Estimating Solar Radiation at the Ground from Space (Clouds, Turbidity); Measuring it Directly at the Ground

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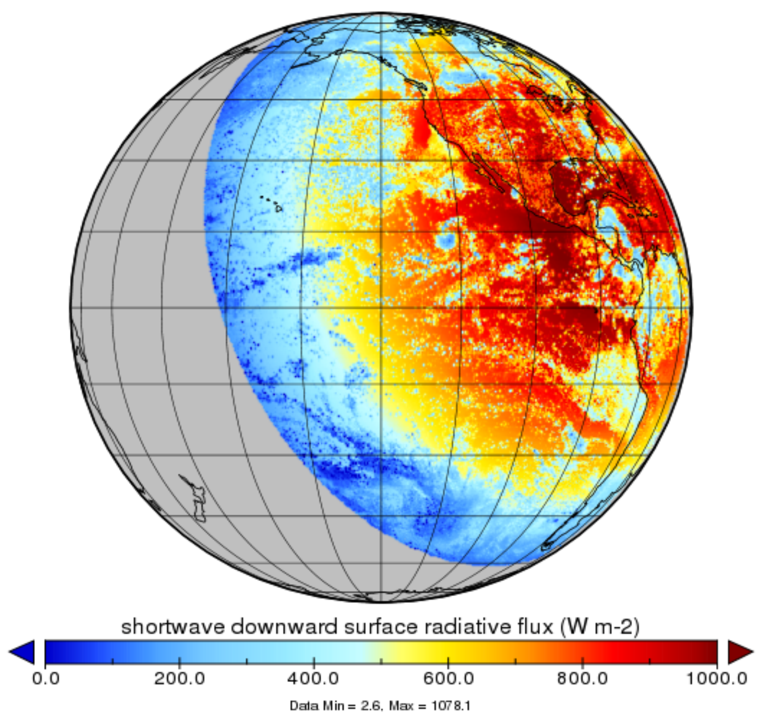


Why make Surface Radiation Measurements

- Surface Radiation is the primary energy source for weather and climate
- Weather and climate models need to get this fundamental energy input right
- We make satellite estimates of surface radiation to provide global coverage
- NWP and satellite programs need surface radiation observations for validation
- Lacking validation leads to more speculation and less sound predictions

Measuring shortwave radiation at the surface

1) Thermopile radiometers ($$$)

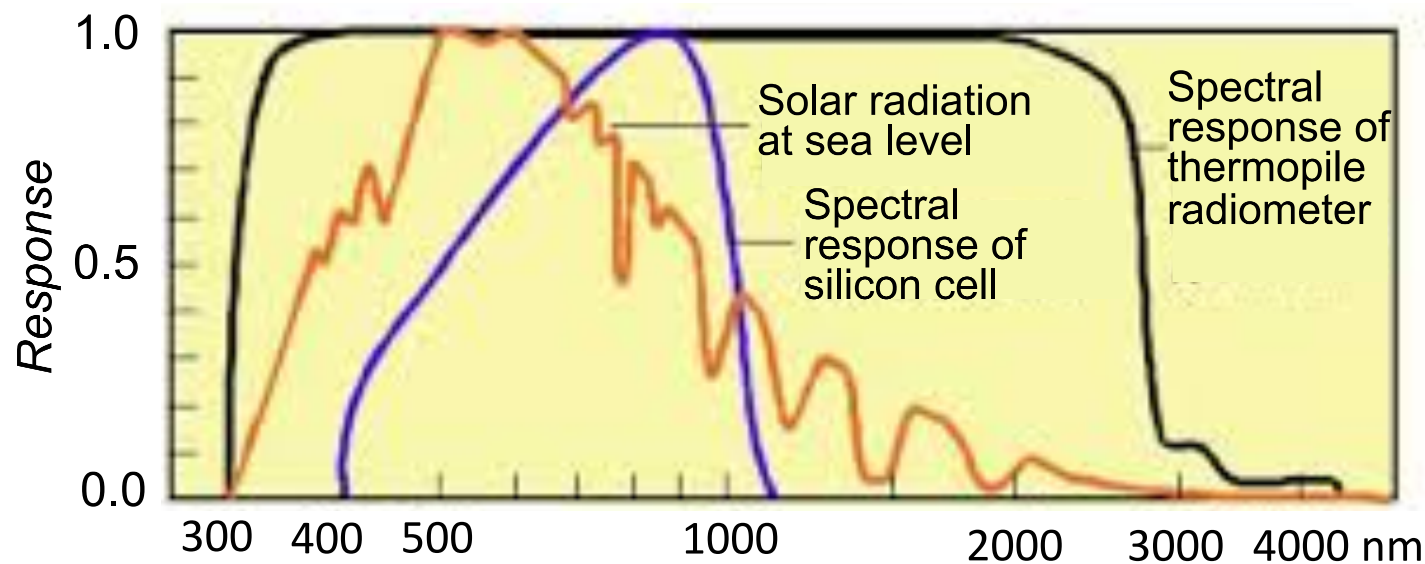
Pyrheliometer for solar beam measurements

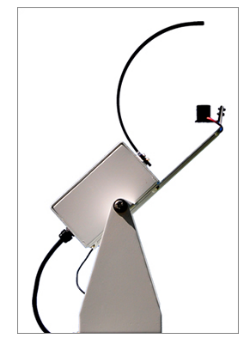
Pyranometer for total and diffuse solar

2) Silicon cell photodiode ($)

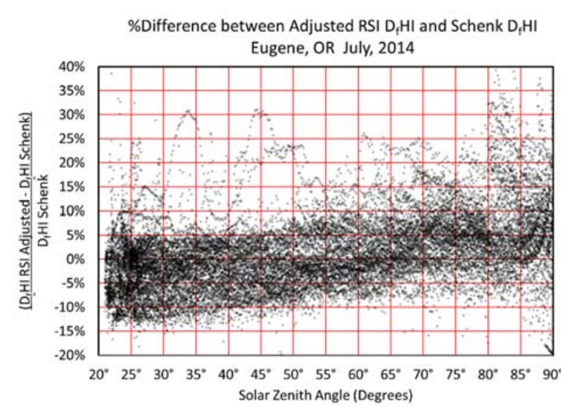
Only Cavity Radiometers ($$$$$) are capable of absolute measurements of solar radiation

Silicon cell and thermopile radiometers differ in spectral response



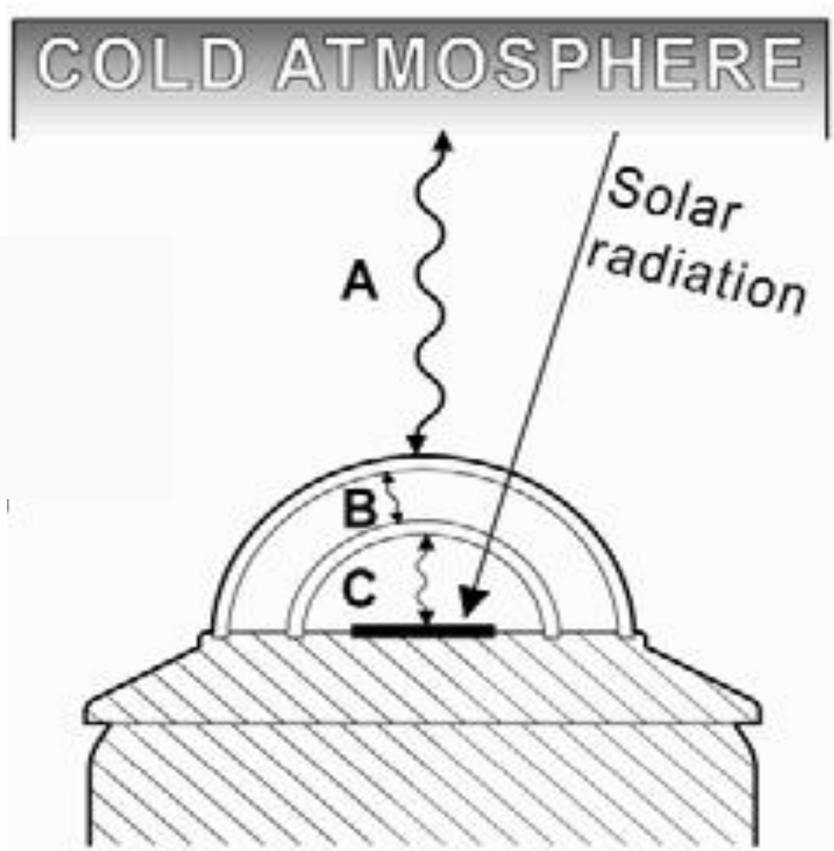


- Thermopile radiometers have full sensitivity across the entire solar spectrum
- Silicon cell sensitivity is not spectrally flat
- Silicon cell temperature sensitivity 6 times greater than that of thermopile radiometers
- Minimum sensitivity at blue wavelengths makes silicon cell <u>clear-sky</u> diffuse measurements highly uncertain. <u>Without proper adjustment ~30% lower than actual clear-sky diffuse</u>

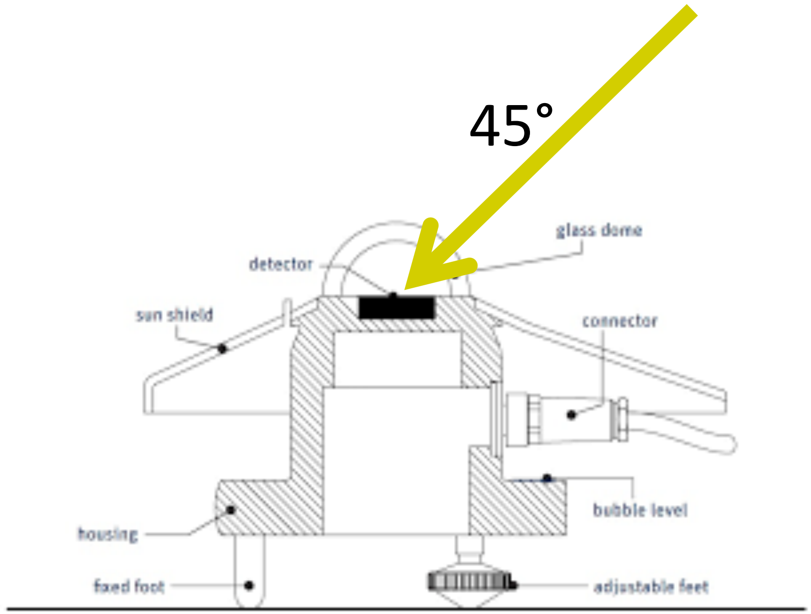


Thermopile pyranometers have issues

The solar signal is artificially depleted by thermal emission causing a negative offset in the reported irradiance



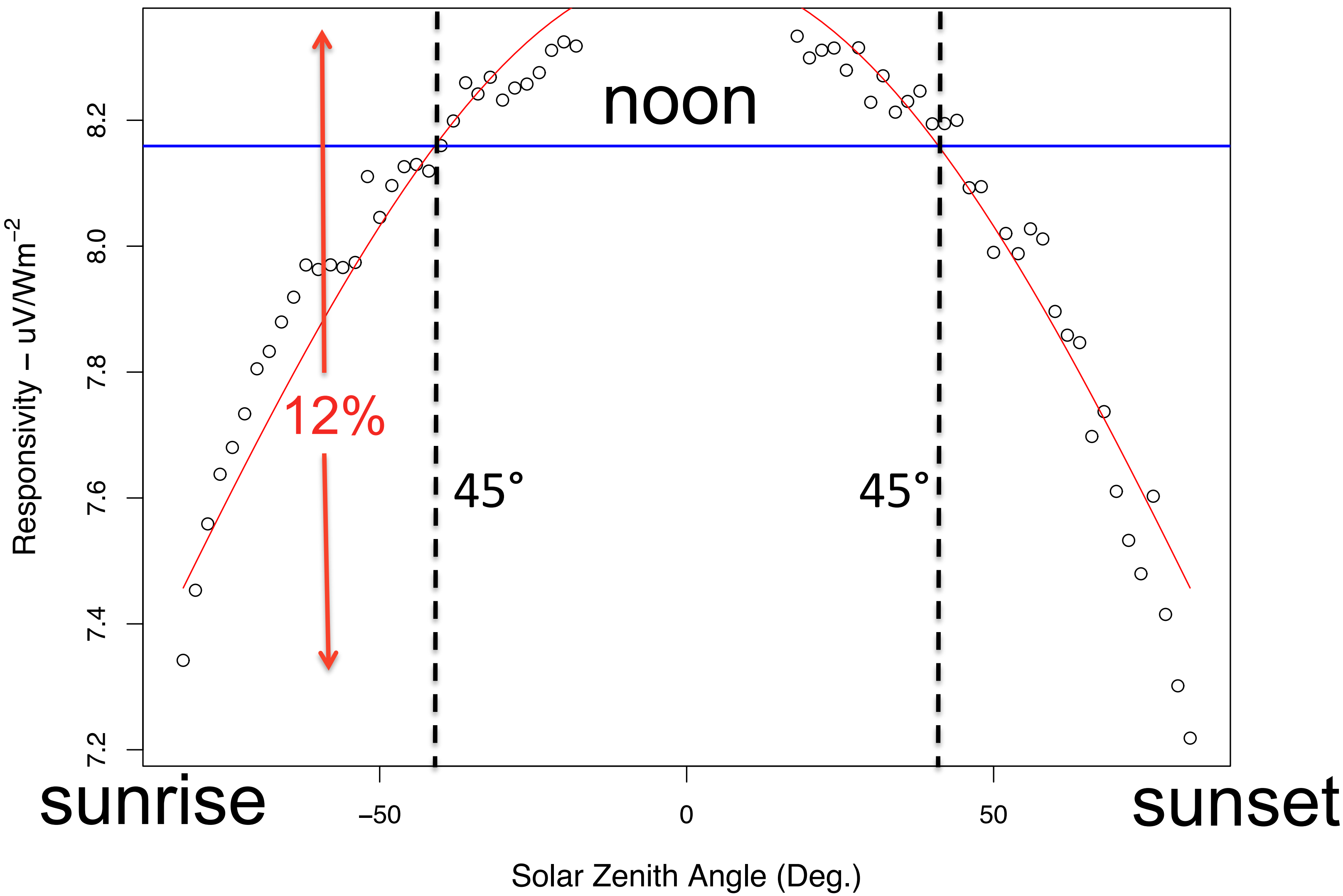
The calibration value is set at 45° solar elevation, but routinely applied all times of the day



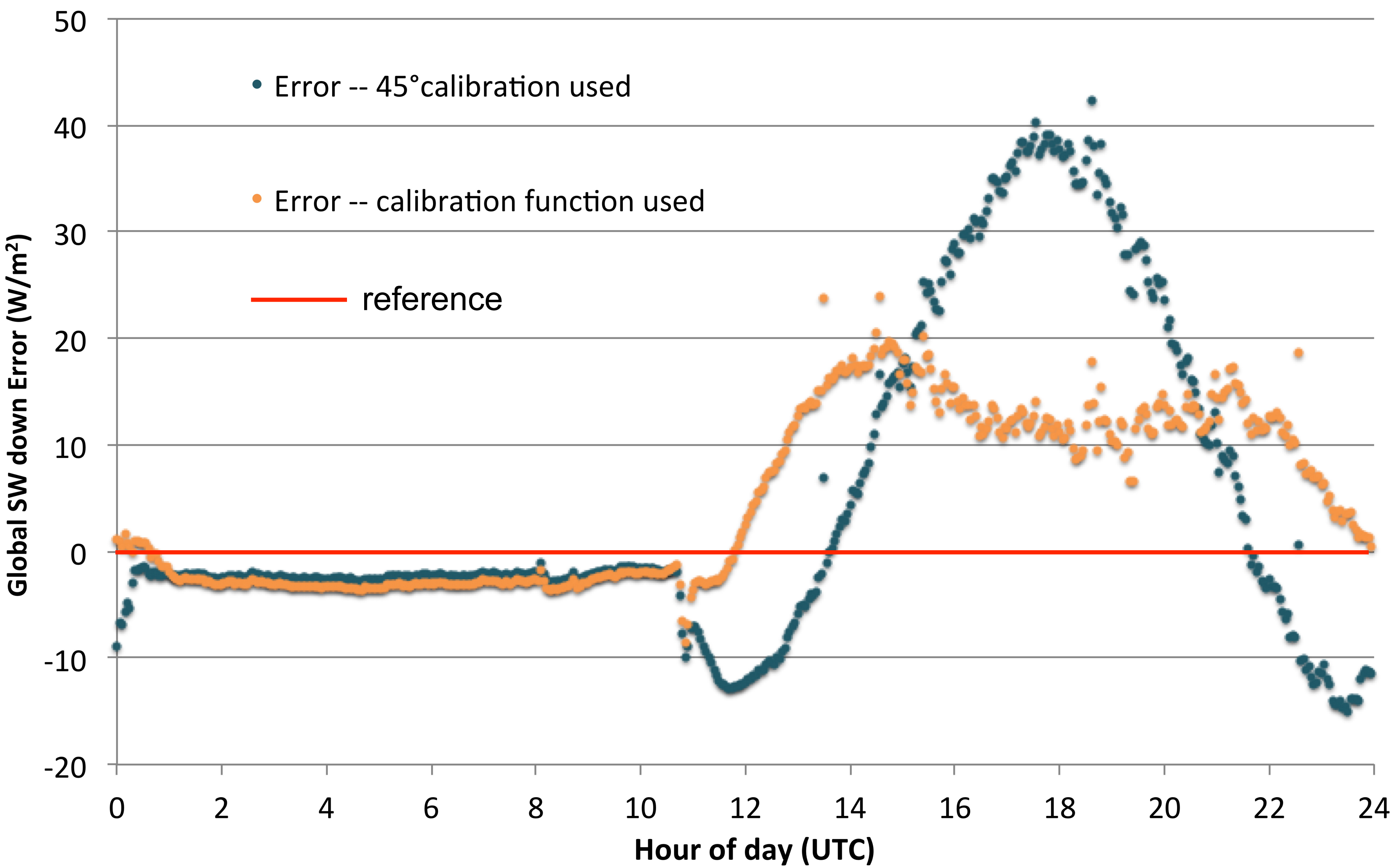
The 45° calibration value is valid for :

1) Overcast conditions
2) When the sun is blocked
3) Clear sky when the sun is at 45°

Pyranometer calibrations actually vary with solar zenith angle



Pyranometer errors associated with diurnal calibration variability and thermal offsets on a clear day



Temperature dependence

- Thermopile type solar radiometers vary <1% to 1.5% over 60°C range
- Silicon cell detectors vary by ~9% over 60°C range
- <u>The temperature dependence in thermopile radiometers is typically not accounted for in practice</u>.

Shortwave radiometer uncertainty

Radiometer	Measurement	Uncertainty*
Thermopile Pyrheliometer	Direct Normal	+/- 2%
Thermopile $Pyranometer_{TP}$	Global or Diffuse	+/- 5%
Silicon cell $Pyranometer_{PD}$	Global Diffuse	+/- 8% +/- 15%

*U_{95}

Source: D. Meyers, NREL (retired), ASA, CSSA, & SSSA International Annual Meeting Nov 2-5, 2014 Long Beach CA

Best practice for measuring total solar:

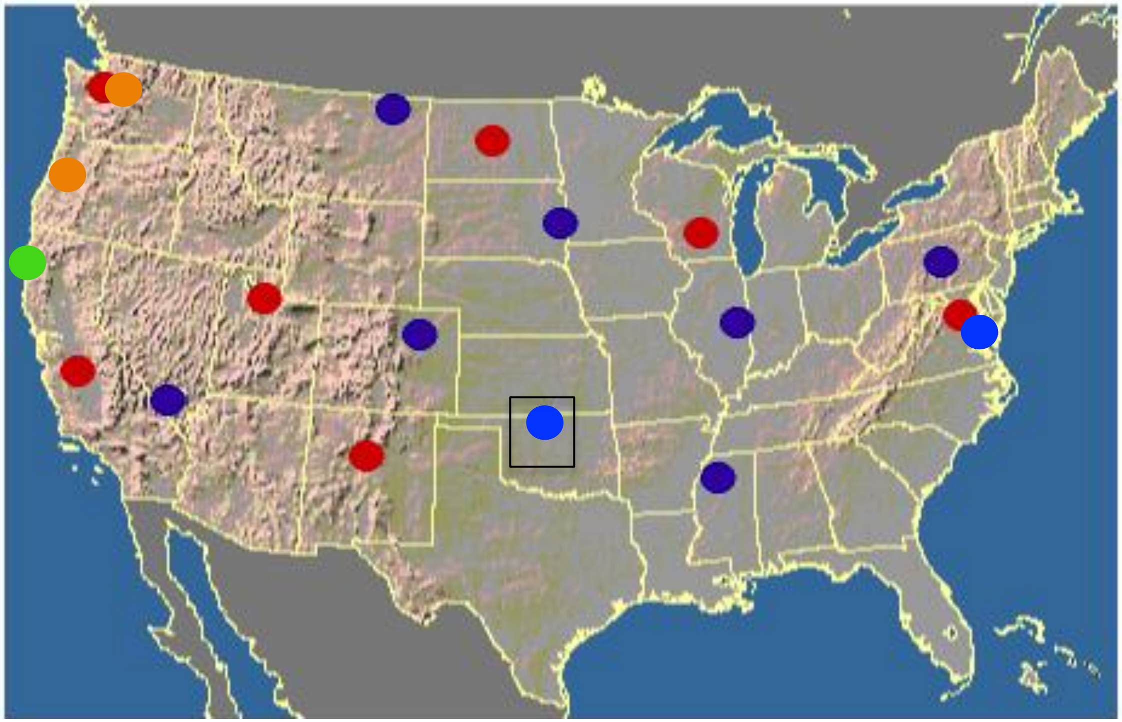
Sum <u>direct</u> and <u>diffuse</u> from <u>thermopile</u> radiometers

- Pyrheliometer (direct beam) measurements have <u>no thermal offset</u>

- <u>The 45° calibration value is appropriate</u> when shading a pyranometer for the diffuse measurement

- The pyranometer generally used for diffuse solar has little to <u>no thermal offset</u>

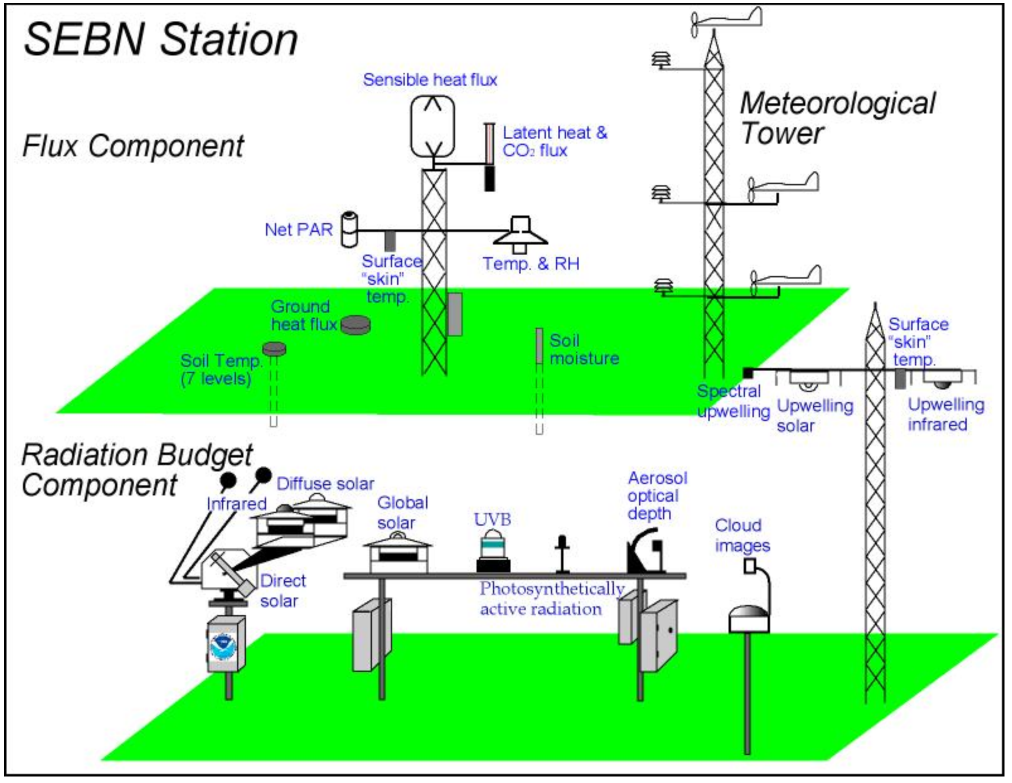
High-quality (direct and diffuse) solar measurements



There are thousands of other solar monitoring sites across the U.S. that use silicon cell sensors with their reduced accuracy

Greatest need: More high-quality solar radiation measurements to cover significant gaps in coverage: e.g., Texas, New England, Intermountain West, Southeast

What we really need is a national <u>Surface Energy Budget Network</u>

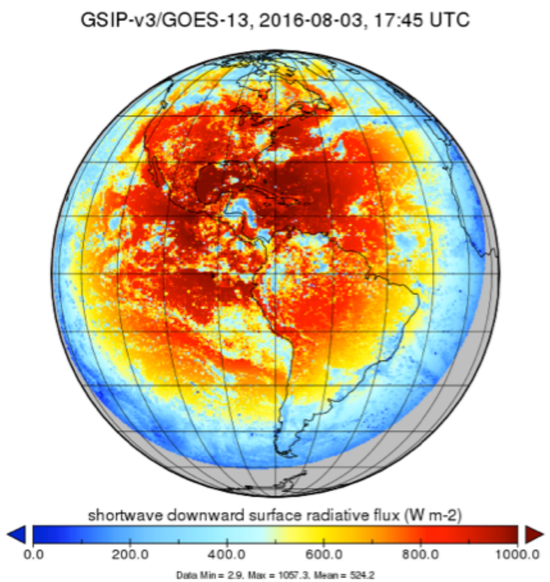


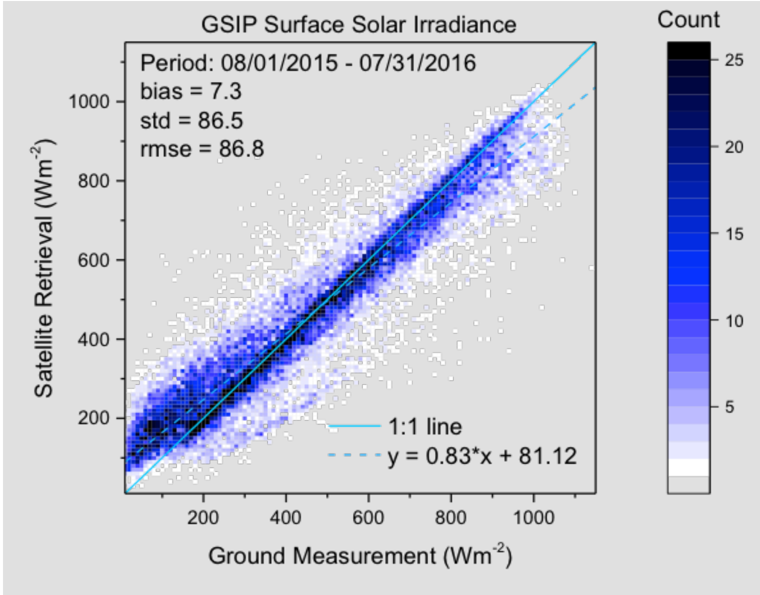
Weather and climate models ultimately need to accurately simulate the surface energy budget, and that also needs to be validated

Satellite estimates of surface solar irradiance

Currently NOAA has the "GOES Surface Insolation Product" (GSIP)

- Algorithm not empirical - Physics based
- Uses upwelling VIS, IR, GFS soundings as input to a radiative transfer model to derive surface solar
- 4 km, 1-hour resolution



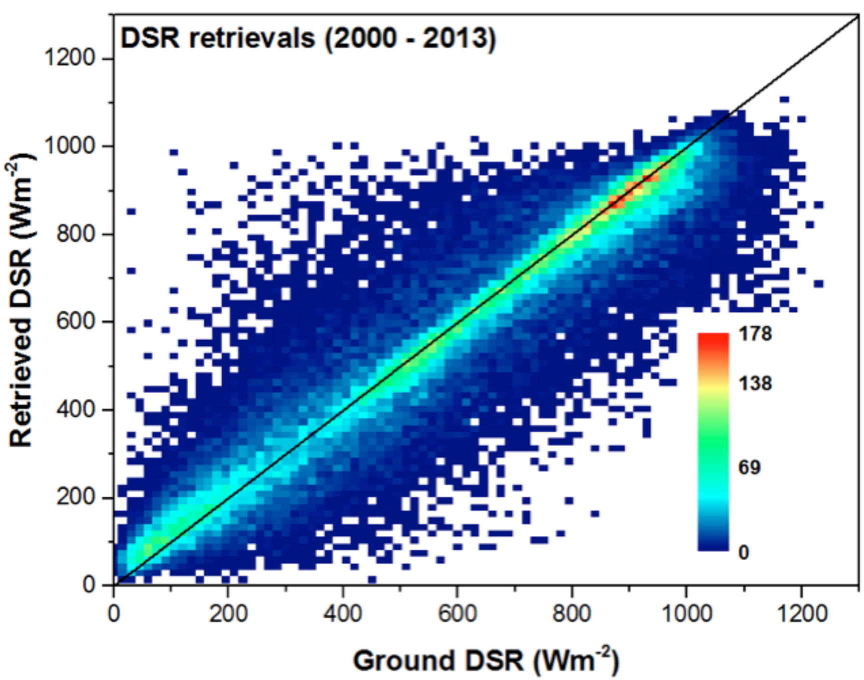


GSIP Shortcomings

- Overestimates surface shortwave for cloudy scenes
- Only one channel in the solar spectrum
- No onboard calibration—subject to drift
- Lower frequency sampling in southern hemisphere (3h)

The new GOES-R surface shortwave product should be much better

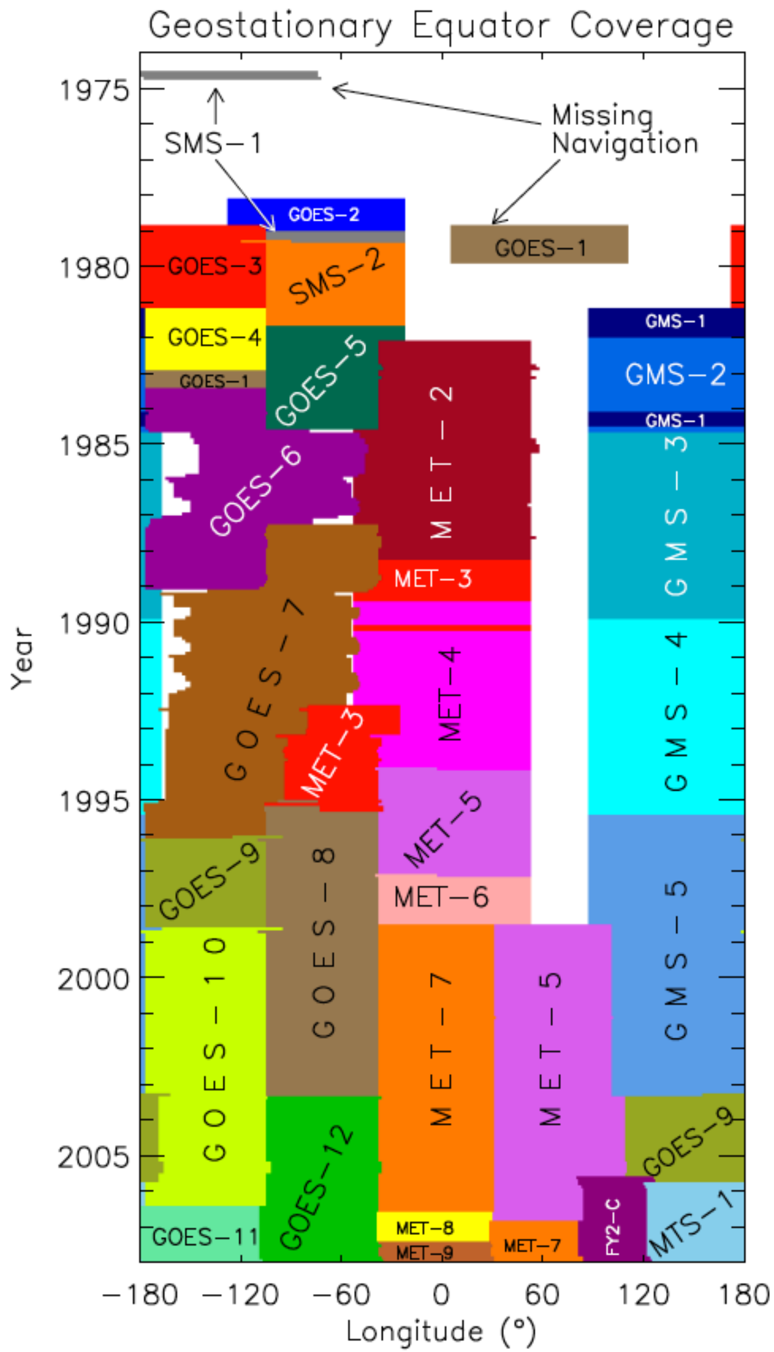
- The new Advanced Baseline Imager (ABI) has 6 shortwave channels– improves inference of surface and atmospheric properties
- Onboard calibration
- A more sophisticated surface shortwave algorithm than GSIP
- 4 km, 5-min. resolution over CONUS, 15-min full disk



GOES-R surface SW algorithm tested with10 years of MODIS data

Less bias in cloudy conditions

Shortcoming: Similar uncertainty as current GOES surface irradiance product



NASA GISS produces "ISCCP FD" surface SW

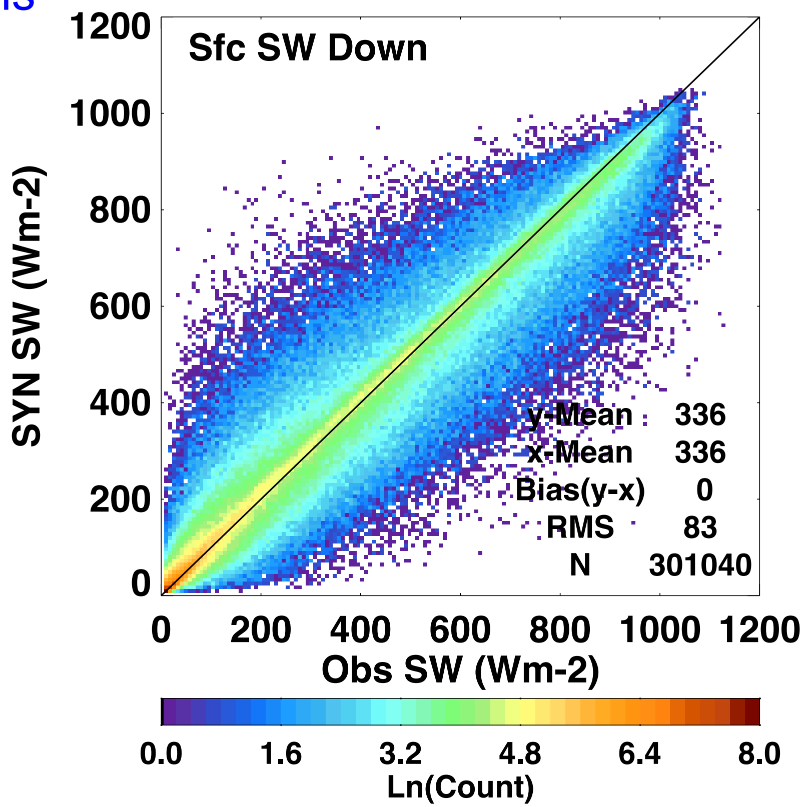
- Global coverage by Geostationary satellites combined through normalized calibration
- Supplemented by polar orbiter data at the poles
- Surface SW flux product from GISS GCM RT model, TOVS soundings, 3-hr, 280 km res
- Similar uncertainties as GSIP

From Knapp, K., (2008) J. Appl. Remote Sensing

NASA estimates surface SW from polar orbiting satellites

CERES SYN 1-deg surface irradiance 3 hr.,1 deg. res.

- Uses MODIS and MATCH for cloud and aerosol information
- Gridded surface albedo and ozone
- Reanalysis atmospheric soundings
- Uses 3-hour cloud information from GOES to better account for diurnal cloud variations

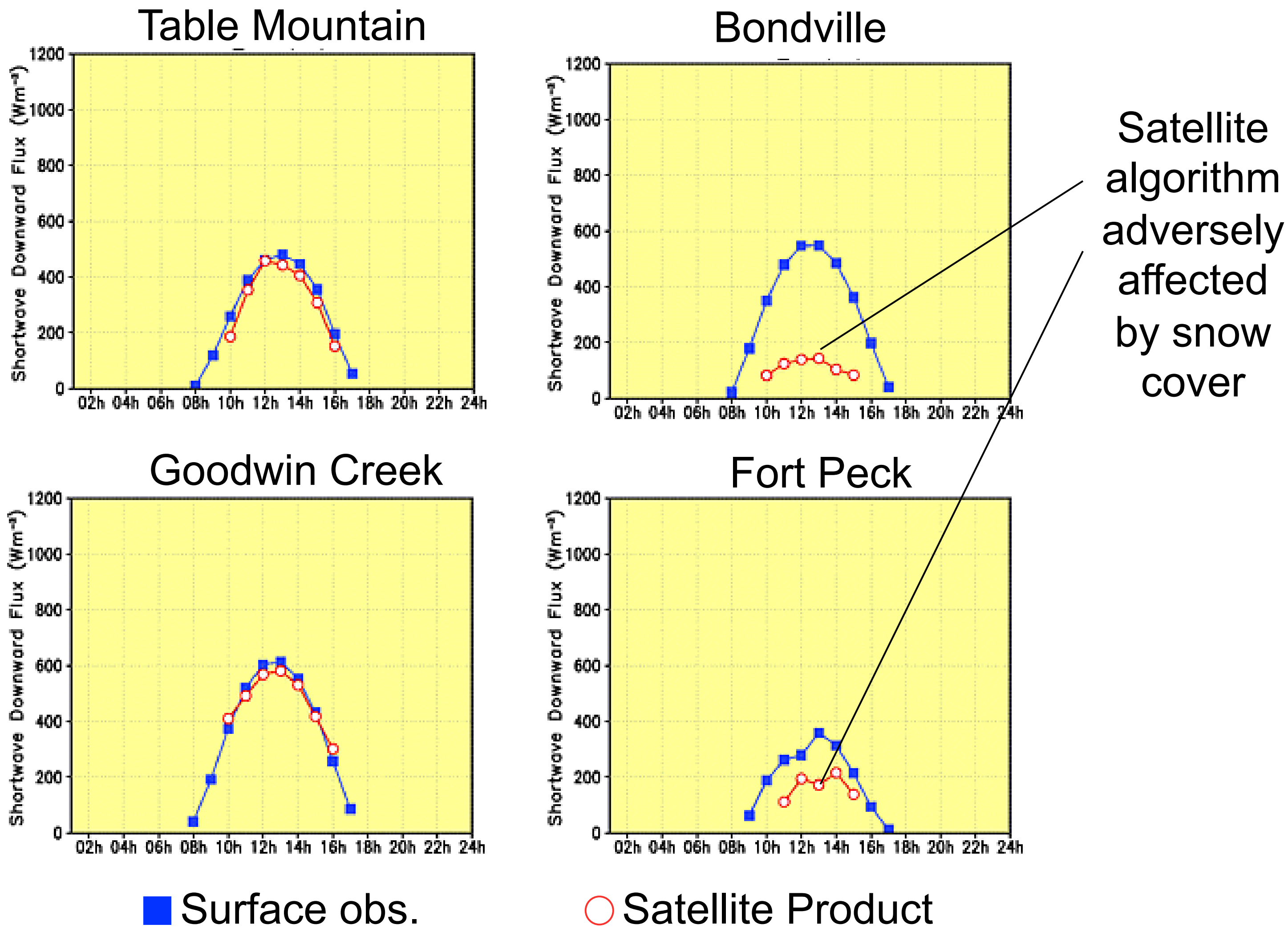


From Rutan et al., 2015, J. Atmos. and Oceanic Tech.

Monthly averages are least uncertain for all satellite surface SW estimates

All satellite surface shortwave algorithms have problems over snow-covered surfaces

Clear sky conditions, 17 Jan. 2003



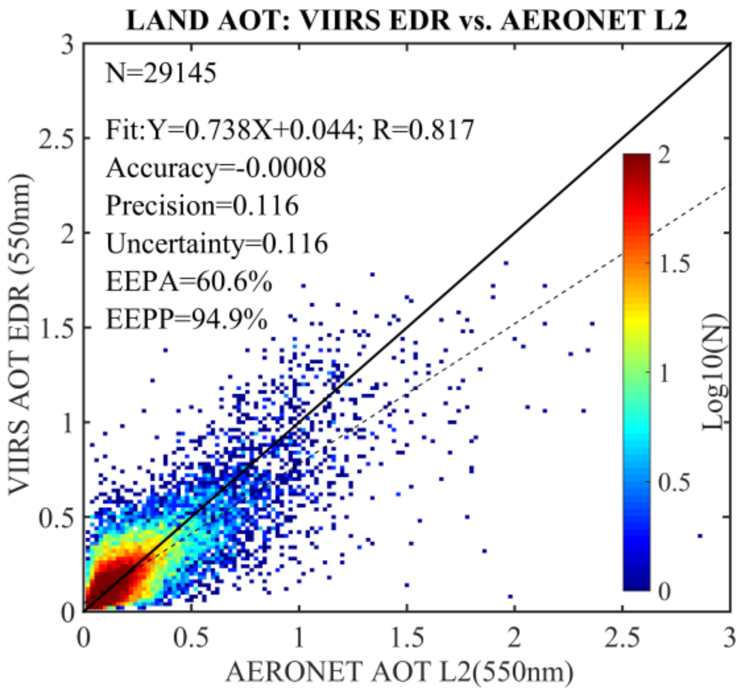
There is potential for improvement with the new multi-spectral GOES ABI

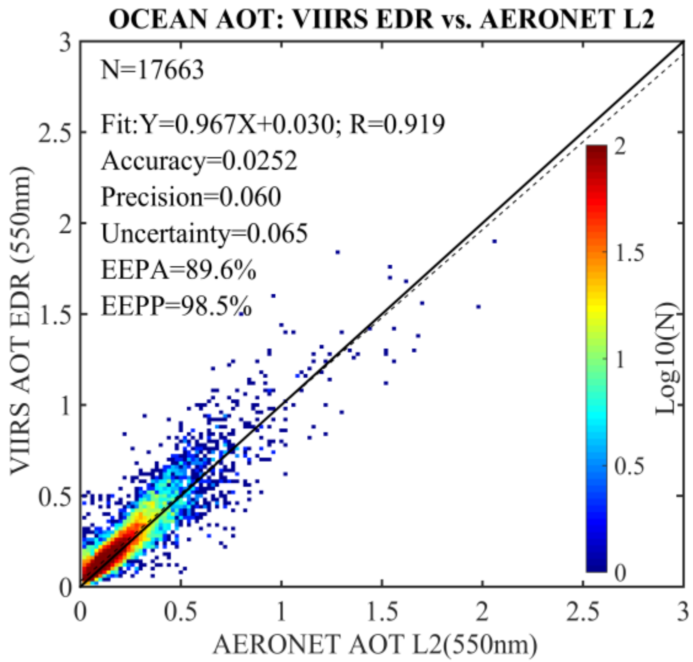
Satellite Aerosol Optical Depth (AOD) products

- 1970s, AOD retrieved only over oceans from NOAA polar orbiters
- Early 2000s, MODIS and NOAA added AOD capability over dark land surfaces
- In 2008 NASA introduced the "Deep Blue" algorithm for MODIS AOD over bright land surfaces (not snow)
- In 2015 "Deep Blue" improved and expanded coverage poleward to all snow-free areas.

Satellite Aerosol Optical Depth

Generally more uncertain over land than over the oceans





MODIS AOD shows similar land vs. ocean uncertainties

Satellite AOD availability and uncertainties

Currently…

Satellite	channels	land uncertainty	ocean uncertainty	Temporal res.	Spatial res.
GOES	550 nm	30%	~.09	30 min.	4 km
AVHRR	550 nm	------	.05	2/day	1 & 4 km
S-NPP (VIIRS, No deep blue, upper AOD limit 2.0)	550 nm	.12	.06	1/day	0.25°
MODIS 6 (with deep blue)	multi. λ	.05	.04	2/day	3 & 10 km

Coming…

Satellite	channels	land uncertainty	ocean uncertainty	Temporal res.	Spatial res.
GOES R	multi. λ	.03	.02	5 min.	2 km
JPSS (deep blue)	multi. λ	.03/.19	.02/.03	1/day	0.75 & 6 km

[<.3 AOD/>.3 AOD] (upper AOD limit increased to 5.0)

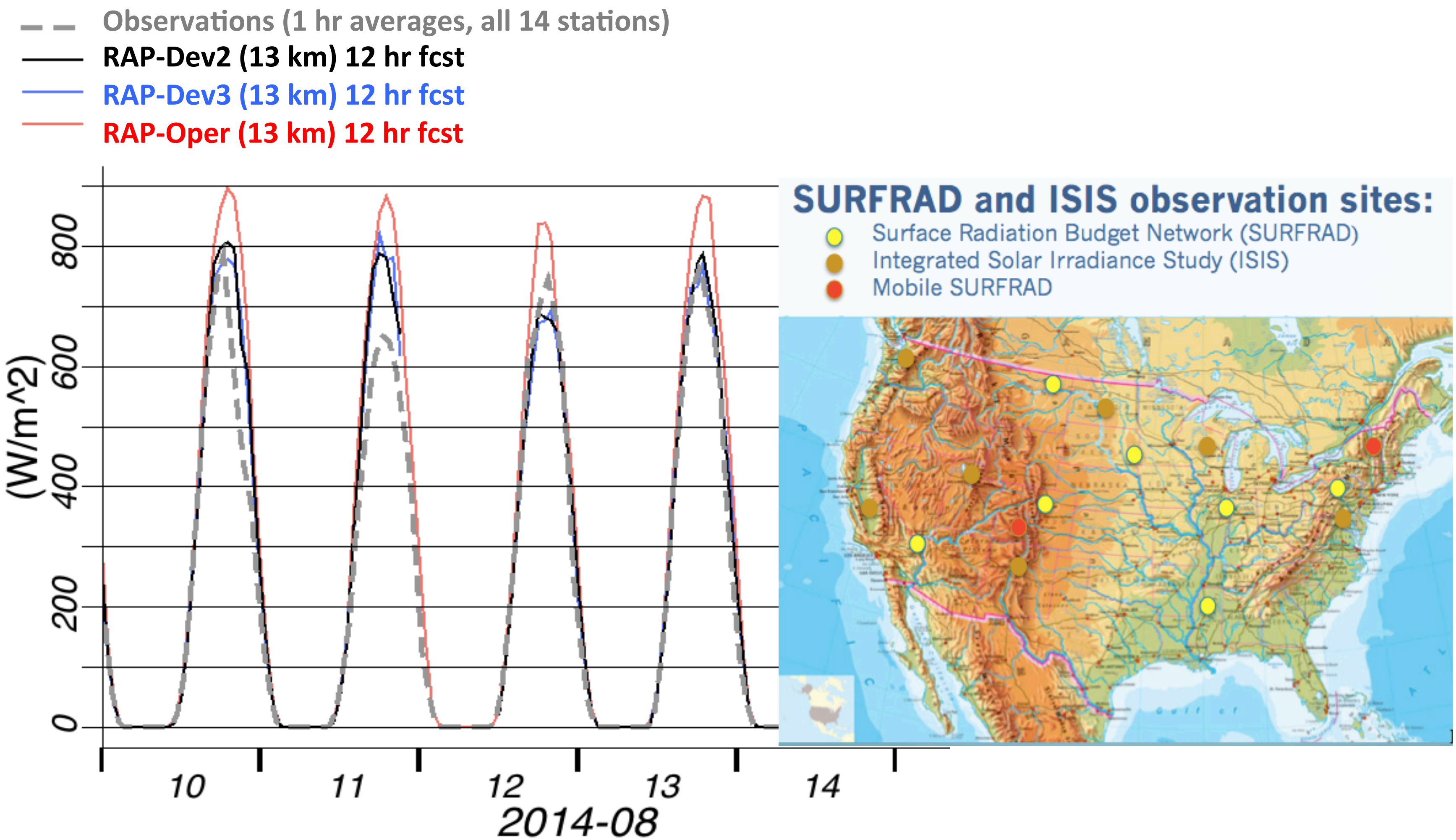
For comparison: Surface AOD measurement uncertainties are better at ±.003 to ± .01

Shortcoming: Satellite AOD not yet possible over snow and ice

Radiation measurements and NWP

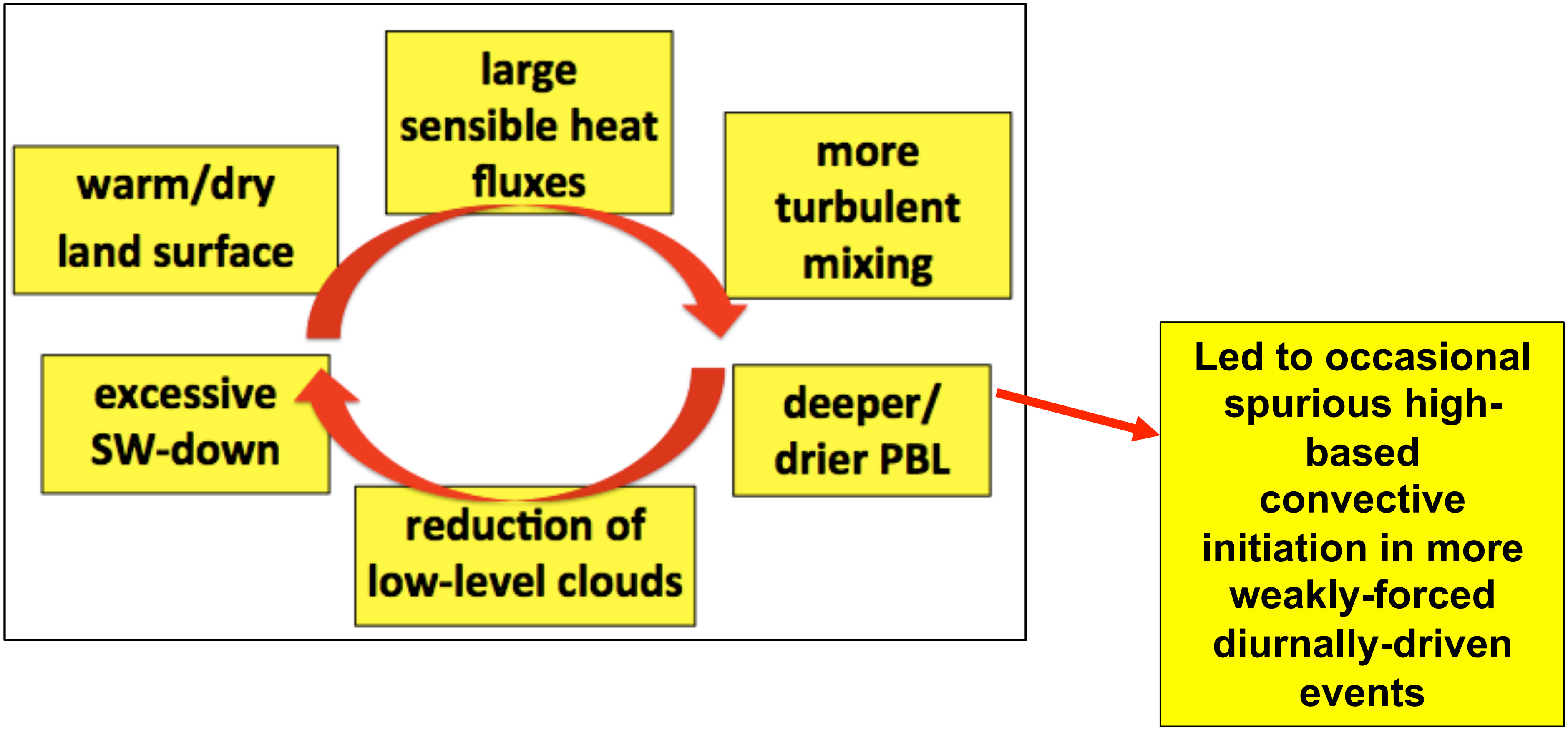
- Radiation observations are not assimilated into NWP models
- But, surface radiation measurements have been instrumental in diagnosing the primary cause of the +3°C surface air temperature bias in NCEP's operational RAP model

The current operational RAP model (red curve) shows a ~200 Wm^{-2} positive bias over the U.S. ground observations (dashed curve)



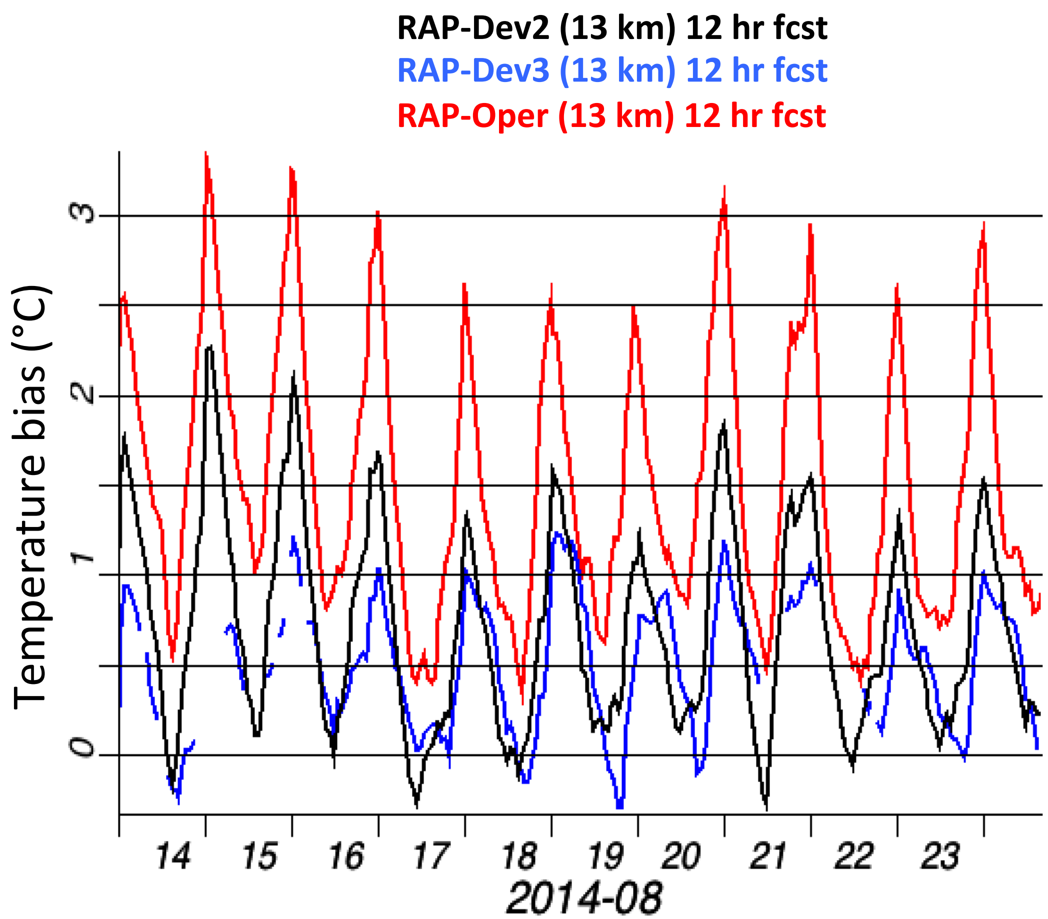
Error feedback loop in RAP model found to be caused by excessive model-computed SW down

Conceptual Model of Positive Feedback Model Bias



from 16th WRF Workshop, C. Alexander, 2015

Resultant model improvements reduced the temperature bias by 70%



Oper: does not include subgrid clouds or LSM modification (WRFv3.4.1)

Dev2: has improved subgrid-scale clouds and sh/cu scheme (WRFv3.5.1)

Dev3: Dev2 enhancements + LSM wilting point modifications (WRFv3.6)

Greatest needs regarding surface and satellite radiation observations

- More high-quality surface direct and diffuse solar measurements to fill geographic holes in coverage
- More high-quality surface radiation budget measurements
- A U.S. Surface Energy Budget Network (SEBN)
- Satellite shortwave radiation and AOD retrieval capability over ice and snow