Data Assimilation for Convective Scale NWP

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1 Preliminary work with the Unified Model

The performance of the next generation of very short range forecast system, will depend, in part, on the ability to assimilate observations, especially of precipitation, cloud and fog, with frequent updates. Current and future variational techniques available in the Met Office's Unified Model (UM) system form a sound basis for this, but high resolution and speed requirements bring additional challenges in formulation and performance. The performance of the current Latent Heat Nudging techniques may be very different when convection is partially resolved, and alternative approaches may be needed. Since any convective scale system would be closely coupled to lower resolution (mesoscale) NWP, the performance of the lower resolution system is crucial. A strategy is needed which optimises short range performance and timeliness which may be a combination of different analysis resolutions, update cycles, and techniques (e.g. 4D VAR, 3DVAR and nudging). This strategy needs to be both pragmatic and based on a clear understanding of the assimilation process. At present, we have insufficient information on the potential performance of current and planned technology to formulate proposals for future developments. Our current work is therefore aimed at furnishing this information.

Some of the research will be carried out as part of a collaborative programme on storm scale forecasting between the Met Office groups at the Joint Centre for Mesoscale Meteorology and various groups within the university community. Research projects investigating the assimilation of precipitation data, including Doppler radar, the improvement of the conditioning of the control variable transforms and the inclusion of boundary layer forcing, are being carried out by postgraduate and postdoctoral researchers at the universities of Reading, Essex and Salford (as part of the Universities Weather Research Network).

Once the NWP system is able to capture adequately the state of existing systems (such as convective storms) in its analysis, substantial improvements to very short range forecasts of development should result. This development work is an essential prerequisite.

Our goal is to identify an optimal strategy, given existing assimilation technology, for data assimilation for high resolution models. Validation of the performance of the system against, especially, routine and research radar observations will be undertaken. A literature survey of progress in related areas has been carried out by Dance (2003).

An initial assessment of the performance of the convective scale model initialised with various reconfiguration strategies is underway, and we have started to run 3DVAR at 4km horizontal resolution. Increments are being added via an incremental analysis update procedure, and preliminary results are encouraging.

2 Moisture flux convergence and precipitation

We are investigating a new approach to the assimilation of radar precipitation data into mesoscale, and ultimately, convective scale models. The new approach is based on a strategy in which the model's wind, temperature and humidity fields are adjusted in response to the perceived error in model's representation of moisture flux convergence. The new assimilation scheme will be tested using the high-resolution version of the current mesoscale model that is being developed by the Met Office group at the JCMM in Reading. Tests show that this can be run at 2km resolution with a one-minute time step and produces realistic rainfall fields. The high resolution means that convective precipitation is more likely to be explicitly resolved, rather than being parameterised as occurs in the present 12km operational model.

Our current knowledge of atmospheric water balance suggests the following simple model relating aerodynamic moisture flux to surface precipitation under conditions where surface exchanges are of negligible importance:

$$P = -\alpha \int \mathrm{d}\sigma(\nabla_h.(\mathbf{v}\rho_\nu)) + \epsilon, \tag{1}$$

where P is either the model or 'observed' precipitation rate over a model grid box; α is some unknown constant of proportionality, $\mathbf{v}$ is horizontal wind velocity, ρ_ν is absolute humidity, ϵ is a residual error resulting from the approximations employed, and σ is the vertical coordinate.

The flux convergence term can be decomposed to represent the influence of convergence and advection, and if the contribution of the divergent part of $\mathbf{v}$ in the advection is small, we have

$$-\int \nabla_h.(\mathbf{v}\rho_\nu)\mathrm{d}\sigma = -\int \rho_\nu \nabla_h.\mathbf{v}_\chi \mathrm{d}\sigma - \int \mathbf{v}_\psi.\nabla_h \rho_\nu \mathrm{d}\sigma.$$

According to Robertson (1999), the dominant contribution is from the kinematic convergence term, at least on the scale of a single model grid box. Such a result suggests a simple variational adjustment strategy, involving only changes to ρ_ν and $\mathbf{v}_\chi$ on the model grid subject to the constraint that the adjusted total convergence is consistent with observed precipitation rates according to (1).

However, such an adjustment does not necessarily result in an adjusted state that lies on the slow manifold of the model. An alternative approach is to relate P to the *vertical humidity flux*, by making the approximation

$$-\int \nabla(\mathbf{v}\rho_\nu)\mathrm{d}\sigma = w\rho_\nu,$$

where w is vertical velocity at some model level. It is possible to express w as the solution of a suitable balance equation which expresses the divergent motion in terms of the model's prognostic variables. This methodology is to be used as the basis of a 'forward model' relating incremental variations in P to incremental variations in the prognostic variables. Equation (1), and the approximations discussed, can be used to derive a tangent linear model to predict the variation in P in response to the model wind, temperature and humidity variables. An important feature of this approach is that it implies some impact on the model analysis in *any* region where observed and predicted precipitation rates differ.

The first stage has been to confirm the relationship between the precipitation and the moisture flux convergence as resolved by the high resolution model. This work has been completed and we are now adapting 3DVAR to modify the model analysis so that the diagnosed moisture flux convergence into each model grid box is consistent with that implied by the co-located precipitation rate observed by the radar. The impact of the scheme on mesoscale forecasts will be evaluated at various resolutions and the sensitivity to errors in the radar derived rainfall examined.

References

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