# Comparison of GPS/SAC-C and MIPAS/ ENVISAT Temperature Profiles and Its Possible Implementation for EOS MLS Observations

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**Summary.** This analysis presents comparisons of the atmospheric temperatures retrieved from GPS/SAC-C radio occultation observations using the JPL retrieval software, and from MIPAS/ENVISAT infrared spectrum measurements using the IMK data processor. Both individual profiles and zonal means of the atmospheric temperature at different seasons and geo-locations show reasonable agreement. For the temperatures at altitudes between 8-30 km, the mean differences between the correlative measurements are estimated at less than 2 K with rms deviations less than 5 K. A similar cross comparison technique can be used to help validate the observed temperatures from the new EOS MLS instrument, to be launched in 2004.

**Key words:** GPS/SAC-C, MIPAS, EOS MLS, temperature.

## 1 Introduction

Global Positioning System (GPS) radio occultations are active limb sounding measurements of the Earth's atmosphere, with the advantages of global coverage, high vertical resolution, self-calibration, and capability to operate under all-weather conditions. By placing a GPS receiver on a low earth orbiter (LEO), the phase delays of GPS carrier signals induced by the intervening medium can be accurately measured as the GPS-LEO satellite link descends through the atmosphere. Under the assumption of geometric optics and local spherical symmetry of the atmosphere, the phase delay measurements can be directly inverted to yield the index of refraction profile with vertical resolution that varies from about 0.5 km in the lower troposphere to about 1 km in the lower stratosphere [*Kursinski et al.*, 1997; *Hajj et al.*, 2002]. Coupled with the hydrostatic equation, the index of refraction profile can be converted unambiguously into a temperature profile above ∼5 km, where the water vapor contribution is small. This concept of GPS occultation was successfully demonstrated with the GPS/MET (GPS Meteorology) mission in 1995 [*Ware et al.*, 1996]. The recently launched, polar orbiting, Argentinian satellite SAC-C (Satelite de Aplicaciones Cientificas-C) carries a new-generation occultation-enabled GPS receiver, the "BlackJack" supplied by the Jet Propulsion Laboratory (JPL). GPS/SAC-C has been collecting occultation data nearly continuously since July 2001, with a typical throughput of about 200 soundings per day. The data are routinely processed at JPL, and are publicly available.

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on board the ENVISAT satellite provides vertical profiles of stratospheric temperature and volume mixing ratio (VMR) of various gas species by limb-observing mid-infrared emissions [*Fischer and Oelhaf*, 1996]. The IMK data processor provides simultaneous retrieval of temperature and line-of-sight parameters, as well as pressure from measured spectra and the spacecraft ephemerids. Details of the retrieval scheme and its accuracy have been discussed by *Clarmann et al.* [2003] and *Stiller et al.* [2003]. The IMK MIPAS temperatures have been compared with a number of other satellite observations [e.g. *Wang et al.* 2003], including GPS/CHAMP (Challenging Mini-Satellite Payload for Geoscientific Research and Application), HALOE (Halogen Occultation Experiment), and SABER (Sounding of the Atmosphere using Broadband Emission Radiometry), as well as with UKMO (United Kingdom Meteorological Office) stratospheric assimilated data. Both individual profiles and zonal means of the atmospheric temperature at different seasons and geo-locations show reasonable agreement. The overall mean differences are on the order 1 K with root-mean-square (rms) deviations of ~5 K.

| Time | MIPAS Total | SAC-C Total | MIPAS/SAC-C |
|---|---|---|---|
| 24-JUL-2002 | 204 | 186 | 41/45 |
| 20-SEP-2002 | 480 | 183 | 117/136 |
| 21-SEP-2002 | 384 | 175 | 82/96 |
| 22-SEP-2002 | 412 | 174 | 96/107 |
| 23-SEP-2002 | 214 | 135 | 16/16 |
| 24-SEP-2002 | 213 | 180 | 52/58 |
| 26-SEP-2002 | 475 | 141 | 101/114 |
| 27-SEP-2002 | 568 | 166 | 109/129 |
| 11-OCT-2002 | 292 | 166 | 61/66 |

**Table 1.** Number of coincidence profiles used for comparison. Coincidence Criteria: latitude and longitude differences are less than 5° and 10°, respectively, the time differences are less than 6 hours.

In this study, we will compare temperatures measured by MIPAS and GPS/SAC-C. This analysis benefits not only the two different limb-viewing observation systems, but also the future cross-comparison with temperature measurements from the soon-to-be launched EOS MLS instrument.

## 2 Data Description and Comparison Methods

The GPS/SAC-C temperature data are produced by the JPL retrieval software. The data provide global coverage with more than one hundred temperature profiles per day (see the 3rd column of Table 1). The retrieval uses Abel inversion under the assumption of hydrostatic equilibrium, spherical symmetry of the atmosphere about the ray tangent point, a refractivity expression and the equation of state [*Hajj et al.*, 2002]. Water vapour is negligible except in the lowest 5 km of tropical atmosphere where NCEP analysis is used to provide water vapour profile. The NCEP temperature at 30 km is used as an initial guess in the JPL retrieval. For brevity, we here-after call the GPS/SAC-C data simply as SAC-C data or SAC-C measurements.

The MIPAS temperature data used in this study are version V1.0 of the IMK data products. The MIPAS limb-viewing observations from ENVISAT provide global coverage with 14.4 orbits per day. At a given latitude over the course of a day, about 30 longitudinal points are sampled, 15 each in the ascending and descending modes. The sampling in the two legs corresponds to two different local times, each of which remains approximately constant for successive orbits, changing by only 20 minutes per day. The V1.0 retrieval is performed between 6 and 70 km with a grid spacing of 1 km below 44 km and 2 km above. Local thermodynamic equilibrium (LTE) is assumed in the retrievals, since the non-LTE effects are not significant in the region below 70 km except for the lower mesosphere in the polar winter regions. Some measurements were rejected due to severe cloud contamination. The number of available measurements for each day is usually a few hundreds (see the 2nd column of Table 1).

The temperature data used for this comparison analysis are taken from different geo-locations for two periods in 2002 when the MIPAS data are available. Due to characteristics of the sampling scenarios for the two datasets, it is difficult to achieve excellent spatial and temporal coincidence for individual pairings of MIPAS profiles with correlative SAC-C measurements. As a first order approximation, individual paired-profile comparisons are conducted for those measurements with latitude and longitude differences smaller than 5° and 10° , respectively. The time differences between the paired profiles are limited to $< 6$ hours. The paired profiles are then interpolated to a common altitude grid as that used by the MIPAS data. No averaging kernel is used in this study.

## 3 Results

Individual temperature profile comparisons are performed for the MIPAS and SAC-C measurements between 5-30 km. The total MIPAS, SAC-C sampling profiles and the numbers of MIPAS/SAC-C correlative profiles used for this study are listed in Table 1. One MIPAS profile may have multiple SAC-C coincidences due to the sampling characteristics and our coincidence criteria.

Note that by the time this study was conducted, MIPAS measurements were only available for July 24 and 15 days in September-October (8 days used in this study). During the later period, an unprecedented Antarctic winter stratospheric sudden warming event occurred [*Manney et al.*, 2004].

For brevity, plots of detailed profile-by-profile comparisons are not displayed here. The mean differences and the rms deviations averaged over all available paired profiles are presented in Figure $1_{\mathrm{left}}$ for July 2002 and Figure $1_{\mathrm{right}}$ for the September/October periods. In general, the MIPAS and SAC-C temperature profiles agree well, with overall mean differences <2 K and the rms deviations <5 K or more throughout troposphere and lower-stratosphere. For the July 24 profile, the mean MIPAS temperatures are slightly warmer (~1 to 2 K) than the SAC-C temperatures. Both data sets show good agreement above 20 km, although the mean MIPAS temperatures are somewhat cooler by ~1 K near the tropopause (~12-18 km).

In order to examine the latitudinal behavior of the two data sets, we compare the daily zonal means of these temperature differences. To determine the zonal means, all available longitudinal data at individual heights are sorted into latitude-bins of a specified width (10° in latitude are used for this study, in order to have enough data points available in each bin). The daily means of available data points are computed separately for each leg. Figure 2 show the daily zonal mean temperature differences between the correlative MIPAS (descending mode) and SAC-C measurements. In general, there are random differences of 2-4 K in wide latitude and altitude regions. The noticeable large differences are about 6-10 K at high latitude of 60°S around 20-25 km during 22-27 September, 2002, when the MIPAS temperature measurements reported a major polar stratospheric warming event [*Manney et al.*, 2004]. The cause of this MIPAS warm-bias over SAC-C, however, is not clear at present.

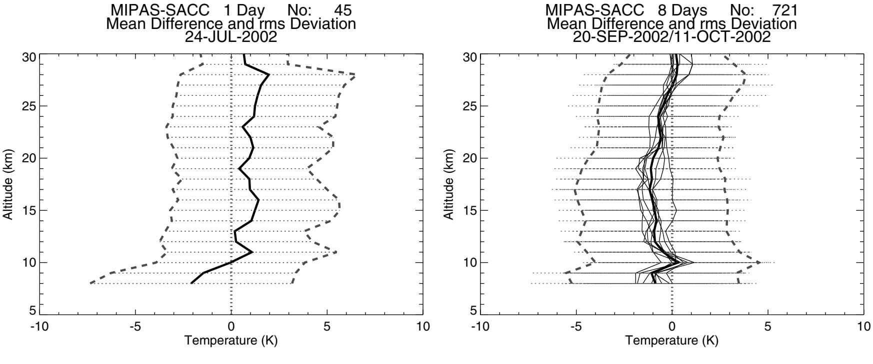

**Fig. 1.** Mean differences (solid) and rms deviations (dotted) of MIPAS and SAC-C temperatures (K). The light-lines are data averaged over all available paired profiles on a single day, dark solid-lines are averaged over all the measurement days: 1 day for July 24 (left), 8 days for September-October (right).

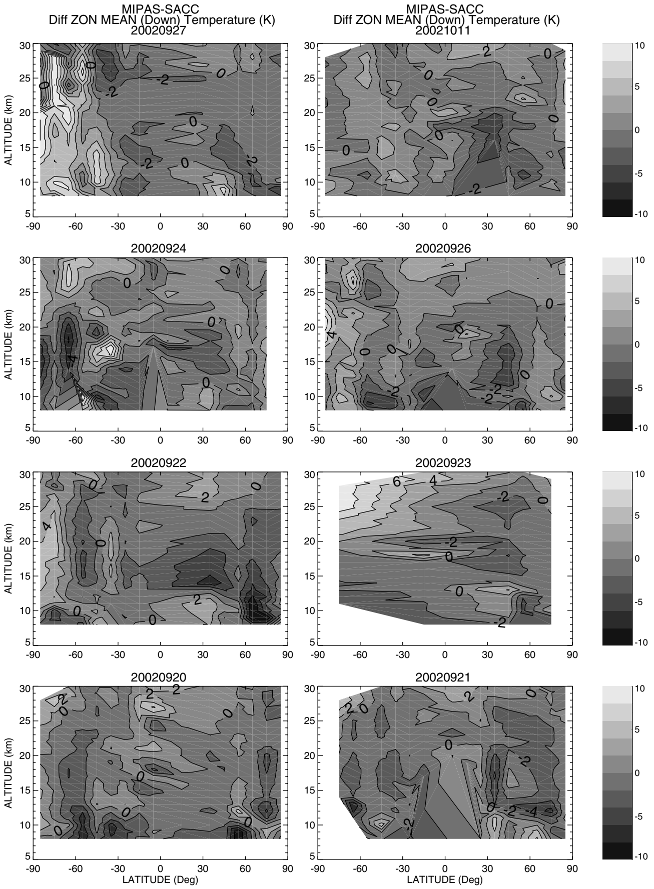

**Fig. 2.** Daily zonal averaged temperature differences (K) of correlative MIPAS and SAC-C measurements. MIPAS observations are taken from the descending mode. The temperatures are contoured by 2 K interval.

# 4 Future comparison with EOS MLS

The Earth Observing System (EOS) Microwave Limb Sounder (MLS) is a 'second-generation' MLS experiment [*Waters et al.*, 1999] to be launched onboard the NASA EOS Aura satellite in 2004. EOS MLS measures atmospheric composition, temperature, cloud ice, and pressure from observations of thermal emission at microwave wavelengths as the instrument field-of-view is scanned through the atmospheric limb. For temperature measurement, EOS MLS has a vertical and global coverage similar to that of MIPAS. The standard MLS temperature product is expected to have ~2 K precision or better from 500 to 0.001 hPa (some smoothing will be applied between 10-0.001 hPa in both vertical and along-track direction). The cross-comparison technique that is used in this study provides a useful comparison and validation tool for the temperature measurements from EOS MLS. In addition, cross-comparison and validations of temperatures, water vapor, ozone and other species measured by MLS and MIPAS will be especially valuable for studies related to stratosphere ozone depletion, greenhouse gases transformation, troposphere-stratosphere exchange, and radiative forcing of climate change.

## 5 Concluding Remarks

We compared ∼770 correlative profiles of MIPAS and SAC-C temperatures between 5-30 km. Both, individual profiles and zonal means of the temperature at two different seasons and various geolocations show reasonable agreement. The overall mean differences are estimated to be less than ∼2 K with rms deviation of less than  5 K. No apparent height dependence exists. Similar technique can be applied for a cross-comparison between MIPAS and EOS MLS instruments.

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