

IMPACT OF TEMPERATURE AND HUMIDITY PROFILES FROM MODIS ON MICROSCALE MODELLING

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Abstract

In the subtropical areas like the southern coast of China, the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard the Earth Observing System (EOS) satellites *Terra* and *Aqua* provide high density profiles of temperature and humidity at a resolution of about 0.01 degree in latitude, 0.1 degree in longitude and 20 pressure levels in the vertical. These profiles are useful in capturing the mesoscale to microscale variations of thermodynamic fields. The impact of MODIS data on numerical weather prediction in a localized area like Hong Kong is considered through two case studies, namely, terrain-disrupted airflow at the airport (which is mainly related to the temperature profile in the boundary layer) and shower development around the territory (in which humidity distribution has a great effect). The use of MODIS-retrieved temperature and humidity profiles is shown to improve the simulation results. This is found to be due to better representation of the thermodynamic fields of the troposphere.

INTRODUCTION

Continuous availability of dynamic and thermodynamic profiles of the atmosphere would be advantageous to operational weather forecasting services, such as the monitoring of weather conditions and prediction of the weather through numerical simulations. In places like Hong Kong, networks of radar wind profilers are operated to measure the upper-air winds continuously, at least covering the boundary layer and the middle troposphere. On the other hand, conventional upper-air temperature and humidity measurements are still made several times a day by launching weather balloons. The use of microwave radiometers (Chan and Tam 2005) is becoming more common, but a dense network of radiometers has not yet been operated. Moreover, the profiles so obtained are only representative of the column of air above the instrument, especially considering the rapid variation of the tropospheric humidity in a subtropical coastal place like Hong Kong in the summer.

Temperature and humidity profiles retrieved from satellite's radiances are another important source of thermodynamic profiles of the troposphere at non-synoptic hours when weather balloon measurements are not available. Moreover, they cover a large area (the satellite's scanning region) in high spatial density. As a result, these profiles have the potential of improving the analysis and forecast of those weather conditions that are sensitive to the changes of the tropospheric stability, such as development of convective rain and airflow disruption due to terrain. The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard the Earth Observing System (EOS) satellites *Terra* and *Aqua* provide such profiles in high spatial density. Zavodsky et al. (2004) demonstrated the improvement of upper-air temperature and humidity analysis in Florida, U.S.A. with the assimilation of MODIS profiles. Xavier et al. (2006) showed that the ingestion of MODIS data into a mesoscale model had positive impact on the prediction of heavy rain associated with a subtropical low pressure system.

MODIS data have been received at the Hong Kong Observatory (HKO) since 2004. This paper uses two examples to discuss the impact of MODIS-derived temperature and humidity profiles on numerical weather prediction at meso- to microscale in the vicinity of Hong Kong.

MODIS DATA AND THE MODEL

The temperature and humidity profiles from MODIS Atmospheric Profile Level 2 products retrieved from sensors onboard the EOS satellites are used in this study. They are available at 20 vertical pressure levels at a resolution of about 0.01 degree in latitude, 0.1 degree in longitude along the south China coast. Quality control measures have been implemented based on cloud mask and sensor zenith angle. Only those profiles with zero cloud mask and a sensor zenith angle less than or equal to 50 degrees would be ingested into the numerical model.

The Regional Atmospheric Modelling System (RAMS) version 4.4 is employed in this paper. The model setup is similar to that in a previous study of low-level windshear at the Hong Kong International Airport, HKIA (Szeto and Chan 2006). The MODIS temperature and humidity profiles are reformatted as the conventional thermodynamic profiles available from weather balloon launches. They are ingested into the model at the start of the simulation through the standard four dimensional data assimilation (FDDA) system of RAMS. Model runs are only performed up to 12 hours ahead because it is expected that the impact of MODIS data on the simulation results would decrease rapidly with time.

CONVECTIVE SHOWERS

Because the MODIS thermodynamic profiles would only be ingested by the model when there is very small amount of clouds, they would be useful in the forecasting of convective shower development triggered by solar heating on days that are relatively cloud free. One such event occurred in the daytime of 6 September 2006. From the hourly accumulated rainfall imagery of the radar (Figure 1), besides intense convective development over 100 km to the northeast of Hong Kong, there were also isolated showers along the coast such as those at 50 km to the northeast of Hong Kong and at about 100 km west of the territory. The Operational Regional Spectral Model (ORSM) at 20 km resolution captures the rainband over the inland area and along the eastern coast of southern China very well (Figure 2), but fails to forecast the showers along the western coast.

K index is commonly used in Hong Kong to assess the potential of shower development. The K analysis field at 03 UTC (=11 a.m., HKT = UTC + 8 hours), 6 September 2006 shows that, while the K value is high (at and over 35) over inland area and eastern coast of southern China, there is a tongue of lower value at western coast extending from the northern part of South China Sea (Figure 3). On the other hand, MODIS analysis of K index (Figure 4) depicts rather high value (at and over 30) along the whole south China coast and the adjacent waters. It is expected that the ingestion of MODIS's thermodynamic field would improve the model forecast results.

RAMS simulation is performed with two nested grids (4 km and 800 m horizontal resolution) using 20-km ORSM as the boundary condition. It is initialized at 03 UTC, 6 September 2006 (non-conventional hour of weather balloon measurements) without and with the MODIS data. The results are shown in Figures 5 and 6 respectively. Without the use of MODIS data, the simulation is essentially a downscaling of the ORSM result using the same set of actual measurements in the analysis of the thermodynamic field. Heavy rain is forecast to the northeast of Hong Kong. There is a band of light rain to the south of the territory extending to the western coast of southern China, but the rainfall distribution is not quite the same as in reality (Figure 1). On the other hand, with the use of MODIS data, there is signature of shower development just to the northeast of Hong Kong and over the western coast of southern China, more consistent with actual observation. It could be seen from this example that the MODIS data have positive impact on the forecast of shower development up to at least 4 hours later. After that, the simulation results with and without the use of MODIS data look quite the same.

TERRAIN-DISRUPTED AIRFLOW

HKIA is situated in an area of complex terrain. To the south of it is the mountainous Lantau Island with peaks rising to about 1 km AMSL and valleys as low as 300 m in between. In springtime, terrain-

disrupted airflow occurs over HKIA during the prevalence of east to southeasterly winds in a stable boundary layer.

An example can be found in the early morning of 15 January 2006. From the LIDAR's velocity image (Figure 7), while easterly flow prevailed over the airport, there is an area of reverse flow at the northwestern coast of Lantau Island. It is related to the wake of the mountains on Lantau Island in a stable boundary layer. However, numerical simulation using RAMS in three nested grids (4 km, 800 m and 200 m) as initialized at 15 UTC, 14 January 2006 using conventional data (when weather balloon data are not available) does not forecast the occurrence of this mountain wake (Figure 8). Only rather uniform easterly flow is simulated in the whole airport area.

There is abundant amount of MODIS-derived temperature and humidity profiles around Hong Kong at 15 UTC, 14 January (Figure 9). In particular, the profile at the location of the radiosonde station in Hong Kong (upstream of Lantau Island) shows that there is a nearly isothermal layer up to 500 m AMSL with capping by a saturated adiabatic layer (Figure 10). The MODIS data are ingested into RAMS to see if there could be improvement in the analysis of the stable boundary layer and thus the forecast of mountain wake flow near HKIA.

The forecast result is shown in Figure 11. It could be seen that, although the prevailing easterly flow over the airport is slightly stronger than reality, the mountain wake at the northwestern coast of Lantau Island is successfully reproduced. The improvement in forecast result is related to better prediction of the temperature profile of the lower troposphere. Without the use of MODIS data, RAMS forecasts that, at 19 UTC, 14 January 2006, the temperature drops with altitude near the ground with a capping inversion of several degrees between 800 and 1000 m AMSL at a location upstream of Lantau Island (Figure 12). It is interesting to note that the capping inversion results in a large area of reverse flow to the west of Lantau Island (Figure 8) but does not lead to the mountain wake flow at the northwestern coast of the island. On the other hand, with the ingestion of MODIS data, RAMS forecasts the occurrence of a more or less isothermal layer up to around 1500 m above which the temperature drops gradually with height (Figure 13). Since weather balloon data are not available at 19 UTC, we use the radiosonde ascent measurements at the nearby times, viz. 12 UTC, 14 January 2006 and 00 UTC, 15 January 2006 (Figure 14), for comparison with the model results. In that overnight period, the temperature profile became more isothermal between the ground and 1000 m, namely, with a temperature drop of 4.2 degrees at 12 UTC, 14 January (from near-the-ground level to 1000 m) decreasing to 2.5 degrees at 00 UTC, 15 January. The temperature profile obtained with the use of MODIS data appears to be more consistent with the actual observation. Again, MODIS data appear to have positive impact on the simulation up to 4 hours.

CONCLUSIONS

MODIS provides thermodynamic profiles at high spatial density in relatively cloud-free situations. Thus it is an important source of upper-air temperature and humidity distribution supplementing the radiosonde ascents, which are only available twice a day. The impact of these profiles on microscale modelling results is studied through two examples in this paper, namely, shower development as triggered by solar heating, and terrain-disrupted airflow in a stable boundary layer. In both cases, MODIS data are shown to improve the simulation up to at least 4 hours ahead. Though the application of MODIS profiles in operational weather forecasting is limited by its relatively low frequency of availability (a few times every day) and the sensor zenith angle, it appears to be a useful source of upper-air thermodynamic data for improving numerical weather prediction.

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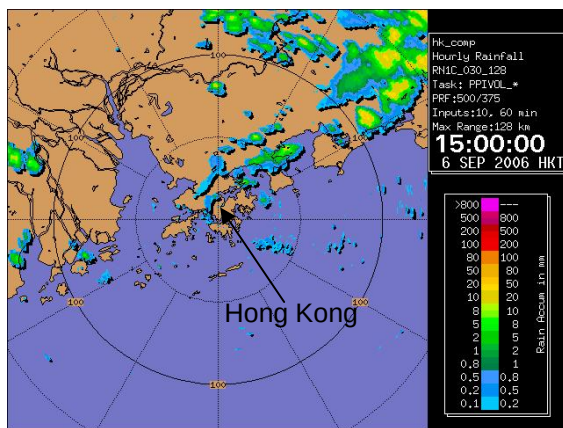


Figure 1 Hourly accumulated rainfall image of the radar at 15 HKT(07 UTC), 6 September 2006.

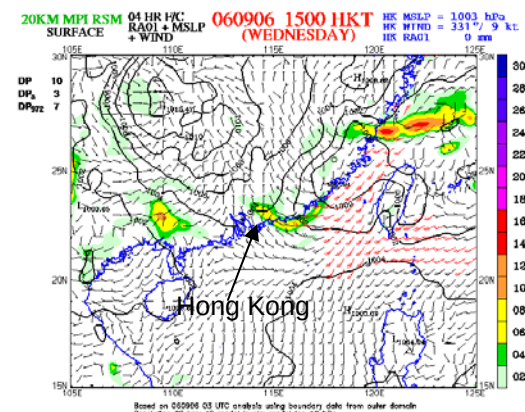


Figure 2 Forecast rainfall, surface winds (wind barb) and pressure at 15 HKT, 6 September 2006 of 20-km ORSM as initialized at 11 HKT (03 UTC), 6 September.

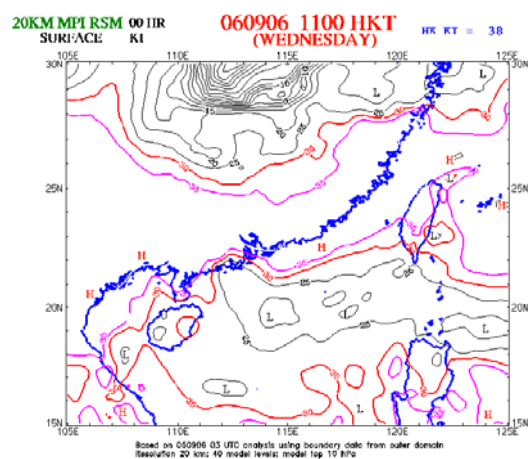


Figure 3 The analyzed K index field in the 20-km ORSM run at the initial time of 11 HKT, 6 September 2006.

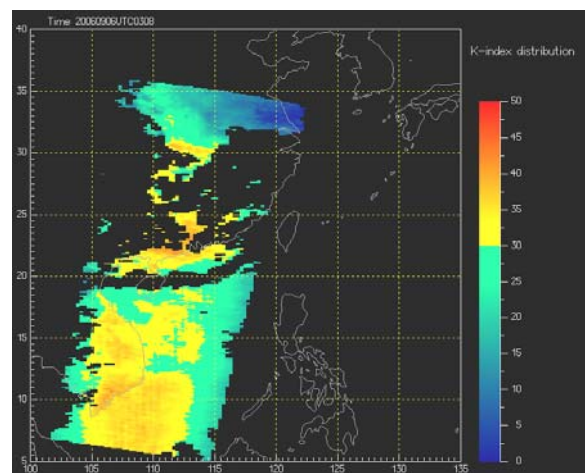


Figure 4 MODIS-derived K index field at 11 HKT, 6 September 2006.

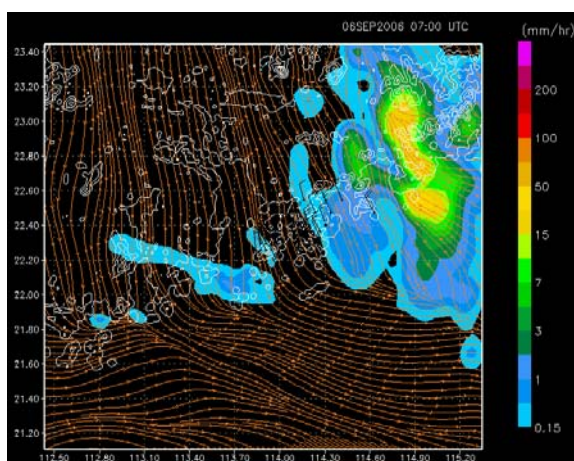


Figure 5 The forecast rainfall along the South China coast at 15 HKT(07 UTC), 6 September 2006 for the RAMS run initialized at 11 HKT, 6 September 2006 without the use of MODIS data.

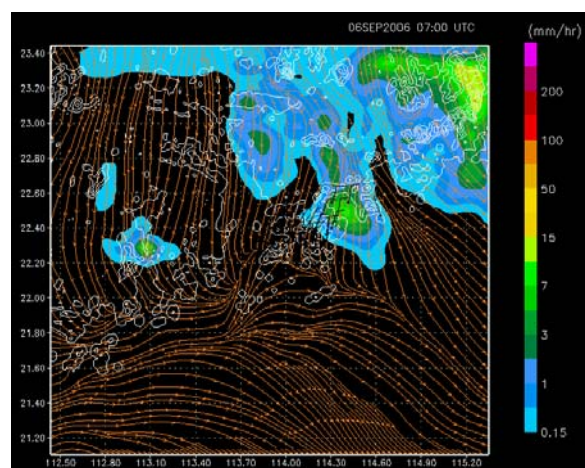


Figure 6 The same as Figure 5 but with the use of MODIS data.

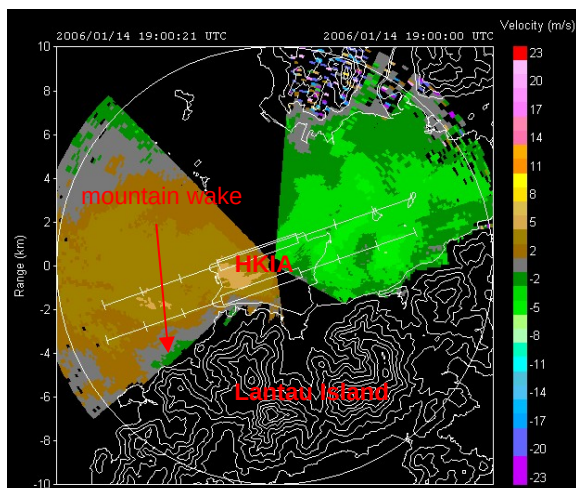


Figure 7 LIDAR velocity image at horizontal scan (50 m AMSL) at 19 UTC, 14 January 2006 (=03 HKT, 15 January).

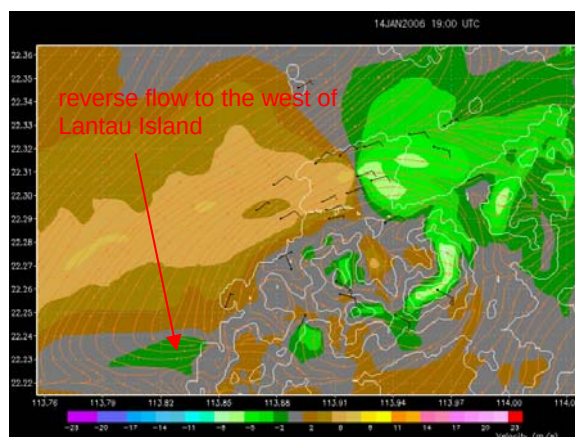


Figure 8 Model simulated LIDAR velocity at 50 m AMSL at the same time as Figure 7 for the model run initialized at 15 UTC (23 HKT), 14 January 2006 without the use of MODIS data.

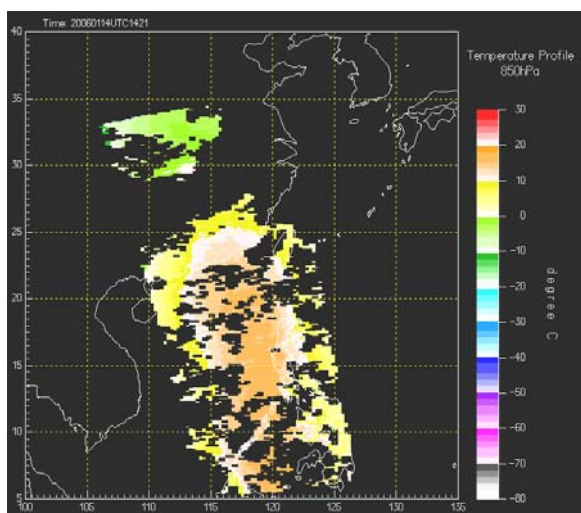


Figure 9 MODIS-derived K index field at 14:21 UTC (22:21 HKT), 14 January 2006.

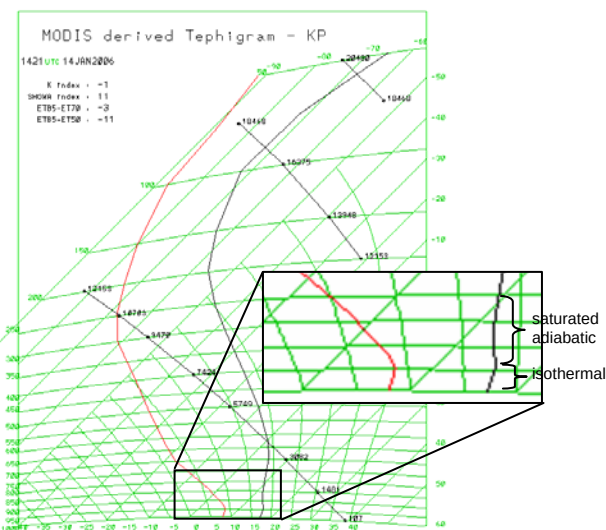


Figure 10 MODIS-derived temperature and dew point profiles at the radiosonde station in Hong Kong at 14:21 UTC (22:21 HKT), 14 January 2006. The zoom-in of the boundary layer profiles is given in the inset.

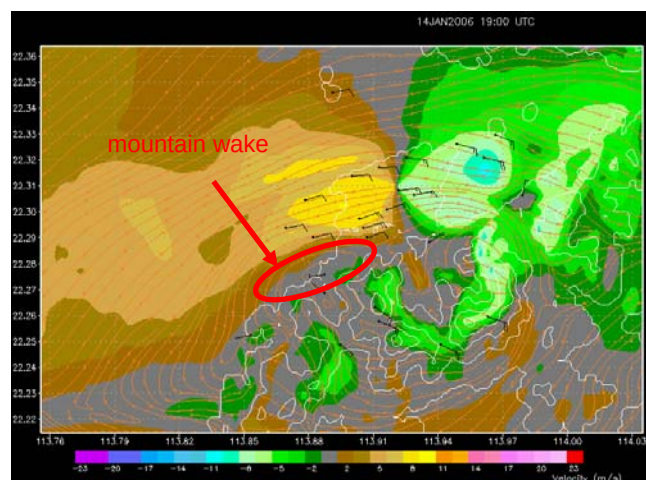


Figure 11 Same as Figure 8 but with the use of MODIS data.

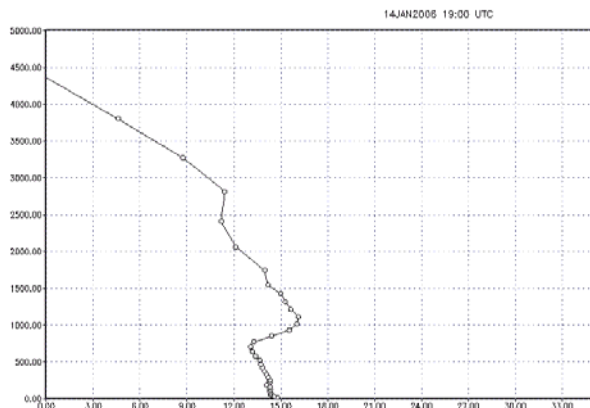


Figure 12 Forecast temperature profile (x-axis: temperature in degrees Celsius and y-axis: height in m) at a location upstream of Lantau Island at 19 UTC, 14 January for the model run initialized at 15 UTC, 14 January without the use of MODIS data.

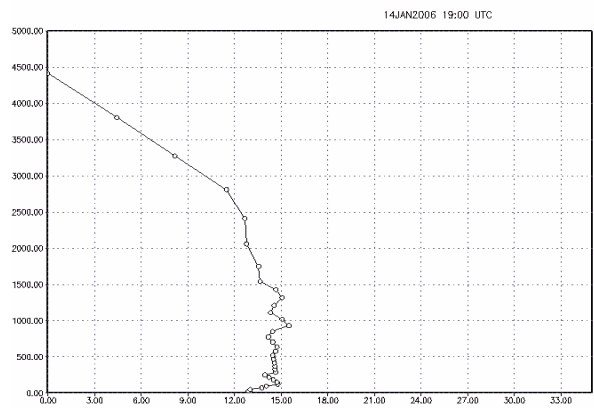


Figure 13 Same as Figure 12 but with the use of MODIS data.

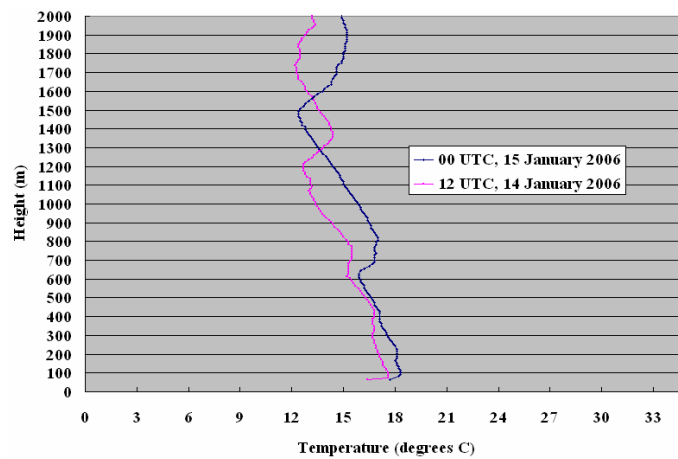


Figure 14 Temperature profiles as obtained from the weather balloon ascent in Hong Kong at 12 UTC, 14 January 2006 (pink) and 00 UTC, 15 January 2006 (blue).