Ship-based Observations of the Marine Atmospheric Boundary Layer

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Atmospheric measurements aboard research ships: Needs, opportunities and challenges, ARICE April 13, 2021

- Near-surface observations (20 m): Air-sea interaction, SST and fluxes
- Atmospheric profiling (up to 3 km): Boundary-layer dynamics, clouds, interaction with free troposphere

Outline

- Background of PSL work
  - Research air-sea interaction
  - Ocean observing system
- Atmospheric Boundary Layer profiles
- Issues in ship in situ observations
  - Accuracy requirements
  - Sampling, sensors, ship effects, contamination
- Near-surface Meteorology
- Radiative flux

PSL Air-sea Research

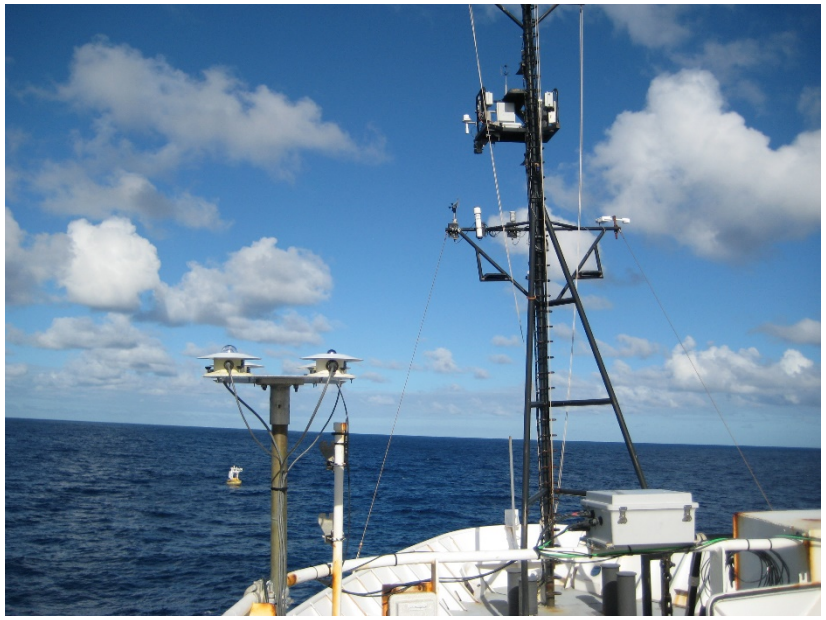
- Direct observations of air-sea fluxes and associated bulk variables: stress, turbulent heat, trace gases, radiative fluxes
- Characterization of interactions with Boundary Layer
- Bulk flux algorithms – COARE
- Parameterization variables: waves, whitecaps, clouds, …

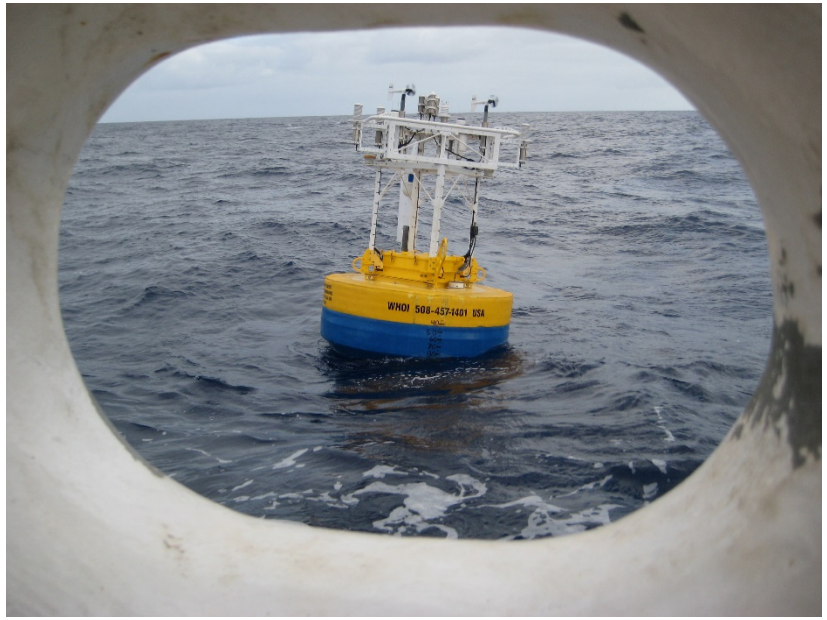
$$Met\ Flux: \overline{w'x'} = C_x \mathrm{S}(X_s - X_r) = C_x S \Delta X$$

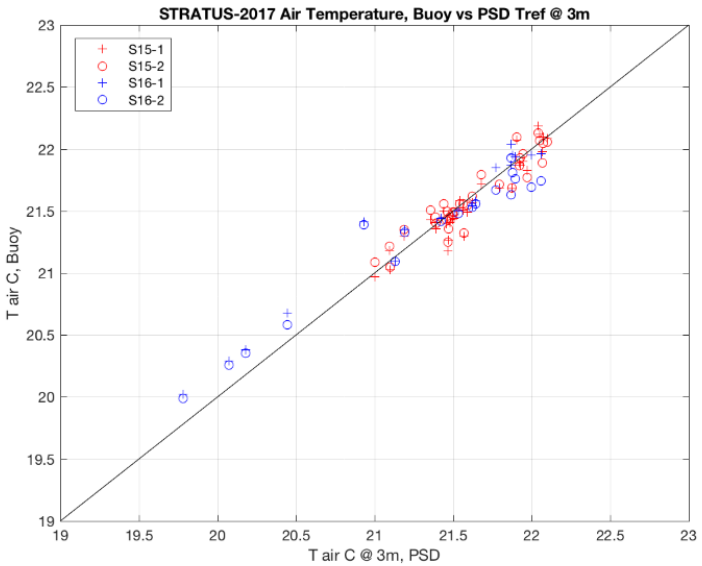
$$H_{latent} = \rho L_e \overline{w'q'}$$

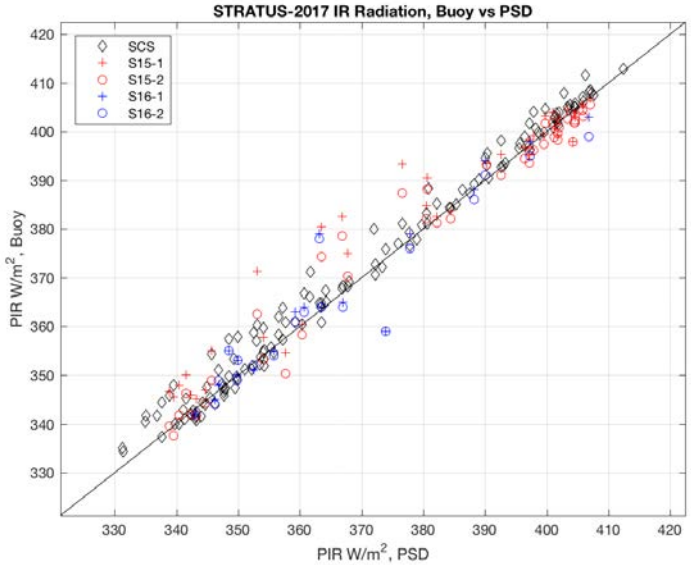
X_s ocean value
X_r air value
S wind speed
C_x transfer coefficient

PSD Roving Ship Calibration Standard for Air-Sea Fluxes: Example STRATUS 2017









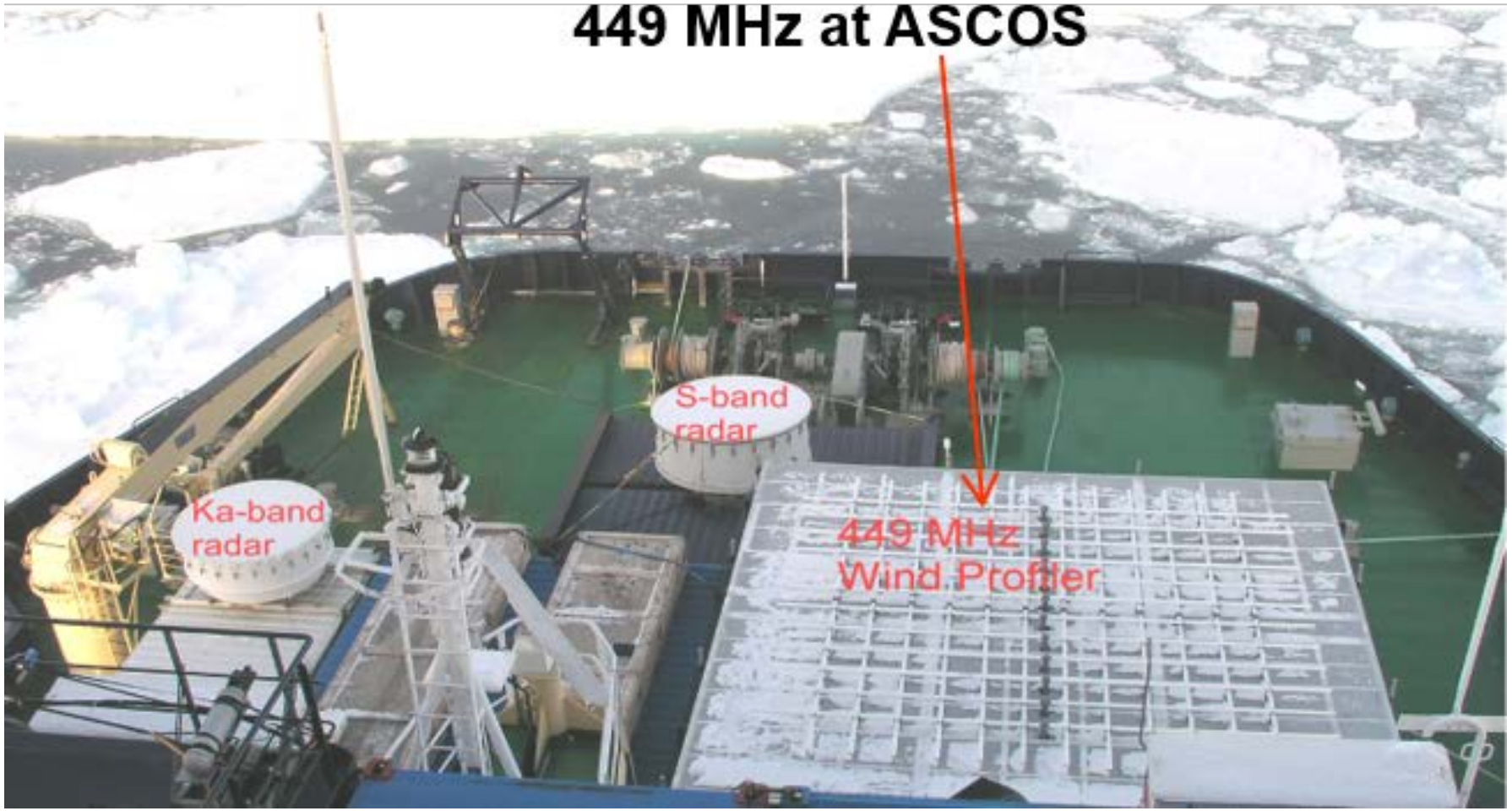
Accuracy for 10 W/m^2 net guideline

Windspeed	2% or 0.2 m/s
SST, Ta	0.1 C
RH	2%
Solar, IR	5 W/m^2

Boundary Layer Profiling

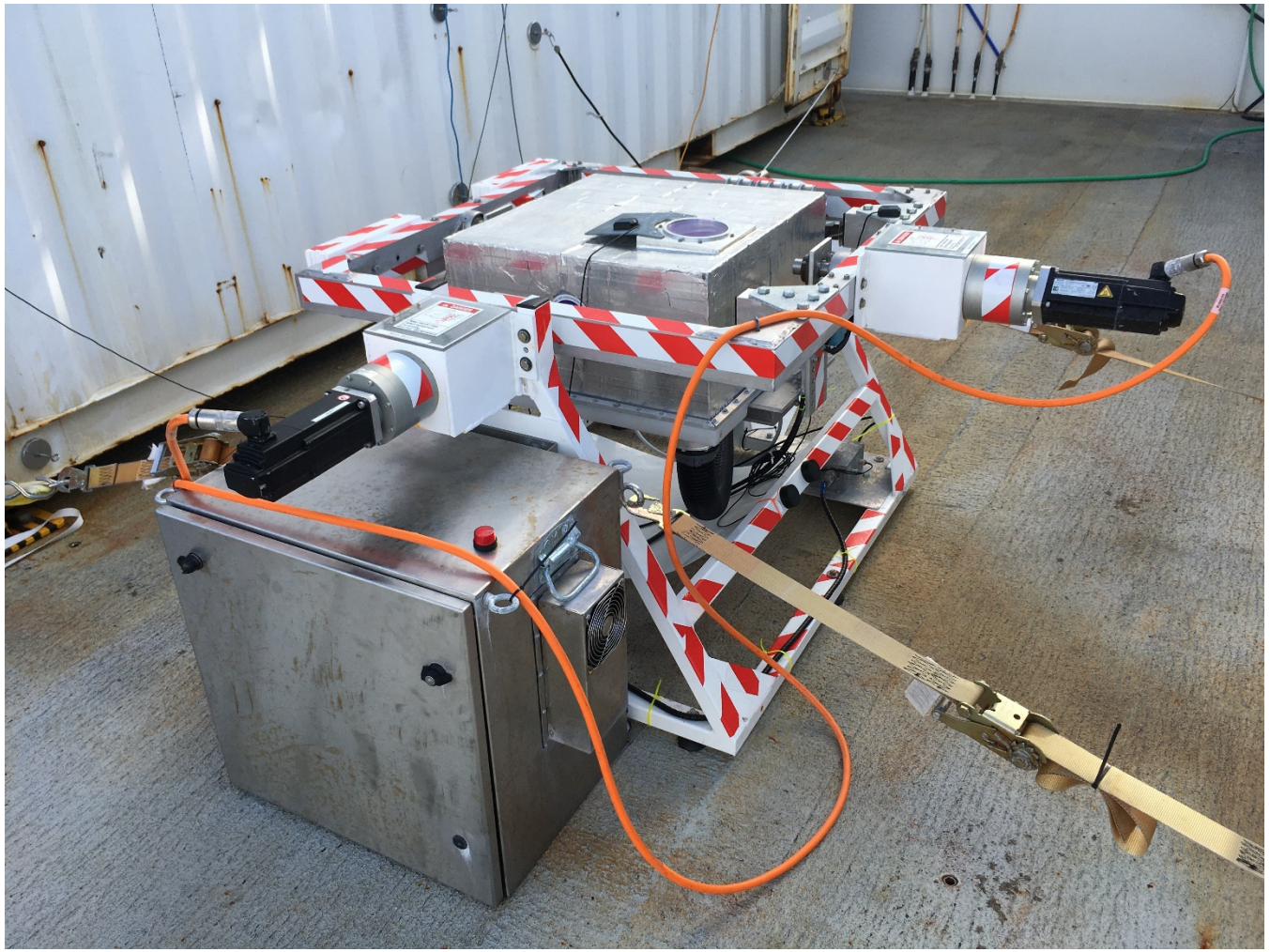
- Rawinsonde
  - U, T, RH, P function of altitude, 0-30 km, 10-m resolution
  - Sonde station about USk$75, About US$300 per launch
- Lidar cloud ceilometer
  - Cloud base height, cloud fraction statistics
  - Commercial systems USk$25, fully automated, rugged
- Wind profiling
  - Radar and Lidar Doppler
  - Pitch/roll stabilized and motion corrected
- Temperature/humidity profiling
  - Microwave and IR
  - Pitch/roll stabilized

Radar Wind Profiler



*Commercially available, unstabilized
*Sensitivity a problem in polar regions
*Expensive
*Large antenna means Space and stabilization issues

Doppler Lidar Profiler



*Commercially available, unstabilized
*Practical range 2 km
*Do not penetrate clouds
*Aerosol and ceilometer information

Guidebook for Climate Quality Ship Obs

ftp://ftp1.esrl.noaa.gov/BLO/Air-Sea/wcrp_wgsf/flux_handbook/

NOAA Technical Memorandum OAR PSD-311

A GUIDE TO MAKING CLIMATE QUALITY METEOROLOGICAL AND FLUX MEASUREMENTS AT SEA

F. Bradley
C. Fairall

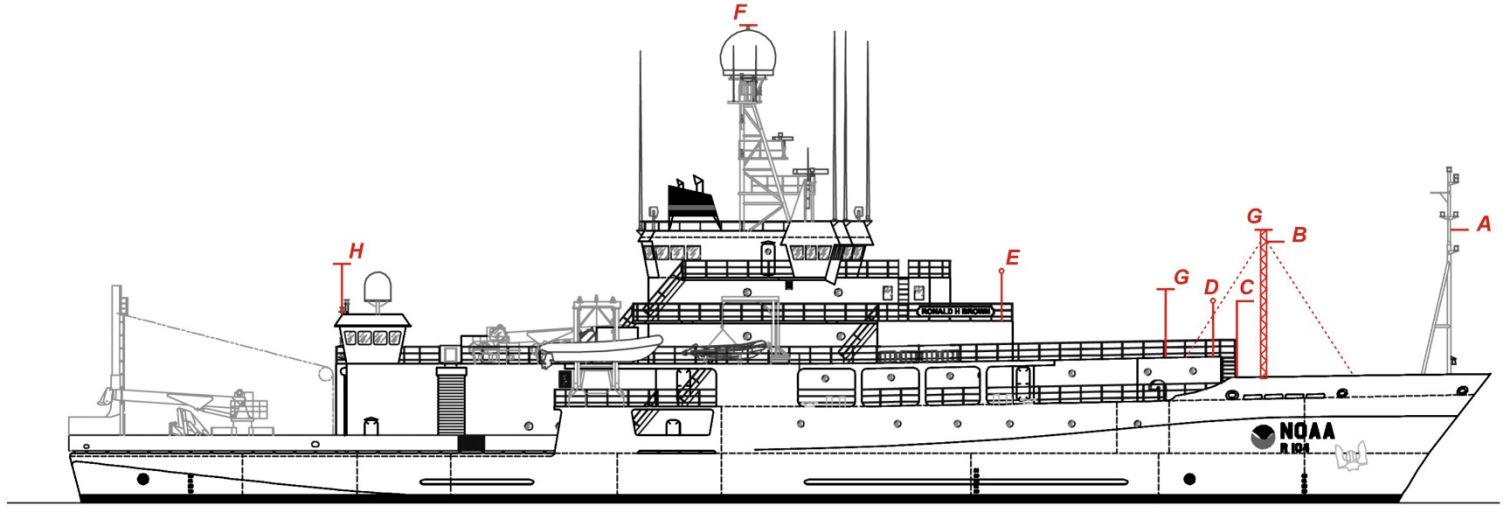
Earth System Research Laboratory
Physical Sciences Division
Boulder, Colorado
October 2006

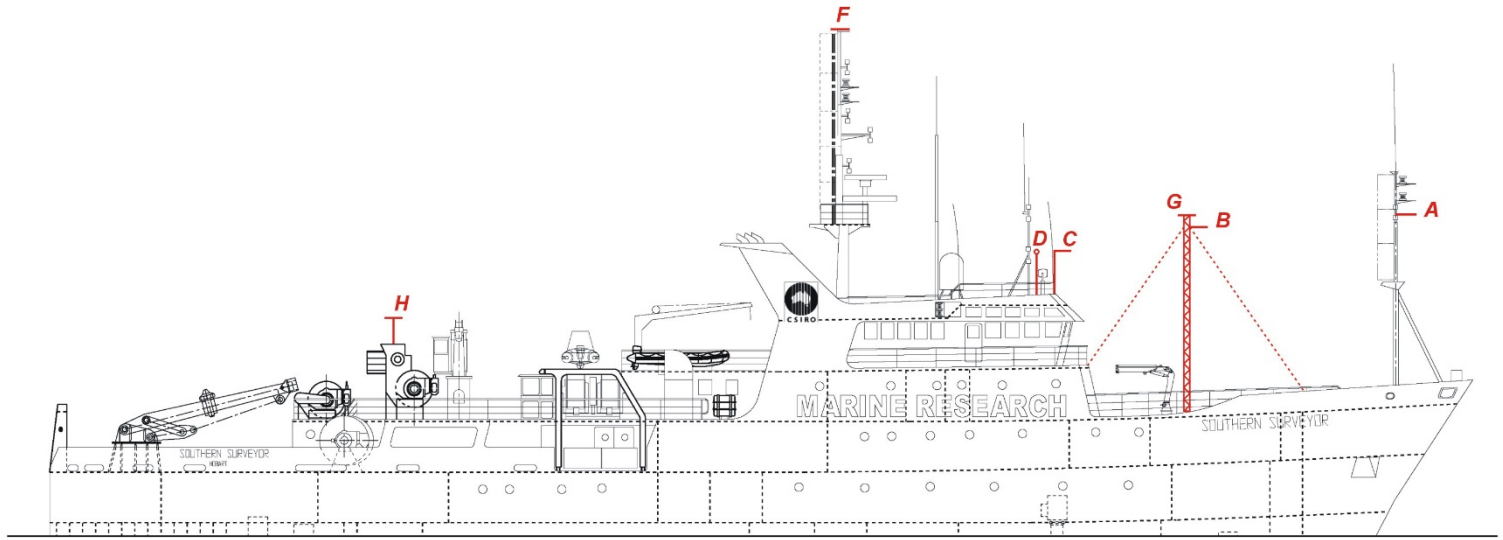
Near-surface Meteorology and Fluxes

- Sensor issues
  - Calibration, stability, environmental (sea salt, birds, etc)
- Placement
  - Flow distortion, heat island
  - Sky field of view, shadows
- Motion corrections (pitch, roll, COG, SOG, heading, heave)
- Sensor to archive chain
  - Digital latency
  - Transmission modes (analog, RS-232, Ethernet,…)
  - A/D vs digital
  - Processing/archive

Sensor Placement to Minimize Interference

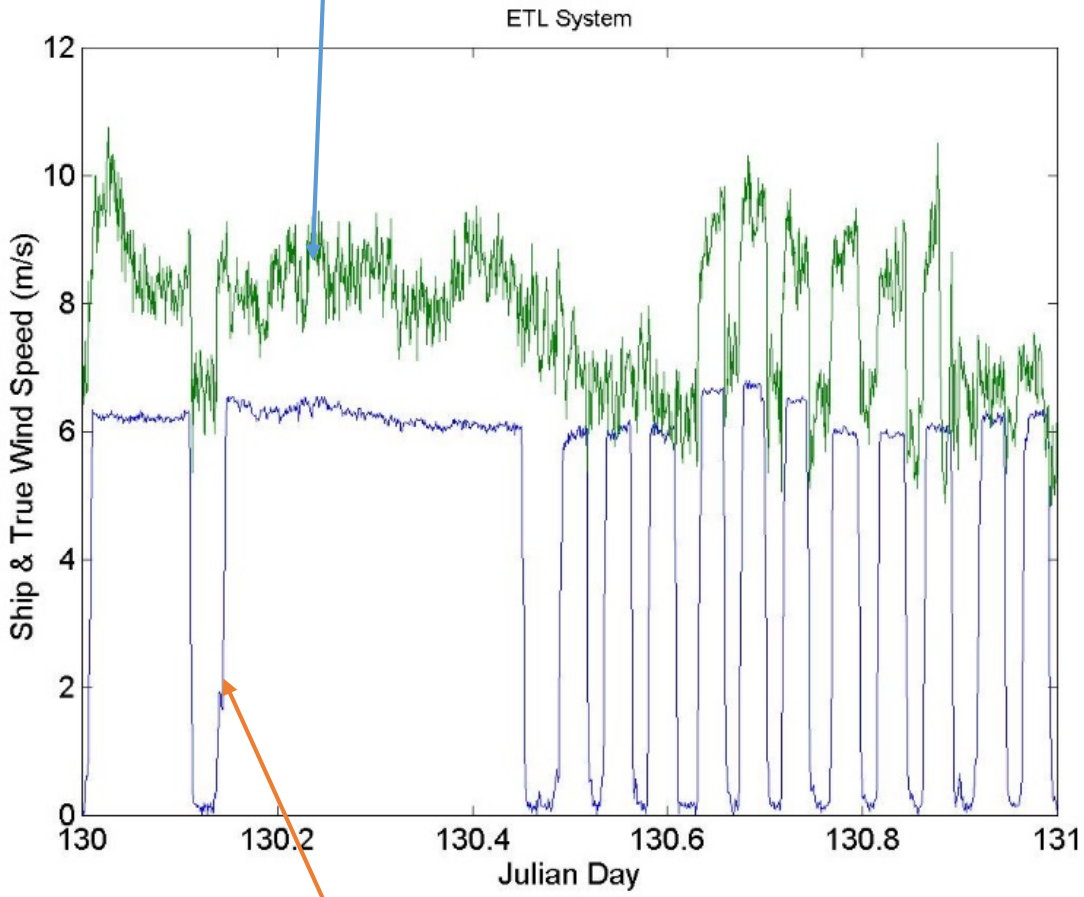
- Flow distortion
- Ship plume
- Radiative FOV
- Tradeoffs:
  - Maintenance
  - Cables
  - Physics





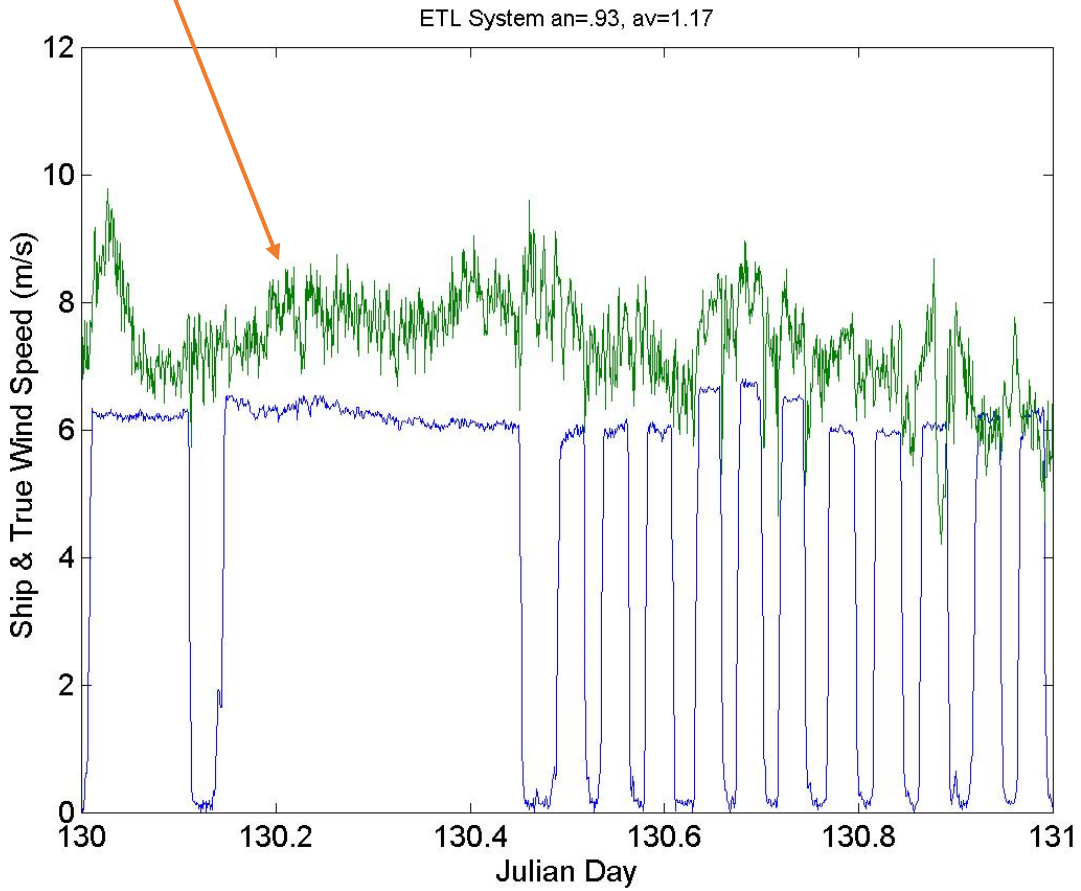
Flow Distortion of Wind Speed Measurements

Measured True Wind at position A



Speed over ground

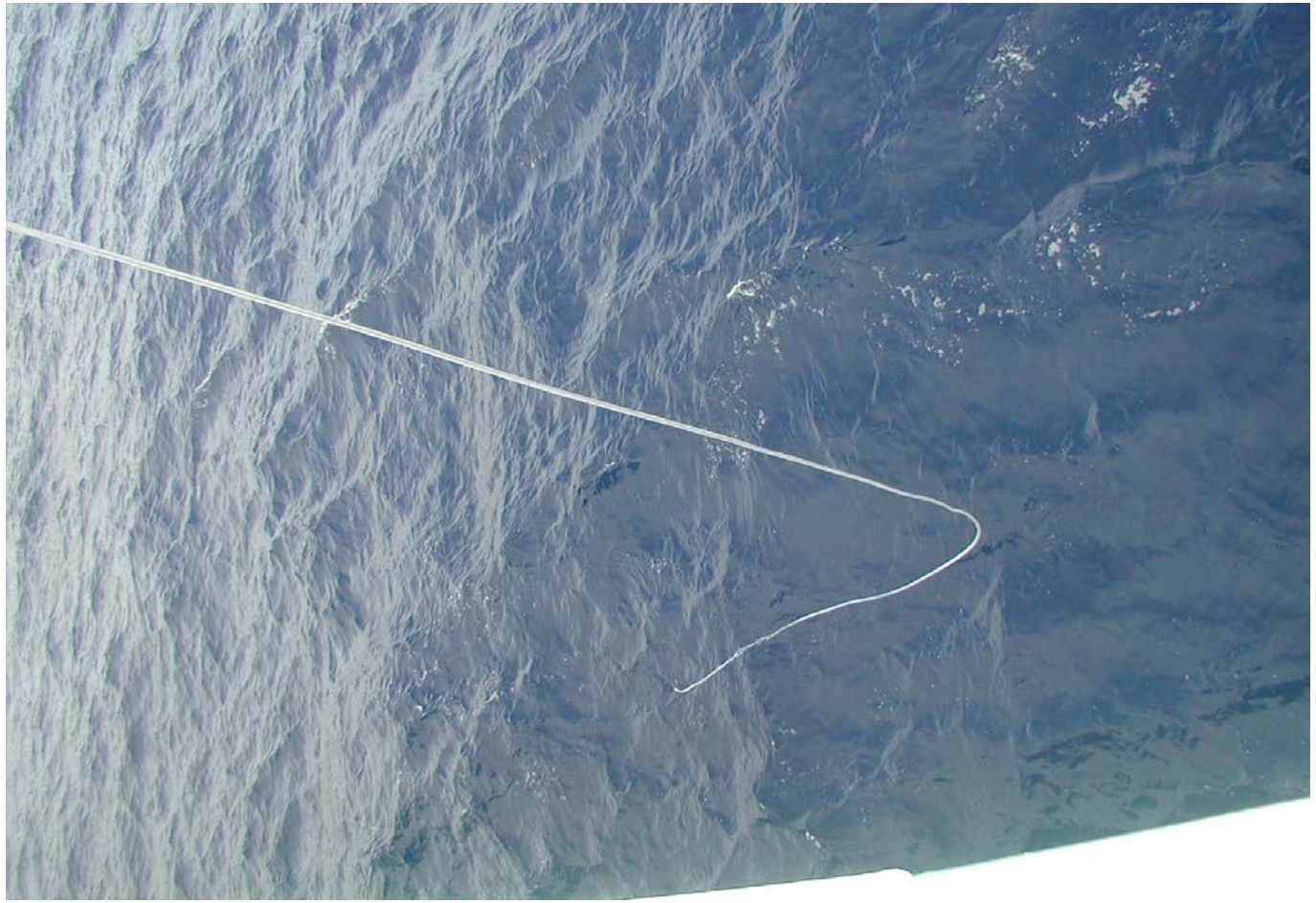
Distortion-corrected True Wind



PSL Measurements: Flux Hardware

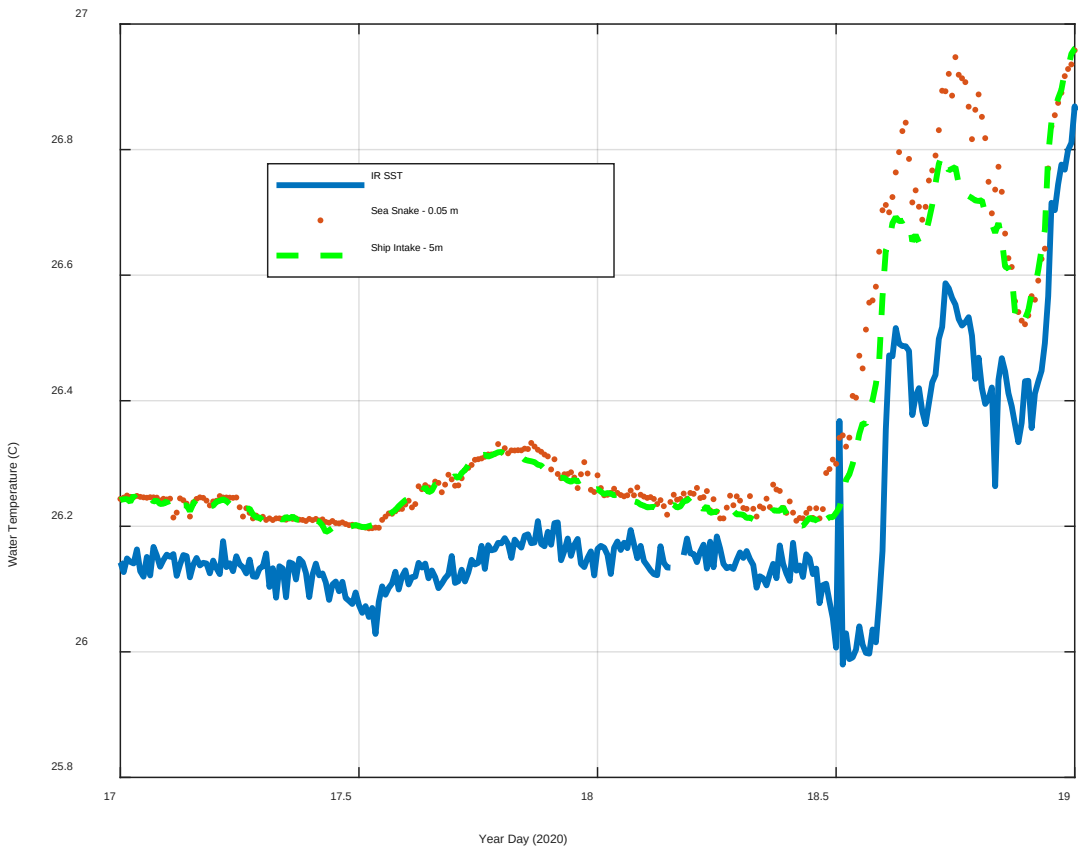
- Wind speed: 3-D sonic anemometer
  - Motion corrected, flow distortion corrected
  - Arctic: heated sonic
- Air T, RH, P: Vaisala system
  - Ventilated radiation shield
  - Arctic: dual system with heated RH
- Water temperature:
  - PSL sea snake floating thermistor (impractical for routine use in sea ice)
  - ROSR dual-IR system – true interface, SST
  - Ship's intake – 5 m
- Radiative flux: Kipp-Zonen or other radiometers
  - Calibrated at GML Boulder
- Rain rate: Long path optical scintillometer
  - No wind speed-induced error

SST: Sea snake and Dual-IR radiative



Vertical Structure in Twater

- Cool skin (1 mm thick)
- Warm Layer (1 m thick)



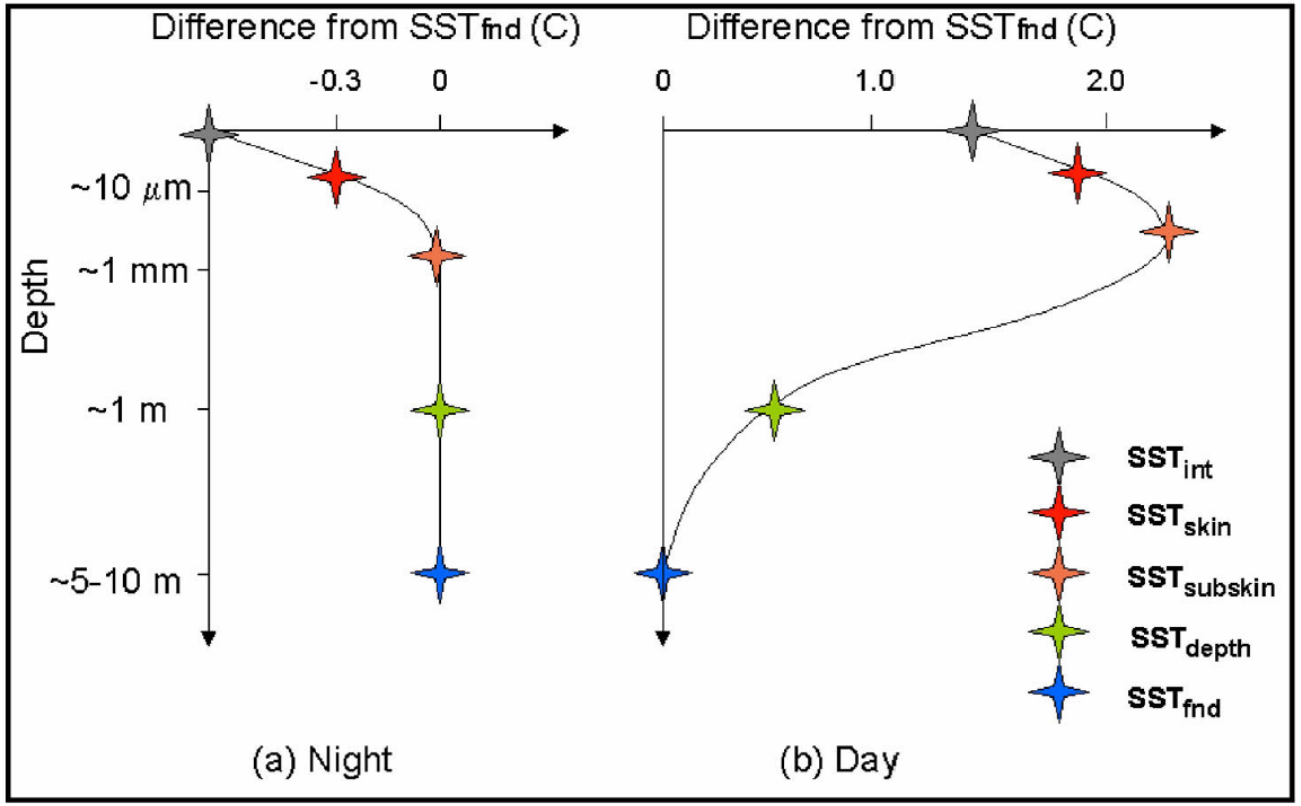
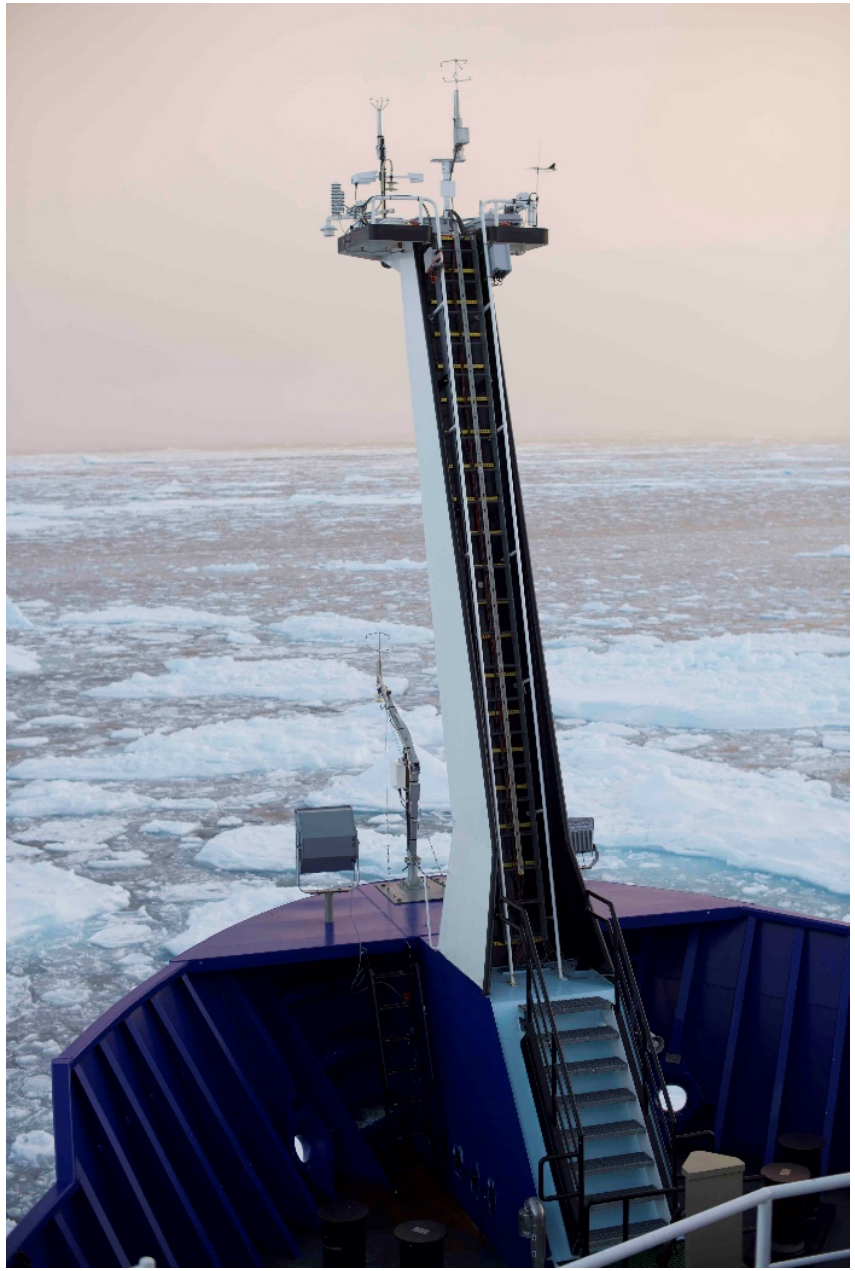


Fig. 1. Schematic showing (a) idealized nighttime vertical temperature deviations from the foundation SST and (b) idealized daytime vertical temperature deviations from the foundation SST in the upper ocean. From Donlon and the GHRSST-PP Science Team (2005). Courtesy of C. J. Donlon.



Icing on Solar and IR Radiative Flux Sensors

Cox, et al, 2021: The De-Icing Comparison Experiment (D-ICE): a study of broadband radiometric measurements under icing conditions in the Arctic. *Atmos. Meas. Tech*., **14**, 1205-1244. https:/doi.org/10.5194/amt-14-1205-2021 .

Examined 26 radiometer/housing combinations
Heat, ventilation, etc.
Some units found to be better than 90% effective at preventing icing

Conclusions

- Fully automated bulk meteorology ‘climate system’ can be built for about 35 k$ hardware. Issues are mostly well understood.
- Combine IR SST and ship intake water temperature
- High quality solar/IR flux quite feasible. Sensors are cheap (3k$ ea).
  - Pitch/roll stabilization would likely reduce biases (poorly explored)
  - Dome Frost issues are likely mitigated
- Atmospheric boundary layer profiling
  - Rawinsonde is standard but 4/day is a lot – totally worth it
  - Lidar ceilometer ideal for simple cloud statistics
  - Active/passive remote profiling systems are expensive and difficult to stabilize, Lidar may be better bet right now