Journal of Atmospheric and Solar-Terrestrial Physics 102 (2013) 252–260

Contents lists available at SciVerse ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Impact of atmospheric variability on validation of satellite-based temperature measurements

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ARTICLE INFO

Article history:
Received 9 January 2013
Received in revised form
8 May 2013
Accepted 31 May 2013
Available online 20 June 2013

Keywords:
Coincidence
Mismatch error
Natural variability
Validation

ABSTRACT

Satellite validation is often based on straight forward comparison of satellite-based data with non-satellite based measurements. For functional reasons satellite and reference measurements do usually not correspond exactly in time and space. Dynamical effects in the atmosphere lead to temporal and spatial variability of atmospheric parameters (e.g. temperature). This causes considerable differences that do not necessarily hint to an incorrect satellite measurement, so called mistime and misdistance errors.

In this paper, the natural variability of the atmosphere is studied on scales effecting validation measurements. The approach is applied to temperature data from the ERA-40 reanalysis as well as to radiosonde (SIGMA-1) and satellite-based (SABER) measurements. Mistime and misdistance errors are quantified in dependence of geographic position, altitude, season and the temporal and spatial mismatch. The results allow a quantitative estimation of the impact of natural variability on validation analyses. In general, values lie in the range of a few Kelvin (e.g. up to 5 K for 500 km misdistance or 6 h mistime in the stratosphere), which indicates considerable effects on validation results. The determined results also point out regions in the atmosphere where the impact of natural variability is in general relatively high (e.g. the winter stratosphere in mid-latitudes) or rather low (e.g. the lower summer stratosphere). Altitudes, which are characterized systematically by only small mismatch errors, are indicated at about 10 and 25 km, respectively. These quiet layers are of special interest for validation activities.

1. Introduction

Besides the pure numerical values of atmospheric quantities (e.g. temperature and ozone) obtained from satellite instruments, detailed knowledge about errors and precision of these measurements is essential for interpretation and further processing of these data. Thus, satellite-based measurements are normally validated by comparing them with already validated independent reference data—mostly ground-based. This paper concentrates on geophysical validation, which is based on the comparison of pairs of temporal and spatial matching measurements. In practice, measurements of the instrument to be validated seldom agree exactly in time and space with reference measurements. In order to get a sufficient number of matching pairs, small temporal and spatial mismatches between both measurements have to be tolerated, typically some hours and some hundred kilometers. Within these small mismatches, the natural variability of the atmosphere leads to differences between the measurements, so called mistime and misdistance errors, combined addressed as mismatch error. Quantification of this atmospheric impact is necessary in order to separate it from instrumental errors.

It is generally known that natural variability disturbs the comparison of validation measurements. Different approaches are applied to account for this problem. For example, validation methods of MIPAS and ACE use the validation measurements itself to estimate the variability (Ridolfi et al., 2007; Sica et al., 2008). Another way is the interpolation of reference measurements to time and location of the validation measurements with modeled background information in order to avoid biases induced by

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http://dx.doi.org/10.1016/j.jastp.2013.05.022

background variability (e.g., Ridolfi et al., 2007; Lahoz et al., 2007). Von Clarmann (2006) describes a method which adds a correction term to the reference measurement. However, all these methods are connected to some additional effort. Thus the mismatch effect is often not considered in practice in order to simplify data comparison.

To take the mismatch error on validation into account, in general, information about the effect of natural variability is necessary, but not commonly available. There are a few studies that analyze natural variability for the purpose of validation. Sofieva et al. (2008) used pairs of radiosonde measurements with temporal differences between 1 min and 7 h in order to examine temperature variations in the stratosphere at the Scandinavian station 'Sodankylä'. McDonald et al. (2010) determined estimates of the misdistance error based on temperature measurements by the COSMIC instrument.

In this paper, the mismatch error is determined on a global scale based on an independent data set. Therefore the ERA-40 reanalysis temperature data are used. This offers the advantage that results are available depending on location, time, and altitude as well as different combinations of the temporal and spatial mismatches. The results based on ERA-40 are compared to equivalent calculations with radiosonde (SIGMA-1) and satellite-based (SABER) measurements.

In general, the mismatch error is quantified to about 1–7 K for temporal mismatches up to 24 h and spacial mismatches up to 500 km. This indicates considerable effects on validation results. The results concerning the mismatch error point out possibilities for novel validation approaches that take into account this impact of natural variability. Even if it is not possible to quantify the mismatch error accurately enough to completely remove it from the validation results, there are opportunities to keep it low through an optimal planning of validation activities.

2. Data

2.1. ECMWF reanalysis

The analyses of this paper are based on reanalyzed temperature data in order to get a global coverage. The regular grid of the dataset provides the opportunity for several combinations of mistime and misdistance. In addition, seasonal variations can be studied.

ERA-40 is a reanalysis of meteorological observations from September 1957 to August 2002 generated by the ECMWF (*E*uropean *C*entre for *M*edium-range *W*eather *F*orecasts). A three-dimensional variational (3D-Var) data assimilation system combines observations and background information to produce an estimate of the state of the atmosphere at a particular time. The background information comes from a short-range forecast initiated from the previous analysis step.

Analyses of atmospheric temperature (and further atmospheric and surface quantities) are produced for 00, 06, 12 and 18 UTC on a horizontal grid with a resolution of 2.5° in latitude and longitude. The 60 pressure levels of the assimilation model cover a vertical range from 10 m to approximately 65 km. Vertical resolution decreases with altitude. It is about 0.5 km in the mid-troposphere and about 1.5 km in the mid-stratosphere. A reduction of horizontal and temporal variability through the assimilation process and the resolution should be kept in mind for the interpretation of the results. Further information on the ERA-40 reanalysis can be obtained by Uppala et al. (2005).

General numerical values for the errors in the dataset are not available. Inaccuracies and jumps in ERA-40 temperature occur over the whole period. They are caused by coverage and changes in the observing system and subdivision of the period in three processing streams (1989–2002, 1957–1972, 1972–1988). For example, temperature shows cold biases up to 5 K towards end of the period in the upper stratosphere (Uppala et al., 2005). Since temperature fluctuations on rather small scales are of interest instead than absolute temperatures, these biases do not affect the results of our study. We used ERA-40 data for a period of 24 years from September 1978 to August 2002, because the amount of assimilated measurements increases with availability of satellite data since the 1970s.

2.2. Radiosonde measurements

The *SIGMA-1* campaign (*S*atellite validation: *I*mpact of *G*ravity *W*aves in the *M*iddle *A*tmosphere – 1st campaign) was carried out in November 2009 in the Alpine region in order to study gravity wave signatures. SIGMA-1 was a cooperation of the German Aerospace Center, DLR-DFD, the Environmental Research Station Schneefernerhaus, UFS, and the German Weather Service, DWD. Data are achieved at and are available from the WMO/ICSU World Data Center for Remote Sensing of the Atmosphere, WDC-RSAT (http://wdc.dlr.de). Temperature was measured by radiosondes, airglow spectrometers, lidar and satellite in different altitude ranges. For the results of this paper temperature profiles of 60 radiosondes (Vaisala-RS92) launched at the observatory 'Hohenpeissenberg' (47.8°N, 11.1°E) are used. These radiosondes were started in short time intervals (mostly within 2 h apart from each other), distributed to four measurement salvoes. These salvoes were chosen by background wind situations with expected enhanced gravity wave activity.

Balloon-carried radiosondes provide temperature profiles with high vertical resolution (~25 m) from the ground up to about 35 km height. The sensor of the Vaisala-RS92 measures temperature directly through the temperature-dependent capacitance of a dielectrium. The accuracy of the measurements is denoted by 0.5 K (Vaisala, 2010).

2.3. Satellite-based measurements

SABER (*S*ounding of the *A*tmosphere using *B*roadband *E*mission *R*adiometry) is a limb-viewing instrument on the satellite TIMED (*T*hermosphere *I*onosphere *M*esosphere *E*nergetics and *D*ynamics). Kinetic temperature is retrieved from 15 μm CO_2 emission measurements (e.g., Russell III et al., 1999). For the study of this paper the data version 'SABER V1.07' is used. This version accounts for conditions of non-local thermodynamic equilibrium (NLTE) above 65 km height in the retrieval algorithm (Remsberg et al., 2008). Vertical temperature profiles are provided with ~400 m altitude resolution from about 15 to 130 km since January 2002 and can be downloaded from the SABER homepage (http://saber.gats-inc.com/). Comparison of SABER data with reference measurements and analyses indicate that uncertainties in SABER temperature data lie in the range of 1–3 K in the stratosphere and lower mesosphere and increase up to 5 K in the upper mesosphere (Remsberg et al., 2008). The temporal resolution between consecutive measured profiles is ~1 min. So, the circular orbit of TIMED leads to ~400 km horizontal distance in average between two consecutive measurements.

3. Results

Our aim is to quantify the impact of atmospheric variability on validation measurements. Therefore, the natural variability is examined on scales that are in the range of common coincidence criteria.