Application of Microwave Temperature Profiler (MTP) Data to MM5 Modeling of the August 2000 Houston-Galveston Ozone Episode

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1. Introduction

During the Texas 2000 Air Quality Study (TexAQS-2000), M.J. Mahoney of the California Institute of Technology operated a Microwave Temperature Profiler (MTP) instrument on the NCAR Electra aircraft. This instrument was designed to produce vertical profiles of temperature along the flight track of the aircraft. Because of the obvious potential usefulness of this data in validating and improving MM5 simulations of the vertical extent and horizontal variations of the planetary boundary layer (PBL), this project was initiated to investigate the application of the MTP data for numerical modeling of the August 2000 Houston-Galveston ozone episode.

2. Background

The MTP instrument is a passive microwave instrument that scans forward at various elevation angles both upward and downward from the aircraft. The multiple angles provide it with information on the vertical structure of temperature, which can then be retrieved using a statistical technique which compares the observed set of radiances with those which would theoretically be obtained from a set of reference temperature profiles.

In the past, the MTP has been used on high-altitude aircraft to study the upper troposphere, the tropopause, and the lower stratosphere. The TexAQS-2000 field program was the first use of the instrument at low levels in the atmosphere.

3. Initial Data Evaluation

Microwave emissions are produced not just by the atmosphere but also by the Earth's surface. Independent measurements of surface temperature showed that the surface skin temperature over land was highly variable and would likely contaminate the measurements. Therefore, Mahoney utilized mainly upward-looking and horizontal scans and devalued most of the measurements from downward-looking scans. Also, Mahoney used proximity National Weather Service soundings from Lake Charles, Corpus Christi, and other nearby sites to obtain reference soundings.

Initial evaluation of the data showed that these choices prevented the MTP retrievals from being used for model improvements. First, the retrievals failed to represent low-level inversions such as might be observed near sea breezes or during low-level jet episodes. Second, the retrievals failed to represent the slight variations in lapse rate which are markers for the top of the daytime planetary boundary layer (PBL).

4. Improvements to the Retrieval Technique

Based on this evaluation, the bulk of the effort under this work order was devoted to making improvements to the retrieval technique. (Indeed, the effort on this aspect of the work alone was greater than what had been anticipated for the entire project.) First, we noted that none of the observed reference soundings included low-level (but not ground-based) inversions such as sea breeze inversions. Mahoney had originally thought that such inversions did not appear during Electra flight times. Second, we noted that because the reference soundings were from National Weather Service sites, they were taken only at 0000 UTC and 1200 UTC, while the Electra typically flew between 1500 UTC and 2300 UTC. Therefore, the reference soundings would not include the variability in PBL depth that would occur during flight times. Third, we noted that the soundings were taken at inland locations and would not represent meteorological conditions found offshore or along the immediate coast.

To solve these problems, we decided to use soundings from existing MM5 simulations as reference soundings for the temperature retrievals. In order to reasonably represent the variety of temperature structures encountered by the aircraft, we elected to extract model soundings at 1500 UTC, 1700 UTC, 1900 UTC, 2100 UTC, and 2300 UTC on each of the days during the ozone episode in which the aircraft flew. Through careful examination of the three-dimensional temperature structure in the MM5 simulations, bogus sounding sites were identified to represent conditions far offshore, near to shore, over Galveston Bay, along the eastern and western shores of Galveston Bay, near Houston, and at more distant locations to the southwest, northwest, and northeast. So as to minimize the possibility that the MTP retrievals would reproduce biases in PBL structure caused by a particular MM5 PBL scheme, bogus soundings were constructed from both the mar5 driver run, which uses the MRF PBL scheme, and the may05 run , which uses the Gayno-Seaman scheme. These schemes differed in their representation of superadiabatic layers, PBL tops, sea breeze intensity, and low-level jet inversions. Thus, we hoped that the range of model-simulated structures would allow the MTP retrievals to accurately reflect true atmospheric conditions.

The new reference soundings also required a new retrieval technique. Because of the importance of temperature profiles below aircraft flight level to model validation efforts, Mahoney reconsidered possible ways of retaining temperature information near the ground. Eventually, he decided to try introducing bogus surface skin temperatures into the bogus soundings and allow the MTP retrieval algorithm to retrieve both the atmospheric temperature profile and the surface skin temperature simultaneously. The bogus skin temperatures were taken from a random set of temperatures based on the range of skin temperatures observed by the downward-looking Electra radiometers.

5. Results

The new retrieval technique was tested by Mahoney on a set of seven reference airsonde soundings. We selected these seven soundings based on the lack of noise or other contamination in the soundings and their depiction of important low-level atmospheric structures. We judged that if the retrieval technique would be able to faithfully reproduce the temperature structures in these particular soundings, it would be able to reproduce all the key aspects of temperature structure encountered by the Electra during the ozone episode.

The results of this test were successful. The new retrieval technique is able to identify low-level inversions below aircraft flight level, as well as distinguish between shallow and deep PBL structures. On the basis of the success of this test, Mahoney is computing new temperature retrievals for all MTP observations during the ozone episode. These new retrievals are expected to be delivered to TAMU within the next week or so.

6. Conclusions and Recommendations

On the basis of the test results, we expect that the MTP data will be able to distinguish PBL structure and depths. The MTP will not be the best instrument available for estimating PBL heights with absolute accuracy, but it will be quite valuable for measuring horizontal and vertical variations of PBL height. It is also expected to be useful for measuring the variations of PBL structure over Galveston Bay during the evolution of the bay breeze. Because turbulence is suppressed over water, the MTP is the only instrument with this capability. While final judgment will await the evaluation of the revised retrievals, we believe that we have developed a new technique that allows for accurate retrieval of vertical temperature structure within the PBL by the MTP instrument.

We recommend that the MTP data be used as validation data for MM5 simulations of the August 2000 ozone episode, particularly in combination with other data that provide accurate point estimates of PBL height. Especially over water, the MTP provides measurements of vertical temperature structure and its horizontal variations that cannot be matched by any other available instrument.

7. Further Information

Mahoney has prepared a web site devoted to the use of the MTP instrument during TexAQS-2000. This site is <http://mtp.jpl.nasa.gov/missions/texaqs/texaqs.html>. In addition to a more detailed discussion of the issues described above, this web site includes complete descriptions of the MTP instrument and its operation during TexAQS-2000.