



Challenges in the observation of radiation fluxes over land and ocean

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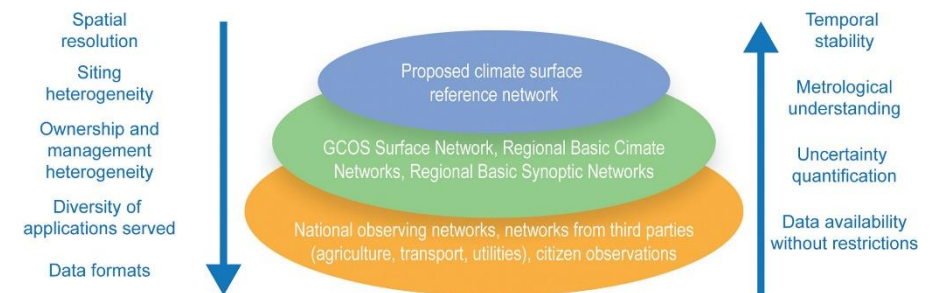
Rational: Land and Ocean communities to interact in the frame of radiation measurements

- Immediate goal: Establish a dialog across communities to **harmonize** the different methods of **in-situ** and **remote sensing** assessment of surface radiation balance
- Long-term goal: Establish the foundation for integrating surface shortwave and longwave radiation measurements into global fields.
- Share knowledge and experience across different comms
- Document calibration methods
- Assess uncertainties of different methods
- Improve in-situ sampling
- Validate and assess climate models / satellite products
- Contribute to understanding of earth's energy balance
- www.oceandecade.org, airseaobs.org, www.oceanbestpractices.org, ...



Land / BSRN approach

- Stations Representative of wider areas. Acting as radiation reference network over Land for **climate monitoring, climate model** and **remote sensing products** validation
- Established in early 90's with ~20 stations
- **Host data from 70+** stations across the world (land) different surface type and climate regimes over ~30 years
- **Candidate (8+2)/ Operational (57) / Inactive (0) / Closed (16)** (Update: Apr 2021)
- **Geographical gaps** still an issue on some areas
- Archive (AWI) www.pangaea.de (11,000+ monthly)

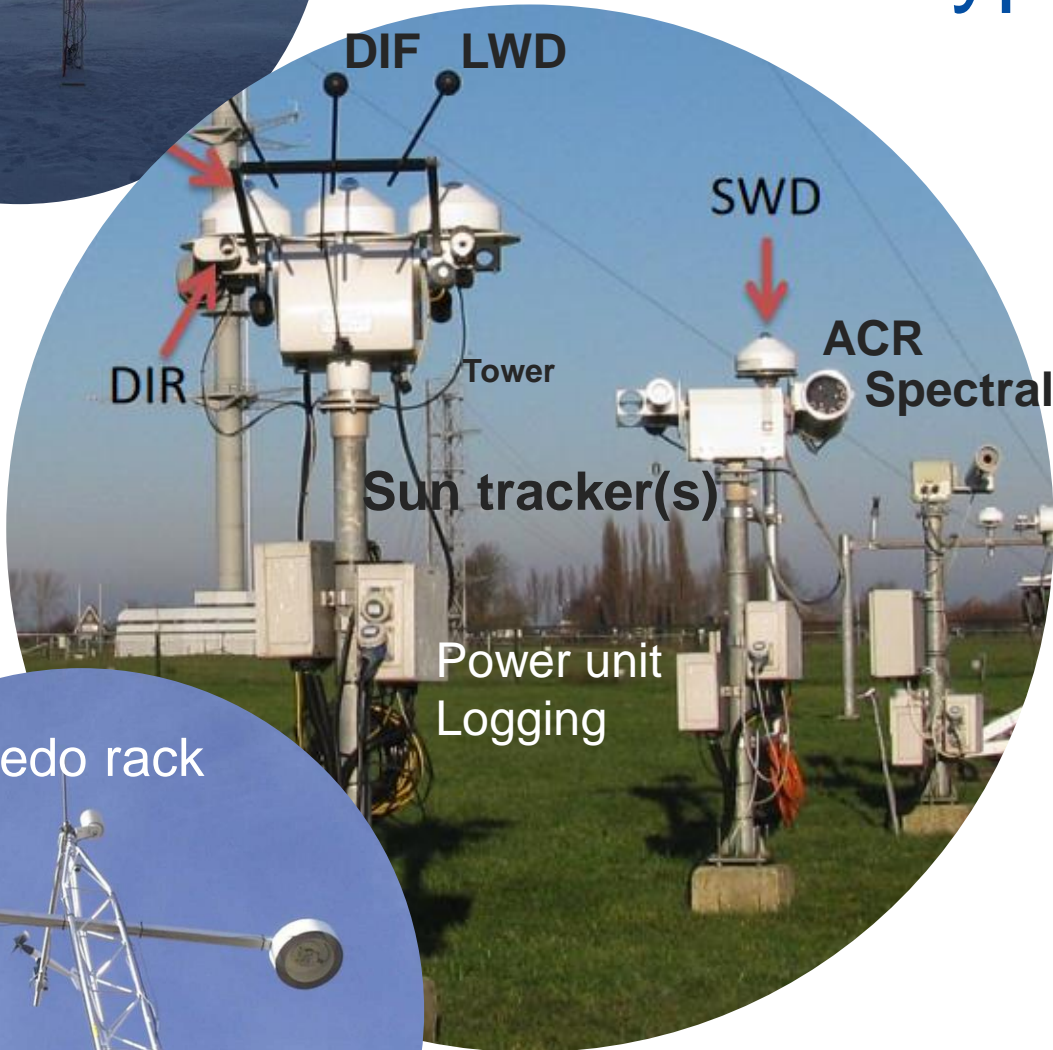
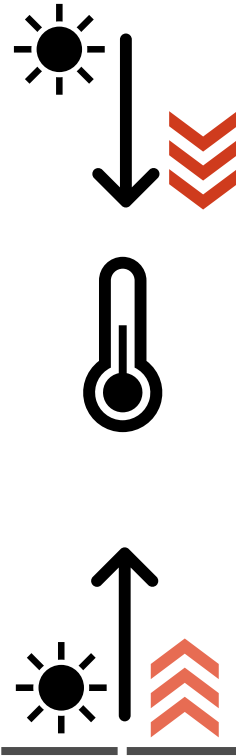


(P.Thorne et al., IJC JC2018)



A typical BSRN station collects

- Basic measurements
 - the downwelling components of the **shortwave** (glo, dif, dir) and **longwave** (lwd) broadband radiation at the surface
- Temperature, pressure, RH (2m)
- Extended measurements:
 - reflected shortwave (swu) and longwave (lwu) to close the radiative budget at the surface
 - 3m, 10m, 30m
- Upper air, UVa UVb, spectral, ...



Equipment of a BSRN station

- Thermopiles
 - Pyranometer (swd, swu and dif)
 - Pyrhelimeter (dir normal)
 - Pyrgeometer (lwd, lwu)
- Sun tracker/albedo rack
- Datalogger



Table 1 — Pyranometer classification list

Specification parameter No. (see 4.3.2)	Parameter	Name of the classes, acceptance intervals and width of the guard bands (in brackets)		
	Name of the class	A	B	C
	<i>Roughly corresponding class from ISO 9060:1990¹⁾</i>	<i>Secondary standard</i>	<i>First class</i>	<i>Second class</i>
a	Response time (see also 4.3.3 on fast response pyranometers): time for 95 % response	< 10 s (1 s)	< 20 s (1 s)	< 30 s (1 s)
b	Zero off-set: a) response to $-200 \text{ W}\cdot\text{m}^{-2}$ net thermal radiation b) response to $5 \text{ K}\cdot\text{h}^{-1}$ change in ambient temperature c) total zero off-set including the effects a), b) and other sources	$\pm 7 \text{ W}\cdot\text{m}^{-2}$ (2 $\text{W}\cdot\text{m}^{-2}$) $\pm 2 \text{ W}\cdot\text{m}^{-2}$ (0,5 $\text{W}\cdot\text{m}^{-2}$) $\pm 10 \text{ W}\cdot\text{m}^{-2}$ (2 $\text{W}\cdot\text{m}^{-2}$)	$\pm 15 \text{ W}\cdot\text{m}^{-2}$ (2 $\text{W}\cdot\text{m}^{-2}$) $\pm 4 \text{ W}\cdot\text{m}^{-2}$ (0,5 $\text{W}\cdot\text{m}^{-2}$) $\pm 21 \text{ W}\cdot\text{m}^{-2}$ (2 $\text{W}\cdot\text{m}^{-2}$)	$\pm 30 \text{ W}\cdot\text{m}^{-2}$ (3 $\text{W}\cdot\text{m}^{-2}$) $\pm 8 \text{ W}\cdot\text{m}^{-2}$ (1 $\text{W}\cdot\text{m}^{-2}$) $\pm 41 \text{ W}\cdot\text{m}^{-2}$ (3 $\text{W}\cdot\text{m}^{-2}$)
c1	Non-stability: percentage change in responsivity per year	$\pm 0,8 \%$ (0,25 %)	$\pm 1,5 \%$ (0,25 %)	$\pm 3 \%$ (0,5 %)
c2	Nonlinearity: percentage deviation from the responsivity at $500 \text{ W}\cdot\text{m}^{-2}$ due to the change in irradiance within $100 \text{ W}\cdot\text{m}^{-2}$ to $1\,000 \text{ W}\cdot\text{m}^{-2}$	$\pm 0,5 \%$ (0,2 %)	$\pm 1 \%$ (0,2 %)	$\pm 3 \%$ (0,5 %)
c3	Directional response (for beam radiation): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction (with an incidence angle of up to 90° or even from below the sensor) a beam radiation whose normal incidence irradiance is $1\,000 \text{ W}\cdot\text{m}^{-2}$	$\pm 10 \text{ W}\cdot\text{m}^{-2}$ (4 $\text{W}\cdot\text{m}^{-2}$)	$\pm 20 \text{ W}\cdot\text{m}^{-2}$ (5 $\text{W}\cdot\text{m}^{-2}$)	$\pm 30 \text{ W}\cdot\text{m}^{-2}$ (7 $\text{W}\cdot\text{m}^{-2}$)

NOTE The acceptance intervals should not be used for uncertainty estimations for conditions different from the ones stated for each criterion. In particular the spectral error can be different under different conditions. The spectral error for diffuse horizontal irradiance measurements is also different from that for global horizontal irradiance.

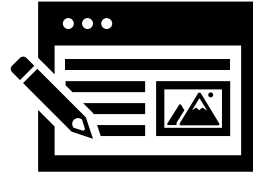
<https://www.pangaea.de/ddi?request=bsrn/BSRNMethods&format=html&title=BSRN+Methods>

List of instruments deployed to BSRN stations (not necessarily up to date)

BSRN best practices at a glance

- ~1-Hz acquisition, **1-minute** stats (to catch sky variability / cloud effects)
- Ventilation (reduce IR offsets, riming, dusting)
- Shadowing LWD
- Datalogger (~0.1 W/m²)
- Store 1-Hz raw data (*mV*) for any **review** of calibration “constants”
- Store T_b , T_d of the pyrgeometer(s)
- Corrections: Cosine resp, k (Temperature), nighttime offset
- **QC procedures (auto/manual)**
- Instrument **redundancy**
- **Traceability to Standards** (PMOD/WRC Davos): calibration every ~2-years
 - Pyrgeom (LW): **WISG**
 - Pyranom (SW): **WRR** (group of 4 pyranometers, CM21 CM22 mainly)
 - Pyrhelium (SW direct): **WSG (ACRs)**
- Uncertainty (following FRM terminology is still **not completely mature**)
- This is a very active research area (see the amount of “*frm4**” projects/initiatives VEG, ocean color, ...)

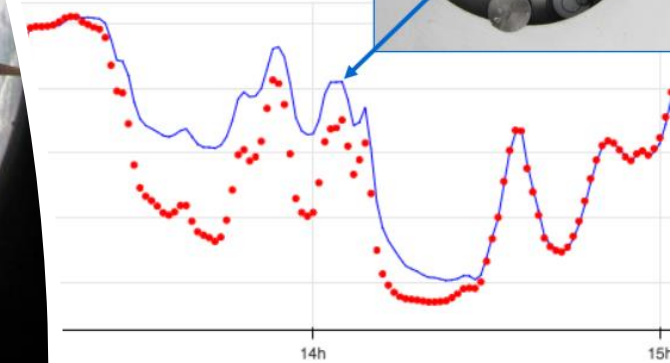
Data screening QC Tests



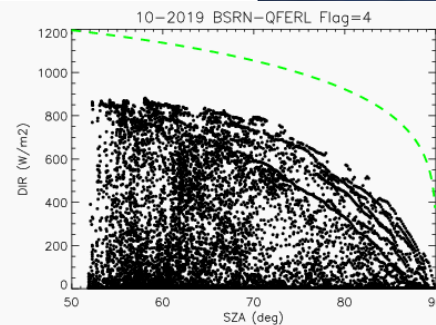
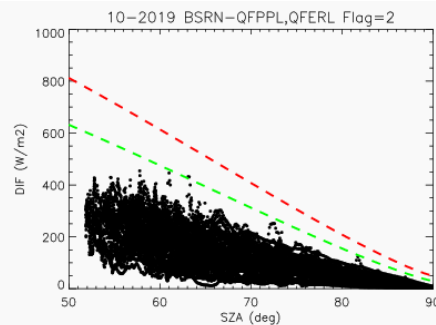
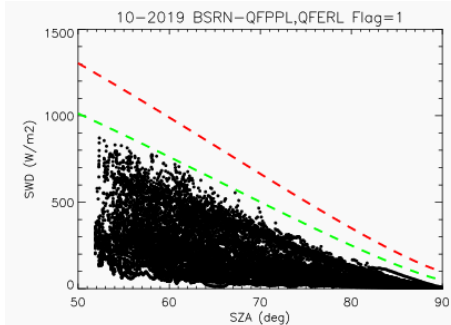
- Tilting, Dusting, water on the domes, riming, Birds, Cleaning operations, Nighttime spikes, raining effects, ...



Water on the pyrheliometer
creates a positive
bias offset



- Physically possible limits
- Extremely rare limits
- Across quantities



Quality Control: across quantities

Ratio of Global over Sum SW:

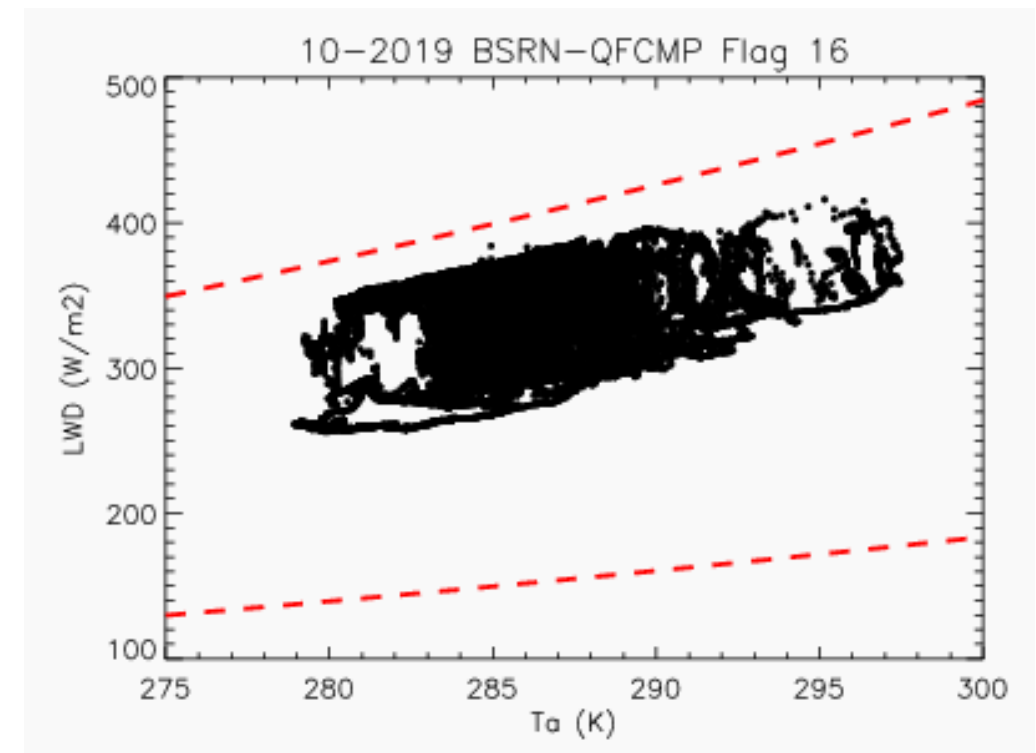
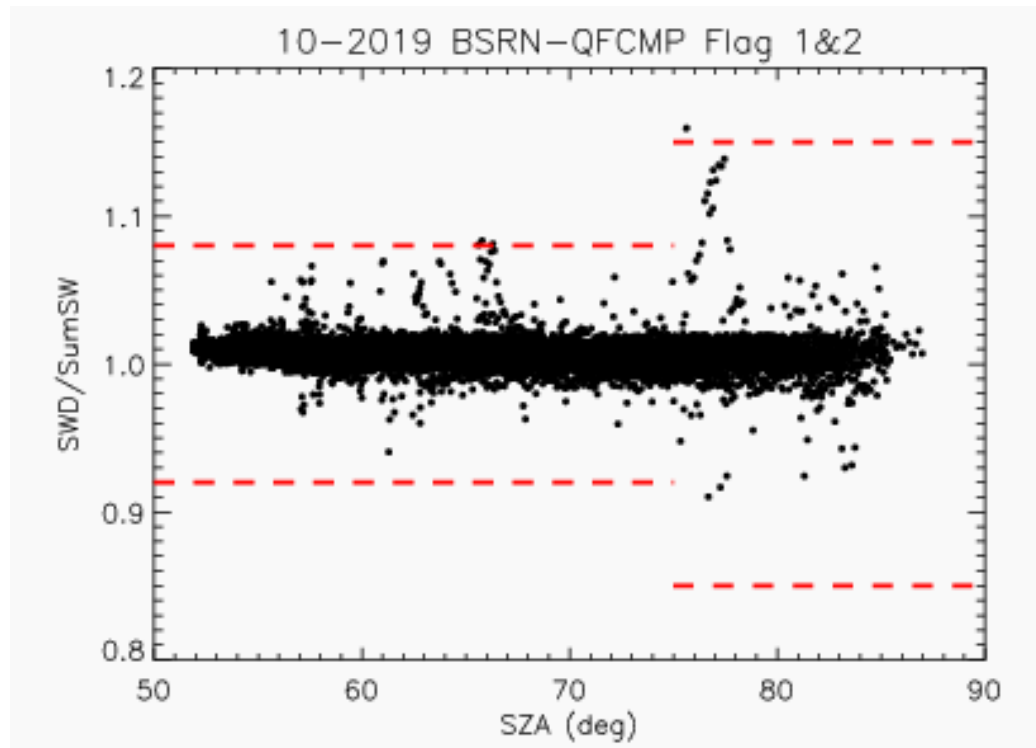
(Global)/(Sum SW) should be within +/- 8% of 1.0 for $\text{SZA} < 75^\circ$, $\text{Sum} > 50 \text{ Wm}^{-2}$

(Global)/(Sum SW) should be within +/- 15% of 1.0 for $93^\circ > \text{SZA} > 75^\circ$, $\text{Sum} > 50 \text{ Wm}^{-2}$

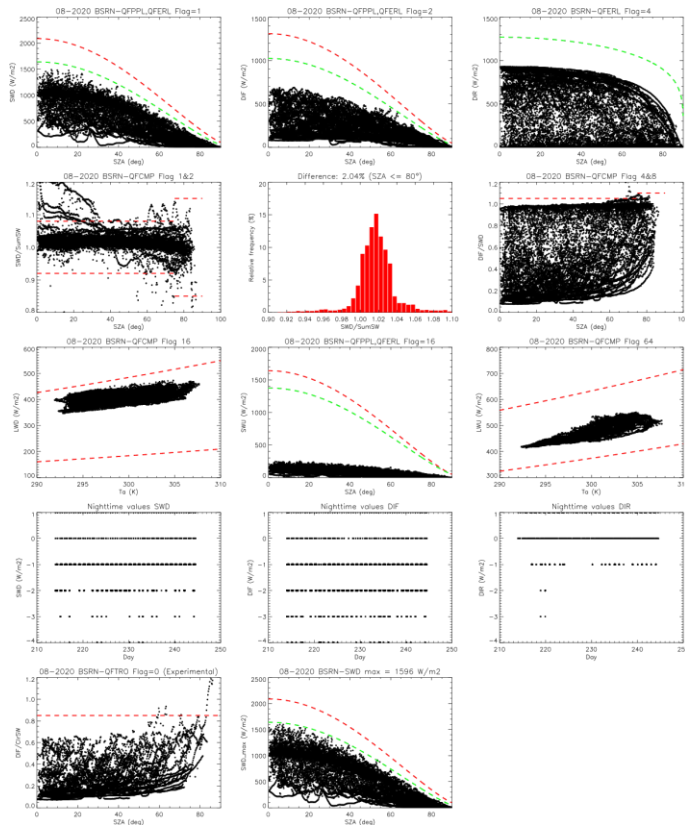
For $\text{Sum SW} < 50 \text{ Wm}^{-2}$, test not possible

LWdn to Air Temperature comparison

$$0.4 \times \sigma T_a^4 < \text{LWdn} < \sigma T_a^4 + 25$$

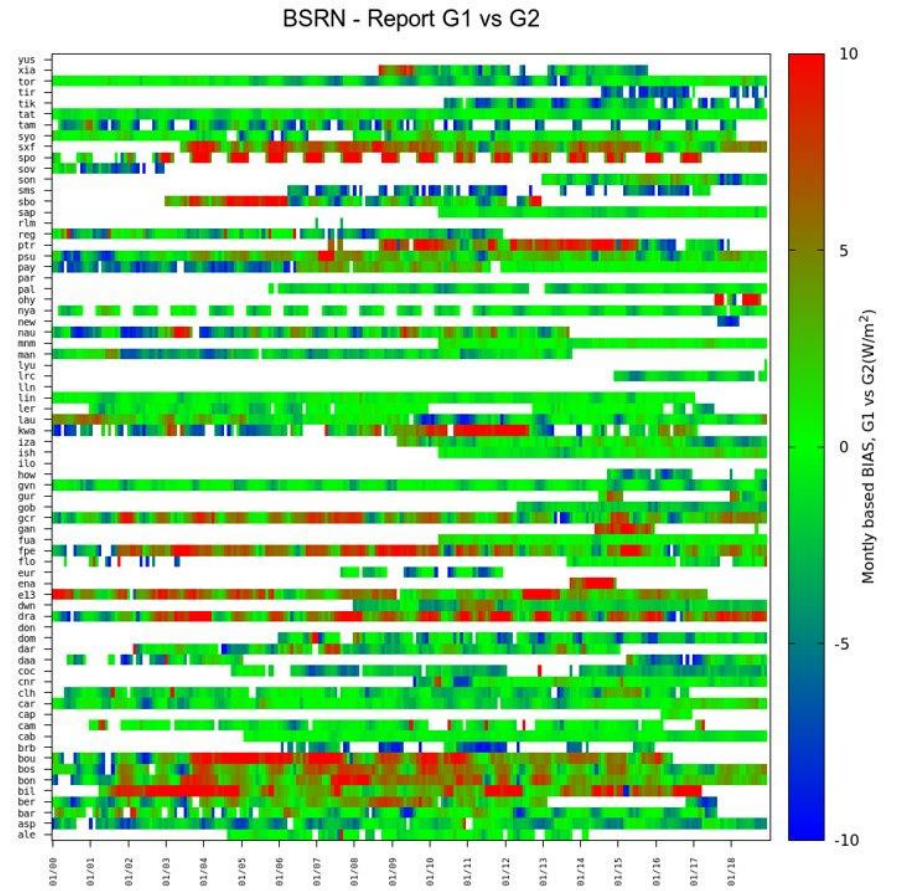
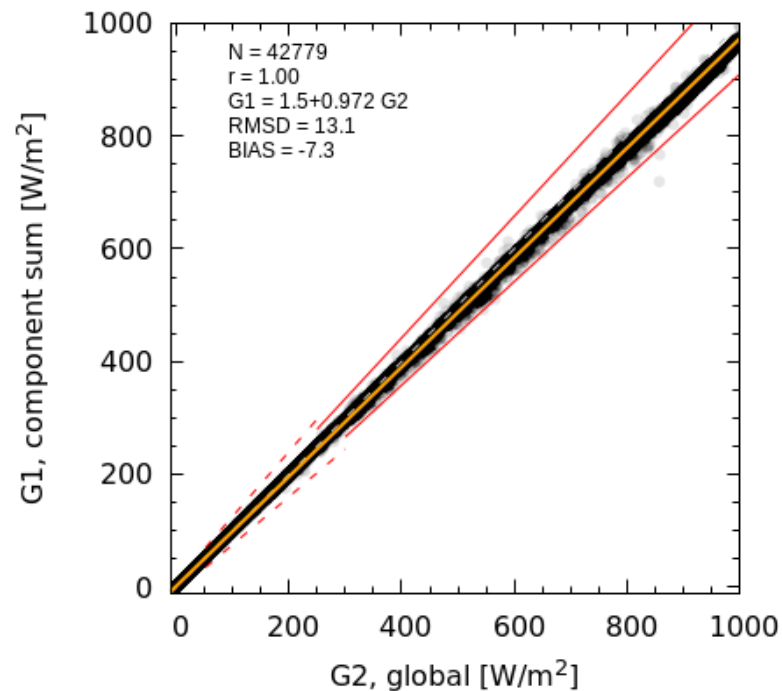


Quality Control: across quantities



Pilot: **BSRN-QC**
(W. Knap, KNMI)

Global SWD
 $G1 = dif + dirn \cos Z$
 $G2 = global$



Land vs Ocean practices

	Land	Ocean	
	BSRN	vessels	buoys
Site characteristics			
Free horizon	buildings/mountains	ship structures	
Site should be representative of wider areas	point measurements	track	drifting/fixed
Accessibility	daily/weekly	continuous	monthly/yearly
Acquisitions			
Quantity measured	swd,dir,dif,lwd,(swu,lwu)		
Instruments used (technology)	thermopiles (eventually silicon for redundancy or testing)		silicon (for high freq)
Meteorological variables	T,p,RH		
Sun tracker	yes		
Acquisition rate	1hz		
Redundancy	highly recommended		
Ventilation (reduce IR offsets, riming, dusting)	all ventilated		
Shadowing LWD	yes		
Datalogger resolution	0.1 Wm-2		
Store raw data (mV), @acquisitions rate, for any review of calibration "constants"	yes		
Store pyrgeometer temperatures (Tb,Td)	yes		

[Link](#)



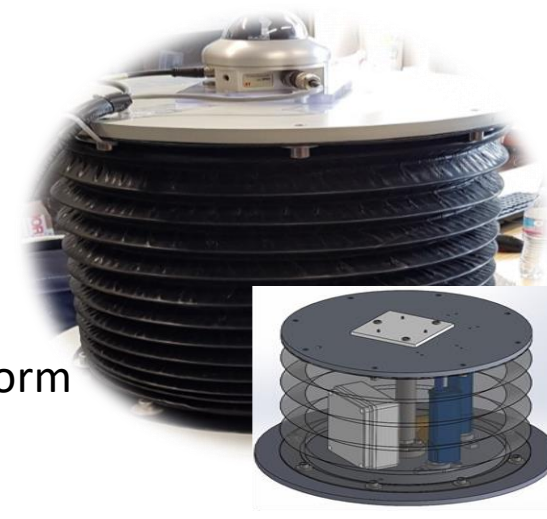
PMEL Saildrone
(D. Zhang & M. Cronin)



ISP-CNR
Pan-Tilt platform
stabilizer
(V. Vitale)



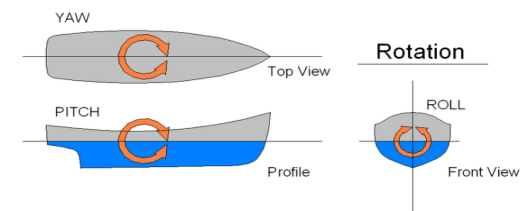
WHOI WHOTS
surface mooring
(R. Weller)



Gulf of Alaska
PMEL buoy (M. Cronin)



ARM, SHIPRAD
System (L. Riihimaki)

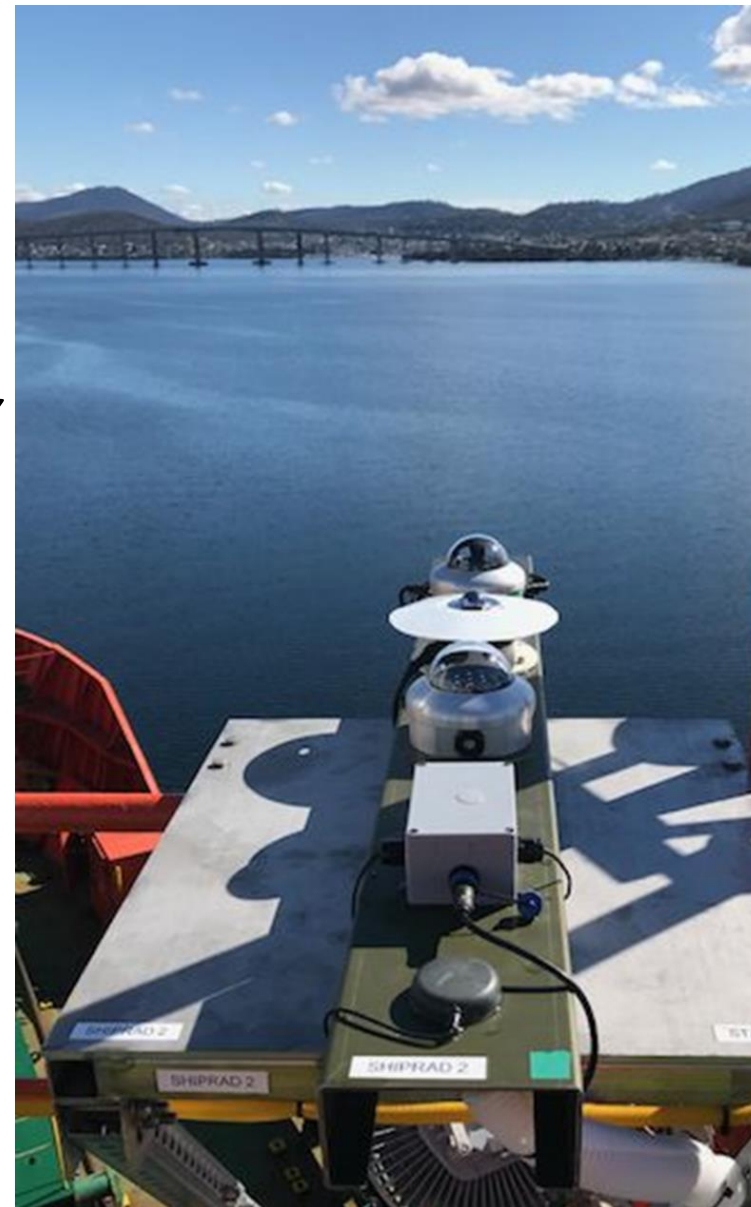




US DEPARTMENT OF ENERGY **ARM SHIPRAD SYSTEM**

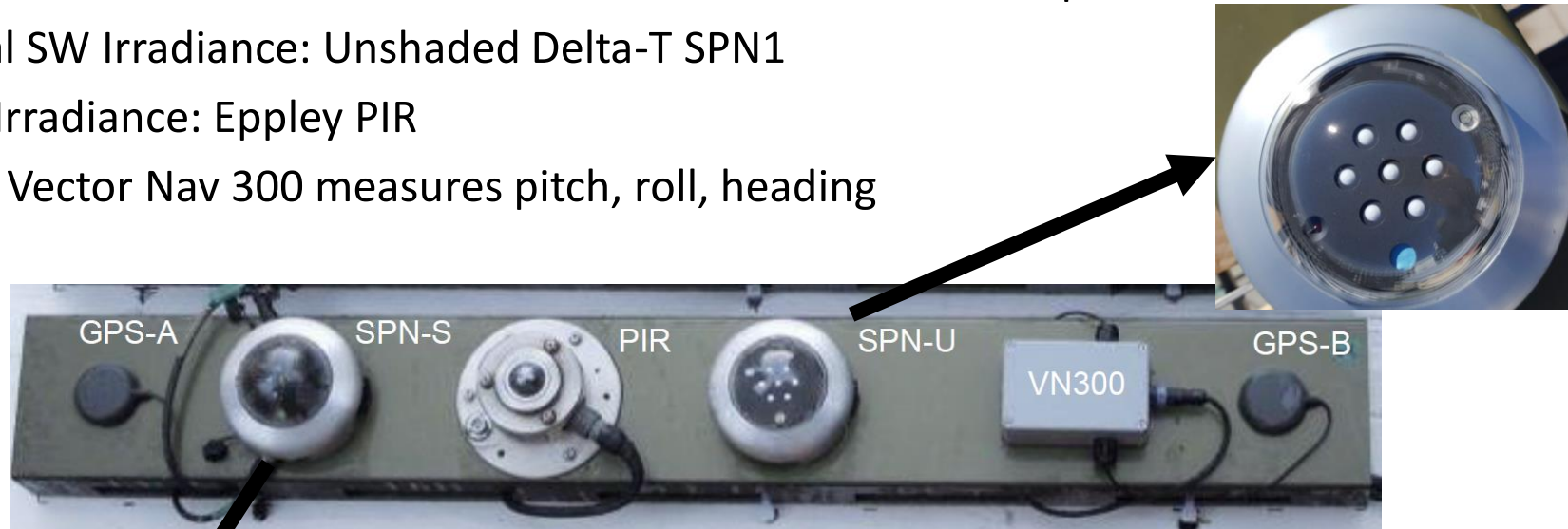
Acknowledgements:

- Chuck Long who pioneered this system
- R. Michael Reynolds, Jim Wendell, and Emiel Hall for building it and working on calibration/characterization methodologies



ShipRad systems correct SW irradiance for tilt and gives measurements of components:

- Diffuse SW Irradiance: Shaded SPN1 measures diffuse component of SW irradiance
- Total SW Irradiance: Unshaded Delta-T SPN1
- LW Irradiance: Eppley PIR
- Tilt: Vector Nav 300 measures pitch, roll, heading



Advantages

- Measures components with no moving parts
- Small thermopile sensors with fast response time
- Internal heaters keep frost free and also mitigate IR loss

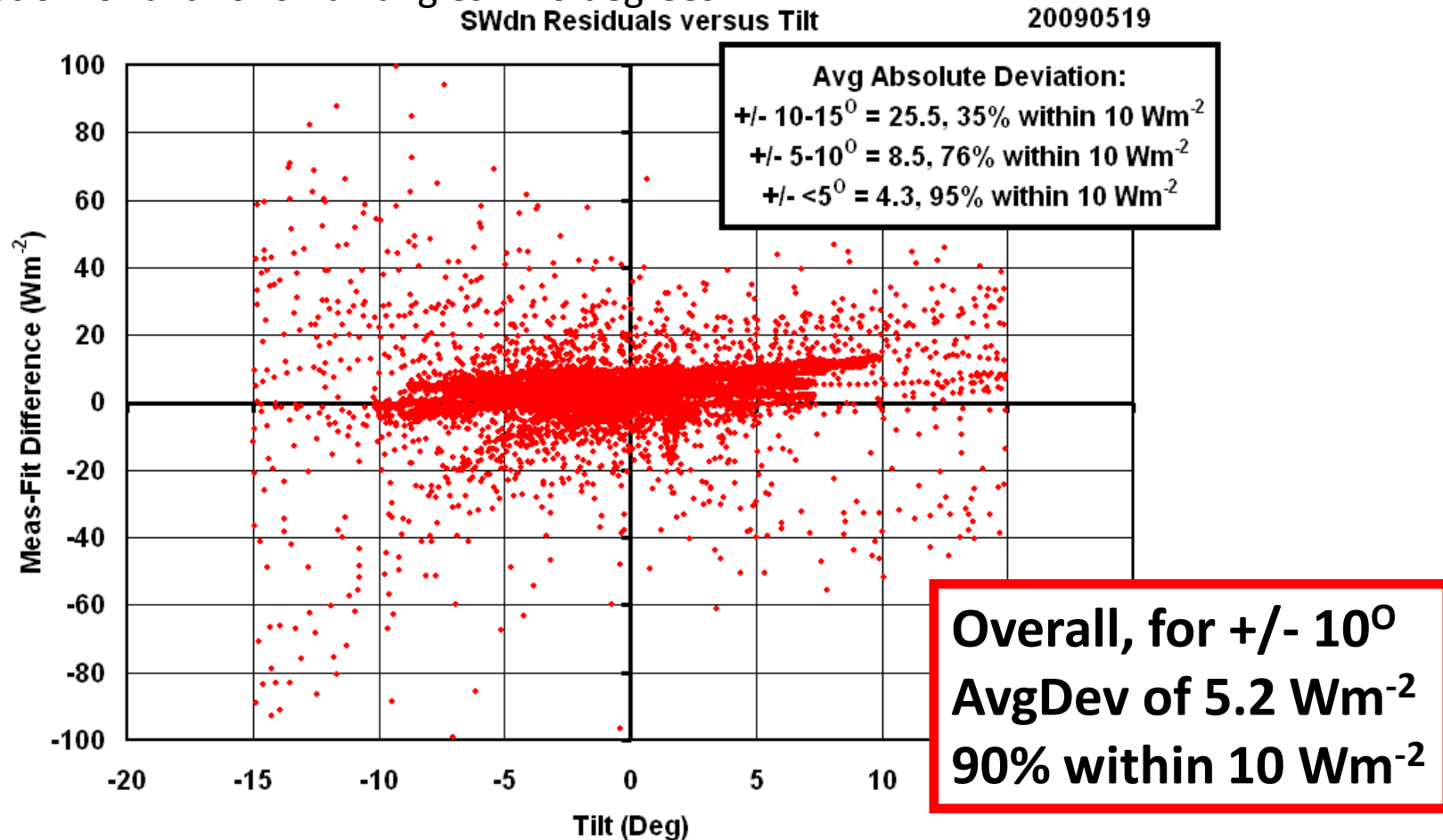
Disadvantages

- Differences between individual sensor leveling/cal cause step function jumps in total measurements
- Shading pattern blocks diffuse disproportionately with zenith angle
- Challenging to calibrate

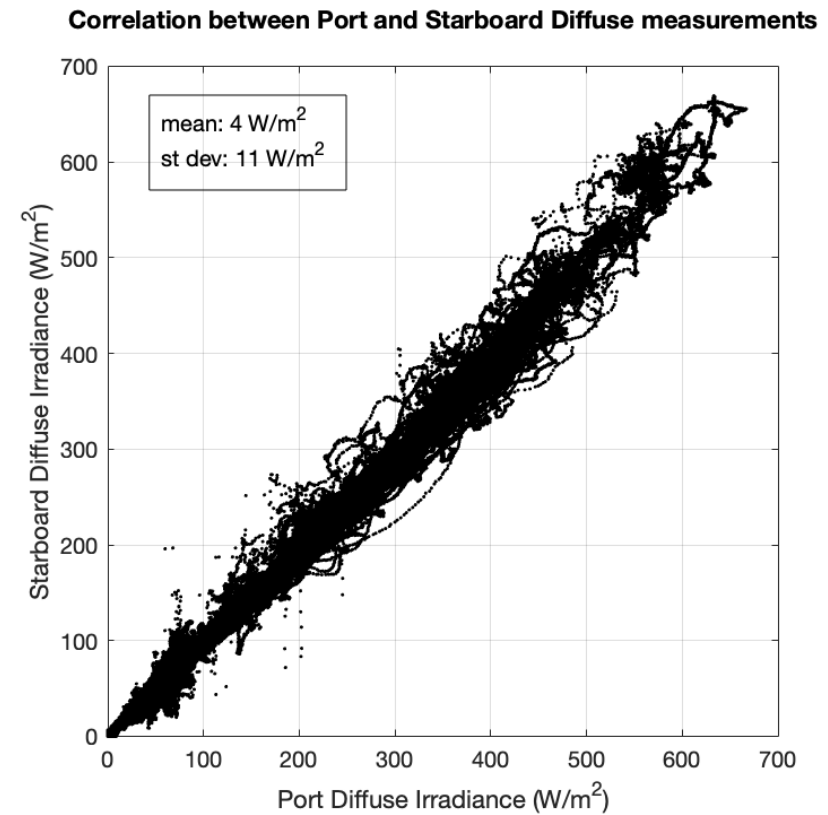
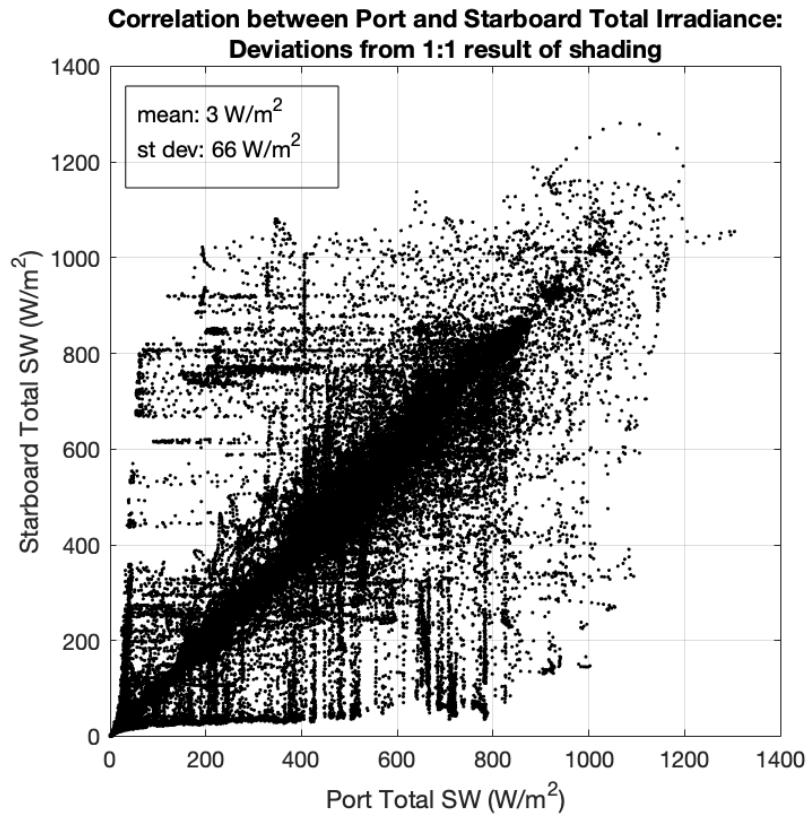


Tilt Correction Methodology

Tilt correction assumes that tilted diffuse = diffuse on a horizontal surface. This assumption is valid for small angles < 10 degrees

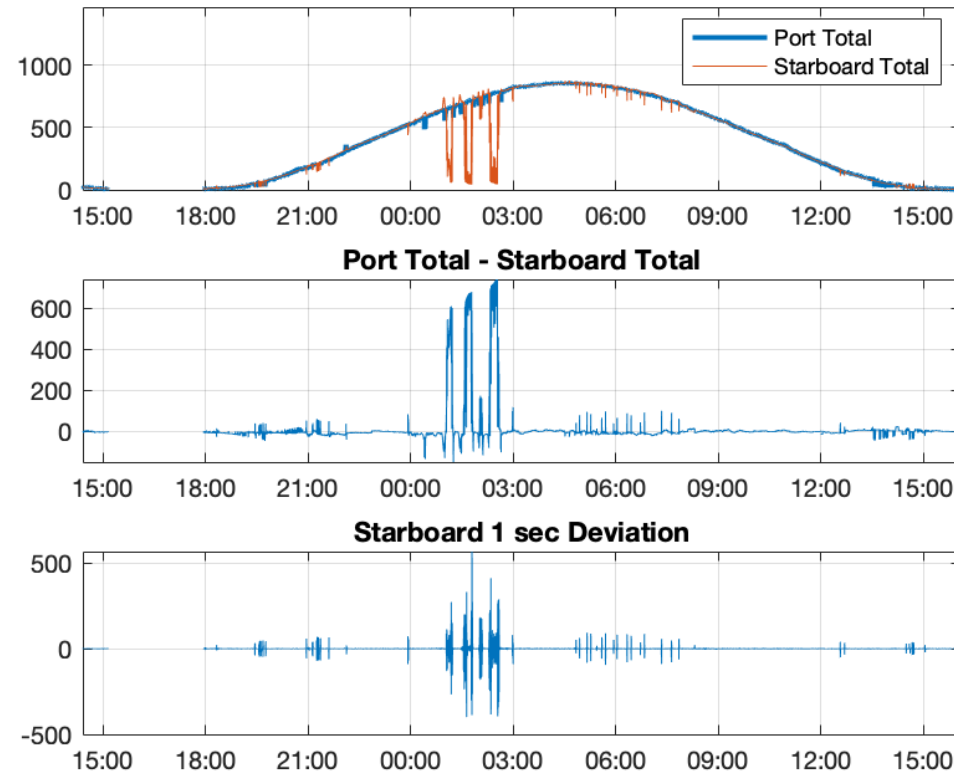


Port and Starboard Comparison—Total shows deviations due to shading not seen in diffuse

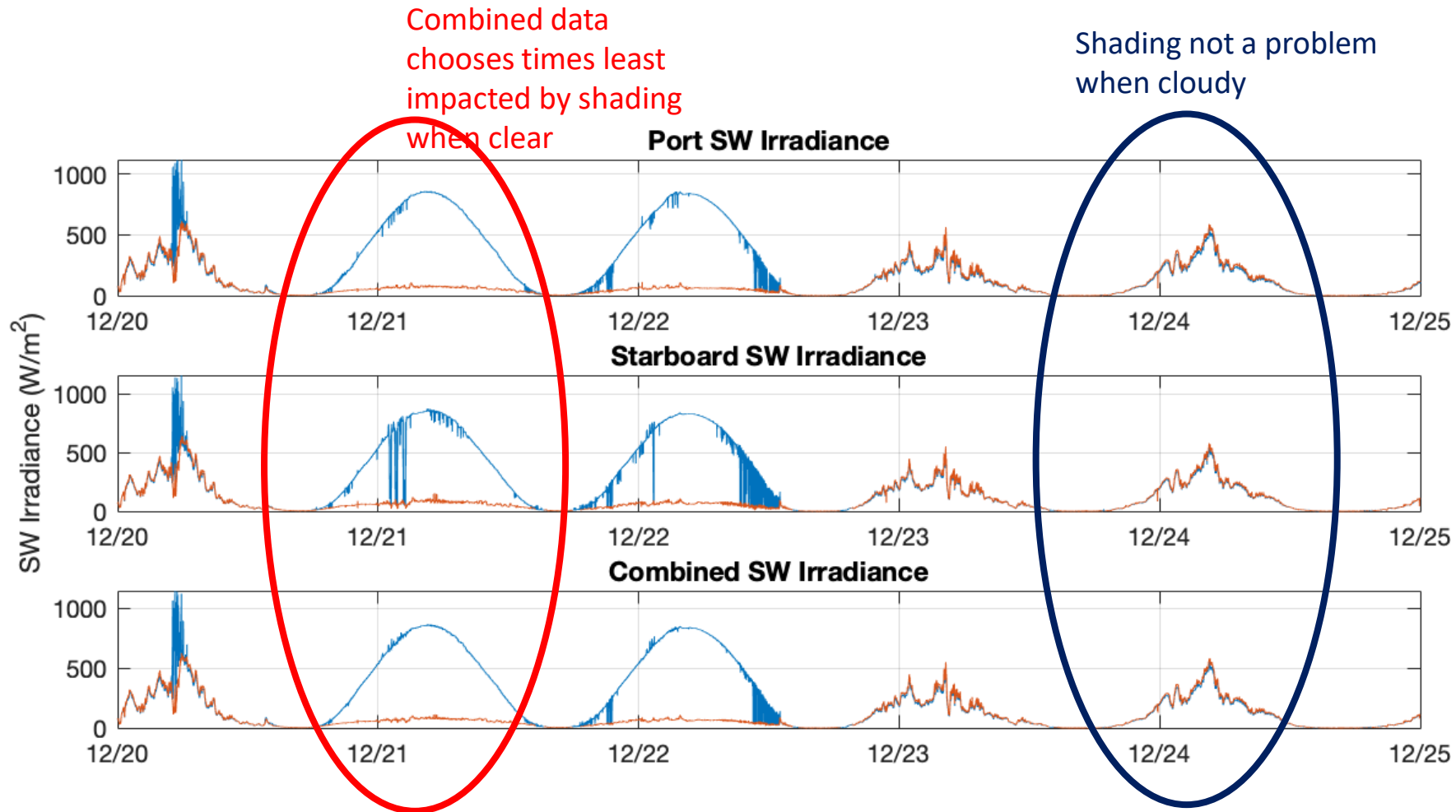


Shading correction methodology

- Downwelling LW & Diffuse SW—average of both measurements when tilt angle $< 10^\circ$
- Total SW--use average unless shaded:
 - When Port/Starboard Total is $>100 \text{ W/m}^2$ than Starboard/Port Total
 - Shaded when 1-second deviation greater than 5 W/m^2 , and data from port/starboard not included

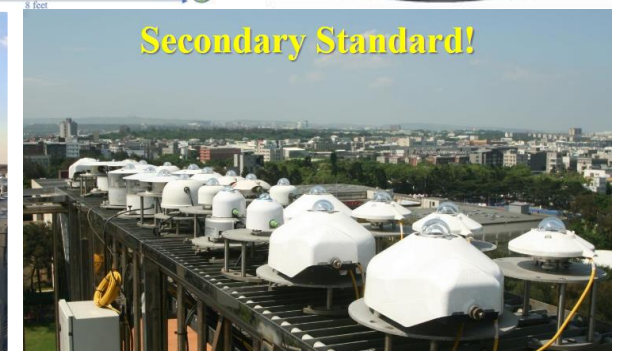
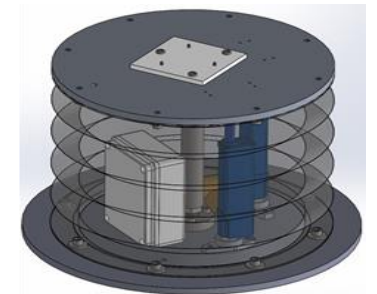
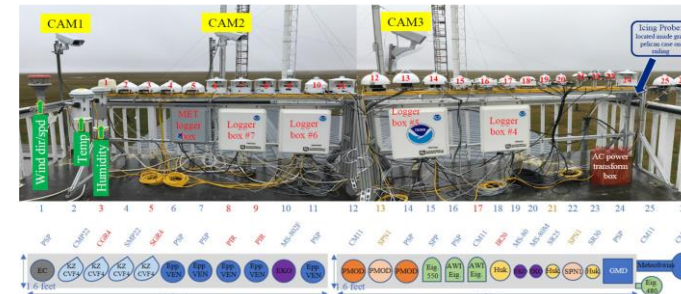


Deploying ShipRad systems on both port and starboard to reduce shading from ship structures when possible.



Towards an harmonization, and FRM concept

- **Ships as a bridge** between land and buoy systems
- Common **field campaigns**
- **Active pan-tilting** on land to **simulate** ocean waves alongside fixed platforms
- **Intercomparisons** of thermopiles and silicon sensors
- Sensor Throughput, thermal offsets, cosine responses
- Automatic cleaning operations
- Stabilized vs Oscillating systems
- Ocean stations on board BSRN?



References

Driemel, A., et al. 2018 Baseline Surface Radiation Network (BSRN): structure and data description (1992–2017), Earth Syst. Sci. Data, 10, 1491-1501, [doi:10.5194/essd-10-1491-2018](https://doi.org/10.5194/essd-10-1491-2018).

- McArthur L.J.B. 2005: Baseline Surface Radiation Network (BSRN). **Operations Manual**. WMO/TD-No. 1274, WCRP/WMO ([Link](#)).
- König-Langlo, G. , et al. 2013: The Baseline Surface Radiation Network and its World Radiation Monitoring Centre at the Alfred Wegener Institute ([GCOS-174](#)).
- Hegner H., et al. 1998: Update of the Technical Plan for BSRN Data Management. WMO/TD-No. 882, WCRP/WMO ([Link](#))
- Long C.N. and Dutton E.G. 2002 BSRN Global Network recommended **QC tests**, V2.0, BSRN Technical Report, 3 pp. ([Link](#))
- Long C.N. and Shi Y. 2008, An Automated Quality **Assessment and Control** Algorithm for Surface Radiation Measurements. TOASJ, 2, 23-37 ([Link](#)).
- Roesch A., et al. 2011 Assessment of BSRN radiation records for the computation of monthly means Atmos. Meas. Tech., 4, 339-354 ([Link](#))
- Taiping Z., et al. 2013 The validation of the GEWEX SRB surface shortwave flux data products using BSRN measurements: A systematic quality control, production and application approach, J. Quant. Spectrosc. Radiat. Transfer, 122, 127–140 ([Link](#))
- <https://bsrn.awi.de/other/publications/>

Thank you



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Slide xx: **element concerned**, source: **e.g. Fotolia.com**; Slide xx: **element concerned**, source: **e.g. iStock.com**

EXTRA SLIDES



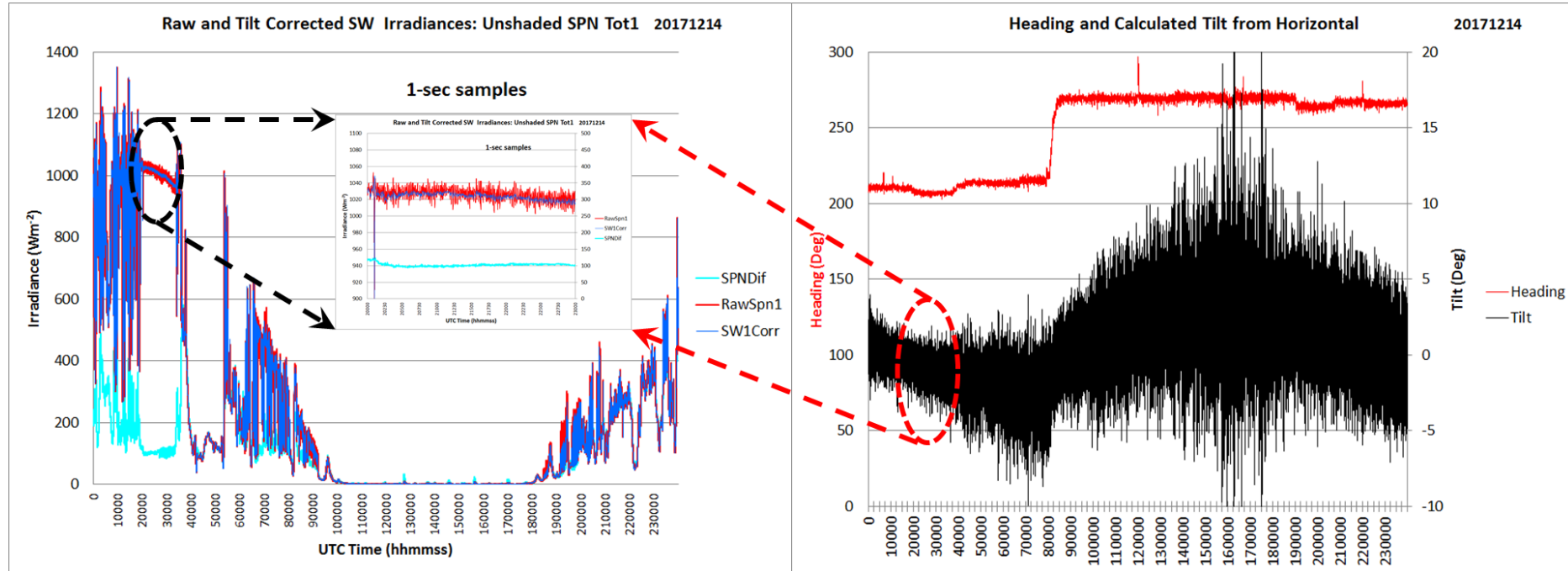
Cooperative Institute for Research in Environmental Sciences
UNIVERSITY OF COLORADO **BOULDER** and **NOAA**



Summary of lessons of good practices for ship measurements

- SW Instrument choice important for moving platform when tracker can't be used
 - Thermopile
 - Choose model that minimizes cosine response/IR loss errors
- Calibration should be done to with traceability to the World Radiometric Reference at Davos
- Measuring components is challenging on moving platforms, but SPN1 can give measure diffuse for small tilts with no moving parts.
- In concert with more accurate SW pyranometer, SPN1 can correct tilt within 10 Wm^{-2} for tilt less than 10° .

Example of tilt correction, Dec. 14, 2017



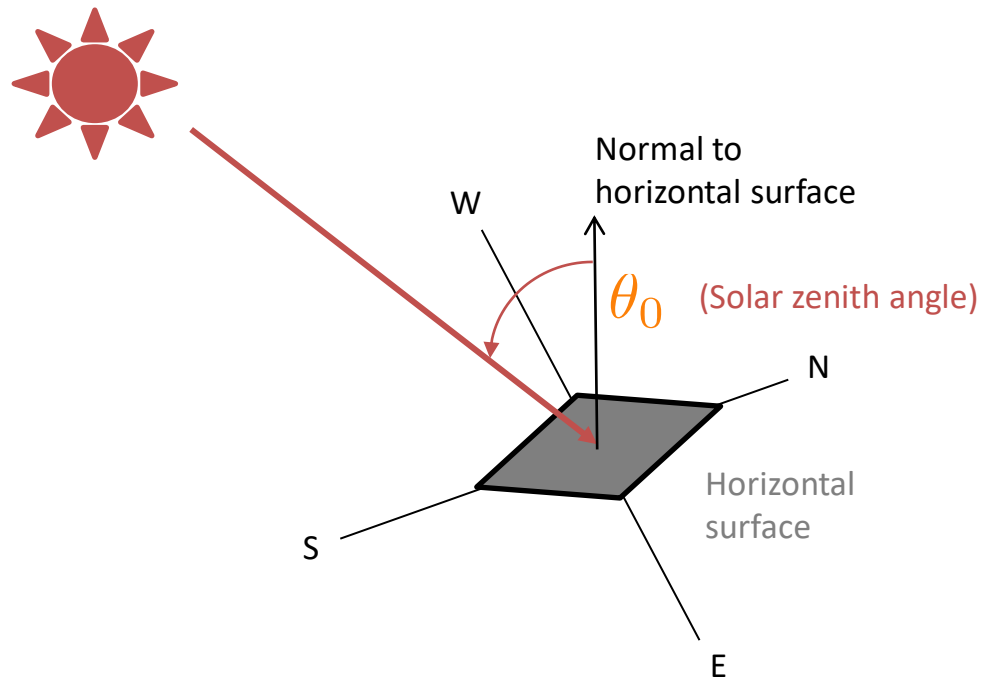
A brief nearly clear-sky period (dashed circle) shows the effectiveness of the preliminary tilt correction. As the zoom plot shows, the noise in the 1-second samples is decreased from a spread of 30-40 Wm⁻² to only a few Wm⁻². This despite the rapidly changing tilt from horizontal (black) shown in the right hand plot.

Causes of Errors in SPN1 measurements

Badosa (2014) identifies the main errors and differences in SPN1 measurements in detail. These are summarized here.

1. Calibration mismatch between detectors can cause jumps in the Direct part of the output as the sun moves across the sky, changing which of the detectors are fully exposed.
2. Lensing of light by the glass dome can cause an additional mismatch between detectors which varies with solar position.
3. Detector cosine response can cause a changing Direct beam sensor response which varies with solar zenith angle.
4. The SPN1 diffusers have a reduced transmission of blue light. This causes a variation in Diffuse sensitivity between blue-sky and cloudy conditions which is not fully corrected by the instrument.
5. The shape of the shadow mask pattern gives an effective opening angle which varies with solar position, between $\pm 5^\circ$ and $\pm 20^\circ$. This changes the measured partition between Direct and Diffuse light in conditions with a large solar aureole.
6. There are smaller effects due to temperature change, internal electronics, time response and soiling.

Tilt Correction Methodology



Relationship between Total SW and components on horizontal surface

$$G = D + N\mu_0$$

G : Total SW irradiance

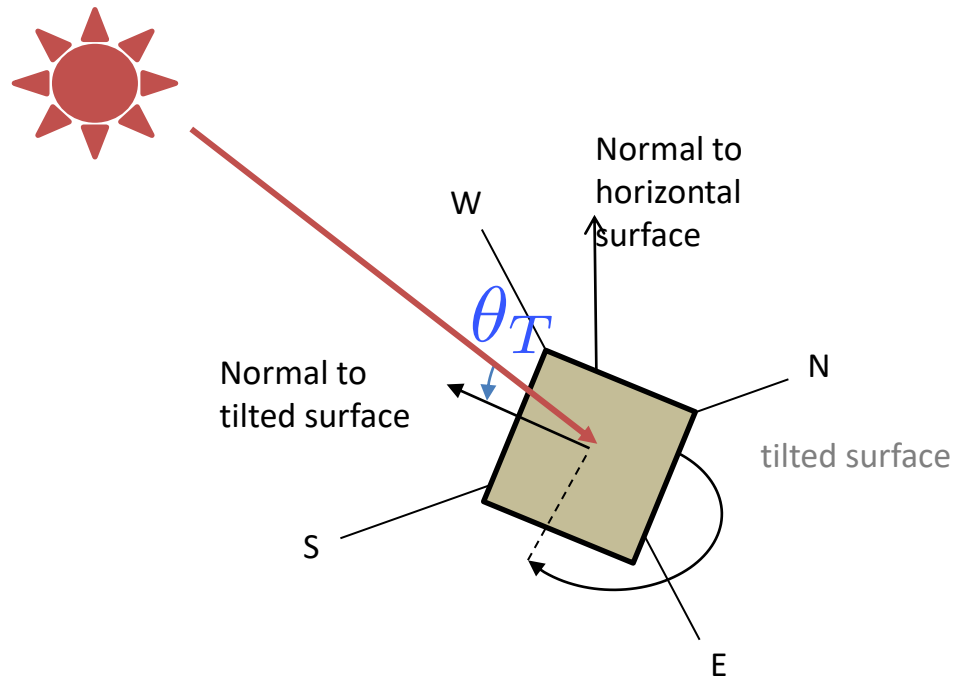
D : Diffuse SW irradiance

N : Direct normal irradiance

$$\mu_0 = \cos(\theta_0)$$

Long, C. N., A. Bucholtz, H. Jonsson, B. Schmid, A. Vogelmann, and J. Wood (2010): A Method of Correcting for Tilt from Horizontal in Downwelling SW Measurements on Moving Platforms, TOASJ, 4, pp.78-87, doi: 10.2174/1874282301004010078.

Tilt Correction Methodology



Relationship between Total SW and components on tilted surface

$$G_T = D_T + N\mu_T$$

G_T : Total SW on tilted surf

D_T : Diffuse SW on tilted surf

N : Direct normal irradiance

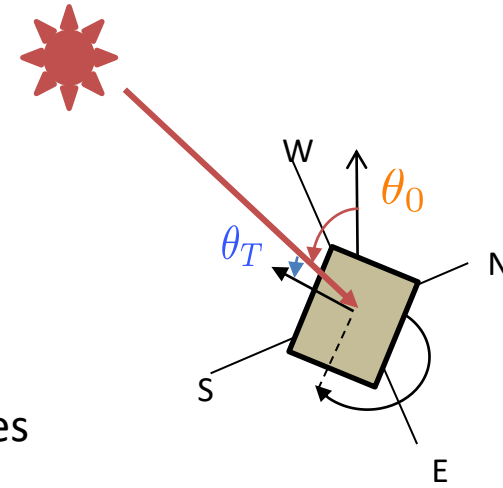
$$\mu_T = \cos(\theta_T)$$

Long, C. N., A. Bucholtz, H. Jonsson, B. Schmid, A. Vogelmann, and J. Wood (2010): A Method of Correcting for Tilt from Horizontal in Downwelling SW Measurements on Moving Platforms, TOASJ, 4, pp.78-87, doi: 10.2174/1874282301004010078.

Tilt Correction Methodology

$$G = G_T \left(\frac{\mu_0 + D/N}{\mu_T + D_T/N} \right)$$

Equation for total irradiance as a function of measured variables



D_T, G_T : Measured by ShipRad

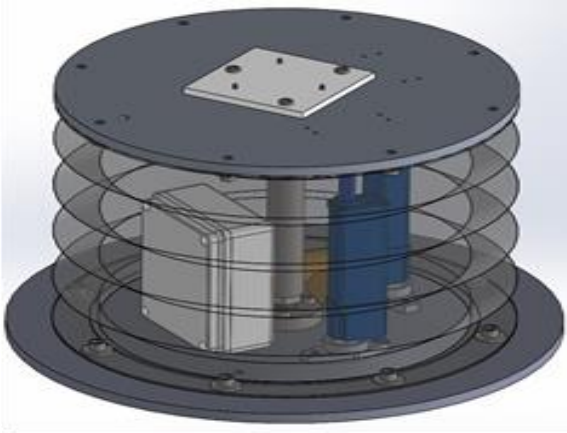
$\mu_T = \cos(\theta_T)$: Calculate tilt zenith angle as a function of pitch, roll, heading

$D = D_T$: Assume Diffuse and tilted Diffuse equal for small tilt angles

μ_0, N : Calculated from other measurements

Long, C. N., A. Bucholtz, H. Jonsson, B. Schmid, A. Vogelmann, and J. Wood (2010): A Method of Correcting for Tilt from Horizontal in Downwelling SW Measurements on Moving Platforms, TOASJ, 4, pp.78-87, doi: 10.2174/1874282301004010078.

Radiation measurements on a ship

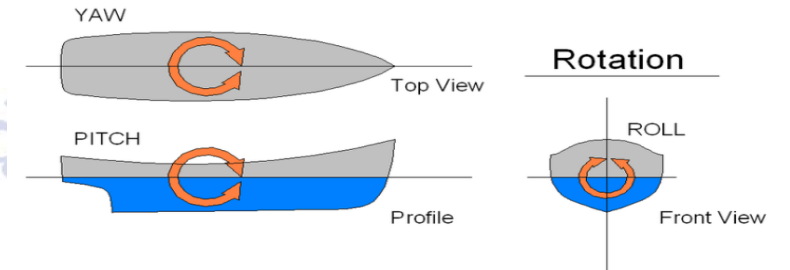


TARGET:

development of a system able to maintain the horizontal reference

APPLICATIONS:

radiation measurements on a mobile platform (ship, buoy), telemetry etc.



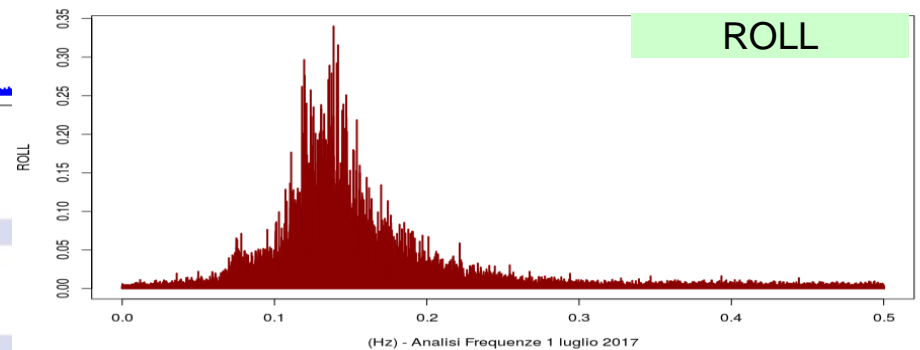
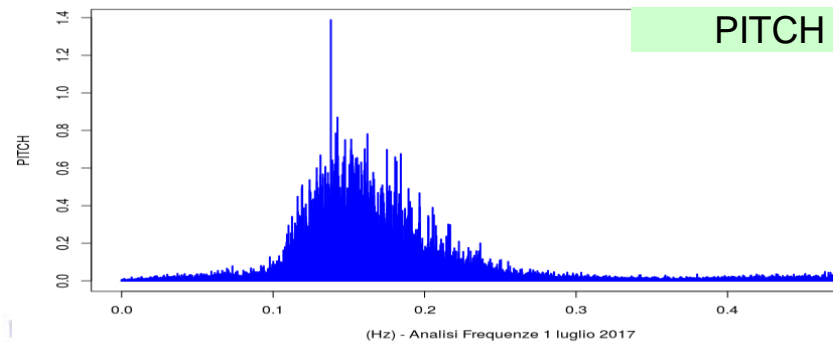
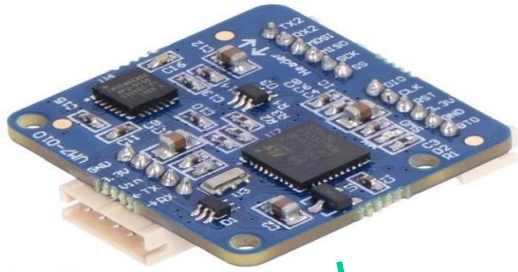
The Inertial measurement UNIT

Along each axis 3 sensors are oriented: 1 accelerometer, 1 gyroscope, 1 magnetometer. We use the signals of the first two only.

the accelerometers allow, by detecting the gravitational acceleration, to calculate the angles of roll and pitch.

The gyroscopes measure the angular velocity [degree / s], and processed able to remove acceleration component induced by translation movements on the axis.

The IMU unit is connected to the custom board CPU, and provides all the data necessary to the PID algorithm to calculate the movements along the axes (direction and speed).



Frequency distributions 1 July
2017

Quality Control: PPL, ERL



BSRN-Toolbox

[doi:10.1594/PANGAEA.901332](https://doi.org/10.1594/PANGAEA.901332)

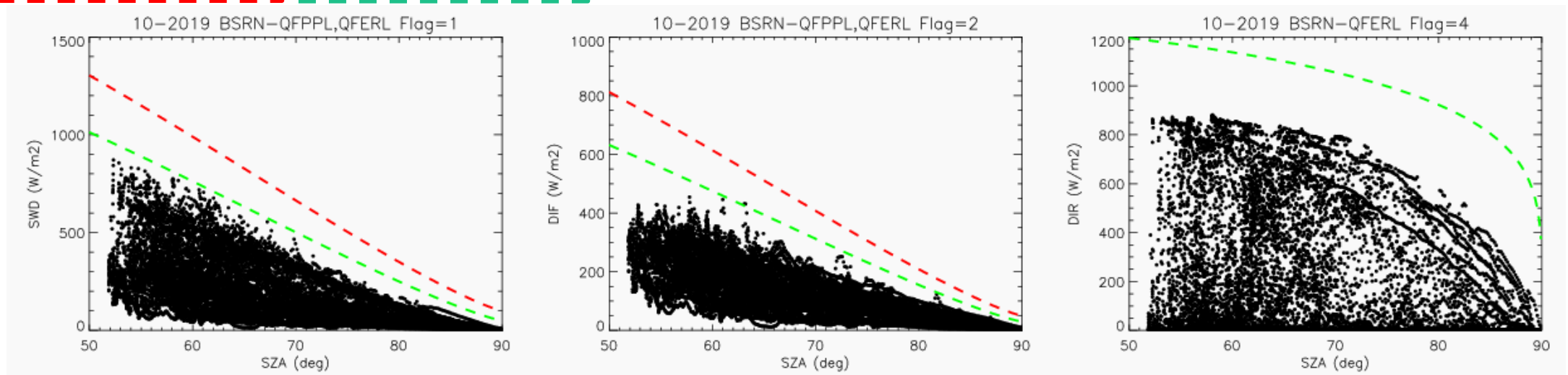
- Physically possible limits
- Extremely rare limits
- Across quantities

BSRN Global Network recommended QC tests, V2.0

C. N. Long and E. G. Dutton

Global SWdn
Min: -4 Wm^{-2}
Max: $S_a \times 1.5 \times \mu_0^{1.2} + 100 \text{ Wm}^{-2}$

Global SWdn
Min: -2 Wm^{-2}
Max: $S_a \times 1.2 \times \mu_0^{1.2} + 50 \text{ Wm}^{-2}$



https://bsrn.awi.de/fileadmin/user_upload/bsrn.awi.de/Publications/BSRN_recommended_QC_tests_V2.pdf

https://www.esrl.noaa.gov/gmd/grad/meetings/BSRN2018_documents/Tu4_BSRN_2018_Knap_updated_expanded.pdf