WCRP CLIVAR High Latitude WG
SEAFLUX 2010 Meeting
Boulder, Colorado
March 17, 2010

Observational challenges for turbulent and radiative fluxes at high latitudes

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Physics of air-surface interactions and coupling to ocean-ice/atmosphere BL

Aspects:

- Emphasize surface fluxes
- Direct versus Bulk Flux Parameterizations
- Observing Technologies
- High Latitude Issues
  - Ice covered vs non-ice covered
  - Sampling versus Parameterizations

Sample Applications:

- Model lower BC (PBL, Meso, NWP, GCM)
- Ocean budgets (stress, heat, waves, sea-ice)
- Carbon budgets
- Pollution deposition (particle, ozone)
- Cloud microphysics (aerosol source, DMS)

Flux Definitions

$$Sensible\ Heat: H_s = \rho_a c_{pa} \overline{w'T'}$$

$$Latent\ Heat: H_l = \rho_a L_e \overline{w'q'}$$

$$Stress: \vec{\tau} = \rho_a \overline{w'u_x'}\hat{i} + \rho_a \overline{w'u_y'}\hat{j}$$

$$Rain\ Heat: H_p = c_{pw} P(T_s - T_{wet})$$

$$BuoyAir: F_b = H_s / \rho_a c_{pa} + 0.61T\ H_l / \rho_a L_e$$

$$BuoyWater: F_b = -\alpha g H_{net} / \rho_w c_{pw} + \beta g(E - P)$$

$$Gas\ Exchange: F_x = \overline{w'r_x'}$$

$$Particle\ Exchange: F_n = \overline{w'n(r)'} - w_g \overline{n(r)} + \overline{w_s'n(r)'}$$

Present Status of *Surface* Flux Parameterizations

Turbulent Fluxes: Bulk Parameterization

Mean correlation of turbulent variables represented in terms of mean flow variables – wind speed, surface-to-air variable difference

MetFlux – Dominated by atmospheric turbulent xfer

GasFlux – Dominated by oceanic molecular xfer;
Enhanced by whitecap bubbles

$$Met\,Flux: \overline{w'x'} = C_x U (X_s - X_r) = C_x U \Delta X$$

$$Gas\,Flux: \overline{w'x'} = k_x \alpha_x \Delta X \qquad \alpha = sol.$$

Radiative Surface Fluxes:

R=F(lat, lon, time, T, q, clouds)

Direct in situ measurement pyanometers & pyrgeometers

Indirect in situ (MetObs, cloud obs plus a formula)

Indirect satellite (Upward radiation converted to surface flux)

Flux Observing System

- In Situ
  - Point, Direct U, Ts, Ta, RH, indirect Hs, Hl, indirect or indirect Rs, Rl
- Satellite
  - Grid (space/time), volume average, Indirect U, Ts, Ta, RH; indirect flux
- NWP
  - No fluxes, assimilated ‘OBS’ consistent with dynamics and energy balance
  - Ocean, Land, aircraft, balloons, satellite
  - Massively developed, routine quality evaluation process

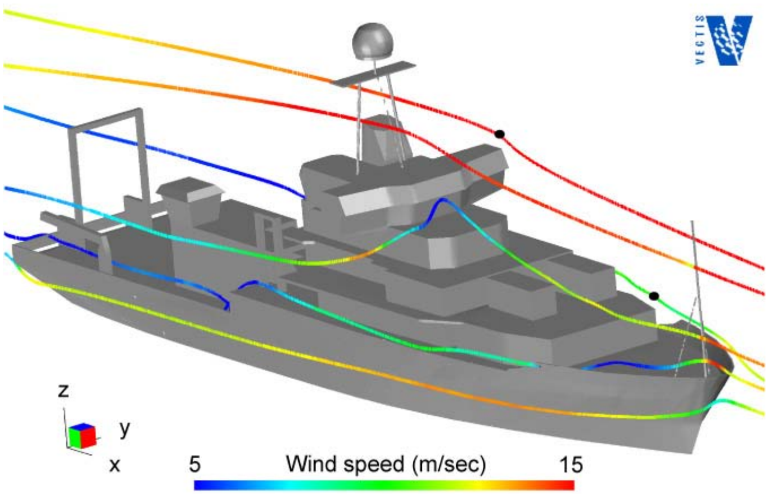
Direct Flux Sensing Technologies

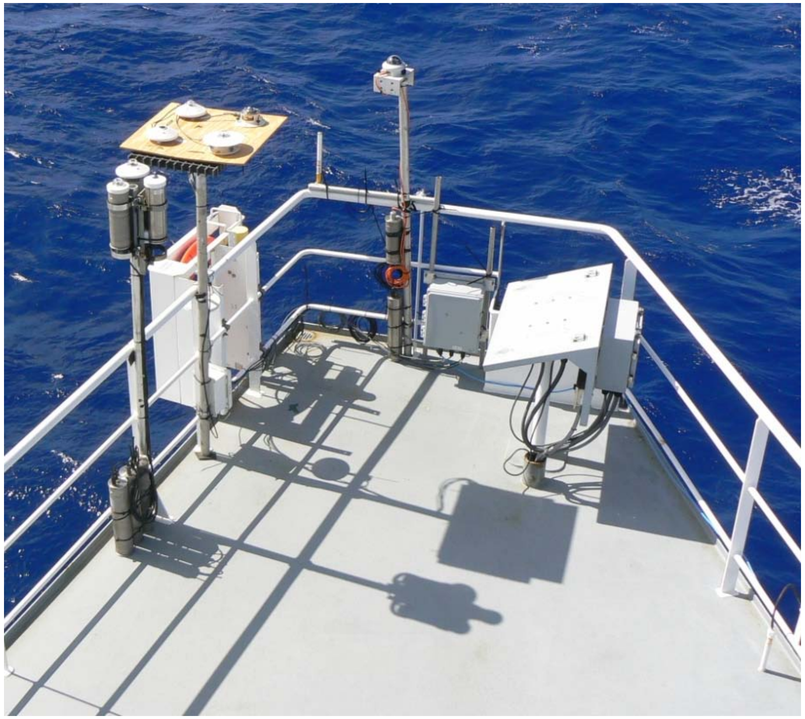
- Near-surface in situ
  - Sonic anemometer/thermometer
  - IR fast hygrometer, fast CO2
  - Chemilum. Fast ozone, DMS
  - High quality mean T, q, Ts
  - Eppley solar/IR radiometers
  - Surface waves
- Direct data used principally to develop parameterizations, improve the observing system, and 'verify' model results
  - Empirical coefficients computed from direct flux measurements

Table 1. *In situ* observing system components and their flux bias uncertainties estimated for a 1-month period such as could be used for intercomparison with remote sensing, reanalysis, or NWP net flux estimates. All platforms measure basic bulk meteorological variables. The flux uncertainties are given parenthetically in column 3 for estimates of turbulent fluxes by bulk [Bulk Turb] or direct covariance [Direct Turb] methods and radiative fluxes based on visual cloud observations and near-surface bulk variables [Bulk Rad] or direct measurement with radiometers [Direct Rad]. The net bias in column 4 is the square root of the sum of the squares of the appropriate values in column 3 [e.g., in VOS line 28=sqrt(24^2+14^2)]. In some cases, estimates for both direct and bulk method options are given [e.g., VOS-CLIM]. General latitude bands where data are sufficiently available are indicated by N (north), S (south), or blank if not significantly available.

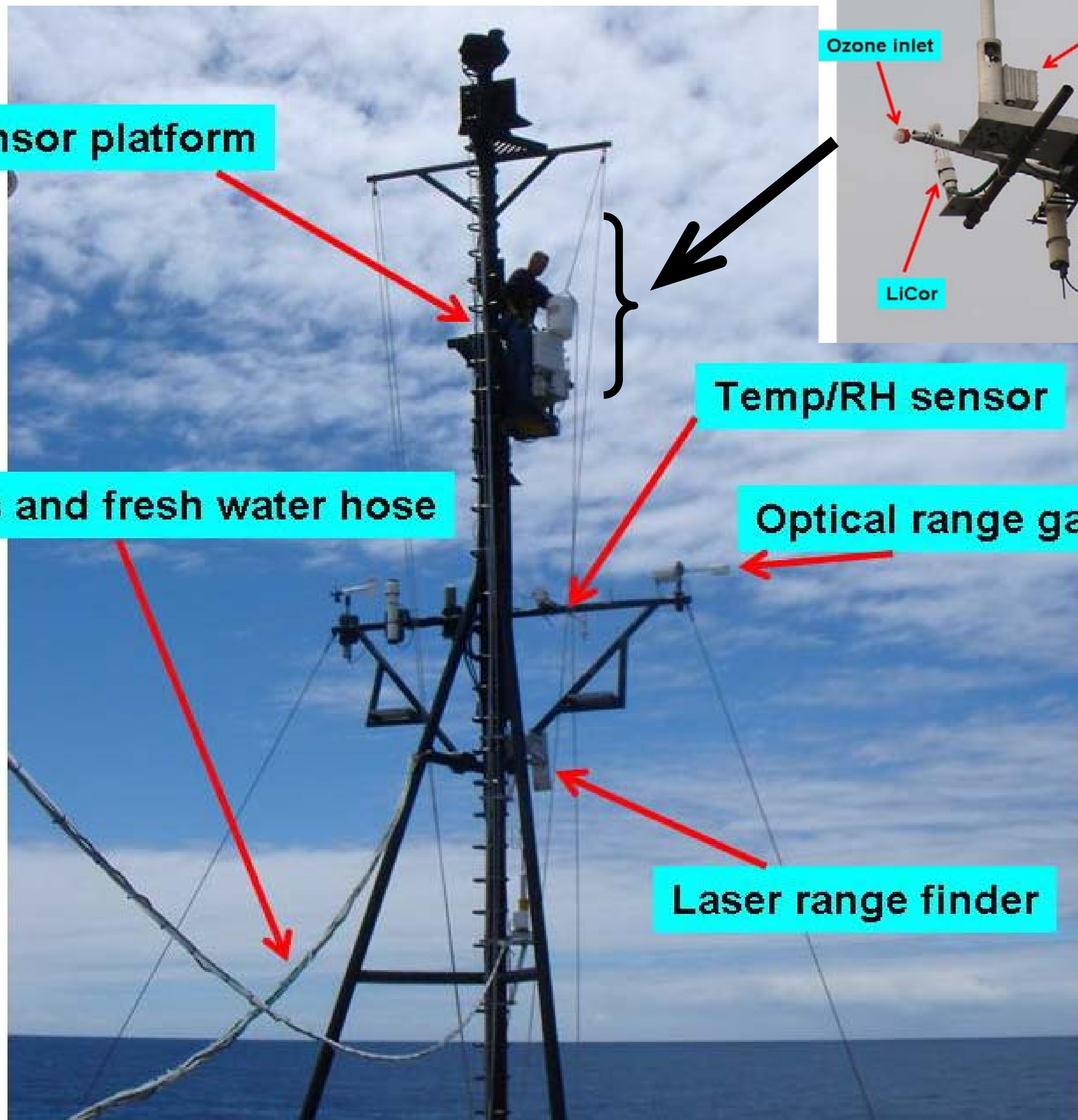
Type	**Platform**	**Observations**	**Net Bias**	**Sampling**	**Applications**
VOS	Commercial Ship	Bulk Turb (24) Bulk Rad (14) Param Precip	28	Variable in space and time, concentrated in NH and major shipping lanes	Used in gridded flux products Assimilated into reanalysis
VOS-CLIM	Commercial Ship	Bulk Turb (19) Bulk Rad (14) Direct Rad (8) Param Precip	 24 20	Variable	Used in gridded flux products Assimilated into reanalysis
SAMOS	Research Vessel	Bulk Turb (12) Direct Turb (7) Direct Rad (8) Precip Gauge	14 11	Variable	Satellite, NWP intercomparisons
Buoy Networks	TAO, PIRATA, TRITON	Bulk Turb (11) Direct Rad (8) Precip Gauge	14	Typically coastal and equatorial arrays	Used in gridded flux products Assimilated into reanalysis
Flux Reference Sites	Buoy	Direct Turb (5) Bulk Turb (9) Direct Rad (6) Precip Gauge	8 11	Dispersed by climate zone requirements	Satellite, NWP intercomparisons. Climate research
Research	R/V, ASIS, Coastal Platforms, Ocean Station Ship, Ice camps	Direct Turb (5) Bulk Turb (9) Direct Rad (5) Precip Gauge	7 10	Variable, based on research priorities	Improved flux parameterizations and understanding of processes and variability

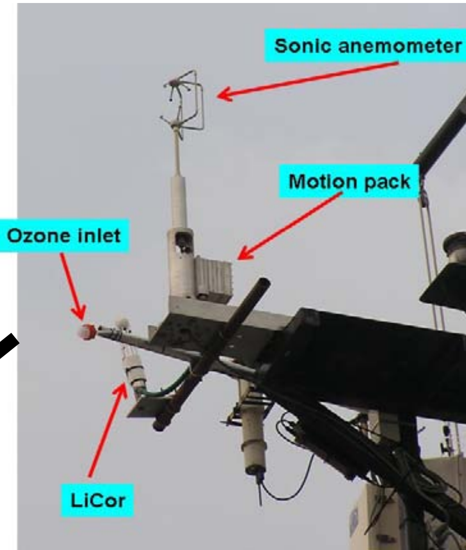
Direct Flux Measurements from Ships



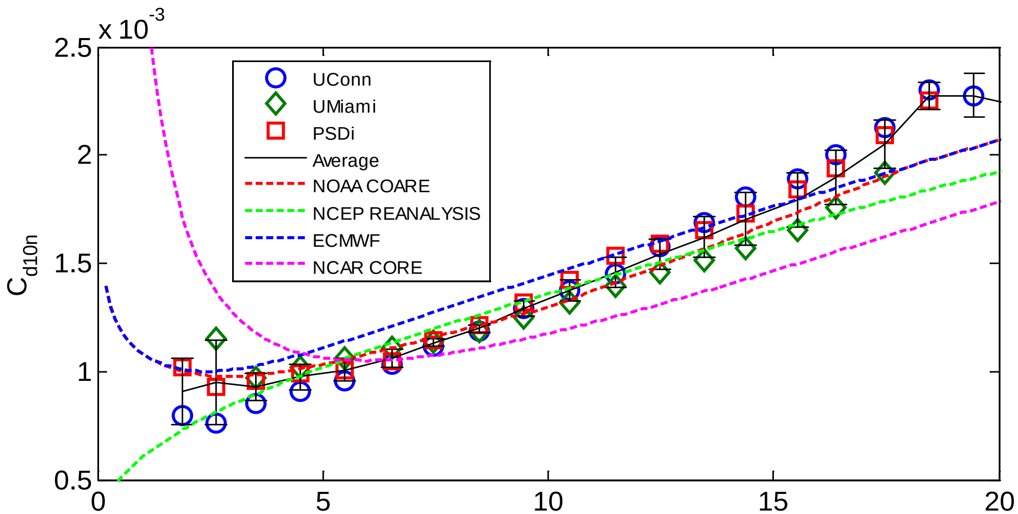


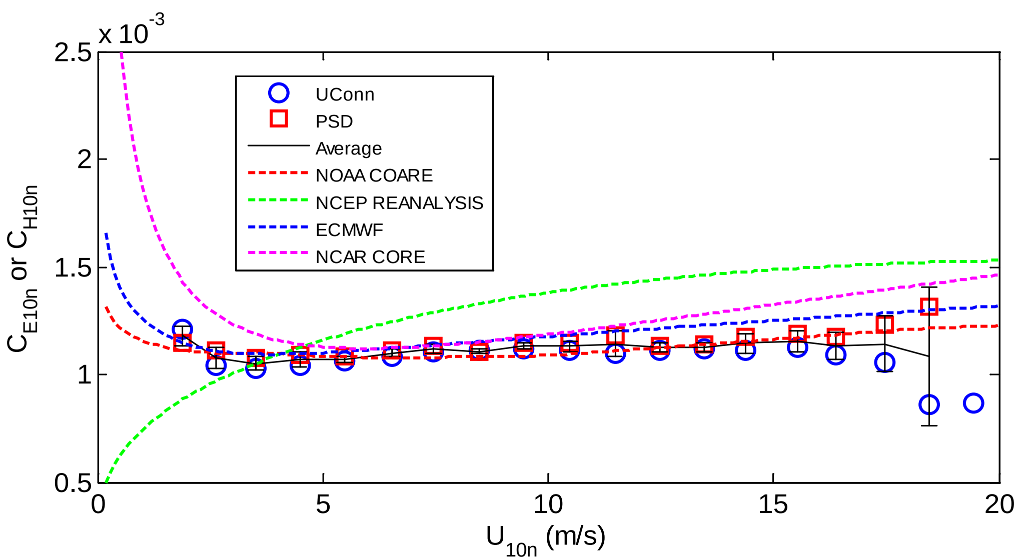
Example of Instrumented Mast





Synthesis On Ocean Turbulent Flux Parameterizations: Combined Observations from ESRL, UConn, UMiami





Neutral turbulent transfer coefficients at z=10 m as a function of wind.

Symbols are **Direct Data** (14,450 observations; 90% between 3 and 17 m/s)

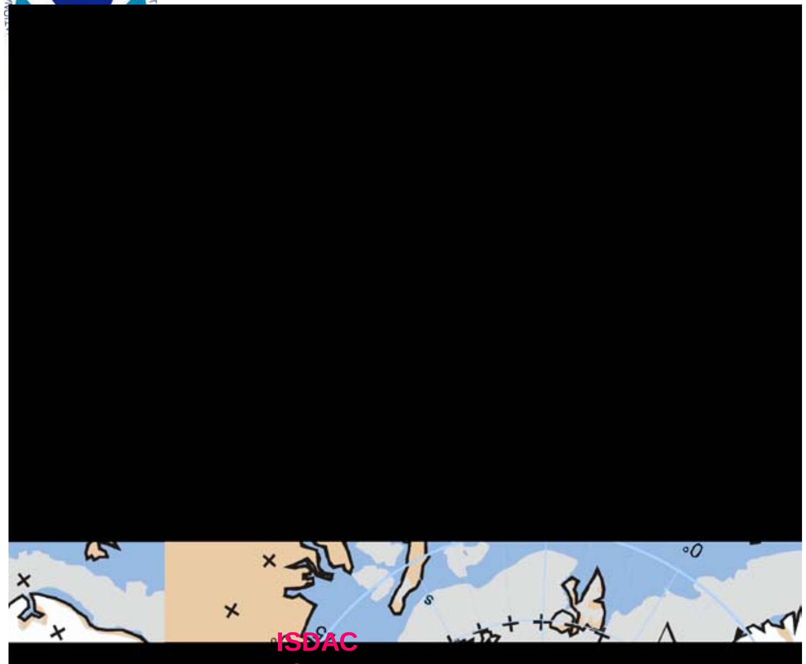
Dash Lines are **Parameterizations**

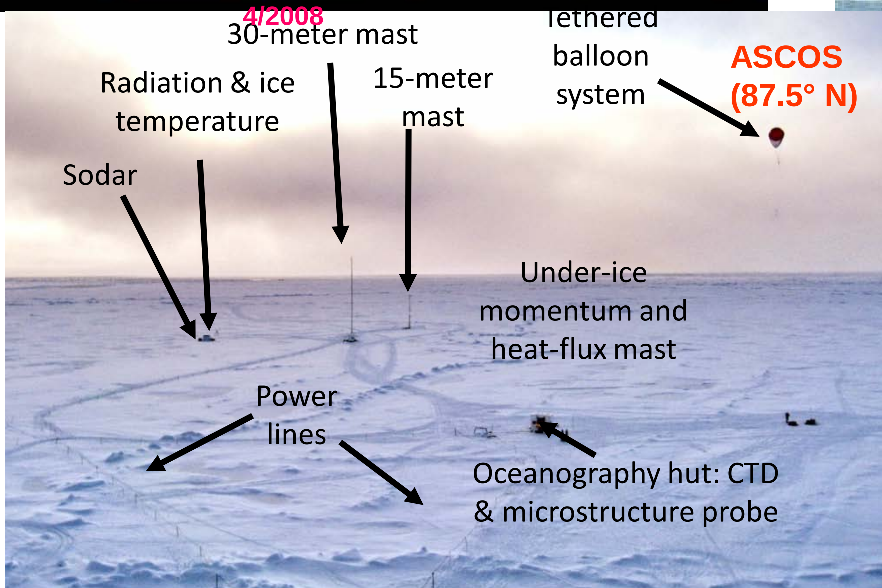
***Observations of 3 Research Groups Agree Closely (with 5%) But Need More High Speed Data**

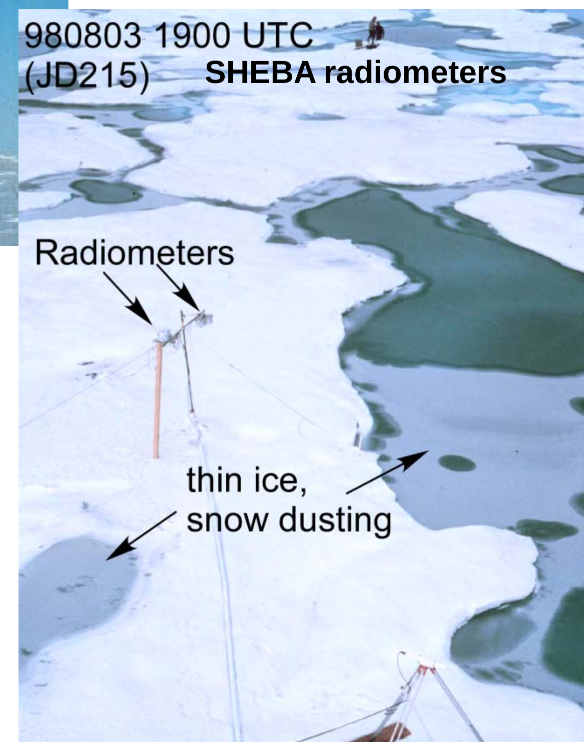
***Spread of Parameterizations is Greater Than Spread of Observations**

***NOAA *COARE* model is the best fit**

Direct Observations Over Sea Ice

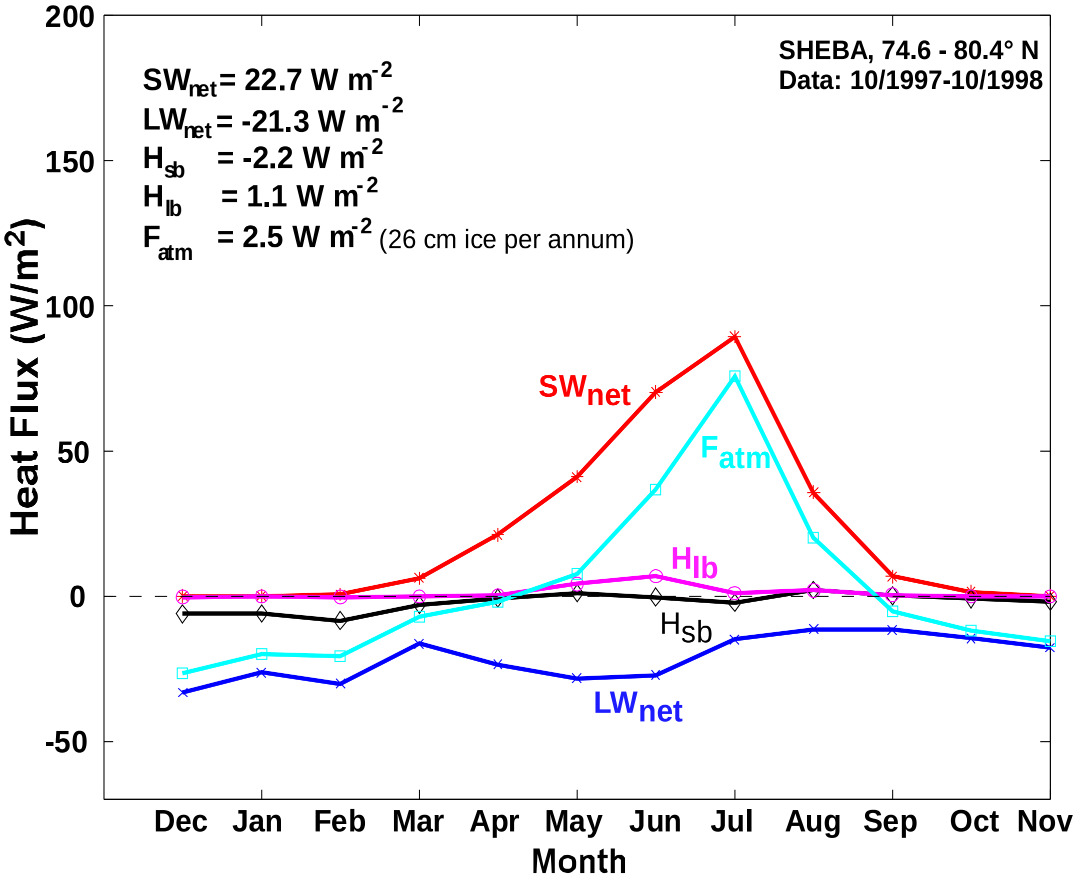






SHEBA only year-round turbulent and radiative flux observations over sea ice

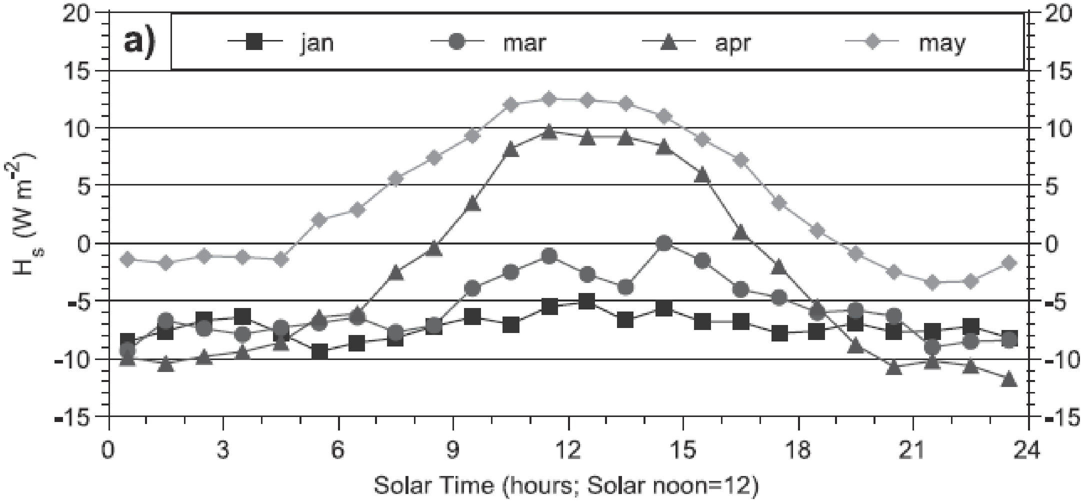
Multi-Year Pack Ice Site (SHEBA)



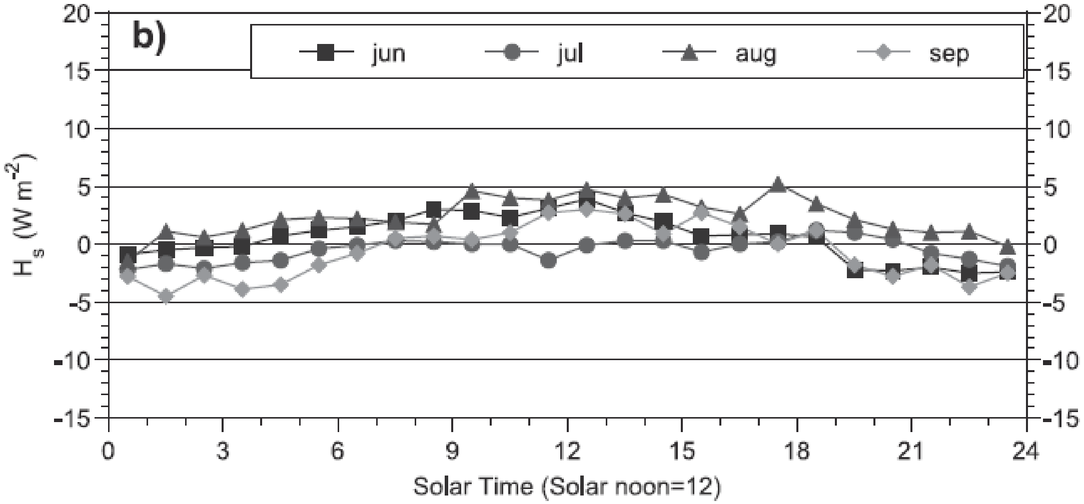
-turbulent fluxes order of magnitude smaller than individual radiative fluxes but comparable to net radiative fluxes

- annual mean net energy gain of **2.5 W m^{-2} is equivalent to annual melting of 26 cm of ice**. Hence, H_s (H_l) annual values of 1-3 W m^{-2} are significant.

SHEBA Turbulent Fluxes
Diurnal Cycle as Function of Season



- when T_s is free to vary and solar radiation is present, a significant diurnal cycle occurs



- when T_s is fixed due to melting, diurnal cycle is damped

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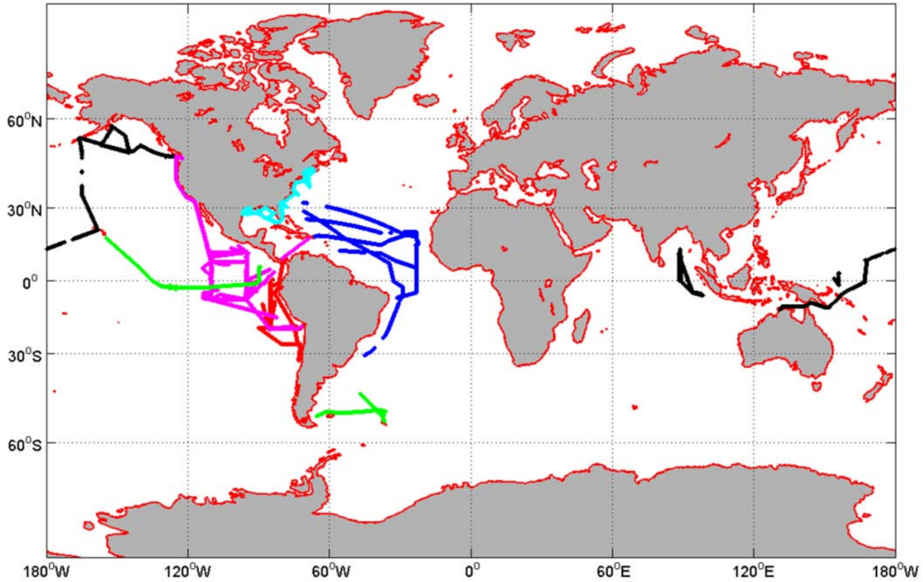
High Latitude **Sampling** Issues

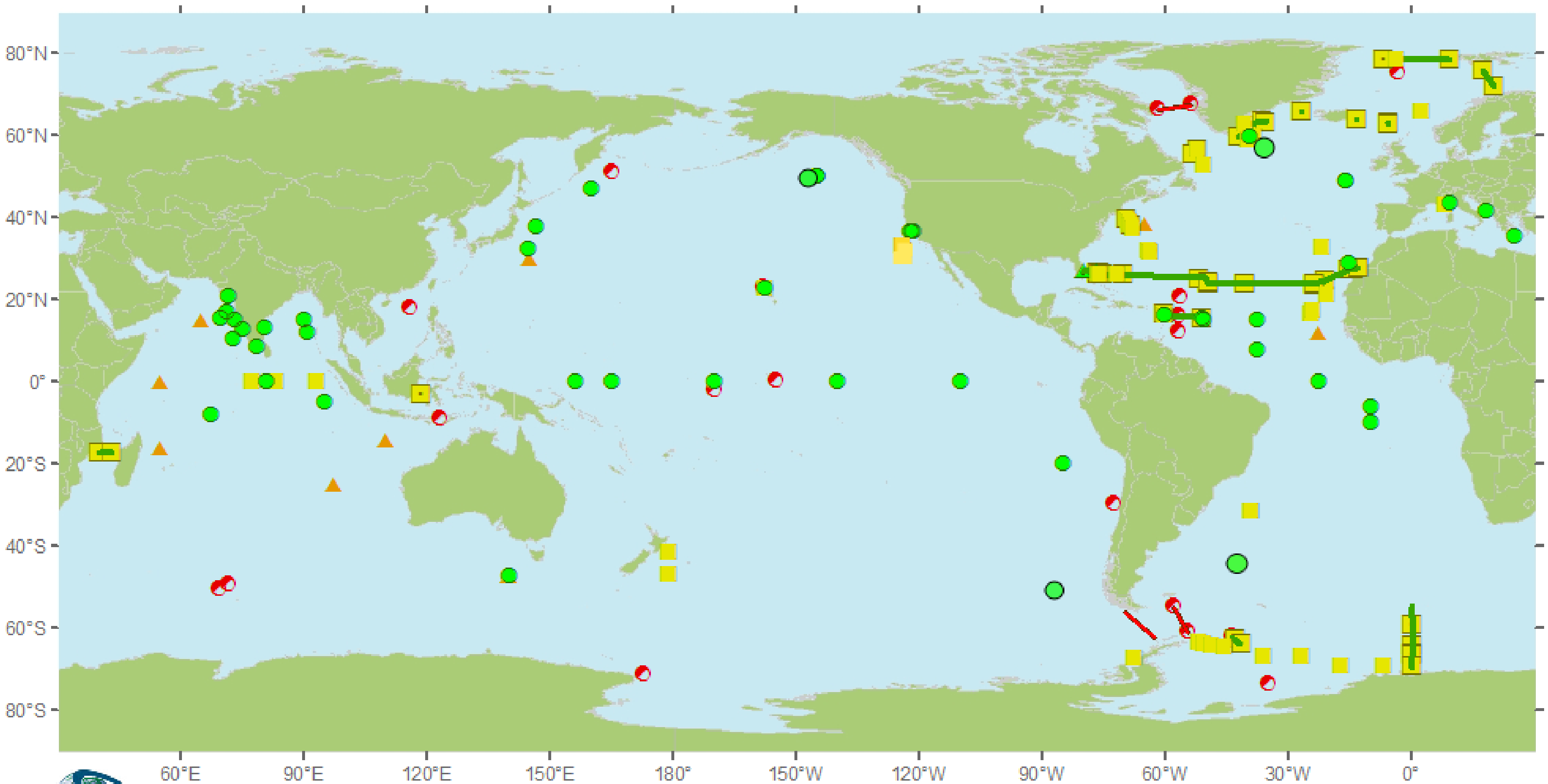
- In Situ
  - Essentially no VOS, VOS-CLIM, TAO buoys
  - Very Few Flux Reference buoys or R/V's
  - Almost nothing over the ICE
- Satellite
  - GOES not very useful
  - No wind speed over ICE
  - Low cloud and ice albedo complicates retrievals
- NWP
  - See Above



ESRL cruises on NOAA R/V Ron Brown

High Quality In Situ System

Send et al. 2009



OceanSITES

OceanSITES Vision Map 2009 - All Planned Sites

jcommops

JCOMM in-situ Observing Platform Support centre

OceanSITES Moorings and Observatories (87)
- OPERATING Real time data (45)
- OPERATING Delayed Mode data (39)

Planned or Discontinued (30)
- PLANNED Real time data (14)
- PLANNED Delayed Mode data (3)
- DISCONTINUED (17)

Transport sites (19)
- OPERATING (16)
- DISCONTINED (3)

Transport Stations (73)
- OPERATING Real time data (2)
- OPERATING. Delayed Mode data (65)
- DISCONTINUED (6)

Note: This status was based on information provided in early 2009.

High Latitude **Parameterization** Issues

Number of Dirt Effects for Direct Measurements
Items in RED worse in High Latitudes

- Severe motion corrections
- Contamination by salt, ship exhaust, sea gulls, …
- Flow distortion (Ship, tower, other sensors)
- Sensor separation, time delays, decorrelation, frequency response, path averaging,…
- Surface boundary conditions (currents, ocean/snow gradients)
- Extreme cold, icing, frost formation, fog/rain impact
- Poor signal to noise, weak stratified turbulence
- Sensor-variable crosstalk (Webb, motion, chemical)
- Artificial (self-) correlation
- A lack of field programs focused on parameterization

The Ocean at U10=25 m/s
When Viewed From 100 m Altitude

The Ocean at U10=20 m/s When Viewed From A Ship

Riming Problem for Radiative Flux Measurements

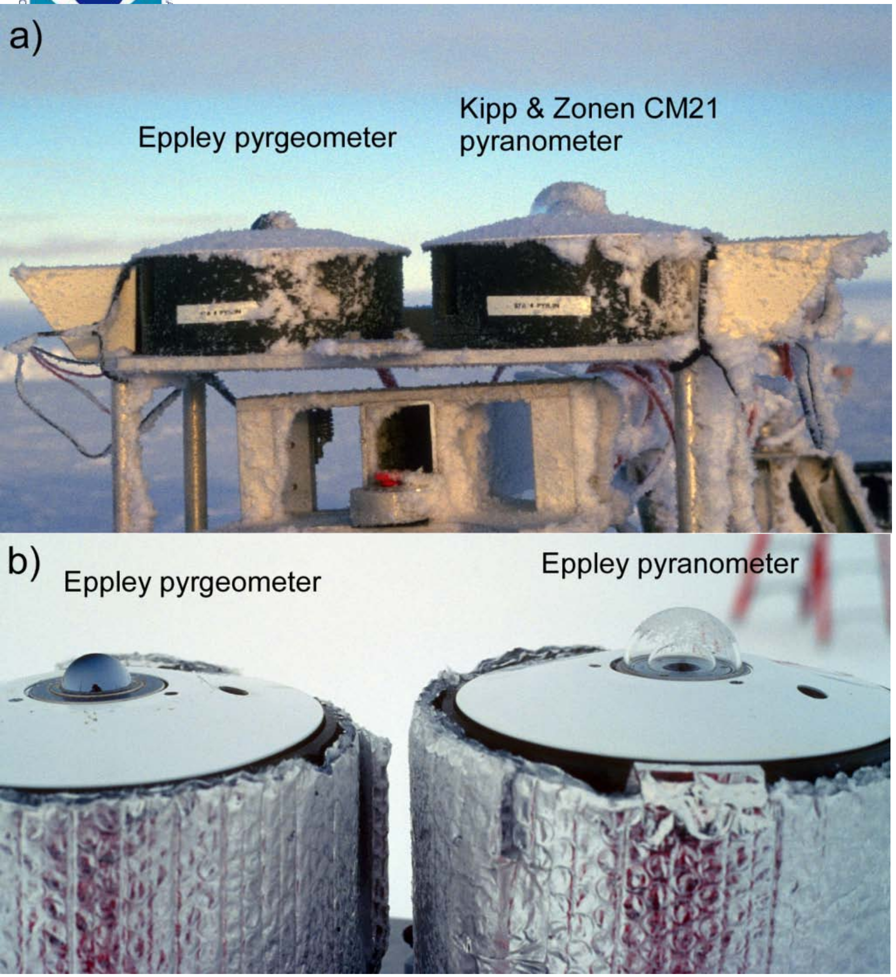


Fig. 1: a) Rimed pyrgeometer and pyranometer on Cleveland PAM station at SHEBA on 980404 at 1805 UTC (~0805 solar time). The radiometers are ventilated with DC power. b) Rimed pyranometer and unrimed pyrgeometer on ASFG mast at 1750 UTC 980408. These radiometers are ventilated (and heated) by AC fans. Logbook indicates this riming on ASFG domes is similar to or slightly less than that on the ASFG domes at time of photo in a). (photos: O. Persson)

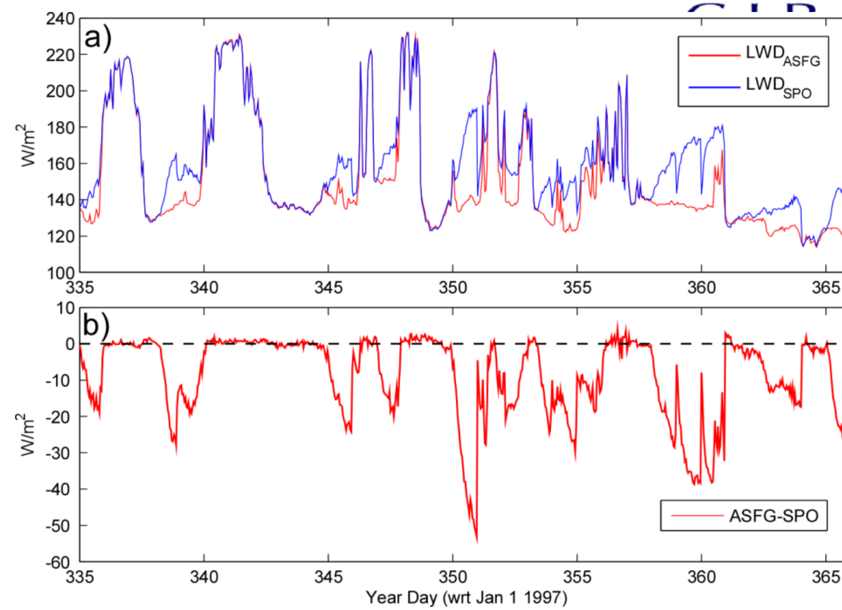


Fig. 2: Time series of a) LW_d at the ASFG tower(red) and the SPO site (blue) at SHEBA for the month of December 1997and b) the difference LW_d (ASFG) -LW_d (SPO). The dashed line in b) is 0 W m^{-2}.

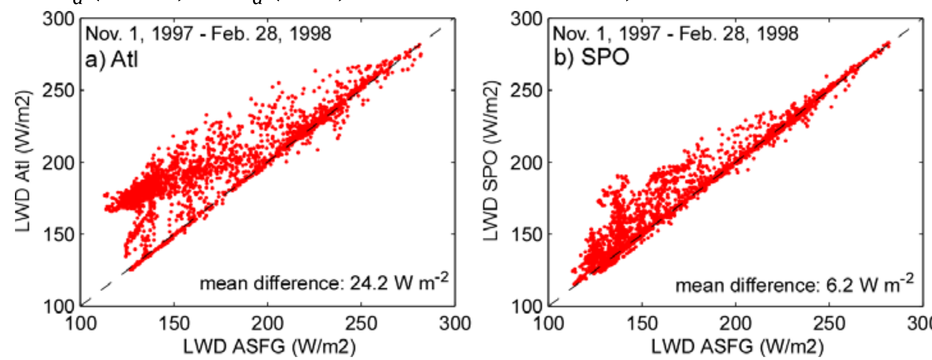


Fig. 3: Scatterplot of downwelling longwave hourly radiative fluxes from a) the automated station Atlanta and b) the DC-ventilated SPO radiometers at SHEBA simultaneous to ones from the AC-powered and heated/ventilated ASFG site for November through February.

Automated Radiative Flux Measurements Difficult

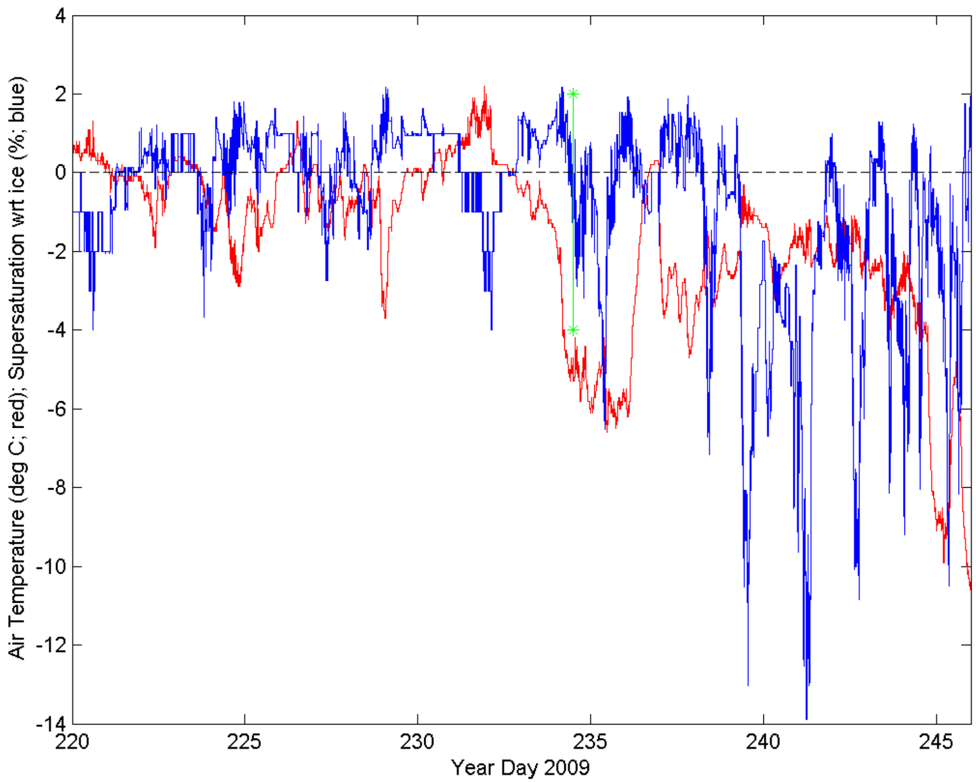


Fig: a) Riming on Eppley pyranometer on Aug. 21, 2009, at 1211 UTC during ASCOS and b) time series of ASCOS air temperature (red) and supersaturation wrt ice (blue). The vertical green line shows the time of photo, which was just after a period of ice supersaturation.

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Some Creativity Will be Required

Fig.7: Example of extreme riming on a heated and ventilated Kipp and Zonen pyranometer at Eureka, Ellesmere Island in late October 2009. Although the dome isn't rimed, the build-up around the dome will degrade the radiation measurement.

Wintertime Sea Ice Temperature Heterogeneity Impacts Surface Fluxes

Method to obtain spatial distribution of T_s, H_s, snow/ice thickness

1) uses simple 1-D snow/ice model and formation time of SAR-identified FYI
   - validation shows reasonable and consistent results
2) start in fall and identify areas named FYI0, FYI1, … FYI4, and examine surface H_s near end of January

GCM-scale aggregate T_s and H_s surrounding SHEBA site

1) month-long period on an hourly basis for both clear and cloudy conditions
2) best estimate for the aggregate H_s averages 6.2 W m^{-2} greater than the simultaneous H_s on the MYI
   - less than 10-12 W m^{-2} difference suggested by AVHRR assessments by Overland et al. (2002) - due to clear-sky sampling bias of the AVHRR measurements.
3) aggregate H_s typically greater than the MYI values for both cloudy and clear conditions, ranging 0 - 20 W m^{-2} during month

FUTURE

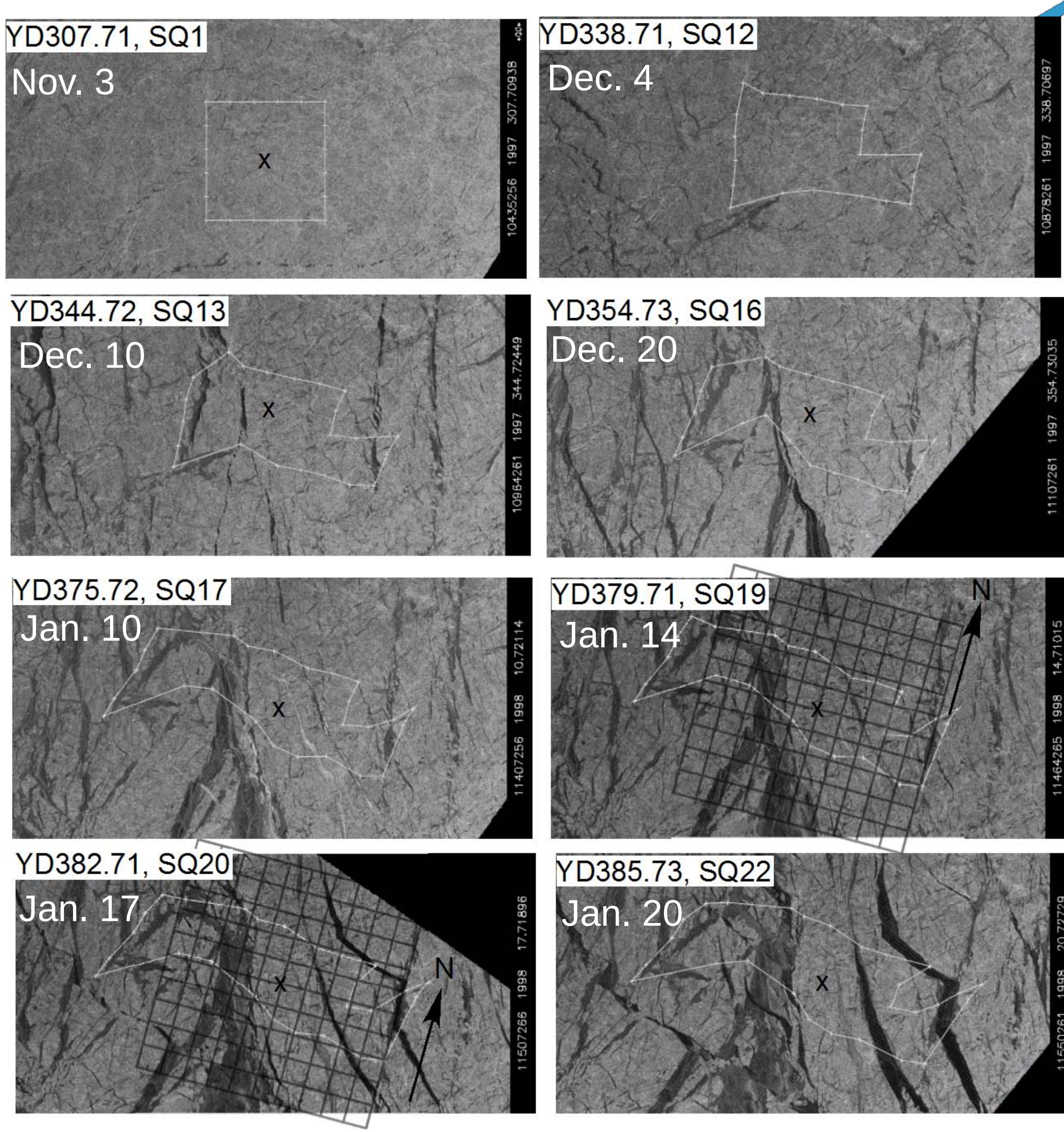
Snow depth and ice thickness fields from SAR/1D method used as lower boundary condition to 3-D mesoscale models

- provide mesoscale flux estimates

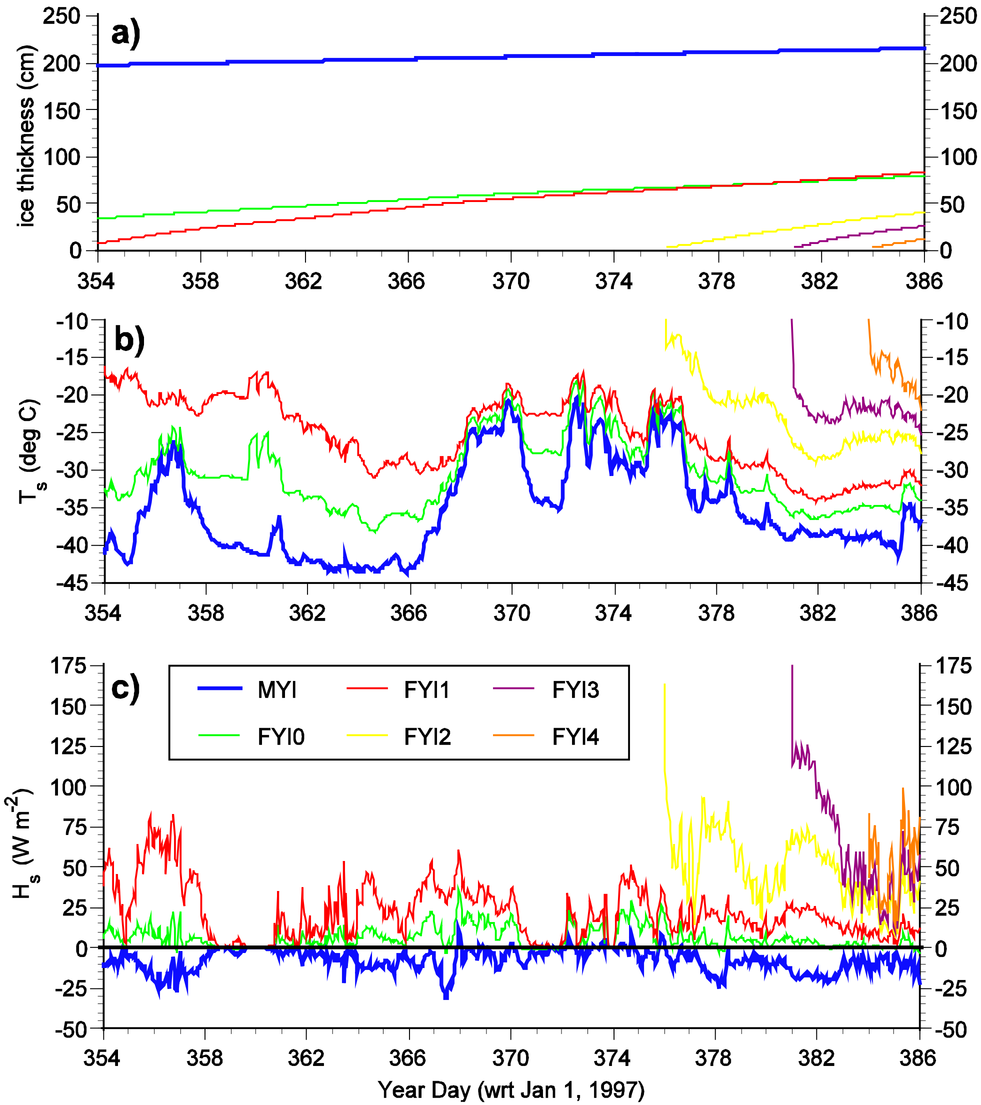
SAR Imagery

- to first order, radar backscatter intensity distinguishes FYI (dark) from MYI (light)

- FYI formed by opening of lead and freezing

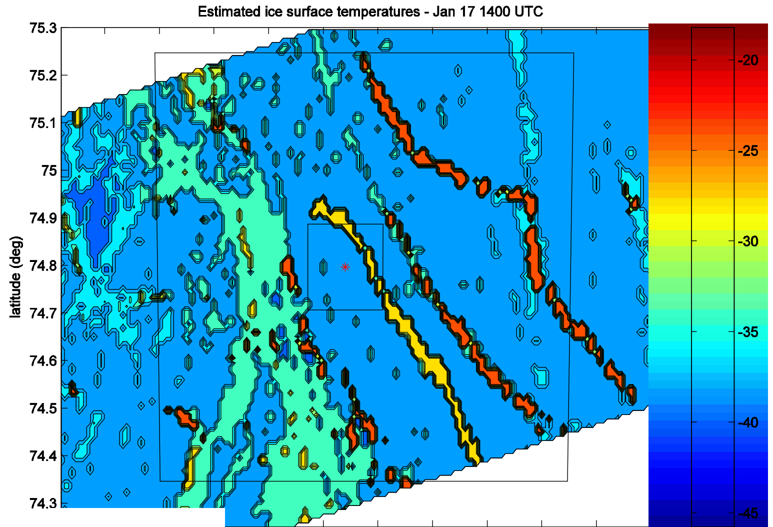


SAR/1-D model results

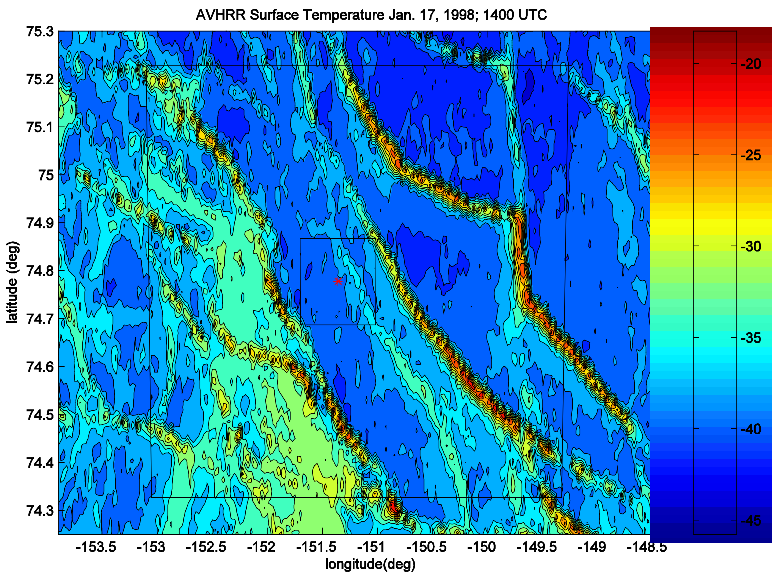


T_s distribution- 14 UTC Jan. 17

SAR/1-D model



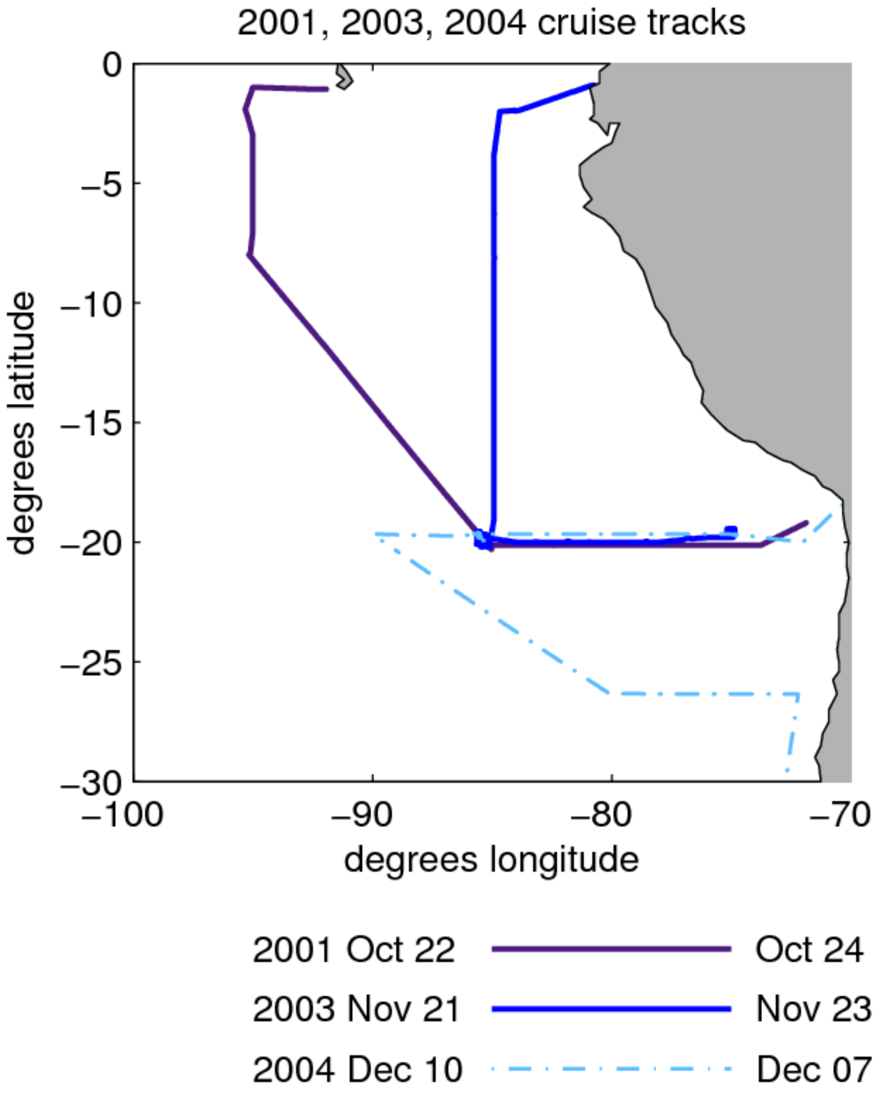
AVHRR

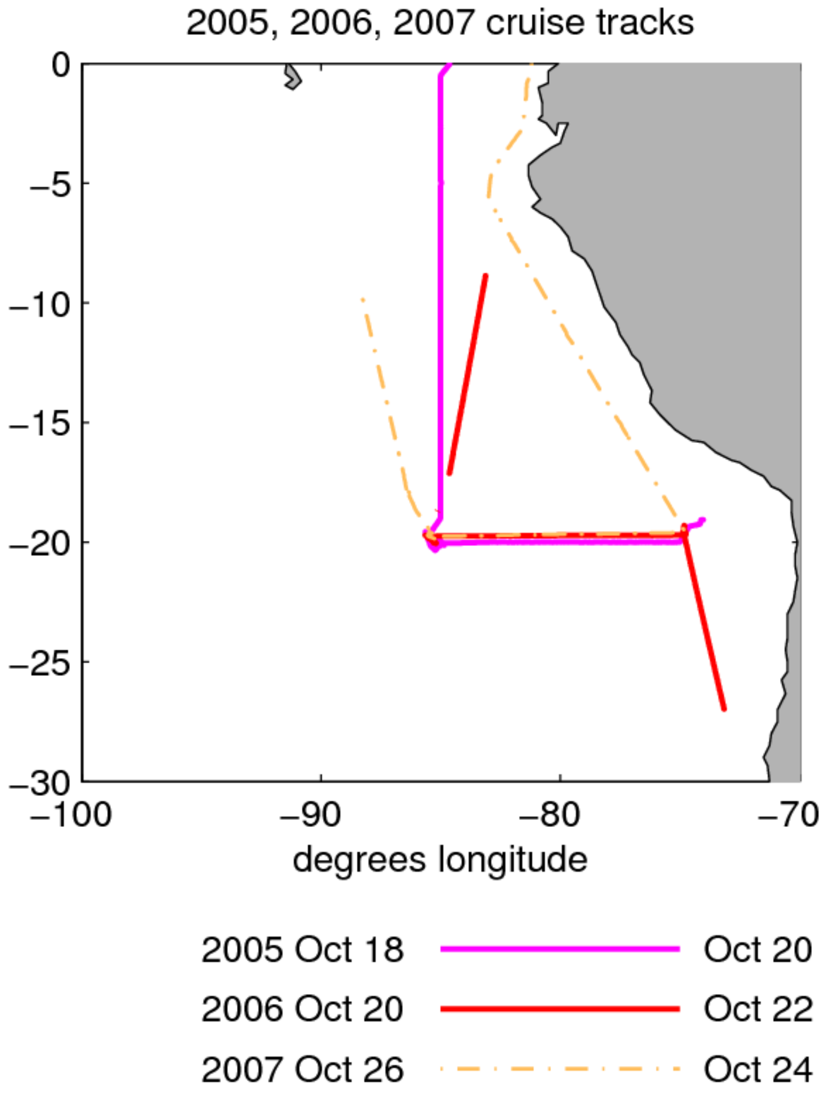


Low Latitude Example of the Possibilities

- Routine repeat cruises and flux reference buoys
- Tropical, subtropical
- Demonstrates accuracy of blended flux products

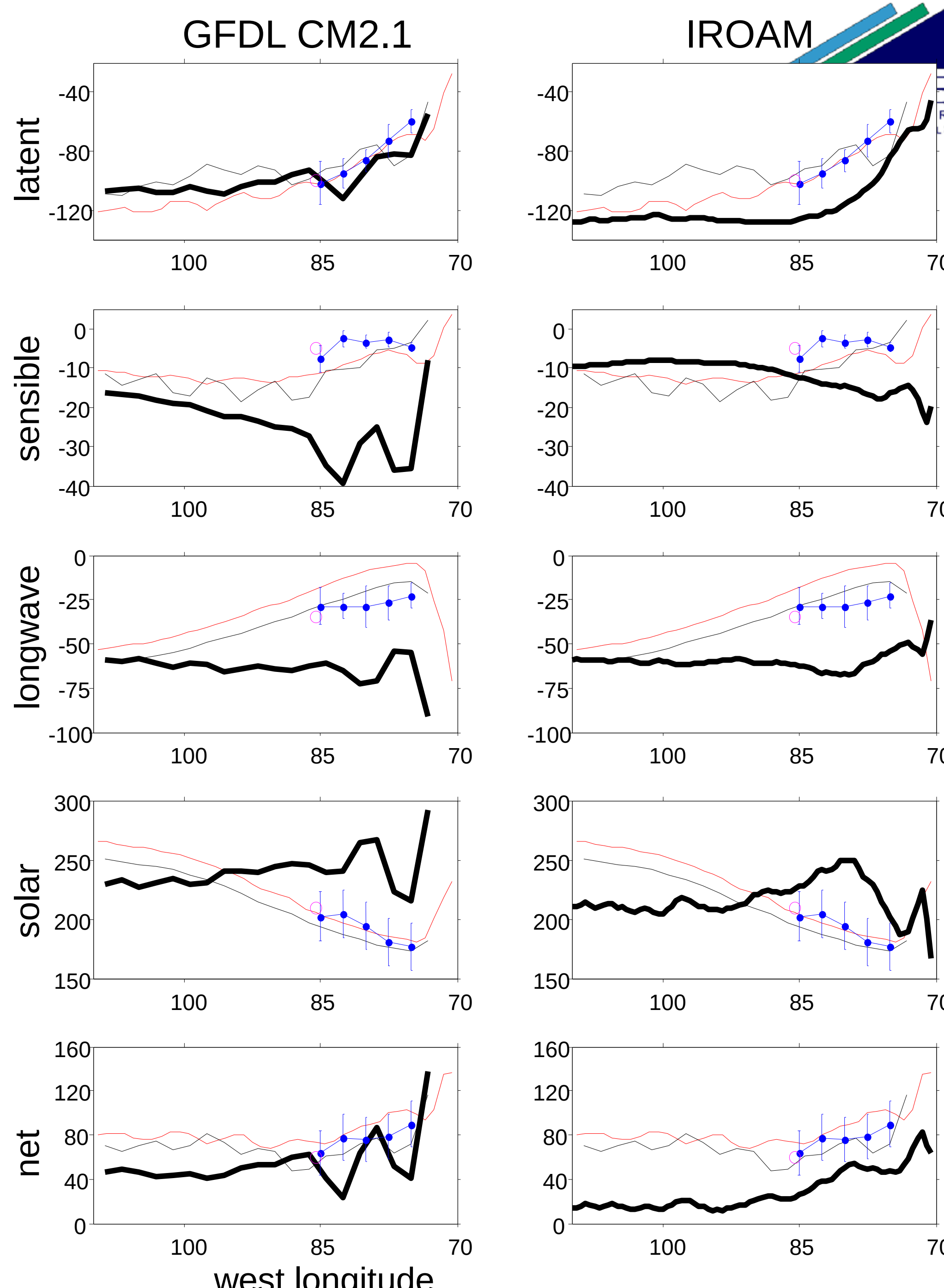
Stratus cruise tracks





October heat fluxes at 20˚S:

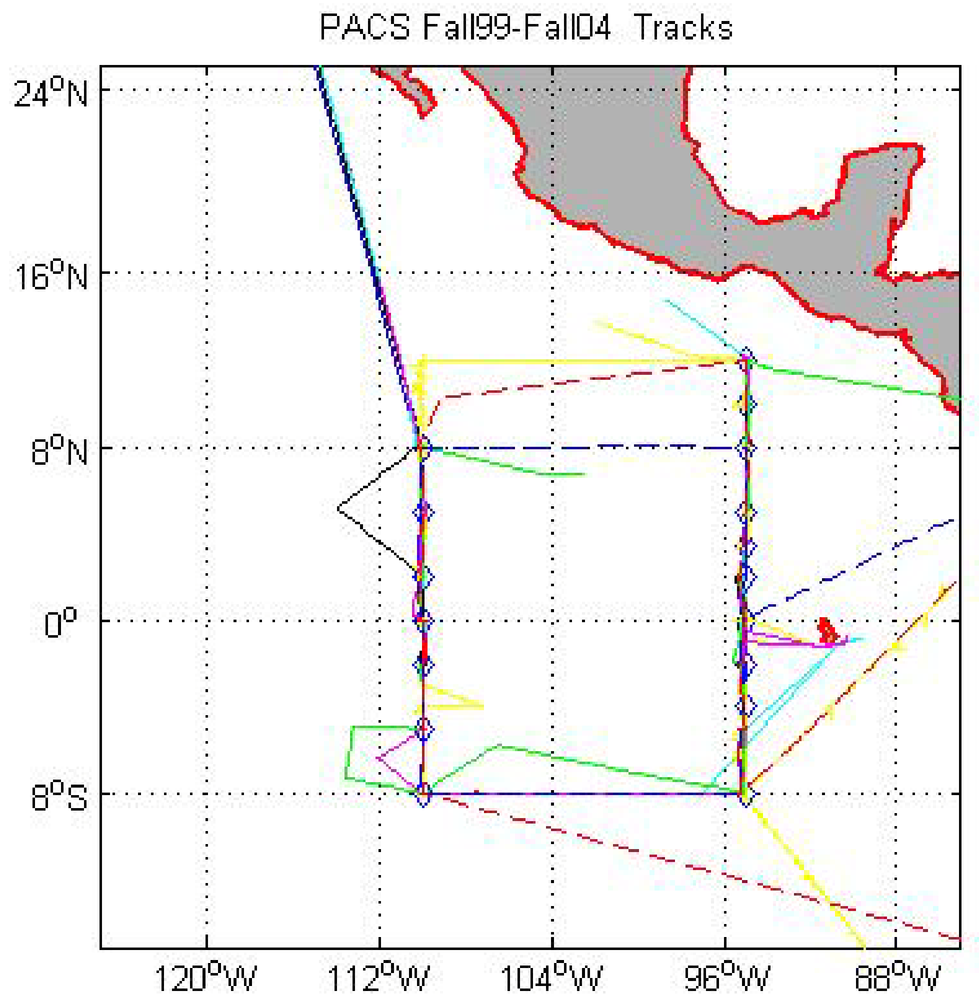
assess analyses and models



- Model
- WHOI ORS buoy
- WHOI (1984-2002) product
- CORE (1984-2004) product
- NOAA ship observations

PACS cruise tracks

9 PACS Cruises Conducted Before Stratus Cruises



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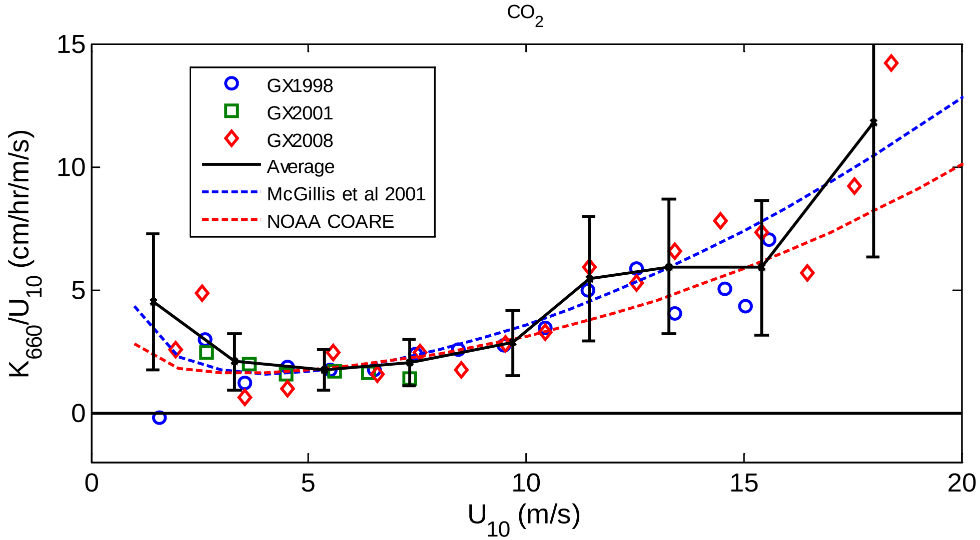
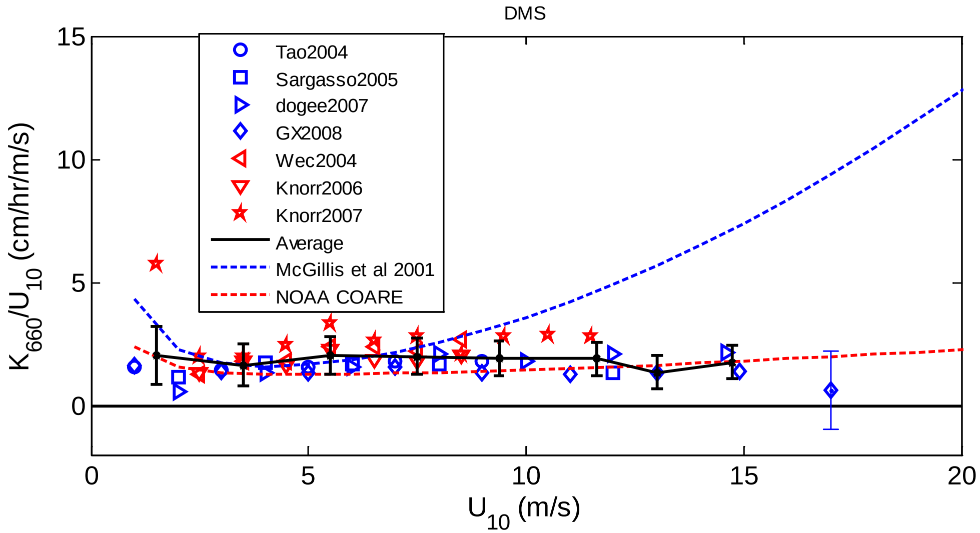
Contrast to Stress/Heat Coefficients: Large Uncertainties Remain for **Gas Transfer**





Gas Transfer Sensitivity to:

*Solubility
*Wave breaking
*Bubbles
*Tangential vs Pressure (wave) stress
*Surfactants
*Temperature
*Complex chemistry
*Biology