Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction:

Impact of Deployment of Mobile Services on Meteorological Operations in 1695-1710 MHz

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Background

- In March 2014, the Federal Communications Commission reallocated the 1695 – 1710 MHz band to shared use with mobile wireless services
- Advanced Wireless System-3 (AWS-3) Auction completed in January, 2015
  - Spectrum to be used for Uplink for AWS-3 User Equipment to the Base Station
- 27 Protection Zones established to protect incumbent operation of 47 Federal earth stations (Protection Zones may include multiple antennae)
  - Two difference radii are defined for each Protection Zone, one each for maximum User Equipment EIRPs of 20 dBm and 30 dBm
- Federal earth stations in the 1675 – 1710 MHz band will continue to receive satellite signals indefinitely
  - on a primary basis in the 1675-1695 MHz band
  - on a co-primary basis in the 1695-1710 MHz band
- Under the AWS-3 Report & Order, Rules require successful coordination with Federal incumbents prior to operation in Protection Zones
- AWS-3 licensees are permitted to operate anywhere outside of the Protection Zones without prior coordination, but must not cause interference to incumbent operations

Spectrum Sharing Assumptions

- Incumbent operations must be protected to allow incumbent agencies to accomplish their missions
- Operating conditions and mitigations for spectrum sharing exist to efficiently utilize the AWS-3 spectrum
- Operator Agreements codify coordination of AWS-3 operations inside federal Protection Zones, including:
  - Coordination Process
  - Methodology for modeling operations and approving AWS-3 tower deployments
  - Interference Notifications and access to historical EME data
  - Mitigating actions, if and when interference events occur
  - Disputes and Modifications

Spectrum Sharing Impacts

Impacts to federal operations are not just due to potential for Radio-frequency Interference (RFI)

- Sharing spectrum changes how agencies conduct and manage operations, and creates the need for a new capability to deal with the "business" of sharing spectrum. This requires:
  - Coordination agreements with each Licensee, including administration of the agreements to manage modifications and resolve disputes
  - Modeling of the interoperability between earth station receivers and the to-be developed and implemented AWS-3 network
    - Must be sustained by updates as technologies evolve
  - Centralized monitoring for Interference and of Electro-magnetic Environment (EME)
- Responding to RFI events requires:
  - Functionality for Detection, Classification, Identification, and Notification
  - Mitigating actions by Licensee
  - Operational adjustments and associated modifications to existing Agreements
  - Possible need for enforcement actions by spectrum regulator

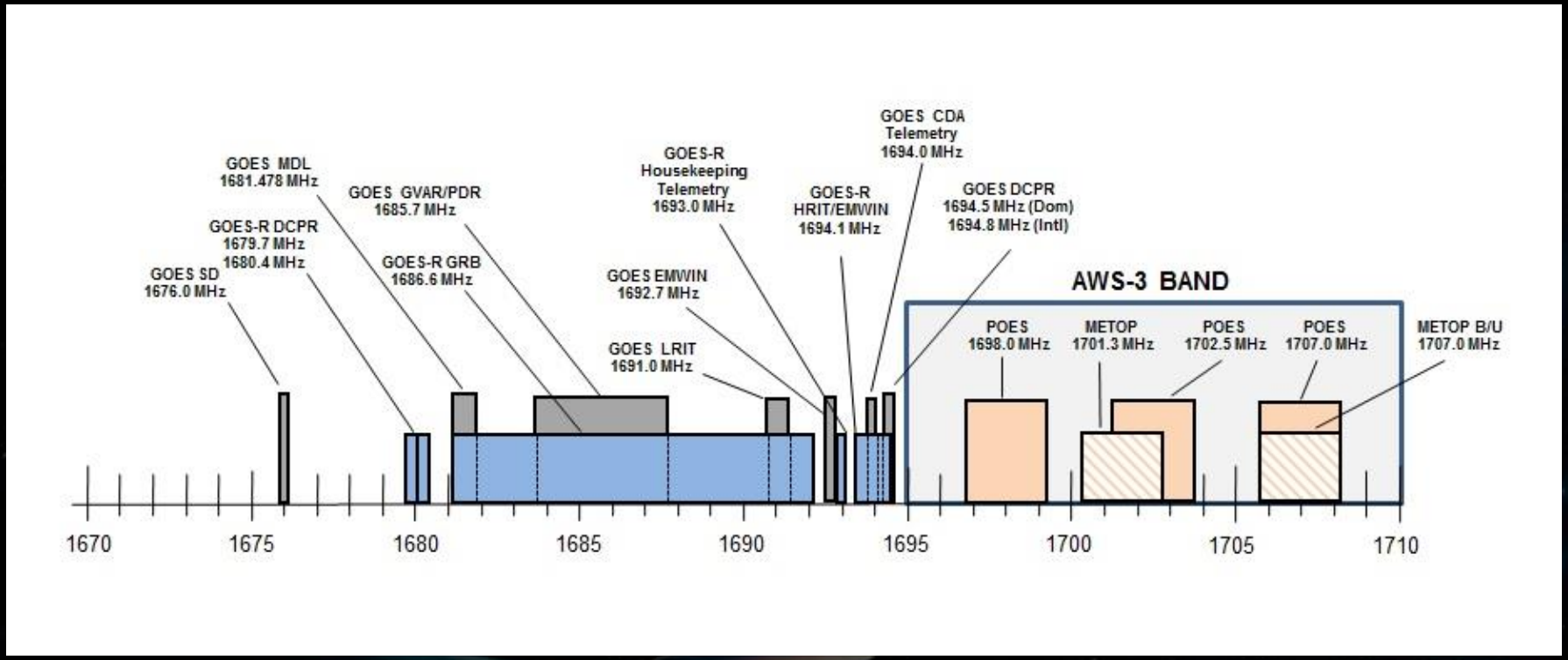
FCC Rules and Coordination Principles

- Rules require each AWS-3 licensee, prior to its first operations in its AWS-3 licensed area, to reach a coordination arrangement with each Federal agency on an operator-to-operator basis
- Incumbents and Licensees will share information regarding each other's operations to facilitate successful sharing of the AWS-3 spectrum
- Provide the Licensee an interface to a Radio Frequency Interference Monitoring System (RFIMS) to enable real-time notification of interference events and access to measured electro-magnetic environment data archive
- The Licensee will adjust or limit its network operations when its AWS-3 operations causes interference
- If AWS-3 operations change in such a way to invalidate the established model, the analysis methodology will be updated to reflect the changes and the coordination process is repeated

Satellite Operations

- Geostationary Satellites: GOES is in a geostationary (GEO) Orbit, ~35,000 km altitude (1675 – 1695 MHz band, adjacent band)
  - "Parked" in a particular location over the equator
  - Large footprint/field of view
  - Orbital period is 24 hours, stays over the same location as the earth rotates
  - Data is collected 24/7 since satellite is always in view
- Polar Orbiting Satellites: POES and METOP are in Low Earth Orbit (LEO), ~500 km (1695 – 1710 MHz band, co-channel)
  - LEO orbits fly over the earth's poles (polar orbit)
  - Much smaller footprint/field of view compared to GEO
  - Orbit is Sun Synchronous – the orbit rotates relative to the earth, approximately 1^{o} per day
  - Orbital period is about 102 mins, and the satellite circles the earth approximately 14 times per day (for polar orbiting newer satellites)
  - Typical signal contact period for earth station receiver is 12-15 minutes

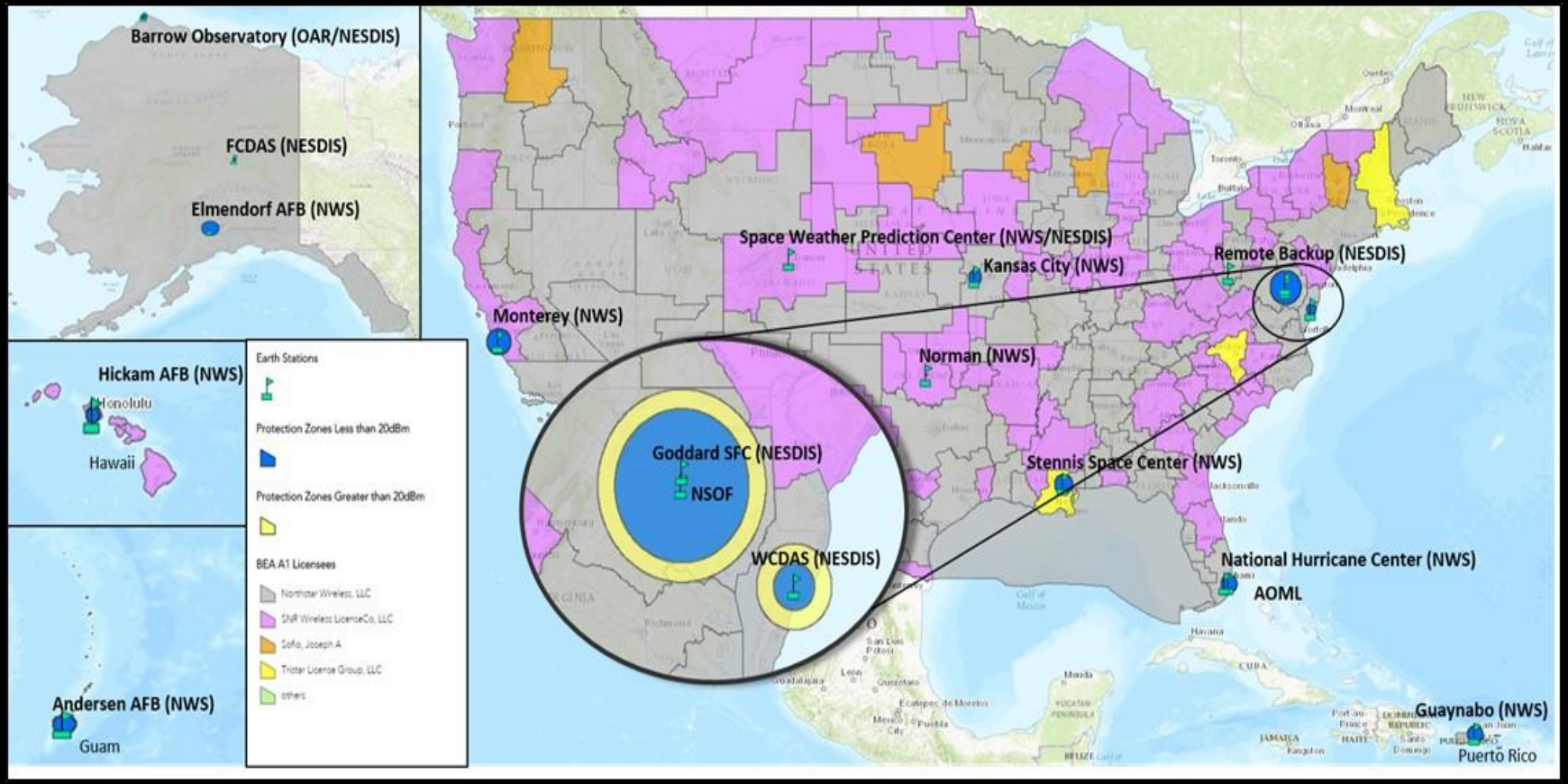
NOAA GOES & POES Satellite Downlink Frequencies



Federal Earth Station Sites

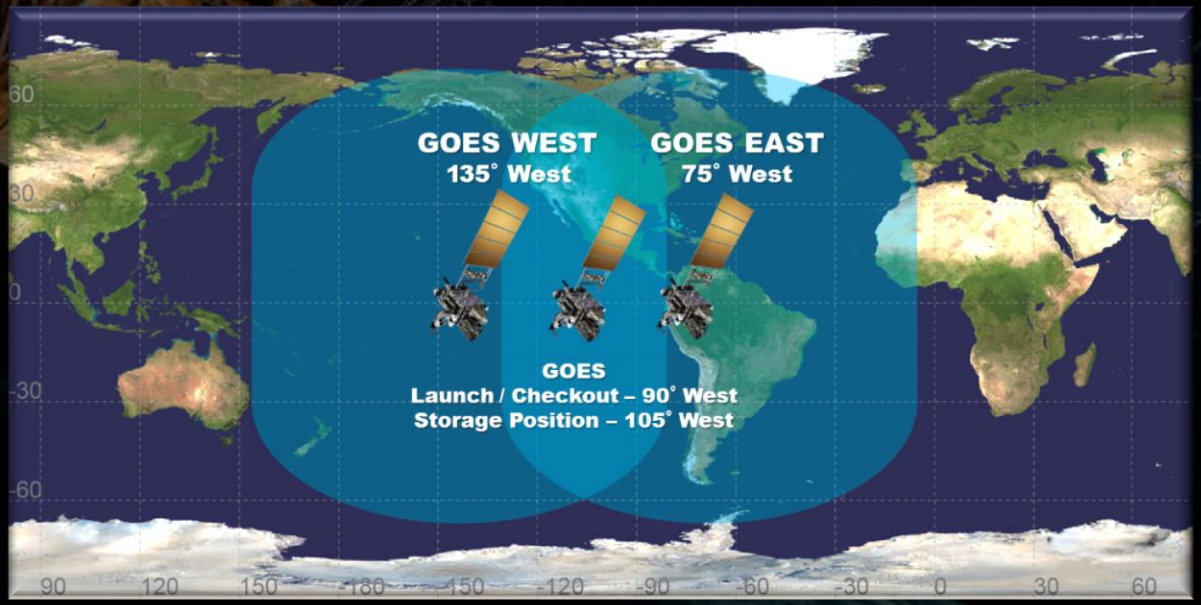
- Satellite Operations
  - Command and Control
    - Wallops Island, VA; Fairbanks, Alaska; Suitland, MD; Fairmont, West Virginia; Greenbelt, MD
    - Transmit and Receive
- National Weather Service Centers for Environmental Prediction
  - National Hurricane Center (Miami), Aviation Weather Center (St. Louis, MO), Space Wx Prediction Center (Boulder, CO), Storm Prediction Center (Norman, OK), NOAA Center for Weather and Climate Prediction (College Park, MD)
    - Receive only
- Oceans and Atmospheric Research Laboratories
  - Atlantic Oceanographic and Meteorological Laboratory (AOML) (Miami, FL), Earth System Research Laboratory (ESRL) (Boulder, CO)
    - Receive only
- Other Agencies
  - Defense and Interior Departments
    - Receive only

AWS-3 Basic Economic Areas and Federal Protection Zones



GEO Satellite Constellation

- Current Satellites:
  - GOES-East - 75^{0}W Longitude
  - GOES-West - 135^{0}W
  - GOES-Spare - 105^{0}W



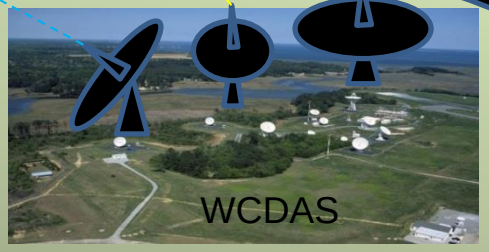
GOES Visibility from Earth

GOES-West
135^0 W

GOES-Spare
105^0 W

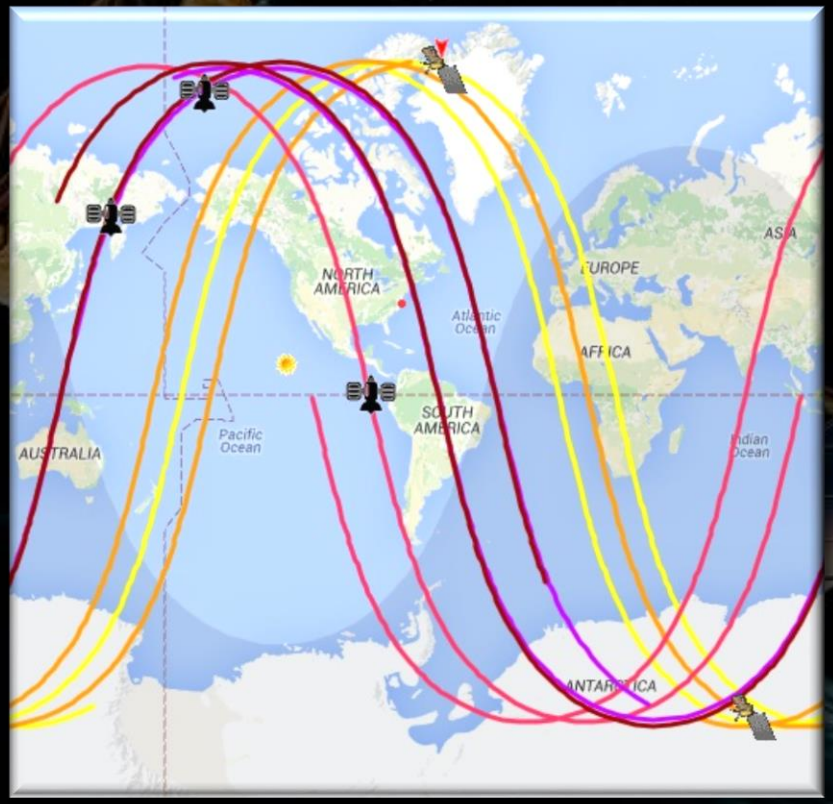
GOES-East
75^0 W

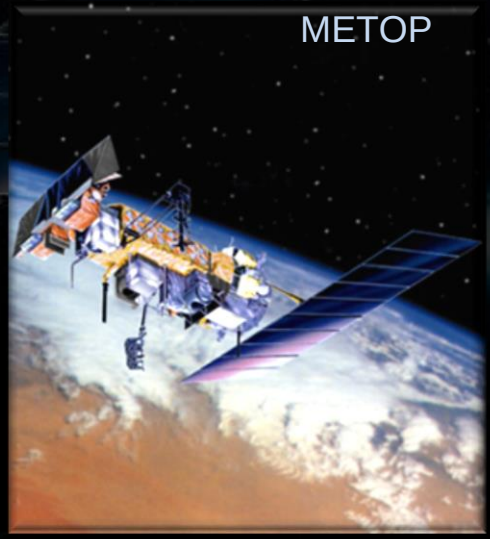
- The farther away the satellite is from the ground station, the lower the elevation angle of the antenna
- Antennas are interchangeable and can be switched to another satellite when necessary
- Satellites can drift to other locations if necessary



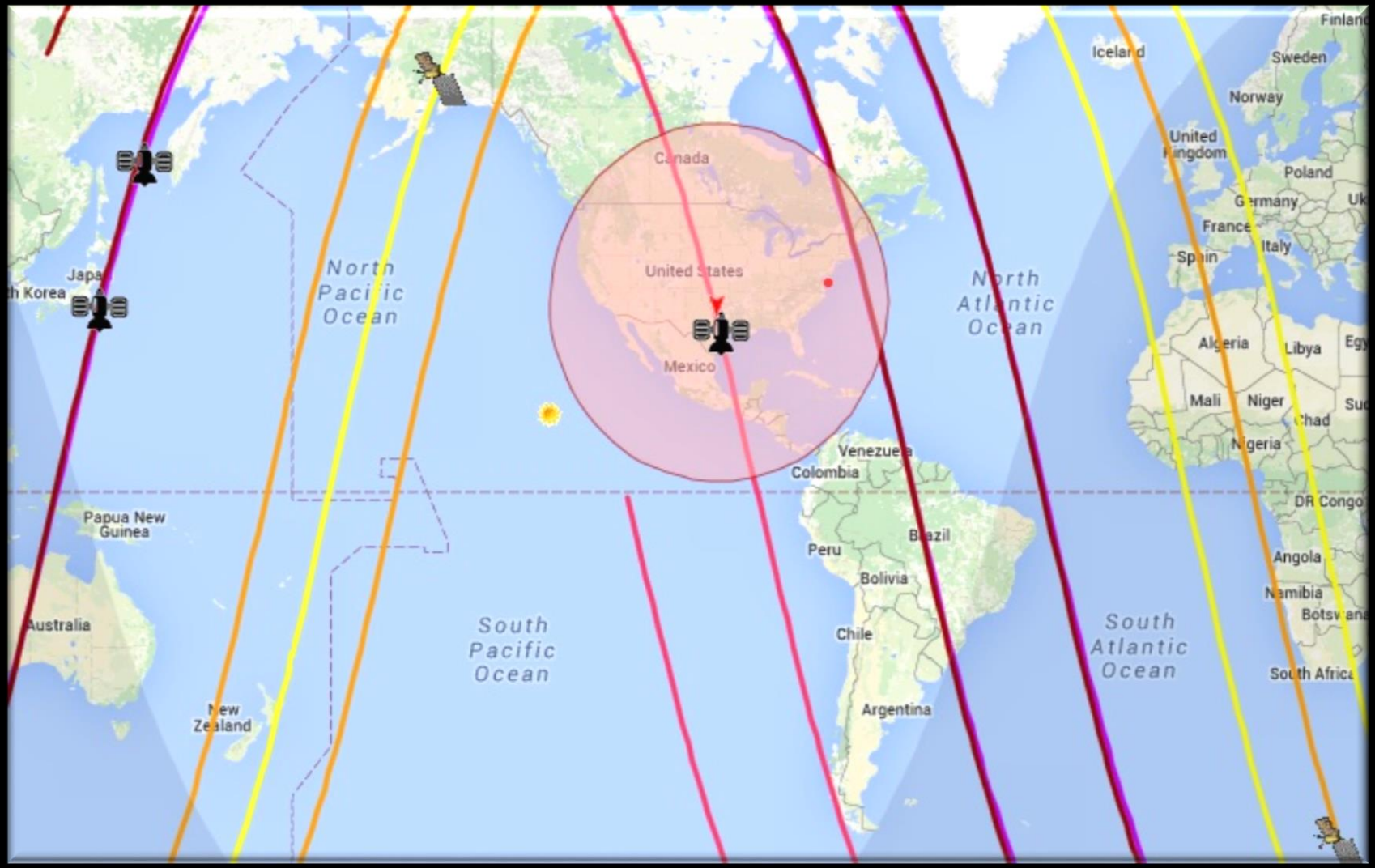
Polar (LEO) Satellite Constellation

- Satellites:
  - POES-15, POES-18, POES-19
  - METOP-A, METOP-B





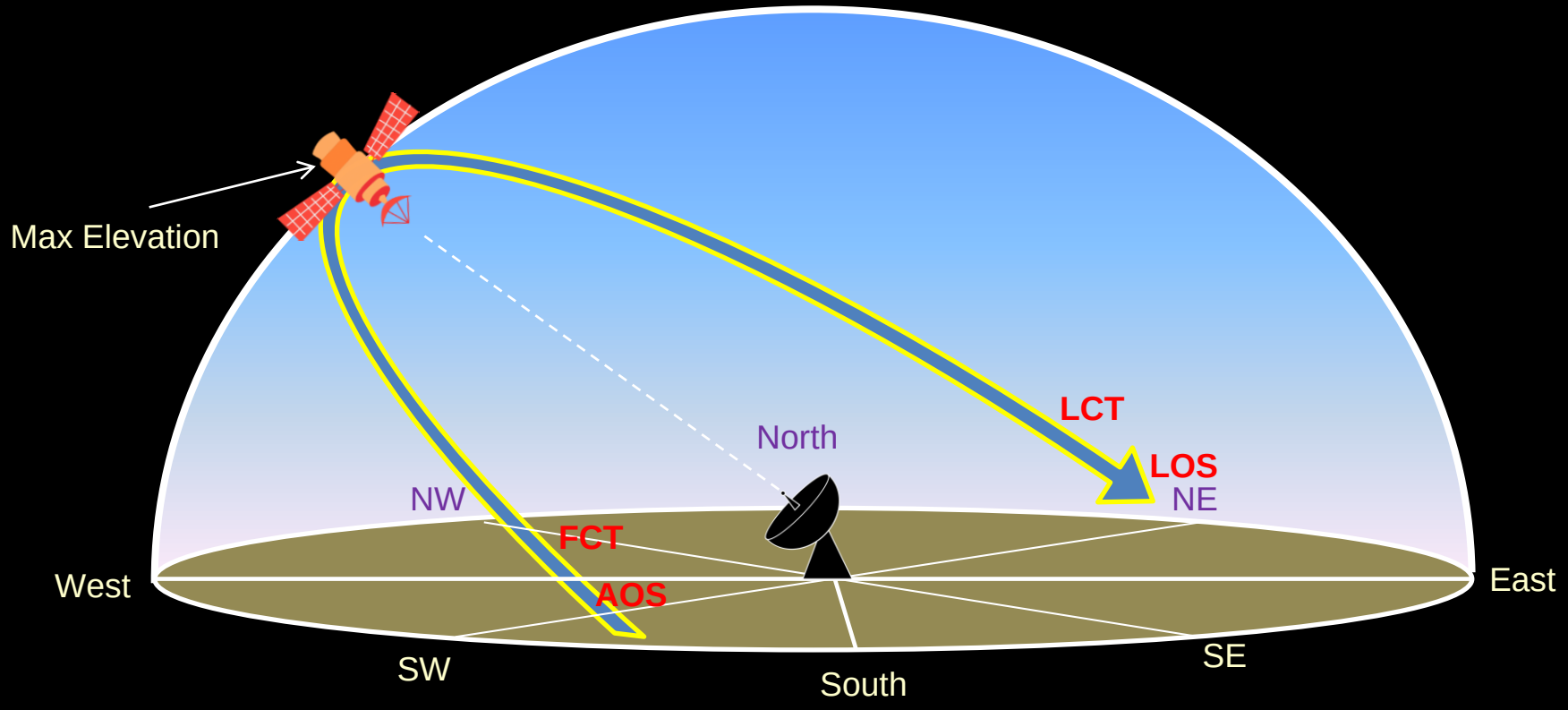
POES Field of View (Footprint)



http://www.n2yo.com

Tracking Polar Satellites

Antenna's vulnerability to coupling with interfering source is not static



AOS => Acquisition of Signal
FCT => First Contact
LCT => Last Contact
LOS => Loss of Signal

Critical antenna angle for acquiring the satellite presents the greatest vulnerability

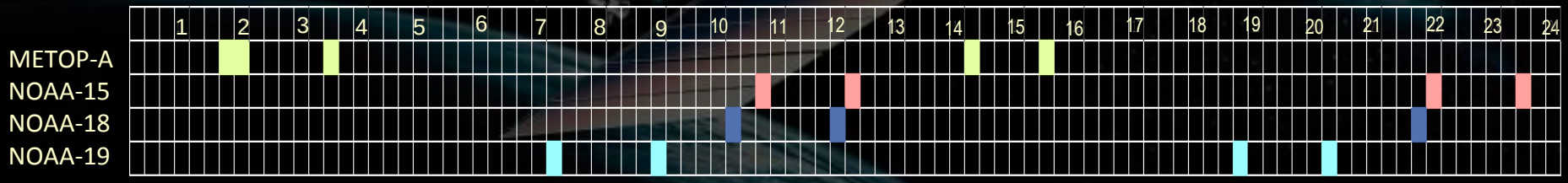
WCDAS 10-day POES Plan

- Typical day of POES/METOP contacts at WCDAS
  - 15 contacts
  - Avg. contact: 13.5 minutes
  - Shortest contact: 9 minutes
  - Longest contact: 18 minutes
  - Max elevation range: 16^0 - 57^0
- 10-day pass plans are generated once per week, unless there are changes

JDAY 102 DATE = 04-11-2016

S/C	REV	AOS	FCT	LCT	LOS	MAX EL
M01	18489	013450	013610	014830	014830	56.86
M01	18490	031620	031800	032720	032720	16.34
N19	36970	070110	070240	071430	071500	27.69
N19	36971	084150	084310	085520	085610	36.03
N18	56131	100420	100600	101650	101720	20.74
N15	93148	102600	102720	103920	104010	36.04
N18	56132	114440	114550	115830	115840	47.10
N15	93149	120600	120740	121830	121920	26.40
M01	18496	135400	135530	140650	140730	26.00
M01	18497	153400	153520	154720	154810	36.30
N19	36977	182600	182720	183950	183950	43.92
N19	36978	200730	200900	201920	201920	22.09
N18	56138	212900	213020	214240	214240	34.71
N15	93155	214430	214540	215740	215740	48.74
N15	93156	232510	232650	233610	233610	18.51

A Day in the Life Schedule at WCDAS



Predicting Satellite Position

- Satellite orbits are defined using two-line element sets (TLE)
  - TLE's list a satellite's orbital elements that define it's orbit, provides it's location in space at a given time (epoch), which can be used to predict it's position in the future.
  - TLE's are routinely updated to account for planned orbit adjustments and changes in the orbit due to atmospheric drag
  - TLE's available from: https://www.space-track.org

Example of Two-line Element Sets for POES Satellites

NOAA 15 [B]
1 25338U 98030A 16122.55346240 .00000076 00000-0 50871-4 0 9990
2 25338 98.7833 126.6092 0009912 327.0511 33.0049 14.25720867934341

NOAA 18 [B]
1 28654U 05018A 16122.58747574 .00000067 00000-0 62052-4 0 9990
2 28654 99.1980 128.3064 0014971 142.2884 217.9339 14.12281498564153

NOAA 19 [+]
1 33591U 09005A 16122.53454044 .00000137 00000-0 99532-4 0 9999
2 33591 99.0359 78.9362 0013961 355.1124 4.9909 14.12067293372552

Coordination Process

- Coordination Requests are submitted by Licensees via a government operated Coordination Portal
  - Based on License Block and Basic Economic Area
  - Corresponding agency is notified and must acknowledge receipt within five days
- Each Agency will use its own computer simulation capability to model interoperability between AWS-3 and MetSat receivers in accordance with agreed upon methods
- Incumbent response is due within 60-days after the Coordination Request is deemed to be valid
- Licensee receives a Results Letter after analysis is complete
  - Indicates which sectors are approved and which are denied
  - May approve sectors with certain operating conditions (restrictions) imposed
    - Note: These restrictions may be mutually agreed upon by AWS-3 operator to function as mitigations, enabling greater access to spectrum within the Protection Zone

Modeling Interference for Coordination

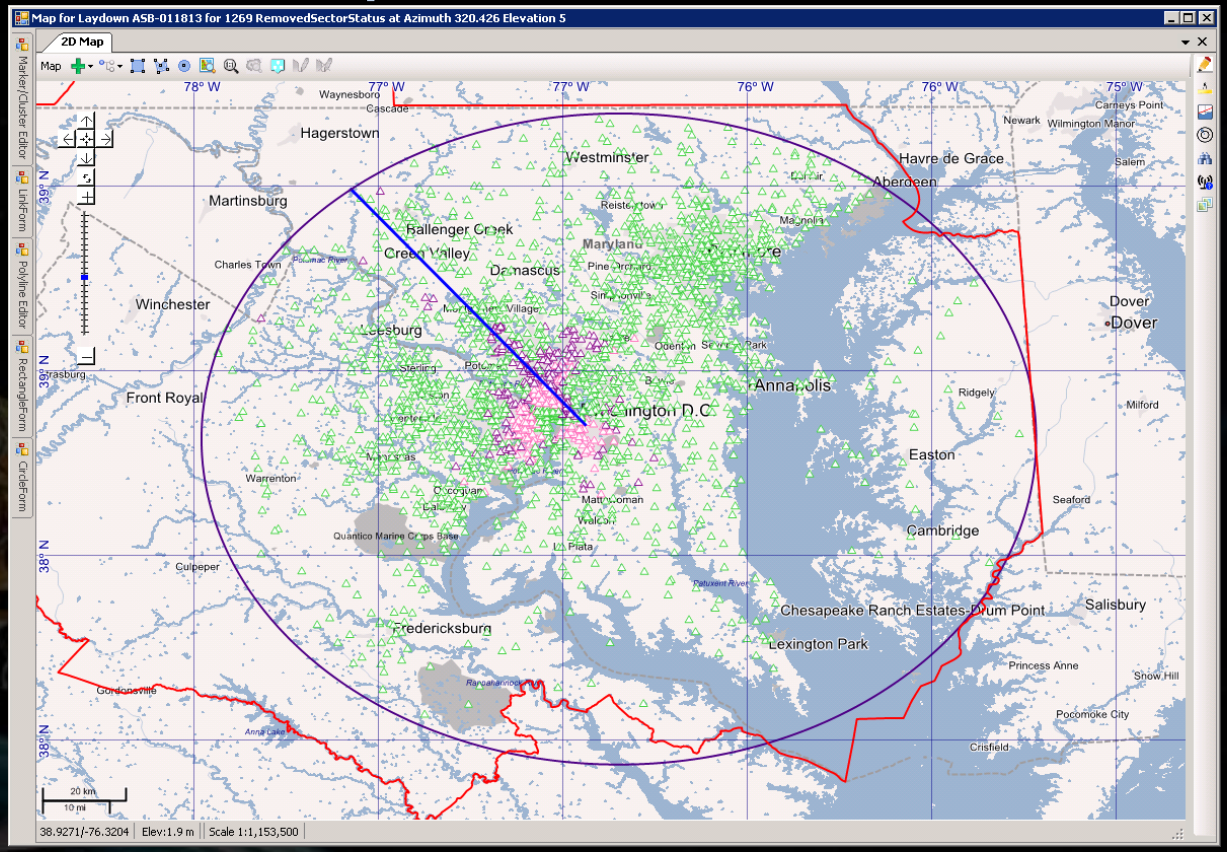
Green indicate sectors that may operate when MetSat antenna is pointing at 5 degrees elevation, 320.426 degrees azimuth

Purple indicate sectors that may NOT operate when MetSat antenna is pointing at 5 degrees elevation, 320.426 degrees azimuth (in this example)

Pink indicate sectors that may NOT operate no matter where the MetSat antenna is pointing

Note: This possible simulation assumes a temporal sharing environment, which has not been agreed upon.

Sample simulation result



Interference Monitoring

- Simulation of mobile devices is difficult and carries risks for errors. Errors may result in -
  - An overly conservative model, resulting in underutilized spectrum, or
  - an overly optimistic model, resulting in interference
  - Monitoring of the EME will allow operators to "calibrate" the model based on empirical measurements, correlating observed interference noise power level to data loss metrics and network traffic data
- If and when interference occurs, the monitoring system will aid in differentiating interference sources and provide "evidence" for identification

Current Interference Event Procedures

- GOES
  - Operator monitors GOES downlink with built-in alarms that alert operators
  - Alarms: Link Margin, Bit Error Rate, Frame Lock Loss, Total Number of Frames
  - GOES downlink signal split out to individual payload receivers (LTIR, EMWIN, DCPR, etc.)
  - GOES payload operators monitor individual downlink signals
- POES
  - POES frames collected are compared with plan post-pass
  - If signal degradation is detected, troubleshooting may include:
    - Data compared across payloads
    - Antennas swap
    - Coordination with local spectrum monitors
    - Data not collected in real-time is lost

Future Interference Event Procedures

- Workflow being developed based on Licensee locations, License Block, and implemented AWS-3 service
  - Licensee network is in development
  - Planning for LTE operation using 4G technology
  - Expecting shift to Narrowband Internet-of-Things service, possibly using 5G technology in the future
- Must sustain current procedures to rule out equipment malfunctions as source of signal loss
- Rely on interference monitoring capability to detect, classify, and identify the source(s) of RFI
  - Provides interface to automate notification to identified AWS-3 operator

Interference Monitoring System Prototyping and Testing

- **Establishing Interference Monitoring Testbed**
  - Objectives:
    - Characterize interference power and waveform
    - Characterize effectiveness of monitoring solutions
  - Resources:
    - Existing NOAA antenna and receiver equipment
    - Test facility in Boulder, Colorado

What's Next

- Licensees develop network and provide incumbents with finalized operating characteristics and mitigation techniques employed to maximize utilization of spectrum
- Incumbents complete interference analysis model to use as the basis for coordination
- Parties sign Coordination Agreements
- Develop, test and deploy an Interference Monitoring capability at federal earth station locations
- Process coordination Requests in accordance with Operator Agreements
- Operate using shared spectrum
- Monitor for Interference and mitigate as required


Questions?