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Performance of Temperature and Dew Point Data Based on Collection 5 algorithm of MODIS and Their Application in Numerical Modelling of Tropical Cyclones

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P1.1 **Performance of temperature and dew point data based on Collection 5 algorithm of MODIS and their application in numerical modelling of tropical cyclones**

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1. INTRODUCTION

MODerate resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra and Aqua satellites. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. Among all the MODIS products, Atmospheric Profile Product (MOD07) and Cloud Mask Product (MOD35) are of the interest to weather monitoring and numerical weather prediction (NWP) applications. In particular, the MODIS-derived profiles of temperature and humidity cover a wide area (the swath of the satellite) and may have significant impact on the forecasts by NWP models.

In Chan and Koos (2007), the MODIS Collection 4 data are used in microscale NWP prediction over Hong Kong. The MODIS data are found to have positive impact on the simulation of rain and terrain-disrupted airflow. However, there appears to be some quality issue with the MODIS Collection 4 data, namely, the "stepping" phenomenon in which the retrieved air temperatures and dew point temperatures tend to be higher near the centre of the swath and lower at the edges. Further improvements of the data quality would be required.

The "stepping" phenomenon is mentioned to be improved in MODIS Collection 5 algorithms through the modifications in retrievals based on the zenith angle. The cloud identification is improved at the same time, so that the retrieved atmospheric profiles could be more accurate. From the images of the Atmospheric Profile Product (Figure 1), it could be seen that there does not appear to be "stepping" problem with the Collection 5 products.

This paper firstly studies the quality of Atmospheric Profile Product of MODIS Collection 5 by comparing with model analysis, microwave radiometer data and upper-air ascent measurements. The impact of the atmospheric profiles is then examined through a number of simulations of the movement of tropical cyclones over the South China Sea.

2. COMPARISON WITH MODEL ANALYSIS

The Operational Regional Spectral Model (ORSM) is used at the Hong Kong Observatory (HKO) for mesoscale weather forecasting. It has a spatial resolution of 20 km and it is nested with the global spectral model of Japan Meteorological Agency (JMA). The model analysis is used operationally in the weather forecasting service, e.g. in the analysis of the synoptic and mesoscale weather systems over China and the South China Sea. It makes use of the synoptic weather observations and other satellite-derived products, but has not ingested any MODIS atmospheric profile products. As such, the ORSM analysis could serve as an independent dataset in the verification of atmospheric profile product from MODIS.

Because of the large volume of the model analysis data, only a small set of the analysis is involved in the present study. A total of 12 MODIS scans from November 2008 to February 2009 with clear sky status have been selected. The ORSM grid data point is taken at the centre of a box of 0.2 x 0.2 degrees, and the MODIS data point within this box and closest to its centre is selected. Moreover, the MODIS data points with zenith angle < 5° are analyzed separately for determining any improvement of Collection 5 algorithm over Collection 4 algorithm, in view of the "stepping" phenomenon of the latter. Only comparison with temperature data is considered in the present Section.

The results of the comparison analysis are given in Table 1. From the regression results of data points with zenith angle < 5°, Collection 5 algorit hm performs better than Collection 4 algorithm for lower levels of the troposphere (700 hPa to 920 hPa), and the two algorithms have comparable performance for the middle troposphere (500 hPa). However, the two algorithms have rather poor performance at the upper troposphere, namely, 200 hPa level. This may be related to the occurrence of thin cirrus clouds as well as the overlapping of cirrus and stratus clouds, which may not be totally eliminated by the cloud mask algorithm.

Considering Collection 5 algorithm alone without the constraint of the zenith angle, the regression results of temperature profiles are shown in Table 2. Only the lower to the middle troposphere is considered. In general, the correlation coefficient is rather high (in the order of 0.8 to 0.9). It could be seen that the "stepping" phenomenon with the temperature profiles basically do not show up with the use of Collection 5 algorithm. The scatter plots are given in Figures 2 and 3 with and without the constraint of zenith angle respectively, by considering all the data points in the lower to middle troposphere.

3. COMPARISON WITH MICROWAVE RADIOMETER DATA

A ground-based, multi-channel microwave radiometer is used by HKO at the Hong Kong

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International Airport (HKIA) for continuous monitoring of the temperature and humidity profiles of the troposphere. It measures the radiation emissions in oxygen and water vapour channels and uses such information in the retrieval of the thermodynamic profiles. Technical details of the radiometer could be found in Chan (2009).

The radiometer data in the period April to June 2009 are considered. The MODIS data points within 30 km from HKIA are considered, and the point closest to the location of the radiometer is used in the analysis. The analysis results for air temperature are shown in Table 3. It could be seen that, as in the case of comparison with ORSM analysis, the correlation of the two datasets is higher for the lower to middle troposphere than the higher troposphere. The correlation coefficient is in the order of 0.8 to 0.9. However, the slope of the best-fit straight line of the data points deviates further away from unity for the lower troposphere. It is expected to be more challenging for the space-borne system (MODIS) to accurately retrieve the thermodynamic quantities lower in the troposphere.

The comparison results of dew point are given in Table 4. The correlation coefficients for the two sets of data (MODIS and ground-based microwave radiometer) are quite high, generally in the order of 0.7 to 0.9. The slopes of the best-fit straight lines of the two datasets are closest to unity in the middle to upper troposphere. For the lower troposphere, the slopes deviate further away from unity and the corresponding results for the retrieved air temperatures. Once again, it would be more challenging for the space-borne system to accurately measure the humidity lower in the troposphere, which is spatially more changeable compared to the air temperatures.

4. COMPARISON WITH UPPER-AIR ASCENT MEASUREMENTS

The MODIS-retrieved thermodynamic profiles are also compared with upper-air ascent (radiosonde) data at King's Park in Hong Kong. The study period is still April to June 2009. The 2-second data obtained from the balloon measurement are used.

The performance of Collection 4 and Collection 5 algorithms is considered. The statistical results of comparison with radiosonde measurements are shown in Table 5 for air temperature. It could be seen that Collection 5 algorithm performs much better. The slopes of the best-fit straight lines are closer to unity, and the correlation coefficients are higher. No constraint of zenith angle is used in this comparison between the radiosonde data are already limited in amount (available only twice a day, i.e. at 00 and 12 UTC only). If further constraint is enforced, the amount of data for comparison may become statistically insignificant.

Though Collection 5 algorithm performs better, in general the slopes of the best-fit straight lines are in the order of 0.4 to 0.6 only, still quite far away from 1. There appears to be bias in the MODIS-retrieved results, and such bias may need to be taken into account before the retrieved profiles could be used for other purposes, e.g. ingestion into numerical models. Also, the y-intercept of the best-fit straight line becomes larger at the lower troposphere. This points to the difficulty for space-borne system to be used in the retrieval of the thermodynamic profiles lower in the atmosphere. The bias values are much larger in the comparison with radiosonde data than those in the comparison with radiometer data. The reasons for the discrepancies of the bias values require further investigations.

The comparison results for dew point temperatures are given in Table 6. Once again, from the correlation coefficients, the Collection 5 algorithm performs much better. We could also see from the y-intercepts that the quality of the retrieval in the lower troposphere is not that good. Bias correction is even more important in the use of the dew point data.

5. IMPACT ON THE FORECAST MOVEMENT OF TROPICAL CYCLONES

In this study, the Weather Research and Forecasting (WRF) model Version 2.2 is used. It has a spatial resolution of 4 km and nested with the 20-km ORSM. The MODIS-retrieved thermodynamic profiles are input into the model through its 3D variational system (Barker et al., 2004). As a first step, no bias correction has been applied to such profiles.

Two tropical cyclone cases are considered. The first one is Typhoon Molave in July 2009. The model is initialized at 03 UTC, 18 July and a forecast of 24 hours is made. The forecast tracks of using different data sources are shown in Figure 4, namely, without assimilation of MODIS data, assimilation of temperature profiles only, assimilation of both temperature and dew point profiles, and assimilation of temperature profiles as well as total precipitable water (TPW). It turns out that, with the assimilation of temperature profiles, the forecast track is closer to the actual one than the track obtained without MODIS data assimilation. The use of both temperature and TPW improves the result further. However, the assimilation of dew point causes deterioration of forecast, i.e. the forecast track deviates more from the actual one in the latter part of the forecast period (after landfall of the tropical cyclone). This may be related to the lower quality of the dew point data of MODIS, as discussed in the earlier Sections.

The second case is Tropical Storm Mujigae in September 2009. The simulation is initialized at 06 UTC, 10 September, and a forecast of 24 hours is made. The forecast racks are shown in Figure 5. Once again, with the assimilation of temperature only and the assimilation of both temperature and TPW, the forecast tracks are closer to the actual one than the simulation without assimilation of MODIS data. On the other hand, the assimilation of MODIS dew point results in deterioration of the forecast track.

6. CONCLUSIONS

The results of the present study show that, despite bias, the MODIS-retrieved temperature profiles are of reasonably good quality in comparison with model analysis, ground-based microwave radiometer measurements and radiosonde measurements. They could result in better forecasts of the movement of tropical cyclones when assimilated into a numerical weather prediction (NWP) model. On the other hand, dew point data retrieved from MODIS do not have equally good quality and may result in deterioration of the forecast tracks of tropical cyclones through data assimilation.

Further studies would look at bias corrections of both temperature and dew point data, and the impact of bias-corrected data on the NWP simulation results. Moreover, the quality of other MODIS-retrieved quantities, such as TPW, would be examined through comparison with other measurements.

References

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Level (hPa)	Slope	Intercept	R-value	Data Points
200	0.1517	-47.3842	0.2059	2904
500	0.9228	-1.7811	0.9482	2910
700	0.9094	2.3164	0.8907	2910
850	0.8451	2.8632	0.8879	2908
920	0.7475	5.0406	0.8871	2895

Level (hPa)	Slope	Intercept	R-value	Data Points
200	0.0308	-51.7442	0.0322	2904
500	0.8733	-3.3232	0.9465	2910
700	0.9465	1.5158	0.9101	2910
850	0.9602	1.5924	0.9201	2908
920	0.8441	3.6676	0.9068	2895

Table 1 Regression between ORSM data and MODIS temperature profile data, zenith angle ≤ 5^{o}. (Upper - Collection 4; Lower - Collection 5)

Level (hPa)	Slope	Intercept	R-value	Data Points
500	0.8270	-3.1651	0.9310	45346
700	0.8567	2.3857	0.8801	44932
850	0.8830	3.2751	0.8774	43646
920	0.7964	4.9671	0.8700	42093

Table 2 Regression between ORSM data and MODIS collection 5 temperature profile data, without constraint of zenith angle.

Level (hPa)	Slope	Intercept	R-value
300	-0.3294	-38.1607	0.1193
400	1.0897	-12.1889	0.3810
500	0.9361	-9.1578	0.3940
620	1.0787	-8.0645	0.8119
700	0.8073	-2.1607	0.8430
780	0.9051	-0.3680	0.8684
850	0.7573	6.3786	0.8789
920	0.6443	9.5459	0.8600
950	0.6142	10.2724	0.8564
1000	0.5822	11.0002	0.8872

Table 3 Regression between microwave radiometer data and MODIS Collection 5 atmospheric profile data for air temperatures.

Level (hPa)	Slope	Intercept	R-value
300	0.8445	-26.1800	0.6873
400	0.7068	-21.3542	0.7804
500	0.8589	-8.9408	0.8785
620	0.9459	-4.3898	0.8918
700	1.1008	-2.7672	0.8469
780	0.8707	1.2462	0.8119
850	0.4985	7.2158	0.7510
920	0.3484	11.6759	0.7057
950	0.3110	13.8466	0.6929
1000	0.3073	16.4693	0.7068

Table 4 Regression between microwave radiometer data and MODIS Collection 5 atmospheric profile data for dew points.

Level (hPa)	Slope	Intercept	R-value	Level (hPa)	Slope	Intercept	R-value
300	-0.3785	-55.9586	0.0883	300	0.7405	-9.9925	0.6310
400	-0.4092	-36.7109	0.0961	400	0.6038	-8.4623	0.6187
500	-0.4726	-21.5127	0.1177	500	0.5918	-4.1453	0.7117
620	-0.0185	-8.4984	0.0056	620	0.5152	0.4061	0.7430
700	-0.0475	-2.5498	0.0179	700	0.4319	4.6732	0.7159
780	0.1416	0.1882	0.0598	780	0.4594	7.9472	0.7138
850	0.1207	4.0500	0.0484	850	0.5983	8.2843	0.7746
920	0.0750	9.3220	0.0387	920	0.5100	11.9830	0.7514
950	0.0441	11.8837	0.02533	950	0.4666	13.7653	0.7313
1000	0.00475	14.60319	0.00301	1000	0.4168	15.2851	0.7360

Table 5 Regression between King's Park ascent data and MODIS atmospheric profile data for temperatures: left - Collection 4, right - Collection 5.

Level (hPa)	Slope	Intercept	R-value	Level (hPa)	Slope	Intercept	R-value
300	0.3664	-43.4372	0.4298	300	0.6780	-18.8770	0.8292
400	0.3455	-31.6389	0.4896	400	0.6153	-12.4894	0.8041
500	0.3834	-20.2687	0.5884	500	0.5359	-5.5331	0.8348
620	0.2526	-13.4821	0.3827	620	0.4084	-0.6412	0.7285
700	0.2109	-8.9883	0.3294	700	0.3260	2.3755	0.6579
780	0.1902	-4.1023	0.2450	780	0.3240	6.2832	0.6250
850	0.1582	0.2955	0.2336	850	0.2318	10.5089	0.6109
920	0.1905	3.4399	0.2238	920	0.2775	12.7861	0.6220
950	0.1698	4.8897	0.1866	950	0.3102	13.3993	0.6739
1000	0.1632	6.1350	0.1646	1000	0.3611	14.3972	0.7435

Table 6 Regression between King's Park ascent data and MODIS atmospheric profile data for dew points: left - Collection 4, right - Collection 5.

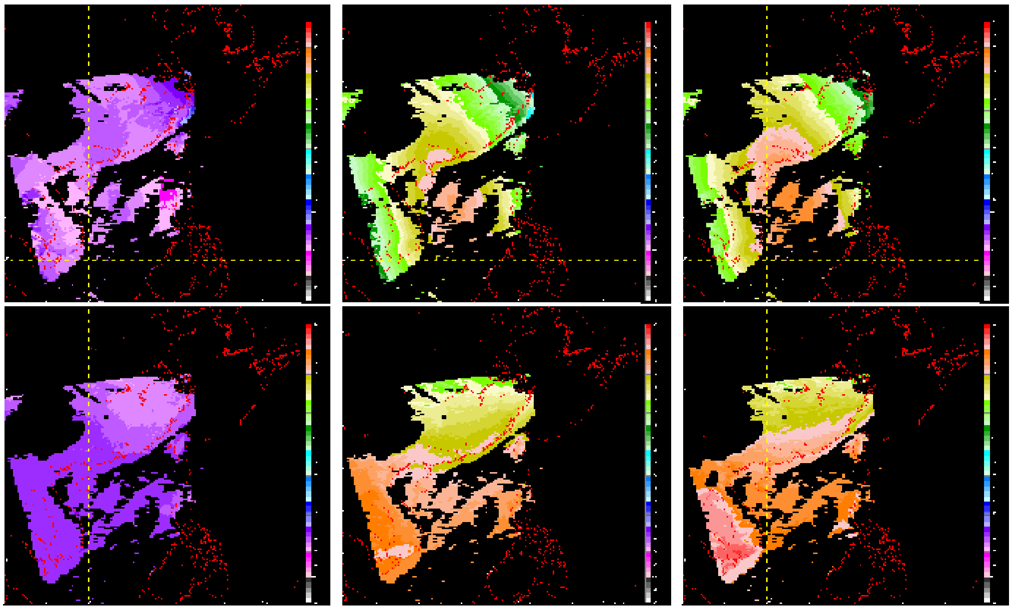

Figure 1 MODIS upper-air temperature profile plots: upper - Collection 4; lower - Collection 5; left – 200 hPa; centre – 850 hPa; right – 920 hPa.

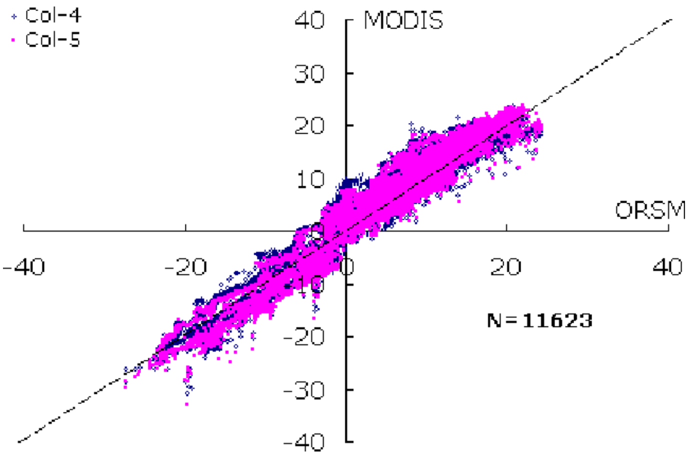

Figure 2 Comparison of upper-air temperatures as retrieved from MODIS and those obtained with ORSM analysis. Only temperature data points with zenith angle within 5 degrees are considered.

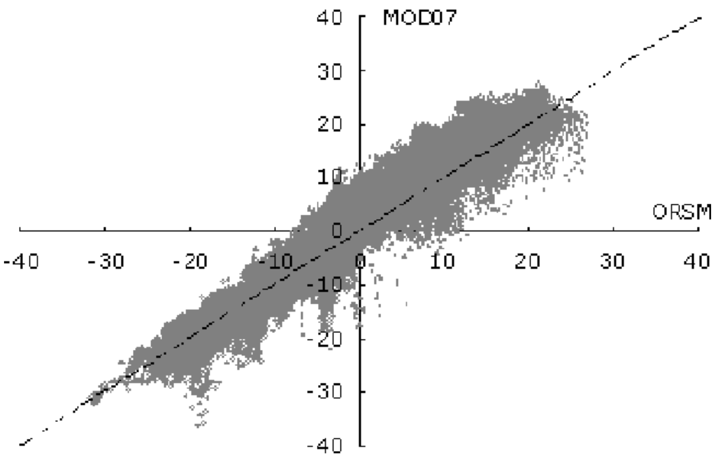

Figure 3 Same as Figure 2, but for Collection 5 only and without the constraint of zenith angle.

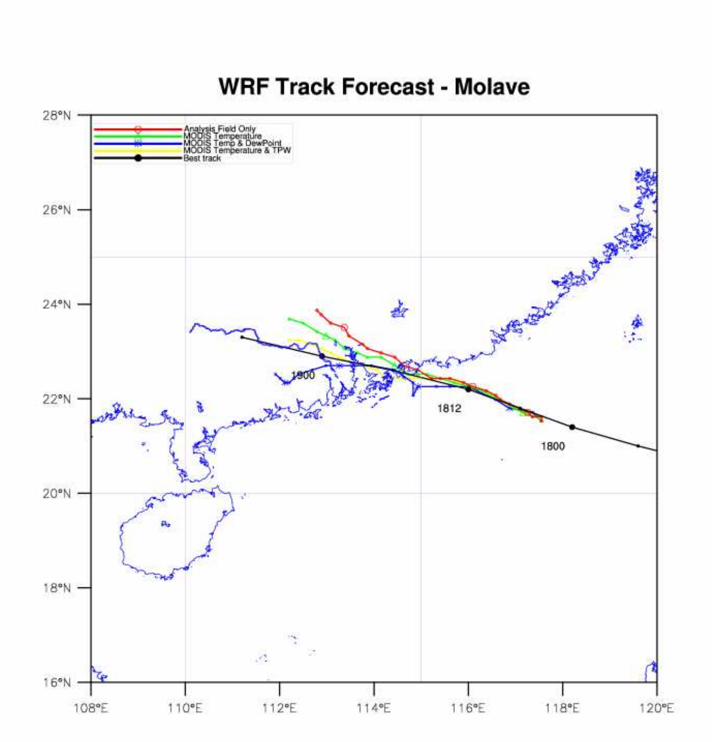

Figure 4 WRF forecast track of Typhoon Molave: red – using ORSM only; green – assimilating MODIS temperature profiles; blue – assimiating MODIS temperature and dew point profiles; yellow – assimilating MODIS temperature profiles and TPW; black – best track.

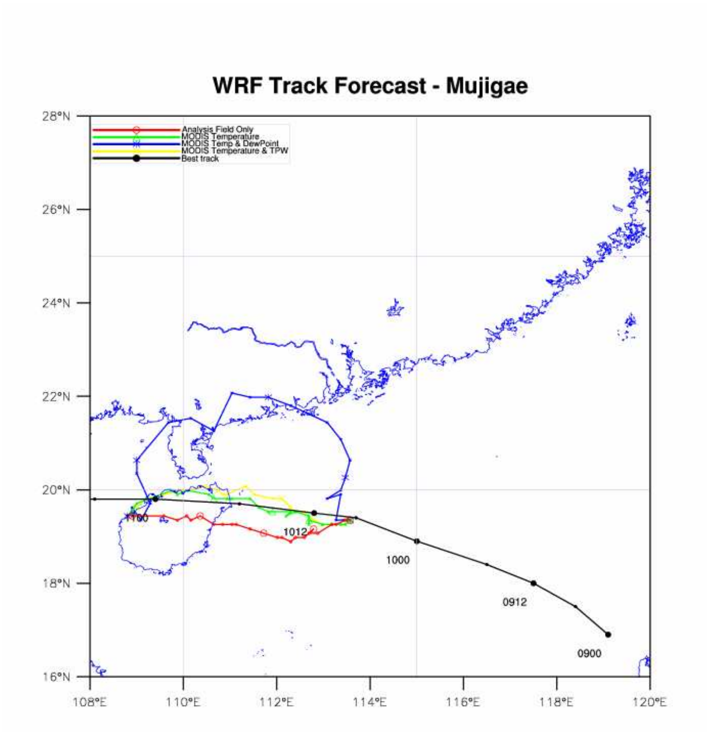

Figure 5 Same as Figure 4, but for Tropical Storm Mujigae.