The CHAMPCLIM project:
Buliding Radio Occultation based climatologies

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Introduction

The GNSS (Global Navigation Satellite System) radio occultation (RO) technique is based on a satellite-to-satellite limb sounding concept using GNSS microwave signals to probe the Earth's atmosphere. The propagation of the signals is influenced by the atmospheric refractivity field resulting in deceleration and bending of the signal (Figure 1). The atmospheric phase delay as the principle observable is measured with millimeter accuracy. It is the basis for high-quality retrievals of atmospheric key variables, such as pressure, geopotential height, temperature, and humidity profiles. Highest accuracies (e.g., temperature < 1 K) are obtained in the upper troposphere and lower stratosphere. The global coverage, all-weather capability, high accuracy, and self-calibrated nature of RO data suggests them as a promising tool for global short- and long-term monitoring of atmospheric temperature change.

The German/US research satellite CHAMP was launched in July 2000 into low Earth orbit carrying NASA's "Black Jack" GPS flight receiver. Since 2001 it continuously records ~ 200 profiles per day. CHAMP radio occultation data provide the first opportunity to create RO based climatologies on a longer term. The overall aim of the CHAMPCLIM project is to ensure that the CHAMP RO data are exploited in the best possible manner, in particular for climate monitoring. Main objectives of CHAMPCLIM are:

1) RO data processing advancements for optimizing climate utility,
2) RO data and algorithms validation based on CHAMP/GPS data,
3) Global RO based climatologies for monitoring climate change.

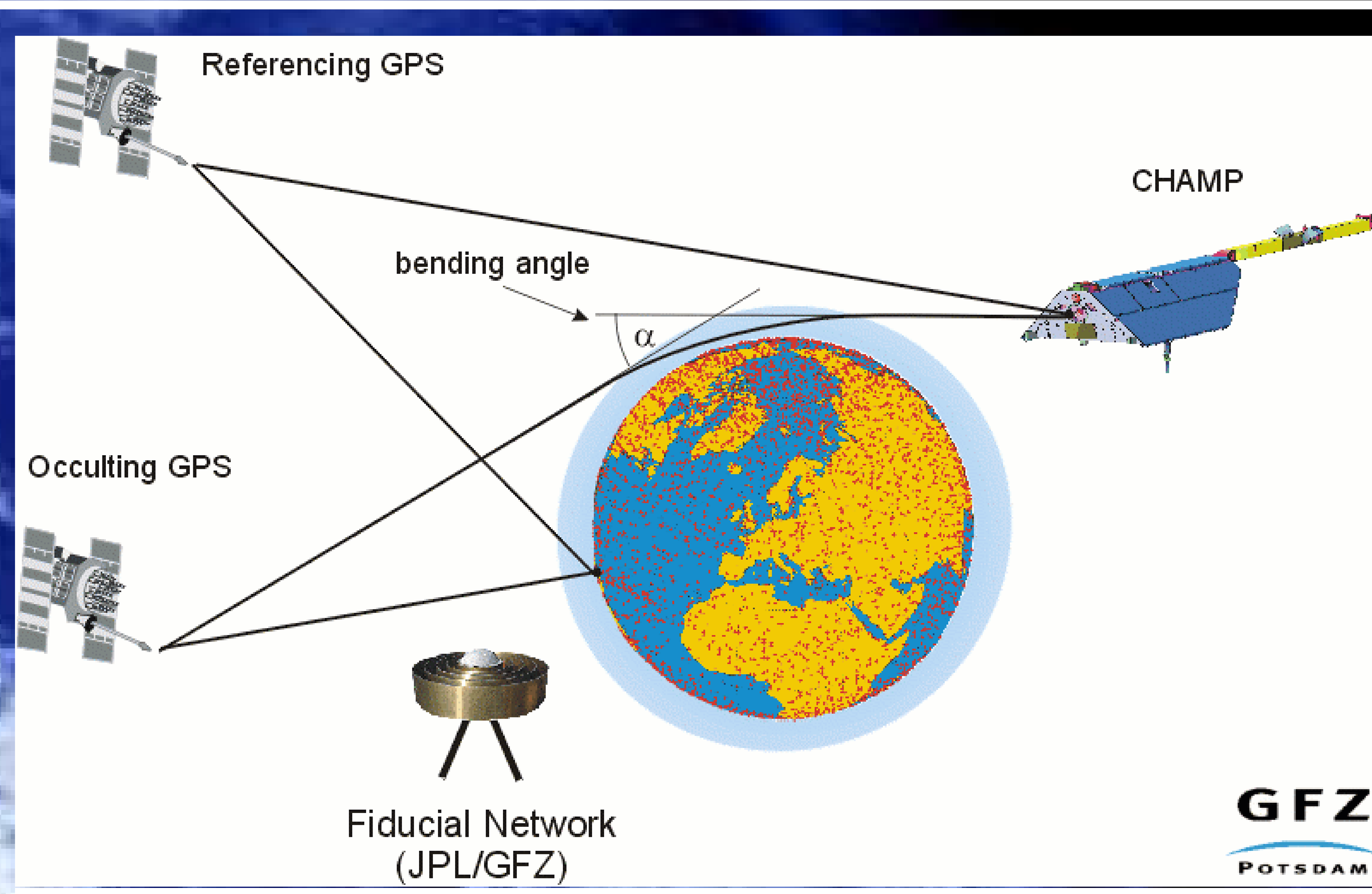

Figure 1: Radio occultation geometry. Data from the referencing GPS satellite are used to determine the satellite positions. Red dots on the globe indicate the distribution of occultation events.

(1) RO data processing advancements for optimizing climate utility.

This part of the study aims at advancing the RO retrieval algorithms with focus on upper stratospheric retrieval performance (ionospheric correction, statistical optimization), on better characterization of observation errors, and on the advancement of lower tropospheric retrieval quality.

So far, an advanced statistical optimization scheme has been developed using background information derived from the MSISE-90 climatology. The key feature of this scheme is the ability to correct for biases in background information. Results from the basic IGAM retrieval scheme (without background bias correction) and the advanced IGAM scheme are shown in Figure 2.

The characterization of observation error covariances has been analyzed in simulation studies and is currently object of studies using measured data from CHAMP (not shown here). The results of these studies aim at advancing the above mentioned statistical optimization and the utility of RO data for use in data assimilation systems.

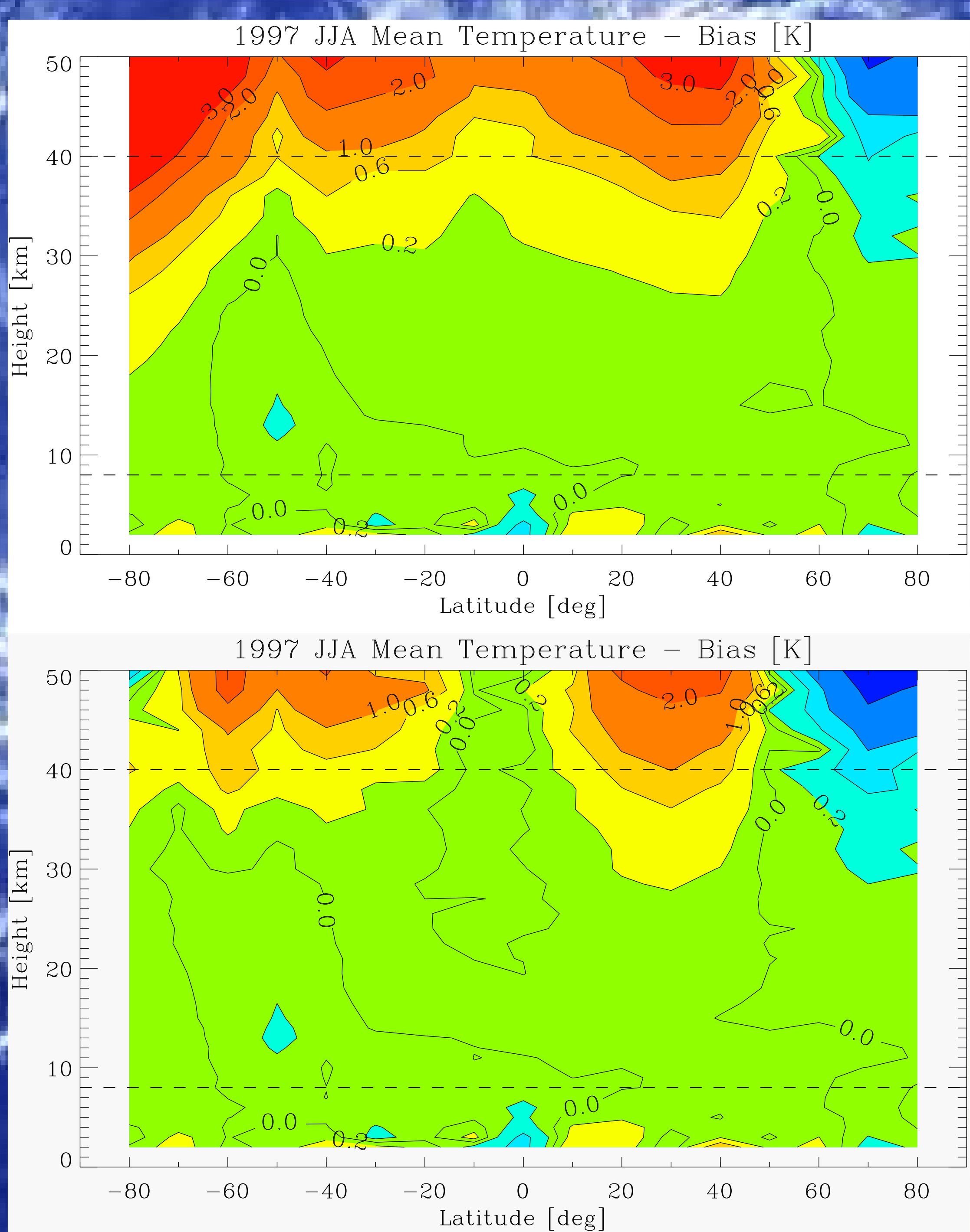

Figure 2: Bias in seasonal mean dry temperature for a typical summer season based on a set of ~1000 simulated RO profiles. Upper panel: Basic retrieval scheme. Lower panel: Enhanced IGAM retrieval scheme.

(2) RO data and algorithms validation based on CHAMP/GPS data.

Atmospheric profiles derived from CHAMP RO data are validated against ENVISAT/GOMOS&MIPAS-derived profiles as well as co-located ECMWF analyses (see Figure 3). Furthermore, GFZ Potsdam retrieval algorithm performance will be compared with IGAM EGOPS4 (End-to-end GNSS Occultation Performance Simulator, Version 4) algorithms for retrieval of bending angle, refractivity, pressure, geopotential height, temperature, and humidity profiles, respectively, with particular focus on upper stratosphere and lower- to mid troposphere performance.

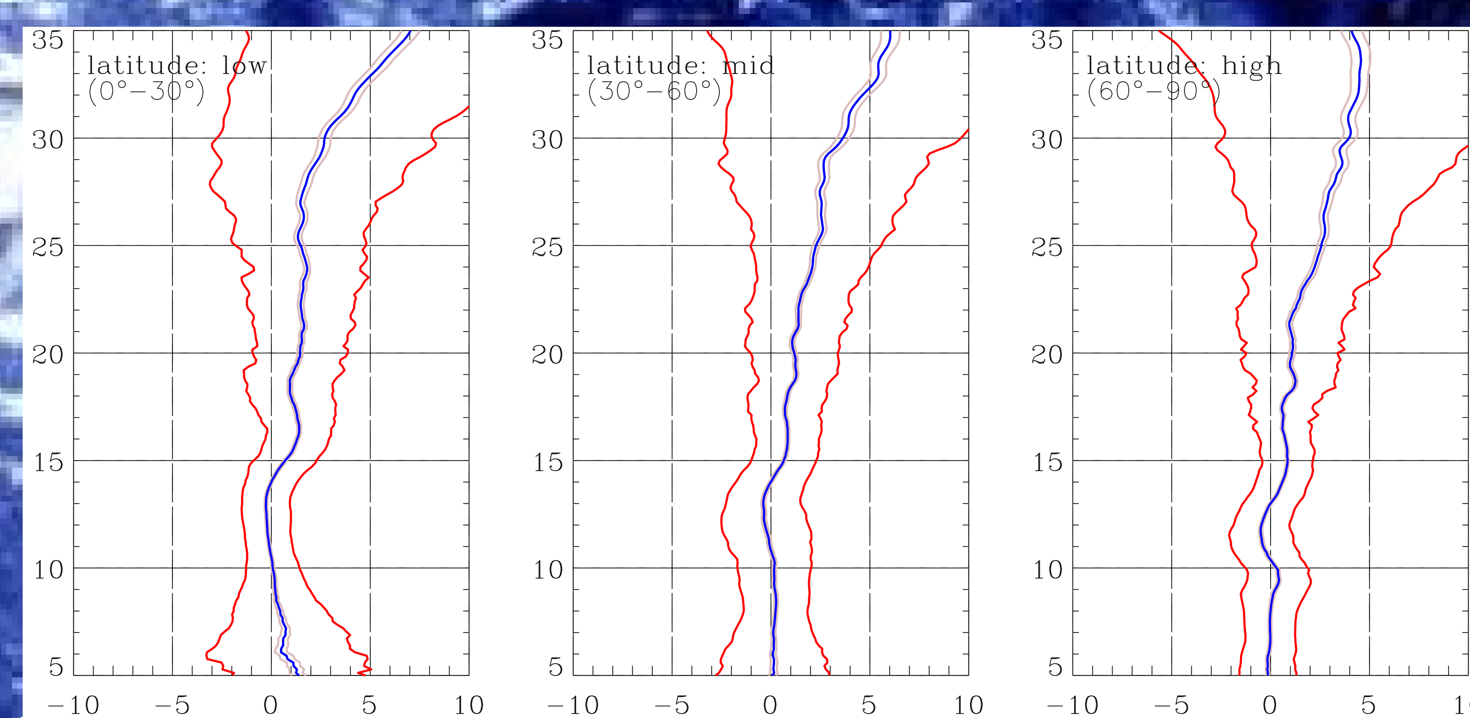

Figure 3: Sample of 991 CHAMP temperature profiles (1.1. – 6.1. 2003, enhanced IGAM retrieval) compared to ECMWF analyses. Blue: bias, red: standard deviation [K]. Low: 304 events, mid: 364 events, high: 323 events.

(3) Global RO based climatologies

In a first approach, this part of the study aims at direct (Model independent) monitoring of the evolution of climatological refractivity, temperature, geopotential height, and humidity fields. Given the somewhat unfavorable single LEO satellite situation the sampling error has to be considered carefully in this context. Figure 4 shows the distribution of ~1000 CHAMP occultation events in a selected geographical domain during a typical summer season and the temperature sampling errors which have to be expected in this case. Due to the high inclination of the satellite (87.3°), the event density in low latitudes is particularly small. Comparatively small temperature variations in these bins, however, prevent the sampling error from increasing dramatically.

In a second approach we will perform optimal fusion of the CHAMP RO-derived refractivity data and ECMWF analysis fields into global climate analyses by use of 3D-variational assimilation. Figure 5 shows first results of a simulation study to test the assimilation scheme for monthly mean fields (T21L60, 625 km horizontal resolution). The background field (first-guess) was obtained by disturbing the "true" atmospheric mean field with reasonable errors using the error pattern superposition method. Simulated RO measurement have been derived from the "true" atmospheric fields. Realistic errors have been superimposed based on empirical error covariance matrices. About 2000 globally distributed RO profiles have been assimilated assuming a Gaussian error characteristic for the background. The assimilation scheme is tuned for high vertical and low horizontal resolution. The cost-function is minimized employing a quasi-Newton decent algorithm.

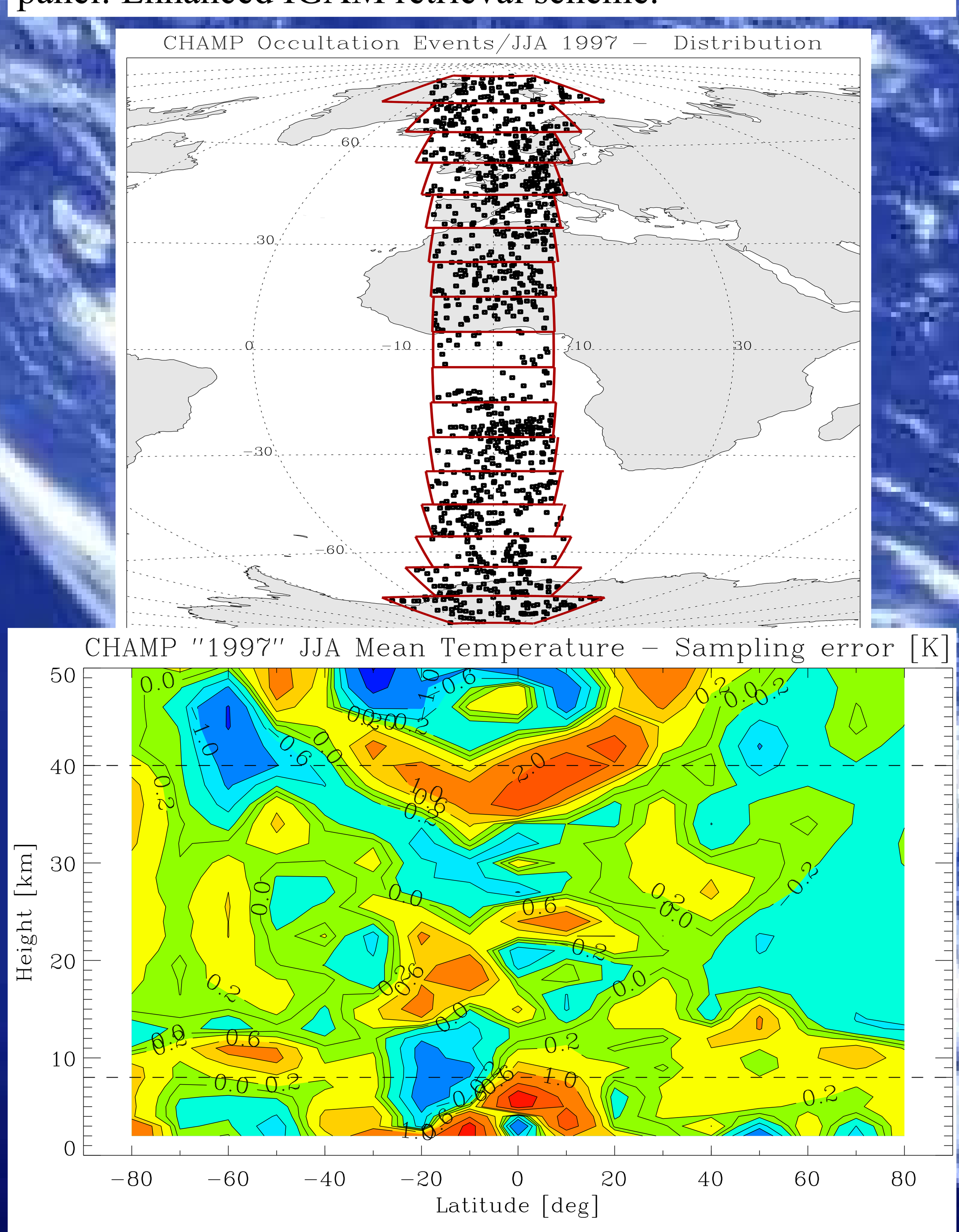

Figure 4: Distribution of ~1000 CHAMP occultation events in a selected geographical domain during a typical summer season (upper panel) and corresponding temperature sampling errors (lower panel).

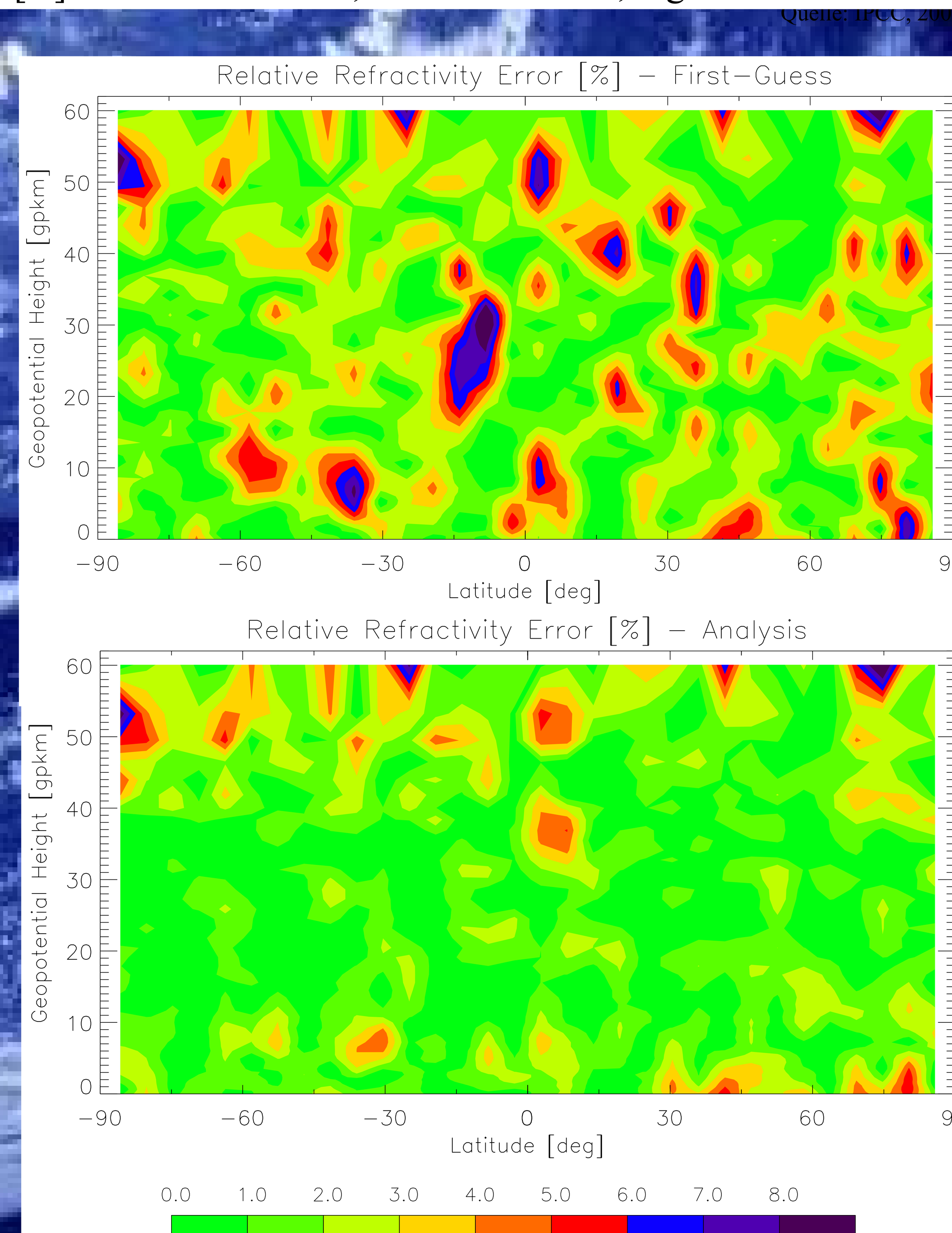

Figure 5: Impact of assimilating ~2000 RO profiles into a background refractivity field (slice at 56°E longitude). Relative error of the background (upper panel) and the analysis (lower panel), respectively.