National Aeronautics and
Space Administration

EXPLORE EARTH

The Interplay Between Technology and Research for Earth System Science: A “Technoturtle’s” View

Jack A. Kaye
Associate Director for Research
NASA Earth Science Division

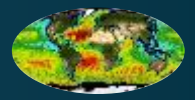
June 11, 2019

* Prepared with inputs from numerous colleagues from NASA HQ, centers, and research community

NASA Earth Science Division Elements

Flight (incl. Data Systems)

Develops, launches, and operates NASA's fleet of Earth-observing satellites, instruments, and aircraft. Manages data systems to make data and information products freely and openly available.

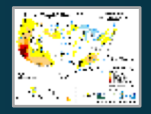


Research & Analysis

Supports integrative research that advances knowledge of the Earth as a system. Six focus areas plus field campaigns, modeling, and scientific computing.

Technology

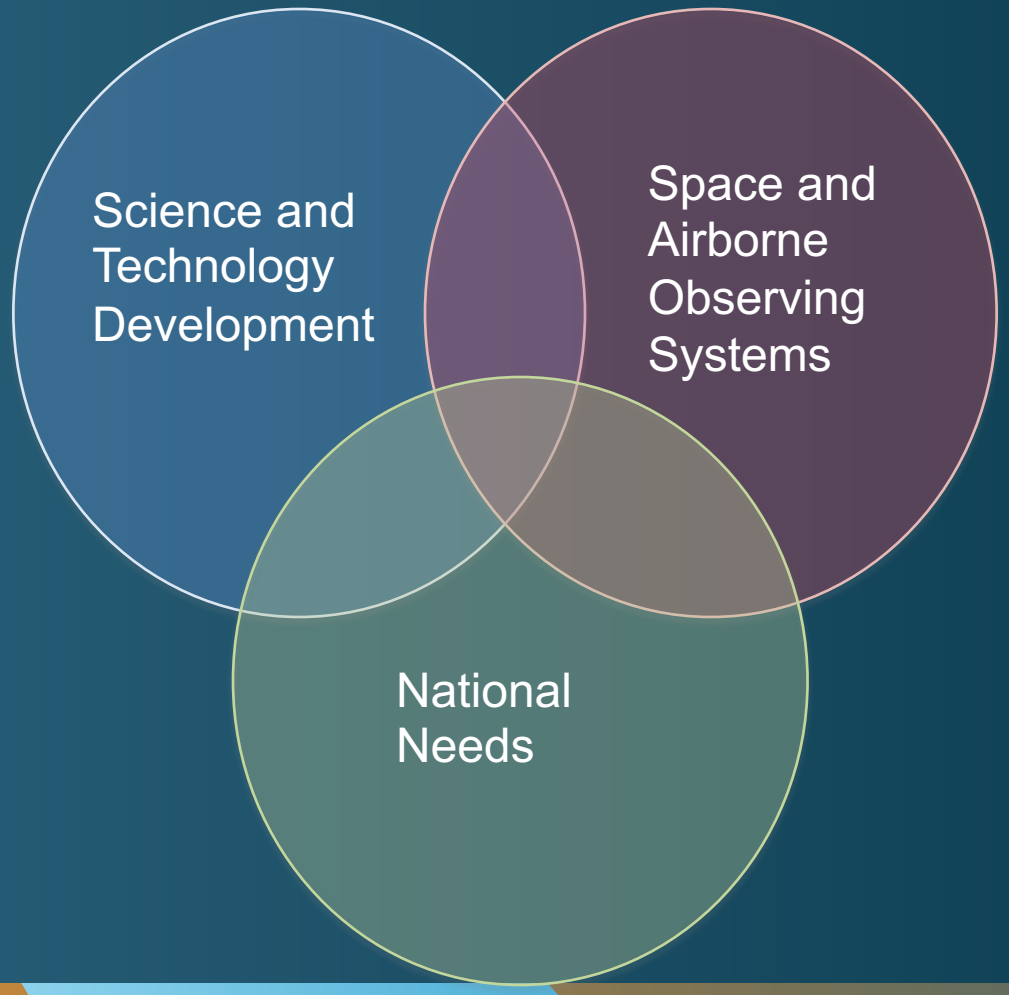
Develops and demonstrates technologies for future satellite and airborne missions: Instruments, Information Systems, Components, InSpace Validation (CubeSat and SmallSat form factors).



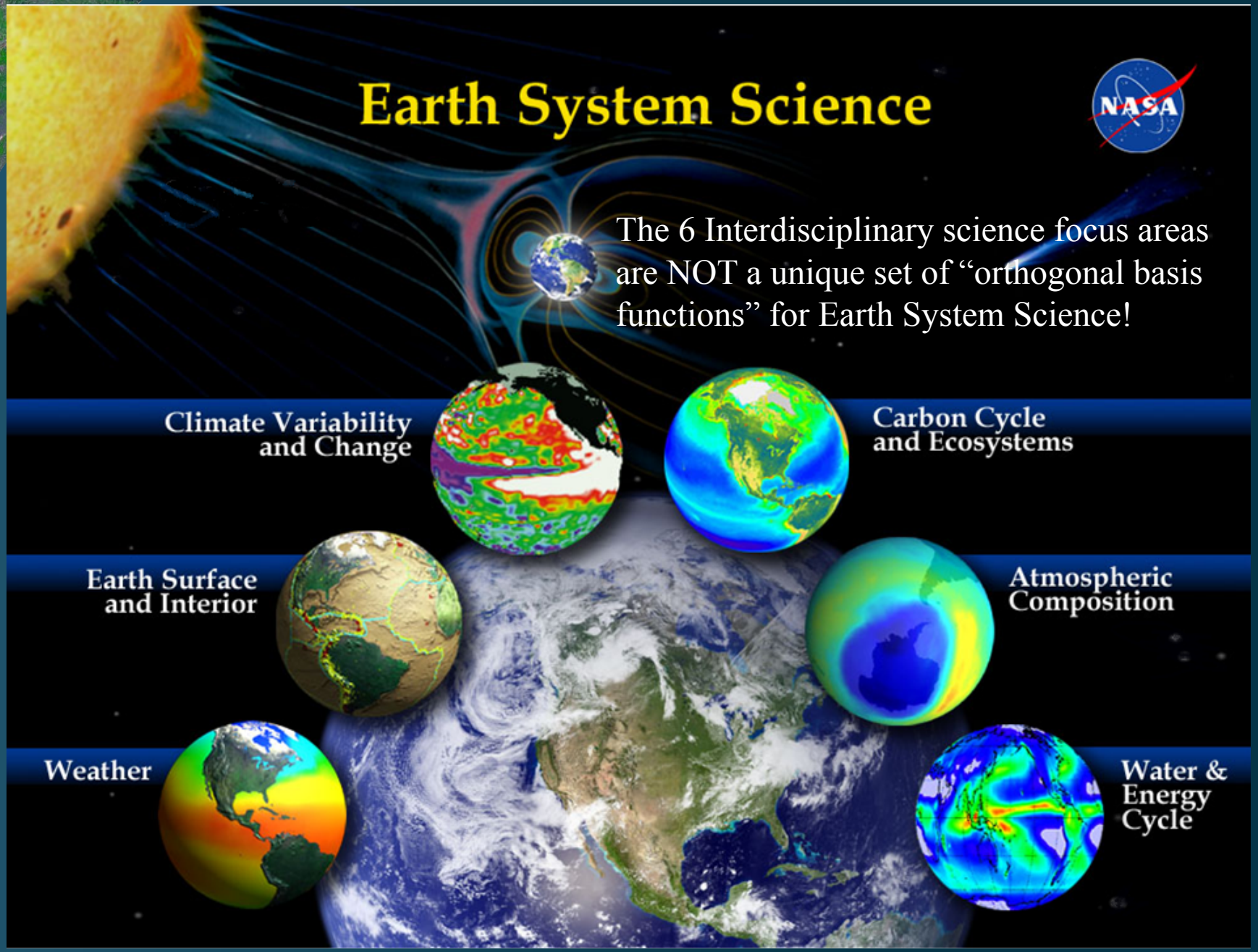
Applied Sciences

Develops, tests, and supports innovative uses of Earth observations and scientific knowledge to inform private and public sector planning, decisions, and actions. Activities include disaster response support and capacity building.

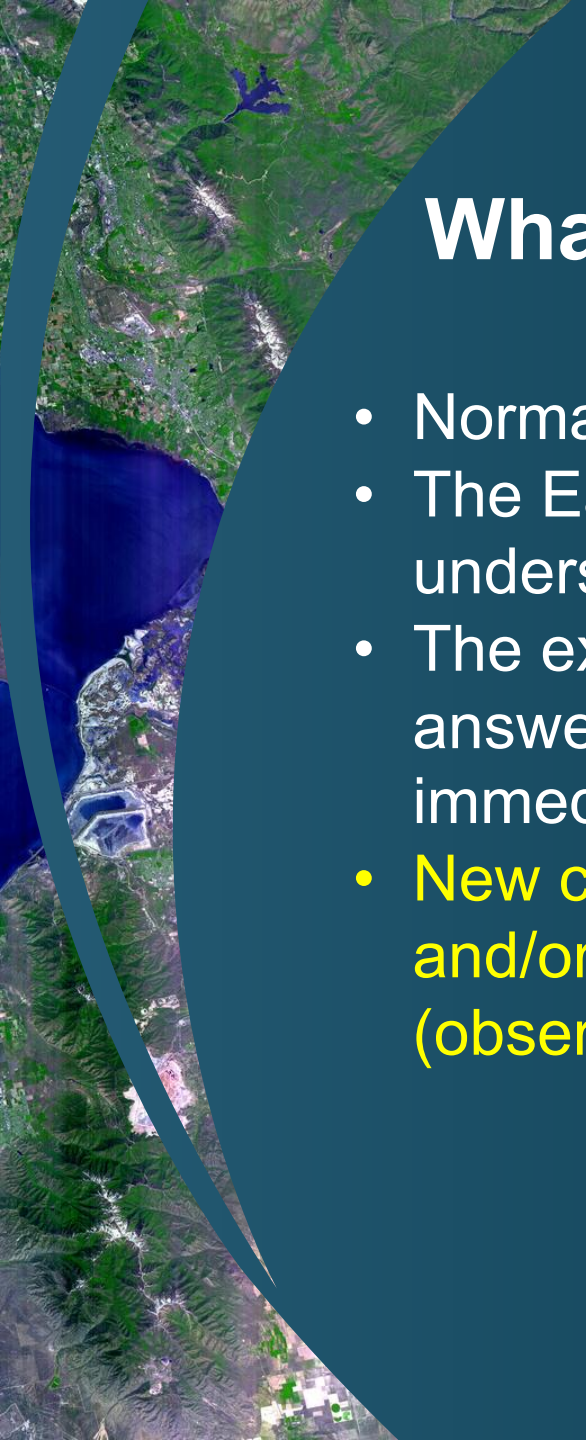
NASA ESD's Unique National Role



NASA's Earth Science program engages its scientific community in three overlapping areas!



The 6 Interdisciplinary science focus areas are NOT a unique set of "orthogonal basis functions" for Earth System Science!



What Makes for an Earth Science Research Priority?

- Normal advance of science – “we learn something”
- The Earth does something “unexpected” in a way that cries out for understanding and/or enhanced predictive capability
- The external environment (e.g., policy) changes in a way that makes answering specific questions and/or providing specific products more immediately important
- New capabilities come along that open up new areas of inquiry and/or provide for improved performance over their predecessors (observations, modeling, data, …)

What do I Mean by New Capabilities?

- Observational – can be new observables and/or better observing characteristics (emphasized in this talk!)
  - New satellites being launched
  - New airborne instruments
  - New surface measurements
  - New platforms – note NASA does not normally invest in platform development but can benefit from utilization
  - New laboratory equipment (incl. cal/val, spectroscopy, kinetics)
- Computational/Modeling
  - Bigger/faster computers
  - Better models (higher resolution, more comprehensive, better process representation, bigger ensembles)
- Data Analysis
  - Improved tools to analyze large data sets and/or model outputs

Not Emphasized in this talk – but open for questions!

What do I Mean by “Better”?

- *Temporal Resolution* - ability to watch the Earth system evolve with more frequent measurements to see higher frequency behavior and also capture extreme events
  - For satellites, that typically means higher altitude orbits or constellations of (smaller) satellites
  - For airborne instruments, that can mean sampling rate
- *Vertical Resolution* – ability to characterize “third dimension” - both to examine structure and inform analysis of lower resolution (including column) observations
- *Horizontal Resolution* – ability to view the Earth at smaller spatial scales, working towards being able to resolve processes and properties at local (actionable!) scales
- *Spectral Resolution/Range* – ability to more fully sample electromagnetic spectrum to get more complete information about what is being seen
- *Better Operational Characteristics* (especially important for surface-based and airborne measurements)
  - Increased accuracy/precision/stability
  - Increased availability of ancillary information (on its own or through co-location …)
  - Increased reliability/service length
  - Increased mobility/”deployability”/platform flexibility
  - Increased autonomy
  - Increased intelligence, including sampling and on-board processing and/or ways to decrease data rate, if needed
- *Reduced Cost* – cheaper is always nice, too (not just initially, but over lifetime)

Where do New Capabilities Come From?*

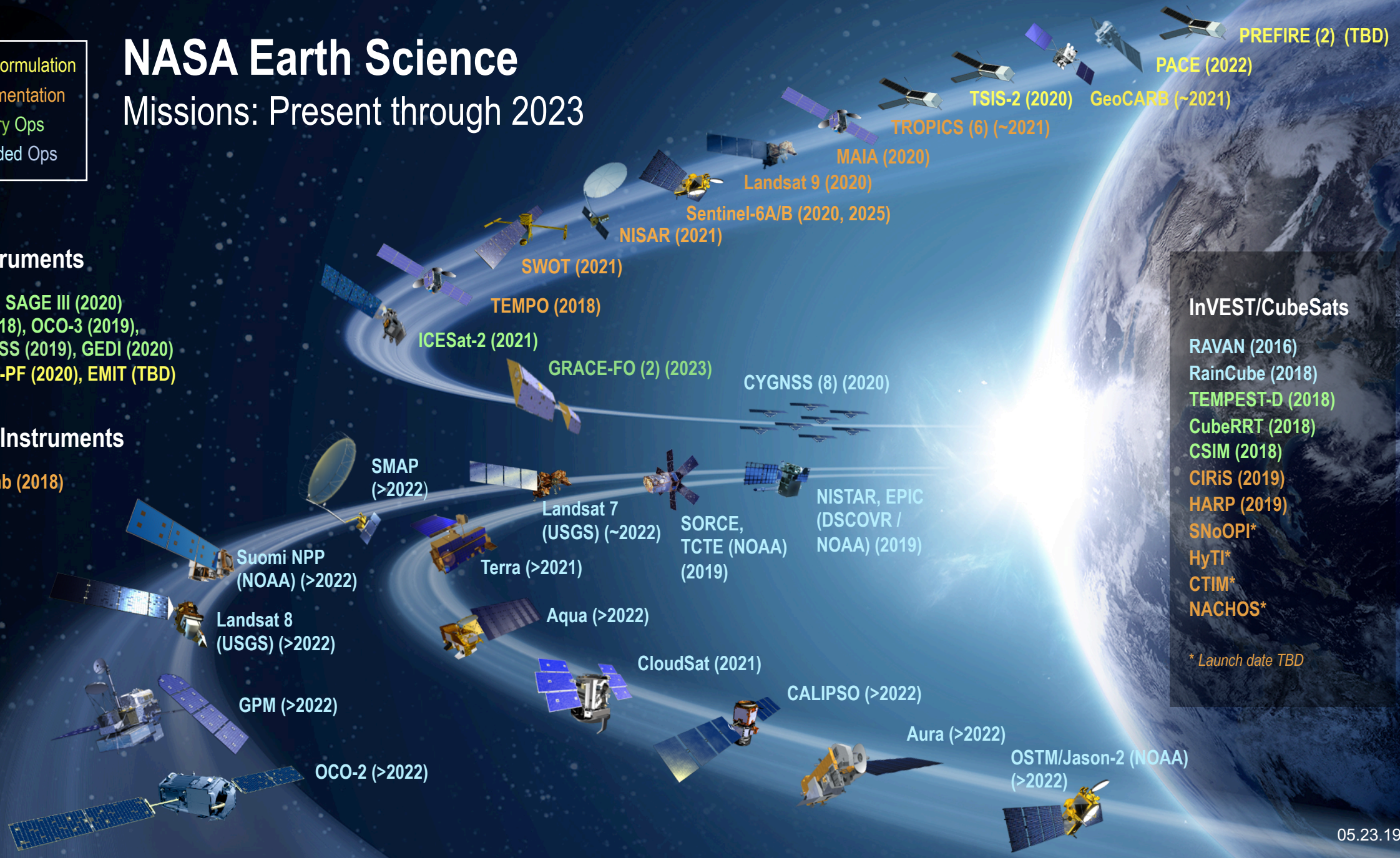
- NASA Technology Development Programs (ESTO! – also SBIR, ….)
- NASA Center Investment Funds
- Evolutionary Advances Supported by NASA R&A and Flight Programs
- Other US Government Agency Programs
- University/Non-Government Investments
- Private Sector Investments
  - Observational Capabilities (Instruments AND complete missions for data buy)
  - Computing Capabilities (typically NOT developed for our purposes)
  - Data Storage and Networking
  - Observational Platforms (esp. airborne, including UAS)
- Foreign Government Contributions
  - Earth Observing Satellites from our “Observational Partners” (Research AND Operations)
  - ”Other” (e.g., other nations’ GNSS programs that complement US GPS)

* This is NOT intended to be a fully inclusive list!

NASA Earth Science

Missions: Present through 2023

- (Pre)Formulation
- Implementation
- Primary Ops
- Extended Ops



ISS Instruments

LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2019),
ECOSTRESS (2019), GEDI (2020)
CLARREO-PF (2020), EMIT (TBD)

JPSS-2 Instruments

OMPS-Limb (2018)

InVEST/CubeSats

RAVAN (2016)
RainCube (2018)
TEMPEST-D (2018)
CubeRRT (2018)
CSIM (2018)
CIRiS (2019)
HARP (2019)
SNoOPI*
HyTI*
CTIM*
NACHOS*

** Launch date TBD*

05.23.19

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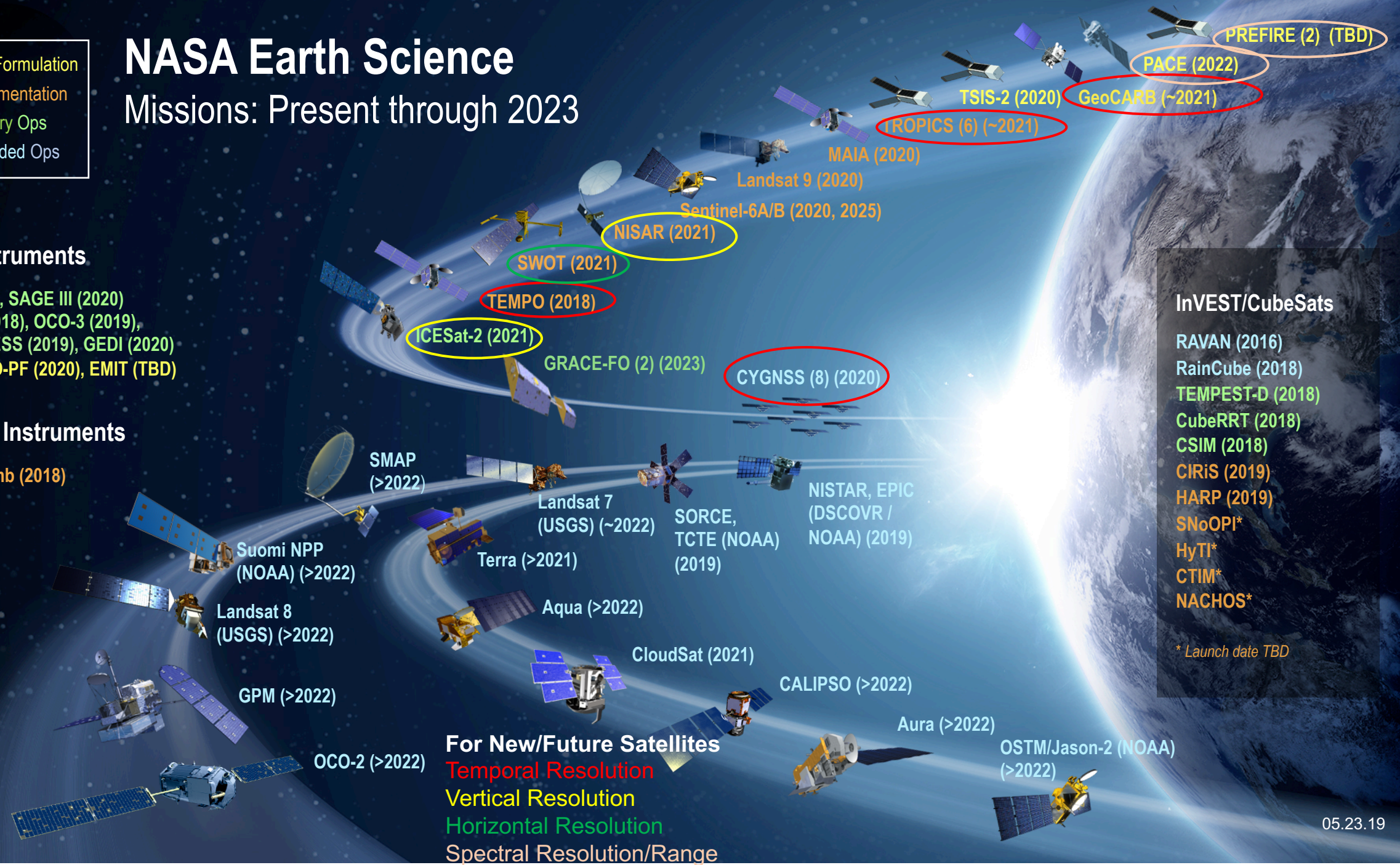

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** Launch date TBD*

For New/Future Satellites
Temporal Resolution
Vertical Resolution
Horizontal Resolution
Spectral Resolution/Range

05.23.19

Observing System Priorities from NASEM 2017 Decadal Survey

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	Aerosol properties, aerosol vertical profiles, and cloud properties to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection and Precipitation	Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	Large-scale Earth dynamics measured by the changing mass distribution within and between Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	Earth surface geology and biology, ground/water temperature, snow reflectivity, active geological processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	CO2 and methane fluxes and trends, global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar **		X	
Ice Elevation	Global ice characterization including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar **		X	
Ocean Surface Winds and Currents	Coincident high-accuracy currents and vector winder to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift	Radar scatterometer		X	

*** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables*

Observing System Priorities from NASEM 2017 Decadal Survey (*cont.*)

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Ozone and Trace Gases	Vertical profiles of ozone and trace gases (including water vapor, CO, NO2, methane, and N20) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth and Snow Water Equivalent	Snow depth and snow water equivalent including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	3D structure of terrestrial ecosystem including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation and forest degradation	Lidar**		X	
Atmospheric Winds	3D winds in troposphere/PBL for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	Diurnal 3D PBL thermodynamic properties and 2D PBL structure to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling and DIAL lidar; and lidar** for PBL height			X
Surface Topography and Vegetation	High-resolution global topography including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

*** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables*

Other ESAS 2017 Targeted Observables not allocated to a Flight Program element: Aquatic Biogeochemistry, Magnetic Field Changes, Ocean Ecosystem Structure, Radiance Intercallibration, Sea Surface Salinity, Soil Moisture

See: https://science.nasa.gov/earth-science/decadal-surveys

ESD has decided to treat Atmospheric Winds as Explorer

Earth Science Division Responses to 2017 Decadal Survey

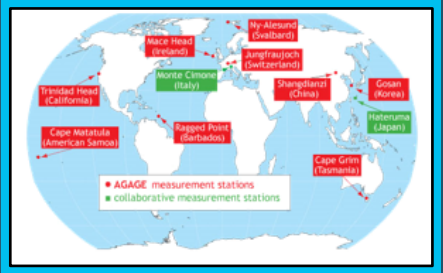
- Multi-center study teams were created to assess possibilities for Designated Observables
  - Aerosols-Clouds/Convection/Precipitation (combined!)
  - Surface Biology and Biogeochemistry
  - Surface Deformation and Change
  - Mass Change
- Announcement of Opportunity released for first Earth Venture Continuity (EVC) mission, focused on Earth's radiation budget
- ROSES element released for development of science plans for Incubator (Planetary Boundary Layer, Surface Topography & Vegetation)
- Developing RFPs for awards to facilitate program implementation and enhance community participation
- Major communications effort internally and with community
  - Weekly meetings of ESD leadership team
  - Biweekly listening sessions for ESD staff
  - Creation of web site and opportunity for community to pose questions and get answers
  - Monthly (now bi-monthly) webinars with NASA centers
  - Webinar with full community held every four months (on-site first few times) and town hall sessions at meetings.
- Limited funding flexibility ("Budget Wedge") while completing Program of Record has precluded release of Announcement of Opportunity for Explorer Missions

Incubation Study Team ROSES Element (ROSES19 A.54)

- The purpose of this program element is to assemble two study teams (one each) for advancing (1) Planetary Boundary Layer (PBL) and (2) Surface Topography and Vegetation (STV) Incubation Targeted Observables (TO) Program Goals as outlined in the NASEM 2018 Decadal Survey, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space.*
- The objective of the incubation study teams is to identify methods and activities for improving the understanding of and advancing the maturity of the technologies applicable to these two TOs and their associated science and applications priorities.
- Team membership will be determined through this program element via a competitive selection process that includes a peer review.
- It is expected that each team will solicit input from the broader scientific community including academia, government agencies, and private industry. At least one in-person community meeting in an open forum should be held by each study team during the first six months of the period of performance, and allowance for virtual participation in this meeting is strongly encouraged.
- POCs: Gail Skrofonick-Jackson (PBL), Ben Phillips (ST&V), NOIs due 6/17, Proposals due 8/1/ Special Thanks to Amber Emory (ESTO) for he help.

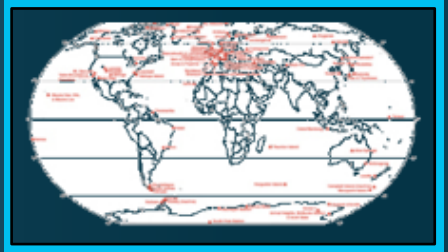
Examples of NASA-supported Ground Networks

AGAGE

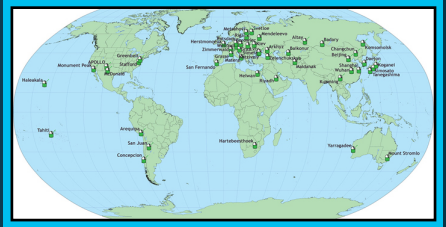


GGN

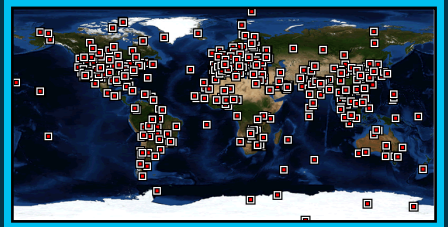
NDACC



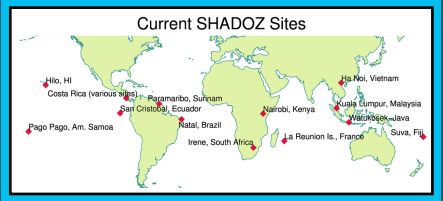
NSGN



AERONET



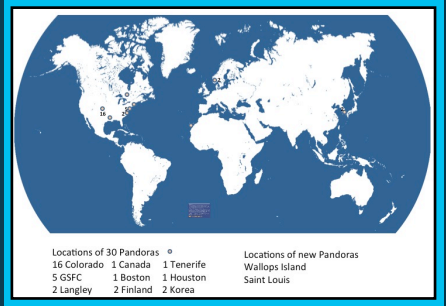
SHADOZ



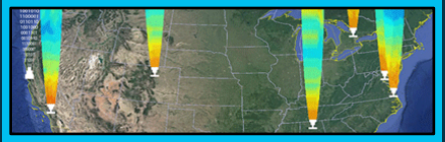
MPLNet

TCCON

PANDORA



TOLNet



TOLNet Deployments in Field Campaigns

Location	Date	Campaign	TOLNet Institution
Horsepool, UT	Winter 2013	Uintah Basin	NOAA/ESRL
South East U.S.	Summer 2013	SEAC4RS/SENEX	UAH
Clark County, NV	Summer 2013	LVOS	NOAA/ESRL
Houston, TX	Summer/Fall 2013	DISCOVER-AQ	NOAA/ESRL
Denver, CO	Summer 2014	DISCOVER-AQ/FRAPPE	NASA/GSFC; NASA/LaRC; NOAA/ESRL
Seoul, KR	Summer 2016	KORUS-AQ	NASA/GSFC
San Joaquin Valley, CA	Summer 2016	CABOTS	NOAA/ESRL
Wrightwood, CA	Summer 2016	SCOOP	NASA/GSFC; NASA/LaRC; NOAA/ESRL; JPL/TMF; ECCC
Clark County, NV	Summer 2017	FAST-LVOS	NOAA/ESRL
Hampton Roads, VA	Summer 2017	OWLETS	NASA/GSFC; NASA/LaRC;
Baltimore, MD	Summer 2018	OWLETS-2	NASA/GSFC; NASA/LaRC;
NJ, NY, CT	Summer 2018	LISTOS	NASA/GSFC; NASA/LaRC;
USA&Canada	Summer 2019	FIREX-AQ	Ground Support from All TOLNet Sites

Developing a MOBY-NET Instrument, Suitable for a Federation Network for Vicarious Calibration of Ocean Color Satellites

(Ken Voss – U Miami, Carol Johnson-NIST, Mark Yarbrough-MLML, Art Gleason-U Miami)

The Specific goals are

A) A MOBY structure that can fit in a 40’ container and be able to accept a modular optical system.

B) A modular, stable, optical system allowing installation and removal from buoy hull as one intact piece.

C) A separate stable source and radiometer, with sufficient stability to verify system performance pre/post deployment at the chosen remote site.

Meets IOCCG White paper OC-VCAL requirements!

HyperNav: Autonomous Hyperspectral Radiometer for Satellite Vicarious Calibration

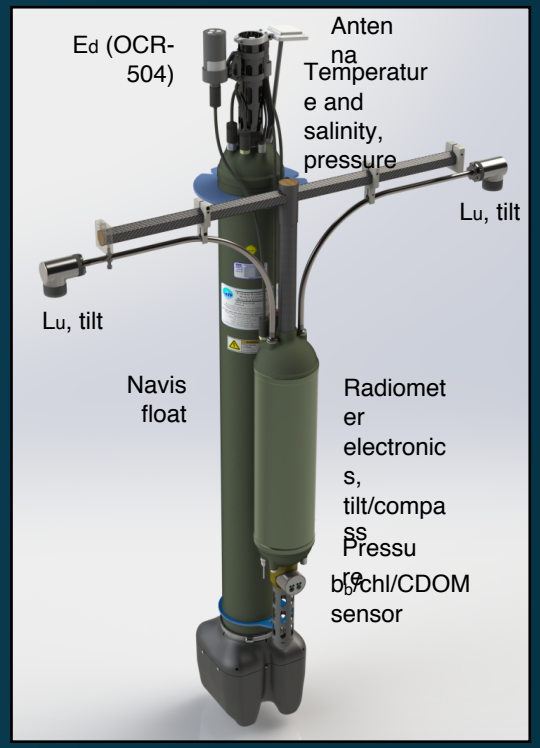
PI: Andrew Barnard, NASA Award NNX14AP86G

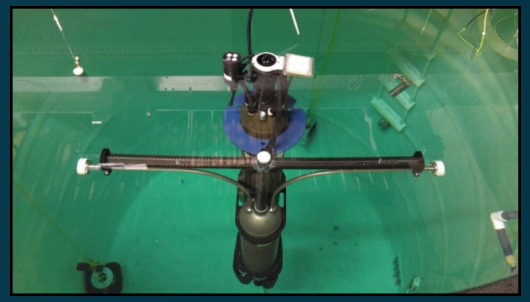
Goals

- Next-generation hyperspectral radiometric sensors for calibration/validation.
- Utilize autonomous floats as a platform to collect hyperspectral radiometric to minimize uncertainty.
- Develop an end-to-end system/strategy for new ocean-color satellite calibration – including float deployment, radiometric data quality assurance, data delivery and satellite inter-comparison.

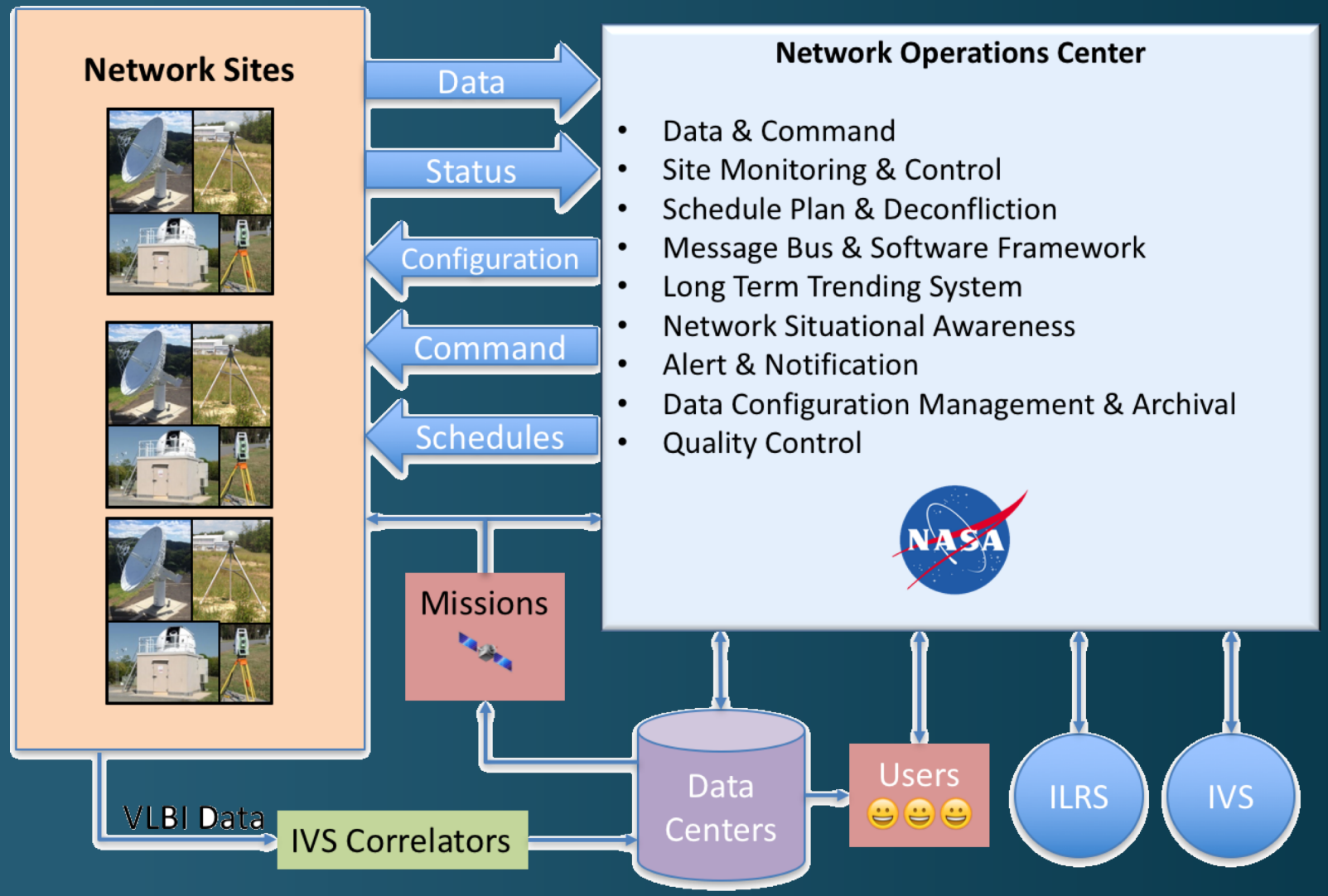
HyperNav autonomous float system advantages

- Risk reduction approach to the vicarious calibration program for PACE and other missions.
- Deployment floats at the start of a satellite mission - Rapid characterization of in flight satellite radiometer.
- Provide radiometric measurements across a broader range of solar angles and geographic regions, to assess the satellite dependencies on out-of-band response, BDRF, etc.
- Augments other moored cal/val sites throughout satellite lifetimes, enables rapid collection of vicarious calibration data.





Next-Generation Space Geodesy Network Operations Center (NOC)



Goal of the NOC

- Stream space geodesy data to a centralized facility to enable remote operations and engineering support
- Facilitate required simultaneous observations at distributed sites
- Lower operations costs

Status

- Next-gen SLR and VLBI systems were designed to support remote and autonomous operations – hardware (sensors and actuators) are in place
- Software development to address all safety and IT security requirements remains a significant effort
- Autonomous SLR operations will require approval of updated outdoor laser safety guidelines currently being developed under NASA leadership within the SAE G-10T Working Group

Airborne Science Program

Observing Platforms for Earth System Science Investigations

http://airbornescience.nasa.gov

ER-2

G III

G V

P-3

DC-8

Other Available Aircraft

C-130

B-200

C-23 Sherpa

Global Hawk

WB-57

HU-25C Falcon

Twin Otter

SIERRA

IKHANA

S-3B

What Airborne Science Means at NASA

- Airborne Science at NASA integrates unique capabilities in the following areas:
  - Platforms: airborne platforms that can fly instrument packages (from a single instrument to several dozen) to locations needed for the desired observations
  - Sensors: remote sensing and/or *in situ* sensors that can work individually or collectively to address science and/or technology questions and opportunities
  - Systems: data, information, and operational systems that enable data to be acquired, transmitted, shared, and to allow investigator interactions with crew to optimize flight trajectories
  - People: the human capital that allows airborne missions to be carried out safely and effectively in remote locations, frequently under harsh conditions with little indigenous local support; also the ability to design experiments/campaigns and turn acquired data into knowledge
  - Opportunities: program-directed and competitive solicitations for mission/campaign development and also instrument development/evolution; well-defined flight request approach for use of platforms/facility sensors
- The linkage among these is critical – especially the “marriage” between platforms and sensors (pods/viewing ports for remote sensing instruments, well-characterized inlets for *in situ* sensors)
- Airborne Science is fully integrated with space-based measurements, surface-based measurements and modeling into an “integrated whole” with involvement of all components included in planning/design

CPEX 2017: A Field Experiment to study Convective Processes in the Tropics

25 May – 24 June 2017

DC-8 based in Fort Lauderdale, Florida

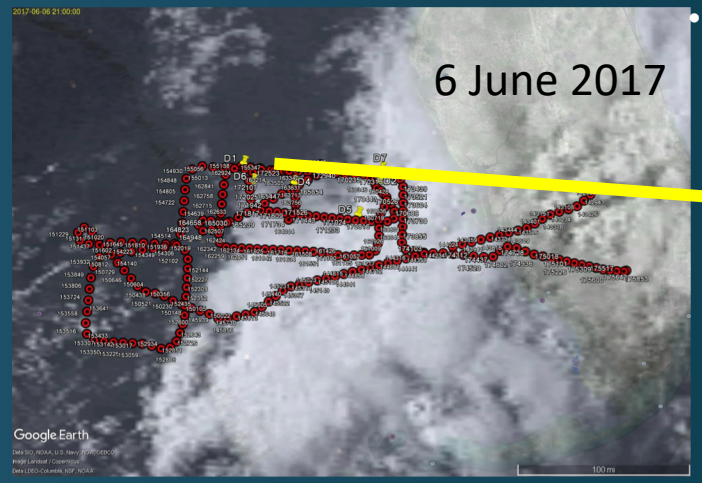
DAWN, APR-2, HAMSR, MTHP, Dropsondes, MASC

CPEX Science Objectives

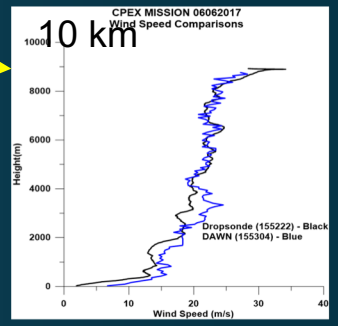
1. **Improve understanding of convective processes** including cloud dynamics, downdrafts, cold pools and thermodynamics during initiation, growth, and dissipation
2. **Obtain a comprehensive set observations, especially from DAWN,** in the vicinity of scattered and organized deep convection in all phases of the convective life cycle
3. **Improve model representation of convective and boundary layer processes** over the tropical oceans using a cloud-resolving, fully coupled atmosphere-ocean model
4. **Improve model assimilation of the wind, temperature and humidity profiles** from the wind lidar and dropsondes into numerical weather prediction models

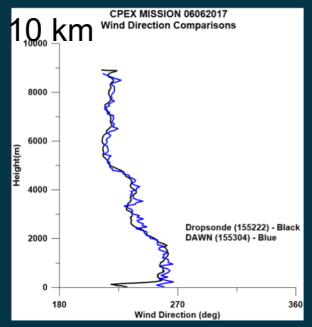
LaRC DAWN on NASA DC8

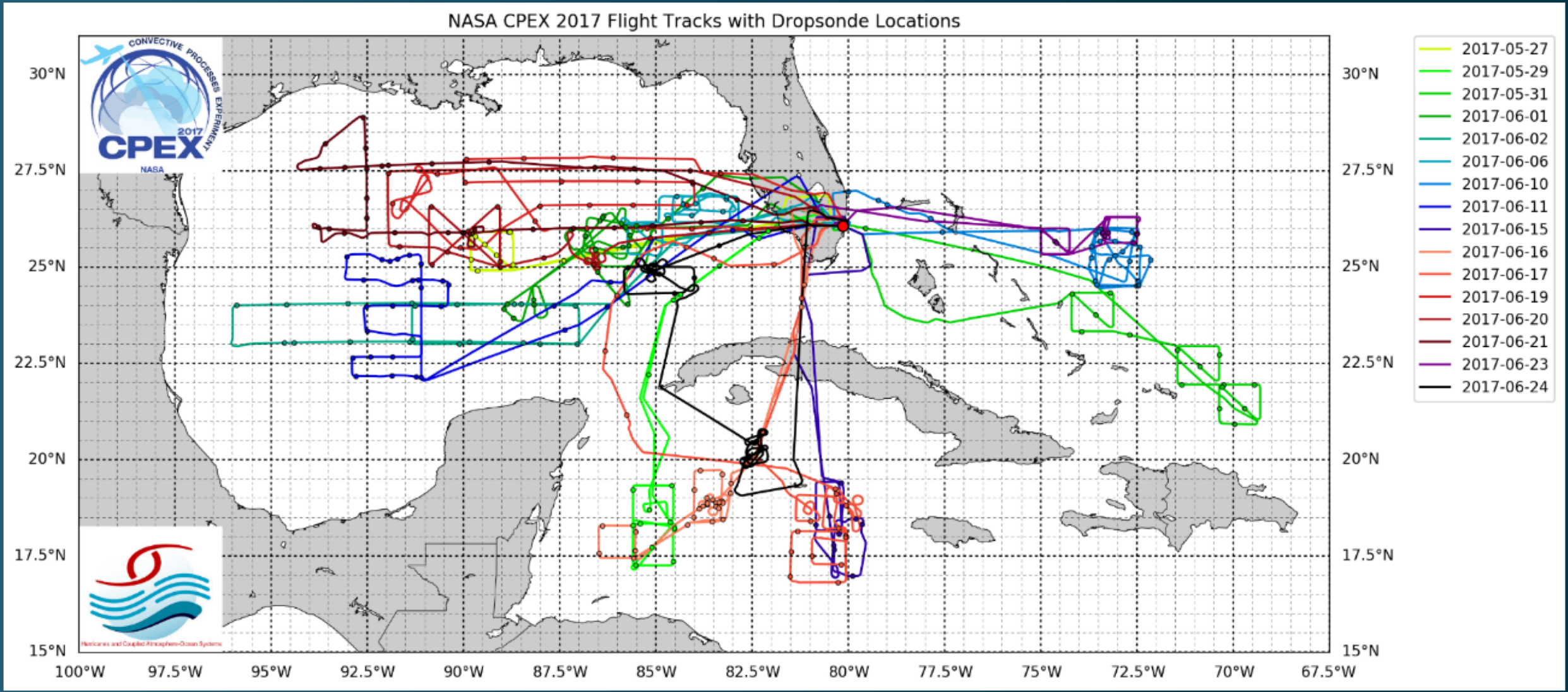
- DAWN is NASA's most capable airborne wind-profiling lidar
- Previously participated in NASA GRIP (2010) and Polar Winds (2014-15) airborne campaigns
- Laser pulses at 2-micron wavelength and 10 Hz are eyesafe at any range; daytime observations not compromised by solar background
- Data may be post flight processed multiple times with various number of shots accumulated (horizontal resolutions), vertical resolutions, and wind search bandwidths for maximum information extraction
- CPEX science flights indicate excellent vertical coverage and agreement with dropsonde winds (e.g. from 9.5km in plots below)



DAWN (blue) vs Dropsonde (black)






NASA CPEX 2017 Flight Tracks with Dropsonde Locations
CONVECTIVE PROCESSES EXPERIMENT
CPEX
2017
NASA
30°N
27.5°N
25°N
22.5°N
20°N
17.5°N
15°N
100°W
97.5°W
95°W
92.5°W
90°W
87.5°W
85°W
82.5°W
80°W
77.5°W
75°W
72.5°W
70°W
67.5°W
2017-05-27
2017-05-29
2017-05-31
2017-06-01
2017-06-02
2017-06-06
2017-06-10
2017-06-11
2017-06-15
2017-06-16
2017-06-17
2017-06-19
2017-06-20
2017-06-21
2017-06-23
2017-06-24

April 2019 ADM Aeolus Validation Test Flights

Kristopher Bedka (LaRC, Mission Lead), LaRC DAWN Team (PI: Michael Kavaya), LaRC HALO Team (PI: Amin Nehrir), Dave Emmitt and Steven Greco (Simpson Weather Associates), Sammy Henderson (Beyond Photonics)

EXPLORE EARTH

Flight Campaign Details, Payload, and Supporting Datasets

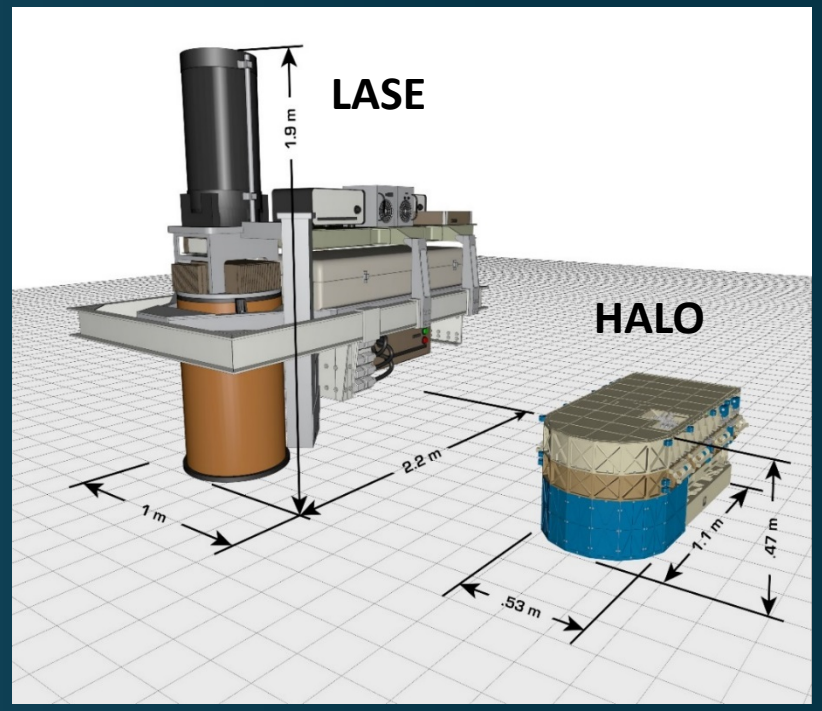
- **25 DC-8 flight hours (~5 flights) out of Palmdale, CA from 1-30 April 2019**
  - Target mostly cloud free regions for ADM Aeolus validation, focusing on ~6 PM Aeolus overpasses (3-4 flights). Coordinate with ESA to understand their Cal/Val needs. Explore other targets of opportunity with remaining flight hours.
- **Doppler Aerosol WiNd (DAWN) Lidar**
  - Vector wind profiles, ~100-200 m vertical resolution in PBL, possibly coarser aloft depending on aerosol conditions. 2-5 km horizontal resolution. 1.8 m/s wind speed and ~7º wind direction precision demonstrated during CPEX.
- **High-Altitude Lidar Observatory (HALO)**
  - HSRL aerosol backscatter/extinction and cloud profiles at 30-300 m vertical and 1-12 km horizontal resolution. DIAL water vapor (WV) mixing ratio profiles at ~150-300 m vertical and 1-20 km horizontal resolution, with <5% (10%) accuracy (precision). Resolutions dependent on aerosol/WV conditions.
- **55 Yankee Environmental Systems XDD Dropsondes:** Characterization of DAWN, Aeolus, and AMV winds. Validation of HALO water vapor profiles.
- **GOES-17 1-minute Resolution "Mesoscale Scan" Imagery** to be requested from NOAA to support AMV and cloud process studies.

Follow-On Aeolus Cal/Val Campaign in 2020

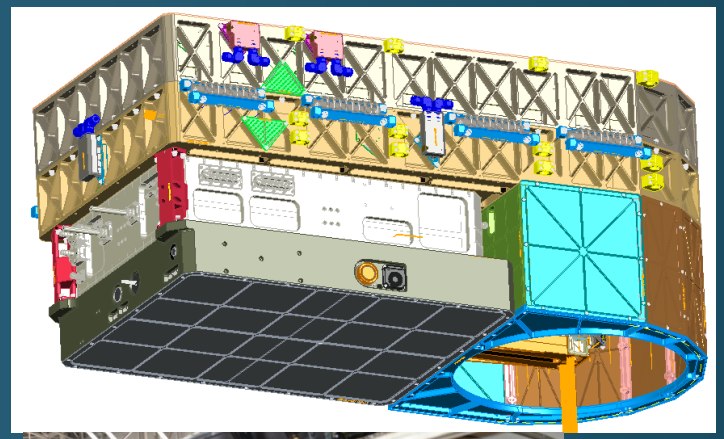
- **ESA suggests joint NASA-DLR Aeolus Cal/Val flights in 2020 out of Cape Verde.** DLR could participate with their Aeolus ALADIN Airborne Demonstrator (A2D) and 2 micron coherent Doppler Wind Lidar.
- **Aeolus Cal/Val during EUREC4A (Jan-Feb 2020) was also considered by ESA** due to EUREC4A's wealth of instrumentation and important science questions. ESA determined that reaching Barbados with the DLR Falcon would be more time-consuming/costly than Cape Verde. In addition, EUREC4A aircraft are committed to pre-specified flight plans, leaving little opportunity for Cal/Val activities.
  - Summertime Saharan dust layers and tropical jet streams near Cape Verde offer better opportunity for DWL wind retrieval throughout the troposphere. Winds are likely to be retrieved over a much shallower depth during EUREC4A due to lesser aerosol loading.

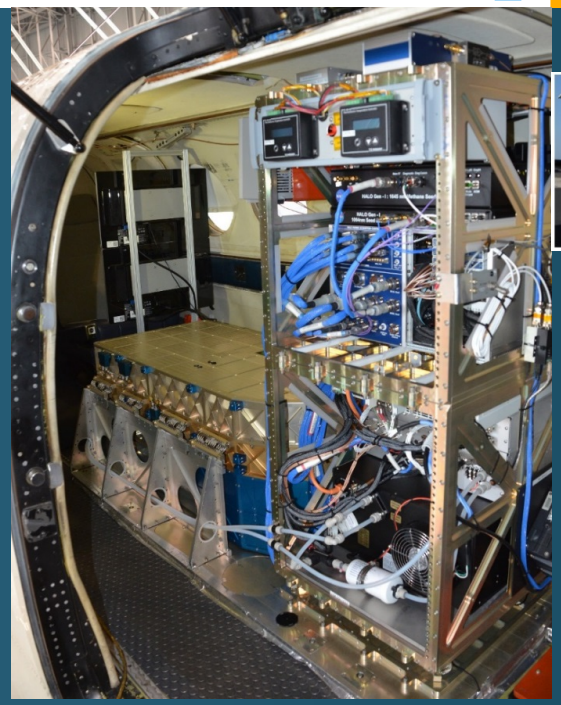
Advanced Airborne Demonstrator

- New capability to measure H_2O profiles from smaller and high altitude airborne platforms
  - Currently: LASE is only capable of going on large aircraft (DC-8)
  - Development of more compact H_2O DIAL system with additional (CH_4) DIAL and HSRL measurement capabilities
- Transceiver capable of rapid reconfiguration to support H_2O/HSRL or CH_4/HSRL or H_2O/CH_4
- DIAL measurements along with measurements of aerosol/cloud properties combines many of the measurement requirements for airborne campaigns and satellite calibration and validation
- Technology test-bed for maturing technologies and algorithms required for future DIAL missions



HALO Attributes and Development Cycle





- H_2O DIAL Capabilities: 4 λ DIAL
  - Accuracy: <5%
  - Precision: <10%*
  - Vertical resolution: 100-330 m*
  - Horizontal resolution: 1-12 km*
  - Sensitivity: .001-30 g/kg
  - TPWV: σ~1%, bias ~ 1%, 200 m res.
- HSRL Capabilities: *1-α, 2-β, 2-δ*
  - HSRL at 532 nm
  - Backscatter 1064 nm
  - Depolarization at both 532, 1064 nm
- History
  - 2015-2018: instrument development
  - May 2018: first test CH_4flight on UC-12
  - April 2019: first test H_2O flight on DC-8
  - 2018: 1 field campaign (CH_4)
  - 2019: 2 field campaigns (H_2O &CH_4)

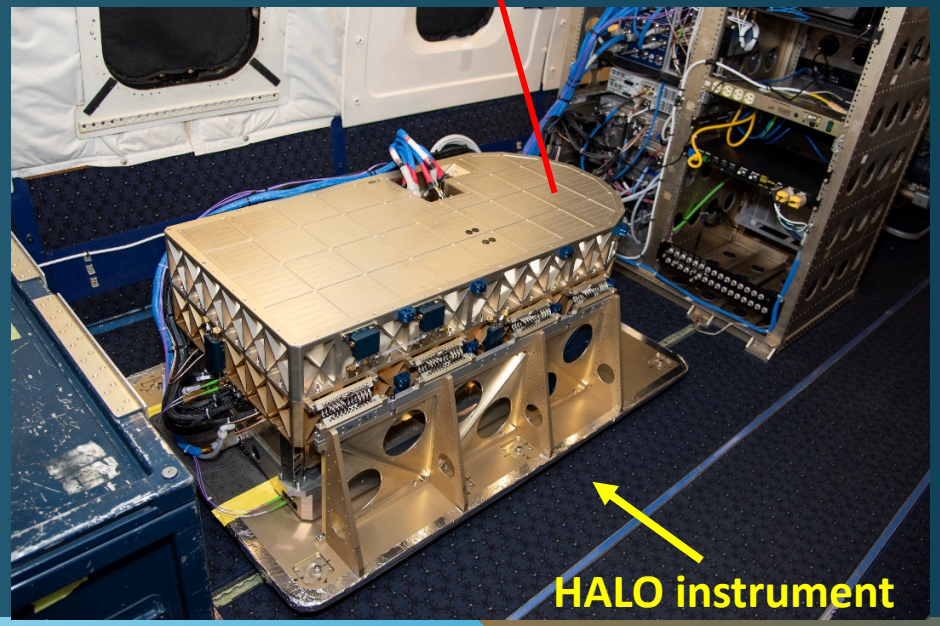
*Vertical and horizontal averaging can be traded for precision and adapted for different applications. Nominal resolution is 315 **m** and 6 km.

HALO Important System Characteristics

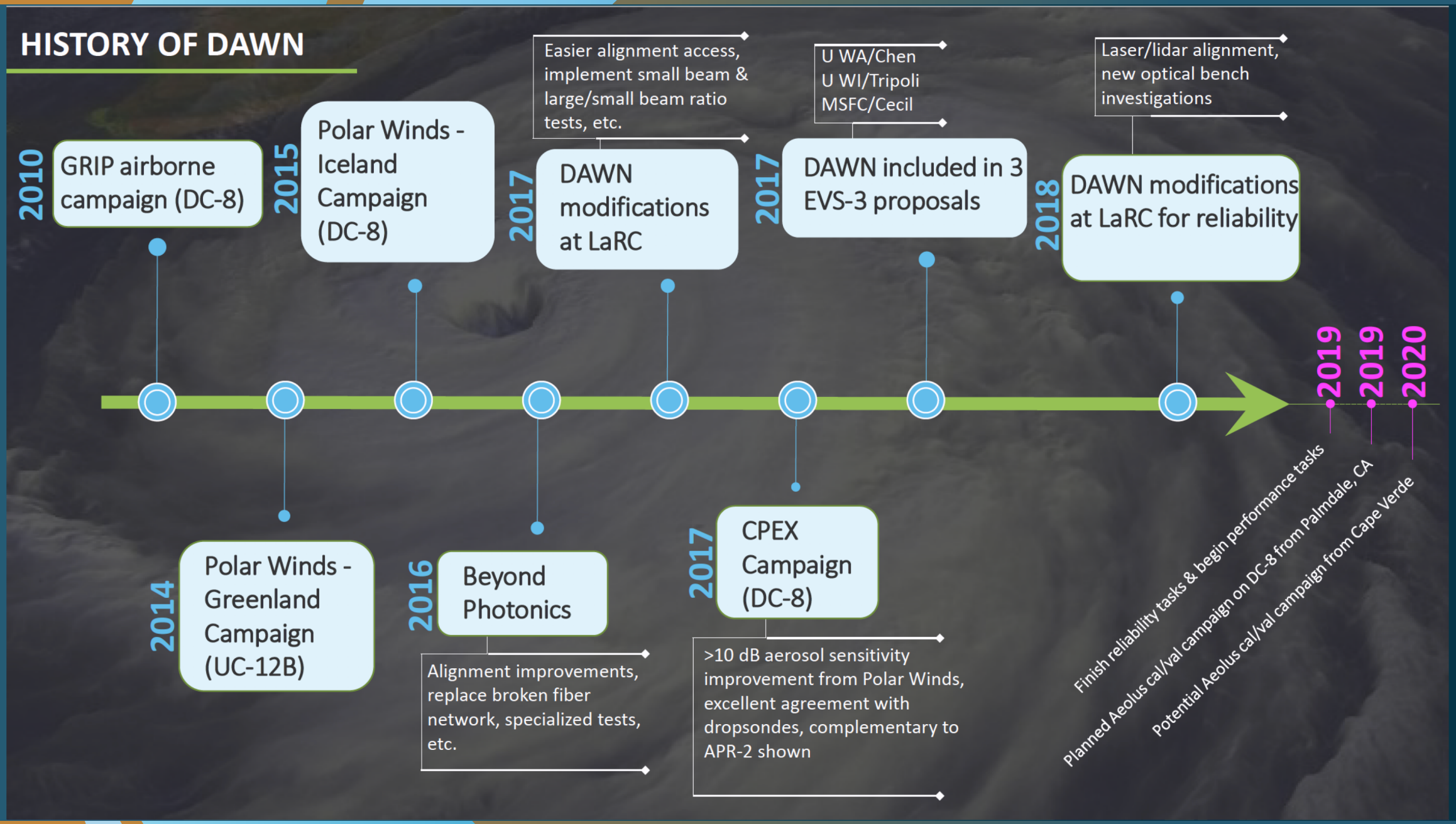
- Calibration
  - *Self calibrating* water vapor profiles using the DIAL technique
  - Self calibrating CH_4 columns using clear air DIAL signal
  - *Large H_2O dynamic range* enabled by multi-wavelength transmitter
  - *Internal calibration* of electro-optic gains between parallel and perpendicular polarization HSRL channels
  - *Internal calibration* of "molecular" to parallel backscatter channel at 532 nm
    - 532 nm aerosol backscatter, depolarization, and extinction retrieved *without external calibration* to atmospheric target
  - 1064 nm backscatter calibrated using information from 532 nm aerosol backscatter
- Rapidly reconfigurable to support different science objectives from different airborne platforms
  - H_2O+HSRL or CH_4 + HSRL or H_2O + CH_4
  - Compatible to fly on most NASA Airborne Science aircraft including ER-2
- 1.25 meter vertical resolution on all HSRL channels for cloud studies and future ocean profiling

HALO Water Vapor configuration on NASA DC8-ADM Aeolus Validation Campaign

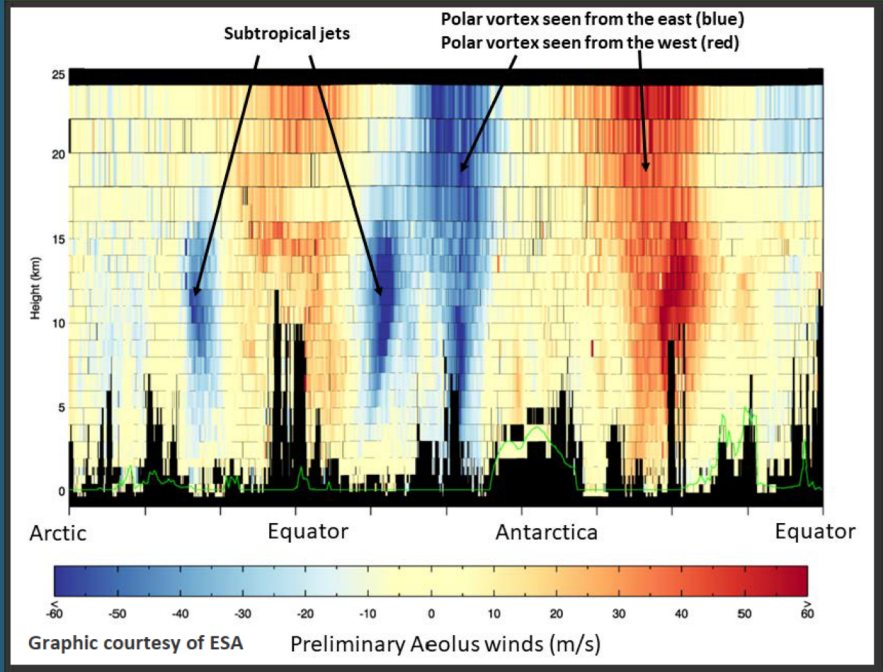
- HALO was installed over the nadir 9 portal on the NASA DC-8 during April 2019
- ADM Aeolus cal/val mission served as maiden test flights for water vapor measurements
- >45 flight hours with varying atmospheric conditions
- Demonstrated capability to tune transmitter to adapt to varying atmospheric conditions
- Demonstrated feasibility of state of the art laser transmitters on NASA airborne platforms



HISTORY OF DAWN



Science Questions and Investigations Enabled By DC-8 Datasets From 2019 and 2020 Flights



1) **What are the accuracies of ADM Aeolus line-of-sight wind speed and aerosol products?**
   - How does the accuracy of Mie (aerosol) winds differ from Rayleigh (molecular) winds?
   - What depth of motions do Aeolus winds truly represent?
   - How does the Aeolus HSRL aerosol measurement compare with HALO HSRL aerosol backscatter and extinction?

2) **What flows and processes can air- and space-borne Doppler Wind Lidar (DWL) observe?**
   - Eastern Pacific and Cape Verde feature unique wind, cloud, and aerosol conditions. Data from 2019 and 2020 flights can be combined with CPEX data to address this question

3) **Better understand the characteristics and limitations of DAWN, and DWL in general:**
   - How much aerosol is required for DAWN to derive winds? Can adaptive lidar signal integration be used to derive winds in a relatively clean PBL and free troposphere?
   - Can DWL "see through" some clouds? What is the cloud optical depth limit that DWL cannot penetrate? Can DWL sense cloud motions and how do these motions compare to GOES AMVs?
   - How large do cloud gaps need to be for DAWN and Aeolus to sense PBL winds?

4) **How does DWL complement other space-based winds?** How well do GEO AMVs represent the true wind? What flows can be retrieved using GOES-17 at varying image temporal resolution? What PBL flows can scatterometers and passive microwave radiometers resolve?

5) **What is the performance of the new HALO water vapor (WV) DIAL profiling system?** NOTE: 2019 Aeolus Cal/Val Test Flights will be the HALO DIAL WV system's first deployment

6) **How can airborne DWL, DIAL water vapor, and HSRL cloud/aerosol lidar be combined** to study turbulence, fluxes, and cloud processes within the PBL and free troposphere?

7) **How might airborne or space-borne DWL and water vapor lidar profiles be assimilated** into numerical weather prediction and mesoscale process study (e.g. WRF) models? How well can models represent the observed atmospheric state and cloud evolution?

Planning for Subsequent Wind Lidar et al. Campaign

- Weather and Atmospheric Dynamics Element (A.26) in ROSES19 has an section built around a potential future field campaign (2020) for wind lidar measurements in conjunction with ESA to provide complementary and calibration/validation measurements for its Aeolus satellite.
- NOIs are due 8/5, Proposals are due 9/26.
- This 2020 field campaign (not yet named) will provide opportunities to study the dynamics and microphysics related to the Saharan Air Layer, African Easterly Waves and Jets, Tropical Easterly Jet, and deep convection in the ITCZ. The planned field campaign will also provide to the science community unique data to address the science questions while providing further insight into Wind Lidar technologies to support the development of future space borne Wind Lidar systems in Europe and the U.S.

For this field campaign NASA has committed to provide the DC-8 aircraft, a coherent Doppler Wind Lidar (DAWN) for wind retrievals in the planetary boundary layer below 4 km, and dropsondes to provide a broader picture of the tropospheric environment. Other instruments may be deemed essential and added to the field campaign program.Approximately 100 flight hours are planned.

- Through this sub-element NASA is seeking two types of proposals:
  - Type-1, a one-year proposal to provide an instrument that has flown on the NASA DC-8 before and that includes funding for field deployment, data processing, and data archival; and
  - Type-2, proposals of up to three-years duration for using this field campaign data and participating in related research

CAMP^{2}Ex: Clouds, Aerosol and Monsoon Processes Philippines Experiment

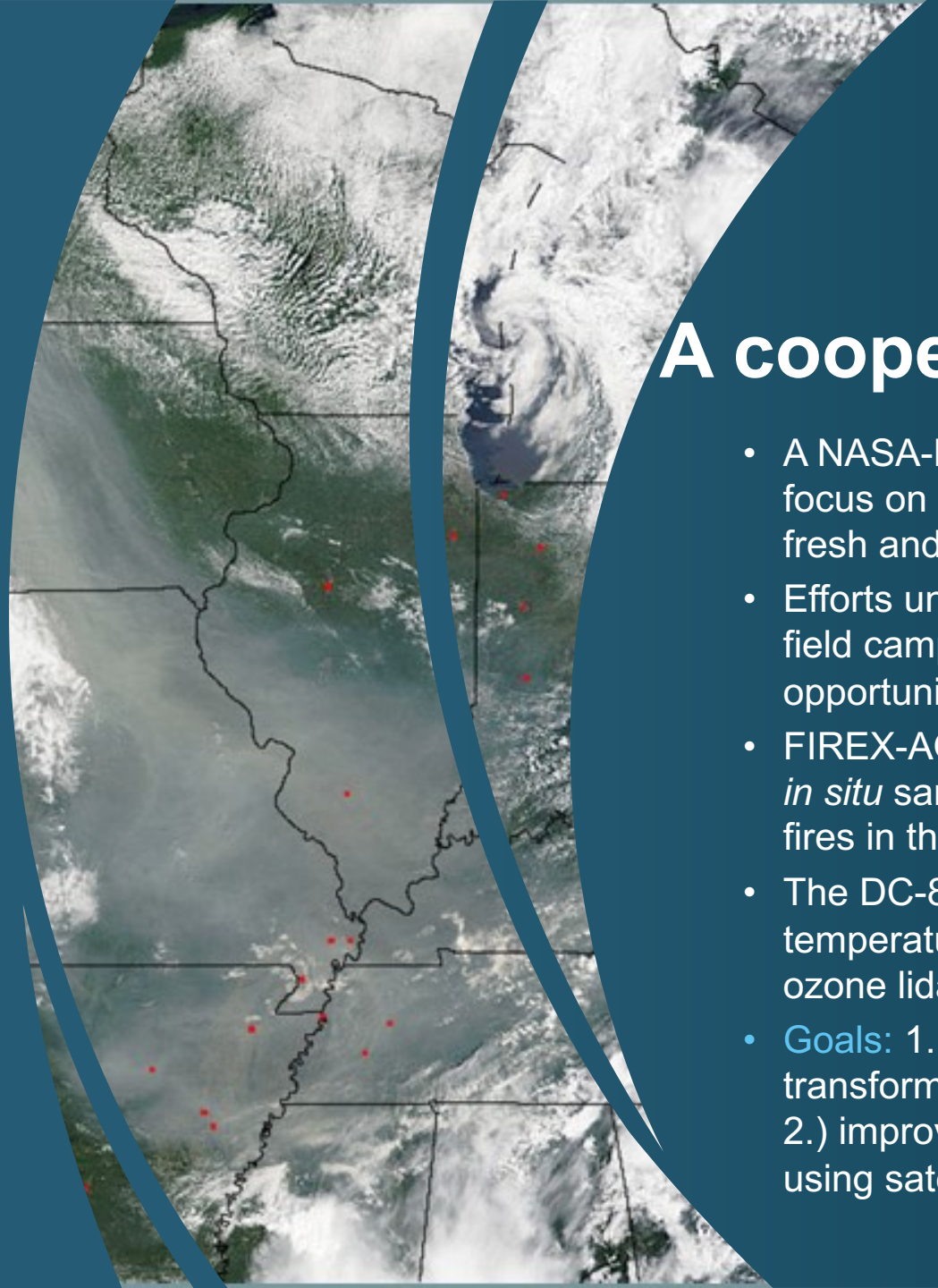
An airborne field campaign planned for mid-August to October 2019

CAMP^{2}Ex Science Questions:

- To what extent are aerosol particles responsible for modulating warm and mixed phase precipitation in tropical environments?
- To what extent do aerosol induced changes in clouds and precipitation feedback into aerosol lifecycle?
- How does the aerosol and cloud influence on radiation co-vary and interact?
- How does land use change affect cloud and precipitation change? Is land use change a confounder for aerosol impacts?

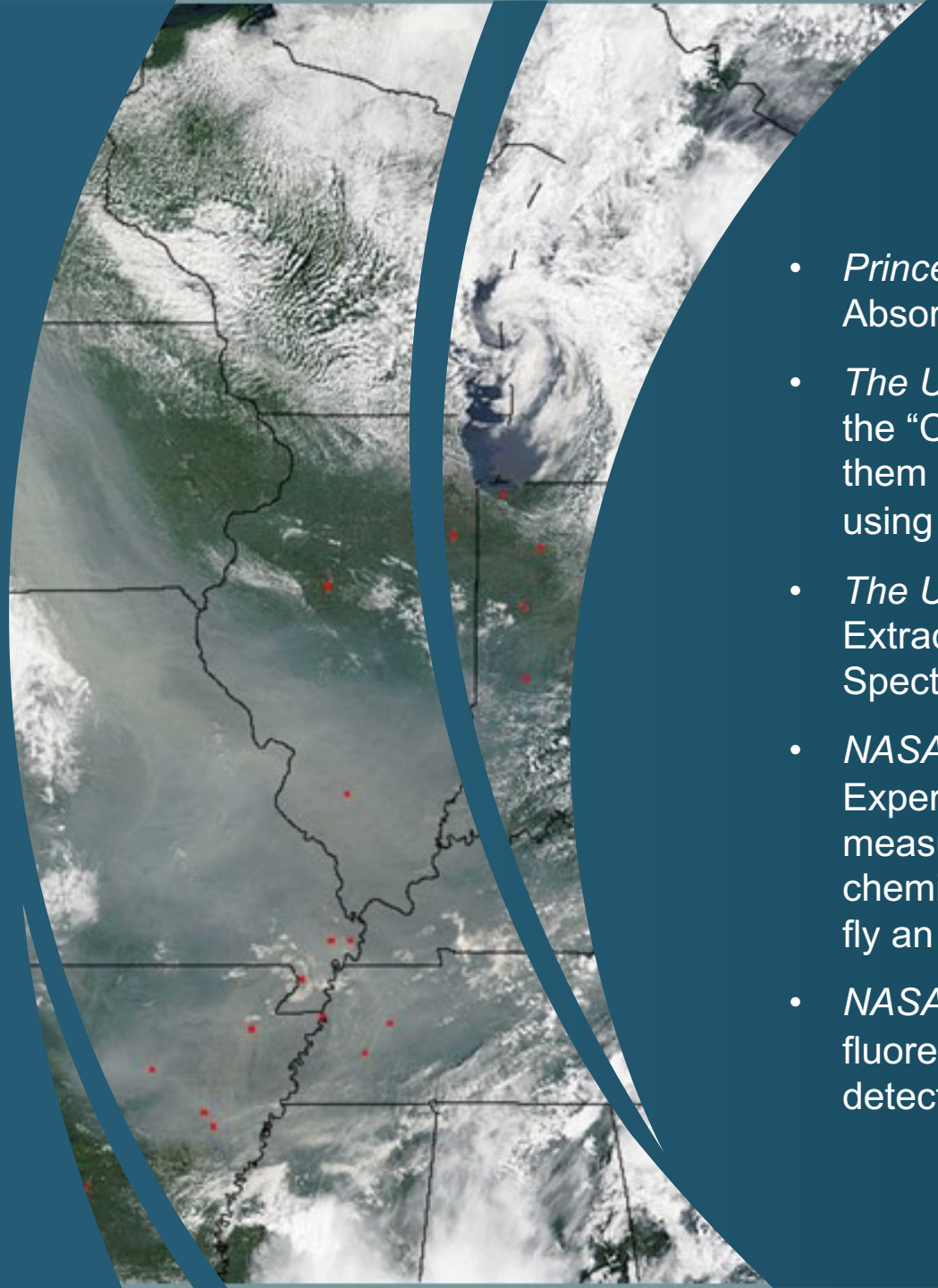
Priority Measurements:

- Aerosol in-situ microphysics:
- Cloud in-situ microphysics
- Cloud/precip remote sensing
- Trace Gases
- Aerosol and wind profiles (lidar)
- Radiation: Solar and IR
- State variables



FIREX-AQ:
A cooperative wildfire air quality field study

- A NASA-NOAA cooperative field study (July 22-September 15, 2019) that will focus on the links between satellite and ground-based measurements of both fresh and aged biomass burning plumes in the continental United States.
- Efforts underway to coordinate with the Joint Fire Science Program FASMEE field campaign. FIREX-AQ team is working with NSF and EPA to leverage opportunities for additional aircraft and ground-based measurements.
- FIREX-AQ includes both NASA DC-8 and NOAA Twin Otter aircraft for airborne *in situ* sampling of Western wildfires, as well as agricultural/land-management fires in the Central and Southeastern U.S.
- The DC-8 aircraft will have several remote sensing instruments to detect fire temperature, fire radiative power (FRP) and plume height, as well as HSRL and ozone lidars.
- Goals: 1.) improve our understanding of the transport of and chemical transformations in biomass burning plumes and their impact on air quality, and 2.) improve the ability to incorporate wildfires into air quality forecast models using satellite products.



New Instruments in FIREX-AQ

- *Princeton University (PI: Mark Zondlo)* is flying for the first time an Open Path Absorption Laser Spectrometer (OPALS) for in situ ammonia measurements.
- *The University of Oslo (PI: Armin Wisthaler)* is flying a new particle inlet called the “CHemical Analysis of AeRosol ONline” (CHARON) inlet which will allow them to measure the chemical composition of atmospheric particles in real time using state-of-the-art proton-transfer-reaction time-of-flight mass spectrometry.
- *The University of Colorado (PI Jose Jimenez)* is flying for the first time an Extractive Electrospray Ionization High Resolution Time of Flight Aerosol Mass Spectrometer for aerosol composition.
- *NASA Goddard (PI: Tom Hanisco)* is flying for the first time the Rapid Ozone Experiment (ROZE) instrument. This is unique because the traditional way of measuring ozone rapidly from aircraft using nitric oxide (NO) chemiluminescence; NO is a toxic gas and it is always difficult/cumbersome to fly an NO cylinder safely on an aircraft.
- *NASA Goddard (PI: Tom Hanisco)* is also testing out a new NO_2 Laser induce fluorescence (LIF) instrument. The traditional NO_2 instrument was struggling to detect the very low levels of NO_2 in the remote atmosphere.

FIREX-AQ ER-2 Campaign, July 21 -August 19 2019

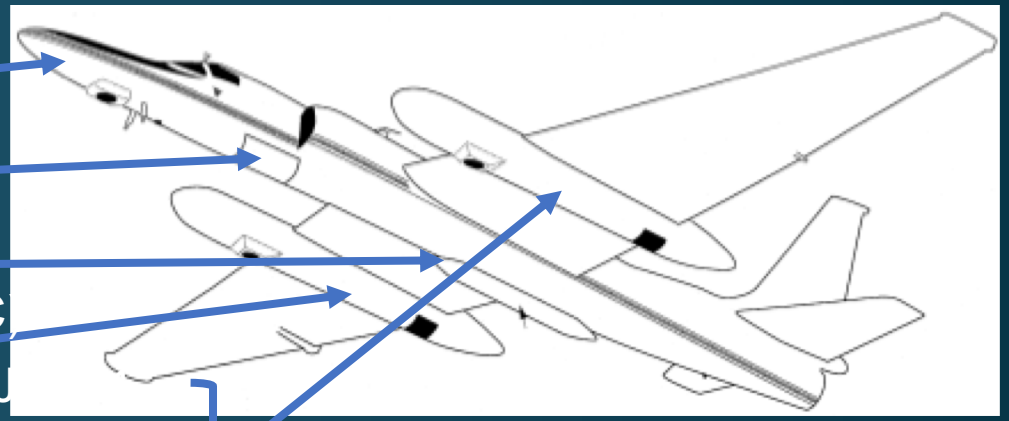
AirMSPI-1 (JPL)

AVIRIS-C (JPL)

S-HIS (UW)

CPL (GSFC) and eMAS (ARC/GSFC

GCAS (GSFC) and NAST-I (LaRC), J
Aug. 5; HyTES (JPL), Aug. 5-19



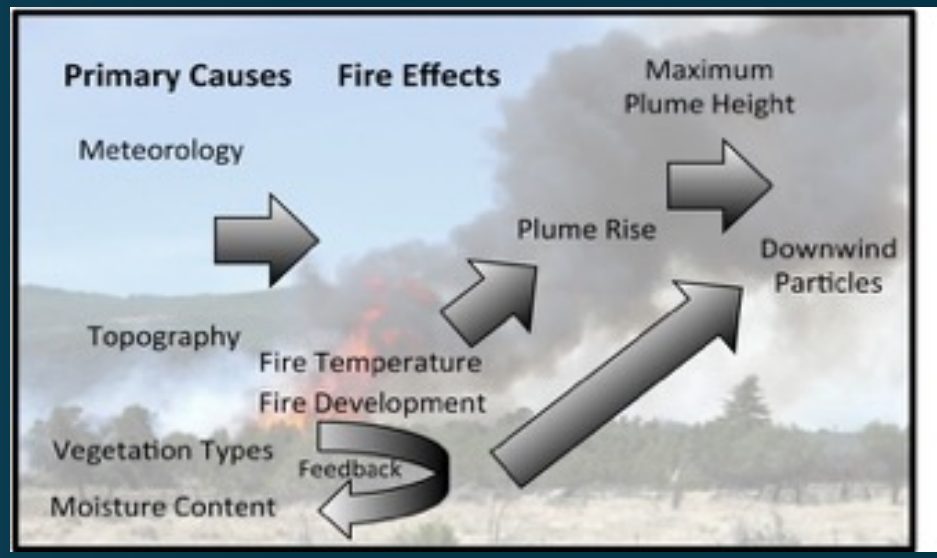
Science PI: Olga Kalashnikova, JPL

NASA Project Scientist: Jay Al-Saadi (NASA LaRC)

NOAA Project Scientist: Greg Frost (NOAA ESRL)

NASA Program Scientist: Barry Lefer (HQ) and Felix Seidel (HQ)

- ER-2 platform and instrument suite are relevant to:
  - All 6 science questions defined in the FIREX-AQ White Paper
  - Operational and research products from current and planned satellite instruments
- Intermediate step between in-situ and satellite observations
- Provide **large scale, high-resolution** observations of area burned, fire intensity
  and temperature, plume heights, and amount of pollutants/smoke
- Deploy from AFRC during the Western phase of FireX-AQ for approx. 70 flight hours
- Intend as much collocation with the DC-8 as possible for the majority of ER-2 flights, although pre-fire, post-fire, diurnal sampling, and satellite collocation are also foci

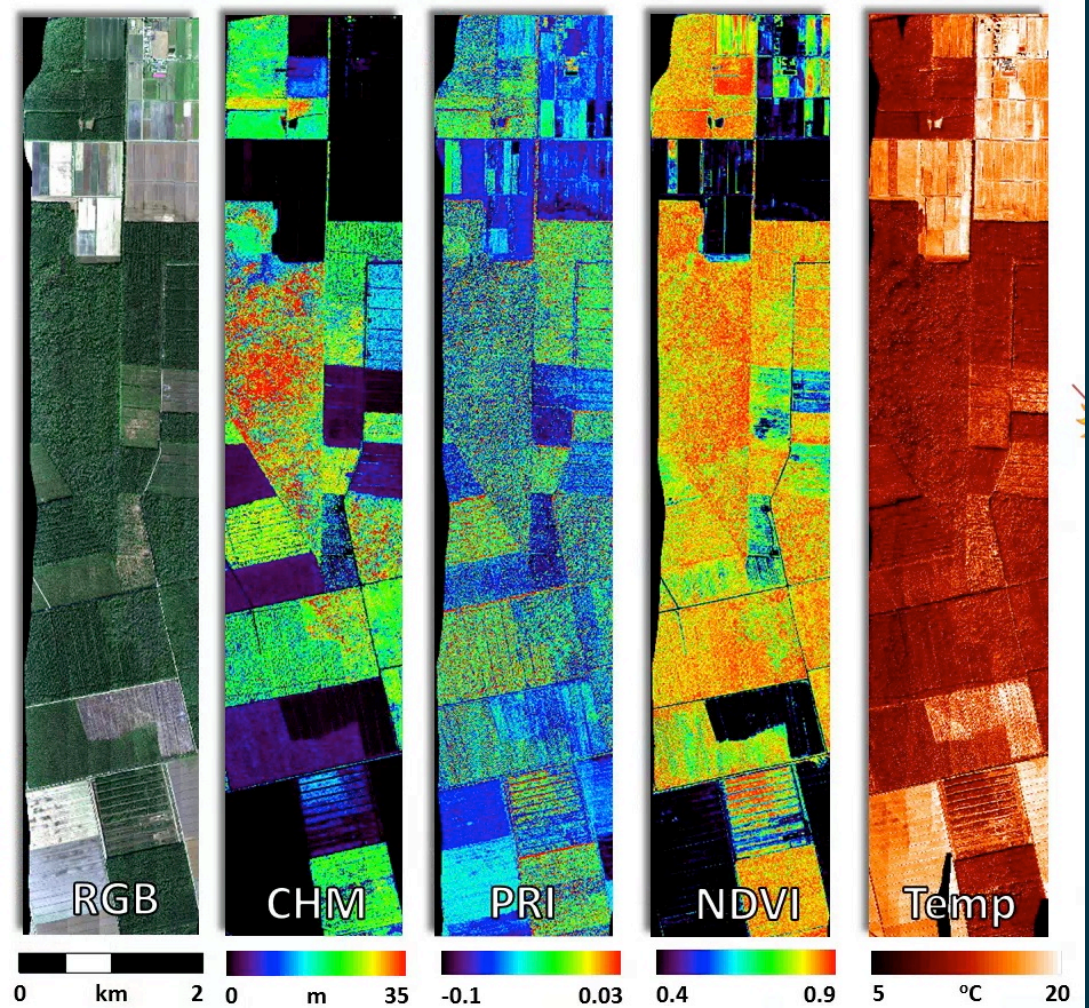


G-LiHT: Goddard's Lidar, Hyperspectral, and Thermal airborne imager

https://gliht.gsfc.nasa.gov/

G-LiHT is a portable, airborne imaging system that simultaneously ***maps the composition, structure, and function of terrestrial ecosystems*** using:

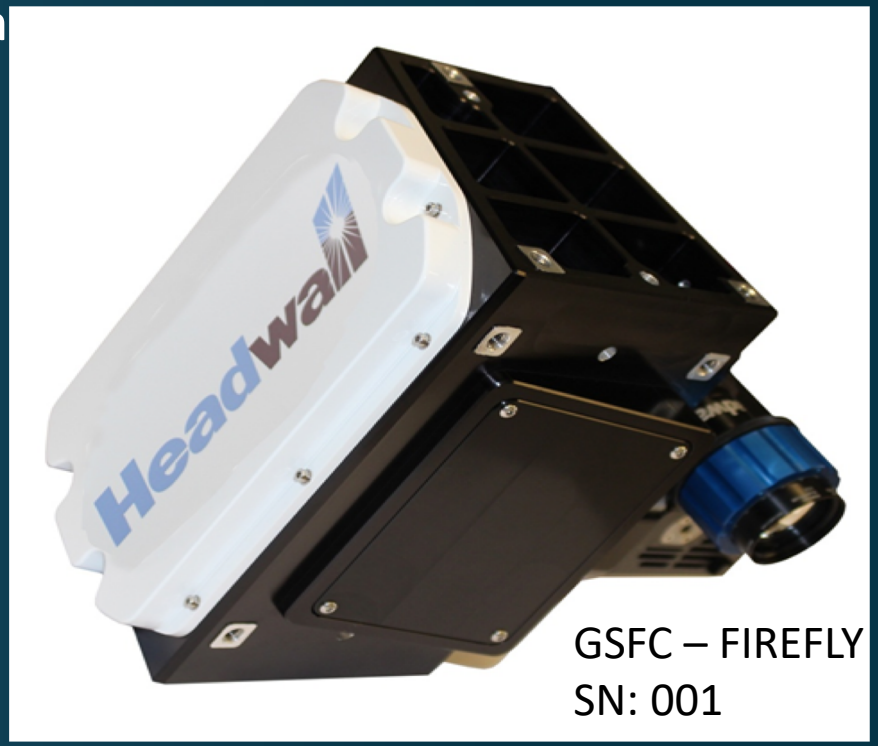
- ***lidar*** to provide 3D information about the spatial distribution of canopy elements;
- ***VNIR Imaging spectroscopy*** to discern species composition and variations in biophysical variables (e.g., photosynthetic pigments);
- ***thermal measurements*** to delineate wetlands and detect heat and moisture stress in vegetation;
- NEW ***stereo RGB photographs*** to identify fine-scale (~3 cm) canopy features; and
- NEW ***Solar-Induced Fluorescence*** (SIF) as a measure actual photosynthetic activity and indicator of vegetation stress.



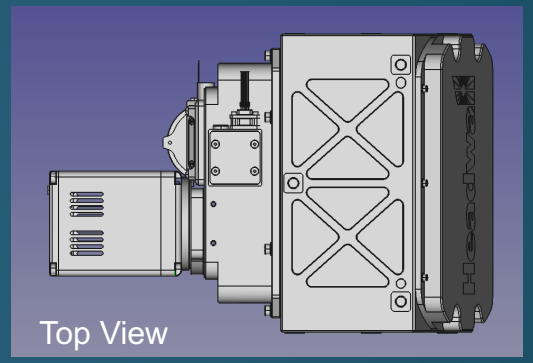
Loblolly pine plantation in lower coastal plan near Plymouth, NC

FIREFLY: Fluorescence Imaging of REd and Far-red Light Yield

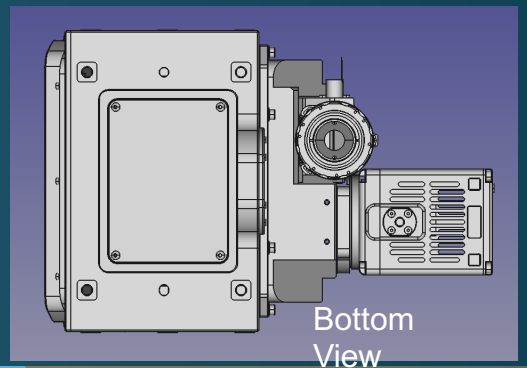
- Design: Aberration Corrected F2.5 Compact Dyson
- Spectral Range: 670 nm – 780 nm
- Spectral Channels : 2,160 w/o binning
- Spectral Resolution (FWHM) ≤ 0.17 nm
- Spatial FOV 23.5 deg with 1,600 samples
- Signal-to-Noise - 680:1
- Dimensions (mm): 300 L x 200 W x 200 H
- Shutter: Electro-mechanical
- Focal Plane: 16 bit TE Cooled sCMOS
- Power ≤ 30 W
- Weight: 6.3 kg



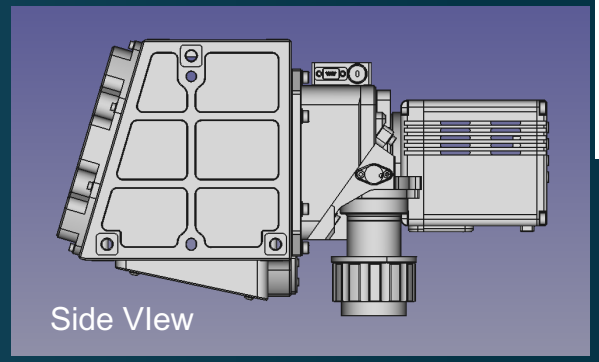
GSFC – FIREFLY
SN: 001



Top View



Bottom View



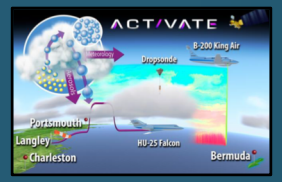
Side VIew

Side View

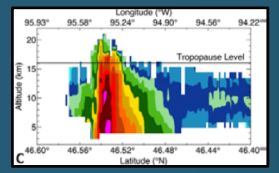
AITT Most Recent (2016) Selection – Current Status

PI	Inst.	Prop. Title	Status
D. Diner	JPL	Upgrade of AirMSPI-2 to operational readiness for scientific field campaigns	AirMSPI-2 team will use remaining funds to maintain seal for instrument. Following last review, emphasis was to ensure properly functioning instrument before proceeding to science flights
L Guild	NASA/ARC	Coastal High Acquisition Rate Radiometers for Innovative Environmental Research (C-HARRIER)	3STAR instrument certification took longer than originally anticipated. Plan to complete certification and science flight will extend into FY20 assuming funding is available.
K. Turpie	UMBC	Development of a Highly Accurate Lunar Spectral Irradiance Measurement Capability - The Airborne LUnar Spectral Irradiance Instrument (air-LUSI)	Demonstration flights planned for September to collect data at different lunar phases. Instrument updates being done. ARTEMIS subsystem (robotic arm) is back in Canada for software upgrades.
D. Perkovic-Martin	JPL	DopplerScatt Operational Ka-band Doppler Scatterometer for Simultaneous Wide-Swath Measurements of Ocean Surface Vector Winds and Currents	DopplerScatt will participate in EVS-3 S-MODE campaign; 2-week pilot campaign in Spring 2020, science campaigns in spring and fall 2021.

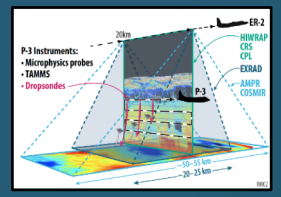
EVS-3 Investigations



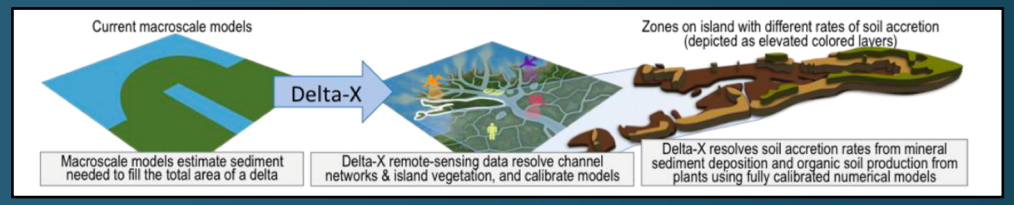
ACTIVATE - Aerosol Cloud meTeorology Interactions oVer the western ATlantic investigates how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean



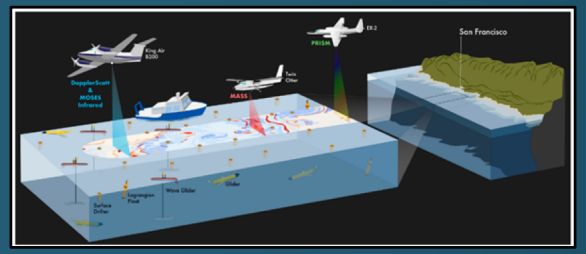
DCOTTS - Dynamics and Chemistry of the Summer Stratosphere investigates how strong summertime convective storms over North America can change the chemistry of the stratosphere



IMPACTS **-** Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms study the formation of snow bands in East Coast winter storms**.**



Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas

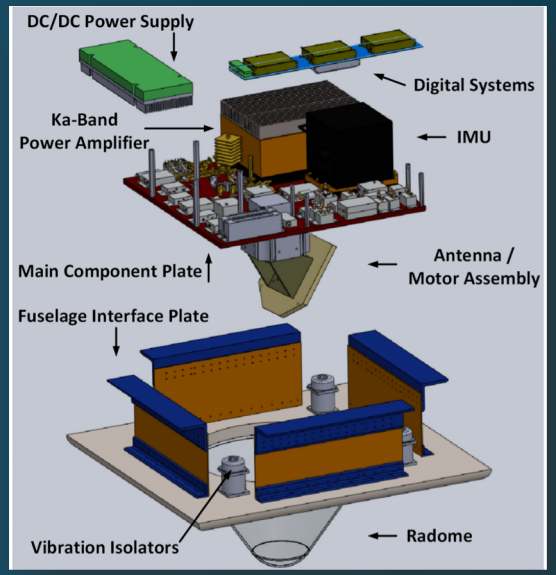


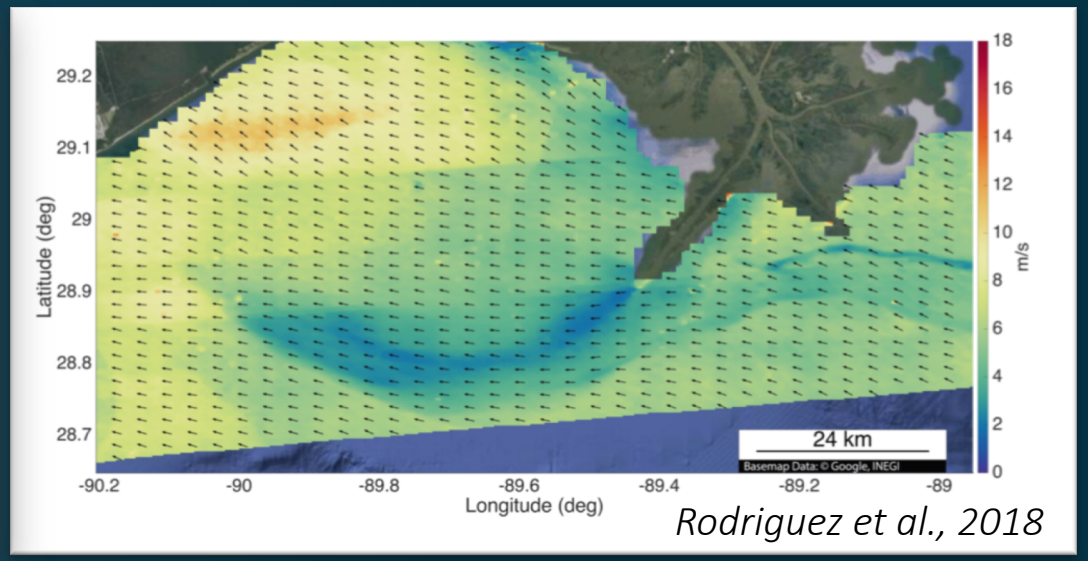
SMODE **-** Submesoscale Ocean Dynamics and Vertical Transport investigation to explore the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere

A total of six NASA centers and 27 educational institutions are participating in these five Earth Venture projects. The 5-year investigations were selected from 30 proposals.

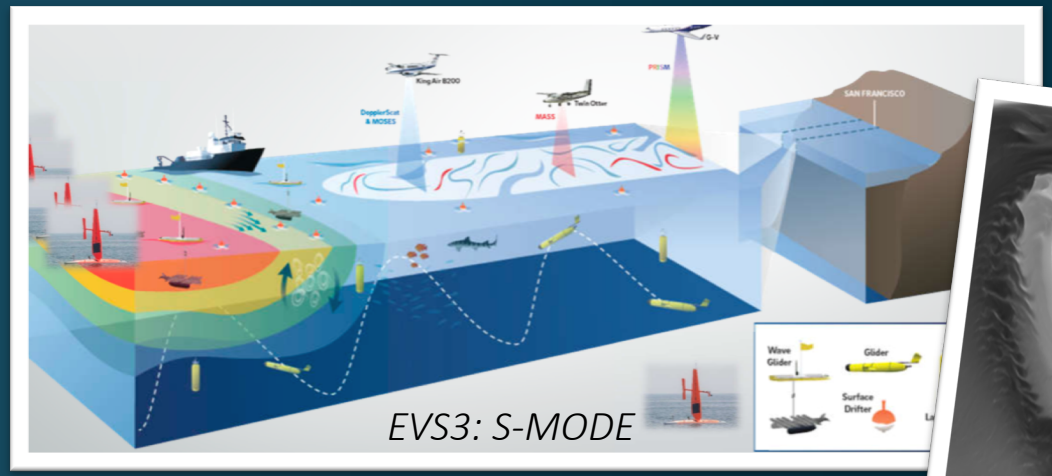
DopplerScatt

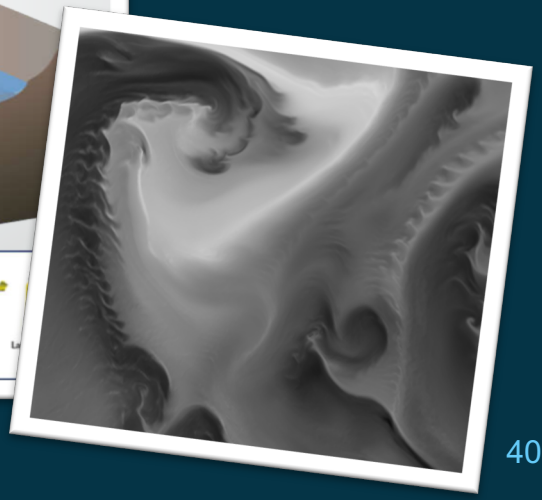
- Concept
  simultaneous retrieval of wind stress and surface currents
- Technology
  pencil-beam scanning Ka-band Doppler scatterometer. Wide-swath coverage will enable global coverage in one day (Rodriguez 2012, 2014).
- Science goal
  improve understanding of two-way interaction between ocean currents and winds, air-sea exchange, vertical mixing, and energy transfer
- Application
  new EVS3 S-MODE to quantify contribution of submesoscale processes (km-scale) to vertical exchange of biophysical variables





Rodriguez et al., 2018





NASA SnowEx Program: Multi-Sensor Campaign for Remote Sensing of Snow

SnowEx is a multi-year airborne snow campaign designed to collect multi-sensor observations & ground truth, to enable algorithm developments and modeling to inform the design of a future satellite mission

Key Science Questions:

- What is the global distribution of snow-water equivalent (SWE), and snow energy balance, in a variety of land covers, & canopy types and densities?
- What is the sensitivity and accuracy of remote-sensing techniques to measure SWE, in a variety of land covers, & canopy types and densities?
- What is the optimum combination of sensing techniques to measure SWE globally?

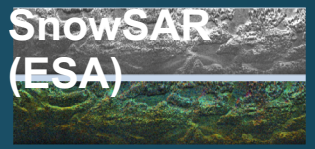
Highlights:

- >100 participants (mostly from USA & Canada)
- >24 institutions Extensive community building
- Investment > USD 5M

http://snow.nasa.gov/snowex

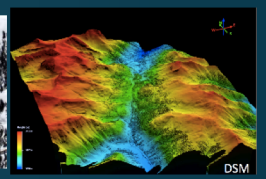
Airborne: 5 Aircraft & 9 Sensors

NRL P-3:
4 sensors: CAR, SnowSAR & 2 IR sensors

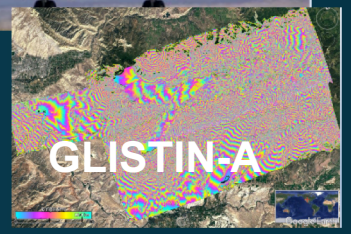


ASO: lidar & VNIR

lidar DEM



GLISTIN-A UAVSAR:
(Ka-band) (L-band)



WISM: 8-40 GHz passive/active snow sensor

UAVSAR

SWESARR Flies inside a Twin Otter (DH-6-300)

2 Instrument Operators
1 Flight-Line Coordinator
6 Active, 3 Passive Observations
1 Antenna

Total Weight: 800 lbs
Total Power: 1.8 kW

Altitude (AGL): 1.5-3km
Max. Altitude (MSL): 6 km

The Collection of L- and S- Band Synthetic Aperture Radar Imagery Over North America

Motivating Science Need

The US lacks a dual L- & S- band (24, 9 cm wavelengths) Synthetic Aperture Radar (SAR) imaging capability that can be used to develop and refine algorithms in advance of the NISAR Mission (Anticipated launch date January 2022).

The simultaneous collection of L+S band SAR imagery is relevant to Earth science research and applications activities in a number of topic areas cryosphere, ecosystems, natural hazards/solid Earth, ocean science and terrestrial hydrology research along with data supporting a wide range of applications including agriculture, oil spills and infrastructure.

There is no L+S band radar dataset in the United States.

Technology Solution

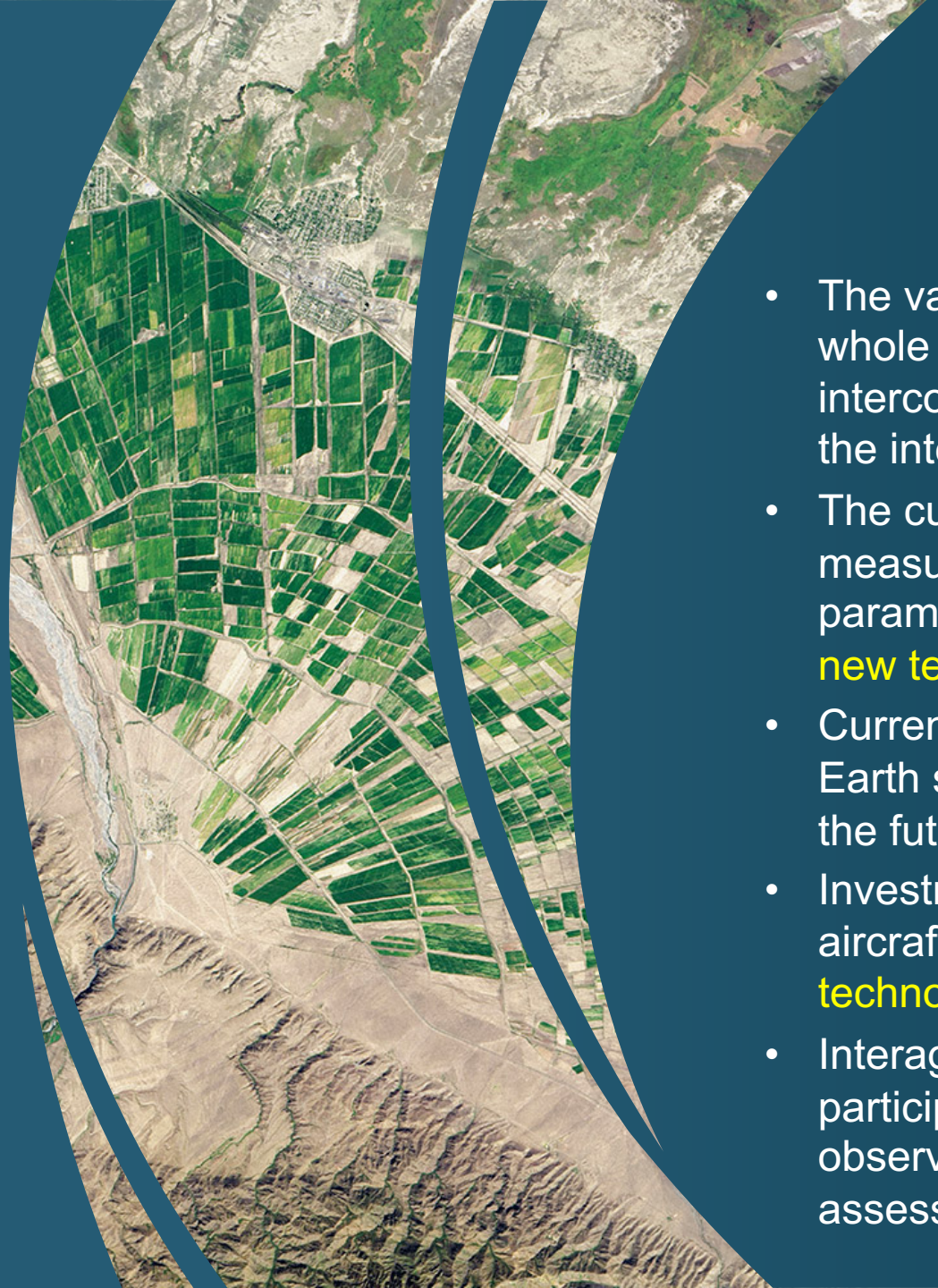
- NASA will collect L+S band SAR data from ISRO's (India) Airborne Synthetic Aperture Radar (ASAR) instrument mounted on NASA's C-20A (Gulfstream III) utilizing the antenna pod and navigation package for the NASA UAVSAR radar system.

ASAR radar system

ISRO ASAR Antenna that will be mounted in the UAVSAR pod

ISRO-ASAR Campaign
Supported by ESD – R&A
Jack Kaye
Program Scientist: Gerald Bawden
Project Executive: Mitra Dutta
Hardware Integration:
UAVSAR team – Yunling Lou
NASA Science Project Lead: Paul Rosen
ISRO Science Project Lead: Raj Kumar

ROSES19 element to be part of science team closes June 19 (A.53)



Concluding Messages

- The vantage point of space provides a good approach to watch the whole planet evolve on a variety of time scales and explore the interconnections between physics, chemistry and biology, as well as the interplay between human and naturally caused change.
- The current and projected suite of space-based environmental measurement capability enables scientific discovery and (for many parameters) monitoring, and is being enhanced by introduction of new technology.
- Current observations show significant changes in many aspects of Earth system, with the potential for even more significant changes in the future.
- Investments in space measurements are synergistic with surface-, aircraft- and balloon-based measurements, along with models. New technology is adding to our capabilities in this area as well.
- Interagency and international cooperation, along with private sector participation, are important components of all efforts, including space observations, field campaigns, surface measurements, research, and assessment.

Job Announcements

SMD has announced competitive permanent civil servant positions within Earth Science (physical oceanography, cryospheric science) and other SMD Divisions

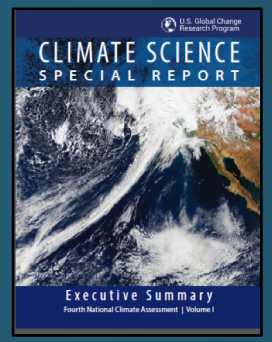
See USAJobs – positions open June 10-14, 2019!

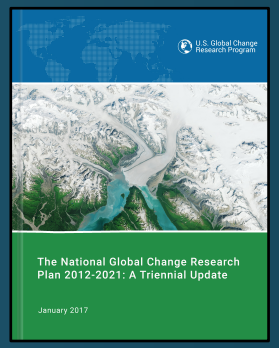
NASA Headquarters Washington, DC

The “Pauli Effect” (from Wikipedia)

- The **Pauli effect** is a term referring to the supposed tendency of technical equipment to encounter critical failure in the presence of certain people. The term was coined after mysterious anecdotal stories involving Austrian theoretical physicist Wolfgang Pauli, describing numerous instances in which demonstrations involving equipment suffered technical problems only when he was present.
- However the Pauli effect was humorously tagged as a second Pauli exclusion principle, according to which *a functioning device and Wolfgang Pauli may not occupy the same room*.
- Lacking an aptitude or interest in experimental work, many theorists have earned a reputation for accidentally breaking experimental equipment. Pauli was exceptional in this regard: it was postulated that he was such a good theorist that any experiments would be compromised by virtue of his presence in the vicinity. For fear of the Pauli effect, the experimental physicist Otto Stern banned Pauli from his laboratory located in Hamburg despite their friendship
- R. Peierls describes a case when at one reception this effect was to be parodied by deliberately crashing a chandelier upon Pauli's entrance. The chandelier was suspended on a rope to be released, but it stuck instead, thus becoming a real example of the Pauli effect

Interagency Coordination Efforts in Earth Science*





Committee on Environment Co-Chairs: EPA, NOAA, OSTP	
Polar Research*	Earth Observations (USGEO)
Global Change (USGCRP)*	Ocean Science & Tech (SOST)
Water Availability & Quality	Aquaculture*

National Science And Technology Council (NSTC)

Committee on Environment (CoE)

Subcommittee on Global Change Research (SGCR)

U.S. Global Change Research Program (USGCRP)

The USGCRP Vision and Mission

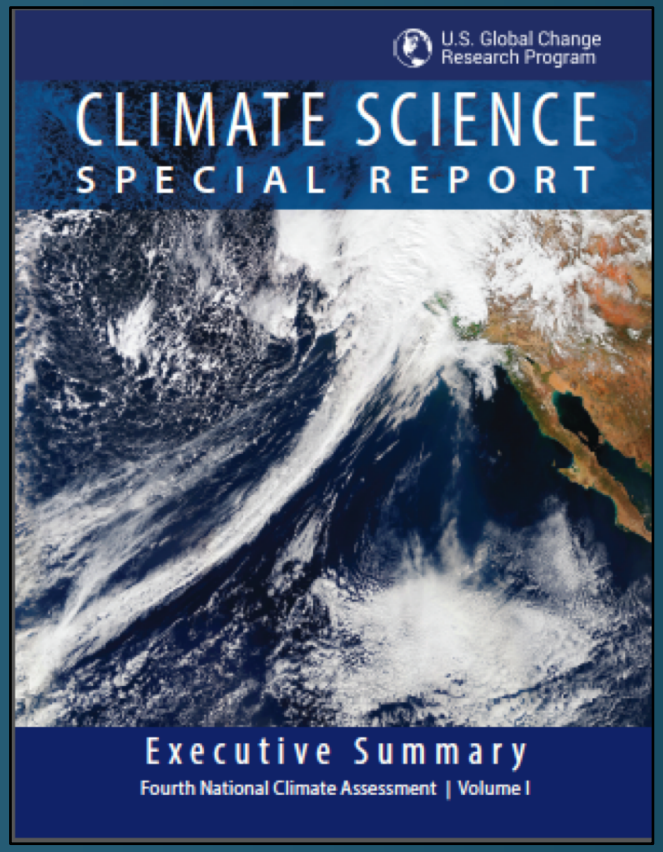
Vision: "A nation, globally engaged and guided by science, meeting the challenges of climate and global change."

Mission: "To build a knowledge base that informs human responses to climate and global change through coordinated and integrated federal programs of research, education, communication, and decision support."

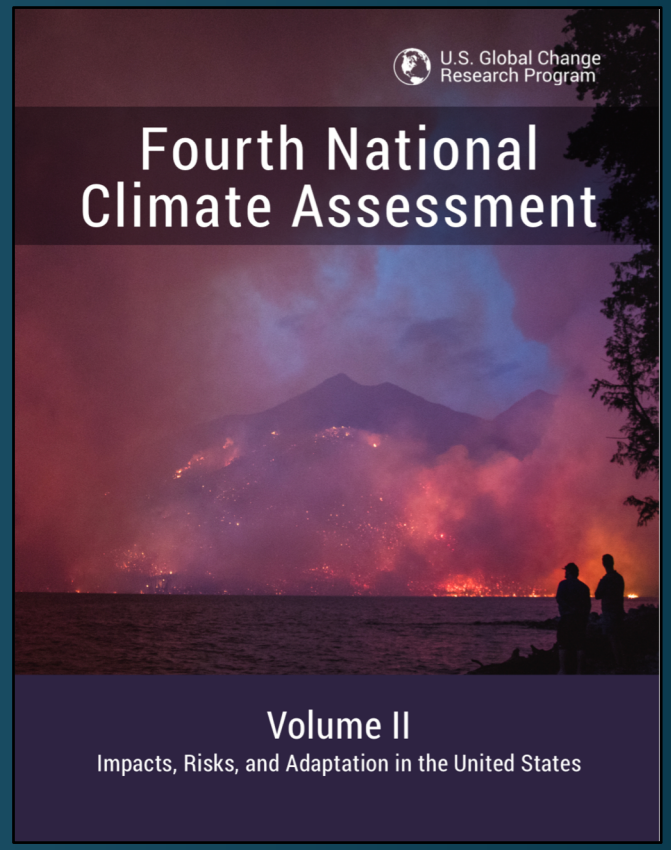
Goals	Objectives
1. Advance Science	1.1 Earth System Understanding 1.2 Science for Adaptation and Mitigation 1.3 Integrated Observations 1.4 Integrated Modeling 1.5 Information Management and Sharing
2. Inform Decisions	2.1 Inform Adaptation Decisions 2.2 Inform Mitigation Decisions 2.3 Enhance Global Change Information
3. Conduct Sustained Assessments	3.1 Scientific Integration 3.2 Ongoing Capacity 3.3 Inform Responses 3.4 Evaluate Progress
4. Communicate & Educate	4.1 Strengthen Communication and Education Research 4.2 Reach Diverse Audiences 4.3 Increase Engagement 4.4 Cultivate Scientific Workforce

USGCRP Recent Reports

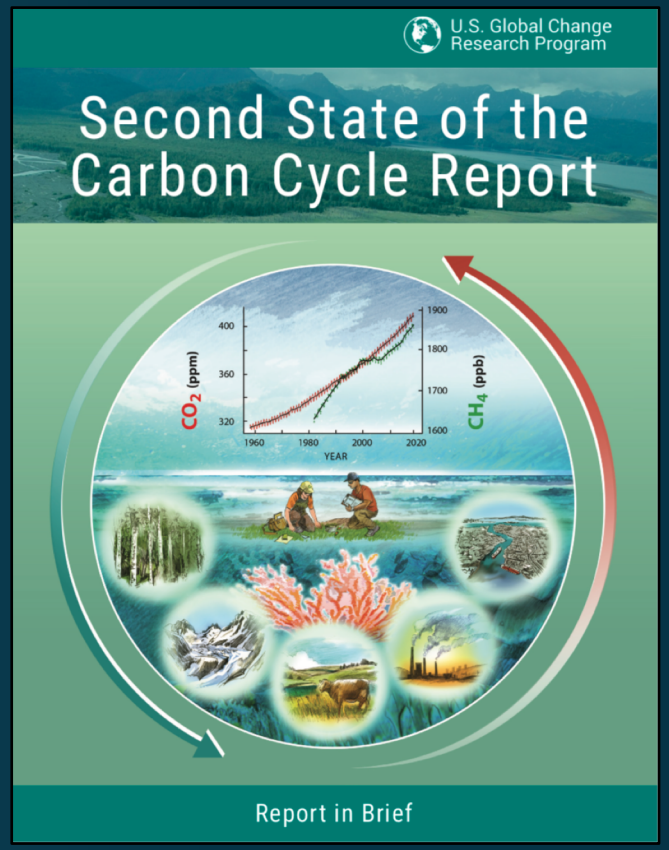
NCA4 Vol. 1 Released 11/3/17



NCA4 Vol. 2 Released 11/23/18



SOCCR-2 RIB Released 11/23/18



NCA4V2: Summary Findings (Abridged) *(1 of 2)*

- Communities: Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth.
- Economy: Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century.
- Interconnected Impacts: Climate change affects the natural, built, and social systems we rely on individually and through their connections to one another. These interconnected systems are increasingly vulnerable to cascading impacts that are often difficult to predict, threatening essential services within and beyond the Nation's borders.
- Actions to Reduce Risks: Communities, governments, and businesses are working to reduce risks from and costs associated with climate change by taking action to lower greenhouse gas emissions and implement adaptation strategies. While mitigation and adaptation efforts have expanded substantially in the last four years, they do not yet approach the scale considered necessary to avoid substantial damages to the economy, environment, and human health over the coming decades.
- Water: The quality and quantity of water available for use by people and ecosystems across the country are being affected by climate change, increasing risks and costs to agriculture, energy production, industry, recreation, and the environment.
- Health: Impacts from climate change on extreme weather and climate-related events, air quality, and the transmission of disease through insects and pests, food, and water increasingly threaten the health and well-being of the American people, particularly populations that are already vulnerable.

NCA4V2: Summary Findings (Abridged) *(2 of 2)*

- Indigenous Peoples: Climate change increasingly threatens Indigenous communities' livelihoods, economies, health, and cultural identities by disrupting interconnected social, physical, and ecological systems.
- Ecosystems and Ecosystem Services: Ecosystems and the benefits they provide to society are being altered by climate change, and these impacts are projected to continue. Without substantial and sustained reductions in global greenhouse gas emissions, transformative impacts on some ecosystems will occur; some coral reef and sea ice ecosystems are already experiencing such transformational changes.
- Agriculture and Food: Rising temperatures, extreme heat, drought, wildfire on rangelands, and heavy downpours are expected to increasingly disrupt agricultural productivity in the United States. Expected increases in challenges to livestock health, declines in crop yields and quality, and changes in extreme events in the United States and abroad threaten rural livelihoods, sustainable food security, and price stability.
- Infrastructure: Our Nation's aging and deteriorating infrastructure is further stressed by increases in heavy precipitation events, coastal flooding, heat, wildfires, and other extreme events, as well as changes to average precipitation and temperature. Without adaptation, climate change will continue to de- grade infrastructure performance over the rest of the century, with the potential for cascading impacts that threaten our economy, national security, essential services, and health and well-being.
- Oceans and Coasts: Coastal communities and the ecosystems that support them are increasingly threatened by the impacts of climate change. Without significant reductions in global greenhouse gas emissions and regional adaptation measures, many coastal regions will be transformed by the latter part of this century, with impacts affecting other regions and sectors. Even in a future with lower green- house gas emissions, many communities are expected to suffer financial impacts as chronic high-tide flooding leads to higher costs and lower property values.
- Tourism and Recreation: Outdoor recreation, tourist economies, and quality of life are reliant on benefits provided by our natural environment that will be degraded by the impacts of climate change in many ways.

The International Effort in Space-Based and Global Observations

- Space-based perspective provides unequalled vantage point for observing entire Earth system
- Efforts of all countries are needed to provide needed breadth, resilience and innovation
- Cooperation among nations, including data sharing calibration/validation and assessment, enhances value of all nations' efforts
- Satellite data can support both long-term climate and near-term operational requirements, and be used to improve quality of life for all the world's citizens
- Numerous entities and mechanisms exist that are facilitating this coordination

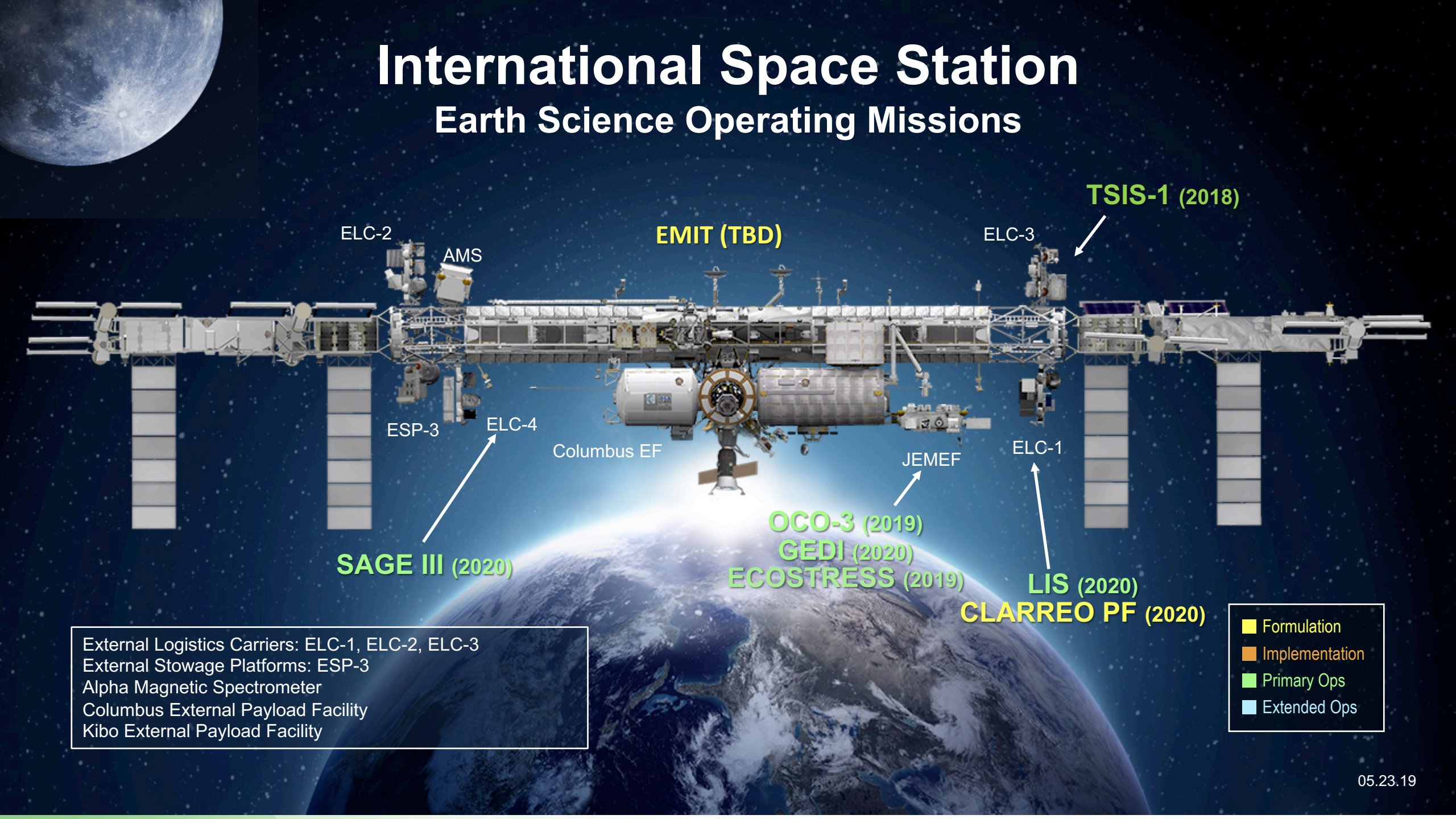
Selected Recent Earth System Satellite Launches

Mission	Agency/Country	Launch Date
Kanopus-V3/V4	ROSHYDROMET	02/01/18
PAZ	Spain	02/22/18
GOES-17	NOAA	03/01/18
Sentinel-3B	ESA, EC	04/25/18
GRACE-FO	NASA, GFZ	05/22/18
GF-5	China	05/09/18
FY-2H	CMA	06/05/18
GF-6	CNSA/CAST	06/06/18
DESIS/ISS	DLR	06/29/18
ECOSTRESS/ISS	NASA	06/29/18
ADM/Aeolus	ESA	08/22/18
HY-1C	CAST/NSOAS	09/07/18
ICESat-2	NASA	09/15/18
NovaSAR	UKSA	09/16/18
Beijing-2 (DMC-3-D)	NRSCC	09/16/18
SAOCOM-1A	CONAE, ASI	10/08/18
HY-2B	CAST,NSOAS	10/24/18
GOSAT-2	JAXA	10/29/19
CFOSat	CNES	10/29/18
KhalifaSat	UAE	10/29/18
Metop-C	EUMETSAT/NOAA/CNES/ESA	11/07/18
HYSIS	ISRO	11/27/18
GEO-KOMPSAT-2A	KARI, KMA, Harris	12/04/18
GEDI/ISS	NASA	12/05/18

Input from Brian Kil**lough**
NASA/LaRC
(CEOS System Engineering Office)

International Space Station

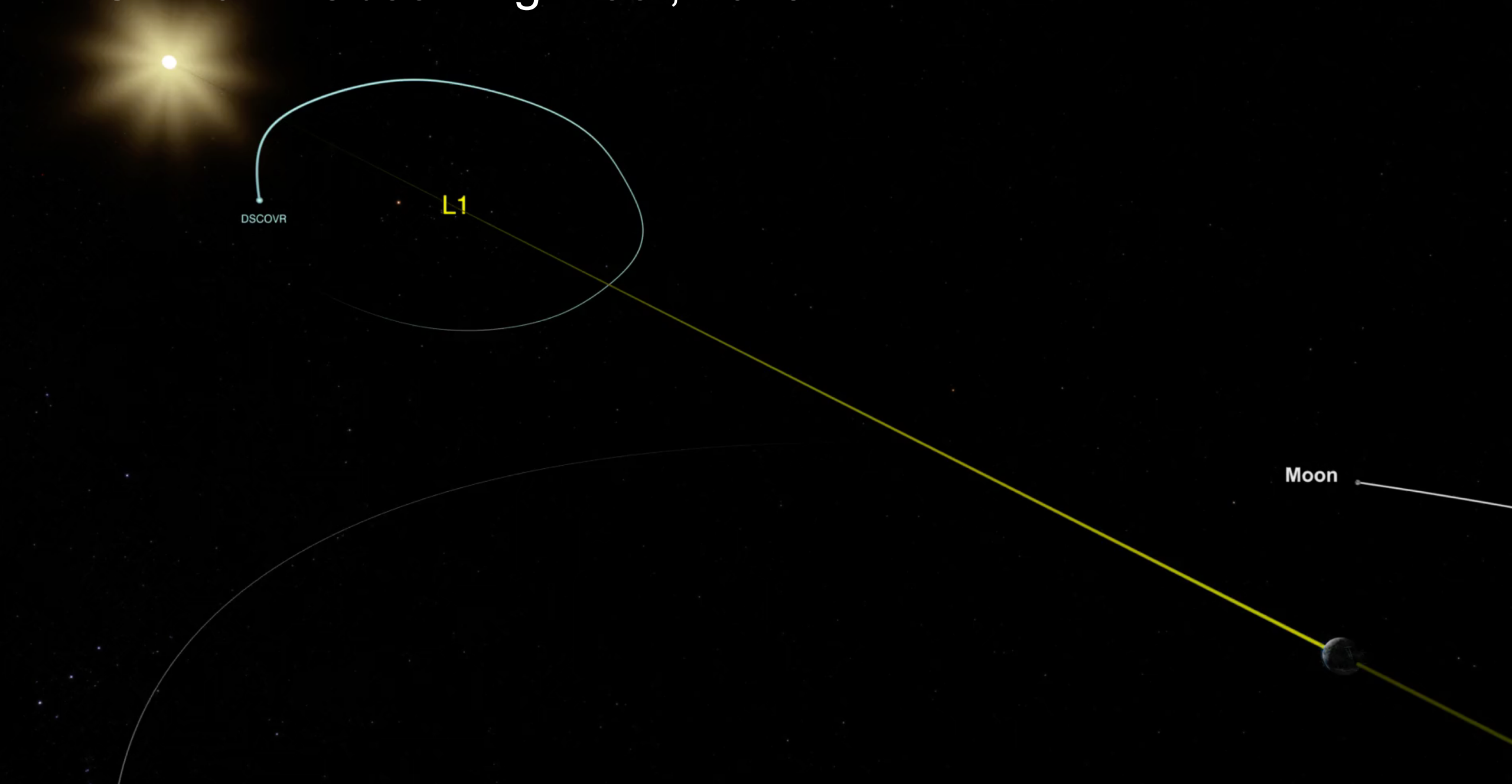
Earth Science Operating Missions



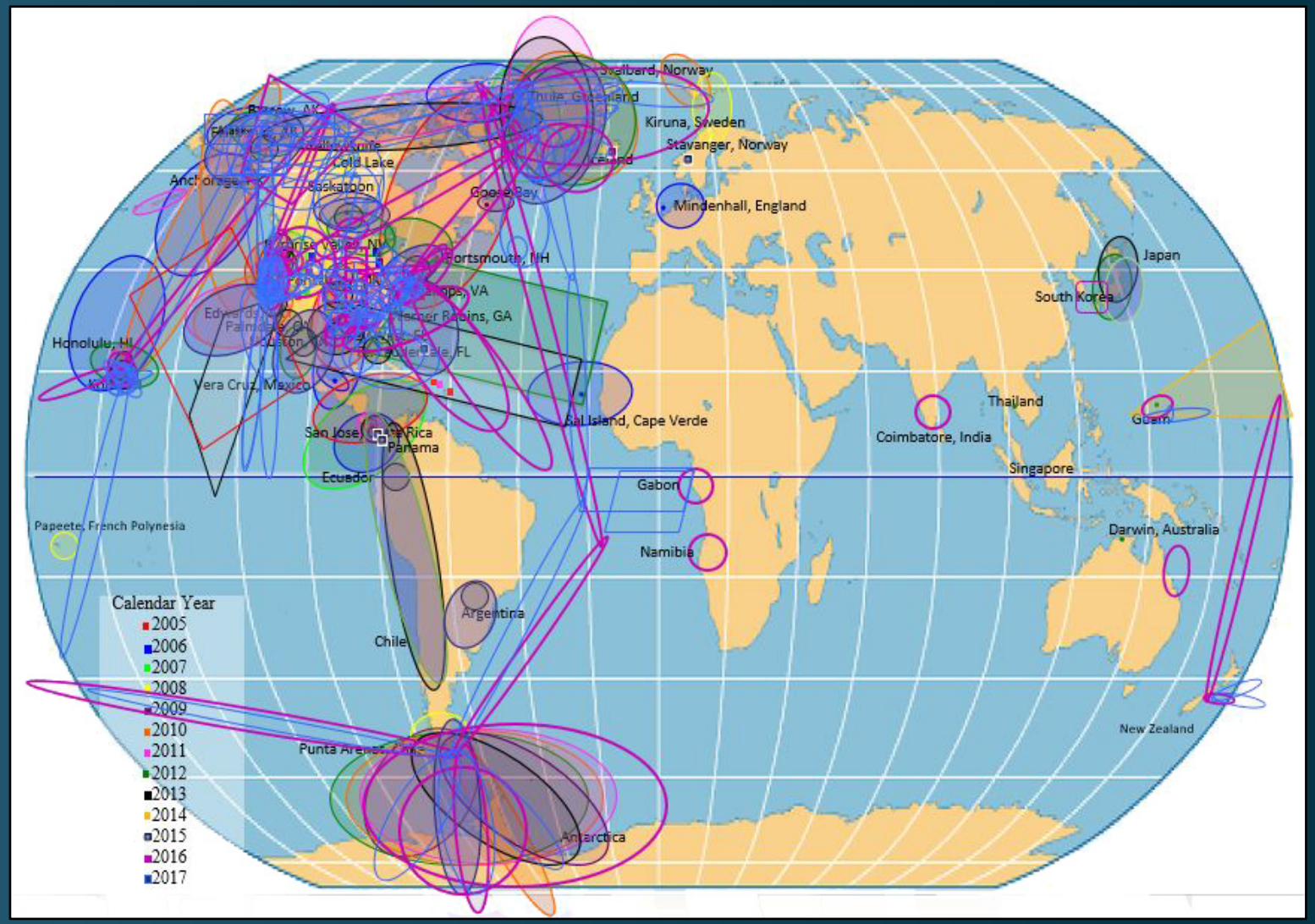
External Logistics Carriers: ELC-1, ELC-2, ELC-3
External Stowage Platforms: ESP-3
Alpha Magnetic Spectrometer
Columbus External Payload Facility
Kibo External Payload Facility

05.23.19

NASA Earth Observing Fleet, 2018



2005-2017 Airborne Campaigns



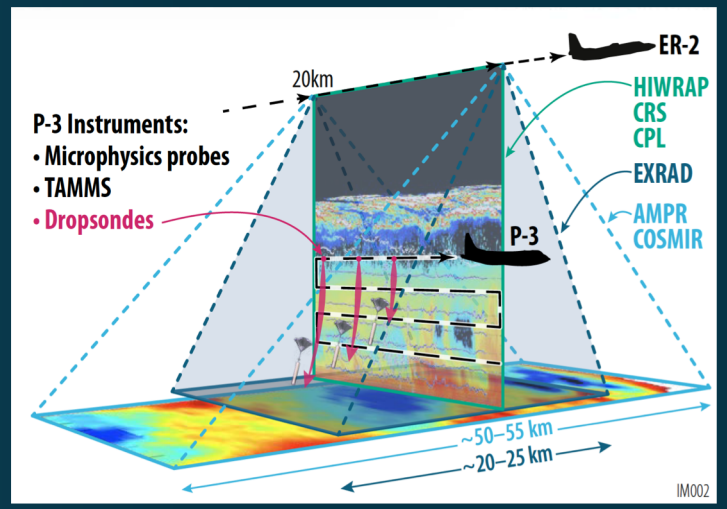
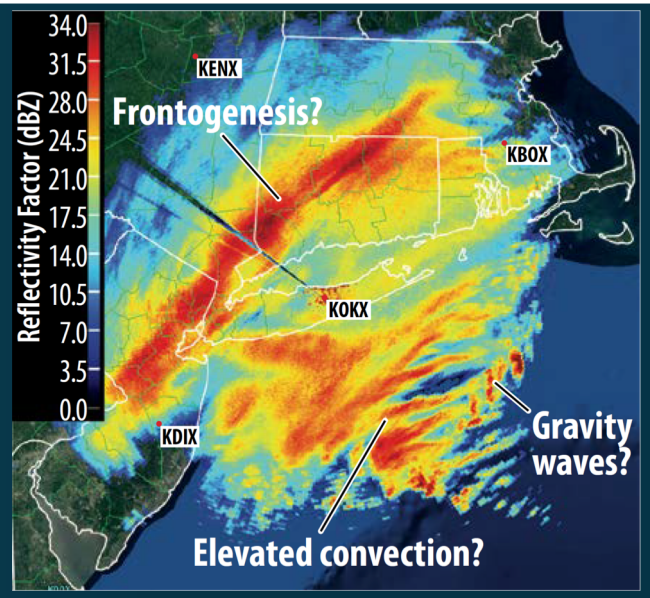
IMPACTS - Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms

PI and Co-I Team

PI: Lynn McMurdie (U Washington)
Deputy PI for Science: Scott Braun (NASA/GSFC)
Deputy PI for Data: Gerald Heymsfield (NASA/GSFC)
Platforms: ER-2 (AFRC), P-3B (WFF)
Deployments: January 16-February 28., 2020, 2021, 2022 – WFF (P3-B), Warner-Robbins AFB (ER-2)
Instruments (ER-2):

- CRS – Matthew McLinden (NASA/GSFC)
- HIWRAP – Lihua Li (NASA/GSFC)
- EXRAD – Gerald Heymsfield (NASA/GSFC)
- CosMIR – (NASA/GSFC)
- AMPR – Timothy Lang (NASA/MSFC)
- CPL – Matthew McGill (NASA/GSFC)

Instruments (P-3B)

- Microphysics Instruments – Michael Poellot (UND)
- CDP, CAPS, 2D-S, HVPS-3V, HVPS-3H, Nevzorov, King, Hawkeye, Rosemount
- WISPER – David Noone (Oregon State U)
- TAMMS – Lee Thornhill (NASA/LaRC)
- AVAPS

Instruments (Ground) – Pavlos Kollias (Stony Brook U)