Passive sensing developments of the past decade and future challenges

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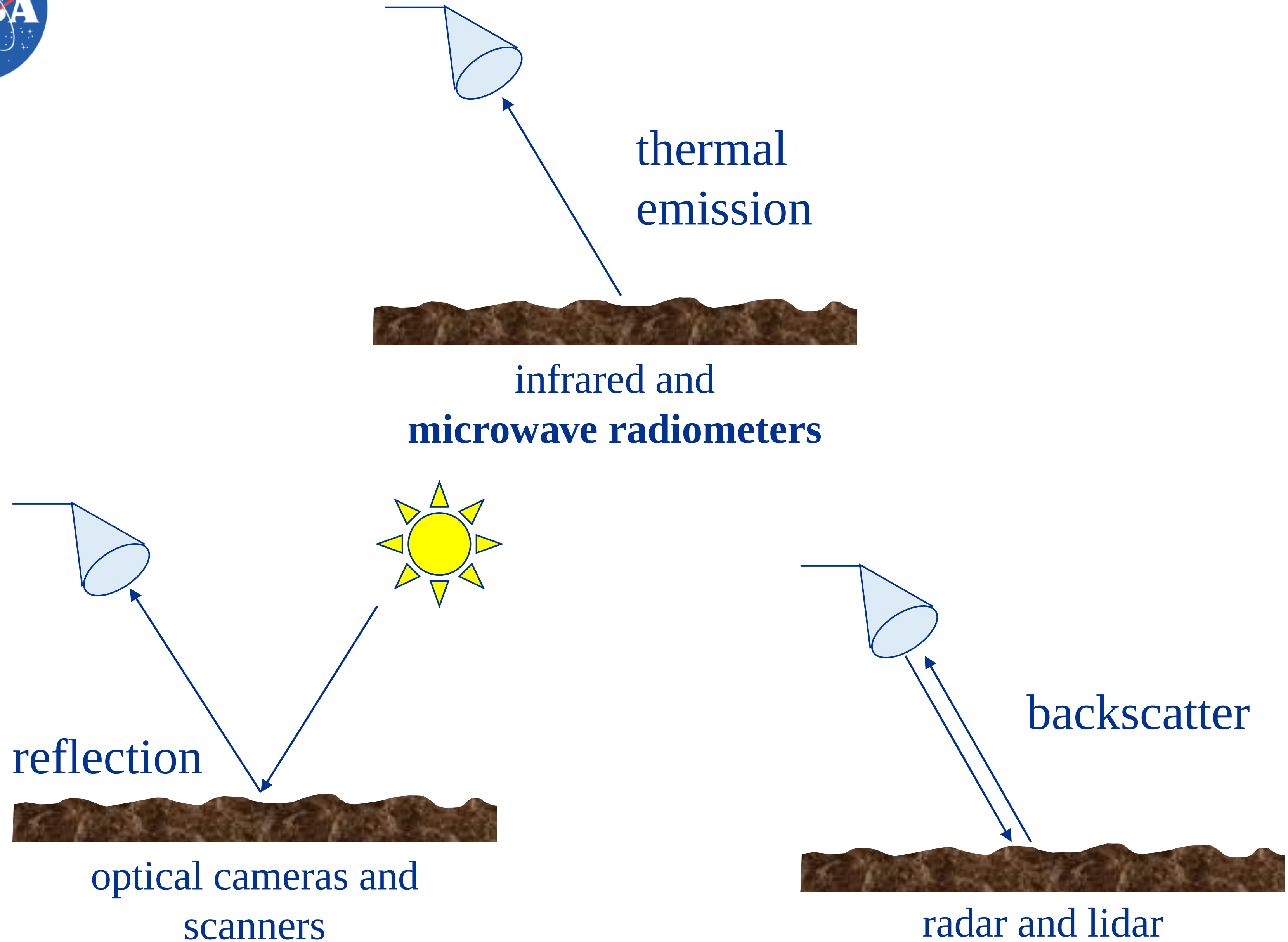
24 October 2017

Outline

- Introduction
- Developments
- Challenges

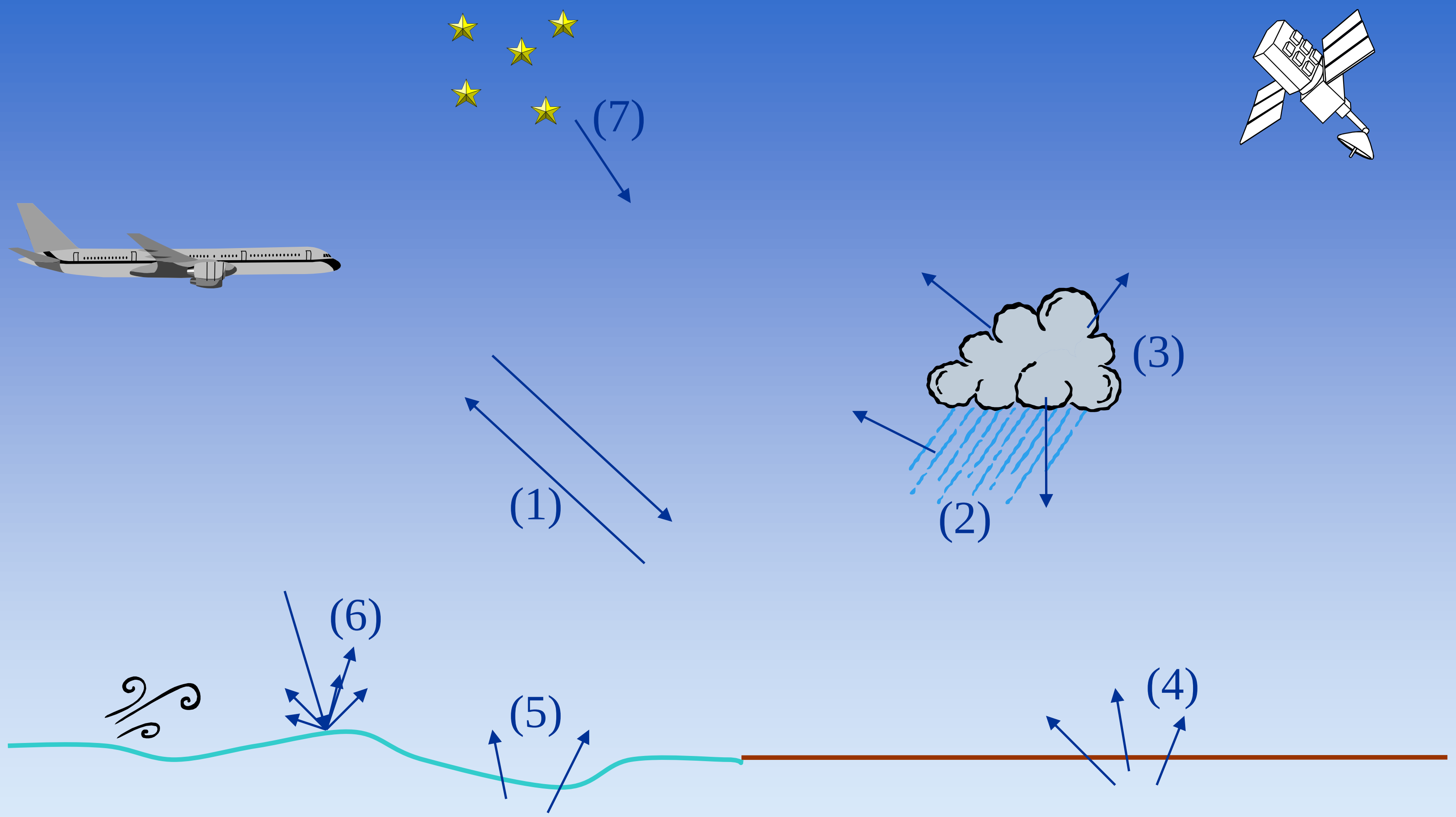
Types of Sensors



Passive sensor operations

- All matter emits, absorbs and scatters electromagnetic energy.
- Passive sensors are *radiometers* which are low noise receivers patterned after radio astronomy instruments.
- Power measured by passive sensors is function of surface composition, physical temperature, surface roughness, and other physical characteristics.

Natural sources of microwave radiation



(1) atmosphere (2) rain (3) clouds
(4) Land (5) oceans (6) scattering
(7) 2.7 K cosmic background

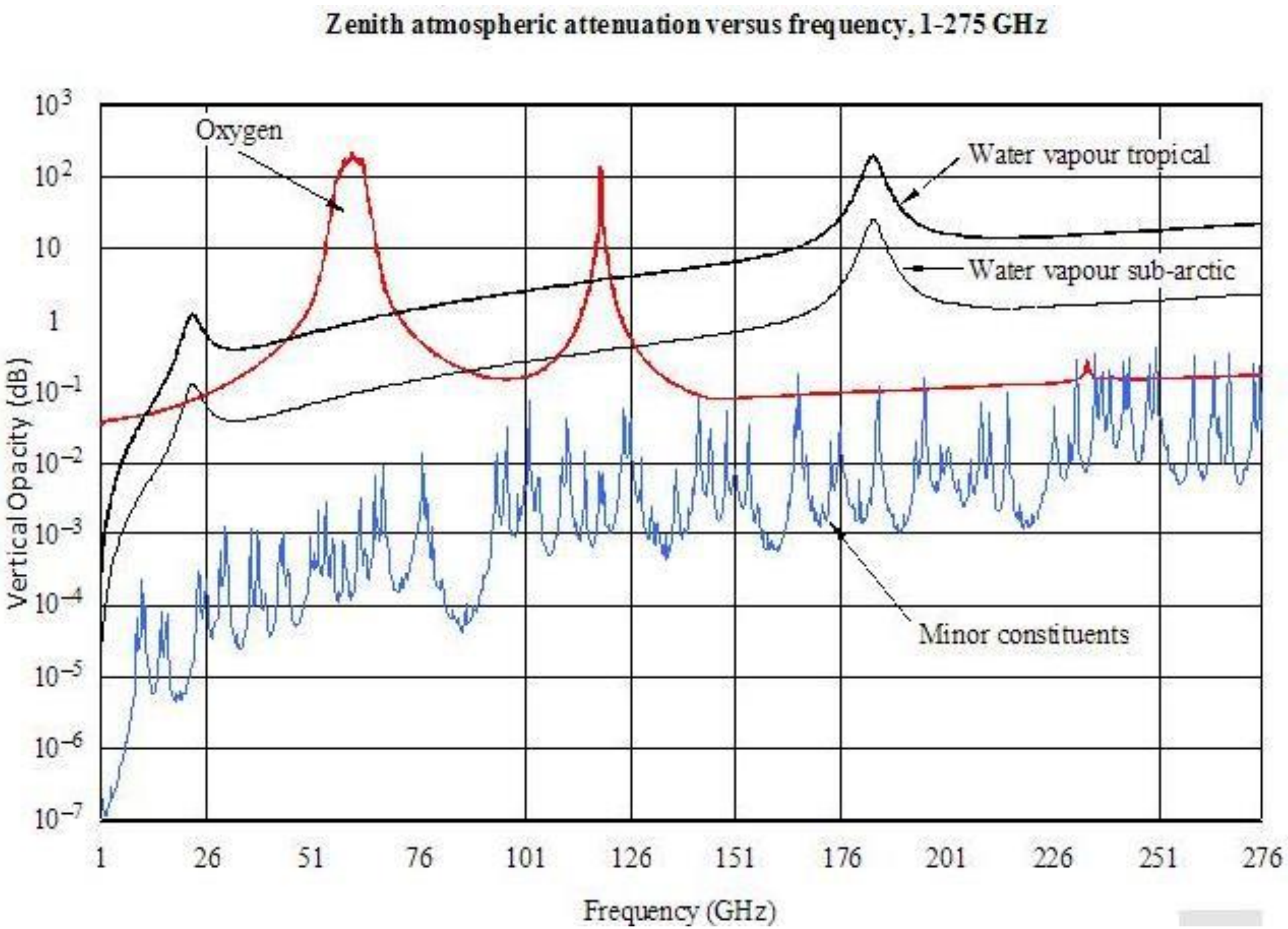
Types of passive microwave sensors

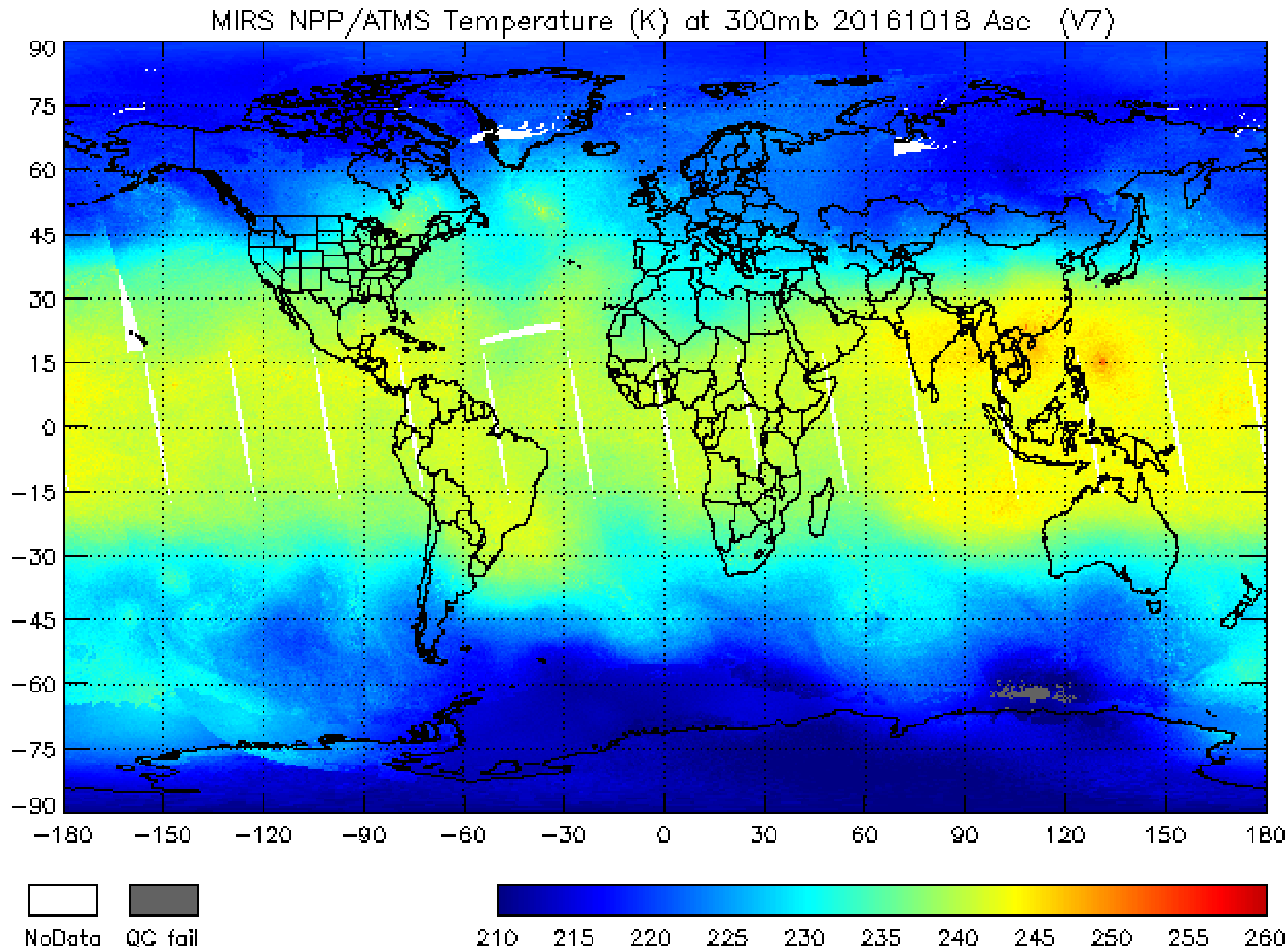
- Imaging sensors
  - Many environmental data products are produced using multivariable algorithms to retrieve a set of geophysical parameters simultaneously from calibrated multi-channel microwave radiometric imagery
- Atmospheric sounding sensors
  - Atmospheric sounding is a measurement of vertical distribution of physical properties of a column of the atmosphere such as pressure, temperature, wind speed, wind direction, liquid water content, ozone concentration, pollution, and other properties
- Microwave limb sounding sensors
  - Limb sounders observe the atmosphere in directions tangential to the atmospheric layers and are used to study low to upper atmosphere regions where the intense photochemistry activities may have a heavy impact on the Earth's climate

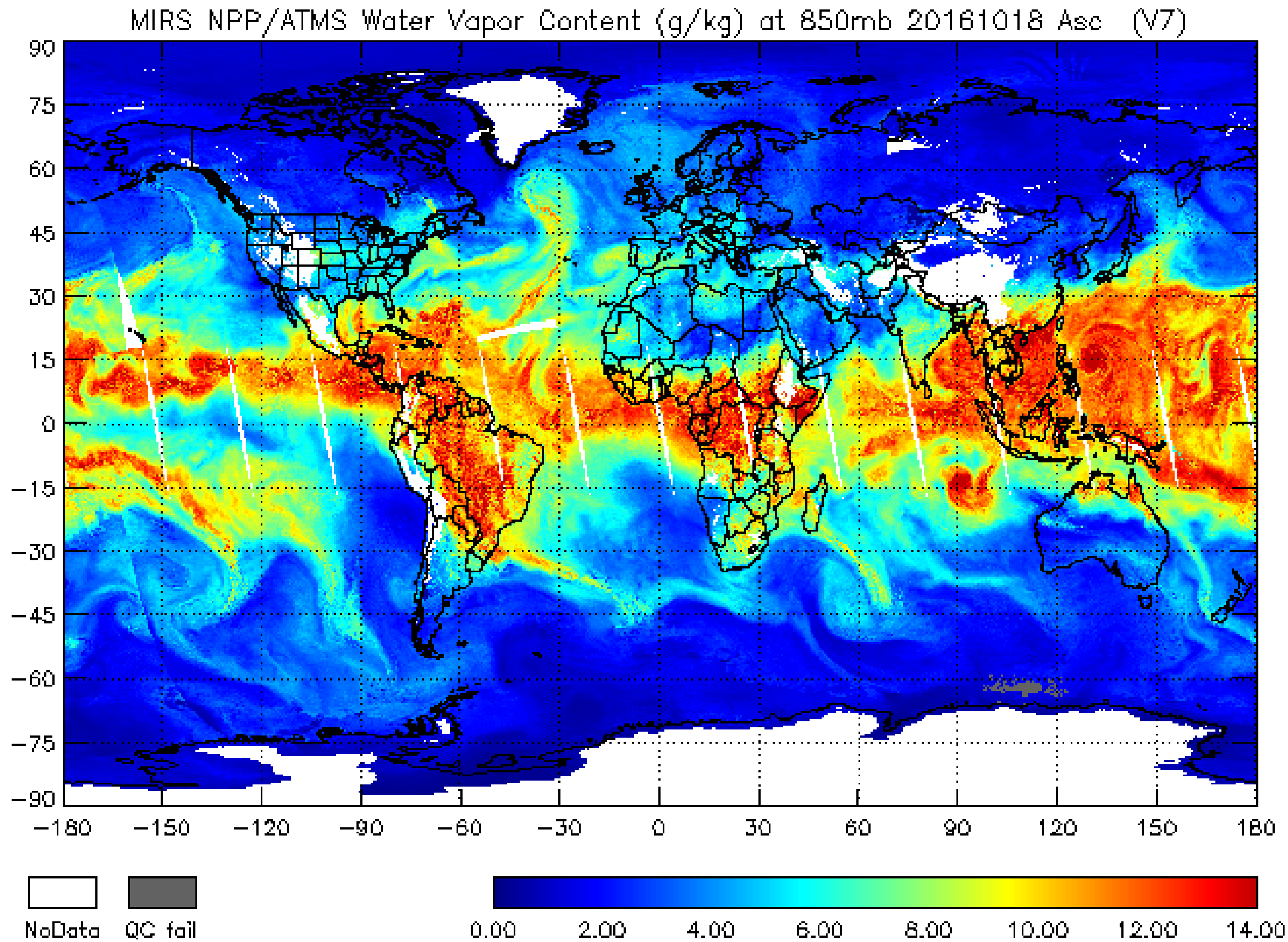
Passive sensor data products (Part 1)

- Measured radiation
  - Occurs naturally
  - Very low power levels
  - Contains essential information on the physical processes
- Radiation peaks indicate presence of specific chemicals
- Absence of radiation from certain frequencies indicates the absorption by atmospheric gases
- Strength or absence of signals at particular frequencies is used to determine whether specific gases are present and, if so, in what quantity and at what locations

Atmospheric attenuation below 275 GHz




MIRS NPP/ATMS Temperature (K) at 300mb 20161018 Asc (V7)
90
75
60
45
30
15
0
−15
−30
−45
−60
−75
−90
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180
NoData
QC fail
210
215
220
225
230
235
240
245
250
255
260


MIRS NPP/ATMS Water Vapor Content (g/kg) at 850mb 20161018 Asc (V7)
90
75
60
45
30
15
0
−15
−30
−45
−60
−75
−90
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180
NoData
QC fail
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00

Passive sensor data products (Part 2)

- Environmental information is obtained through passive sensor measurements
  - Frequency bands determined by fixed physical properties (molecular resonance)
  - Frequencies do not change
  - Information cannot be duplicated in other frequency bands
- Signal strength at a given frequency may depend on several variables
  - Use of several frequencies necessary to match the multiple unknowns
  - Use of multiple frequencies is primary technique used to measure various characteristics of the atmosphere and surface of the Earth

Multiple frequencies used over oceans

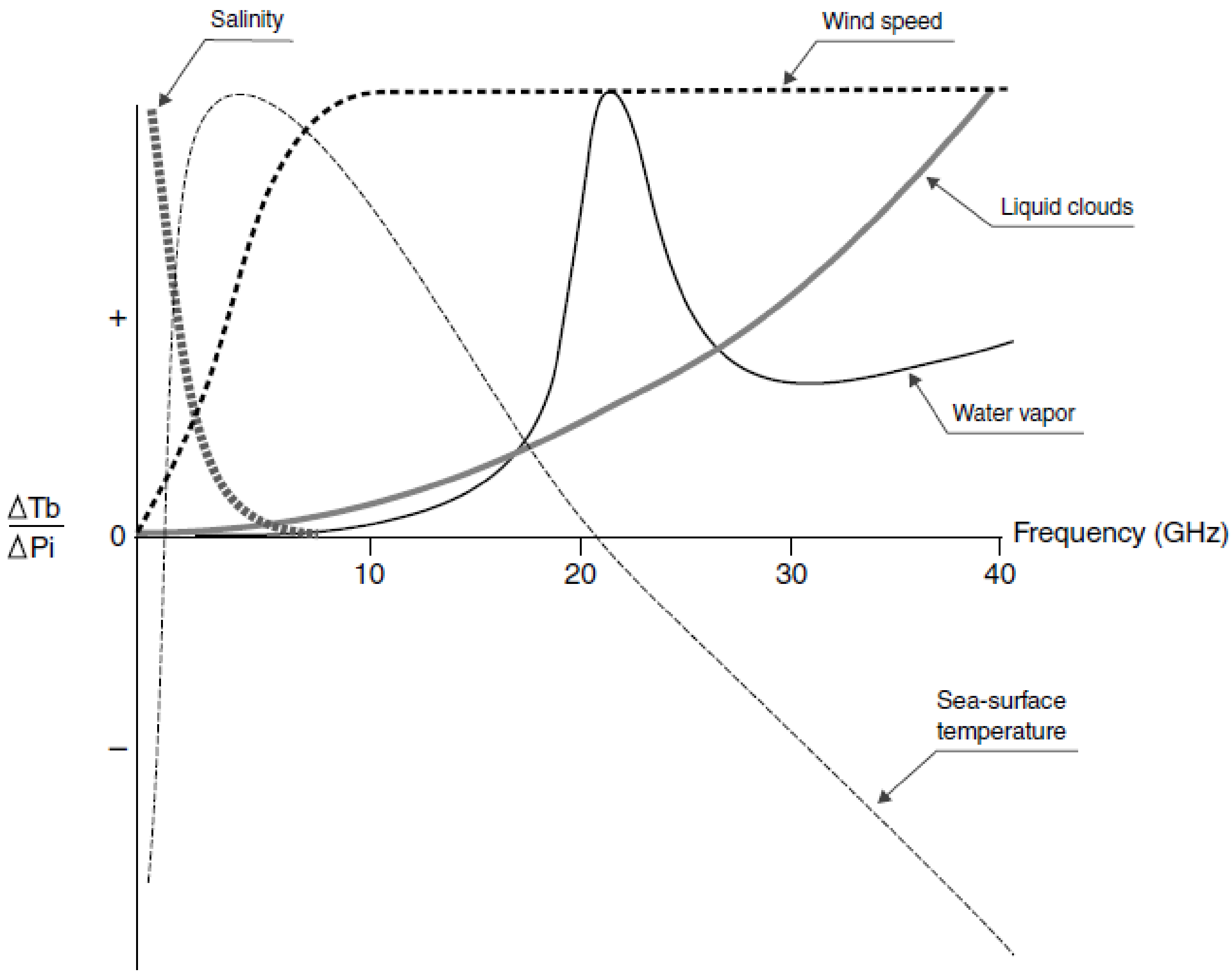
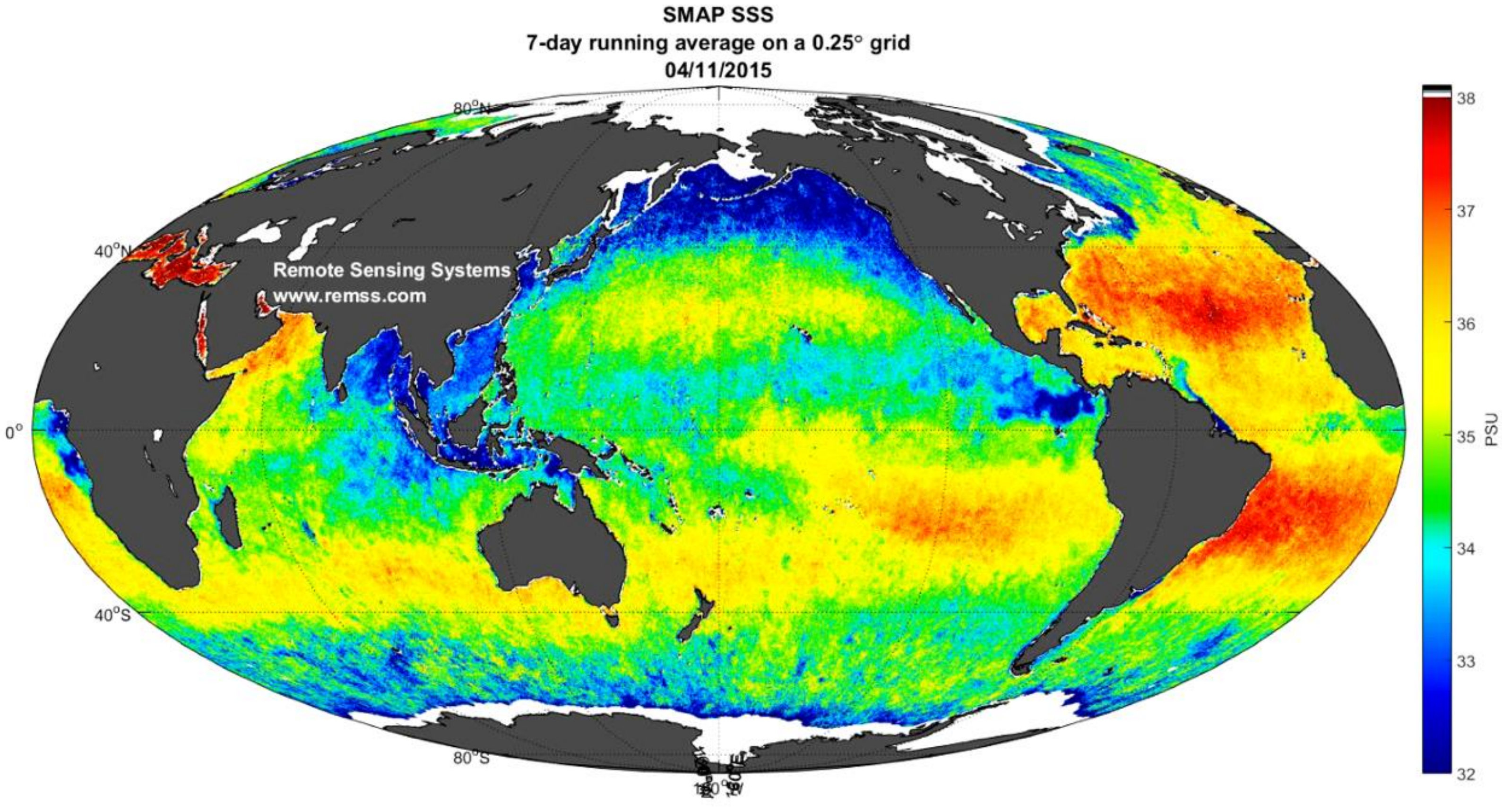


FIGURE 2.11 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over ocean surface).

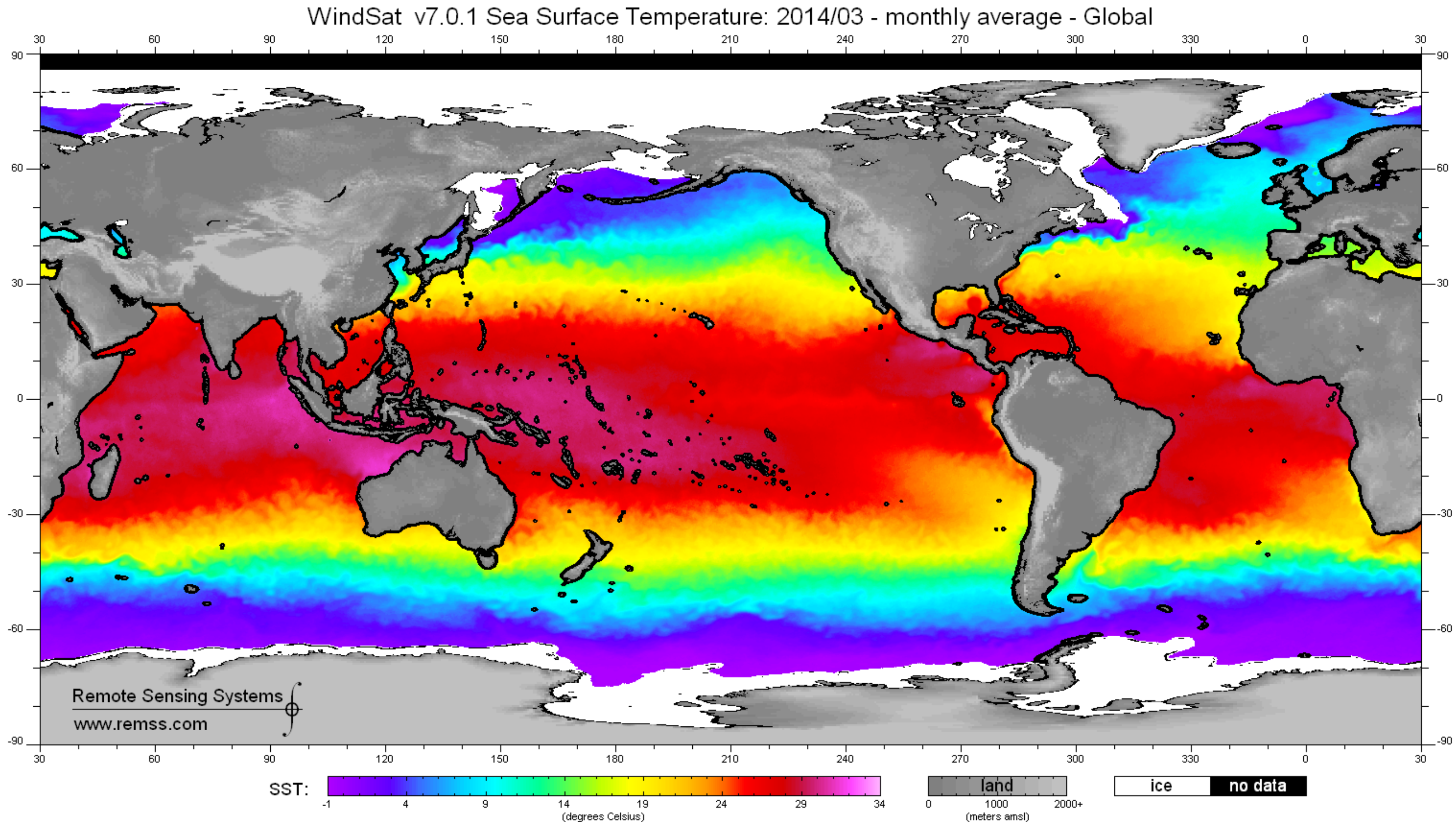
Multiple frequencies used over oceans

- Measurements at 1.4 GHz are useful for ocean salinity
- Measurements around 5 GHz offer the best sensitivity to sea surface temperature
- The 17-19 GHz region, where the signature of sea surface temperature and atmospheric water vapor is the smallest, is optimum for ocean surface emissivity
- Total content of water vapor is best measured around 24 GHz, while liquid cloud data are obtained via measurements around 36 GHz
- Five frequencies (around 6 GHz, 10 GHz, 18 GHz, 24 GHz and 36 GHz) are necessary for determining the dominant parameters

Sea Surface Salinity



Sea Surface Temperature



Land Area Remote Sensing

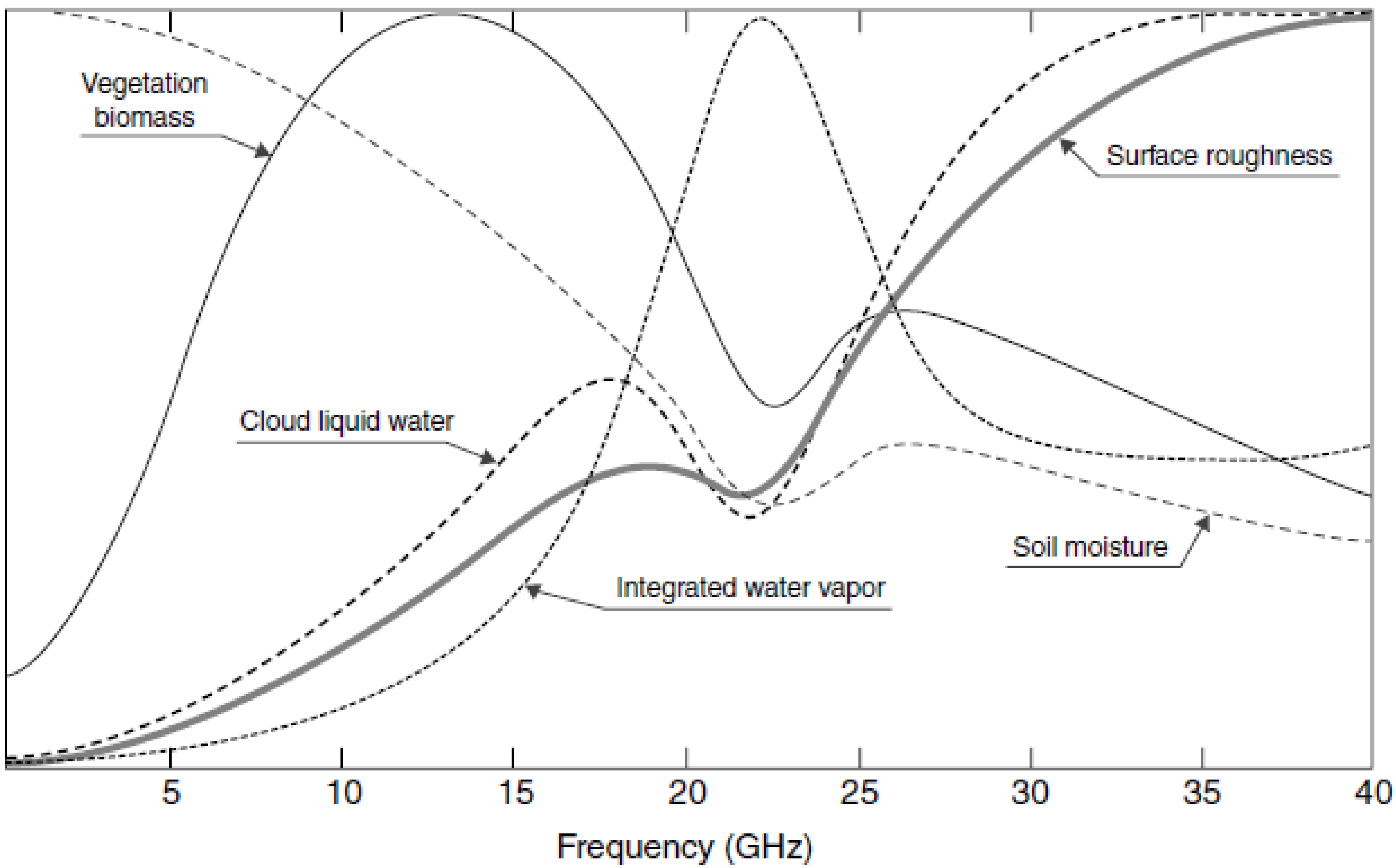
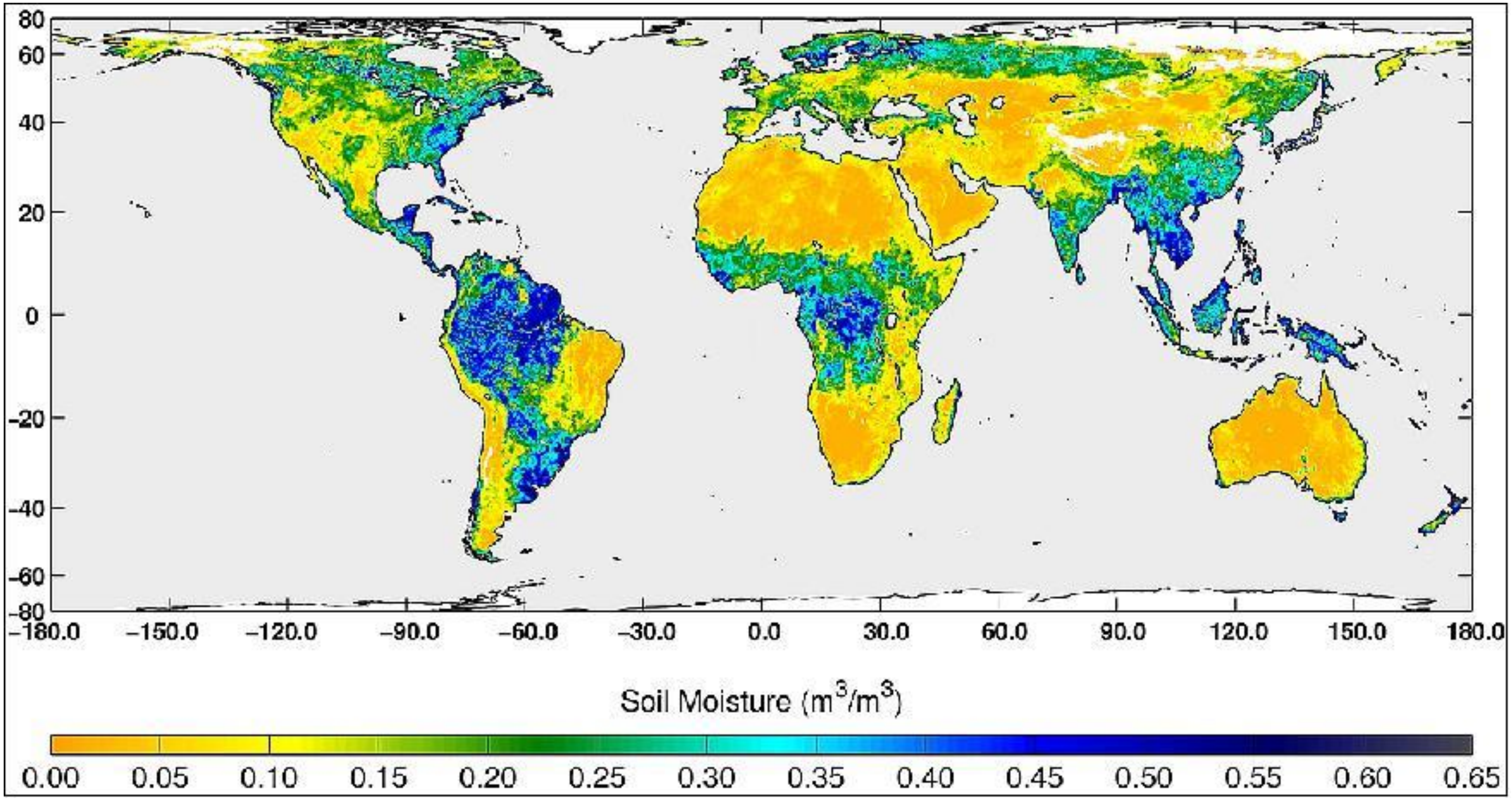


FIGURE 2.10 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over land surfaces).

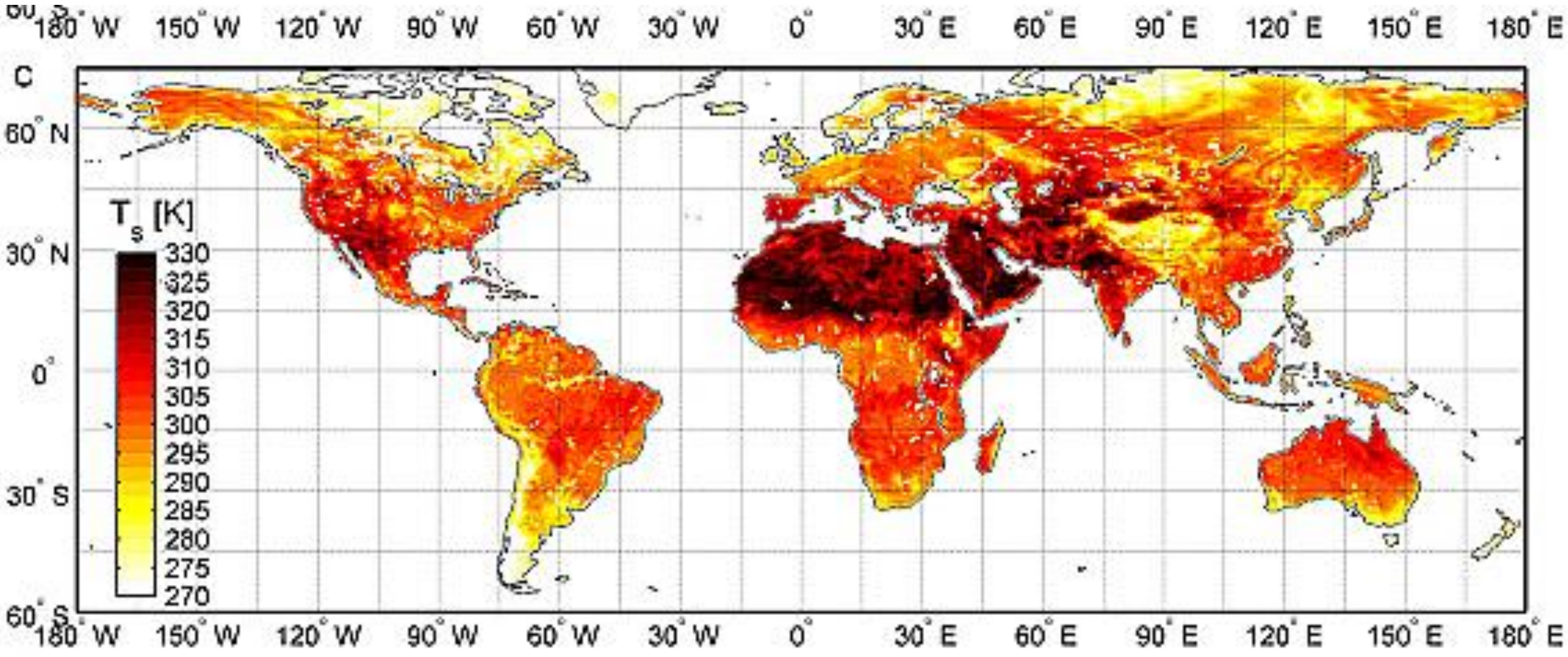
Multiple frequencies used over land

- A frequency around 1.4 GHz is needed to measure soil moisture content
- Measurements in the 5 GHz to 10 GHz range are needed to estimate vegetation biomass once the soil moisture contribution is known
- Two frequencies are needed around water vapor absorption peak (typically 18-19 GHz and 23-24 GHz) to assess atmospheric contribution
- A frequency around 37 GHz has utility for land surface temperature

Soil Moisture

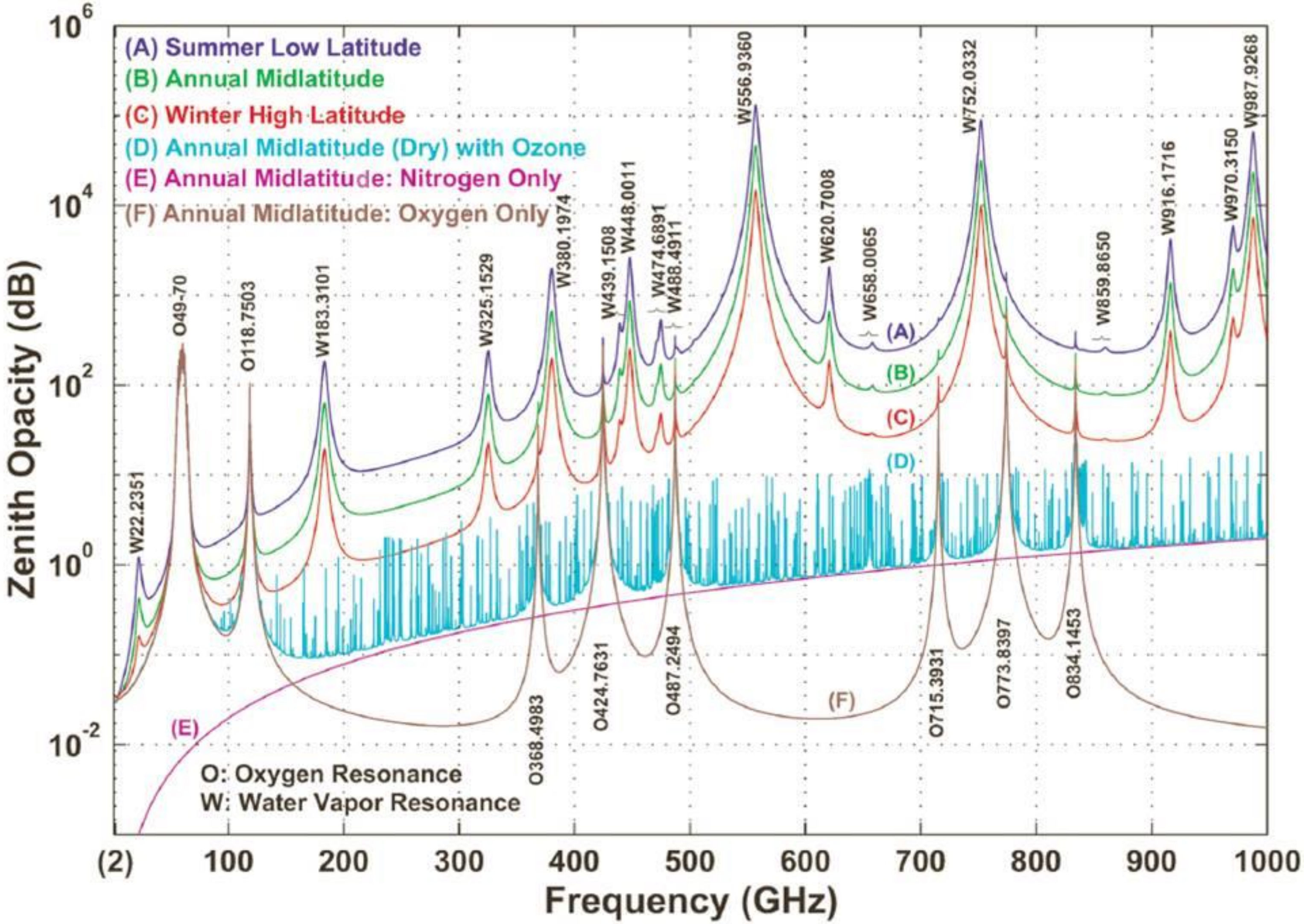


Land surface temperature from 37 GHz



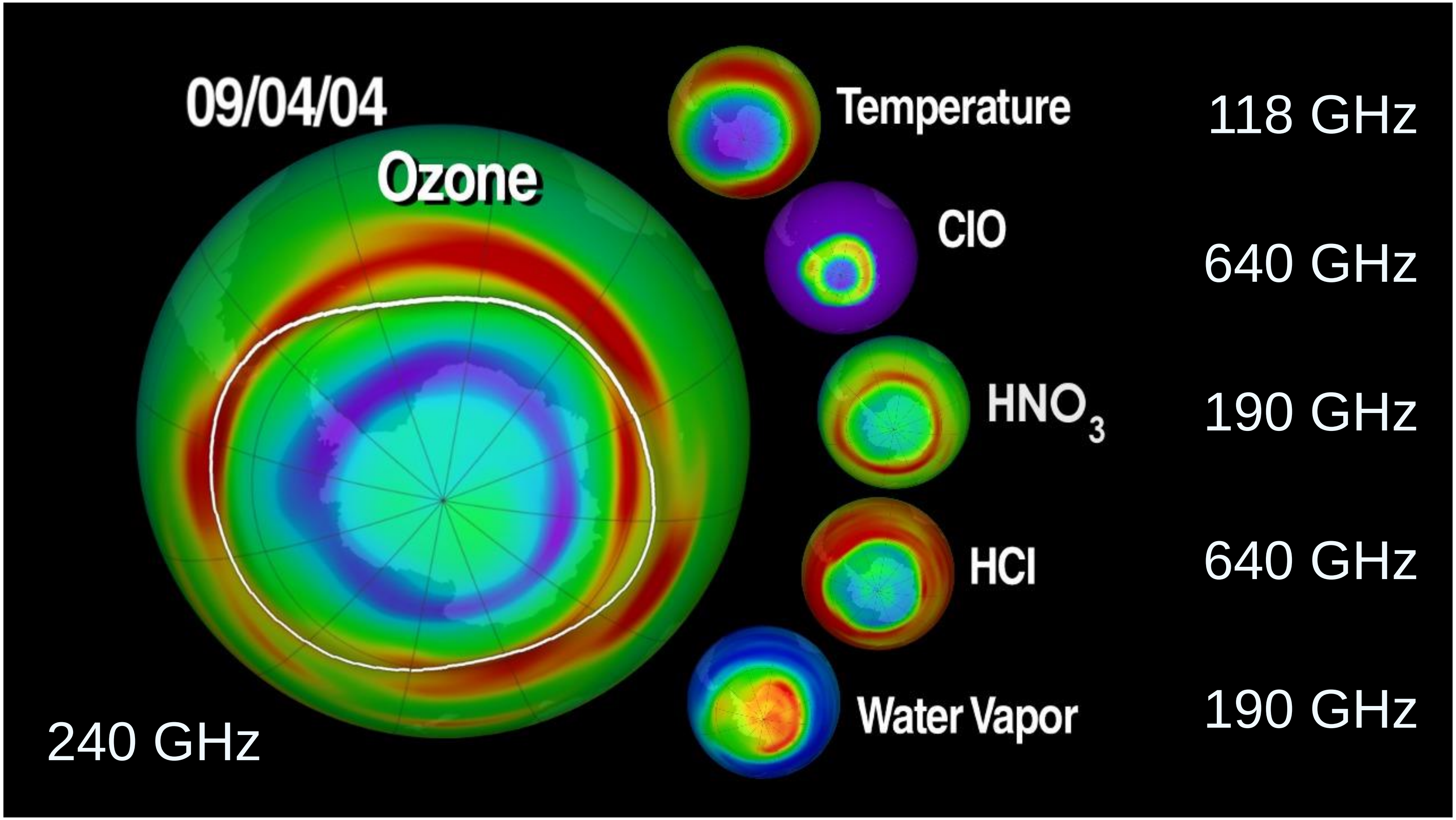
Journal of Geophysical Research: Atmospheres
Volume 114, Issue D4, D04113, 25 FEB 2009 DOI: 10.1029/2008JD010257
http://onlinelibrary.wiley.com/doi/10.1029/2008JD010257/full#jgrd14899-fig-0008

EESS (passive) use above 275 GHz



Limb Sounding

Microwave Limb Sounder (MLS) on Aura



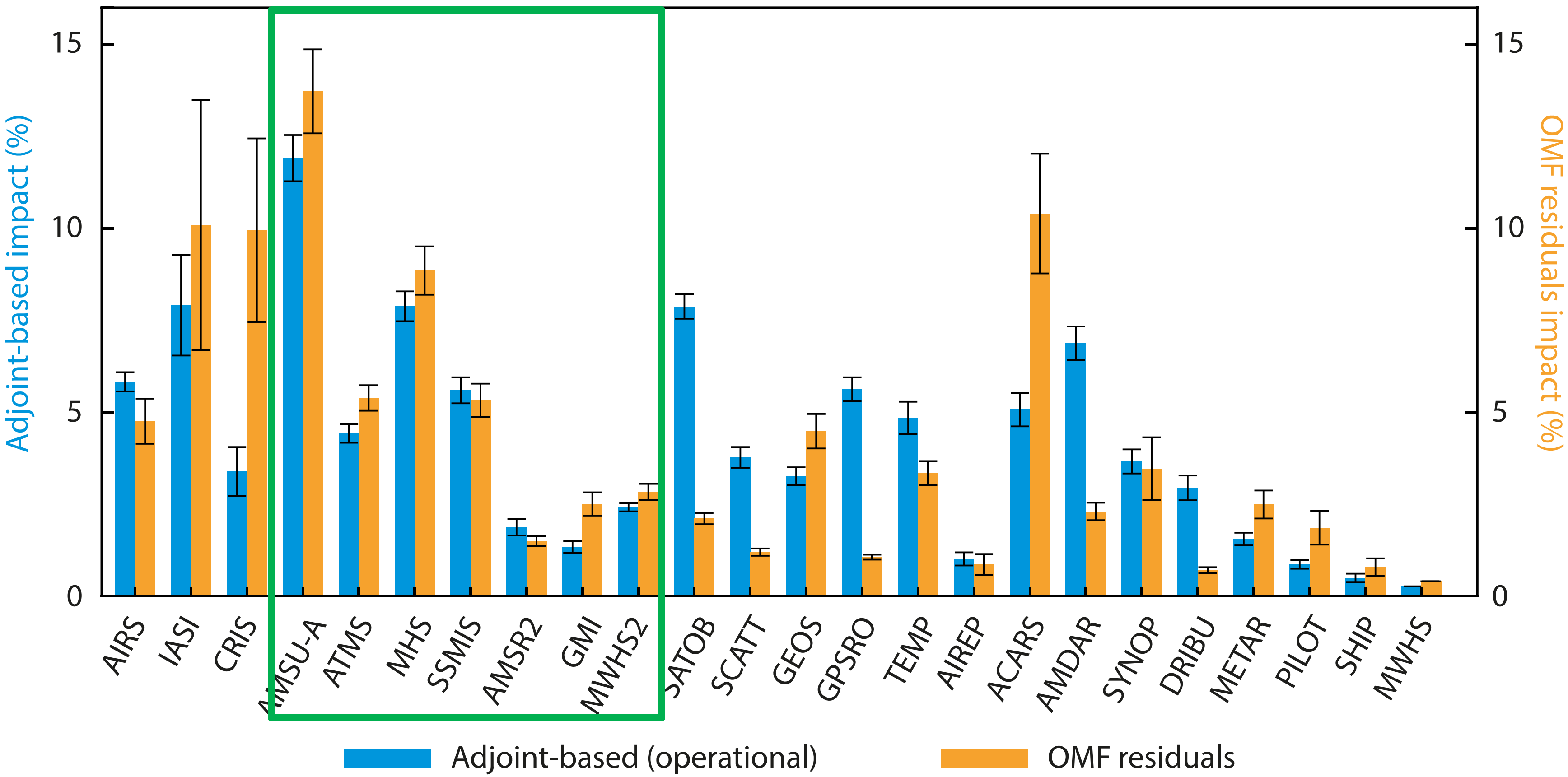
Modern Spaceborne Microwave Radiometry

DEVELOPMENTS OVER LAST DECADE+

Trends

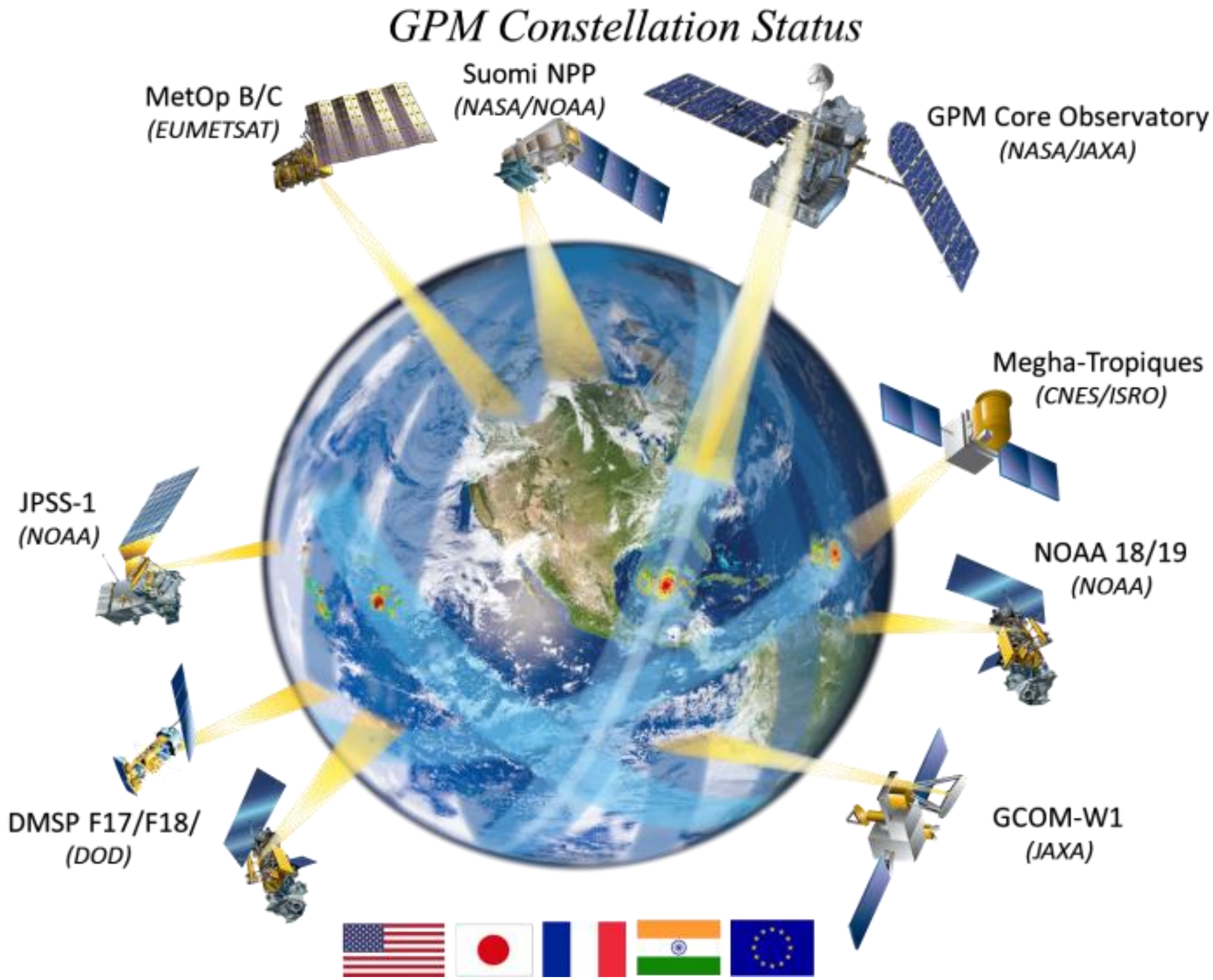
- Imagers and sounders improved capability
- Rise of L-band
- Submillimeterwave in nadir sensors
- Cubesats, cubesats, cubesats

Passive Microwave Impact on Numerical Weather Prediction



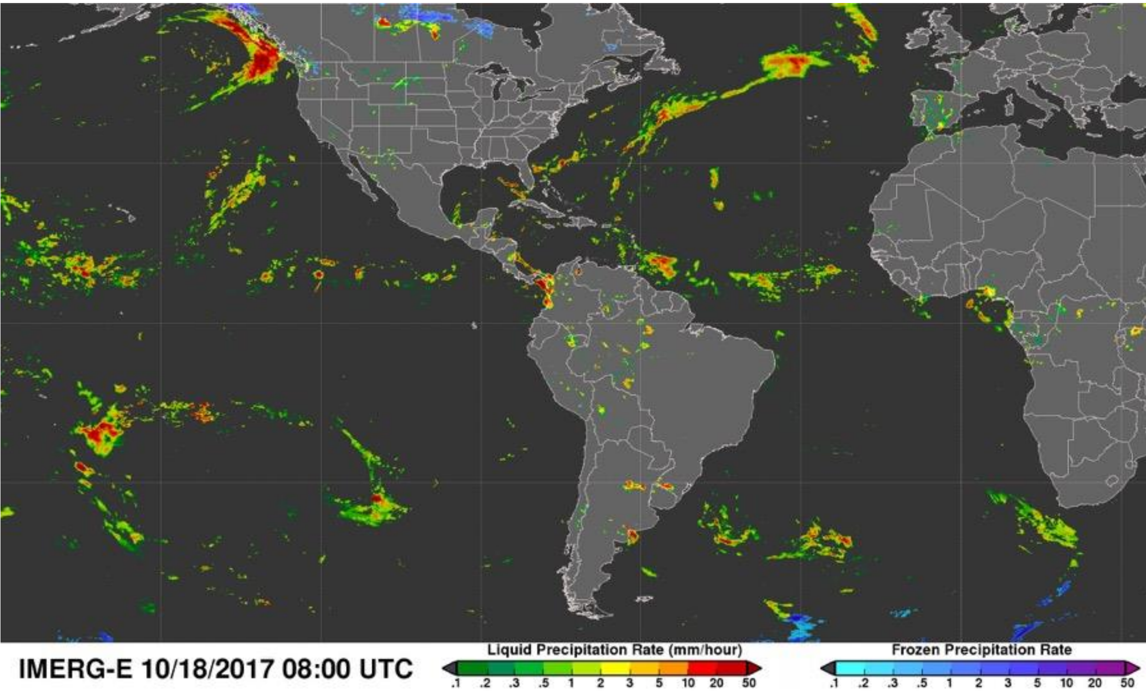
Mohamed Dahoui, Lars Isaksen and Gabor Radnoti, "Assessing the impact of observations using observation-minus-forecast residuals," *ECMWF Newsletter*, Number 152 – Summer 2017, Published in August 2017.
https://www.ecmwf.int/en/newsletter/152/meteorology/assessing-impact-observations-using-observation-minus-forecast

Global Precipitation Measurement



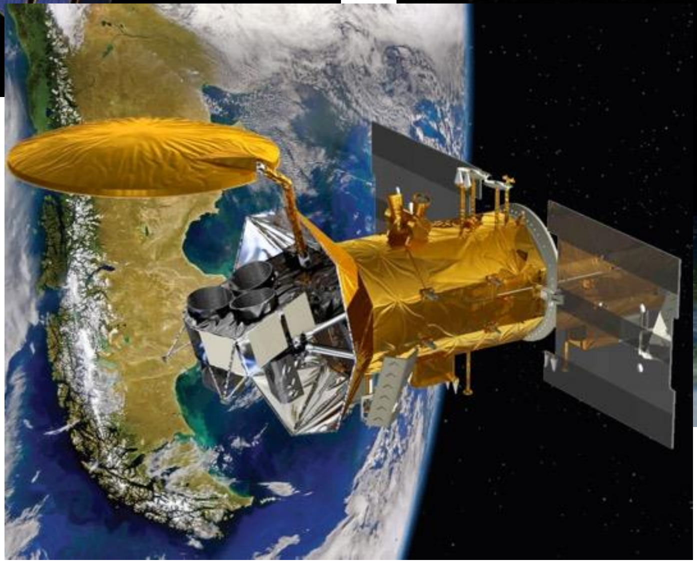
https://pmm.nasa.gov/

30-minute Precipitation Product

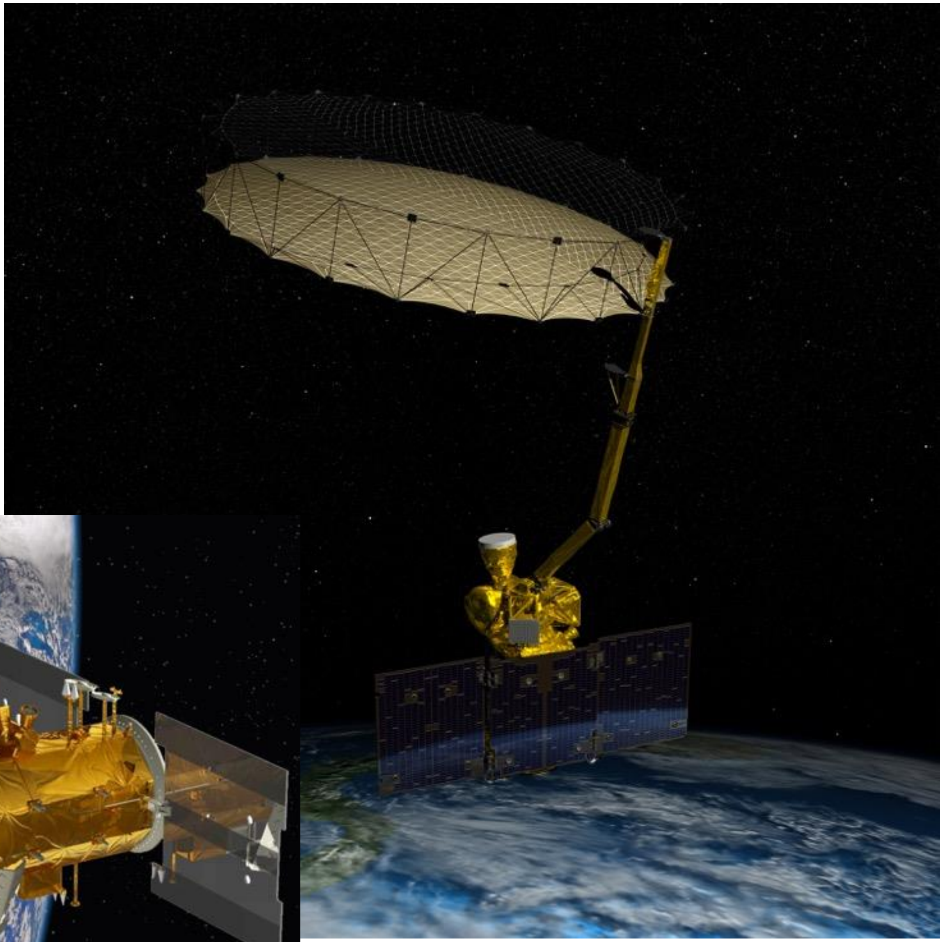


Modern L-band Radiometers

ESA’s SMOS

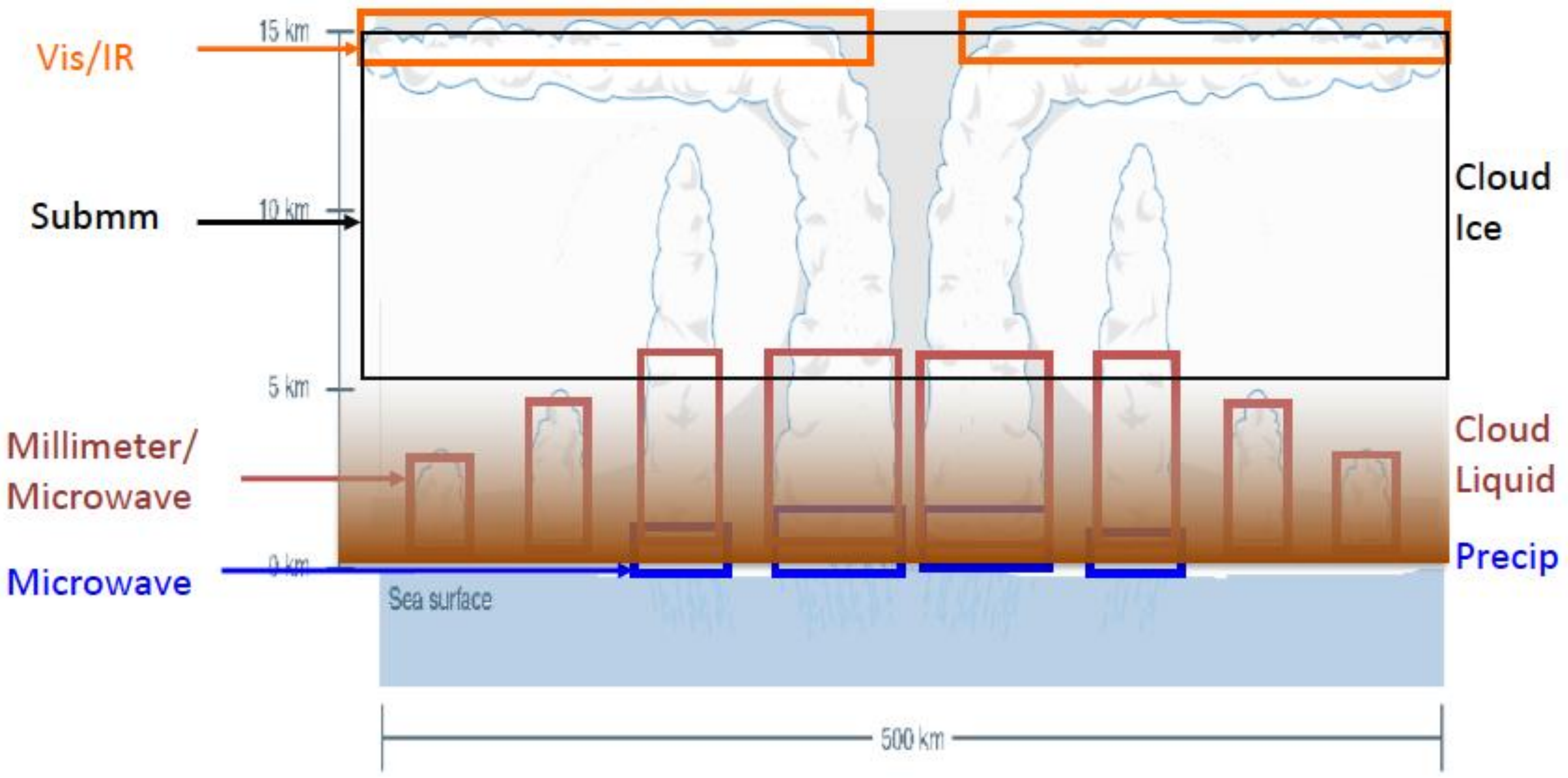


NASA/CONAE
Aquarius/SAC-D

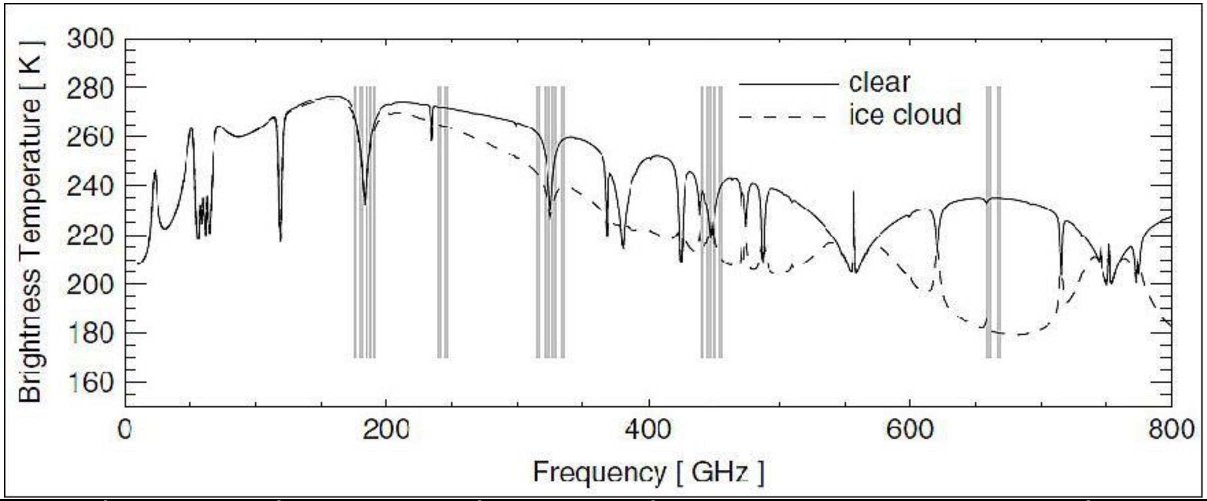


NASA SMAP

Why Submillimeter-Wave Radiometry?
- Critical Gap in Cloud Ice Measurements -



Ice Cloud Imager
MetOp-Second Generation Program

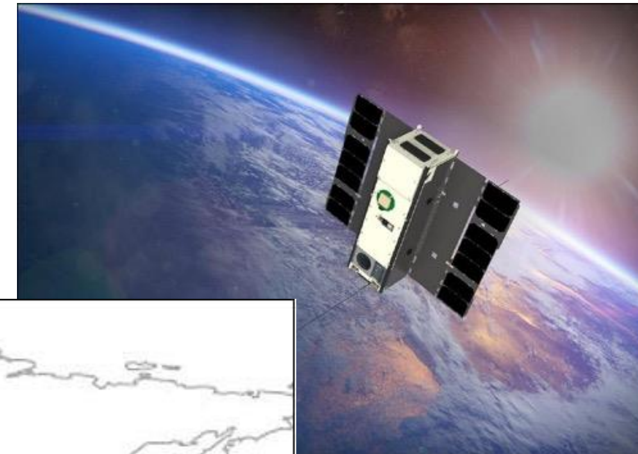


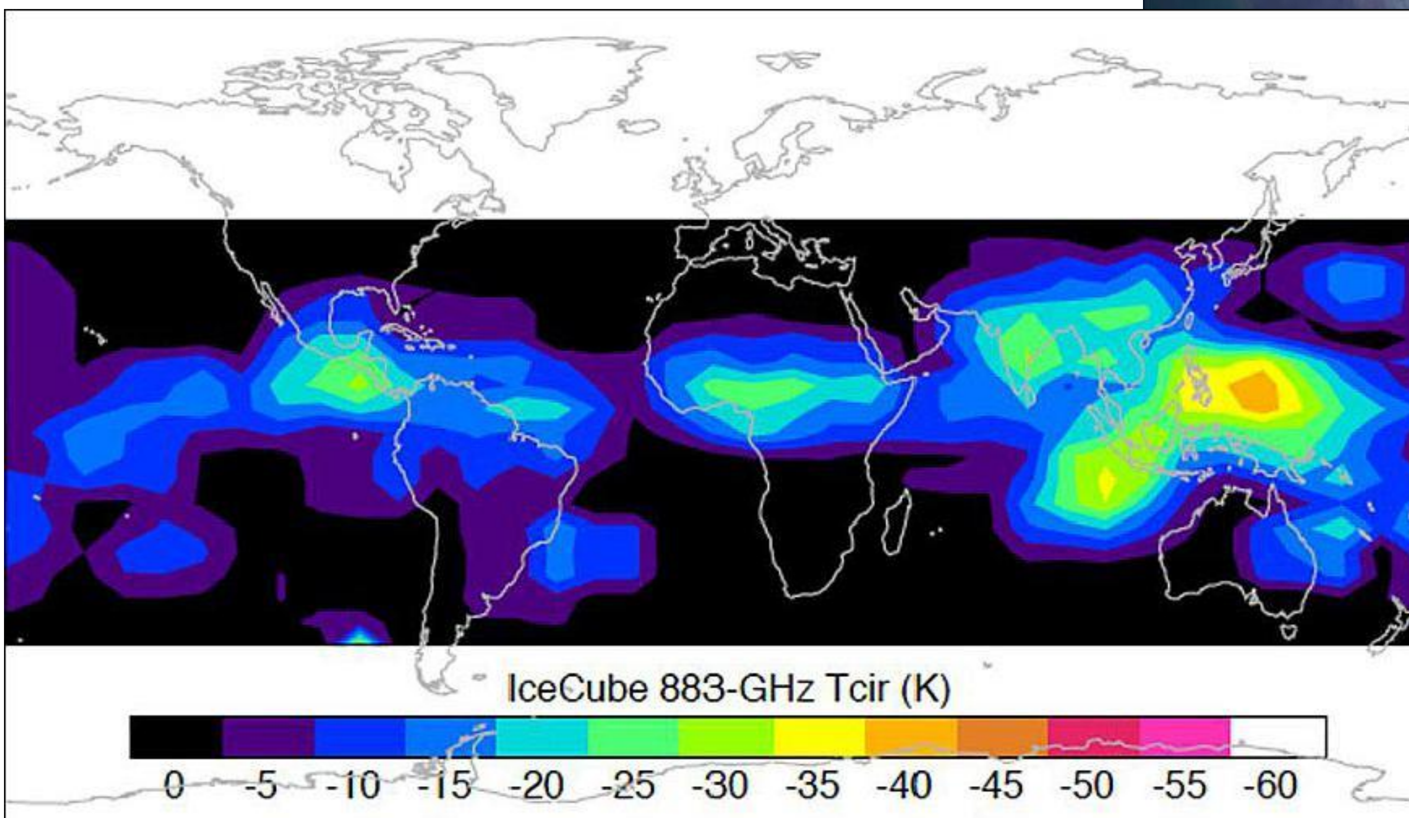
Channel No	Frequency (GHz)	Bandwidth (GHz)	Polarization	Utilization	NEΔT (K)
ICI-1	183.31±8.4	6	V	Water vapor profile and snowfall	0.6
ICI-2	183.31±3.4	3	V		0.7
ICI-3	183.31±2.0	3	V		0.7
ICI-4	243.2±2.5	6	V, H	Quasi-window, cloud ice retrieval, cirrus clouds	0.6
ICI-5	325.15±9.5	6	V	Cloud ice effective radius	1.1
ICI-6	325.15±3.5	4.8	V		1.2
ICI-7	325.15±1.5	3.2	V		1.4
ICI-8	448±7.2	6	V	Cloud ice water path and cirrus	1.3
ICI-9	448±3.0	4	V		1.5
ICI-10	448±1.4	2.4	V		1.9
ICI-11	664±4.2	10	V, H	Quasi-window, cirrus clouds, cloud ice water path	1.5

https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg

883-GHz IceCube 3U CubeSat

- Deployed May 2017
- Successful Technology Demo

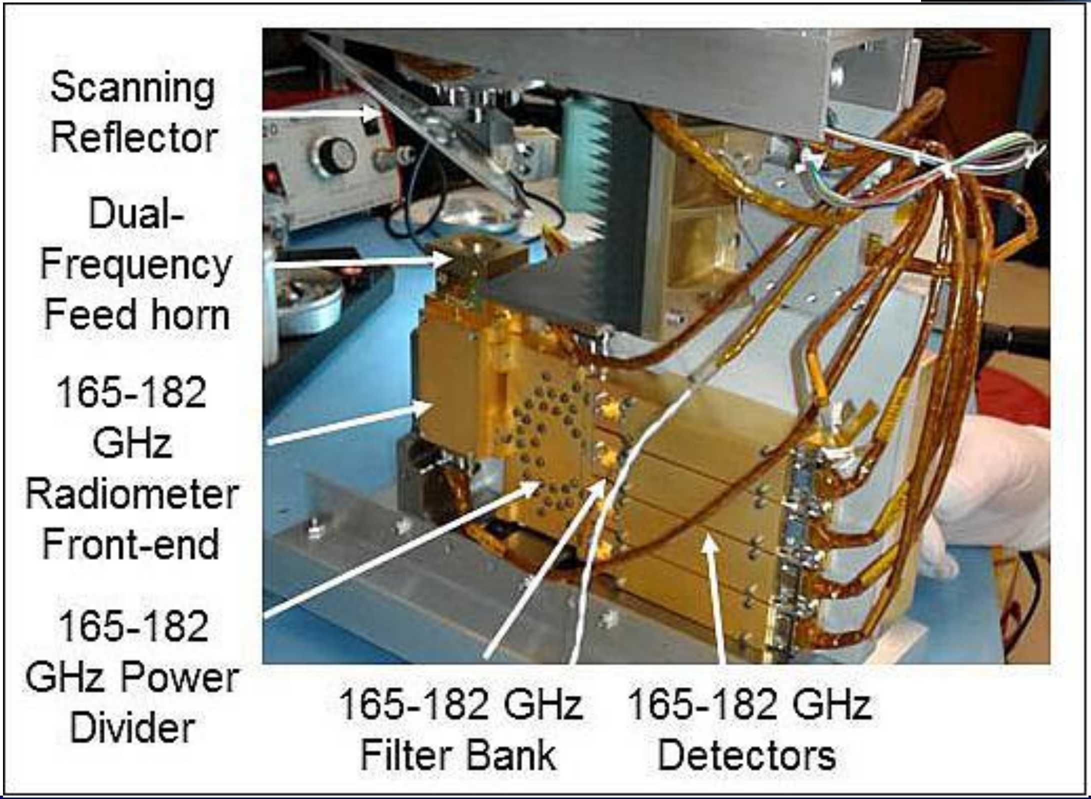




https://atmospheres.gsfc.nasa.gov/climate/index.php?section=259

TEMPEST-D 6U CubeSat

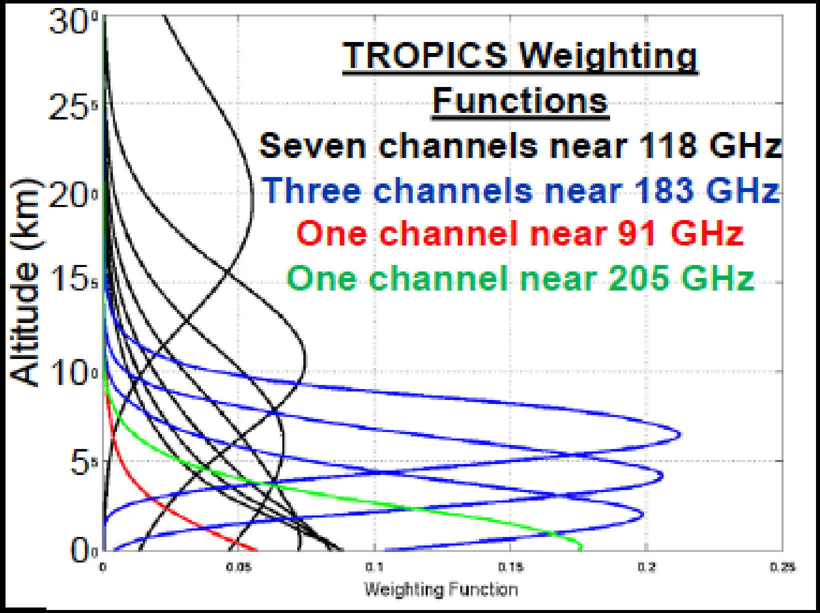
- Cross-track millimeter wave
- Measure precipitation
- Univ. Colorado/JPL

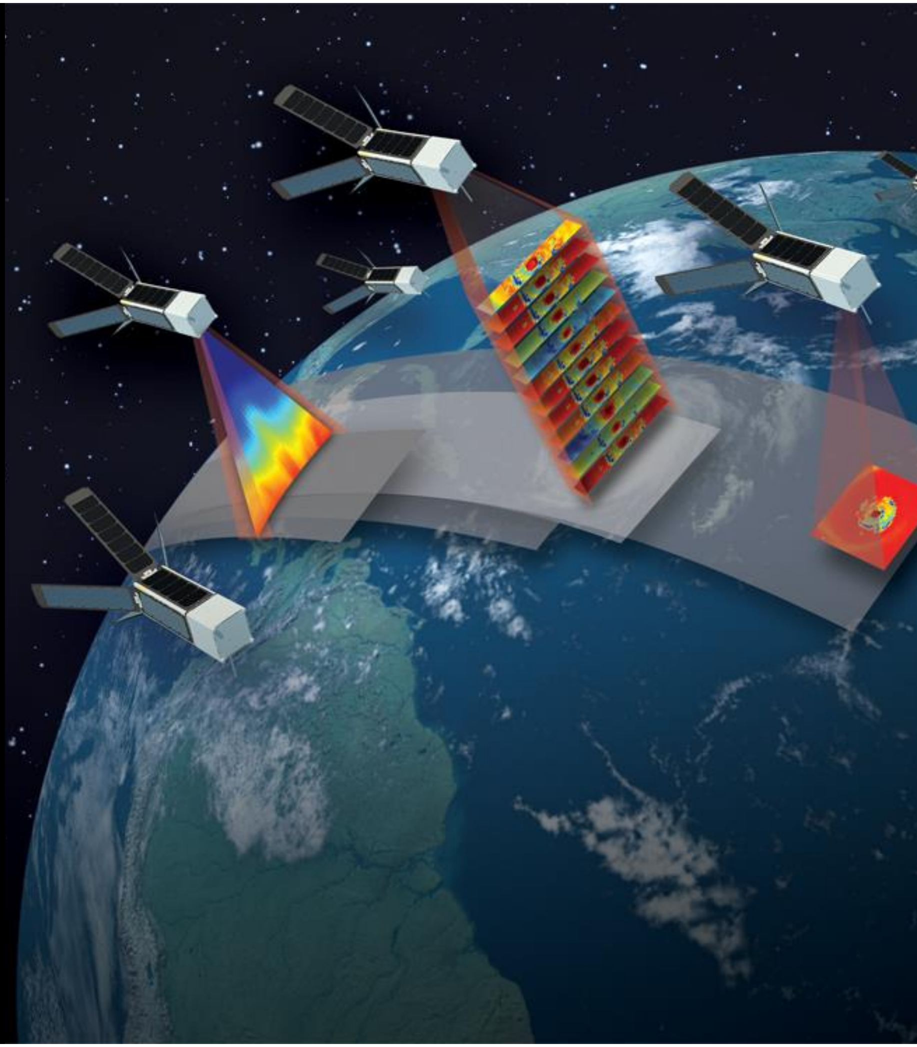


NASA TROPICS
3U CubeSat Constellation
MIT Lincoln Laboratories

12-channel passive microwave radiometer

- 91 & 205 GHz imaging channels
- Temperature sounding near 118 GHz
- Moisture sounding near 183 GHz





CubeRRT CubeSat

***Cube**sat validation of **R**adiometer **R**FI **T**echnology*

6-40 GHz frequency-hopping radiometer with interference detection

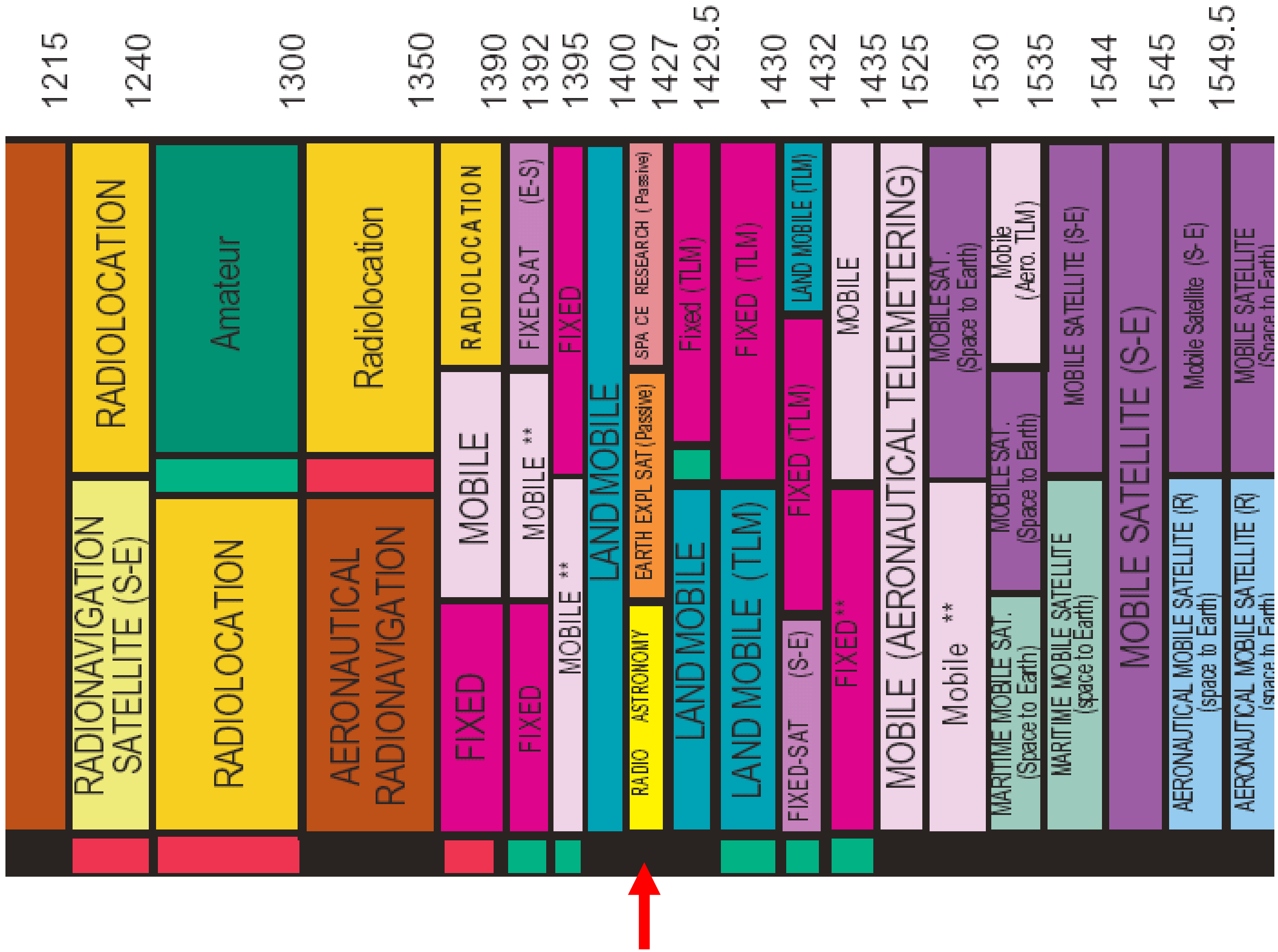
“Quiet Please”

CHALLENGES FOR NEXT DECADE+

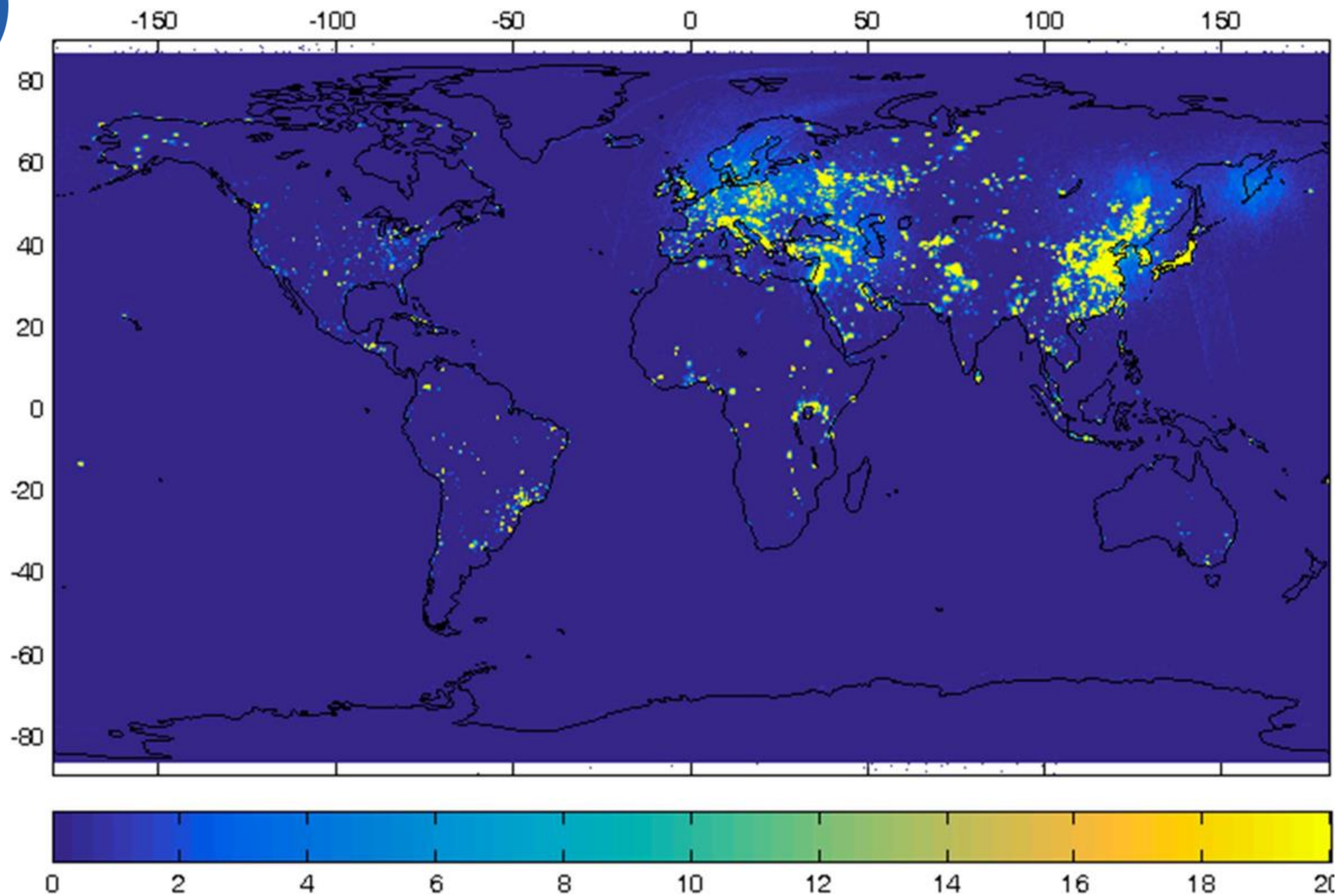
Susceptibility to Interference

- Interference
- Shared spectrum sensing

L-Band Allocation

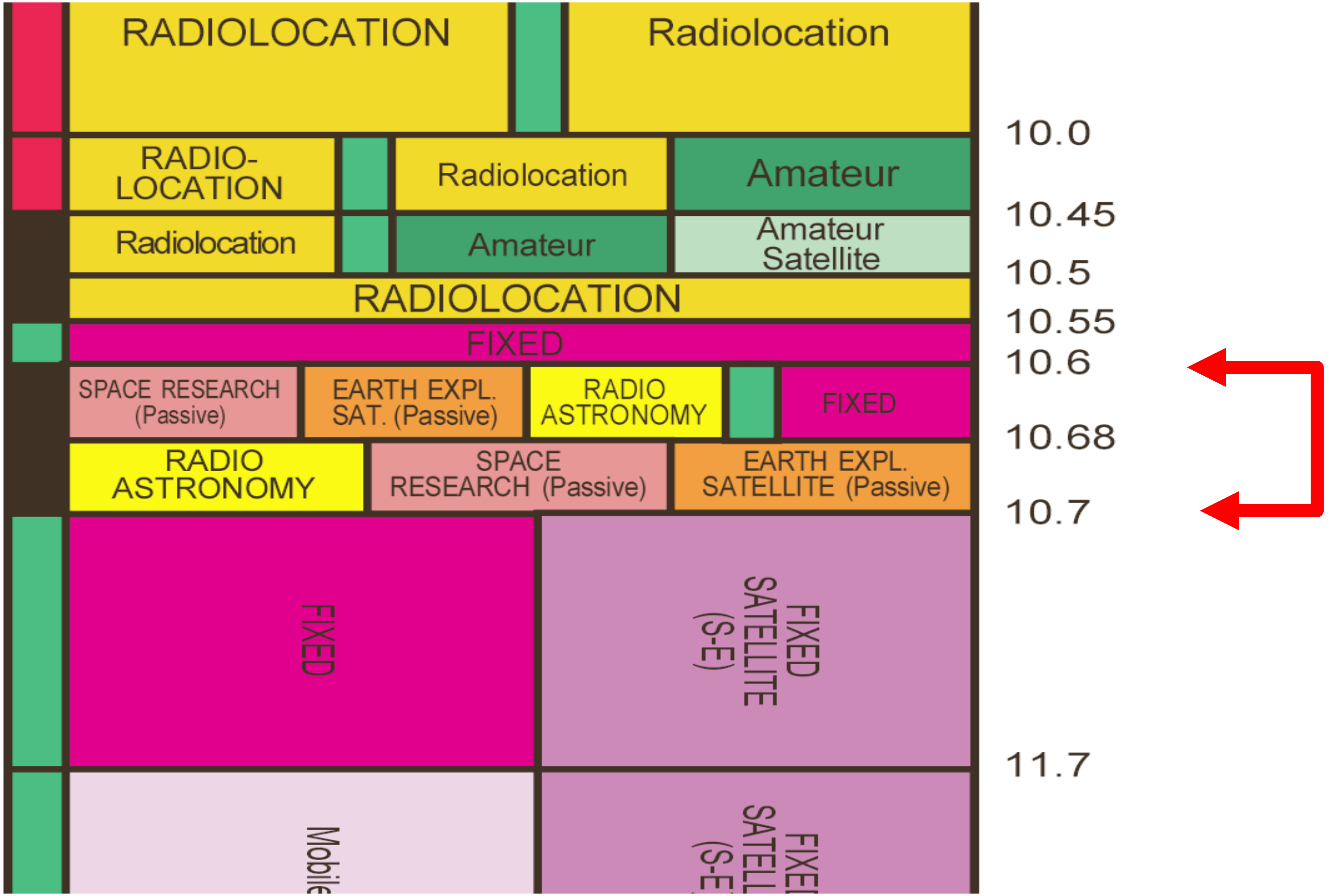


RFI Detected by SMAP



Percent of the time that SMAP detects an RFI level of 5 K or more in horizontal polarization for data from April 2015 to March 2016.

X-band Allocation



10.7-GHz Coastal Ocean Reflections from DBS

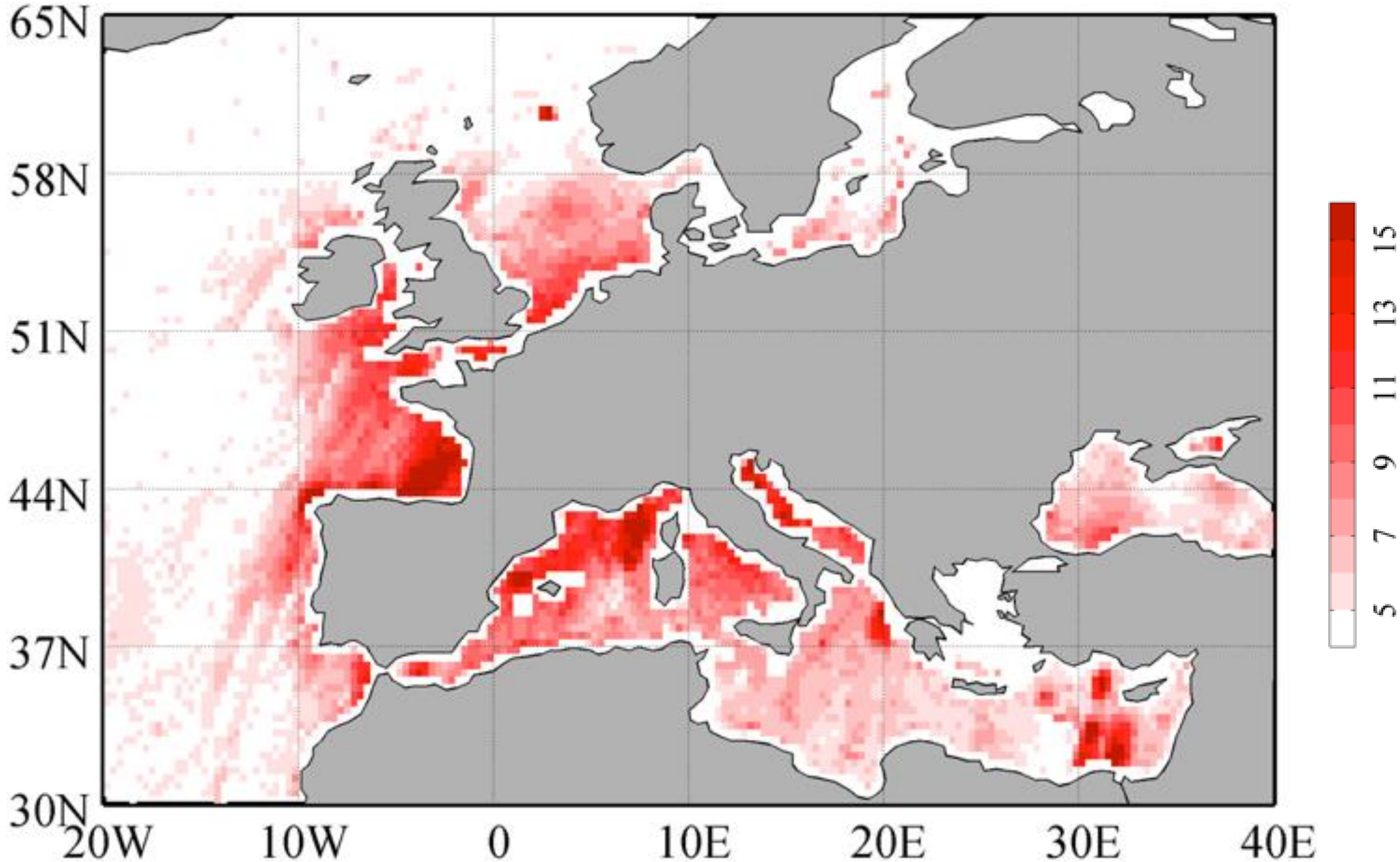
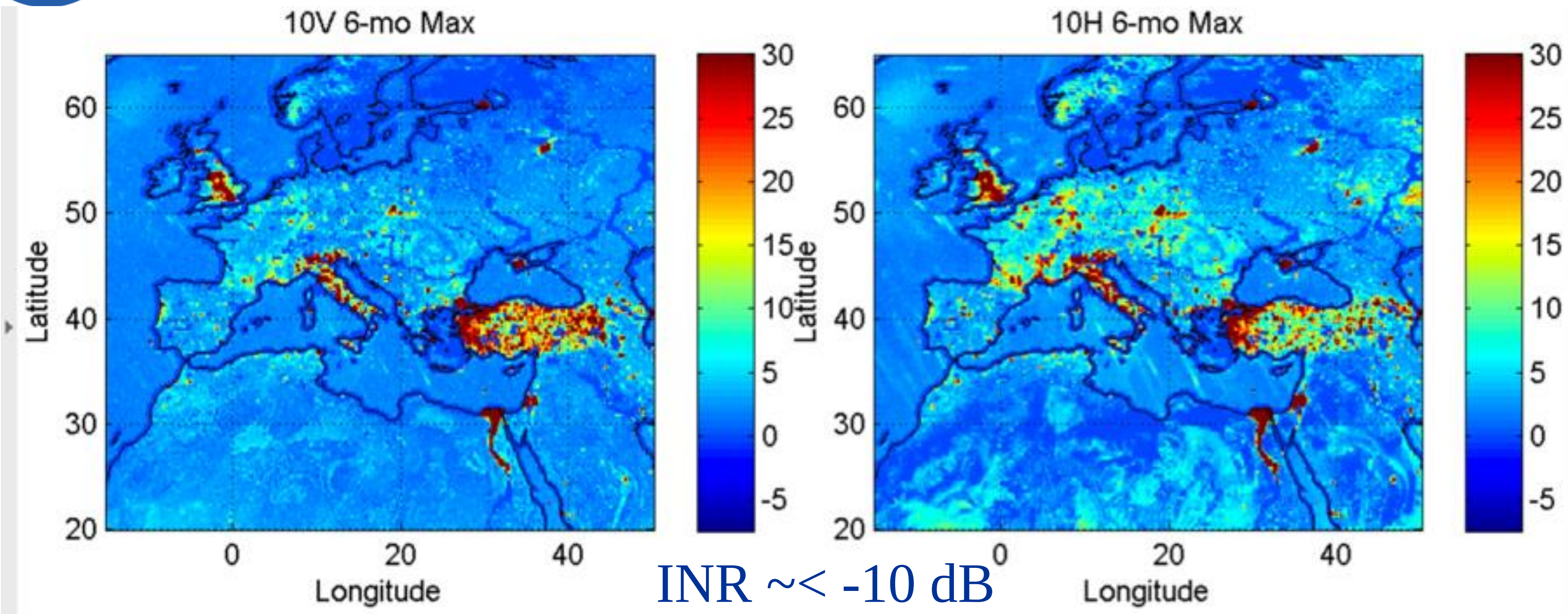


Fig. 7: Monthly average RFI intensity maps for AMSR-E …10.7 GHz … horizontal polarization ... for all descending portions of AMSR-E orbits from February 1 to 18, 2011.

X. Tian, et al., “Detection of AMSR-E Radio Frequency Interference over Ocean”

X-band RFI observed by GMI

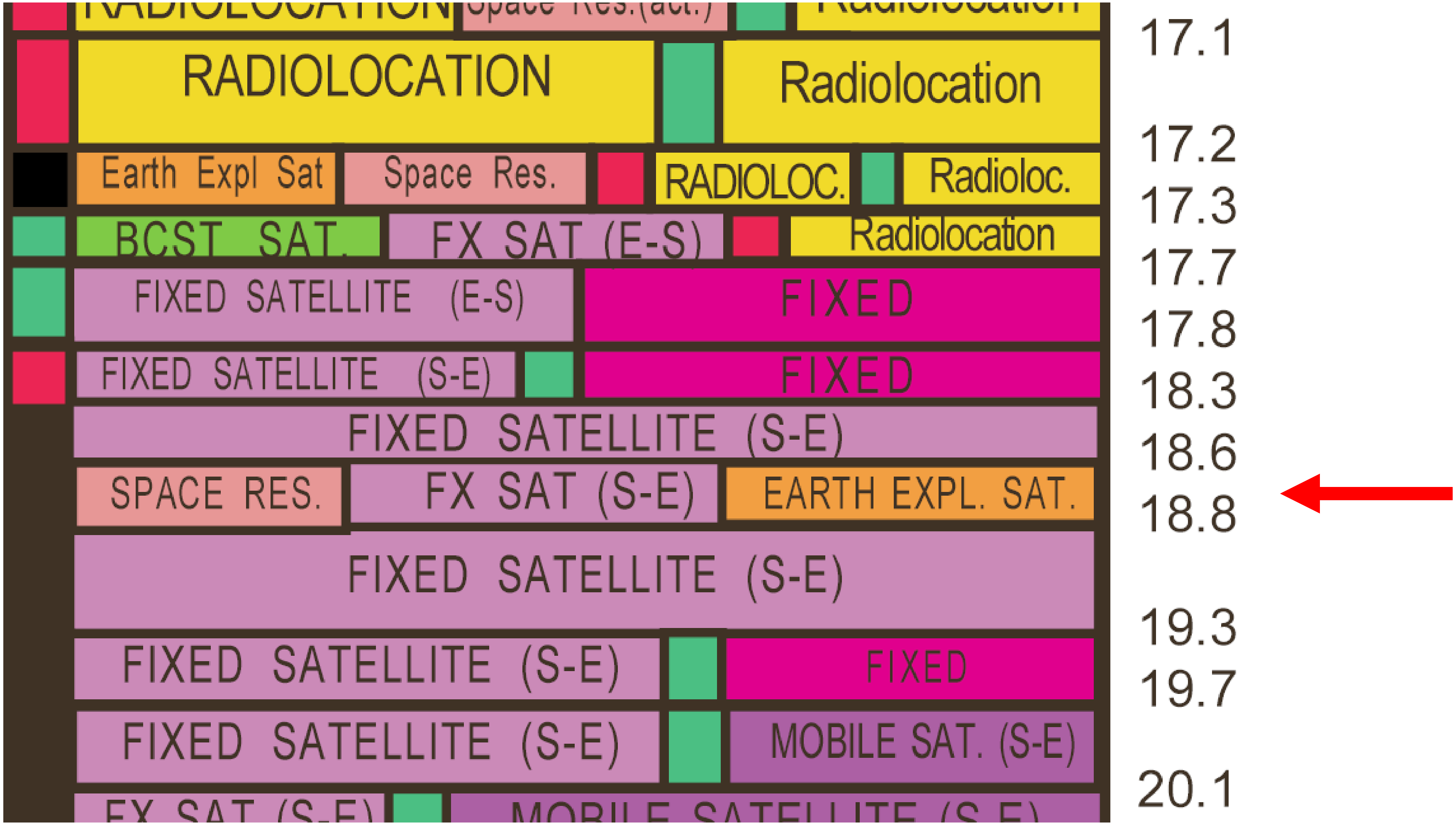


INR ~< -10 dB

- GMI restricts observation to within EESS(passive) allocations
- But most of X-band EESS is **shared** with fixed and mobile

Draper, D. *Report on GMI Special Study #15: Radio Frequency Interference.*

Ku/Ka band Allocation



18.7 GHz Ground Reflections from DBS

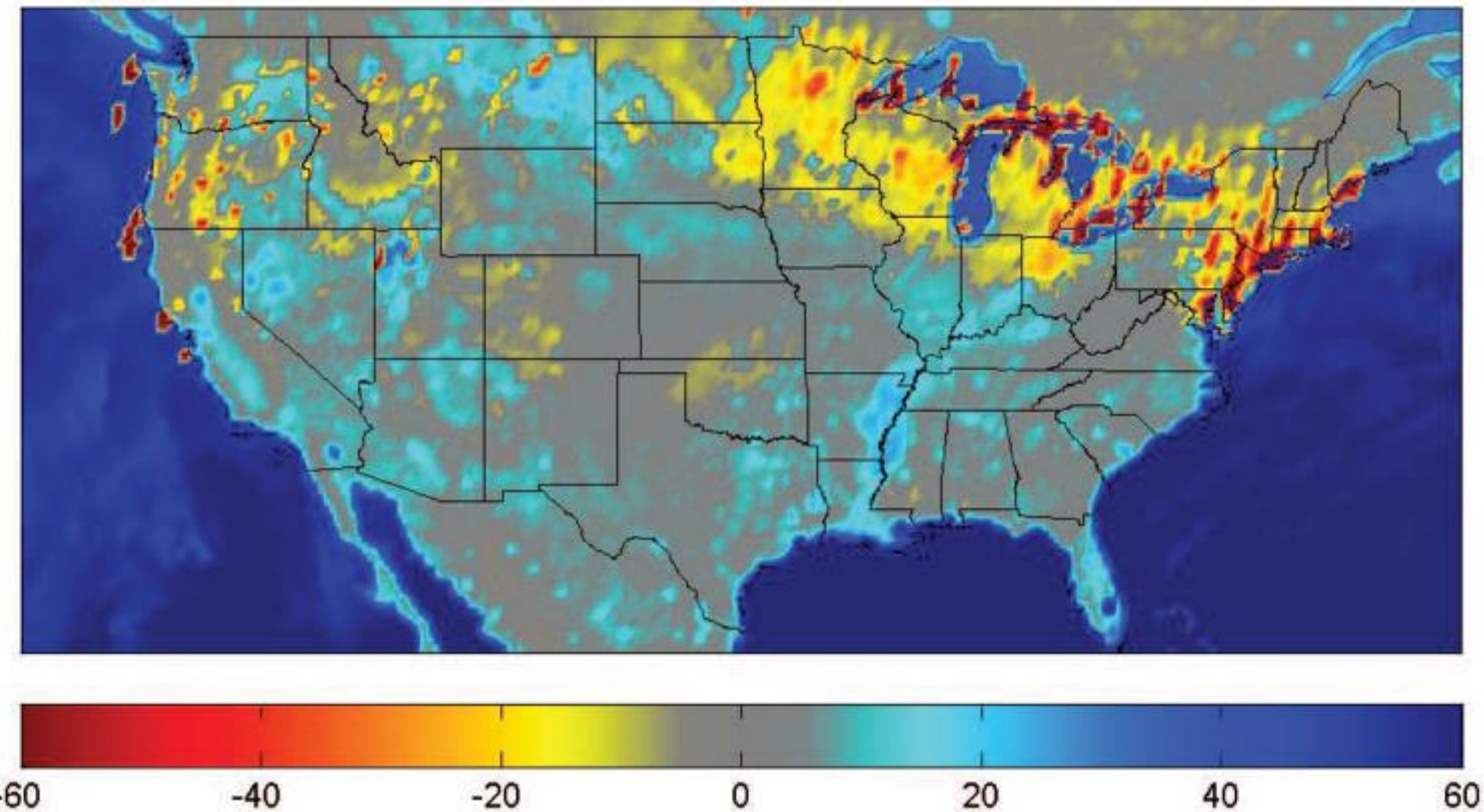


Figure 4. 23.8H – 18.7H Tb differences for AMSR-E, **January 2009**.

- McKague, et al., "Characterization of K-band Radio Frequency Interference from AMSR-E, Windsat AND SSM/I," Univ. Mich.

18.7-GHz DBS Coastal Ocean

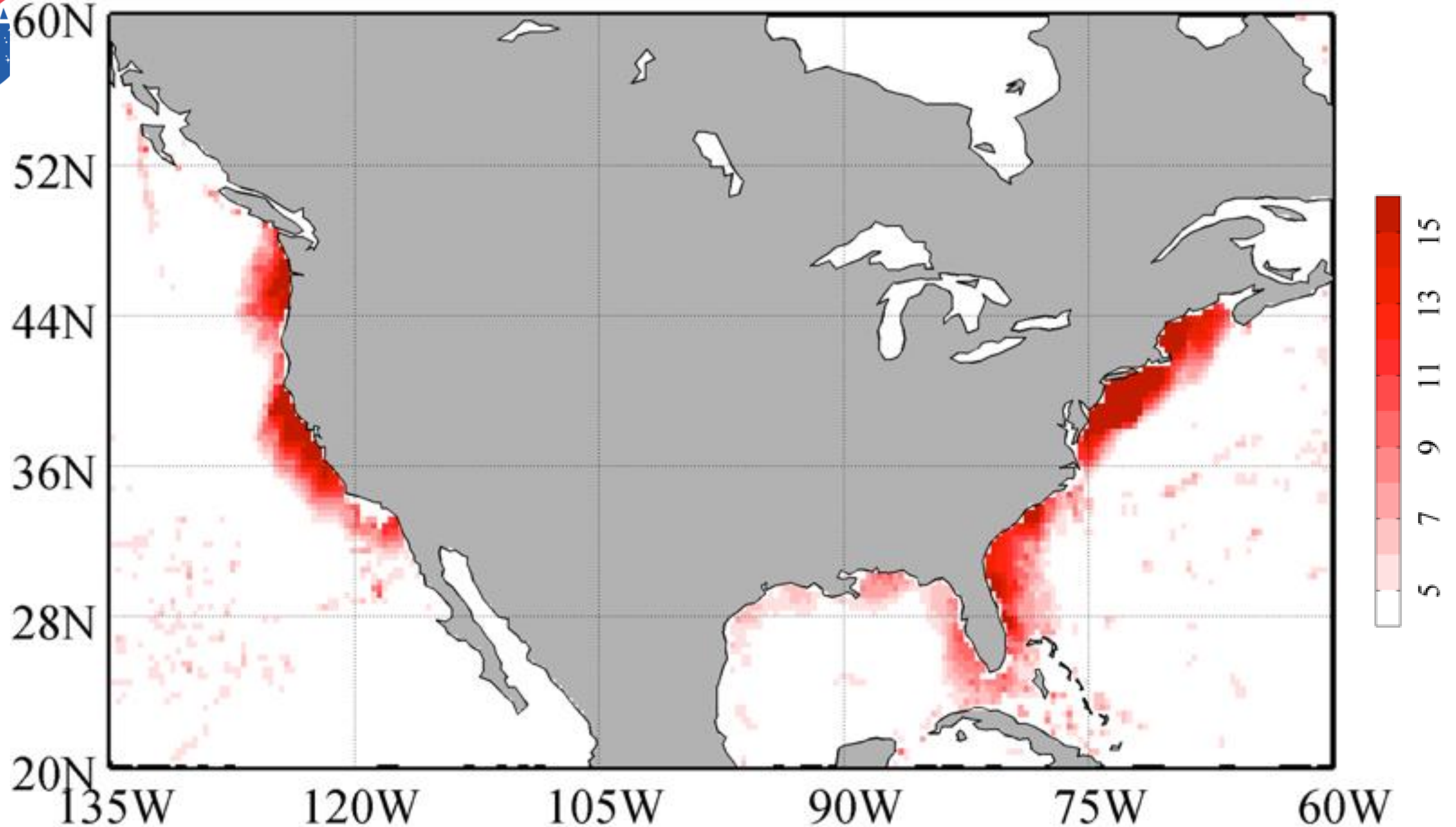


Fig. 7: Monthly average RFI intensity maps for AMSR-E …18.7 GHz … vertical polarization ... for all descending portions of AMSR-E orbits from February 1 to 18, 2011.

X. Tian, et al., “Detection of AMSR-E Radio Frequency Interference over Ocean”

`Conclusions

- Passive microwave sensors provide valuable information for Meteorology
- Passive use of the spectrum is expanding
  - Lower (e.g., L-band) and higher (e.g., submmw) frequencies
  - More sensors (constellations)
  - Increased capability
- Interference exists in passive exclusive allocations
- Interference exists in passive shared allocations
- Interference causes information loss
- Perhaps the biggest threat to passive sensing operations is interference that is undetected, corrupting data that is then mistaken for valid data leading to flawed conclusions