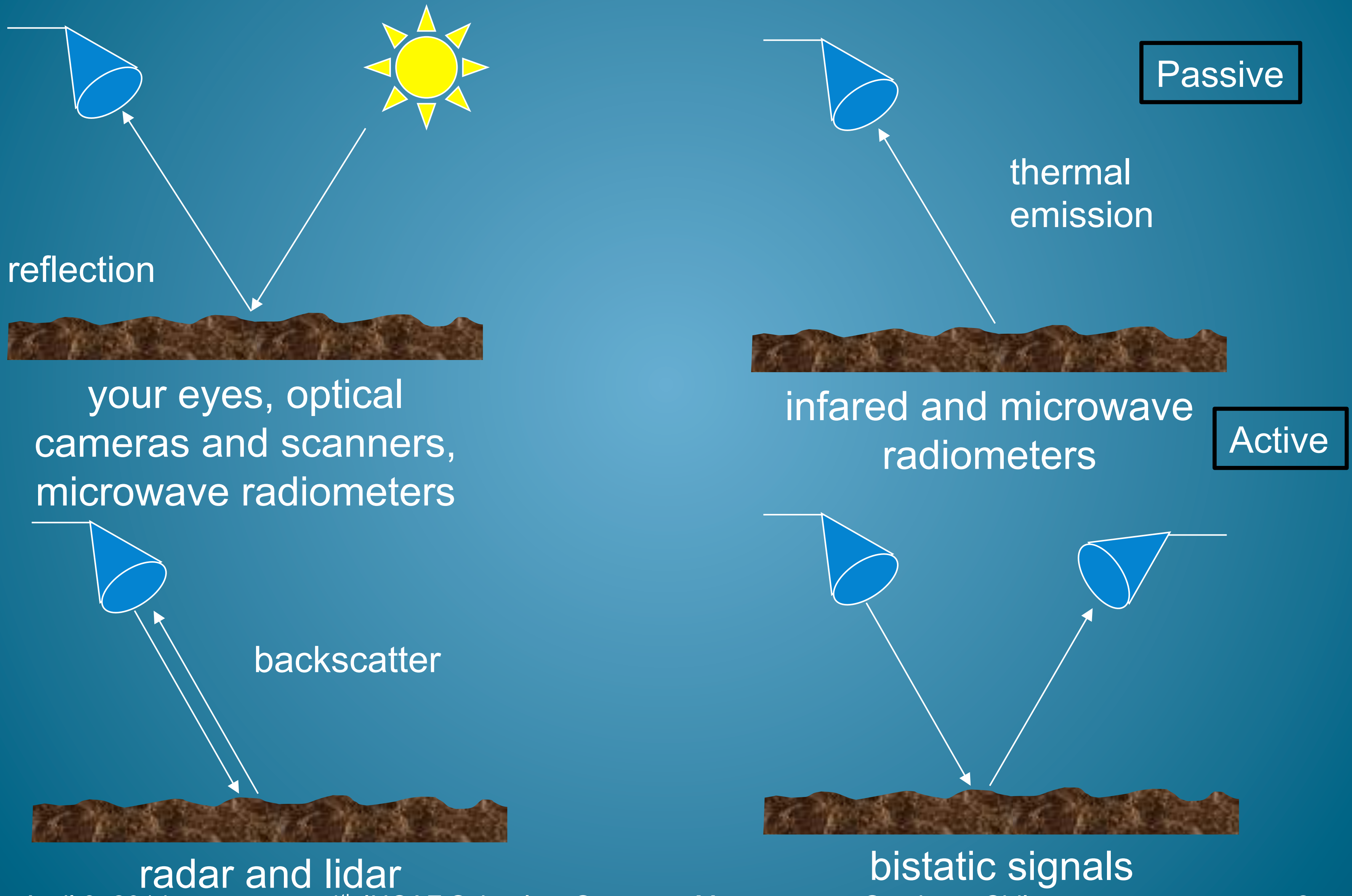
Earth Exploration-Satellite Service: Passive and Active Sensing

Todd Gaier[1] (for Steven C. Reising[2])

[1]Senior Research Scientist
Jet Propulsion Laboratory
Todd.gaier@jpl .nasa.gov
[2]Microwave Systems Laboratory
Colorado State University
Steven.Reising@ColoState.edu

*With extensive contributions from other members of the U.S. National Research Council's Committee on Radio Frequencies (CORF) and Spectrum Study Committee

Types of Remote Sensing

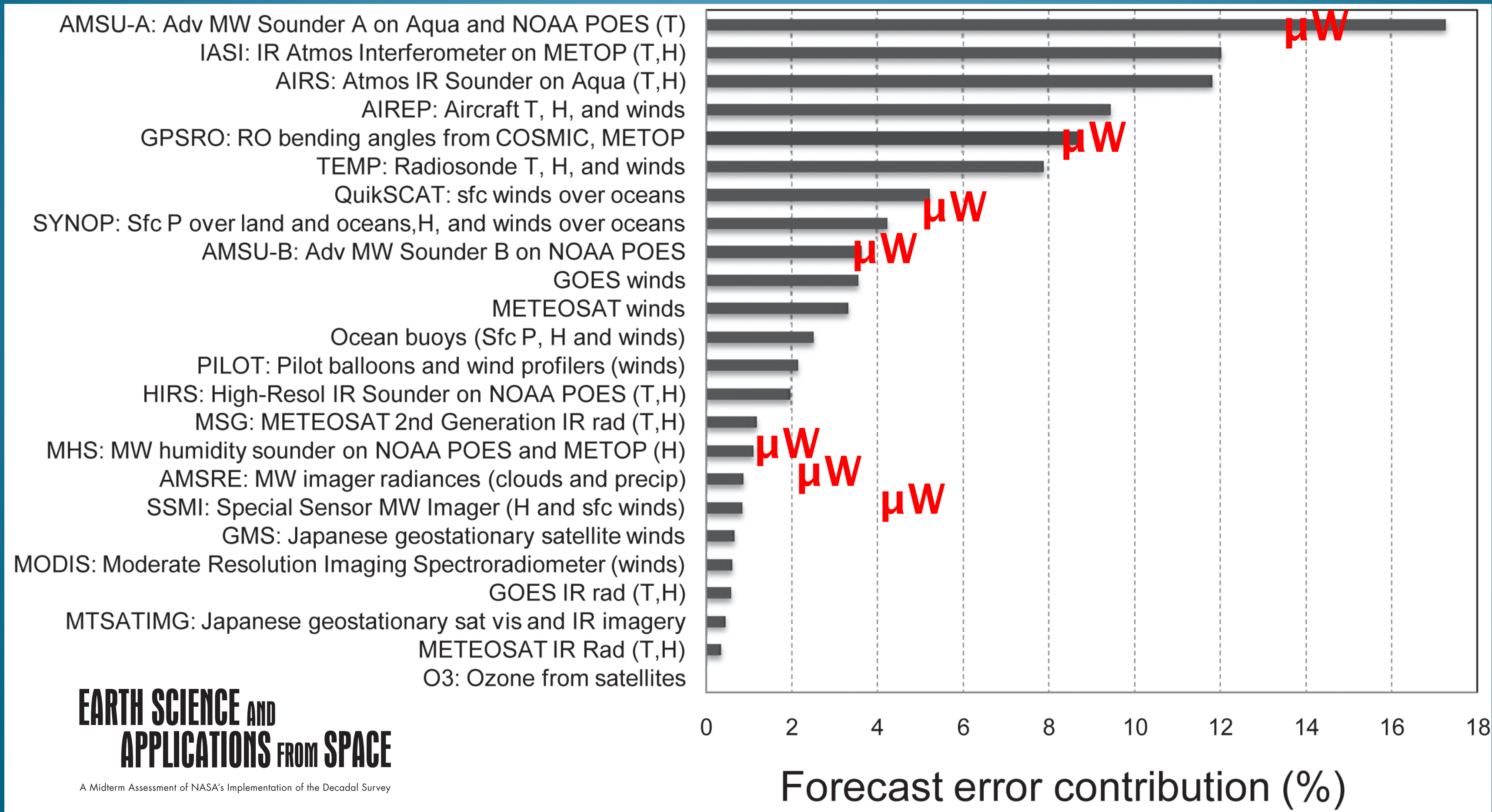


Motivation – Scientific Impacts

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

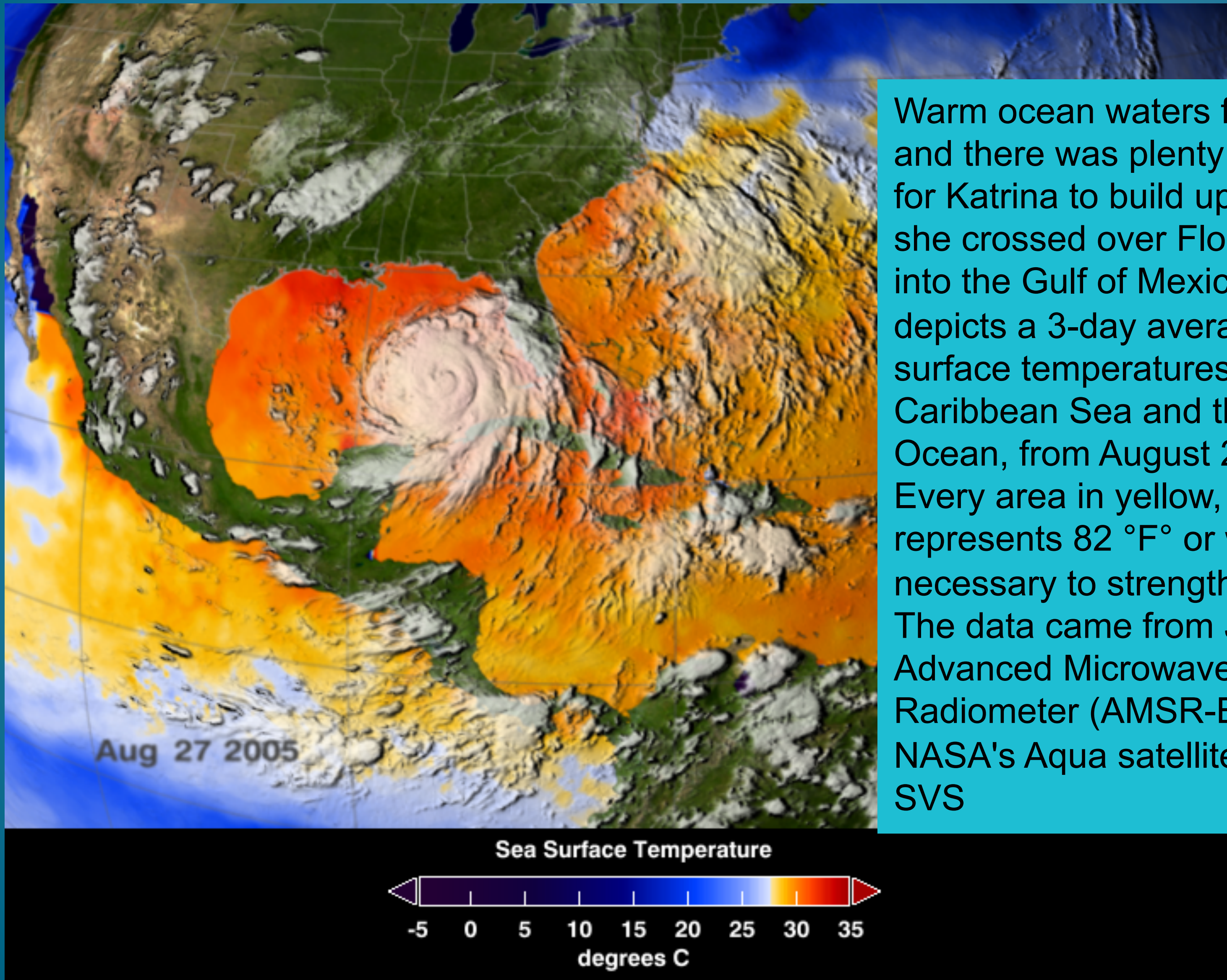
Microwave atmospheric temperature and humidity measurements

- The single biggest factor in global weather forecasting



ECMWF

One View from Space: Hurricane Katrina (2005)



Warm ocean waters fuel hurricanes, and there was plenty of warm water for Katrina to build up strength once she crossed over Florida and moved into the Gulf of Mexico. This image depicts a 3-day average of actual sea surface temperatures (SSTs) for the Caribbean Sea and the Atlantic Ocean, from August 25-27, 2005. Every area in yellow, orange or red represents 82 °F° or warmer, necessary to strengthen a hurricane. The data came from JAXA's Advanced Microwave Scanning Radiometer (AMSR-E) instrument on NASA's Aqua satellite. Credit: NASA/SVS

Impact of Passive Remote Sensing of Soil Moisture on Climate Forecasting

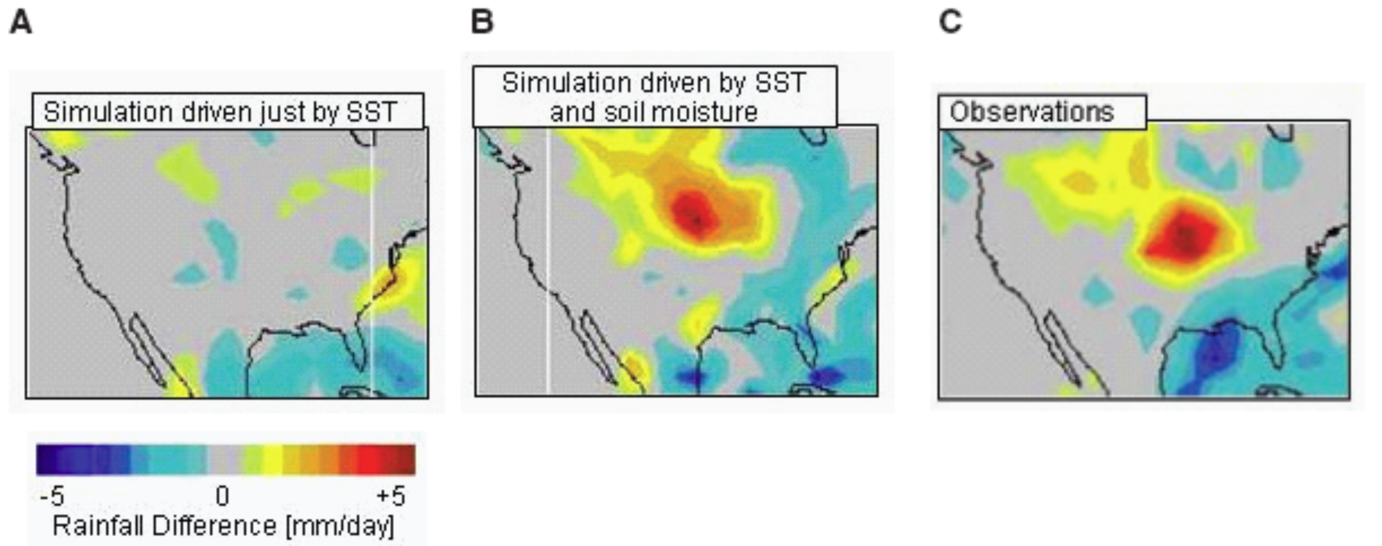


FIGURE 2.5 The value of soil moisture data to climate forecasts. Predictability of seasonal climate is dependent on boundary conditions such as sea surface temperatures (SST) and soil moisture—soil moisture being particularly important over continental interiors. In the results of a simulation driven only by SST (panel A), the climate anomaly in panel C (observed difference in rainfall between the flood year of 1993 minus the drought year of 1988) is not reproduced. Results of the simulation driven by SST and soil moisture (panel B), however, accurately predict this seasonal anomaly. SOURCE: D. Entekhabi, G.R. Asrar, A.K. Betts, K.J. Beven, R.L. Bras, C.J. Duffy, T. Dunne, R.D. Koster, D.P. Lettenmaier, D.B. McLaughlin, and W.J. Shuttleworth, "An Agenda for Land Surface Hydrology Research and a Call for the Second International Hydrological Decade," *Bulletin of the American Meteorological Society*, 80(10): 2043-2058 (1999).

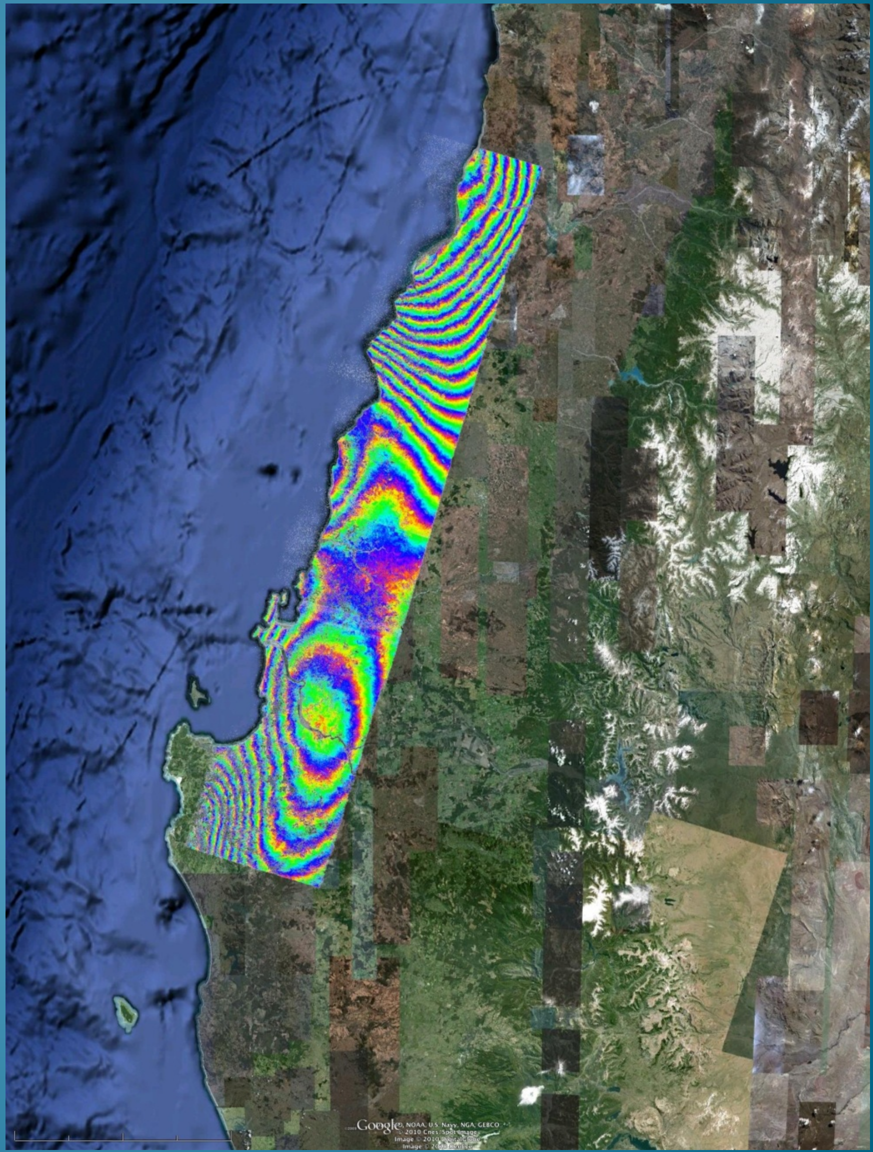
Excerpted from National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010

Life in a subduction zone…

L-band SAR Interferogram of Chile.

Multi-pass interferograms track ground movements of large areas down to cm scales- reflecting built up strains in the crust.

Interferograms derived from ALOS PALSAR data processed by Xiaopeng Tong and David Sandwell using GMTSAR



Passive Microwave Sensing Milestones – 1

- 1968: USSR Cosmos 243
- 1972: NASA Nimbus-5 (NEMS and ESMR)
  - First long-lived satellites for all-weather imaging
- 1973: NASA Skylab (S-194)
- 1975: NASA Nimbus-6 (SCAMS)
- 1978: NASA Nimbus-7 (SMMR)
- 1978: NOAA TIROS-N (MSU & SSU)
  - First operational weather using temperature sounding

Passive Microwave Sensing Milestones – 2

- 1987: USAF DMSP F8 (SSM/I)
  - First operational surface and atmospheric H_2O
- 1991: NASA UARS (MLS)
  - First passive satellite measuring above 90 GHz
- 1997: NASA / JAXA TRMM (TMI)
  - Added 10.7 GHz to SSM/I to increase sensitivity to SST to improve precipitation measurements
- 1998: NOAA-15 (AMSU)
- 2002: NASA EOS Aqua (JAXA's AMSR-E)

Passive Sensor Milestones – 3

- 2003: NRL Coriolis (WindSat)
  – First polarimetric radiometry from space
- 2009: ESA SMOS (MIRAS)
  -- First synthetic aperture radiometry from space
- 2011: NASA Aquarius and SAC-D (CONAE)
  -- Combined passive (1400-1427 MHz) and active (1215-1300 MHz) observations

Passive Sensor Milestones – 4

- 2014: NASA Global Precipitation Mission (GPM)
  – Radiometer suite from 10-183 GHz
  – Radars at K and Ka band
- 2014: DMSP F19 (launched Thursday)
- 2014(upcoming): NASA SMAP

  -- 1.2/1.4 GHz Active/passive soil moisture

  requires RFI detection/removal and front-end filtering

  -- large deployable antenna

Suite of current missions exceeds $10B

Motivation – Sensitivity

- Receive-only ("passive") measurements of weak natural signals in a broad range of frequencies must be made with extreme sensitivity.
- Example:
  - Equivalent temperature (proportional to received power) of 100 K in 100 MHz bandwidth → 0.1 pW
  - Sensitivity to 0.1-K fluctuations → 0.1 fW

Motivation – Stewardship

- The extreme sensitivity required makes it essential:
  - to maintain protected allocations and
  - to properly manage use of the spectrum near the protected allocations.
  - Instantly renewable resource-

"Shared use. Shared responsibility"

Motivation – Requirements

- Dedicated passive allocations exist only in a limited number of bands.
- There is need for protection of bands essential to scientific and societal interests that are not now protected.
- Some observations will need to operate in unprotected bands- infrastructure solutions

Motivation – Opportunity and Challenge

- The receive-only services can sometimes take advantage of uncongested spectra not allocated to them.
- Increasing congestion is increasingly precluding this capability as radar and communications technologies advance.

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

Excerpted from National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, The National Academies Press, Washington, D.C., 2007.

EESS Regulatory Structure

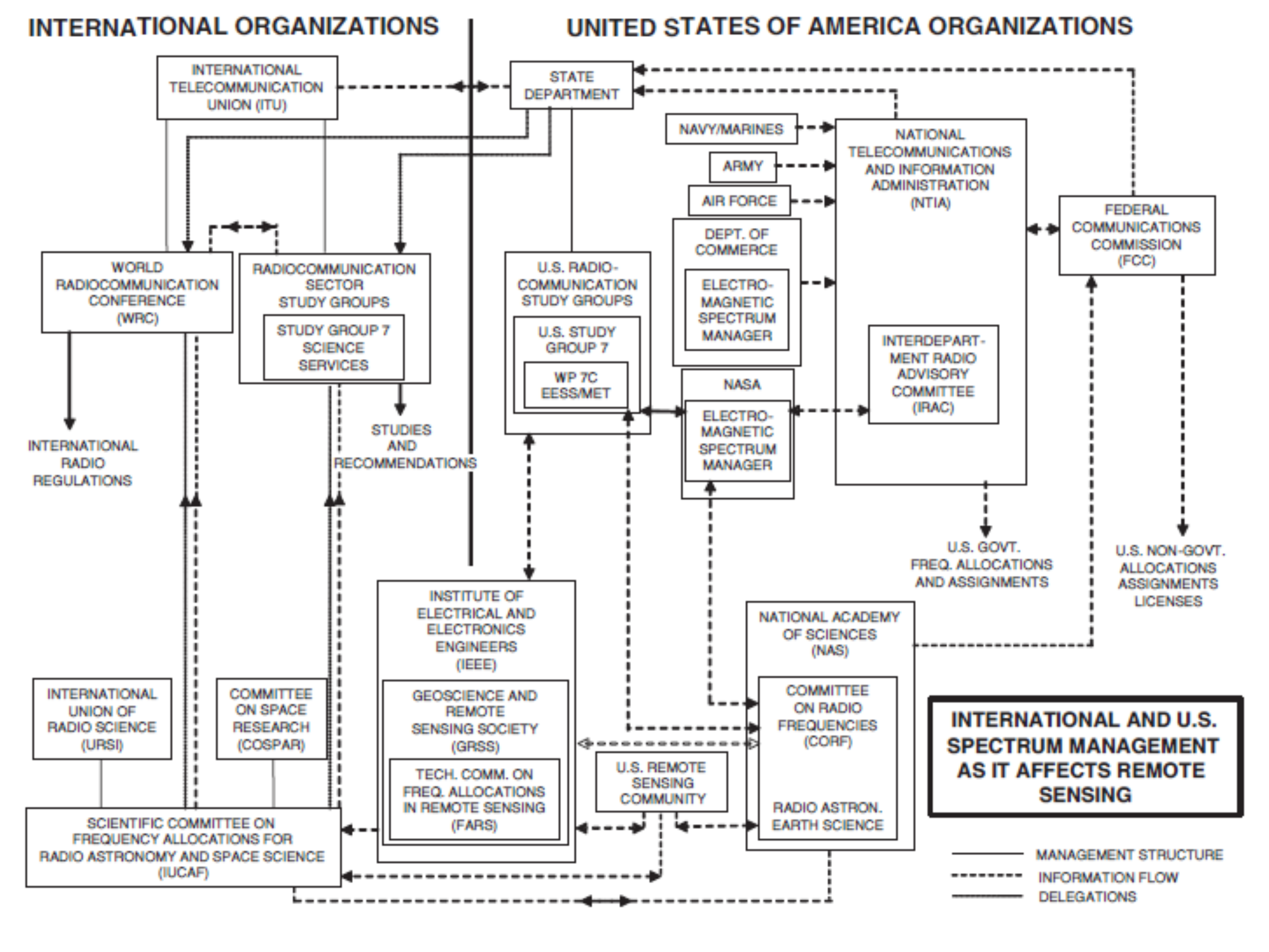


FIGURE 1.2 The diagram depicts the complex relationship among the national and international radio regulatory bodies for the Earth Exploration-Satellite Service.

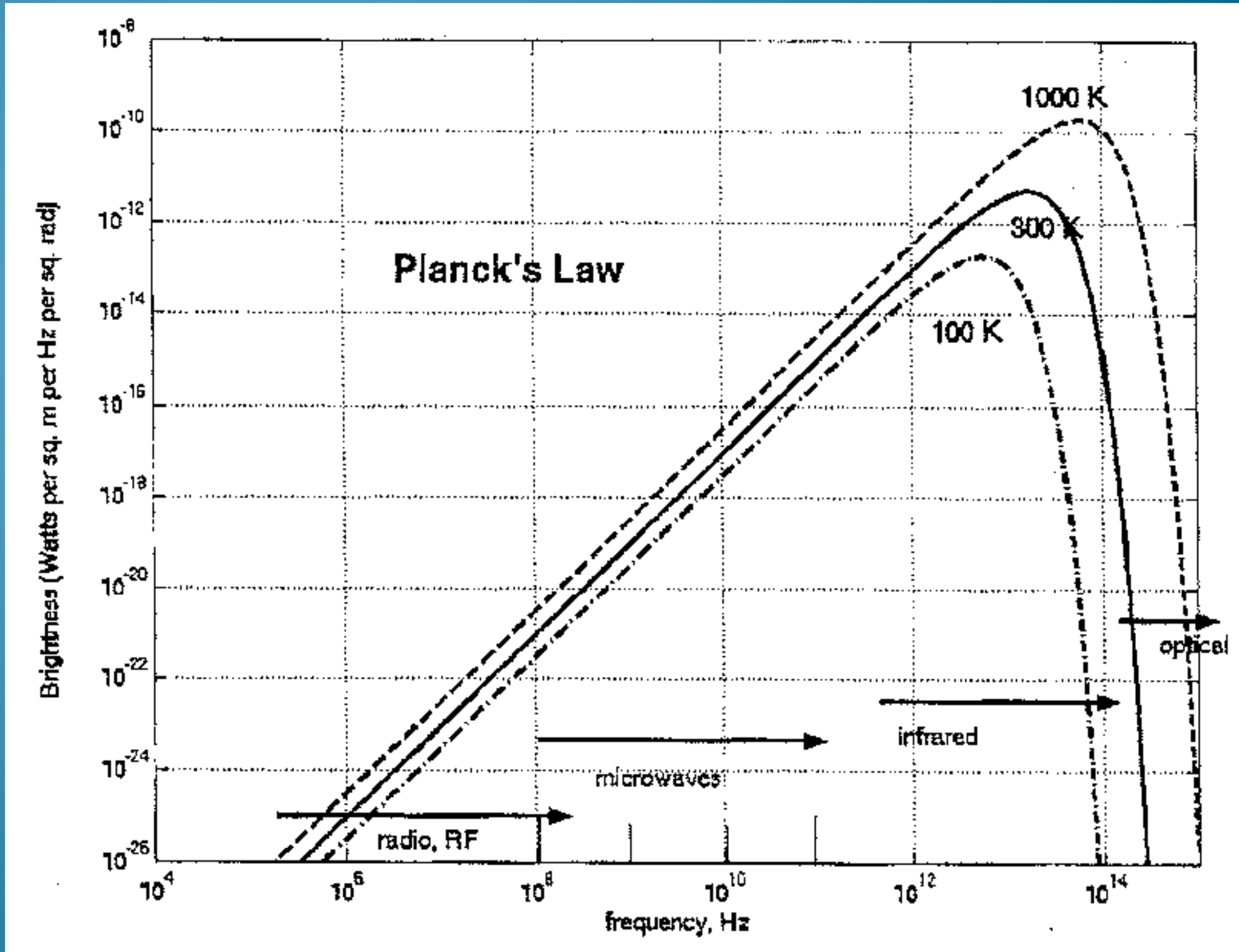
Excerpted from National Research Council, *Handbook of Frequency Allocations and Spectrum Protection for Scientific Uses*, The National Academies Press, Washington, D.C., 2007.

Planck's Law of Blackbody Radiation

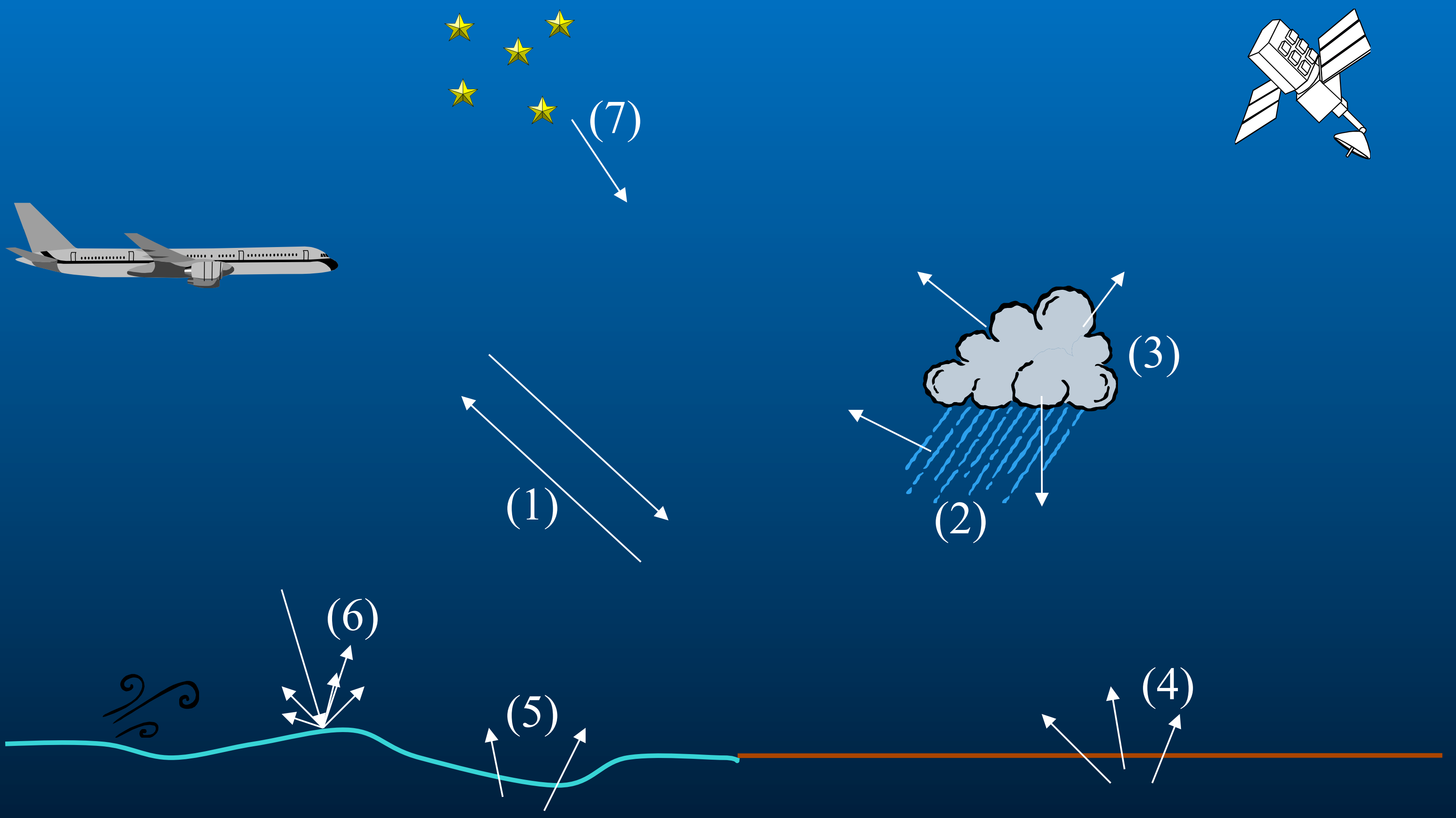
The radiobrightness, spectral brightness or simply "brightness" of a radiating object is given by Planck´s Radiation Law:

$$B_\nu = \frac{2hf^3}{c^2} \frac{1}{e^{hf/kT} - 1}$$

where
h = 6.63 x 10^{-34} J·sec,
f = frequency in Hz,
k = 1.38 x 10^{-23} J/K,
c = 3.0 x 10^8 m/s,
T = absolute temperature in K.



Natural sources of microwave radiation



(1) Atmosphere
(2) Precipitation
(3) Clouds

(4) Land
(5) Oceans
(6) Scattering

(7) 2.7 K cosmic microwave background

Land Surface Remote Sensing

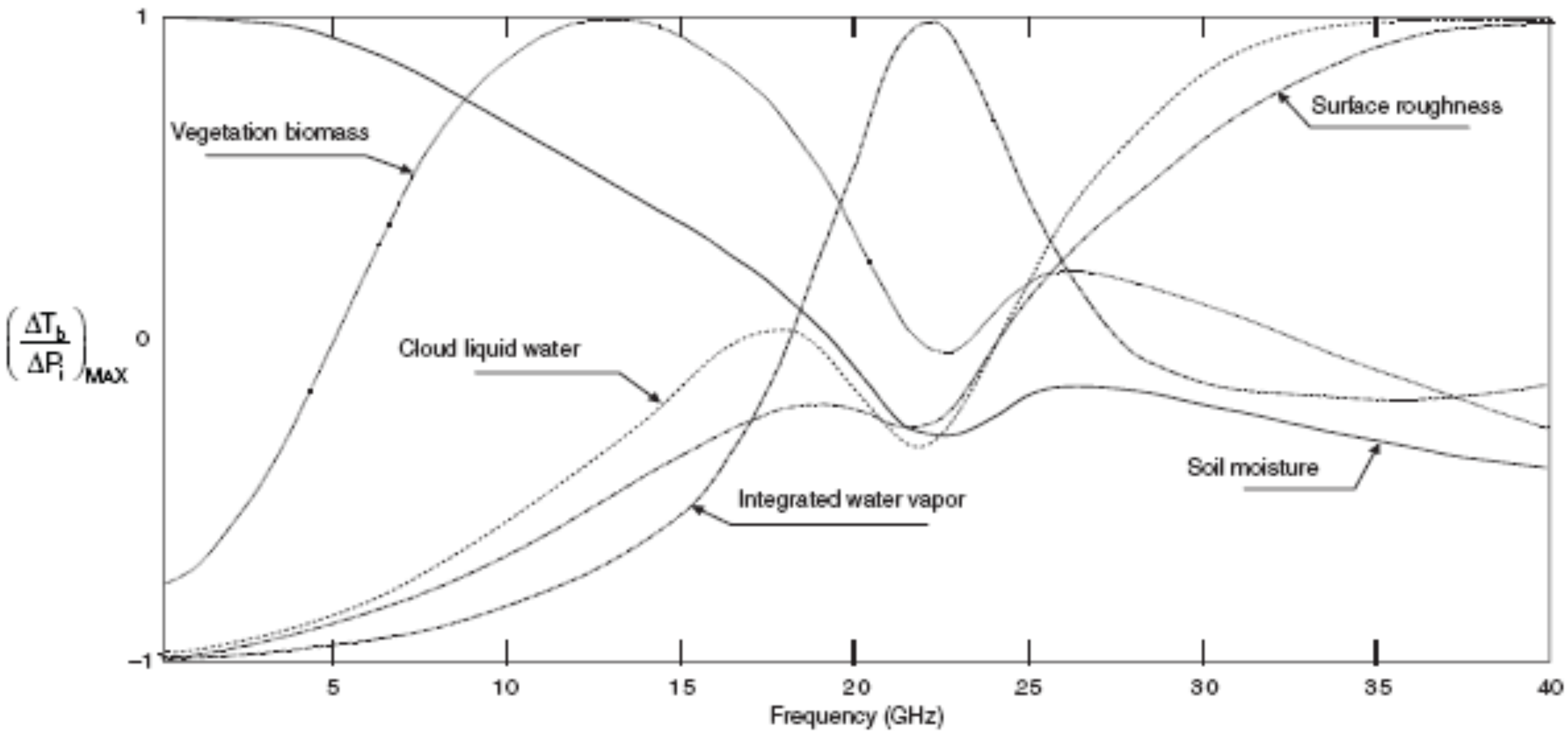


FIGURE 2.12 Land scene: relative sensitivity of the brightness temperature to soil moisture, cloud liquid water, and integrated water vapor as a function of frequency for space-based measurements.

Excerpted from National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010

Ocean Surface Remote Sensing

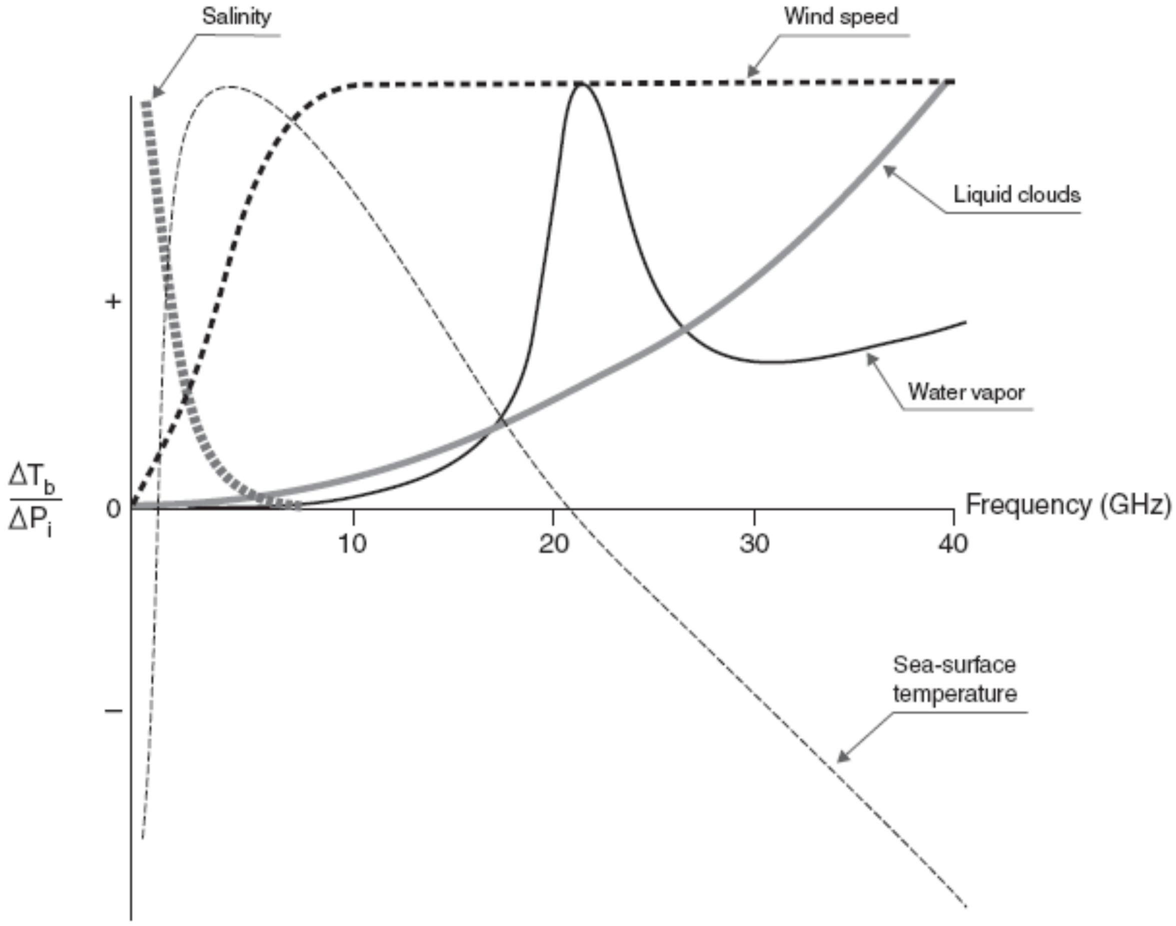
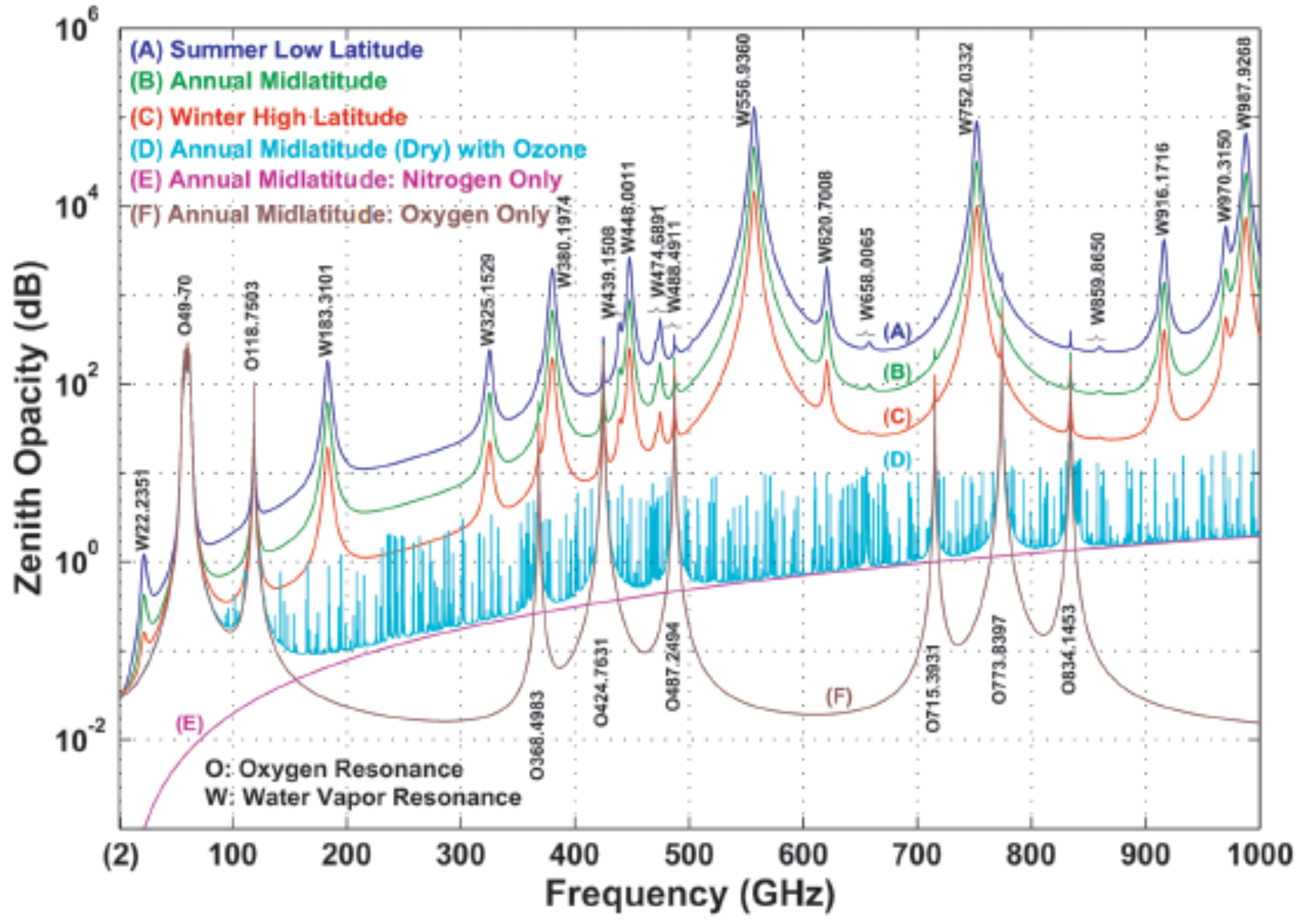


FIGURE 2.11 Ocean scene: relative sensitivity of sea surface salinity, sea surface temperature, cloud liquid water, and integrated water vapor as a function of frequency for space-based measurements. Original figure by Thomas T. Wilheit, NASA-GSFC.

Excerpted from National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010

Atmospheric Absorption to 1 THz

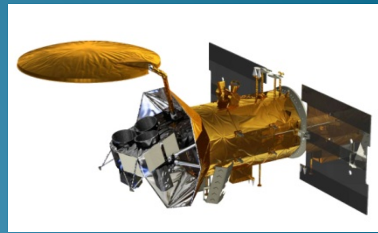


The opacity of Earth's atmosphere in the radio range of frequencies from 1 to 1000 GHz for six scenarios. Courtesy of A.J. Gasiewski, University of Colorado. Excerpted from National Research Council, *Spectrum Management for Science in the 21st Century*, The National Academies Press, Washington, D.C., 2010

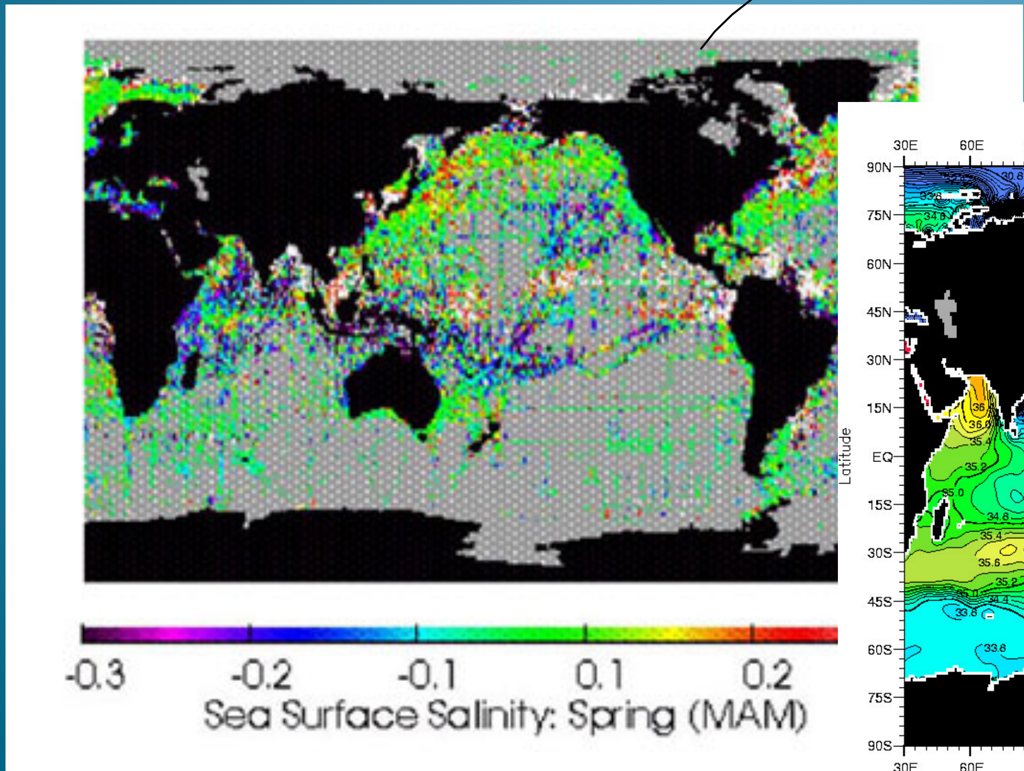
GPM alone uses much of the spectrum

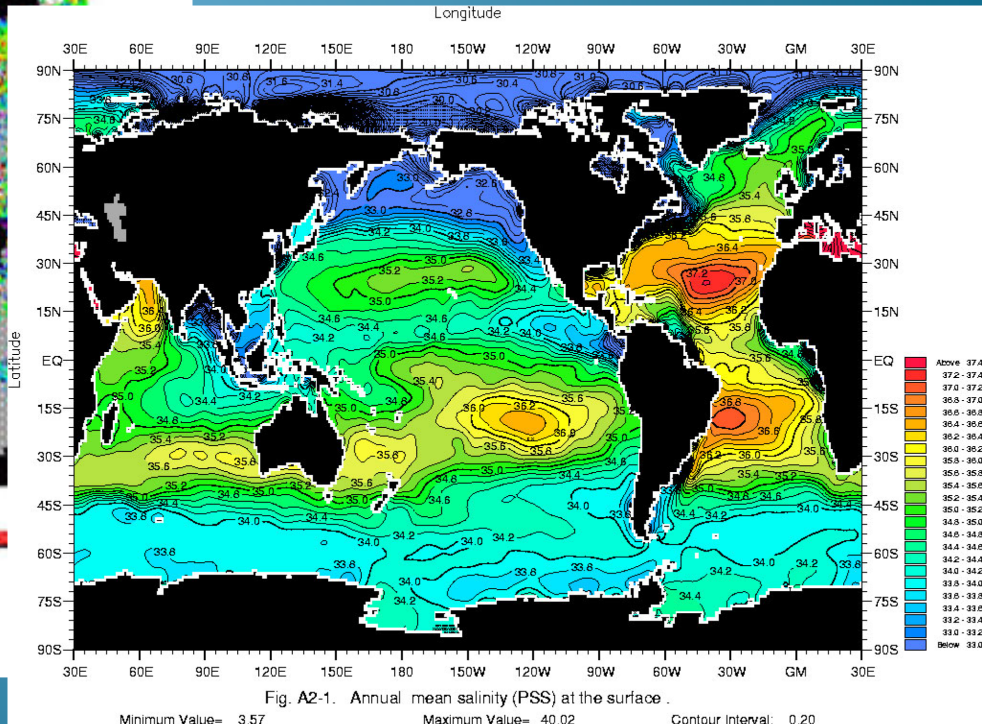
~~1~~ 0.5 – 2 GHz (L band)

- Soil Moisture (through vegetation)
- Ocean Salinity



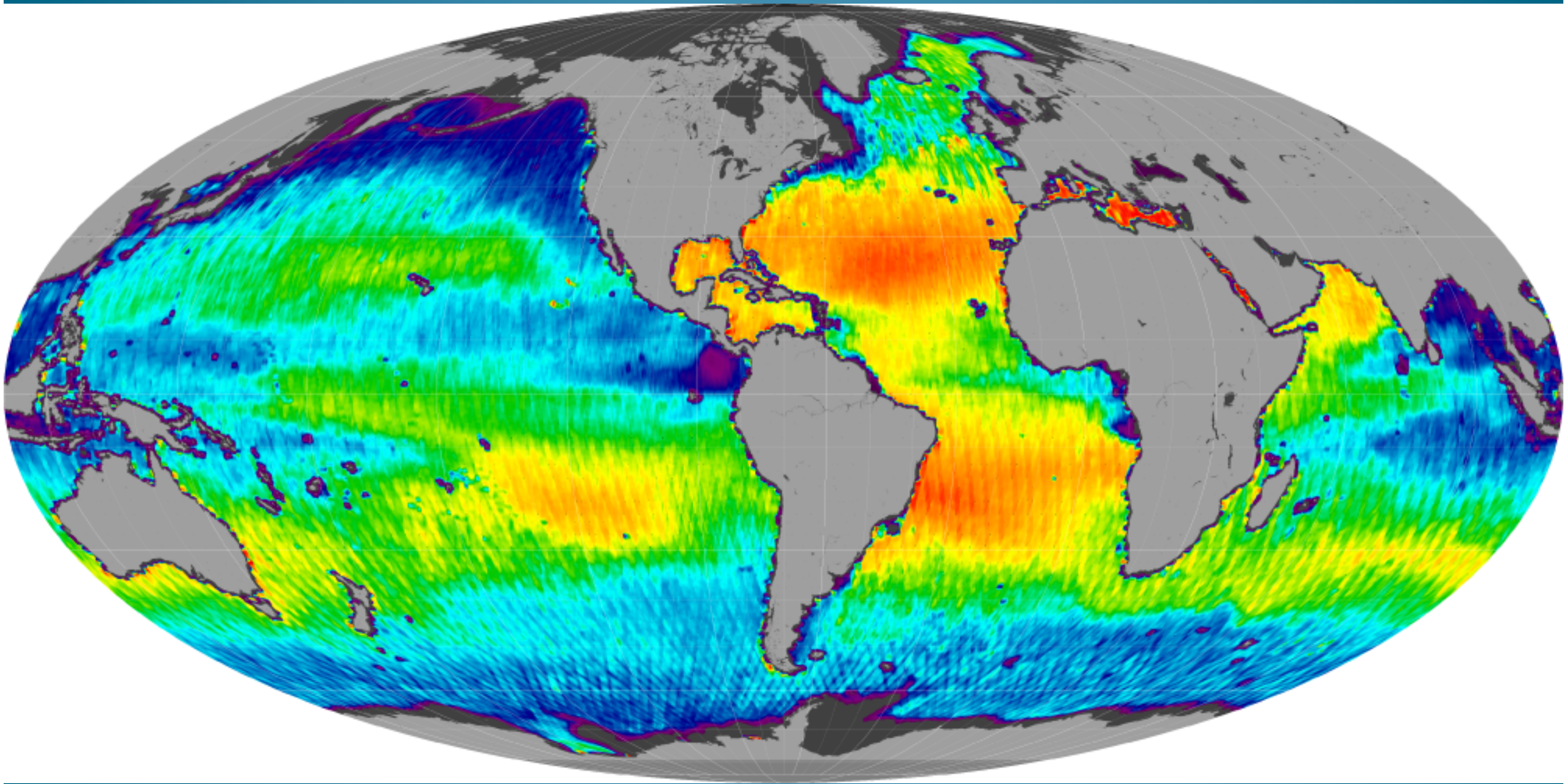
Aquarius/SAC-D



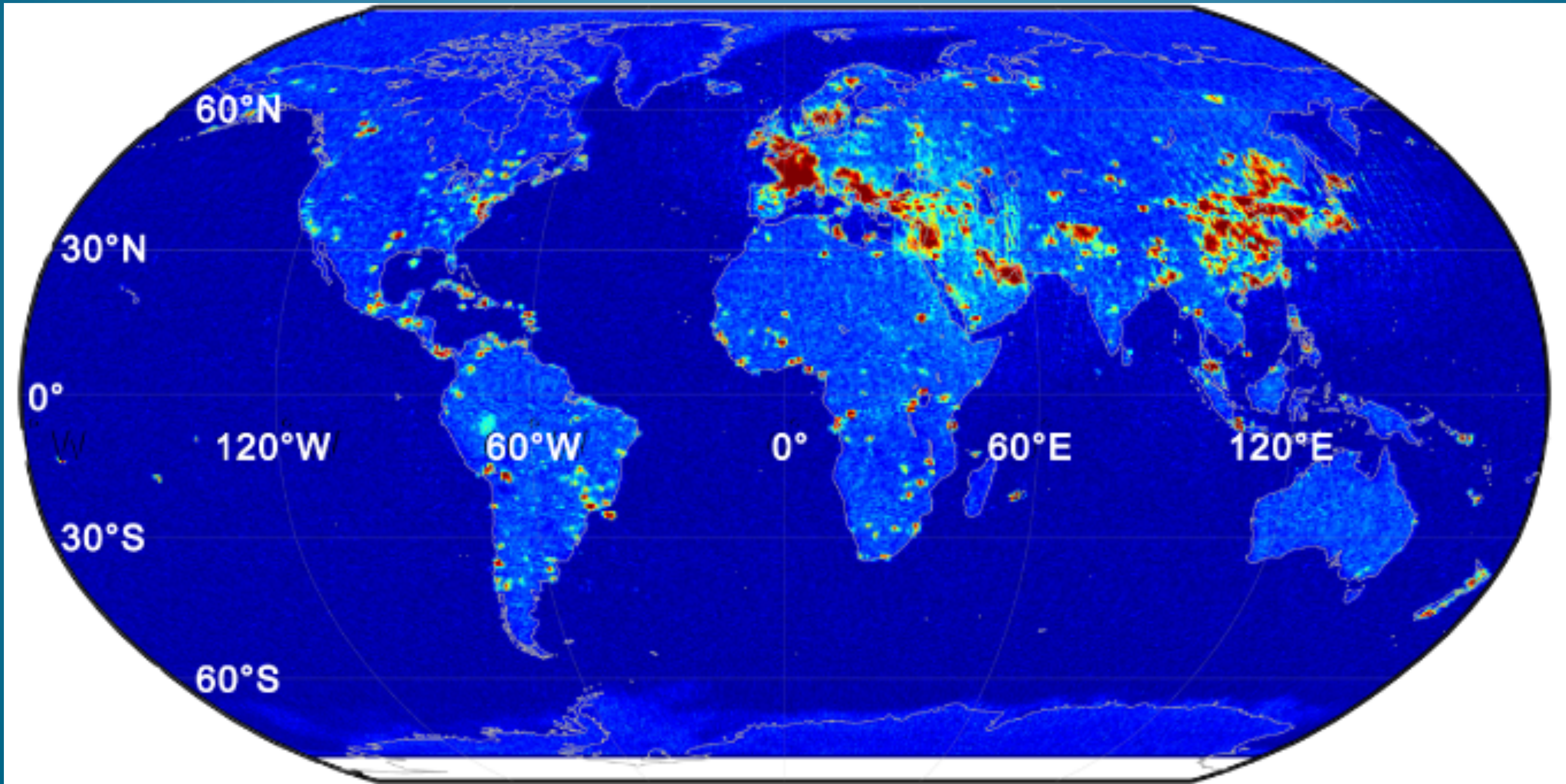


http://aquarius.nasa.gov/

Aquarius Ocean Salinity 2013

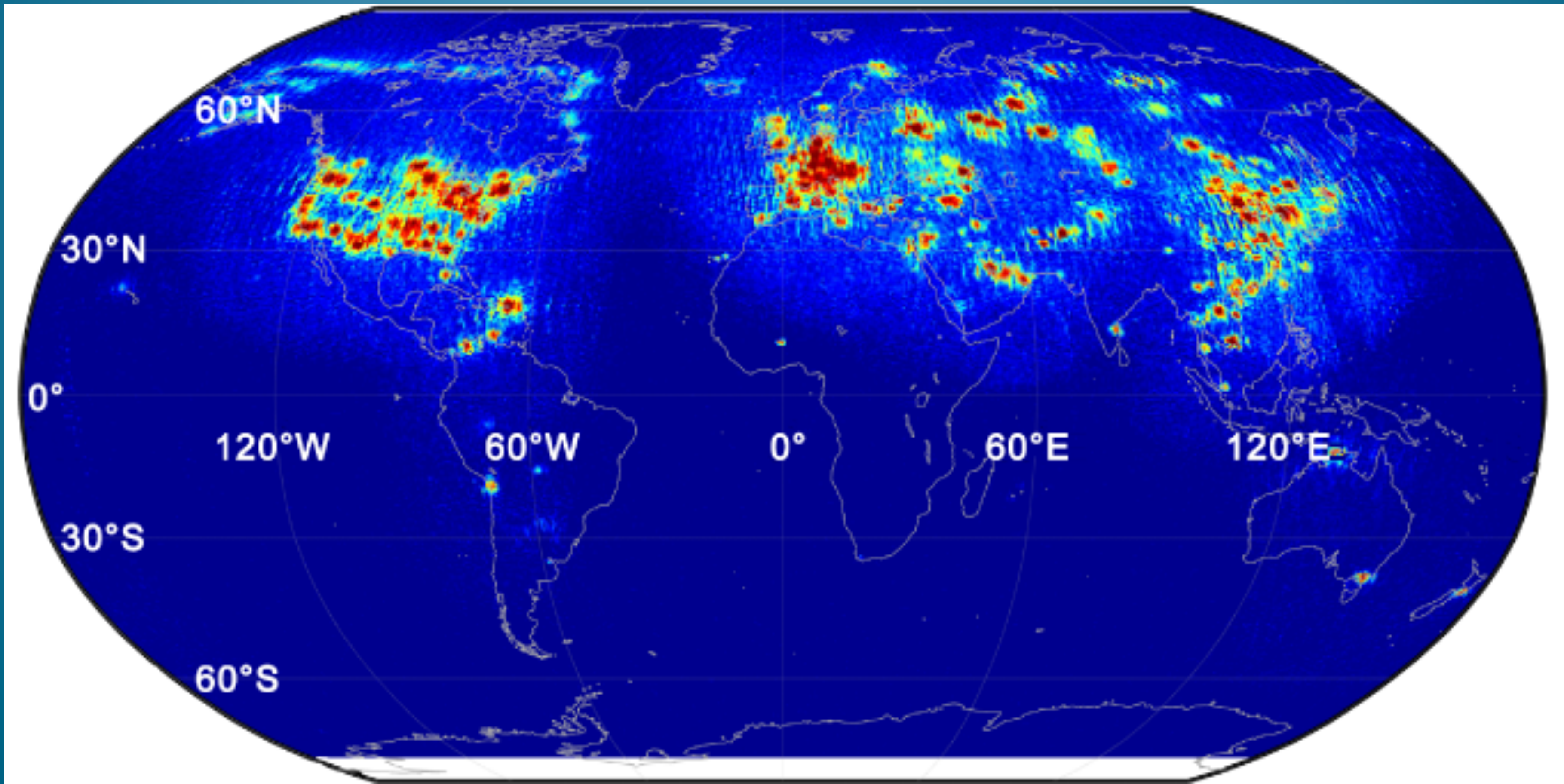


Aquarius RFI 2014 (1400 MHz)

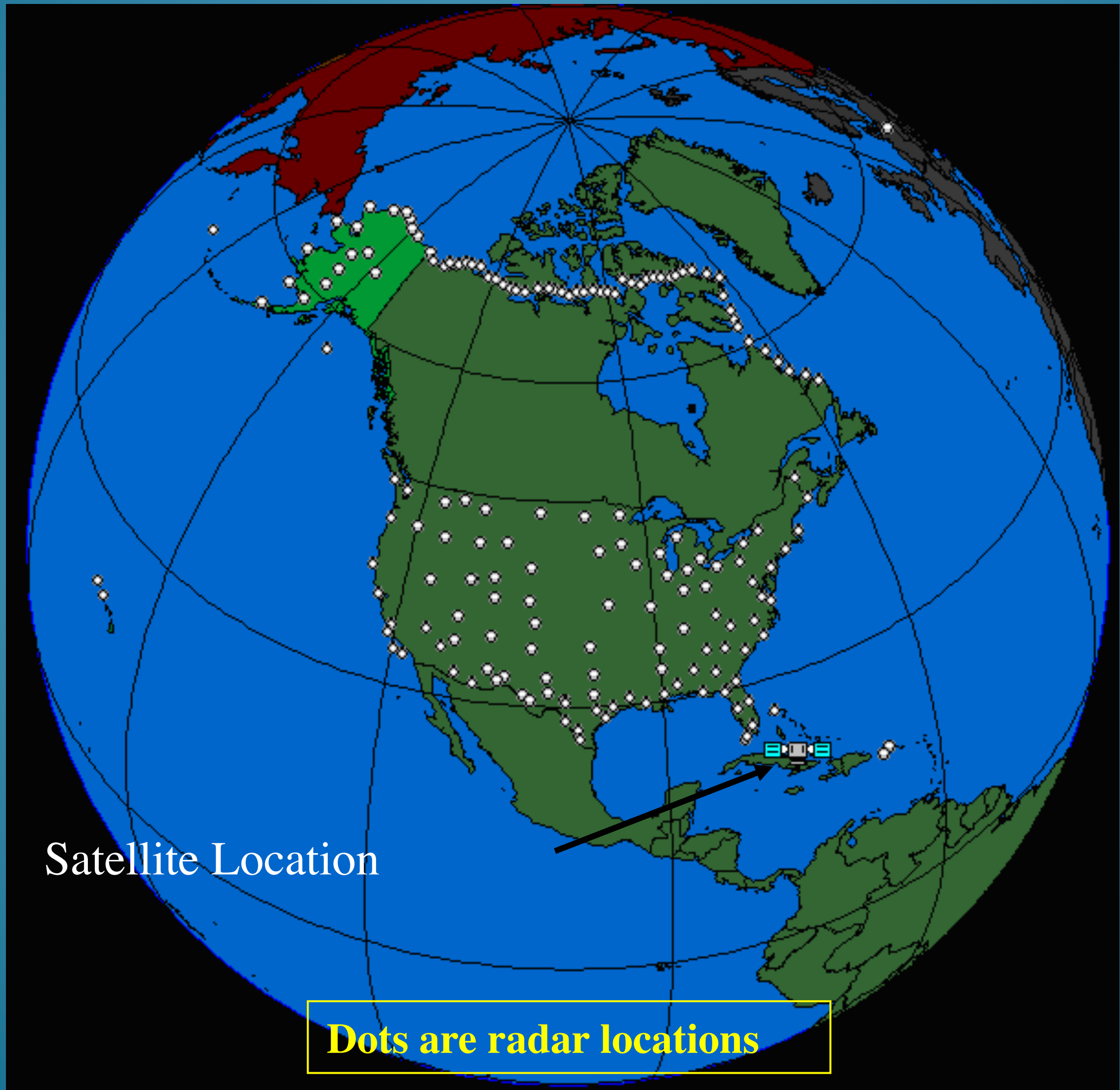


Aquarius RFI 2014 (1200 MHz)

Even Radars are impacted! SMAP must mitigate in both passive and active bands



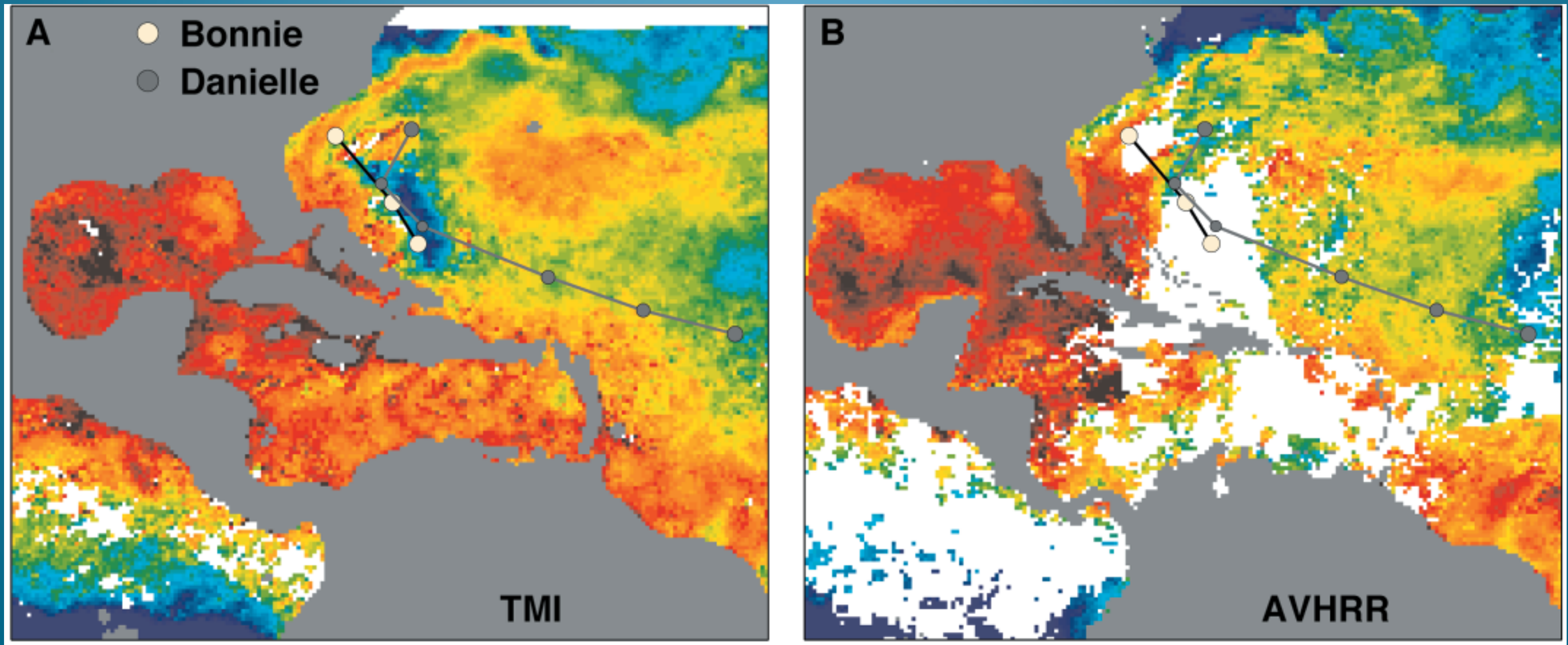
U.S. Radar Locations



From Zuzek, J., NASA Headquarters, MicroRad 2010, Washington, DC, presented March 4, 2010.

4 – 12 GHz (C and X bands)

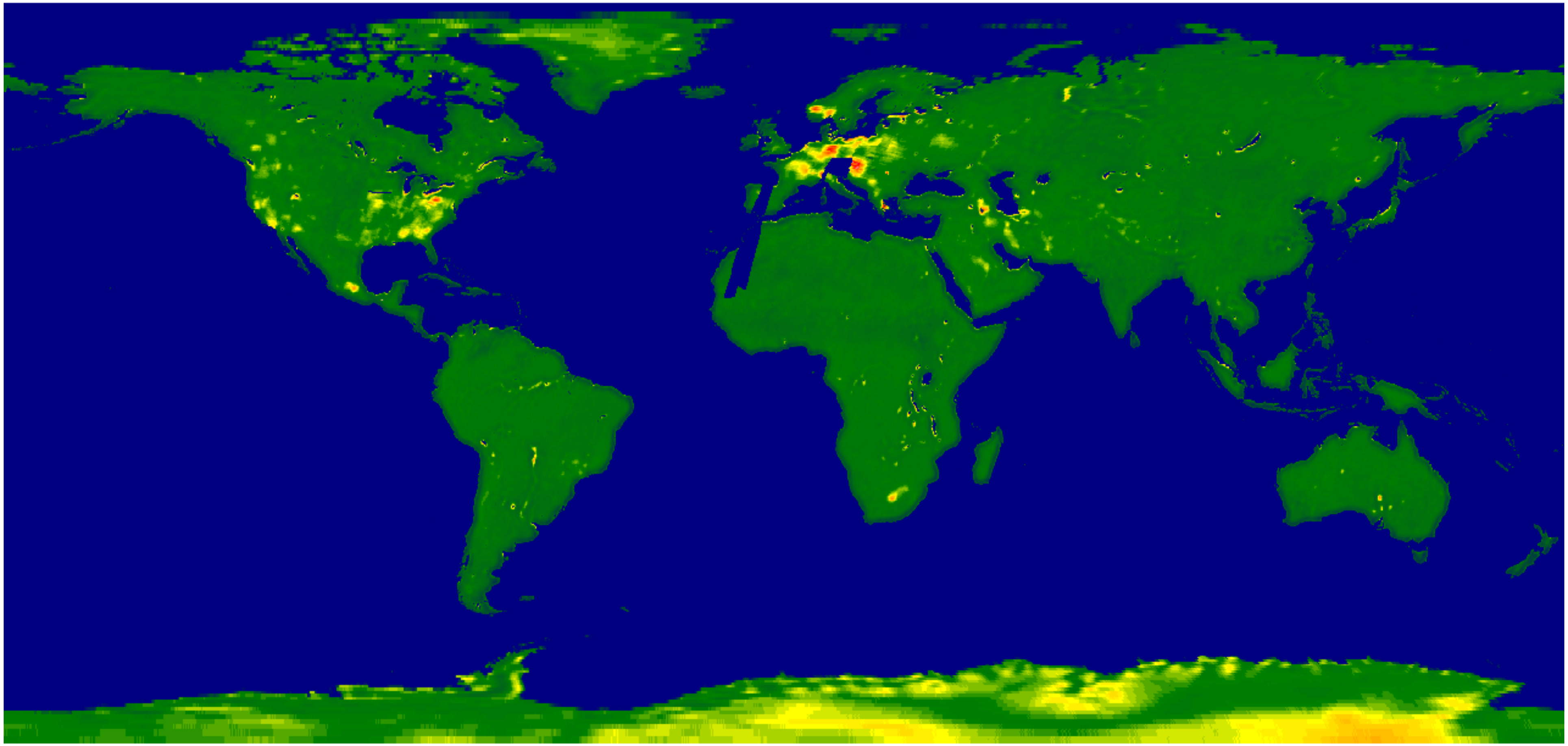
- Soil Moisture (light vegetation)
- Sea Surface Temperature



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

Evolution of C- and X-band Global RFI

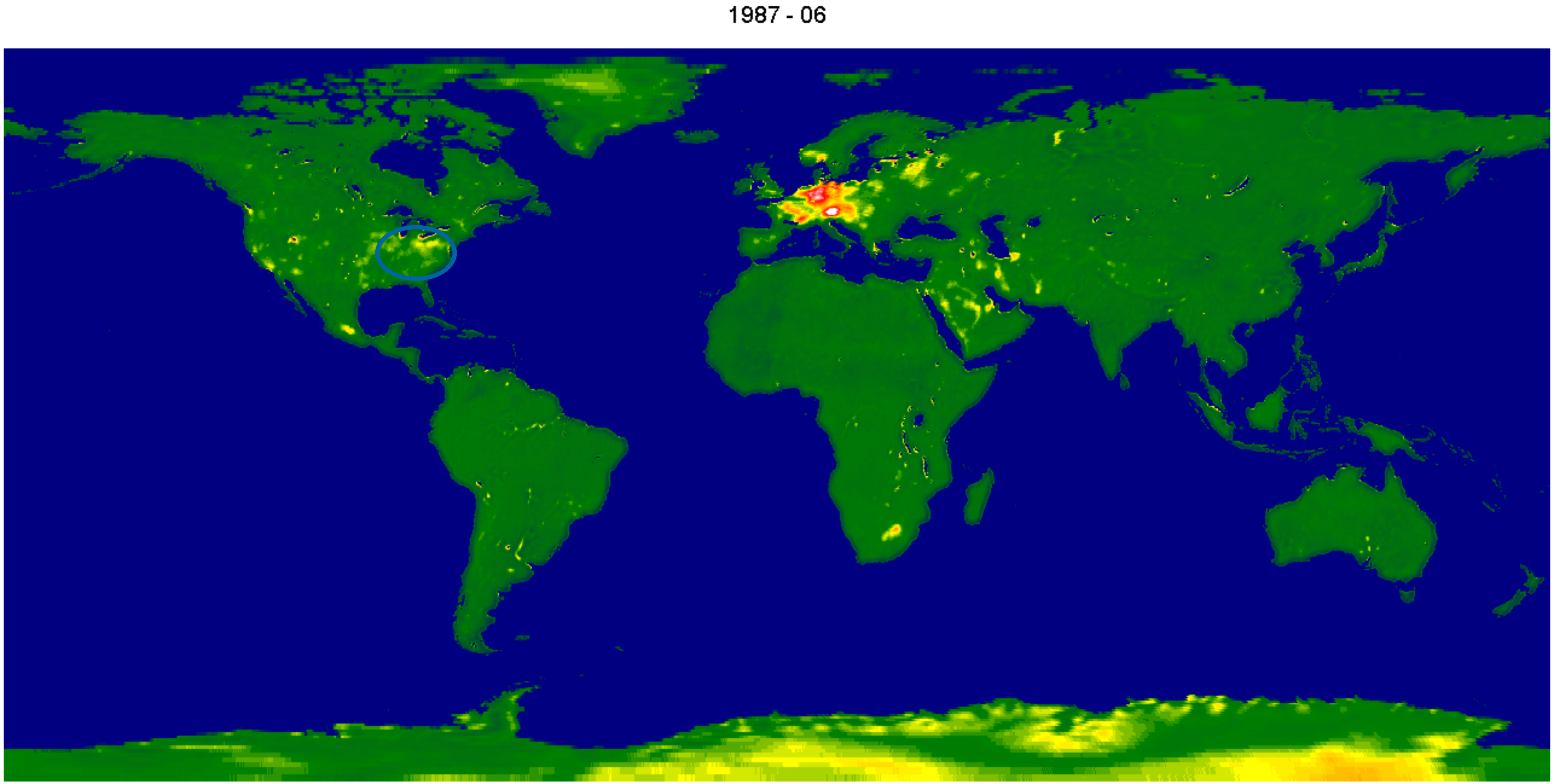
1979 - 06



6.6 GHz

1979 1987 2007

Evolution of C- and X-band Global RFI

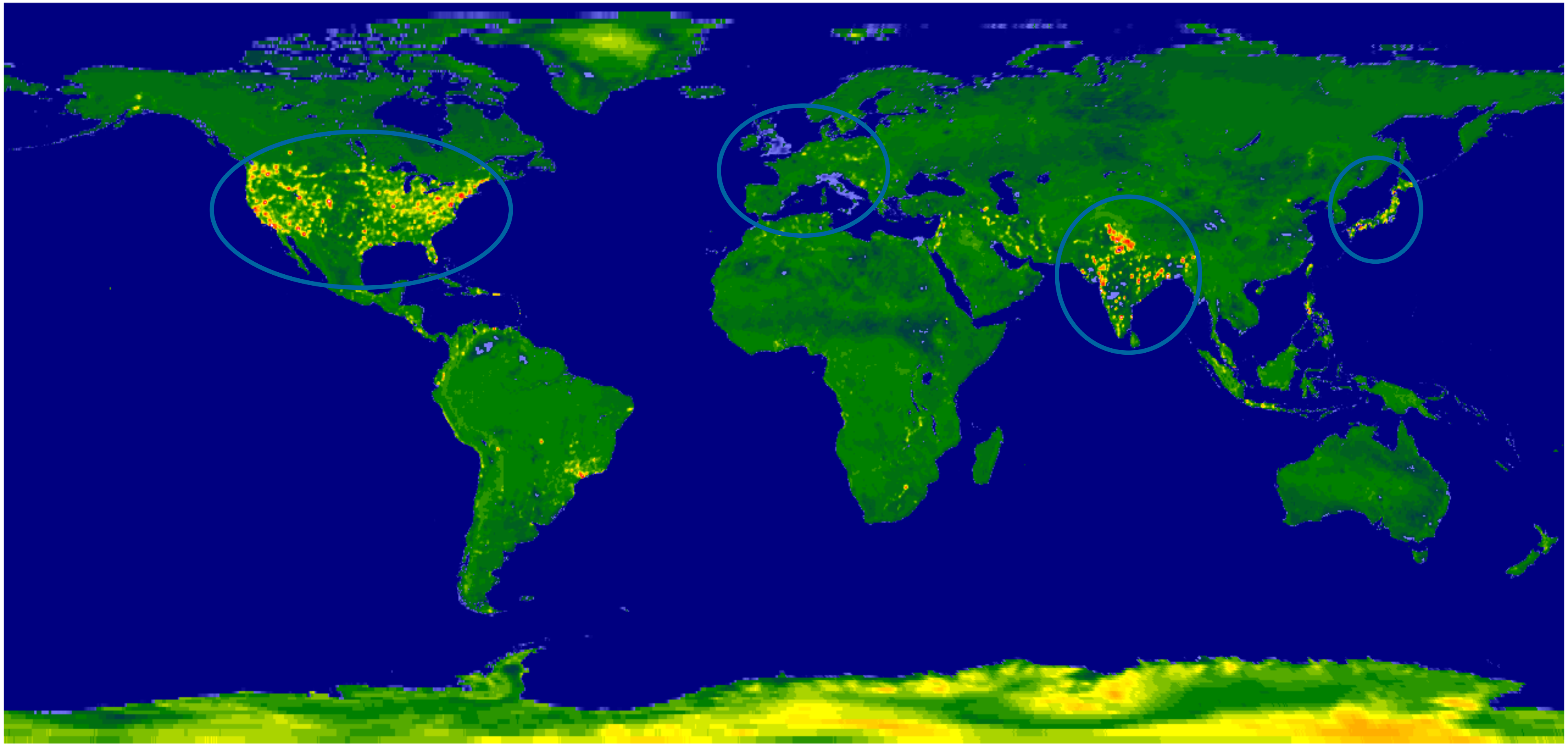


6.6 GHz

1979 1987 2007

Evolution of C- and X-band Global RFI

2007 - 06

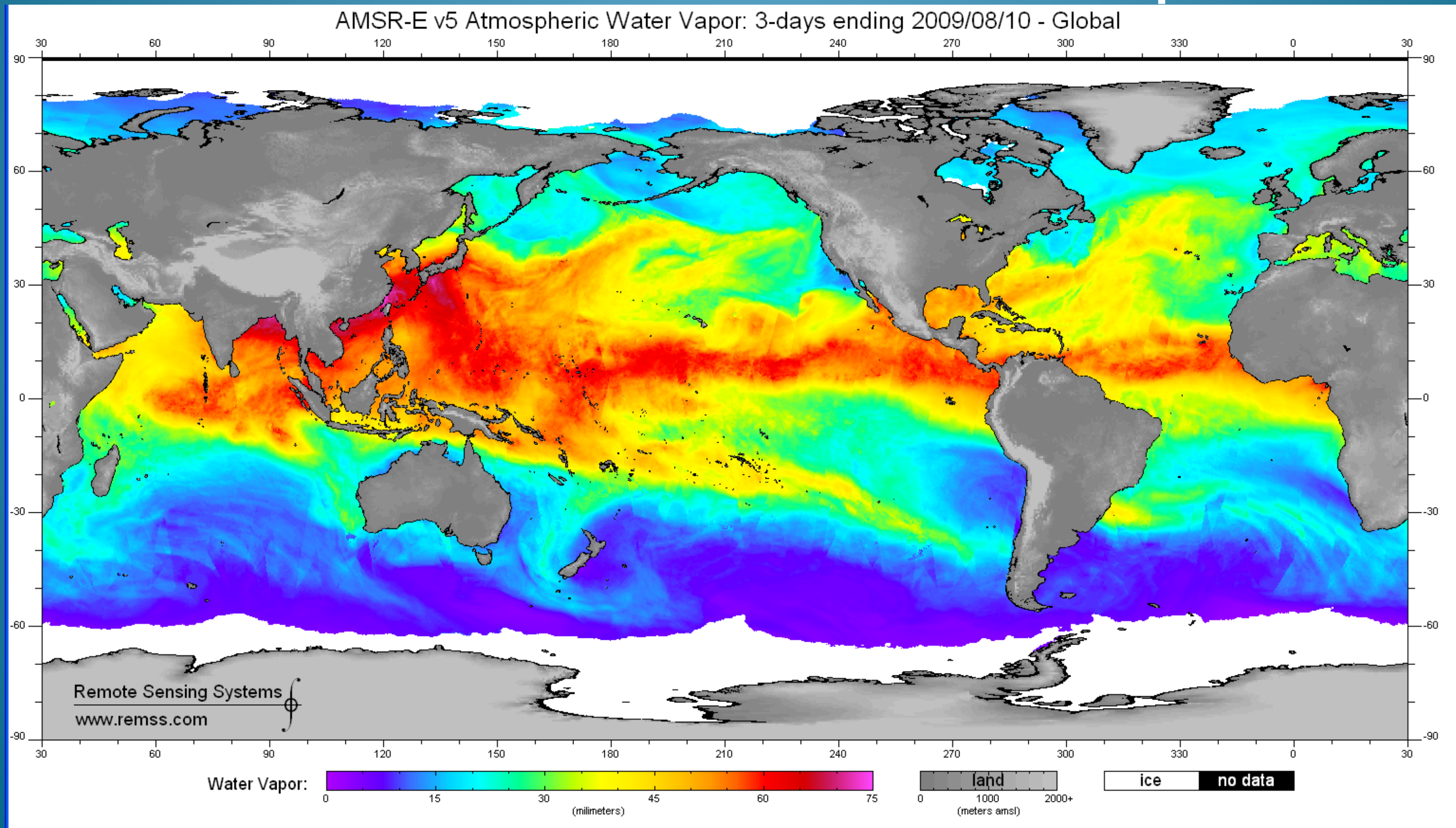


6.9 GHz

1979 1987 2007

12 – 26 GHz (Ku and K bands)

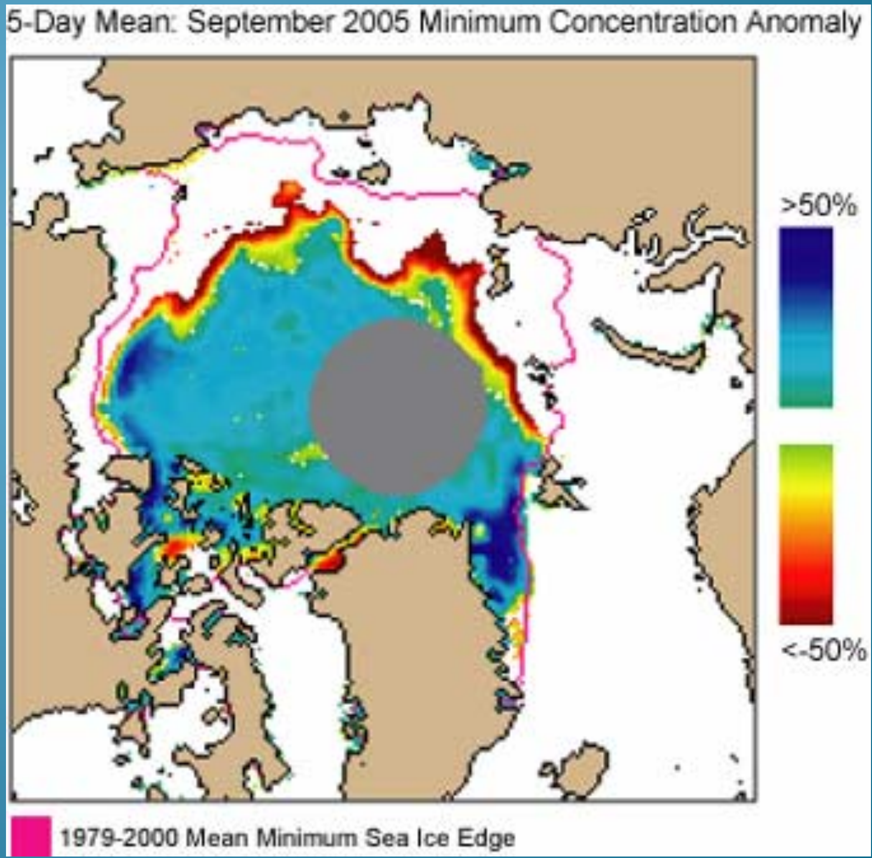
- Snow, sea ice, precipitation, clouds
- Ocean winds
- Water vapor



26 – 40 GHz (Ka band)

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

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

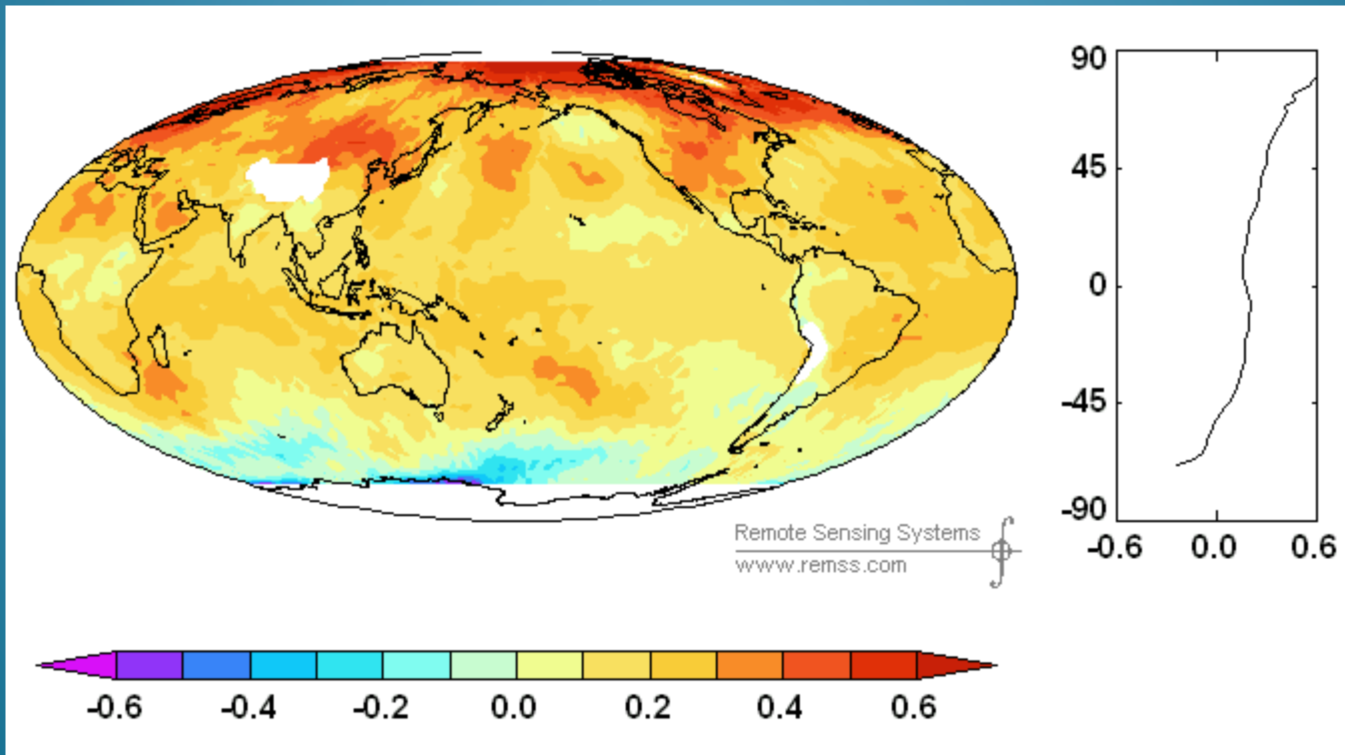


September 2005 broke the record for low summer sea ice extent, the measure of area containing at least 15 percent ice. The ice extent is shown by the edge of the colored region. The long-term average minimum extent contour (1979 to 2000) is in magenta. The grey circle indicates the area where the satellite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

50 – 60 GHz (V band)

- Atmospheric temperature

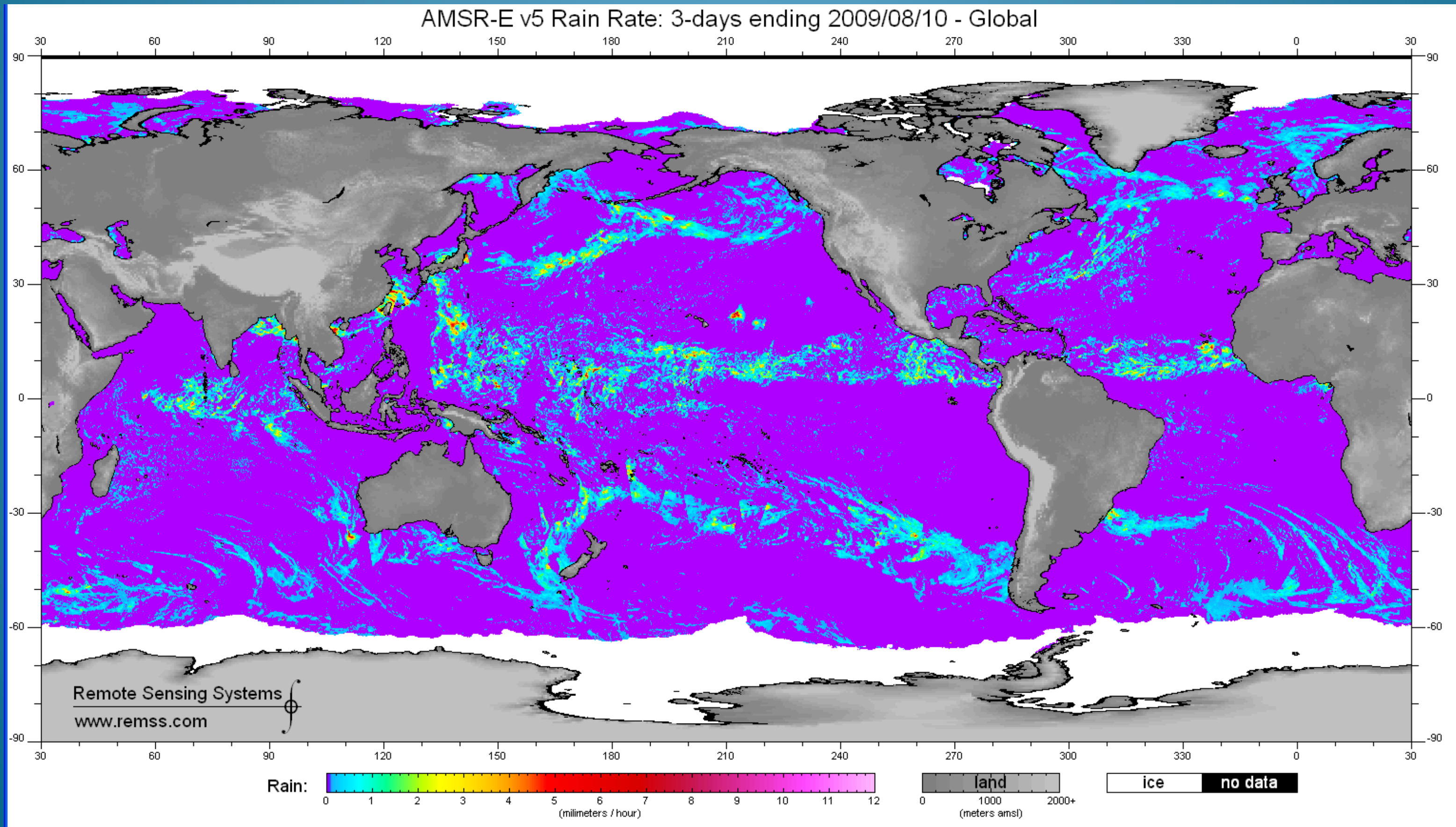
Color coded map of decadal trends in lower troposphere temperature using MSU/AMSU channel TLT:



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

75 – 110 GHz (W band)

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

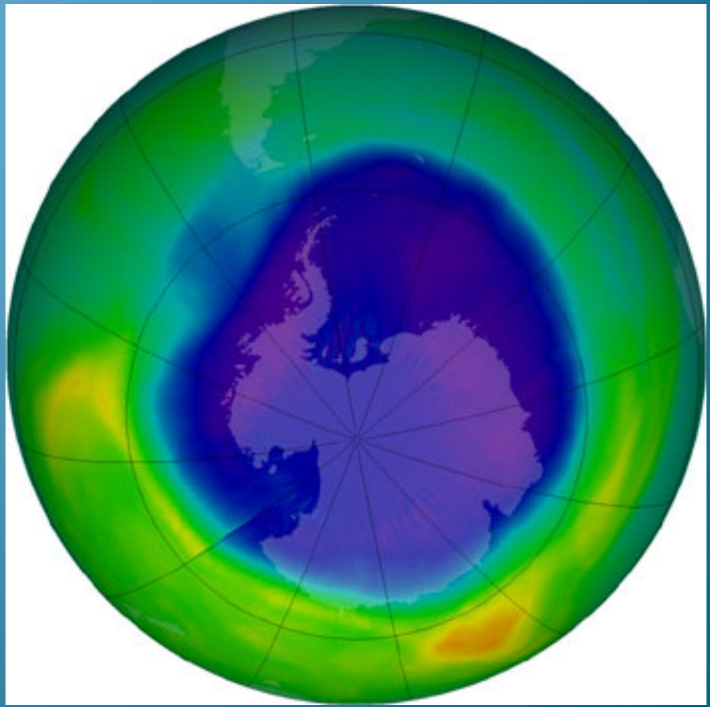


110 GHz – 3 THz (near-mm and sub-mm waves to THz)

- Precipitation and clouds
- Water vapor
- Atmospheric chemistry (trace gases)

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

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

Additional Resources

- Committee on Radio Frequencies (CORF) of the National Research Council: sites.nationalacademies.org/BPA/BPA_048819
- International Telecommunication Union: www.itu.int
- 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
- Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society (GRSS) Frequency Allocations in Remote Sensing (FARS) Committee: www.grss-ieee.org/community/technical-committees/frequency-allocations-in-remote-sensing/
- Committee on Radio Astronomy Frequencies (CRAF) of the European Science Foundation: www.craf.eu
- U.S. National Science Foundation Electromagnetic Spectrum Management (ESM): http://nsf.gov/funding/pgm_summ.jsp?pims_id=5654

Many thanks to ALMA for hosting the 4th IUCAF School on Spectrum Management!