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Assuring Mission Success

Impacts to Remote Sensing and Direct Broadcast from Radio Spectrum Sharing

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Introduction

Spectrum is Essential for Satellite Meteorology

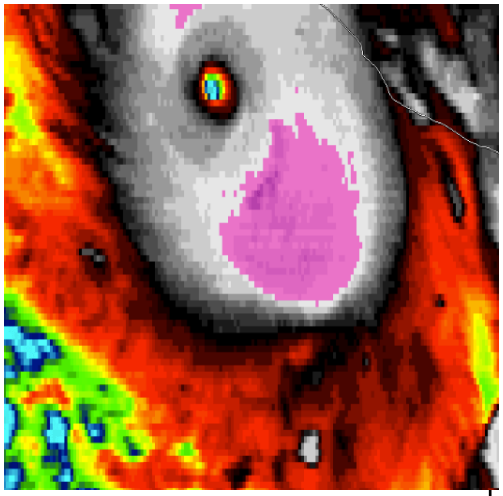
- Modern Satellite Meteorology Has Improved Forecasts and Warnings as Sensor Capabilities and Dissemination Systems Have Grown
- Radio Frequency Spectrum Has a Crucial Role:
  - *"The impressive progress made in the recent years in weather and climate analysis and forecasts, including warnings for dangerous weather phenomena (heavy rain, storms, cyclones) that affect all populations and economies, is to a great extent attributable to spaceborne observation and their assimilation into numerical models." [WMO Position to ITU WRC-15, 29 September, 2015]*
  - *"Also of great importance, sufficient and well-protected … services radio frequency spectrum for telemetry/telecommand as well as for satellite downlink of the collected data" [IBID]*

Satellite Meteorology Has Made Great Improvements in Forecasting Capability

Three Hurricane Examples & Improved Forecasts

Much has Changed in 115 Years

- Satellite Meteorology and effective dissemination of warnings derived from satellite & observational data can save lives



GOES InfraRed: NOAA

- Galveston TX, Sept **1900** – Unnamed
  - *Winds > 130 mph, Storm Surge 15 feet*
  - *3500 homes & buildings destroyed*
  - *Over 8000 deaths*
  - *Minimal knowledge of hurricane path*
  - *Local weather observer warned few people to move to higher ground*
  - *Satellites not yet invented for another 57 years, no meteorological satellites for more than 60 years.*

- Atlantic Coast, October **2012** – Hurricane Sandy
  - *Winds > 80 mph, Storm surge 9 feet*
  - *USD$ 50 billion in damage, 72 US deaths, 147 total deaths*
  - *Significant flooding damage from storm surge & even some snow in West Virginia from post tropical storm*
  - *Gages via GOES DCP report storm surge*

- Western Mexico Pacific Coast, Oct 23, **2015** Hurricane Patricia
  - *Winds at landfall 165 mph, Category 5*
  - *3000 to 3500 homes destroyed, no deaths*
  - *DCP relayed weather stations recorded sustained winds of 185 mph at 295 feet near time of landfall (to be officially validated)*
  - *Efficient communication and dissemination of weather data in rural region allowed for evacuation of over 10,000 people*

More Data, Effectively Communicated = Improved Forecasts that improve Safety of Life

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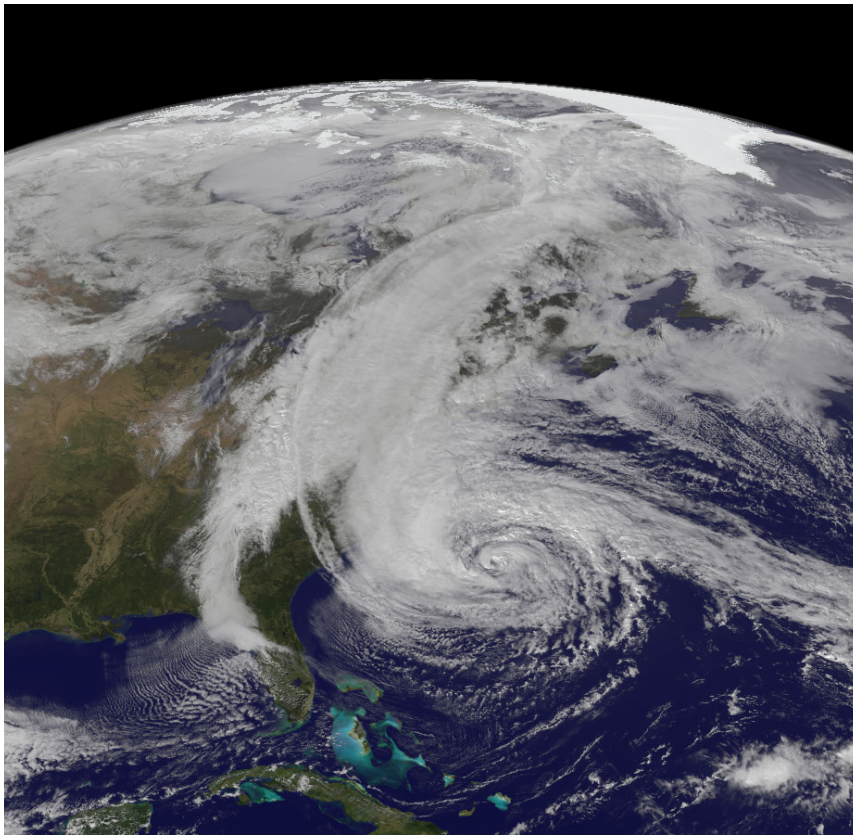
Weather Service Information On Two Hurricanes

TELEGRAM

Washington, D.C.
Sept 9, 1900
To: Manager, Western Union
Houston, Texas
Do you hear anything about Galveston?
Willis L. Moore, Chief
U.S. Weather Bureau

Source: National Archives, General Correspondence

GOES-13 Image Sandy October 2012



Source: NOAA

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Radio Spectrum Needs for Satellite Meteorology

Satellite Meteorology uses radio spectrum in a number of different ways:

- Downlink / direct broadcast of satellite data
- Commercial retransmission of meteorological data
- Acquisition of measurements through microwave remote sensing sensors

Satellite Meteorology Heavily Relies on the Use of Radio Spectrum

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Direct Broadcast, Downlink and MetSat Dissemination

Examples: GOES-R GOES Rebroadcast, Data Collection System, or High Rate Information Transmission (HRIT)

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Sat Met Data Downlinks Require Increasing Spectrum

Radio links are often the only viable method to continuously transmit data from space down to Earth

- Every new generation satellite system acquires more data than the previous generation it replaces
  - *A larger data volume requires more bandwidth to transmit the information to Earth*
  - *More advanced sensors have additional channels and more capabilities, including shorter data scanning durations, which often translates into more measurements and the need for faster data downloads*
- New applications often have data latency or data availability requirements that may be met by faster, more data intensive transmissions
  - *For some critical needs, direct broadcast provides necessary availability or is the best way to deliver data rapidly*
  - *Occasionally severe weather impacts the availability of terrestrial systems, driving alternate delivery methods*

Sat Meteorology Needs for Spectrum Are Growing More and More For Each New Generation System

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Direct Broadcast of Satellite Data

Most GEO and non-GEO MetSats Use Some form of Direct Broadcast

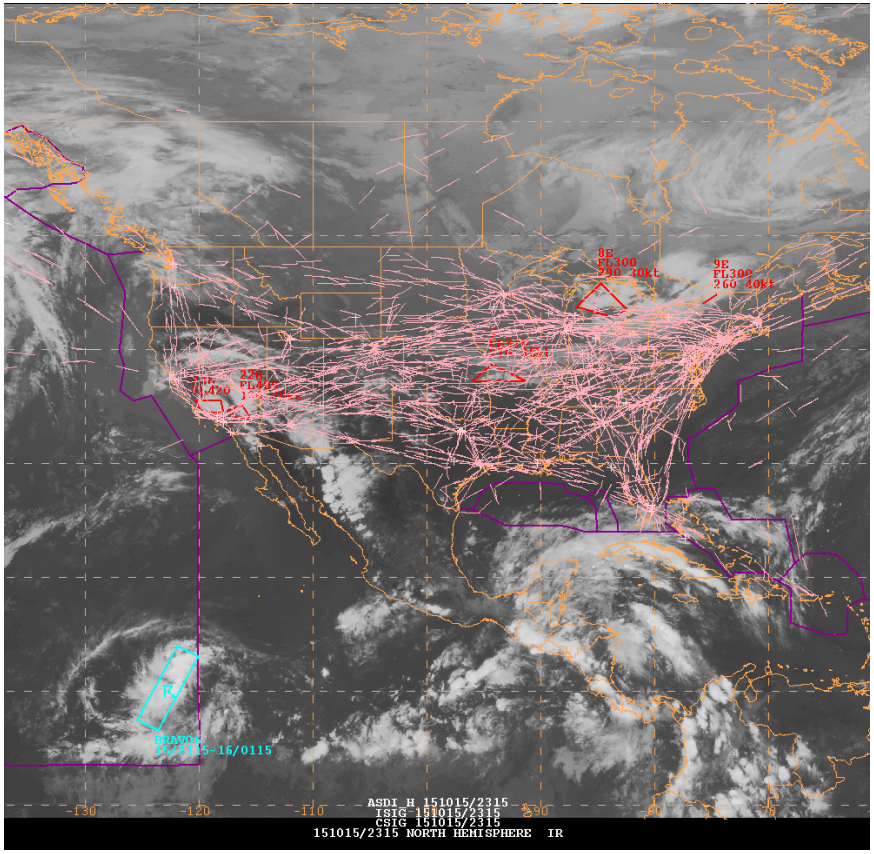
- GOES-R: GRB DCP, HRIT & RAW
  - 1.6 GHz band, 8 GHz band
- MSG: Raw, HRIT, LRIT & DCP
  - 1.6 GHz band
- NPP/JPSS: HRD, SMD
  - 7, 8 & 26 GHZ bands
- METOP A/B/C: HRIT & RAW
  - 1.6 & 7 GHz bands
- FY-4: HRIT, LRIT, DCP & RAW
  - 1.6 & 7 GHz bands
- MSG-S1: Mission Data
  - 26 GHz
- Himawari8: RAW & DCP
  - 18 GHz
- POES: HRPT, APT & DCP
  - 1.6/1.7 GHz, 137 and 400 MHz

Global Observing System - WMO

http://www.wmo.int/pages/prog/sat/globalplanning_en.php

Example of Direct Broadcast Usage

Aviation Warning Products



Source: NOAA, Aviation Weather Center

- GVAR-received GOES or GRB-received GOES-R imagery to support SIGMET and AIRMET warnings to commercial & general aviation
- Aircraft routing shown in pink overlaid with warning areas in red – showing flight routes generally avoiding the red warning areas
- All are derived from full resolution, timely satellite imagery mosaics then used by aviation forecasters for warning & product use

Interference to 1675-1695 MHz Broadcast Can Affect Aviation Warnings

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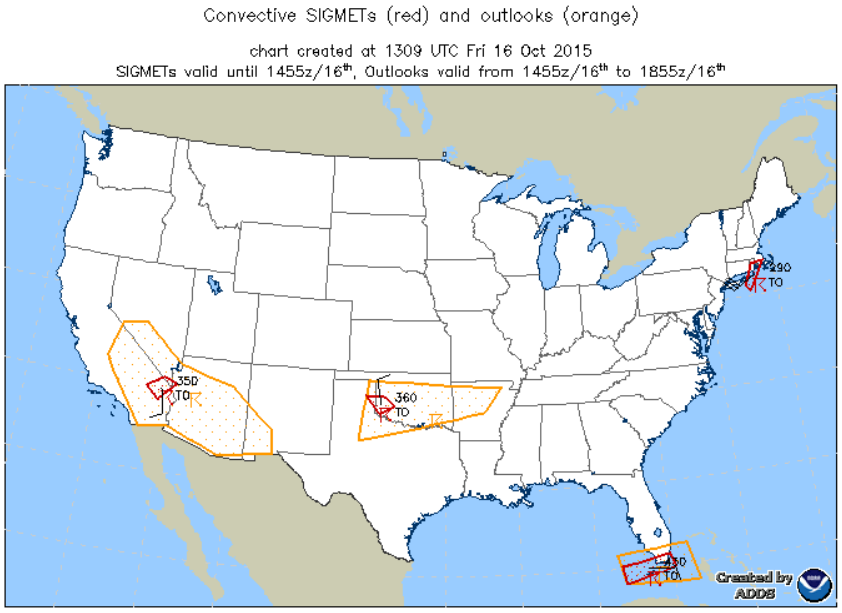
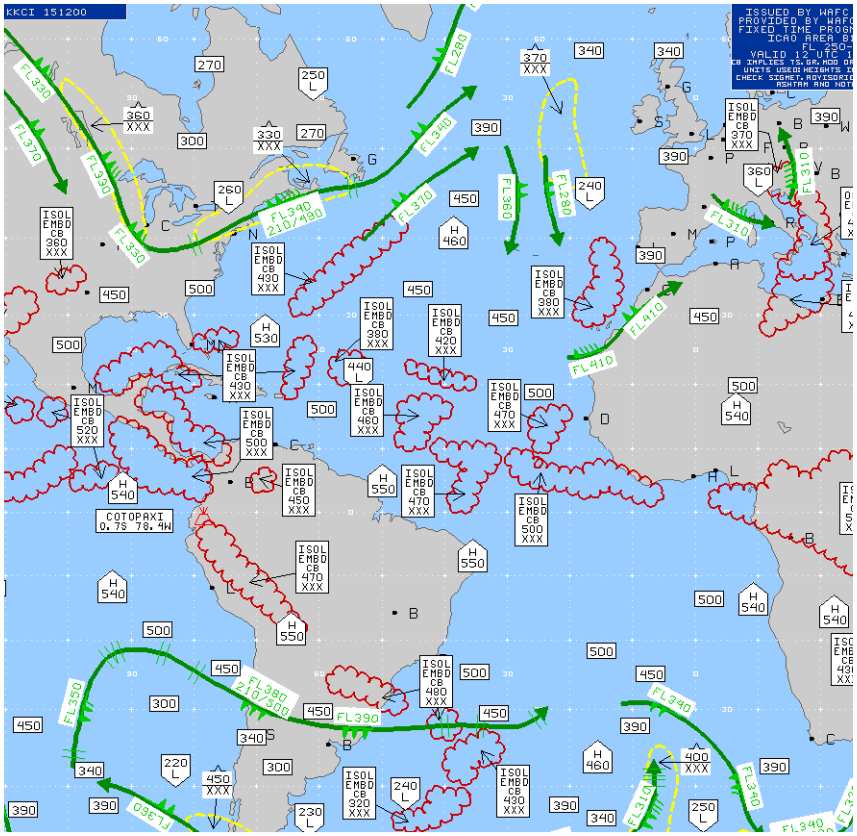
Aviation Products Derived From Images

Significant Meteorological Event Warnings to Airmen



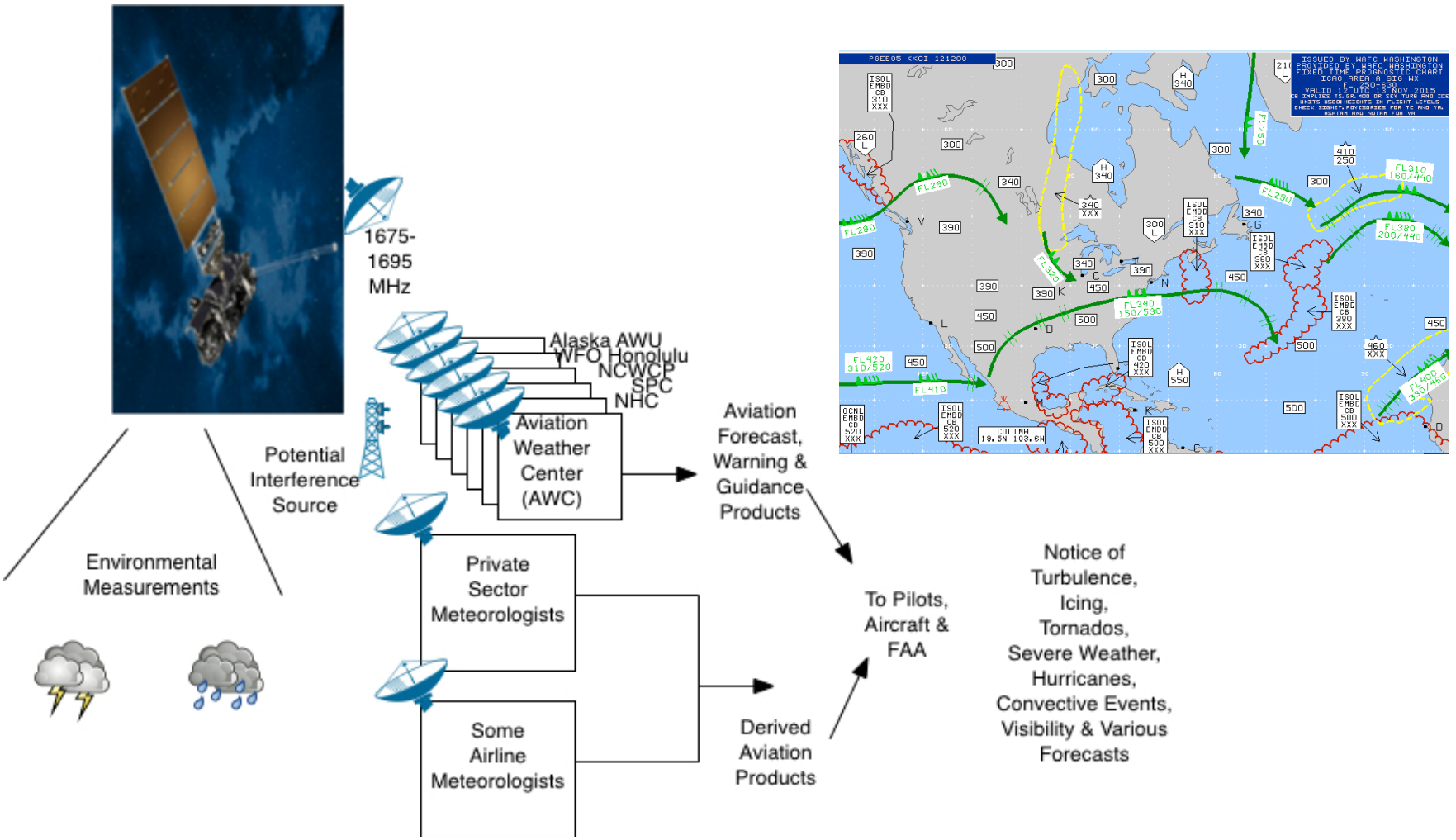
Source: NOAA / Aviation Weather Center
http://Aviationweather.gov

Chart Posted on Government Website Developed From Image



Example Aviation Products Subject to Interference

Pilots & FAA Require Aviation Products For Flight Operations & Routing



Interference Could Have Immediate Impact on Flight Operations

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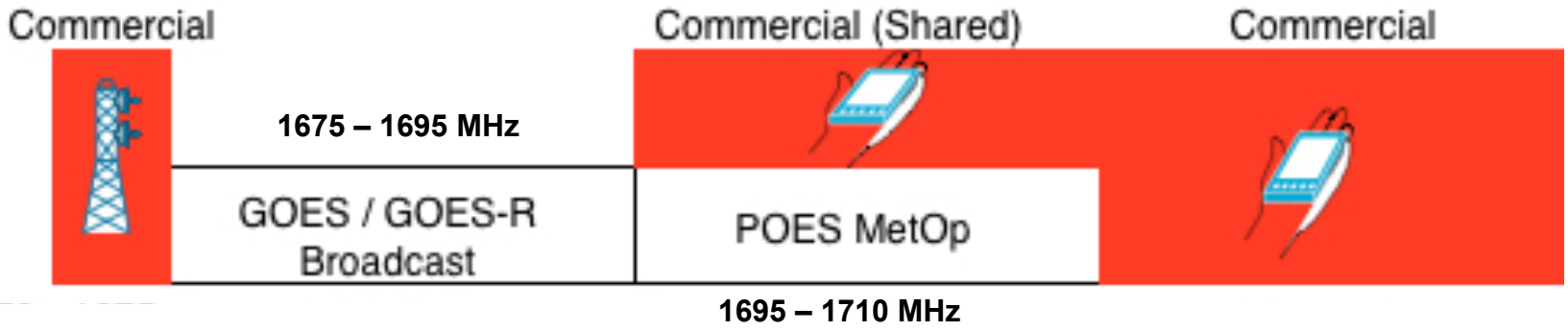
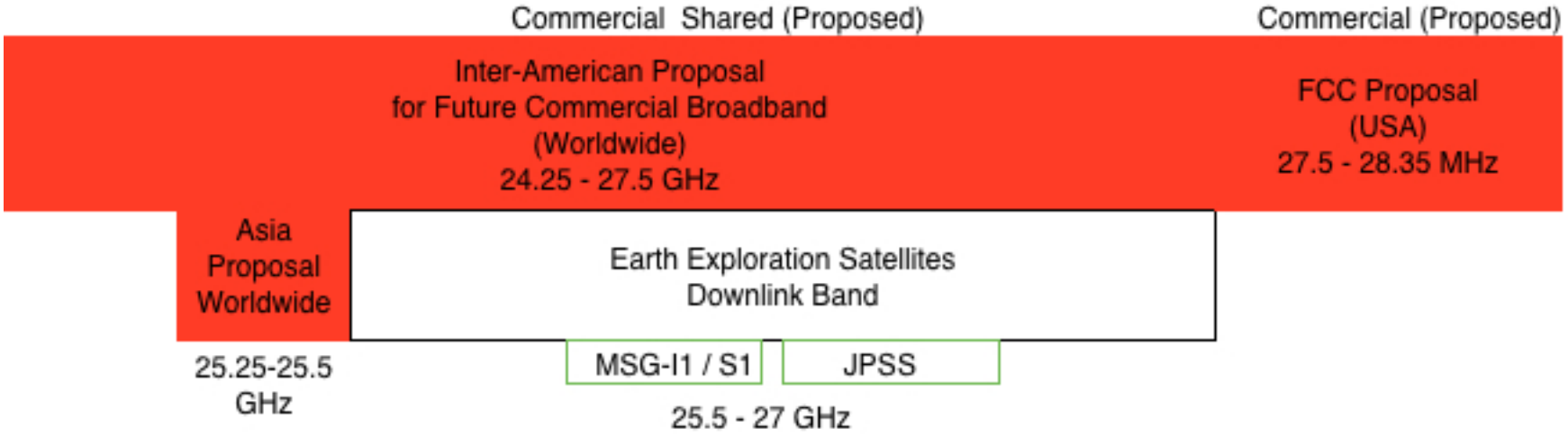
Satellite Direct Broadcast Bands and Commercial Use

Planned or Potential Shared Spectrum Bands





Retransmission of Meteorological Satellite Data

In the US, most common example is NOAAPORT/Satellite Broadcast Network, used to send data to all WFOs, RFCs, NCEP centers.

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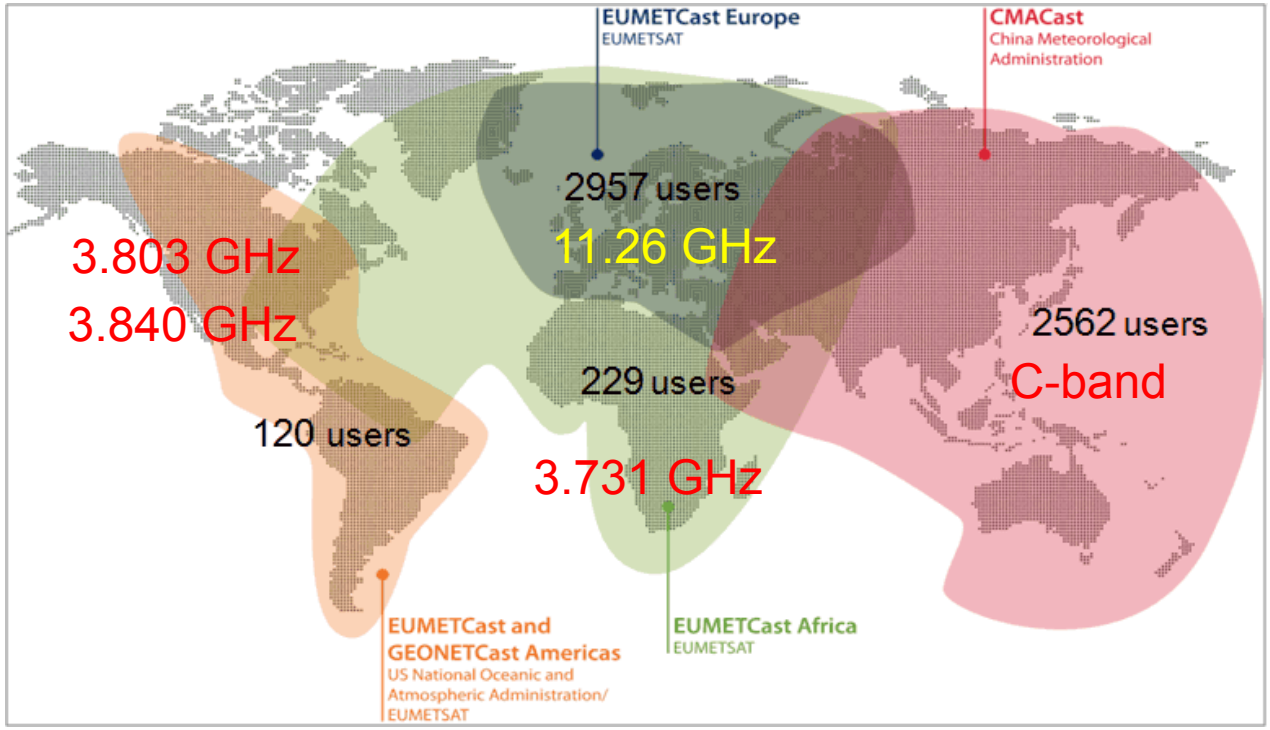
Retransmission of MetSat Data

Regional Re-transmission Services in 3.7-4.2 GHz Shown on Map

- Some administrations are supporting sharing studies of subsets of the commercial satellite bands in the 3.7 – 4.2 GHz band spectrum
- Interference could significantly impact reception of such data



Source: Group on Earth Observations

<u>Other Commercial Satellite Spectrum</u>

NOAAPort/SBN
4.040 GHz

HimawariCast
4.148 GHz

Used to Disseminate Weather, Water, Climate Including Disaster Warnings to Met Agencies & Users

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Spectrum Sharing in 3.7 – 4.2 GHz Satellite Band

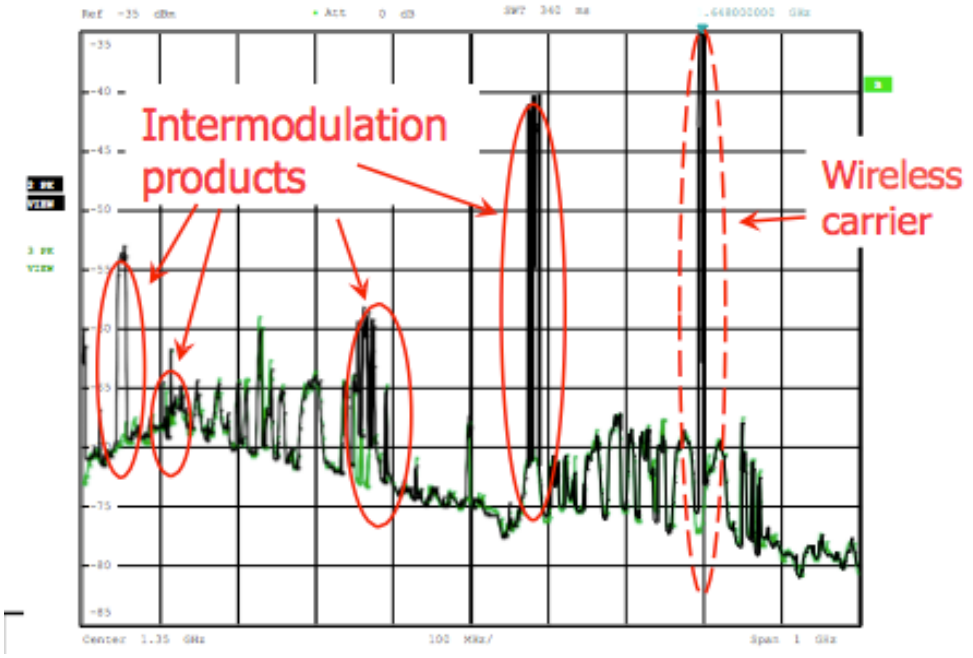
Many Nations Depend on Commercial Satellite for Meteorological Data and Other Uses

Strong terrestrial signals can create undesired intermodulation products in the front end amplifier of satellite receiving systems

These are false signals created within the amplifier due to interference

Image shows a commercial satellite downlink signal with interference from a nearby wireless terrestrial signal

This will impact desired data reception on satellite ground station



Source: David Hartshorn, Global VSAT Forum

Interference Can Degrade Commercial Reception of Satellite Retransmissions

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Microwave-based Remote Sensing

Example: Active and Passive Instruments Used to Obtain Key Parameters of the Atmosphere via Radio Spectrum, Primarily on non-GEO Orbiting Satellites

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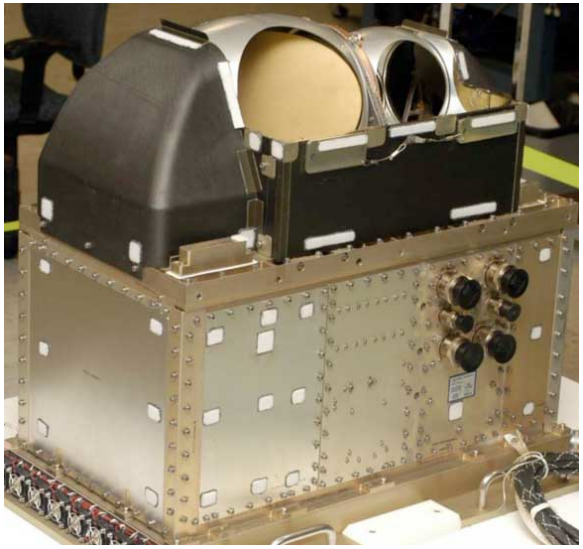
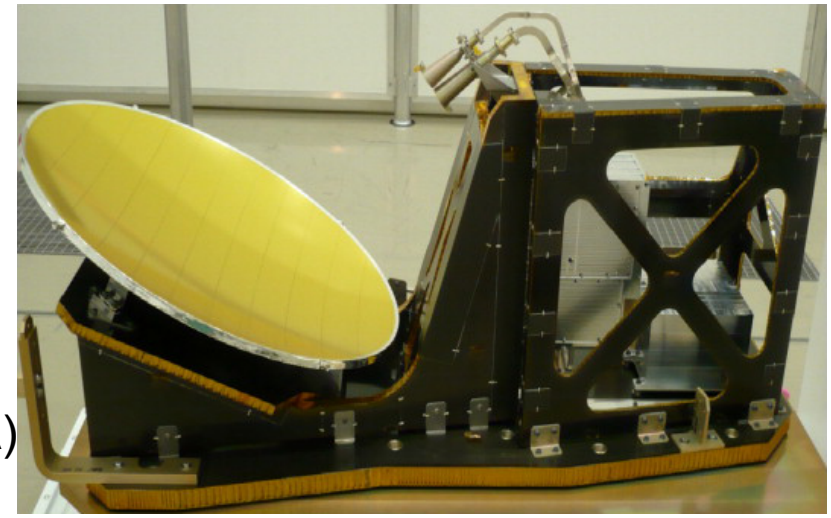
Microwave-based Remote Sensing

LEO Satellites Often Contain Remote Sensing Payloads in the Microwave Region



ATMS
(NASA)

MTR
(ESA)



- Microwave sounders & imagers, radiometers, radar altimeters and SAR radars are critical for determining natural properties in the atmosphere. Active measurements detect return signal
- Sensitive passive measurements often require using multiple lines for comparison to determine differences related to properties (e.g. water vapor versus clouds)

Out of Band Emissions from Terrestrial Sources Can Impact Weak Remote Sensing Emissions or Signals. In-band signals undesirable

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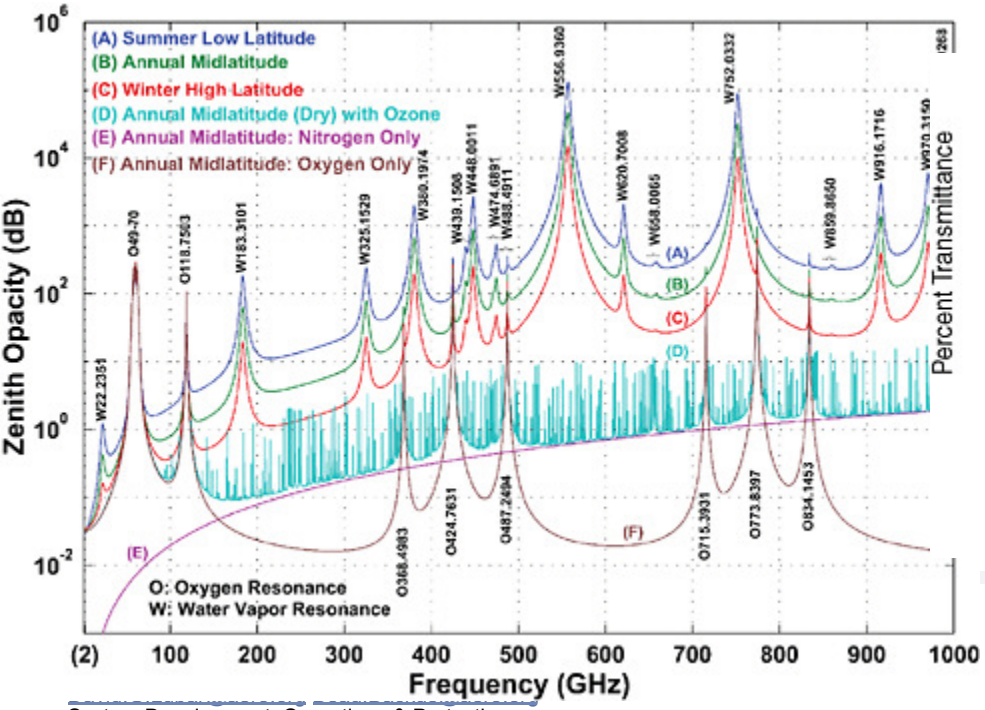
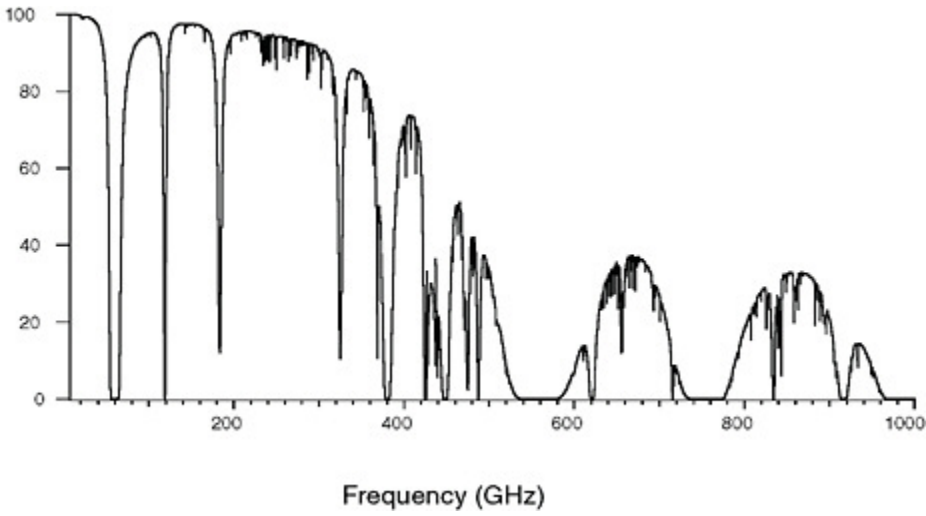
Remote Sensing Spectrum

There are no alternative frequencies for detecting natural properties

- The transmission spectrum of the atmosphere and the opacity of the atmosphere to particular frequencies allow the detection of weak natural radio frequency emissions
- “Line radiation spectra can be used to obtain temperature and humidity profiles in the atmosphere from the surface up into the mesosphere” (Source: NAP, 2010)
- Potential interference to these measurements, as an aggregate due to proposed national licensing or international harmonization for commercial broadband wireless should be investigated





Source: http://www.nap.edu/read/12800/chapter/1

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Passive RFI-Threatened EESS Frequency Allocations

Remote Sensing Impacts Must Be Analyzed Versus Mobile Proposals

New ITU Mobile Proposed Bands (GHz)

24.5-27.5
31.8-33.4
37-40.5
40.5-42.5
42.5-43.5
45.5-47
47-47.2
47.2-50.2
50.4-52.6
66-76
81-86

(FCC or US Legislation May Propose Different Bands)

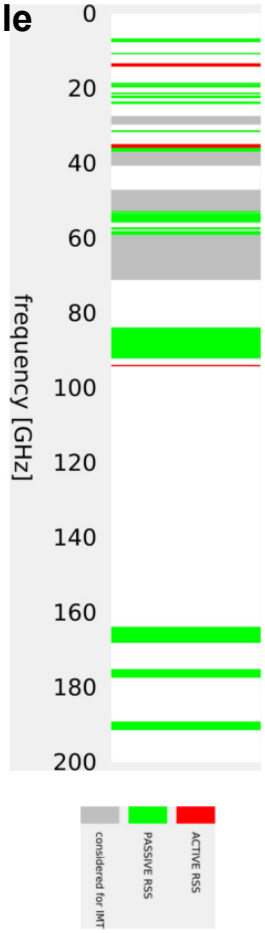

TABLE 1. RFI-THREATENED PASSIVE EESS FREQUENCY ALLOCATIONS.

BANDS (GHZ)	SCIENTIFIC OBSERVATIONS	SPACEBORNE INSTRUMENTS	RFI LEVEL AND SOURCES
1.37–1.40* 1.40–1.427	Soil moisture, sea surface Salinity, sea surface wind, vegetation index	SMOS, Aquarius, SMAP	High; out of band emissions mostly from air surveillance radars.
6.425–7.25**	Soil moisture, sea surface temperature, precipitation	AMSR-2, WindSat	Moderate (especially over the U.S.A.)
10.6–10.7	Precipitation, cloud liquid water, sea surface wind speed, sea surface temperature	TMI, AMSR-2, WindSat GPM GMI	Moderate (especially over Europe)
18.6–18.8	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	JASON-2 AMR, AMSR-2, WindSat	Moderate; potentially from satellite TV service signals.
22.21–22.5 23.6–24	Atmospheric water vapor, Sea surface wind speed, sea ice, precipitation, snow cover	SSM/I, JASON-2 AMR, TMI, AMSR-2, GMI, AMSU-A	Moderate; vehicle anti-collision radars
31.3–31.8 36–37	Precipitation, cloud liquid water, snow cover, sea surface wind speed, sea ice	AMSU-A, SSM/I, TMI, AMSR-2 JASON-2 AMR, WindSat, SSM/IS, GPM GMI	Low; new sources observed off oil platforms near the Indian subcontinent
50.2–50.4 51.4–59.3	Atmospheric temperature profiling	TOVS (MSU), SSM/T, AMSU-A, SSM/IS	Moderate: potential for RFI due to spectrum-sharing rules at 55–57

*Secondary allocation
**Limited protection

IEEE FARS Assembled This List Prior to ITU WRC-15 New Proposed Allocations in 6 Gigahertz – 86 Gigahertz Range

Source: IEEE, 2014

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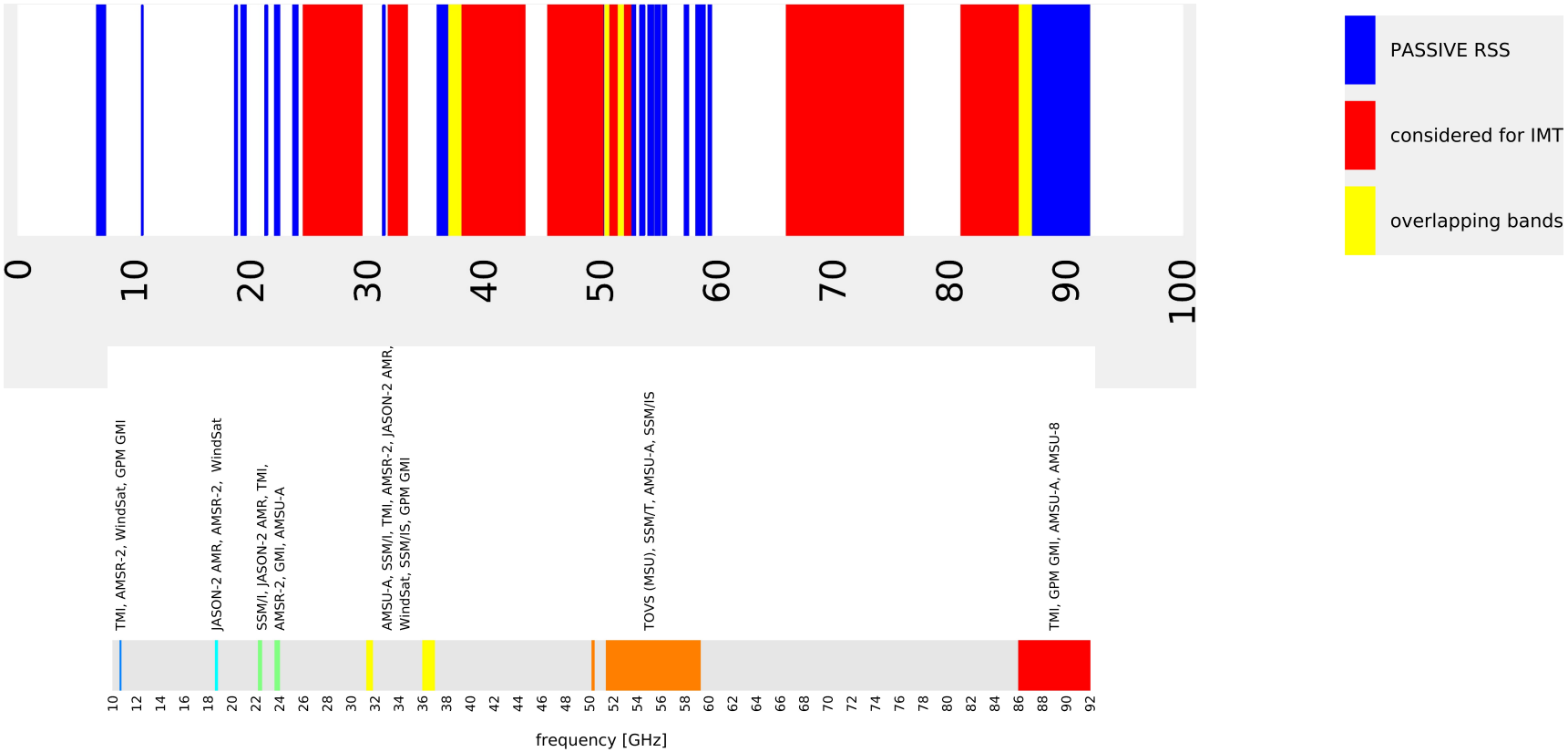
Remote Sensing versus Proposed Commercial Use



Top Figure Shows Spectrum Used for Passive Remote Sensing (Blue) and the bands proposed for commercial wireless (Red)

Yellow shows overlapping commercial and remote sensing bands where Interference is highly possible into passive sensors.

Remote Sensing Instruments Are Not Designed For Rejection of Aggregate Effects from Densely Located Terrestrial Transmitters

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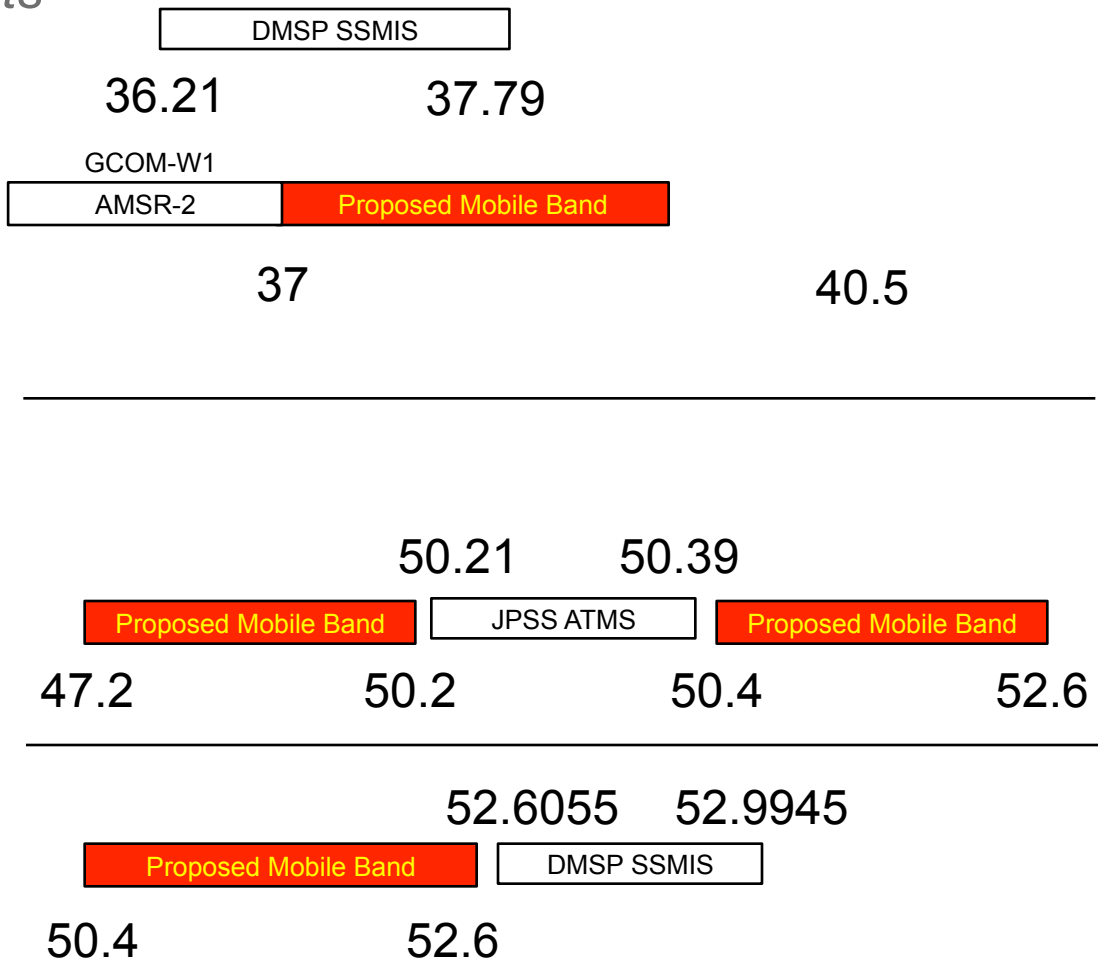
Few Potential Examples of Frequency Overlap

If Remote Sensing Is Impacted, Interference Could Contaminate Specific Band Measurements

- These are three examples, based upon different band proposals for mobile use that are either in-band or adjacent to remote sensing instruments
- Many instruments do not have bandwidth limitations to help mitigate the aggregate impact of many outdoor mobile systems as proposed.



Meteorological Community Inputs to Regulators Are Needed To Describe the Impact to End Users If Interference Occurs

US Domestic Proposals Versus Remote Sensing

FCC Notice of Proposed Rulemaking General Docket 14-177 & Draft 2 of MOBILE NOW act

FCC

From	To
27.5 GHz	28.35 GHz
38.6 GHz	40.0 GHz
64 GHz	71 GHz

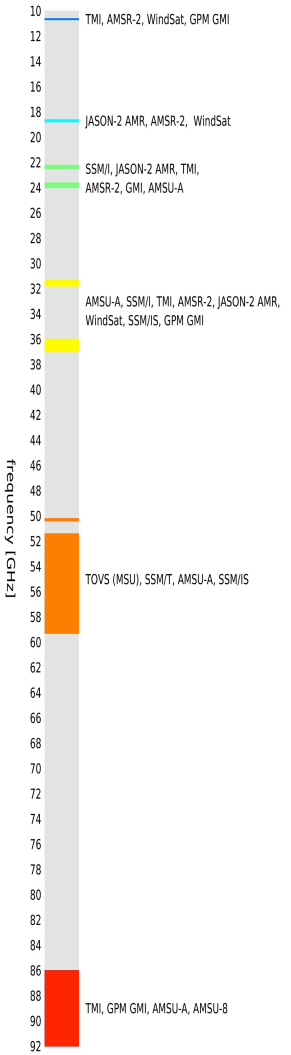
FCC Notice Comments:
Jan 26 2016 & reply comments
Due Feb 23, 2016
General Docket 14-177

MOBILE NOW Act
(Nov 13 draft)

From	To
24.25 GHz	24.45 GHz
25.05 GHz	25.25 GHz
31.8 GHz	33.4 GHz
42 GHz	42.5 GHz
71 GHz	76 GHz
81 GHz	86 GHz
Any frequency between 6 & 90 GHz	

For Comparison International Proposed Bands (GHz)

24.5-27.5
31.8-33.4
37-40.5
40.5-42.5
42.5-43.5
45.5-47
47-47.2
47.2-50.2
50.4-52.6
66-76
81-86



Domestic Proposals, Underway Now, Have Few Comments About How Such Changes Could Impact Meteorology and Remote Sensing

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Other Bands of Meteorological Interest

Where Interference From Potential Spectrum Sharing Should Be Evaluated

- Bands adjacent to EESS Passive in 1400-1427 MHz, used by SMOS and SMAP
- Proposed Sharing of Meteorological Radar Spectrum 2.7-2.9 GHz
- EESS Active services in 5350 – 5470 MHz to be shared with Radio Local Area Networks
- EESS Active band in 13.25-13.75 GHz used by active altimeters, scatterometers and precipitation radars and 35.5-36 and 94-94.1 GHz
- Allocations to small non-geostationary satellites in 230-470 in bands used by meteorological satellites & aids in the 400 MHz band
- Small satellite constellations proposed to use 8025-8400 MHz
- Out of band emissions from High Altitude Platform Systems proposed to operate in 23.6 – 24 and 31.3-31.8 GHz

There is Considerable Activity in the Spectrum Regulatory World in Multiple Bands of Interest to Meteorology and Hydrology

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Issue and Summary

Meteorology *versus* Commercial Wireless Services

Commercial Telecommunication services are occupying larger and larger portions of the spectrum

- Spectrum use by meteorological satellites and for meteorological applications is under threat from great expansion of commercial telecommunication services
- Need for careful coordination for frequency allocation and spectrum sharing

Satellite Meteorology and Commercial Wireless Services Both Need Radio Spectrum

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Commercial Wireless Broadband

Growing Spectrum Demand to Support Smartphones and Tablets

- Complex efforts underway to select domestic and international bands suitable for commercial broadband wireless use
- Often new spectrum sources are current Federal bands in US, where Federal services either share with entrants or are vacated by the Federal user
- US Federal Communications Commission completed one spectrum auction in 2015 and plans another for current television broadcast spectrum in 2016
  - *Plans are underway to find numerous other spectrum bands anywhere from a few hundred MHz to about 100 GHz*

Some Proposed Commercial Bands Overlap or are directly adjacent with Satellite Meteorology Use – where interference is possible

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National Academy Recommendation

Science Community Should Increase Participation in Spectrum Management Processes

"The science community should increase its participation in the ITU, NTIA and FCC spectrum management processes. This includes close monitoring of **all** spectrum management issues to provide early warning for areas of concern.

It also requires regular filings in regulatory proceedings and meetings with decision makers."

"For the spectrum management process to be effective, the science community, NASA, NOAA, NSF and DoD should also articulate the value of science-based Uses of the radiofrequency spectrum. Such value will include both economic Values, through enabling commerce or reducing the adverse economic impacts Natural phenomenon, and noneconomic values that come from science research."

Source: A Strategy for Active Remote Sensing Amid Increased Demand for Radio Spectrum, National Academies Press. http://www.nap.edu/21729

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Meteorological User Input Rare in FCC Proceedings

Weather User Viewpoint Usually Missing in FCC Comments

- Federal spectrum proceedings usually no participation by Meteorological community

- Yet decisions are made on repurposing of spectrum after such rulemaking processes

- Spectrum use above 24 GHz process underway since Oct. 2014

Proceeding 14-177 Details

Bureau Name: General (Multiple Bureaus)
Subject: Spectrum Bands above 24 GHz
Prepared By: Rosa.Bell
Date Created: 10/14/2014
Status: Open
Total Filings: 109
Filings in last 30 days: 11

Recent Public Filings

Filed on Behalf Of		Date Received
Marcus Spectrum Solutions LLC		
Google Inc.		
CTIA--The Wireless Association		
FiberTower Spectrum Holdings, LLC		
Ericsson		
O3b Limited		
CTIA--The Wireless Association	- NOTICE OF PROPOSED RULEMAKING	10/22/2015
NYU WIRELESS		
Satellite Industry Association	- PUBLIC NOTICE	11/25/2014
Covington & Burling LLP		
NYU WIRELESS	- NOTICE OF INQUIRY	10/17/2014
QUALCOMM Incorporated		
FiberTower Spectrum Holdings, LLC		
Satellite Industry Association		
O3b Limited		
Iridium Communications, Inc.		
Vivint Wireless, Inc.		
Mobile Future		
The Small UAV Coalition		
EchoStar Satellite Operating Corporation, Hughes Network Systems, LLC, and Alta		
Straight Path Communications, Inc.		
FiberTower Spectrum Holdings, LLC		

- Although changes in use of these bands could impact remote sensing or Ka band communications from space, no comments filed by Met users

Few Comments Filed by Met Users in Domestic FCC Proceedings --- In Spectrum Management, Silence Means Consent

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Summary

Strong terrestrial networks can adversely impact reception of weak satellite downlinks and could cumulatively affect remote sensing bands

- Spectrum is essential to satellite meteorology
  - *Communications and dissemination*
  - *Microwave remote sensing (active and passive)*
  - *Direct Broadcast from Meteorological Satellites*
- Demand for additional spectrum to support commercial broadband wireless is now examining a wide range of frequency bands
  - *Efforts are Underway both Domestically via the Federal Communications Commission and Internationally via the International Telecommunications Union To Identify New Bands for Commercial Use*
- The compatibility with existing satellite meteorology should be evaluated and users should participate in the public processes leading up to decisions on the repurposing / sharing of spectrum bands in both domestic and international regulatory arenas
  - *Users must understand if spectrum actions may impact their services and voice their concerns to ensure meteorology is considered*

Unencumbered Access To Spectrum Should Not Be Taken For Granted

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