The role of Ocean Reference Stations that withhold data in order to create independent benchmarks for assessing models and remote sensing

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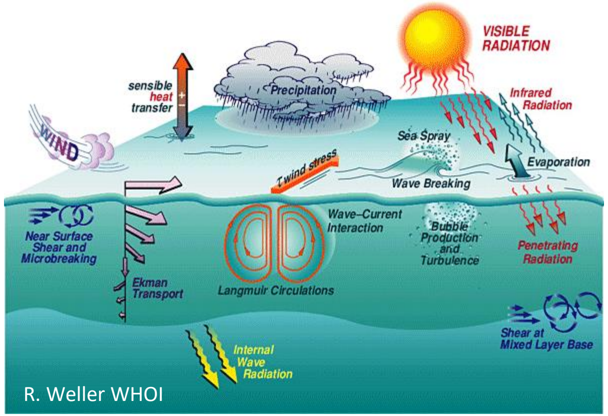
Oceanographers observing surface meteorology – a quick overview



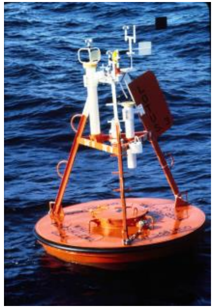
Primary reasons:
- predict/understand the evolution of the ocean surface mixed layer
- surface forcing for ocean models
- assessment of surface fluxes from coupled models
- global ocean circulation and role and earth's heat budget

Programmatic major initiatives:
- World Ocean Circulation Experiment (WOCE) 1990-1998
- Tropical Ocean Global Atmosphere program (TOGA) 1985-1994
- WOCE/TOGA target for Q_{net} was 10 W m^{-2}

1960 – first WHOI surface mooring

Technical challenges

JASIN 1978



LOTUS 1985

ERICA 1989

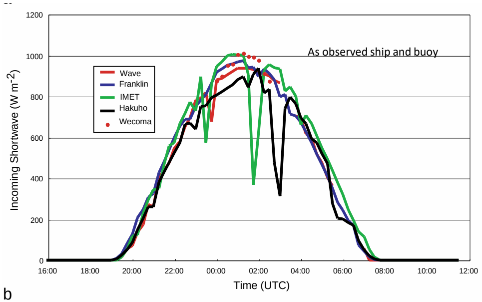
Arabian Sea 1994-1995

Challenges along the way - how good are those surface observations?

- 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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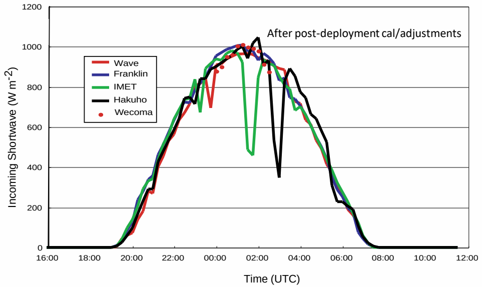

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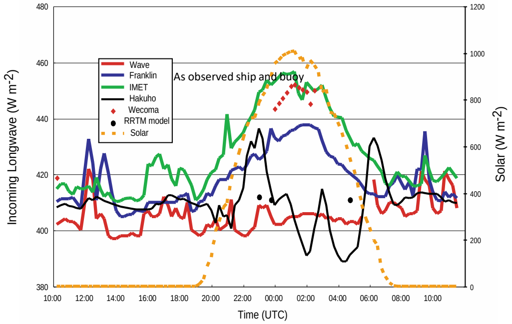

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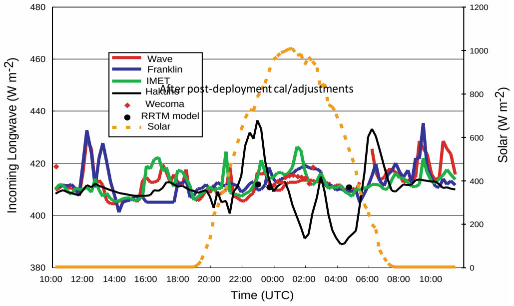
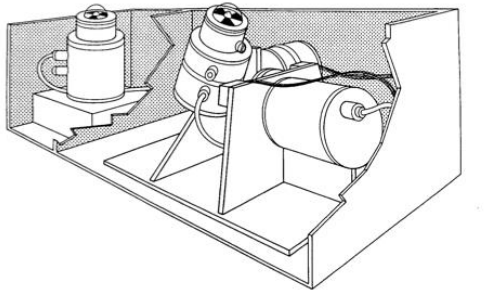


Top (a) As observed incoming longwave from 4 ships and buoy with longwave from radiative transfer model using local radiosondes; overplotted on observed shortwave.

Bottom (b) – after adjustments based on sensor intercomparisons

Digging in to understand and reduce errors – example, concern about platform motion, long-term stability



Degradation of optical black paint on incoming shortwave radiation sensor

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

Measure buoy motion (pitch and roll), use measured motion to drive two-axis motion table on the roof, assess impact of pitch and roll on measured shortwave radiation (MacWhorter and Weller, 1991).

Later, at sea comparisons against Fairall's radiometers, including on a stabilized platform.

Shifting to pyranometers with more stable optical black coatings.

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

Overlapping the standards.

Change in PSP response over 5 years

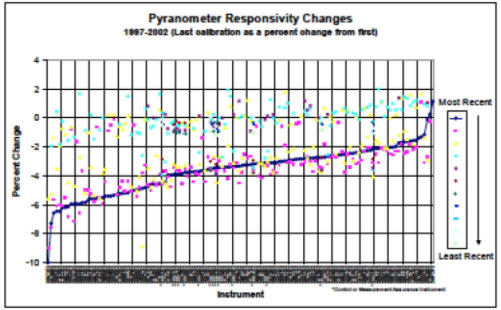


Figure 3. The 1997-2002 pyranometer responsivity changes.

Wilcox et al., 2003

- Eppley PSP, optical black paint ages
- Typically, reduced sensitivity
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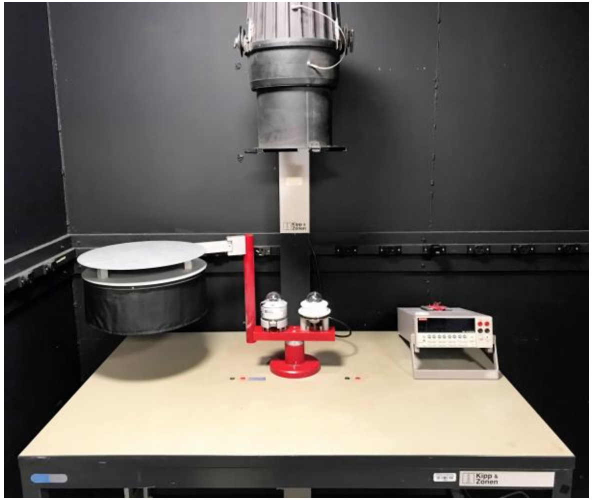
- Most often, -4% to -6%/5 years

Continuous improvement, in calibration, evaluation and use of new sensors

Rooftop calibration facility

Kipp and Zonen reference standards returned for calibration in Boulder



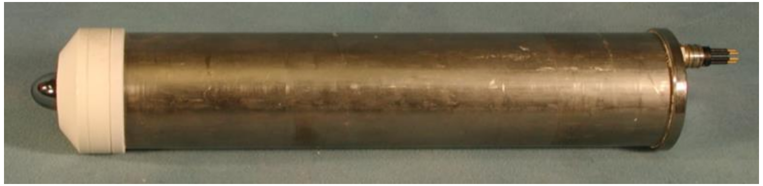
New halogen lamp-based calibration facility

Improved accuracy

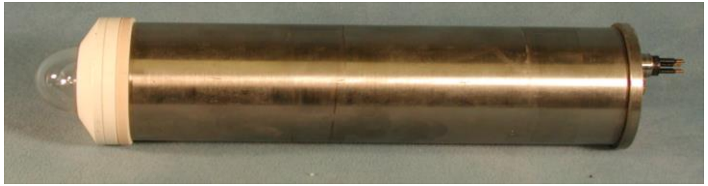
Check coating on longwave radiometers

Improved workflow

Modular Air-Sea Interaction Meteorological (ASIMET) system



Incoming longwave



Incoming shortwave

Redundancy when deployed:

- Data logged in modules and in data logger
- Two complete ASIMET system per buoy
- Additional, stand-alone ASIMET modules

- Signal conditioning as close as possible to sensor (amplification and digitization)
- Stable amplifiers
- Engineering unit output RS-232/485 with sensor ID and 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

Assess, quantify, and document performance

Surface meteorology accuracies

	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%

Bulk formula air-sea flux accuracies

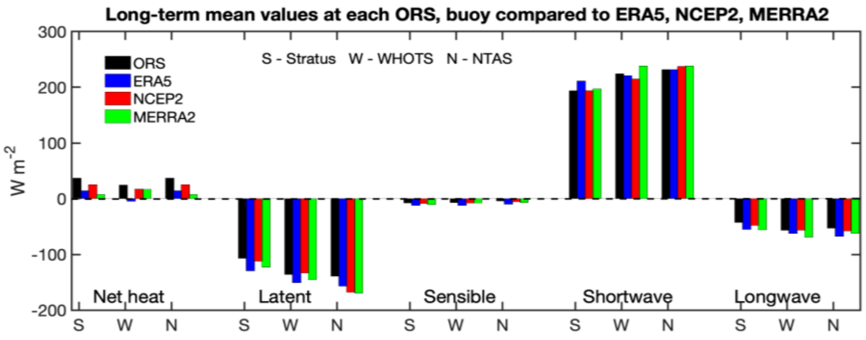
	Instant	Daily	Monthly
Longwave	7.5 W m^{-2}	2 W m^{-2}	2 W m^{-2}
Shortwave	10 W m^{-2}	3 W m^{-2}	3 W m^{-2}
Latent	5 W m^{-2}	4 W m^{-2}	4 W m^{-2}
Sensible	1.5 W m^{-2}	1.5 W m^{-2}	1.5 W m^{-2}
Net Heat Flux	15 W m^{-2}	8 W m^{-2}	8 W m^{-2}
Wind Stress	0.007 N m^{-2}	0.007 N m^{-2}	0.007 N m^{-2}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

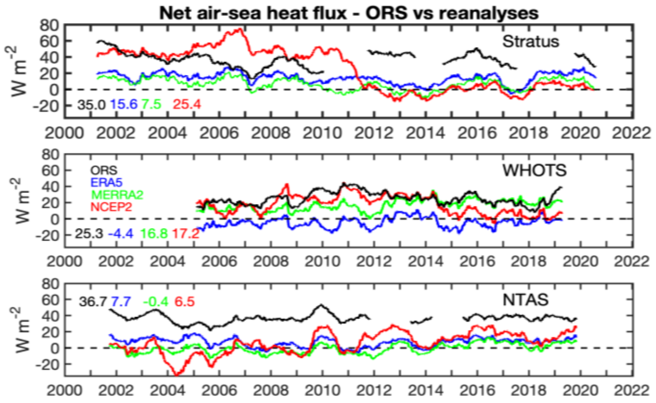
Comparisons with models have been done using net heat flux at the three ORS, taking contemporaneous time periods, and low-passing with 365 day running mean.

Colbo, K. and R. A. Weller 2009. The accuracy of the IMET sensor package in the subtropics. *Journal of Atmospheric and Oceanic Technology*, **26**(9), 1867-1890.

Bigorre, Sébastien P., Robert A. Weller, James B. Edson, Jonathan D. Ware, 2013: A Surface Mooring for Air–Sea Interaction Research in the Gulf Stream. Part II: Analysis of the Observations and Their Accuracies. *J. Atmos. Oceanic Technol.*, **30**, 450–469.

Are atmospheric reanalyses a good source of surface fluxes?



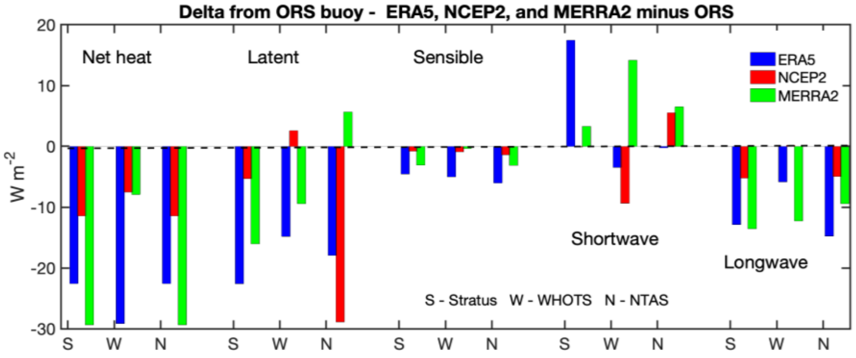


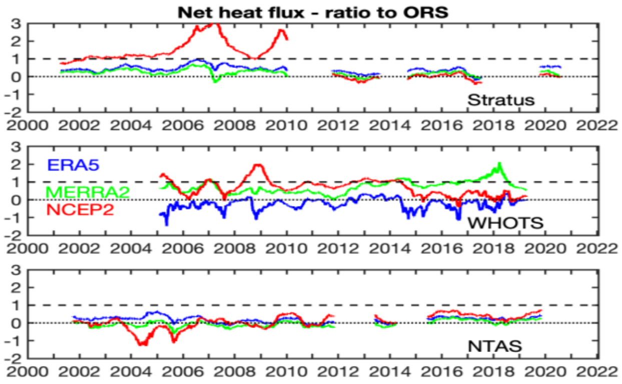
Comparison of low-passed net heat flux

Negative bias in models evident, **at times model net heat flux has the opposite sign,** so the ocean heats atmosphere

Long-term (17-21 year) means and differences

Differences in long-term model means from ORS





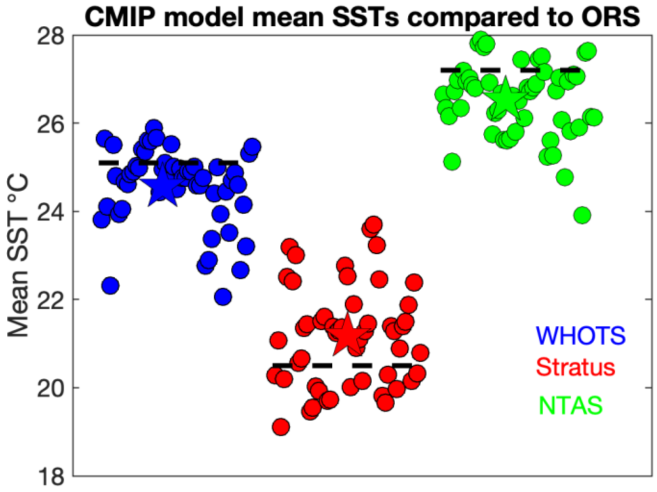
There is strong temporal variability in the model - ORS differences

Comparison of low-passed model net heat flux minus ORS normalized by ORS

All reanalyses put too little heat into the ocean, up to 30 W m^{-2}

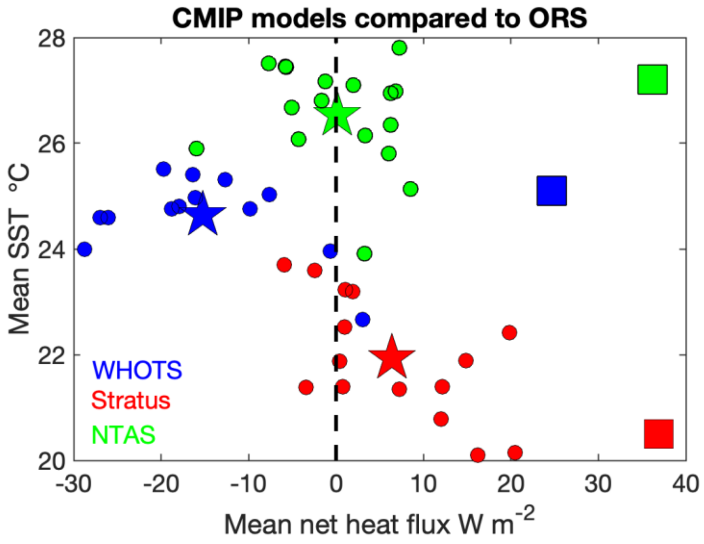
Weller, R., Lukas, R., Potemra, J., Plueddemann, A., Fairall, C., & Bigorre, S., 2022. Ocean Reference Stations: Long-term, open ocean observations of surface meteorology and air-sea fluxes are essential benchmarks. *Bull. Amer. Met. Soc.*., in press.

How well do coupled climate models perform?



Long-term mean SSTs from 51 CMIP6 models at the three ORS sites (filled circles) and ensemble mean of model SSTs (filled stars) compared to ORS long term mean SSTs (dashed lines).

Findings – **many climate models have similar SST biases – too cool at WHOTS and NTAS, too warm at Stratus by up to and over 3°C.** Ensemble means too warm at Stratus, too cool at WHOTS and NTAS.



15 CMIP6 models provided Q_{net} as well as SST. Scatter plot (mean Q_{net} on x-axis and mean SST on y-axis) shows **large models biases in Q_{net}** as well as SST biases. Filled circles – individual CMP6 models; filled stars model ensemble mean. Filled squares – ORS.

Finding – **CMIP6 historical model runs put too little heat into the ocean, by up to 40 W m^{-2}.**

Discussion, questions

Ocean Reference Stations – provide a means to anchor oceanic surface flux fields and motivate and guide model improvement

- ORS surface meteorology and computed air-sea fluxes are accurate enough to identify model biases and errors
- ORS are at locations that have been/can be the focus of process studies that provide quantitative understanding of the oceanic, atmospheric , and coupled processes at work at those locations
- At present, withholding observations from assimilation is the best means to ensure ORS provide independent benchmark observations
- Have done delayed exchange of observations and operational model fields with ECMWF, NCEP
- ORS observations anchor production of hybrid surface fluxes (e.g. Dr. Lisan Yu's OA Flux)
- ORS surface radiation observations used by NASA CERES, Dr. Rachel Pinker to validate remote sensing

How to better utilize ORS observations?

- Hourly telemetry, one-minute sample rate recorded - available

Can tracking of what data are assimilated/rejected by models be improved?

Does assimilation produce a local improvement to model agreement with observations that is not representative of other locations?