ON RADIATION MEASUREMENTS AT SEA

A discussion of the importance of accurate radiation measurements in achieving a usable energy budgets over the sea and the practical problems in achieving them.

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Brookhaven National Laboratory

3 March 2003

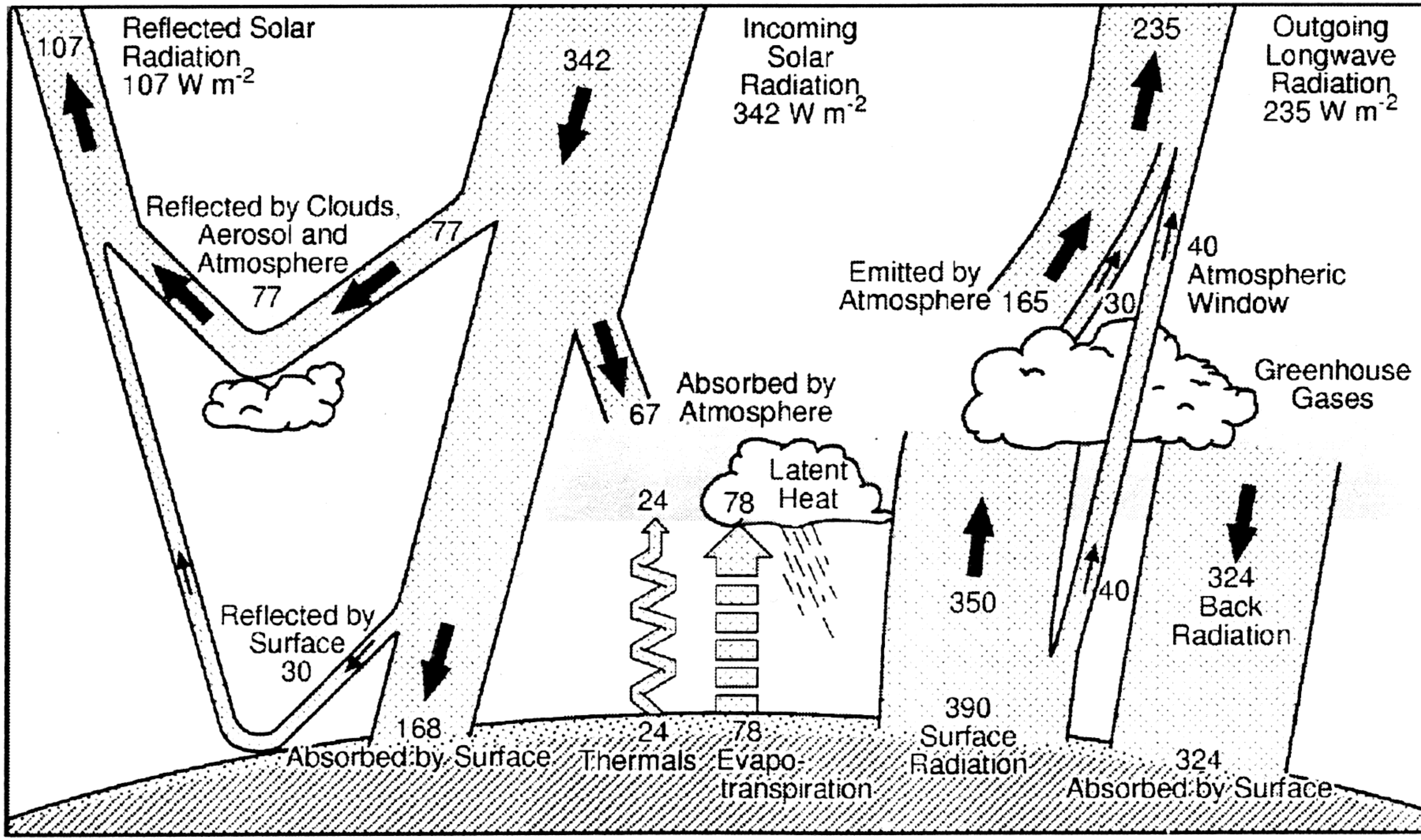
SOAR

SHIPBOARD OCEANOGRAPHIC AND ATMOSPHERIC RADIATION
BROOKHAVEN NATIONAL LABORATORY

- RADIATION AND ENERGY FLUX
- AEROSOLS - THEIR IMPORTANCE AND DISTRIBUTION
- THE FAST-ROTATING SHADOWBAND RADIOMETER (FRSR)
- BROADBAND INSTRUMENTS AND AND CALIBRATIONS
- RECOMMENDATIONS FOR IMPROVED RADIATION DATA

- **RADIATION AND ENERGY FLUX**

Kiehl and Trenberth

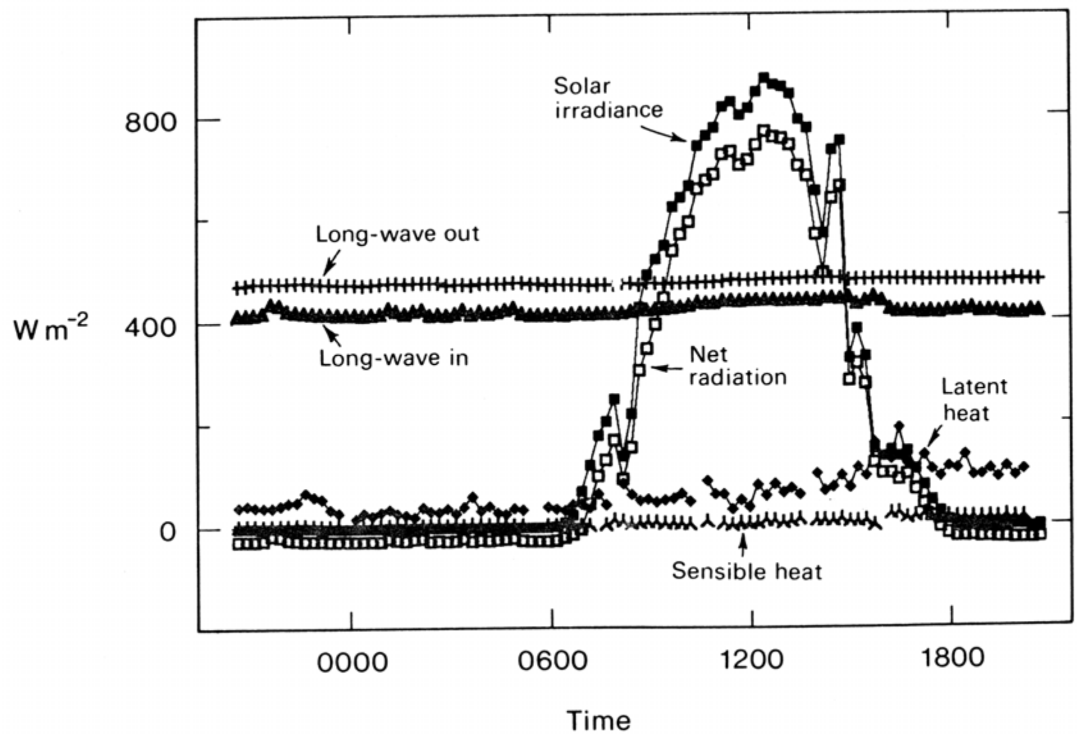


The global surface energy budget (W/m^2) --

Hsw = 168 Hlw = -66 Hs = -24 Hq = -78

R_net = 102

The net heat flux through the ocean surface controls the behavior of the warm pool and the TWP circulation in general. The energy balance is a small difference (10 W/m^2) between several large signals, complicated by several smaller ones of comparable size to the balance.



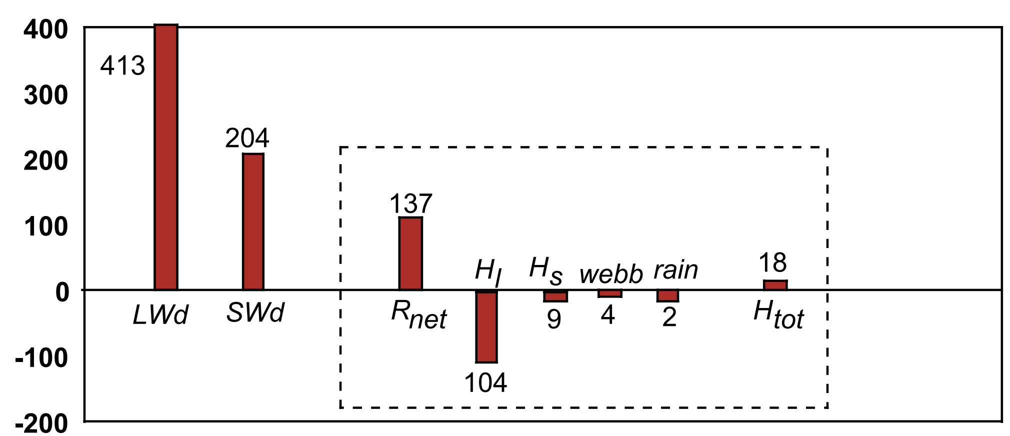
Godfrey et al., JGR, 96, 3391-3400

Fairall, Bradley, Rogers, Edson, and Young, 1996,
"Bulk parameterization of air-sea fluxes for the TOGA COARE",
JGR, **101,** 3747-3764.

" In summary, our ability to diagnose, simulate, and predict climate and climate variability is impaired by ***a general lack of high-quality data*** in the region and inadequate parameterization of air-sea fluxes."

"The TOGA COARE goal of no more than 10 W/m^2 uncertainty in the total surface energy budget of the ocean (including turbulent, radiative, and precipitation heat fluxes) ***implies certain accuracy requirements for the bulk measurements***."

"To meet the COARE goal of a 10 W/m^2 uncertainty in the heat balance of the warm pool, ***unprecedented accuracies must be obtained in fluxes and mean meteorological variables***. This requires examination of sensor calibrations, fast sensor response, flow distortion, and ship influence, and processing methods."



Joint WCRP/SCOR Working Group on Air-Sea Fluxes Intercomparison and Validation of Ocean-Atmosphere Energy Flux Fields

ed. Peter K. Taylor

Four main classes of requirements for flux fields and the characteristics of the various data sources for flux estimation:

1. **High time and space resolution – 3 hrs and 50 km Models**

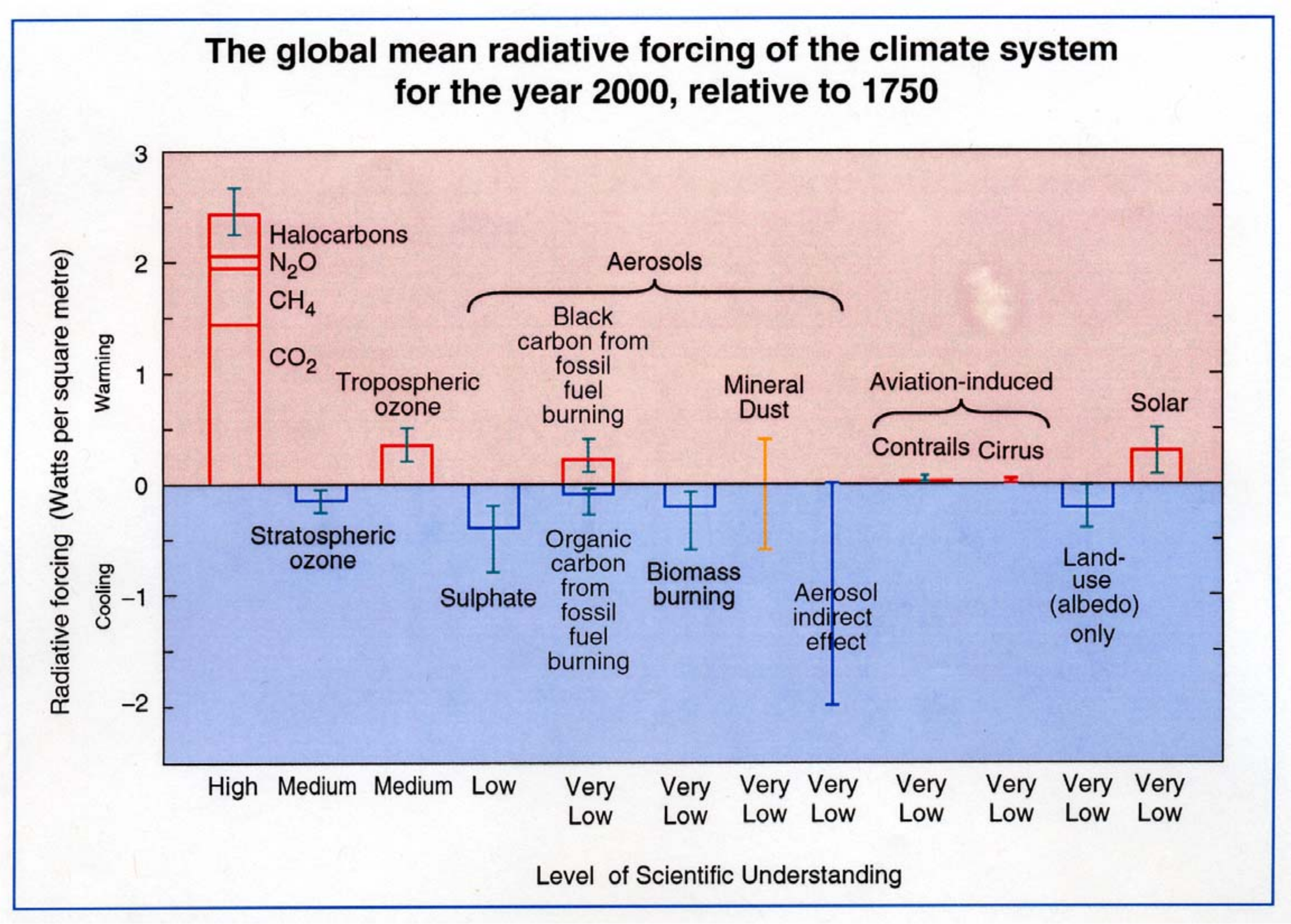
2. **Longer scales but high absolute accuracy – few W/m2**
   Needed for climate and sea-ice modelling.

3. **High accuracy, high consistency and continuity.**
   Climate variability studies.

4. **High quality verification data.**
   NWP models need independent measurements.
   Ocean GCM development need anchor points.
   Satellite cal/val. — ANCHOR POINTS —

http://www.soc.soton.ac.uk/JRD/MET/WGASF/

• AEROSOLS - THEIR IMPORTANCE AND DISTRIBUTION

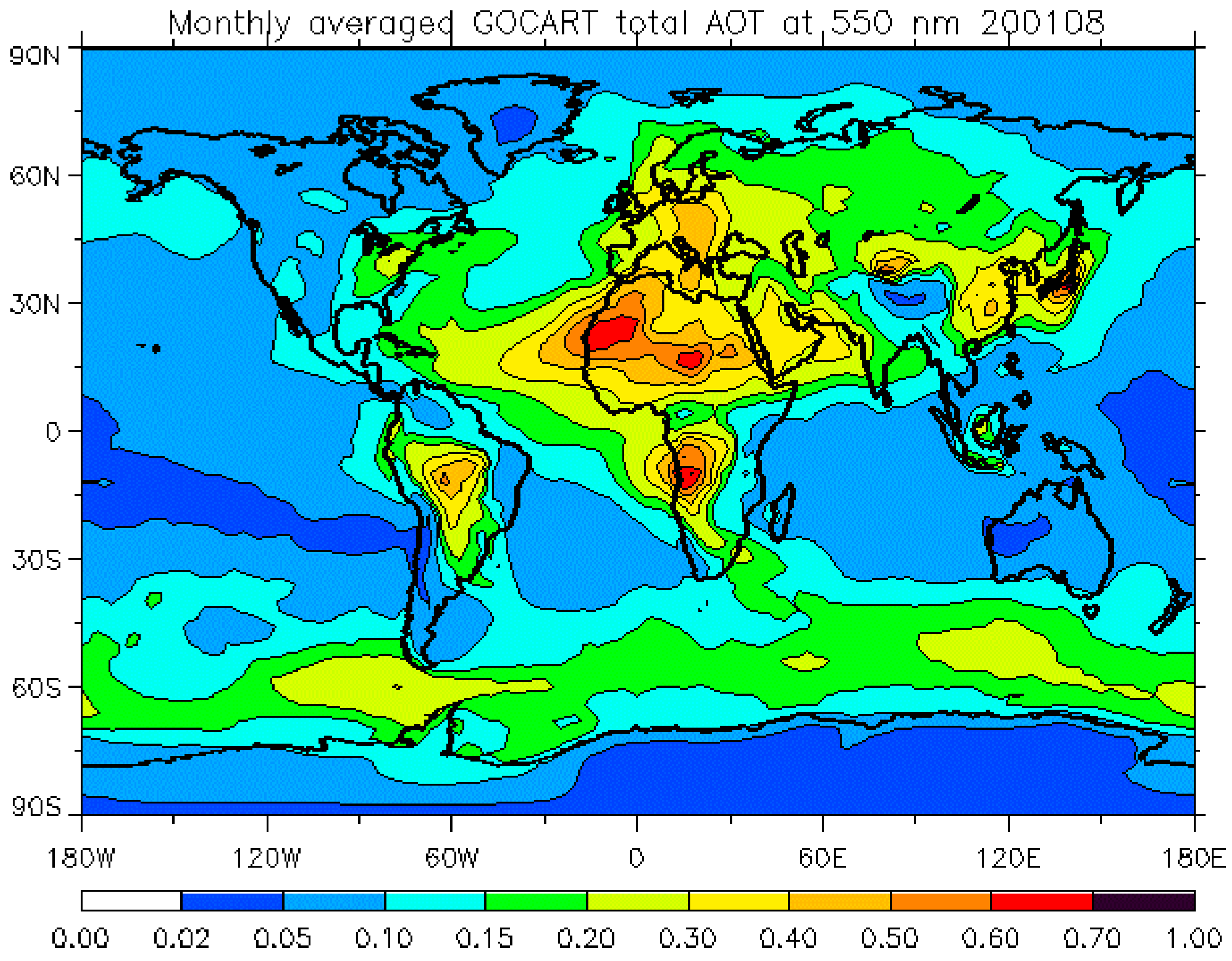


To the present day we do not have a clear picture of the role of aerosols in climate and climate change. (IPCC, 2001)

-- Generally short lived, a few days aloft. But there are exceptions.

-Change of AOT by 0.04 is equivalent to doubling CO_2.

http://code916.gsfc.nasa.gov/People/Chin,_Mian/results/aot.html



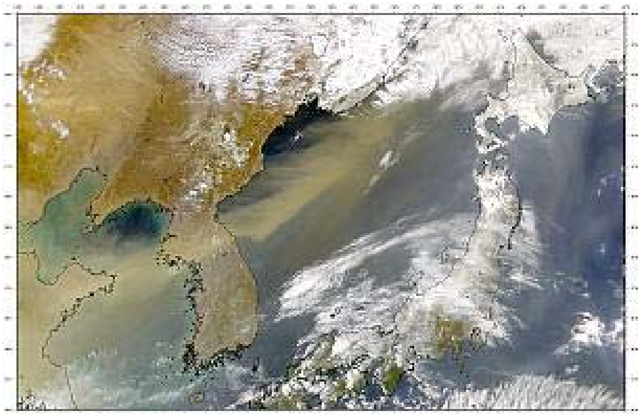
OCEAN COLOR – PEERING THROUGH THE HAZE

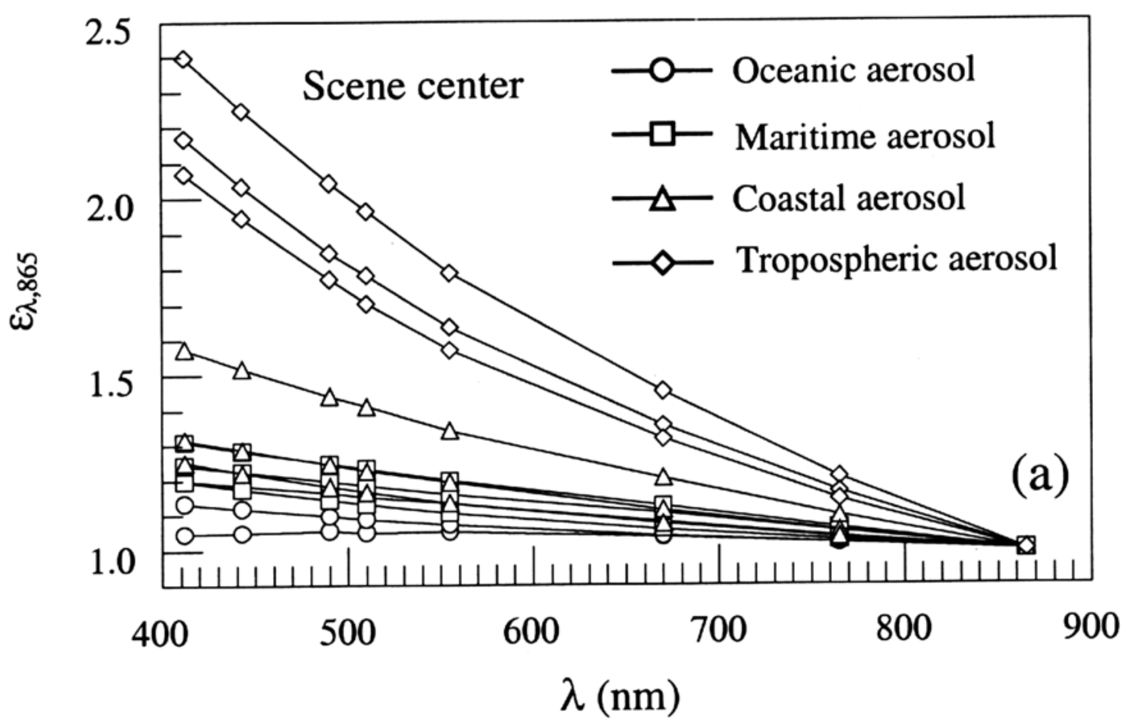
Of ten photons received by the satellite only one comes from the ocean surface.

SeaWIFS algorithm must determine aerosol type from 22 possibilities.

But--MODIS claims an AOT accuracy of 0.02. Some doubt this.

A need for at-sea instrumentation of the same quality as land instruments.





AEROSOL ON THE IR FORCING

Minerals and sea salt have the strongest IR effect.

With equal loadings of dust the forcing can vary 7--25 W/m^2 depending on dust type.

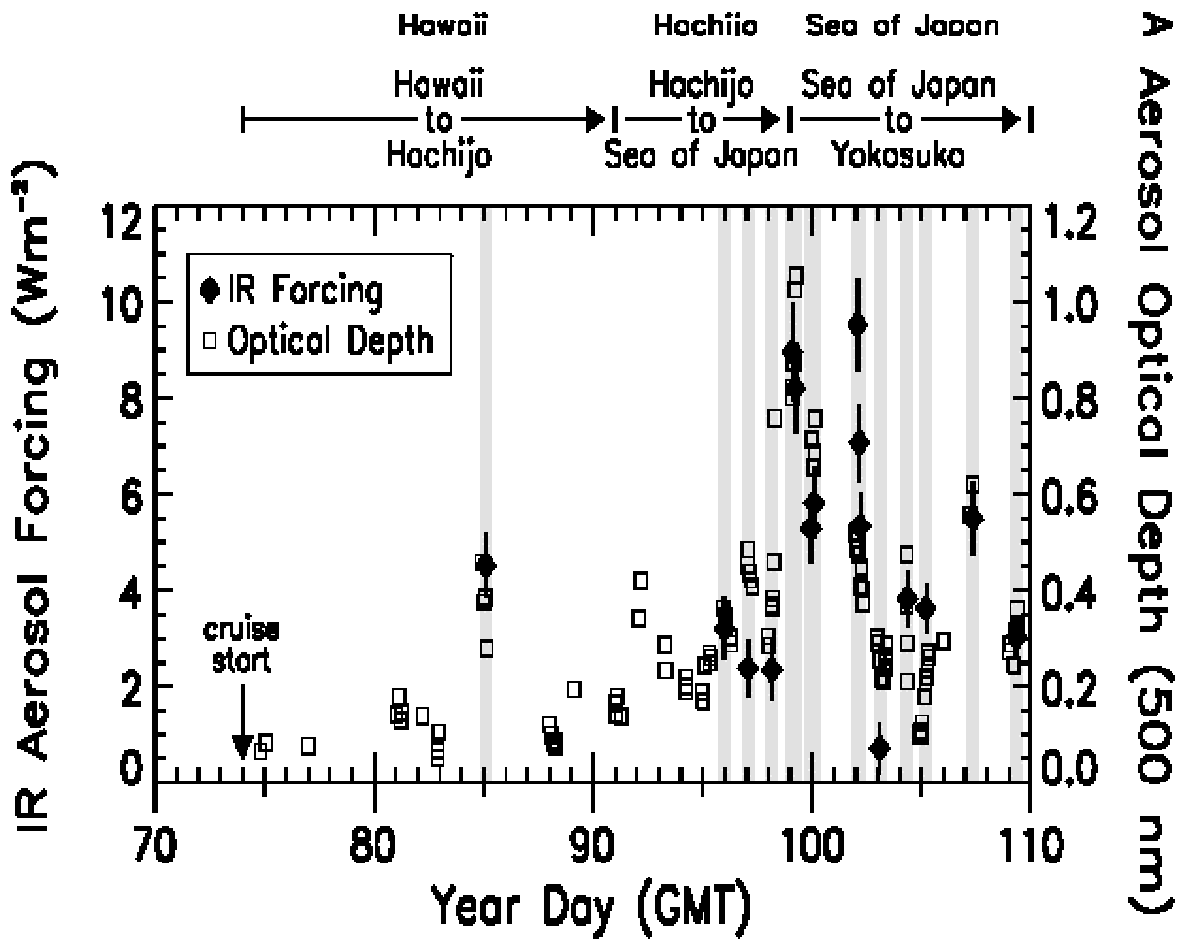


Figure 1. Aerosol IR radiative forcing and optical depth observed during ACE-Asia (from Vogelmann et al. 2002).

• THE FAST-ROTATING SHADOWBAND RADIOMETER (FRSR)

A need for at-sea measurement of AOT.

AERONET by NASA is very important, but land/island bound, hence biased.

Pointing instrumentation is neither affordable nor reliable.

PORTABLE RADIATION PACKAGE (PRP)

PRIEDE

PORTABLE RADIATION PACKAGE (PRP)

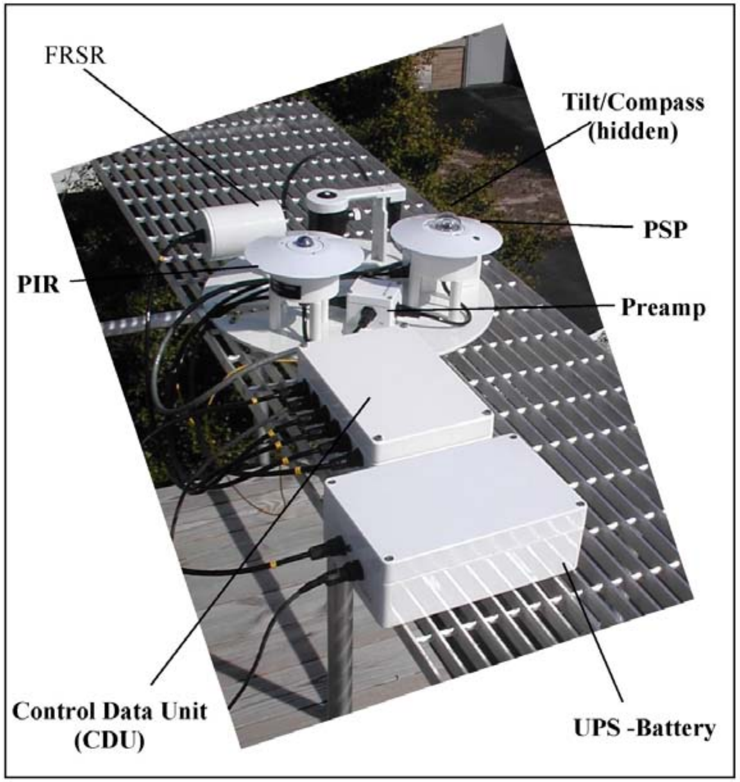
PSP - Shortwave solar insolation (300-3000 nm)

PIR - Longwave downwelling IR (4-50 μm)

FRSR - Direct/Diffuse SW (Si Cell, 410, 500, 615, 675, 870, 910 nm)

Other - X-Y tilt, Flux-gate compass

Portable Radiation Package system components

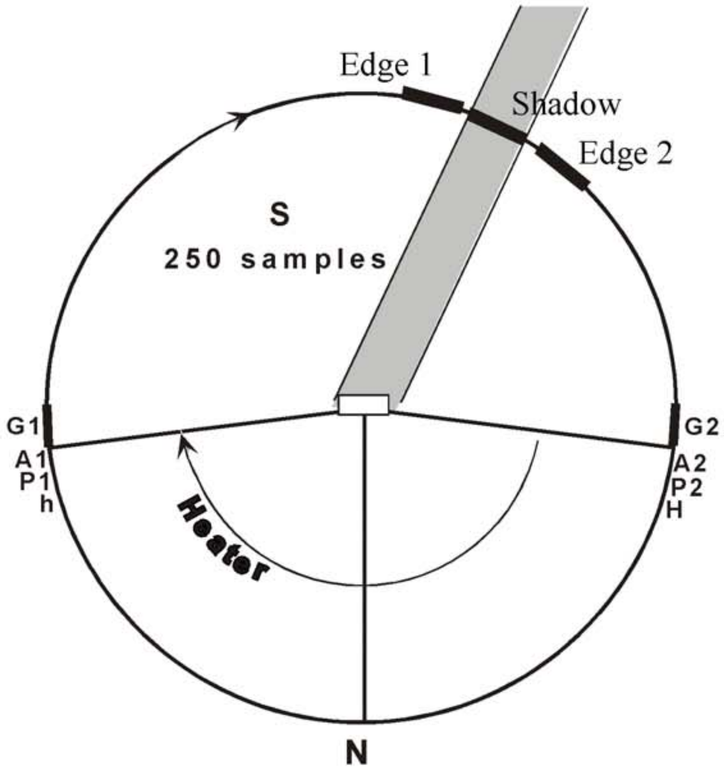


PRP = Portable Radiation Package

FRSR = Fast Rotating Shadowband Radiometer

PIR = Precision Infrared Radiometer

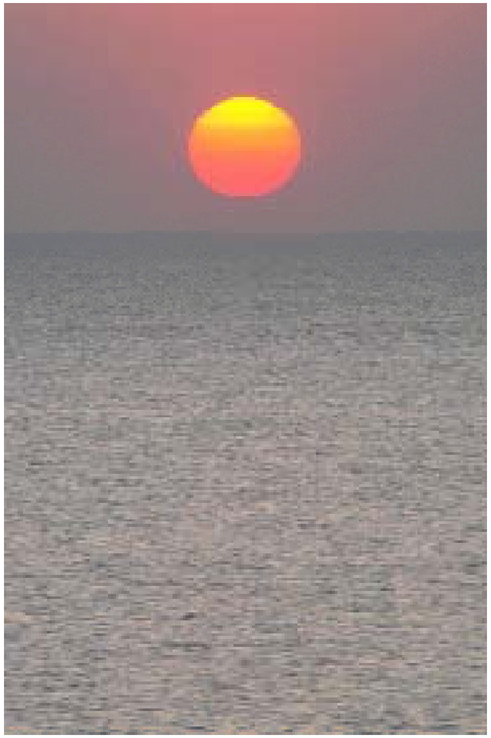
PSP = Precision Spectral Pyranometer

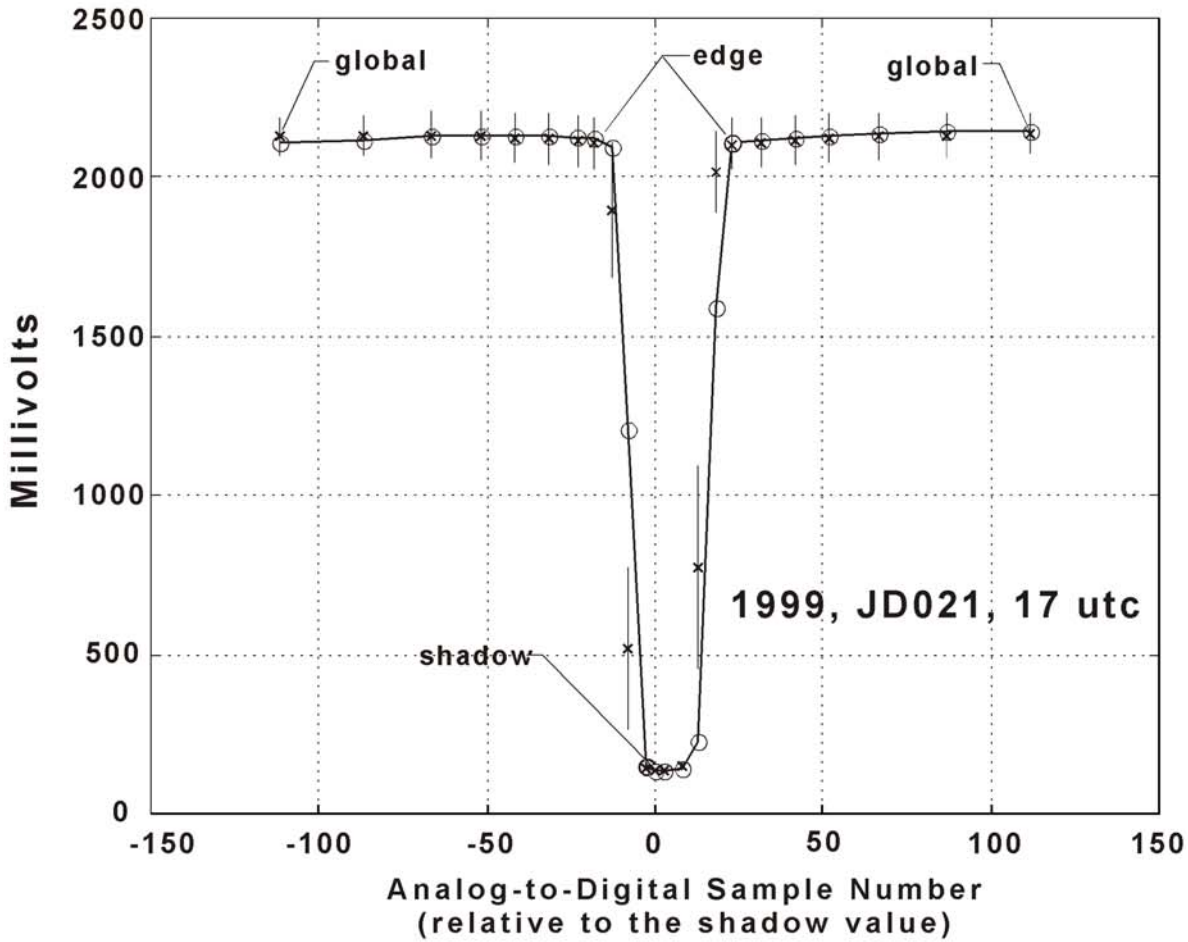


SHADOWNBAND POSITIONS AND FUNCTIONS
At each horizon the PSP, and PIR readings are taken (A1 and A2), the pitch, roll, and compass readings are made (P1 and P2), and global irradiance values are computed (G1 and G2).

The positions of the Shadowband at the edge positions and the shadow position are shown.

There can be problems when the sun is near the horizon, and special software is needed.





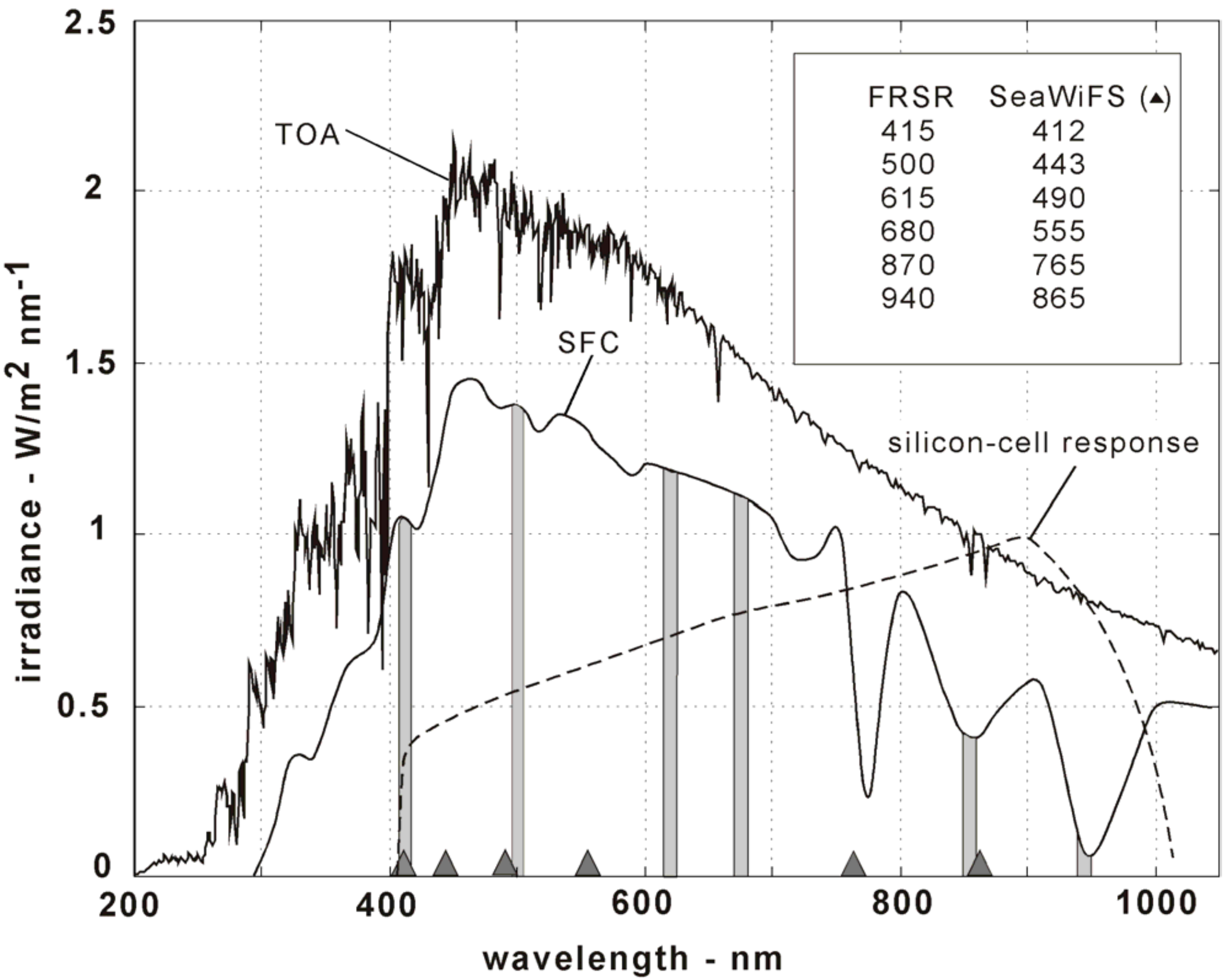
Response of the head detector to the Shadowband on a bright sunny day.

The *global*, *edge*, and *shadow* values are shown in the figure.

$$\text{SHADOW RATIO} = K = \frac{\text{SHADOW - SWEEP MEAN}}{\text{SWEEP STD DEV}}$$

FRSR: six 10-nm bands and a broadband (Si cell) band.

PSP measures over a 300-3000 nm bandwidth.



Calibration is the largest single issue. The FRSR head is highly susceptable to contamination, uv degradation, and filter aging. Requires pre and post calibrations, three monthly is desirable.

Factory calibration is needed because we need absolute measurements to define direct and diffuse irradiance.

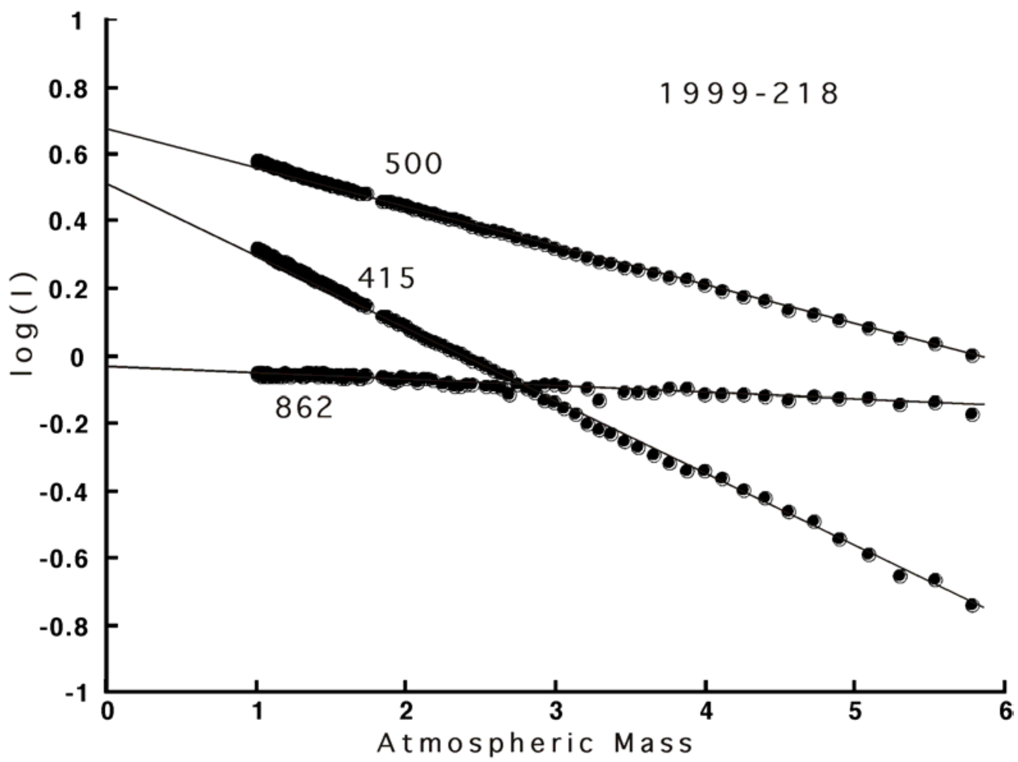
Example of a Langley calibration plot. Taken from Mauna Loa Observatory.

The Langley method is the best, if not the only, way of validating the instrument.

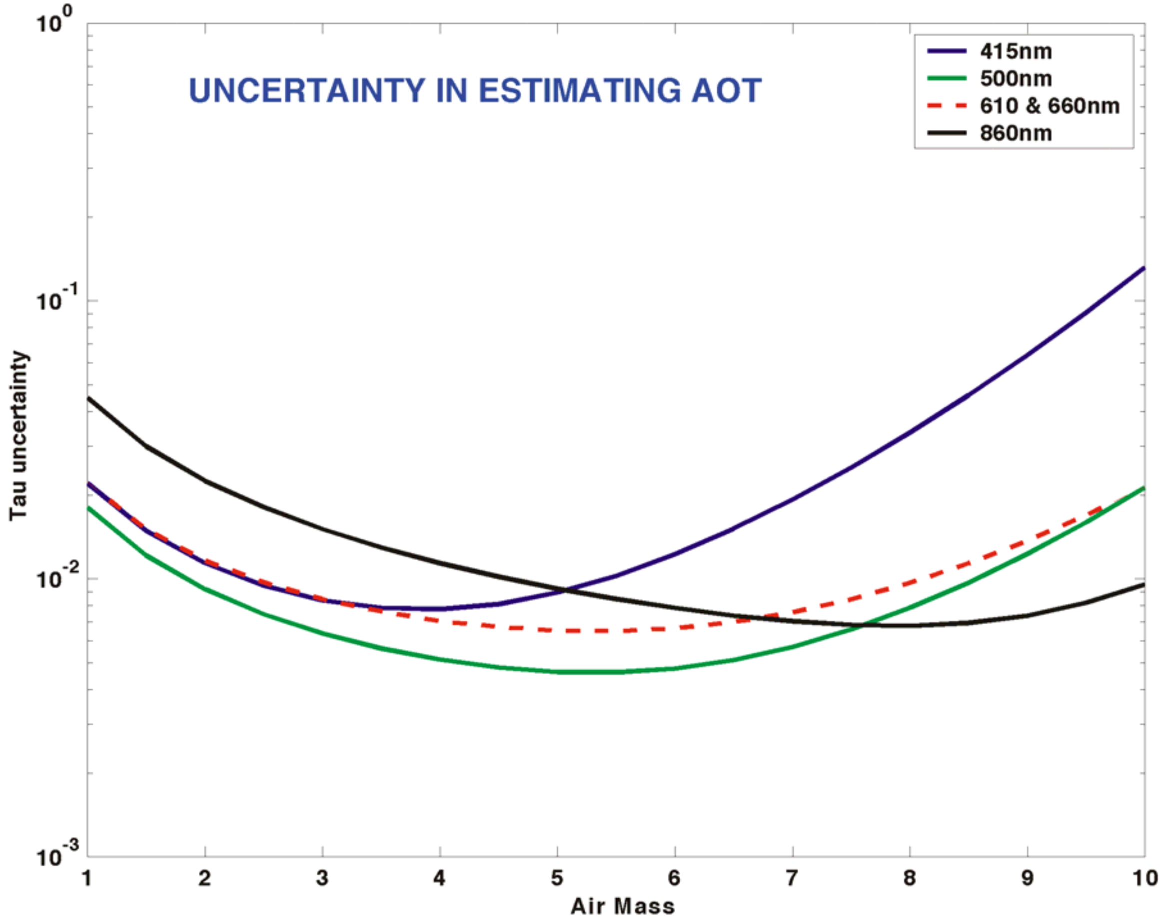
Langley calibrations require cloud-free conditions, especially on the horizon ==> almost impossible at sea.

Note:

- **TOA values must be constant.**
- **Slope is atmospheric transmittance.**
- **M=6 is equivalent to z=80 deg.**



Uncertainty analysis includes electronic noise, ship motion, TOA Io errors, Rayleigh and other corrections, etc.



AOT measurements in the African Plume, 1999, days 27-31

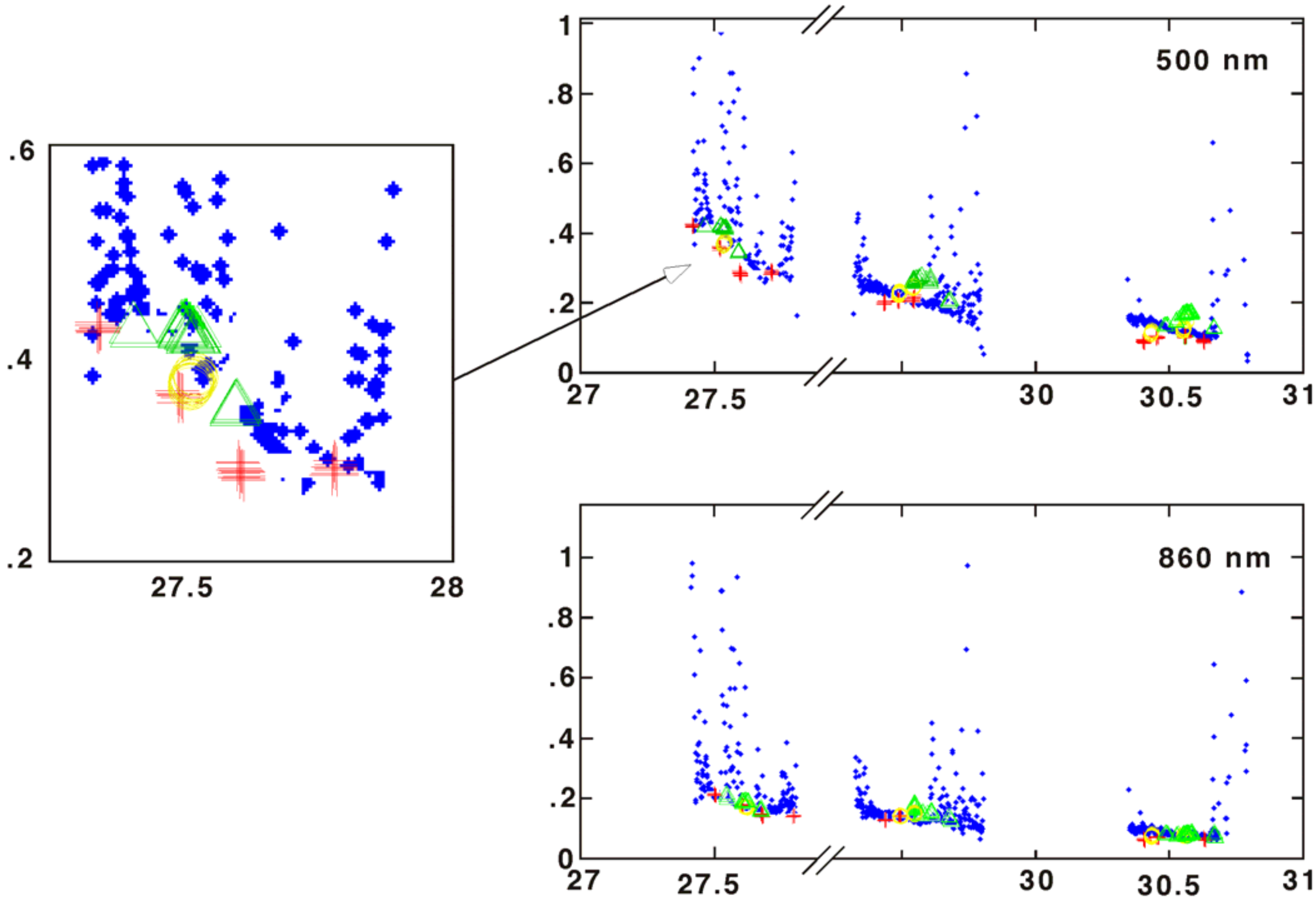
Comparisons with handheld instruments.

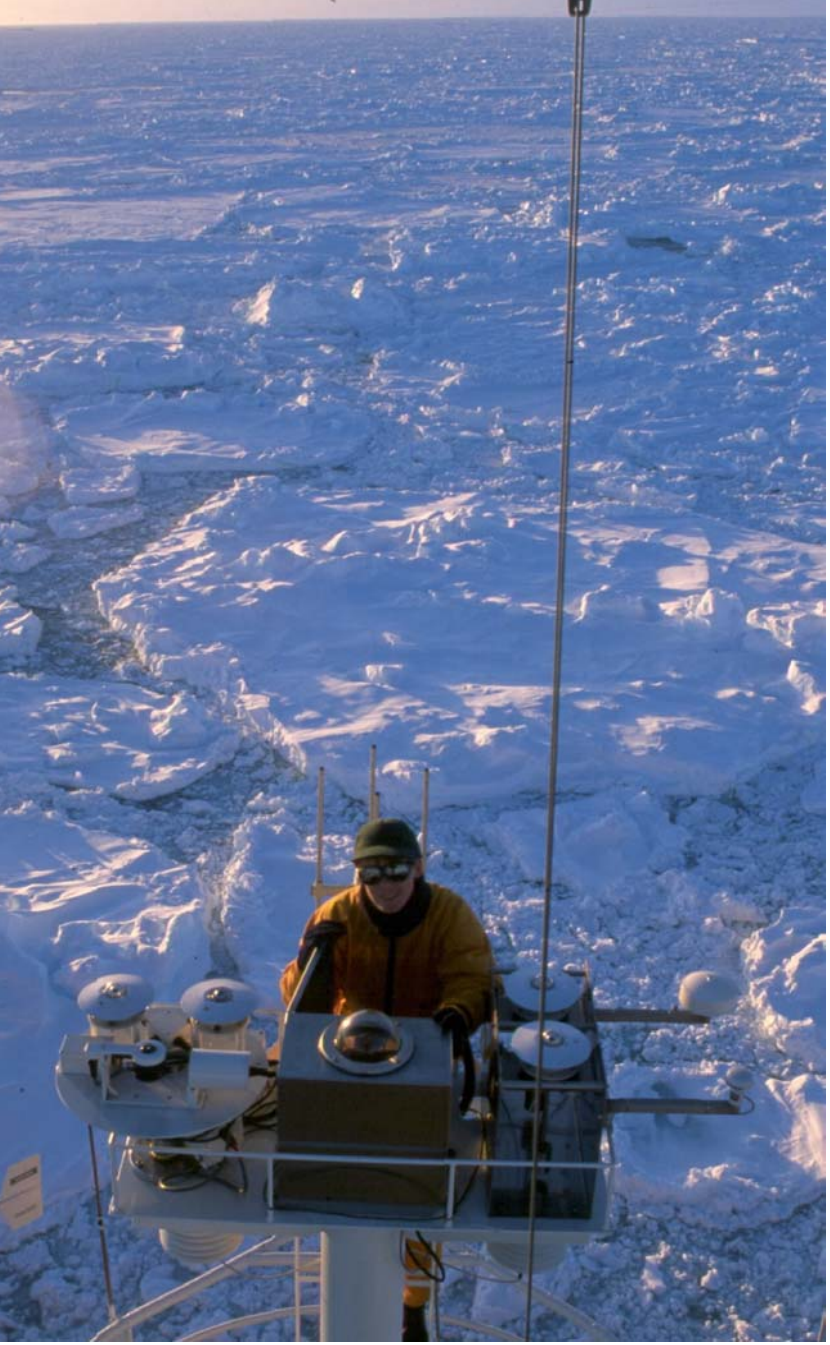
Spikes are caused by cloud contamination.

AOT varies from 0.4 to < 0.1 in three days.

With a calibrated head the FRSR can achieve an uncertainty of < 0.02 under most at-sea conditions.

(Miller et al. 2003)





Reynolds, R. M., M. Miller, and M.J. Bartholmew . 2001. **Design, operation, and calibration of a shipboard fast-rotating shadowband radiometer.** Journal of Atmospheric and Oceanographic Technology, 18(2), 200-214.

Voss, K. J., E.J. Welton, P.K. Quinn, R. Frouin, M. Miller, and R.M. Reynolds. 2003. **Aerosol optical depth measurements during the Aerosols99 Experiment**. Jour. Geophys. Res., mscpt#264.

Miller, Mark A., Mary Jane Bartholomew, and R. Michael Reynolds, 2003. **The Accuracy of Marine Shadow-band Sun Photometer Measurements of Aerosol Optical Thickness and Angstrom Exponent**. Journal of Atmospheric and Oceanographic Technology. In press.

Miller, M., R. Frouin, M.J. Bartholomew, K. Knobelspiesse, R.M. Reynolds, M. Wang, G. Fargion, and P.K. Quinn. 2003. **Shipboard measurements of atmospheric radiation and aerosol optical properties during ACE-Asia.** Jour. Geophys. Res., Submitted.

Explorer of the Seas

142000 gross tons (max aircraft carrier = 105000 tons)

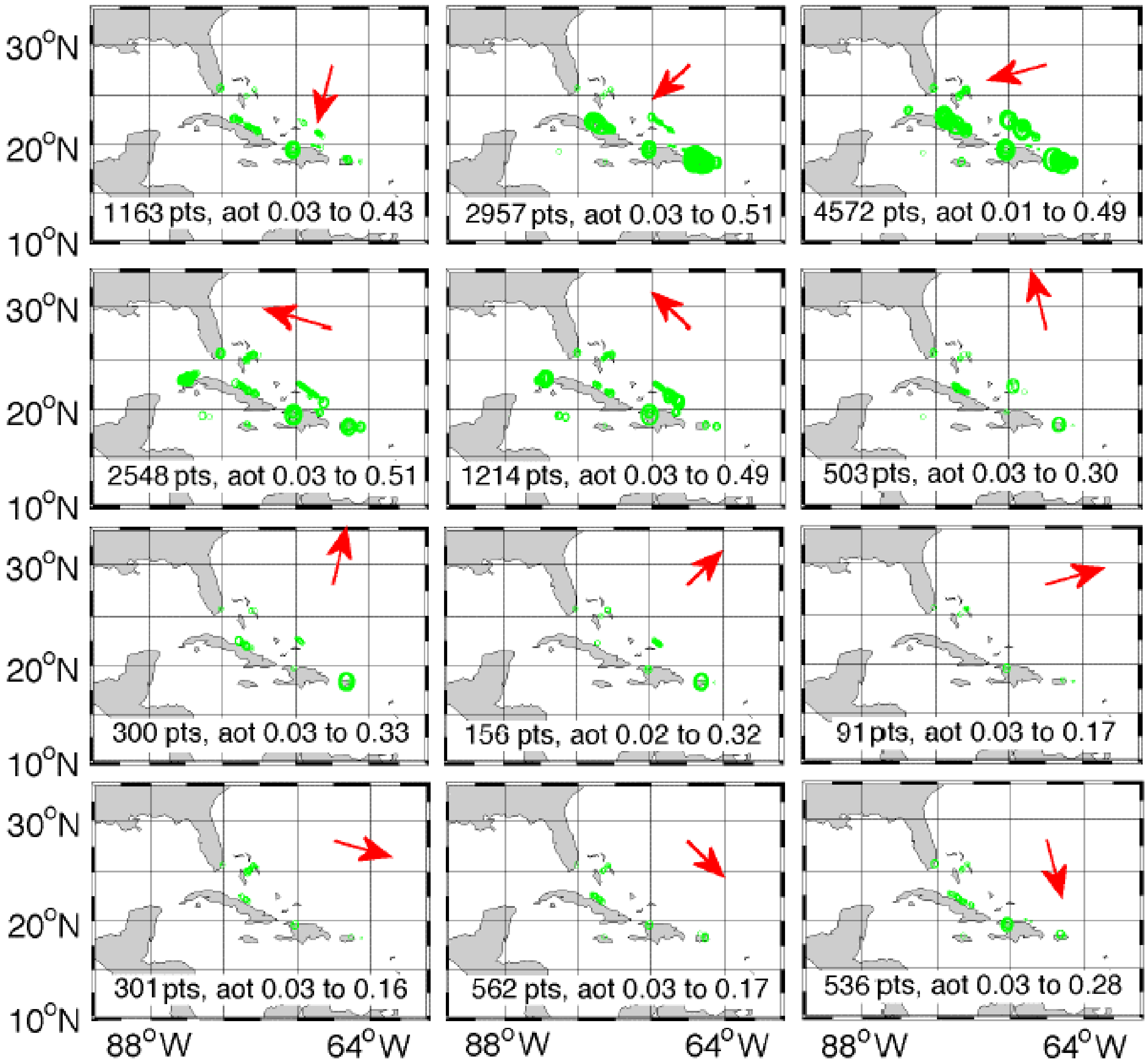
311 m long

3800 passengers

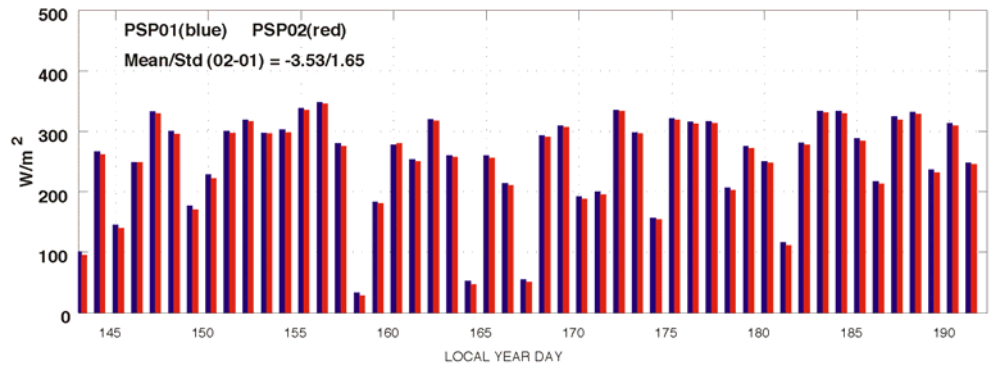
Radiation instruments are placed at the very peak of the ship, well forward and with no shading.

Advantages for AOT Measurement: • stable platform • full-time technician • Confined cruise area • occasional cruises for scientists

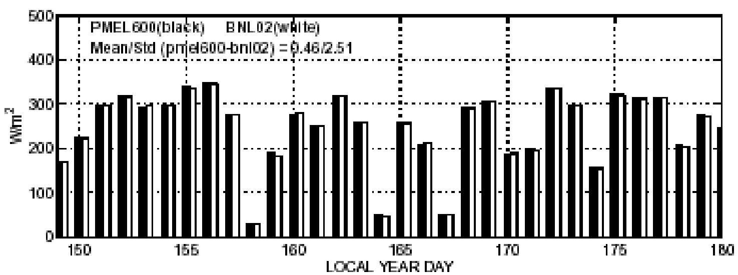
Disadvantages: • In port at noon each day • superstructure shadowing on FRSR

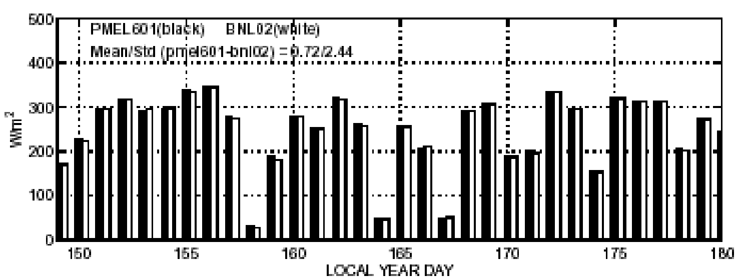

30°N
20°N
10°N
1163 pts, aot 0.03 to 0.43
2957 pts, aot 0.03 to 0.51
4572 pts, aot 0.01 to 0.49
2548 pts, aot 0.03 to 0.51
1214 pts, aot 0.03 to 0.49
503 pts, aot 0.03 to 0.30
300 pts, aot 0.03 to 0.33
156 pts, aot 0.02 to 0.32
91 pts, aot 0.03 to 0.17
301 pts, aot 0.03 to 0.16
562 pts, aot 0.03 to 0.17
536 pts, aot 0.03 to 0.28
88°W
64°W

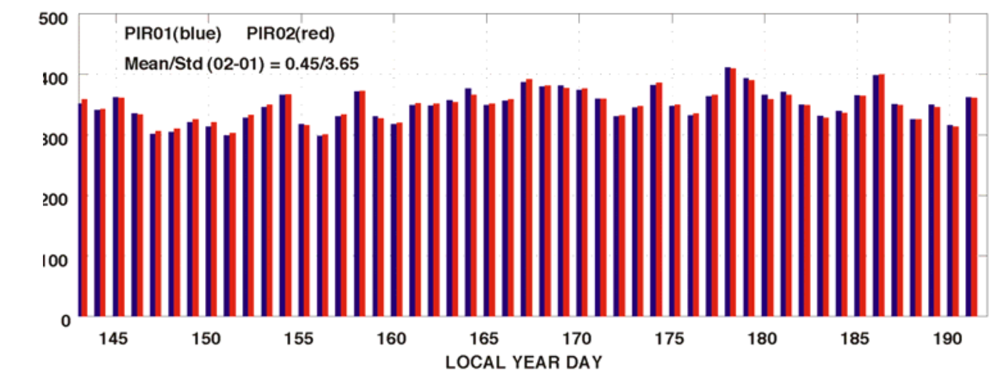
• BROADBAND INSTRUMENTS AND AND CALIBRATIONS



PMEL - BNL COMPARE PSP





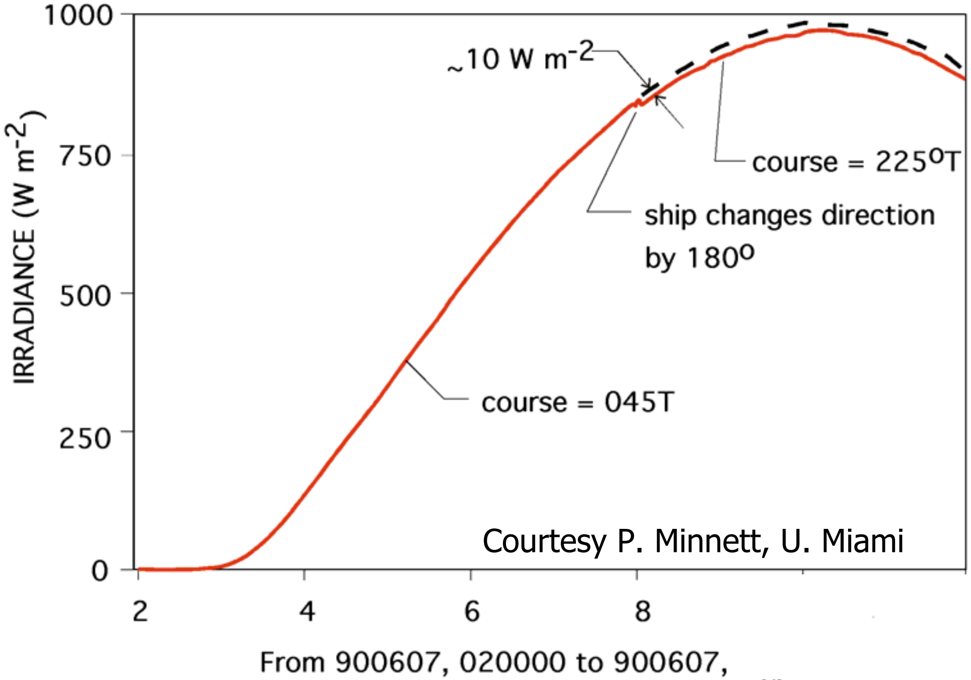


BNL - BNL CROSS COMPARISON

BUT - SENSOR CALIBRATION IS A SMALL PART OF THE PROBLEM

ACCURATE RADIATION MEASUREMENTS REQUIRE EFFORT

- CONSISTENT CALIBRATIONS – STANDARDIZED
- ROUTINE (DAILY) MAINTENANCE
- REAL-TIME QA PROCEDURES
- METADATA AND EDITING



PSP - SOURCES OF UNCERTAINTY

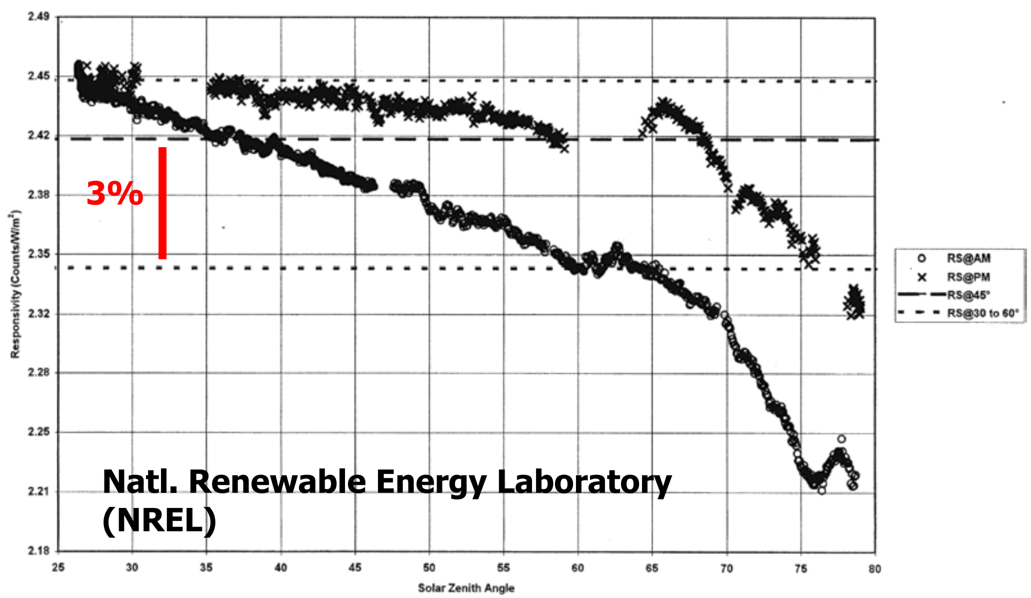
- **Calibration drift**
- **Azimuth and zenith angle dependency**
- **Platform tilt (mean is most crucial)**
- **Contamination of optics**
- **RF noise (μV signals)**
- **Shading or reflections**
- **Dome leakage (IR susceptability)**

Note:

A daily average includes ~12 hours of 0 W/m^2 which is reduces the uncertainty by half.

Normal Incidence + Diffuse for land sites will yield uncertainties of about 5-10 W/m^2. From a single PSP we expect worse.

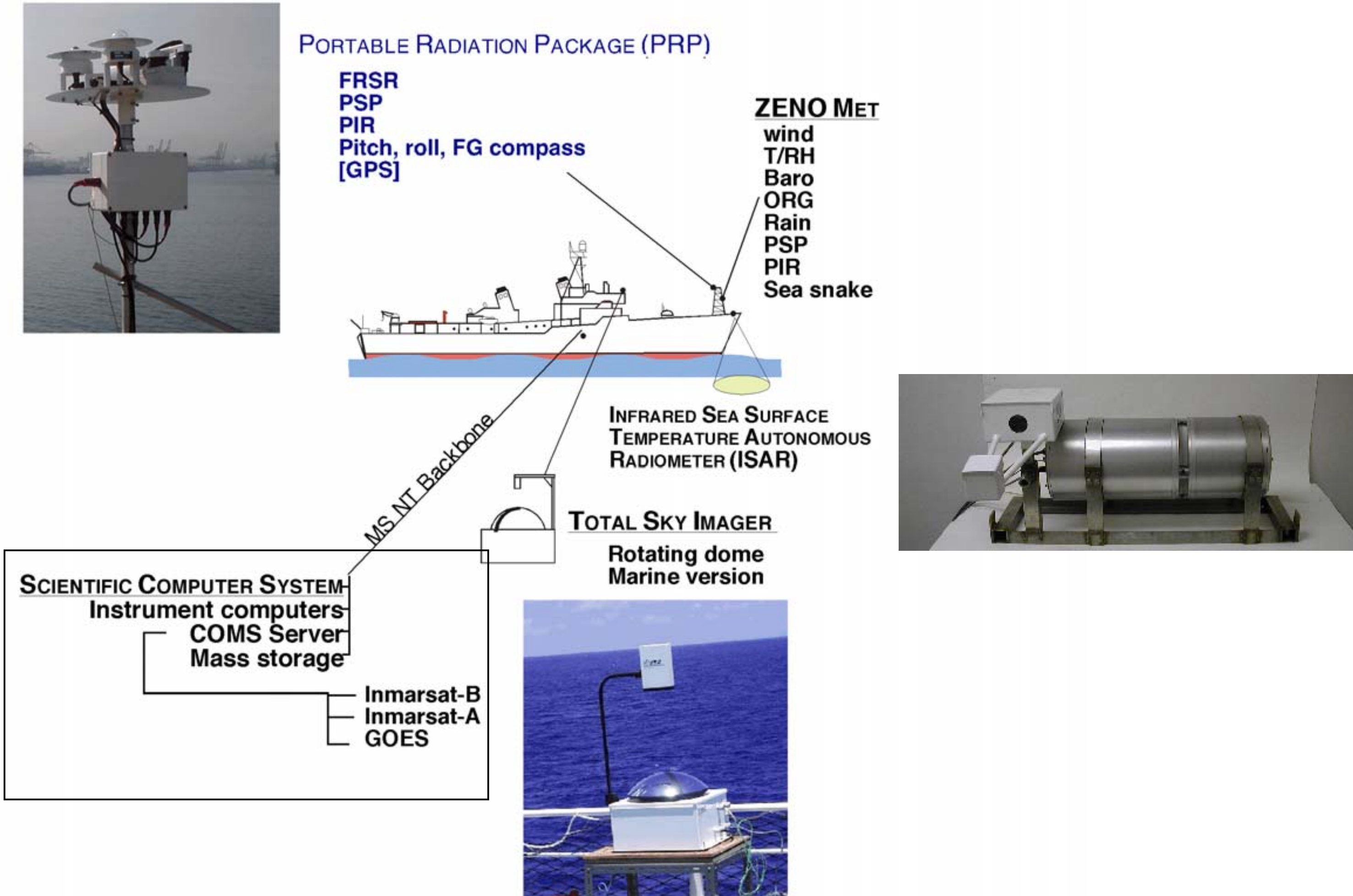
Responsivity vs Zenith Angle for 31618F3
on April 25 and May 7, 2001



LONGWAVE RADIOMETERS - UNCERTAINTY ISSUES

- Thermopile calibration method
- Case-Dome thermistor calibration
- Algorithm
- Shading, reflections, heat sources
- Calibration drift
- Signal-to-noise and RFI
- Dome leakage (SW leaks)

Shipboard Oceanographic and Atmospheric Radiation Program (SOAR)



Brookhaven National Laboratory – Geophysical Instruments and Measurements Group

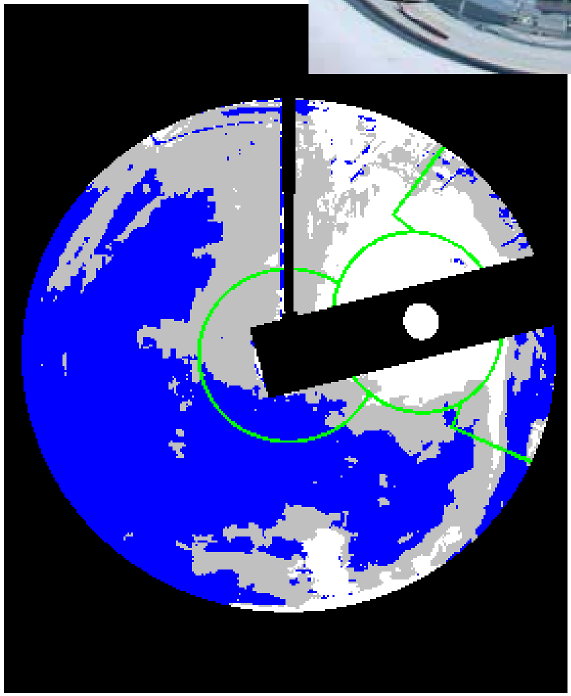
Infrared Sea Surface Temperature Autonomous Radiometer (ISAR)

The outer panel is retracted and the scan drum is rotated for viewing the sea surface or sky.

Goal
To operate un-attended for six months and measure SSST to +/- 0.1 C at one sample each 30 sec.

Total Sky Imager (TSI)

- 1 min images stored
- digitized clear, thick, thin cloud
- cloud fraction



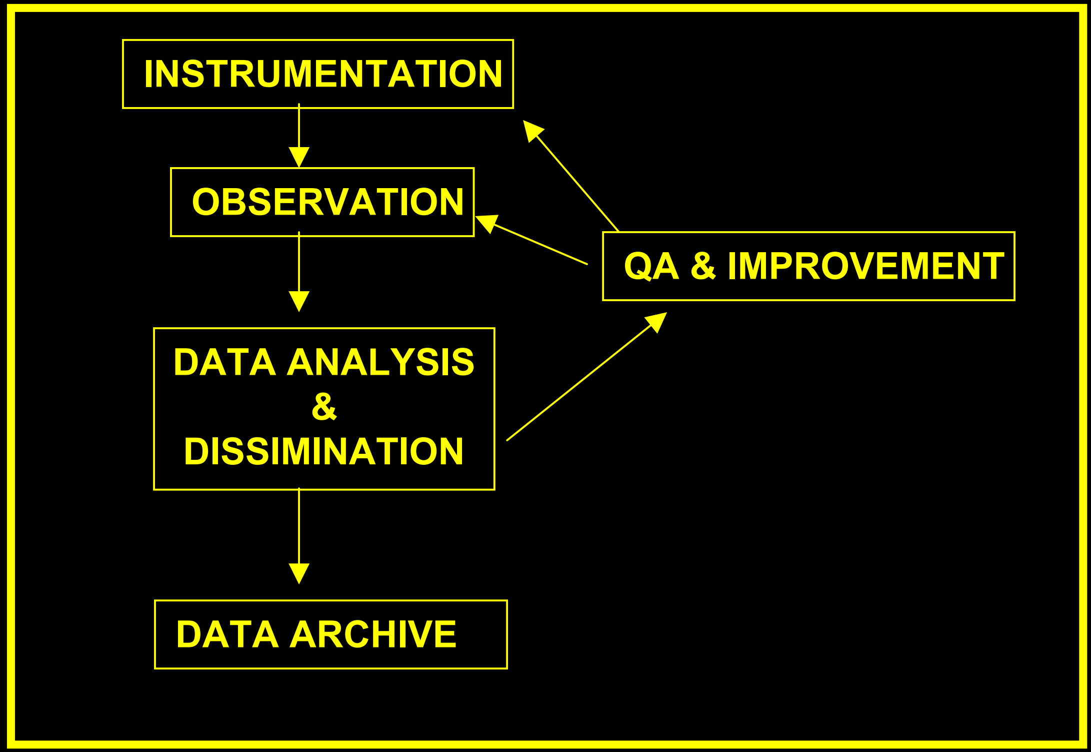
CONCLUSIONS

- CALIBRATION - CALIBRATION - CALIBRATION
- CENTRALIZED CALIBRATION FACILITY OR STANDARDIZED METHODS
- REDUNDANT SENSORS
- COMPARISONS IN THE FIELD
- ACTIVE PURSUIT OF NEW SENSORS AND METHODS
- ISO9000 IS A GOOD MODEL FOR QUALITY MANAGEMENT

CONCLUSIONS

INSTRUMENT-TO-DATA PROCESS

We need a partnership between the agency, the ship, and the researchers.



This suggests an entirely new way of doing business.

www.gim.bnl.gov -> SOAR, UAO

reynolds@bnl.gov

To get a copy of this presentation go to

http://www.gim.bnl.gov/links and look for the workshop