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ZERO MISS TIME AND ZERO MISS DISTANCE EXPERIMENTS FOR VALIDATION OF CRISTA 2 TEMPERATURES

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ABSTRACT

The second mission of the limb sounding CRISTA experiment was from August 8-16, 1997 observing small scale dynamics in the middle atmosphere. During the supporting field campaign, balloon (radiosonde and ozonesonde) and rocket validation measurements (falling sphere and datasonde) from NASA/GSFC Wallops Flight Facility (WFF) were coordinated to obtain minimal miss time and miss distance with respect to the CRISTA measurements. Two new strategies were employed: (1) six validation orbits with the CRISTA tangent point oriented at the launch site; (2) twin falling sphere launches within few minutes to obtain coincident measurements at different altitudes. The pointing maneuvers worked perfectly; the average minimal miss distance for WFF was 33 km. Based on preliminary data, a temperature inversion layer at around 70 km was observed simultaneously with two falling spheres and the closest CRISTA profile. Averaging ten comparisons, the falling sphere temperatures deviate systematically from CRISTA data, being 5 K warmer at 60 km and 8 K colder at 70 km. The result confirms earlier comparisons finding evidence for a systematic temperature bias of falling sphere data in the mesosphere.

VALIDATION STRATEGIES

Satellite observations of the stratosphere and mesosphere have been obtained for more than 20 years, and their accuracy has been continuously improved. Precise temperature measurements are important for climatological studies, and satellite data serve as input for data assimilations and general circulation models. For infrared emission measurements, temperatures are crucial for the accuracy of the derived trace gas mixing ratios. For the construction of a good validation data set, the observations should be as close as possible in space and time to the satellite footprint or tangent point, and a large number of high quality validation measurements is desired.

The temporal criterion can be fulfilled by coordinating ground based, balloon, and rocket observations with the satellite overpasses. For CRISTA (Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere), this was achieved by the CRISTA/MAHRSI Campaigns (Offermann *et al.*, 1999; Lehmacher *et al.*, 1998). In the field campaign during the CRISTA 2 mission from August 8-16, 1997, 49 stations with ground based instruments participated, and 74 balloons and 43 rockets were launched, the majority coordinated with the satellite overpasses. The *miss time* is being defined as time difference between the CRISTA and the validation measurement. The spatial criterion was optimized during CRISTA 2 by orienting the CRISTA-SPAS platform, which was capable of performing yaw maneuvers with angular speeds of up to 7°/min, such that the CRISTA central telescope was pointing exactly at the validation site. The *miss distance* is being defined as (horizontal) distance between the measurements.

Atmospheric variability often increases with altitude due to various dynamic processes, e.g. gravity waves. For CRISTA 2, pairs of falling spheres were launched within a short time interval from NASA/GSFC Wallops Flight Facility (WFF) to have two altitudes for a single CRISTA profile with minimal miss time and miss distance. However, even under the conditions of a perfect spatio-temporal coincidence of satellite and validation measurement, one should remember the inherently different integration schemes of the techniques to be compared. For example, the CRISTA limb emission measurement represents an integral value over a volume of approximately 20x200x2 km^3, recorded within one second (Riese *et al.*, 1999). A radiosonde or falling sphere measures in situ yielding temperatures along a one-dimensional trajectory, or a lidar temperature may be valid for a small area above the experiment site and averaged over e.g. half an hour. This is particularly of importance when comparing small temperature fluctuations or wave amplitudes observed in individual profiles and with different techniques.

POINTING MANEUVERS

An example of three consecutive orbits during CRISTA 2 including one validation orbit on August 10, 1997 is illustrated in Figure 1. Shown are the footprints for each profile of the short-wavelength spectrometer in the central telecope (SCS). CRISTA has three limb scanning telescopes, four spectrometers and 26 detectors simultaneously measuring infrared emission spectra; for instrument details see Offermann *et al.* (1999) and Riese *et al.* (1999). The first and the third orbit were of the so-called ping-pong type, where the platform was turned to the north during ascending nodes and south during descending nodes, thereby increasing CRISTA's latitude coverage up to 74°, considerably above the 57° spacecraft inclination. The second orbit shown was a validation orbit, during which the CRISTA-SPAS yawed with pre-calculated angular speeds based on the spacecraft state vector predictions such that the tangent point of the central telescope was pointing at the two main validation sites, Wallops Island, Virginia (37.9°N, 75.5°W), and Hohenpeissenberg, Germany (47.8°N, 11.0°E), marked by the full diamonds. A total of six validation orbits, one each day, was incorporated in the mission planning, and all pointing maneuvers worked flawlessly. On average, the minimal miss distance over WFF was 31 km.

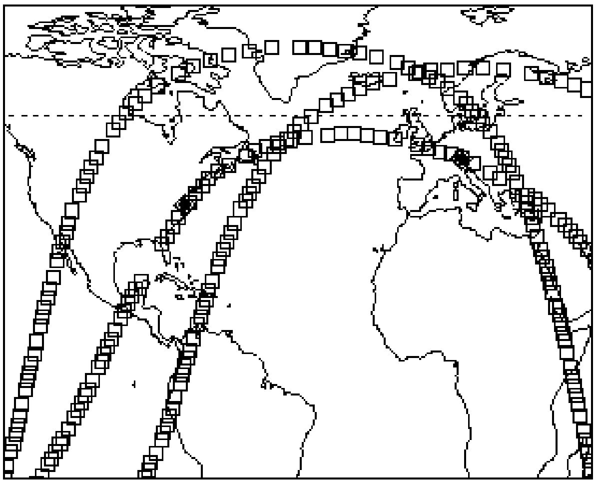

Fig. 1. The footprints of the CRISTA SCS spectrometer (open squares) for three consecutive orbits on August 10, 1997. The second orbit was a validation orbit with CRISTA pointing at Wallops Island, Virginia, and Hohenpeissenberg, Germany (full diamonds). A dotted line is drawn at 57° latitude.

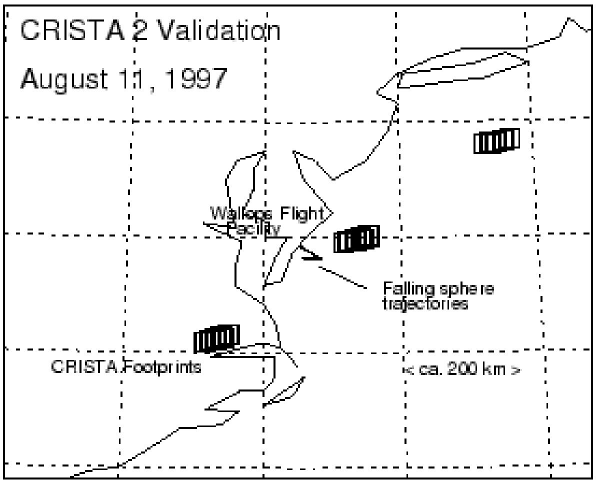

Fig. 2. Detail of validation orbit on August 11, 1997 near Wallops Flight Facility. The CRISTA footprints (squares) are shown for three consecutive limb scans of the SCL spectrometer; for each scan they are slightly shifted for different measurement levels. The V shaped line originating from the coast shows the horizontal projections of two falling sphere trajectories.

A close-up of the region around NASA/GSFC Wallops Flight Facility (WFF) is depicted in Figure 2. Here the footprints for three consecutive CRISTA limb scans of the central long-wavelength spectrometer (SCL) during the validation orbit on August 11, 1997, are marked by the open squares. Each altitude profile consists of 33 steps with spectral measurements, which takes about 36 s causing a 290 km separation between profiles. The small V shaped line originating from the coast is actually the trajectories of two falling spheres launched from WFF. The minimal horizontal miss distance from a reference point (37.7°N, 75.3°W) was 186, 47, 303 km, counting the profiles from south to north. Keeping in mind that the CRISTA limb sampling areas are 20x200 km^2 large, it can be seen that the horizontal extent of the falling sphere trajectories is covered by the middle profile, really fulfilling the *zero miss distance* requirement.

The time-altitude diagram for the same three profiles as the previous example is shown in Figure 3. The curved lines are the trajectories for the two falling sphere payloads launched at 13:38 UT (=0 s) and 13:43 UT (=300 s). The first sphere was launched on a Superloki, the second on a Viper 3A rocket, reaching apogees of 107 and 119 km, respectively. The slanted straight lines represent six CRISTA altitude scans, three of the SCS spectrometer scanning down from 67-11 km and three of the SCL spectrometer scanning down from 89-33 km. It can be noticed that during the altitude scan of the closest SCL profile (middle) the first sphere was falling from 90-70 km, and the second sphere was at about 40 km. For this example, the idea of having two falling spheres in the air measuring during one single CRISTA limb scan worked out perfectly.

TEMPERATURE COMPARISONS

The temperature profiles for both falling spheres and the closest of the three CRISTA SCL limb scans can be seen in Figure 4. The falling sphere profiles show a temperature inversion between 65-70 km and agree with each other within the estimated statistical error of about 3-4 K at these altitudes (Lübken *et al.*, 1994; Schmidlin *et al.*, 1991). The CRISTA temperature profile measured at zero miss distance and zero miss time also agrees very well with the falling sphere data. The inversion layer is clearly visible in the CRISTA data suggesting that the horizontal extent of this feature might be much larger than the tiny volume probed by the in situ measurements. The CRISTA data are preliminary, but we may estimate the total uncertainty from the CRISTA 1 error analysis as 2 K at 70 km (Riese *et al.*, 1999). The neighboring CRISTA profiles (not shown) agree well below 60 km and show larger temperature fluctuations in the region of the inversion.

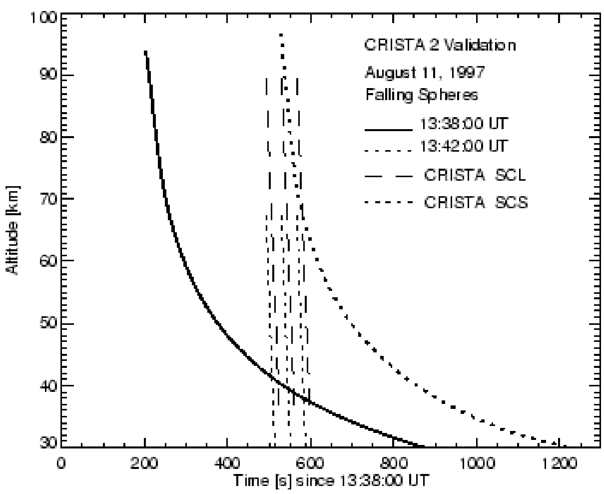

Fig. 3. Trajectories for two falling spheres (thick curves) and six CRISTA limb scans with shortest horizontal miss distances from the spheres.

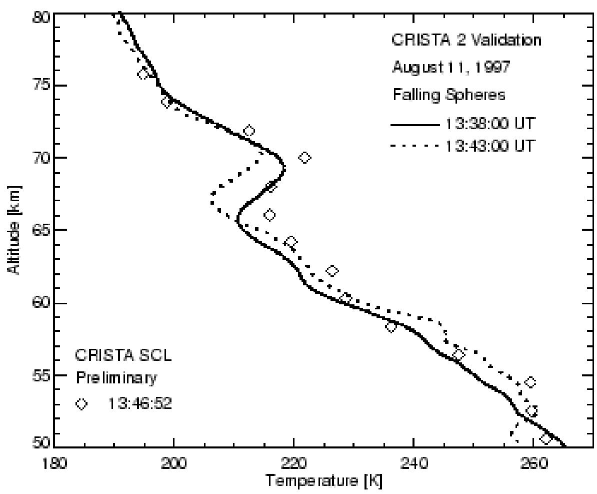

Fig. 4. Temperature profiles for the two falling spheres (solid and dotted lines) and the *zero miss distance* CRISTA SCL limb scan (diamonds).

Figure 5 summarizes the comparisons of falling spheres and CRISTA 2 SCL data for the validation orbits. The average temperature profile of 19 falling spheres shows a typical summer mesosphere with a relatively constant lapse rate of -2.7 K/km. Comparing ten falling sphere with ten CRISTA profiles, the falling spheres show a deviation profile which below 65 km is obviously within the combined error limits. The falling sphere temperatures are 5 K warmer at 60 km than CRISTA and 8 K lower around 70 km. An independent comparison between falling spheres and Rayleigh lidar from winter 1990 reported by Lübken *et al.* (1994) also shows falling spheres being warmer around 60 km and colder around 68 km. Dudhia and Livesey (1996) compare UARS/ISAMS temperature data with falling spheres launched at Cape Canaveral and found a similar bias between 60 and 70 km. The falling sphere speed typically changes from supersonic to subsonic (Mach number Ma=1 transition) at 68 km, which is associated with a drastic change in the drag coefficient. Lübken *et al.* suggested this transition may affect the falling sphere density and temperature analysis at these altitudes.

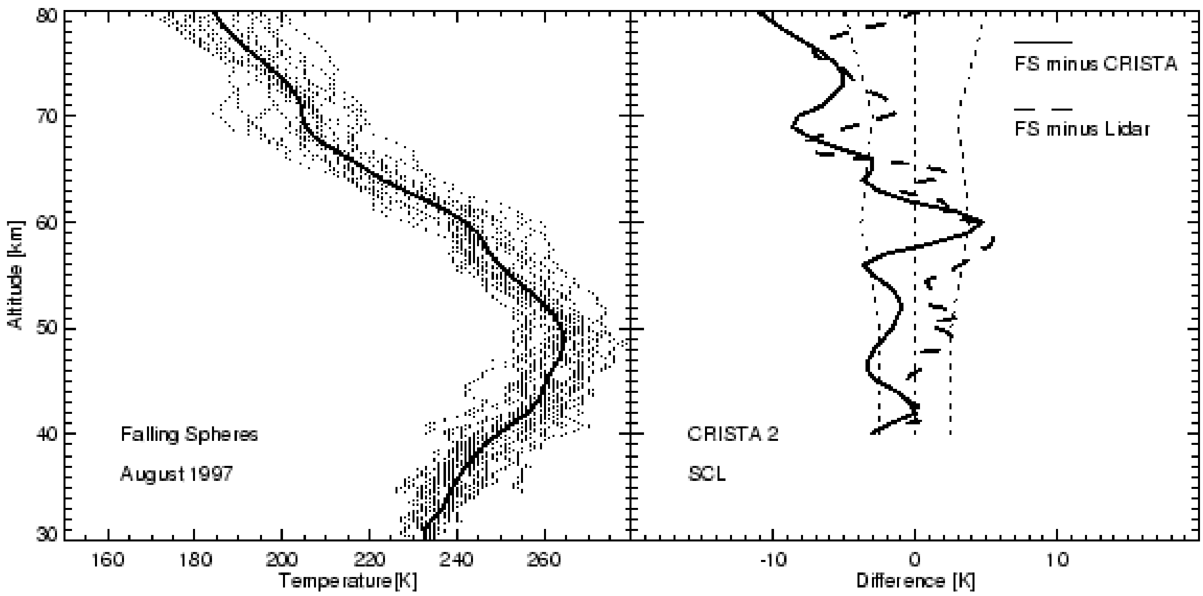

Fig. 5. Left: Individual (dots) and mean (solid line) temperature profiles for 19 falling spheres during CRISTA 2. Right: Mean difference profiles for Falling Sphere minus CRISTA (solid line) for 10 comparisons during the validation orbits and for Falling Sphere minus Lidar (dashed line) from Lübken *et al.* (1994). The thin dotted lines are error estimates for the falling sphere measurement.

The falling sphere comparisons for CRISTA 1 from November 1994 (Lehmacher *et al.*, 1998) showed that the falling sphere deviations were much larger. The mean temperature profile of the falling spheres showed a steep lapse rate (-8 K/km) around 67 km, which may have been partly due to tidal wave activity. The deviation profile, when comparing with CRISTA 1 SCL data, had a positive bias of falling sphere measurements of 7 K at 60 km, and a negative bias of -12 K at 69 km. This result may be interpreted as sensitivity of the falling sphere temperature analysis to the background temperature profile, particularly in the region of the Ma=1 transition.

CONCLUSIONS

The CRISTA 2 zero miss distance experiments were very successful. For Wallops Island, the average minimal miss distance for all six validation orbits was 33 km for the tangent points of the CRISTA SCL spectrometer. Twin falling sphere launches had been coordinated to have zero miss time and zero miss distance at different altitudes for a single satellite overpass. Preliminary data analysis shows that a temperature inversion observed by both falling spheres is also seen in the closest CRISTA profile.

The falling spheres during CRISTA 2 agree better with the satellite instrument data than during CRISTA 1. This may be caused by smaller miss distances during the CRISTA 2 comparisons. However, there is systematic bias of falling sphere temperatures which are warmer at 60 km and colder at 70 km. This was also observed during CRISTA 1, but even much more pronounced. This difference may be associated with the background mesospheric temperature profile which was rather smooth during CRISTA 2 in August 1997, but exhibited a strong negative temperature gradient between 60-70 km during CRISTA 1 in November 1994. The sensitivity of the falling sphere temperature analysis to vertical temperature gradients has to be further investigated.

ACKNOWLEDGMENTS

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