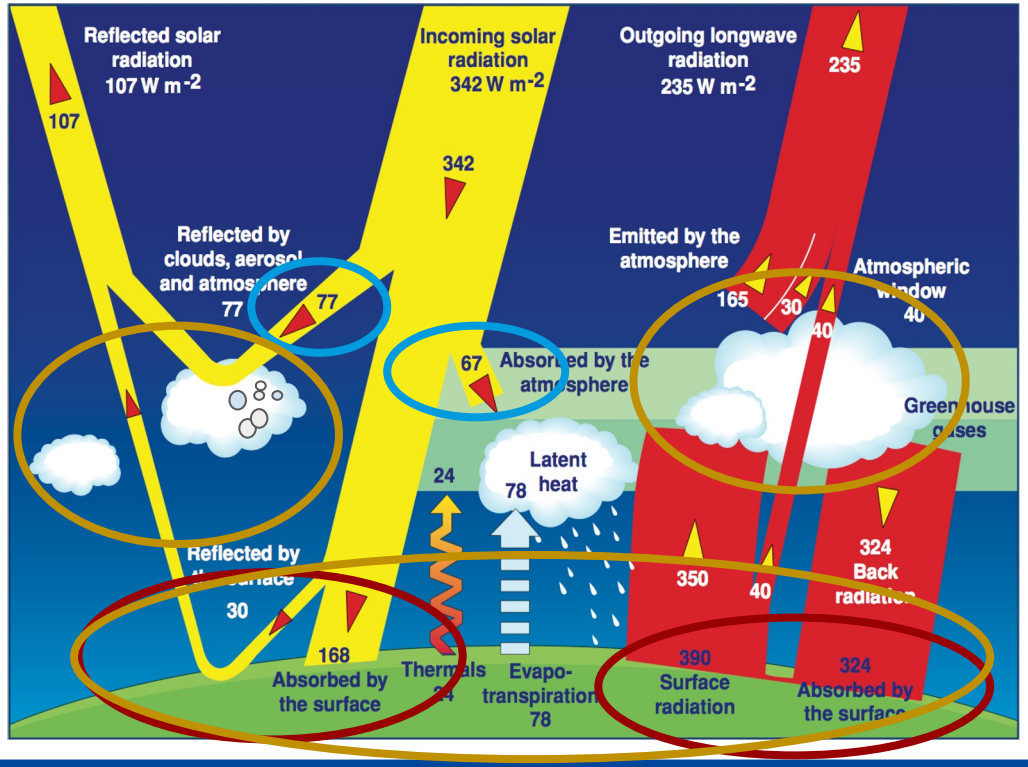
NOAA RESEARCH

Theme 2: Overview

Monitoring and Understanding Aerosols, Clouds, and Surface Radiation

Laura Riihimaki

Mission: Monitor aerosols, clouds, and surface radiation to reduce uncertainties in climate forcing and feedbacks, understand complex processes, and address societal challenges related to a changing climate.

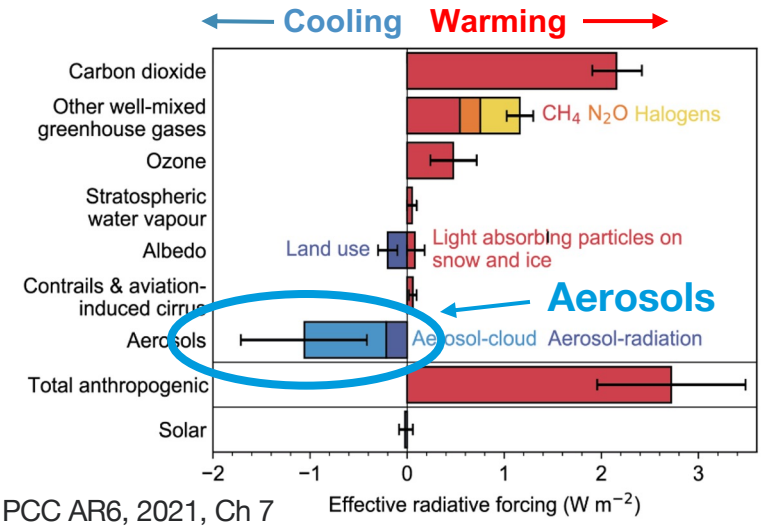


Outline

1. **Overview**
   Laura Riihimaki
2. **In situ Aerosols**
   Betsy Andrews
3. **Surface SW & LW radiation**
   John Augustine
4. **Cloud and PBL Processes**
   Joe Sedlar

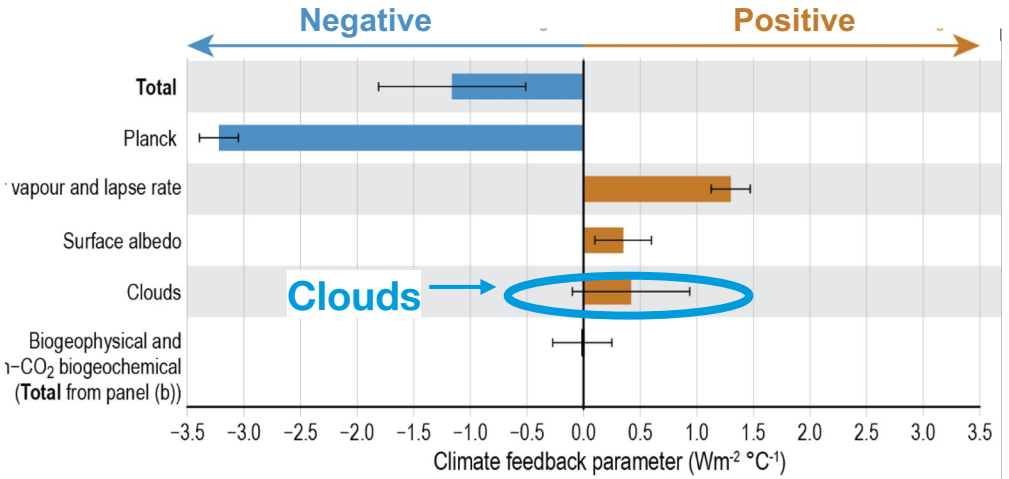
Mission: Monitor aerosols, clouds, and surface radiation to reduce uncertainties in climate forcing and feedbacks, understand complex processes, and address societal challenges related to a changing climate.

Aerosol radiative forcing the largest uncertainty in anthropogenic forcing



IPCC AR6, 2021, Ch 7

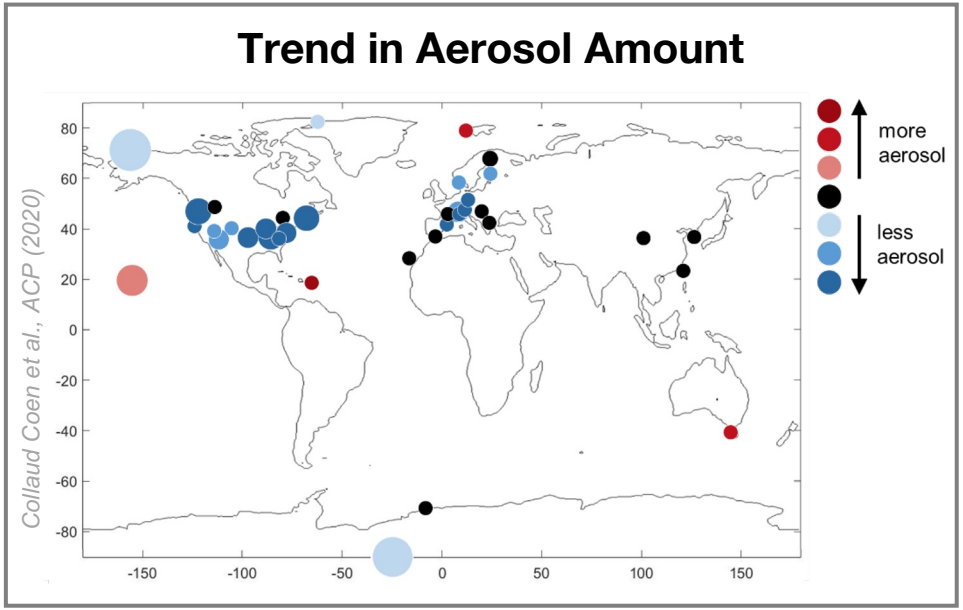
Cloud radiative feedback most uncertain climate feedback mechanism

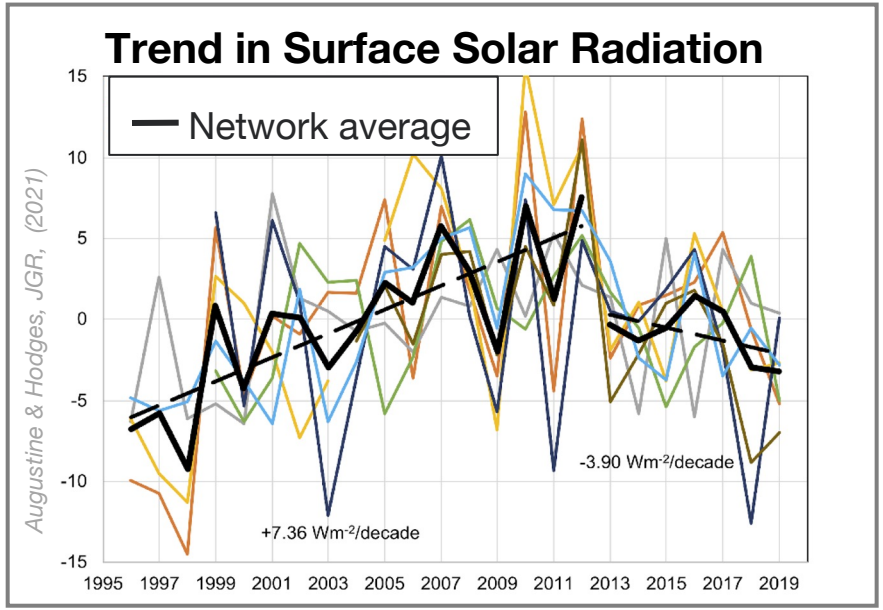


IPCC AR6, 2021, TS17

Relevance: Networks are long-term, high-quality, in strategic locations to reduce climate uncertainties and understand processes.

- **Long-term** measurements allow us to separate anthropogenic influences on climate from internal variability. (*Betsy and John's talks*)





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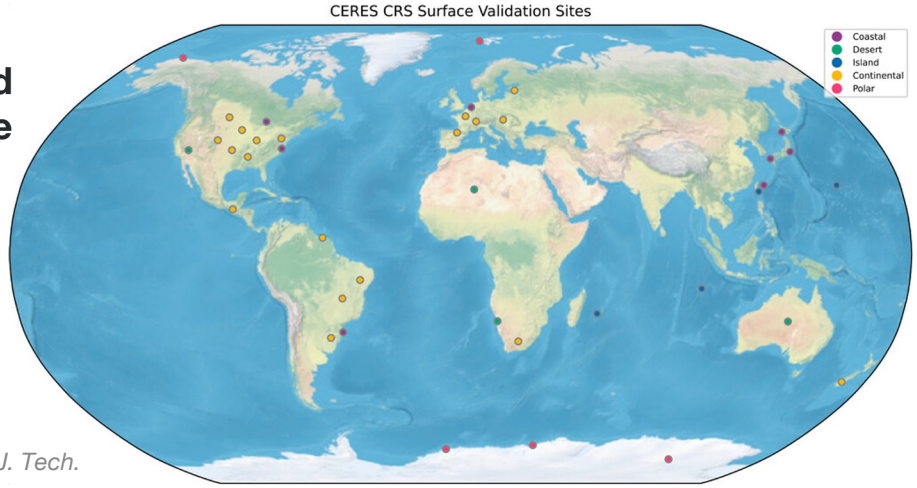
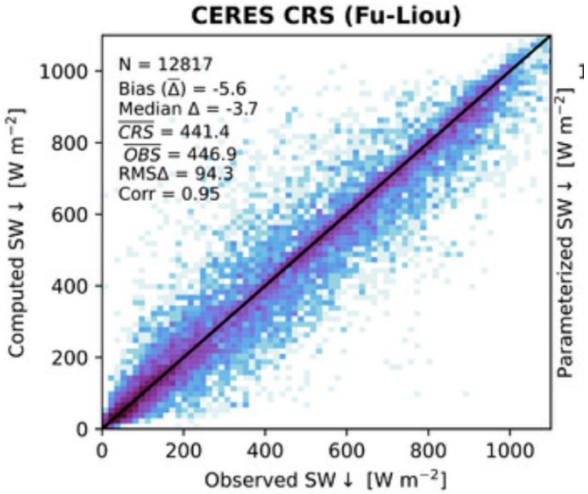
- **Long-term** measurements allow us to separate anthropogenic influences on climate from internal variability.
- **High-quality** measurements are needed to reliably detect changes & provide a critical data source for evaluating satellite-based products and models.

Sites used to validate CERES satellite derived products



Scott et al. (2022) J. Tech.



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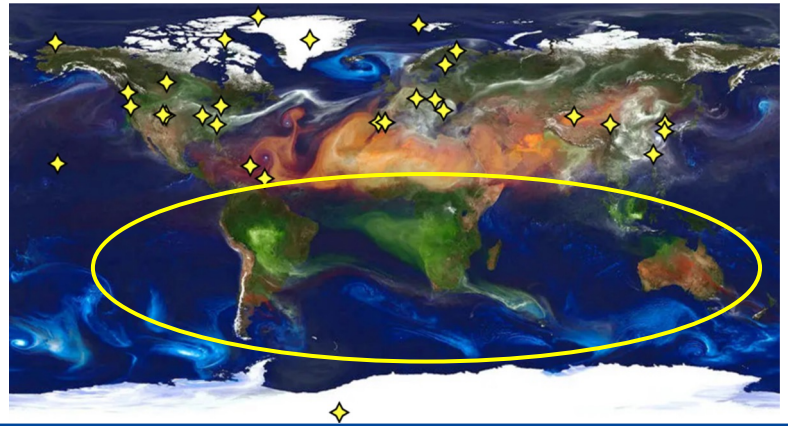
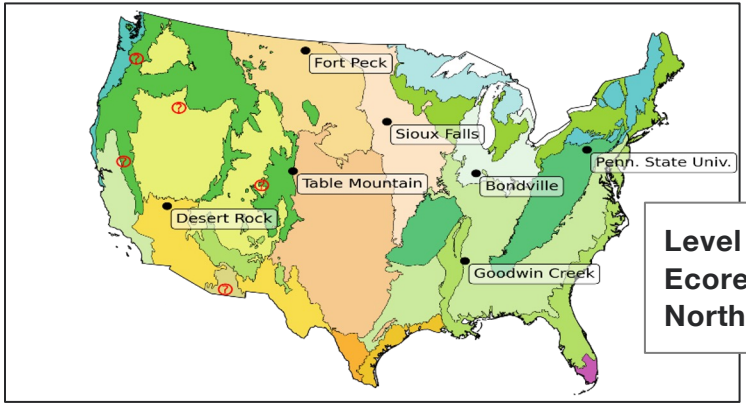
- **Long-term** measurements allow us to separate anthropogenic influences on climate from internal variability.
- **High-quality** measurements are needed to reliably detect changes & provide a critical data source for evaluating satellite-based products and models.
- **Strategic locations** allow us to determine processes relevant to different climate regimes, though there are gaps we would love to fill!

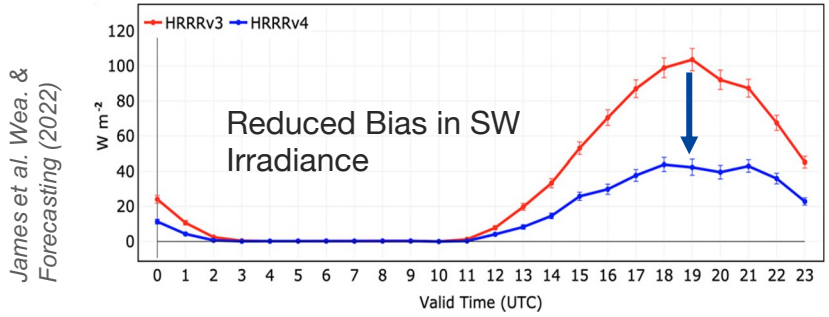




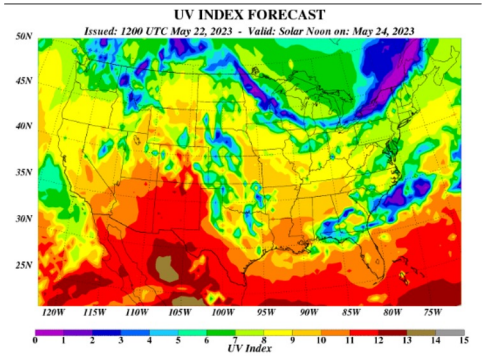
Level II Ecoregions of North America

Relevance: We are sought out to help address societal challenges because of our expertise and the quality of our measurements.

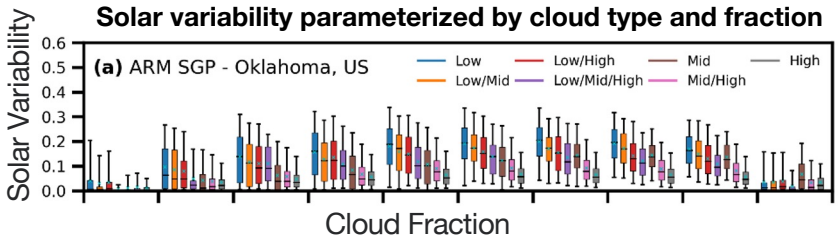
Improve weather forecasts (HRRR/RAP/RRFS) in collaboration with GSL



Evaluate UV index forecasts

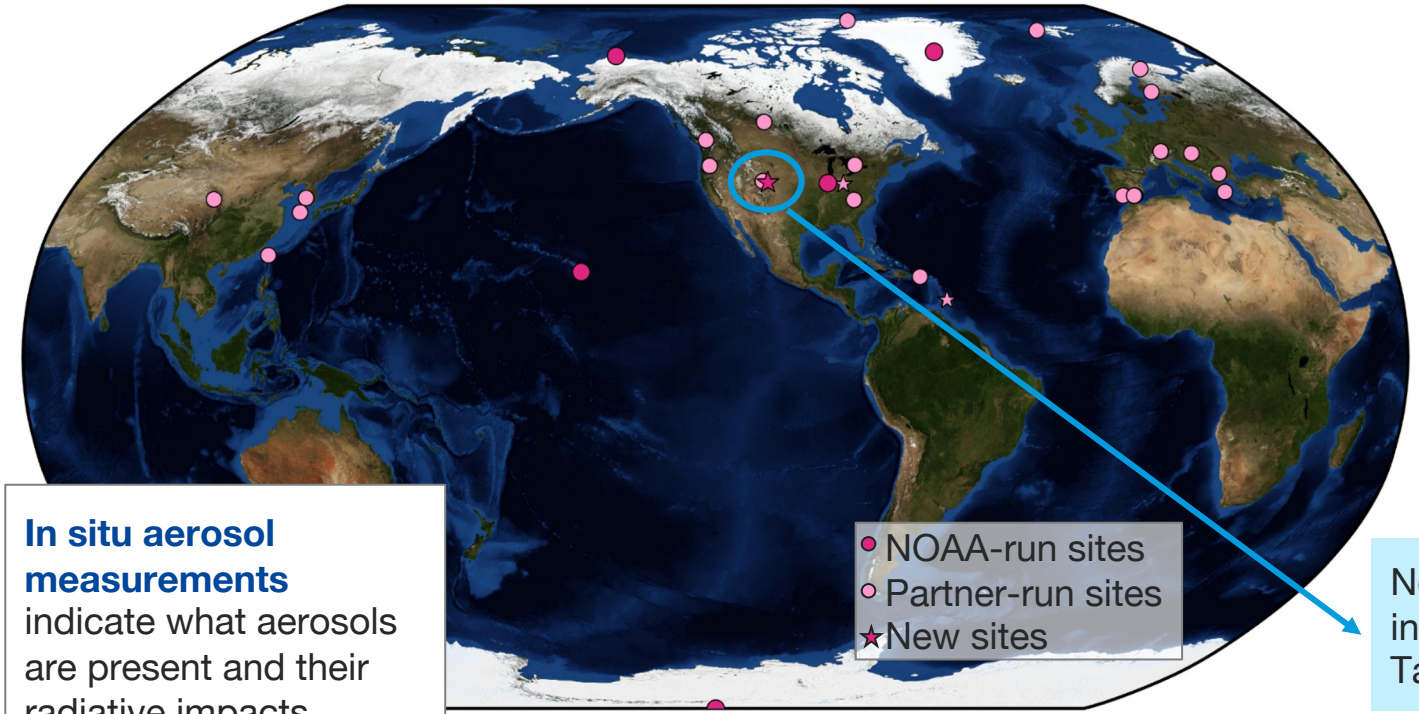


Improve understanding and forecasts for renewable energy (*tour*)



Wildfire research to 1) study radiative impacts and transport of smoke plumes 2) environmental conditions that lead to wildfires and wildfire evolution (*tour*)

Capabilities: Our measurement networks are at the heart of our science



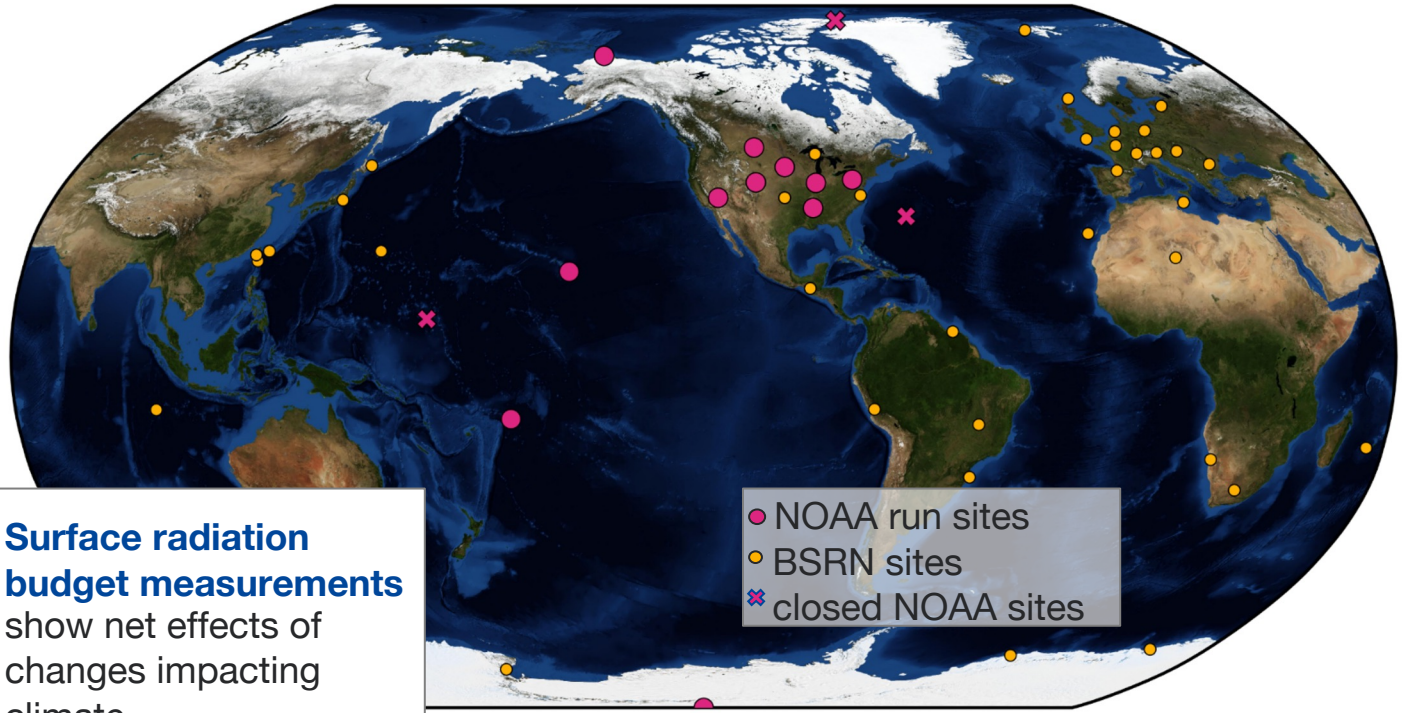
NOAA Federated Aerosol Network

- **30** active stations
- **870** cumulative years of data
- **32** distinct measurement types
- Data in **4** archives

In situ aerosol measurements indicate what aerosols are present and their radiative impacts

New NFAN station installed to make Table Mt a supersite!

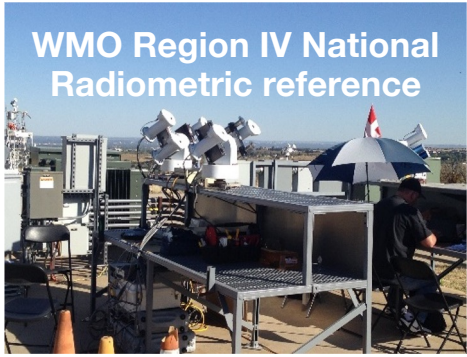
Capabilities: Our measurement networks are at the heart of our science



Surface radiation budget measurements show net effects of changes impacting climate

SURFRAD & Observatories

- **11** active stations
- **519** cumulative years
- **39** distinct measurement types
- Data in **5** archives



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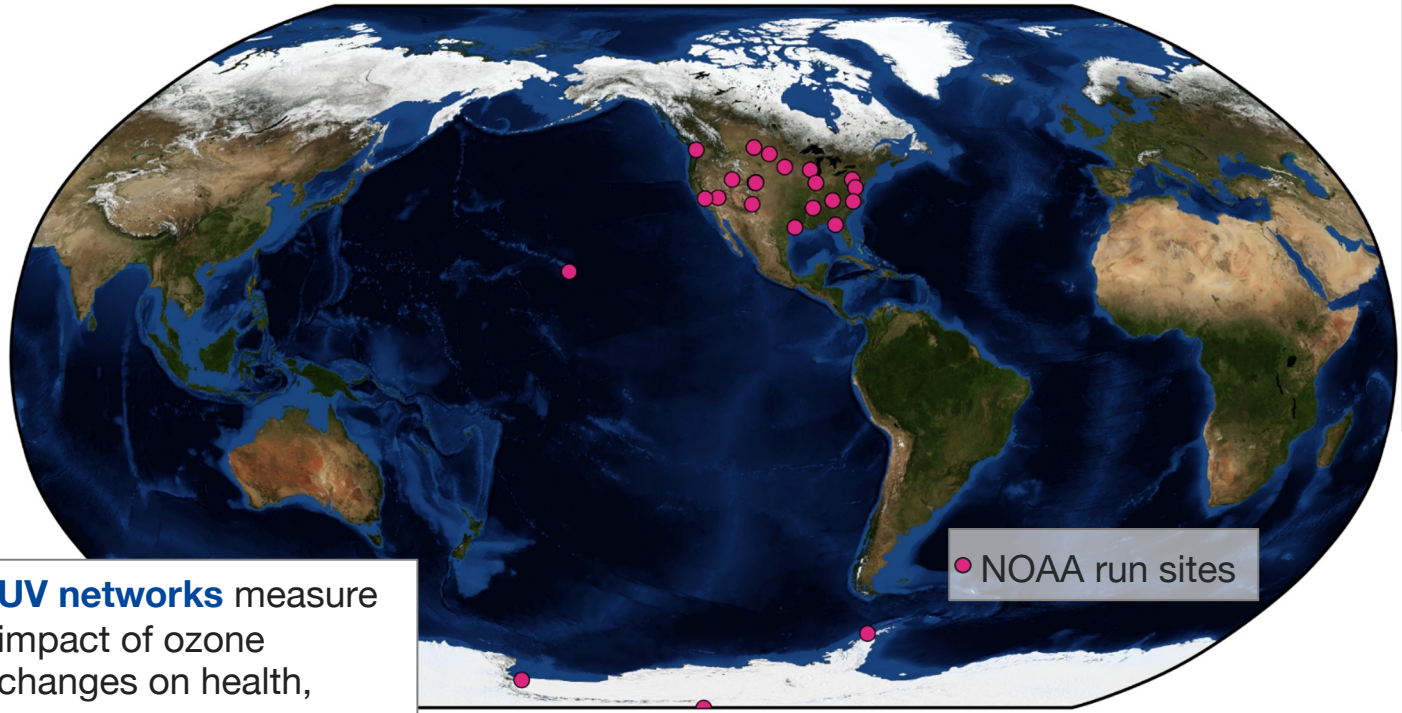
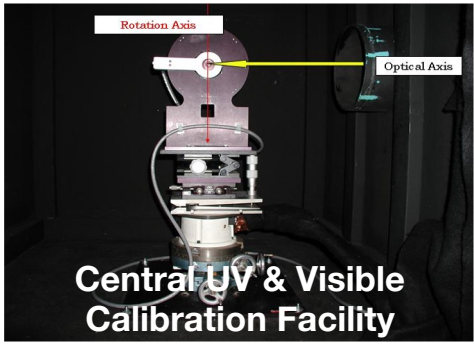


Neubrew, NIWA AntUV, SURFRAD/SOLRAD

- **22** active stations
- **681** cumulative years
- **21** distinct measurement types, spectral UV & column Ozone
- Data in **4** archives

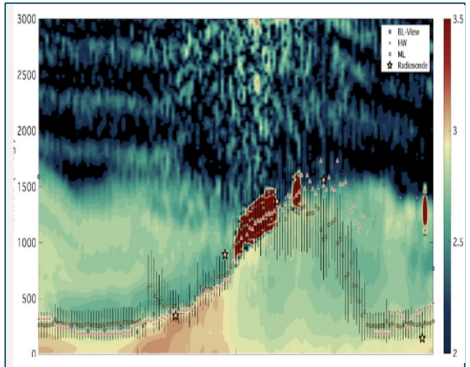
UV networks measure impact of ozone changes on health, agriculture, etc



Capabilities: New instrumentation, products, and collaborative efforts to gain insight into complex processes

Example of new instrumentation & science *(Joe's talk)*

Ceilometers installed at SURFRAD & mobile deployments



PBL retrieval overlaid on ceilometer backscatter

New data products including cloud type and boundary layer height

SPLASH Field campaign with GML, ARL, PSL instruments

Participated in collaborative short & long-term campaigns

Accomplishments

4 collaborative field campaigns

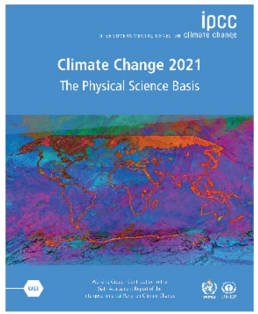
- CHEESEHEAD, SPLASH, WFIP3, Bondville

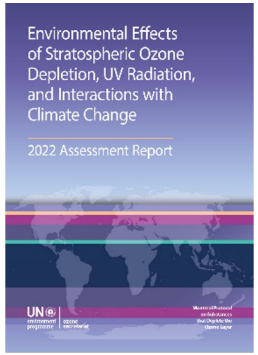
Table Mt, CO supersite

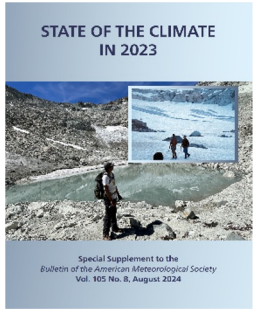
- In situ aerosol, ozone, UV, ARL surface energy fluxes, GHG

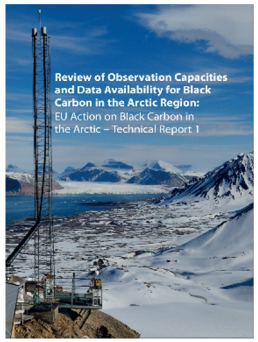
New aerosol property algorithms developed for evaluation of NESDIS satellite products & HRRR-smoke (tour)

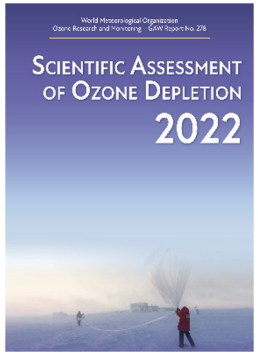
Capabilities: Global leadership in measurements & science (2018-2024)

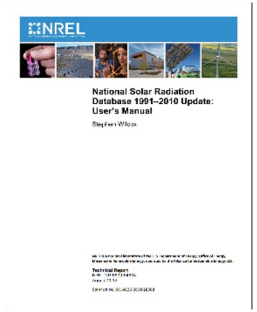












GRAD Leadership by the Numbers

- >20 Funded proposals/contracts beyond base (NOAA, DOE, NASA, USDA, EU)
- 124 Publications
- 6 NOAA/CIRES/External awards
- 8 Contributions to major reports
- 7 Data in international archives
- Scientific committee leadership
  - 13 International Organizations
    - **BSRN Project management**
  - 3 National Organizations
  - 3 NOAA OAR Organizations
- 2 WMO regional calibration facilities

Infrastructure: Investing in science by advancing technology

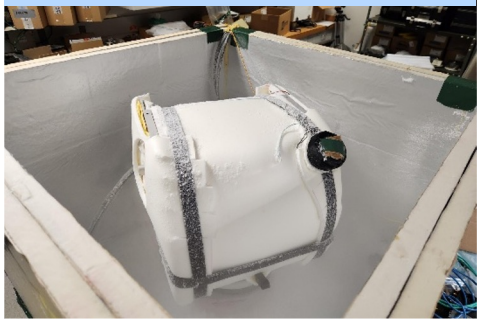
Upgrading instrumentation & infrastructure to maintain excellence

Unite network processing, methods as appropriate for efficiency

Began **upgrading instrumentation & infrastructure**

Current tracker

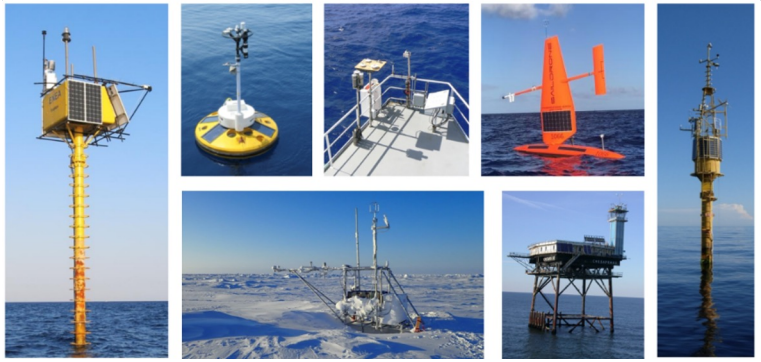
Testing new tracker for South Pole



Technological innovation & leadership

Collaboration with ocean communities

Testing new **spectral instrumentation**



Riihimaki et al. (2024), Frontiers in Marine Science

Future vision

The next three talks highlight research in aerosols, radiation, clouds and atmospheric processes reinforcing these main points:

1. Ensure **high-quality, robust, long-term observations** into the future to **diagnose** the causes of trends and variability in aerosols, clouds, and surface radiation and **reduce climate uncertainties**.
2. Research **complex processes** impacting the surface energy balance through **collaborative efforts and innovative technology** to **address societal challenges related to a changing climate**.

NOAA RESEARCH

Thank you!

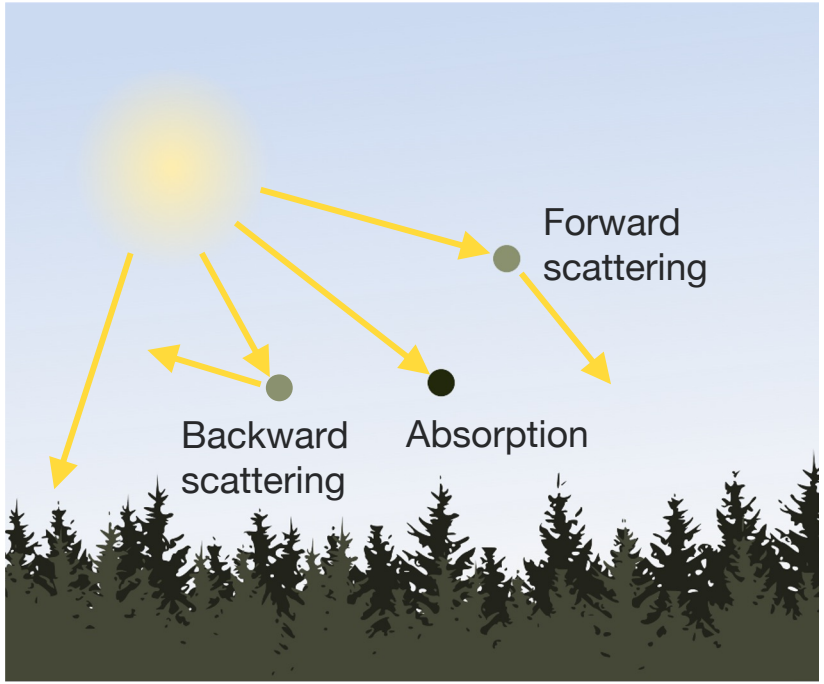
NOAA RESEARCH

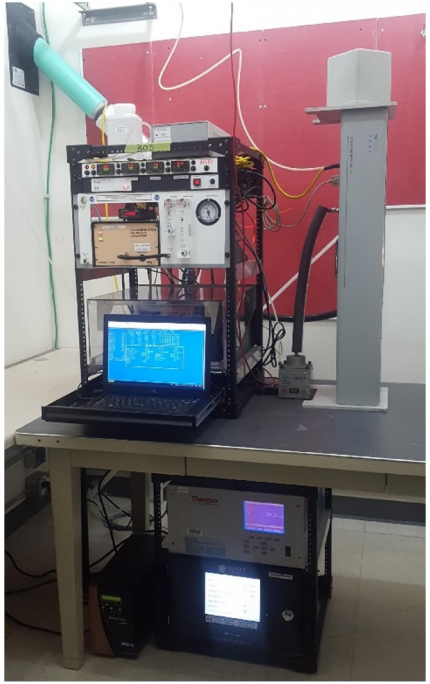
Theme 2: In-situ aerosol optical properties

Monitoring and Understanding Aerosols, Clouds, and Surface Radiation

Betsy Andrews

In-situ aerosol optical properties





- **Surface cooling**: sunlight is prevented from reaching the Earth's surface
- **Atmospheric warming**: energy is transferred as heat by absorbing particles

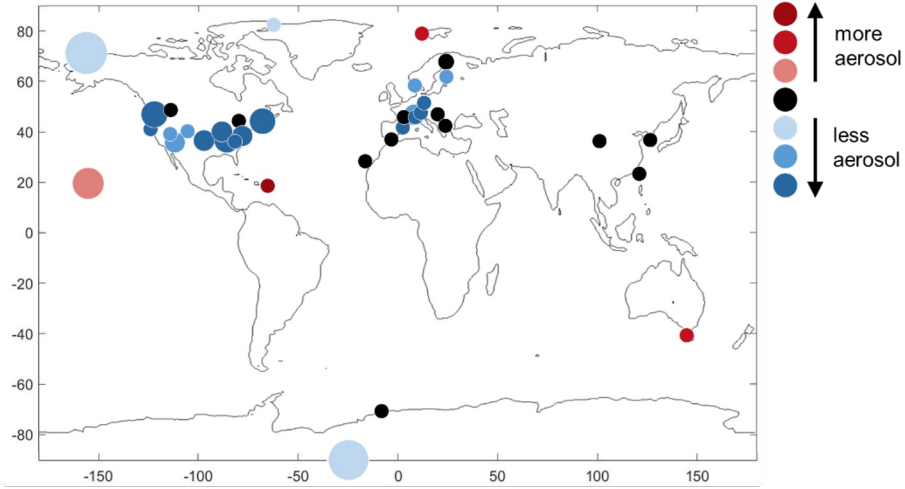
Science Goals: Diagnose key aspects of Earth's climate system relating to aerosols and help to reduce the uncertainty in estimates of aerosol effects.

How does the spatial and temporal variability of aerosol properties reflect changes in sources?

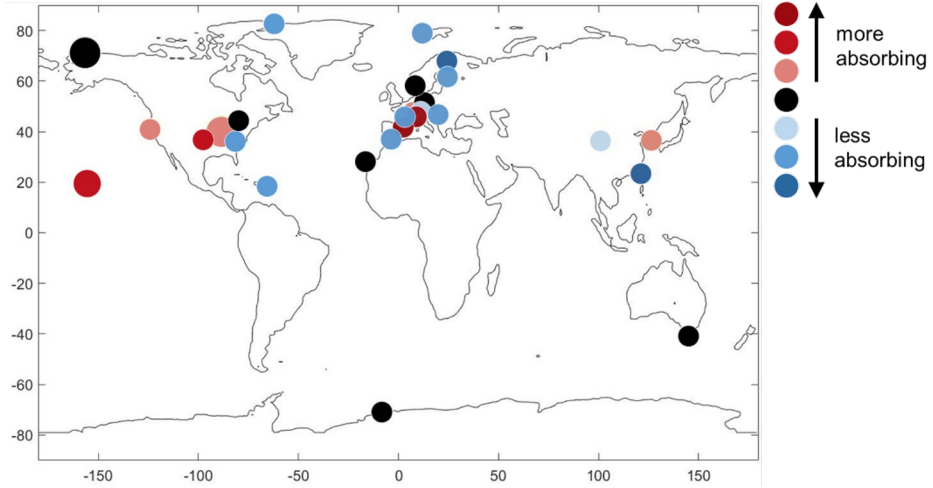
How do aerosol properties influence and respond to a changing climate?

How can our measurements be used to improve aerosol representation in climate models?

Amount of aerosol is decreasing



Change in aerosol characteristics varies with location



Collaud Coen et al., ACP (2020)

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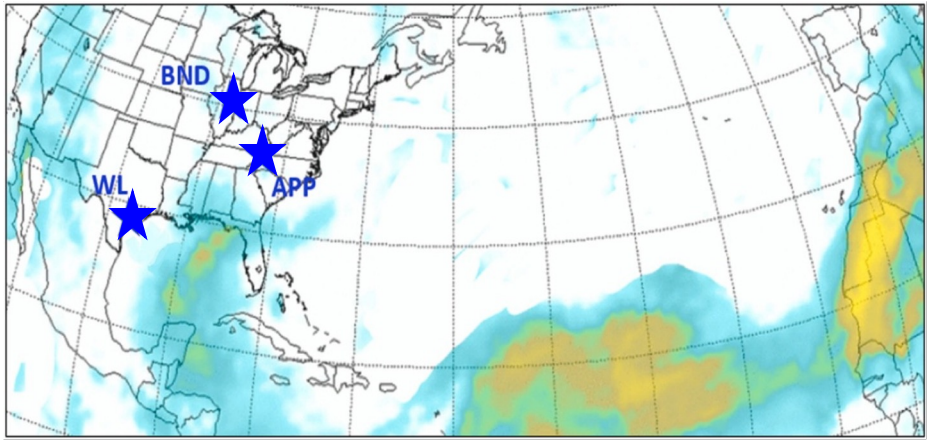
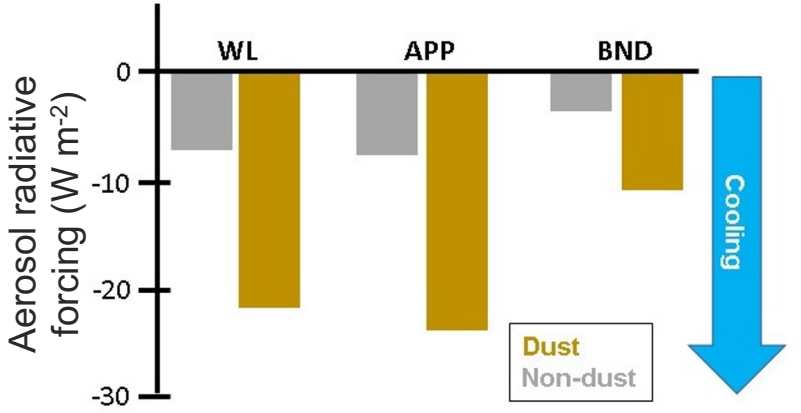
Satellite image of “Godzilla” dust event, June 2020



Dust impacts surface aerosol forcing



Mehra et al., Atmos. Enviro. (2023)

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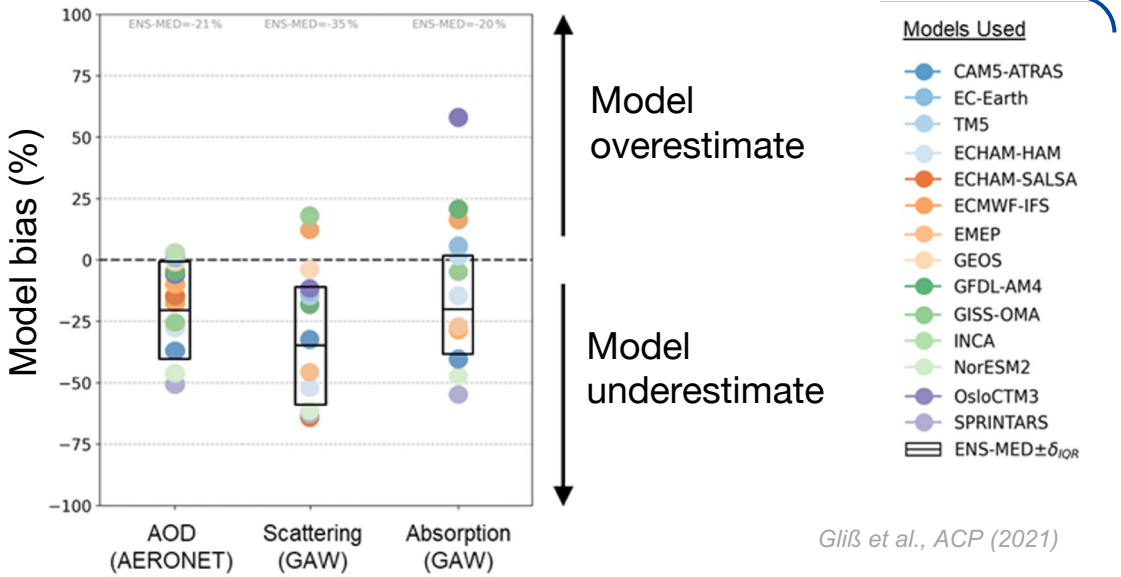
Models consistently underestimate aerosol measurements

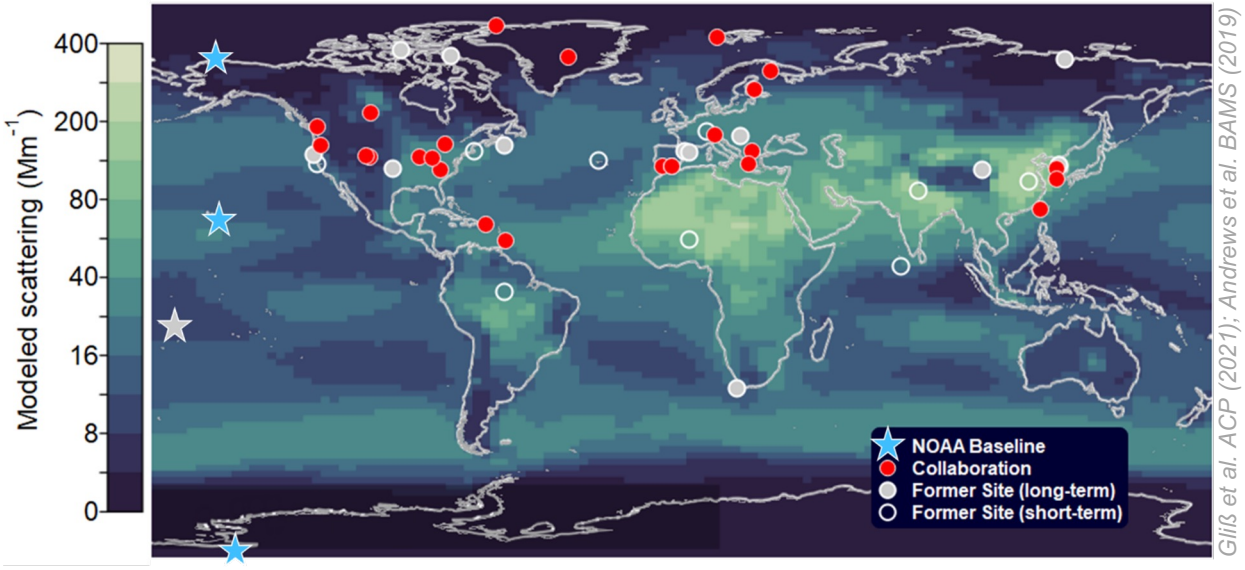


Gliß et al., ACP (2021)

What makes us uniquely suited to answer these questions?

- Collaboration and coordination extend science and reach of GML
- Software and protocols ensure consistency of measurements

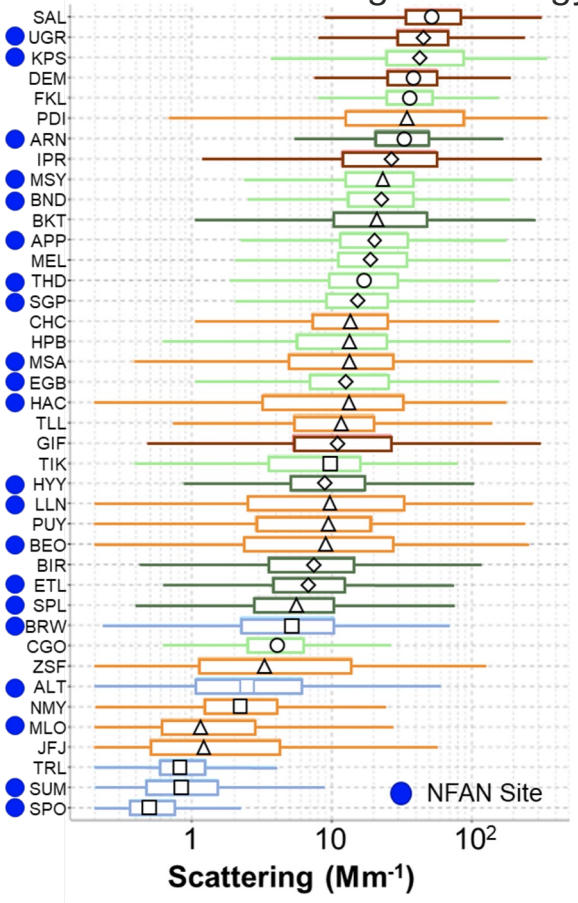
NOAA Federated Aerosol Network (NFAN)



Gliß et al. ACP (2021); Andrews et al. BAMS (2019)

Baseline measurements started 1970s, NFAN started 1992

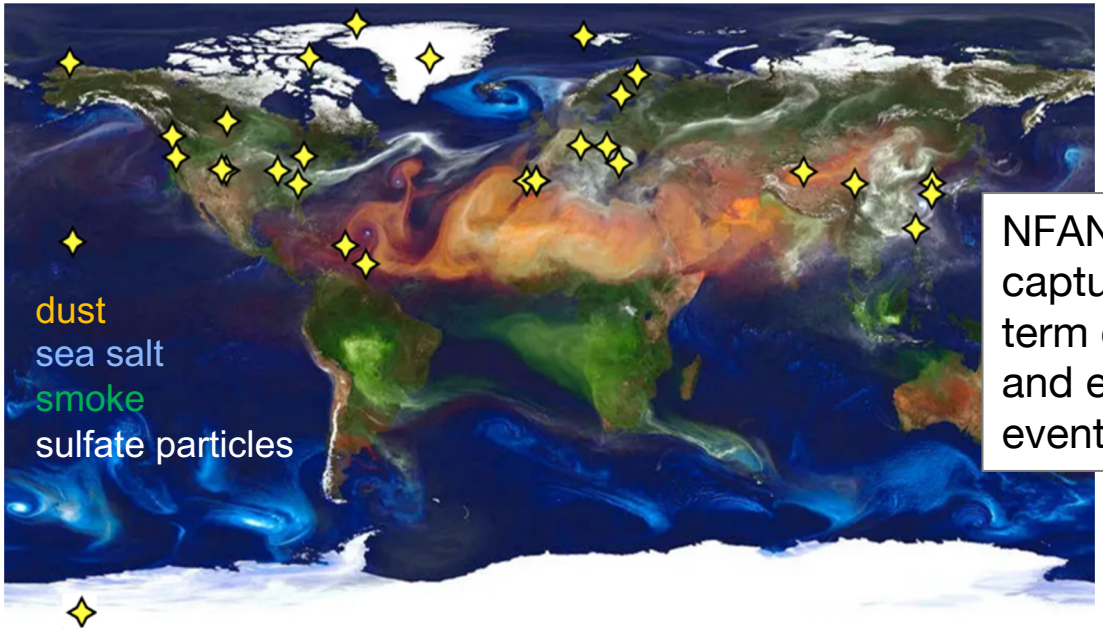
GAW in-situ scattering climatology



Laj et al. AMT (2020)

Relevance: Health, security, and economic well-being are challenged by extreme events tied to climate and weather.

- Regulatory efforts have decreased anthropogenic emissions of aerosols.
- Climate change has increased aerosol emissions from extreme events.

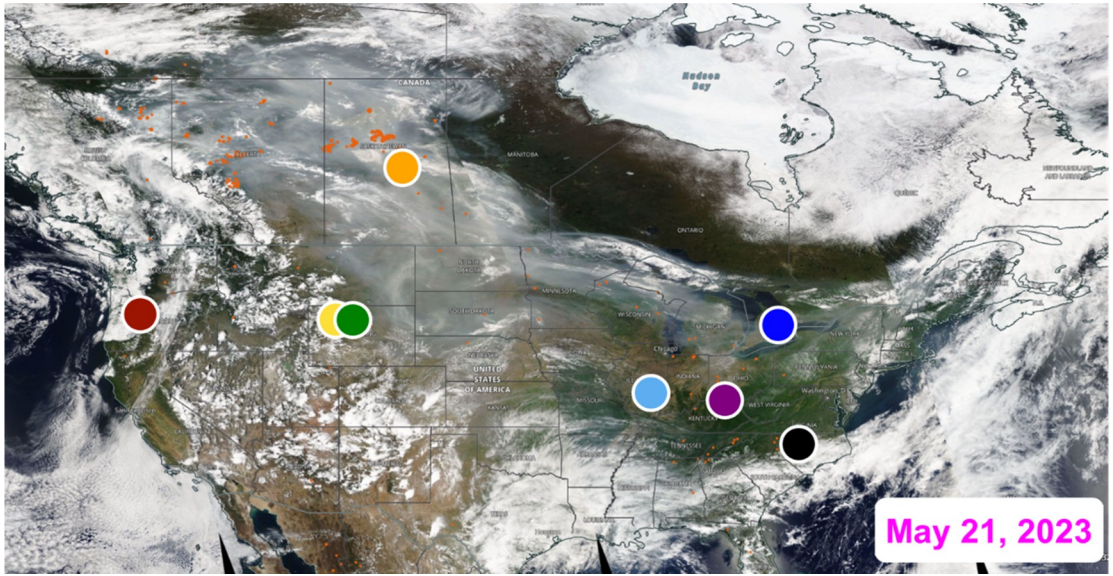


NFAN sites capture long-term change and extreme events.

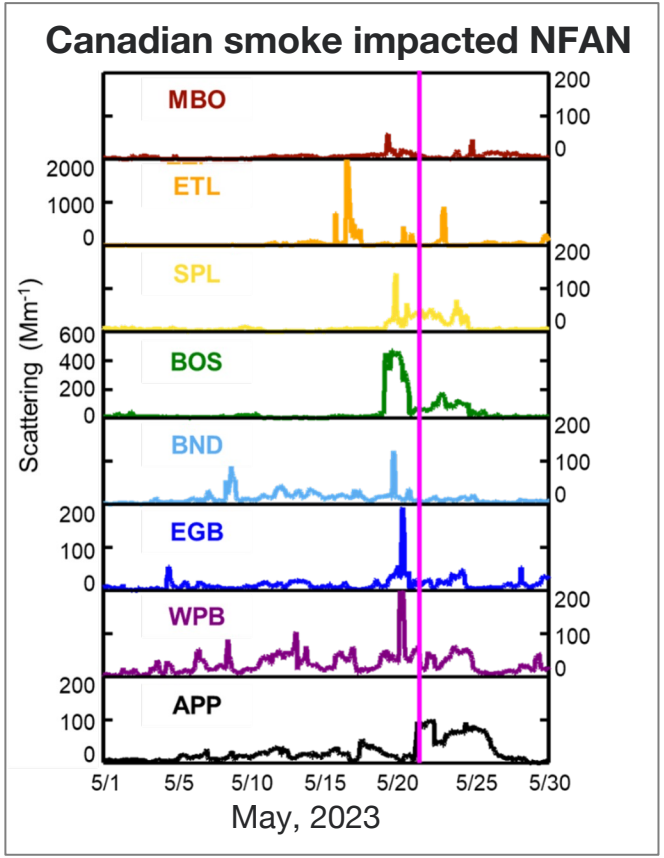
https://www.nasa.gov/multimedia/imagegallery/image_feature_2393.html

NFAN samples extreme events: 2023 Canadian wildfires

- Aerosol optical properties of smoke were measured at multiple NFAN sites across US & Canada
- Some of these regions reported the worst air quality in the world during this event

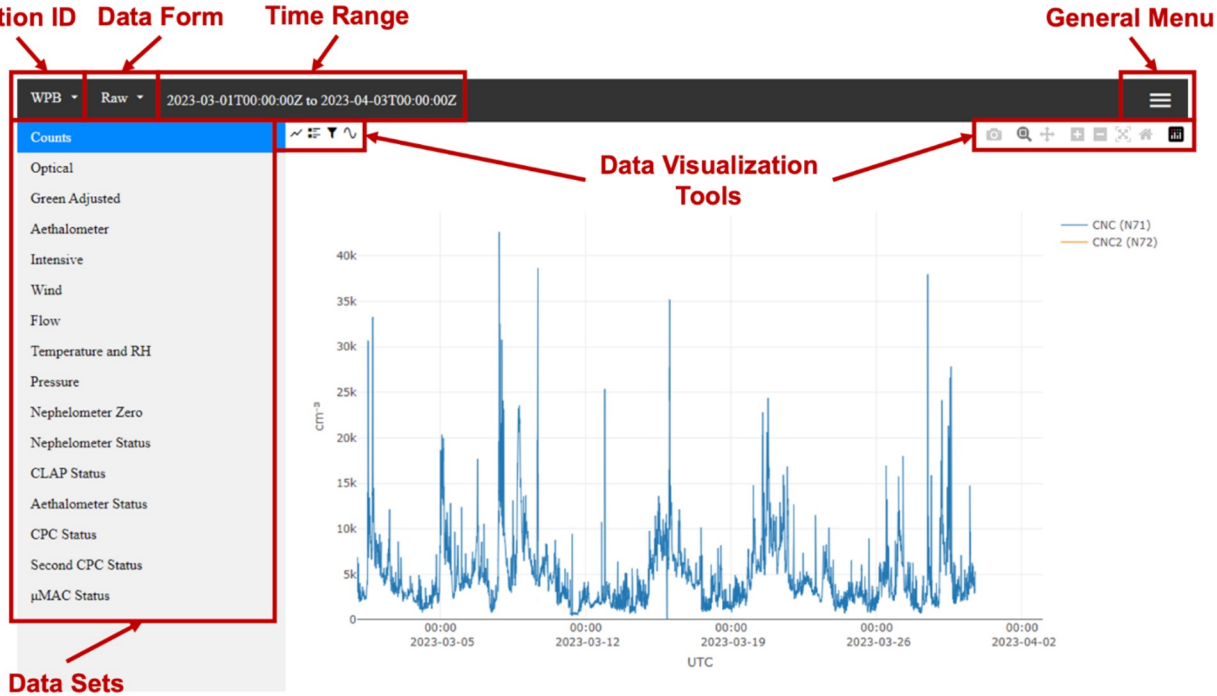


NASA WorldView with fire overlay



NFAN operations: Maintaining high quality measurements takes work

- Instrument maintenance
- **Documentation**
- Training
- Data QA/QC
- **Software** development
- New instrument evaluation
- Site visits
- Shipping & supplies



➡ **Documentation and software are key to supporting our NFAN partners**

Aerosol group by the numbers (2018-2024)

2 CIRES scientists: Elisabeth Andrews & Erin Boedicker
1 CIRES programmer: Derek Hageman - contributes across GML divisions

OPERATIONS

- **6** NOAA sites
- **2** new instrument types
- **24** NFAN partner sites
- **1** new software package
- **270,000** data points/h

RESEARCH

- **45** co-authored papers:
  - Model evaluation
  - Trends and climatology
  - Instrument evaluation
  - And more!

FUNDING

- **~$200k** in 2024
  - **3** proposals
    - DOE/ASR
    - DOE/ARM
    - EU
  - **1** memorandum of understanding

COMMUNITY RESOURCE

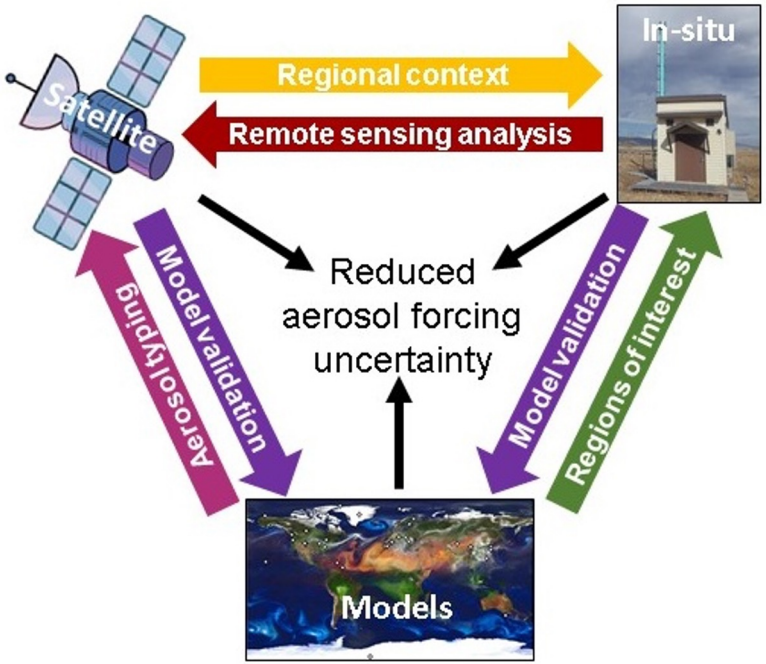
- **5** invited lectures
- **1** invited contribution to WMO/GAW Climate and AQ Bulletin
- **>100** US & international collaborators

MENTORING

- **15** students & post-docs mentored
  - **2** post-docs
  - **7** graduate students
  - **5** undergraduate students
  - **1** high school student

Future directions

- Aerosol properties vary significantly with source, composition, and atmospheric processing.
- Remote sensing retrieves limited aerosol information; models struggle to represent aerosol.



Adapted from Kahn et al. Rev. Geophys. (2023)

(1) Work with modelers to evaluate models and improve aerosol representation
Surface in-situ measurements underutilized

(2) New aerosol instruments for process level understanding
Sub-micron size distribution, CCN, chemistry

(3) In-situ aerosol vertical profiles
Surface is different than above;
profiles useful for remote sensing validation

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Thank you!

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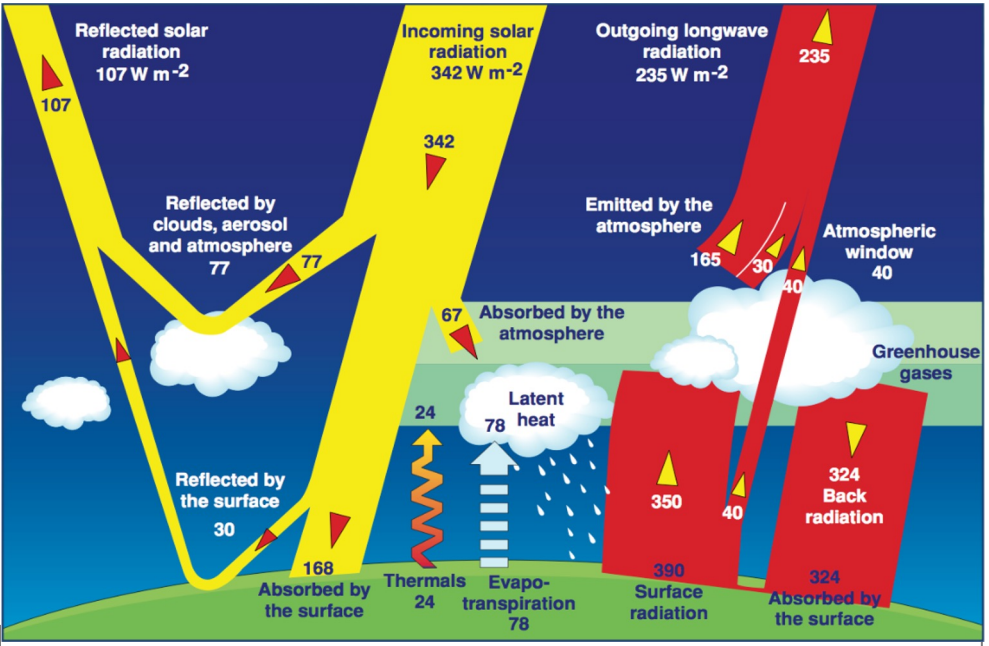
Theme 2

Shortwave and Longwave Radiation

John Augustine

Penn State SURFRAD Site

Main science goal: To monitor climate and climate change through the lens of surface radiation long-term variability and trends



Why do we measure the net surface radiation?

It is the energy available at the surface to heat air & evaporate water, the energy that fuels weather & builds the boundary layer.

Research questions:

How does **net surface radiation vary** across various time scales and climates?

What are the **primary causes of the observed variability** — clouds, aerosols?

How do **anthropogenic forcing and internal variability** in the climate system affect surface radiative forcing in the long term?

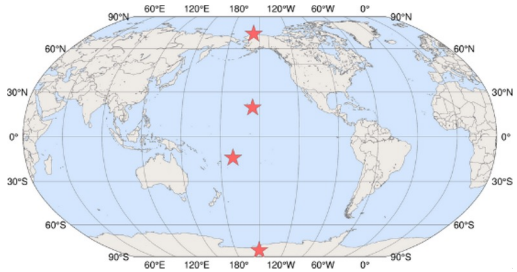
How are we uniquely suited to these tasks?

- GML is a recognized world leader through our roles in the WMO Baseline Surface Radiation Network (BSRN) and working groups.
- Our networks abide by rules for “climate quality” measurements:
  1. Calibrations are traceable to **world standards**.
  2. We do frequent calibrations and instrument exchanges.
  3. Incoming and outgoing instruments are compared.
- Ancillary measurements and products of AOD, cloud fraction, cloud base height, aerosol layers, etc. aid interpretation of the radiation observations.

World Radiometric Reference, Davos

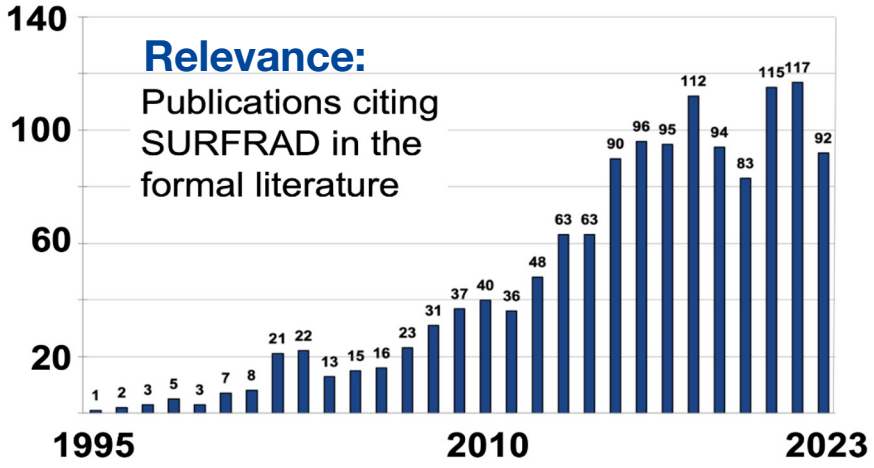
Radiation network metrics

SURFRAD Network (1995)
Surface Radiation Budget



Global Baseline Surface Radiation Network (1958)

High-quality radiation measurements and data format are the same for both networks. Currently, upgrading and modernizing instruments across networks

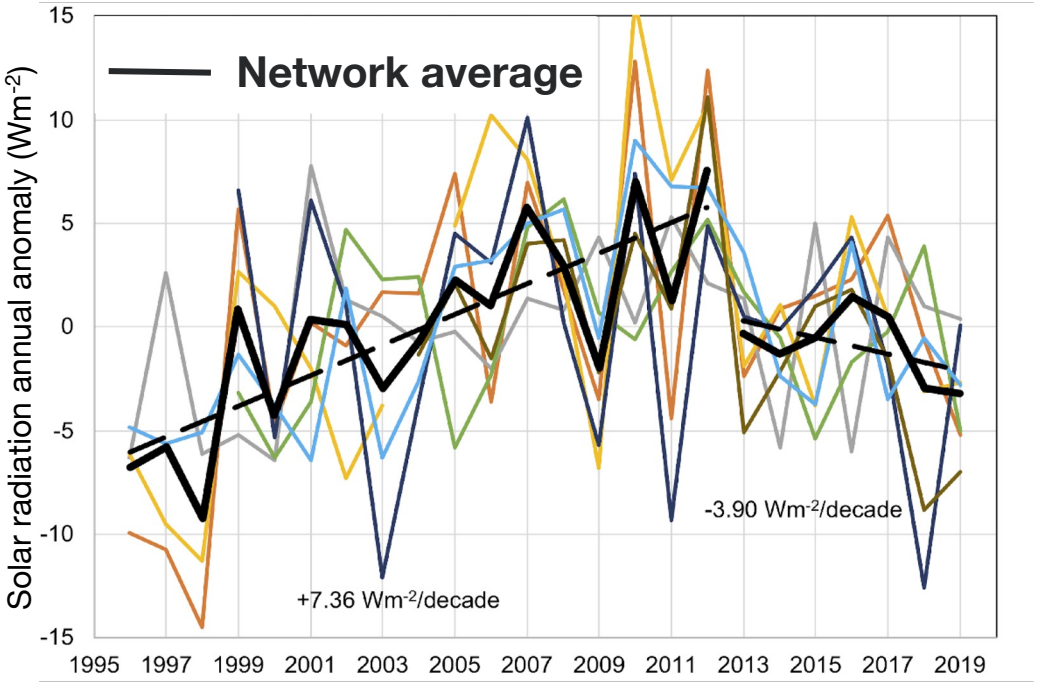


Data archived and accessible at:

- NCEI (1 min. NetCDF and hr. average text files)
- WMO BSRN Archive
- World Radiation Data Center
- GML (QC'd and released daily, monthly averages)
- AOD sent to the GAW archive

Science highlights #1: Long-term radiation trends

Solar annual anomalies across 7 U.S. sites

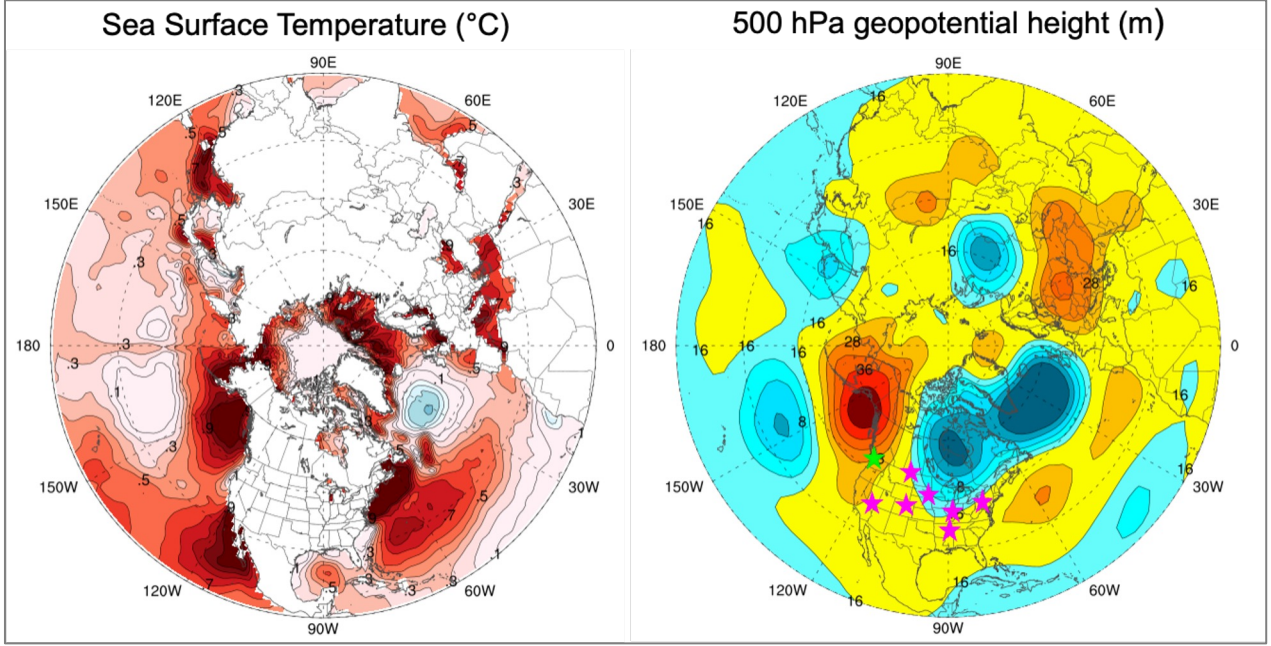


- We've documented significant decadal-scale trends in surface solar radiation over the U.S.
- Variability is due to changes in cloudiness
- And could not be explained by decreasing aerosols

Augustine, J. A. & G. B. Hodges, 2021, JGR Atmospheres

Decadal-scale surface radiation trends could be explained by the effect of long-term SST variability on the upper-level atmospheric long-wave pattern

2013-2019 Anomalies



Relevance:

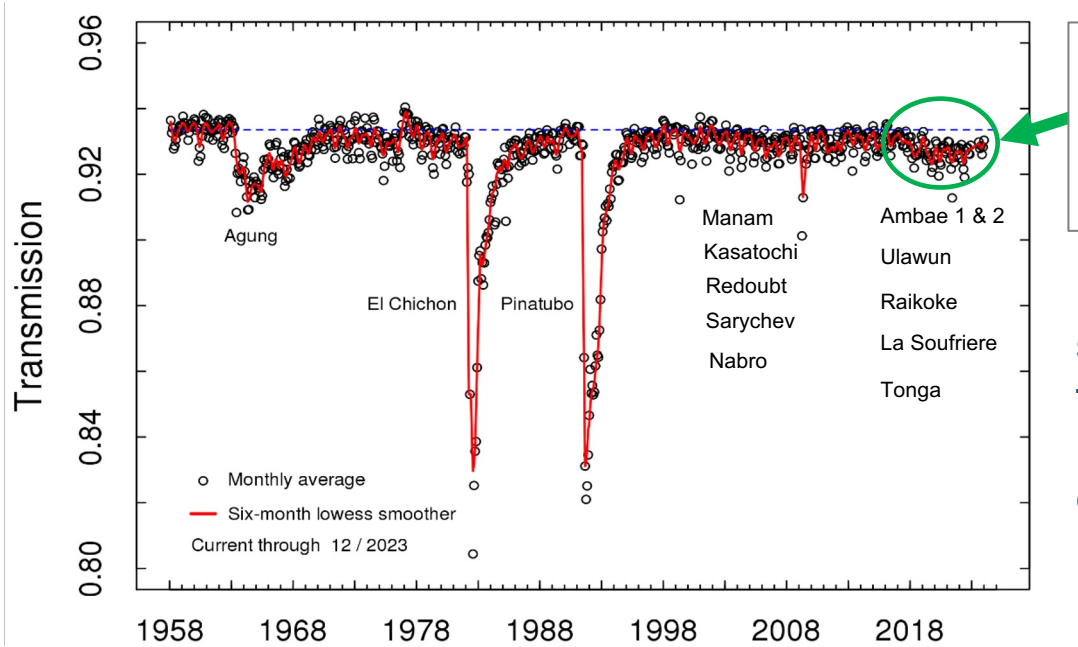
Long-term forecasts (e.g. drought) may be improved if internal variability (SST patterns) is simulated well by models

Augustine, J. A., & A. Capotondi, 2022, JGR Atmospheres

Science highlight #2: Mauna Loa stratospheric aerosol record

Atmospheric solar transmission has been measured at Mauna Loa since 1958

It is one of GML's longest records → It is <u>accurate and precise</u> → Good estimate of the surface radiative effects of stratospheric aerosols

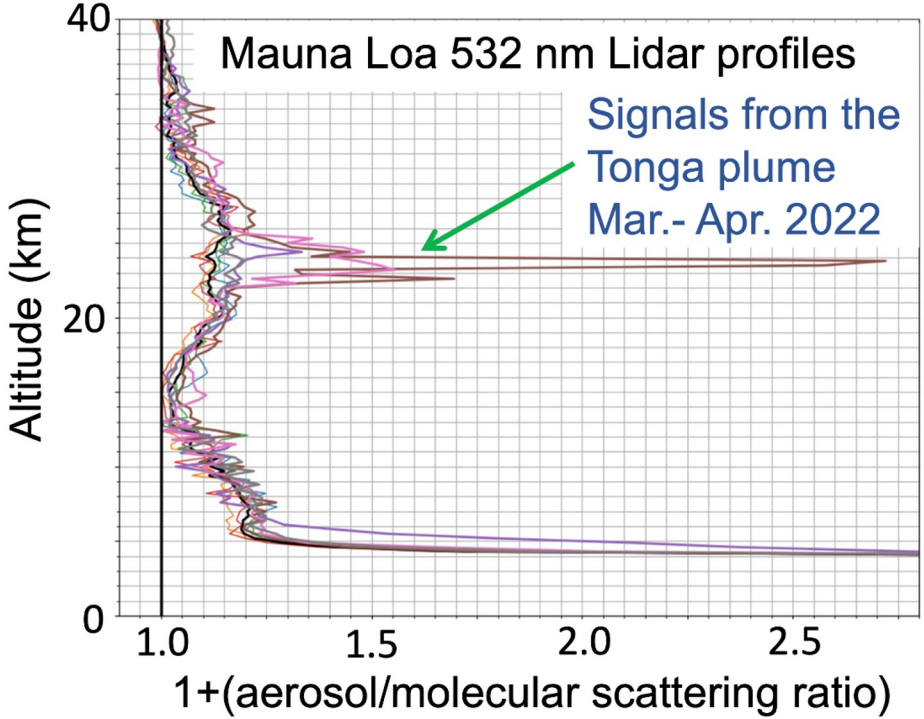


Confirmed by POPS balloon measurements described in a paper co-authored by Lizzy Asher

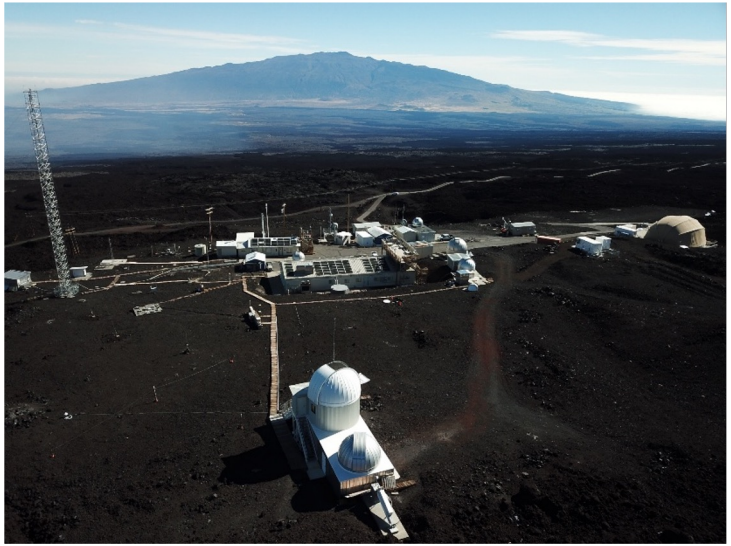
(Yu et al. 2023 GRL)

Relevance: The ability to **detect subtle changes in atmospheric transmission** demonstrates that this product should be able to **detect and quantify geoengineering efforts** that inject aerosols into the stratosphere

An aerosol Lidar has operated at Mauna Loa for over 50 years!

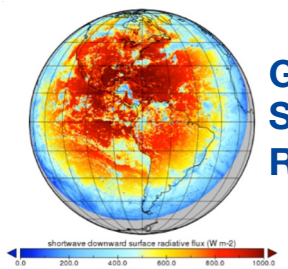


The Lidar complements atmospheric transmission with vertical information – shows where the aerosols are located

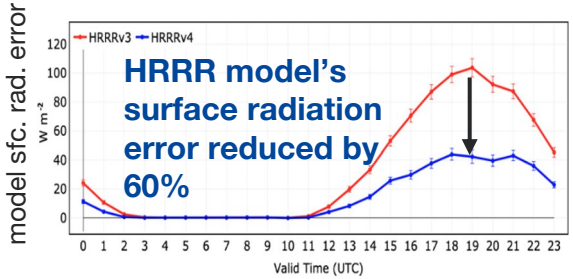


Why it matters? (societal importance/stakeholders)

- Surface radiation variability relates to societal concerns such as **wildfire, drought, water availability, and heat**.
- **Satellite** estimates of surface radiation are global but are modeled from upward signals received above TOA. Our validation measurements are **valued and highly relevant** to the missions of NESDIS, NASA, ESA.
- **Validation of weather model** surface radiation, albedo, clouds, boundary layer height has led to NWP model forecast improvements.
- Our near-real-time solar measurements (released every 15 min.) are valued by the **Renewable Energy** community (*K. Balmes poster*)



GOES Surface Radiation



Future directions

- **Broaden collaboration** with weather and climate modelers, others
- **Collaborate more with other NOAA laboratories,** e.g., work with ARL get the complete surface energy budget at SURFRAD sites (*Joe Sedlar's talk*)
- Develop **new technology and products** for better understanding surface radiation variability (*Hagen Telg's poster*)
- Improve instrumentation and expand networks to **unrepresented regions,** such as the Pacific Northwest to capture drought and wildfire potential, stratocumulus regions, Southeast U.S., others

NOAA RESEARCH

Thank you!

NOAA RESEARCH

Theme 2: Cloud and Planetary Boundary Layer (PBL) Processes

Monitoring and Understanding Aerosols, Clouds, and Surface Radiation

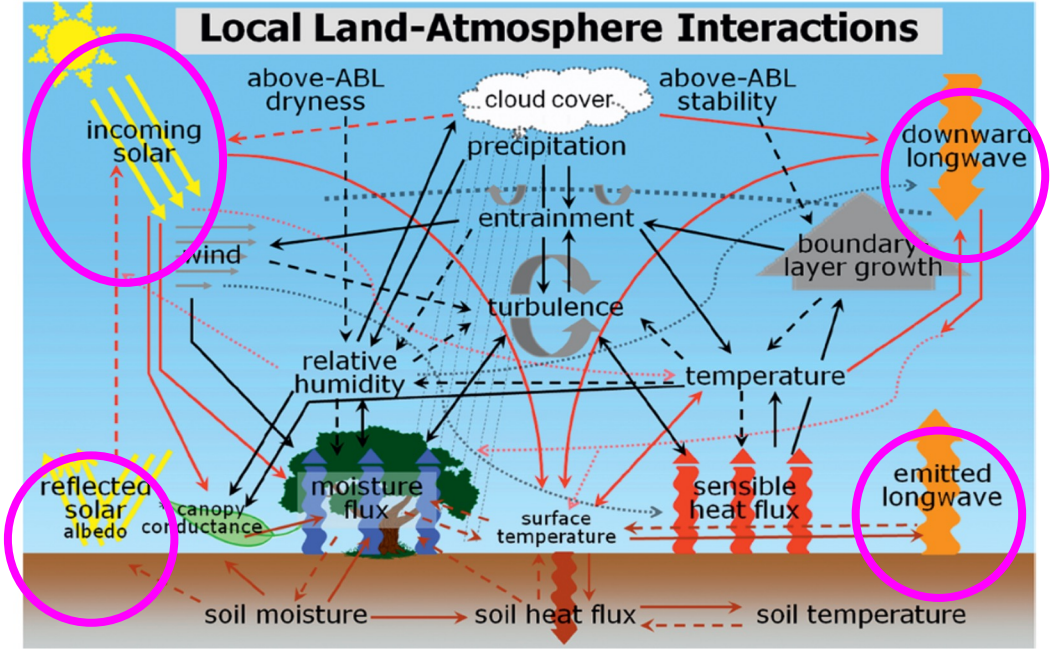
Joe Sedlar

The complex PBL system

Surface Energy Balance

Net Radiation = Sensible Heat Flux + Moisture Flux + Soil Heat Flux + Residual

- PBL is VERY complex.
- Where does the net radiative energy go?
- PBL exchange processes determine weather!



Santanello et al. (2018)

Main science objective: Understand how clouds and energy fluxes interact to characterize the PBL

Key takeaways

PBL system is complex, **requires cross-cutting approach** to monitor crucial energy exchange

Collaborative measurements

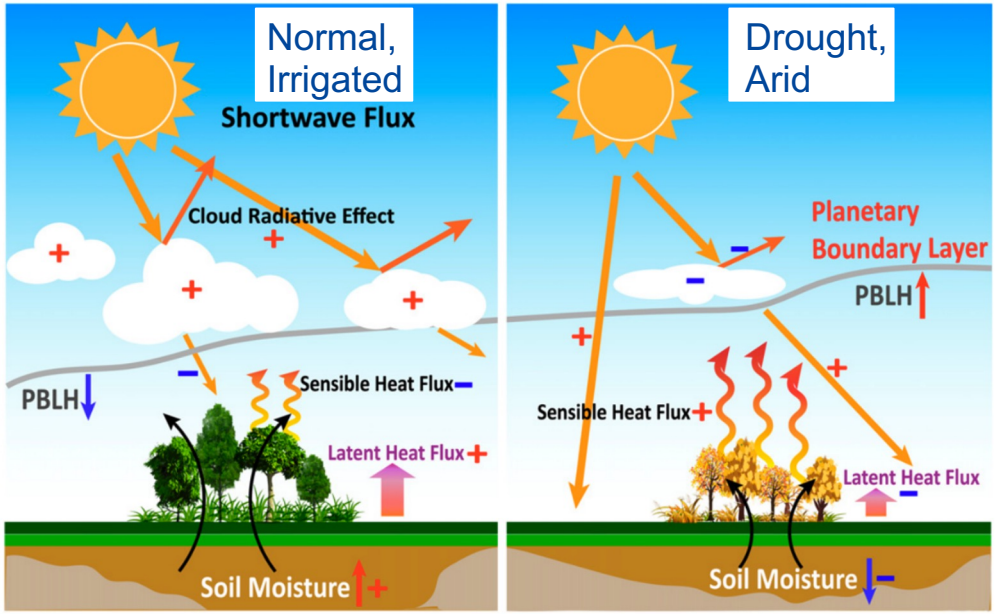
- bring together different pieces of system
- product development and unique process studies

Short-term and **long-term** monitoring efforts are needed moving forward

Relevance of PBL process studies

- **Understanding energy exchange and partitioning among PBL processes is key for:**
  - Hydrologic cycle
    - Water in the West
    - Drought, Heatwaves
  - Air quality
  - Carbon exchange
  - Ecosystem health

- **Climate is changing, what does this mean for key PBL processes?**



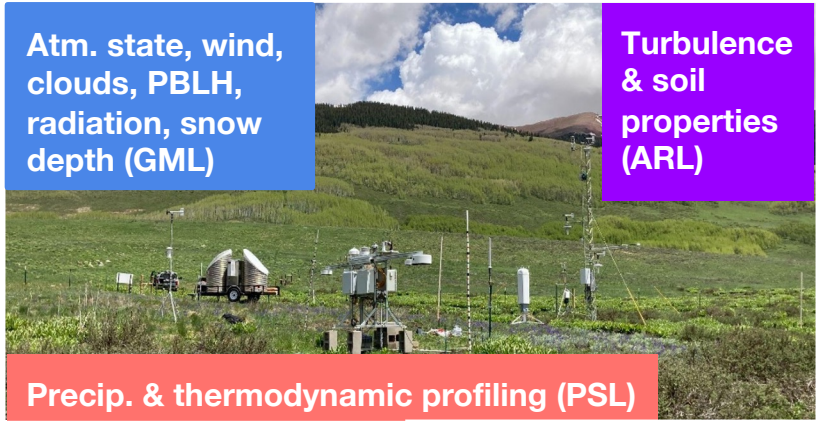
Yu et al. (2021)

How is GML working to realize our science objective?

Investment in collaborative field campaigns

- **Mobile SURFRAD (GML)**
  - Data quality, standards, expertise
  - Technological innovation, engineering
  - Relevance of under-sampled regions?
- **Collaboration across NOAA labs (ARL, PSL)**
  - Unique planning-execution process
  - Unified data
  - Collaborative science
- **By the numbers (2019 - today):**
  - > $3.4M external funding
  - 32 publications
  - Numerous outreach activities

High Mountain Watershed (CO)

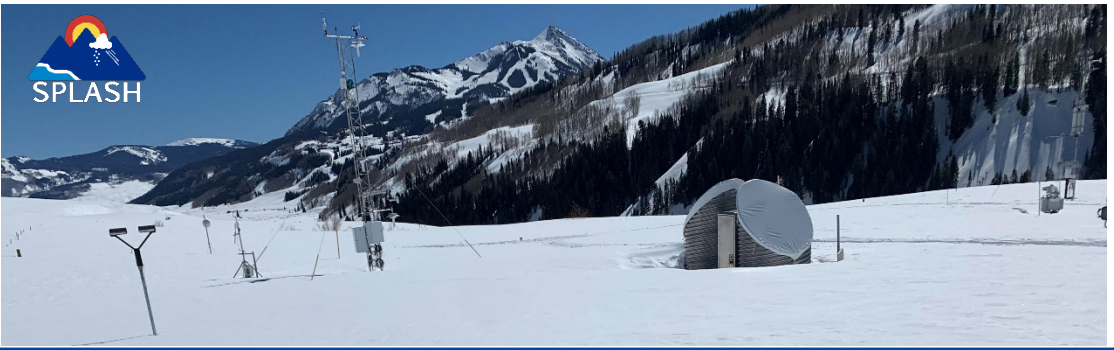


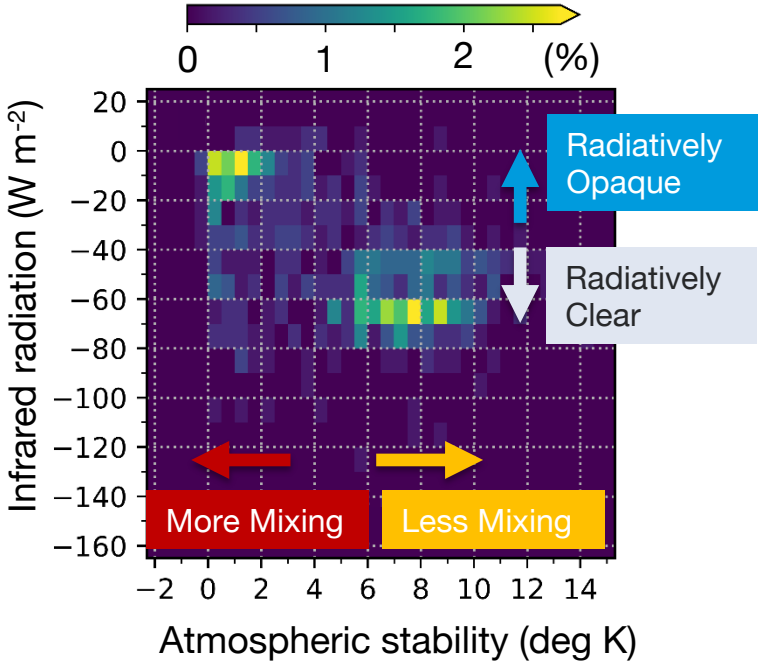
Forested (WI)

Coastal (MA)

Through collaborative measurements …

- **Bi-modal cloud-stability relationship**
  - Supercooled clouds and radiative forcing
  - Impact on surface energy, snowpack
  - First time identified in winter high mountain
  - Guided by Arctic research
- **NOAA's NWP models do not represent this important cloud-PBL relationship!**





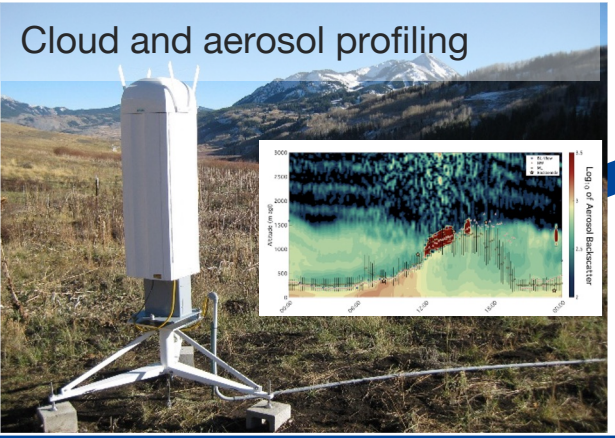
Sedlar et al. (2024)

Developing novel data products

To understand and communicate key PBL energy exchange processes

Radiation and cloud observations

Cloud and aerosol profiling



Machine learning

Cloud type classification product

Boundary layer height product

Applications:

- ✓ Local land-atmos vs large-scale drivers
- ✓ Cloud radiative effect
- ✓ Turbulent flux partitioning differences

Applications:

- ✓ PBL height climatology
- ✓ Atmospheric stability
- ✓ Pollution and mixing
- ✓ Local cloud formation / inhibition

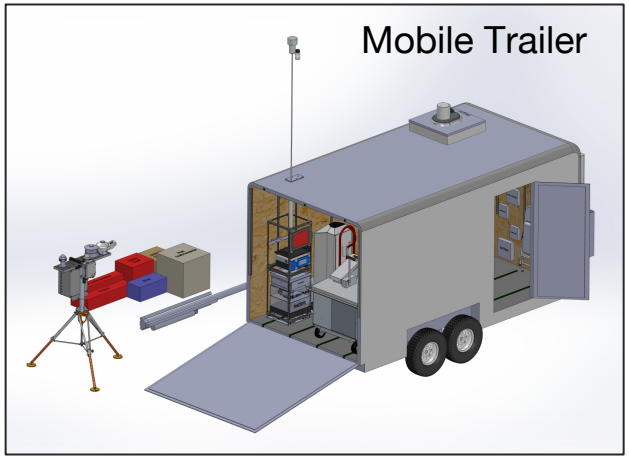
Future directions: How are we ensuring continued collaborative PBL monitoring and process study?

Wildfire Weather Research Program

Objective: Understanding essential weather and climate processes influencing wildfire where the threat is most urgent.

- **Four permanent observatories**
- **Two mobile (rapid deployment) trailers**

} GML, ARL, PSL, GSL



Future directions: How are we ensuring continued collaborative PBL monitoring and process study?

Collaborative monitoring at GML Tall Tower Network

Objective: Improved understanding of GHG fluxes through collaborative characterization of the PBL.

- Install radiation, cloud, and PBL instrumentation
- Joint science initiatives to address societally relevant uncertainties (GH gas exchange, air quality)

GML Colorado Atmospheric Observatory (CAO)

Credit: Phil Handley

Summary:

NOAA RESEARCH

PBL system is complex, **requires cross-cutting approach** to monitor crucial energy exchange

Collaborative measurements

- bring together different pieces of system
- product development and unique process studies

Short-term and **long-term** monitoring efforts are needed moving forward

NOAA RESEARCH

Thank you!

NOAA RESEARCH

Extra Slides Follow

Mission: Monitor aerosols, clouds, and surface radiation to reduce uncertainties in climate forcing and feedbacks, understand complex processes, and address societal challenges related to a changing climate.

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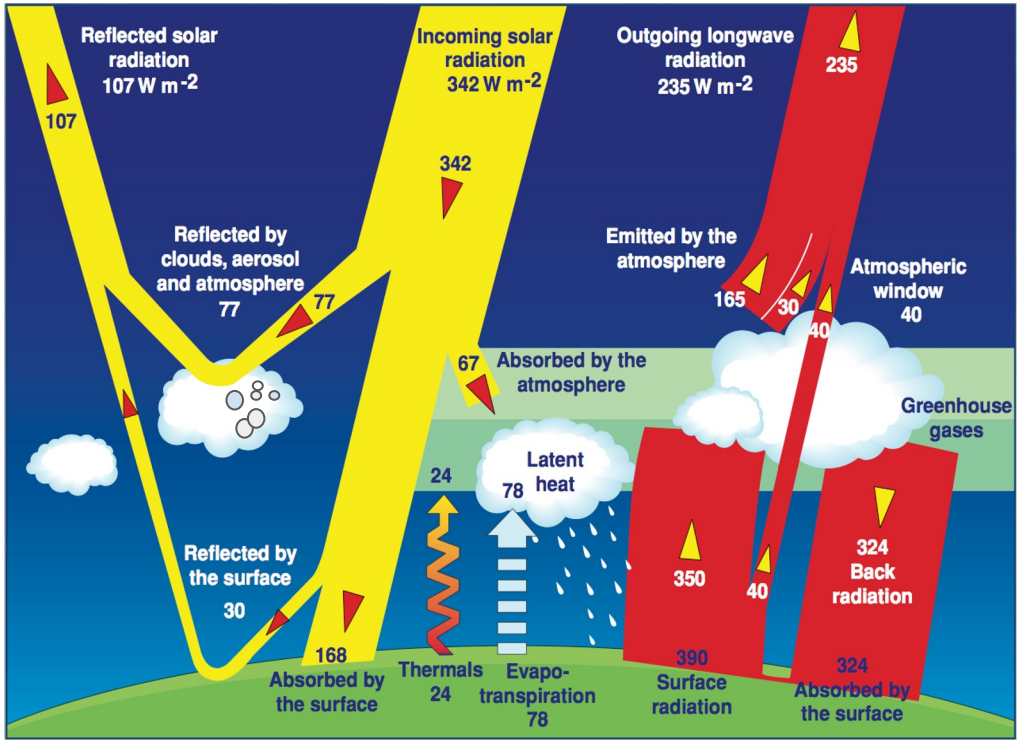

Outline

1. **Overview**
   Laura Riihimaki
2. **In situ aerosols**
   Betsy Andrews
3. **Surface SW & LW radiation**
   John Augustine
4. **Cloud and PBL Processes**
   Joe Sedlar

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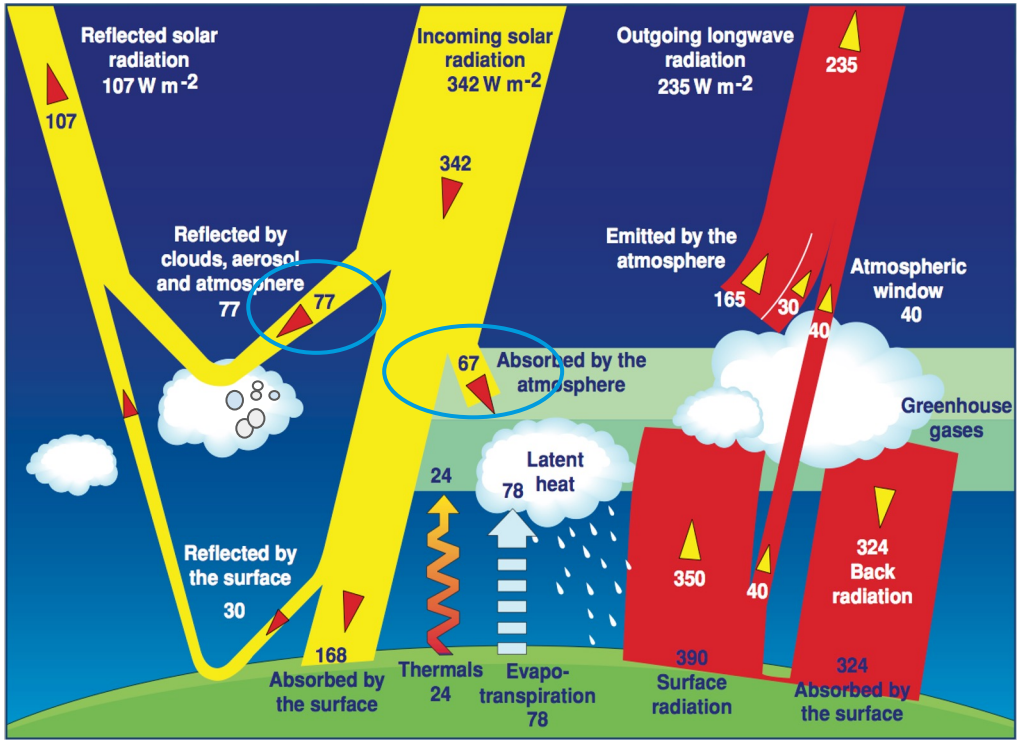

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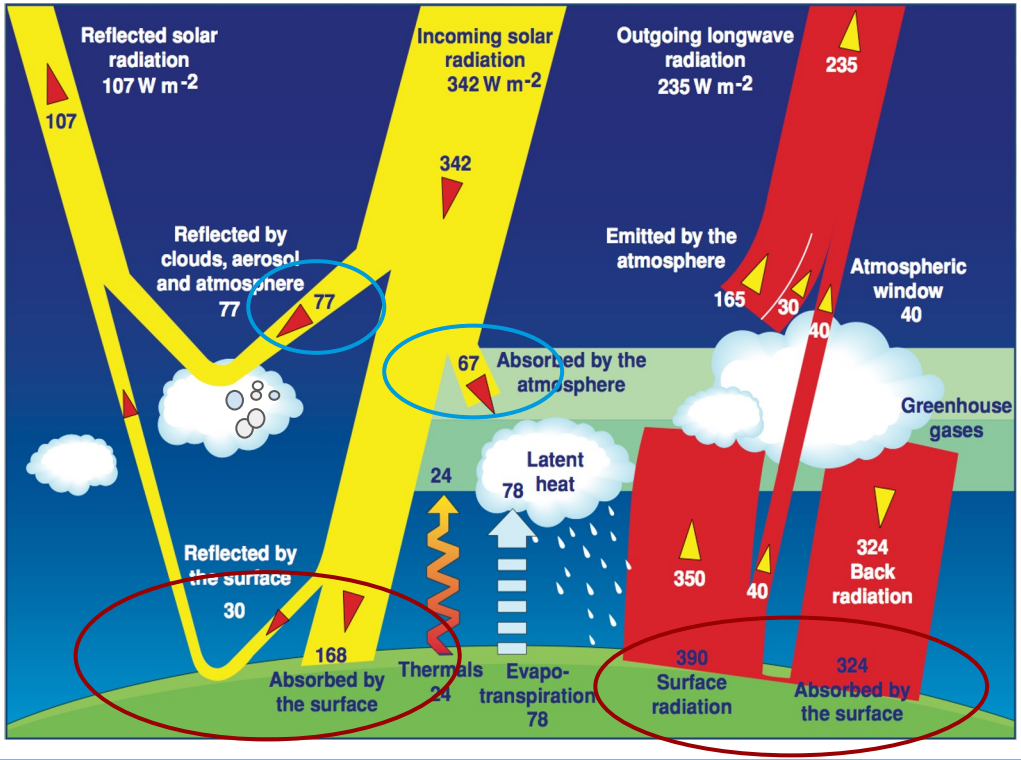

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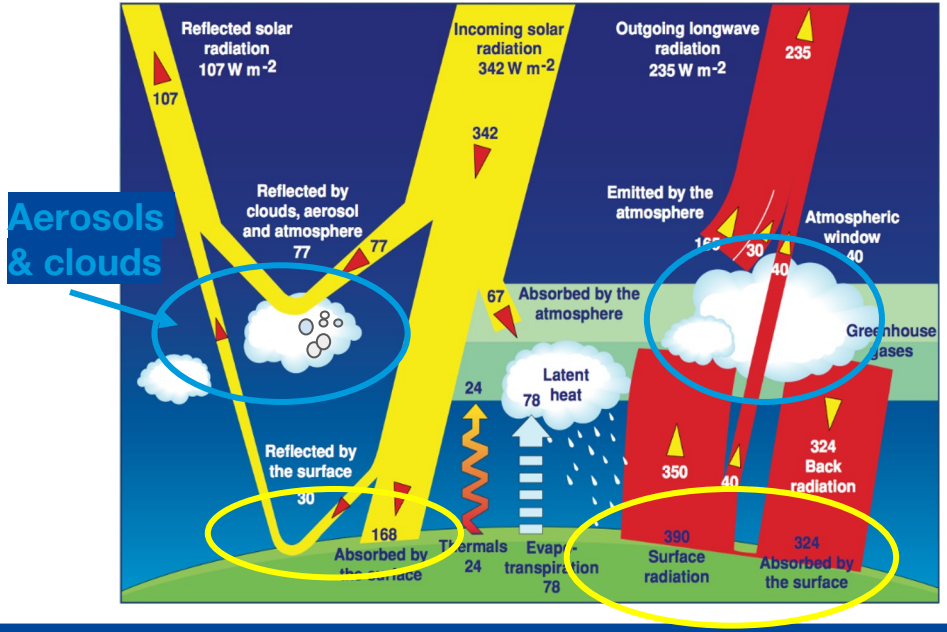
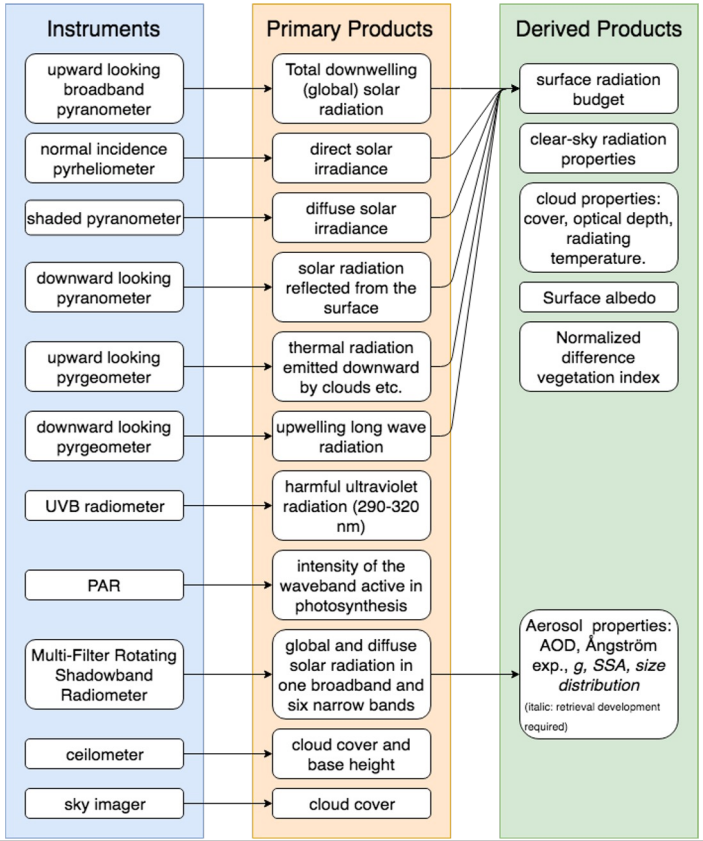
The surface radiation budget drives weather and the exchange of energy, water, and carbon between the surface and the atmosphere



Goodwin Creek SURFRAD station

Capabilities: Targeted scientific variables from derived products



SURFRAD network

Current

39 scientific variables measured or derived currently operational

New Products Under Development (*tours & Joe's talk*):

- New column aerosol properties (size distribution, scattering/absorption info)
- Aerosol layer heights
- Cloud Types
- Boundary Layer Height

NFAN In-Situ Aerosol Properties

Current

13 scientific variables measured or derived now operationally

New Products Under Development *(tour)*

- Aerosol typing to identify aging smoke