Soil moisture assimilation at the UK Met Office

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Introduction

The soil moisture is an important component in a numerical weather prediction (NWP) system as it is a major factor in determining the partition of the available energy into sensible and latent heat fluxes. These in turn directly affect the near surface temperature and humidity which are essential forecasting parameters. Soil moisture is also an important source or sink for atmospheric moisture.

Soil moisture is the most important antecedent condition for runoff, i.e. how much of the rainfall flows off the land into rivers and potentially causes floods. It is essential for agriculture and huge sums are invested in irrigation schemes.

A fairly new application is the 'trafficability' of the terrain. This is the ease of moving off-road vehicles across the land. This is of interest to the military for the movement of heavy equipment such as tanks in their fields of operations but is also of interest to civilian users such as in agriculture for the gathering of the harvest. The ability of the soil to support such large vehicles depends upon the soil strength which is directly related to the soil moisture.

Currently, the Met Office resets the soil moisture in its global weather forecast model to climatology each week with free-wheeling in between. This is not a desirable solution as true anomalies will be missed leading to forecast errors and also the climatology used, Willmott et al (1984), had to be extensively modified to make it compatible with the parametrisation schemes used in the forecast model. The main problem is that Willmott uses a simple bucket model whereas the forecast model has a multi-level soil scheme.

In the mesoscale model, a limited area domain centred on the UK, the soil moisture is again set weekly but this time according to data from MORECS (Hough and Jones 1997), a separate model run weekly mainly for agricultural customers. This is again undesirable as MORECS only covers England, Scotland, Wales and Northern Ireland and therefore climatology is used for the remaining areas. Furthermore, the physics and observation analysis scheme used in MORECS are somewhat dated, it was built in the 1980s when computer power was rather less than present. Like the Willmott climatology, it also uses a simple bucket model.

The question arises why any resetting is done at all. The simplest, and most desirable solution, would be to let the soil moisture run completely freely. However, if this was allowed to happen then model drift would occur resulting in unrealistic drying and severe forecast errors. The problems are most acute in a high evaporative situation, i.e. hot and sunny. In these circumstances, the model tends to over-evaporate resulting in a steady drying of the soil. There are probably many reasons for this but two factors are that the model tends to have too little cloud and a surface dry bias at the start of a forecast period. Both of these are contributed to, at least in part, by radiosonde reports which tend to have a dry bias.

There are insufficient direct measurements of soil moisture available to make any analysis scheme feasible and therefore errors in the forecasting of screen temperature and humidity are used as a proxy for errors in the soil moisture, an approach used by many other centres.

First of all, we relate the errors in screen temperature and humidity to an error in the surface resistance to evaporation, r_s, with the expression:-

$$\Delta r_s = \frac{\alpha\Delta T - \left(1 + \delta \, {r_s}/{r_a}\right)\Delta q}{\left(1 - \delta \, {\bar{r}_a}/{r_a}\right) {E}/{\rho} - \left({\delta}/{r_a}\right)\Delta q}$$

Where,
ΔT and Δq are the forecast errors in temperature and humidity respectively
r_a is the aerodynamic resistance between surface and the lowest model level
$\bar{r}_a$ is the aerodynamic resistance between surface and screen level
E is the turbulent flux of moisture
ρ is the density of water

The term δ is introduced by the assumption that the error in the surface temperature is related to the error in temperature at the lowest model level by the simple relationship

$$\Delta T_1 = (1-\delta)\Delta T_*$$

The full derivation of this expression may be found in Best and Maisey (2002). Once Δr_s is known then the error in the soil water availability factor, β, may be found using

$$\Delta\beta = \frac{\beta\Delta r_s}{(r_s - \Delta r_s)}$$

and since β is defined as the ratio of actual extractable water to the maximum extractable water that the soil can hold under stress conditions

$$\beta = \frac{(m - m_w)}{(m_c - m_w)}$$

an increment to the soil moisture can be calculated. m is the soil moisture, m_c is the critical point (the point at which the soil water starts to limit the amount of evaporation) and m_w is the wilting point (when no more water can be extracted from the soil). m_c and m_w are spatially varying fields according to the soil type.

Increments will only be applied in certain atmospheric conditions. Firstly, the atmosphere must be unstable (i.e. negative Richardson number). This is because in idealised experiments using a single column model δ was only found to be relatively constant in unstable conditions. It exhibited too much variability in stable conditions. Secondly, the temperature and humidity errors must be negatively correlated, i.e. either warm and dry or cool and moist. There may be other factors taken into account such as the amount of solar radiation, one would expect that the greatest errors are when the sun is overhead, wind speed or precipitation. The scheme will be run four times a day.

Work to date has involved adapting the normal 3D-VAR assimilation scheme used in the Met Office operational model (Lorenc et al, 2000)) to perform only a screen variable analysis. The normal analysis is not suitable as firstly screen variables are not included and even if they were it would be contaminated by upper air data. Some work has been done to refine the horizontal correlation scales used.

Some changes have been made to the forecast model to enable the nudging scheme to be coupled to it and some changes have been devised to the original Best and Maisey scheme to take into account changes in the model parametrisation scheme.

In the mesoscale model, MORECS data is being replaced by data from a new model known as the soil state diagnosis model (Smith et al 2004) which is run as part of the Nimrod suite within the Met Office. The Nimrod suite is run hourly producing very short range forecasts of up to 6 hours ahead.

The main advantage of using Nimrod data compared to MORECS data is that the Nimrod model uses the same physics, including the same soil levels, as the main forecast model. Therefore, it is relatively straightforward to transplant data from the Nimrod model into the forecast model. Another important improvement is that Nimrod uses a high resolution land use classification dataset while MORECS assumes all grass. Nimrod is available hourly instead of weekly, although we plan to only reset once per day. A comparison of the physics used in the two models may be found in Blyth (2002).

The actual quantity that will be transplanted is the soil water availability factor, β in the above equation, to take into account differing soil properties between the two models. It is worth mentioning that in the current scheme using MORECS data, it is the evaporation rates that are being transplanted since evaporation is a different function of β in MORECS from that used in the NWP model

Trials have been run throughout the summer to compare the performance of the two schemes. In overall objective verification terms the impact has been neutral but there have been days where a difference in the forecast afternoon screen temperatures has been noticed. The differences are directly related to β in that areas with a lower β have a higher temperature as one would expect.

The reason why β is different between the two models is mainly due to the driving data, especially precipitation data. A key difference between MORECS and the Nimrod system is that MORECS obtains its precipitation data from a network of rain gauges whereas Nimrod uses rainfall radar estimates. To provide a fairer comparison we are currently restricting the use of Nimrod data to only areas that lie within the usual UK rainfall radar area although we do have plans to expand to include the European radar network in the future.

In summary, the Met Office is working to improve its representation of soil moisture in its operational models. New schemes for both the global model and the regional mesoscale model will be implemented during 2005.

References

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