Solar and IR radiative flux observations from research vessels and buoys

C.W. Fairall, Sergio Pezoa, Ludovic Bariteau, Byron Blomquits,NOAA/PSL, Boulder, Co

Robert Weller and Al Pluddemann, WHOI, Woods Hole, MA

For 25 years NOAA and WHOI have been cooperating on measurements of the components of the surface energy budget over the ocean including sensible and latent heat turbulent fluxes and radiative fluxes. Long time series of solar and IR fluxes have been obtained by WHOI from Flux Reference Buoys at three open ocean locations: 1000 km west of the Chilean coast, 100 km north of Hawaii, and 900 km east of Barbados. PSL has deployed radiative flux sensors on research vessels in various field programs since 1990, including on the ships servicing the Flux Reference Buoys. We have worked with GML on calibration, quality control, and interpretation of the radiation measurements and made extensive use of the calibration facility at DSRC. Investigation of different calibration approaches, data logging methods, accuracy of different commercial sensors, pitch-roll stabilization, effects of non-cosine behavior, dome heating/cooling, and environmental contamination has led to steady improvements in the accuracy of the long time series.

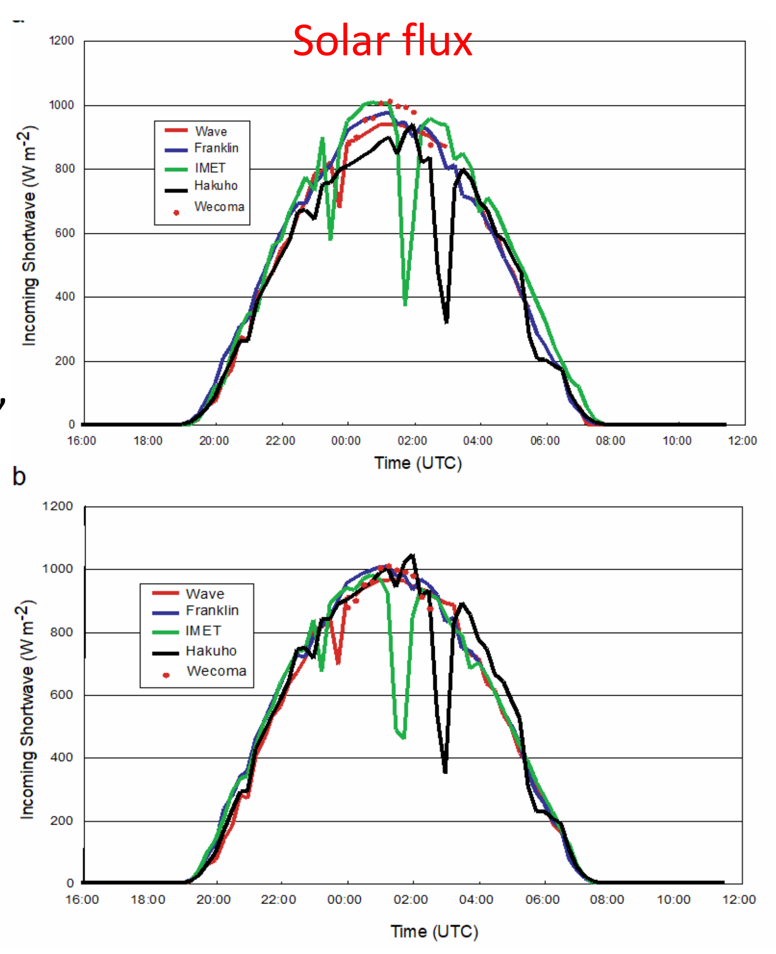
- Historical background
- Issues with ship and buoy observations
- Flux Reference sites analysis
- Future

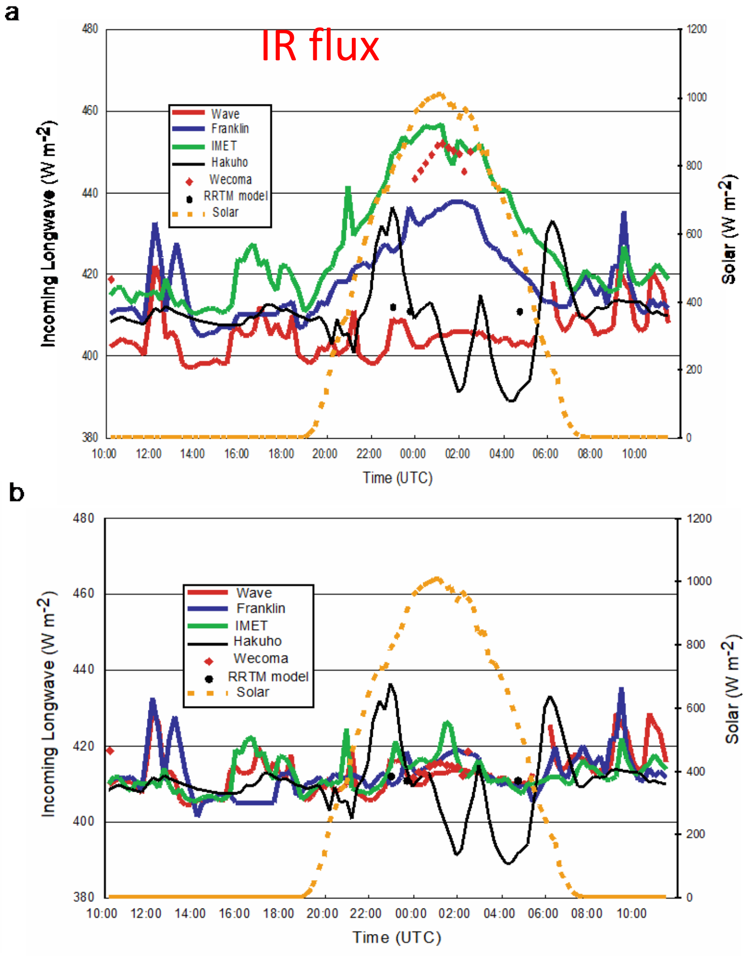
Early Steps in Marine Radiative Flux Observations: TOGA COARE

TOGA Coupled Ocean Atmosphere Response Experiment (western Pacific warm pool, 1992-1993) – two dedicated intercomparison periods, IC1 and IC2

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





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

Basic Issues

- Buoys – unattended for a year, 10 Watts power for everything
- Ships – Plenty of power, superstructure in FOV, RFI, competing demands for space, reasonable maintenance on 1-month process studies but very limited for 1 year deployment
- Platform pitch/roll and heading [conventional suntrackers and shadowbands not practical]
- Sea spray and biological (mostly seabirds) contamination of optics
- Sensor calibration, drift, etc.

- Thus conventional pyranometers and pyrgeometers are used.
- BSRN: Solar - suntracker **direct** beam plus shaded B&W **diffuse**
- BSRN: IR – shaded PIR

Simple Thermopile-Driven Heat Balance Radiative Flux Sensors

$$R_{sol} = A_{sol} \Delta V_{Therm}$$

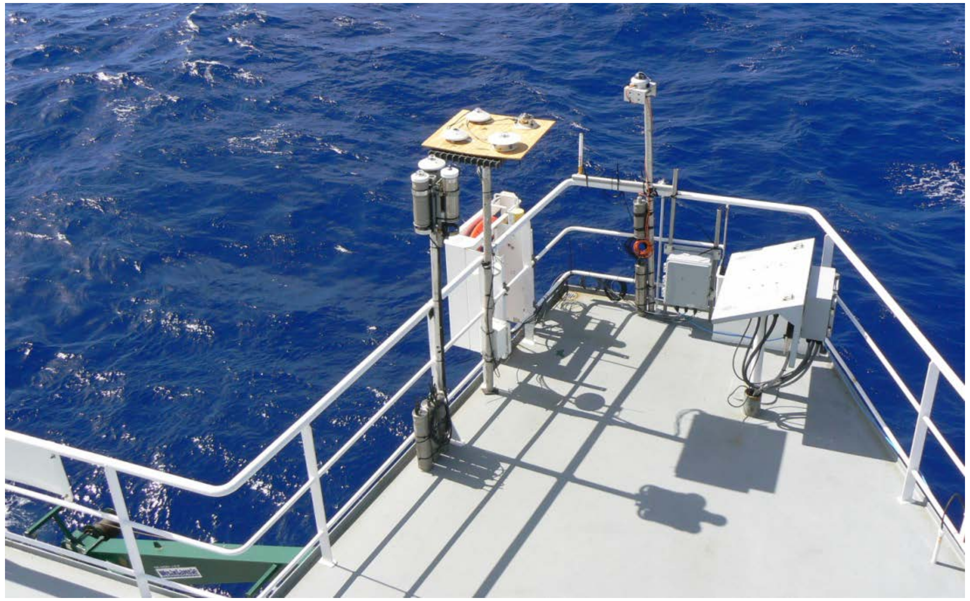
Solar Flux – Pyranometer
Flux = 0 to 1200 W/m^2
Calibration determines A_{sol}
2^{nd} order:

cold sky bias
Non-cosine response

$$R_{IR} = A_{IR} \Delta V_{Therm} + \sigma T_{case}^4 + B\sigma [T_{case}^4 - T_{dome}^4]$$

IR Flux – Pyrgeometer
Flux = 200 to 450 W/m^2
Calibration determines A_{IR} and B
First term = -100 to 0
Second term = 200 to 450
Third term = -50 to +10

Tcase = case temperature
Tdome = dome temperature
2 C difference gives 50 W/m^2



Calibration Methods

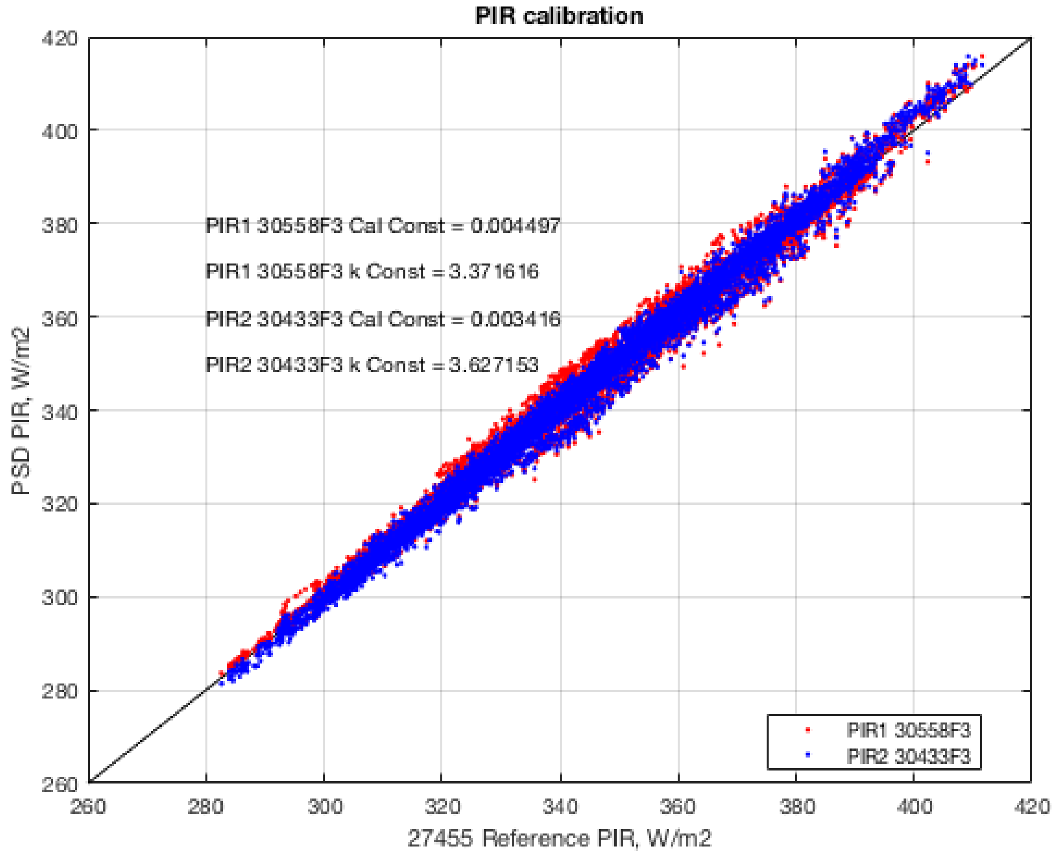
1*Factory calibrations
 1-2 year
 Eppley
 Kipp & Zonen
2*Use special calibration facilities
 NOAA/GMD Boulder Lab
 DOE ARM Oklahoma
3*Keep your own secondary
 standard (see 1 & 2)
4*Field intercomparisons with an
 ensemble of sensors

Rooftop radiative flux sensor
calibration facility
NOAA/ESRL/GMD Boulder, CO

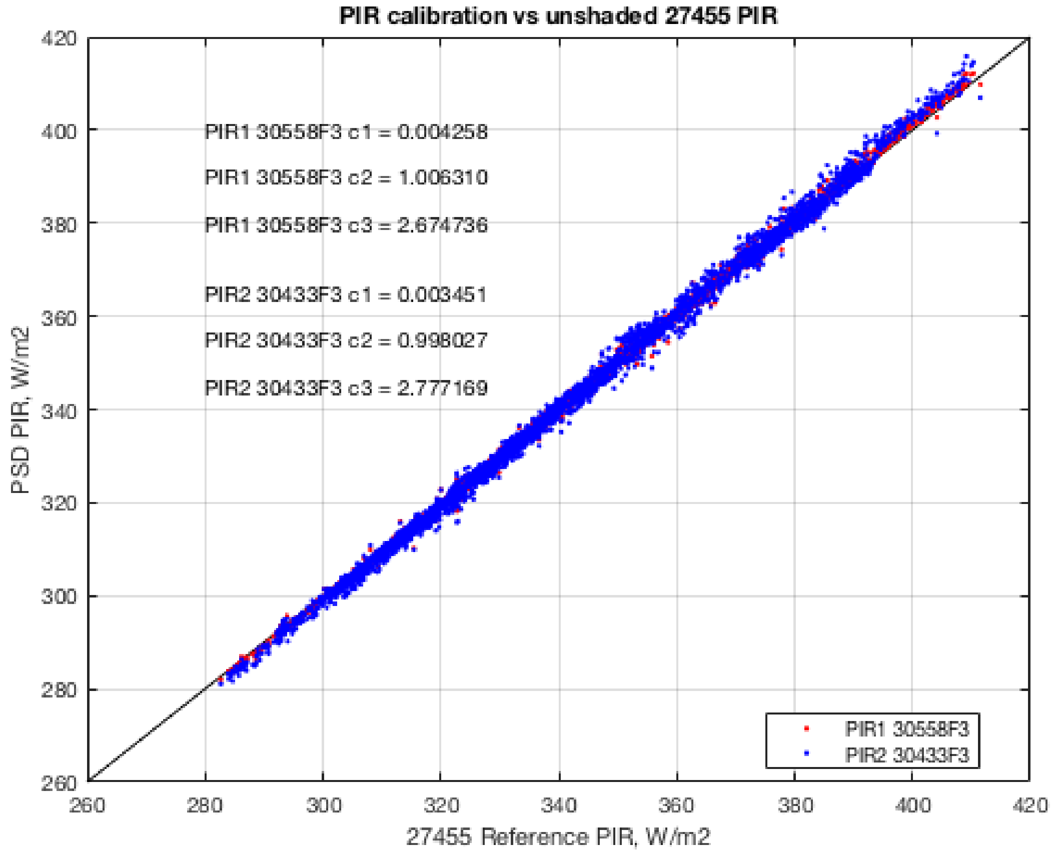
NOTES:
Eppley PSP with integrating sphere thus no cold sky effect.
GML sets sensitivity PSP at 45 deg incidence.
Eppley PIR thermopile coeff only.

GML Rooftop PIR Calibrations

Using Eppley thermopile coeff



Fit all data to determine thermo and dome coeff



GML Rooftop PSP Calibrations

$$R = I_s \cos(\theta_s) d\Omega_s + I_d \int_{-\pi}^{\pi} d\varphi \int_{0}^{\pi/2} \sin(\theta)\cos(\theta) d\theta = R_s \cos(\theta_s) + \pi I_d = R_s \cos(\theta_s) + R_d$$

$$\frac{\alpha_{cal} \Delta V}{R_{st}} = f(\theta)$$

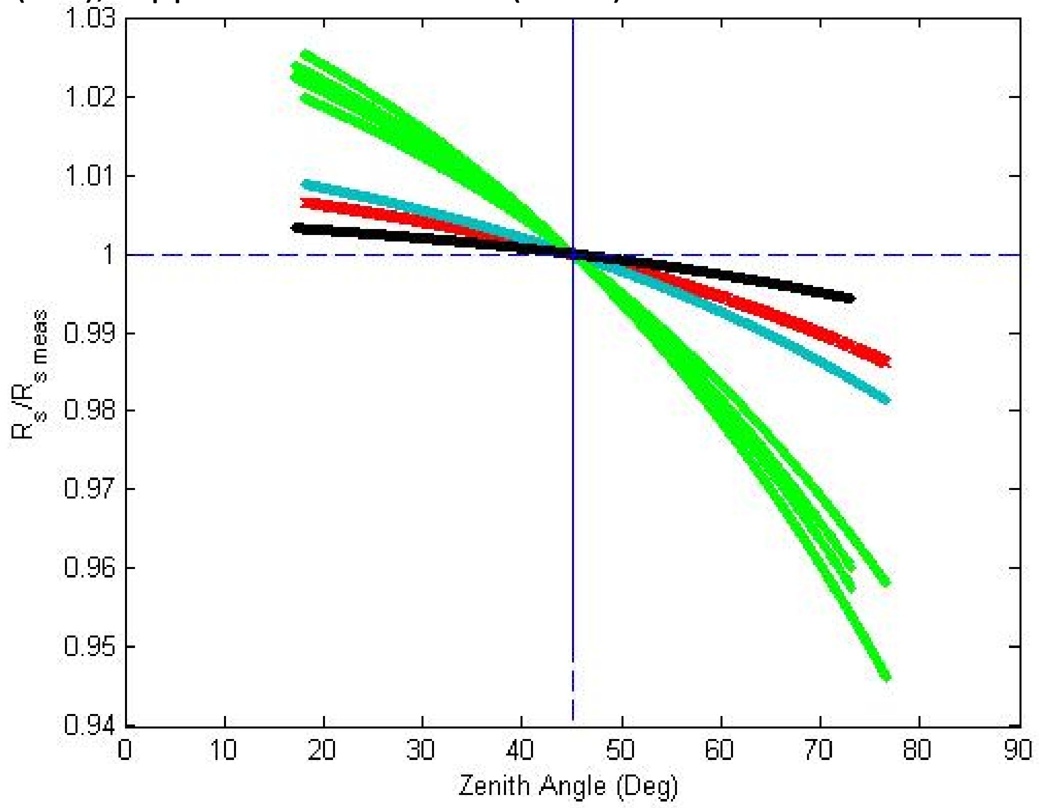
$$f(\theta) = 1 + a \frac{[\exp(45/\theta_0) - \exp(\theta/\theta_0)]}{[\exp(45/\theta_0) - 1]}$$

a is the ratio of the sensitivity at zenith to that at 45 Deg

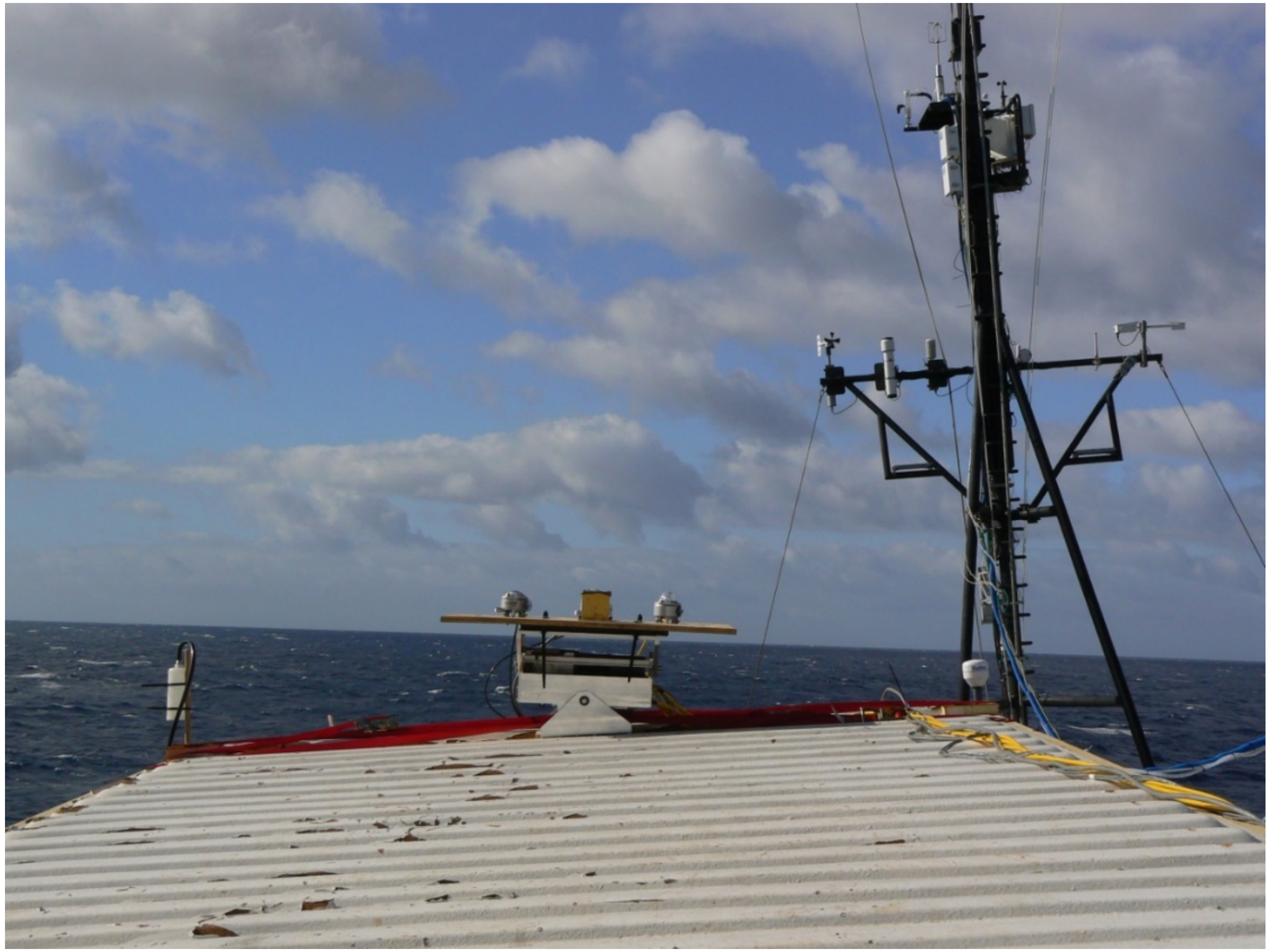
This approach can be applied to all data using a transmission coefficient-dependent value for *a*

KZ and newer technologies have near-ideal cosine response

Ensemble of clear-sky calibration fits to different pyranometers from Boulder and Woods Hole rooftop deployments – four different Eppley PSP (green), Kipp and Zonen CM21 (blue), Eppley 848 (red), Kipp and Zonen CM22 (black).

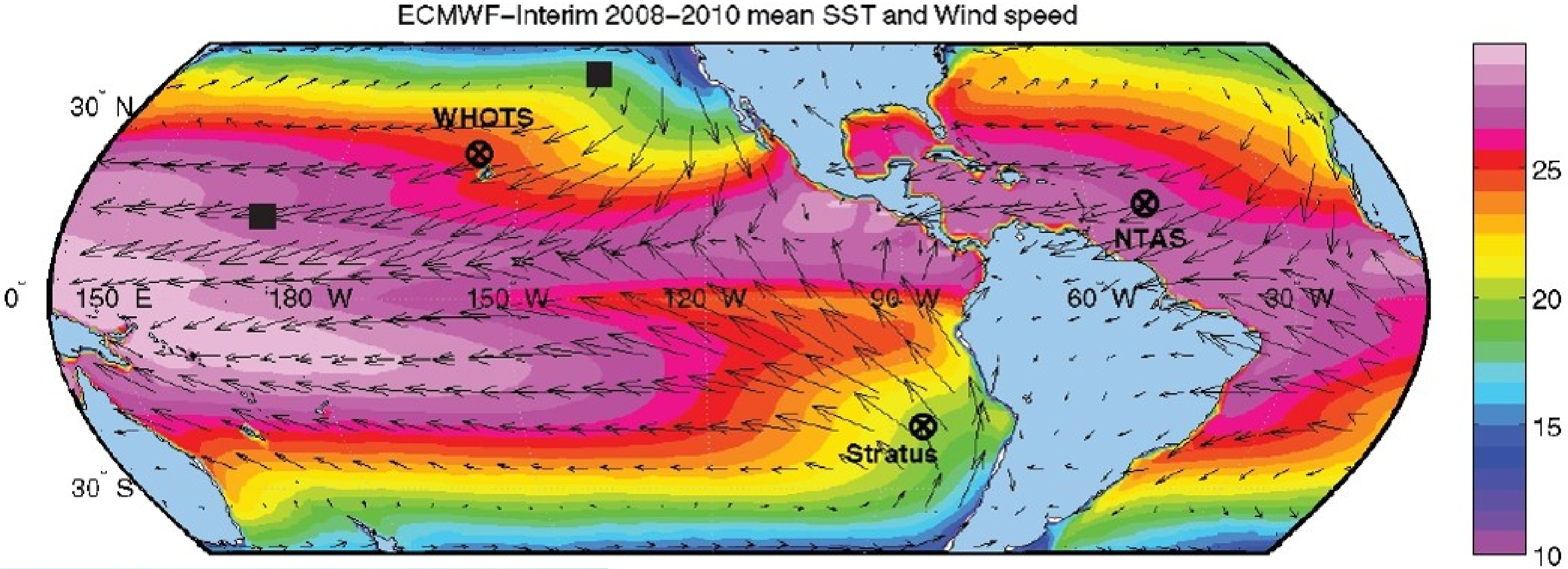


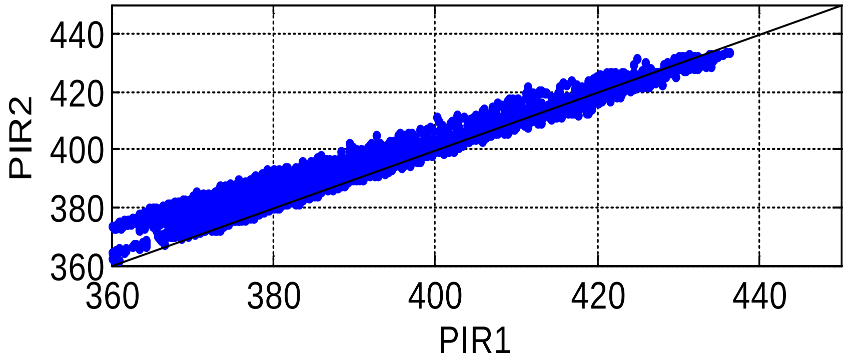
Pitch and Roll Stabilization

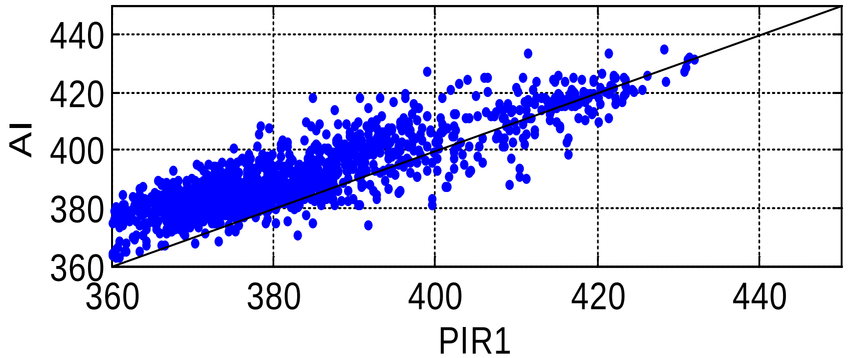


WHOI Flux Reference Buoys

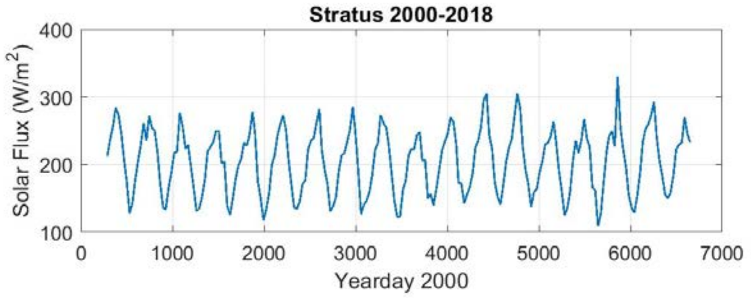
Stratus – 2000 to present
NTAS – 2001 to present
WHOTS – 2004
PSL Ship – 2003 - present

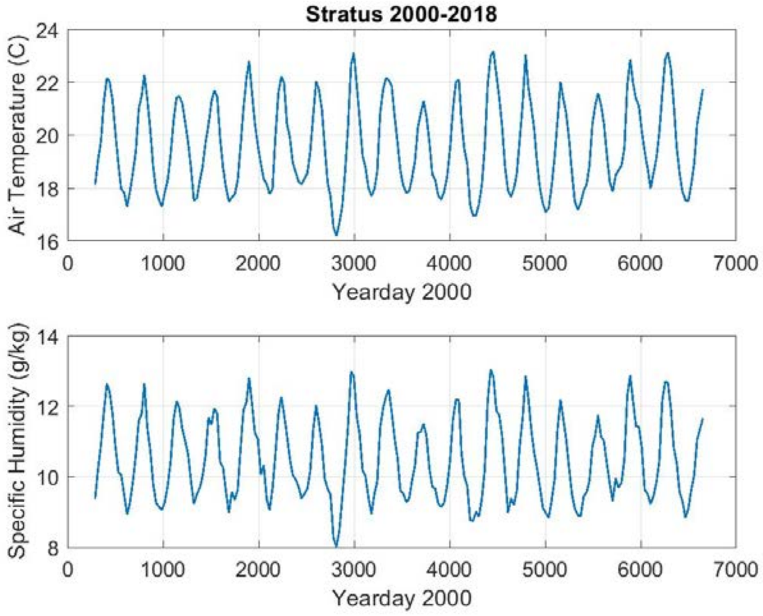


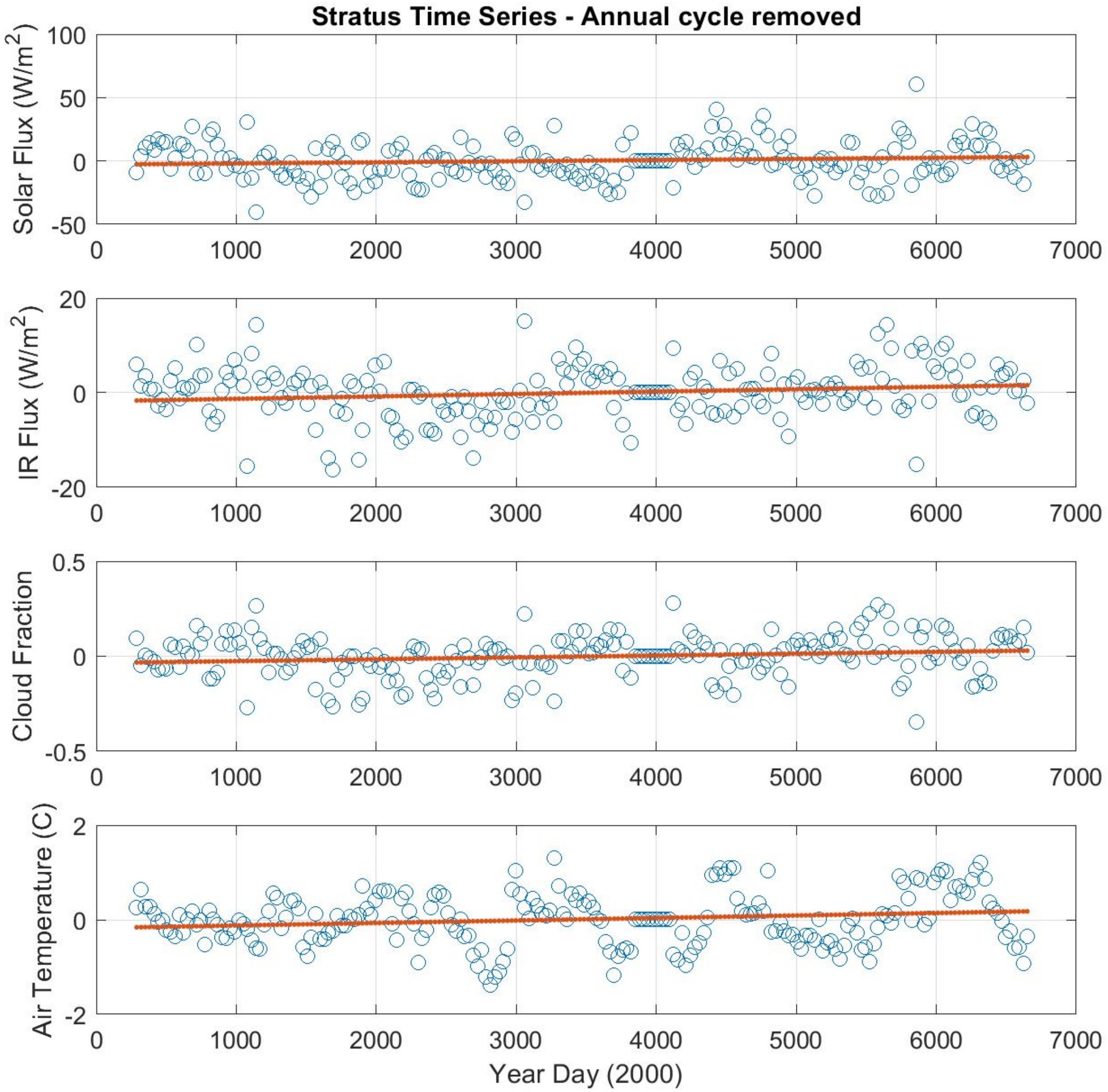




Stratus **Monthly** Average Time Series Analysis





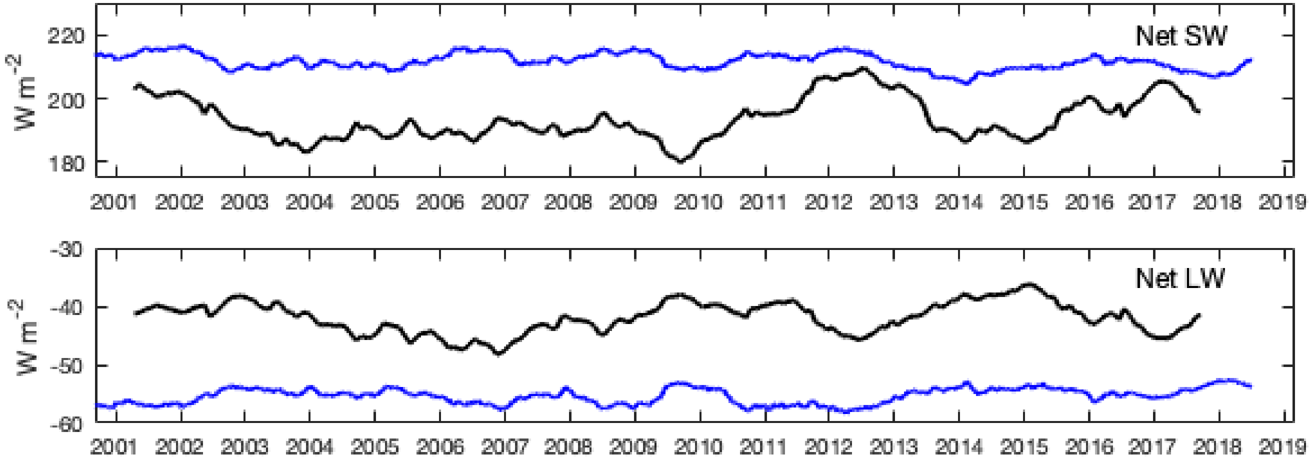


Summary Statistics

Trends

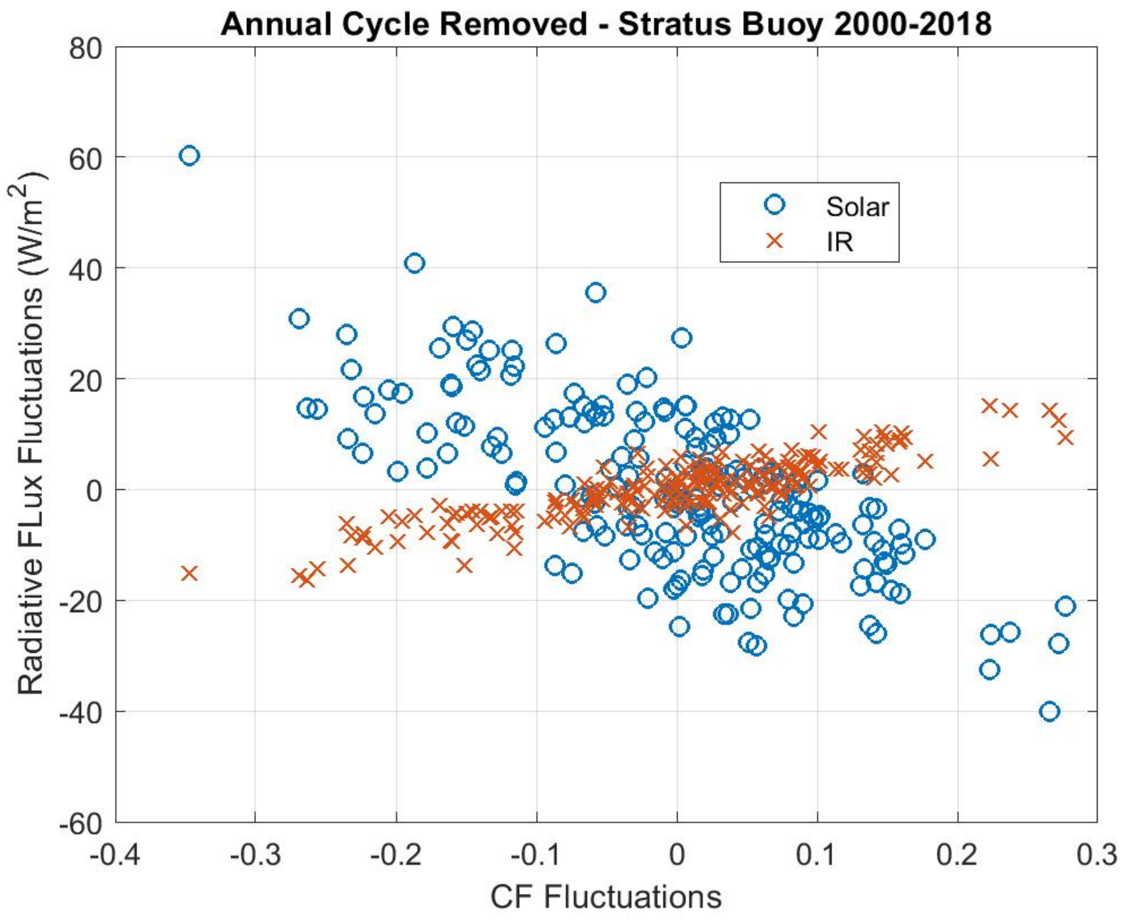
	SITE	Rsolar	Rir	CF	Ta	qa
		W/m^2/dec	W/m^2/dec	1/Dec	C/dec	g/kg/dec
Slope	Stratus	3.2	1.8	0.04	0.2	-0.04
Uncert.	Stratus	2.1	0.8	0.02	0.09	0.07
Slope	NTAS	2.6	0.6	0.01	0.08	-0.04
Uncert.	NTAS	1.5	0.6	0.02	0.06	0.07
Slope	WHOTS	4.4	1	-0.01	0.3	0.03
Uncert.	WHOTS	2.2	1.5	0.03	0.1	0.13

Comparison Stratus observations (black) and ERA5 (blue)



Subseasonal Correlations

Rs – CF correlation 0.70



Future

- Buoys – KZ (or some other new tech) PSP and PIR + SPIN1 (diffuse)
- Ships
  - As with buoys, add pitch/roll stabilizer (commercial?)
  - Research using pitch/roll/heading stabilizer with BSRN suntracker for reference

WHOI Flux Reference Buoy Data   http://uop.whoi.edu/ReferenceDataSets/index.html

PSL ship-based surface meteorological data and turbulent fluxes as part of the WHOTS) and Stratus projects from 2001-10-10 to 2018-04-12 (NCEI Accession 0186688).

NOAA National Centers for Environmental Information. Dataset, doi 10.25921/2dck-3068. https://accession.nodc.noaa.gov/0186688 .