



# Freshwater and Salinity

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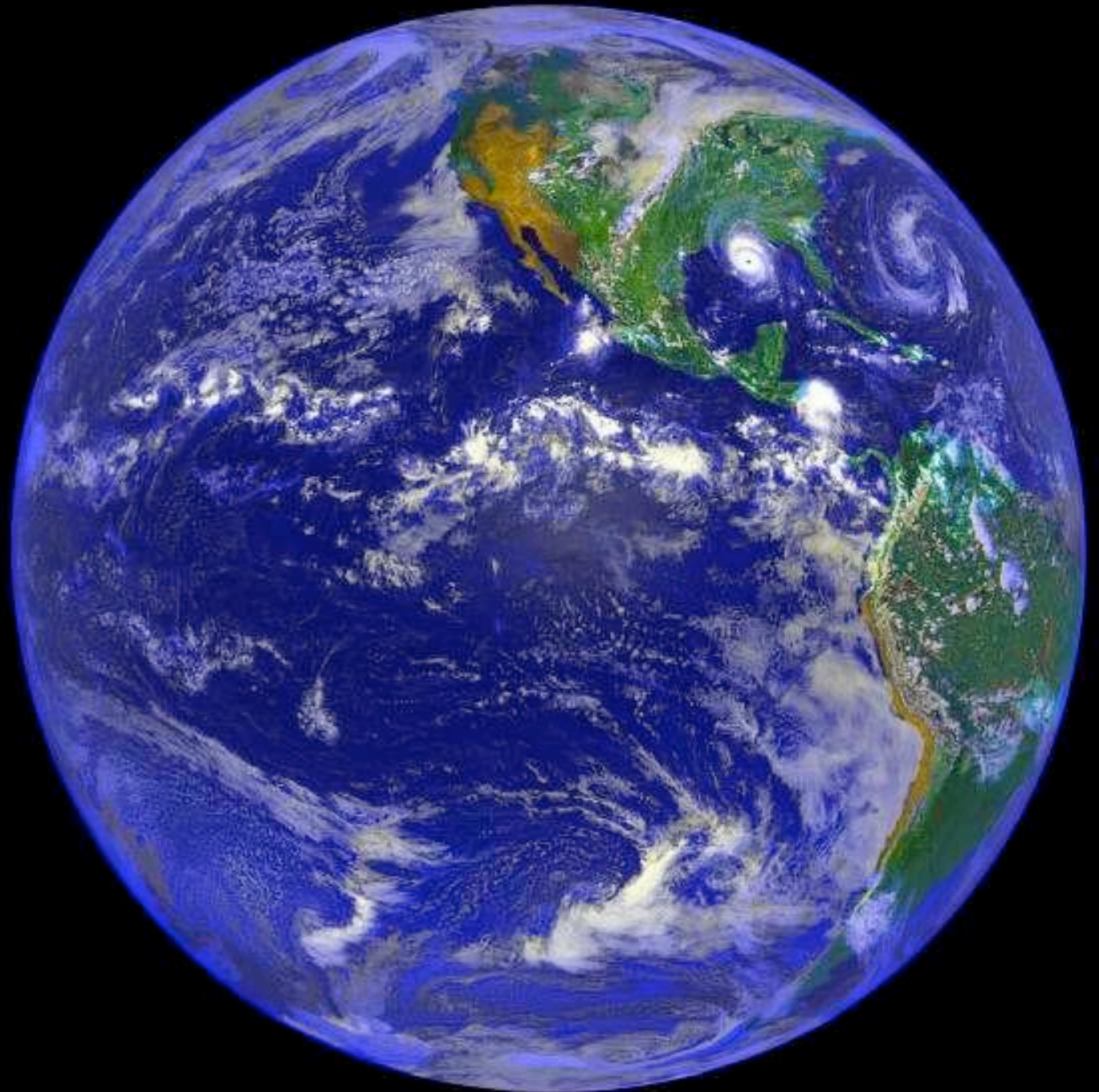
OceanObs '09



**"How inappropriate  
to call this planet  
Earth when clearly it  
is Ocean"**

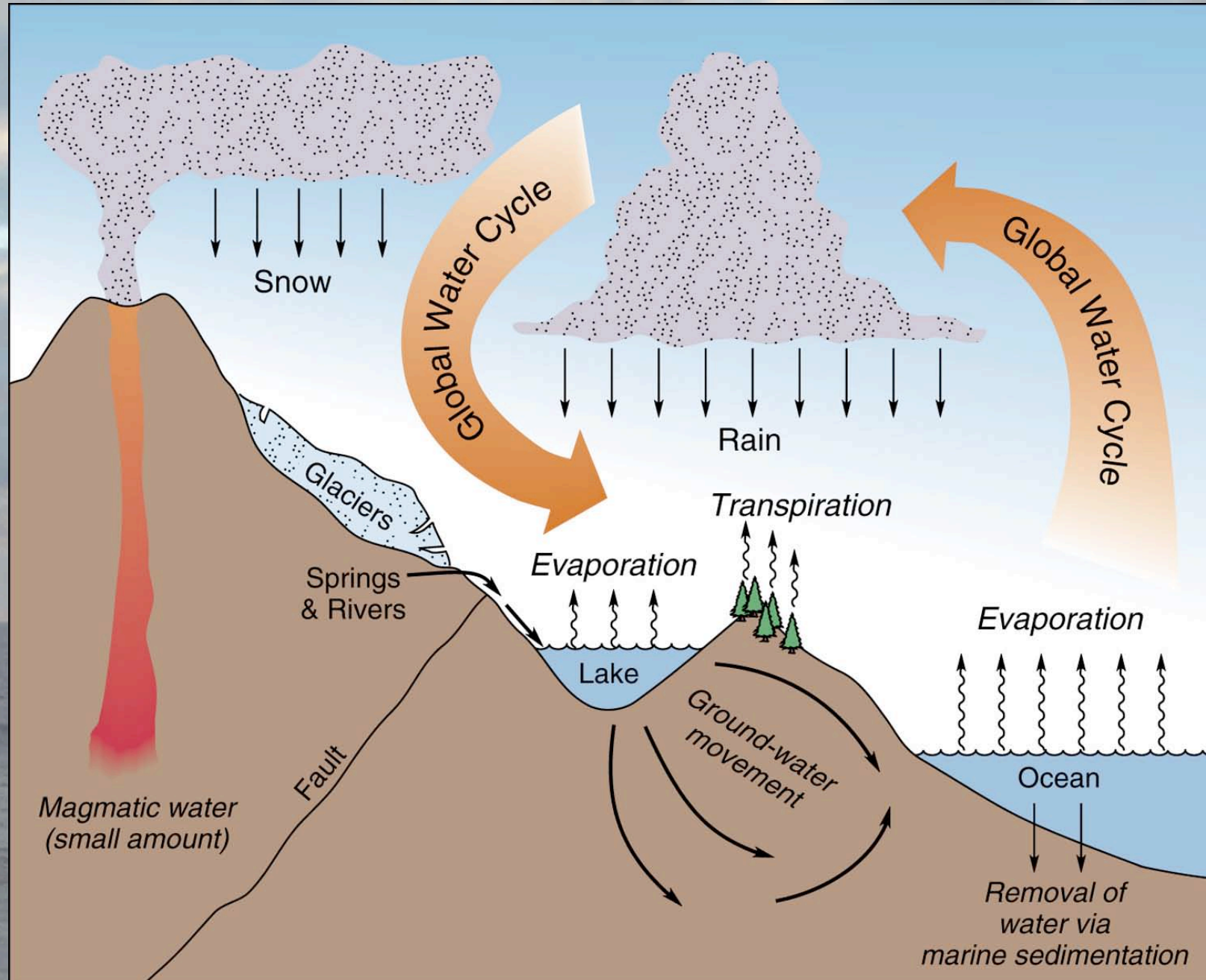
**-- Arthur C. Clarke  
*Nature*, 1990**

**The Oceans have low  
albedo and thus absorb  
most of the solar  
radiation incident on the  
planet. They also have  
1100 times the heat  
capacity of the  
atmosphere and 97% of  
the free water on the  
planet.**

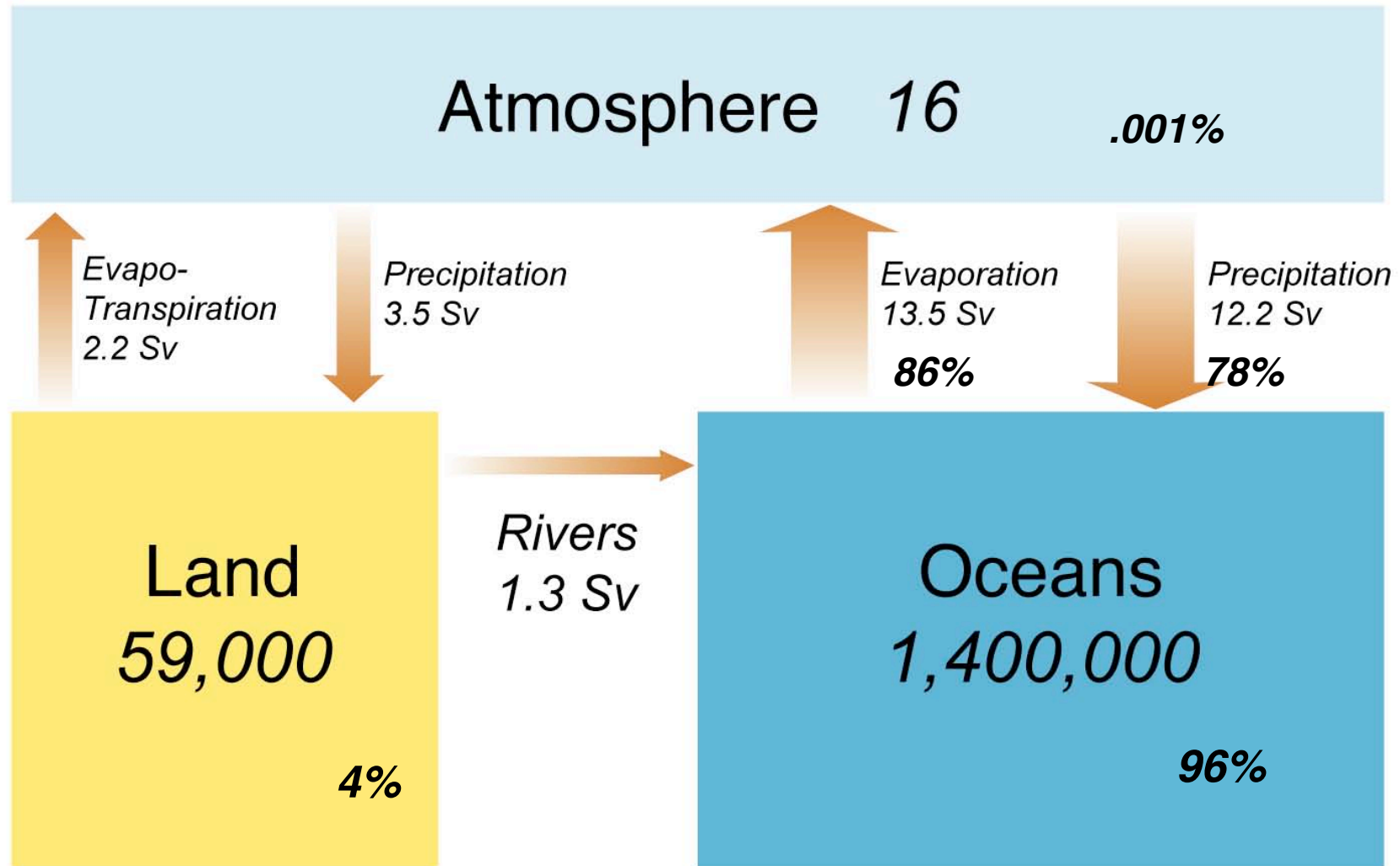




# Many depictions of the global water cycle minimize the ocean!



# Global Water Reservoirs and Fluxes

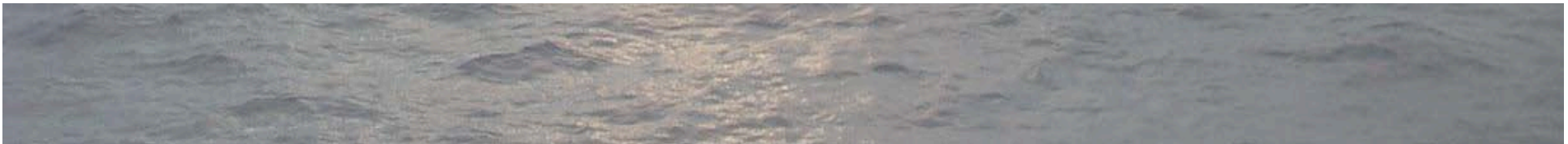
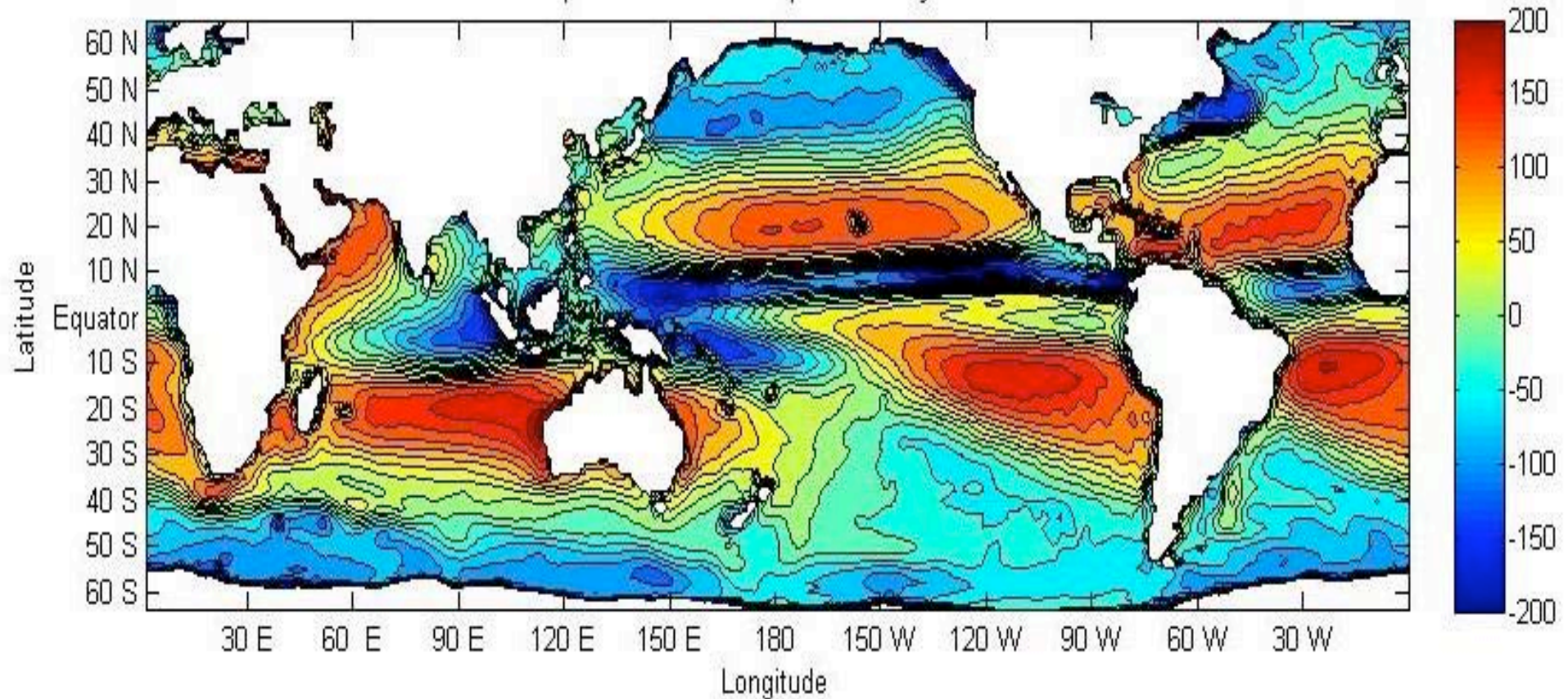


Reservoirs in  $10^3 \text{ km}^3$ , Fluxes in  $10^6 \text{ m}^3/\text{s}$  (= Sv)



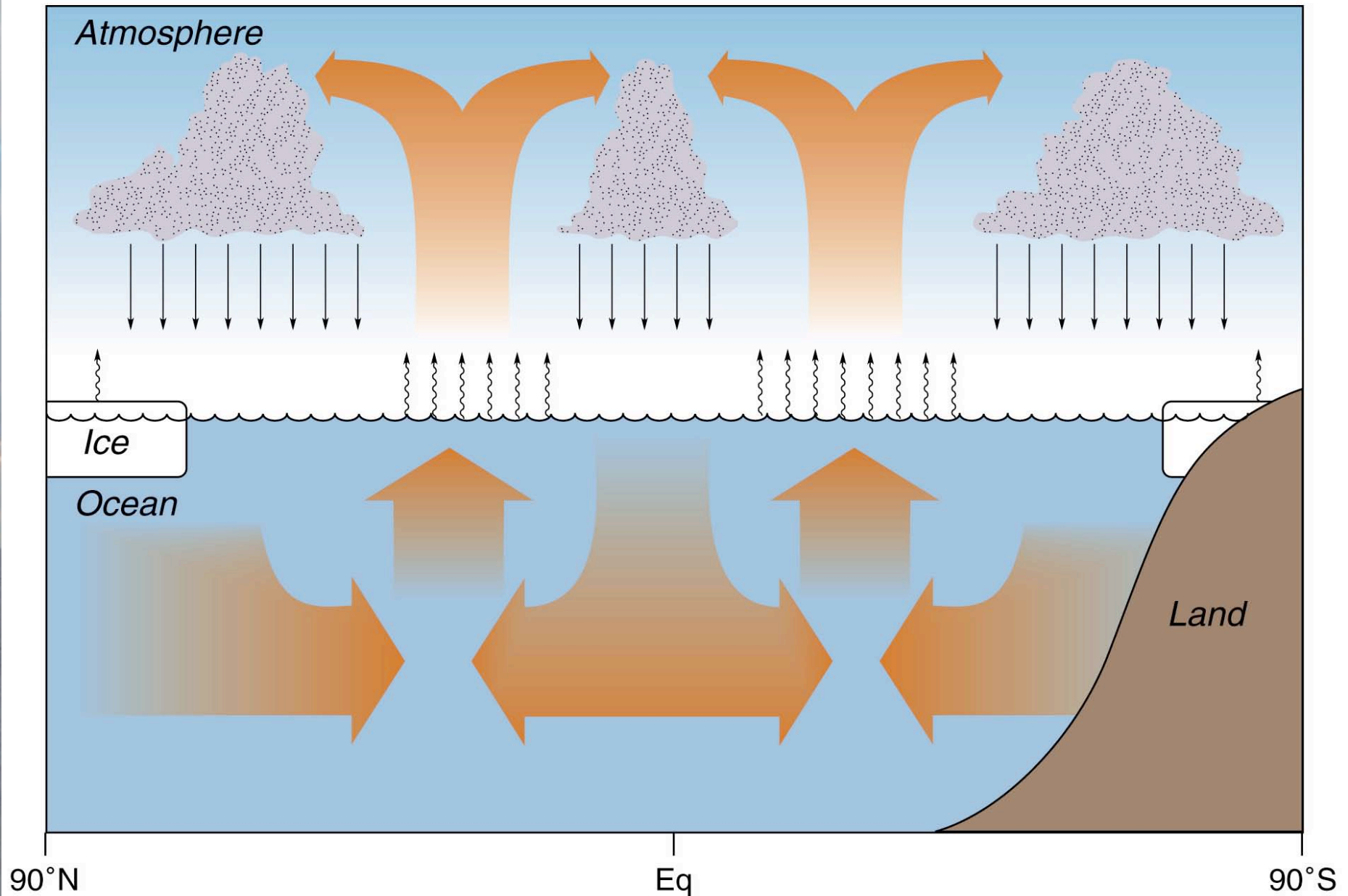
# Global Ocean Evap - Precip

Evaporation Minus Precipitation cm/yr CI = 20



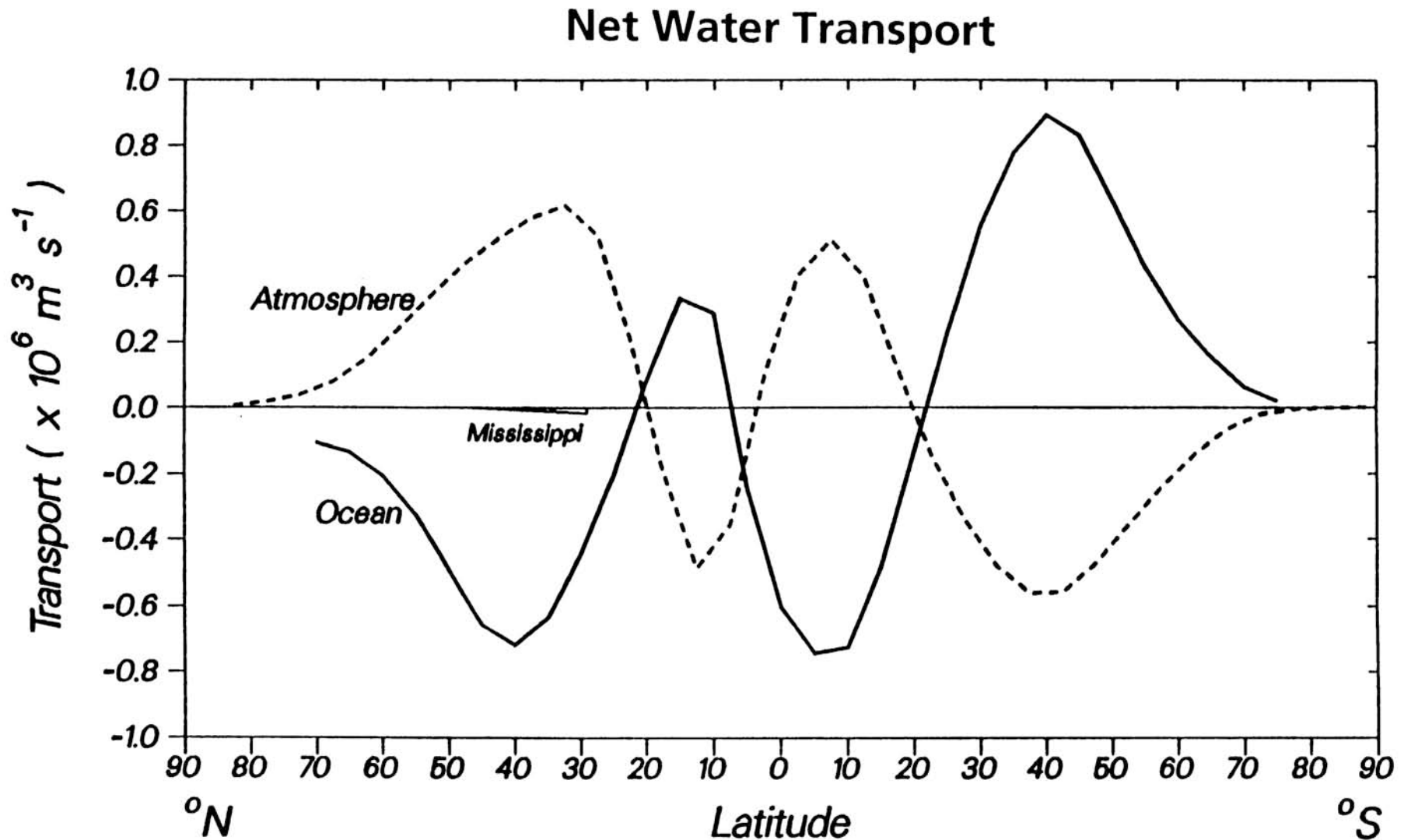
**The Oceans actually dominate the global water cycle**

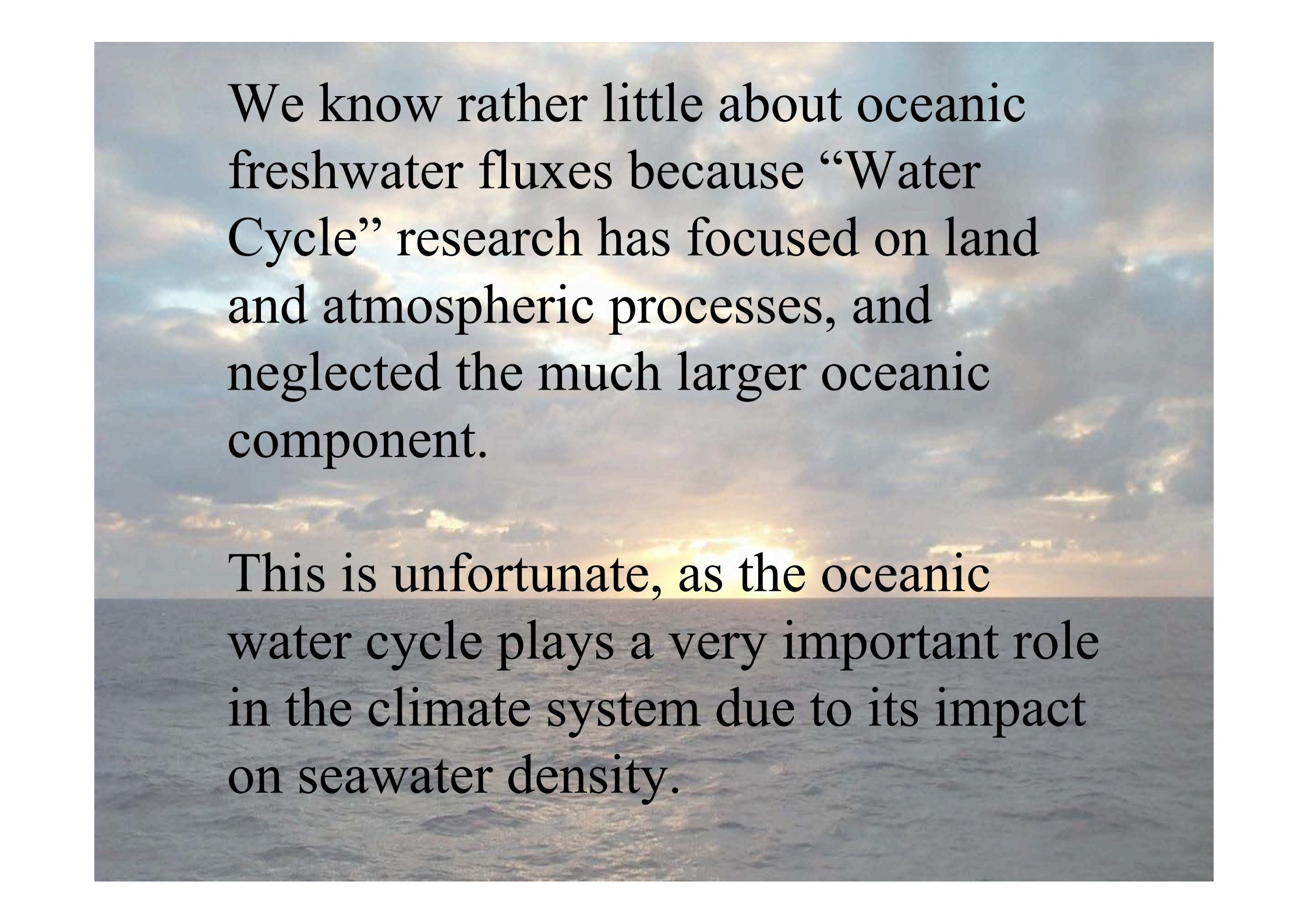
## **Global Water Cycle**





**Ocean and atmosphere compensate in meridional water transport, dwarfing the flow of rivers. Equivalent latent heat flux is significant fraction of planetary heat flux.**



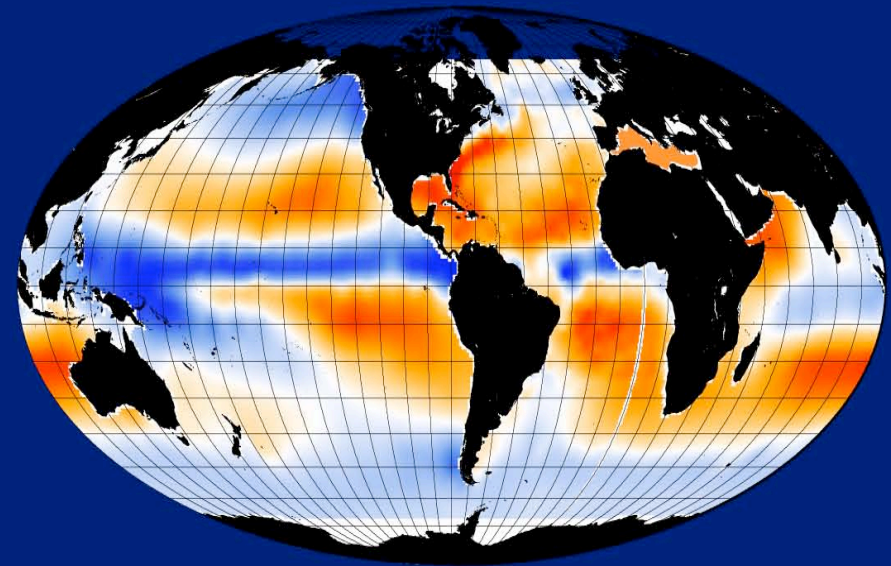
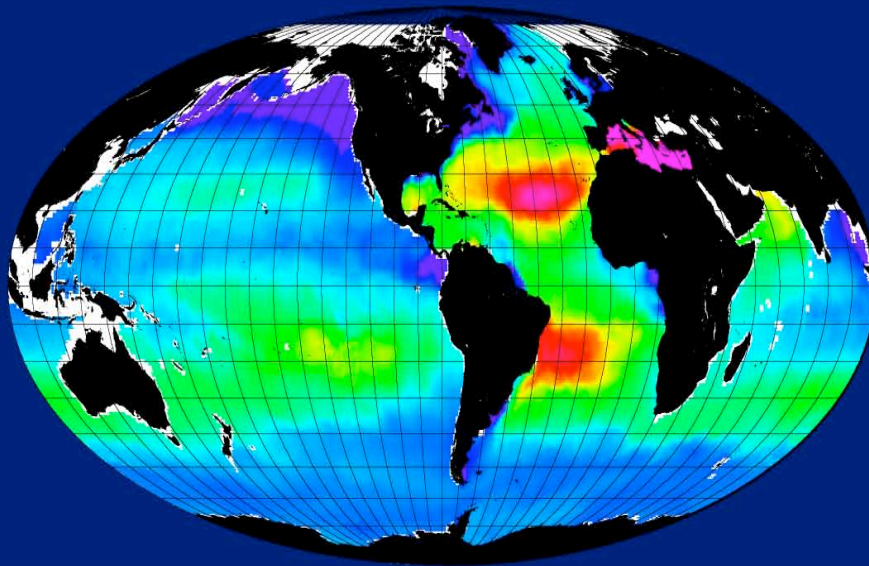


We know rather little about oceanic freshwater fluxes because “Water Cycle” research has focused on land and atmospheric processes, and neglected the much larger oceanic component.

This is unfortunate, as the oceanic water cycle plays a very important role in the climate system due to its impact on seawater density.

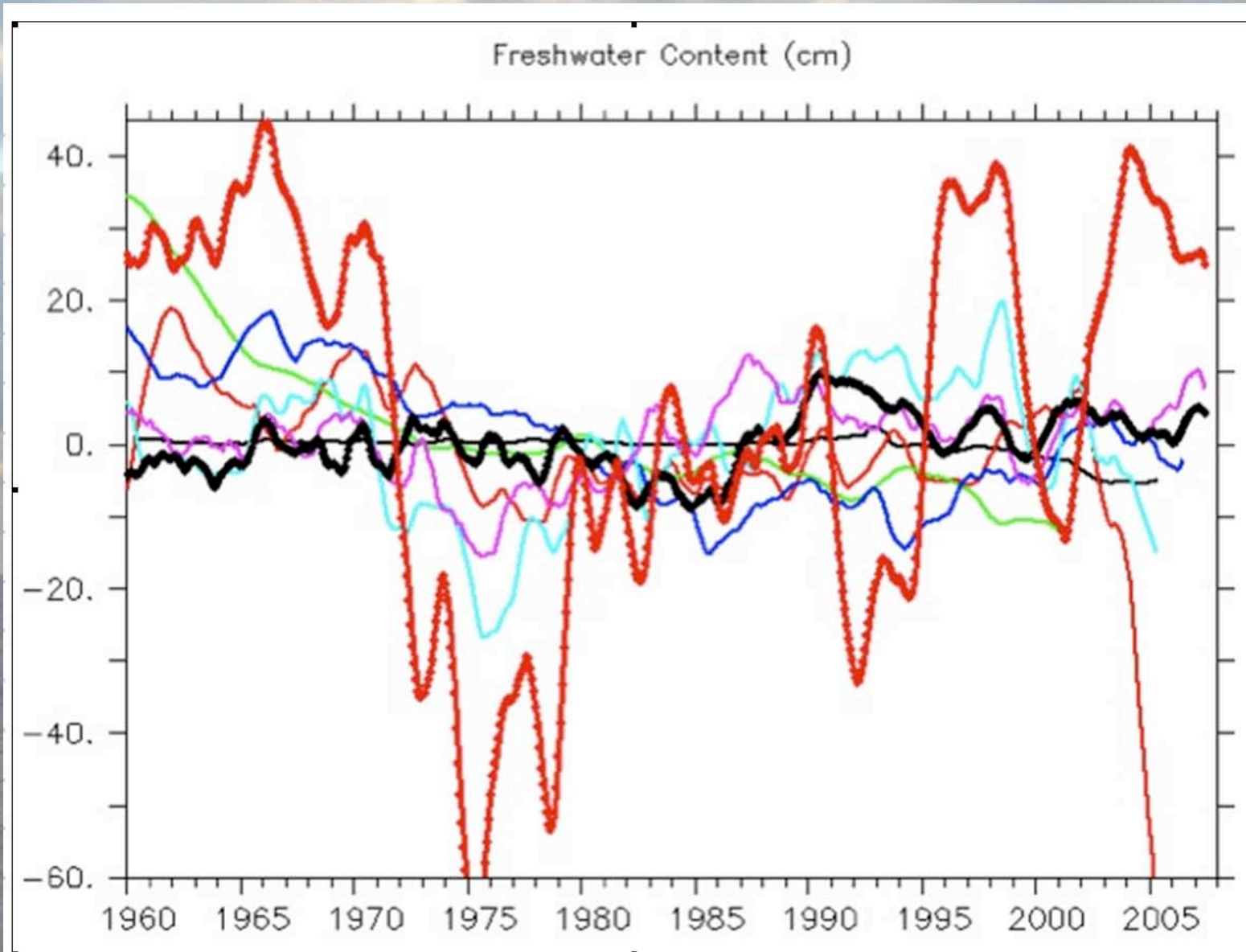


# Surface salinity distributions are closely tied to E-P patterns



Evaporation minus Precipitation (E-P)

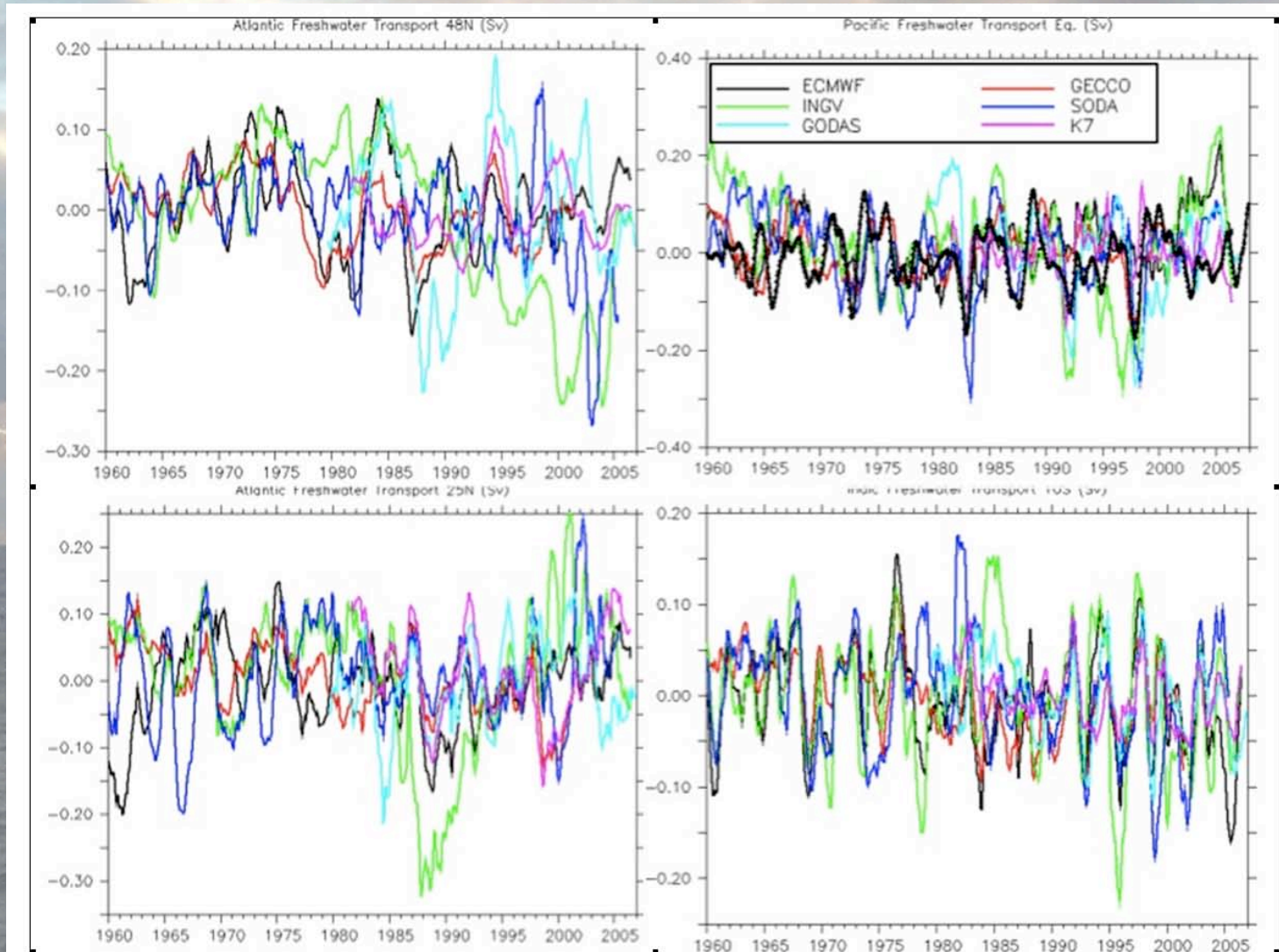
**Lack of salinity data limits reliability of freshwater content estimates. Model comparisons from Stammer et al 2009**





# Variability in model FW transports

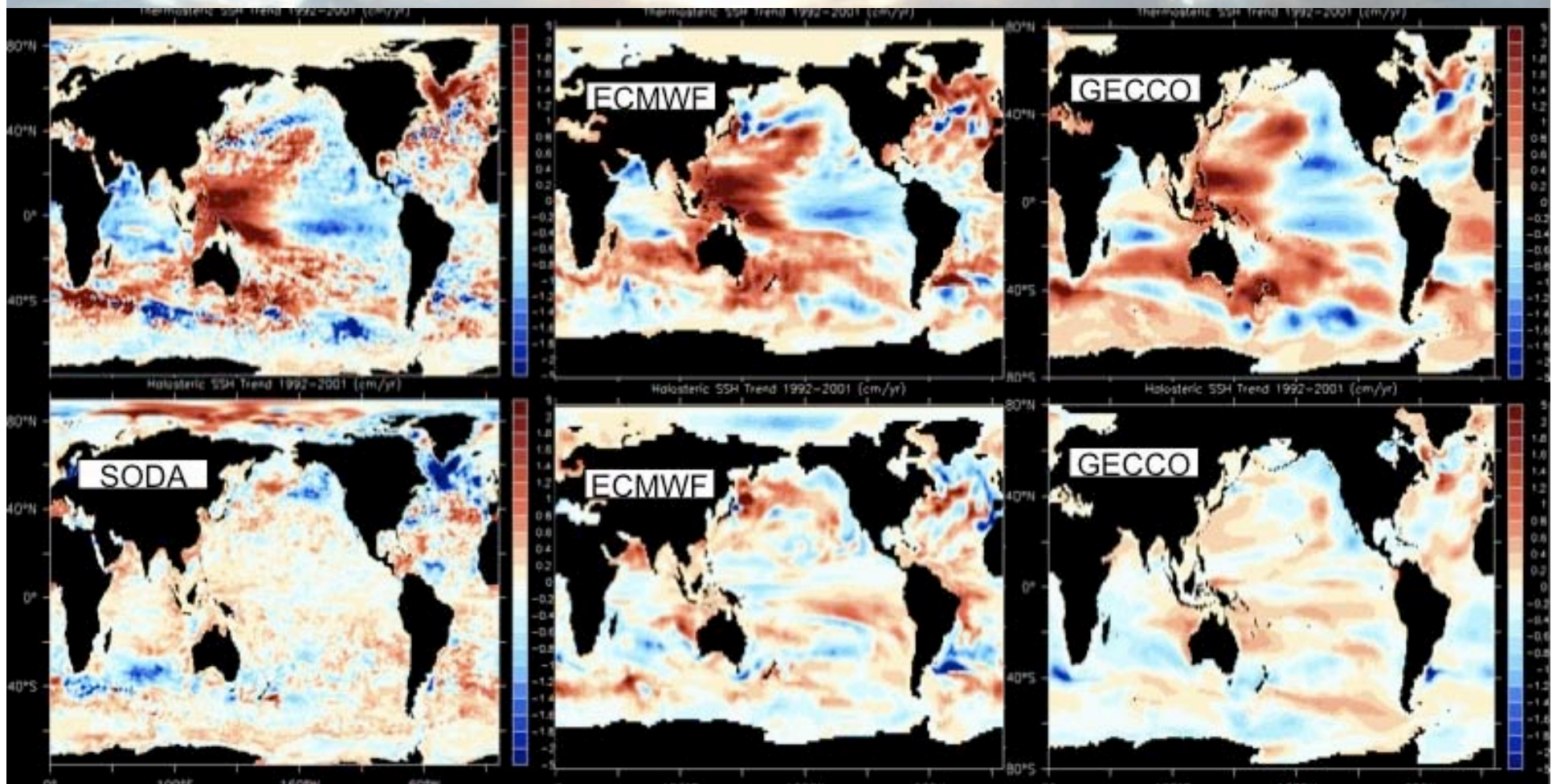
-Stammer et al, 2009





Salinity also affects sea level estimates.  
Thermosteric (top) and Halosteric effects  
(bottom) for 1992-2001 in three models.

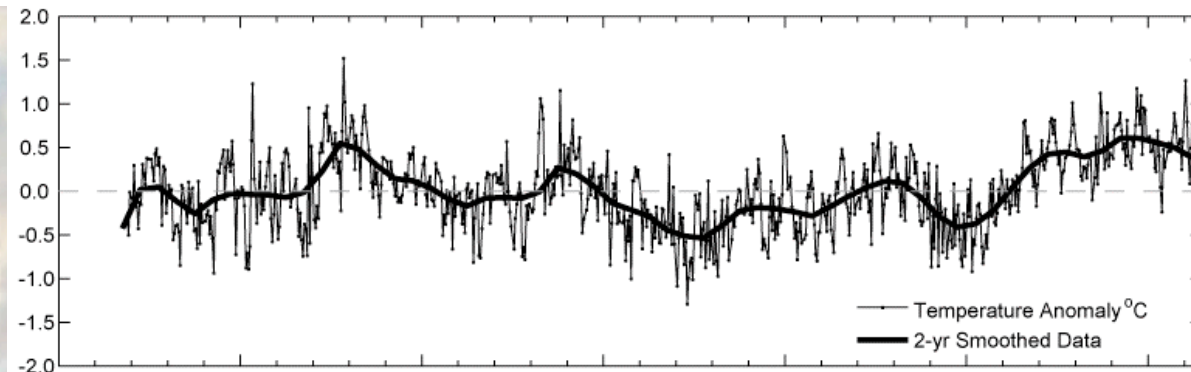
- Stammer et al, 2009



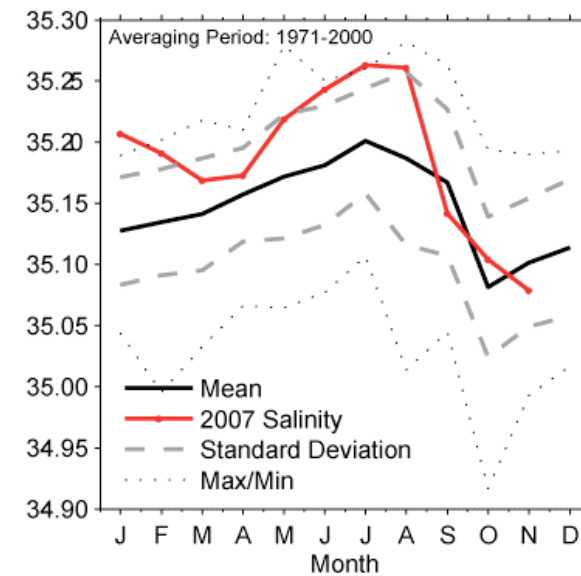
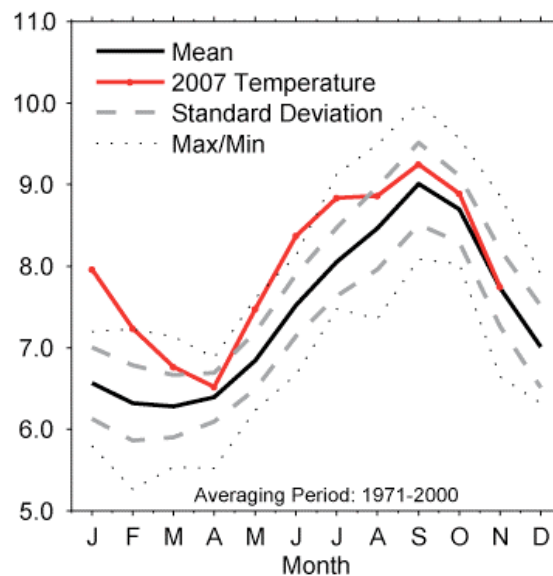
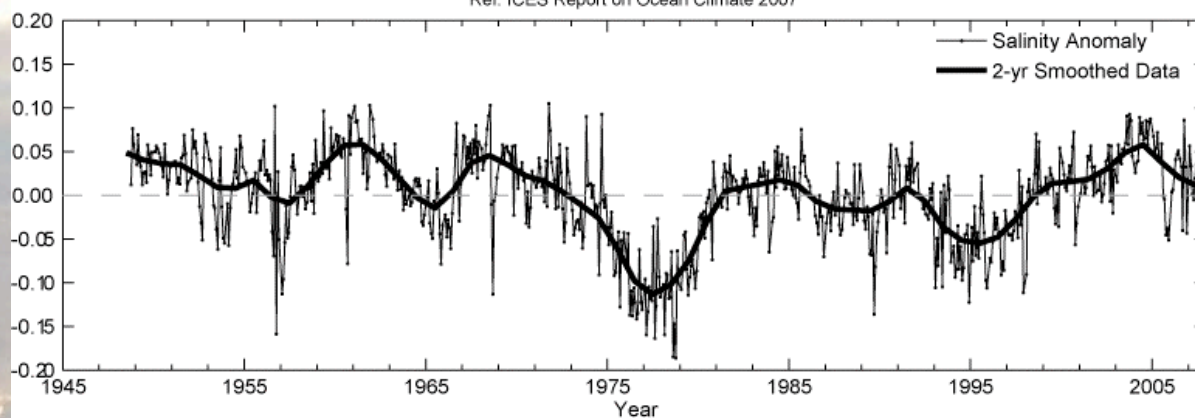


What time series we have show very strong seasonal to decadal variability in salinity.

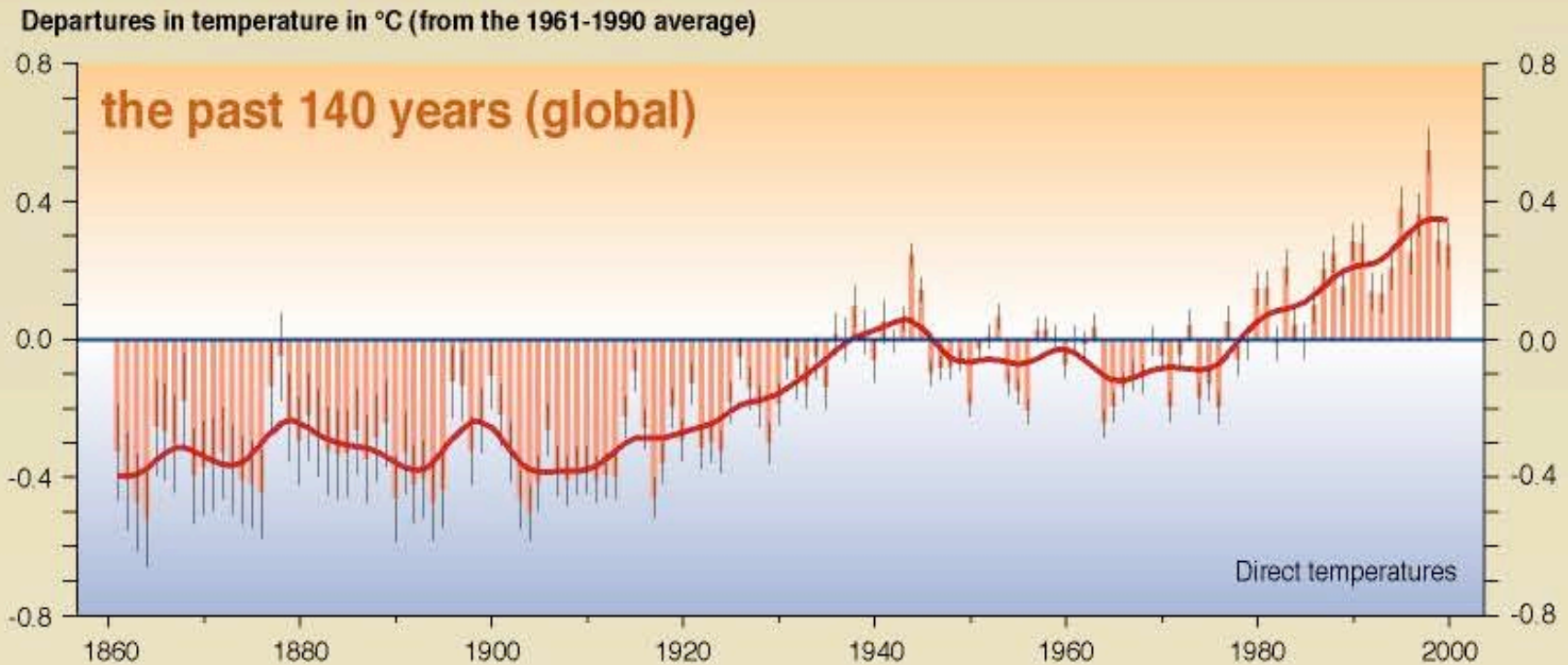
-Station M from Holliday et al 2009



Data Provider: Geophysical Institute - University of Bergen - Norway  
Ref. ICES Report on Ocean Climate 2007



# Surface air temperatures are rising...



from the IPCC Report  
*Climate Change 2001: The Scientific Basis*



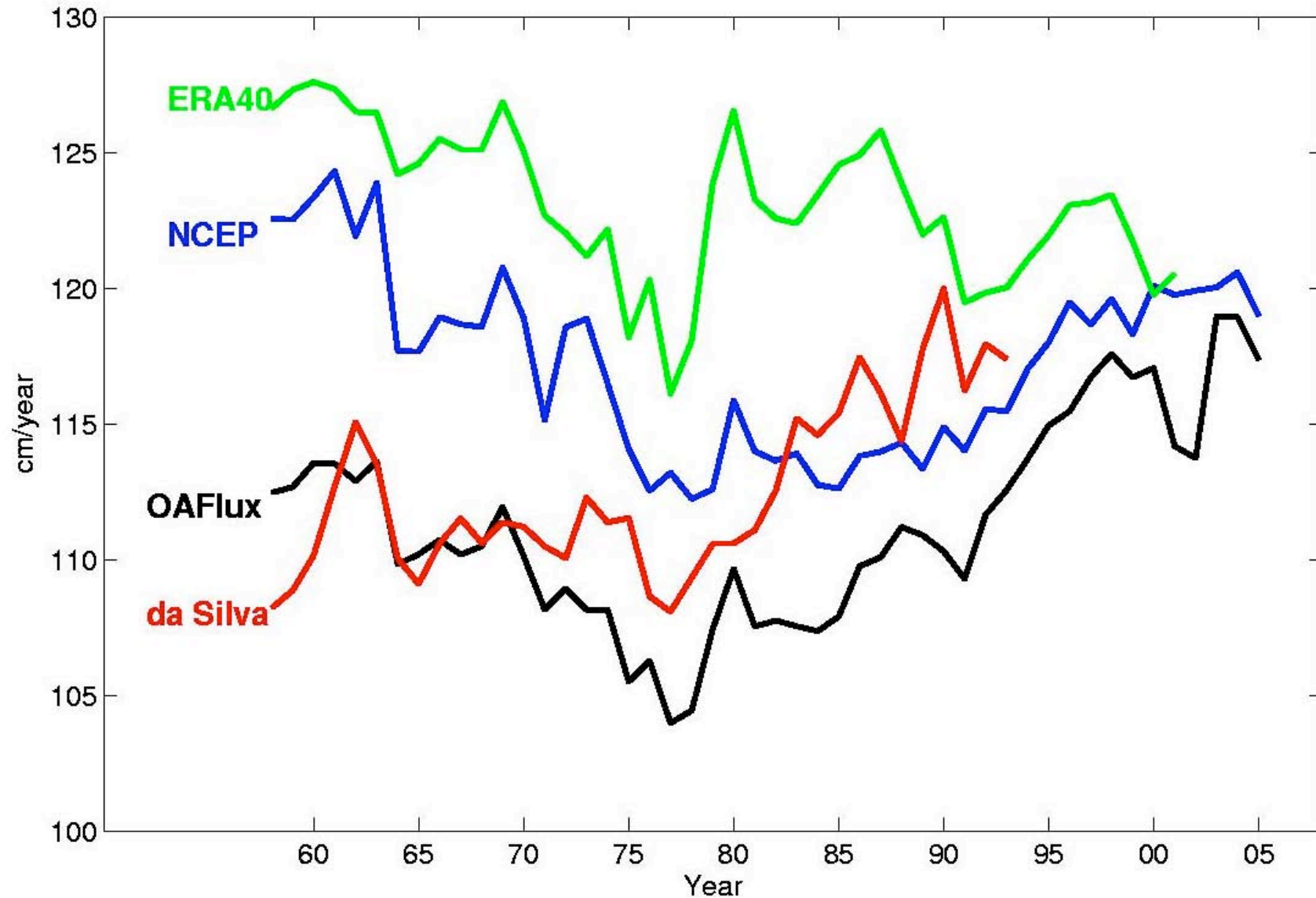
# The Water Cycle May Accelerate With Global Warming

- A warmer atmosphere will carry more water vapor, because of the exponential increase of vapor pressure with temperature.
- An enhanced water cycle will change the distribution of salinity in the upper ocean.

Vapor Pressure, mB



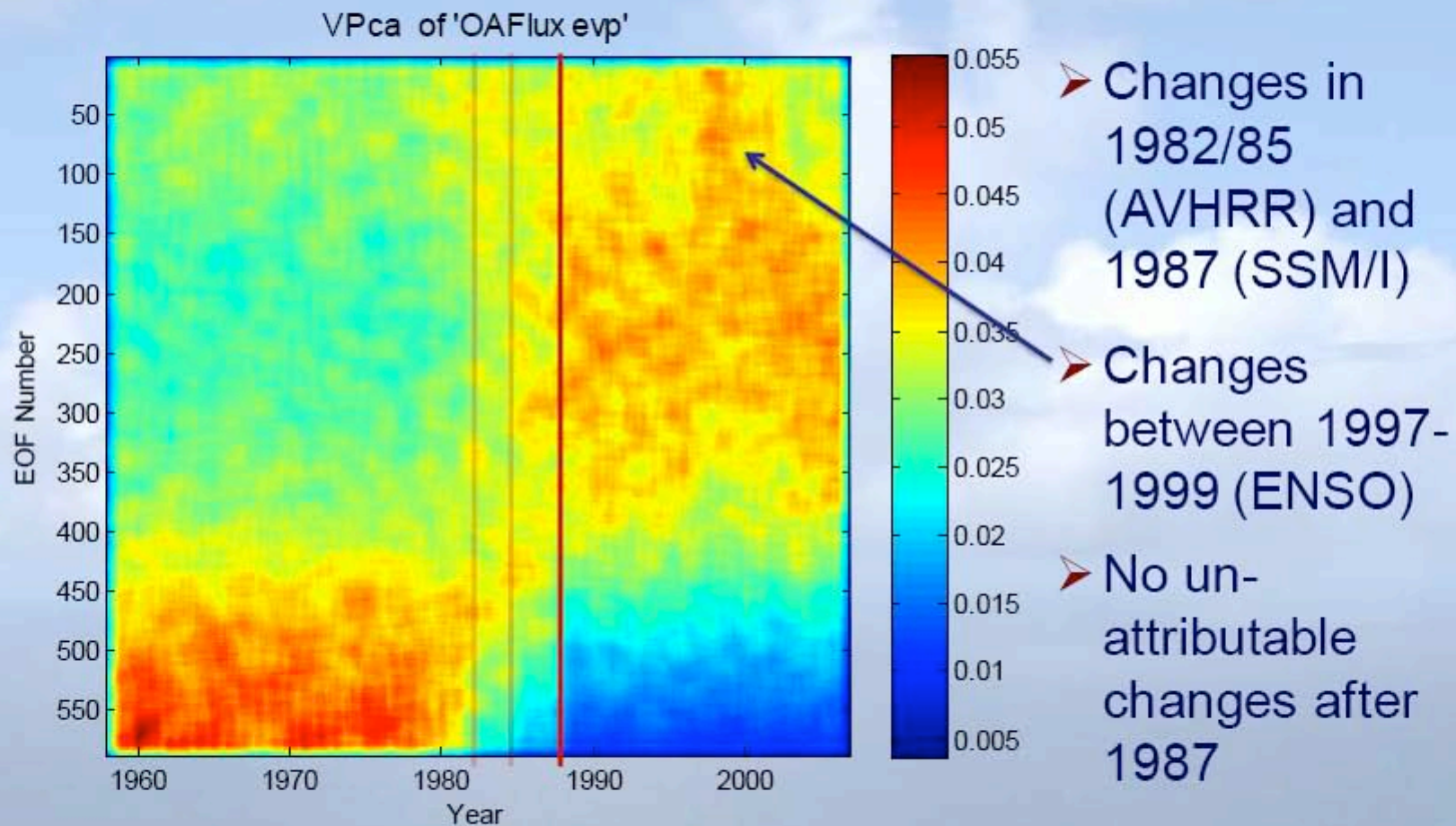
# Evaporation Trends in 4 Climatologies





II

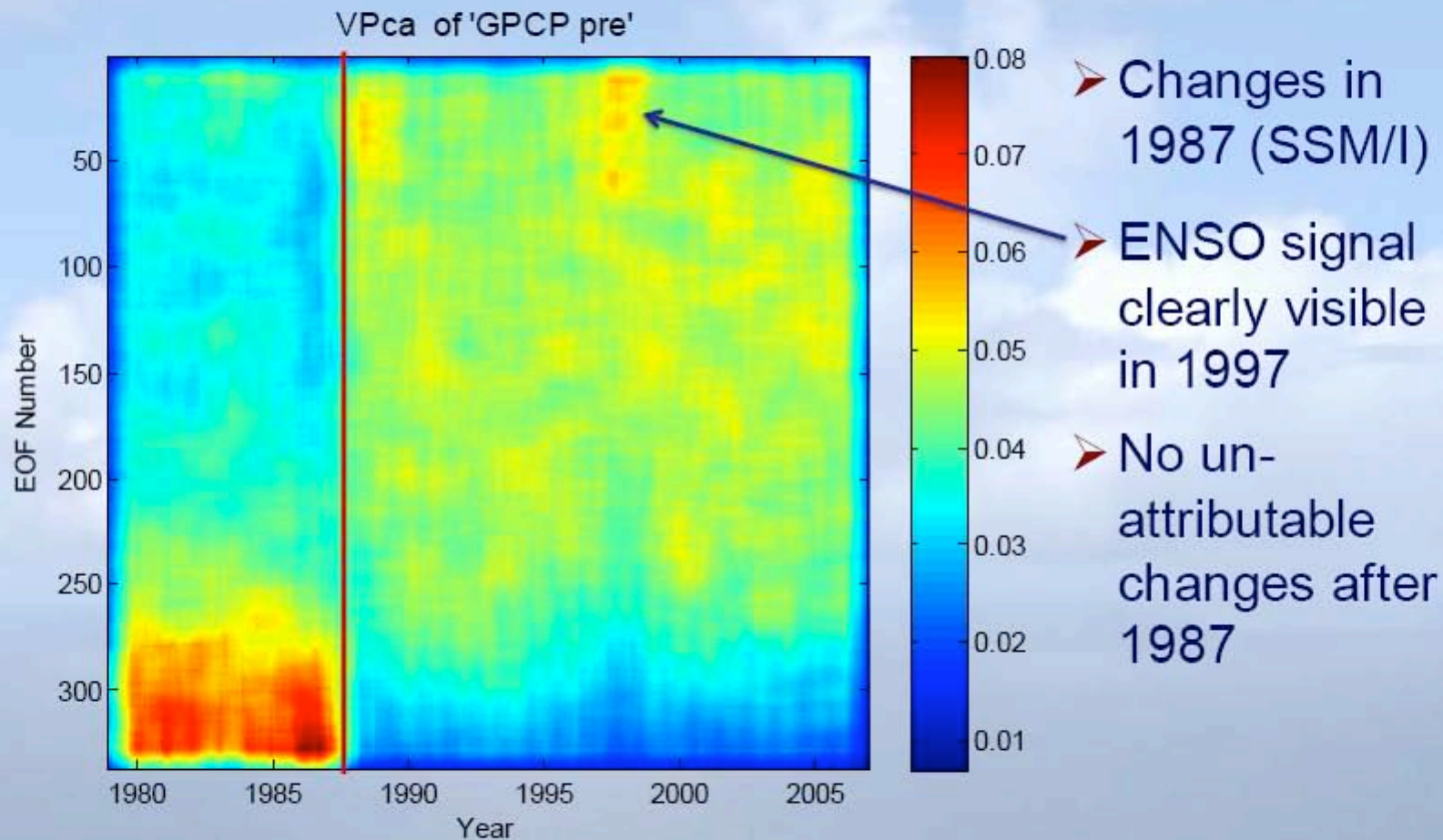
## Data Homogeneity: OAFlux



-Schanze and Schmitt, 2009, in prep.

## II

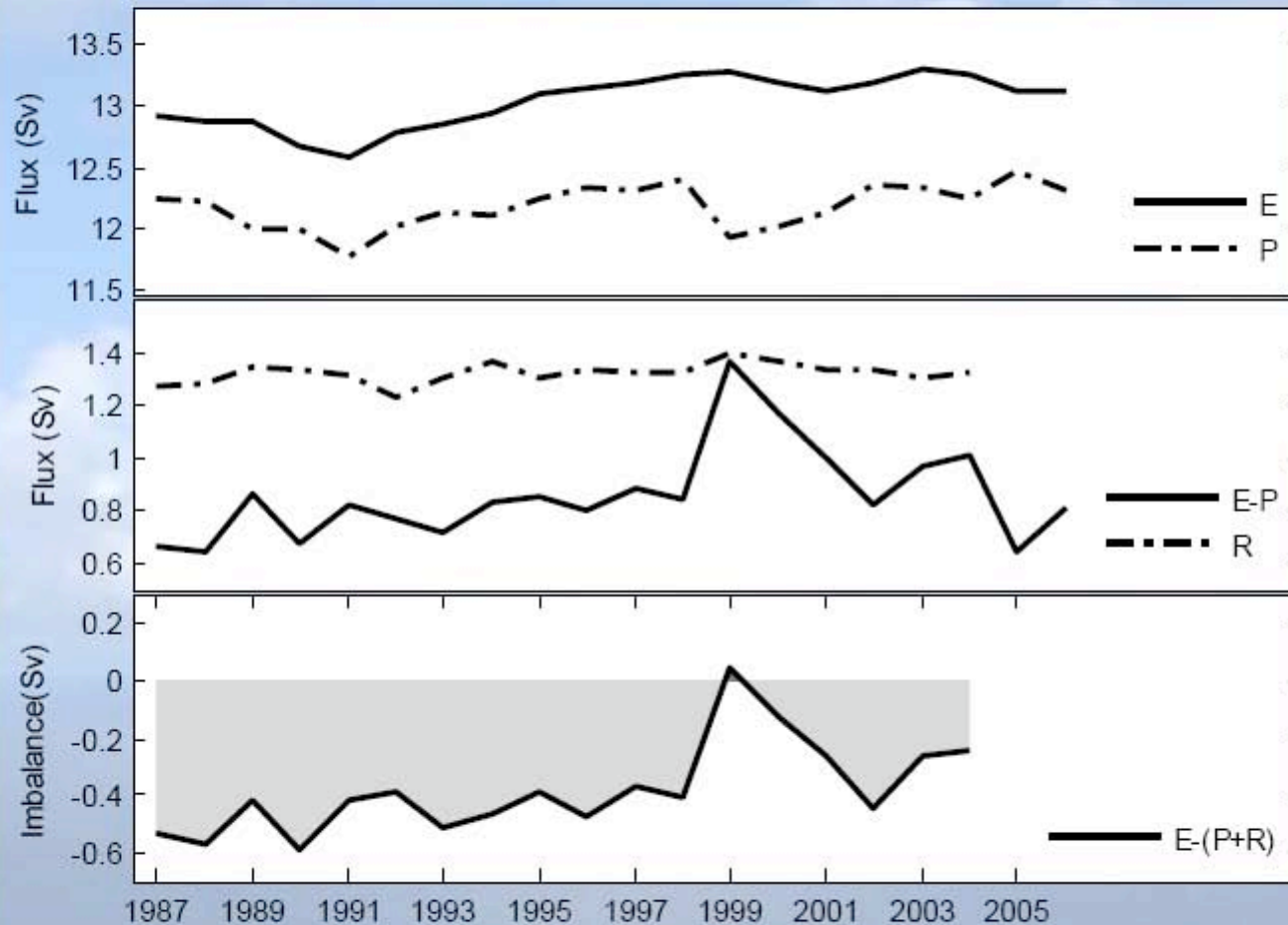
# Data Homogeneity: GPCP







# $E-(P+R)$ Global Balance



➤ Inter-annual variability greater than expected trend

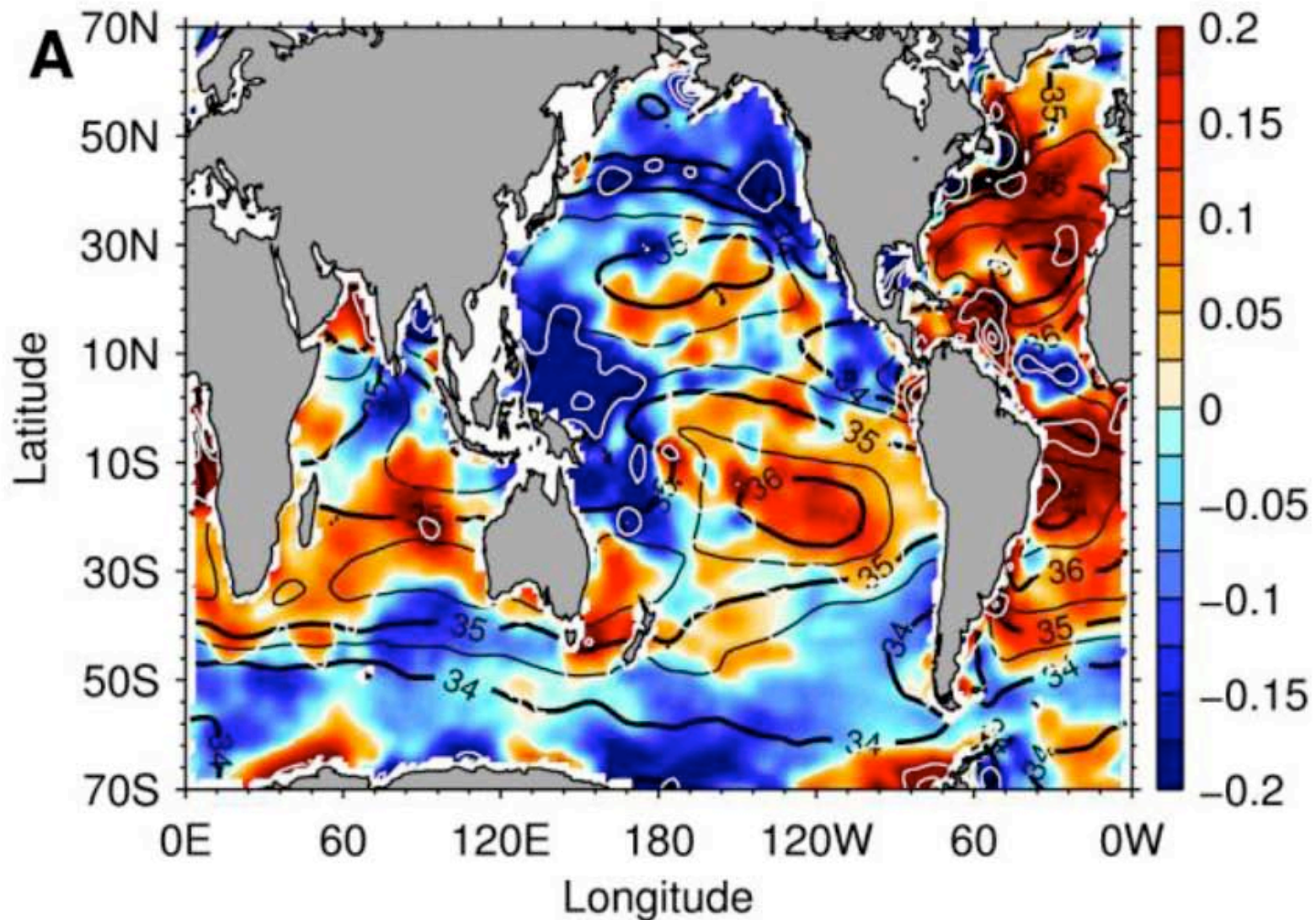
➤ Slight increase in E but P and R stationary

➤ Average imbalance 0.34 Sv



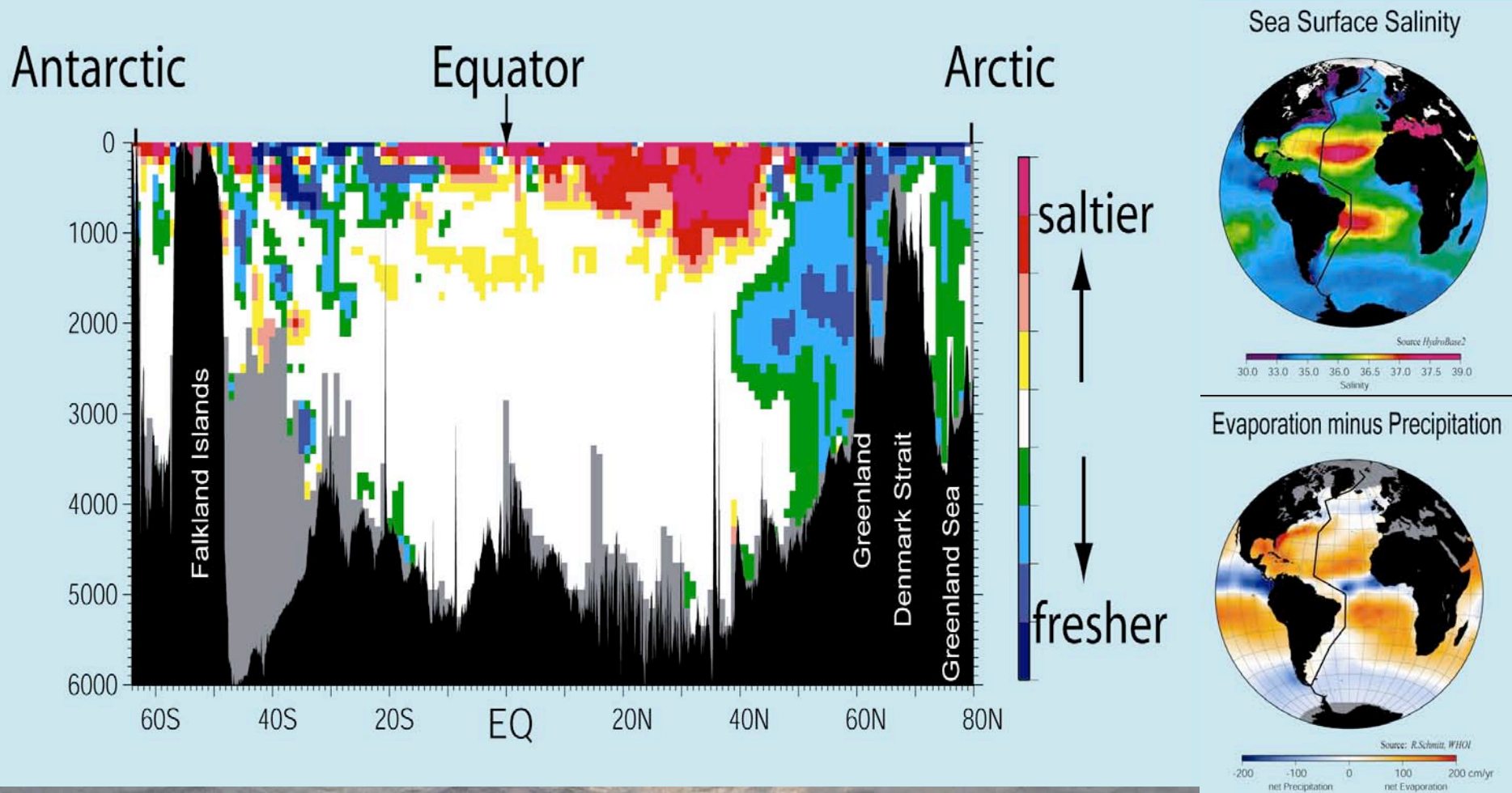
# Fifty year trends in salinity

-Durack and Wijffels, 2009





# Atlantic Ocean Salinity Changes 1990s compared to 1960s

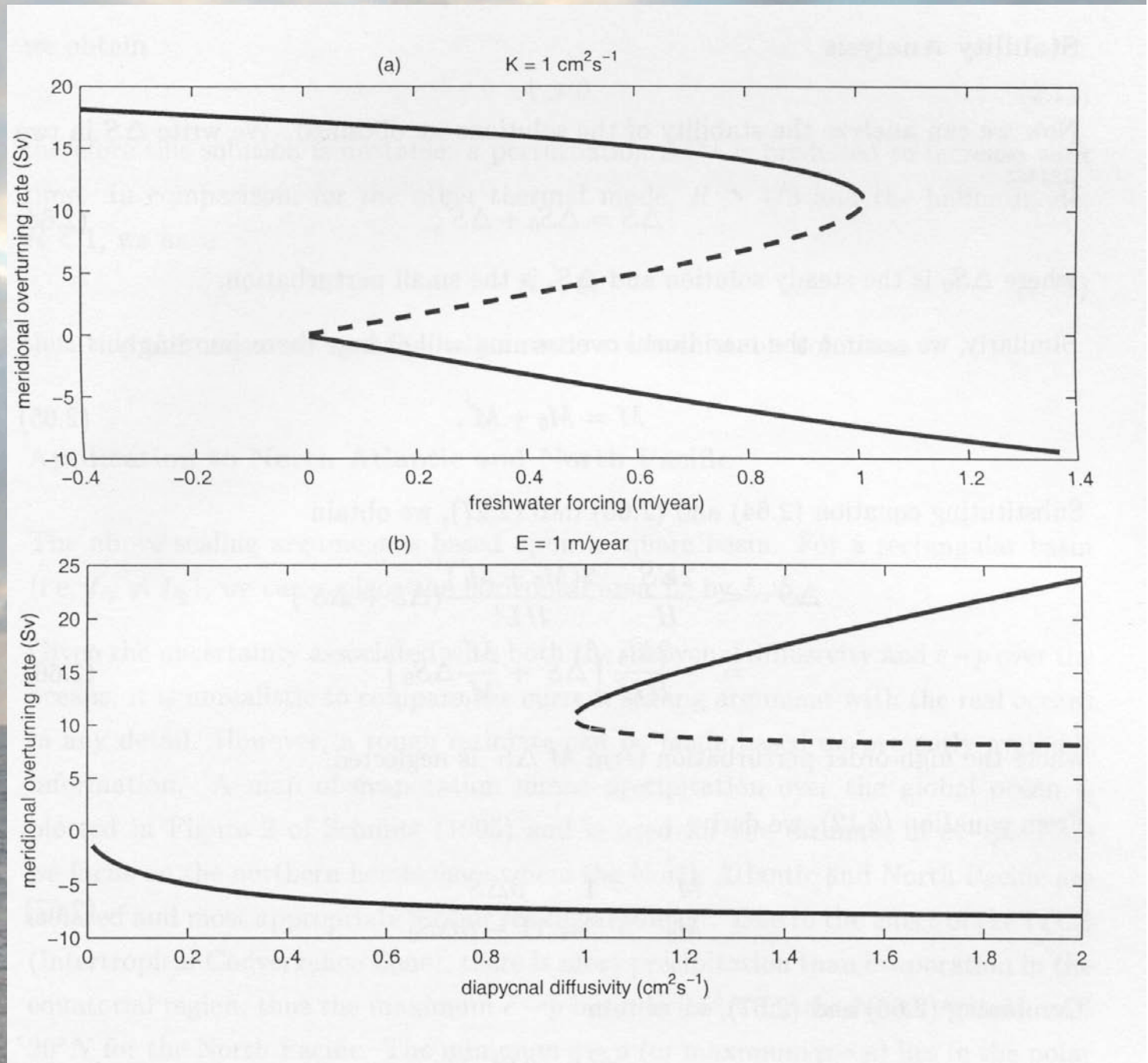


from Curry *et al.* *Nature* (2003)

**Strength of conveyor depends on mixing rate as well as freshwater forcing. But mixing rate will respond to changing stratification**

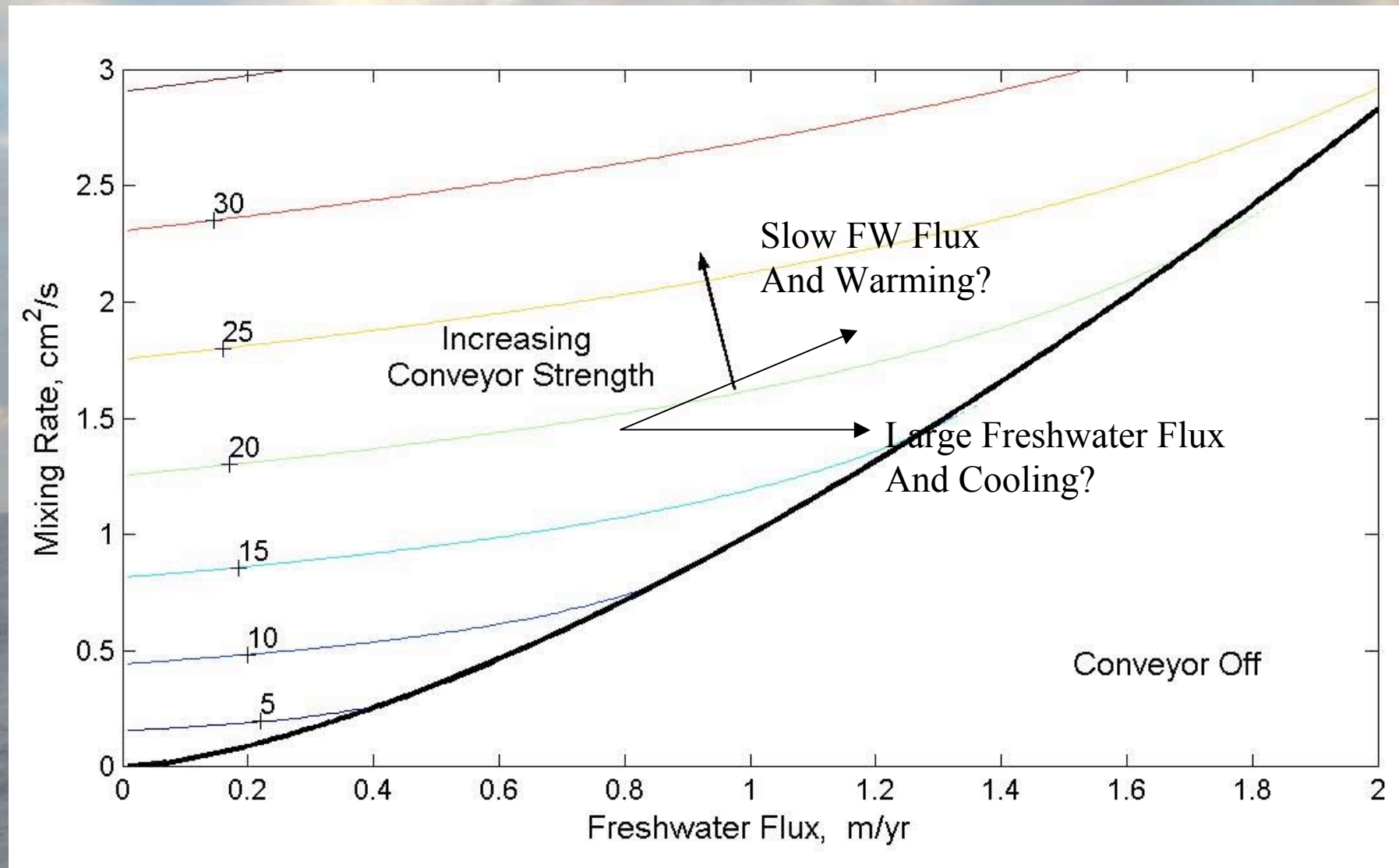
*Huang, 2003;*  
*Nilsson et al,*  
*2003.*

*Zhang, et al, 1999*

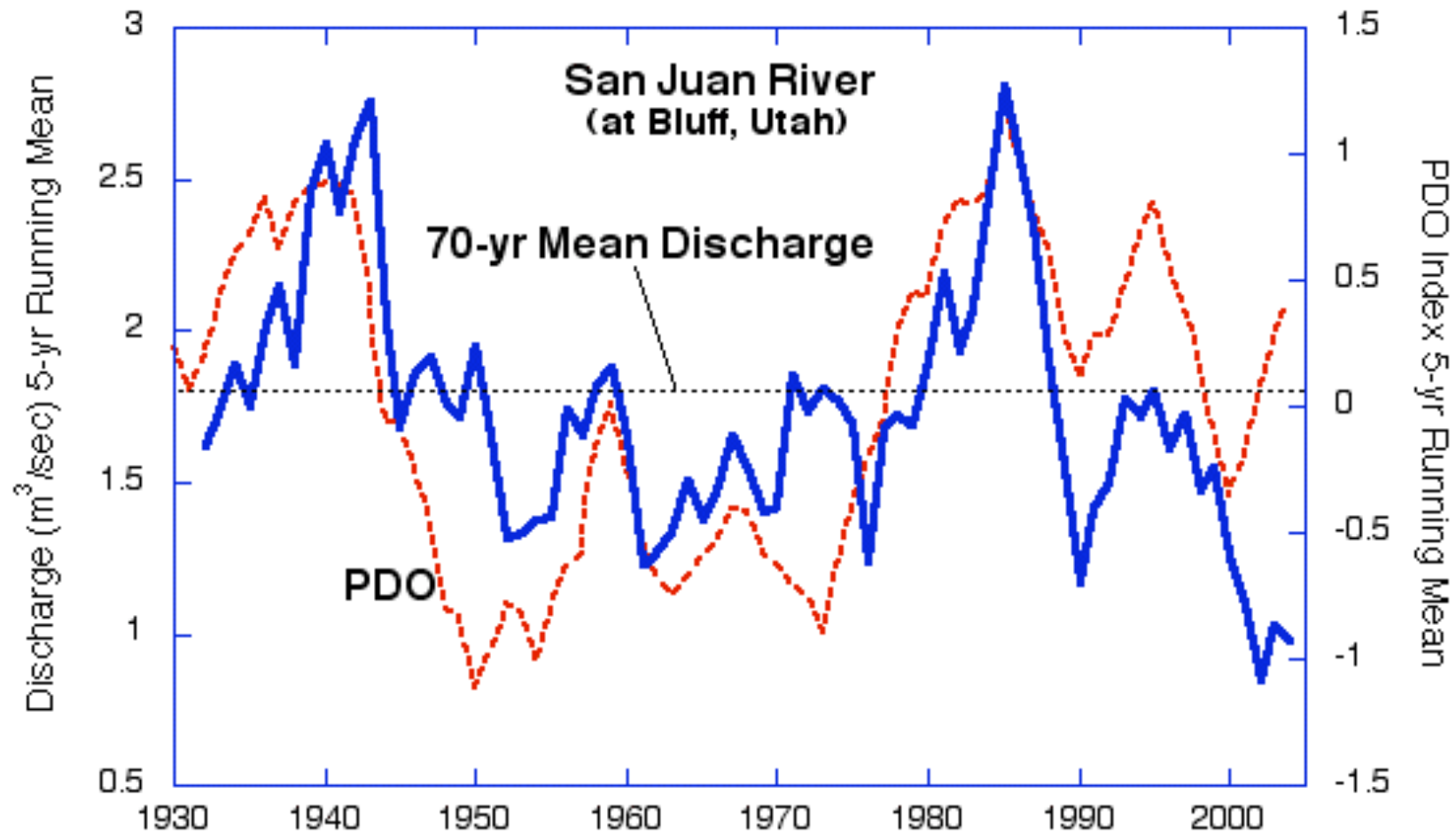




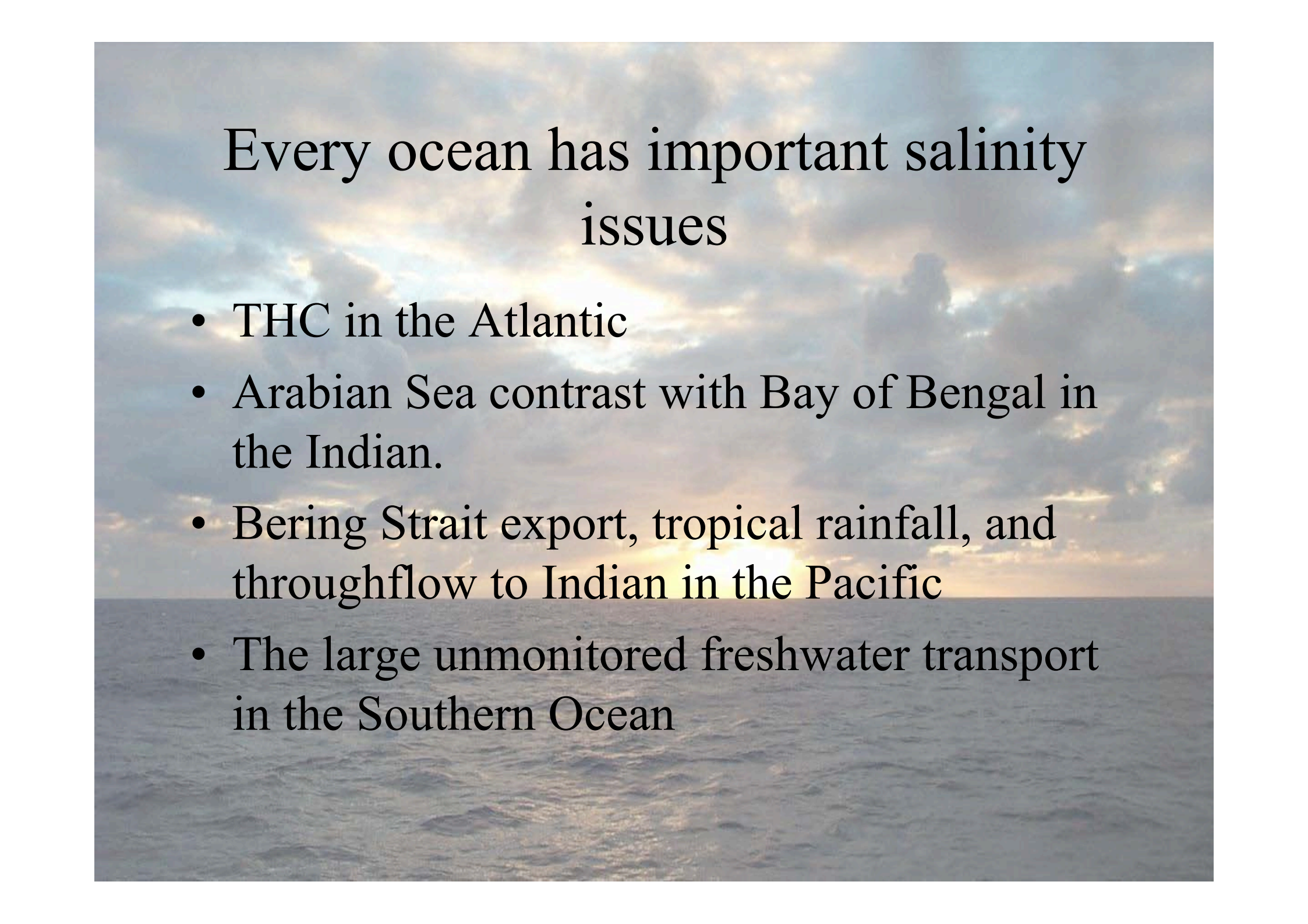
**Stability of conveyor is sensitive to mixing rate and freshwater flux, and some studies indicate that the mixing rate could increase with changing freshwater fluxes and stratification!**



SST has predictive power for precip. on land, so we have something to contribute to the challenge of interannual variability. (PDO vs SJ River discharge from John Milliman)







# Every ocean has important salinity issues

- THC in the Atlantic
- Arabian Sea contrast with Bay of Bengal in the Indian.
- Bering Strait export, tropical rainfall, and throughflow to Indian in the Pacific
- The large unmonitored freshwater transport in the Southern Ocean

A background image of a sunset over the ocean. The sun is low on the horizon, casting a golden glow across the sky and reflecting on the water. The sky is filled with soft, white clouds. The water in the foreground is dark blue with gentle ripples.

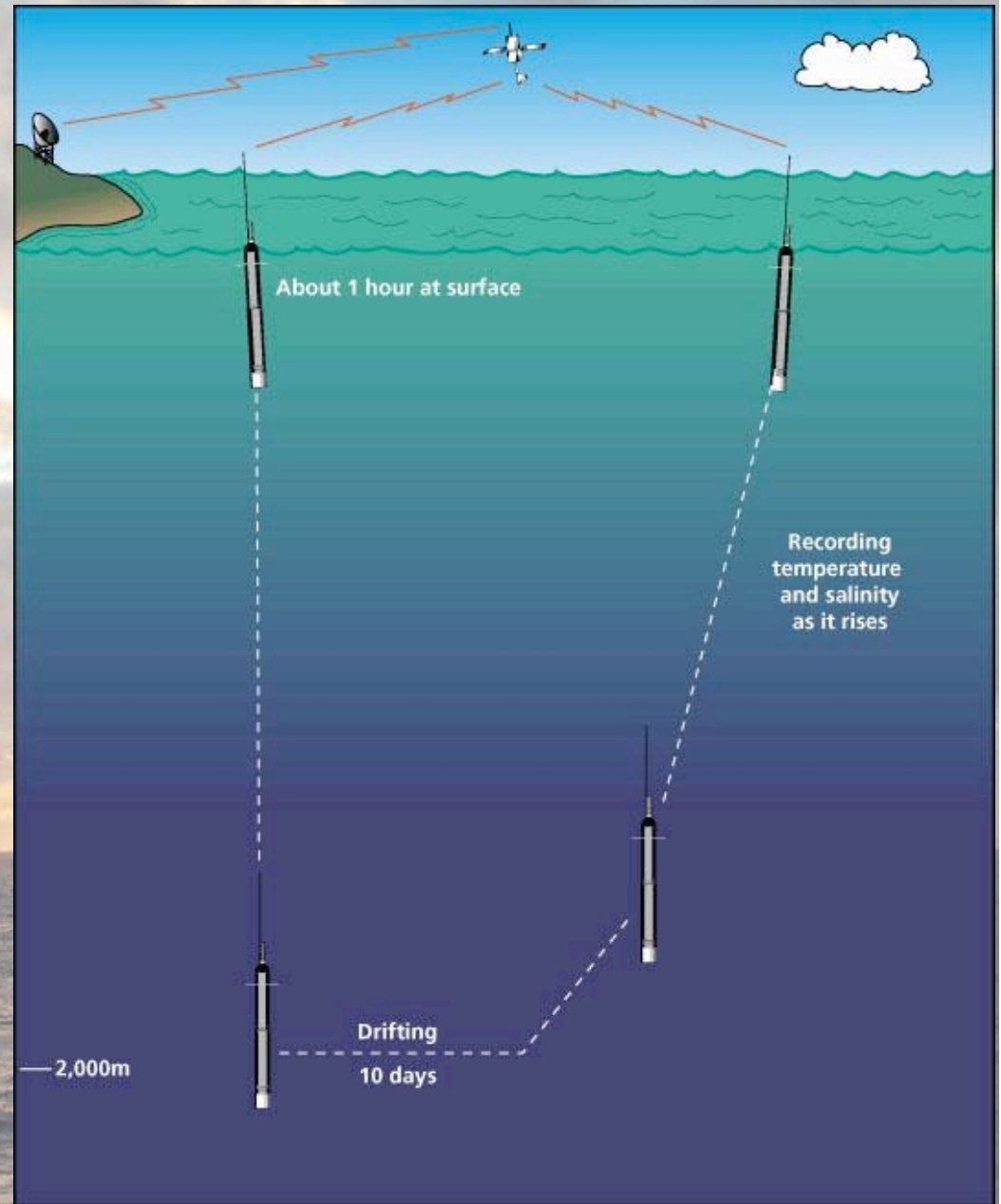
**Salinity is an indicator of the water cycle and impacts sea level, mixing, dynamics, the MOC, etc:**

**How can we do a better job on salinity observations?**

- SSS on ARGO (currently stop profiling at 5 m)
- SSS on drifters
- Expand thermosalinographs on VOS
- Satellites (SMOS, Aquarius)
- Deep ocean profiling

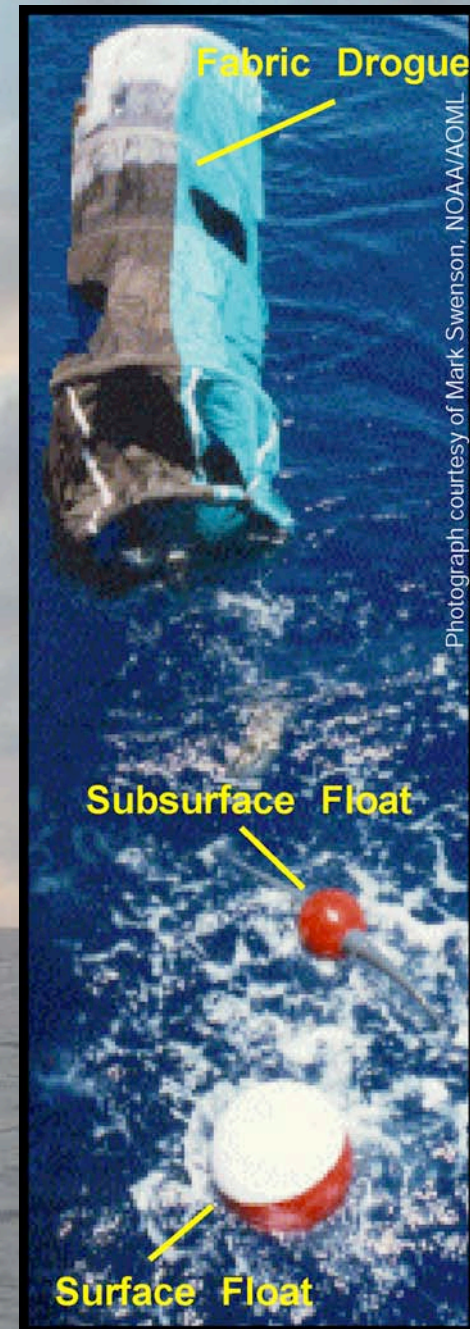


- The ARGO program of 3,000 profiling floats is providing vertical profiles of temperature and salinity every ten days as the floats drift. It is our first truly global salinity observing system. However, it stops at 5 m depth and still has large space/time gaps. Issues remain with dynamic response of sensors.





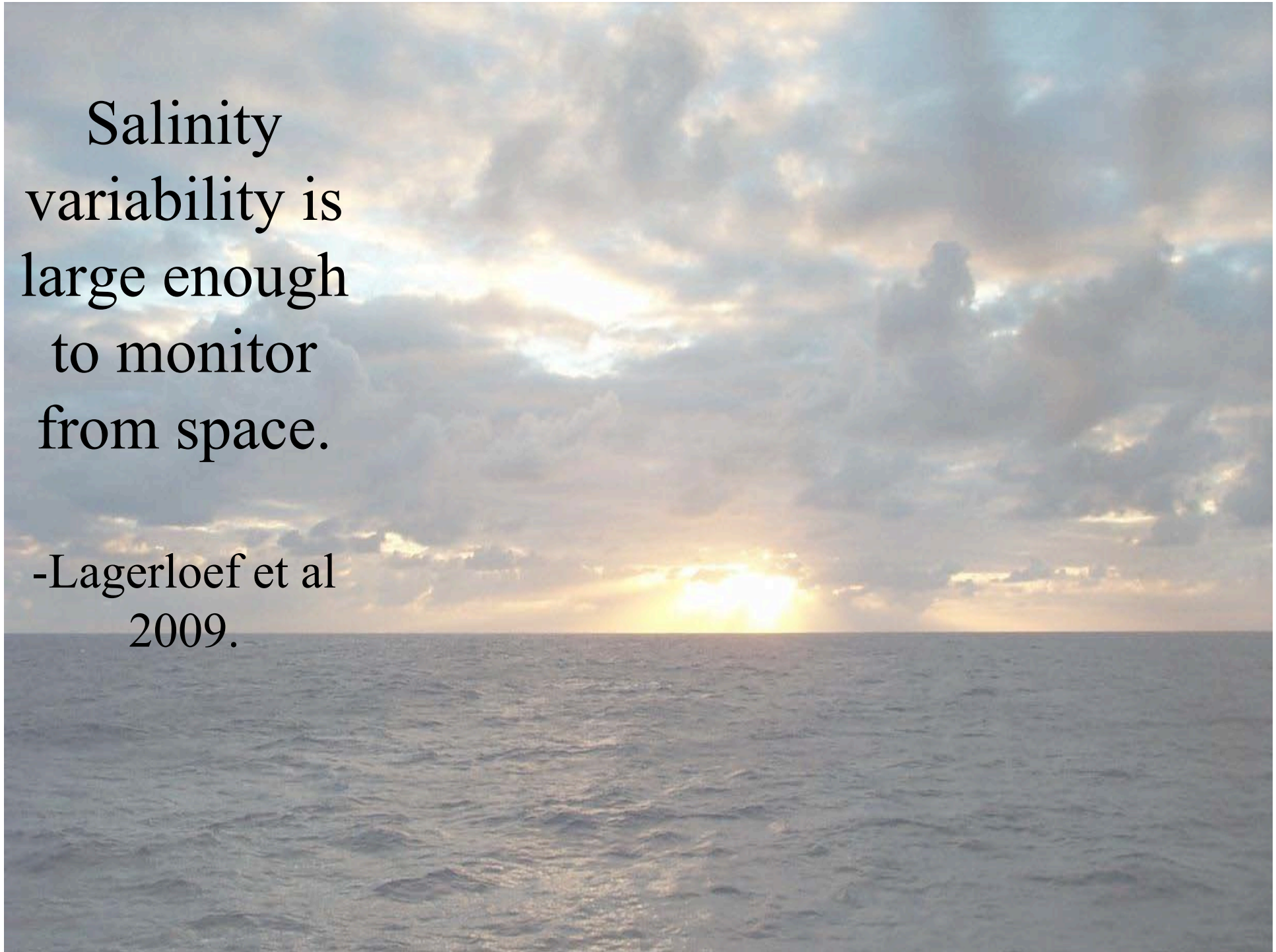
**Surface drifters can be equipped with foul-proof salinity sensors; its time to move beyond 30 year old technology that provides a few months protection at best. There is a great need for an in-situ SSS observing system!**





Salinity  
variability is  
large enough  
to monitor  
from space.

-Lagerloef et al  
2009.



Salinity from space: SMOS to be  
launched this year, Aquarius to be  
launched fall 2010

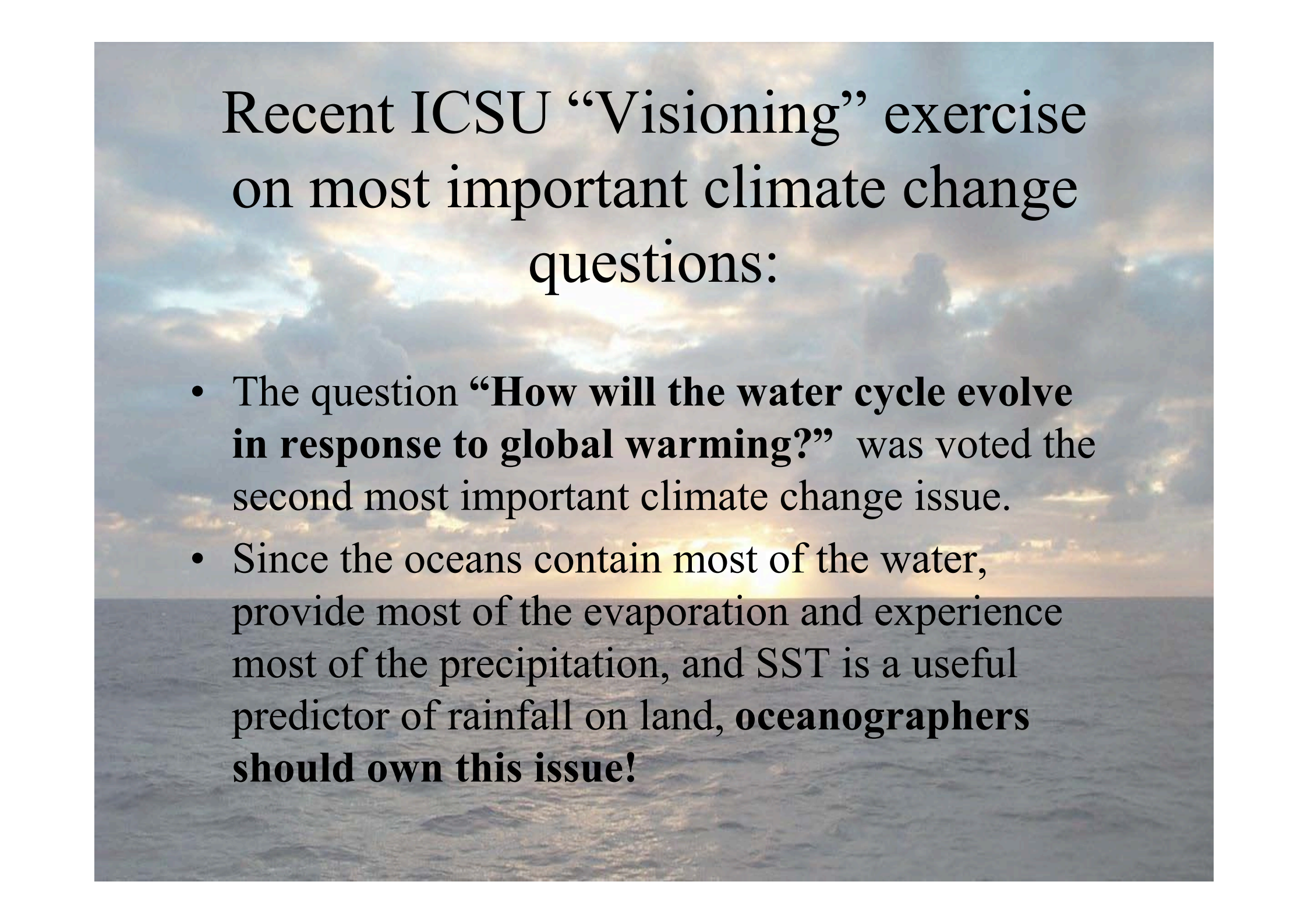




A photograph of a sunset over the ocean. The sun is low on the horizon, partially obscured by clouds, creating a bright glow. The sky is filled with various cloud formations, some dark and some catching the light of the setting sun. The water in the foreground is dark with small waves.

AQUARIUS  
Simulated  
retrievals  
- Lagerloef et al.  
2009

Signal to noise is  
comparable to  
first altimeters



# Recent ICSU “Visioning” exercise on most important climate change questions:

- The question “**How will the water cycle evolve in response to global warming?**” was voted the second most important climate change issue.
- Since the oceans contain most of the water, provide most of the evaporation and experience most of the precipitation, and SST is a useful predictor of rainfall on land, **oceanographers should own this issue!**



## **Freshwater and Salinity Summary:**

- **Changes in the water cycle are of tremendous consequence for society (droughts, floods).**
- **Most of the water cycle occurs over the oceans.**
- **Changes in the water cycle have impact on salinity and seawater density, and thus modulate oceanic mixing, heat storage, sea level and the MOC.**

- **Strong inter-annual to decadal variability in salinity can be seen, and present observing systems cannot distinguish this variability from that due to warming induced trends.**
- **These salinity signals are due largely to changes in evaporation and precipitation over the ocean; river discharges and glacial melt play only a minor role.**
- **An improved upper-ocean salinity data set could be assimilated into models and used as an additional constraint on estimates of the water cycle.**
- **New observing capabilities for salinity must be realized and utilized to monitor this key element of the climate system. This requires investment in new technology, broad deployment and careful quality control. (AQUARIUS, ARGO, SSS from Drifters, Thermosalinographs on the VOS)**
- **Process studies are also necessary.**



# A Salinity Process Study

## Objectives:

- What processes maintain the salinity maximum?
- Where does the excess salt go?
- What processes give rise to temporal variability?
- What is the larger impact on the shallow overturning circulation?

## Location advantages:

- >Low
- >Low precip
- >Modest eddy activity
- >Source of water for northern tropical thermocline
- >Stable S for Cal-Val
- > Warm (better for Aquarius)
- > Leverages other resources: 24 N section, Pirata Array, ESTOC time series (Canary Islands)
- > Logistically tractable

} 1D phys.

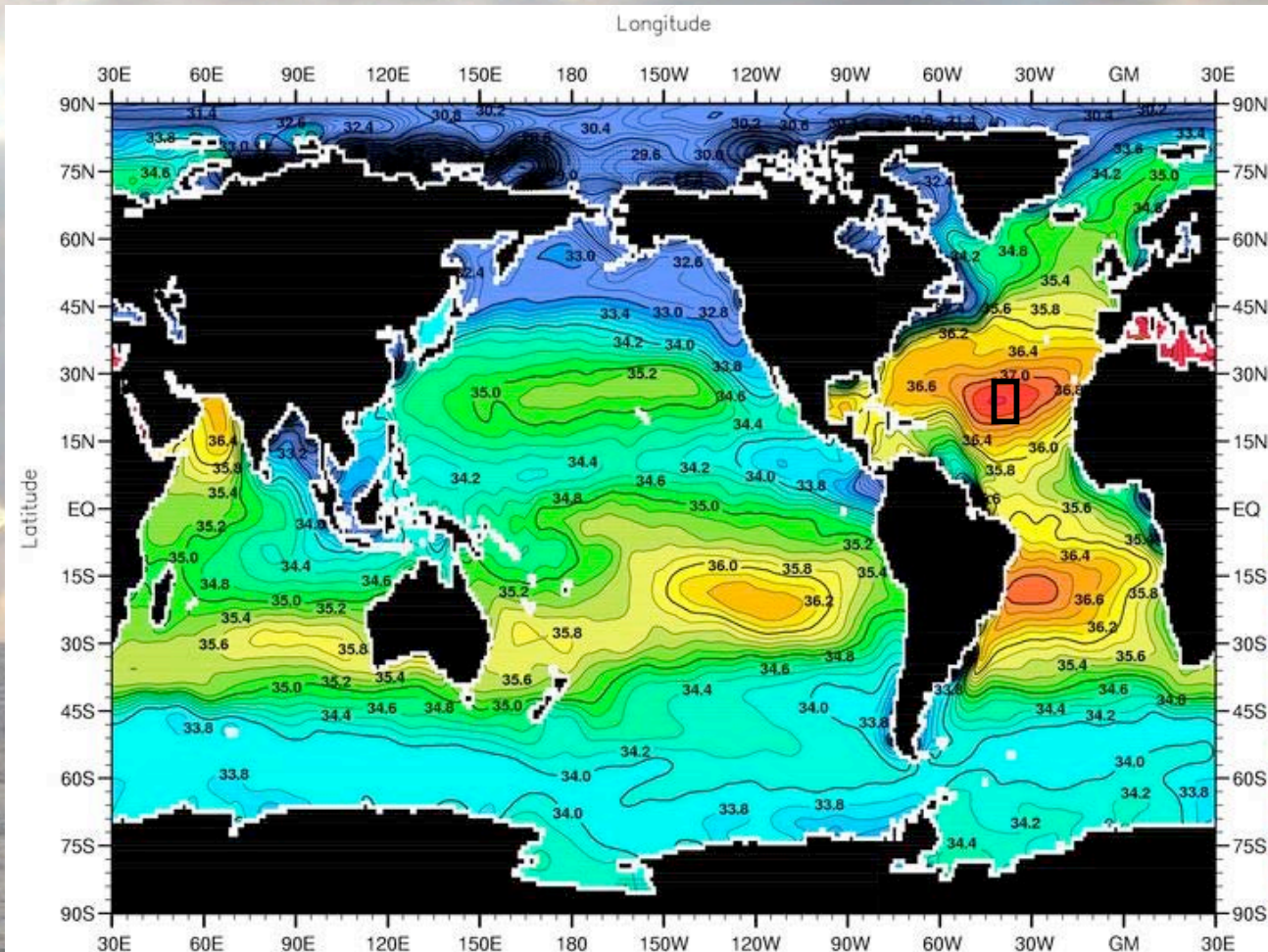


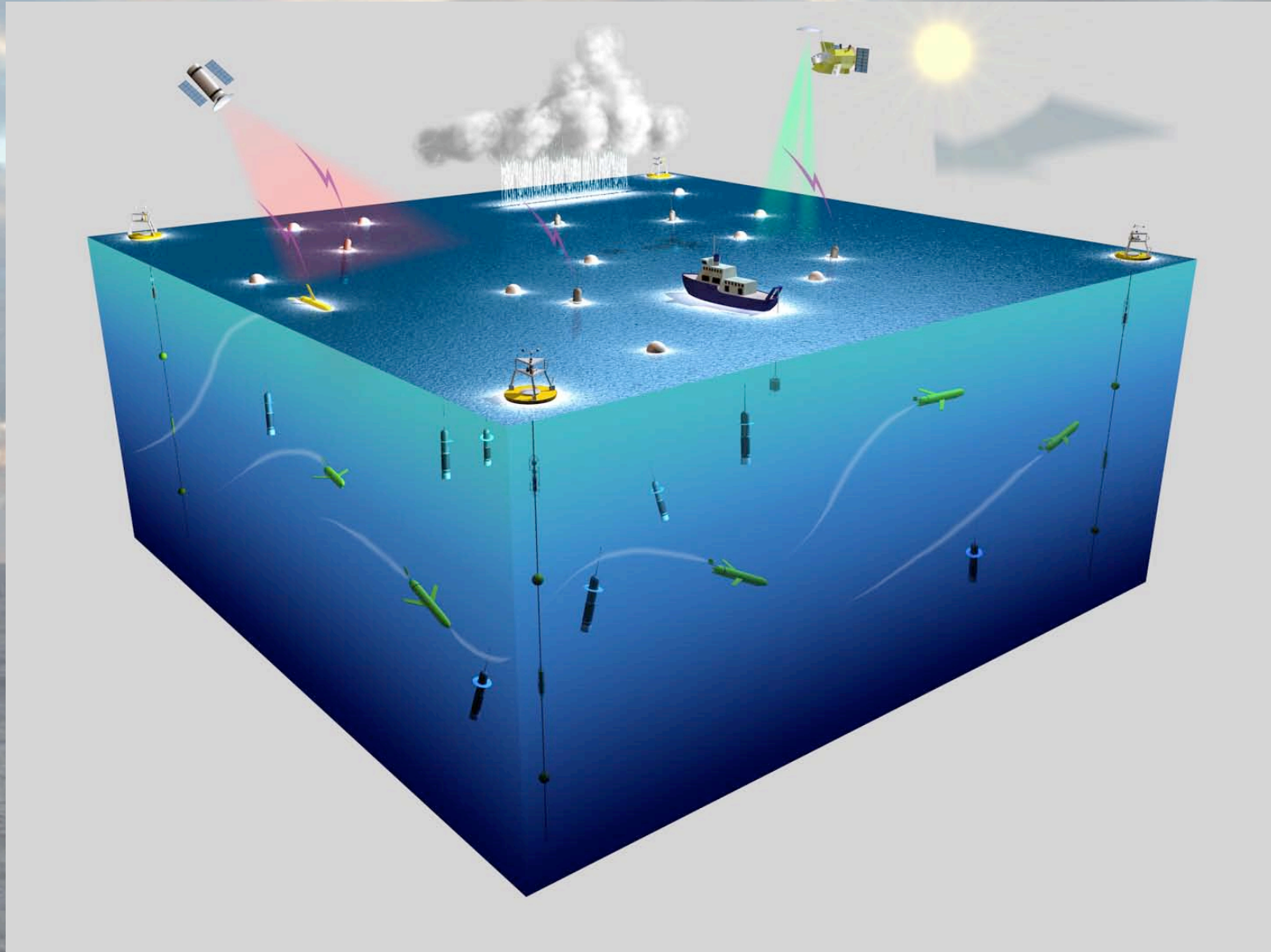
Fig. A2-1. Annual mean salinity (PSS) at the surface.

Minimum Value= 2.37

Maximum Value= 40.37

Contour Interval: 0.20

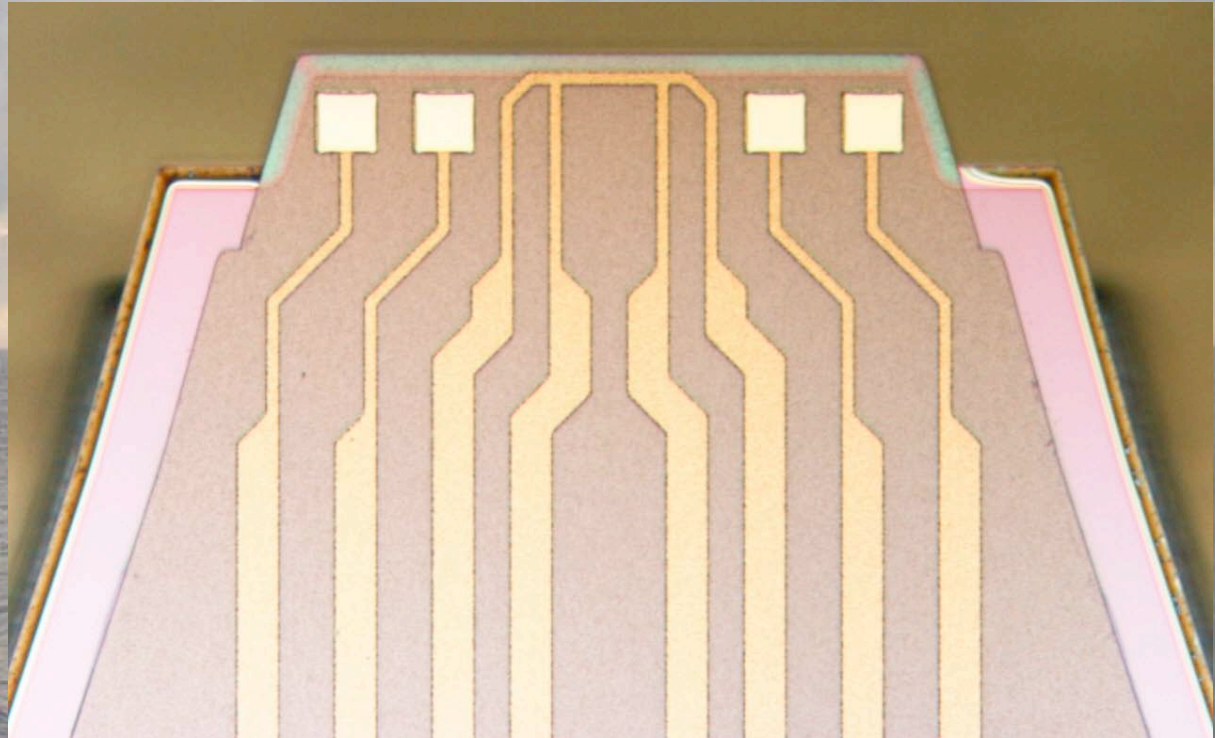
# A “Cage” Experiment





The surface skin T and S is an important issue for remote sensing. Micro-sensors on upward profiling instruments can resolve.

- A new “worlds smallest C/T sensor” is under development: a 1 micron thick coating of CVD diamond covers a 10 micron thick substrate with 4-terminal Pt thermometer and 4-electrode conductivity sensor.



Though 30 year old technology has served us well, we must invest in new salinity sensing technology (As I have been saying since OOSDP ~15 years ago)

- Long-term fouling resistant cells, with lifetimes of years not months.
- Micro T/C for surface skin and microstructure and mixing measurements
- Refractive index approaches using modern fiber-optics





# Links:

Process Study described at:

- [www.ideo.columbia.edu/~agordon/reports](http://www.ideo.columbia.edu/~agordon/reports)

Aquarius SAC-D Meeting (21-23 October) at:

- [http://www.conae.gov.ar/AQ\\_SAC-D\\_5thScienceMeet/indexe.html](http://www.conae.gov.ar/AQ_SAC-D_5thScienceMeet/indexe.html)

