TEMPERATURE VALIDATION USING RAYLEIGH-RAMAN LIDARS

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ABSTRACT

Two temperature products will be available within the MetOp mission. AMSU will provide temperature as already performed by the successive NOAA TIROS-N experiments and also has set up another experiment GRASS that is based on a very promising technology for operational temperature measurements and climate monitoring based on GPS technology. Temperature lidar data available within the NDSC network are also a key component for insuring temperature continuity from space in the GMES/GEOSS strategy. The OHP Rayleigh lidar take part of most of the temperature satellite validations during last 2 decades. Today, more lidar stations are available within the NDSC and provide data from poles to tropics. The Raman scattering is an additional capability that permits to extend temperature profiles downward in the presence of aerosols.

1. INTRODUCTION

The temperature evolution of the middle atmosphere is an important parameter as a finger print of different anthropogenic forcing and also because temperature plays a key role in the atmospheric composition and on the dynamic that can directly or indirectly impact on the climate. The MetOp temperature product validation can take benefit of the temperature obtained on a routine basis within the NDSC network. Past work are presented on both data validation and trends using the Rayleigh lidar at OHP. The synergy of the both activities is described, as MetOp could be a key component to pursue the GMES/GEOSS strategy.

2. TEMPERATURE MEASUREMENTS WITHIN THE NDSC

The network for the Detection of Stratospheric Change (NDSC) is a set of high-quality, remote-sounding research stations for observing the physical and chemical state of the stratosphere and mesosphere [1]. The network consists of five primary stations (fully equipped) and of many other complementary sites (providing a more limited number of instruments), that are located from poles to tropics providing a well adapted spatial coverage for an independent calibration of satellite sensors of the middle atmosphere. Since its inception, the NDSC has provided systematic lidar measurements of ozone and temperature at several places around the world that are well adapted for satellite validations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Date of first operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andoya, Norway</td>
<td>69°N</td>
<td>16°E</td>
<td>1995</td>
</tr>
<tr>
<td>Observatory of Haute-Provence, France</td>
<td>43,9°N</td>
<td>5,7°E</td>
<td>1979</td>
</tr>
<tr>
<td>Table Mountain Facility, California</td>
<td>34,0°N</td>
<td>117,7°W</td>
<td>1988</td>
</tr>
<tr>
<td>Mauna Loa, Hawai`i</td>
<td>19,5°N</td>
<td>155,6°W</td>
<td>1993</td>
</tr>
<tr>
<td>La Réunion, France</td>
<td>21,80°S</td>
<td>55,5°E</td>
<td>1994</td>
</tr>
<tr>
<td>Dumont D’Urville, Antarctica</td>
<td>66,7°S</td>
<td>140,0°E</td>
<td>2006</td>
</tr>
</tbody>
</table>

Table 1. List of stations proposed for MetOp validation.

Rayleigh lidar data cover the altitude range from about the middle to the upper stratosphere and mesosphere. In a pure molecular atmosphere the temperature obtained from a Rayleigh lidar is given in an absolute value as a function of altitude, without any need of external calibration [2]. The lidar measurements, have a good vertical resolution (typically 100 m). Since 1979, lidar temperature measurements above the Haute-Provence Observatory (OHP) in southern France are available and represent consist of one of the longest series. Several other lidar sites have also initiated systematic operations and are now available to contribute and complement temperature trend detections and satellite series assessments (table 1, figure 1).
Quality control is continuously achieved through rigorous calibration procedures and inter-comparison campaigns [3]. Regular exercises have been organized to ensure the data quality at each individual site. These exercises can be separated into three categories: large scale inter-comparisons using multiple instruments, including a mobile lidar; using satellite observations as a geographic transfer standards to compare measurements at different sites; and comparative investigations of the analysis software. NDSC is a research network, so each system has its own history, design, and analysis, and has participated differently in validation campaigns. There are still some technological differences that may explain different accuracies. However, the comparison campaigns performed over the last decade have always proved to be very helpful in improving the measurements. The synthesis of the published works shows that the network can potentially be considered as homogeneous within ±1 K between 35-60 km for temperature.

3. SATELLITE VALIDATION

The NDSC lidar temperature profiles have been intensively used for the Upper Atmosphere Research Satellite (UARS). Comparison between lidar and nearly coincident UARS temperature measurements have revealed, systematically, for the 4 experiments aboard UARS, a significant residual mean difference of up to 3 K around 35-43 km [4, 5, 6]. A comparison between lidar and ISAMS using simultaneous measurements suggests that the bias is associated with the variability of migrating tides and/or the presence of non-migrating tides rather than instrumental characteristics. Tides induce temperature deviations observed in southern France to be as large as ±3 K, with a maximum at the stratopause (figure 2). The amplitudes and phases of the semidiurnal variation change significantly with season and location. Seasonal changes up to 2 K have been clearly identified for the diurnal component. An analytic statistic model of the tides, based on sinusoidal functions has been used to apply time-of-day adjustments [7]. Data comparisons have been improved and bias reduced. The successive versions of the retrieval software of the UARS products are continuously improved and check for consistency with lidar data even after 10 years [8, 9].

Figure 2. Mean diurnal temperature evolution as shown with the MLS/UARS data

The actual satellite validations using temperature profiles obtained within the framework of the NDSC network concern the Envisat/ESA mission. Within the different temperature products provided by experiments aboard Envisat, high-resolution temperature profiles are obtained from photometer technique by GOMOS (figure 3).

Figure 3. Preliminary GOMOS HRTP temperature profile comparisons with OHP Rayleigh lidar.

4. TEMPERATURE TRENDS

The longest temperature series have been also used to detect long-term changes that can be attributed to anthropogenic origins [10]. Trends and variations in global stratospheric temperatures are an integral part of the changes occurring in the Earth’s climate system. Data sets for analyzing long-term (a decade and more) changes in the stratospheric temperatures consist of radiosonde, satellite, rocksonde and lidar measurements; meteorological analyses based on radiosonde and/or satellite data; and products based on assimilating observations using a general circulation
model. Each of these contains varying degrees of uncertainties that influence the interpretation and significance of trends. At northern mid-latitudes the lower stratosphere (16–21 km) cooling over the 1979–1994 period is strikingly coherent among the various data sets with regard to magnitude and statistical significance. The vertical profile of the annual-mean stratospheric temperature change in the northern mid-latitudes over the 1979–1994 period is robust among the different data sets, with 0.75 K/decade cooling in the 20- to 35-km region and increasing cooling above (e.g., 2.5 K/decade at 50 km). OHP lidar series are in good agreement with the investigations using other data sets. Model investigations into the cause or causes of the observed temperature trends are also reviewed. Both well-mixed greenhouse gases and ozone changes contribute in an important manner to the cooling, but model simulations underestimate the observed decadal-scale trend.

5. SATELLITE-GROUND BASED SYNERGY

The only global source of temperature of the middle atmosphere on a long-term basis (decades), from space is provided by the TIROS operational vertical sounders (TOVS), which has been operational since late 1978. A series of TOVS instruments (which includes MSU and SSU) have been put into orbit aboard a succession of operational satellites; these instruments do not yield identical radiance measurements for a variety of reasons, and derived temperatures may change substantially when a new instrument is introduced. Temperature is derived with different techniques and tools.

Figure 4. Temperature difference between lidar and NCEP

Finger et al. [11] have compared the operationally derived temperatures with collocated rocketsondes observations and find systematic biases of the order of 3–6 K in the upper stratosphere. These biases furthermore change with the introduction of new operational satellites, and Finger et al. [11] provide a set of recommended corrections to the temperature data, which have been used by CPC. Comparisons between OHP lidar data from 1979 to 1993 and NCEP data interpolated from the global analyses to the lidar location reveal significant mean temperature differences [12]. Changing biases between lidar and NCEP temperatures above 5 hPa coincide with replacement of satellites used in the NCEP analyses (figure 4). However, some bias differences in upper stratospheric temperatures remain even after NCEP adjustments are made. It was shown that the remaining bias (2-4 K) is caused by tidal influences, heretofore not accounted for by the NCEP adjustment procedure.

The “Nash” [13] data set consists of brightness temperatures from observed (25, 26, and 27) and derived (47X, 36X, 35X, 26X, and 15X) channels of the Stratospheric Sounding Unit (SSU) and High-Resolution Infrared Sounder (HIRS) 2 instruments on these same satellites.

Figure 5. Zonal monthly mean temperature derived from SSU channel 27 compared to corresponding monthly mean of weighted lidar profiles at mid-latitude in Europe at 2 sites OHP and Hohenpeissenberg.

Figure 6. Raman temperature profile derived at La Réunion station

The weighting function for the SSU channels are typically 10–15 km thick. Adjustments have been made in the Nash channel data to compensate for radiometric differences, tidal differences between spacecraft, long-term drift in the local time of measurements, and spectroscopic drift in channels 26 and 27. More
recently, the second generation of instrument AMSU has been launched with a thinner weighting functions. The temperature series show cycles that can be associated to seasonal changes, to the Quasi Biennial Oscillation (QBO) and to the 11-year solar cycle. Trends are also clear at some levels. However, SSU reveal a plateau after 1998 when AMSU where introduced and careful examination are required. The comparison of lidar and SSU temperature series show a good overall agreement.

6. RAMAN LIDAR

Some Raman channels have been implemented on the lidars include in this proposal. This technique allows to measure temperatures with the same method than Rayleigh lidar in an atmosphere including aerosols [14]. So measurements are possible down to the cirrus cloud altitude (12 km at mid-latitude) and sometime lower down [15].

7. CONCLUSIONS

The full altitude range from 12 to 80 km is covered because Rayleigh channels and the Raman channel overlap permitting a continuous density profile that is inverted for obtaining temperature profiles. So the overlap between lidar and MetOp will be quite large. However, while the Rayleigh analysis is an operational product and despite the Raman data are routinely acquired simultaneously with Rayleigh channels, the data analysis required further additional supports to be produced on a routine basis.

The OHP lidar data have been used for a long time for trend detection and satellite validations. Nowadays, in the frame of the NDSC several other stations can provide high quality data. The satellite validation and global trend detection are closely related and can be operationally coupled through the GMES strategy. MetOp in providing AMSU; the same instruments than the one used by NOAA for the longest data series and GRAS based on a very promising techniques involving GPS are an unique opportunity to make quick progress and insure goal of the GMES/GEOSS project.

REFERENCES


