Meso-scale Data Assimilation within BMRC

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Introduction

With the development of the BMRC 3d variational assimilation system, GenSI, there has been considerable discussion on the development of a data assimilation scheme suitable for use within meso-scale numerical weather prediction (NWP). Starting with a summary of current experiences and practices, both here and abroad, the current development path for operational meso-scale assimilation in BMRC scheme will be presented.

For many years, meso-scale data assimilation within the Bureau has been limited to tropical cyclone prediction with TC-LAPS (Davidson and Weber, 2000). Experience with this system, and at overseas centres, has been used to evaluate what is needed for an assimilation system to produce initial conditions appropriate for reliable and accurate forecasts of features of order 10 to 100km in size.

Examining the strengths, weaknesses and likely developments of the four primary components of an assimilation scheme:

- The forecast model,
- The observing system,
- The analysis system and
- The initialisation process

has led to the current development strategy.

As a starting point for the development of a general meso-scale assimilation system, Severe Weather LAPS (SW-LAPS) is currently under development. This assimilation builds on the experiences with TC-LAPS and several important enhancements have already been included. The forecast model is the latest version of LAPS, run at 0.10^o resolution, GenSI as the analysis scheme. A diabatic, dynamic nudging scheme used to initialise the rotational and divergent wind components, and provide mass-wind balance at the meso-scale using the model's dynamics and physics.

Current systems and developments

The suitability of the LAPS forecast model has been demonstrated at scales down to 0.05^o over the last few years, and is considered to be an appropriate model for prediction of the scales under consideration. As with all NWP, however, the forecast performance is strongly dependent on the initial conditions, and therefore the analysis scheme and supporting collection of observations. While significant improvements have been made in analysis schemes, the quality and amount of observed data is still crucial to the performance of the overall prediction system. To maximize the use of the observations, it is crucial that the analysis scheme can accept as much data as possible. GenSI will be capable of assimilating any observations that can be reasonably well predicted from the forecasts, without the severe sub-sampling of the older MVSI system (Seaman et al. 1995).

While GenSI provides a platform for assimilating any form of data, there is still considerable work required to implement any particular set of observations, since at a minimum, issues such as quality control and error characterization must be addressed. The cost of introducing new observation sources along with their likely benefit has been used to assign priorities for further development. The benefit of using a particular system depends on the type of variable being observed and the coverage. With the importance of moist processes to the prediction of many meso-scale phenomena, clearly the inclusion of moisture related observations is a high priority. This must be weighed against results from studies such as Benjamin and Schwartz (2004) that have shown observing systems which provide wide spatial coverage but are irregular in time, (e.g. aircraft reports) can be of more value to meso-scale NWP than observations from a few sites reporting more frequently (e.g. wind profilers). Other studies, such as Koizumi (2004) have found that obtaining an accurate representation of the broad scale moisture fields, as obtained from micro-wave instruments on satellites to be necessary, before small scale information such as radar data can be profitably used.

The GenSI analysis scheme has been designed to allow for analysis at any scales although so far it has been mainly tested within global and regional systems. This 3d variational (3dVAR) analysis scheme can utilize most conventional data, and a version suitable for the direct assimilation of satellite radiances is nearing completion. GenSI also allows for considerable flexibility in the specification of background error covariances, readily permitting the introduction of some flow dependence into the spread of information by the analysis. Work is underway on introducing full flow dependence via an Ensemble Kalman Filter (EnKF), but it will be some time before such a system would be ready for operational testing, particularly for meso-scale phenomena where the stronger non-linearities make the ensemble estimation of background error covariances less accurate.

A drawback of 3d analysis systems is that it is not clear how to adjust vertical motions to reflect the changes in the horizontal flow, requiring an initialisation step. This raises other issues such as ensuring that the analysis step does not interfere with valid meso-scale features in the background. Even in 4d some of these initialisation issues are still difficult. Currently, TC-LAPS uses a nudging scheme for the rotational wind, along with forced diabatic heating in regions of deep convection during a pre-forecast initialisation period. It is intended to build on this system.

Future Developments

Building on the experiences with current systems, both operational and experimental, here and abroad, a plan has been implemented to develop a meso-scale assimilation system that is tailored to the regional needs and resources. The development of GenSI will continue in parallel with the EnKF development, as:

- the EnKF will replace the background error specification within GenSI, but the majority of the code will remain, especially the observation processing and quality control,
- the success of EnKF schemes has not been fully demonstrated for operational NWP, especially at the meso-scale where strongly nonlinear effects are more important,
- the initial EnKF system may well need to be a hybrid 3dVAR/EnKF system, and
- a system will be required in the interim.

In the immediate future, the most important development is to complete the assimilation of satellite radiances, as this has been found to have significant positive impact on the specification of the broad-scales at other centres. The 3d assimilation of satellite radiances also requires the development of model configurations that extend to 0.1 hPa, using 50 vertical levels or more (L50+).

Once the development of the L50+ model and 3dVAR GenSI is completed next year, further observations can be introduced. As mentioned above, a priority had to be established for the introduction of the different observing systems:

- Microwave satellite data – high priority as it provides valuable moisture and surface wind information over the oceans. Use of this data requires a significant effort, although it will have much in common with the current use of ATOVS data.

- AWS and other near-surface in-situ data – high priority, as experiments have shown this data to be important in some limited cases. The development of appropriate quality control and background error specifications for wind and temperature is required. The use of this data will also have much in common with existing systems.
- Aircraft temperature data – high priority, as this data has been shown to be of high value at other centres. The prospect of moisture data also being available increases the potential utility of these observations, and as the inclusion of these data within 3dVAR is straightforward, the potential benefit is significant relative to the required resources.
- Doppler radar winds – lower to moderate priority. A valuable source of low level winds, but quality control and variations in representativity of the data make the assimilation rather more complex. There is also little experience in BMRC on the use of these winds for NWP. Once the radars are installed, the priority can be raised.
- Profiler wind data – lower priority. The lack of profiler data available within the Australian region is a strong limitation on the impact of this data. The other major issue associated with this data is the development of appropriate quality control algorithms, and there are other observations that are likely to have greater impact in the short term.
- GPS moisture data – lower priority. Potentially a very useful source of data, as high frequency measurements of atmospheric moisture are very important to meso-scale NWP given the general lack of moisture data over land. The sparse spatial coverage of the currently available processed data limits the impact at present. When suitable processing of most of the Australian network is in place, the assimilation of this data will become a higher priority.
- Radar and satellite precipitation data – low priority for direct assimilation. Although these are valuable sources of data, the strongly nonlinear signal makes their use within NWP very difficult, and would require considerable resources, severely limiting other developments. It can be argued that the direct assimilation of this data is a major initiative in itself, and should be treated as such, rather than as a component of the development of a meso-scale assimilation scheme. To take full advantage of this data the EnKF system needs to be well established, as does the broad scale moisture fields. Since many other issues must be resolved before this data could be considered for direct assimilation it is considered low priority, especially since some of the information can be introduced during the nudging/diabatic initialisation phase.

The other part of the assimilation that will require some effort is the specification of the error covariances. GenSI is capable of including limited flow dependence via the use of vertical correlations that depend on potential temperature, and horizontal correlations that depend on the geostrophic wind. Idealized tests with just a few observations have shown encouraging results. It is intended that this work will be further developed to the stage of using the full observing system, and is expected to have most benefit with the assimilation of near-surface data. The development of improved covariance models is seen as an interim measure until a full EnKF is available.

The nudging scheme of TC-LAPS has been shown to be successful at capturing and initiating clusters of tropical convection, and so this has been chosen as the basis for the diabatic initialisation of SW-LAPS, although several enhancements have been added. Firstly, the assimilation cycles of SW-LAPS use the high-resolution analyses to produce the next forecast background, as opposed to TC-LAPS, where the broad scale analyses are used during the assimilation process and the high-resolution analyses are only used as targets for the nudging. Another significant difference is the heating due to deep convection is forced during the assimilation cycle to introduce feedback to the rotational flow, and to remove some inconsistency between the target analyses and the model evolution between the nudging phase.

A related topic to the initialisation process is the time between analyses, that is the development of a Rapid Update Cycle (RUC) system. Initial experiments with more frequent insertion have shown some benefit, but this work has suffered from lack of attention. The main issue with more frequent insertion is the amount of noise in the model. If this is controlled by initialisation then the more frequent initialisation associated with the more frequent analyses can overly damp out small-scale features. Alternatively, too much noise in the background has long been recognized as having a negative impact on the analysis. The advantages of developing a RUC such as using much more data, however, means that once the initial configuration is established, assessment of more frequent insertion will be given a high priority.

Summary

Until recently meso-scale data assimilation has been limited to the prediction of tropical cyclones via TC-LAPS. The development of any new assimilation systems has been contingent on the completion of the new analysis scheme, GenSI. With the development of GenSI nearing completion, attention is returning to the implementation of a new meso-scale assimilation scheme. The component that seems to need most attention is still the objective analysis, and a plan has been provided which is expected to maximize the improvement given the data availability, the utility of the data and the resources available. Eventually a full EnKF version of the analysis will be utilized to introduce full flow dependence into the spread of information by the analysis step, but until then, a sequence of interim developments will provide a progressively improving assimilation system.

Assimilation systems are inherently a set of components, and a crucial factor in determining overall performance is how smoothly the components combine, particularly the analysis scheme and forecast models. This is controlled by initialisation, which in the BMRC system builds on the features of TC-LAPS. Initial results have been encouraging, and an initial configuration should be ready for testing next year, with a full EnKF version anticipated to be ready in a few years.

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References

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