeled General Circulation (GCM)

- Average - Hadley Cell



http://en.wikipedia.org/wiki/Atmospheric_circulation

Meridional Mean Streamfunction

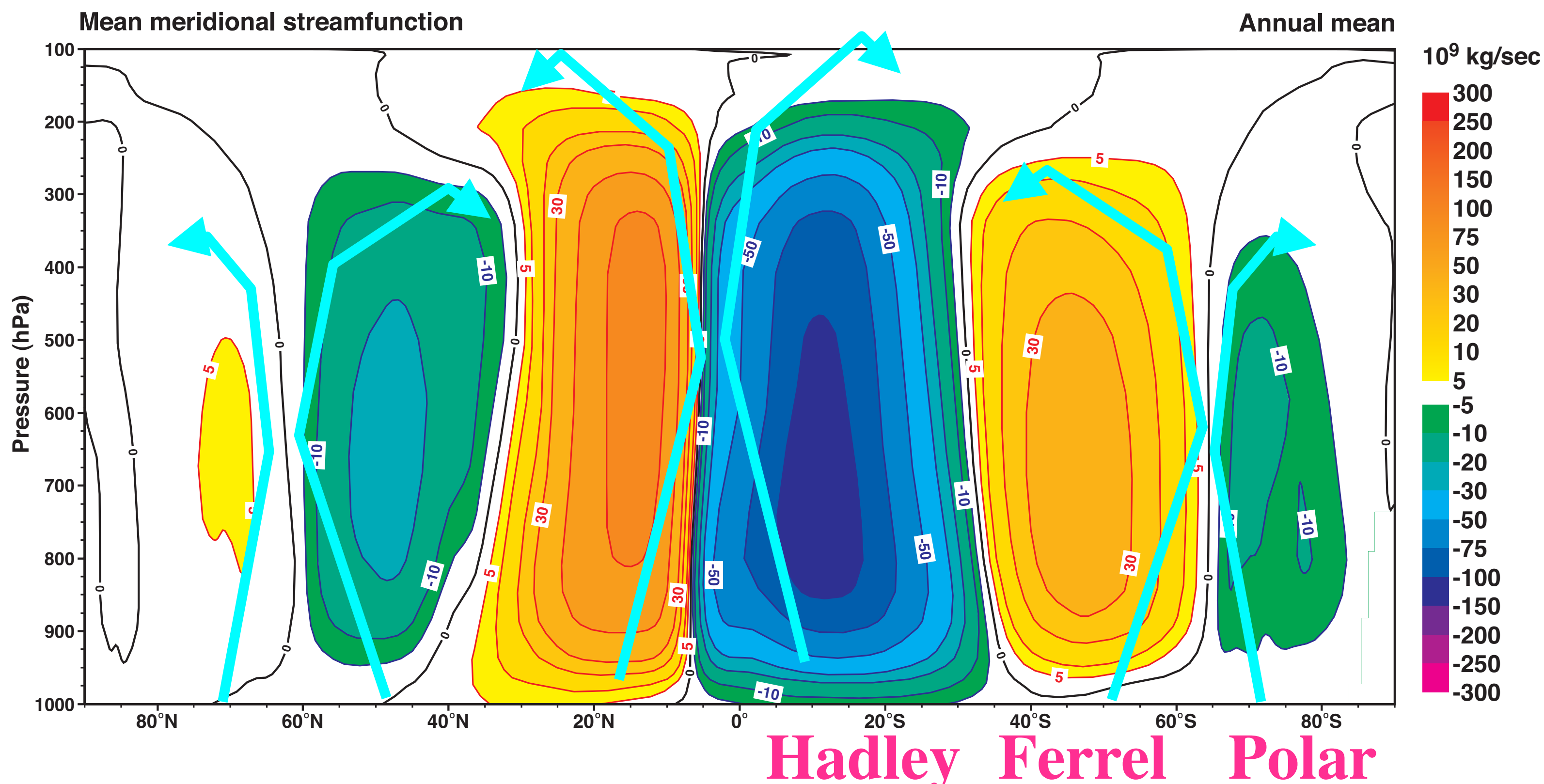


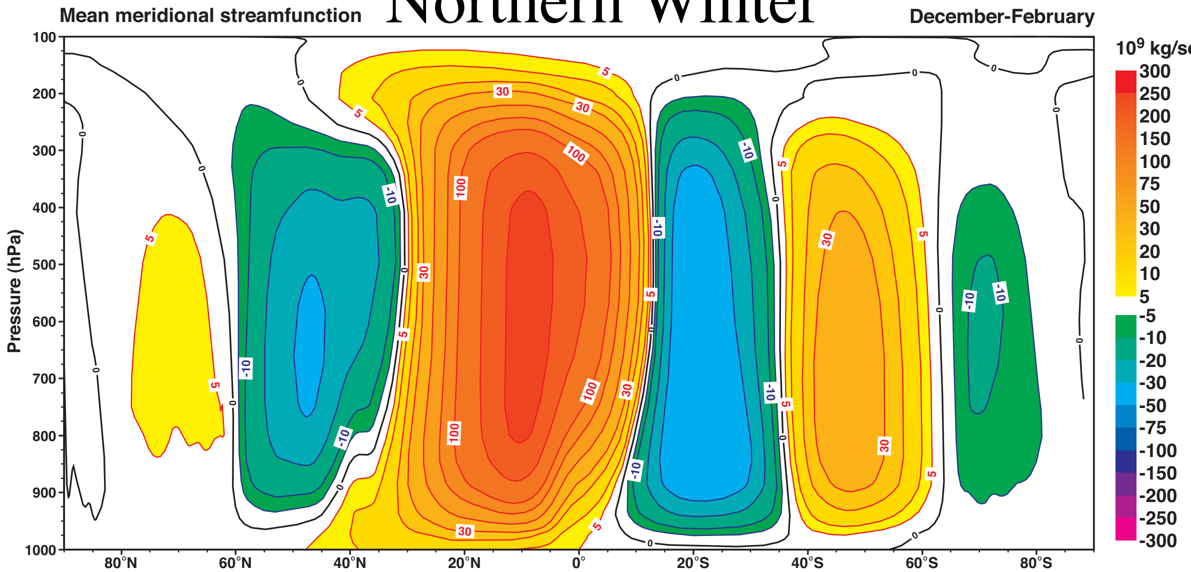
Figure 1: **Mass streamfunction for annual mean .**

Note that the average contour interval is about $10 \times 10^9 kgs^{-1}$ in this and the following figures. Following the definition of Ψ, the red (or positive contours) denote counter-clockwise flow, while the blue (or negative contours) denote clockwise flow.

Streamfunction shows trajectories of particles for a steady flow

D. Strauss, COLA

Northern Winter



Meridional Mean Streamfunction in Dec-Feb & Jun-Aug

North Hem.

Figure 2: **Mass streamfunction for Dec-Jan-Feb mean.**

Note here that the rising motion is just south of the equator (in the Southern or summer hemisphere).

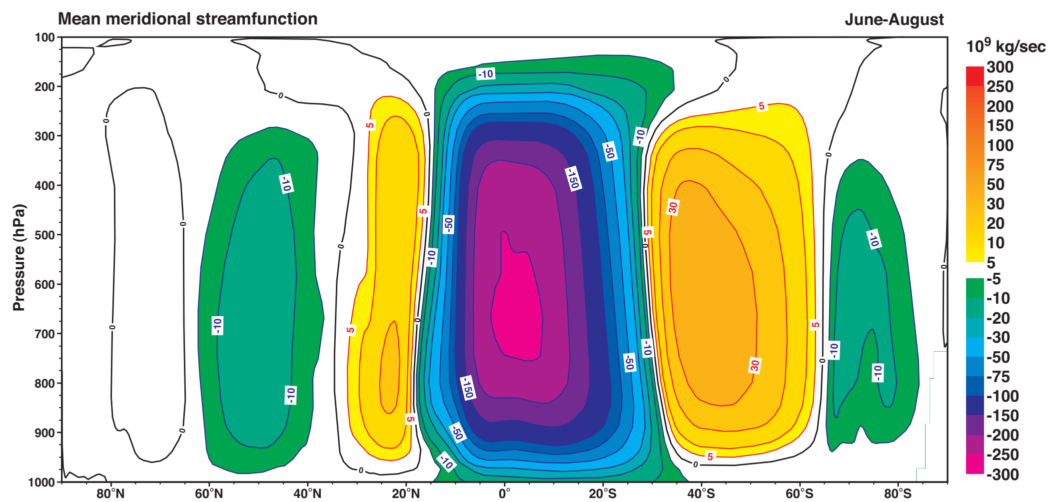


Figure 3: **Mass streamfunction for June-July-Aug.**

Note here, in the Northern summer, that the rising motion is fairly north of the equator, nearly at $20^o N$. This is partly the influence of the Asian summer monsoons.

D. Strauss, COLA

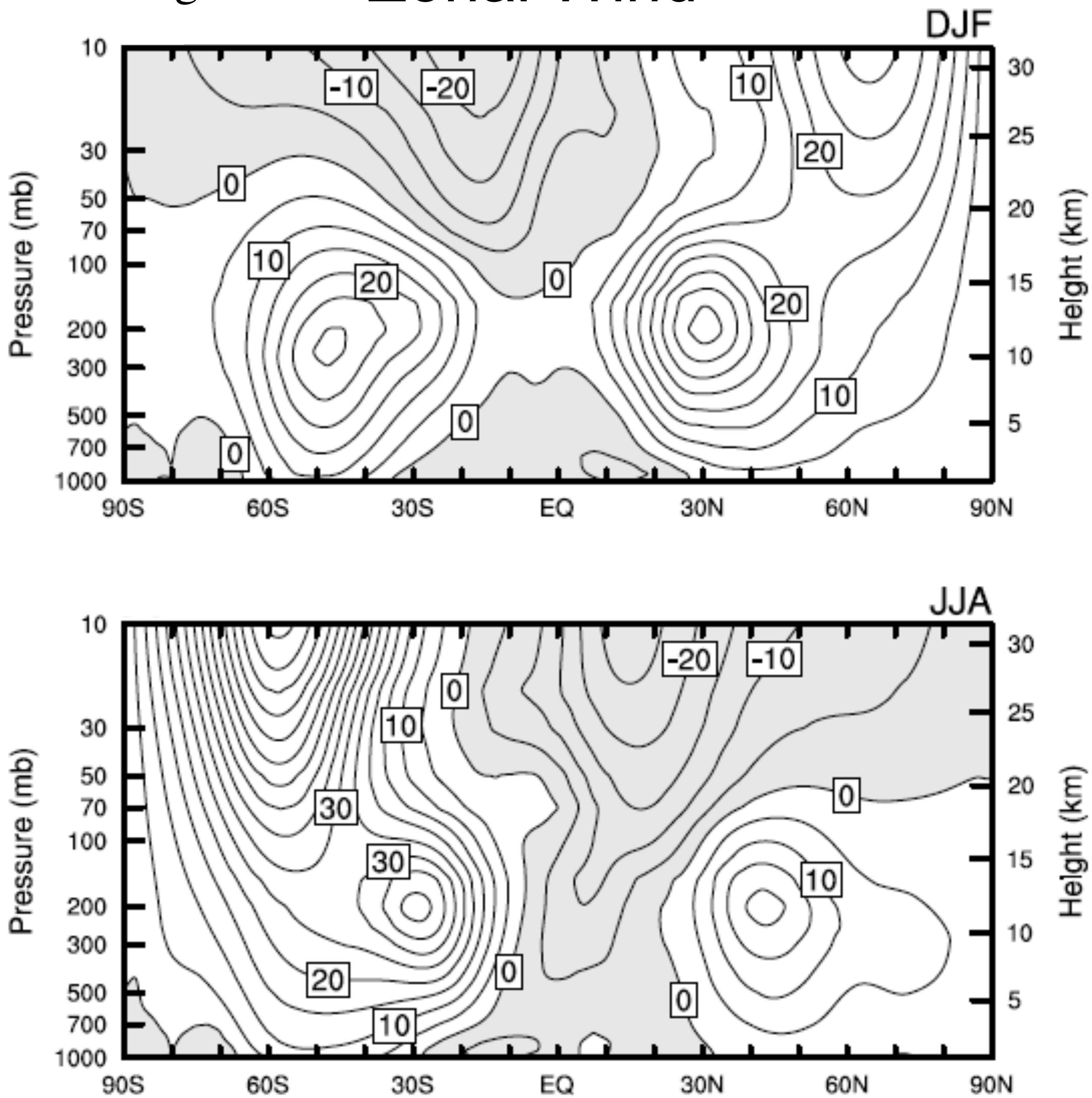
Zonal Average Tropospheric Wind

Eastward positive
Westward negative

Zonal Wind

East-West wind

Units: m/s



- **westerlies**
- **tropical easterlies**
- **Subtropical Westerly Jet at 30N**

•Zonal average meridional and vertical winds Weaker than zonal winds, 1m/s & 0.001m/s

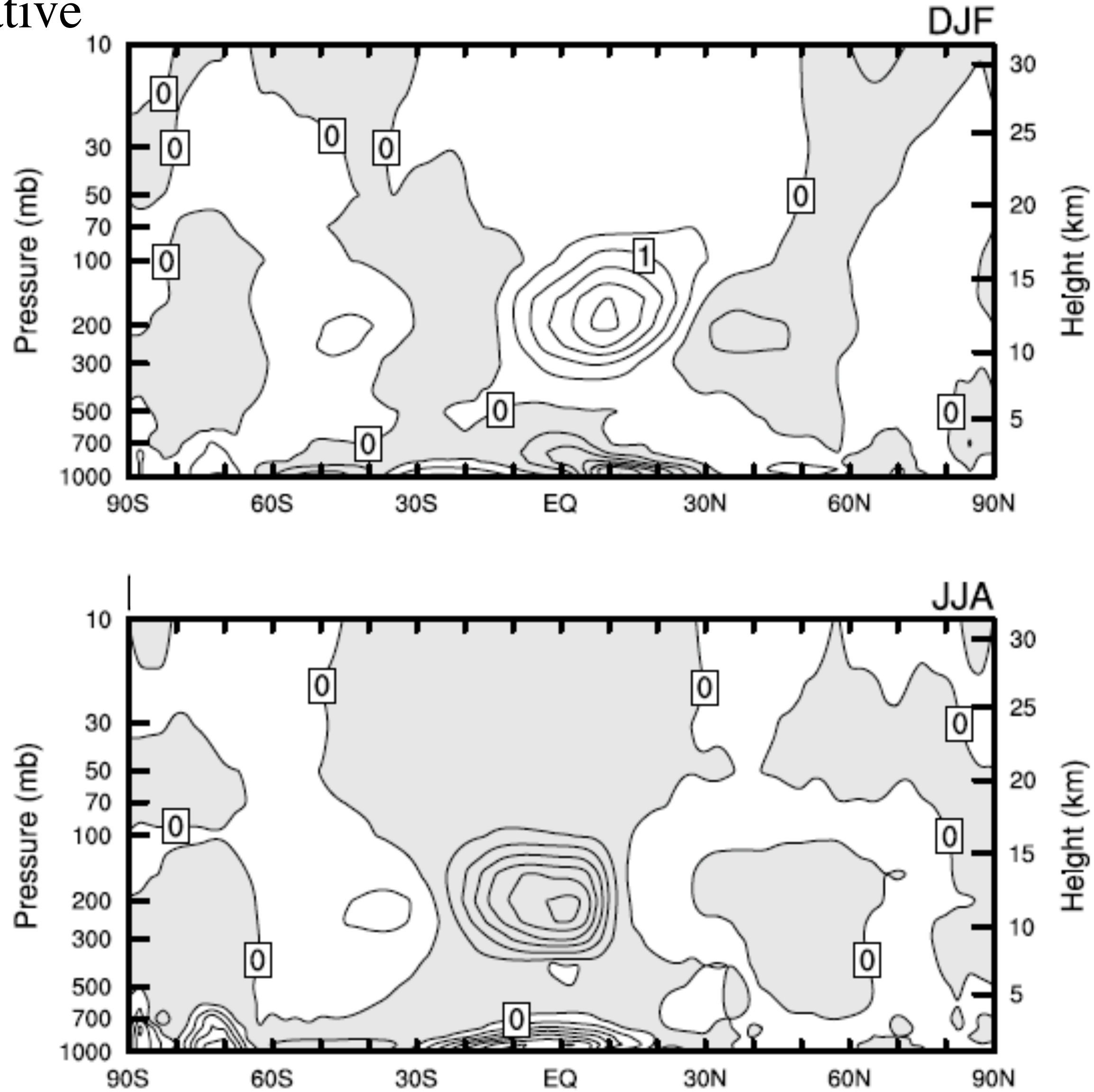
ERA-40

The zonal average tropospheric circulation

northward positive
southward negative

Meridional Wind

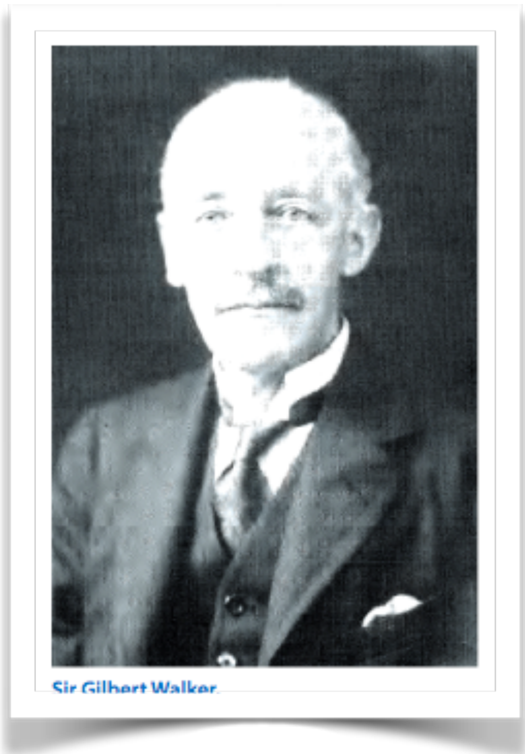
North-South wind

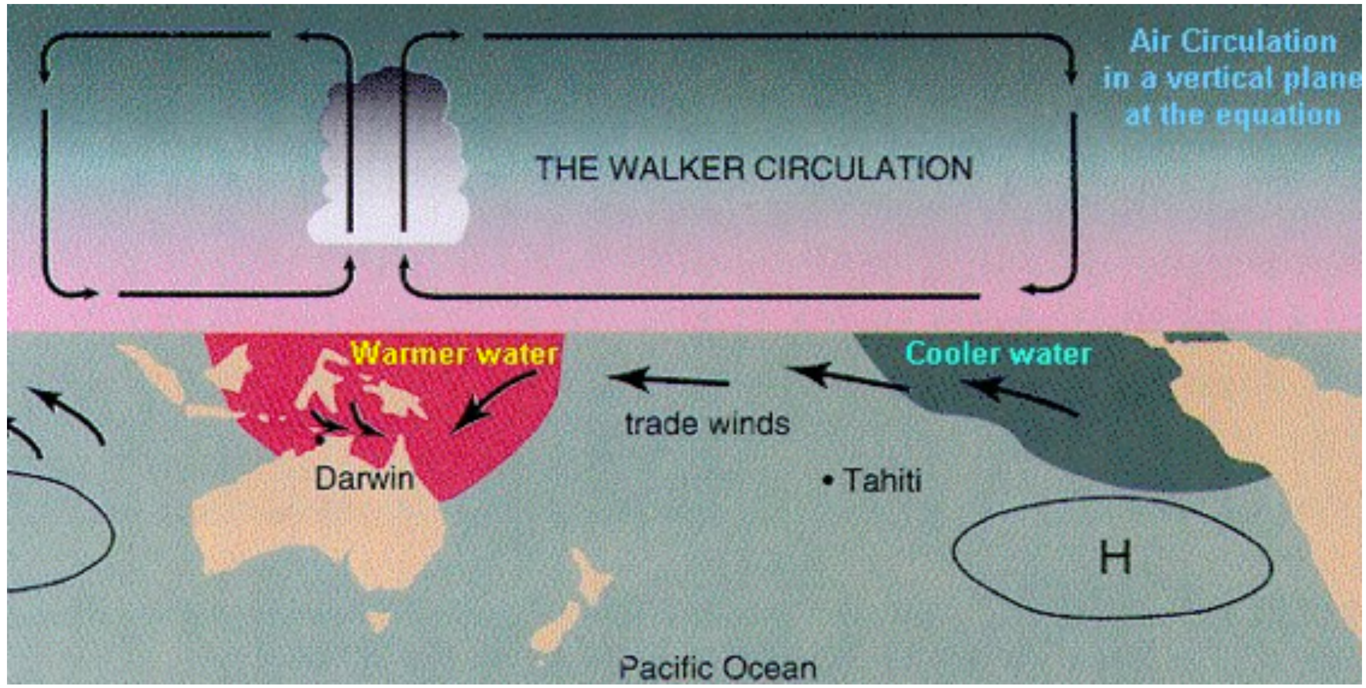


- **Weaker than zonal wind!**

ERA-40

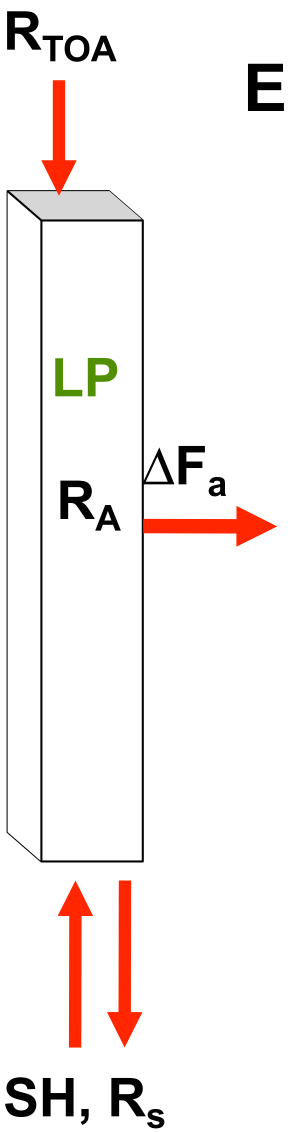
Thermally Direct - Walker Circulation





- **The Walker Cell, discovered by Sir Gilbert Walker, is an east-west circulation along the equator in the Pacific.**
- **Changes in the Walker cell come about during El Niño (more on that later)**
- **Rising motion over the Maritime continent and sinking over the cooler eastern equatorial Pacific.**

Local Energy Balance of Atmospheric Column



Energy flux (energy/time) per unit area

$$\frac{\partial E_A}{\partial t} = R_A + LP + SH - \Delta F_a$$

LP - Heating from water condensation

$$R_A = R_{TOA} - R_S$$

$$R_A + LP + SH = \Delta F_A$$

ΔF_a - Horizontal divergence of energy

R_A Net Radiation is the sum of TOA and surface

Atmospheric Energy Budget: Radiative Effects in Atmosphere Cool the column

- **Net Radiative effect is flat and ~90 W m^{-2}, 1.5K/day cooling**
- **Condensational Heating Larger then Sensible Heating**
- **ΔF_a Resembles Zonally Averaged Precipitation**

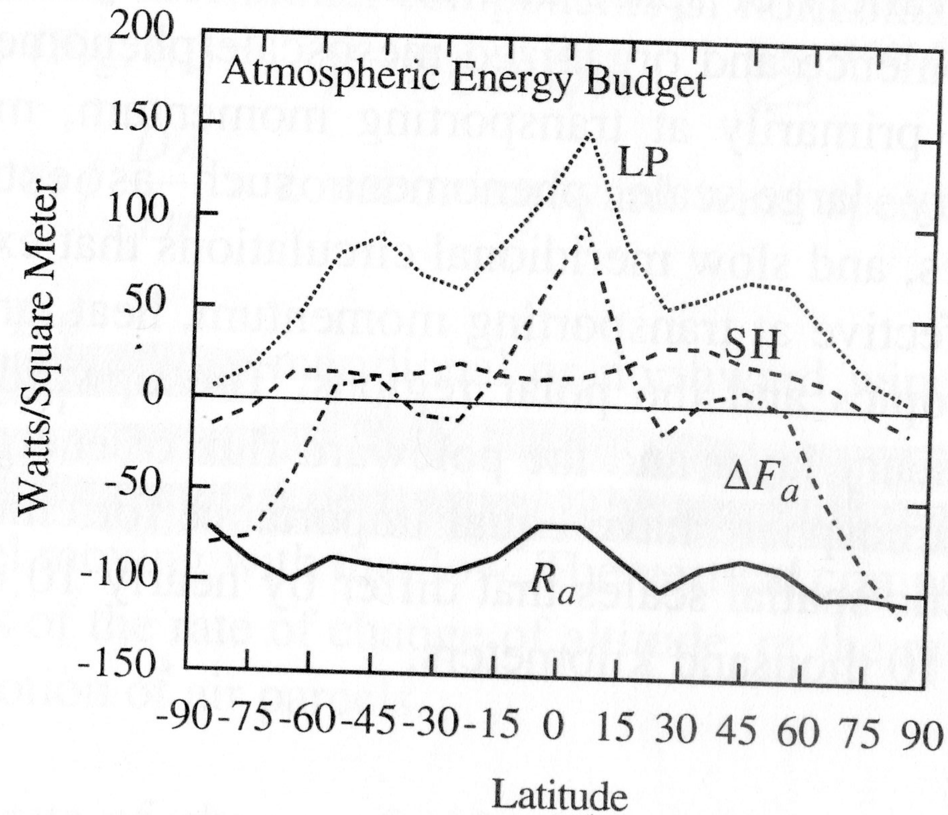
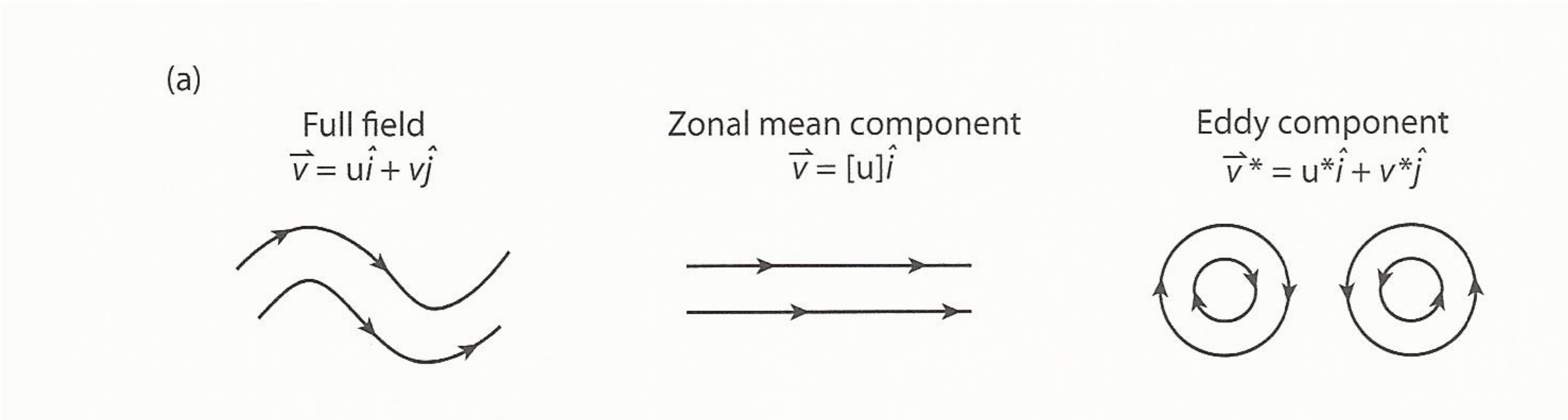


Fig. 6.1 Distribution with latitude of the components of the atmospheric energy balance averaged over longitude and over the annual cycle. Units are W m^{-2}. [Data from Sellers (1965). Used with permission from the University of Chicago Press.]

[Hartmann, 1994]

Decomposing the Atmosphere



[Cook, 2012]

Eddy Circulation and Meridional Transport

- Midlatitude weather fluctuations are deviations from time average

$$x' = x - \overline{x}$$

midlatitude cyclones

- There are also deviations of the time mean from its zonal average

$$\overline{x}^* = \overline{x} - \left[\overline{x}\right]$$

Time mean & zonal mean

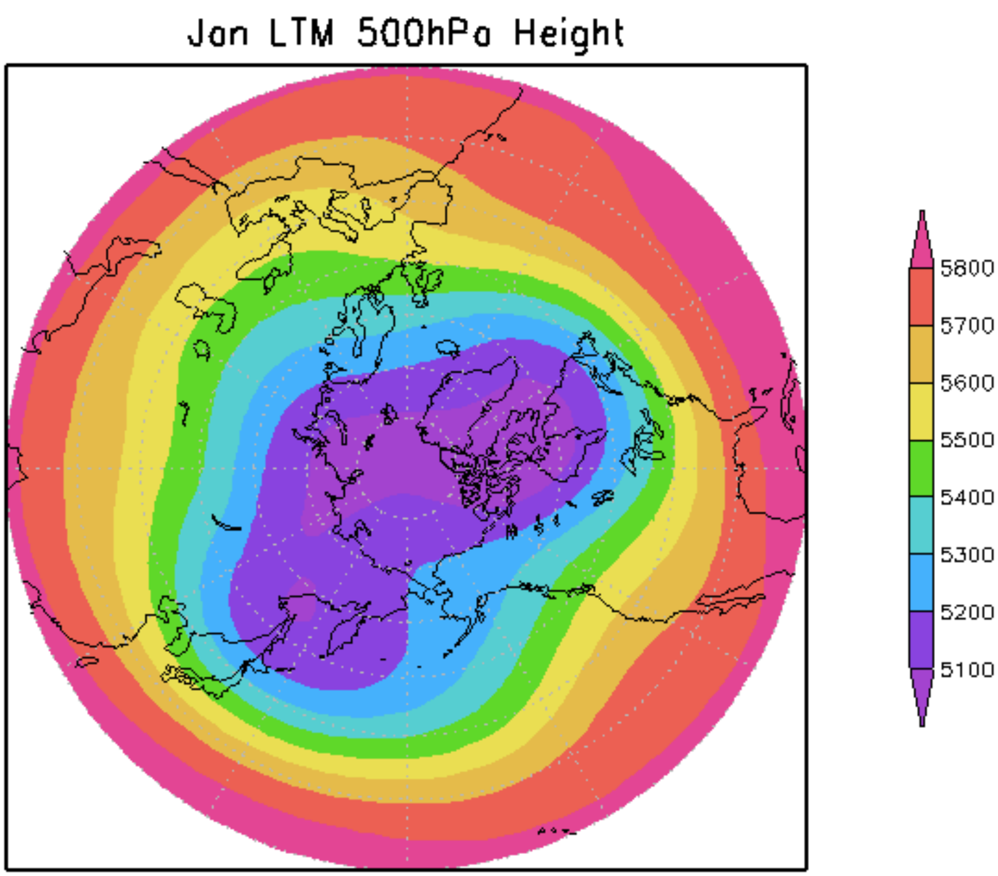
quasi-stationary

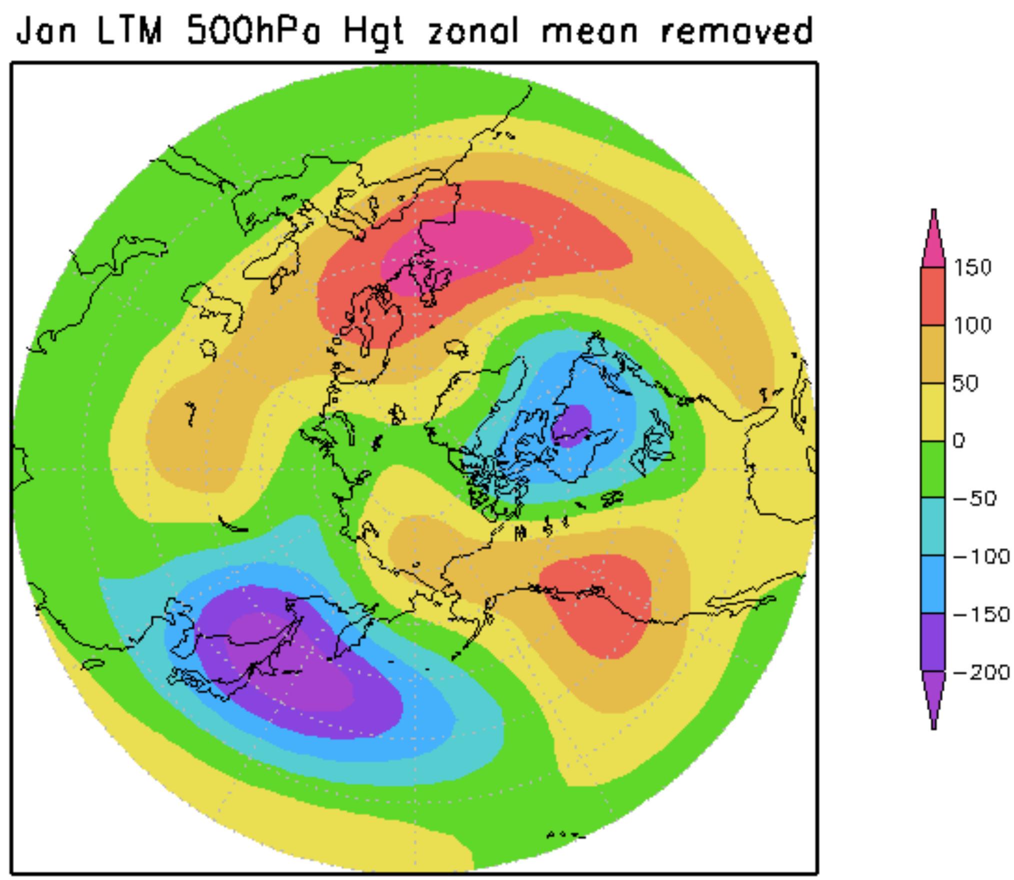
- Sign convention on fluxes: northward eddy fluxes of temperature are produced when northward air is warmer than southward air.

total northward transport MMC Stationary eddy Time mean Transient eddy time varying

$$\left[\overline{vT}\right] = \left[\overline{v}\right]\left[\overline{T}\right] + \left[\overline{v}^*\overline{T}^*\right] + \left[\overline{v'T'}\right]$$

Stationary Eddy with zonal mean taken out



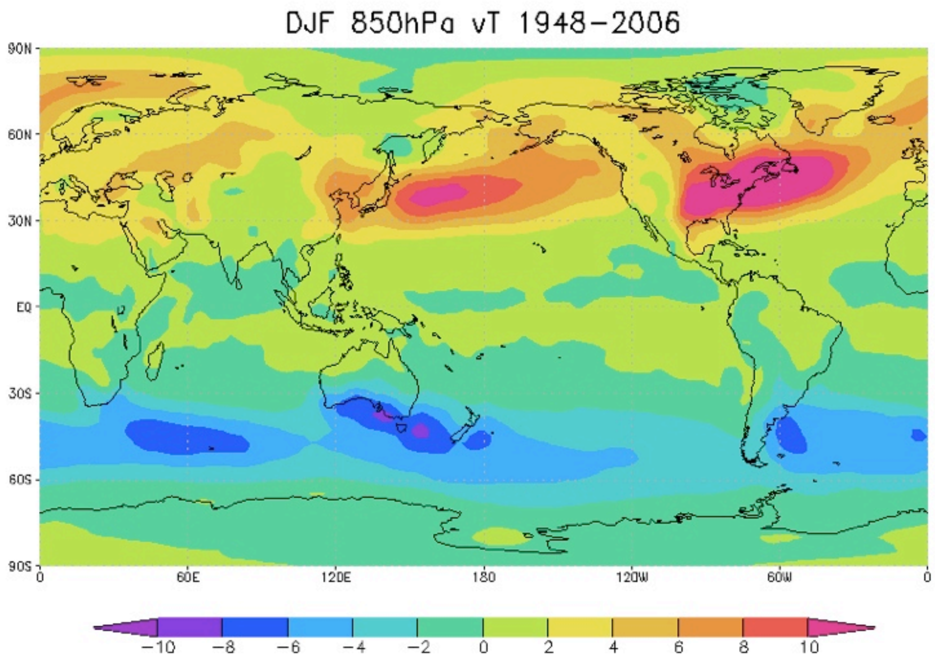


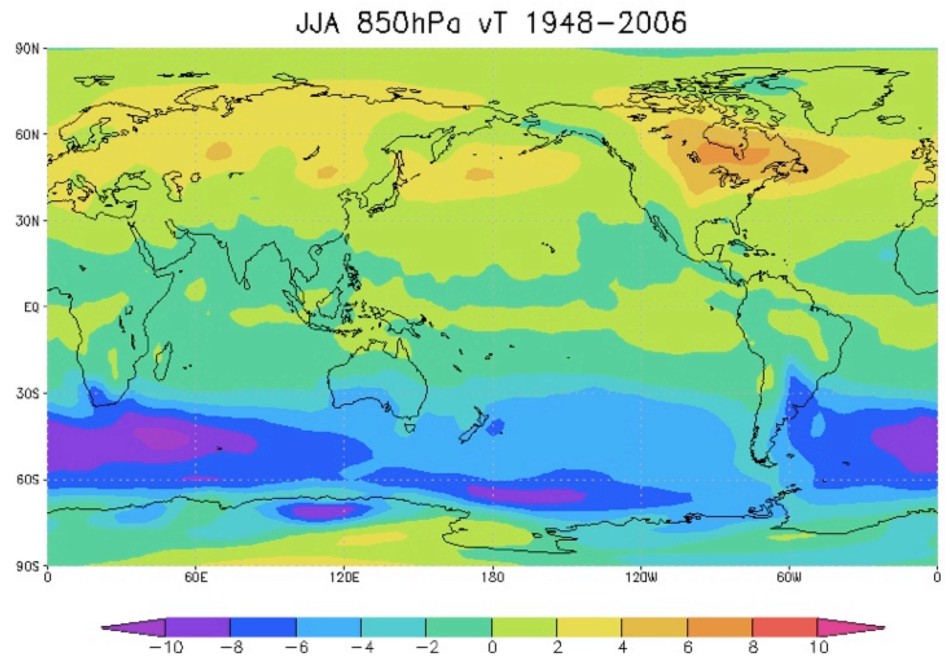
- **Departures of time average from zonal symmetry**
- **Thermal contrast & tied to continents**
- **Largest near mountains**

aka (Hartmann Figure 6.7)

- Standing Eddy
- Stationary planetary waves

Transient Eddies: 850hPa v'T'





- **Climatological values (time mean)**
- **Rapidly changing weather disturbances of midlatitudes.**
- **Larger winter hemisphere values, note signs, +/-**

Northward Eddy flux by latitude in Petawatts

- **Transient Eddy Flux is Key term in midlatitudes**

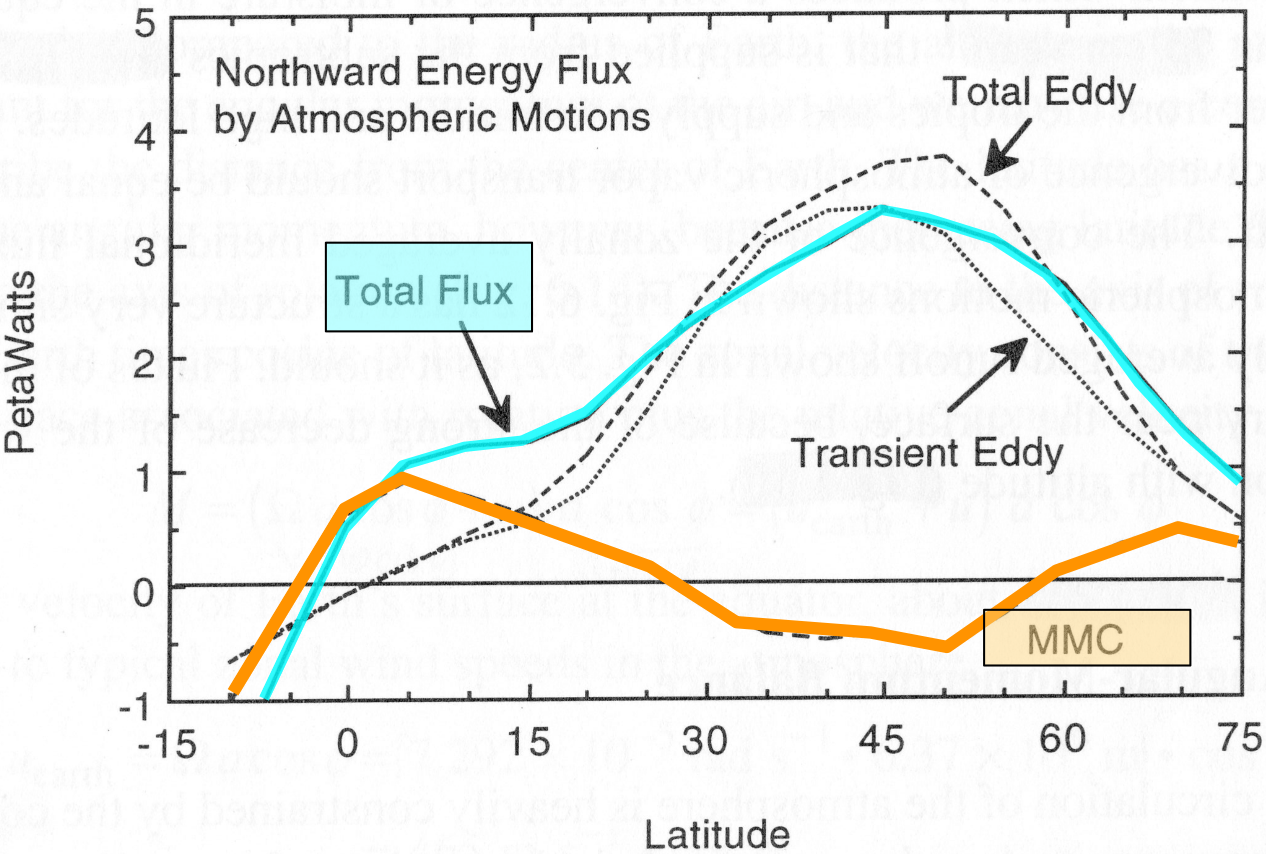


Fig. 6.11 Annual average northward energy flux plotted versus latitude in the Northern Hemisphere. Units are 10^{15} W. Mean meridional circulation (MMC). [Data from Oort (1971). Reprinted with permission from the American Meteorological Society.]

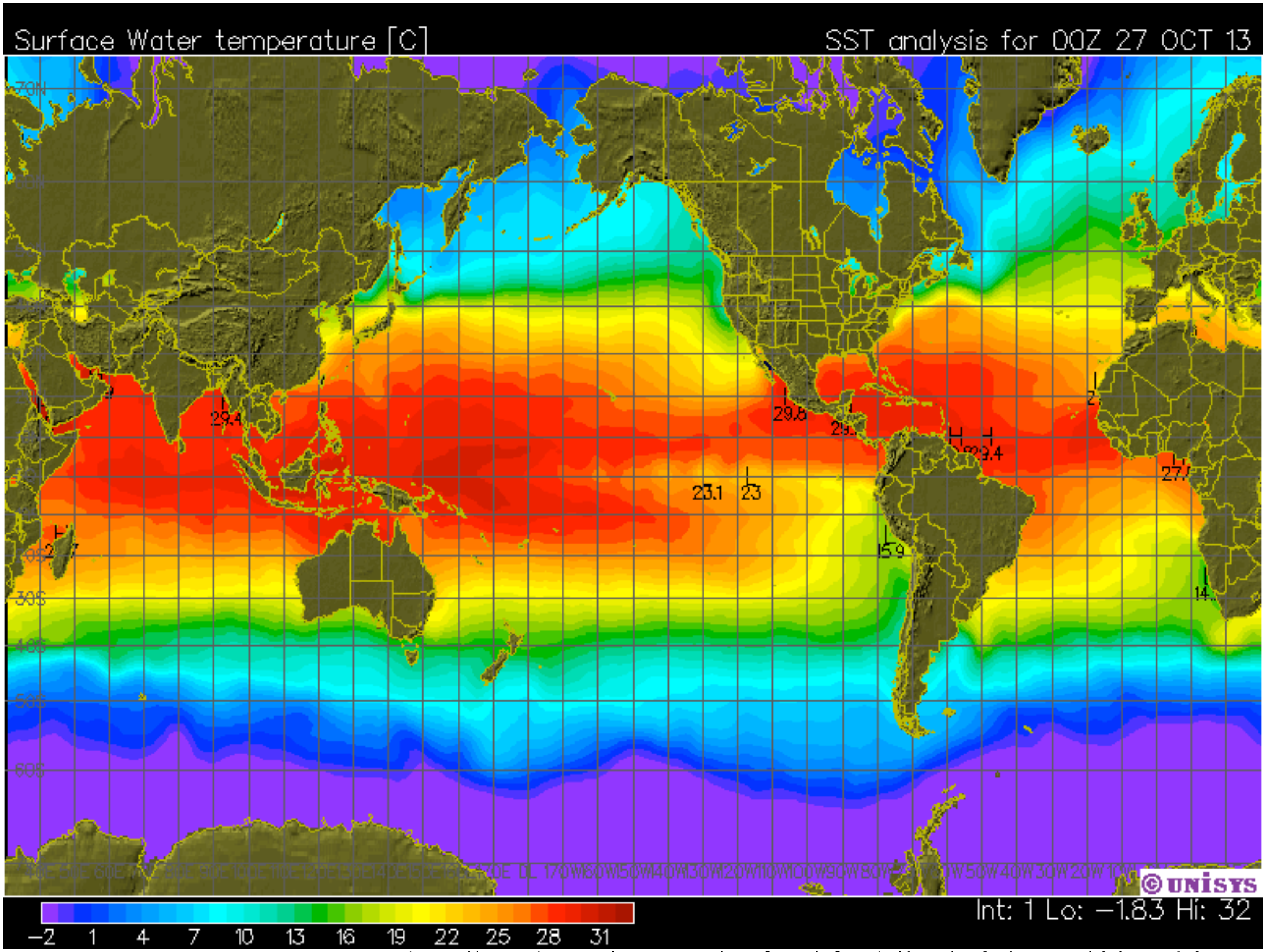
[Hartmann, 1994]

Summary

- **What are the key forces leading to atmospheric motion?**
- **What is a thermally direct circulation? Examples?**
- **What are the three types of Eddy circulations that make up the general circulation?**
- **What roles do the eddy circulations play in transporting energy?**

- **Ocean Dynamics next**

October 27, 2013 SST analysis (Observations)



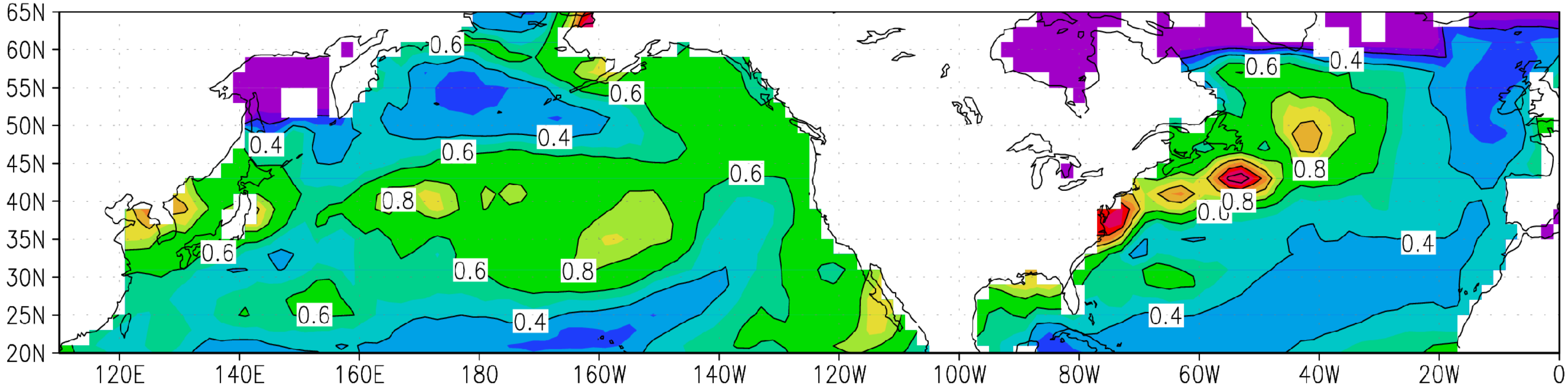
http://weather.unisys.com/surface/sfc_daily.php?plot=ssd&inv=0&t=cur

movie high resolution daily SST

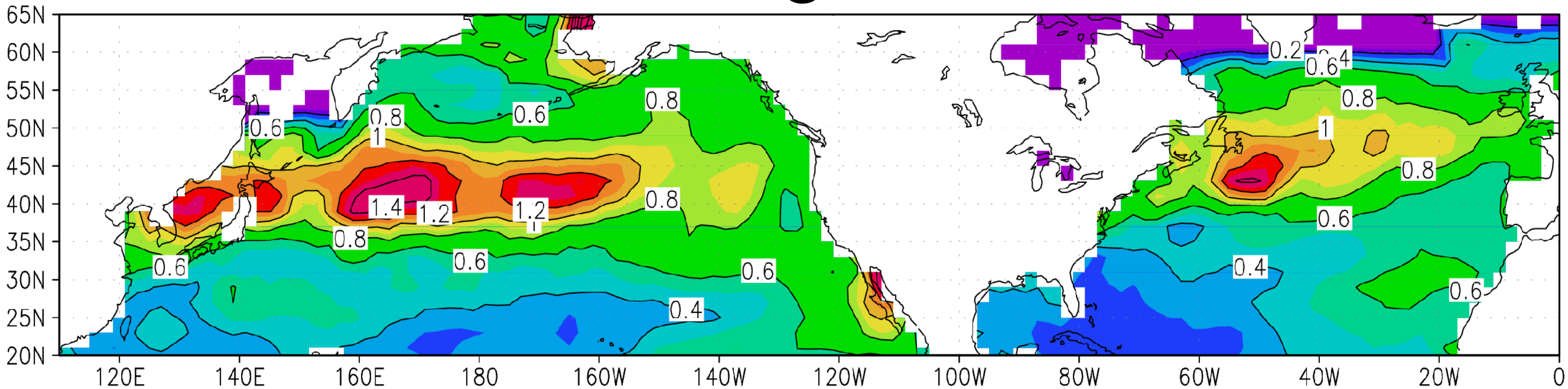
https://www.youtube.com/watch?v=1DNHRLgjLjA

Observed Standard Deviation of SST Anomalies (°C)

March

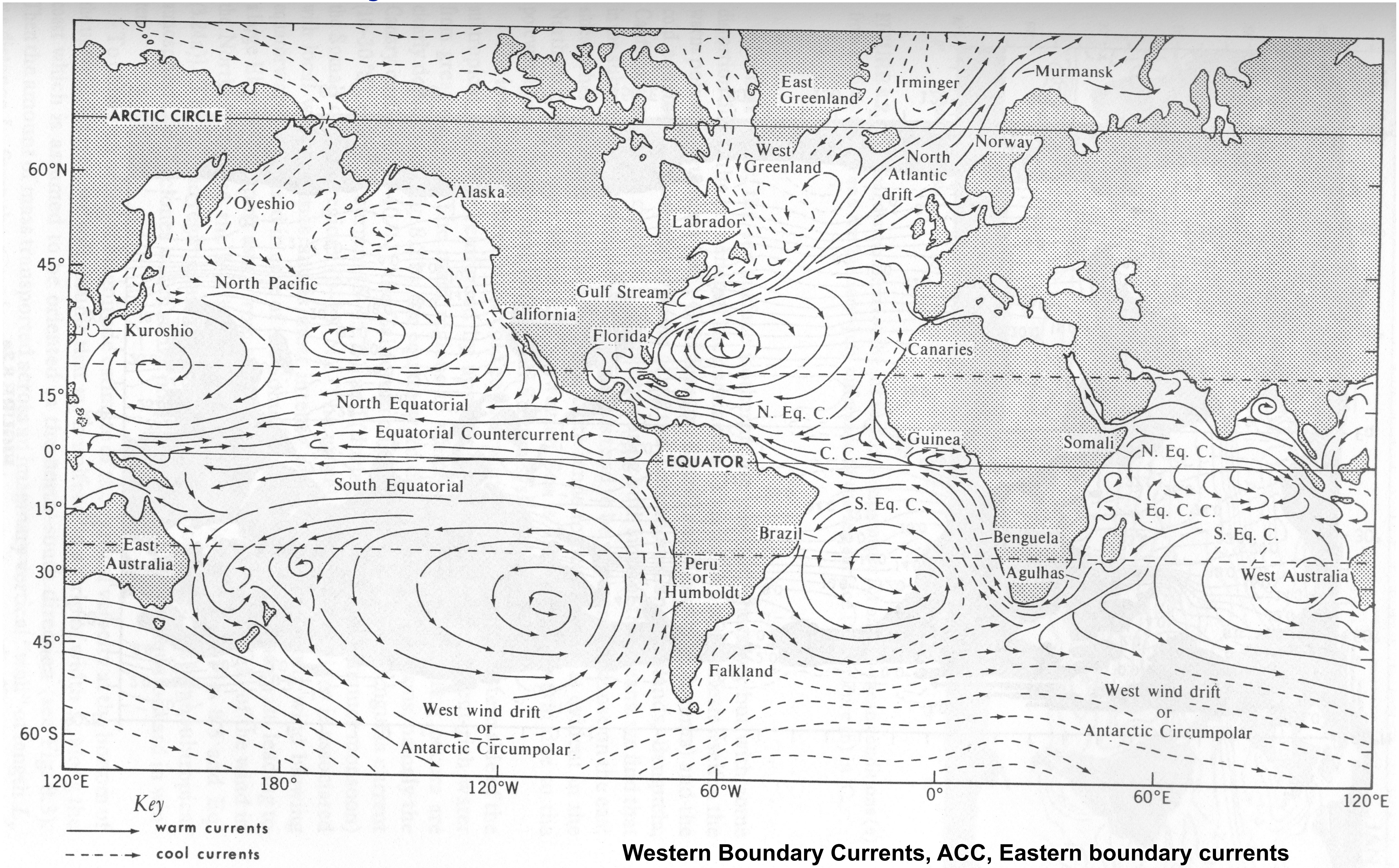


August



[SLIDE FROM MIKE ALEXANDER]

Major Surface Currents of the World



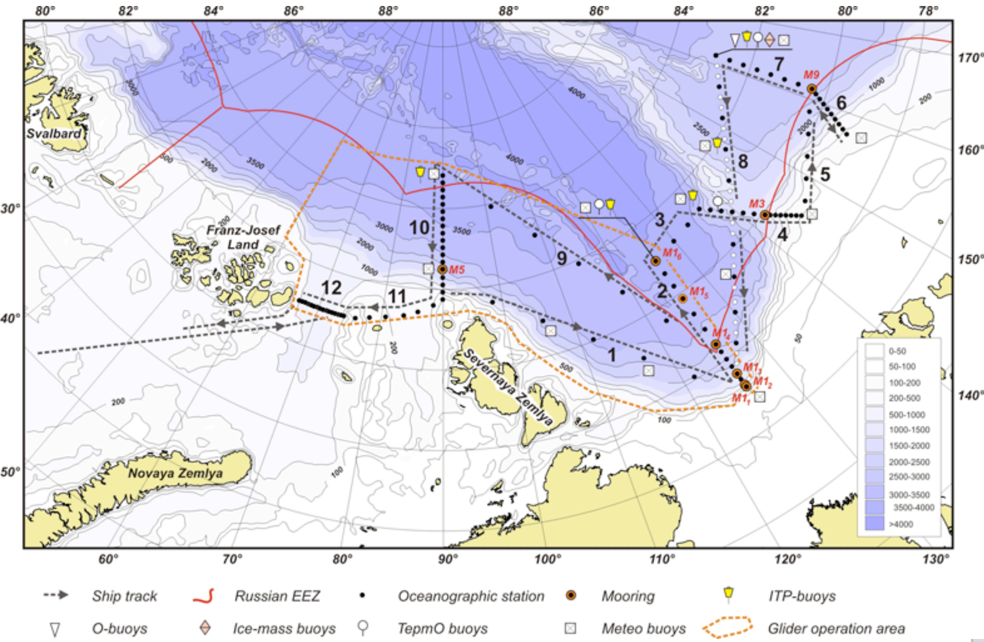
Western Boundary Currents, ACC, Eastern boundary currents

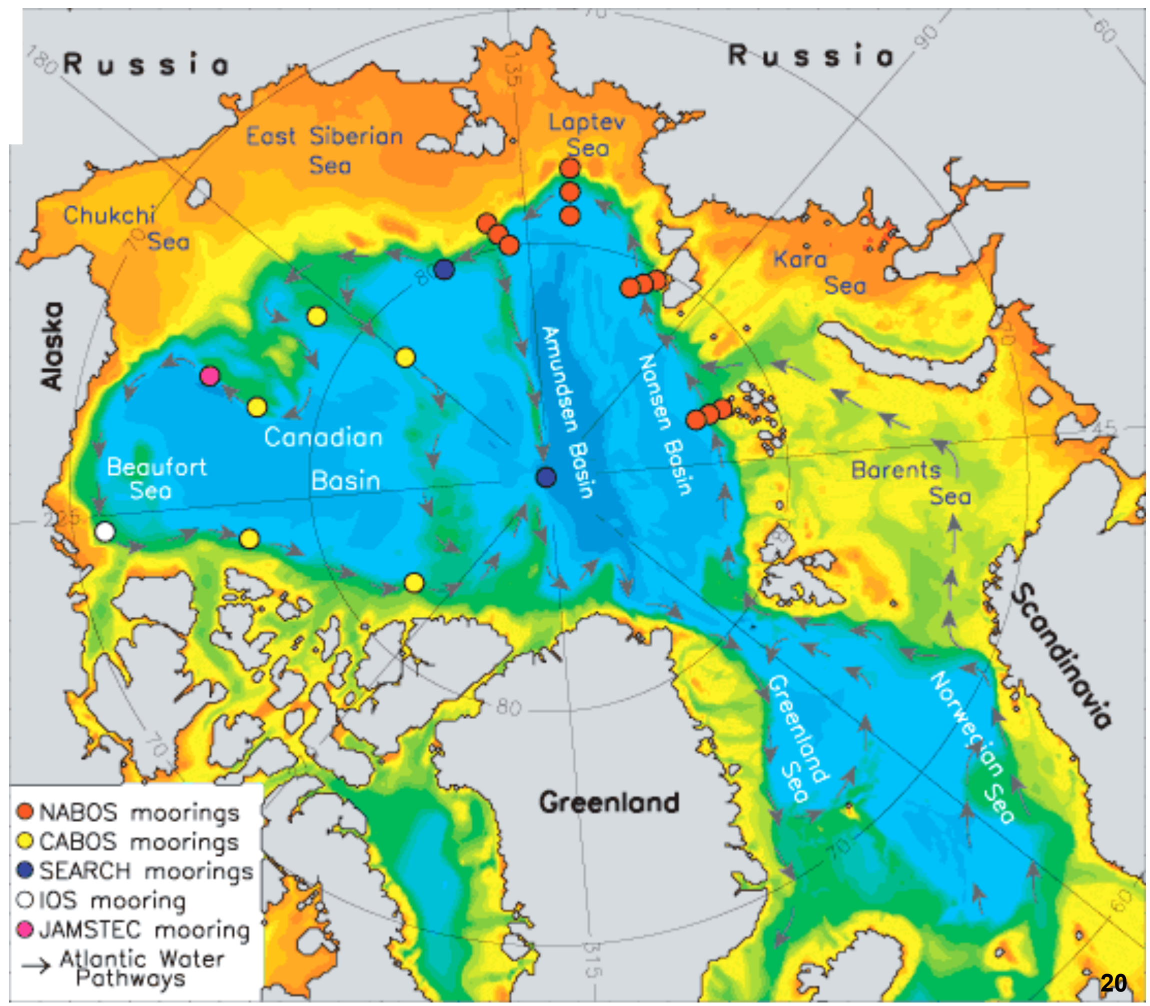
FIGURE 8.1. A map of the major surface currents in the world ocean during northern winter (from Tolmazin, 1985).

[Peixoto & Oort, 1992]

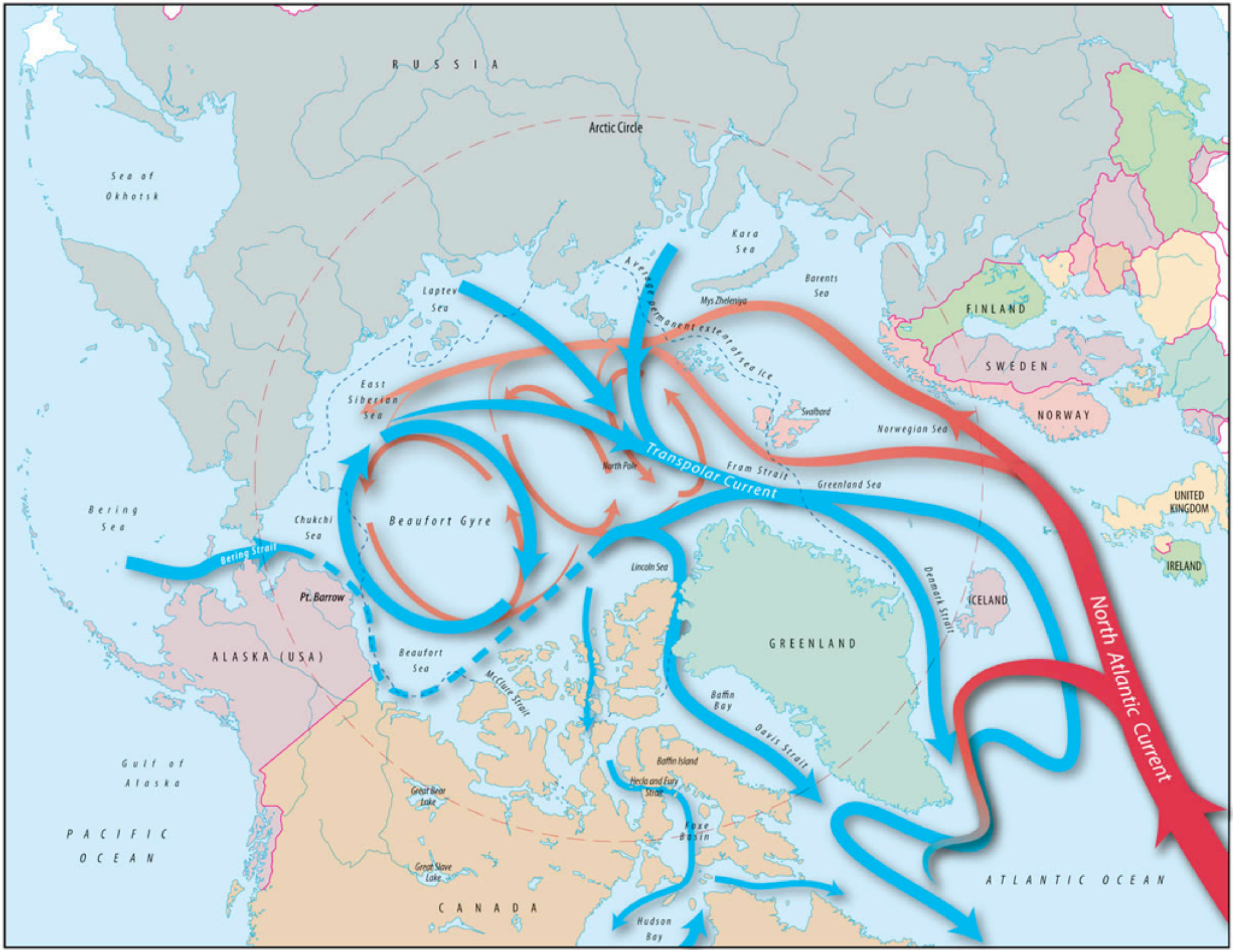
NABOS 2013 Cruise

http://nabos.iarc.uaf.edu/





Major Arctic Currents



Woods Hole Oceanographic Institute

IARC Summer School experiences little ice in Laptev Sea in Sept 2005, NABOS mooring program

Why is Ocean important for Climate?

- **Moderates climate, reduces variability**
- **Moisture source and driver of hydrological cycle**
- **Cloud Condensation Nuclei**

Potential Temperature in Global Zonally Averaged Ocean

- Equation of state of sea water is function of **Temperature**, **Salinity**, & Pressure
- Average S & T are **34.7 ppt & 3.6˚C**
- **upper mixed layer** 20-200m
- Permanent **thermocline** 200-1000m,
- Deep ocean T not so variable
- Nearly incompressible

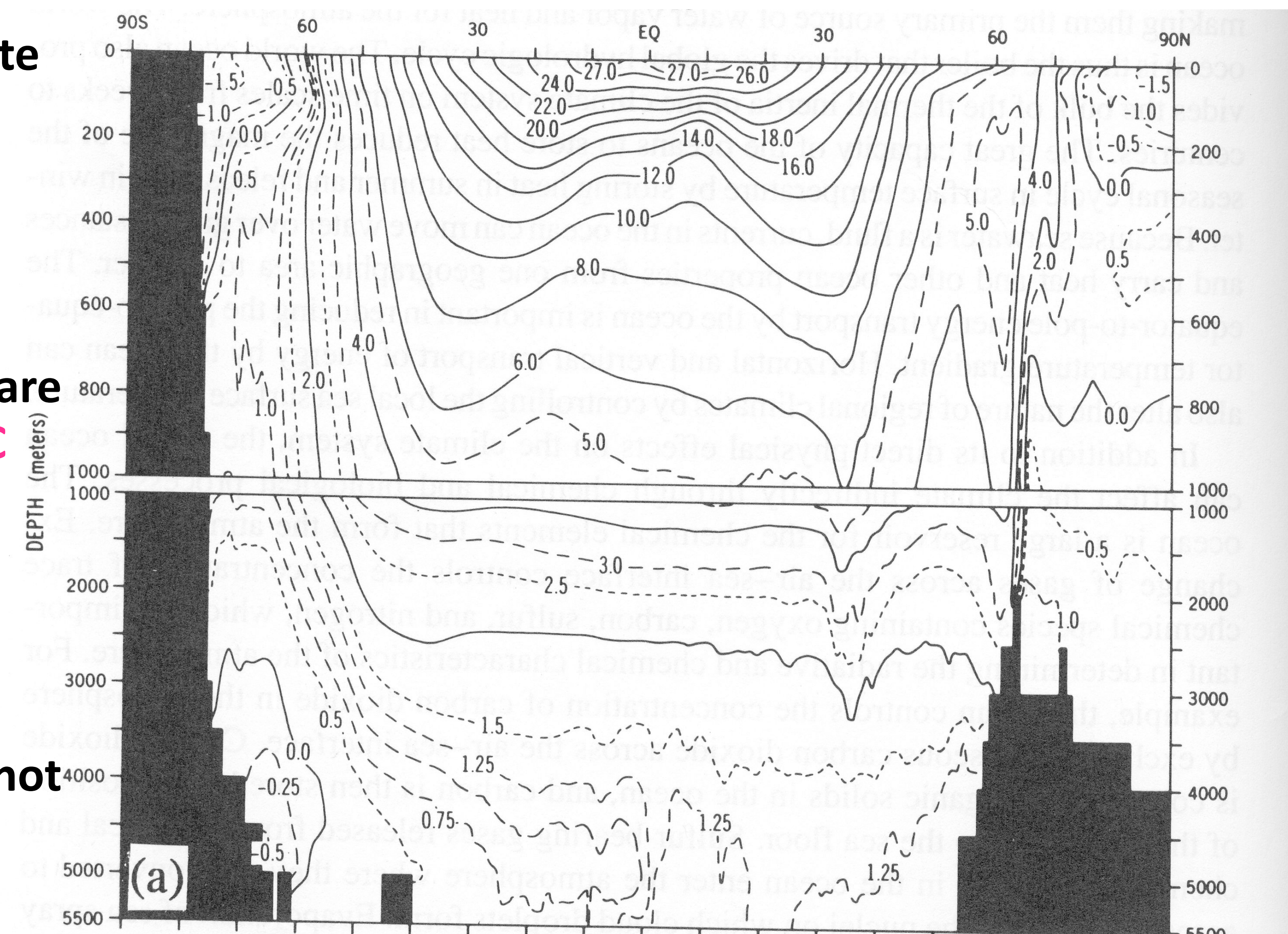
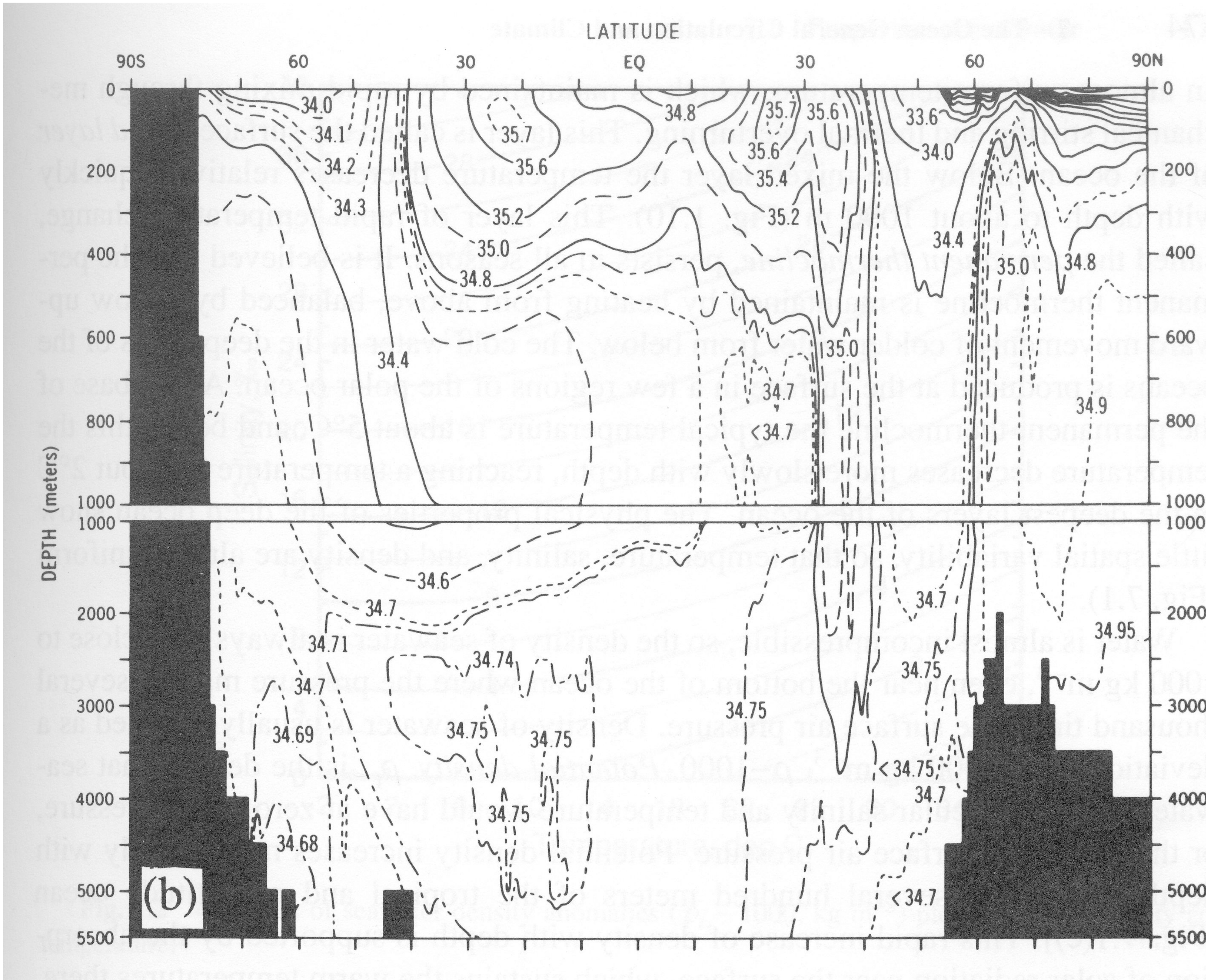


Fig. 7.1 Annual-mean zonal average for the global ocean of (a) potential temperature (˚C), and (b) salinity [‰ (‰ = parts per thousand)], and (c) potential density ($\rho_t - 1000$, kg m^{-3}). [From Levitus (1982).]

[Hartmann, 1994]

Salinity in Global Zonally Averaged Ocean

- Subtropics salty
- Equator fresh
- 25-40 ppt range



[Hartmann, 1994]

Potential Density in Global Zonally Averaged Ocean

- Potential density is the density that sea water at a particular T and S would have at surface air pressure (1000mb). It is written as rho-1000.

- Strongest gradients near surface

- polar oceans connected to deep ocean (*)

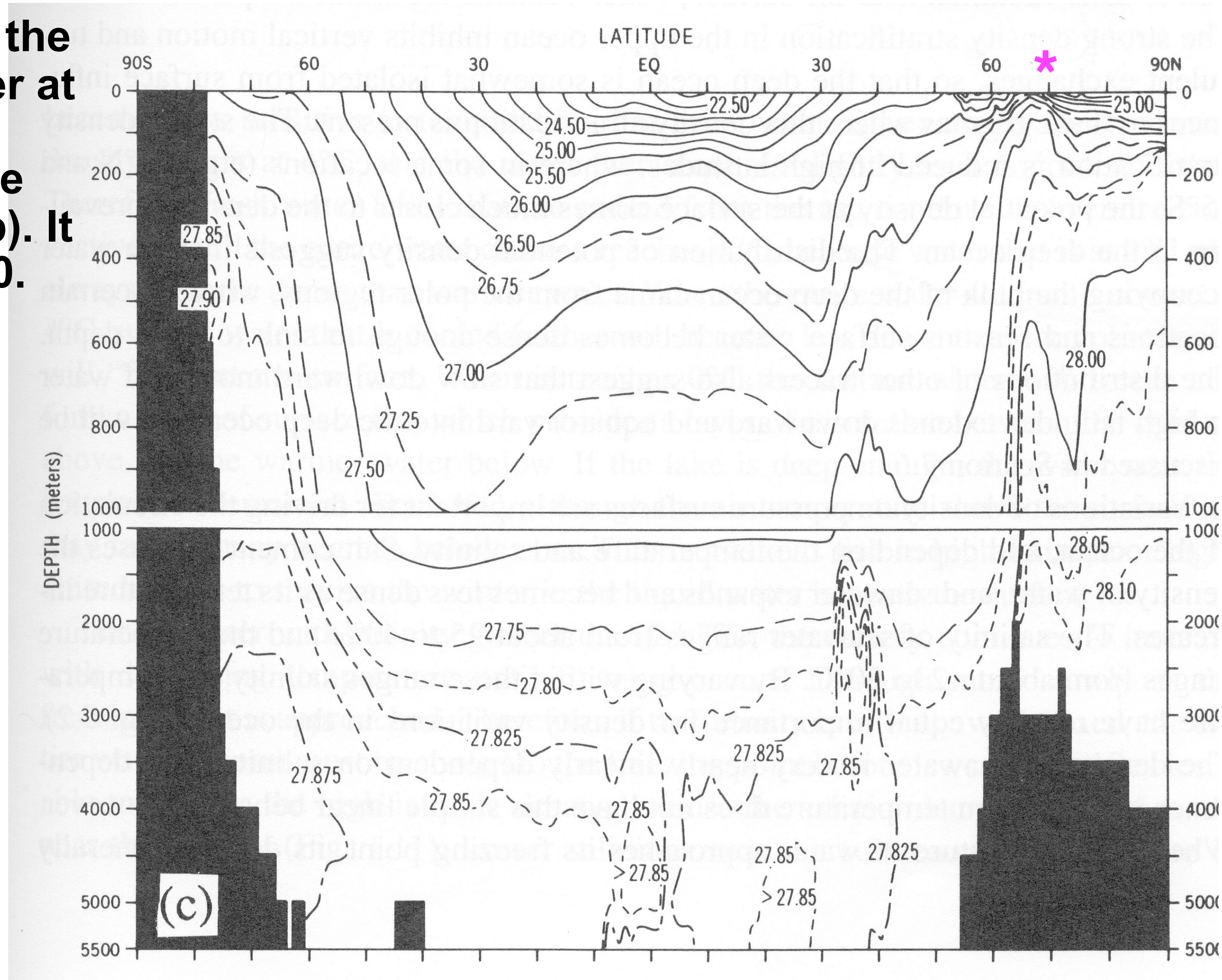


Fig. 7.1—*Continued*

[Hartmann, 1994]

Salinity more important at lower Temperature for determining density

$$\rho = \rho(T,S,p)$$

$$\sigma(T,S,p) \equiv \rho(T,S,p) - \rho_o , \rho_o = 1000\, kg\ m^{-3}$$

$$\sigma_t(T,S) \equiv \rho(T,S,p_o) - \rho_o$$

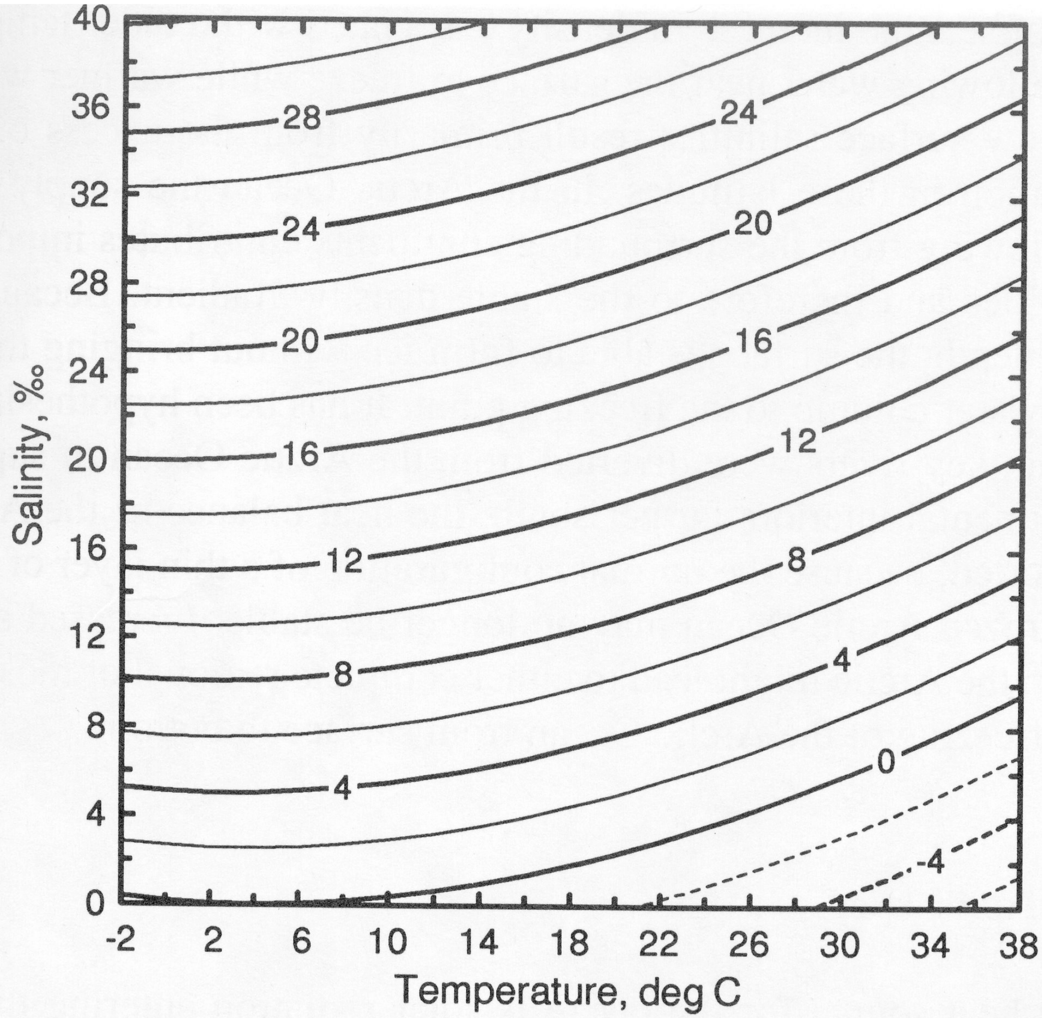


Fig. 7.2 Contours of seawater density anomalies (ρ_t − 1000, kg m^{-3}) plotted against salinity and temperature.

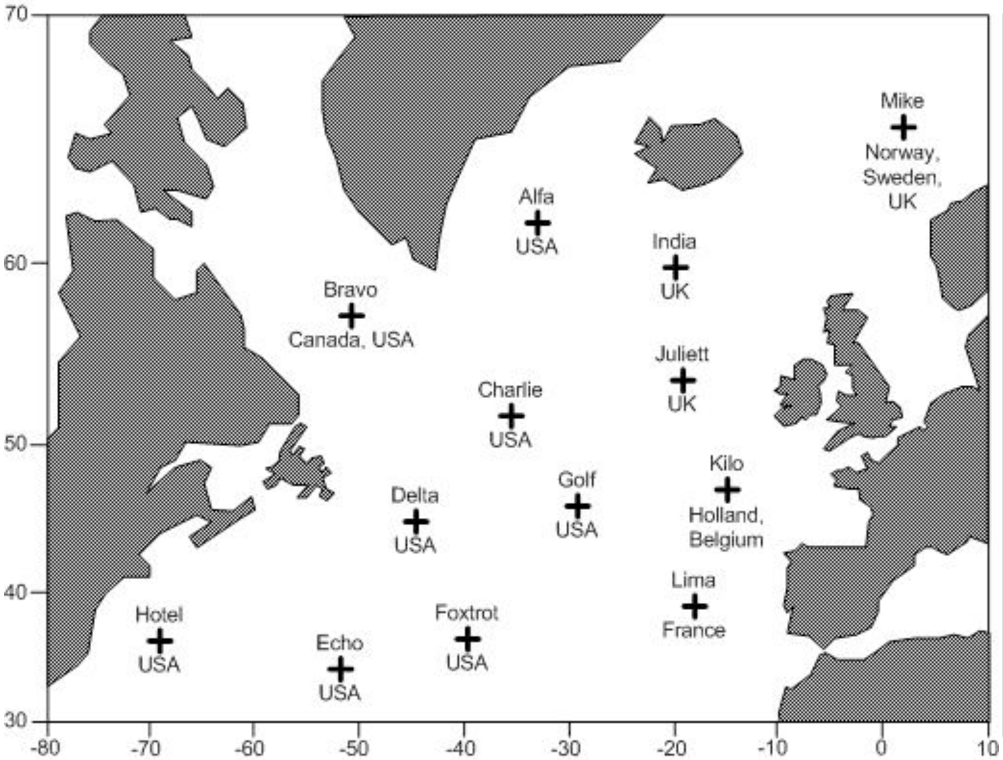
- **Pure water, max density occurs at 4˚C**
- **Warmer than 4˚C less dense**
- **Cooler than 4˚C, less dense so cool water floats, if it cools more ice forms, ice floats**
- **Ice at lake surface yet deep lake at 4, allowing fish to survive**
- **Saltier water more dense, Arctic surface is fresh so easier to form ice. If we reduced freshwater, we would reduce ice!**

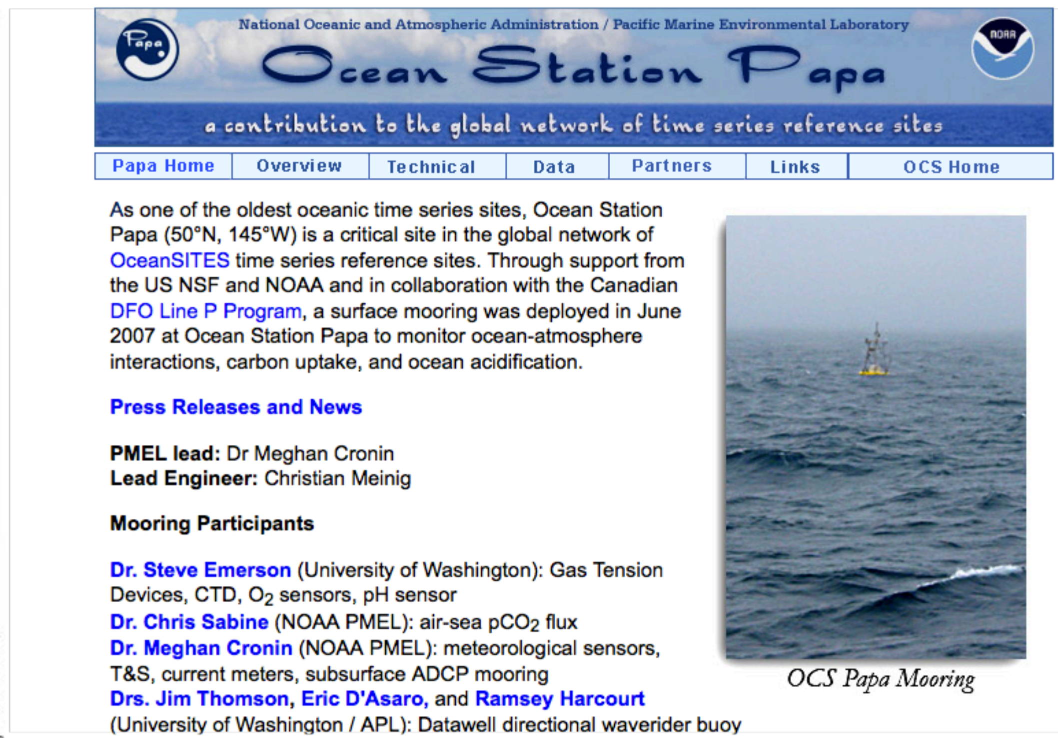
[Hartmann, 1994]

Weather ship

From Wikipedia, the free encyclopedia

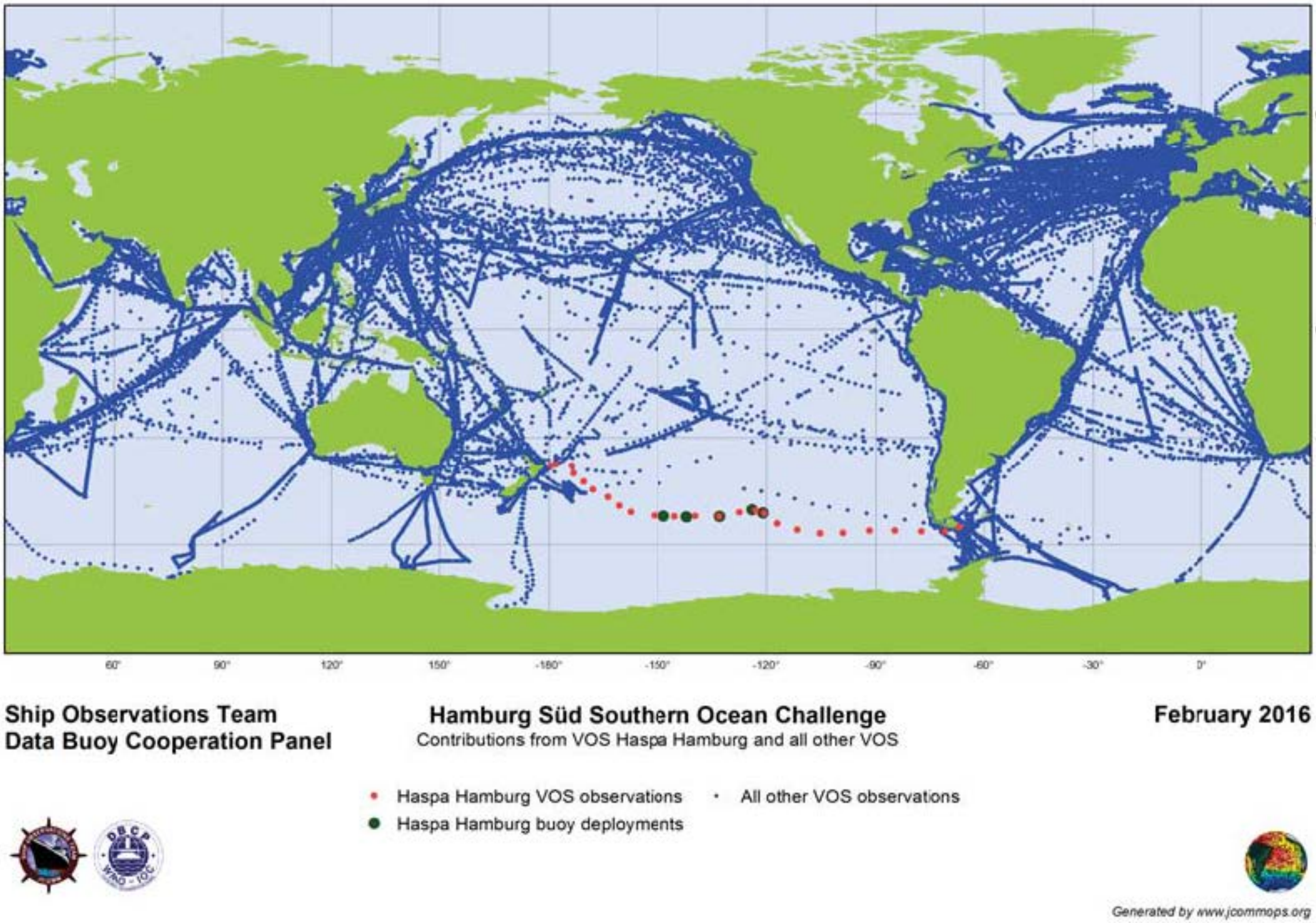
A **weather ship** was a ship stationed in the ocean as a platform for surface and upper air meteorological observations for use in weather forecasting. They were primarily located in the north Atlantic and north Pacific oceans, reporting via radio. In addition to their weather reporting function, these vessels aided in search and rescue operations, supported transatlantic flights,[1][2] acted as research platforms for oceanographers, monitored marine pollution, and aided weather forecasting both by weather forecasters and within computerized atmospheric models. Research vessels remain heavily used in oceanography, including physical oceanography and the integration of meteorological and climatological data in Earth system science.





The last weather ship was *Polarfront*, known as weather station M ("Mike"), which was removed from operation on January 1, 2010.

Voluntary Ship observations



http://www.vos.noaa.gov/MWL/201604/sailing.shtml

Recent plot above, earlier plots show much more traffic in Atlantic, so this recent ship track plot reflects economic changes!

Vertical profile of T, S, and ρ over the oceanic mixed layer

- Sharp gradients below the well mixed upper layer.
- Solar absorbed in top 100m, half in first meter
- turbulent mixing, convective overturning and mean vertical motion (upwelling)

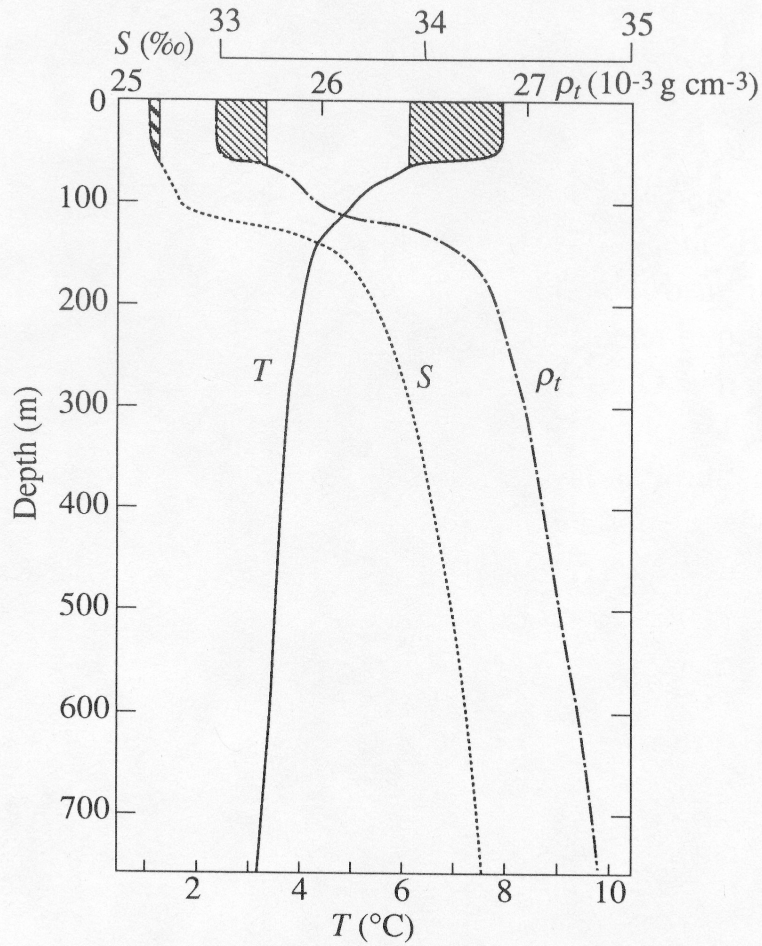


Fig. 7.4 Vertical profiles of temperature (T, °C), salinity (S, ‰), and potential density ($\rho_t - 1000$, kg m^{-3}) at Ocean Station P, 50°N, 145°W, on June 23, 1970 showing the mixed layer in the top 50 m. The hatched area shows the change since May 19, 1970 and indicates the springtime warming and thinning of the mixed layer. [From Denman and Miyake (1973). Reprinted with permission from the American Meteorological Society.]

[Hartmann, 1994]

Processes that Force Changes in Mixed-Layer Profile

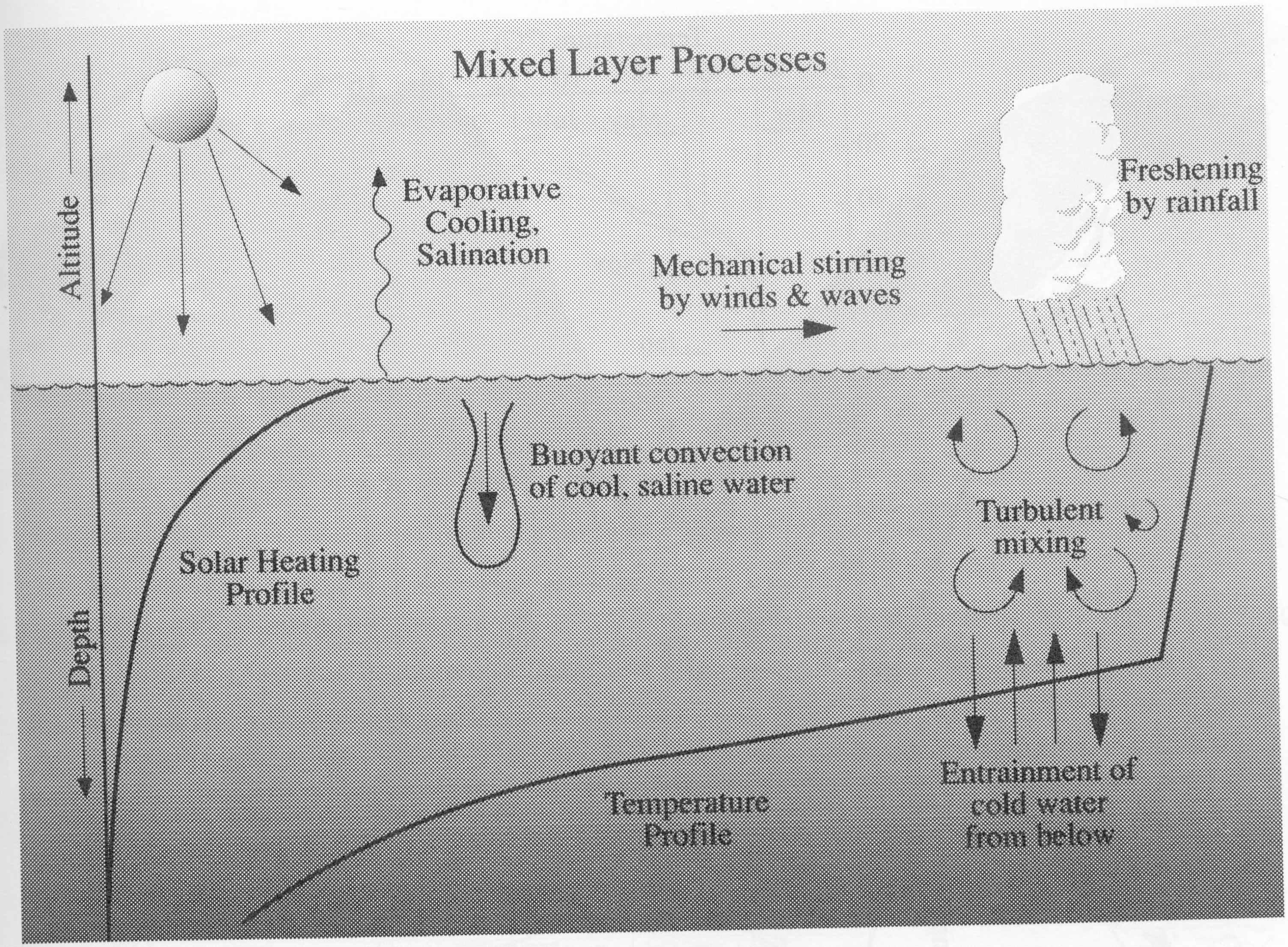


Fig. 7.5 Diagram showing important mixed-layer processes.

How do these processes impact ocean temperature and salinity?

- Solar Heating
- Evaporation
- Wind Mixing
- Rainfall

[Hartmann, 1994]

Annual Cycle of Mixed-Layer Depth

- Deepest in late spring after long winter of cooling and storminess
- Shallowest in August after heating from above in summer
- Describes midlatitude oceans well

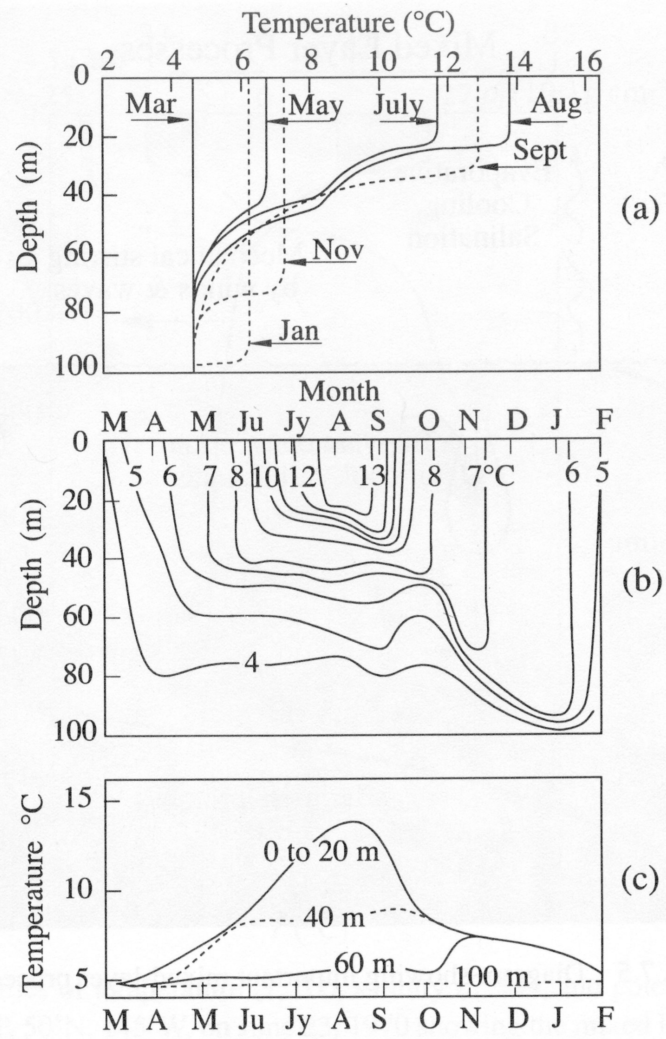
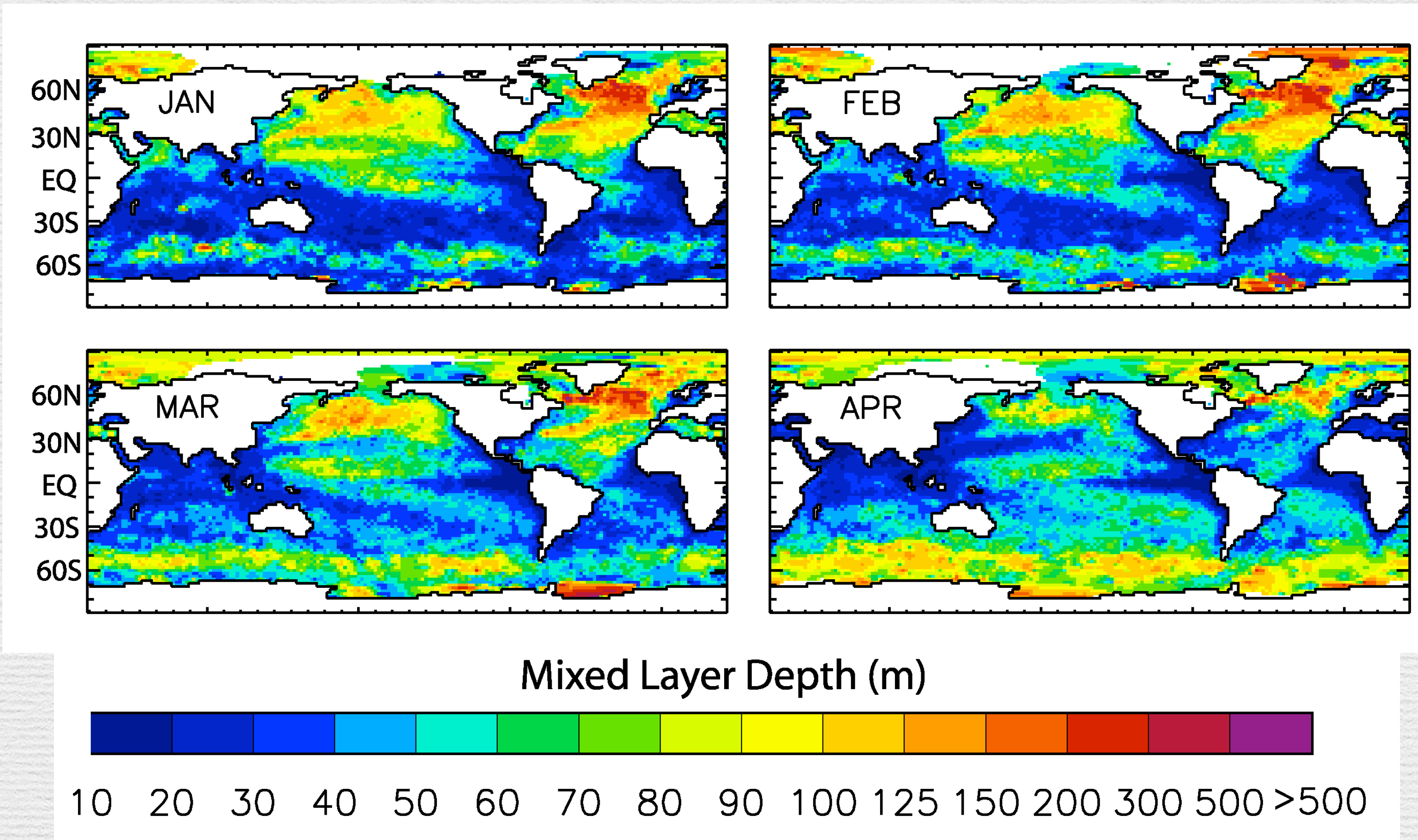


Fig. 7.6 Seasonal variation of temperature in the upper ocean at 50°N, 145°W in the eastern north Pacific. (a) Vertical profiles of temperature by months, (b) temperature contours, and (c) temperatures at various depths versus time of year. [From Pickard and Emery (1990). Reprinted with permission from Pergamon Press, Ltd., Oxford, England.]

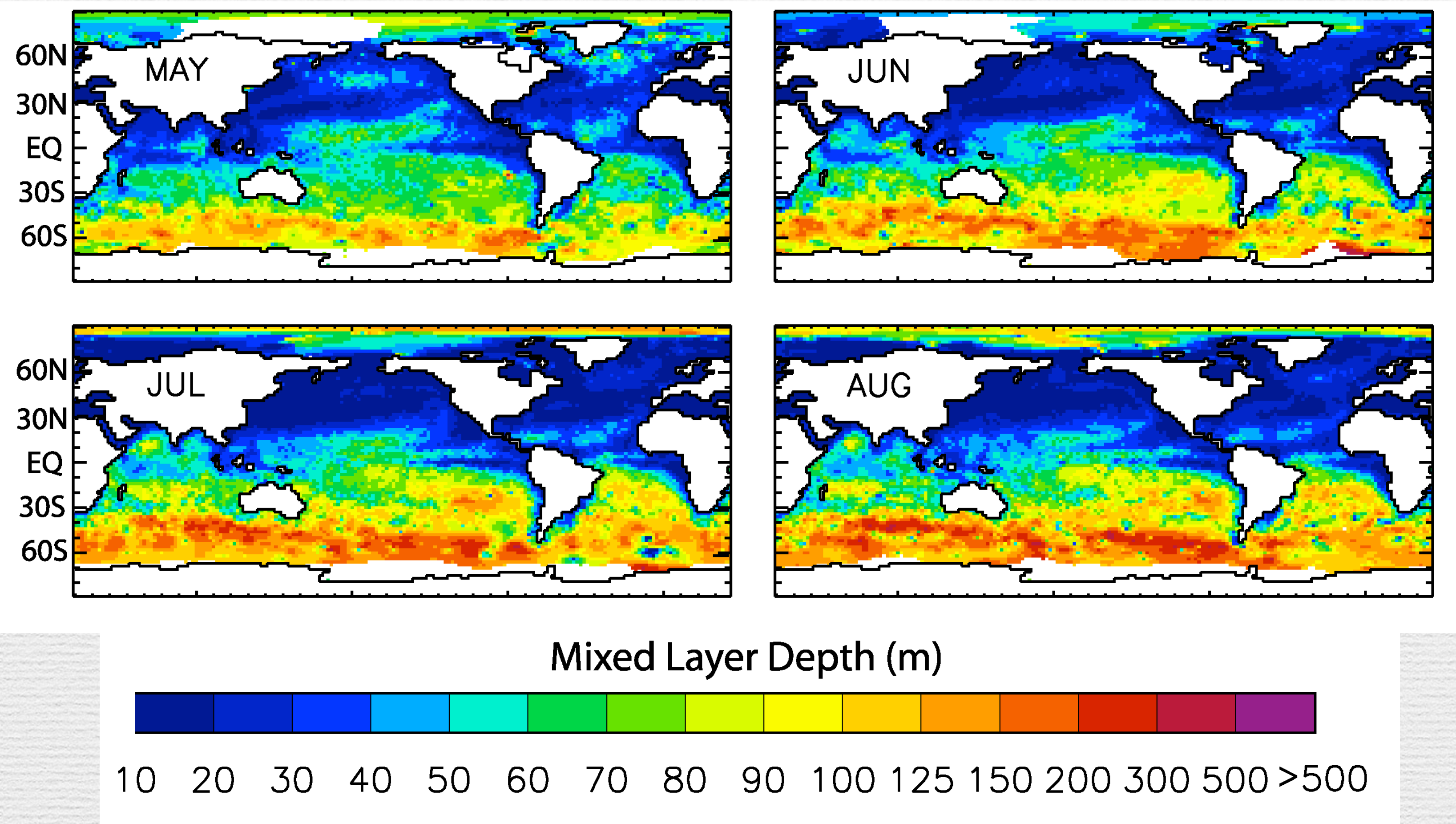
[Hartmann, 1994]

Global MLD Climatology Shows Large Spatial Variability



[Montegut et al. JGR 2004]

Deeper Mixed Layers in Winter Hemisphere



- Largest seasonal cycle in extra-tropics

[Montegut et al. JGR 2004]

Slab versus Variable Depth ML

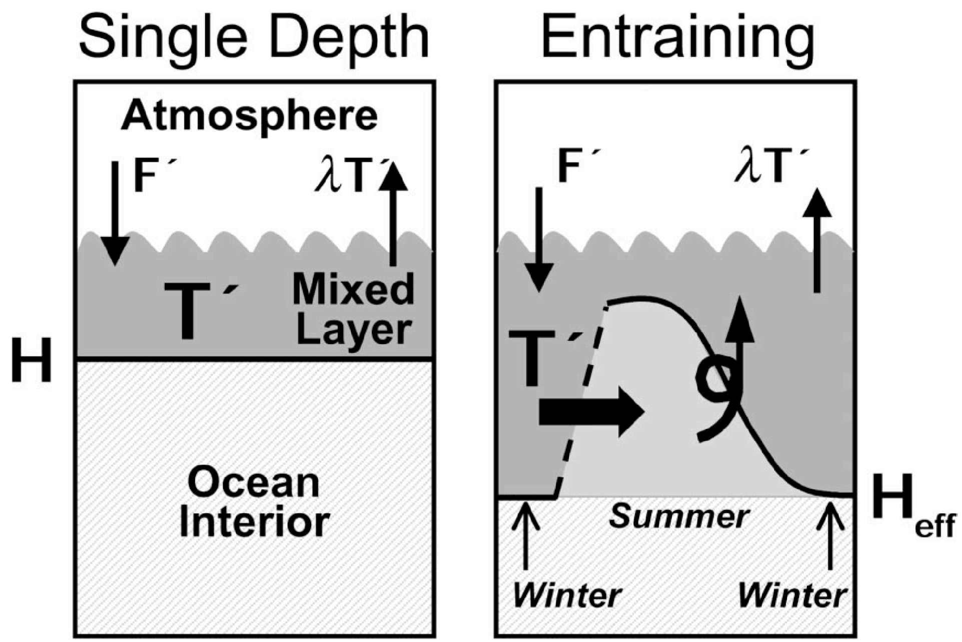
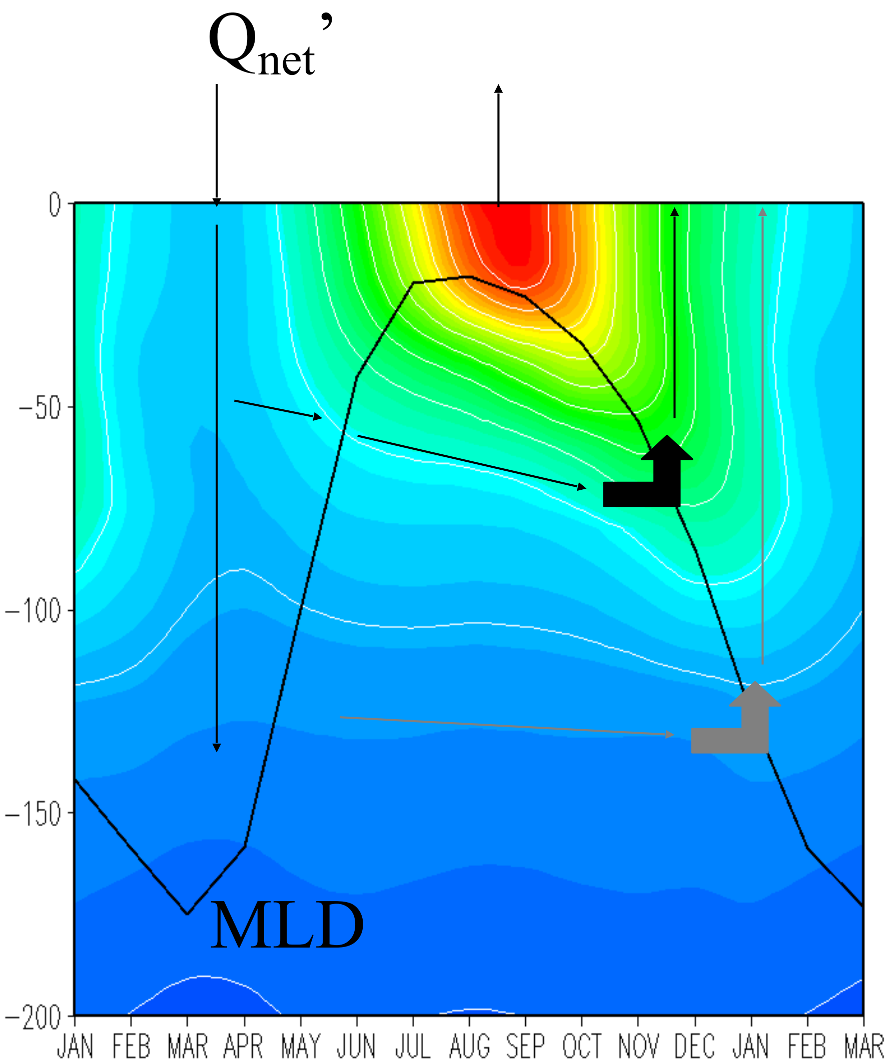


FIG. 1. Conceptual ocean–atmosphere systems considered in this study. (left) The original simple stochastic climate model of Frankignoul and Hasselmann (1977) and (right) the proposed extension. In both systems, temperature anomalies (T') in the ocean mixed layer are assumed to result from atmospheric forcing (F') only and damp back to the atmosphere at a rate $\lambda T'$. In the original model, the mixed layer depth (H) is constant; in the extended model, H undergoes a strong seasonal cycle, with largest extent in winter and smallest in summer. In this configuration, T' created in winter can persist beneath the summer mixed layer and become reentrained into the mixed layer the following winter, as indicated schematically by the thick black arrows. The effective thermal capacity of this system depends upon the depth of the winter mixed layer (H_{eff}).

[Deser et al. 2003]

Seasonal cycle of Temperature & MLD in N. Pacific Reemergence Mechanism



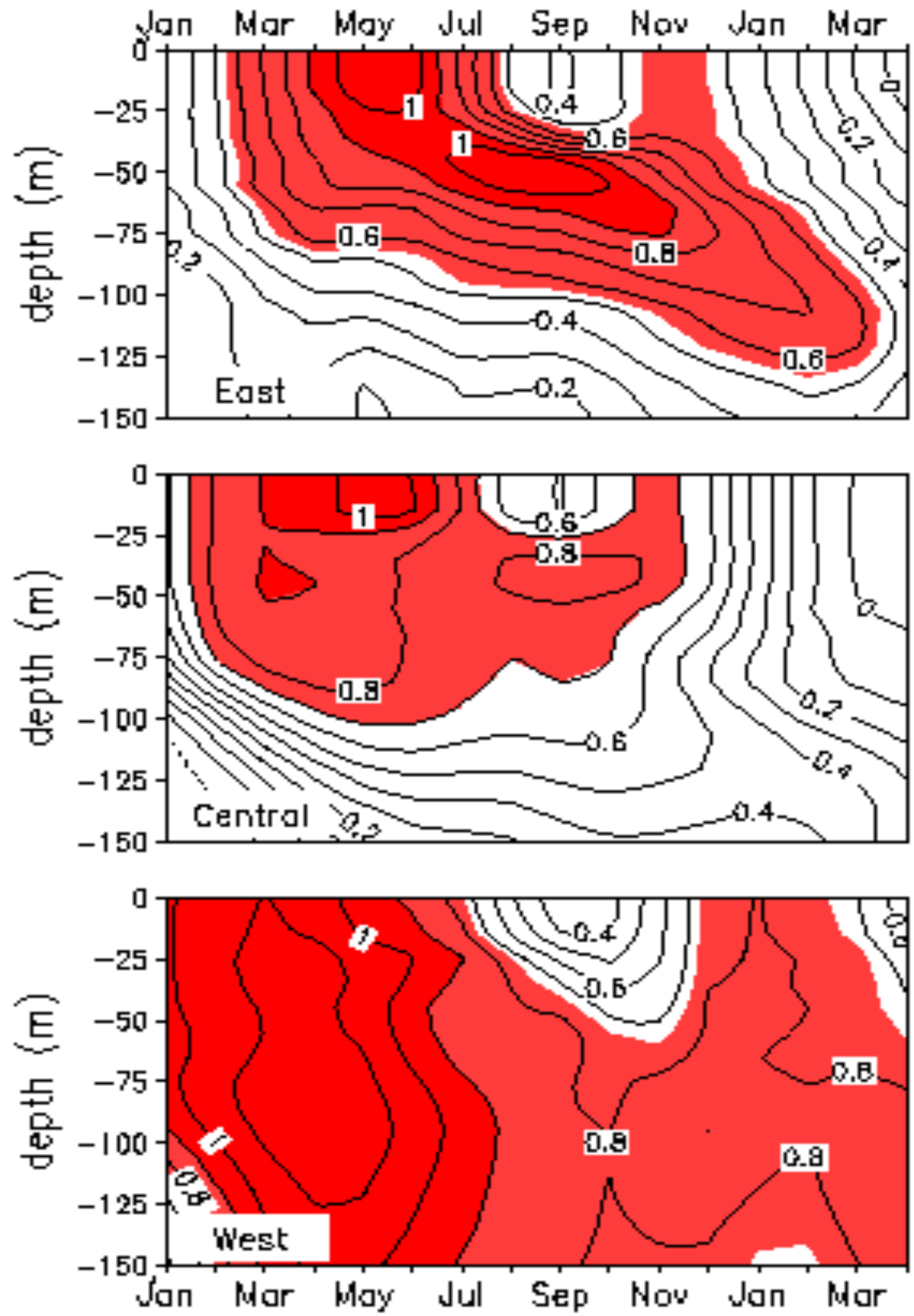
- Winter Surface flux anomalies
- Create SST anomalies which spread over ML
- ML reforms close to surface in spring
- Summer SST anomalies strongly damped by air-sea interaction
- Temperature anomalies persist in summer thermocline
- Re-entrained into the ML in the following fall and winter

Alexander and Deser (1995, JPO), Alexander et al. (1999, J. Climate)

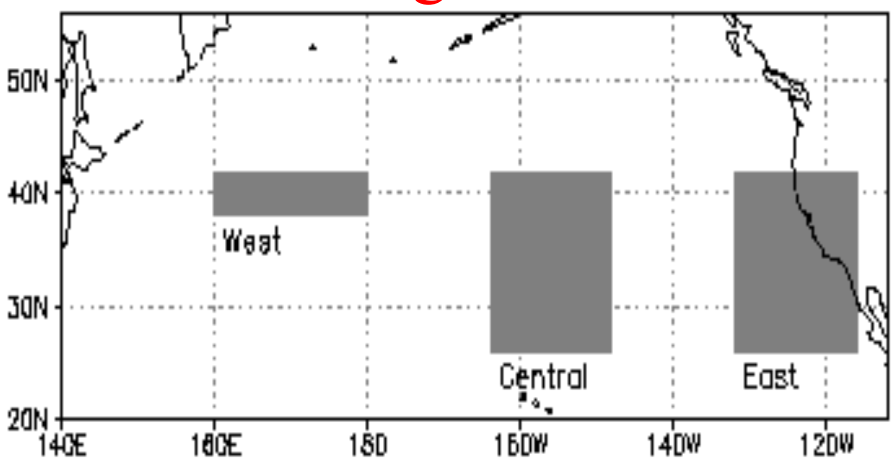
[SLIDE FROM MIKE ALEXANDER]

Reemergence in three North Pacific regions

Regression between SST anomalies in April-May with monthly temperature anomalies as a function of depth.



Regions



Alexander et al. (1999, J. Climate)

[SLIDE FROM MIKE ALEXANDER]

Summary

- **Salinity more important at cooler temperatures for ocean density**
- **Ocean adds LOTS of interesting variability to the climate system (re-emergence mechanism, long-term persistence...**