Assessing the added value of MOSES-PDM as a source of soil moisture for the Met Office's 4 Km UK model

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Abstract

We assess the added value of an uncoupled land surface model (MOSES-PDM), driven by high resolution radar and satellite observations, as a source of soil moisture for the Met Office's 4-Km UK NWP model. This is achieved by comparing operational forecasts using soil moisture analyses derived from MOSES-PDM, with experimental runs initialised with either interpolated Global model soil moisture or climatology. Our experimentation is conducted during a three-month trial period over the summer of 2008 and includes three severe flooding events in the United Kingdom. Our main finding is that MOSES-PDM soil moisture gives no overall improvement in screen temperature and relative humidity verification over that obtained with interpolated soil moisture from the Global model's soil moisture nudging scheme. Both MOSES-PDM and Global soil moisture outperform climatology, which gives a relative warm dry bias of forecast surface temperature and relative humidity. For the three flooding case studies considered, MOSES-PDM soil moisture analyses do give a better representation of the high saturation of upper soil levels in the presence of significant precipitation when compared with interpolated Global model soil moisture analyses or climatology.

1 Introduction

When soil moisture is allowed to freely evolve within Numerical Weather Prediction (NWP) models, the error growth in soil moisture analyses may lead to an increase in the cool/wet or warm/dry biases of forecast surface temperature and relative humidity. Few direct in-situ measurements of soil moisture are currently taken globally although new sources of satellite data are becoming available, for example, global soil wetness products derived from satellite observations from the Advanced SCATterometer (ASCAT) by the Microwave Remote Sensing group at the Vienna University of Technology [1]. Even so, such products only consider the top 1cm layer of the soil and this lack of global observations make direct assimilation of soil moisture impossible. Because of the lack of direct observations of soil moisture, NWP relies on a variety of different types of meteorological observations used as a proxy in constructing an accurate soil moisture analysis.

In this study we assess the added value of the Met Office Surface Exchanges Scheme (MOSES) incorporating a Probability Distributed Moisture model (MOSES-PDM) as a source of soil moisture for the Met Office's 4 Km UK model (UK4). To achieve this, we evaluate three schemes: (i) an operational UK4 configuration run as a control experiment using a soil moisture analysis produced from the MOSES-PDM scheme; (ii) a UK4 model configuration using a soil moisture field produced by the Met Office Global model interpolated to the grid of the regional model; (iii) a UK4 configuration using a soil moisture analysis based on climatological values. We hypothesise that the MOSES-PDM soil moisture analysis has the advantages of high-resolution and good quality driving data, with the slight drawback that different soil properties necessitate a rescaling of soil moisture before use in the UM. Verification of each experiment is undertaken by running regular forecasts for a three month period during the 2008 summer season and by analysis of severe precipitation events occurring during this time.

2 Models

Before describing the detailed methodology used in this study, we give a brief overview of models used in this study.

2.1 MOSES-PDM

MOSES-PDM is an operational system developed at the Met Office for the real-time diagnosis of soil state and surface hydrology. It is based on the Met Office Surface Exchanges Scheme (MOSES) modified to take account of unresolved soil and topographic heterogeneity when calculating surface runoff by incorporating a Probability Distributed Moisture (PDM) scheme developed by the Centre for Ecology and Hydrology. High resolution soil characteristics and land cover data together with analyses of precipitation amount and type, cloud cover and near-surface atmospheric variables are used to drive MOSES-PDM. Hourly values are calculated of snowmelt, runoff, net surface radiation, evaporation, potential evaporation, soil temperature, soil moisture and soil moisture deficit on a 5km grid. A fuller description of the implementation of MOSES-PDM can be found in Smith et. al [8] and Moore [7]. Precipitation amount is derived from radar and surface observations and radiation is calculated from 3-dimensional cloud analyses derived from satellite data and surface observations.

At the time of this study, MOSES-PDM was implemented within a high resolution operational short-range forecasting system developed at the Met Office called NIMROD [6]. NIMROD was developed to fill the gap that exists between very short range nowcasting and NWP. This is achieved by integrating short-range NWP model guidance with nowcasting techniques using satellite and radar composite data encapsulated within five major components: observation processing (satellite and radar), NWP (assimilation and prediction), data blending, merged forecast and product generation. Since this study, the NIMROD system operating on a 5km grid was replaced in November 2008 by the UKPP (UK Post Processing) system with fields on a 2km grid.

2.2 The Met Office's 4 Km UK NWP model

The UK4 model is a regional NWP model with a domain centred over the United Kingdom, shown in Figure 1. It has a horizontal resolution of one grid point every 4 km on a rotated latitude/longitude grid and 70 vertical levels. Observations are assimilated every three hours with a 3DVAR assimilation scheme for conventional data and a Latent Heat Nudging scheme for rain rate data. The UK4 soil model used is similar to that in all other Met Office NWP models, comprising four layers each of the following depths in metres. $\{0.1, 0.25, 0.65, 2.0\}$. Soil type classification is based on the Wilson and Henderson-Sellers [10] data set and the hydrology scheme used is Clapp-Hornberger [3]. Soil parameters used in the Clapp-Hornberger scheme are calculated from fractions of clay/silt/sand using equations proposed by Cosby et. al [4].

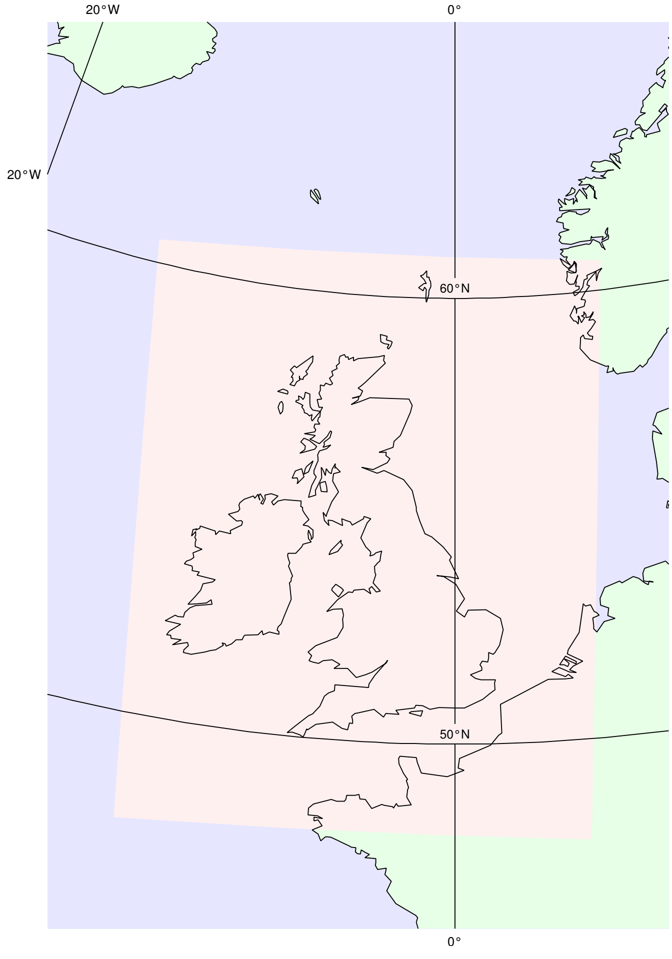


Figure 1: Domain of Met office UK 4 km model.

Parameter	Description
θ_f	Frozen soil moisture on a layer as a fraction of the amount of liquid water at saturation.
θ_u	Unfrozen soil moisture on a layer as a fraction of the amount of liquid water at saturation.
θ	Soil moisture content on a layer made up of θ_f and θ_u and converted to an absolute value by multiplying by θ_s.
θ_w	Wilting point: the soil moisture content below which evapotranspiration from vegetation is shut off.
θ_s	Saturation point: the point at which the soil is said to be fully saturated with water.
θ_c	Critical point: the soil moisture content below which evapotranspiration is restricted.
β	Soil water availability factor. Used in the calculation of actual evapotranspiration, a value of zero indicates wilting point and a value of unity indicates critical point.

Table 1: Soil moisture parameters considered in the UK4 to construct a soil moisture analysis. Equivalent parameters exist within the MOSES-PDM scheme and are denoted in this paper with an over-bar (eg $\bar{\theta}$).

3 Methodology

Soil moisture within the operational UK4 model is updated daily at 09 UTC, which is also the data time for one of the four 36-hour forecasts run each day. In this study we modify the starting analysis by inserting soil moisture fields constructed using a data source that reflects each different scheme being evaluated. The schemes under test are implemented in three UK4 model configurations discussed in more detail in the following sections.

UK4Ctrl: The soil moisture analysis is produced from data supplied by the MOSES-PDM scheme. This is the operational UK4 configuration.

UK4Glbl: A soil moisture analysis is constructed from an interpolated soil moisture analysis generated by the Met Office's 40 Km Global NWP model.

UK4Clim: A soil moisture analysis is created from a monthly-varying climatological mean.

3.1 UK4 coupled with MOSES-PDM (UK4Ctrl)

In its current operational configuration, the UK4 model uses data from MOSES-PDM to create a soil moisture analysis. The soil moisture analysis makes use of a range of parameters listed in Table 1 and an equivalent set, in this paper denoted with an over-bar (eg $\bar{\theta}$), exist in the MOSES-PDM scheme run off-line (ie uncoupled to the NWP model). These parameters are needed for the interpolation and scaling between the two sets of soil properties.

Although MOSES-PDM is run hourly, only data valid at 09 UTC are used in the UK4 model. The MOSES-PDM hydrology scheme is based on the van Genuchten [9] method and this differs from the Clapp-Hornberger approach used in the UK4 model. To ensure the same evaporation rate in the UK4 as that implied by the soil moisture in MOSES-PDM, it is important to ensure that the soil water availability factor (β) is conserved. This is achieved by determining the value of β in MOSES-PDM and then recalculating the soil moisture content (θ) in in the UK4

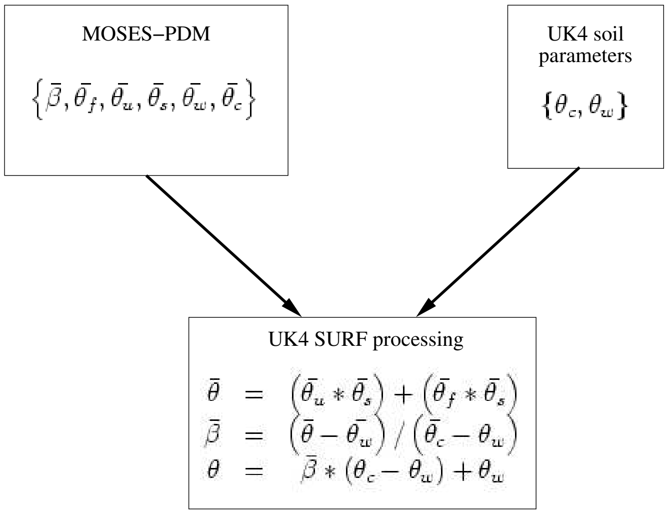


Figure 2: Schematic flow between UK4 model and MOSES-PDM to maintain consistency in the presence of differing hydrology schemes. The nomenclature used here is that given in Table 1.

model using this value of(β). Figure 2 summarises the processing undertaken to ensure consistency between the hydrology schemes in both models.

3.2 UK4 coupled with interpolated global soil moisture analysis (UK4Glbl)

Experiment UK4Glbl uses a soil moisture analysis derived by interpolating a 40 Km Global model soil moisture analysis [2]. This analysis uses a soil moisture nudging technique based upon screen temperature and humidity errors. A spiral searching methodology is used to set values at any points unresolved after the initial interpolation process. Following the interpolation, a check is made to ensure that the soil moisture has neither exceeded the saturation value (θ_s) nor fallen below some minimum value, currently $(0.1 * \theta_c)$. It is important that the soil moisture at vegetated points is kept sufficiently above zero to ensure numerical stability in the Unified Model and that the same soil hydrology scheme is used in both Global and UK4 models.

3.3 UK4 coupled with climatology soil moisture field (UK4Clim)

This experiment simply uses a climatological soil moisture analysis over the whole domain, constructed from a 10-year integration of a global offline version of the MOSES land surface scheme forced by observational data from the Global Soil Wetness Program 2 (GSWP2) [5]. The climatology exists at 4 different soil depths and 12 different temporal periods.

4 Results

In Section 4.1 we present summary verification scores covering the whole of the summer trial period 1 July to 30 September 2008 and then proceed to evaluate the analysed volumetric soil moisture of the two experiments with the greatest utility in Section 4.2. Following this, we investigate the correlation of T and RH errors in each experiment and the correlation of differences (UK4Ctrl - UK4Glbl) errors in Sections 4.3 and 4.4 respectively. Finally, we examine a series of case studies relating to severe precipitation events occurring within the domain of the UK4 model and which are discussed in Section 4.5.

Before considering the results, it is useful to place them in context by summarising the precipitation totals during the trial period. In July 2008, rainfall was generally above or well above average across Northern Ireland, England and Wales, but close to average across East Anglia. Rainfall over Scotland ranged from below average across the north-west to above average across the south-east. August 2008 was a very wet month across much of the UK with widespread flooding reported in Northern Ireland and parts of eastern Scotland. Northern Ireland had its wettest August in a series back to 1914. September 2008 was a very wet month across the Midlands and NE England, with some stations in Northumberland recording around 300% of their average rainfall. In contrast, northern areas of Scotland had well below average rainfall.

4.1 Summary verification scores

Verification scores are calculated from the mean forecast-minus-observation Root Mean Square Error (RMS) error verified against surface observations taken from a set of land-based stations distributed across the domain of the UK4 and shown in Figure 3(a). For the following meteorological parameters, mean verification statistics are calculated:

T forecast temperature at station height,

RH forecast relative humidity at station height,

Fcc forecast fractional cloud cover at station height,

W forecast wind speed at station height.

Figures 4(a)-(b) and Figure 5(a) show the plots for the forecast-minus-observation mean and RMS error for T, RH and Fcc respectively for each forecast range. Figure 5(b) shows mean forecast-minus-observation mean speed and RMS vector error for W. From these figures we can draw the following conclusions:

- The RMS scores show that UK4Glbl and UK4Ctrl perform equally well at all forecast ranges for $\{T, Fcc, W, RH\}$.
- The RMS error is greater in UK4Clim for $\{T, Fcc, W, RH\}$ at all forecast ranges compared with UK4Ctrl and UK4Glbl.
- Verification of 6- and 30-hour forecasts valid at 15 UTC shows a cool moist bias in UK4Ctrl and UK4Glbl. By contrast UK4Clim appears marginally warmer and drier at the same forecast ranges.
- Conversely, verification of 18-hour forecasts valid at 03 UTC exhibit a warm dry bias in all experiments, although climatology appears slightly drier.

Having noted the poor performance of experiment UK4Clim we discount it and proceed to focus on the performance of experiments UK4Ctrl and UK4Glbl. Figures 6(a) and (b) show the percentage difference (UK4Glbl

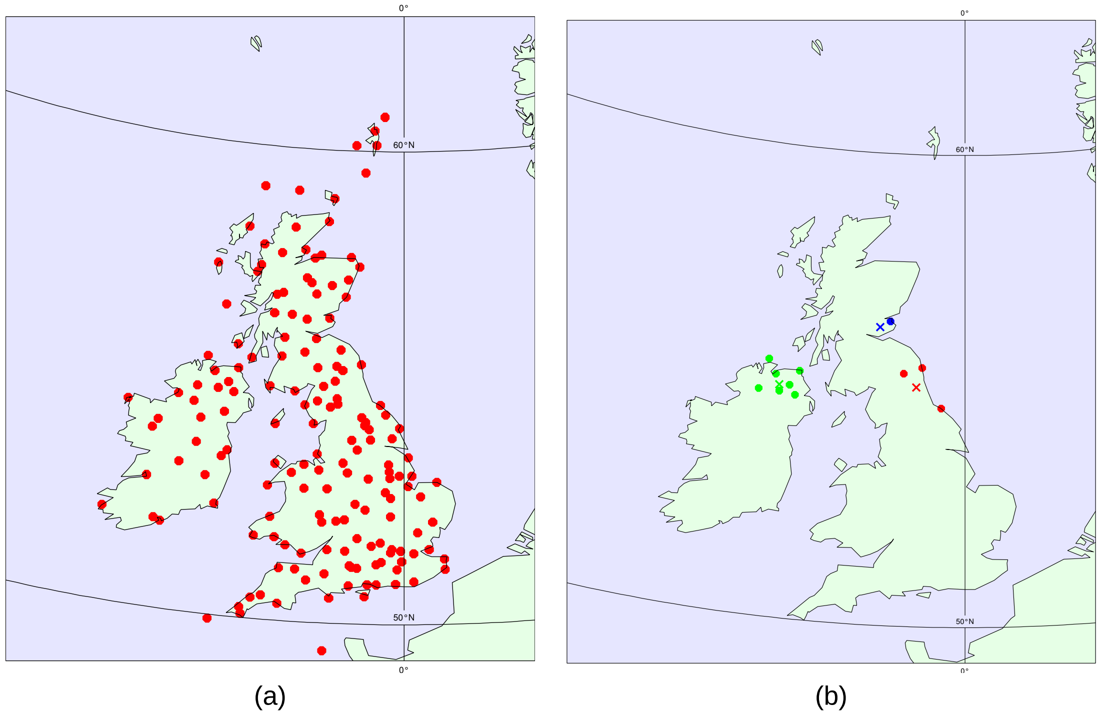
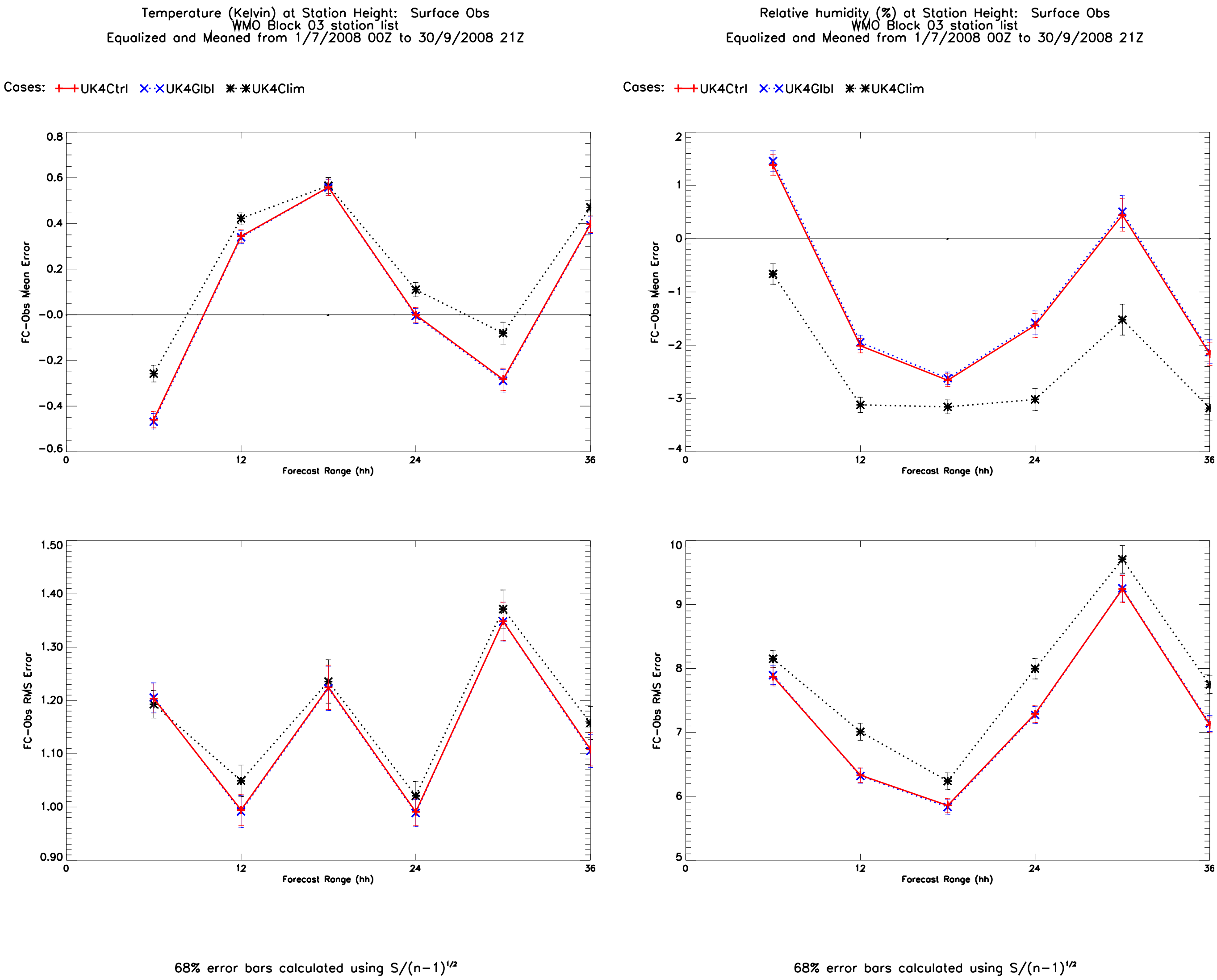


Figure 3: The location of surface stations supplying observations used in verification of UK4 forecasts in this study for: (a) the whole trial period and (b) for case studies. Case studies in figure (b) are colour coded: Fife case in blue; Northern Ireland case in green; Morpeth case in red. A cross indicates approximate location of event and each point is a land station selected to provide observations for verification according to colour coded cases.

minus UK4Ctrl) in mean forecast-minus-observation RMS error for the months of July, August and September 2008 respectively for forecast T and RH at 6-hourly intervals out to a 36 hour range. Verification is undertaken against the land-surface stations shown in Figure 3(a). In Figures 6(a) and (b), a plotted bar value below the horizontal line with a negative value indicates a positive impact in the experiment UK4Glbl and bars above the line, a positive impact in experiment UK4Ctrl. From these plots we can draw the following conclusions:

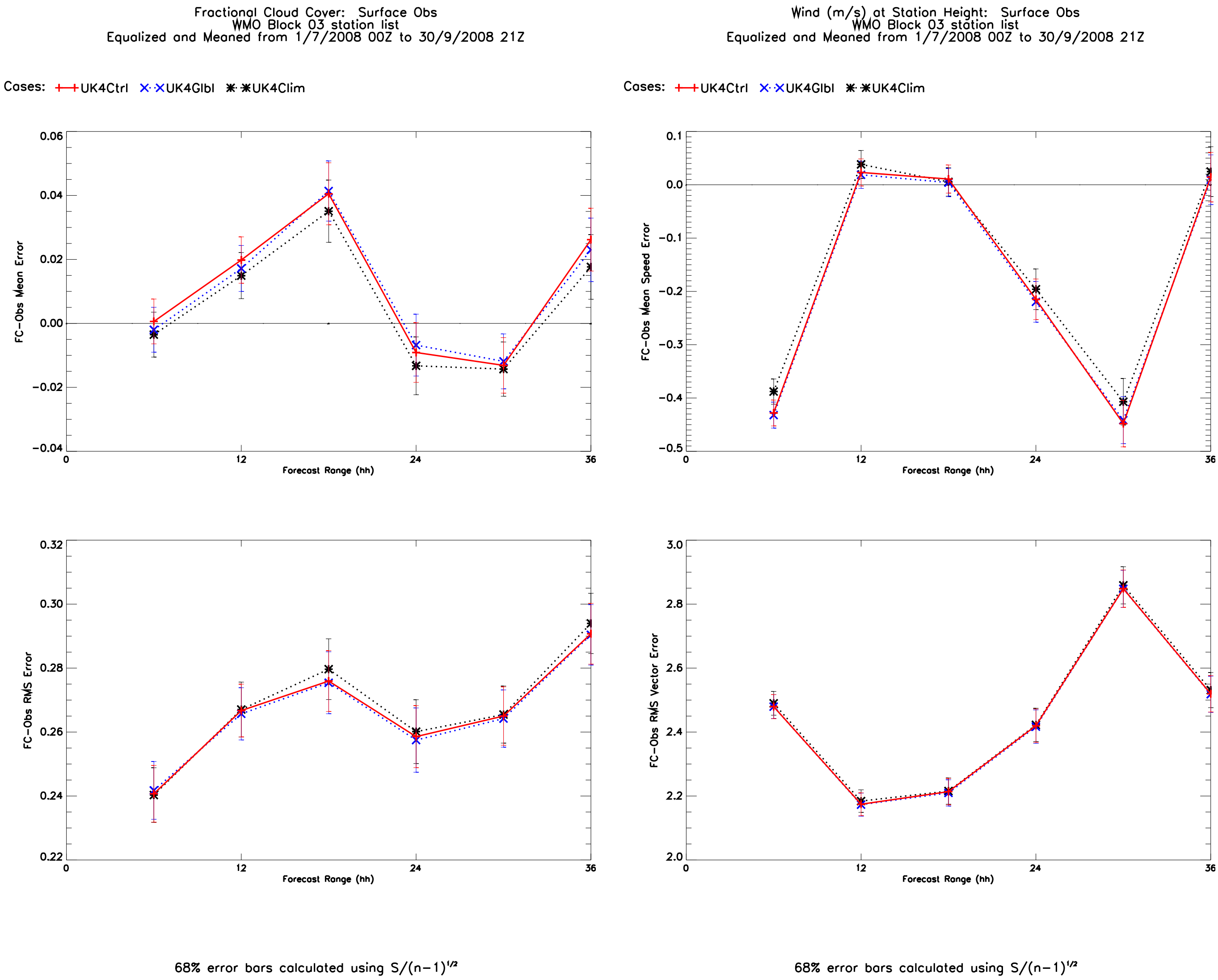
- In Figure 6(a) for July, we see a positive impact in UK4Glbl for T at all ranges except the 6 and 30-hour forecasts which verify at 15 UTC close to the time of maximum temperature. Possibly the high resolution soil moisture provided by MOSES-PDM to UK4Ctrl gives a very small advantage at this time, a conclusion supported by the fact that the corresponding RH in Figure 6(b) shows the same signal. In August, UK4Glbl utility is improved at selected forecast ranges, although UK4Ctrl out-performs in 6-hour forecasts. In September, UK4Ctrl utility is improved for forecast ranges 12, 18 and 24 hours, while the 30-hour range reveals a large positive impact in UK4Glbl.

- July's monthly mean forecast RH, shown in Figure 6(b), is positive at forecast ranges 12, 18 and 24 hours for UK4Glbl. In August we observe a smaller positive impact in this experiment at the same ranges and at the very short forecast range of 6-hours a negative impact in UK4Glbl. In September we return to a mixed impact signal at different ranges for UK4Glbl and UK4Ctrl with a pattern that matches the signal for T.



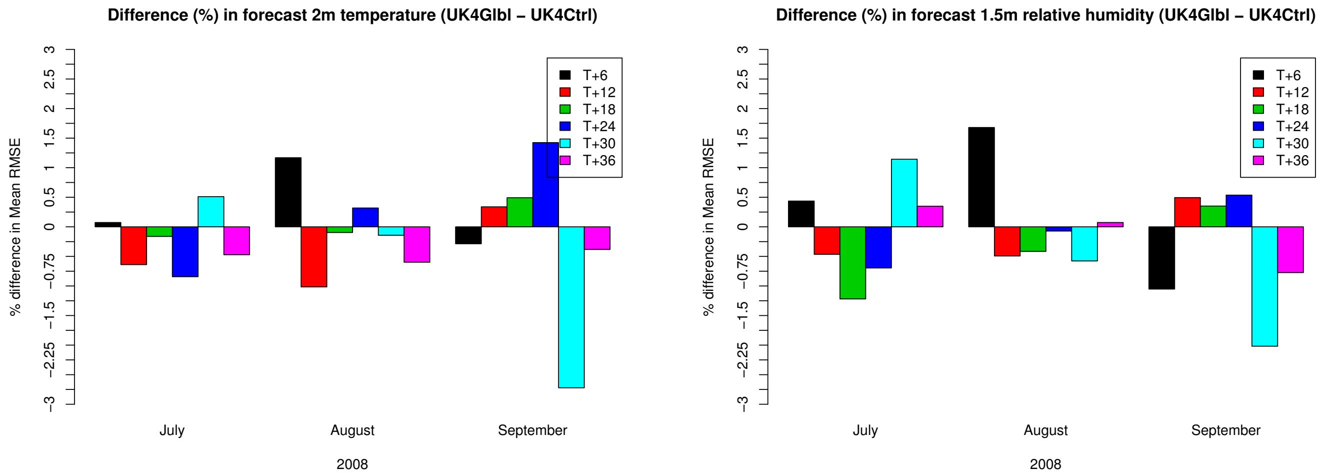
(a) (b)

Figure 4: Forecast-minus-observation mean and RMS error verified against surface observations shown in Figure 3(a) for (a)-(b): T and RH respectively for each forecast range.



(a) (b)

Figure 5: Forecast-minus-observation mean and RMS error verified against surface observations shown in Figure 3(a) for (a): Fcc for each forecast range. Figure (b) shows mean forecast-minus-observation mean speed and RMS vector error for W verified against identical surface observations for each forecast range.



(a) (b)

Figure 6: Percentage difference (UK4Glbl minus UK4Ctrl) in mean forecast-minus-observation RMS forecast against land-surface stations shown in Figure 3(a) for each month at different forecast ranges for (a) and (b): T and RH respectively.

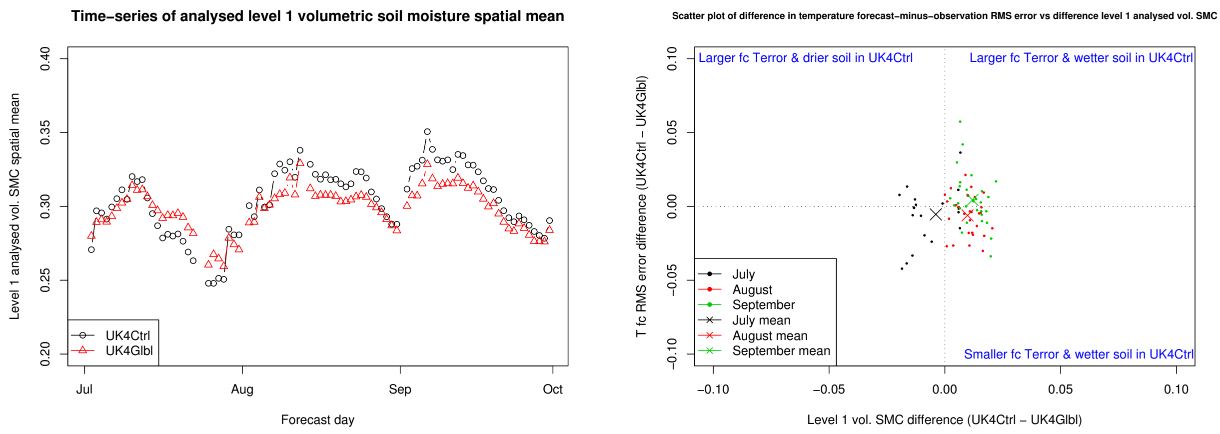
4.2 Evaluation of analysed volumetric soil moisture

We consider the evolution of the analysed level 1 volumetric soil moisture spatial mean from experiments UK4Ctrl and UK4Glbl. The time-series of analysed soil moisture valid at 09 UTC from each experiment is shown in Figure 7(a). From this plot we see at the start of the trial period, the mean analysed volumetric soil moisture is broadly similar in UK4Ctrl and UK4Glbl but by mid-July this field diverges resulting in the UK4Ctrl becoming drier. We noted that high rainfall totals occurred during the trial period and hypothesise they are more accurately captured by the high-resolution radar observation used in MOSES-PDM in the UK4Ctrl experiment. This also is apparent during September 2008 where we see wetter values for upper level soils in UK4Ctrl compared to UK4Glbl in the presence of further high rainfall totals.

Figure 7(b) shows a scatter plot of the difference in volumetric level 1 soil moisture (UK4Ctrl - UK4Glbl) versus the difference in T forecast-minus-observation RMS error (UK4Ctrl - UK4Glbl). Each point represents a T+6 forecast valid at 15 UTC initialised from an analysed soil moisture field valid at 09 UTC colour coded by the trial month the forecast is valid. The larger colour-coded “X” indicates the monthly mean for all forecast/soil moisture pairs valid in that month. For UK4Ctrl, the smaller T forecast RMS error in July was accompanied by drier level 1 soil compared with UK4Glbl. The wetter soil layer in August seen in the UK4Ctrl was still accompanied by a smaller T RMS error. During September 2008, experiment UK4Ctrl is even wetter compared with UK4Glbl although this is seen with an increased T forecast RMS error.

4.3 Analysis of the correlation of T and RH errors

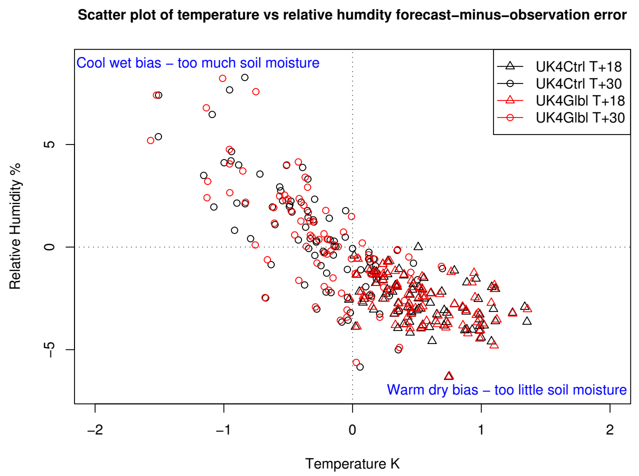
To investigate the performance of each experiment further, we investigate the relationship between forecast-minus-observation errors in T and RH in UK4Ctrl and UK4Glbl. This is undertaken at key points during the diurnal cycle, namely 18-hour forecasts verifying at 03 UTC and 30-hour forecasts verifying at 15 UTC the next



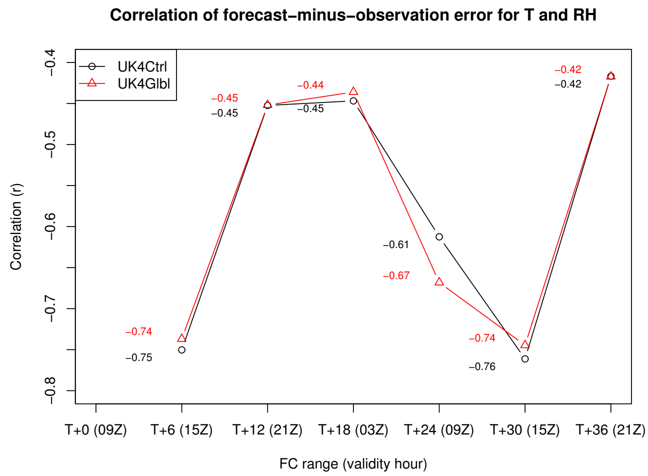
(a) (b)

Figure 7: (a) Time-series of analysed level 1 volumetric soil moisture content at 09Z for UK4Ctrl and UK4Glbl during the summer 2008 trial period. (b) Scatter plot of difference in T vs difference in level 1 analysed soil moisture content spatial mean. All differences are constructed using UK4Ctrl - UK4Glbl. Each point is based on a T+6 forecast valid at 15Z and analysed soil moisture at 09Z colour coded by the trial month during the summer of 2008. The mean for each month is identified by the cross point.

day. At these validity times, the effect of errors in the soil moisture analyses will differ most. From Figures 4(a) and (b) described previously, the difference in mean forecast-minus-observation error at these forecast ranges appears small. To assist in differentiating performance between the two experiments, we construct the scatter plot in Figure 8(a) showing the spread of all forecast errors for T versus RH at 18 and 30-hour forecast ranges. A qualitative assessment of this plot indicates a stronger linear correlation in 30-hour forecast errors (marked by circles) for T versus RH compared with the 18-hour range (marked by triangles) in both experiments. During the summer months when these experiments have been undertaken, verification of 30-hour forecasts, valid at 15 UTC the following day, have a greater sensitivity to errors in soil moisture compared with 18-hour forecasts, valid at 03 UTC. In both experiments for 30-hour forecasts, we see forecast errors in T and RH display a predominately cool wet **and** a warm dry bias, evidence of too much and too little soil moisture respectively. The correlation between forecast errors for T and RH is shown in Figure 8(b) for each experiment at each forecast range. We observe a strong negative correlation coefficient ($r = -0.75$ and $r = -0.76$) at 6 and 30-hour ranges verifying at 15 UTC for experiment UK4Ctrl. A marginally weaker correlation $(r = -0.74)$ exists at the same forecast ranges for UK4Glbl. Because both experiments are constrained by similar initial conditions for forecast runs, differences in the observed correlation coefficients are small. This result may though provide evidence of smaller error in all soil moisture analyses used during the three-month trial period in experiment UK4Glbl. We are cautious though to draw too much significance from such small differences in the correlation pairs. Other sources of error such as radiation or cloud errors that may affect T and RH can be discounted as they are identical in the initial conditions of both experiments.



(a)



(b)

Figure 8: Evaluation of T and RH forecast error; (a) scatter plot of 18 and 30-hour forecast-minus-observation error for UK4Ctrl (black) and UK4Glbl (red); (b) correlation of T and RH forecast error for UK4Ctrl (black) and UK4Glb (red). Correlation coefficient shown at each forecast range (validity time shown in brackets on x-axis).

4.4 Analysis of the correlation of differences (UK4Ctrl - UK4Glbl) in T and RH errors

The high negative correlation at verifying time 15 UTC noted previously in Figure 8(b) is consistent with T/RH errors and these are often attributable to soil moisture errors. Figures 9 shows the correlation of the differences (UK4Ctrl - UK4Glbl) in T and the differences (UK4Ctrl - UK4Glbl) in RH error at different forecast ranges during the trial period. From this we note that T/RH differences are due to soil moisture differences and therefore the correlations verifying at 15 UTC are unsurprisingly even bigger than those in Figure 8(b).

4.5 Case studies

In an attempt to identify a clearly discernible signal to separate the utility of UK4Glbl and UK4Ctrl, we proceed to review the synoptic character of each month and evaluate the performance of each UK4 configuration in the presence of severe precipitation events. Due to the large scale nature of the verification scores presented so far, benefit from MOSES-PDM may have been masked. By undertaking a series of case studies, we anticipate that any benefit may become more apparent in local areas associated with particular weather events. We examine the performance of each UK4 configuration in the presence of notable weather events occurring within the domain. The following weather events were noted by the National Climate Information Centre (NCIC):

- May-August 2008 flooding events: Information on heavy rainfall/flooding disruption over May-August 2008 - including Fife/Lothianshire early August, Fair Isle daily record on 10th August and Northern Ireland on 16th August.
- 4 - 6 September 2008: Heavy rainfall over England and Wales. Over 150 mm in 48 hours in parts of NE England led to significant flooding in Morpeth (Northumberland).

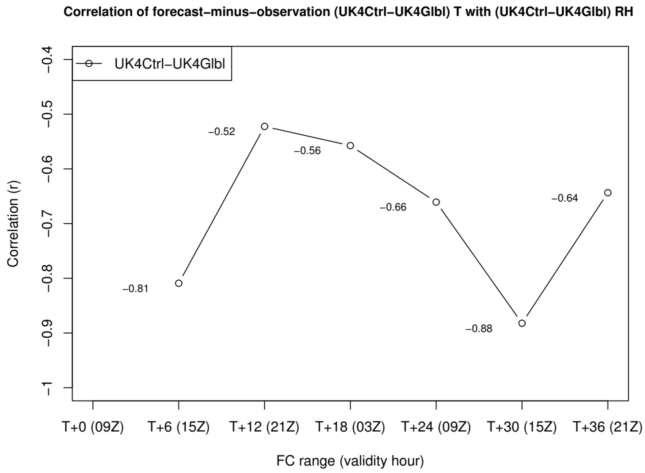


Figure 9: Evaluation of T and RH forecast error over trial period showing the correlation of differences in forecast minus observation error of T and RH between UK4Ctrl and UK4Glb. Correlation coefficient shown for each forecast range (validity time shown in brackets).

To aid in the detection of a signal from the complete set of verification data, we undertake a qualitative evaluation of Hovmøller plots. These are shown in Figure 10 as a time-series of zonal mean soil moisture analyses at soil level 1 from each UK4 configuration. Note that there is missing data for 23 and 24 July and 13 August. The colour bar range in each plot is identical across levels to facilitate ease of comparison. The locations of the three case study weather events are indicated on each plot by a solid magenta line at Fife (56°N), a solid blue line in Northern Ireland (54.5°N) and a solid green line at Morpeth (53.5°N).

Without independent soil moisture observations, it is not possible to undertake a validation of these analyses. Instead we look at the mean forecast-minus-observation forecast error for forecast fields T and RH at forecast ranges $\{12, 18, 24, 30, 36\}$ following these key events. For each event we undertake verification of a 10-day period centred on the date of the event and verify forecast fields against observations from the relevant case selected land stations identified in Figure 3(b). Errors in the level 1 soil moisture analyses are most likely to manifest themselves in errors in the forecast of these near surface parameters. Plots for mean forecast-minus-observation forecast error for each experiment are shown in Figures 11(a)-(f) for Fife T and RH, Northern Ireland T and RH and Morpeth T and RH respectively. Each of these case studies is discussed in more detail in the following sections.

Flooding in Fife, Scotland around 9 August 2008

By August 9 2008, up to 200% of monthly average accumulated rainfall had been recorded in some areas of Fife, Scotland (56°N). The Hovmøller plot for soil moisture content for soil level 1 in UK4Ctrl, clearly indicates higher values of soil moisture at the 56°N in the first half of August, shown by the magenta line in Figure 10. For experiment UK4Glbl we see smaller values of soil moisture and no indication of this event in the climatology experiment, UK4Clim. It is hypothesised that the saturation of upper soil layers during the first half of August in UK4Ctrl will affect forecast errors of T and RH. From Figures 11(a) and (b), we observe a smaller forecast error

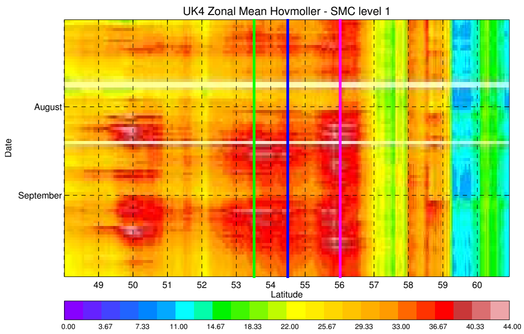
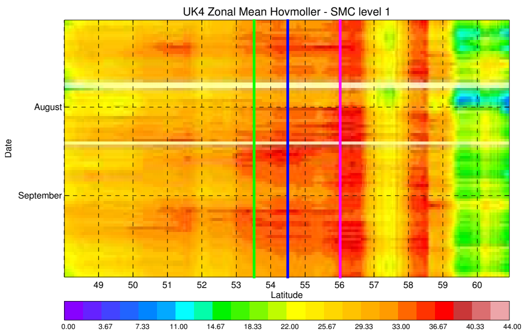
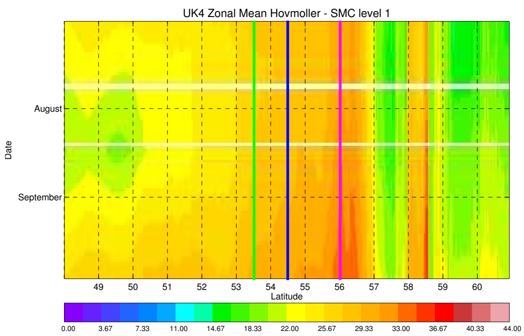
Experiment	Level 1 soil moisture
UK4Ctrl	
UK4Glbl	
UK4Clim	

Figure 10: Hovmøller plots plots of soil moisture content by experiment for soil level 1. The location of case study weather events discussed in this paper are indicated by a solid magenta line for Fife (56°N) case study around 9 August 2008, a solid blue line for Northern Ireland (54.5°N) case study around 16 August 2008 and a solid green line for Morpeth (53.5°N) case study around 16 August 2008.

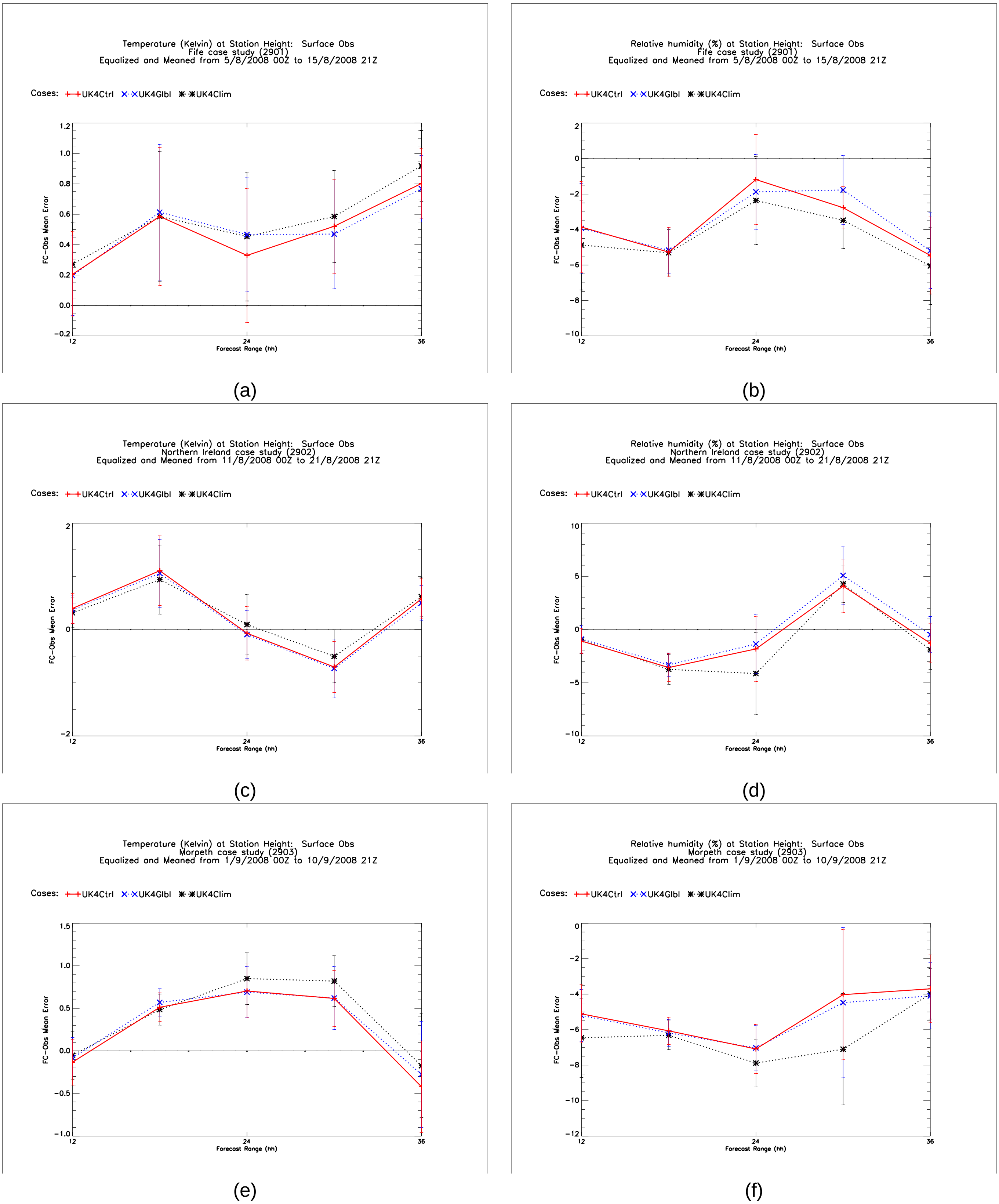


Figure 11: Mean forecast - observation forecast error for each experiment against land-surface stations shown in Figure 3(b) for different forecast ranges and forecast fields: (a) and (b) T and RH for Fife case study around 9 August 2008; (c) and (d) T and RH for Northern Ireland case study around 16 August 2008; (e) and (f) T and RH for Morpeth case study 4 - 6 August 2008. The majority of cases show a warm dry bias at all forecast ranges consistent with too little soil moisture over the period.

at the 12 and 24-hour forecast ranges for T and RH in UK4Ctrl. At forecast ranges 30 and 36 hours, the forecast error for T and RH is greater in UK4Ctrl than in UK4Glbl. The climatology run, UK4Clim, has larger forecast errors at all forecast ranges in T and RH. The warm dry bias in T and RH apparent in all experiments, is smaller in UK4Ctrl at forecast ranges within the first 24 hours as consequence of the increased soil moisture content.

High rainfall accumulations in Northern Ireland around 16 August 2008

131mm of accumulated rainfall had been recorded by 16 August 2008 in Northern Ireland (54.5°N). The Hovmøller plots shown in Figure 10 indicate a drier zonal mean (marked by the blue vertical line) for this event in the first half of August 2008 for both UK4Ctrl and UK4Glbl when compared with the Fife event. During the first half of August, the analysed zonal mean of soil moisture for experiment UK4Ctrl and UK4Glbl are similar but considerably wetter than the climatology UK4Clim. This similarity in modelled soil moisture content is reflected in the mean forecast-minus-observation forecast error for forecast fields T and RH shown in Figures 11(c) and (d). For experiments UK4Ctrl and UK4Glbl there is no clear signal to differentiate NWP performance for this event. The climatology experiment, UK4Clim, also gives a mixed signal.

Flooding in Morpeth, England on 4 - 6 September 2008

Between 4 - 6 September 2008, accumulated rainfall returns for Morpeth, England (53.5°N) indicated nearly 300% of the September average. The Hovmøller plots shown in Figure 10 and delineated by the green line, indicate that during the first half of September, the time-series of UK4Ctrl zonal mean of soil moisture is wetter than UK4Glbl and UK4Clim for this event. In turn, during the 10-day verification period of the Morpeth floods, we see that the mean forecast-minus-observation forecast error for forecast fields T from UK4Ctrl, shown in Figure 11(e), has equal or smaller error at the 18, 24 and 30-hour forecast ranges compared to UK4Glbl, and at all ranges for RH as shown in Figure 11(f). The warm dry bias of T and RH in UK4Ctrl being reduced as a consequence of the more saturated soil which appears consistent.

It is difficult to discern a signal differentiating the relative utility of UK4Ctrl compared to UK4Glbl from the large scale verification undertaken in Section 4.1. By undertaking an analysis of each experiment using case studies and linking the relationship of T and RH with available soil moisture, we have shown that each experiment exhibits a warm dry bias at the majority of forecast ranges consistent with too little available soil moisture. We have identified cases where MOSES-PDM has more accurately captured available soil moisture leading to a reduction in this bias. This was especially evident in the Morpeth flooding case and to a lesser extent, in short-range forecasts in the Fife case.

5 Conclusions

The aim of this study was to assess the added value of MOSES-PDM as a source for soil moisture in the Met Office's 4 Km UK model, relative to interpolated soil moisture from the Global model's soil moisture nudging scheme. Our main finding is that MOSES-PDM soil moisture gives no overall improvement in screen temperature and relative humidity verification over that obtained with interpolated Global soil moisture. For the three flooding case studies considered, MOSES-PDM soil moisture analyses did give a better representation of the wetter upper soil layers in the presence of significant precipitation when compared with interpolated Global model soil moisture analyses or climatology. Analysis of forecast errors at a selection of local verification stations indicated that at certain forecast ranges, UK4Ctrl may marginally out-perform UK4Glbl. Both MOSES-PDM and Global soil moisture outperform climatology, which gave a relative warm dry bias of forecast screen temperature and relative humidity for the trial period.

It may seem surprising that the higher resolution MOSES-PDM, driven by observed precipitation and radiation estimates, is not able to improve on the coarser resolution output from a global soil moisture nudging scheme. On the other hand, assessment of forecasts against screen temperature and humidity observations may give some advantage to a soil moisture analysis system which is constructed to minimise errors in those variables. If we coupled the different soil moisture analyses to river routing models and assessed them in terms of suitability for hydrological applications, the advantages of MOSES-PDM may be more evident. The flooding case studies certainly suggest that the high resolution radar observations used in MOSES-PDM are better able to capture high precipitation events than the Global model.

It is possible that the different soil hydraulics schemes used in MOSES-PDM and the UK4 model may have a slight impact on the results presented. MOSES-PDM uses van Genuchten soil hydrology, while the UK4 at present uses the Clapp-Hornberger scheme, a difference which requires us to interpolate the soil moisture availability factor between the models, rather than the soil moisture directly. Any impact from this should virtually disappear when the UK4 model adopts van Genuchten soil hydraulics (likely in 2009), although interpolation of soil moisture availability will still be required due to the difference in soil property fields.

The generally good performance of the Global soil moisture nudging scheme in the present study may be a function of the data rich area covered by the UK4 domain, within which there is a high density of good quality screen level observations to force the nudging scheme. In an area where surface data are more sparsely distributed, an offline model like MOSES-PDM may perform relatively better if realistic precipitation and radiation forcing could be obtained from satellite data.

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