RE-EVALUATION OF SABER TEMPERATURES TRIGGERED BY COMPARISON WITH MaCWAVE MET ROCKET MEASUREMENTS

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ABSTRACT

Sequences of MET rockets launched from Andøya Rocket Range during the MaCWAVE/MIDAS Program in July 2002 were used to evaluate the meteorology of the mesosphere/lower thermosphere (MLT) region (55–90 km). Two of the falling sphere flights were coordinated with TIMED Satellite overflights, particularly when the SABER IR radiometer tangent point was near 85 km, to help validate SABER temperatures. The observed discrepancies between the temperature profiles produced by each technique indicated a need to refine the SABER algorithms used to derive temperature, mainly in the polar summer mesosphere. Further study of this discrepancy has established the importance of the large non-local thermal equilibrium effects (NLTE) affecting this region, primarily because of its cold temperatures and large temperature gradients. Finally, after also accounting for the redistribution of ν_2 quanta among various CO_2 isotopes, the retrieved summer polar mesopause altitudes moved upward by 2–4 km, in better agreement with both the falling sphere measurements and climatological models of this region. Review of these measurements and results is used to demonstrate the high value of inter-comparisons between satellite remote sensing measurements and ground truth provided by various techniques including coordinated rocket underflights.

1. INTRODUCTION

The MaCWAVE/MIDAS Campaign was conducted during July, 2002 at the Andøya Rocket Range, Norway (69.3°N, 16.0°E, Magnetic L = 6.2°). Here, MaCWAVE represents **M**ountain **a**nd **C**onvective **W**aves **A**scending **VE**rtically, while MIDAS represents **MI**ddle Atmosphere **D**ynamics **a**nd **S**tructure). The primary objectives of this extensive rocket, lidar, and radar measurement program were to a) quantify gravity wave propagation and effects in the polar summer mesopause region, b) measure the influences of wave instability processes in constraining wave amplitudes and fluxes, c) measure gravity wave forcing of MLT circulation and thermal structure -mean and variable, and d) provide validation of TIMED/SABER temperature measurements. Furthermore, when coupled with the winter MaCWAVE Program from Esrange, Sweden (67.9°N, 21.0°E., Magnetic L = 5.5°), the two campaigns permitted comparisons between the summer and winter mesopause regions at polar latitudes. Objectives a, b, and c have already been discussed for the summer program in a series of papers which appeared in the December 28, 2004 issue of Geophysical Review Letters (GRL Vol. 31). The same objectives "a–c" were discussed in greater detail including the wintertime results in a special issue of Annales Geophysicae, (Vol.24, #4, 2006). Overviews [1, 2] can be found in each of these issues.

In this presentation we concentrate on objective "d", which was not presented in the above-mentioned journals. As part of the summer program, it was possible to coordinate overflights of the TIMED (**T**hermosphere, **I**onosphere, **M**esosphere **E**nergetics and **D**ynamics) Satellite with sequences of meteorological falling sphere (MET-FS) rocket payloads [3], which were included on two separate days as part of the MaCWAVE/MIDAS launch sequences. In particular, comparisons were made in the look direction of the SABER (**S**ounding of the **A**tmosphere using **B**roadband **E**mission **R**adiometry) instrument, which is a limb scanning infrared radiometer with 10 broadband channels (1.27–17 μm). The instrument is capable of extracting many minor atmospheric constituents including CO_2, O, NO, O_2, OH, O, H, and most recently H_2O. Our prime interest from SABER is the kinetic temperature, which is a derivative from the 15 μm CO_2 channel.

First comparisons with the rocket data showed an unacceptable discrepancy, which provided incorrect temperature profiles for the summer mesopause region, based on comparisons with the rocket data, with climatological models, and consistency with the presence of ice particles known to be responsible for existing polar mesospheric summer echoes (PMSE) and

Noctilucent Clouds (NLC). The remainder of this paper shows the results, and explains how adjustments to the algorithms responsible for temperature extraction, using non-local thermal equilibrium (NLTE) considerations have corrected this problem. The results demonstrate how a few point measurements from simple rocket flights can provide valuable information for reconsideration of satellite measurements on a global scale.

2. RESULTS

Fig. 1 depicts the sequences launched during MaCWAVE/MIDAS on the nights of July 1/2 and 4/5, 2002. Our concern here is for the data from the MET-FS, indicated by the short vertical bars in each diagrammed sequence. Reference [4] provides a comparison of the satellite results on July 2, 2002 with the mean profile of the MET-FS rocket data (cf. figure 4 of that paper), which is similar to the comparison made in [5]. Also shown is the climatological model of Lübken [6] obtained from a sequence of MET-FS summer measurements at Andøya over multiple years. Reference [4] demonstrates close agreement between the model and the MaCWAVE MET-FS flights, but not with the SABER results. The SABER interpretation is based on SABER V1.04. The value of this comparison was an alert that there could be a problem with the extraction of temperature from the SABER data.

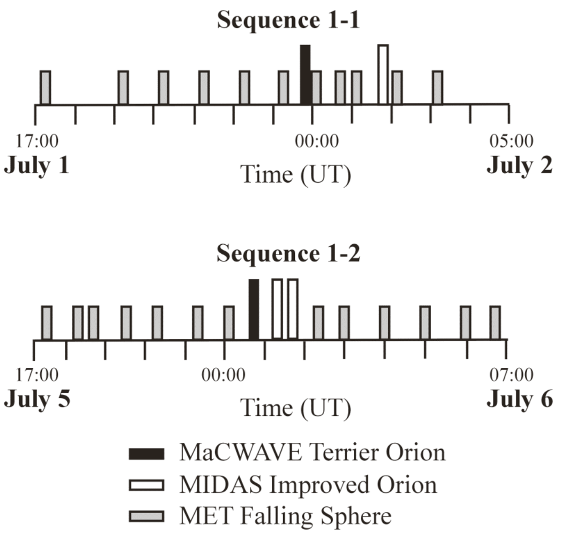

Figure 1. Launches during MaCWAVE/MIDAS campaign.

One should keep in mind that the accuracy of the MET-FS temperature data degrades rapidly at higher altitudes, especially above 85 km. altitude, and must be treated with caution there. This occurs since the falling sphere is a passive instrument, which must be tracked by a high-precision radar. The fall rate of the sphere is a function of atmospheric density, which can no longer provide measurable buoyancy for the sphere at the upper altitudes. Temperature is calculated from the obtained density profile. Nonetheless, the shape of the profile should still be preserved up to altitudes approaching 90 km.

The next section outlines the approach used to properly include NLTE considerations in the interpretation of SABER data, and the obtained results when this approach was applied.

3. ANALYSIS

The details on the analysis of NLTE effects on the interpretation of the SABER data from the 15μm channel have been published by [4]. In their work, they found that the inclusion of the CO_2 ν_2 quanta V-V exchange was critical to bring the SABER temperature in better agreement with the measurements from other sources. In the lower atmosphere, inelastic molecular collisions determine the population of molecular levels.

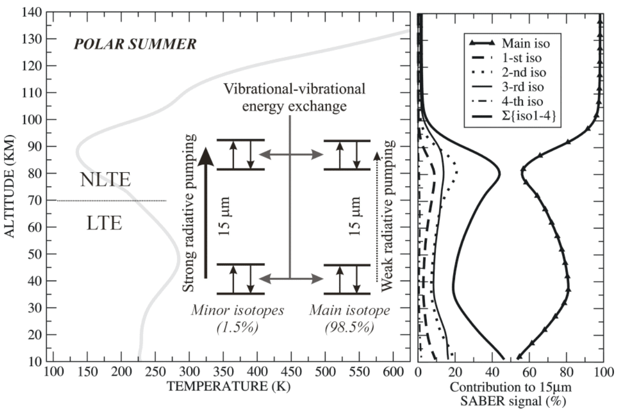

Figure 2. Explaining the role of V-V energy exchange in 15 μm radiance formation.

As a result, local thermodynamic equilibrium (LTE) exists where populations obey the Boltzmann Law with the local kinetic temperature T_{kin}. In the middle and upper atmosphere, the frequency of collisions is lower and other processes that populate and depopulate molecular levels (e.g., absorption and emission of radiation in molecular bands, redistribution of excitation between colliding molecules, chemical excitation, etc.) must be taken into account. In this region of the atmosphere, LTE no longer applies and the populations of vibrational levels deviate from the Boltzmann distribution for the local T_{kin}. As mentioned above, such conditions are referred to as non-LTE or NLTE, and the populations must be found by a self consistent solution for the system of rate equations expressing the balance of all processes which populate and depopulate vibrational levels, and of the radiative transfer equation in the rotational-vibrational bands. The assumption of LTE in the vibrational states of the CO_2 molecule corresponding to the bending mode breaks down near 75 km altitude. Therefore, an accurate simulation of the broadband SABER 15 μm limb radiances from the mesosphere and lower thermosphere, including retrieval of the temperatures in these atmospheric layers, requires a detailed accounting for NLTE in CO_2.

In the work of [4], it was found that the inclusion of the CO_2 ν_2 quanta V–V exchange was critical to bring the SABER temperatures in better agreement with measurements from other sources. The right hand panel of Fig. 2 shows that minor isotopes can contribute nearly half of the 15 μm broadband signal. The upwelling radiance from minor isotopes in the warm stratosphere reaches the mesosphere through optically thin 15μm bands and pumps the ν_2 levels of the isotopes (see the left hand panel of Fig. 2). The absorbed energy is partially transferred to a principal isotope where it is efficiently thermalized. If one doesn't account for this process, the outgoing 15 μm radiance is overestimated, which leads to an underestimation of the temperature during retrieval.

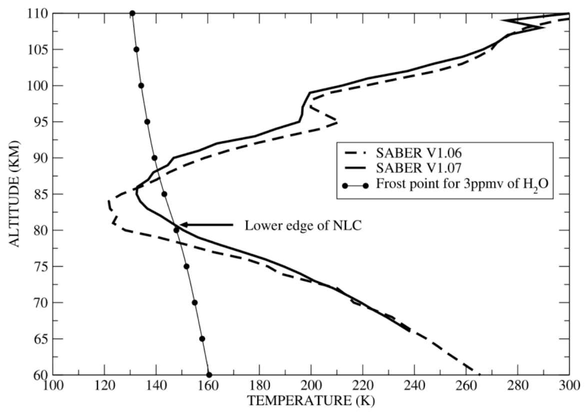

Figure 3. Effects of accounting for V-V exchange between CO_2 isotopes. Coincident measurement with ALOMAR station (69N,16E), 08-JUL-2002, 23:25UT.

By adjusting the temperature retrieval to take NLTE considerations into account, one finds much better agreement with the climatology and the rocket data (cf. [4]). Fig. 3 describes vertical temperature profiles from SABER as retrieved in V1.04/1.06 (no V-V exchange) and V1.07 (V-V exchange included) approaches. These data were obtained on July 8, 2002, at which time a large and stable noctilucent cloud was present and measured by the ALOMAR RMR lidar at Andøya Rocket Range (von Zahn and Lübken, pvt. com.). Note that the V1.07 profile exhibits a warmer but higher mesopause region than the V1.06 retrieved profile. Furthermore, when the calculated frostpoint is superimposed on the figure, it crosses the V1.07 profile at 80 km altitude, which was the base of the observed NLC.

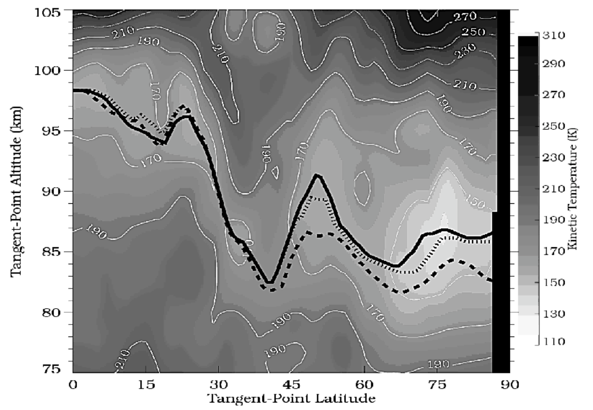

Figure 4. Meridional distribution of temperatures for events 25–51, orbit 3094, July 4, 2002. Solid line – mesopause altitude in V1.07, dashes – no V-V exchange (V1.06), dots – half rate.

Fig. 4 provides an overview of the V1.07 meridional temperature distribution for the Northern Hemisphere on July 4, 2002. To demonstrate the effect, the mesopause level is compared with that of V1.06. For comparison, the version with a consideration of the V-V exchange at half rate is also shown. It is clear that the mesopause is shifted upward throughout the entire region, although the shift is far more prominent at latitudes above 45°N, as we enter the coldest mesopause region. Larger difference between the stratospheric and mesospheric temperatures in polar summer region enhances the influence of the V-V exchange in the retrieval (Fig. 2). These results clearly demonstrate the importance of accurate accounting for NLTE effects on a global scale, and emphasize the value of the MET-FS payload flights in exposing the need for NLTE considerations in the retrieval algorithm.

4. FINAL REMARKS

This presentation is meant to illustrate the value of point measurements by rockets for improving or validating satellite data. For this case, a few MET-FS rockets from the MaCWAVE/MIDAS summer program in Norway were used to improve the temperature retrieval by the SABER instrument aboard TIMED. The result demonstrated a discrepancy, which was later resolved by taking the V-V exchange processes from NLTE considerations. Future comparisons of this type should lead to further refinement in the retrievals.

5. REFERENCES

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