National Aeronautics and
Space Administration

EXPLORE EARTH

Airborne Science in NASA's Earth Science Division

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October 16, 2020

** Prepared with inputs from numerous colleagues from NASA HQ, centers, and research community.*
Special thanks to Maudood Khan (Booz Allen Hamilton, NASA Earth Science Division)

Overview

- NASA Earth Science Satellite Fleet
- Different vantage points for Earth system science
- What Airborne Science means at NASA
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- NASA Earth Venture Suborbital – 3 (EVS-3) competed investigations
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- Student Airborne Research Program (SARP)
- Radio frequency spectrum application processing challenges
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NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

SWOT (CNES)
LANDSAT-9 (USGS)
SENTINEL-6 Michael Freilich/B (ESA)
TROPICS (6)
GEOCARB
NISAR (ISRO)
MAIA
TSIS-2
TEMPO
PREFIRE (2)
PACE (NSO)
GLIMR
ICESAT-2
GRACE-FO (2) (GFZ)
CYGNSS (8)
NISTAR, EPIC (DSCOVR/NOAA)
CLOUDSAT (CSA)
TERRA (JAXA, CSA)
AQUA (JAXA, AEB)
AURA (NSO, FMI, UKSA)
CALIPSO (CNES)
GPM (JAXA)
LANDSAT 7 (USGS)
LANDSAT 8 (USGS)
OCO-2
SMAP
SUOMI NPP (NOAA)

ISS INSTRUMENTS

EMIT
CLARREO-PF
GEDI
OCO-3
TSIS-1
ECOSTRESS
LIS
SAGE III

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb
LIBERA

09.23.20

INVEST/CUBESATS

RainCube
CSIM-FD
HARP
TEMPEST-D
CIRiS
CTIM
HyTI
SNoOPI
NACHOS

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

Features of Different Vantage Points for Earth System Science

Satellite

- Can provide global or near-global coverage
- Can potentially get long time series, but that will typically require overlap across sensors, platforms, and programs since lifetimes of individual satellites is limited (at least in terms of design lifetime)
- Consistent approach should yield measurements that can be applied globally (subject to appropriateness for environment)
- Significant resources can (must!) go into calibration/validation
- Has potential for global sharing and use, thanks to open data policy and investment in capacity and tools
- May not support full set of desired observations, but constellations can help by providing synergy
- May support routine global observation, or observables may be targeted (depending on sensor, program, etc.)
- Orbital mechanics limit flexibility for observation (important for sensors with narrow swath widths)
- Measurement frequency may be low with LEO satellites; higher frequency requires higher orbits or constellations
- May allow for vertical profiling (especially through use of active remote sensing, or limb profiling/occultation)

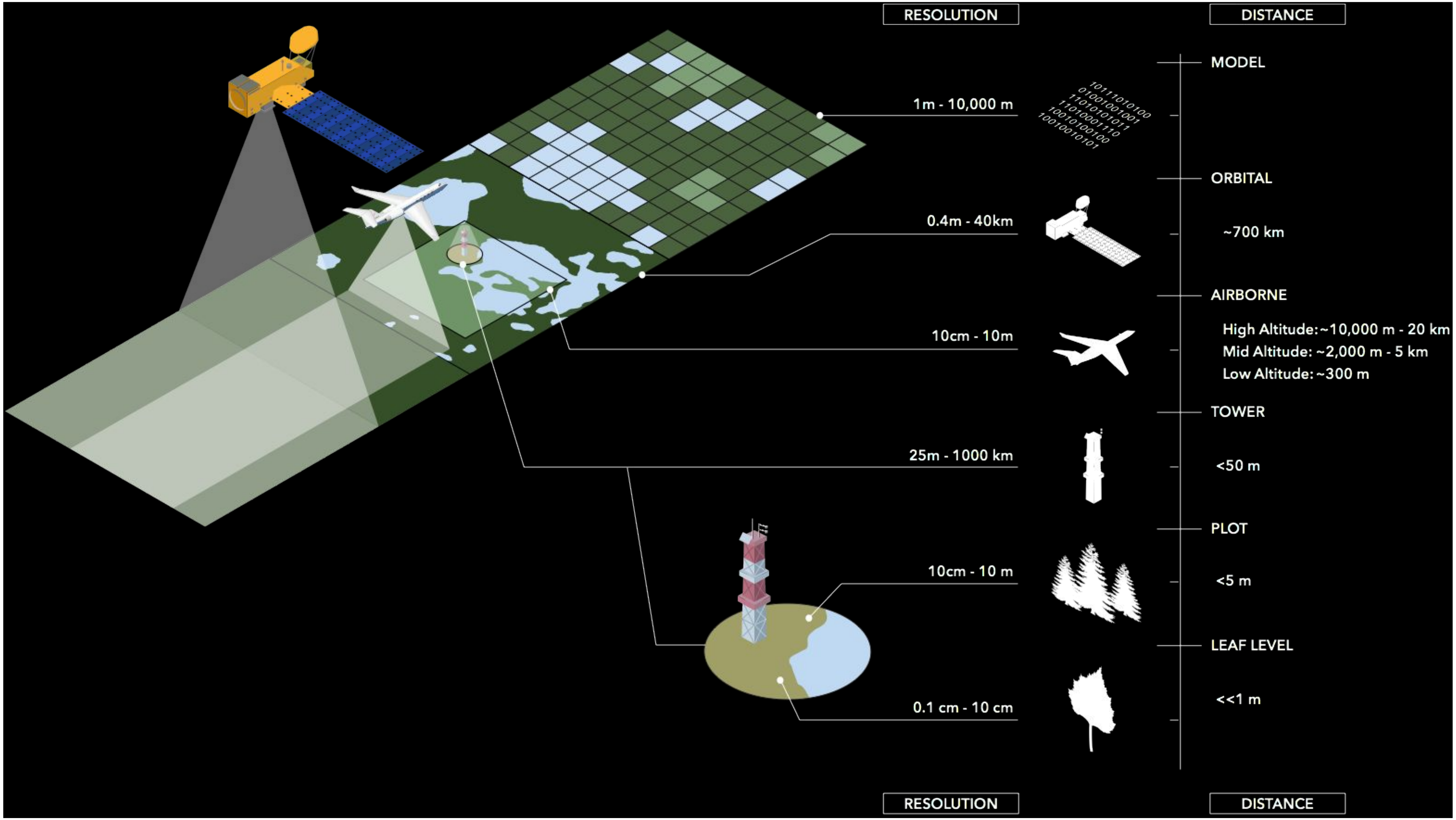
Airborne

- Can build on satellite observations, allowing for a more comprehensive set (“load up a plane”)
- Can provide mobile, controllable, and targetable platform for remote sensing (“virtual satellite”)
- May integrate in situ and remote sensing and get vertical profile information
- Allows for instruments to be calibrated before AND after flight
- May provide hands-on opportunities for students and early career professionals
- Can be very useful for satellite product validation (especially coincident measurements)

Surface

- Allows for sustained in situ observations (mostly) around the world (better on land than sea!)
- Shorter-term campaigns can provide comprehensive data sets
- Ability to look up and see what’s under clouds (can do column and/or vertical profiles)

Scaling Strategy for Field Campaigns

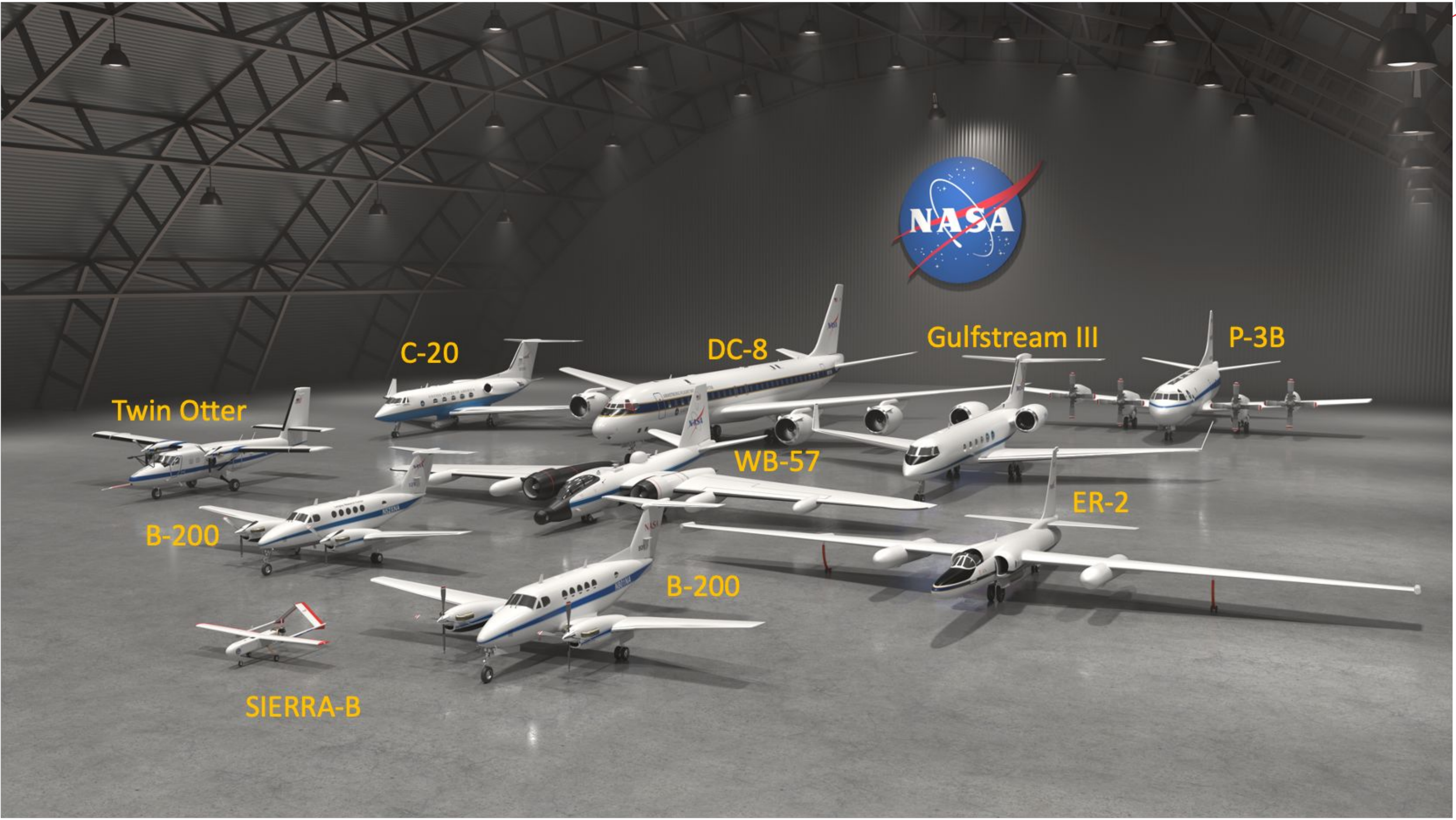


What Airborne Science Means at NASA

- The Airborne Science program 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 and information 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

https://airbornescience.nasa.gov/

NASA Airborne Science Fleet

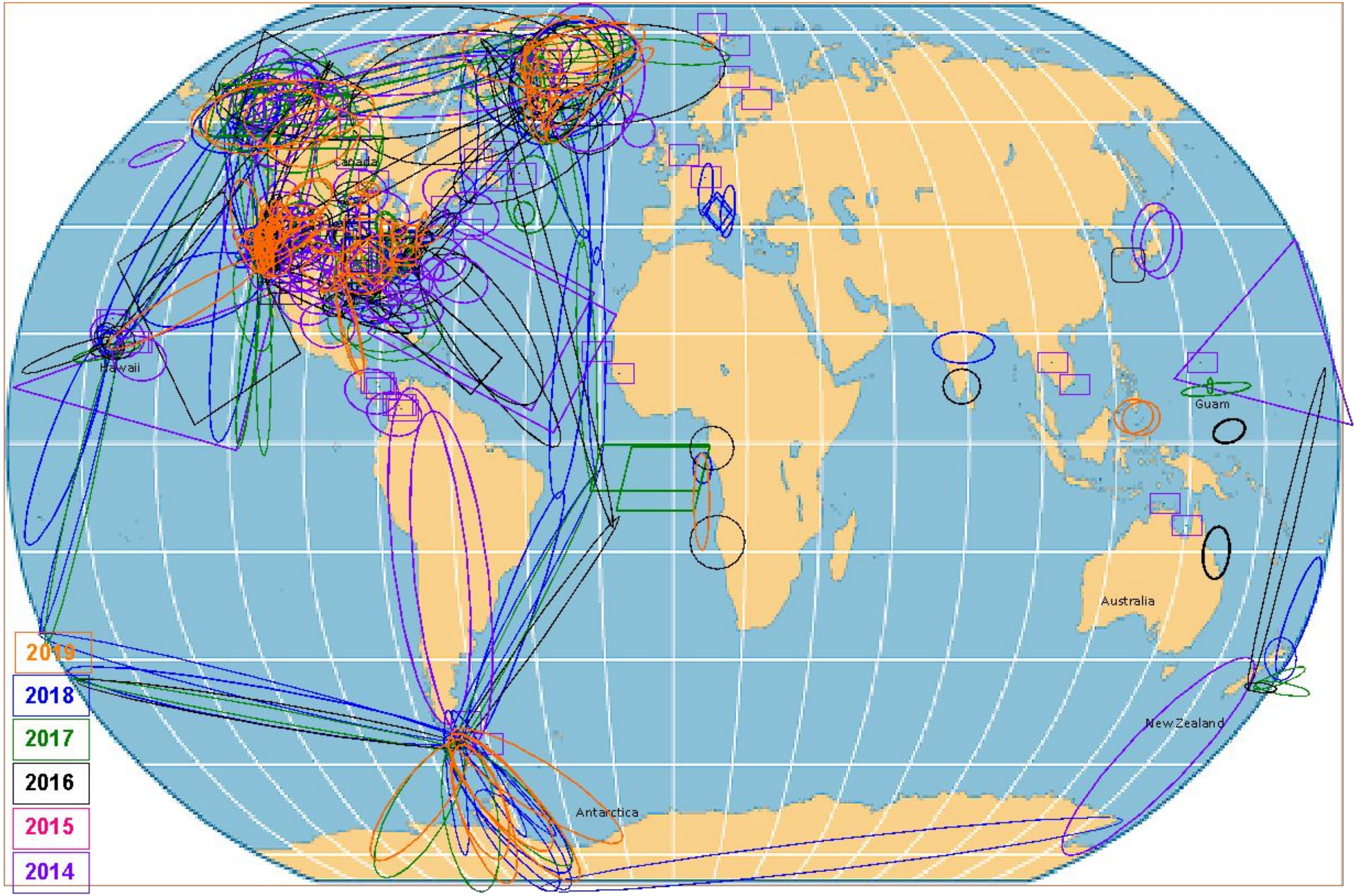


NASA Airborne Science Fleet

Platform	Center	Duration (hours)	Useful Payload (lbs)	GTOW (lbs)	Maximum Altitude (ft)	Air Speed (knots)	Range (Nmi)
DC-8	Armstrong Flight Research Center (AFRC)	12	30,000	340,000	41,000	450	5,400
ER-2	Armstrong Flight Research Center (AFRC)	12	2,900	40,000	70,000	410	5,000
Gulfstream C-20A (GIII)	Armstrong Flight Research Center (AFRC)	7	2,500	69,700	45,000	460	3,400
Gulfstream III	Johnson Space Center (JSC)	7	2,610	69,700	45,000	460	3,650
Gulfstream III	Langley Research Center (LaRC)	7.5	2,610	69,700	45,000	459	3,767
Gulfstream V	Johnson Space Center (JSC)	13	8,000	91,000	51,000	500	5,500
P-3 Orion	Wallops Flight Facility (WFF)	14	14,700	135,000	28,000 MSL	400	3,800
B-200 (UC-12B)	Langley Research Center (LaRC)	6.2	4,100	13,500	31,000	260	1,250
B-200 (#801)	Langley Research Center (LaRC)	6	1,850	13,420	35,000 (restricted airspace); 28,000 MSL (national airspace)	280	1,300
B-200	Langley Research Center (LaRC)	6.2	4,100	13,500	35,000	260	1,250

	Center	Duration (hours)	Useful Payload (lbs)	GTOW (lbs)	Maximum Altitude (ft)	Air Speed (knots)	Range (Nmi)
C-130H	Wallops Flight Facility	10	36,000	155,000	25,000	320	3,200
Cessna 206H	Langley Research Center (LaRC)/ Wallops	5.7	1,175	3,600	15,700	150	700
Cirrus Design SR22	Langley Research Center (LaRC)	6.1	932	3,400	17,500 (limited to 12,500 ft without supplemental oxygen)	175	970
HU-25A Guardian	Langley Research Center (LaRC)		3,000	32,000	39,000	430	2,075
Matrice 600	Armstrong Flight Research Center (AFRC)	1	6	15		35	3
SIERRA	Armstrong Flight Research Center (AFRC)	9	110	480	13,000	60	520
Twin Otter	Glenn Research Center (GRC)	3	3,600	11,000	25,000	140	450
Viking-400	Ames Research Center (ARC)	11	100	520	15,000	60	600
WB-57	Johnson Space Center (JSC)	6.5	8,800	72,000	60,000 and above (payload dependent)	410	2,500

NASA Airborne Science Campaigns (2014-2019)



Earth Venture Suborbital – 3 Investigations

ACTIVATE - Aerosol Cloud meTeorology Interactions oVer the western ATlantic is investigating how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation is focusing on marine boundary layer clouds over the western North Atlantic Ocean. It is a 5-year project running from January 2019 to December 2023.

DCOTTS - Dynamics and Chemistry of the Summer Stratosphere will investigate 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 is studying the formation of snow bands in East Coast winter storms. Three 6-week campaigns run from mid-January through February 2020-2022.

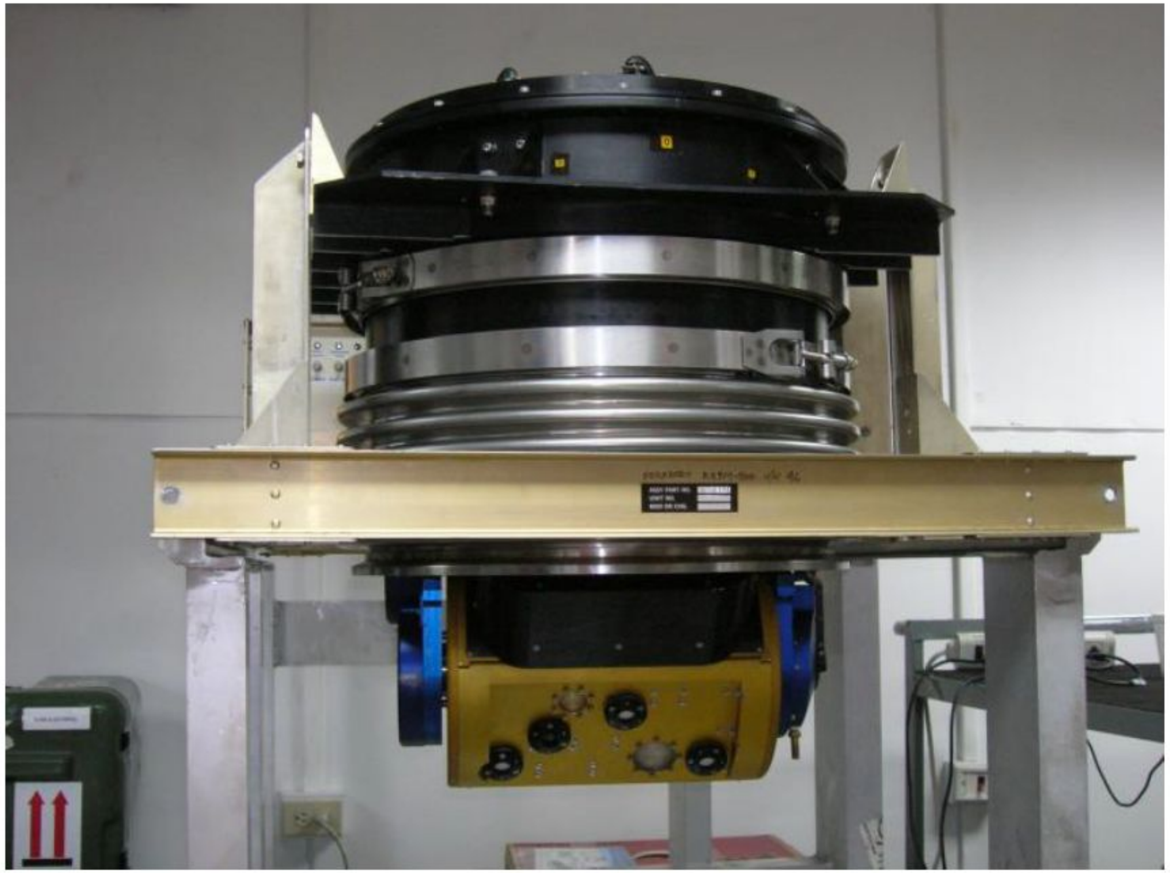
Delta-X will investigate the natural processes that maintain and build land in major river deltas threatened by rising seas. This campaign is scheduled to fly over the Atchafalaya and Terrebonne Bay coastal wetlands and deltas in Fall and Spring of 2021.

SMODE – Sub-mesoscale Ocean Dynamics Experiment will investigate 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 competitively selected from 30 proposals.

Configurable Scanning Submillimeter-wave Instrument Radiometer (CoSSIR)

- **CoSSIR** is 12-channel (183 - 874 GHz) total power imaging radiometer.
- After transitioning to a dedicated, standalone airborne sensor, CoSSIR will become NASA's premier sub-millimeter-wave radiometer.
- Submillimeter wave brightness temperatures contain significant information content from ice clouds and frozen precipitation. This portion of the electromagnetic spectrum complements microwave and millimeter-wave bands for a comprehensive understanding of clouds and precipitation.
- The instrument's scanning capability will include conical, across-, and along-track geometries. The proposed along-track scan pattern will facilitate multiple angle views of clouds.



NASA Airborne Instrument Technology Transition

Multichannel Snow Radar (MSR)

- **MSR** is a 2-18 GHz tunable or frequency stepping ultra-wideband snow radar that will be integrated onto the NASA P3 aircraft.
- The major improvement of this instrument over the current single channel snow radar is that it can measure snow thickness over land.
- Detectability will be improved due to the ability to combine multiple spatial channels for greater signal gain along with reduced surface and volume clutter.
- An upgrade to the transmitter/receiver to enable polarimetric measurements related to snow density will be provided by the University of Kansas.

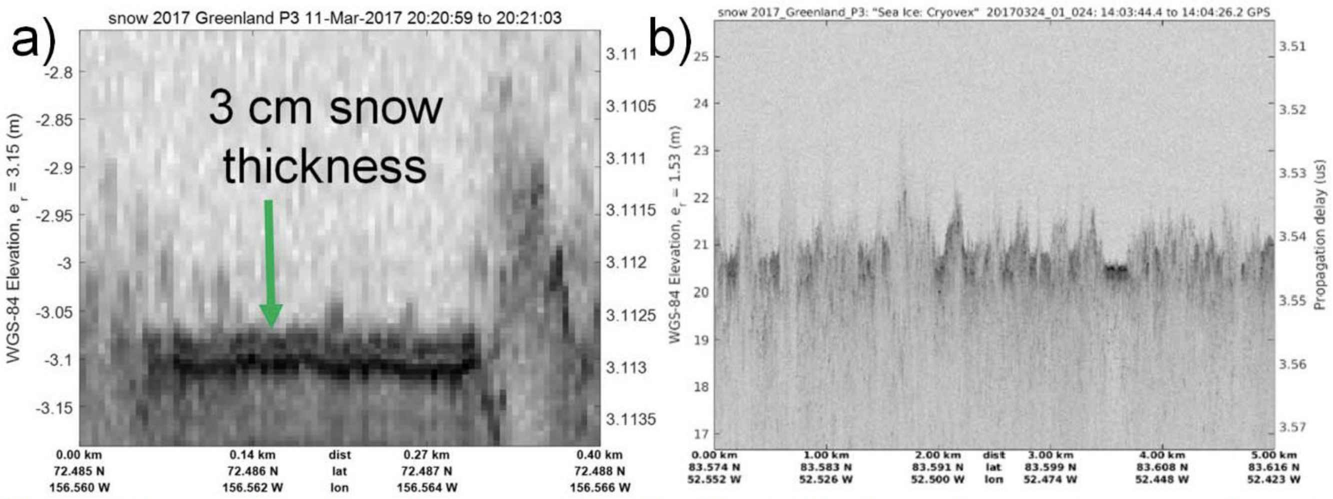


Fig. 3. a) Echogram shows the resolving power of 16 GHz of bandwidth where a thin, smooth 3-cm snow layer is resolved clearly. b) Rough snow and sea ice interfaces make the echogram difficult to interpret.

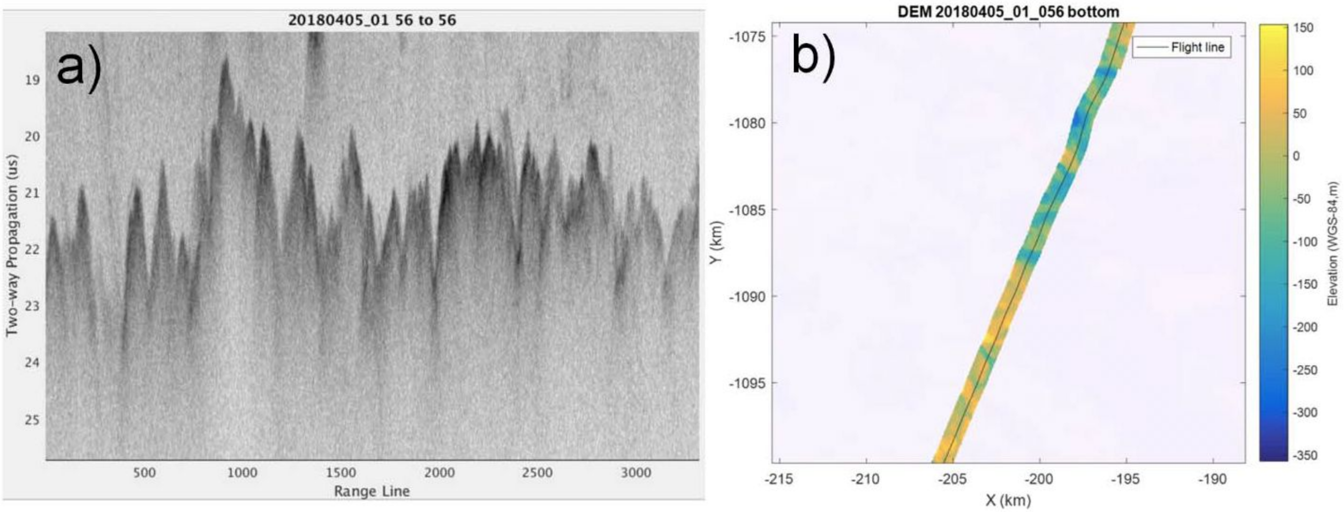
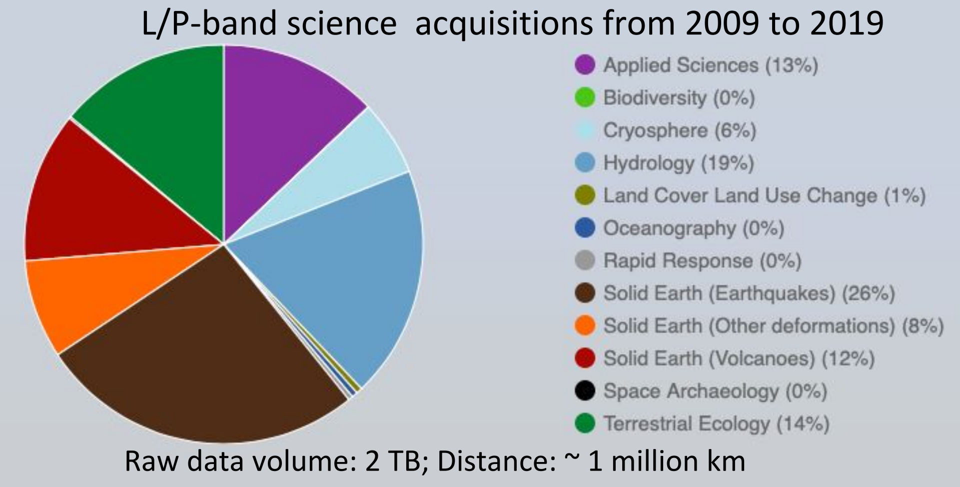
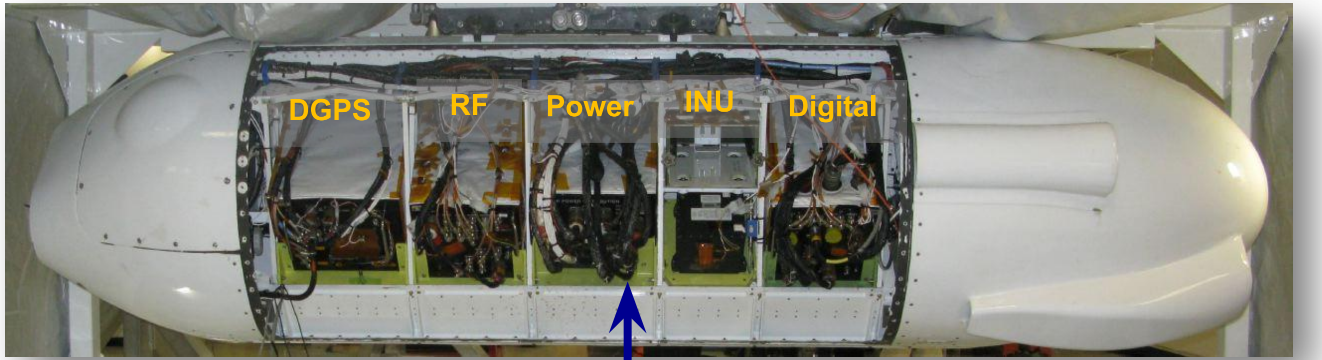


Fig. 4. a) Radar depth sounder image over a rough ice bottom that is similar in nature to the snow radar image of a rough snow surface on sea ice. b) Using the multichannel capability of the radar depth sounder, the right image shows the 3D tomographic surface reconstruction that shows the complicated texture in the 2D image is caused by lots of crossing valleys or channels.

Unmanned Aerial Vehicle Synthetic Aperture Radar (UAVSAR): Overview

- UAVSAR is a reconfigurable, polarimetric L-band (1217.5-1297.5 MHz), synthetic aperture radar (SAR) system specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements.
- Use of precision real-time GPS and a sensor-controlled flight management system enables the aircraft to fly predefined paths with precision (within a 10m diameter tube about the desired flight track).
- Since 2018, the UAVSAR facility instrument suite has been enhanced with two additional bands:
  - P- (280-440 MHz) **(AirMOSS)**,
  - Ka- (35,620-35,700 MHz) (**GLISTIN-A)** band radars
- The compact, modular, and adaptable non-pressurized instrument pod has air inlets that allow cooling of radar electronics.

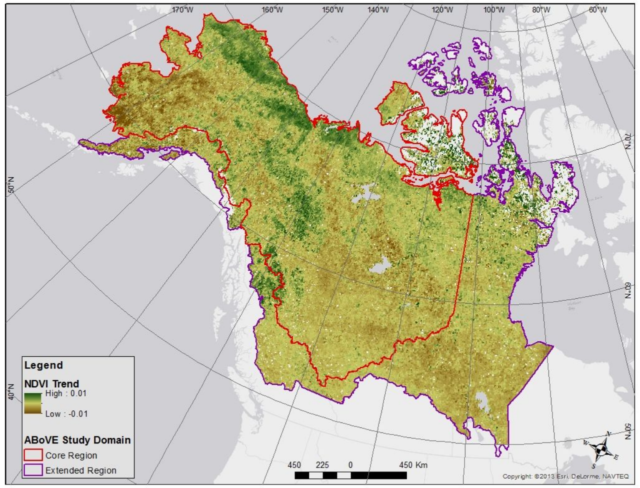




Electronics bay common to all frequencies

Arctic-Boreal Vulnerability Experiment (ABoVE) Campaign

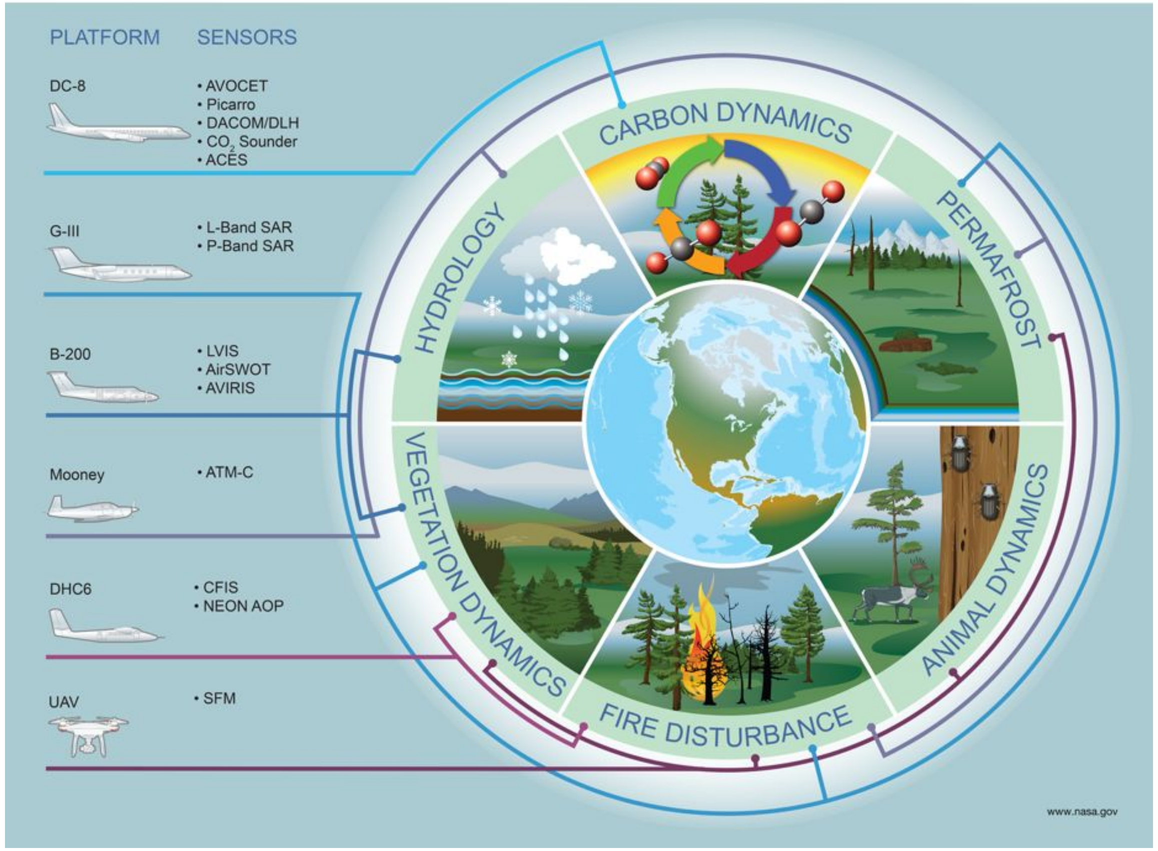
The ABoVE campaign used aircraft to measure landscape-scale changes in vulnerable Arctic-boreal ecosystems of Alaska and western Canada that satellites and ground instruments alone could not. Key findings:



1. **Wildfires are changing the Arctic-boreal landscape**: Measurements showed where wildfire had thawed permafrost, creating rougher, wetter terrain that may change the distribution and growth of local plant species, and accelerate CO_2 and CH_4 methane released into the atmosphere.

2. **Understanding what ”green” means**: Improving our ability to interpret NDVI in tundra and boreal ecosystems, where high NDVI values could mean high concentrations of either moss or vascular plants. This distinction could have wide ranging consequences for everything from water and carbon fluxes to future fire disturbances.

3. **Estimate CO_2 and CH_4 fluxes on large and small scales**: Instruments observed increase in methane bacterial respiration and decrease in CO_2 from plant photosynthesis near the surface of the Earth. The DC-8 also detected large scale boundary concentrations of the two gases above the Arctic Ocean.



SnowEx 2020 – Grand Mesa Intensive Observing Period

Campaign Objective:

- Collect data needed to test and validate Snow Water Equivalent (SWE) retrieval from active and passive microwave sensors
- Collect thermal IR data to assess the value of km-scale satellite IR observations (e.g., GOES-16/-17) for snow energy balance modeling

Strategy:

- Focus on flat, open shrubland and meadows and transitioning into forests
- Acquire ground observations of snow depth and surface temperature spatial variability; vertical profiles of snow stratigraphy and microstructure

NASA Airborne platforms & instruments:

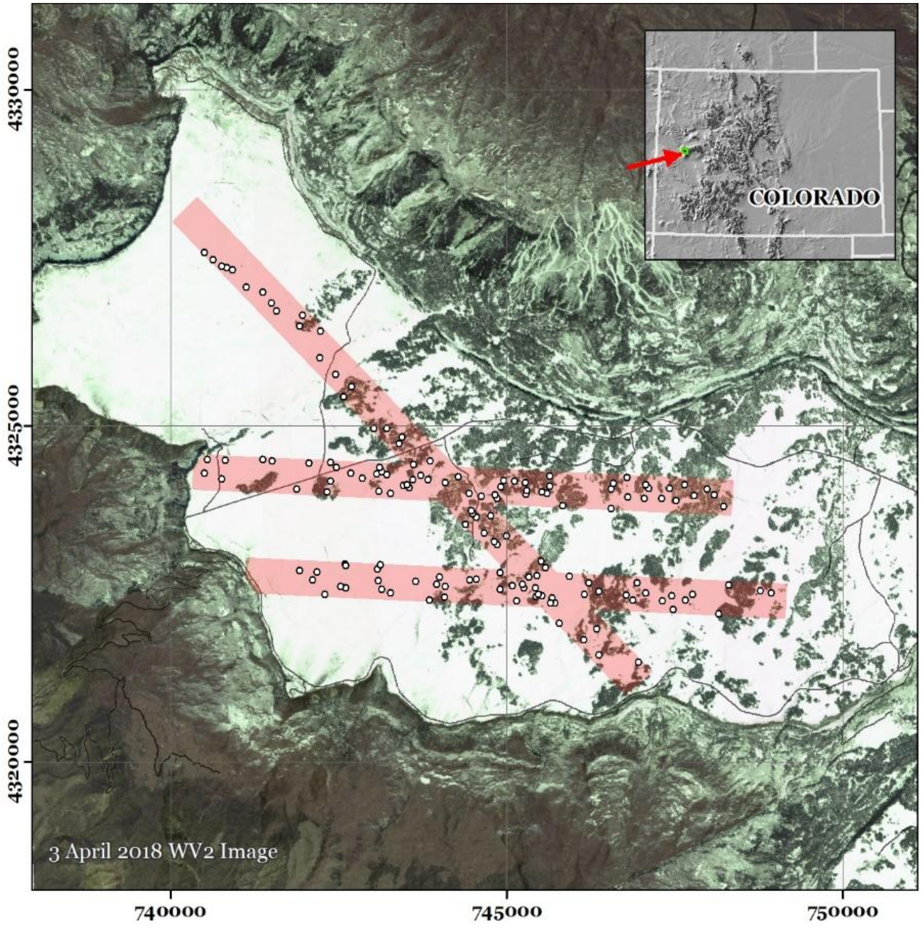
- Gulfstream-III (Johnson Space Center)
  - L-band InSAR
  - UAVSAR
- Twin Otter (Naval Postgraduate School CIRPAS)
  - Snow Water Equivalent SAR and Radiometer (SWESARR) is a tri-band (X-, dual Ku-band) SAR, and a tri-band (X-, K-, Ka-band) radiometer.
  - Thermal IR from the University of Washington

Dynamic Aviation A90

- Reigl 1560i Lidar
- CASI hyperspectral

Partner airborne observations

- FMCW Radar led by University of Alabama TOI Twin Otter
- Gamma Airborne Survey led by NOAA NOHRSC on Twin Commander

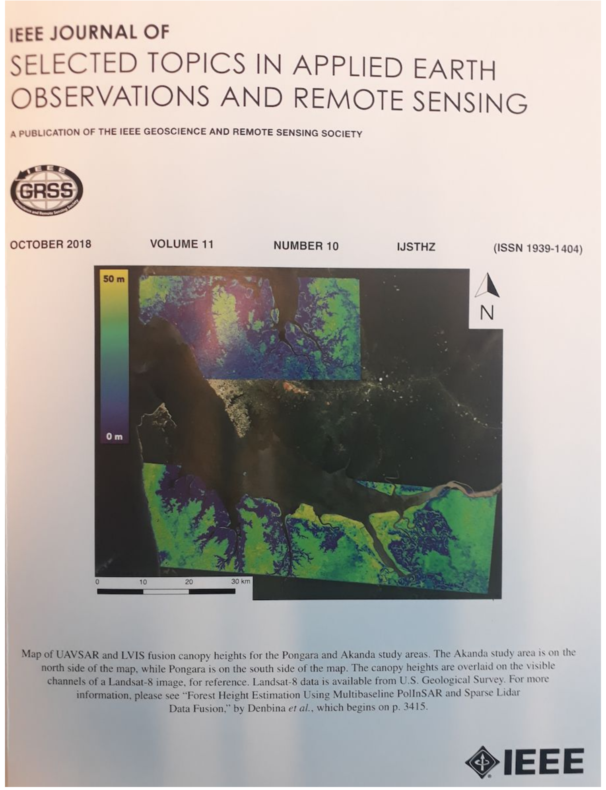


2016 ESA-NASA AfriSAR in Gabon

Campaign Objective:

- Extend results from the previous TropiSAR campaign in French Guiana to an African tropical rainforest with different structure and environmental conditions
- Provide feedback on BIOMASS mission operations and Level-2 product quality
- Assess changes in P-band signal as a function of time over same sites

We acquired 89% of all planned flight lines including 100% of high priority sites.



Highlights:

- First extensive TomoSAR and PolInSAR data acquisitions over natural tropical forest with in situ measurements to develop new techniques for studying forest structure.
- IEEE Special Issue on Forest Structure Observations from Space, Co-edited by ESA, NASA, DLR and ONERA staff was published October 2018
- 19 papers addressing remote sensing of forest structure and related missions such as Biomass, L-band SAR missions, GEDI and others.

B-200/LVIS: Summary Metrics

- Total Flight Hours: 106.5
- Science Hours: 32.4
- Science Flights: 8
- Days in Field/Gabon: 23

C-20A/UAVSAR Summary Metrics:

- Total Flight Hours: 84.6 Science Hours: 39.6 hours
- Science Flights: 8
- Days in Field/Gabon: 18

NASA-ISRO L- and S-band SAR Campaign over North America (Dec. 2019)

Motivation and Scope

- The campaign acquired over North America L- and S-band Synthetic Aperture Radar (SAR) data from Space Research Organization (ISRO) Airborne Synthetic Aperture Radar (ASAR) instrument mounted on NASA's Gulfstream III aircraft
- The antenna pod and navigation package for the NASA UAVSAR radar system were utilized, allowing the aircraft to fly over predetermined path with precision
- The imagery is needed by the US to develop and refine algorithms in advance of launch of NASA ISRO Synthetic Aperture Radar Mission (2022)
- The data are relevant and useful to NASA Earth science research and application areas: cryosphere, ecosystems, natural hazards, solid Earth, ocean science, terrestrial hydrology, agriculture, oil spills, and infrastructure.

Legend

asar_flight

- Glacial dynamics, snow on glacier
- Calibration
- Landslides
- Permafrost
- Volcanoes
- Agriculture
- Sea Ice
- Soil Moisture
- Forest
- Inundation / surface water extent
- River Hydrology
- Oil spills
- Snow
- Wetlands

NASA-ISRO campaign flights over Alaska

NASA-ISRO campaign flights over western United States

High Flying Interns: NASA Student Airborne Research Program (SARP) 2009-2019

SARP Objectives

- Expose and engage participants in NASA Airborne Science and its role in Earth system research.
- Provide participants with hands-on experience of the end-to-end aspects of a scientific mission using NASA research aircraft and instrumentation.
  - Do this such that authentic student projects can be completed
- Inspire, motivate, and recruit students from institutions that do not offer research experiences and who might otherwise choose fields other than Earth System Science.
- Infuse fresh cross cutting ideas from other disciplines into Earth System Science research.
- Address future workforce needs in the earth science, airborne science and aerospace communities.
- Increase future workforce diversity.
- Perform scientifically useful measurements and anticipate the possibility of publishable results.

SARP 2017 participants, mentors and faculty pose in front of the NASA Sherpa at Armstrong Flight Research Center in Palmdale (June 23, 2017)

Madison Lichak, a molecular biology major at Barnard College, ran through a tunnel created by her fellow SARP participants after flying on the final west coast research flight

SARP Results

- 333 alumni from 212 schools in 49 states and Puerto Rico (2009-2019)
- 93% of alumni are currently employed in STEM fields or pursuing advanced degrees in STEM fields
- Almost 50 alumni now have PhDs in STEM fields
- American Geophysical Union Fall Meeting
    - 64 student first-author presentations of SARP research projects in scientific sessions at AGU Fall Meetings (2011-2019) of SARP summer research
    - 4 students awarded AGU Outstanding Student Paper Awards
    - SARP annual alumni reunion reception at AGU typically draws ~40-50 Alumni
- 2009-2019 Long term dataset of remote sensing and atmospheric sampling over Southern and Central California
    - Over 10 publications have used SARP data
- **Alumni now participating as scientists and engineers in NASA Airborne Science Program missions all over the world (GRIP, HS3, KORUS-AQ, DISCOVER-AQ, DC3, PECAN, SEAC4RS, AJAX, LMOS, AirMSPI, UAVSAR, NAAMES, ABoVE, FIREX-AQ, CAMP2Ex)**

Dr. Laura Judd, SARP 2012 alumna, now a research scientist at NASA Langley Research Center

Radio Frequency Spectrum Application Processing Challenges (1 of 2)

- We have been working diligently with NTIA to accommodate the constantly evolving restrictions imposed on NASA airborne radars by utilizing arbitrary waveform generators in our radars to maintain flexibility
  - We never received a single complaint about interference in the history of NASA airborne SAR program dating back to 1980s
- RF spectrum application process for low frequency radars (P- and L-band) is long, arduous, and sometimes untenable
- Spectrum application is taking longer to process, and over the years, more requirements are being levied on existing NASA airborne and spaceborne radars, sometimes requiring us to modify our instrument design (NISAR and SMAP)
- The P-band (225-450 MHz) has suitable vegetation penetration characteristics. The spectrum is shared with the DoD. AirMOSS is operating in this spectrum.
  - AirMOSS spectrum application with NTIA in 2011 took more than 18 months in order to secure an experimental license (stage 2) with many restrictions and pre-coordination requirements
  - AirMOSS was only allowed to operate in 20 MHz bandwidth instead of the 160 MHz bandwidth that the instrument was designed for, whereas GeoSAR built ~10 years earlier was permitted to operate the 160 MHz with frequency notches

Radio Frequency Spectrum Application Processing Challenges (2 of 2)

- L-band (1220-1300 MHz) is commonly used for sensitivity to vegetation structure and solid earth deformation, but part of this spectrum is shared with the FAA ground-based air-route surveillance radars near major airports
  - UAVSAR’s L-band radar has been operating with an experimental stage 2 license for 10 years, and just recently received approval for a “permanent” stage 4 license (renewable every 5 years).
  - The Stage 4 license imposed new requirements on UAVSAR where we are now required to notch our transmitted spectrum whenever transmitting within 200 nautical miles of FAA air-route surveillance radars
  - In 2018-19, ISRO’s airborne SAR we are hosting took 1 year of coordination/negotiation with the FAA to receive temporary licenses to operate in select states in the U.S.
- The research science community has requested multi-frequency co-collection capability in the next generation UAVSAR instrument with greater spectral diversity. UAVSAR currently operates individual instruments at P, L, and Ka bands. The community asks NASA to consider adding S, X, and Ku, where different multifrequency combinations can be evaluated.
- **We welcome any assistance that NASEM can provide in facilitating a dialogue regarding potential accommodations for the science community who desire infrequent and transitory use of the spectra**

Concluding Messages

- Airborne science is an important part of NASA's Earth Science program, supporting all elements, especially research and applications.
- Airborne science is combined with other approaches (satellite, surface-based, modeling) to provide integrated information about Earth system processes and testing and evaluation of satellite measurements.
- NASA's integrated approach to airborne science brings a unique mix of platforms, sensors, systems, people, and opportunities to its activities.
- The measurement suite aboard NASA's airborne platforms includes both in situ and remotely sensed measurements - using both active and passive techniques for the latter, covering a variety of wavelength regions.
- NASA's Airborne Science program is carried out in partnership with numerous other organizations (domestic and internationally). The ability to make needed measurements with appropriate techniques under a range of conditions is important to our success.

backup

NASA Airborne Microwave Instruments (1)

- **Advanced Microwave Precipitation Radiometer (AMPR)** is a total power passive microwave radiometer producing calibrated brightness temperatures at 10.7, 19.35, 37.1, and 85.5 GHz. These frequencies are sensitive to the emission and scattering of precipitation-size ice, liquid water, and water vapor.
- **Airborne Cloud Radar (ACR)** for profiling cloud vertical structure was developed by the Jet Propulsion Laboratory and the University of Massachusetts in 1996. It is a W-band (95 GHz) polarimetric Doppler radar designed as a prototype airborne facility for the development of the 94 GHz Cloud Profiling Radar (CPR) for NASA CloudSat mission. The ACR is a third-generation millimeter-wave cloud radar. While adopting the well tested techniques used by its predecessors, ACR also has a number of new features including an internal calibration loop, frequency agility, digital I and Q demodulation, digital matched filtering, and a W-band low-noise amplifier.
- **Airborne Multichannel Microwave Radiometer (AMMR)** measures thermal microwave emission (in degrees Kelvin of brightness temperature) from surface and atmosphere. The up-looking radiometer at 21 and 37 GHz is a component of AMMR that was developed in the 1970's for precipitation measurements from an aircraft. The entire AMMR assembly covers a frequency range of 10-92 GHz. The 21/37 GHz unit has been flown in many types of aircraft during the past three decades in various field campaigns. It was refurbished during the year 2000 and is ready for flight again.
- The core of **AirSWOT** is a a Ka-band SWOT Phenomenology Airborne Radar (KaSPAR). It collects two swaths of across-track interferometry data - between nadir and 1 km and between 1 km and 5 km, respectively - which can be used to obtain centimeter-level topographic maps of water surfaces. In addition, KaSPAR has an along-track interferometer that can be used to measure the temporal decorrelation of water surfaces, as well as the water radial velocity.

NASA Airborne Microwave Instruments (2)

- **Airborne Rain MApping Radar (ARMAR)** operates at 13.8 GHz (Ku-band) and was developed for the purpose of supporting future spaceborne rain radar systems. ARMAR flies on the NASA DC-8 aircraft Doppler and multi-polarization capabilities. In addition to acquisition of radar parameters, it also spends a small fraction of its time operating as a radiometer, providing the 13.8 GHz brightness temperature.
- **Airborne Precipitation Radar** – second generation (APR-2) is a dual-frequency (13 GHz & 35 GHz), Doppler, dual-polarization radar system. It has a downward looking antenna that performs cross track scans, covering a swath that is +/- 25 to each side of the aircraft path. Additional features include: simultaneous dual-frequency, matched beam operation at 13.4 and 35.6 GHz (same as GPM Dual-Frequency Precipitation Radar), simultaneous measurement of both like- and cross-polarized signals at both frequencies, Doppler operation, and real-time pulse compression (calibrated reflectivity data can be produced for large areas in the field during flight, if necessary).
- **Airborne Precipitation Radar** – third generation (APR-3) is a three frequency (13, 35, and 94 GHz), Doppler, dual-polarization radar system.
- **Cloud Radar System (CRS)** is a fully coherent, polarimetric Doppler radar capable of detecting clouds and precipitation from the surface up to the aircraft altitude in the lower stratosphere. The radar is especially well suited for cirrus cloud studies because of its high sensitivity and fine spatial resolution.
- **ER-2 Doppler Radar (EDOP)** is an X-band (9.6 GHz) Doppler radar nose-mounted in the ER-2. The instrument has two antennas: one nadir-pointing with pitch stabilization, and the other forward pointing. The general objectives of EDOP are the measurement of the vertical structure of precipitation and air motions in mesoscale precipitation systems and the development of spaceborne radar algorithms for precipitation estimation.

NASA Airborne Microwave Instruments (3)

- **Frequency Modulated Continuous Wave Snow Thickness Radar (FMCW)** is an ultra-wideband radar that operates over the frequency from 2 to 8 GHz to map near-surface internal layers in polar firn with fine vertical resolution. The radar has also been used to measure estimate sea ice thickness from ice freeboard measurements performed with satellite radar and laser altimeters. This radar has been successfully flown on NASA P-3 and DC-8 aircraft.
- **Global Ice-sheet Mapping Orbiter (GISMO)** is a NASA Instrument Incubator project is intended to design a spaceborne radar system capable of measuring surface and basal topography of terrestrial ice sheets and to determine the physical properties of the glacier bed. The technology will enable estimate the mass of polar ice sheets, with the ultimate objective of providing information to modelers estimating the mass balance of polar ice sheets and estimating the response of ice sheets to changing climate. The technology aims to employ VHF and P-band interferometric radars using a novel clutter rejection technique for measuring the surface and bottom topographies of polar ice sheets.
- **High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)** is a dual-frequency radar (Ka- and Ku-band), dual-beam (300 and 400 incidence angle), conical scan, solid-state transmitter-based system, designed for operation on the high-altitude (20 km) Global Hawk UAV.
- **High Altitude Monolithic Microwave integrated Circuit (MMIC) Sounding Radiometer (HAMSR) is** a microwave atmospheric sounder with 25 spectral channels in 3 bands (50-60 GHz, 118 GHz, 183 GHz). The measurements can be used to infer the 3-D distribution of temperature, water vapor, and cloud liquid water in the atmosphere, even in the presence of clouds. It provides observations similar to those obtained with microwave sounders currently operating on NASA, NOAA and ESA spacecraft**.**

NASA Airborne Microwave Instruments (4)

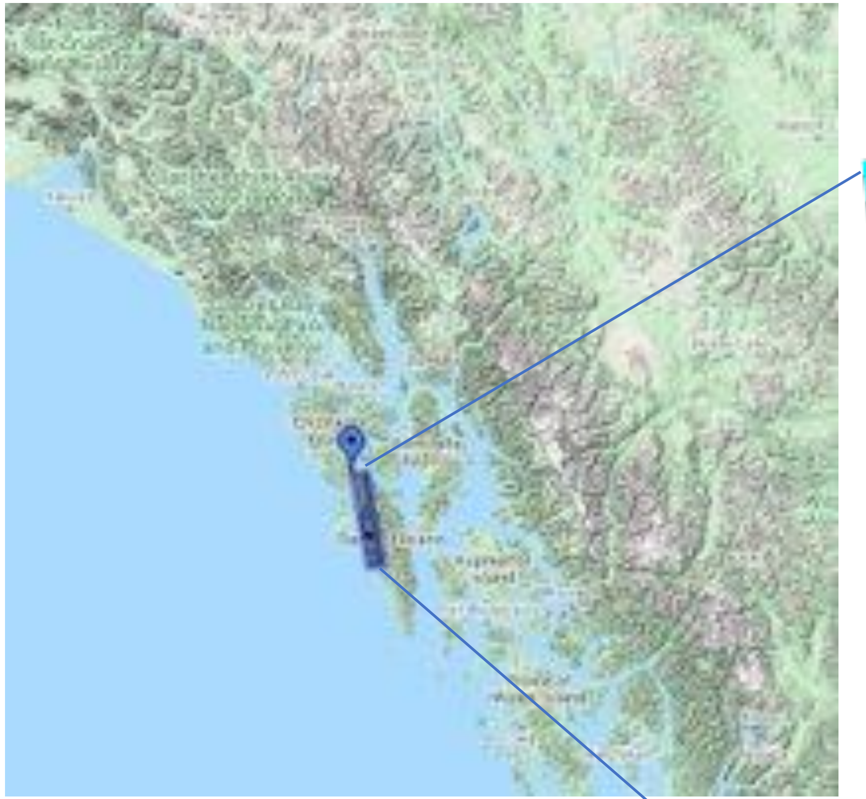
- **Ku-band Radar Altimeter** is a wideband radar altimeter that operates in 13 to 17 GHz frequency range. The primary purpose of this radar is high precision surface elevation measurements over polar ice sheets. The data collected with this radar can be analyzed in conjunction with laser-altimeter data to determine thickness of snow over sea ice. The radar has been flown on a NASA DC-8 aircraft, and the NSF provided a Twin Otter aircraft.
- **Passive Active L- and S-band Sensor (PALS)** is a combined L-band polarimetric radiometer and NASA licensed scatterometer operating at 1.413 GHz and 1.26 GHz respectively. The PALS radar and radiometer time share a dual pole, dual frequency planner array antenna. The antenna configuration can be fixed or rotating. It provides scalable resolution, between 3,000 and 20,000 feet AGL. It served as an Aquarius and SMAP test bed and was designed and built to investigate the benefits of combining passive and active microwave sensors for Ocean salinity and Soil moisture remote sensing. It is the prototype for the Aquarius and SMAP missions and its flexible design is compatible with many aircraft. PALS has flown on the NCAR C-130, NASA's P-3 and Twin Otter.
- **Polarimetric Ku-Band Scatterometer (PolSCAT)** is a Ku-band polarimetric scanning scatterometer operating at 13.95 GHz. with an approved NASA license. It was designed and built to investigate the benefits of active microwave for the remote sensing of high-resolution snow-water-equivalent (SWE). Its flexible design is compatible with many aircraft and has flown on the NCAR C-130, NASA's DC-8, P-3, and Twin Otter
- **Scanning L-band Active Passive (SLAP)** is airborne SMAP simulator in stand-by mode with good past performance, gearing up for domestic and international campaigns in the next 12 months (FY21); past aircraft availability issue suggests integration on an additional aircraft as risk reduction for any campaigns in FY22 and beyond

NASA Airborne Microwave Instruments

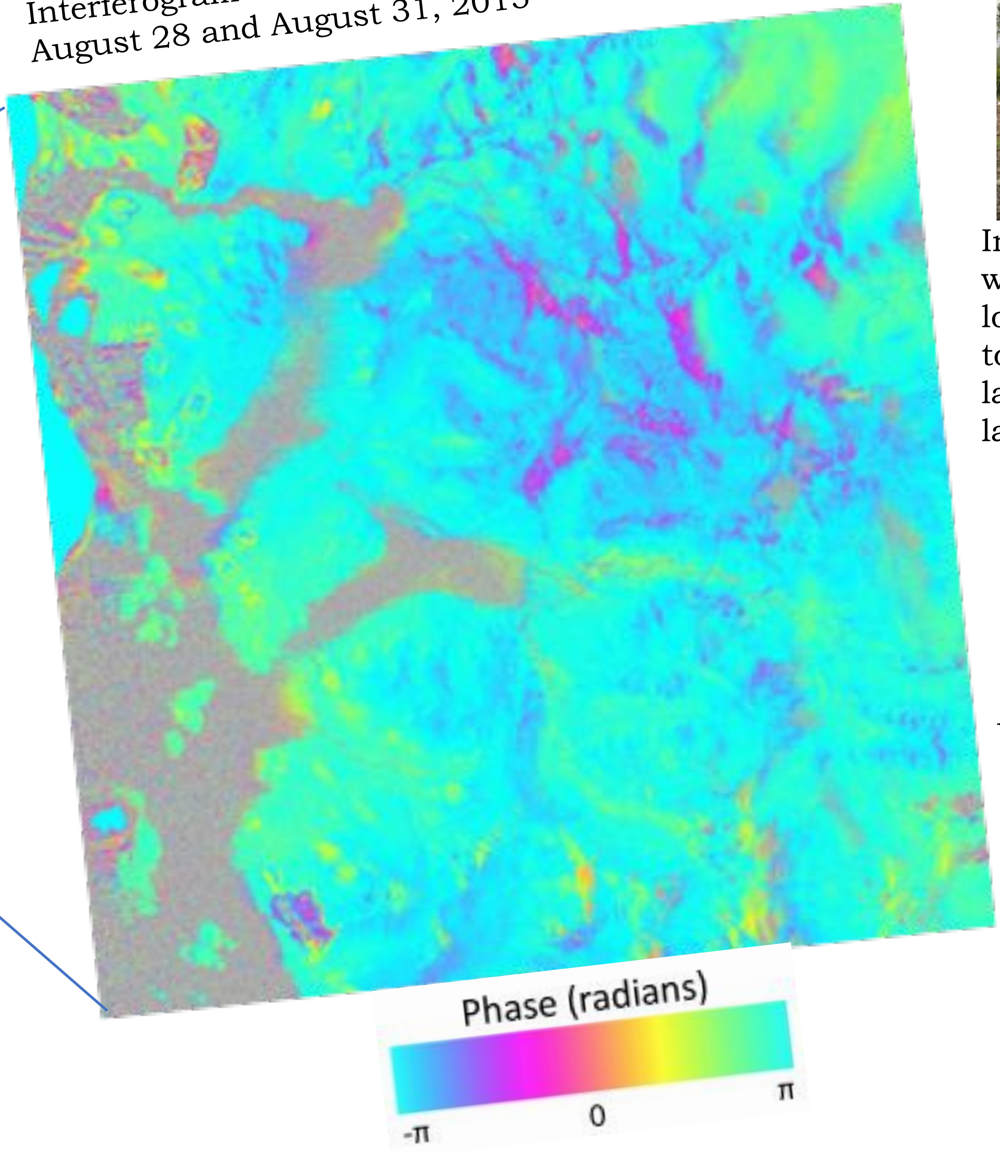
- **Snow Water Equivalent SAR and Radiometer (SWESARR)** is a tri-band synthetic aperture radar (SAR) and a tri-band radiometer. Both the active and passive bands utilize a highly novel current sheet array (CSA) antenna feed. A combination of radar and radiometric measurements spanning this 8-40 GHz spectrum shows great promise for quantifying the geospatial distribution of surface snow.
- **Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)** is a reconfigurable, polarimetric L-band synthetic aperture radar (SAR) system specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. Differential interferometry can provide key deformation measurements, and is important for studies of earthquakes, volcanoes and other dynamically changing phenomena. Using precision real-time GPS and a sensor-controlled flight management system, the system can fly predefined paths with great precision (to be within a 10 m diameter tube about the desired flight track).
- Since 2018, UAVSAR facility instrument suite has been enhanced with two additional bands: **P-band (AirMOSS)** and **Ka-band (GLISTIN-A)**. The P-band capability was originally added in 2012 to support the EVS-1 AirMOSS mission to observe sub-canopy and subsurface root zone soil moisture. The modification was accomplished by replacing UAVSAR's L-band front-end electronics and antenna with components that operate at P-band (420-440 MHz). The Ka-band single-pass interferometric SAR capability (GLISTIN-A) was added through NASA's Advanced Instrument Technology Transition program (AITT). The horizontally polarized GLISTIN-A (35.62-35.70 GHz) instrument generates high-precision, high resolution, large-swath digital surface models for ice surface topography mapping.

Demonstration of P-band Differential Interferometric SAR

Island in Gulf of Alaska



Interferogram of UAVSAR P-band data acquired on August 28 and August 31, 2015



Interferometry typically does not work well in heavily vegetated terrains. The longer wavelength P-band SAR was able to penetrate the forest and resolve landslide motion associated with the land surface and tree trunks.

Phase changes between 2 observations made 3 days apart in August 2015, showing landslide detection (pink areas) in Sitka, Alaska by P-band synthetic aperture radar

ABoVE Campaign: L-band SAR of fire induced subsidence; Kakisa Lake

Burned

Unburned

K Schaefer

Subsidence (cm)

0.010000	
0.757500	
1.505000	
2.252500	
3.000000	