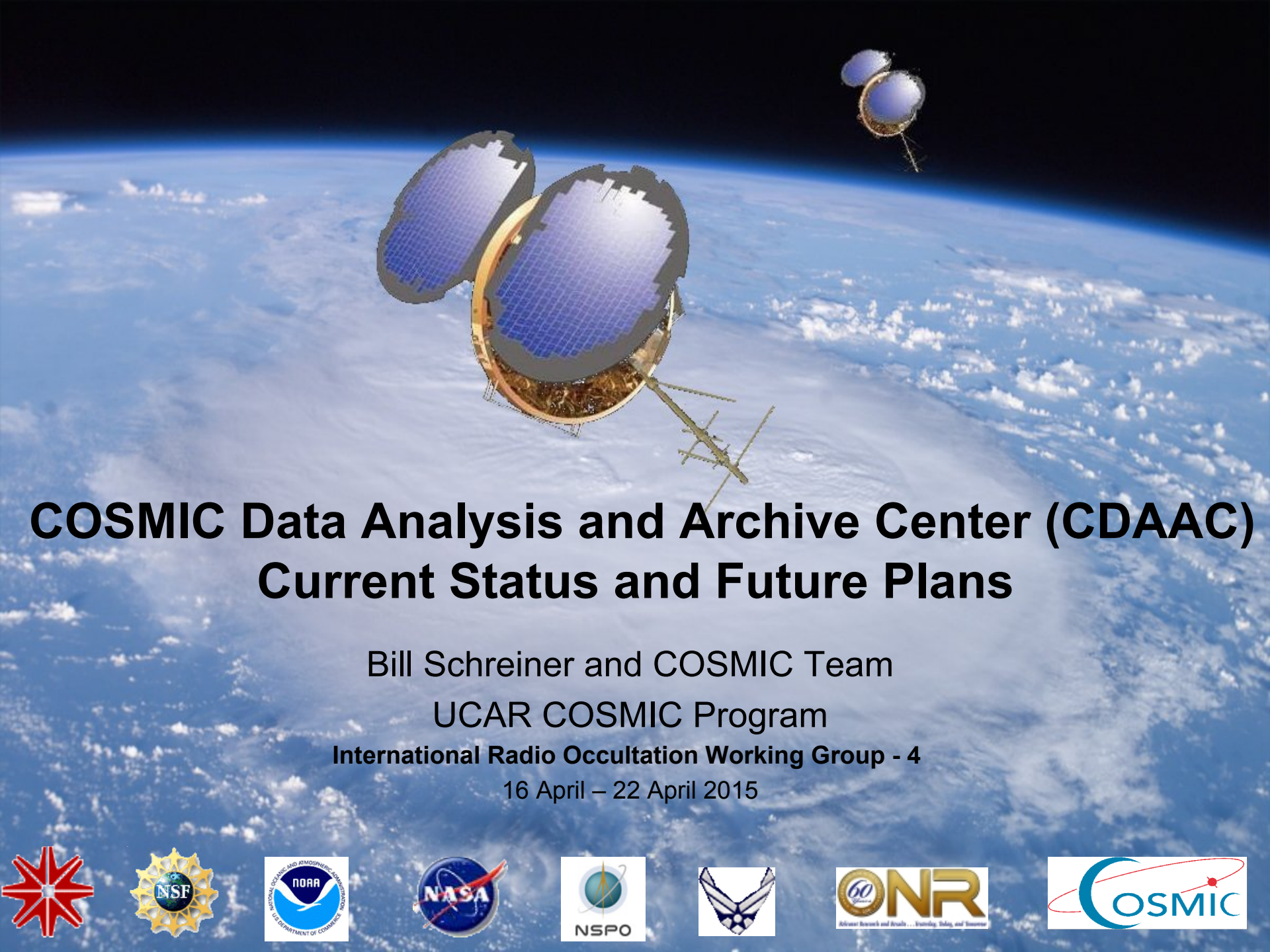


COSMIC Data Analysis and Archive Center (CDAAC) Current Status and Future Plans

Bill Schreiner and COSMIC Team

UCAR COSMIC Program

International Radio Occultation Working Group - 4

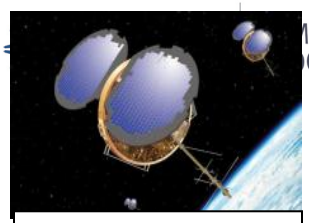
16 April – 22 April 2015

UCAR COMMUNITY PROGRAMS

COSMIC and CDAAC Staff

Outline

- COSMIC/CDAAC Overview
- Status of COSMIC and other missions
- Neutral Atmospheric Retrieval updates
- Ionospheric Status
- Re-processing Status
- Data Access Overview



COSMIC Operational Processing

COSMIC
C/NOFS
Metop-AB/GRAS

RTSs
Alaska
Norway
McMurdo
Hanscom AFB

Input Data
- COSMIC data
- GPS ground data
- GFS Forecast

TACC

CDAAC

UCAR/Unidata's
LDM

WGET

Research Community

1000-2000 WMO
BUFR Files
per day with
Latency ~ 75-90min

SFTP

AFWA

Science & Archive

NESDIS

GTS

BOM

JCSDA

NCEP

ECMWF

CWB

UKMO

JMA

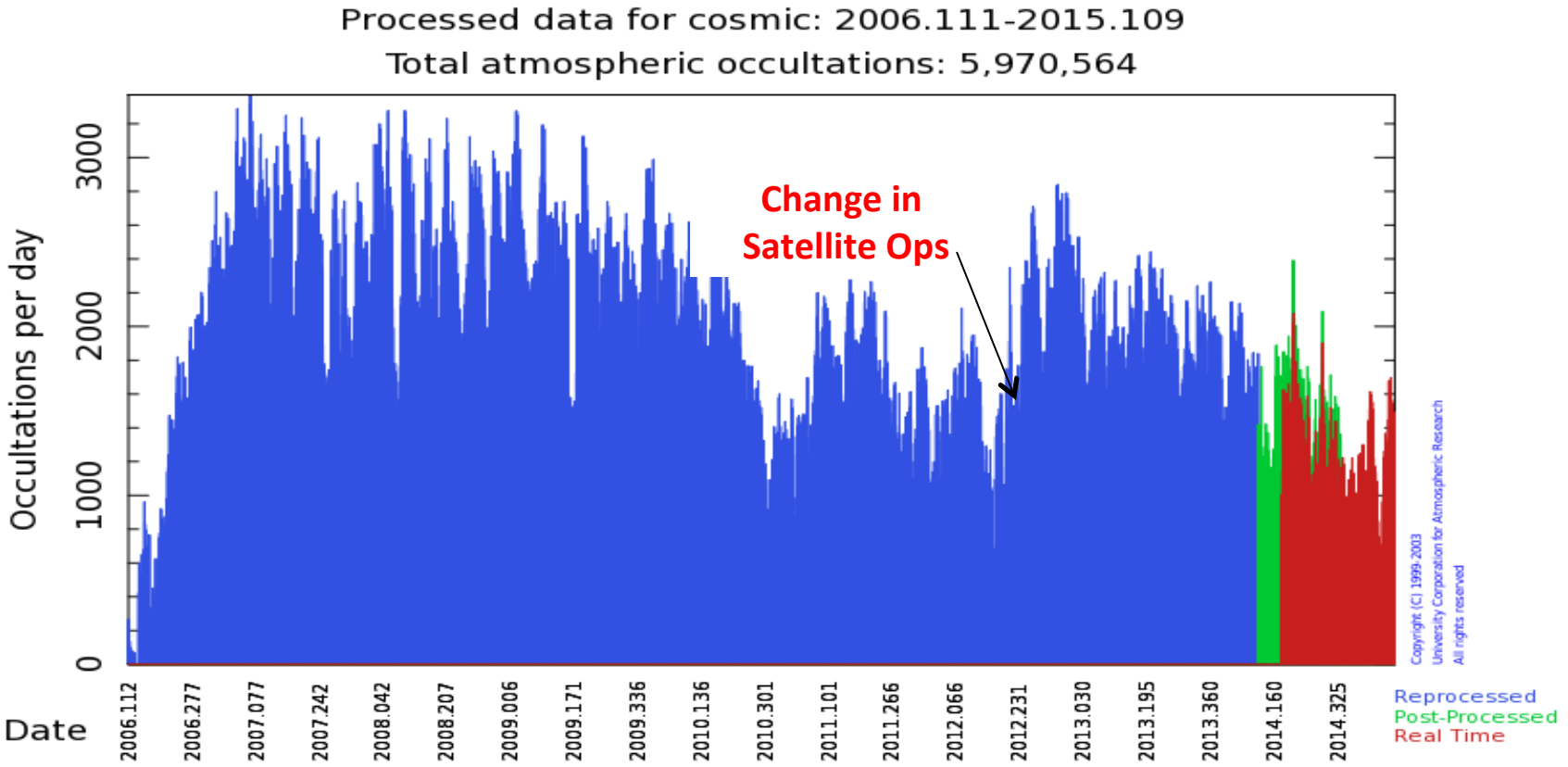
Canada Met.

Meteo France

Providing data to > 2,932 registered users from 79 countries

> 5.9 Million COSMIC Profiles

4/21/06 – 4/19/2015



COSMIC: Four of six currently operating nine years after launch (design life: 2-3 yr)

- FM#3 dead since August 2010
- FM#4 not operating since Jan 11, 2015

COSMIC continues to provide 1,000-2,000 GPS radio occultation soundings per day

COSMIC Data Products

- **LEO POD and excess phase (~15 cm, ~0.15mm/s 3D rms)**
- **~ 6M neutral atmospheric profiles:**
  - Bending angle noise ~1.5-2.0 μ-rad between 60-80km
- **> 4M Absolute TEC data arcs:**
  - Absolute accuracy ~ 1-3 TECU
- **> 4M Electron Density Profiles:**
  - NmF2/hmF2 Accuracy ~20%/20km (compared to Ionosondes)
- **Scintillation Indices (S4):**
  - ~6M 50-Hz tracks available from RO profile events (altitudes < 120 km)
  - > 4M 1-Hz tracks from POD antennas
- **TIP Night-side Radiances:**
  - TIP set new standard for sensitivity of UV instruments, ~500 counts/s/ Rayleigh
  - > 17,800 hours of quality controlled data

COSMIC Firmware Status

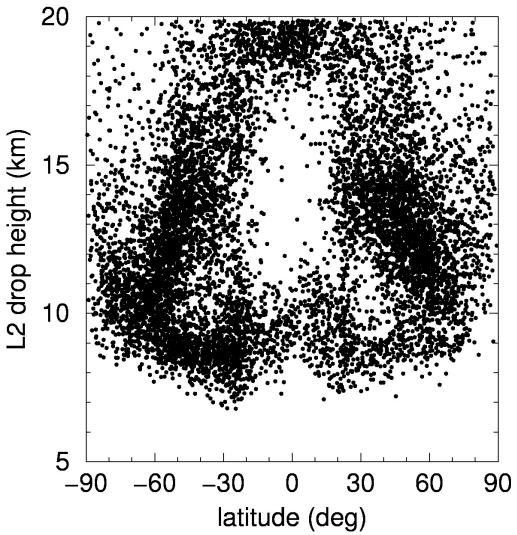
- Same firmware running on all spacecraft since Jan 2012
  - L2C setting occultations are of high quality with few L2 failures
  - Improved tracking for rising occultations after reboot
- Future enhancements to firmware
  - Implement L2C tracking for rising occultations
  - Evaluate 100 Hz tracking capability
  - Multiple correlator tracking

Acknowledgement to JPL for developing COSMIC receiver firmware updates!

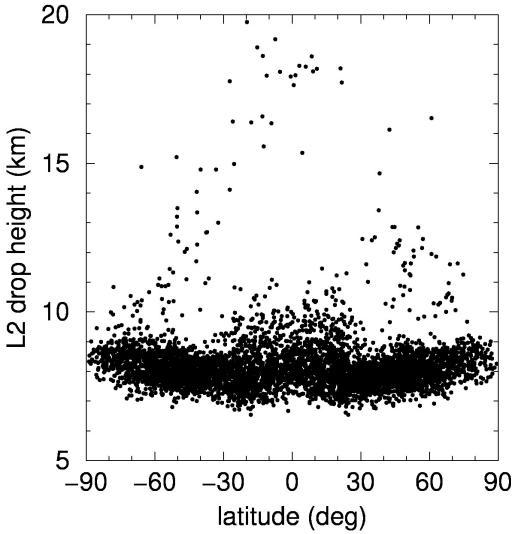
And to NSPO for uploading new firmware to COSMIC spacecraft!

Penetration of L2 Signal

COSMIC L2P



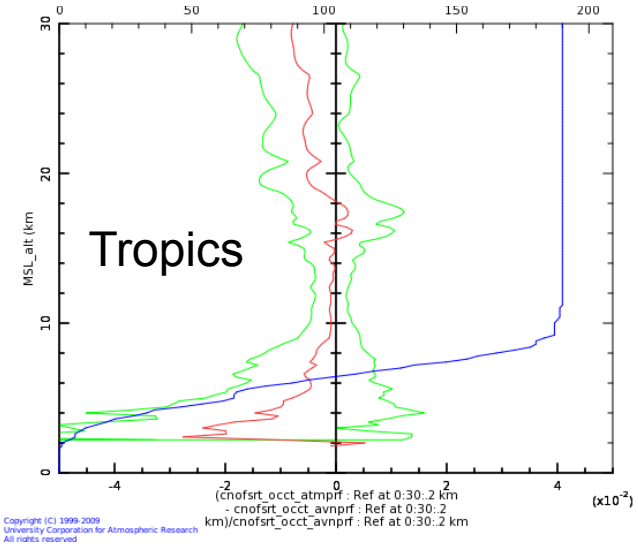
COSMIC L2C



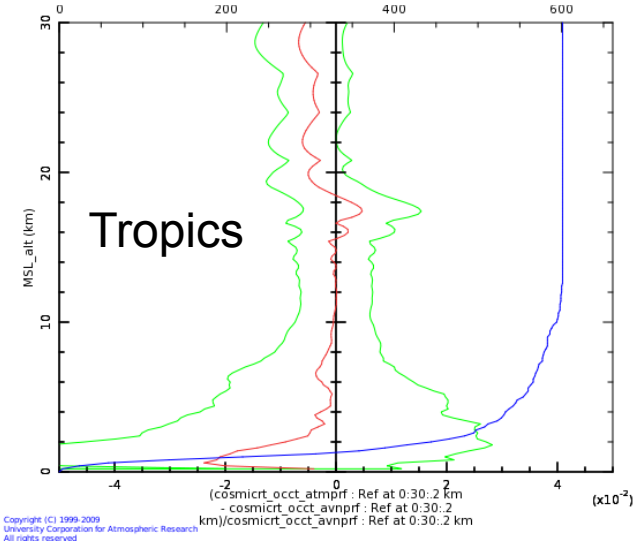
C/NOFS Mission Status

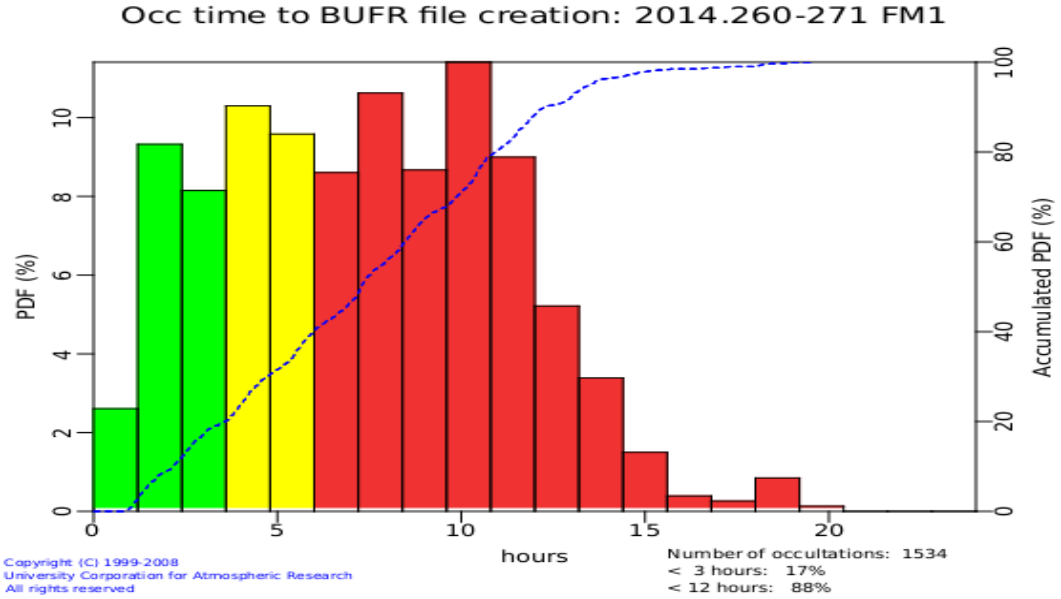
- C/NOFS Occultation Receiver for Ionospheric Sensing and Specification (CORISS)
- USAF has continued to fund C/NOFS operations
- ~ 125 occultations/day, maybe can go higher
- **Right:** C/NOFS and COSMIC agree similarly with NCEP refractivity in tropics
- **Below:** C/NOFS data latency too high for NWP applications – UCAR has asked USAF to reduce latency and correct out-of-order dumps
- Stay tuned

C/NOFS vs NCEP 2014.271-272



COSMIC vs NCEP 2014.271-272

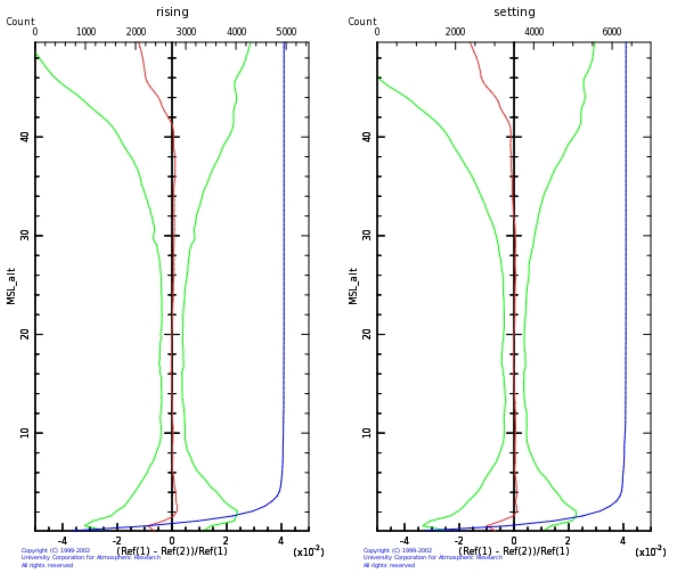




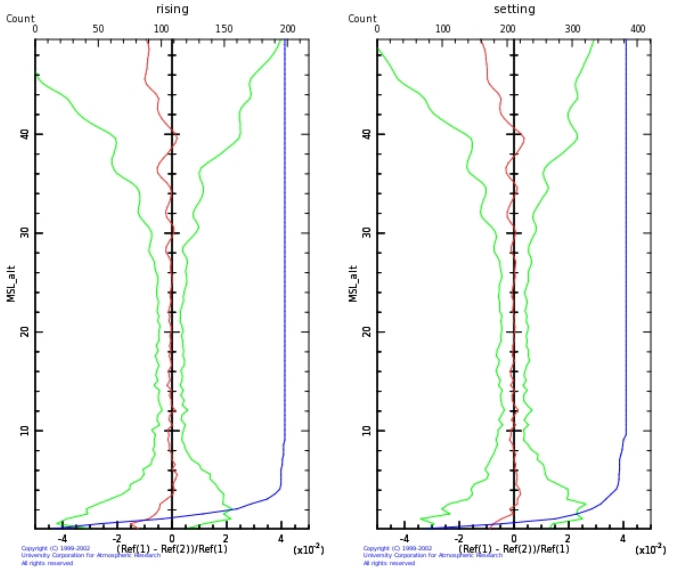
KOMPSAT-5 Mission Status

- KOMPSAT-5 (S. Korea)
- CDAAC evaluated initial RO data – ~460 occultations per day with similar high quality as COSMIC
- Ground station architecture not currently adequate for NWP
- Only forward occultation antenna has been turned on due to the limitation of downlink budget for the ground station
- Raw RO data is currently available from April 2014 to present, but can't be processed due to lack of clock reference data
- Investigation underway

COSMIC FM1 vs ECMWF (Aug 2013)



KOMPSAT-5 vs ECMWF (Aug 24-25 2013)



CDAAC Processing Status

- Near Real-Time to GTS
  - COSMIC
- Near Real-Time
  - C/NOFS
  - Metop-A/GRAS, Metop-B/GRAS
- Post/Re-Processing for 9 RO missions
  - GPS/MET, CHAMP, GRACE-A, SAC-C, COSMIC, TerraSAR-X, Metop-A/GRAS, Metop-B/GRAS, C/NOFS
- New/Future Missions
  - GRACE-B
  - KOMPSAT-5/Korea (Launched in late 2013)
  - PAZ/Spain (Launch in Aug 2015), NRT?
  - COSMIC-2 (Launch in May 2016), NRT

Last Updated: Sun Apr 19 23:25:02 MDT 2015

MISSION	Total Atm Occs	Total Ion Occs
CHAMP	443911	306416
CNOFS	143243	0
COSMIC	5970564	4094326
GPSMET	5002	0
GPSMETAS	4666	0
GRACE	326026	155953
METOPA	1232813	0
METOPB	289152	0
SACC	353756	0
TSX	277484	0
Total	**9046617**	**4556695**

NEW Neutral Atmospheric Retrieval SW

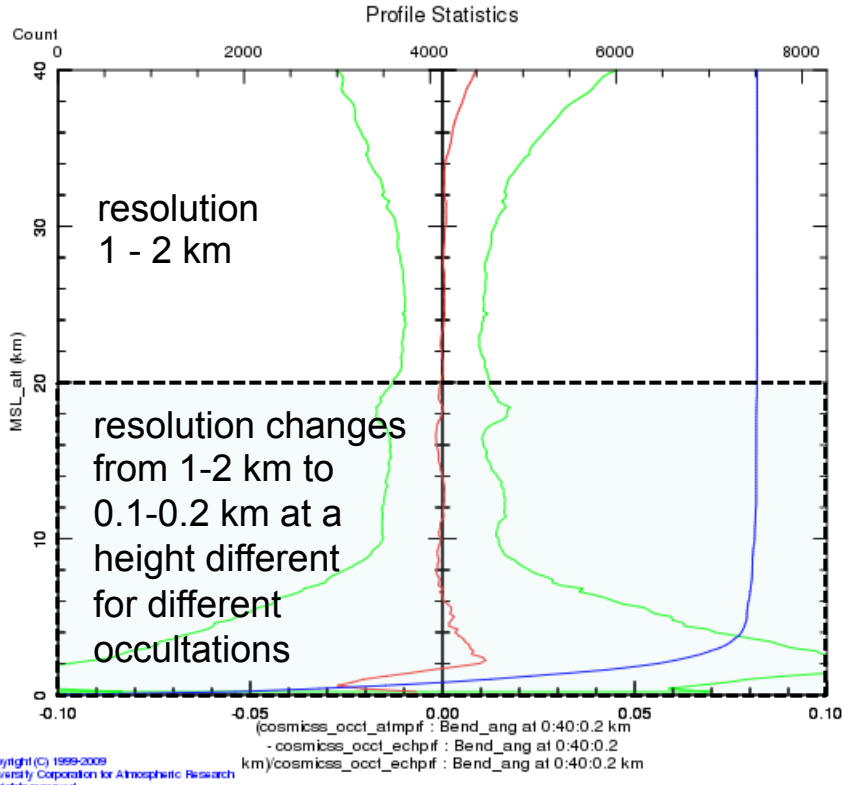
- Now using Bernese v5.2
- All occultations are processed and made available
- Wave Optics (Phase Matching) Algorithm
- Fixed height (20 km) for GO/WO transition
- New statistical optimization algorithm
- Filtering of Doppler for GO processing consistent with Fresnel scale (different in time for different occultations)
- Calculation of lat. & lon. of TP: use of BA from climatology (CIRA+Q) instead of raw BA obs.
- New QC
- BA error characterization
- Additional scalar output parameters
- New output files

OLD vs New Retrievals

Old processing:

The height to replace GO (resolution 1-2 km) by WO (resolution 0.1-0.2 km) and replace ionospheric correction by extrapolation is determined dynamically (individually for each occultation); can be any height below 20 km.

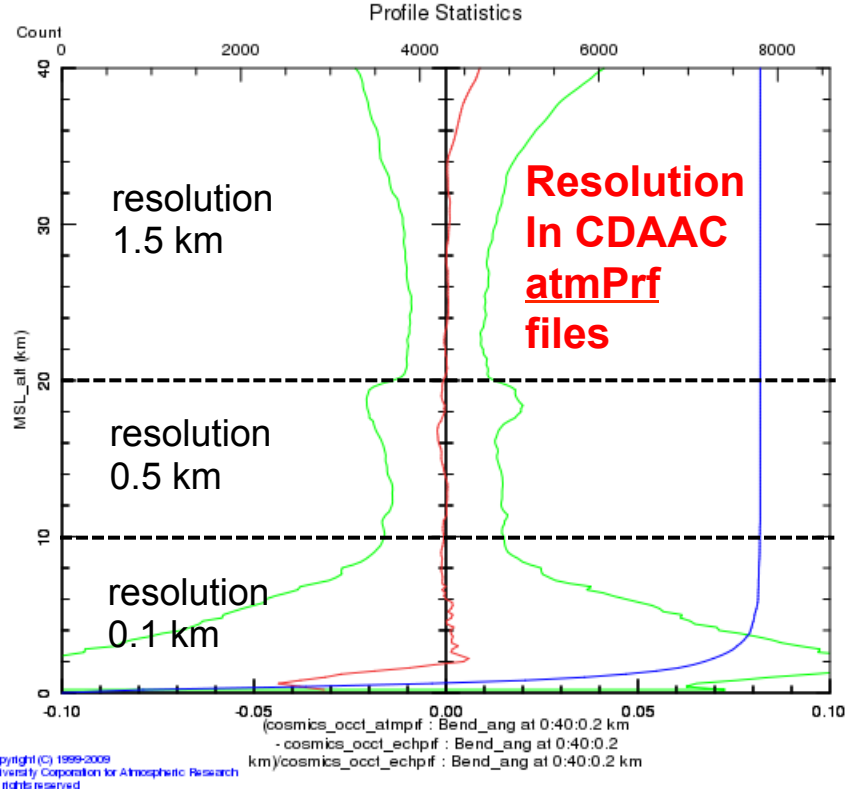
Vertical resolution below 20 km is different for different occultations.



New processing:

GO is replaced by WO at fixed height (20 km). Ionospheric correction is replaced by extrapolation at fixed height (20 km).
Resolution of GO is fixed to 1.5 km (Fresnel)
Resolution of WO is fixed to 0.1 km and 0.5 km.

Vertical resolution is the same for all occultations.

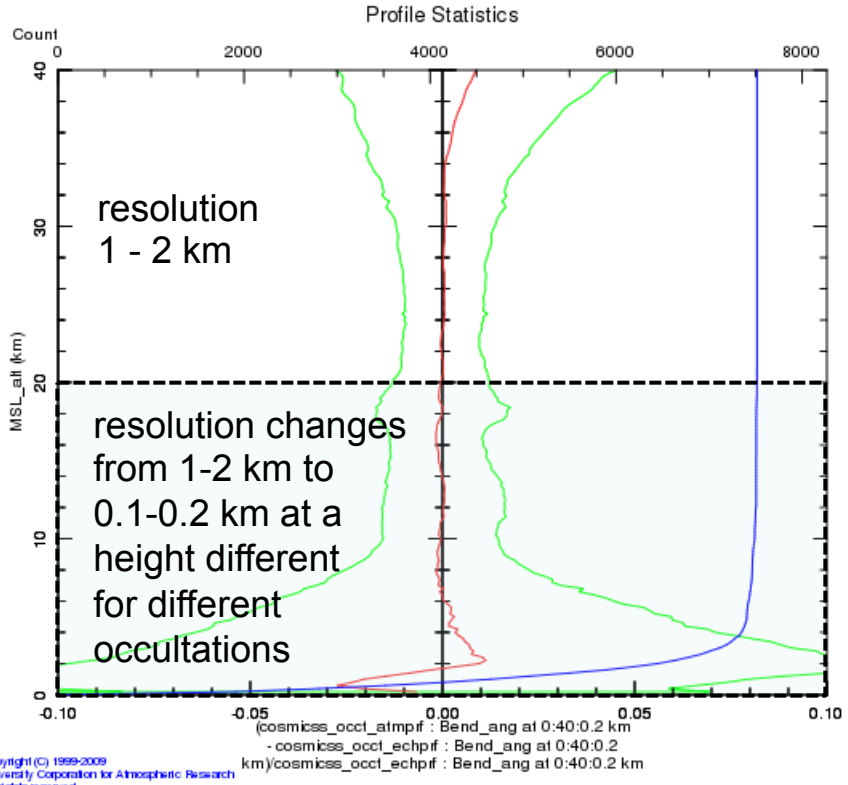


OLD vs New Retrievals

Old processing:

The height to replace GO (resolution 1-2 km) by WO (resolution 0.1-0.2 km) and replace ionospheric correction by extrapolation is determined dynamically (individually for each occultation); can be any height below 20 km.

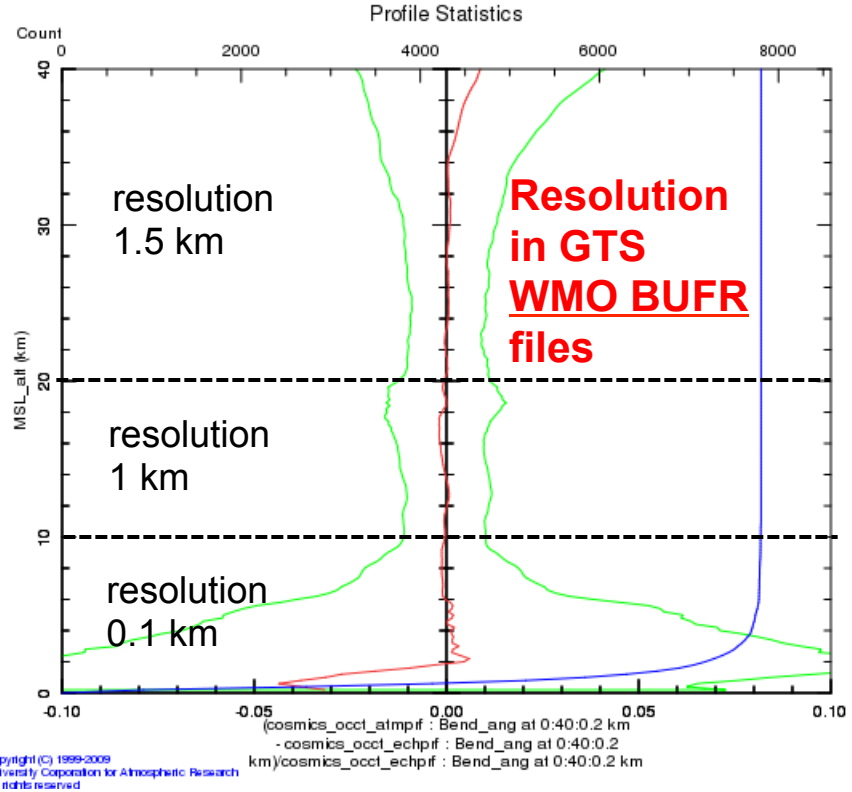
Vertical resolution below 20 km is different for different occultations.



New processing:

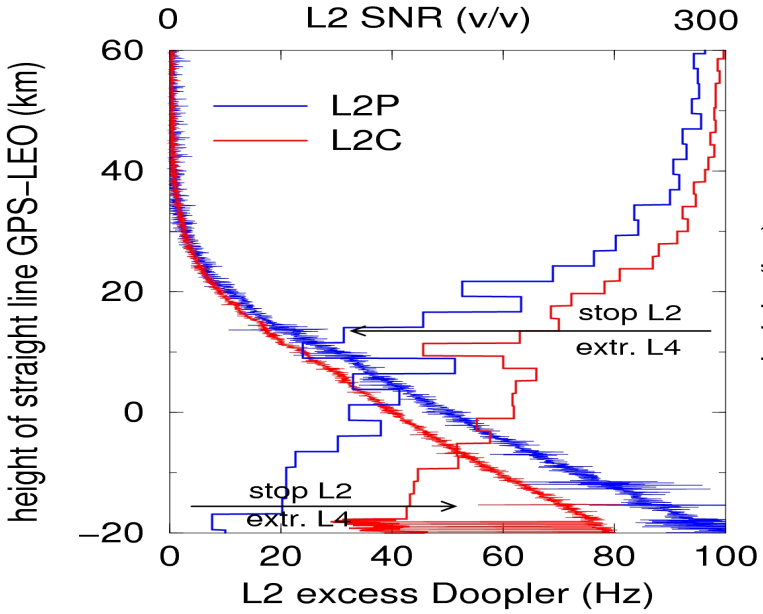
GO is replaced by WO at fixed height (20 km). Ionospheric correction is replaced by extrapolation at fixed height (20 km).
Resolution of GO is fixed to 1.5 km (Fresnel)
Resolution of WO is fixed to 0.1 km and 1 km.

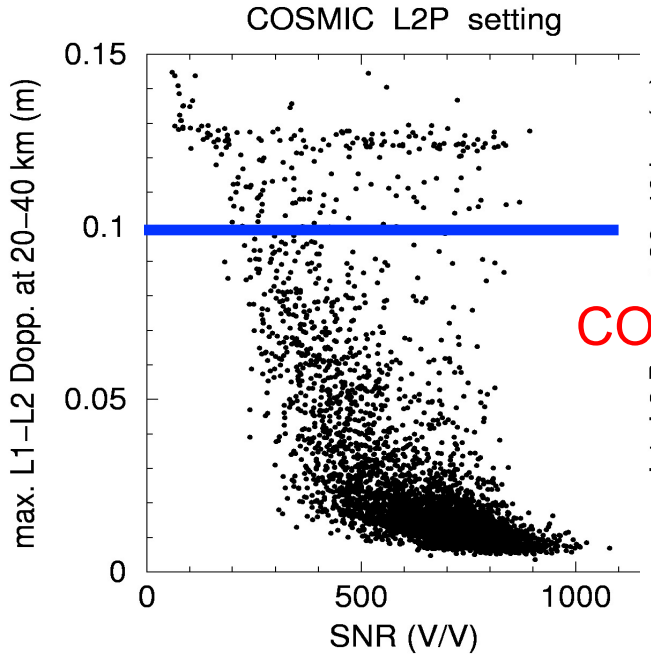
Vertical resolution is the same for all occultations.

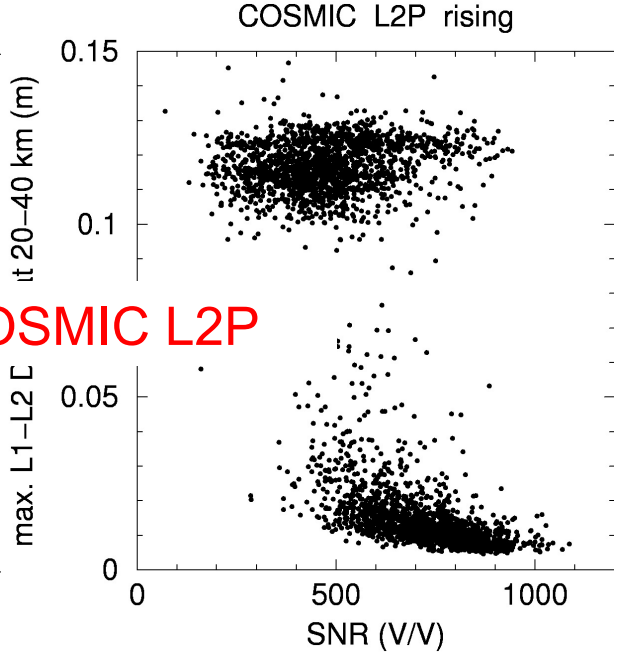


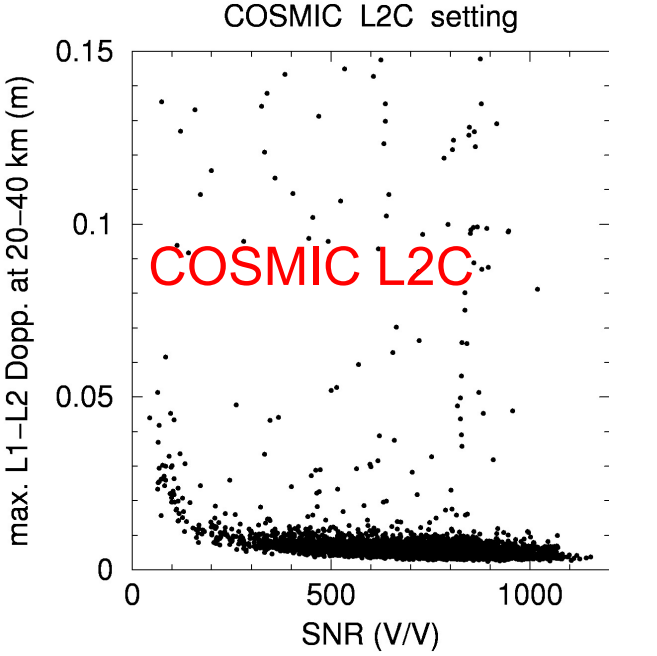
New Quality Control Algorithm

- L2 quality control (QC)
  - Via max. difference of raw |L1-L2| Dopplers between 20 and 40 km
  - Via L1CA SNR between 60 and 80 km
- An occultation is marked “bad” if
  - the |L1-L2| Doppler difference > 0.1 m/samp OR
  - L1CA SNR < 200 V/V
- This algorithm has passed ~500,000 more occultations than previous algorithm without degrading comparison statistics with NWP models







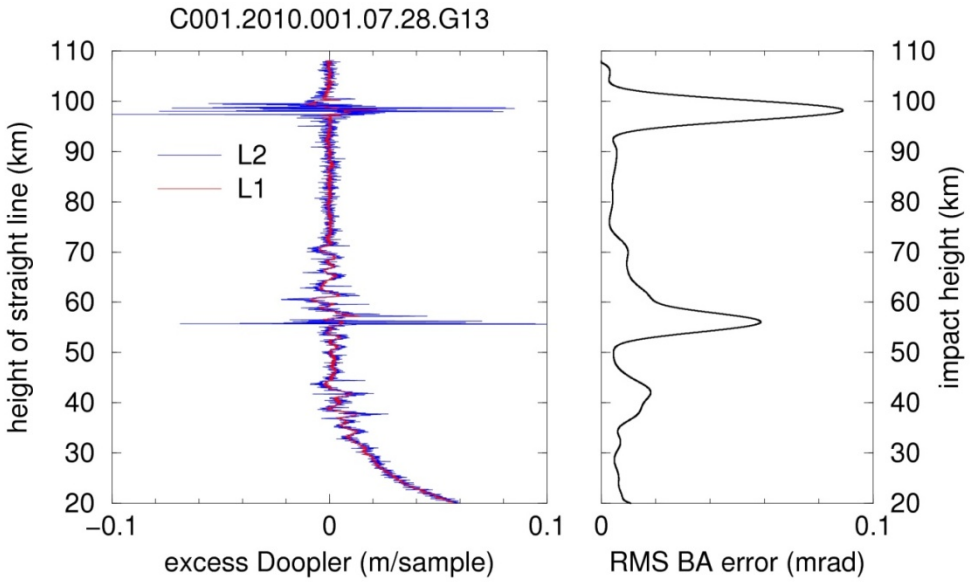


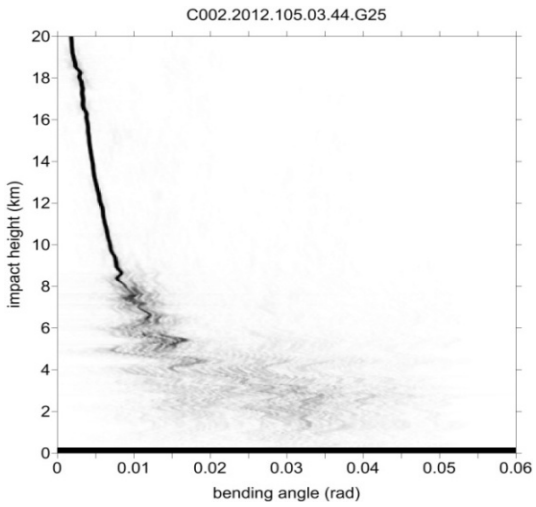
Dynamic (individual for each occ.) BA error characterization

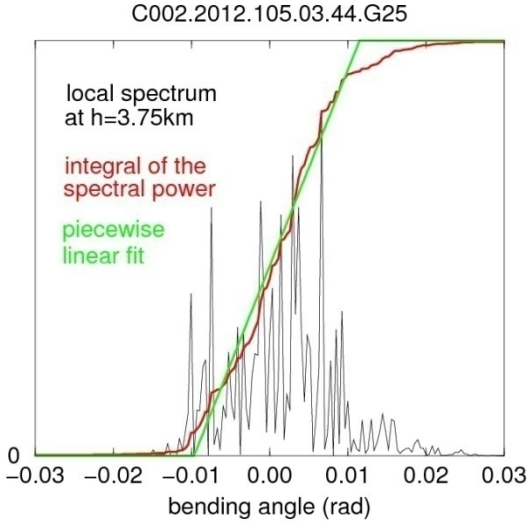
Available in atmPrf and bfrPrf files

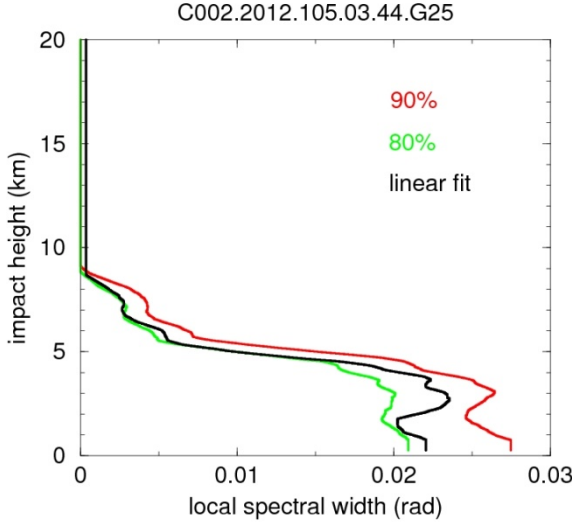
In the stratosphere: based on RMS fluctuation of the LC Doppler in 1 s sliding window.

In the troposphere: based on local spectra of WO-transformed RO signal (Gorbuonv et al., JGR, 2006) but with different definition of the local spectral width.









Neutral Atmospheric Profiles – Scalar Output Parameters

Area of Interest	atmPrf Scalar Variable	Description
Bending angle uncertainty for an occultation	smean	Mean deviation of ionosphere-free BA from climatology
Bending angle uncertainty for an occultation	stdv	Standard deviation of ionosphere-free BA from climatology
Signal-to-Noise Ratio for an occultation	snr1avg, snr1del snr2avg, snr2del	Mean SNR, linear trend of SNR, for L1 and L2, between 60 and 80 km
Tropopause Height and Temperature	trtwmo, trhwmo trtwmo2, trhwmo2 trtcp, trhcp	Tropopause height and temperature from WMO definition (incl. 2nd tropopause), and cold point definition
Atmospheric Boundary Layer characterization	balmax zbalmax	max. BA lapse in variable sliding window and median height
Atmospheric Boundary Layer characterization	bpnmax zbpnmax	N break point (lapse of N-gradient by sliding linear regression in 0.5 km window) and median height
Ionospheric Scintillation	S4	L1CA Amplitude scintillation
New Scalar Parameters		
Sporadic E-clouds	nes, hes, wes	Detection of multiple Es effects: heights of TP and intervals of amplitude fade
Atmospheric Boundary Layer characterization	dnmin, zdnmin bpnmax, zbpnmax	Max N lapse (0.3 km window), N break point (sliding linear regression in 0.3 km window)
Convection in the moist troposphere	zlswmax, zlswtop	Height of max local spectral width; depth of convective layer (under revision)
Multiple profile truncation heights	TBD	Truncation heights based on WO amplitude, stationary point, terrain (under development)
Super-refraction in ABL	TBD	Height of SR layer (also, existence of reflected and interfering signals) (under dev.)

Auxiliary Output Files

Purpose: running applications such as: different BA optimizations, deducing Tropospheric/ionospheric structures from high-res WO transform; error estimation, QC, etc, without re-running the main inversion code

level2/benPrf ; argument: impact height; vectors: 2

- High-res L1 and L2 bending angles for entire profile

level2/wotPrf; argument: impact height; vectors: 4

- I and Q of the Wave Optics transform (Phase Matching) at the full resolution 1 m for L1 and L2 (when L2C is available)

level2/qcfPrf; argument: time; vectors: 8

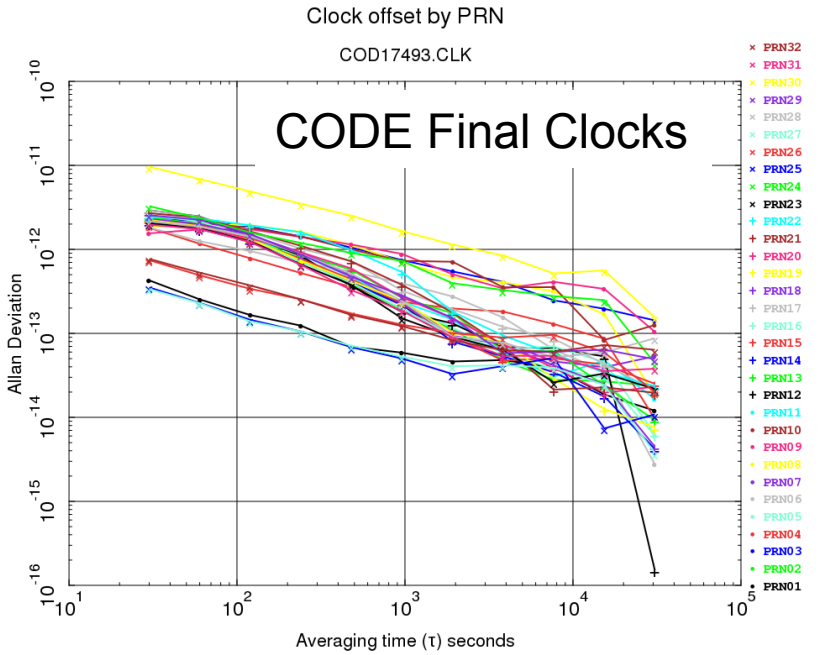
- L1 and L2 excess phases after removal of nav. data modulation and re-connection of the phases with the post-processing model based on orbits and BA climatology
- L1 and L2 SNRs
- height of straight line between GPS and LEO
- impact height based on orbits and BA climatology
- difference between the receiver and the post-processing Doppler models

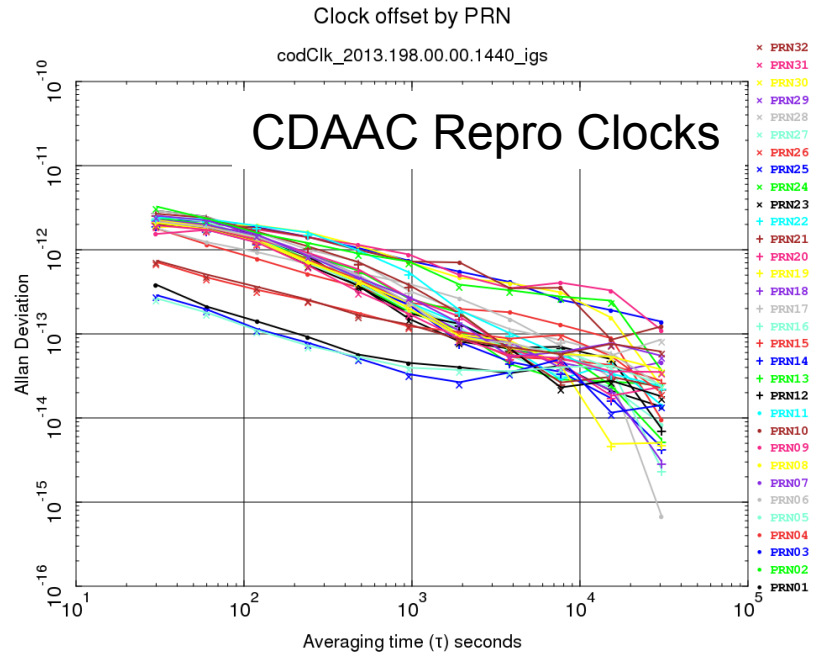
Level3/mmcBin;

- To be developed soon

CDAAC Re-processing

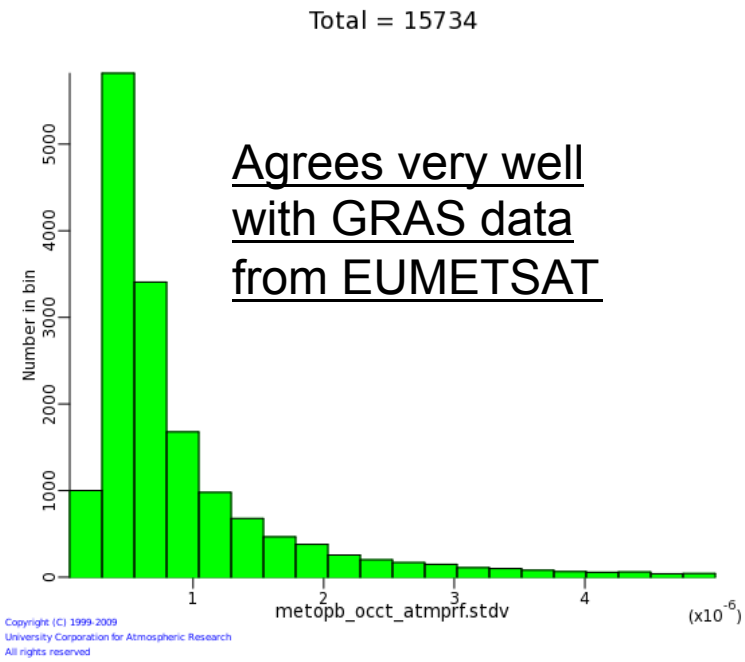
- New CDAAC RO re-processing uses NEW retrieval SW and a fully consistent set of satellite orbit, clock, and earth rotation products that are not subject to occasional reference frame discontinuities
- CDAAC re-processed 30-second clocks are based on CODE (Center for Orbit Determination Europe)products that have been submitted to the IGS “repro2” reprocessing effort
- The CODE repro2 products (orbits, ERP, station coordinates, troposphere) are available from 1994.001 - 2013.363
  - Bernese V5.3 used for repro2. CDAAC uses V5.2 (most current public version of the software).
  - fully consistent with IGb08 reference frame, IGS08 antenna phase center models
  - Satellite block-specific nadir angle absolute phase center variation (PCV) for all satellites as specified by IGS08_1748.atx.
  - Absolute calibration (elevation and azimuth) of ground antenna PCV as specified by the IGS08_1748.atx
  - Follows all IERS 2010 conventions
  - VMF tropospheric mapping functions based on ECMWF analysis (6-hour global grids)
  - 3 term HOI (higher order ionospheric) corrections in CODE repro2 products. Only 1st order (linear combination) used in the clock calculation.
  - IERS 2010 tidal modeling, earth orientation modeling
  - Number of stations steadily increases from ~150 in 2001 to more than 250 in 2013.
  - EGM 2008 geopotential model, FES2004 ocean loading





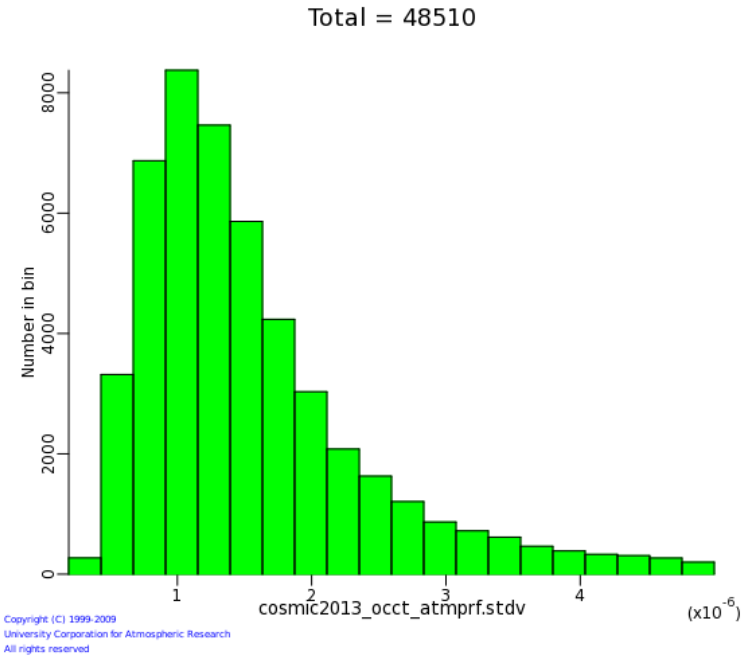
Re-processed
COSMIC and Metop-B Bending Angle noise between 60-80 km
June 2013

Metop-A/GRAS – Zero Diff.



Agrees very well with GRAS data from EUMETSAT

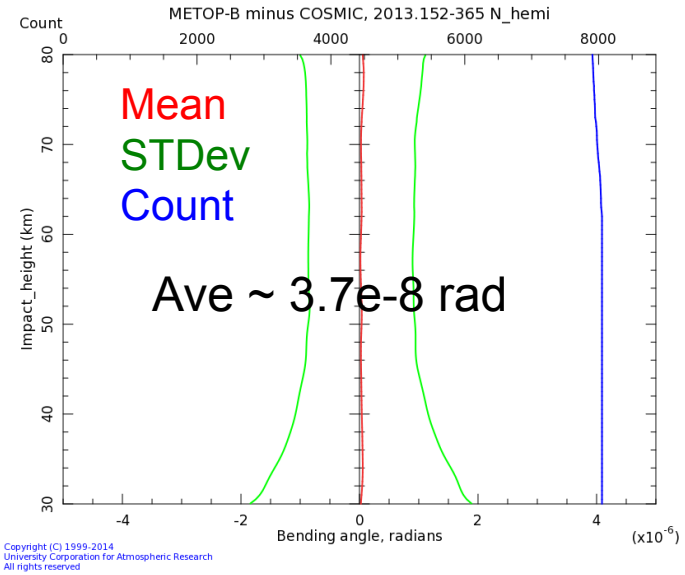
COSMIC – Single Diff.



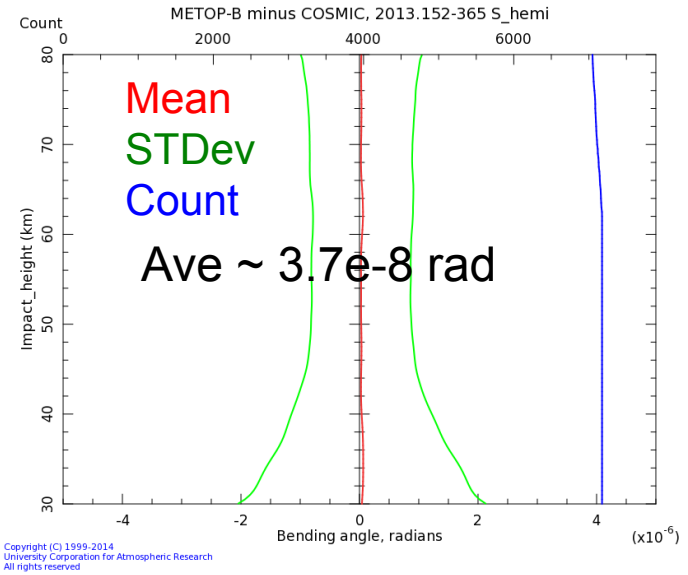
Bending Angle Differences COSMIC vs Metop-B/GRAS

(Collocations within 2 hours/300 km, June 2013 - Dec 2013)

0 < LAT< 90

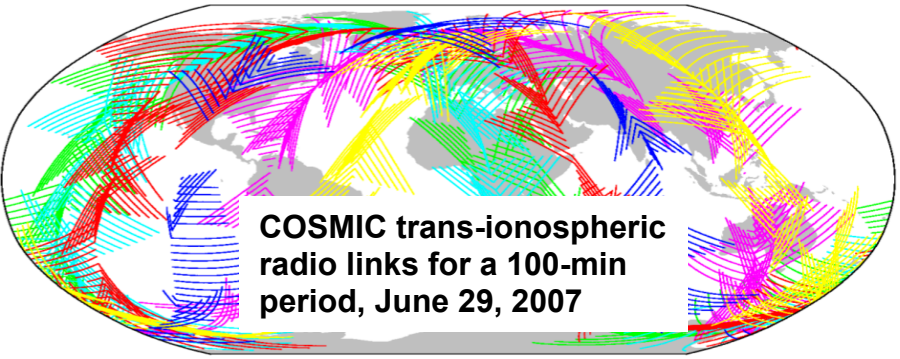


-90 < LAT< 0



BA bias between COSMIC and Metop-B to be further investigated with other missions and other data processing centers

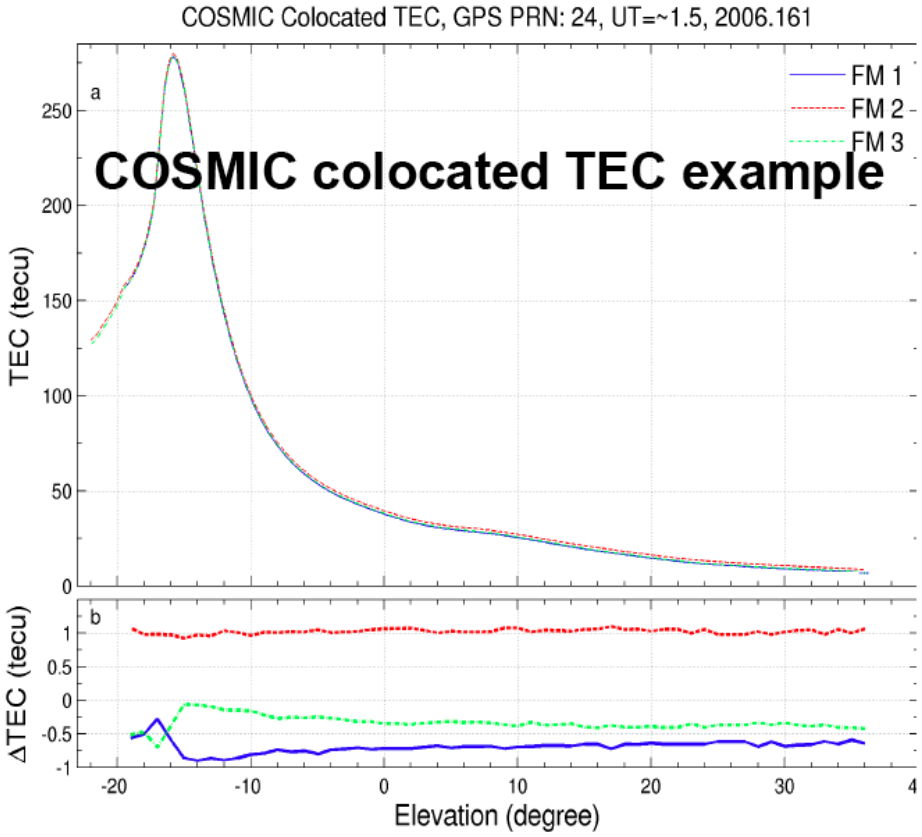
TEC Uncertainty from Collocated Tracks COSMIC (2006.230-245)

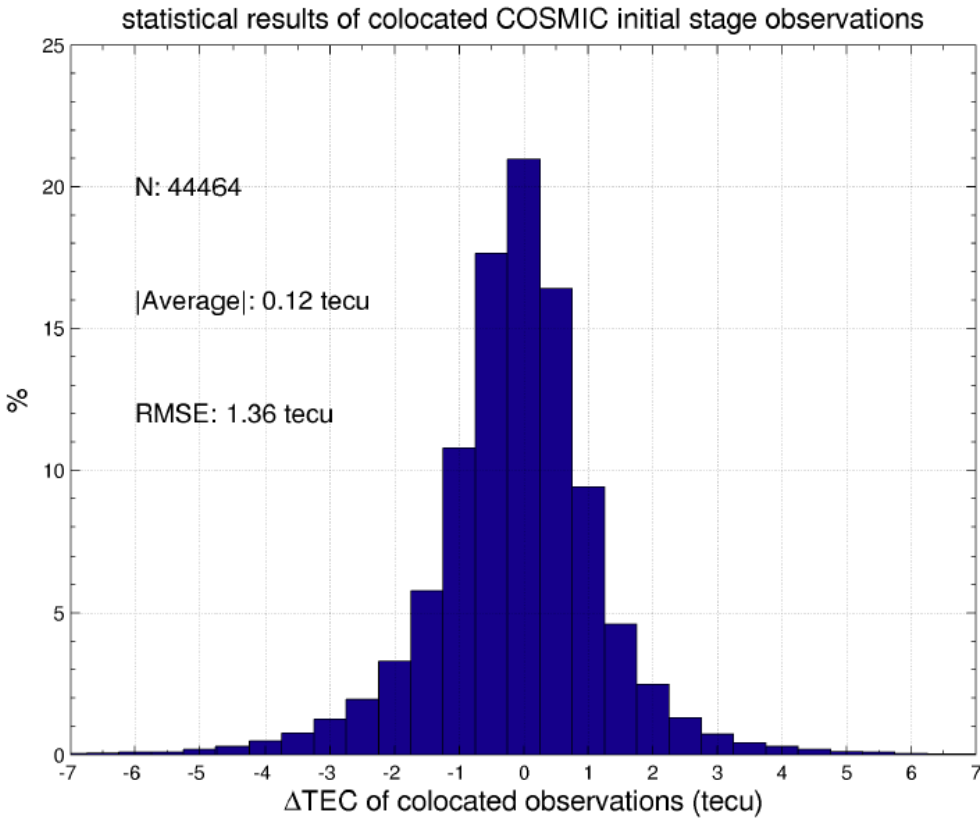


COSMIC trans-ionospheric radio links for a 100-min period, June 29, 2007

Statistical of difference between colocated TEC:

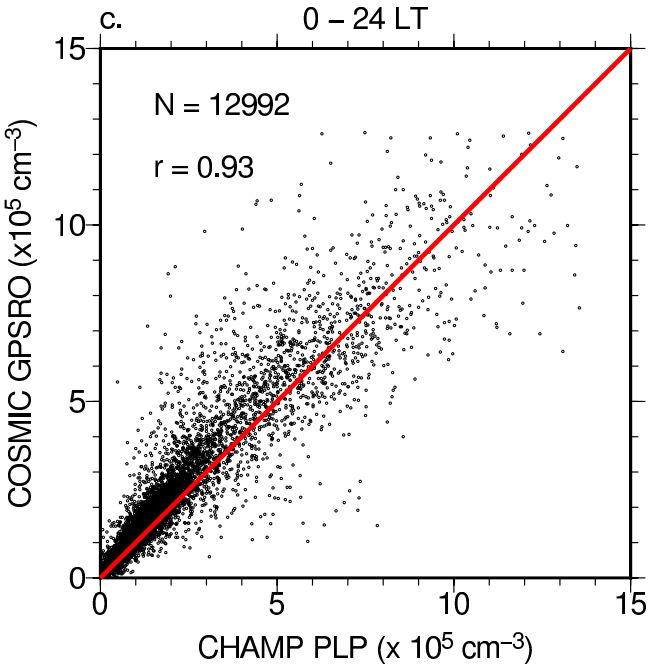
- ✓ **Mean difference: 0.12 tecu**
- ✓ **RMSE: 1.36 tecu**

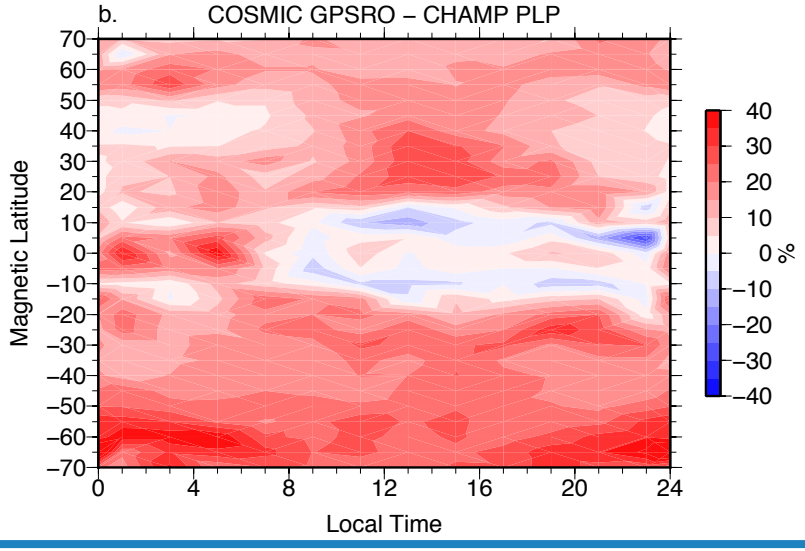


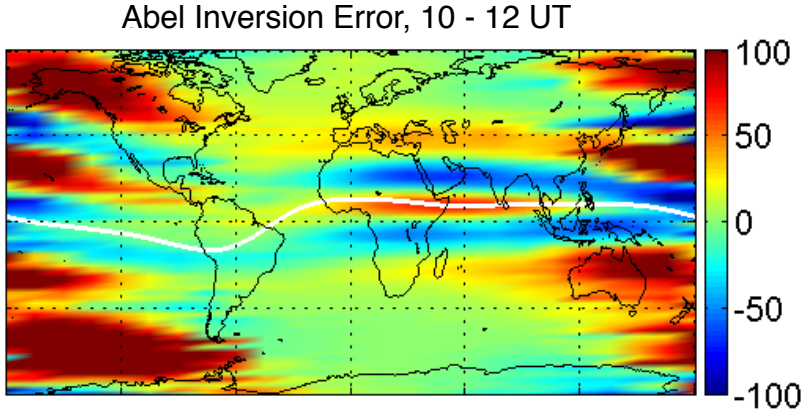


Global validation of COSMIC electron density profiles through comparison with collocated in-situ satellite observations.

- Previous validation is limited in that it does not capture potential systematic structures in the error distribution, and is unreliable above the F-region peak.
- To understand the global structure to the error, we have compared COSMIC electron density profiles with spatially (within 2° lat/lon) and temporally (within 15 minutes) collocated in-situ PLP satellite observations from CHAMP
- Results of the comparison indicate that GPS RO observations are within ± 20-25% of CHAMP observations.
- The latitude-local time distribution of the error is consistent with theoretical studies



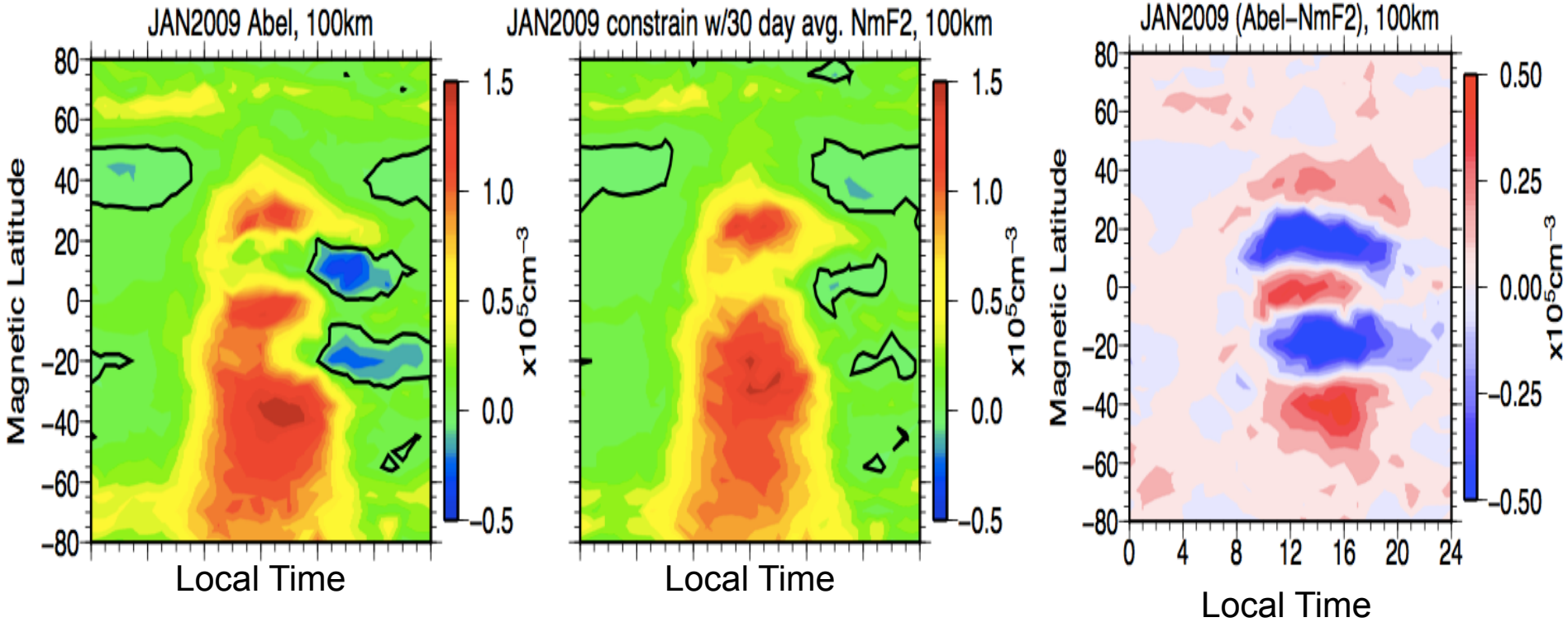




(*Yue et al.*, 2010)

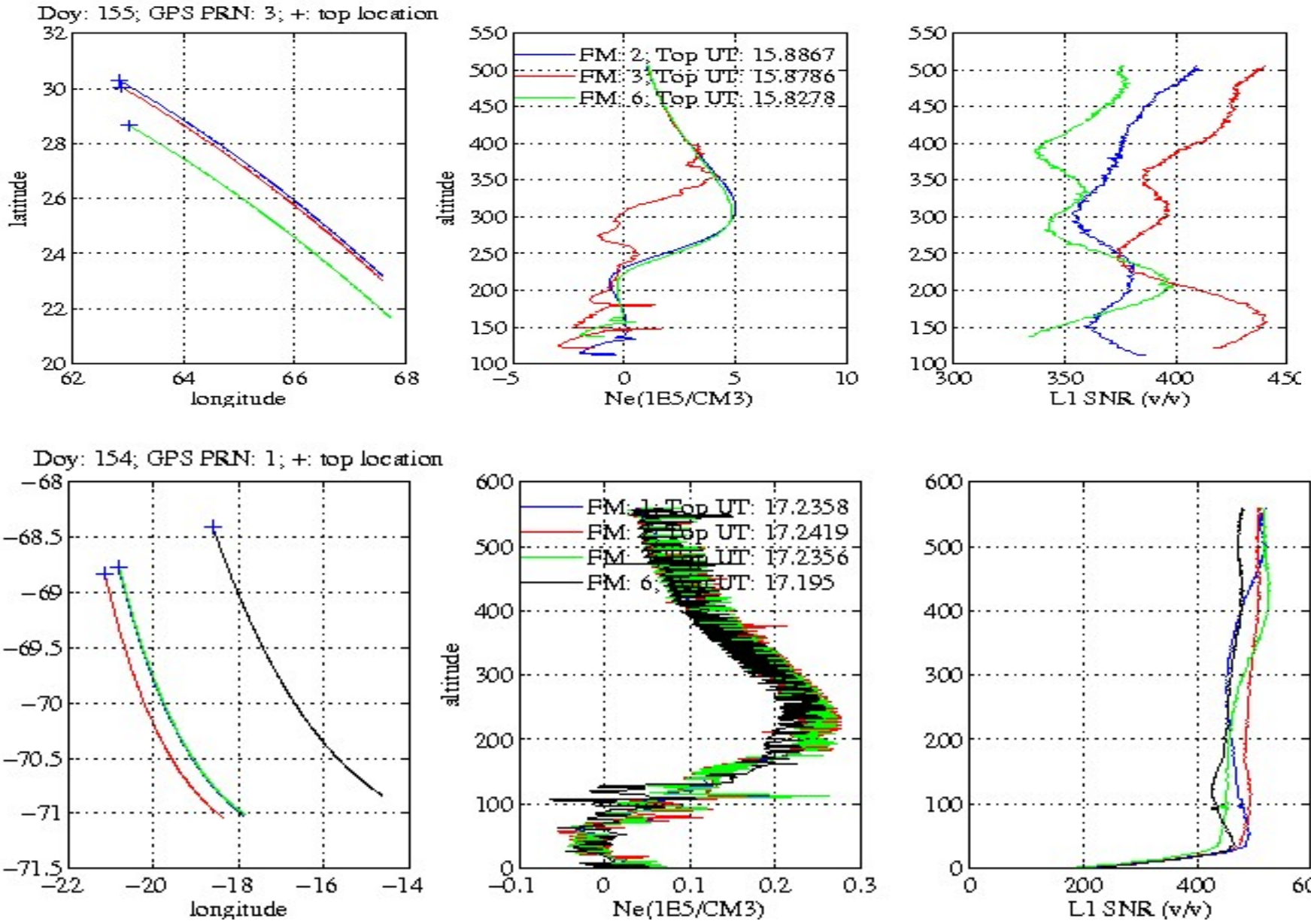
Enhanced EDP Retrieval

- Using background information based on the 30-day running average of COSMIC Abel NmF2 (lat, lon, local time)
- Biggest improvements are at 100 and 200 km.
- Constrained inversions reduce the negative electron densities at lower altitudes, but thy are not fully eliminated.
- The "plasma cave" feature around 200 km is reduced, essentially eliminated
- Plan to start making this product available in 2-3 months



QC of EDP Retrievals

(Under investigation)

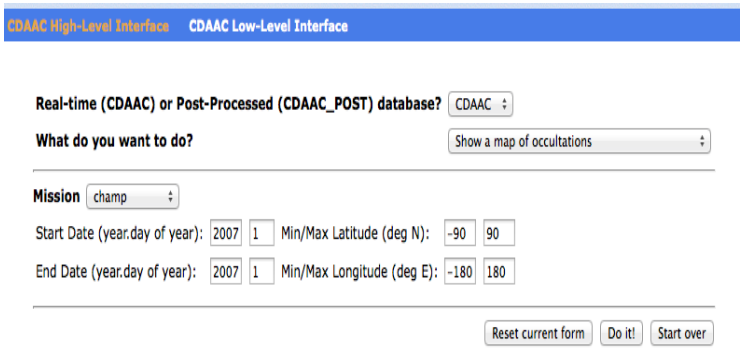


CDAAC Data Access

- CDAAC research tools on web
  - High-level interface
  - Low-level interface for data analysis
- Data download interface
  - For single or daily tar files
- CDAAC FTP Batch delivery system
  - For large batches of data from multiple days
- Collaborated with NCAR/CISL to make data available via NCAR High Performance Storage System (HPSS) as ds723.0.
- Other download methods
  - GTS, Unidata/LDM,
  - HTTP, Loaded HD
  - GoogleMaps
  - Field Project interface
- COSMIC website updated and re-written with latest web techniques

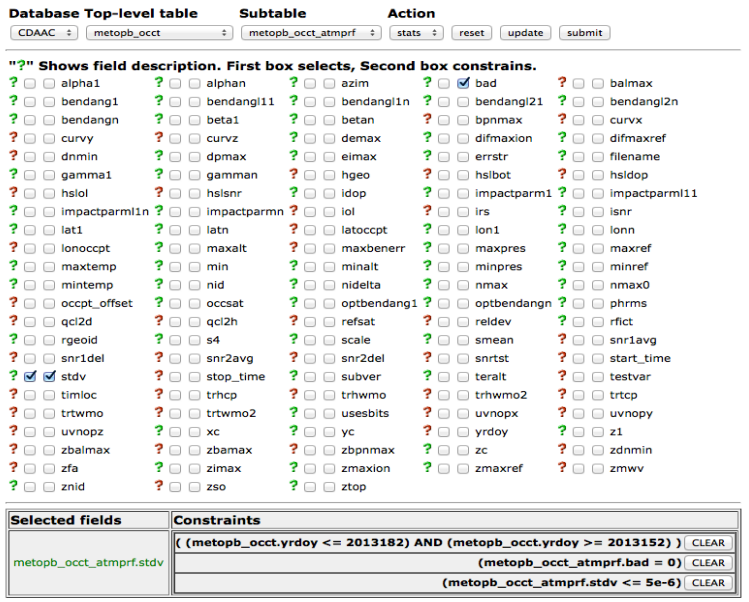
http://cdaac-www.cosmic.ucar.edu/cdaac/DBif/cdaac_highlevel.cgi

High-Level Interface



http://cdaac-www.cosmic.ucar.edu/cdaac/DBif/tableselect.cgi

Low-Level Interface



Data Download Interface: Download single or daily tar files

1.- Web Interface: http://cdaac-www.cosmic.ucar.edu/cdaac/tar/rest.html

Welcome to the CDAAC Data Download Interface!

By selecting a mission, file type and day from the form below, you can either get:

- **A daily data tarball.**
- **A list of files, where you can further click on a file link to download the data.**
- **Find out the mission's data availability.**

- **Please select a mission:**

  (•) COSMIC ( ) COSMICRT ( ) GRACE ( ) CHAMP ( ) CHAMP 2014

  ( ) MetOp-A ( ) MetOp-A 2011 ( ) MetOp-B ( ) TerraSAR-X

  ( ) SACC ( ) GPSMET ( ) GPSMETAS ( ) CNOFS

- **Please select a data type:**

  -- Please Select --

  Daterange available for COSMIC data:
  Please note, these are beginning and end dates.
  Data might not be available for some days during this period:
  4/21/2006 - 2/27/2014 (2006.111 - 2014.058)

- **Please select a day:**

  Reset | Get a List of Files | Get a Tarball

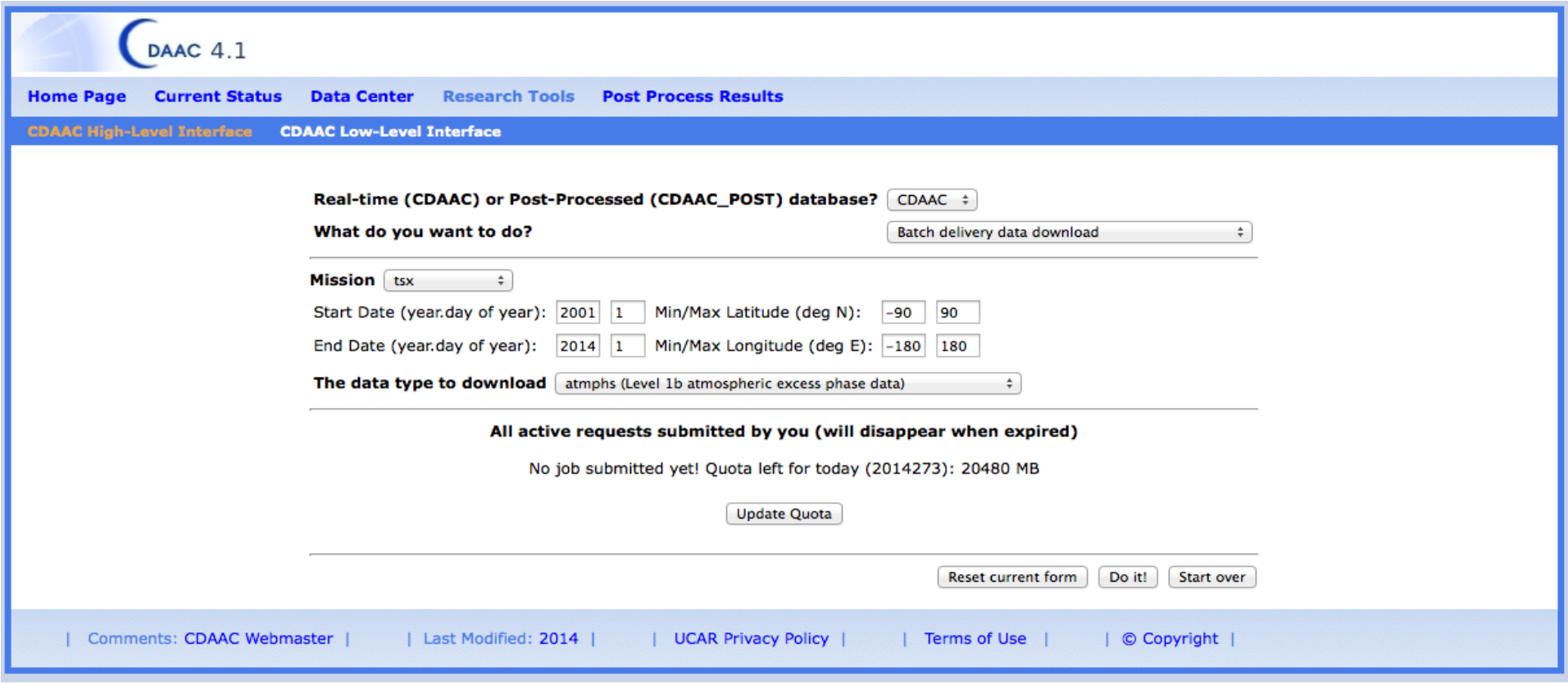
2.- Use wget commands to download data or to include in a script:

For wget examples please visit: http://cdaac-www.cosmic.ucar.edu/cdaac/tar/rest.html

CDAAC FTP Batch Delivery

http://cdaac-www.cosmic.ucar.edu/cdaac/DBif/cdaac_highlevel.cgi

- **FTP Batch Delivery System**
  - **Increases download speed significantly for large volume transfers**
  - Online since Oct. 2, 2012
  - ~20 GB/user/day with unlimited file counts
  - When the job is done, user will get notification email with download links



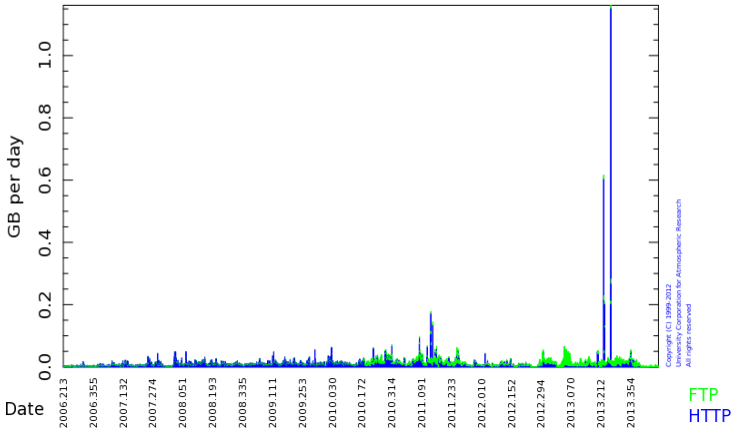
CDAAC Support to the Community

- Supporting 2932 data users from 79 countries – 400-500 supports/year
- Providing NRT data to NWPs, AFWA
- Providing NRT, Post-Processed, and climate Re-analysis products from 9 RO missions
- Development of improved RO data processing algorithms
- Providing data, user support, and science data processing software to community (~10 U.S. and Int'l universities)
- Maintain webpage of RO publications (access via COSMIC database and OpenSky)

Last Updated: Sun Apr 19 23:25:02 MDT 2015

MISSION	Total Atm Occs	Total Ion Occs
CHAMP	443911	306416
CNOFS	143243	0
COSMIC	5970564	4094326
GPSMET	5002	0
GPSMETAS	4666	0
GRACE	326026	155953
METOPA	1232813	0
METOPB	289152	0
SACC	353756	0
TSX	277484	0
Total	**9046617**	**4556695**

Data Downloaded ~462TB
(1/3 from university community)



CDAAC Near Term Plans

- Work with NWPs to migrate New CDAAC software into operations
  - Investigate increased vertical correlations with NEW retrievals
  - Implement BUFR changes if possible
  - Provide 3 1-mon test datasets (3 smoothings) to NWPs. Ready by Aug 1
- Continue Re-processing efforts with New CDAAC software
  - CHAMP (champ2014) and COSMIC (cosmic2013) done
  - Metop's reprocessing just started. Available in 3-6 months
  - Other missions to follow
- Ionospheric Products
  - Publish New EDP retrieval products in ~3 months
  - Improve QC of EDP products

Acknowledgments

- NSF
- Taiwan's NSPO
- NASA/JPL, NOAA, USAF, ONR, NRL
- Broad Reach Engineering
- Other RO Missions, CHAMP, SAC-C, GRACE, TerraSAR-X, C/NOFS, Metop-A/GRAS

UCAR

NSF

NASA

USAF

NOAA

NSPO

ONR