Ocean Reference Stations: Long-term observations of surface meteorology and air-sea fluxes are an essential component of the observing system.

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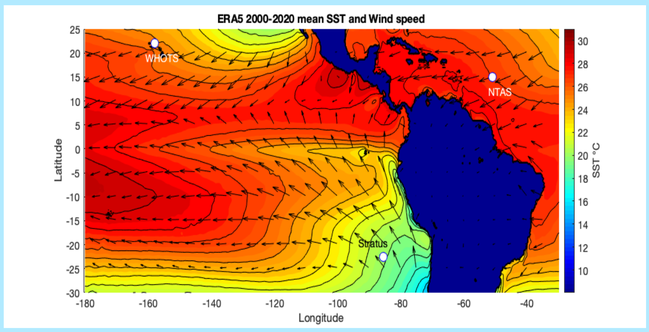
In order to:

create long climate quality time series of surface meteorology and air-sea fluxes;
anchor global ocean air-sea flux fields;
assess the realism of reanalyses, models, and remote sensing;
motivate improvement to models and predictive capabilities; and
guide design and improvement of the ocean observing system.

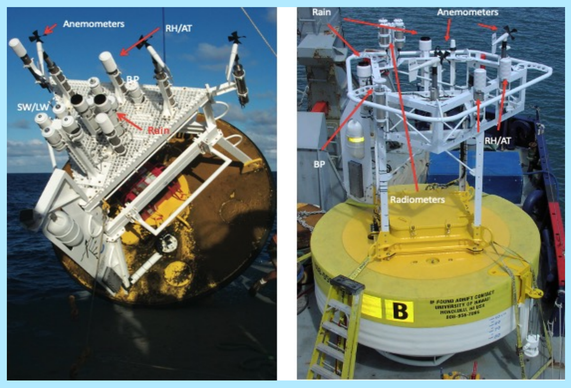
Sustained, long-term Ocean Reference Stations (ORS) are needed at key locations, where:

surface moorings collect quality observations with high reliability;
observations are withheld from assimilation;
field and laboratory calibrations/comparisons are done to provide well-documented quantification of accuracies;
merged long time series are provided to facilitate use of the data.

Three ORS in the Trade Winds: Stratus ORS since 2000, NTAS ORS since 2001, WHOTS ORS since 2004:



Locations of Stratus, NTAS, WHOTS



ORS surface buoys with older, 3 m aluminum hull (left) and present 3 m foam hull (right). A wind vane with radar reflector and data telemetry antenna orients the buoy with respect to the wind, and anemometers and air temperature and humidity modules (RH/AT) are placed on the upwind side of the tower. The cluster of four radiometers, one each for shortwave (SW) and longwave (LW) from two ASIMET systems, is placed above all other structures. Rain gauges, barometric pressure (BP) sensors are placed aft of the forward face.

Two redundant ASIMET meteorological systems, additional 3rd set of stand alone sensors for key variables. Basic sampling rate of one minute

Accuracies of in the field bulk meteorological observations and air-sea fluxes computed using COARE bulk formulae:

Pre- and post-deployment laboratory calibrations;
Overlapped deployment of new and old buoys;
At sea inter-comparisons against freshly calibrated shipboard sensors; and
Analyses of coincident observations from redundant sensors.

Error estimates in meteorology propagated through COARE bulk formulae to obtain flux error estimates.

	Instant	Daily	Monthly
Net longwave	7.5 W m^{-2}	2 W m^{-2}	2 W m^{-2}
Net 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}
Freshwater	20%	20%	20%

Uncertainties in observed surface meteorology.

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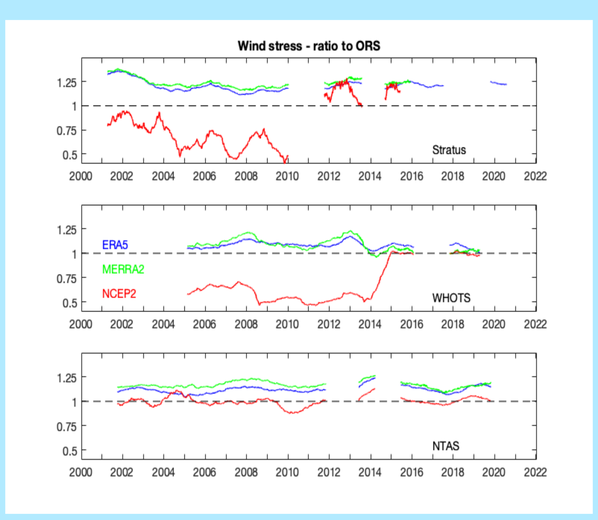
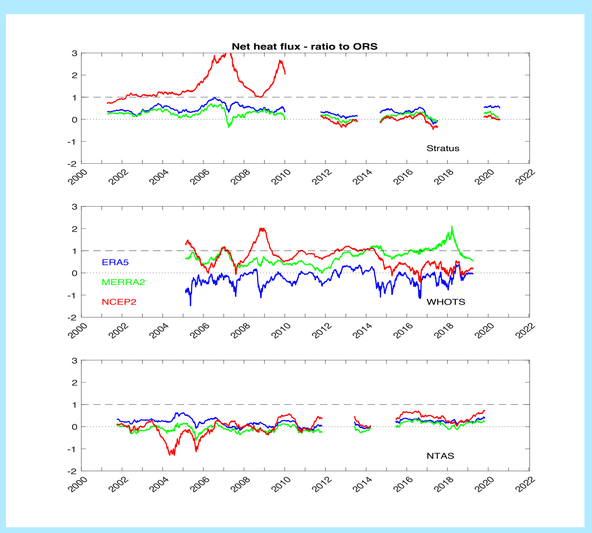
Uncertainties in observed surface fluxes.

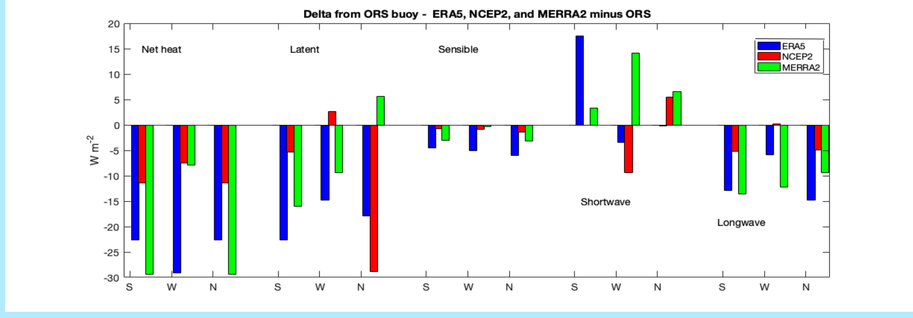
How well do modern reanalyses do at providing accurate, low-passed time series of surface meteorology and air-sea fluxes in the trade winds?



Reanalysis time series, coincident, co-located with ORS from ERA5, NCEP2, and MERRA2. Ratio of 365-day running mean of reanalyses to ORS for each ORS and each model. ERA5-blue, MERRA2-green, NCEP2-red. Magnitude of wind stress - left. Net heat flux - right.

Note the temporal variability in the ratios.





Differences between long-term means (same time periods ORS and model at each site) of reanalyses and ORS. Net heat flux and its four components.

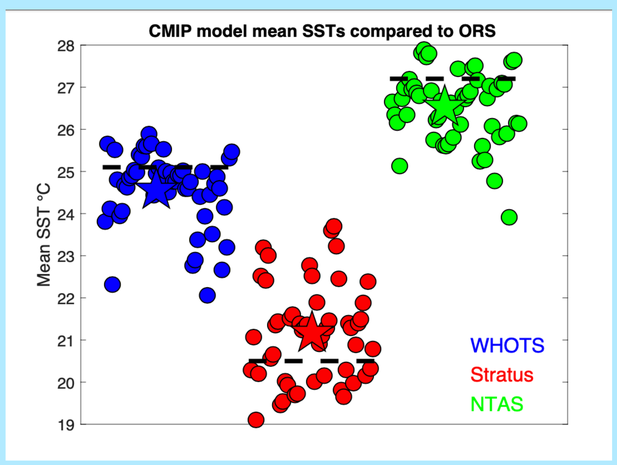
All reanalyese provide too little heat to the ocean in the mean. Biases stem from radiative heat fluxes as well as latent heat flux.

Note that the differences are often large compare to the uncertainties in the ORS fluxes.

Do climate models provide accurate sea surface temperatures (SSTs) and net air-sea heat fluxes in the trade winds?

Long-term mean SSTs from 51 CMIP6 models at each ORS compared to the observed long-term mean SST. ORS mean SST - dashed black line. Each model mean SST - filled circle. Ensemble mean model SST at each site - filled star.

Note models typically biased cool at WHOTS and NTAS but biased warm at Stratus. Note model mean SSTs as much as 3°C in error.

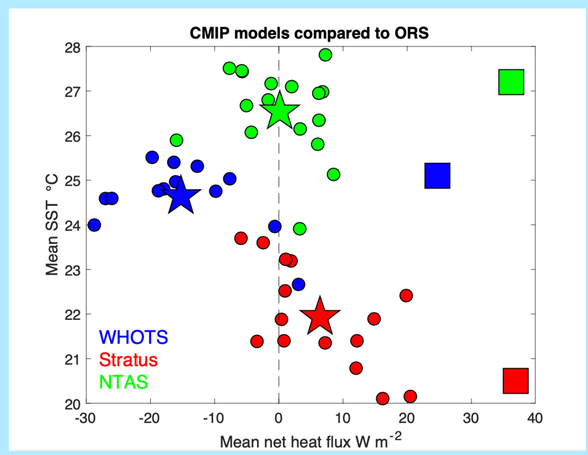


15 of the 51 models provided heat fluxes. Here both long-term mean net heat fluxes and long-term mean SSTs are compared in a scatter diagram with heat flux on the x axis and SST on the y axis.

Model mean (het heat, SST) - each model marked by filled circle; ensemble mean marked by filled star.

ORS mean (net heat, SST) marked by filled square.

Note: all models provide too little heat into the ocean by ~30 to 40 W m^{-2}, with ocean cooling at WHOTS in contrast to observed ocean heating.



Lessons learned:

- The withheld observations from Ocean Reference Stations, together with well documented estimates of their accuracies, provide the means to assess:
  - The utility of reanalyses as sources of realistic low-passed time series of surface forcing
  - The ability of historical runs of coupled climate models to replicate mean sea surface temperatures and mean net air-sea heat flux
- Models provide too little heat into the ocean under the Tradewinds by 10 to 30 W m^{-2}
- Reanalyses used frozen model code but have temporal variability in their realism stemming from variations in the types and distributions of data assimilated
- Coupled climate model historical runs show similar biases in SST at each ORS; improved availability of their net heat fluxes and components needed
- ORS in key regions providing quality, withheld observations are needed to provide the means to assess the performance of the combined model and observing system and motivate improvements to ocean predictive capabilities.

Further discussion in: Weller, R.A., Lukas, R., Potemra, J., Plueddemann, A.,J., Fairall, C., and 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.

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