Earth Remote Sensing and Spectrum Protection

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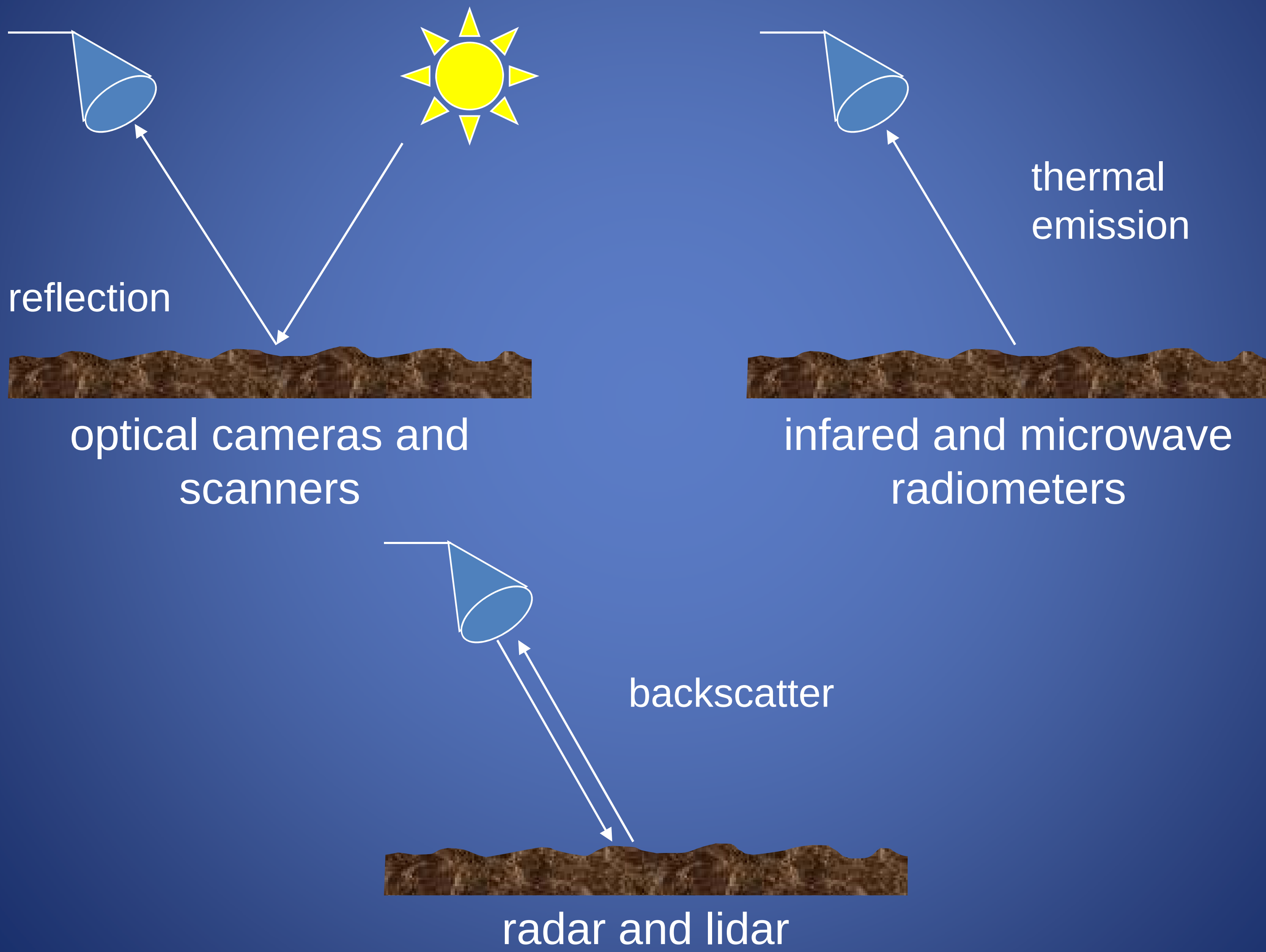
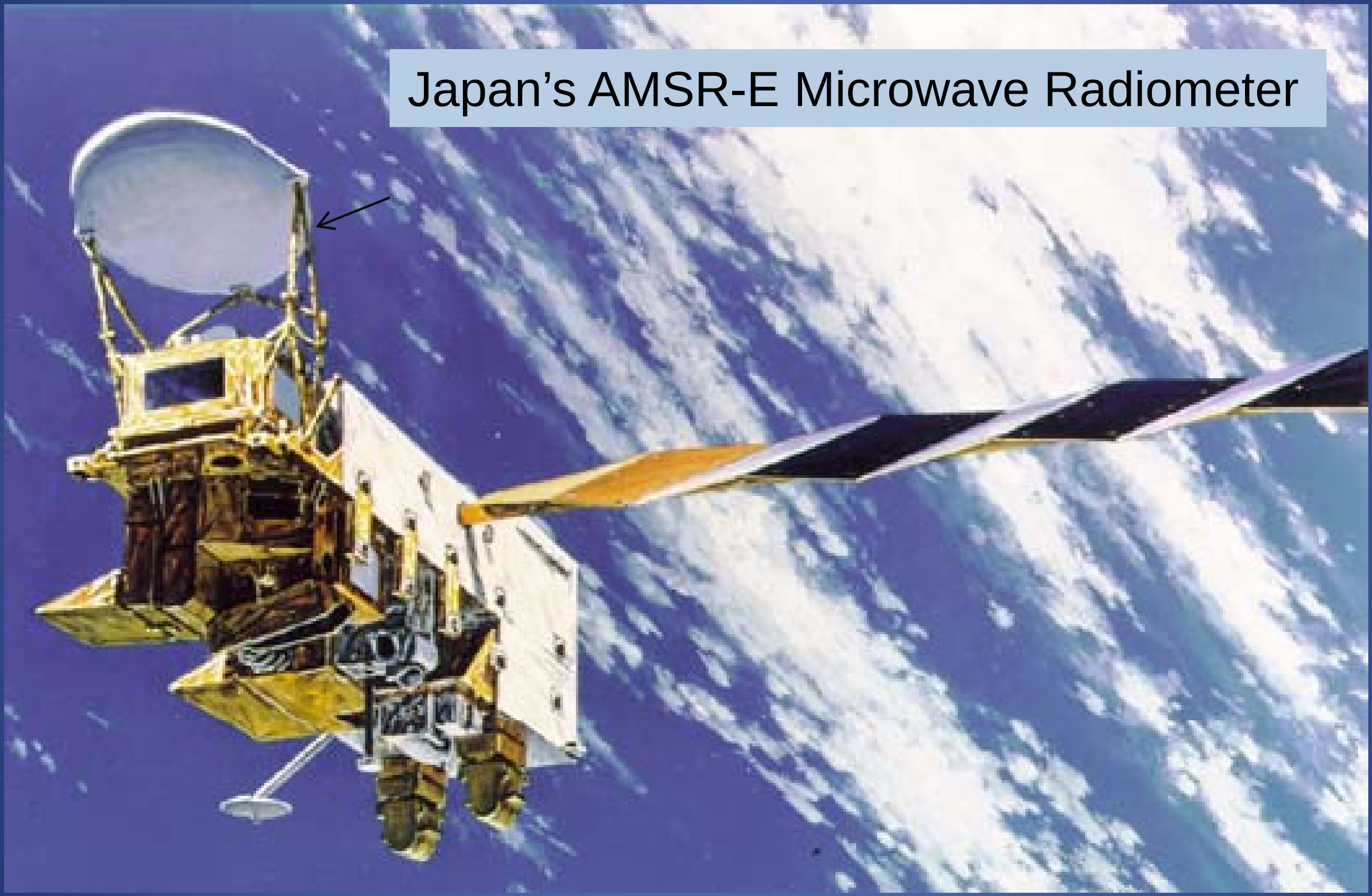
Types of Sensors



NASA's Aqua Satellite (EOS)



Observes Earth at 6.9, 10.7, 18.7, 23.8, 36.5 and 89.0 GHz

Launched 2002

Motivation – Scientific Impact

- Radio-frequency measurements of natural phenomena provide essential information with broad scientific and economic impacts.
- Examples
  1. Atmospheric humidity and temperature
  2. Sea surface temperature
  3. Soil moisture

Motivation – Sensitivity

- Receive-only ("passive") measurements of weak natural signals in a broad range of frequencies must be made with extreme sensitivity.
- Example
  - 100 K in 100 MHz bandwidth (0.1 pW)
  - Sensing 0.1-K fluctuations (0.1 fW)

Motivation – Stewardship

- The extreme sensitivity required makes it essential
  - to maintain protected allocations and also
  - to properly manage use of the spectrum near the protected allocations.
- Examples
  - WRC-07 mandatory emission limits

Motivation – Requirements

- Dedicated passive allocations exist only in a limited number of bands.
- There is need for protection of some bands essential to scientific and societal interests that are not now protected.

Motivation – Opportunity and Challenge

- The receive-only services can sometimes take advantage of uncongested spectra not allocated to them.
- Increasing congestion may deny this capability in the future.

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 Organizations

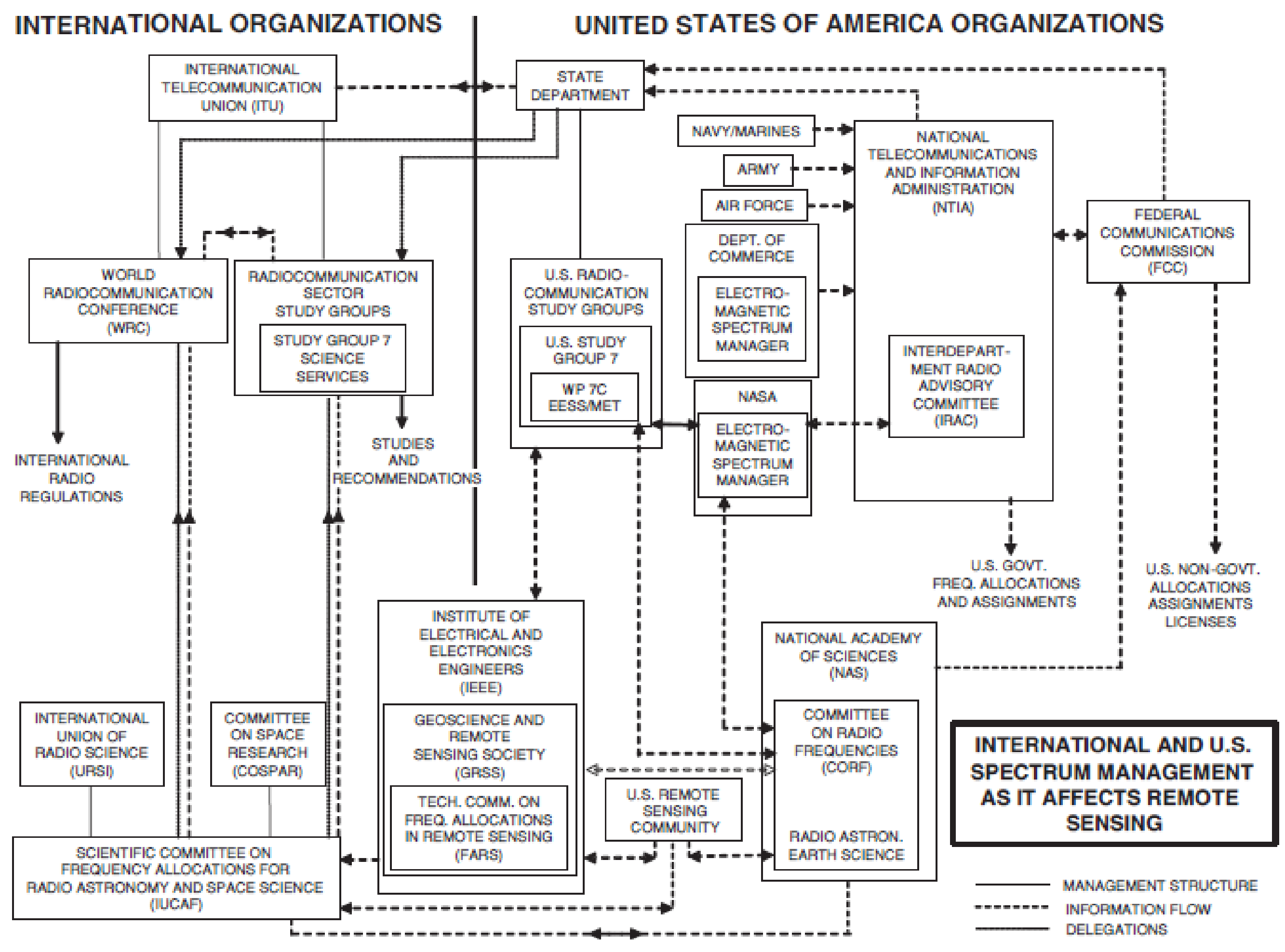


FIGURE 1.2 The diagram depicts the complex relationship among the national and international radio regulatory bodies for the Earth Exploration-Satellite Service.

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

U.S. Sensor Milestones – 1

(1968: USSR Cosmos 243)

- 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)

U.S. Sensor Milestones – 2

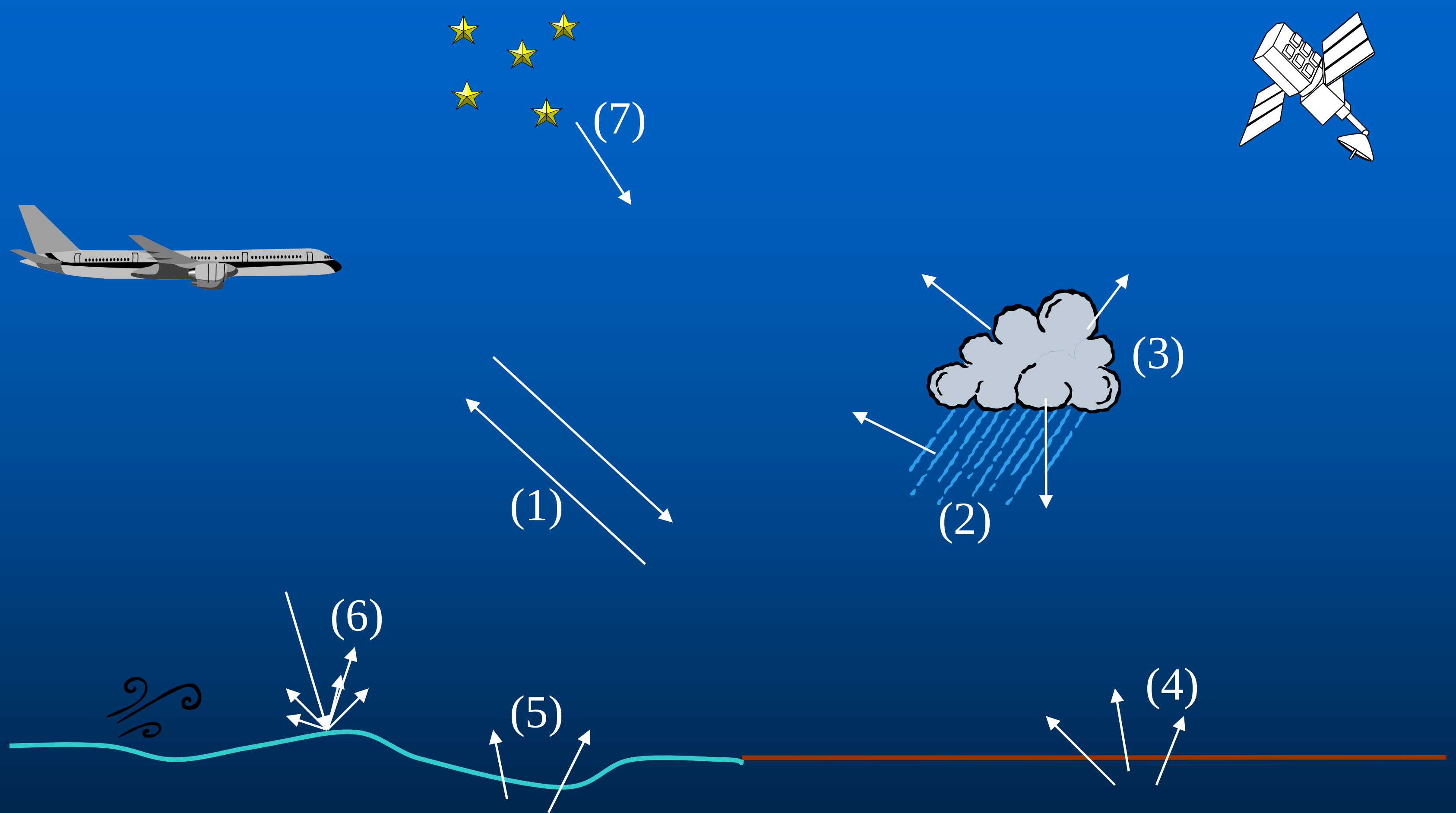
- 1991: NASA UARS (MLS)
- 1997: NASA TRMM (TMI)
- 1998: NOAA-15 (AMSU)
- 2002: NASA EOS Aqua (JAXA AMSR-E)
- 2003: NRL Coriolis (WindSat)

(2009: ESA SMOS (MIRAS))

2010: NASA Aquarius/SAC-D (CONAE)

Represents over three decades of contiguous atmospheric sounding and surface imagery.

Natural sources of microwave radiation



(1) Atmosphere (2) Precipitation (3) Clouds
(4) Land (5) Oceans (6) Scattering
(7) 2.73 K Cosmic Microwave Background

Land Area Remote Sensing

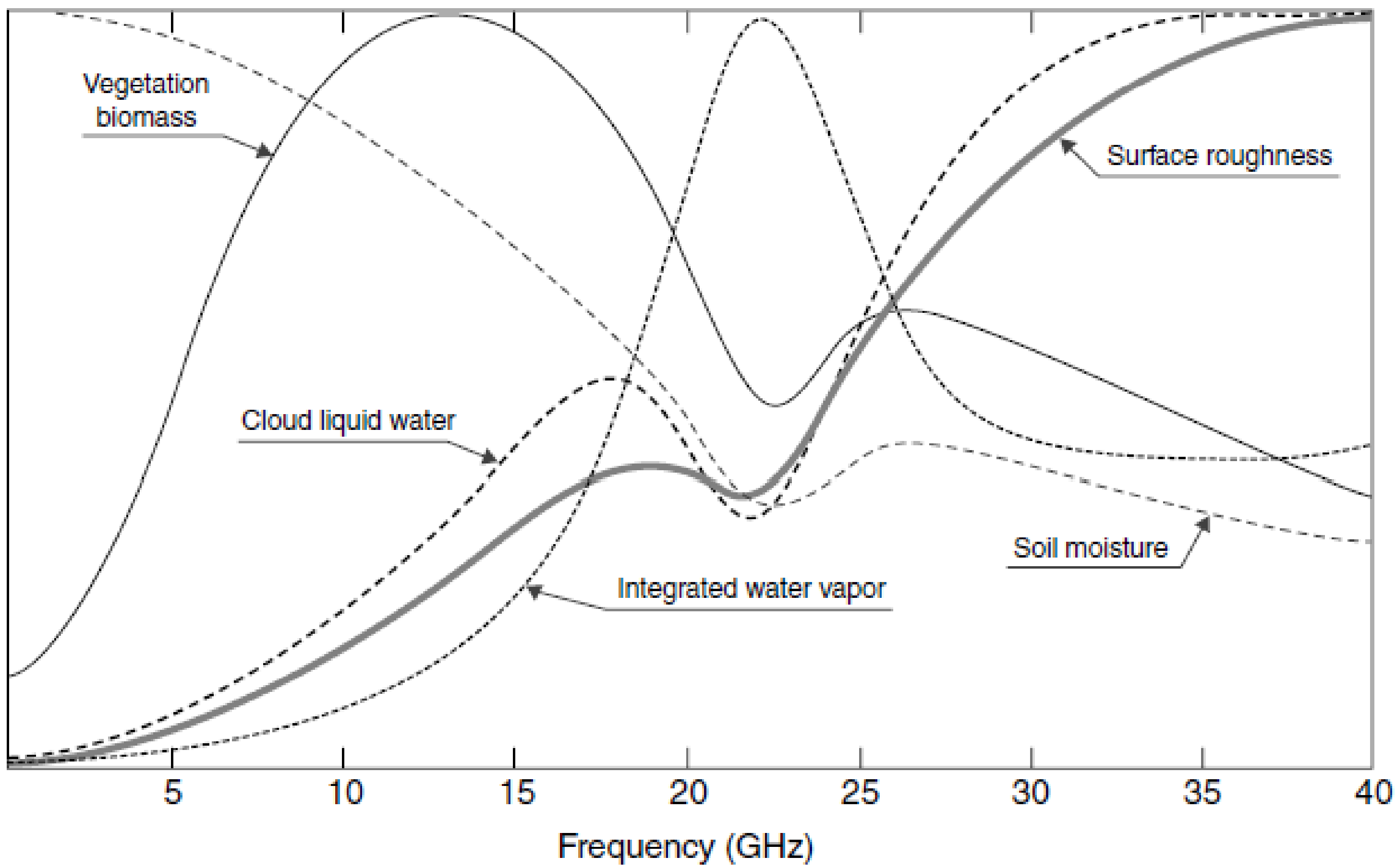


FIGURE 2.10 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over land surfaces).

Ocean Surface Remote Sensing

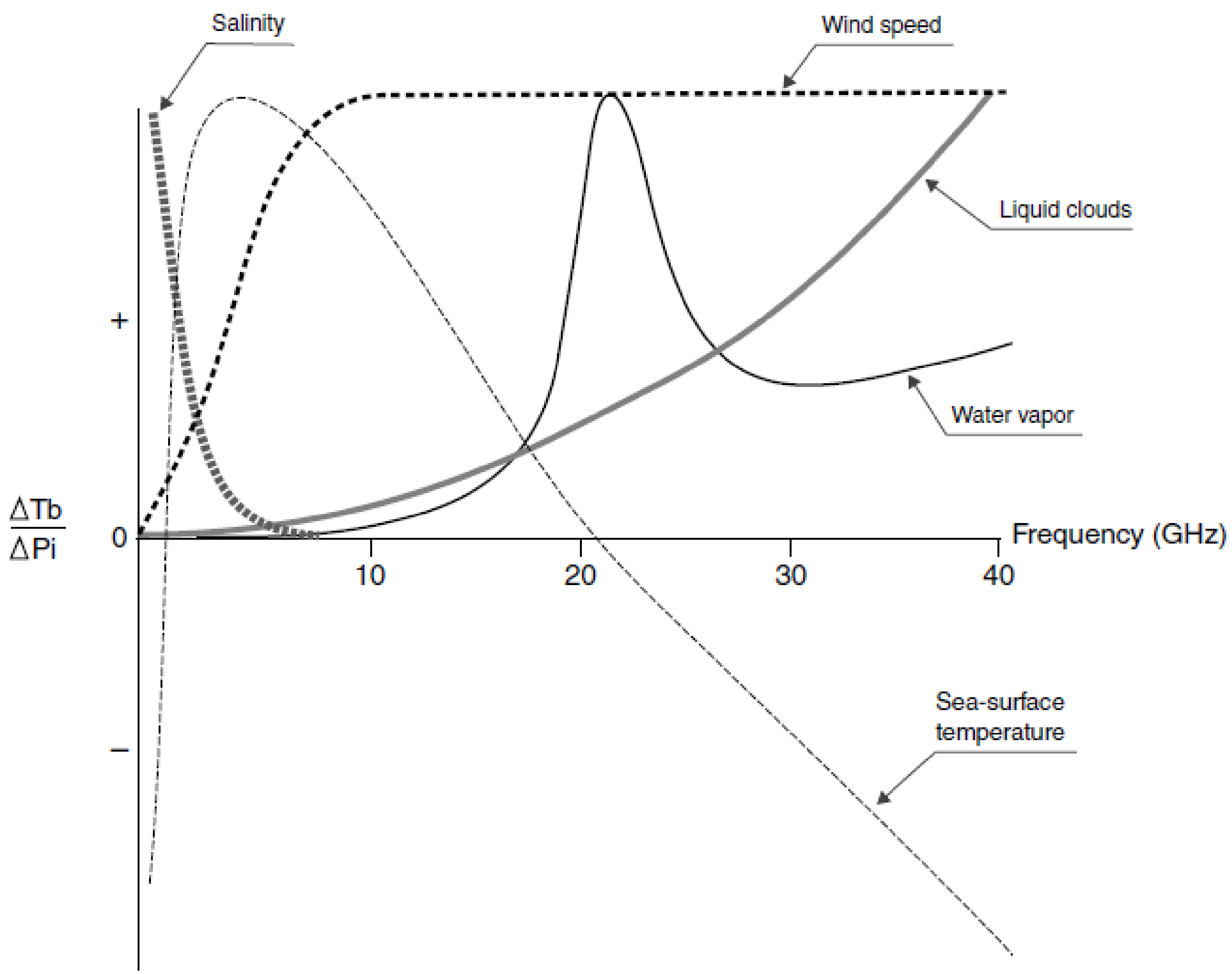
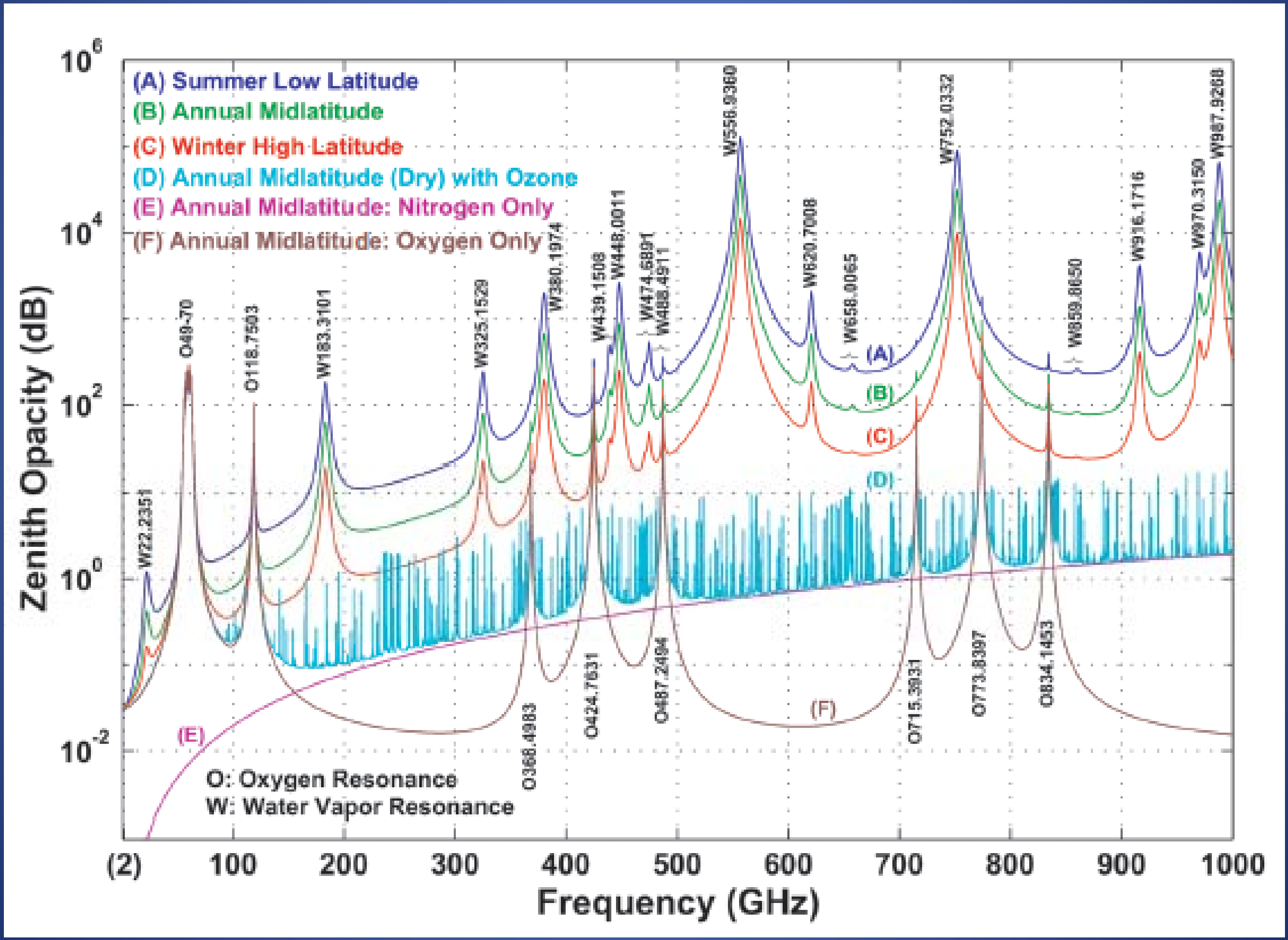


FIGURE 2.11 Relative sensitivity of brightness temperature to geophysical parameters as a function of frequency (over ocean surface).

Atmosphere to 1 THz

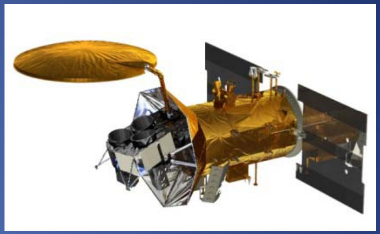


Satellite Passive Sensing Bands

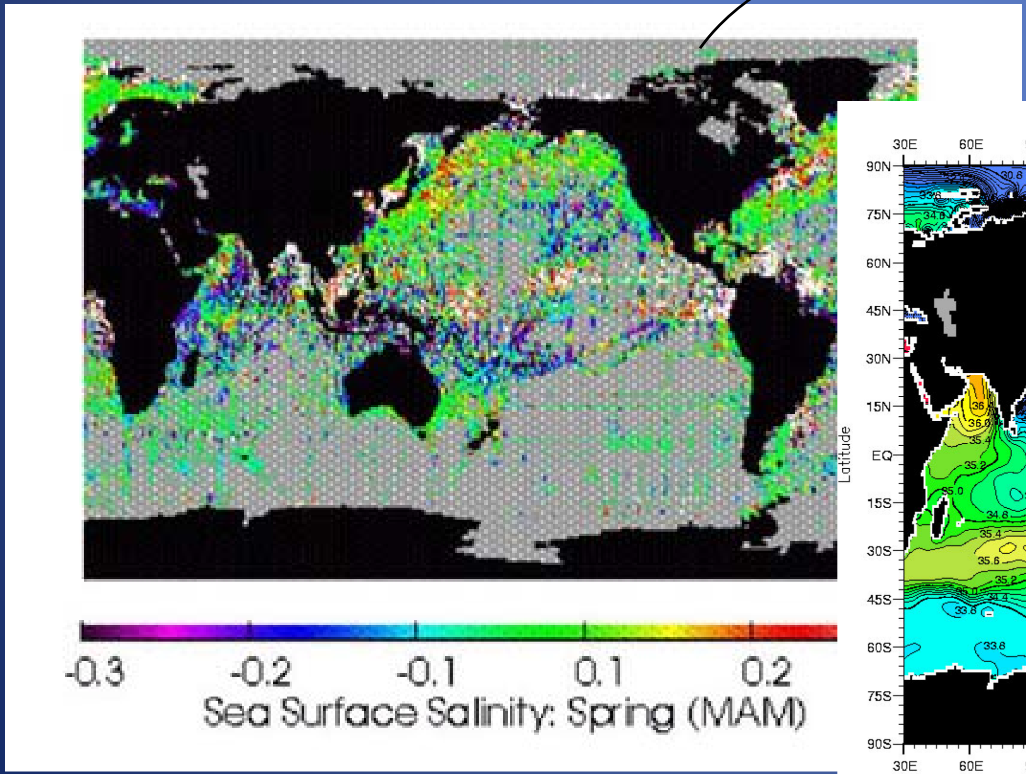
• 1 to 3 GHz	(L and S bands)
• 3 to 10 GHz	(S, C and X bands)
• 10 to 25 GHz	(X, Ku, and K bands)
• 25 to 50 GHz	(K, Ka and V bands)
• 50 to 71 GHz	(V band)
• 71 to 126 GHz	(W band)
• 126 to 400 GHz	(mm and sub-mm waves)

1 – 3 GHz (L and S bands)

- Soil Moisture through vegetation
- Ocean Salinity



Aquarius/SAC-D



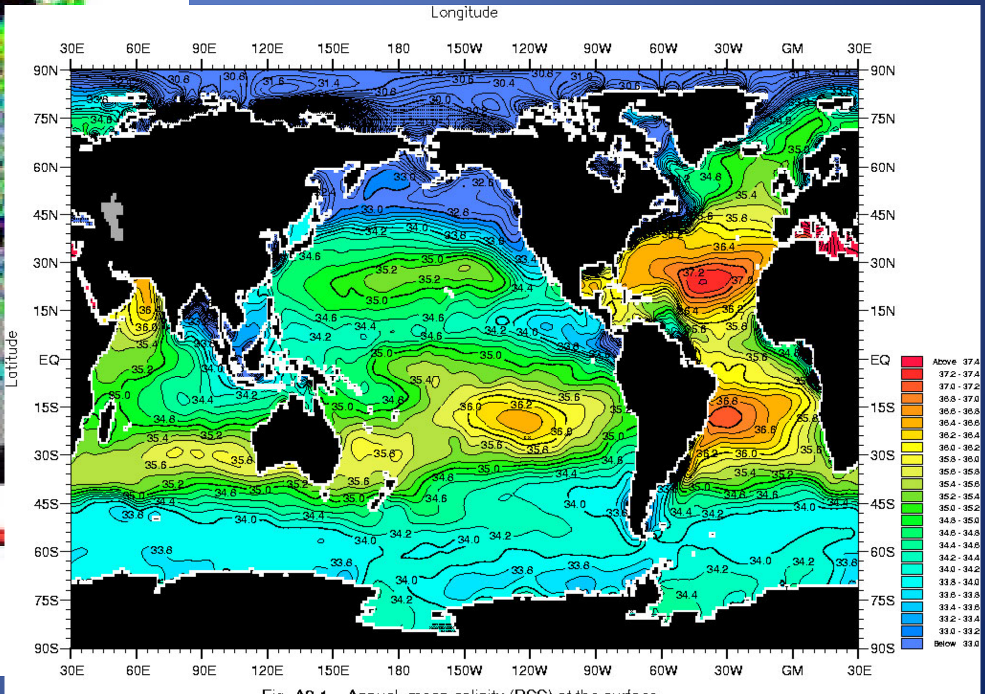


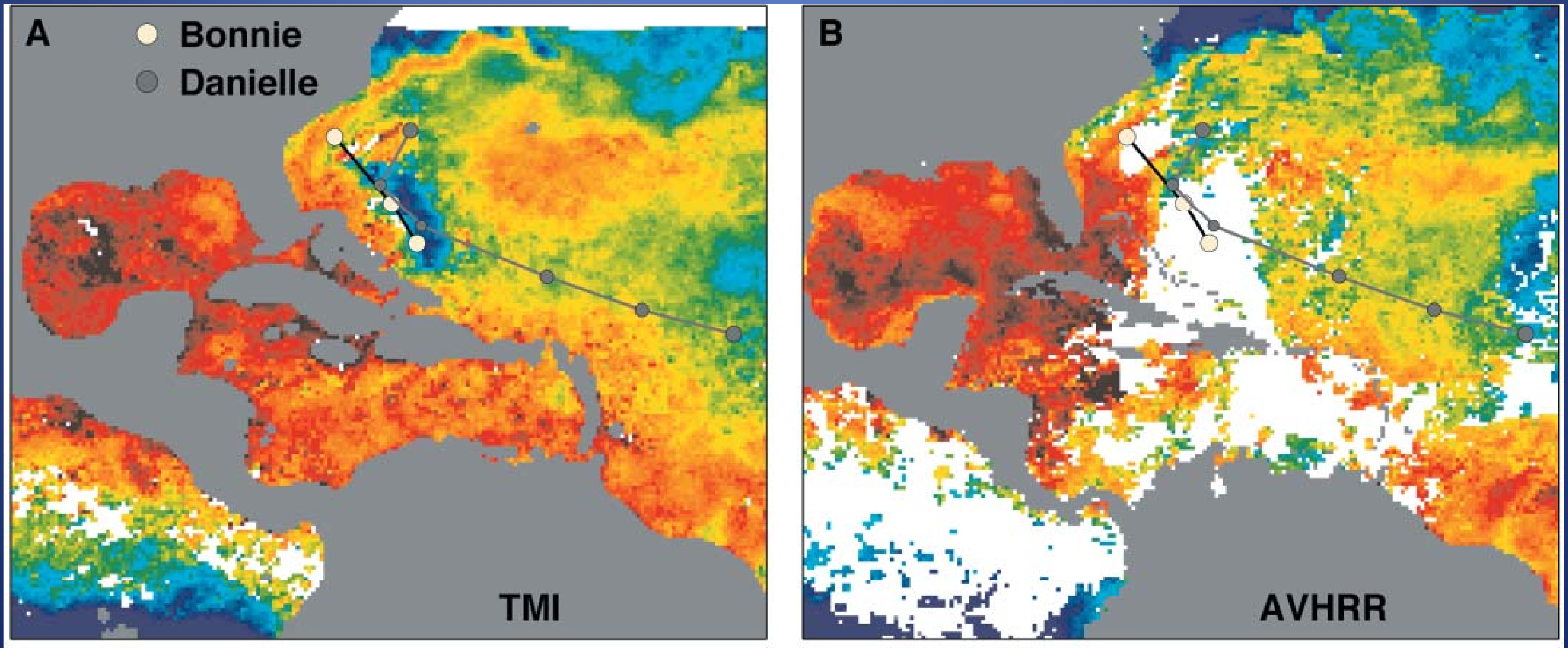
Fig. A2-1. Annual mean salinity (PSS) at the surface .

Minimum Value= 3.57 Maximum Value= 40.02 Contour Interval: 0.20

http://aquarius.nasa.gov/

3 – 10 GHz (S, C and X bands)

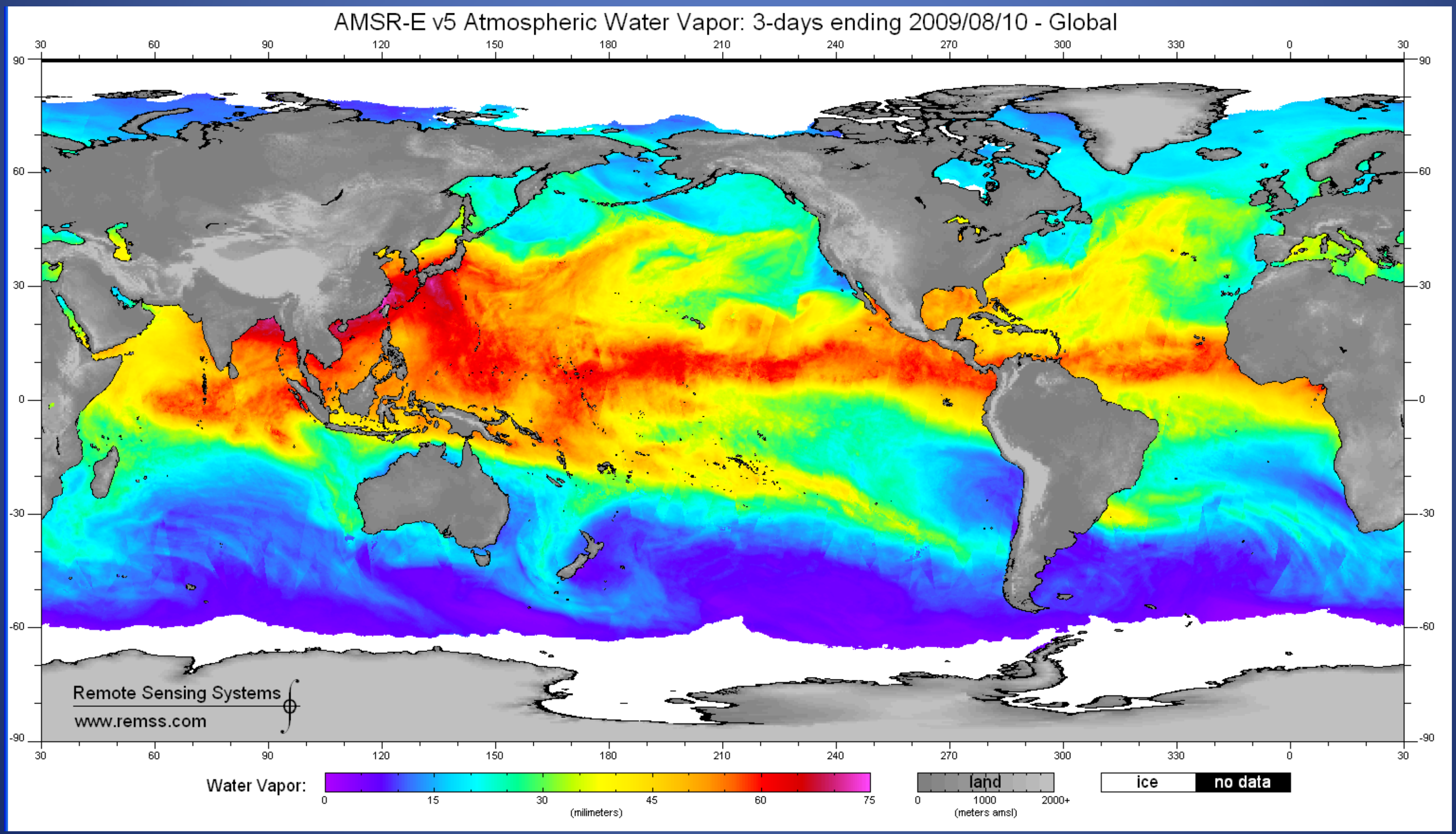
- Soil Moisture (light vegetation)
- Sea Surface Temperature



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

10 – 25 GHz (X, Ku, and K bands)

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

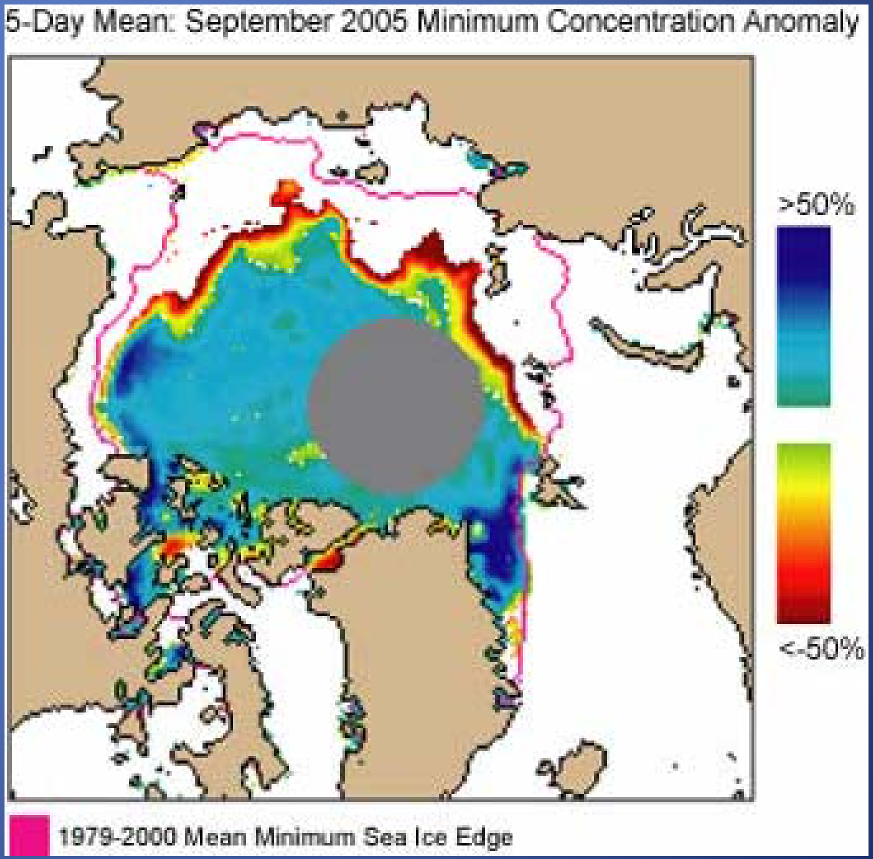


25 – 50 GHz (K, Ka and V bands)

- Snow, sea ice, precipitation, and clouds
- Ocean winds

http://nasadaacs.eos.nasa.gov/articles/2006/2006_seaice.html

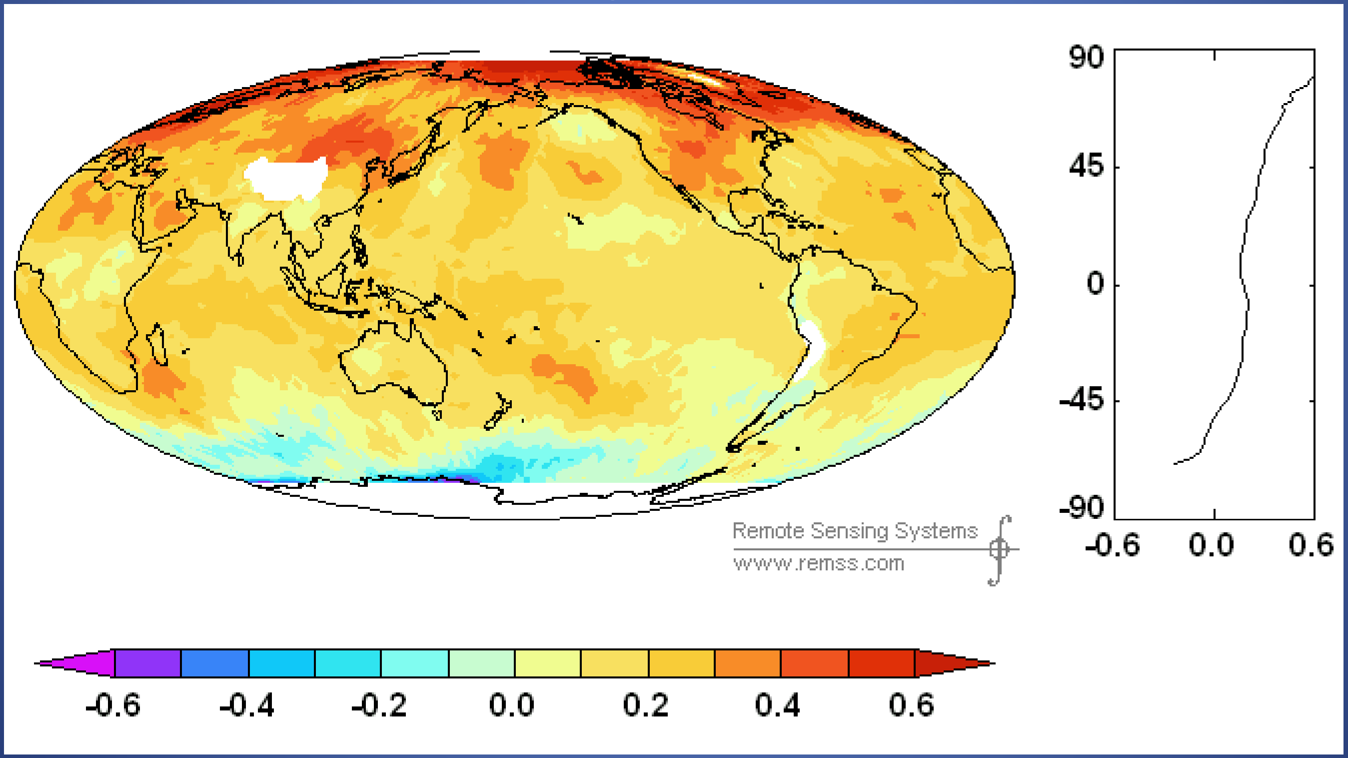
September 2005 broke the record for low summer sea ice extent, the measure of area containing at least 15 percent ice. The ice extent is shown by the edge of the colored region. The long-term average minimum extent contour (1979 to 2000) is in magenta. The grey circle indicates the area where the satellite does not take data. Data are from the Special Sensor Microwave/Imager (SSM/I). (Courtesy NSIDC)



50 – 71 GHz (Ka and V bands)

- Atmospheric temperature

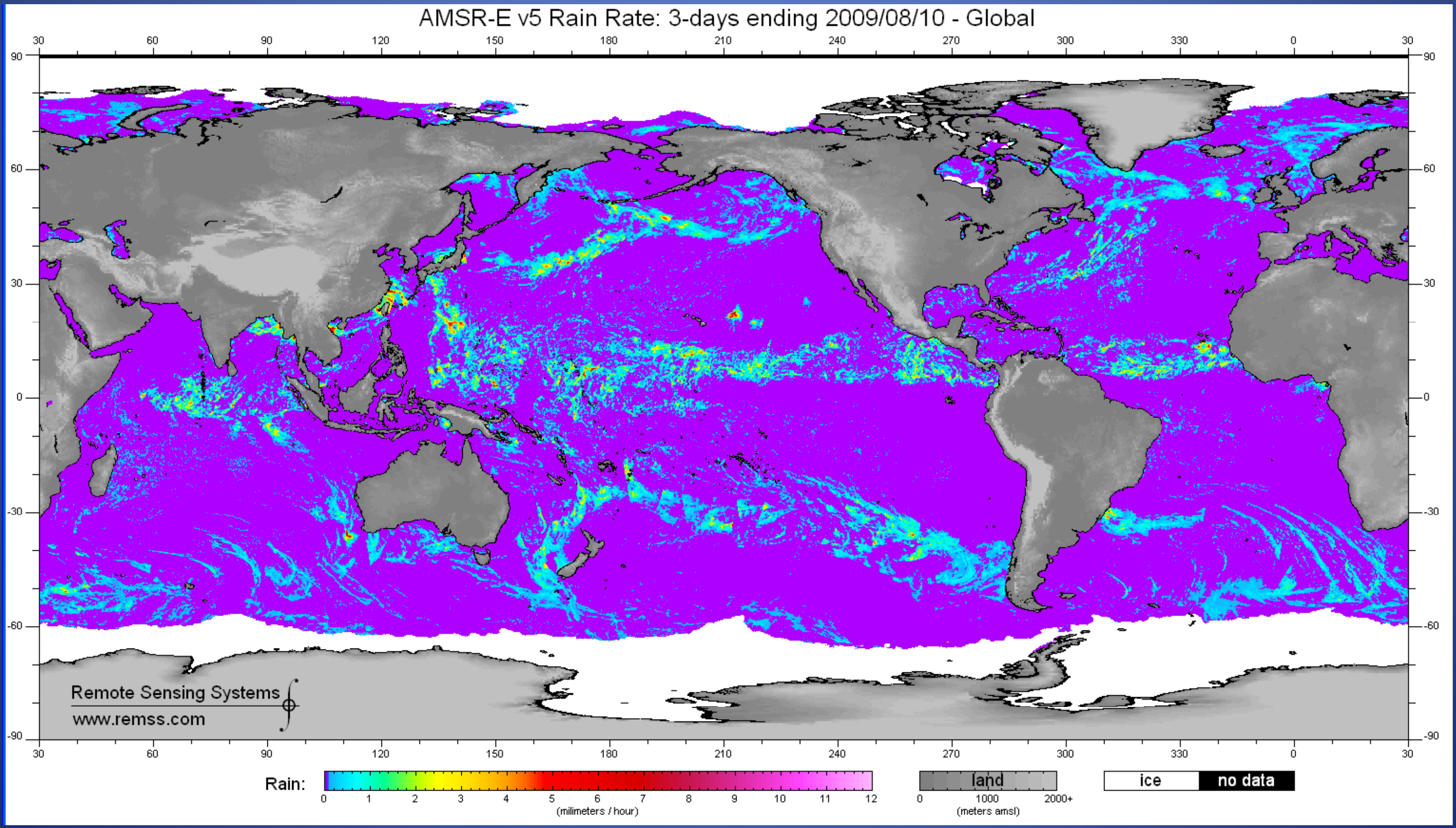
Color coded map of decadal trends in lower troposphere temperature using MSU/AMSU channel TLT:



Degrees Centigrade per Decade: 1979 - 2007 (29 Years)

71 – 126 GHz (W band)

- Snow, sea ice, precipitation, clouds
- Atmospheric temperature

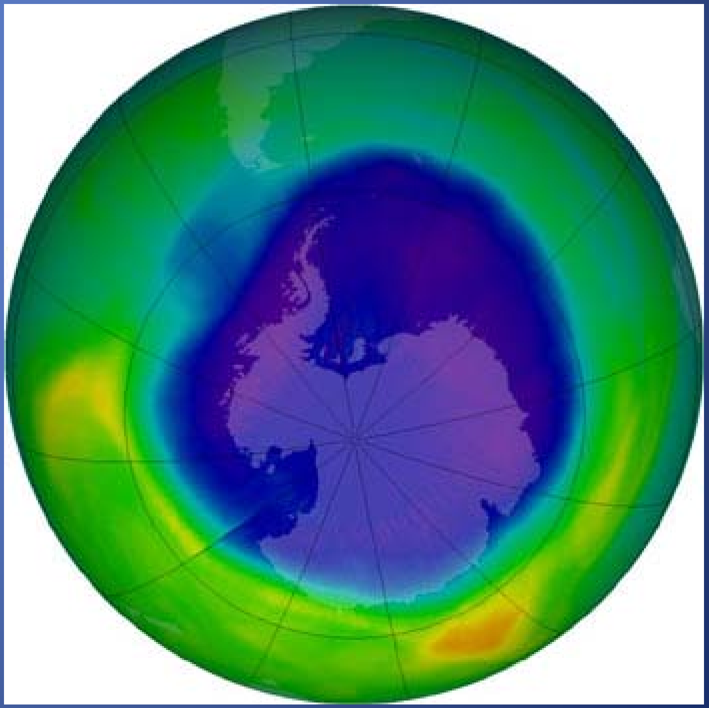


126 – 400 GHz
(millimeter and sub-mm waves)

- Precipitation, clouds
- 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



Technical Aspects – 1

- EESS and RAS (my comments)
  - Shared bands of interest
    - Atmospheric windows
    - Gaseous emission spectral lines
  - Fundamental difference
    - RAS generally requires local protection
    - EESS generally requires global protection

Technical Aspects – 2

- Modulation and Filtering
  - Use modulation schemes minimize to OOB emissions (e.g. GMSK)
  - Filters in EESS sensors required but not always effective
  - Filters in transmitters are effective but challenging
- Interference Mitigation in EESS sensors
  - Frequency sub-banding
  - Time-domain pulse excision
  - Kurtosis technique for low-level RFI detection

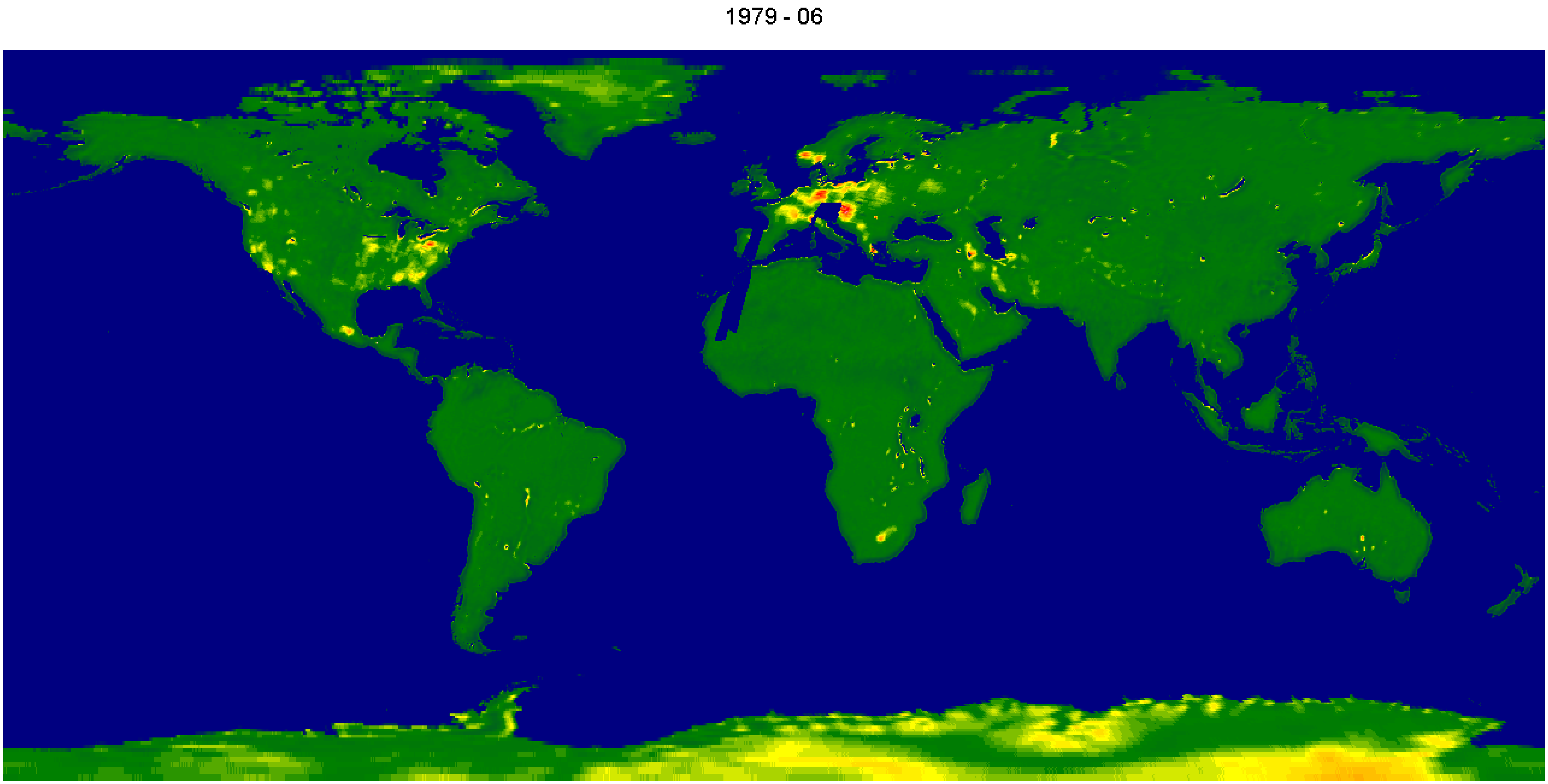
Additional Protection – 1

- Unwanted Emissions
  - Progress made at WRC-07(mandatory limits)
  - Challenge of shared allocations
    - Assumption FSS(S-E) and EESS can be shared
    - Recent EESS practice shows difficulties
  - Call for updated standards (limiting and controlling spurious, OOB, and harmonic emissions)

Additional Protection – 2

- Bandwidth
  - Need 1-2% allocation at a minimum
  - Desire 5% for emerging applications
- New Frequencies
  - C-band important for EESS operational systems
  - F>275 GHz footnote update in works for WRC-11

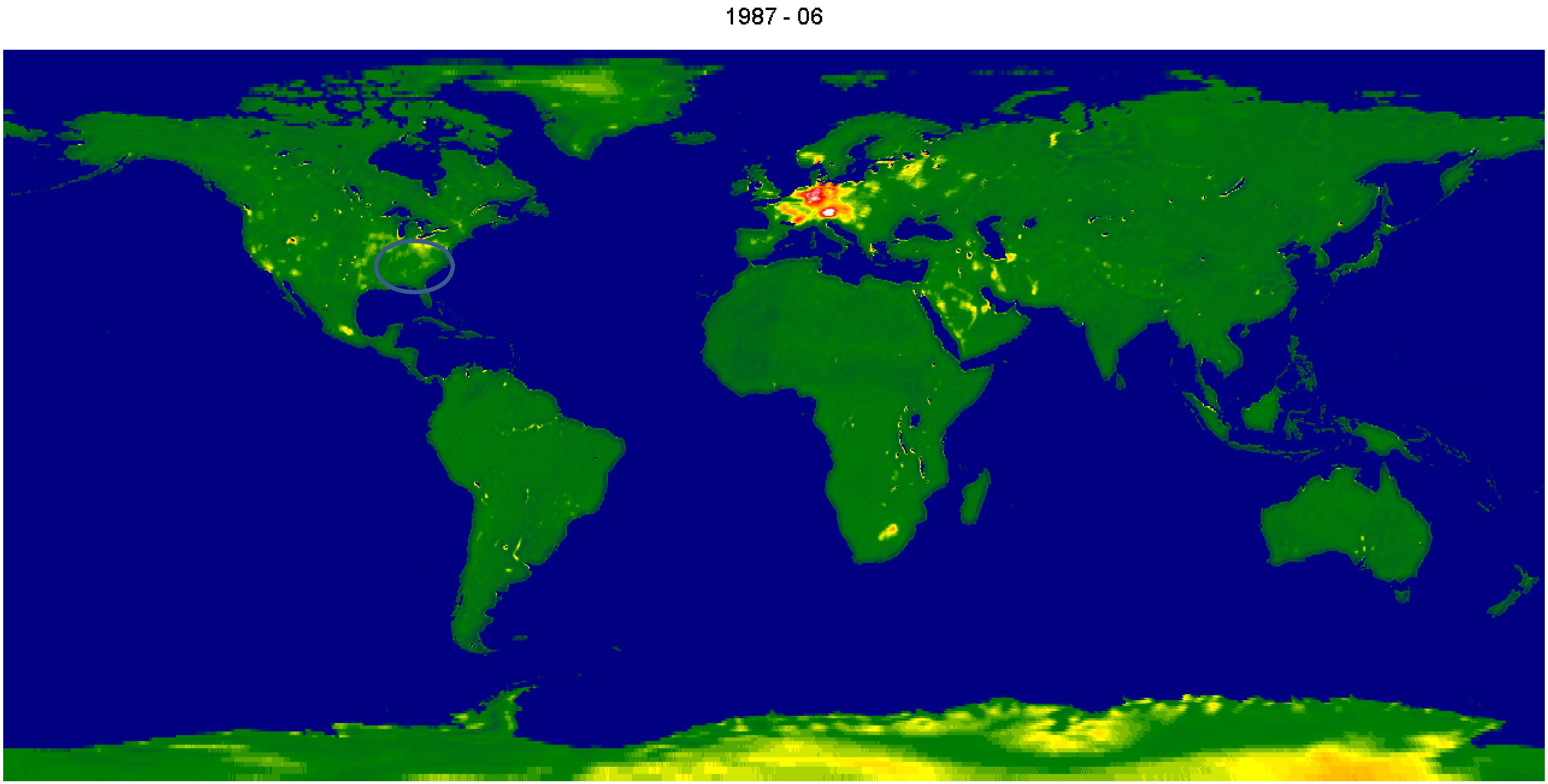
Evolution of C- and X-band



6.6 GHz

1979 1987 2007

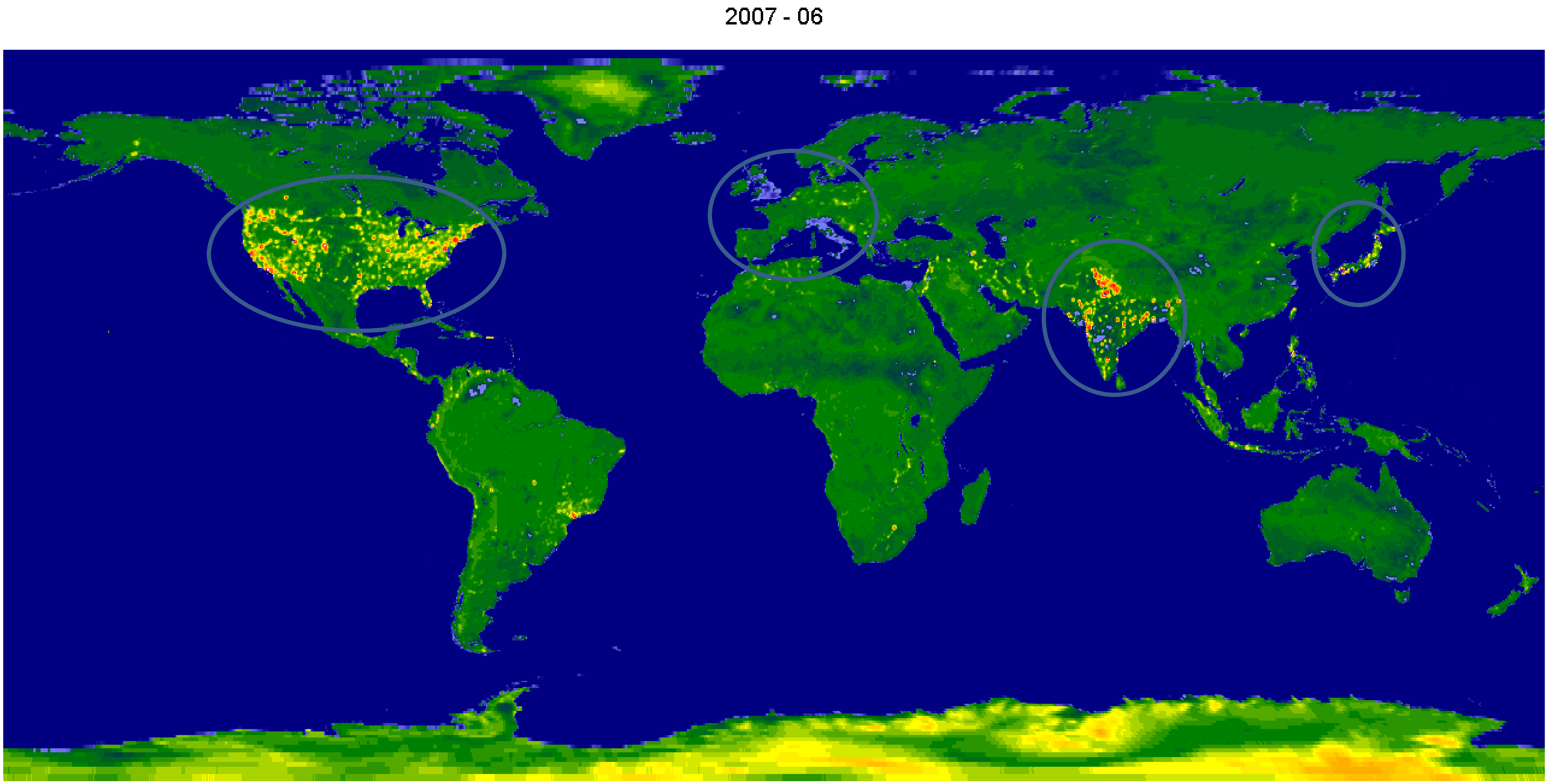
Evolution of C- and X-band



6.6 GHz

1979 1987 2007

Evolution of C- and X-band



6.9 GHz

1979 1987 2007

Additional Resources

- Committee on Radio Frequencies (CORF) of the National Research Council: www.nationalacademies.org/corf
- International Telecommunication Union: www.itu.org
- Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF) of the International Council for Science: www.iucaf.org
- U.S. Federal Communications Commission: www.fcc.gov
- U.S. National Telecommunications and Information Administration: www.ntia.doc.gov/osmhome/redbook/redbook.html
- U.S. National Radio Astronomy Observatory Spectrum Management: www.cv.nrao.edu/~hliszt/RFI/RFI.htm
- Geoscience and Remote Sensing Society (GRSS) of the Institute of Electrical and Electronics Engineers' (IEEE) Frequency Allocations in Remote Sensing (FARS) Committee: http://www.grss-ieee.org
- Committee on Radio Astronomy Frequencies (CRAF) of the European Science Foundation: www.astron.nl/craf
- U.S. National Science Foundation Electromagnetic Spectrum Management (ESM): http://nsf.gov/funding/pgm_summ.jsp?pims_id=5654