COSMIC GPS Radio Occultation Observations: Algorithm Improvements and Science Applications

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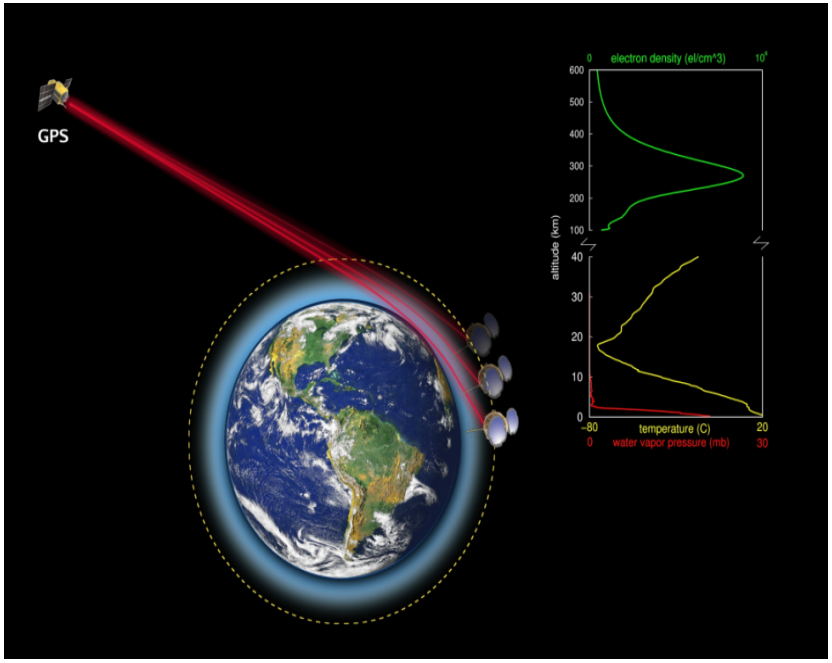
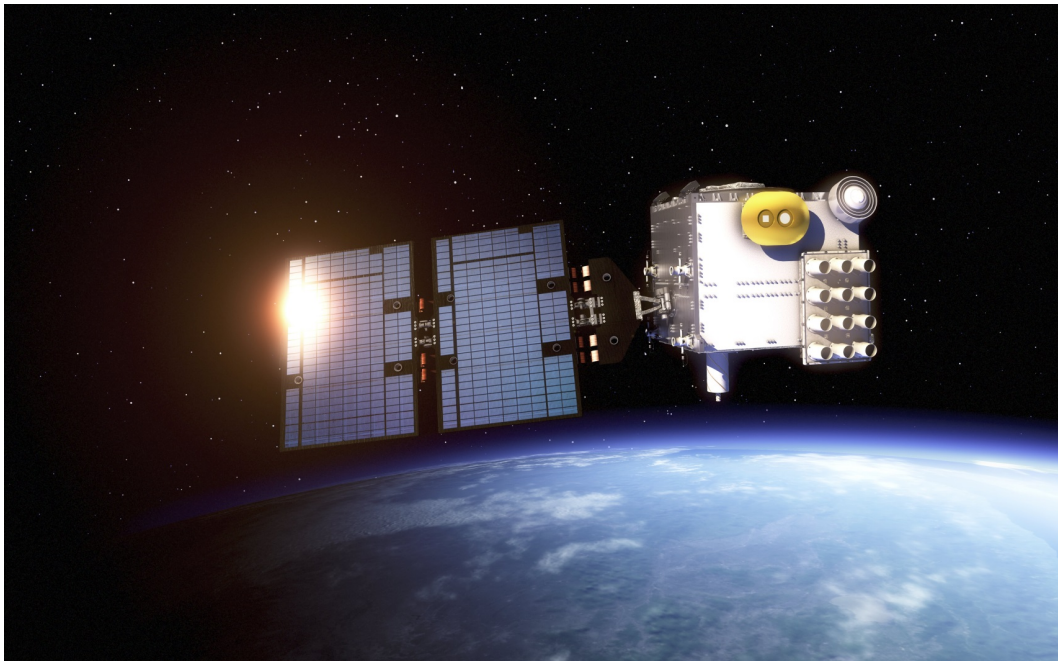
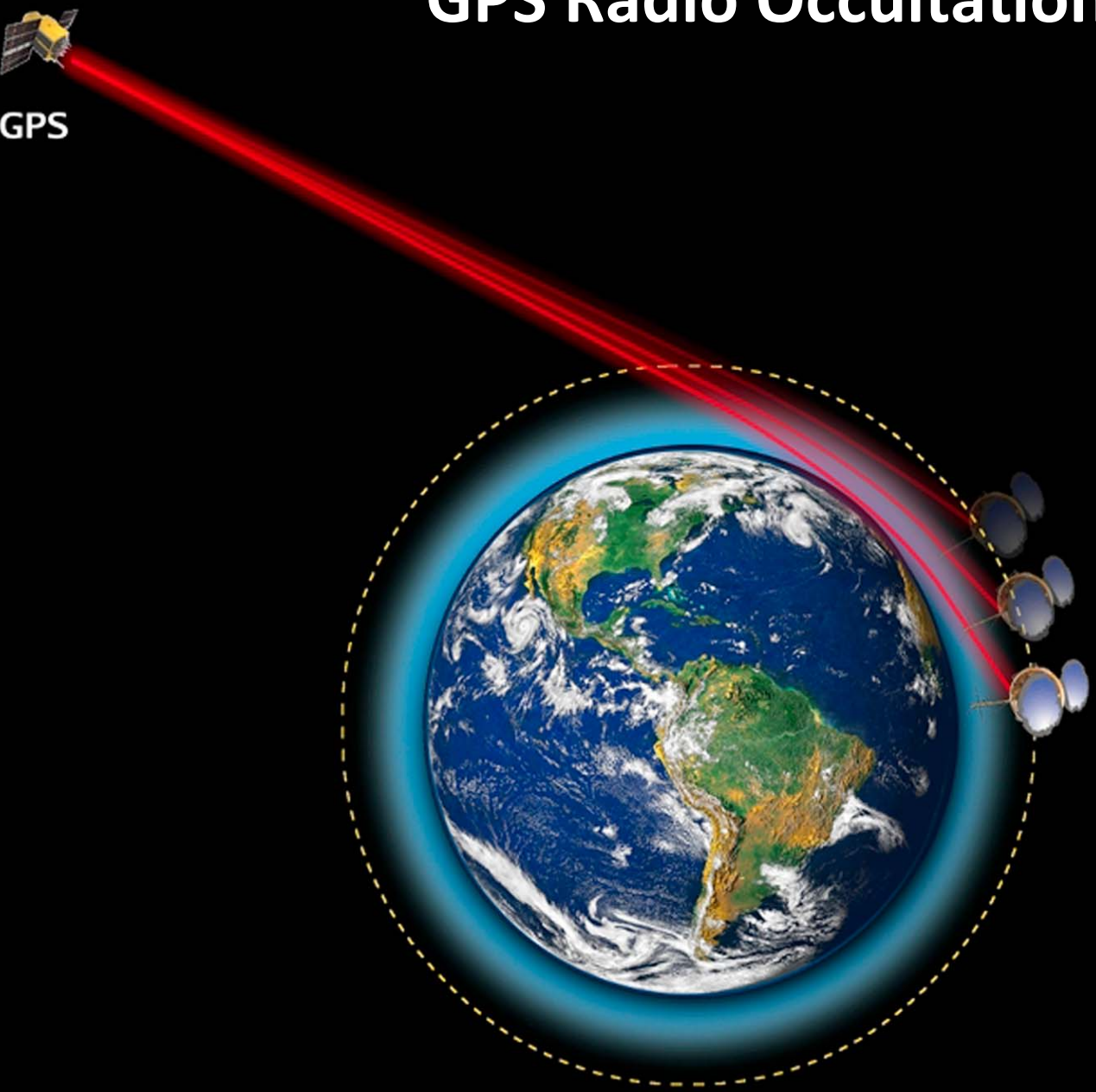


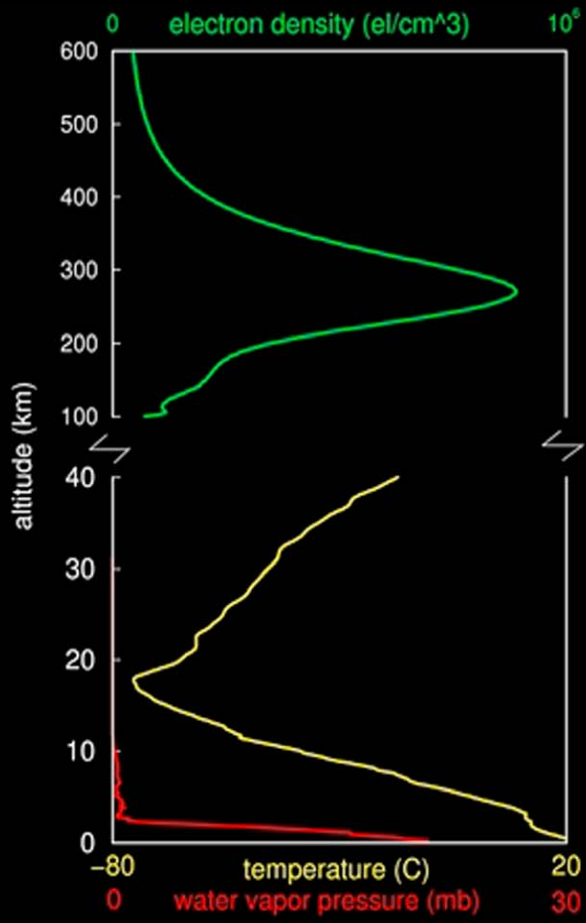


Outline

- COSMIC-1 Update
- Ionosphere data processing
  - Improved Abel Inversion
  - Monthly Mean Reanalysis
- COSMIC-2 Overview & Status

FORMOSAT-3/COSMIC
GPS Radio Occultation

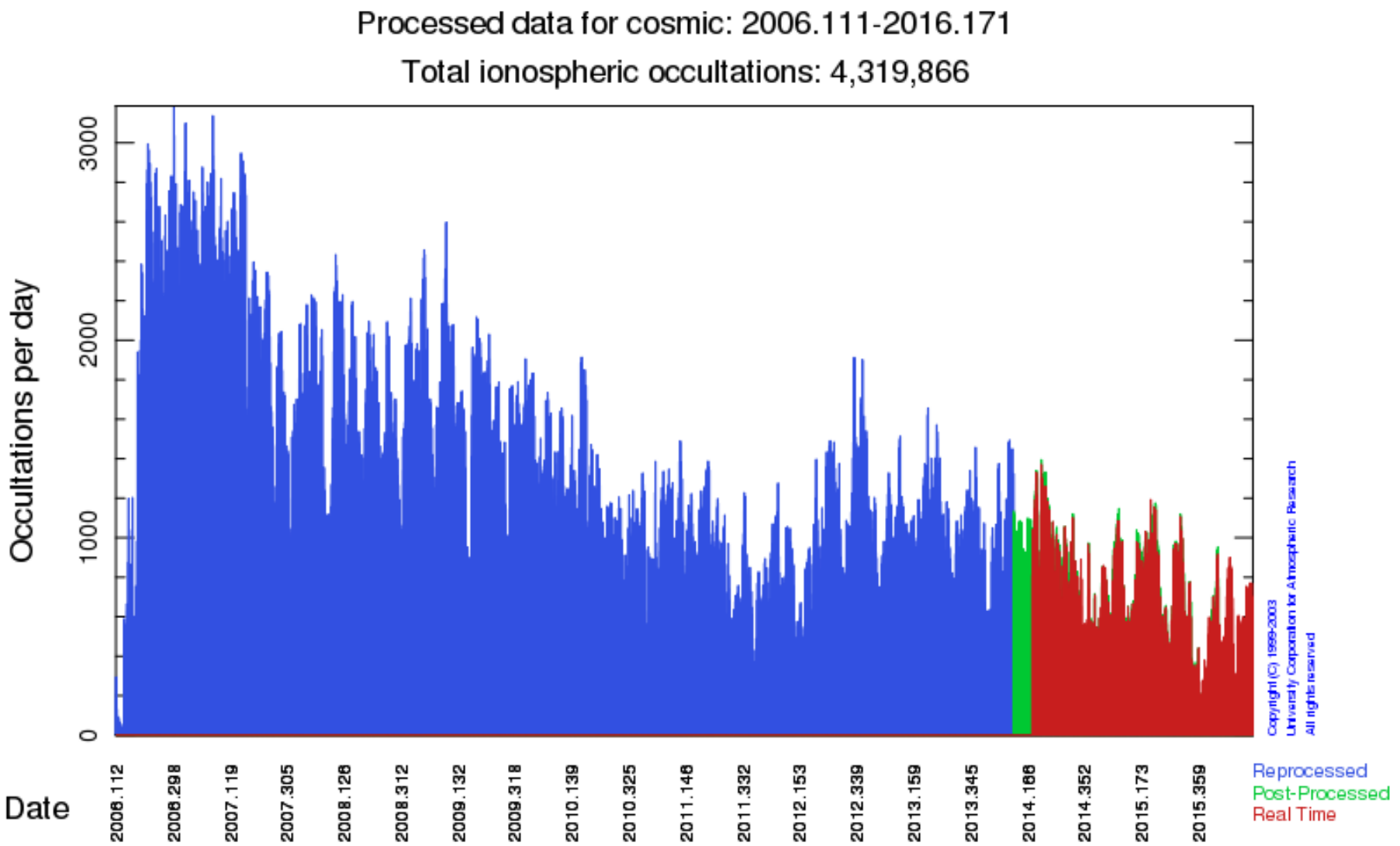




FORMOSAT-3/COSMIC

- COSMIC celebrated its 10th anniversary in April 2016.
- Still providing useful atmosphere and ionosphere data well beyond the 5 year design life.

> 4.3 Million COSMIC Profiles



Current Status

2016.174:

FM 1: 392 atm / 273 ion
FM 2: 141 atm / 230 ion
FM 6: 147 atm / 164 ion

Total:
680 atm / 667 ion

2016.175:

FM 1: 314 atm / 240 ion
FM 2: 203 atm / 194 ion
FM 6: 133 atm / 154 ion

Total:
650 atm / 588 ion

2016.176:

FM 1: 345 atm / 251 ion
FM 2: 177 atm / 171 ion
FM 6: 99 atm / 119 ion

Total:
621 atm / 541 ion

2016.177:

FM 1: 289 atm / 216 ion
FM 2: 211 atm / 205 ion
FM 6: 188 atm / 238 ion

Total:
688 atm / 659 ion

COSMIC still providing ~500-800 occultations per day

Three (FM #1, #2, and #6) of six currently operating ~10 years after launch

- FM#3 inoperable since August 2010
- FM#4 inoperable since July 2015 due to battery degradation
- FM#5 lost contact in April 2016. Expected to return

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Improved Abel Inversion

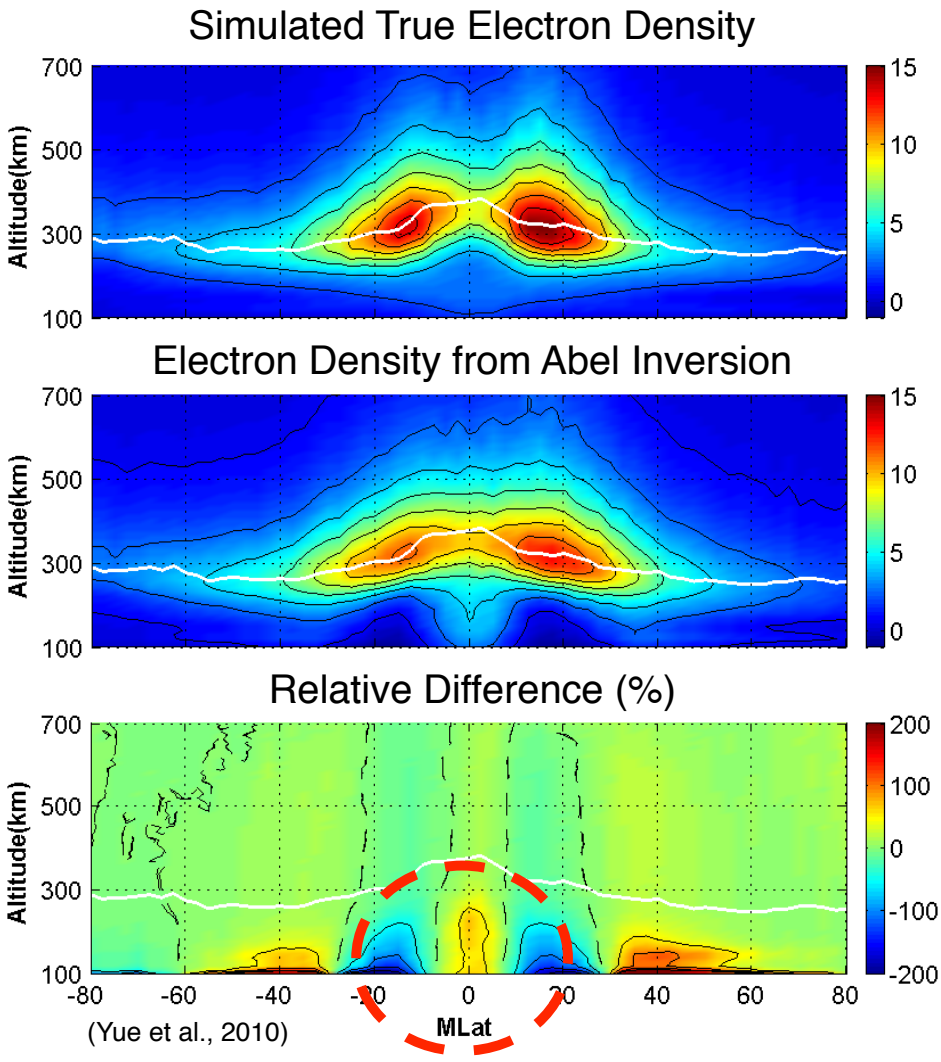
- Abel inversion spherical symmetry assumption introduces large errors in the equatorial E-region

- We have developed a new inversion that uses monthly mean maps of NmF2 to obtain information on the horizontal gradients

- New inversion reduces error in the E-region and results in more distinct equatorial ionization anomalies

- Electron density profiles obtained using the new inversion are available via CDAAC

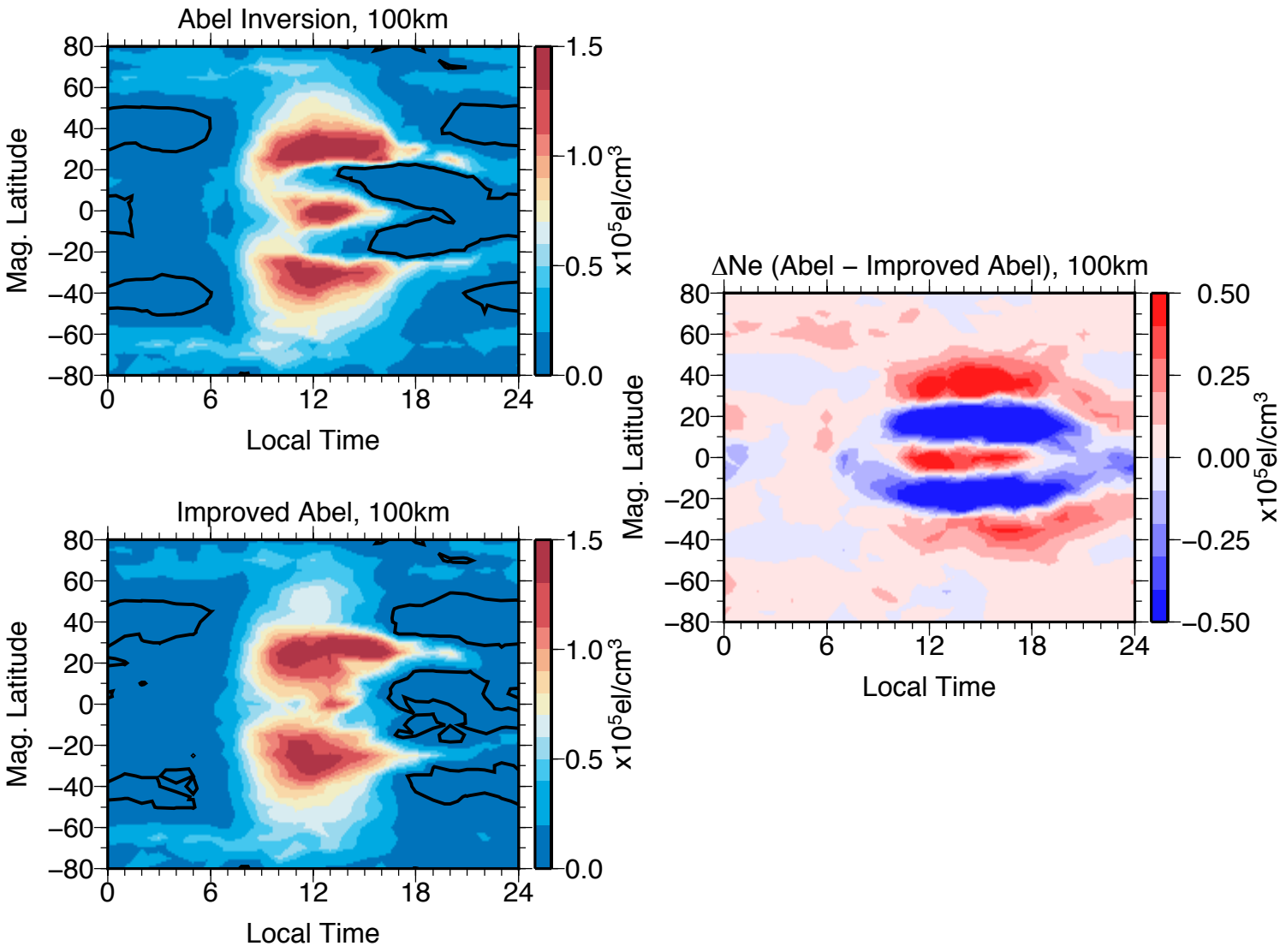
  data type: **igaPrf**



Pedatella, N. M., X. Yue, and W. S. Schreiner (2015), An improved inversion for FORMOSAT-3/COSMIC ionosphere electron density profiles, *J. Geophys. Res.*, *120*, doi:10.1002/2015JA021704.

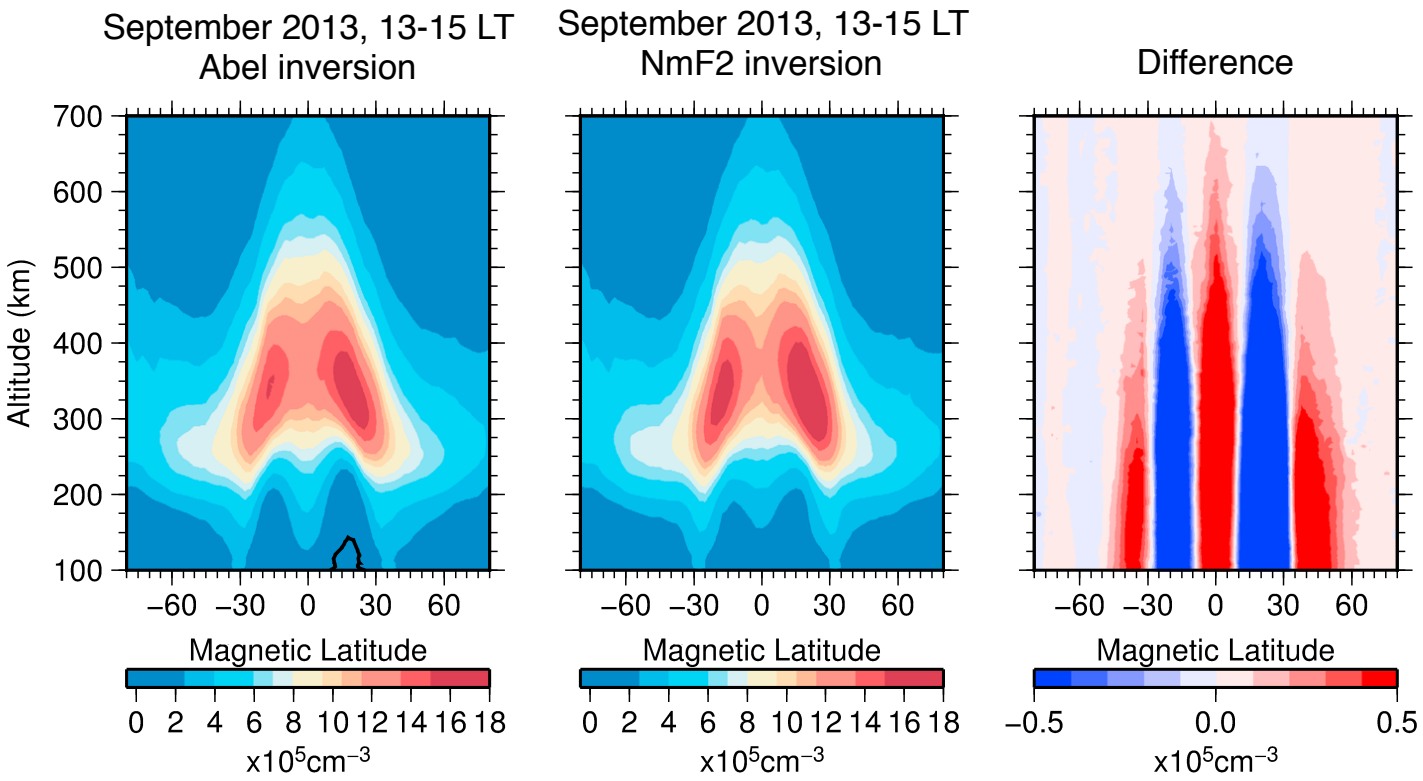
Improved Abel Inversion

March 2009, Zonal Mean

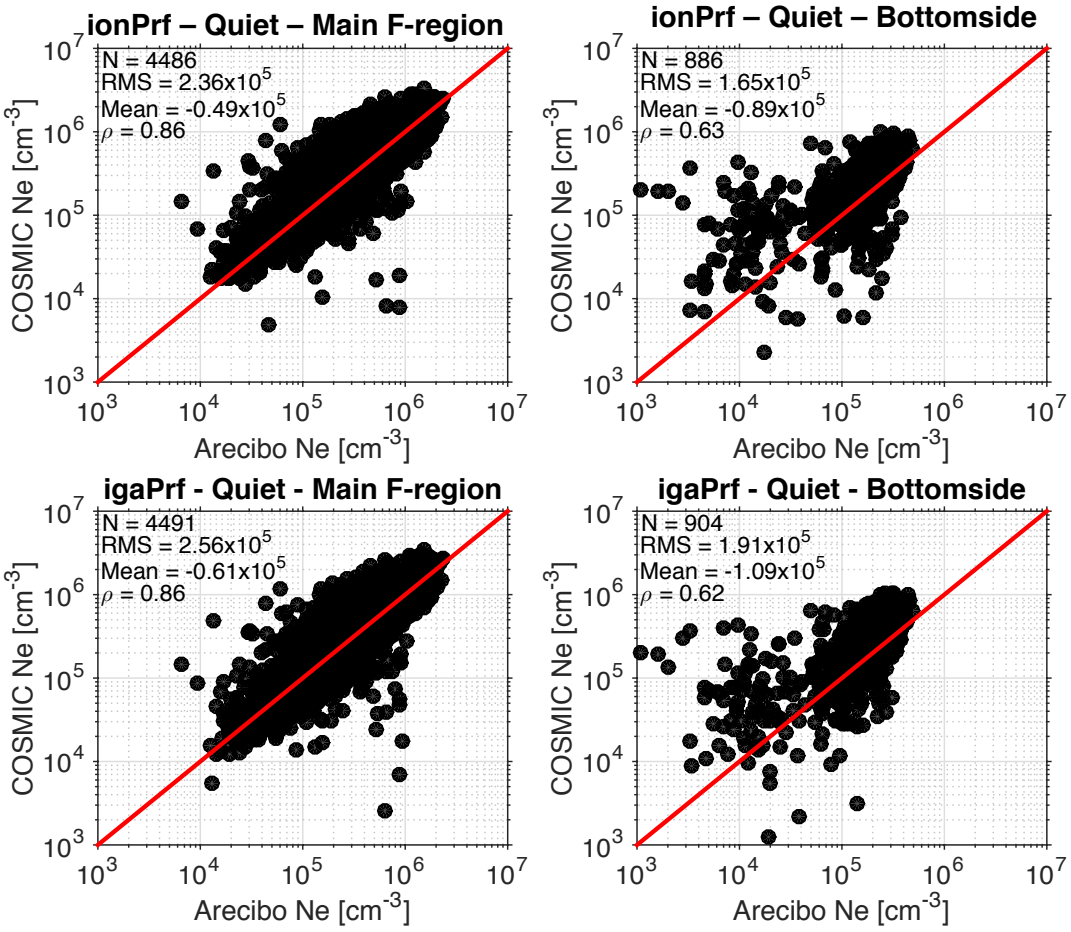


Improved Abel Inversion

September 2013, Zonal Mean



Improved Abel Inversion



- Comparison of COSMIC electron density profiles with collocated Arecibo ISR observations
- Tangent point within ± 5° latitude, ± 10° longitude, and ± 10 minutes
- Similar statistics obtained for both Abel inversion (ionPrf) and improved inversion (igaPrf)

(Courtesy of F. Rodrigues, UTD)

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Ionosphere Reanalysis

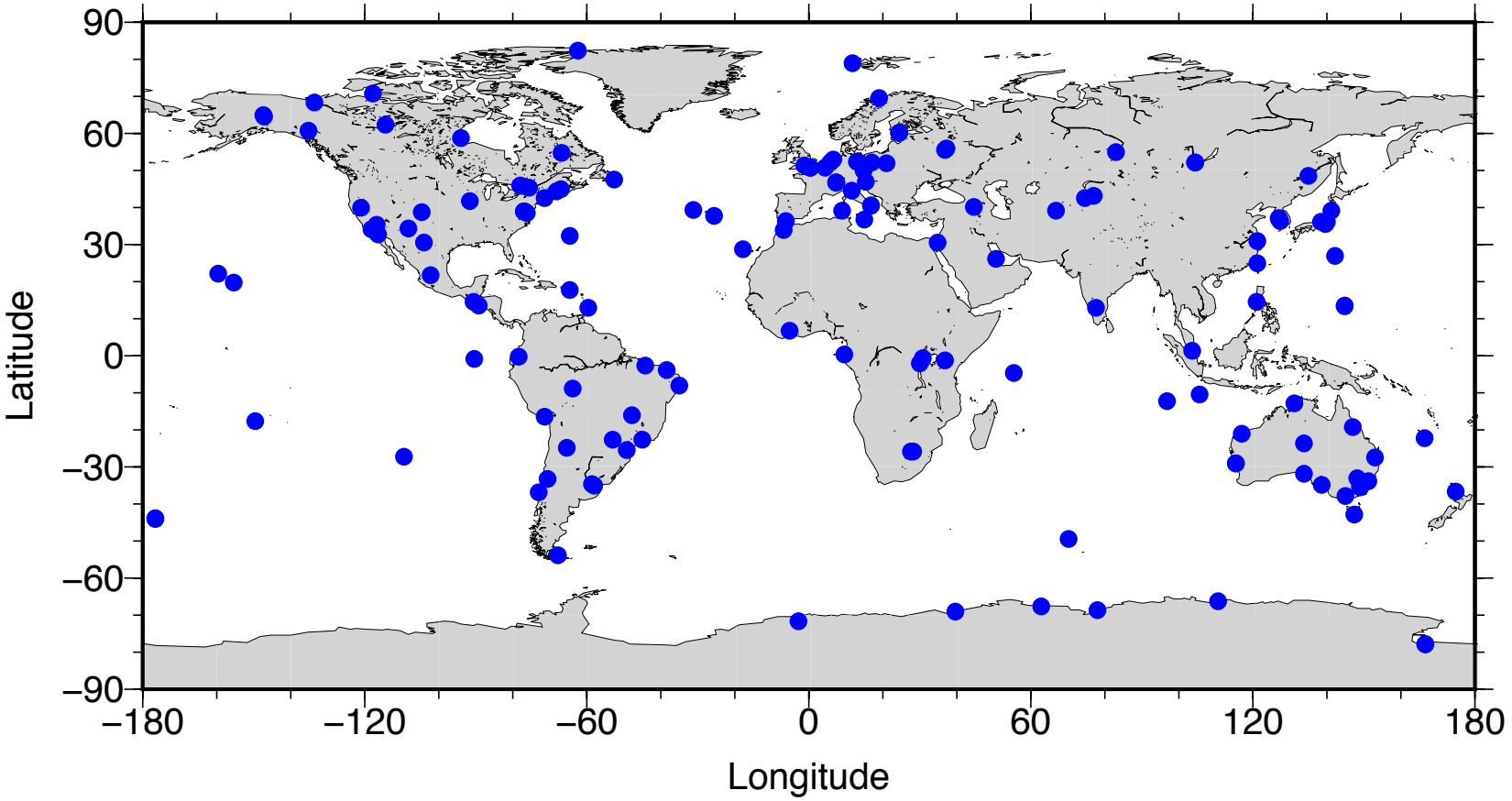
- CDAAC has developed an ionosphere reanalysis product
- Method based on *Yue et al*. [2012], and uses a Kalman filter to assimilate ground and space based GNSS TEC
- IRI is used as the background model
- Grid dimensions are 1 h UT, 10-20 km altitude, 5° latitude, and 15° longitude
- Result is a 4-dimensional monthly mean electron density reanalysis based on the 14 quietest days of the month.
- Monthly mean gridded electron densities will be available to the community via CDAAC (http://cdaac-www.cosmic.ucar.edu/cdaac/) within the next several months.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, A09325, doi:10.1029/2012JA017968, 2012

Global 3-D ionospheric electron density reanalysis based on multisource data assimilation

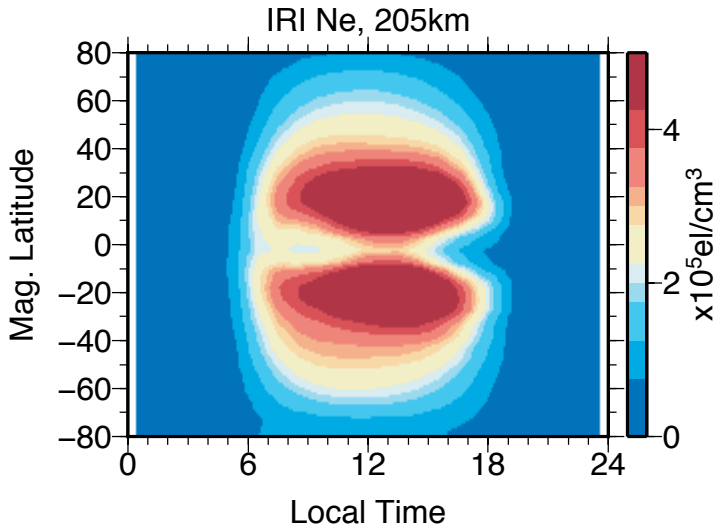
Xinan Yue,[1] William S. Schreiner,[1] Ying-Hwa Kuo,[1] Douglas C. Hunt,[1] Wenbin Wang,[2] Stanley C. Solomon,[2] Alan G. Burns,[2] Dieter Bilitza,[3] Jann-Yenq Liu,[4] Weixing Wan,[5] and Jens Wickert[6]

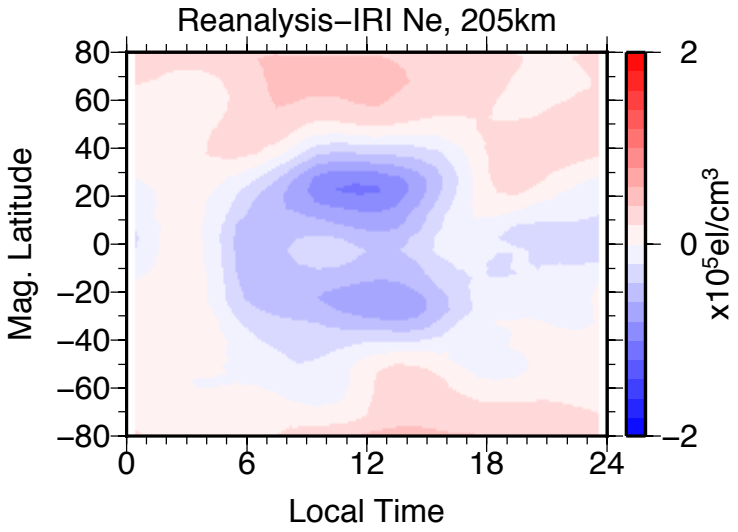
Reanalysis Ground Stations

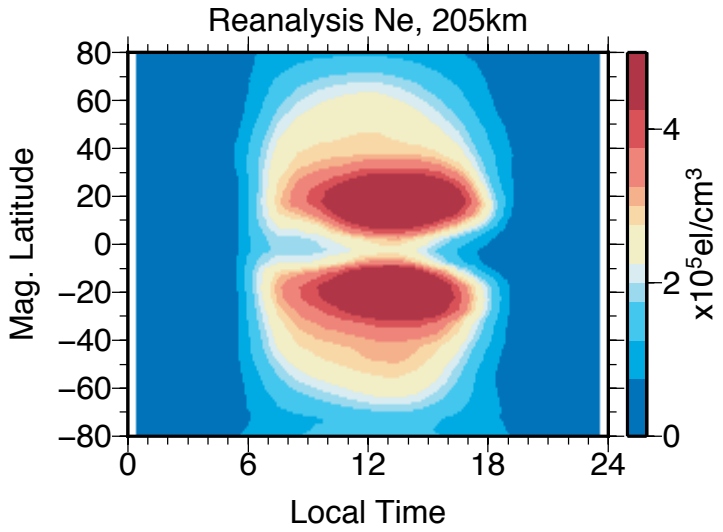


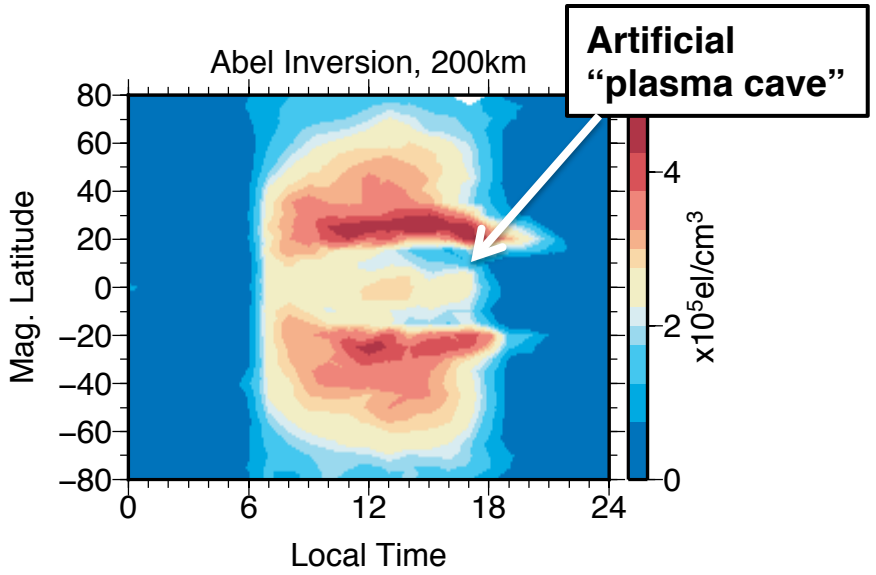
Reanalysis Results

March 2009, Zonal Mean









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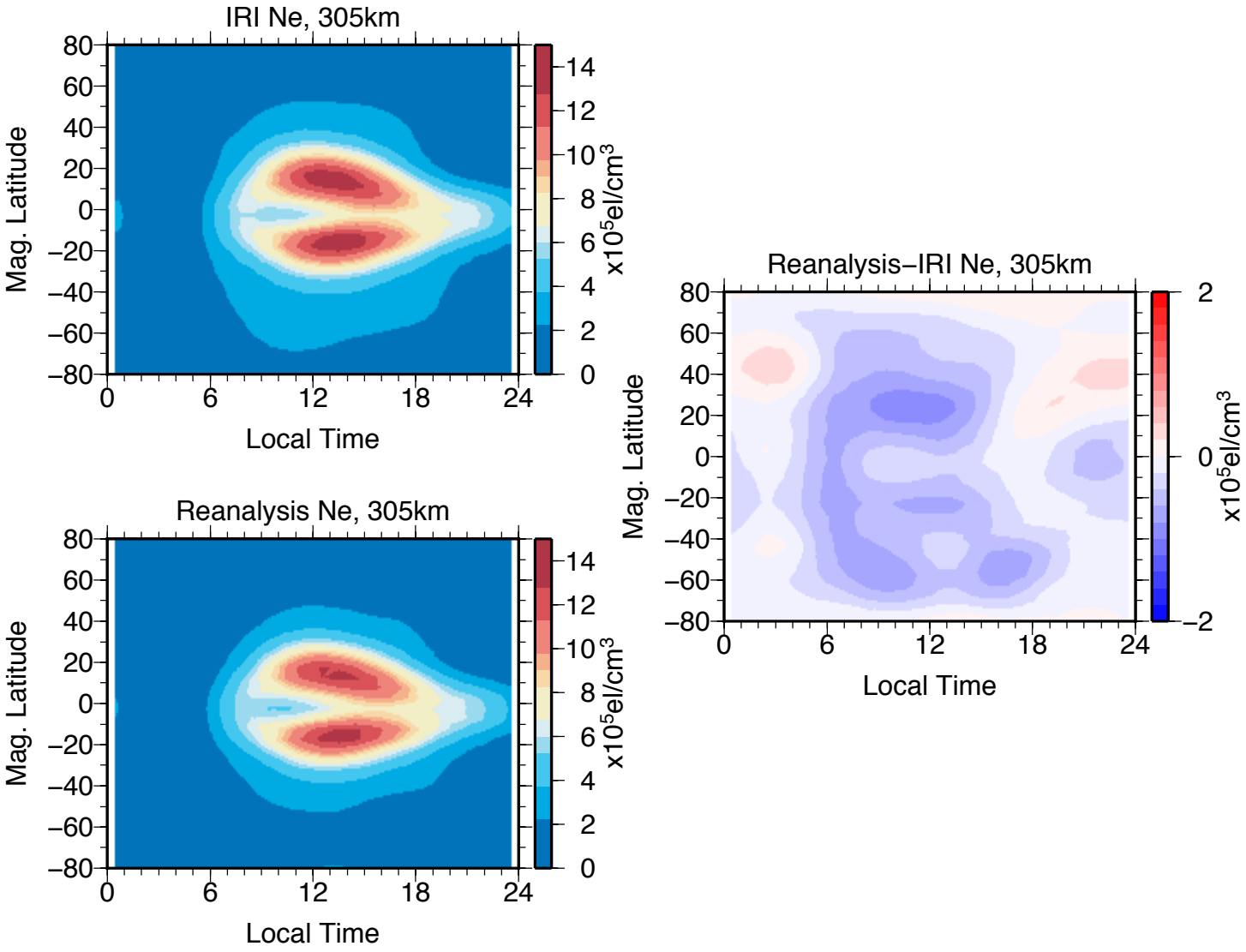

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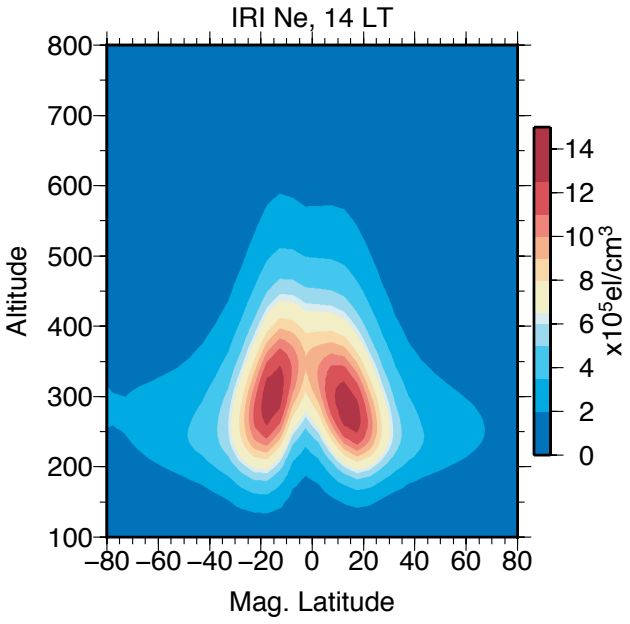
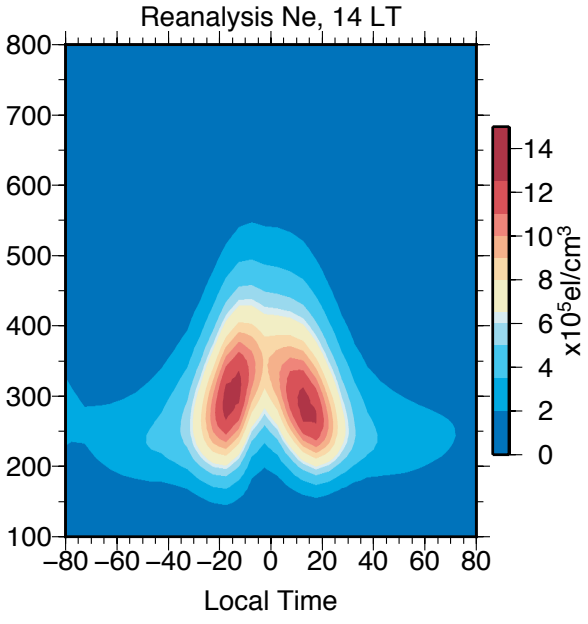
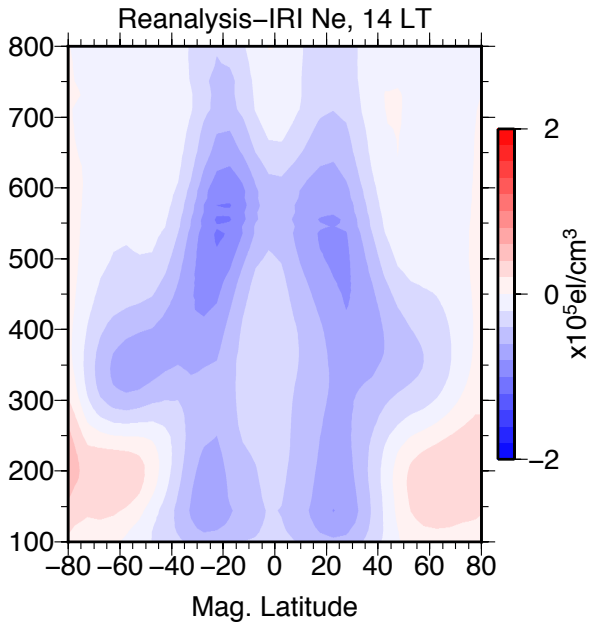
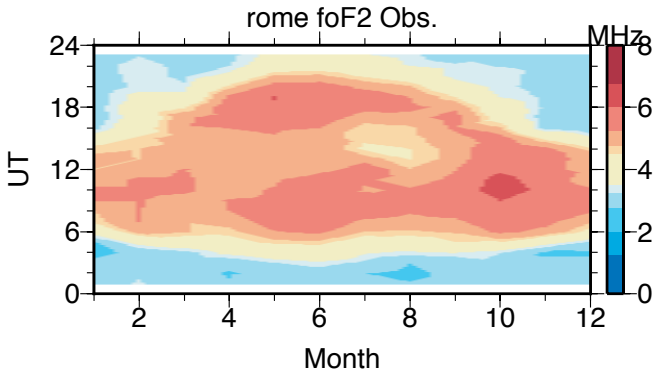
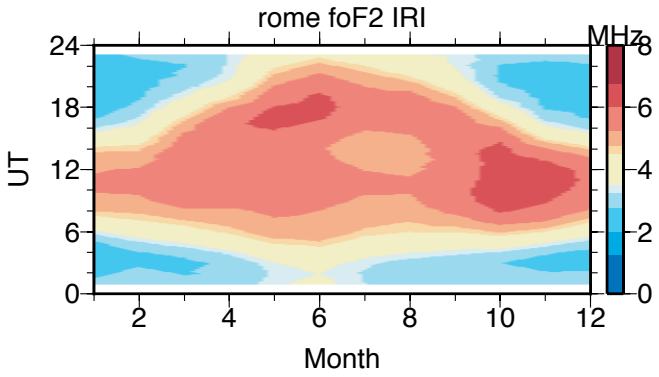


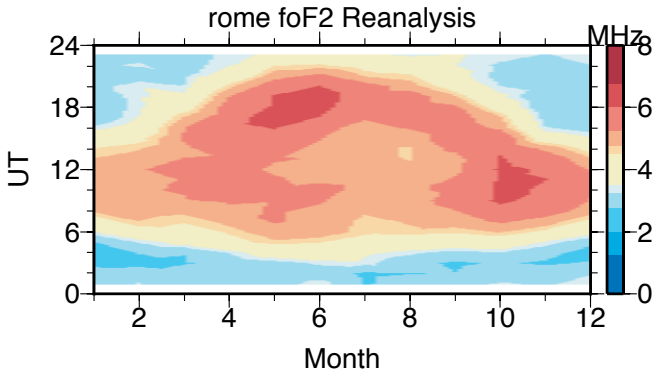


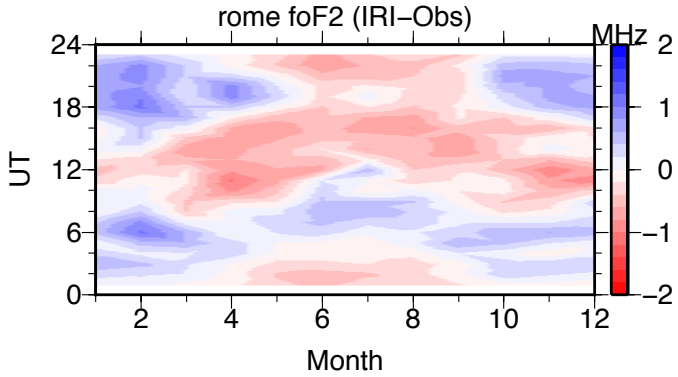


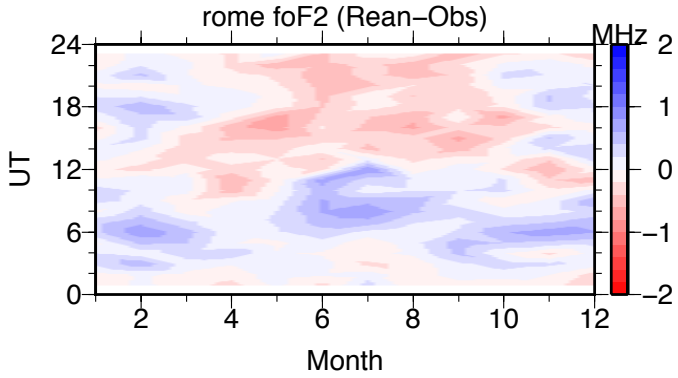
Comparison with Ionosonde Observations











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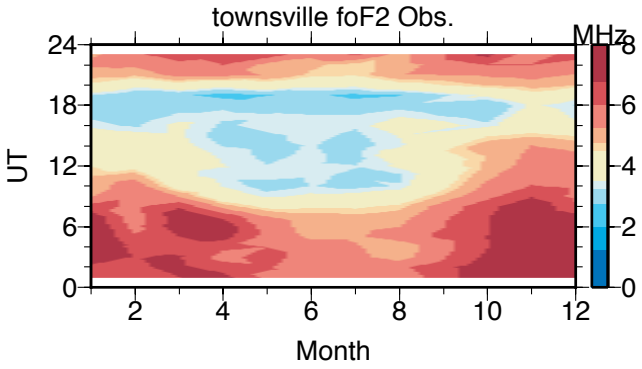
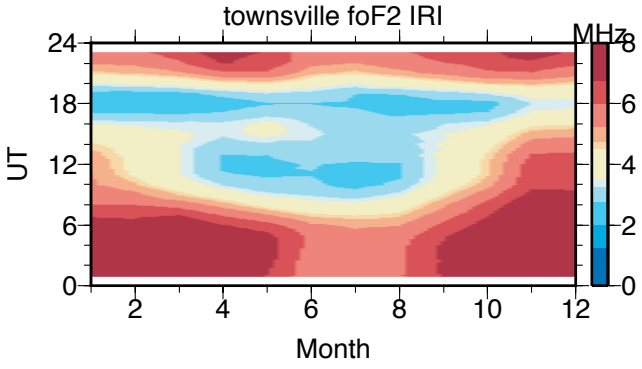
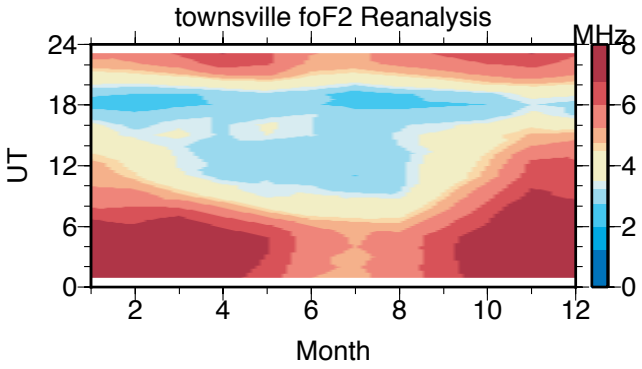
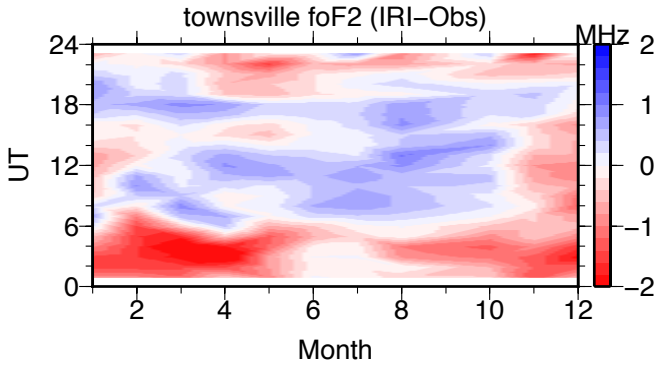
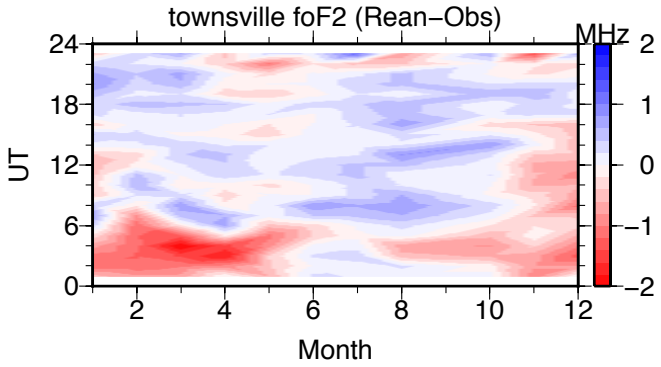




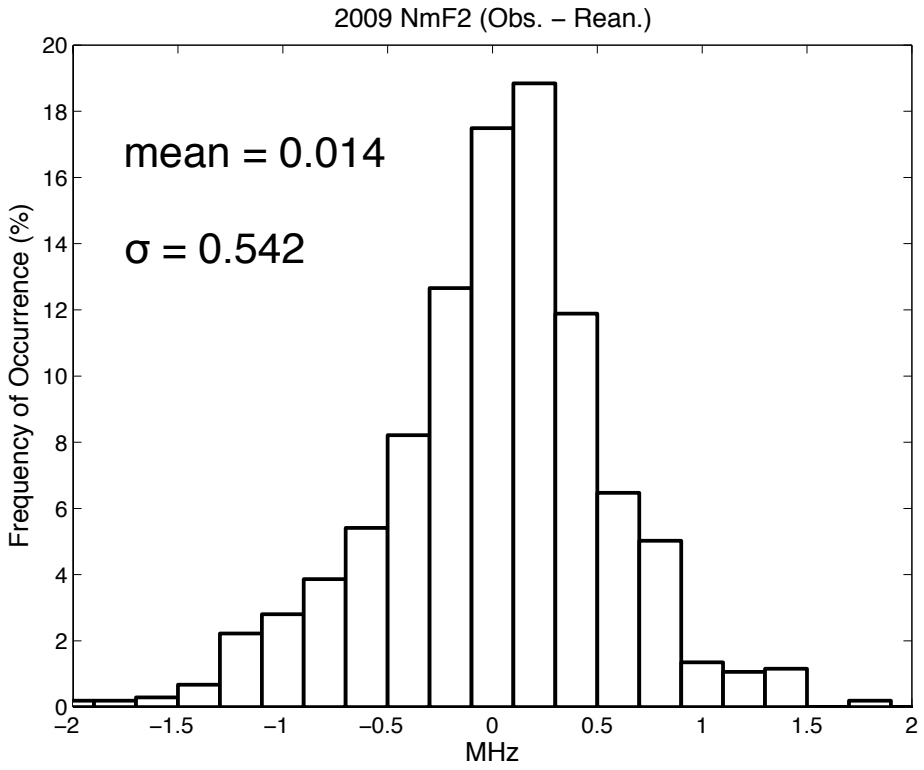


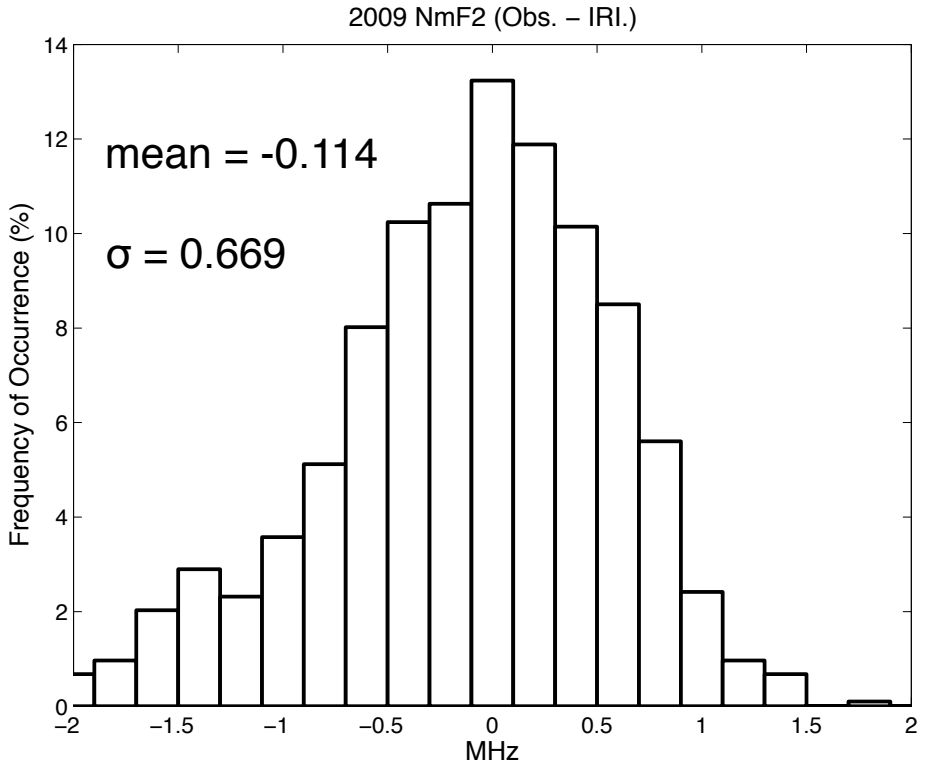




Comparison with Ionosonde Observations

Jan-Dec 2009
Jicamarca, Millstone Hill, Rome, Townsville





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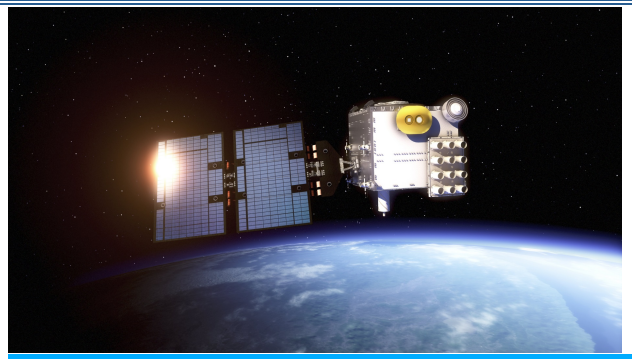
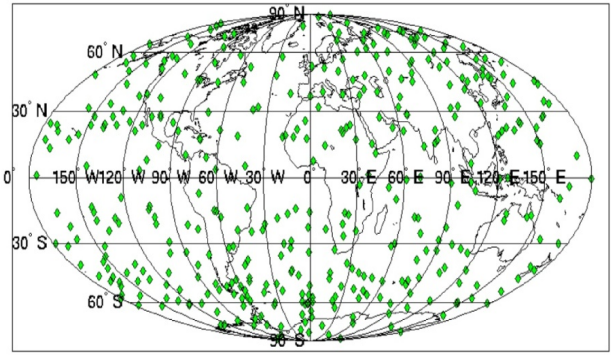
COSMIC-2 Mission Overview

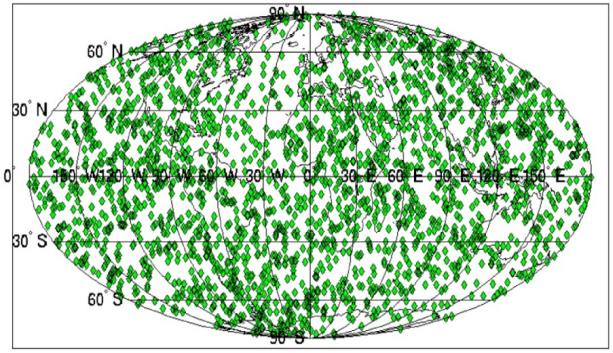
- U.S./Taiwan partnership
- 12 low Earth orbiting satellites, tracking GPS, GLONASS and possibly GALILEO
  - First Launch: 6 in low inclination (24°) at 520km – carries Space Weather Payloads
  - Second Launch: 6 in high inclination (72°) at 800km – Not fully funded
- Will produce up to 10,000 occultations per day
- 30-min average data latency
- Expected first launch in March 2017, second in 2020
- Additional first launch space weather payloads:
  - Ion velocity meter
  - RF Beacon Transmitter
- UCAR COSMIC funded by NOAA/USAF to provide COSMIC-2 Data Processing Center for GNSS RO and IVM
- Data processed in near-real time



COSMIC Occultations-3 Hrs Coverage



COSMIC-2 Occultations - 3 Hrs Coverage



Current/Future CDAAC Data Products

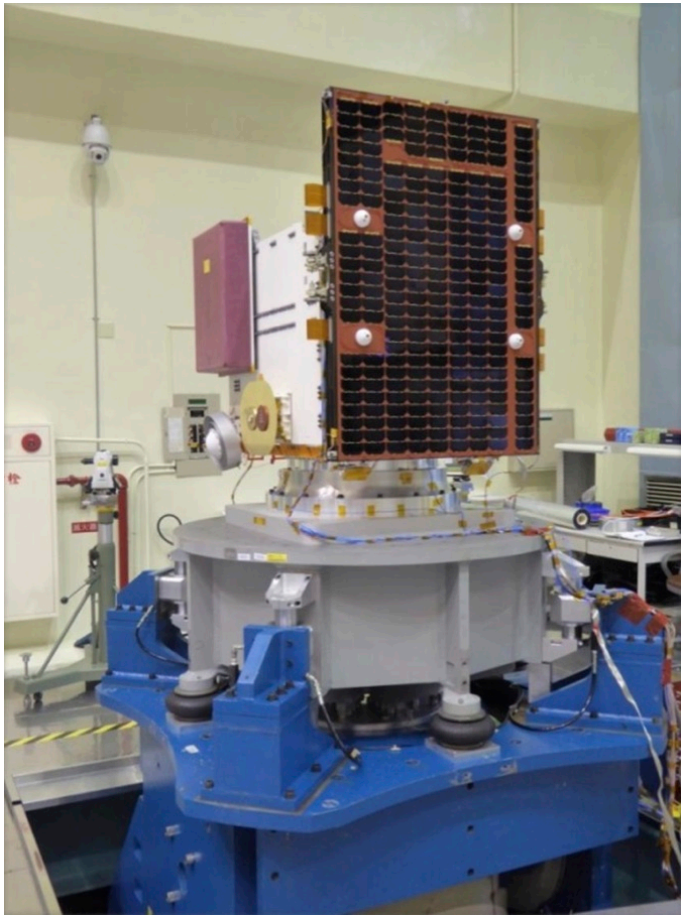
- **COSMIC-I Space Weather Data:**
  - Absolute line of sight total electron content (GPS)
  - Retrieved electron density profiles
  - Scintillation (S4)
  - UV Radiances from Tiny Ionosphere Photometer (TIP)
- **COSMIC-II Equatorial Space Weather Data:**
  - Absolute line of sight total electron content (GPS+GLONASS)
  - Retrieved electron density profiles
  - Scintillation (S4 and σ_ϕ).
  - S4 will be included with TEC data files – perhaps useful for QC.
  - In-situ plasma drift velocities, and ion density, composition, and temperature

http://cdaac-www.cosmic.ucar.edu/cdaac/products.html

COSMIC-2 Current Status

- First spacecraft fully integrated and tested at Surrey (UK) in May 2015
- All payloads have been delivered to Taiwan, and the remaining five spacecraft are nearing completion of integration and testing
- Software development for RO and IVM data processing is on schedule
  - All RO and IVM data will be available through UCAR CDAAC

    cdaac-www.cosmic.ucar.edu
- COSMIC-2 Polar status:
  - Dependent on U.S. funding
  - Anticipated launch in ~2020



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- Broad Reach Engineering

UCAR NSF NASA USAF NOAA NSPO ONR