Challenges for Satellite (Scientific) Use of the Spectrum

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Greenbelt, MD

Radio Frequency Spectrum Management Workshop
May 24, 2016
UPR Mayaguez

Signals and Noise

- One person's noise is another person's signal
- One person's signal is another person's noise

Junk into Art

Sound Wave
Jean Shin

Science Services

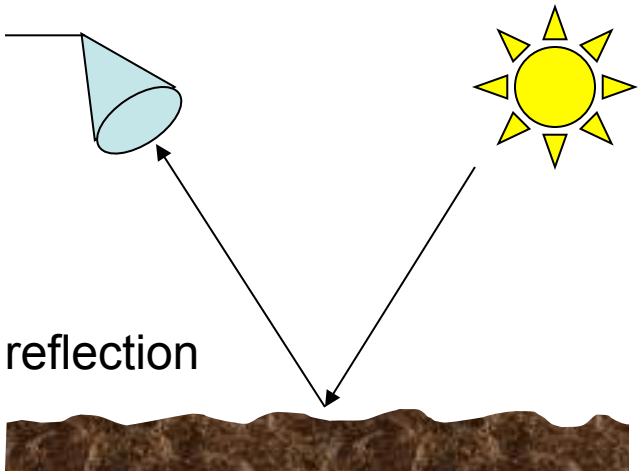
TABLE 1.1 Science Services

Service	Abbreviation	Description of Service
Earth Exploration-Satellite Service	EESS	Remote sensing from orbit, both active and passive, and the data downlinks from these satellites
International Global Navigation Satellite System (GNSS) Service	IGS	Accurate position and timing data
Meteorological Aids Service	MetAids	Radio communications for meteorology, e.g., weather balloons
Meteorological Satellite Service	MetSat	Weather satellites
Radio Astronomy Service	RAS	Passive ground-based observations for the reception of radio waves of cosmic origin
Space Operations Service	SOS	Radio communications concerned exclusively with the operation of spacecraft—in particular, space tracking, space telemetry, and space telecommand
Space Research Service	SRS	Science satellite telemetry and data downlinks, space-based radio astronomy, and other services

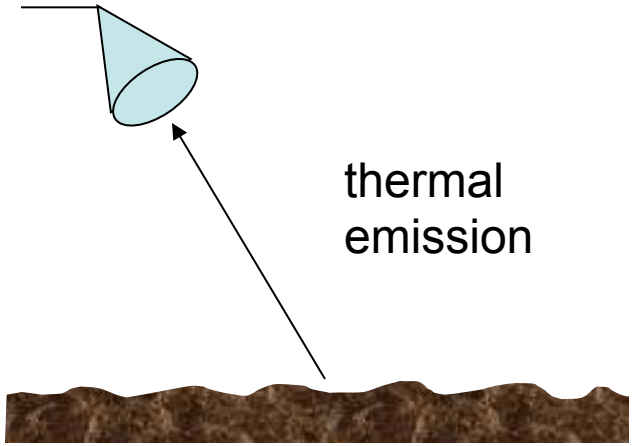
EESS Evolution

- WARC-71: EESS(communications) established
- WARC-79: EESS(passive) and EESS(active)
- WRC-97: 50-60 GHz (passive) realigned
- WRC-2000
  - >71 GHz realigned
  - >275-1000 GHz stated in footnote
  - 18.7 GHz gained passive allocation
- WRC-07: mandatory out-of-band emission limits
- WRC-11,15 …. >275 GHz allocations

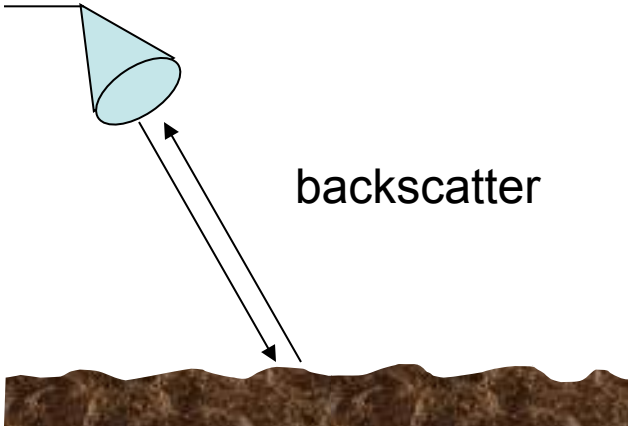
Types of Sensors



optical cameras and scanners

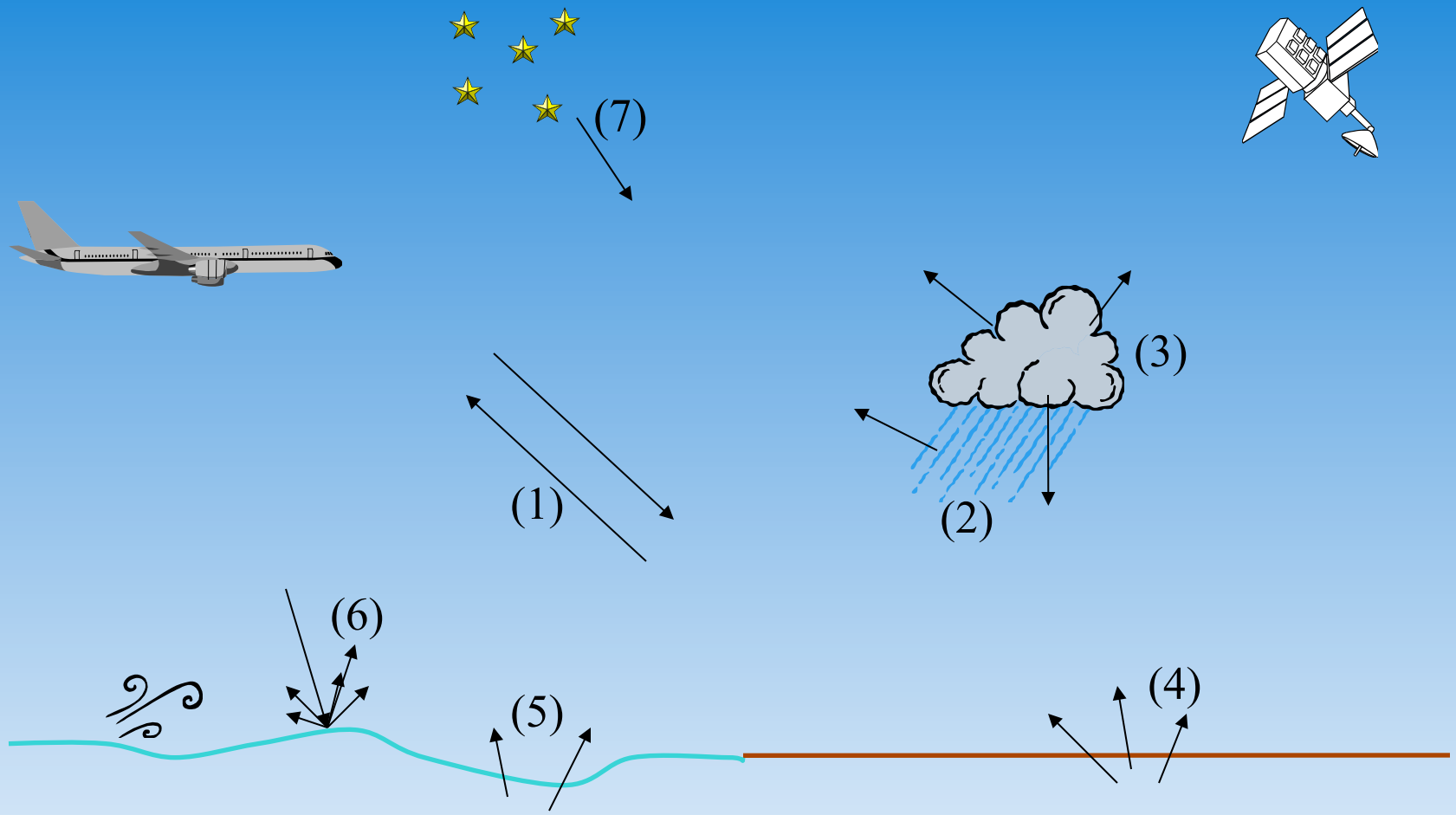


infared and microwave radiometers



radar and lidar

Natural sources of microwave radiation



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

Ocean Surface Remote Sensing

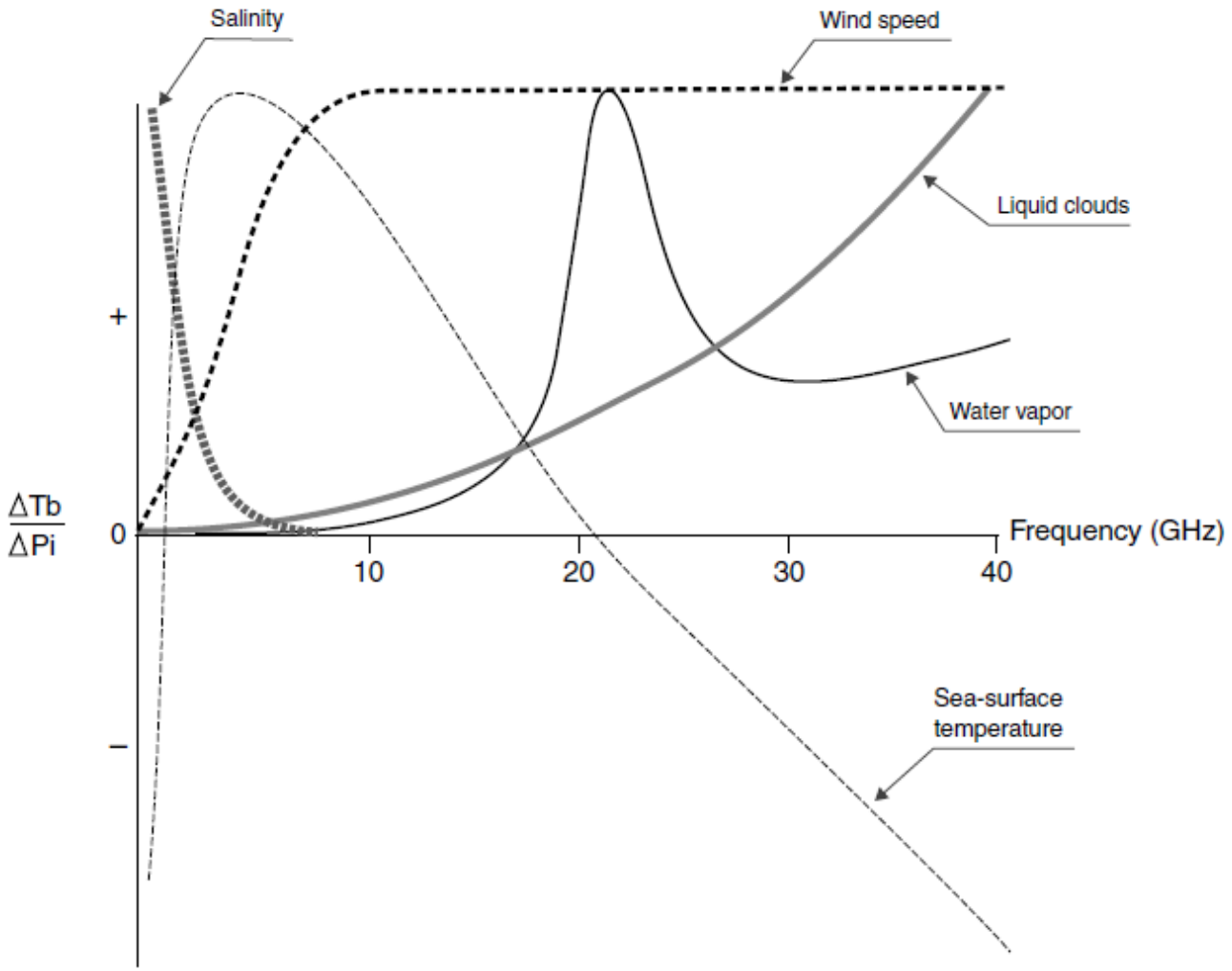


FIGURE 2.11 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over ocean surface).

Land Area Remote Sensing

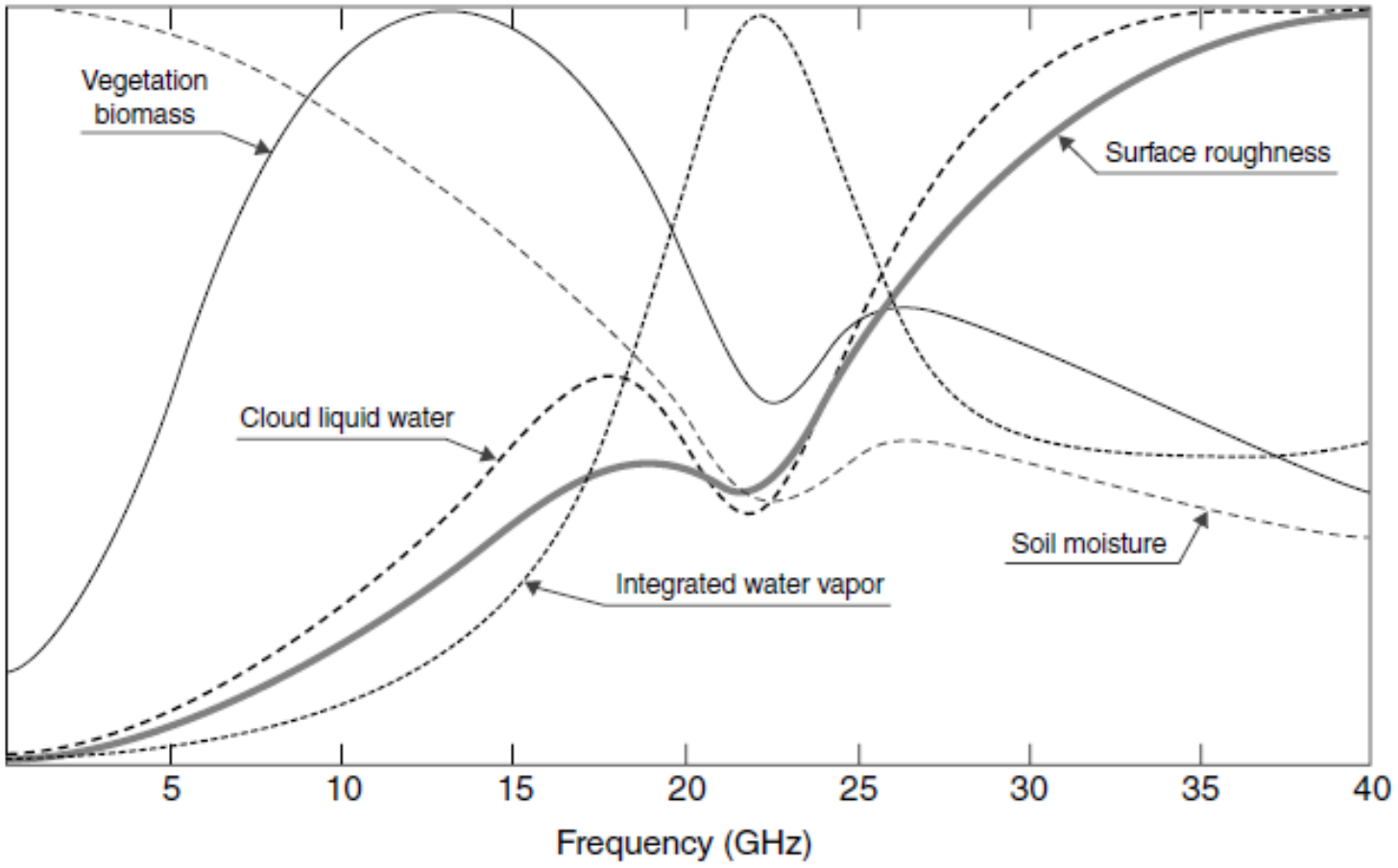
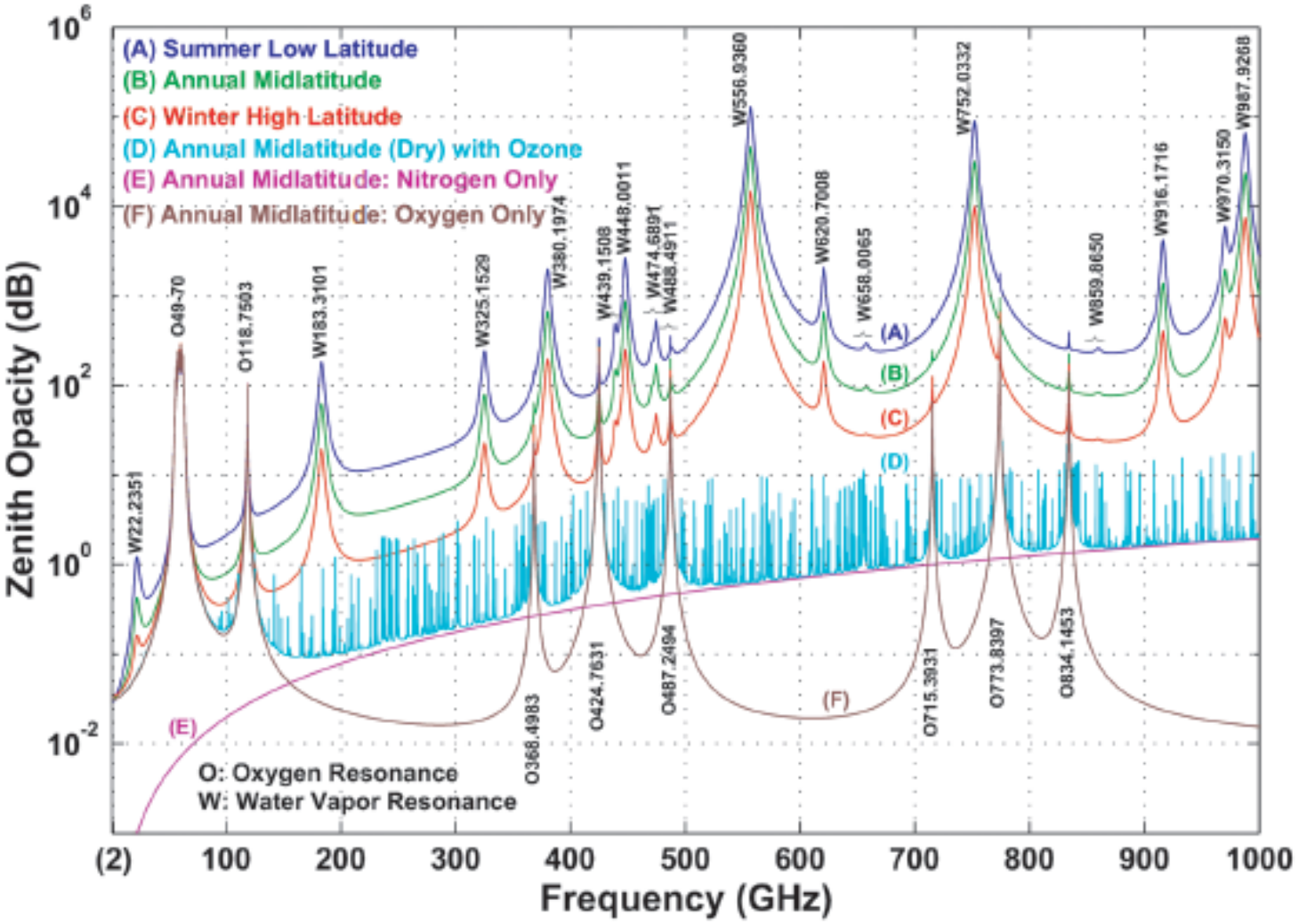


FIGURE 2.10 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over land surfaces).

Atmosphere to 1 THz



Major U.S. Passive Sensor Milestones

- 1972: NASA Nimbus-5 (NEMS and ESMR)
- 1973: NASA Skylab (S-194)
- 1975: NASA Nimbus-6 (SCAMS)
- 1978: NASA Nimbus-7 (SMMR)
- 1978: NOAA TIROS-N (MSU & SSU)
- 1987: USAF DMSP F8 (SSM/I)
- 1991: NASA UARS (MLS)
- 1997: NASA TRMM (TMI)
- 1998: NOAA-15 (AMSU)
- 2002: NASA EOS Aqua (JAXA AMSR-E)
- 2003: NRL Coriolis (WindSat)
- 2003: USAF DMSP F16 (SSMIS)
- 2004: NASA EOS Aura (MLS)
- 2010: NASA Aquarius/SAC-D (CONAE)
- 2011: NASA/NOAA NPP (ATMS)
- 2014: NASA GPM (GMI)
- 2015: NASA SMAP

EESS Organizations

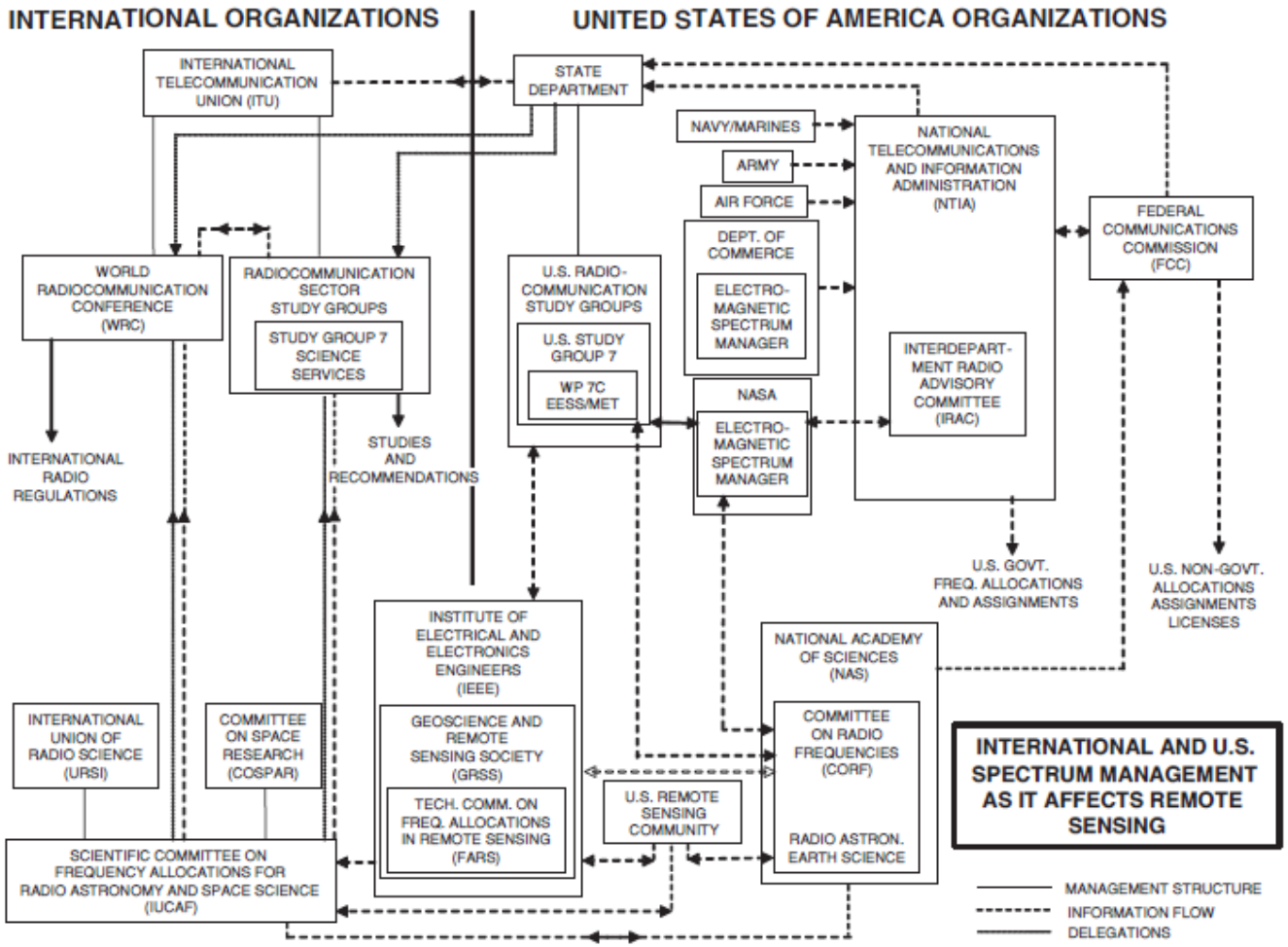
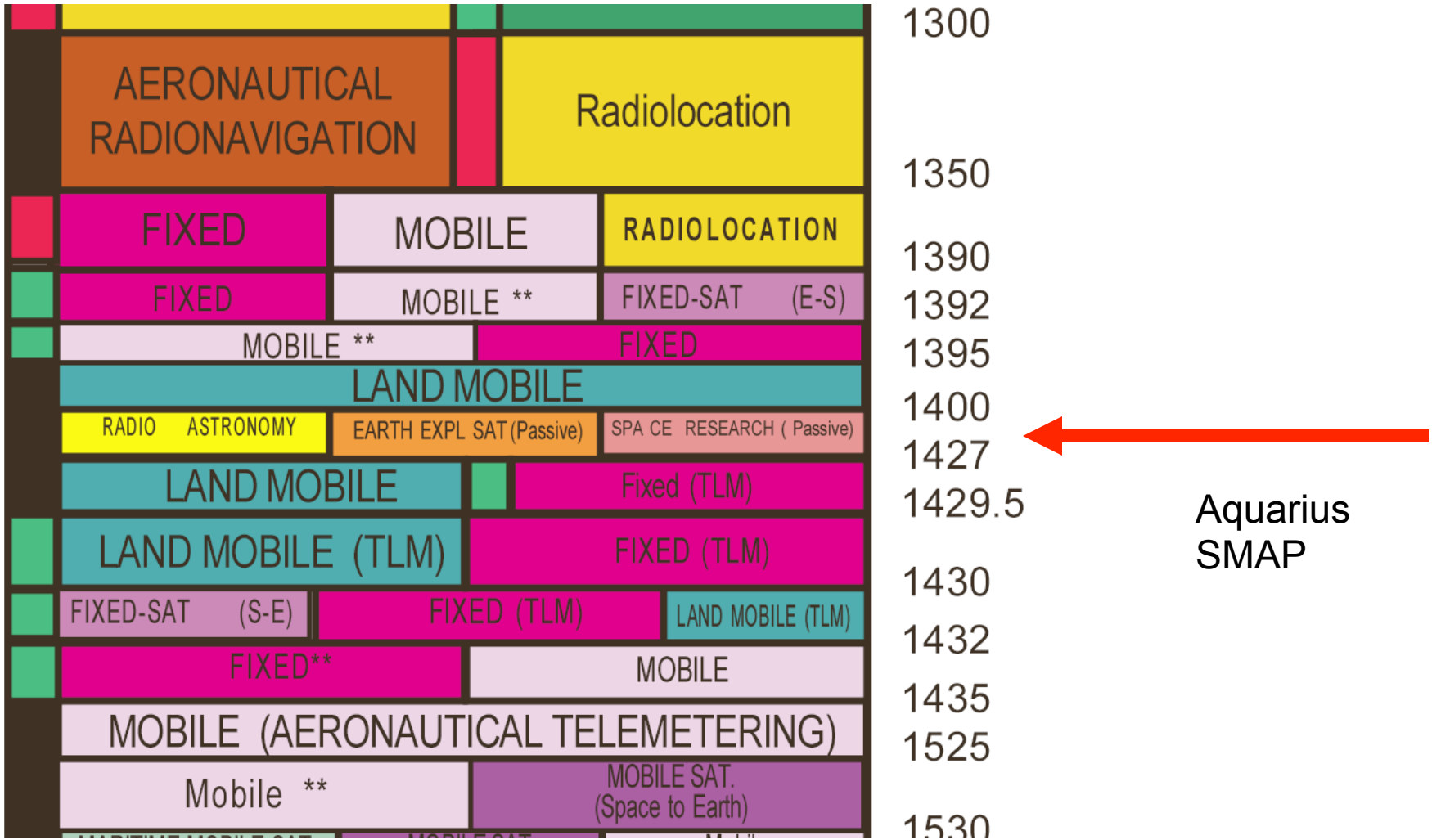


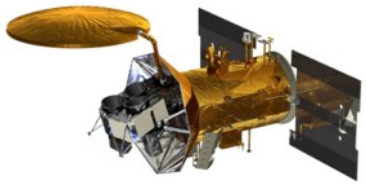
FIGURE 1.2 The diagram depicts the complex relationship among the national and international radio regulatory bodies for the Earth Exploration-Satellite Service.

L-band Allocation Allocations

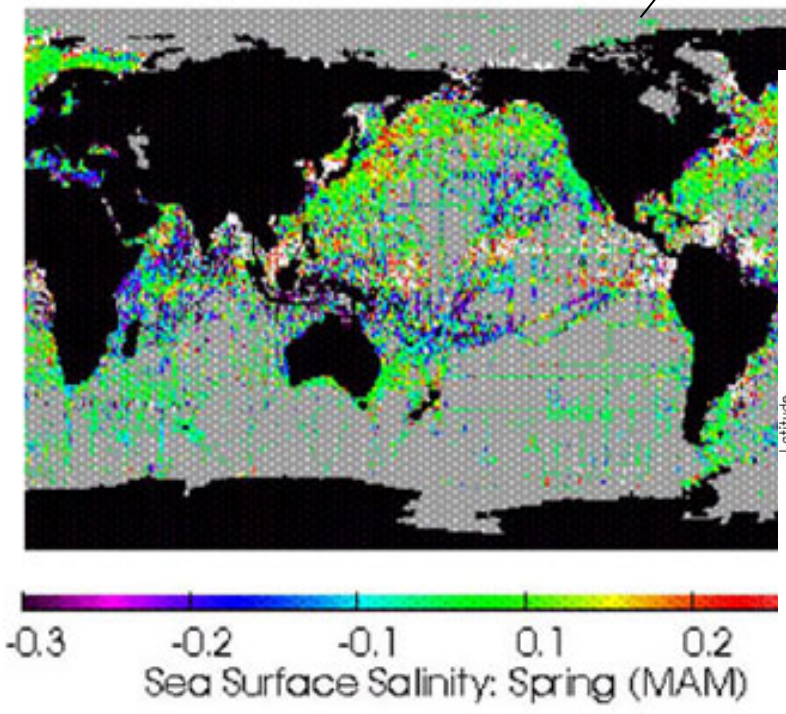


1 – 2 GHz (L-band)

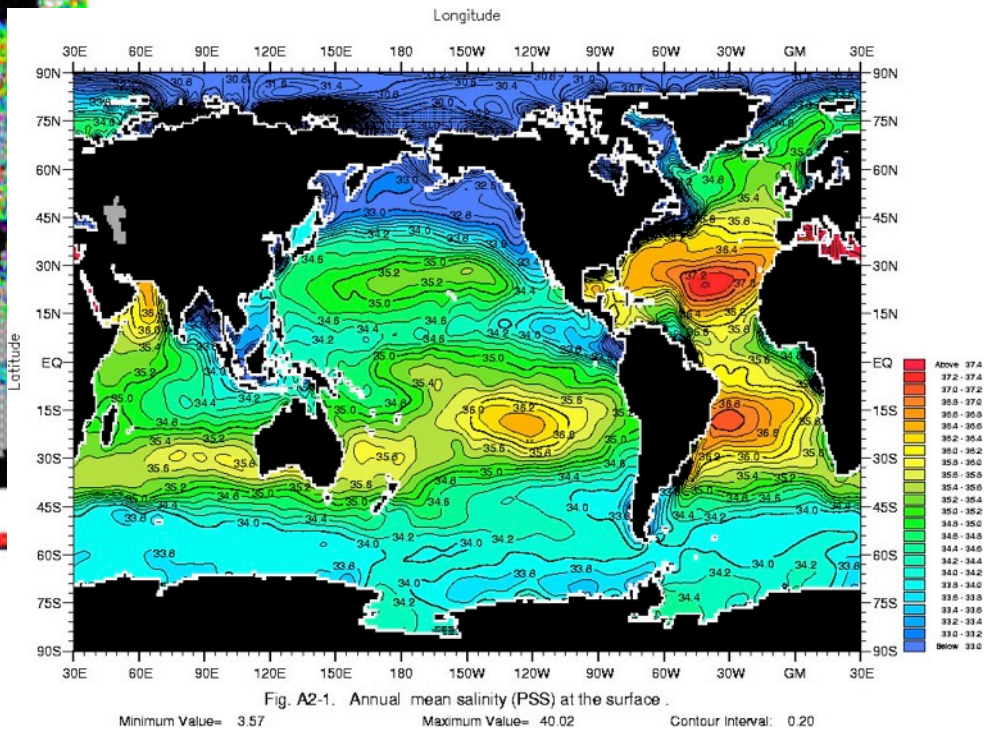
- Soil Moisture through vegetation
- Ocean Salinity



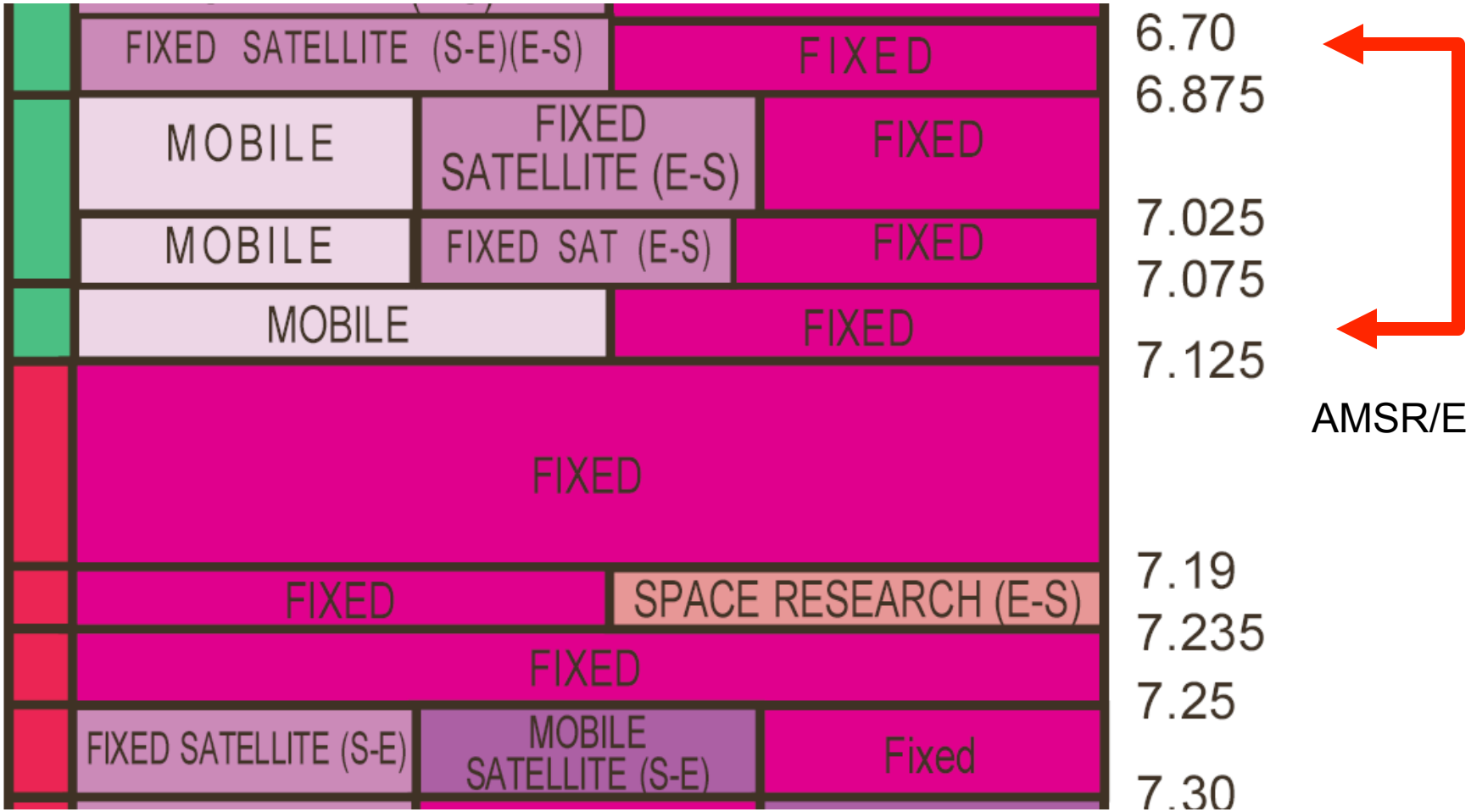
Aquarius/SAC-D



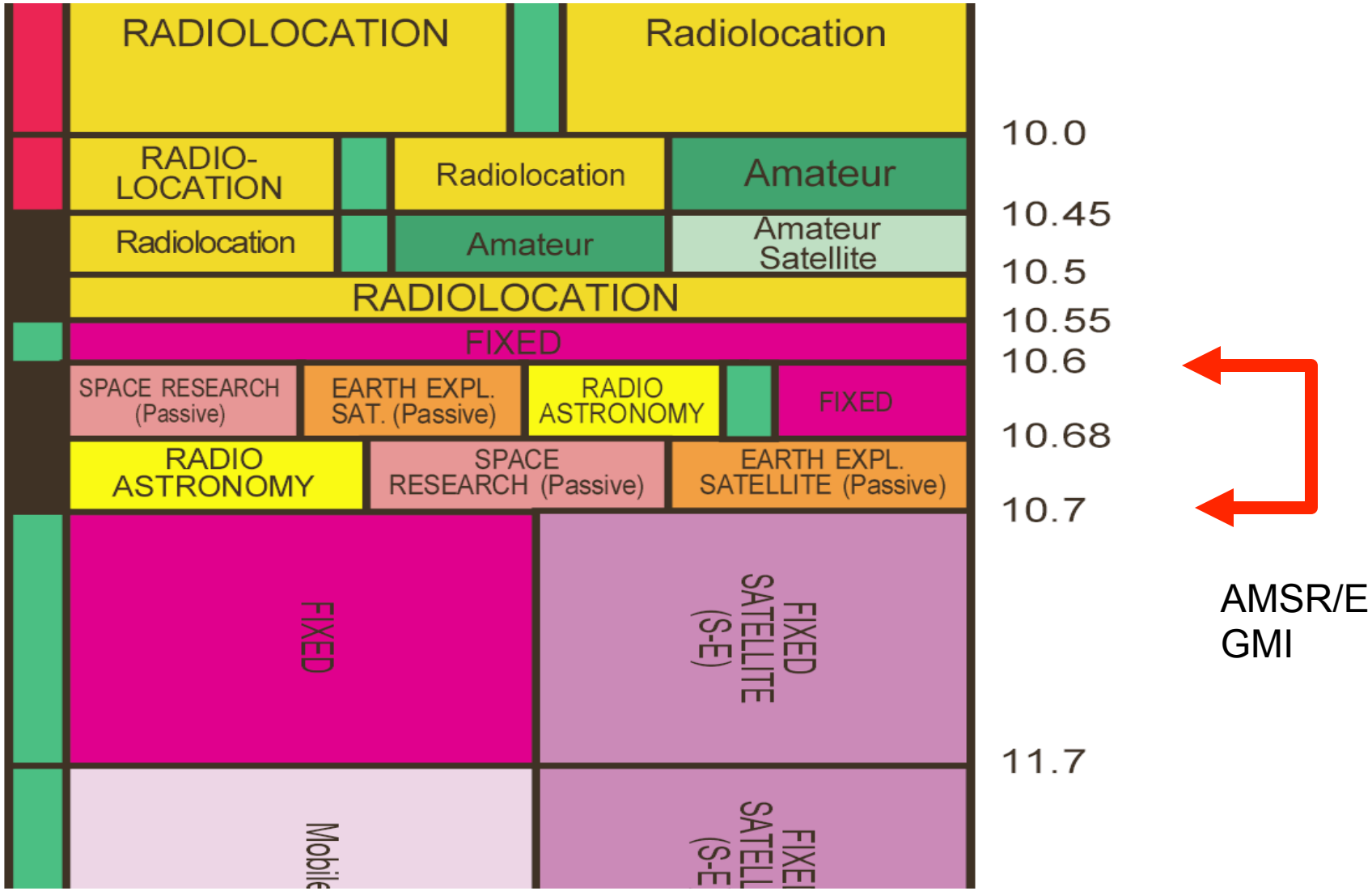
http://aquarius.nasa.gov/



C-band Allocations

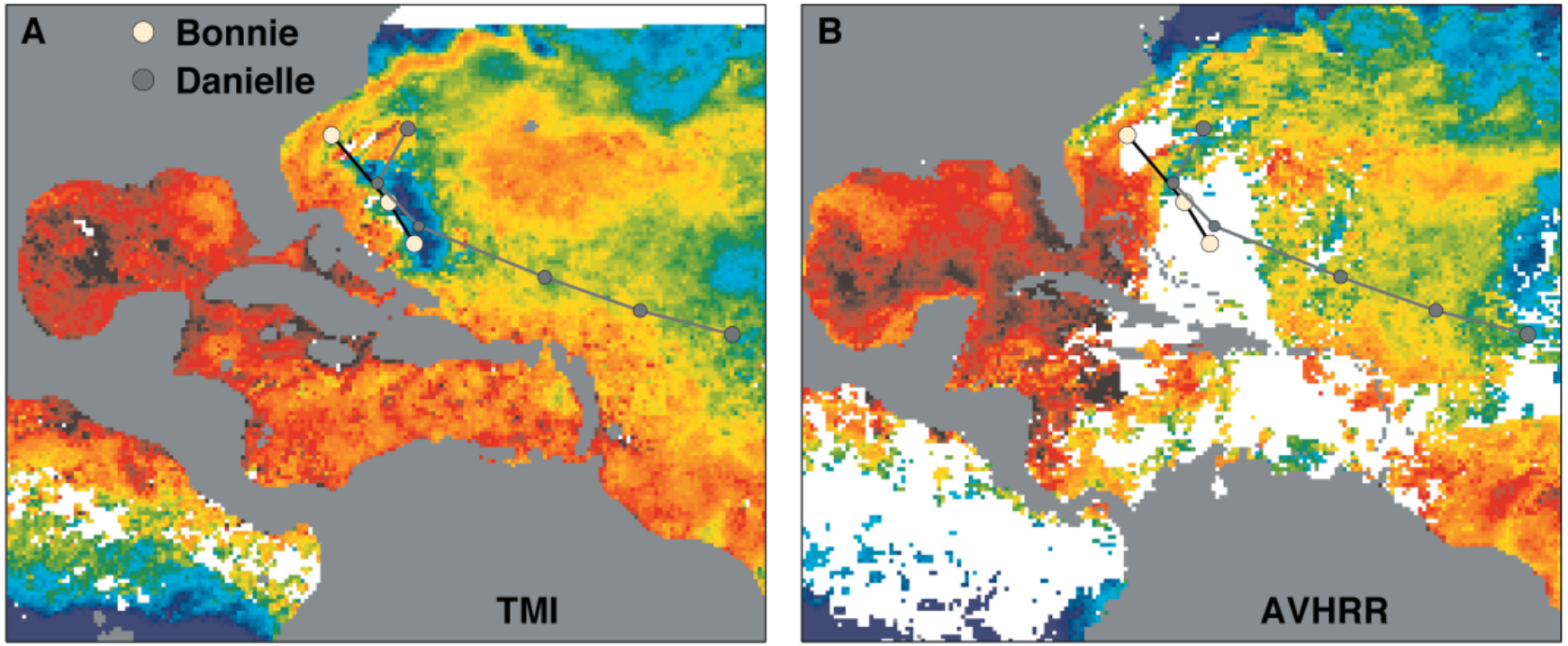


X-band Allocation



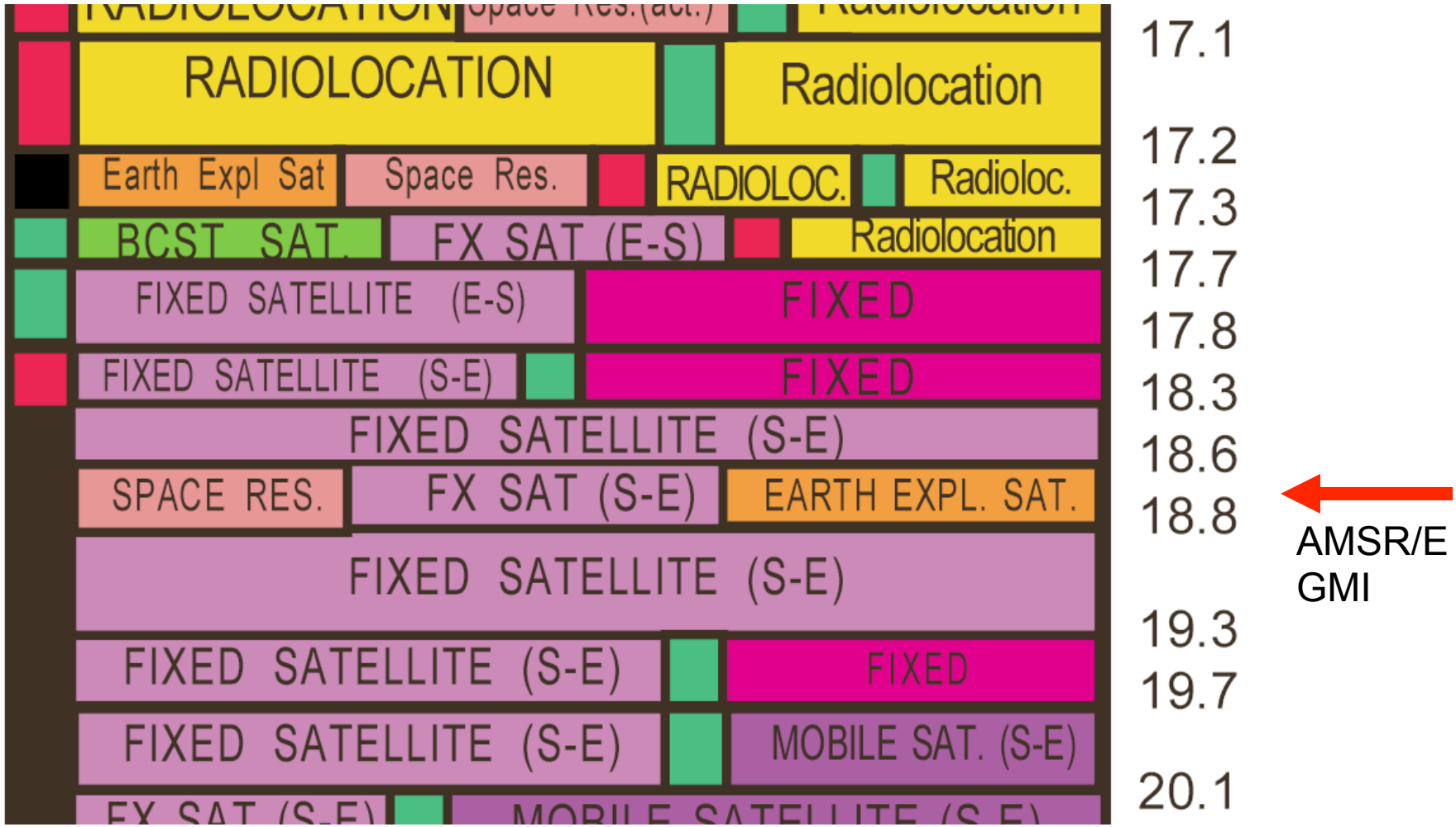
4 – 12 GHz (C, X-bands)

- Soil Moisture (light vegetation)
- Sea Surface Temperature

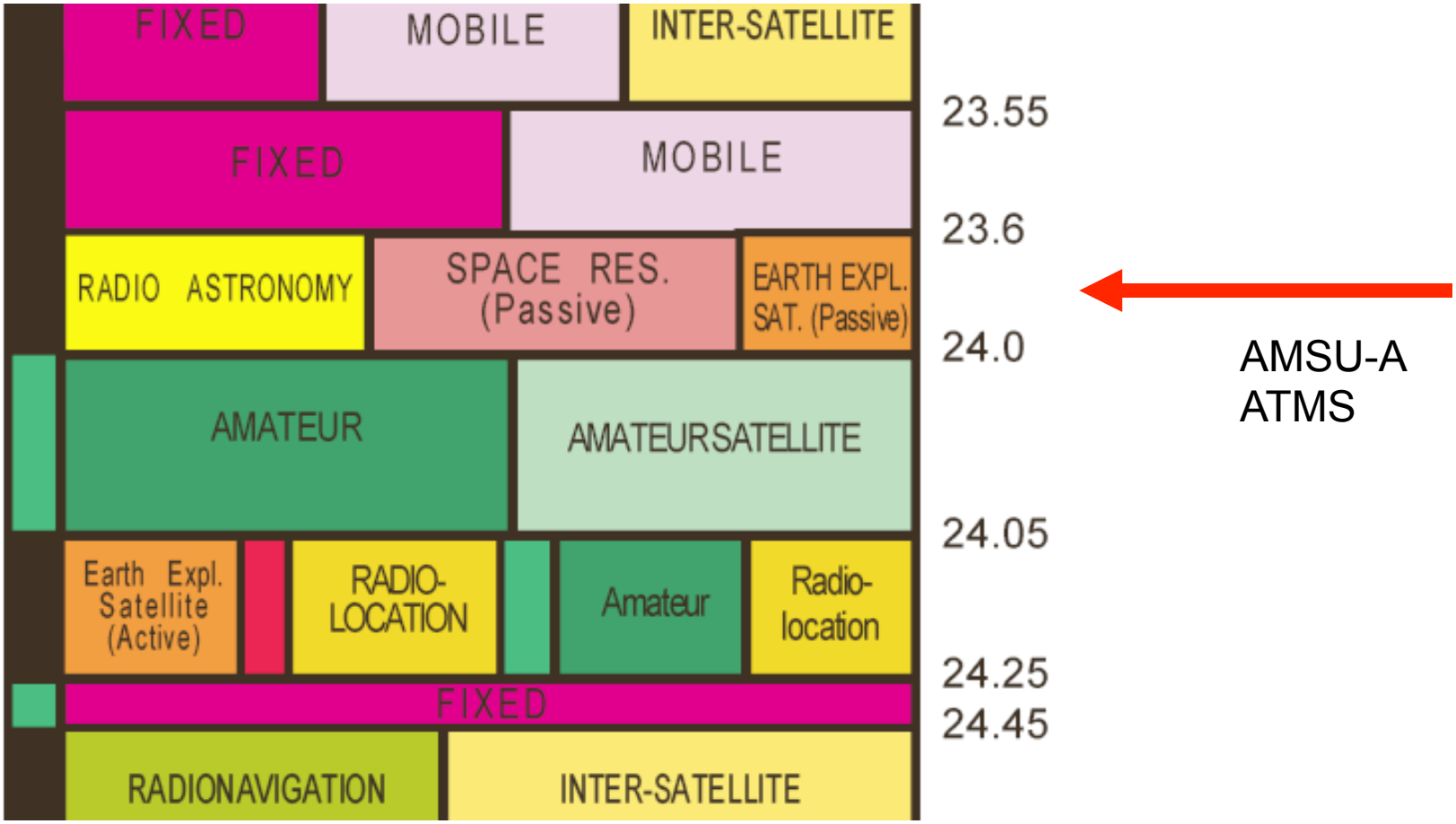


Wentz, FJ, CL Gentemann, DK Smith and others, 2000, Satellite measurements of sea surface temperature through clouds, *Science*, 288, 847-850.

K band Allocation

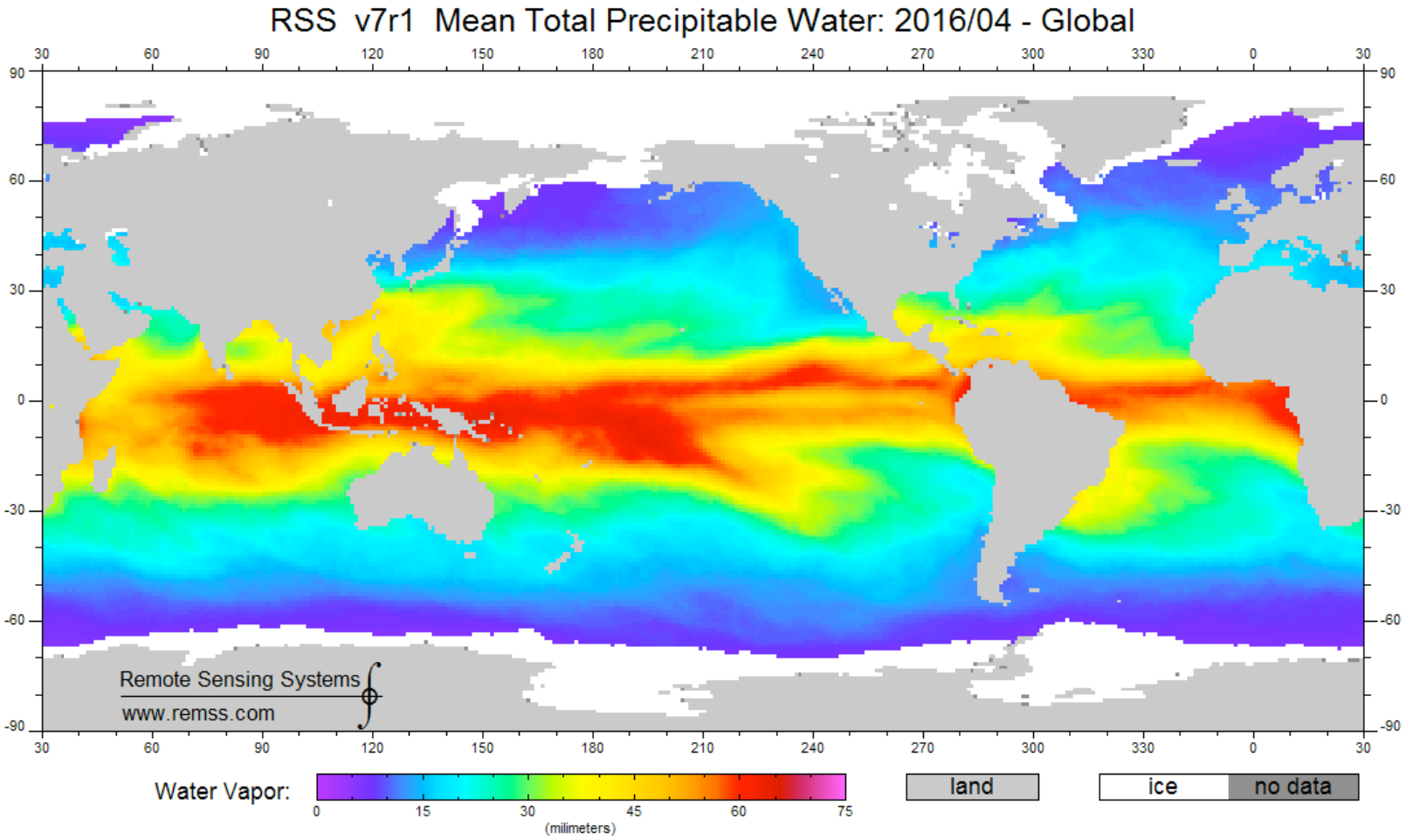


K-band (water vapor) Allocations



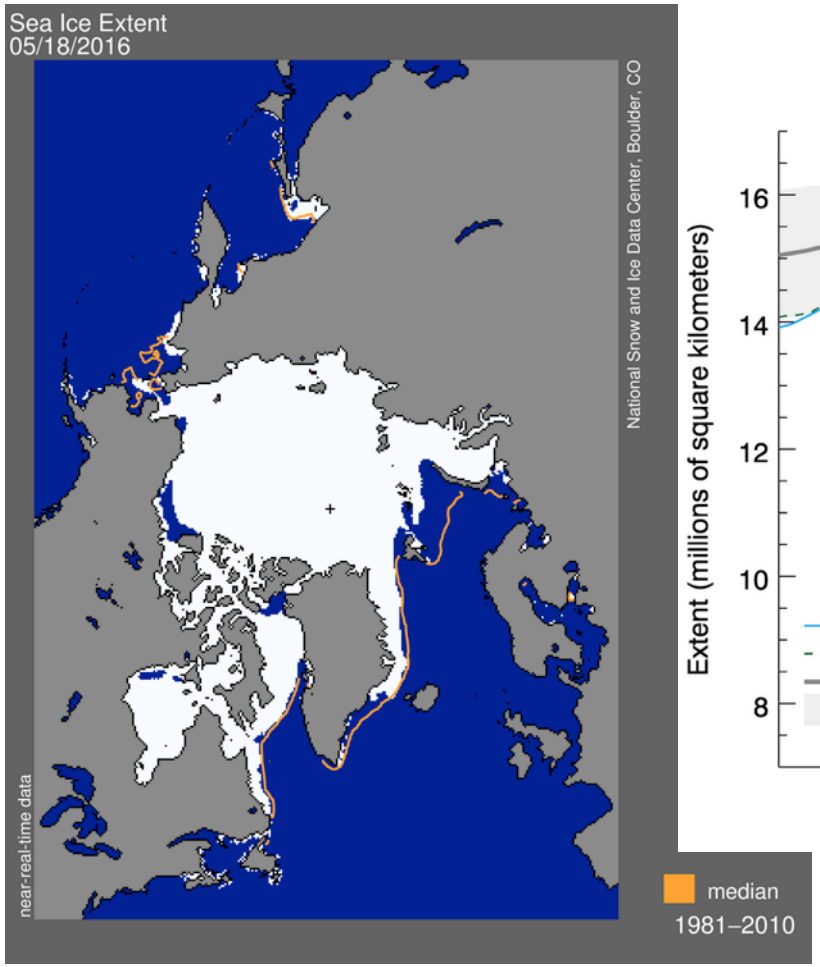
8 – 40GHz (X, Ku, K and Ka bands)

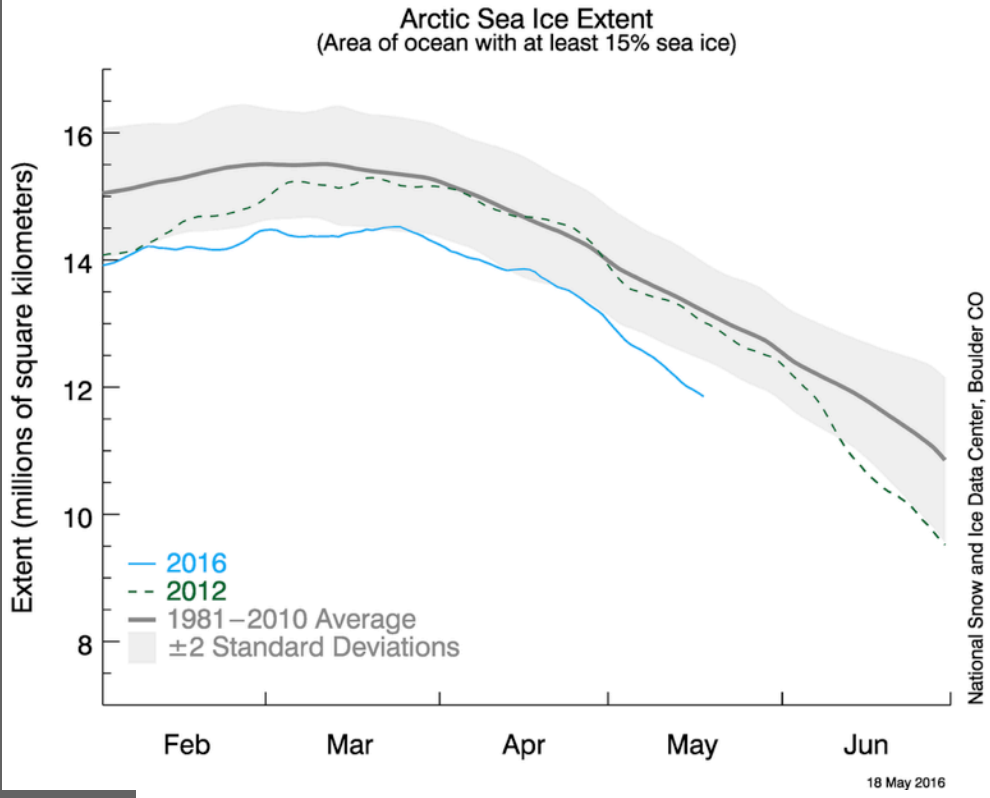
- Snow, sea ice, precipitation, clouds
- Ocean winds
- Water vapor



18 – 40 GHz (K andKa bands)

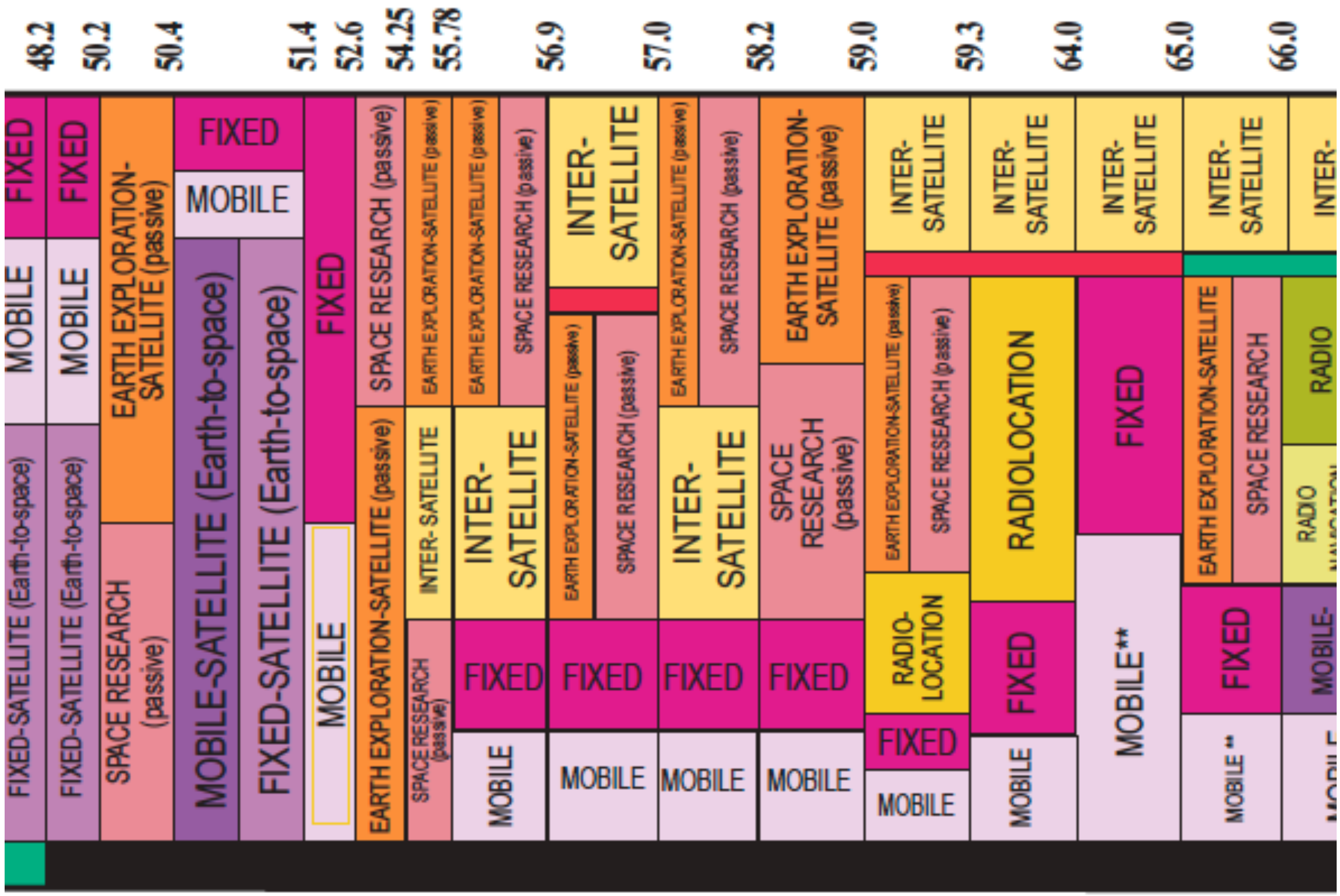
- Snow water equivalent, sea ice, precipitation, clouds
- Ocean winds





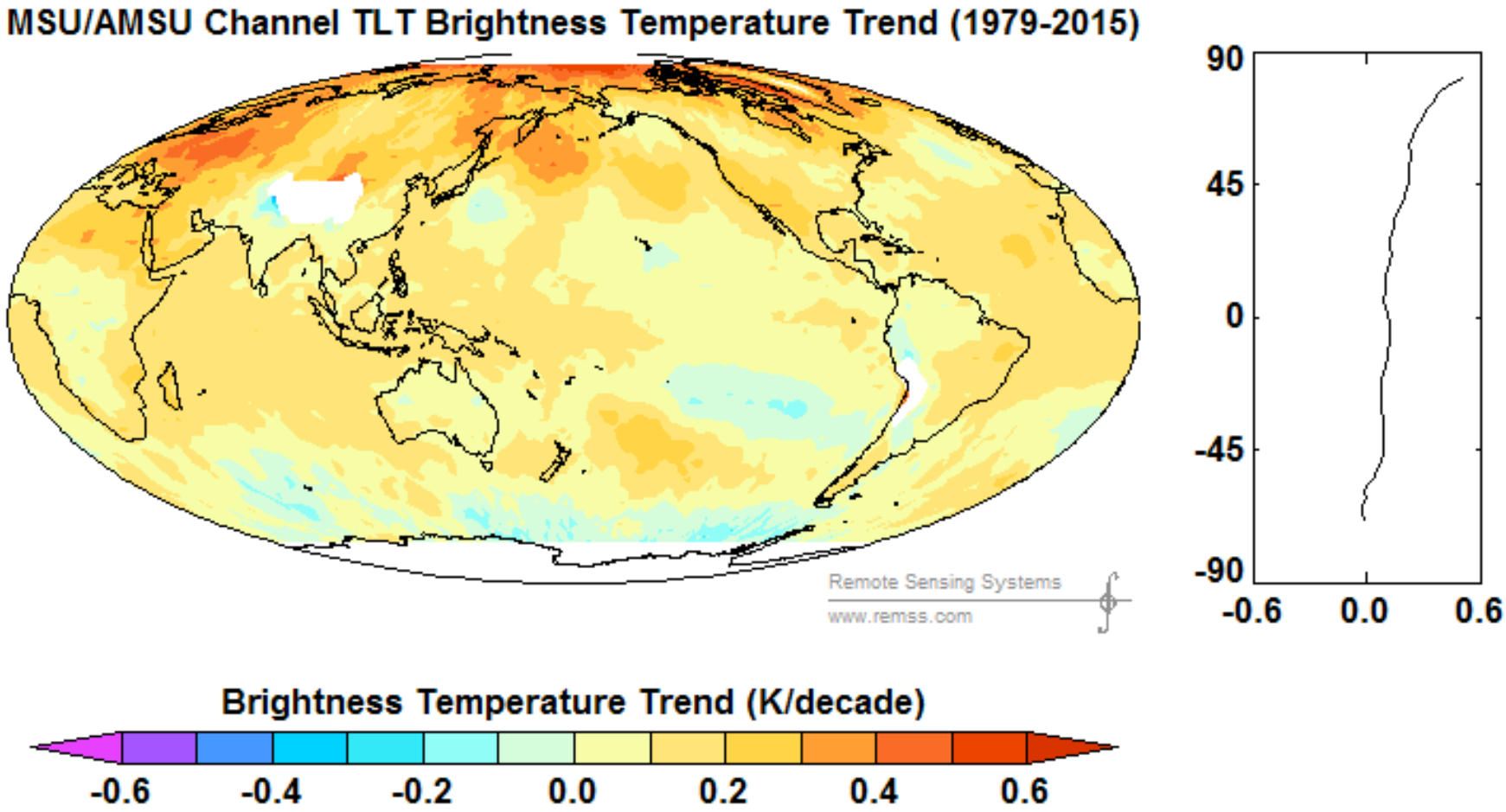
http://nsidc.org/arcticseaicenews/

V Band Allocation

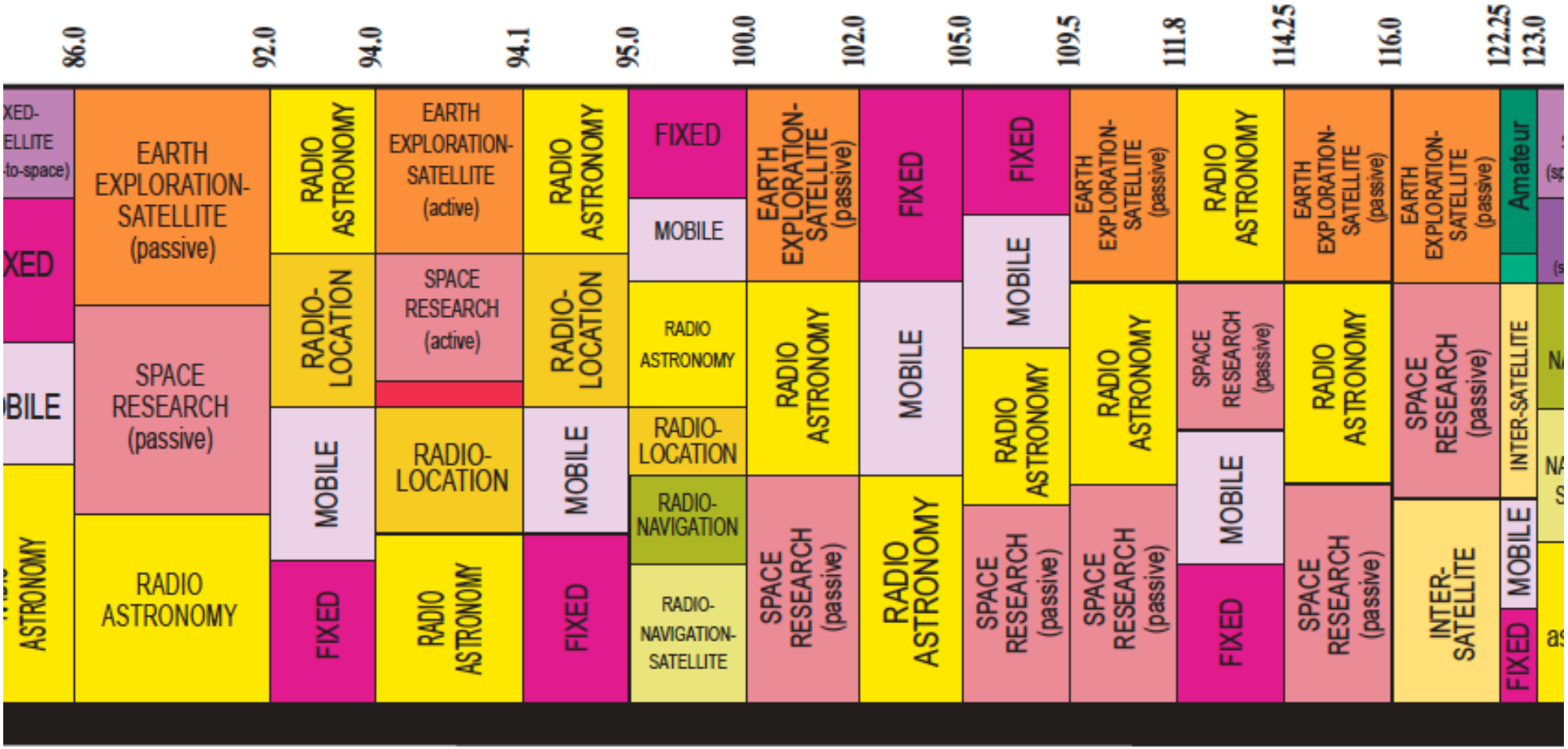


40 – 75 GHz (V band)

- Atmospheric temperature

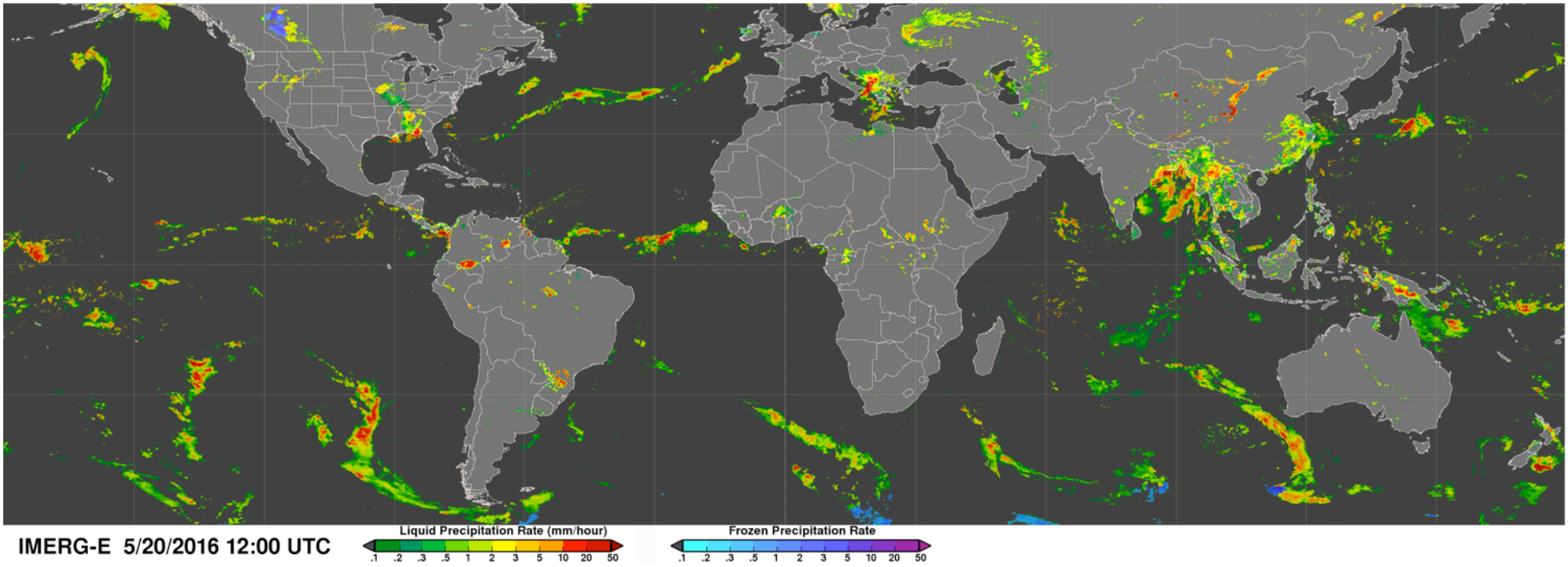


W-Band Allocations

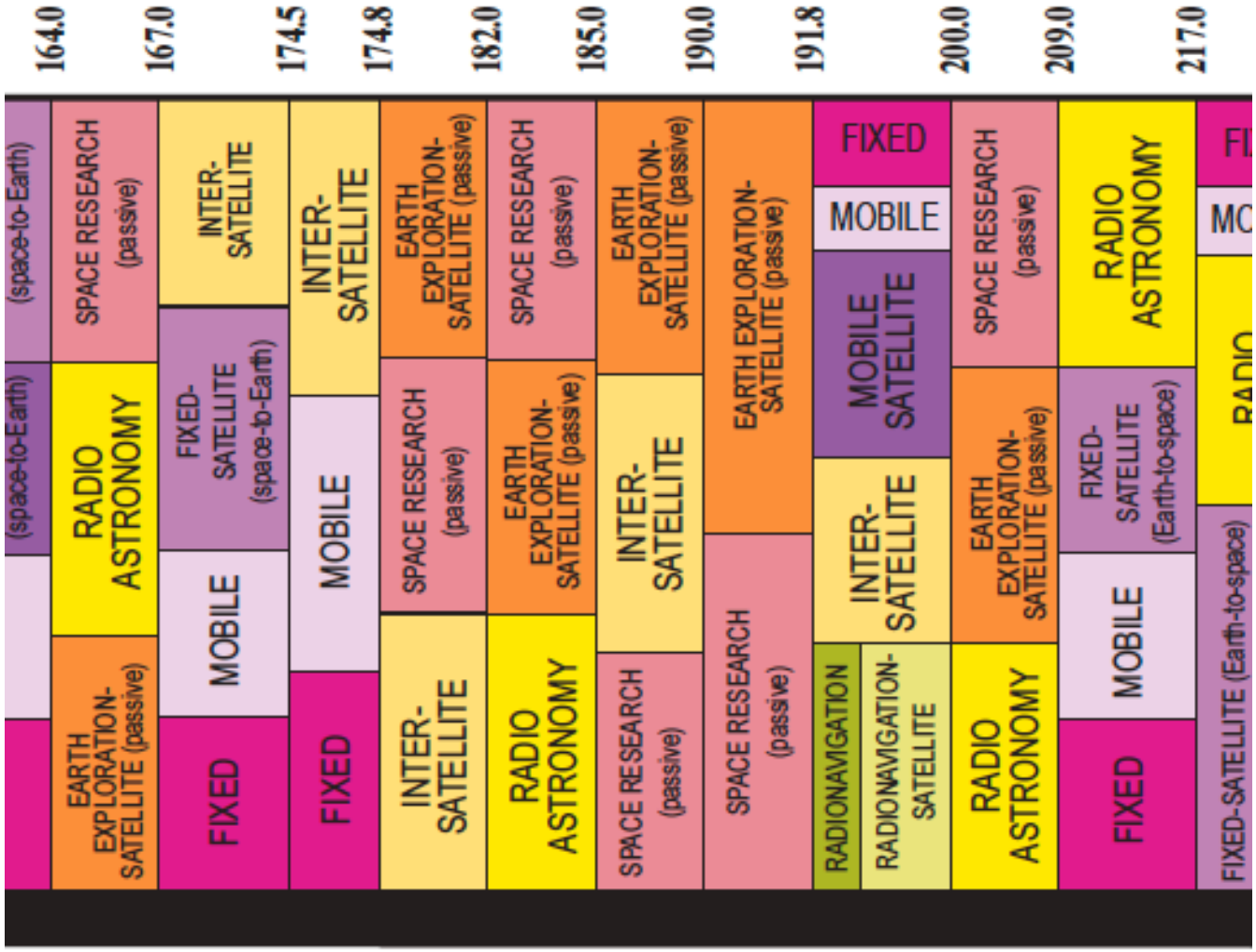


75 – 110 GHz (W band)

- Precipitation, hurricane intensity, clouds



G-band Allocations (subset)

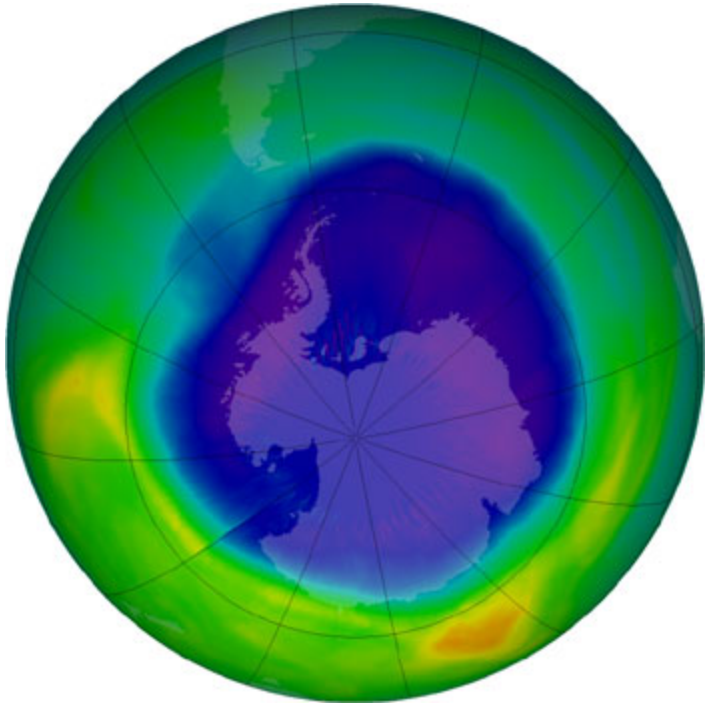


110 – 300 GHz (G Band)

- Precipitation, clouds
- Atmospheric Temperature
- Water vapor
- Atmospheric chemistry

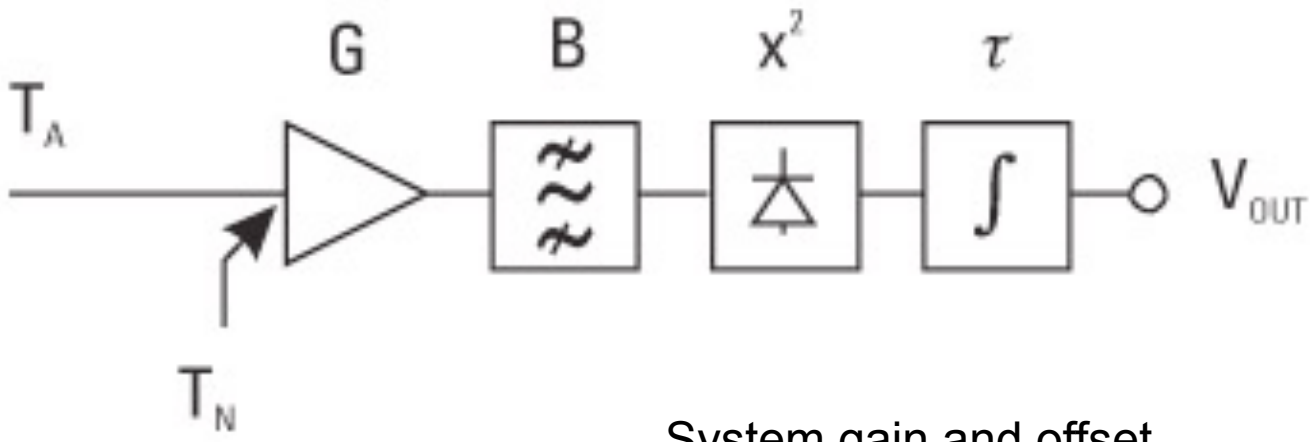
Data from NASA's Earth-observing Aura satellite show that the ozone hole peaked in size on Sept. 13, reaching a maximum area extent of 9.7 million square miles – just larger than the size of North America. That's "pretty average," says Paul Newman, an atmospheric scientist at NASA Goddard Space Fight Center, when compared to the area of ozone holes measured over the last 15 years. Still, the extent this year was "very big," he says, compared to 1970s when the hole did not yet exist.

http://www.nasa.gov/vision/earth/environment/ozone_resource_page.html



Radiometer Basics

- Basic Total Power Radiometer



System gain and offset

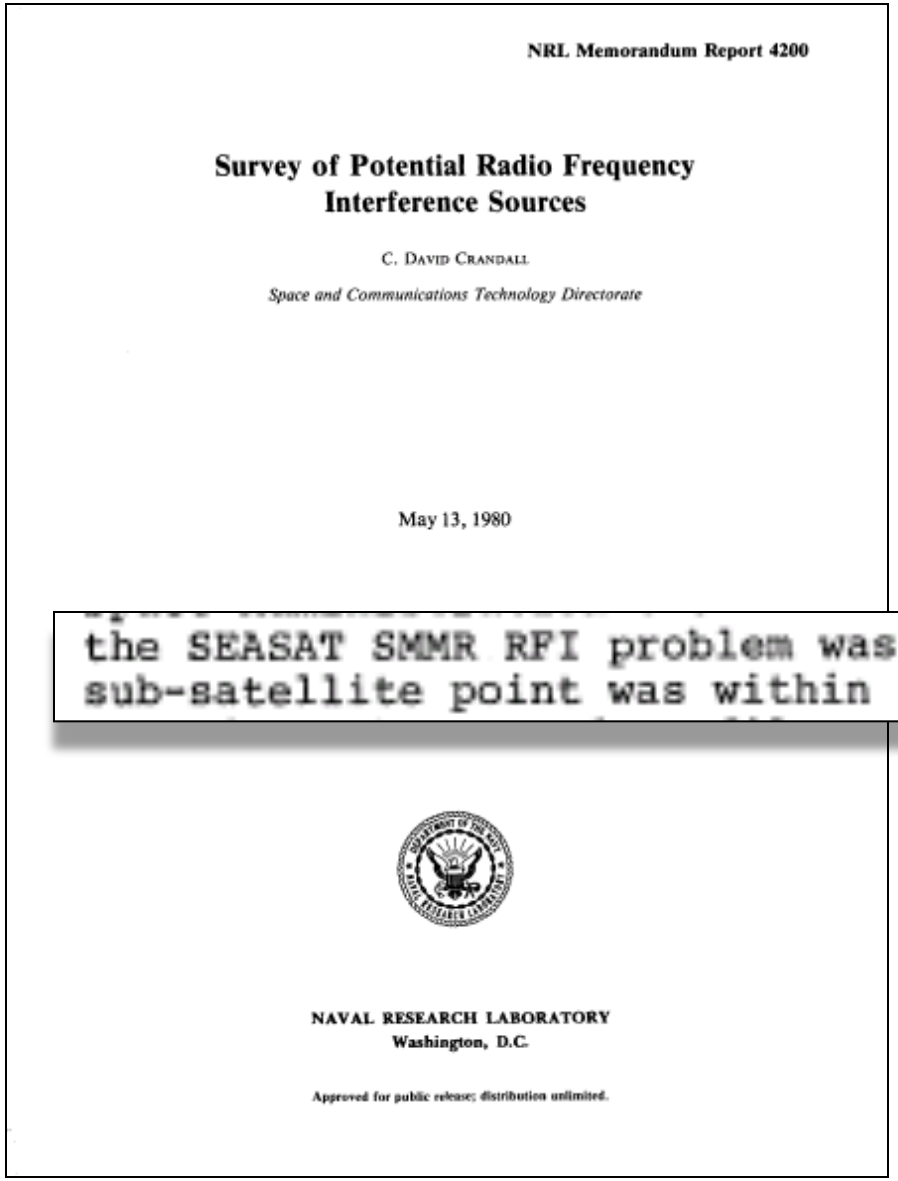
$$< V_{out} >= (T_A + T_N)kBGc$$

Want T_A

What happens when anthropogenic signals enter the passband?

David LeVine
http://www.globalspec.com/reference/70770/203279/chapter-4-radiometer-principles

First Spaceborne Radiometer RFI



NRL Memorandum Report 4200

Survey of Potential Radio Frequency Interference Sources

C. David Crandall

Space and Communications Technology Directorate

May 13, 1980

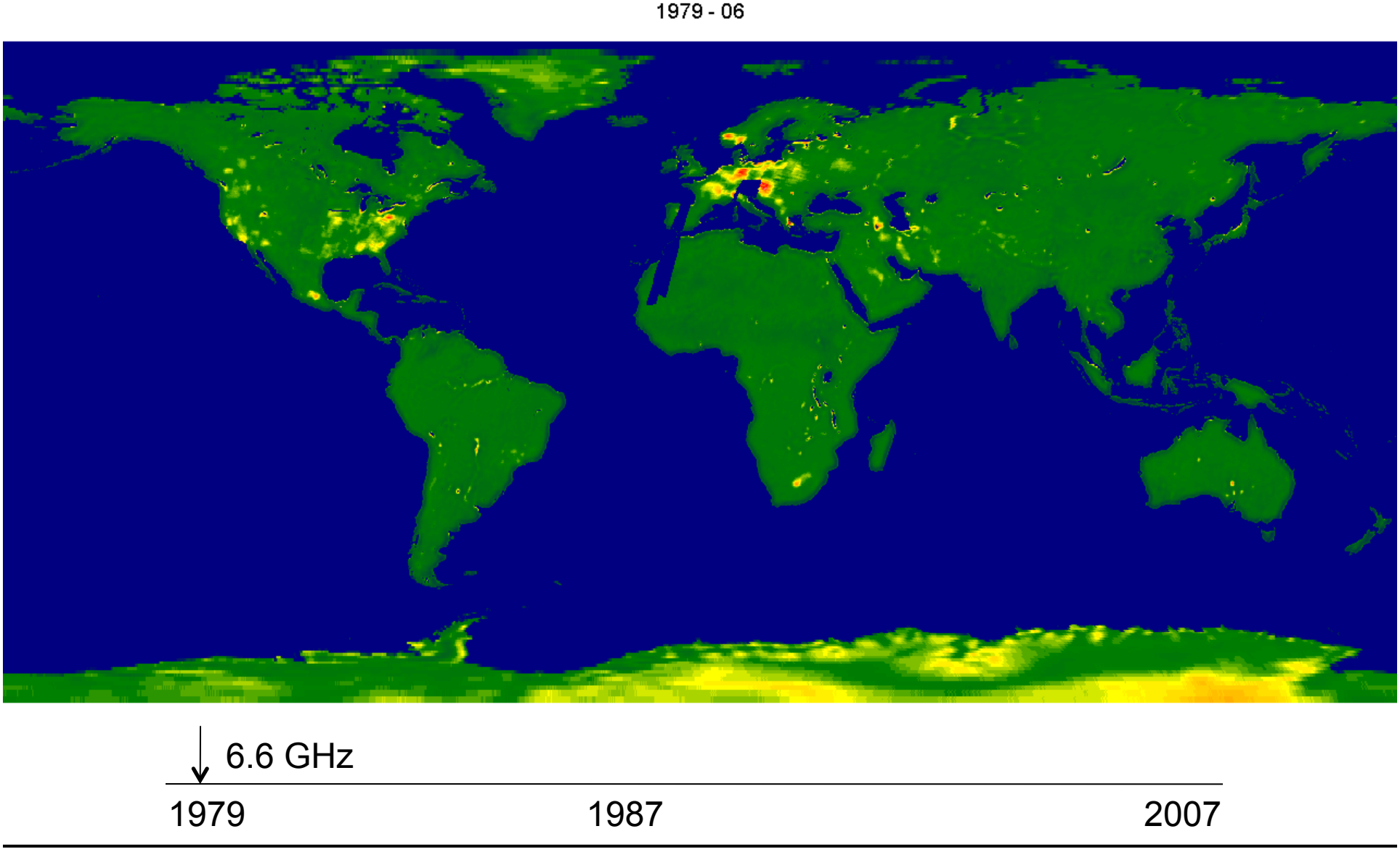
the SEASAT SMMR RFI problem was observed when even satellite sub-satellite point was within 500 nautical miles of the coast.

NAVAL RESEARCH LABORATORY
Washington, D.C.

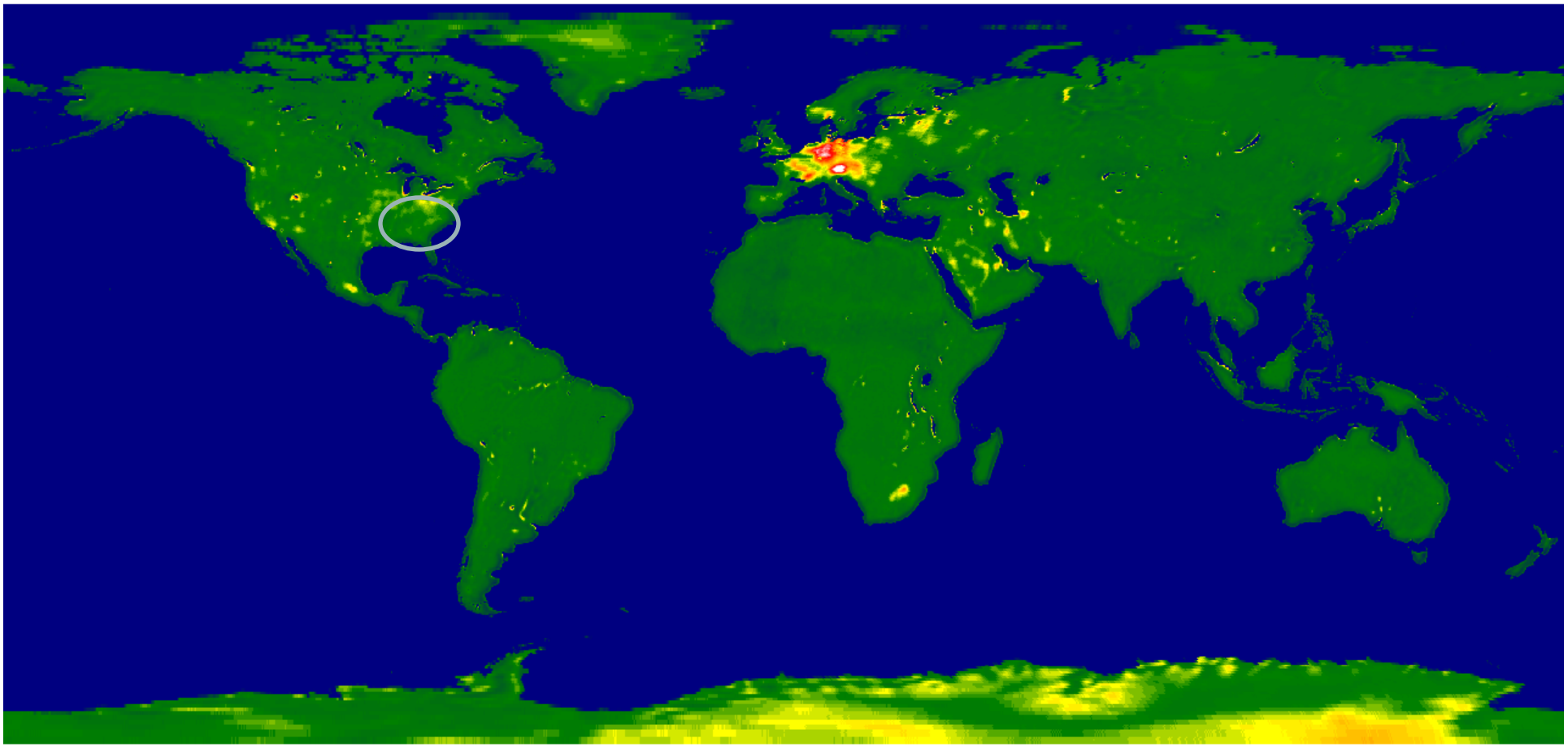
Approved for public release; distribution unlimited.

- SMMR: 1978-1987
- 6.5-6.7 GHz passband
- Fixed & mobile services
- West coast of N. America

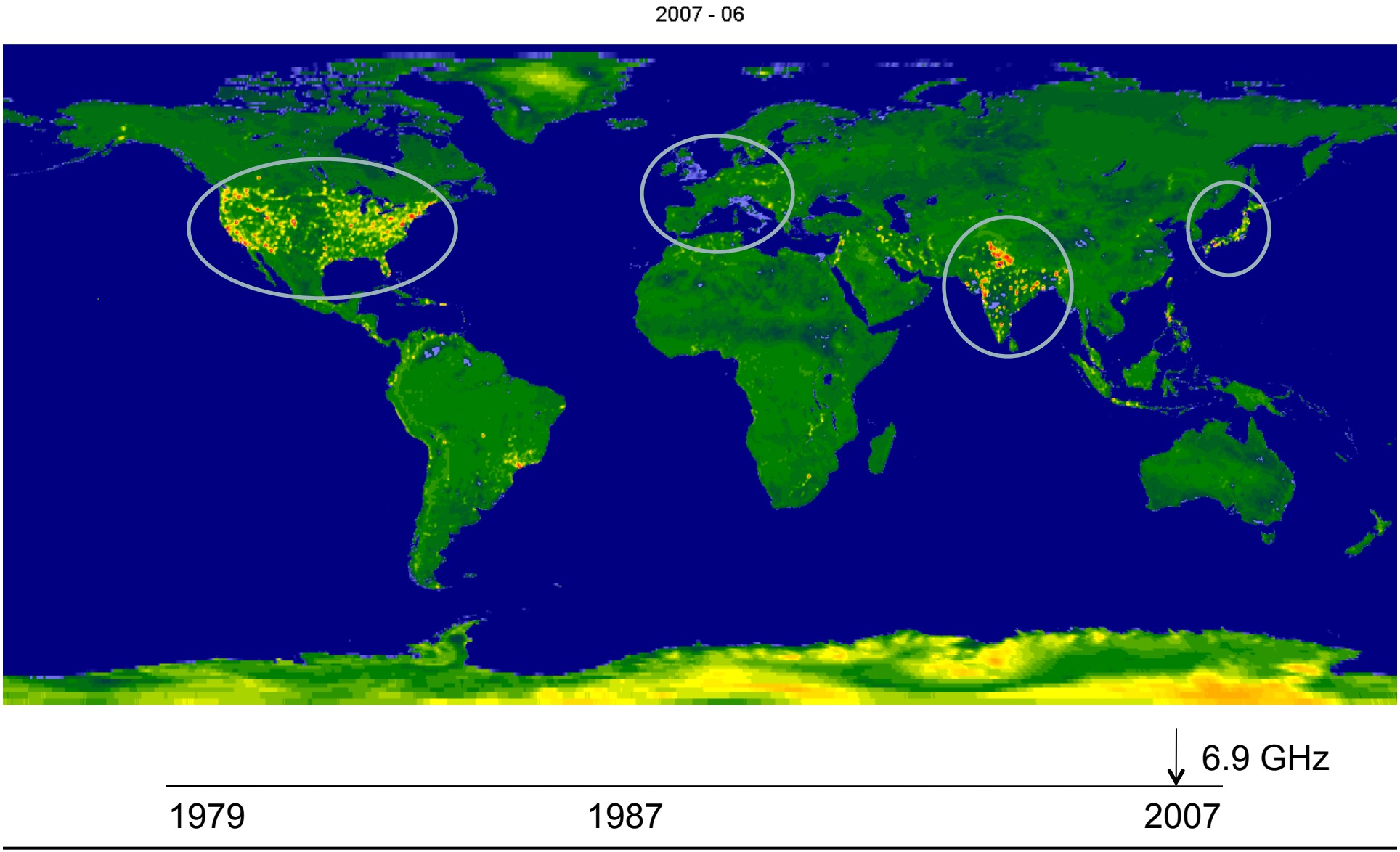
Evolution of C- and X-band Global RFI



Evolution of C- and X-band Global RFI

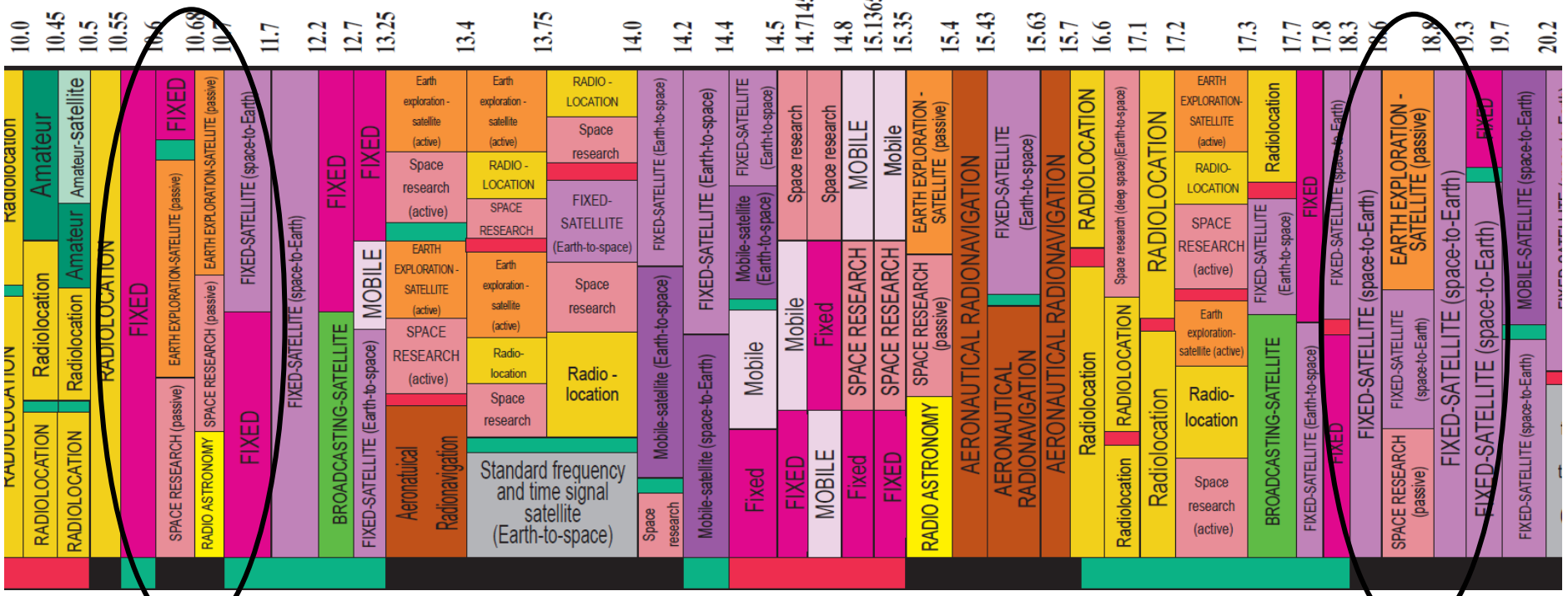


Evolution of C- and X-band Global RFI

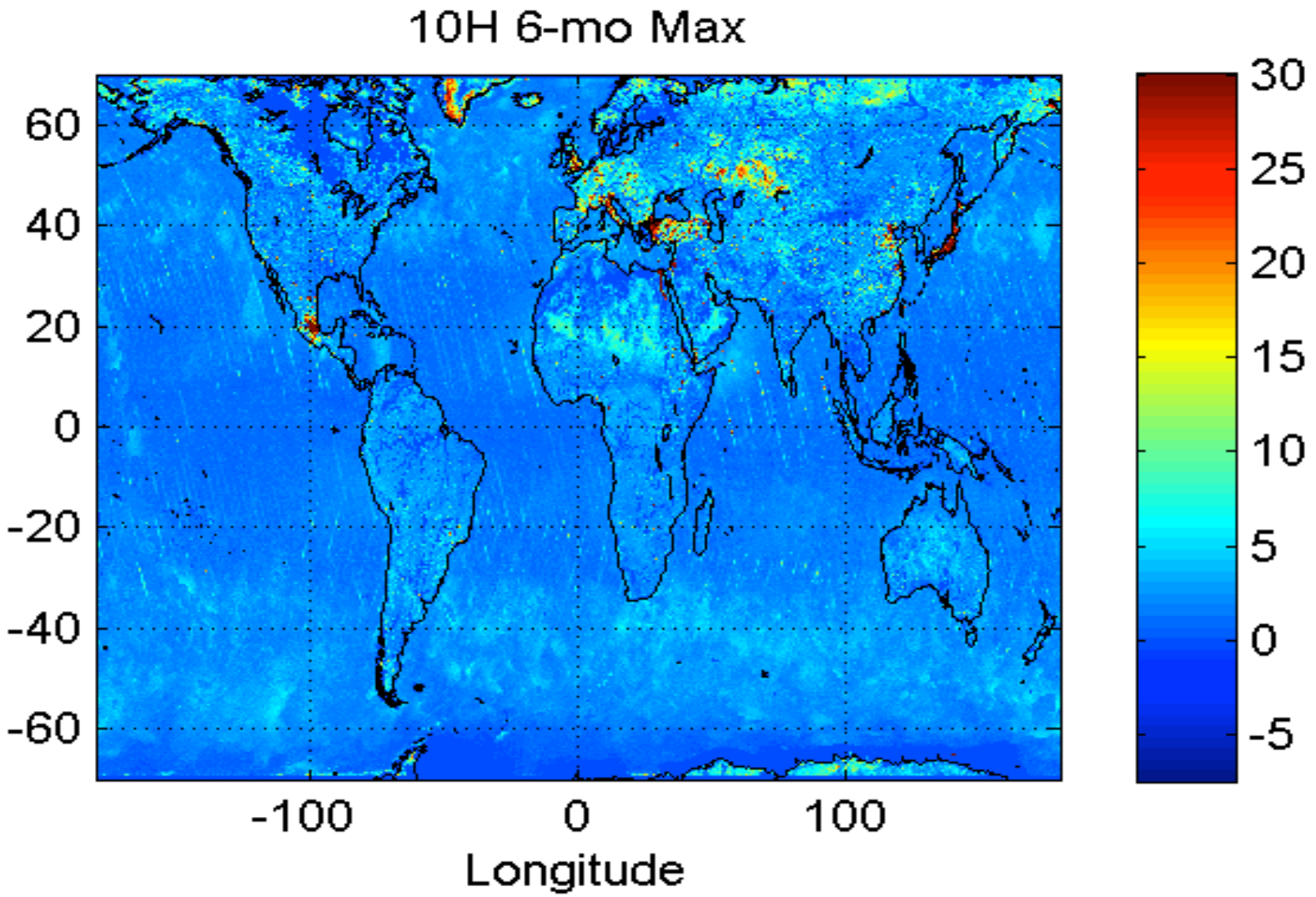


GMI Spectral Allocations

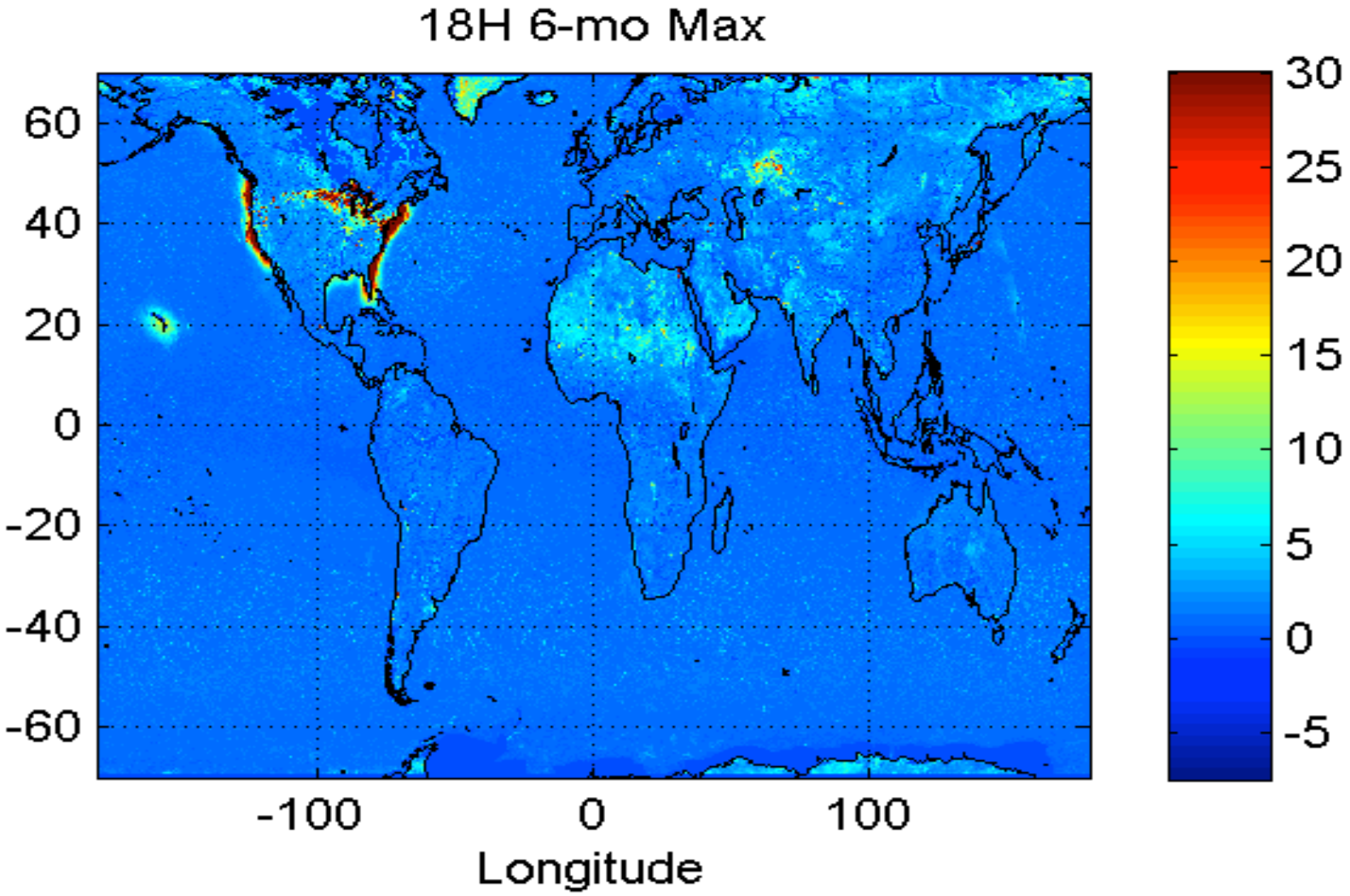
- NTIA Spectral Allocations are shown below
  - 10.6 to 10.7 GHz band is shared with “FIXED” (i.e. ground) transmitters
  - 10.7 GHz neighbors “Fixed Satellite” (space to earth)
  - 18.6 to 18.8 GHz band is shared with “Fixed Satellite” (space to earth)
- These allocations suggest that the 10 and 18 GHz channels should expect corruption in the earth and cold views



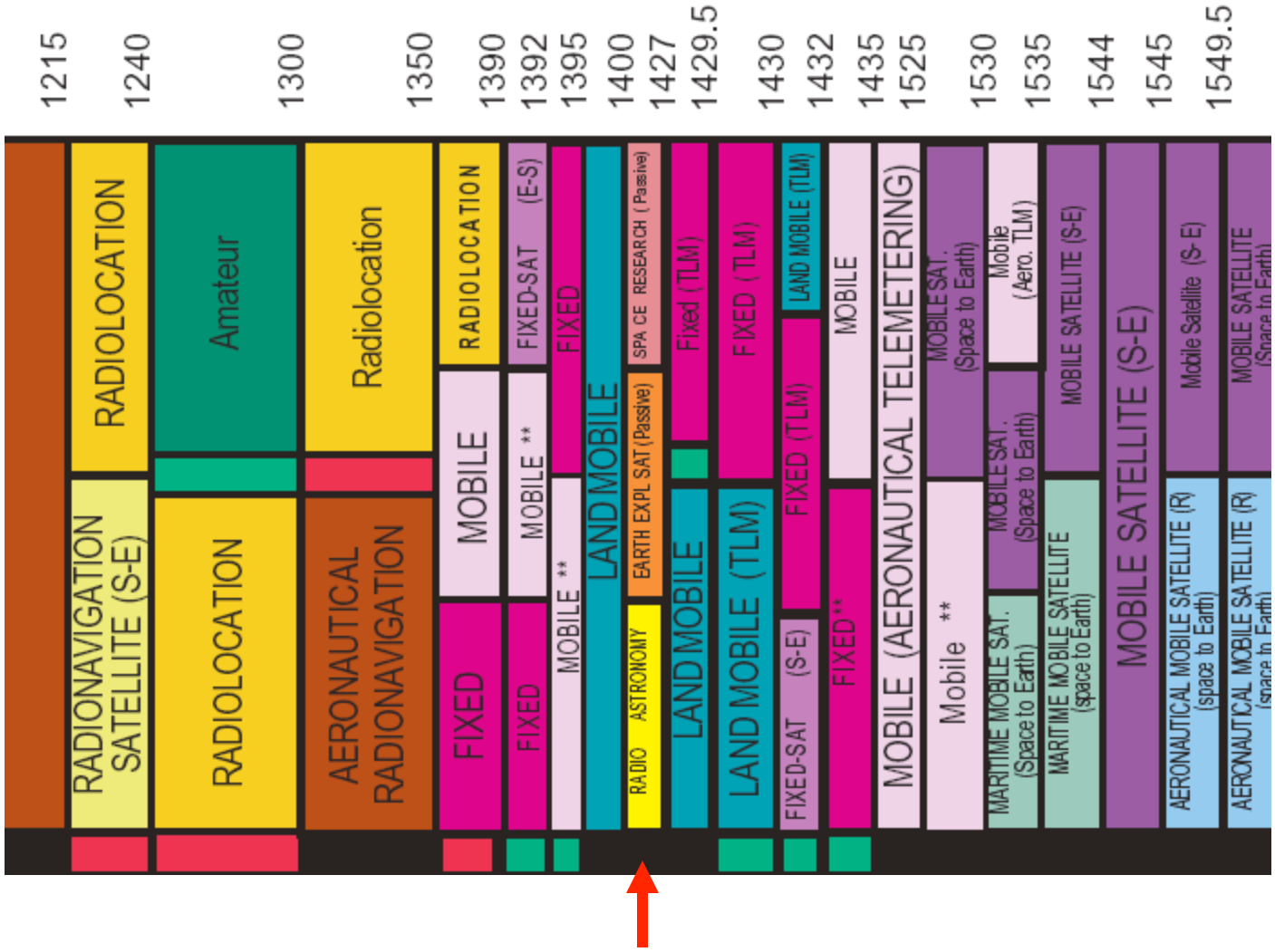
GMI - 10 GHz RFI Map)



GMI - 18 GHz RFI Maps



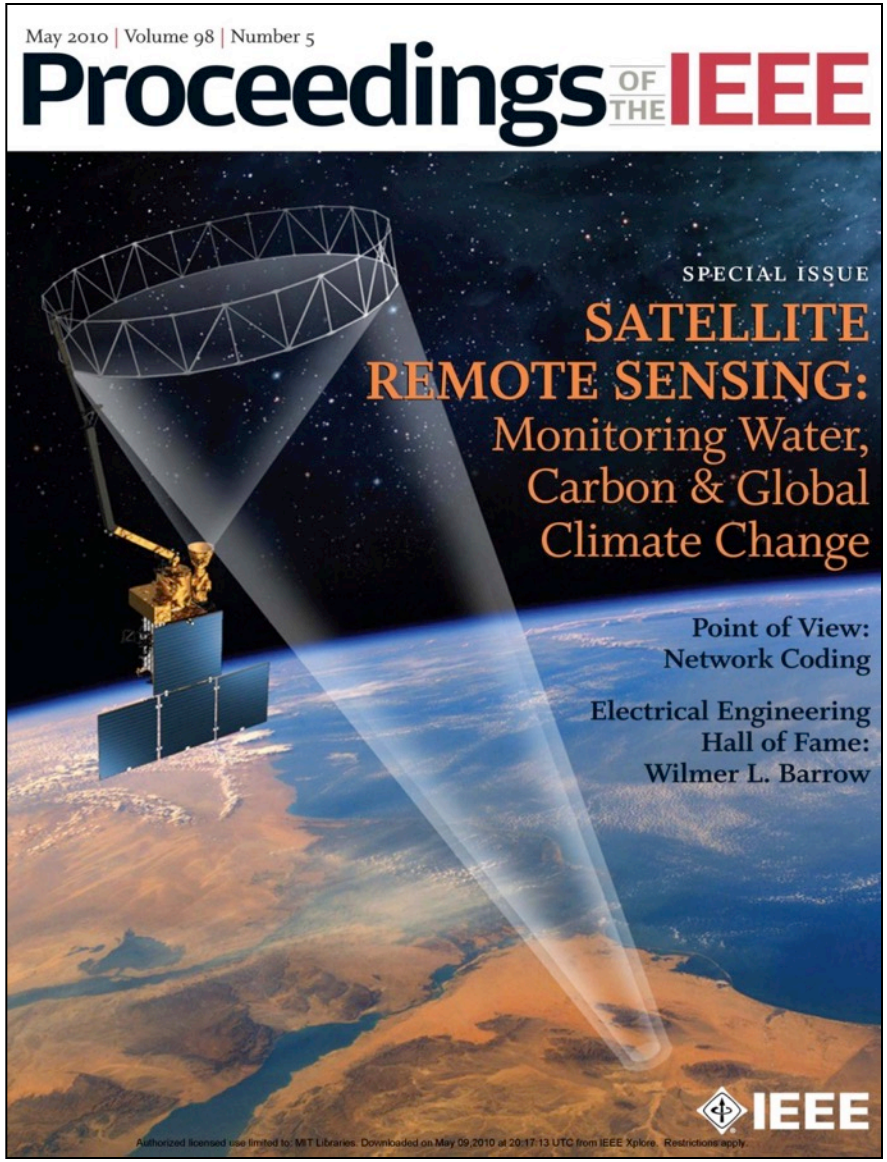
L-Band EESS(Passive) Spectrum Allocation



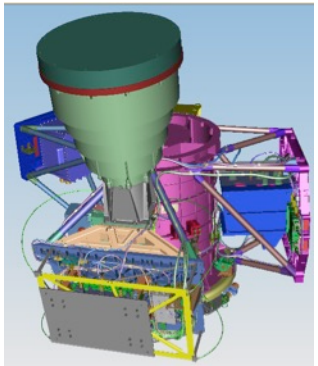
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

SMAP Mission Concept



- L-band Unfocused SAR and Radiometer System, Offset-Fed 6 m Light-Weight Deployable Mesh Reflector. Shared Feed For
  - 1.26 GHz Radar at 1-3 km (HH, VV, HV) (30% Nadir Gap)
  - 1.4 GHz Polarimetric Radiometer at 40 km (H, V, 3rd & 4th Stokes)
- Conical Scan at Fixed Look Angle
- Wide 1000 km Swath With 2-3 Days Revisit
- Sun-Synchronous 6am/6pm Orbit (680 km)
- Launch 2014
- Mission Duration 3 Years



Mission Context

SMAP is one of four Tier-1 missions recommended by the U.S. NRC Earth Science Decadal Survey

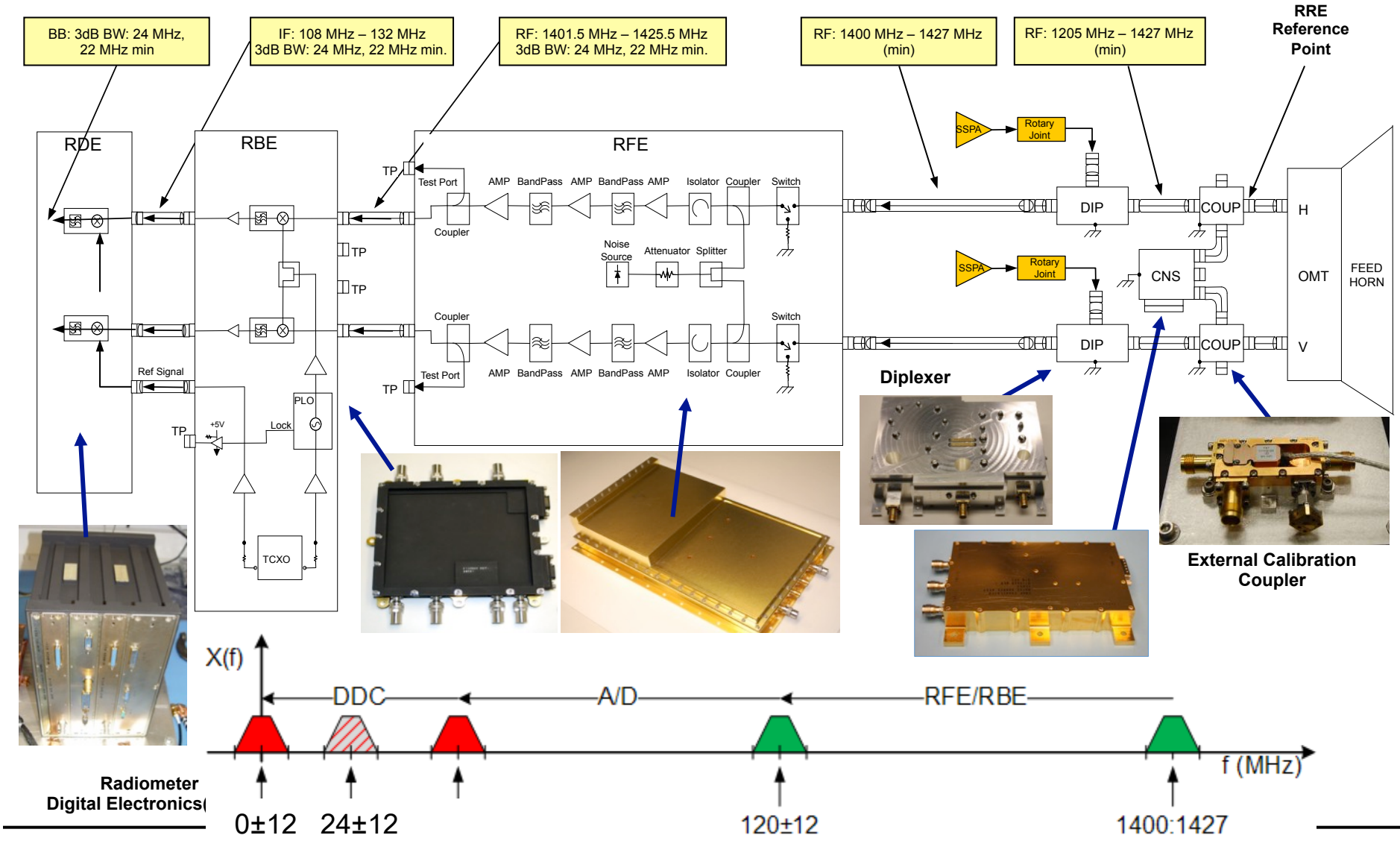
"Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond"

(National Research Council, 2007)
http://www.nap.edu

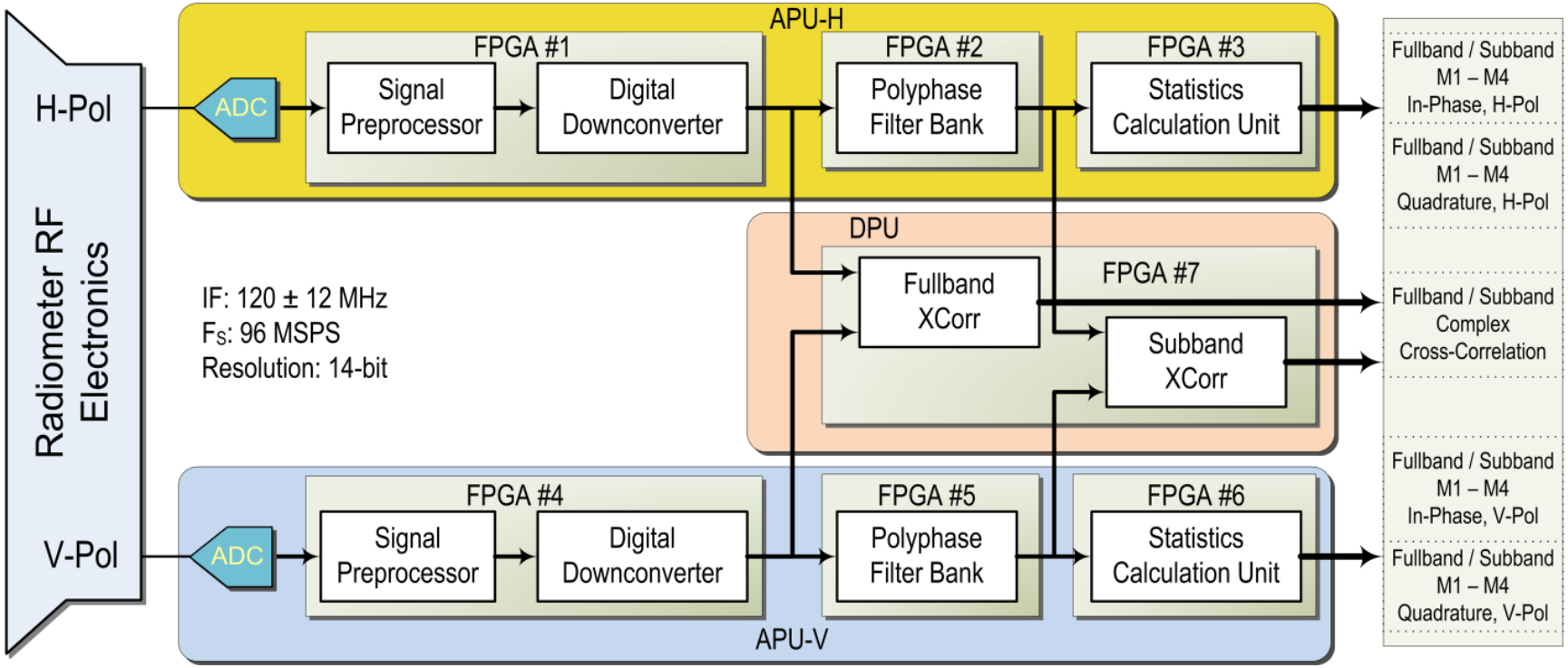
Tier 1:	
	Soil Moisture Active Passive (SMAP)
	ICESAT II
	DESDynI
	CLARREO
Tier 2:	
	SWOT
	HYSPIRI
	ASCENDS
	GEO-CAFE
	ACE
Tier 3:	
	LIST
	PATH
	GRACE-II
	SCLP
	GACM
	3D-WINDS

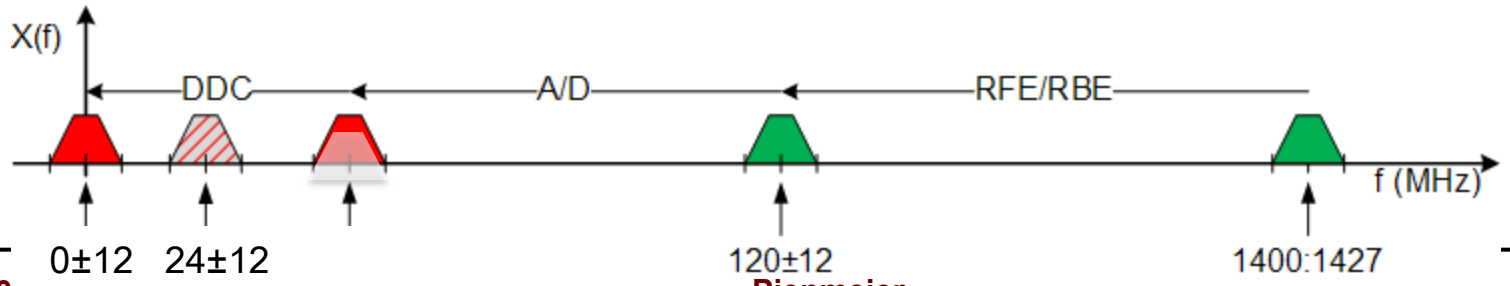
- SMAP was initiated by NASA as a new start mission in February 2008
- SMAP leverages work done under Hydros & Aquarius
- SMAP about to enter Phase C/D – CDR scheduled for May 2012
- Target launch date for SMAP is October 2014

SMAP Radiometer Block Diagram

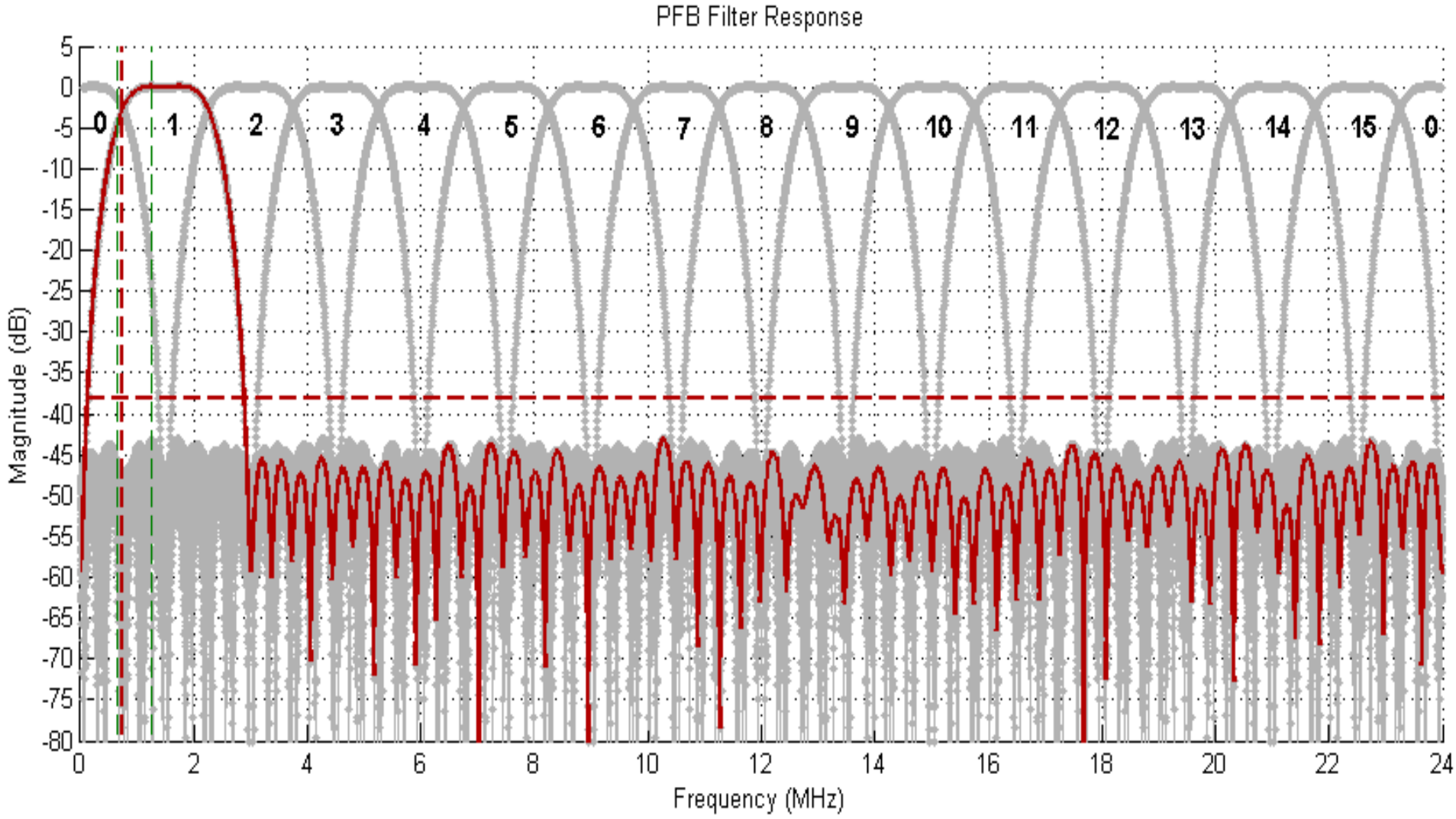


RDE Architecture: DSP Data Flow



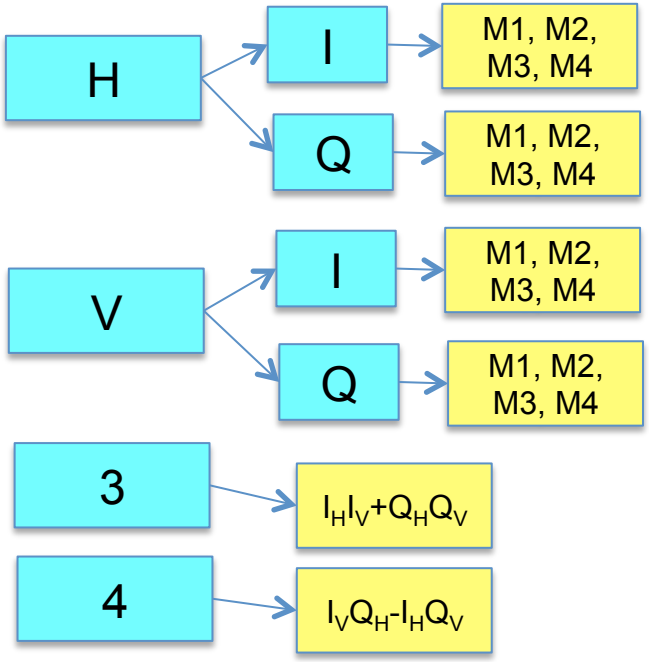


Filterbank Frequency Response

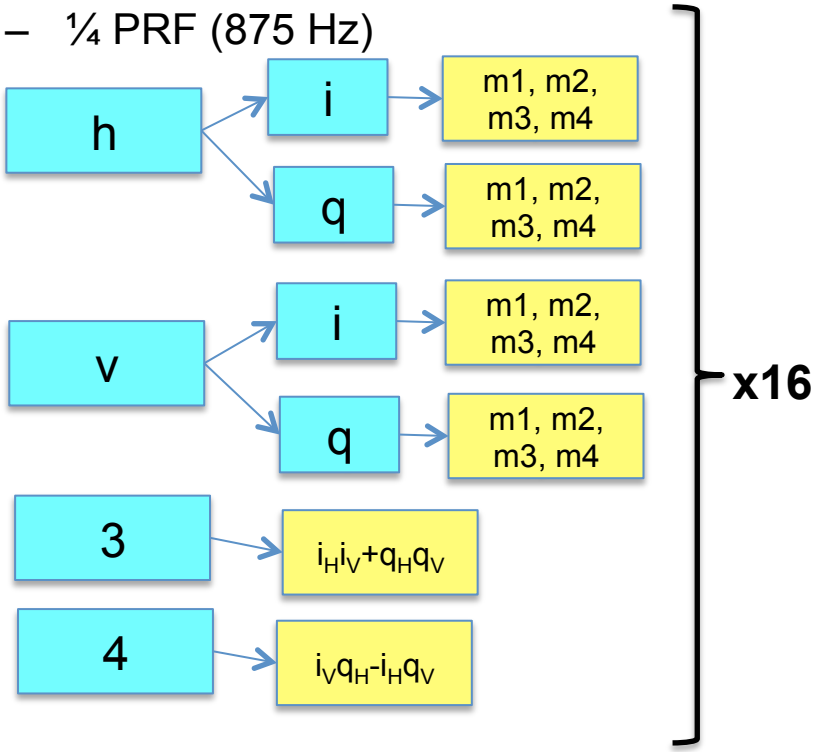


SMAP Radiometer "Detector" Counts

- Full-band high-rate, every PRI (300 us)
  - V, H
  - 1st, 2nd, 3rd, 4th moments, I, Q
  - 3rd and 4th Stokes
  - PRF (3.5 kHz) rate



- Sub-banded data, **16 subbands**, every 4 PRIs, (1200 us)
  - V, H
  - 1st, 2nd, 3rd, 4th moments, I, Q
  - 3rd and 4th Stokes
  - ¼ PRF (875 Hz)

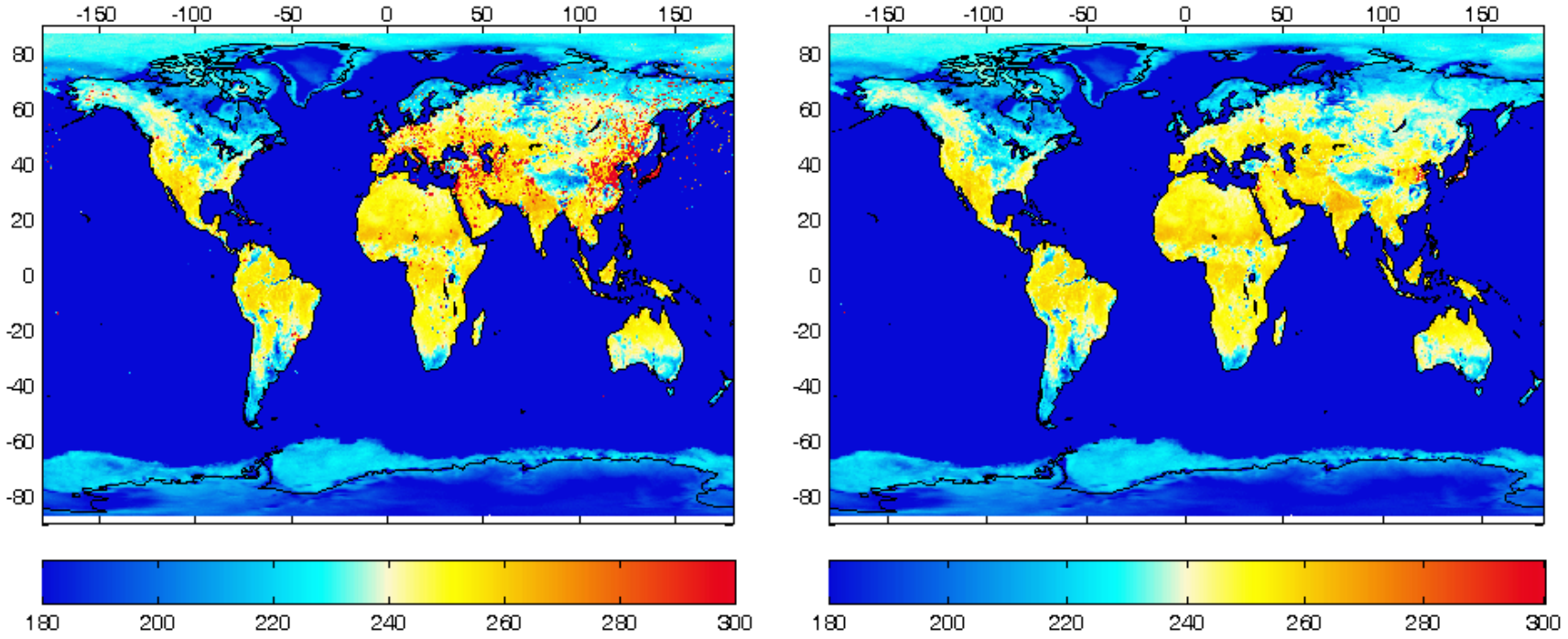


Time/Frequency diversity: 360 words every ~1ms (packet)

RFI Movie

SMAP Launch: January 31, 2015

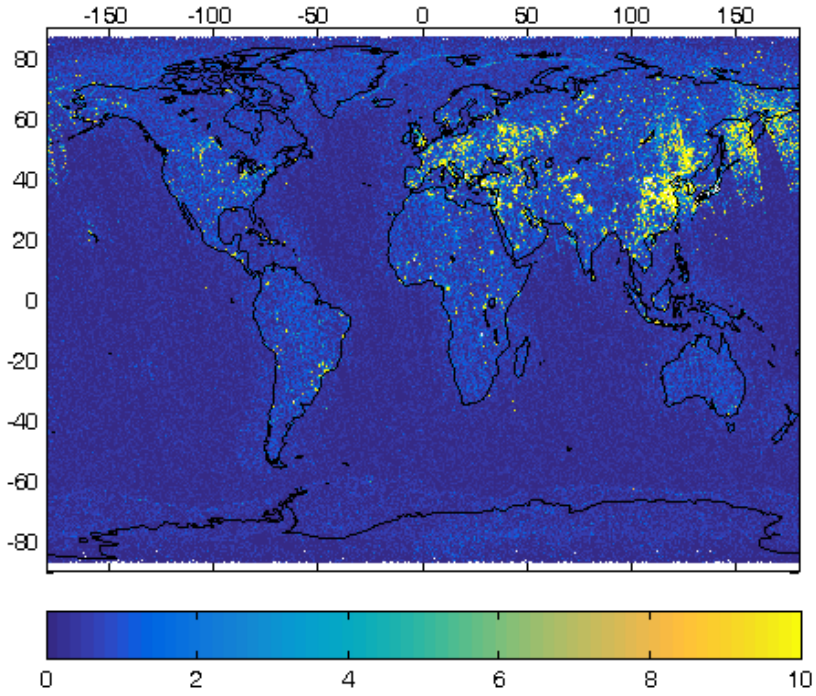
TA H-pol Before and After RFI Mitigation



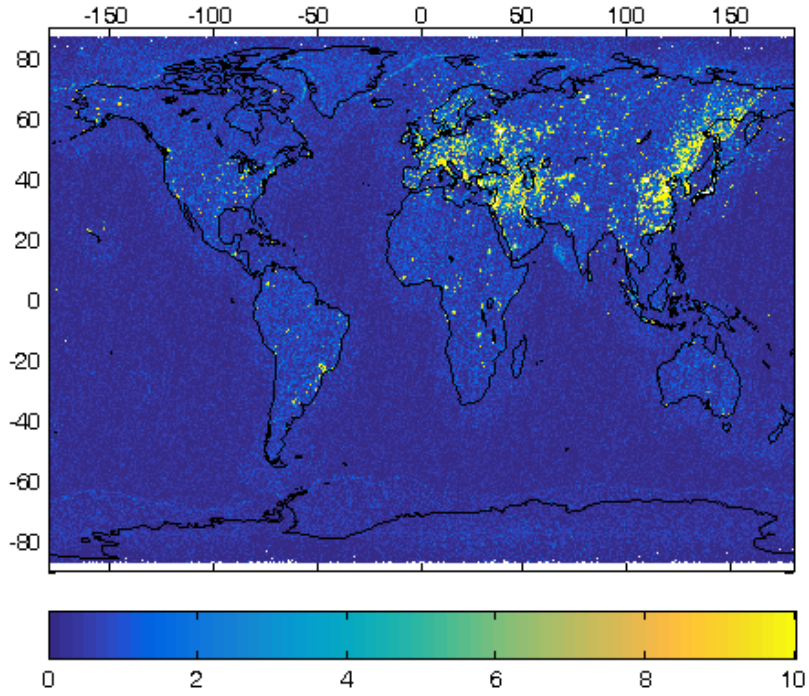
Peak hold data for the period June 3 – 9, 2015, before and after RFI detection and mitigation

Color scale limited to 300 K to better show RFI events

RFI Level



TA H-pol: ascending/fore

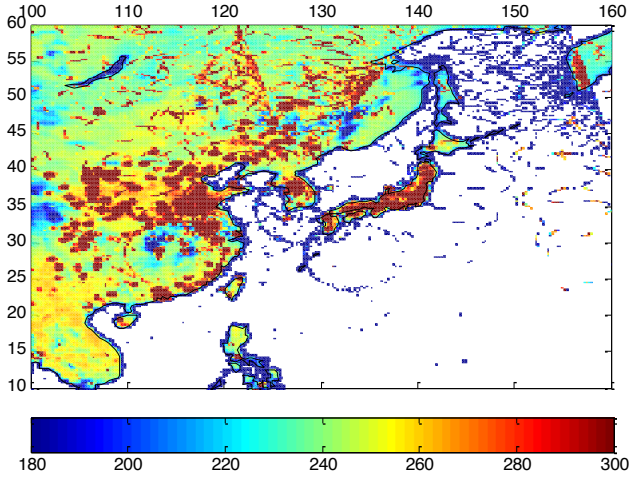


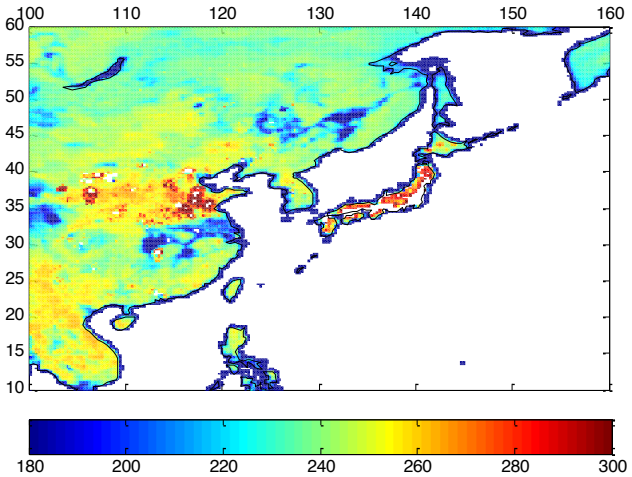
TA H-pol: descending/fore

- 0.25° grid
- June 3-9, 2015
- RFI looks different with time of day and azimuth angle
- Color scale limited to 10 K to better show RFI events

TA H-pol Asia

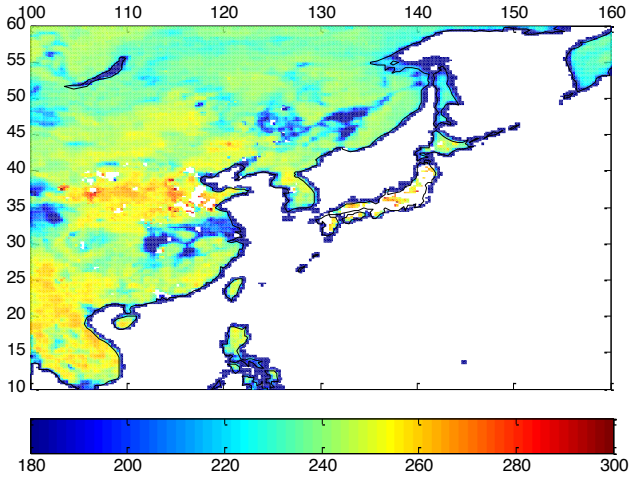
TA unfiltered





TA filtered

- 0.25° grid
- June 3-9, 2015

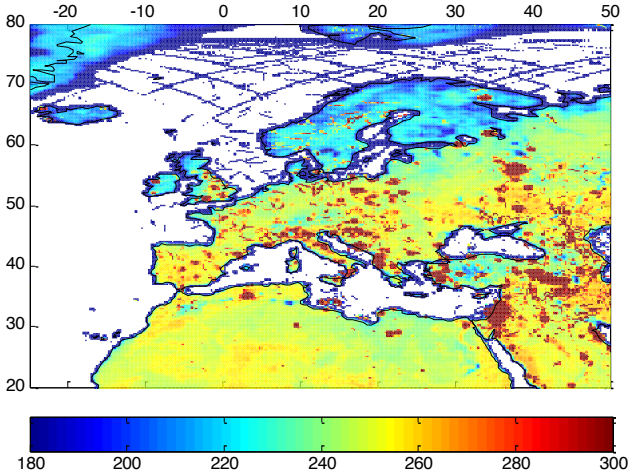


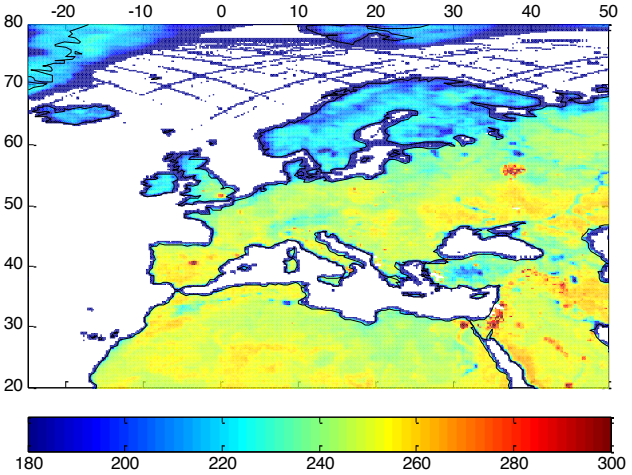
TA filtered

Discarding measurements flagged by TB quality flag; residual RFI appear to still be in product

TA H-pol Europe

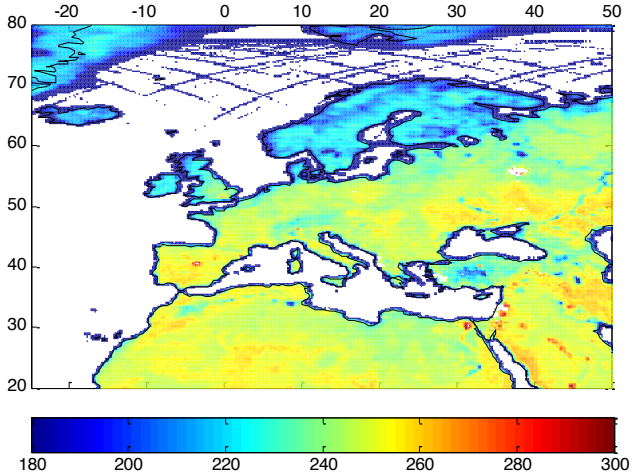
TA unfiltered





TA filtered

- 0.25° grid
- June 3-9, 2015

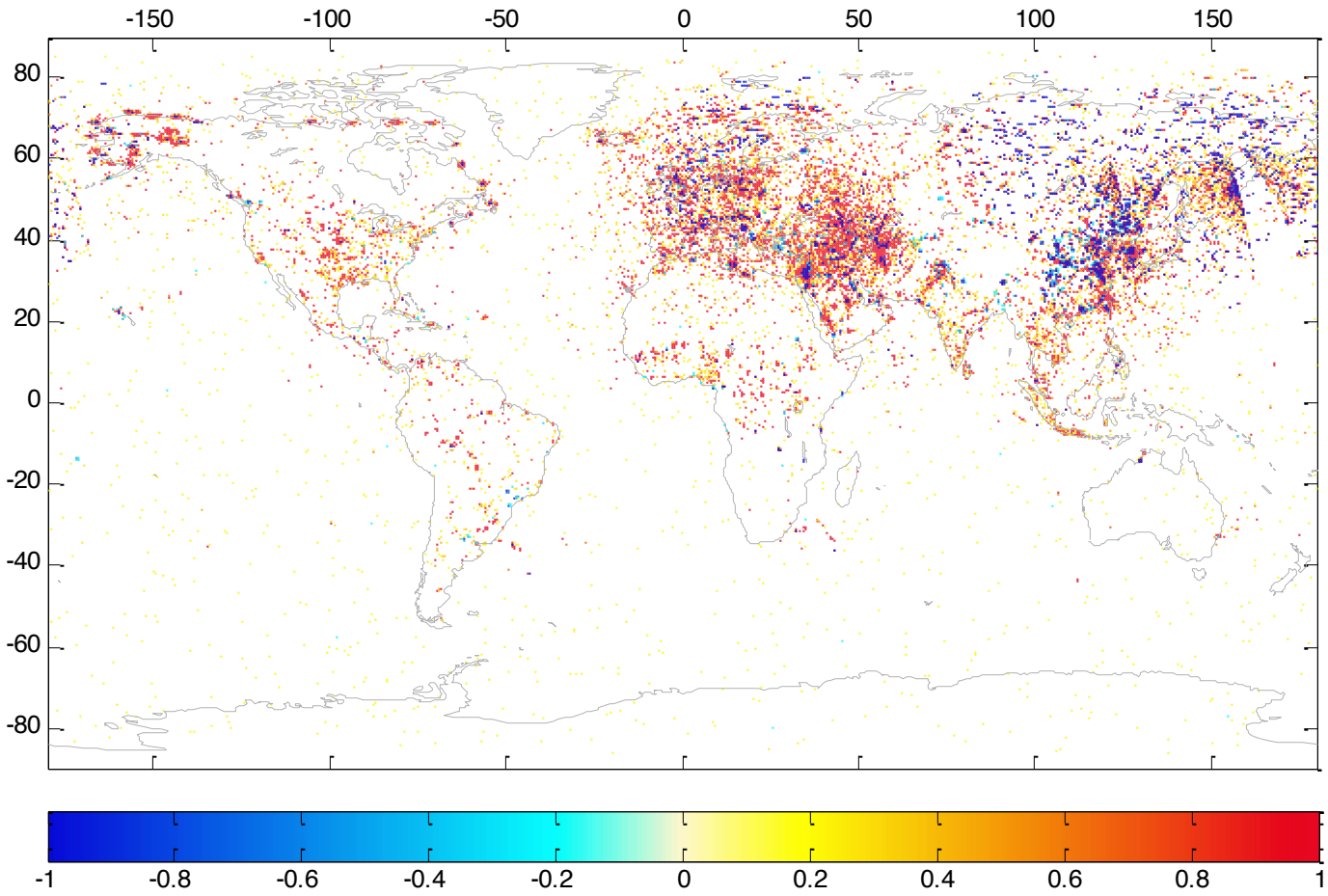


TA filtered

Discarding measurements flagged by TB quality flag; residual RFI appear to still be in product

Fullband Kurtosis

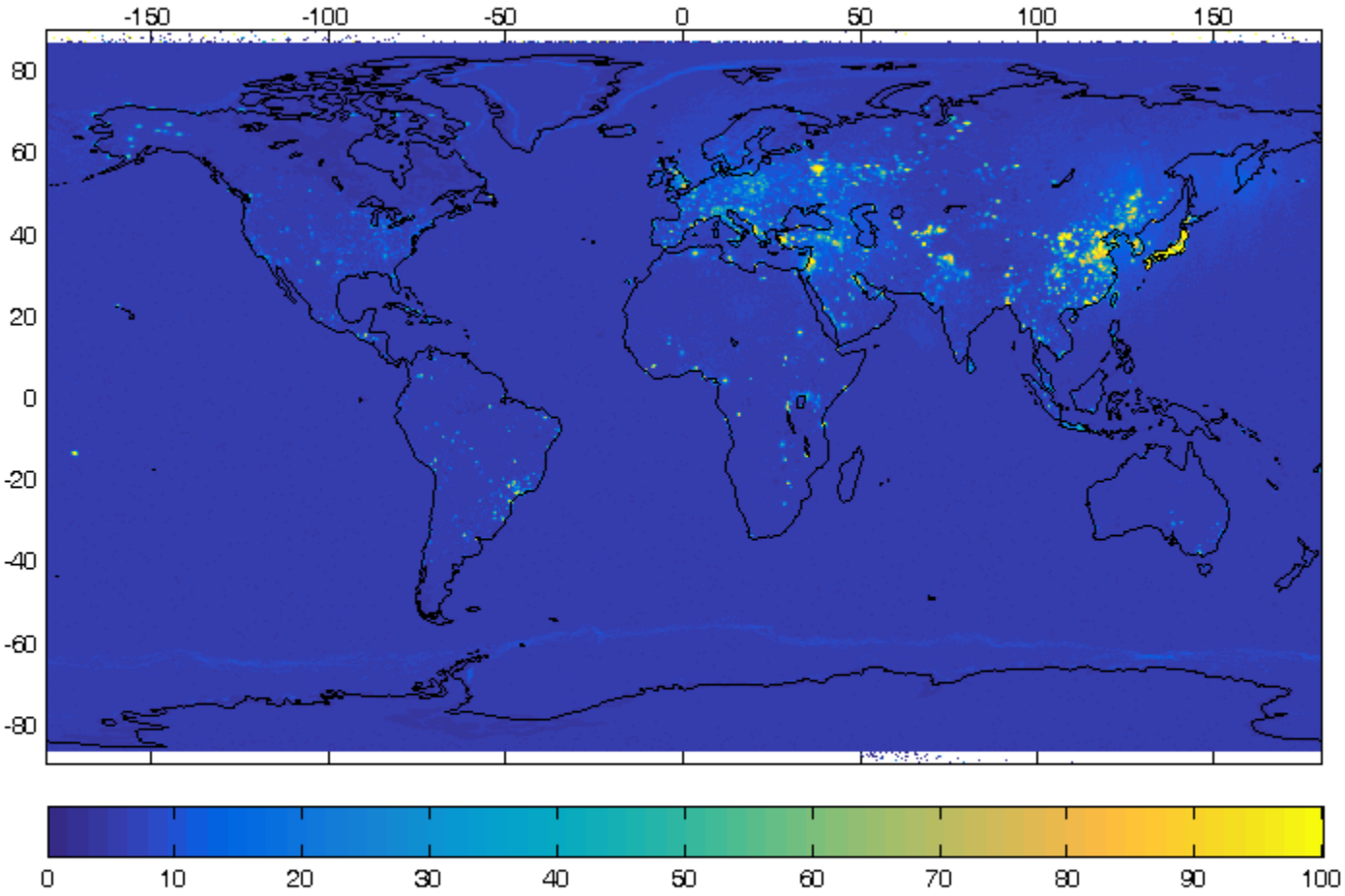
- 0.25° grid
- June 3-9, 2015



Kurtosis – 3
Max and Min kurtosis for a week

MAXPD Detection Rate

- 0.25° grid
- Data from April to October 2015



Detection Rate (%)
Probability of RFI occurrence

Discussion

- Spectrum Management works very well to enable scientific use from satellites
- Regulations, however, do not guarantee exclusive access
- Technical solutions offer improvements but are not perfect
- Technology innovation and cooperation with other services are on the path to maintaining and improving the EM environment for scientific passive use