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The EUMETSAT Network of Satellite Application Facilities

ROM SAF
Radio Occultation Meteorology

www.romsaf.org

Climate Data Records Generated from GNSS Radio Occultation Measurements

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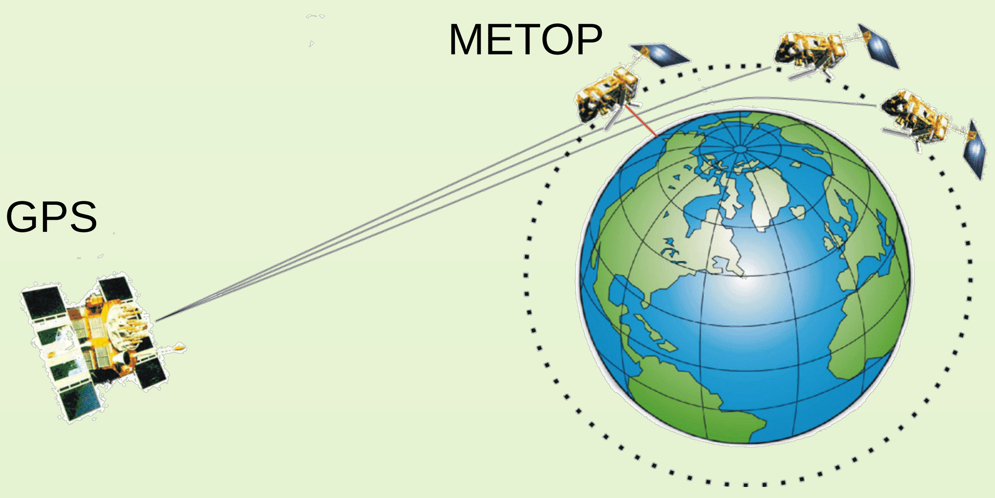


Figure: *Principle of GNSS radio occultation measurements.*

The GNSS radio occultation (RO) technique utilizes the refraction of radio waves to probe the Earth's atmosphere. The observed phase delay of a radio wave as a transmitting GNSS satellite sets or rises behind the Earth is converted to vertical profiles of bending angles, refractivity, pressure, temperature, and humidity. The GRAS instrument onboard the Metop satellite provides around 1300 profiles per day distributed across the globe. Together with data from other RO missions, such as FORMOSAT-3/COSMIC, thousands of atmospheric profiles are generated each day, covering the troposphere and the lower/middle stratosphere. The ROM SAF processes these data into global climate data sets for use in climate research.

The GNSS radio occultation (RO) technique

The GRAS instrument onboard the Metop low-Earth orbit satellite measures the arrival time and frequency of the radio signals emitted by GNSS satellites that are setting or rising behind Earth. From the phase shift as function of time, when the radio signal successively traverses deeper and deeper layers of the atmosphere, the *bending angle* as a function of height can be computed.

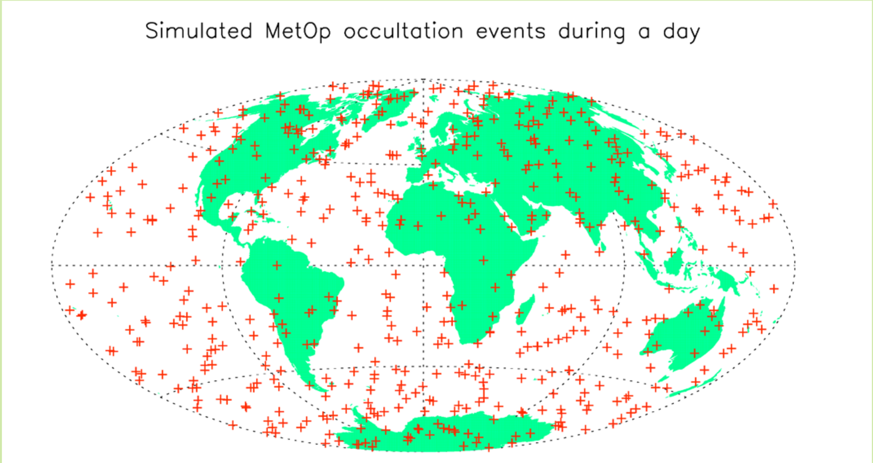
The bending angle can be converted to *refractivity*, *N,* as a function of height, which itself can be regarded as an atmospheric state variable,

$$N \equiv (n-1)\cdot 10^6 = a\frac{p}{T} + b\frac{p_w}{T^2}$$

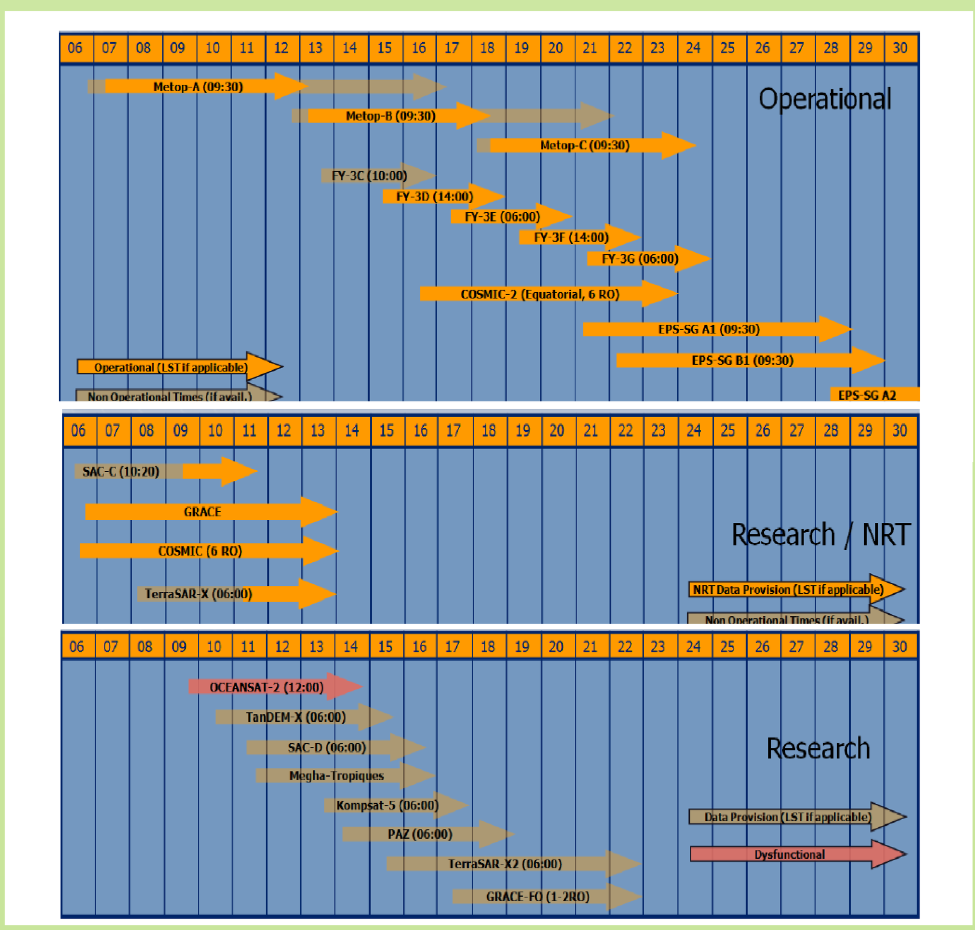
since it is a simple function of the more commonly used geophysical variables pressure (p), temperature (T), and water vapor pressure (p_w). The final products of the RO observations are vertical profiles of bending angle, refractivity, pressure, temperature, and water vapour.

A global RO observational system

Each day, around 1300 vertical profiles are observed by the GRAS instrumentts onboard Metop-A and -B. The profiles are irregularly distrubuted across the globe, providing a good spatial coverage.



EUMETSAT plans for a third operational satellite in the EPS programme (Metop-C), followed by a series of satellites in the EPS-SG programme, all carrying RO instruments. Together with several other RO missions – both currently operational and those planned for – the RO observational system extends well into the 2030's, providing thousands of atmospheric profiles each day.



ROM SAF global climate data

Many of the characteristics of RO data suggest them as a near-ideal source of data for climate studies: the global coverage, the insensitivity to clouds, and the unbiased nature of the raw measurements (based on time differences rather than radiative fluxes). The closer to the raw measurements, the easier it is to keep a tight control of potential biases. Bending angles are less susceptible to bias than refractivities, and refractivity is less susceptible to bias than temperature or humidity.

The ROM SAF process data from all major RO missions into global climate data – standard and non-standard climate variables. Our gridded climate data consist of monthly means on a zonal (latitude-height) grid, and are provided together with estimates of the corresponding errors (sampling and observational). We also provide information related to the data quality and the observational information content: QC screening results and estimates of the amount of *a priori* data.

Climate Data Product	2D Zonal Grid: Climate + Errors (1)	Time Resolution	Spatial Resolution (2)	Formats, Graphical	Formats, Numerical
Bending angle	yes	Monthly	5 deg. latitude	PNG	netCDF
Refractivity	yes	Monthly	5 deg. latitude	PNG	netCDF
Temperature	yes	Monthly	5 deg. latitude	PNG	netCDF
Specific humidity	yes	Monthly	5 deg. latitude	PNG	netCDF
Geopotential height	yes	Monthly	5 deg. latitude	PNG	netCDF

Figure: *Primary ROM SAF climate products, released in a first version during 2013.*

The data are provided as a user service for climate research and monitoring. The ROM SAF primarily develops single-mission RO climate data sets but we also investigate the joint use of data from several RO missions.

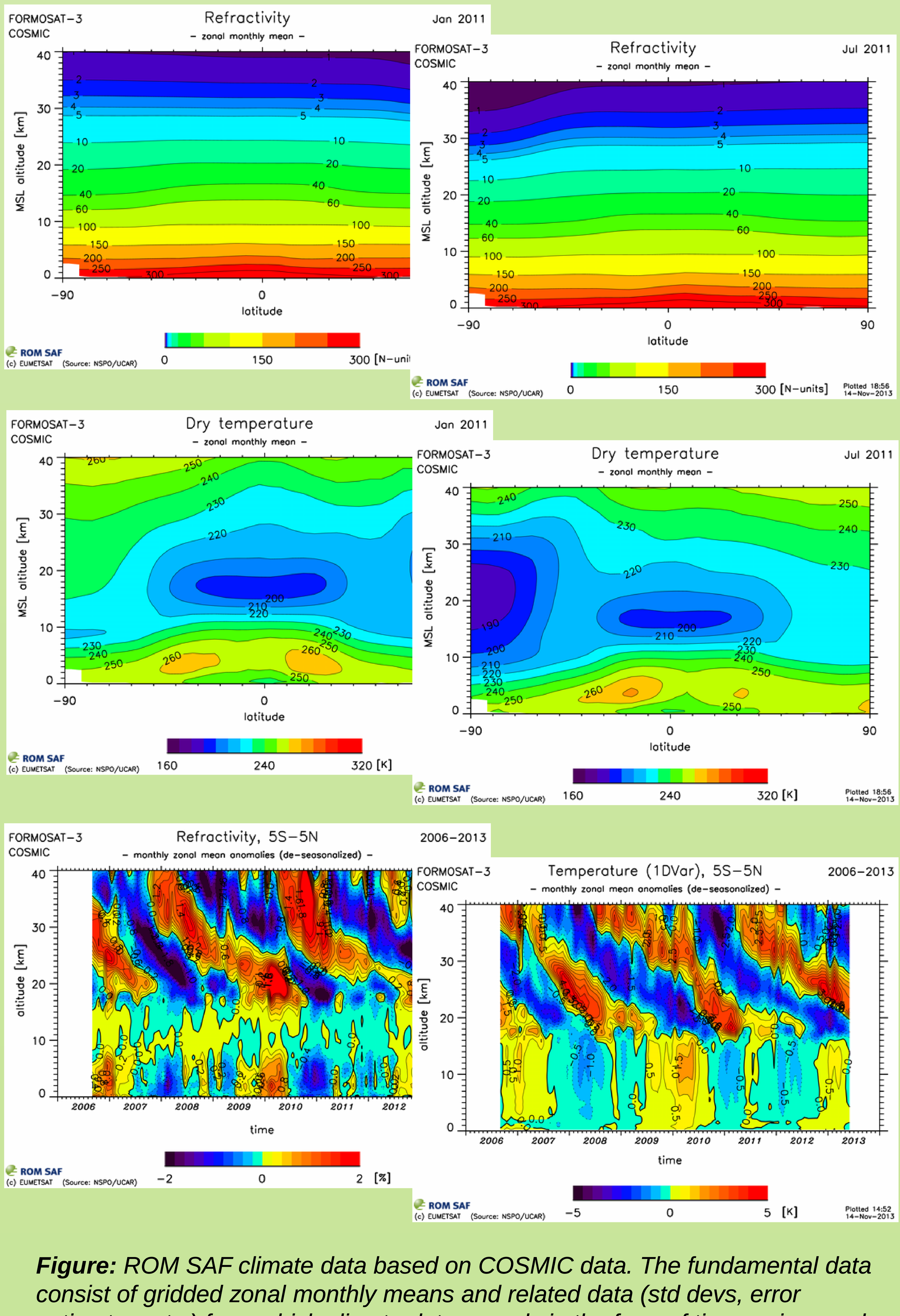


Figure: *ROM SAF climate data based on COSMIC data. The fundamental data consist of gridded zonal monthly means and related data (std devs, error estimates, etc.) from which climate data records in the form of time series can be derived (here QBO and ENSO structures in refractivity and temperature).*

Observational and sampling errors

There are two types of errors: *observational errors* and *sampling errors*. The observational errors include all differences – due to the instrument or due to the data processing – between the observed profiles and the truth. The truth is hidden to us, and all we can do is to investigate the inconsistencies between data sets, which may, or may not, indicate observational errors. All errors that are *systematic*, i.e. not randomly distributed, cause biases in the derived climate data. Biases that vary over time may cause problems for important climate studies, such as detection of climate trends.

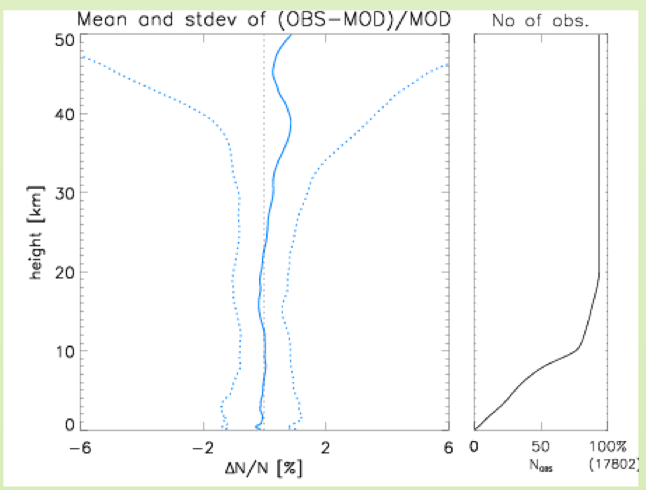


Figure: *Mean and standard deviation of the relative differences between observed refractivities and ECMWF 6-hour forecasts, from the month of February 2011.*

Even though the GRAS/Metop data have a good spatial coverage, the near-polar orbit of the Metop satellite gives an uneven sampling in local time with related structures in universal time. In the plots below, we show the scatter of GRAS/Metop observations for a full month. We find that over a broad mid-latitude interval, the climate system is only sampled at two local times whereas at high latitudes, either day-time or night-time observations tend to dominate.

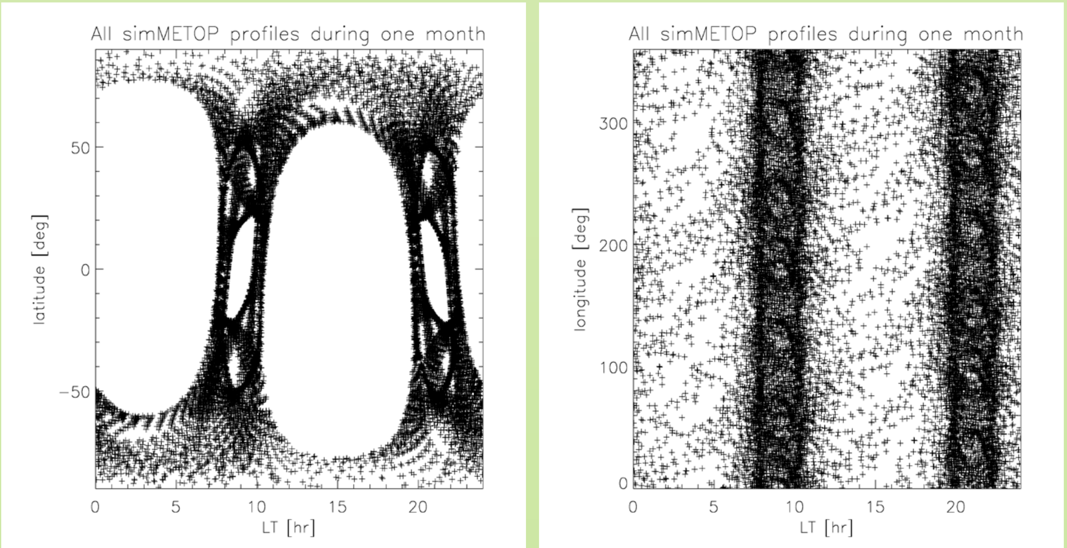


Figure: *Scatter of GRAS/Metop occultations in local time, latitude (left panel) and longitude (right panel). These characteristics are typical for a satellite in a polar, Sun-synchronous orbit.*

The effects of sampling on climate data may be estimated by sampling a model field (e.g., ECMWF analyses) at the same locations and times as the observed data, and compute an error field.

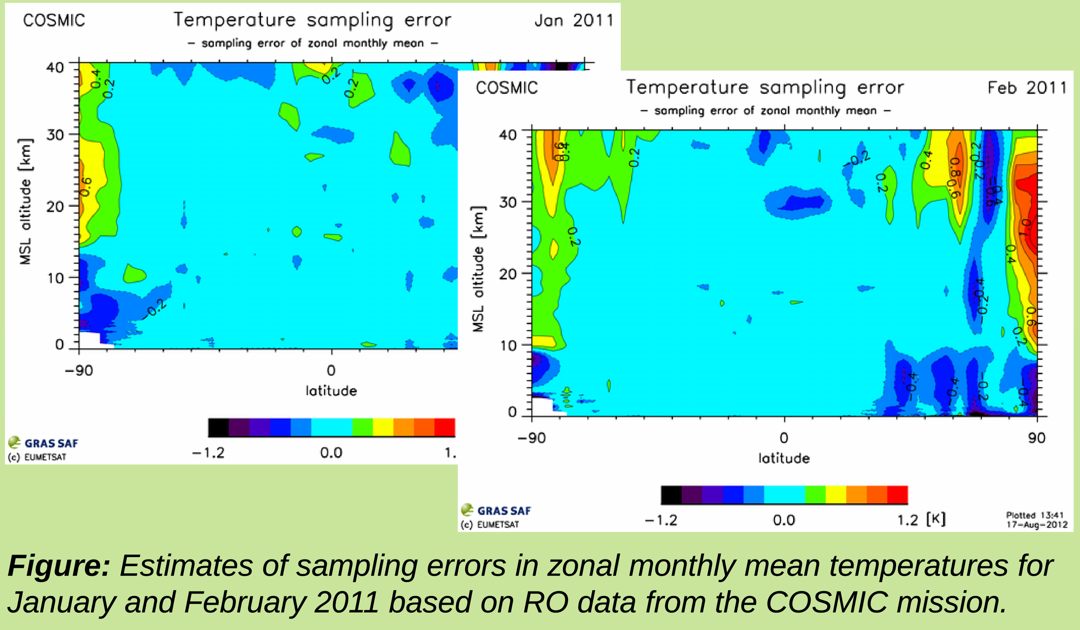


Figure: *Estimates of sampling errors in zonal monthly mean temperatures for January and February 2011 based on RO data from the COSMIC mission.*