Observing at the Ocean-Atmosphere Interface

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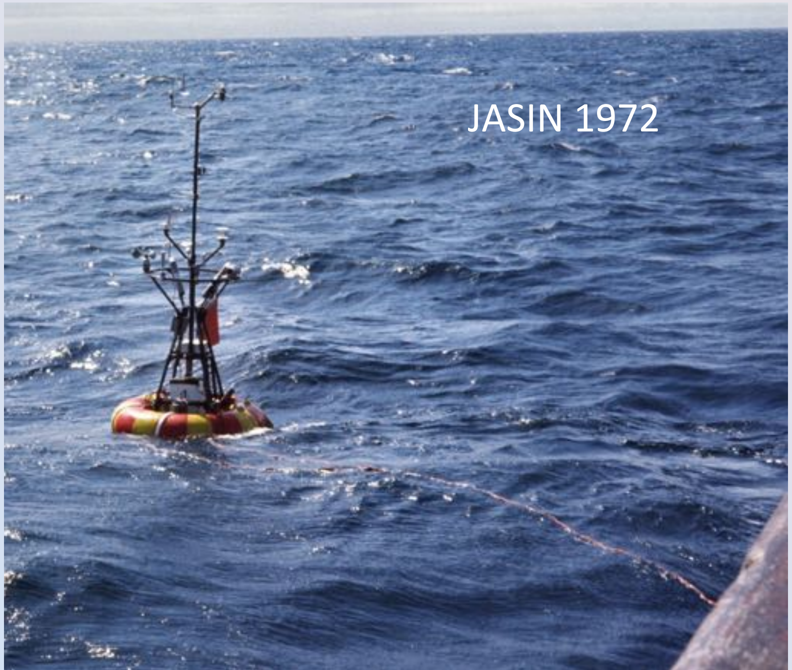
Overview

- Driven by both short-term localized process studies and longer-term, climate monitoring and research, ocean-based lower atmosphere observing capabilities have improved and will continue to expand.
- Opportunities to better integrate, intercalibrate, and coordinate ocean-based lower atmosphere observations with land-based lower atmosphere observations?

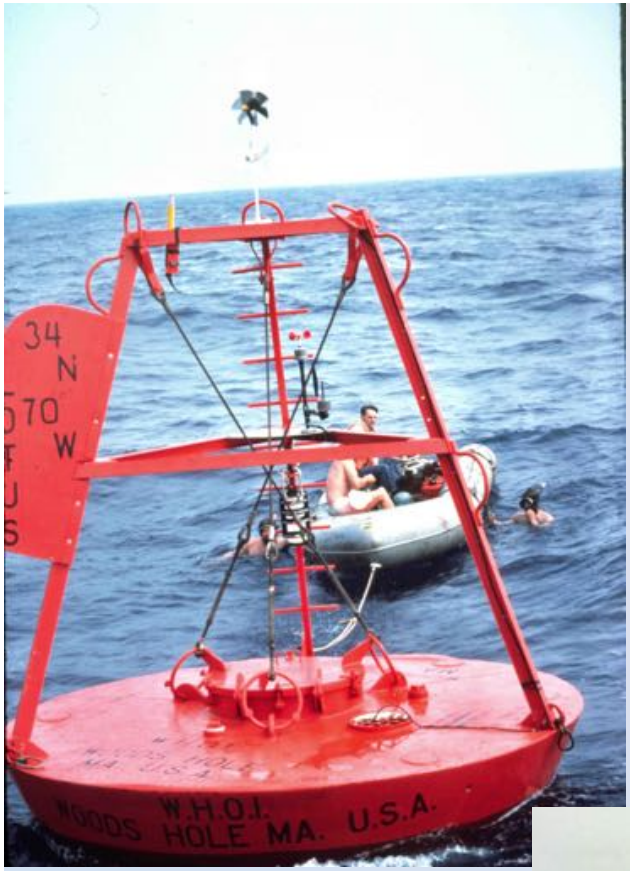
Moving beyond shipboard observing, including the Ocean Weather Stations

- Sustained surface presence began to ramp up in the 1970's with early surface moorings
- Manned platform - FLIP (Floating Laboratory Instrumented Platform)

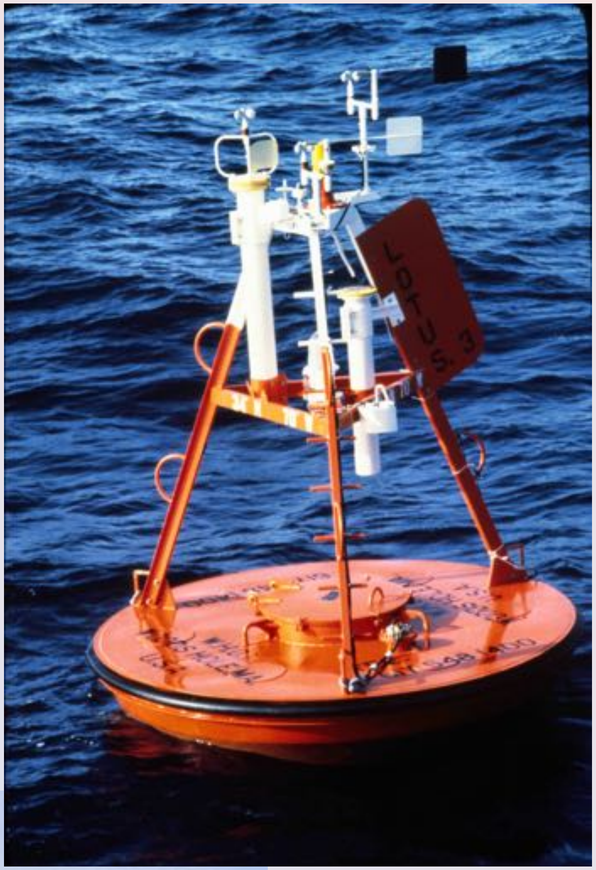
The 1970's – surface mooring deployments



MILE (Mixed Layer Experiment - 1976)



LOTUS
Long-Term Upper Ocean Study
(1982-1984)
- ocean temperature, velocity



RP *FLIP*

MILDEX	(Mixed Layer Dynamics) 1979, 1981, 1983
SWAPP	(Surface Wave Processes) 1990
MBL	Marine Boundary Layer 1995

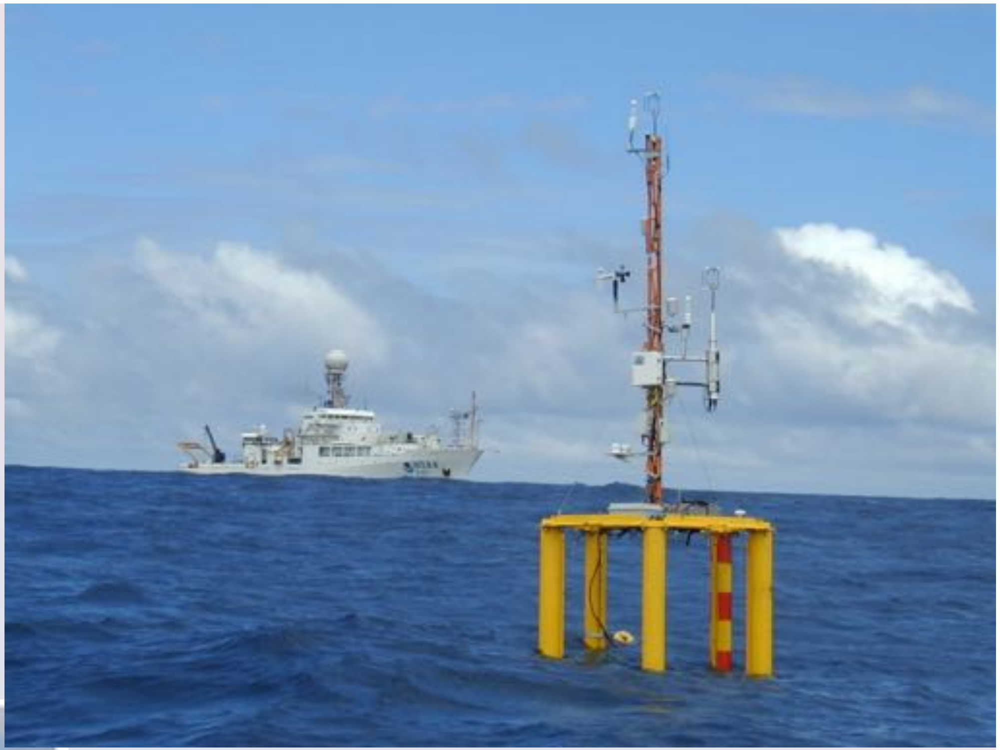
Many recent air-sea interactions experiments in diverse and challenging locations

ERICA - off eastern Canada in winter

1994-1995 Arabian Sea

Turbulent fluxes on ships and now on buoys

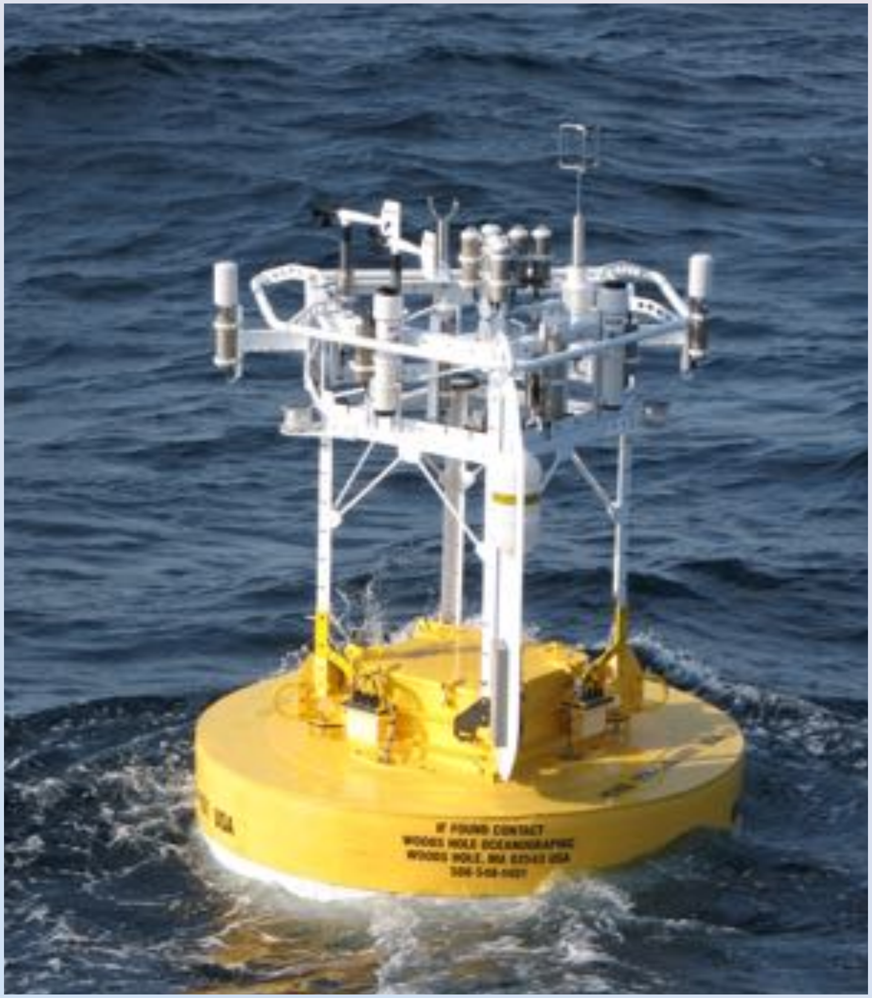
Key to improving fluxes in low wind, high wind, high sea state regimes



(Jim Edson, Gene Terray)

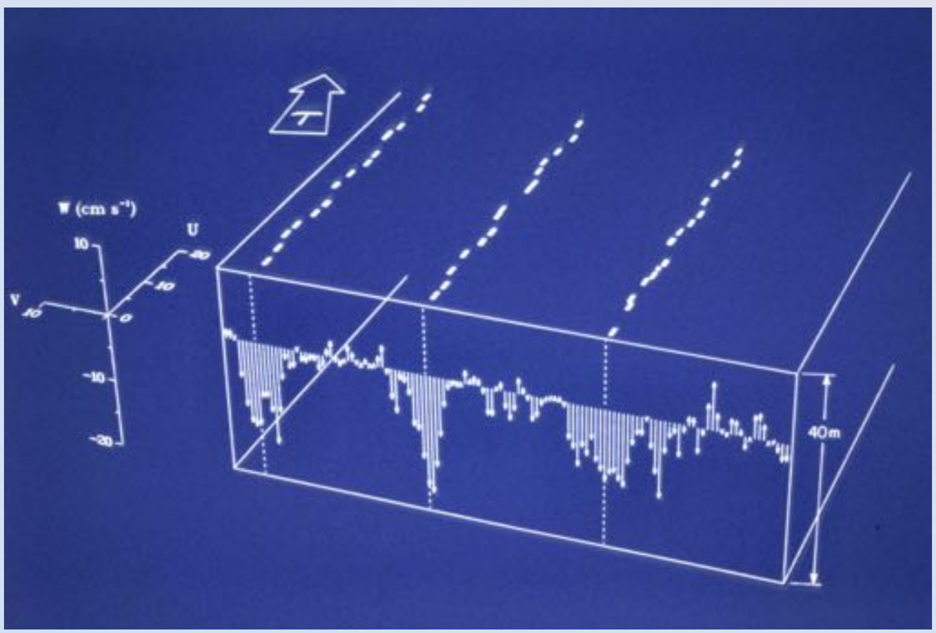
(Jim Edson)

Moored buoy capabilities – 1-year deployments



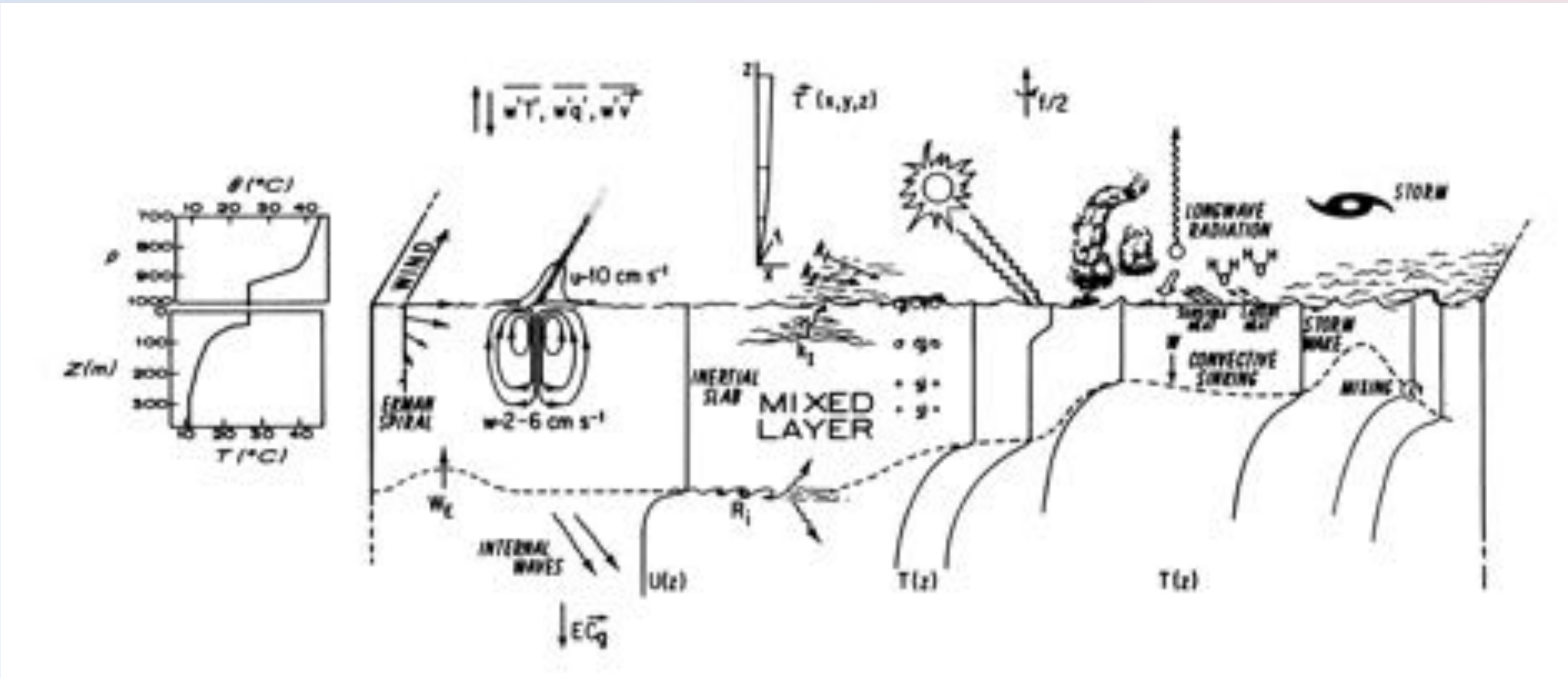
Present – once per minute surface meteorology, 2 to 3 redundant systems plus Direct Covariance Flux

Developing – increased power generation and directional antenna for 2-way, higher bandwidth telemetry

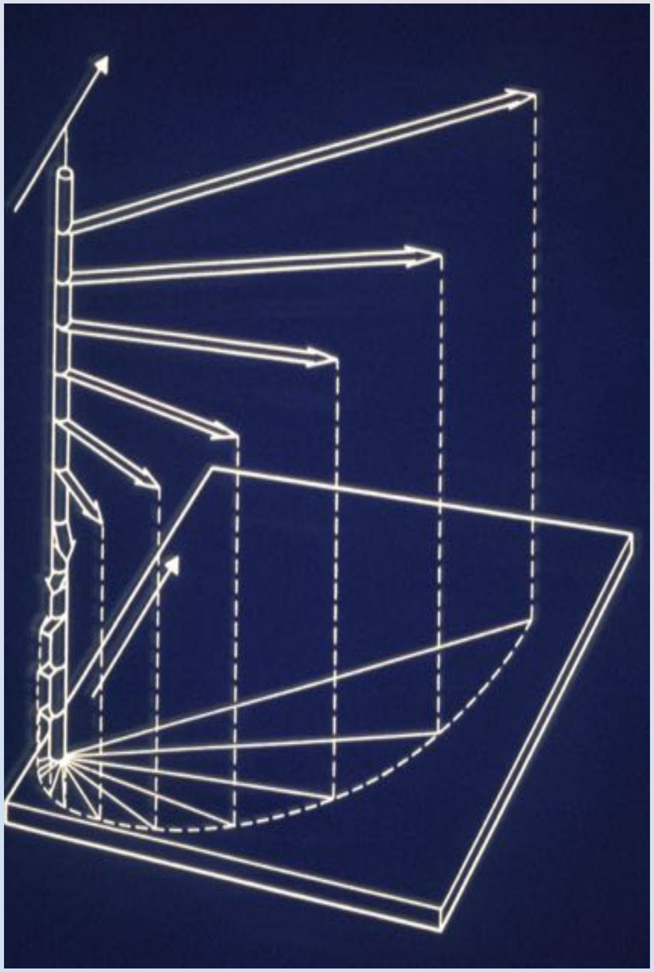


Mixed layer dynamics

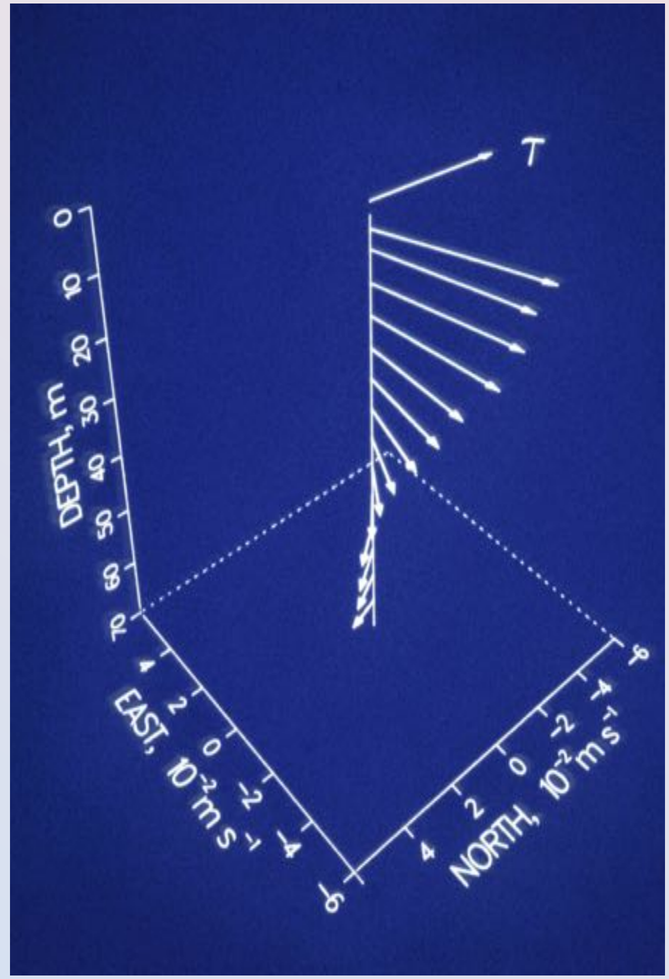
Upper ocean dynamics, biology strongly dependent on surface fluxes



Ocean mixed layer response is strongly governed by buoyancy as well as by momentum flux



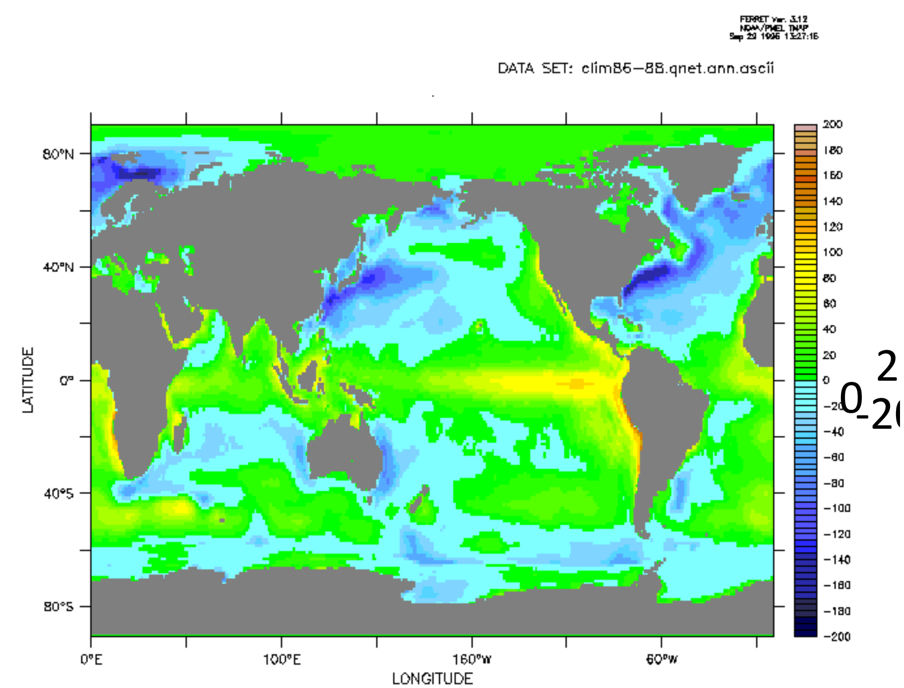
Theoretical Ekman Spiral



Observed velocity profile

The technical challenge: observe the fluxes

- Annual means close to 0 W m^{-2}
- Climate change signals of ~4 W m^{-2}
- TOGA (Tropical Ocean Global Atmosphere) and WOCE (World Ocean Circulation Experiment) asking for accuracy in net heat flux of ~10 W m^{-2}



ECMWF ann net heat flux (86–88 Barnier)

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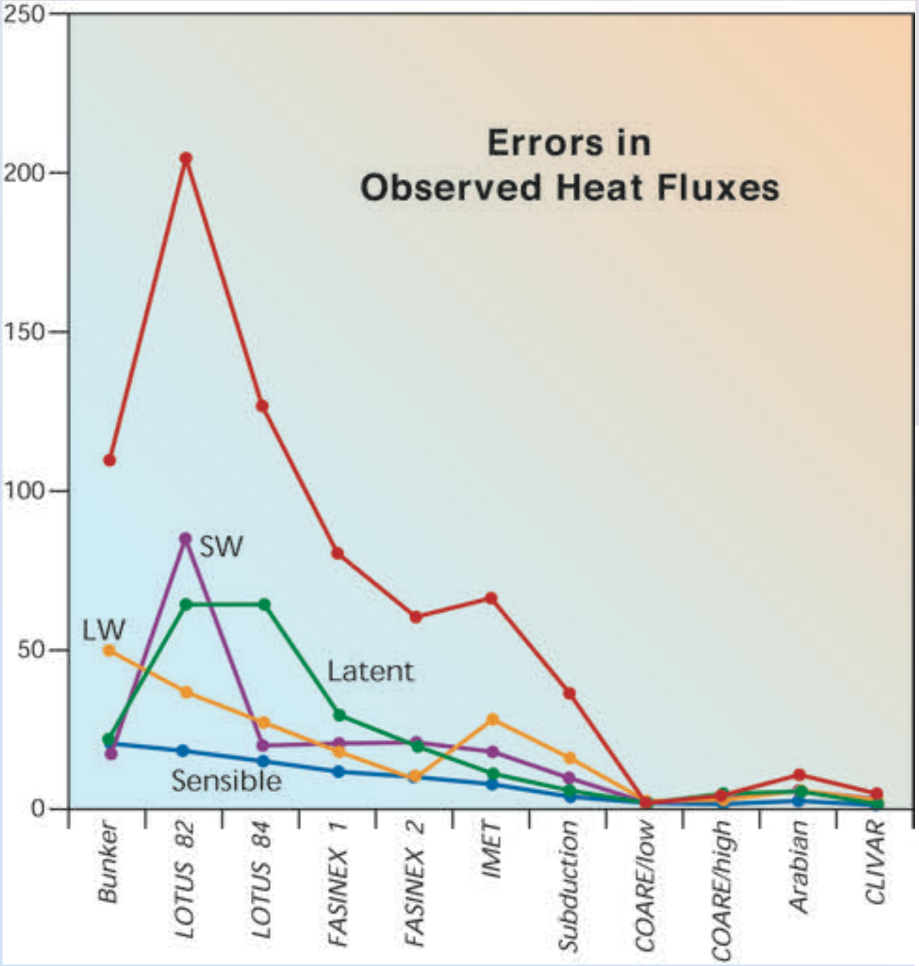
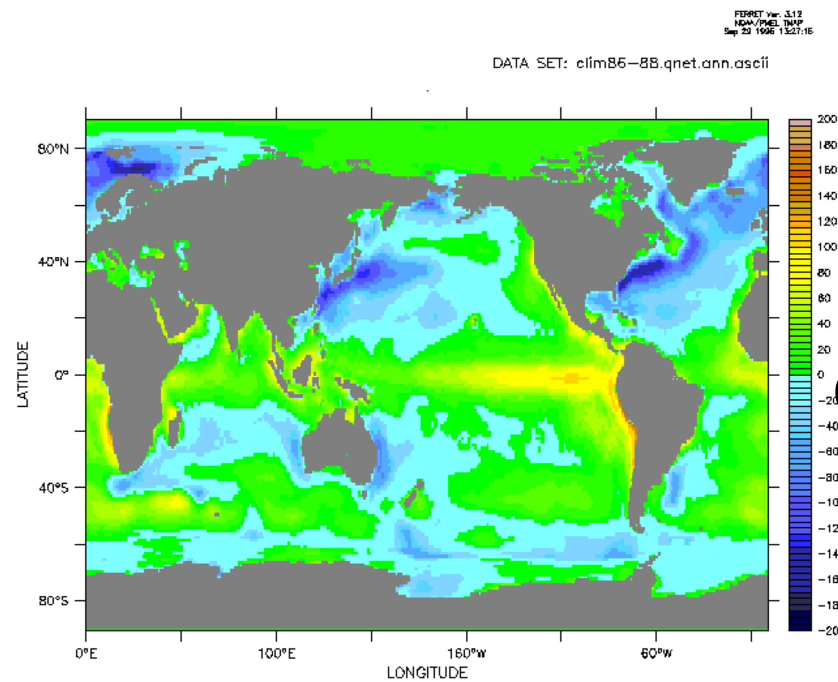
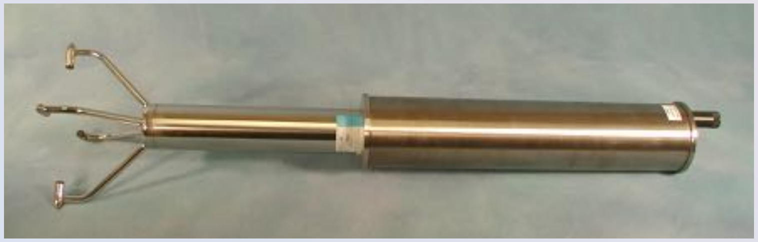




ECMWF ann net heat flux (86–88 Barnier)

2
0
-2

During WOCE NSF OCE funding lead to modular, ASIMET system, highly redundant, providing ascii engineering units, easily interfaced to, with key information (eg. calibration) stored internally



Sonic anemometer

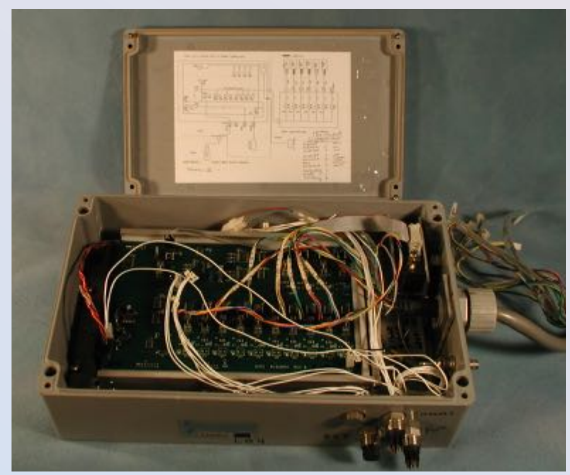
Humidity/air temperature

Incoming longwave

Incoming shortwave

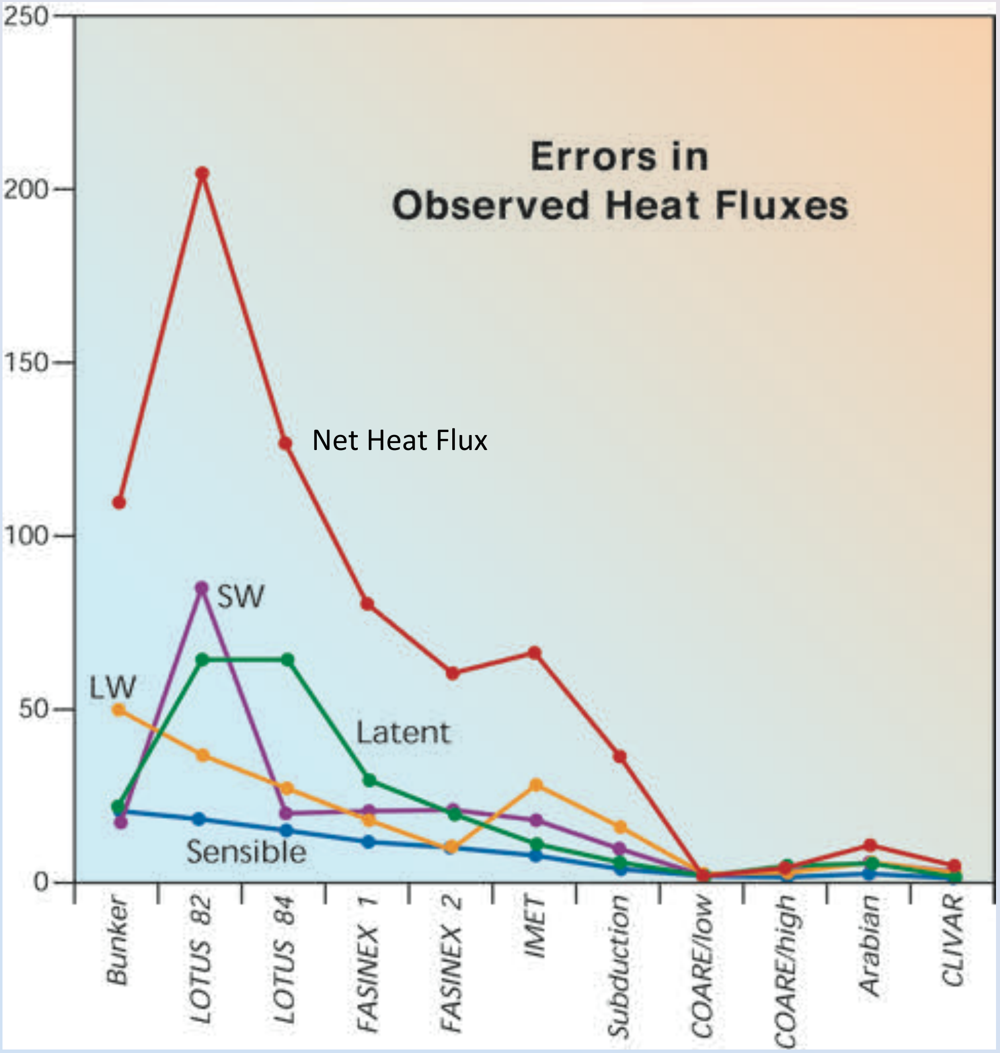
Siphon rain gauge

Barometer



Data logger

Independent of the buoy, a strong emphasis needs to be on the sensors



Three decades of effort to improve sensor performance on unattended ocean buoys.

<u>Essential complements</u>

- Field comparisons
  - Ship vs Buoy
  - Overlapping Buoys
- Calibration
  - Before and after
- Ongoing sensor investigation

Evaluating present capabilities

Moored buoy accuracies

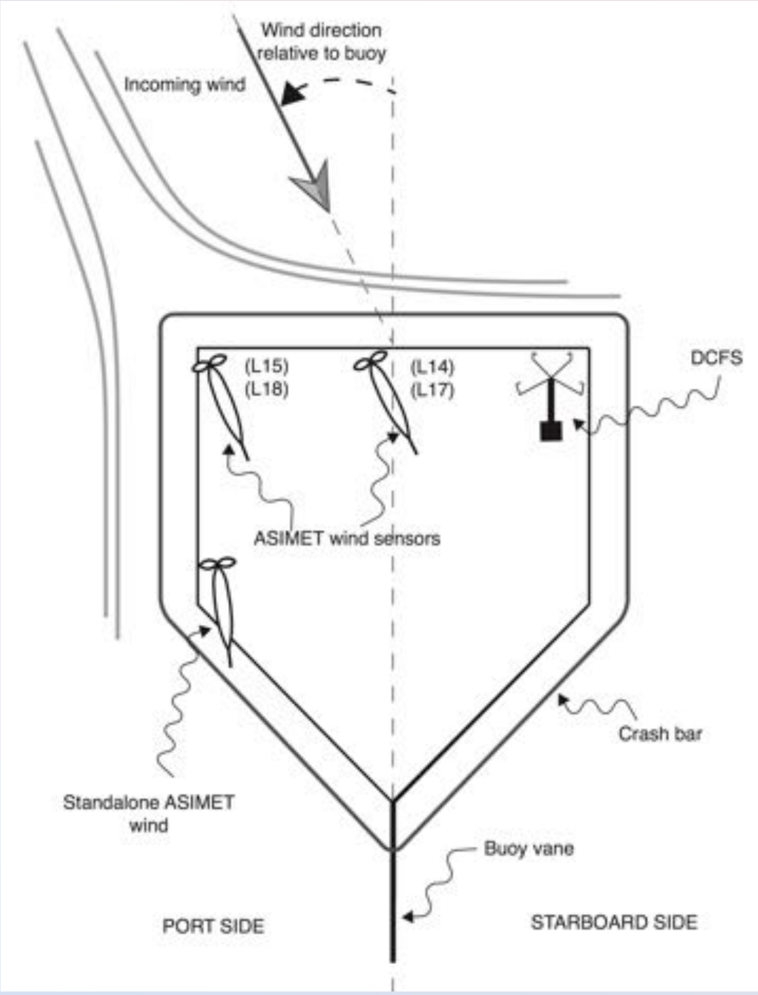
	Instant	Daily	Monthly
Longwave	7.5 W m^{-2}	2 W m^{-2}	2 W m^{-2}
Shortwave	10 W m^{-2}	3 W m^{-2}	3 W m^{-2}
Latent	5 W m^{-2}	4 W m^{-2}	4 W m^{-2}
Sensible	1.5 W m^{-2}	1.5 W m^{-2}	1.5 W m^{-2}
Net Heat Flux	15 W m^{-2}	8 W m^{-2}	8 W m^{-2}
Wind Stress	0.007 N m^{-2}	0.007 N m^{-2}	0.007 N m^{-2}
Precipitation	20%	20%	20%

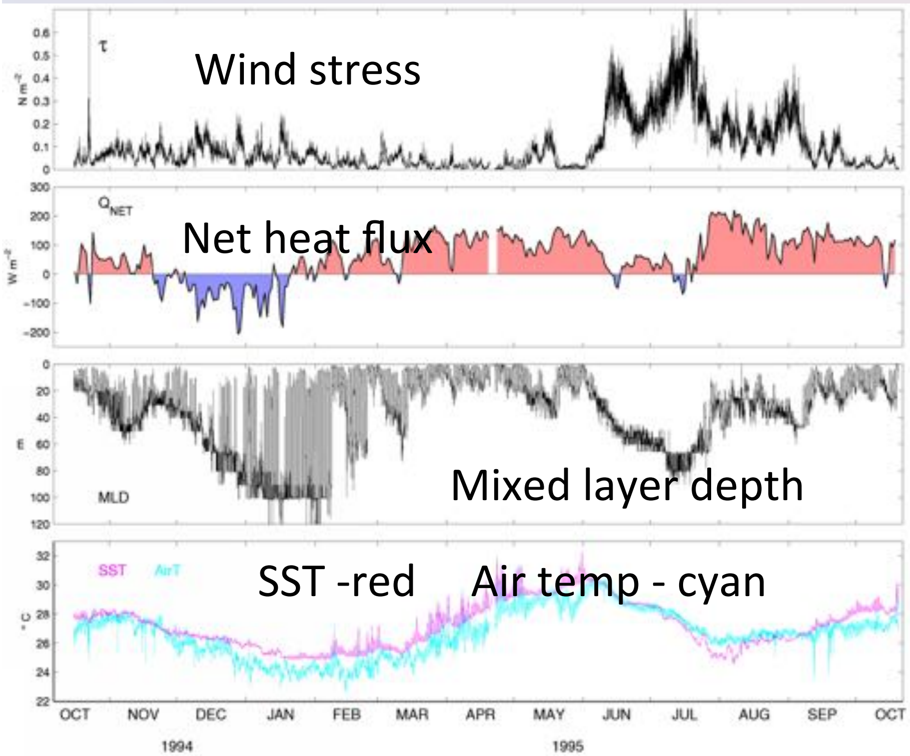
Notes:

1) Below 15 – 20 m s^{-1}, with bulk formulae
2) Supported by sensor redundancy, in-situ calibration by ship, shoreside QA/QC
3) There is need for DCFS and wave package for higher winds, sea states
4) Flow distortion by the buoy structure is an issue

Present surface buoys as platforms

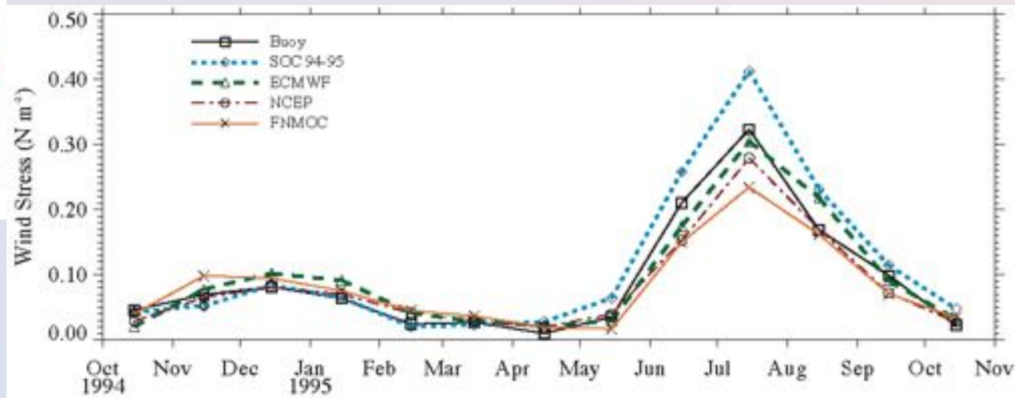
- Very stable, ~2,000 lb tension on buoy bridle
- Targets for improvement: radiometers, wind sensors
- Target: improve superstructure design to reduce flow distortion
- DCFS deployment, continued improvements to bulk formulae methodology
- Additional sensors





In the Arabian Sea, air-sea fluxes from weather prediction/climate models are inaccurate, with the wrong sign, and up to 50 to 100 W m^{-2} in error.

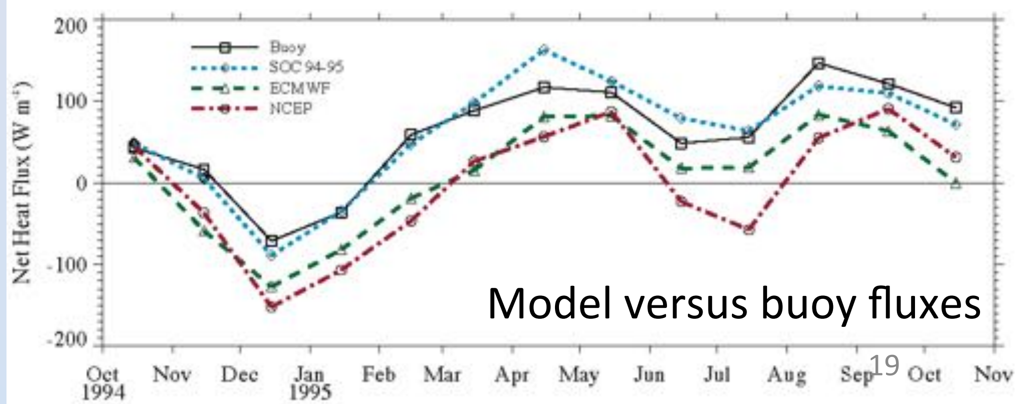
The correct fluxes are needed to explain the physics of the ocean response.



Process Study example:

Arabian Sea - strong monsoonal forcing with twice per year SST cooling.

Why? Heat loss in summer monsoon? No - heat gain plus wind mixing.



VOCALS REx: *R H Brown* Leg 1

Research groups:

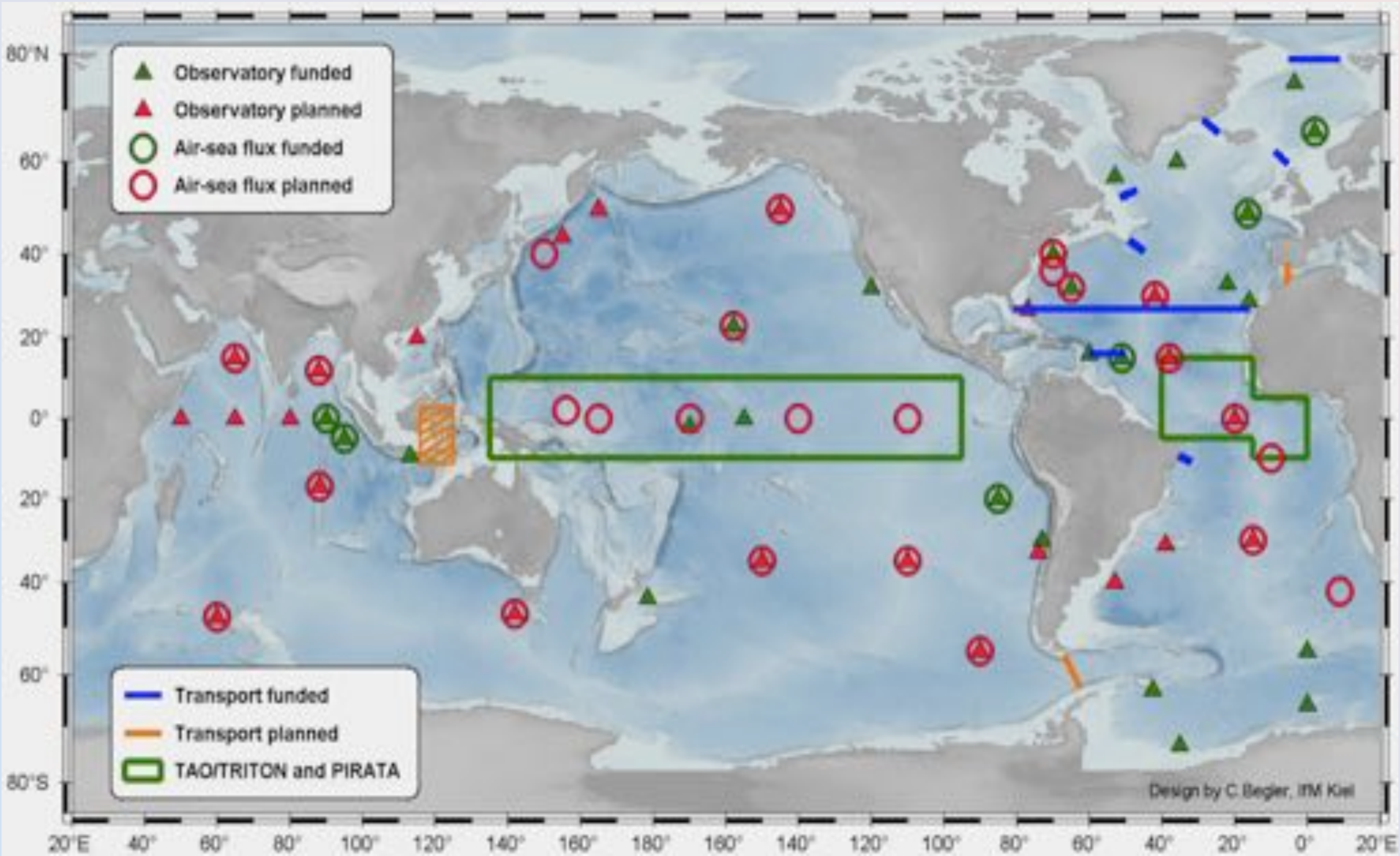
- WHOI Weller/Straneo – moorings, UCTD, Argo Floats, drifters
- LDEO/WHOI Zappa/Farra – moored instrumentation
- PMEL – Sabine, moored PCO_2
- INOCAR - Ecuadorian Navy Inst of Oceanography
- IMARPE – Inst for Marine Research, Peru
- SHOA – Chilean Navy Hydrographic and Ocean. Service, DART mooring
- NOAA ESRL Fairall - air-sea fluxes, radiosondes, cloud opt. properties
- NOAA ESRL Brewer – scan Doppler LIDAR
- NOAA ESRL Feingold – lidar-cloud radar aerosol-LWP
- NCSU – Yuter – C-band radar, drizzle
- U Miami – Albrecht, cloud drizzle/aerosol interactions
- U Miami – Minnett radiometric SST
- Bigelow – Matrai, DMS production
- U Washington/NOAA PMEL/SIO – Covert/Bates, aerosols
- CU – Volkamer, atmos. Chemistry
- UH Huebert – DMS flux
- PMEL – underway DMS
- NOAA- Teacher-at-Sea

Heavy equipment:

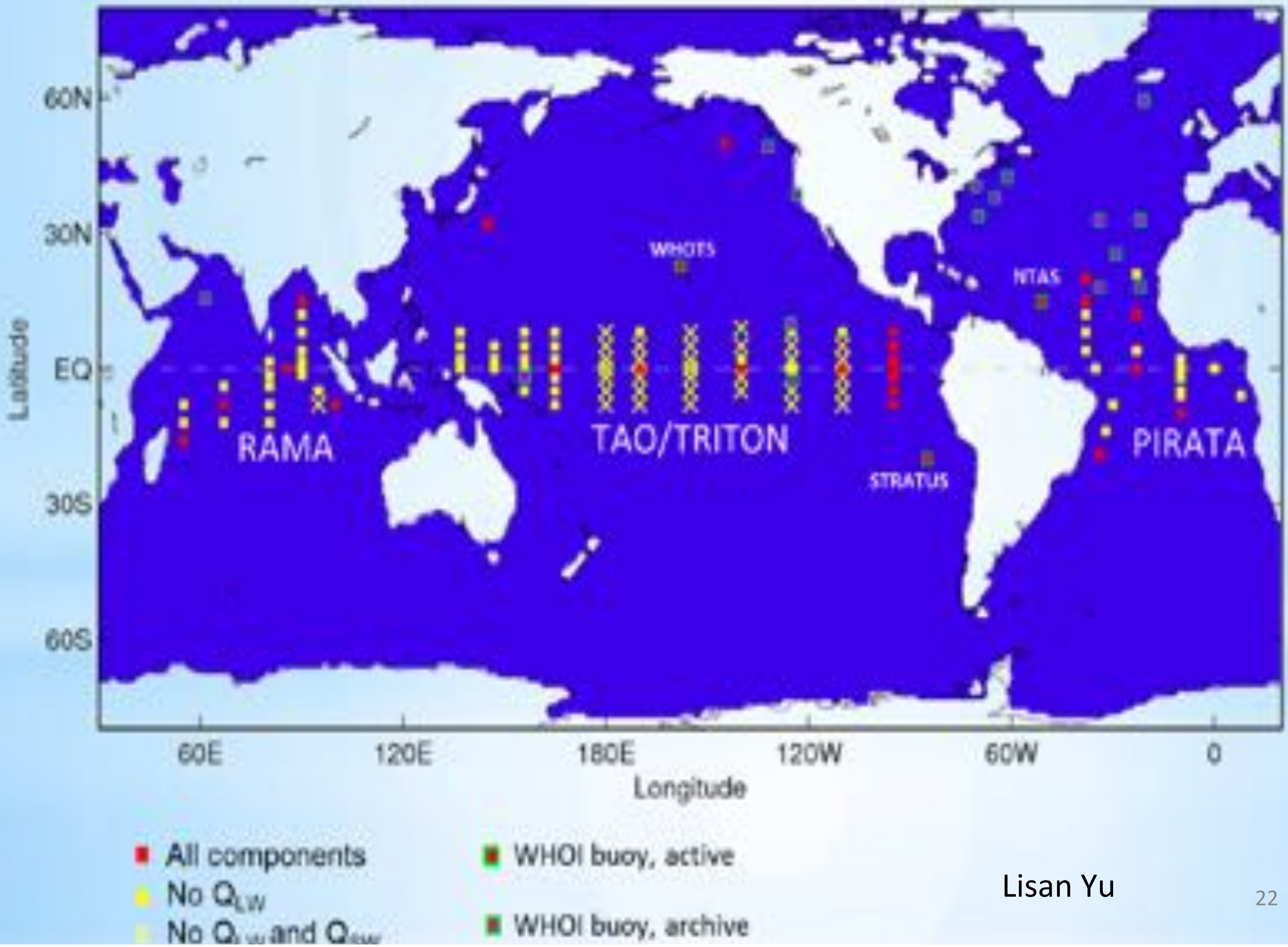
- Mooring winch, anchors, and related
- 7 Vans: 1) Albrecht/Miami; 2) PMEL1/Aerosol/Chem; 3) PMEL2/Aerosol/Phys; 4) PMEL3/Chem; 5) PMEL4/spares; 6) WHOI/mooring; 7) ESRL/lower atmos
- Radiosondes/helium
- Instruments on upper decks

Large, recent multi-disciplinary process study

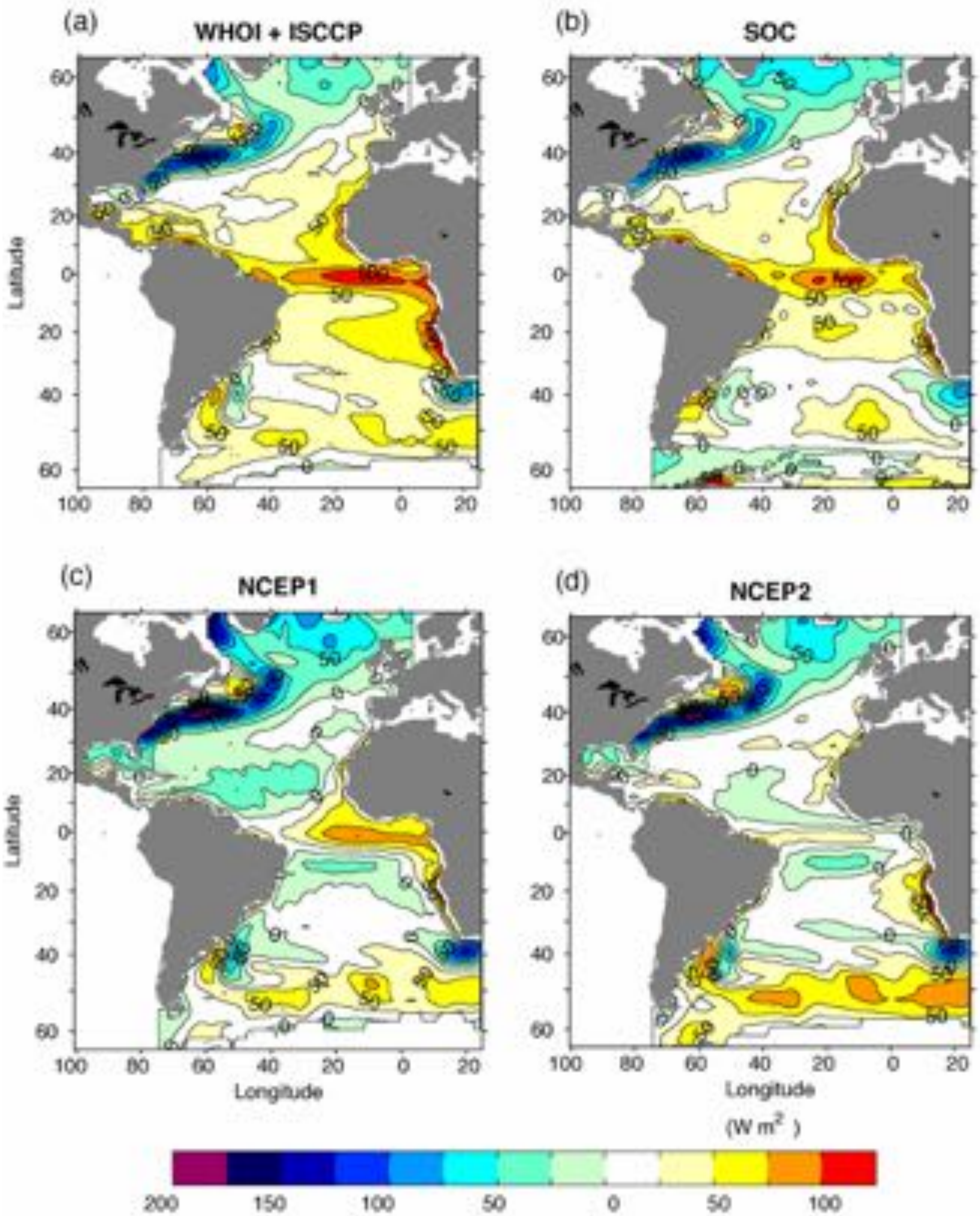
OceanSITES: Internationall Time Series Science Team



Moored surface flux buoy sites (Active and Archived)



Lisan Yu



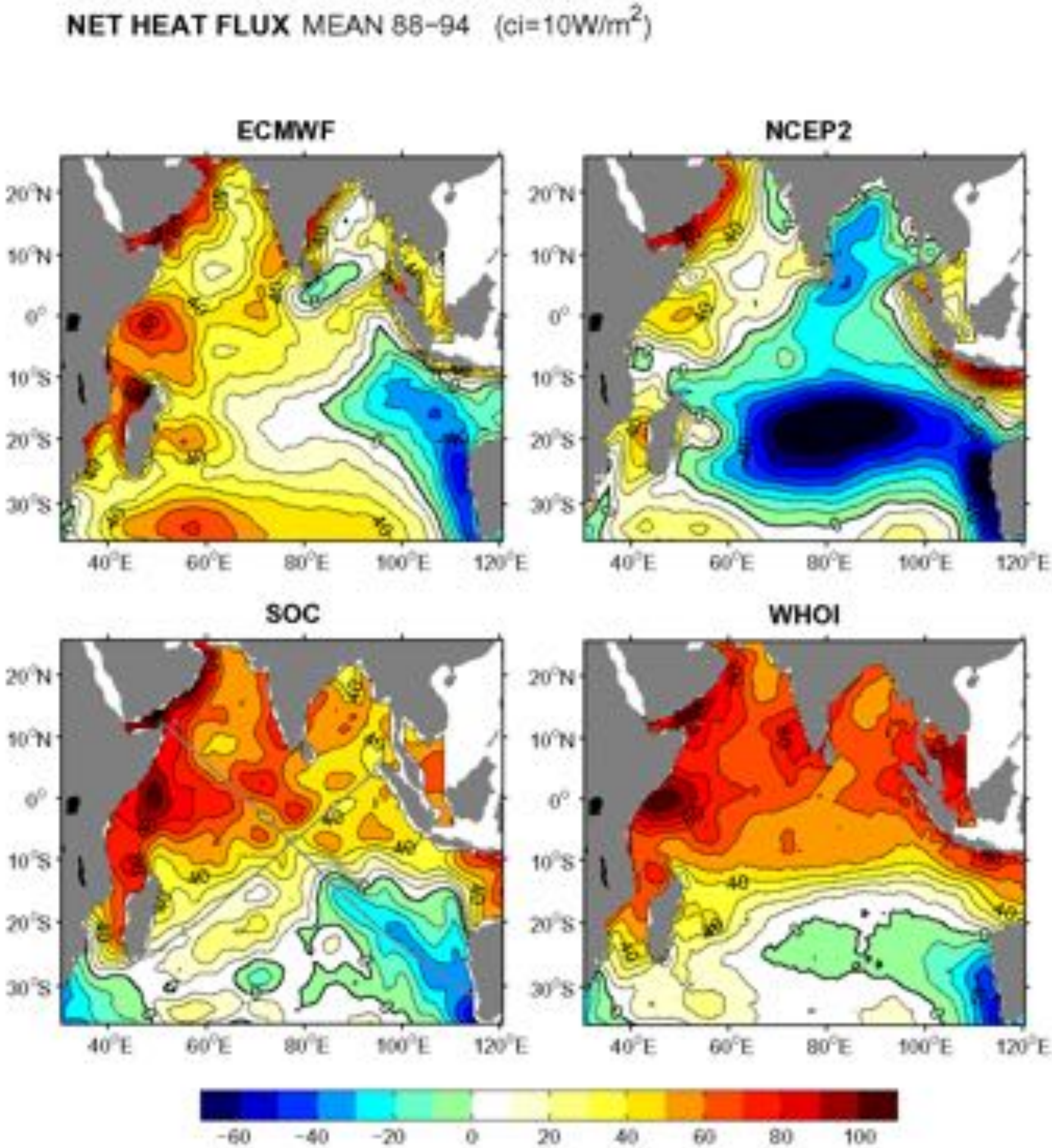
(Lisan Yu)

Annual mean net heat flux in the Atlantic.

Which one is correct?

Is the equatorial Atlantic warmed by the atmosphere in the eastern Atlantic?

What is the average over the basin?



Accurate in-situ fluxes validate and verify flux fields, provide means to develop new more accurate flux fields, as Lisan Yu is doing.

The WHOI OAFlux Project: Methodology and Strategy

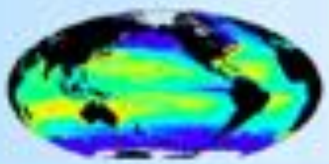
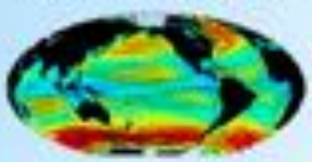
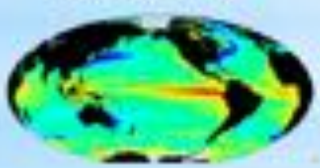
Global air-sea fluxes of heat, freshwater, and momentum are computed from bulk flux parameterizations using observed/modeled air-sea variables as inputs.

Existing Problems	Our Remedies
Not all flux-related variables can be observed by satellites.	Use atmospheric reanalyses to fill in missing information.
All data have errors, particularly the reanalyzed variable fields.	Obtain the best possible estimate through **objective synthesis** of all available sources (least-squares estimation based on the Gauss-Markov theorem)
Error in each dataset needs to be quantified for optimization.	Global flux buoys as validation database

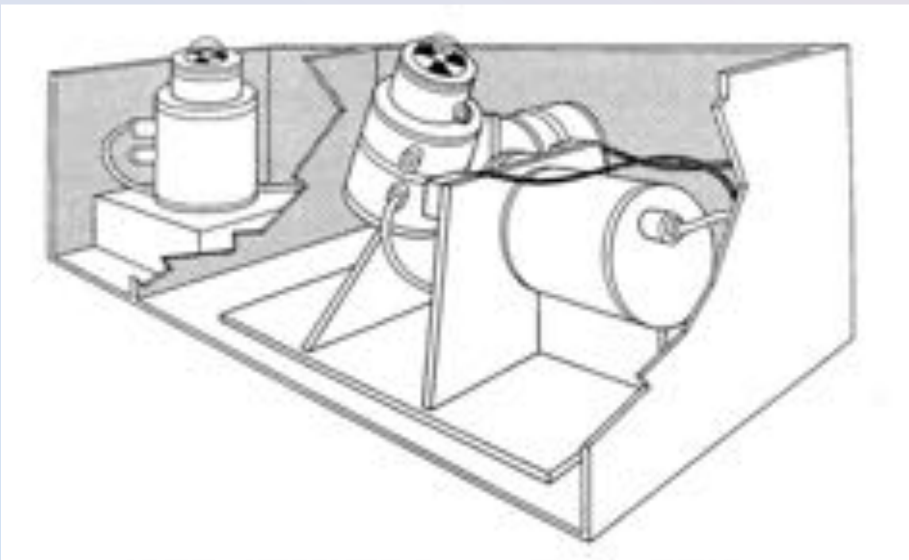
OAFlux = Objectively Analyzed air-sea variables + bulk flux parameterization (COARE3.0)

OAFlux Research Products

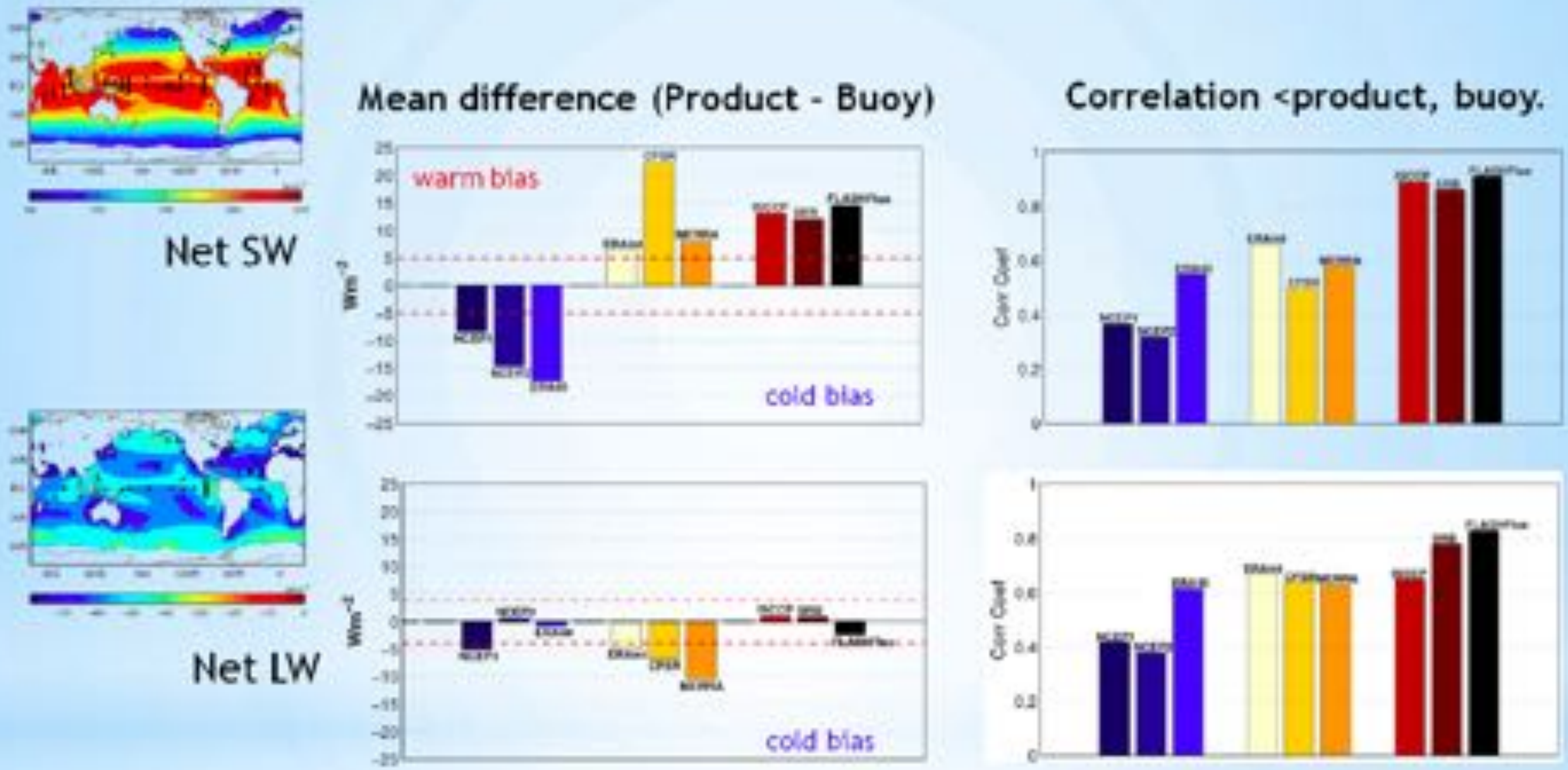
Project website: http://oaflux.whoi.edu

• **Evaporation** • **Latent and Sensible heat fluxes** 	• 1958-present, 1°, daily, monthly • 1999-present, 0.25°, daily • Objective synthesis of satellite products (wind speed, SST, qair and Tair) and selected atmospheric reanalysis fields from NCEP, ERA40, and ERA-interim.	**Freshwater flux (E-P)** OAFlux evaporation GPCP precipitation 1979 to present (>30 yrs)
Wind and Wind Stress 	• 1987-present, daily, 0.25° • 1° analysis is from a spatial average of 0.25° • Objective synthesis of 11 satellite sensors (SSMI, SSMIS, AMSRE, QuikSCAT, and ASCAT).	**Momentum flux** OAFlux wind stress 1987 - present (>24 yrs)
Net Heat flux 	Work in progress • 1983-present, 1°, daily • Synthesis of satellite products and selected reanalysis fields	**Net heat flux** Explore a combined use of OAFlux latent/sensible heat fluxes FLASHFlux/SRB surface radiation from 1983 - present

Ongoing work on radiometer performance and calibration



Comparison summary: all buoy sites

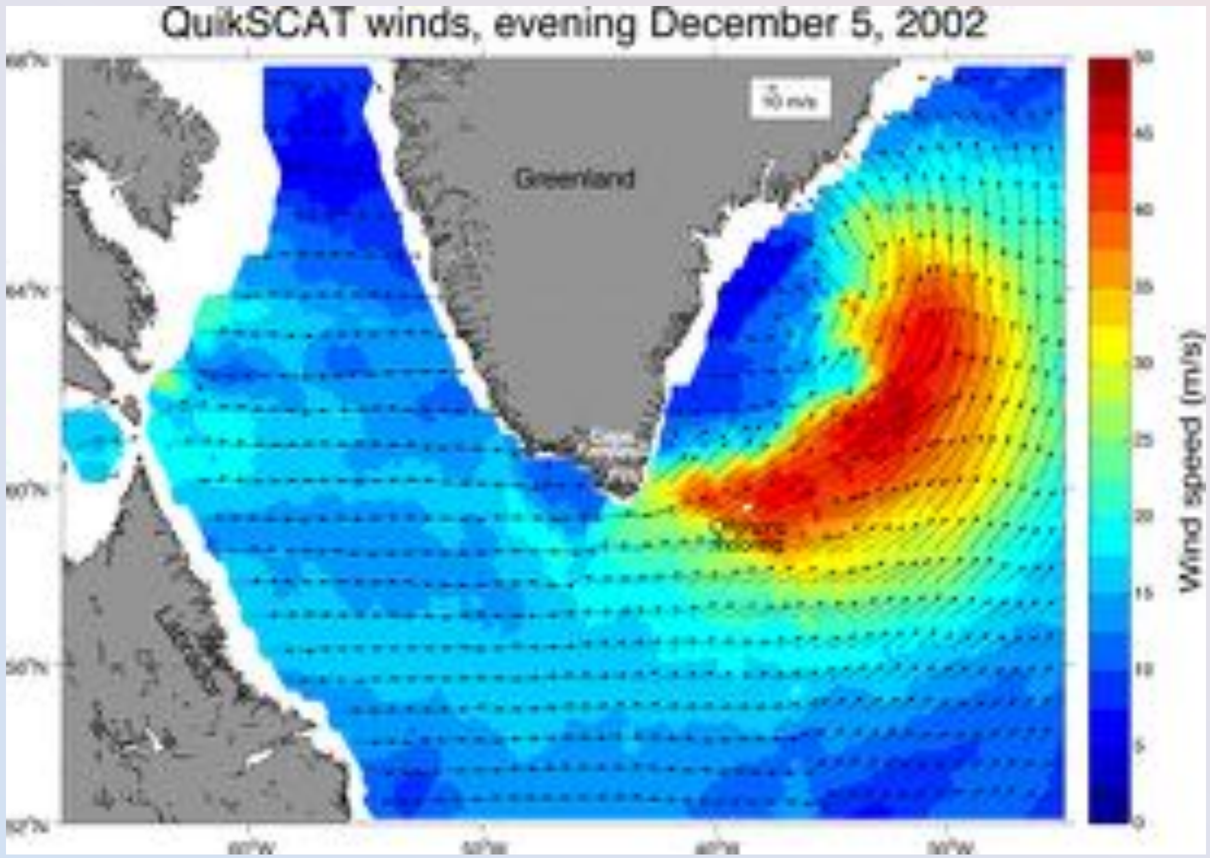


- Overall, satellite products are compared more favorably with buoy.
- Satellite SW products: mean is biased warm, correlation with buoy is high (>0.83)
- Satellite LW products: mean is unbiased wrt buoy accuracy, but correlation is lower (<0.83)

NSF OCE OOI Science and Technical Challenge

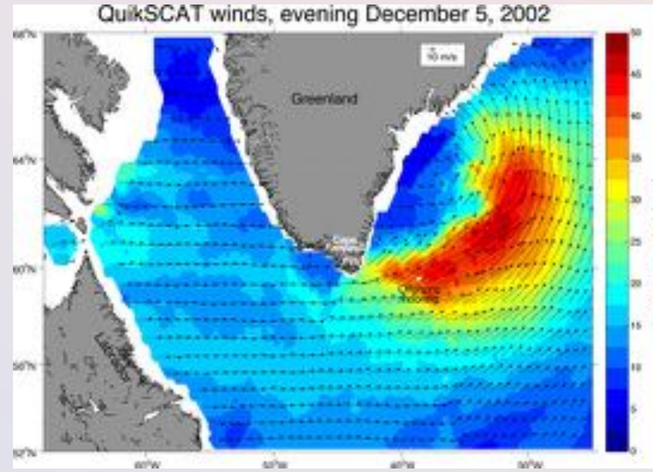
Remote locations, strongly forced

For example, Irminger Sea, where North Atlantic Deep Water is formed



CGSN Science – Technical challenge

Remote locations, strongly forced



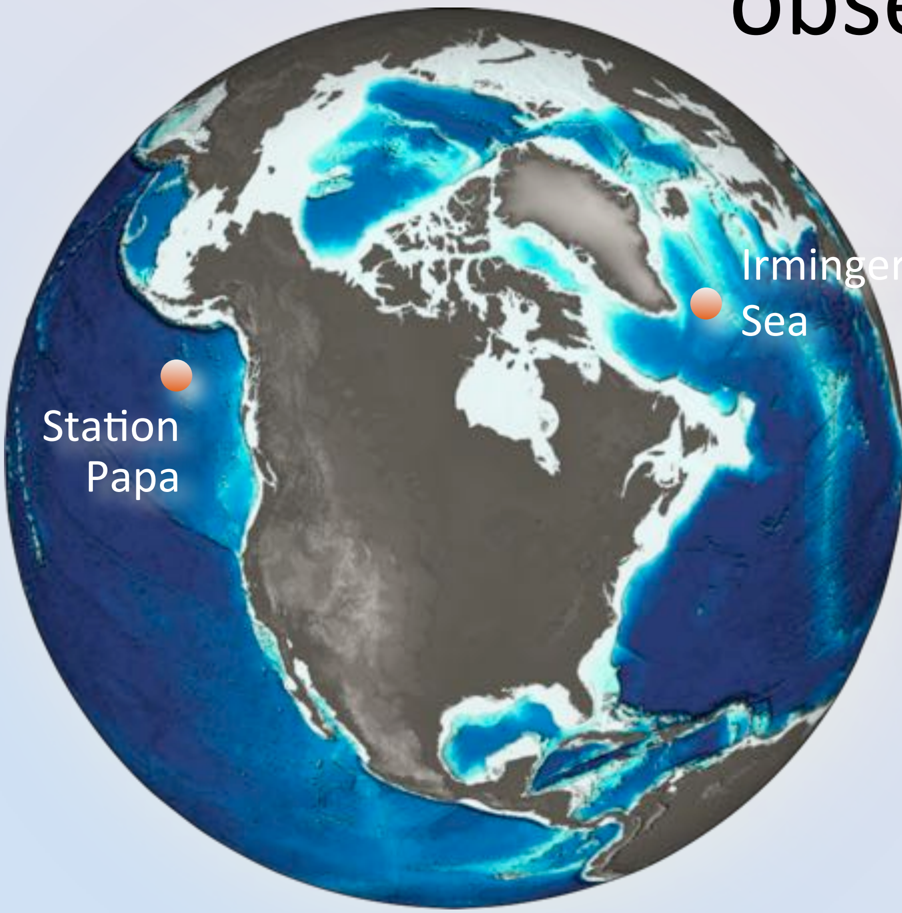
Energetic surface waves, cyclic fatigue in a corrosive environment.

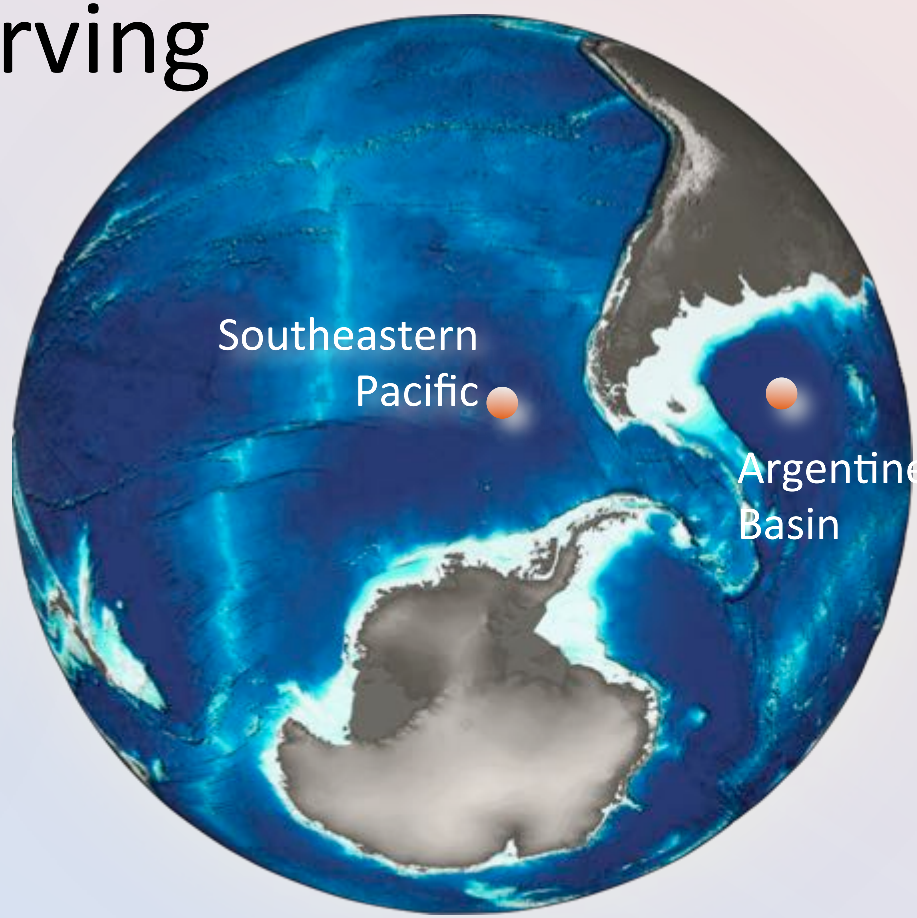
Deliver more power and bandwidth and real-time, two-way communication. Wind, solar, fuel cell/ Fleet Broadband.

One-year service life.

Extension of Bulk Formulae to higher wind speeds, higher eaves

Sustained high latitude ocean observing



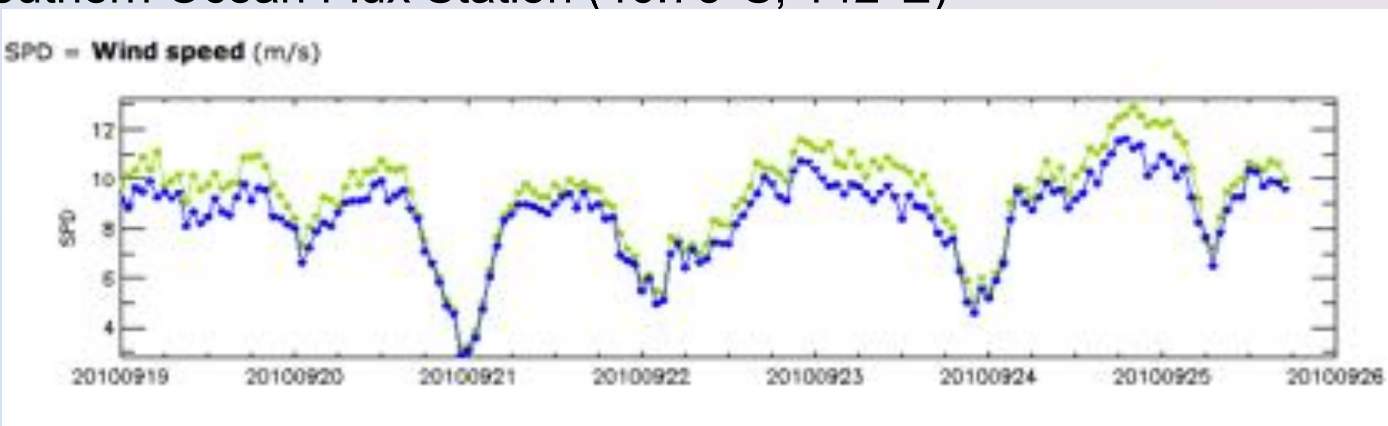


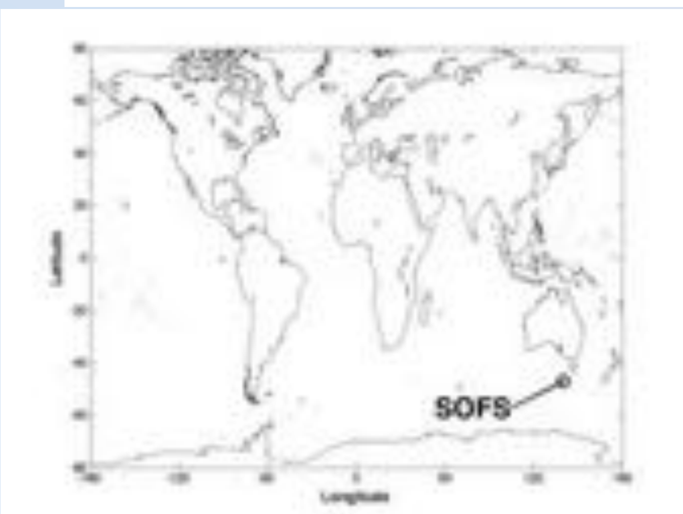
PAPA 50°N 145°W Irminger Sea 60°N 39°W Argentine Basin 42°S 42°W SE Pacific 55°S 90°W

Global partners

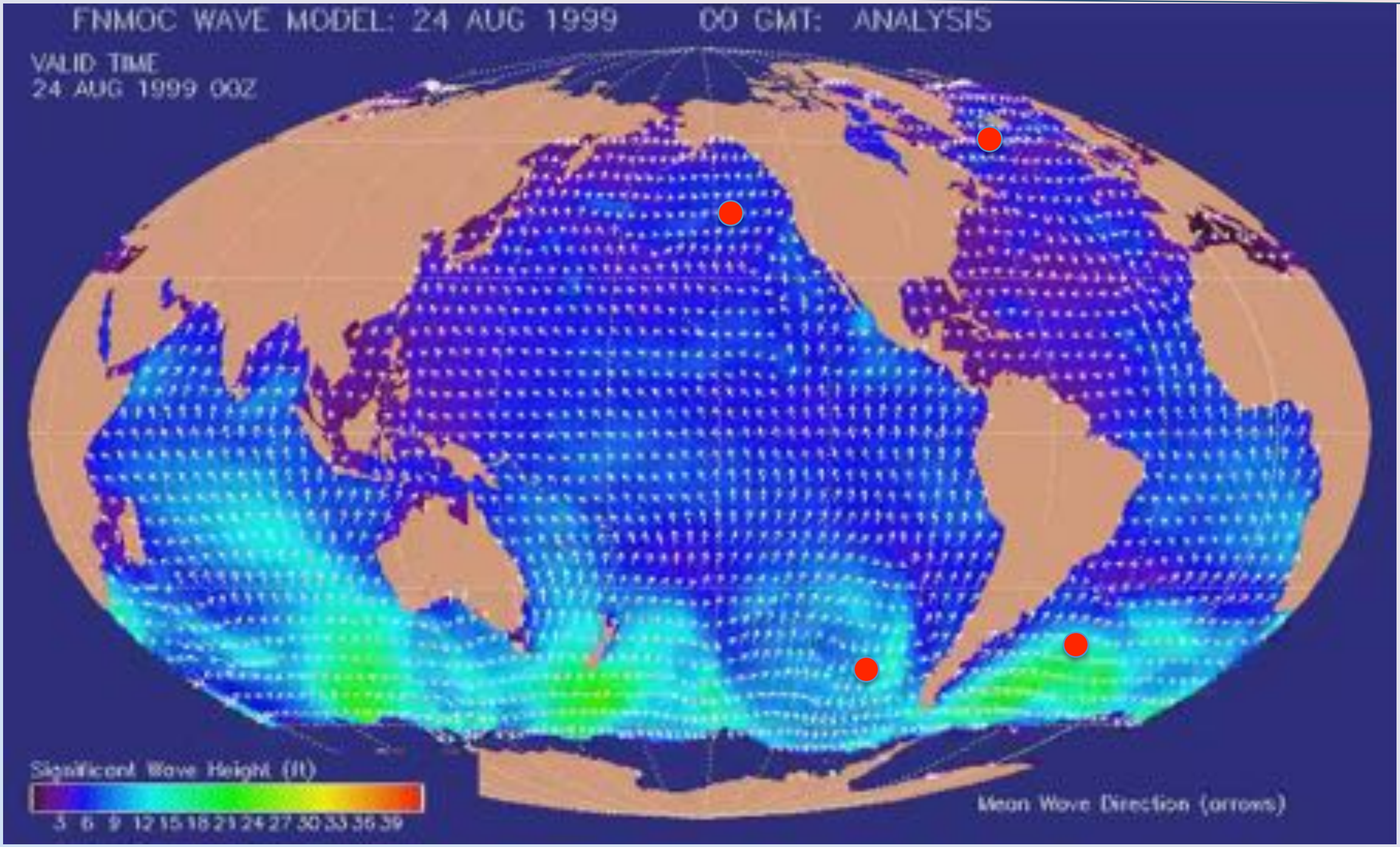
IMOS Integrated Marine Observing System

Southern Ocean Flux Station (46.75°S, 142°E)



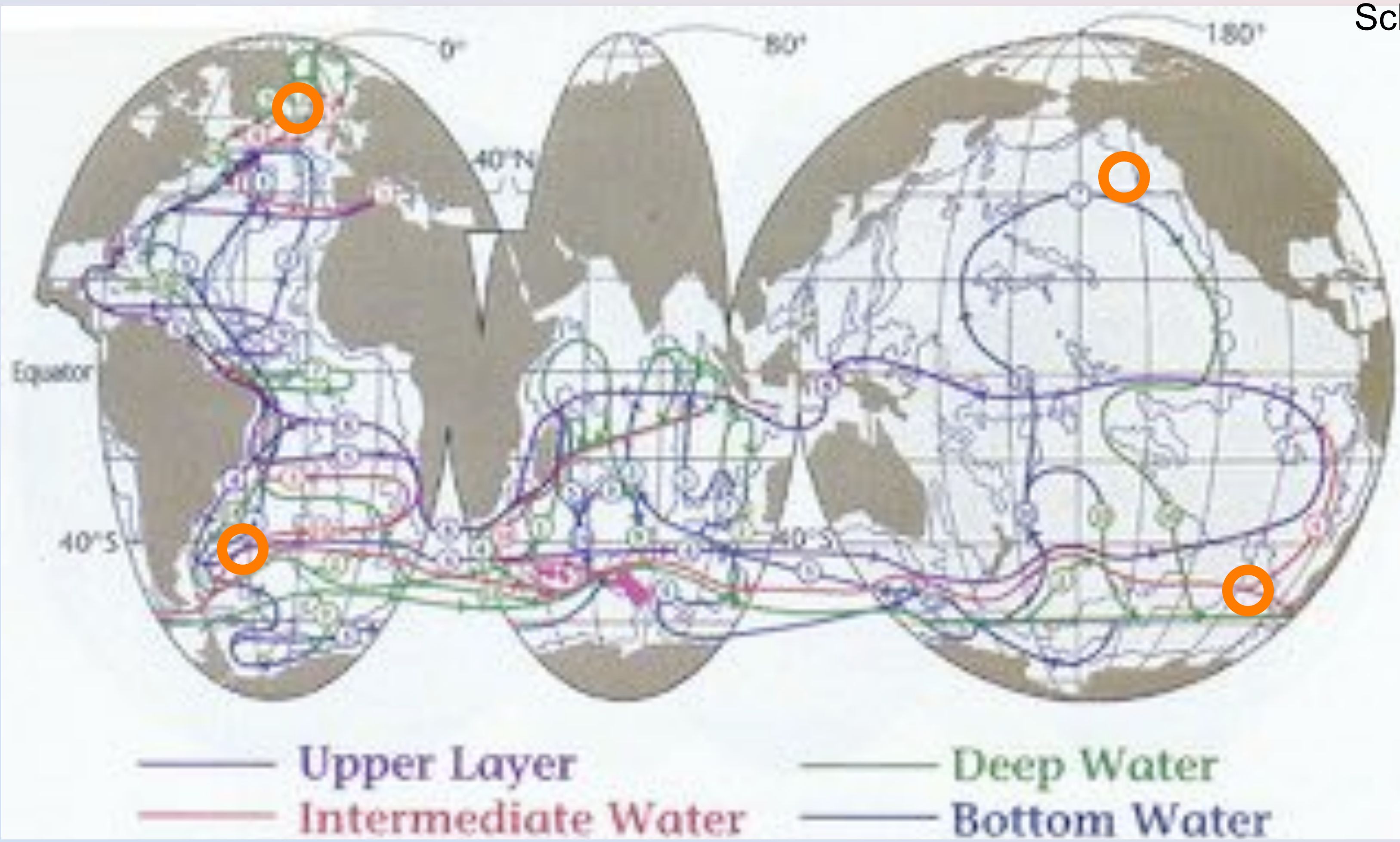


CGSN – quantifying air-sea fluxes in strongly forced regimes

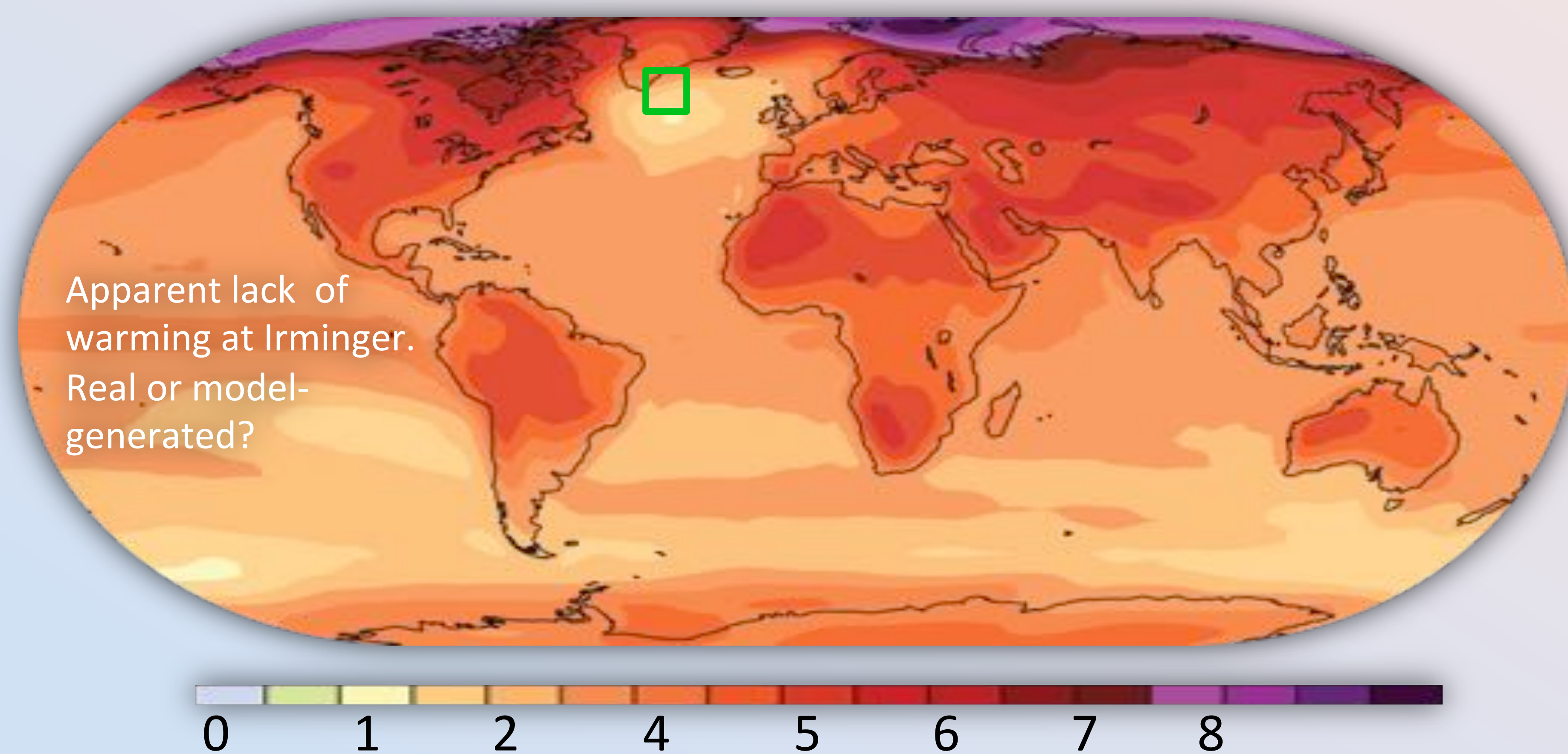


Global science – Key Regions on the Thermohaline Pathways

Schmitz

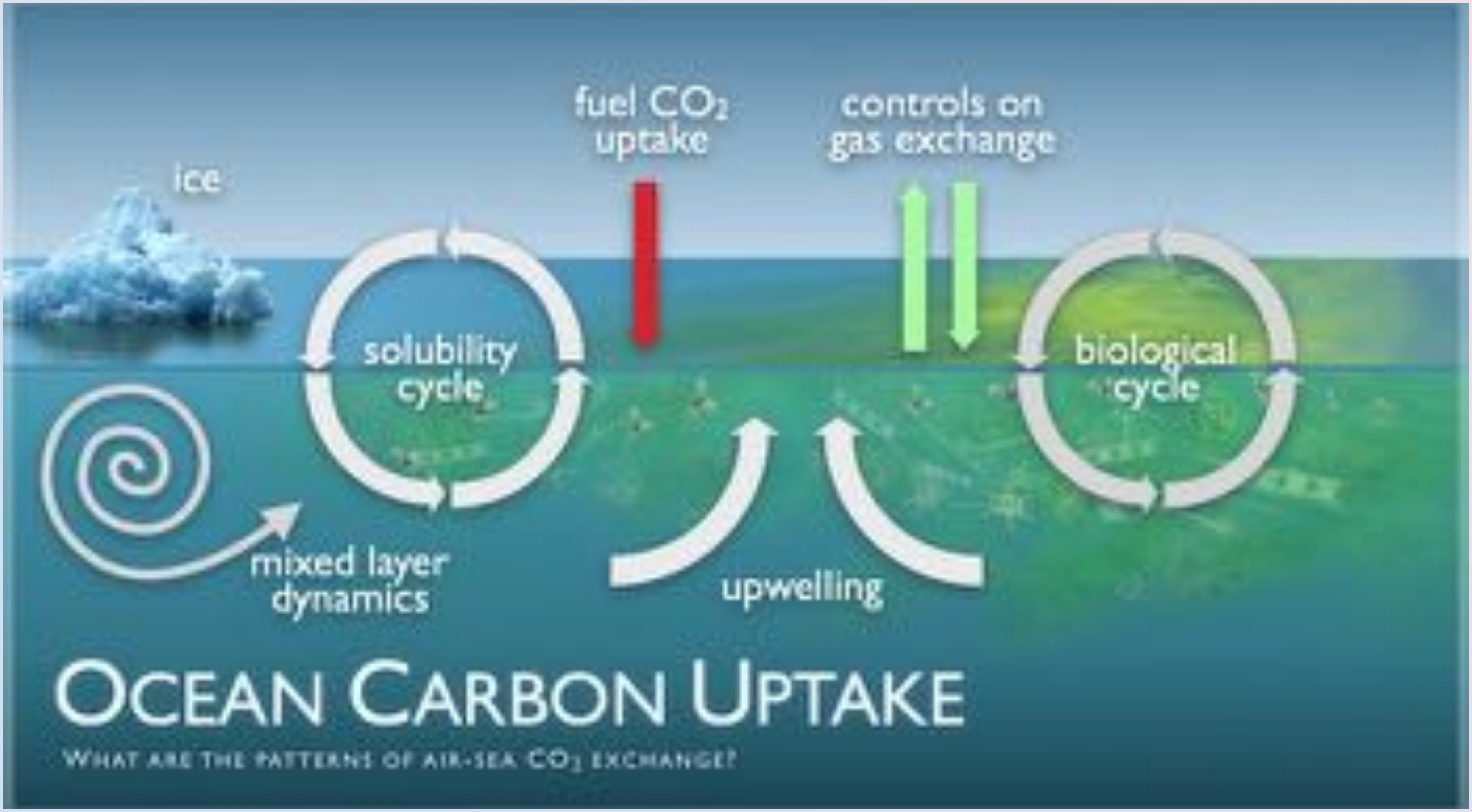


CGSN Context – Benchmark Time Series for Climate Change

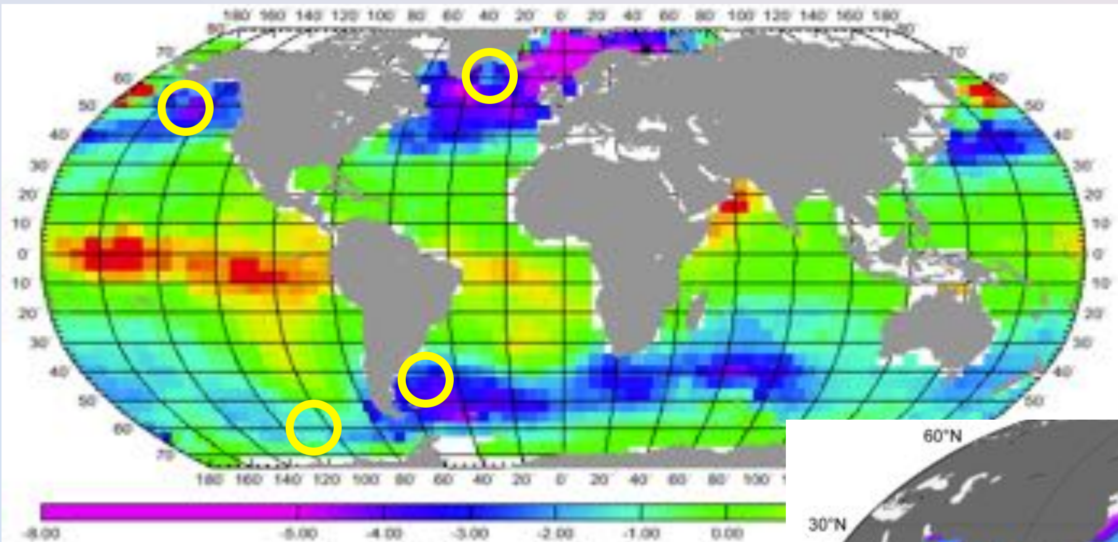


IPCC projection of surface temperature change (2090-2099 wrt 1980-1999)

Ocean's role in the carbon cycle

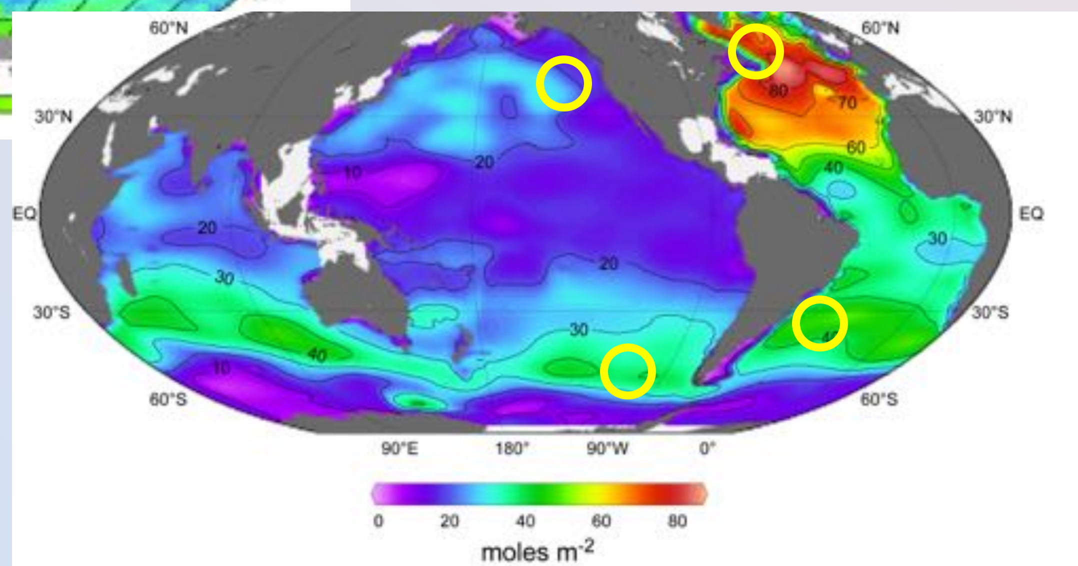


Global science – Global carbon cycle

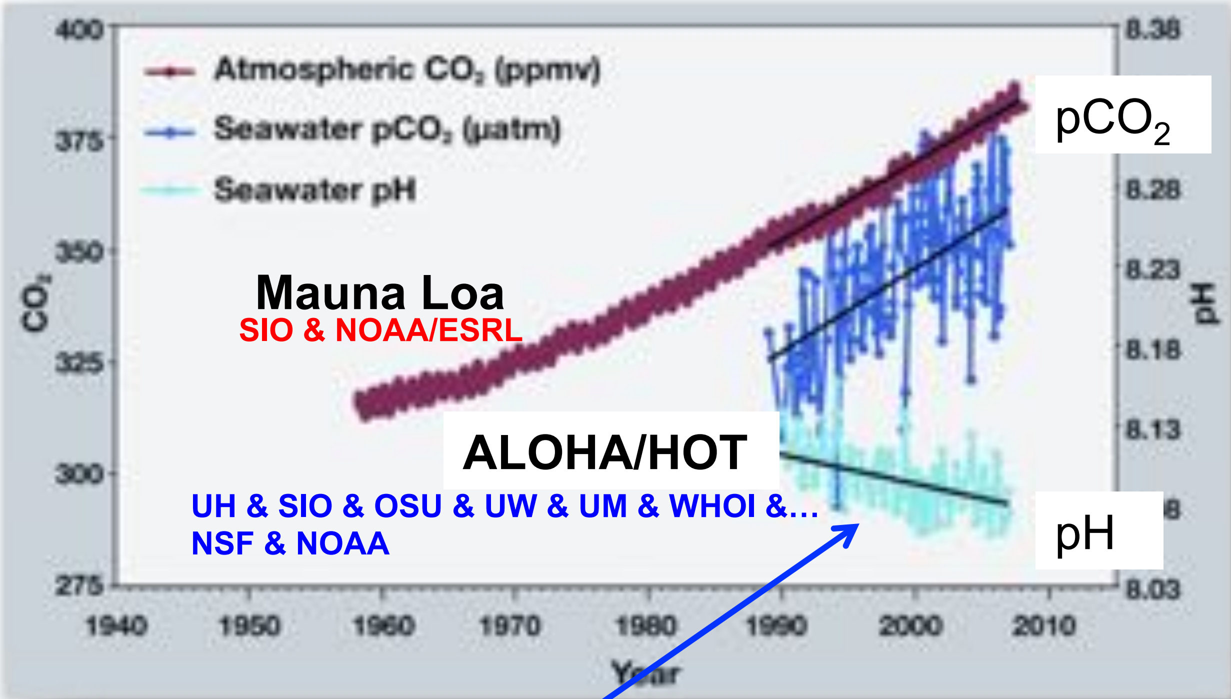


Total CO_2 flux

Anthropogenic CO_2 inventory

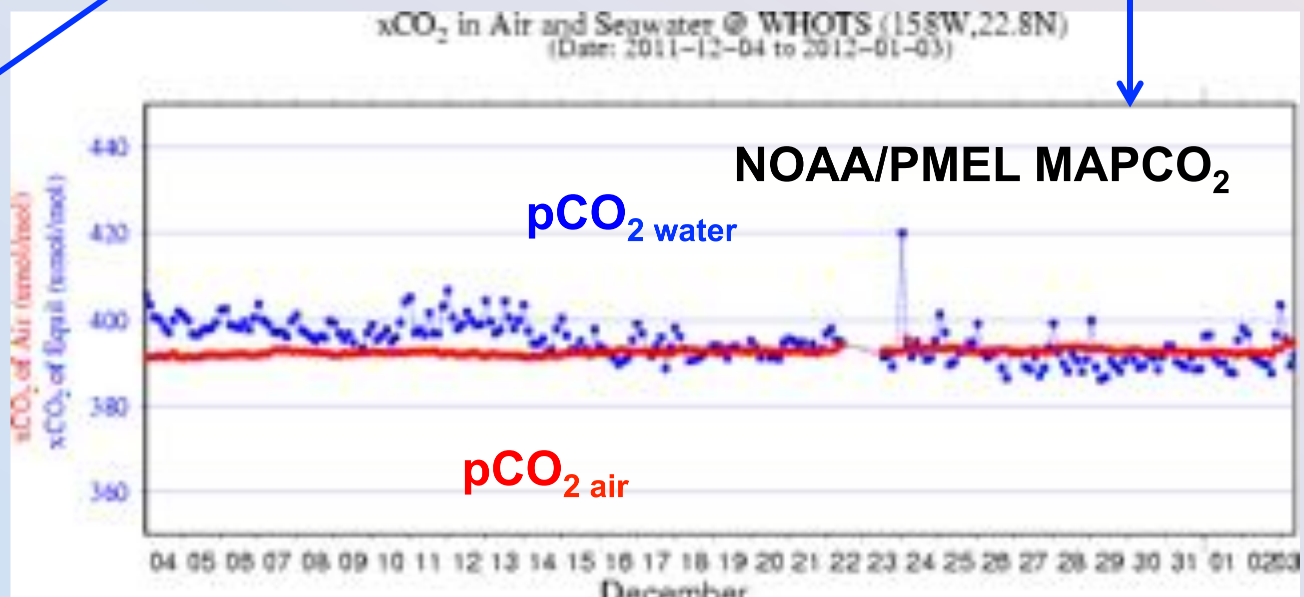


Observe the fluxes and inventory changes, and the physical/ biological processes that determine and modulate CO_2 fluxes.



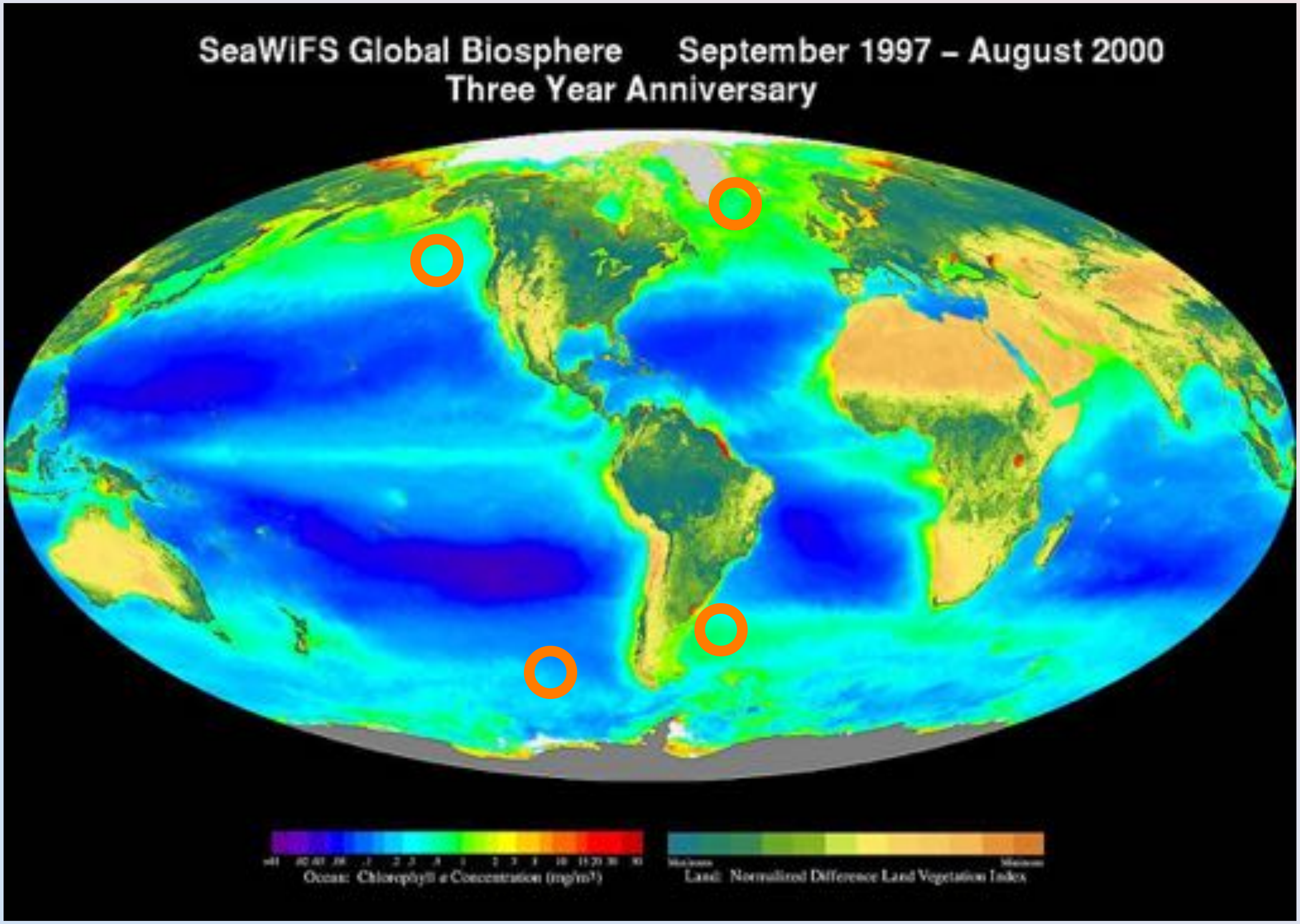
trends, ENSO and annual cycle resolved by HOT

effects of eddies and storms are not resolved by HOT but are resolved by WHOTS (NOAA&NSF)

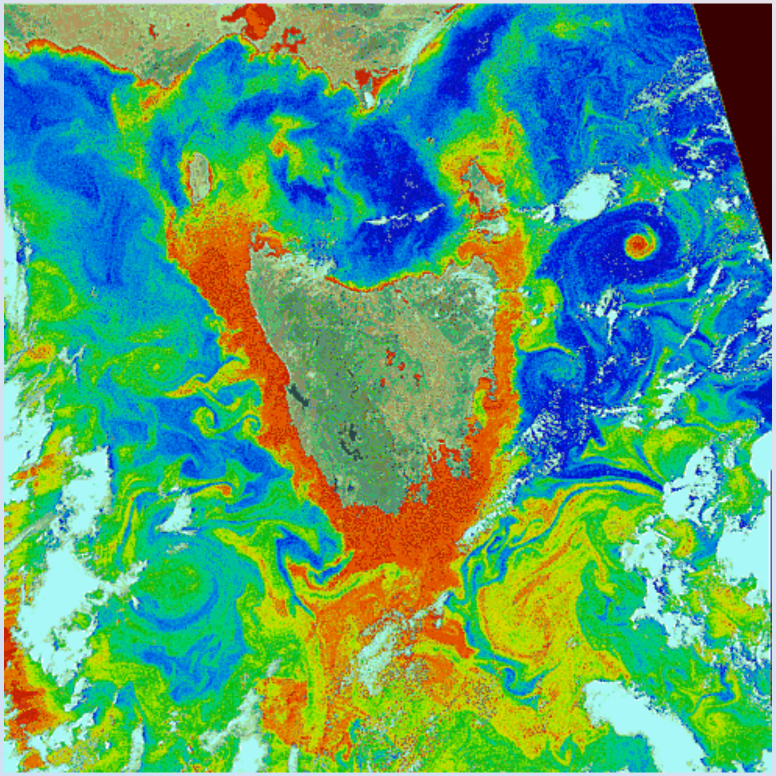


from PMEL ocean carbon website

Global science – Examining Productivity in Contrasting Regimes

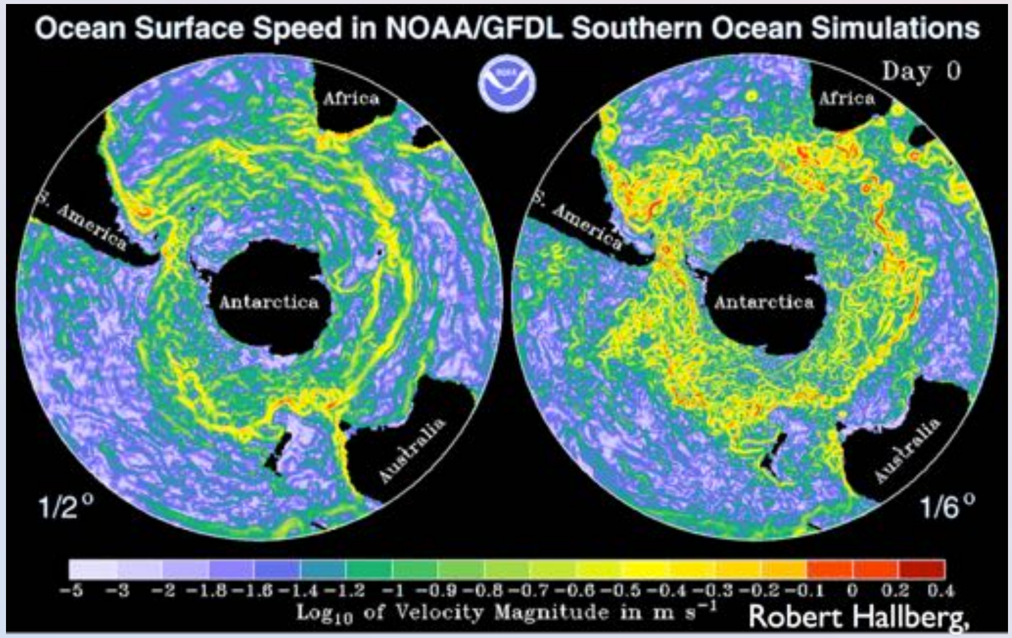


CGSN Science – coupled physics and biology



NASA ocean color image of the ocean around Tasmania.

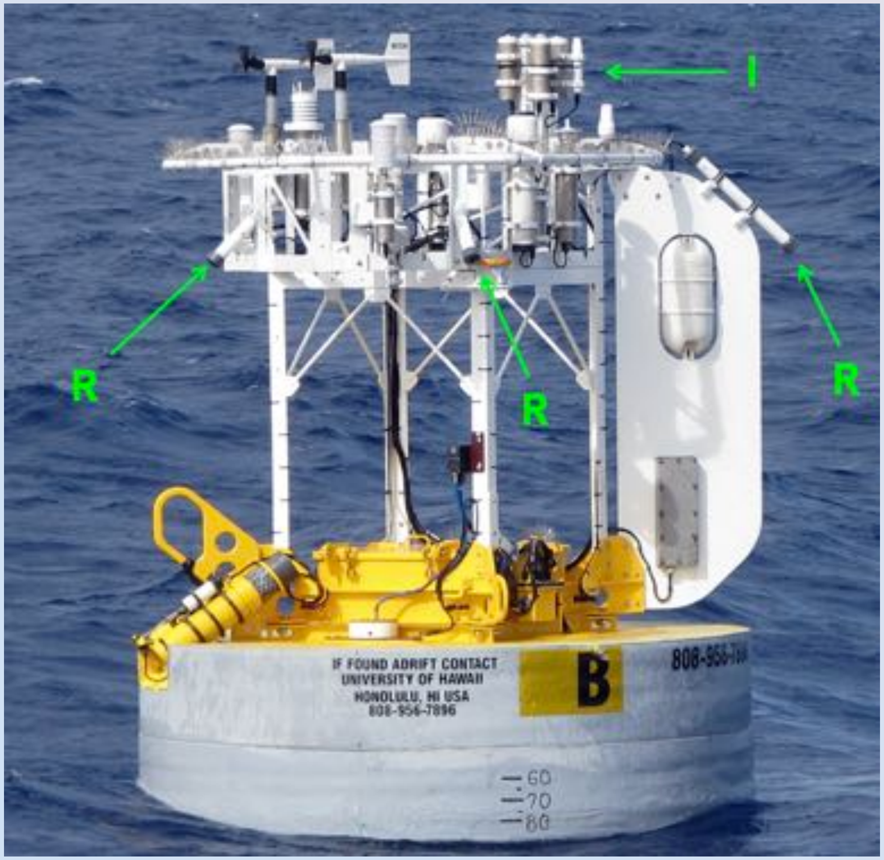
The important scales must be resolved. Both observations and models point to the criticality of resolving the role of the ocean mesoscale, its influence on mixing and transports.

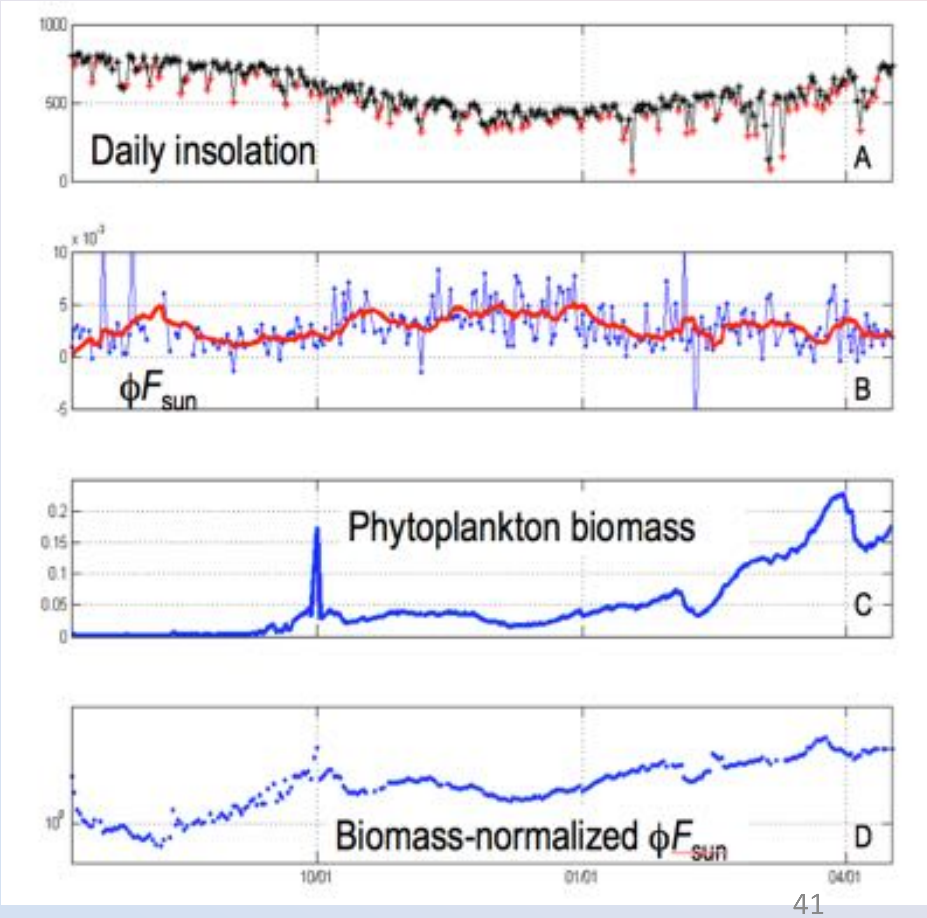


NOAA ocean model with higher vertical mixing when mesoscale is better resolved.

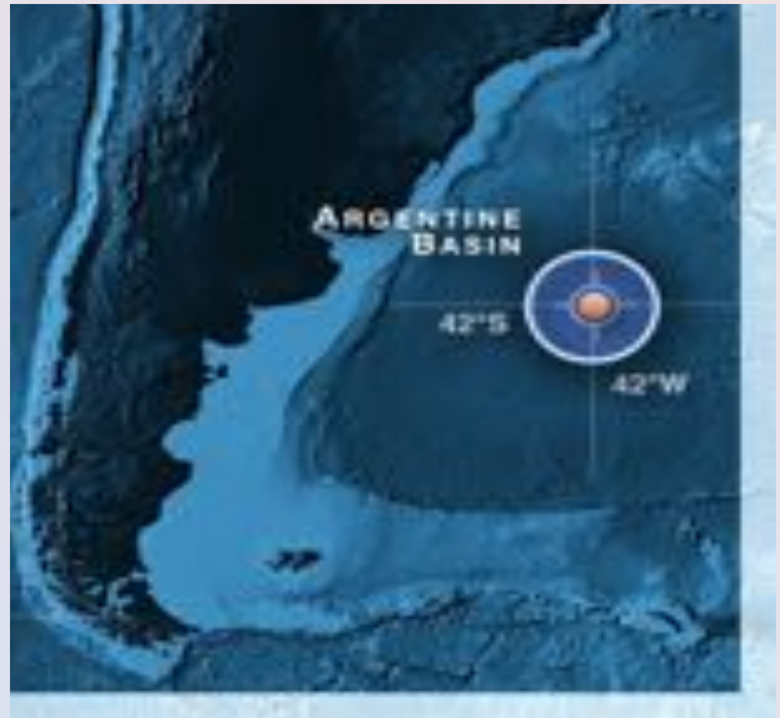
Ocean biology and optics – Sam Laney (WHOI)

"Down-looking hyperspectral radiometers (R) & the up-looking hyperspectral irradiance sensor (I). The down-looking radiometers observe the ocean at 45 degrees from nadir; one radiometer always observes glint-free ocean. Subsurface instruments mounted to the hull monitor the biomass of phytoplankton in the ocean. The phytoplankton fuel marine food webs and produce half of all the oxygen on the planet."





Argentine Basin – physics and biology forced by the atmosphere



High winds, large waves   Air-sea energy and gas exchange CO_2 sequestration

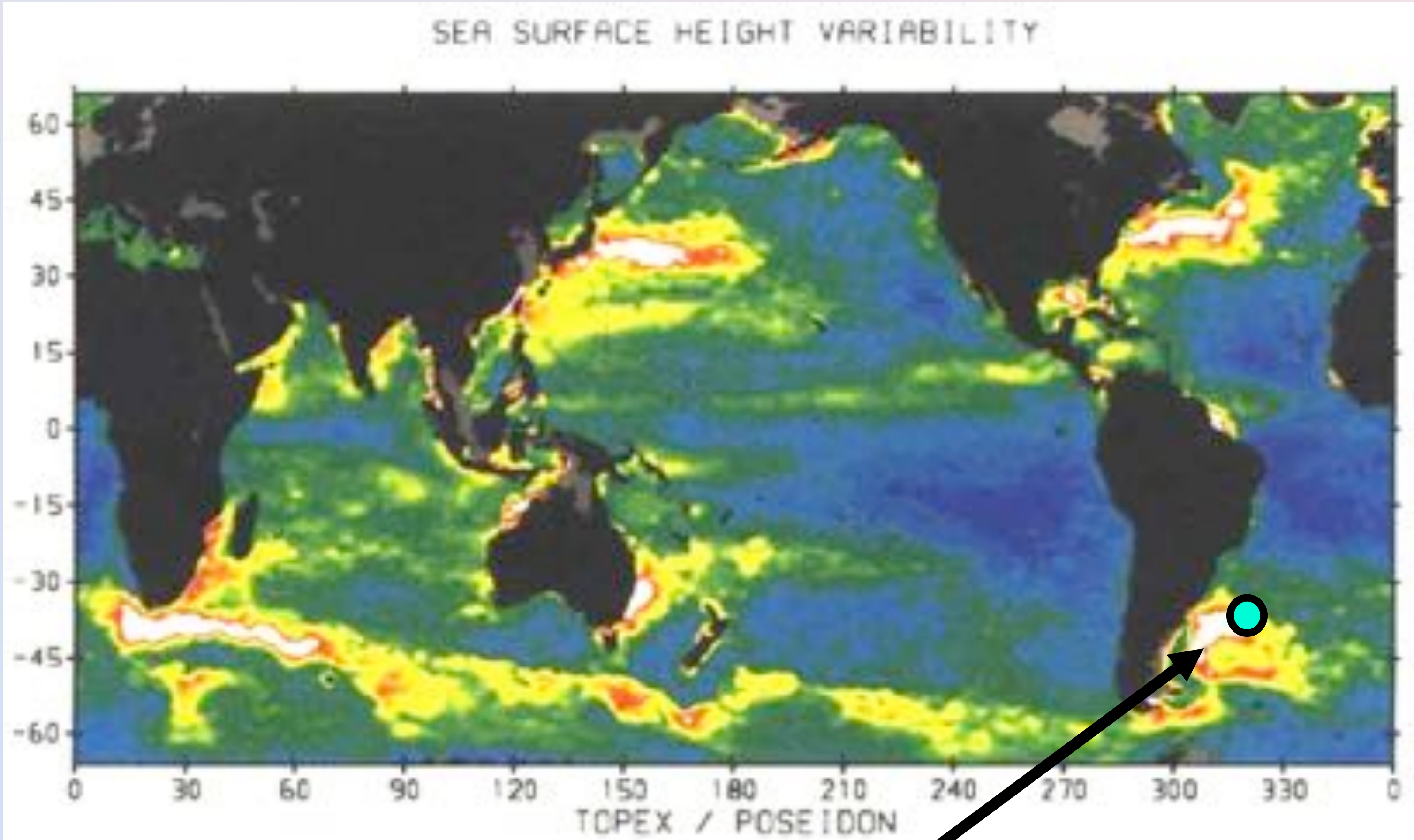
Strong permanent mesocale variability   High productivity

Atmospheric dust impacts on biogeochemistry   Water column forcing of sea bed morphology

Contrast with others sites sensitivity to acidification

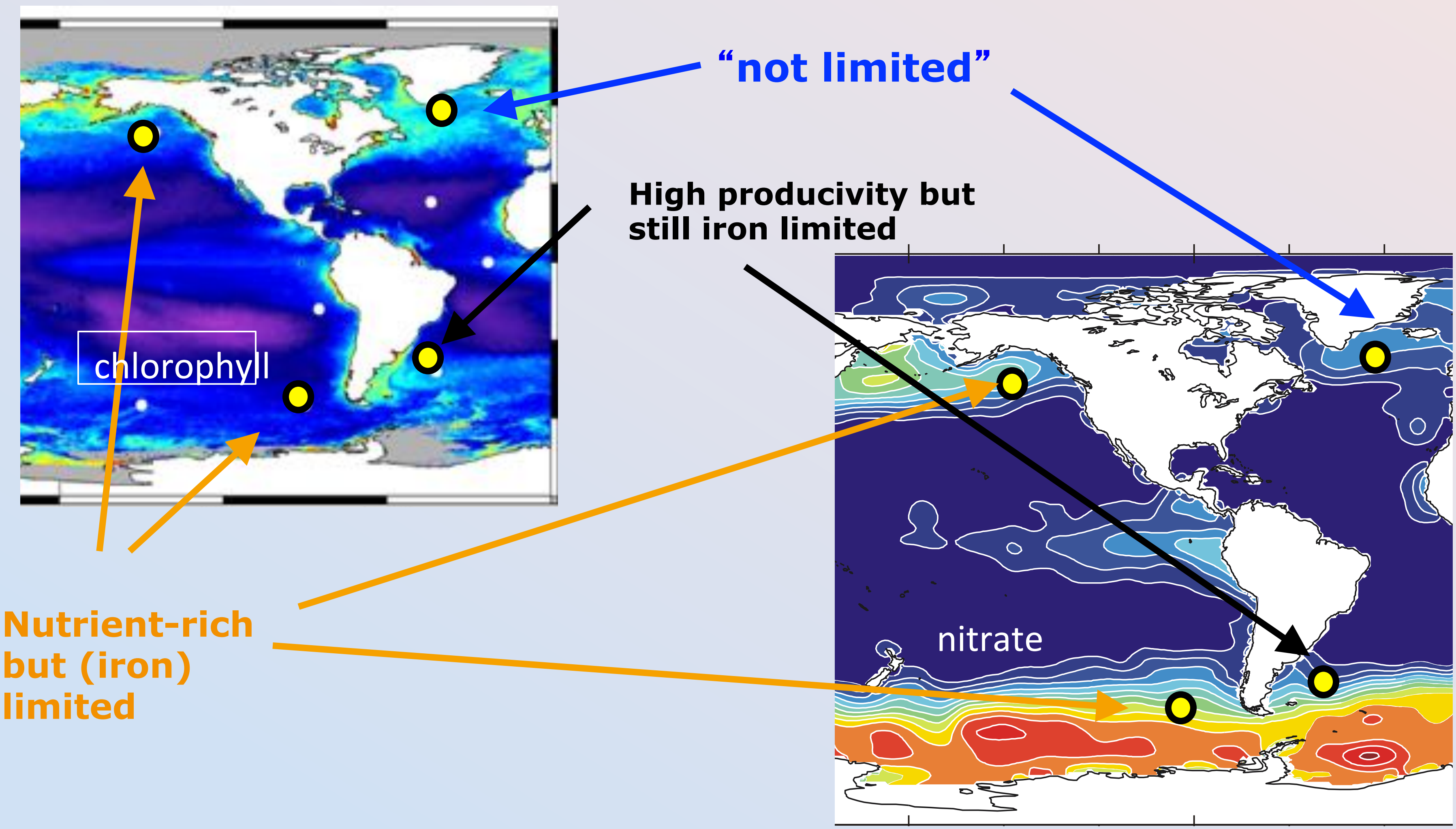
Abyssal warming   Coordination with UK Geotraces, Argentina

Argentine Basin – testbed for investigating the role of eddies



Energetic circulation variability

CGSN Context – Examining Productivity in Contrasting Regimes



Argentine Basin – productivity due to micronutrients from dust

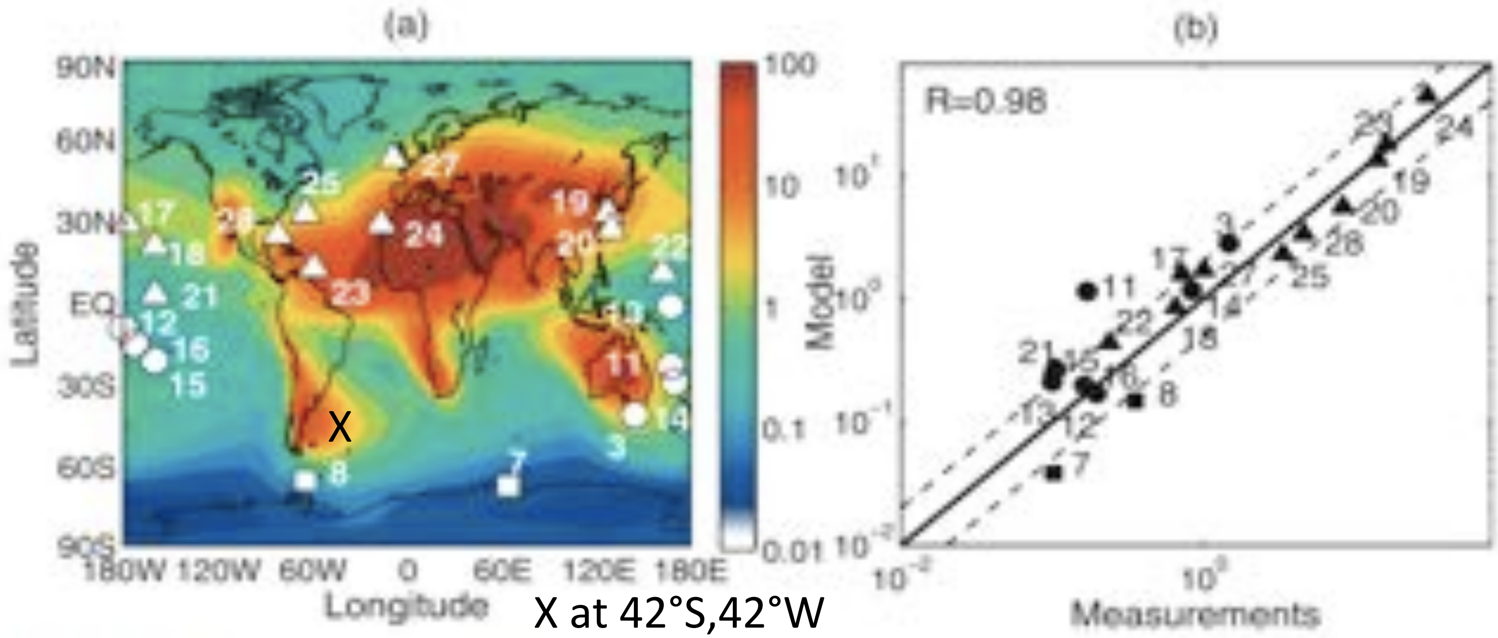
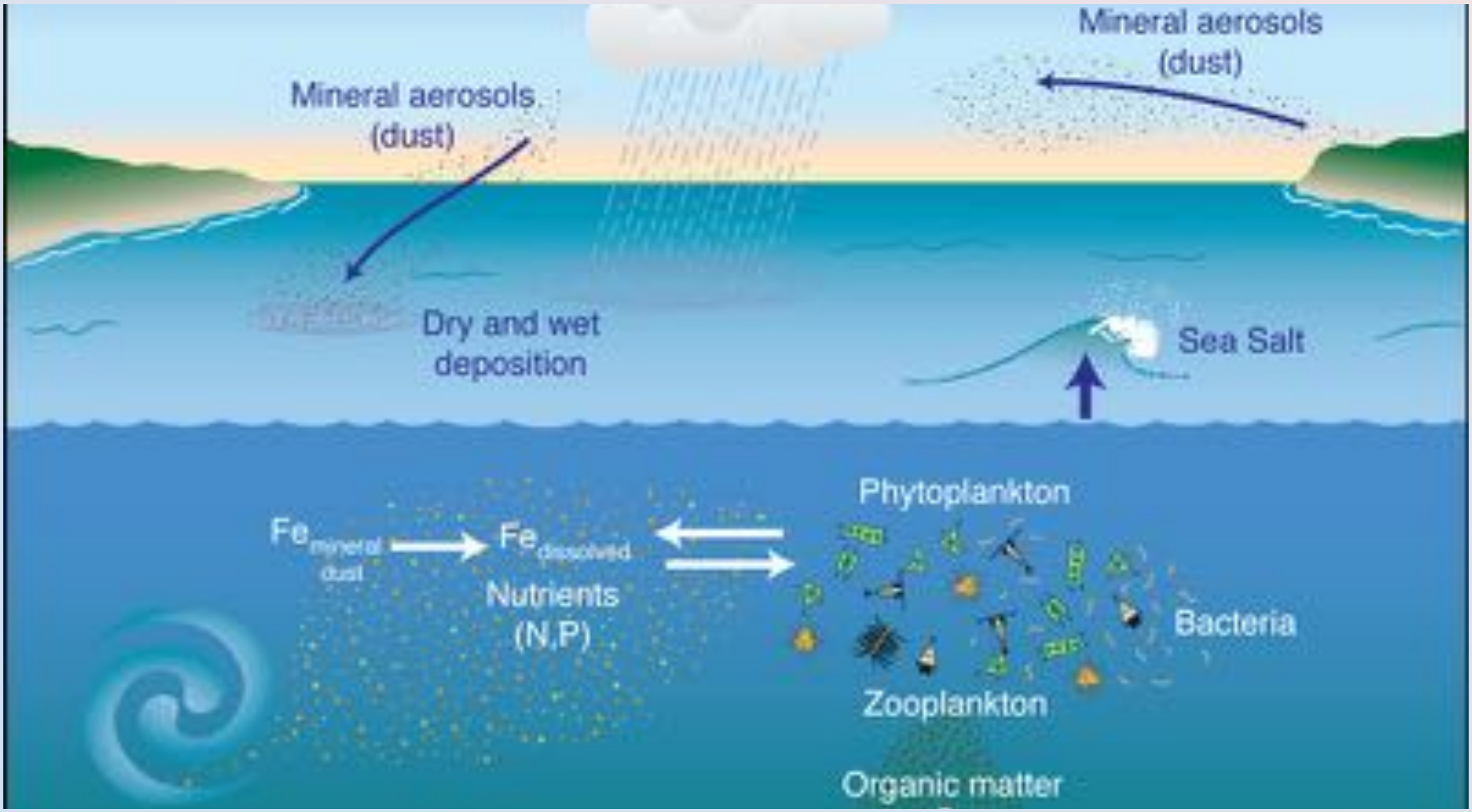


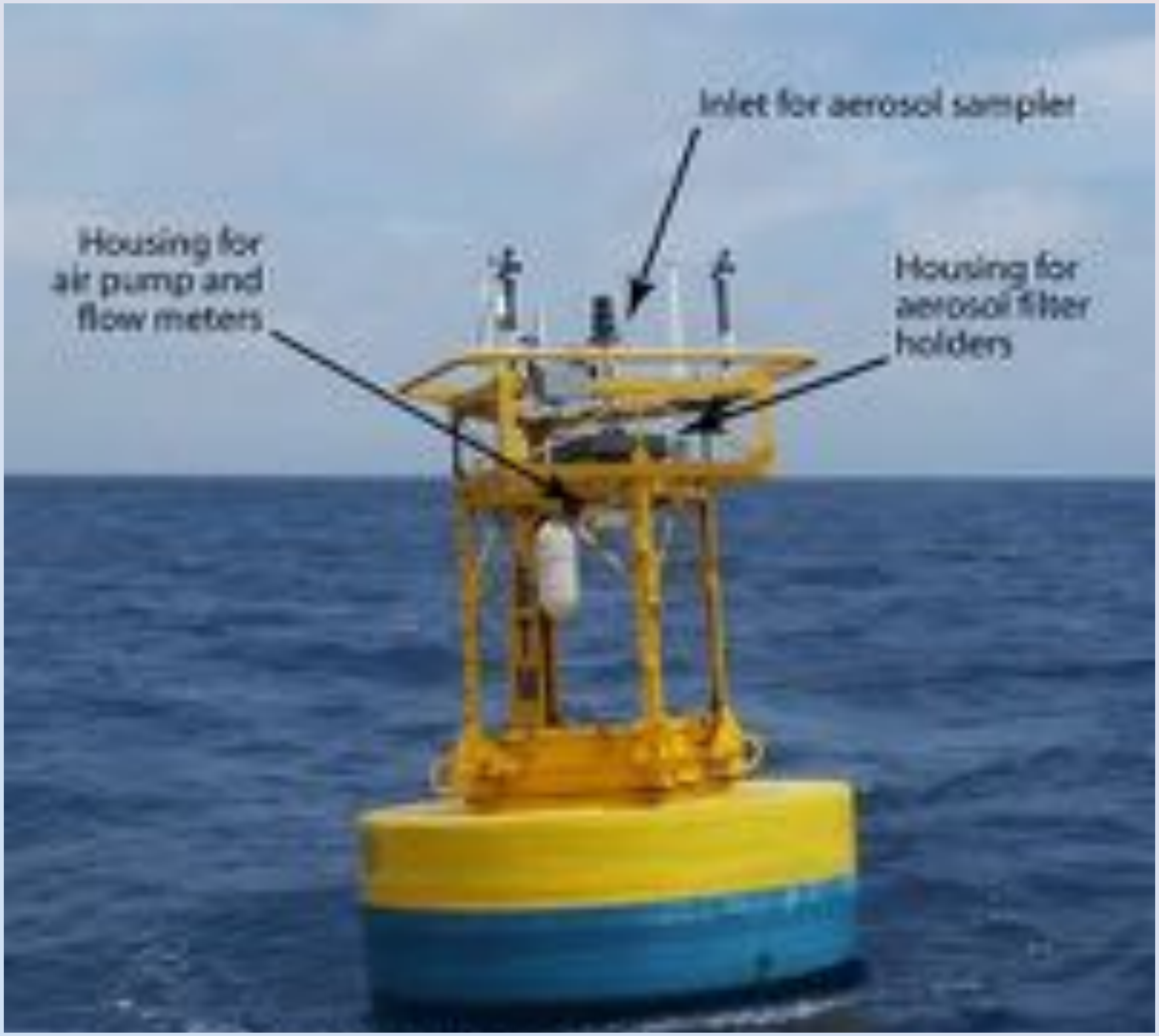
Figure 4. (a) AM2 simulated annual dust concentration at the surface (1979-1998), in units of μ gm^{-3}, with the locations of 20 sites operated by the University of Miami indicated by symbols. (b) Comparison of annual mean dust concentration, simulated and observed in 20 sites in 1988, in units of μ gm^{-3}. The dashed lines are factor of 2 lines. In both (a) and (b), the two sites in Antarctica are shown in squares. The other SH sites are indicated by circles and NH sites are indicated by triangles.

Li et al. 2008 Journal of Geophysical Research 113: D10207

Aerosols – biological productivity, impacts on surface radiation and on cloud physics

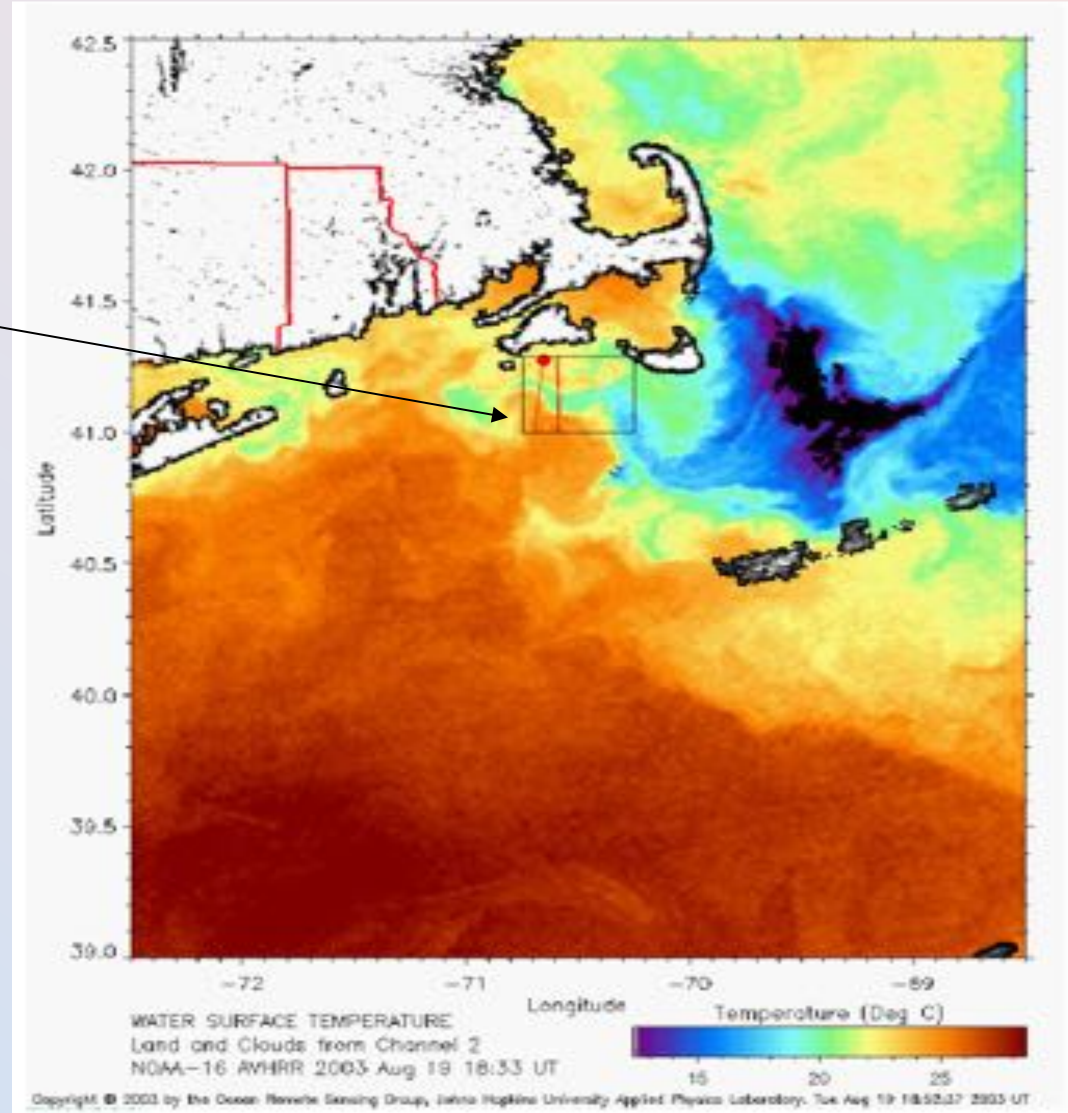


Aerosol sampling



Foci:
- micronutrients
- salt particles
- DMS production
- role of organic surface films
- bubble processes
  - gas transfer
  - ocean sound

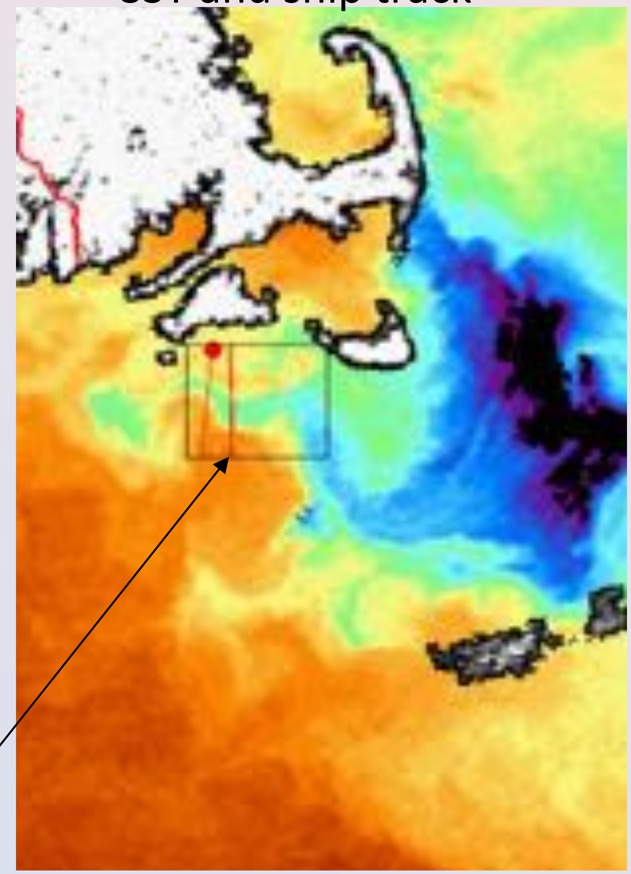
Satellite SST and ship track from August 19, 2003

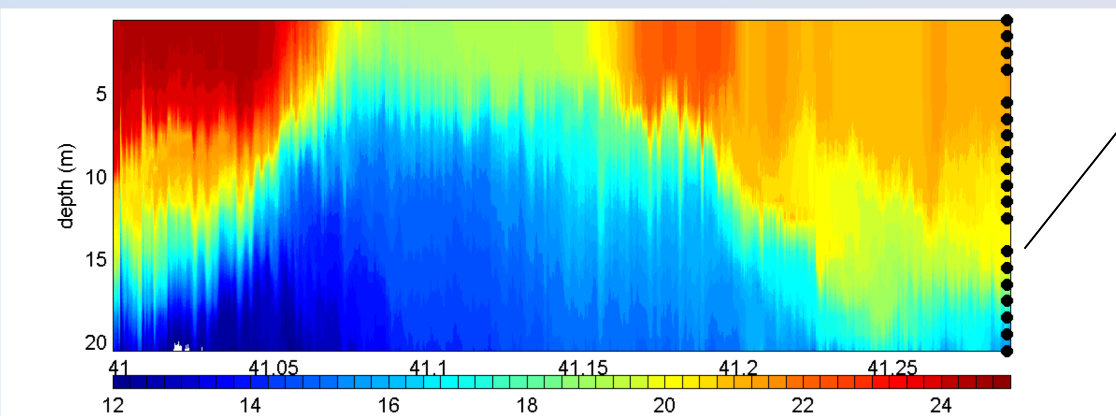


[SST from Ocean Remote Sensing Group, Johns Hopkins University, APL]

Boundary layer coupling at local scales: impacts on dynamics, on EM propagation.

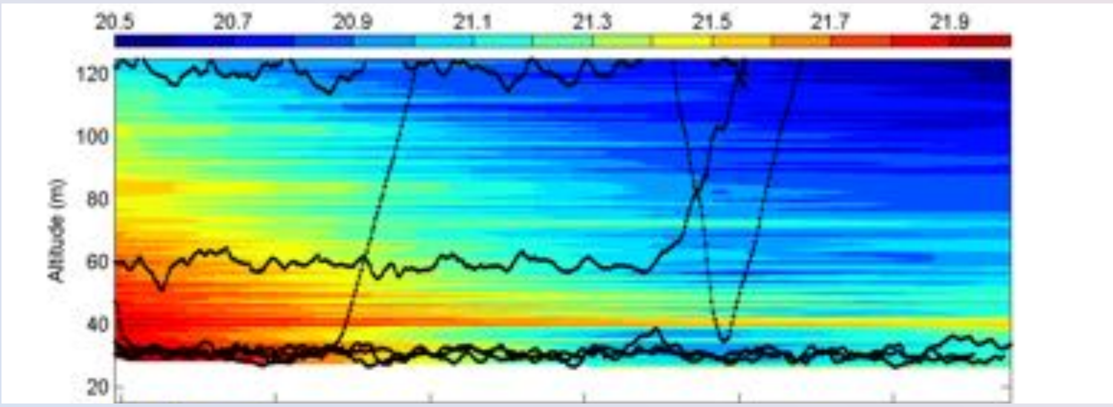
SST and ship track



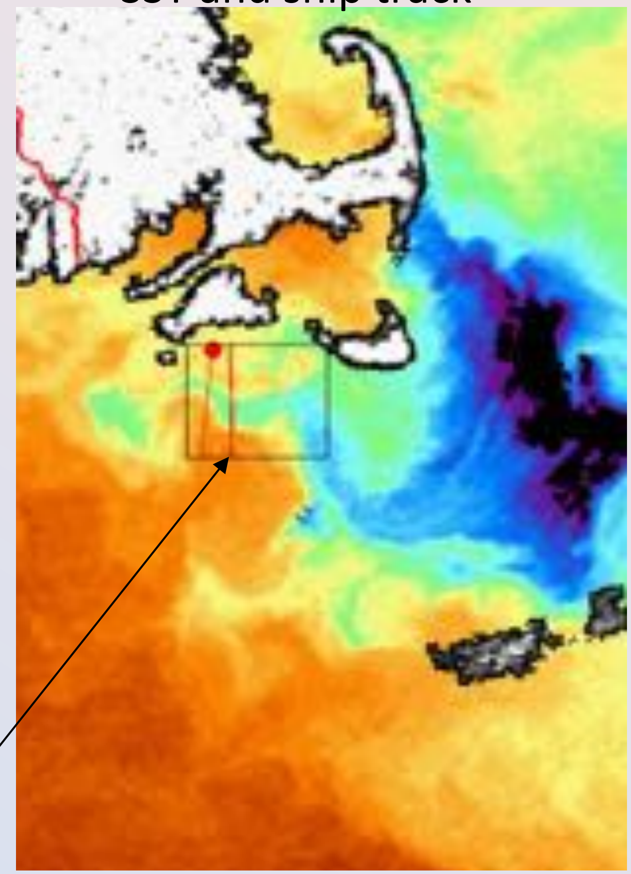


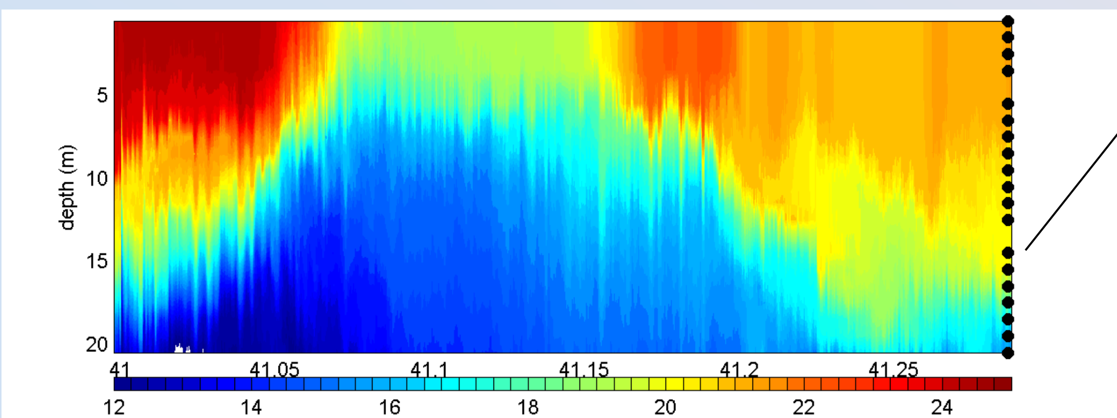
Subsurface temperature (°C)

Pelican air temperature (°C)



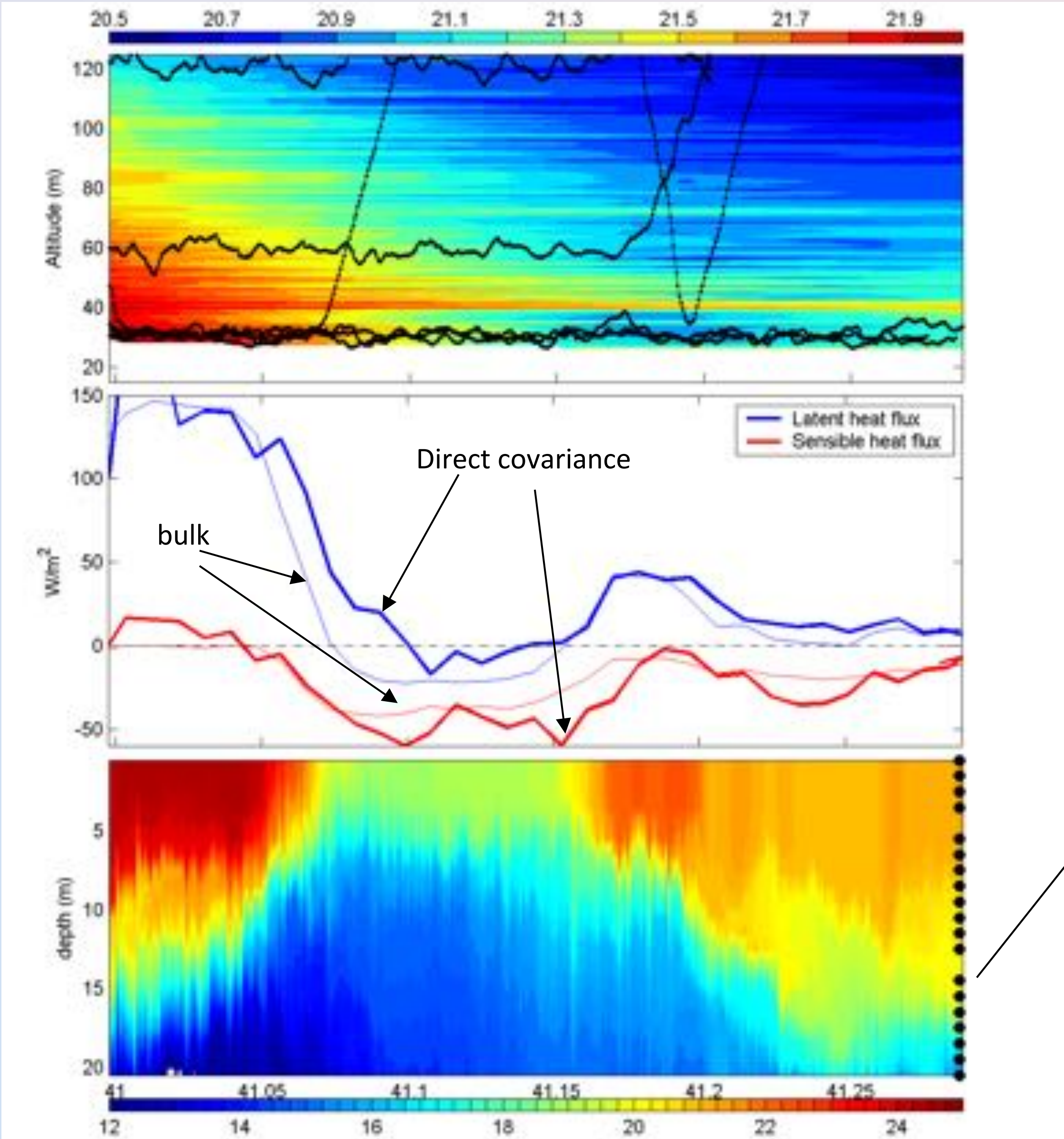
SST and ship track



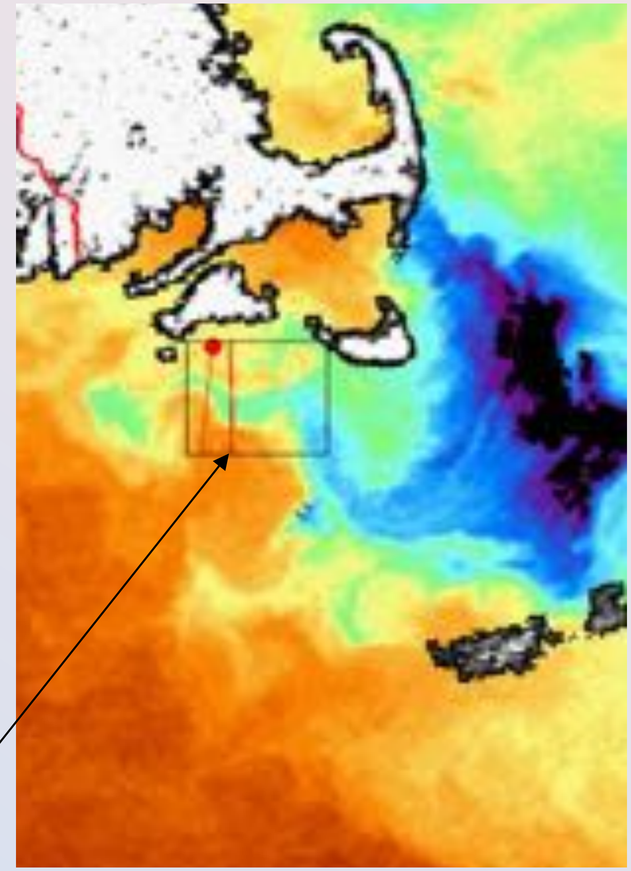


Subsurface temperature (°C)

Pelican air temperature (°C)

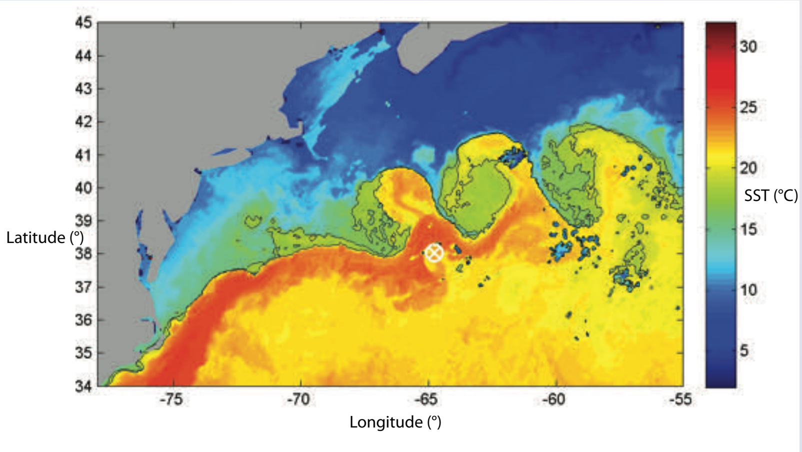


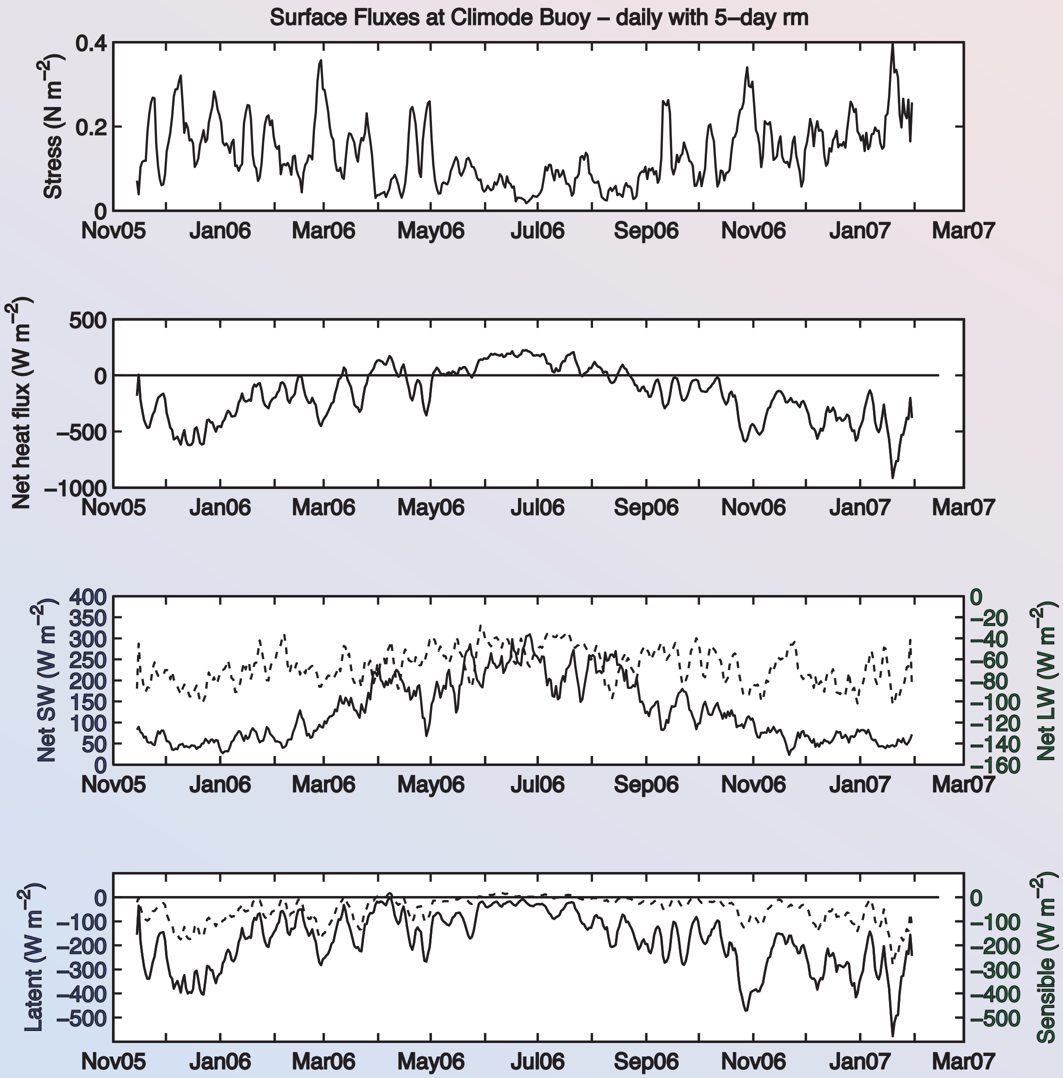
Regional ocean variability introduces spatial variability in air-sea fluxes



Subsurface temperature (°C)

Strongly forced regions, roll of SST gradients

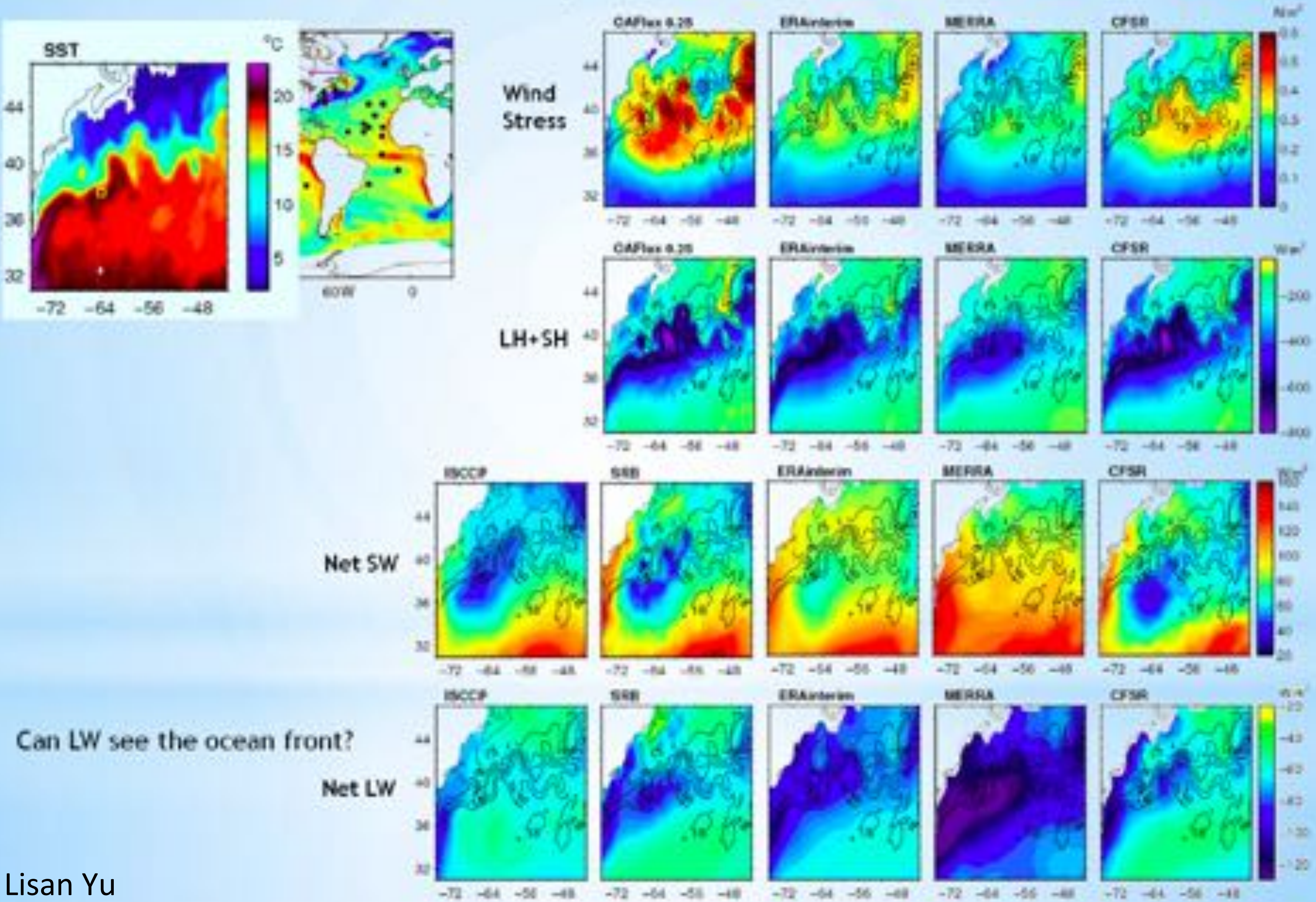




Largest hourly-averaged net heat loss by ocean during a cold air outbreak = -1407.9 W m^{-2}

(i) Coupling between SST, wind, and surface fluxes over the Gulf Stream

A cold air outbreak event during February 1-14, 2007



Lisan Yu

Summary

- 1) steady progress leading to greater capabilities (sensors, Bulk Formulae methods, DCFS) and user-friendly instrumentation (e.g., ASIMET modules)
- 2) strong interest in basin and global scale fields and climate variability and thus in better integration/cross calibration land to ocean
- 3) sustained observing on global basis, some as withheld, reference sites working toward model improvement
- 4) strong interest in the regional, mesocale, submesoscale coupling of ocean and atmosphere
- 5) will have buoys coming on line with 100 Watts of power so can host an increasing suite of lower atmospheric instruments and profilers
- 6) increased multidisciplinary instrumentation