Multi-mission radio occultation climate reprocessing at the UCAR/COSMIC program

Doug Hunt, Shu-Peng Ho, Teresa VanHove
COSMIC Program, University Corporation for Atmospheric Research, Boulder, CO

Abstract

An active radio occultation data reprocessing effort has been underway for over 5 years at UCAR/COSMIC involving many important international RO missions including COSMIC, METOP-A/B, and CHAMP. The software used is the latest version of the mature CDAAC RO processing software which has been developed over the last 23 years and tested on 10 different radio occultation missions. In this study, the processing details are presented, along with inter-comparisons of the various missions. A new gridded dataset is also being generated with enhanced quality control which should be of interest to climate researchers. All data are available on the UCAR/COSMIC web site along with advanced tools for sub-setting and study. Products are archived along with complete software, configuration and processing system details in an effort to satisfy the demands of a climate-quality dataset.

The importance of reprocessing for developing climate data records

Long-term Climate Data Records (CDRs) constructed from stable and accurate measurements with adequate temporal and spatial coverage are essential for monitoring global and regional climate variability and understanding its forcing mechanisms. Current long-term measurements used to generate CDRs are mainly derived from satellite observations and in situ measurements. Global Positioning System (GPS) Radio Occultation (RO) data are currently the only satellite data that maintain SI traceability, providing measurements that are traceable to the international standard of time, the SI second. This traceability makes GPS RO a strong candidate for use as a climate benchmark.

Reprocessing at UCAR

- UCAR/CDAAC periodically reprocesses all radio occultation data for a specific satellite using uniform software
- Reprocessings include:
  - metopa2011
  - cosmic2013
  - champ2014
  - metopa2016
  - metopb2016
- In each case, the year indicates the year in which the reprocessing is undertaken
- Each of these is a major effort, usually requiring 6-9 months of time and a large compute cluster

Reprocessing steps

1. Create an SVN branch for the reprocessing (make sure no active CDAAC development impacts this reprocessing while it is going on)
2. Build a custom CDAAC release from this reprocessing branch (a new set of CDAAC RPMs)
3. Run the 37-step processing procedure for one sample month
4. Release to COSMIC staff to vet the dataset
5. Process whole mission
6. Release to COSMIC staff to vet
7. When approved, archive to NCAR mass storage system
8. Publish on CDAAC web site

Repeat as necessary

Repeat as necessary

The CPU time alone for processing METOP-A was over a month on a 150 processor Linux cluster

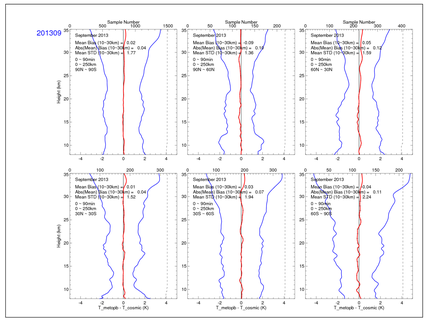
Archiving at UCAR/CDAAC

- Create monthly tar files of all important data product types (currently 59 file types stored for METOP)
  - Raw data, clock files, orbit files, pole files, model data, excess phase, dry profiles, wet profiles, etc
- Transfer these to the NCAR High Performance Storage System (HPSS). This is our 160 Petabyte archive system that has been continuously active since the 1970s.
- Archive as much data as possible about the software and operating environment used, including:
  - Full CDAAC source code, configuration, and database
  - Original install media for the Linux distribution used for processing
  - Full KVM virtual machine image of the installed and configured system
  - Sample days of processed data in required directories
  - Full SVN source tree of all CDAAC software
- A total of 11.1 TB of data archived for metopa2016, 4.3 TB for metopb2016

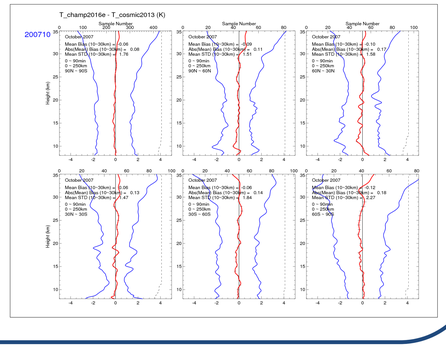
Inter-mission comparisons

- As part of our reprocessing strategy, periodic comparisons between separate missions must be performed
- These two plots show temperature comparisons between METOP-B, CHAMP, and COSMIC for one month
- Many other combinations of variable, mission, and time range are done

Metop-B – COSMIC2013 temperature profiles

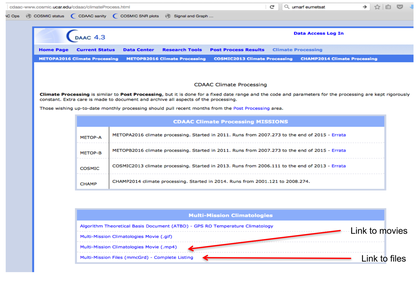


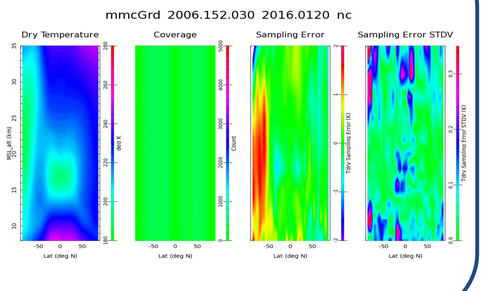
CHAMP2016 – COSMIC2013 temperature profiles



Multi-mission climatologies

- For several years as part of the ROTRENDS project, UCAR/CDAAC has been creating monthly mean climatologies for our various reprocessings
- Now, Ben Ho of CDAAC has unified several recent reprocessings into a set of Marvelous Multi-Mission Monthly Mean Climatologies
  - NetCDF format monthly files, in the format developed for the ROTRENDS project
  - Sampling error corrected using 3 models: NCEP, ERA-Interim, and MERRA
  - Thus not only the sampling error, but the sampling error error is computed
  - First version available contains only dry temperature. Other variables expected to follow





One application: Testing of weather models at high altitude

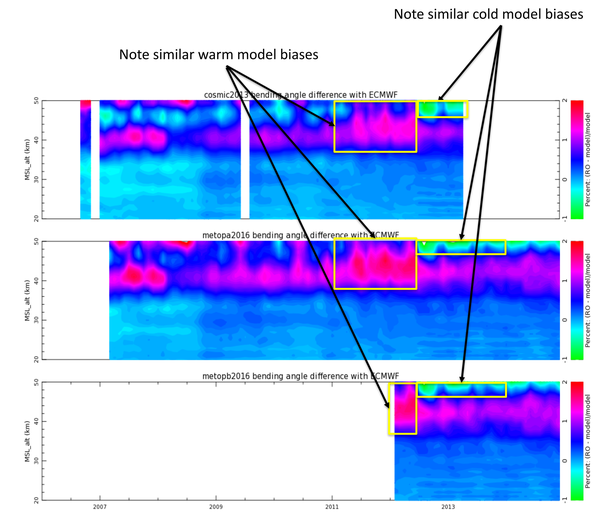
For many years, it was assumed that RO bending angle data above 40 km was too noisy to be of much use. The high altitude statistics comparing with model data showed large, seemingly random bias and large spread.

Now that we have several data sets from different missions processed in the same way, and consistent model data to compare them to, we can test this assumption.

The figure on the right shows COSMIC, METOP-A and METOP-B monthly average reprocessed bending angles compared to ECMWF high resolution analysis.

No climatology is used in bending angle retrievals.

Note the excellent correlation over time between RO missions.



How to obtain these reprocessed data

These reprocessed data and gridded climatologies are all available on the CDAAC web site at cdaac-www.cosmic.ucar.edu. They can be analyzed and downloaded in several different ways

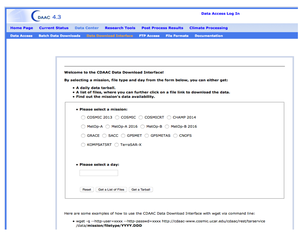
Available data

File Type	Description
podCrx	Low rate (1 second) Compressed RINEX for orbit determination
opnGps	High rate GPS occultation data
leoClk	LEO clock corrections
comClk	GPS clock corrections
podTec	Absolute TEC
leoOrb	LEO orbits
echPrf, eraPrf, gfsPrf, sonPrf	Comparison profiles from weather models and radio sondes
atmPhs	Occultation excess phase
atmPrf	Dry inverted profiles
wetPrf	pressure/temperature/moisture profiles
bfrPrf	BUFR profiles

CDAAC data download interface

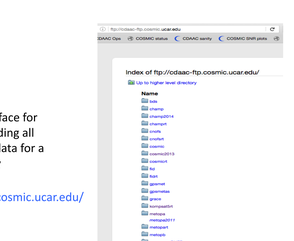
Web interface for downloading data by date, mission and file type.

Can be used either manually or in a script via wget or curl



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

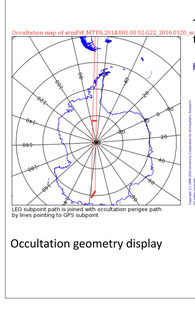
CDAAC FTP interface



FTP interface for downloading all mission data for a given day

ftp://cdaac-ftp.cosmic.ucar.edu/

CDAAC web tool



Occultation geometry display

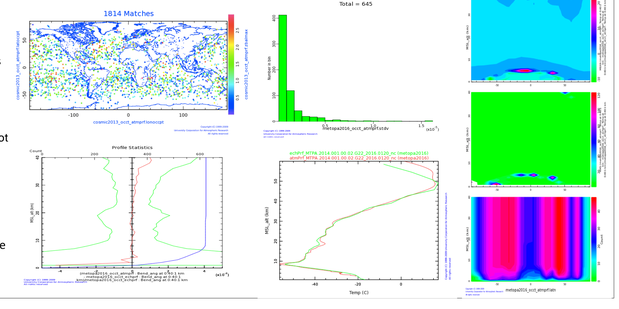
The CDAAC web site has a powerful research tool that is open to the public:

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

- Queries and displays database and file data from all processed CDAAC missions including reprocessed missions
- Can be used to download .tar files containing files selected by custom queries
- Over 430 Gigabytes of database in 900 database tables
- Over 25 TB of processed RO mission data
- Dozens of SQL database tables with hundreds of attributes can be queried and displayed

Numerous plots and displays available to all users.

- 3D scatter plot map
- Histogram
- Profile comparison
- Profile statistics
- Binned profile statistics



Conclusion

- Reprocessing at UCAR is a long-term commitment that was started in 2011
- 4 missions have so far been reprocessed: COSMIC, METOP-A, METOP-B, and CHAMP.
- Complete archiving and documentation is done.
- Extensive inter-comparisons are done, including participation in the **rotrends** project to compare with other centers.
- Multi-mission climatologies are available for those who prefer to work with gridded data.
- Well-developed tools are available for download and analysis on the cdaac-www web site.

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