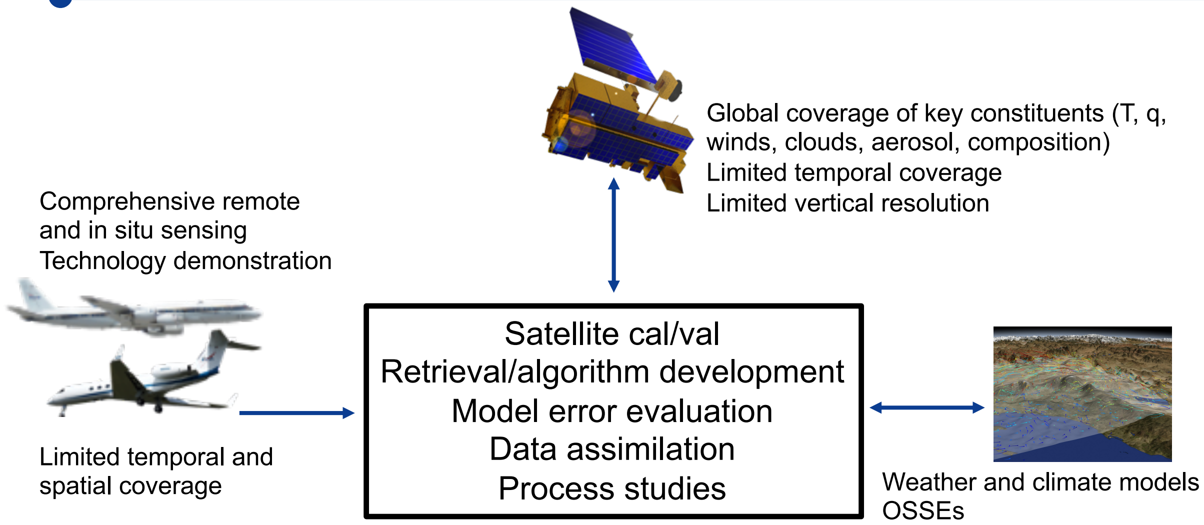
Payload Considerations for Future Weather and Climate Focused Airborne Science Investigations

Amin Nehrir

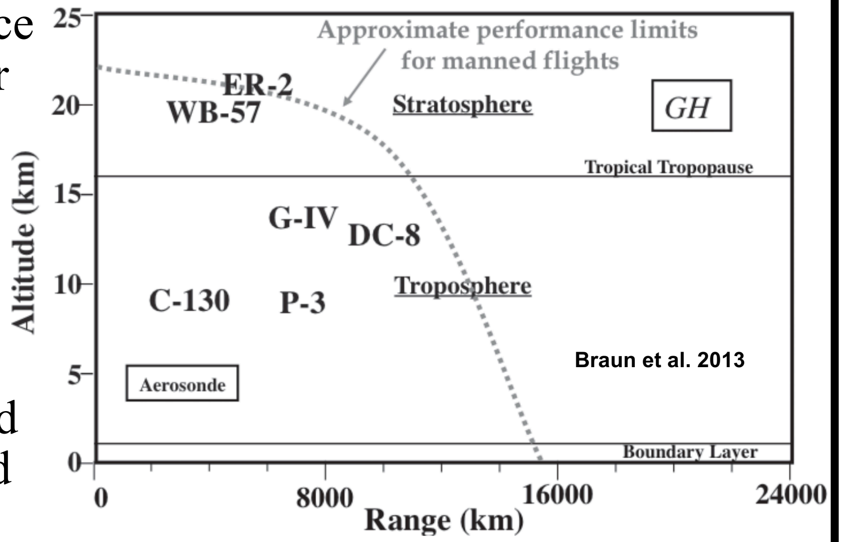
NASA Langley Research Center

07/30/2020

Drivers of airborne sampling and measurement requirements



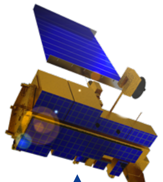
- Historically, weather and dynamics focused missions have required heavy lift long endurance aircraft to access remote oceans with long loiter times
- The two-body (airplane) approach is often preferred for optimizing remote and in situ observations, however, this is challenging in practice
- Aircraft that can simultaneously support a broad range of remote and in situ instruments has and will continue to be the workhorse platform for future weather and climate focused airborne investigations



- Weather and Dynamics (DC-8)
  - TOGA-COARE
  - CAMEX-3
  - KWAJEX
  - CAMEX-4
  - NAMMA
  - TC^4
  - GRIP
  - DC^3/$SEAC^4RS$
  - PECAN
  - CPEX
  - HIWC
  - IMPCATS (P3, ER-2)
  - DCOTSS (ER-2)
  - CPEX-AW
- Cloud, Climate, Radiation
  - ACTIVATE (HU-25, B200)
  - ORACLES (ER2, P3)
  - CAMP2EX (P3)
  - ARISE (C130)
  - Many more…

1992 → 2021

Drivers of airborne sampling and measurement requirements

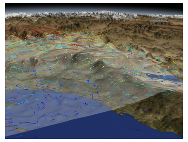


Global coverage of key constituents (T, q, winds, clouds, aerosol, composition)
Limited temporal coverage
Limited vertical resolution

Comprehensive remote and in situ sensing
Technology demonstration

Limited temporal and spatial coverage

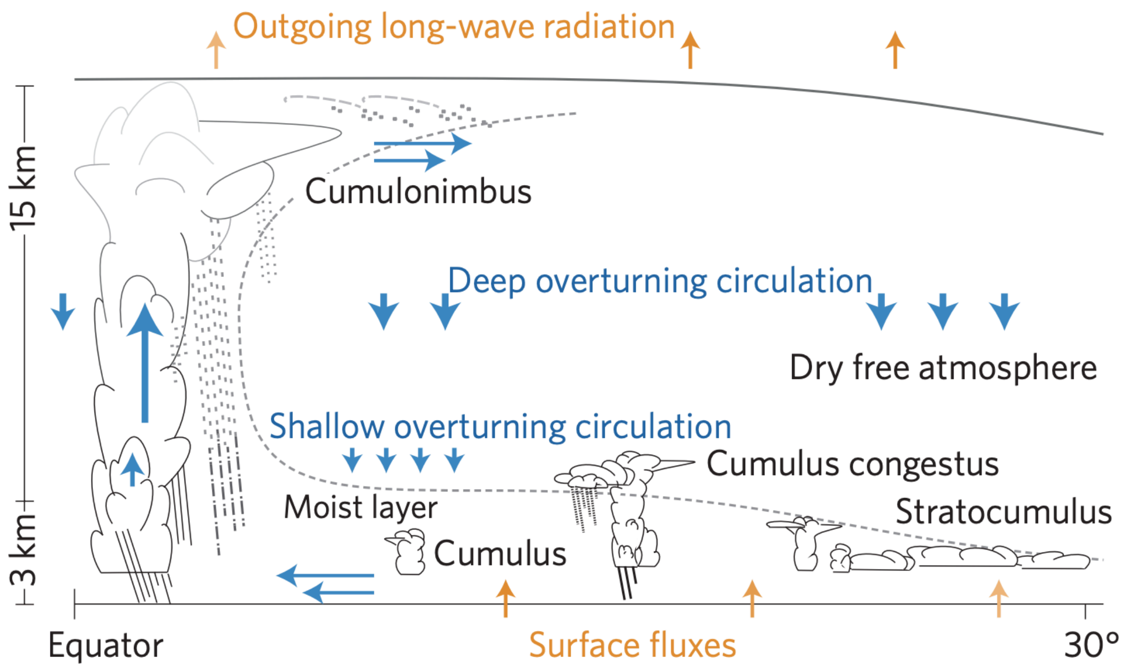
Satellite cal/val
Retrieval/algorithm development
Model error evaluation
Data assimilation
Process studies



Weather and climate models
OSSEs

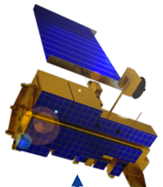
WEATHER AND AIR QUALITY PANEL

SCIENCE			MEASUREMENT	
Societal or Science Question/Goal	**Earth Science/Application Objective**	**Science/Application Importance**	**Geophysical Observable**	**Measurement Parameters**
QUESTION W-1. **Planetary Boundary Layer Dynamics.** What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean and sea ice) exchanges of energy, momentum, and mass, and how do these impact weather forecasts and air quality simulations?	**W-1a.** Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts at minutes to subseasonal time scales.	**Most Important**	3D temperature in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 0.3 K/0.3 K
			3D humidity in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 0.3 g/kg
			3D horizontal wind vector in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 1 m/s
			3D PM component and trace gas (ozone, NO_2) concentrations	Horizontal resolution 5 km, vertical resolution 0.2 km, temporal resolution 2 hr
			2D PBL height	Horizontal resolution 20 km, temporal resolution 3 hr, 0.1 km
			2D PBL cloud LWP	Horizontal resolution 20 km, 20%
			2D cloud base	Horizontal resolution 20 km, 0.1 km
			2D precipitation	Horizontal resolution 10 km, 20%



Bony et al. 2015

Drivers of airborne sampling and measurement requirements

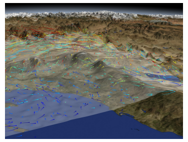


Global coverage of key constituents (T, q, winds, clouds, aerosol, composition)
Limited temporal coverage
Limited vertical resolution

Comprehensive remote and in situ sensing
Technology demonstration

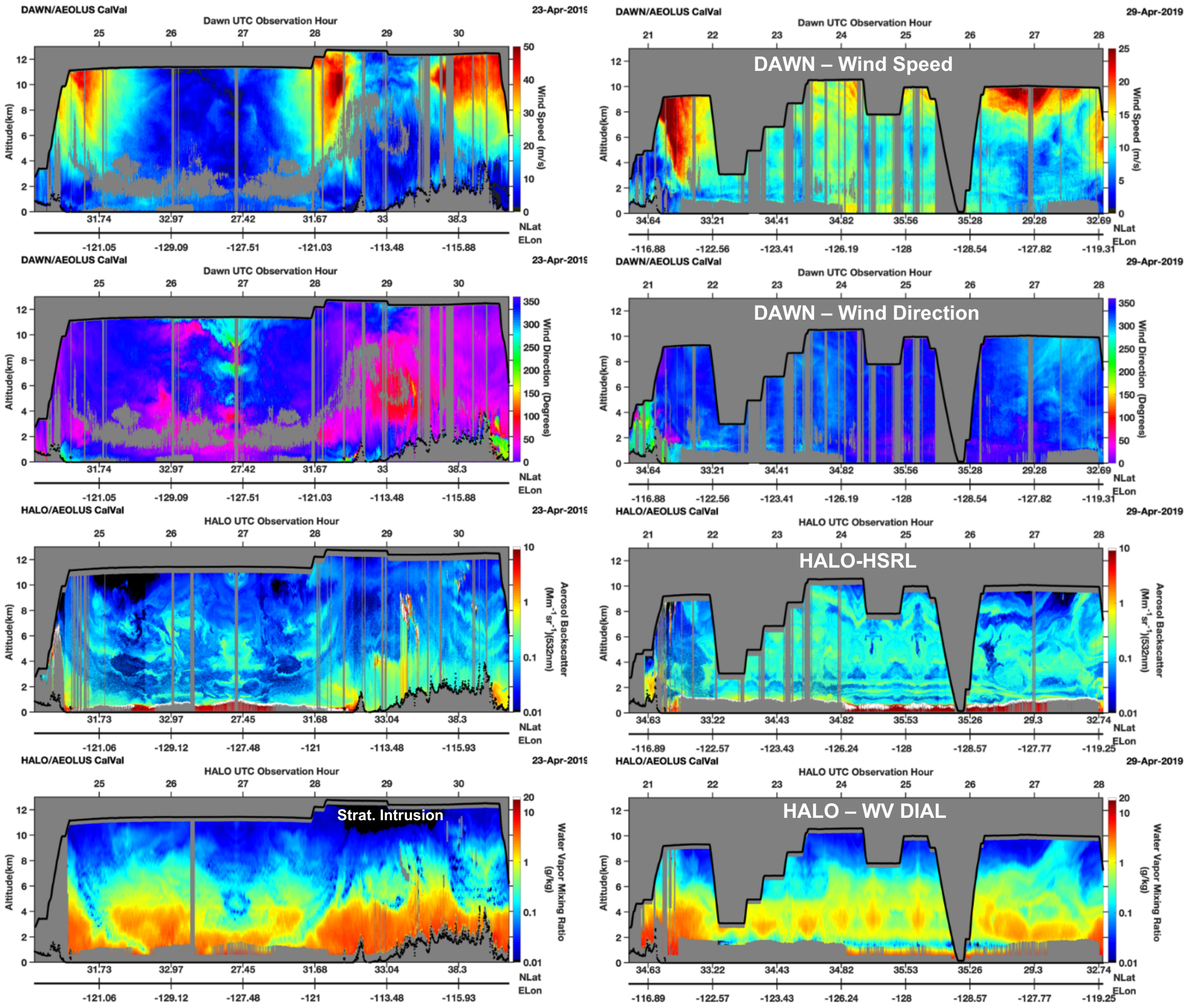
Limited temporal and spatial coverage

Satellite cal/val
Retrieval/algorithm development
Model error evaluation
Data assimilation
Process studies



Weather and climate models
OSSEs

airborne science essential for complimenting DS missions

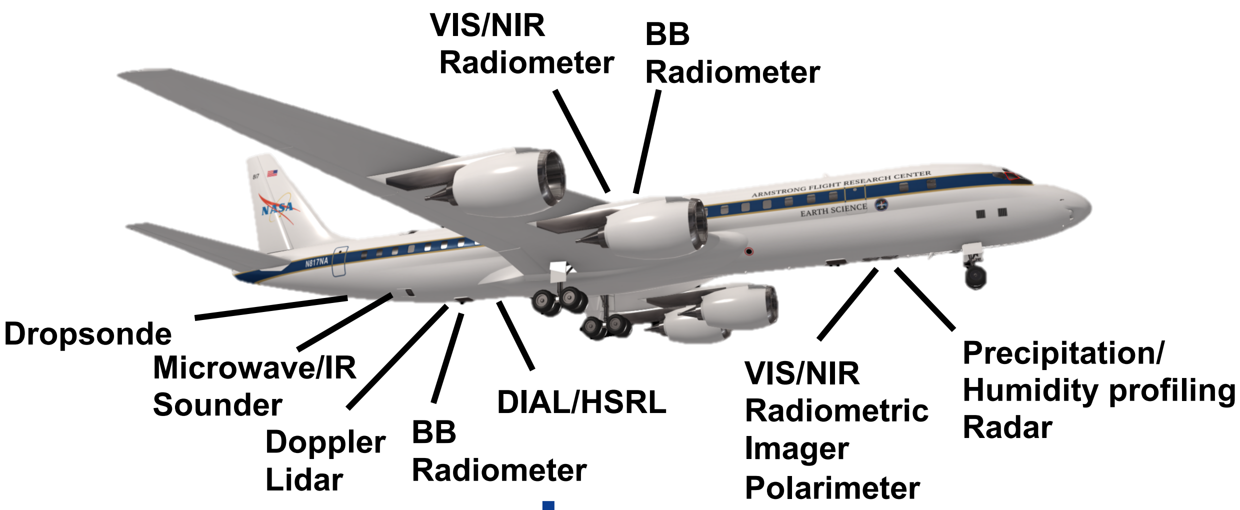


WEATHER AND AIR QUALITY PANEL

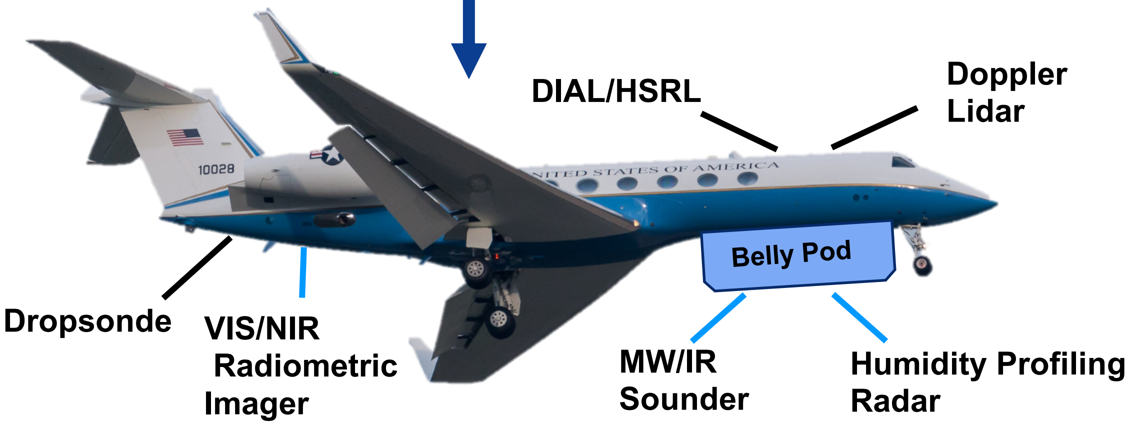
SCIENCE			MEASUREMENT	
Societal or Science Question/Goal	Earth Science/Application Objective	Science/Application Importance	Geophysical Observable	Measurement Parameters
QUESTION W-1. **Planetary Boundary Layer Dynamics.** What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean and sea ice) exchanges of energy, momentum, and mass, and how do these impact weather forecasts and air quality simulations?	W-1a. Determine the effects of key boundary layer processes on weather, hydrological, and air quality forecasts at minutes to subseasonal time scales.	**Most Important**	3D temperature in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 0.3 K/0.3 K
			3D humidity in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 0.3 g/kg
			3D horizontal wind vector in PBL	Horizontal resolution 20 km, vertical resolution 0.2 km, temporal resolution 3 hr, 1 m/s
			3D PM component and trace gas (ozone, NO_2) concentrations	Horizontal resolution 5 km, vertical resolution 0.2 km, temporal resolution 2 hr
			2D PBL height	Horizontal resolution 20 km, temporal resolution 3 hr, 0.1 km
			2D PBL cloud LWP	Horizontal resolution 20 km, 20%
			2D cloud base	Horizontal resolution 20 km, 0.1 km
			2D precipitation	Horizontal resolution 10 km, 20%

Practical Considerations – Remote Sensing

- NASA Decadal Survey places a strong emphasis on the coupling between PBL, clouds, and large-scale circulation
  - A ‘PBL’ focused remote sensing payload would also have broad applicability to weather focused research regimes across scales
- A future NASA airborne platform in support of atmospheric physics and dynamics would require:
  - 10+ hour endurance with ceiling >45kft
  - ≥ 4 nadir portals to enable synergetic observations atmospheric state, dynamics, and composition
    - Optical pressure barriers for lidars, unpressurized portals (‘doghouse’) for radars and sounders, unobstructed hemispherical view (polarimeter, scanning systems), FOD shutters
  - >2 zenith portals for radiation (aerosols, broadband flux) and UT/LS observations – unobstructed hemispherical view
  - Easy access is critical for for new instruments and mentoring early career scientist through hands on experiences
  - Access to navigator station for real-time mission optimization



-GV currently supports two remote sensors (tight fit)
-A belly pod would enable additional sounders/radar



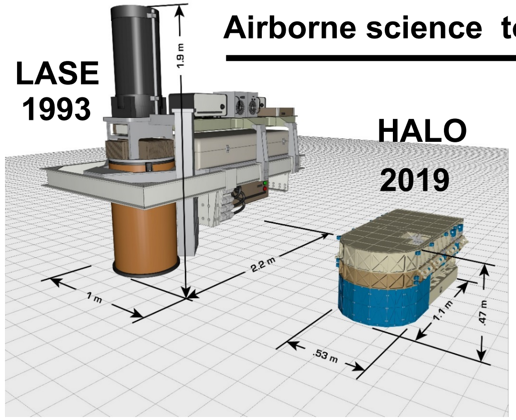
Practical Considerations – In Situ Sampling

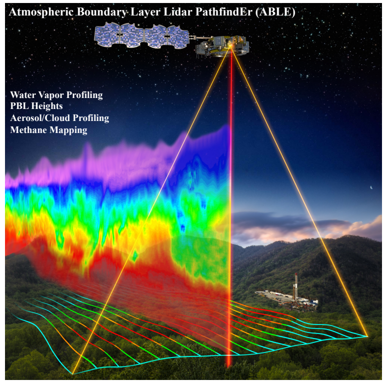
- Although weather and dynamics primarily focus on remote sensing, in situ observations are becoming more important for constraining model physics
- Dedicated in situ aircraft is ideal for improved/coordinated sampling (e.g. ACTIVATE sampling strategy), but not always practical for remote locations (e.g. remote oceans, high/low latitudes)
- In situ payload should include (in addition to remote sensing suite) but not limited to:
  - Fast T,q, U,V
  - Aerosol optical properties
  - Cloud microphysics
  - Cloud water
  - Composition (atmospheric tracers and chemistry, AQ)
  - Dropsonde
- Practical considerations
  - Enough probe locations after considering remote sensing payload
  - Utilizing windows for probes minimizes cost of aircraft modifications
    - Not possible with above wing jet engines
    - Dynamics of aircraft boundary layer needs to be considered when positioning probes
  - Pylons for cloud probes
  - Easy access is critical for for new/mature instruments instruments (swapping filters/samples, optimizing flow, troubleshooting..etc.) and mentoring early career scientist through hands on experiences

Opportunities – Enabling the next generation technologies & scientists

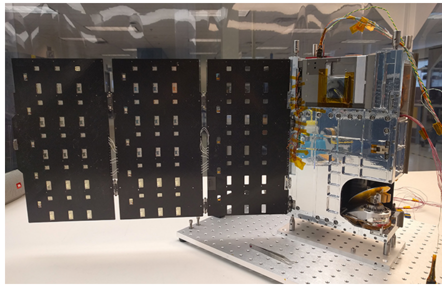
- Large platforms such as the DC-8 have served as the catalyst/incubator for developing the next generation of atmospheric scientists
- Opportunities for students to engage with mentors/science teams during field deployments is critical
- Flights of opportunity important for future space missions and future airborne workhorse instruments

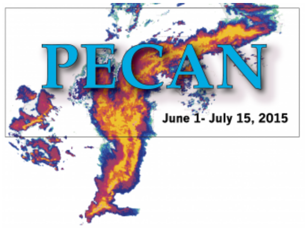
Airborne science to Flight

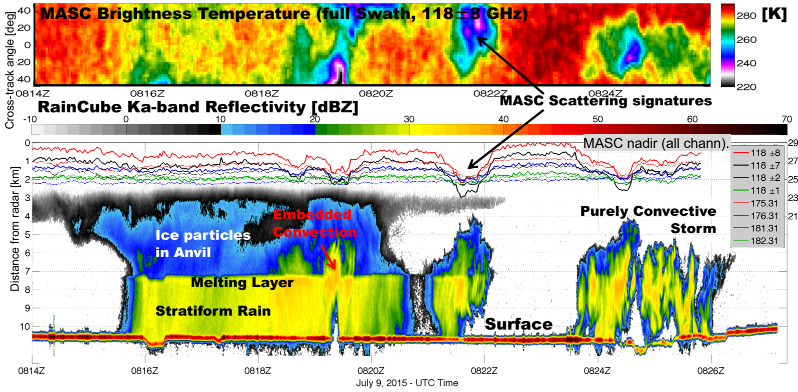




Tempest-D Cubesat Mission



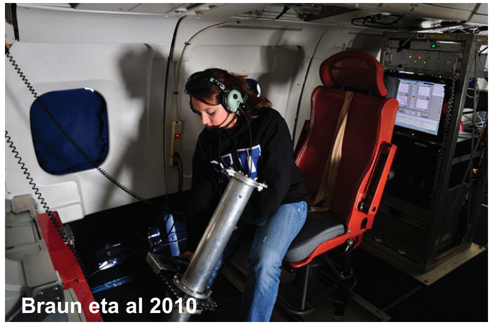


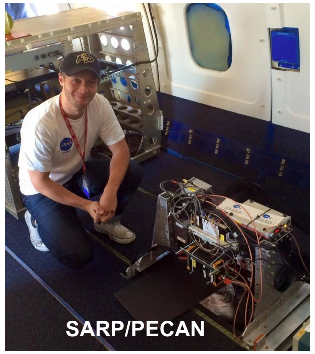


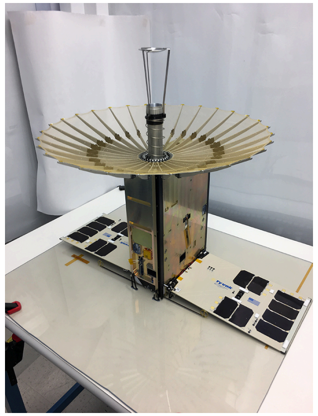
MASC

Tech Demo

RainCube







RainCube Mission