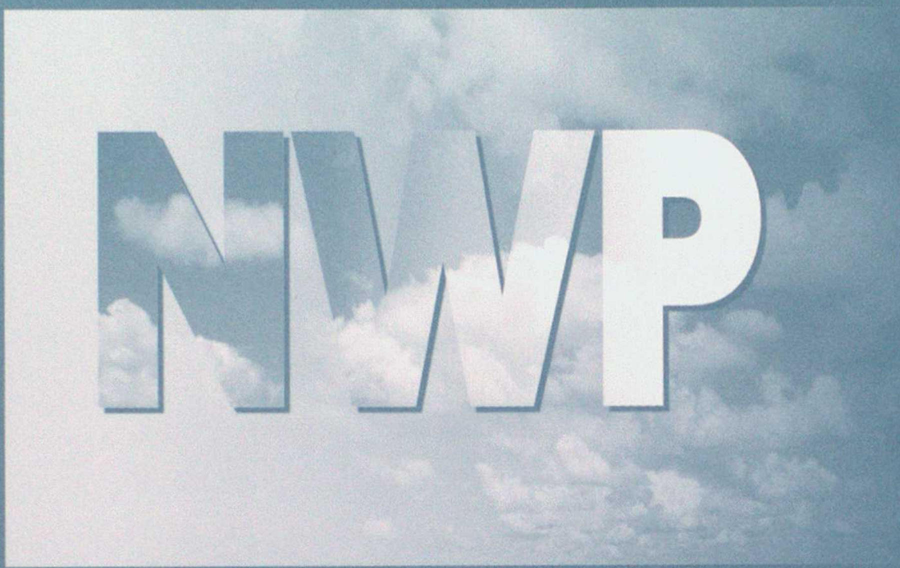
# Numerical Weather Prediction




Forecasting Research Technical Report 341

## Mesoscale Model Upgrade - Introduction of the land surface tile scheme (MOSES 2)

December 2000

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## Abstract

The Met Office Surface Exchange Scheme (MOSES 1) was introduced into the operational U.K. mesoscale model in May 1999 and into the global model in June

2000. This report discusses the upgrade to the mesoscale model to MOSES 2, which allows for non-uniformity of the land surface in a grid box. Each box may be split into up to 9 different types (tiles) and separate fluxes and temperature calculated for each, before amalgamating their effects on the atmosphere.

The scheme was tested for 16 cases, with full data assimilation for 12 hours and with forecasts to 48h. The overall impact as measured by the 5-component U.K. Index is 1.68 points using all stations in the whole of the mesoscale area, 1.55 points for WMO block 03 stations, and 0.44 if just restricted to the 41 UK index stations. The latter estimate is generally less reliable due to the small sample of verification observations for 16 cases only, and so the impact is more likely to be closer to the estimate for WMO block 03. The main improvements are to 10m winds and screen temperatures. Two weeks of trial suite running, in parallel with the operational version, was also carried out, and with accompanying objective verification and subjective assessment.

The increase in total run time is estimated to be about 6.5%.

It was recommended that the upgrade is implemented operationally and this occurred on 26th October.

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## 1 Introduction

The differences between MOSES 2 and MOSES 1 are as follows:-

TILED SURFACE:
Except for those classified as land-ice, a land gridbox can be made up from a mixture of these surface types:
Broadleaf trees
Needle leaf trees
C3 (temperate) grass
C4 (tropical) grass
Shrubs
Urban
Inland water
Soil

Complete surface energy and water balance is calculated for each surface tile instead of a single surface with aggregate parameters.

VEGETATION DISTRIBUTION:
New AVHRR vegetation maps have been used to replace the Wilson/Henderson-Sellers dataset. These AVHRR maps are at 25m. resolution over the U.K. and 1 Km. resolution over the remaining mesoscale domain. Vegetation dependent parameters are calculated on-line from Leaf Area Index (LAI) and vegetation height rather than being read from ancillary files.


Figure 1: *Tile fractions in the Mesoscale area*

MOSES 2 could in future be run with leaf phenology which would allow the growth and decay of vegetation. This enables the potential of investigating the use of seasonally varying vegetation.

LW RADIATION:
Penman-Monteith elimination of surface temperature is extended to include downward LW. This means that the surface temperature feedback on longwave radiation is included between radiation calls and within the timestep calculation of the surface energy balance.

SOIL EVAPORATION:

The surface resistance for bare soil has been reformulated, following advice from CEH Wallingford, to include soil moisture dependence.

CANOPY MODEL:
Reformulation of canopy heat capacity and coverage for vegetation. Heat capacity is now calculated using biomass, rather than being set to a constant value. This enables different vegetation types to have different heat capacities.

SOIL HYDROLOGY AND THERMODYNAMICS:
Implicit numerical scheme for updating temperature and moisture content of soil layers. This removes the possibility of instabilities in the soil calculations.

RESTRUCTURED BOUNDARY-LAYER CODE:
The boundary-layer and surface code has been restructured so that future maintenance and development can be made more effective and efficient. The restructuring also means that constraints placed upon the surface fluxes can be correctly distributed throughout the boundary layer instead of only changing the first model level, which will eliminate unrealistic temperature and humidity profiles.

## 2 Case Study Tests

The cases used in the tests, chosen for the dominant weather types as indicated, were:

| | | |
|---|---|---|
| 3/12/99 | 00Z | land gales |
| 20/9/98 | 00Z | radiation fog and stratus* |
| 24/12/99 | 00Z | land gales |
| 11/7/99 | 12Z | clear summer day* |
| 16/10/98 | 12Z | active fronts |
| 2/10/98 | 00Z | clear winter night |
| 5/11/99 | 12Z | active fronts |
| 18/12/99 | 12Z | snow |
| 12/1/99 | 00Z | mixed snow and rain |
| 9/11/98 | 12Z | organized convection |
| 5/6/99 | 00Z | land-based convection |
| 2/6/99 | 00Z | organized convection |
| 1/10/99 | 12Z | active fronts |
| 2/12/98 | 00Z | cold easterlies in south |
| 4/9/99 | 12Z | clear summer day |
| 19/3/99 | 00Z | stratocumulus |

After reconfiguration for the new scheme, the cases were run with 12-hour data assimilation previous to the nominal data time, followed by forecasts to T+48h.

### 2.1 Objective verification

Mean sea-level pressure, 10m (surface) winds, screen temperature and relative humidity, total cloud amount and base and visibility were verified against synoptic stations for 3 areas: the full mesoscale domain (red), WMO block 03 stations (blue) and the UK index (green) station list (N.B. only 41 stations). The mean results for the 16 cases are discussed below.

For surface pressure there was very little difference between control (full lines) and trial (dashed lines) as expected, with changes in rms error being of the order 0.5% to 1% or less. See figure 2.

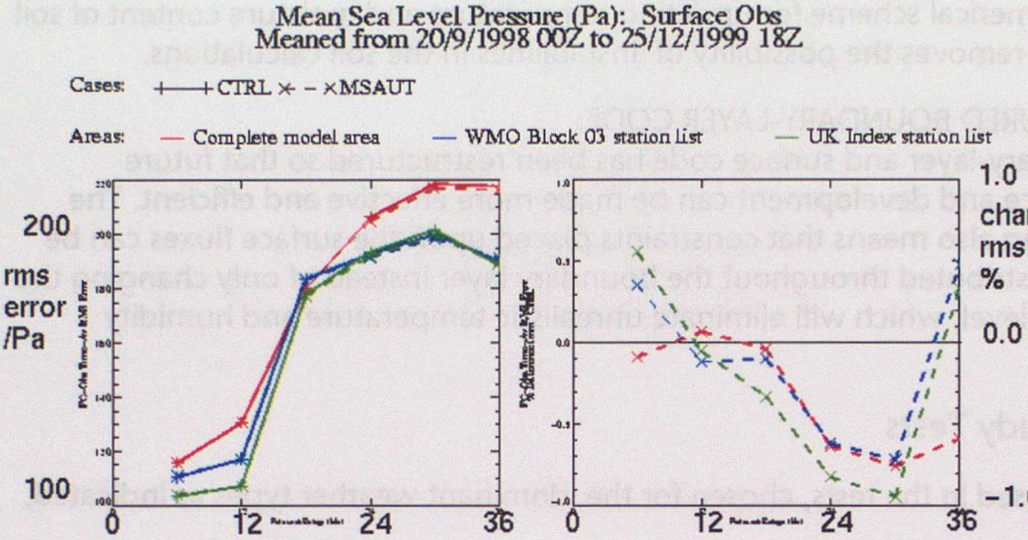



Figure 2

Temperature rms error changes were larger and more significant, up to 4% for WMO block 03 and mostly 2-4% for the full domain and the UK index list. There were small but generally beneficial improvements in the mean bias as well, as in figure 3.

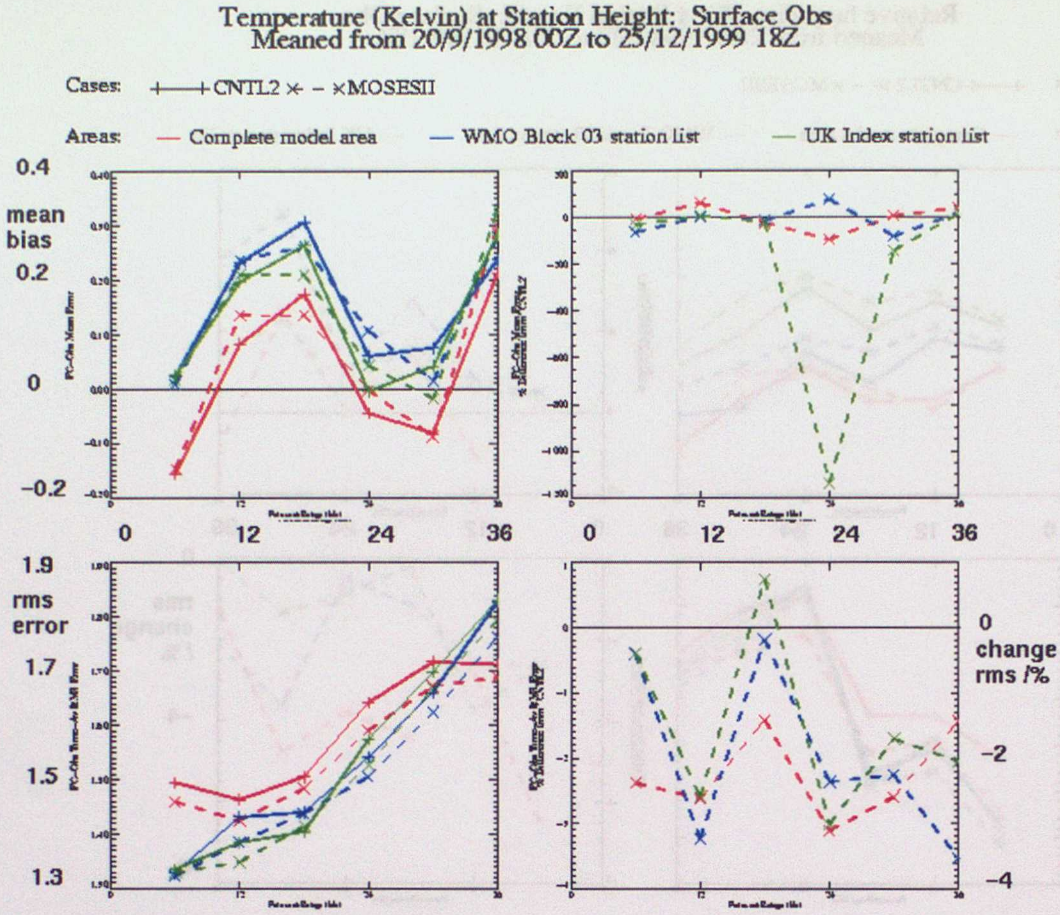



Figure 3

Although the mean bias for relative humidity is slightly worse the rms errors are generally better, by ~2-4%. See figure 4.

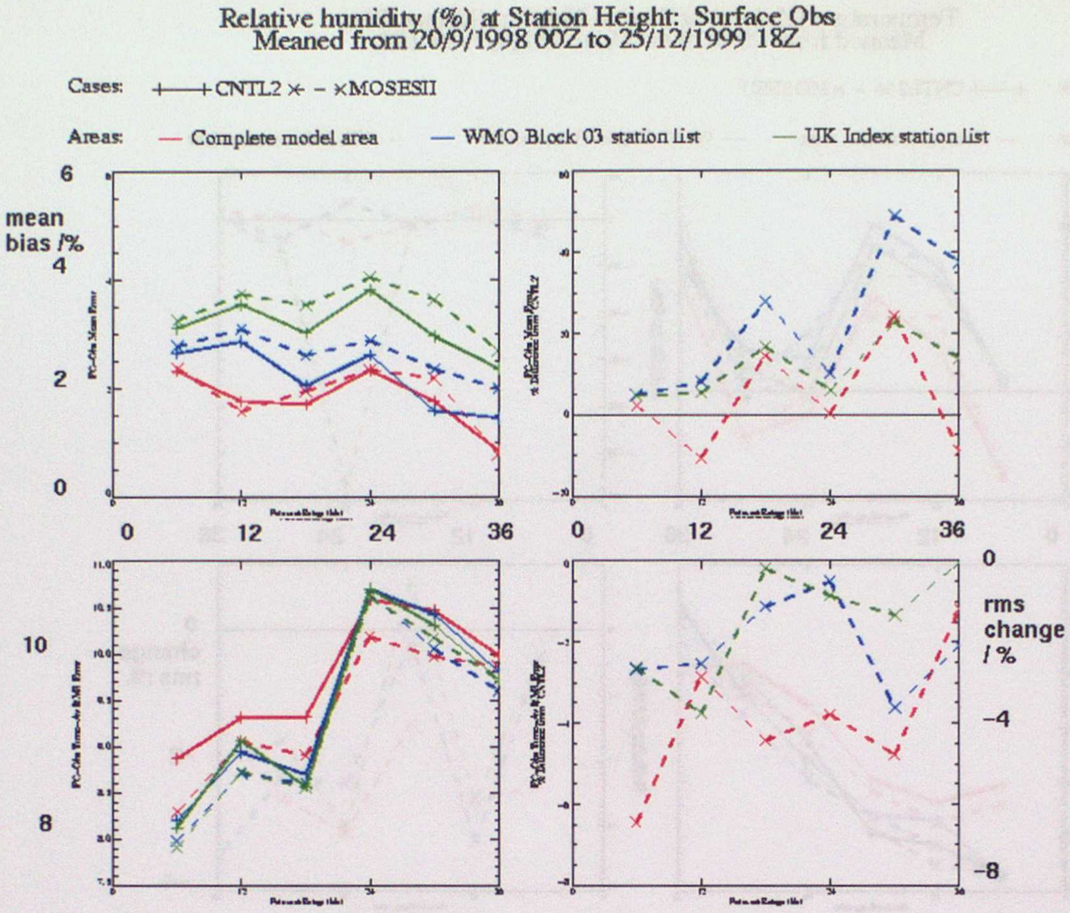



Figure 4

There were also large improvements for the 10m winds with a uniform reduction in rms vector wind errors of 2-3% for all 3 verification areas throughout the forecast periods to +36h. The wind speed bias was reduced at all forecast times, being a slight degradation at earlier periods (+6 ,+12h) and a slight improvement at later periods (+24 to +36h), and so neutral overall. As figure 5.

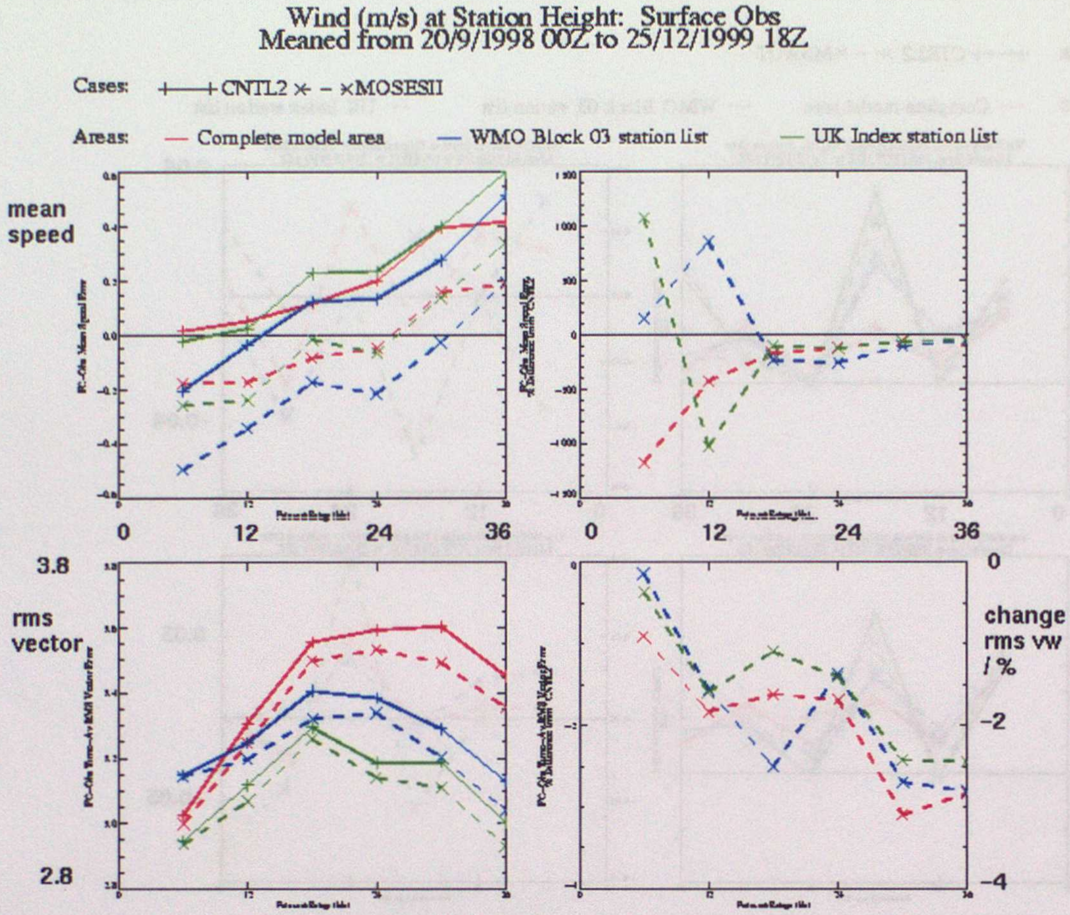



Figure 5

The impact on visibility appears to be more mixed. There are large variations (positive and negative) in changes to the equitable threat score (ETS) for the UK index list, which is to be expected from a limited sample size. The more representative block 03 list shows small improvements at the 1km threshold and a mixture of improvements and degradations for the fog (200m) and higher category (1-5km). See figure 6. The erratic behaviour of the UK index statistic is largely responsible for the smaller estimate of the overall Index change of 0.44 compared to 1.55 for the estimate from the block 03 list.

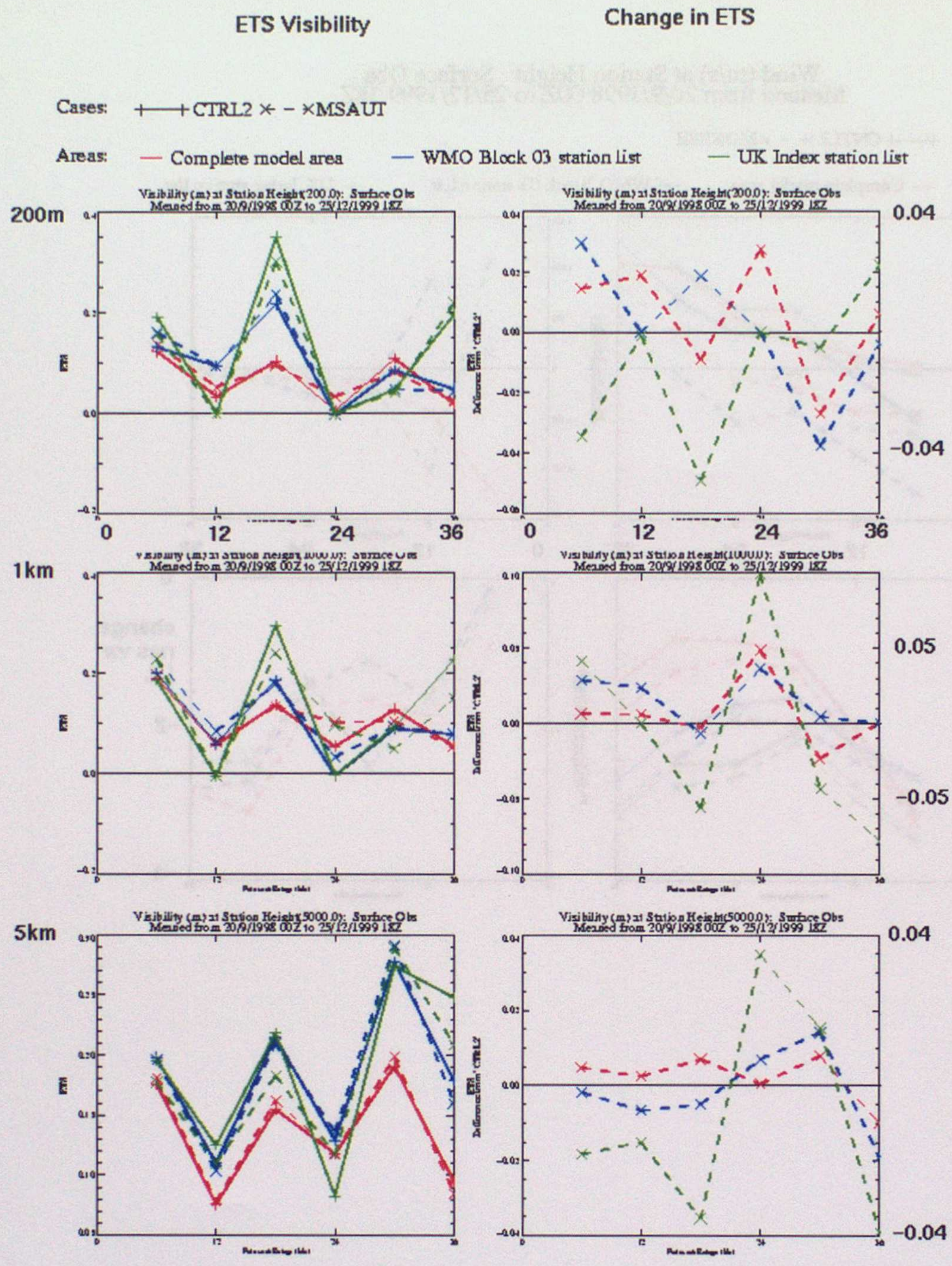



Figure 6

The change in cloud cover is also rather mixed but probably neutral overall. The ETS change for the UK list of 41 stations is again very erratic and not a reliable estimate of the expected impact when operational. The WMO block 03 scores show some positive benefits for 0.3 and 0.6 cover with an overall detriment at the higher threshold (0.8), as in figure 7.

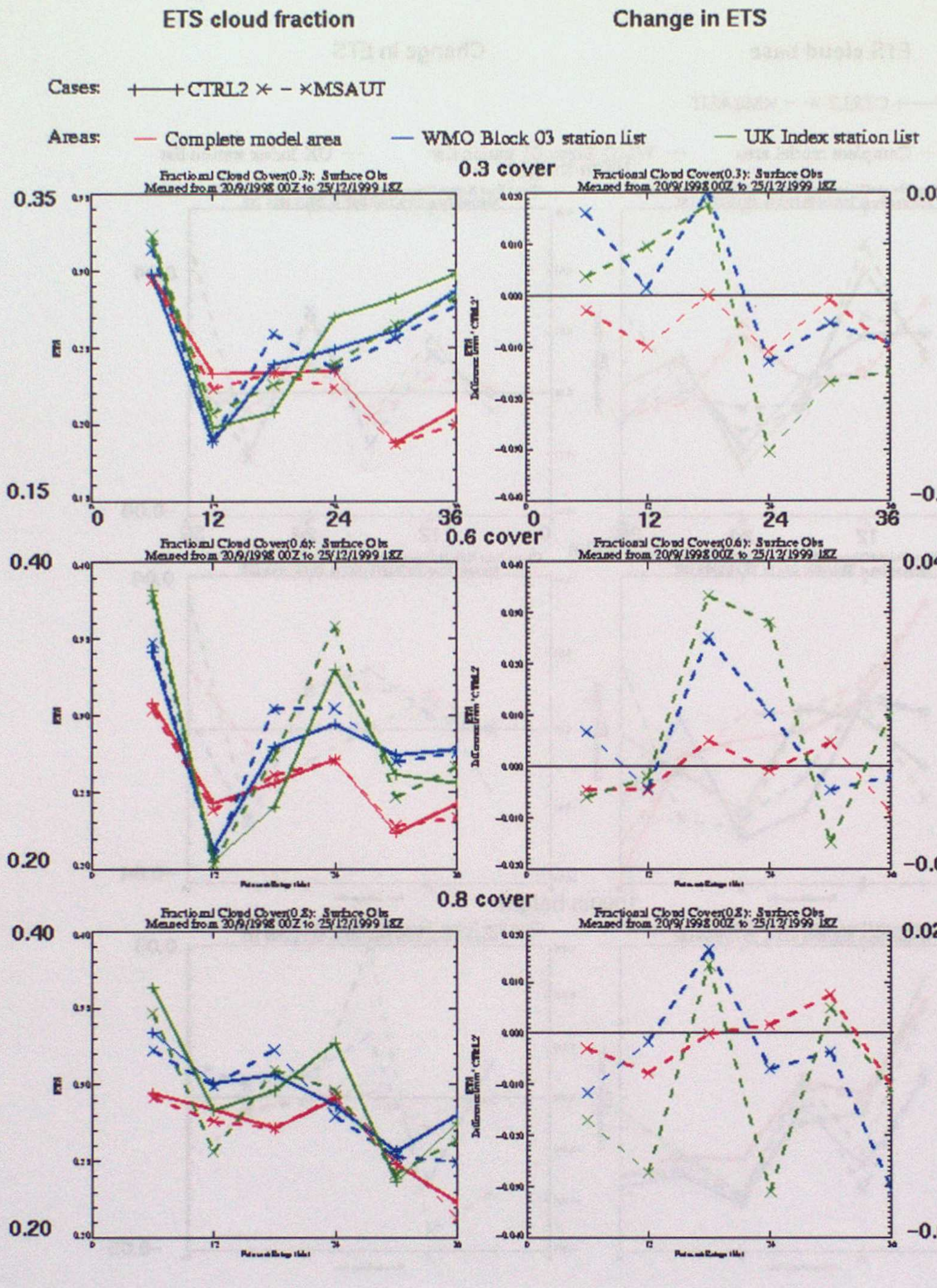



Figure 7

Cloud base height scores are also a mixture of improvements and detriments, slightly better overall if the statistics for block 03 are a reliable guide, as in figure 8.

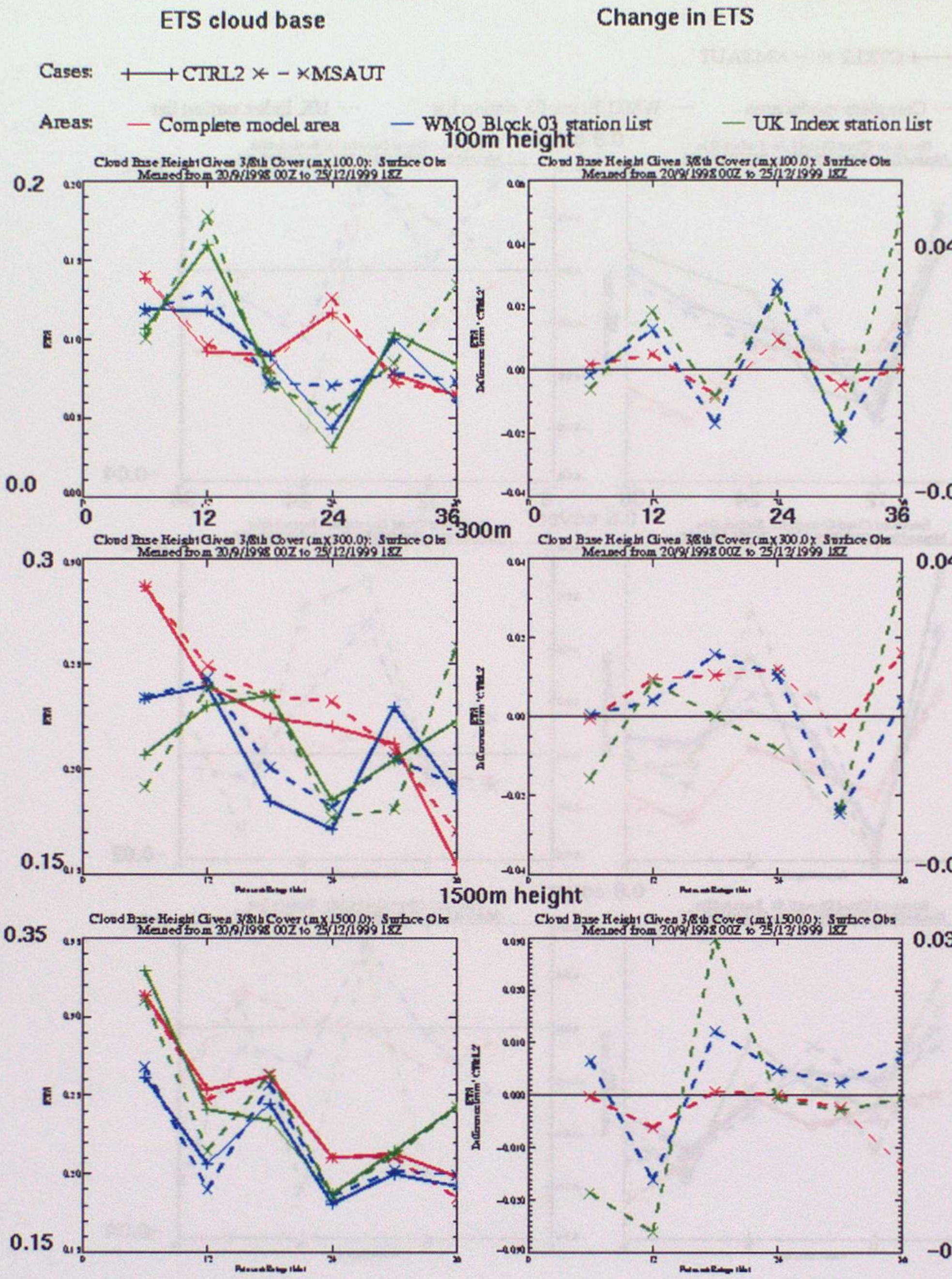



Figure 8

The precipitation scores show small improvements at 0.2mm/6h and 1mm/6h thresholds, with a similar degradation at the largest threshold (4mm/6h), if we disregard the UK list statistics. See figure 9. Overall there is a largely neutral impact as was confirmed by the subjective verification of the hourly precipitation rate charts.

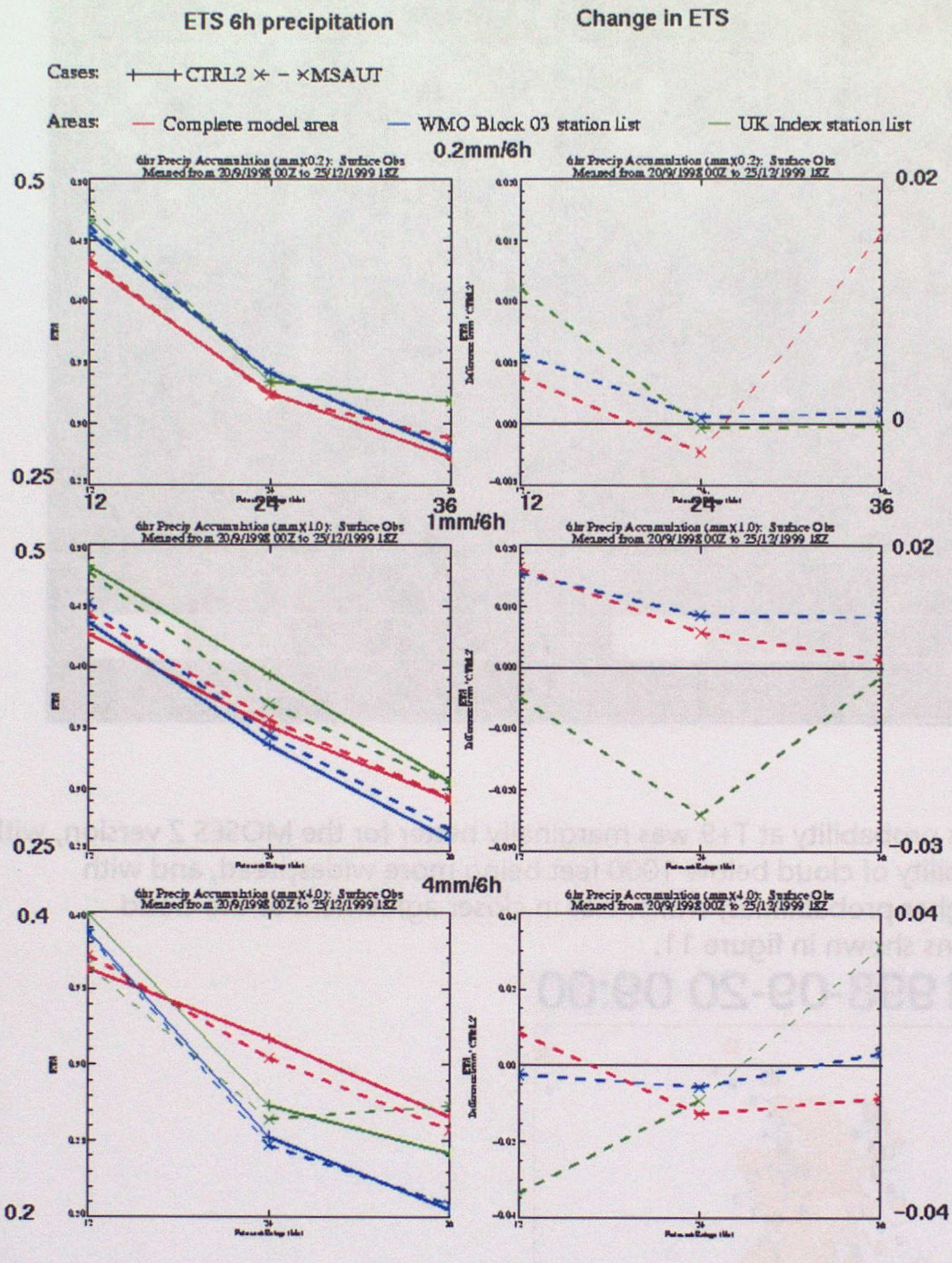



Figure 9

## 2.2 Subjective assessment of the case studies

For this assessment the identity of the trial and control forecasts was not revealed to the assessor Byron Chalcraft. This is the first time a "blind" assessment has been performed. Overall the changes were very small and there was little to choose between the matched pairs of forecasts. Only the cases for 20 September 1998 radiation, fog and stratus (figure 10) and that for 11 July 1999, clear summer day, showed any noticeable differences, albeit for one or two time periods only.

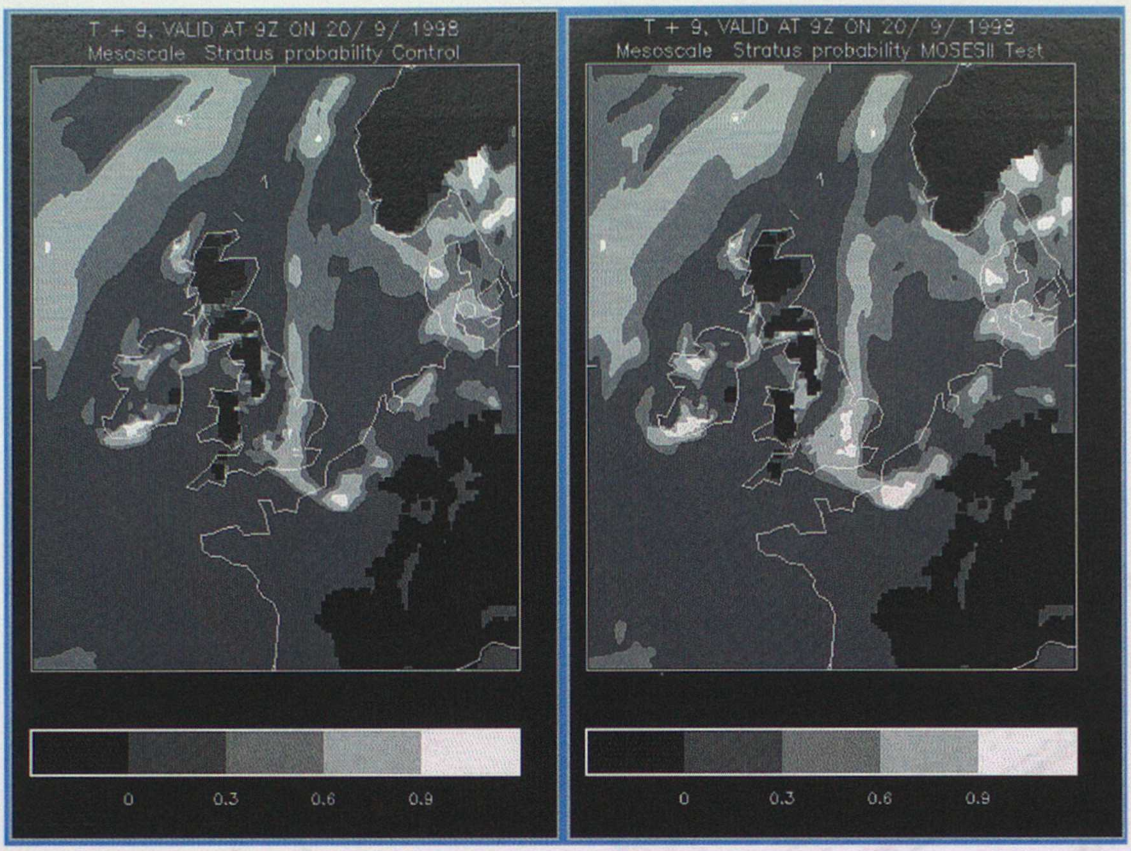
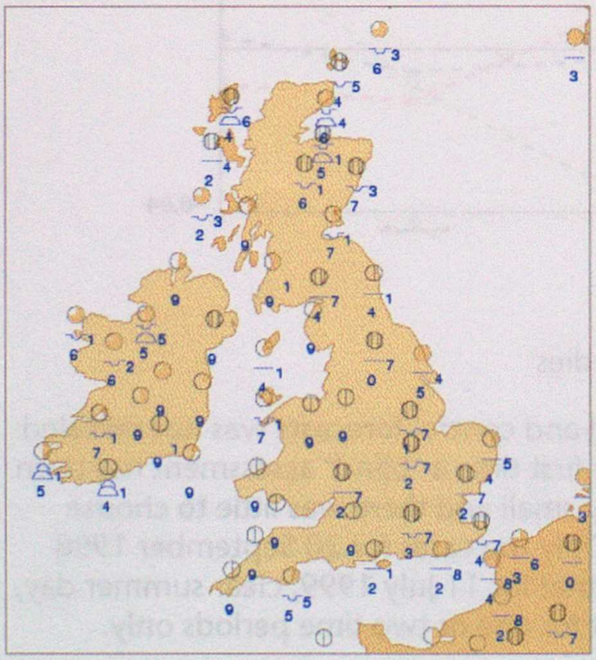



Figure 10

The stratus probability at T+9 was marginally better for the MOSES 2 version, with the probability of cloud below 1000 feet being more widespread, and with slightly higher probabilities, which was in closer agreement to the cloud observations shown in figure 11.

Obs 1998-09-20 09:00



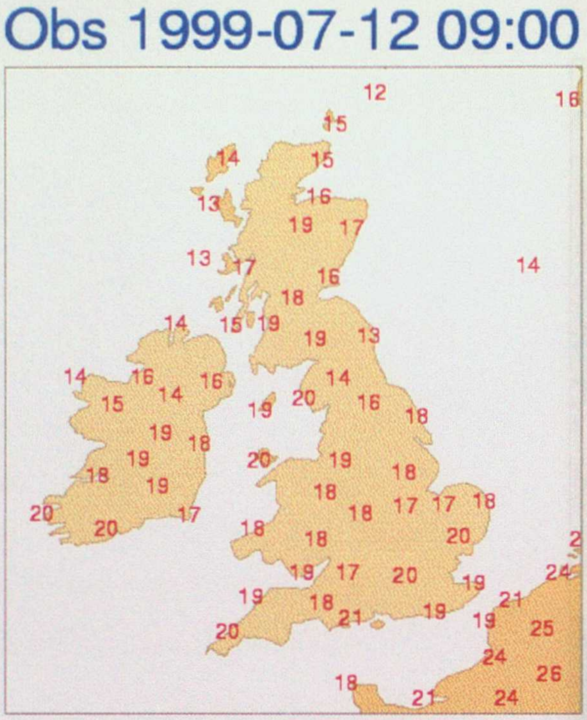
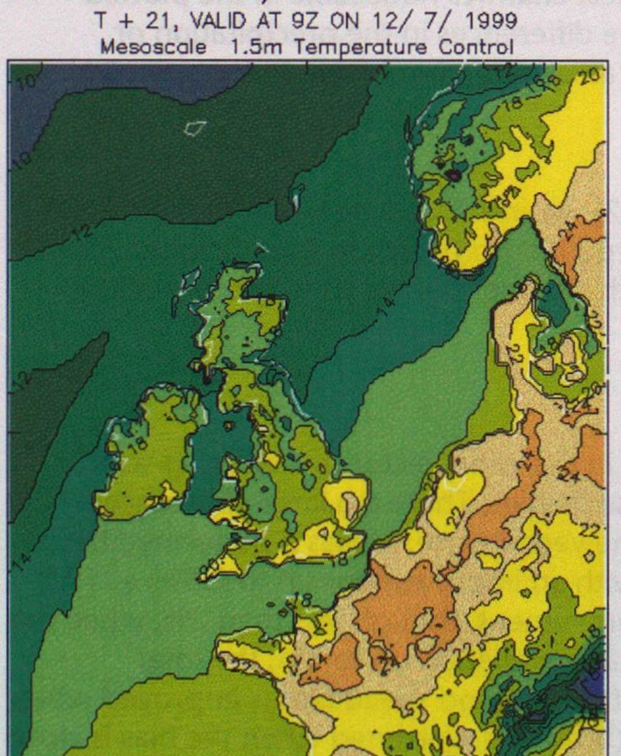



Figure 11

The surface (screen) temperatures for the July case at T+21 (fig.12) were about equal for both control and MOSES 2 version compared to the observations, with some areas cooler, others warmer and overall no preference.



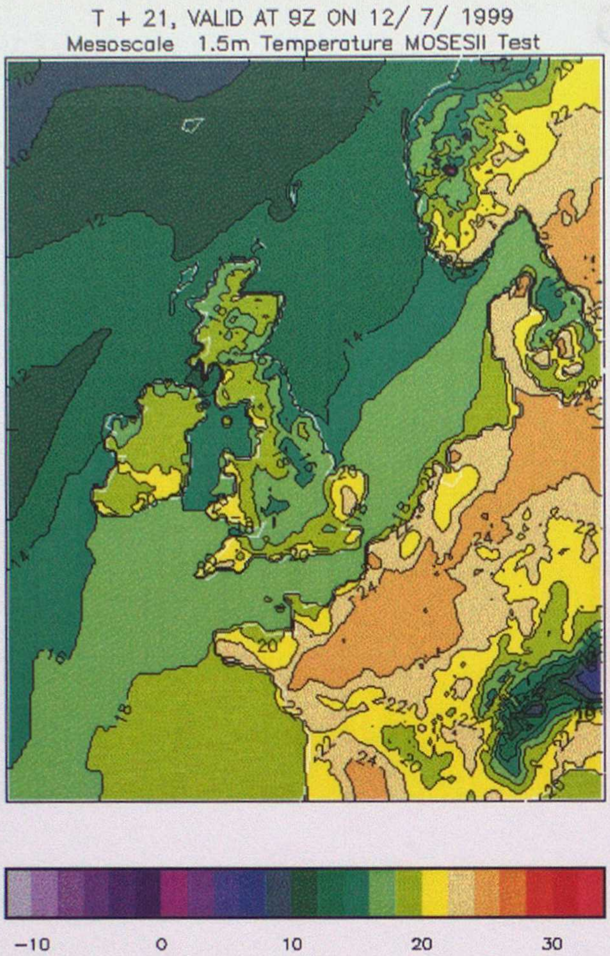



Figure 12

The above two examples show the greatest changes noticeable in the plotted output charts. There were no appreciable differences in the precipitation or surface pressure charts. Subjectively the assessment is overwhelmingly neutral.

## 3 Parallel runs

The mesoscale model trial suite (MOSES2) was run in parallel with the operational Mesoscale (MOSES1) re-runs during the period from 17th to 31st October 2000. The verification was performed from 18th October 00Z to 30th October 2000 18Z.

### 3.1 Objective verification

The parallel run shows an improvement in the wind vector rms error, as well as the same shift in the bias than the 16 case studies. There is a large difference verifying at 12Z and at 00Z, regarding the vector rmse. Moses 2 performed better than the operational Mesoscale at 00Z with an improvement up to 2.5%; at 12Z, the whole Mesoscale area keeps the improvement, though less than 2%, while the UK Index and WMO block 3 areas show a degradation up to 3%, the total verification results show a mixture of both. The wind speed bias is improved when the operational run shows positive bias (00Z) and worsened when the bias is close to zero or takes negative values (12Z), with the overall result for all the validity times neutral. See figure 13.

Cases: +——+ UK-MES ×······× MOSESII

Areas: — Complete model area — WMO Block 03 station list — UK Index station list

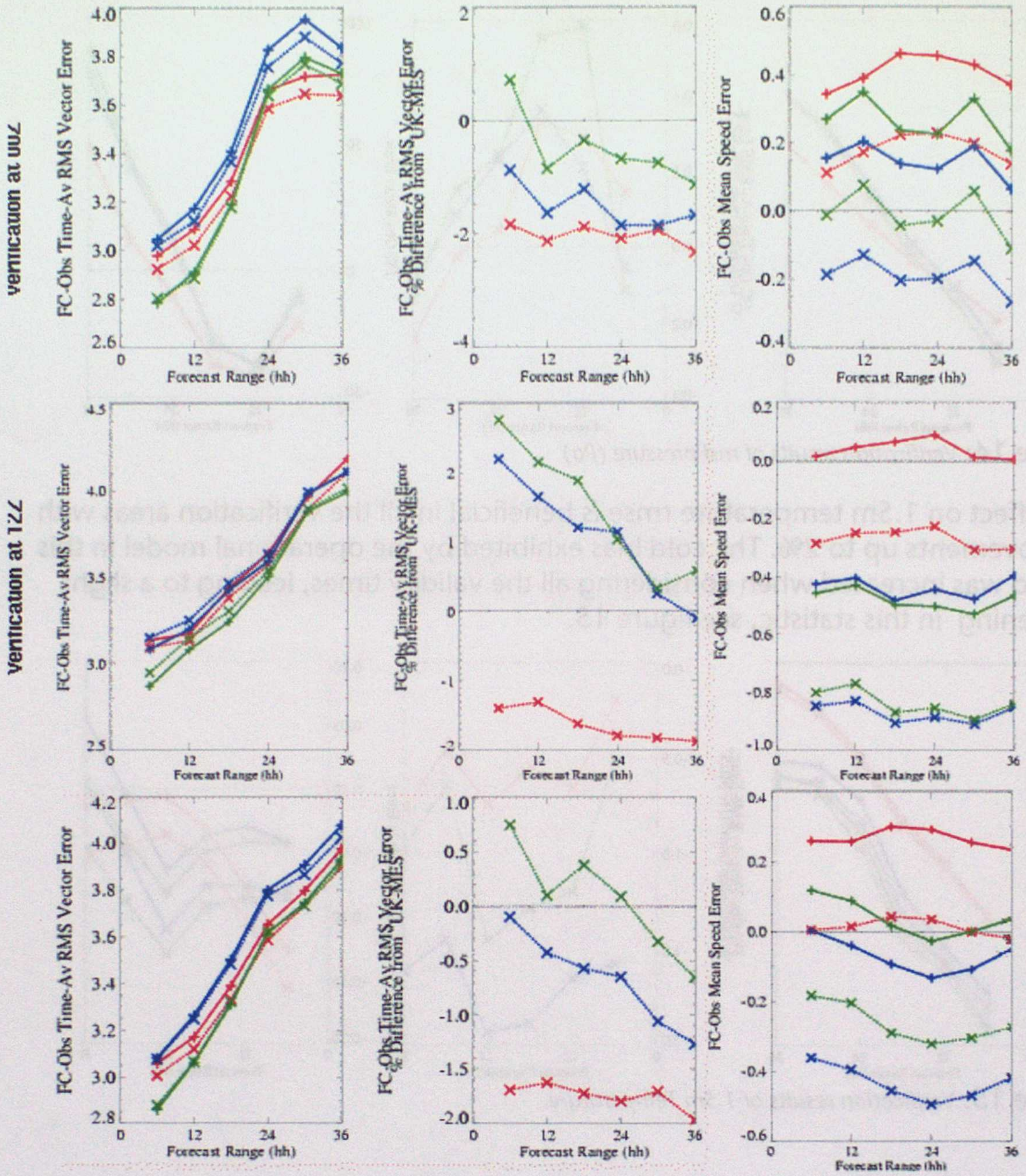



Figure 13: *Results verifying 10m wind at 00Z, 12Z and total*

MOSES 2 does not affect the msl pressure bias, while the effect in the rmse is less than 1%. Figure 14.

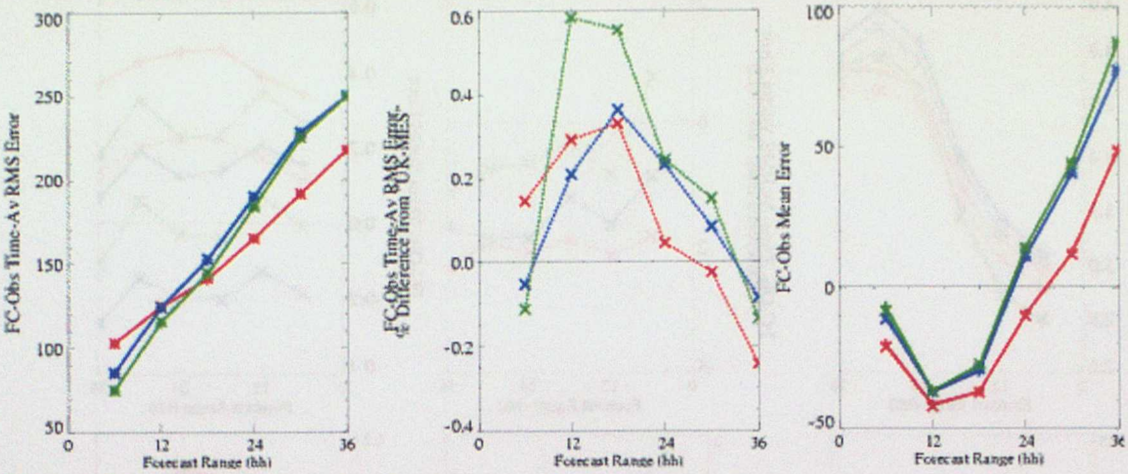



Figure 14: *Verification results of msl pressure (Pa)*

The effect on 1.5m temperature rmse is beneficial in all the verification areas with improvements up to 2%. The cold bias exhibited by the operational model in this period was increased when considering all the validity times, leading to a slight worsening  in this statistic, see figure 15.

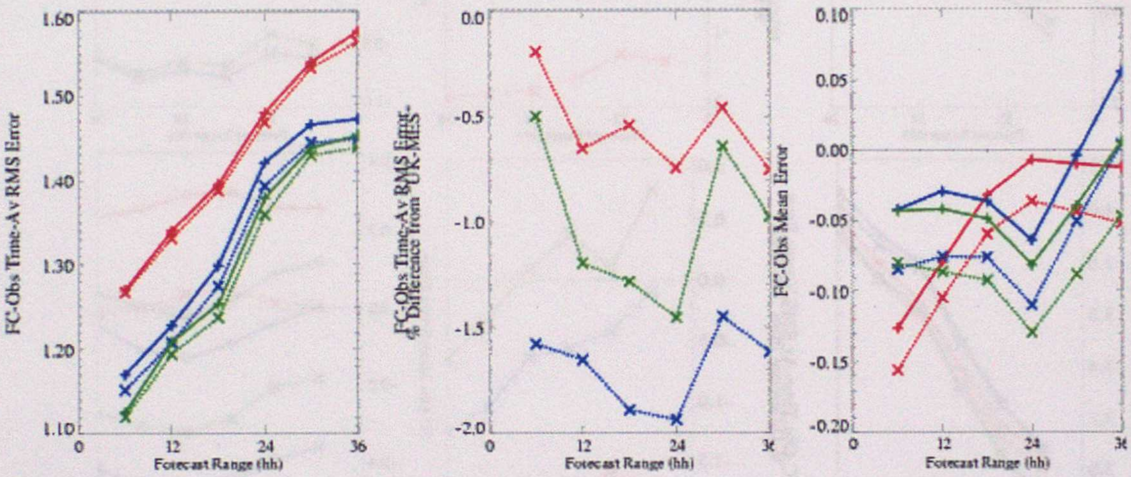



Figure 15: *Verification results of 1.5m Temperature*

The relative humidity was slightly worse with MOSES 2, reducing the rmse by 2% for the whole area, but increasing it by 2.5% for the UK Index area and with very little effect in the WMO block 03 area. The wet bias in the operational run is enhanced in MOSES 2 giving a poorer result, as figure 16.

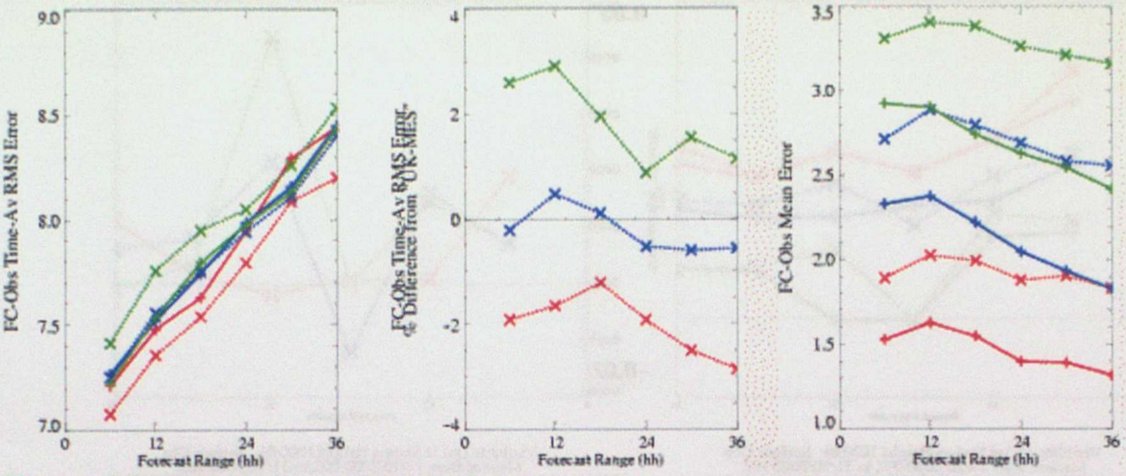



Figure 16: *Verification results of 1.5m Relative Humidity*

The ETS for visibility is generally improved for 200m and 5000m thresholds, while the impact on the 1000m threshold is overall neutral, though variable. As in the case studies the UK index area shows the highest impact, though the amplitude of the oscillations is lower. See figure 17.

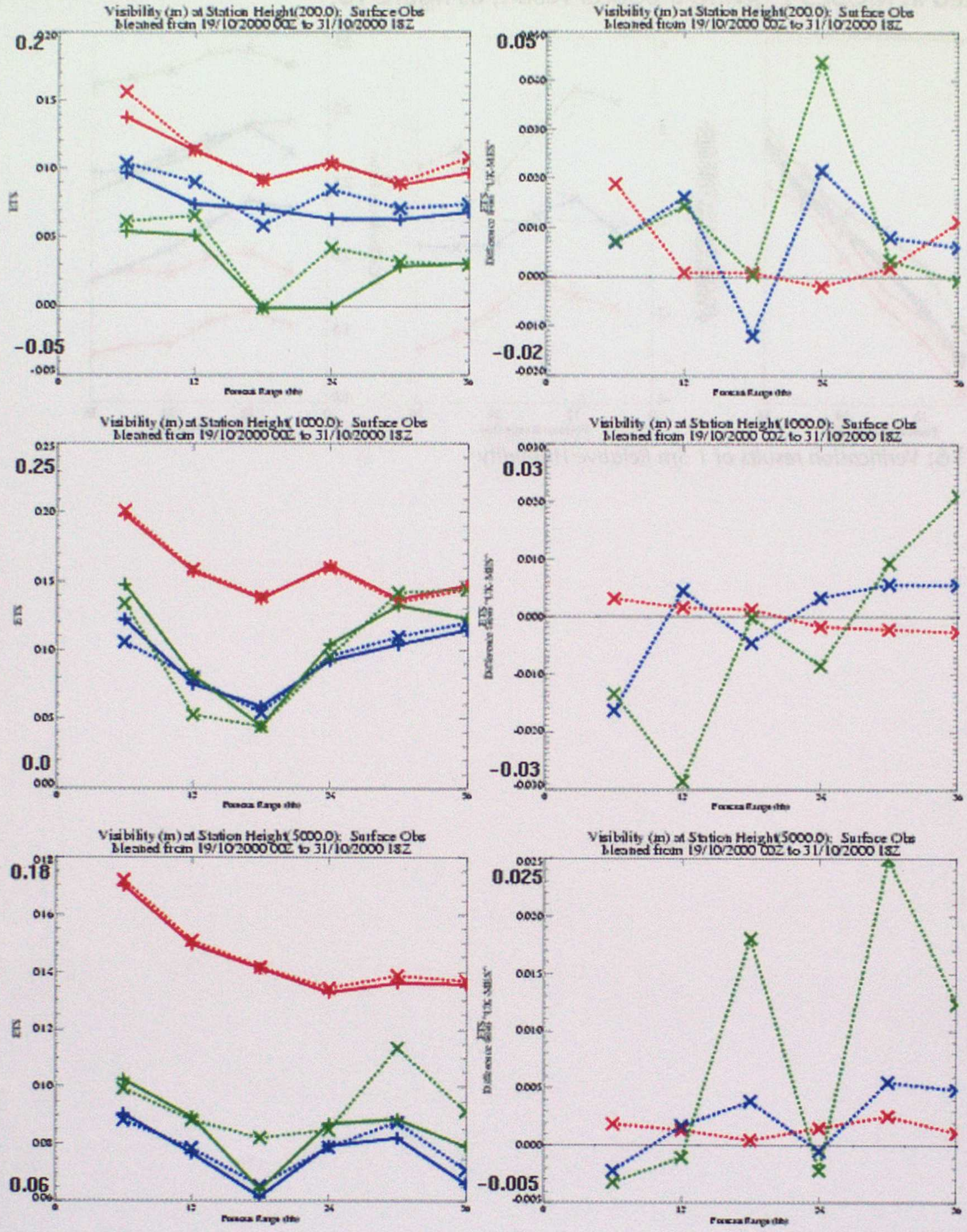



Figure 17: *ETS (left) and change in ETS (right) for visibility at 200m threshold (top), 1000 m threshold (middle) and 5000 m threshold (bottom)*

Regarding the cloud cover, the ETS is improved at all thresholds, performing better than in the case studies, the most notable improvement is achieved for the 0.6 threshold, as figure 18.

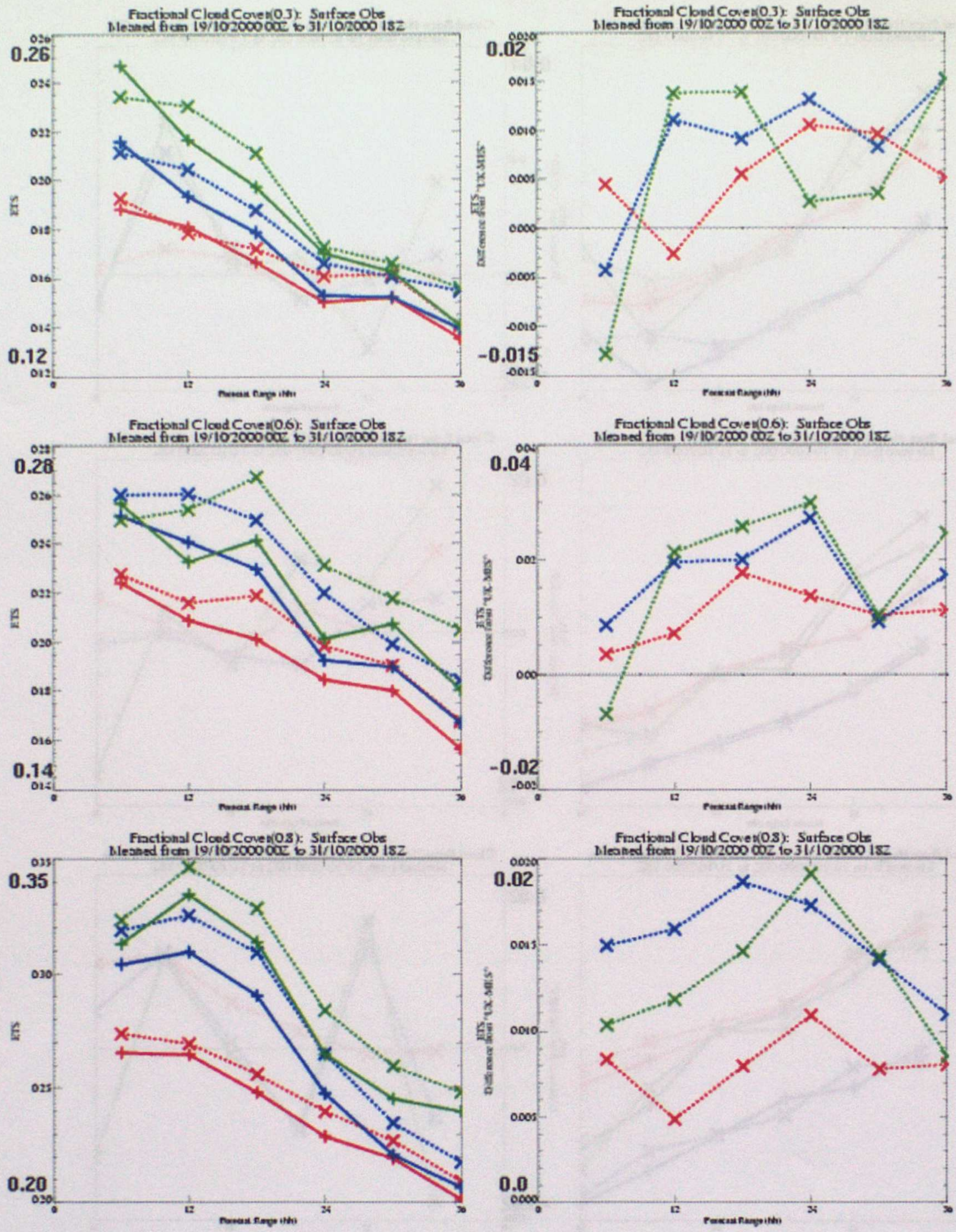



Figure 18: *ETS (left) and change in ETS (right) for Fractional Cloud cover at 0.3 (top), 0.6 (middle) and 0.8 (bottom) thresholds*

The ETS for Cloud base heights show a slight overall improvement, mainly when the WMO block 03 area is considered. The threshold showing the greatest improvement is 100m. See figure 19.

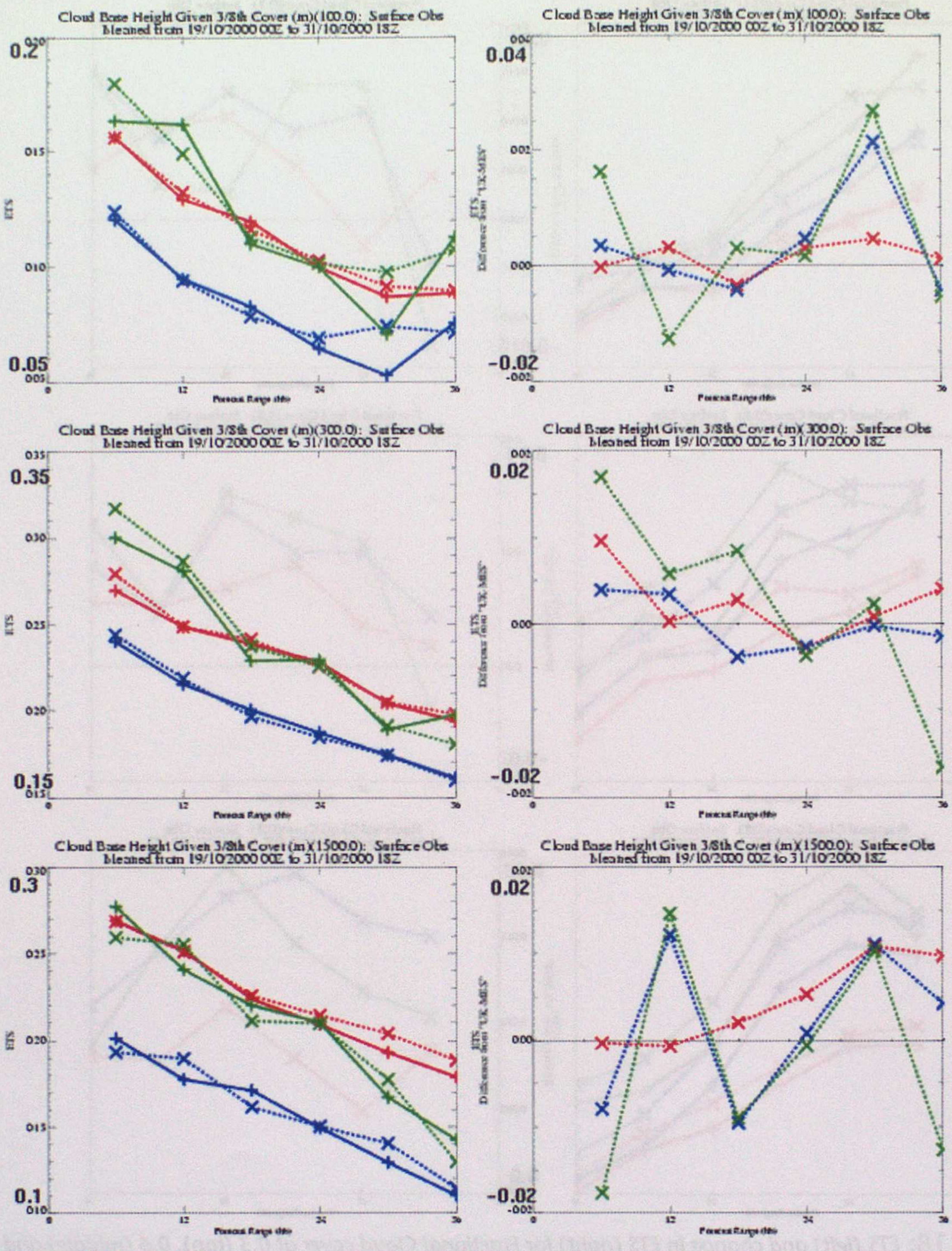



Figure 19: *ETS (left) and change in ETS (right) for Cloud base height at 100m (top), 300m (middle) and 1500m (bottom) thresholds*

The precipitation ETS scores are improved for the UK Index and WMO block 03 areas, while the whole model area shows a slight degradation in the highest thresholds (4mm/6h and 1mm/6h) and a general improvement in the lowest (0.2mm/6h), as figure 20. The improvement in rain forecast was better in the parallel run than in the case studies.

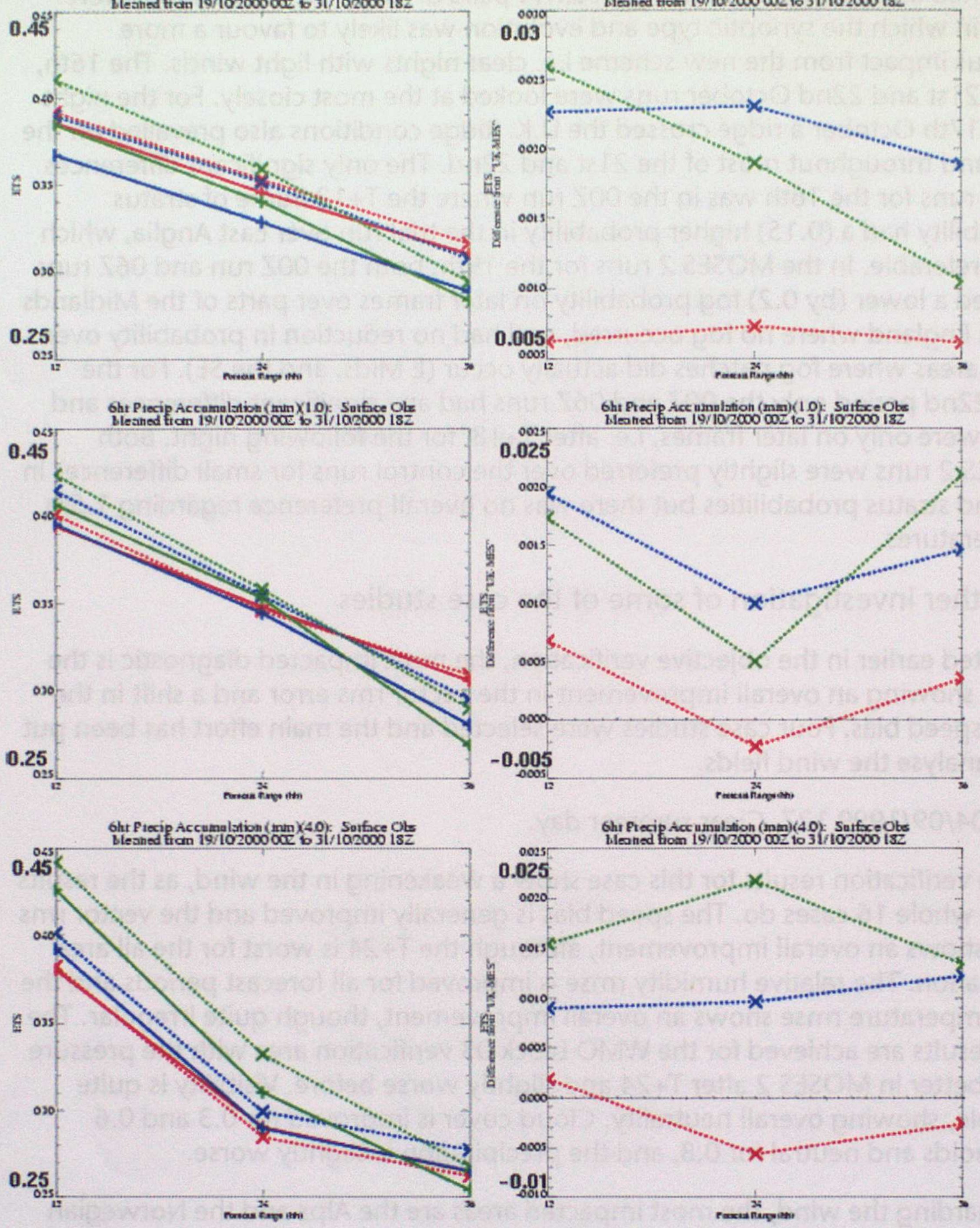



Figure 20: *ETS (left) and change in ETS for precipitation at 0.2mm/6h (top), 1mm/6h (middle) and 4mm/6h (bottom) thresholds*

### 3.2 Summary of objective verification

The verification of the parallel run confirms the results of the case studies. Negligible impact in surface pressure, positive impact in the 1.5m temperature with an rms error improvement up to 2%, slight worsening in the relative humidity bias without impact in the rms error, overall improvement in the wind rms error, although not as good as the case studies, and shift in the wind speed bias to lower values. The rest of the variables show very slight variation with overall positive results.

### 3.3 Subjective assessment of parallel runs

Since the impact of this change was broadly neutral, a selection of runs were examined and compared rather than all 44 pairs of runs. The runs chosen were those in which the synoptic type and evolution was likely to favour a more obvious impact from the new scheme i.e. clear nights with light winds. The 16th, 19th, 21st and 22nd October runs were looked at the most closely. For the night of 16-17th October a ridge crossed the U.K. Ridge conditions also prevailed on the 19th and throughout most of the 21st and 22nd. The only significant differences in the runs for the 16th was in the 00Z run where the T+12 frame of stratus probability had a (0.15) higher probability in the trial run over East Anglia, which was preferable. In the MOSES 2 runs for the 19th, both the 00Z run and 06Z runs showed a lower (by 0.2) fog probability on later frames over parts of the Midlands and N England where no fog occurred, and had no reduction in probability over those areas where fog patches did actually occur (E Mids. and the SE). For the 21st/22nd period only the 00Z and 06Z runs had any significant differences and these were only on later frames, i.e. after T+18, for the following night. Both MOSES 2 runs were slightly preferred over the control runs for small differences in fog and stratus probabilities but there was no overall preference regarding 1.5m temperatures.

## 4 Further investigation of some of the case studies

As stated earlier in the objective verification, the most impacted diagnostic is the wind, showing an overall improvement in the vector rms error and a shift in the wind speed bias. Four case studies were selected and the main effort has been put in to analyse the wind fields.

Case 04/09/1999 12Z. Clear summer day.

The verification results for this case show a weakening in the wind, as the results of the whole 16 cases do. The speed bias is generally improved and the vector rms error shows an overall improvement, although the T+24 is worst for the all area verification. The relative humidity rmse is improved for all forecast periods and the 1.5 temperature rmse shows an overall improvement, though quite irregular. The best results are achieved for the WMO block 03 verification area with the pressure rmse better in MOSES 2 after T+24 and slightly worse before. Visibility is quite variable, showing overall neutrality. Cloud cover is improved for 0.3 and 0.6 thresholds and neutral for 0.8, and the precipitation is slightly worse.

Regarding the wind, the most impacted areas are the Alps and the Norwegian mountains, which shows vector differences often greater than 2 m/s and sometimes above 5 m/s. At T+24 and beyond there is an area of large differences on the French shore of the English Channel, related to a local cyclonic circulation with weak winds, where the perturbations have been advected and increased from T+3. Over Great Britain and Ireland, the highest differences appear in Southern Britain, related to the previously stated feature.

Case 05/11/1999 12Z. Active fronts.

As in the previous case, the wind is weaker in the new scheme. The speed bias shows a slight degradation for the WMO block 03 area between T+12 and T+24 and for the UK Index area at T+12 and T+18, improving at other times; the best result is for the whole area, where T+12 is the only forecast time without any improvement. The vector rmse is improved for the complete model area during the forecast and also for the WMO block 03 and UK Index areas except for the period from T+12 to T+24. The 1.5m temperature rmse is improved, the pressure rmse is slightly worse, the relative humidity rmse is worse at the beginning of the forecast, improving later and the cloud cover shows an overall improvement.

Again, the main impact in the wind field takes place over the Alps and Norway, with vector differences up to 5 m/s, and greater in some cases. A synoptic cyclonic circulation advects the differences over the North Sea. In this area differences increase with increasing forecast lead-time, reaching values greater than 5 m/s at T+24 and beyond. Over Britain, the differences were around 1 m/s, although at the beginning of the forecast reached up to 3 m/s over large areas of Ireland and the Midlands.

Case 18/12/99 12 Z. Snow.

The shift in the wind speed is also present in the verification plots for this case, with the bias improved after T+18 for all the station sets and slightly worsened before. The vector rmse is improved in, with MOSES 2 better than MOSES 1 by 8% at T+24 for the UK Index area and by 6% for the WMO block 03 area. The 1.5m temperature rmse is largely improved, the pressure rmse shows slight improvement at the beginning and end of the forecast and is worse in the central hours while the impact on relative humidity and cloud cover is neutral overall.

The wind field is affected mostly over the Alps and Norway, with vector differences up to 5m/s all through the forecast. There are also differences over the North Sea, which are advected to the southeast shore during the forecast. Over Britain the differences are small, rarely greater than 1m/s and always below 3m/s, the biggest differences appearing in the north of Scotland.

Case 24/12/99 0Z. Land Gales.

This case also shows the wind speed reduction, here, as the bias is negative for MOSES 1 in almost all the verification areas for all the forecast periods, the reduction of the wind speed leads to an overall worsening of the bias. The wind vector rmse results vary between a 4% improvement and a 4% degradation. The msl pressure is barely impacted in either bias or rmse, the 1.5m temperature is generally improved, the relative humidity is mostly worse, although the bias is reduced in the first forecast periods, and the effect on the cloud cover is variable and overall neutral.

The Alps is again one of the areas that shows the highest wind vector differences between the two schemes, greater than 5 m/s in all the times examined. The differences in the Norwegian Mountains vary from more than 5m/s at T+30 to less than 2m/s at T+3. Over the Southeast coast of Norway the MOSES 2 wind differs from MOSES 1 by up to 3m/s when the wind blows perpendicular to the coast from sea to land. There are two areas where the wind field is affected over the North Sea and the western Norwegian coast, related to two cyclonic circulations that are developed to T+24 and from T+27. There is also another area where the wind field is highly changed moving over the sea from the Atlantic south of Ireland at T+21 to Biscay at T+36 following the tail of the second frontal system. Over Great Britain and Ireland, the impact was higher than in the previous cases, most of Ireland shows differences between 1m/s and 3m/s during all the forecast and at T+36 there is a broad area where they reach 5m/s, and the same happens over South Wales, Cornwall and Devon. In summary, this case shows differences greater than the others but with more spatial and temporal variation, related to the synoptic systems.

Common features.

a) There is a general reduction in the wind speed for all the cases.
b) The 1.5-m. Temperature forecast is improved in most of the cases.
c) The areas where an impact in the wind field is present most of the time are the Alps and Norway, likewise large differences also arise in other areas, generally related to synoptic systems or local cyclonic circulations. In Great Britain and Ireland the differences in wind are usually much lower than in theses areas. Most of the results were obtained only over Great Britain and Ireland (47.5N to 63N, 12.5W to 7E). See figure 21.

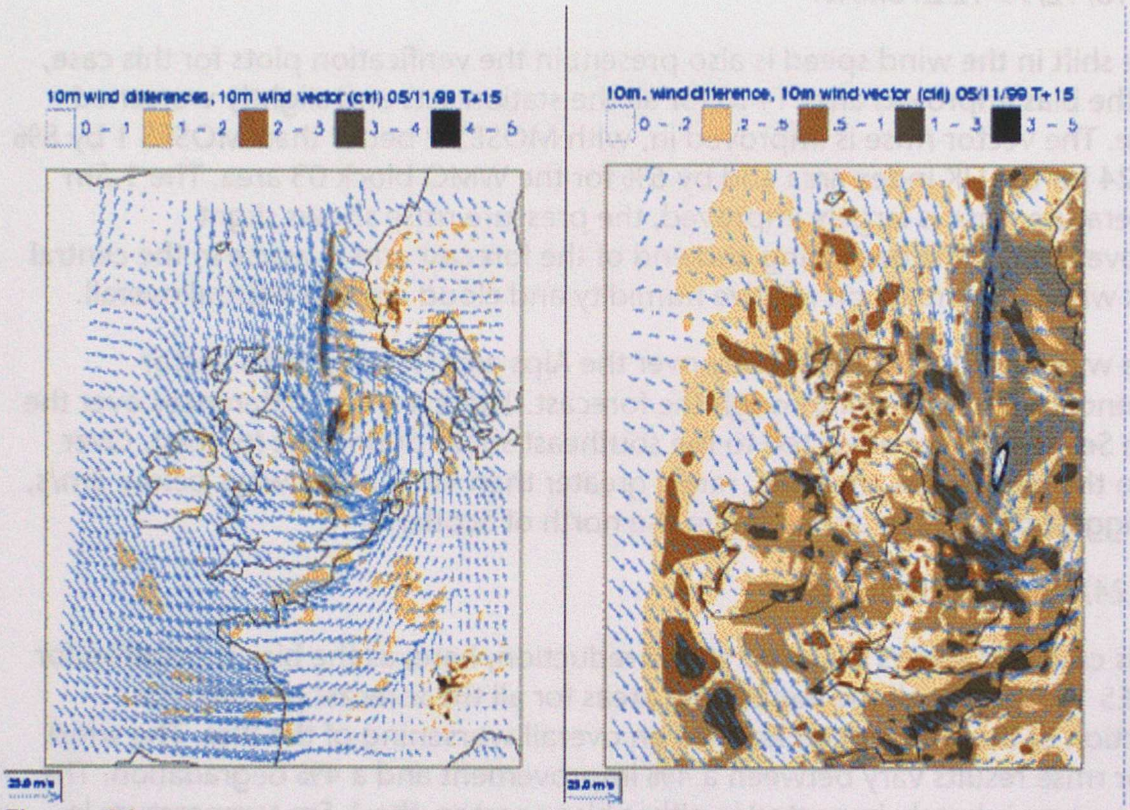



Figure 21: *Module of wind differences vector in m/s (shaded) and wind field in control run (vector) in the whole mesoscale area (left) anr Britain, for the case 05/11/1999 at T+15*

d) The 1st model level wind differences follow closely the 10m wind differences, this is expected since the 10m wind is obtained by interpolating from the 1st model level. The only areas where a disagreement is found are the Alps and the Norwegian Mountains, due to the differences found in the drag coefficient CD and hence in the interpolation coefficient. See figure 22.

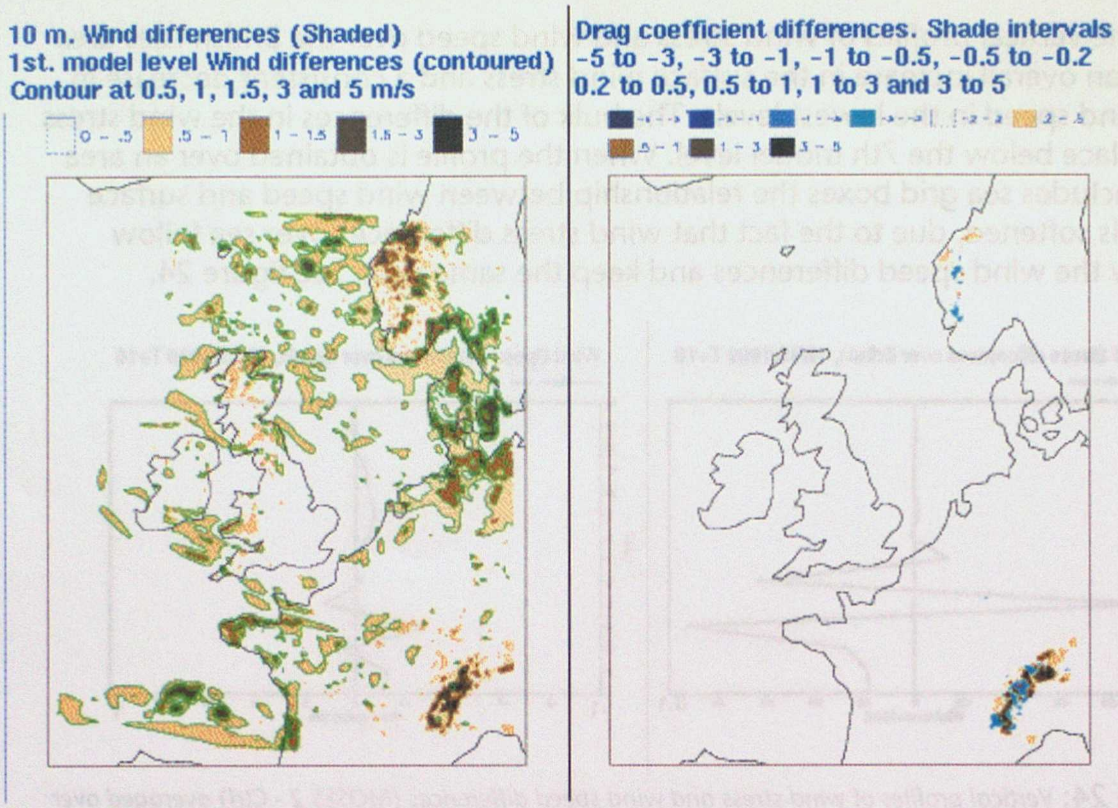



Figure 22: *10 m. wind, 1st model level wind and drag coefficient CD for the case study 18/12/1999 at T+0*

e) The impact in the wind field is mostly due to differences in the wind speed, rather than in the direction. This was also found for the Site Specific Forecast Model (M.Best, W.Hopwood and S.Jackson, 1997 Forecasting Research Division Technical Report no. 220). See Figure 23.

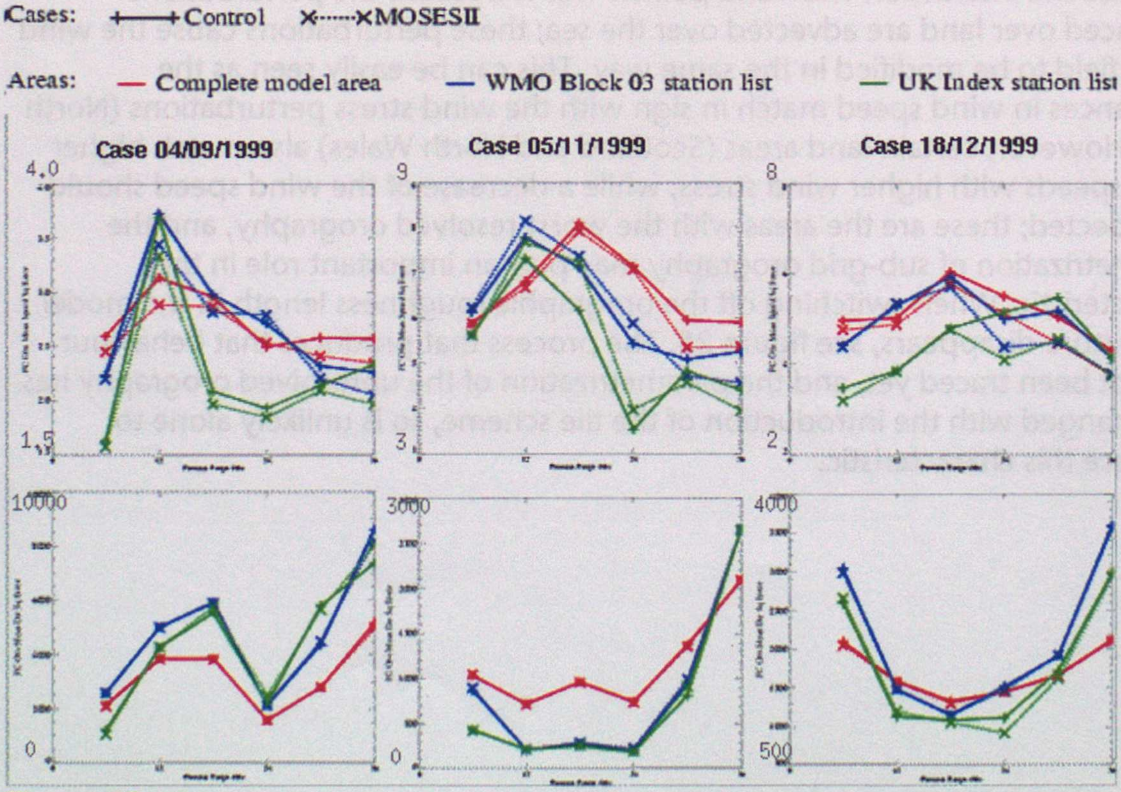



Figure 23: *Mean speed squared error (top) and Mean direction squared error (bottom) for three case studies*

f) The vertical profiles of wind stress and wind speed over the British Isles area show an overall increase in the surface wind stress and a consistent decrease in the wind speed in the lowest levels. The bulk of the differences in the wind stress take place below the 7th model level. When the profile is obtained over an area that includes sea grid boxes the relationship between wind speed and surface stress is softened, due to the fact that wind stress differences over sea follow closely the wind speed differences and keep the same sign. See figure 24.

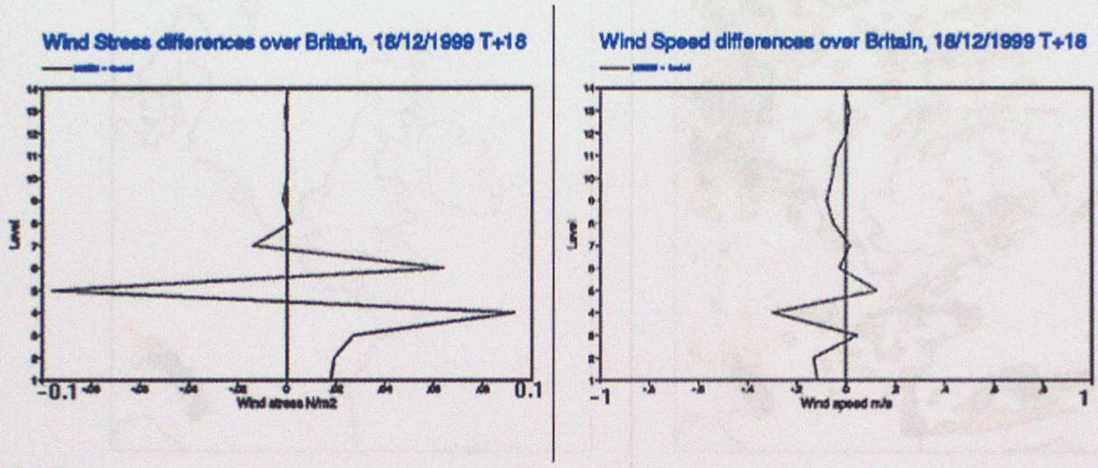



Figure 24: *Vertical profiles of wind stress and wind speed differences (MOSES 2 - Ctrl) averaged over the area 47.5N to 63N, 12.5 W to 7 E*

g) The wind field is changed over sea as well as over land, when MOSES 2 only modifies the interaction with land points. This is because the perturbations produced over land are advected over the sea; these perturbations cause the wind stress field to be modified in the same way. This can be easily seen as the differences in wind speed match in sign with the wind stress perturbations (North Sea). However, certain land areas (Scotland and North Wales) also match higher wind speeds with higher wind stress, while a decrease of the wind speed should be expected; these are the areas with the worst resolved orography, and the parametrization of sub-grid orography may play an important role in this characteristic. When switching off the orographic roughness length in the model this feature disappears, see figure 25. The process that produces that behaviour has not been traced yet, and the parametrization of the unresolved orography has not changed with the introduction of the tile scheme, so is unlikely alone to produce this characteristic.

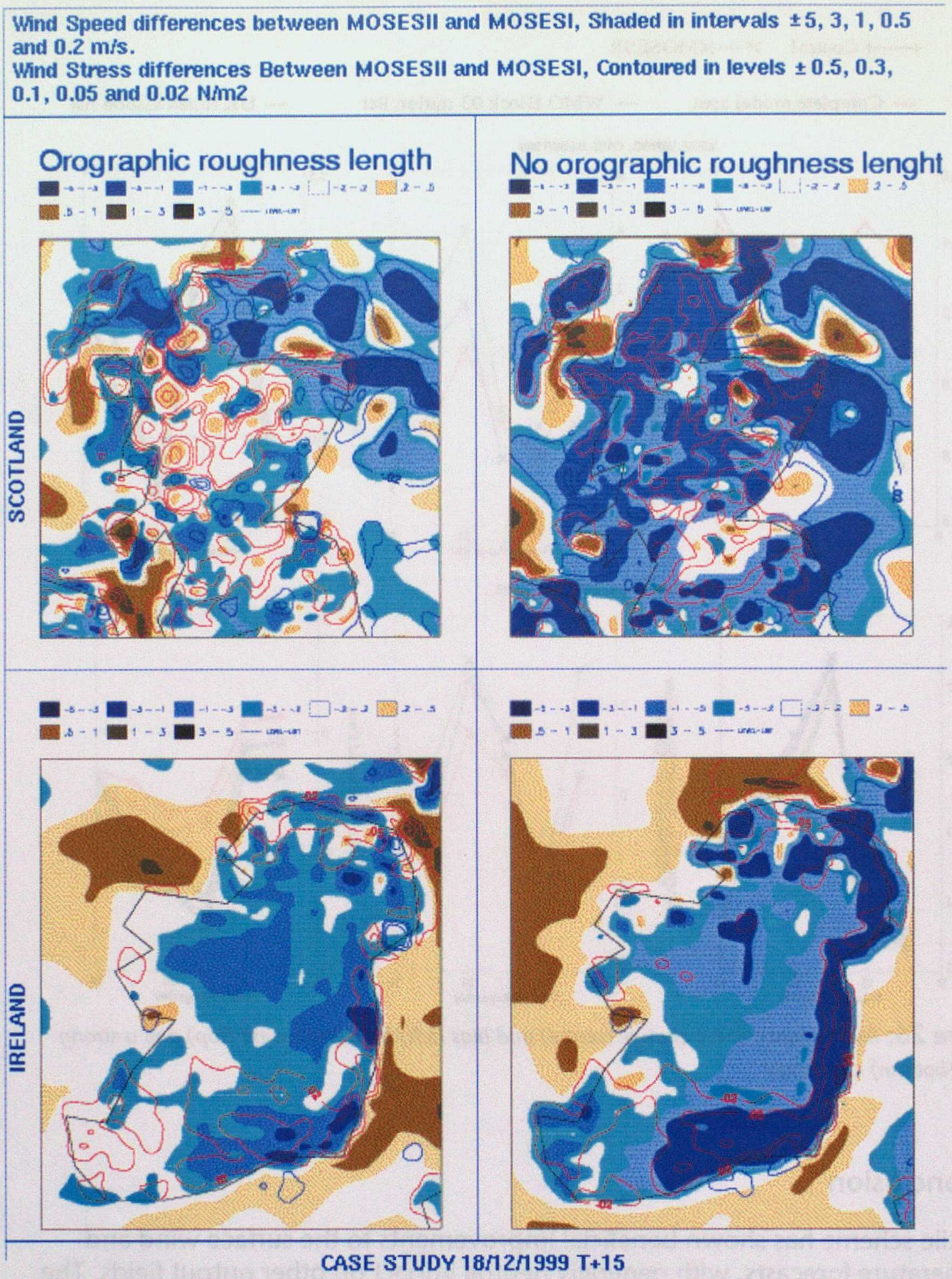



Figure 25: *MOSES 2 - MOSES 1 wind speed (shaded) and wind stress (contoured). Effect of orographic roughness length.*

## Summary of investigations

MOSES 2 is increasing the momentum flux from the boundary layer to the surface; the wind speed is consistently reduced in the lowest boundary layer levels, and this reduction is shifting the wind speed bias as a whole, which means an overall improvement. However, the weakening of the strong winds may increase the negative wind speed bias in winter and reduce the chances of forecasting extreme events; in fact, from the four case studies, the vector rmse and wind bias show greater improvement in those cases with weakest winds, as in figure 26.

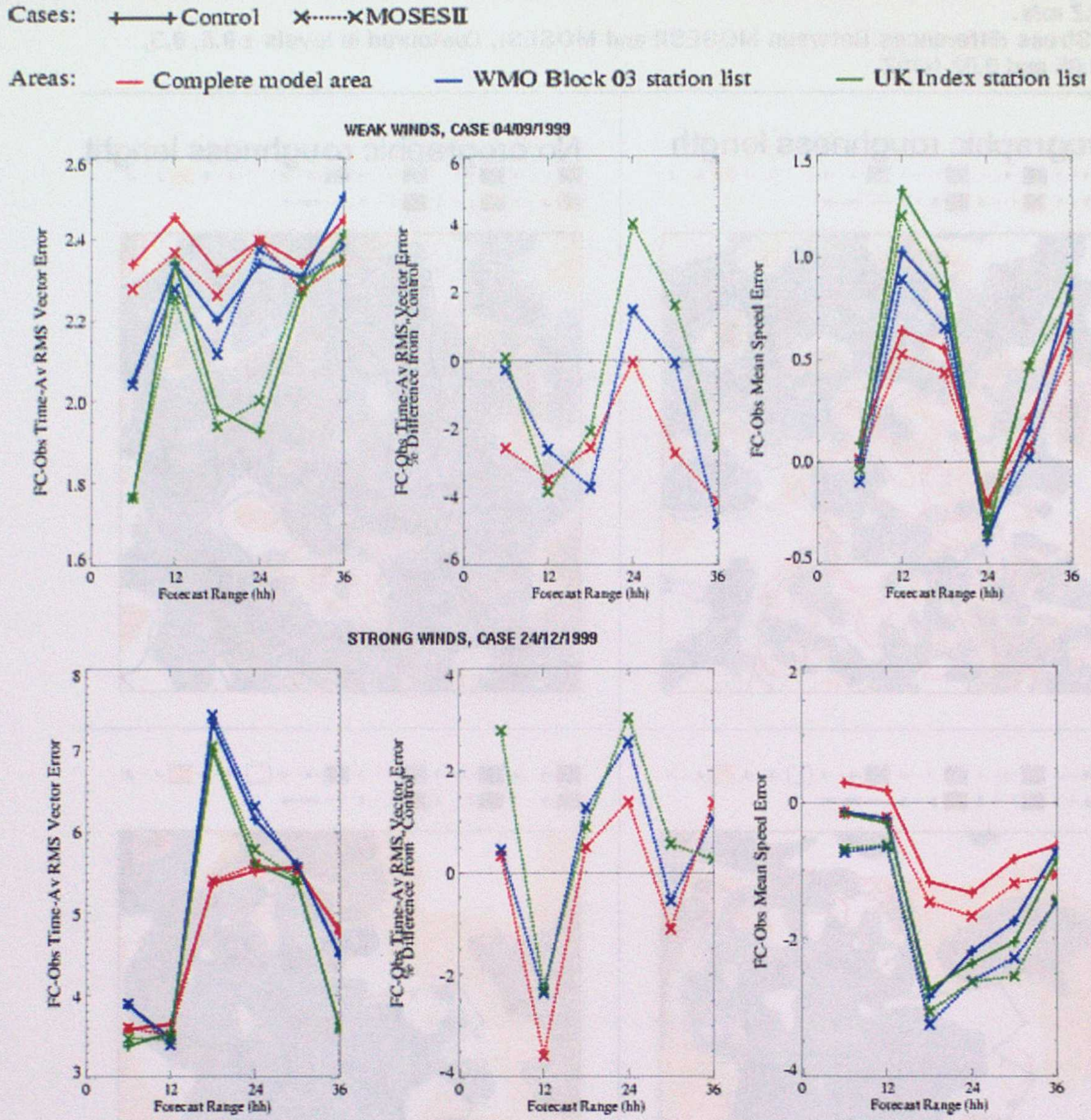



Figure 26: *RMSE (right), RMSE change (centre) and bias (left) for a weak wind (top) and a strong wind (bottom) case study*

## 5 Conclusion

The tile scheme has shown beneficial improvements to the surface wind and temperature forecasts, with generally neutral impact on other output fields. The estimated impact on the UK Index is 1.5 points. The scheme is the basis of a new soil moisture model to replace MORECS, and so is better matched for the updating of the soil moisture analysis in the mesoscale model. The change was implemented operationally on the 26th October 2000.