# Global Monitoring Division

## Theme 2 Networks: Monitoring and Understanding Changes in Surface Radiation, Clouds and Aerosol Distributions

## 2013-2017 Review

### May 21-24, 2018

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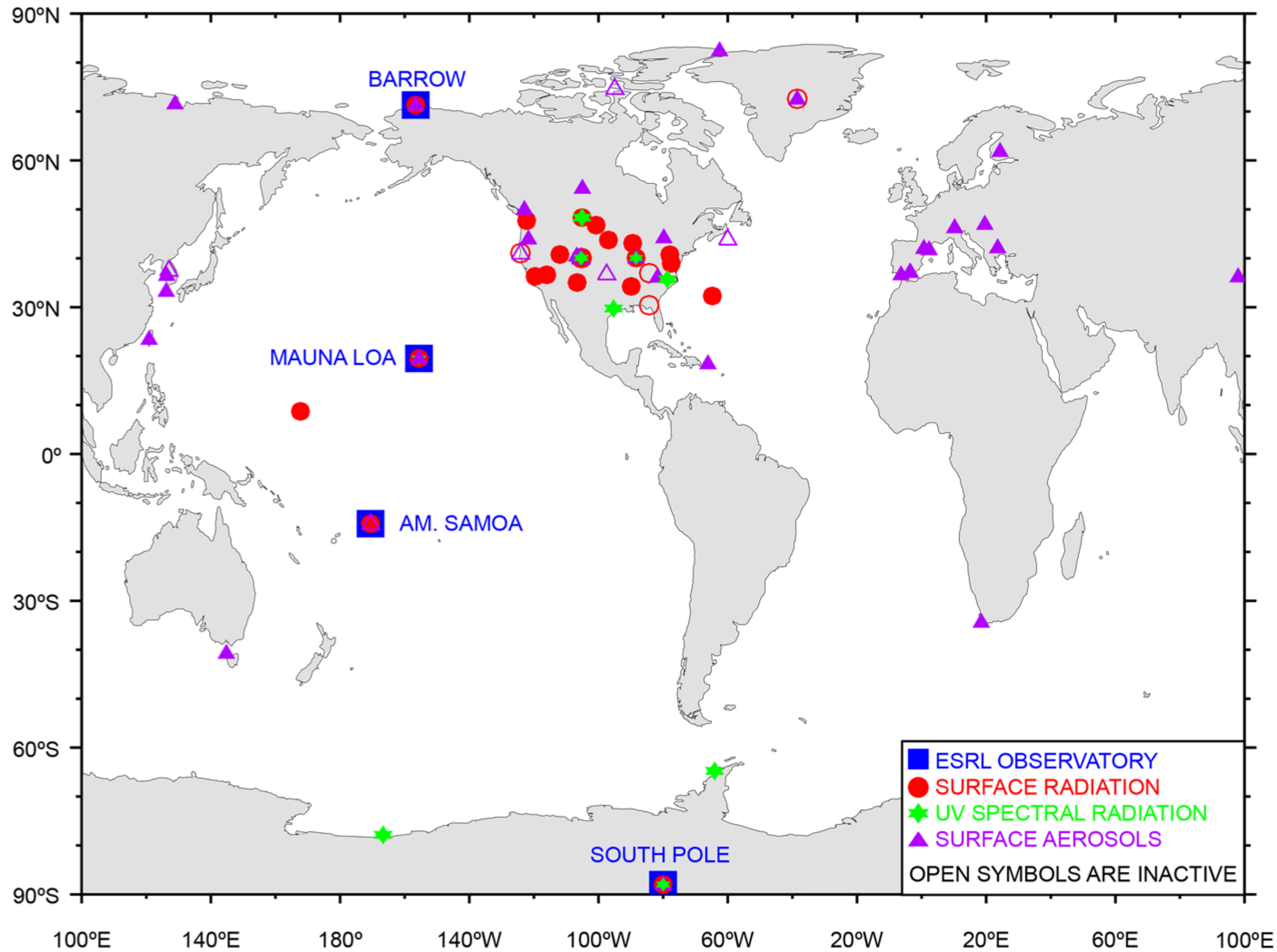
## Monitoring and Understanding Changes in Surface Radiation, Clouds, and Aerosol Distributions



# Theme 2, Part 1: GMD Radiation Networks (G-RAD)

***"Without SURFRAD, we would rely on satellites alone for radiation data over the U.S.; this would mean more supposition and speculation, and less sound analysis and prediction."*** *Dr. Bruce Wielicki, first NASA Clouds and the Earth's Radiant Energy System (CERES) satellite program science team leader.*

## Why make solar radiation measurements?

The Sun's radiant energy at the earth's surface encompasses the short wavelengths in the UV (ultraviolet), visible, and near infrared. The earth's surface, clouds, and atmosphere emit radiation at long (thermal infrared) wavelengths. The difference between incoming and outgoing shortwave and longwave at the surface, the surface radiation budget (SRB), represents the available energy for atmospheric sensible and latent heat fluxes.

- **The SRB is the major source of energy that drives weather and climate.**
- **Spatial variation in the SRB causes weather.**
- **Systematic changes in the SRB affect climate.**

**Thus, to succeed, weather and climate models must simulate the SRB well.**

- **G-RAD provides the valuable, high quality SRB and ancillary observations required for better understanding of variability in the SRB and the controls on that variability.**
- **UV measurements are needed for health research and to understand impacts of the changing ozone layer, in Antarctica and also at the more populated mid-latitudes.**

The surface radiation measurements made at G-RAD sites are used to retrieve information on cloud and aerosols, the primary atmospheric components that modulate the surface radiation budget (SRB). Monitoring these components permits improve understanding of the processes that drive changes in the SRB, processes that arise from both natural and anthropogenic perturbations to the Earth system.

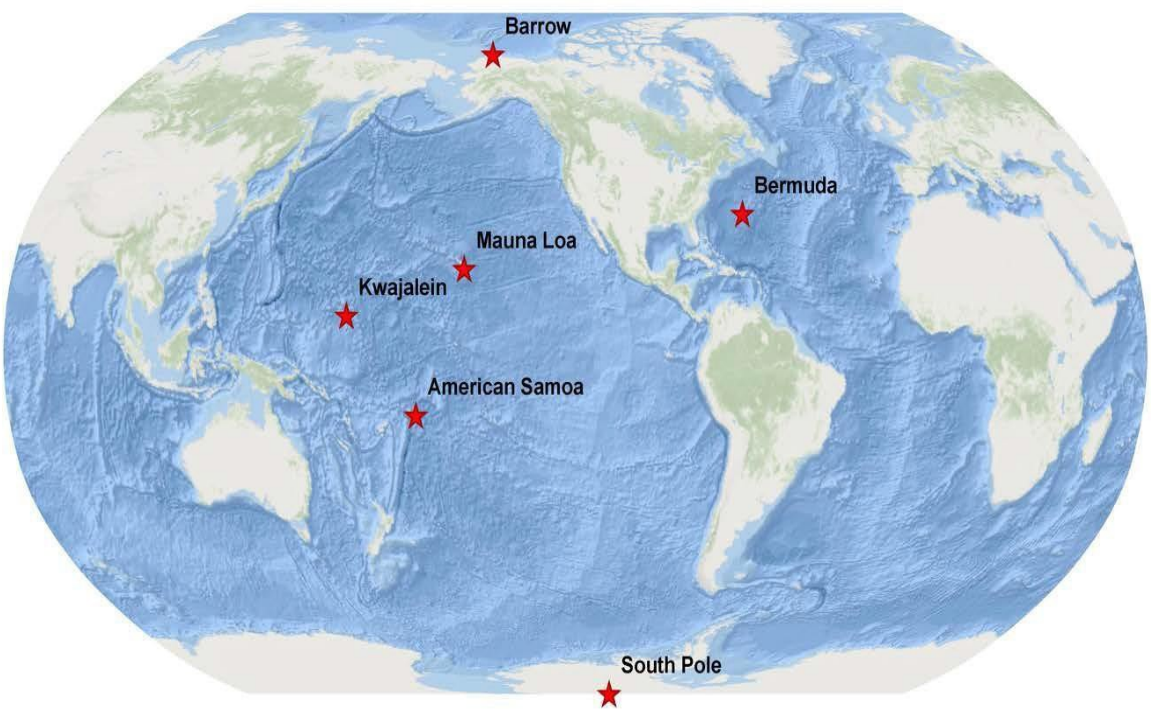
## NOAA G-RAD Networks Measure:

- The surface radiation budget and ancillary measurements at 2 global sites and 7 U.S. Surface Radiation Budget (SURFRAD) sites.
- Downwelling* solar and infrared, and ancillary measurements at 4 global sites.
- Downwelling* solar and UVB at 7 U.S. SOLRAD (urban) sites.
- Spectral UV measurements at 6 U.S. and 3 Antarctic stations.

*These stations do not have upwelling radiation measurements because they would not be representative of the greater environment of the station, e.g., islands and cities.

## Baseline and Regional Observatories

GMD Baseline Observatories are located in clean locations representative of the global background atmosphere. G-RAD regional observatories at Kwajalein and Bermuda are operated in conjunction with the U.S. Army and Bermuda Biological Station, respectively.




GMD Baseline Observatories are located where the measurements are representative of large regions of the globe. G-RAD operates two additional regional observatories to represent critical marine environments at Kwajalein and Bermuda.

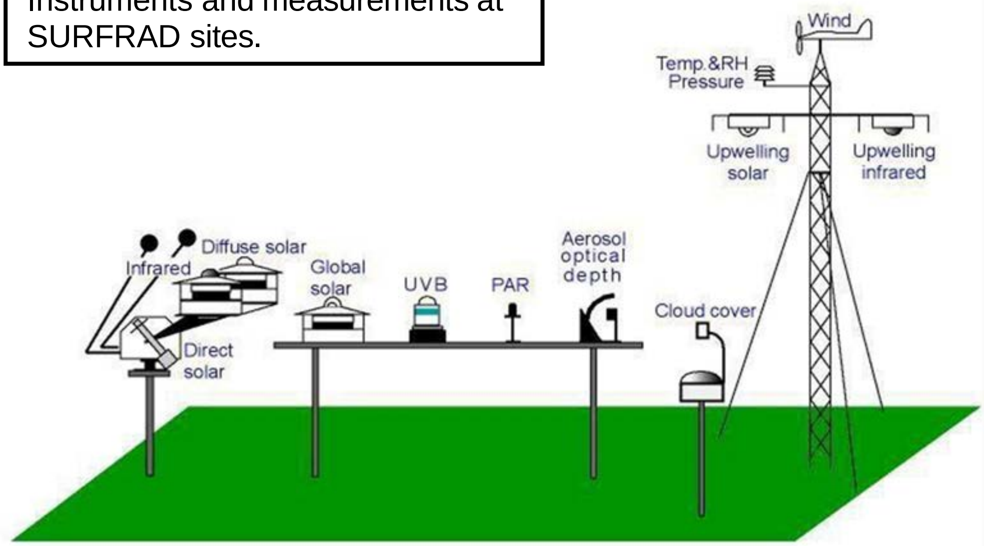
# SURFRAD Network

The seven U.S. SURFRAD stations are operating in climatologically diverse regions: Montana, Colorado, Illinois, Mississippi, Pennsylvania, Nevada and South Dakota in regionally representative locations away from local urban aerosol influences and are representative of differing biomes across the U.S. They measure upwelling and downwelling; solar and infrared; direct and diffuse solar; photosynthetically active radiation; UVB, spectral solar (for AOD and spectral albedo); and meteorological variables. Total Sky Imagers are also deployed to visually track cloud cover over the hemispheric view of the sky. Data are ingested, quality controlled, and processed into daily files that are distributed in near real time by anonymous FTP and the WWW (http://www.esrl.noaa.gov/gmd/grad/surfrad/).


All SURFRAD stations are members of the international World Meteorological Organization Baseline Surface Radiation Network (BSRN).

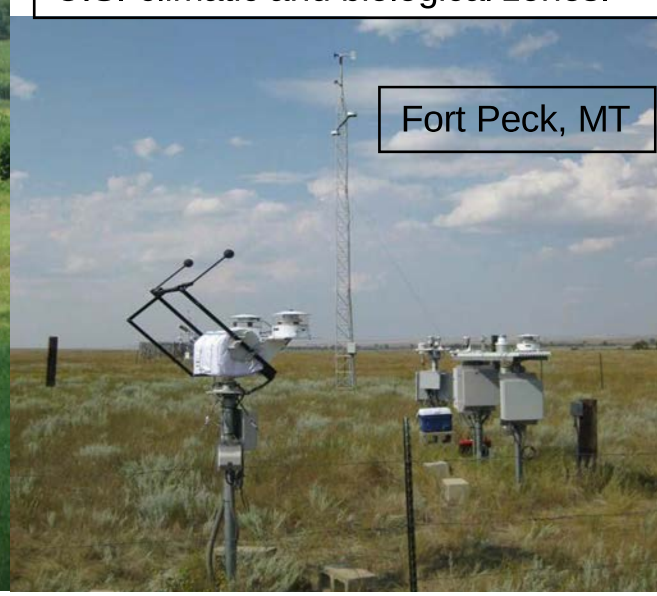
Observations from SURFRAD are used for basic understanding of atmospheric radiation processes, evaluating satellite-based estimates of surface radiation; validating hydrologic, weather prediction, and climate models; renewable energy research; and many other uses. Quality assurance built into the design and operation of the network and good data quality control ensure that a continuous, high quality product is released.

Instruments and measurements at SURFRAD sites.





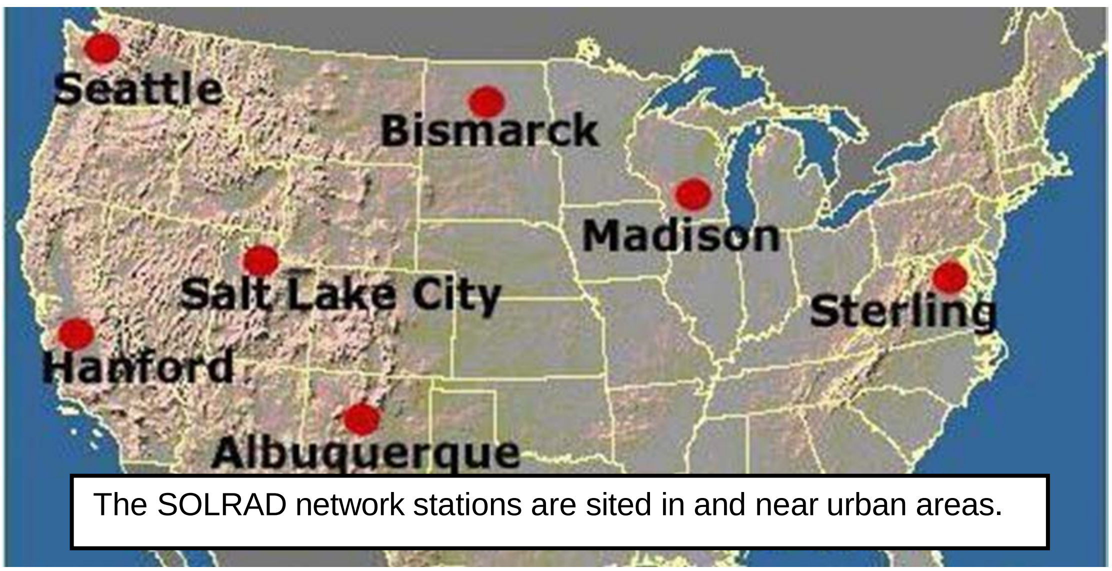

SURFRAD sites are in diverse U.S. climatic and biological zones.



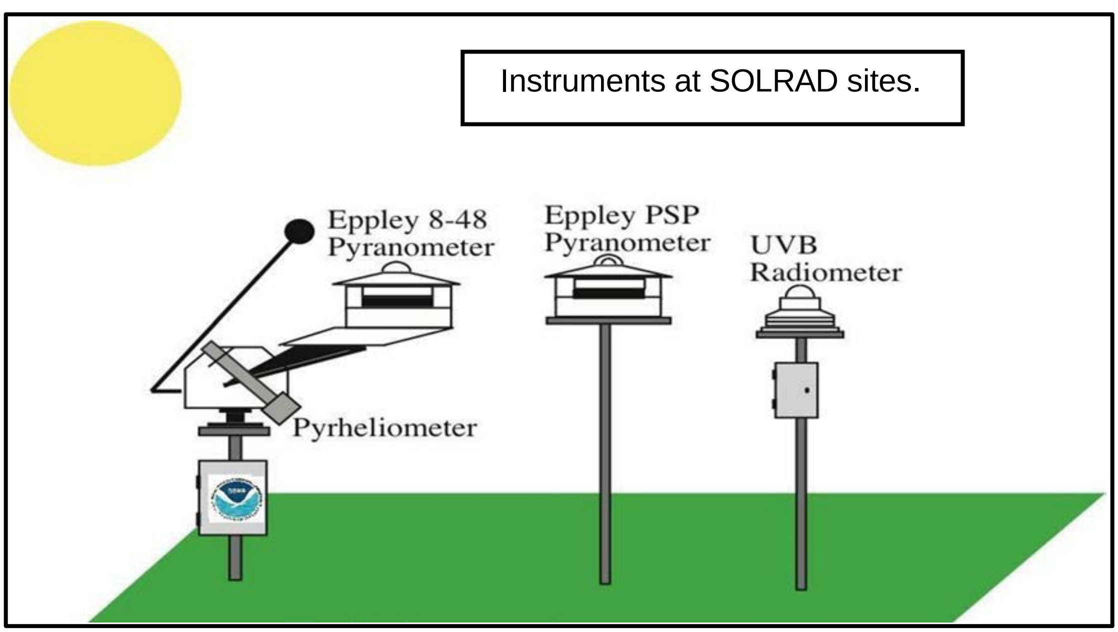
## SOLRAD Network

The first SOLRAD stations were inaugurated in the 1970s and placed primarily in urban areas to map solar energy for renewable energy development. Aerosols typical of urban environments are different than background aerosols at SURFRAD sites, and thus have different direct effects on radiation reaching the surface and indirect effects on cloud lifetime and extent. G-RAD plans to deploy spectral solar instruments at SOLRAD sites for monitoring aerosol optical depth in these more urban regions.

These considerations have become important to the numerical modeling communities as forecast models have become more sophisticated. Both SOLRAD and SURFRAD measurements have become indispensable tools in efforts to improve those models.




The SOLRAD network stations are sited in and near urban areas.




Instruments at SOLRAD sites.

SOLRAD site in Seattle, WA.

SOLRAD site in Sterling, VA.

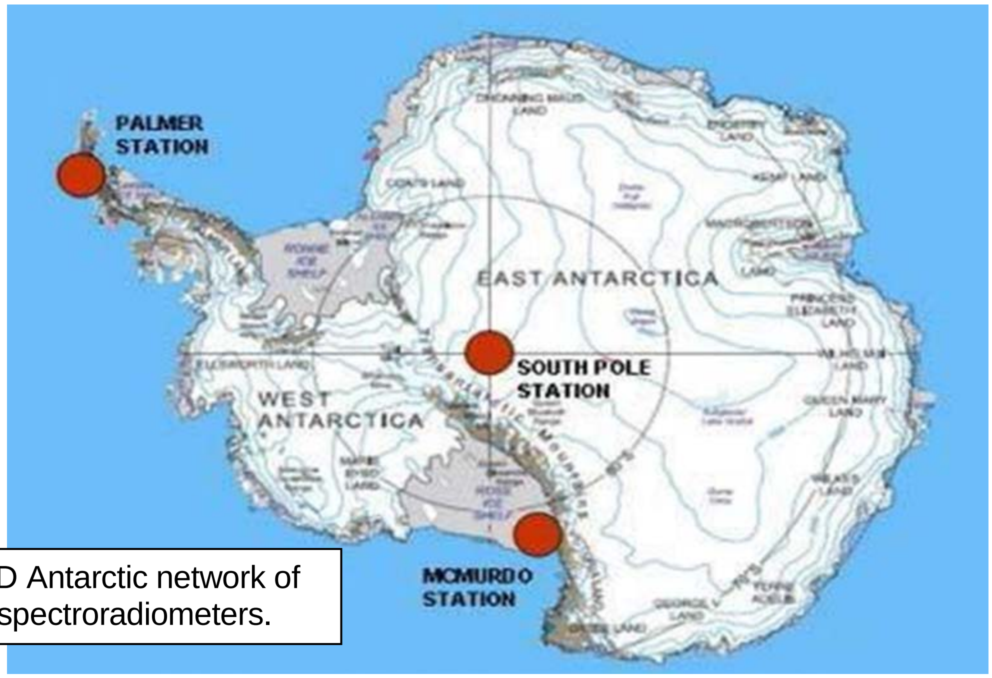
## NOAA NEUBrew Measurement Network

The NOAA GMD Brewer Spectrophotometer Network established in 2006 consists of six stations located in the western, central and eastern United States (Ft. Peck, MT; Boulder, CO; Niwot Ridge, CO; Bondville, IL; Houston, TX; and Raleigh, NC. Brewer spectrophotometers provide daily UV irradiance and Total-Column Ozone measurements. Three Brewers are co-located at NOAA SURFRAD stations equipped with Total Surface Radiation Budget instrumentation and Total Sky Imagers.

## Antarctic UV Network

The Antarctic UV Monitoring Network was established in 1987 by the National Science Foundation (NSF) in response to ozone depletion in the Antarctic stratosphere. Biospherical Instruments (BSI) installed the first instruments and operated the network until 2009. NSF transitioned operation of the Antarctic UV Network to NOAA/ESRL/GMD in 2010.

This Antarctic UV Network provides data for studying the effects of ozone depletion on terrestrial and marine biological systems, ozone hole monitoring, validation of satellite observations, and verification of atmospheric radiation transfer models. The network consists of three stations: South Pole Station, McMurdo Station, and Palmer Station. Each station is equipped with a BSI SUV-100 Spectroradiometer, a GUV Multi-Channel Radiometer, an Eppley PSP Pyranometer, and an Eppley Total UV (TUVR) Radiometer. Data are collected every 15 minutes and processed into daily UV products.

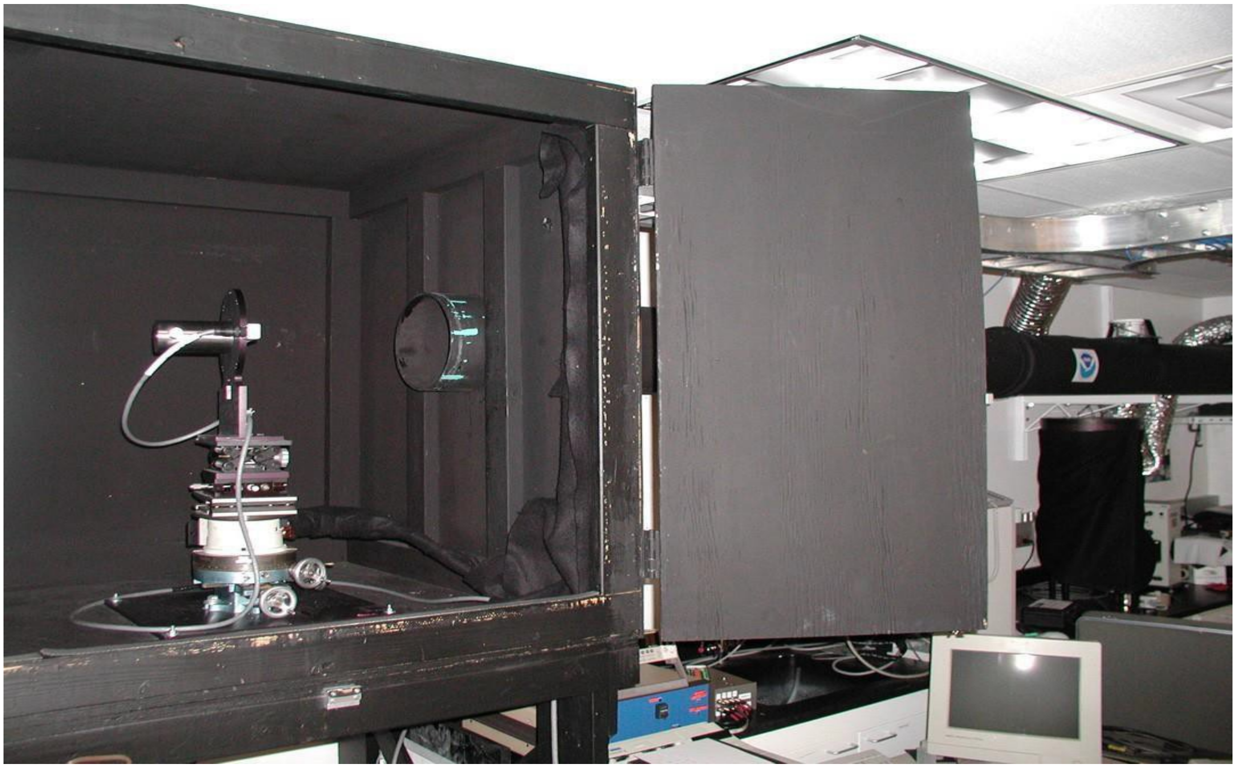



GMD Antarctic network of UV spectroradiometers.

## Central UV Calibration Facility (CUCF)

The basic operations of CUCF will be introduced in the Standards and Calibrations section of this report. In addition, the CUCF has several additional functions, such as:

- Generating standard lamps for the calibration of UV radiometers.
- Producing absolute calibrations of UV spectroradiometers both in the lab and in the field.
- Characterizing the angular response of spectral instruments such as the visible and UV Multi-Filter Rotating Shadowband Radiometers (MFRSRs).
- Providing absolute MFRSR channel calibrations for spectral albedo at SURFRAD sites, a measurement that was requested by NESDIS for GOES-R validation.



Characterizing the angular response of an MFRSR head. MFRSRs are used in the SURFRAD network for aerosol optical depth (AOD) and spectral albedo measurements.

In Boulder, CO World Meteorological Organization (WMO) calibrated-reference-traceable standard instruments are used to transfer calibrations to field radiometers at GMD’s Region IV Regional Radiation Center facility, shown above.

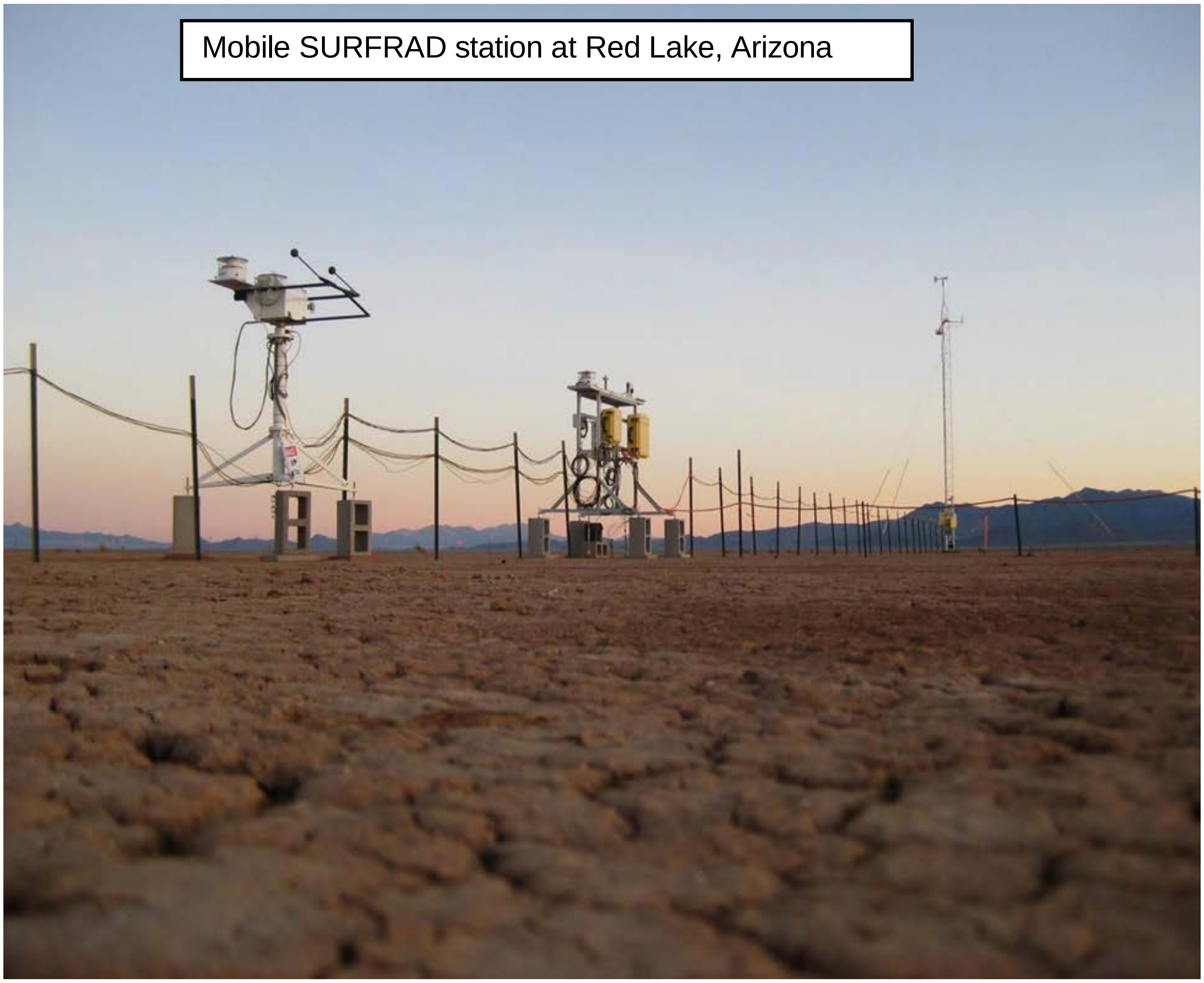
A Brewer UV spectroradiometer being calibrated at the GMD Table Mountain, Boulder CO Measurement and Calibration Facility. Many of the GMD CUCF calibrations are conducted in the field including the three UV instruments distributed across Antarctica.

## Mobile SURFRAD Stations

Over the past 5 years two mobile SURFRAD stations were developed to take part in research campaigns and validation experiments where measurements of the SRB, aerosol optical depth, and spectral albedo are needed, such as:

- GOES-R validation, a three-week deployment on a dry lake bed in Arizona.
- In situ data for renewable energy research near large solar arrays for DOE's SunShot Initiative (Rutland, VT, and San Luis, CO).
- The DOE/NOAA Wind Forecasting Improvement Project-2, Columbia River Basin, OR.
- NASA-sponsored DISCOVER-AQ air quality experiments in the Central Valley of CA: and Houston, TX; the FRAPPE campaign along the Front Range of CO, and the DOE-sponsored TCAP (two-column aerosol project) in Massachusetts.

Mobile SURFRAD station at Red Lake, Arizona



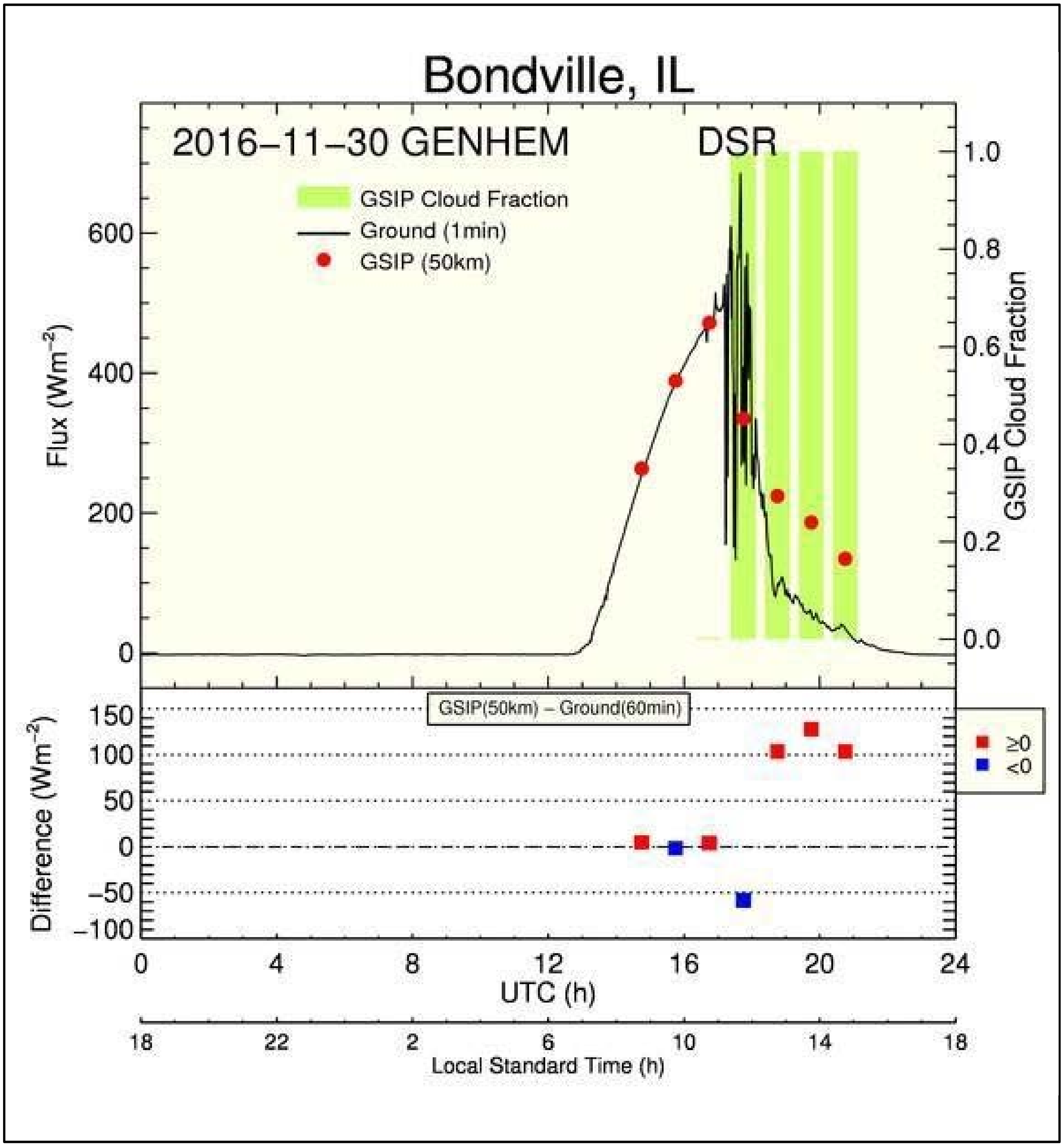
## Satellite Validation

Estimates of surface radiation from weather (GOES, JPSS) and climate (NASA EOS A-train) satellites expand surface radiation coverage spatially to the globe.

Unfortunately, satellites only sense upwelling radiation and, from that information, must model the downwelling irradiance at the surface.

G-RAD measurements play a crucial role in validating many satellite-based surface radiation products produced by NASA and NOAA-NESDIS.

Below is an example of a NESDIS GOES product validation using SURFRAD data.



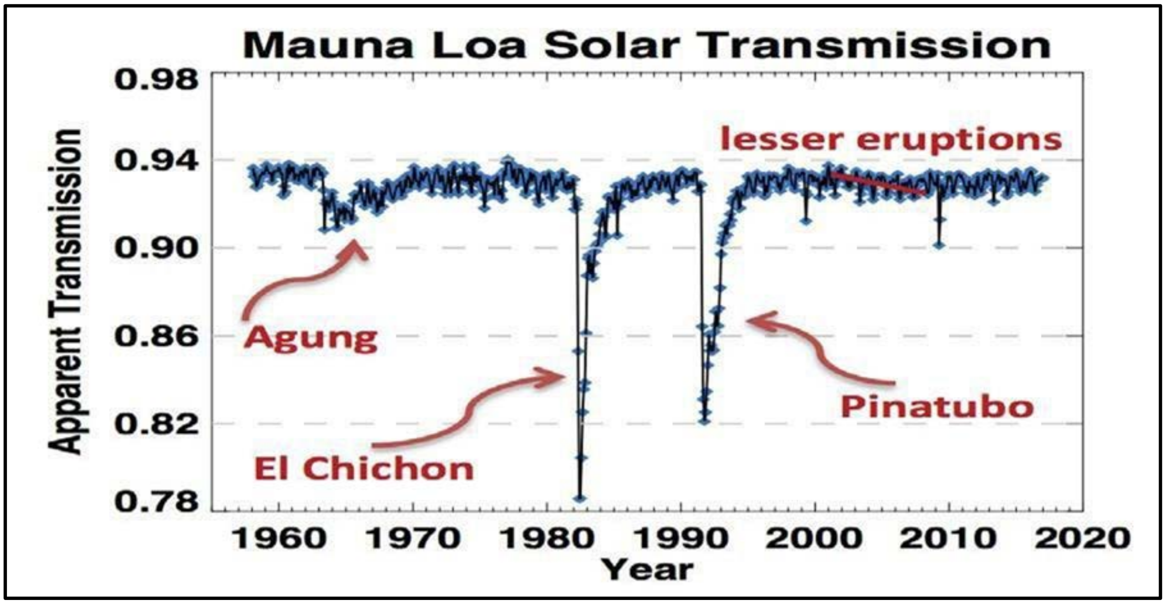

NESDIS GOES satellite estimated shortwave radiation and corresponding G-RAD in situ measurements.

Comparisons of NESDIS daily GOES-estimated shortwave down (red dots) and ground measurements for November 30, 2016 at the Bondville SURFRAD station. Comparisons such as this are published by NESDIS each day.

This example shows that the GOES algorithm generally does well for clear skies (morning in the above plot) but overestimates the actual surface irradiance under cloudy conditions in the afternoon.

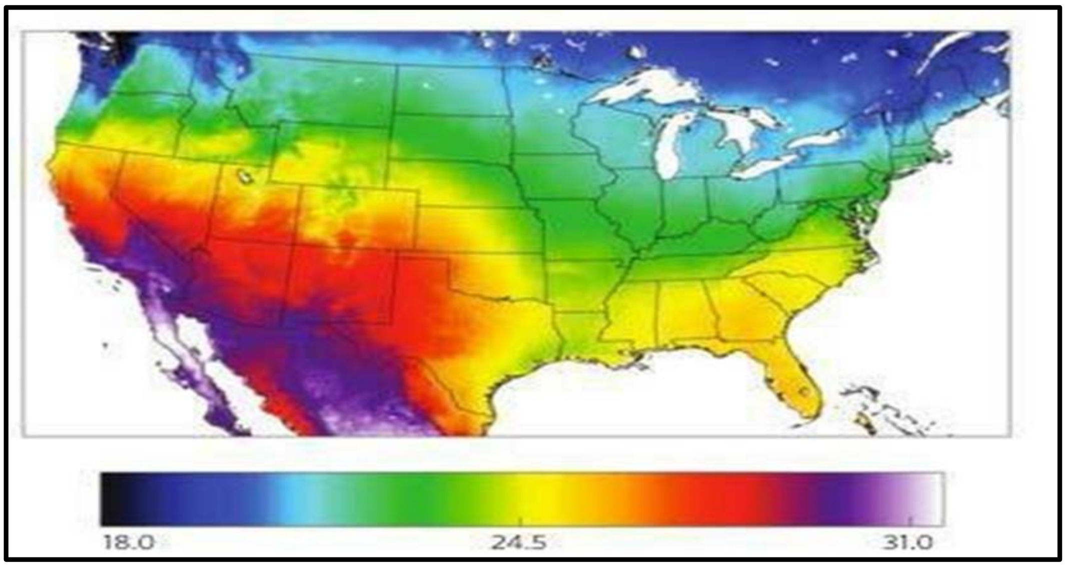
# Some Notable GMD G-RAD Network Achievements:

- **Volcanic Reduction of Solar Transmission.**



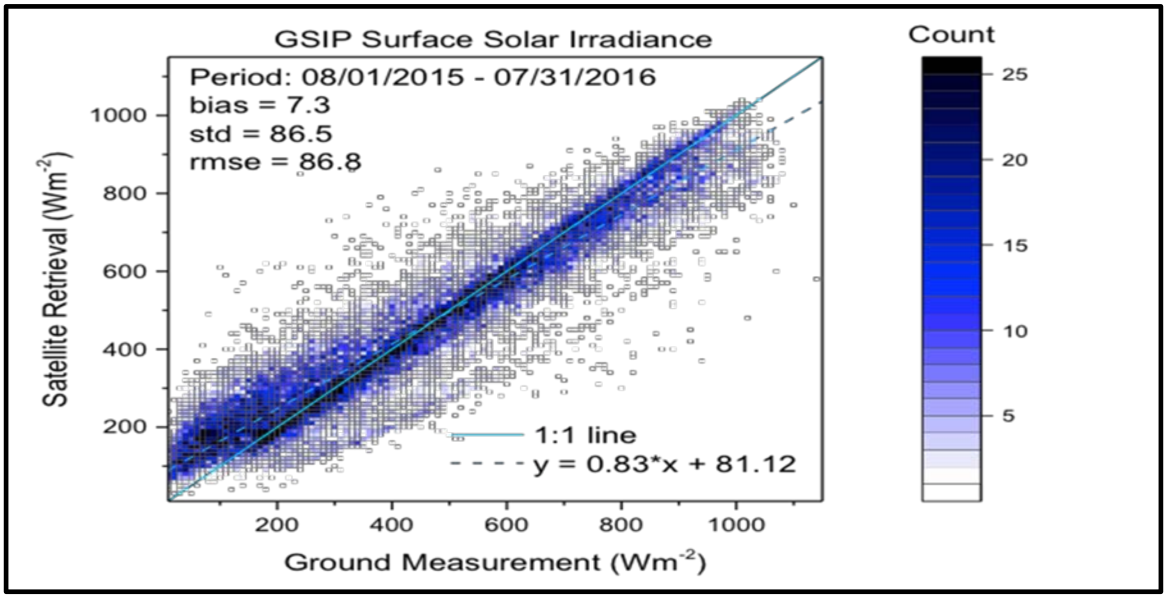

The unbroken Mauna Loa atmosphere transmission record that goes back to the IGY (1956) is the longest such record in existence.

- **Development of a solar resource map for the solar electric industry.**



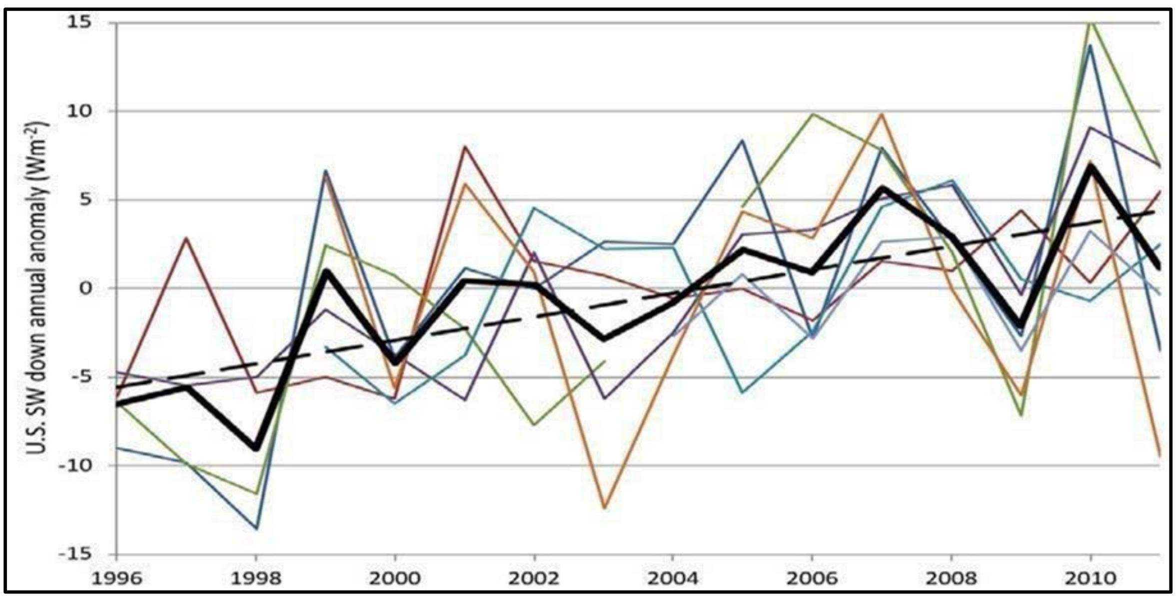

GMD SURFRAD and SOLRAD data were used to produce this unique solar energy resource map (units: "capacity factor" in %) used as the basis for configuration of a cost-competitive alternative electrical system for the U.S.

- **Correcting bias in a GEOES satellite measurement.**



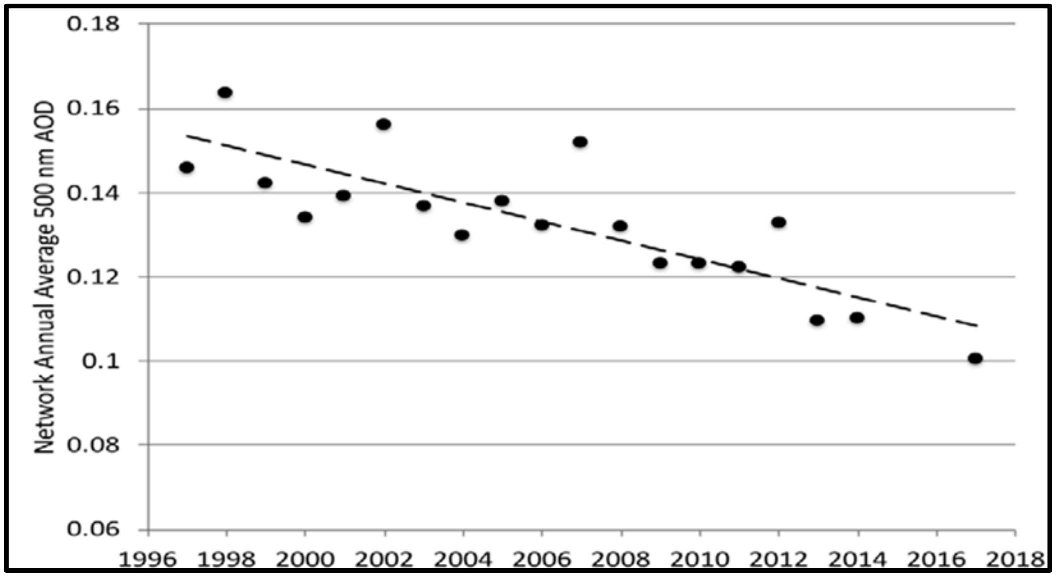

SURFRAD measurements revealed a high bias in GOES-based estimates of surface shortwave under low irradiance (cloudy) skies, that subsequently were corrected for in the GOES-R algorithm.

- **Documenting a persistent solar brightening across the US.**

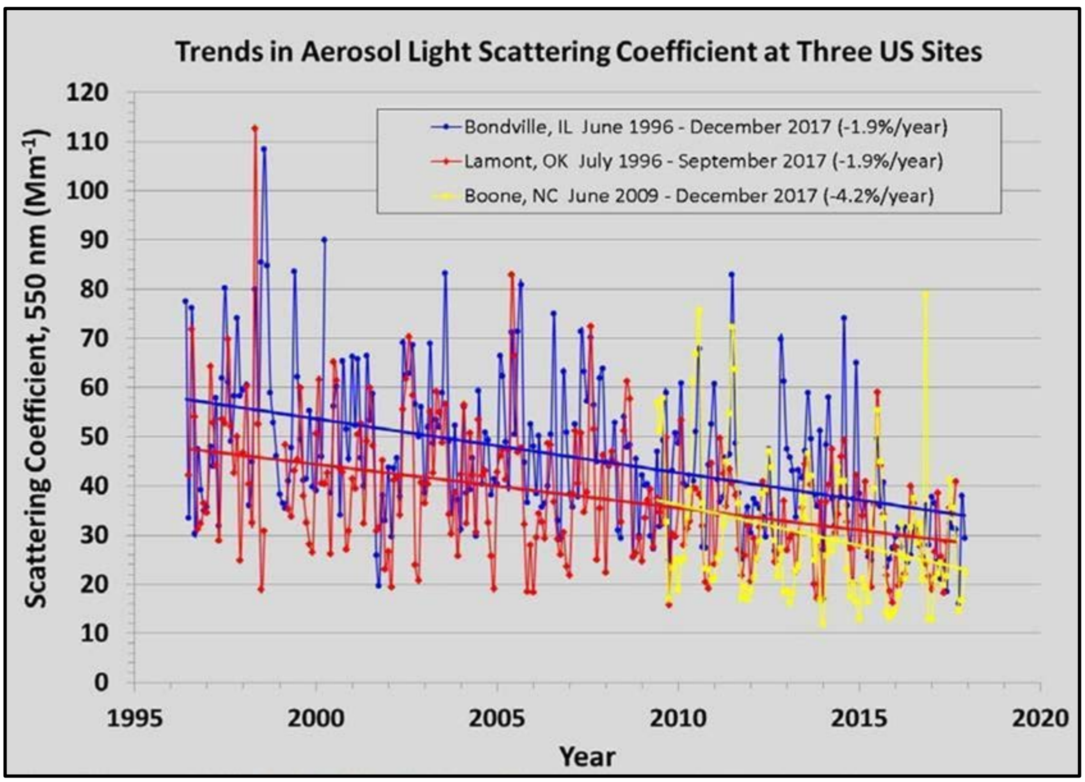



Systematic solar brightening at all SURFRAD stations (colored lines). The U.S. average (thick black line) of 10 $Wm^{-2}$ over 16 years is nearly three times that expected from the doubling of $CO_2$. Ancillary data from SURFRAD stations revealed that this brightening was caused primarily by a general decrease in cloud cover over that time period.

- **Decrease in aerosol optical depth and aerosol light scattering across the U.S.**

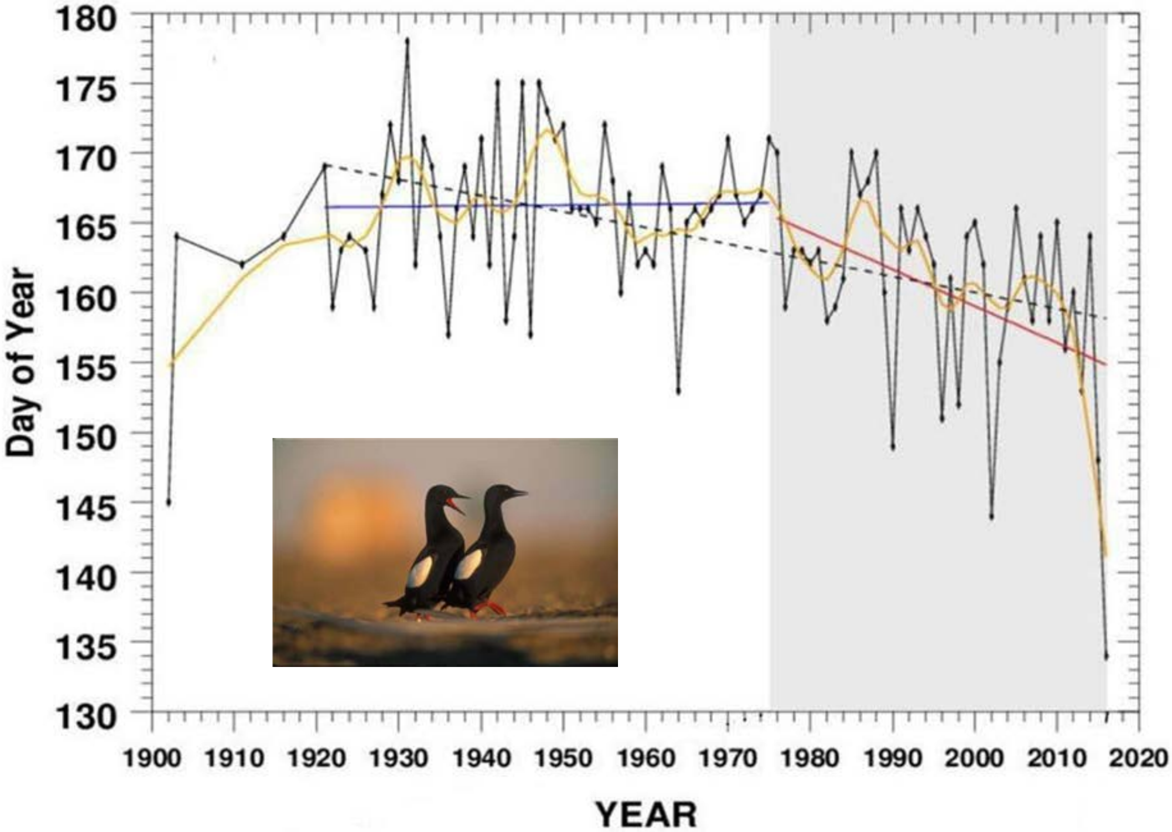



A 20 year decrease in aerosol optical depth over the U.S. in agreement with known reductions in aerosol emissions due to regulations.




Aerosol light scattering at the surface has also been decreasing over the past 20 years across the U.S. as measured in the GMD Surface Aerosol Network and agrees with data on decreasing optical depth in the U.S.

- **Documenting advancing springtime in the Arctic**




Time series of snowmelt dates at Barrow, Alaska; orange line is a ten-year running mean and linear fits are shown for 1920-1975 (blue), 1920-2016 (dashed) and 1975-2016 (red). The 1975-2016 linear trend is -2.86 days decade$^{-1}$, meaning that the snowmelt is occurring on average almost 3 days earlier each decade since 1975. The date that black guillemots (inset) lay their first egg on nearby Cooper Island is influenced by snow cover and highly correlated with the date of snowmelt at the nearby Barrow Observatory. (Photo credit: Joe McNally, Cooper Island Bird Observatory)

The GMD Barrow Observatory comprises the longest running and most comprehensive set of climate variables in the Arctic. This figure shows the retreat of the snow melt date to earlier in the year since the Barrow Observatory record began (1973). The retreat is occurring at 3 days/decade over this time period. Earlier snow melt dates are a function of many interconnected processes termed Arctic Amplification that work to warm the region at a faster rate than other areas of the globe. (From Cox et al. 2017 BAMS).

- **GMD radiation data used to correct a large error in a NWS weather prediction model.**

SURFRAD and SOLRAD measurements were the key to finding the source of a +3°C temperature bias in the National Weather Service's operational Rapid Update Cycle weather forecast model and its subsequent improvement.

## G-RAD Network Data Processing and Storage

Radiation and meteorological data from all G-RAD networks are downloaded, processed, quality controlled, and made available on local FTP servers daily.

SURFRAD and SOLRAD data are downloaded and processed every 15 min. and made available on FTP in near-real time for the model and satellite communities.

Radiosonde soundings are interpolated to all SURFRAD sites for 0000 and 1200 UTC each day using all data from the NWS sounding network. Interpolated soundings at SURFRAD sites and all U.S. soundings used are made available on FTP on a daily basis.

SURFRAD data are compiled as hourly averages and sent in monthly files to NOAA's official archive at NCEI in Asheville, NC. From there they are reformatted and sent to the World Radiation Data Center in St. Petersburg, Russia.

SURFRAD data and baseline site data from Barrow, South Pole, Bermuda, and Kwajalein are periodically processed in monthly files for submission to the BSRN archive in Bremerhaven, Germany.

SURFRAD data are processed using the RadFlux algorithm that produces several computed research products such as clear-sky equivalent irradiance and sky cover fraction. RadFlux files are produced and made available on FTP on a quasi-monthly basis.

Aerosol optical depth from MFRSR data at all SURFRAD sites is produced periodically throughout the year and made available on FTP. SURFRAD AOD data are submitted to the international GAW archive on an annual basis.

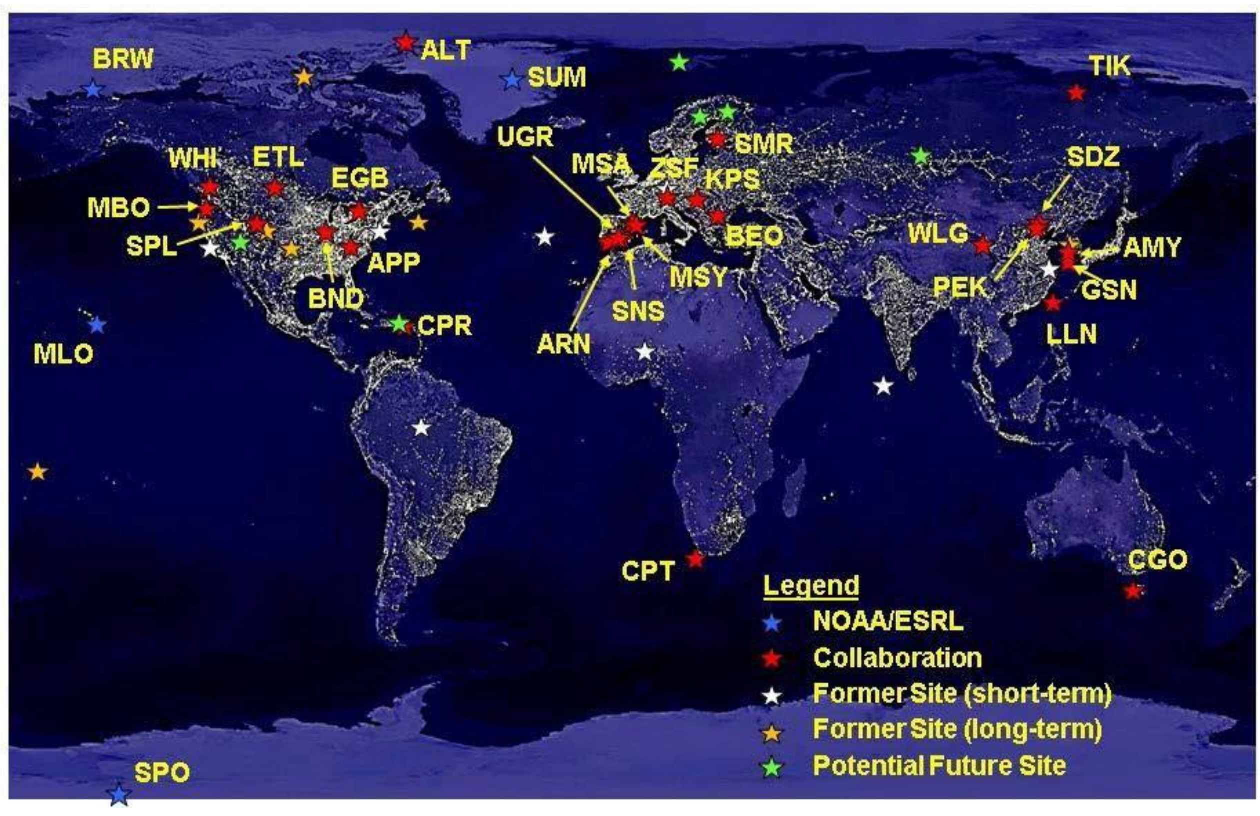
Products from new MFRSRs at SURFRAD sites such as spectral albedo and aerosol property retrievals are currently being developed.

Soon, all radiation data products produced at G-RAD will be available in NetCDF format at NCEI.

# Theme 2, Part 2: NOAA Federated Aerosol Network (NFAN)

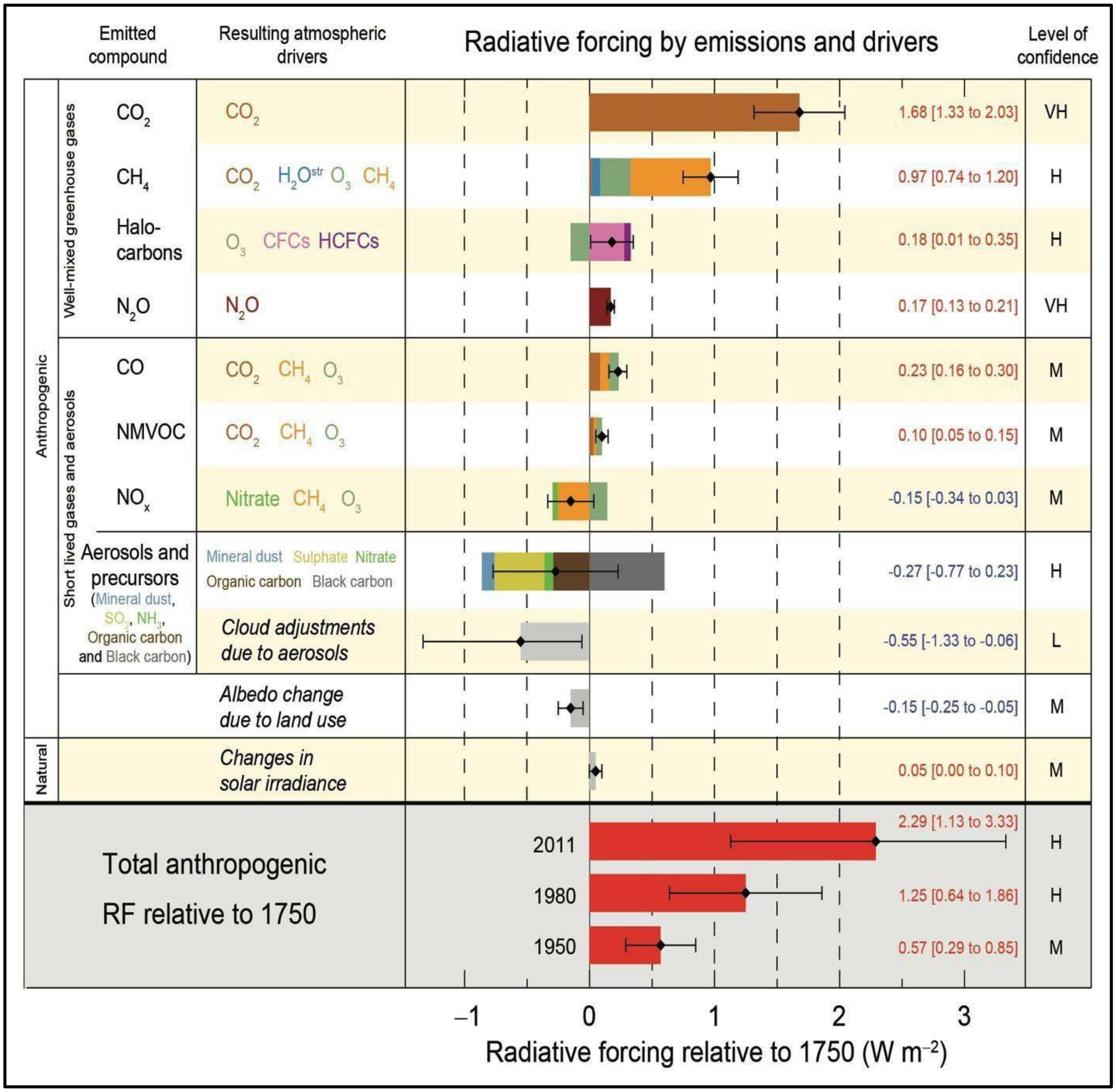
**Uncertainties in the effect of aerosols on the radiative balance of the atmosphere result in aerosol particles (and clouds, which form on aerosol particles) having the largest error bars of all atmospheric radiative forcing species. Aerosol particles may either heat or cool the atmosphere. Given these facts, it is important to monitor aerosol particles around the Earth in a consistent and continuous basis.**

**As such, the global Monitoring Division has established and operates a 30 station (and growing) global aerosol measurement network as shown below.**




The station names, locations and cooperating agencies are presented in the following pages as well as important scientific results from the network.

# Radiative Forcing by Emissions and Drivers (IPPC AR5, Summary for Policy Makers, 2013)




Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF14), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing. Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Note that aerosol effects have the largest error bars.

# Aerosol Systems at the NFAN Stations

Aerosol systems deployed in the NOAA Federated Aerosol Network (NFAN) measure aerosol optical properties (e.g., light scattering and absorption) to determine the effects of aerosol direct radiative forcing. Other standard measurements include particle number concentration and wind speed and direction to augment and interpret the optical measurements. All stations are essentially identical in instrumentation and operating procedures. Data collection is handled with identical software and monitored by a GMD staff scientist and by partners for each site.

**All 30 stations measure with identical equipment, operational procedures and data processing software. The 30 station NFAN is operated by 1.5 GMD scientists, 1 programmer and a 0.5 engineer at GMD along with the aid of U.S. and international partners.**

Other measurements performed at a subset of stations include the aerosol hygroscopic growth factor, cloud condensation nucleus concentration, particle size distribution, aerosol chemistry, and real-time weather (i.e., fog, haze, drizzle, rain, snow, etc.) conditions.

One minute data from most NFAN stations comes to Boulder electronically on an hourly basis, but a few stations, owing to communication limitations, transfer data less frequently (daily). The incoming data are checked daily for errors and instrument problems that are attended to either from Boulder through remote access and control, or through email interactions with site personnel.

The Aerosol Group archives NFAN aerosol data in-house, at a primary site in NOAA, Boulder and at an offsite location. All aerosol data are also submitted to the WMO/GAW World Data Centre for Aerosols in Norway. (https://www.gaw-wdca.org/). Additionally, within the past year, to comply with the directives set forth in the NOAA Big Earth Data Initiative (BEDI) project, GMD submits aerosol data to the NOAA National Centers for Environmental Information (NCEI) archive (https://doi.org/10.7289/V55T3HJF) .

## NOAA Federated Aerosol Network (NFAN) Locations

Alert, Nunavut (ALT)
Anmyeon-do, Korea (AMY)
Appalachian State, North Carolina (APP)
Barrow, Alaska (BRW)
Beijing, China (PEK)
Beo Moussala, Bulgaria (BEO)
Bondville, Illinois (BND)
Cape Grim, Australia (CGO)
Cape Point, South Africa (CPT)
Cape San Juan, Puerto Rico (CPR)
East Trout Lake, Saskatchewan (ETL)
Egbert, Ontario (EGB)
El Arenosillo, Spain (ARN)
Granada, Spain (UGR)
Gosan, Korea (GSN)
Hyytiala, Finland (SMR)
K'Puszta, Hungary (KPS)
Mauna Loa, Hawaii (MLO)
Montsec, Spain (MSA)
Montseny, Spain (MSY)
Mount Bachelor, Oregon (MBO)
Mount Lulin, Taiwan (LLN)
Mount Waliguan, China (WLG)
Shangdianzi, China (SDZ)
Sierra Nevada, Spain (SNS)
South Pole, Antarctica (SPO)
Summit, Greenland (SUM)
Tiksi, Russia (TIK)
Whistler, British Columbia (WHI)
Zeppelin, Ny Alesund, Norway (ZEP)
Zugspitze, Germany (ZSF)

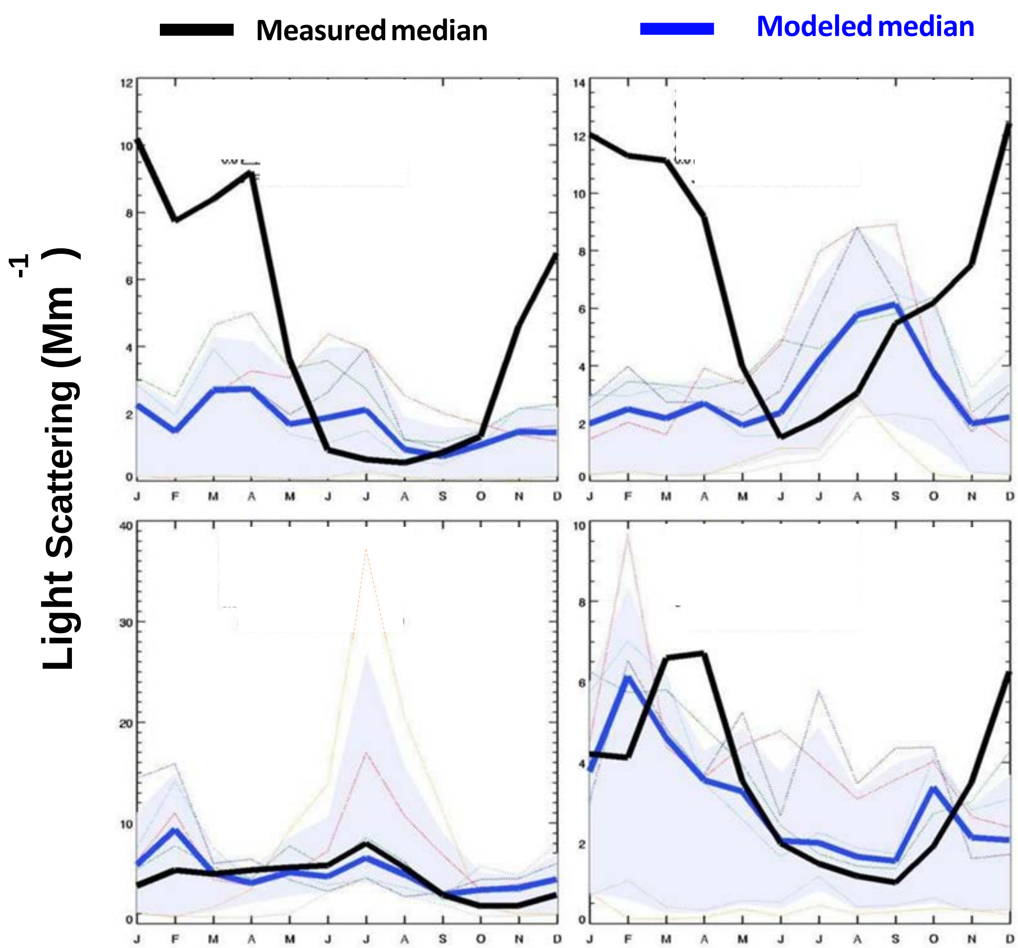
**Sites in discussion phase for possible set-up in 2018-2023:**

Pico del Este, Puerto Rico
New Mexico Tech, New Mexico
Varrio, Finland
Norrunda, Sweden
Pallas, Finland
Tomsk, Russia

# Some GMD Aerosol Network Results of Note

*(The model results are from widely used global climate models for predicting aerosol characteristics and distributions).*

## NFAN Arctic In Situ Data vs Modeled Aerosol Light Scattering



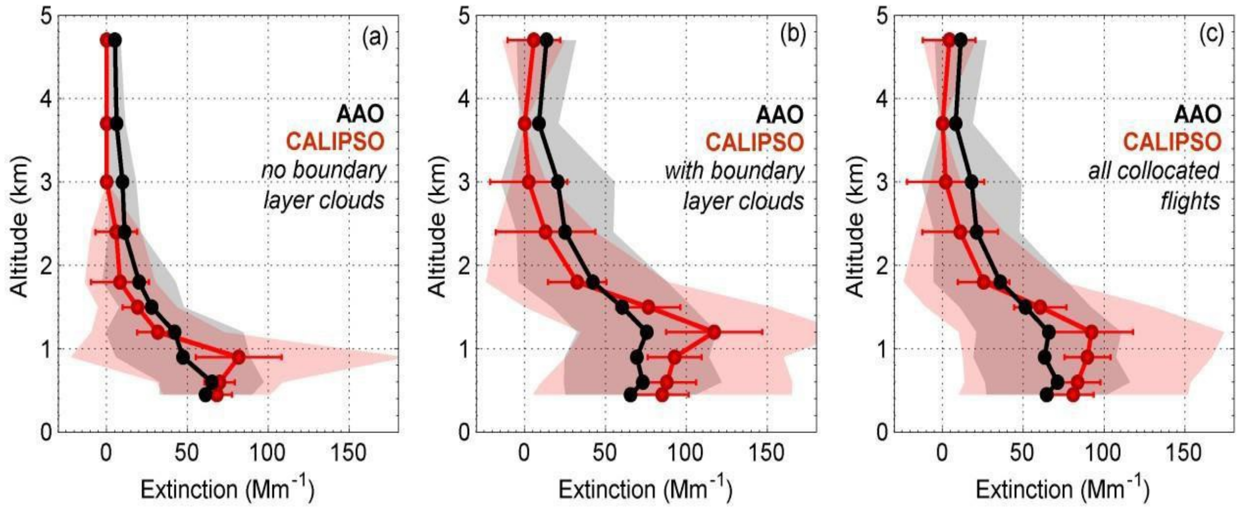

Model/measurement discrepancies can suggest atmospheric processes to focus on. For example, what causes the model peak in summer at Barrow? Could it be overestimating forest fire emissions? Or, underestimating removal processes such as wet deposition?

Why is model/measurement agreement better in the European Arctic than the North American Arctic?

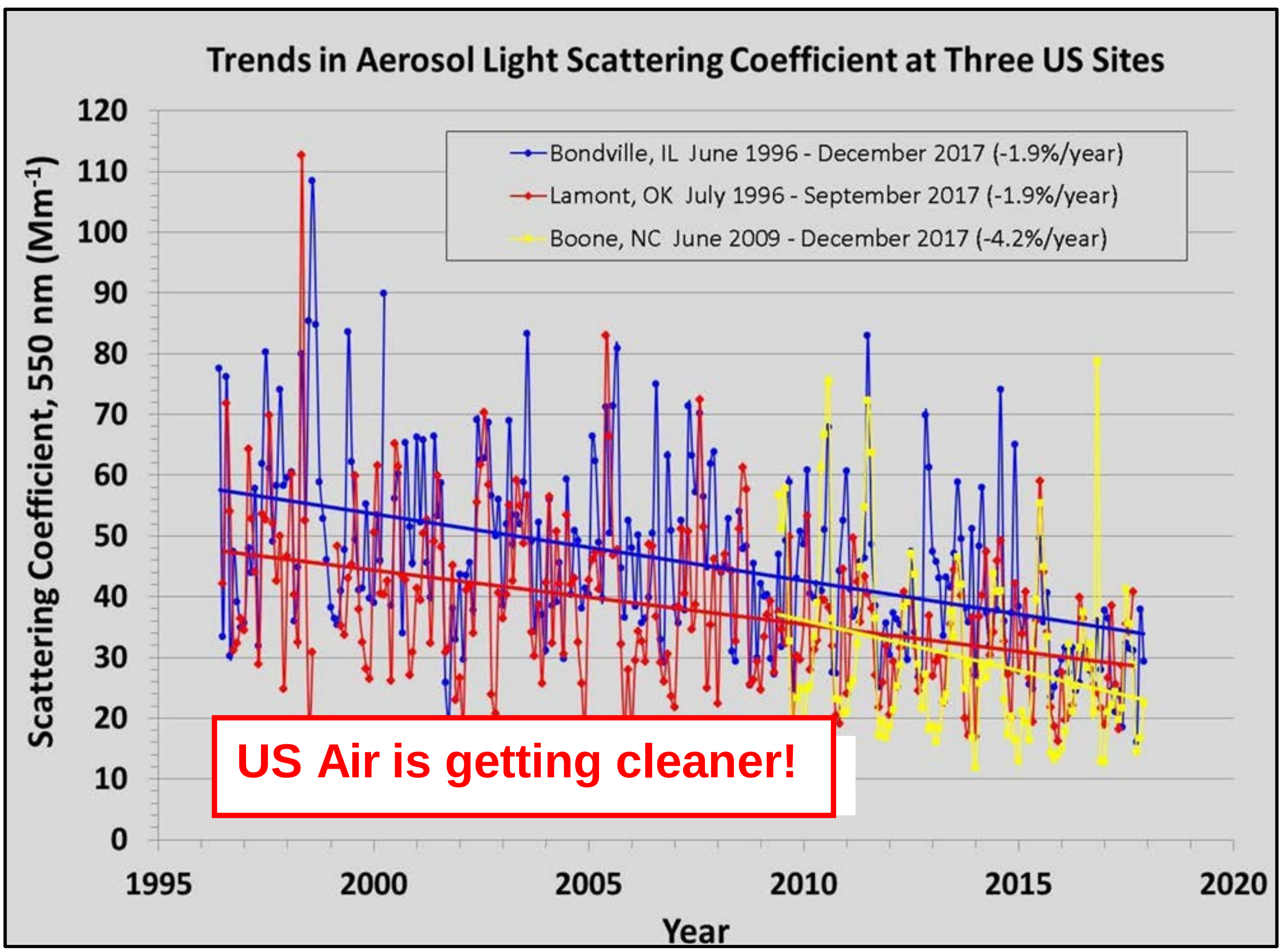
For the 13 models tested, the median is shown in blue, one standard deviation in shaded blue, and the outlier models in red and green.

*(The model study by a group of international scientists is in progress).*

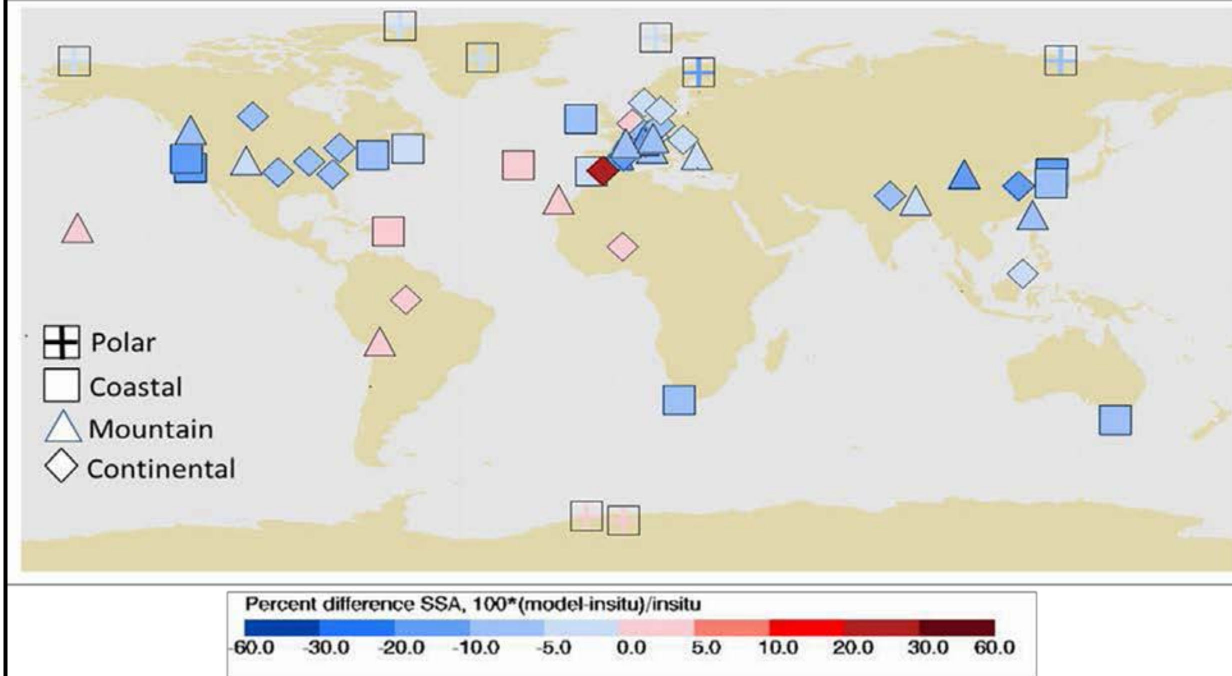
# GMD Airborne vs. CALIPSO Satellite Aerosol Extinctions




For 3.25 years GMD operated a light aircraft (AAO) to measure in situ aerosol parameters on 405 profiles at Bondville, IL; 63 coincided with CALIPSO overflights. The shaded envelopes are standard deviations of the data and the CALIPSO error bars are the uncertainties in the CALIPSO lidar measurement. It is apparent that CALIPSO overestimates extinction in the boundary layer and underestimates it in the free troposphere. *From Sheridan et al., 2012.*

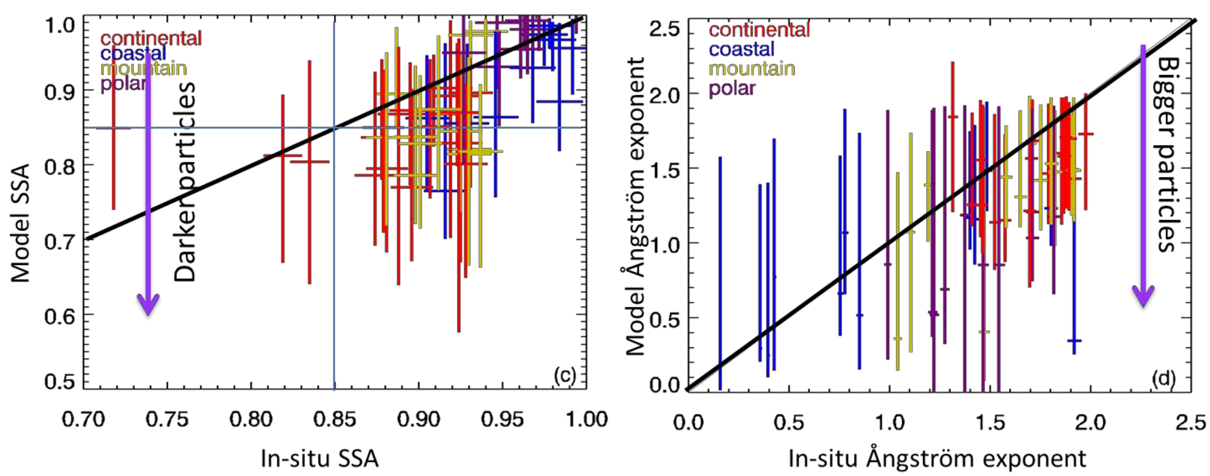


## Model Evaluation – Single Scattering Albedo

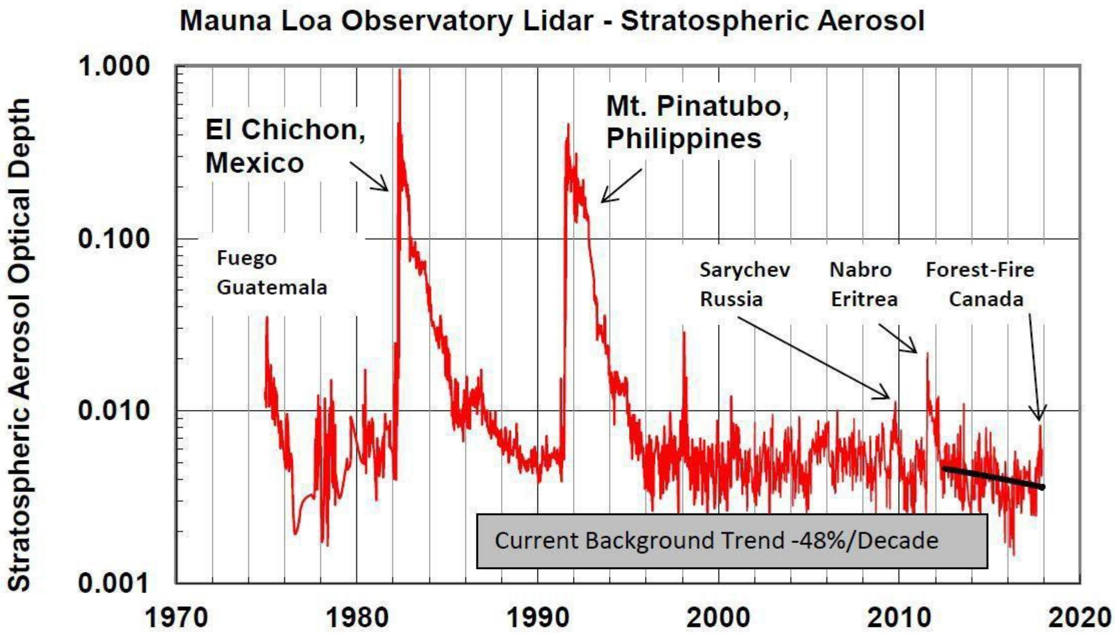



**Model median values (based on 14 global climate models) suggests models underestimate observed SSA (i.e., models simulate a darker aerosol than is observed).**

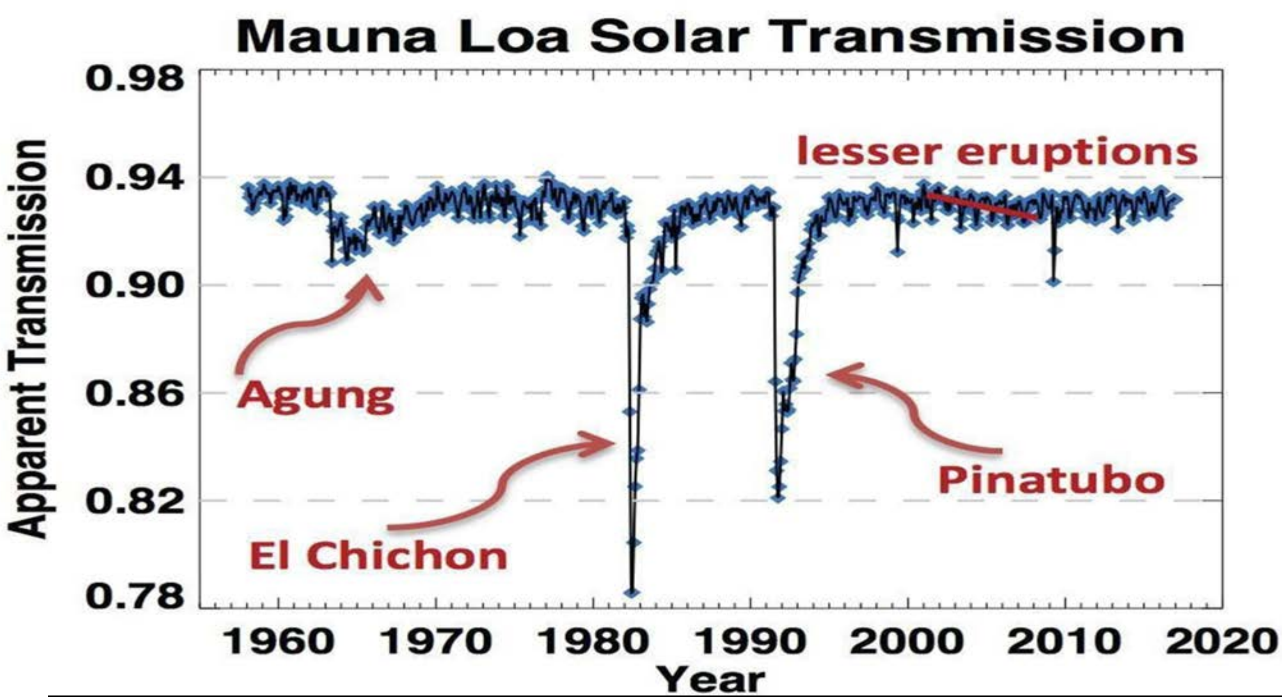
## Model Evaluation: Single Scattering Albedo and Ångström Exponent




Model Single Scattering Albedo (SSA) tends to be lower (more absorbing) than in-situ SSA partly driven by model under-prediction of scattering. Modelled Ångström exponents suggest larger particles than observed by in-situ measurements.




This is the longest lidar measurement of stratospheric aerosol in existence. Note the close relationship between elevated stratospheric aerosol and reduced solar radiation transmission in the following graph.



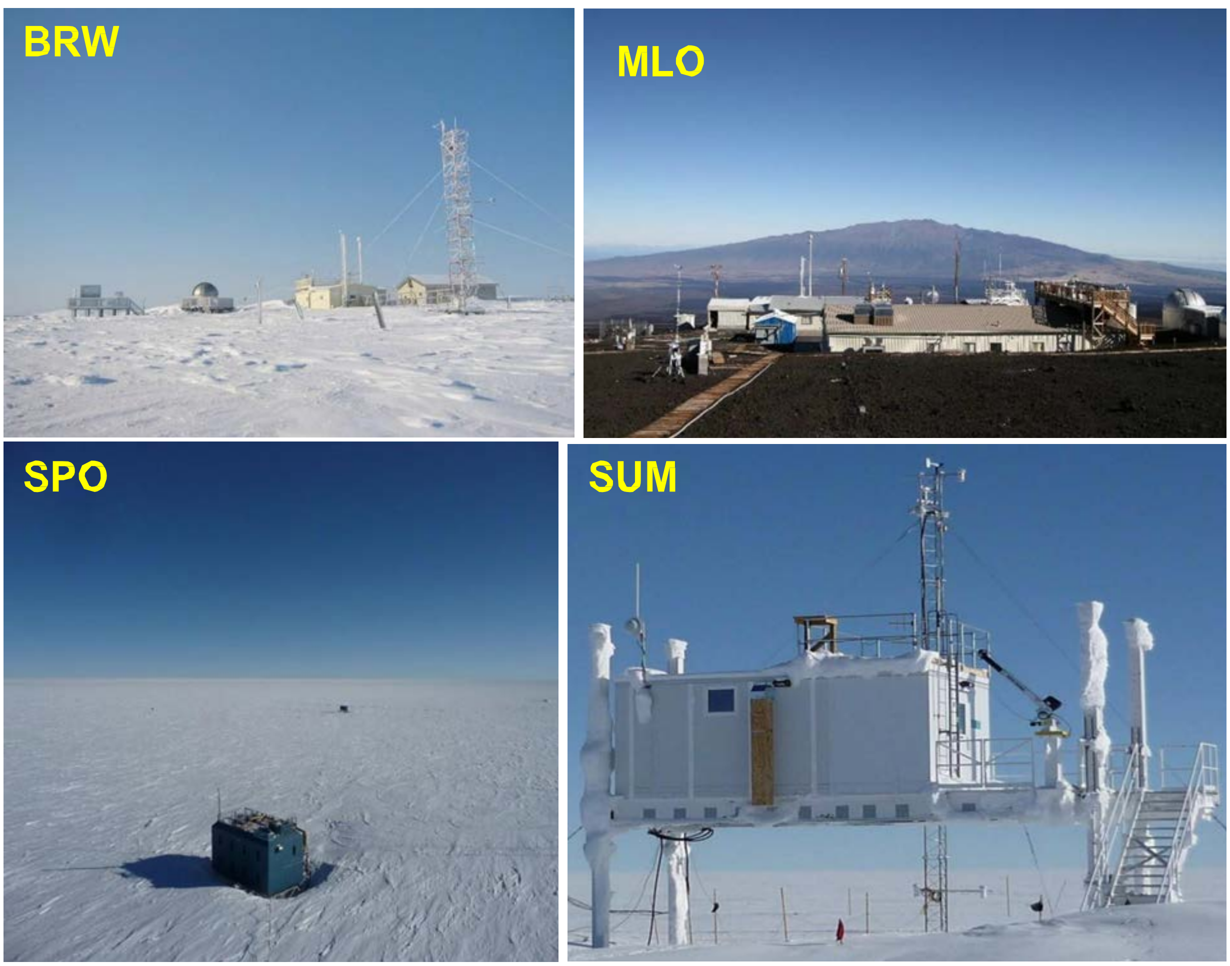

The Mauna Loa atmospheric transmission record began in 1957 and has recorded the effects of three explosive volcanic eruptions (Agung, El Chichon and Pinatubo and lesser events (1999 and 2010). In later years, the annual reduction in solar transmission is from springtime aerosol and air pollution outflow from Asia. This is the oldest record of aerosol effects on solar transmission on Earth.

## NOAA Aerosol Cooperative Program Partners: NFAN and other Aerosol Research Partners

Appalachian State University: Cooperative aerosol measurements and research.
Bulgarian Academy of Sciences, Bulgaria: Cooperative aerosol measurements and research.
Center for International Climate and Environmental Research, Norway: Aerosol research.
China Meteorological Agency, China: Cooperative aerosol measurements and research.
CSIRO, Australia: Cooperative aerosol measurements and research.
Desert Research Institute, Steamboat Springs, CO: Aerosol research.
Duke University, Durham, NC: Aerosol research
Environment and Climate Change Canada: Cooperative aerosol measurements and research.
Federal Office of Meteorology and Climatology, Switzerland: Aerosol research.
Finnish Meteorological Institute, Finland: Cooperative aerosol measurements and aerosol research.
German Weather Service, Germany: Cooperative aerosol measurements and research.
Institute of Environmental Assessment and Water Research (IDAEA-CSIC), Spain: Cooperative aerosol measurements and research.
Institute of Nuclear and Radiological Science & Technology, Greece: Aerosol research
Jozef Stefan Institute, Ljubliana, Slovenia: Aerosol research
Korea Meteorological Administration: Cooperative aerosol measurements and research.
Leibniz Institute for Tropospheric Research, Germany: Aerosol research.
NASA Goddard Space Flight Center, Greenbelt, MD: Aerosol research.
NASA Langley Research Center, Hampton, VA: Aerosol research.
National Central University, Taiwan: Cooperative aerosol measurements and research.
National Institute of Aerospace Technology (INTA), Spain: Aerosol research.
National Institute of Polar Research, Japan: Aerosol research
NOAA/ESRL/CSD, Boulder, CO: Aerosol research.
NOAA/ESRL/PSD, Boulder, CO: Aerosol research.
Norwegian Institute for Air Research, Norway: Aerosol research. Norwegian Meteorological Institute (MetNo), Norway: Aerosol research.
Pacific Marine Environmental Laboratory, Seattle, WA: Cooperative aerosol measurements and research.
Paul Scherrer Institute, Switzerland: Aerosol research.
Seoul National University, Republic of Korea: Cooperative aerosol measurements.
Sierra Negre Mexican High Altitude Observatory, Mexico: Cooperative aerosol measurements.
South Africa Weather Service, South Africa: Cooperative aerosol measurements.
Stockholm University, Sweden: Cooperative aerosol measurements and research.
University of California: Aerosol research

University of Granada: Cooperative aerosol measurements and research.
University of Helsinki, Finland: Aerosol research.
University of Illinois, Urbana-Champaign: Cooperative aerosol measurements.
University of Nevada: Cooperative aerosol measurements and research.
University of Pannonia, Hungary: Cooperative aerosol measurements and research.
University of Puerto Rico: Cooperative aerosol measurements and research.
University of Utah: Cooperative aerosol measurements and research.
University of Washington, Seattle, WA: Cooperative aerosol measurements and research.
University of Washington-Bothell, Bothell, WA: Cooperative aerosol measurements and research.
V.E. Zuev Institute of Atmospheric Optics, Tomsk, Russia: Aerosol research.

# NOAA Federated Aerosol Network Sites



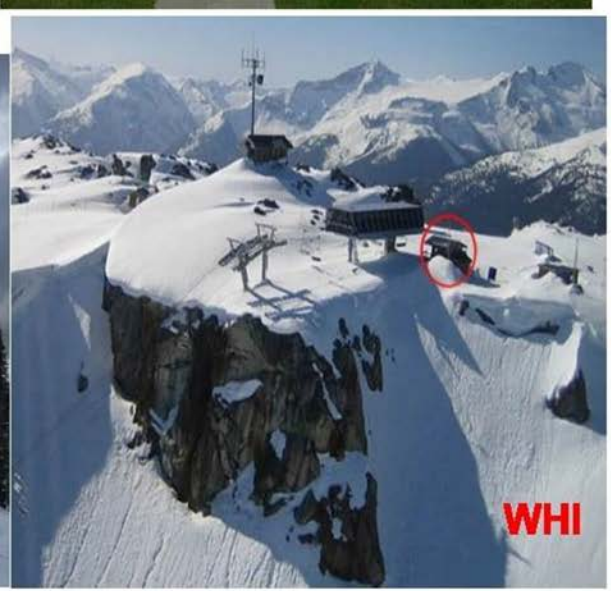

APP


BND


CPR


EGB

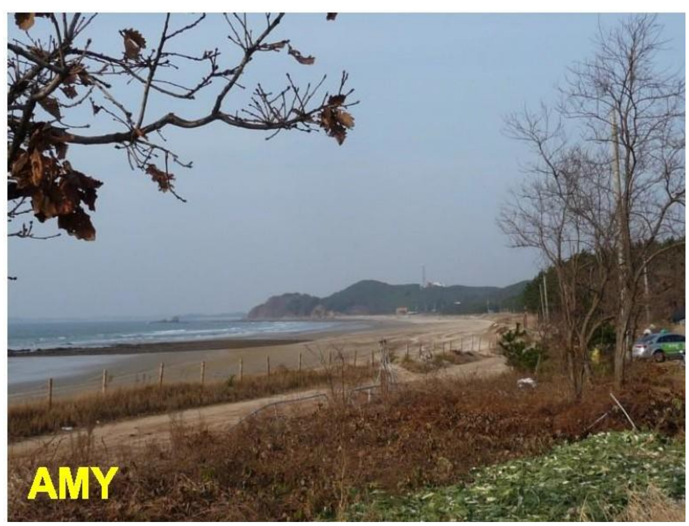

SPL


WHI



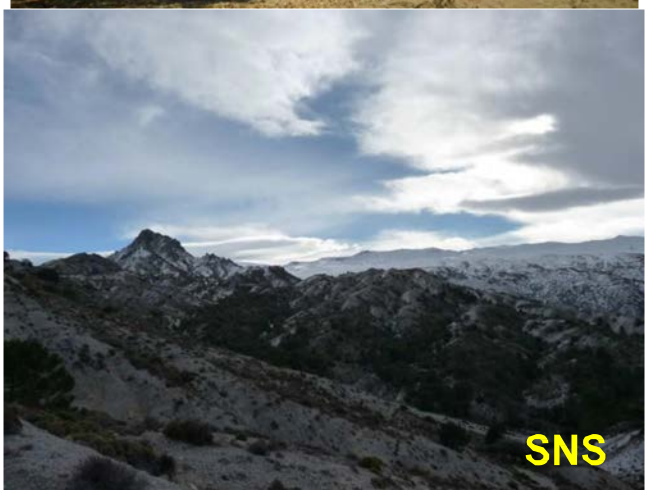

WLG

GSN




ARN


MSA


SNS


MSY


BEO


TIK


KPS


UGR


ZSF
ZUG
ZSF


SMR


MBO


CGO


CPT


SGP – closed 2017


WSA – closed 2000


THD – closed 2017