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THE 1994 TIMS AIRBORNE CALIBRATION EXPERIMENT: CASTAIC LAKE, CALIFORNIA

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1. INTRODUCTION

This summary describes the 9 March 1994 Thermal Infrared Multispectral Scanner (TIMS) airborne calibration experiment conducted at Castaic Lake, California. This experiment was a collaborative effort between the TIMS and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) science teams at the Jet Propulsion Laboratory (JPL). TIMS was flown on the NASA/Ames Research Center C-130 with the new retractable air fence installed in the TIMS instrument bay. The purpose of this experiment was to determine if the fence would reduce the air turbulence in the TIMS instrument bay, thereby reducing the errors in calibration caused by wind-blast cooling of the blackbody reference sources internal to TIMS. Previous experiments have indicated that the wind blast effect could cause TIMS to over-estimate surface temperatures by more than 10 °C.

We have examined the TIMS data from twelve lines flown over Castaic Lake. Four of the lines were flown at an altitude of ~2.5 km (MSL), four at an altitude of ~6.7 km, and four at ~8.3 km. At each altitude there were flights with northern and southern headings, with the aircraft level and at a positive pitch (nose-up attitude). The suite of twelve flights was designed to subject the TIMS/air fence system to different wind conditions and air temperatures.

The TIMS flights were supported by a ground-truth team, who measured lake surface temperatures from a boat, and an atmosphere characterization team, who launched an airsonde and measured solar irradiance with a Reagan Sun Photometer. The Reagan measurements were used to construct a time-series of estimates of the total abundance of water vapor in the atmospheric column. These estimates were used to constrain modifications of the airsonde water vapor profile measurements made when processing the TIMS data with a customized version of the MODTRAN radiative transfer code.

2. DESCRIPTION OF EXPERIMENT AND DATA REDUCTION

Castaic Lake is located approximately 56 km northwest of JPL. Magic Mountain Amusement Park, the site of the airsonde launch and the Reagan photometric measurements, is approximately 10 km south of Castaic Lake. A failure of the battery pack powering the airsonde receiver terminated the atmosphere profile measurements at an altitude of approximately 5 km. The pressure, temperature, and relative humidity values from the mid-latitude summer climatic model of MODTRAN were used to augment the airsonde profile at altitudes greater than 5 km. Despite the equipment problems, the airsonde measurements did cover the crucial region below 5 km which contains over 90% of the atmospheric water vapor.

We have long recognized that a single airsonde profile cannot describe the spatial variation in atmospheric water vapor within a single TIMS scene or the temporal variation between successive scenes. In addition, the absolute accuracy of the carbon hygristors used to measure relative humidity is not known (the manufacturer's calibration is performed at a single relative humidity level of 33%). We attempted to verify our airsonde measurements by using a Reagan Sun Photometer to obtain a time-series of estimates of water vapor column abundance. While the airsonde profile is probably an accurate estimate of the relative vertical distribution of water vapor in the atmosphere, the photometer measurements suggest that the airsonde over-estimated the total column abundance of water vapor.

To correctly process TIMS data, we must often modify the column abundance of water vapor in an airsonde (or radiosonde) profile prior to running the radiative transfer code. The constraint on this modification is to achieve an agreement between the temperature estimates in the six TIMS channels over an extended water target, which we assume to have a flat emissivity spectrum (emissivity equal to 1.0 in each TIMS channel) and uniform surface temperature distribution. If our assumptions are correct, then we can attribute disagreements between the channel temperature estimates to atmospheric effects and modify the profile accordingly. Our photometer measurements of water vapor column abundance were used to further constrain the modification of the airsonde profile to process the data from each of the TIMS flights.

Prior to processing the TIMS data, MODTRAN was run with the airsonde profile to determine the apparent total (surface to 9 km altitude) column abundance of water vapor. To process the data from each flight, MODTRAN was run with the airsonde profile to determine the apparent amount of water vapor between TIMS and the lake surface. This quantity was divided by the apparent total column abundance to determine the fraction of the total between TIMS and the lake surface. This fraction was used to scale the corresponding Reagan total column water vapor measurement. MODTRAN was then run a second time, with a scaling factor applied to the airsonde profile to bring the water vapor column abundance reported by MODTRAN into agreement with the scaled Reagan measurement. This processing strategy allowed us to accommodate temporal variations in the total water vapor content of the atmosphere, but we did not accommodate temporal or spatial variations in the vertical or horizontal distribution of water vapor. We used the mid-latitude summer ozone profile packaged with MODTRAN to process the TIMS data.

3. DISCUSSION OF RESULTS

The ground-truth team collected 49 measurements of lake surface temperatures, using two infrared radiant thermometers and a single boat. This sample of lake surface temperatures has a mean of 14.6 °C and a standard deviation of 0.3 °C.

3.1. Surface Temperatures Acquired from an Altitude of 2.5 km

Figure 1 is a plot of the one standard deviation spread in the ground-truth temperature measurements (broken lines) and TIMS temperature estimates from an altitude of 2.5 km (solid lines). The TIMS temperature estimates were derived from 145 X 145 pixel subareas of the four Castaic Lake scenes. The TIMS precision envelope encloses the mean estimates plus or minus the corresponding standard deviations from all four flight lines. The TIMS temperature estimates in all six channels agree with the ground truth, within the level of precision of the measurements. It is interesting to note that the TIMS temperature estimates acquired from 2.5 km have larger standard deviations than those acquired from the higher altitudes. This phenomena is in part due to variations in the surface temperature of Castaic Lake resulting from wave action and boat traffic.

3.2. Surface Temperatures Acquired from an Altitude of 6.7 km

Figure 2 compares the precision of the temperatures acquired from the four 6.7 km flights and the ground-truth temperature measurements. The TIMS temperature estimates were derived from subareas of 55 X 55, 65 X 65, and 85 X 85 pixel subareas. As in Figure 1, the envelopes enclose one standard deviation of the variation in measurements. The TIMS temperature estimates in all six channels agree with the ground-truth within the precision level of the measurements.

3.3. Surface Temperatures Acquired from an Altitude of 8.2 km

Figure 3 compares the precision of the temperatures acquired from the four 8.2 km flights and the ground-truth temperature measurements at the level of one standard deviation. The temperature estimates for all of the flights are the mean values of 45 X 45 pixel subareas. The TIMS temperature estimates in Channels 2, 3, 4, and 6 agree with the ground-truth within the precision level of the measurements. The disagreement in Channel 1 is most likely due to the combined effects of errors in estimates of water vapor abundance and wind-blast cooling of the TIMS blackbody references. The disagreement in Channel 5 is most likely due to the cooling effect.

4. CONCLUSIONS

The general progression in surface temperature estimates with flight altitude suggests that there is some remaining wind-blast cooling of the TIMS blackbody references when the air fence is deployed. Over-estimation of the water vapor abundance of the atmosphere can likewise cause the temperature estimates to increase with increasing altitude. The apparent increases in ground temperature between the lowest temperatures acquired from 2.5 km and the highest temperatures acquired from 8.3 km are less than 1.5 °C in Channels 2 through 6. For Channel 1, which is most strongly affected by water band absorption, this increase is 2.5 °C. Refinements in our assessment of the accuracy of TIMS will follow improvements in our calibration experiment procedure; we must make efforts to improve our ability to characterize both the atmosphere and our ground targets.

Based on the 9 March 1994 experiment, we conclude that the C-130 air fence has greatly reduced the TIMS calibration problem by reducing the wind turbulence in the TIMS instrument bay. Given supporting airsonde (or radiosonde) launches and solar photometry, together with favorable weather conditions, investigators should be able to recover ground temperature estimates with an absolute accuracy of 2.0 °C. This conservative accuracy range, based largely on the results for Channel 1, accommodates (1) remaining wind-blast cooling of the TIMS blackbody references, (2) inaccuracies in our characterization of the atmosphere, and (3) variations in the surface temperature of Castaic Lake due to boat traffic and wave action.

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FIGURE 1: GROUND TEMPS FROM 2.5 KM ALTITUDE (MSL)

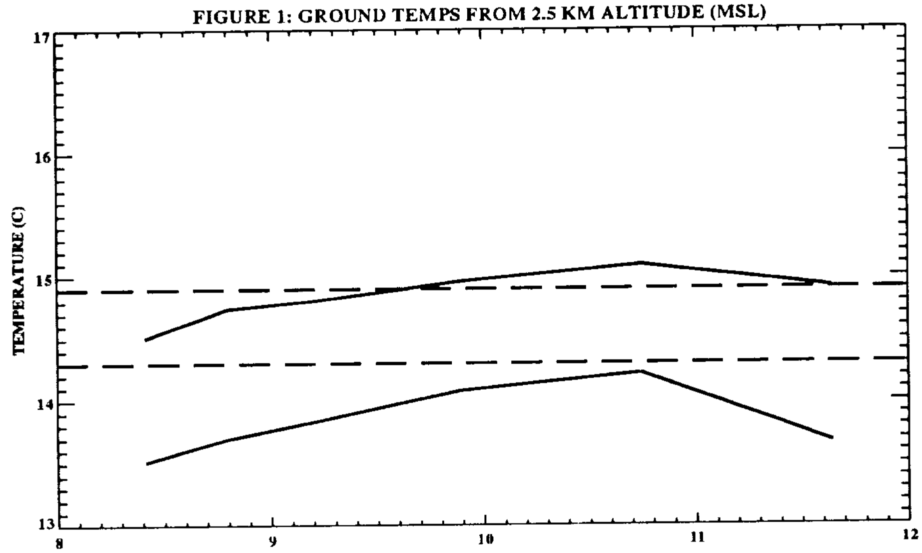

FIGURE 2: GROUND TEMPS FROM 6.7 KM ALTITUDE (MSL)

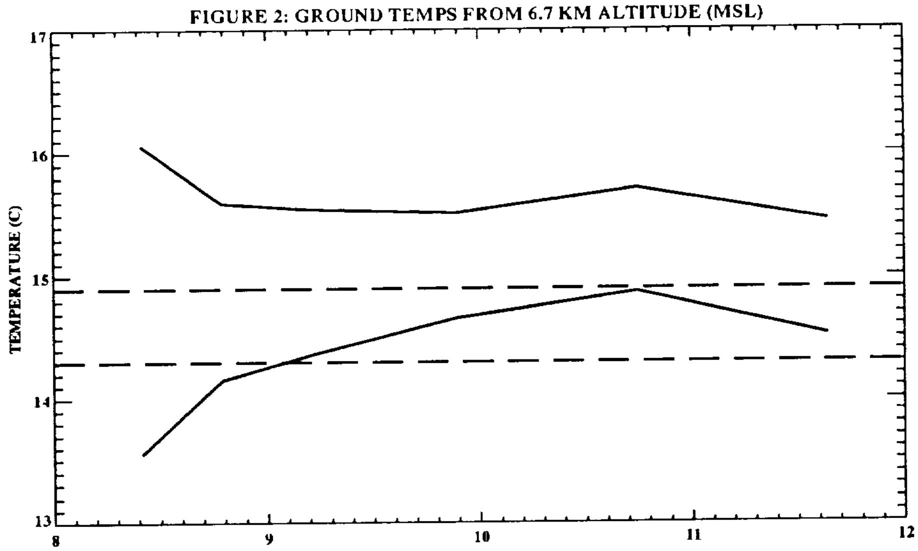

FIGURE 3: GROUND TEMPS FROM 8.2 KM ALTITUDE (MSL)