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NCMRWF & UKMO Global Model Forecast Verification: Monsoon 2010

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9	Originating Unit	National Centre for Medium Range Weather Forecasting (NCMRWF), Ministry of Earth Sciences (MoES), Government of India, Noida
10	Abstract (100 words)	This report summarizes the results of an evaluation of the model forecast errors of the NCMRWF Global Forecasting Systems (T254L64 & T382L64) and the U.K. Met Office (UKMO) forecasts over India, during the Southwest Monsoon season (JJAS) of 2010. Forecast verification of these models against their respective analyses and the upper air observations (both radiosonde and GPSsonde) clearly indicate that the UKMO forecasts feature smaller RMSE compared to the NCMRWF forecasts. The Equitable threat score (ETS) for rainfall forecasts show that for lower thresholds (0.0, 0.1 and 0.6) the scores are comparable in all three models. For higher rainfall amounts, the ETS scores are low and UKMO consistently shows marginally higher values than the T254 and T382 models.
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Contents

Global Model Forecast Verification during Indian Summer Monsoon 2010: Mean Characteristics and Forecast Errors

1. Introduction

This report summarizes the results of an evaluation of the model forecast errors of the NCMRWF Global Forecasting Systems (T254L64 & T382L64) and the U.K. Met Office (UKMO) forecasts over India, during the Southwest Monsoon season (JJAS) of 2010. The two models at NCMRWF mainly differ in the spatial resolution (T254 ~ 50Km and T382 ~ 35 Km) and the data assimilation. The UKMO model features an intermediate grid spacing of ~ 40 Km and the forecast output is obtained from the U.K. Met Office, Exeter (UK). The orographic features as resolved by the three models are as shown in Figure 1, over the monsoon region. The purpose of the analysis is to characterize, describe and compare the model forecast errors of the above systems using a select set of measures which are widely used and also well understood. The significant points pertaining to this comparison are given below.

- The comparison is done for 24hr, 48hr, 72hr, 96hr and 120hr forecasts against the analysis from the respective forecast-analysis system (UKMO and NCMRWF) for 00UTC. The period of the analysis is 1 June to 30 September (122 days) which is the Southwest Monsoon Season.
- Analysis was carried out on a regular 1^{o} latitude-longitude grid (which is coarser than the model grids) and on standard pressure levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150 and 100hPa levels). Interpolation to 1^{o} grids is done using bilinear interpolation or conservative area-weighted smoothing. Grid points lying over the topography above the pressure surfaces were excluded from the analysis (masked). No seasonal trend removal was used in this evaluation.

- The results are presented for Day-1, Day-3 and Day-5 forecasts in this report.
- The prepared data set is archived for future reference. All data format conversions (grib to netCDF), editing of meta data, interpolation, smoothing and the final computations were all carried out using the open source software NCO and CDO.
- The parameters considered are; geopotential height of the isobaric surface (GHT), air temperature (TEMP), relative humidity (RH), zonal wind (U) and the meridional wind (V).
- Verification procedures include intercomparison of forecast mean characteristics with the mean analysis and forecast errors are shown in terms of systematic errors.
- The scores considered are: Root Mean Square Error(RMSE), and Time series of daily spatial RMSE

In this analysis we have generally used the measures given by the 'WWRP/WGNE Joint Working Group on Verification' (WWRP 2009) regarding the verification of continuous variables. Though we have carried out a comprehensive analysis, it is practically not possible and is not necessary to describe every aspect of the results of the analysis. Our aim in this report is to concisely present such aspects of the results that could be acted upon. We include only a limited but the most significant and useful subset of the analysis results.

2. Mean Analysis.

In this section we present the seasonal (JJAS, 2010) mean analysis of wind, temperature and relative humidity at 850 & 200 hPa level. Monthly mean characteristics are presented as and where necessary.

2.1 Mean Monsoon Circulation: 850 & 200 hPa Winds:

The cross-equatorial flow (CEF) is one of the main characteristic features of low level monsoon circulation that stands out as the strongest low-level flow on the earth during the boreal (northern) summer. The wind speed in the core of the Somali jet exceeds 25 m/s (Findlater, 1969a), the jet core is located about 1.5 Km above sea level, 200-400 Km east of the east African highlands. This CEF, which is now referred to as the Findlater jet or Somali jet, is an essential component of the Asian monsoon system. It transports moisture from the southern Indian Ocean to south Asia, connects the Mascarene high and Indian monsoon trough, and completes the lower branch of the Hadley cell of the Asian monsoon.

The three panels in the first column of Figure 2 show seasonal mean (JJAS) winds (vectors) (m/s) and geopotential height (contour) (gpm) in the initial condition of T382, T254 and UKMO models at 850 hPa. Similarly column 2, 3 and 4 correspond to the Day-1, Day-3 and Day-5 forecasts respectively. Shading in the figure indicates geopotential height (gpm). The panels indicate that the basic circulation characteristics, i.e., south-westerly flow over the Arabian Sea at 850 hPa are fairly well captured in the analysis and the forecasts. As can be seen from Figure 2, the model forecasts show well developed monsoon trough in the form of a narrow trough extending from northwest of India to the head Bay of Bengal. *The forecasts features a relatively deeper monsoon trough compared to the initial analysis particularly in all the forecasts of T254 and T382 models and Day-3 and Day-5 forecasts of UKMO model. This feature of stronger monsoon trough in the model forecasts compared to the model analysis is prominently seen in each of the months during June-Sept 2010* (Figures in Appendix). The mean seasonal and monthly 850 hPa winds and geopotential height in the model forecasts clearly indicate that all the three models consistently feature a common tendency to forecast stronger monsoon circulation at 850 hPa.

An extremely important component of the monsoon circulation is the upper-level (200-hPa) monsoon ridge, which normally extends from the Middle East region to southeastern Asia at approximately 27.5°N. This 200 hPa ridge normally develops during June and reaches full strength in July and August. Accompanying this evolution is a pronounced shift of the midlatitude westerly winds from south to north of the Tibetan Plateau by mid-June. Figure 3 shows the winds and geopotential height at 200 hPa in the analysis and forecasts. The JJAS mean forecasts seem to closely match the respective analysis in all three models. However, unlike in the T382 and UKMO forecasts, the T254 model forecasts feature weaker and diffused structure of the 200 hPa ridge. This is prominently seen during the months of June (Figure 4) and September (not shown). Monthly mean 200 hPa winds and geopotential height for each of the months during June to September 2010 are presented in the Appendix. *The UKMO model analysis and forecasts show well defined structure of the 200 hPa ridge in each of the months from June to September 2010 with clear changes in the areal extent and migration of position indicating the advance and retreat of monsoon. In the T382 model the forecasts show close agreement with the observations only during July and August. During advance (June) and retreat (September) the T382 forecasts show rather weak and diffused anticyclone at 200 hPa.* In the T254 model the analysis features a weak anticyclone in all the four months and the forecasts indicate even weaker and diffused patterns (see Appendix).

2.2 Mean Temperature 850 & 200 hPa

The low level circulation over South Asia is the most intense during JJAS, essentially due to the extensive Himalayan-Tibetan Highland, with input of diabatic heating over a large area in the middle troposphere oriented in nearly east-west direction. To the south of India lies extensive mass of Indian Ocean waters. During the northern summer season, this configuration of land mass and water mass creates strong meridional gradients of temperature indicating flow of air from cool ocean area to warm land area. Accurate representation of the observed land sea temperature contrast and its evolution in the model initial analysis is crucial for predicting the onset and advance of the monsoon over India. Figure 5 presents the seasonal (JJAS, 2010) mean temperature distribution at 850 hPa in the initial conditions (analysis) and the forecasts. As earlier discussed, the first column in the Figure 4 corresponds to the model analysis and the columns 2, 3 and 4 correspond to the Day-1 , Day-3 and Day-5 forecasts. Similar analysis is carried out for each of the months and the figures are presented in the Appendix. In the model initial analysis (column 1), all the three models indicate a strong north-south temperature gradient over the Indian land region with the highest temperature excess of 295 ºK over north-west India. However, over adjoining Pakistan region, higher temperatures of up to 298 ºK persist. Over central India and Gangetic plains, temperatures are in the range of 292-295 ºK in the analysis. The model forecasts (column 2, 3 and 4) indicate relatively higher mean temperatures over north-west India and the Gangetic plains compared to analysis. This feature is mainly seen during June and is not very prominent in July, Aug and Sept (Figures in Appendix). Parts of peninsular India, Arabian Sea and Bay of Bengal feature lower temperatures in the range of 290-292 ºK in the T254 and T382 models. The UKMO model initial analysis features *higher temperatures over the peninsula and the neighboring seas* by at least 3 ºK. This is also prominent in the UKMO forecasts too. The higher temperature values over the entire north Indian Ocean is prominent in the UKMO analysis and forecasts in each of the months during JJAS 2010.

The mean temperature distribution at 200 hPa is shown in Figure 6. Both analysis and forecasts show higher temperatures over the continents with decreasing temperatures to wards the Indian Ocean. Only UKMO forecasts seem to closely agree with the analysis. Both T382 and T254 models underestimate the warm temperatures over continent. Further UKMO model analysis and forecasts show *relatively cooler temperatures (compared to other two models) over the Indian Ocean; particularly over eastern Indian Ocean.* The above two aspects of 200 hPa temperature distribution in the model forecasts is seen during all four months (see Appendix).

2.3 Mean Relative Humidity at 850 & 200 hPa

Similar to the discussion in the earlier sub-section, mean condition of moisture distribution (relative humidity) in the initial analysis and the forecasts are presented here. The Asian summer monsoon plays a crucial role in moisture transport. The most remarkable moisture channel originates in the southern Indian Ocean, crossing the equator near the Somali coastal region, flowing to the Arabian Sea and the Bay of Bengal.

The seasonal (JJAS) mean relative humidity at 850 hPa for the three models is shown in Figure 7. This field is similar to the mean seasonal rainfall distribution over the region. The high moisture content in all the models can be indicated by relative humidity exceeding 80% covering the Indian land region and Bay of Bengal. Arabian Sea and Indian Ocean feature relatively lower relative humidity. High values of relative humidity exceeding 90% along the west coast of India and west coast of Myanmar suggest the impact of steep orography. High humidity seen over the Indo-Gangetic basin (>80%) are manifestation of the monsoon trough and the associated convection in that region. The high moisture in this region seen in the seasonal mean can be associated with the monsoon depression that travels along the monsoon trough. The reduced humidity over the north-west India is by and large well captured in the forecasts. However, monthly mean 850 hPa relative humidity plots (appendix) show relatively drier conditions in June and September mainly over central and northwestern India. During July and August UKMO model analysis and forecasts typically show large area over India with relative humidity above 90% (Figure 8a,b). Similar analysis for the 200 hPa relative humidity shows that the forecasts closely agree with the analysis. However, it is striking to note that the UKMO analysis as well as forecasts are *excessively dry over large parts of Indian ocean and India* (Figure 9). This is seen in all the months of the season (appendix). Based on the monthly and seasonal mean relative humidity discussed in this section, it can be concluded that UKMO model analysis and forecasts clearly feature a relatively wetter (drier) lower (upper) troposphere compared to T254 and T382 models.

2.4 Evolution of Low level Monsoon Circulation:

The strong cross-equatorial low level jet stream with its core around 850 hPa is found to have large intraseasonal variability. Figure 10a,b (and Figure 11a,b) show the Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 60–70°E (and 75–80°E) and smoothed by a 5-day moving average for the period 1 June–30 September 2010 for the T382 and UKMO models respectively. The top panel in each figure shows the analysis and the middle and the lower panel depict the Day-3 and Day-5 forecasts respectively. The active monsoon spells are characterized by strong cores of zonal wind. The monsoon had set in over Kerala on 31st May. Subsequent advancement of the monsoon across west coast was delayed by about one week due to the formation of a very severe cyclonic Storm (PHET, 31st May–2nd June). Thereafter, the monsoon covered nearly half of the country by the middle of June. There was a prolonged hiatus in the advancement of monsoon till the end of June due to weakening of monsoon current. The southwest monsoon covered the entire country by 6th July. As seen from the analysis panel of the T382 model the zonal wind flow was quite weak during most parts of June and in the first fortnight of July. The low level westerly flow picked up strength with a core of zonal wind of about 20 m/s in the second fortnight of July and remained so till the end of the month. This was followed by a spell of weak core of zonal wind for a period of two weeks. Another spell of strong core of zonal wind of about 15 m/s was seen in the first fortnight of September. The UKMO analyses show comparatively stronger zonal winds. The Day-3 and Day-5 forecasts of both the models agree reasonably well with the analysis and are able to depict the active and weak spells of the monsoon flow. However the wind strength is weaker during the active spell in the Day-5 forecasts.

Figure 11 shows the Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 75–80°E and smoothed by a 5-day moving average for the period 1 June–30 September 2010 for the T382 and UKMO models respectively. As in Figure 10, the top panel shows the analysis and the middle and the lower panel depict the Day-3 and Day-5 forecasts respectively. Both the T382 and UKMO analysis show a prominent northward movement of the core of zonal wind during the second fortnight of July. Two weak spells are seen in the second and third weak of June and from the fourth week of August to the second week of September. The Day-3 forecasts compare well with the analysis. However, the Day-5 forecasts of the T382 model are not able to depict the northward movement of the core of zonal wind as seen in the analysis. However, the UKMO Day-5 forecasts depict this feature comparatively better than the T382 model.

3. Forecast Errors

Here we present the model forecast errors expressed in terms of systematic error and Root Mean Squared Error (RMSE), with an aim to provide qualitative description of the spatial distribution of errors.

3.1 Systematic Errors in Wind at 850 & 200 hPa:

Figures 12 illustrates the systematic errors in the model forecast wind fields (vectors) (m/s) for JJAS at 850 hPa in the three models. The panels in the first column correspond to the mean analysis and the columns 2, 3 and 4 correspond to systematic errors in Day-1, Day-3 and Day-5 forecast. The shading in the panels indicates errors in the forecast zonal wind. The forecasts of all three models show (i) westerly bias over north Arabian Sea, Central India extending to South-east Asia. (ii) South of this east-west region easterly bias is seen. This broadly suggests that the forecast generally produce a monsoon circulation that is slightly shifted northwards. (iii) Central and eastern equatorial Indian Ocean feature strong easterly bias, particularly in the UKMO model forecasts. Other than these three prominent features, Figure 10 shows easterly bias over the Gangetic plains in the UKMO and T254 forecasts. The above mentioned biases are seen in all the months of the season (Appendix). Similarly the systematic errors in the winds at 200 hPa are presented in Figure 13. Strong westerly bias in the eastern Indian Ocean in the Day-3 and Day-5 forecasts is prominent particularly in the T254 and T382 models.

3.2 Systematic Errors in Temperature at 850 & 200 hPa

Figure 14 shows the Seasonal (JJAS, 2010) mean 850 hPa temperature in the analysis and the systematic errors in the forecasts. The T254 and T382 models show slight cold bias over the north Arabian Sea (about -0.4°K) with strong warm bias over the Pakistan region (>1.2°K). The UKMO model forecasts show strong warm bias over the north Arabian Sea (>1.4°K) and strong cold bias over the heat low region (<-1.2°K). Similar analysis for the months of July and August is shown in Figure 15. *The features of warm (cold) bias over the heat low region (north Arabian Sea) in the T254 and T382 models is persistent in all the months. Forecast errors in the UKMO over* *this region are just the opposite with cold bias over the heat low region and warm bias over the north Arabian Sea.* These aspects are consistently seen during all the months of the season and are shown for July and August in Figure 15.

At 200 hPa (Figure 16), T254 and T382 models feature comparable/similar pattern of systematic errors while UKMO model features completely different pattern. In the T382 model large area covering Bay of Bengal (Arabian Sea) dominantly shows warm (cold) bias in Day-1, Day-3 and Day-5 forecasts. T254 model also shows similar biases over the entire domain in the Day-1 and Day-3 forecasts, while the Day-5 forecasts show large part of land and Sea under cold bias. UKMO forecasts feature warm bias over continents and cold bias over the Indian ocean. Only the UKMO forecasts consistently show warm (cold) bias over the continent (Indian Ocean) during all the months of the season (see Appendix).

3.3 Root Mean Squared Error (RMSE)

The Root Mean Squared Error is given by-

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$$

-where F_i and O_i respresent forecast and observed fields respectively. The RMSE measures the "average" error, weighted according to the square of the error. However, it does not indicate the direction of the deviations. With values ranging from 0 to ∞, *RMSE* puts greater influence on large errors than smaller errors, which may be a good thing if large errors are especially undesirable, but may also encourage conservative forecasting.

The geographical distributions of the root mean square error of the forecasts (for each month and the season as a whole) were calculated from the difference at each grid point on each day. Grid points lying below ground were excluded from the computation. These charts are given for all the variables at the pressure levels 850 and 200 hPa. The time series of the spatial root mean square error for a variable over India (68-95°E,5-38°N), as a time series of 1, 2, 3, 4 and 5 day forecasts were computed for all the variables at 850, 700, 500 and 200 hPa levels. In combination with the other scores the time series provides useful information on consistency in the error characteristics of the forecast during the season (day to day variations in forecast errors).

The RMSE of winds (zonal and meridional), geo-potential height, temperature and relative humidity for UKMO and NCMRWF (T254 and T382) Day-1, Day-3 and Day-5 forecasts are discussed in detail below. The time series of daily spatial RMSE of the above variables over the Indian region are also discussed.

(i) Zonal Wind:

Panels in Figure 17 show the RMSE of 850 hPa zonal wind for Day-1, Day-3 and Day-5 forecasts of the T254, UKMO and T382 models respectively. The magnitude of RMSE at 850 hPa is of the order of 2-4 m/s in Day-1 forecast in all the model forecasts. The T382 and T254 models show a marked increase in the RMSE from Day-1 to Day-5 forecast as compared to UKMO, especially over the north-west and plains of India. Figures 18 is same as Figure 17 but for 200 hPa level. At 200 hPa, the magnitude varies from 2-4 m/s in UKMO and 2-6 m/s in Day-1 forecast of T382/T254 models over the Indian region. T382 and T254 model shows a considerable increase in RMSE from Day-1 to Day-5 forecast especially over the southern peninsula where the Tropical Easterly Jet (TEJ) is prominent.

(ii) Meridional Wind:

Panels in Figure 19 are same as in Figure 17 but for meridional winds. At 850 hPa, the magnitude of RMSE in meridional component of the wind is of the order of 2-4 m/s in Day-1 forecast in all the models over the Indian and neighborhood region. All the models show a consistent increase in RMSE from Day-1- to Day-5 forecast with the magnitude of about 4-6 m/s. Figures 20 is same as Figure 18 but for meridional winds. The magnitude of RMSE is of the order of 2-4 m/s and 2-6 m/s in Day-1 forecasts of the UKMO and T382 models respectively over the Indian region. The T382 and T254 models show a consistent increase (more than 6 m/s) in RMSE from Day-1- to Day-5 forecast.

(iii) Temperature:

Panels in Figure 21 show the RMSE of 850 hPa temperature forecasts. At 850 hPa, the magnitude of RMSE is of the order of 1-1.5°K in Day-1 forecast over the northwest India for T254 and T382 whereas the magnitude is slightly smaller in UKMO. There is increase in RMSE from Day-1 to Day-5 forecast in all the model forecasts. The T254 and T382 models show consistently higher RMSEs over the north-west parts of India as compared to the UKMO forecasts. Figures 22 show the RMSE of 200 hPa temperature forecasts. At upper level (200 hPa), the magnitude of the errors is less as compared to the lower level (850 hPa). The order of the magnitude at 200 hPa is ~0.5-1°K over the Indian mainland and its neighborhood. The magnitude of RMSEs in Day-5 forecasts of all the model forecasts is about 0.5-2°K, over the Indian region, with larger errors over the northern parts.

(iv) Geo-Potential height:

Panels in Figure 23 show the RMSE of 850 hPa geopotential height forecasts. The magnitude of RMSE in UKMO and T382 Day-1 forecasts over India is similar and of the order of 5-10 gpm. The increase in RMSE from Day-1 to Day-5 in T254 is very much high as compared with UKMO and T382 model. High values of RMSE in the T254 forecasts are seen over the Indian land regions as well as the Arabian Sea and Bay of Bengal. Panels in Figure 24 show the RMSE of 200 hPa geopotential height forecasts. The magnitude of RMSE in UKMO and T382 forecasts over India is similar and of the order of 0-10 gpm. The magnitude of RMSEs in Day-5 forecasts of UKMO and T382 forecasts is about 10-40 gpm, over the Indian region, with larger errors over the northern parts. The T254 model shows larger RMSEs as compared to the UKMO and T382 model.

(v)Relative Humidity:

Panels in Figure 25 show the RMSE of 850 hPa relative humidity forecasts. The Day-1 forecasts errors of all three models are rather similar. *The magnitude of RMSE is higher in UKMO as compared to T254 and T382 model forecasts.* High values of RMSE are observed over the northwest and plains of India in the Day-3 and Day-5 forecasts of the UKMO and T382 models. Panels in Figure 26 show the RMSE of 200 hPa relative humidity forecasts. At 200 hPa, the RMSE in UKMO model is less as compared to T254 and T382 model. *The magnitude of RMSE is almost constant up to 5th day forecast for UKMO model over the Indian mainland while it is consistently increasing for T254 and T382 models and goes more than 40 % in the Day-5 forecasts.*

(vi) Time Series of RMSE of Zonal Wind:

The RMSE of zonal wind at 850, 700, 500, and 200Pa levels of Day-1, Day-3 and Day-5 forecasts for each day have been computed for the Indian domain of 5-38°N and 68-94°E. Figure 27 shows the time series of RMSE of zonal wind at above mentioned four levels. The black, red and green lines correspond to the T254, UKMO and T382 model forecasts respectively. The average seasonal RMSE at each level are also shown in similar colors. *The RMSE in the UKMO forecasts is lower than the T254 and T382 models in all the forecasts.* In the beginning of June, all the models show a large spatial RMSE, which was due to the errors in the forecast of the tropical cyclone 'Phet' which developed over the Arabian sea. UKMO model shows a high value in the last week of September in Day-1 forecast.

(vii) Time Series of RMSE of Meridional Wind:

Panels in Figure 28 show similar figures for the meridional component of the wind. *They also show the lower magnitudes of RMSE in UKMO forecasts at all the levels.*

(viii) Time Series of RMSE of Temperature:

The time series of daily RMSE of temperature (Figure 29) is almost similar to that of winds except two peaks in last two weeks of September shown by UKMO model in Day-1 forecast. One peak around 23 September at all the levels can be consistently seen in all days forecast of UKMO. *However the magnitude of RMSE in UKMO forecasts are less as compared to T254 and T382 models at all the levels.* At

850 hpa level, the magnitude of RMSE is more in June as compared to the other months in Day-3 and Day-5 forecasts.

(ix) Time Series of RMSE of Geo-Potential height

The time series of daily RMSE of geopotential height (Figure 30) shows that the UKMO model have smaller RMSEs as compared to the other two models. There are very much large variations in error in all days forecast. T254 model predicts geo-potential height very badly at all the levels.

(x) Time Series of RMSE of Relative Humidity:

RMSE in relative humidity at 850 hPa and 700hPa is higher in UKMO as compared to T254 and T382 model forecast while the same is lower at the upper levels (500 and 200 hPa) as shown in Figure 31. The RMSE values are higher during the first week of June in all days forecast and errors are high at all the levels in UKMO in the last week of September.

The RMSE computations discussed above show the model errors as a function of time within the season. Table 1 gives the average RMSE values corresponding for the season as a whole. UKMO forecasts feature relatively smaller RMSE for meridional wind (v), geopotential height (HGT) for both 850 and 200 hPa; and RH for 200 hPa.

Table 1. Day1-Day5 Root Mean Square Error (RMSE) of Wind(Zonal, Meridional), Temperature, Relative Humidity and Geo-potential height over the Indian region (68-94E,5-38N) of different Models (UKMO, T254, T382)

UKMO	**Day1**		**Day2**		**Day3**		**Day4**		**Day5**	
	850 hPa	**200 hPa**	**850 hPa**	**200 hPa**	**850ha**	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**
u(m/s)	2.11	3.10	2.57	3.76	3.03	4.17	3.44	4.55	3.77	4.95
v(m/s)	1.93	2.96	2.33	3.47	2.63	3.80	2.89	4.16	3.11	4.47
T(^{0}K)	0.60	0.50	0.74	0.64	0.85	0.72	0.94	0.79	1.02	0.88
RH(%)	7.37	10.70	8.91	12.29	9.98	12.86	10.90	13.49	11.61	13.96
HGT(m)	5.19	7.03	6.73	9.05	8.06	11.72	9.68	13.95	11.25	16.77
T382	**Day1**		**Day2**		**Day3**		**Day4**		**Day5**	
	850 hPa	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**
u(m/s)	2.80	4.23	2.57	5.30	3.89	5.77	4.24	6.09	4.61	6.49
v(m/s)	2.51	3.88	3.04	4.64	3.29	4.94	3.50	5.36	3.72	5.73
T(^{0}K)	0.67	0.63	0.84	0.83	0.93	0.90	1.01	1.00	1.10	1.08
RH(%)	6.84	16.38	8.39	20.58	9.07	21.94	9.61	22.87	10.05	24.08
HGT(m)	6.97	8.53	9.53	12.73	10.01	15.52	11.18	18.37	12.47	21.29
T254	**Day1**		**Day2**		**Day3**		**Day4**		**Day5**	
	850 hPa	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**	**850 hPa**	**200 hPa**
u(m/s)	2.88	4.62	3.57	5.46	4.03	5.85	4.37	6.18	4.79	6.60
v(m/s)	2.53	4.13	3.06	4.84	3.37	5.23	3.66	5.48	3.92	5.77
T(^{0}K)	0.66	0.70	0.83	0.89	0.93	0.98	1.02	1.05	1.07	1.15
RH(%)	5.91	16.23	7.83	20.78	8.65	21.75	9.24	22.54	9.77	23.14
HGT(m)	9.83	14.87	11.85	18.11	12.87	20.51	14.05	23.89	14.73	26.68

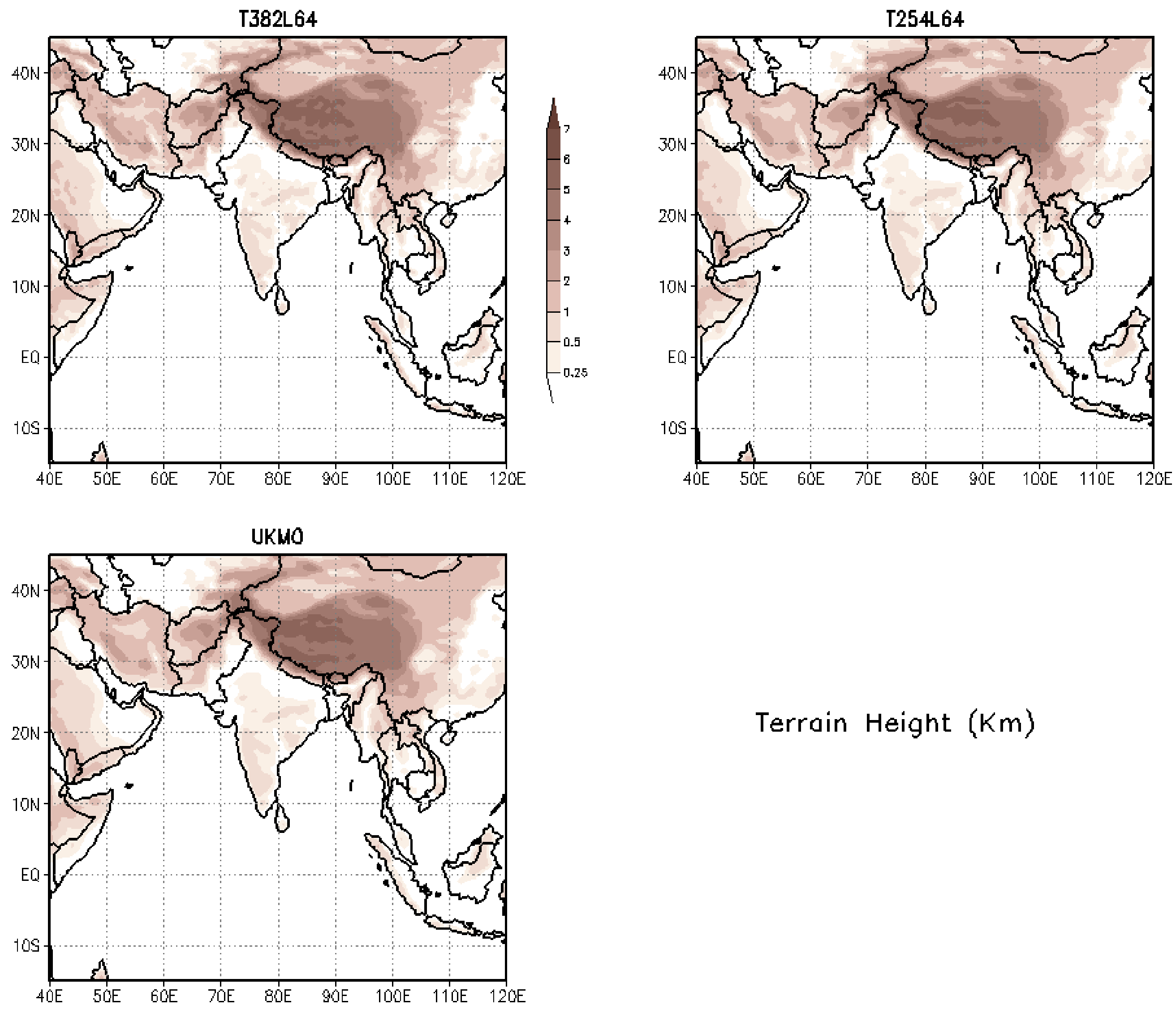


Figure 1.Terrain height (Km) in T254, T382 and UKMO global models.

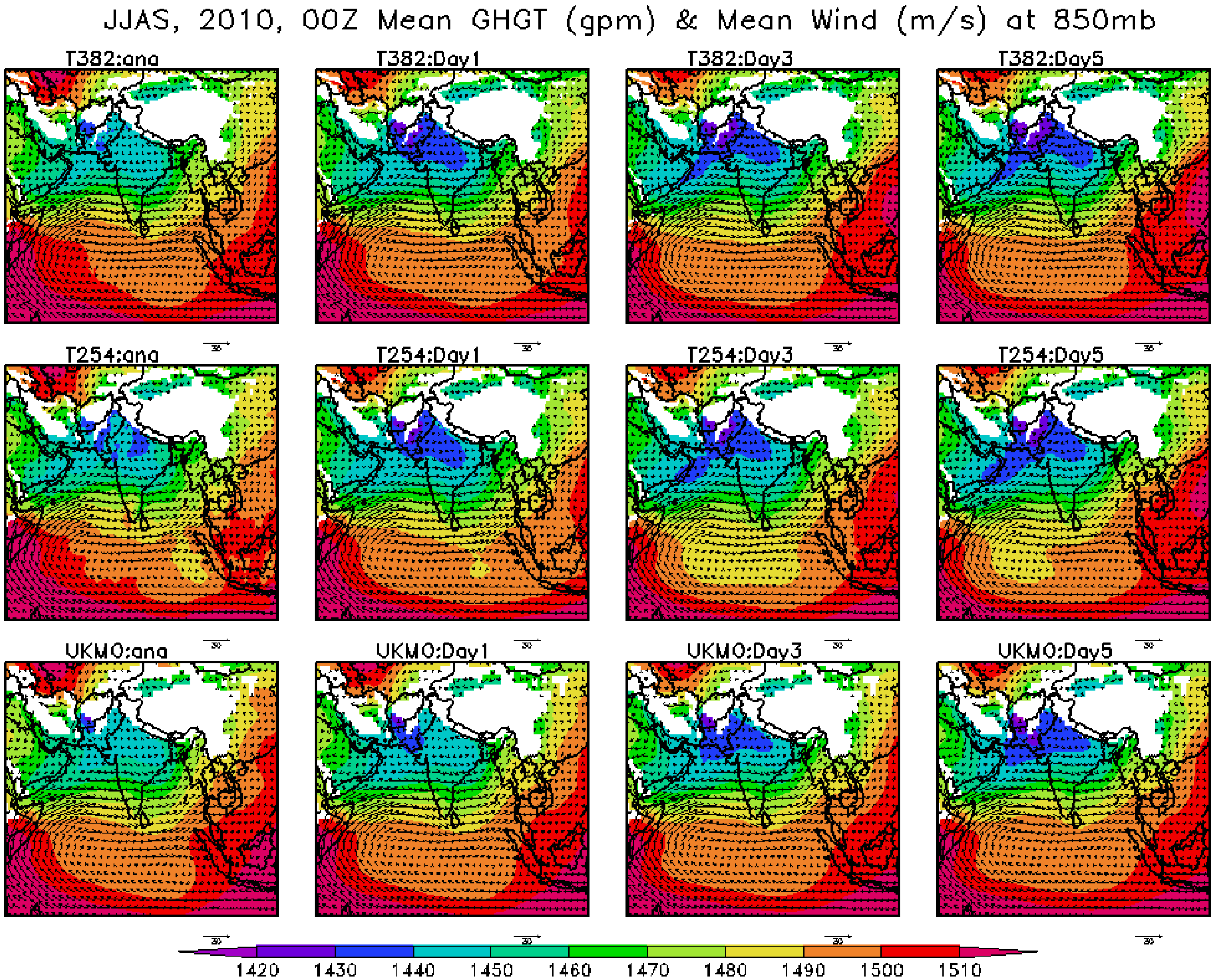


Figure 2.Mean analysis of 850 hPa winds and geopotentials for JJAS 2010 from T254, T382 and UKMO global models.

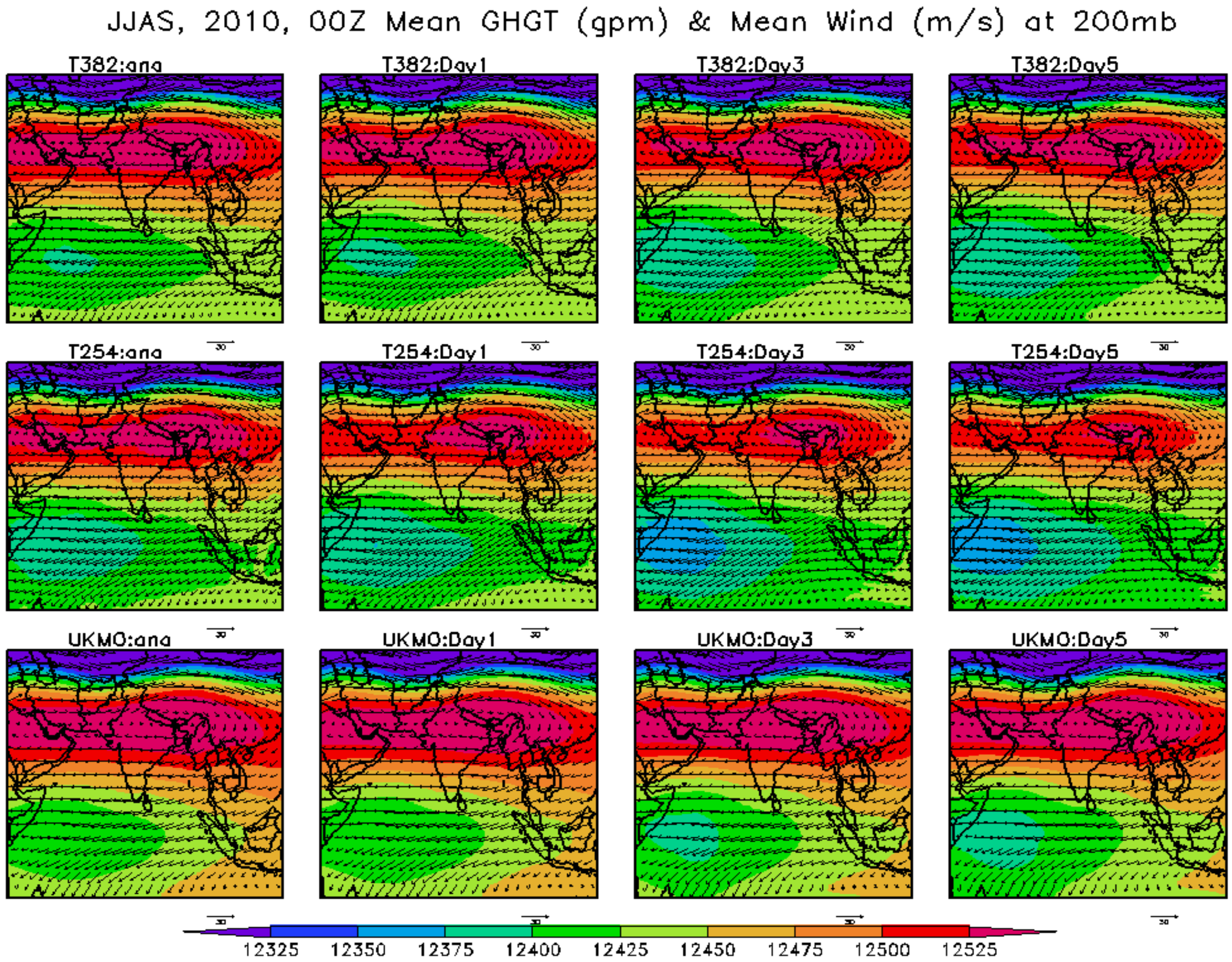


Figure 3.Mean analysis of 200 hPa winds and geopotentials for JJAS 2010 from T254, T382 and UKMO global models.

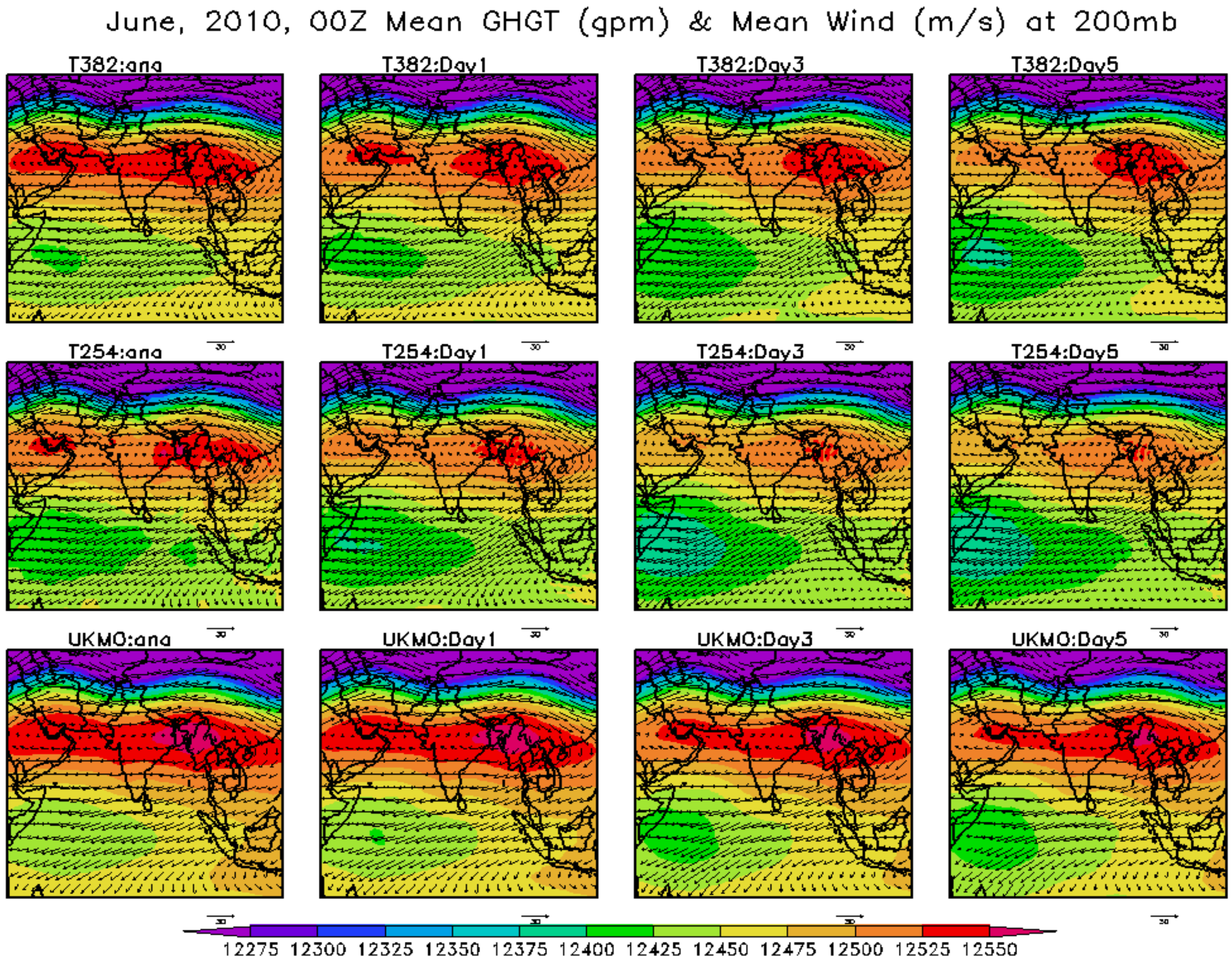


Figure 4.Mean analysis of 200 hPa winds and geopotentials for June 2010 from T254, T382 and UKMO global models.

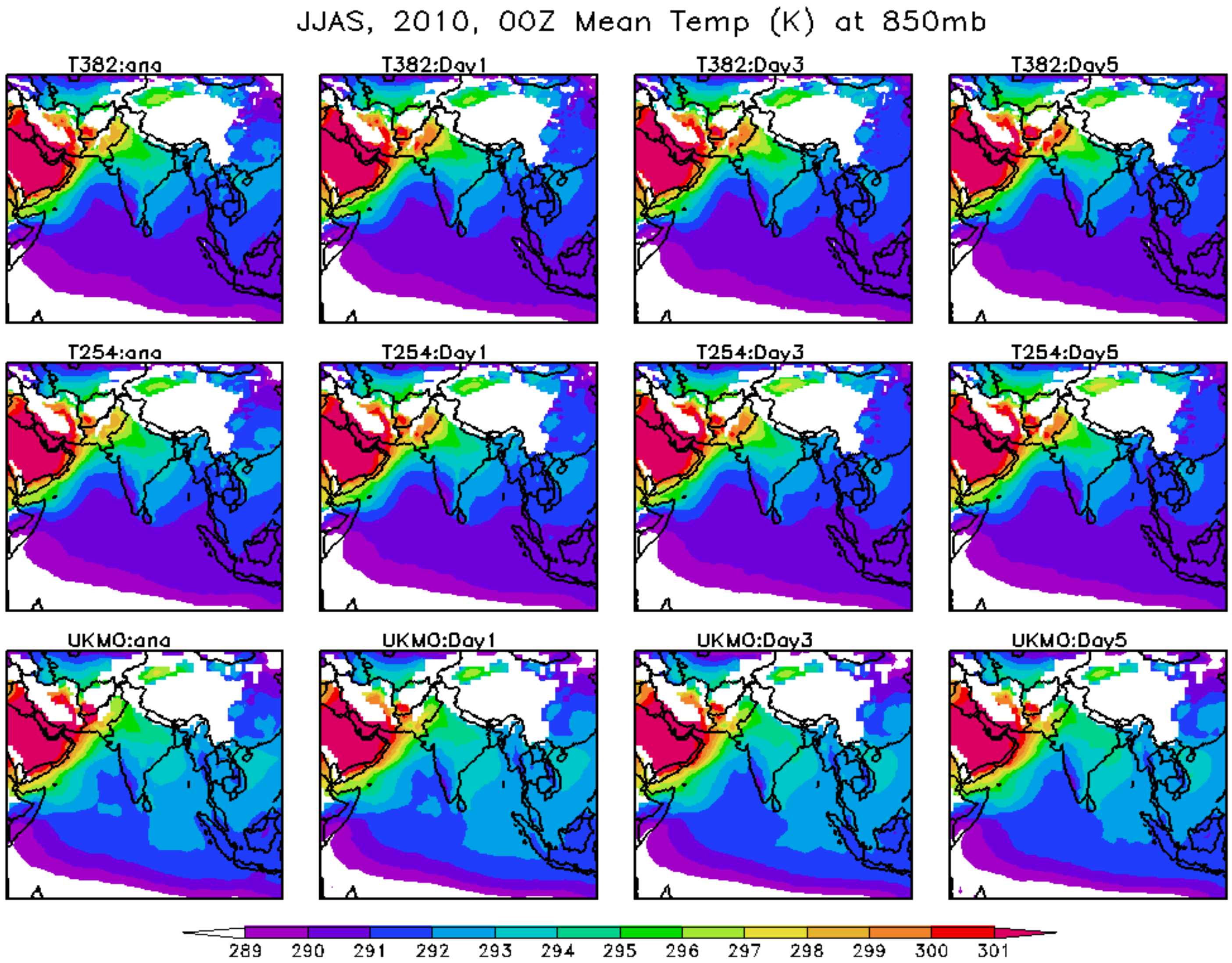


Figure 5. Mean analysis of 850 hPa Temperature (ºK) for JJAS 2010 in T254, T382 and UKMO global models.

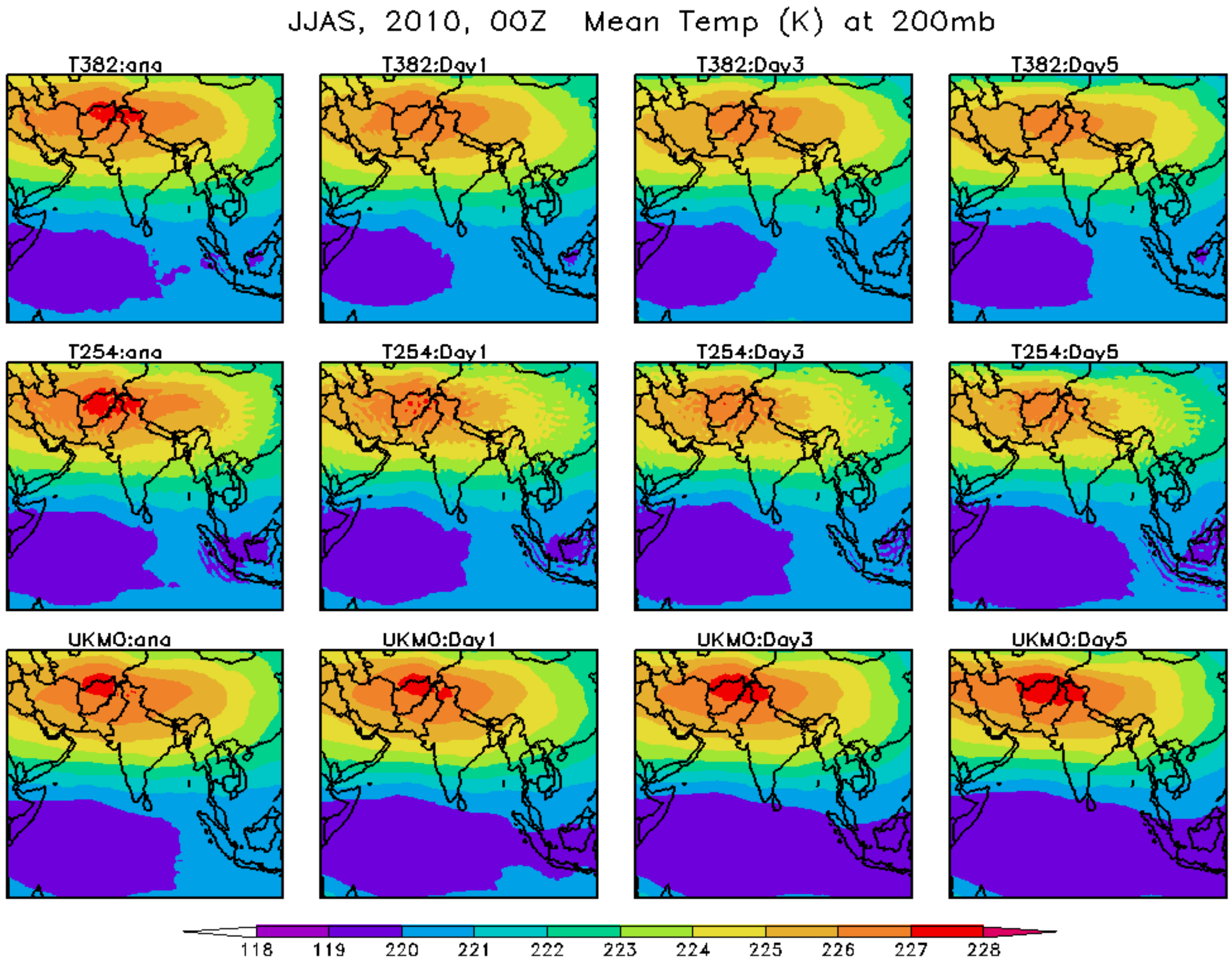


Figure 6. Mean analysis of 200 hPa Temperature (ºK) for JJAS 2010 in T254, T382 and UKMO global models.

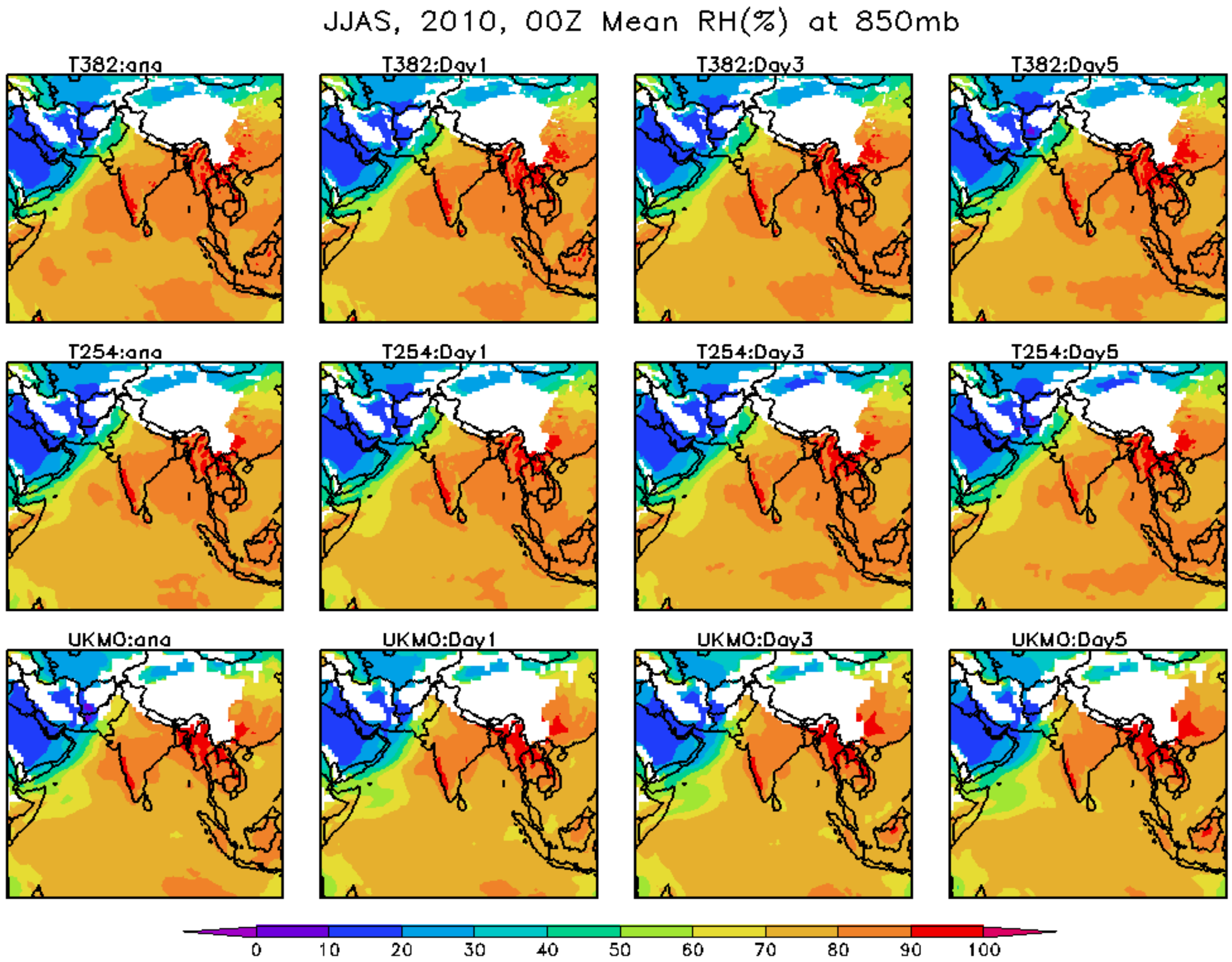
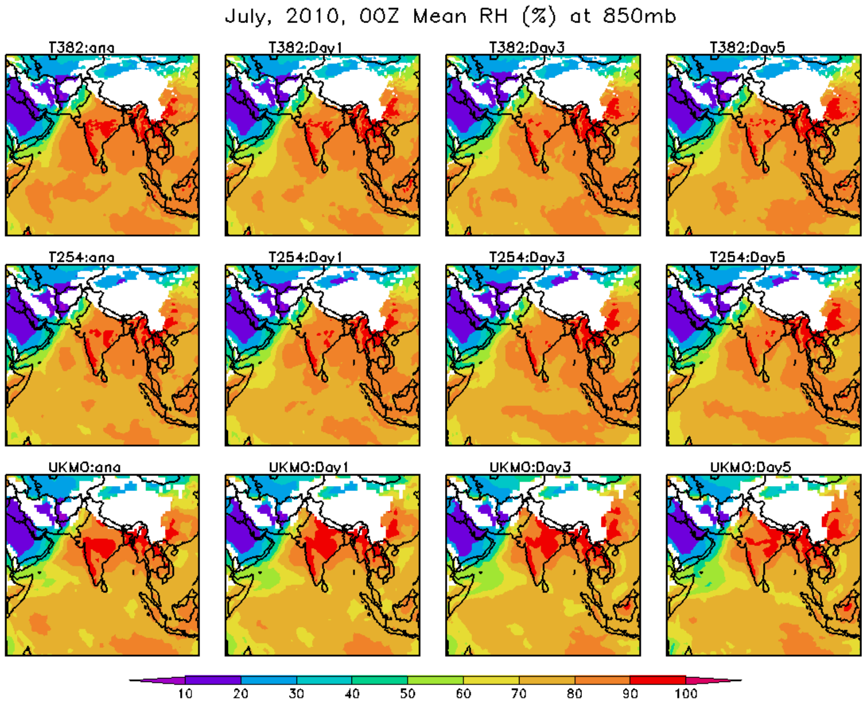


Figure 7. Mean analysis of 850 hPa Relative Humidity (%) for JJAS 2010 in T254, T382 and UKMO global models.

(a)



(b)

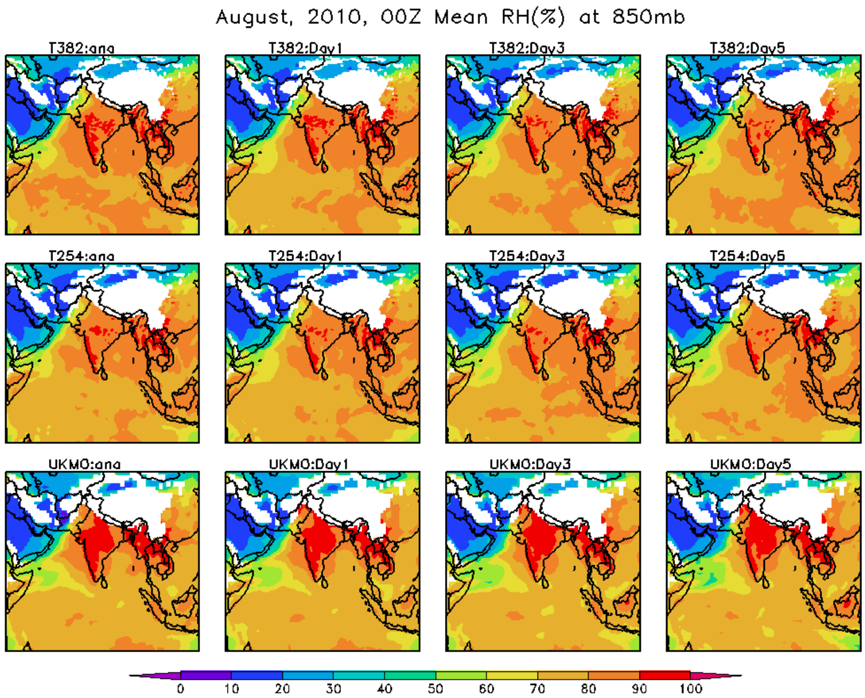


Figure 8. Mean analysis of 850 hPa Relative Humidity (%) for (a) July and (b) August 2010 in T254, T382 and UKMO global models.

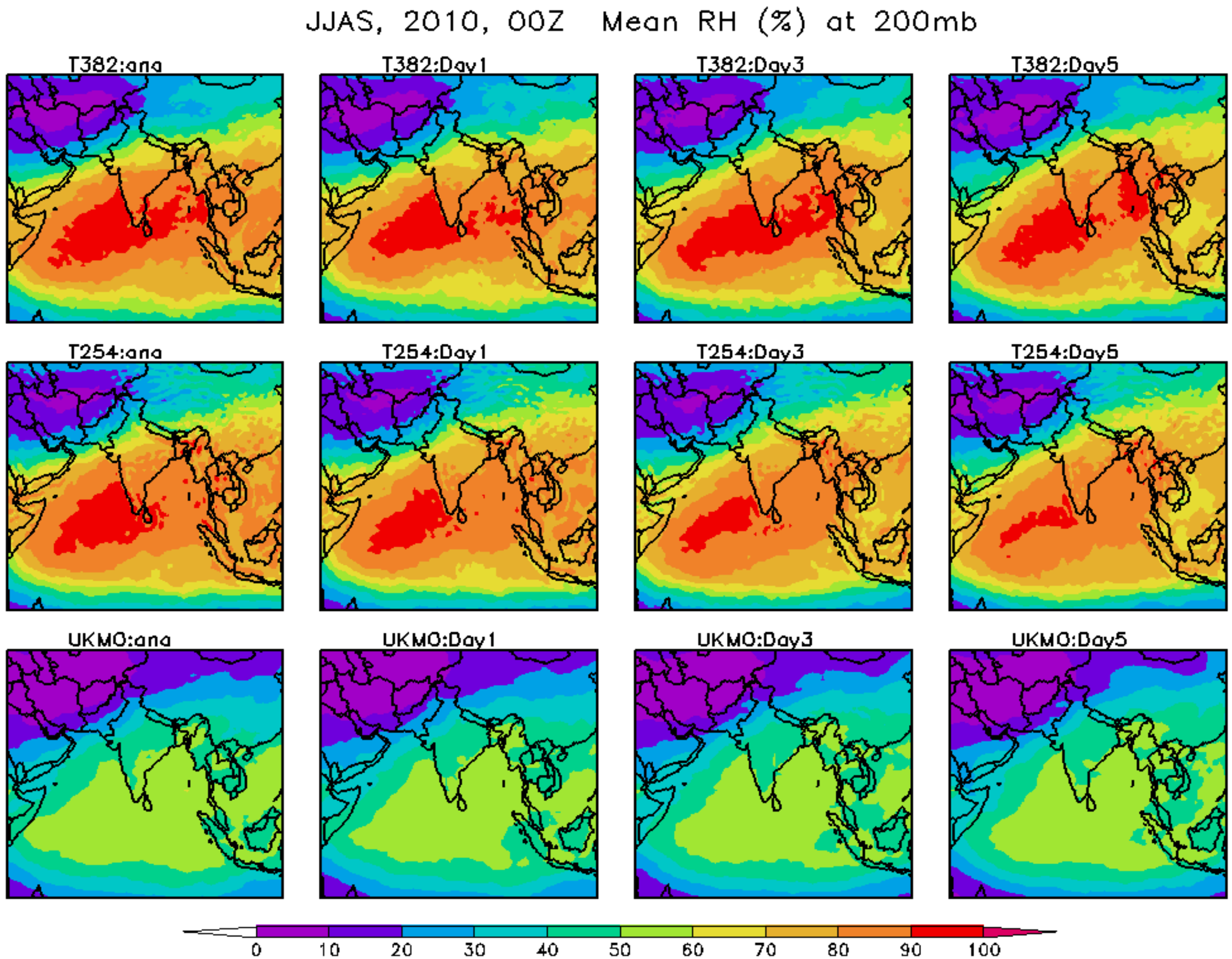


Figure 9. Mean analysis of 200 hPa Relative Humidity (%) for JJAS 2010 in T254, T382 and UKMO global models.

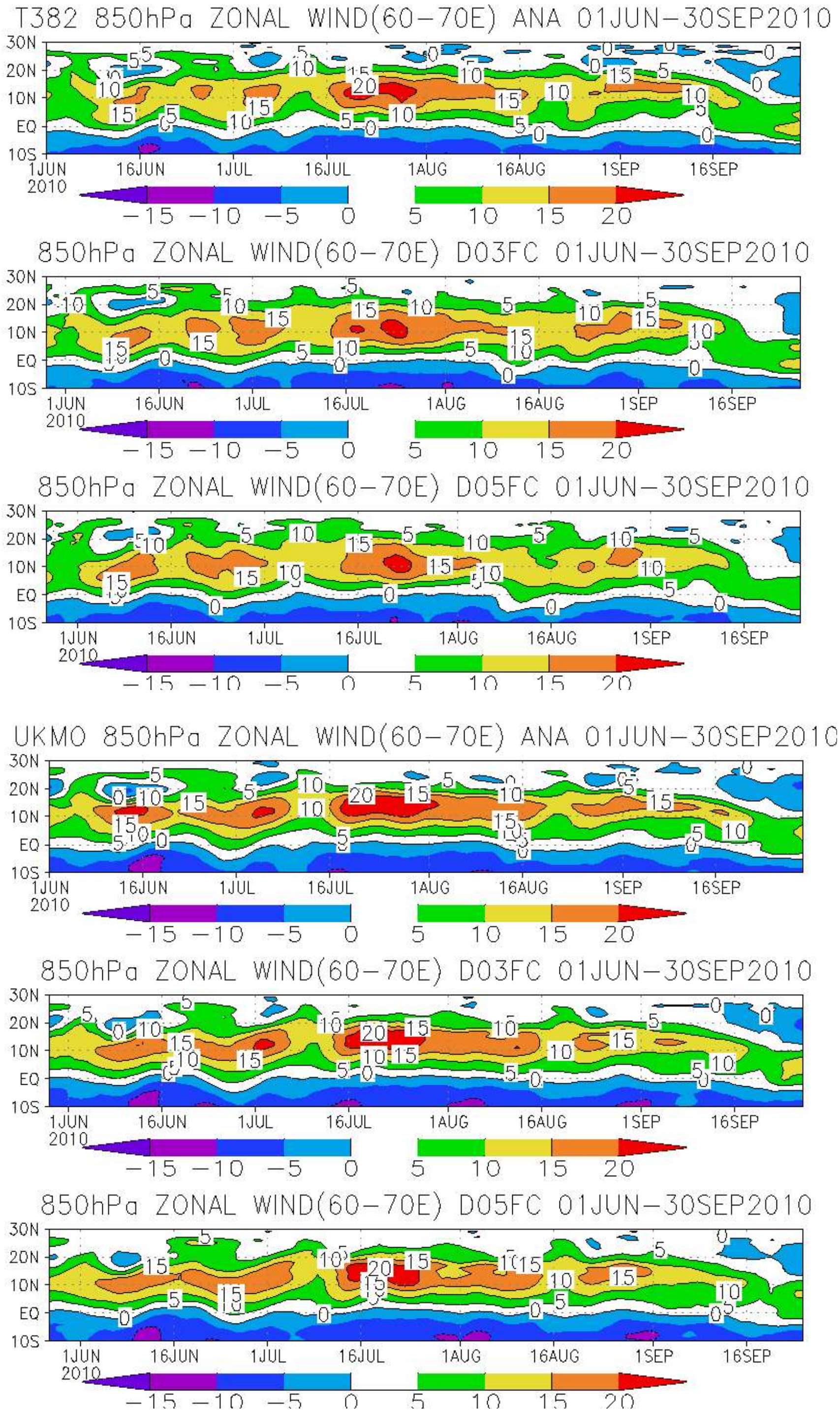


Figure 10. 850 hPa Zonal wind (m/s) averaged over 60-70 E during JJAS 2010 in the analysis and forecasts of (a) T382 and (b) UKMO models.

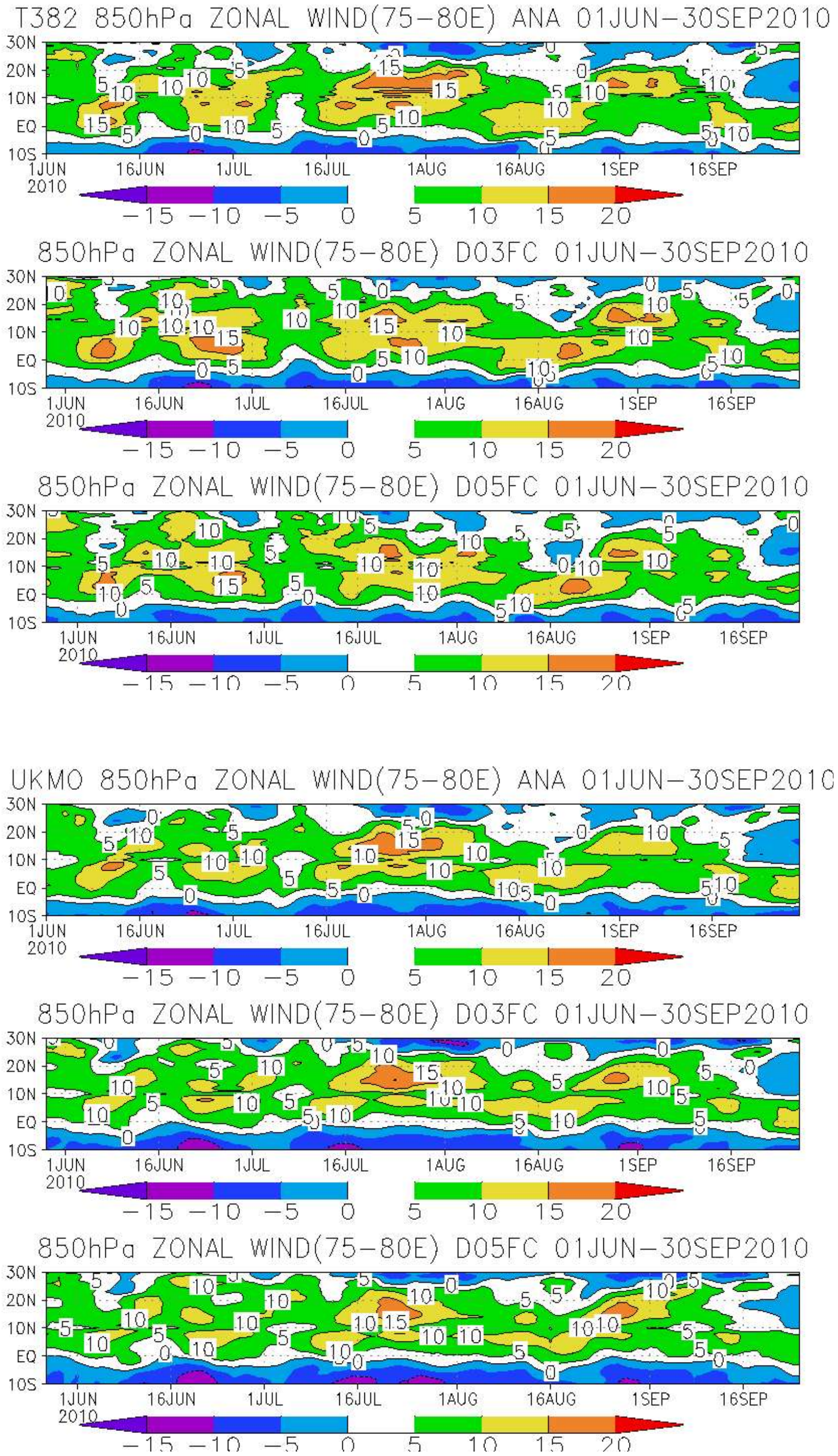


Figure 11. 850 hPa Zonal wind (m/s) averaged over 75-80 E during JJAS 2010 in the analysis and forecasts of (a) T382 and (b) UKMO models.

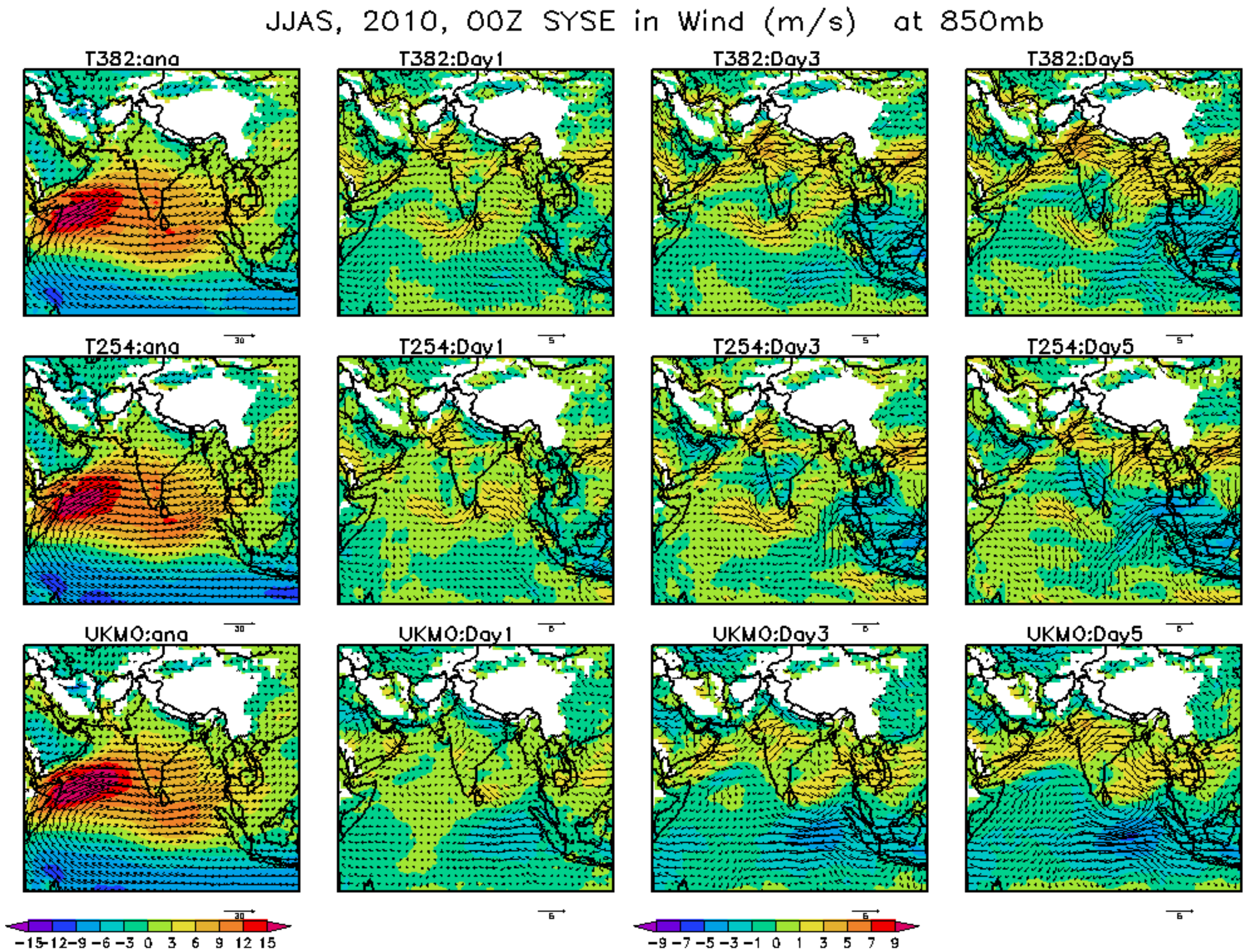


Figure 12. Systematic error in 850 hPa wind for JJAS 2010 in T254, T382 and UKMO global models.

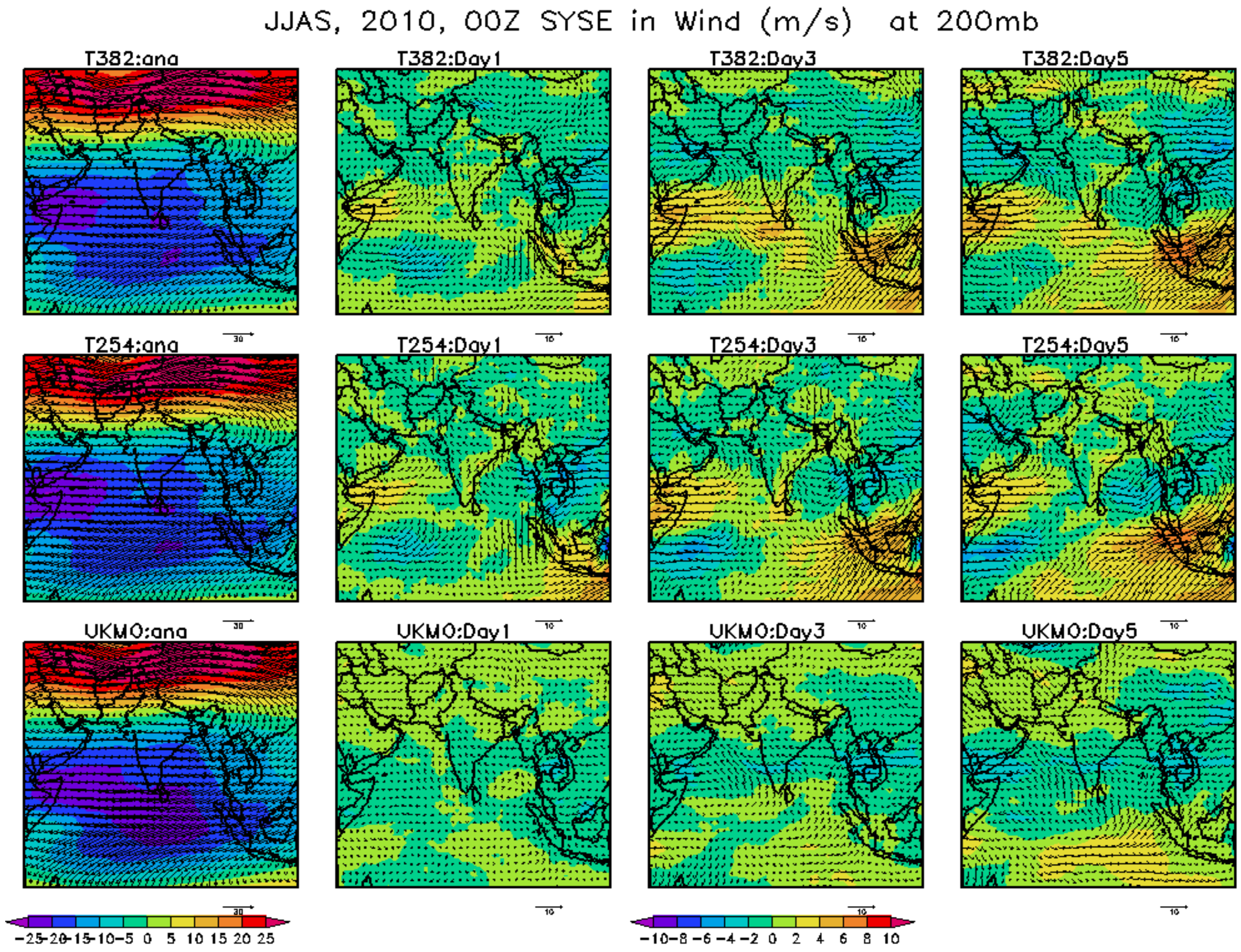


Figure 13. Systematic error in 200 hPa wind for JJAS 2010 in T254, T382 and UKMO global models.

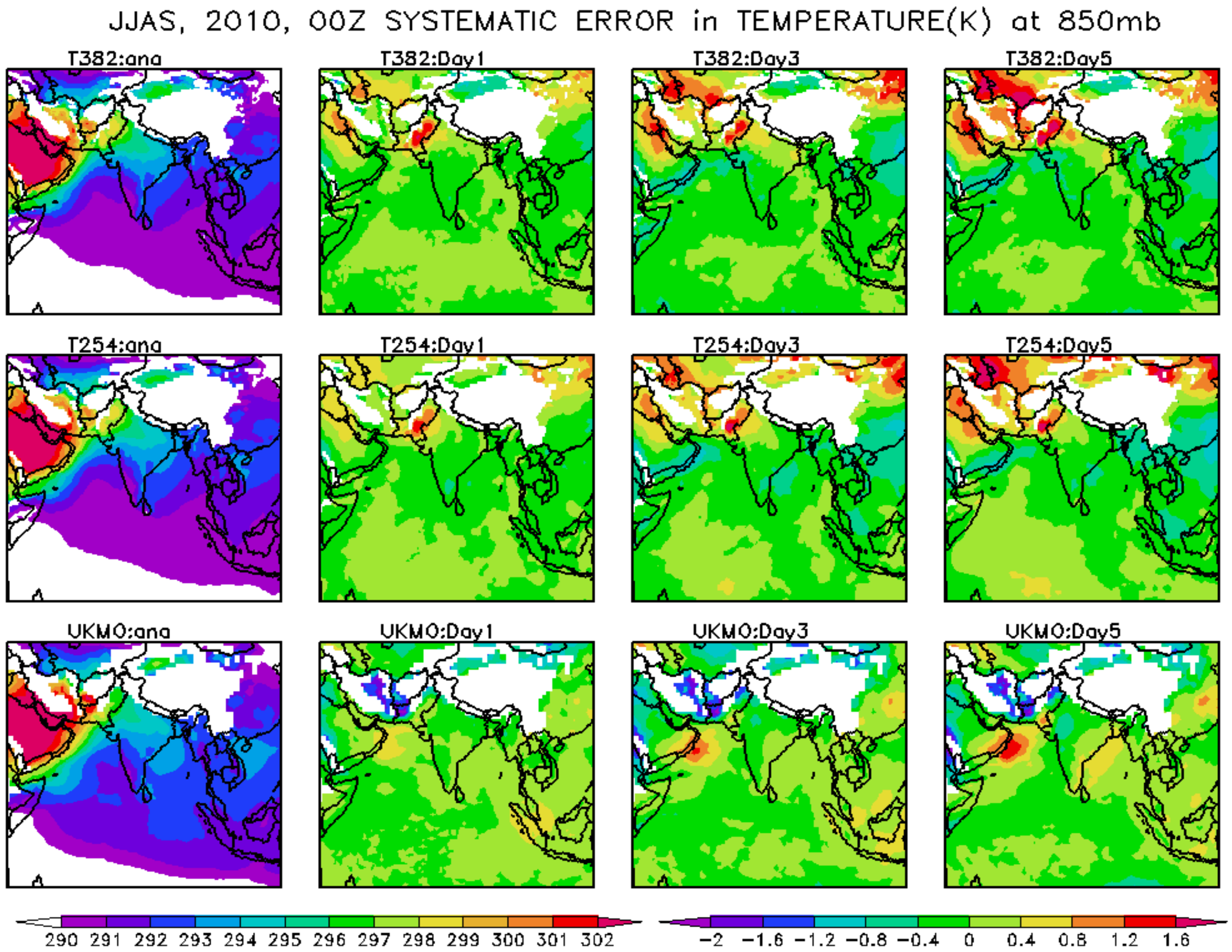


Figure 14. Systematic error in 850 hPa Temparature for JJAS 2010 in T254, T382 and UKMO global models.

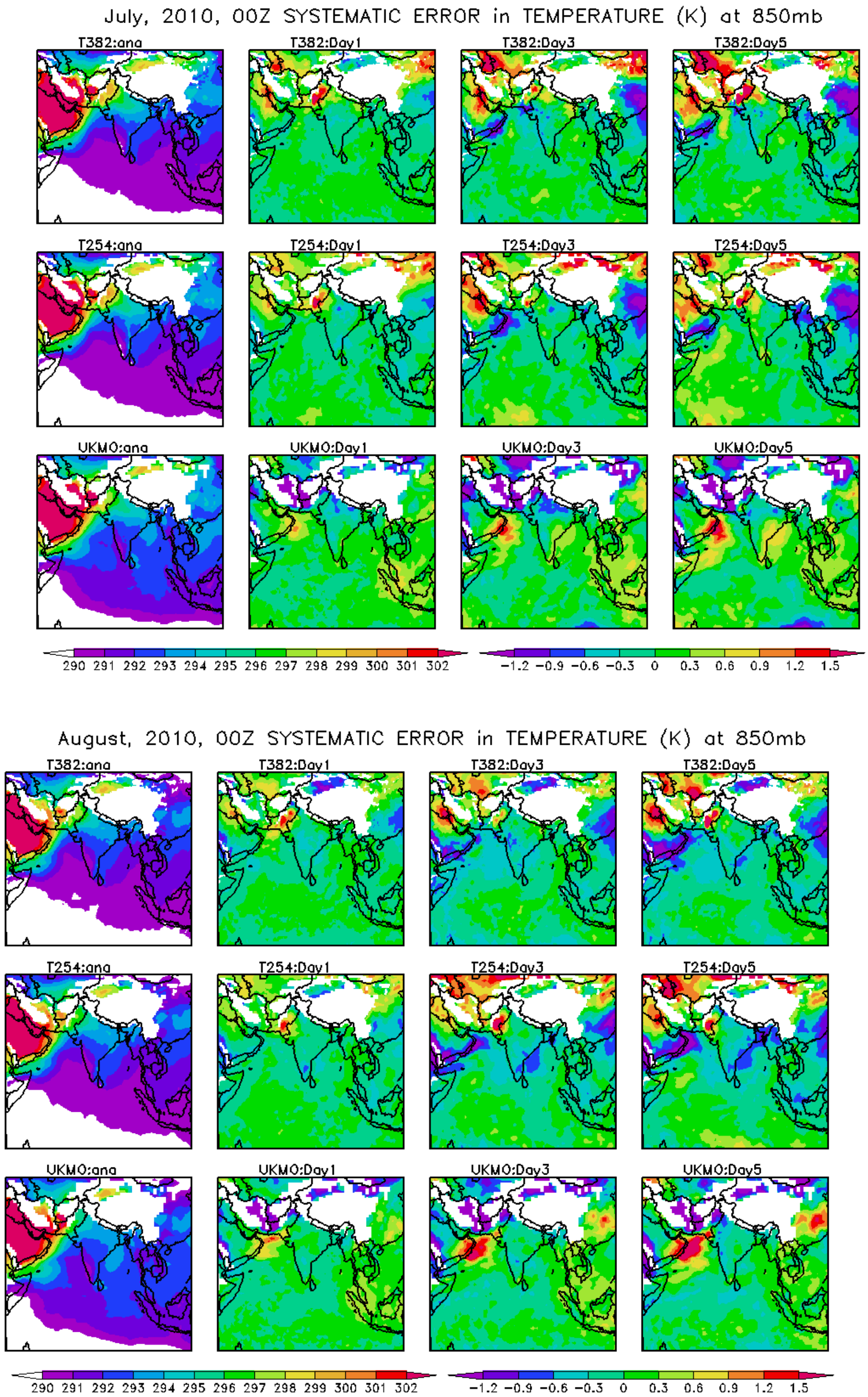


Figure 15. Systematic error in 850 hPa Temparature for (a) July and (b) August 2010 in T254, T382 and UKMO global models.

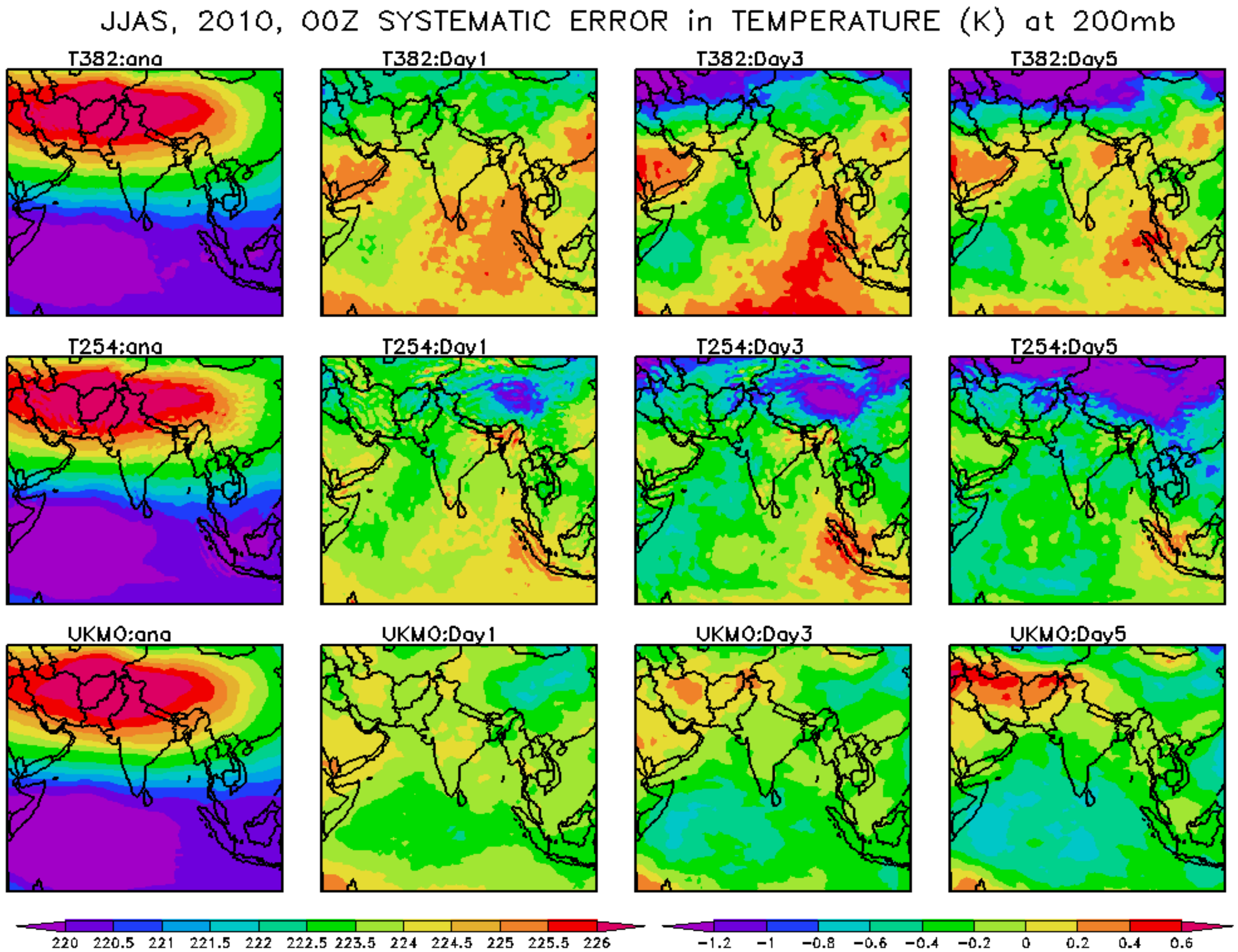


Figure 16. Systematic error in 200 hPa Temparature for JJAS 2010 in T254, T382 and UKMO global models.

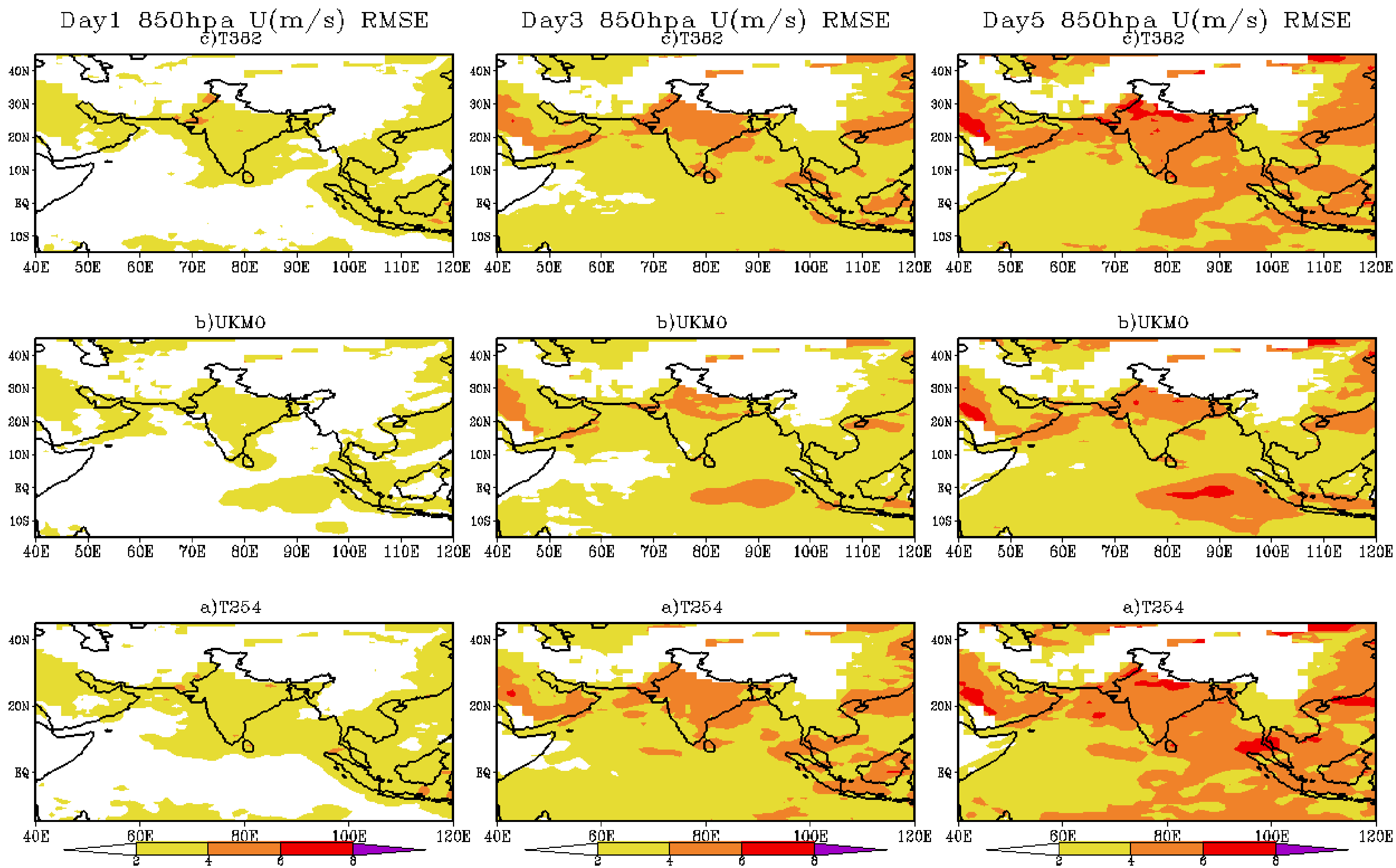


Figure 17. RMSE of 850hPa zonal wind for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

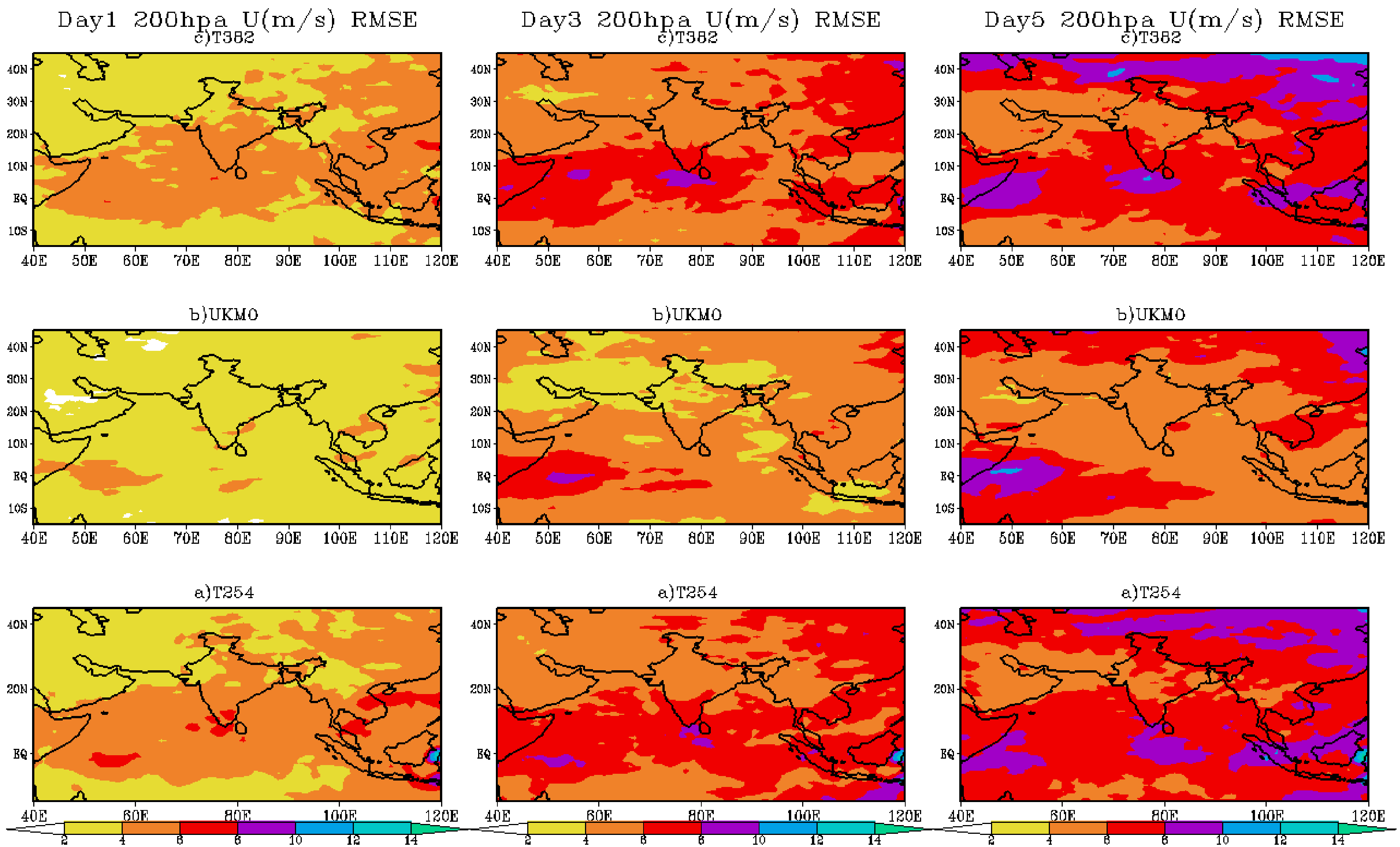


Figure 18. RMSE of 200hPa zonal wind for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

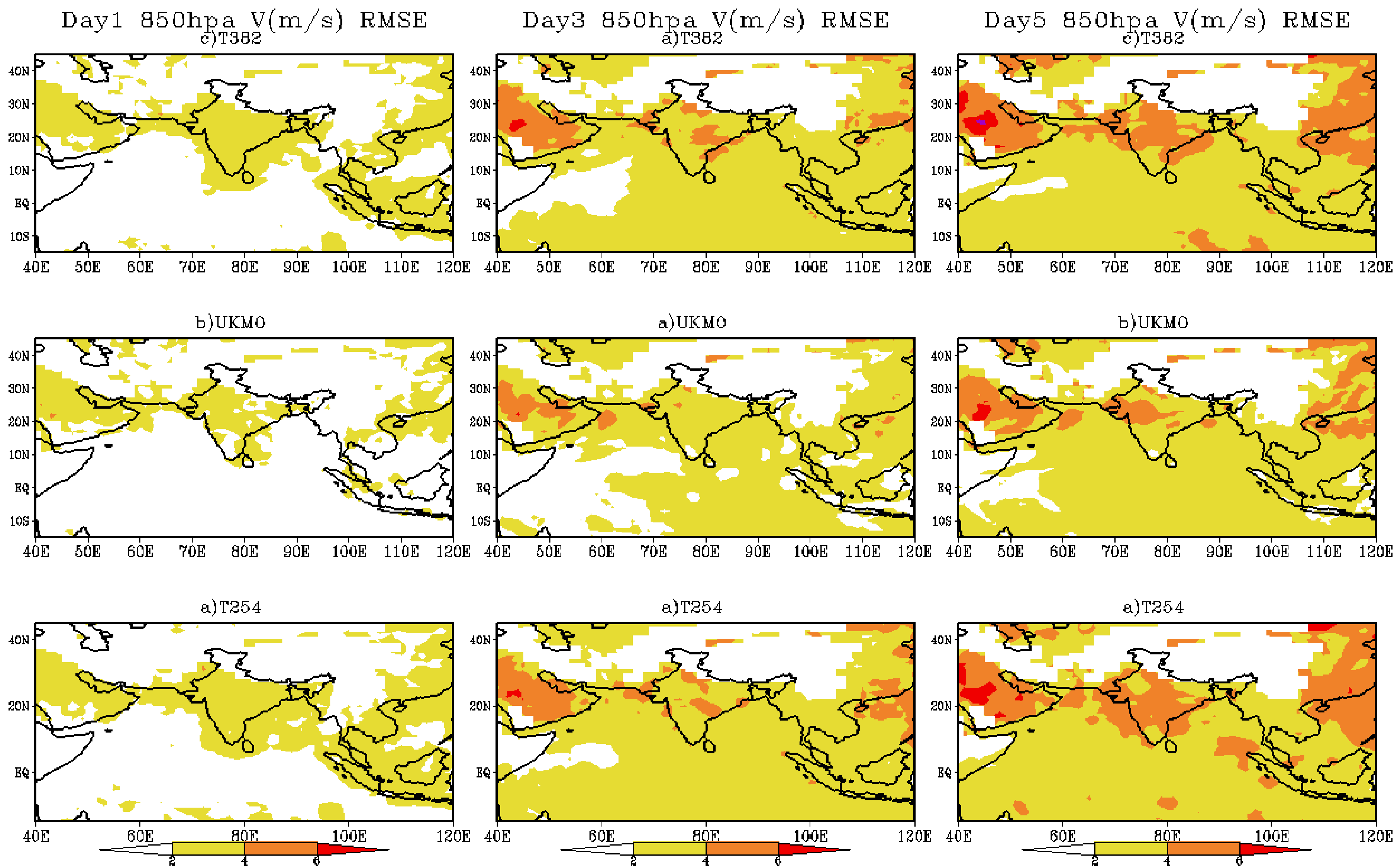


Figure 19. RMSE of 850hPa meridional wind for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

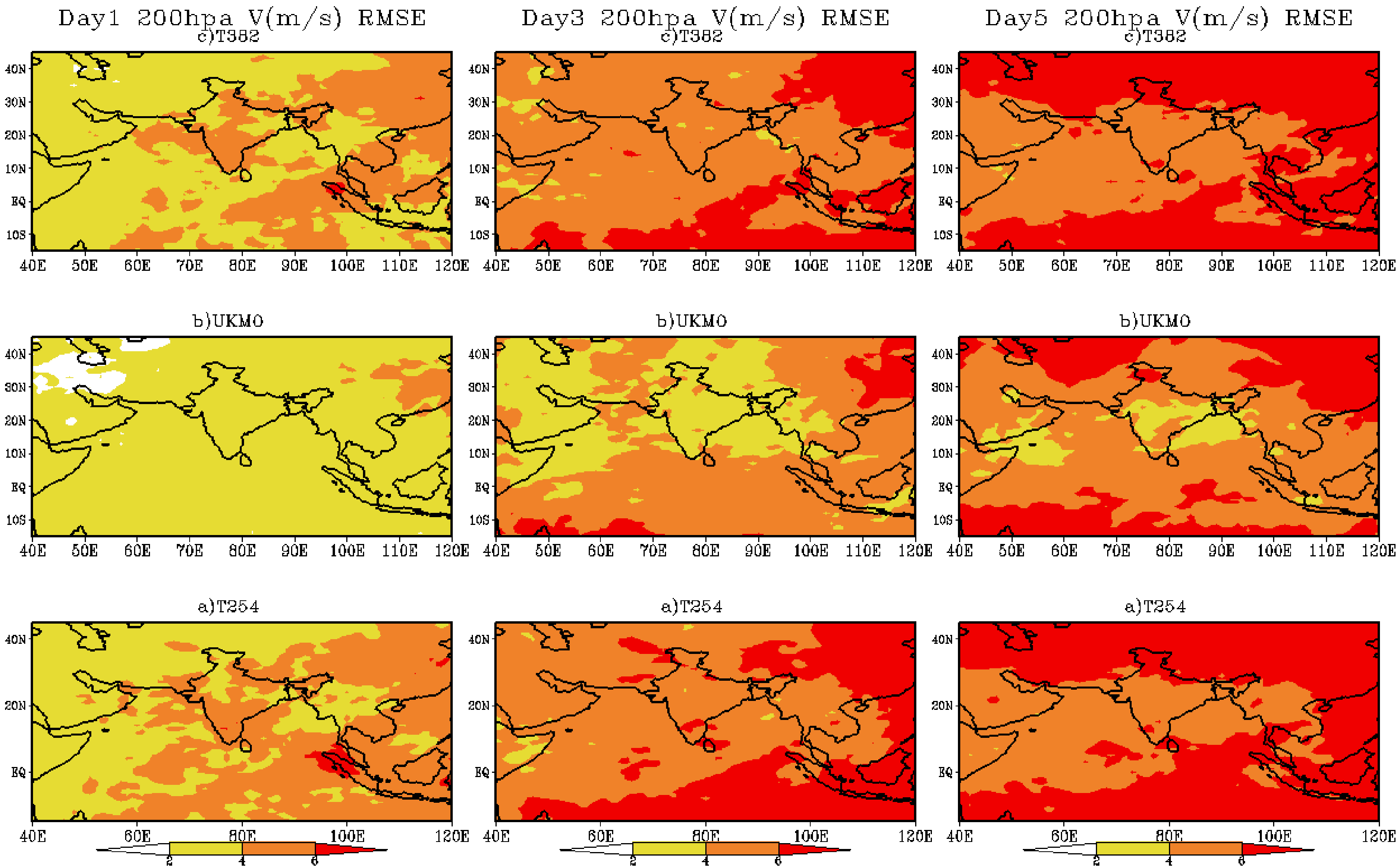


Figure 20. RMSE of 200hPa meridional wind for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

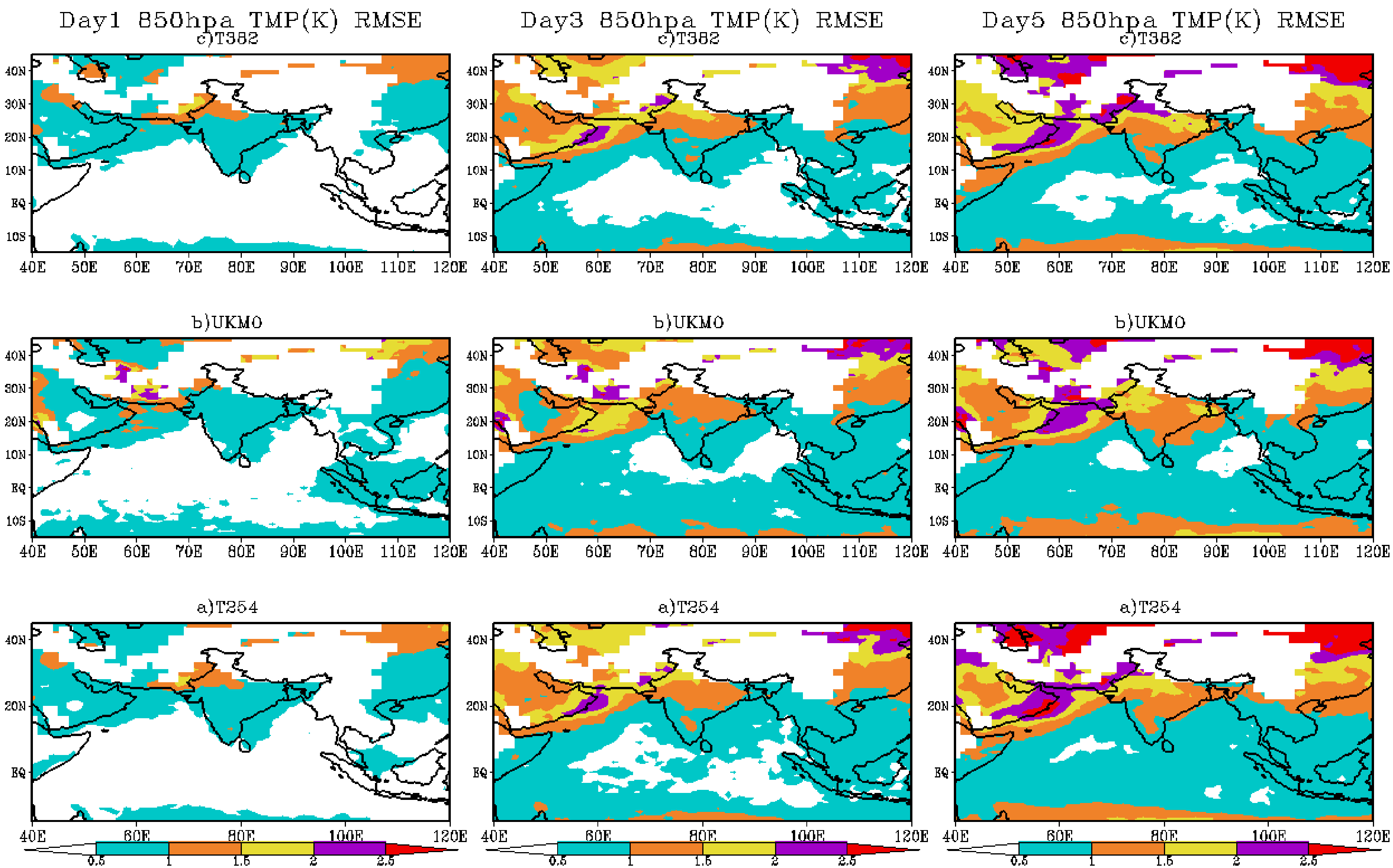


Figure 21. RMSE of 850hPa temperature for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

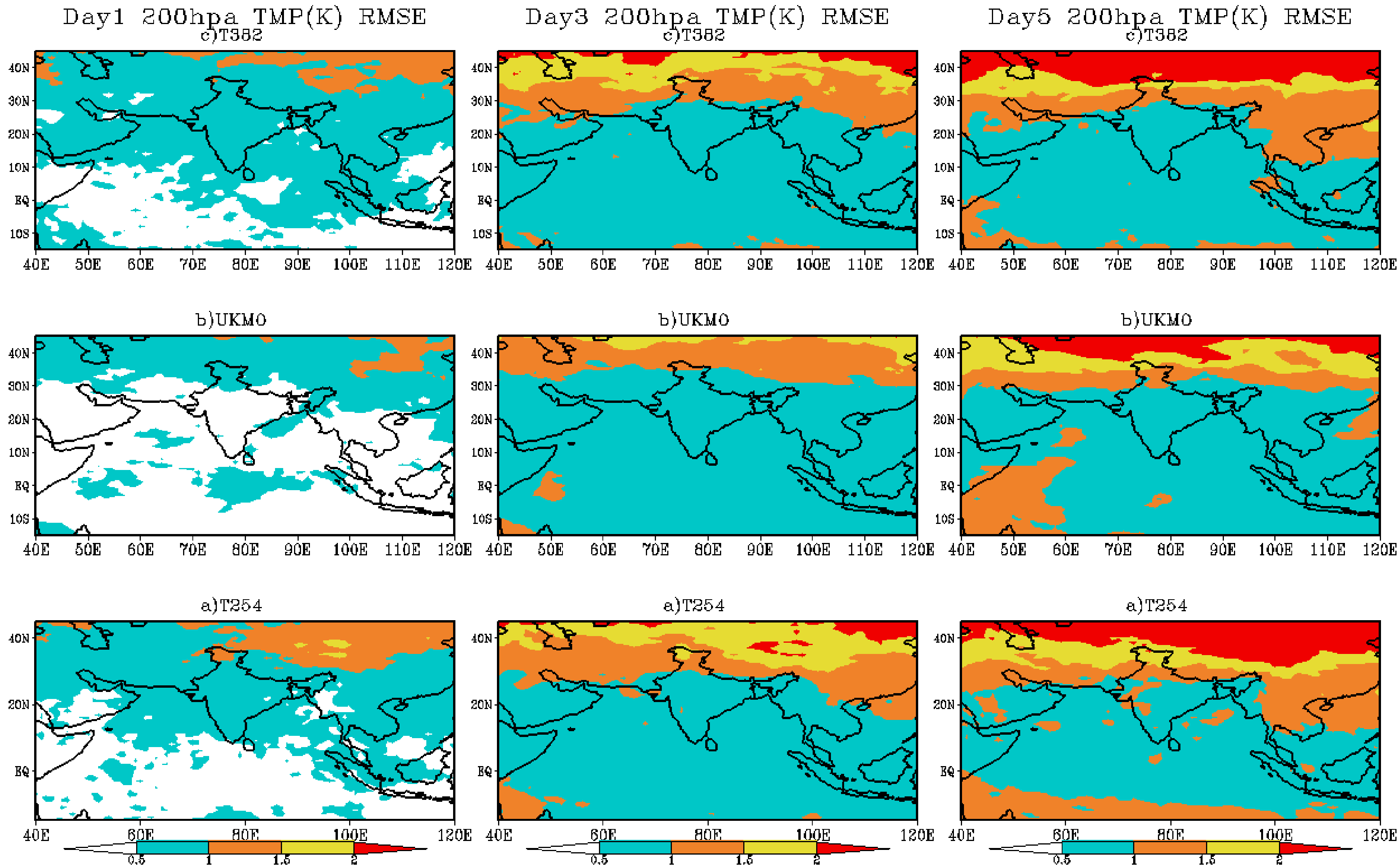


Figure 22. RMSE of 200hPa temperature for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

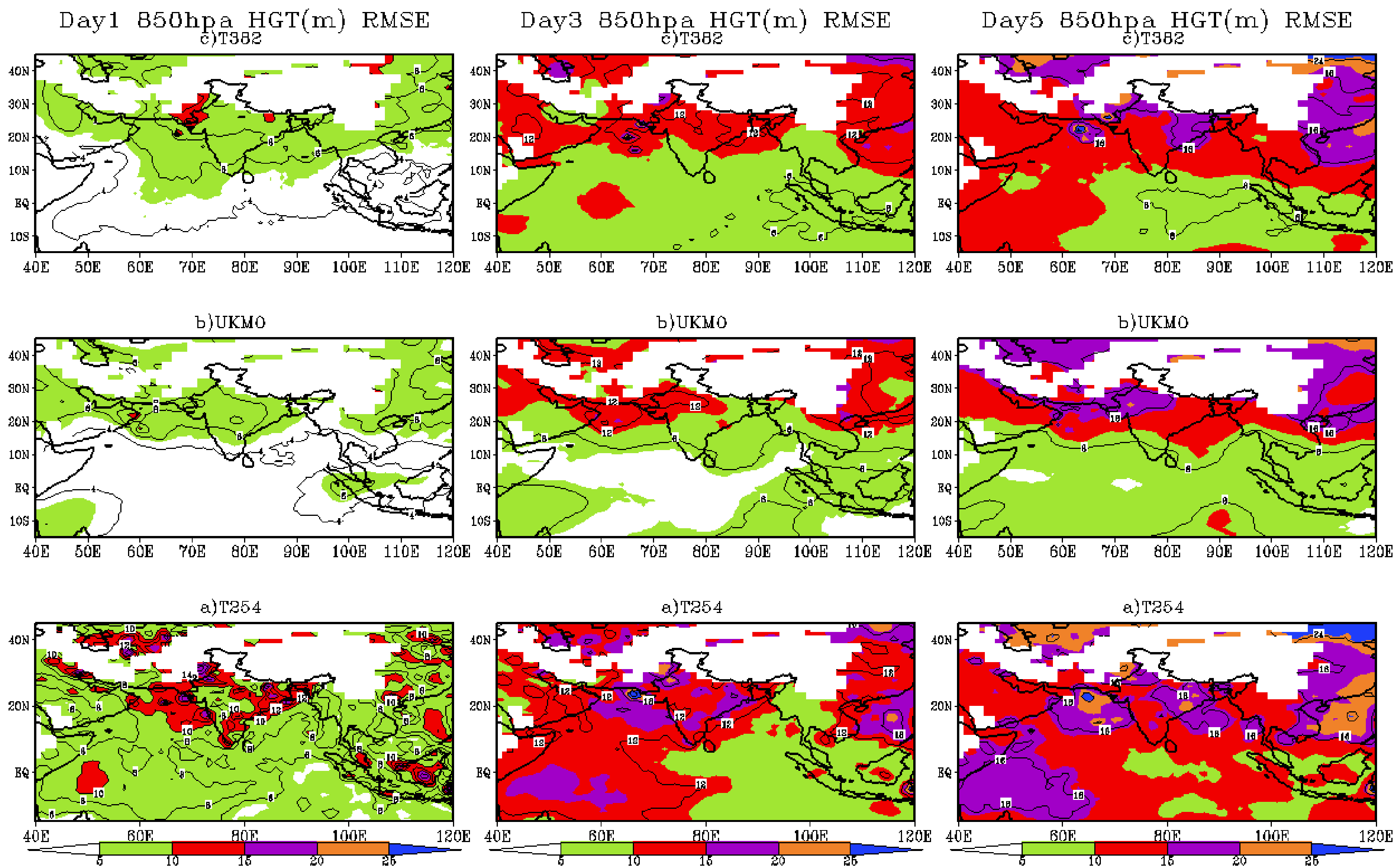


Figure 23. RMSE of 850hPa geopotential height for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

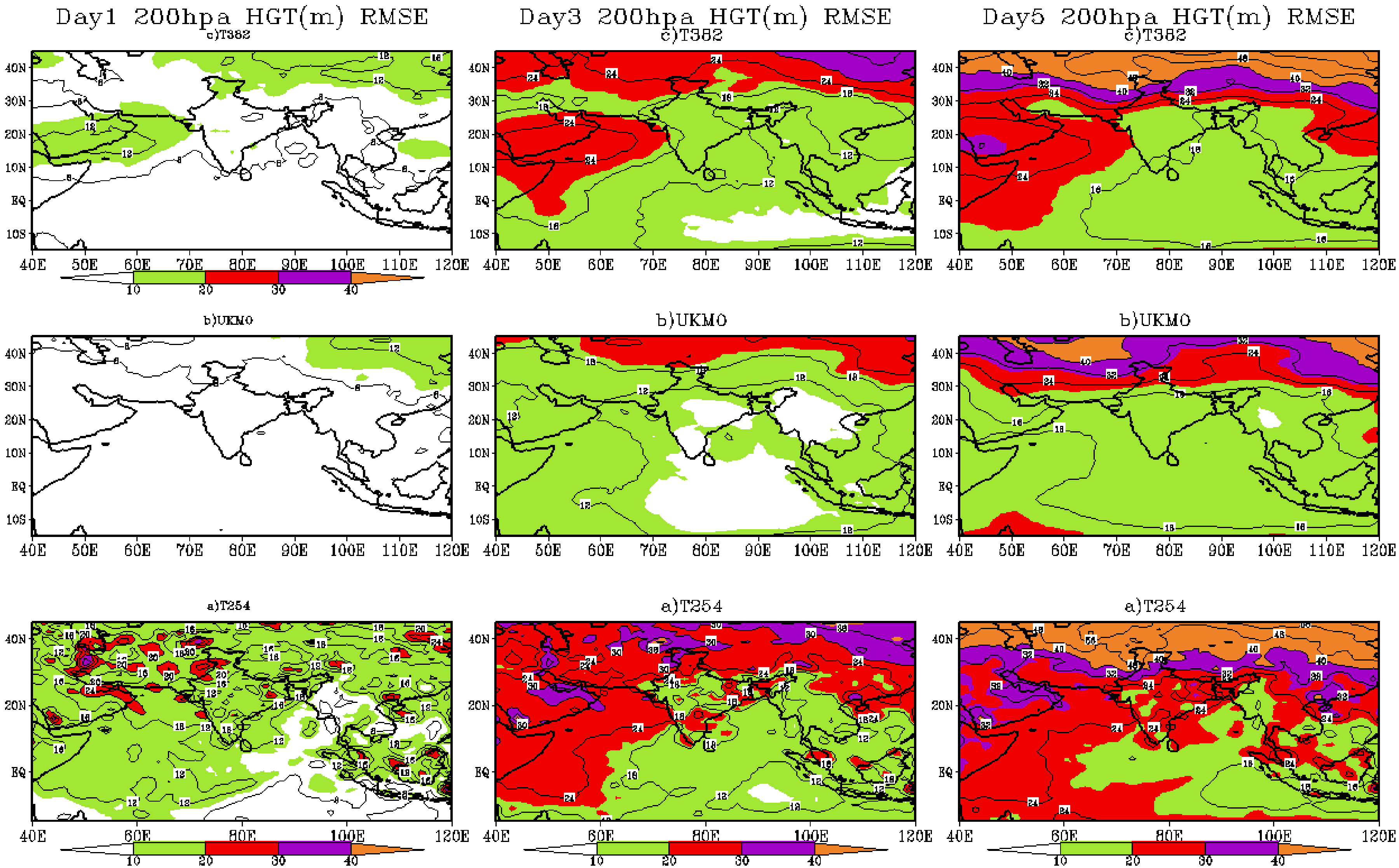


Figure 24. RMSE of 200hPa geopotential height for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

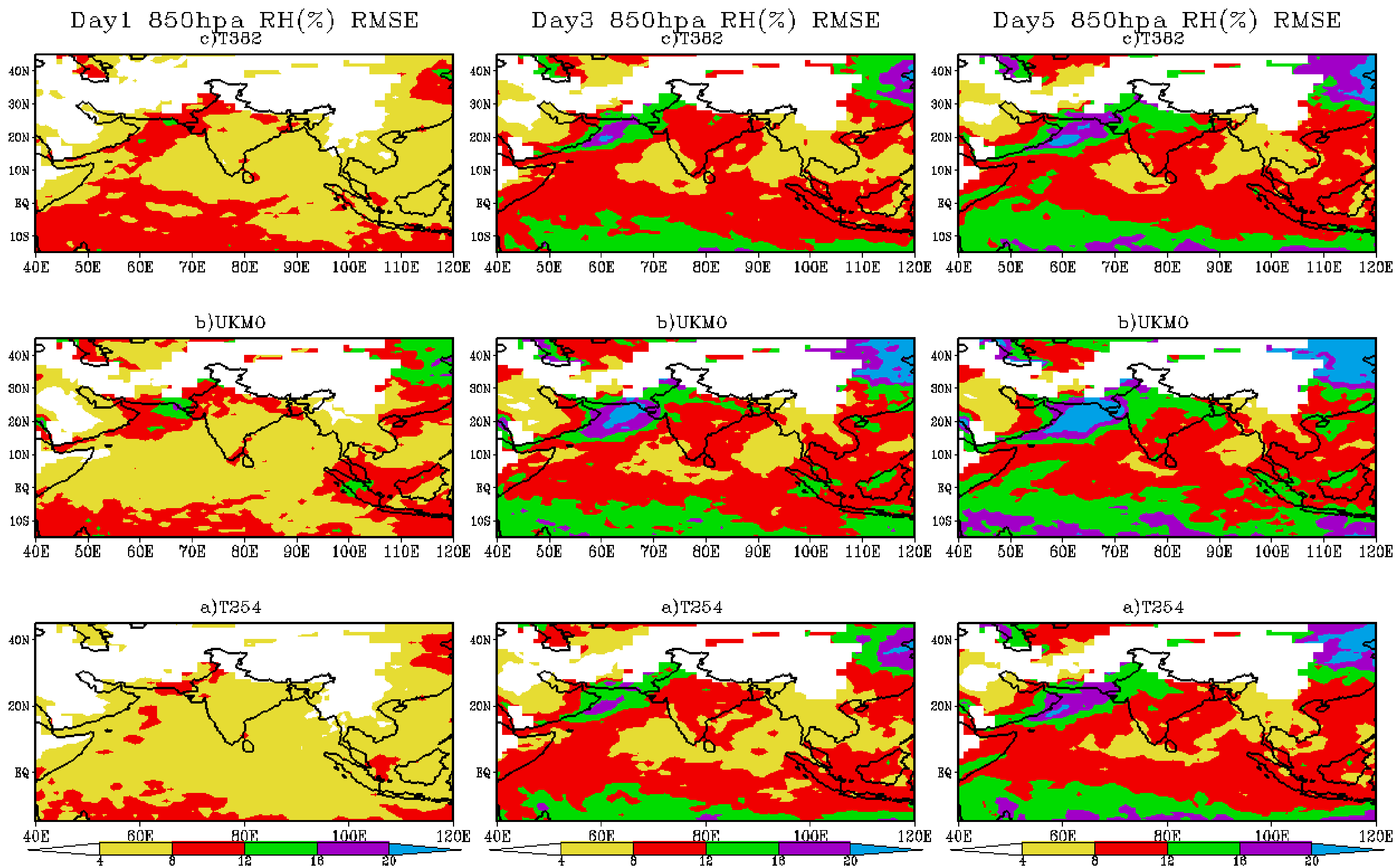


Figure 25. RMSE of 850hPa relative humidity for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

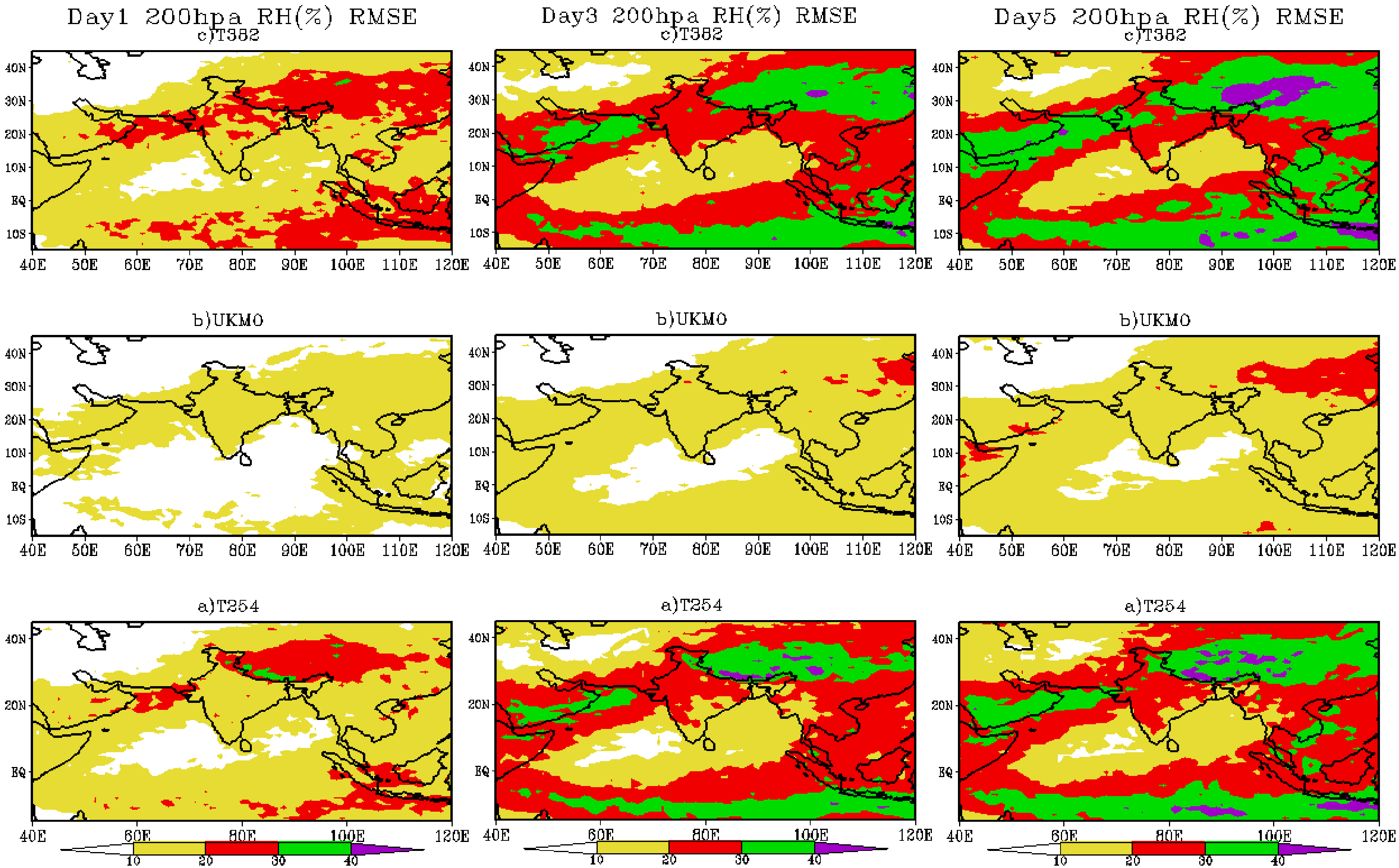


Figure 26. RMSE of 200hPa relative humidity for Day-1, Day-3 and day-5 forecasts of the T382, UKMO and T254 models.

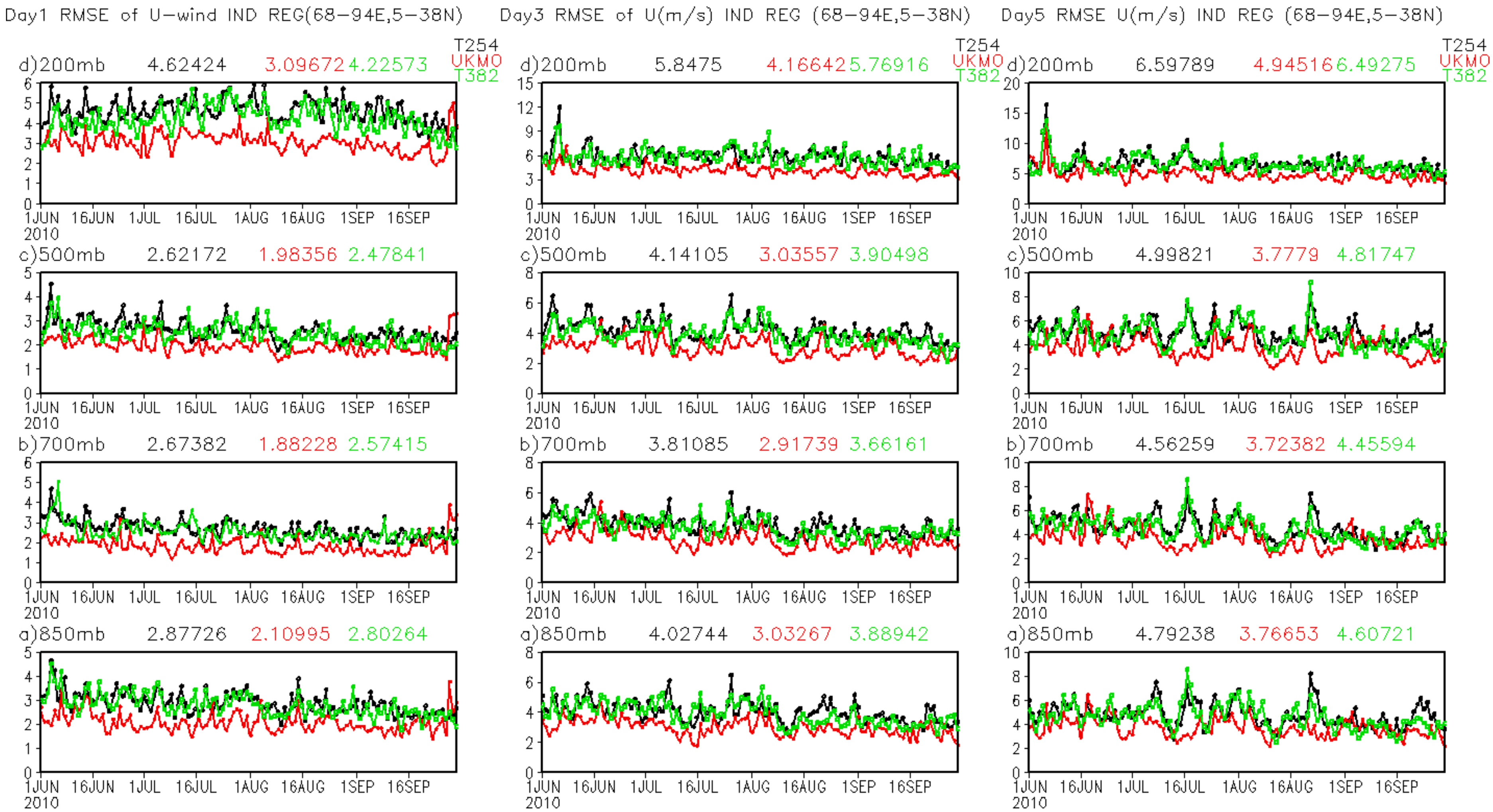


Figure 27. Time series of RMSE of zonal wind at 850, 700, 500, and 200Pa levels for Day-1, Day-3 and Day-5 forecasts of T382, UKMO and T254 models.

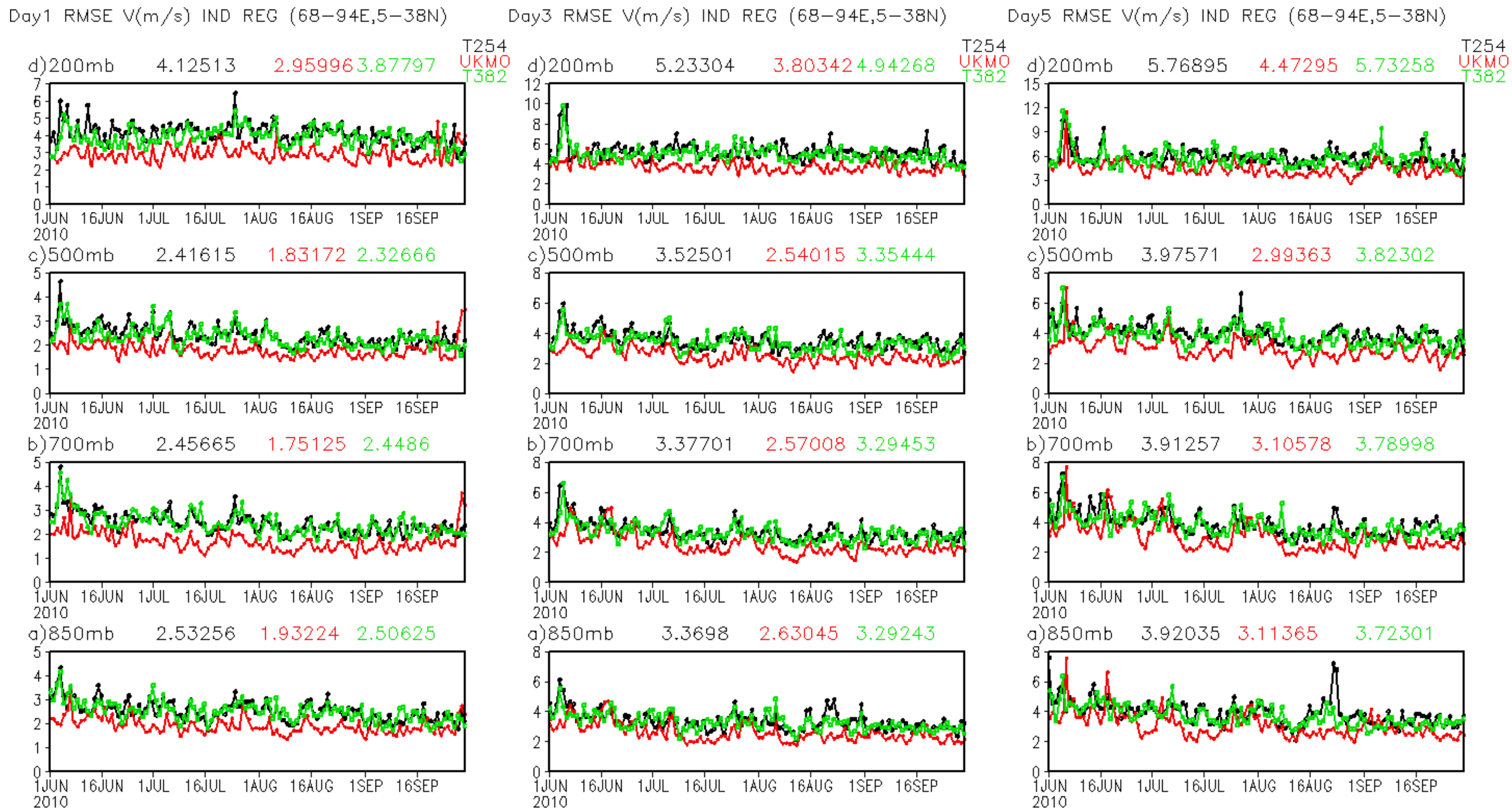


Figure 28. Time series of RMSE of meridional wind at 850, 700, 500, and 200Pa levels for Day-1, Day-3 and Day-5 forecasts of T382, UKMO and T254 models.

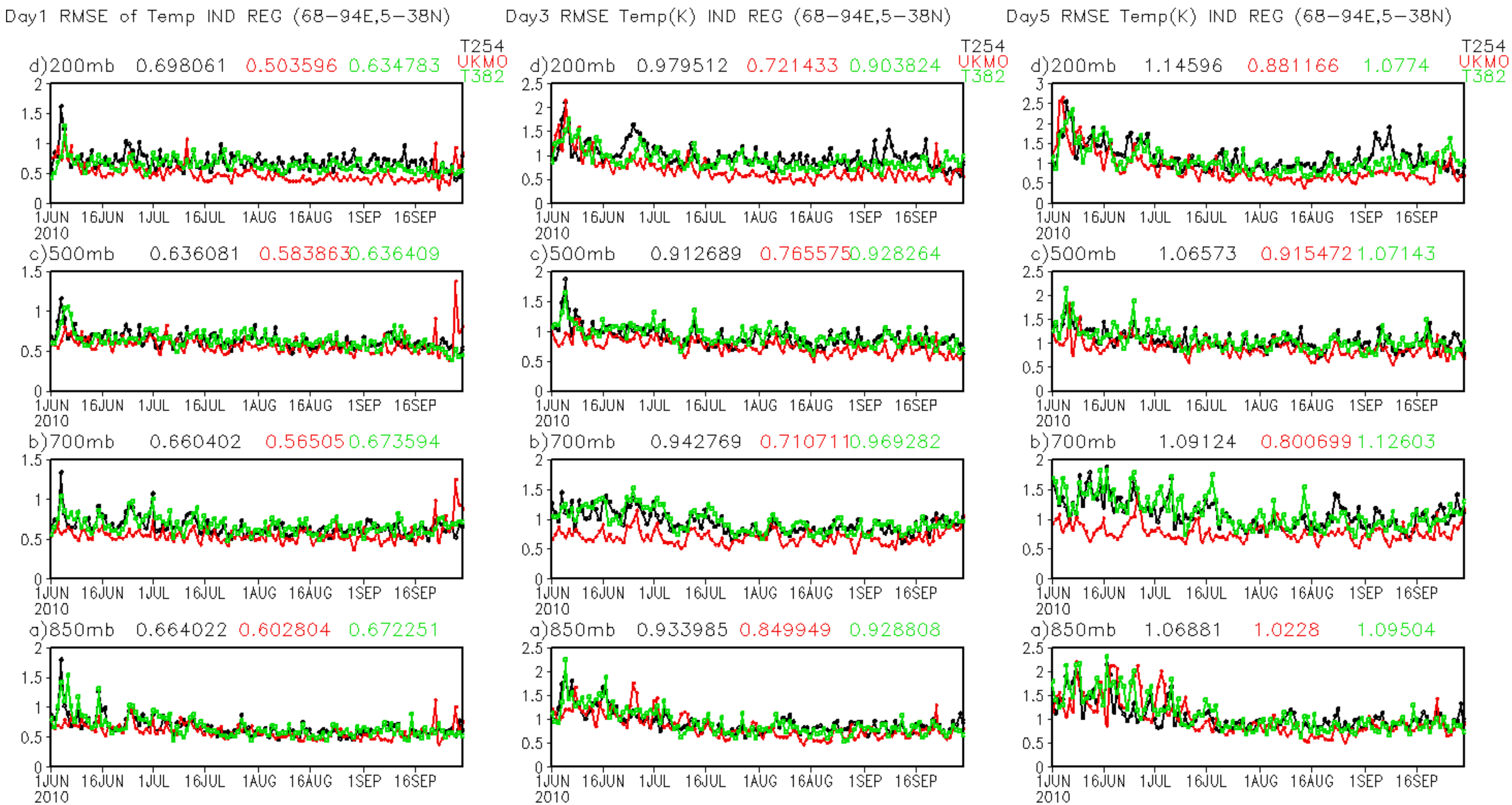


Figure 29. Time series of RMSE of temperature at 850, 700, 500, and 200Pa levels for Day-1, Day-3 and Day-5 forecasts of T382, UKMO and T254 models.

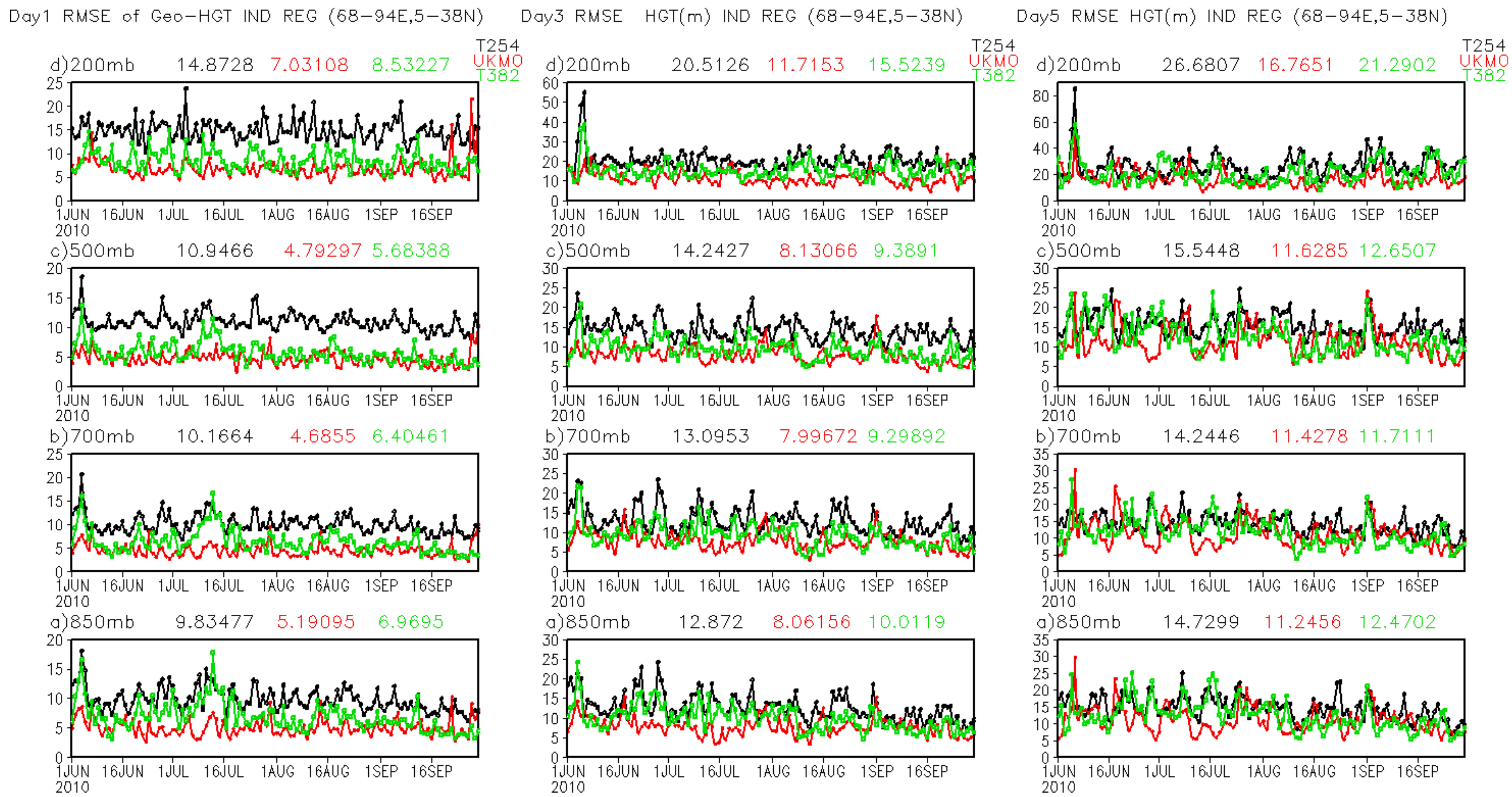


Figure 30. Time series of RMSE of geopotential height at 850, 700, 500, and 200Pa levels for Day-1, Day-3 and Day-5 forecasts of T382, UKMO and T254 models.

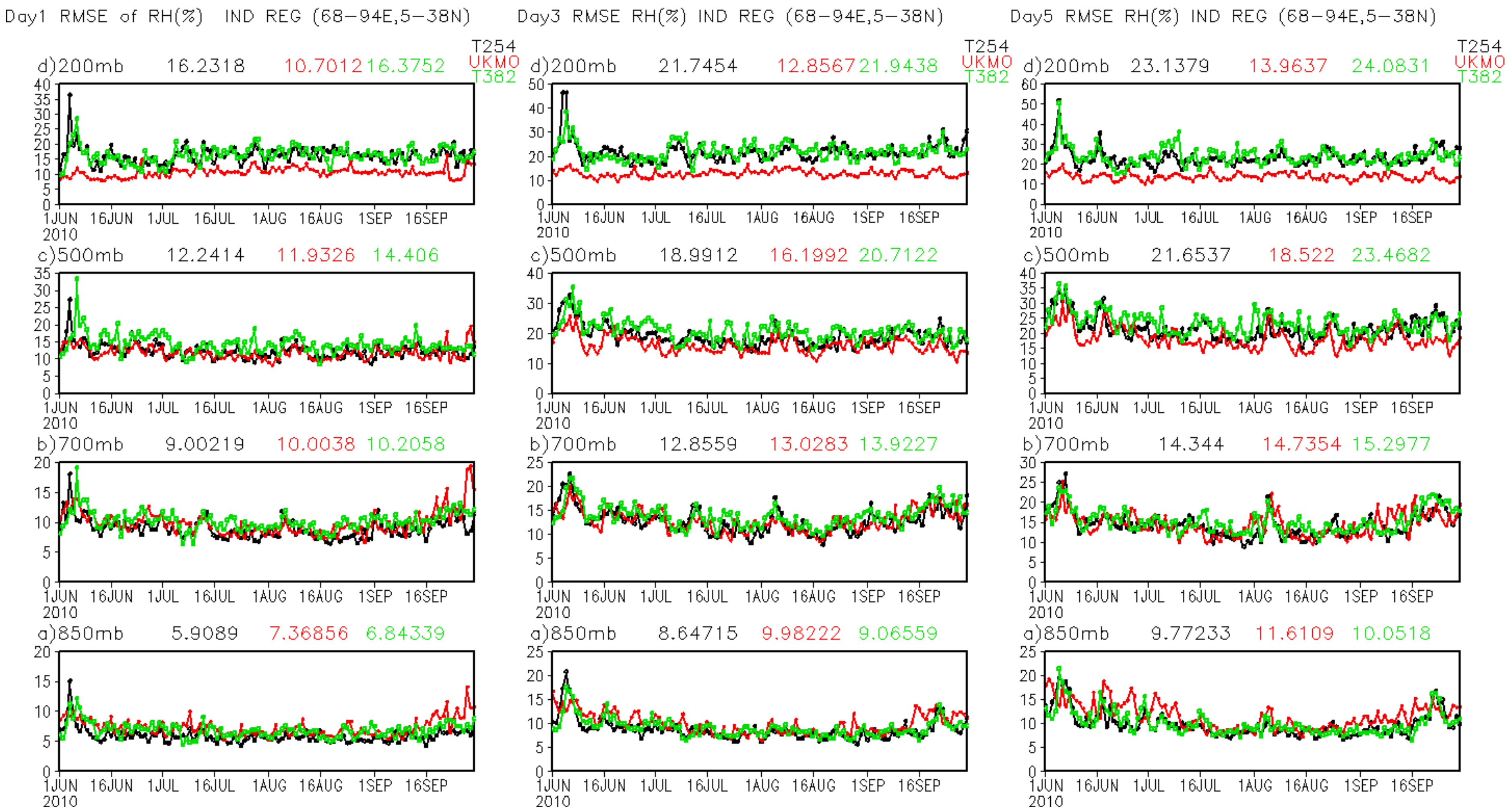


Figure 31. Time series of RMSE of relative humidity at 850, 700, 500, and 200Pa levels for Day-1, Day-3 and Day-5 forecasts of T382, UKMO and T254 models.

Global Model Forecast Verification during Indian Summer Monsoon 2010: Verification against Observations

1. Verification against radio-sonde observations over India

Objective verification scores for the NCMRWF T382 and UKMO forecasts of winds and temperature against the observations valid for 00UTC at standard pressure levels (850 and 250 hPa levels) as recommended by the WMO were computed for the Indian region for the monsoon season of 2010. Table 2 gives the average RMSE values corresponding for the season as a whole. UKMO forecasts feature relatively smaller RMSE for winds at both 850 and 250 hPa levels. However RMSE for temperature are comparable in both the model forecasts at 850 hPa, whereas the T382 model has relatively smaller RMSE at 250 hPa level.

2. Verification against observations at different GPS sonde stations over India

A number of changes occur in the circulation of the atmosphere along with the onset of south-west monsoon over the Indian subcontinent. A complete reversal of wind takes place at many places over India. Temperature pattern also exhibits a drastic change with occurrence of rainfall. Though the large scale features of monsoon are captured well by numerical modelling systems, the accurate prediction of these parameters, at any location has remained a challenging task. In this section an attempt has been made to verify wind and temperature as analysed and predicted by UKMO and NCMRWF T382L64 global model against upper-air observations (GPS-sonde) at various Indian stations during monsoon season of 2010.

Since March 2009, India Meteorological Department has upgraded its 11 radio-sonde stations by GPS-sonde, resulting in improved quality of upper-air observations over India. The locations of these stations are depicted in figure 32.

An attempt has been made to verify the analysed and predicted temperature and wind of both the models against respective observations at these 11 stations. It is worthy to mention here that, during this period there are large data gaps at many stations except Delhi. Figures 33 and 34 depict the daily variations in analyses (0000 UTC) and subsequent predictions (day-1,3,5) of zonal wind (u) at 850 and 200 hPa level respectively, along with observations at Delhi. The count in each figure indicates the total number of days on which observation is available out of the 122 days of monsoon season. For this verification, observations are taken from NCMRWF operational archives. The root mean square error (RMSE) of analyses and predictions computed against observations are also shown in the plot.

As seen from the plot, though the RMSE of analysis of NCMRWF system is lesser than that of UKMO system the RMSE of predictions of NCMRWF model are higher than that of UKMO model over Delhi. During 2010 JJAS, there are two episodes of strong easterly over Delhi at 850 hPa, one on 4th July and other on 27th July, both of which are well captured in UKMO and NCMRWF analyses. Though both the models more or less predicted the change over of wind regime from westerly to easterly, the predictions of UKMO model for these episodes are better than that of NCMRWF model. However UKMO model has shown easterly bias over Delhi in contrast to westerly bias seen in NCMRWF model, especially in 120hr. predictions.

In the upper level, zonal wind variation over Delhi is related to the position and movement of subtropical anticyclone. The observed variation of 200 hPa zonal wind at Delhi is well captured by both UKMO and NCMWRF analyses and predictions. Both the models have shown westerly bias in the upper level.

Figure 35 depicts the daily variations in analyses (0000 UTC) and subsequent predictions (day-1,3,5) of temperature (t) at 925 hPa level. In 2010, the progress of south-west monsoon over Delhi, and neighboring region took place on 5th July, and there after this region received a good amount of rainfall throughout the season resulting in a seasonal rainfall 21% above the long period average (LPA) rainfall over this region. As seen from the plot, the observed temperature of Delhi at 925 hpa level also shows a slight fall on 3rd July onwards and after that it remains moderate throughout the season. This sudden fall of temperature associated with progress of monsoon was well captured by UKMO model, but apart from 24hr. prediction, NCMRWF model could not predict the same. UKMO model has shown cold bias in contrast to warm bias in NCMRWF model.

Seasonal RMSE and bias (Analysis/prediction - observation) of temperature (t) and zonal(u) component of wind for both UKMO and NCMRWF T382L64 model analyses and 24hr., 72hr. , 120hr. predictions are shown in Table 3 and 4 respectively.

In general it is seen that, though RMSEs of NCMRWF analyses are lower compared to that of UKMO, as the forecast progresses, prediction from NCMRWF model deteriorates very rapidly and in many cases Day-5 RMSE of NCMWRF is equal to that of Day-3 of UKMO model. Both the models have shown large RMSE for temperature and zonal wind at Visakhapatnam at all levels, which may be associated with poor prediction of the track of cyclonic circulations (monsoon low) over this region. Since observations of Minicoy were very few during this period, the statistics for the same are not shown in the table.

UKMO global analyses and model predictions (up to 5 days) for zonal wind and temperature at different levels of atmosphere for 0000 UTC 1st June – 30th September 2010 have been verified against all available radio-sonde observations. UKMO forecasts feature relatively smaller RMSE for winds at both 850 and 250 hPa levels. However RMSE for temperature are comparable in both the model forecasts at 850 hPa, whereas the T382 model has relatively smaller RMSE at 250 hPa level. The verification against the 11 GPS-sonde observations over Indian region is also carried out. The scores computed also have been compared with that from NCMRWF (T382L64) analysis-forecast system. Results of this verification study are summarised as follows:

(i) Transition observed in different meteorological parameters with onset of monsoon are captured well in daily variation of UKMO analysed and predicted fields.

(ii) RMSE of UKMO analyses are larger compared to that of NCMRWF analyses, especially in the lower levels.

(iii) However the prediction errors in NCMRWF system are larger than that of UKMO system.

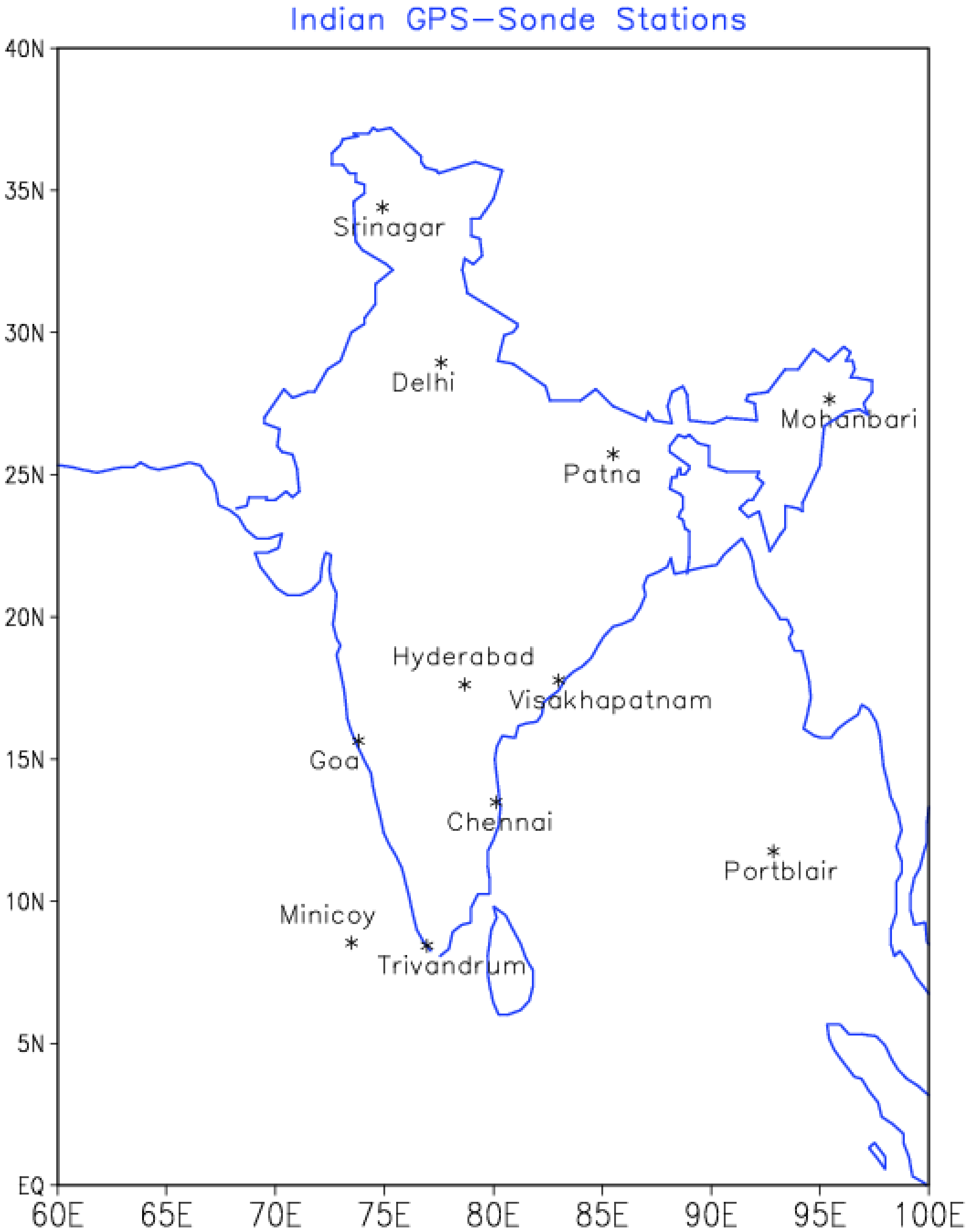


Figure 32 Location of 11 upgraded Indian upper-air sonde stations

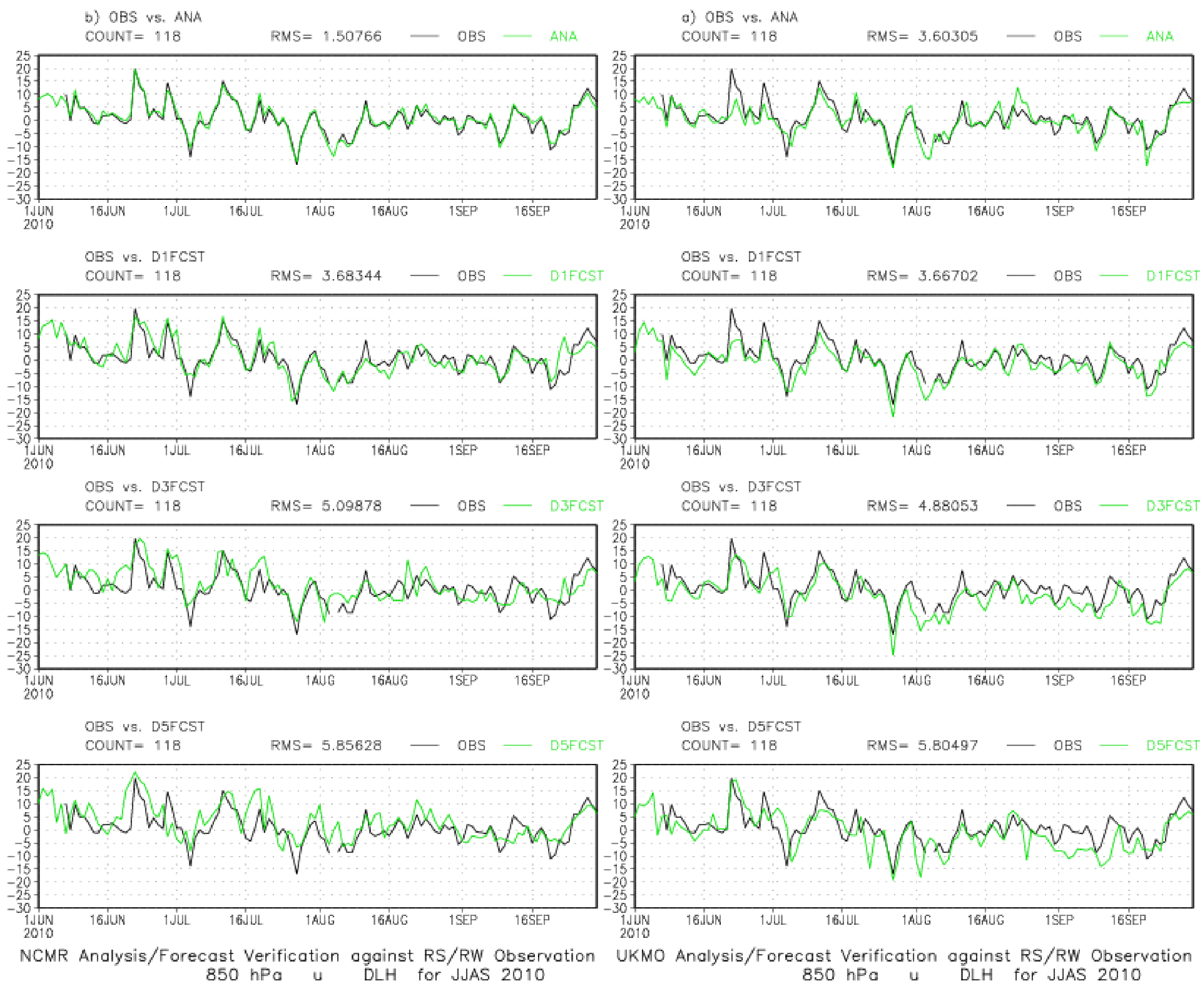


Figure 33. Daily variation of observed & analysed/predicted zonal wind (u) at Delhi at 850 hPa level for 0000UTC 1st June-30th September 2010 (a) UKMO (b) NCMRWF T382L64

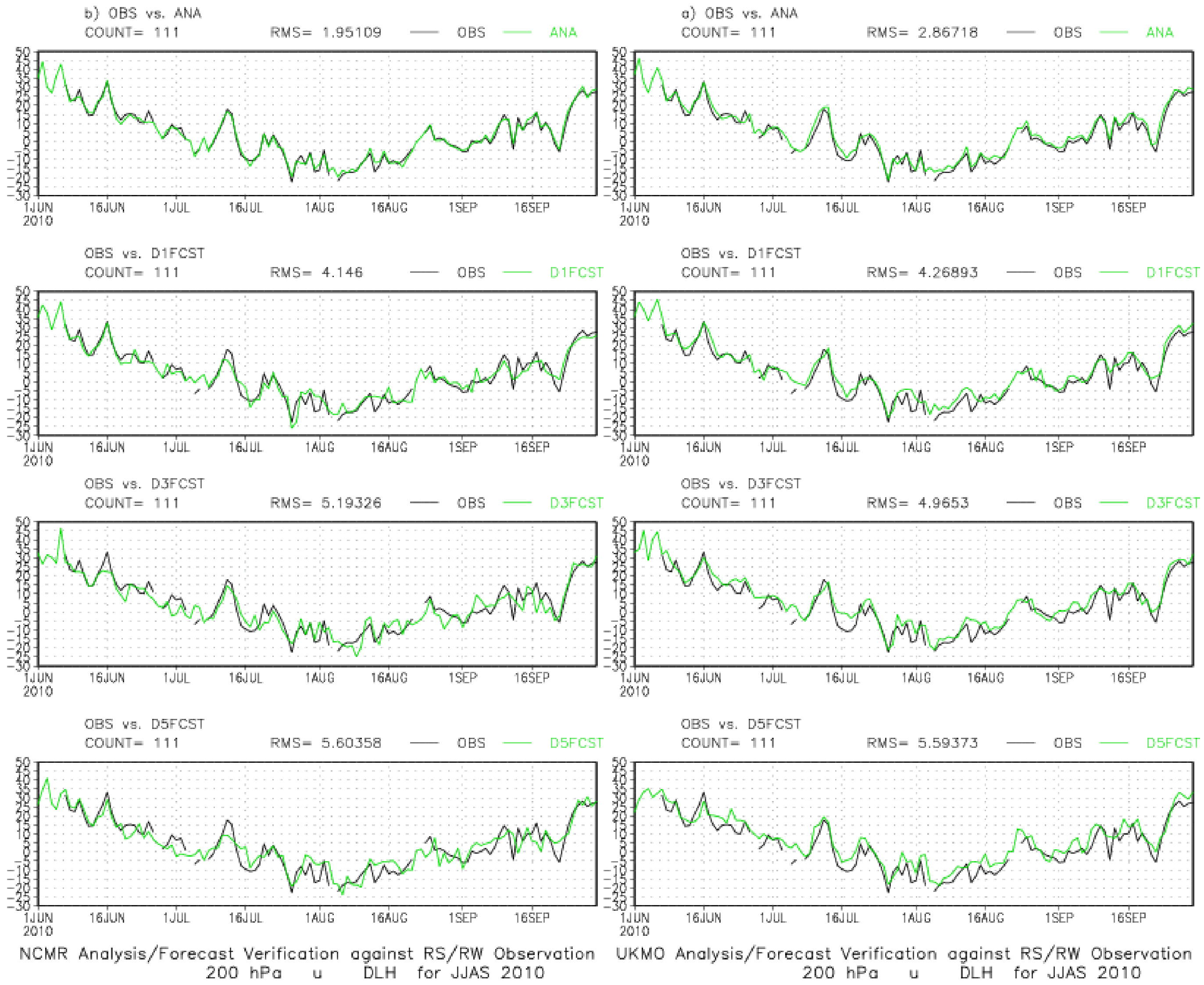


Figure 34. Daily variation of observed & analysed/predicted zonal wind (u) at Delhi at 200 hPa level for 0000UTC 1st June-30th September 2010
(a) UKMO (b) NCMRWF T382L64

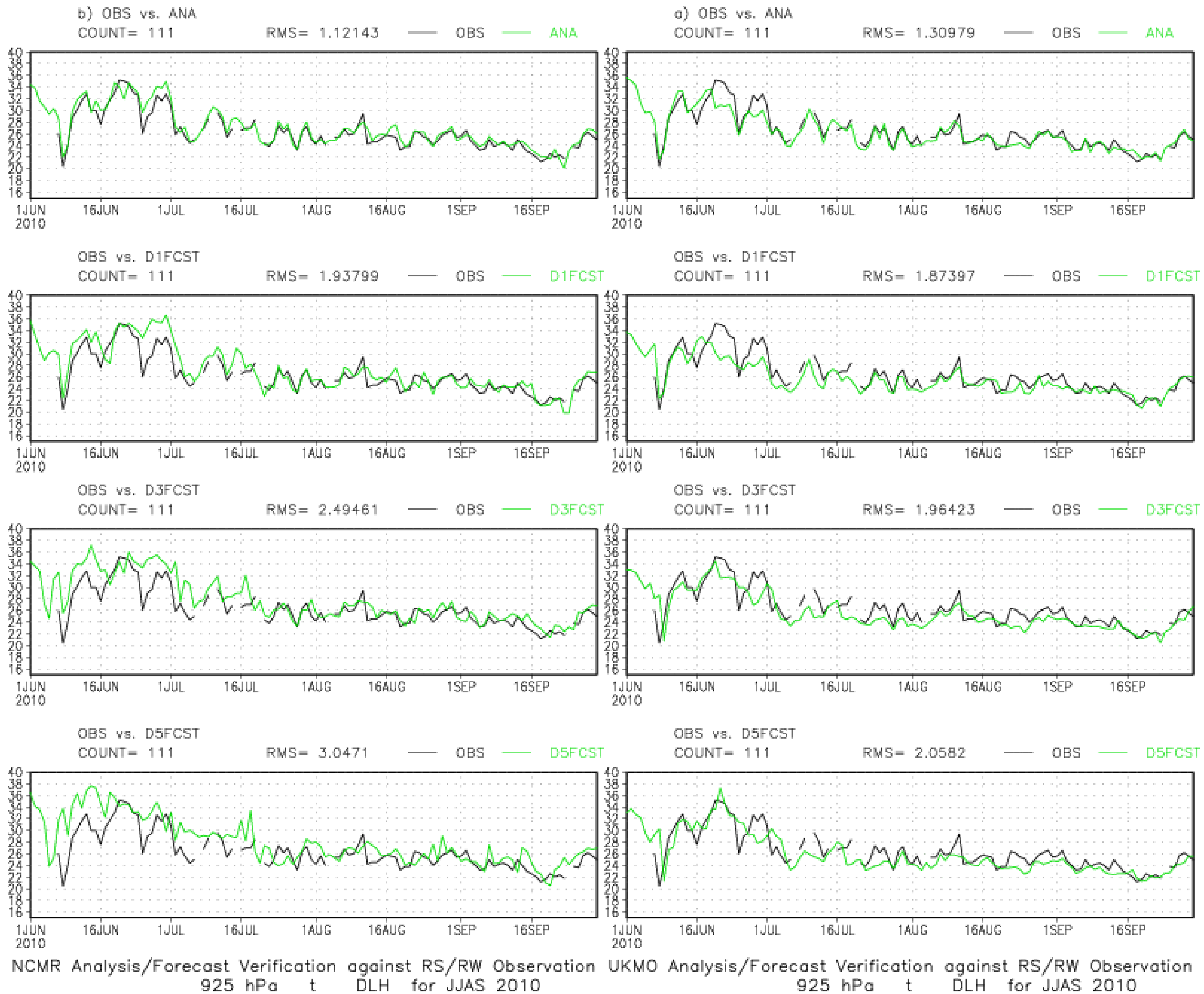


Figure 35. Daily variation of observed & analysed/predicted zonal temperature (K) at Delhi at 925 hPa level for 0000UTC 1st June-30th September 2010
(a) UKMO (b) NCMRWF T382L64

Table 2: RMSE of the UKMO and NCMRWF forecasts computed against Indian upper air radio-sonde observations, for 0000 UTC Wind (m/s) and Temperature (K) at 850, and 200 hPa levels for JJAS 2010

UKMO	**Day1**		**Day3**		**Day5**	
	850hPa	**250hPa**	**850hPa**	**250hPa**	**850hPa**	**250hPa**
Wind(m/s)	4.76	5.77	5.44	6.12	6.19	6.58
Temp(^{0}K)	1.89	3.32	1.95	3.30	2.03	3.31
T382	**Day1**		**Day3**		**Day5**	
	850hPa	**250hPa**	**850hPa**	**250hPa**	**850hPa**	**250hPa**
Wind(m/s)	5.11	6.06	5.88	6.69	6.51	7.22
Temp(^{0}K)	1.92	3.14	1.97	3.10	2.00	3.10

Table 3: RMSE and Bias computed against Indian GPS–sonde observations, averaged for 0000 UTC Temperature (K) analyses and predictions at 850, 500 and 200 hPa levels for JJAS 2010

Station	Level (obs count)	Analysis		D1 (24hr) FCST		D3 (72hr) FCST		D5(120hr) FCST	
		UKMO	NCMR	UKMO	NCMR	UKMO	NCMR	UKMO	NCMR
Srinagar	500	1.48	1.5	1.8	1.7	2.03	1.95	2.23	2.03
	(68)	0.15	0.02	0.22	0.12	0.67	0.71	0.55	0.67
	200	0.76	0.91	1.23	1.28	1.12	1.51	1.41	1.83
	(66)	0.53	0.36	0.61	0.12	0.56	-0.10	0.55	-0.36
Delhi	850	0.86	0.91	1.20	1.80	1.53	2.25	1.74-	2.73
	(114)	-0.22	0.46	-0.53	0.79	-0.55	1.15	0.23	1.46
	500	0.83	0.66	1.09	1.19	1.17	1.30	1.23	1.44
	(114)	-0.01	0.03	-0.19	0.27	0.08	0.28	0.03	0.27
	200	0.74	0.56	0.79	0.76	0.87	0.87	0.94	0.88
	(110)	0.54	0.06	0.45	0.01	0.44	-0.01	0.46	0.08
Mohanbar i	850	0.73	0.73	0.96	1.04	1.01	1.12	1.06	1.15
	(81)	0.24	0.04	0.24	0.04	0.05	0.05	0.15	-0.20
	500	0.89	0.92	1.09	1.13	1.18	1.59	1.17	1.43
	(77)	0.32	0.29	0.15	-0.81	0.27	1.08	0.26	0.91
	200	0.96	1.06	1.09	1.18	1.14	1.11	1.15	1.15
	(76)	0.51	0.34	0.32	0.35	0.34	0.55	0.49	0.52
Patna	850	0.76	0.85	1.29	1.06	1.37	1.12	1.45	1.24
	(64)	-0.32	-0.40	-0.84	-0.26	-0.99	-0.14	-0.97	-0.53
	500	0.63	0.63	1.06	1.04	0.98	1.10	1.12	1.16
	(62)	0.09	-0.03	-0.23	0.35	-0.12	0.26	-0.11	0.25
	200	1.08	0.88	1.36	1.06	1.33	1.27	1.51	1.24
	(56)	0.78	0.31	0.89	0.43	0.90	0.75	1.12	0.72
Vishaka-Patnam	850	1.90	1.94	2.11	2.13	2.04	2.11	2.01	1.99
	(74)	-1.36	-1.30	-1.48	-1.47	-1.32	-1.33	-1.07	-1.23
	500	1.32	1.31	1.39	1.39	1.52	1.36	1.58	1.52
	(76)	-0.56	-0.52	-0.61	-0.37	-0.68	-0.39	-0.70	-0.27
	200	1.04	1.11	1.14	1.23	1.17	1.20	1.07	1.33
	(73)	0.41	0.45	0.39	0.62	0.18	0.48	0.05	0.53
Hyderaba d	850	0.76	0.62	1.17	0.89	1.22	0.99	1.27	1.03
	(64)	-0.36	0.02	-0.61	-0.26	-0.66	-0.37	-0.41	-0.30
	500	0.82	0.81	1.02	1.06	1.21	1.08	1.26	1.28
	(64)	-0.17	-0.03	-0.19	0.14	-0.35	0.11	-0.42	0.11
	200	0.92	0.99	1.08	1.26	1.07	1.27	1.05	1.32
	(60)	0.33	0.30	0.48	0.42	0.45	0.25	0.27	0.35
Goa	850	0.54	0.67	0.77	0.97	0.75	1.09	0.74	1.06
	(65)	0.01	-0.38	-0.11	-0.56	-0.13	-0.68	-0.17	0.62
	500	0.59	0.68	0.88	0.87	1.06	0.96	1.19	1.09
	(64)	0.02	-0.01	-0.07	0.09	-0.23	-1.17	-0.28	0.02
	200	0.86	1.27	1.08	1.52	1.02	1.22	1.01	1.27
	(64)	0.51	0.74	0.52	0.86	0.40	0.68	0.17	0.66
Chennai	850	0.65	0.78	1.03	1.13	1.17	1.25	1.13	1.28
	(70)	-0.25	-0.34	-0.11	-0.46	0.02	-0.56	0.01	-0.63
	500	0.57	0.63	0.91	0.98	1.02	1.21	1.03	1.18
	(66)	-0.02	-0.04	-0.01	-0.15	-0.31	-0.14	-0.38	0.15
	200	0.82	1.01	0.93	1.26	0.94	1.21	0.92	1.14
	(66)	0.47	0.61	0.48	0.79	0.42	0.69	0.29	0.54

Port Blair	850 (78)	1.02 0.30	1.22 -0.66	1.33 0.60	1.40 -0.74	1.34 0.55	1.51 -0.86	1.38 0.55	1.44 -0.83
	500 (75)	0.83 0.36	0.71 0.13	0.93 0.24	0.88 0.18	0.89 0.12	1.00 0.11	0.93 -0.03	0.99 0.00
	200 (69)	1.88 1.38	2.02 1.55	1.90 1.34	2.19 1.80	1.83 1.31	2.22 1.78	1.81 1.20	2.14 1.67
Trivandrum	850 (95)	0.84 0.60	0.79 -0.30	1.09 0.77	1.04 -0.47	1.11 0.68	1.08 -0.49	1.15 0.74	1.09 -0.40
	500 (95)	2.44 -0.23	2.41 -0.38	2.51 0.35	2.47 -0.32	2.58 -0.56	2.57 -0.41	2.66 -0.60	2.59 -0.51
	200 (89)	1.28 0.81	1.43 0.99	1.31 0.62	1.82 1.35	1.21 0.38	1.65 1.25	1.18 0.14	1.67 1.15

Table 4: RMSE and Bias computed against Indian GPS–sonde observations, averaged for 0000 UTC zonal wind (m/s) analyses and predictions at 850, 500 and 200 hPa levels for JJAS 2010

Station	Level (obs count)	Analysis		D1 (24hr) FCST		D3 (72hr) FCST		D5 (120hr) FCST	
		UKMO	NCMR	UKMO	NCMR	UKMO	NCMR	UKMO	NCMR
Srinagar	500	2.34	2.30	3.87	3.48	4.17	3.92	4.12	4.04
	(69)	-0.65	-0.4	0.39	0.66	0.67	1.54	0.90	1.35
	200	2.37	2.65	4.18	5.72	4.71	5.62	6.25	7.44
	(67)	-0.49	0.57	0.20	0.78	0.73	-0.04	1.06	0.69
Delhi	850	3.60	1.50	3.66	3.68	4.88	5.09	5.8	5.85
	(118)	-0.69	0.19	-2.03	0.33	-2.48	1.39	-2.14	2.13
	500	2.42	1.75	3.15	3.40	3.20	3.72	4.12	4.20
	(113)	0.63	-0.23	0.70	-1.02	0.38	-0.37	0.89	0.07
	200	2.86	1.95	4.26	4.14	4.96	5.19	5.59	5.60
	(111)	1.73	0.19	2.28	-0.02	2.79	-0.59	3.47	0.35
Mohanbari	850	3.38	2.70	4.06	4.46	4.80	4.51	4.61	5.24
	(84)	0.94	0.72	1.51	1.51	2.27	0.62	1.80	1.16
	500	2.72	1.66	3.10	3.76	4.15	4.31	4.96	5.20
	(82)	-1.12	0.00	-0.28	-1.05	0.27	-0.48	-0.94	-1.02
	200	3.79	2.65	4.13	4.71	4.13	5.52	5.70	6.67
	(76)	-1.41	0.78	-1.02	-0.42	-0.72	-0.61	-1.87	0.44
Patna	850	1.98	2.34	4.29	4.16	4.65	4.41	4.43	5.59
	(71)	-0.62	-0.53	-2.87	-1.23	-1.92	1.08	-0.80	0.64
	500	1.75	2.12	3.59	3.98	4.29	4.68	4.54	5.36
	(62)	0.67	0.20	1.35	0.72	2.33	1.45	2.42	2.38
	200	2.33	2.53	4.34	4.74	5.16	5.39	5.80	5.67
	(53)	0.39	1.00	2.58	2.01	3.23	2.15	3.61	2.20
Visakha-Patnam	850	6.02	6.27	6.82	5.77	6.92	5.85	6.81	6.63
	(81)	2.53	3.63	3.15	3.31	2.86	2.30	2.34	1.75
	500	4.40	4.42	4.81	5.61	5.12	5.71	5.26	6.21
	(76)	0.90	1.20	1.02	1.23	1.19	-0.79	1.30	-1.13
	200	4.92	4.91	5.25	5.64	5.39	5.67	6.06	6.06
	(75)	-1.16	0.62	-1.66	0.81	-1.87	0.12	-2.28	-0.66
Hyderabad	850	2.14	1.77	2.99	3.31	3.21	4.24	3.85	5.44
	(64)	-0.33	0.75	0.63	0.70	0.74	-1.27	-0.16	-2.03
	500	2.15	2.34	3.26	4.51	4.02	5.73	4.71	7.01
	(62)	0.67	0.23	0.69	0.51	0.93	-1.74	0.77	-2.06
	200	2.10	3.14	5.09	5.86	5.59	6.29	5.59	6.49
	(61)	0.14	1.24	-0.59	1.84	- 1.76	2.10	-1.38	0.88
Goa	850	1.58	1.67	2.65	3.21	2.62	3.48	3.07	4.10
	(68)	-0.02	0.35	0.61	0.37	0.21	-0.34	-0.21	-0.86
	500	2.47	2.65	3.63	4.61	4.21	5.85	4.91	7.18
	(66)	0.02	0.67	-0.43	0.74	-1.10	-1.52	-1.35	-2.64
	200	3.10	2.88	4.86	6.92	5.74	5.99	5.90	6.07
	(64)	0.41	0.66	0.67	2.35	-0.98	1.72	-1.03	0.05
Chennai	850	2.41	2.40	3.52	4.42	4.40	4.35	4.90	5.90
	(68)	-0.67	-0.70	-0.65	-1.09	-1.37	-1.10	-1.81	-1.98
	500	1.82	2.18	3.93	4.37	4.67	4.93	5.38	6.75
	(68)	0.04	-0.16	-1.23	-0.01	-1.61	-0.30	-1.62	-1.71
	200	2.02	2.60	5.07	6.35	6.31	6.56	6.47	6.42
	(65)	0.28	1.43	-0.47	2.27	-1.57	2.68	-0.76	1.81

Port Blair	850 (79)	1.60 0.02	1.80 0.47	3.32 0.78	3.78 1.42	3.65 1.34	4.92 1.78	4.13 1.93	4.78 0.90
	500 (76)	1.91 0.34	1.83 -0.15	3.38 0.52	3.84 -0.18	3.83 0.68	4.32 0.22	3.90 1.10	4.53 -1.47
	200 (77)	2.78 0.79	3.74 2.31	4.36 1.91	7.74 3.94	4.95 1.28	8.26 3.33	5.34 0.99	7.91 1.78
Trivandrum	850 (96)	2.76 0.58	2.24 0.50	4.15 1.11	3.86 0.41	4.20 0.63	3.74 0.72	4.23 0.19	4.28 0.08
	500 (89)	2.63 0.56	2.38 0.23	3.88 0.81	3.54 0.54	4.62 0.60	4.51 -0.28	4.51 -0.11	5.98 -0.39
	200 (84)	3.43 1.40	3.36 1.52	5.35 1.87	6.67 3.30	6.36 3.11	8.26 5.37	6.24 2.63	8.10 4.01

Global Model Forecast Verification during Indian Summer Monsoon 2010: Precipitation Forecasts from the Models

For India as a whole, nearly 78% of the annual rainfall is produced in the summer monsoon season. However, the rainfall in the monsoon season over the homogenous southern peninsular of India contributes about 60% of the annual mean, and a significant amount (nearly 40% of the annual) also occurs in the post monsoon season or the north-east monsoon rainy season. For annual as well as monsoon season rainfall, the two prominent high rainfall belts due to orographic effects are: (i) off the west coast of India and (ii) along north-east India and the foothills of the sub-Himalayan ranges. There is a general decrease of rainfall from east to west in central India and along the Gangetic plains. The rainfall over the arid regions of west Rajasthan, Saurashtra, and Kutch is less than one-third of its magnitude over the Gangetic west Bengal in the east. The monsoon season features intraseasonal variations in rainfall amount and distribution. These are mainly dictated by the active and weak cycles in the monsoon and the Bay of Bengal low pressure systems that move inland causing heavy rainfall over land regions.

1 Mean Monsoon Rainfall during JJAS 2010

The models with high spatial resolution are expected to resolve the mesoscale processes in the storms and impact of high resolution orography to give better rainfall prediction compared to the coarse resolution global models. In this section the performance of the three models (T382, T254 and UKMO) for medium range rainfall forecasting has been examined during monsoon (JJAS) 2010. For a detailed and quantitative rainfall forecast verification, the IMD's 0.5° daily rainfall analysis (Rajeevan and Bhate 2008, Rajeevan etal 2005) is used. This is the high resolution daily gridded rainfall data set suitable for the high resolution regional analysis. The daily rainfall data from the four models is gridded on to the observed rainfall grids over Indian land regions for the 122 days from 1st June through 30th September 2010. Table 2 shows the contingency table for categorical forecasts of a binary event and the following statistics are computed. *The statistics are computed taking into account only the rainy days i.e., days with rainfall >= 0.5 cm at each grid over land regions.*

The panels Figure 36 presents observed and forecasts of rainfall (cm/day) for JJAS obtained from the three models. The observed distribution of rainfall indicates the maximum rainfall of up to 2 cm/day along the west coast of India surrounded by rainfall in the range of 1-2 cm/day. Similar rainfall amounts in the range of 1-2 cm/day can be prominently seen over parts of North-east India, Gangetic plains and a large region covering West Bengal and Orissa. Over the west coast and parts of north-eastern India the model forecasts (all days) show mean rainfall in excess of 2 cm/day at many locations surrounded by rainfall in the range on 1-2 cm/day. The forecasts clearly overestimate the observed rainfall over these two regions. Clearly *the rainfall over the Gangetic plains is over estimated in all three models particularly in Day-5 forecasts*. During the month of June (Figure 37) the monsoon is yet to completely cover the Indian sub-continent. As seen in the observations, a large part of central and northern India is covered with very little rainfall in the model forecasts too. *Except for the Day-5 forecasts of UKMO, it can be said that the other forecasts closely match the observed nature of the advance of monsoon during June 2010*. During the month of July (Figure 38) the region is fully under the grip of monsoon and the models capture this aspect very well with rainfall all over India. However, all models overestimate (in Day-5 forecast) the observed rainfall over Gangetic plains. The T254 and T382 models underestimate the rainfall over northwest India on all days. Rainfall overestimation over Gangetic plains is seen in the month of August (Figure 39) as well as in September (Figure 40). During each of the months UKMO model forecasts underestimate the rainfall over the peninsula. The observed rainfall minima in the rain shadow region of the peninsula is exaggerated in the UKMO model forecasts.

2 Rainfall Forecast Verification

A detailed and quantitative rainfall forecast verification is presented in this section using the IMD's 0.5° daily rainfall data (Rajeevan and Bhate 2008) for the entire period of JJAS 2010. Table 5 shows the contingency table for categorical forecasts of a binary event and the following statistics are computed. The statistics are computed taking into account only the rainy days i.e., days with rainfall >= 0.5 cm at each grid point over land regions. The rainfall forecast verification is expressed in terms of three different scores discussed below.

2.1 Mean Error: The difference between the observed and forecast mean rainfall (Figure 41) is presented to bring out the areas of overestimated and underestimated rainfall over India. *Models consistently overestimate the rainfall over the Gangetic plains. Rainfall over the dry regions of NW India is under predicted in all the forecasts. Rainfall over the peninsula is under predicted and this is prominently seen in the UKMO forecasts.*

2.2 Equitable threat score (Gilbert skill score)-

$$ETS = \frac{hits - hits_{random}}{hits + misses + false\ alarms - hits_{random}}$$

where

$$hits_{random} = \frac{(hits + misses)(hits + false\ alarms)}{total}$$

This is a standard skill score that is being used by various weather services to evaluate their precipitation forecasts. It is frequently used to assess skill of rainfall forecasts above certain predefined thresholds of intensity of rain. ETS tells us how well did the forecast "yes" events correspond to the observed "yes" events (accounting for hits due to chance)? ETS ranges from -1/3 to 1, 0 indicates no skill and 1 meaning perfect score. ETS measures the fraction of observed and/or forecast events that were correctly predicted, adjusted for hits associated with random chance (for example, it is easier to correctly forecast rain occurrence in a wet climate than in a dry climate). It is most suited for verification of rainfall in NWP models because its "equitability" allows scores to be compared more fairly across different regimes. This score is sensitive to hits. Because it penalizes both misses and false alarms in the same way, it does not distinguish the source of forecast error. Figure 42 shows the ETS computed on the forecast rainfall from all models. The gray shading in the plots indicate no skill. *Large parts of peninsula shows no skill and this is true in all the forecasts. Forecasts over the central India including NW India show some skill in predicting the rainy day*. ETS computations for different rainfall threshold is shown in Figure 43. For lower thresholds (0.0, 0.1 and 0.6) the scores are high in all three models and there is not clear and consistent higher skill for any model. *For higher rainfall amounts, the scores are low and UKMO consistently shows marginally higher ETS values than the ETS of T254 and T382 models*. For higher rainfall thresholds (>9cm/day) the ETS values are very small and the number of occurrences are also very low.

2.3 False Alarm Ratio

$$FAR = \frac{false\ alarms}{hits + false\ alarms}$$

False Alarm ratio (FAR) is a measure of fraction of the predicted "yes" events that actually did not occur (i.e., were false alarms). This score ranges from 0 to 1 and a score of 0 implies perfect forecast. This score is sensitive to false alarms, but ignores misses. It is very sensitive to the climatological frequency of the event. Figure 44 shows the FAR computed for the forecast rainfall for all models. *All the models indicate higher forecast skill along the west coast, north-eastern states and along the foothills of Himalayas. All the models show very similar patterns over dry regions with higher FAR values over the northwestern region and south-eastern tip of the peninsula*.

Table 5. Contingency table for categorical forecasts of a binary event. Here *a, b, c* and *d* are the number of events observed to occur in each category.

Event Forecasts	**Event Observed** Yes	No	**Total**
Yes	*a* (hit)	*b* (false alarm)	*a + b*
No	*c* (miss)	*d* (correct rejection)	*a + d*
Total	*a + c*	*b + d*	*a + b + c + d = n*

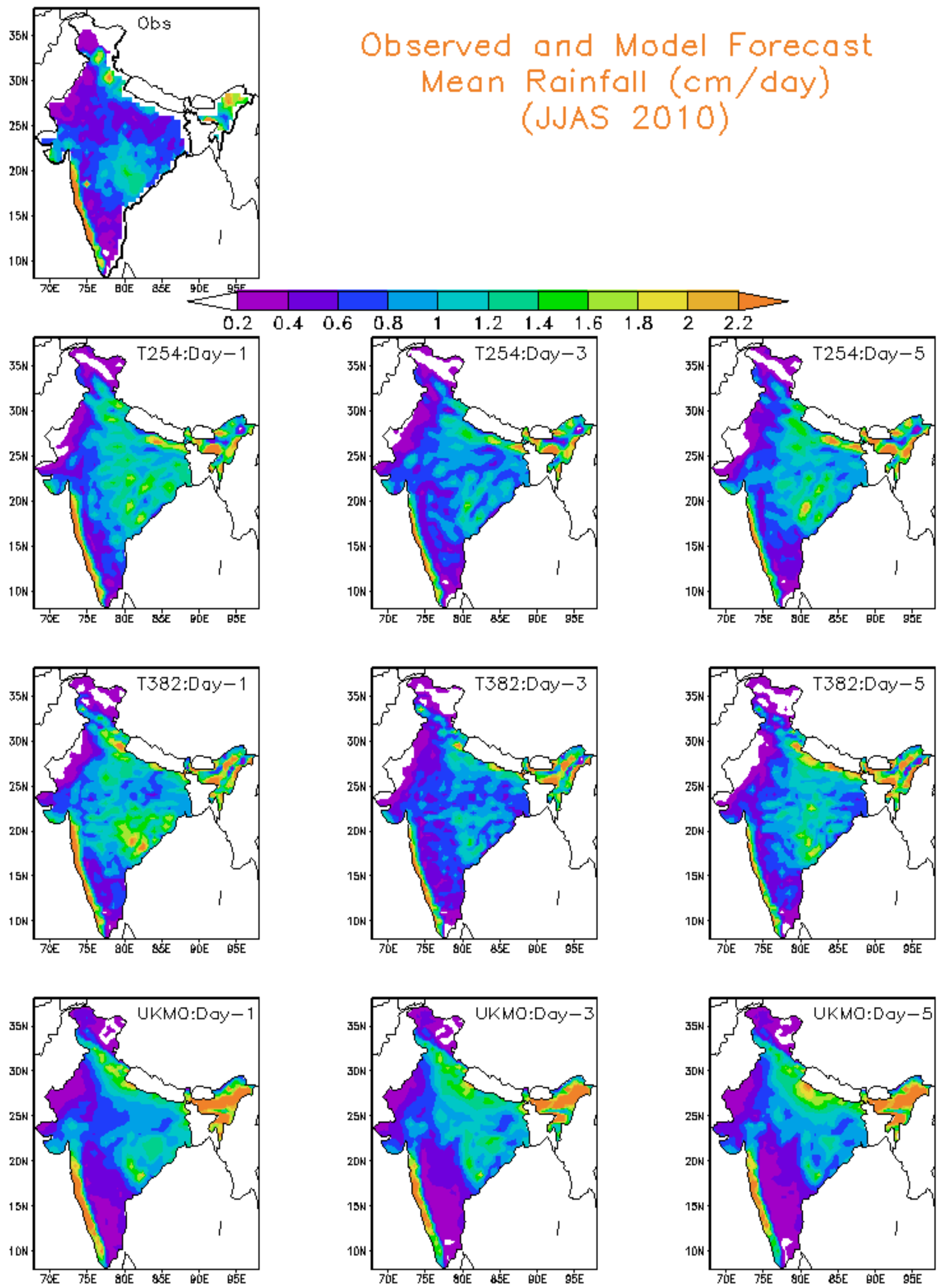


Figure 36. Observed and forecast mean rainfall during JJAS 2010.

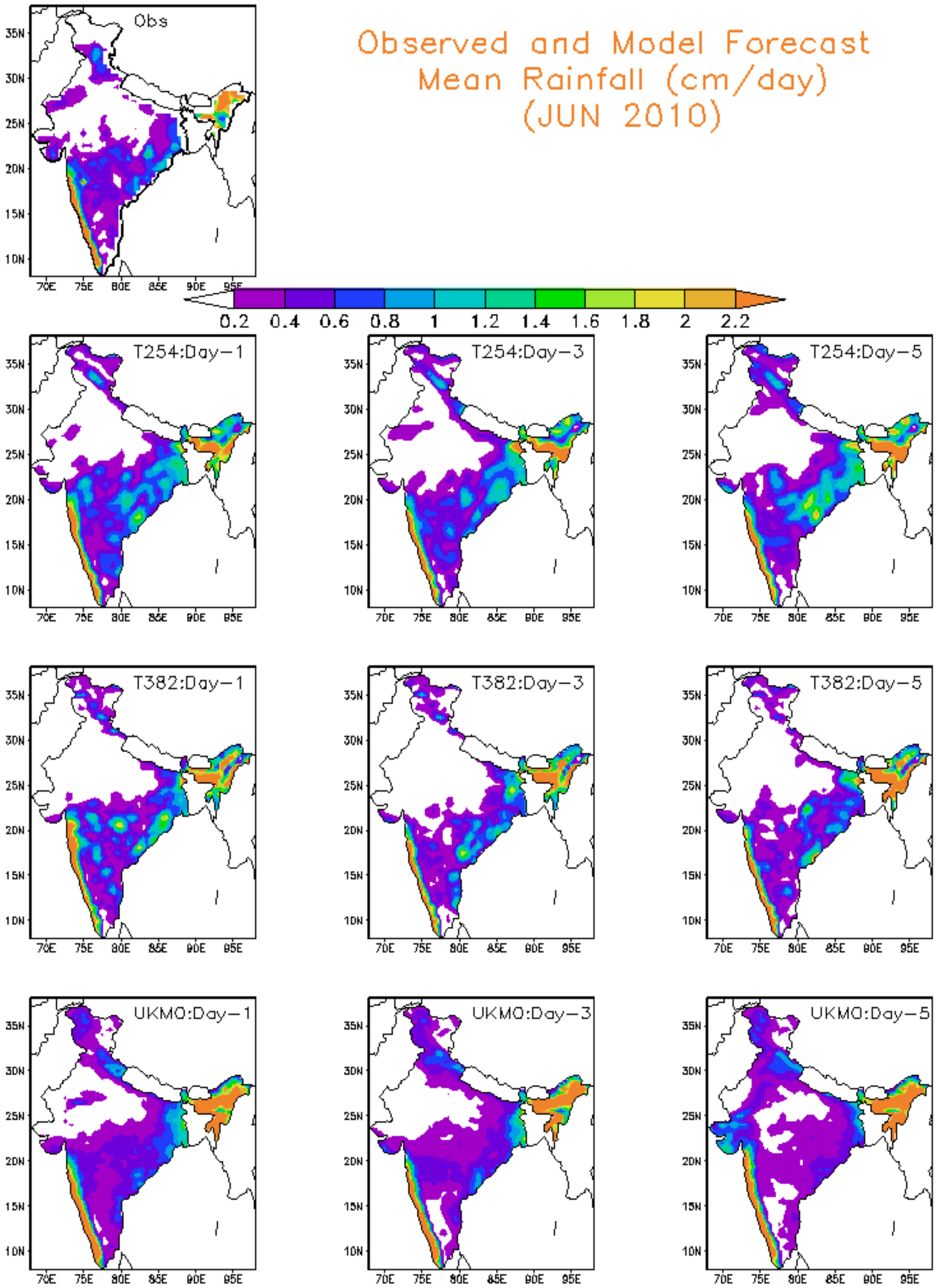


Figure 37. Observed and forecast mean rainfall during June 2010.

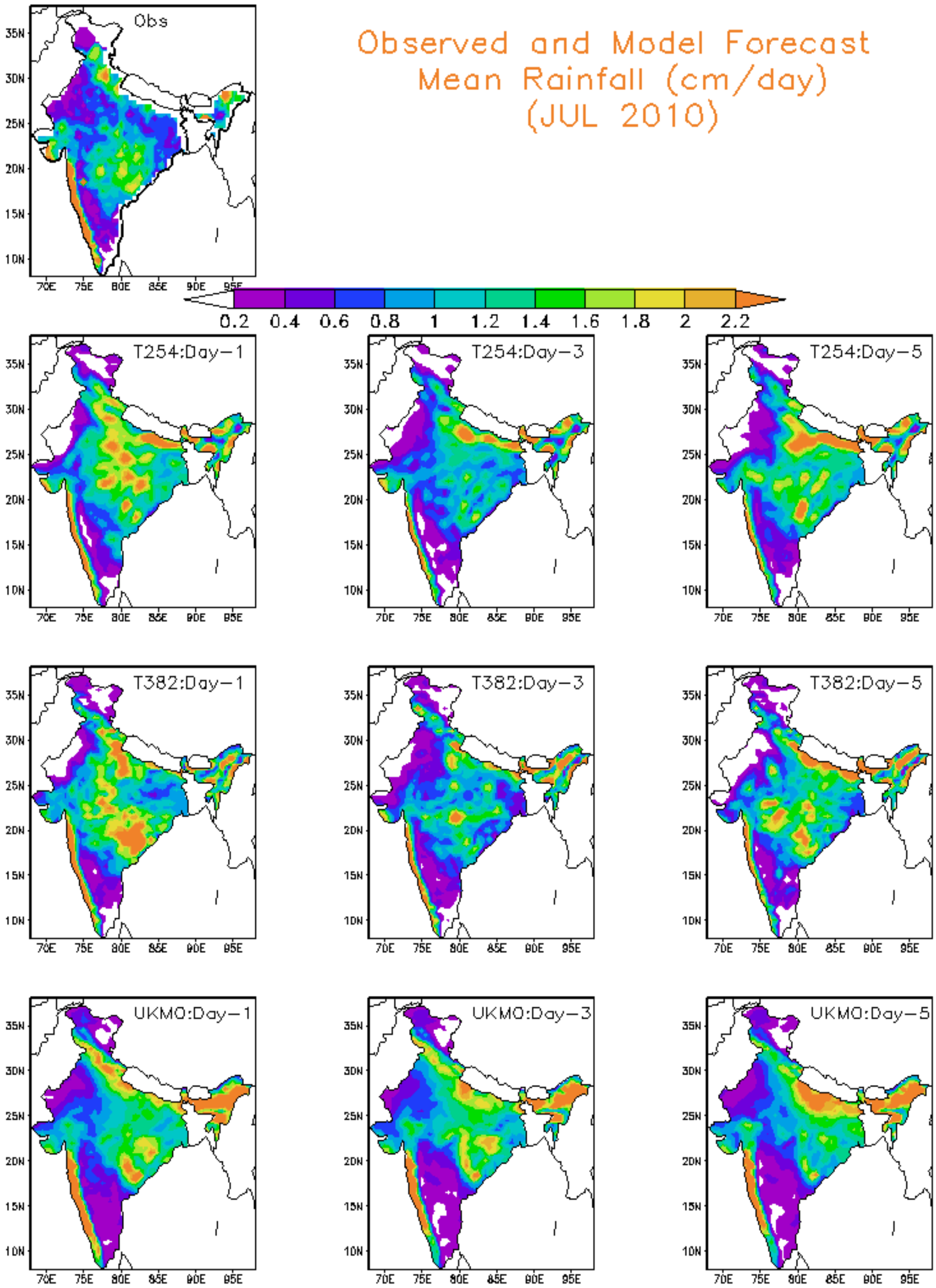


Figure 38. Observed and forecast mean rainfall during July 2010.

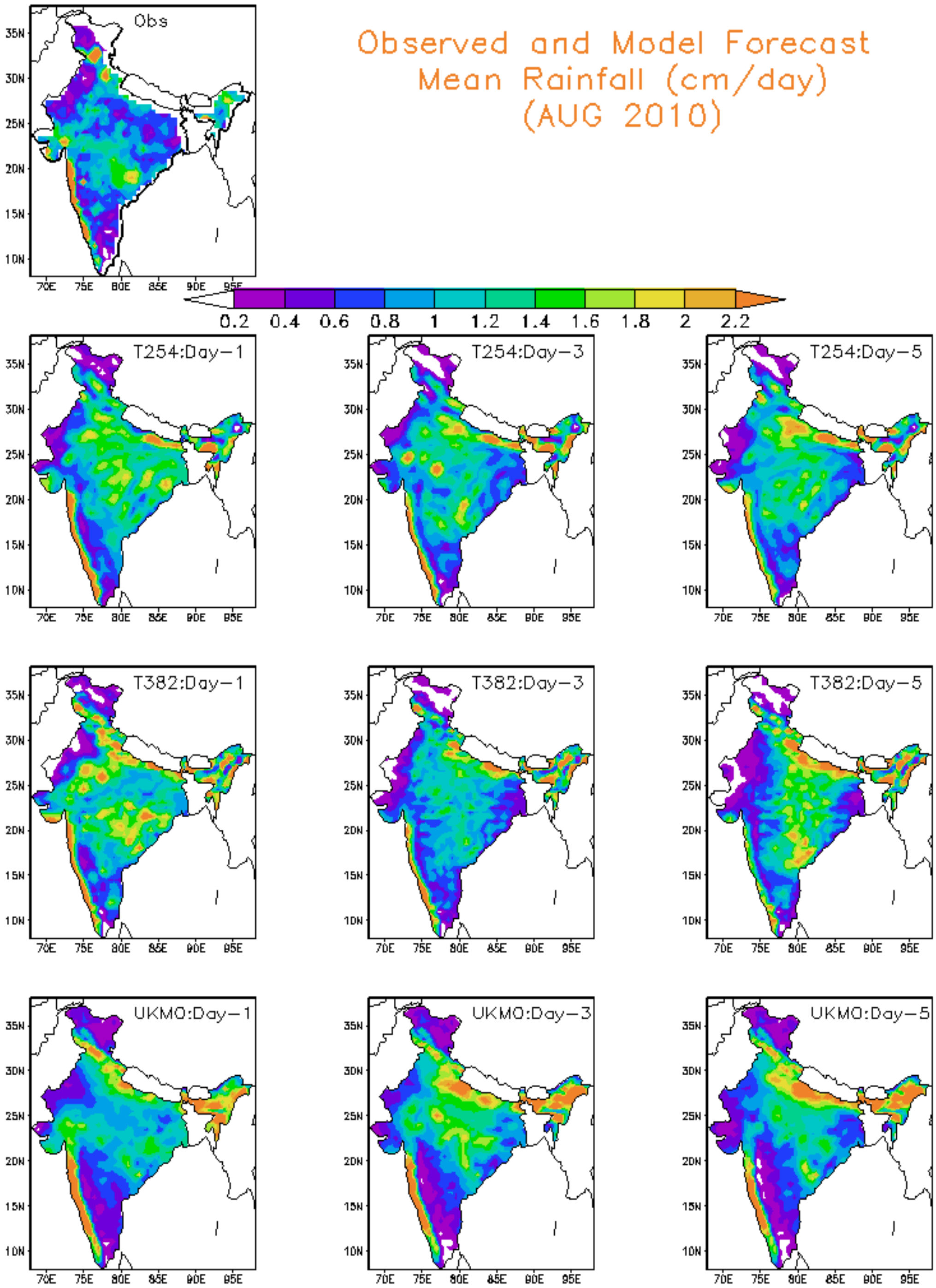


Figure 39. Observed and forecast mean rainfall during August 2010.

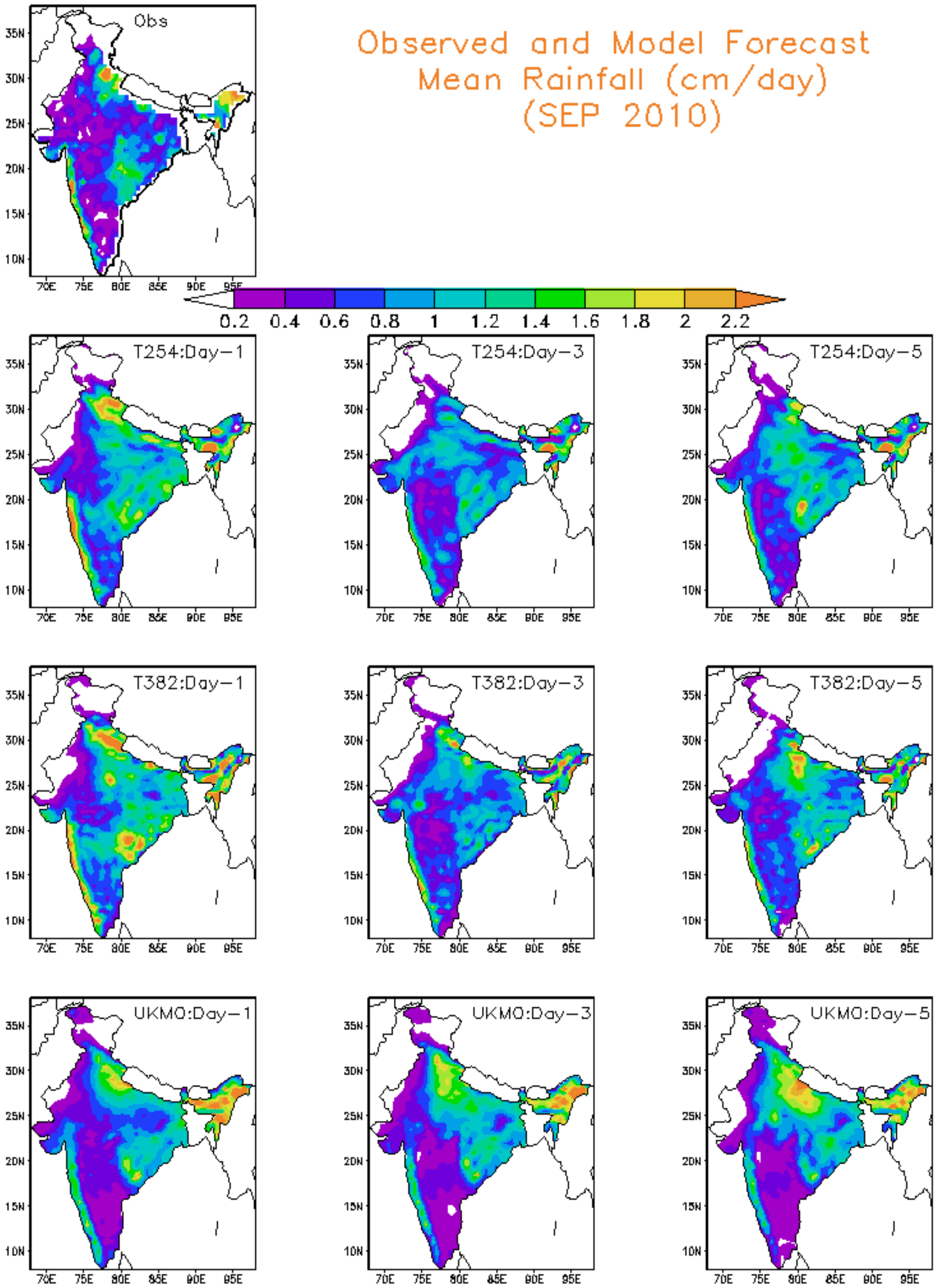


Figure 40. Observed and forecast mean rainfall during September 2010.

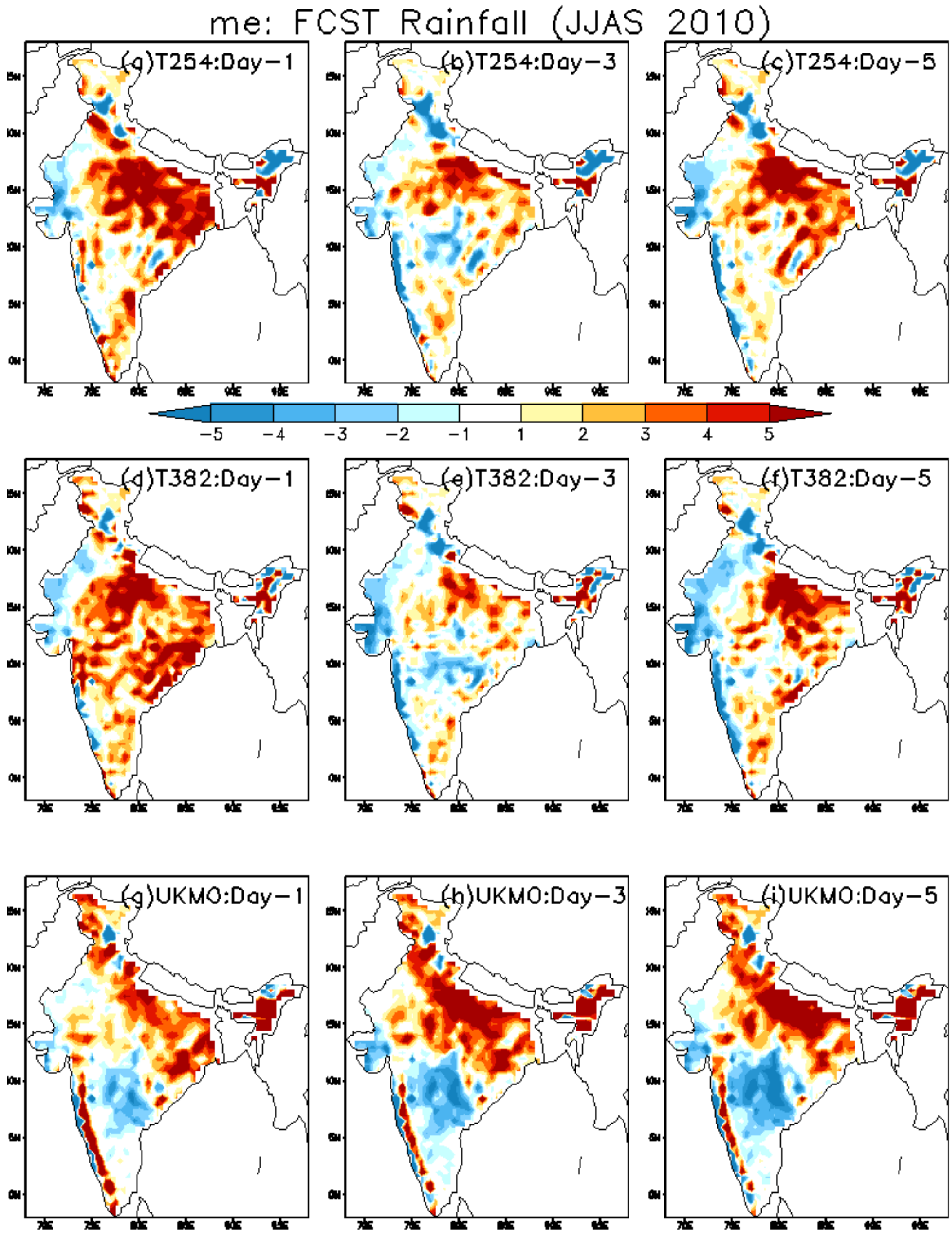


Figure 41. Mean error in the forecast rainfall during JJAS 2010.

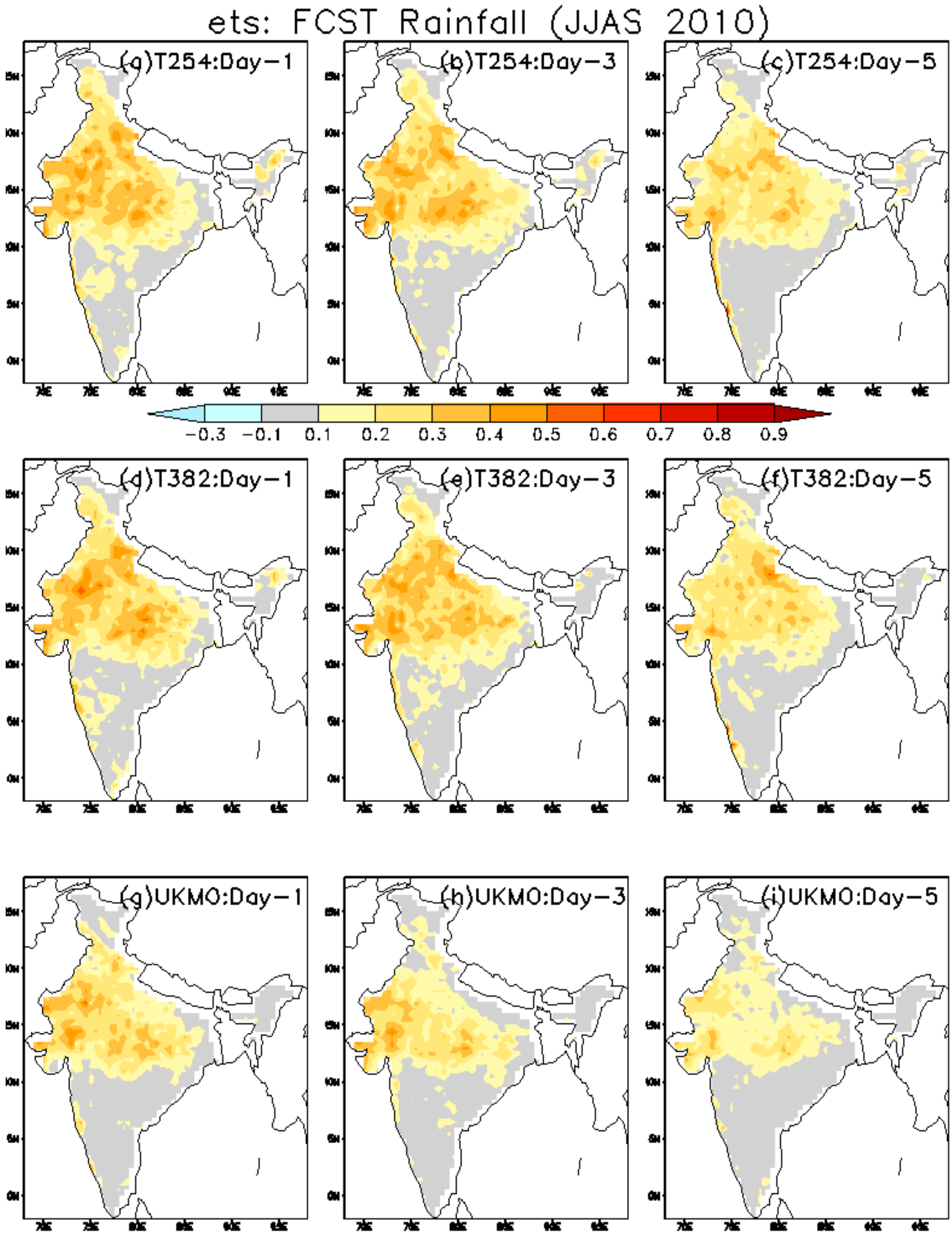


Figure 42. Equitable Threat Score for forecast of rainy day during JJAS 2010.

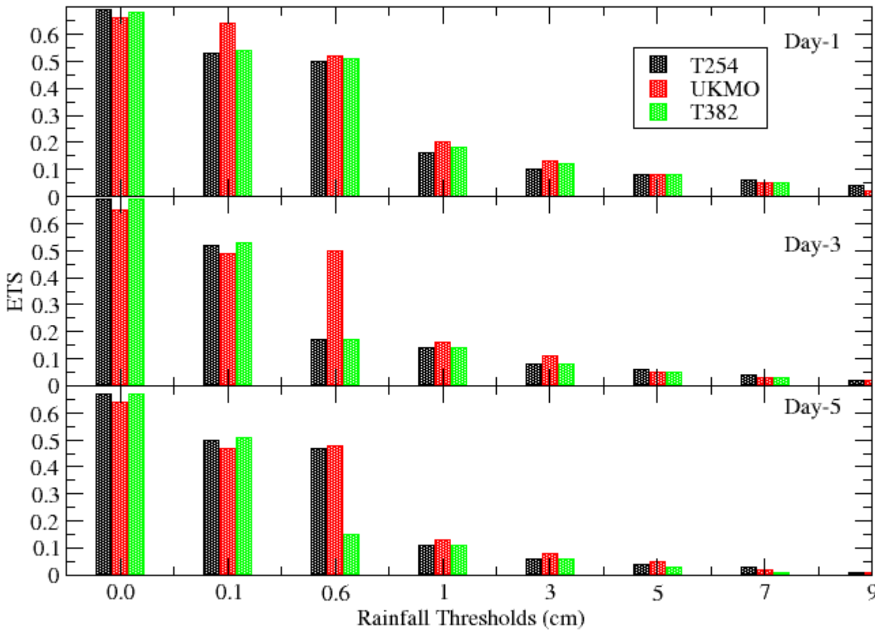


Figure 43. Equitable Threat Score for predicted rainfall exceeding different thresholds.

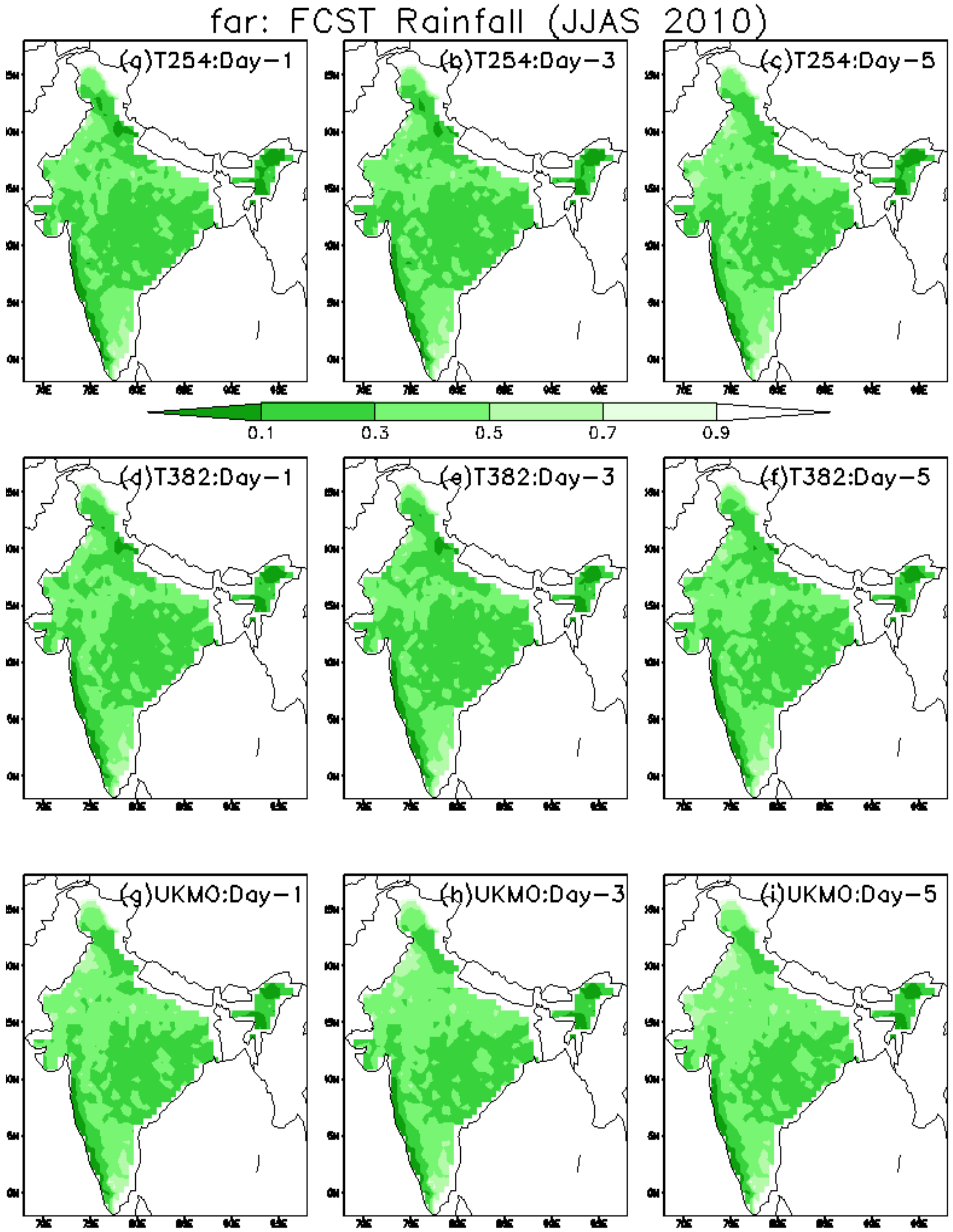


Figure 44. False Alarm ratio for forecast of rainy day during JJAS 2010

Conclusions

Forecast Mean Characteristics:

- The 850 hPa mean circulation suggests that model forecasts feature relatively deeper monsoon trough compared to the initial analysis. (all forecasts of T254 and T382 models and Day-3 and Day-5 forecasts of UKMO). The 200 hPa mean circulation suggests that the T254 model forecasts feature weaker and diffused structure of the 200 hPa ridge. The 200 hPa ridge in the UKMO analysis and forecasts is well developed and prominent during all the months.
- The forecasts show relatively higher mean (JJAS) temperatures at 850 hPa over north-west India and the Gangetic plains compared to analysis. Parts of peninsular India, Arabian Sea and Bay of Bengal feature lower temperatures in the range of 290-292 ºK in the T254 and T382 models. The UKMO model initial analysis and forecasts feature higher temperatures over the peninsula and the neighboring seas by at least 3 ºK. At 200 hPa level only UKMO forecasts seem to closely agree with the analysis (and is cooler than the T382 and T254 models). Both T382 and T254 models underestimate the warm temperatures over continent.
- The 850 hPa mean relative humidity in analysis and forecasts both indicate broad pattern of rainfall activity. However, dry conditions in June and September (mainly over central and northwestern India are prominent in T254 and T382. At 200 hPa level, it is striking to note that the UKMO analysis as well as forecasts are excessively dry over large parts of Indian ocean and India indicating UKMO model analysis and forecasts feature wetter (drier) lower (upper) troposphere compared to T254 and T382 models.
- To study the occurrence of active and weak spells of monsoon, time-longitude sections are constructed over Arabian Sea and over Peninsula. While the Day-3 and Day-5 forecasts agree with analysis, (i) the UKMO analysis show

comparatively stronger zonal winds. (ii) the wind strength is weaker during the active spell in the Day-5 forecasts.

Forecast Errors:

- The forecasts of all three models show at 850 hPa, (i) westerly bias over north Arabian Sea, Central India extending to South-east Asia. (ii) to the south of this east-west region easterly bias is found which implies northward shift of circulation in forecasts) (iii) Central and eastern equatorial Indian Ocean features strong easterly bias, particularly in the UKMO model forecasts. The Gangetic plains shows easterly bias in the UKMO and T254 forecasts.
- The T382 and T254 models show a marked increase in the RMSE (U,V) from Day-1 to Day-5 forecast as compared to UKMO, especially over the north-west and plains of India. At 850 hPa, the magnitude of RMSE in meridional component of the wind is of the order of 2-4 m/s in Day-1 forecast in all the models over the Indian and neighborhood region. All the models show a consistent increase in RMSE from Day-1 to Day-5 forecast with the magnitude of about 4-6 m/s.
- Systematic errors in the winds at 200 hPa level suggest strong westerly bias in the eastern Indian Ocean in the Day-3 and Day-5 forecasts which is prominent particularly in the T254 and T382 models. The RMSE magnitude varies from 2-4 m/s in UKMO and 2-6 m/s in Day-1 forecast of UKMO and T382/T254 models over the Indian region. T382 and T254 model show a considerable increase in RMSE from Day-1 to Day-5 forecast especially over the southern peninsula where the Tropical Easterly Jet (TEJ) is prominent.
- At 850 hPa level the T254 and T382 models show slight cold bias over the north Arabian Sea (about -0.4°K) with strong warm bias over the Pakistan region (>1.2°K). The UKMO model forecasts show strong warm bias over the north Arabian Sea (>1.4°K) and strong cold bias over the heat low region (<-1.2°K).

The magnitude of RMSE is of the order of 1-1.5 °K in Day-1 forecast over the northwest India for T254 and T382 whereas the magnitude is slightly smaller in UKMO. The T254 and T382 models show consistently higher RMSEs over the north-west parts of India as compared to the UKMO forecasts.

- At 200 hPa, all forecasts of T382 (and Day-1 and Day-3 forecasts of T254) show large area covering Bay of Bengal (Arabian Sea) having warm (cold) bias. The UKMO forecasts feature warm bias over continents and cold bias over the Indian ocean. The magnitude of RMSEs in Day-5 forecasts of all the model forecasts is about 0.5-2°K, over the Indian region, with larger errors over the northern parts.
- Forecast verification against the upper air observations (both radiosonde and GPS-sonde) clearly indicate that the UKMO forecasts feature smaller RMSE compared to the NCMRWF forecasts.

Rainfall Forecast.

- The observed distribution of rainfall indicates the maximum rainfall of up to 2 cm/day along the west coast of India surrounded by rainfall in the range of 1-2 cm/day. Similar rainfall amounts in the range of 1-2 cm/day can be prominently seen over parts of North-east India, Gangetic plains and a large region covering West Bengal and Orissa. Over the west coast and parts of north-eastern India the model forecasts (all days) show mean rainfall in excess of 2 cm/day at many locations surrounded by rainfall in the range on 1-2 cm/day. The forecasts clearly overestimate the observed rainfall over these two regions. Clearly the rainfall over the Gangetic plains is over estimated in all three models particularly in Day-5 forecasts.
- While the dry conditions of June are well captured in all forecasts of all models, the wet conditions (particularly Gangetic plains) of July, August and September are overestimated in all the forecasts.

- Over the peninsula the UKMO model forecasts underestimate the rainfall in all months. The observed rainfall minima in the rain shadow region of the peninsula is exaggerated in the UKMO model forecasts.

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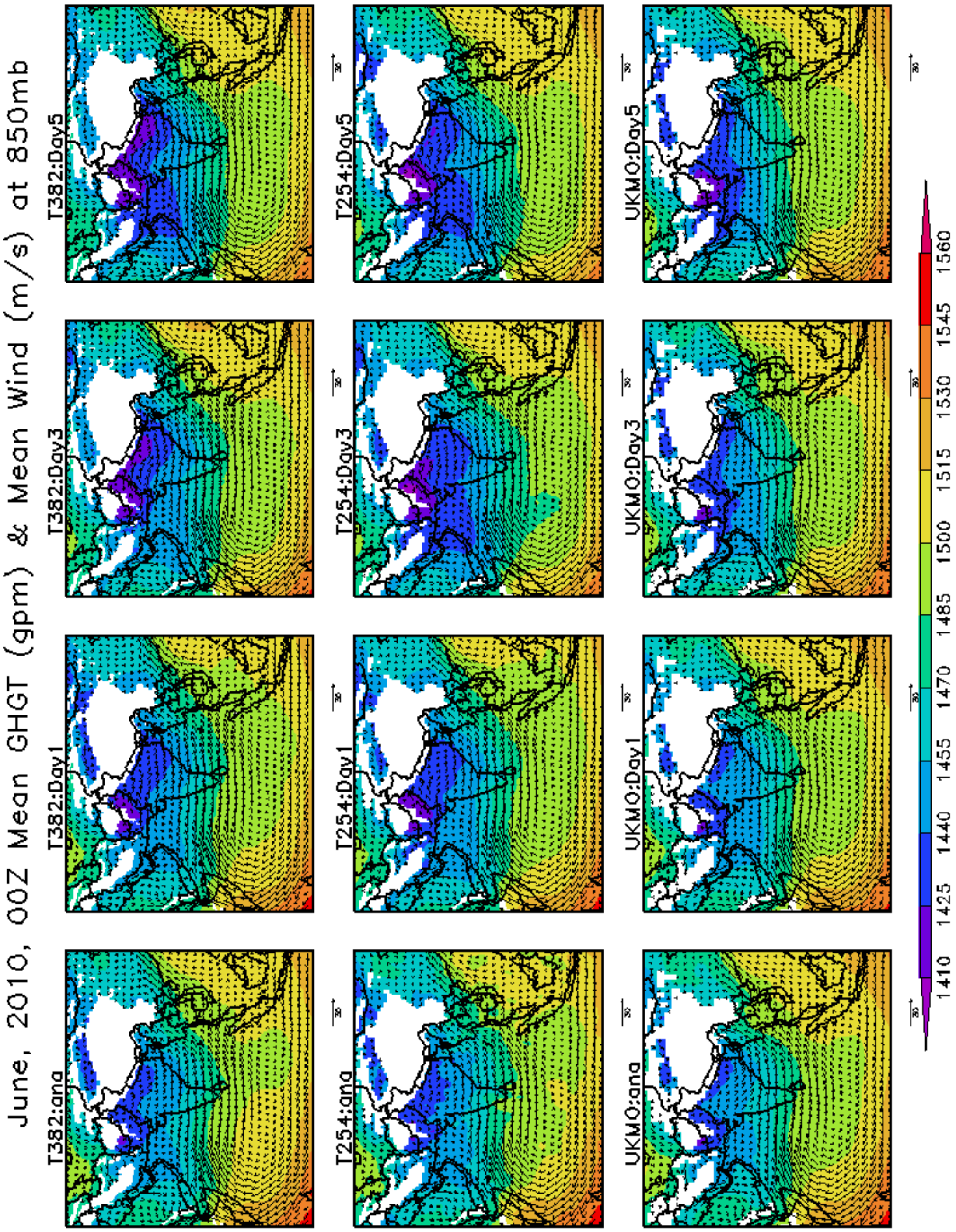
Appendix


June, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
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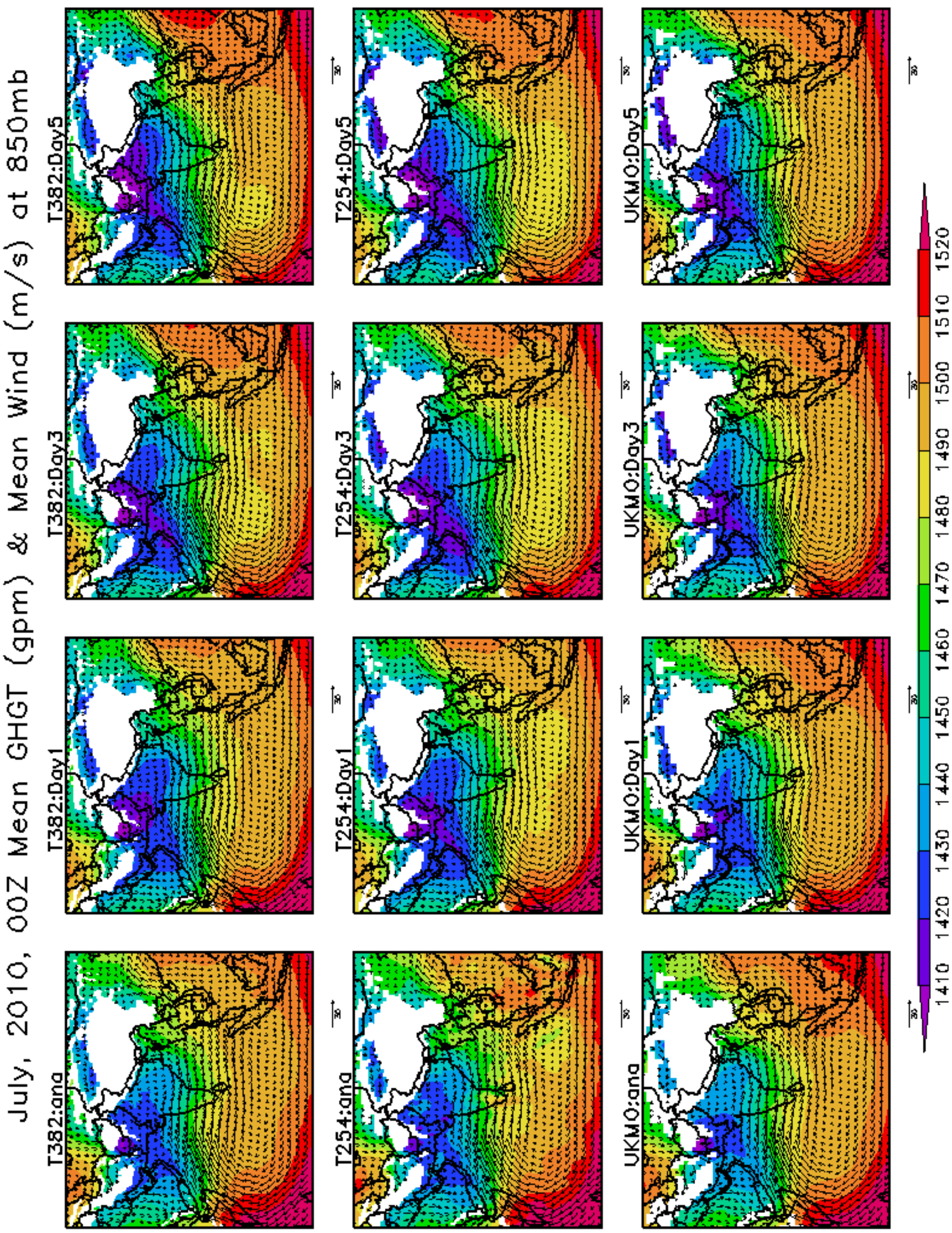
July, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
1410
1420
1430
1440
1450
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1470
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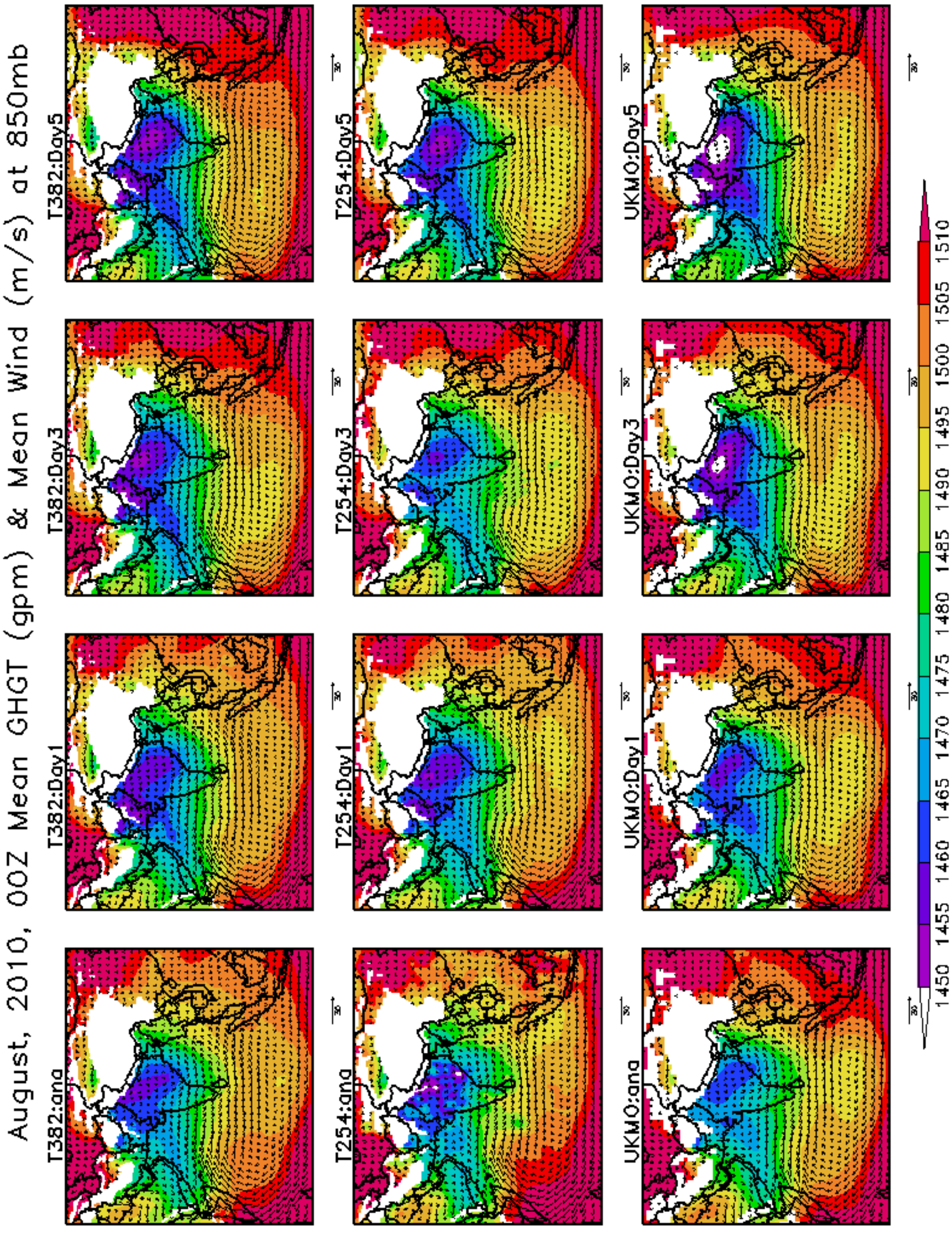
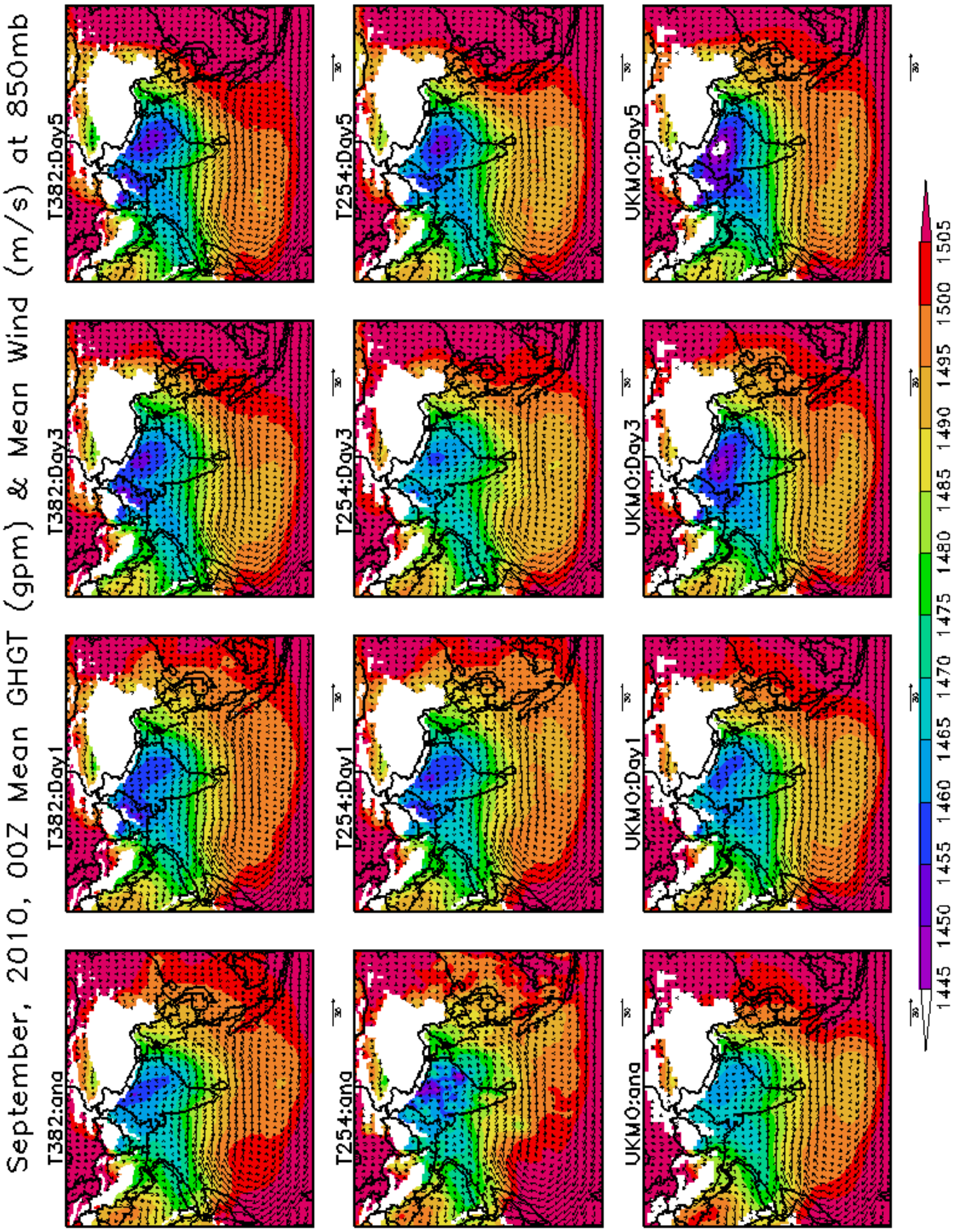
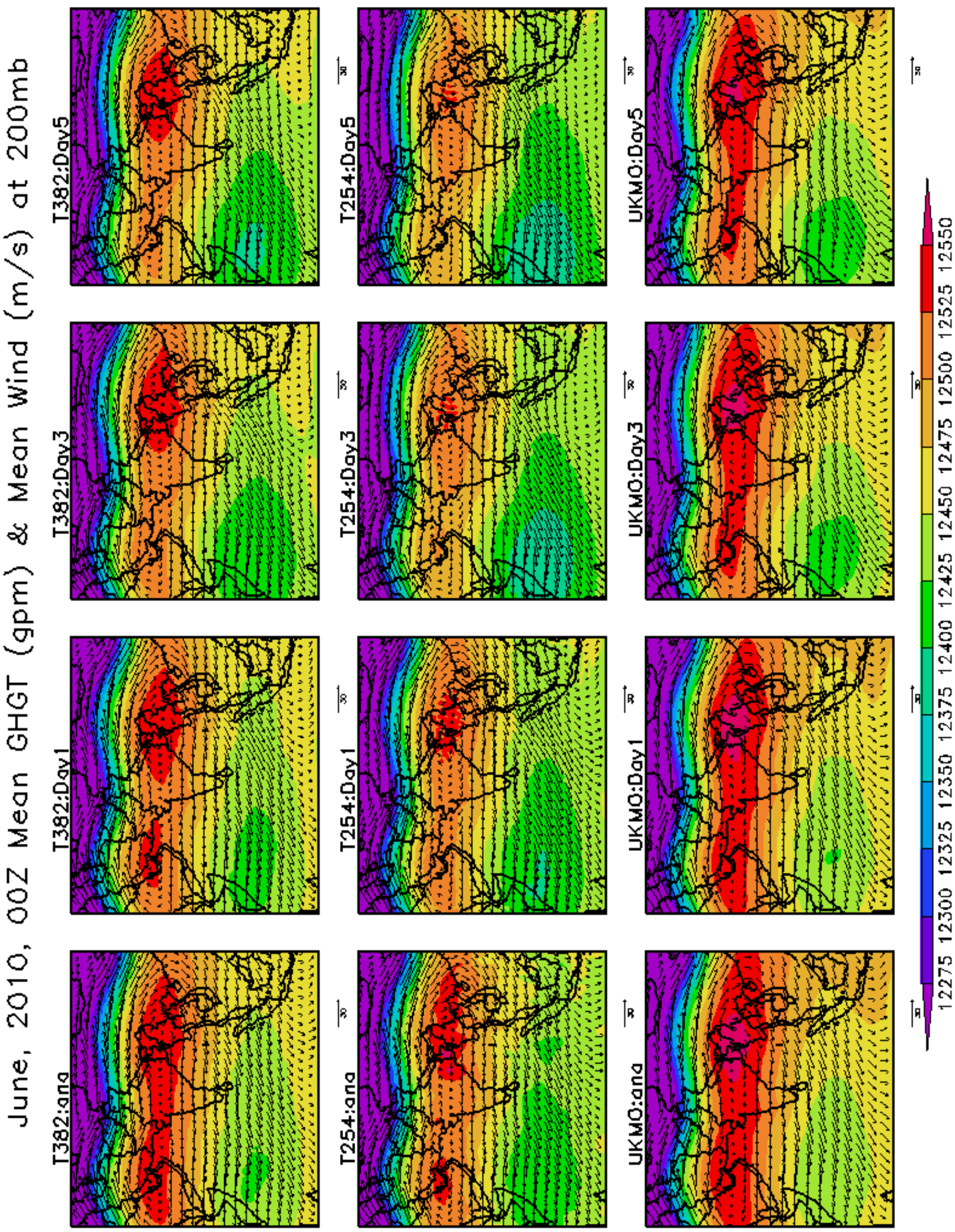
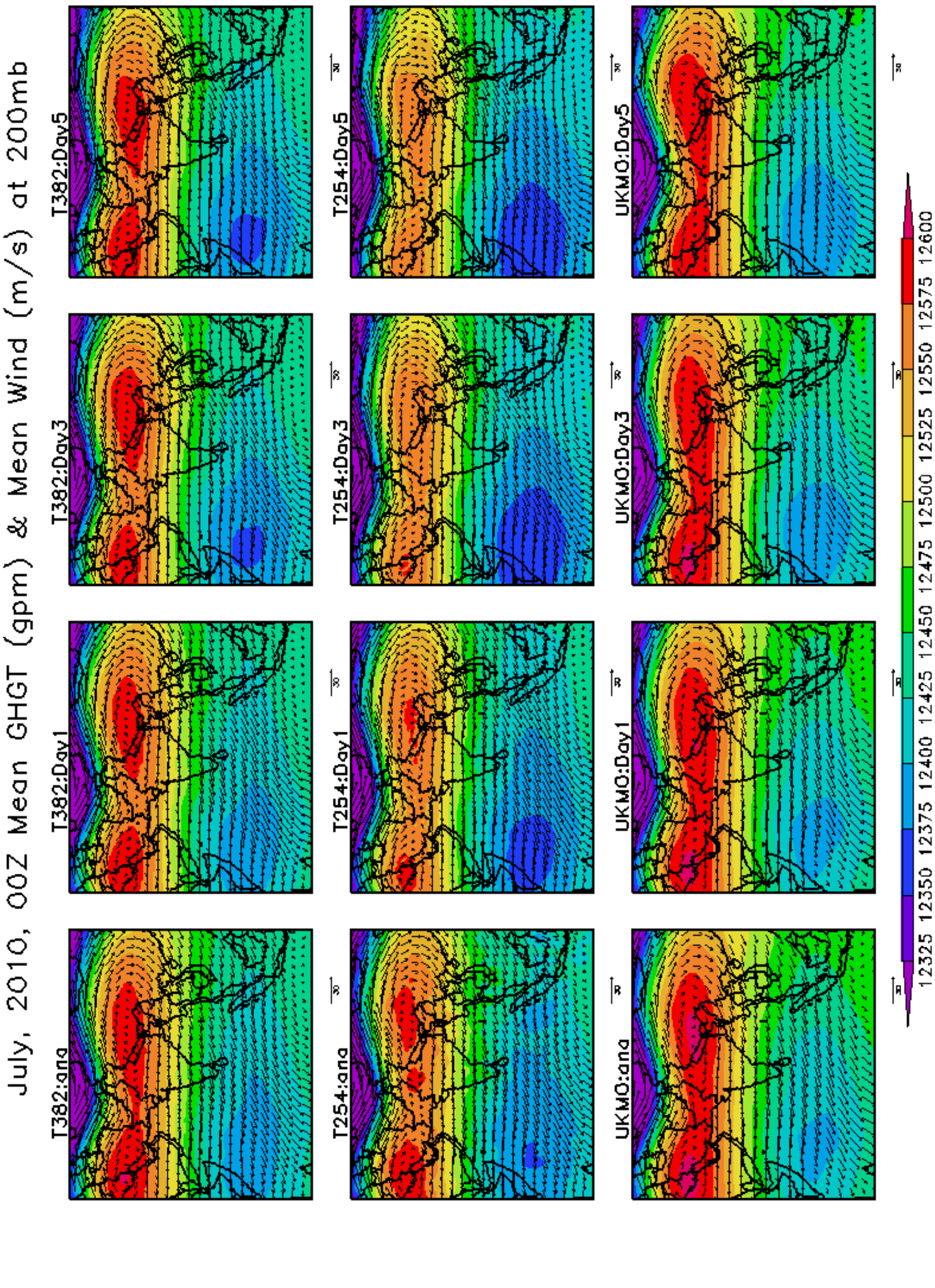
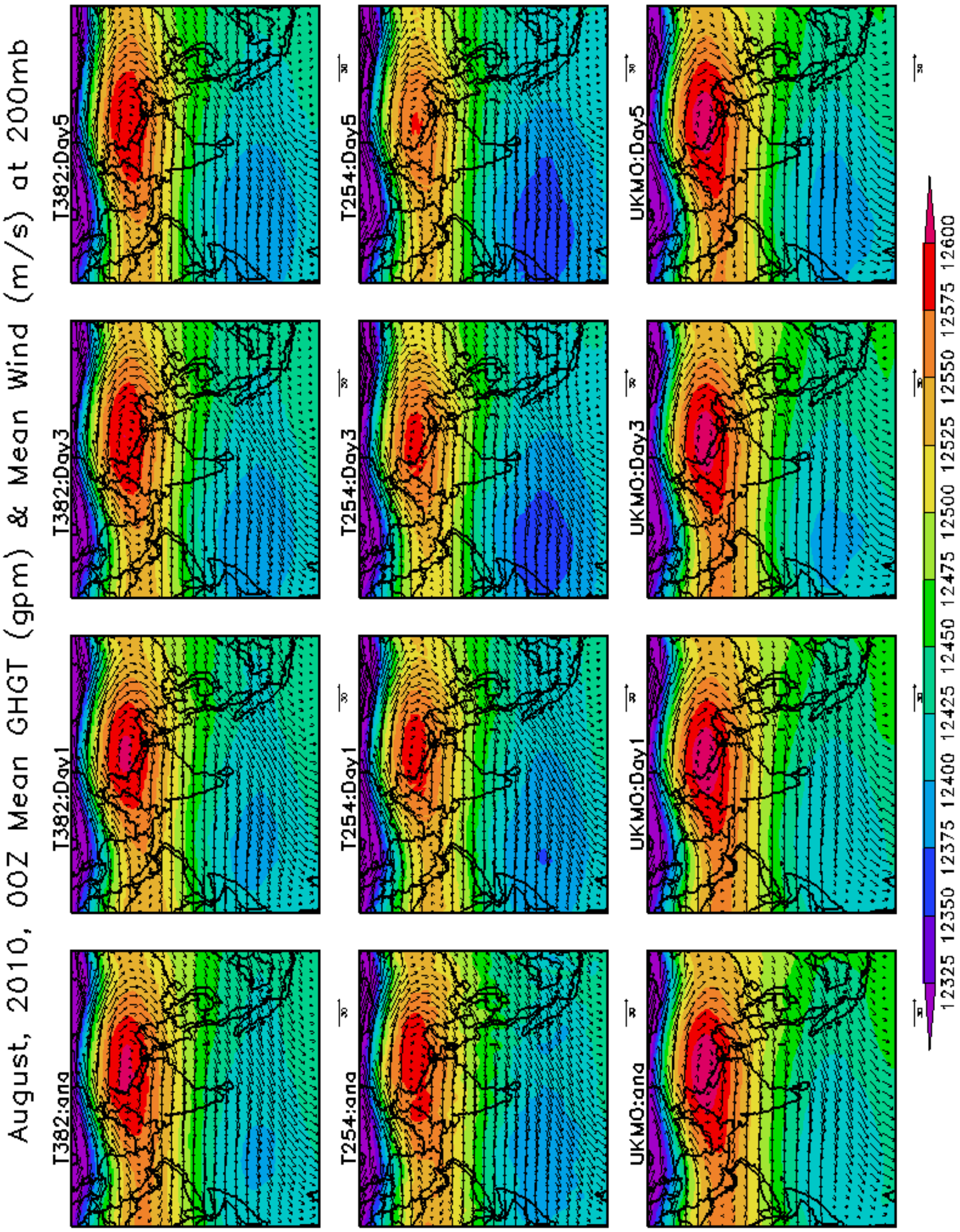
1500
1510
1520

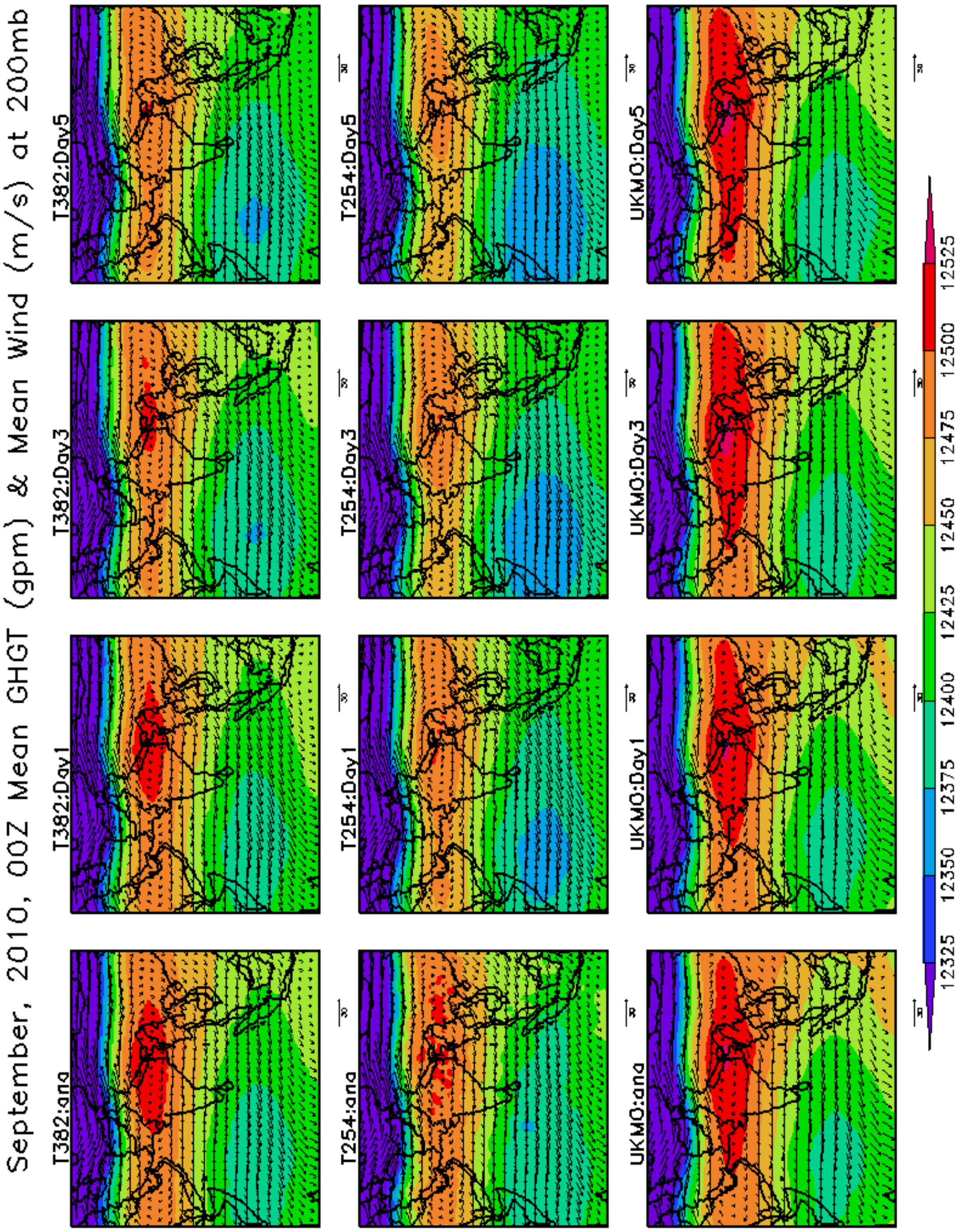

August, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510


September, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505

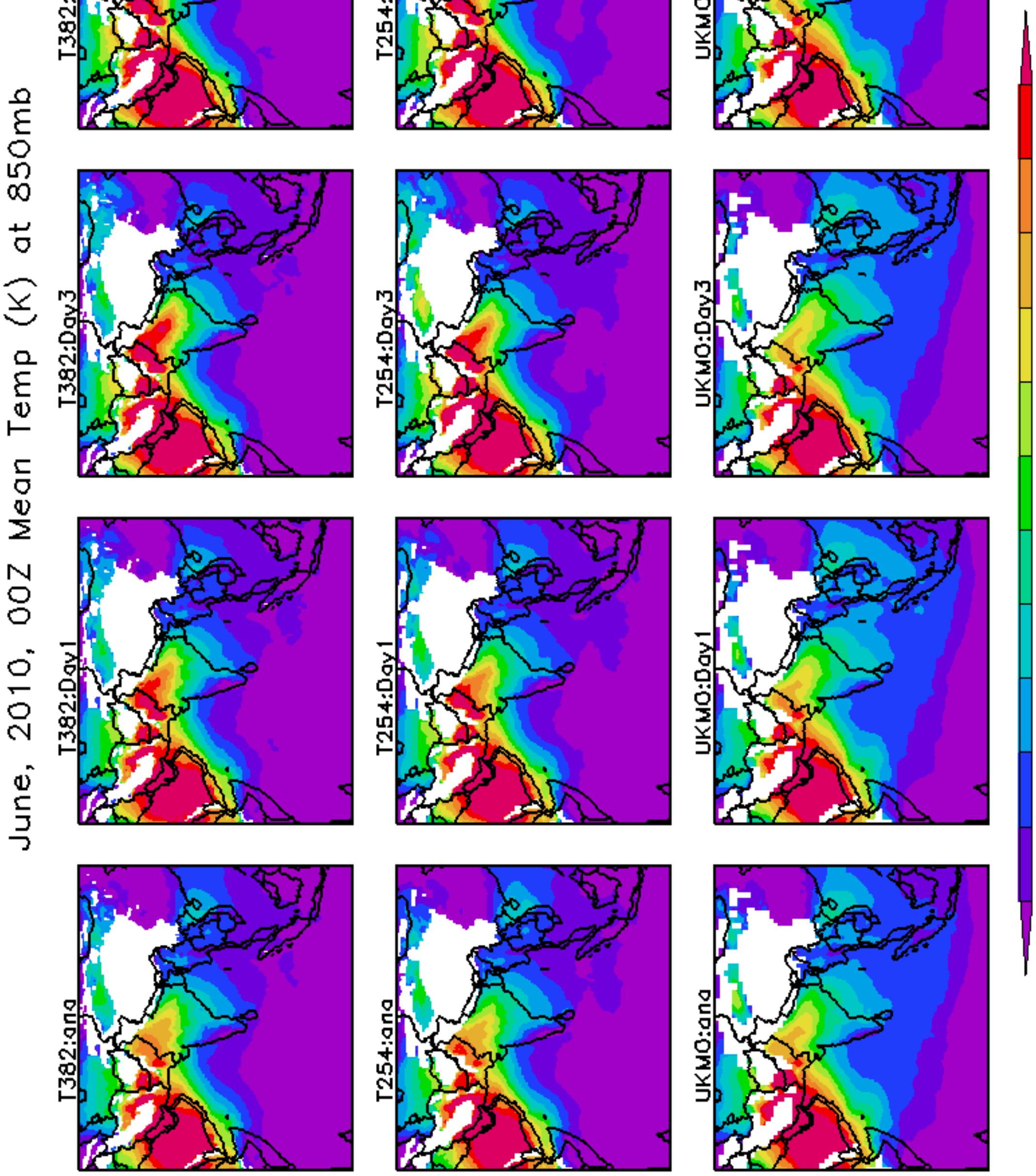

June, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
12275 12300 12325 12350 12375 12400 12425 12450 12475 12500 12525 12550


July, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
12325 12350 12375 12400 12425 12450 12475 12500 12525 12550 12575 12600


August, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
12325 12350 12375 12400 12425 12450 12475 12500 12525 12550 12575 12600



September, 2010, 00Z Mean GHGT (gpm) & Mean Wind (m/s) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
12325
12350
12375
12400
12425
12450
12475
12500
12525



June, 2010, 00Z Mean Temp (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
291
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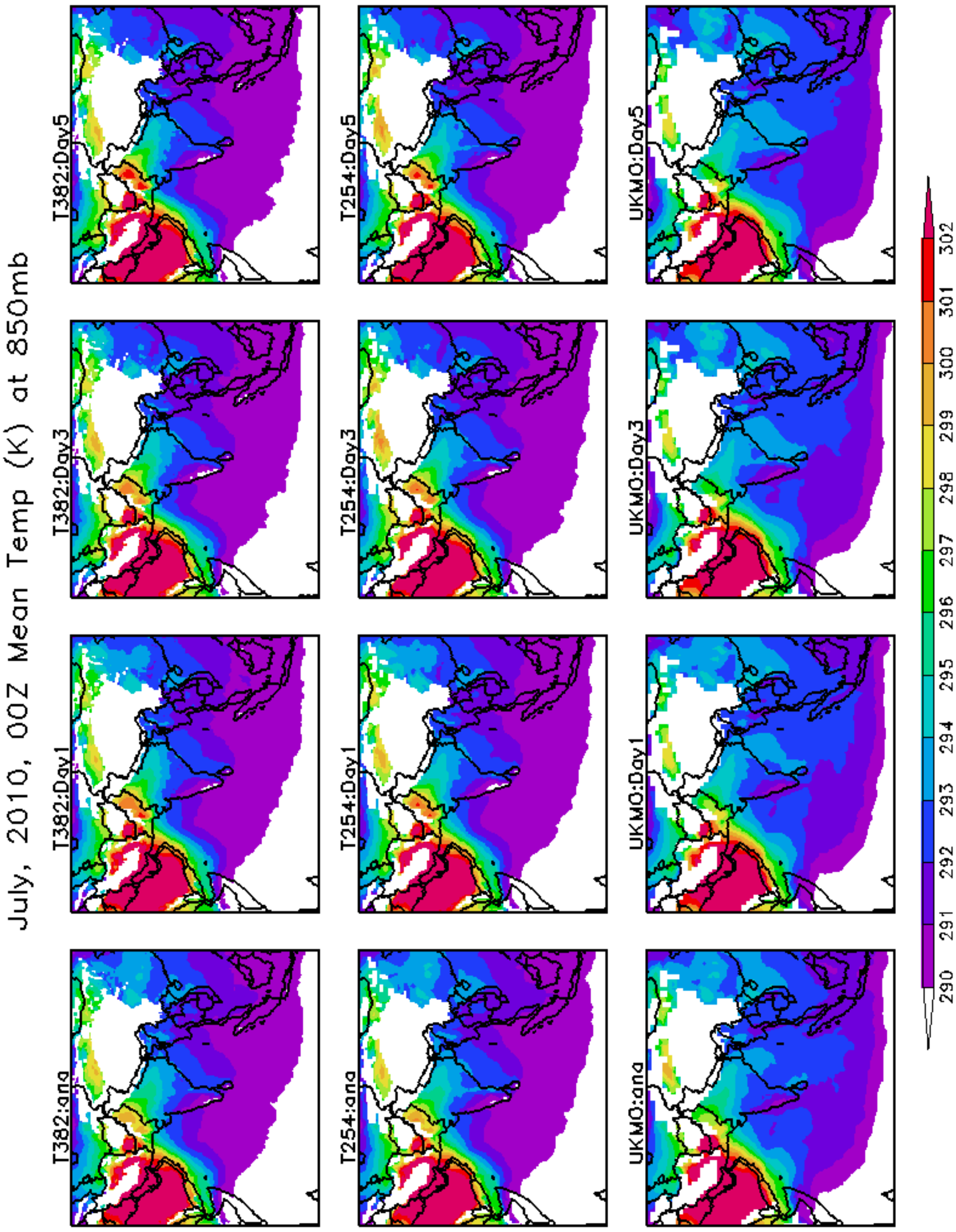
July, 2010, 00Z Mean Temp (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290
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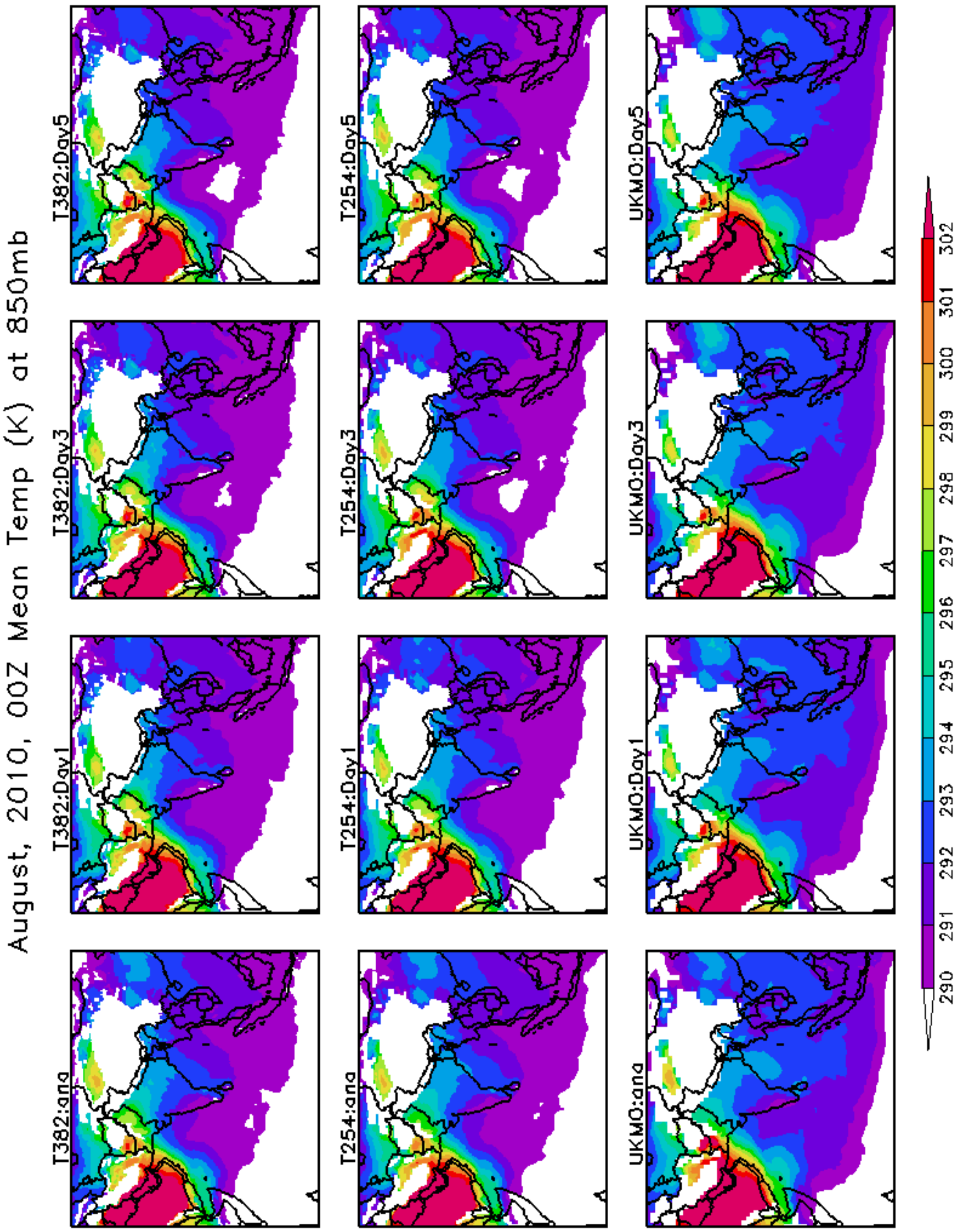
August, 2010, 00Z Mean Temp (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290
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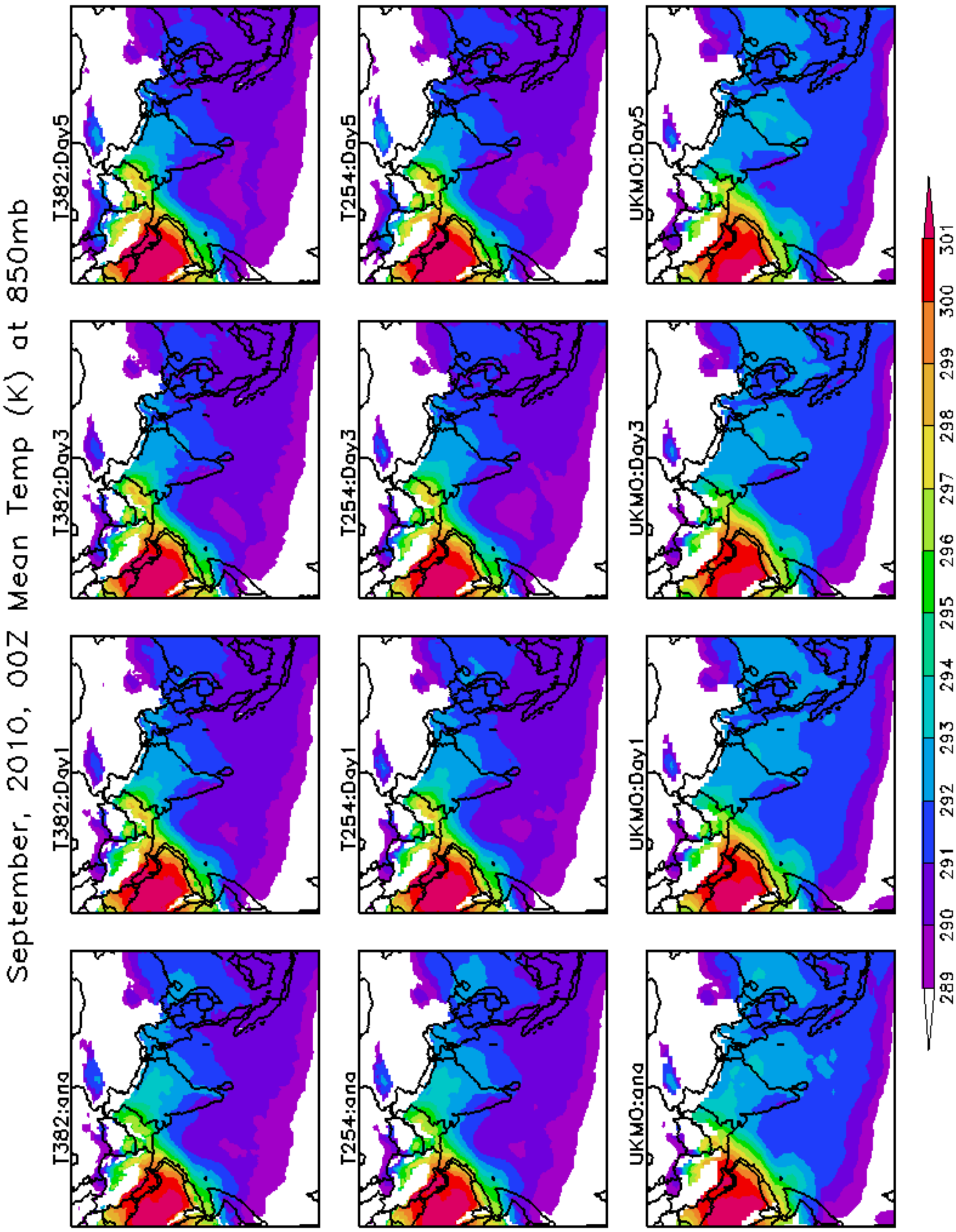
301
302



September, 2010, 00Z Mean Temp (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
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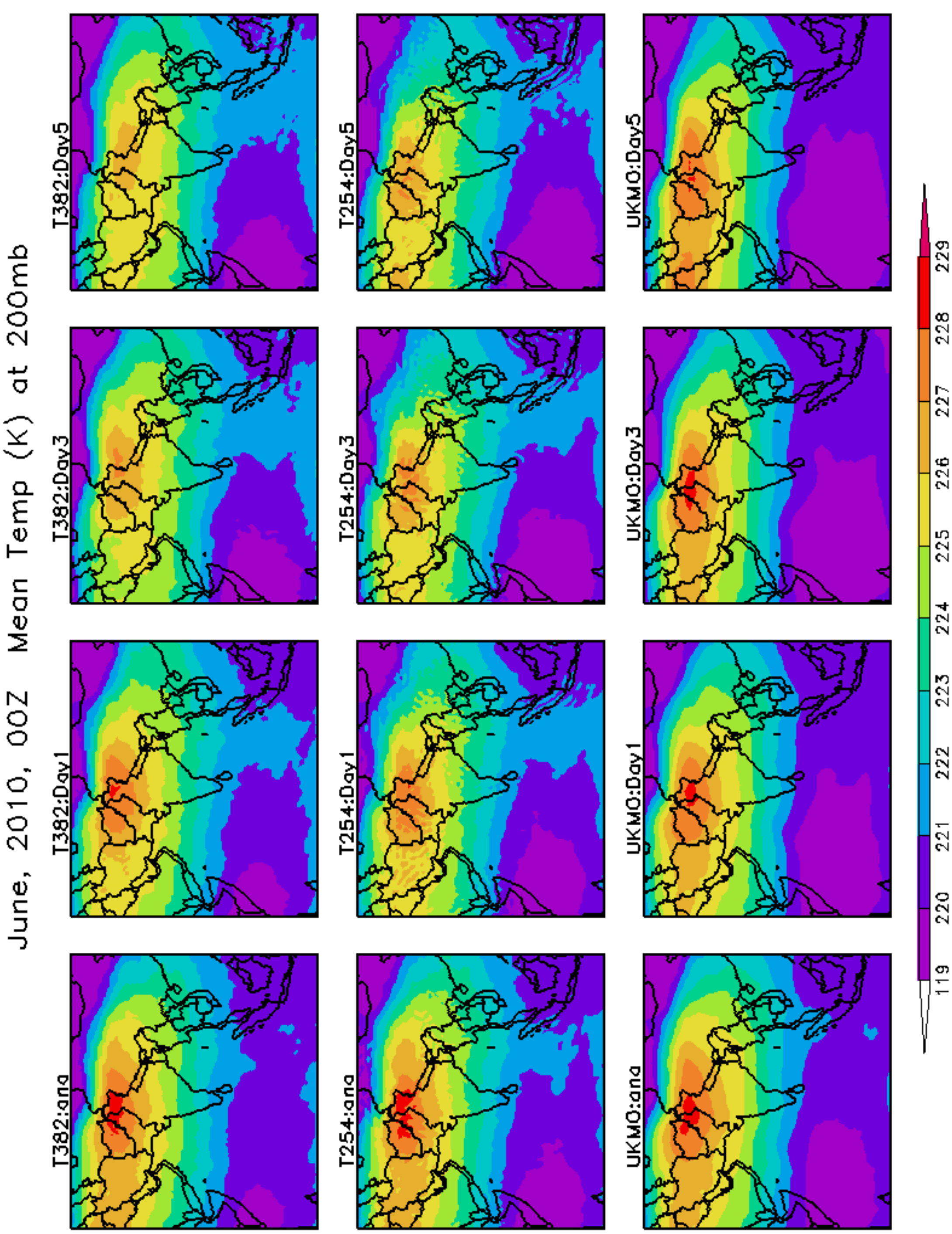
June, 2010, 00Z Mean Temp (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
119
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221
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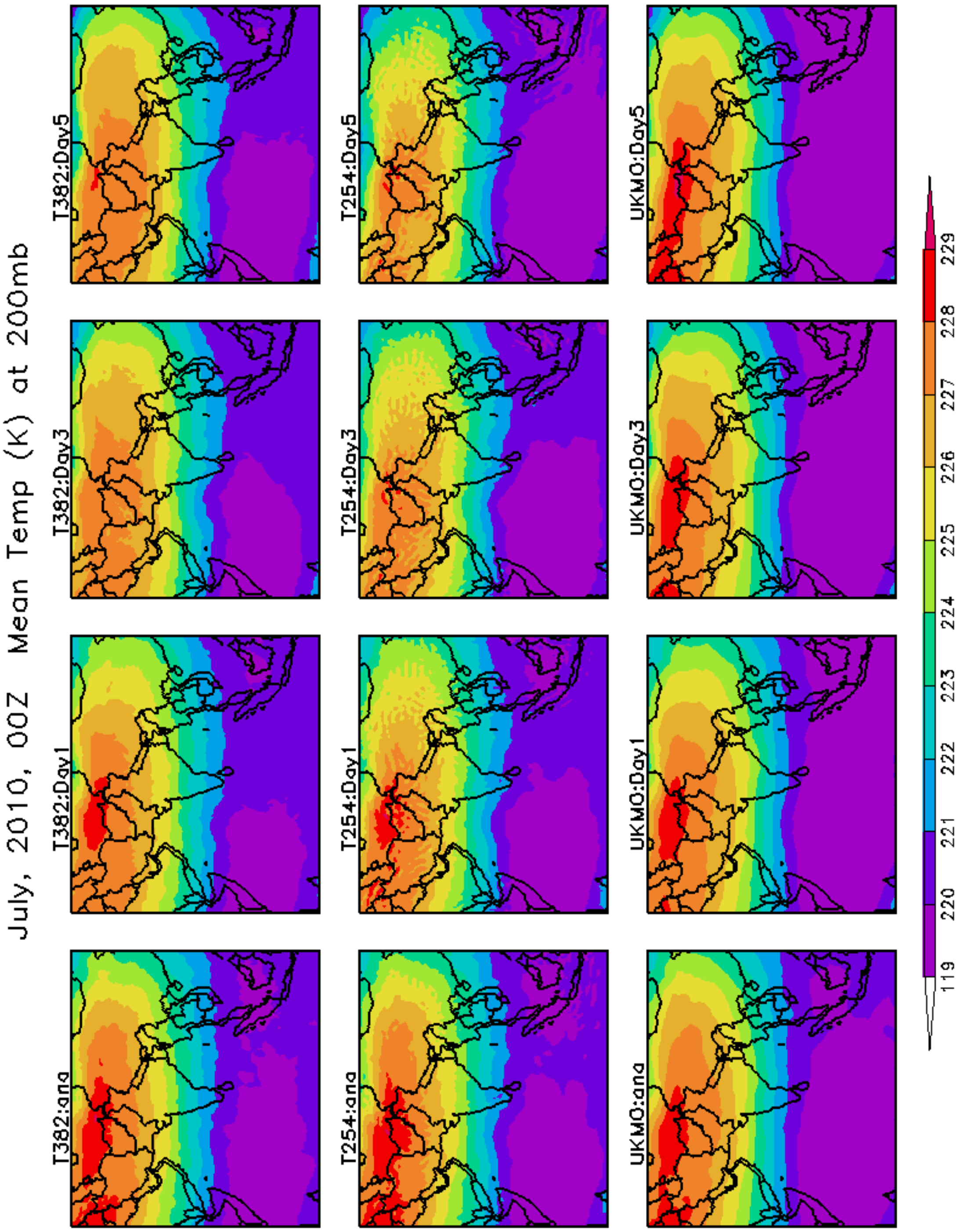
229



July, 2010, 00Z Mean Temp (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
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222
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228
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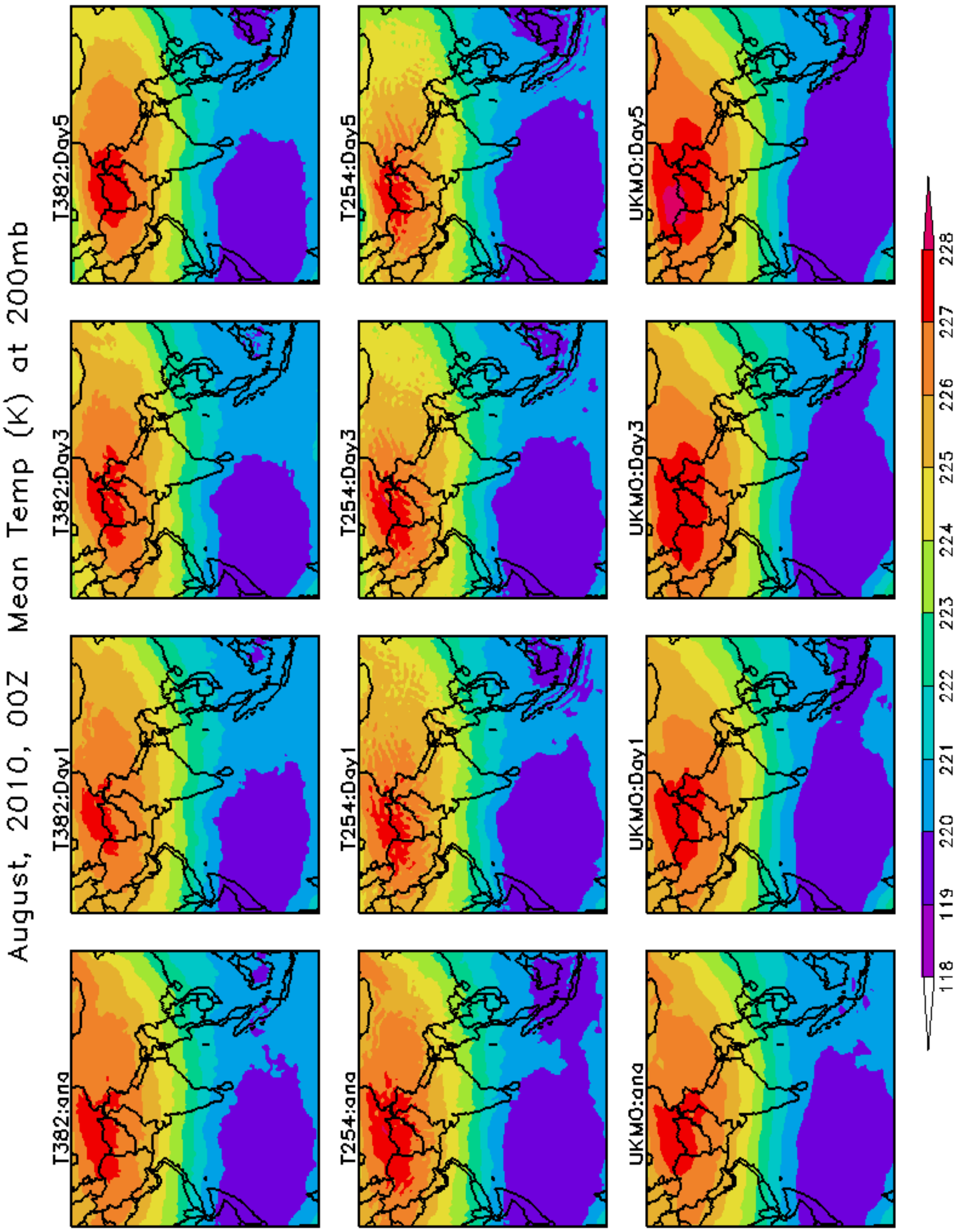
August, 2010, 00Z Mean Temp (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
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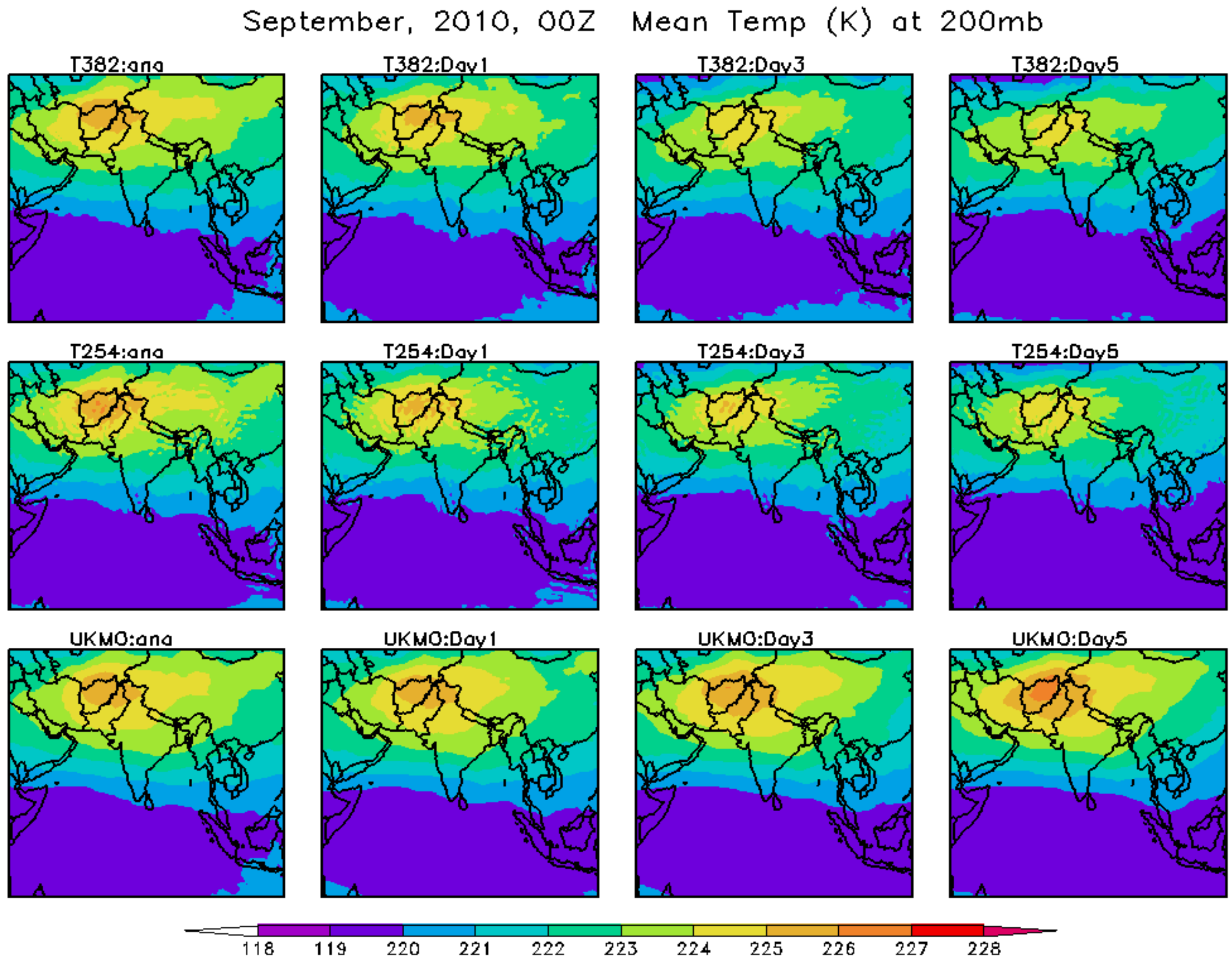
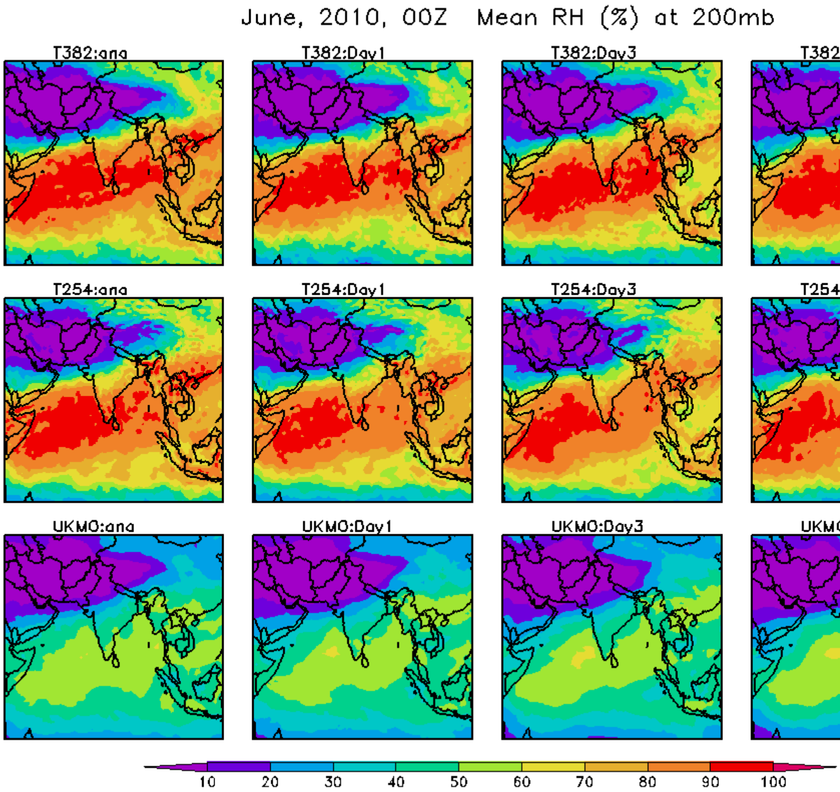
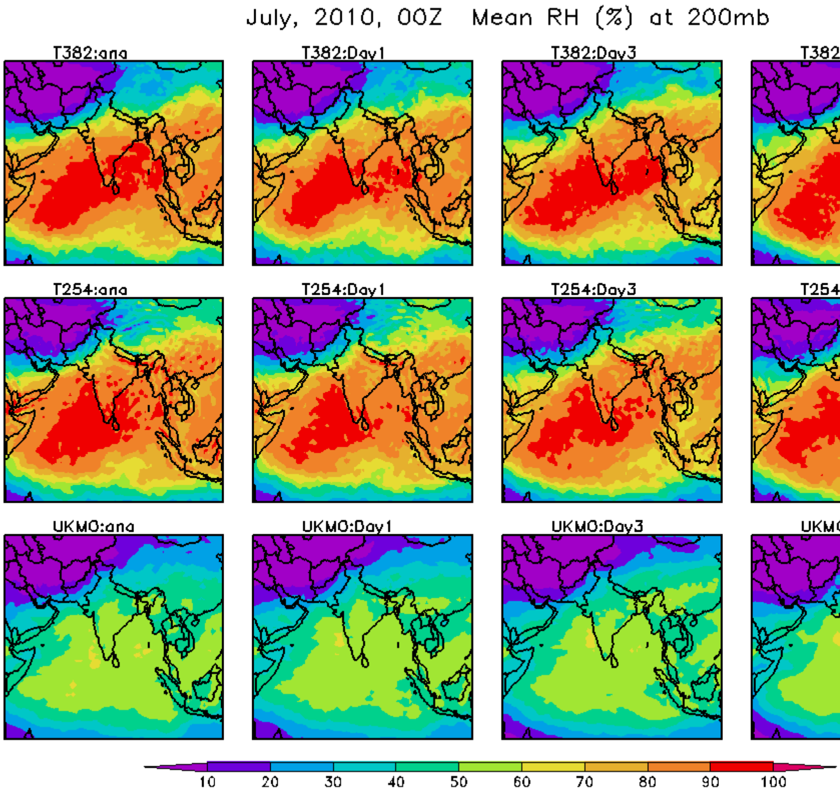
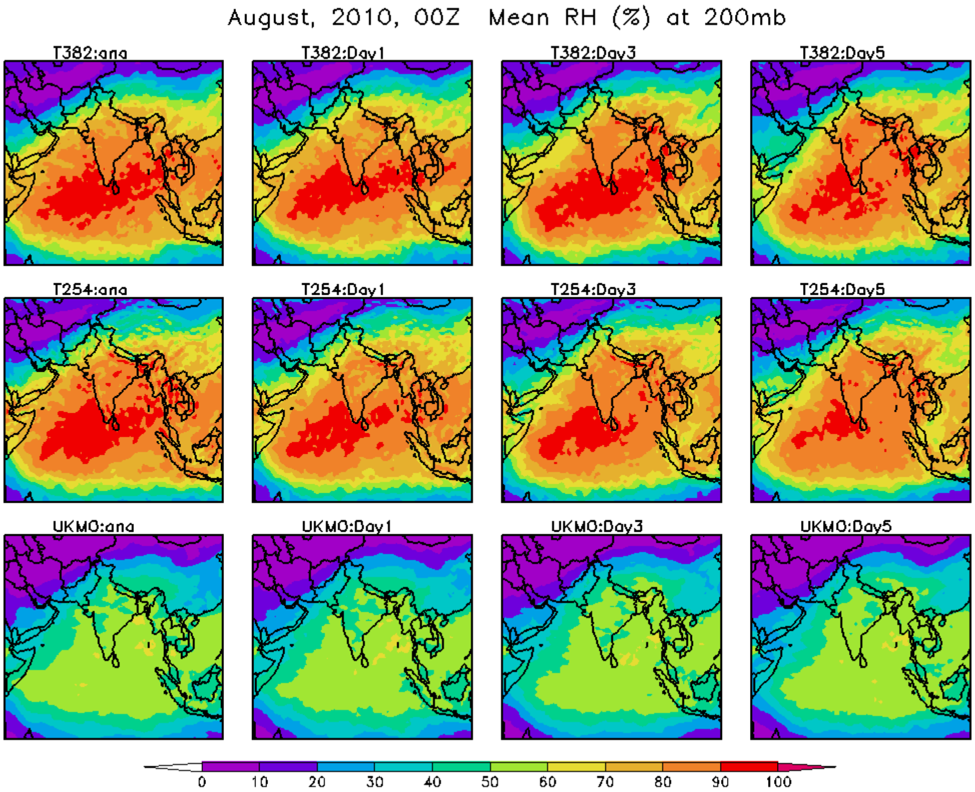

September, 2010, 00Z Mean Temp (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
118 119 220 221 222 223 224 225 226 227 228


June, 2010, 00Z Mean RH (%) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
10 20 30 40 50 60 70 80 90 100


July, 2010, 00Z Mean RH (%) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
10 20 30 40 50 60 70 80 90 100


August, 2010, 00Z Mean RH (%) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
0
10
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40
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70
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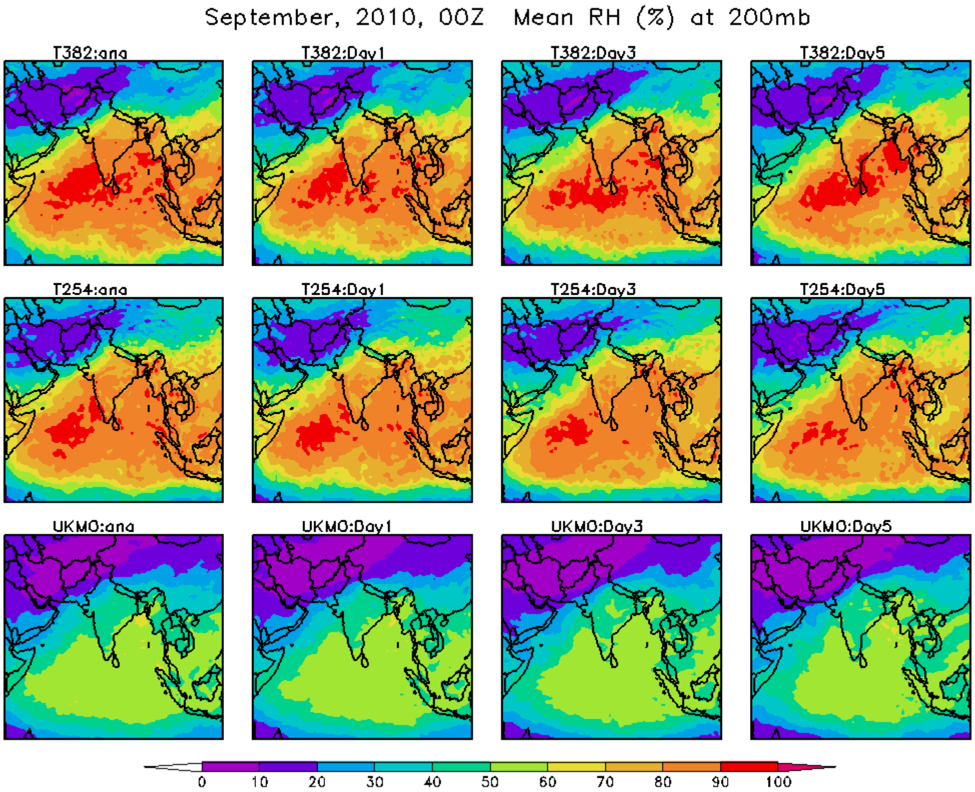
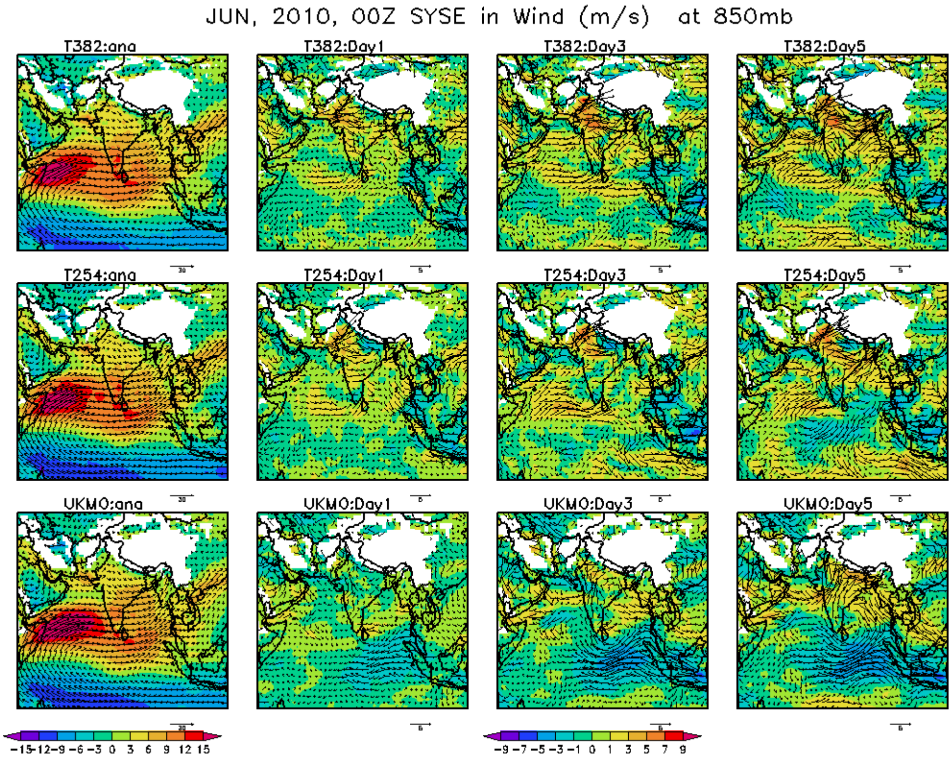
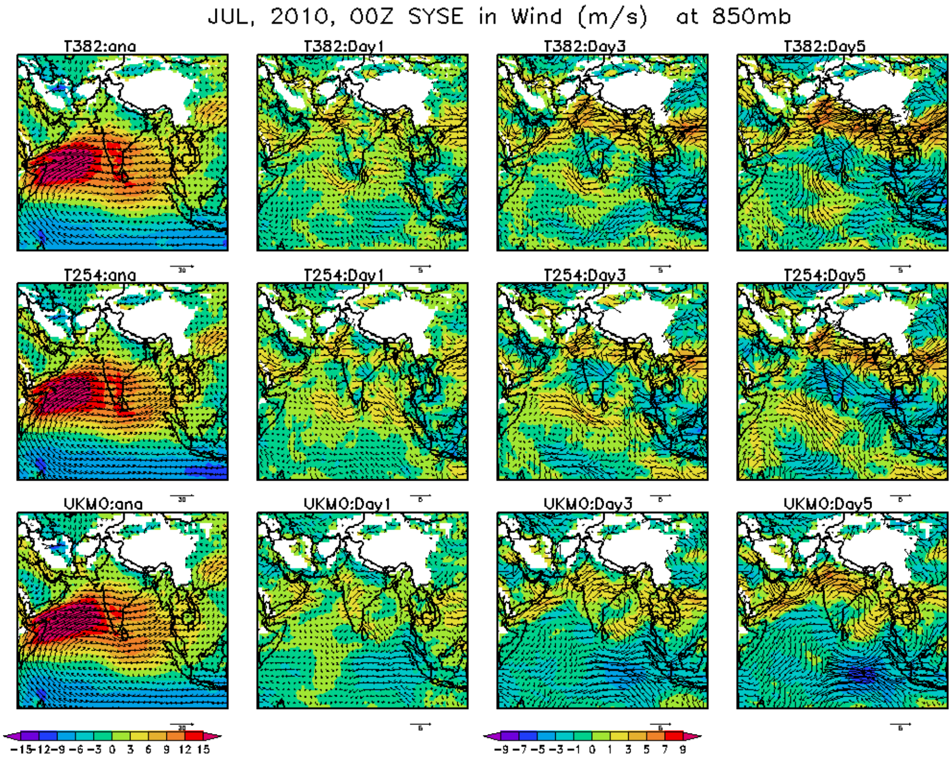
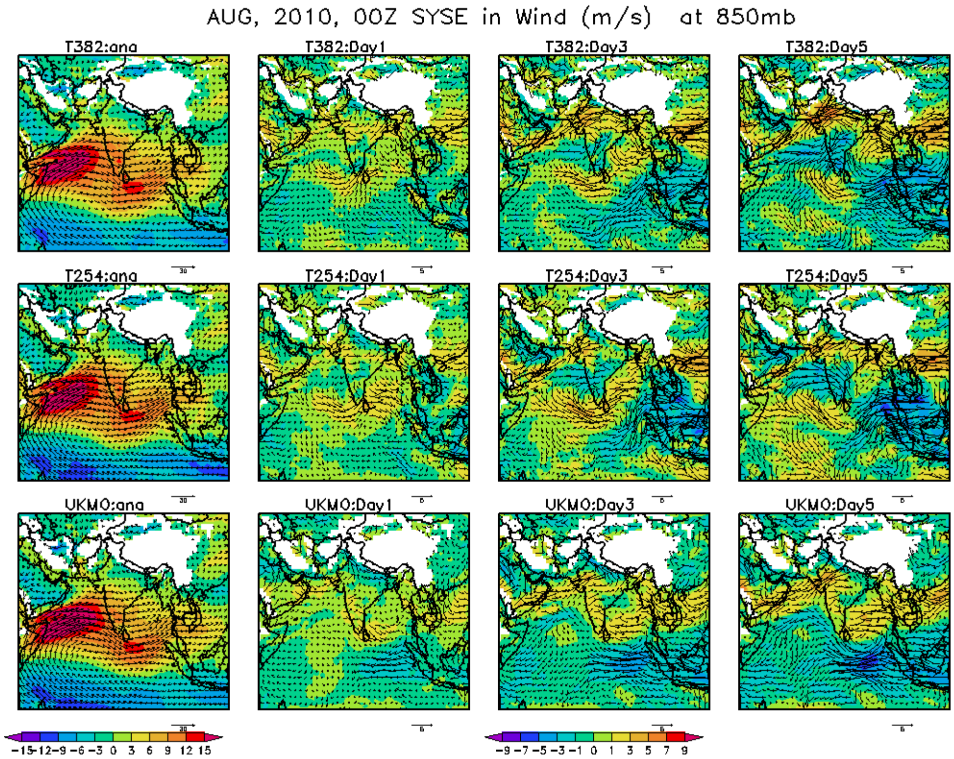
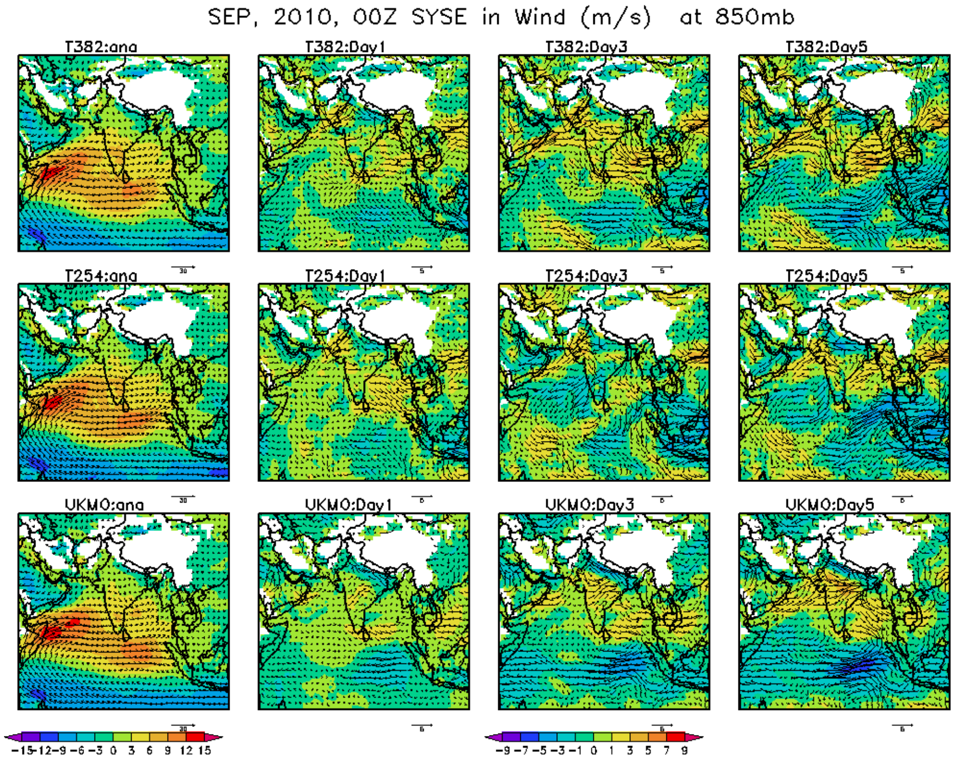
90
100

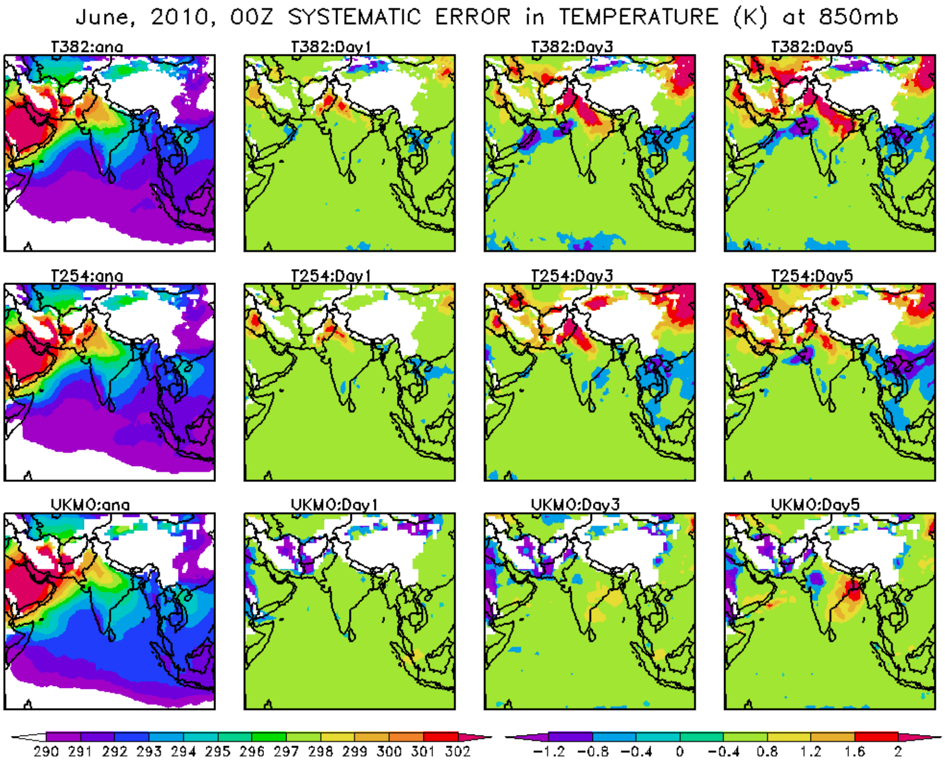

September, 2010, 00Z Mean RH (%) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
0
10
20
30
40
50
60
70
80
90
100

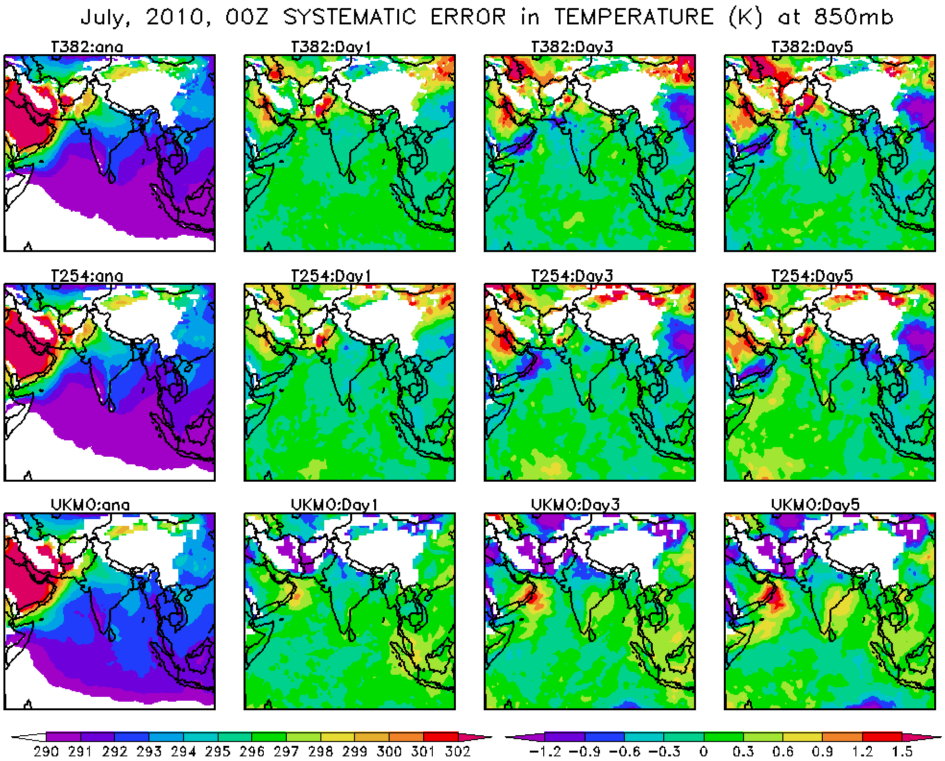

JUN, 2010, 00Z SYSE in Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
-15-12-9 -6 -3 0 3 6 9 12 15
-9 -7 -5 -3 -1 0 1 3 5 7 9

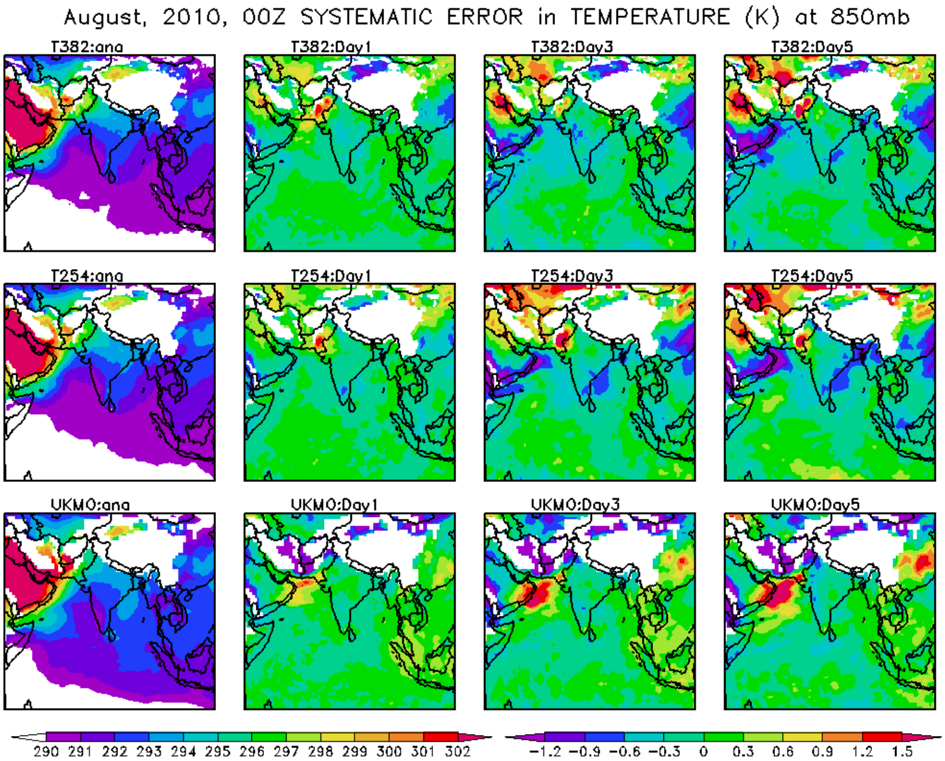

JUL, 2010, 00Z SYSE in Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
-15-12-9 -6 -3 0 3 6 9 12 15
-9 -7 -5 -3 -1 0 1 3 5 7 9

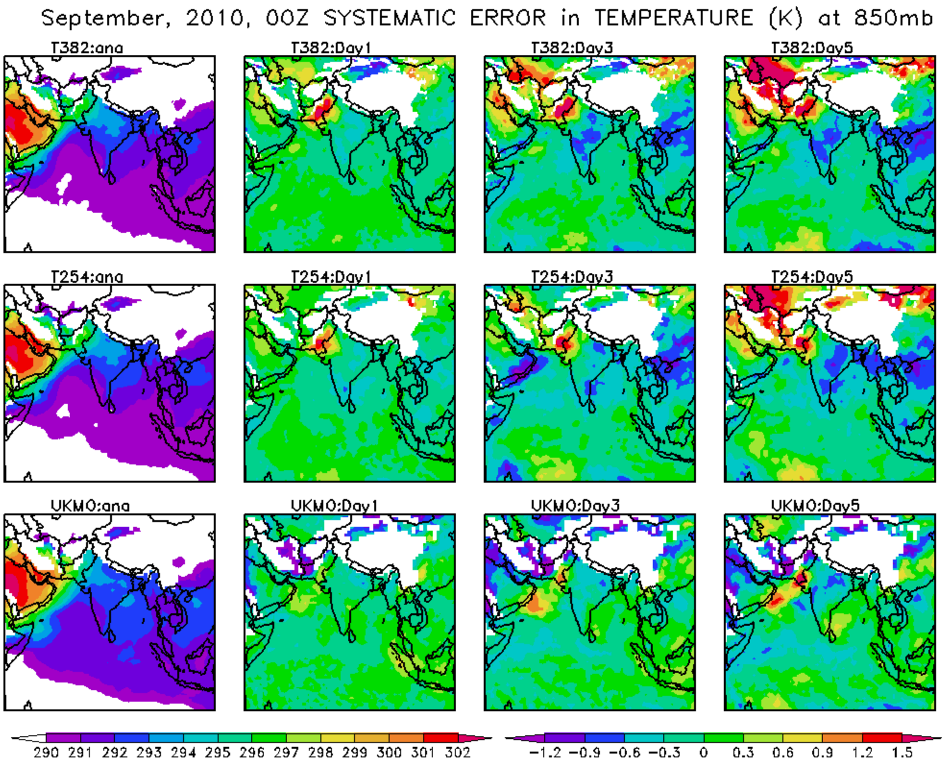

AUG, 2010, 00Z SYSE in Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
-15 -12 -9 -6 -3 0 3 6 9 12 15
-9 -7 -5 -3 -1 0 1 3 5 7 9

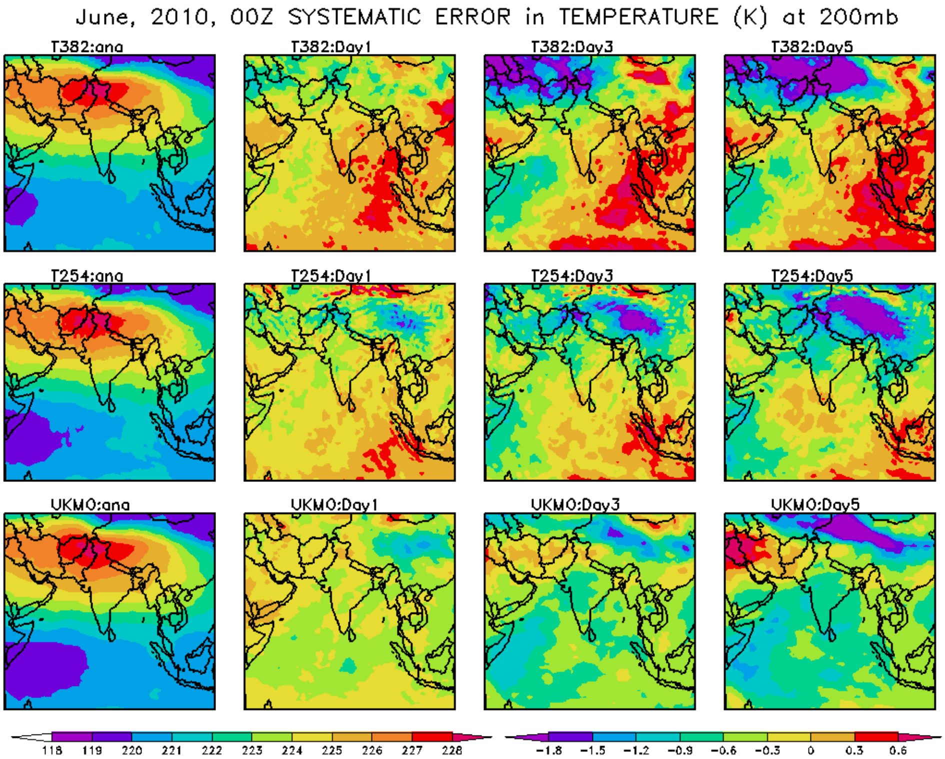

SEP, 2010, 00Z SYSE in Wind (m/s) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
-15 -12 -9 -6 -3 0 3 6 9 12 15
-9 -7 -5 -3 -1 0 1 3 5 7 9

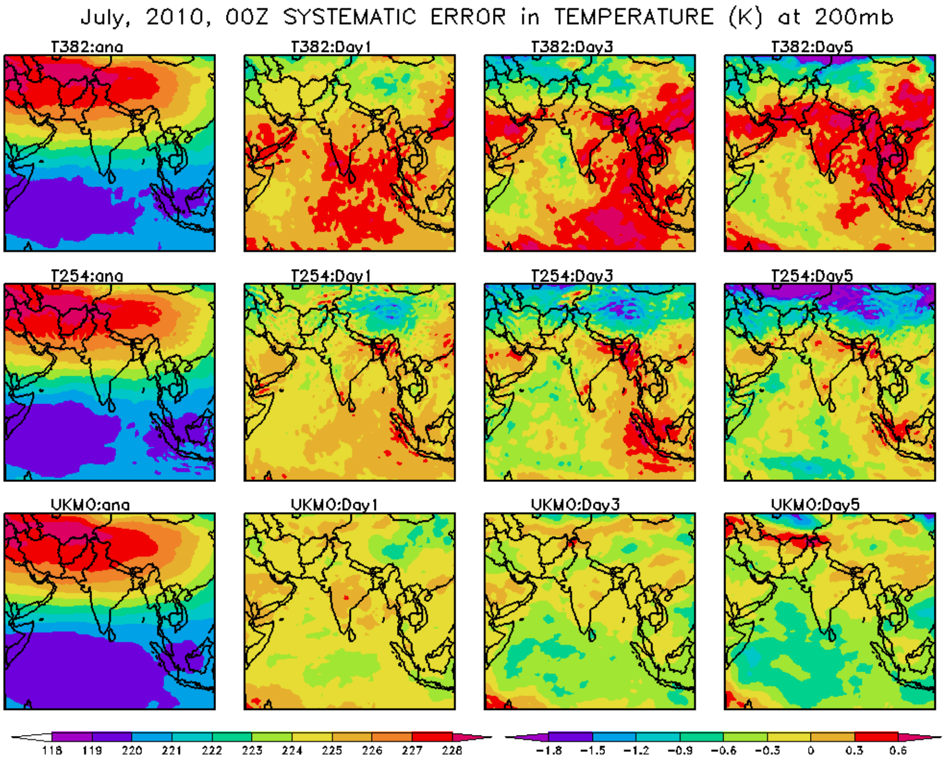

June, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290 291 292 293 294 295 296 297 298 299 300 301 302
−1.2 −0.8 −0.4 0 −0.4 0.8 1.2 1.6 2


July, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290 291 292 293 294 295 296 297 298 299 300 301 302
−1.2 −0.9 −0.6 −0.3 0 0.3 0.6 0.9 1.2 1.5

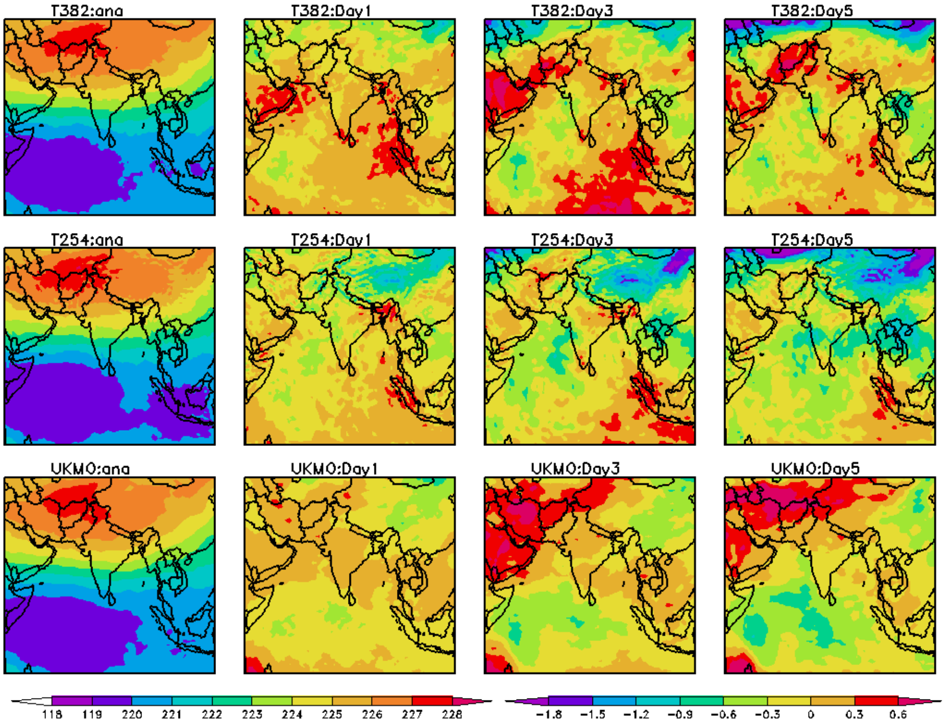

August, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290 291 292 293 294 295 296 297 298 299 300 301 302
−1.2 −0.9 −0.6 −0.3 0 0.3 0.6 0.9 1.2 1.5


September, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 850mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
290 291 292 293 294 295 296 297 298 299 300 301 302
−1.2 −0.9 −0.6 −0.3 0 0.3 0.6 0.9 1.2 1.5


June, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
118 119 220 221 222 223 224 225 226 227 228
-1.8 -1.5 -1.2 -0.9 -0.6 -0.3 0 0.3 0.6


July, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 200mb
T382:ana
T382:Day1
T382:Day3
T382:Day5
T254:ana
T254:Day1
T254:Day3
T254:Day5
UKMO:ana
UKMO:Day1
UKMO:Day3
UKMO:Day5
118 119 220 221 222 223 224 225 226 227 228
-1.8 -1.5 -1.2 -0.9 -0.6 -0.3 0 0.3 0.6

August, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE(K) at 200mb



September, 2010, 00Z SYSTEMATIC ERROR in TEMPERATURE (K) at 200mb