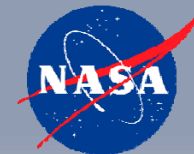


National Aeronautics and Space Administration



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Science Services and Harmful Interference

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Overview

1 Harmful Interference to Science Services

- What is “Harmful Interference”?
- Typical sources of interference to science services

2 Radio Frequency Interference to Science Services

- Aqua Mission & AMSR-E Instrument
- Frequency bands affected by RFI on AMSR-E and AMSR2
 - RFI from Ground-based
 - RFI from GSO satellite surface reflections, and direct broadcast satellites
- General Impact to Measurements & Consequences of Interference
- Radio Frequency Interference Mitigations

3 Worldwide Science Services Passive Sensing Frequencies

4 Worldwide Science Services Passive Sensing Bands

5 Importance of Passive Sensing

6 Summary

7 Science Services: Passive and Active Remote Sensing

- [Video: NASA | Getting the Big Picture](#)

8 References



Harmful Interference to Science Services

What is “Harmful Interference”?

- ITU-R Radio Regulations Sec. 1.169 - harmful interference: Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations.

Typical sources of interference to science services

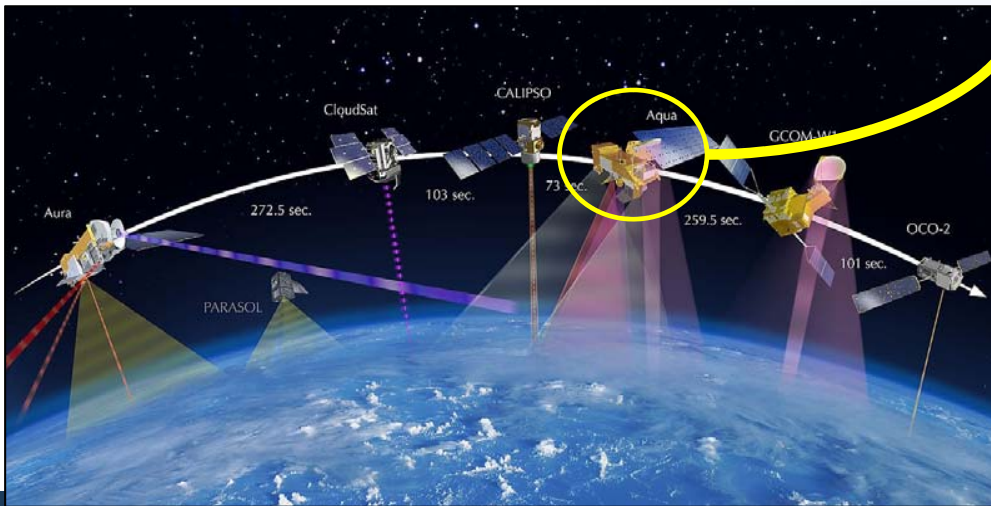
- Authorized transmitters operating in shared bands
- Unauthorized transmitters operating in the band
- Unwanted emissions from systems operating in adjacent bands
- For Radio Astronomy sites: Nearby strong signals



Radio Frequency Interference to Science Services

Example: Aqua Earth-observing satellite mission (Originally filed at ITU as EOS-PM)

- An international effort by NASA with instruments from Japan and Brazil launched in May 4, 2002
- The Aqua satellite was the first member of a group of satellites, termed the Afternoon Constellation or the A-Train Constellation that work collaboratively to collect data from the Earth's atmosphere and surface



As of 2018, the A-Train consists of five satellites and two no longer officially part of the constellation



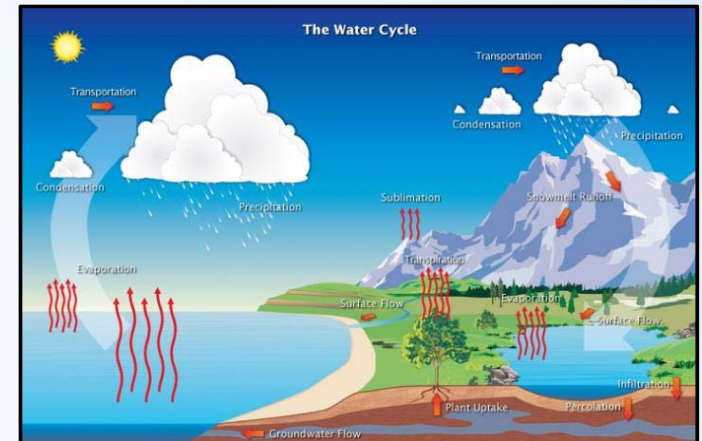
Aqua Spacecraft

- Measurements from the Aqua Spacecraft provide:
 - Systematic, continuous observations from low-Earth, sun-synchronous orbit
 - Coverage through the equator crossings in a northerly direction in the early afternoon at about 1:30 PM local solar time (as well as a southerly nighttime equatorial crossing at about 1:30 AM)

Radio Frequency Interference to Science Services

Example: Aqua Earth-observing satellite mission

- The A-Train Constellation, including the Aqua Spacecraft:
 - Combining the satellites and their data, allows scientists to gain a better understanding of important parameters related to the aspects of the Earth's environment and climate, including the behavior of hurricanes, and climate change
 - The A-Train formation allows for simultaneous coordinated measurements
 - Data from several different satellites can be used together to obtain comprehensive information about atmospheric components or processes that are happening at the same time
 - Combining the information collected simultaneously from several sources gives a more complete answer to many scientific questions than would be possible with data from any one satellite taken alone at different times
- Aqua Spacecraft:
 - Collects data about the Earth's water cycle, including evaporation from the oceans, water vapor in the atmosphere, clouds, precipitation, soil moisture, sea ice, land ice, and snow cover on the land and ice
 - Scientists, weather forecasters, farmers, policymakers, businesses, and relief agencies use the Aqua data to make vital decisions that affect us all
- The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) is one of the instruments on the Aqua Spacecraft

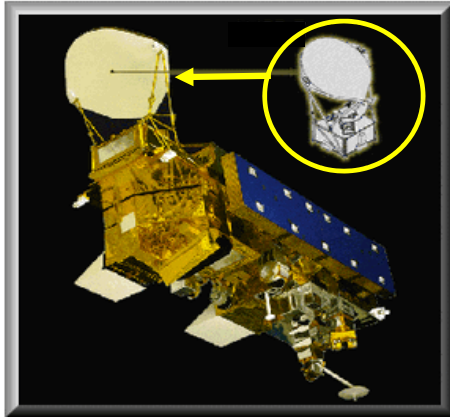


September 2019, Aqua Images
Typhoon Lingling Heads Towards the Korea

Radio Frequency Interference to Science Services

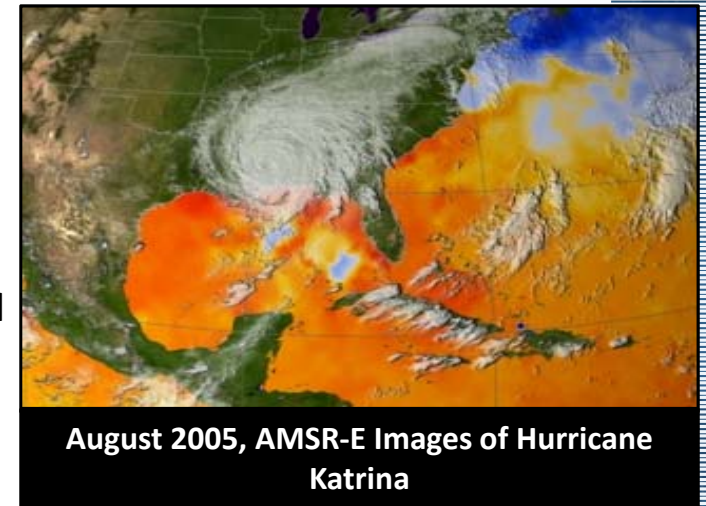
Advanced Microwave Scanning Radiometer – Earth Observing System (EOS)

AMSR-E



- Designed to measure precipitation rate, cloud water, water vapor, sea surface winds, sea surface temperature, ice, snow, and soil moisture
- Passive-microwave radiometer that uses 12 channels (6 frequencies x 2 polarizations) to measure the intensity of microwave radiation that is constantly emitted by Earth's surface and atmosphere
 - Frequencies range from 6.9 GHz to 89 GHz

- Scientists use their knowledge and the signals received by the different channels and polarizations
 - Frequencies are determined by nature/physics
 - Measurements are not just single channel measurements; differential measurements between multiple channels are essential
- On 2012, a successor of the AMSR-E was launched, which is the AMSR2 instrument on board the GCOM-W1 satellite
- AMSR-E has been augmented by AMSR2 along with other AMSR instruments on other satellites (such as Sentinel)

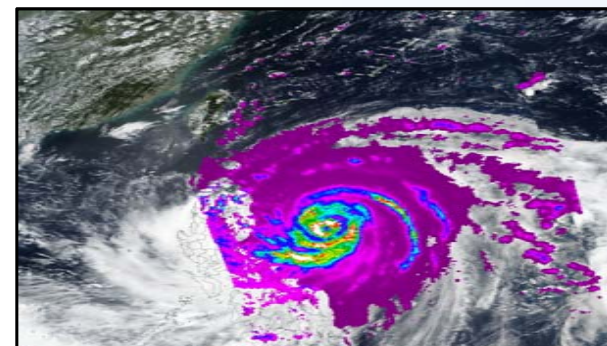


August 2005, AMSR-E Images of Hurricane Katrina

Radio Frequency Interference to Science Services

Frequency bands affected by Radio Frequency Interference on AMSR-E and AMSR2

- The radio-frequency interference (RFI) impacts the 6 GHz, 10 GHz and 18 GHz lower frequency channels bands; specifically 6.9 GHz, 10.65 GHz and 18.7 GHz
 - The 6.9 GHz band is used by Fixed, Fixed-Satellite, and Mobile services. However, it is used opportunistically without allocation or protection by EESS, primarily over oceans
 - The 10.65 GHz band is used for fixed and mobile ground transmissions, passive space research, and radio astronomy, in addition to EESS (passive) use. It is adjacent to a band allocated for fixed satellite space-to-Earth (i.e. geosynchronous) transmissions
 - The 18.7 GHz band shares its allocation with fixed and mobile ground transmissions and satellite space-to-Earth transmitters
- The transmitters near and around the AMSR-E/AMSR2 bands provide radio-frequency interference that corrupts the measurements
- Three types of RFI are found:
 - Land-based RFI
 - RFI from geosynchronous satellites directly
 - RFI from geosynchronous satellites reflecting off the ocean surface

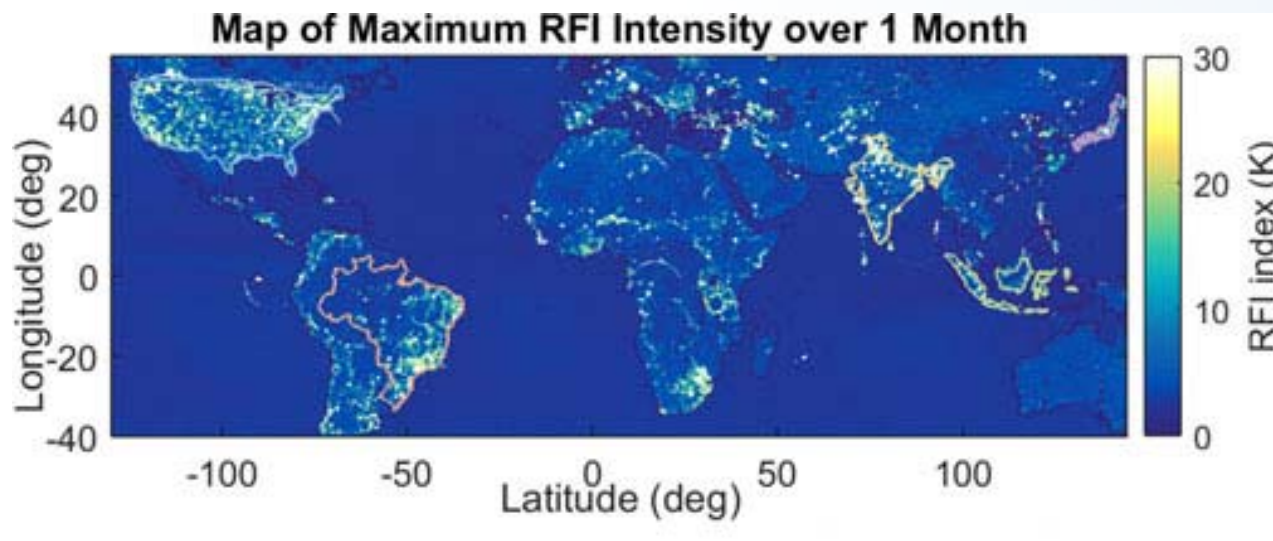


Sept 2018, AMSR-2 rainfall data from Typhoon Mangkhut approached the Philippines

Radio Frequency Interference from Ground-based Interference Sources

AMSR-E and AMSR2

- AMSR-E and its follow-on, AMSR2, have provided continuous multiyear RFI trending data from 2002 through 2017
- Due to high levels of RFI observed at 6.9 GHz, the soil moisture retrievals use only the 10.7 GHz and higher frequencies
- Eliminating the 6.9 GHz channels potentially reduce the accuracy of the global soil moisture retrievals
- The figure below examines the vertical polarization (V-pol) channels because they are less sensitive to atmospheric effects and varying surface types that cause a larger natural variation in the RFI index

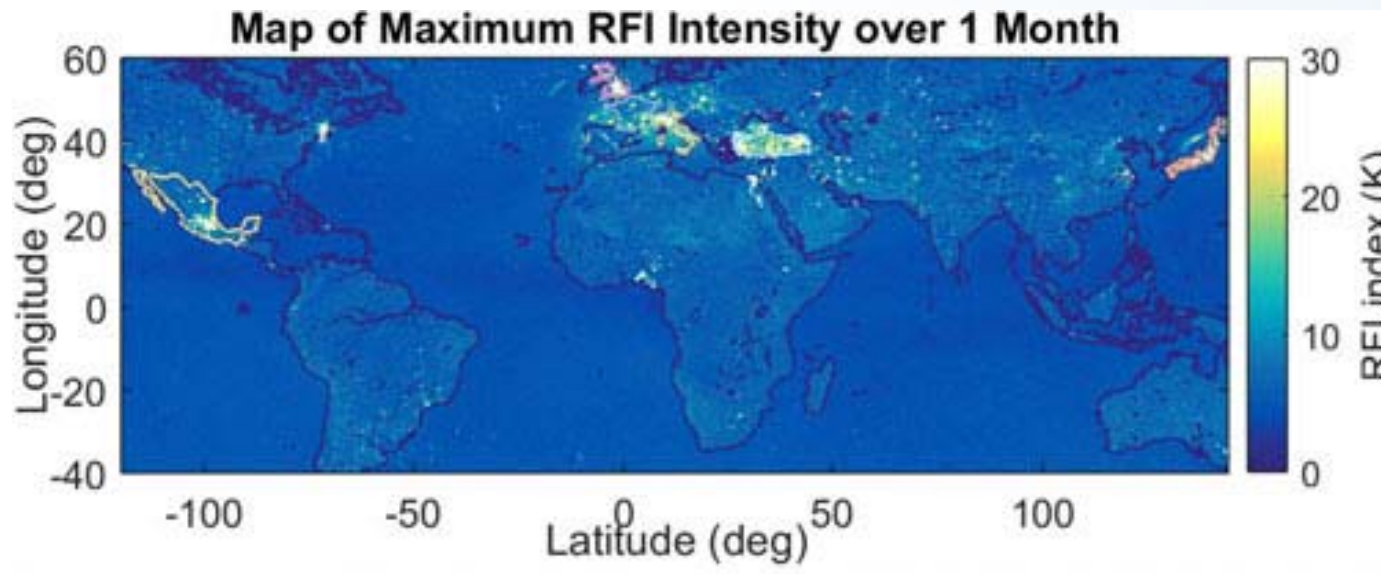


World-wide RFI measured for the 6.9 GHz V-pol channels of AMSR-E and AMSR2.
Maximum measured RFI index detected over the last month of data collection (October 2017)

Radio Frequency Interference from Ground-based Interference Sources

AMSR-E and AMSR2

- RFI may originate from transmitters operating in the shared bands, including in aggregate
- RFI may also originate from emitters operating in adjacent bands
- The 10 GHz channels are corrupted by ground-based fixed transmitters centered in various metropolitan areas of the world

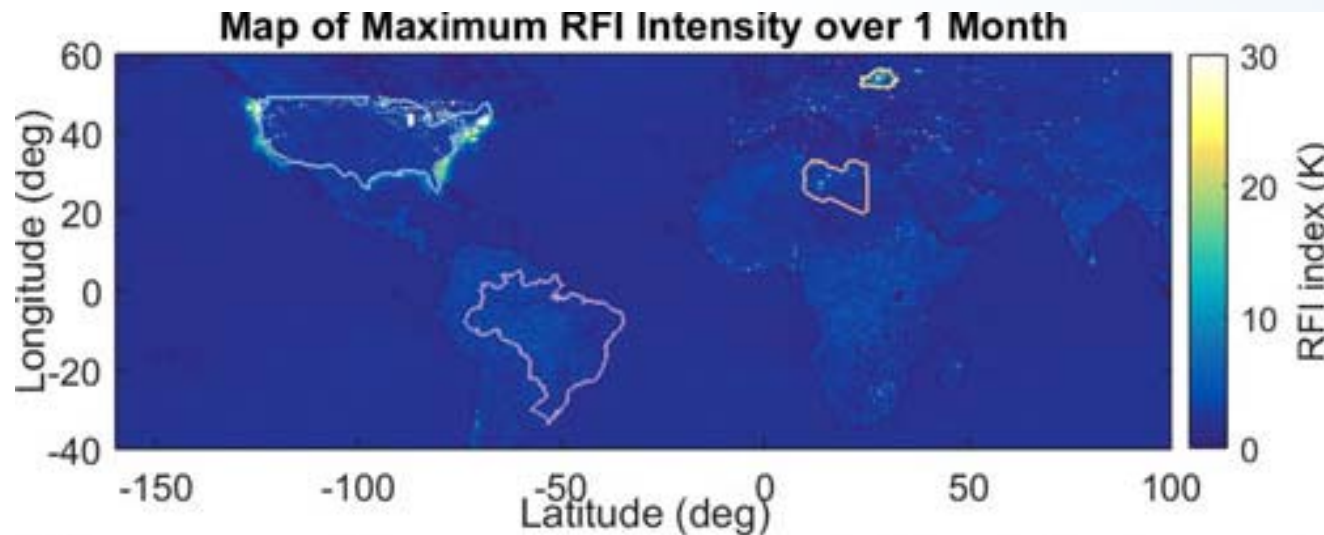


World-wide RFI measured for the 10.65 GHz V-pol channels of AMSR-E and AMSR2.
Maximum measured RFI index detected over the last month of data collection (October 2017)

Radio Frequency Interference from Ground-based transmitter, GSO Satellite surface reflections, and Direct Broadcast Satellites

AMSR-E and AMSR2

- RFI may originate from authorized emitters in the same band; the 18 GHz is shared with Fixed, Mobile and Fixed Satellite Services
- For the 18 GHz channels, RFI is detected from ground-based transmitters in several specific countries, from surface reflections of geosynchronous (GSO) satellites transmissions from lakes and frozen areas in the USA, and can be traced back to direct broadcast and internet satellites operating in the 18 GHz band and reflecting off land and water surfaces



World-wide RFI measured for the 18.7 GHz V-pol channels of AMSR-E and AMSR2.
Maximum measured RFI index detected over the last month of data collection (October 2017)

General Impact to Measurements & Consequences of Interference for all instruments including AMSR-E and AMSR2

Radio Frequency Interference (RFI) affects measurements in two ways:

- **When RFI is correctly detected:**
 - > the contaminated samples are discarded, resulting in loss of data or increased measurement noise
- **When RFI is not detected:**
 - > the RFI-contaminated samples are unknowingly passed on to the users

Consequences of Radio Frequency Interference:

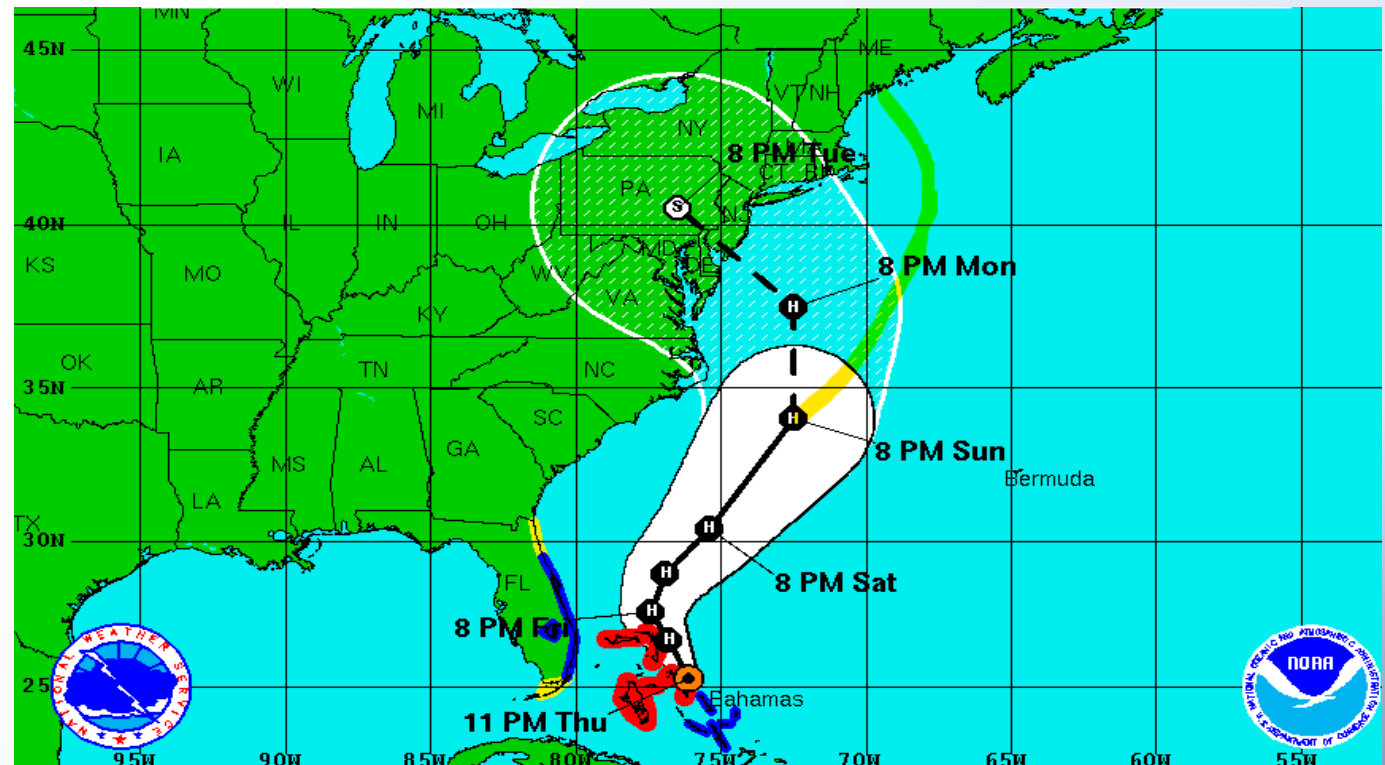
- **When data corruption is evident:**
 - > data has to be filtered out or completely discarded
 - > some filtering may be possible but this degrades the prediction models and can lead to larger errors
- **When data corruption is not detected:**
 - > invalid data may be used in prediction models
 - > use of invalid data can lead to misleading or erroneous results

Data loss or increased noise can be quantified, but it is difficult to quantify how much “science value” is lost due to RFI

Consequences of Interference

General Example of Loss of Data

- Interference may corrupt the collected data and this impairs the sensing product (e.g. Weather forecasting)
- Interference that is undetected but subsequently used in the sensing product produces flawed conclusions with potentially serious consequences

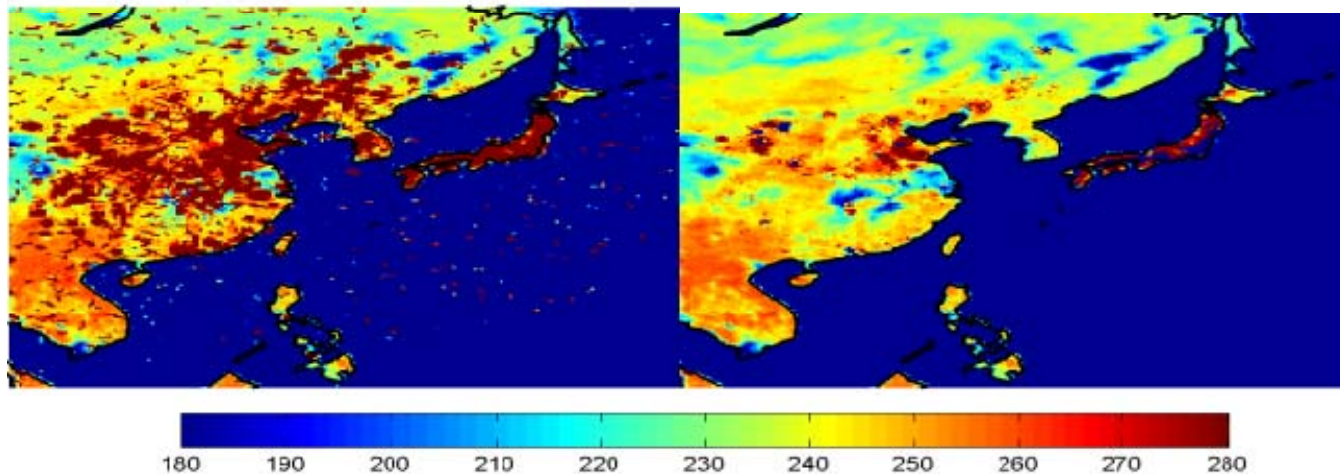


Hurricane Sandy ran through the Caribbean Ocean and up the East Coast of the United States in 2012
The yellow line represents the predicted path if the water vapor data collected by EESS satellites is removed

Consequences of Interference

General Example of Corrupted Data

- Measurements of soil moisture in the 1400-1427 MHz band over extensive areas in East Asia have to be discarded due to RFI pollution
- Interference is seen worldwide in this band from both unauthorized sources in-band as well as unwanted energy from adjacent bands
- SMAP has some RFI filtering algorithms to identify some of the sources as interference and remove their contribution, but some data is still lost and other satellites using this band do not have the same capability
- The result of applying the filtering, shown on the right, still has significant corruption and is unusable for sensing products



Radio Frequency Interference Mitigations

Mitigation steps taken:

- > Some missions have developed algorithms and procedures to detect and remove some Radio Frequency Interference affecting their data
- > Some missions have developed and refined the capability to geolocation sources of RFI to a small area. This information can be reported to the ITU-R and to the relevant regulatory authority for further localization and mitigation
- > A database of RFI sources is being developed, including latitude, longitude, country and city of terrestrial emitters, and position in geosynchronous orbit for space emitters. This will aid in determining trends in interference and their sources

Possible mitigation steps:

- > More missions need to dedicate time and effort to locate the sources of RFI to report to administrations and the ITU-R
- > Establish a consistent, timely process for detecting and reporting these interference sources so that the reports are understandable and actionable by the relevant administrations
- > Full cooperation of administrations to locate and mitigate sources of interference in their territory is needed

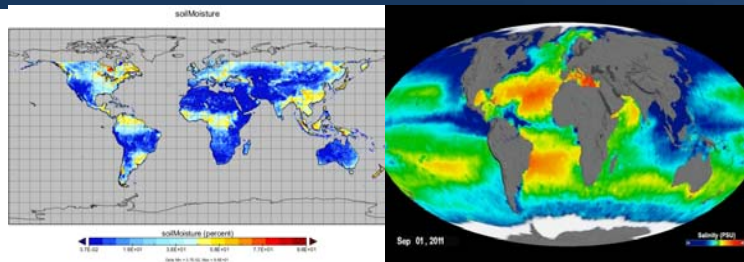
And most importantly

- > Establishing sharing conditions that protect incumbent users, based on studies
- > Establishing adequate limits on adjacent band emissions to protect users in adjoining bands

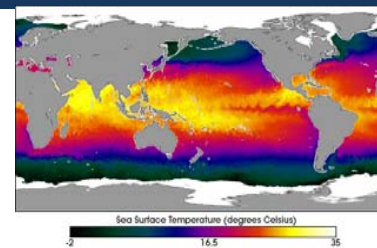
Worldwide Science Services Passive Sensing Frequencies

Critical Frequencies Bands and Parameters

Measurements at around 1.4 GHz are best for determining soil moisture and ocean salinity



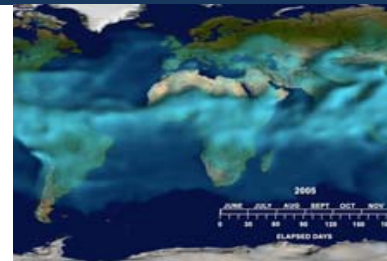
Measurements around 6 GHz offer the best sensitivity to sea surface temperature



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 the water vapor absorption peak (typically 18-19 GHz and 23-24 GHz) to assess the atmospheric contribution



A frequency around 37 GHz is needed, in combination with these above frequencies, to refine estimates of vegetation biomass and atmospheric contribution

Worldwide Science Services Passive Sensing Bands

Passive Frequency Bands in ITU Regions 1, 2 and 3

Passive “exclusive” bands per ITU RR No. 5.340

| | |
|-----------------------|-----------------|
| 1400-1427 MHz | 100-102 GHz |
| <i>2690-2700 MHz</i> | 109.5-111.8 GHz |
| <i>10.68-10.7 GHz</i> | 114.25-116 GHz |
| <i>15.35-15.4 GHz</i> | 148.5-151.5 GHz |
| 23.6-24 GHz | 164-167 GHz |
| 31.3-31.5 GHz | 182-185 GHz |
| 31.5-31.8 GHz* | 190-191.8 GHz |
| 50.2-50.4 GHz | 200-209 GHz |
| 52.6-54.25 GHz | 226-231.5 GHz |
| 86-92 GHz | 250-252 GHz |

Passive measurement bands that are shared with active services

| | |
|-----------------|----------------|
| 10.6-10.68 GHz | 116-122.25 GHz |
| 18.6-18.8 GHz | 174.8-182 GHz |
| 21.2-21.4 GHz | 185-190 GHz |
| 22.21-22.5 GHz | 235-238 GHz |
| 31.5-31.8 GHz** | |
| 36-37 GHz | |
| 54.25-59.3 GHz | |

Note:

* In Region 2 only; essentially North and South America;

** In Regions 1 and 3 only;

The bands shown in italics have some exceptions by country

Importance of Passive Sensing

Applications derived from passive sensing data include:

- Rice production in India
- Desert expansion
- Sea ice concentration
- Hydrological products (rainfall, water vapor, snow cover)
- Ocean circulation patterns
- Monitoring of areas prone to erosion and desertification
- Extreme Event Forecasting

- Study of Earth's water cycle
- Global warming models
- Crop yield forecasting
- Identification of potential famine areas
- Drought analysis
- Irrigation planning
- Flood protection
- Forest fire protection
- Hurricane/Cyclone monitoring

Passive Sensor Data is an indispensable component of the world's weather models

Summary

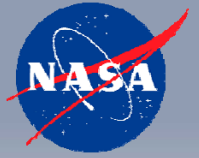
- Passive services, especially those in the passive only bands, are particularly susceptible to interference
- Passive science missions are critically important to global economies and global weather prediction
- Interference already exists and degrades passive sensing products
- Interference comes from both in-band and adjacent band sources
- The frequency bands used for passive sensing are determined by physics and the needed data cannot be provided by other frequency bands
- Study results guide the implementation of applications, systems, and services in order to protect passive services

Science Services: Passive and Active Remote Sensing

Video: NASA | Getting the Big Picture:

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Thank You!