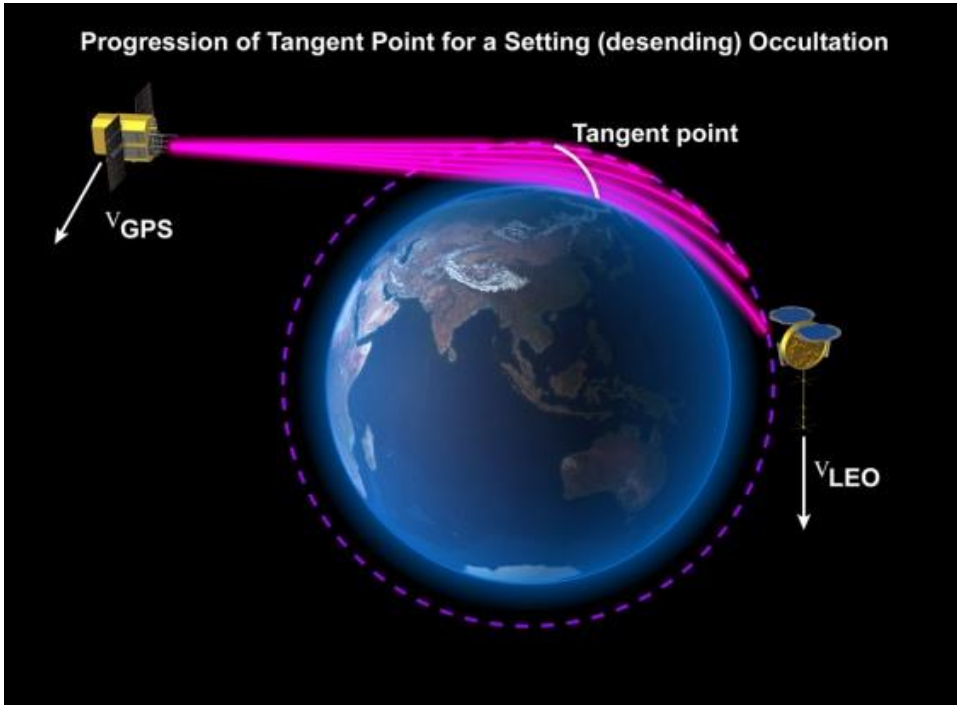
An Update on the COSMIC-2 mission

Lidia Cucurull
NOAA COSMIC-2 Chief Scientist
and
Chief, Global Observing Systems Analysis (GOSA) Group
NOAA OAR

Lidia.Cucurull@noaa.gov
http://www.esrl.noaa.gov/gsd/gosa/

Radio Occultation concept

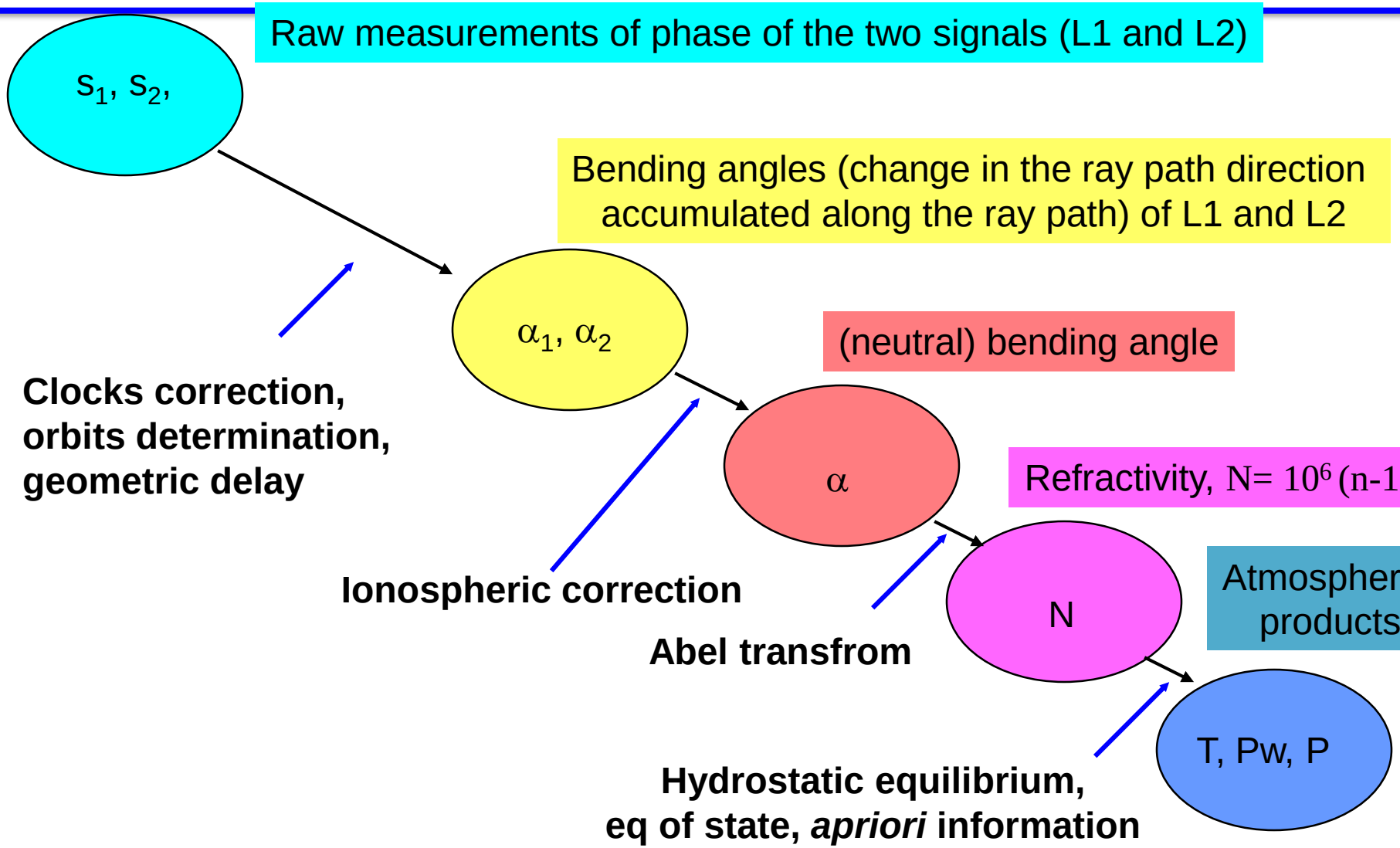
- An occultation occurs when a GNSS satellite rises or sets across the limb wrt to a LEO satellite
- A ray passing through the atmosphere is refracted due to the vertical gradient of refractivity (density and moisture)
- During an occultation (~ 3min) the ray path slices through the atmosphere



Raw measurement: change of the delay (phase) of the signal path between the GNSS and LEO during the occultation. (It includes the effect of the neutral atmosphere and the ionosphere)

GPS transmits at two different frequencies: ~1.6 GHz (L1) and ~1.3 GHz (L2)

RO processing steps

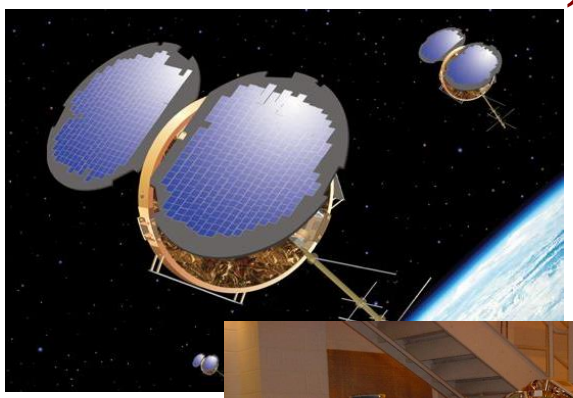


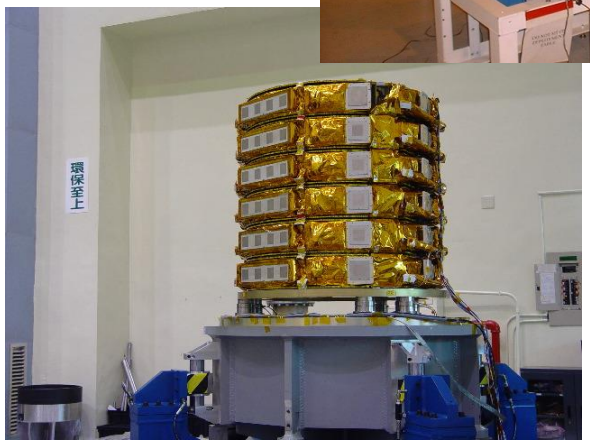
Radio Occultation characteristics

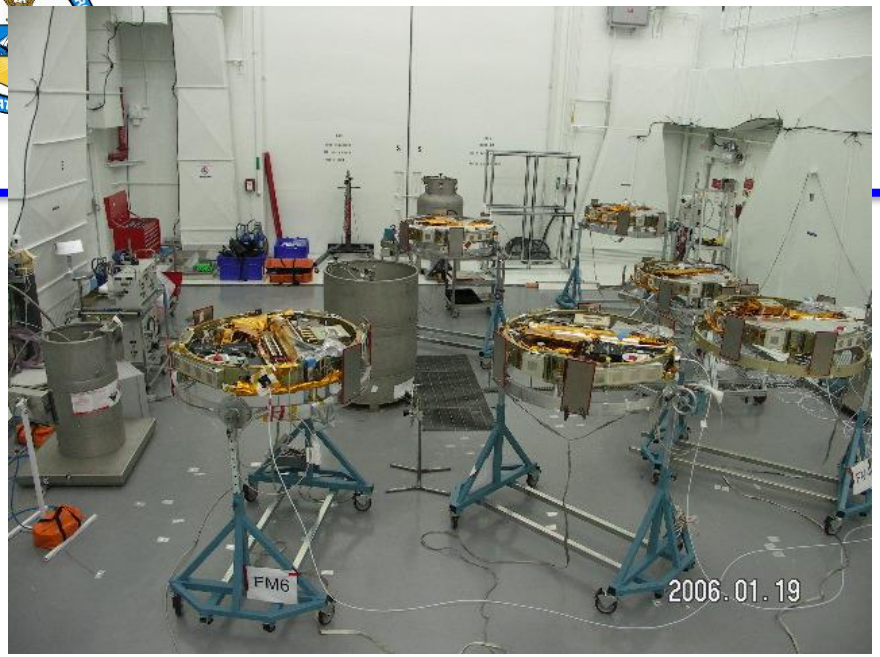
- Limb sounding geometry complementary to ground and space nadir viewing instruments
  - High vertical resolution (~100 m)
  - Lower ‘along-track’ resolution (~200 km)
- All weather-minimally affected by aerosols, clouds or precipitation
- High accuracy (equivalent to ~ 0.1 Kelvin from ~7-25 km)
- Equivalent accuracy over ocean than over land
- No instrument drift, no need for calibration
- Global coverage
- No satellite-to-satellite measurement bias
- Observations can be used in NWP without a bias correction scheme – enhances the bias correction and overall impact of nadir satellites
- RO is one of the top contributors in improving global operational weather forecast skill
- Provides terrestrial and space weather (i.e. electron density, TEC, scintillation) products

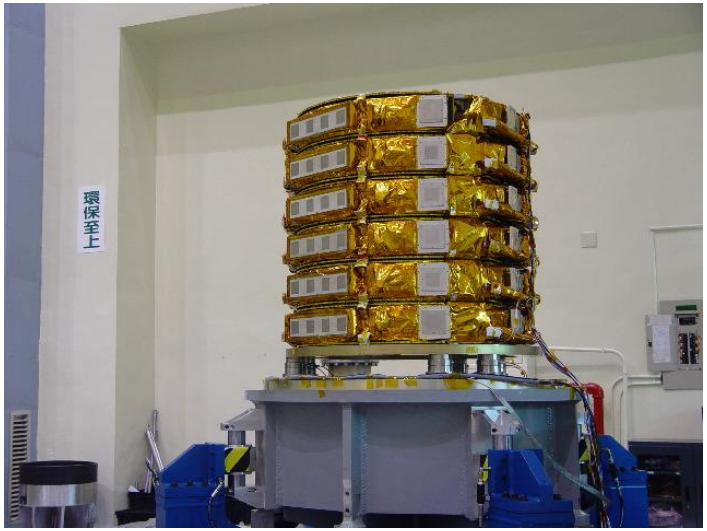
COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate)

- Joint US-Taiwan mission
- 6 LEO satellites launched April 2006
- Three instruments: GPS receiver, TIP, Tri-band beacon
- Demonstrate “operational” use of GPS limb sounding with global coverage in near-real time
- web page: www.cosmic.ucar.edu






FM6
2006.01.19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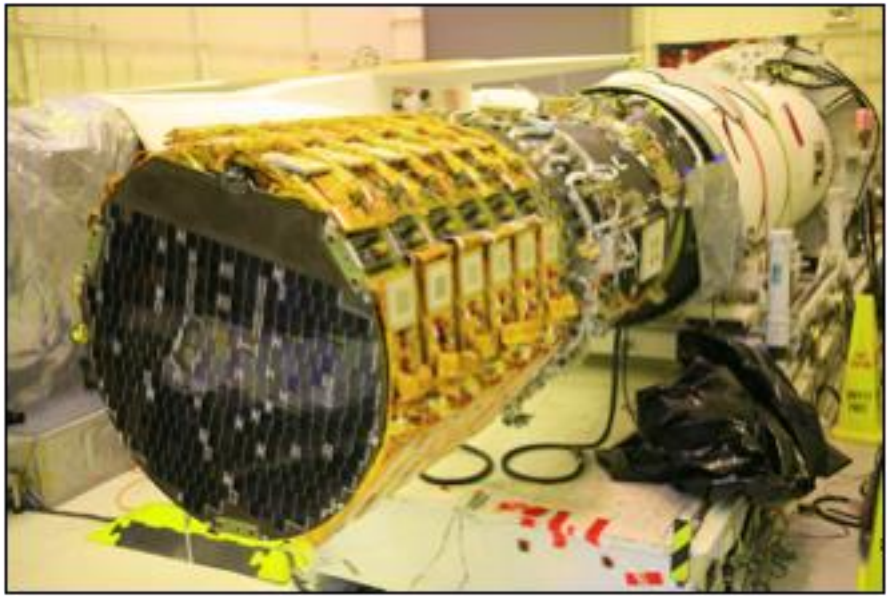
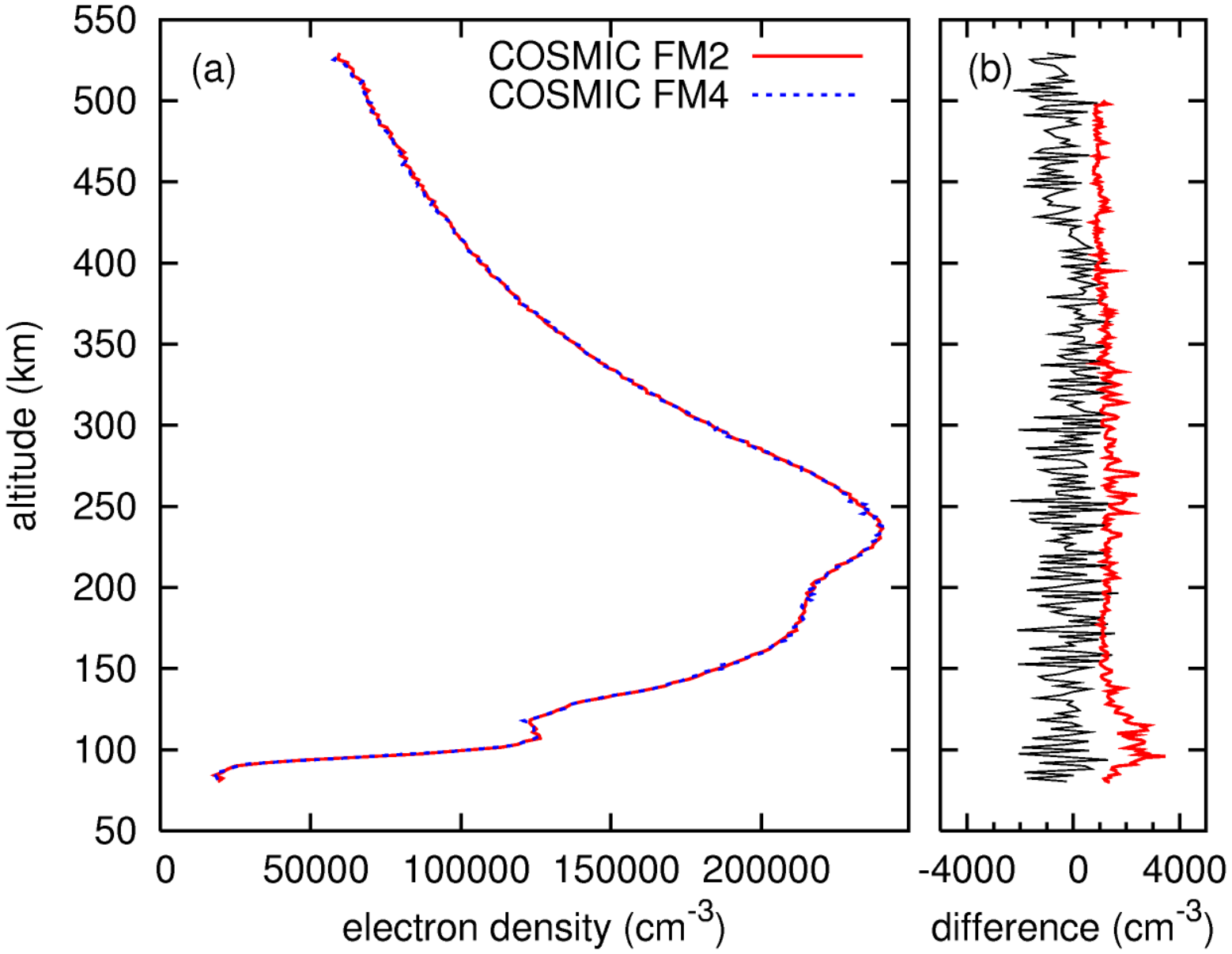


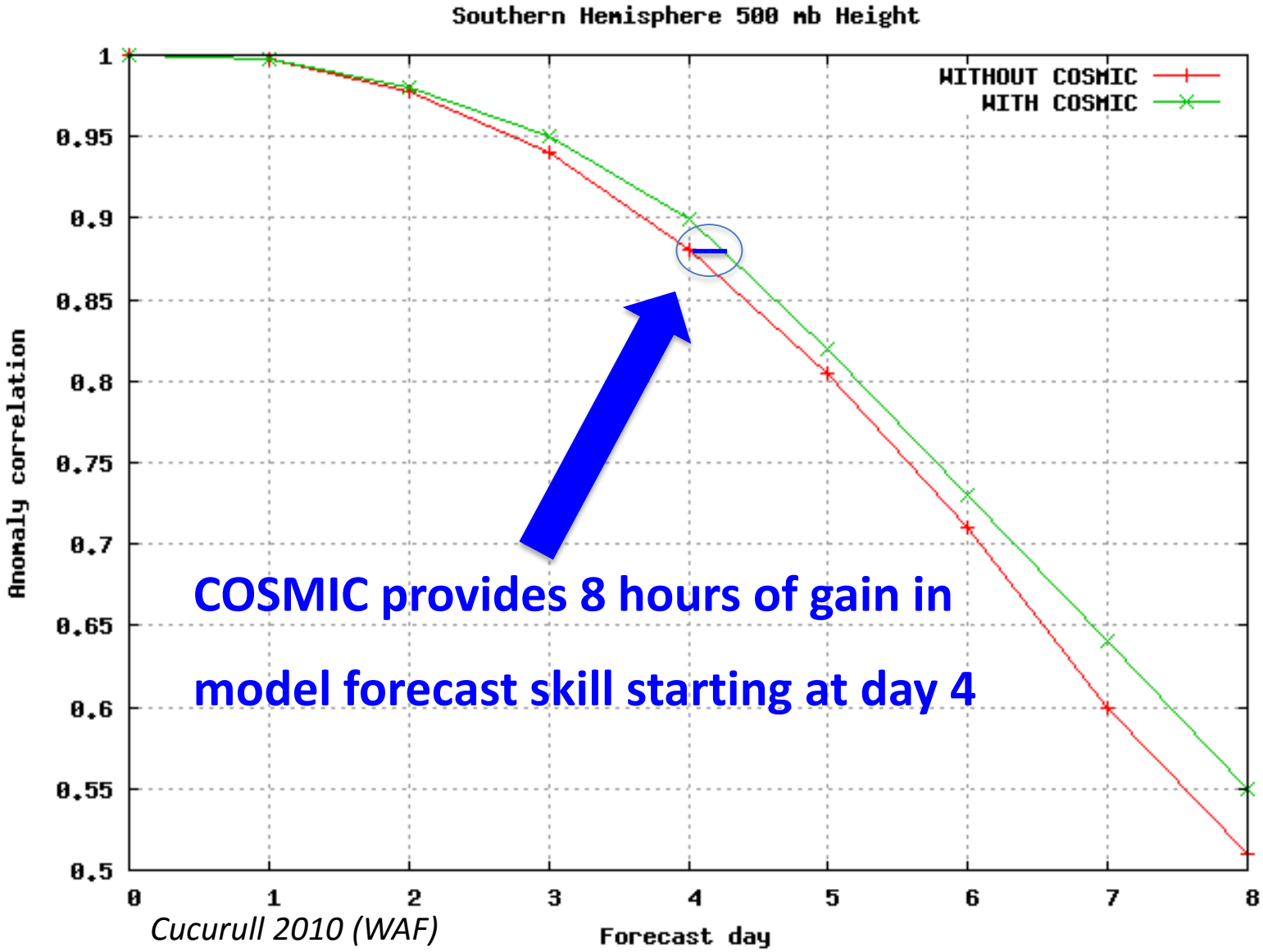
First collocated ionospheric profiles



From presentation by S. Syndergaard,

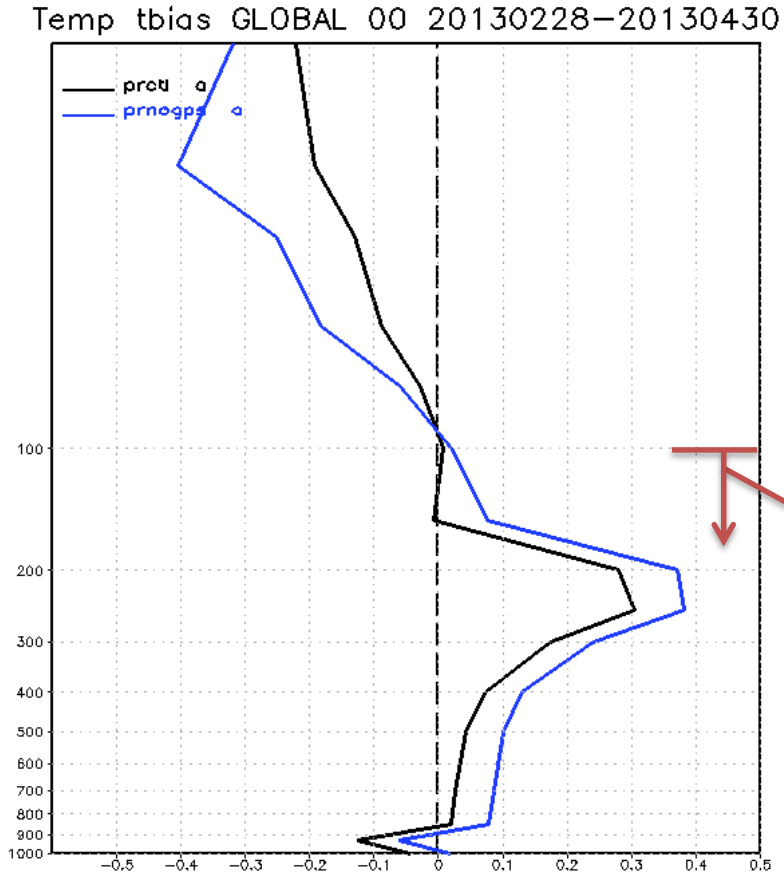
UCAR/COSMIC

Early impact of RO data at NCEP

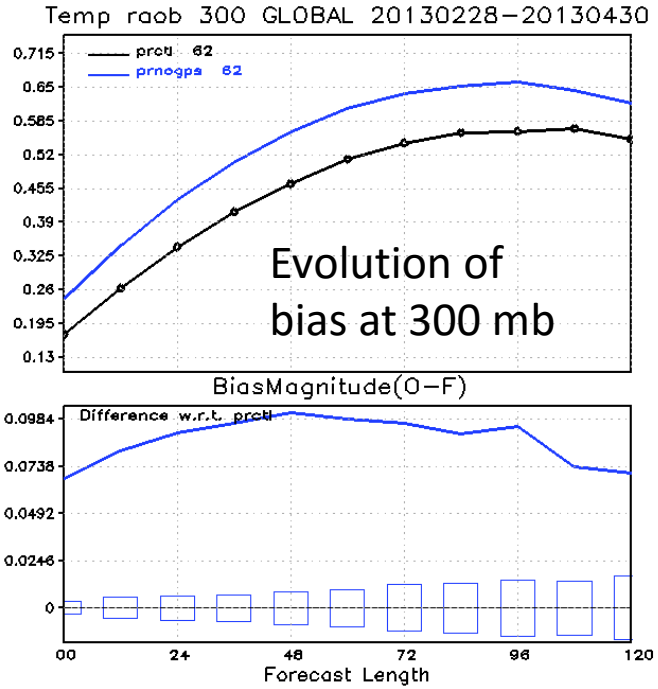


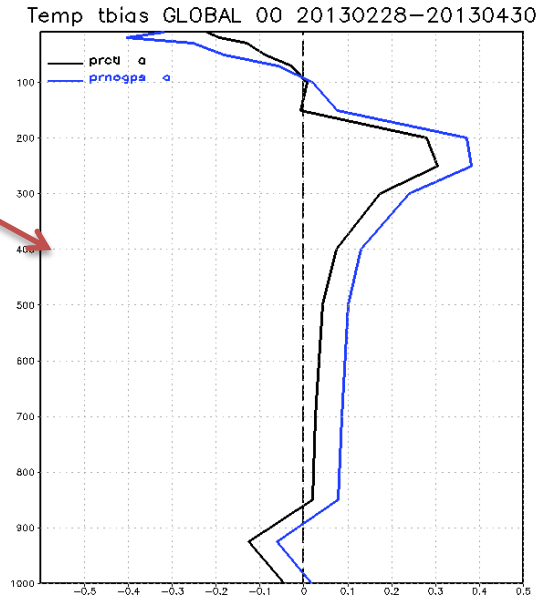
Cucurull 2010 (WAF)

Fit to radiosondes



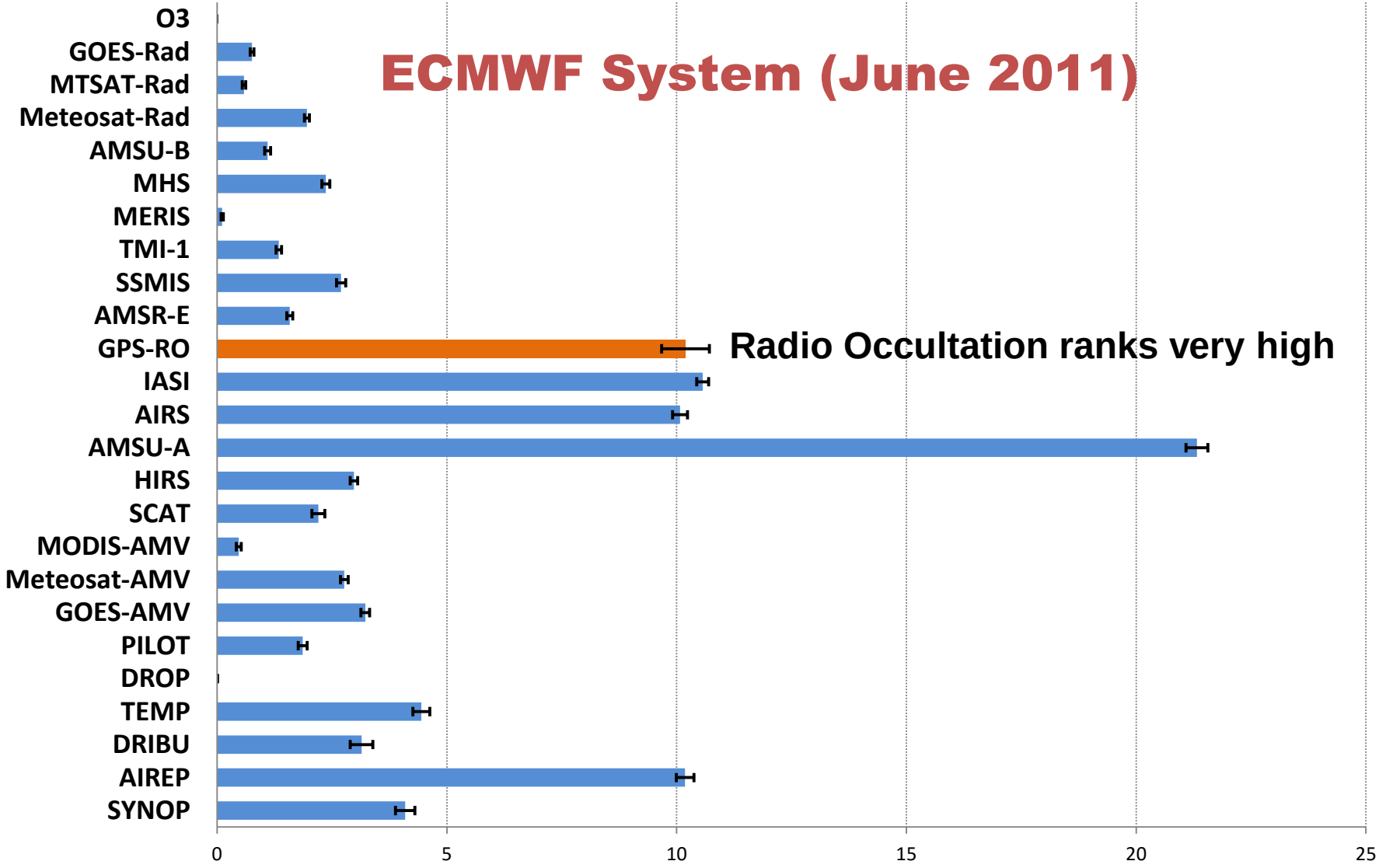
A-O temperature (K)





Cucurull and Anthes 2015 (WAF)

ECMWF System (June 2011)



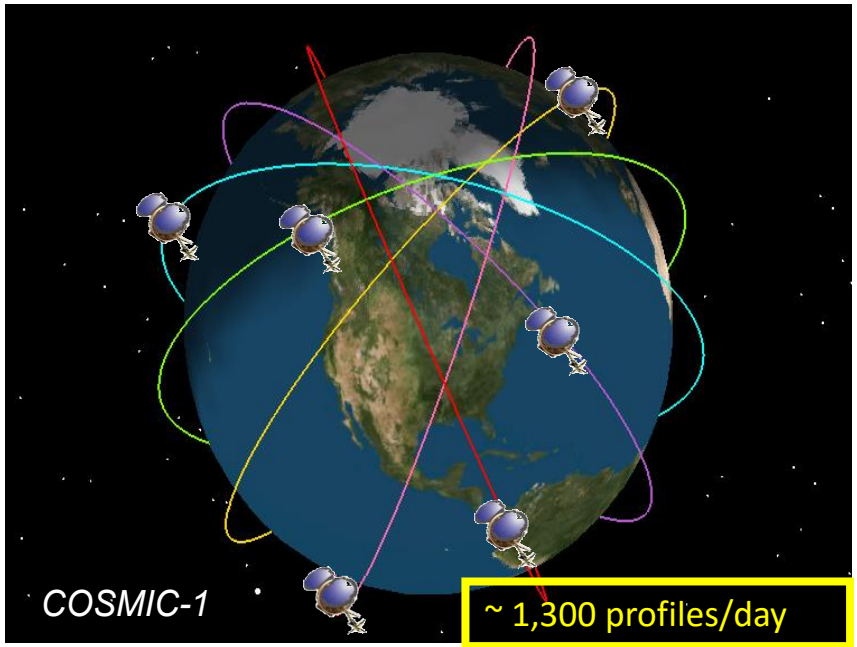
Contribution in Forecast Error Reduction (%)

RO Data Assimilation at NCEP

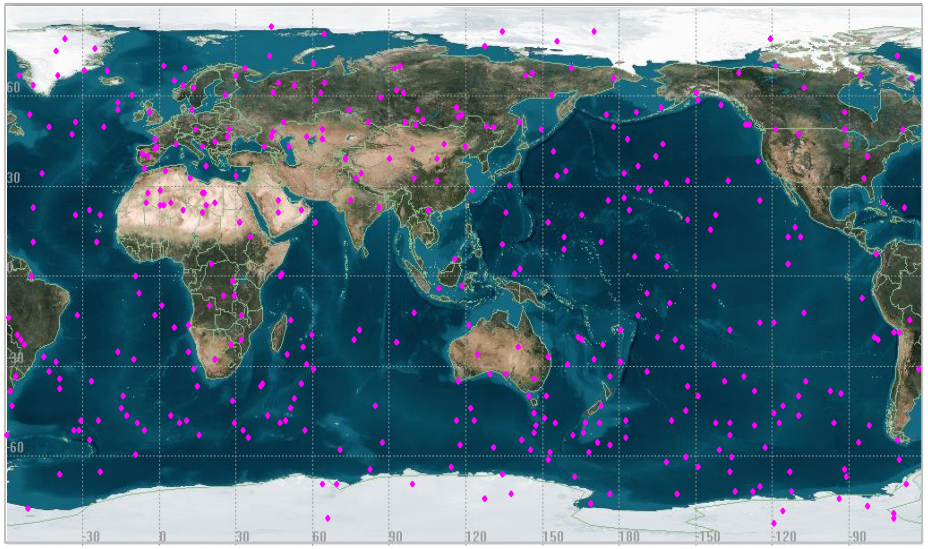
- A forward operator for refractivity was initially used to assimilate RO observations from the COSMIC mission into the NCEP's operational global model starting in May 2007
- Operational assimilation of RO at NCEP switched from soundings of refractivity to soundings of bending angle in May 2012. Top of the profiles raised from 30 to 50 km
- An improved forward operator for the assimilation of bending angles is under current development – expected to improve the use of the RO observations in the lower troposphere, very important for COSMIC-2. This work is being done under a 3-way MOU between NOAA OAR, NESDIS, and NWS
- Operational assimilation of RO (refractivities) in the NCEP's regional modeling system started in October 2011. However, the use of RO observations in the global model already provided positive feedback to the regional – through boundary and initial conditions. Assimilation of bending angles replaced the assimilation of refractivities operationally in August 2014

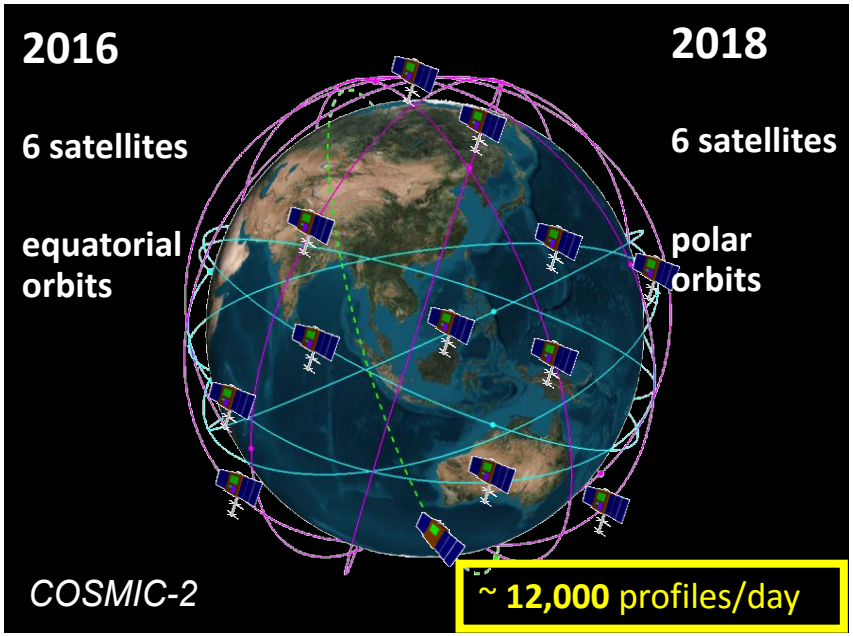
GNSS RO Soundings

- NCEP assimilates operationally the following RO instruments for total daily soundings of ~ 2,000:
  - **COSMIC 1-6** (US and Taiwan) – since May 2007
  - **MetOp-A/GRAS** (Eumetsat) - since February 2010
  - **GRACE-A** (Germany) - since February 2010
  - **SAC-C** (Argentina) – since May 2011 – RIP SAC-C August 2013
  - **C/NOFS** (US Air Force) – since May 2011 - placed in SAFE mode on 4 June 2013 due to funding issues. Restarted late 2013, but data latency was too high for operations. RIP C/NOFS in 2015.
  - **TerraSAR-X** (Germany) - since May 2011
  - **MetOp-B/GRAS** (Eumetsat) – since August 2013
  - **TandemX** and **GRACE-B** (Germany) – expected in May 2016
- COSMIC is significantly degrading (~ 500 soundings/day) – urgent demand for data gap mitigation
- Low latency is critical to enable operational use of the data in NWP
- Near-operational monitoring of the systems above can be found in: http://www.emc.ncep.noaa.gov/gmb/gdas under "GPSRO Monitoring"

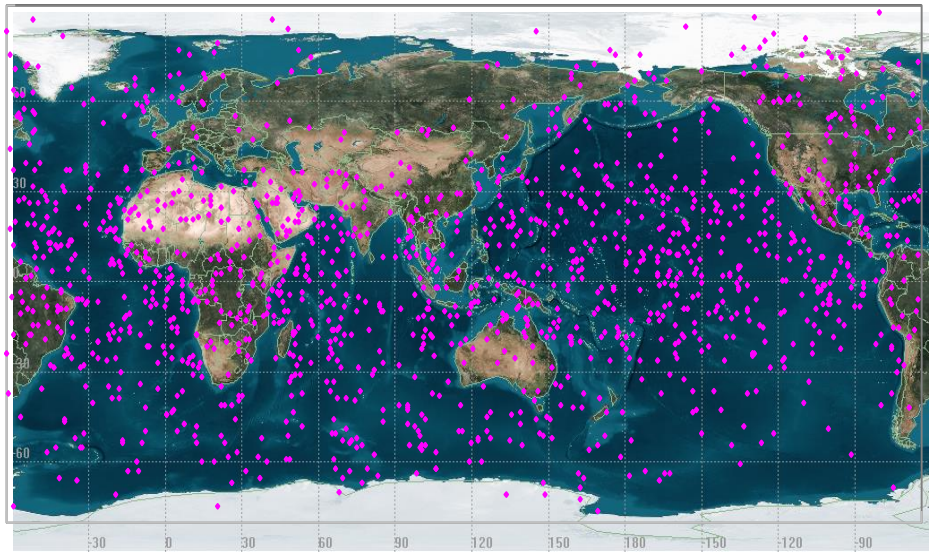


COSMIC-1 Occultations – 3 Hrs Coverage





COSMIC-2 Occultations – 3 Hrs Coverage

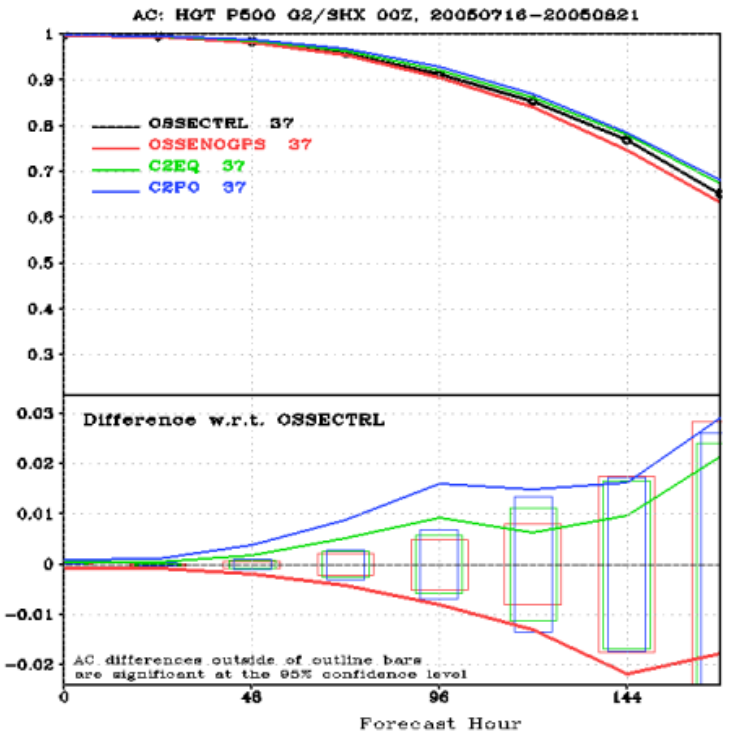


Courtesy of UCAR

Preliminary OSSE results with COSMIC-2

- Overall, increasing the number of assimilated RO satellites from 6 to 18 results in better weather forecast skill: 18 satellites is better than 12 satellites; 12 satellites is better than 6 satellites

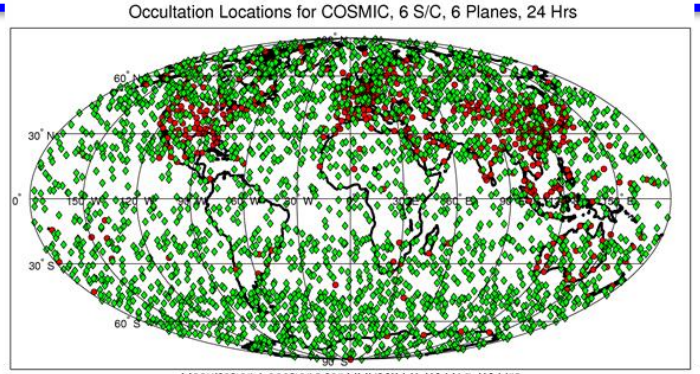
  - **OSSECTRL**: control, all observations (**6 RO satellites**)
  - **OSSENOGPS**: control without RO observations (**0 RO satellites**)
  - **C2EQ**: control + COSMIC-2 equatorial (**12 RO satellites**)
  - **C2PO**: control + COSMIC-2 equatorial + COSMIC-2 polar (**18 RO satellites**)



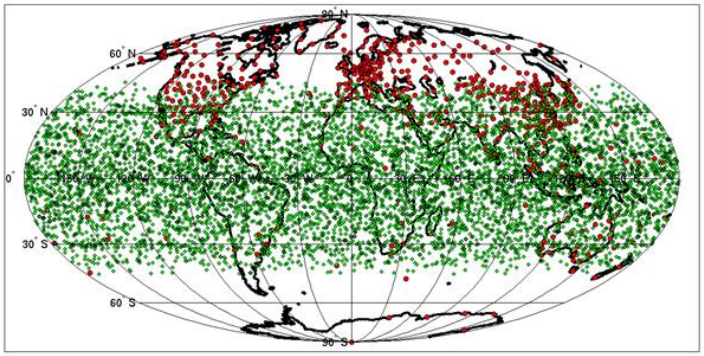
FORMOSAT-7 / COSMIC-2
Program Objectives

- Continue collecting atmospheric and ionospheric data similar to the FORMOSAT-3 / COSMIC-1 mission
- Provide continuity of GPS-RO data as well as provide Global Navigation Satellite System-RO data to users
- Collect a large amount of atmospheric and ionospheric data primarily for operational weather forecasting and space weather monitoring as well as meteorological, climate, ionospheric and geodetic research.
- Collect data over unmanned and remote regions (oceans and poles)
- Demonstrate an operational constellation for the continuous and uniform collection of atmospheric and ionospheric data as inputs to daily near-real-time weather forecasts, space weather research, and climate change studies.
- For operational numerical weather prediction and space weather monitoring, the Radio Occultation (RO) data profiles from the reliable global constellation system will number approximately 8,000 profiles on average per day with the data latency being 30 minutes on average.
- Provide Global Coverage
  - 6 satellites to 24 degree inclination (equatorial)
  - 6 satellites (+1 NSPO satellite) to 72 degree inclination (polar)

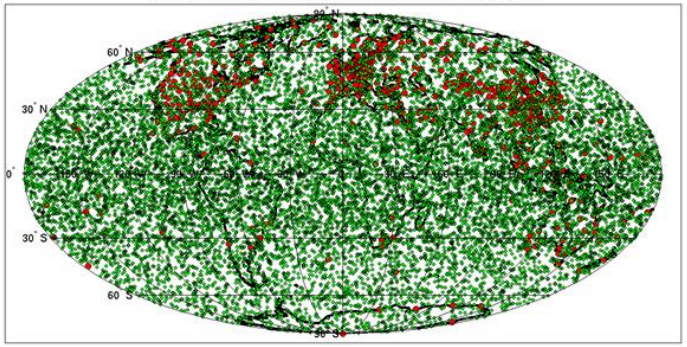
Comparison of Global Coverage



FORMOSAT-3
/ COSMIC-1
6 spacecraft
(72 degree)



FORMOSAT-7
/ COSMIC-2A
6 spacecraft
(24 degree)

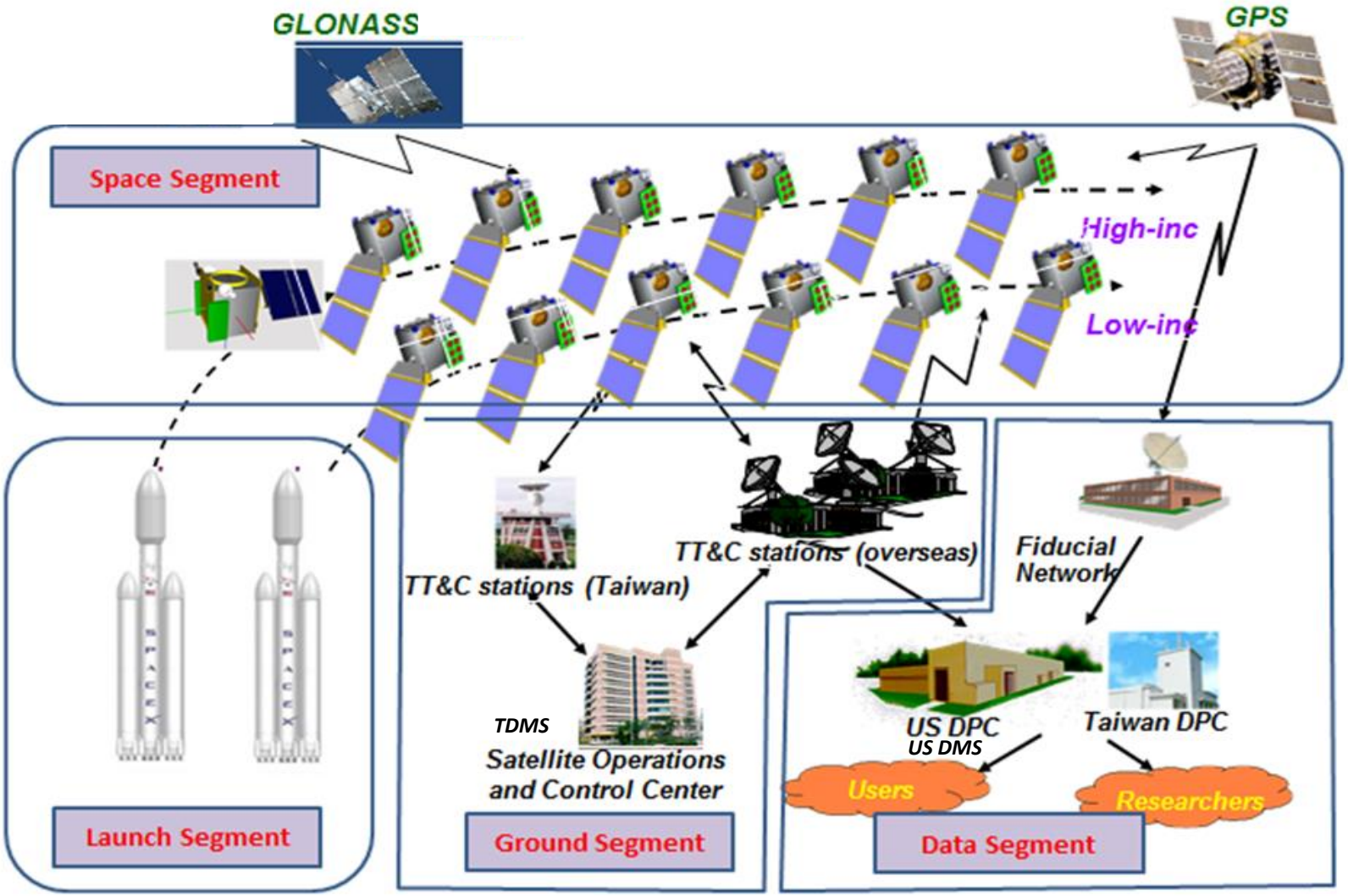


FORMOSAT-7 /
COSMIC-2B
6 spacecraft+1
(72 degrees)

Plot shows
12 spacecraft (C2A & C2B)

16

Mission Architecture/Segment Overview



Key Organizational Responsibilities

- NOAA Responsibilities:
  - Instruments via USAF (C2A)
  - Instrument (TGRS) via NASA (C2B)
  - Launch Service (via USAF C2A)
  - US and International Ground Stations
  - US Data Management System and Data Processing Center via UCAR
  - Data Distribution to Users
  - Data Archival
  - Model Updates; Data V&V
  - Project Management

- NSPO Responsibilities:
  - Spacecraft Bus (SSTL-UK)
  - Spacecraft and Instrument Integration
  - Spacecraft System/Environmental Testing
  - Launch Site Integration and Ops
  - Satellite Operations & Control Center and Taiwan Data Management System
  - Taiwan Ground Stations
  - Taiwan Data Processing Center with CWB/NCU
  - Mission Operations
  - Scientific Instruments (set 2)
  - Project Management

- USAF SMC/AD-LE Responsibilities:
  - C2A Launch via SpaceX
  - Verify SC Compliance to LV ICD
  - Verify SC Compliance to Range Safety (91-710)
  - Assess all Spacecraft with respect to “do no harm” for the STP-2 stack
  - Launch Site Payload Processing Facility

- USAF SMC/RS Responsibilities:
  - Instruments for C2A
    - TriG GNSS Radio Occultation System (TGRS)
    - Ion Velocity Meter (IVM)
    - RF Beacon(RFB) & Ground Stations
  - Mark IV-B Ground Stations
    - Hawaii - Honduras
    - Guam - Kuwait

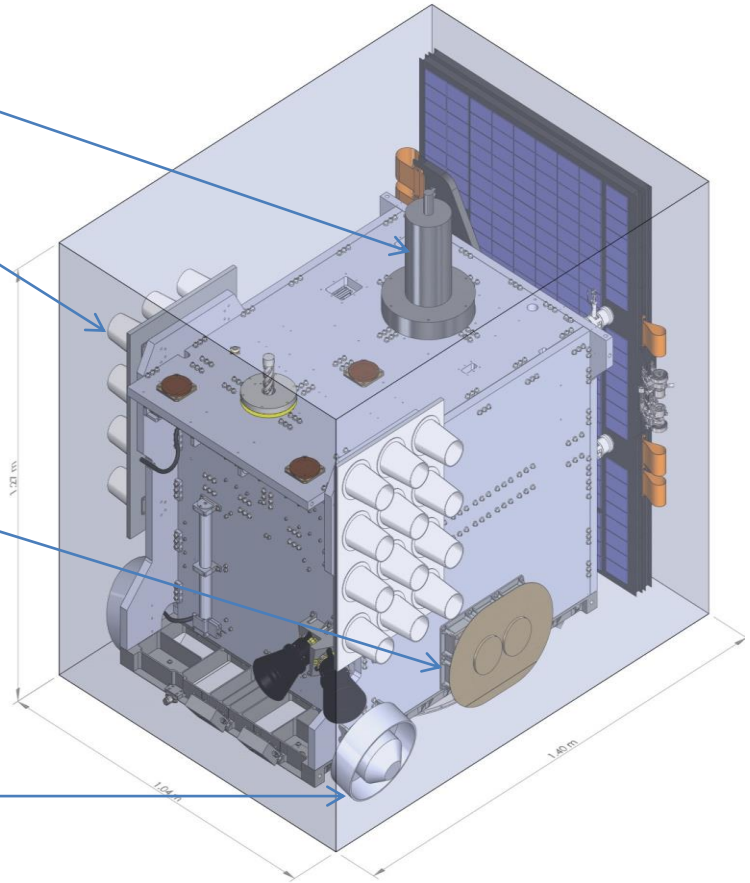
Payload Components On COSMIC-2 Spacecraft

Radio Frequency Beacon Antenna

TGRS Radio Occultation Antenna (2X)

TGRS Precision Orbit Determination Antenna (2X)

Ion Velocity Meter & Electronics

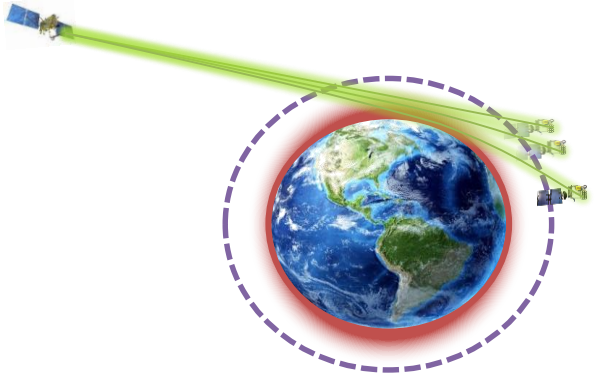


Courtesy of Chong Le

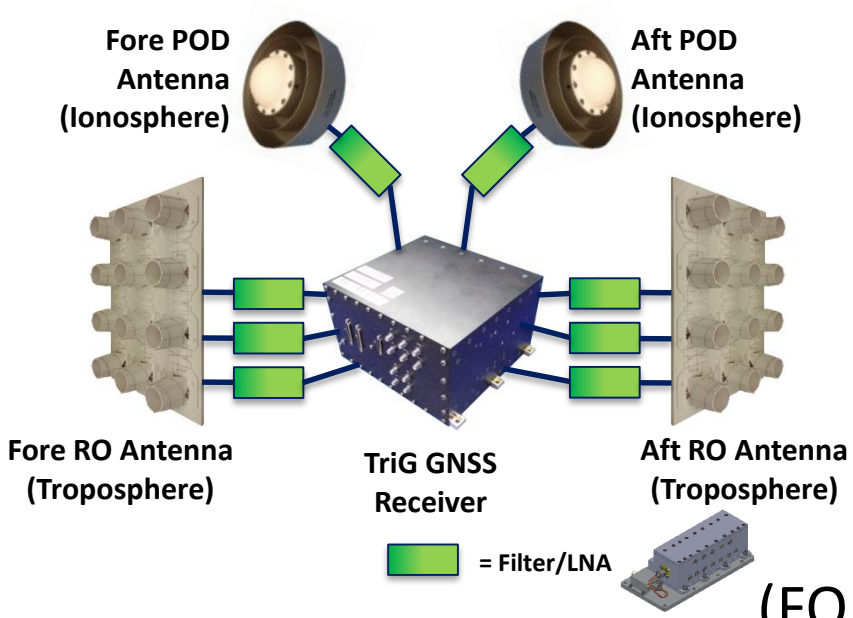
Picture from NSPO/SSTL CDR slides

Tri-Band Global Navigation Satellite System (GNSS) Receiver System (TGRS)

- Mission Objective
  - Collects global atmospheric and ionospheric data for weather prediction and climate research



- Key Features
  - Direct heritage from Blackjack GPS receivers
  - Ability to track GPS and GLONASS
  - Neutral atmospheric soundings
  - Ionospheric soundings and overhead TEC
  - Ionospheric scintillation observations
- Contractor: JPL
  MBRE (TriG Receiver)
- TGRS is composed of
  - One TriG receiver electronics
  - Two Precise Orbit Determination/ Ionosphere sensing antennas
  - Two limb-viewing RO antennas
  - Eight assemblies with filters and low Noise amplifiers
- Mass (25.3 kg)/Power (66 W)/ Design life (5 years)



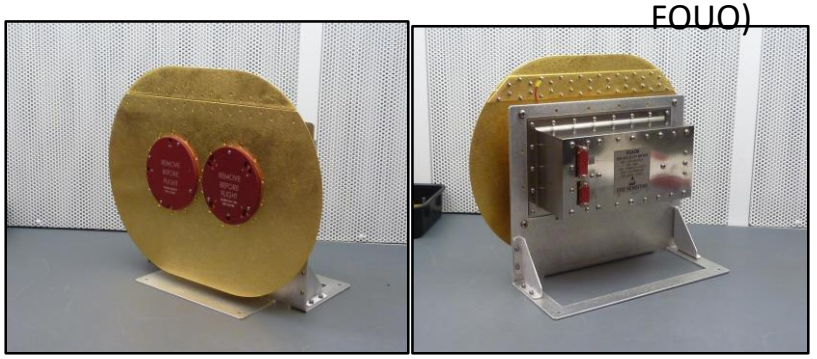
Courtesy of Chong Le

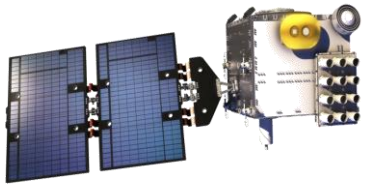
(FOUO)

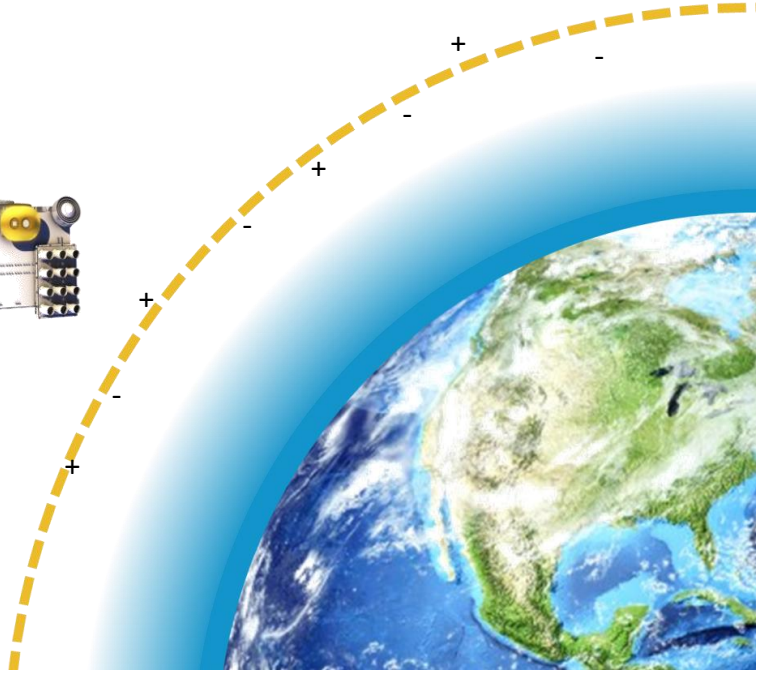
Ion Velocity Meter (IVM)

- Mission Objective
  - Measures background ionospheric density, ion composition, ion velocity, and ion temperature for ionospheric modeling
- Key Features
  - Direct heritage from Dynamics Explorer-2, DMSP, and C/NOFS missions
  - IVM is a gridded electrostatic analyzer designed to observe & characterize in-situ plasma characteristics
  - Instrument can be fully configured with only seven commands
  - Key observations include ion drifts (E-fields), density, and irregularity structures
  - Ability to measure the ram energy of the ions with the Retarding Potential Analyzer (RPA)
  - Ability to measure the ion arrival angle with the Drift Meter (DM)
- Contractor: UTD (DQU, FM1)
  Ball (FM2 -6)
- IVM is composed of
  - Retarding Potential Analyzer (RPA)
  - Drift Meter (DM)
  - Electronics
- (FOUO) Mass (4.2 kg)/Power (4.5 w)/Design life (5 yrs)

FOUO)







Courtesy of Chong Le

(FOUO)

Radio Frequency Beacon (RFB)

- Mission Objective
  - Measures ionospheric scintillation and relative TEC by transmitting phase coherent signals in UHF, L-Band and S-Band RF received by ground-based receivers

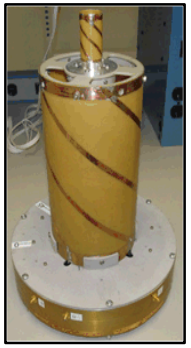
- Key features
  - Sensor is a new design
  - Transmit UHF, L, S tones
  - Channel Probe designed to gain insight into scintillation impacts on UHF spread spectrum communications
  - Ground-based receivers measure RF Beacon signals (amplitude & phase) to determine scintillation environment

- Contractors
  - SRI (EM BEU, FM1 BEU)
  - SMI (BEU FM2 to 6)
  - AFRL (AU FM1 to 6)

- RF Beacon is composed of
  - Beacon Electronic Unit (BEU)
  - Antenna Unit (AU)
  - In-line filters between BEU and AU

- Mass (5.4 kg)/Power (25 w)/Design life (5 years)

FOUO



FOUO

Courtesy of Chong Le

(FOUO)

RF Beacon Ground

The RF Beacon Transmitter utilizes a ground receiver to measure effects of equatorial scintillation

RF Beacon Receiver Network (6 sites selected)

- Contractors: Space Dynamics Laboratory
- The RF Beacon Ground program is managed by SMC/RSS
  - Prototype Ground Receiver built
  - 6 worldwide locations ready to integrate receivers
  - (FOUO) Procurement of receivers currently unfunded
  - (FOUO) Baseline plan is to use prototype to check out RFB performance & Calibration activities

Courtesy of Chong Le

Summary

- Improvement on the utilization of current and future RO observations through advanced assimilation algorithms is ongoing effort at NOAA
- R2O activities at NOAA are on schedule for the assimilation of the COSMIC-2 products in NOAA's operational models at day 1 after launch
- Low latency is critical to enable operational use of the data in NWP
- COSMIC is significantly degrading (~ 400 soundings/day) – urgent demand for data gap mitigation
- NOAA is fully committed to COSMIC-2 (Equatorial launch expected ~ Feb-March 2017)