WHOTS-2021 REPORT - 9/10/21, BWB

a. Existing Ship Met Instruments

The NOAA *R/V Oscar Elton Sette* (OES) is outfitted with sensors for air temperature (Ta), relative humidity (RH), barometric pressure (P), wind speed (U), and wind direction (DIR). The ship's SST/Salinity system was not operational for WHOTS 2021.

The ship's Ta and RH is from an RM Young system (model 41382VC) at the top of the main mast (height ~69 ft ASL). Pressure is a Vaisala PTB 330 on the bridge (height ~48 ft. ASL) with pressure corrected to sea level. Wind speed and direction are from an RM Young 05103 prop-vane anemometer on the main mast (height ~73 ft. ASL). (Height for ship met sensors on the mast is taken as ~ 70 ft. or 21.3 m in this analysis). Relative wind speed and direction are corrected to true components using ship heading and speed.

b. NOAA/PSL Met System for Bulk Fluxes

The PSL Boundary Layer Observations group collected surface meteorology and sea surface temperature data throughout the cruise. The PSL met system deployed on WHOTS 2021 consists of five components (see photos in Figs 1-5):

1. Two Vaisala WXT520 weather stations for U, Ta, RH, P and rain rate @ 13.67 m ASL, installed on the bow mast from struts extending ~ 2 ft. forward of the mast.
2. Two Kipp & Zonen pyranometers (CM22 and CMP22) and Two Epply PIR pyrgeometers located on the starboard aft corner of the pilot house roof.
3. Differential GPS unit measuring 1 Hz SOG, COG, heading and pitch angle.
4. Floating thermistor sea surface temperature measurement (YSI 46040 thermistor, sea snake) deployed from a davit off the starboard bow.
5. Vaisala PTB 220 digital barometer @ 12.9 m ASL on the aft pilot house roof.

These were all logged on a serial data acquisition system in the ship's main lab. Measurements were continuous through the duration of the WHOTS cruise and for the preceding two weeks while the ship was in-port and at sea on another cruise (sea snake not deployed during this period). Raw motion and GPS data are 1 Hz. WXT data are 1 Hz. Others are averaged to 1 min.

Additional details on PSL instruments are given in Table 1.

c. Notes on PSL and Ship Measurements

Ta / RH / wind / P: OES measurements are quite close to observed PSL values for all of these, as shown in Table 2. PSL deployed duplicate measurements for these parameters. PTB and WXT2 pressures agree to within 0.1 mb and WXT2 pressure is about 0.5 mb high. RH from the two WXT sensors differs by ~ 2% (absolute), and we have taken the mean of these as the reference RH in this analysis. Mean Ta from the WXTs is also used as the reference for air temperature, but WXT and the SCS Ta measurements are all very close.

The reference wind speed and direction are taken from the WXT sensors, depending on relative wind direction; for relative wind within +/-60° of the bow, we use the mean wind

speed and direction from the two WXT sensors; for relative wind directions >60° from the bow, the starboard WXT wind is preferred; and for relative wind directions <–60° the starboard WXT is used.

Radiation Measurements: The K&Z pyranometer calibrations were last performed in 2017 at the NOAA/GML roof-top radiation calibration facility. Solar radiometers are calibrated against the sum of two GML reference standards: a sun-tracking pyroheliometer for direct flux and a shaded Eppley model 848 pyranometer for the diffuse component. A direct comparison was also made to a secondary reference PSP maintained by GML (S/N 73-36). This calibration can be reverified post-cruise at ESRL. The two measurements are in close agreement and the mean value from the two pyranometers is used in this report for the reference solar flux.

The PIR radiometers were calibrated at the GML facility in July 2021. The calibration is referenced to an unshaded, unventilated GML PIR maintained by as a secondary standard, referenced to BSRN instruments as the primary standard. Following the recommendation of GML, the PSL recalibration was determined from a 3-coefficient form of the Albrecht-Cox equation:

$$LWR = \frac{mV}{c_1} + \sigma_{sb}T_c^4 - 4\sigma_{sb}(T_d^4 - T_c^4)$$

where mV is the thermopile signal in millivolts, T_c and T_d are case and dome temperatures in °K and calibration coefficient c_1 is determined from a regression to the reference measurement.

d. Bulk Met Comparisons with WHOTS-16 and -17

Comparisons are based on the hourly mean WHOTS real-time data available from the UOP website. Tables 2–8 give the mean, median and standard deviation measurement bias for ship and mooring systems relative to the PSL measurements. Pressures are adjusted to sea level for all systems. PSL wind speed is also adjusted for mean flow distortion effects at the ship's bow: Raw U is increased by 5% and raw V decreased by 15%. For the comparison with buoy systems, PSL data (U, Ta, RH) are adjusted to z = 3 m with the COARE bulk flux model (v.3.5). For the ship SCS comparison, PSL U, Ta, and RH are adjusted to 21m.

Measurement comparisons are computed for WHOTS-17 and SCS data collected at station ALOHA over both mooring intercomparison periods: 8/27/21 0800 to 8/28/21 1600 at the WHOTS-16 site and 8/30/21 1200 to 8/31/21 1600 at the WHOTS-17 site. Statistics are also computed separately over individual intercomparison periods for each mooring.

The moorings have duplicate met sensor and logging systems (systems 1 and 2). Tables 2-4 present comparison statistics for the ship and WHOTS-17 systems over the two comparison periods. Tables 5-8 are mooring comparisons for times when the ship was closest each mooring (within 2 N.Mi.). Figure 6 shows the ship-to-mooring distances over the entire period at station ALOHA. Figures 7-22 illustrate these intercomparisons in graphical format.

Figures 23-36 are representative time series plots of the raw ship measurements and COARE bulk flux results for one day, 8/27/21, which is notable for a couple rain events that occurred from 0500 to 0700.

e. Notes on results

Pressure: Generally close agreement between all systems except for WHOTS-16 which is biased about 0.8-0.9 mb low with greater variability.

Air temperature: All systems except WHOTS-16 system 2 are about 0.07-0.15°C high with respect to the mean WXT air temperature. This is within measurement uncertainty. No data for WHOTS-16 system 1.

Relative humidity: No RH data for WHOTS-16 system 1. Otherwise, agreement between the various systems is ~1.5% (absolute) or better. Note that the two PSL WXT RH measurements differ by ~2% absolute.

Solar radiation: Agreement between PSL and mooring measurements is generally good but scattered, likely due to cloud shading during the intercomparison.

Infrared radiation: Agreement with WHOTS-16 and WHOTS-17 system 2 is better than 10 W/m^2 overall, but both WHOTS-16 systems show periods of higher IR flux, maybe due to cloud shading. WHOTS-17 system 1 shows a warm bias during several hours of the intercomparison, but system 2 does not (see Figure 37).

Sea surface temperature: Agreement between all mooring systems and the PSL sea snake is better than 0.1°C.

Wind: No wind data from WHOTS-16. Wind speed agreement with WHOTS-17 is good. True wind direction for system 1 is biased about 10° high for some reason, perhaps an offset in the magnetic declination adjustment? Wind speed from the SCS anemometer shows a trend of increasing positive bias with increasing speed, which may be a flow distortion effect.

Table 1: PSL instrument details

Sensor	Calibration coefficient(s)	Make / Model	Serial Number	Date of calibration
Pyranometer PSP1	0.00900	K&Z CM22	50122	2017
Pyranometer PSP2	0.00951	K&Z CMP22	170518	2017
Pyrgeometer PIR1	0.00296	Eppley PIR 1	38519F3	July 2021
Pyrgeometer PIR2	0.00257	Eppley PIR 2	38521	July 2021
Sea Snake SST thermistor 0C to 40C	C4=0.00144694 C5=0.0037006 C6=0.000000101	YSI 46040 series	n/a	n/a
PTB Barometer	n/a	Vaisala PTB330	L2820128	n/a
WXT-1	n/a	Vaisala WXT-520	G2950010	2021
WXT-2	n/a	Vaisala WXT-520	L4720496	2021

Difference Tables: PSL-measured values minus mooring or ship-measured values over both intercomparison periods. Only possible for SCS and WHOTS-17, since WHOTS-16 was out of the water during the WHOTS-17 intercomparison.

Table 2: PSL – Ship SCS, entire period at ALOHA - raw wind/T/RH data, not height corrected

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.16	1.0	-	-0.6	-5.5	-	-	0.20
median	-0.15	0.8	-	-0.6	-6.1	-	-	0.20
std dev	0.06	0.8	-	0.3	6.5	-	-	0.03

Table 3: PSL – W17-1, entire period at ALOHA

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.12	-1.4	0.00	0.1	-10.4	-12	-9	0.44
median	-0.15	-1.2	0.03	0.1	-10.9	-7	5	0.45
std dev	0.13	0.9	0.09	0.4	3.9	34	30	0.07

Table 4: PSL – W17-2, entire period at ALOHA

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.07	0.3	0.01	0.0	4.0	-20	1	0.49
median	-0.08	0.4	0.03	0.0	3.2	-4	1	0.50
std dev	0.13	1.0	0.09	0.3	4.1	37	5	0.07

Difference Tables: PSL-measured values minus mooring-measured during the intercomparison periods for each mooring.

Table 5: PSL – W16-1, near buoy

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-	-	0.06	-	-	23	-4	0.80
median	-	-	0.05	-	-	-5	-2	0.75
std dev	-	-	0.03	-	-	89	14	0.13

Table 6: PSL – W16-2, near buoy

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.03	0.4	0.07	-	-	16	-9	0.91
median	-0.02	0.3	0.05	-	-	-7	-8	0.88
std dev	0.07	0.7	0.03	-	-	51	15	0.10

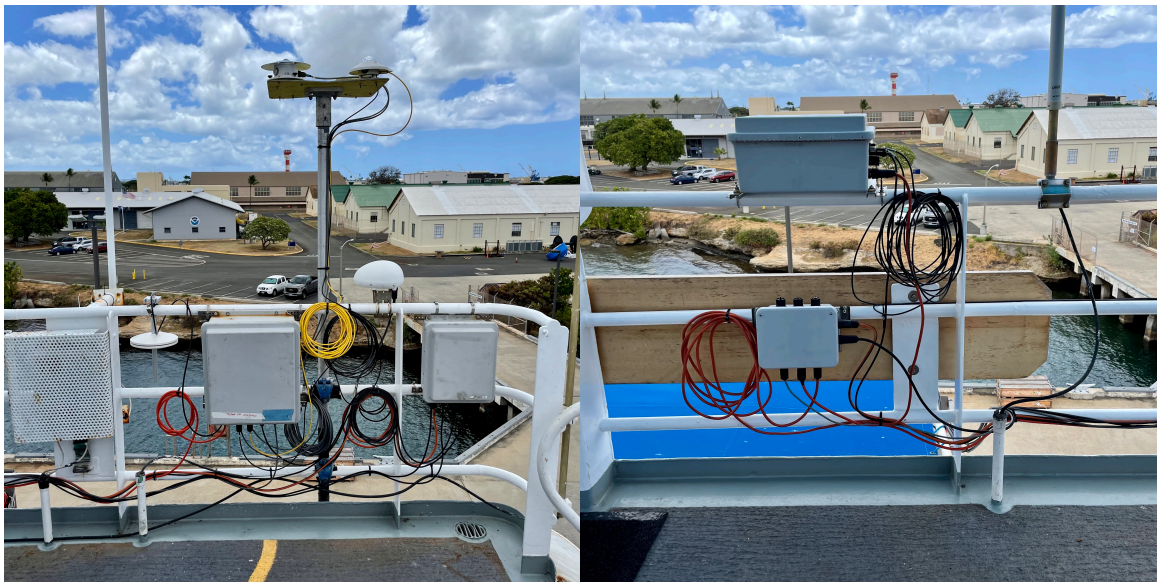
Table 7: PSL – W17-1, near buoy

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.18	-1.2	-0.01	0.2	-8.9	-17	-27	0.50
median	-0.16	-1.2	0.05	0.1	-10.8	-7	-41	0.50
std dev	0.07	0.4	0.13	0.3	4.2	33	36	0.03

Table 8: PSL – W17-2, near buoy

	T air, C	RH, %	SST, C	Wspd, m/s	Wdir, deg	Rs W/m2	Rl, W/m2	P, mb
mean	-0.12	0.6	0.00	0.0	4.0	-23	1	0.53
median	-0.09	0.4	0.05	0.0	3.2	-4	0	0.56
std dev	0.07	0.4	0.12	0.3	4.1	43	3	0.06

Figure 1: RV Oscar Elton Sette, bow and bridge profile.


Figures 2-3: Pilot house roof installations: Radiometer mount, mean met and network switch boxes; heading box and power distribution box.

Figures 4-5: Bow installation for two WXT weather stations; starboard sea snake boom.

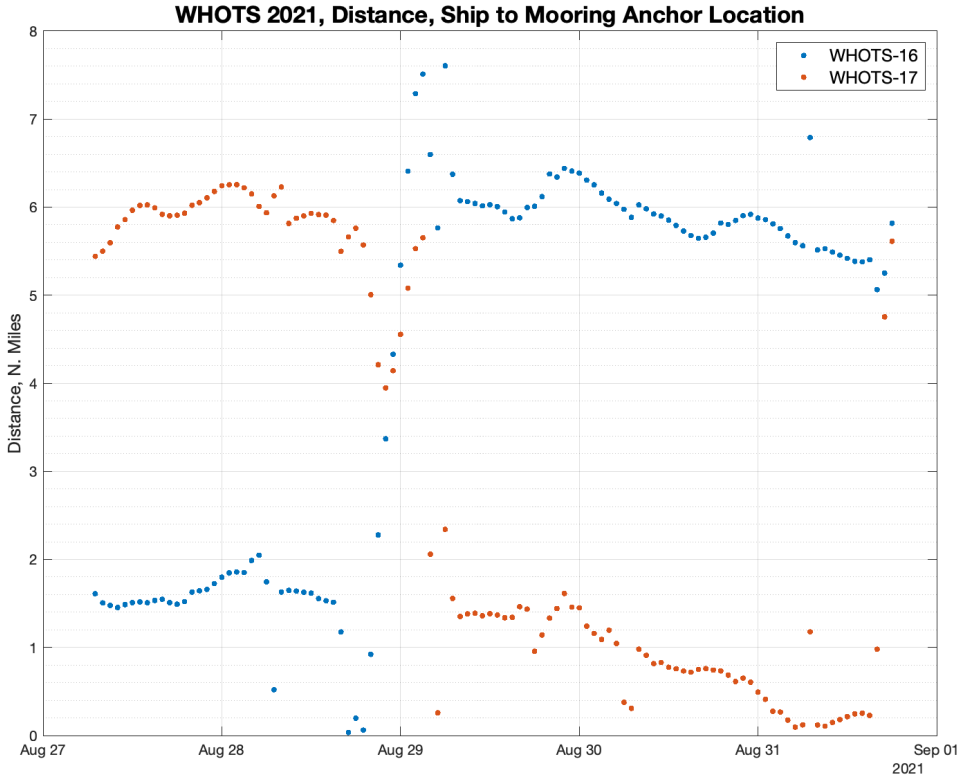
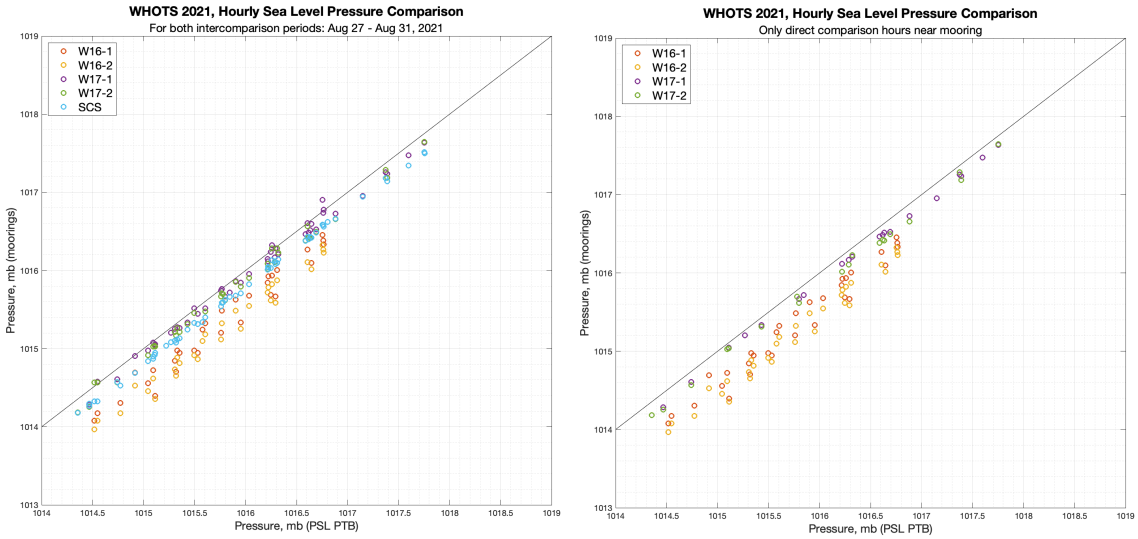
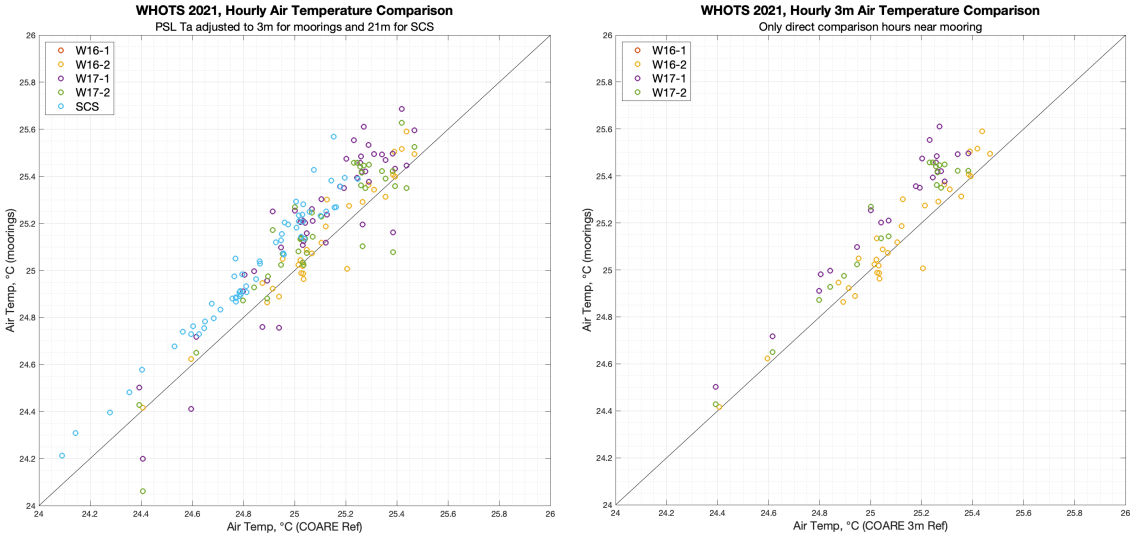


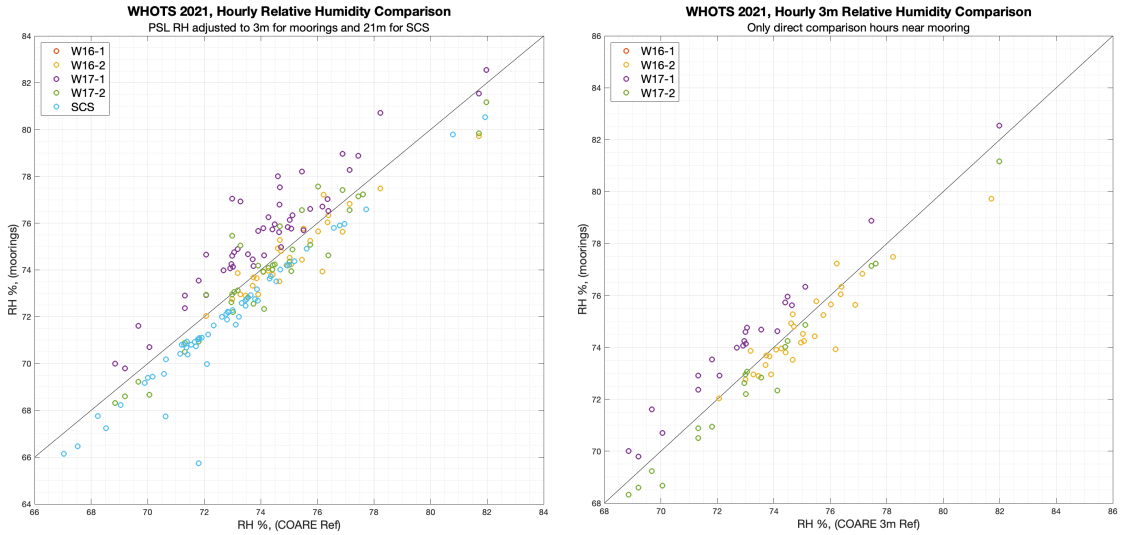
Figure 6: Distance from the ship to the two mooring anchor locations during the comparison period at Station ALOHA.



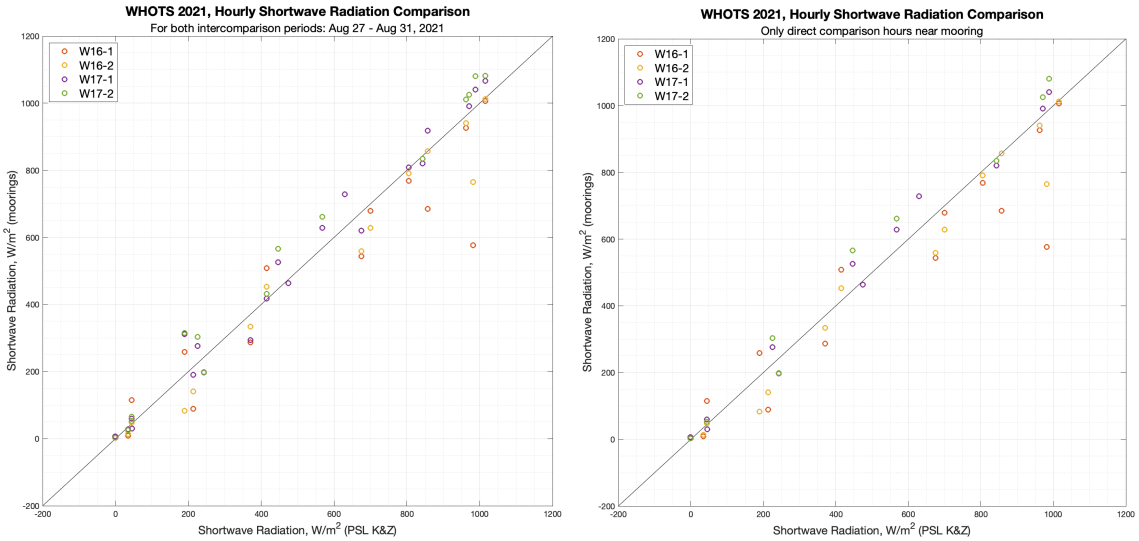
Figures 7-8: Atmospheric pressure comparison.



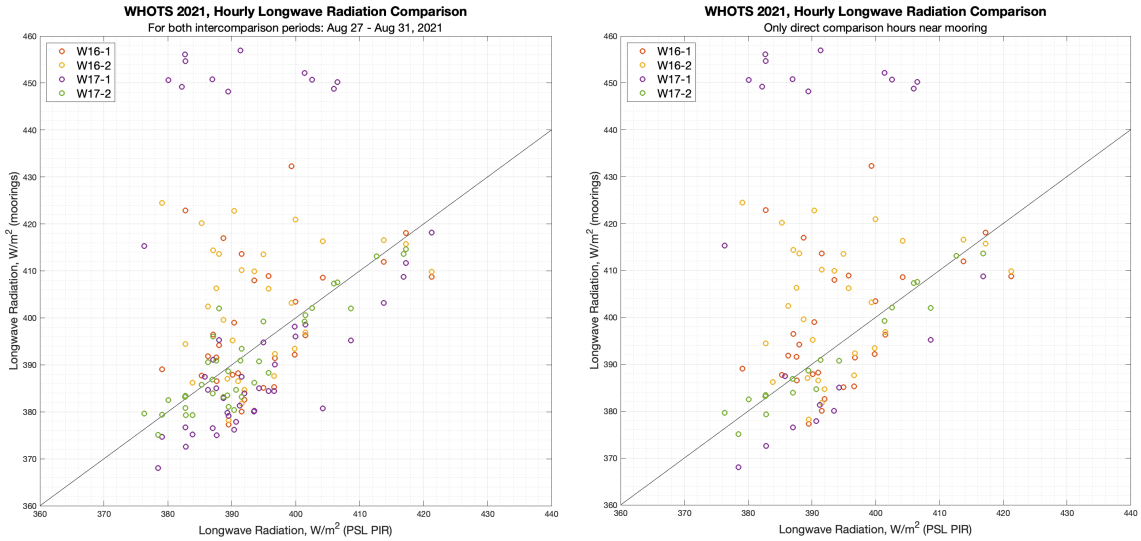
Figures 9-10: Air temperature comparison. PSL-SCS data not height corrected.



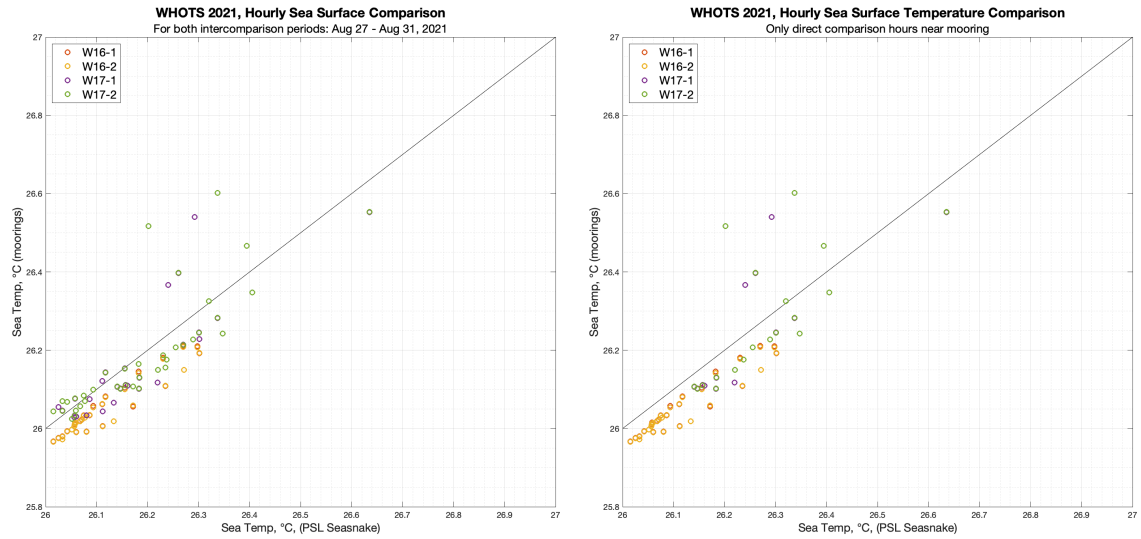
Figures 11-12: Relative humidity comparisons. PSL-SCS data not height corrected.



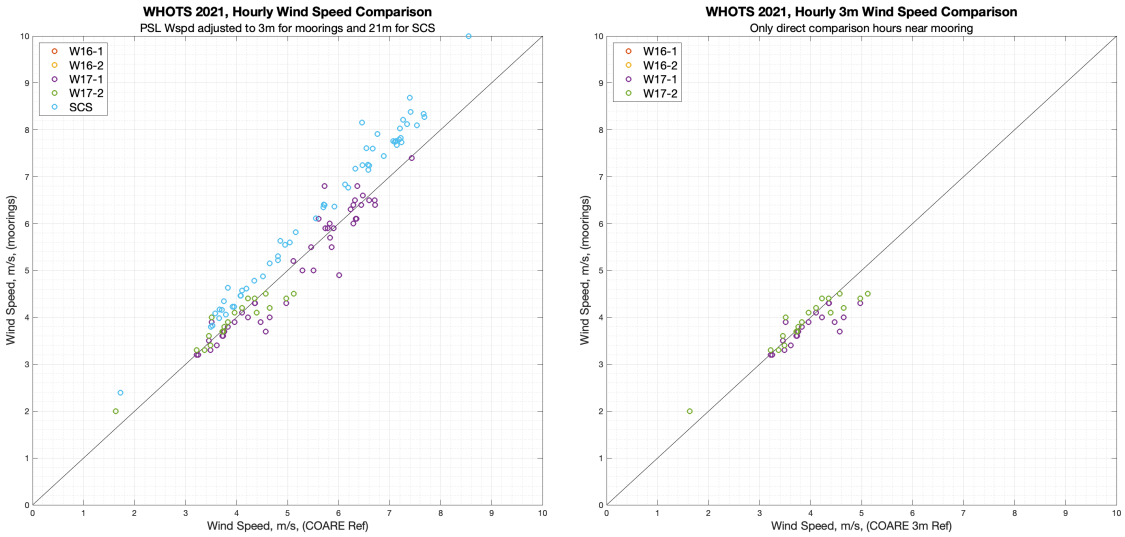
Figures 13-14: Solar radiation comparisons.



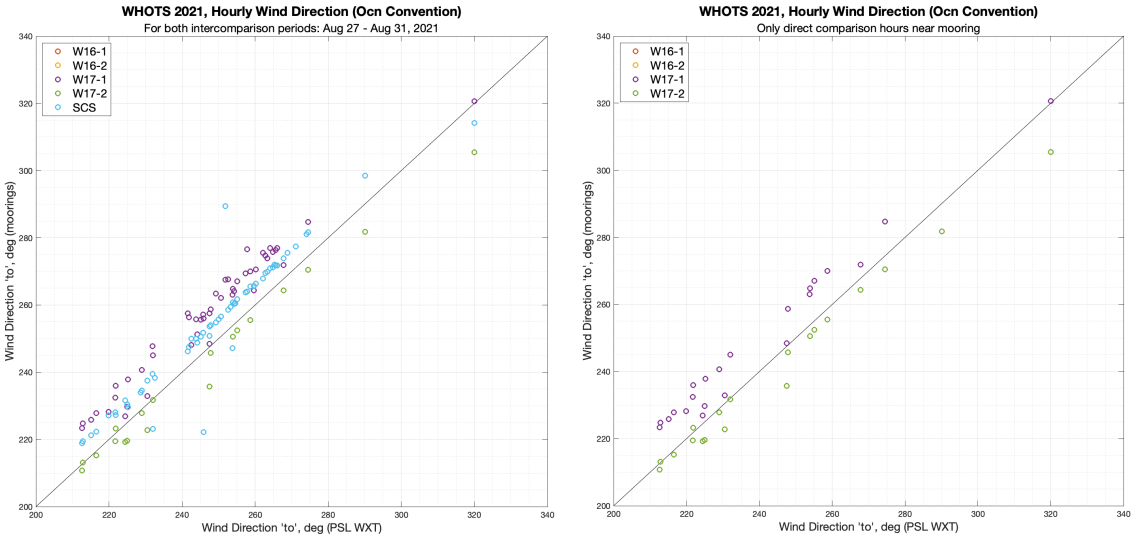
Figures 15-16: Longwave radiation comparisons.



Figures 17-18: Sea surface temperature comparisons.



Figures 19-20: Wind speed comparison. PSL-SCS data not height corrected.



Figures 21-22: Wind direction comparison.

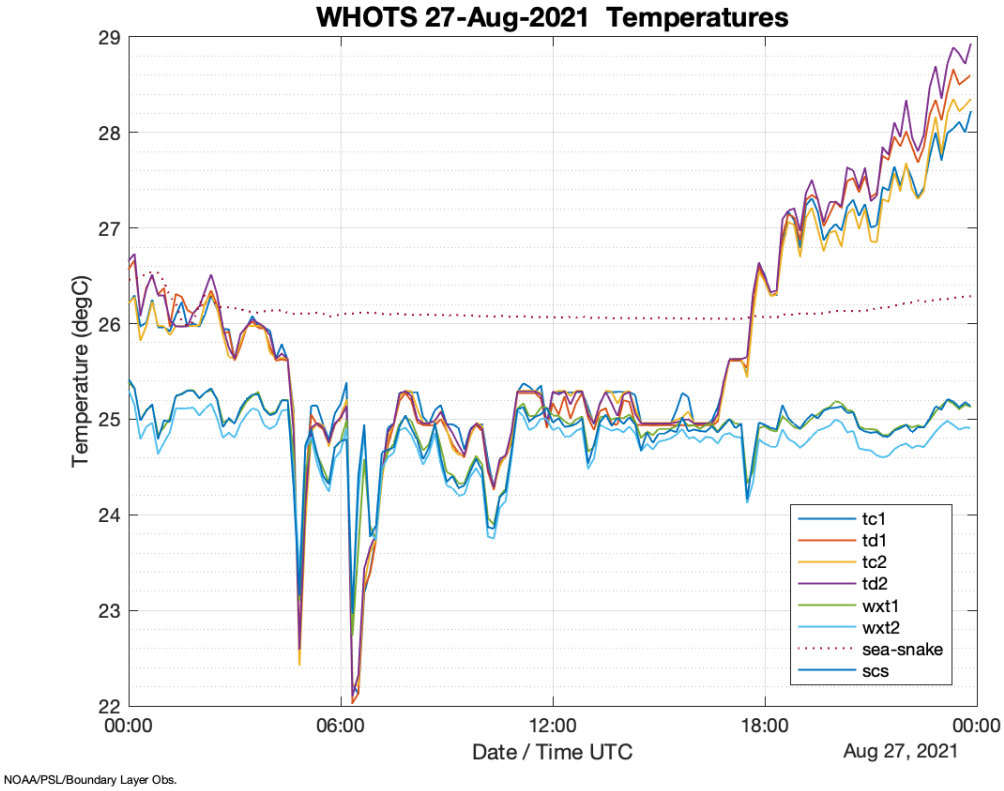


Figure 23: Temperatures. Tc and Td are PIR case and dome temperatures.

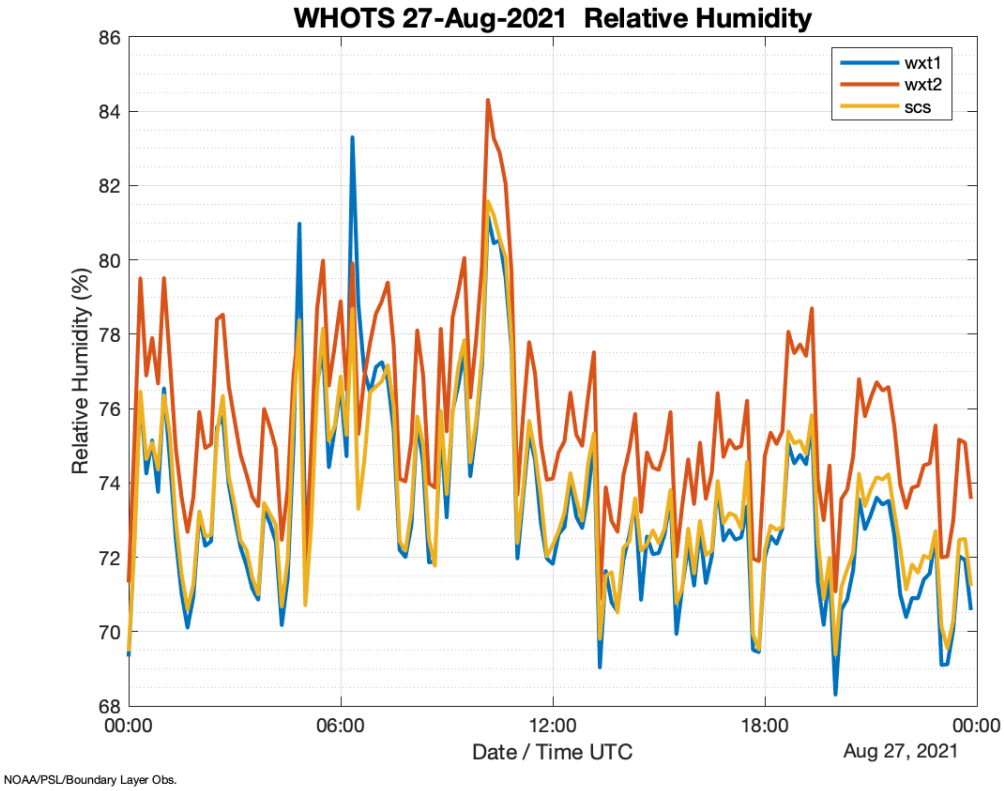


Figure 24: Relative humidity.

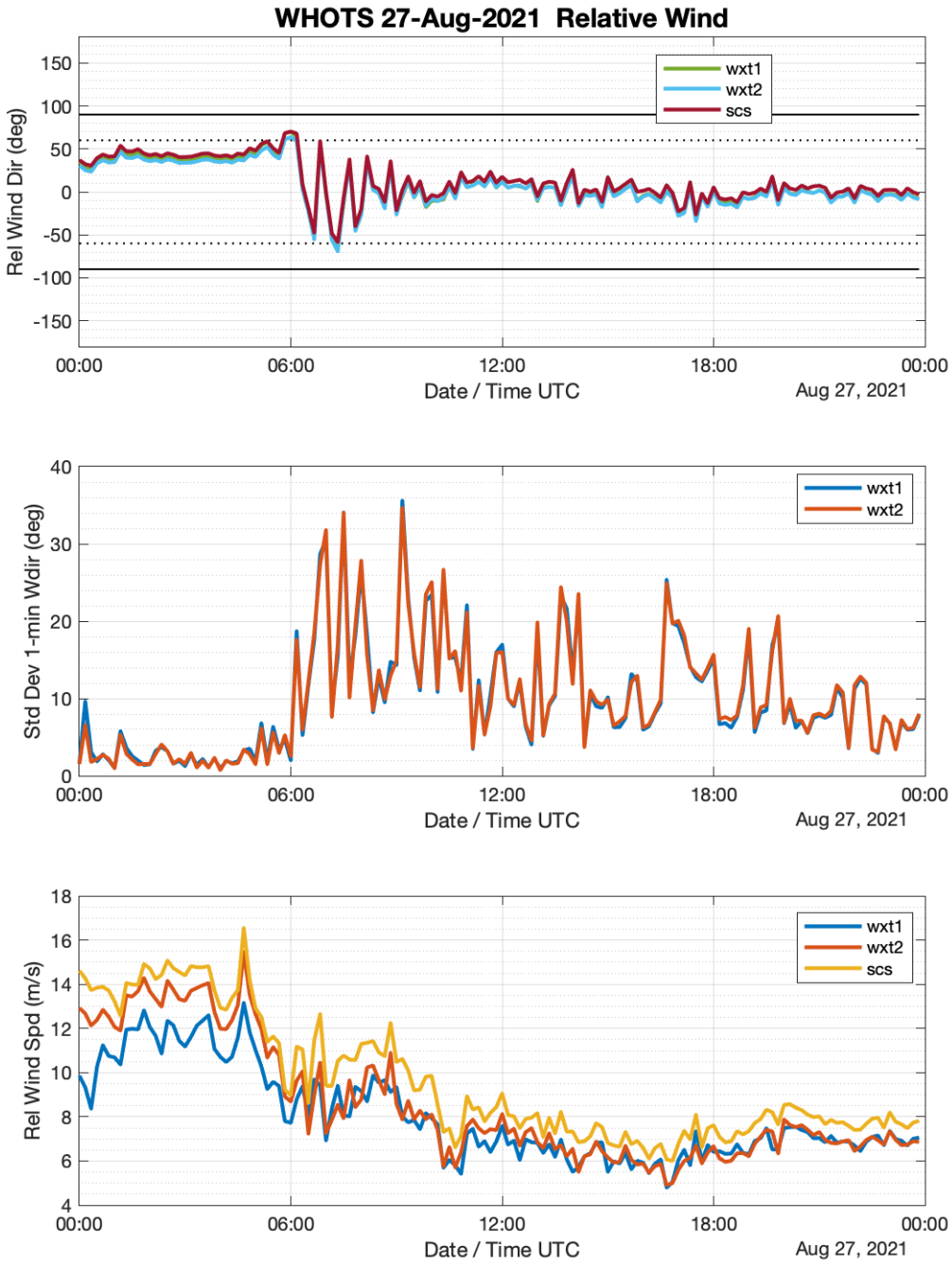


Figure 25: Relative wind speed and direction.

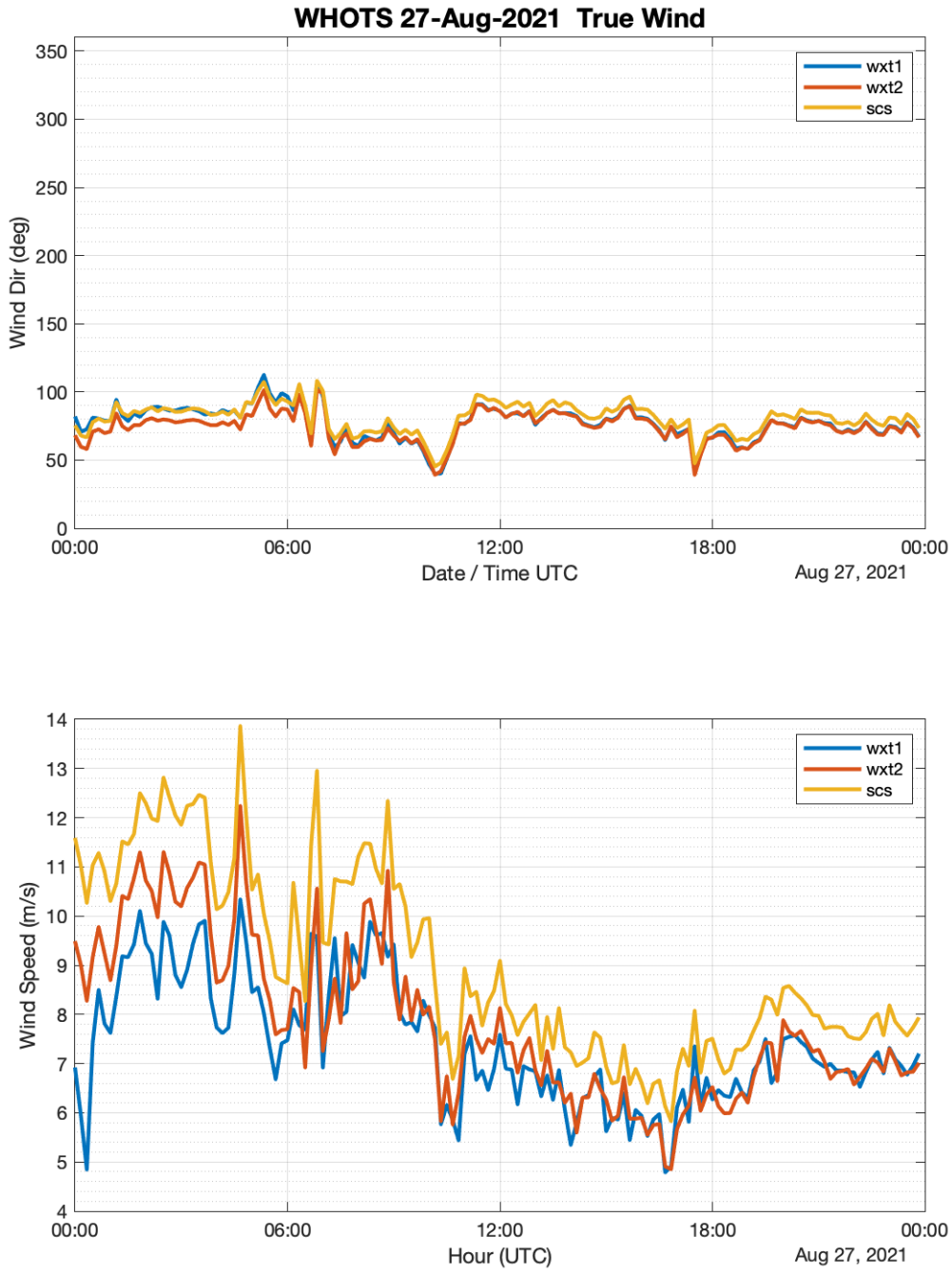


Figure 28: True wind speed and direction.

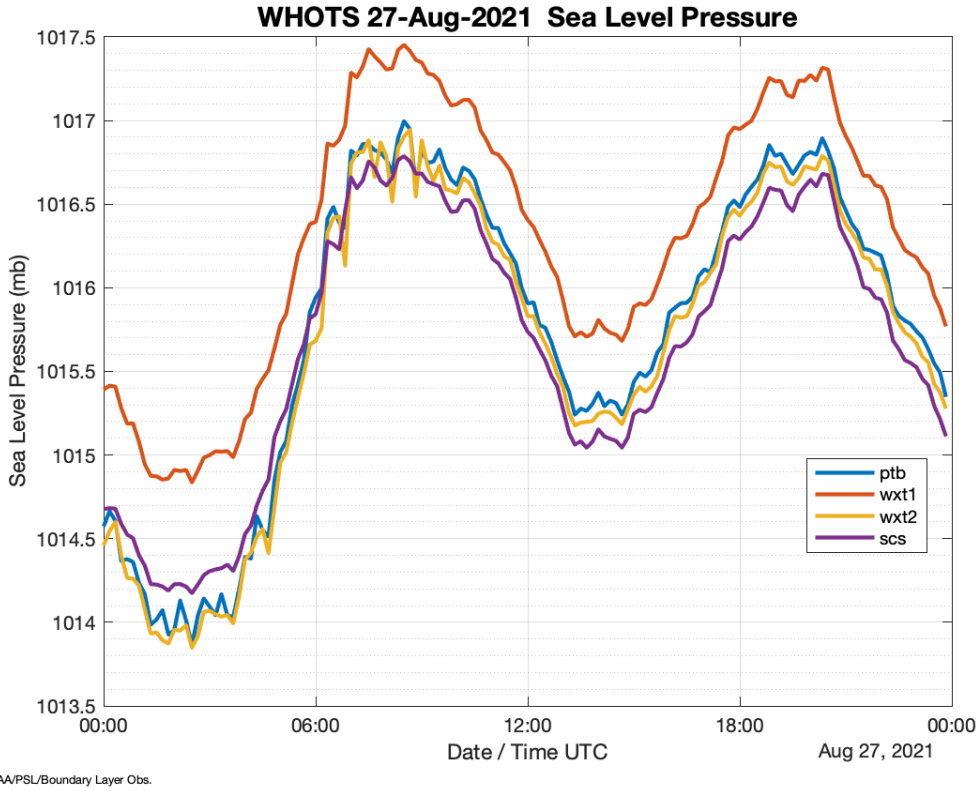


Figure 29: Atmospheric pressure.

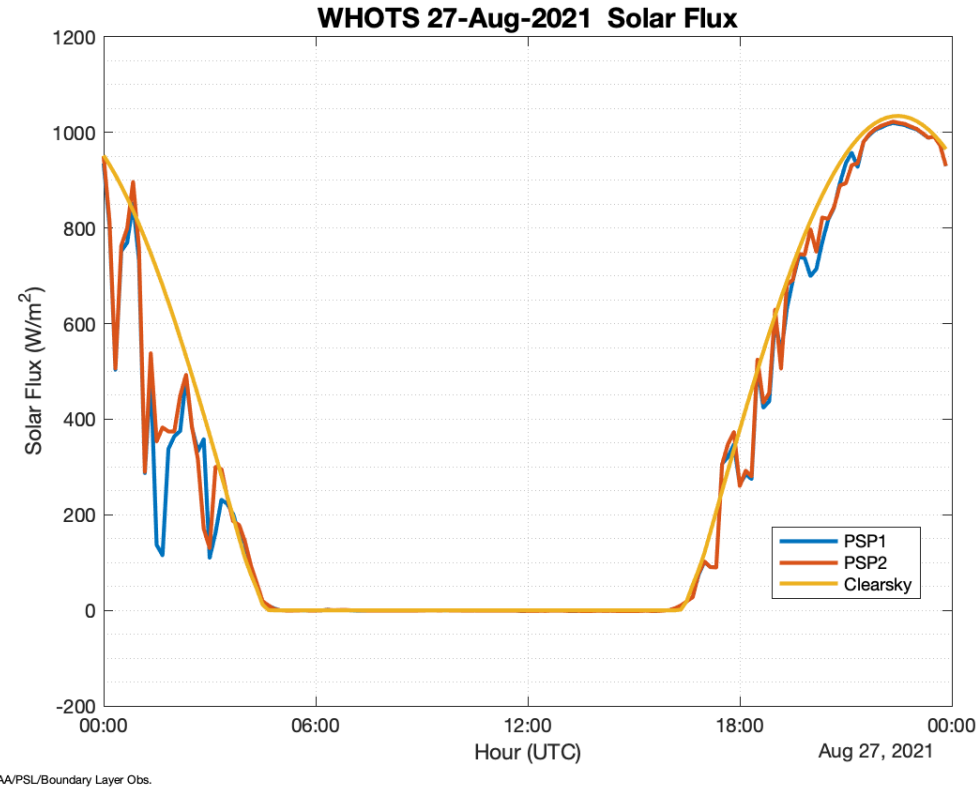


Figure 30: Shortwave (solar) radiation.

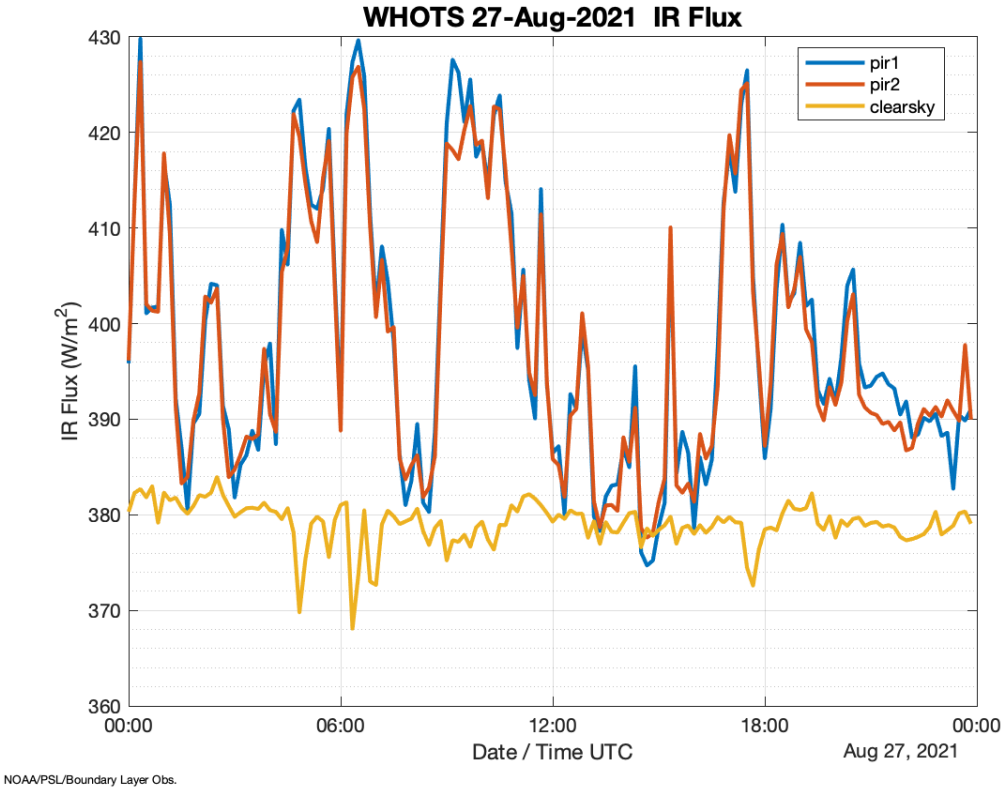


Figure 31: Infrared radiation.

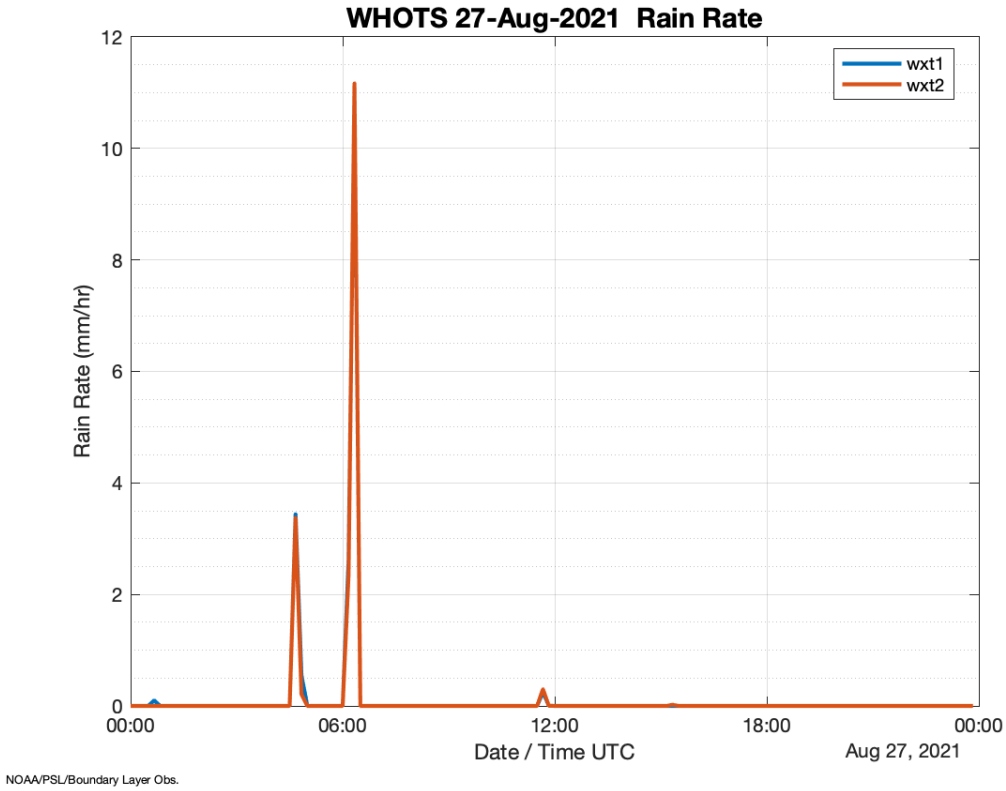


Figure 32: Rain rate.

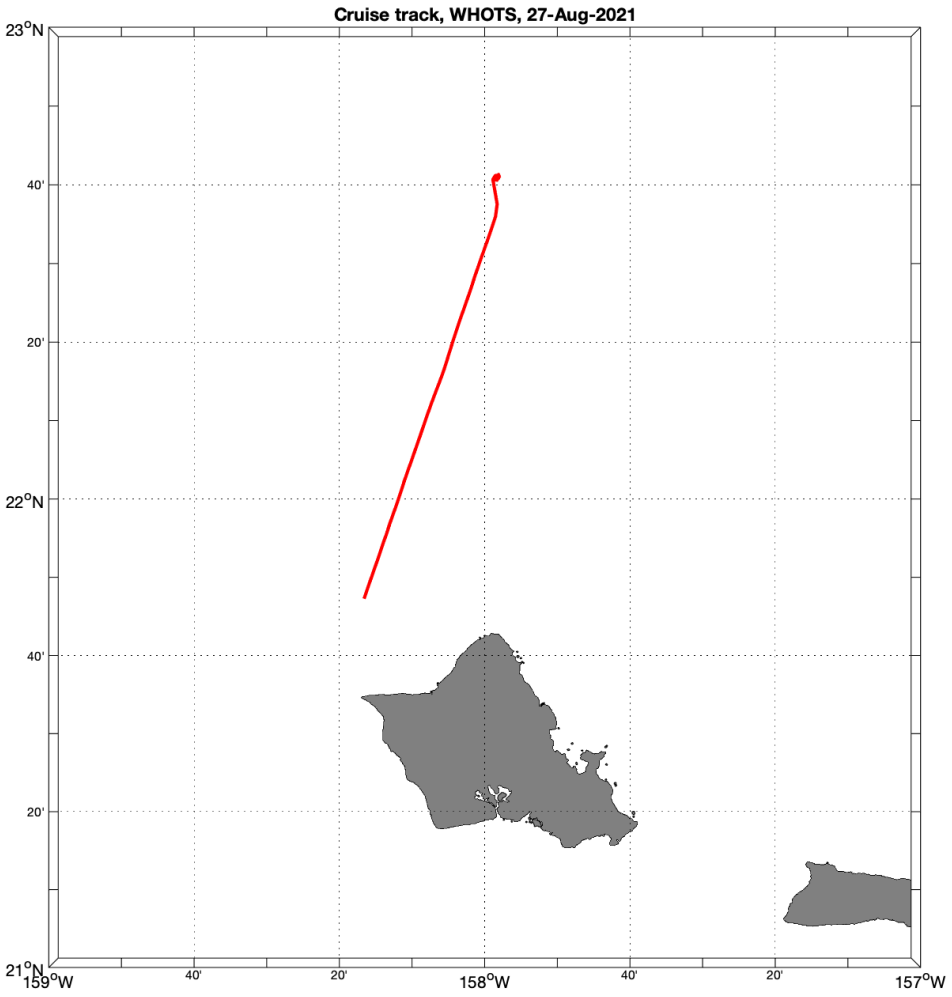


Figure 33: Ship track on Aug 27. Early hours of 8/27 were a return transit from Oahu.

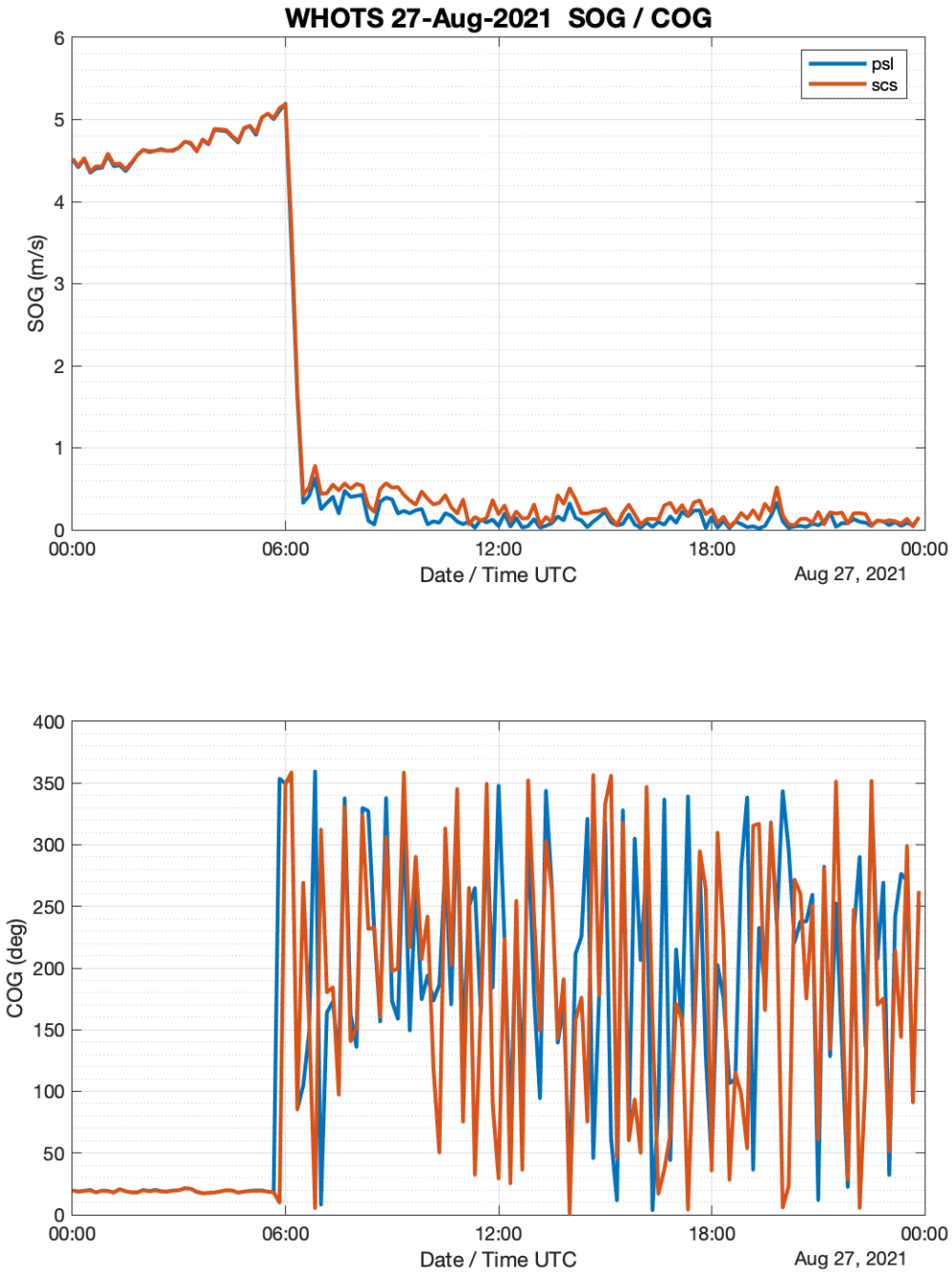


Figure 34: Speed-over-ground and course-over-ground.

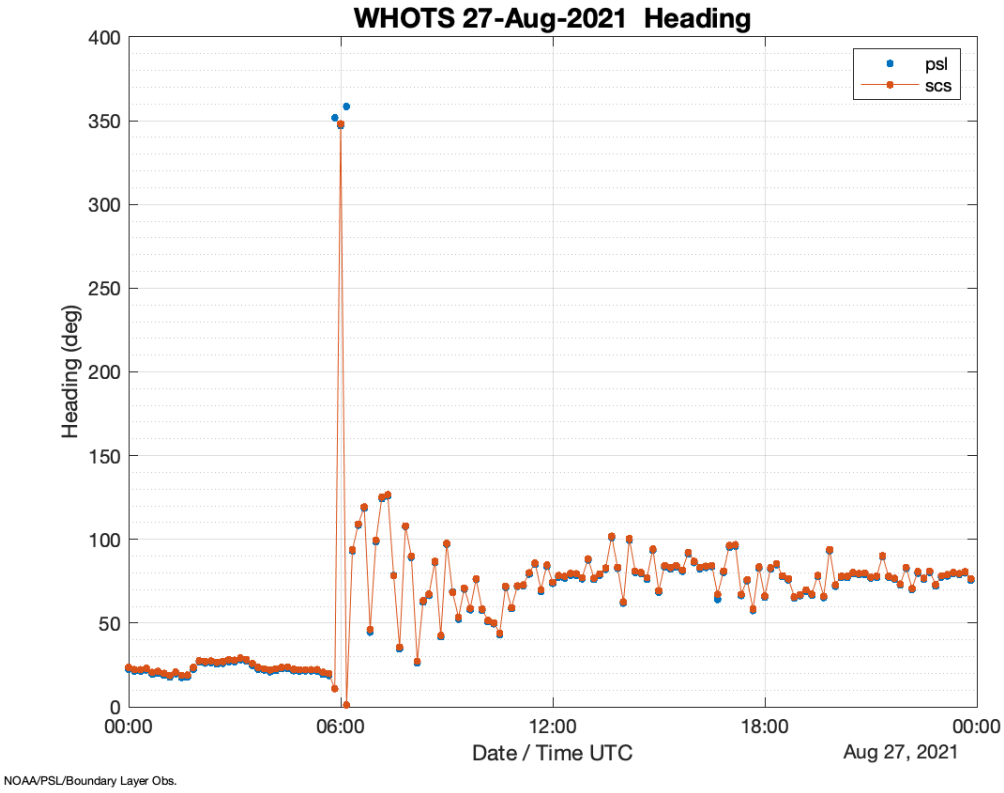


Figure 35: Ship heading.

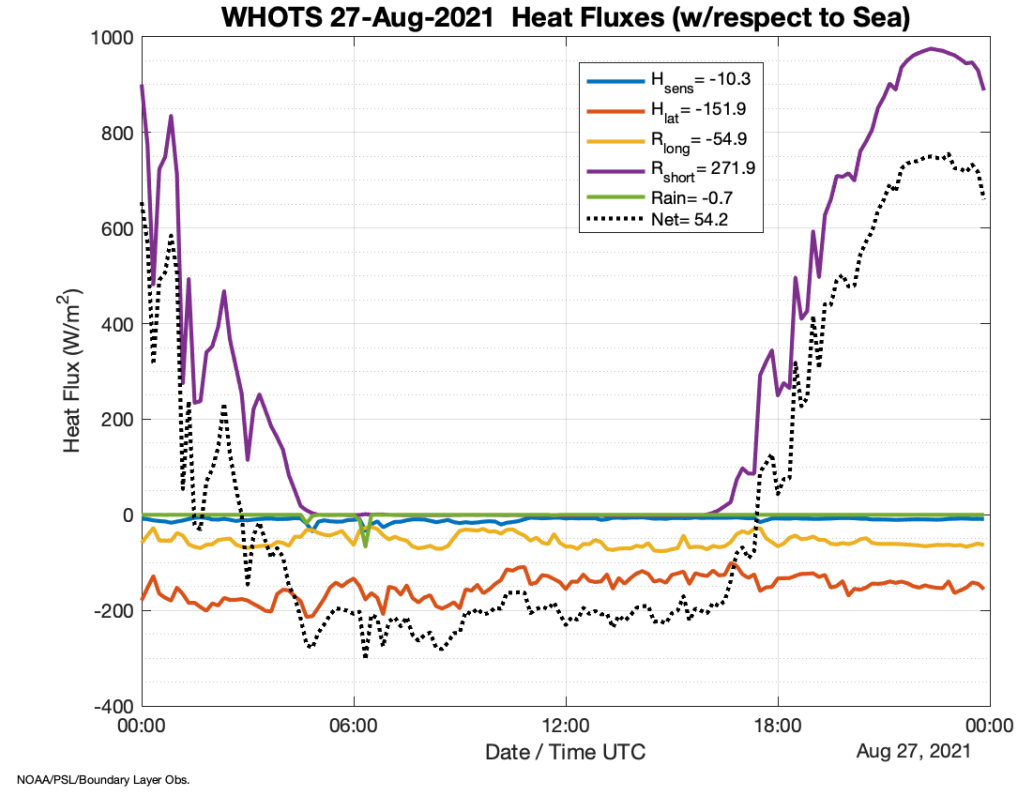


Figure 36: Measured and bulk heat flux components with respect to the ocean.

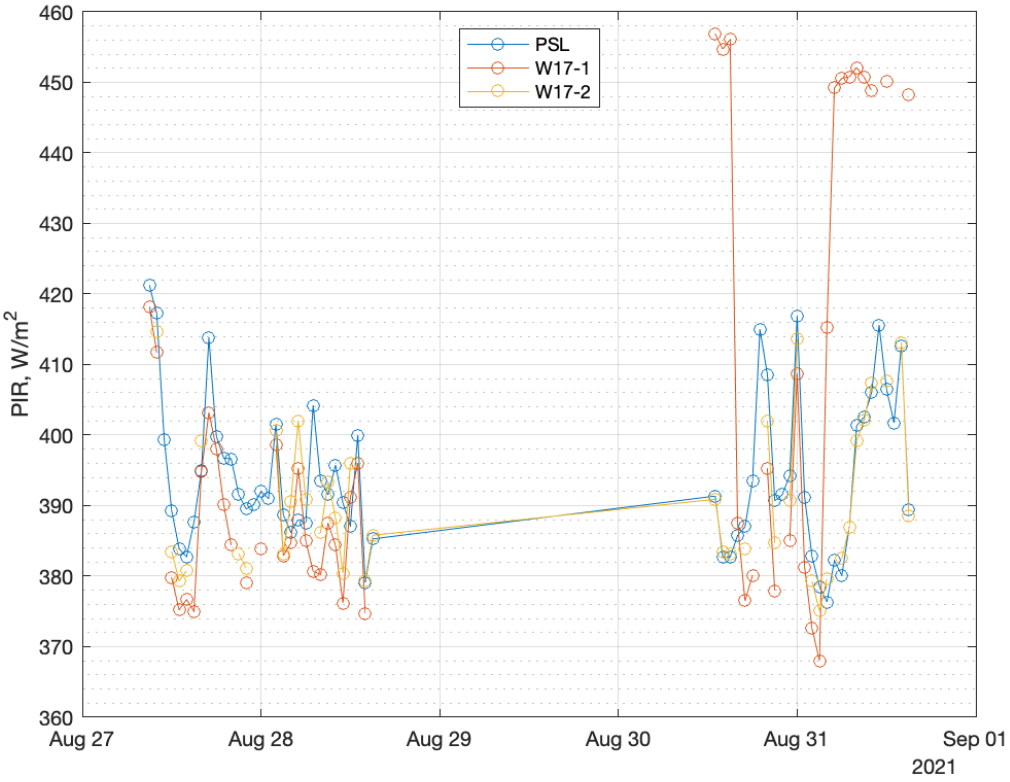


Figure 37: Timeseries of IR flux measurements during the two intercomparison periods. WHOTS-17 system 2 looks good over the entire period, but System 1 has several hours of anomalously high values during the Aug 30-31 period.