

Numerical Weather Prediction

Upgrades to the Crisis Area Mesoscale Model Service



Forecasting Research Technical Report No. 464

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Upgrades to the Crisis Area Mesoscale Model Service

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Abstract

Prior to this project, three Crisis Area Mesoscale Models (CAMMs) forecasts were in operation covering the Balkans¹, Afghanistan and the Middle East. These models were set up quickly without optimization, in response to urgent operational requirements. The Mobile Met Unit had noted their benefits over the global model but there was much scope to improve the forecasts further. For example only the Middle East CAMM included the assimilation of observations and all of the CAMMs lagged some way behind in science compared with the operational UK Mesoscale model². The aim of the project was to address these shortcomings.

During the lifetime of this project the CAMMs science has been upgraded a number of times converging towards the latest preferred science as used in the Met Office operational global model and new North Atlantic European (NAE) model. The assimilation of all appropriate observation data types has been added to each operational CAMM and routine objective verification is in place to monitor the performance of each CAMM against the global model. This confirms that the CAMMs are adding value over the global model forecasts.

A 'generic' CAMM suite has been developed that can be readily relocated around the globe. This suite has been trialled in a selection of climate regimes: Indonesia, Sahara, Korea and North America. Its performance in each of these domains has been collated alongside the current operational CAMMs performance and compared with the global model. The winter and summer performance within these climate regimes provides a useful guidance on how future CAMMs may perform compared with the global model, especially noting strengths and weaknesses.

Overall this project has delivered a much enhanced CAMM capability. CAMMs based upon the preferred latest science may be readily relocated, at short notice if required, around the globe. For example, a Bay of Bengal CAMM was introduced within a week in response to the Asian Tsunami disaster, providing weather forecasts for the aid relief teams.

The CAMMs shall continue to follow the NAE development path ensuring that the CAMMs remain at the leading edge of NWP.

History

Version 1.0	"Upgrade to the Crisis Area Mesoscale Model Service" end of project report supplied to the Research Acquisition Organisation (RAO), Defence Academy, Shrivenham	4 th August 2005
Version 1.1	Revised following initial comments by Stuart Bell.	24 th August 2005

¹ The Balkan model was to become redundant upon the introduction of the North Atlantic European (NAE) model and hence was not considered within this CAMM project.

² The NAE model shall replace the 12km UK Mesoscale Model and thus the CAMMs will now follow NAE developments.

This report reviews each stage of the project in turn, summarizing the CAMM developments and their impact on CAMM performance. The first two stages were essential for the CAMMs, bringing their science up to date. The third and final stage developed a 'generic' CAMM, which can be readily relocated. Its performance is compared with the global model, presenting its strength and weaknesses around the globe. This insight is most useful for providing guidance to forecasters on how a new model may perform compared with the global model.

Stage 1: Upgrading the operational CAMMs science. (May-Oct 2003)

Main Deliverables:

- **Report on Middle East model performance, with comparison of models.**
- **Bring the CAMMs science up to date.**

Originally each CAMM did not assimilate observational data at their own model resolution (17km), instead they relied upon the interpolation of data from the global model (60km resolution). Prior to Operation Telic the Met Office received a request to upgrade the Middle East CAMM and the model was developed to assimilate observations, including satellite data, thus providing an improved service.

The Met Office was not alone in developing its forecast capability in the Middle East region. Two US models are also available: the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) by the Naval Research Laboratory (NRL) , used by FNMOC/ US Navy and the Mesoscale Model 5 (MM5) from Pennsylvania State University and the National Center for Atmospheric Research (NCAR), used by AFWA/USAF.

The Met Office carried out a short study (**reference 1**) during April and May 2003 objectively comparing the three models performance. The Met Office Middle East CAMM was seen to be highly competitive against both American models and also the Met Office own global model. For example, the Middle East CAMM provided more accurate forecasts of station temperatures (**figure 1**) and 10m winds (**figure 2**).

The Middle East CAMM clearly had the lowest Root Mean Square Error (RMSE) (Forecast-Observations), *i.e. higher* accuracy, for both station temperature and 10m winds during the period. The Middle East CAMM and MM5 tended to slightly over forecast the wind speeds.

Objective verification alone does not provide a full impression of a model's performance. It is important that forecasters have confidence in a model's output and that they do not have to manually adjust each forecast. CMetO at DMC reported that *there were no occasions where the mission specific short term forecast was in serious error and it was also acknowledged that the improvement in medium and high level cloud fields was significant* post the assimilation upgrade.

Even though the Met Office Middle East CAMM was highly competitive it lagged some way behind the preferred model science at the time. So there was much room to further improve the CAMMs performance, hence the justification for the CAMM upgrade project.

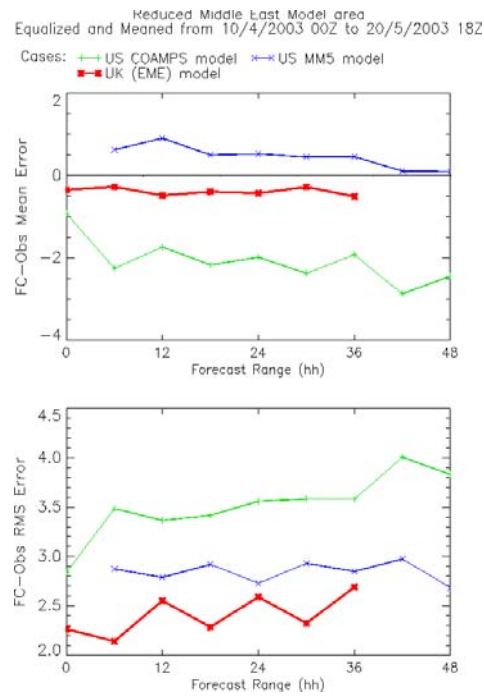


Figure 1: Mean Bias (top) and RMSE (bottom) of station temperatures within the Middle East CAMM domain, Met Office Middle East CAMM (red), COAMPS (green) and MM5 (blue).³

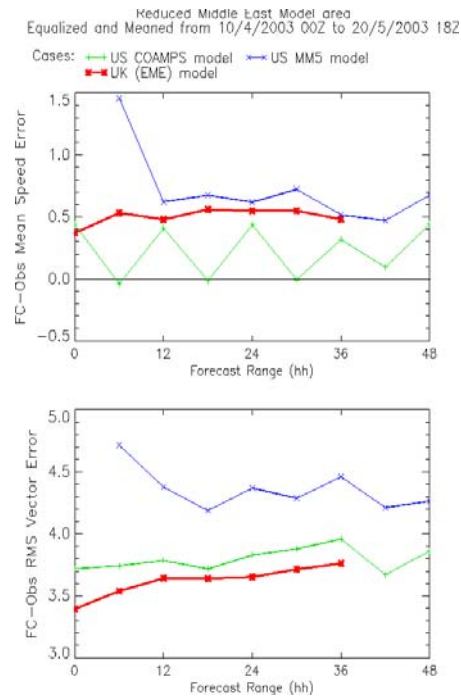


Figure 2: Mean 10m wind speed bias (top) and RMS Vector error (bottom) within the Middle East CAMM domain, Met Office Middle East CAMM (red), COAMPS (green) and MM5 (blue).

³ Appendix A provides a guide to each figure type presented in this report.

During the summer of 2003 the operational CAMMs were unreliable, failing frequently with Grid Point Storms (GPSs). These occurred when the modelling of convection ran out of control, leading to a numerical instability. The only way to counter GPSs at the time was to re-run the CAMM forecasts with a shorter model timestep, leading to an increased run time cost. This was clearly not acceptable in high profile models. The operational global model included 'targeted diffusion of moisture' (a redistribution of moisture locally when the onset of a GPS was diagnosed) and this had proved to be a successful counter measure. The CAMMs science required an immediate upgrade.

Major changes made to the CAMMs science during summer 2003 included:

- A new version of the Unified Model code, UM5.5
- The addition of a gravity wave drag scheme (GWD)
- Use of the new Convection scheme 4A (also known as CMODS)
- Grid Point Storm counter measure, 'targeted diffusion'
- A new orography ancillary file derived from a high resolution 1 degree GLOBE dataset.
- Cloud formulation changes as used in the UK Mesoscale model.

Each of the summer 2003 CAMM failures were re-run with the above science changes without failure; the GPSs were alleviated. The science upgrade appeared to yield a much more stable model. The science upgrade also yielded a number of improvements to the forecast performance in both the SW Asia and Middle East CAMMs. For example, the introduction of the GWD scheme provided significantly improved forecasts of 10m winds (**figure 3**). During the trial period September 2003, the operational Middle East CAMM 10m wind forecasts were actually poorer than the global model forecasts. The introduction of the GWD scheme within the Middle East CAMM yielded forecasts better than from the operational (UM5.3) global model at the time.

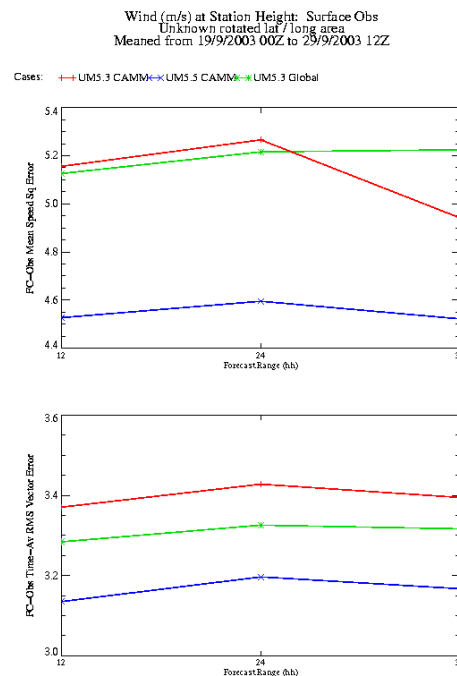


Figure 3: Mean 10m wind speed bias (top) and RMS vector error (bottom) within the Middle East CAMM, Control ME CAMM (red), Upgraded ME CAMM (blue) and operational global model (green).

Winds at all levels were improved within the SW Asia CAMM. Other fields seen to improve from the science upgrade included: PMSL and cloud cover.

The science upgrade was a resounding success: the models were more robust and forecast performance had been seen to improve within the model upgrade trials. These findings were collated within a short report (**reference 2**). The science upgrade went operational in both the SW Asia and Middle East CAMMs in Nov 2003.

Stage 2: Including the assimilation of observations within all CAMMs and the introduction of real-time verification. (Nov 2003- Jun 2004).

Main Deliverables:

- **Add data assimilation and routine monitoring to the SW Asia CAMM**
- **Port the CAMMs to the new super computer, NEC SX6.**

The Middle East CAMM remained the only CAMM to assimilate observations, having its performance routinely monitored and compared with the global model, providing objective evidence that showed that the CAMM added value to the global model forecasts. *The SW Asia CAMM remained a lesser 'sibling' compared with the Middle East CAMM; it would be beneficial if all CAMMs were routinely monitored.*

With the introduction of a new NEC SX6 supercomputer at the Met Office, significantly more computer resources became available. This provided the capability to add data assimilation and real time monitoring to each operational CAMMs. This in turn provided the opportunity to observe and document the positive impact a data assimilation scheme has on an operational CAMM, in SW Asia.

The new SW Asia CAMM forecast suite, including the assimilation of observations was built and tested on the NEC SX6. The same selections of observation types (Surface, RadioSonde and Satellite) as used in the Middle East CAMM are assimilated. The suite also included the required tasks to monitor the CAMMs performance, objectively verifying forecasts against observations enabling its comparison with the global model.

As mentioned previously, the performance of the operational SW Asia CAMM at the time was not routinely monitored. Thus during the testing of the new SW Asia CAMM, a verification system was put in place to objectively compare the 'old' operational SW Asia CAMM and the global forecast model within the SW Asia region with the new forecast suite. As expected the addition of the data assimilation scheme was very beneficial; full details are presented in **reference 3**.

For example, there was a significant improvement in the station temperature forecasts, **figure 4**. The above time series shows that for every day the new SW Asia CAMM was clearly the most accurate model (lowest RMSE). Other fields to improve with the addition of the assimilation of observations included: PMSL, 10m winds and cloud cover forecasts. The forecasts are improved because data assimilation improves the initial state of the models, matching the model closer to observations.

This is most noticeable in the T+0 (analysis) 10m wind fields, **figure 5**. The forecast only version of the SW Asia CAMM was initialised daily with global model data. The global model resolves less orography within the Himalayas. The sudden change of model orography to that used in the SW Asia CAMM introduces some large wind velocities which are clearly undesirable as the model attempts to adjust to the orography change. The model with data assimilation is not initialised by global model data and hence the wind field is not prone to these problems.

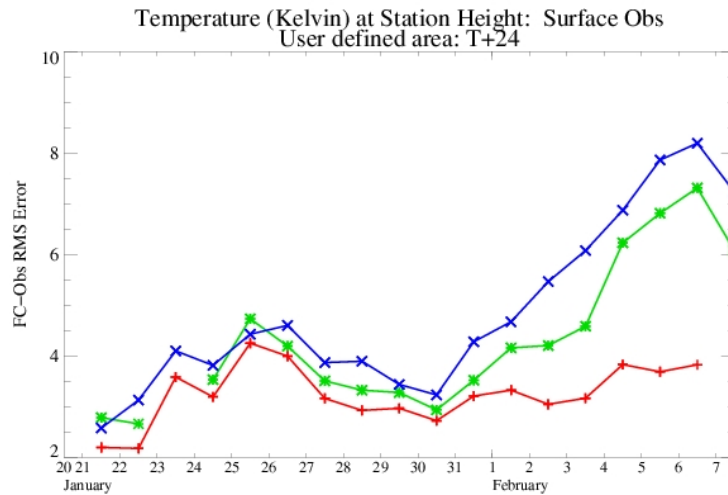


Figure 4: A timeseries of T+24 Station temperature RMS errors, global model (blue), Control (forecast only) SW Asia CAMM (green) and new SW Asia CAMM including data assimilation (red).

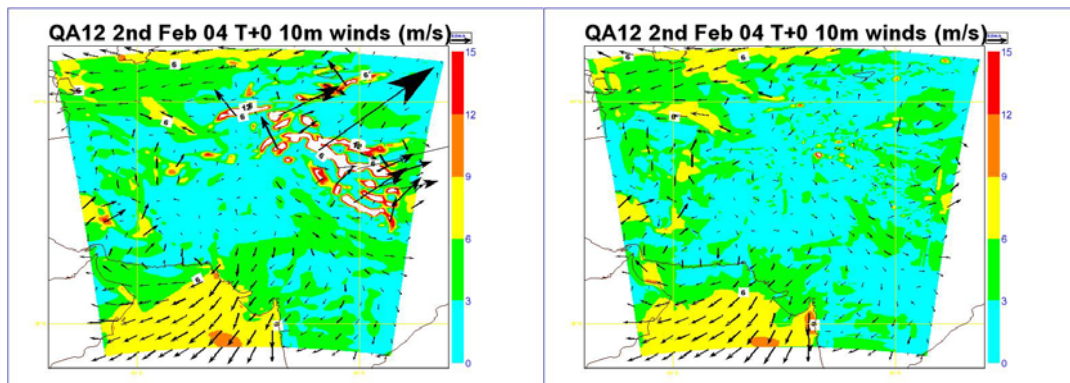


Figure 5: Example T+0 10m wind fields, Forecast only SW Asia CAMM initialised with global model data (left) and the SW Asia CAMM including data assimilation (right).

IGBP ancillaries

Each operational forecast model is dependent on a number of supplied climatological fields, for example the predominant vegetation type in a grid box, the average soil moisture, soil type etc. Ideally the source datasets for these fields would be of a higher resolution than the models. Prior to April 2004 the vegetation climatological fields employed (Wilson & Henderson-Sellers) were of 1 degree resolution, coarser than the 17km (~0.15 degree) resolution of the CAMMs. A new 1km resolution dataset of vegetative land cover fields became available, the IGBP (International Geophysical Biophysical Programme) dataset and it was decided that this should be included within the CAMMs when they went operational on the NEC SX6.

Figure 6 presents example comparisons of the climatology changes; to the water and soil fractions in a land grid box. Note how the IGBP dataset can ‘resolve’ the River Nile while previously it was a lake! The new ancillaries were tested in both the SW Asia and Middle East CAMMs, but they yielded little change to the models forecast skill. However the higher resolution datasets will enable future upgrades to the horizontal resolution of the CAMMs.

The Middle East and SW Asia CAMMs (including data assimilation, routine monitoring and the new IGBP fields) went live on the NEC during April 2004.

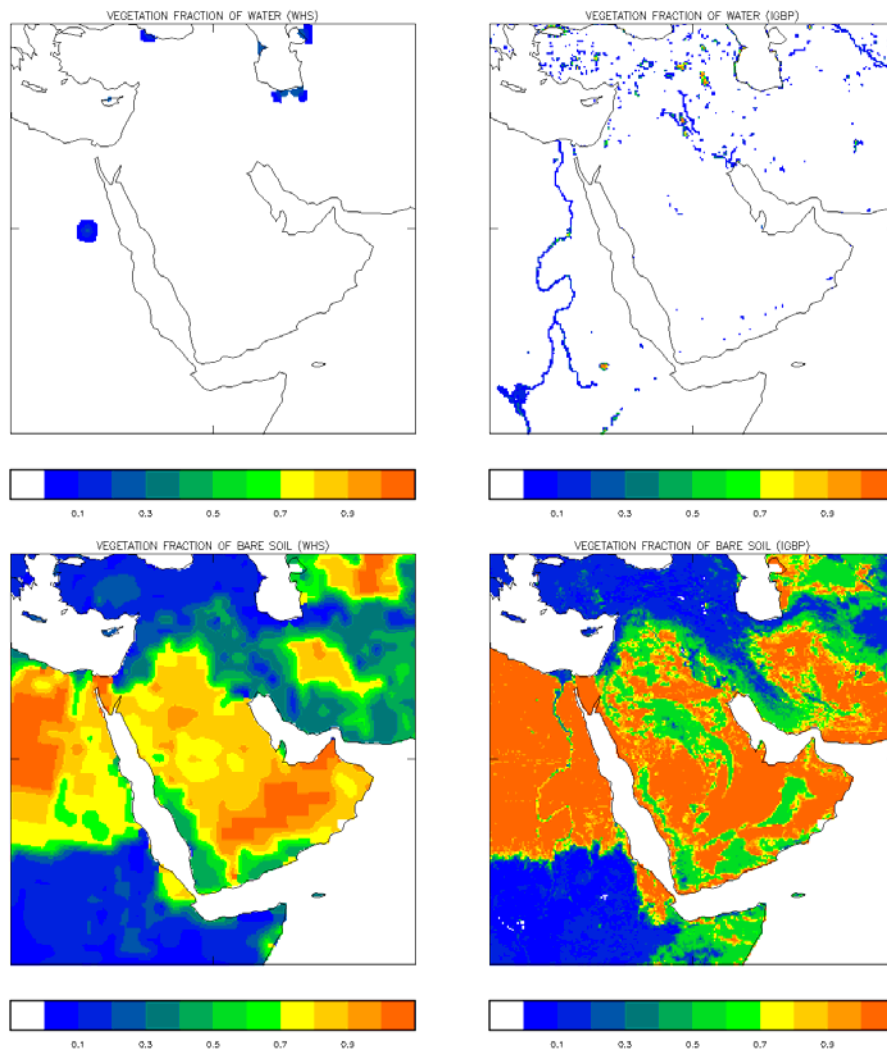


Figure 6: Vegetative fractions in a grid box, Water WHS (top left) IGBP (top right), bare soil WHS (bottom left), IGBP (bottom right).

Improved Data Assimilation settings.

Data assimilation was added quickly to the Middle East CAMM prior to Operation Telic. It is more than likely that the settings used in its implementation (and subsequently in the SW Asia CAMM) are not optimal, leaving some room for further improvement. The remainder of stage 2 looked at the impact of using the latest preferred NAE data assimilation settings.

The aforementioned summer 2003 GPSs in the Middle East CAMM had a strong correlation with some assimilated station temperature and relative humidity (RH) observations. It was thus decided at the time (prior to this project) to withdraw the assimilation of these observation types with the aim to improve model stability.

However the removal of the station temperature and RH observations from the assimilation cycle did not entirely resolve the model stability problems. As presented in stage 1 the upgrade of the CAMMs science, including 'Targeted Diffusion' alleviated the GPSs. With this in mind it was decided to see if it was now possible to re-introduce station temperature and RH observations along with the latest preferred Data assimilation settings as used in the developing NAE model.

Initial trials of the assimilation upgrade showed that it was not possible to re-introduce all station T and RH observations. On rare occasions a small number of observations may be at great 'odds' with the model. This yields large increments (~9K) to the model from the assimilation scheme that can kick off GPSs leading to model failure.

Re-initialising a failed CAMM run from global data will lose all the high resolution structures in the spun up CAMM model fields. Instead a compromise solution was proposed where the vast majority of the station temperature and RH observations are assimilated, while excluding observations that are at great odds with the model. This compromise yields objective improvements to the model analyses and subsequent forecasts of station temperature (**figure 7**), RH (**figure 8**) and cloud cover while maintaining model stability.

The longer term goal is to assimilate all surface observations that pass through quality control. The reason why we currently have to exclude a very small minority of quality controlled surface observations, which are in disagreement with the model, is being actively investigated. It is probably linked to a current deficiency in the model science.

Improvements are small and are not easily seen within day to day forecasts. **Figure 9** depicts an example geographical distribution of station temperature error (forecast-validating observations) for a randomly selected case from the trials of the compromise data assimilation upgrade. The upgrade (RHS) at both analysis time and twelve hours later has marginally reduced errors.

This upgrade was not implemented during stage 2 due to its minimal improvements; instead it was decided that this would be introduced as part of the next major upgrade to the operational CAMMs, full results are presented in **reference 4**.

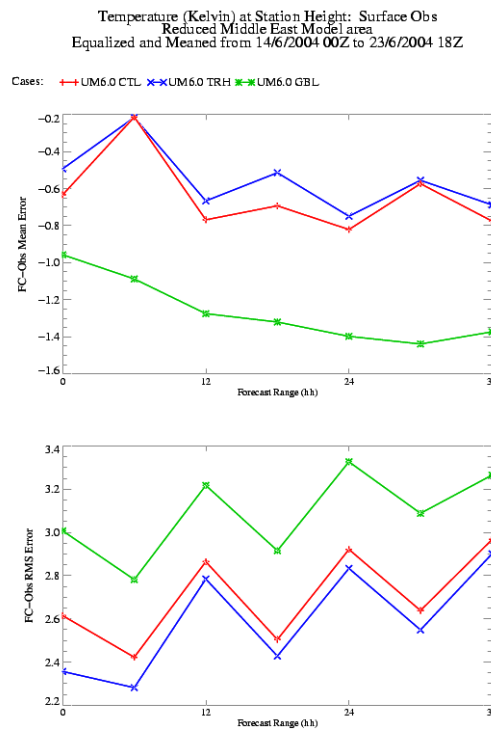


Figure 7: Mean station temperature bias (top) and RMSE (bottom) within the Middle East domain, Control ME CAMM (red), Upgraded ME CAMM (blue) and global model (green).

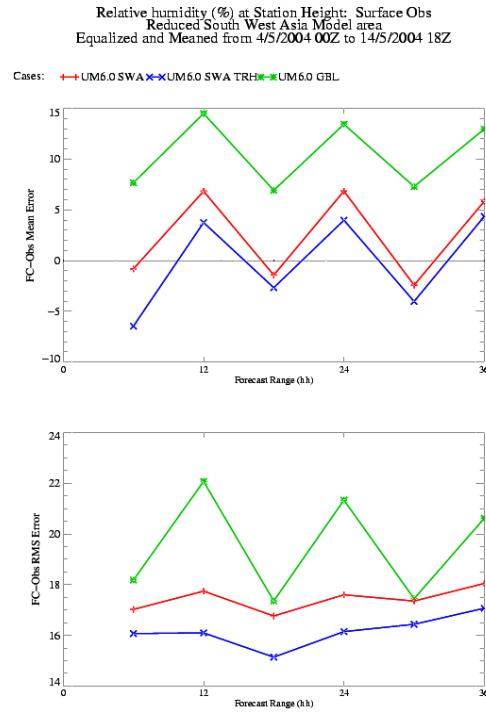


Figure 8: Mean station RH bias (top) and RMSE (bottom) within the SW Asia domain, Control SWA CAMM (red), Upgraded SWA CAMM (blue) and global model (green)

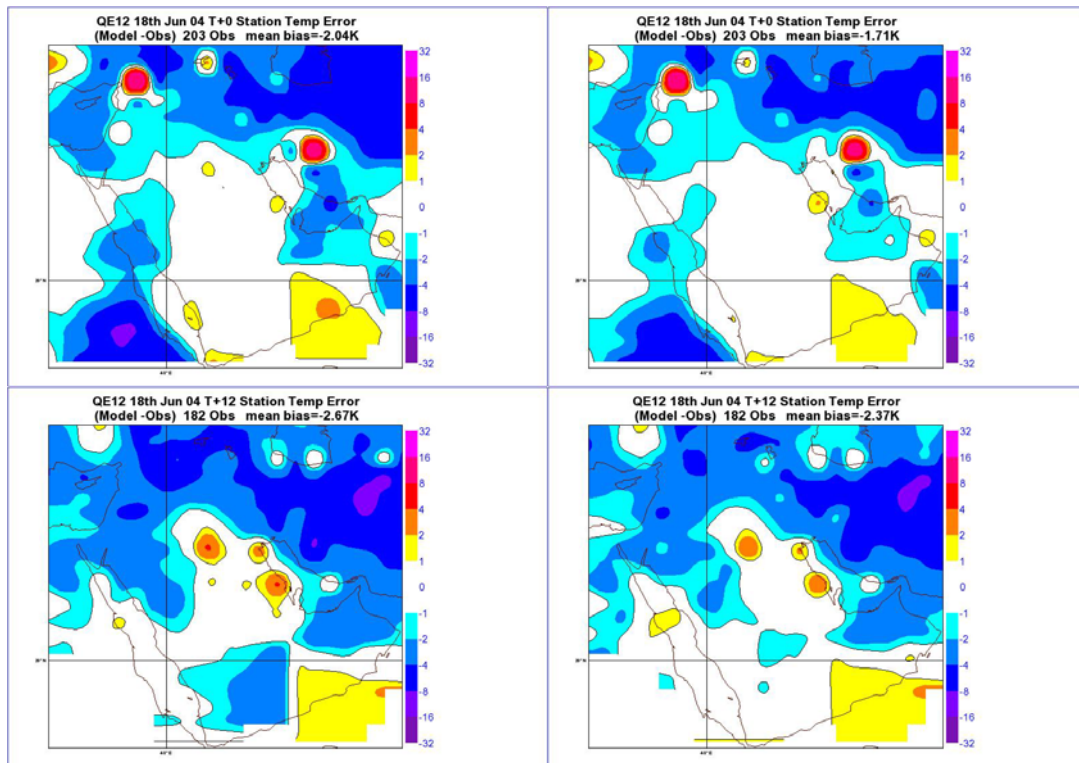


Figure 9: QE12 18th June 2004 Station temperature errors at T+0 (top) and at T+12 (bottom). The control is on the left and the upgrade CAMM on the right.

Stage 3: Generic CAMM suite and systematic model errors (Jul 04-Mar 05)

Main Deliverables:

- Create a generic CAMM suite easily relocated around the globe.
- Test the generic CAMM suite in a selection of climate regimes
- Document the CAMMs performance in these regimes in both a winter and summer season.

Stage 3 was the most ambitious stage within the CAMMs upgrade project. The collective aim of the above was to provide the capability to locate a CAMM (with the latest preferred science options), within a reasonable time-frame, anywhere on the globe and also have some insight into how we would expect it to perform compared with the global model.

Creating a generic CAMM suite requires an understanding of each component within the CAMM forecast suite; for example creating underlying climatological files (ancillaries), the Suite Control System (SCS), the Unified Model (UM) forecast components, the Observation Processing System (OPS) , Data Assimilation (VAR), and the objective verification suite (VER). It was most important to establish whether and how each of these tasks was domain dependent. Upon documenting each required change to relocate a CAMM, a 'generic' CAMM forecast suite was built, including a similar selection of observation types (Surface, RadioSonde and Satellite) as used in the operational CAMMs.

*This documentation has since evolved into a complete 'step by step' user's guide to relocating limited area models around the globe, **reference 5**, not relying upon a detailed understanding of either VER, VAR or OPS systems. The guide has proved most useful in the creation of new operational limited area models both for Defence (the Falklands and Bay of Bengal) and other Met Office projects (Africa and New Zealand).*

Test Domain	Trial Period
Sahara CAMM	28 th Jun-27 th Jul 2004
Korea CAMM	11 th Aug-25 th Aug 2004
Indonesia CAMM	24 th Aug-26 th Sept 2004
North America CAMM	13 th Sep-21 st Sept 2004

Table 1: Trial periods for each test CAMM scenario.

The 'generic' suite was tested in a selection of climate scenarios, these included: Indonesia, Korea, the Sahara and North America, **figure 10**. Trials were run, during late summer 2004, in real time spanning 2-4 weeks in length, **table 1**. Results from each of the trials and the operational CAMMs are collated in a summer 2004 CAMM performance report, **reference 6**.

The aim was also to run each test domain during a *winter* season, but this proved impossible upon the redistribution of resources to develop a selection of new CAMMs (see below). Instead the corresponding winter report collates results from the operational CAMMs at the time (Middle East and SW Asia CAMM) and a selection of new models; the Bay of Bengal, Falklands and Southern Asia Model, see **reference 7**.

A major positive result from these studies has been to show that it is straight forward to relocate the CAMM system anywhere on the globe. Each test domain ran successfully, even with the assimilation of observations.

The benefits gained from the test CAMM scenarios:

New CAMMs, as required for operations, may now be created quickly anywhere on the globe using the generic CAMM suite and its related documentation.

The generic CAMM suite has already proved its worth in the creation of new operational CAMMs covering the Falklands and the Bay of Bengal, the latter in quick response to the Asian Tsunami disaster, see below.

The CAMMs provide added value over the global model forecasts, for surface temperature, RH, the portrayal of precipitation events and low level winds.

The two systematic error reports together form a significant comparison study of the CAMMs with the global model. *(A taster/summary of what is covered within the summer and winter systematic error reports is presented in Appendix B.)*

The reports provide a valuable insight into what may be expected from future CAMMs and also upon increasing the global model resolution. They present both the strengths and the weaknesses of the CAMMs across differing climate regimes; the weaknesses are being addressed in future model upgrades.

The test CAMMs also identified a small number of domain dependent bugs/errors in the underlying Unified Model code. These have been corrected and hence the generic CAMM has proved most useful in rooting out previously unknown issues.

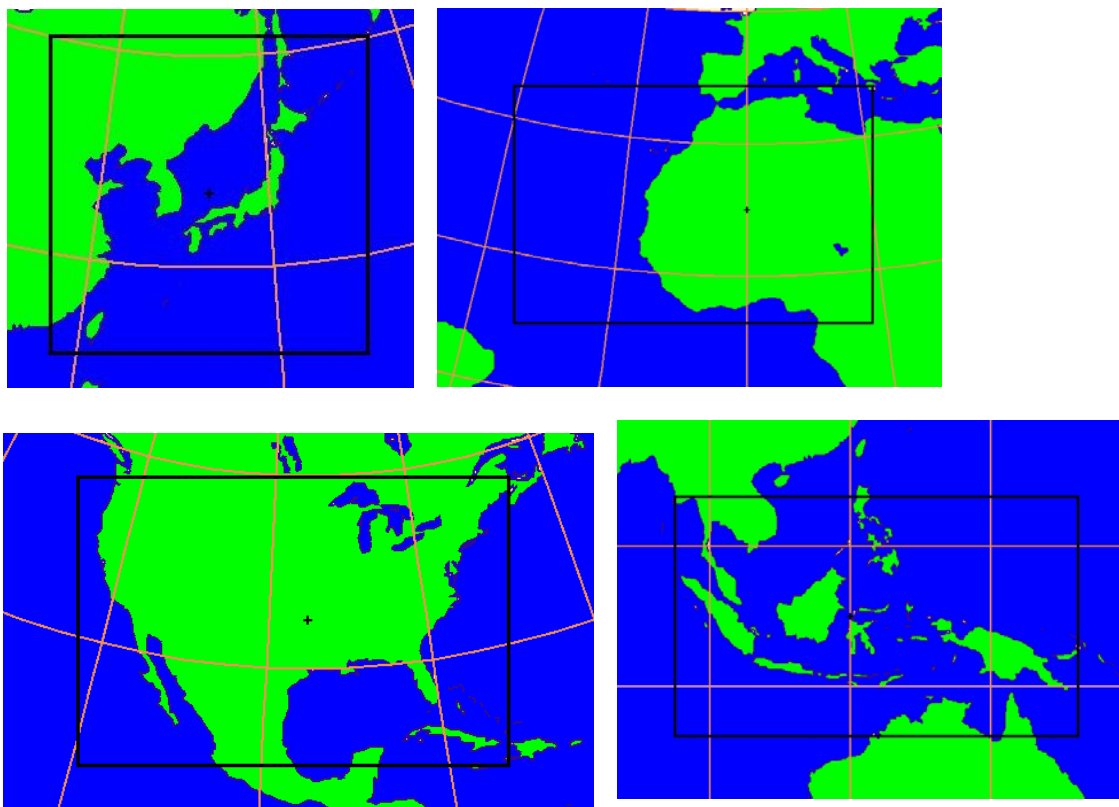


Figure 10: The test scenario CAMM domains, Korea, Sahara, North America and Indonesia.

Falklands CAMM

During summer 2004 a request was received from PMetO MPA for a trial Falklands CAMM to be run, initially for 6 months. It was agreed that the daily forecast cycle of the Falklands CAMM would only include a single main forecast, at 18z out to T+48. This fitted in well with MPA forecasters' daily schedules, ensuring they had time to subjectively assess the Falklands CAMM performance comparing it with the global model. The Falklands CAMM went operational on 5th October 2004.

Forecasters at MPA have had some problems with data feeds and hence they have not received all the forecasts. The trial has been extended to 12 months so to include a Falklands winter and enable MPA to gather more subjective evidence. The Falklands CAMM objective performance during the first 6 months has been summarized in a short report, **reference 8**.

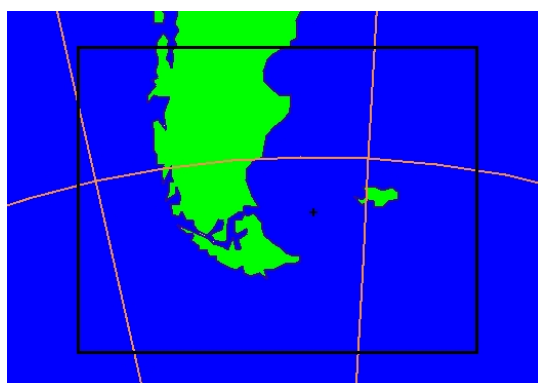


Figure 11: Falklands CAMM domain.

The Falklands CAMM provides more detailed forecasts but these do not appear to yield a better forecast skill than already available from the global model. The small sample of available validating observations within the domain may be having an impact on the objective verification. Thus far a couple of case studies received from MPA (one linked to a heavy precipitation event and the second rotor activity) have shown that the CAMM provides useful added value. A decision whether to continue funding the Falklands CAMM is to be made once MPA supply their complete subjective evaluation.

Bay of Bengal CAMM

In response to the Asian Tsunami disaster the Met Office decided it would set up a CAMM to aid the relief efforts by freely providing forecasts for the region on the Met Office external web pages.

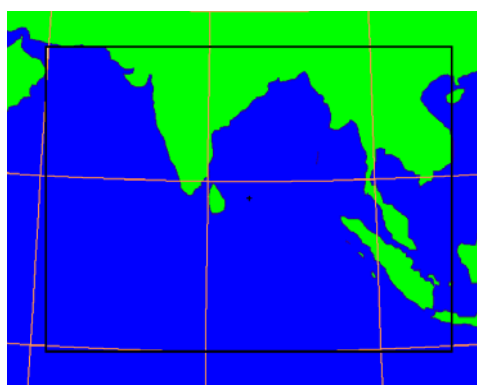


Figure 12: The Bay of Bengal domain.

Drawing upon experience gleaned from the SW Asia CAMM and the test Indonesian CAMM, a Bay of Bengal (BOB) CAMM (**figure 12**) went operational within seven days and products appeared on the external web **figure 13**. Forecast guidance was available for Sri Lanka, Aceh, the Maldives and Western Thailand.

The CAMMs upgrade project provided the capability to deliver a full CAMM suite, including data assimilation at short notice. The 'generic' suite climate regime tests also provided advance insight into the expected BOB CAMM performance compared with the global model and hence a short guidance note was supplied to the Met Office forecasters, **reference 10**.

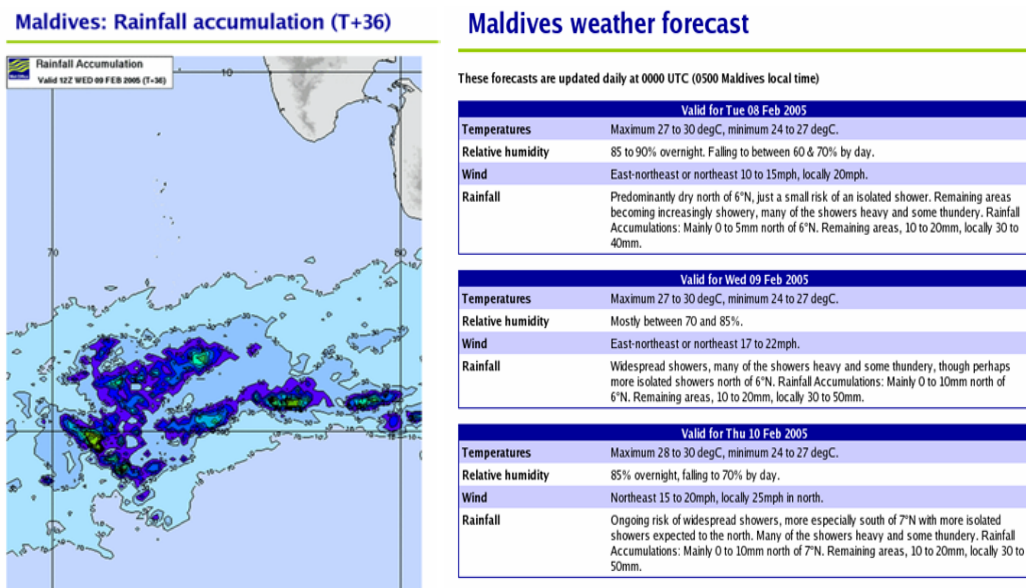


Figure 13: Example Maldives forecast guidance derived from the Bay of Bengal model, as was available on the Met Office external web site.

<http://www.metoffice.gov.uk/weather/asia/seasia.html>

While BOB CAMM was being set up to aid relief efforts, another new CAMM with a new science package was also being developed, the Southern Asia Model (SAM). SAM is a large regional model replacing both the Middle East and SW Asia CAMMs. As it also encompassed a large part of BOB CAMM it was decided that BOB CAMM would be retired once SAM was operational.

The Southern Asia Model

The Southern Asia Model (SAM), **figure 14**, replaced both the current Middle East and SW Asia CAMMs on 14th June 2005, with BOB CAMM being switched off a week later. SAM is a major upgrade ensuring that the CAMMs remain at the forefront of NWP forecast capabilities.

The new model included:

- A new larger domain encompassing both the current Middle East and SW Asia CAMMs, resolution remains the same.
- The inclusion of HadGEM physics
- Assimilation of station temperature and RH observations and the use of the preferred data assimilation settings, as in the NAE.

The new domain yields a number of benefits, for example, a simplified operational forecast suite, only a single model need be maintained for the region. A larger section of the Himalayas lies within the CAMM rather than forming a boundary as in the previous SW Asia CAMM; the latter can lead to numerical problems. The previous operational CAMMs overlapped and thus computer resources were wasted running two forecasts for similar areas.

The global model was recently (18th January 2005) upgraded with the new physics package, HadGEM physics (Milton et al 2005), bringing the NWP model closer to the new climate version of the Unified Model. This included upgrades to both the boundary layer and microphysics schemes and a small number of corrections.

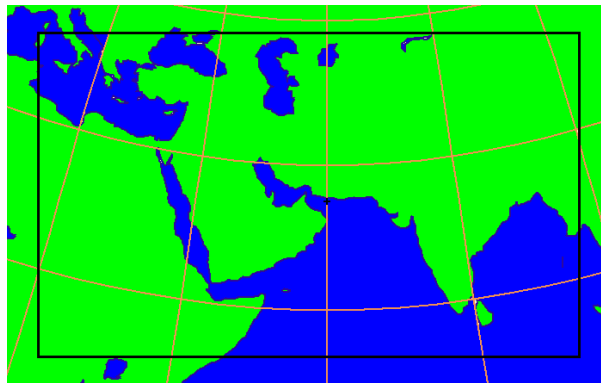


Figure 14: The Southern Asia Model domain.

The physics upgrade has been shown to counter a notorious winter low cloud problem over Iraq where previously erroneous low cloud could remain throughout a forecast, in turn depressing forecast surface temperatures. HadGEM physics also improves global tropical model performance, for example the tropical winds and convective precipitation over the sea. These promising results made a strong case for the inclusion of HadGEM within the new Southern Asia Model.

As previously described, new data assimilation settings and the re-introduction of station temperature and RH observations was trialled within stage 2. These settings are also included within the SAM alongside RTTOV vn7 processing of ATOVS satellite data, now used in both the NAE and global model.

The Southern Asia Model is a major upgrade and thus has undergone rigorous trials spanning January to June 2005, (detailed results spanning Jan-April 05 are presented in **reference 9**) checking model stability and model performance. It was essential that the introduction of SAM did not lead to a significant detrimental impact on forecast performance within the region, thus SAM was compared against both the previous CAMMs and the global model. The trials yielded some encouraging results. SAM, like the previous CAMMs, adds value to the global model supporting operations within the region. Within the SW Asia domain, SAM provides improved forecast accuracy for station temperatures (**figure 15**) RH and cloud amount. The 10m wind speed bias is slightly increased. Within the Middle East domain SAM does not fair quite so well. It generally outperforms the global model but does not quite match the previous CAMM objective performance. For example, SAM is systematically $\sim 0.3\text{K}$ cooler than the Middle East CAMM, (the global model is $\sim 0.5\text{K}$ cooler than SAM), **figure 16**.

The slightly cooler forecasts within the Middle East domain appear to be linked to occasional poor forecasts valid at 00z ($\sim 4\text{am}$ local time, near the diurnal minima). One such example was the T+12 forecast on 5th Feb 2005, **figure 17**. The slightly cooler bias is not that perceptible to the eye, but upon looking at the corresponding error chart (Model-observations), **figure 18**, one can see that both the global model and SAM do indeed have a cooler bias valid at 00z 6th Feb 2005. Overnight cool errors appear to be linked to the HadGEM physics rather than a synoptic weather type and investigations continue. SAM forecasts valid at 12z are similar to those in the Middle East CAMM.

The Southern Asia Model does better for other fields outperforming the current Middle East CAMM in forecasts of broken cloud cover (the winter systematic error report showed us that HadGEM physics reduces low cloud cover amounts) and short range station RH forecasts. Again the wind speed bias is slightly increased.

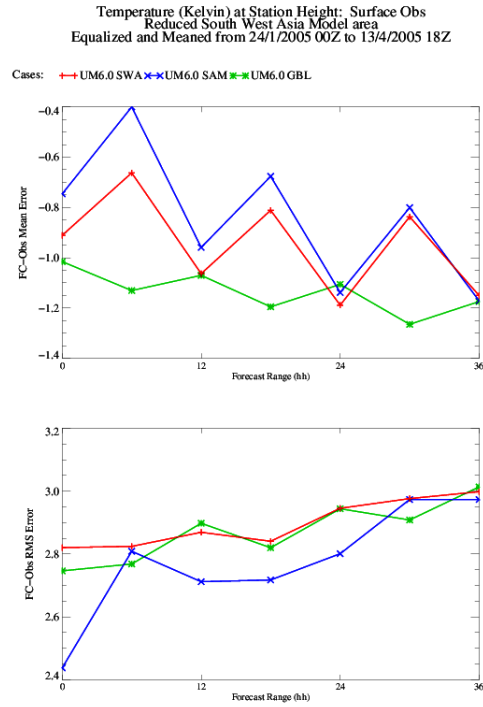


Figure 15: Station temperature bias (top) and RMSE (bottom) within the SW Asia domain, SW Asia CAMM (red), SAM (blue) and global (green).

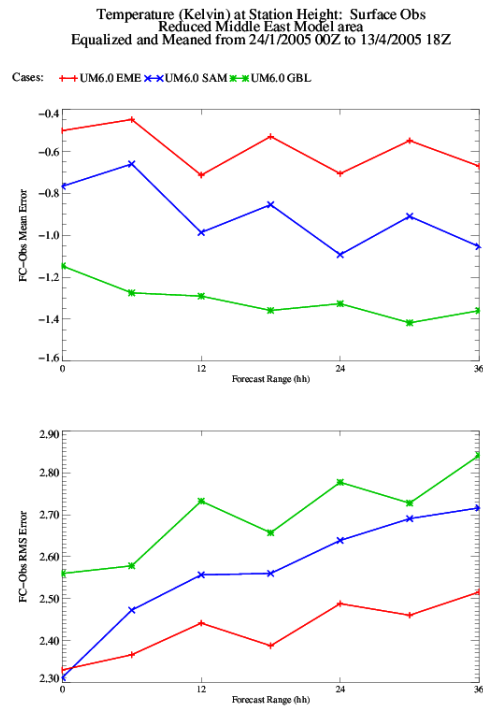


Figure 16: Station temperature bias (top) and RMSE (bottom) within the Middle East domain, Middle East CAMM (red), SAM (blue) and global (green).

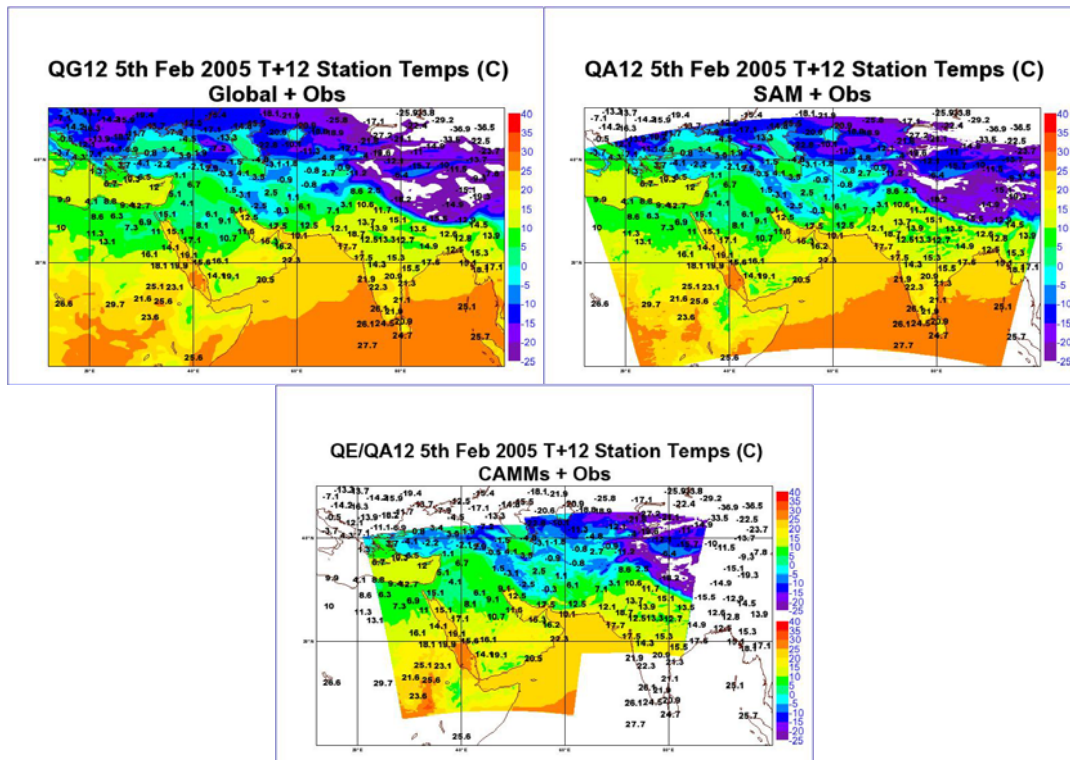


Figure 17: Example 12z 5th Feb 2005 T+12 Station temperature forecasts, Global model (top left), SAM (top right) and Middle East/SW Asia CAMMs (bottom) with validating observations over-plotted

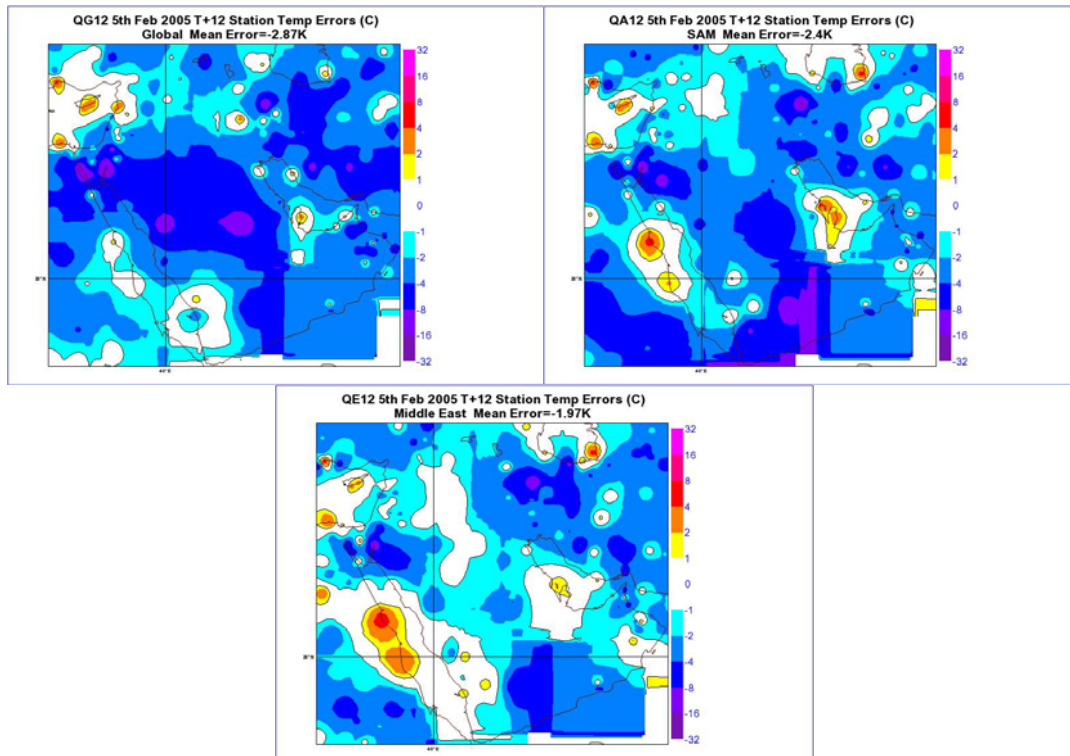


Figure 18: 12z 5th Feb 2005 T+12 Station temperature errors within the Middle East domain, Global model (top left), SAM (top right) and Middle East CAMM (bottom).

Future Work:

The continued maintenance and upgrade of the CAMMS capability will now be funded through a joint Defence Met Programme (DMP), which enables pull through of MoD corporate S&T projects into operations.

The CAMMs shall continue to follow the development path of both the global and NAE models to ensure that the CAMMs remain at the forefront of NWP capabilities.

Future upgrades will also aim to address current CAMM weaknesses identified in the generic CAMM systematic error reports.

For example; there appears to be a link between a slow but systematic increase in CAMM station temperatures with time. In regions where arid bare soil is prevalent (for example in the Middle East or the Sahara) there is a strong correlation between station temperature systematic errors (forecast-analyses) and the soil moisture climatology. Currently the soil moisture in the operational CAMMs is reset daily to climatology, thus prohibiting the surface forcing of the CAMMs from responding to local precipitation events. A soil moisture analysis is currently being developed for the global model. Feeding this analysis into the CAMMs is likely to have a beneficial effect on the slow temperature drift. (See Appendix B for more details.)

The current assimilation settings used within the CAMMs still leave much room for improvement. The covariance statistics (Covstats) employed within the NAE and CAMMs data assimilation schemes were originally calculated for the UK Mesoscale model. Covstats are domain dependent and future studies will consider a more appropriate set of covstats for the region, derived from a subset of the routinely calculated global model covstats.

Future upgrades include⁴:

1. employing the latest released version of the UM code, e.g. UM6.1
2. a periodic upgrade of model science, using the preferred options, eg prognostic cloud.
3. a periodic upgrade of data assimilation to utilising the latest available observations.
4. the use of global soil moisture analyses
5. an increase in vertical resolution.

⁴ If compute resources are available and trial results demonstrate a positive impact.

Appendix A: A guide to the report figures.

Within this report a number of differing figure types are presented. Here we provide an explanation of the two of the main types.

Objective Verification: These plots provide a direct objective comparison between models, where each model forecast is compared with the validating observations.

The majority of the verification plots in this report are averaged over a given model domain (area average) and also over a given period (trial period). The plots present the average bias ($forecast - observations$)

and the Root Mean Square Error (RMSE)

$$\left(\overline{(forecast - observations)^2} \right)^{1/2}$$

against forecast range. The latter provides an insight into the pattern matching of the forecast with the observations; the better forecast skill.

This does have its limitations. Small scale features (more readily resolved in high resolution models) can appear to yield worse forecast skill than forecasts from a low resolution model. In data sparse regions of the globe the observation field does not resolve small scale features and hence it is likely to match with a smooth low resolution model better. Secondly in an area of large gradients in a field, a high resolution model may correctly predict the gradients but any positional error in the feature will have a large detrimental effect on the RMSE, again a smooth low resolution model will appear to provide the better forecast skill while never actually forecasting such an extreme event.

Figure 4 is a timeseries plot which presents the forecast skill (RMSE) from each model forecast in turn rather than averaging them over the trial period.

Systematic error/mean plots:

Stage 3 collated a selection of 'systematic' error/mean plots as included in Appendix B. These plots are averaged over a large number of forecasts ($forecast - analysis$) for a given forecast range. They depict the geographic systematic drift of the model away from model analyses. We assume here that validating analyses are 'truth'. Systematic model errors tend to grow with forecast range and T+36 is the greatest forecast range available from the test trials.

Occasionally single case event model errors ($forecast - observations$) are also presented (i.e. figure 9 and 18). Here the model forecast grid is interpolated onto the known observation points, the errors are calculated and then interpolated back to the model grid, with the resulting error map portrayed.

Appendix B: Generic CAMM results in differing weather regimes.

The summer report compares CAMM performance in each domain with the global model. Rather than purely concentrate on objective verification (forecast skill) the report also investigates re-occurring systematic model errors and proposes links between current known model deficiencies and the systematic errors. A number of the systematic errors will be addressed in future model upgrades.

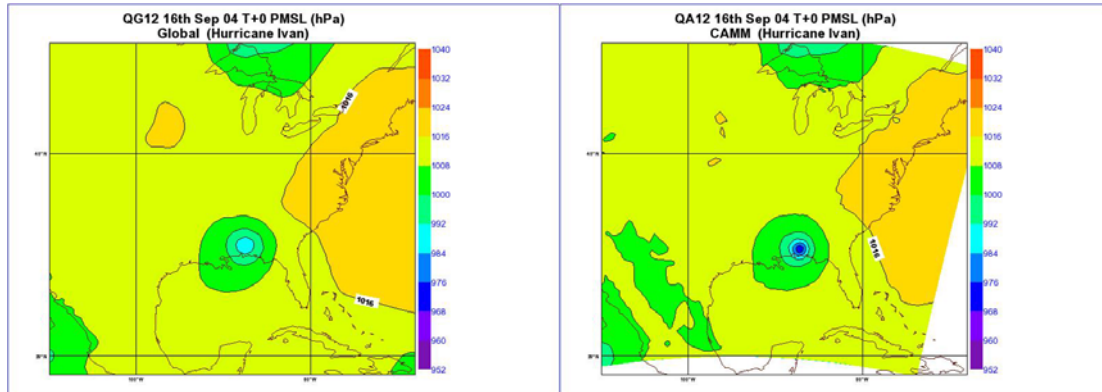


Figure 19: Analysed PMSL Sep 16th 12z 2004, global (left) and North American CAMM (right).

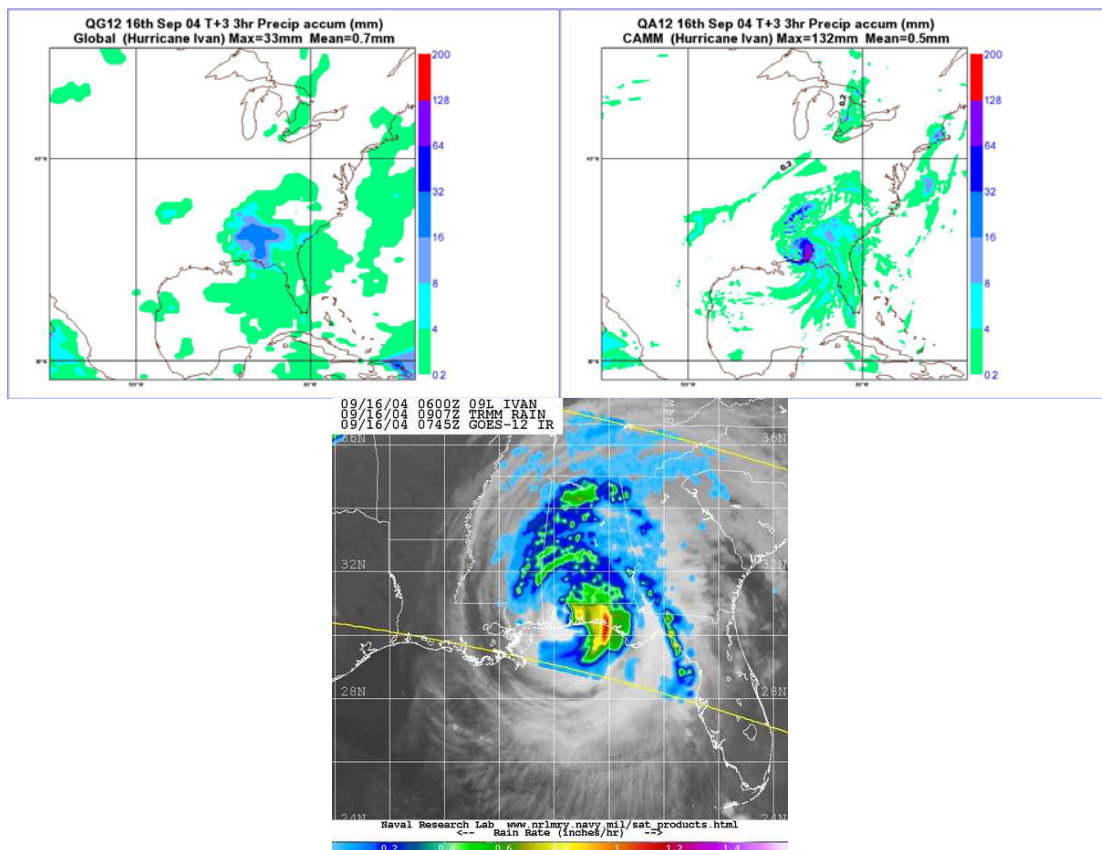


Figure 20: 3hr accumulations of precipitation (mm) 12z-15z 16th Sept, global (top left), CAMM (top right) compared with TRMM observation of rain-fall rate (inches/hr) at 0907Z

The test CAMMs were in place for a couple of ‘extreme’ weather events; namely Hurricane Ivan and Typhoon Megi. This provided the opportunity to see the positive impact that model resolution can have on extreme event forecasting. The extra model resolution in the CAMMs enabled the models to resolve deeper central pressures in these systems, (**figure 19**) closer to observations

and forecast more realistic stronger winds. Subjectively the CAMMs also yielded more accurate portrayals of the precipitation structure in both storms, **figure 20**.

In general the CAMM station temperature biases in both analyses and subsequent forecasts are closer to observations than those in the global model; the latter tends to be cooler. There appears to be a link between a slow but systematic increase in CAMM station temperatures with time and a supplied climatology. In regions where arid bare soil is prevalent (for example in the Middle East or the Sahara) there is a strong correlation between station temperature systematic errors (forecast-analyses) and the soil moisture climatology, **figure 21** and **22**, *note the 'blocky errors'*.

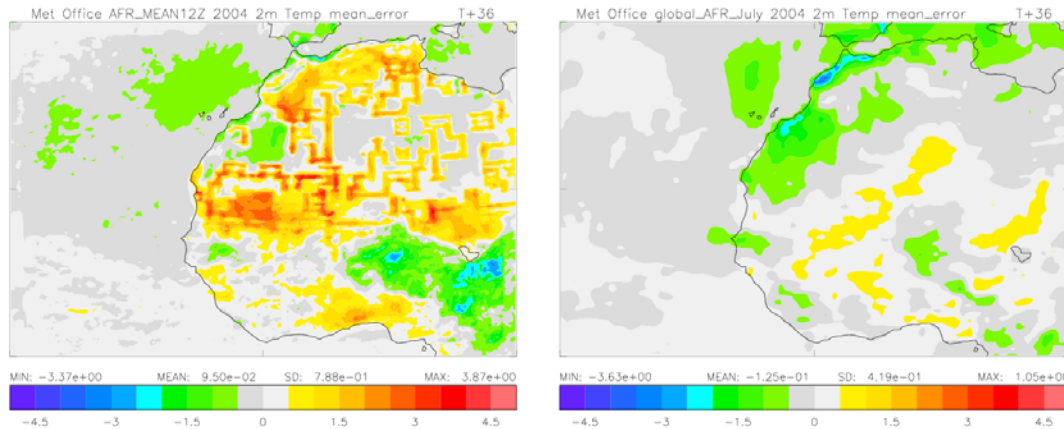


Figure 21: Systematic mean T+36 station temperature error (forecast-analysis) within the Sahara domain, CAMM (left) and global model (right). [July 2004].

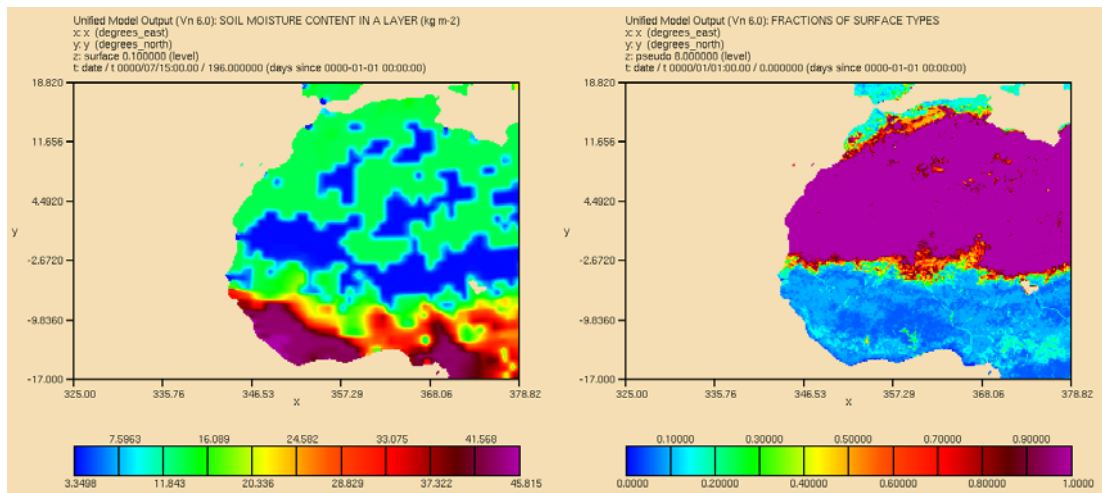


Figure 22: Sahara CAMM July ancillary fields of Soil Moisture (left) and bar soil fraction (right).

Currently the soil moisture in the operational CAMMs is reset daily to climatology, while the global model is reset weekly. This resetting prohibits the surface forcing of the CAMMs (and the global model to a lesser extent) from responding to local precipitation events. A soil moisture analyses is currently being developed for the global model. Feeding this analysis into the CAMMs is likely to have a beneficial effect on this slow temperature drift. *Note: Stage 2 investigated the reintroduction of station temperature and RH observations within the CAMM assimilation step. It is planned that the CAMMs will assimilate these observations from summer 2005 and this will further improve the forecasts of station temperatures.*

Mean twenty four hour accumulations of precipitation from each CAMM match better with satellite TRMM (Tropical Rainfall Measuring Mission) observations than those from the global model. The increased model resolution enables the CAMMs to forecast more intense localised events, while the global model tends to smooth out the precipitation fields. **Figure 23** presents the July average 24 hr precipitation within the Middle East domain.

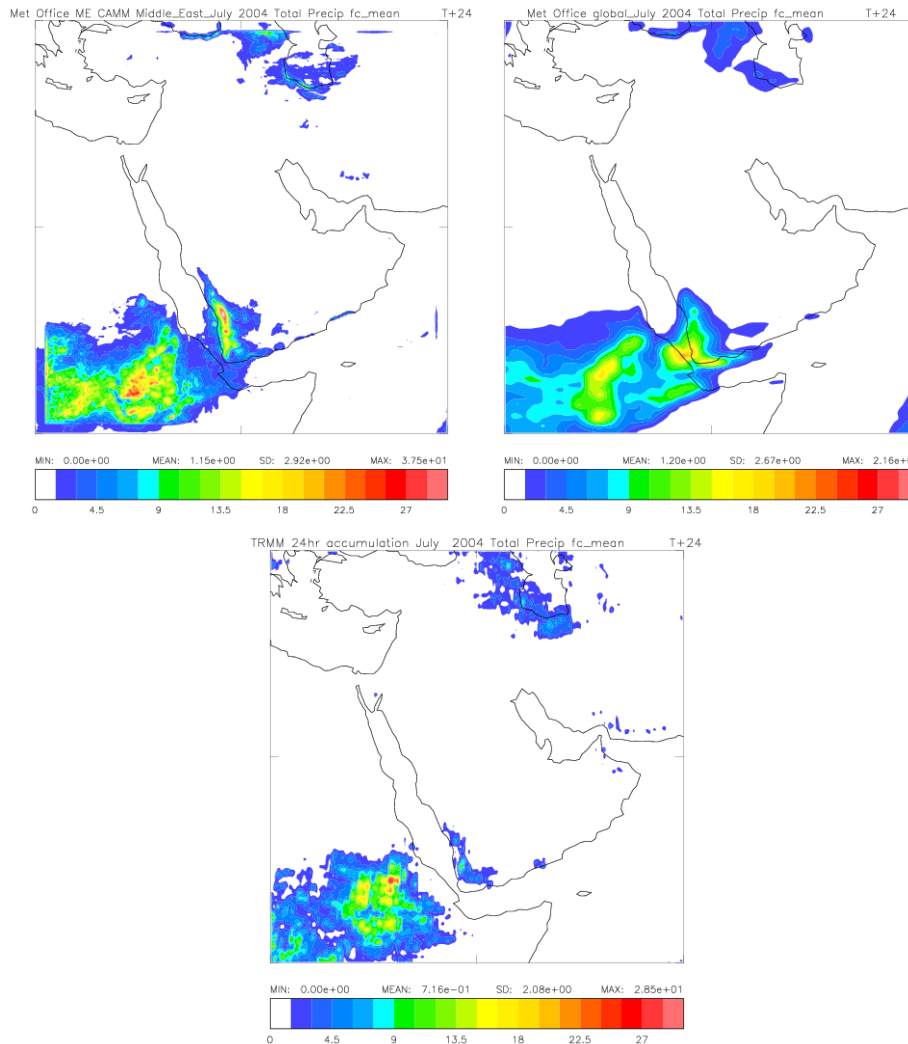


Figure 23: Mean 24hr accumulation of precipitation within the Middle East domain, CAMM (top left), global (top right) and TRMM observations (bottom).

A more detailed study of the diurnal cycle within the tropics using the Indonesian CAMM has shown signs that as model resolution increases the diurnal cycle within the tropics may be improved, with precipitation initiating and ending later in the day. Currently most NWP models initiate convective rain events too early in the day. This study is being collated with a project looking at 4km modelling within tropical Africa and results will be presented at this year's RMetSoc conference in September.

CAMM 10m wind speeds tend to be slightly stronger than those seen in the global model. This is a direct consequence of the increase in model resolution and its ability to resolve sharper synoptic/model features and their related gradients. **Figure 24** depicts example mean analysed 10m wind speeds during the Korean trials. Forecasters at Strike Command have noted that Middle East CAMM 10m wind speeds are, in general, closer to observations than those forecast by the global model. This is particularly important for dust storm forecasting.

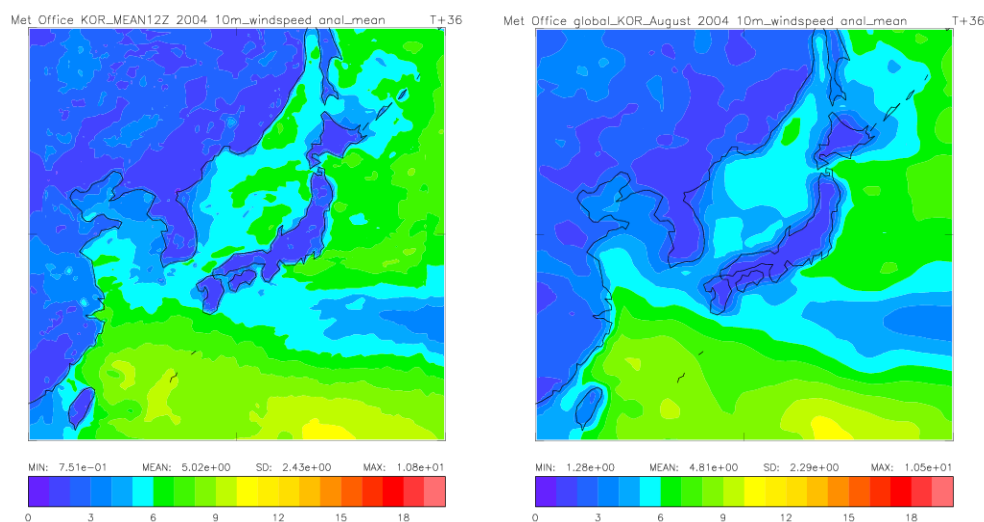


Figure 24: Mean analysed 10m wind speed within the Korean domain, CAMM (left), and global model (right).

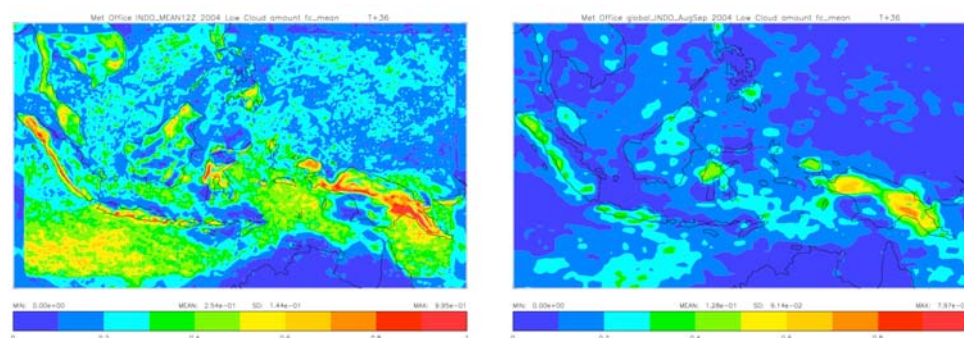


Figure 25: Mean forecast low level cloud within the Indonesian domain, CAMM (left) and global (right).

The CAMMs tend to forecast more cloud cover than the global model, especially low level cloud over oceans; **figure 25** depicts example low level cloud cover within the Indonesian domain. A problem over Iraq of erroneous fog and low cloud prediction by the CAMMs and the global model has been previously highlighted by forecasters. This leads to suppressed forecast model temperatures. A new science package proven to successfully dissipate the Iraq fog problem (HadGEM physics) went live in the global model in January 2005. This is planned to go operational within the CAMMs in June 2005.

Testing of the latest preferred physics package (HadGEM which includes improved boundary layer and microphysics schemes) within a couple of the CAMMs appears to have a positive impact on the low level cloud amounts over oceans, reducing the cover towards that forecast by the global model, **figure 26** and improving the forecast skill.

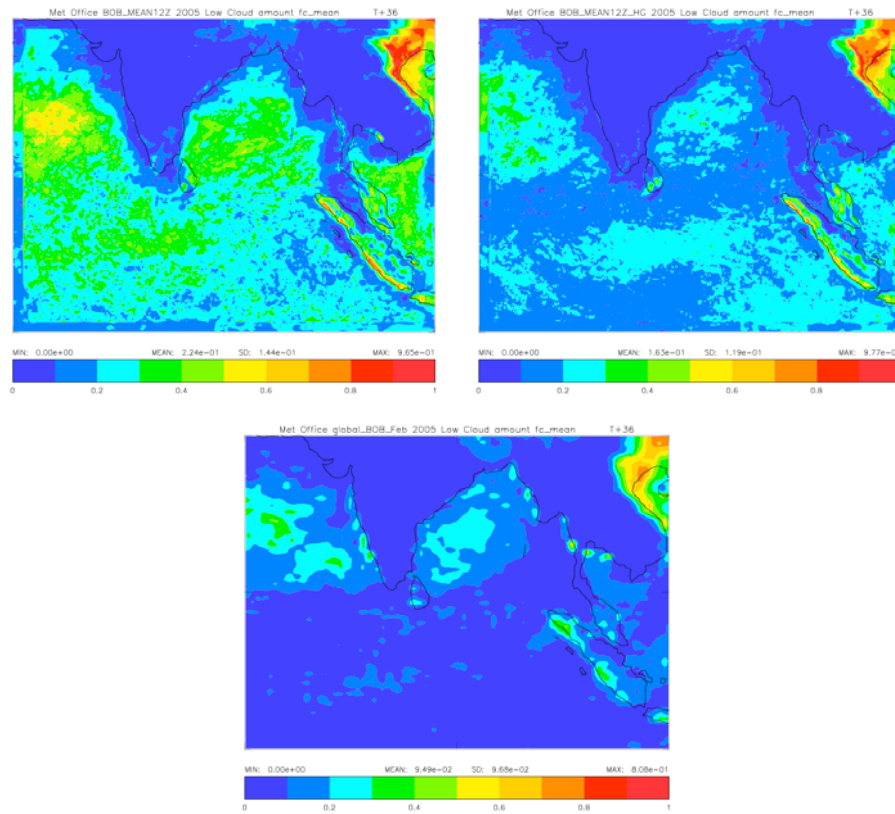


Figure 26: Mean diagnosed forecast low level cloud amount during February within the Bay of Bengal domain, Original BOB CAMM (top left), HadGEM BOB CAMM (top right) and global model (bottom).

The two systematic error reports together form a significant comparison study of the CAMMs with the global model. They present the strengths and the weaknesses of the CAMMs across differing climate regimes. They also provide a valuable insight to what may be expected in future CAMMs and by increasing the global model resolution.

References⁵

Reference 1: The Middle East CAMM operational performance April-May 2003.
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Reference 2: Upgrade of the CAMMs to UM5.5, Middle East and SW Asia Results.
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Reference 3: Adding Data Assimilation to the SW Asia CAMM
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Reference 4: A data assimilation upgrade for the CAMMs.
Internal Project Report (July 2004)

Reference 5: Creating Limited Area Models: the tasks involved.
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Reference 6: Systematic Errors in the Crisis Area Mesoscale Models, summer 2004.
Internal Project Report (November 2004)

Reference 7: Systematic Errors within the Crisis Area Mesoscale Models, winter 2004.
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Reference 8: The Falklands CAMM (Oct 04-Mar05) *Internal Project Report* (March 2005)

Reference 9: The Southern Asia CAMM *Internal Project Report* (April 2005)

Reference 10: A Crisis Area Mesoscale Model for the Bay of Bengal, some notes for forecasters.
Internal Memo (January 2005)

Milton S, M. Brooks, A. Lock, E. Whelan, D. Wilson and R. Allen (2005): HadGEM1 physics package for the Global NWP model (Cycle G34), *Forecasting Research Technical report No. 458*, Met Office.

⁵ References are available from Glenn Greed (CAMMs project manager, Met Office).