Surface-Atmosphere Exchange

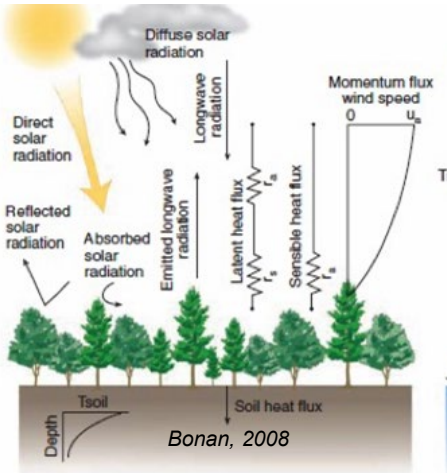
Rick D. Saylor

Understanding the processes and environmental variables that control surface-atmosphere exchanges, and translating this understanding into more accurate model parameterizations, is a core research activity that leads to improved weather, climate, and air quality predictions.

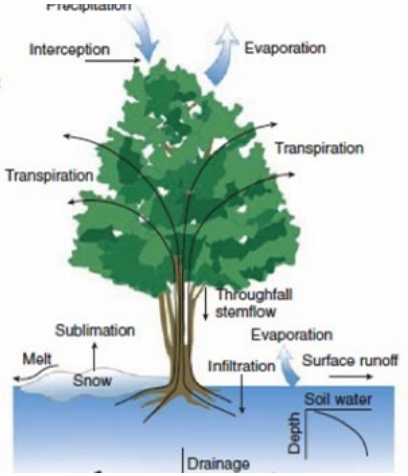
Surface–Atmosphere Exchange

- The surface-atmosphere exchange of momentum, energy, moisture, trace gases and aerosols drive much of the dynamic behavior and composition of the atmosphere and play an important role in affecting weather, climate and air quality.
- An accurate and consistent representation of these processes in atmospheric models is essential for improving the predictive performance of weather, climate and air quality numerical models.
- The biological, physical and chemical processes that mediate surface-atmosphere exchanges occur at multiple spatial and temporal scales and often occur across substantial surface heterogeneity.
- Integrated measurement and modeling efforts are required to fully understand the complexities of surface-atmospheric exchanges over real-world surfaces and to develop robust parameterizations for incorporation into atmospheric models.

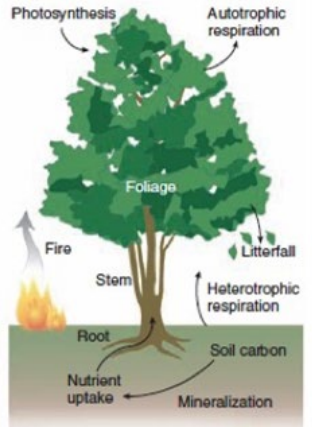
Surface energy fluxes

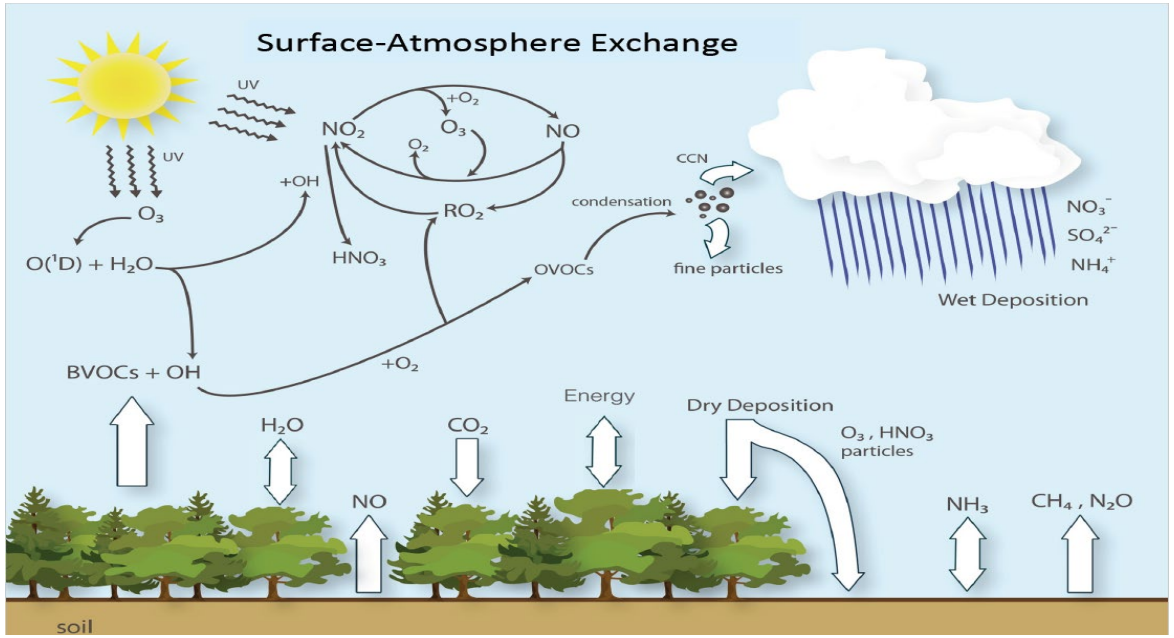


Water cycle



Carbon cycle





Relevance to NOAA OAR goals

Make Forecasts Better

- *Design tools and processes to forecast high-impact weather, water, climate, ocean, and ecosystem events*

  -- OAR Strategy 2020-2026

- *Transition science that meets users' current and future needs*

  -- OAR Strategy 2020-2026

- *Develop Interdisciplinary Earth system models*

  -- OAR Strategy 2020-2026

- *Improve weather & climate predictions by increasing our understanding of Planetary Boundary Layer (PBL) processes*

  -- OAR Implementation Plan 2021-2026

Detect Changes in the Atmosphere

- *Produce, analyze, and interpret observation records to understand the Earth system and inform the public*

  -- OAR Strategy 2020-2026

- *Optimize the greenhouse gases (GHG) observing system… to accurately track GHG [emissions]… and direct feedback to mitigation of emissions.*

  -- OAR Implementation Plan 2021-2026

Drive Innovative Science

- *Cultivate and deliver mission-relevant research to lead the environmental science community*

  -- OAR Strategy 2020-2026

Pre-Recorded Presentations

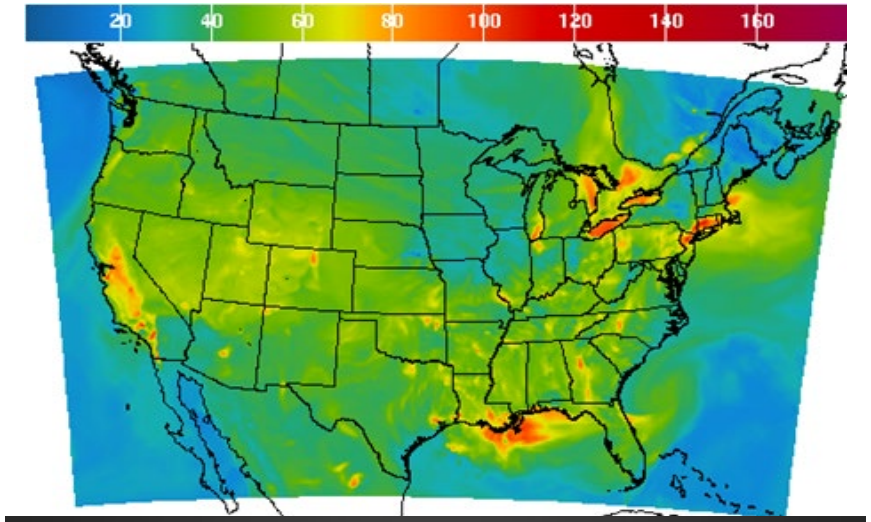
- Advancements in the National Air Quality Forecast Capability *Patrick Campbell*
- UFS Atmospheric Composition Modeling
  Barry Baker
- ARL Surface Energy Budget Network (SEBN)
  John Kochendorfer
- Surface-Atmosphere Exchange Processes
  Praveena Krishnan
- Chemical Surface-Atmosphere Exchanges:
  Experimental Approach and Modeling
  Nebila Lichiheb
- Aircraft Measurements of Air Pollutants and Greenhouse Gases *Xinrong Ren*

Advancements in the National Air Quality Forecast Capability

National Air Quality Forecast Capability (NAQFC)

Overview

The NWS's NAQFC provides operational air quality forecast guidance for surface O_3 and $PM_{2.5}$ over the U.S., thus improving the lives of Americans and saving billions of dollars per year.

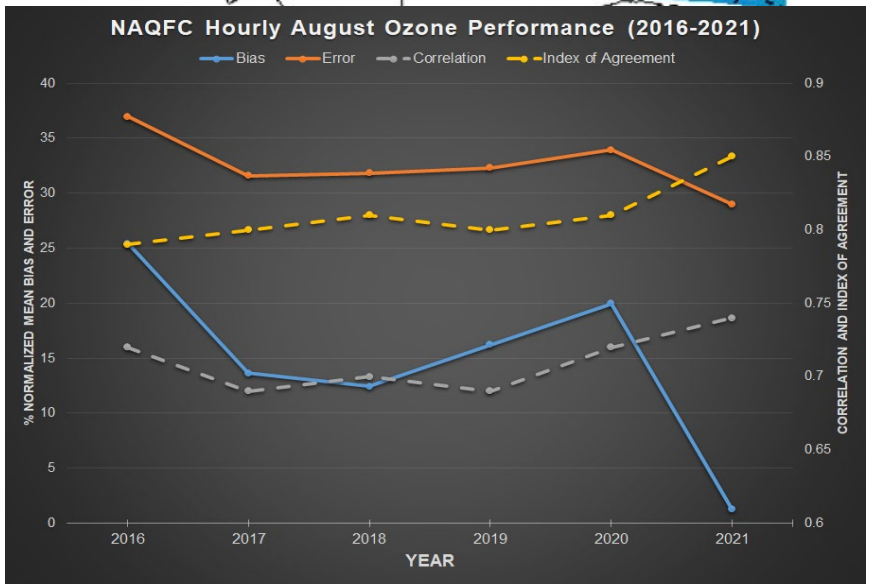


ARL's Role

ARL performs research and development in support of the NAQFC to continuously improve forecast performance by updating model components, enhancing emissions and other inputs and advancing the science basis of the system.

Forecast Performance

NAQFC forecast performance has continued to improve over 2016-2021 and compares favorably against other national air quality forecast systems over North America.

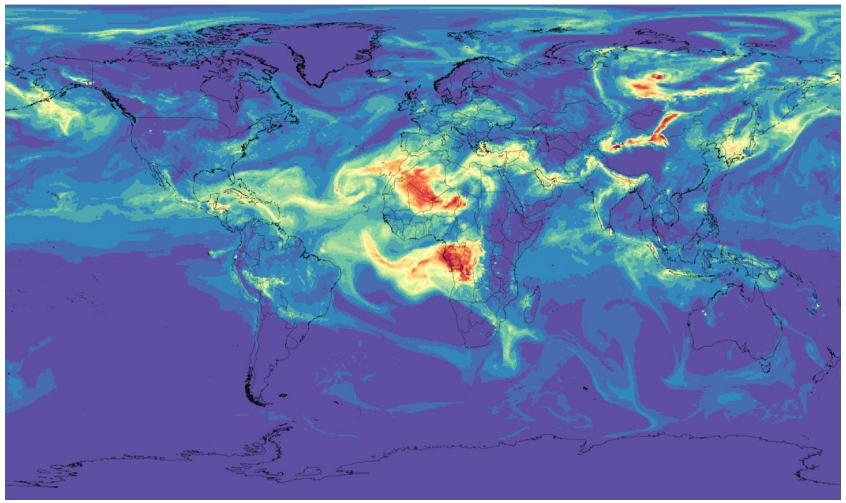


https://www.weather.gov/sti/stimodeling_airquality_predictions

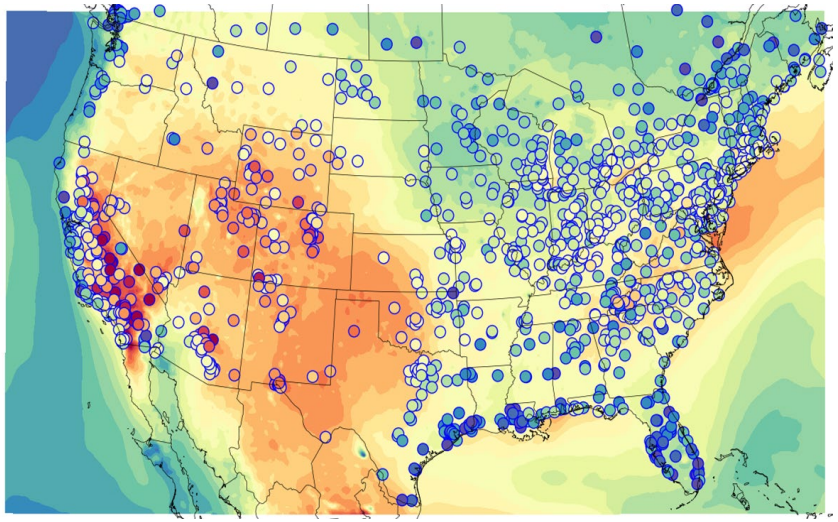
UFS Atmospheric Composition Modeling

Unified Forecast System (UFS)

GEFS-Aerosol (GEFSv12) & UFS-Aerosol (GEFSv13)

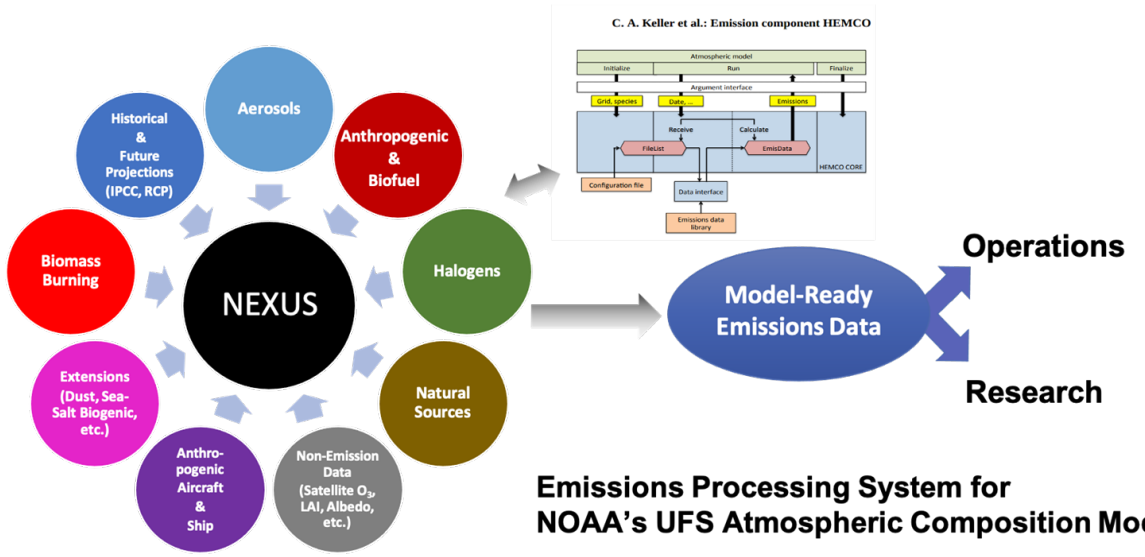


RRFS-CMAQ & RRFS-Smoke/Dust



- ARL is a key member in both global- and regional-scale projects to create aerosol and atmospheric composition models in UFS.
- GEFS-Aerosol is a currently operational global aerosol model which is part of the Global Ensemble Forecast System version 12 (GEFSv12)
- UFS-Aerosol is the fully UFS-based global aerosol model which will be part of GEFSv13, to be implemented in FY24-25.
- The Rapid Refresh Forecast System (RRFS) is the UFS replacement for HRRR and ARL is participating in the development of RRFS-CMAQ and RRFS-Smoke/Dust.

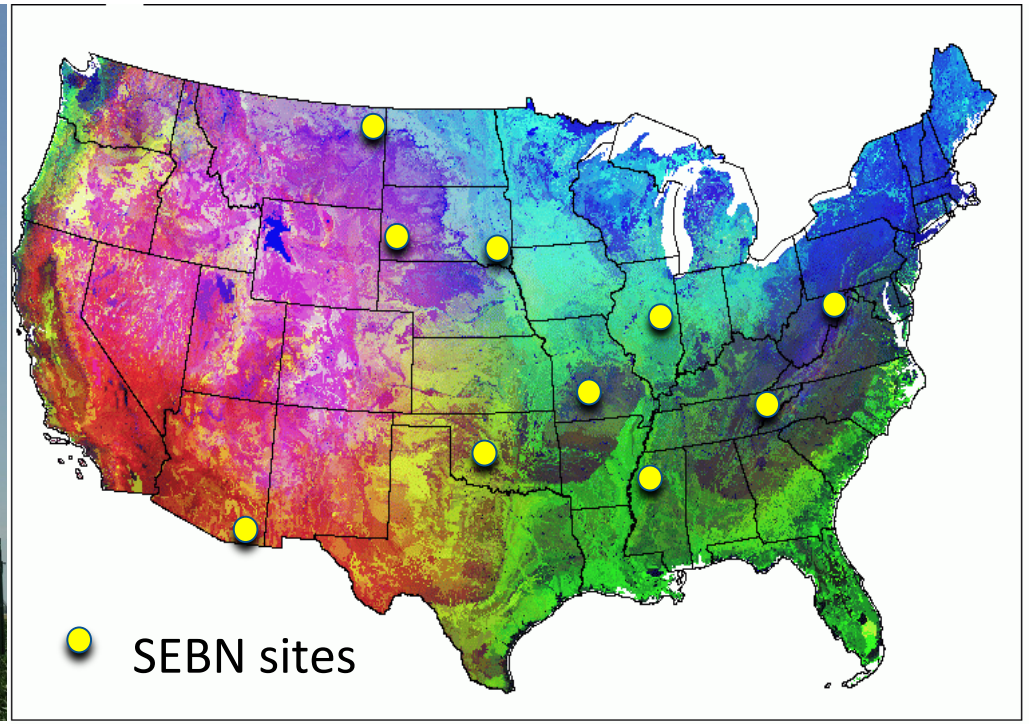
ARL's roles in UFS aerosol and atmospheric composition model development include: regional and global emissions datasets via the NOAA Emissions and eXchange Unified System (NEXUS) and development and implementation of the FENGSHA dust emission scheme.

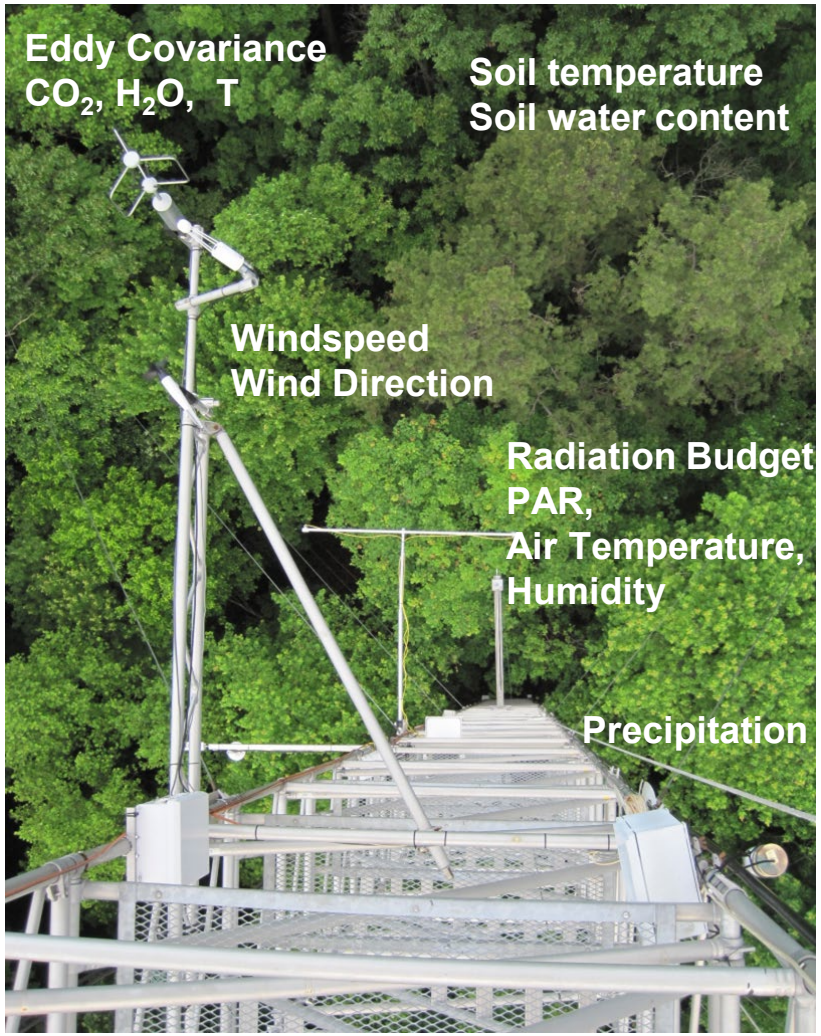


Emissions Processing System for NOAA's UFS Atmospheric Composition Models

Surface Energy Budget Network (SEBN)

- Assess land-surface feedbacks and related exchange processes
- Better understand drivers of regional climate and improve weather predictions
- Heat, water, and CO_2 exchange are monitored continuously
- Radiation, meteorology, and soil measurements are also recorded
- SEBN measurements can be used to improve NOAA's models



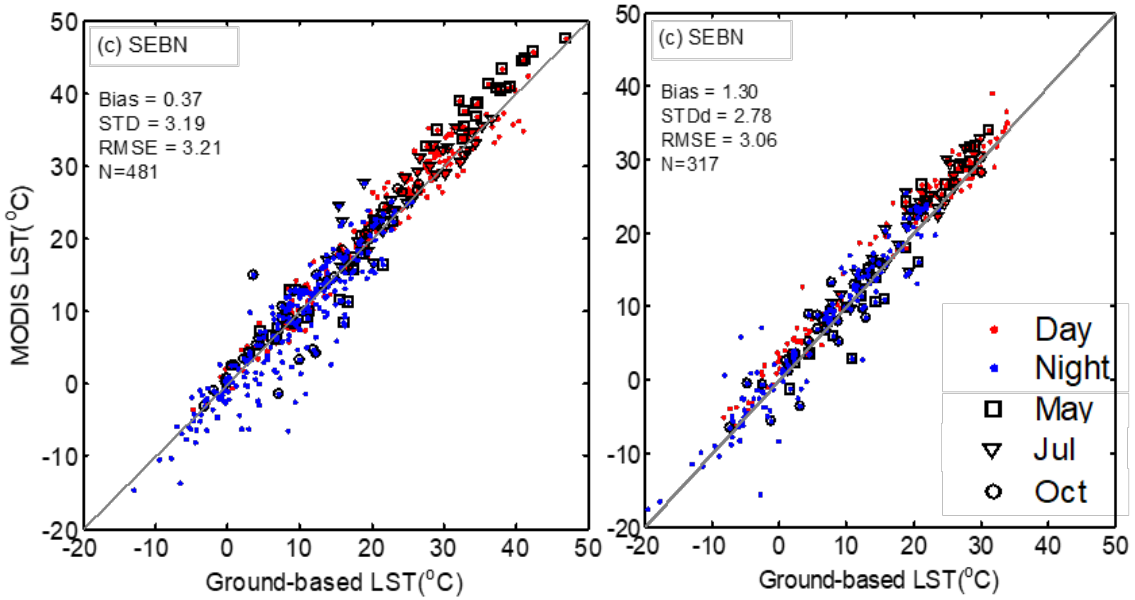


Surface-Atmosphere Exchange Processes

The FOCAL campaign during the summer of 2013 demonstrated how CH_4 fluxes could be successfully measured over large regions using airborne eddy covariance measurements from a small, low-flying aircraft. The first airborne eddy-correlation flux measurements of isotopologues of CH_4 and CO_2 in the Arctic (Sayres et al., 2017). FOCAL2 to be undertaken in August 2023.

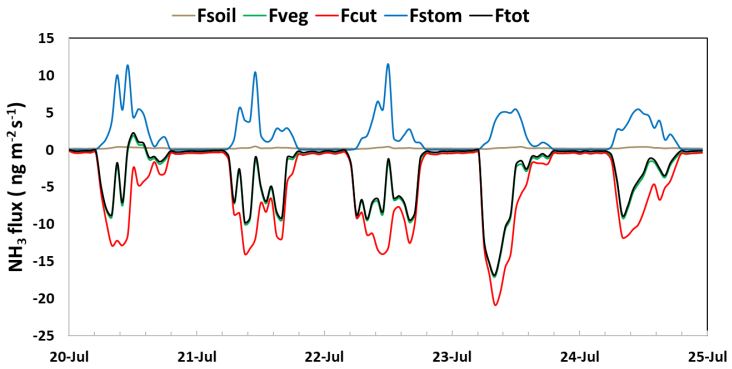
Collaboration: NOAA/ATDD & ORAU, Harvard U, Columbia U and Aurora Flight Sciences

- Land surface temperature (LST) is a key variable in the study of land surface–atmosphere exchange processes from local to global scales and is widely used in many research fields
- LST measurements derived from infrared temperature sensors (IRT) or longwave radiation (LWR) measurements
- Validation of satellite LST data for accuracy and assessment of retrieval algorithms

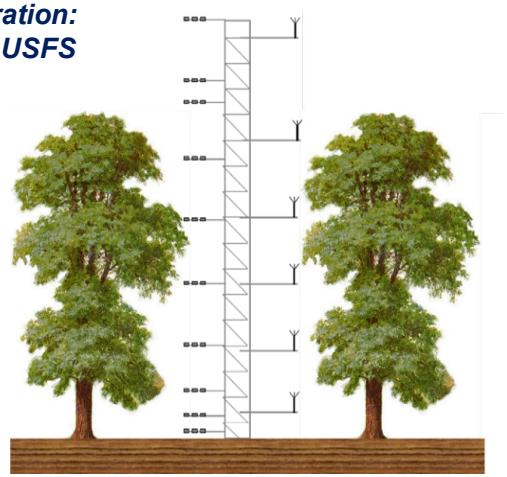


Chemical Surface-Atmosphere Exchange

Modeled NH_3 fluxes over a mixed deciduous forest

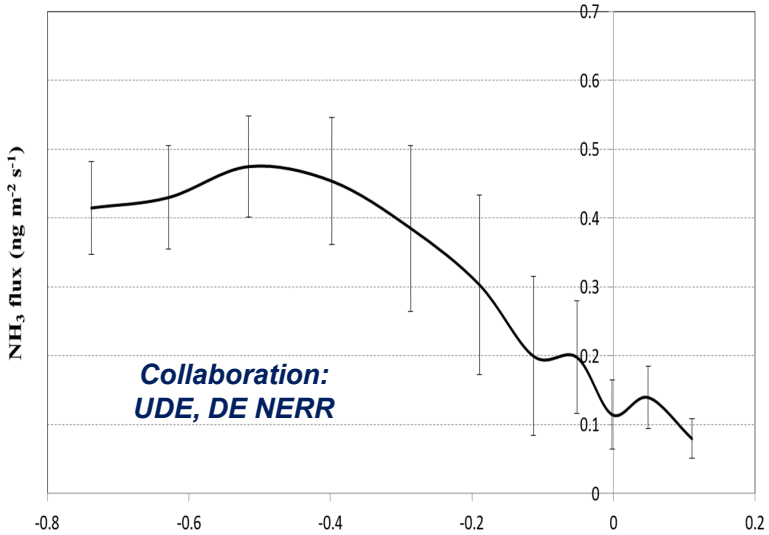


Collaboration: USEPA, USFS



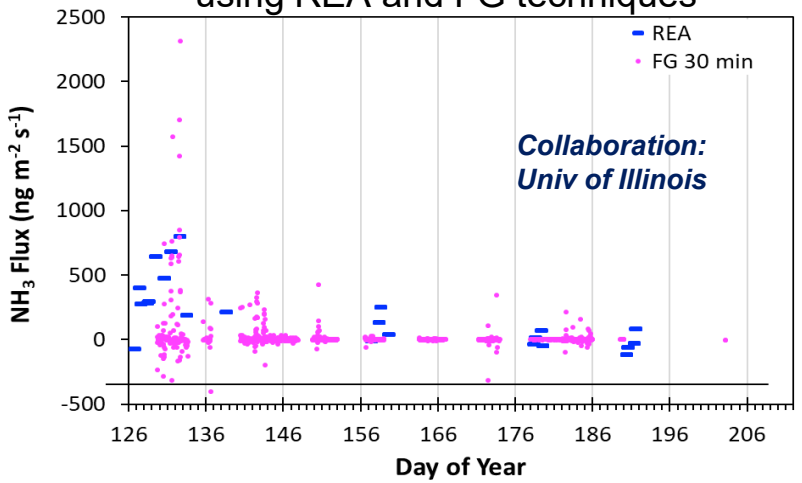
Eddy flux tower at Coweeta Hydrologic Laboratory (Western NC)

NH_3 concentrations and fluxes over a Mid-Atlantic tidal salt marsh

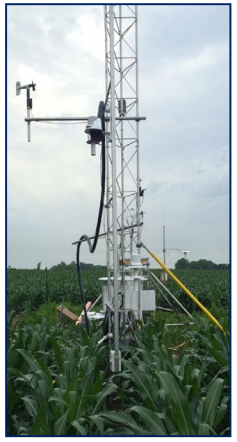


Average diurnal cycle of NH_3 fluxes as a function of tidal depth.

NH_3 fluxes over a maize canopy using REA and FG techniques



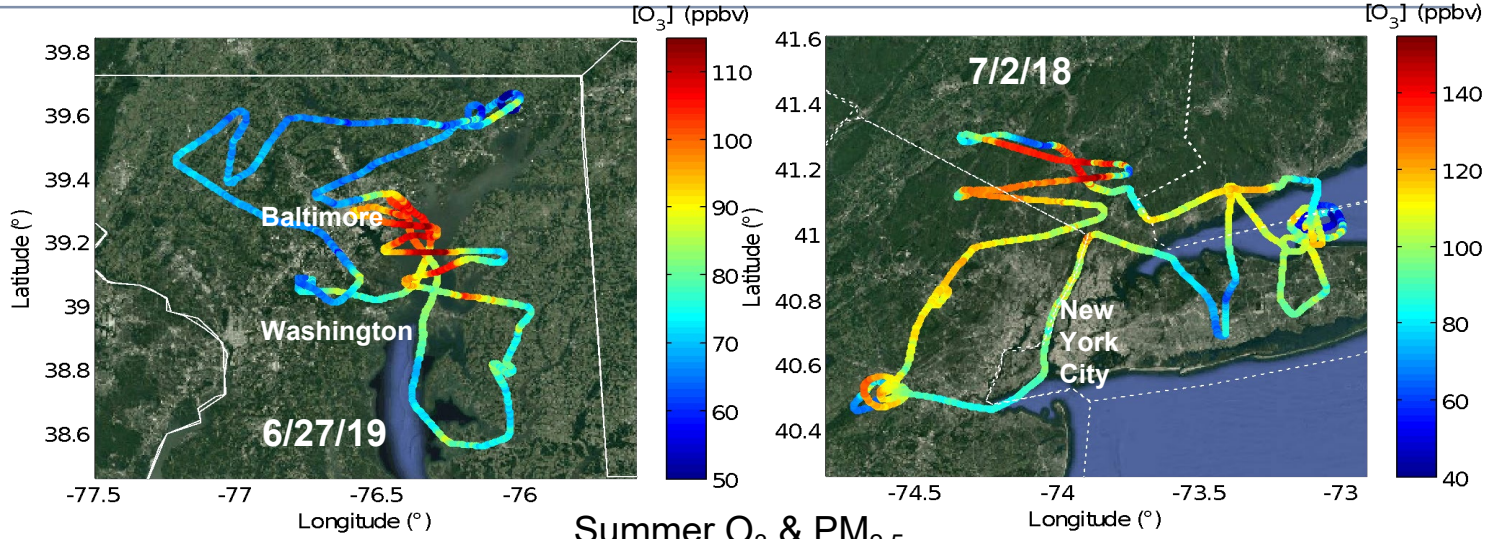
Relaxed Eddy Accumulation



Flux Gradient

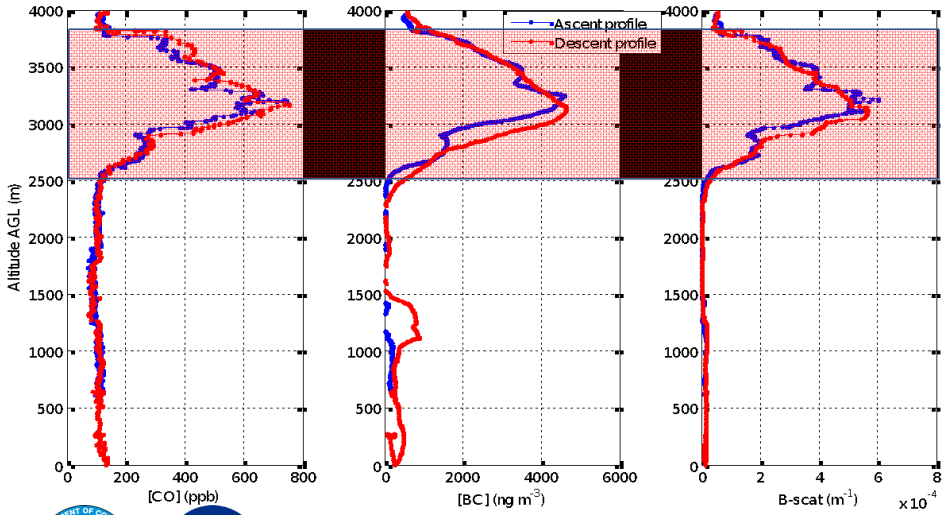
Aircraft Measurements of Air Pollutants and Greenhouse Gases

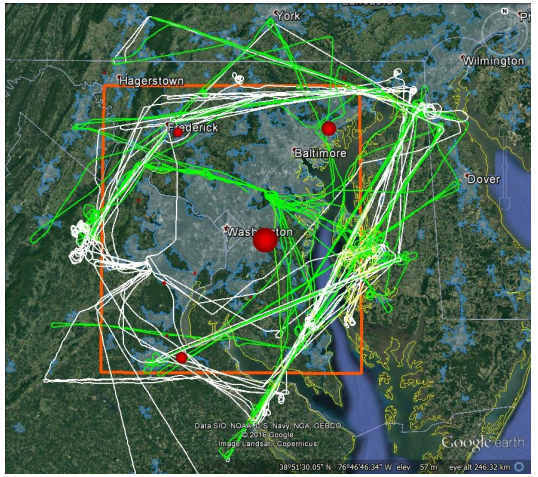
Cessna 402 Research Aircraft

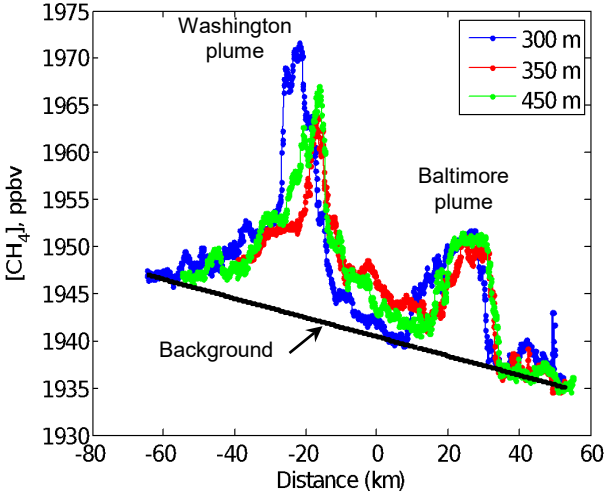


Summer O_3 & $PM_{2.5}$

West coast wildfire plume observed on 9/16/2020



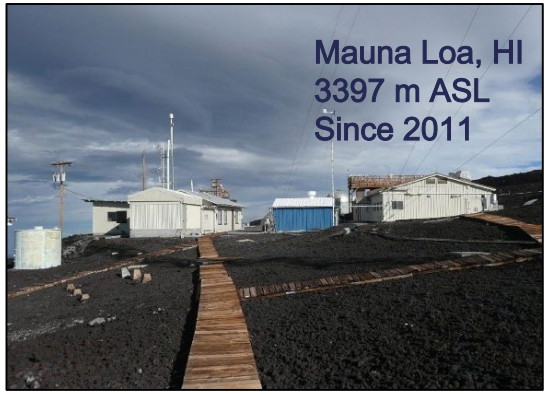




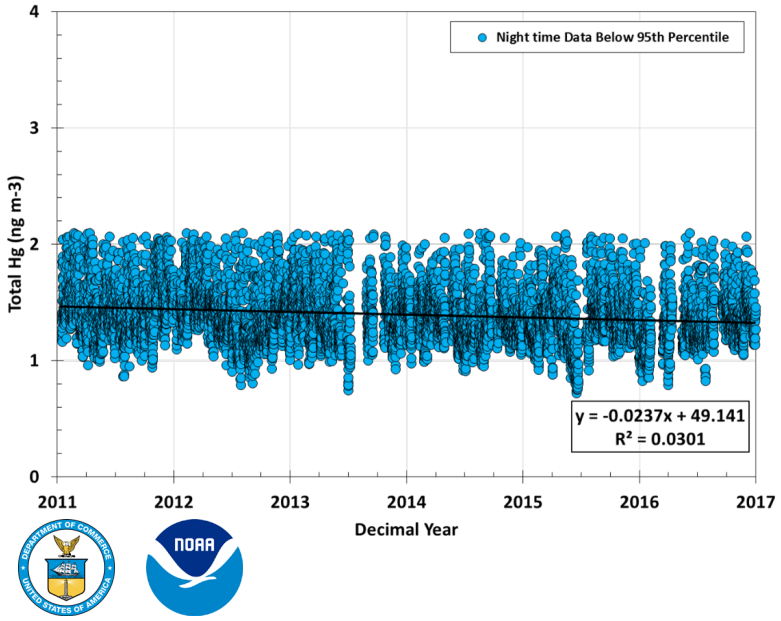
The national inventory underestimates CH_4 emissions for this area by a factor of 2.8.

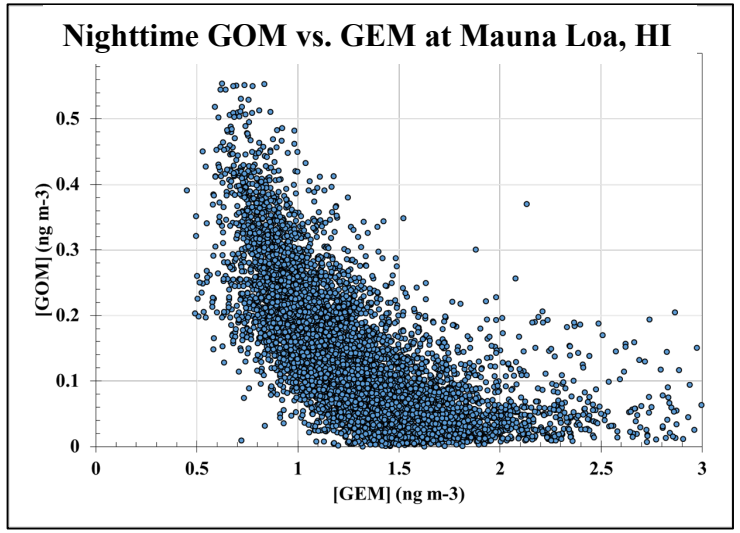
Long-Term Monitoring of Atmospheric Mercury

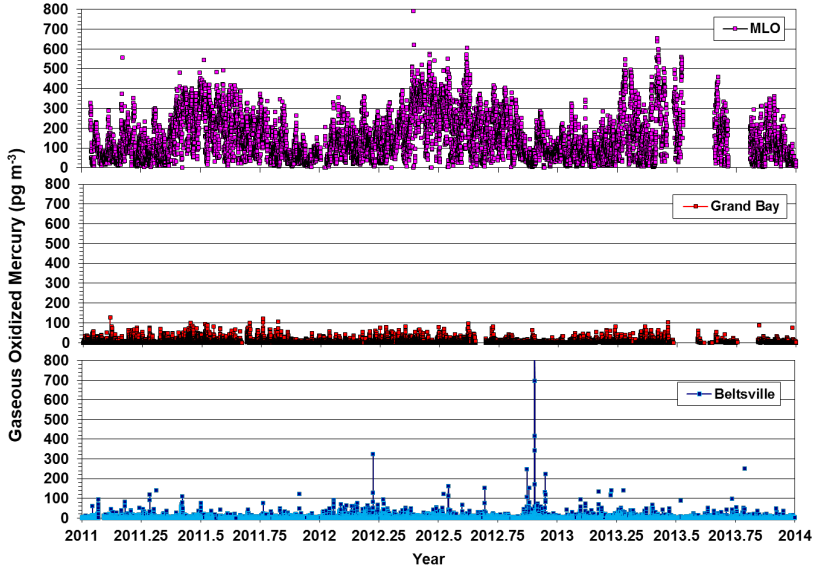
ARL operates 3 sites for long -term monitoring of Hg species: Barrow, AK, Mauna Loa, HI (both w/NOAA GML) & Beltsville, MD



Sites operate within the National Atmospheric Deposition Program's (NADP's) Atmospheric Mercury Network (AMNet)







Major Accomplishments

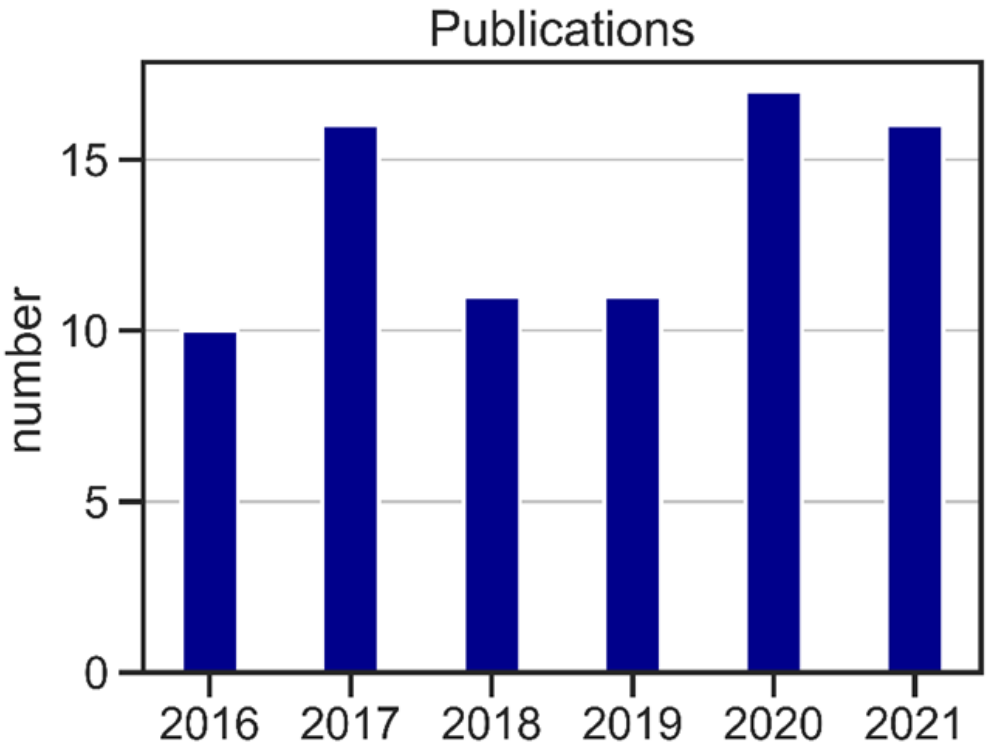
Operational Implementations

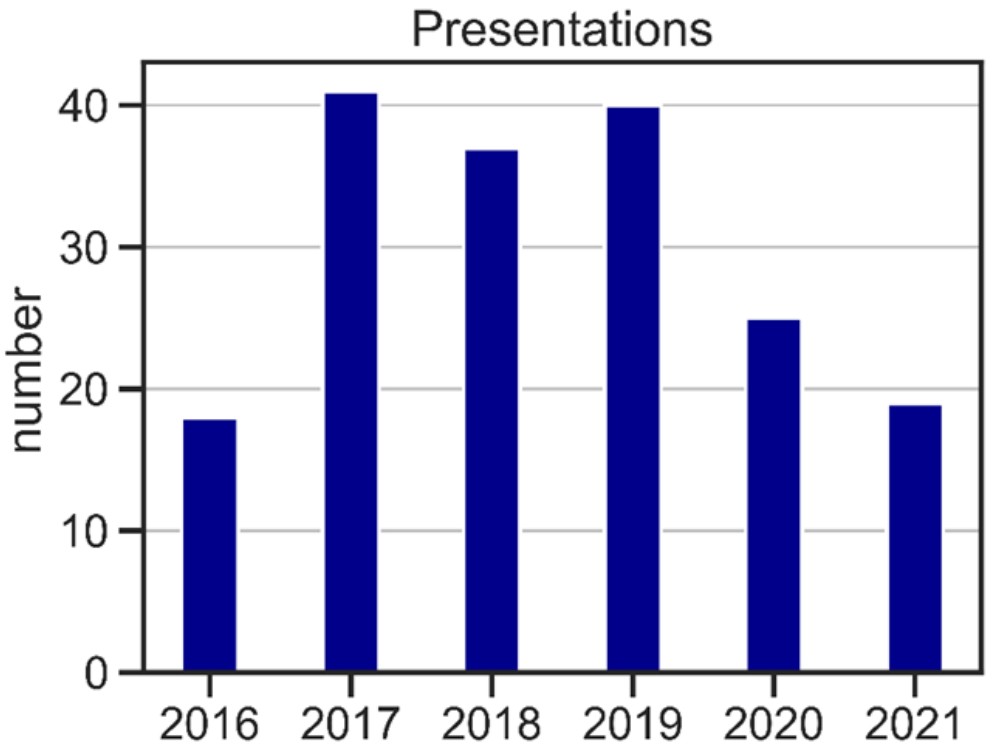
- NAQFC major updates (2016-2021):
  - Meteorological drivers (e.g., NAMv3 → NAMv4)
  - Chemical model updates (e.g., CMAQv4.6.5 → CMAQv4.7.2 → CMAQv5.0.2)
  - Natural emissions source models (e.g., ARL-developed FENGSHA windblown dust scheme)
  - Anthropogenic emissions inventories (e.g., NEI2005 → NEI2011 → NEI2014v2), incl. annual point source emissions projections
  - New NAQFC system, based on GFSv16/NACC-CMAQv5.3.1: July 2021
- GEFS-Aerosol in GEFSv12
  - FENGSHA dust scheme implementation in NOAA's new global aerosol model: September 2020

Scientific and Policy-Relevant Accomplishments

- ARL is a founding member of AMNet and operates 3 flagship Hg measurement sites in the 13-site network.
- ARL scientists are members of the U. S. Government Mercury Interagency Group (MIG) to inform U. S. policy on the Minimata Convention on Mercury.
- Flux of Carbon from an Airborne Laboratory – Campaign 2 (FOCAL2) NSF grant awarded to Harvard University, Aurora Flight Sciences and ARL to study CH_4 and CO_2 fluxes in the Arctic.
- Successful measurement of NH_3 atmospheric fluxes over a tidal salt marsh in the Mid-Atlantic U. S.
- Aircraft measurements of CH_4 led to correction of the Maryland Department of the Environment's estimates of leakages from the state's landfills.
- Continuation of a multi-decade record of surface energy budget measurements for representative land surface types.

Publications and Presentations





Total = 81

ACP, GMD, JGR-Atmos, GRL, STOTEN, Science, AtmEnv, JGR-Biogeo, Sensors, AgForMet, ES&T, WAF, Elementa, Tellus, Atmosphere, JAWMA, et al.

Total = 180

AMS, AGU, CMAS, NADP, ICMGP, IWAQFR, et al.

Surface-Atmosphere Exchange: Collaborations

NOAA SATELLITES

Asia Pacific Mercury Monitoring Network

JCET
The Joint Center for Earth Systems Technology

Future Goals and Plans

- Maintain forecast performance improvements of the current operational NAQFC and GEFS-Aerosol and collaborate with other OAR laboratories and NOAA Line Offices to develop, evaluate and transition regional and global UFS-based atmospheric composition models.
- Leverage existing boundary-layer and surface flux measurement capabilities to collaborate with other OAR laboratories to expand the impact of ARL's observations on surface-atmosphere exchange research across NOAA and improve weather, climate and air quality model representation of these processes.
- Maintain and enhance long-term observations of energy, water and carbon fluxes over different land surface types to advance the scientific understanding of land-atmosphere interactions and work to develop capabilities to bridge the gap between local, landscape and regional-scale measurements using surface and airborne measurements, remote sensing data, and modeling tools.
- Enhance capabilities for measuring and modeling chemical surface-atmosphere fluxes, especially over heterogeneous surfaces and complex terrains and promote collaborations with partners internal and external to NOAA to accomplish this goal.
- Continue airborne and surface measurements of air pollutants and GHGs, develop inverse modeling tools to estimate emissions from urban areas, and maintain efforts to provide policy-relevant science to local, state and regional environmental agencies to improve air quality and accurately quantify GHG emissions.
- Maintain leadership in long-term Hg measurements and research by testing and refining novel measurement methods, hosting comparisons of new, low-cost measurement methods and providing training for AMNet site operators and independent auditors.

Awards and Recognition

- U. S. Department of Commerce Bronze Medal for Scientific or Engineering Achievement for 2021, "*For the development of the Global Ensemble Forecast System – Aerosols (GEFS-Aerosols) model to support air quality alerts and visibility forecasts",* G. Frost, G. Grell, R. Saylor, J. McQueen, I. Stajner, J. Wang, S. Kondragunta

- NOAA Administrator's Award in 2019: *"For implementing and upgrading NOAA's Air Quality Forecasting Capability thereby improving the lives of Americans and saving billions of dollars per year",* Pius Lee and Rick Saylor.

- NOAA Certificate of Commendation in 2020: *"For implementing and upgrading NOAA's Air Quality Forecasting Capability thereby improving the lives of Americans and saving billions of dollars per year"*, CISESS Scientists in ARL.

- NASA Group Achievement Award to OWLETS: "*For designing and executing an unprecedented scientific investigation in the upper and lower Chesapeake Bay to understand the ozone pollution at the land-water interface",* Barry Baker, Mark Cohen, Paul Kelly, Christopher Loughner, Winston Luke, and Xinrong Ren

- U. S. Department of Commerce Bronze Medal for Scientific or Engineering Achievement for 2019. *"For sustained excellence in measurements and modeling leading to improved understanding of the emissions, transport, and fate of atmospheric mercury."* Winston Luke and Mark Cohen