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VARIATIONAL MESOSCALE DATA ASSIMILATION: THE NEW ZEALAND LIMITED AREA MODEL (NZLAM-VAR)

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1 INTRODUCTION

To date much of the research on mesoscale prediction reported in the literature has assumed that the data assimilation problem is less important than the modeling problem (e.g. Colle et al., 2000). In such cases the mesoscale model is run in an “interpolator” mode – whereby output from a low resolution global or regional model is interpolated onto a mesoscale resolution model grid - and the model integrated using boundary forcing from the lower resolution model. This approach will more accurately resolve the orography in the model domain and allow some of the physical processes to be modeled more explicitly, but does not provide information about the sensitivity of the predictions to mesoscale resolved initial conditions. A recent review by Gall and Shapiro (2000) indicates that even in the case of strong orographic and / or topographic forcing, “the main requirement of accurate forecasts of mesoscale phenomena would be an accurate forecast of large-scale flow”

In 1999, the National Institute of Water and Atmospheric Research (NIWA) embarked on a research programme to develop a data assimilating mesoscale weather prediction system for the New Zealand region. The underpinning hypothesis of this ongoing research programme is that prediction of the evolution of mesoscale weather systems over New Zealand, including their interaction with the orography and the synoptic systems in which they are embedded, will be significantly improved through assimilation of the information in high spatial and temporal resolution (mesoscale resolving) meteorological observations. This implies a need for observations at high spatial density and therefore the requirement to optimize the use made of data derived from satellite observing systems. In this respect the New Zealand region is an ideal environment in which to test the hypothesis – it is a relatively small land mass (268,670 km^2) surrounded by a marine environment stretching more than 1000 km in all directions.

This research effort is investigating the impact of data assimilation in general on a high-resolution mesoscale weather prediction system, and of particular components of the modeling and observing systems.

2 THE NZ MESOSCALE PREDICTION SYSTEM

The prediction model utilized here is called the New Zealand Limited Area Model (NZLAM) and is a local implementation of the Met Office Unified model (Cullen and Davies, 1991) – currently version 4.5n. The NZLAM is integrated on a 324 × 324 rotated latitude longitude grid having 0.11° resolution (approximately 12 km) and at 38 levels.

A large model domain has been chosen, both to allow synoptic development (since the Tasman Sea is an important area for cyclogenesis), and so that data from radiosonde soundings along the east coast of Australia, from Macquarie Island, New Caledonia and the Chatham Islands can be assimilated without substantial influence from the boundary region.

The vertical grid is terrain following near the surface, evolving to constant pressure surfaces higher up. The top of the model is at 5 hPa, and there are 14 levels below 750 hPa. Soil temperature and moisture is modeled at 4 levels. The dynamics time step is 5 minutes and the physics is updated every 20 minutes. A prognostic cloud scheme is used (Smith, 1990), and the precipitation scheme explicitly calculates transfers between vapor, liquid and ice phases (Wilson and Ballard, 1999). The convection scheme is that of Gregory and Rowntree (1990).

Data assimilation is carried out using the Met Office 3DVAR scheme (Lorenc et al., 2000), where the cost function minimization is solved using an analysis of increments approach. The analysis variables are stream function (ψ), velocity potential (χ), unbalanced pressure (^{A}p), and relative humidity (μ). The linearisation state resolution used is identical to that of the model, allowing the possibility of assimilating data at high spatial density. To damp fast gravity modes excited by the analysis and/or the reconfigurations required by the analysis, the increments are introduced using an incremental analysis update (IAU) procedure.

Initial NZLAM-VAR experiments, have utilized a forecast background error covariance identical to that used in the UK Mesoscale model and 6 point deep lateral boundary conditions derived from hourly output from the Unified Model run in global configuration on a 432 × 325 grid (i.e. 0.83° × 0.56°) and 30 levels.

3 DATA

In the experiments that will be reported at the conference, the NZLAM-VAR will be used to assimilate SYNOP, Ship, DRIBU, AMDAR, AIREP, rawinsonde, PILOT, HIRS and AMSU-A radiances, AMVs (GMS) and SSM/I wind speed data. Sea surface temperatures will be forced from (locally derived) 12 km resolution analyses (Uddstrom and Oien, 1999).

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4 AN EXAMPLE FORECAST

Fig. 1 shows 36 hour forecasts of total water q_T over the model domain at level 15 (approximately 725 hPa), for the global, and NZLAM-VAR models. AMSU-B 89 GHz “verifying” data from a NOAA 15 pass, two hours later, are shown in Fig. 2.

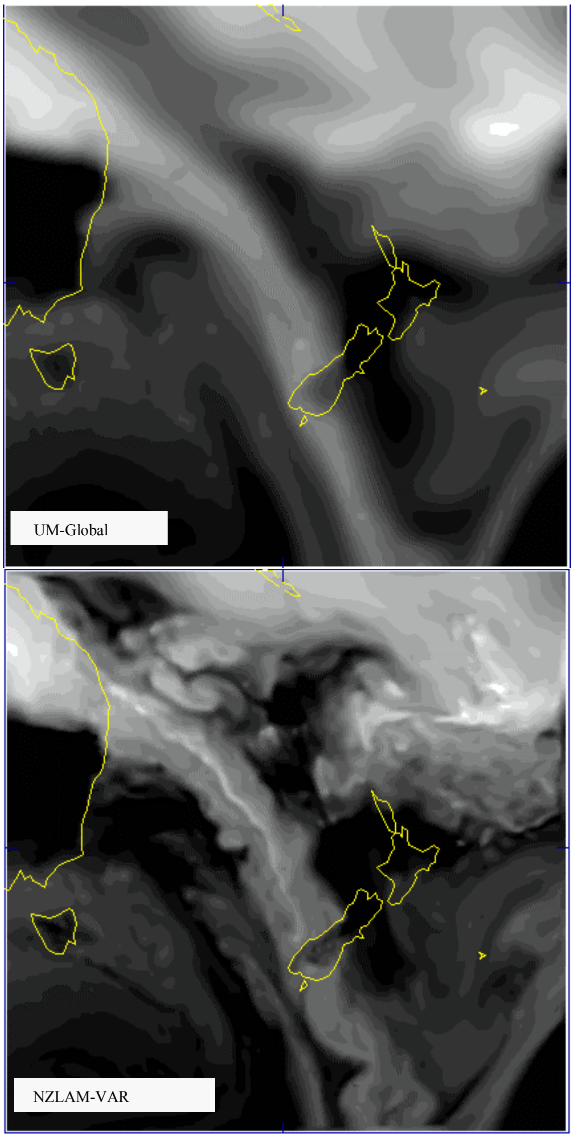

Fig. 1 NZLAM model area showing 36 hour total water (q^T forecasts) at ~725 hPa for the global model (top) and NZLAM-VAR (bottom). White indicates high values; black, low values.

The most obvious difference between the global and mesoscale predictions is the sharpness and detail in the frontal system over the Tasman Sea and in the vicinity of the deep convection in the north-eastern part of the domain. Whether such fine structure exists in reality and whether it is in the right location is of interest. The AMSU-B, 15 km resolution 89 GHz data (i.e. Fig. 2) indicate that the water vapor, rain and ice scattering fields have significant small scale structure, not dissimilar to that revealed in the mesoscale model prediction.

Assuming the scattering (warm) signature indicates the location of the main rain feature, and that the model level 15 q_T field is also indicative of this feature, then comparison of the NZLAM-VAR prediction with the AMSU-B data suggests that the forecast location of at least the main-frontal feature (and its curvature close to the South Island) is good.

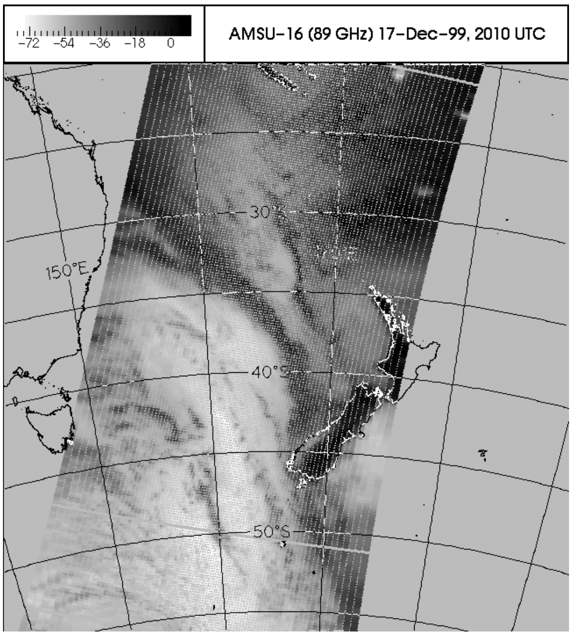

Fig. 2 AMSU-B 89 GHz scattering / emission observations from NOAA15 (Orbit 8292). Units are °C, and each instantaneous field of view is drawn separately.

5 ERROR COVARIANCE MATRIX

As already noted, initial experiments with NZLAM-VAR assume 3 hour forecast error characteristics (variances and length scales) identical to those used at the Met Office in the UK Mesoscale prediction system. However on the basis of observational data density arguments alone, this is unlikely to be an appropriate estimate of the error characteristics of the New Zealand model. The accuracy of a prediction model over the north Atlantic, should be better than that over the more sparsely observed Tasman Sea / south-west Pacific. If this is the case then the background error variances assumed for the New Zealand domain will be too small, reducing the relative weight given to the observations. Also, given the size of the New Zealand model domain (sub-tropics to sub-Antarctic), these variances should probably vary with latitude (they are homogeneous in the UK Mesoscale Model). Secondly, the UK Mesoscale model implementation of VAR assumes the model error de-correlation length scales for the control variables (ψ, χ, ${}^{A}p$, μ) are homogeneous both in the horizontal and vertical. This will not be true in general.

To investigate these questions, estimates of forecast-error were computed from February 2000 forecasts over the NZLAM domain, sea points only, using the method introduced by Parrish and Derber (1992). Differences between 112 six and twelve hour forecast pairs (valid at the same time) were computed at the analysis resolution then averaged together.

EOF decomposition of the vertical covariance matrix of ψ indicated complex vertical structure after the first few EOFs, and there was much mixing between levels making these functions somewhat unsuitable for specifying altitude dependent horizontal error characteristics. Application of Varimax rotation (Richman, 1986) led to much simpler vertical structures, and therefore less mixing between levels. When the Varimax rotated vertical transforms were applied to the assumed isotropic (spatially lagged) forecast error data, differing altitude dependent horizontal length scales were resolved.

In case of ψ (rotated) mode 1, the observed error de-correlation length scale is 330 km. When all vertical modes are considered, length scales vary from approximately 270 km near 450 hPa to more than 1000 km above 50 hPa. For velocity potential (χ) the scales lie between 350 km near 750 hPa and around 900 km above 50 hPa. There is much less separability in the vertical modes of unbalanced pressure $\hat{p}$, with the first two modes (essentially covering the lower and upper troposphere) explaining 85% of the variance. The upper tropospheric mode length scale is 340 km while that of the lower mode is 420 km. The (rotated) vertical modes of relative humidity (μ) are concentrated in the height range 850 to 180 hPa. The length scales range from 20 km in the boundary layer to 30 – 45 km in the middle troposphere, and 90 km near 150 hPa.

All of these values differ significantly from the current homogeneous values, and indicate that forecast errors will need to be modeled as a function of height. One further interesting point arising from this analysis is that the μ length scales suggest that high spatial resolution water vapor observations (e.g. AMSU-B) should be able to be used at full resolution – thereby leading to significant forecast accuracy improvement – at least for the moist fields, such as rain.

6 PROGRESS REPORT

The conference presentation will report on progress to date, with particular emphasis on forecast verification analysis.

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