Best practices for surface radiation observations from long-term moored buoys

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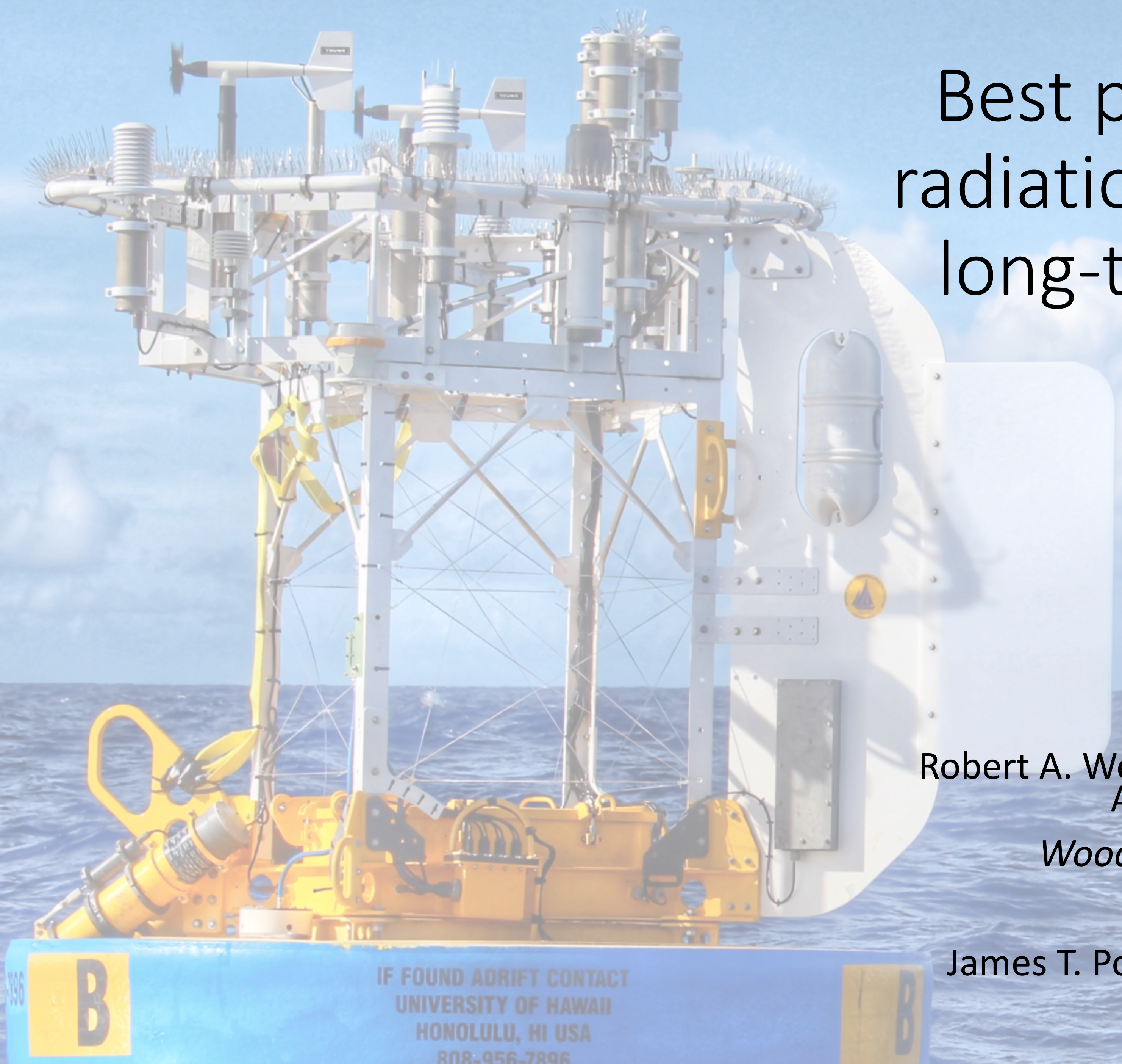


Development of the TAO array and the desire to measure the air-sea heat flux during process studies drove efforts to add radiometers to surface buoys beginning in the 1970's …….

JASIN 1978

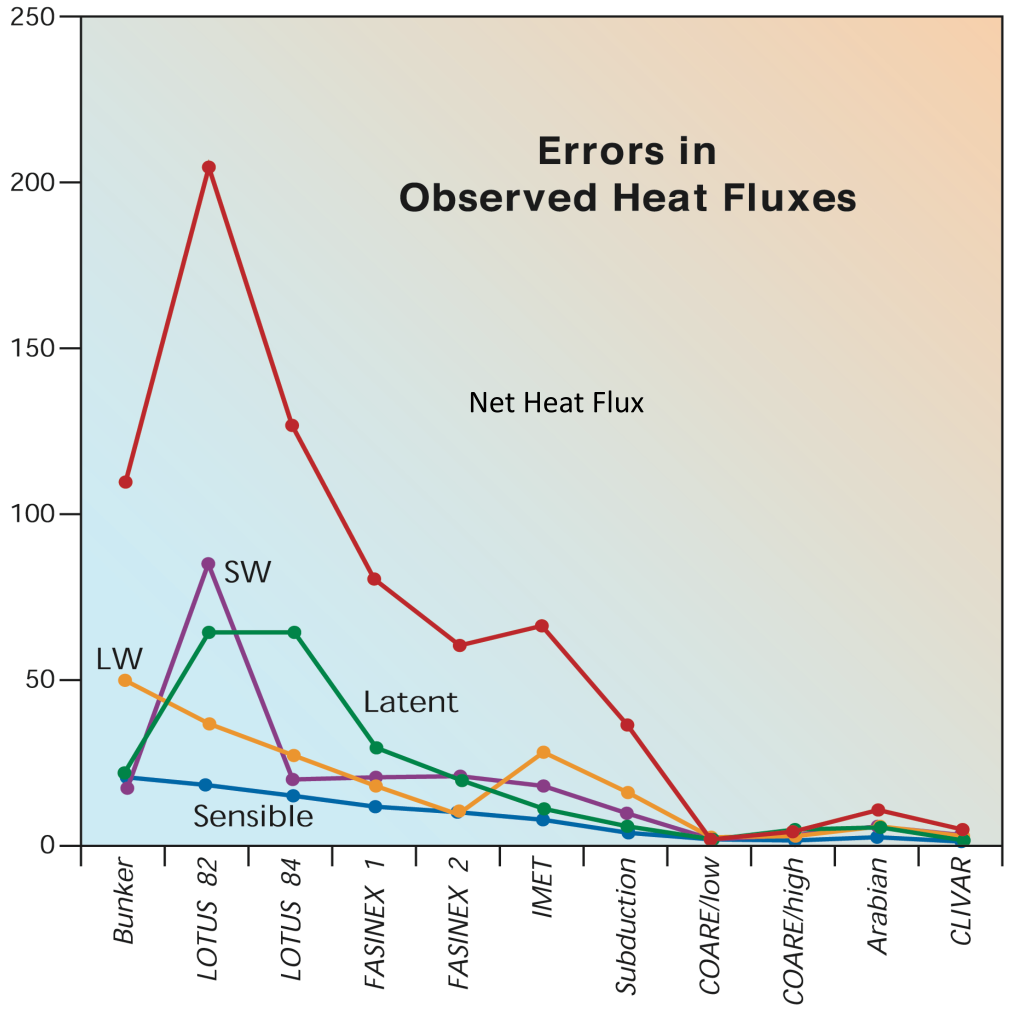
Surface buoys with meteorological sensors on their towers, as deployed in the Join Air-Sea Interaction Experiment (JASIN) in the Rockall Trough in 1978.

Eppley Black and White 8-48 sensors were often used for incoming shortwave. Deployments of longwave sensors were rare.

Eppley 8-48

However, assessing the accuracy of the shortwave and longwave radiation sensors being added to oceanographic surface buoys, observing errors were found initially to be large.

Estimates of error in buoy heat flux observations



1980s 1990s

WOCE and TOGA recognized improved accuracy was needed – set the goal of Q_{net} accurate to 10 W m^{-2}

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

The TOGA Coupled Ocean Atmosphere Response Experiment (COARE) conclusions were:

<u>Essential complements</u>

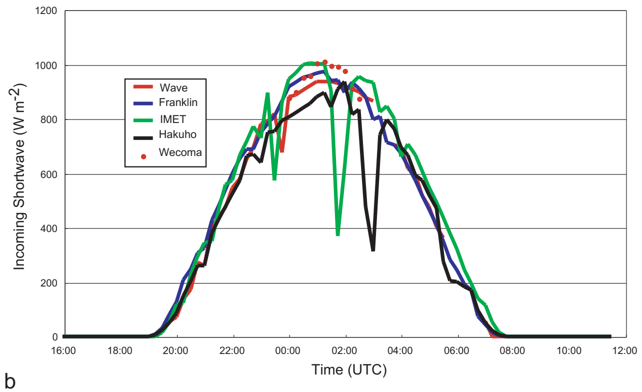
- Field comparisons
  - Ship vs Buoy
  - Overlapping Buoys
- Calibration
  - Before and after
- Ongoing sensor investigation

How best to merge radiometers from different platforms?

- TOGA Coupled Ocean Atmosphere Response Experiment (western Pacific warm pool, 1992-1993) – two dedicated intercomparison periods, IC1 and IC2
- Major challenges were encountered bringing diverse measures of incoming shortwave and longwave radiation together.

Top (a) – as observed incoming shortwave from 4 ship and 1 buoy, midday differences > 100 W m^{-2}

Bottom (b) – after adjustments based on intercomparing sensors and evaluation of radiometers



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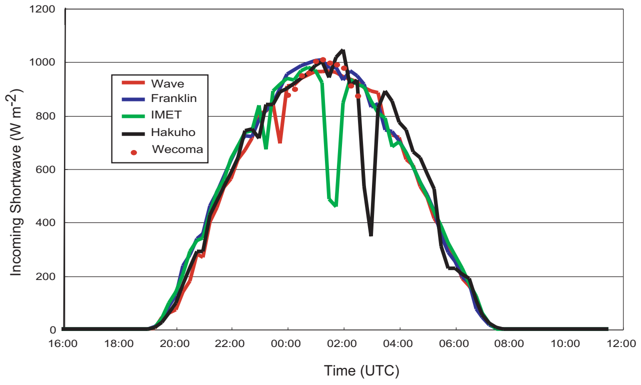

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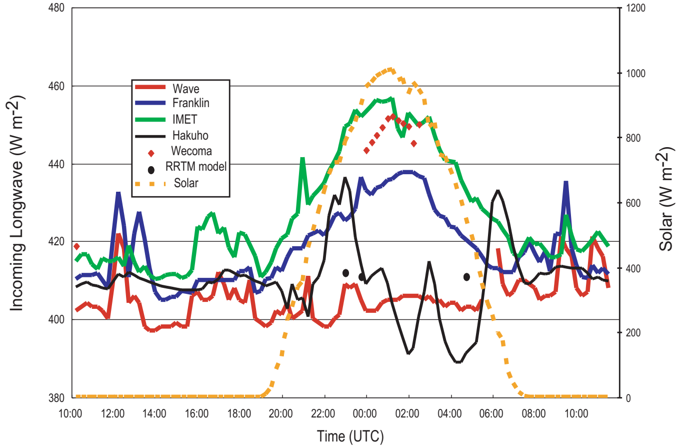

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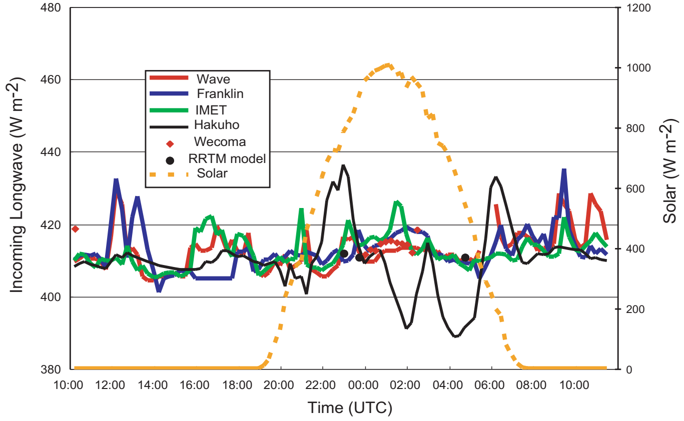


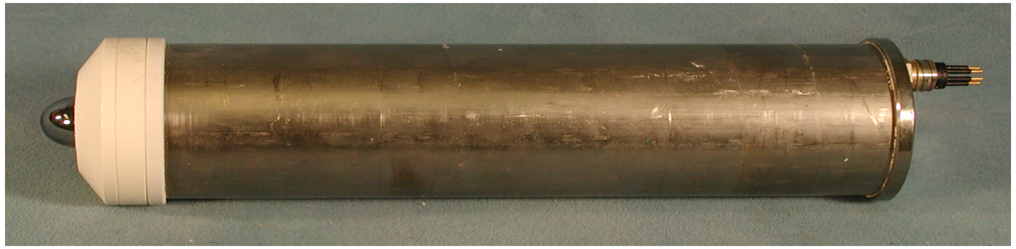
Top (a) As observed incoming longwave from 4 ships and buoy with longwave from radiative transfer model using local radiosondes; overplotted on observed shortwave.

Bottom (b) – after adjustments based on sensor intercomparisons

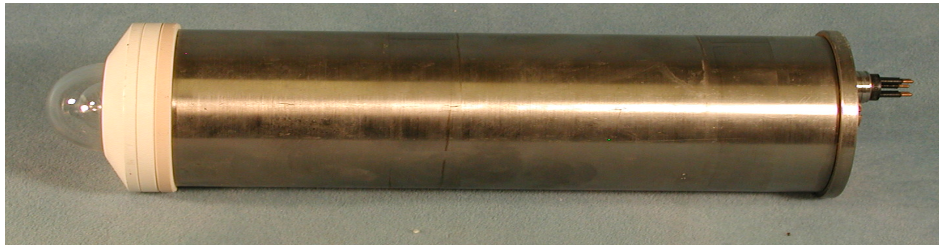
Radiometer challenges for observing at sea:

- Small signal from thermopile networks
  - Stable amplification
  - Minimization of Radio Frequency Interference (RFI) – especially from data telemetry transmitters on buoy
  - End-to-end calibration: sensor + signal conditioning + digitization
- Shortwave sensors
  - Stability of optical back paint
  - Case heating effects
- Longwave sensors
  - Moving away from in-sensor correction for body, dome thermal radiation
  - Pin hole leaks, coating defects
  - Case heating effects
- At sea exposure
  - Salt spray, dust, organics
  - Corrosion
  - Birds and bird guano
  - Rain
- Platform motion, issues
  - Pitch, roll
  - Mean tilts
  - Shadows
- Routine, unattended campaigning
  - Regular laboratory calibration
  - In the field verification, intercomparison
  - Metadata, calibration information and sensor identify included in data stream
- Low power
  - Not ventilated
  - No moving parts

Addressing challenges: modular, ASIMET system, providing ascii engineering units, easily interfaced to, with key information (eg. calibration) stored internally



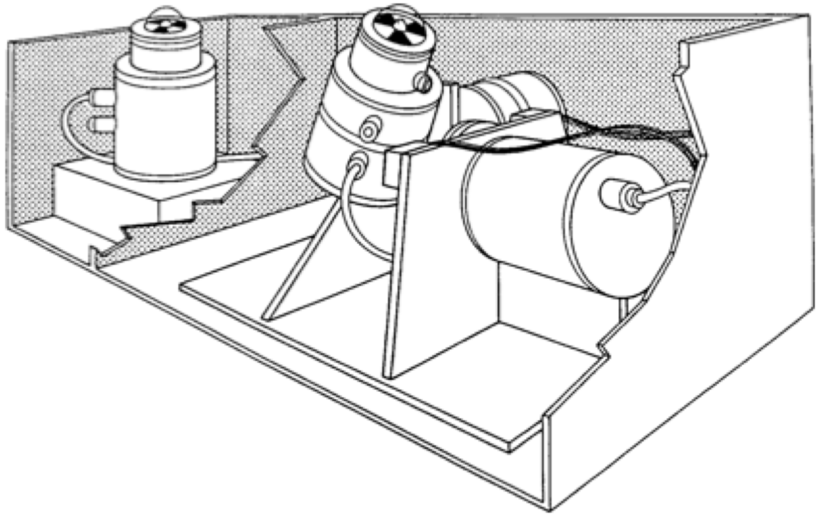
Incoming longwave



Incoming shortwave

- Signal conditioning as close as possible to sensor (amplification and digitization)
- Stable amplifiers
- Engineering units output RS-232/485 with calibration stored internally
- 1 Hz sampling of thermopile voltage, and for longwave of body and dome thermistors
- Calibrated as a whole using digital output as well as checking sensor calibrations

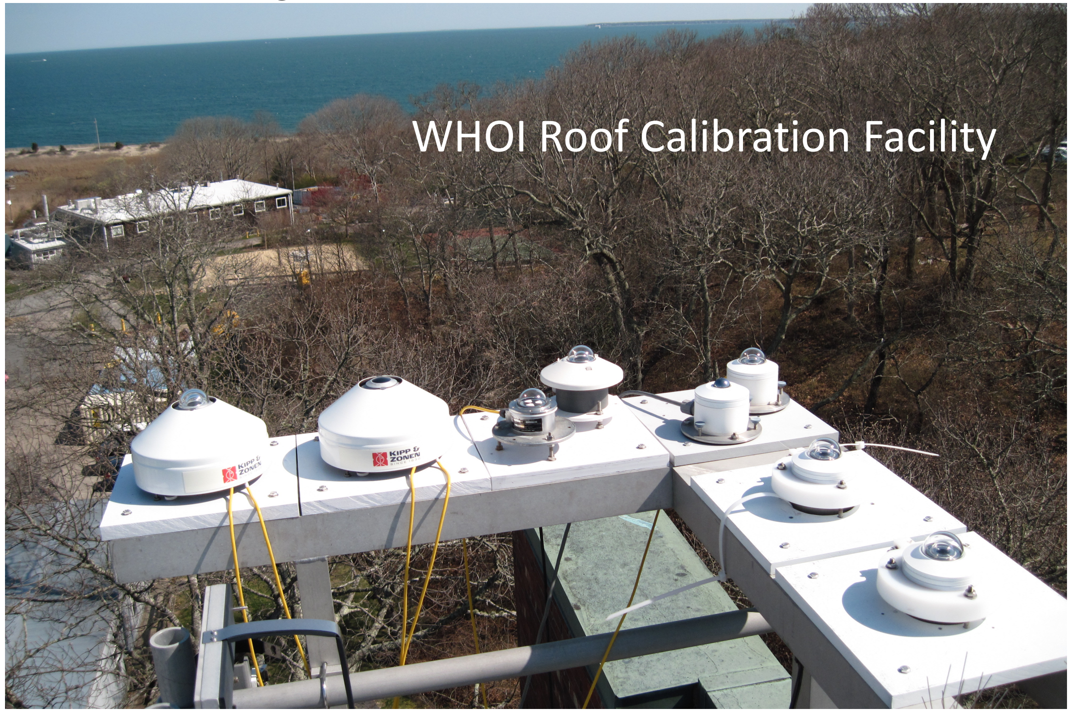
Addressing challenges: Initial assessments of buoy shortwave and longwave



Measured buoy motion, used observed motion to drive 2-axis platform and compare to level sensor on rooftop. MacWhorter and Weller (1991).

First look: Buoy motion is an issue, but these surface buoys have high loads and relatively stable.

At this point other errors were found to be larger: thermopile output is small, microvolts, signal conditioning, amplifier stability, and calibrations were not good enough..



Shortwave:

- Comparisons against BSRN site on Chesapeake Bay Light Tower
- Comparisons against Chris Fairall's radiometers
- New calibration processes
- Shift to more stable sensor

Longwave:

- Improved amplified
- Black body calibration

Chesapeake Bay Light Tower

Among early findings: degradation of optical black paint on Eppley PSPs

Shifting to pyranometers with more stable optical black coatings.

Rotating 3 calibration standards, once per year (one on roof, one out for cal, one in drawer)

Overlap the standards

- Eppley PSP, optical black paint aging
- Typically, reduced sensitivity
- Up to 9% change/5 years
- Most often, -4% to -6%/5 years

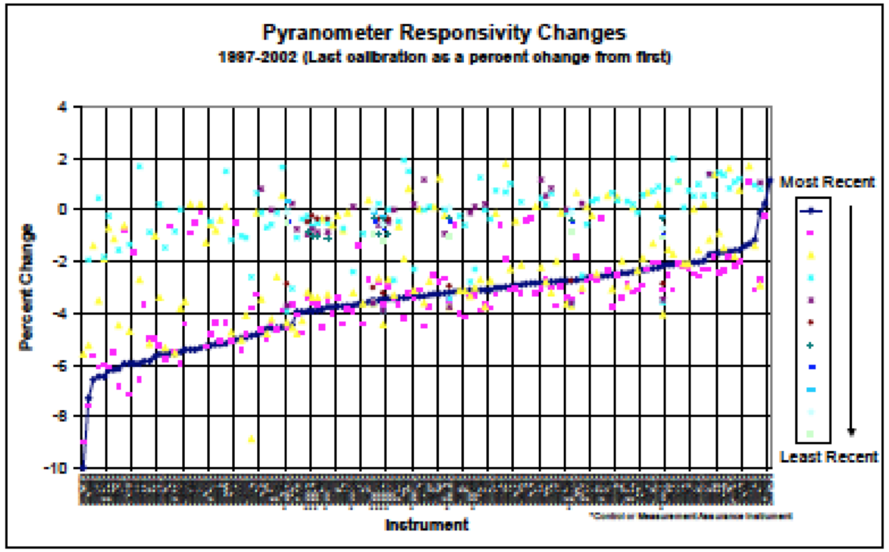
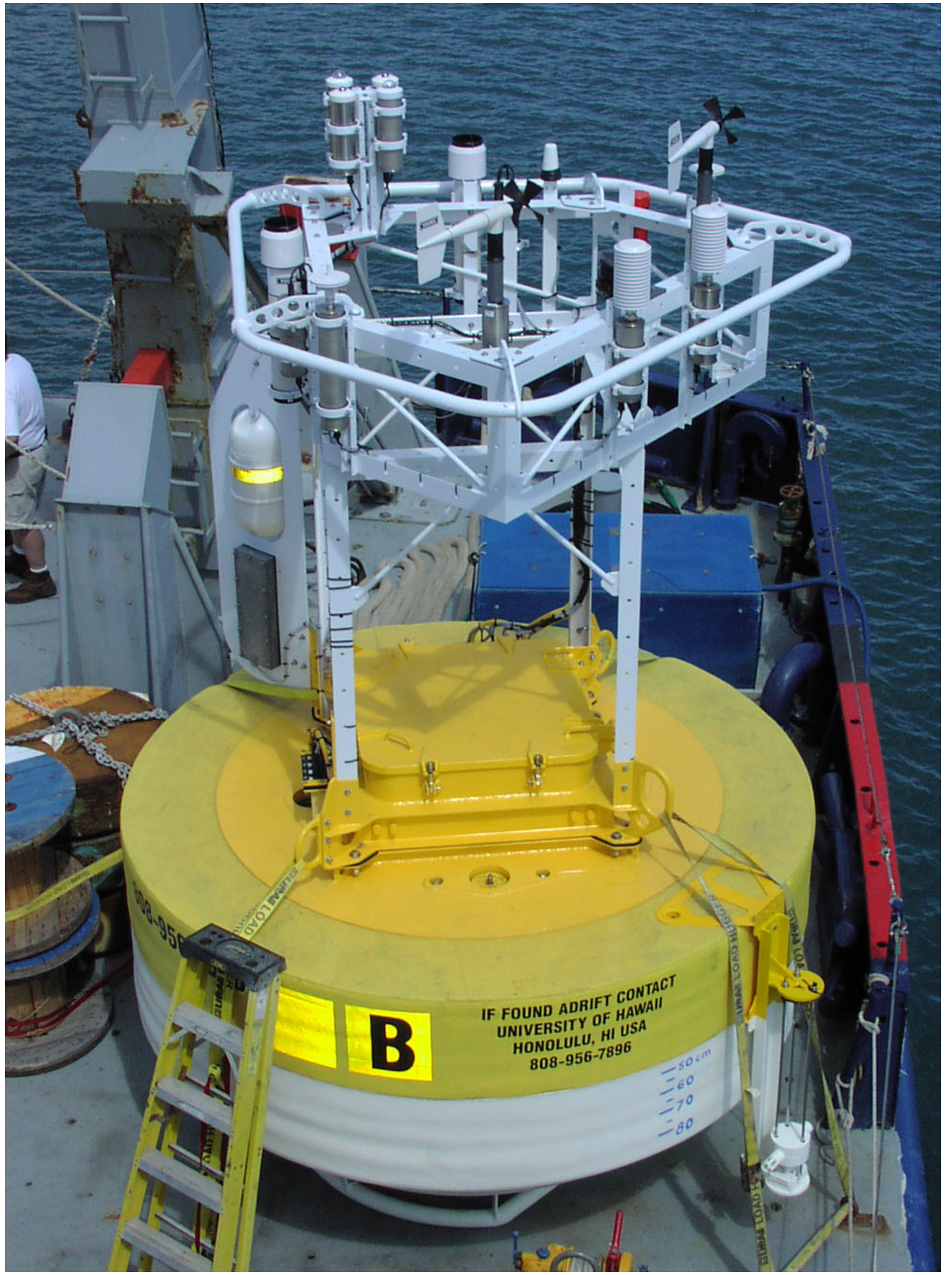


Figure 3. The 1997-2002 pyranometer responsivity changes.

Wilcox et al., 2003



•Routine deployments of up to 12 months,
two to three redundant sets of radiation sensors, with typical yield of 100% return of a complete 1-minute set of time series.

Some sites now have close to 20 years sustained time series

- Radiometers deployed as redundant pairs, mounted above all else – no shadows.

- New buoy deployed and run for 1-several days overlapping with old buoy – incoming radiation intercompared.

- Ship doing the work carries independent meteorological sensors, and shipboard observations compared to old and new buoy time series.

On some cruises, Fairall has deployed motion stabilized platform for shipboard radiometers.

Our assessment of uncertainties in WHOI buoy surface meteorology capabilities

	Instant	Daily	Monthly
Incoming Longwave	7.5 W m^{-2}	4 W m^{-2}	4 W m^{-2}
Incoming Shortwave	10 W m^{-2}	6 W m^{-2}	5 W m^{-2}
Relative humidity	1% RH, 3% low wind	1%, 3% low wind	1%
Air temperature	0.2°	0.1°	0.1°
Barometric pressure	0.3 mb	0.2 mb	0.2 mb
SST	0.1°	0.1°	0.04°C
Wind speed	1.5% 0.1 m s^{-1}	1% 0.1 m s^{-1}	1% 0.1 m s^{-1}
Wind direction	6°	5°	5°
Precipitation	20%	20%	20%

Total in the field uncertainties: based on laboratory calibrations, field comparisons, and comparisons of redundant, coincident sensor data; includes clock drift impacts.

Typical: Eppley PSP and Eppley PIR

Quality-controlled, one-minute data have been shared

- Satellite surface radiation products have advanced significantly

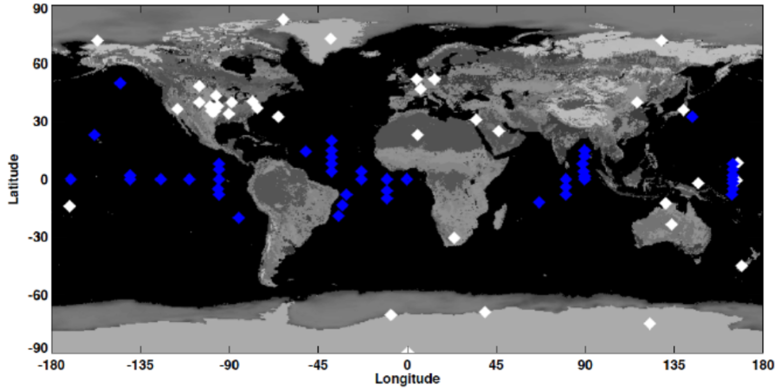


Figure 4: Location of 46 buoys (blue diamond) and 36 land surface sites (white diamond) where downward irradiances used in this study were taken (After Rutan et al. 2015).

CERES Ed4 1°x1°, hourly

Uncertainties:

SW↓~ 4 W m^{-2}
SW↑ ~ 3 W m^{-2}
LW↓ ~6 W m^{-2}
LW↑ ~3 W m^{-2}
LW+SW ↓↑ ~8 W m^{-2}

Kato et al., Surface Irradiances of Edition 4.0 Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Data Product . Submitted to J. Climate

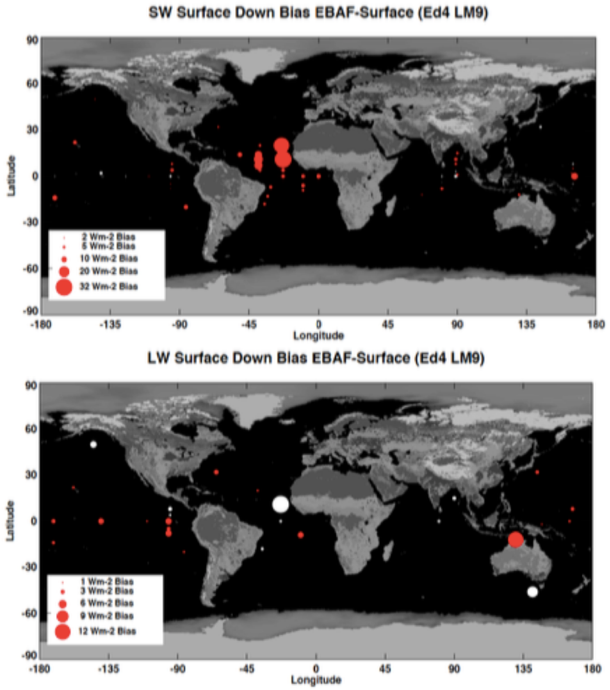
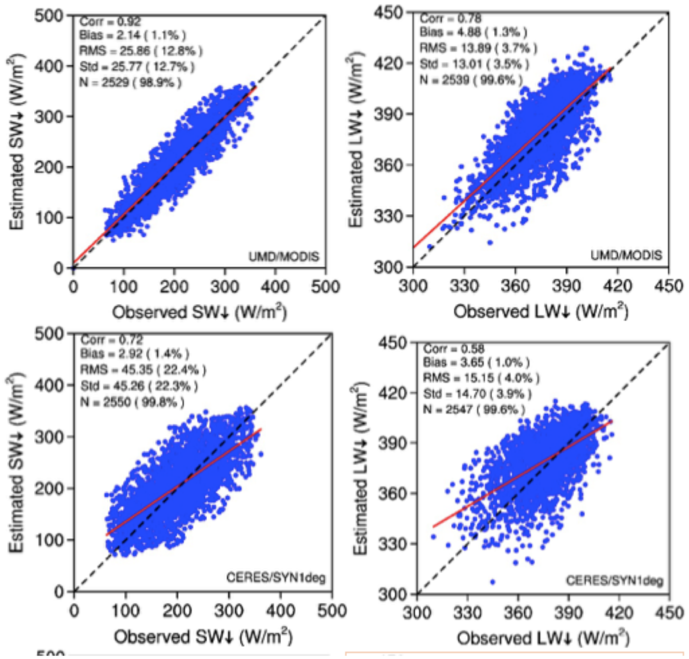


Figure 6: Difference of EBAF monthly 1°x1° mean surface (top) shortwave and (bottom) longwave downward irradiances from observed irradiances at buoys (computed minus observed). The size of the circle is proportional to the difference. The red and white circles indicate, respectively, a positive and a negative difference. The number of months used for comparisons varies depending on buoys.



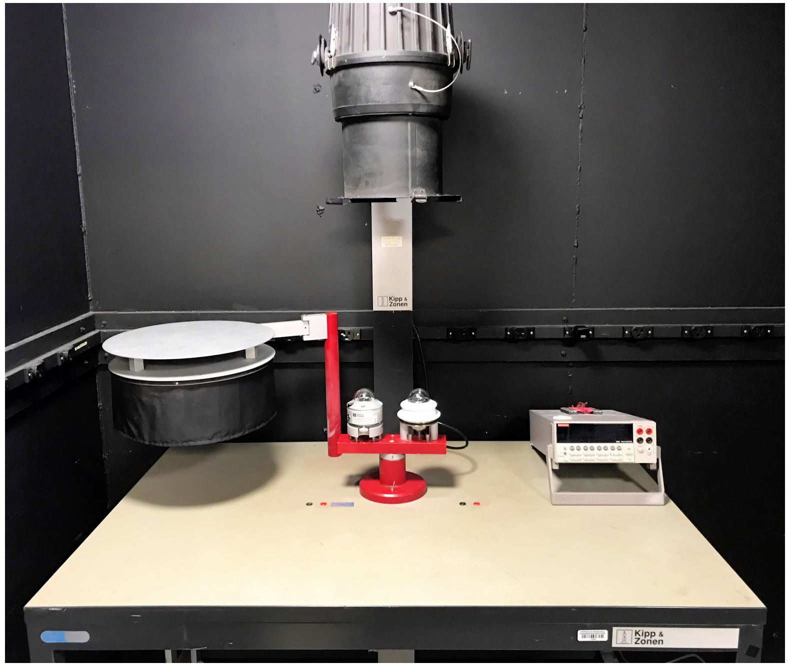
Pinker et al., 2017, submitted.

UMD/MODIS surface radiation

SW↓ at Stratus 2.1 W m^{-2} bias
LW↓ at Stratus 4.9 W m^{-2} bias

Further work on observing challenges going forward

Visits to Hukseflux and Kipp and Zonen prompted further thinking about calibration, sensor choice.



Developing halogen lamp-based calibration facility at WHOI.

HEATED FOR HIGH DATA AVAILABILITY, FEATURING NEW RVHTM TECHNOLOGY

High data availability is attained by heating of the outer dome using ventilation between the inner and outer dome. RVHTM - Recirculating Ventilation and Heating - technology, developed by Hukseflux, suppresses dew and frost deposition and is as effective as traditional ventilation systems, without the maintenance hassle and large footprint.

compliant with IEC 61724-1:2017 Class A

The dome of SR30 pyranometer is heated by ventilating the area between the inner and outer dome. RVHTM is much more efficient than traditional ventilation, where most of the heat is carried away with the ventilation air. Recirculating ventilation is as effective in suppressing dew and frost deposition at 2 W as traditional ventilation is at 10 W. RVHTM technology also leads to a reduction of zero offsets.

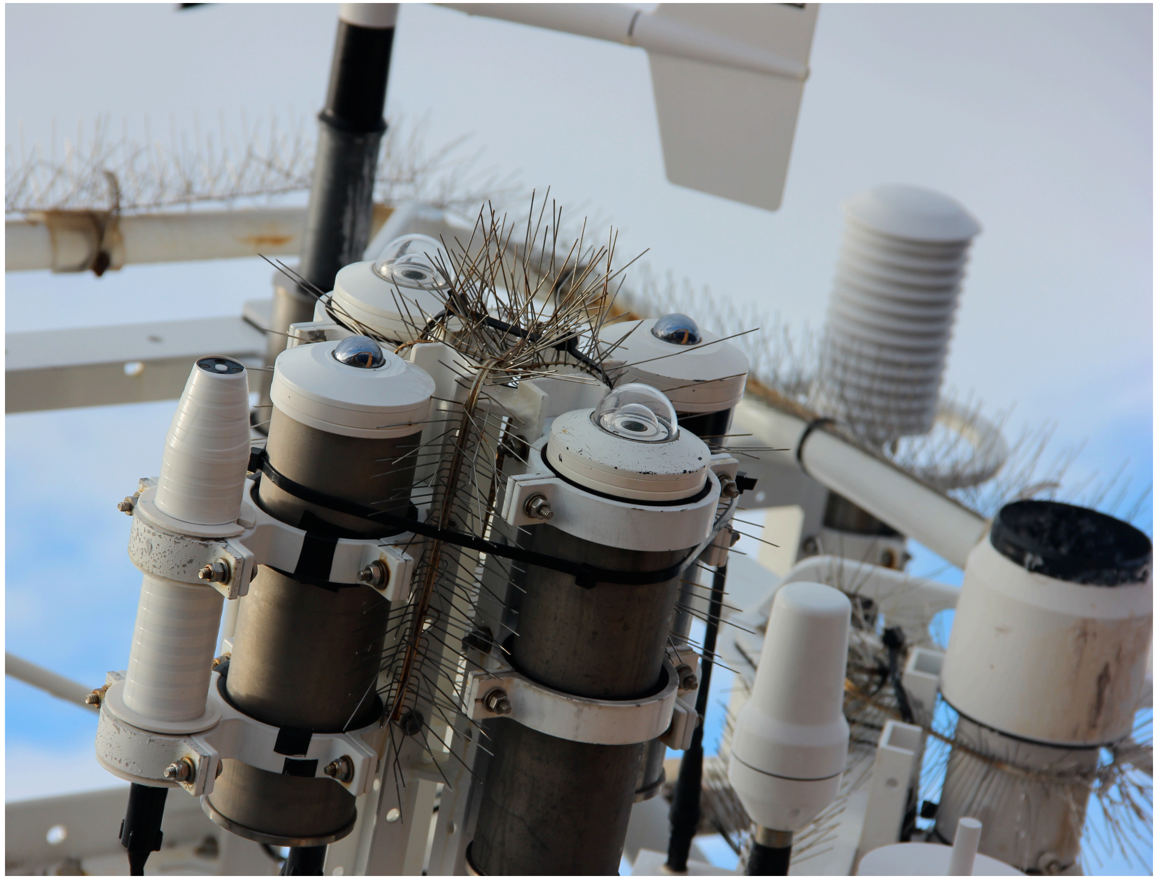
Example: Huskeflux SR30
- Heat, ventilated
- Measures tilt
- 1.2% for radioemeter
- 1° for tilt

Deals with ice and frost
Reduces thermal offsets
Quantifies tilt related error

Are there better choices for sensors? Should ventilation be implemented?

Further work on observing challenges going forward

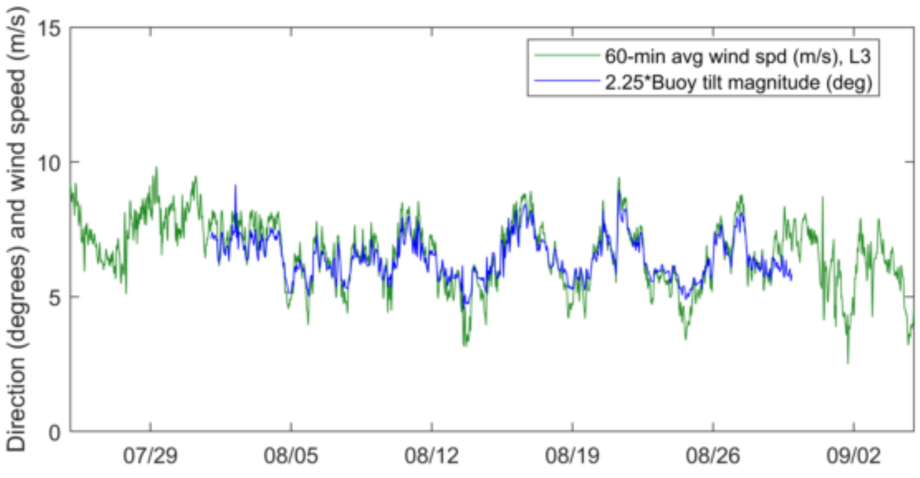
An immediate issue – birds sitting on the radiometers. Long-term buoys draw a local ecosystem, including seabirds. They will roost on radiometers and leave guano behind. How do deter them?



(left) Wire used for deterring birds – not enough to eliminate problem. (above) More robust spikes, their impact on sensor performance now being evaluated.

Further work on observing challenges going forward

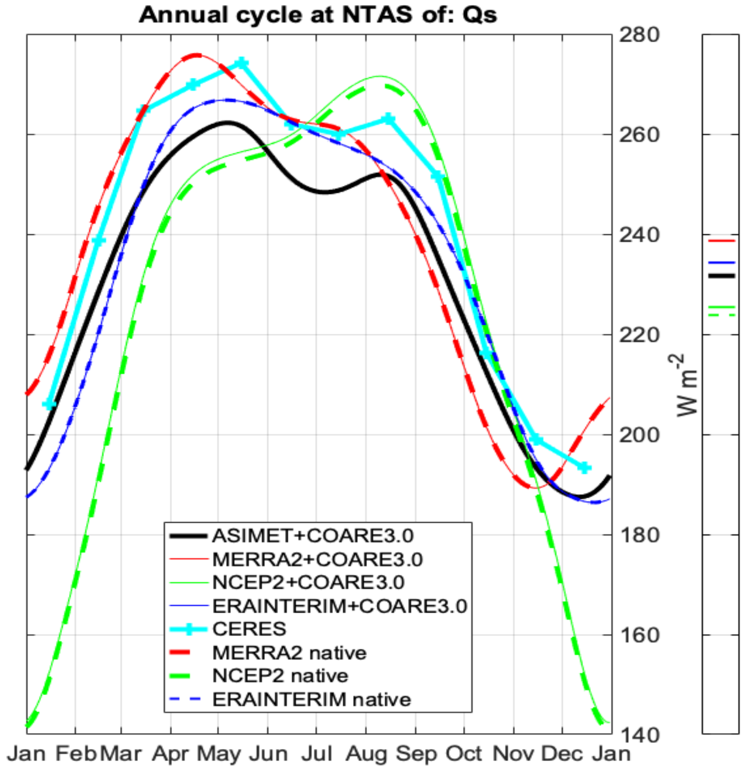
As calibration procedures have improved and other progress made, now returning to address the issues of the impact of platform motion on radiometer data. Prompted by new capabilities of measuring buoy motion and desire new use new, less stable platforms.



Example time series from WHOI NTAS buoy. Buoy tilt multiplied by 2.25 tracks wind speed. Buoy tilts are between ~1.5° and 4.2°.

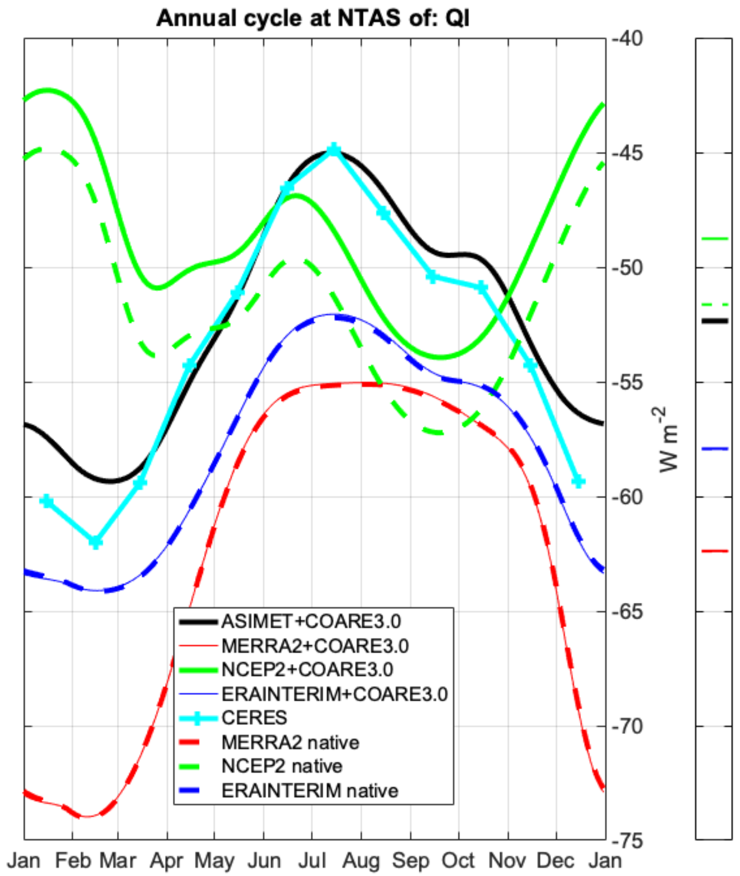
Jennifer Keane, NOAA PMEL

For now, buoy accuracies support assessment of models, reanalyses, and hybrid flux products.



shortwave

Climatological annual cycle of surface radiation. NTAS buoy (black) and CERES (cyan) agree for shortwave (left) and longwave (right); models more different , especially for longwave.



longwave

The annual cycle at NTAS of the net shortwave (Qs) and longwave (Ql) radiation, on the left and right respectively. In-situ ASIMET data (black), MERRA-2 (red), NCEP-2 (green), ERA-Interim (blue), CERES (cyan). Dashed lines are adjusted to common values of surface parameters (emissivity, albedo). The vertical bar on the right of each panel shows the annual averages. Positive values mean ocean heating. (From S. Bigorre)

Desire going forward:

- Work with ocean observing community to quantify and improve surface radiation sensing capabilities
- Work across ocean, land, atmosphere, remote sensing communities towards an integrated surface radiation observing capability.