Scientific Utilization of Millimeter- and Submillimeter-Wave Spectrum

Ian S. Adams

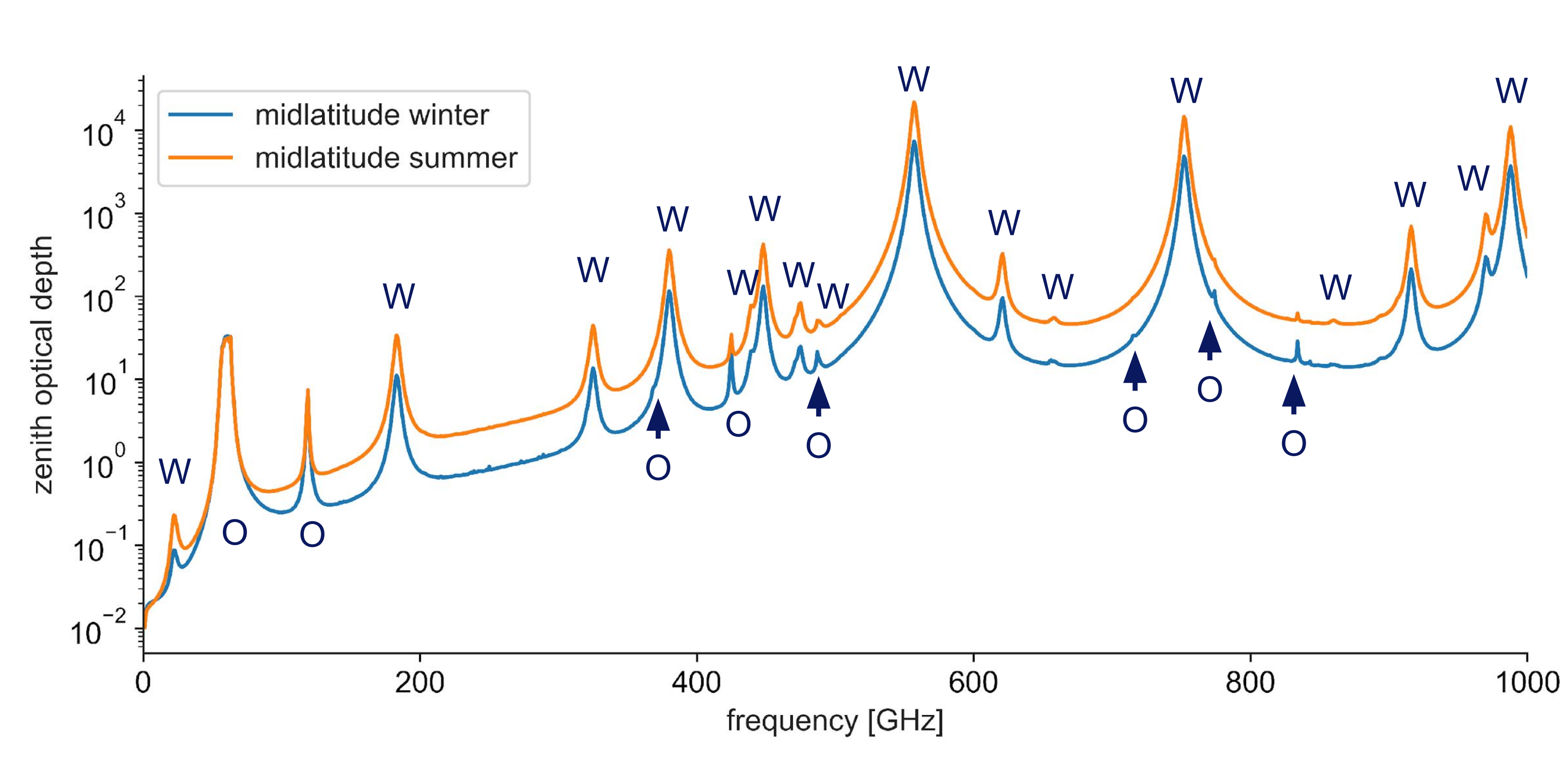
NASA Goddard Space Flight Center

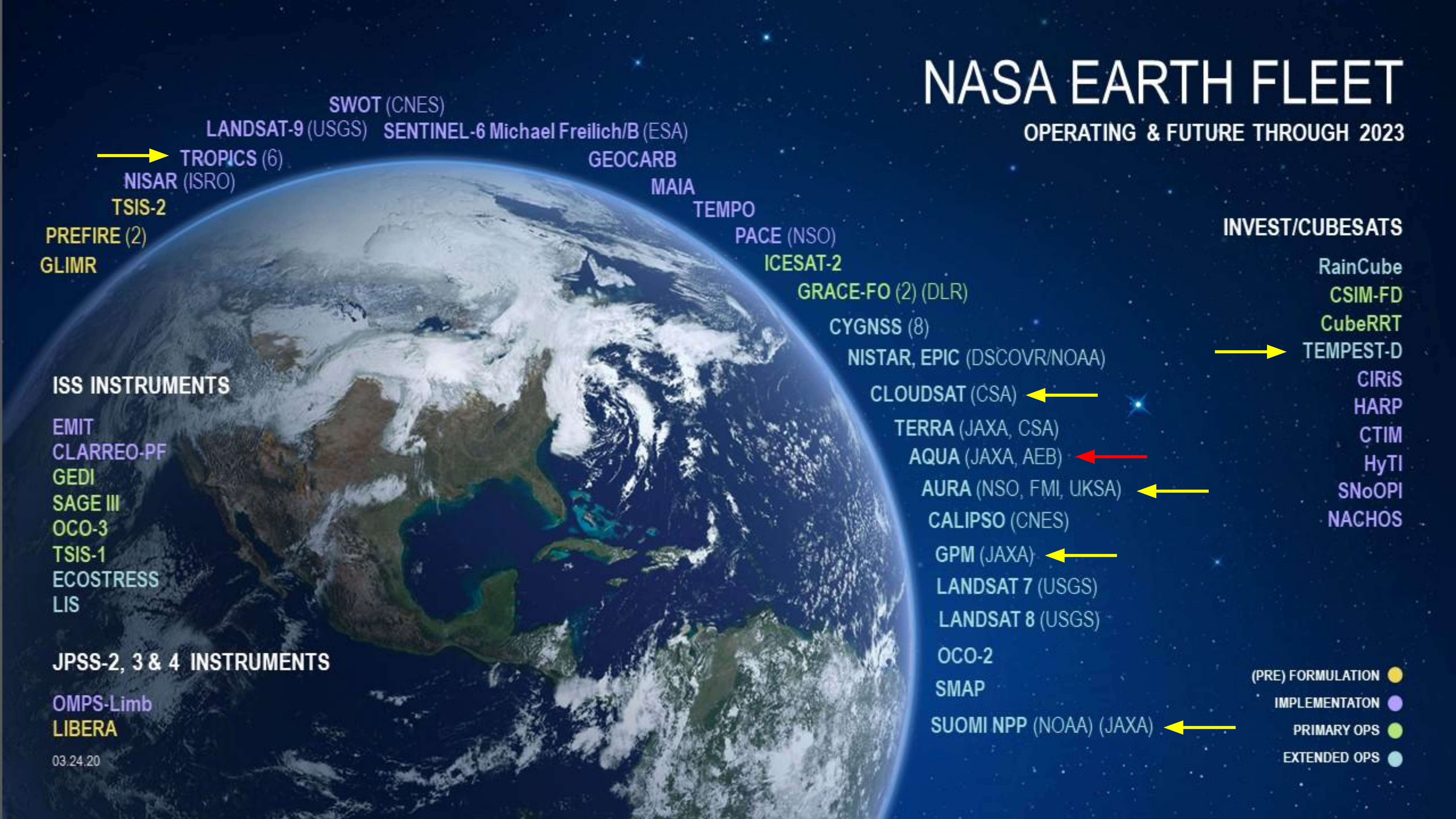
Contributors

- Scott Braun, NASA GSFC
- Matthew Lebsock, JPL
- Nathaniel Livesey, JPL
- Raquel Rodriguez Monje, JPL
- Lisa Milani, University of Maryland
- S. Joseph Munchak, NASA GSFC
- Steven Reising, Colorado State University

Overview

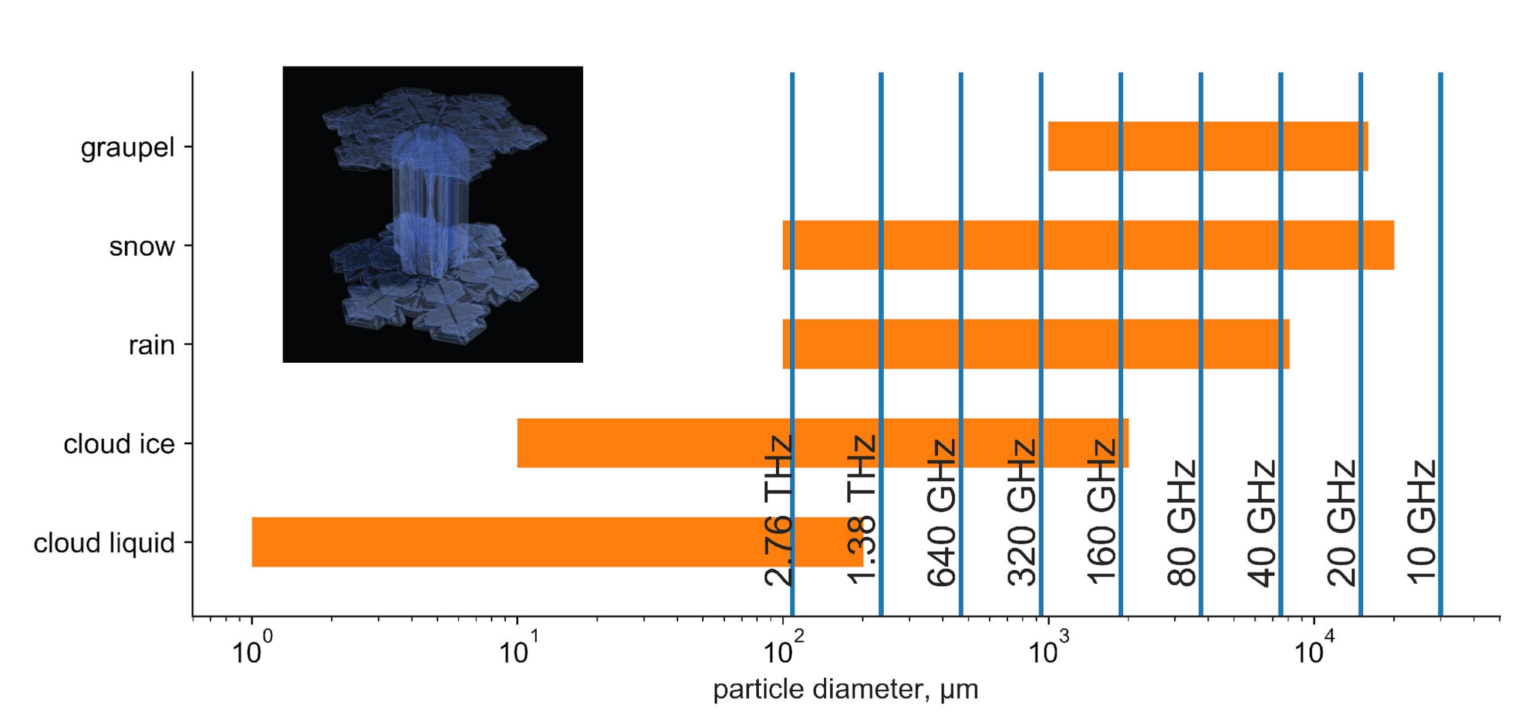
The Earth Science community has a rich history of using radio spectrum above 70 GHz. As with other users of the spectrum, the Earth Science community is increasingly bridging the gap between microwave and infrared. The accelerated use of higher frequencies has been enabled by smaller, more efficient components and subsystems.





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) (DLR)
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) (JAXA)
ISS INSTRUMENTS
EMIT
CLARREO-PF
GEDI
SAGE III
OCO-3
TSIS-1
ECOSTRESS
LIS
JPSS-2, 3 & 4 INSTRUMENTS
OMPS-Limb
LIBERA
03.24.20
INVEST/CUBESATS
RainCube
CSIM-FD
CubeRRT
TEMPEST-D
CIRiS
HARP
CTIM
HyTI
SNoOPI
NACHOS
(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

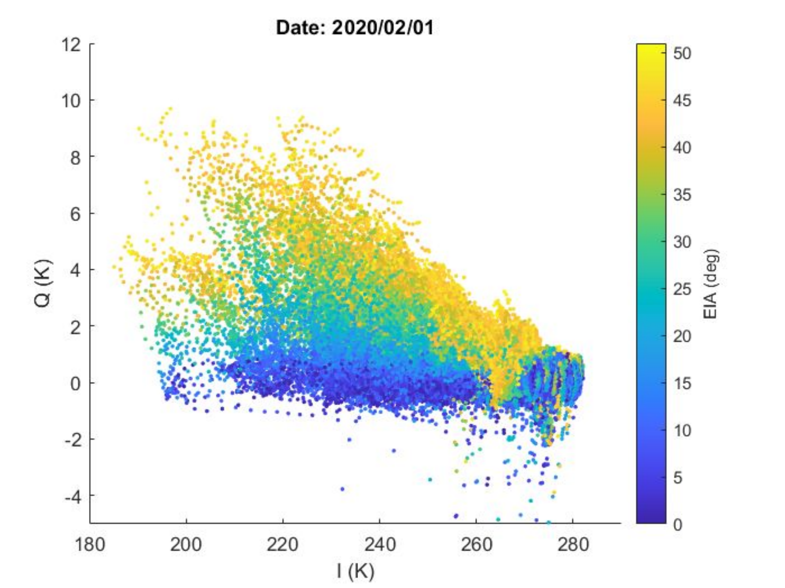
Cloud and Precipitation Sensing

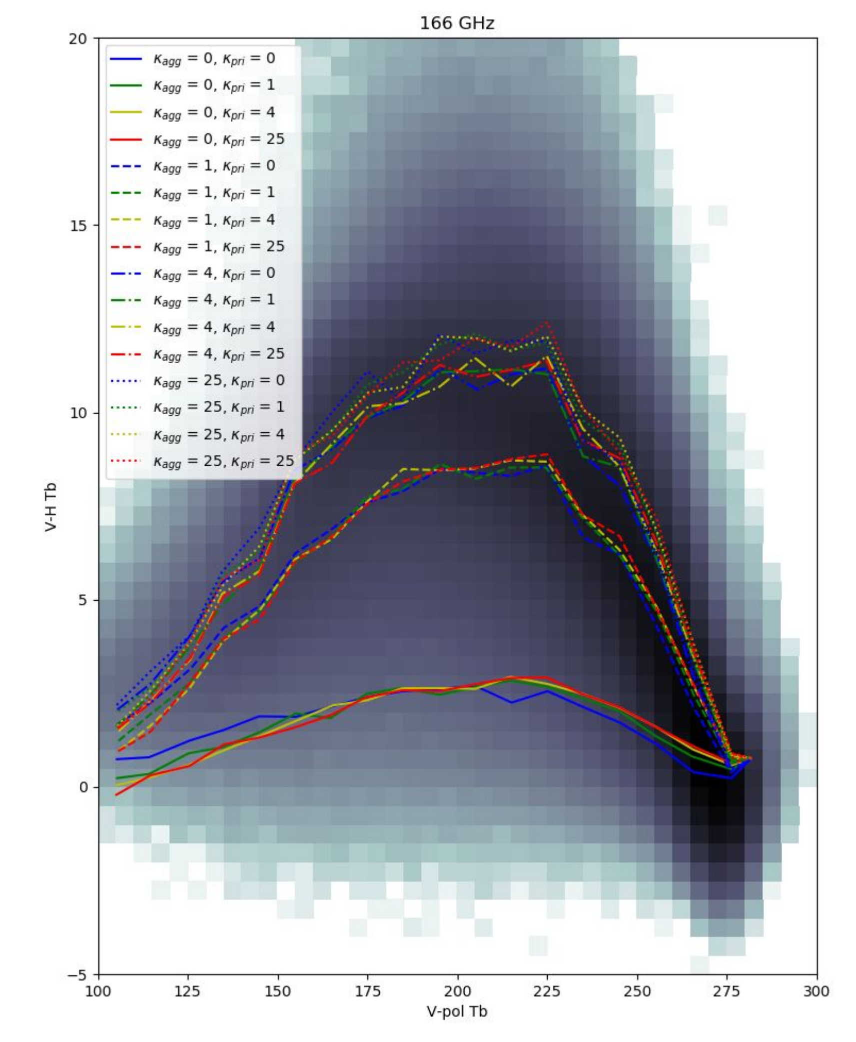


Millimeter and submillimeter wavelengths are on the order of the size of a range of hydrometeors, resulting in size- and shape- dependent responses to populations of cloud and precipitation particles. This spectral regime is particularly important for sensing snow and cloud ice, with extinction of upwelling radiation inducing brightness temperature depressions.

Polarization Linked to Microphysical Properties

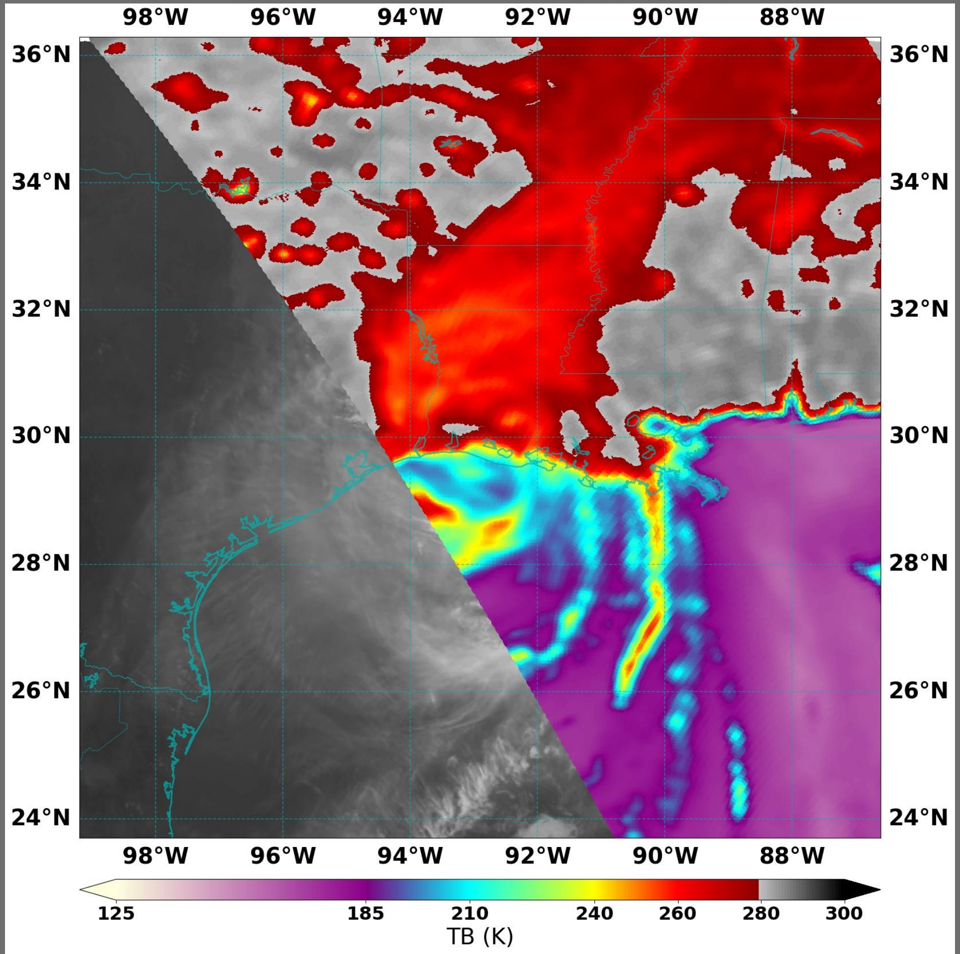
Polarization signatures are dependent on particle orientation, size, and shape. These properties are linked to microphysical processes and radiative forcing.



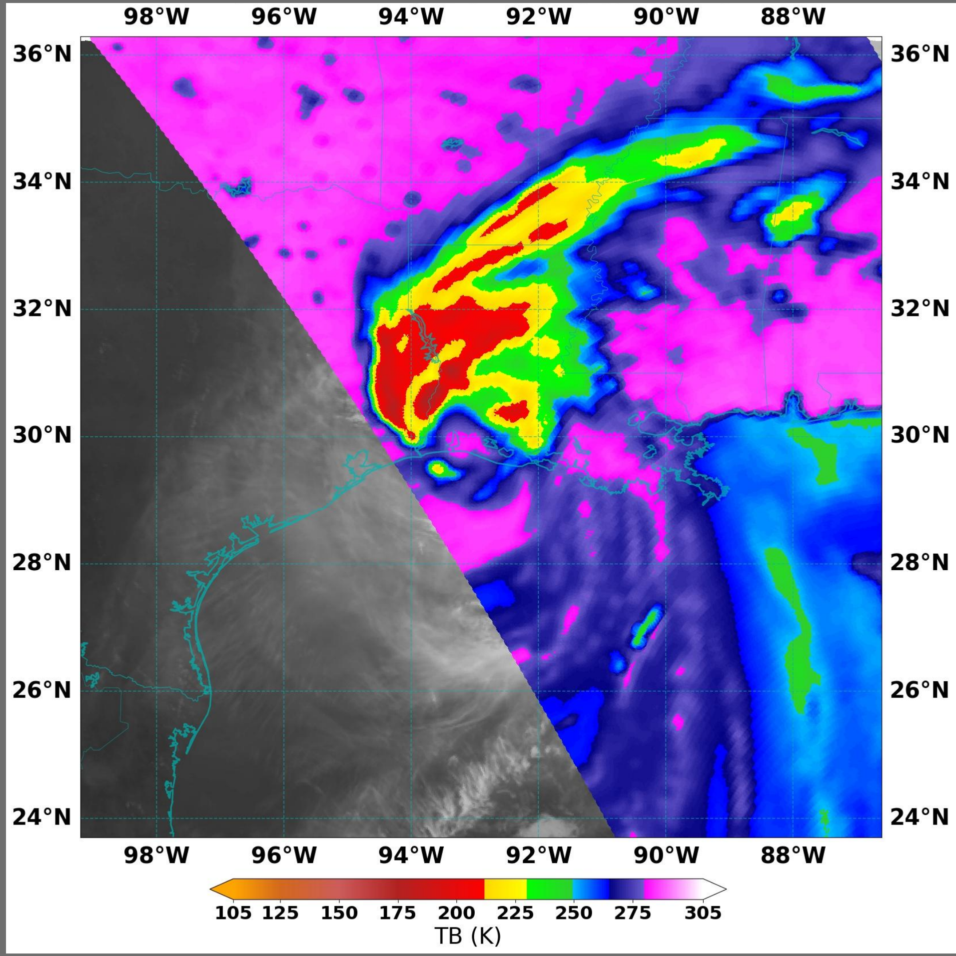


GPM Observes Hurricane Delta

GMI 37 GHz



GMI 89 GHz

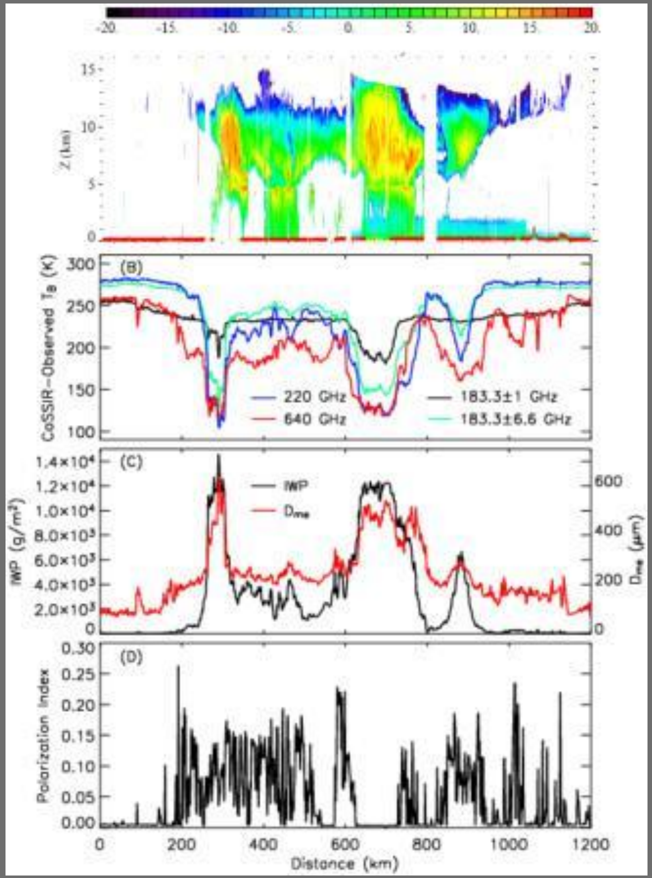


High frequencies are vital for sensing falling precipitation over land. Note the lack of contrast over land at 37 GHz.

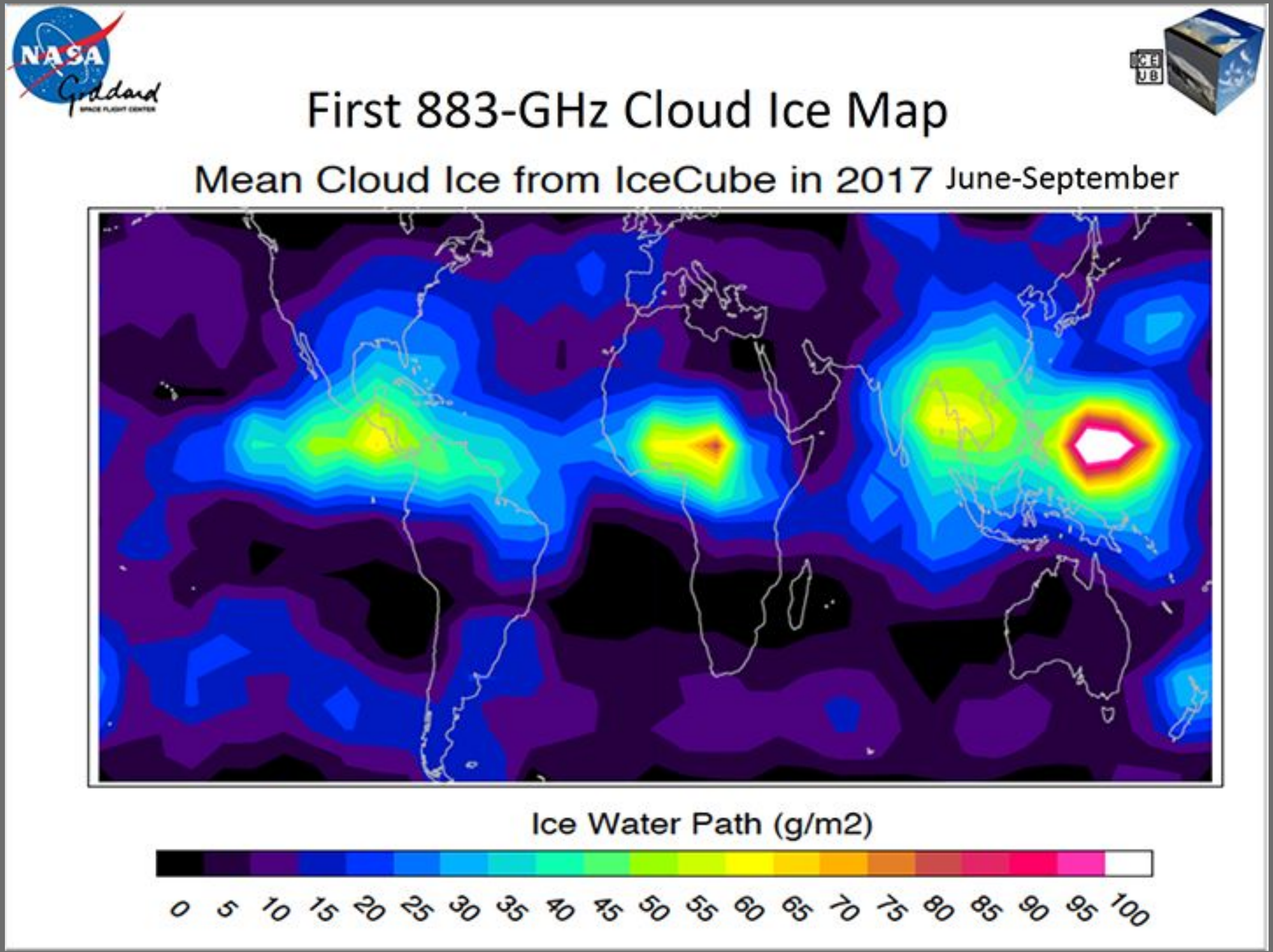
10 October 2020, 2343 UTC

http://www.nrlmry.navy.mil/TC.html

Submillimeter Sensing of Ice Clouds

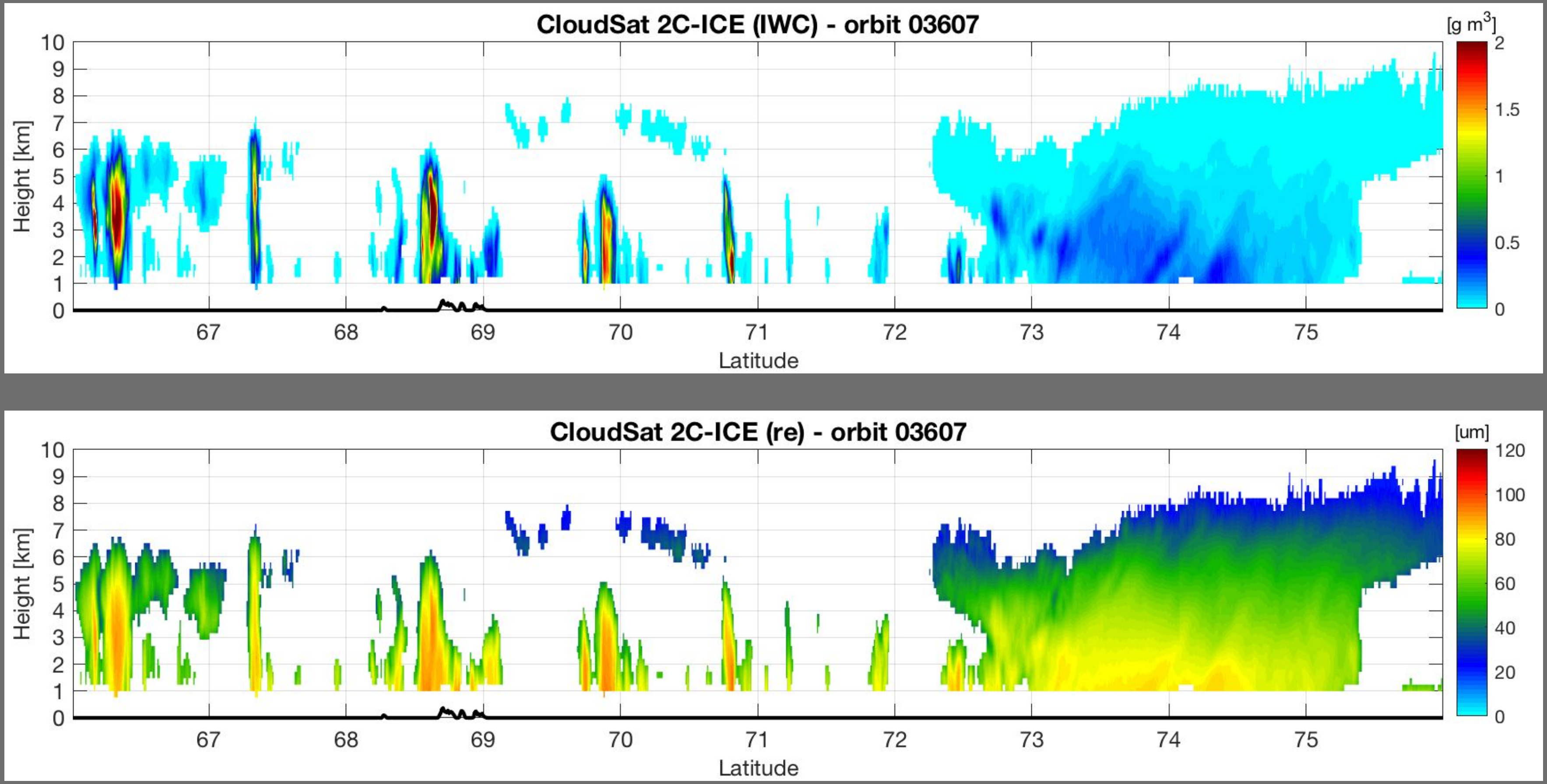


CRS and CoSSIR observations of ice clouds near Costa Rica on 27 January 2006



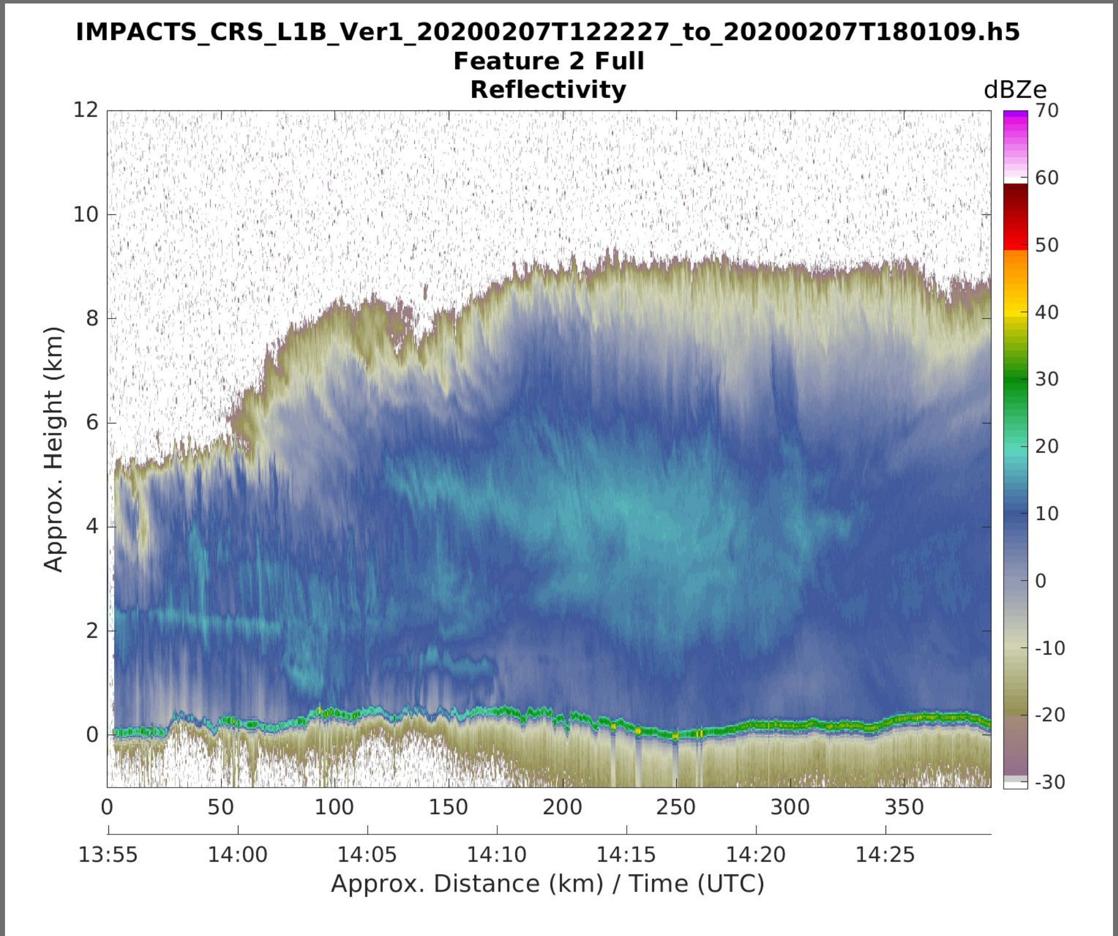
CloudSat: A Cloud Radar in Space

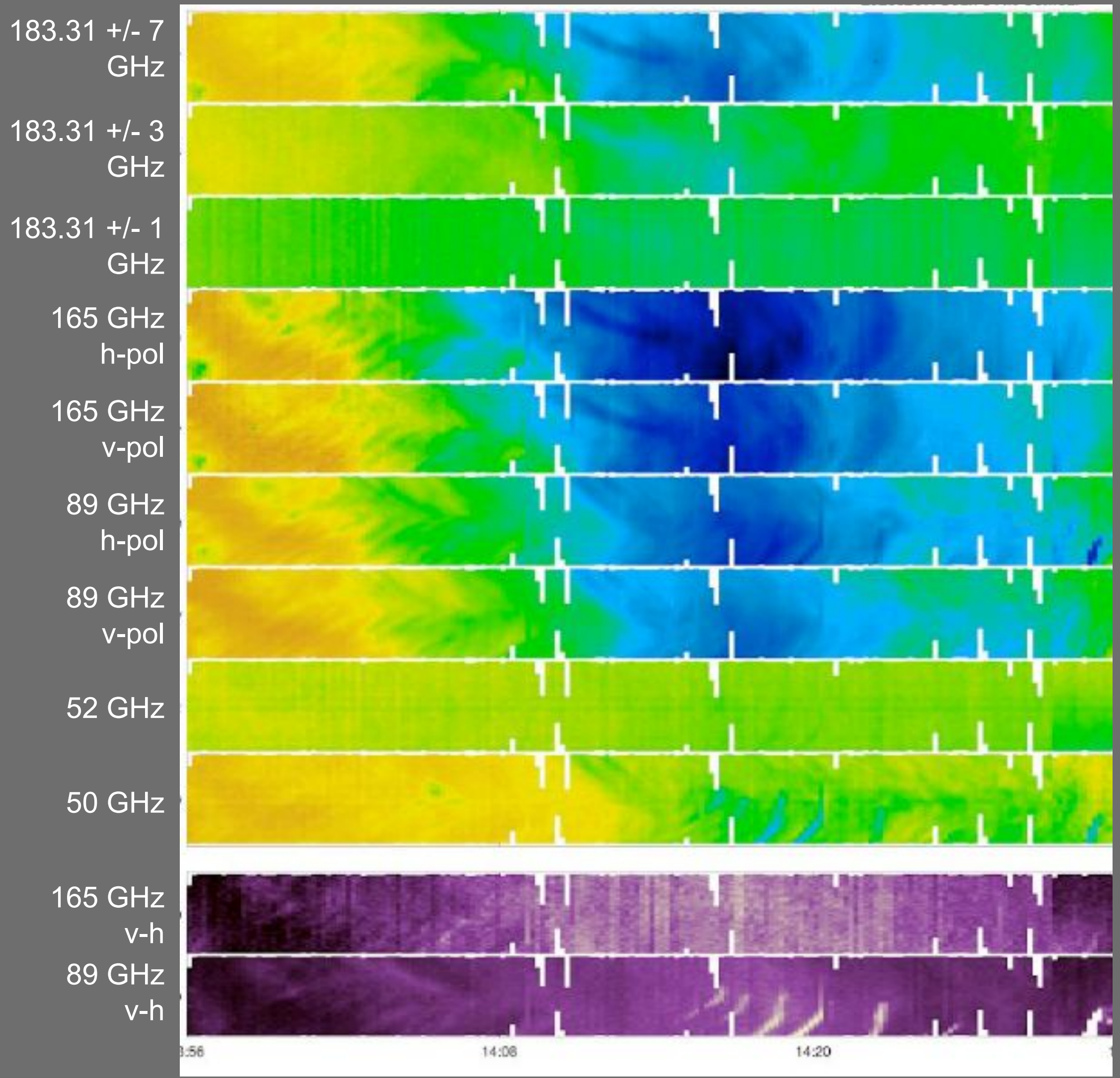
Cloud radars provide high spatial resolution observations of clouds and precipitation features with high sensitivity.



Combining Radars and Radiometers for Snowfall

Cloud Radar System (CRS)





Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR)

Clouds and Precipitation Observational Heritage

passive mmWave precipitation sensing

SSM/I
85 GHz

TRMM
85 GHz

SSMIS
91, 157, 183 GHz

GMI
89, 165, 183 GHz

MWI (EUMETSAT)
89, 118, 165, 183 GHz

passive submmWave ice cloud sensing

CoSSIR (airborne)
183, 325, 448, 642/684, 874 GHz

IceCube
883 GHz

ICI (EUMETSAT)
183, 243, 325, 448, 664 GHZ

TWICE/ENTICE*
118, 183, 243, 310, 380, 664 850 GHZ

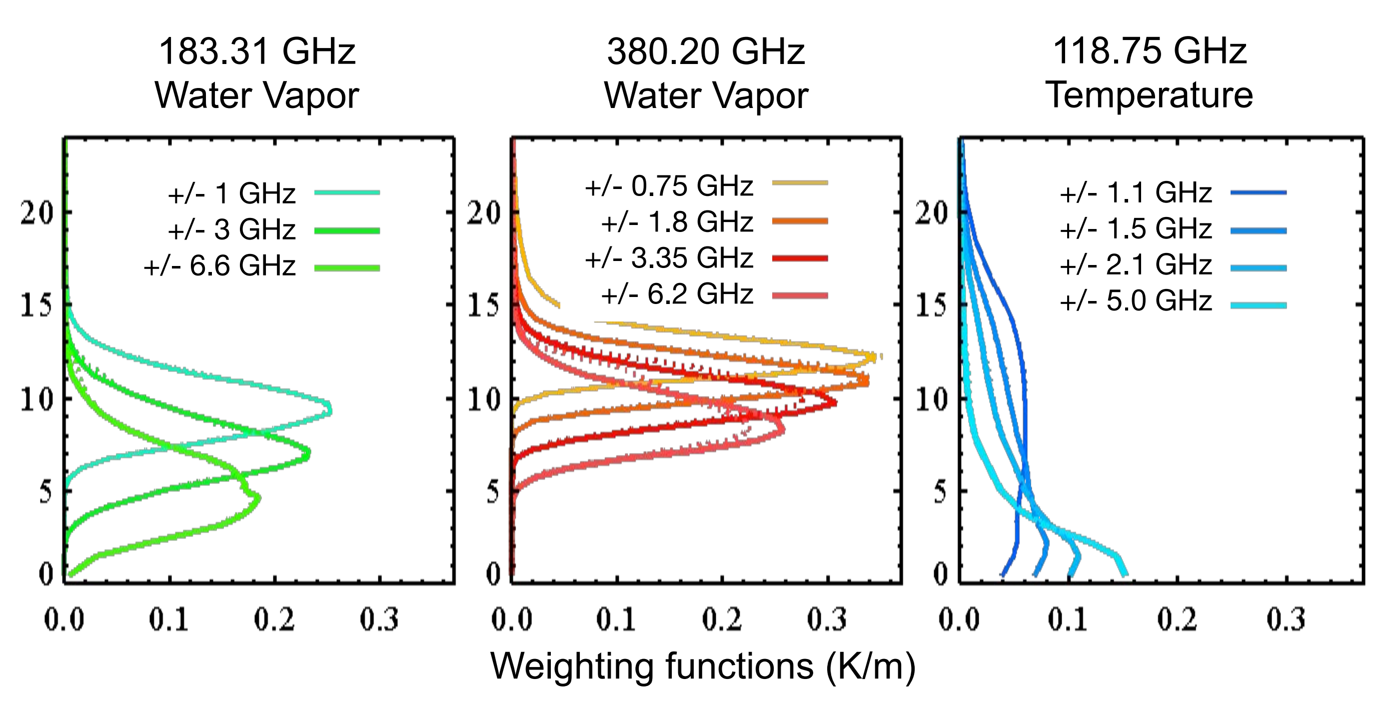
active cloud and precipitation sensing

CloudSat
94 GHz

CloudCube*
94, 238 GHz

Current
Future (*concept)
End of life
Other

Humidity and Temperature/Pressure Sounding



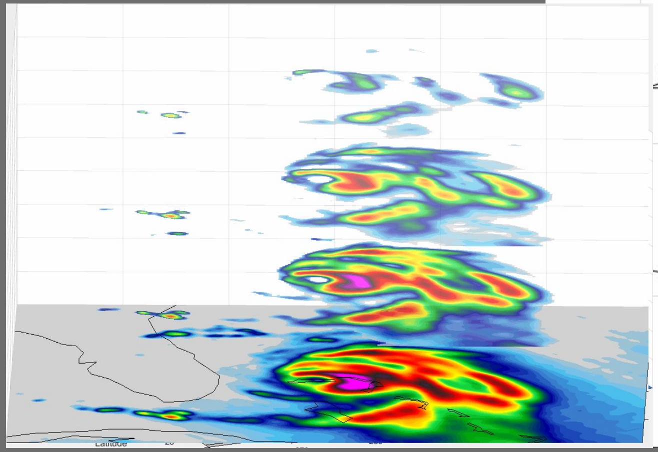
Weighting functions for water vapor and oxygen absorption lines for the Tropospheric Water and Cloud ICE (TWICE) concept.

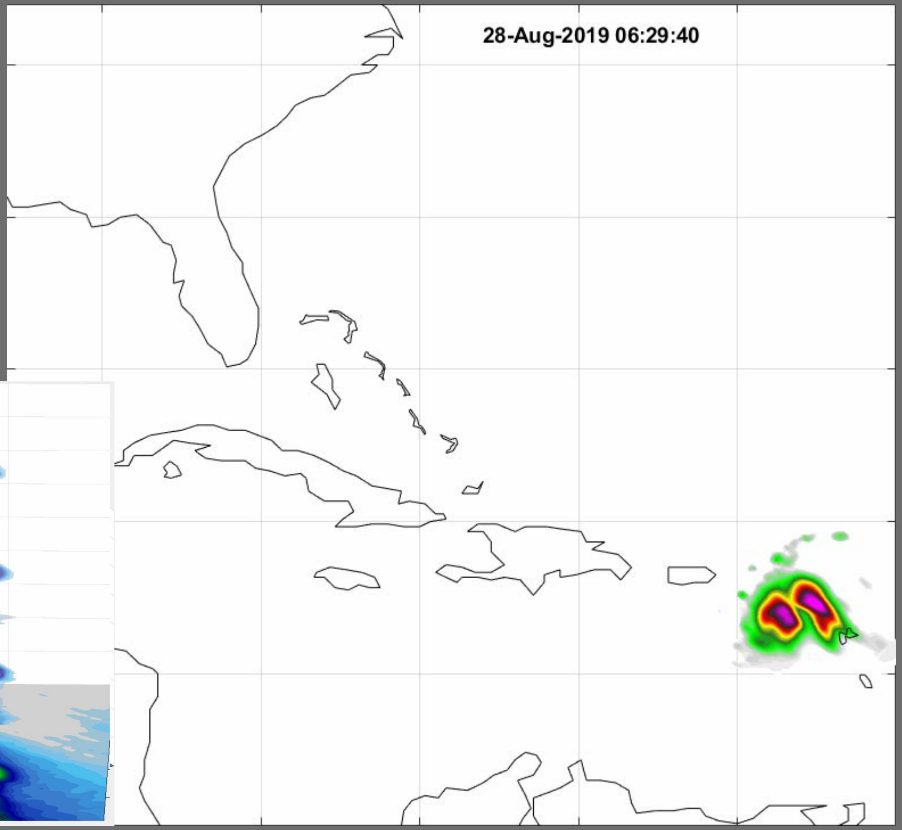
Millimeter- and submillimeter-wave sounders provide vertical profiles of humidity and temperature by sensing near H_2O and O_2 molecular transitions. Sounding data are assimilated for numerical weather prediction (NWP) and used to understand precipitation structure.

Atmospheric Sounding with a CubeSat

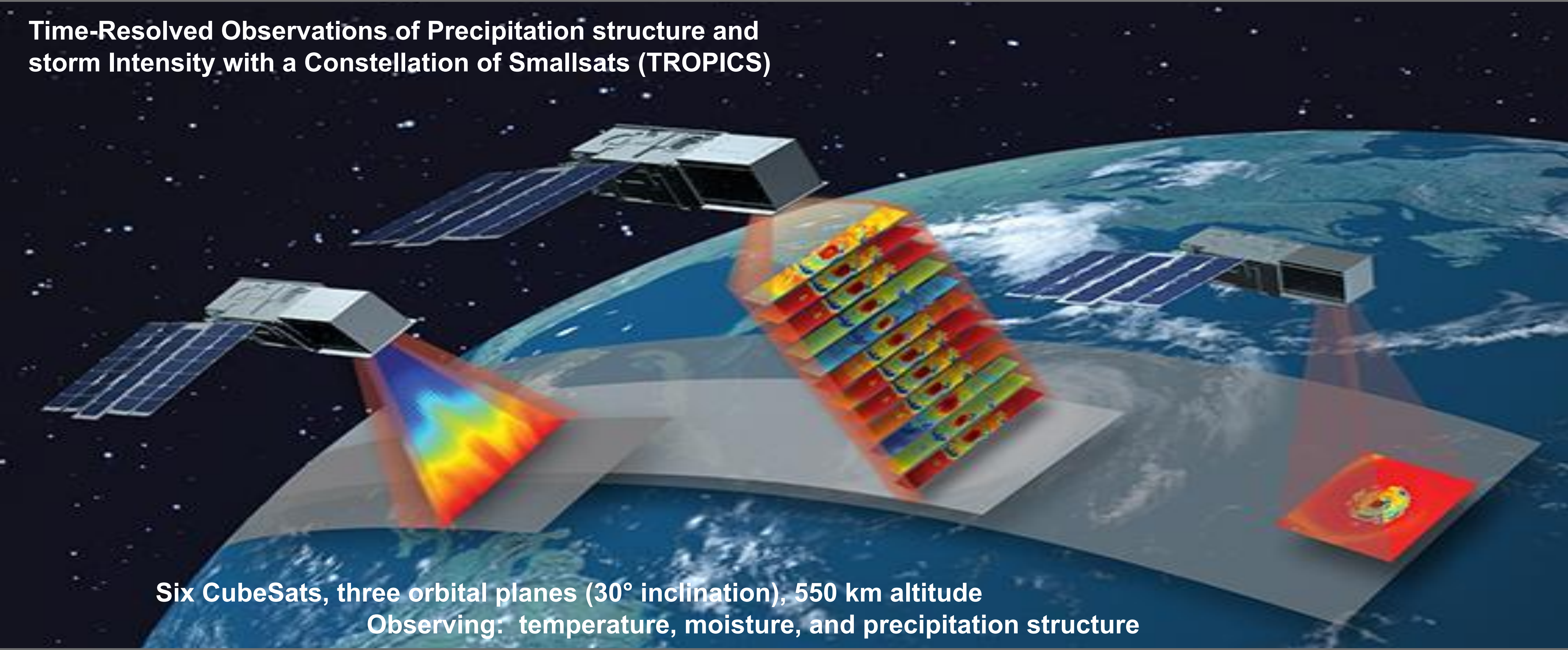
Advances in monolithic microwave circuits (MMICs) are reducing the size and cost of millimeter-wave sounders by providing what amounts to a radiometer on a chip.

TEMPEST-D Observes Hurricane Dorian





CubeSat Architectures Enable Innovative Constellations

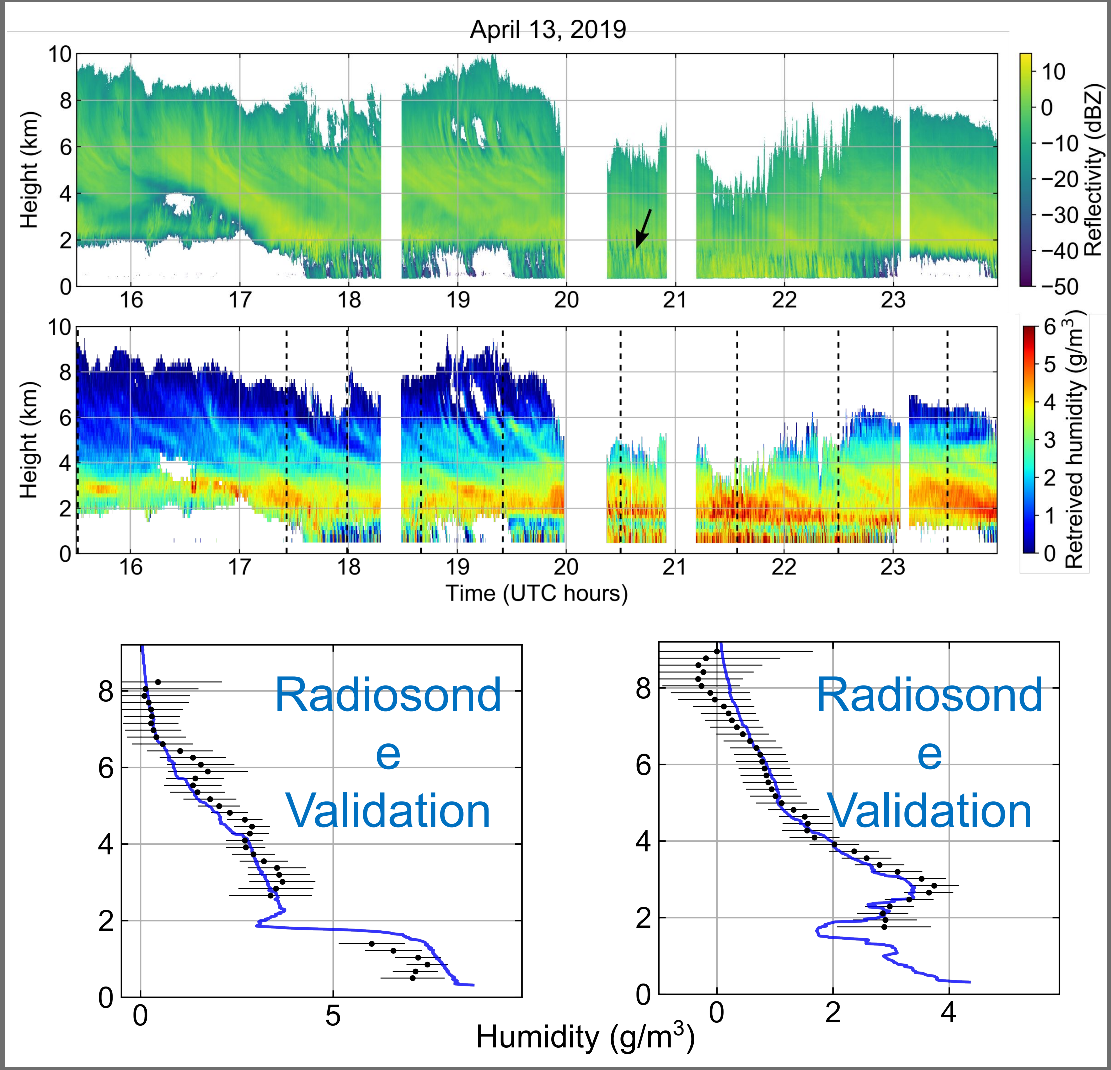


Differential Attenuation Radar

By transmitting multiple tones near a molecular feature, the differential attenuation of the returned signals can be used to infer atmospheric quantities. Proof of concept (VIPR) Vapor In-cloud Profiling Radar Airborne instrument developed at JPL

- 155.5/167/174.8 (100 MHz @ each channel) – operating on temporary experimental license
- ~300 mW continuous wave transmit power
- Spaceborne concept includes 100 W transmit power, 25% duty cycle
- Future interest includes unregulated absorption lines near 325/380 GHz which are optimized for upper tropospheric clouds.

Other concepts use multiple observations between 65 and 71 GHz to infer surface pressure.



Humidity and Temperature Observational Heritage

AMSU-B/HSB/MHS
89,150/157, 183 GHz

TEMPEST-D
87, 164, 174, 181 GHz

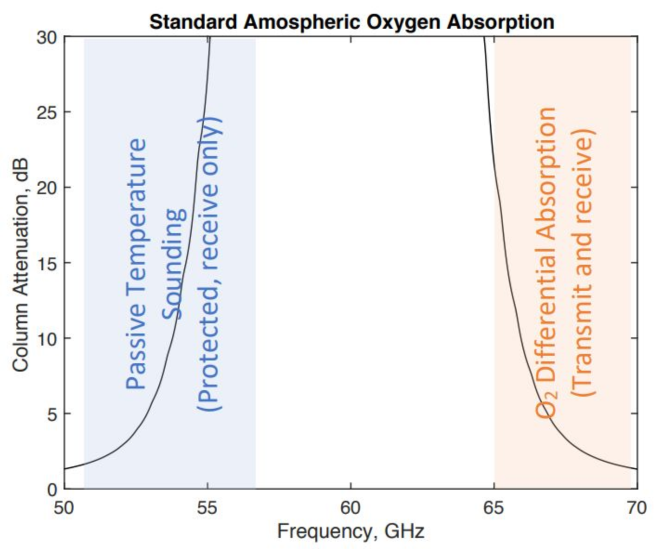
TROPICS
90, 118, 183, 206 GHz

MWS
90, 165, 183, 229 GHz

SSMIS
91, 157, 183 GHz

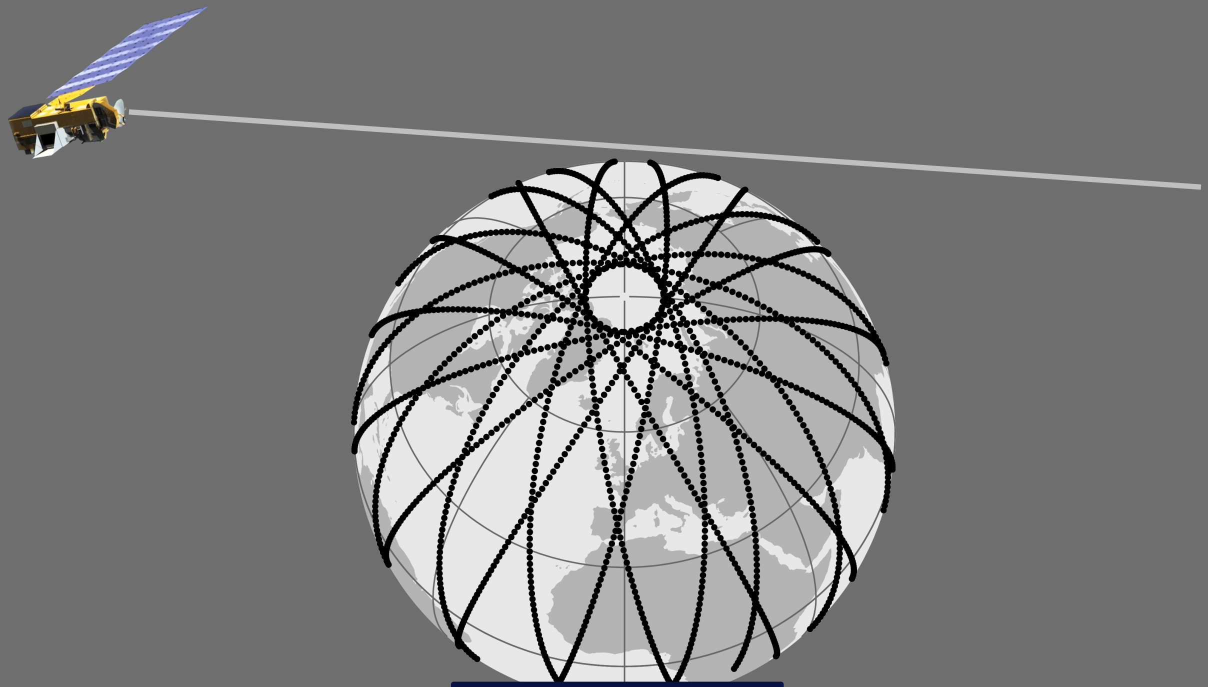
VIPR (airborne)
155.5, 167, 174.8 GHz

Pressure DAR*
65 – 71 GHz



Current
Future (*concept)
End of life

Limb Sounding of the Upper Atmosphere



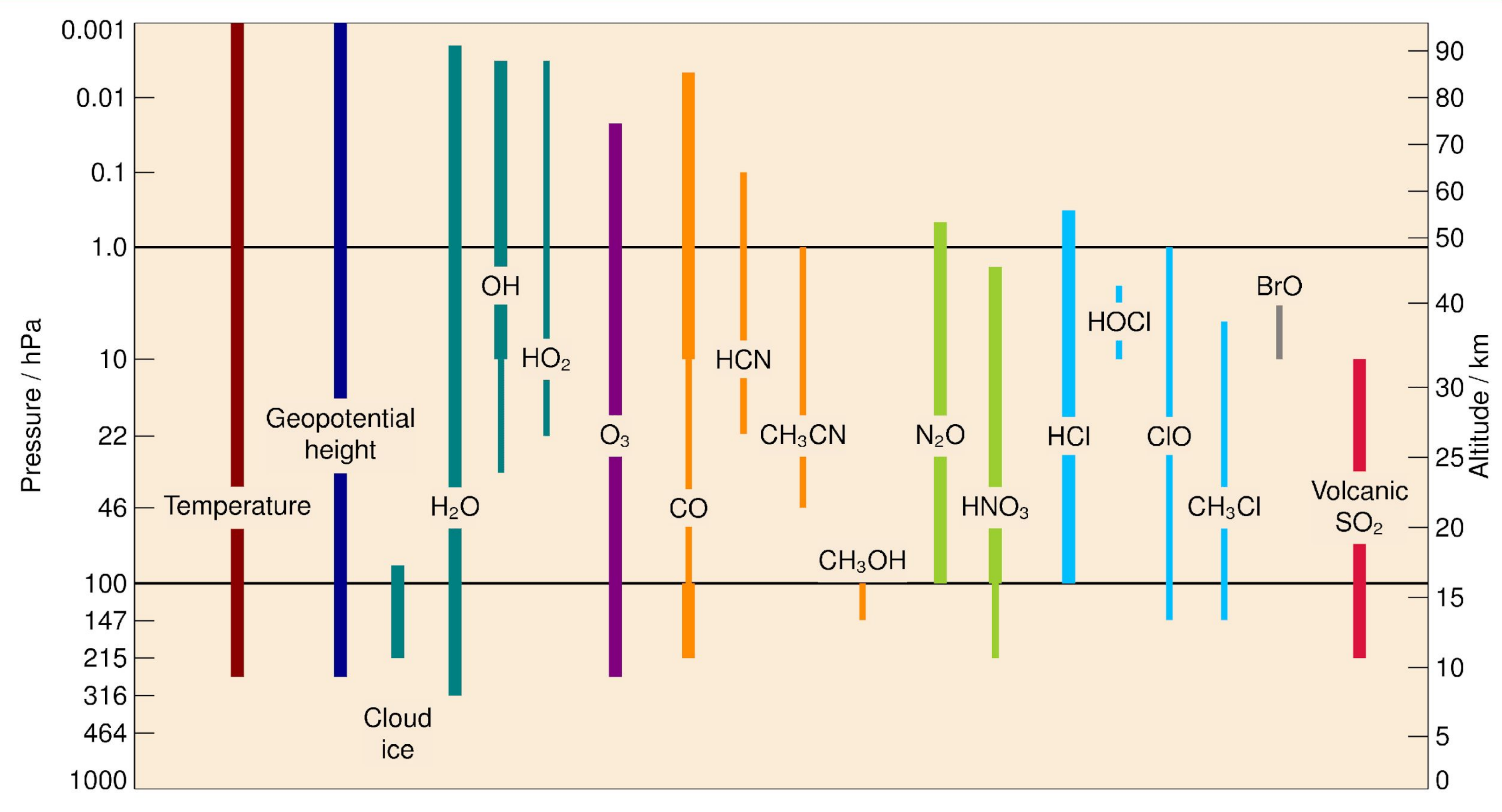
MLS observation locations for a typical day.

With perhaps the longest mmimb sounding of the atmosphere provides superior vertical resolution, compared with nadir sounders, at the expense of horizontal (especially in range) resolution.

The long path lengths do offer one advantage: increased signal strength for sensing tenuous trace gasses.

In addition to upper atmospheric trace gasses, millimeter- and submillimeter-wave limb sounders can measure clouds and volcanic ash.

Microwave Limb Sounder



Frequency	Main objectives
118 GHz	Temperature and pressure (from O_2)
190 GHz	Water vapor, N_2O, and HCN
240 GHz	O_3, CO, HNO_3, and cloud ice
640 GHz	Stratospheric halogens and radicals
2.5 THz	Stratospheric and mesospheric OH

Thinner lines show where the signal to noise is such that averaging (e.g., weekly map, monthly zonal mean, etc.) is typically needed.

MLS Support Essential Ozone Science

MLS observations at ~18 km for 2006, a representative Antarctic winter

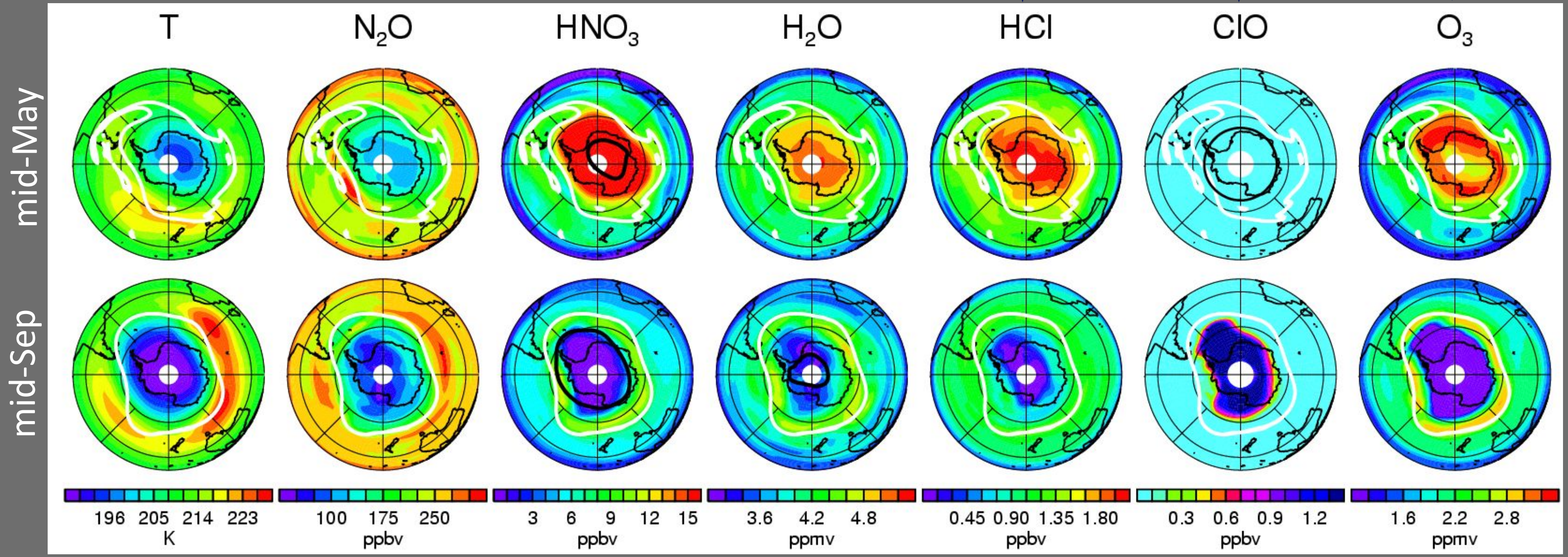
Low temperatures

and descending air

lead to formation of HNO_3 / H_2O clouds.

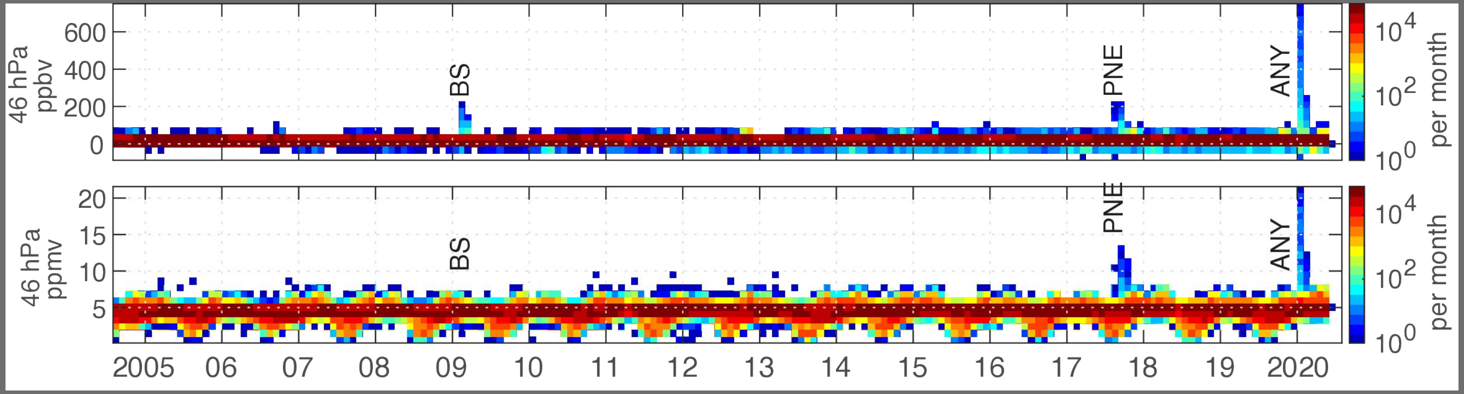
Reactions on the surfaces of these cloud droplets convert chlorine from “safe” HCl into forms that promote ozone destruction, principally ClO,

leading to chemical ozone loss.

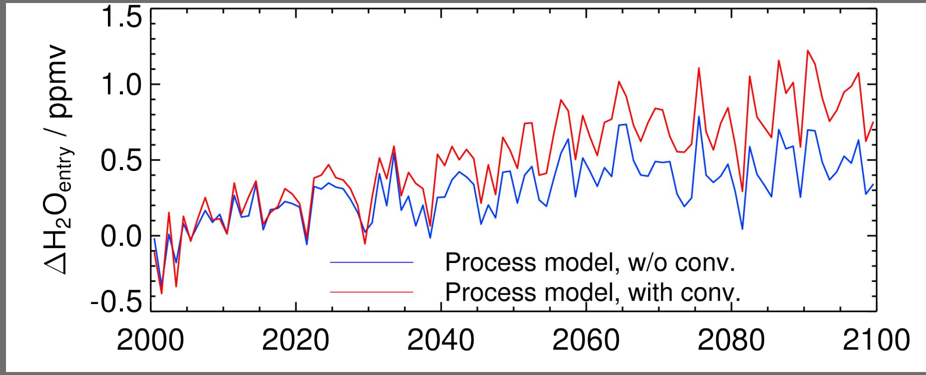


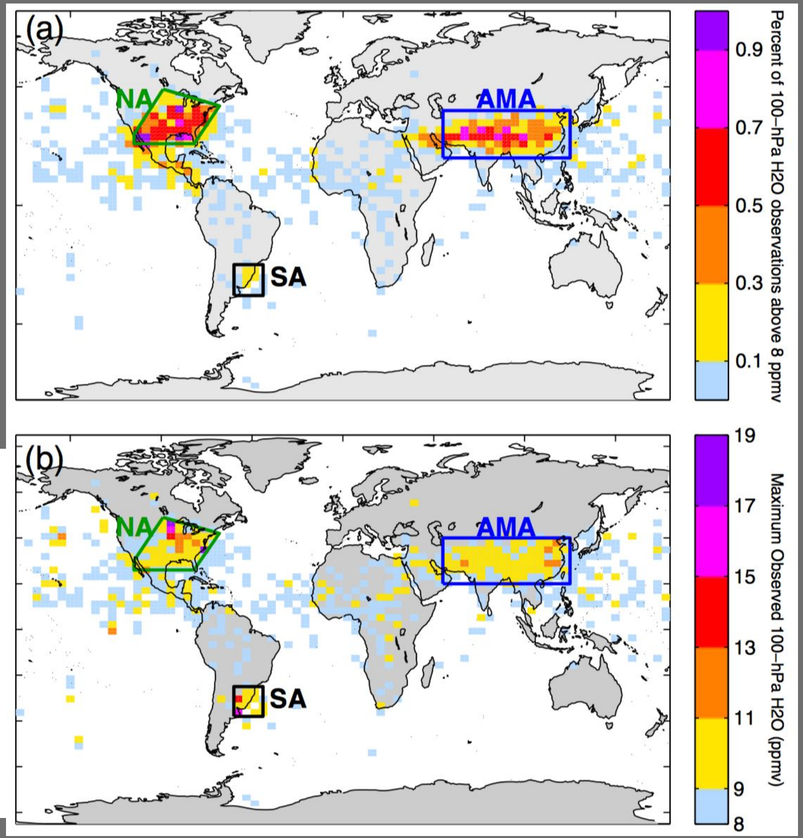
Water Vapor Injection into Lower Stratosphere

Water vapor and carbon monoxide injected into lower stratosphere by Australian wildfires



Water vapor is also injected into the stratosphere by overshooting convection, bypassing the prevailing mechanism for transporting air from troposphere to stratosphere





Limb Sounding Observational Heritage

UARS MLS
63, 183, 205 GHz

ODIN SMR
119, 486-581 GHz

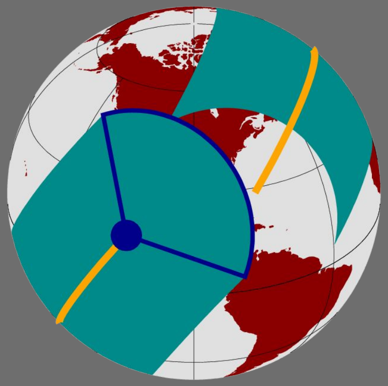
AURA MLS
118, 190, 240, 640, 2500 GHz

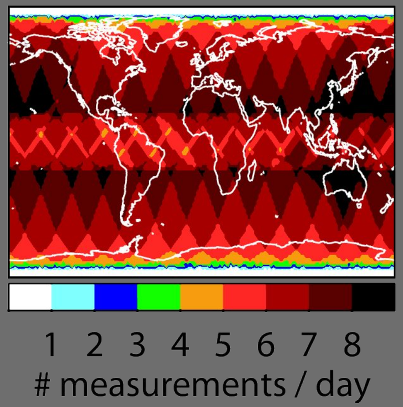
CAMLS*
340, 640 GHz

Scanning

A-SMLS (airborne) → SMLS*

SMLS coverage for a single orbit (left) and during 24 hours (right) in an inclined orbit.





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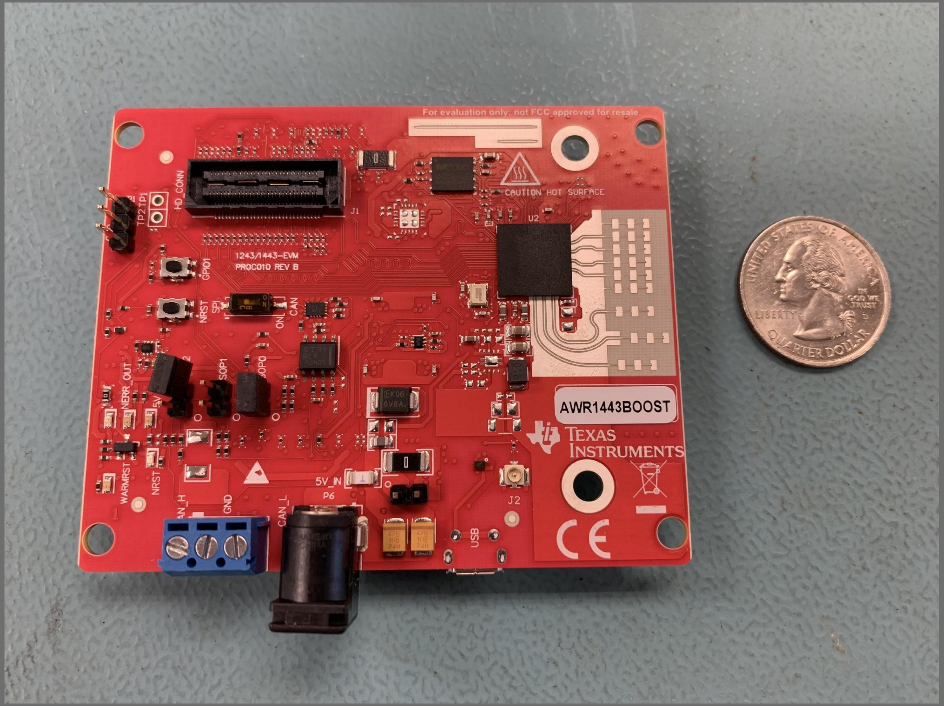
Future (*concept)
End of life

Summary

Millimeter- and submillimeter-wave Earth observational sensors utilize spectrum at 70/80/90 GHz and 95+ GHz for high societal benefit

- Active and passive sensors provide key information on clouds and precipitation for weather observation/forecasting and climate science
- Millimeter-wave sounders are used provide essential data for numerical weather prediction
- Limb sounders track composition and chemistry in the upper atmosphere



Can we use 77-81 GHz automotive radars for Earth Science?