

Use and impact of satellite data in the NZLAM mesoscale model for the New Zealand region

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Abstract

We describe the current configuration of the New Zealand Limited Area Model (NZLAM) and associated data assimilation system, summarise current data use and present recent work on quantitative verification of NZLAM forecasts. We compare the accuracy of global model forecasts and NZLAM forecasts with initial conditions derived a) from interpolated global analyses and b) using variational data assimilation, and quantify the impact of the use of ATOVS data in the NZLAM variational data assimilation system. Future research directions are described briefly.

Introduction

A combination of intense synoptic flows and mountainous terrain make New Zealand communities susceptible to weather-related hazards – high winds, heavy rainfall, flooding and untimely snowfalls. To forecast such events requires mesoscale modelling of flows and relevant physical processes, and the mesoscale forecast model must have accurate initial conditions. At NIWA we are implementing a limited area model, the New Zealand LAM (NZLAM), with variational data assimilation for forecasting in the 6 – 48 hour range for this purpose (Uddstrom et al., 2002).

In this paper we briefly describe the current configuration of the NZLAM and associated data assimilation system and summarise current data use. We then present recent work on quantitative verification of NZLAM forecasts. We compare the accuracy of global model forecasts and NZLAM forecasts with initial conditions derived a) from interpolated global analyses and b) using variational data assimilation, and quantify the impact of the use of ATOVS data in the NZLAM variational data assimilation system.

NZLAM and data assimilation configurations

The NZLAM is a local implementation of the mesoscale configuration of the Met Office Unified Model version 4.5 (Cullen and Davies, 1991). The NZLAM domain is illustrated in Figure 1. We use a 324×324 grid point rotated latitude-longitude grid, corresponding to a horizontal resolution of 0.11° or ~ 12 km. The model is discretised on 38 levels in the vertical. Lateral boundary conditions are supplied from a global model configuration of the Unified Model, and are updated hourly. The large area modelled

allows the evolution and interaction of synoptic and mesoscale flows to be resolved explicitly within the domain.

Observations are processed and assimilated using a local implementation of the Met Office variational data assimilation system. Data are currently assimilated using 3D-Var with a 3-hour analysis cycle. We assimilate surface data from land and ship SYNOP stations and BUOYS, upper air data from TEMP and PILOT radiosondes and AMDAR aircraft reports and the satellite data streams discussed in detail below.

We run a cycling forecast-assimilation system, but do not as yet process data in real time. Results presented in this paper are for our February 2000 validation case study period, using observational data supplied by the Met Office.

During the February 2000 case study period the synoptic flows in the New Zealand region were characterised by the predominance of anticyclonic flows over the north central Tasman Sea, and the passage of a number of fronts across the southern region of the domain. A large frontal system traversed the western region of the domain and developed into a cutoff low just west of New Zealand during a 5 day period in mid February.

Satellite data use

TOVS/ATOVS

Radiances from the HIRS, MSU and AMSU instruments on NOAA-14 and NOAA-15 are assimilated directly. The channels assimilated are summarised in Table 1 for the possible scene surface and cloud classifications. Radiances are thinned to one observation per $1^\circ \times 1^\circ$ box, with preference given to clear scenes.

Radiances are corrected for scan-dependent bias, derived from observed – background radiance differences in clear scenes over the whole domain for the case study period. No correction is currently applied for air-mass dependent biases as radiance-based air-mass dependent bias corrections did not give any statistically significant reduction in variance (for the limited time series in question). Similarly, there are insufficient samples to calculate reliable corrections using the method of Harris and Kelly (2001) in the vicinity of radiosondes.

Scan bias corrections derived for the NZLAM domain have been compared with those used operationally at the Met Office in 2000. The two sets of coefficients are in close agreement for the HIRS channels 2–4, MSU channels 3–4 and AMSU channels 6–11 assimilated in the NZLAM. More significant differences (0.2 – 0.5 K) are found for the lower tropospheric sounding channels (HIRS 5, MSU 2 and AMSU 4–5). Large differences (1.0 – 2.0 K) are found in HIRS channels 11–12 (not assimilated at present).

SSM/I

Surface wind speed is retrieved from SSM/I radiances in a 1D-Var observation preprocessing step, and assimilated in 3D-Var. Wind speed retrievals are thinned to one observation per $0.5^\circ \times 0.5^\circ$ box.

Table 1: TOVS/ATOVS channels assimilated for different scene surface and cloud classifications. Conditional channels are used for all scenes except 1: high cloud; 2: high land; 3: microwave rain classifications.

| Satellite | Instrument | All scenes | Conditional | Clear, sea |
|-----------|------------|------------|--|------------|
| NOAA-14 | HIRS | 2 | 3 ¹ | 4 5 |
| NOAA-14 | MSU | 3 4 | 2 ² | |
| NOAA-15 | AMSU | 9 10 11 | 6 ^{1,2,3} 7 ^{2,3} 8 ^{2,3} | 4 5 |

SSM/I radiances are bias-corrected with the global bias correction coefficients used operationally at the Met Office in 2000. Examination of observed – background statistics for surface windspeed indicates no significant bias in retrieved windspeeds.

GMS atmospheric motion vectors

Atmospheric motion vectors derived by the Japanese Meteorological Agency from GMS-5 radiances, and their corresponding height assignment, are assimilated in the NZLAM. Following the Met Office, winds derived from visible radiances are only used in the lower troposphere over sea, winds derived from infrared window radiances are only used in the upper troposphere, and in the lower troposphere over sea, and winds from infrared radiances in the water vapour ν_2 ($6.7 \mu\text{m}$) band are only used in the upper troposphere. Observations are thinned based on (standard Met Office) quality control decisions and buddy checks. Detailed study of the monitoring statistics for atmospheric motion vectors is underway.

Objective verification of NZLAM forecasts

As in any modelling activity, validating model predictions and characterising model errors are key to understanding, exploiting and improving model performance.

In NZLAM development we have been particularly interested in comparing NZLAM forecasts from analyses derived using variational data assimilation (NZLAM-VAR) with global model forecasts (from analyses derived using VAR) and with NZLAM forecasts initialised with global analyses interpolated onto the NZLAM grid. These comparisons aim to characterise the accuracy of a cycled mesoscale model with data assimilation, and quantify the benefit of such a model over global model forecasts and mesoscale model forecasts initialised with low resolution fields. For such studies, observations are the only natural choice of reference for verification.

In this work we have run forecasts from 00Z and 12Z UTC out to 48 hours, and verified against TEMP, PILOT, AMDAR, SYNOP (Land and Ship) and BUOY observations at six-hourly intervals. Although we will only discuss radiosonde verifications here we note that the verification results are robust – all the major characteristics of the verification with TEMP and PILOT observations are also borne out in verification with AMDAR observations.

Observational data density is a general issue for quantitative verification, and a particular issue for the New Zealand region and NZLAM domain, where the conventional observing network is sparse.

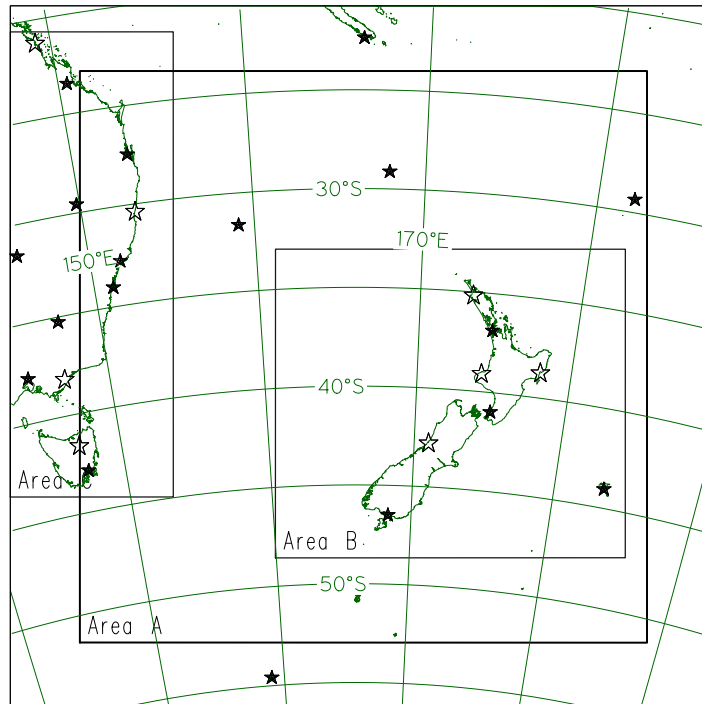


Fig. 1: Illustration of the the New Zealand Limited Area Model domain and verification areas A, B and C. Stars indicate location of the radiosonde stations in the NZLAM domain; open stars indicate stations which only launch PILOT balloons. Radiosondes in area A are used in the current model validation studies. However, all but one the New Zealand sondes are not currently used for verification at 00 and 12 UTC.

Radiosonde stations in the NZLAM domain are illustrated in Figure 1.

Verification is currently performed on area A (defined to exclude sites near the domain boundaries and the interior of the Australian land mass). However, all but one the New Zealand sondes are not currently used for verification at 00 and 12 UTC. This is because the unused sondes were launched at 10 and 22 UTC (i.e. 2 hours earlier than the nominal synoptic observation time) during the case study period and hence excluded by our ± 1.5 hour verification time window. Consequently, verification statistics predominantly reflect model performance in the North Tasman and the eastern Australian coastal regions. On the order of 200 temperature profiles and 700 wind profiles have gone into the radiosonde verification statistics presented here.

Comparison of global and NZLAM forecasts

Figure 2 illustrates the bias and root-mean-square (RMS) difference between observed and forecast temperatures as a function of pressure for forecasts at the 24 hour range.

In the mid troposphere (700 – 400 hPa), where temperature variability is largely governed by synoptic scale flows and small scale vertical temperature gradients are generally small, the performance of the three models is comparable. However, in the upper troposphere/tropopause region and the planetary

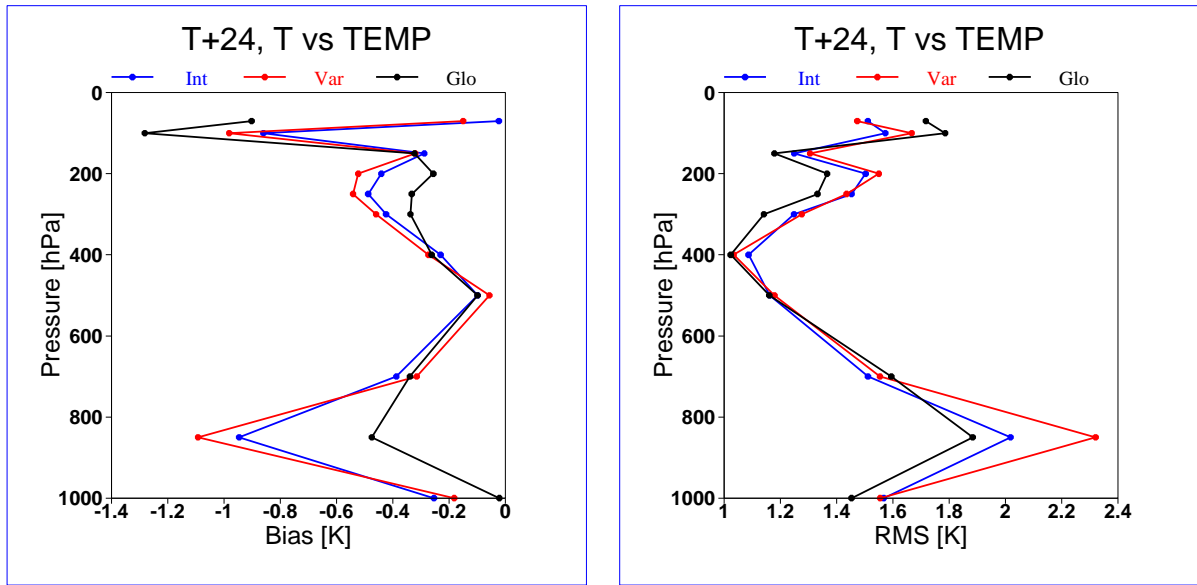


Fig. 2: Bias (lefthand panel) and RMS differences (righthand panel) between forecast and observed temperatures (fc-ob) as a function of pressure for the 24 hour forecast range. Results are illustrated for the global model with initial conditions derived using variational data assimilation (Glo) and for the mesoscale model with initial conditions derived using variational data assimilation (Var) and global analyses interpolated onto the mesoscale grid (Int). Statistics are calculated for the period from 01 to 29 February 2000.

boundary layer, where there are marked small scale vertical temperature gradients, the RMS differences between mesoscale model forecasts and observations are greater than global model RMS differences. Bias makes a significant contribution (a third to a half) to the RMS differences at 850 hPa and in the stratosphere.

It is not unexpected for high resolution model fields to verify worse than low resolution fields: high resolution models will generate sharper features and gradients which will verify worse than smoother, weaker fields if subject to position or timing errors. To characterise model performance we need to identify if and why position and/or timing errors are the source of observed differences, and distinguish these from other sources of model error.

Detailed examination shows that the large differences between NZLAM and global forecasts of the 850 hPa temperature are associated with large differences in modelled low level temperature inversions in the anticyclonic flow regime in the northern central Tasman Sea, over a six day period. These structures will be strongly governed by model physics, and suggest other sources of model error (e.g. modelled convection) may be the source of the observed differences in this instance. In particular, in forecast – observed differences in temperature (negative bias at the 850 hPa inversion layer level) and humidity (positive bias in the planetary boundary layer) and a 1 – 2 K warm bias in the sea surface temperature (SST) assumed in the NZLAM-VAR assimilation experiments (as compared to observed SST's) are all consistent with and overestimation of convective activity in the NZLAM-VAR run. Experiments are

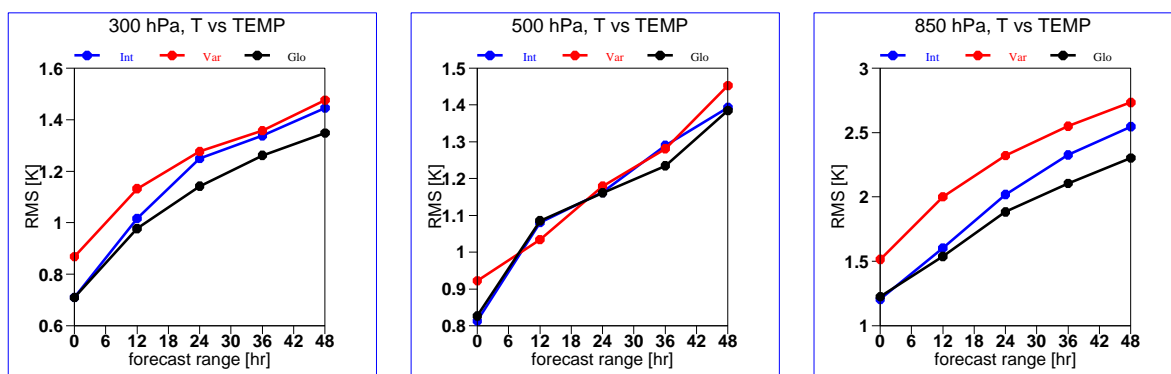


Fig. 3: RMS differences between forecast and observed temperatures as a function of forecast range for three selected pressure levels 300, 500 and 850 hPa.

underway to test this hypothesis.

Figure 3 illustrates the evolution of the RMS differences as a function of forecast range at three characteristic pressure levels, 300, 500 and 850 hPa. At 500 hPa RMS differences increase quasi-linearly with forecast range and the three models are comparable at all forecast ranges. At 300 hPa and 850 hPa the NZLAM-VAR RMS differences are larger than global model RMS differences at all forecast ranges, but the rate of increase of the RMS difference with forecast range is comparable.

RMS differences for forecasts with the NZLAM model initialised using interpolated global analyses rapidly increase from global model RMS levels and tend to NZLAM-VAR RMS levels at longer forecast ranges. We interpret this as a measure of the characteristic time scales for the NZLAM model to generate the stronger small scale structures and gradients we hypothesize are responsible for the larger RMS differences. Again, the validity of this hypothesis is being tested in ongoing studies.

Impact of ATOVS data on forecast accuracy

We have examined the impact of ATOVS data on the accuracy of NZLAM-VAR forecasts from analyses derived using variational data assimilation.

RMS differences between forecast and observed temperatures at the 24 hour forecast range are reproduced in Figure 4. RMS differences for NZLAM-VAR forecasts are compared for experiments where ATOVS data is included and excluded from assimilated data sets. Global model RMS statistics are traced for reference.

Assimilation of ATOVS data has a clear, positive impact on the accuracy of forecast temperature throughout the free troposphere (700 – 300 hPa), with improvements in RMS differences of 0.0 – 0.1 K. ATOVS data has little effect in reducing RMS differences at 850 hPa as is to be expected: the vertical resolution of the satellite observations is too low to provide information on the small vertical scales associated with the boundary layer temperature inversion.

The impact of ATOVS data in the upper troposphere/lower stratosphere is not as large as might have been expected. This may be related to strong latitudinal gradients in tropopause height within

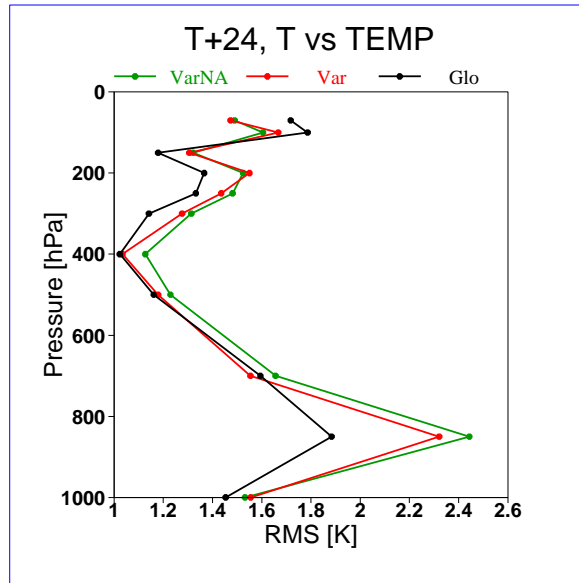


Fig. 4: Comparison of RMS differences between forecast and observed temperatures as a function of pressure for the 24 hour forecast range for the period from 01 to 29 February 2000. Results are illustrated for the global model with initial conditions derived using variational data assimilation including ATOVS (Glo) and for the mesoscale model with initial conditions derived using variational data assimilation with ATOVS data included (Var) and excluded (VarNA) from assimilated data sets.

the NZLAM domain, which may mask the impacts of ATOVS data above and below the tropopause at any given latitude. Alternatively, this may reflect suboptimal use of satellite data in the stratosphere due to errors in modelled stratospheric temperatures (coupled with bias correction and stratospheric extrapolation). Detailed study of these points is planned.

Figure 5 illustrates the evolution of RMS differences as a function of forecast range for 500 hPa temperature and wind, and surface pressure. Assimilation of ATOVS data has a positive impact on 500 hPa temperature RMS differences in the 0 – 36 hour forecast range. A small impact is also found for the 500 hPa RMS vector wind differences and surface pressure differences are reduced at all forecast ranges on assimilation of the ATOVS data.

Taken together, these results suggest that the ATOVS data have a positive impact in constraining the synoptic (quasi-geostrophic) flows.

Conclusions and future work

We have described the implementation of a mesoscale model for the New Zealand region which allows the evolution and interaction of synoptic and mesoscale flows to be resolved explicitly within the model domain.

Preliminary quantitative model validation (and quantitative comparisons of model fields not presented here) suggest that synoptic scale flows are well modelled and constrained by data and lateral boundary conditions.

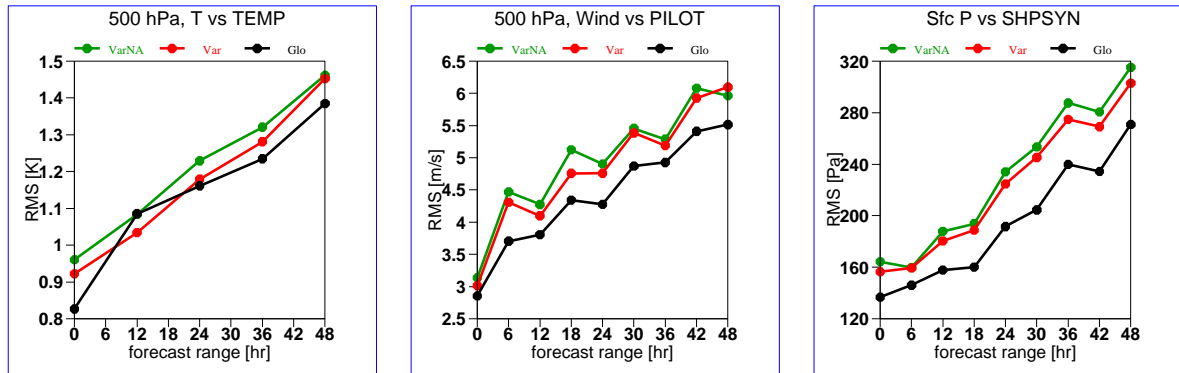


Fig. 5: Comparison of RMS differences between forecast and observed 500 hPa temperatures and vector winds, and surface pressure, as a function of forecast range when ATOVS data are included and excluded from assimilated data sets.

Marked differences in modelled small scale structure are observed, particularly in the planetary boundary layer. Our verification studies suggest these differences are principally governed by model physics and largely unconstrained by currently assimilated data or lateral boundary conditions.

This work is in its infancy, and we envisage numerous extensions to the current validation studies. We intend to extend the case studies in time – an extended (three month) time series, enabling eventual diurnal dependencies and error characteristics on spatial subdomains (Australian and New Zealand land masses) to be examined, and extension to other periods to examine eventual seasonal dependencies. Methods for scale dependent verification and characterisation of position/timing errors are also being explored.

These studies will enable poorly modelled physical processes to be identified, and lead to improvements in both the mesoscale model and the characterisation of its errors. In turn this will lead to improved data use through improved specification of the background error covariance.

Extensions to our use of satellite data – the use of radiances containing information on tropospheric humidity and the use of satellite-derived sea surface temperatures in specifying surface boundary conditions – are also planned. These data streams could be of particular use in providing additional constraints to the boundary layer dynamics (convective processes) which have been called into question in these preliminary validation studies.

Ultimately we are working towards an operational mesoscale forecasting model, with output serving as input to hazard prediction models (hydrological models, storm surge and wave models) specific to the New Zealand region.

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References

- Cullen, M. and T. Davies: 1991, A conservative split-explicit integration scheme with fourth order horizontal advection. *Quart. J. Roy. Meteor. Soc.*, **117**, 993–1102.
- Harris, B. and G. Kelly: 2001, A satellite radiance bias correction scheme for data assimilation. *Quart. J. Roy. Meteor. Soc.*, **127**, 1453–1468.
- Uddstrom, M., P. Andrews, H. Oliver, A. Korpela, and X. Zheng: 2002, The impact of data assimilation on a mesoscale model of the New Zealand region. *Technical Proceedings of the Twelfth International TOVS Study Conference, Lorne, Australia, 27 Feb.-5 Mar. 2002*.