The mixed layer and upper ocean observing system

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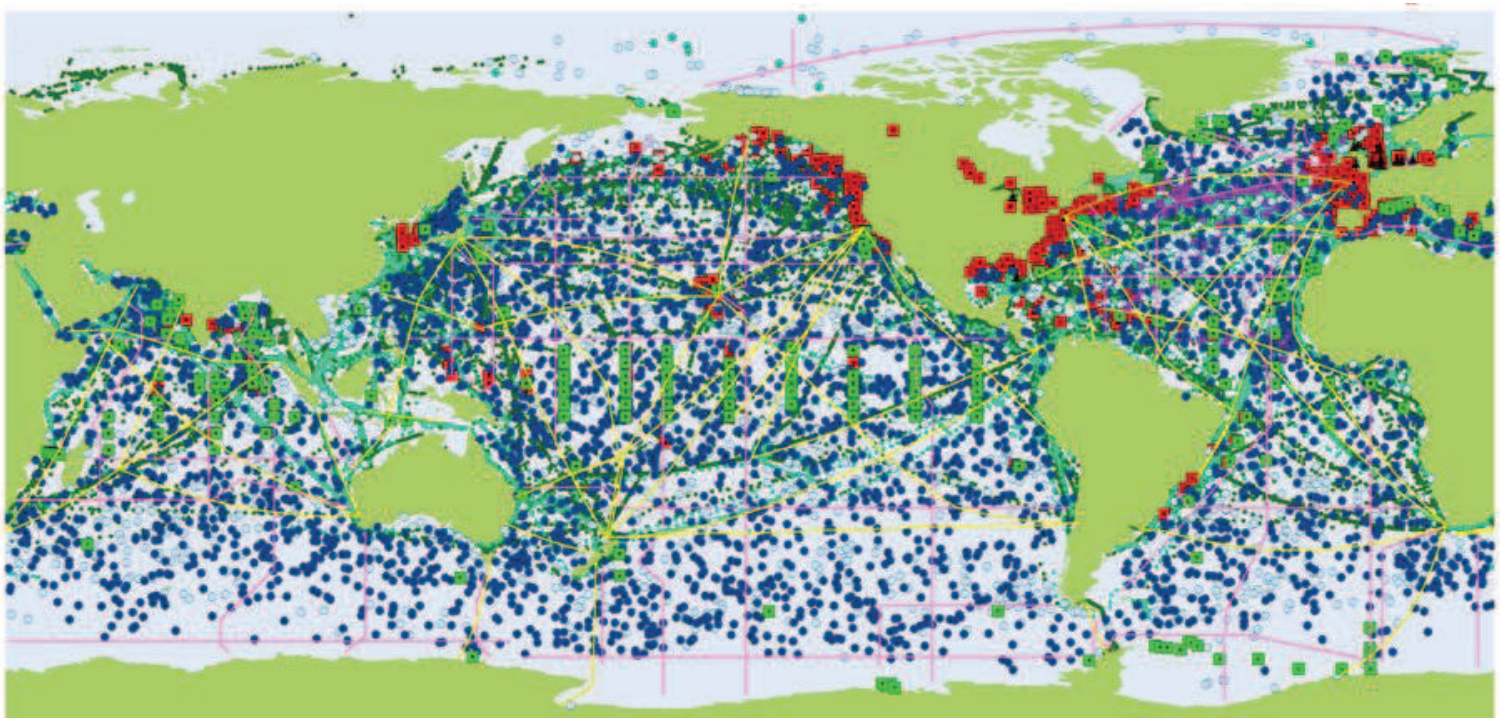
NOAA/AOML, Miami, FL



U.S. CLIVAR Summit, Baltimore, August 8-10, 2017

Outline

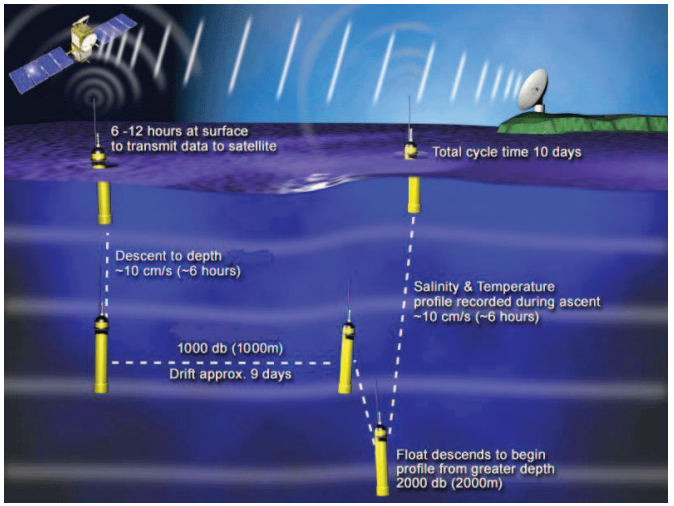
- Observing system components
- Timescales: mixing to climate change
- Summary of strengths and weaknesses

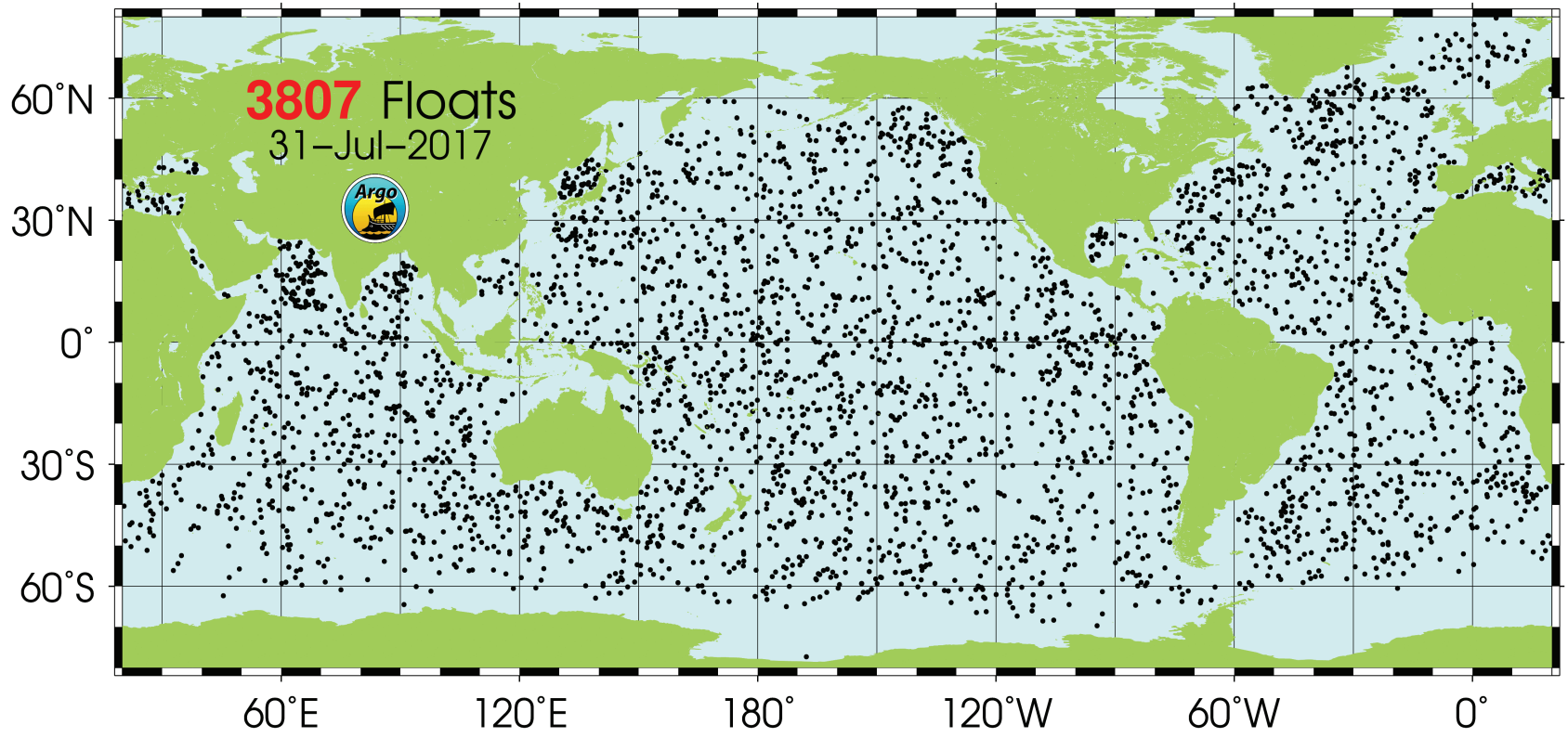
Not covered: AMOC, satellites, coastal

Argo

- Temp., salin., pressure to 2000 m

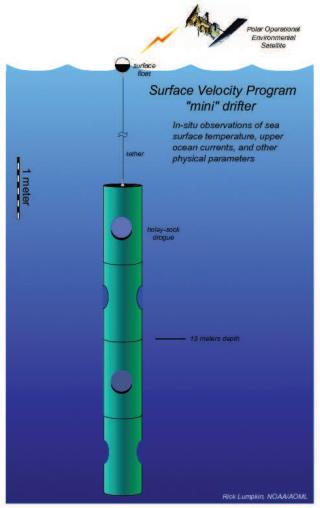
- BGC on subset of floats

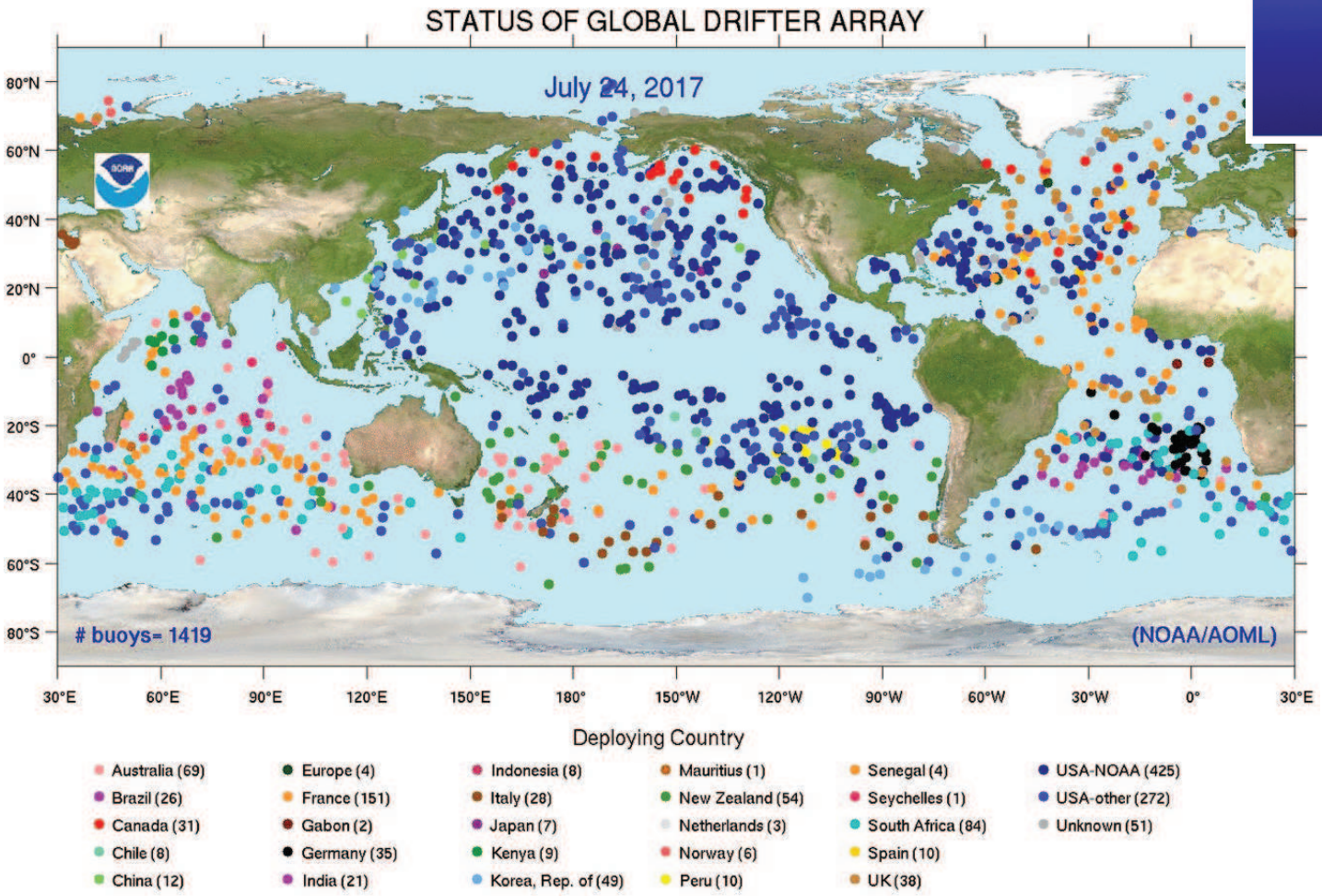




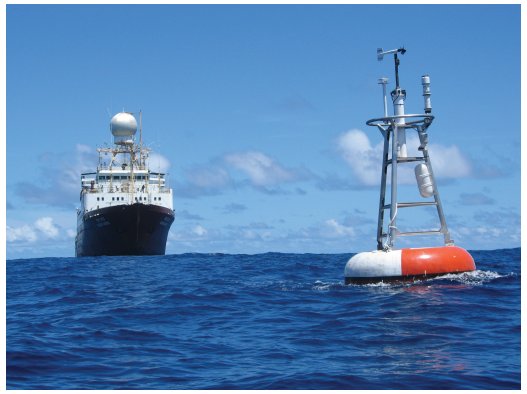
Surface drifting buoys

- SST, ocean velocity (drogue centered at 15 m)

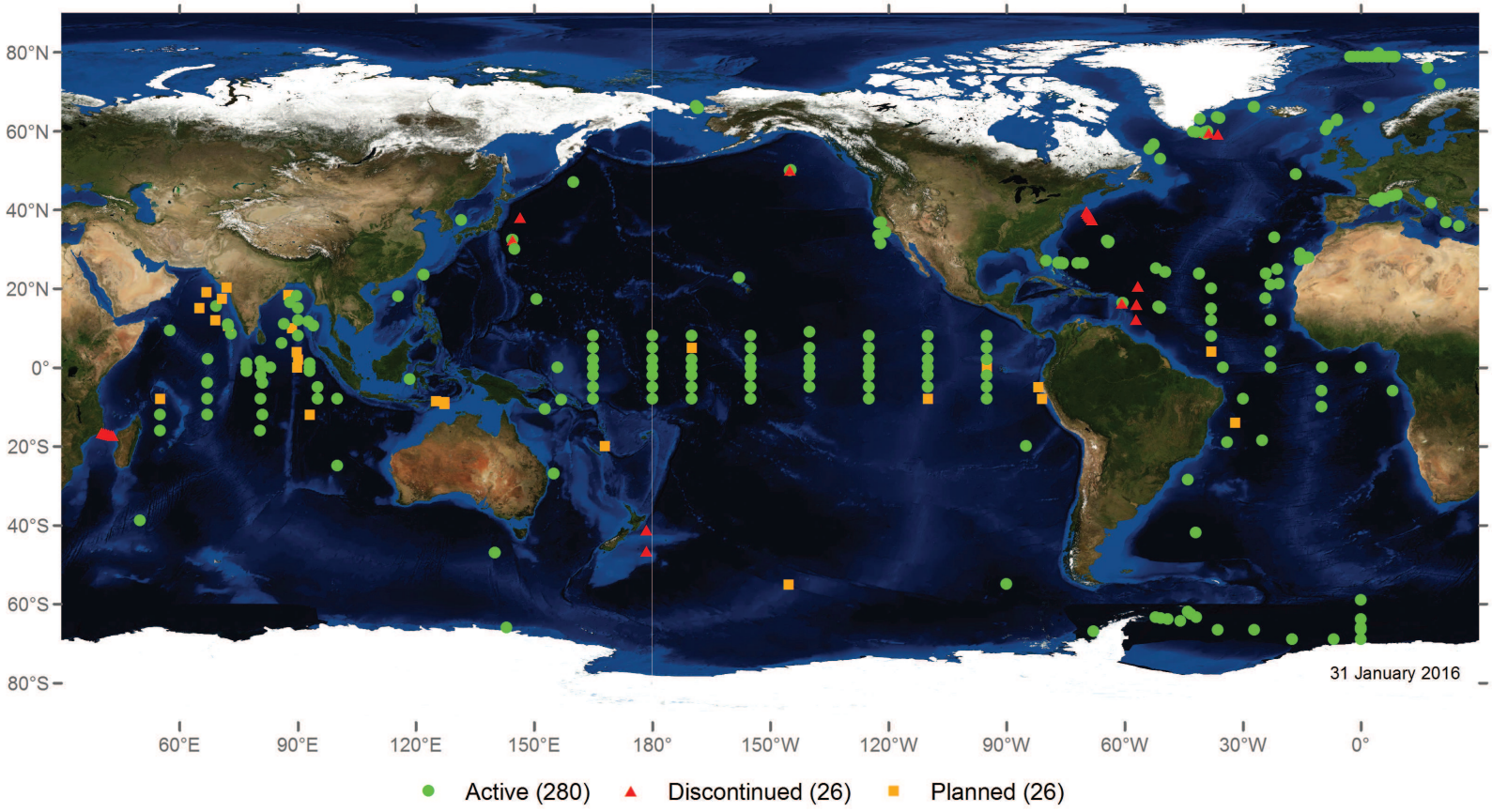




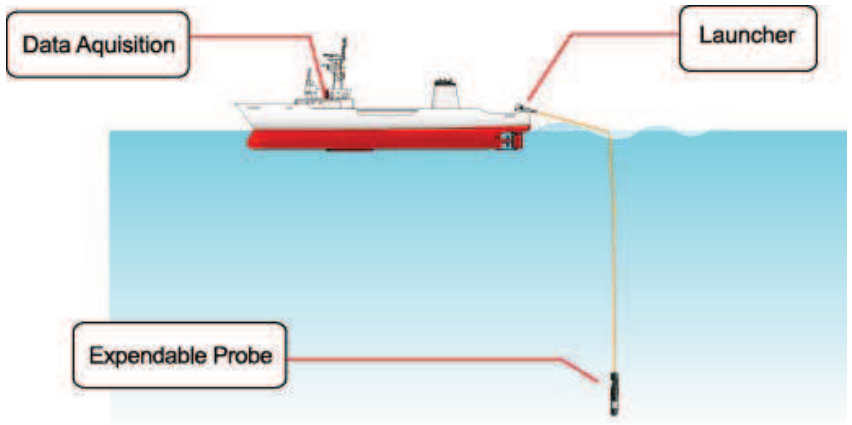
Moored buoys



- Temp., salin., ocean vel. (some), sfc. met.
- High temporal resolution

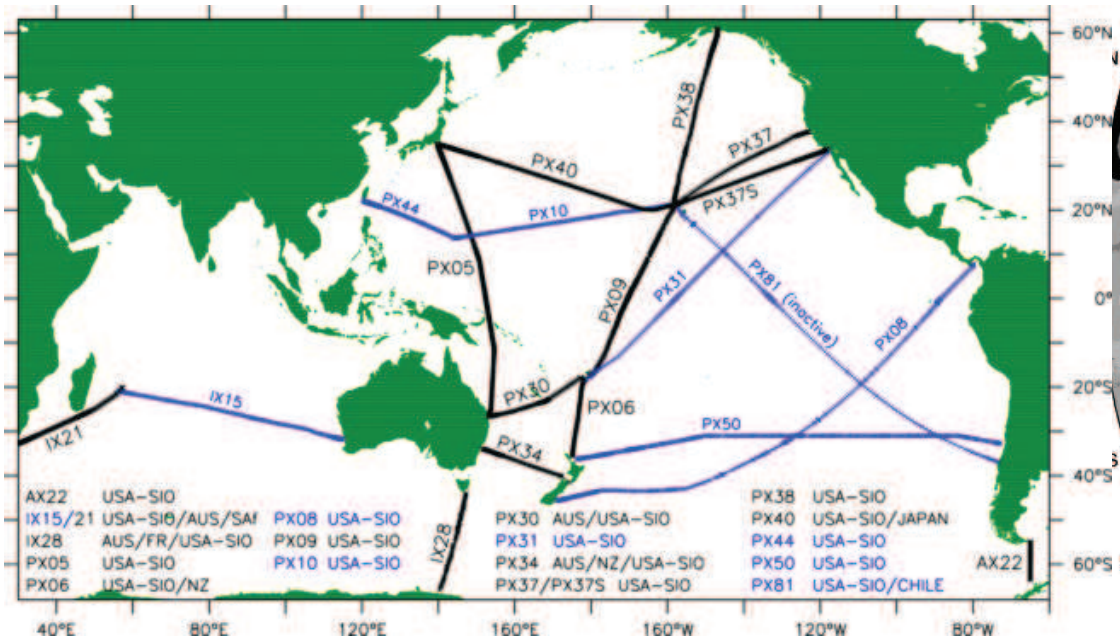


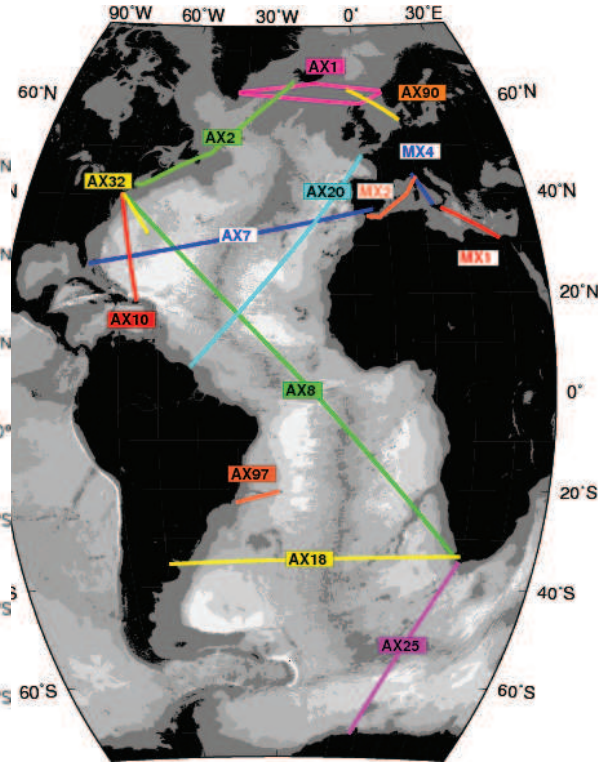
Ships of opportunity



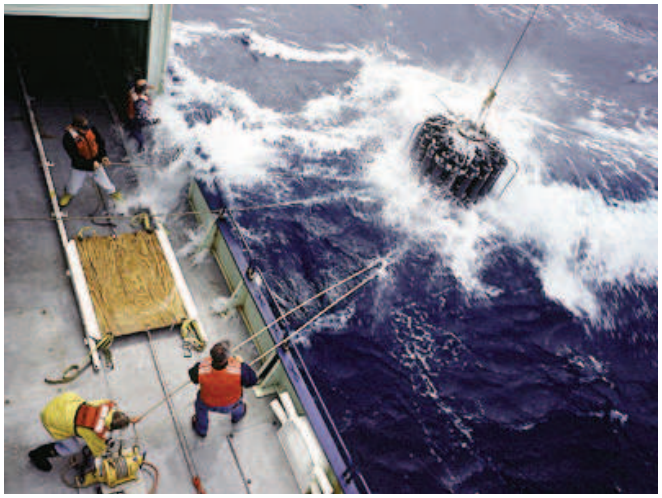
- Temperature (0-800 m)

- Each track repeated every 3 mo., XBT every 10-40 km along track

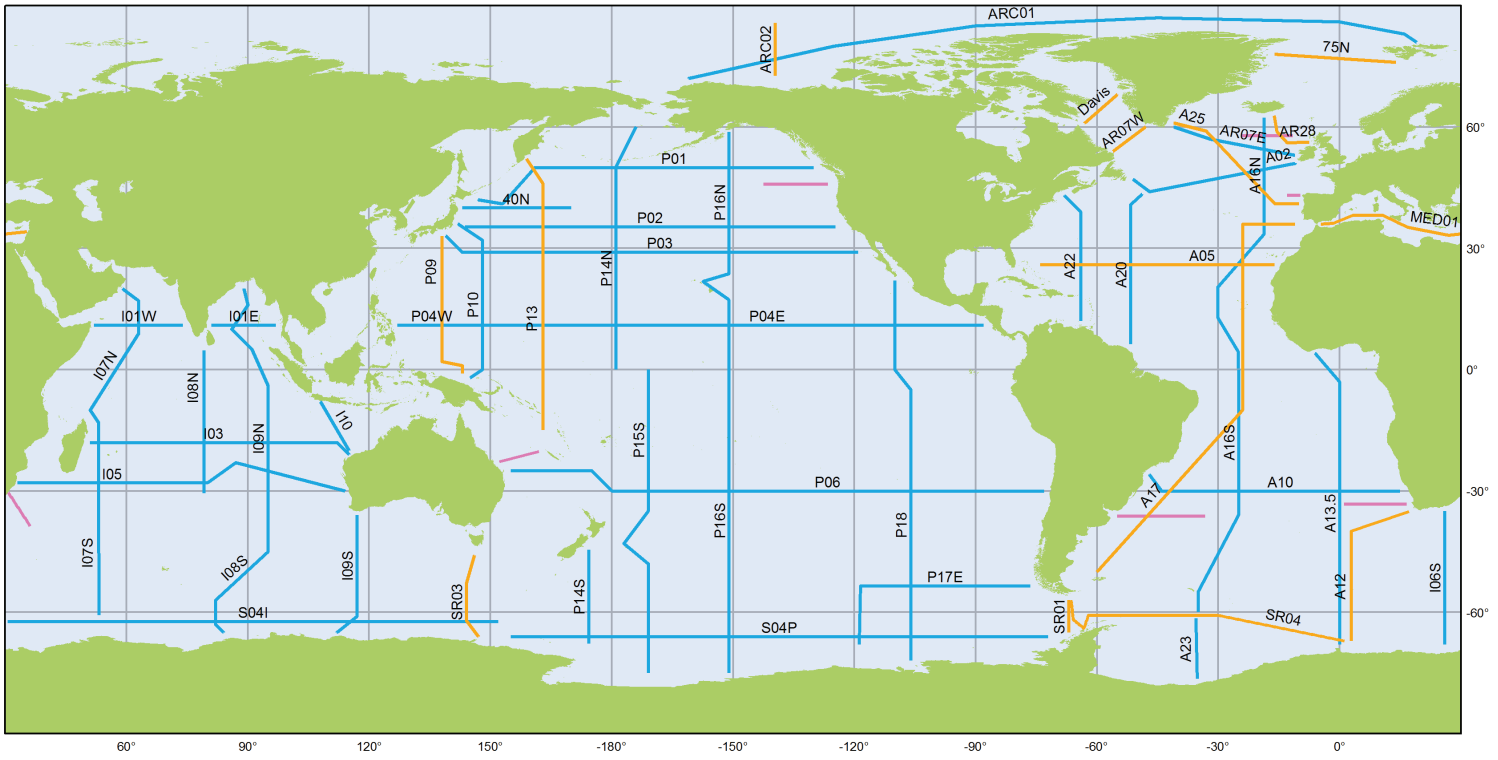




Global Ocean Ship-Based Hydrographic Investigations Program (GO-SHIP)



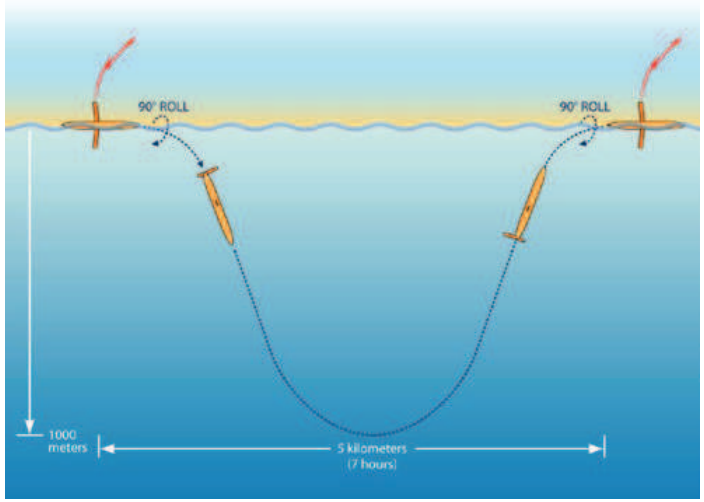
- Temp., salin., vel., BGC (full depth)



GO-SHIP **Reference Lines of 2012-2023 Survey** **January 2017**

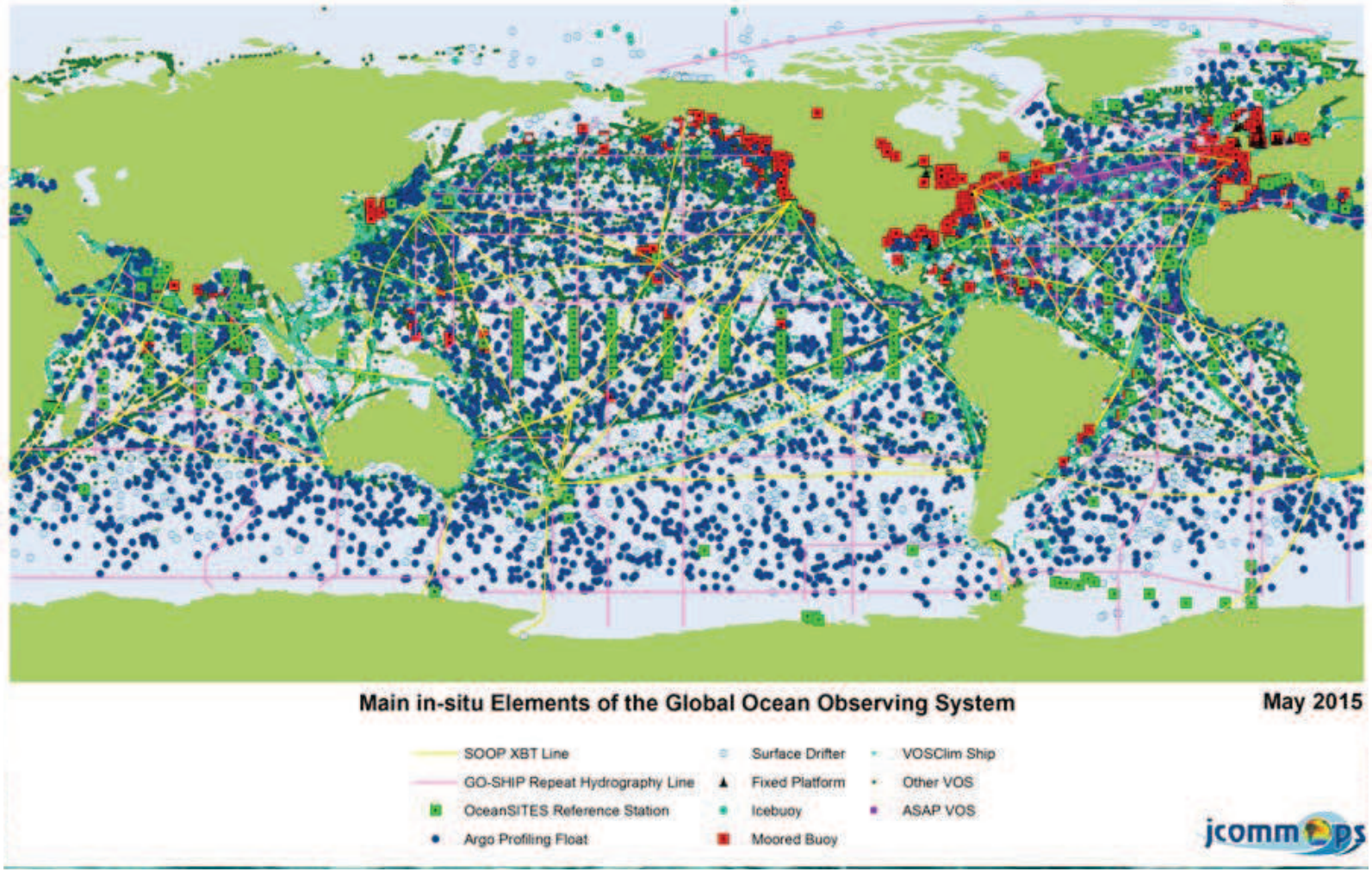
Underwater gliders

- Temp., salin., vel., BGC
  - Programmable, remotely operated



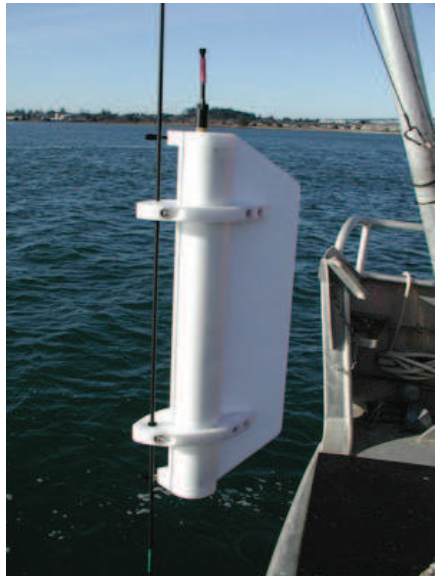
Glider tracks along the U.S. coast since 2002.

All observations

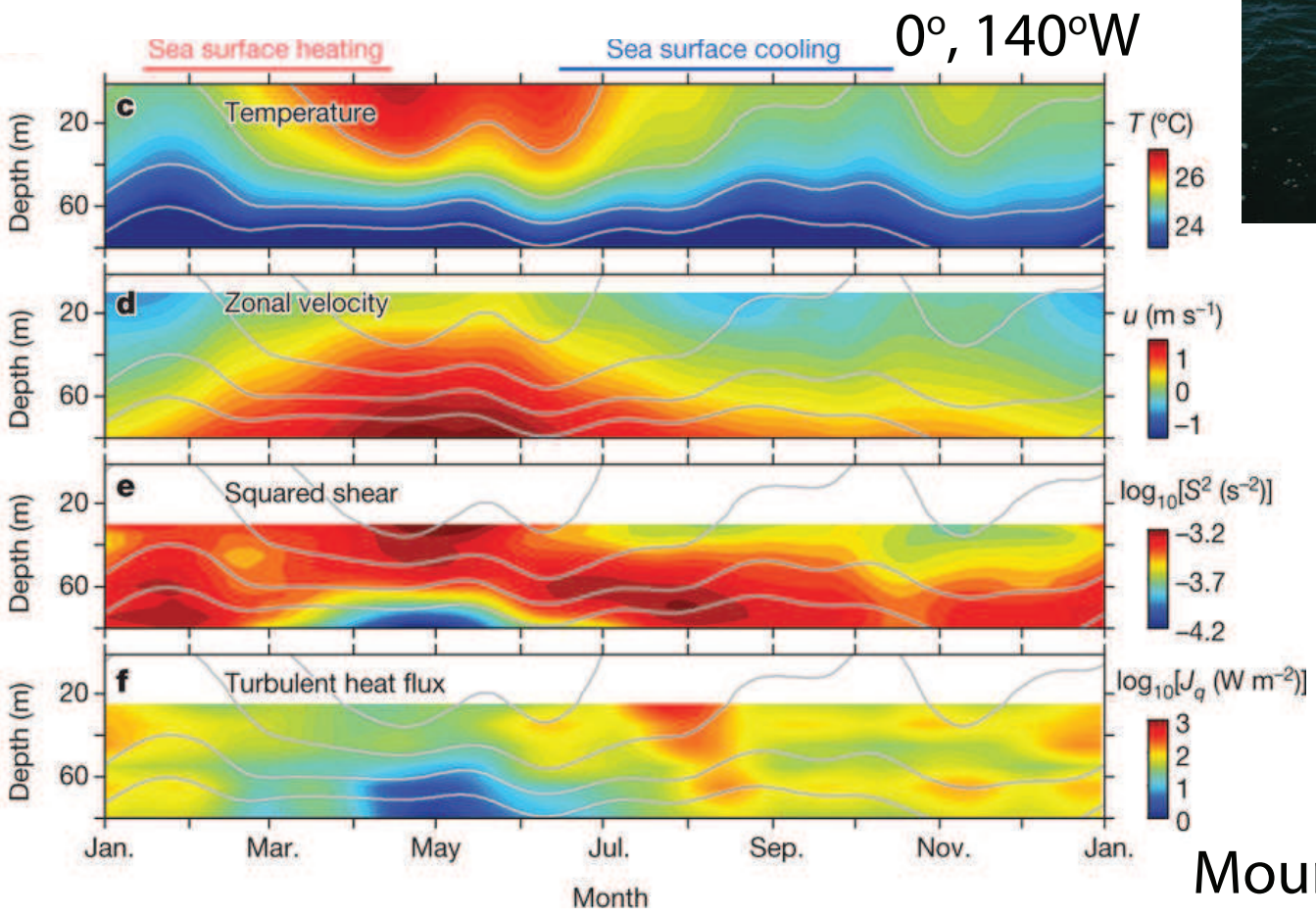


Vertical turbulent cooling in the equatorial Pacific

- Dominant role of mixing to establish and maintain cold tongue



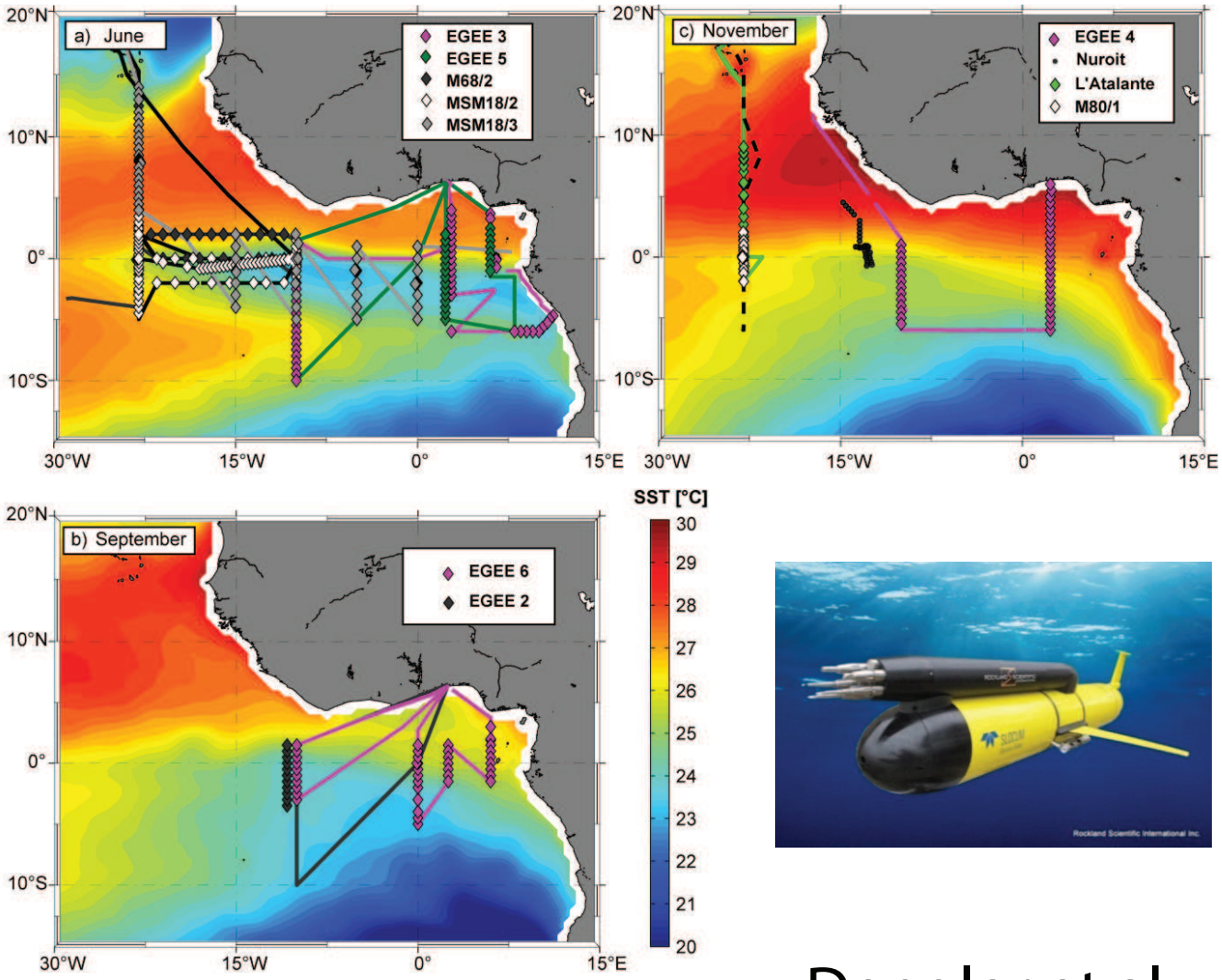
Chipod



Moum et al. (2013)

Microstructure gliders in the eastern Atlantic

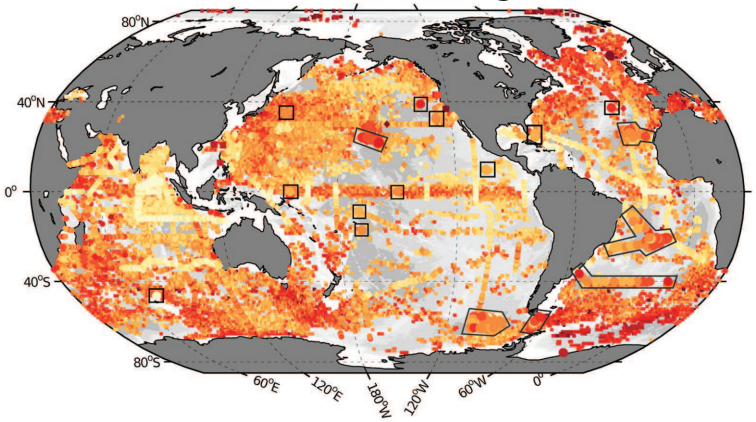
- >2000 profiles during 2005-2011



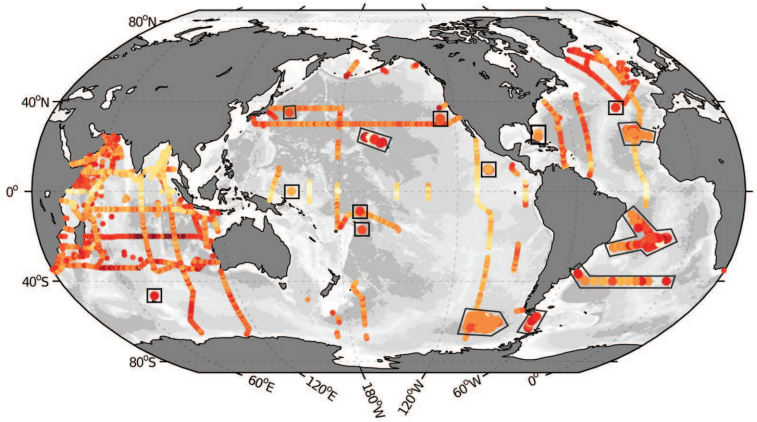
Dengler et al.

Vertical diffusivity from microstructure, Argo

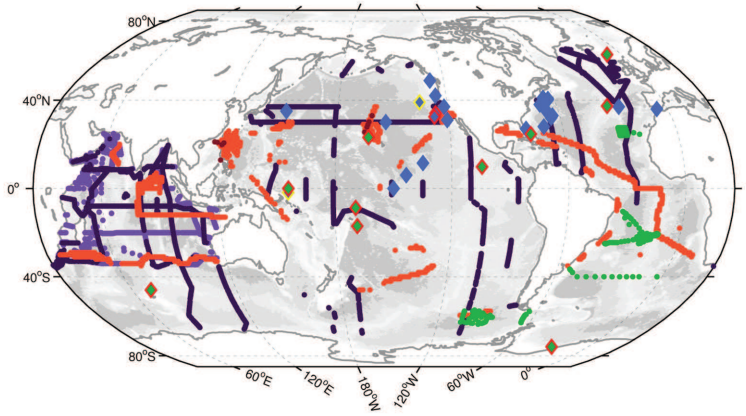
0-1000 m microstructure, finescale strain (Argo)

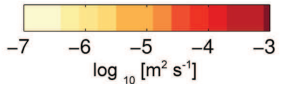


Full depth microstructure



Microstructure obs.

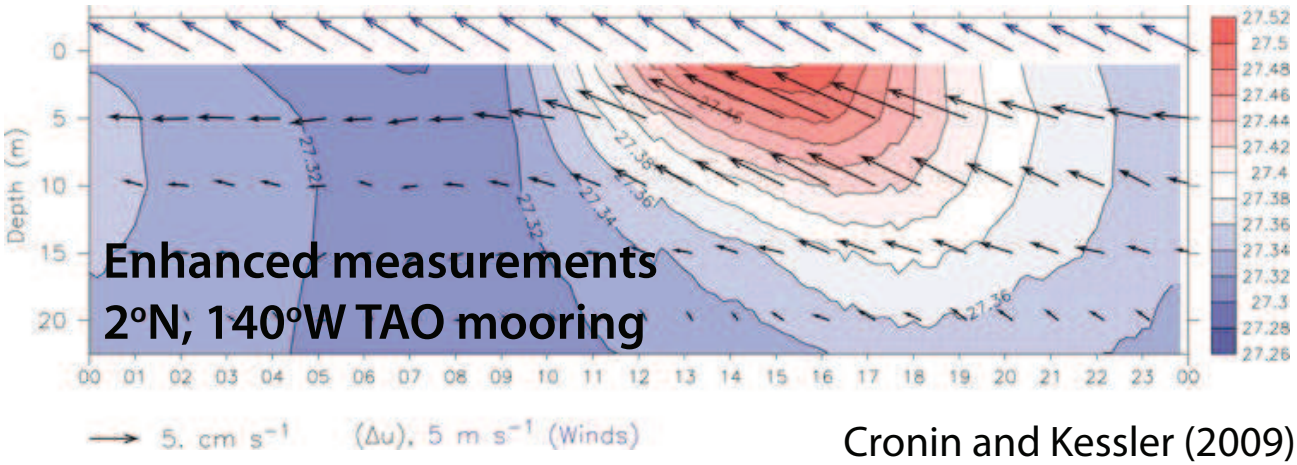




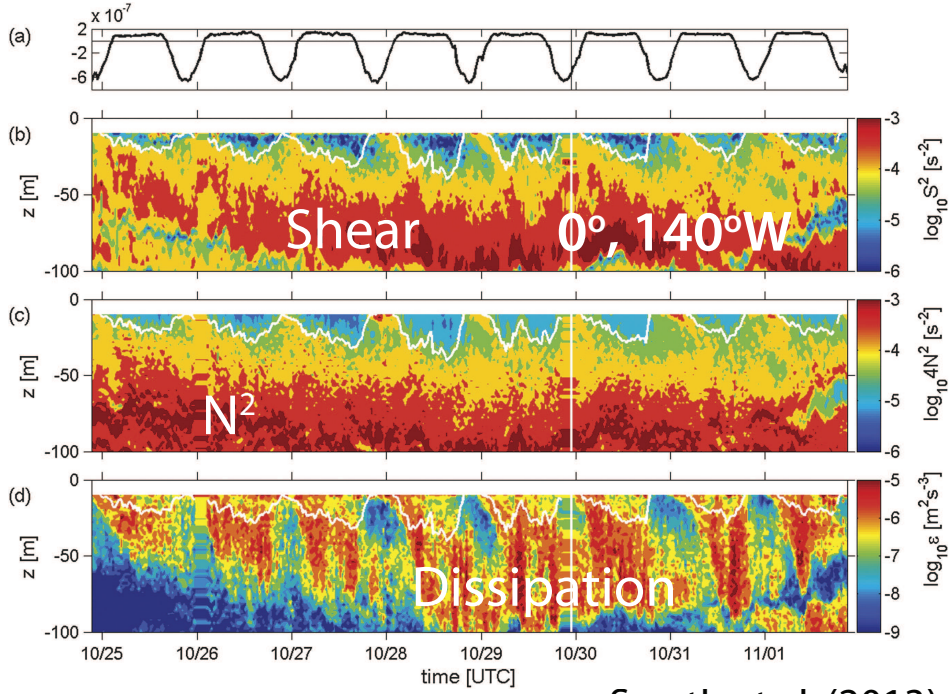
- Argo T(z), S(z) can be used to estimate diffusivity

Waterhouse et al. (2014)

Diurnal cycle in the tropics



Cronin and Kessler (2009)



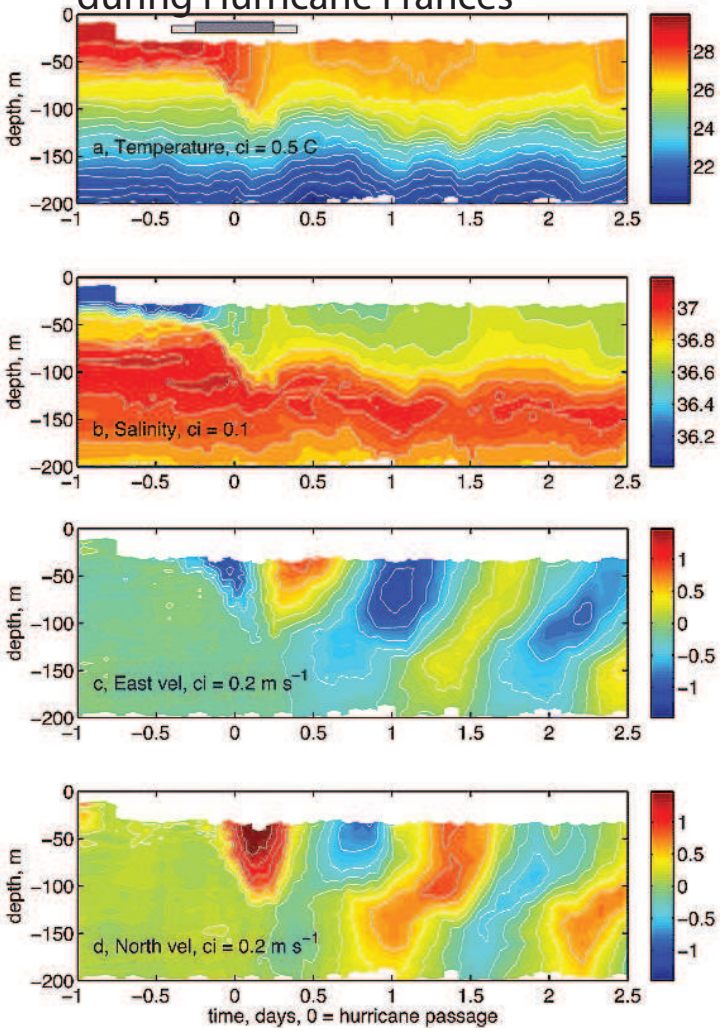
Smyth et al. (2013)

- Diurnal cycle modulates currents, shear, stratification, mixing in the equatorial ocean

- Moorings typically do not have high enough vertical resolution to resolve the diurnal cycle.

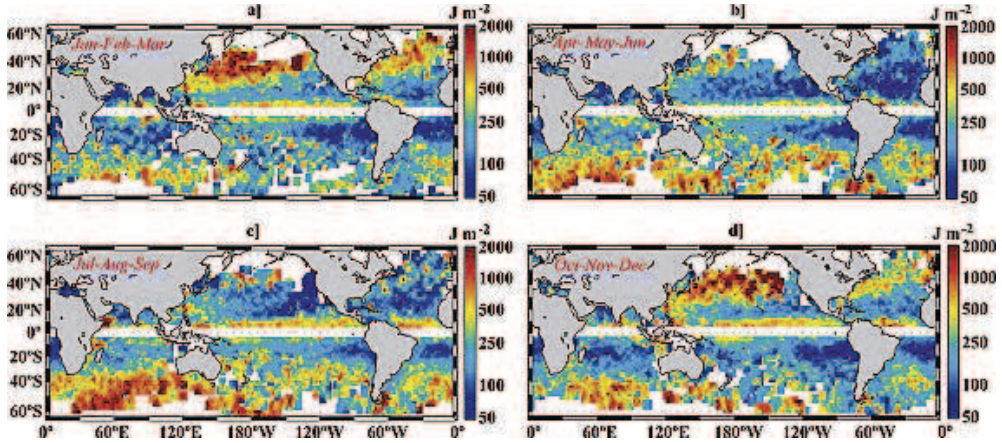
Inertial oscillations

Measurements from profiling float during Hurricane Frances



Sanford et al. (2007)

Seasonality of inertial energy from surface drifters

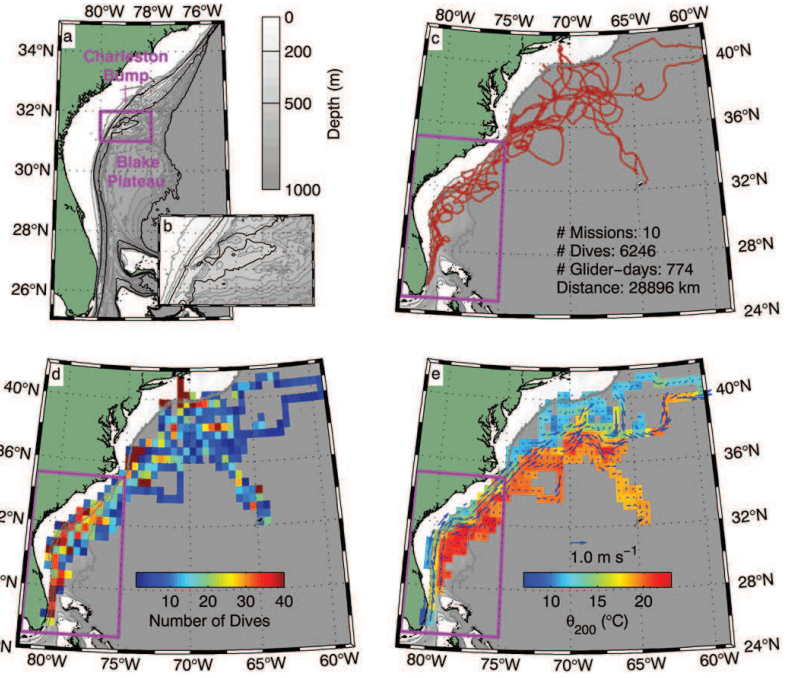


Chaigneau et al. (2008)

- Inertial currents generate vertical mixing and affect SST

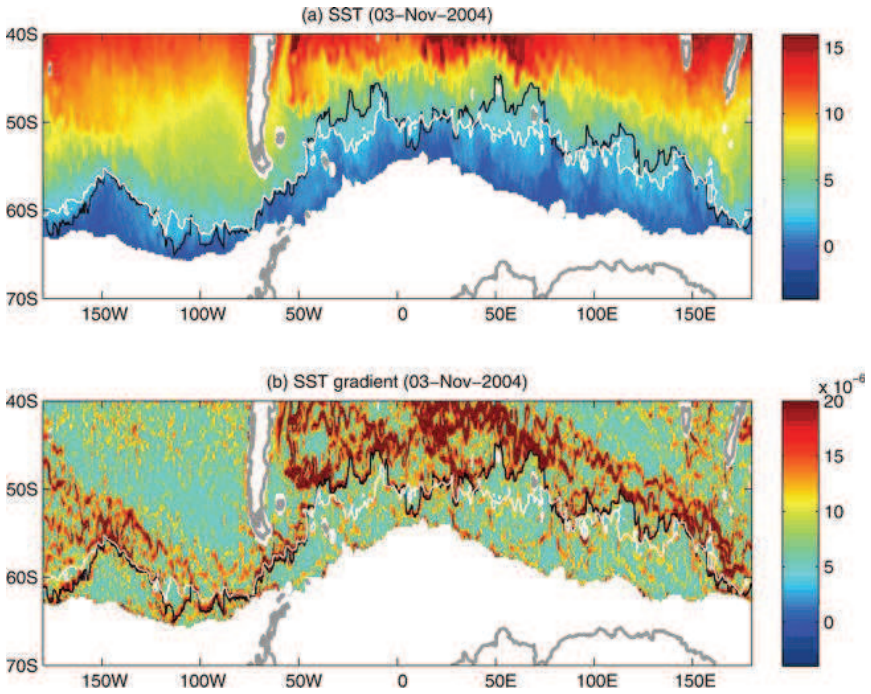
Fronts and eddies

Gliders in the Gulf Stream



Todd (2017)

Location of Antarctic polar front



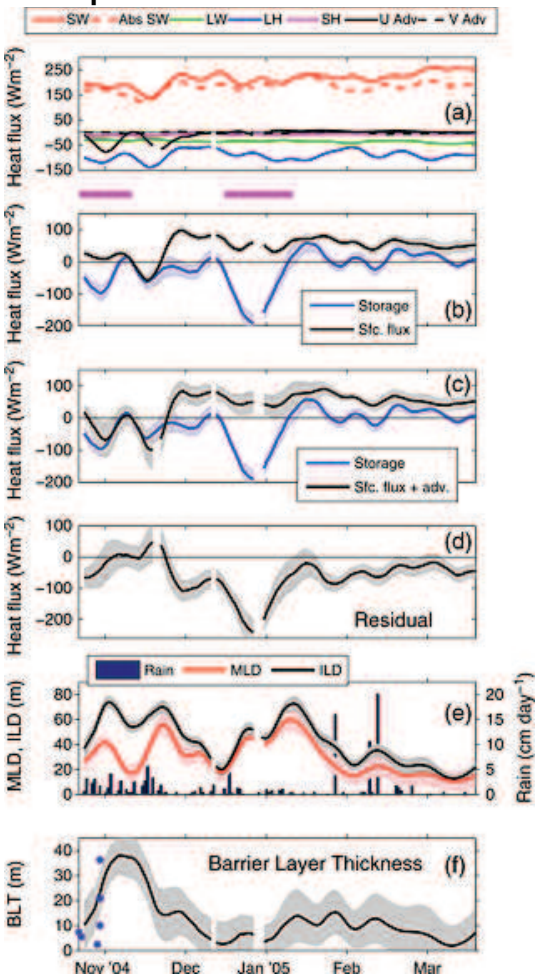
Dong et al. (2006)

- Fronts and eddies affect air-sea heat fluxes and ocean circulation

Madden-Julian Oscillation

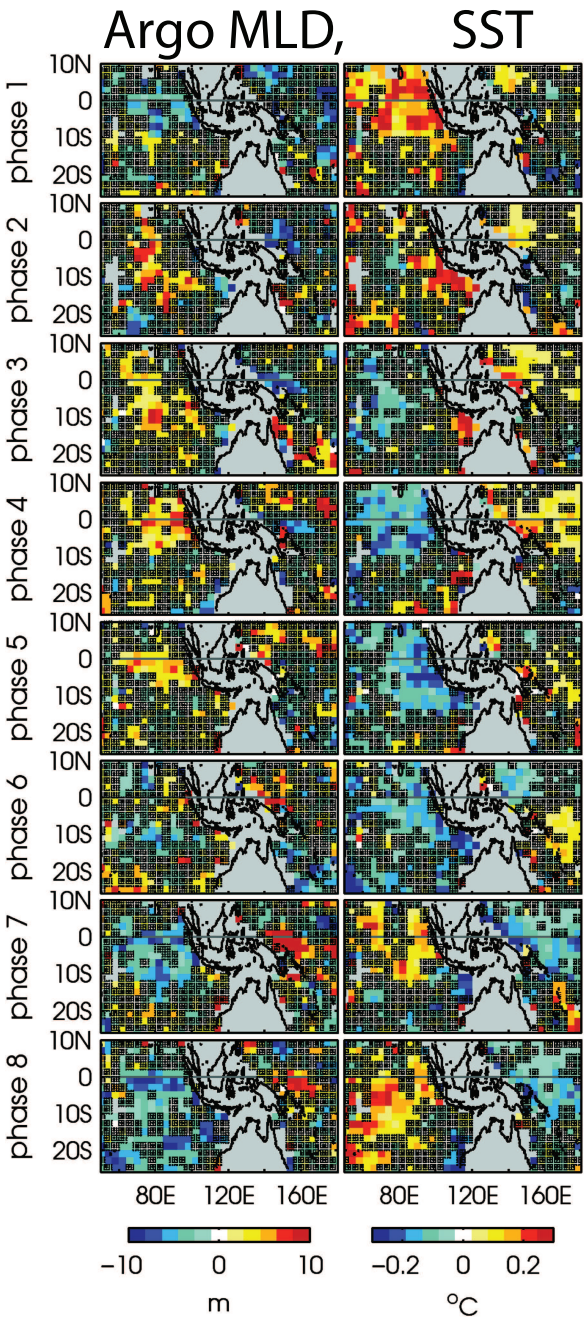
- Strong oceanic response to MJO
- Barrier layer reduces MJO-induced SST cooling

RAMA mooring
Eq. Indian Ocean



McPhaden and Foltz (2013)

Argo MLD, SST

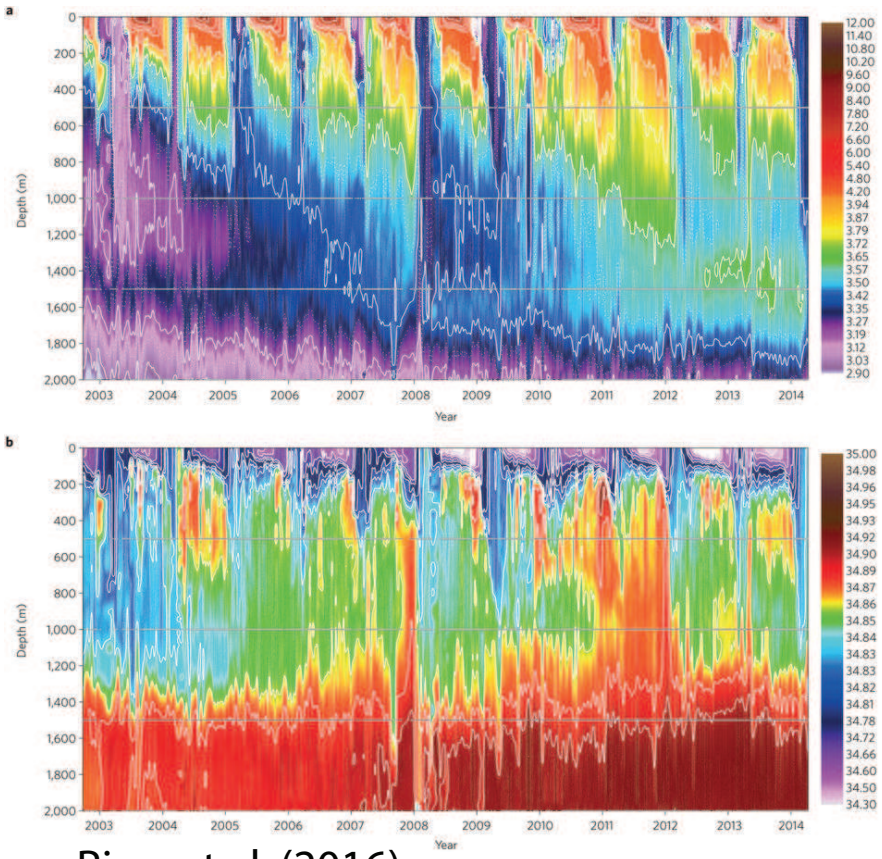


Drushka et al. (2012)

Seasonal cycle

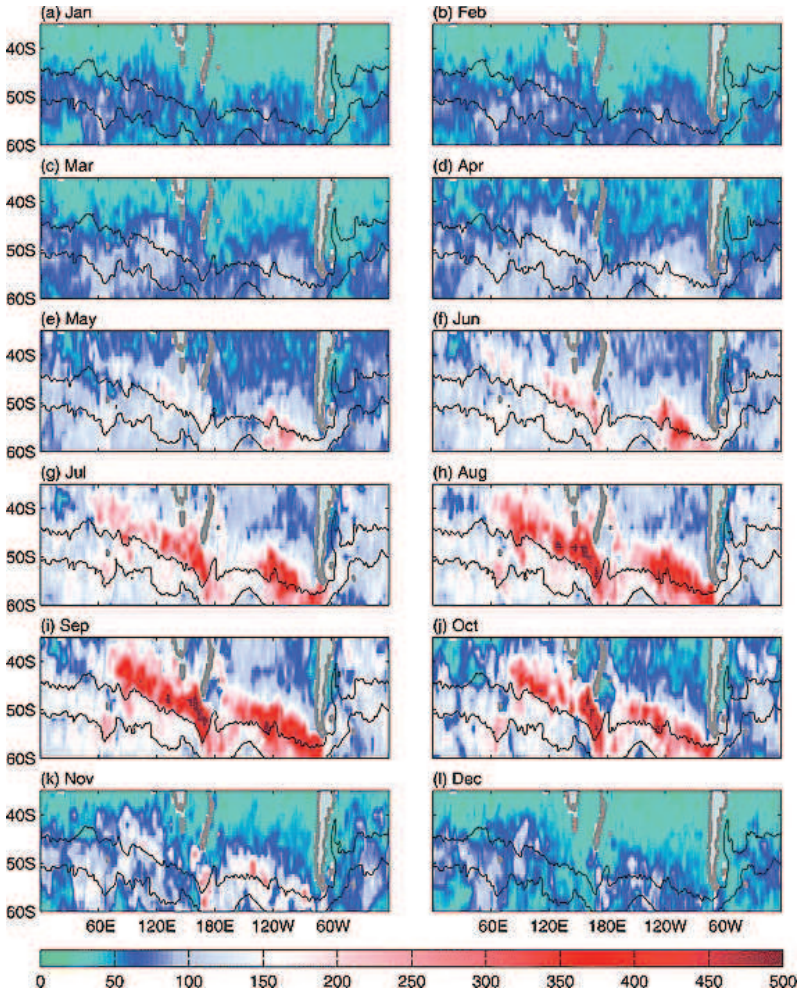
- Argo can resolve seasonal T(z), S(z) globally

Pot. temp. and salin. in Labrador Sea



Riser et al. (2016)

MLD in Southern Ocean

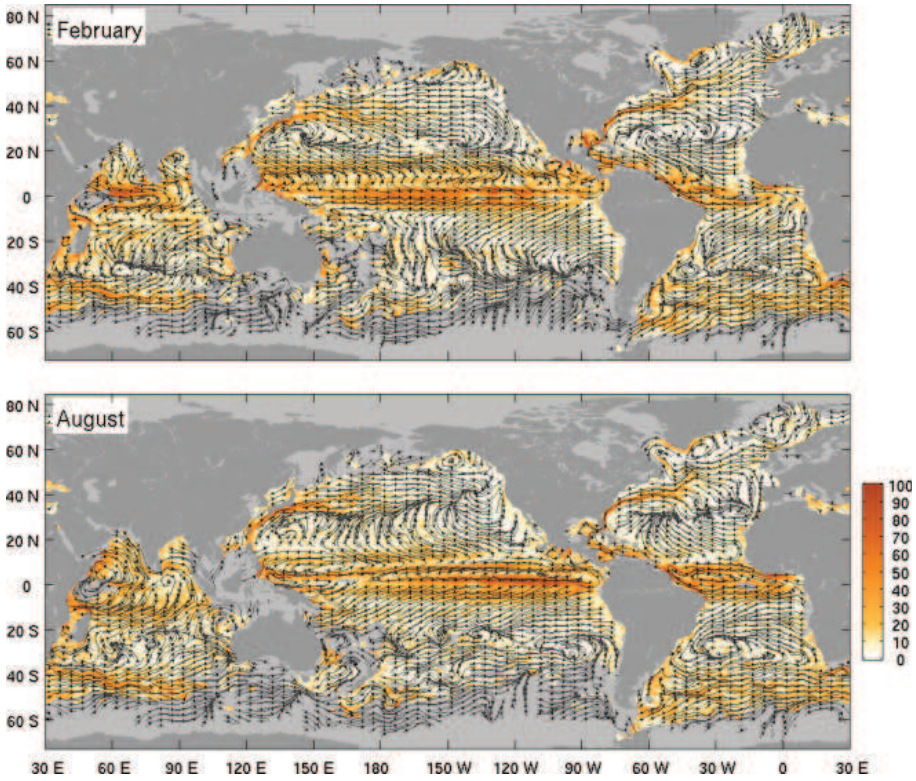


Dong et al. (2008)

Seasonal cycle of currents

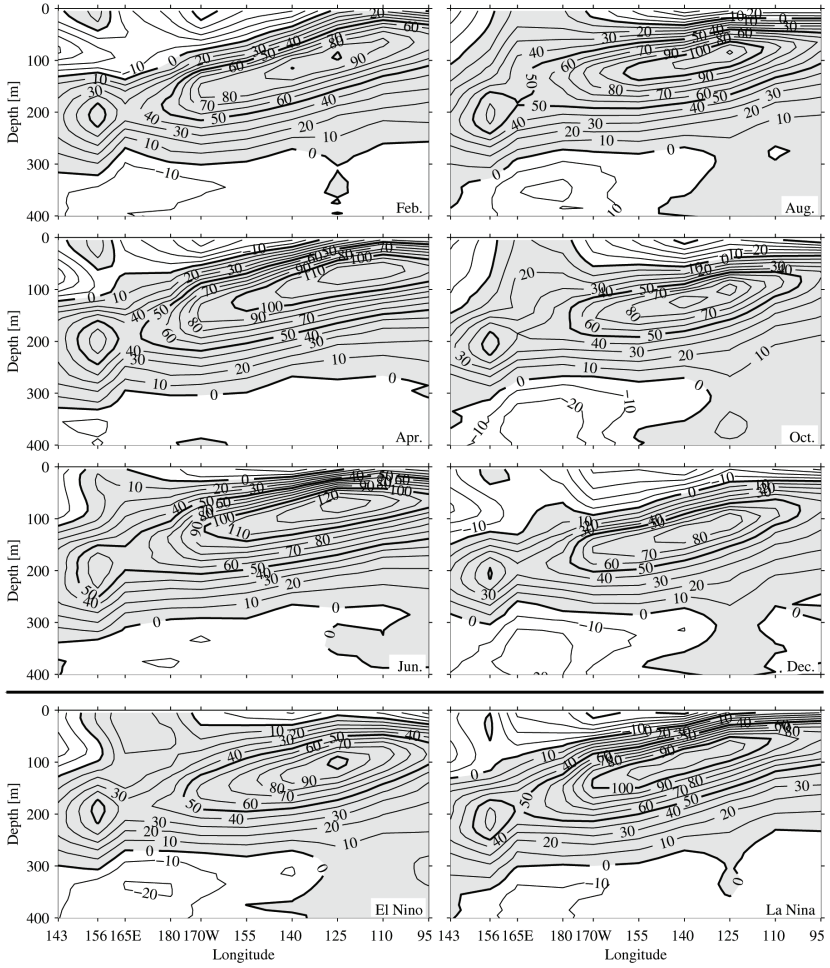
- Strong seasonal variations of currents in the tropics

Near-sfc. velocity from drifters



Lumpkin and Johnson (2013)

Eq. Pacific zonal velocity from ADCPs

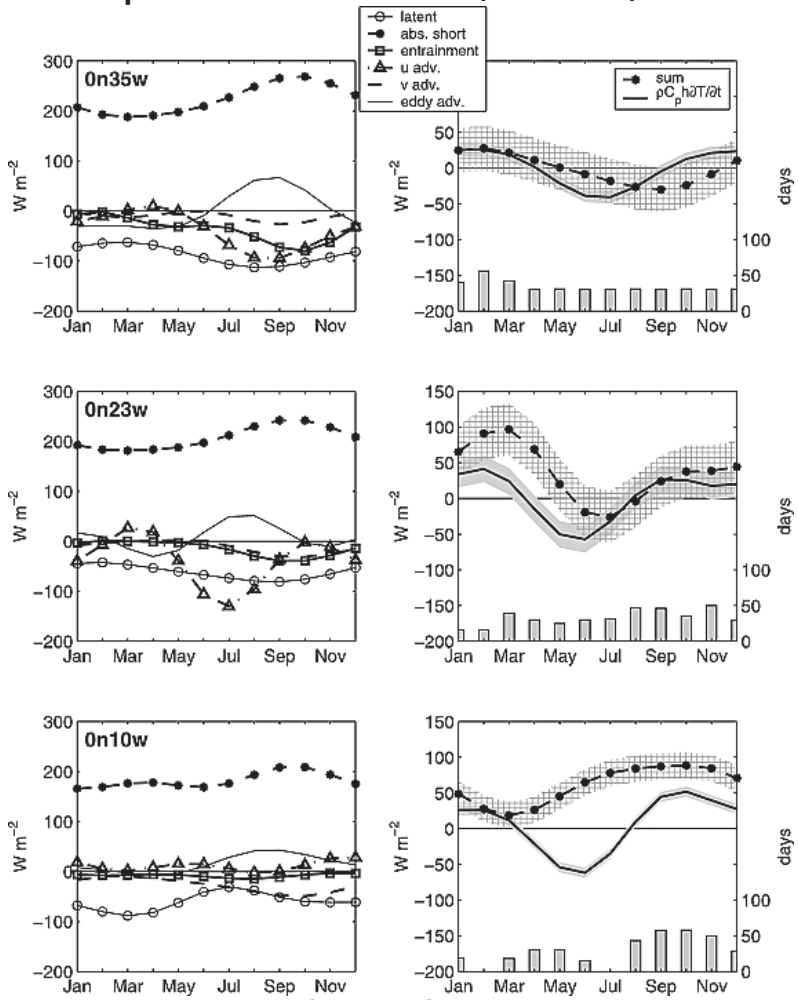


Johnson et al. (2002)

Seasonal mixed layer heat budgets

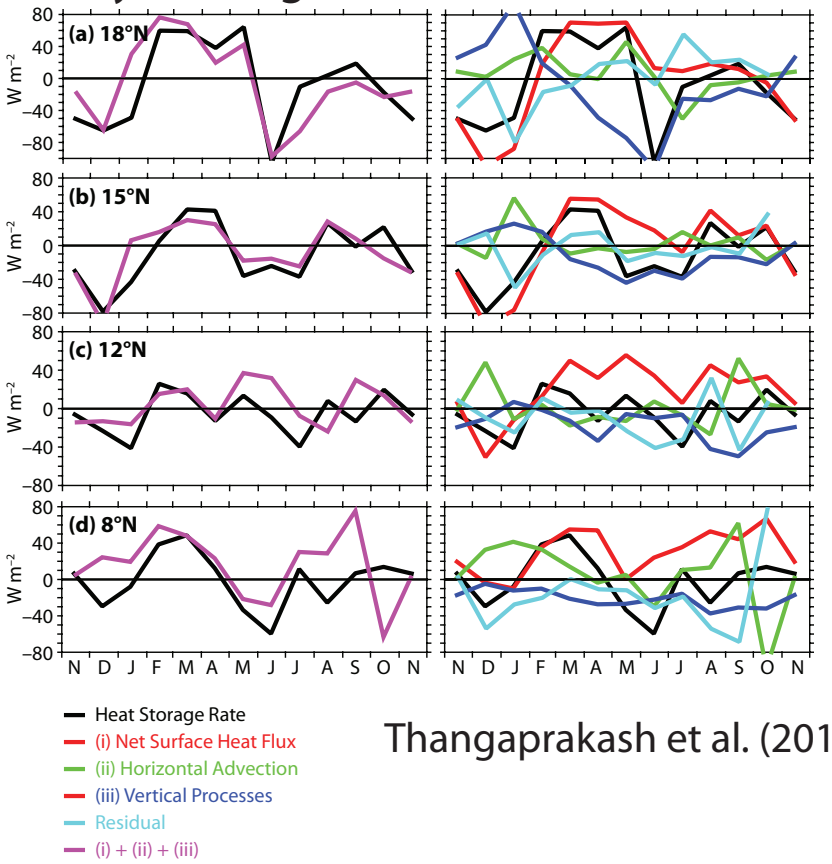
- Large spatial variations in the mixed layer heat budget

Equatorial Atlantic (PIRATA)



Foltz et al. (2003)

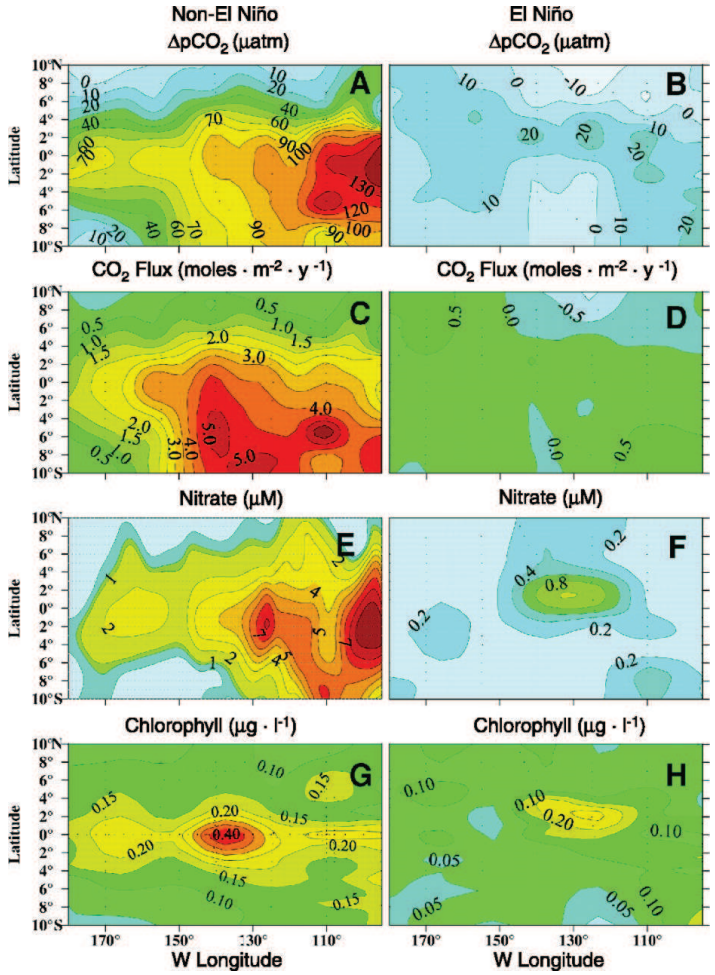
Bay of Bengal (RAMA)



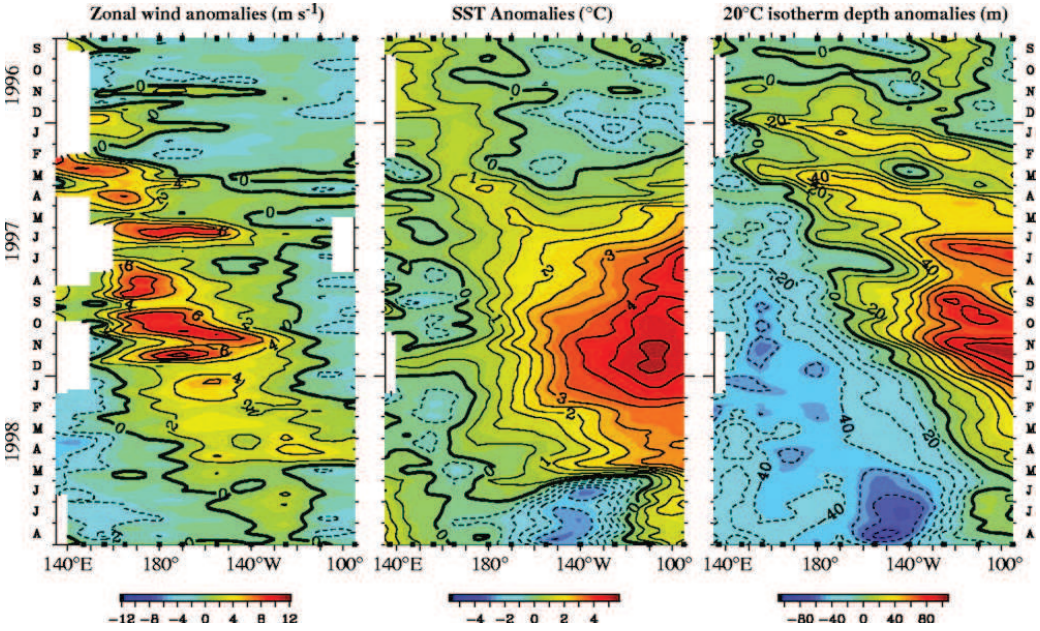
Thangaprakash et al. (2016)

Interannual variability

- Importance of WWBs; large changes in carbon, nutrients, chl during 1997-98 El Nino



Chavez et al. (1999)

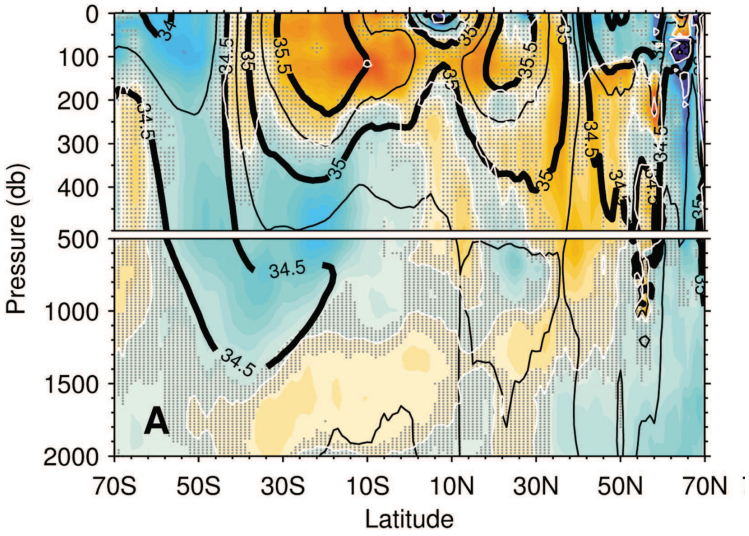


McPhaden (1999)

Trends in salinity and dissolved oxygen

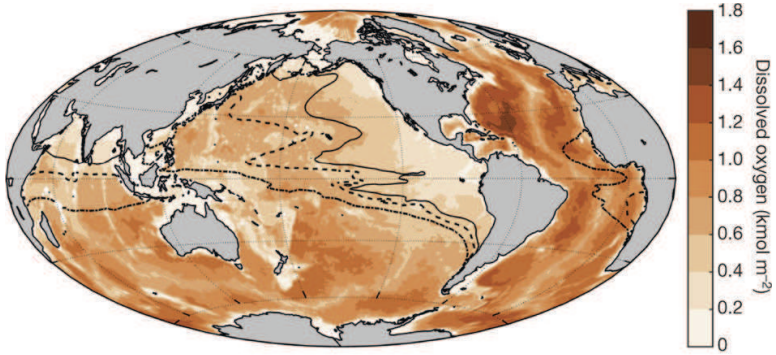
- Salinity trends suggest strengthening of hydrological cycle
- Oxygen mimimum zones are expanding

Salinity trend, 1950-2008

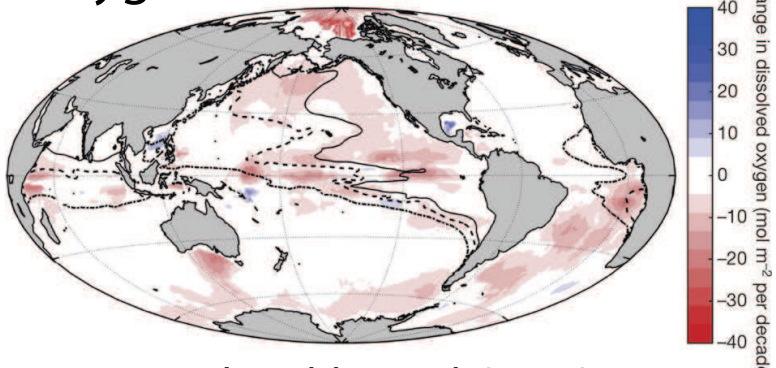


Durack and Wijffels (2010)

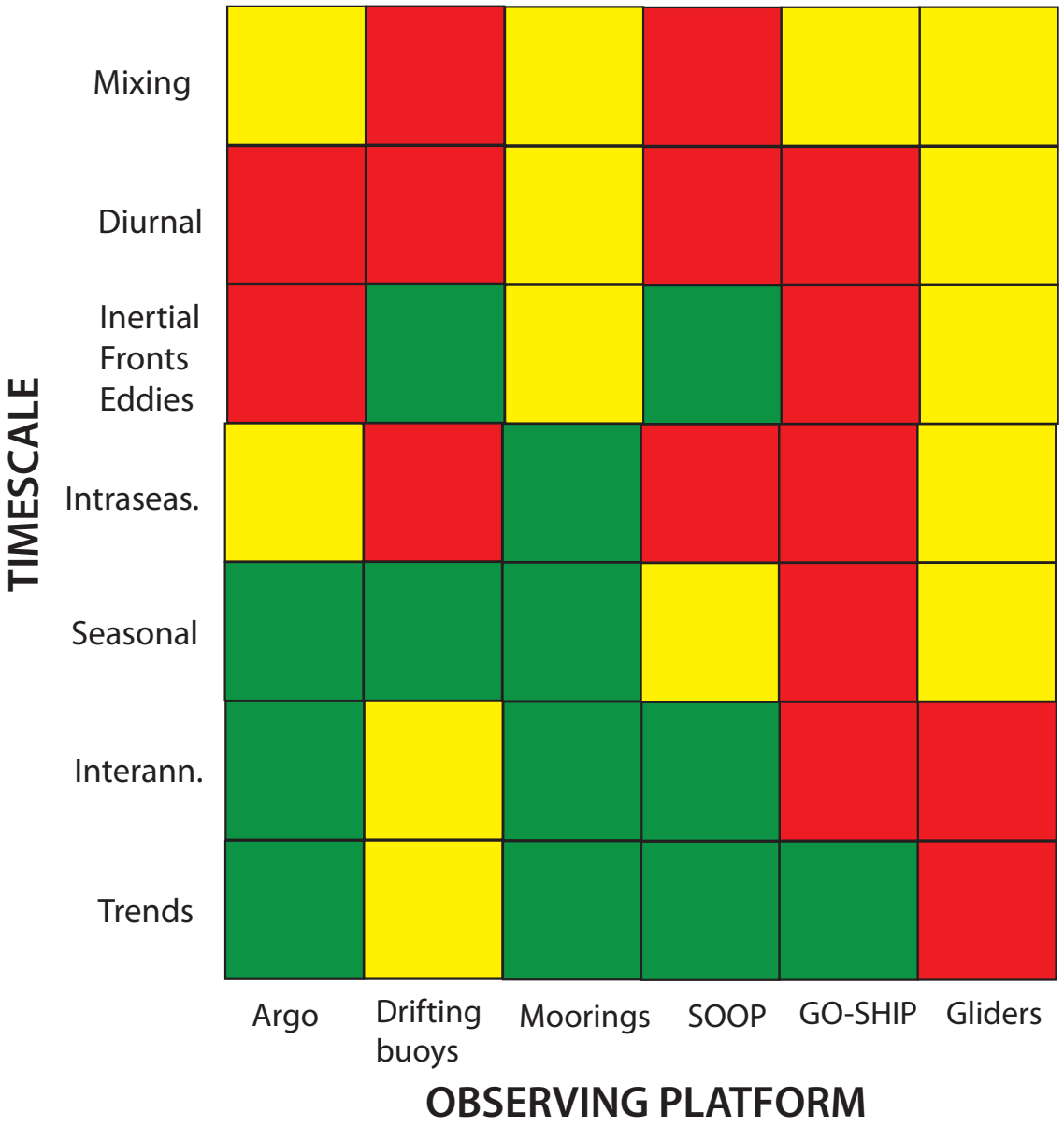
Oxygen concentration



Oxygen trend since 1960



Schmidtko et al. (2017)



Sustained direct measurements globally

Indirect measurements globally or direct measurements locally

Not resolved

- Observing system is giving good information for some timescales. Improvements needed for mixing, diurnal.

Conclusions

- **Argo and surface drifters** have global coverage, but with reduced temporal sampling compared to moorings.

- **Moorings** are invaluable for monitoring and understanding timescales not resolved by Argo and mixed layer heat and salinity budgets.

- **Ships of Opportunity** provide repeat transects valuable for observing ocean eddies and fronts and their interactions with the atmosphere.

- **GO-SHIP** measurements are of highest quality and include BGC, but aliasing of shorter timescales is an issue for the upper ocean.

- **Gliders** provide measurements in specific areas, especially useful in regions with strong currents and sharp horizontal gradients of T/S/v.

Conclusions

- **Additional measurements of mixing, diurnal cycle** would be beneficial. Moorings, gliders may be best platforms (TPOS2020 recommendation).

- **If one system suffers, others will too**. Example: eliminating TAO moorings will reduce number of opportunities for Argo deployments and ocean-atmos. measurements during servicing cruises.

- Moorings and their servicing cruises provide unique opportunities for low-cost process studies and additional atmospheric and BGC measurements (**microstructure**, **aerosol sampling**, **carbon flux**, **oxygen concentration**, **pH**, **chlorophyll**, **tracking of marine animals**, ...).

- Mooring and surface drifter measurements are used to **validate satellite retrievals of SST, wind**. More in situ obs. of wind, air-sea fluxes needed in Southern Ocean.

- **After vertical mixing, horizontal advection is the term with largest errors for local heat budgets** due to uncertainties in upper-ocean velocity, SST gradients, MLD.