ECMWF/GRAS SAF workshop on:
Assimilation of GPS Radio-Occultation Measurements

The Work of the GRAS SAF

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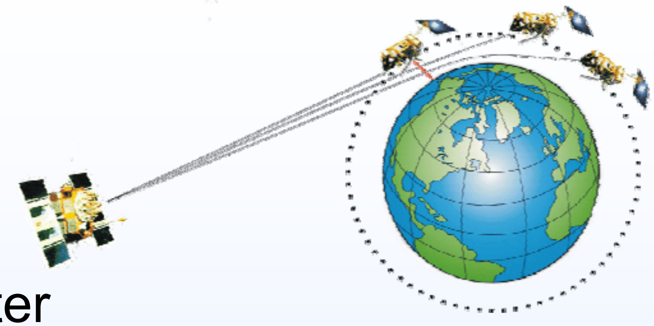
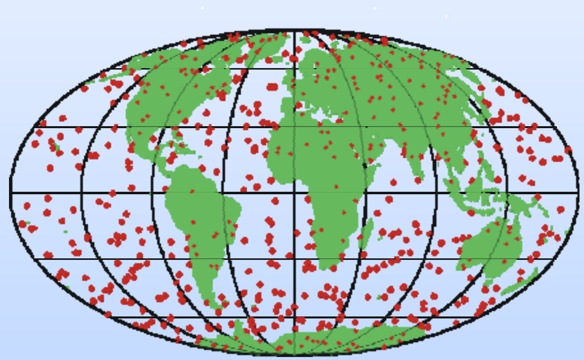
GRAS SAF

Outline

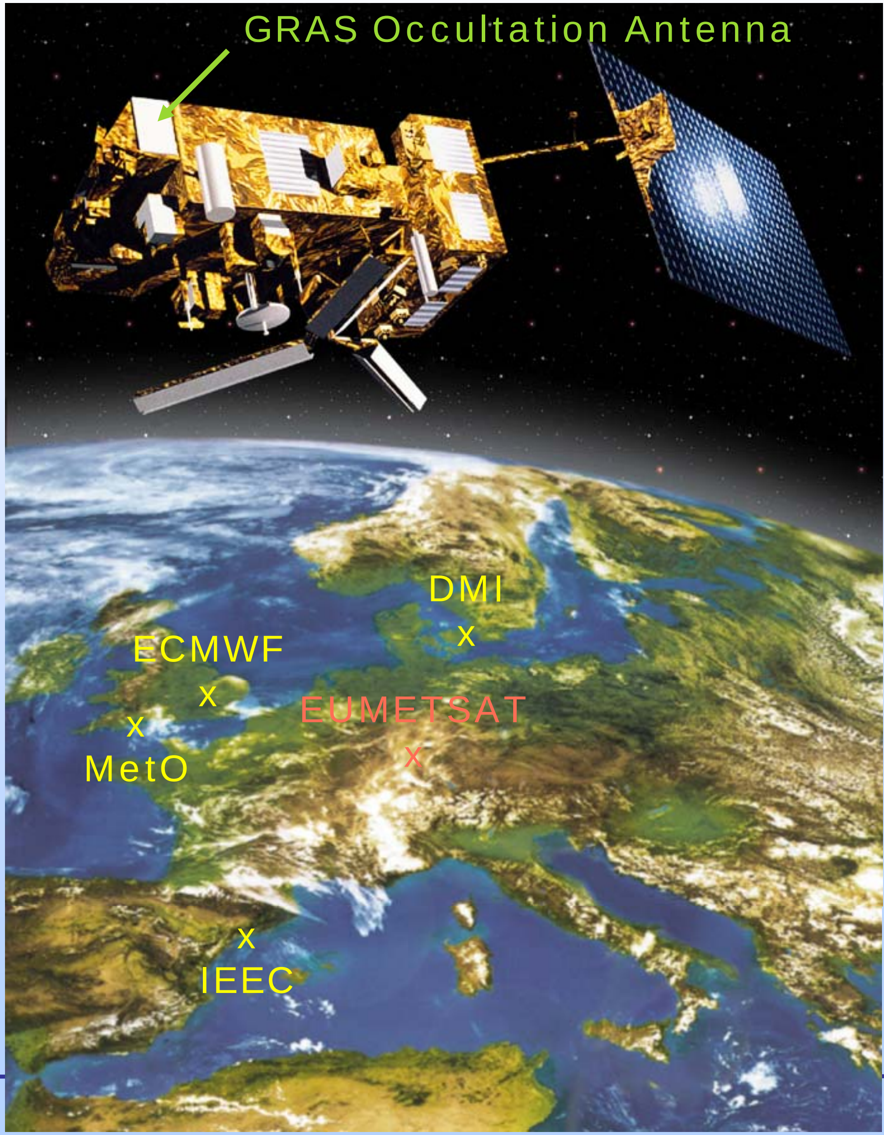


- The GRAS SAF Project
  - Operational Processing and Archiving Center
  - NRT, Offline and Climate Products
- ROPP software package
  - 2D bending angle operators
- Analyses of GRAS data from MetOp
- Climate applications of RO data
- Surface reflections
- Summary



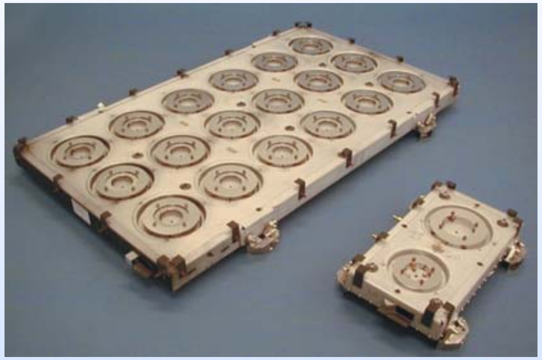
The GRAS Instrument on MetOp

***MetOp**: successfully launched on Oct 19, 2006*



***GRAS**: built by Saab Space, Sweden*
(2 R & 2 S channels; raw sampling)

GRAS Antennas



GRAS Electronics

GRAS: **G**lobal navigation satellite system **R**eceiver for **A**tmospheric **S**ounding

GRAS SAF Consortium

Global navigation satellite system
Receiver for
Atmospheric
Sounding
(instrument on MetOp)

Satellite
Application
Facility
(of EUMETSAT)

Leading Entity: Danish Meteorological Institute (Copenhagen, Denmark)

Kent B. Lauritsen (Project Manager), Hans Gleisner, Rune Larsen (Operations Manager), Frans Rubek, Stig Syndergaard, Martin B. Sørensen

Partners: ECMWF (Reading, UK)

Sean Healy

Institute d'Estudis Espacials de Catalunya (IEEC, Barcelona, Spain)

Estel Cardellach, Santi Oliveras, Antonio Rius

Met Office (Exeter, UK)

Dave Offiler, Huw Lewis, Michael Rennie

***Associate Scientist**: Josep Aparicio (MSC)*

The GRAS SAF Objectives

EUMETSAT-funded project that develops an operational radio occultation system based on RO data from the GRAS instrument onboard MetOp

Led by DMI, Denmark, with three partner institutes:
1) ECMWF, 2) IEEC (Barcelona), 3) Met Office

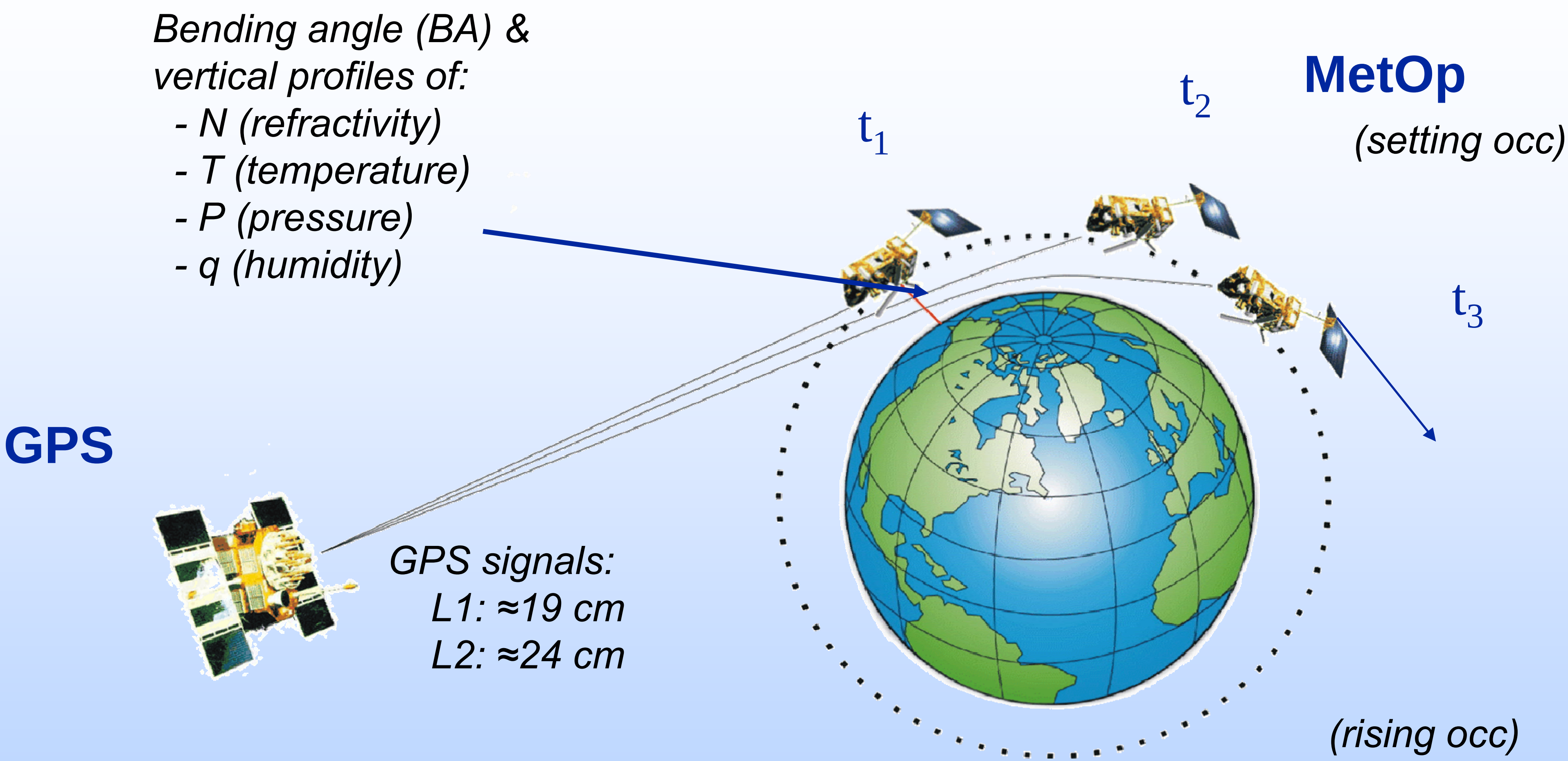
Objectives

Operational processing and archiving center for GRAS radio occultation data

Center for knowledge of RO processing and related research

Deliver NWP assimilation software (**ROPP**) and radio occultation data products:
- operational products in **NRT** (refractivity, temperature, pressure, humidity profiles)
- **offline products**, monthly (reprocessed, improved profiles)
- **climate products**: e.g., maps of refractivity, temperature, geopotential height

Atmosphere Profiling by Radio Occultation (RO)



While a GPS satellite 'sets' or 'rises' behind the horizon:

- Additional bending of the GPS signal's ray path due to refraction in the atmosphere
- The GPS receiver measures the excess Doppler shift

GRAS SAF

GRAS Occultations: 1 day (~650 occ's)

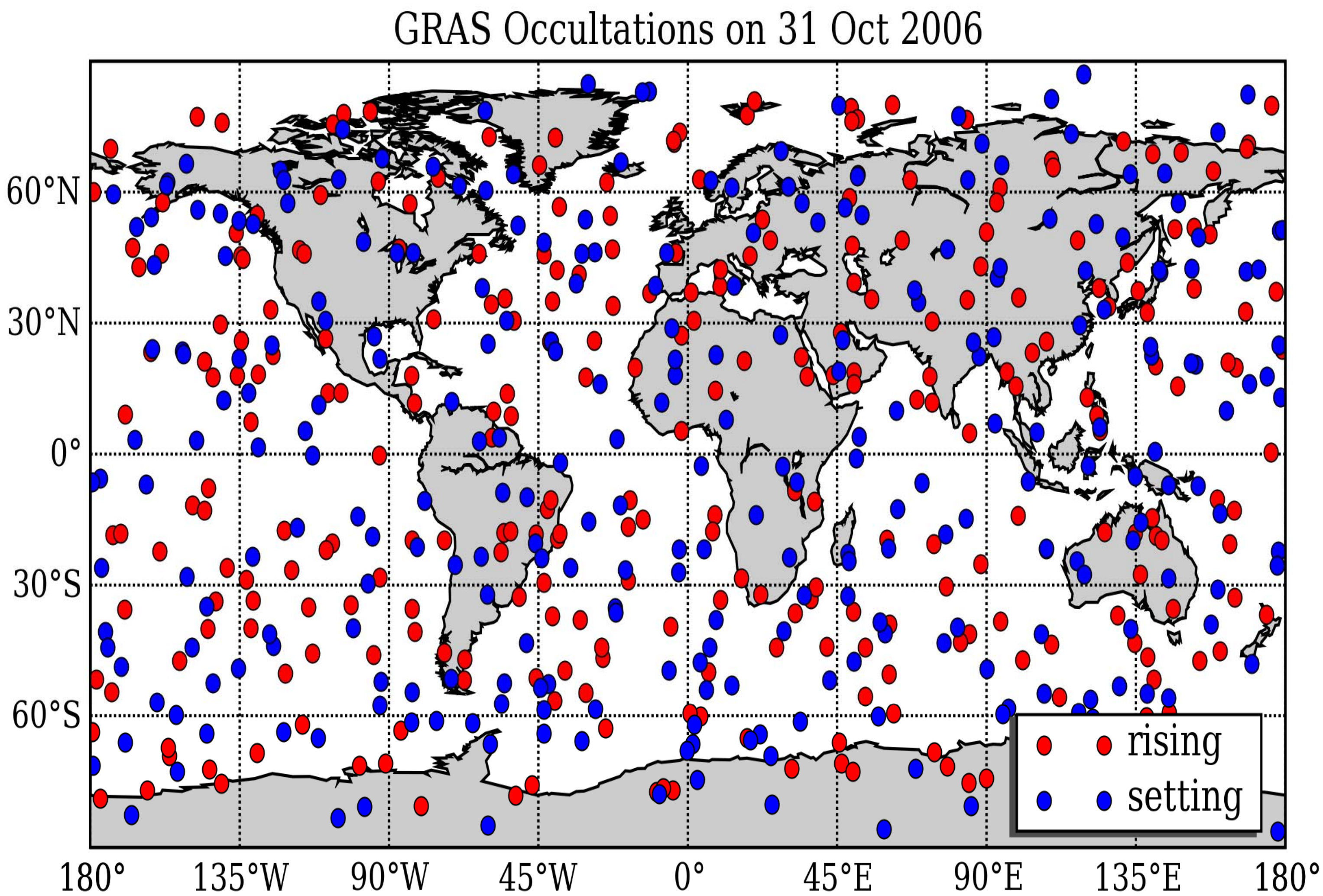


Figure from Christian Marquardt, EUMETSAT

GRAS Occultations: 9 days

(9 days: 27/28 Dec 2006, 20 – 26 February 2007, ~ 5600+ occultations)

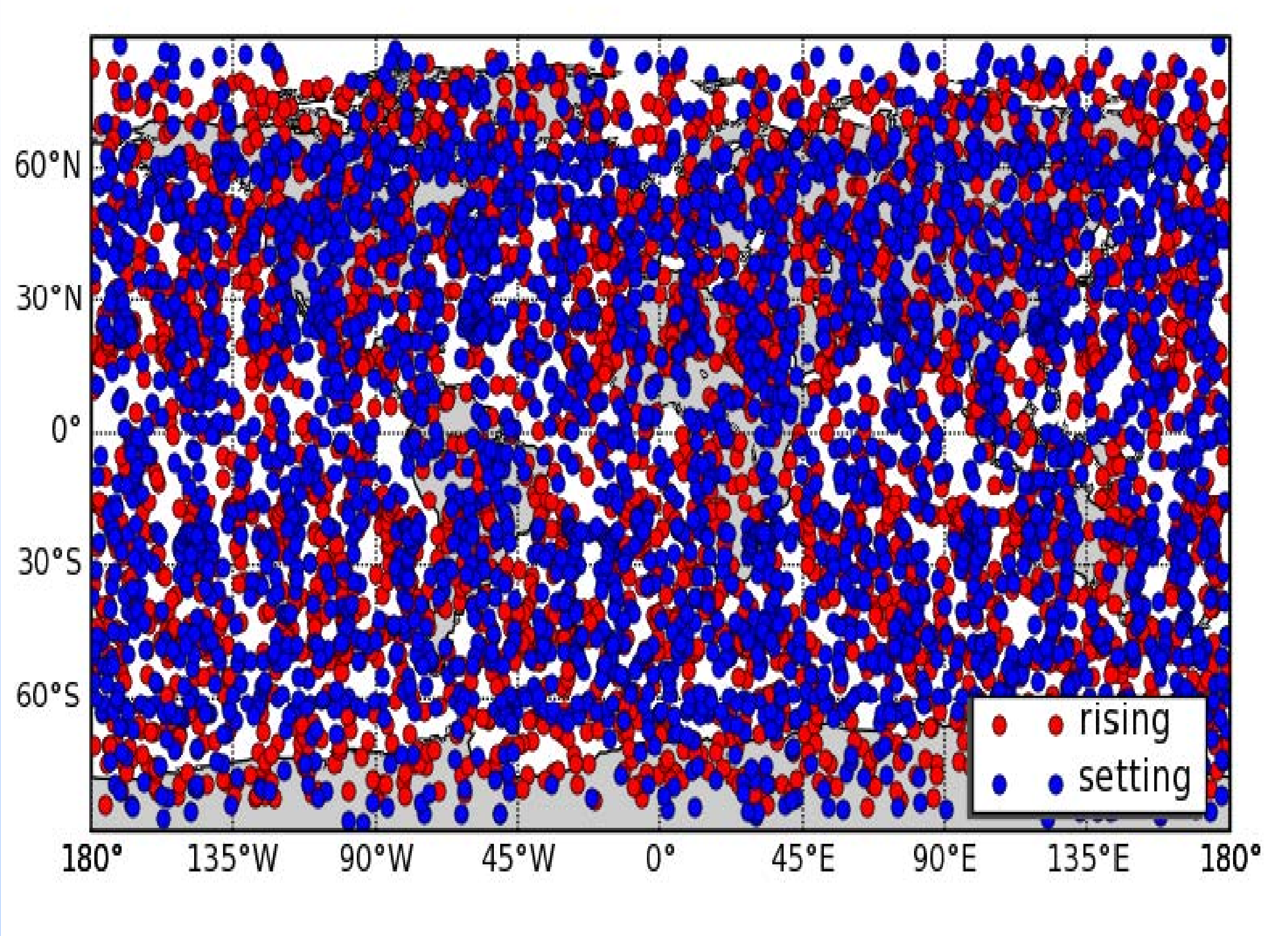


Figure from Christian Marquardt, EUMETSAT

Advantages of GPS Atmosphere Profiling

Absolute measurement

The radio occultation (RO) technique needs no calibration. The basics of the observation is a measurement of time.

Global coverage

The geometry of the observation for one satellite leads to evenly distributed data on a 24-hour interval. Observations over land and oceans (covering about 70% of the Earth) minimize the major error source of weather forecast and climate models.

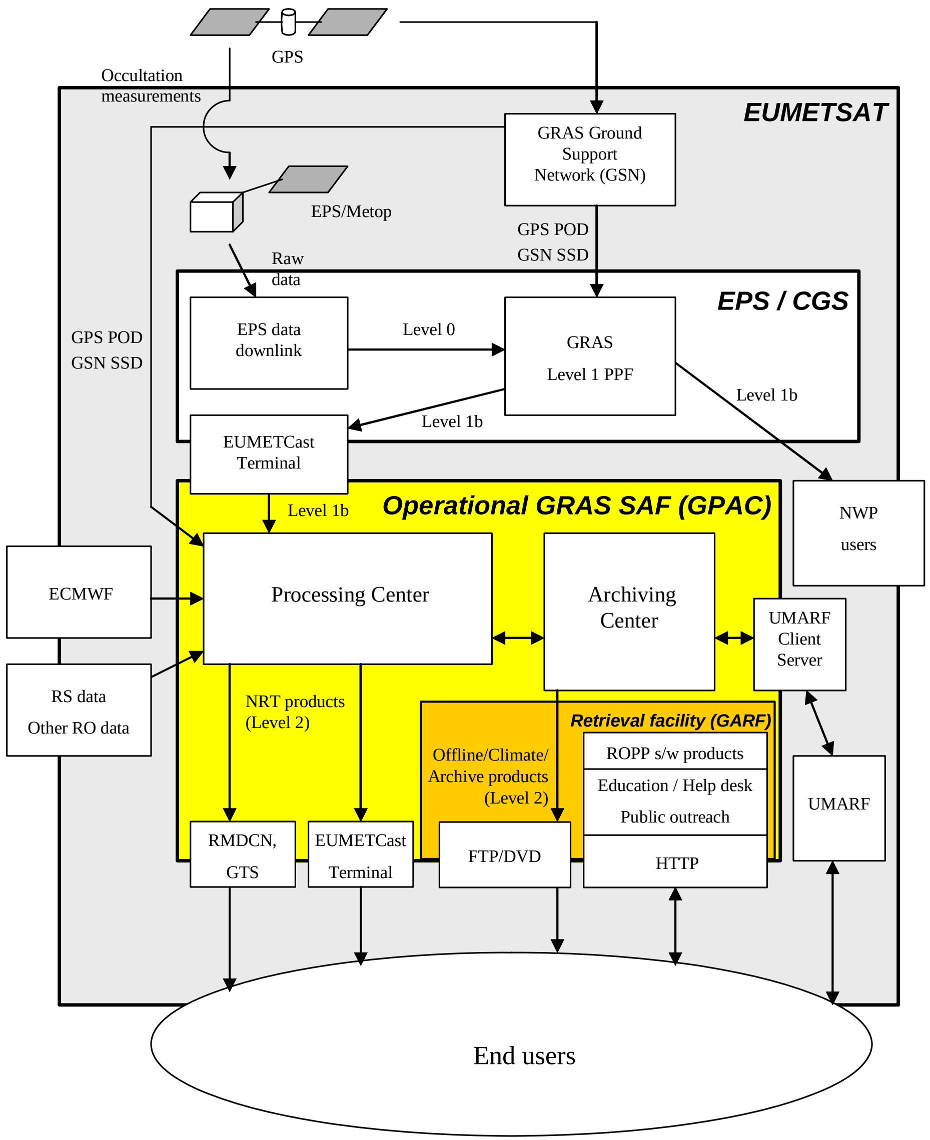
Very high vertical resolution

The vertical resolution when using canonical transform methods (FSI, CT2) leads to information of atmosphere phenomena with scale sizes of about 100-200 m.

Insensitive to clouds and precipitation

The applied GPS wavelengths (L1: ≈19 cm; L2: ≈24 cm) makes the measurement transparent to clouds and rain hampering other space techniques.

GRAS SAF Processing and Archiving Center



GPAC

GRAS SAF Processing and Archiving Center

(*Operational system at DMI for processing and archiving of products, and containing the GARF product retrieval facility*)

GARF

GRAS SAF Archive and Retrieval Facility

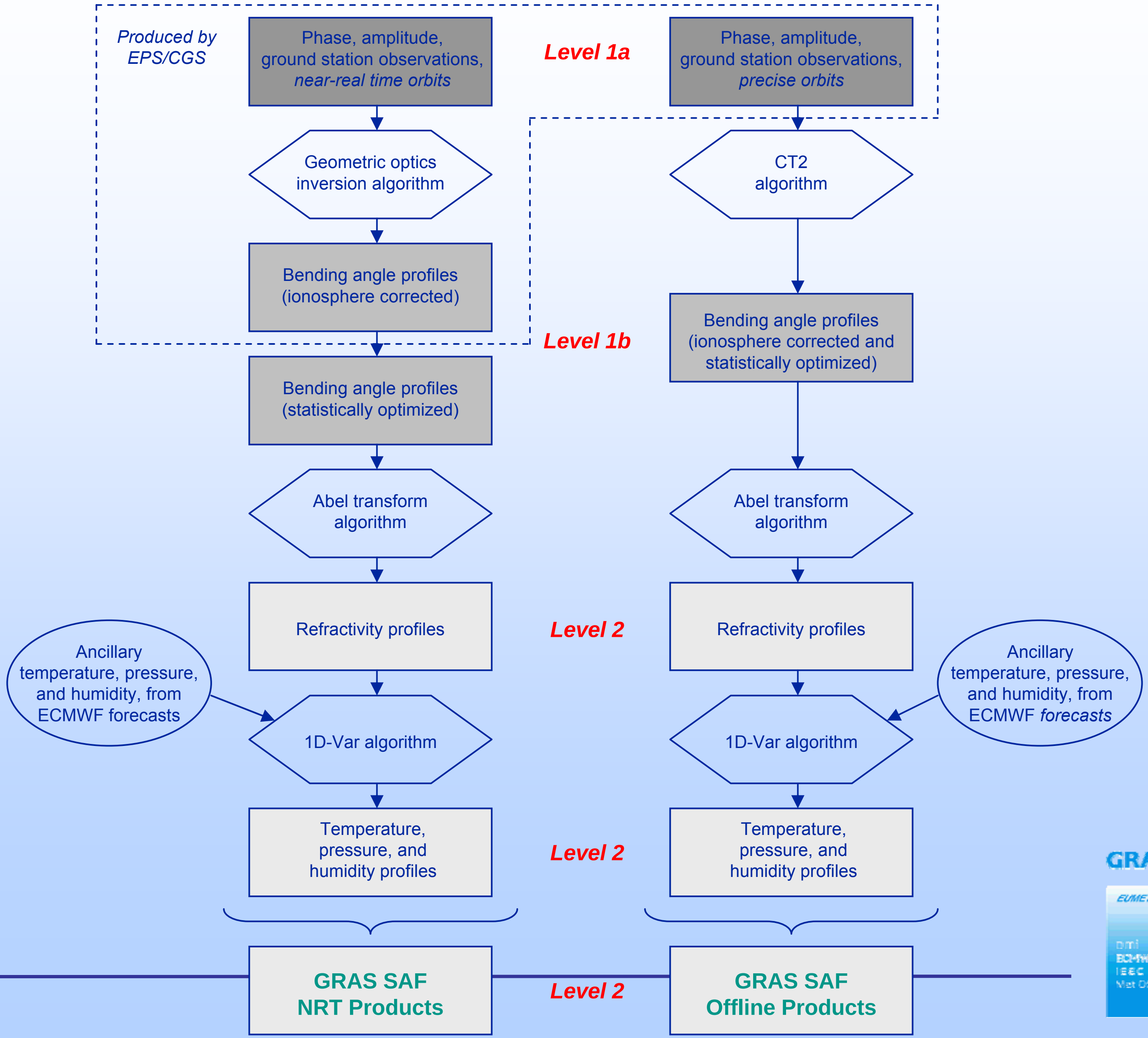
(*Webtool subsystem (of the operational system) for registration, helpdesk, and retrieval of data and software (ROPP) products*)

ROPP

Radio Occultation Processing Package

(*Software deliverable to assist NWP users in using RO products*)

NRT and Offline Processing Overview



GRAS SAF Main Products Overview

Data Product	*Characteristics*
Bending Angle	Bending angle as a function of impact parameter (only offline)
Refractivity Profile	Neutral Refractivity as a function of height and location of the occultation
Temperature, humidity, and pressure profiles	Temperature, specific humidity, pressure and error estimates as a function of height and location of the occultation
Climate Data	Offline profiles (reprocessed data), and maps of refractivity, temperature, and geopotential height
ROPP Assimilation S/W	Statistically optimal 1D-Var refractivity & BA retrieval code; Forward models for 3D/4D-Var assimilation: - Plane-averaged refractivity forward model for assimilation into an NWP model - Direct assimilation of bending angle (1D or 2D) into an NWP model

ROPP Objectives

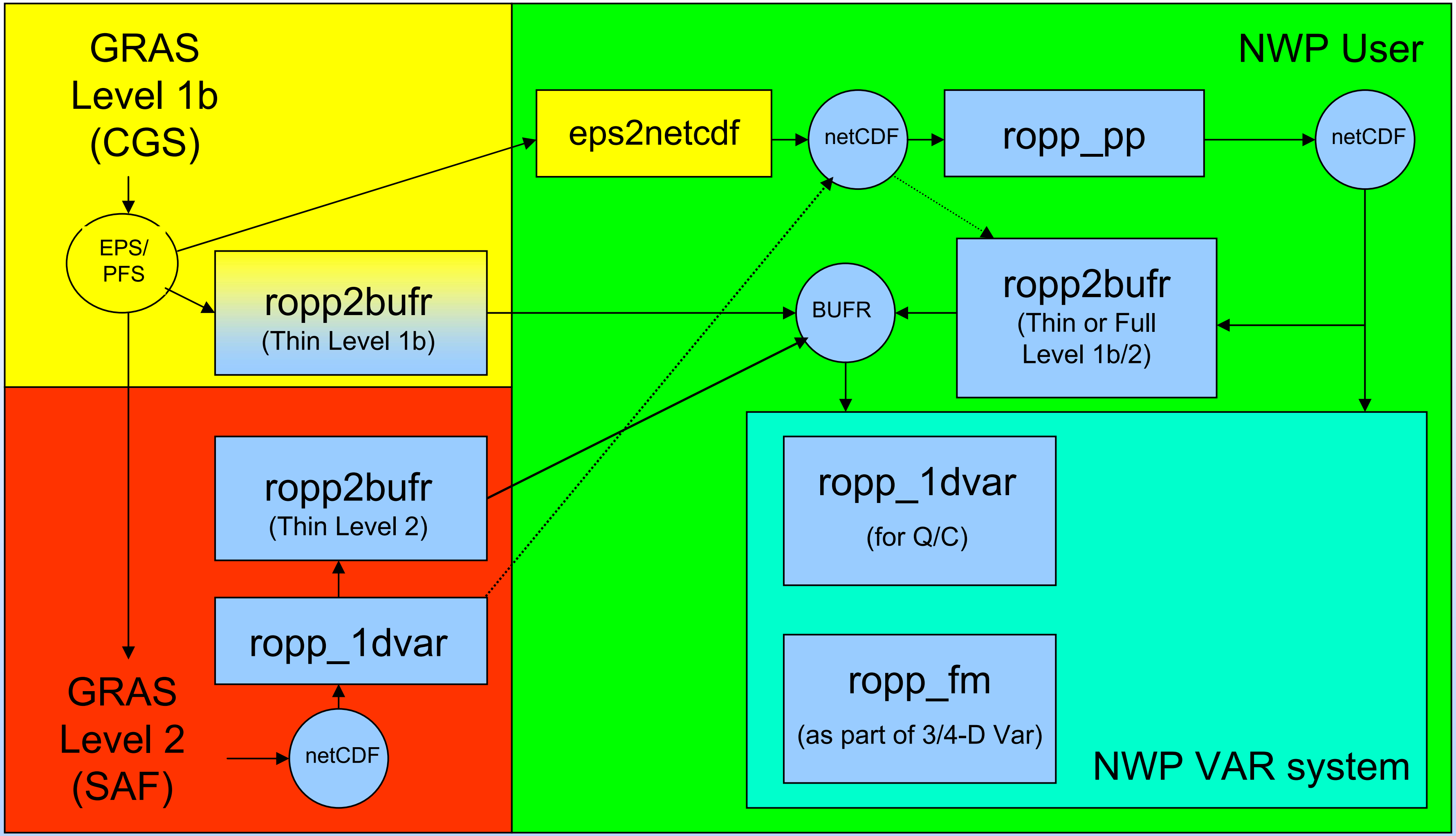
To provide users with a comprehensive software package, containing all necessary functions to pre-process RO data from CGS Level 1b files or GRAS SAF Level 2 files, plus RO-specific components to assist with the assimilation of these data.

Implemented as a set of pick'n'mix modules. Some 3rd party freeware support libraries required (e.g. netCDF)

Releases

- ROPP-1 (v1.0) formally released on 12 April 2007
- Update (v1.1) formally released on 10 April 2008

ROPP Context



NWP Assimilation of GPS RO Data

Several results at Met Office and ECMWF (and M-F, MSC, NCEP, DWD) have demonstrated the **positive impact** of GPS RO on NWP forecasts;

Within the GRAS SAF:

Met Office
4D-VAR (assimilating N with 1D operator)
CHAMP, GRACE-A, COSMIC RO data used operationally
GRAS to be added later this year

ECMWF
4D-VAR (assimilating BA with 1D & 2D operators)
COSMIC, GRACE-A, COSMIC RO data used operationally
GRAS: since May 2008

Status of GRAS data

EUMETSAT:

- GRAS on MetOp performs very well (inc. raw sampling mode)
- pre-operational level 1b bending angle data: 15 March 2008
- operational level 1b bending angle data: 17 April 2008

GRAS SAF:

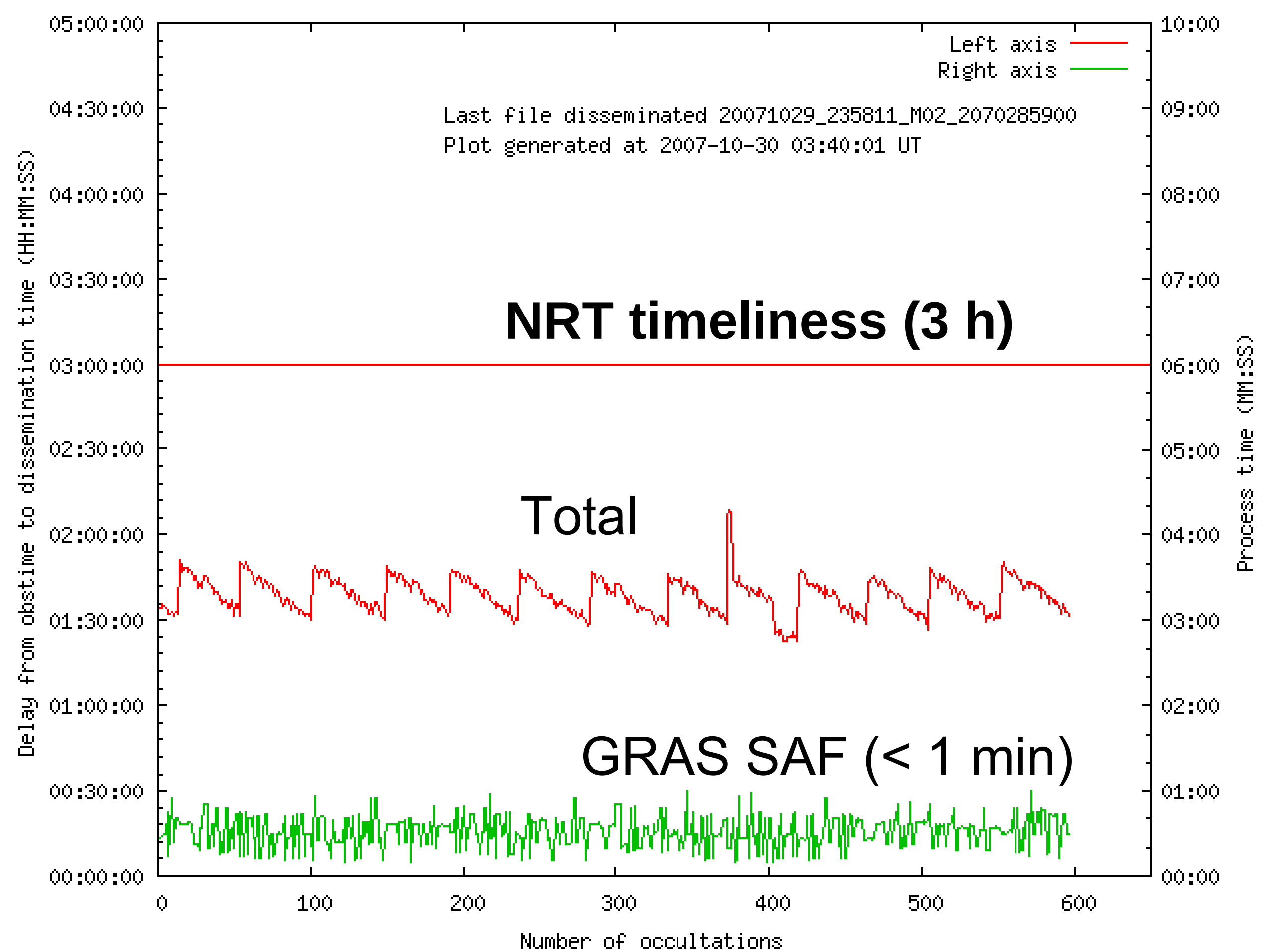
- refractivity data (level 2) currently being validated
- refractivity data (and thinned level 1b BA data) expected from Sept 2008
- available in BUFR file over GTS and BUFR/netCDF over EUMETCast

Archived GRAS SAF data will be obtainable here:

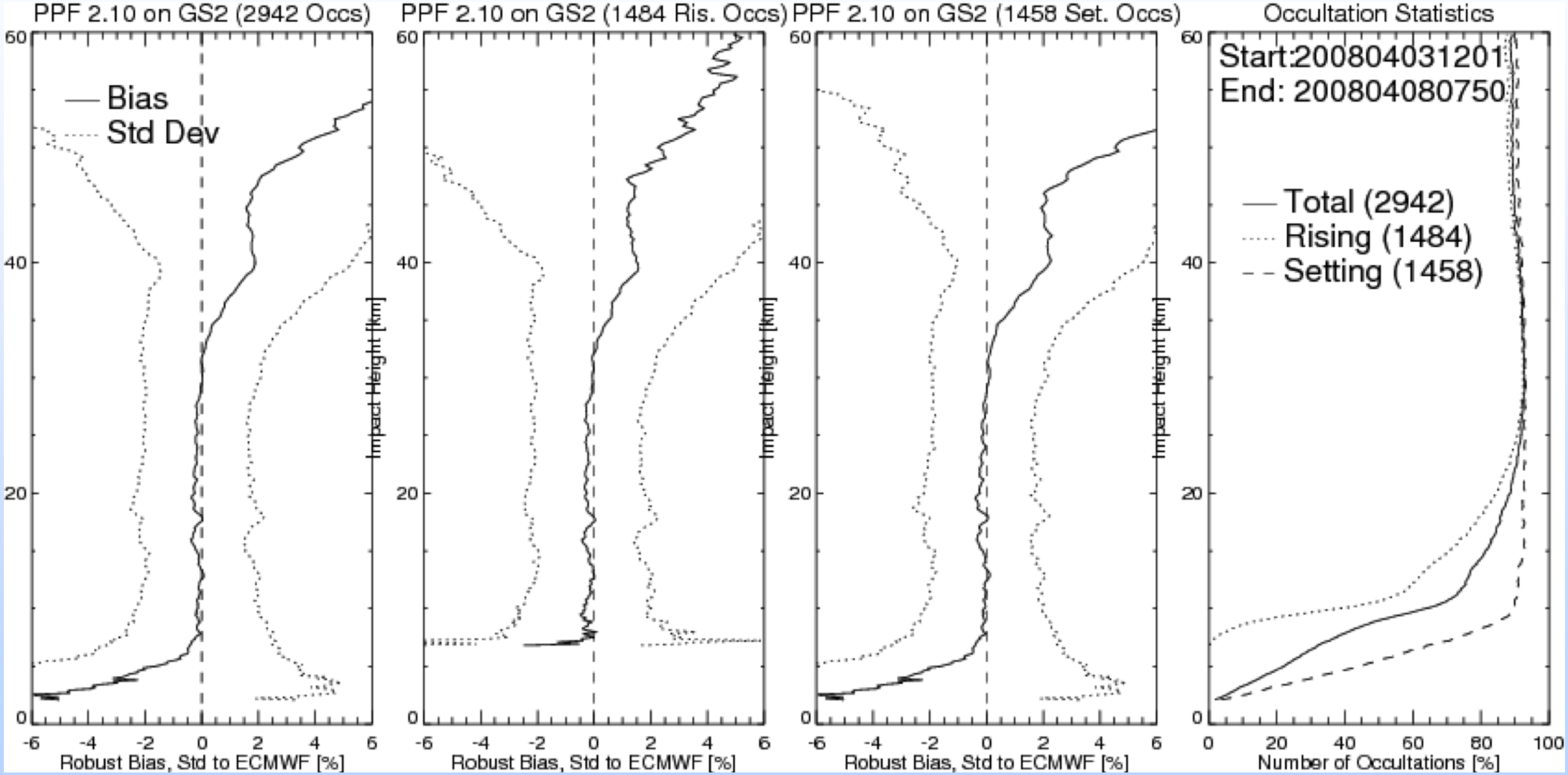
→ www.grassaf.org

Processing times

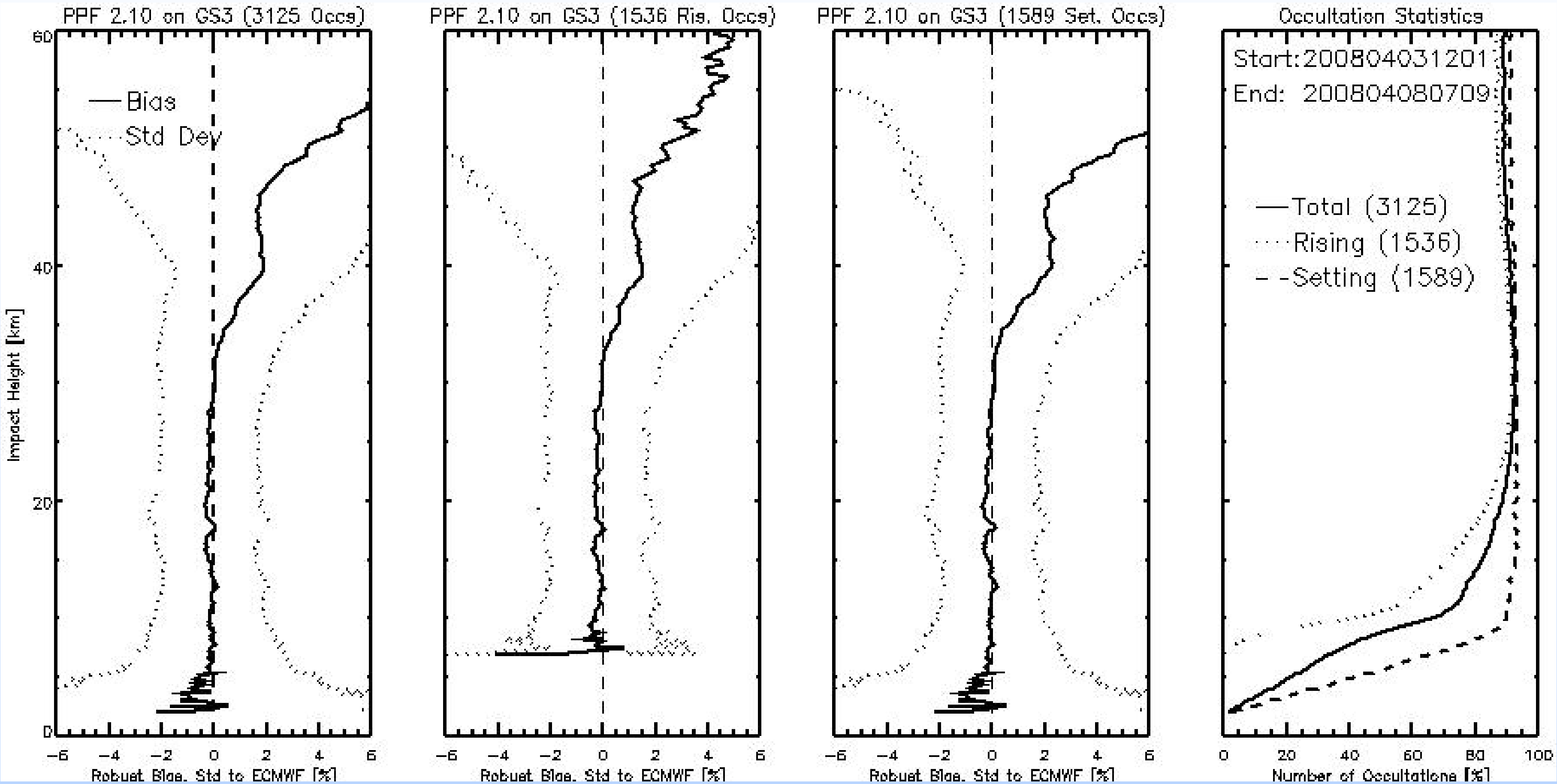
29 Oct 2007: GRAS SAF level 1b to level 2 processing and dissemination



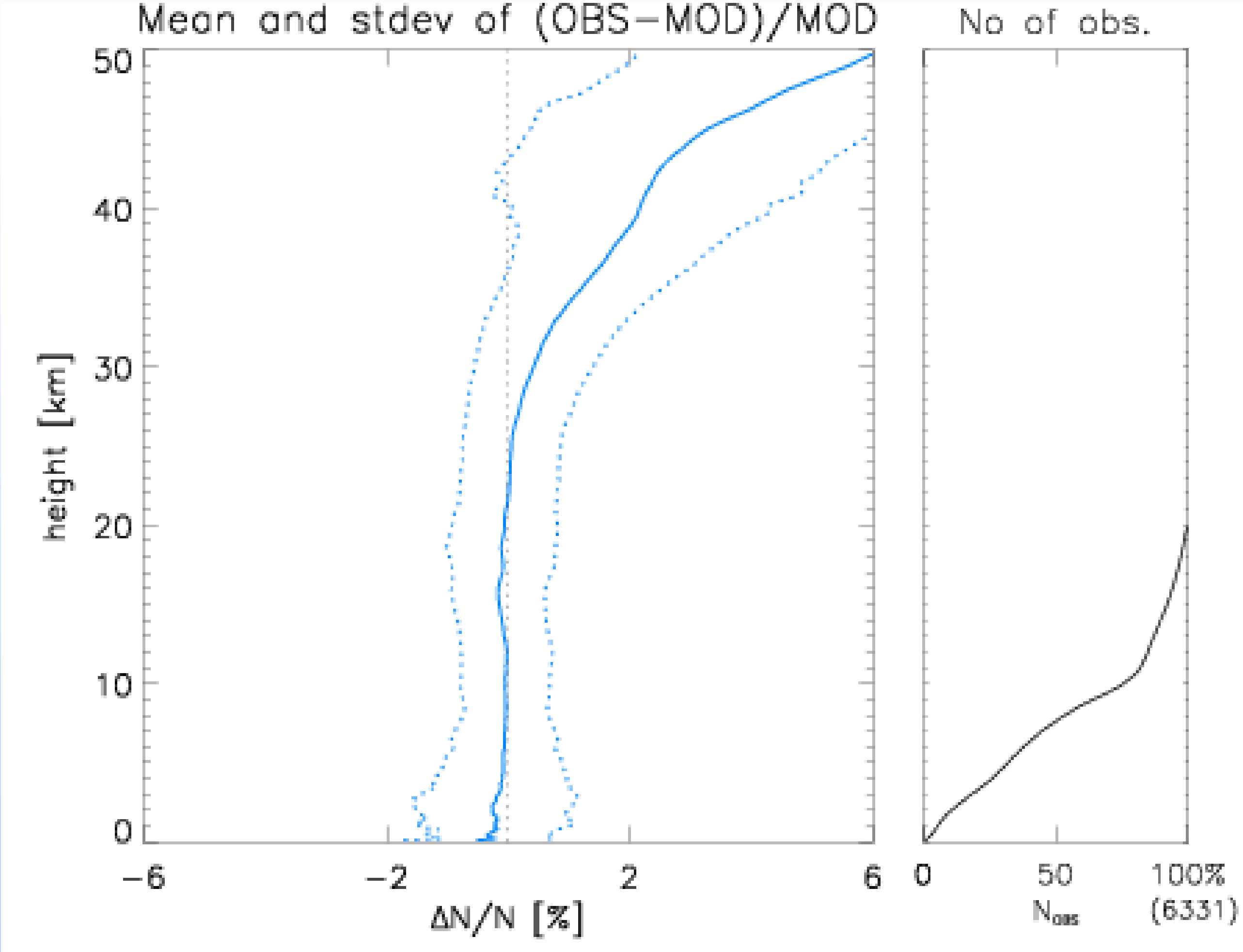
EUMETSAT bending angles (PPF 2.10)



EUMETSAT BA with sorting (PPF 2.10)

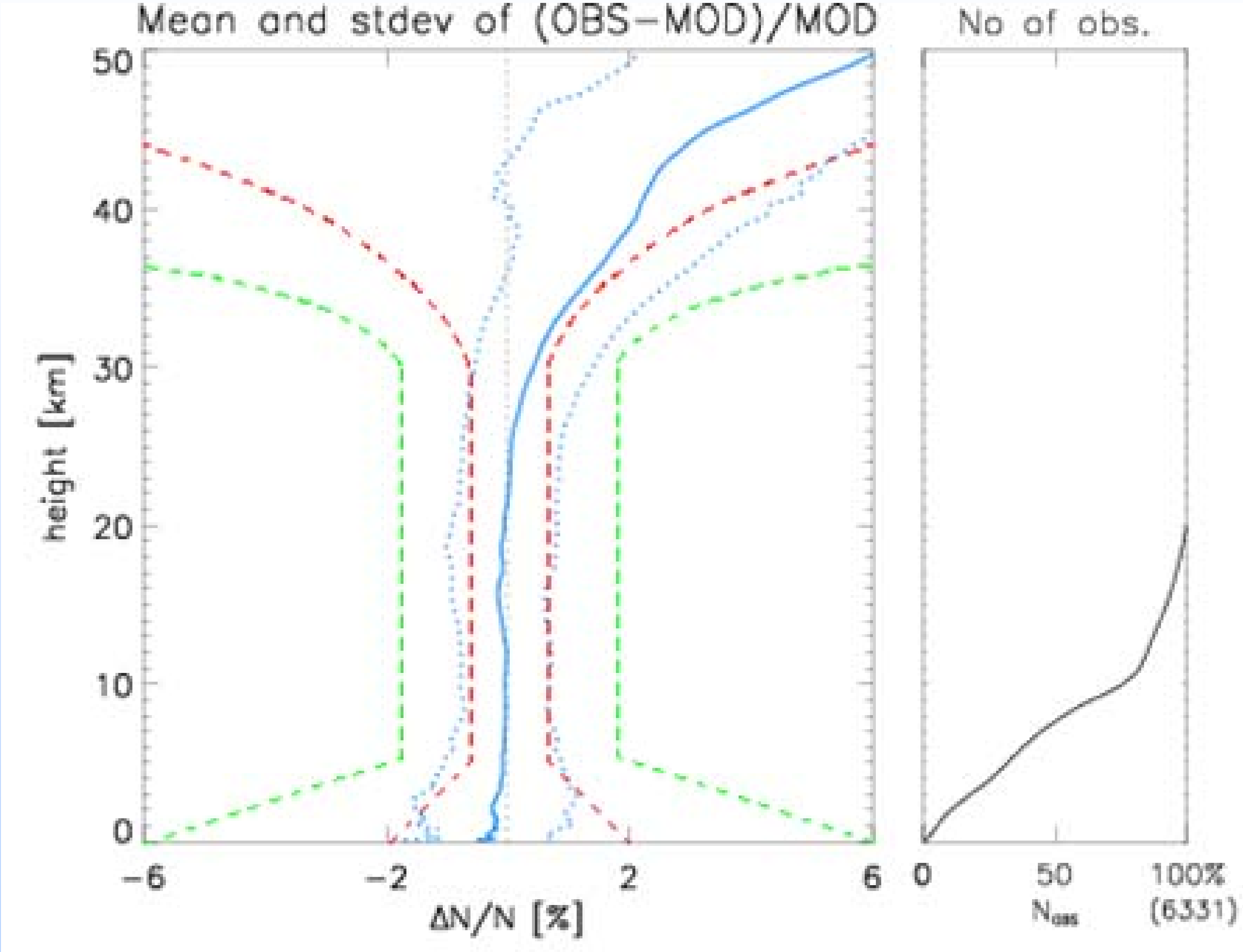


Refractivity: O-B/B (all occultations, two weeks of May)

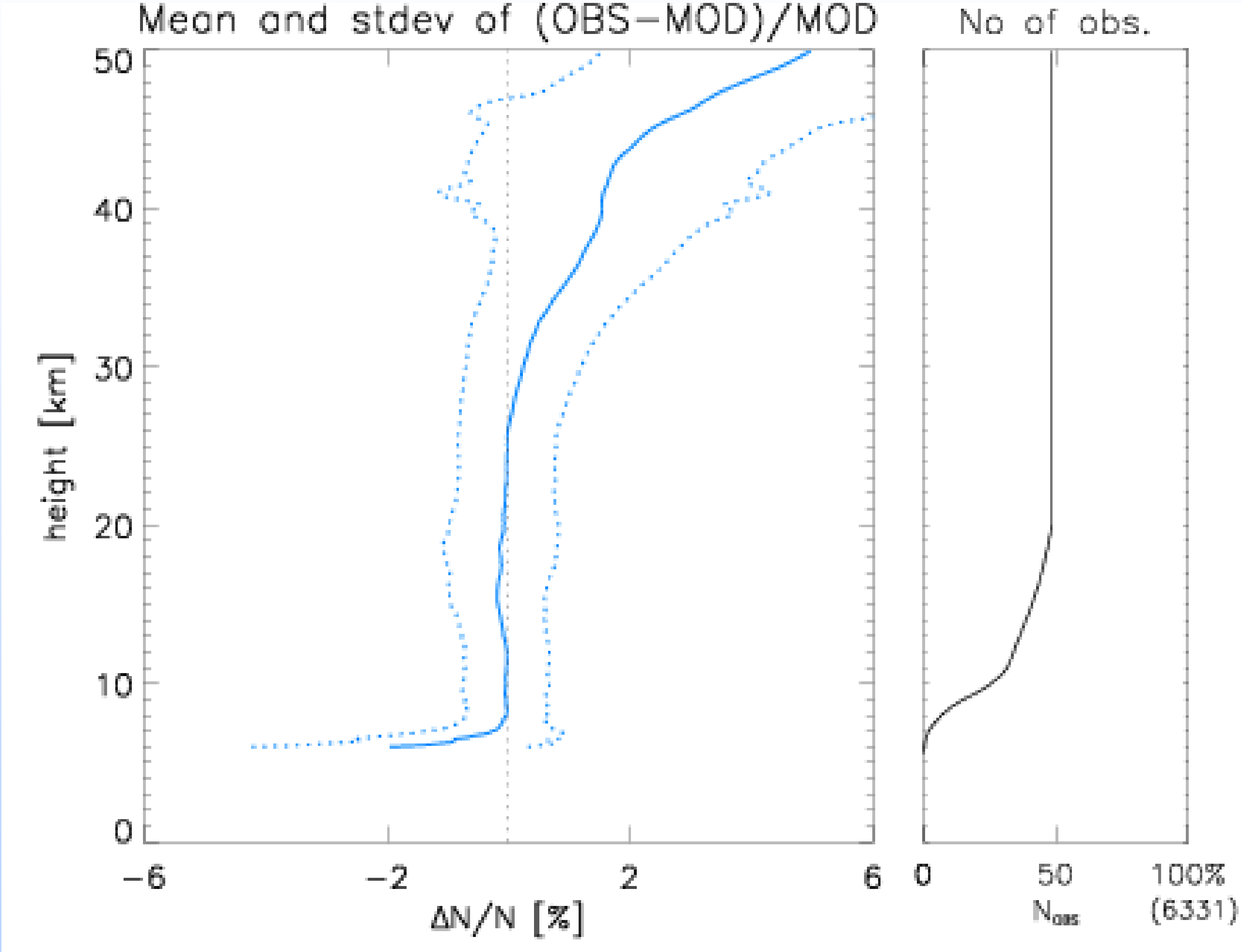


GRAS SAF
EUMETSAT
dmi
ECMWF
IEEC
Met Office

Refractivity target and threshold accuracies



Rising only



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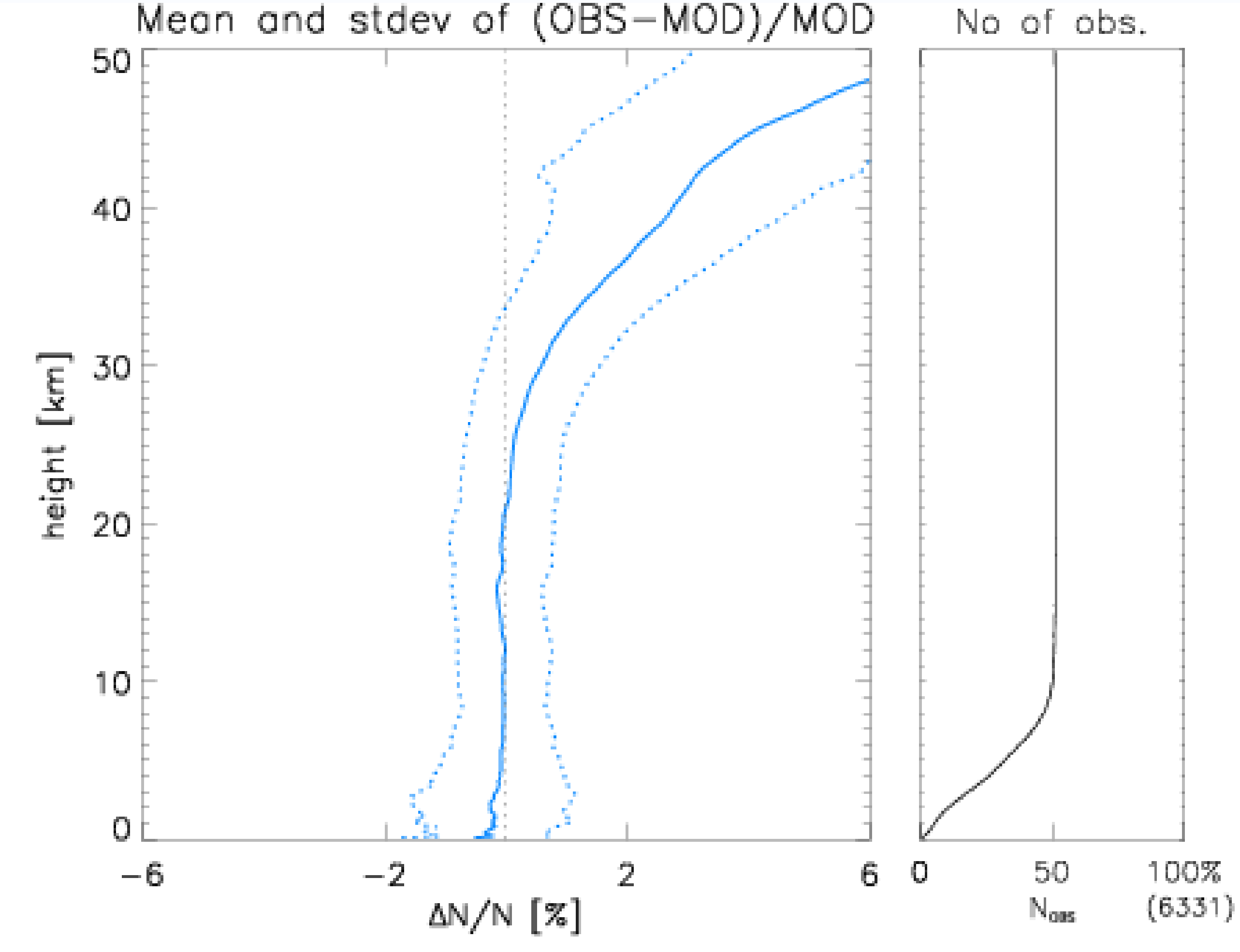
Setting only



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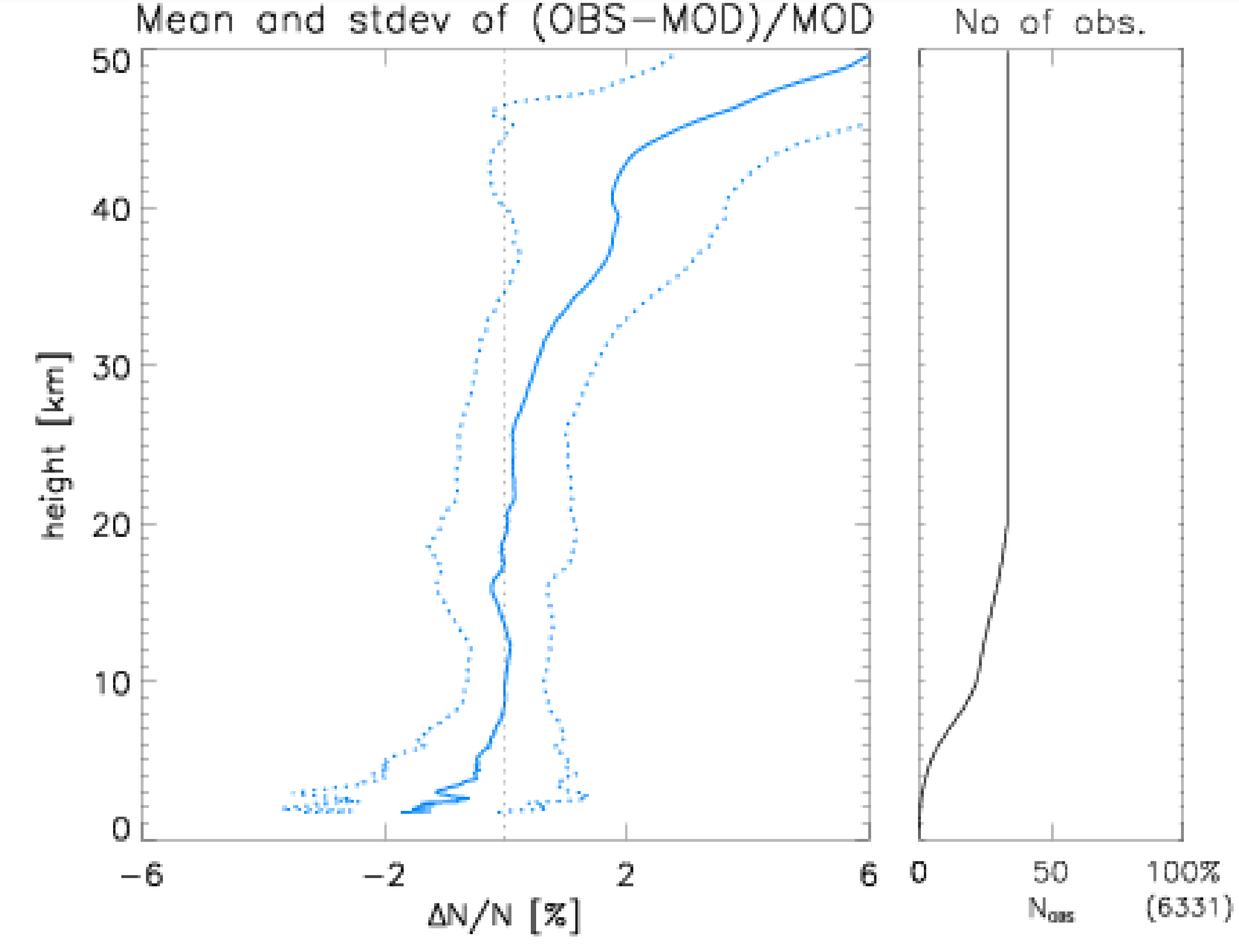
Low latitudes



Current QC criteria on refractivity

Profiles are flagged if one of the following occurs:

- Refractivity profile does not reach below 20 km
- Abs((O-B)/B) ≥ 10% somewhere below 35 km
- Refractivity profile reach below model surface
- Altitude is not monotonically increasing
- Refractivity is negative

GRAS SAF climate data products

– development plans –

- *process the RO profile data into climate data products, consisting of*
  - – standard climate variables: temperature, humidity, geopotential heights
  - – non-standard climate variables: RO bending angle, RO refractivity
  - – estimates of errors (sampling + observational)
- *develop and study relevant climate data sets, including*
  - – investigations of the joint use of CHAMP / COSMIC / MetOp RO data
  - – comparisons of RO based climate data with data sets based on radio-sondes, MSU/AMSU, and reanalyses
- *provide climate data as a user service for climate research and monitoring*

GRAS SAF climate data products

The GRAS SAF climate data products are built upon the existing offline products.
The climate products extend the range of such products offered to users.

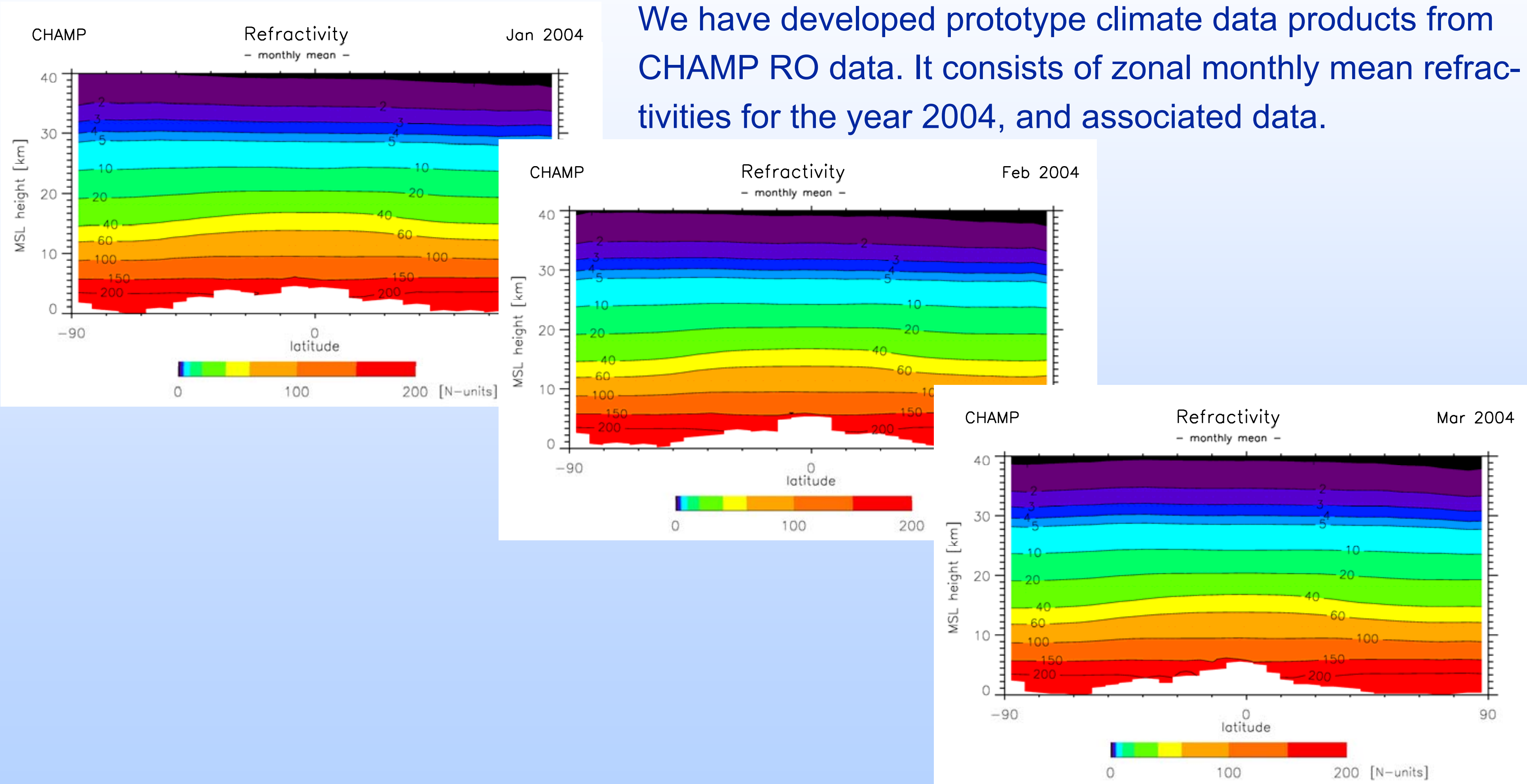
Climate data product	2D zonal grid: [1] climate + errors	Time resolution	Spatial [2] resolution	*Formats, graphical*	*Formats, numerical*	*Time plan* [3]
CBA: bending angle	yes	Monthly	5 deg latitude	PNG, JPG	ASCII, netCDF	Q2 2010
CRG: refractivity	yes	Monthly	5 deg latitude	PNG, JPG	ASCII, netCDF	Q2 2010
CTE: temperature	yes	Monthly	5 deg latitude	PNG, JPG	ASCII, netCDF	Q2 2010
CHG: spec. humidity	yes	Monthly	5 deg latitude	PNG, JPG	ASCII, netCDF	Q2 2010
CZG: geopot. height	yes	Monthly	5 deg latitude	PNG, JPG	ASCII, netCDF	Q2 2010

[1] A latitude-height grid where the height can be expressed in MSL height, geopotential height, or in terms of pressure.
[2] The maximum resolution in height is determined by the height resolution of the profiles.
[3] Suggested start of operations, assuming a Climate ORR in Q1 2010.

Prototype climate data products

– zonal monthly-mean refractivity from CHAMP RO data –

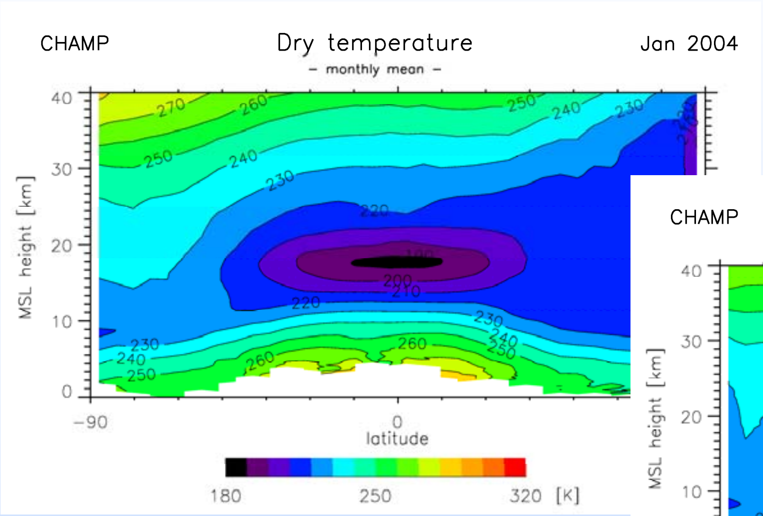
We have developed prototype climate data products from CHAMP RO data. It consists of zonal monthly mean refractivities for the year 2004, and associated data.

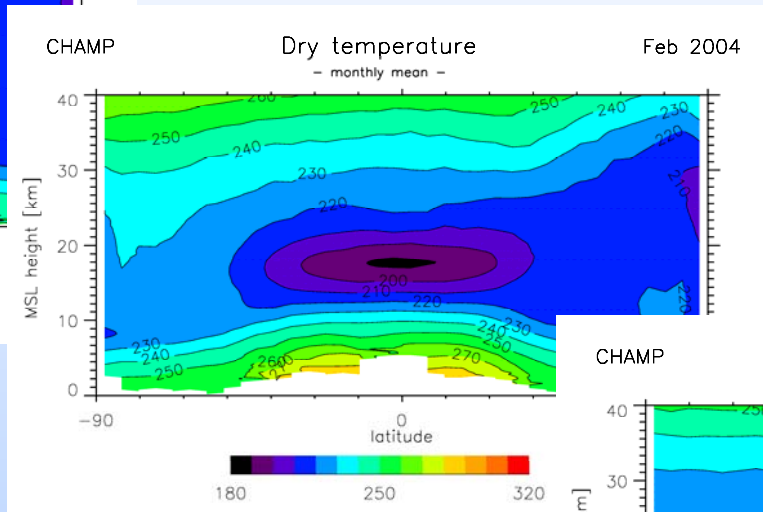


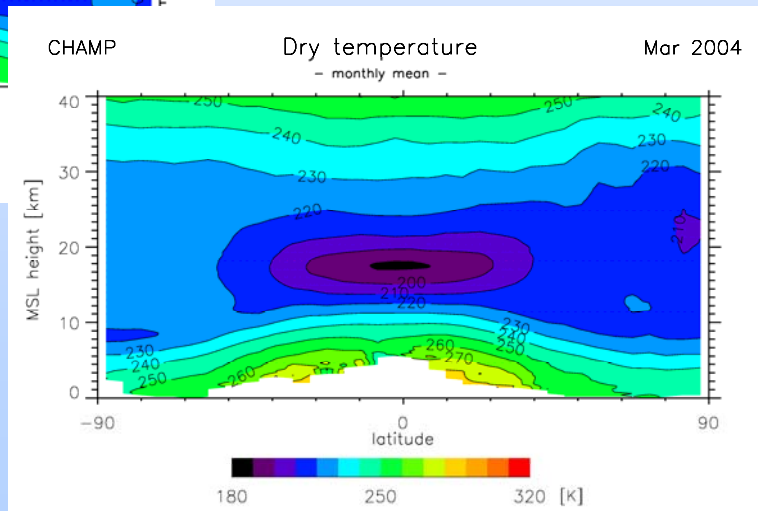
Prototype climate data products

– zonal monthly-mean “dry” temperature from CHAMP RO data –

Dry temperature is not a formal GRAS SAF climate product. However, above 10 km it is essentially identical to ordinary temperature.

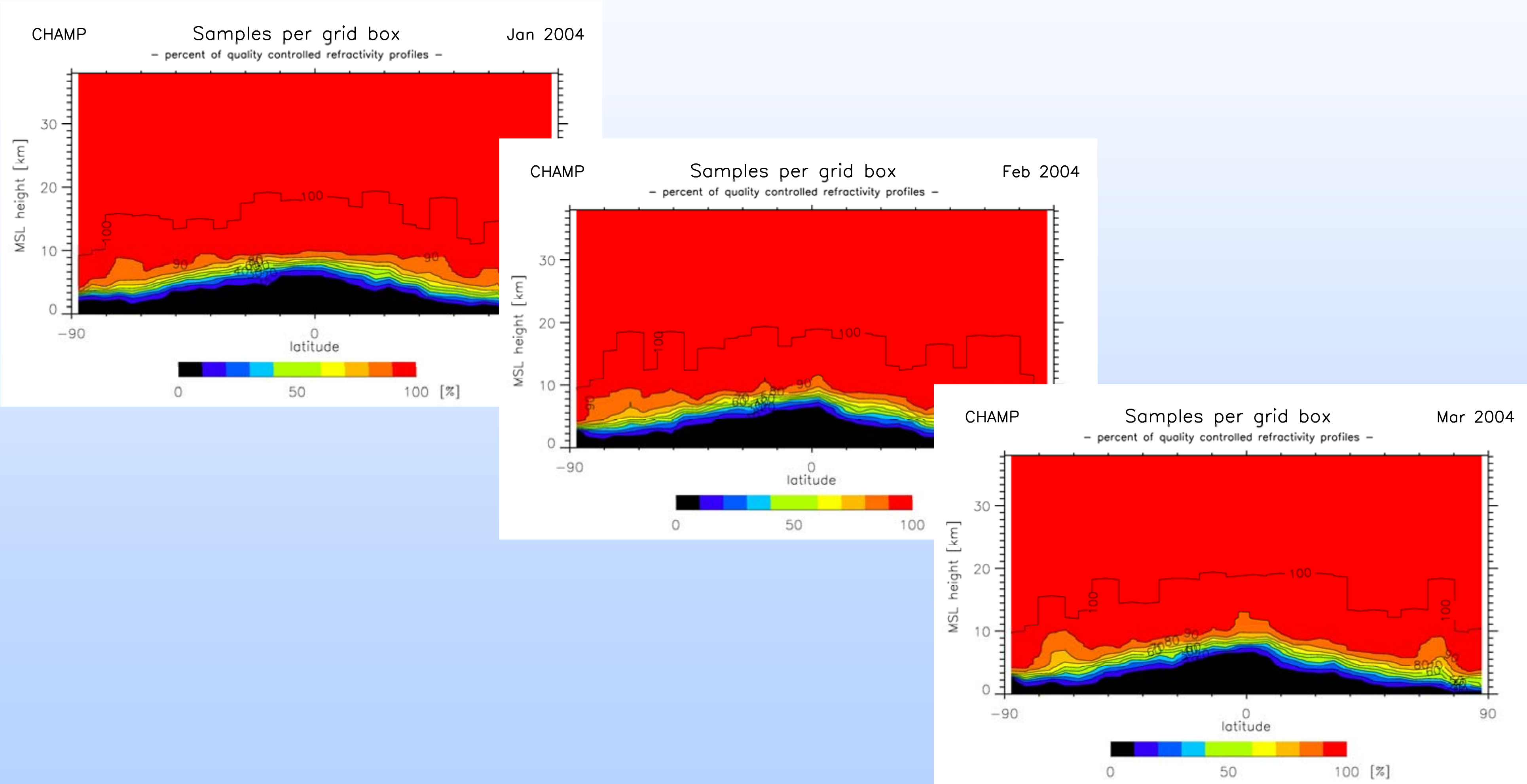






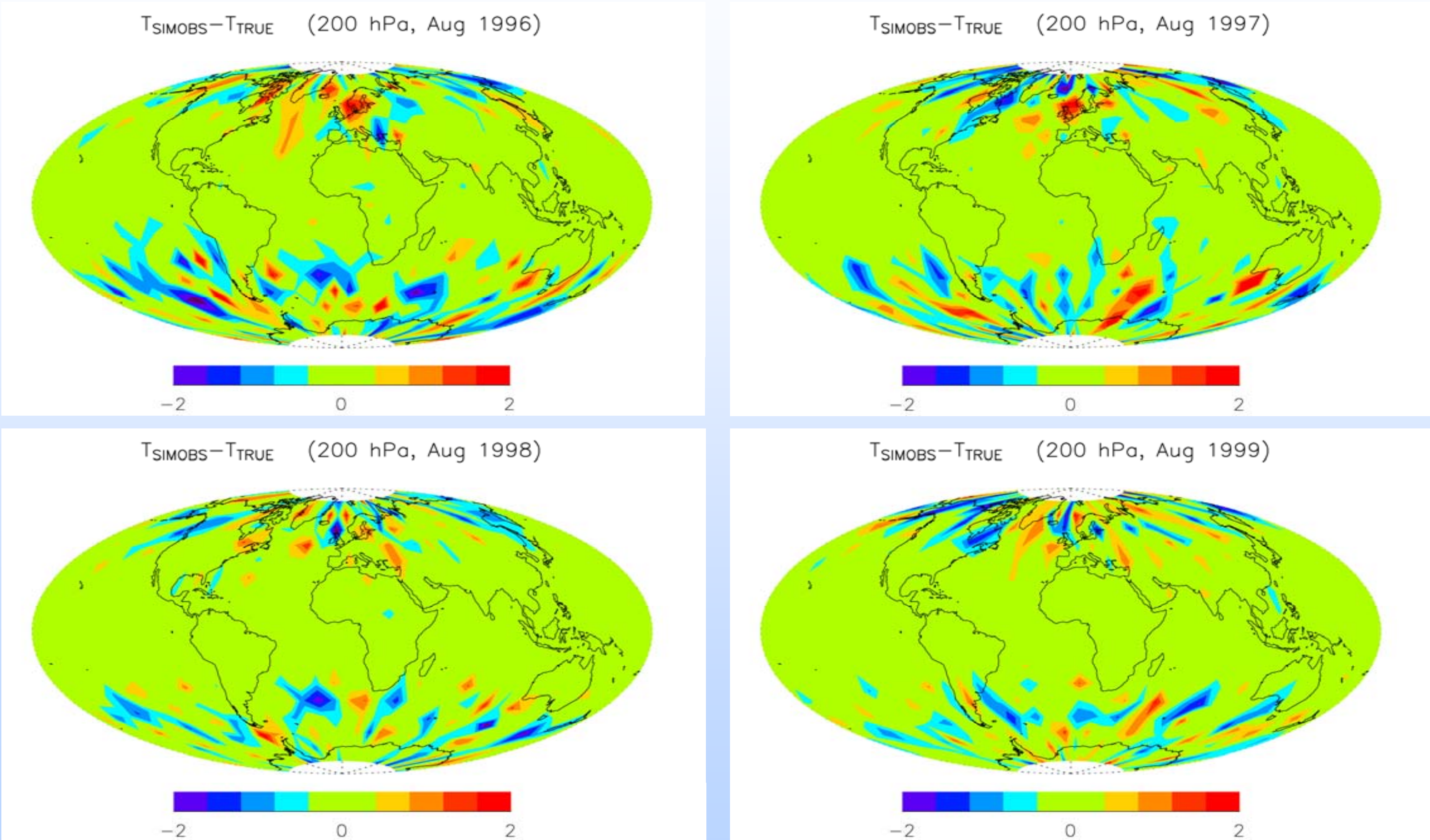
Prototype climate data products

– relative grid-box sampling density from CHAMP RO data –



GRAS SAF climate data products

– estimates of sampling errors –

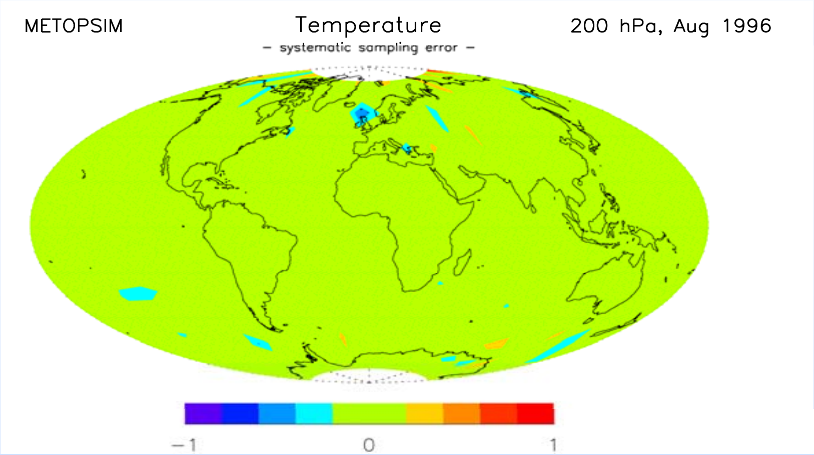


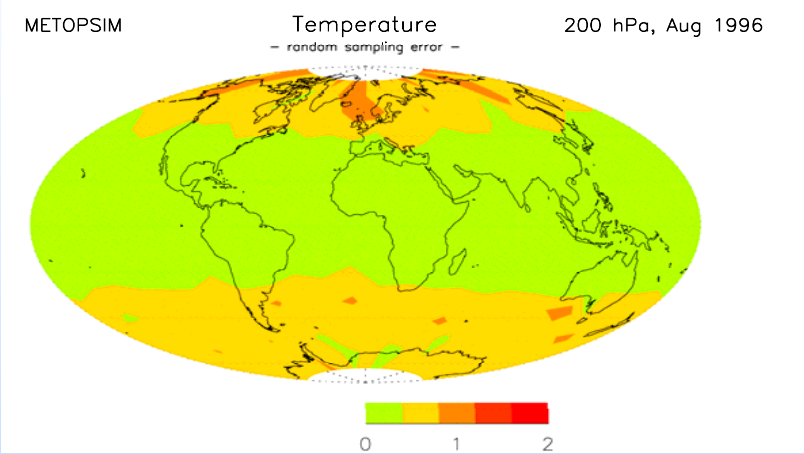
Make ”observations” during 25 August months in ERA-40 at the actually observed locations and times.
Compute the ”observed” climate data, the corresponding ”true” climate data, and get 25 error fields.

GRAS SAF climate data products

– estimates of sampling errors –

Systematic and random errors due to the sampling





GRAS SAF

GRAS SAF climate data products

– summary –

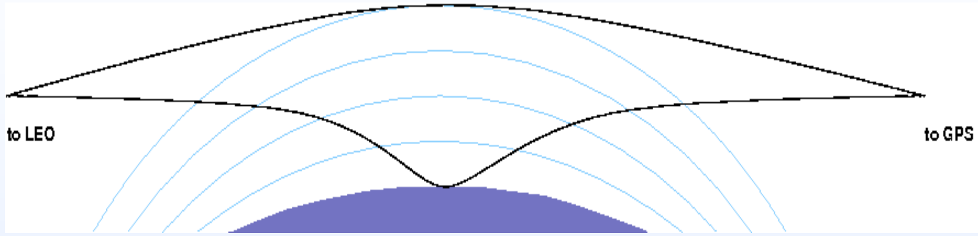
- we plan to extend the range of offline products by developing a set of GRAS SAF climate data products: zonal monthly means of BA, N, T, q, and Z (geopot. height) at a 5 degree latitudinal resolution
- the primary climate data grid will be supplemented by lower temporal (seasonal, annual) and spatial (hemispheric, global) resolutions
- the focus is on GRAS RO data, but we will also investigate the joint use of data from other RO missions (e.g., CHAMP, COSMIC)
- the climate data products will be made available to users on GARF during the first half of 2010 (following a Climate ORR review)
- prototype climate data products have already been developed from CHAMP data for the year 2004, with a focus on refractivity but also temperature. A range of associated climate data and statistics are also produced for monitoring and development purposes.

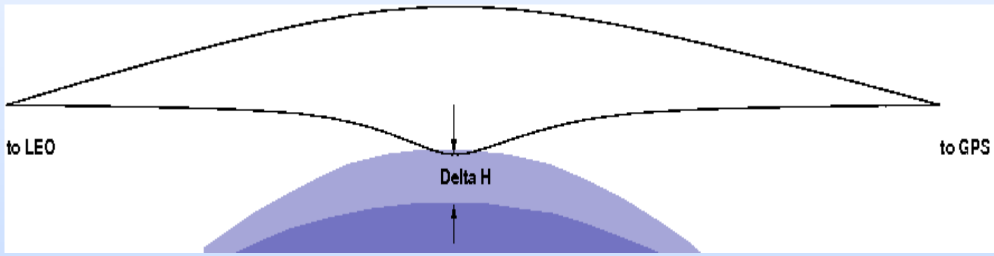
RO Surface Reflections

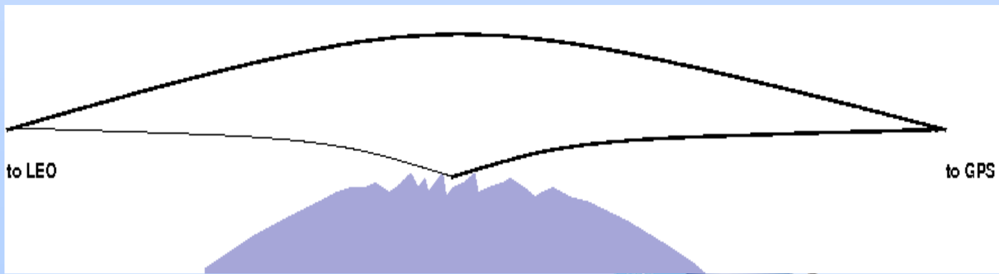
Quality check of RO data;

Additional possible applications:

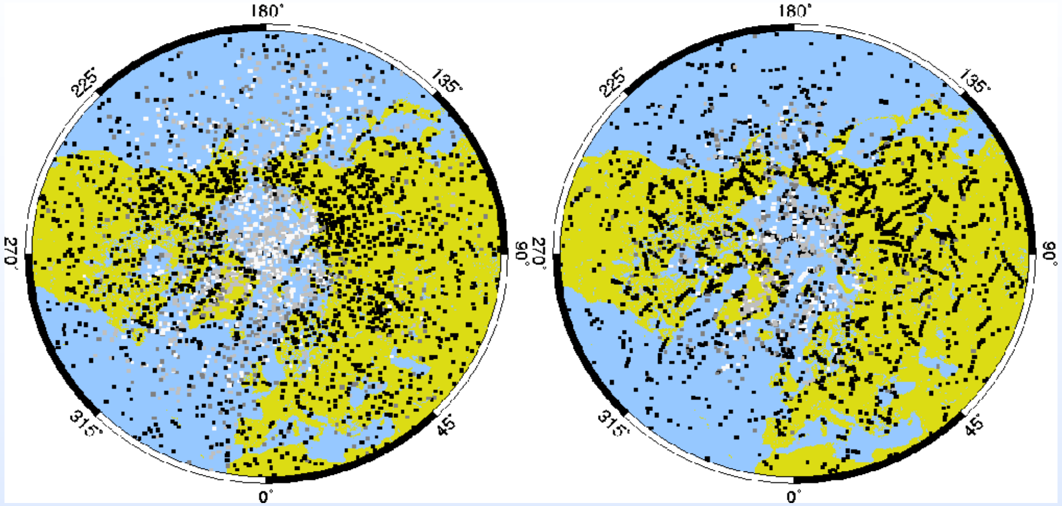
- Altimetry: vertical displacements of the reflecting surface change the delay of the reflected signal with respect to the direct;
- Sea Ice type/coverage: dielectric and structural properties of the surface might modify the reflecting capabilities of the surface;







Sea and Ice RO Reflections



North pole region:
Feb (left) and
Sept (right) 2004+2005

Sea Ice type/coverage: preliminary work show seasonal patterns in the quantity/quality/power of reflected signals over the Polar Ice.

- Power: how to define Reflected Power? normalization?
- Other effects: is the Reflected Power affected by atmospheric conditions? other effects rather than/in addition to surface properties?
- Scattering Modelst: are there ice/ice-type scattering models suitable for L-band and grazing angles of elevation?
- Land: any reflection over land?

Summary & Outlook

- **GRAS SAF:** Will supply continuous, operational radio occultation data for NWP weather forecasts (in near-real time) and climate research (offline) as part of EUMETSAT's EPS system; RO refractivity products from GRAS on MetOp are expected to be available from Sept 2008

- **NWP:** RO impact results are very encouraging and support the case for assimilating GPS RO measurements operationally

- **CLIMATE:** RO data are ideal for climate studies (global, calibration free)

- **New applications**:
  - Surface reflections
  - Planetary boundary layers

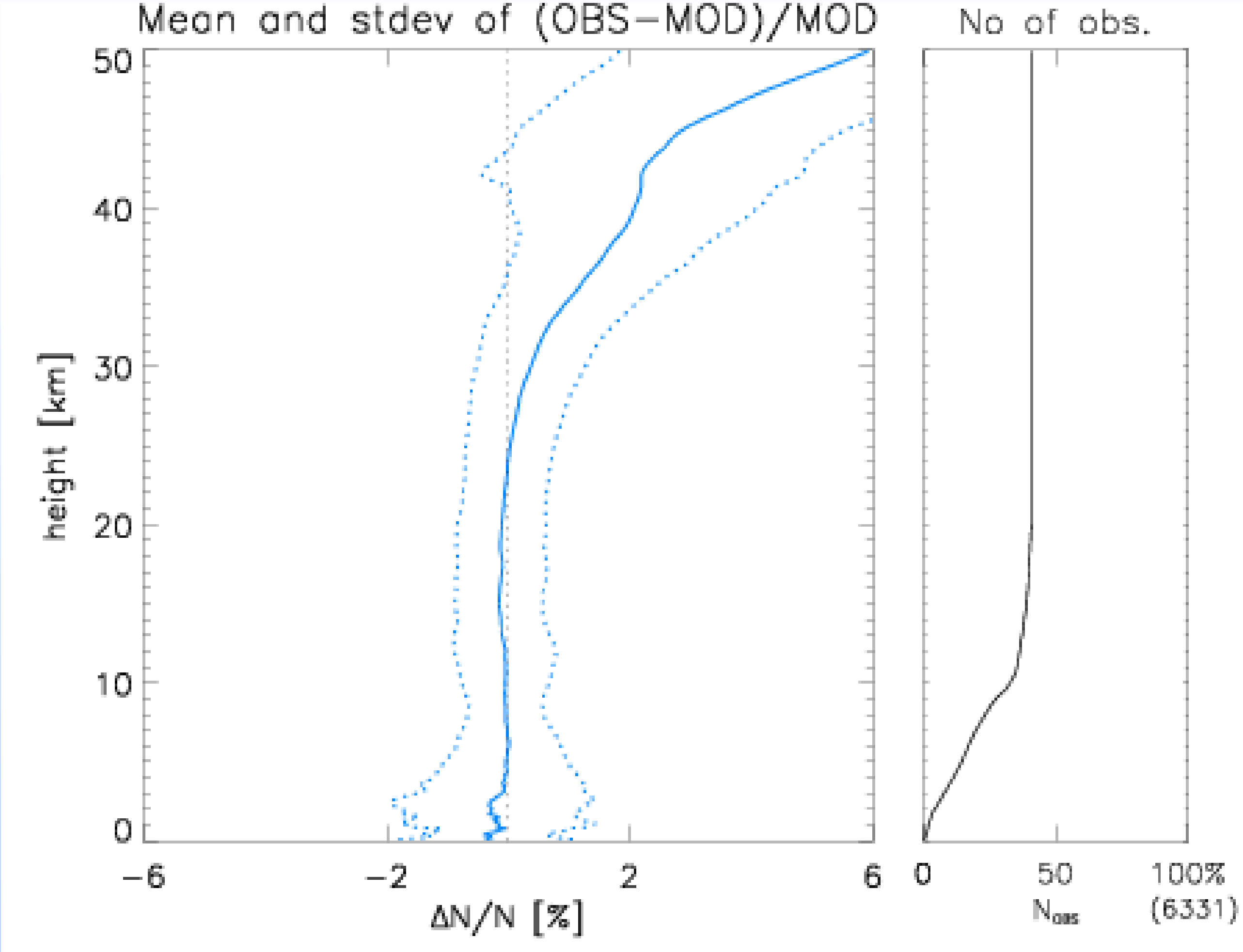
GRAS SAF data, ROPP, information:

→ ***www.grassaf.org***

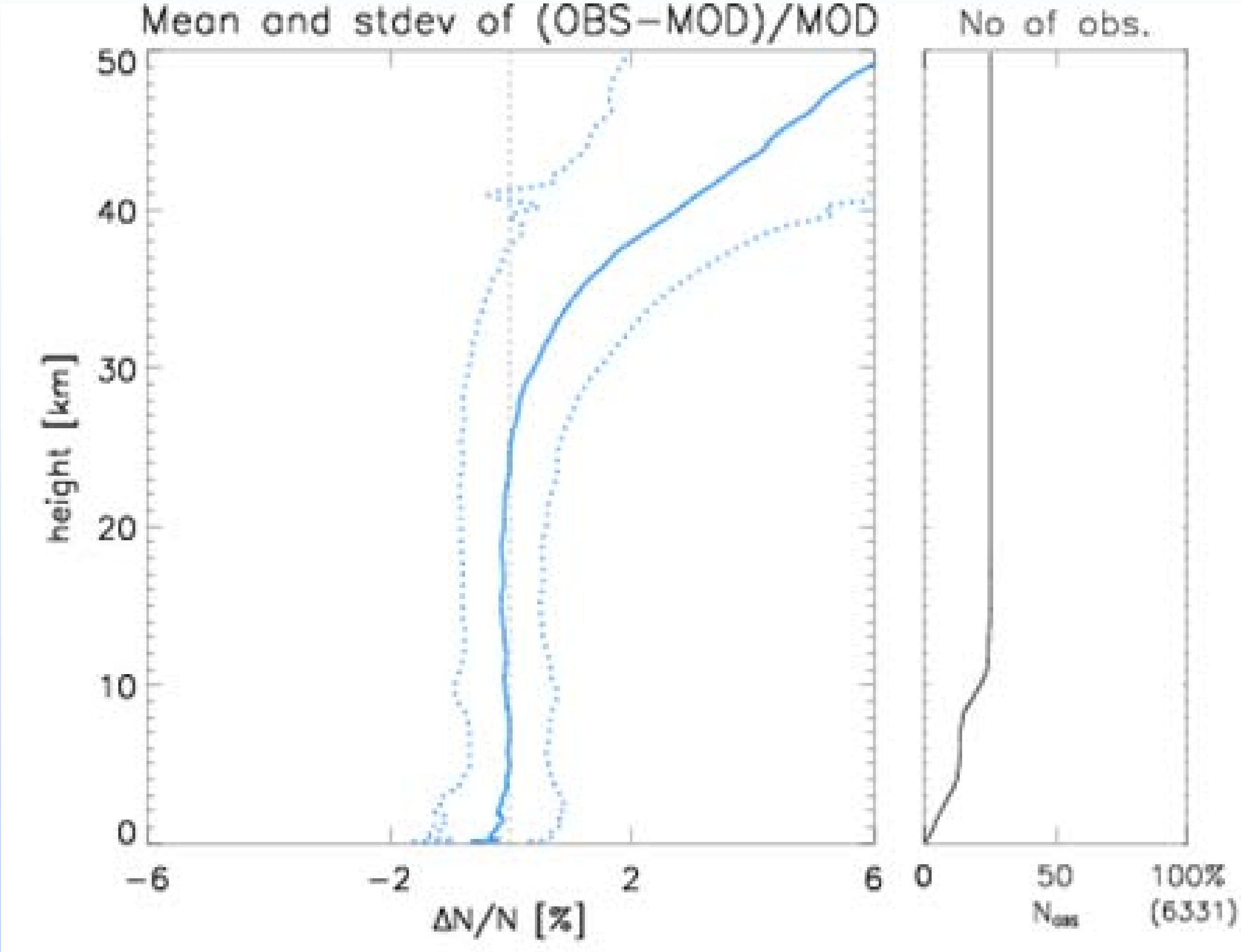
GRAS SAF

end...

Mid latitudes



High latitudes



GRAS SAF

Processing/inversion steps

- Elimination of impact parameter ambiguities (monotonization)
- Linear interpolation to a fixed impact parameter grid with steps ~100 m
- Smoothing of bending angles using a sliding cubic polynomial fit (~1 km window)
- Identification of a climatological refractivity profile (from the MSIS90 model)
- Calculation of MSIS90 climatological model bending angle using the Abel transform
- Calculation of fitting factor from linear regression of the data to the climatological model bending angle profile in the height interval 30-50 km.
- Multiplication of climatological bending angle profile with the fitting factor
- Combined ionospheric correction and statistical optimization
  - Calculation of strongly smoothed ionospheric signal (L1 – L2)
  - Estimation of ionospheric signal and noise covariances using the highest part (above 50 km)
  - Calculation of relative mean deviation of neutral bending angle from the model bending angle using the data at heights 12-35 km
  - Optimal linear combination using the covariances
- Inversion to refractivity via the Abel transform assuming exponential decrease of the bending angle profile above ~100 km

GRAS SAF

Prototype climate data products

– zonal monthly-mean refractivity from ECMWF –

We also generate climate data from ECMWF profiles taken at the locations and times of the observed RO profiles. This adds to the information from profile (O-B) statistics.