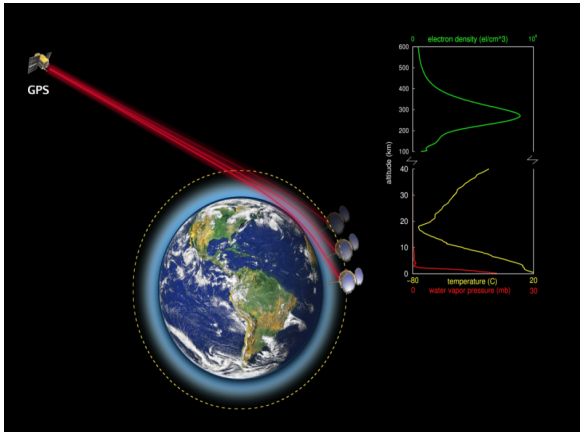
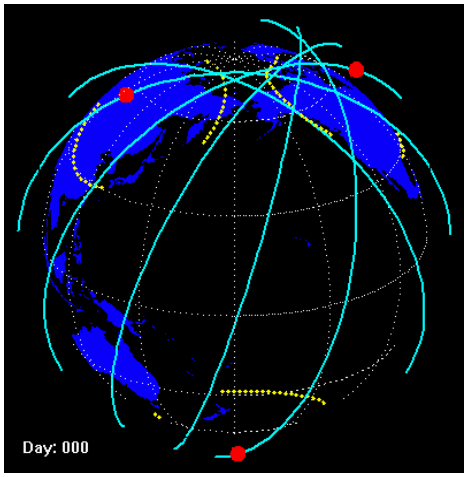
GNSS Radio Occultation Constellations for Meteorology, Ionosphere and Climate: Status of the COSMIC and Planned COSMIC-2 Missions

Bill Schreiner, C. Rocken, X. Yue, B. Kuo
COSMIC Program Office, UCAR, Boulder CO
www.cosmic.ucar.edu

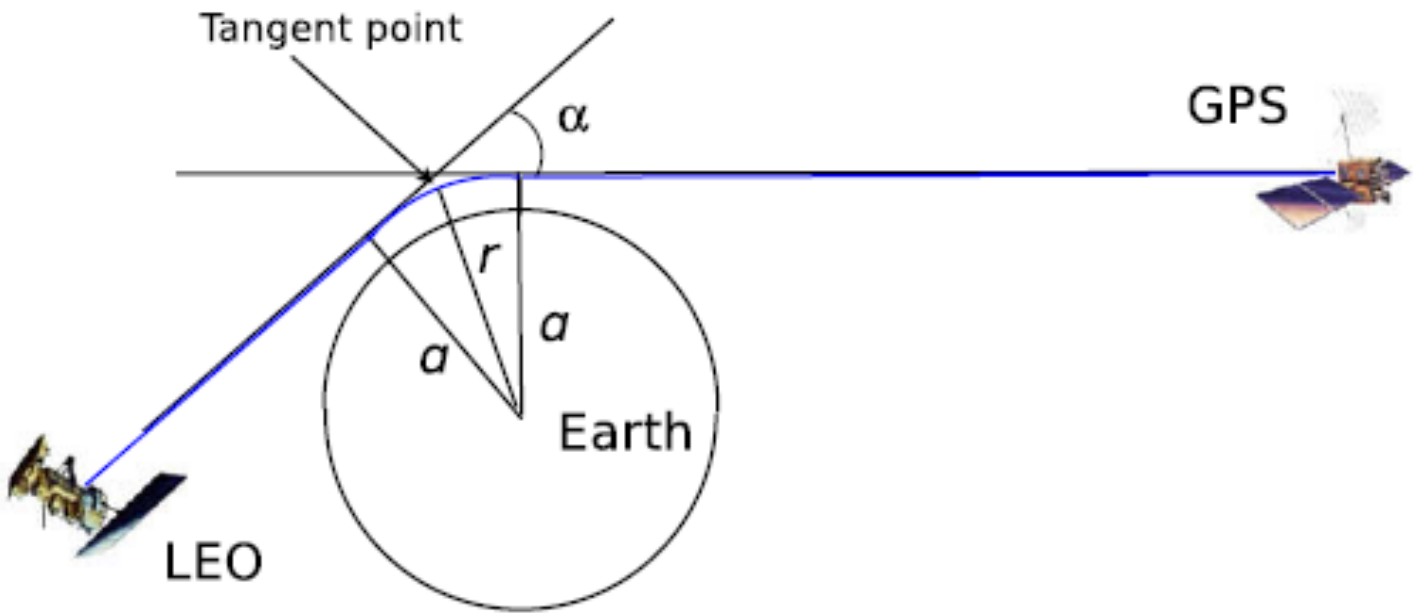
D. Mamula, D. Ector
NOAA/NESDIS Office of Systems Development, Silver Springs, MD



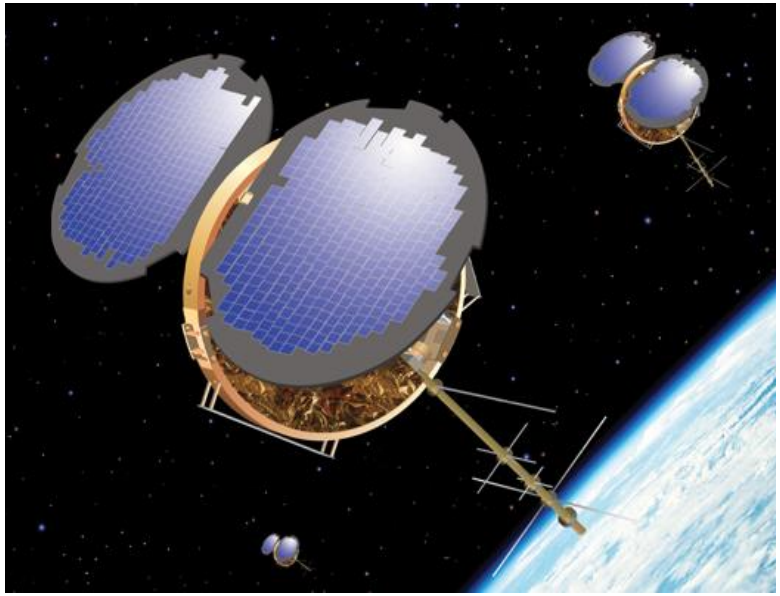


Outline

- COSMIC Mission Status
- COSMIC-2 Mission Planning
- Summary

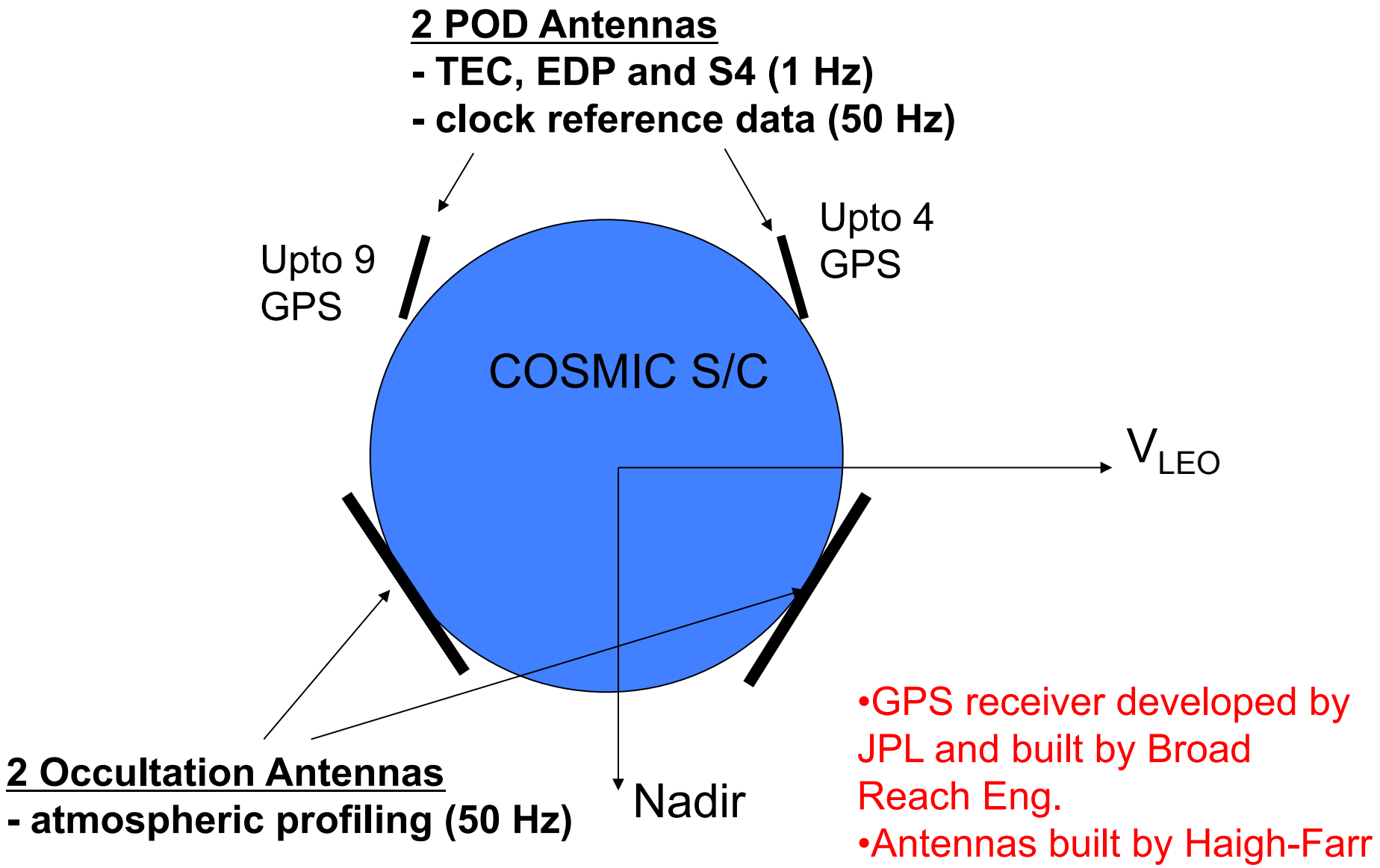


COSMIC
(Constellation Observing System for Meteorology, Ionosphere and Climate)



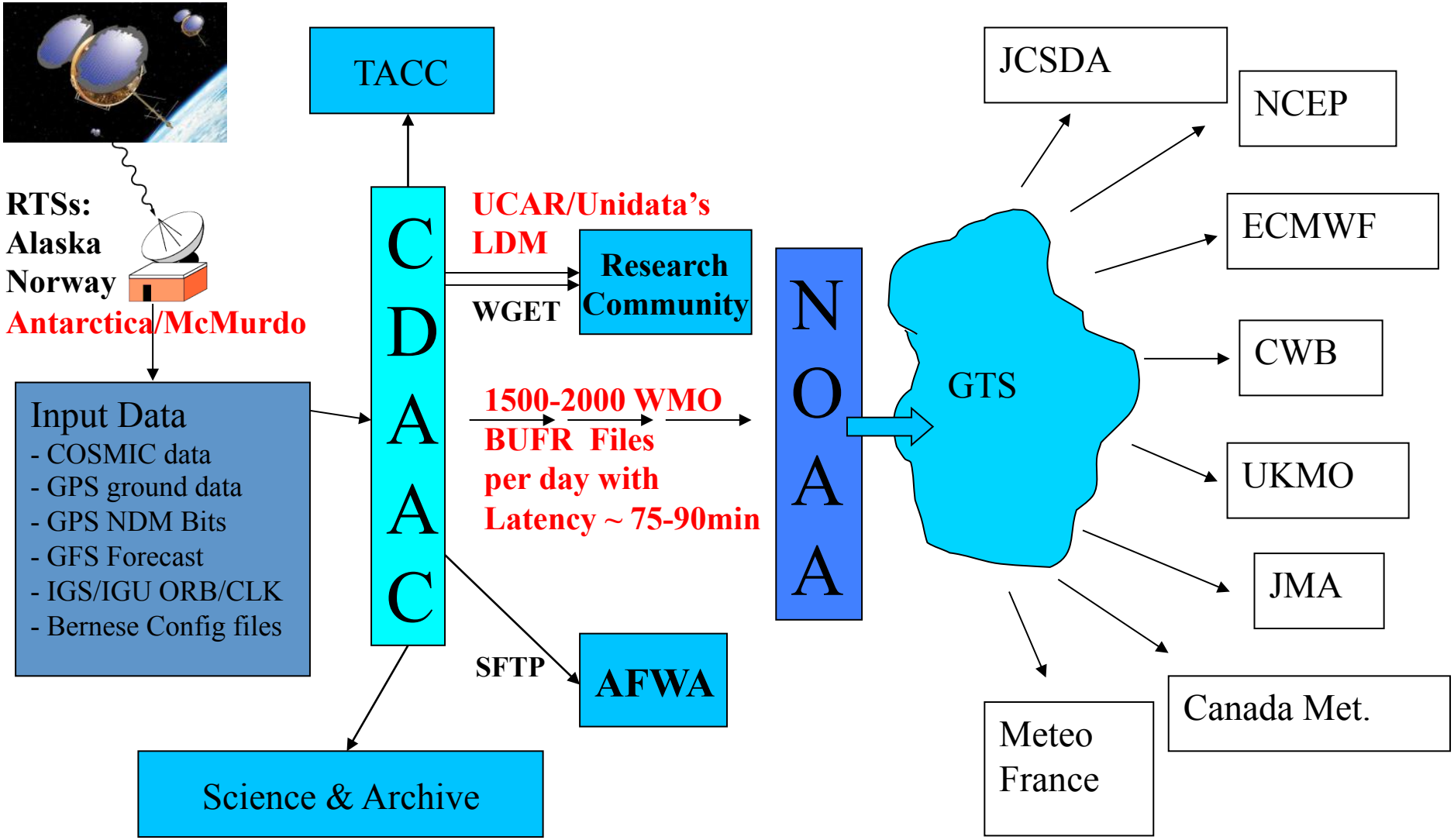
- Joint Taiwan and US project
- NSF is U.S. lead agency
  - NOAA, NASA, Air Force, Navy
- 6 Satellites launched April 14, 2006
- **GPS Radio Occultation Receiver**
  - Refractivity
  - Pressure, Temperature, Humidity
  - **Absolute Total Electron Content (TEC)**
  - **Electron Density Profiles (EDP)**
  - **Ionospheric Scintillation (S4 amplitude)**
- Tiny Ionospheric Photometer (TIP) – UV Radiances
- CERTO Tri-Band Beacon Transmitter
- Complete global and diurnal sampling
- Demonstrated forecast value of GPS radio occultation soundings in near-real time
- Total cost ~$100M; Taiwan paid for 80% of costs
- Mission on time, within budget, and exceeding expectations

GPS Antennas on COSMIC Satellites



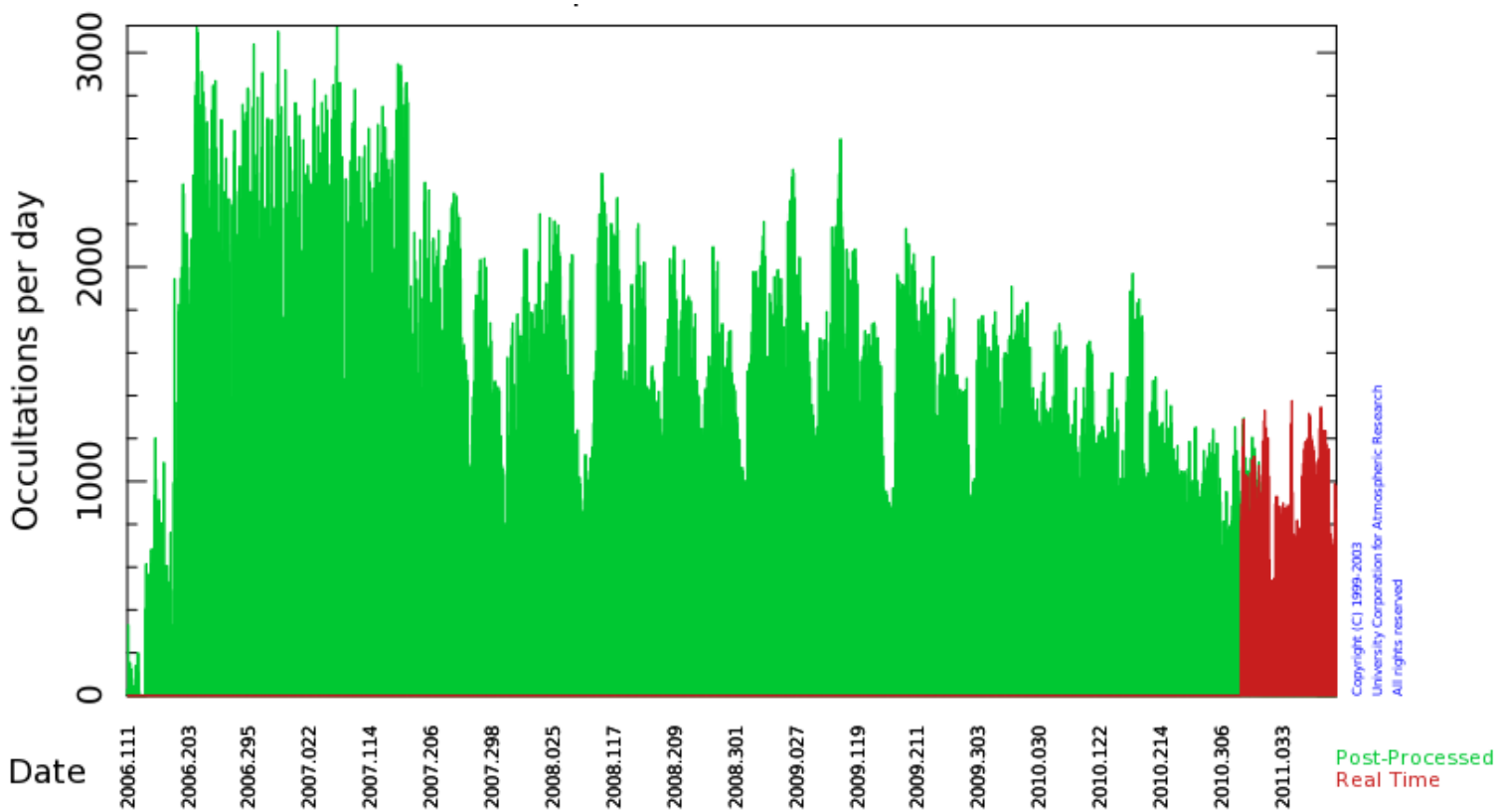
- GPS receiver developed by JPL and built by Broad Reach Eng.
- Antennas built by Haigh-Farr

COSMIC Operational Processing



Providing data to > 1,549 registered users from 59 countries

2.8+ Million COSMIC Ionospheric Profiles 4/21/06 – 4/11/2011

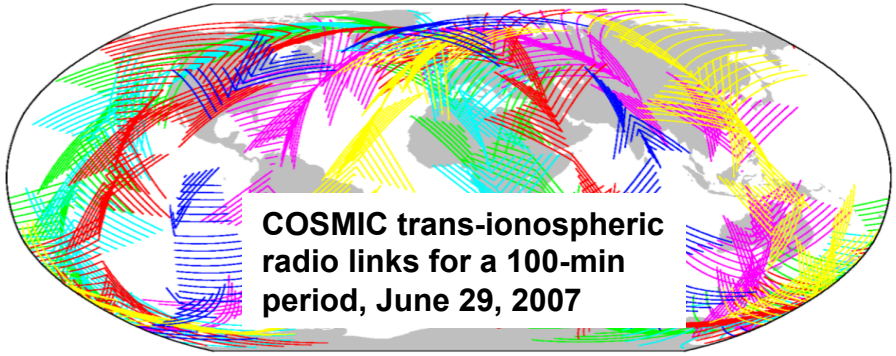


COSMIC Data Products

- **> 3M Absolute TEC data arcs:**
  - Absolute accuracy ~ 2-3 TECU, Relative accuracy ~ 0.0024 TECU at 1-Hz
- **> 2.8M Electron Density Profiles:**
  - NmF2/hmF2 Accuracy ~20%/20km (compared to Ionosondes)
- **Scintillation Indices (S4):**
  - ~2.8M available from occultation profile events (altitudes < 120 km)
  - 1 Hz data available from > 3M line of sight tracks to all GPS in view
- **TIP Night-side Radiances:**
  - TIP set new standard for sensitivity of UV instruments, ~500 counts/s/Rayleigh
  - > 17,800 hours of quality controlled data

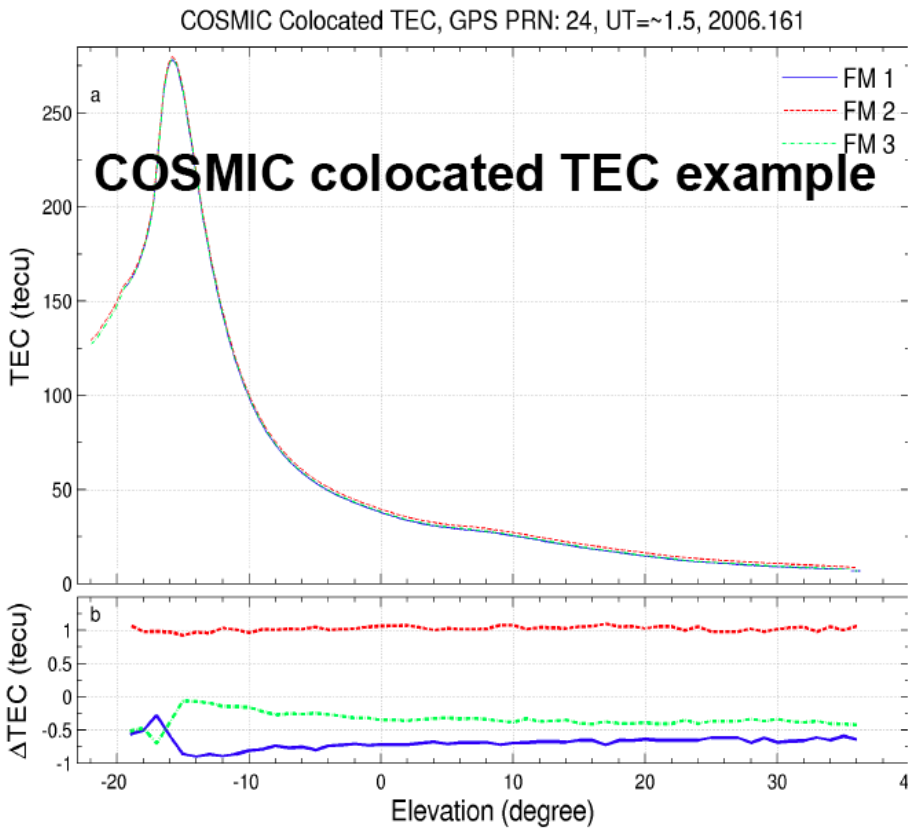
TEC Precision from Collocated Tracks

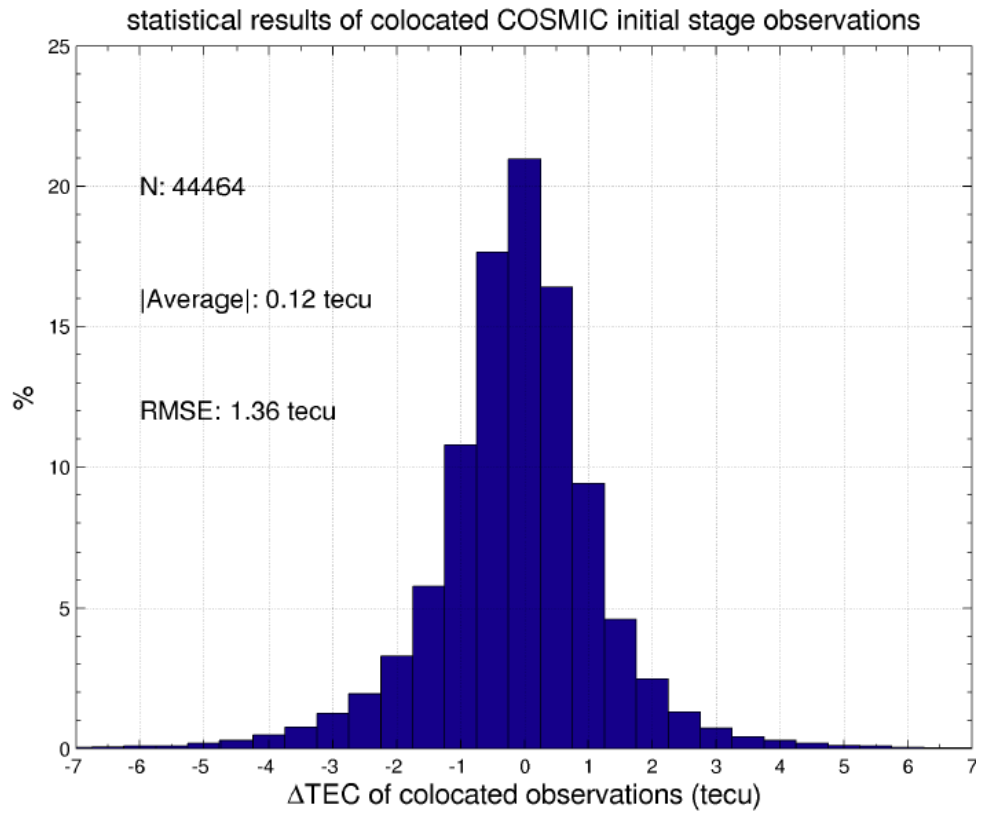
COSMIC (2006.230-245)



Statistical of difference between colocated TEC:

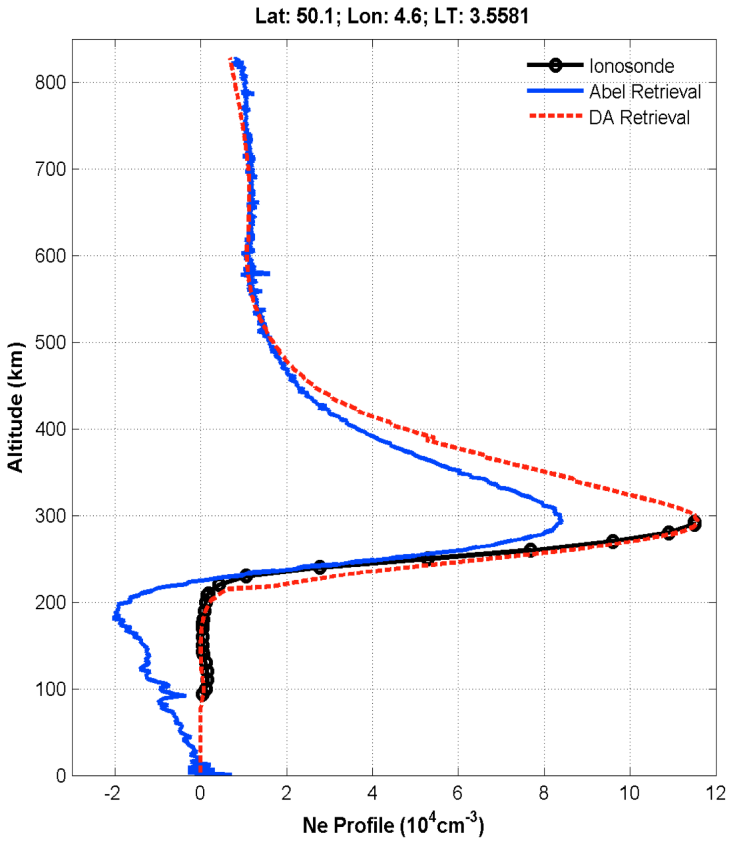
- ✓ **Mean difference: 0.12 tecu**
- ✓ **RMSE: 1.36 tecu**





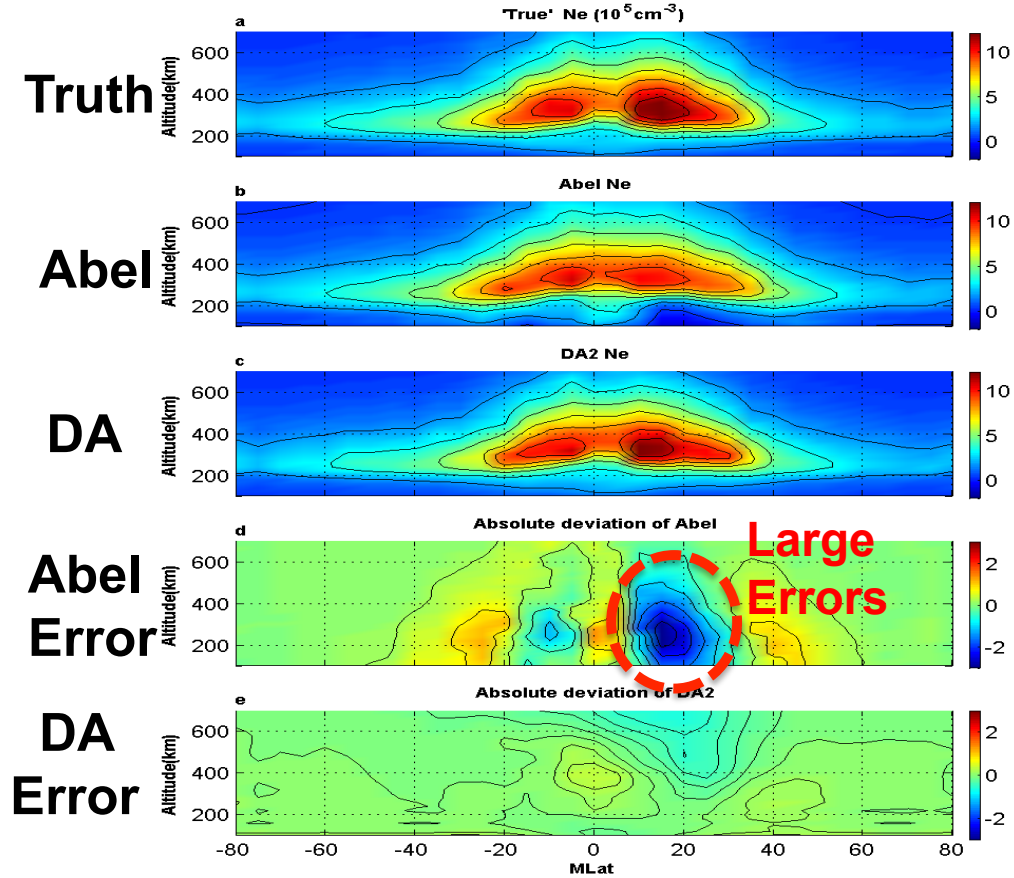
Data Assimilation Retrieval of Electron Density Profiles from Radio Occultation Measurements

Comparison of standard COSMIC Abel retrieval and data assimilation retrieval with Ionosonde data



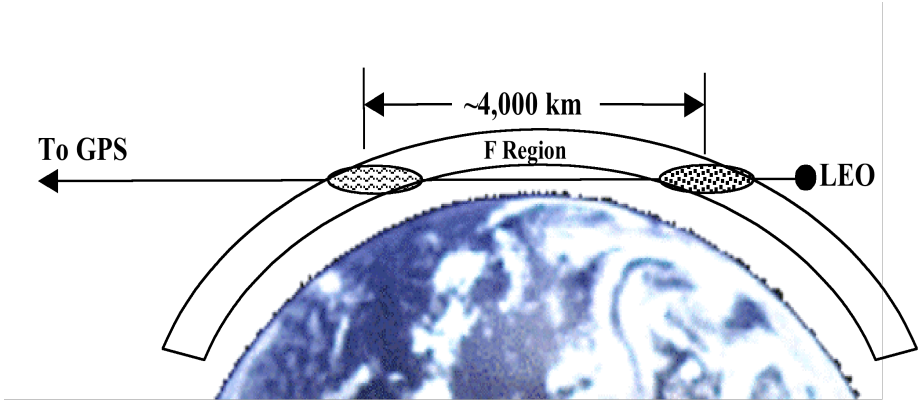
Yue, X., W. S. Schreiner, Y.-C. Lin, C. Rocken, Y.-H. Kuo, and B. Zhao, 2010: Data Assimilation Retrieval of Electron Density Profiles from Radio Occultation Measurements. *J. Geophys. Res., 116, A03317, doi:10.1029/2010JA015980*

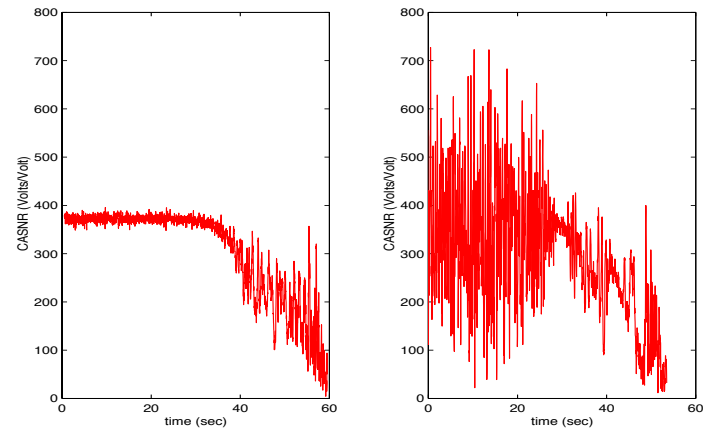
Simulation of retrieval errors for standard COSMIC Abel retrievals and data assimilation retrievals



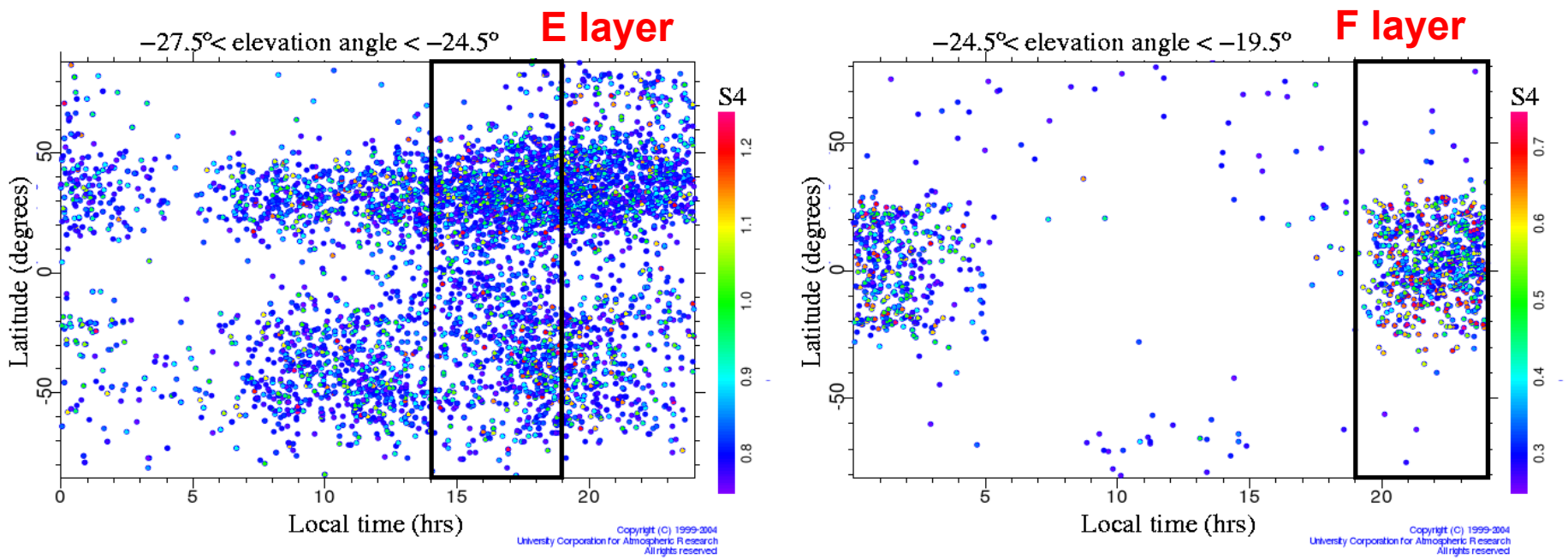
Geomagnetic latitude and altitude variations of electron density during noon time (LT=13)

GPS L-band Scintillation

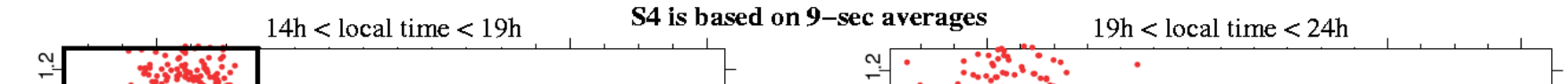




Where is the source region of the scintillation?
Localize irregularities: [see Sokolovskiy et al., 2002]

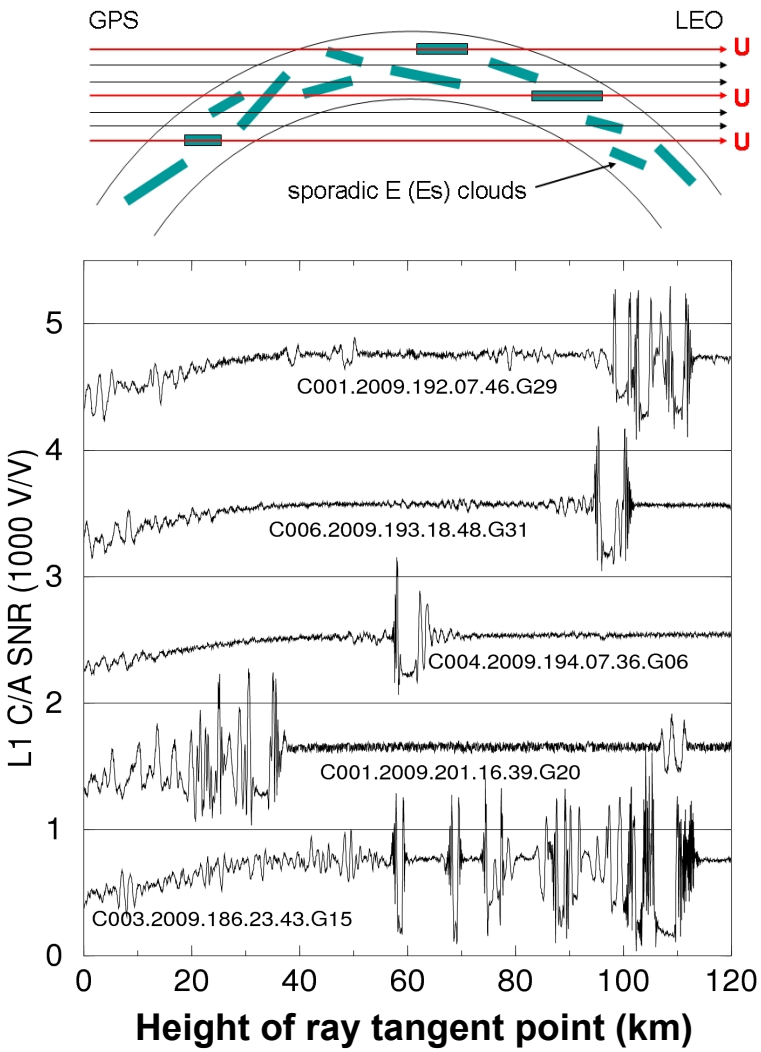


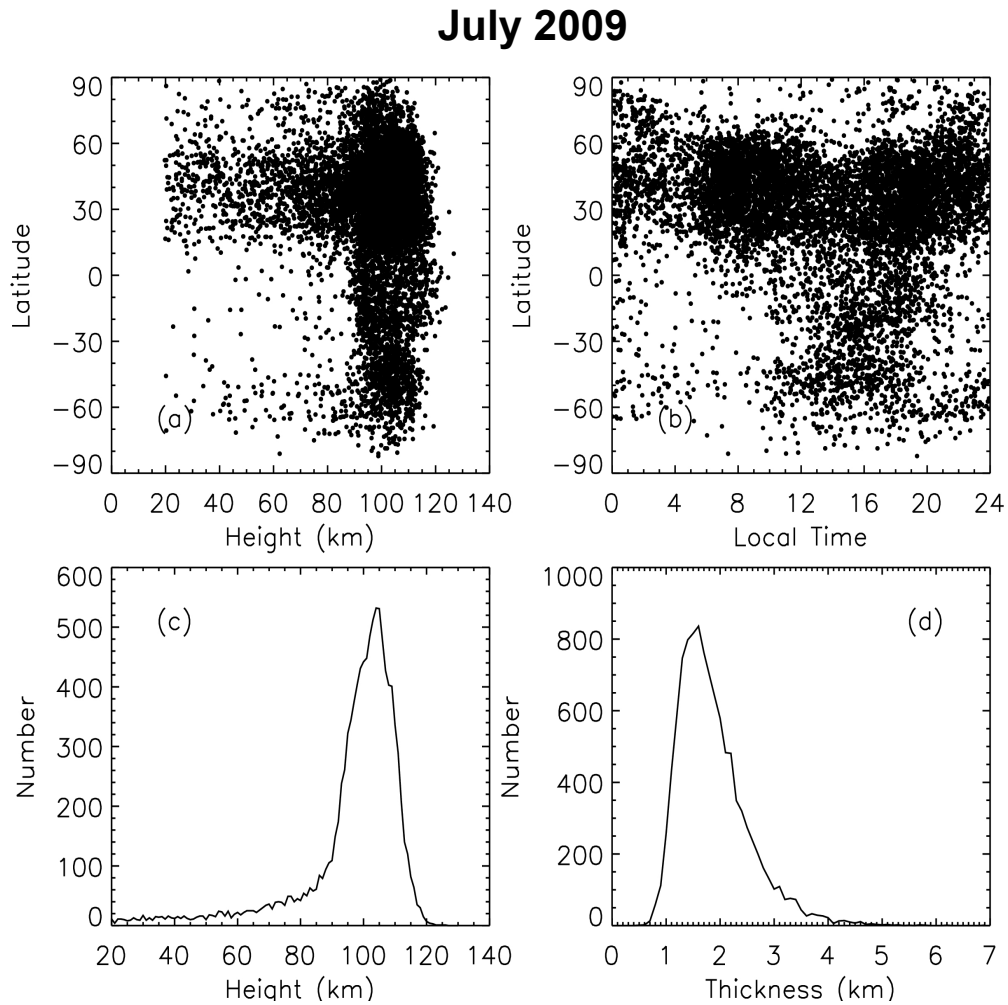
S4 is based on 9−sec averages



Study of the sporadic E (Es) layer by GPS RO (new approach)

When Es clouds are aligned with the propagation direction they result in specific **U-shaped** structures observed in the GPS RO signals. This allows to study morphology of the Es clouds.





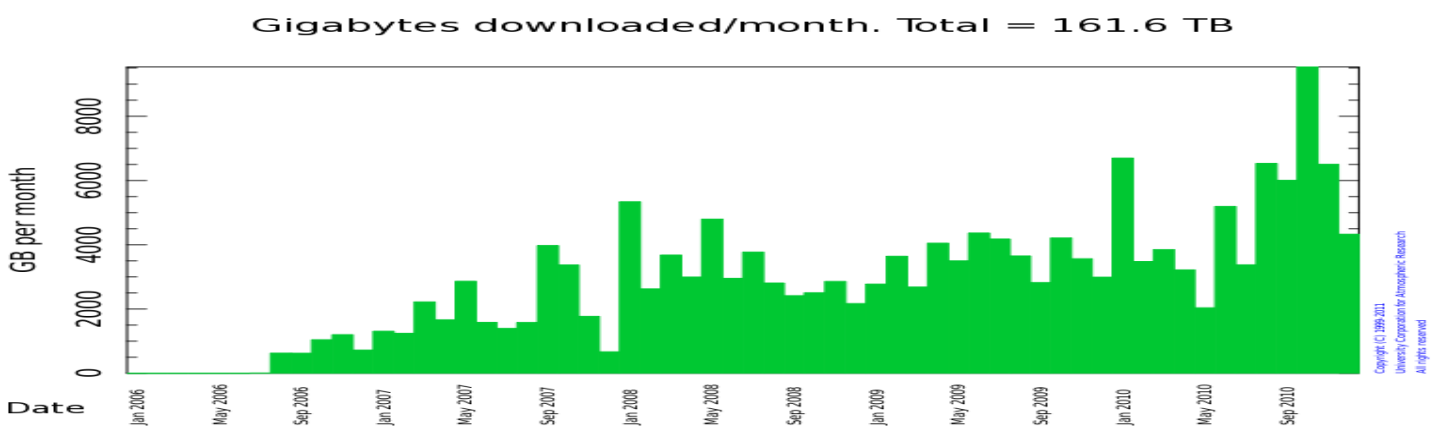
Z.Zeng and S.Sokolovskiy, GRL, 2010

CDAAC Processing Status

Mission	Mission Duration	Near Real-Time	Re-Processed Data	Re-Processed Product Version
GPSMET	1995 – 1997		1995.111 – 1997.047	2007.3200
GPSMET-AS	1995 – 1997		1995.111 – 1997.047	2007.3200
CHAMP	2001 – 2008		2001.139 – 2008.274	2009.2650
SAC-C	2001 – present	YES	Now Starting	2010.2640
GRACE	2002 – present		2007.059 – 2010.365	2009.2650-2010.2640
COSMIC	2006 – present	YES	2006.194 – 2010.365	2010.2640
Metop-A/GRAS	2006 – present	YES	2008.315 – 2010.365	2010.2640
C/NOFS	2008 – present	YES	Now Starting	2010.2640
TerraSAR-X	2008 – present		Now Starting	2010.2640

Ionospheric Products will be provided for all missions

Data Downloaded ~162 TB (1/3 from univ. community)



Boulder, CO

CDAAC Near Term Plans
for Ionospheric Products

- Process absolute TEC and EDPs for all CDAAC missions
- Further test/validate DA retrieval method with climatology/GIMs
- Process and disseminate DA EDP retrievals
- Scintillation (provide 10-sec average S4)
- Continue Data Processing and Validation Efforts
- Support Upcoming Missions of Opportunity (KOMPSAT-5, PAZ, ..)

COSMIC-2 Mission Overview

- NOAA Operational RO Follow-On mission funded in President's FY2011 budget
- NASA has funded JPL to develop advanced GNSS RO payload (TriG)
- Preliminary design calls for 12 low Earth orbiting satellites, with TriG tracking GPS, GALILEO and possibly GLONASS
  - First Launch 6 in low inclination (24 deg) at 520km – carries Space Weather Payloads
  - Second Launch 6 in high inclination (72 deg) at 800km
- Will produce > 8,000 RO soundings per day, up to 24 TEC tracks
- Space Weather payloads
  - VIDI (Velocity, Ion Density and Irregularities) Instrument
  - RF Beacon
- 45-min (TBR) Average Data Latency
- Expected first launch in mid-2015, second in mid-2017

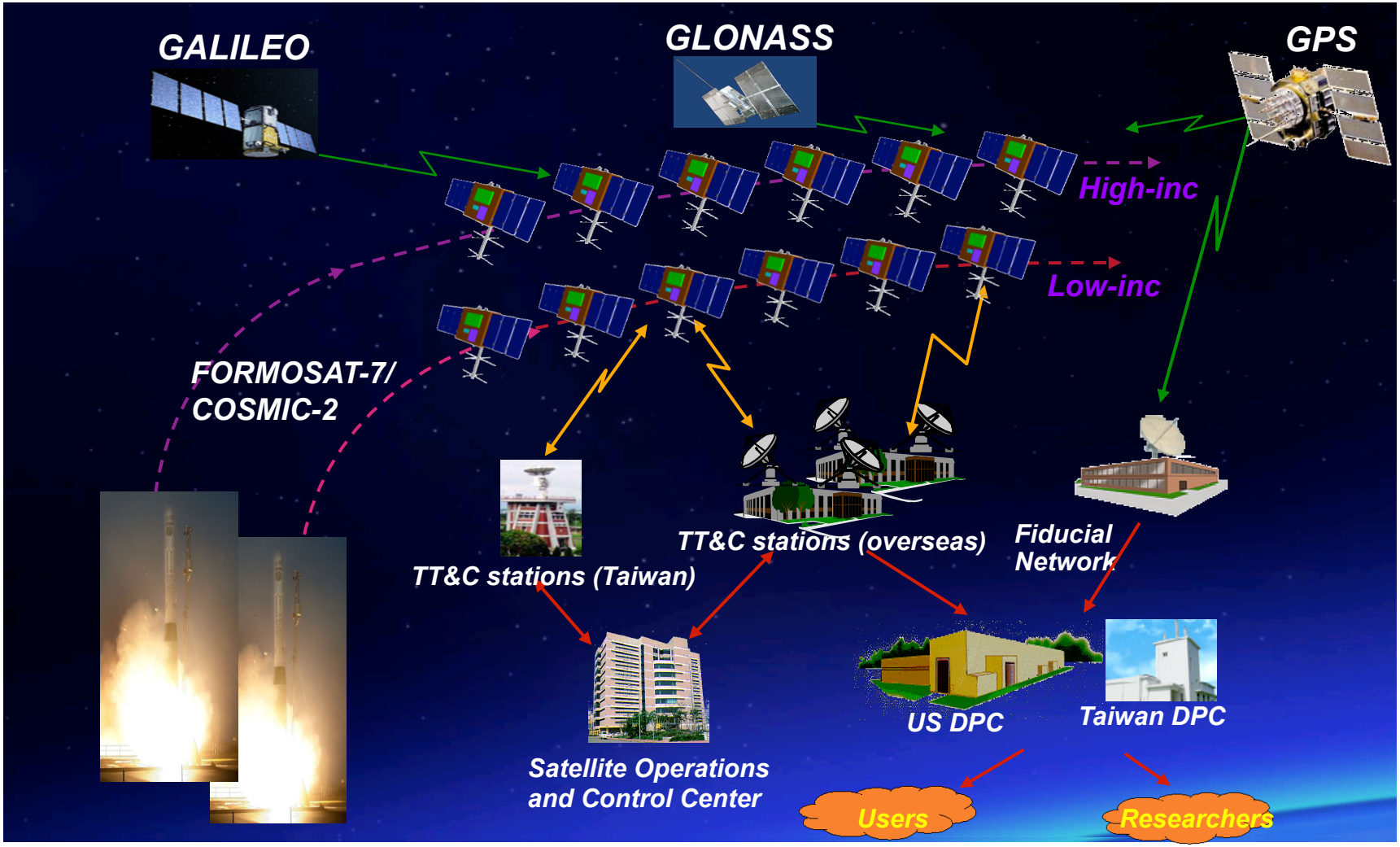
COSMIC-2 Mission Overview

Partnership:

- NASA providing: Non Recurring Engineering (NRE) for new sensor design
- Taiwan to provide: 12 spacecraft and integration of payloads onto spacecraft, mission operations center, command & control station, and limited data recovery
- Air Force to provide: Launch Services for all 12 spacecraft and provide 12 AF payloads (2 per spacecraft) for 24 degree launch orbit
- NOAA to provide: 12 sensors, data recovery stations, command and control stations, payload data processing, and archival.

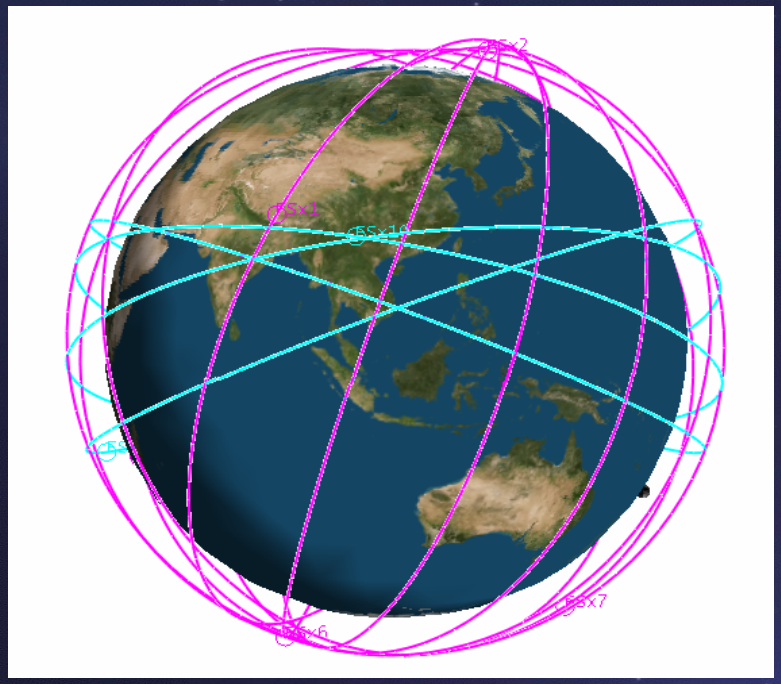
FORMOSAT-7/COSMIC-2 GNSS RO

Notional Architecture [USA-Taiwan]



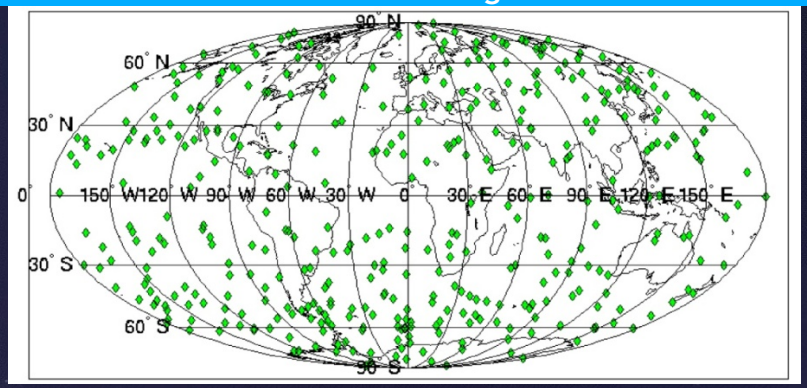
Data Flow Architecture and format for ionospheric products being designed

FORMOSAT-3/COSMIC vs FORMOSAT-7/COSMIC-2
3 hrs Coverage

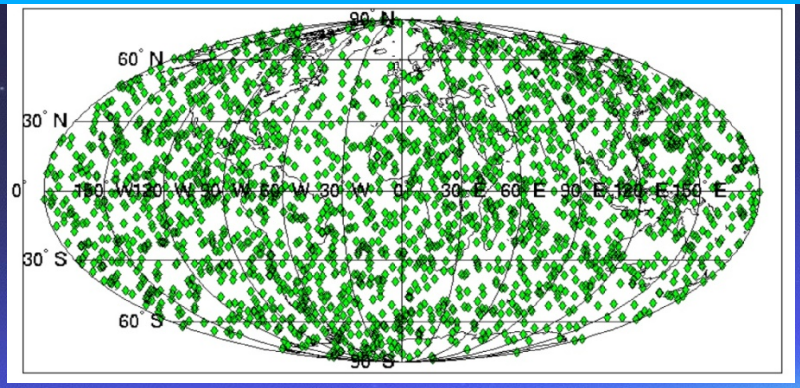


12 Satellites - 2 inclinations
Data are distributed more homogeneously

COSMIC Occultations-3 Hrs Coverage



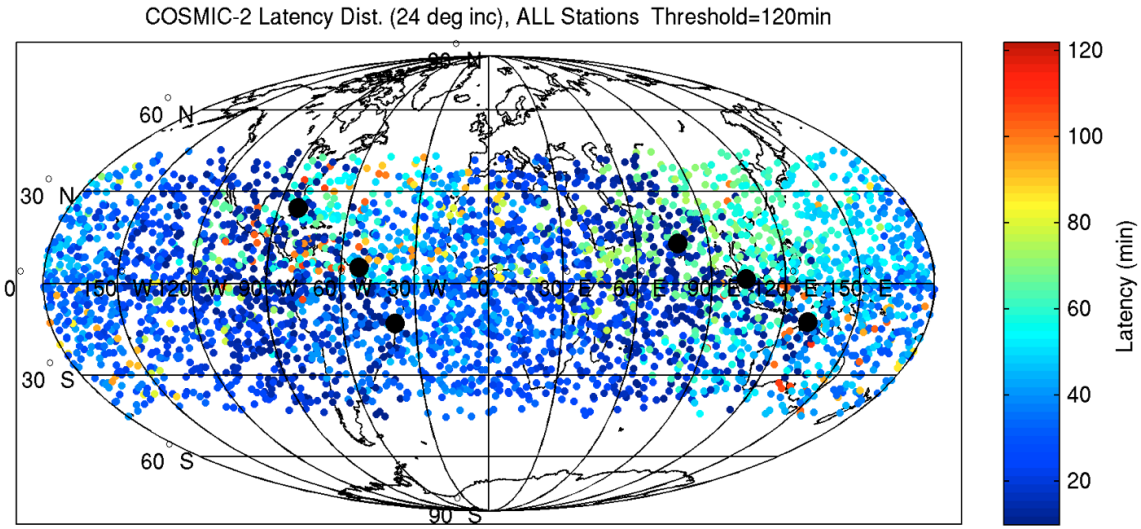
COSMIC-2 Occultations - 3 Hrs Coverage



Pre-Decisional - Not for Public Release

Data Latency Requirement

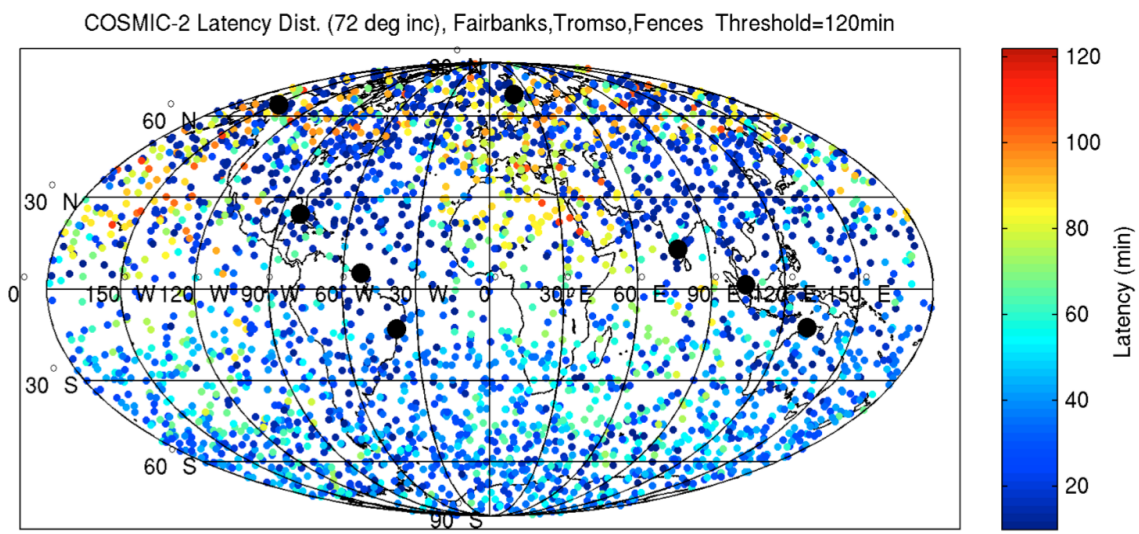
Latency: 24 Deg Orbit



Average Data Latency

LEO Inc. (deg)	RTS Network	Elev 10° (min)	Elev 5° (min)
72	Fairbanks, Tromso, 2 Fences	46	40
24	2 Fences	35	33
Total		41	37

Latency: 72 Deg Orbit



2 Low Latitude Fences:
Darwin, Singapore, Bangalore, KeyWest, Kourou, Salvador

Summary

- COSMIC Space Weather Data Products
  - > 3 Million Absolute TEC data arcs
  - > 2.8 Million EDPs
  - Large amount of scintillation data
  - ~90% available within 3 hrs
  - Having positive impact on ionosphere and space weather studies
  - TEC/EDP data available for other missions
- NOAA moving ahead with COSMIC-2 planning
- NOAA collaboration with Taiwan, 12 satellites launched ~ 2015/2017
- ~ 8,000 RO's per day with near uniform geographic and LT sampling
- Data Latency should meet 45-min (TBR) requirement

Acknowledgments

- NSF
- Taiwan's NSPO
- NASA/JPL, NOAA, USAF, ONR, NRL
- Broad Reach Engineering

UCAR NSF NASA USAF NOAA NSPO ONR