METOP-A and -B GRAS Reprocessing at UCAR: Details of this Interesting New Dataset

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Overview

• Introduction
• Steps involved in UCAR/COSMIC reprocessings
• Processing steps used for METOP/GRAS data
• Improvements since last METOP-A reprocessing (metopa2011)
• New UCAR climate products
• Tools available to the public for downloading and analyzing the results
• An interesting comparison of CDAAC reprocessings
• Conclusion
METOP processing at UCAR

- UCAR has been processing METOP-A and –B data in real-time, post-processing and reprocessing modes since 2007.
- The last METOP reprocessing was the METOP-A 2011 reprocessing. There have been many changes in the METOP processing suite at UCAR and also METOP-B has come online. It was time for a new reprocessing!
- `metopa2016` and `metopb2016` reprocessings now available on the CDAAC web site:
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Reprocessings 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

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
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Approach to processing GRAS data

1. Pre-process all the different packet types into one uniform, gap-filled 50Hz phase-connected file per occultation
2. Push these through CDAAC’s standard closed-loop excess phase and inversion processing

Our investigation has shown that in most cases it is sufficient to down-sample the 1000Hz data to 50Hz without substantial loss of information, rather than to process the 1000Hz data separately at full resolution. This also makes it easier to use the existing CDAAC processing stream.
CDAAC processing of METOP data

Level 0 data → IMT/GPS processing → level 0-1 converter

- 1s POD data
- NAV solutions
- 50Hz occ data
- 1000Hz occ data

- LEO orbit processing
- METOP attitude processing

- LEO orbits
  - LEO clocks
  - Attitude data

- occ table generation
  - occ table

New for METOP
External data source

- GPS NAV bits
- GPS orbits
- GPS clocks
- 50Hz full phase
- Standard CDAAC processing
Standard CDAAC processing

1. Excess phase processing: Combine the 50Hz occultation data with GPS and LEO clocks and orbits to generate an excess phase (atmPhs) file
2. Inversion processing: Run a closed-loop version of the CDAAC inversion software (newroam) including geometric optics and wave optics processing to generate bending angle, refractivity, and dry temperature profiles
3. Generate profiles from radio sondes and weather models for comparison and as first guess in the 1D var step
4. 1D variational assimilation: Combining refractivity with ERA-Interim model data to generate pressure, temperature and moisture profiles
5. Generate BUFR files
6. Create Monthly Mean Climatologies
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CDAAC software improvements since the metopa2011 reprocessing

- **Low-level processing**
  - Full cycle slip fixing in 1000Hz data
  - Smooth joining of open-loop and closed-loop data sections
  - Updated to Instrument Data Base v1.2 from EUMETSAT (new antenna phase patterns for POD antenna)

- **New excess phase code**
  - Includes METOP-specific QC checks and corrections

- **New inversion code (newroam)**
  - Processes all occultations and applies modified QC
  - In support of climate applications, uses uniform heights for:
    - Blending of climatology in the stratosphere
    - Transition to wave optics processing
    - Transition from ionospheric correction to extrapolation
  - Much higher occultation count (22% increase!)
  - See Sokolovskiy’s presentation to the 2014 ROM SAF workshop for details on other changes
Old METOP-A reprocessing

Ref: metopa2011-echprf, 2009.001-031 LEO1
New METOP-A reprocessing

Ref: metopa2016-echprf, 2009.001-031 LEO1
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New 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.
New Multi-Mission Climatologies

CDAAC Climate Processing

Climate Processing is similar to Post Processing, but it is done for a fixed date range and the code and parameters for the processing are kept rigorously constant. Extra care is made to document and archive all aspects of the processing.

Those wishing up-to-date monthly processing should pull recent months from the Post Processing area.

CDAAC Climate Processing MISSIONS

<table>
<thead>
<tr>
<th>MISSION</th>
<th>Description</th>
<th>Details</th>
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Multi-Mission Climatologies

- Algorithm Theoretical Basis Document (ATBD) - GPS RO Temperature Climatology
- Multi-Mission Climatologies Movie (.gif)
- Multi-Mission Climatologies Movie (.mp4)
- Multi-Mission Files (mmcGrd) - Complete Listing

Link to movies

Link to files
New Multi-Mission Climatologies

mmcGrd 2006.152.030 2016.0120 nc
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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

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

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
Single profile comparison with model or radiosonde data

- Can plot any pair of parameters from multiple views of an occultation
- Here is shown an METOP-A temperature profile compared with ECMWF
1-, 2- and 3-D scatter plots of database scalar parameters or data file slices. If lat/lon are selected, a map will be displayed.

- Here is a plot of COSMIC boundary layer height for the latter half of 2010.
Statistics plots:
- Histograms for scalar variables (here is shown bending angle noise for METOP-A for day 2014.00)
For profile variables, standard ‘mean, stdv and count’ plots are shown

- Here are shown 0-40km bending angle differences between METOP-A and ECMWF
Binned statistics plots can also be generated. Here is a 0-40km temperature comparison between METOP-A and ECMWF binned by occultation latitude. Comparisons with NCEP and radio sondes are also available.
Direct comparisons between different missions are also possible, with user-specified time-and-space window between occultations.

- Here is a 0-40km bending angle comparison for one day between METOPA2016 and COSMIC2013
• This is a very short introduction to the CDAAC web database tool
• New, updated help pages can be found at:
• A simpler, less powerful interface to some of the same functionality can be found at:
  – http://cdaac-www.cosmic.ucar.edu/cdaac/DBif/cdaac_highlevel.cgi
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Comparing high altitude data from CDAAC reprocessings of multiple missions

- I had always assumed that RO data above 40km was so noisy as to not be useful
- 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 next slide shows a movie of COSMIC, METOP-A and METOP-B reprocessed bending angles compared to ECMWF high resolution analysis
- Note that no climatology is used in bending angle retrievals
Correlation between reprocessings and ECMWF (bending angle)
Comparing high altitude data from several CDAAC reprocessings

- So, bending angle biases also correlate well between missions.
- What does this imply?

- Either there is something consistently going wrong in our processing from 35-50 km, something which varies by month, or the model has biases at these altitudes which vary by month. Investigation is needed...
Conclusion

- A six-month long reprocessing of METOP-A and METOP-B has been finished at CDAAC. Results are on our web site:
- These data are improved with respect to our previous reprocessings, including many more occultations and algorithms designed to better support climate research
- A Multi-Mission Monthly climatology is now also available, along with full documentation
- Advanced tools exist on the CDAAC web site to delve into these data: