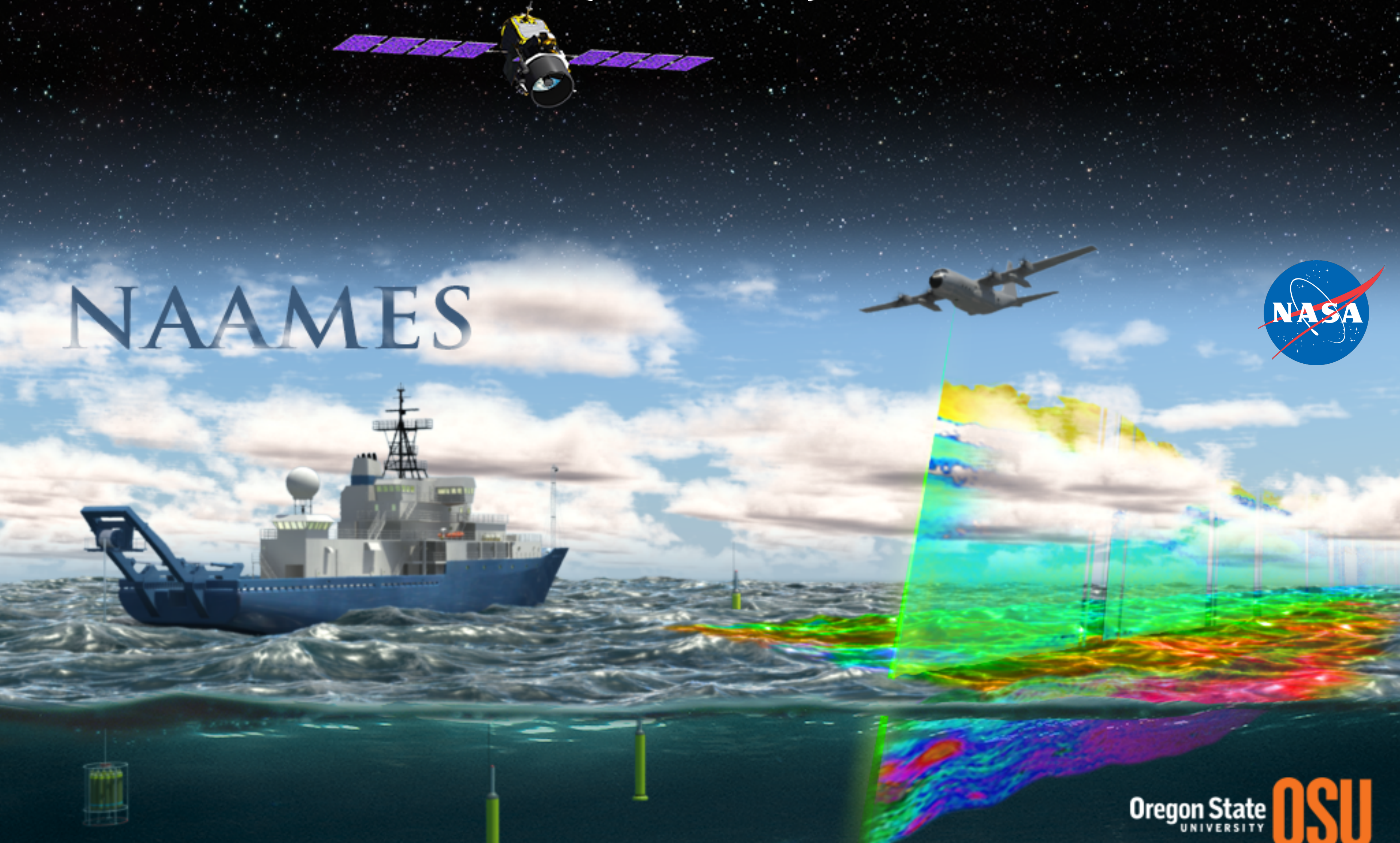
# North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)




http://naames.larc.nasa.gov

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# Why?

The abundance and growth of the plankton is critical to ocean health, fisheries production, atmospheric carbon dioxide levels, and the human goods and services provided by the sea

‘Hot Spots’ of ocean production (i.e., blooms) occur in many subpolar regions, but we do not yet understand how climate and ecology control their vital annual plankton cycles

Plankton ecosystems also emit aerosols into the atmosphere that impact clouds and climate

The NAAMES project aims to provide new insights on the function of plankton ecosystems and their connection to atmospheric aerosols, clouds, and climate

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*NAAMES is an interdisciplinary investigation of the annual plankton cycle and its associated atmospheric aerosols*

## Overarching Science Goals

*Goal #1:* Define environmental and ecological controls on plankton communities to improve predictions of their structure and function in a warmer future ocean

*Goal #2: Define linkages between ocean ecosystem properties and biogenic aerosols to improve predictions of marine aerosol-cloud-climate interactions with a warmer future ocean*

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# Baseline Science Objectives

*Objective #1: Characterize plankton ecosystem properties during primary phases of the annual cycle in the North Atlantic and their dependence on environmental forcings*

*Objective #2: Determine how primary phases of the North Atlantic annual plankton cycle interact to recreate each year the conditions for an annual bloom*

*Objective #3: Resolve how remote marine aerosols and boundary layer clouds are influenced by plankton ecosystems in the North Atlantic*


### Project Management

| Participants | Role | Affiliation |
|---|---|---|
| Behrenfeld, Mike | Principal Investigator | OSU |
| Kleb, Mary | Project Manager | NASA LaRC |
| Hostetler, Chris | Project Scientist | NASA LaRC |
| Moore, Richard | Deputy Project Scientist | NASA LaRC |
| Proctor, Christopher | Project Data Manager | NASA GSFC |
| Chen, Gao | Flight Planner | NASA LaRC |
| Shook, Michael | Meteorologist | LaRC/SSAI |
| Ziemba, Luke | Logistics /C-130 Platform Manager | NASA LaRC |

### Project Science

| | | |
|---|---|---|
| Doney, Scott | BEC-CESM Modeling | WHOI |
| Franz, Bryan | Ocean Color Analyses | NASA GSFC |
| Gaube, Peter | Mesoscale Physics | APL |
| Hu, Chuanmin | GCAS Analyses | USF |
| Hu, Yongxiang | Ocean/Cloud Satellite Analyses | NASA LaRC |
| Lindo, David | Mesoscale Modeling | City College, NY |
| Liu, Hongyu | GEO-Chem Aerosol Modeling | NASA LaRC |
| Milligan, Allen | Ocean Primary Production | OSU |
| Westberry, Toby | Satellite Analysis /In Situ Optics | OSU |
| Wood, Robert | Cloud modeling | UW |

### Ship Science & Instruments

| | | |
|---|---|---|
| Bates, Tim | Aerosol Flux | UW |
| Boss, Emmanuel | Ocean optics, Profiling Floats | UM |
| Brooks, Sarah | Aerosol and CCNuclei | TAMU |
| Carlson, Craig | DOC Measurements | UCSB |
| Giovannoni, Stephen | VOCs, Plankton Taxonomy | OSU |
| Halsey, Kimberly | VOC precursors & processing | OSU |
| Maritorena, Stephane | OC Algorithm Development | UCSB |
| Menden-Deuer, Susanne | Microzooplankton Grazing | URI |
| Nelson, Norman | CDOM /Bio-Optics | UCSB |
| Russell, Lynn | In Situ Aerosol | UCSD |
| Saltzman, Eric | In Situ Trace Gases & Aerosol | UCI |
| Siegel, David | Ocean optics, Remote Sensing | UCSB |

### Airborne Science & Instruments

| Participants | Role | Affiliation |
|---|---|---|
| Anderson, Bruce | LARGE Aerosol &Trace Gases | NASA LaRC |
| Cairns, Brian | RSP; Ocean-Aerosol-Cloud RS | NASA GISS |
| Chowdhary, Jacek | RSP; Aerosol Analyses | NASA GISS |
| Ferrare, Richard | HSRL; Aerosol Analyses | NASA LaRC |
| Hair, John | HSRL; Ocean-Aerosol-Cloud RS | NASA LaRC |
| Janz, Scott | GCAS; Ocean Color RS | NASA GSFC |
| Moore, Richard | LARGE; Cloud Microphysics and Aerosol-Cloud Interactions Analyses | NASA LaRC |
| Redemann, Jens | 4STAR; Aerosol Optical Depth | NASA ARC |
| Wisthaler, Armin | PTR-MS; Organic Trace Gases | Innsbruck |

### Support Flight Operations

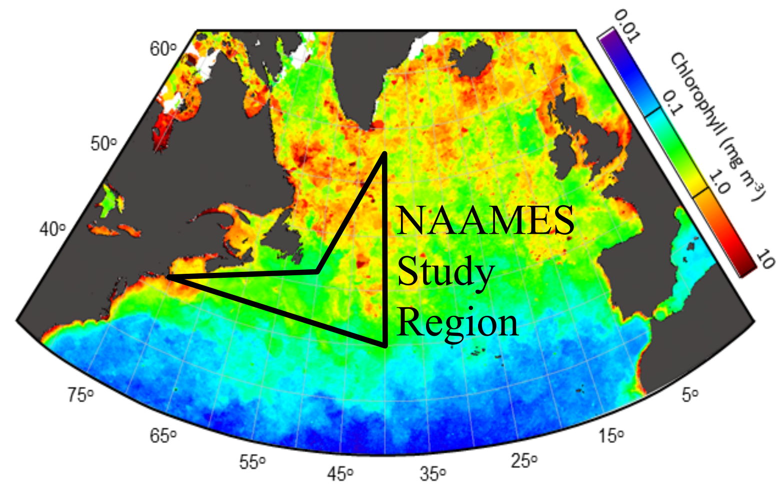
| | | |
|---|---|---|
| Cropper, Mike | C-130 Airborne Science Mission Manager | NASA WFF |
| Griffin, Kelly | C-130 Logistics and Mission Manager | NASA WFF |
| Nowicki, Martin | C-130 Integration/Operations Engineer | NASA WFF |

# NAAMES Science Team Members


## Science / Investigation Overview

- Annually repeated North Atlantic plankton bloom is the largest in global ocean
- Bloom is associated with significant biogenic aerosol loads, with long-distance transport
- Ecological and physical processes controlling bloom development are strongly debated, but clearly linked to climate variability
- Improved understanding of bloom dynamics and associated aerosols will reduce uncertainties in projections of future change and implications to ocean productivity and climate

North Atlantic Phytoplankton Bloom



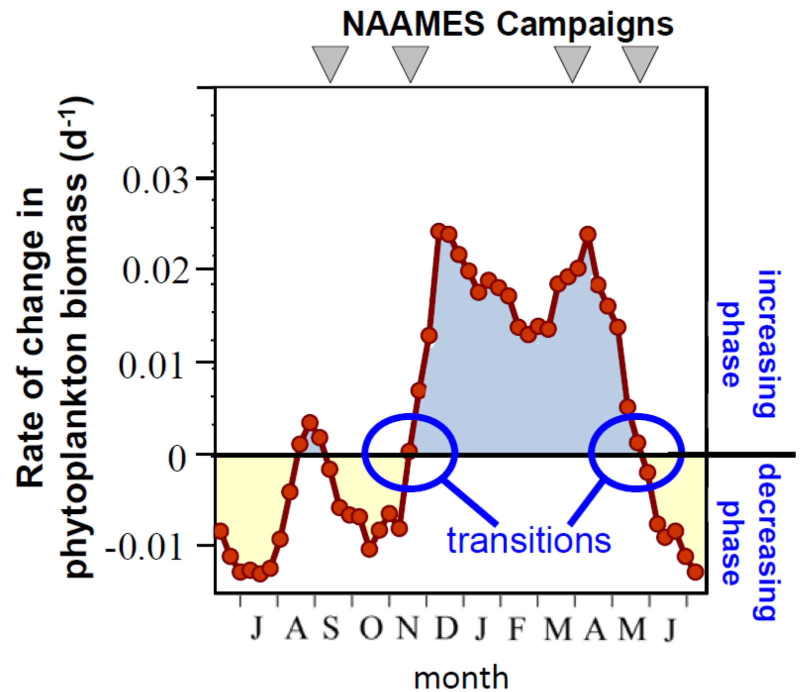

## Science / Investigation Overview

- Four field campaigns
- Target contrasting 'states' of the annual plankton cycle and associated aerosols

  ***Bloom initiation:*** *November-December*
  ***Accumulation phase:*** *March-April*
  ***Bloom climax:*** *May-June*
  ***Deceleration phase:*** *September-October*

- Capitalize on natural meridional gradients to plankton 'states'

**The *Contrasting States* of the Plankton Cycle**



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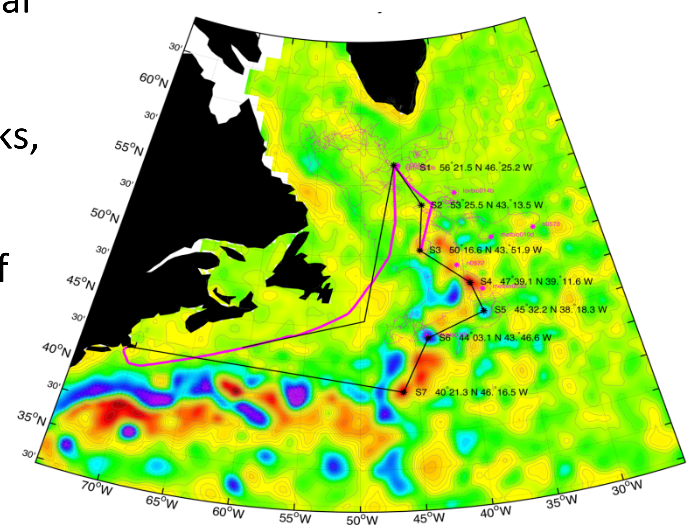
## Science / Investigation Overview

- **26-day ship deployments** during each campaign
  - Campaign #1: *Bloom initiation; R/V Atlantis, Nov 5 - Dec 2, 2015*
  - Campaign #2: *Bloom climax; R/V Atlantis, May-June 2016*
  - Campaign #3: *Deceleration phase; R/V Atlantis, September 2017*
  - Campaign #4: *Accumulation phase; R/V Atlantis, March, 2018*
- **Common default profile:** Woods Hole - transects to/from turning points, primary science w/ daily stations (40°N - 57°N, ~40°W)
- **Flexibility:** Departure/arrival port, direction of transect, latitudinal extent (particularly Deceleration and Accumulation phases)
- **Ocean Biological Measurements**: Biological composition & stocks, rates of production, accumulation, and loss processes
- **Aerosol Measurements**: Concentrations and production rates of aerosol precursors in the surface ocean, sea-air transfer rates, lower troposphere biogenic aerosol concentrations
- **Optical Measurements**: Inherent optical properties, apparent optical properties, water leaving radiance spectra - *optical measurements link in-situ data to remote sensing*


*Actual transect is informed by real-time eddy field*

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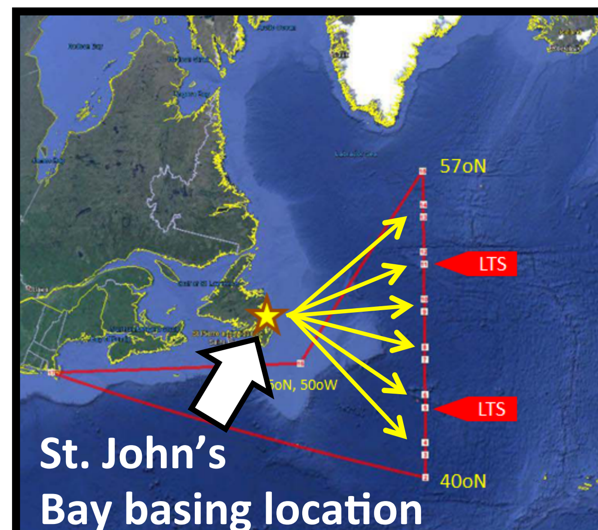
## Science / Investigation Overview

- **Autonomous Bio-Argo Floats:** 3 to 6 deployments per campaign along primary science transect
- **Surface Drifters:** 20 deployments per campaign along primary science transect
- **Autonomous Assets:**
    1) Provide sustained observations pre-campaign and post campaign and enable station targeting
    2) Provide 'bread crumb trail' for airborne observations
    3) Allow evaluation of predictive capacity from ship measurements ('ecological forecasting' skill)



## Science / Investigation Overview

- High- and low-altitude remote sensing and in-situ aerosol measurements conducted from **NASA C-130 aircraft**
- Aircraft deployments based at **St. John's Bay, Canada**
- **Deployment profile**: Departure flight toward ship location during primary science transect, measure ocean and aerosol properties at/around ship location, overfly surface drifter areas, overfly upcoming ship transect, return to base.
- **Goal**: 6 successful science flights per campaign
- **Aircraft measurements**:
    1) link ship aerosol and ocean biological observations to satellite spatial scales
    2) allow aerosol/cloud sampling upwind and downwind of ship
    3) allow assessment of spatial variability

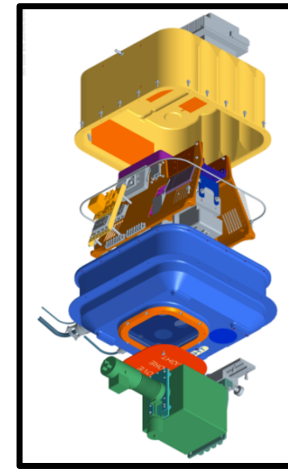

**HSRL**


## Science / Investigation Overview

- High Spectral Resolution Lidar (HSRL): Vertical profiling of clouds, aerosols, and ocean plankton
- Research Scanning Polarimeter (RSP): Column-integrated cloud, aerosol, and plankton properties
- GeoCAPE Airborne Simulator (GCAS): Plankton and carbon stocks from hyperspectral ocean color measurements
- Spectrometer for Sky-Scanning Sun-Tracking Atmopheric Research (4STAR): Downwelling sunlight and atmospheric chemical composition

**RSP**

**GCAS**



**4STAR**


## Science / Investigation Overview

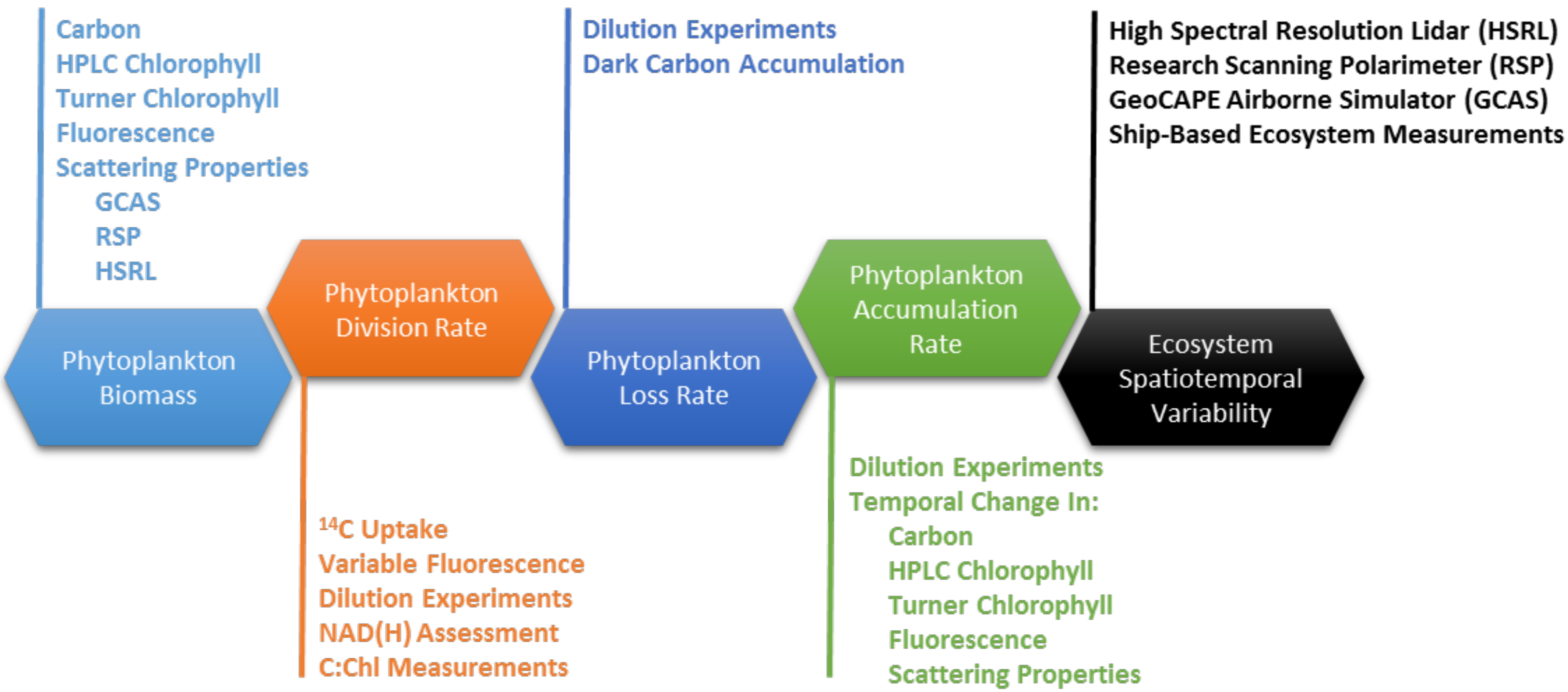
- **Satellite remote sensing**: ocean color, lidar, and altimetry provide long-term, basin scale context of NAAMES field observations
- **Modeling**: Allows integration of NAAMES observation into system function, extension of NAAMES results to future forecasts, comparison of NAAMES-resolved processes to other ocean areas, and campaign planning

  Ocean circulation-ecosystem modeling (WHOI)
  Mesoscale processes (UW/City College of NY)
  Aerosol modeling (LaRC)
  Cloud modeling (UW)

- **NAAMES Website**: [http://naames.larc.nasa.gov/](http://naames.larc.nasa.gov/)


## Baseline and Threshold Mission Requirements

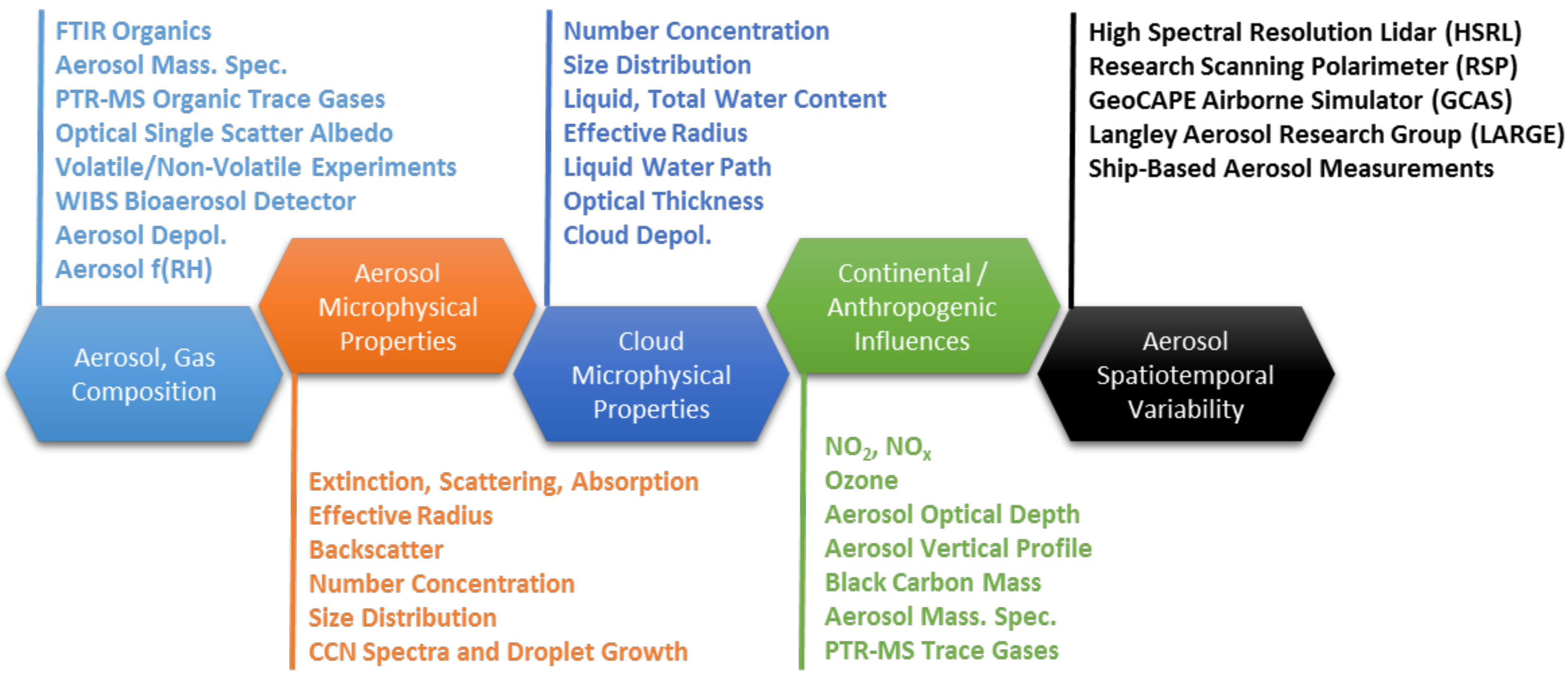
1. Redundancy in ecosystem observations - ‘property’ not ‘measurement’




*Measurements also include characterization of zooplankton communities, bacterial diversity, dissolved and particulate organic carbon stocks and remineralization, viral mortality, phytoplankton diversity, optical and physical properties, and much more…*


## Baseline and Threshold Mission Requirements

2. Redundancy in aerosol observations - ‘property’ not ‘measurement’




*Measurements also include a diversity of ship-based measurements providing a thorough characterization of aerosols immediately above the ocean surface, air-sea transfer, in-water aerosol precursors, and much more…*


## Baseline and Threshold Mission Requirements

3. Redundancy in airborne observations - ‘property’ not ‘measurement’

   *“Are core ecosystem properties observed from the ship representative of properties measured at the satellite pixel level?”*

**Essential Core Objective:**

Ecosystem spatial variability

Aerosol spatial variability

- *High Spectral Resolution Lidar* (HSRL)
  clouds, aerosols, ocean plankton
- *Research Scanning Polarimeter* (RSP)
  clouds, aerosols, ocean plankton
- *GeoCAPE Airborne Simulator* (GCAS)
  ocean plankton
- *Langley Aerosol Research Group Experiment* (LARGE)
  aerosols

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# Data Management

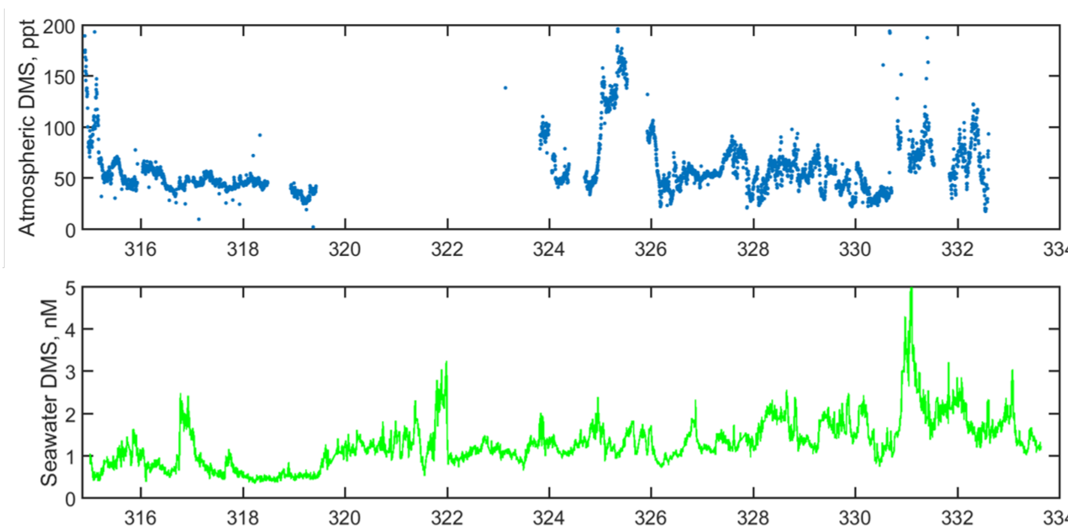
| | Ship Measurements / Ocean Properties | Aircraft Measurements / Aerosol Properties |
|---|---|---|
| Data manager | Christopher Proctor | Gao Chen |
| DAAC | Ocean Biology DAAC (GSFC) | Atm. Sci. Data Center (LaRC) |
| Project Data Repository | Ocean Bio. Processing Group site (OBPG @ GSFC) | Airborne Sci. Data for Atm. Composition site (ASD-AC @ LaRC) |
| Preliminary data latency | 6 months | 1 month |
| Final data latency | 12 months after field experiment ends | 12 months after field experiment ends |

# Campaign #1

**Highlights (preliminary)**

- Phytoplankton concentrations were low, populations were diverse (including many larger species), and all in very good physiological condition
- Phytoplankton division rates were generally greater than loss rates (the bloom was already beginning!)
- Some of the lowest aerosols ever measured (major potential for cloud effects)
- Aerosols were a mixture of sea salts and continental/marine organics
- Autonomous floats and drifters followed very different trajectories

No data has been collected in this region before (in November)



# Campaign #2

**Highlights (preliminary)**

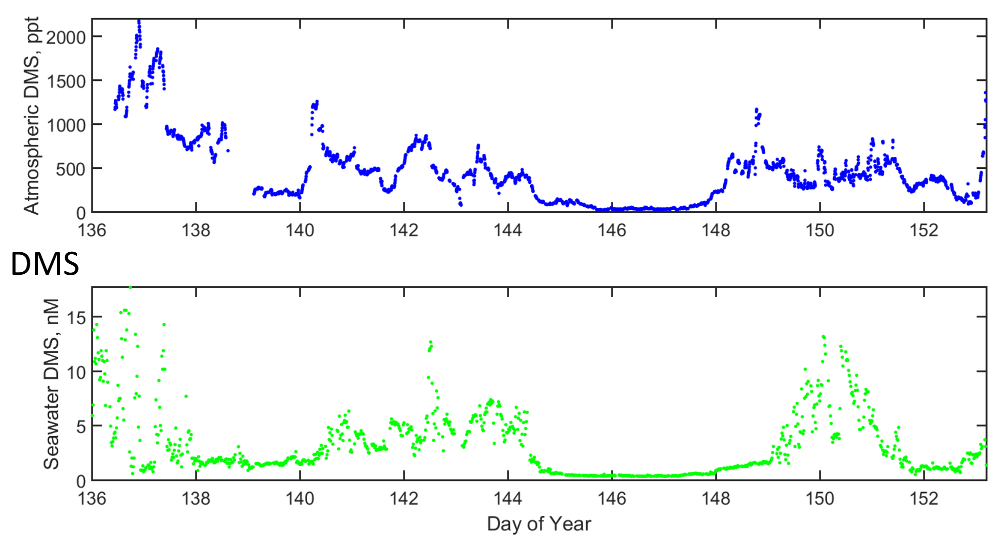
- Phytoplankton concentrations were at the bloom climax, populations were diverse, diatoms were not dominant, good physiological condition

- Phytoplankton division and loss rates were both proportionately elevated

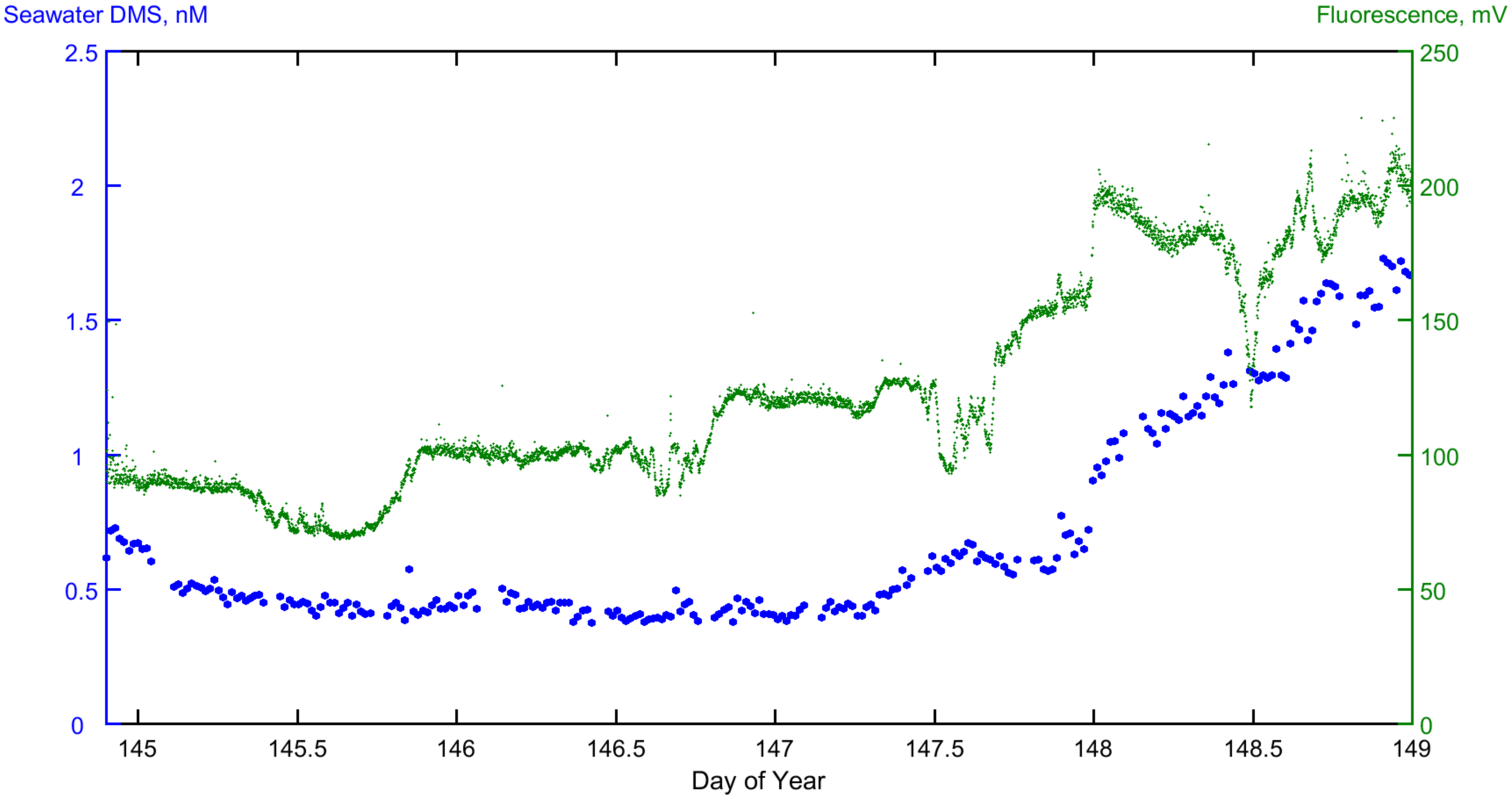
- Aerosol levels elevated with significant marine biogenic component

- Witnessed a ‘disturbance - recovery’ event, and documented evolution of plankton populations and biogenic aerosols

- Sampled aerosol sea-air transfer at the highest wind levels on record

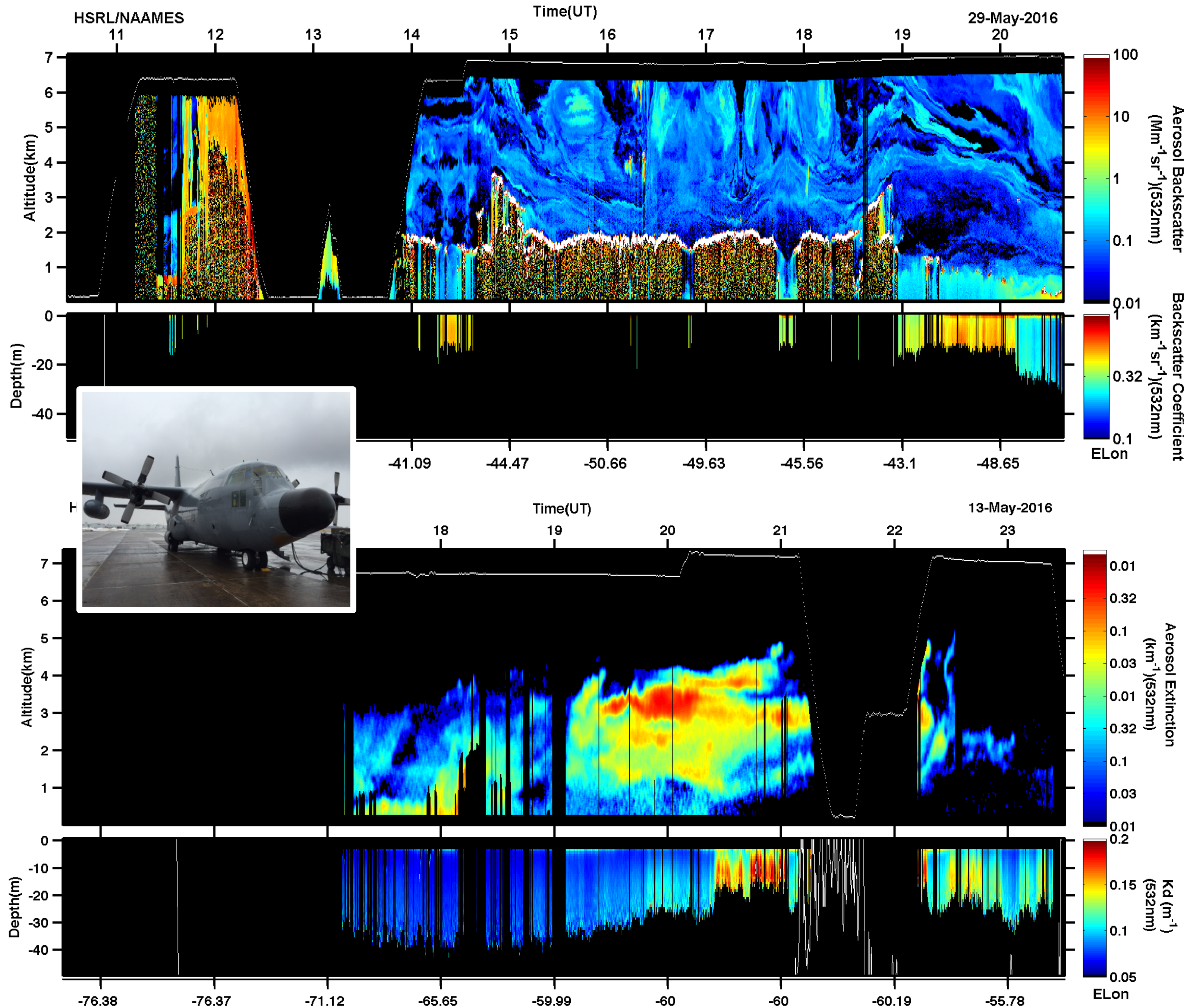


# May Cruise, Station 4: Recovery after wind mixing event



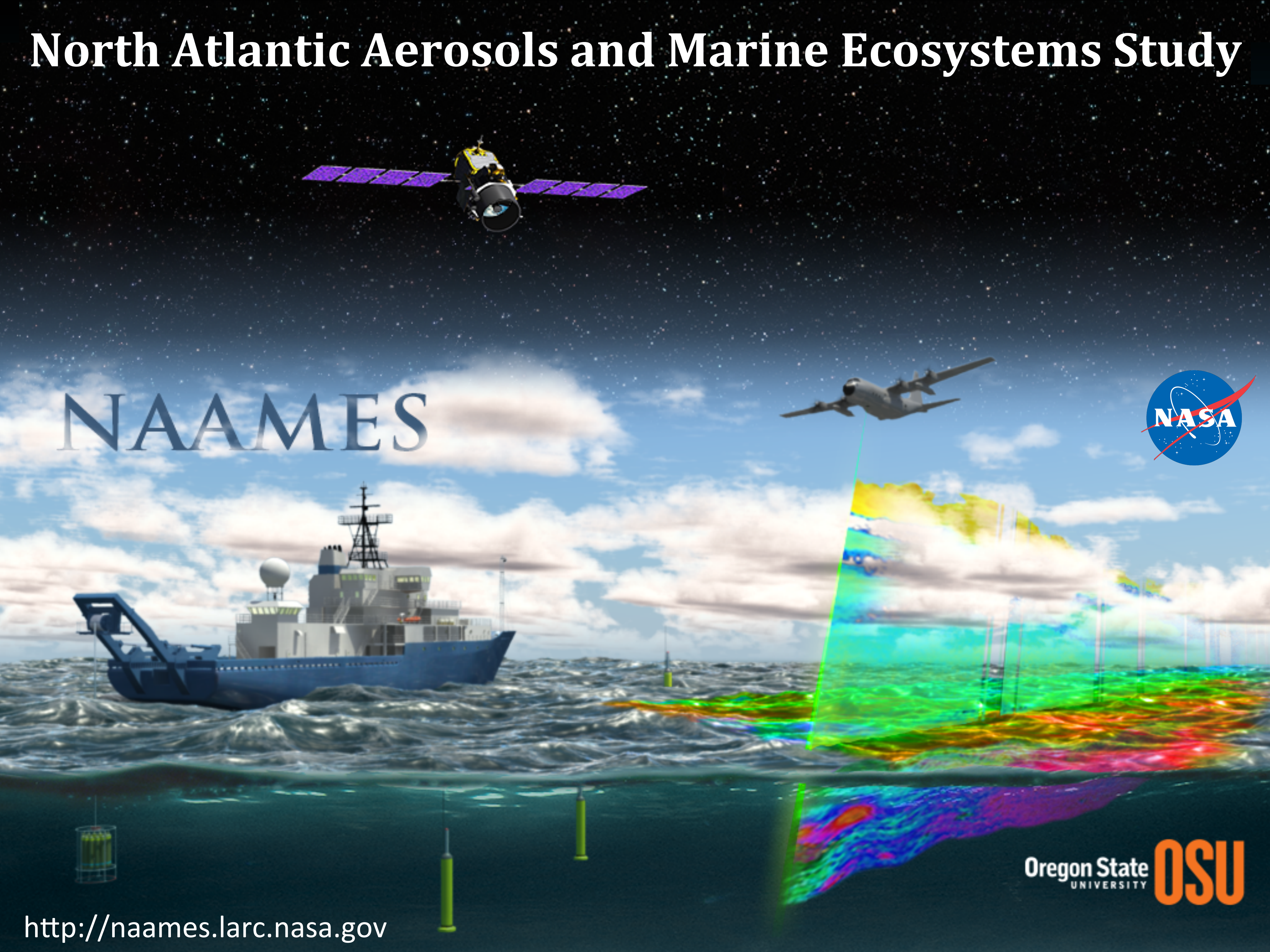

Thomas Bell, UCI

# Example Airborne Data: HSRL lidar




# Challenges

- Assignment of C-130:  increased costs, modification challenges to schedule, breakdowns
- Ship scheduling: requirement for fixed features challenges flexibility within UNOLS scheduling (particularly as NAAMES proceeds), hits to reserves for relocating ship
- Cloudiness: compromising ship-aircraft match-ups
- Interdisciplinary Science

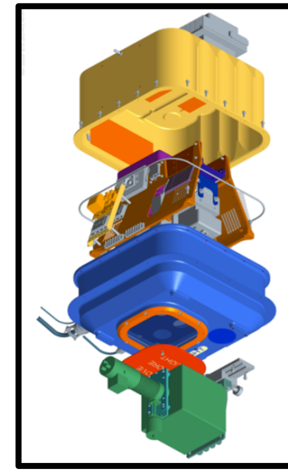

North Atlantic Aerosols and Marine Ecosystems Study
NAAMES
NASA
Oregon State
UNIVERSITY
OSU
http://naames.larc.nasa.gov


# Backup


# Measurements/Instruments/Payload – *Continued*

**HSRL**


**GCAS**



**RSP**

**4STAR**


## Airborne Remote Sensing Instruments and Measurements

| Instrument and Relation to Objectives | Geophysical Products |
|---|---|
| **GCAS**<br>• Hyperspectral ocean color products<br>• Atmospheric trace gas measurements<br>• Relate ship-scale to satellite-scale measurement<br>• GeoCAPE prototype satellite instrument | Chlorophyll-a concentration |
| | CDOM absorption (440nm) |
| | Particulate backscatter coeff. (440nm) |
| | Diffuse attenuation coeff. (Kd490) |
| | Euphotic depth |
| | Slant column atmospheric NO-$_2$ |
| | Slant column atmospheric O$_3$ |
| **HSRL-1**<br>• Aerosol and cloud properties<br>• Ocean properties<br>• Relate ship-scale to satellite-scale measurements<br>• ACE prototype satellite instrument | Aerosol backscatter (532/1064nm) |
| | Aerosol extinction (532nm) |
| | Aerosol & cloud depolarization (532/1064nm) |
| | Ocean diffuse attenuation coeff. (532nm) |
| | Ocean particulate backscatter coeff. (532nm) |
| **RSP**<br>• Aerosol and cloud properties<br>• Ocean properties<br>• Relate ship-scale to satellite-scale measurements<br>• ACE prototype satellite instrument | Aerosol optical depth for each mode of a bimodal distribution |
| | Aerosol size: effective radius |
| | Aerosol size: effective variance |
| | Aerosol Single Scatter Albedo |
| | Cloud top effective radius |
| | Cloud top effective variance |
| | Cloud mean effective radius |
| | Cloud optical depth |
| | Liquid Water Path |
| | Cloud Thickness |
| | Cloud droplet number concentration |
| | Water Leaving Radiance |
| | Chlorophyll concentration |
| | CDOM absorption (410nm) |
| | Ocean particulate backscatter coeff. |
| **4STAR**<br>• Facilitate RSP and GCAS retrievals | Spectrally resolved aerosol optical depth (350 to 1000nm) above the aircraft for constraining nadir-viewing RSP and GCAS retrievals. |

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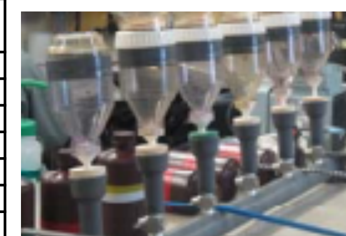
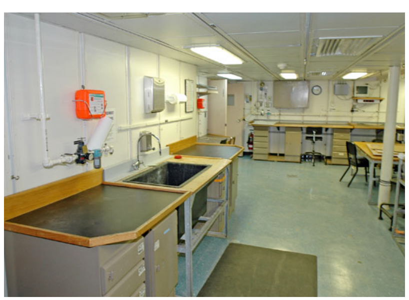
# Measurements/Instruments/Payload – *Continued*

## Ship-Based Ecosystem Measurements

| Geophysical Property | Instrument / Measurement |
|---|---|
| Spectral absorption and scattering | WetLabs AC-S |
| Spectral backscattering | WetLabs bb-3, WetLabs ECO BBFL |
| Spectral water-leaving radiance, up/downwelling irradiance | C-OPS, Satlantic PAR |
| Phytoplankton pigments | Turner 10AU fluorometer, HPLC, WetLabs ECO BBFL |
| Phytoplankton biomass | BD Influx, Shimadzu TOCN |
| Particle size distributions | BD Influx, Coulter Counter |
| Colored dissolved organics | 2m liquid waveguide spectrophotometer, WetLabs ECO-cDOM, Wetlabs AC-S |
| Total particulate carbon | Exeter Analytical 440 CHN Analyzer |
| Phytoplankton taxonomy | HPLC/CHEMTAX, BD Influx, TAG 16S/18S rRNA, UVP/ IFCB |
| Zooplankton abundance | UVP/ IFCB |
| Heterotrophic bacterial taxonomy | TAG 16S/18S rRNA |
| Phytoplankton growth rates | Dilution experiments, NPP/biomass |
| Net primary production | $^{14}C$ uptake, Biomass*division |
| Phytoplankton accumulation rate | Temporal change in chlorophyll, biomass |
| Phytoplankton loss rate | Dilution experiments |





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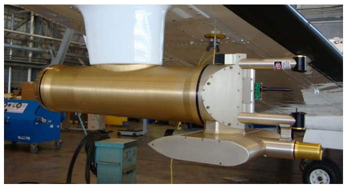
## Measurements/Instruments/Payload – *Continued*



### Airborne and Ship-Based
### Aerosol and Trace Gas Measurements

| Geophysical Property | Instrument | Platform |
|---|---|---|
| CO | LGR CRD | Aircraft |
| NOx | LGR CRD | Aircraft |
| Ultrafine CN, Total, Nonvolatile CN | TSI 3025, (2) TSI 3772 | Aircraft |
| Aerosol Particle Size | TSI SMPS, DMT UHSAS, TSI 3321 | Aircraft |
| Nonvolatile Particle Size | TSI SMPS | Aircraft |
| CCN spectra | DMT-CCN | Aircraft |
| Scattering (450, 550, 700nm λ) | TSI 3563 | Aircraft |
| Scattering humidity dependence, f(RH) | TSI 3563 | Aircraft |
| Absorption (467, 530, 660nm λ) | PSAP | Aircraft |
| Black carbon mass and size | DMT SP2 | Aircraft |
| Water Soluble Organics | Filter Sampling - TOC | Aircraft |
| Non-Refractory Aerosol Composition | HR-ToF-AMS | Aircraft |
| Bio-Aerosol Number, Size | DMT WIBS-IV | Aircraft |
| Cloud Particle Size | DMT CAPS | Aircraft |
| Ultrafine CN | GRIMM 5.400 | Ship |
| Aerosol Particle Size | BMI SEMS, TSI APS (3321), GRIMM 1.1.08 | Ship |
| Nonvolatile Particle Size | BMI SEMS | Ship |
| Scattering (450, 550, 700nm λ) | TSI 3563 | Ship |
| Absorption (467, 530, 660nm λ) | PSAP | Ship |
| CCN Spectra | DMT CCN | Ship |
| Black carbon mass | DMT SP2 | Ship |
| Non-refractory Composition | HR-ToF-AMS | Ship |
| Organic composition | Filter/FTIR, PILS/ESI/MS | Ship |
| Gas-phase organics | PTR/MS | Ship |
| Gas-phase DMS Seawater volatile organics | CIM Sequil./PTR/MS | Ship |
| Volatile carbon production/ consumption rates | PTR/MS | Ship |