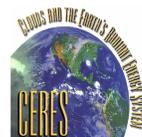




NASA's Clouds & The Earth's Radiant Energy System (CERES) Synoptic (SYN1deg) Data Product

Validation Using Buoys & Ship Borne Radiometers

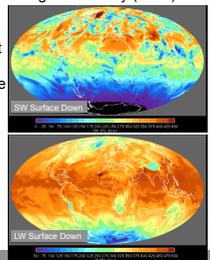
David Rutan¹, David Doelling², Fred Rose¹ and Seiji Kato²



CERES Synoptic (SYN1Deg) Data Product

The CERES SYN1deg product provides climate quality globally gridded and temporally complete maps of top of atmosphere, in atmosphere, and surface irradiance. Irradiances are computed hourly using a radiative transfer code based on inputs from Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) as well as geostationary (GEO) imager derived cloud properties and atmospheric profiles from the GMAO GEOS4 & GEOS 5 re-analyses. GEO visible and infrared imager calibration is tied to the Aqua MODIS instrument to ensure uniform MODIS-like cloud properties across satellite boundaries. These data are the initial source of TOA and surface irradiance then used for the derivation of the CERES Energy Balanced and Filled (EBAF) data product.

CERES Product	Spatial Resolution	Temporal Resolution	Vertical Resolution	Available
SYN1deg	Global	3(1)-hour, Daily	5 levels (hPa)	Mar 2000
Edition 3(4)	1°x1°	Monthly Mean	TOA, surface, 500, 200, 70	Thru Feb 2016



SYN1Deg Validation Page:
<https://ceres-tool.larc.nasa.gov/cave/jsp/CAVESelection.jsp>
 Information on Surface Sites Used & SYN1deg radiative transfer:
<http://www.cave.larc.nasa.gov>

Buoy and Ship Comparisons to SYN1deg Ed3

Longwave Irradiance	Observed Monthly Mean Wm ⁻²	Monthly Mean Bias Wm ⁻² (%)	RMS Wm ⁻² (%)		
			Hour	Day	Month
TAO Array	410	-4 (1.0)	16 (3.9)	3 (0.7)	7 (1.7)
PIRATA Array	406	-5 (1.2)	14 (3.4)	2 (0.5)	8 (2.0)
RAMA Array	420	-5 (1.2)	11 (2.6)	2 (0.5)	6 (1.4)
WHOI buoys	391	-2 (0.5)	16 (4.1)	8 (2.1)	5 (1.3)
KEO & PAPA**	355	-5 (1.4)	18 (5.1)	9 (2.5)	7 (2.0)
MAGIC Cruise	372	1 (0.3)	18 (4.8)	-----	-----
STRATUS Cruises	381	5 (1.3)	16 (4.2)	-----	-----
EPIC Cruises	408	-8 (2.0)	16 (3.9)	-----	-----

Shortwave Irradiance	Observed Monthly Mean Wm ⁻²	Monthly Mean Bias Wm ⁻² (%)	RMS Wm ⁻² (%)		
			Hour	Day	Month
TAO Array	461 [246]*	5 (1.1) [3 (1.2)]	108 (23.4)	18 (3.9)	[10 (4.1)]
PIRATA Array	437 [233]	12 (2.7) [6 (2.6)]	98 (22.4)	17 (3.9)	[15 (6.4)]
RAMA Array	407 [226]	7 (1.7) [5 (2.2)]	108 (26.5)	15 (3.7)	[11 (4.9)]
WHOI buoys	431 [228]	9 (2.1) [5 (2.2)]	93 (21.6)	25 (5.8)	[8 (3.5)]
KEO & PAPA**	266 [141]	-2 (0.8) [-1 (0.7)]	75 (28.2)	14 (5.6)	[7 (5.0)]
MAGIC Cruise	412	14 (3.4)	82 (19.9)	-----	-----
STRATUS Cruises	384	6 (1.6)	83 (21.6)	-----	-----
EPIC Cruises	445	9 (2.0)	99 (22.2)	-----	-----

* Brackets [] indicate SW statistics that include 0 at night for a true monthly mean. Non-bracketed numbers indicate daytime only statistics.
 ** KEO buoy located at 32.37N, 144.57E; PAPA buoy located at 50.11N, -144.84W

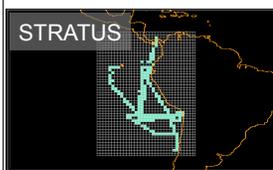
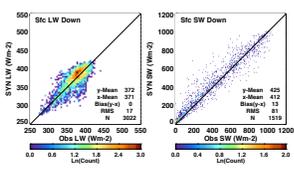
Monthly Mean Accuracy Wm ⁻²	SYN1deg ^a	Ocean Observation ^b	Aggregate
Longwave	12	4	12.6
Shortwave	9	6	10.8

^a Kato et al. 2013: *Uncertainty Estimate of Surface Irradiances Computed with MODIS, CALIPSO, and CloudSat-Derived Cloud and Aerosol Properties*, Surv. Geophys. DOI: 10.1007/s10712-012-9179-x
^b Colbo and Weller, 2009: *Accuracy of the IMET Sensor Package in the Subtropics*, J. Atmos. And Ocean. Tech., DOI: 10.1175/2009JTECH0667.1

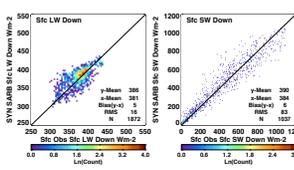
Ship Campaigns



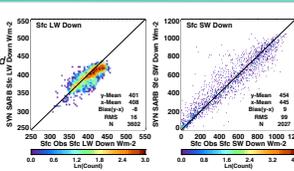
MAGIC
 Marine ARM GPCI Investigation of Clouds
 ARM Mobile Facility 2 was deployed on the Horizon Lines cargo ship *Spartan* on the route between Los Angeles and Honolulu for one full year.
 Oct 2012 through Sep 2013.
<http://www.arm.gov/campaigns/amf2012MAGIC>



STRATUS
 A synthesized dataset of in situ and remote sensing observations from research ships deployed to the southeastern tropical Pacific stratocumulus region across 7 years in boreal fall.
<http://www.esf.noaa.gov/psd/psd3/synthesis/>

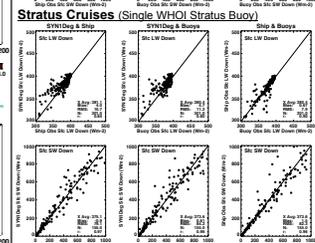
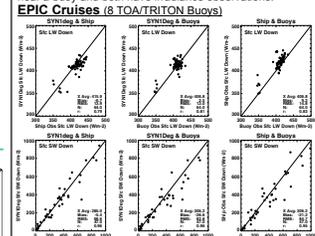


EPIC
 East Pacific Investigation of Climate
 Twice-yearly maintenance cruises along the 95W and 110W TAO buoy lines included ship-based cloud and flux observations on board NOAA Ships *Ka'imimoana* and *Ronald H. Brown*.
 Apr 2000 through Nov 2004 (boreal fall and spring)
<http://ftp.etl.noaa.gov/BLO/Air-Sea/EPIC/epicmonitor/>
 Fairall et al. 2008: *Observations of Cloud, Radiation, and Surface Forcing in the Equatorial Eastern Pacific*, J. Clim. DOI: 10.1175/2007JCLI1757.1



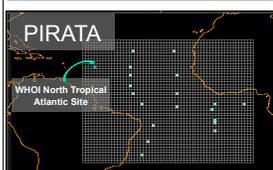
Accuracy

Assessing the accuracy of radiometry on buoys is difficult. Below we collect hours when the service ship is moored near a buoy and both have irradiance observations.

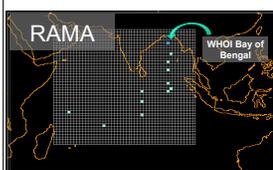
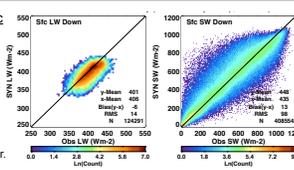


WHOI Multi Instrument Comparisons
 The Woods Hole group deploys two radiation instrument packages on each buoy. These data are released early then filtered for quality in their final version. A comparison of the two instrument sets provides insight into instrument degradation over time thus supplying an estimate of accuracy for buoys, most of which, only have one LW and SW instrument.

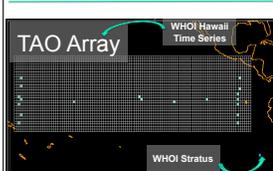
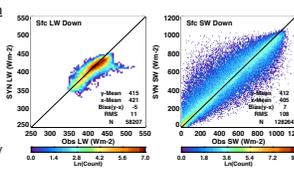
Buoy Arrays



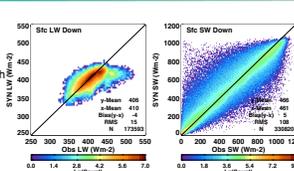
PIRATA
 Pilot Research Moored Array in the Tropical Atlantic
 PIRATA is a multinational observation network by Brazil, France, and the US to improve our understanding of ocean atmosphere variability in the tropical Atlantic Ocean. Various buoys span Jan 2000 through Apr 2015. Data are distributed from NOAA/PMEL at:
http://www.pmel.noaa.gov/tao/data_deliv/frames/main.html
 Bourles, B., et al., 2008: "The PIRATA Program: History, Accomplishments, and Future Directions", Bull. Amer. Meteor. Soc., 89, 1111-1125.



RAMA
 Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction
 RAMA is a multinational observation network by India, Indonesia, France, Japan, the ASCMIE and the US to improve our understanding of ocean atmosphere variability in the Indian Ocean. Various buoys span Nov 2004 through Aug 2014. Data are distributed from NOAA/PMEL at:
http://www.pmel.noaa.gov/tao/data_deliv/frames/main.html
 McPhaden, et al. 2009: "RAMA: The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction", Bull. Am. Meteor. Soc., 90, 459-480.



TAO Array
 Tropical Atmosphere/Ocean Array
 TAO/TRITON consists of approximately 70 moorings in the tropical Pacific Ocean. Various buoys span Apr 2000 through Oct 2013. Data are distributed from NOAA/PMEL at:
http://www.pmel.noaa.gov/tao/data_deliv/frames/main.html
 Fairall et al. 2008: *Observations of Cloud, Radiation, and Surface Forcing in the Equatorial Eastern Pacific*, J. Clim. DOI: 10.1175/2007JCLI1757.1



Acknowledgements

MAGIC data are made available from U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program.
 East Pacific STRATUS cruise synthesis data set was developed by Dr. Simon de Zoeko, College of Oceanic and Atmospheric Science, Oregon State University.
 ETL-10 cruise PACS/EPIC dataset, Release #2.0 Provided by C. Fairall, D. Wolfe, S. Pezsa, J. Hare, A. Grachev, L. Barbeau, and D. Welsh and NOAA/ Environmental Technology Lab (ETL).
 STRATUS, WHOTS, NTAS & Bay of Bengal Ocean Reference Station data made available by Dr. R. Weller (Woods Hole Oceanographic Institution) with support from the Pan American Climate Study and Climate Observation Programs of the Office of Global Programs, NOAA Office of Oceanic and Atmospheric Research.
 TAO, RAMA, EPIC, KEO & PAPA buoy observations are made available by the TAO Project Office of NOAA/Pacific Marine Environmental Lab (PMEL).
 CERES SYN1deg made available from the NASA Langley Research Center Atmospheric Sciences Data Center.
 SURFRAD data are made available through NOAA's Air Resources Laboratory/ Surface Radiation Research Branch.