Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

CSIRO

CAWCR Research Letters

Issue 5, December 2010

P.A. Sandery, T. Leeuwenburg, G. Wang, A.J. Hollis, K.A. Day (editors)

www.cawcr.gov.au

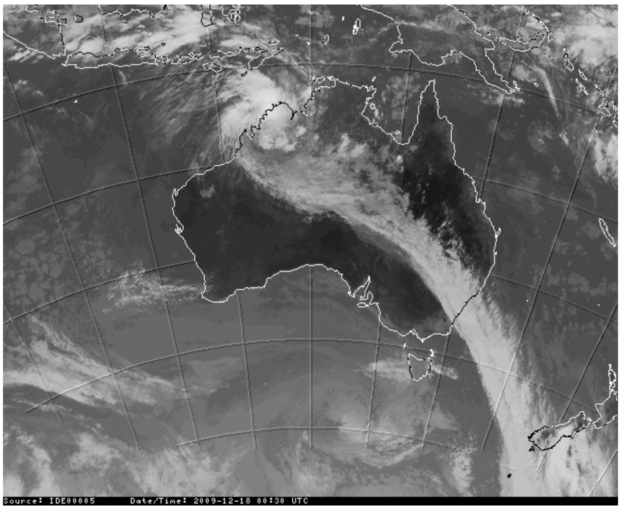
ISSN: 1836-5949

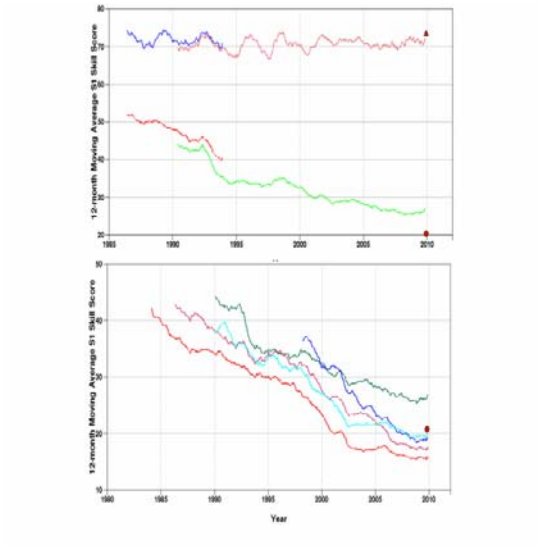
Series: Research Letters (The Centre for Australian Weather and Climate Research); Issue 5.

Copyright and Disclaimer

Contents

Gridded OCF Low, Middle and High Cloud Forecasts	S. Cooper, T. Hume and P. Riley	4
Parameterization of boundary layer decoupling in ACCESS NWP	V. Barras, P. Steinle, A. Lock	10
Preliminary results from Numerical Weather Prediction implementation of ACCESS	The ACCESS NWP Team	15





Editors: P.A. Sandery, T. Leeuwenburg, G. Wang, A.J. Hollis, K.A. Day
Enquiries: Dr Paul Sandery p.sandery@bom.gov.au
CAWCR Research Letters
The Centre for Australian Weather and Climate Research
Bureau of Meteorology
GPO Box 1298 Melbourne VICTORIA 3001

CAWCR Research Letters is an internal serial online publication aimed at communication of research carried out by CAWCR staff and their colleagues. It follows on from its predecessor *BMRC Research Letters.* Articles in *CAWCR Research Letters* are peer reviewed and typically 4-8 pages in length. For more information visit the *CAWCR* website.

Gridded OCF Low, Middle and High Cloud Forecasts

Shaun Cooper, Tim Hume and Phil Riley

Centre for Australian Weather and Climate Research

Bureau of Meteorology

700 Collins St, Docklands, VICTORIA, 3008

s.cooper@bom.gov.au

Introduction

The Bureau of Meteorology's Gridded Operational Consensus Forecast (Gridded OCF or GOCF system) creates gridded, bias corrected, weighted average forecasts of meteorological variables from Numerical Weather Prediction (NWP) model data. GOCF is described by NMOC (2008 and 2010a) and is similar to the site-based Operational Consensus Forecast system of Woodcock and Engel (2005).

GOCF forecast lead times usually have a temporal resolution of 6 hours that can then be temporally interpolated to 1 or 3 hour steps when required (NMOC 2010a). The system currently produces hourly forecasts of 2 m temperature, 2 m dew-point temperature, mean sea level pressure (MSLP), rainfall accumulations, probability of precipitation and 3 hourly total cloud cover forecasts out to 228 hours. The spatial domain of GOCF is 5°S to 50°S and 105°E to 160°E with a resolution that has recently been upgraded from a 1.25° grid to a 0.5° grid (NMOC 2010b).

The intention of this letter is to report the introduction of low, middle and high cloud cover fields to the GOCF. Total cloud cover has been produced for some time, but some users of the product have noted shortcomings. For example, the previous 1.25° resolution is coarser than desired. Also, the GOCF cloud forecasts are delivered to the Graphical Forecast Editor (GFE) which wants to forecast the percentage of duration the sky directly above is covered by significant low and/or middle level cloud, something that is not possible with only the total cloud field. Furthermore, the product over-predicts the amount of cloud. The latter is a result of the total cloud cover fields from NWP models not distinguishing between the low, middle and high cloud layers. In particular, optically thin high cirrus cloud is not distinguished from denser cloud, with the result that a layer of very thin high cloud may produce a total cloud forecast of "overcast" while users of public weather forecasts may perceive such conditions as having relatively clear skies. To address these issues, separate low, middle and high cloud GOCF forecasts have been created.

Table 1 *The NWP models used in the current total cloud forecast ensemble.*

Institution/Name	Abbreviation
Canadian Meteorological Centre Global Environment Multiscale model.	CMC
European Centre for Medium-Range Weather Forecasting.	ECMWF HR (High Resolution) ECMWF LR (Low Resolution, used for long range forecasts only, i.e > 192 hours.)
Australian Community Climate and Earth-System Simulator system	ACCESS-G (Global Domain) ACCESS-R (Regional Domain)
National Centers for Environmental Prediction's Global Forecast System	NCEP GFS

GOCF Methodology

The OCF and GOCF methodology has been described in detail by Woodcock and Engel (2005), NMOC (2008), NMOC (2009), NMOC (2010a) and NMOC (2010b) and will only be briefly discussed here.

The NWP models used in the current total cloud forecast ensemble are presented in Table 1. For the 00Z run the ECMWF LR and ACCESS-G models are lagged by 12 hours; the other models are not lagged. A lagged model has a basetime that is older (12 hours in this case) than the other ensemble members. The same ensemble is used for the 12Z run with one exception, the ECMWF LR model is lagged by 24 hours. GOCF forecasts use a Poor Man's Ensemble (PME) (Ebert 2001) with no bias correction and equal weighting.

All NWP models have been rescaled to 0.5° by 0.5° resolution. The ensemble average for each forecast lead time is determined and then these are temporally interpolated to three hour timesteps.

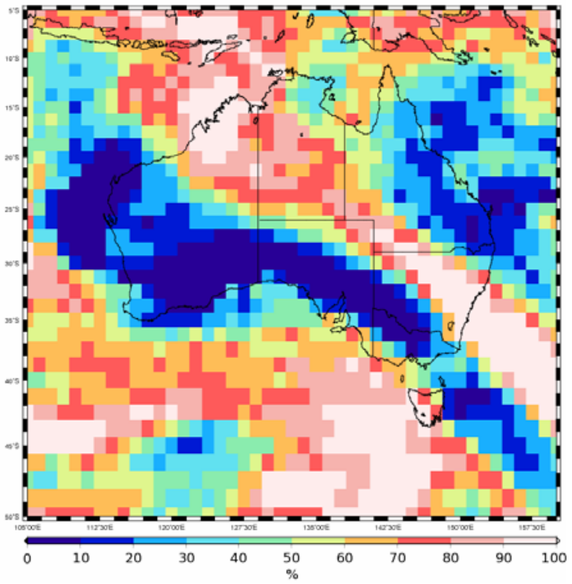


Figure 1 *24 hour forecast of total cloud cover from the current operational ensemble valid for 00Z December 18 2009 on the old 1.25° by 1.25° grid.*

Current Total Cloud Product

As mentioned the resolution of the total cloud product has recently been upgraded from a 1.25° grid to a 0.5° grid. Figure 1 shows an example of a 24 hour total cloud forecast from the total cloud forecast ensemble valid for 00Z December 18 2009 on the old 1.25° by 1.25° grid. The infrared (IR) image from 00:30z on December 18 2009 is shown in Figure 2. A comparison of these two figures shows that the overall total cloud cover has been reasonably well forecast. With the increase in resolution, Figure 3 shows that the new GOCF (valid for the same time) is able to better capture some of the smaller scale structure in the total cloud cover. For example, it captures structures in the cloud cover over the Northern Territory (NT) that are not captured by the coarse resolution forecast.

New Cloud Products

Distinguishing between the different layers of clouds would allow GOCF to supply a forecast that does not include the high cloud contribution to total cloud cover. A layer of optically thin high cirrus clouds is not as significant for a public weather forecast as layers of denser low and middle cloud. Low, middle and high cloud NWP data that allow such a product to be constructed are now available in the Bureau of Meteorology from the ACCESS-G, ACCESS-R and NCEP's GFS models. The definition of low, middle and high clouds for the ACCESS models (Protat, 2010) and the NCEP GFS (Luo and Krueger, 2004) are given in Table 2.

Table 2 *Definition of cloud types in the NWP models included in the low, middle and high cloud forecast ensembles.*

Model	Low Cloud (hPa)	Middle Cloud (hPa)	High Cloud (hPa)
ACCESS (R and G)	1000–800	800–500	> 500
NCEP GFS	< 680	680 – 440	> 440

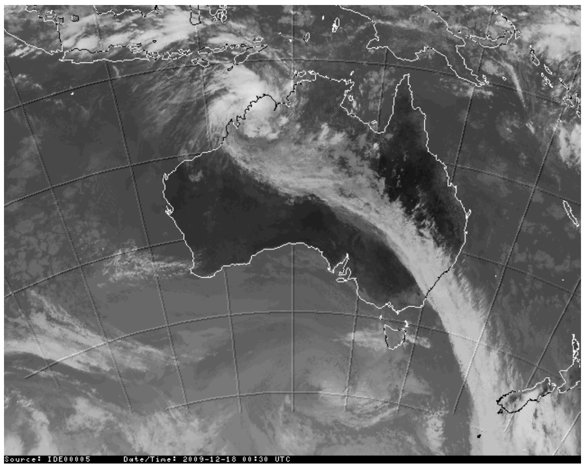


Figure 2 *IR satellite image valid for 00:30Z December 18 2009, 30 min after the GOCF forecast.*

Although the low, middle and high cloud definitions from the models are not exactly the same the aim of these cloud component products is to allow optically thin, high cirrus cloud to be omitted from the forecasts. This can be done using this composite products generated by the GOCF.

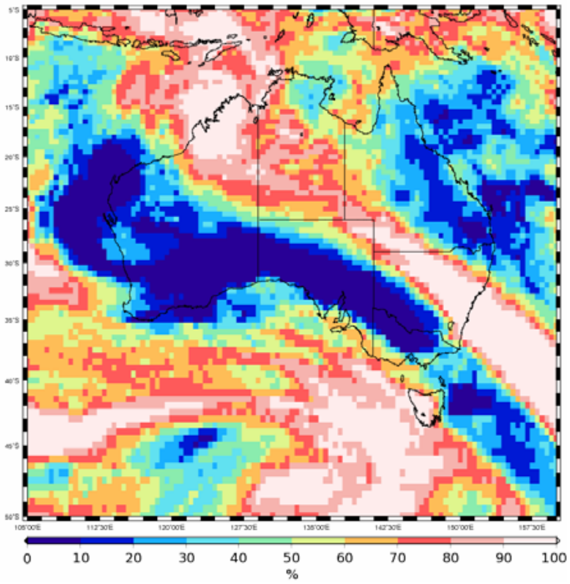


Figure 3 *24 hour forecast of total cloud cover from the new operational product valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

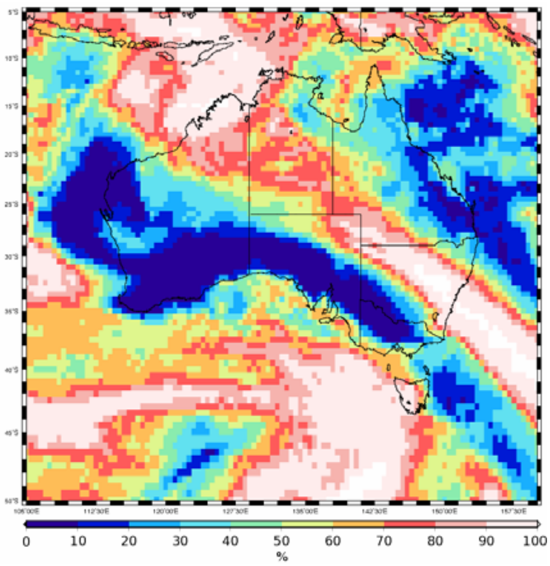


Figure 4 *24 hour forecast of total cloud cover from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

PMEs have been created from these to produce forecasts of low, middle and high cloud. As there are only 3 models that currently supply the cloud layer data, expanding the ensembles by adding older runs of the same models was tested. Three ensembles for each cloud product have been evaluated: the '3latest' ensemble includes the latest runs of each model, the '6latest' include the latest set of runs plus one time lagged run of each model and the '9latest' ensemble includes two time lagged runs from each model along with the latest runs.

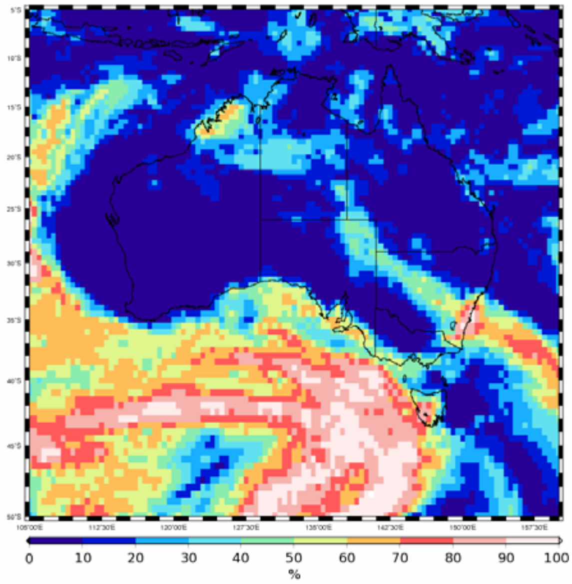


Figure 5 *24 hour forecast of low cloud cover from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

Point based verification against a limited set of data (example below) showed that the '6latest' ensemble to be more accurate than the '3latest' and '9latest' ensembles. Durrant et al. 2009 gives evidence that suggests 5 or 6 ensemble members are optimal for OCF. More rigorous verification work will be undertaken in the future as the forecast dataset grows.

To ensure that using a smaller ensemble than the operational total cloud GOCF does not compromise the cloud component forecasts a total cloud forecast using the '6latest' ensemble was created (Figure 4). Comparing Figures 3 and 4 shows that the reduced ensemble does affect the forecast however it still retains the prominent features of the operational forecast and indeed the IR image, Figure 2. It could be argued that the forecast in Figure 4 is a better forecast than the 1.25° grid operational ensemble forecast that has recently been replaced. The detail in the forecast in Figure 4 is much greater than the 1.25°

grid forecast of Figure 1, for example over the NT. Given that the reduced ensemble produces comparable total cloud forecasts it is reasonable to use this ensemble to forecast low, middle and high clouds.

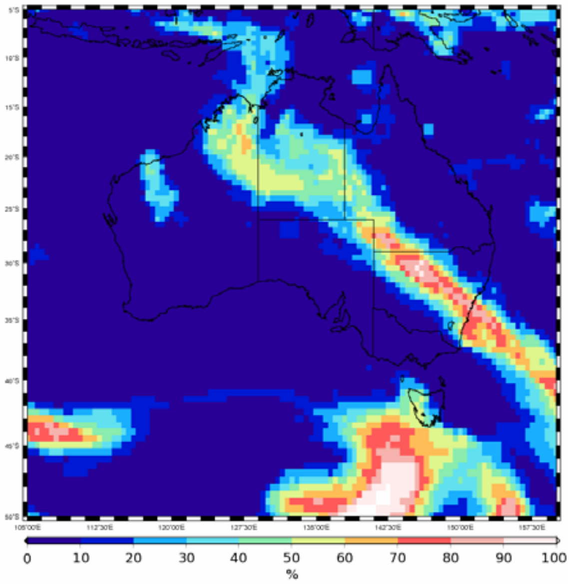


Figure 6 *24 hour forecast of middle cloud cover from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

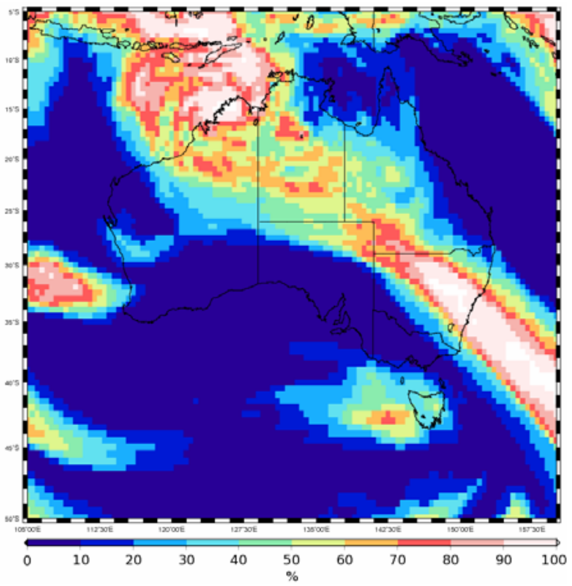


Figure 7 *24 hour forecast of high cloud cover from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

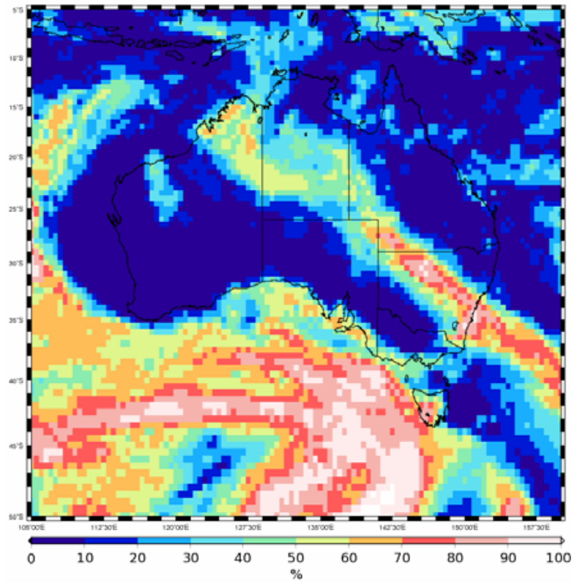


Figure 8 *24 hour forecast of combined low and middle cloud cover assuming maximum overlap from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

Case Study: December 18, 2009

Using the '6latest' ensemble 24 hour forecasts of low, middle and high clouds valid for 00Z December 18 2009 have been plotted in Figures 5, 6 and 7, respectively. Tropical cyclone Laurence was located near Broome at this time. The low cloud, Figure 5, and the middle cloud, Figure 6, products are the cloud components of greatest interest to forecasters.

The high cloud forecast product plotted in Figure 7 shows the amount of high cloud that could potentially be removed from the cloud forecast if the high cloud is of little interest. The amount of high cloud that was present at this time can be observed in Figure 2 as the whitest coloured clouds.

Forecasting the three cloud components allows the possibility of combining the low and middle cloud forecasts to create a different product that may be of more interest to forecasters than the total cloud cover product. These two clouds components have been combined using two different cloud overlap assumptions: maximum overlap and random overlap.

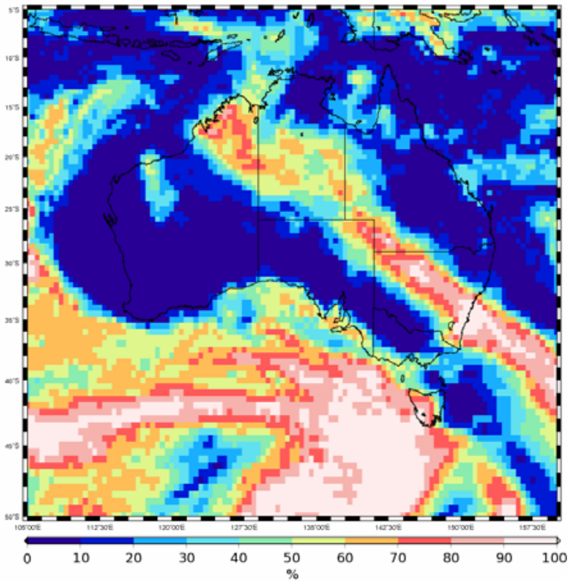


Figure 9 *24 hour forecast of combined low and middle cloud cover assuming random overlap from the '6latest' ensemble valid for 00Z December 18 2009 on a 0.5° by 0.5° grid.*

The maximum overlap assumption compares the low and middle cloud cover at each grid point and assigns the maximum of the two fields to that grid point. The random overlap assumption determines the cloud cover from (Wang, 2006):

$$R = L + M(1 - L) \qquad (1)$$

Where R is the cloud cover assuming random overlap, L is the low cloud cover fraction and M is the middle cloud cover fraction. The actual cloud overlap at a particular location is a function of the location, cloud type, cloud spatial scale and the synoptic situation (Wang, 2006). Although the cloud overlap may be better represented by some other overlap assumption Figures 8 and 9 give an example of what is now possible.

Figure 8 shows the combined cloud coverage of the low and middle cloud assuming maximum overlap while Figure 9 shows the cloud product assuming random overlap. Comparing Figures 8 and 9 shows that, as expected, more cloud is forecast when the random overlap assumption is employed. However, the operational total cloud forecast for this time, Figure 3, contains substantially more cloud than the forecast in Figure 9. The combined cloud fields may be more useful to forecasters under certain conditions.

The low, middle and high cloud forecasts are now delivered to the GFE and a smart tool, SkyFromLowMiddleHigh, has been written to allow forecasters to determine the type of overlap that is appropriate.

Thus far, point based verification at 9 locations within Victoria and NSW has been completed on 57 ceilometer observations. The results of these indicate that the '6latest' ensemble produces the most accurate forecasts. An example plot of the verification work undertaken so far is presented in Figure 10 and the coefficients of determination for the lines of best fit are given in Table 3.

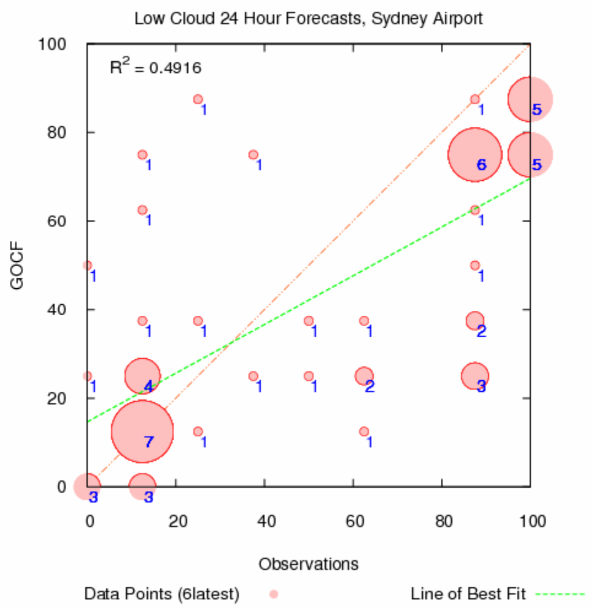


Figure 10 *A plot of 24 hour low cloud coverage forecasts against low cloud observations at Sydney Airport.*

The red points in Figure 10 are the forecast/observation pairs with the size representing the number of such pairs (also presented in blue text). The line of best fit is green and the ideal diagonal line is the dashed red line. Although there are not a large number of data here the plot indicates that there is some skill in the forecasts. The coefficients of determination for the different ensembles for their low and total cloud forecasts are presented in Table 3. These are determined from the line of best fit from a plot of forecasts against observations. These have been averaged over all ceilometer observations and all forecast lead times.

Table 3 *The coefficients of determination for different ensembles for their low and total cloud forecasts.*

Ensemble	Low Cloud	Total Cloud
Operational Total Cloud	-	0.4594
'3latest'	0.3756	0.3850
'6latest'	0.4073	0.4041
'9latest'	0.4047	0.4040

New low, middle and high cloud NWP data streams from the JMA, ECMWF and ACCESS-A models should become available in the near future. These will then be included in the forecast ensemble and a more rigorous verification process will be undertaken and presented.

Conclusions

The GOCF system has recently had the spatial resolution of the total cloud product increased from a 1.25° grid to a 0.5° grid, and new low, middle and high cloud forecasts have been added to the suite. The ensemble used for these contains fewer models than that of the operational total cloud product, however, because fewer models output separate low, middle and high cloud amounts.

Because, only three NWP models provide forecasts of the cloud components, ensembles expanded by inclusion of time lagged members were tested. Initial verification of the system indicated that an ensemble including the latest and next-latest runs of each model plus the most recent time lagged run from each model provided the best results. A more rigorous verification process will be undertaken and presented in the future when a number of new models can be included in the ensemble and when the forecast data set has become sufficiently large.

Acknowledgements

The authors would like to thank Xiaoxi Wu from NMOC for installing and maintaining the operational system along with Frank Woodcock and Michael Foley for reviewing the letter.

References

Ebert, E., 2001. Ability of a Poor Man's Ensemble to Predict the Probability and Distribution of Precipitation, *Monthly Weather Review*, Volume 129, 2461-2480.

Durrant, T., F. Woodcock, and D. J. M. Greenslade, 2009. Consensus Forecasts of Modeled Wave Parameters, *Weather and Forecasting*, Volume 24, 492-503.

Lou, Y. and S. K. Krueger, 2004. Cloud Types Simulated by the NCEP GFS Model, *Fourteenth ARM Science Team Meeting Proceedings,* 1-26.

NMOC, 2008. Operational Implementation of the Gridded OCF System, *Analysis and Prediction Operational Bulletin No. 74.*

NMOC, 2009. Operation Description of the Daily PME System, *NMOC Operations Bulletin No. 81*

NMOC, 2010a. Operational Implementation of the new Gridded OCF and PME suite, *NMOC Operations Bulletin No. 82.*

NMOC, 2010b. Operational Upgrades to the Gridded OCF and PME Systems, *NMOC Operations Bulletin No. 85.* In production.

Protat, A. 2010, Private Communication.

Wang, L., and A. E. Dessler, 2006. Instantaneous cloud overlap statistics in the tropical area revealed by ICESat/GLAS data, *Geophys. Res. Lett.*, 33, L15804, doi:10.1029/2005GL024350.

Woodcock, F., and C. Engel, 2005. Operational Consensus Forecasts, *Weather and Forecasting*, Volume 20, 101-111.

Parameterization of boundary layer decoupling in ACCESS NWP

Vaughan Barras[A], Peter Steinle[A], Adrian Lock[B]

[A] Centre for Australian Weather and Climate Research

Bureau of Meteorology, Victoria, Australia

[B] Met Office, Exeter, United Kingdom

v.barras@bom.gov.au

1. Introduction

The reduction in solar heating during the hours around sunset causes rapid changes in the planetary boundary layer (PBL). Under relatively calm conditions and clear skies, large variations are observed in near-surface temperature and humidity (Fitzjarrald and Lala, 1989). Atmospheric model intercomparisons have shown that the representation of this evening transition is generally poor, particularly in capturing the variability of near-surface state variables under stably stratified boundary layer conditions (Holtslag, 2006; Cuxart et al., 2006; Svensson and Holtslag, 2007).

The Australian Community Climate and Earth System Simulator (ACCESS; Puri et al., 2010) is the new atmosphere-ocean forecast model for numerical weather prediction (NWP) and climate research in Australia. In recent months, forecasters have reported excessive values of the screen-level (1.5m) specific humidity diagnostic (q1.5) predicted by ACCESS-A (the local area model for the Australasian domain). Overprediction of q1.5 was noted to occur under light wind conditions over inland Australia during the evening transition. Results from an investigation into this model behaviour are presented and an alternative parameterization of decoupling is tested.

2. Present formulation and testing

2.1 Overprediction of 1.5m specific humidity

The existing operational version of ACCESS-A showed a tendency to forecast lines or confined areas of very high screen-level specific humidity over inland Australia in the hours around sunset. A marked difference arose between the humidity values at screen-level and model level 1 (20m) during this time. Comparison of several case studies revealed that this apparent over-prediction occurred under conditions of near-surface convergence occurring near trough lines in which wind speeds would fall below 2m/s. The New South Wales Regional Forecasting Centre (NSWRFC) identified a particular case study in which excessive humidity was forecast over the region to the northwest of Bourke, NSW (as indicated in Figure 1a and b). Here, local maxima exceeded 24g/kg at 09Z (Figure 1a), values deemed to be excessive given the absence of any significant local precipitation or high soil moisture content. Furthermore, the ‘spotting’ of the forecast humidity pattern and its apparent association with calm wind conditions was an indication that the over-prediction may be associated with a weakness of the interpolation algorithm in this regime.

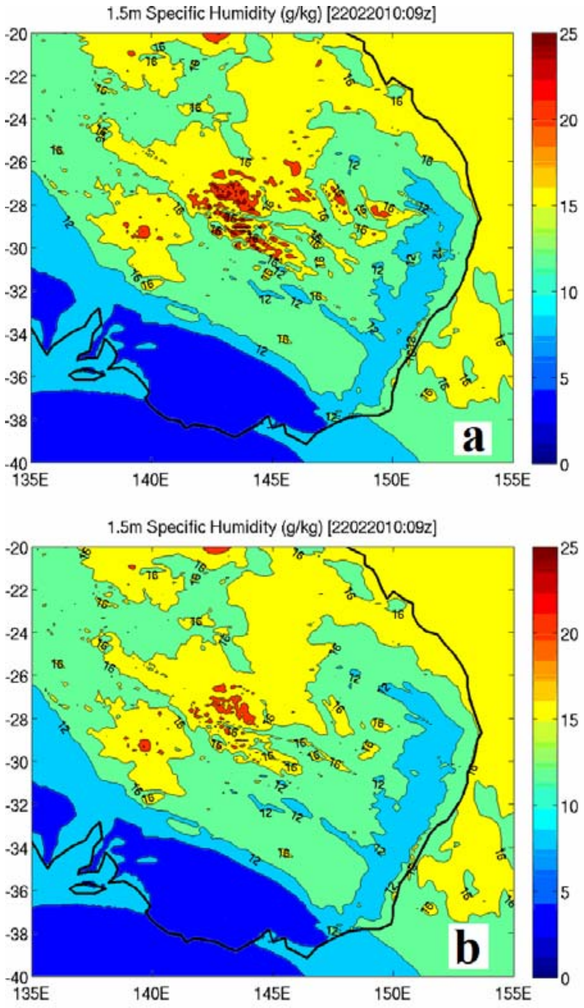


Figure 1 *ACCESS-A T+9 specific humidity forecast for 22/02/2010 (09Z) for (a) Monin-Obukhov and (b) decoupled scheme. Location of Bourke AP indicated by black dot. Units are g/kg.*

2.2 Model verification

Model verification in this instance was complicated by the fact that the peak errors occurred in a largely unpopulated region with sparse observational coverage. The closest set of observations with high temporal resolution was from Bourke airport (marked in black in Figure 1). These observations show a sharp decrease (increase) in temperature (specific humidity) during the evening between 05 and 11Z (3pm and 9pm local standard time). The magnitudes of these changes are slightly underpredicted but generally well captured by the model (Figure 2).

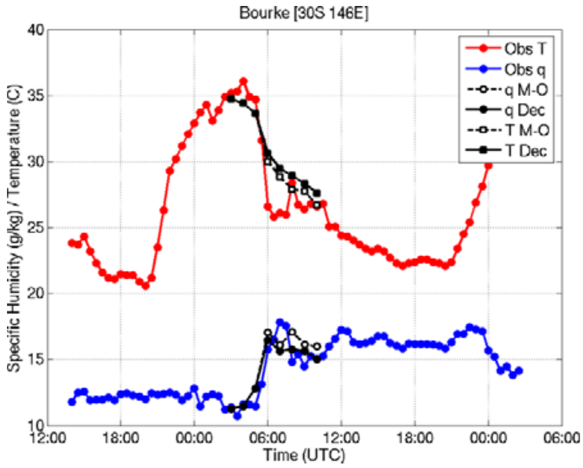


Figure 2 *Observations of temperature and specific humidity for 22/02/2010 at Bourke AP. Model predictions using Monin-Obukhov (dashed) and decoupled (unbroken) scheme overlaid in black.*

The observed changes in temperature and humidity at Bourke are consistent with previous observational studies that have observed rapid changes in near-surface specific humidity and temperature during the evening transition (Fitzjarrald and Lala, 1989). These changes are characteristic of the early evening transition (EET) under clear skies and light winds at low lying unobstructed locations (Acevedo and Fitzjarrald, 2001).

Time-height sections of the evolution of the lowest model layers during the evening (Figure 3a) illustrates the near doubling in magnitude of q1.5 in forecast humidity between 08Z and 09Z at a point where a local moisture maximum was diagnosed (to the northwest of Bourke). It is at this time that the surface friction velocity (u_*) falls to near zero[1] (not shown) resulting in unrealistically large values in the presently used Monin-Obukhov-based interpolation to screen height:

$$X_{ob} = X_0 + \gamma_C \qquad (1a)$$

[1] To avoid numerical error a lower limit of 1×10^{-5} ms^{-1} is imposed on the surface friction velocity in ACCESS-A.

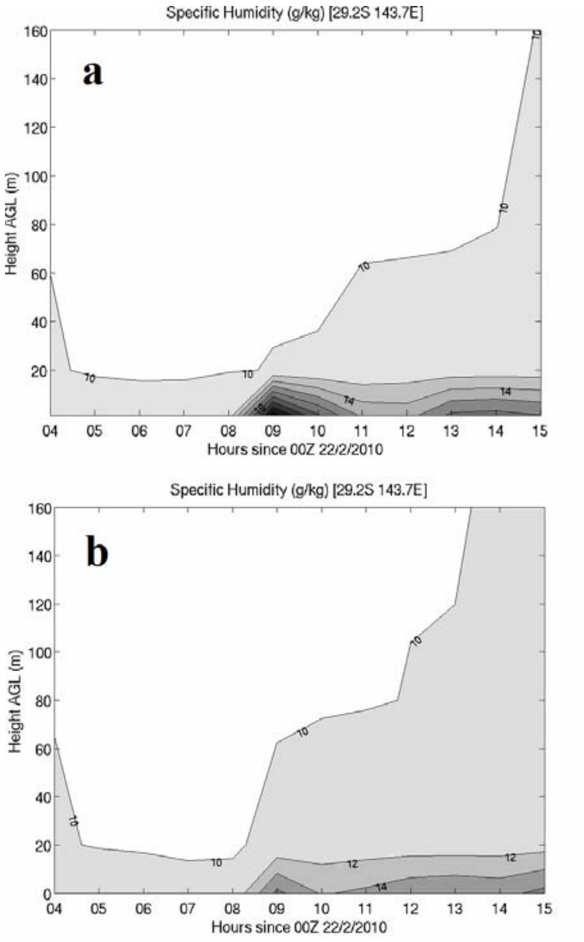


Figure 3 *Time-height section of q1.5 at grid point to the northwest of Bourke for (a) Monin-Obukhov and (b) decoupled scheme. Lowest height is 1.5m.*

where the screen level interpolation coefficient, γ_C is defined:

$$\gamma_C = \frac{C_H}{\kappa v_*}\Phi_H\left(X_1 - X_0\right) \qquad (1b)$$

Here, X_{ob} is the screen level scalar value, X_0 and X_1 are the respective surface and first model level scalar values, C_H is the surface conductance coefficient, κ is the Von Kármán constant, and v_* is the surface scaling velocity (Lock, 2007). Under light wind conditions as $v_* \to 0$, the first term of (1b) can become large. This has been noted to affect temperature, but is stronger for specific humidity as it is a more sensitive parameter by several orders of magnitude.

Interpolation to screen level using Monin-Obukhov similarity has been recognised as not always being applicable under stable boundary layer conditions (Mahrt, 1999). It has been observed that under such conditions the screen level diagnostics of temperature and humidity would follow the surface value (θ_0) too closely (Edwards et al., in press). This was particularly pronounced with respect to temperature.

Comparison of the ratio of the difference in potential temperature between screen level ($\theta_{1.5}$) and the first model level ($\theta_{k=1}$) indicated that in increasingly stable conditions the ratio

$$R = \frac{\theta_{1.5} - \theta_0}{\theta_{k=1} - \theta_0} \qquad (2)$$

should be ≈ 0.5, whereas under the initial formulation this ratio would fall to < 0.3 (Edwards, pers. comm.)

3. Revised parameterization

3.1 Surface layer decoupling (version 1)

To better represent surface layer decoupling under strongly stable conditions, a revised calculation of the interpolation to screen level was devised. Under calm and clear conditions during the evening transition, the close link between screen level and the surface introduced cold and moist biases in the 1.5m diagnostics (Edwards et al., in press). In order that the ratio of temperature between screen level and the first model level (R) might better represent observations, the calculation of the interpolation coefficient to screen level was set based upon simulations of an idealised cooling surface such that:

$$\gamma_C = a + \frac{b}{z_1^{tq}} - \frac{c}{\left(z_1^{tq}\right)^2} \,:(\mathrm{Ri_B} \geq 0.25) \qquad (3)$$

where a = 0.335, b = 1.78, c = 1.19, z_1^{tq} is the height of the lowest level of the model (20m for scalar variables) and Ri_B is the Bulk Richardson Number whose value greater than 0.25 is a recognised threshold for the existence of turbulence[2] (Stull, 1988). It should be noted that

[2] Although strictly this value is applicable to local gradients, less so for finite differences across layers of increasing thickness.

the revised parameterization was constructed purely in terms of temperature and not specific humidity. However, owing to the equivalent diffusive mixing characteristics of temperature and moisture near the surface (Garratt, 1992), the UM uses the same interpolation coefficient (γ_C) for both scalar variables, therefore changes made to the calculation of screen level temperature will also be reflected in the moisture diagnostics.

3.2 Response by screen-level diagnostics

The change to the calculation of the scalar screen level interpolation coefficient specifically targets conditions of high boundary layer stability. The differences between the two formulations are therefore highly region specific according to local values of Ri_B.

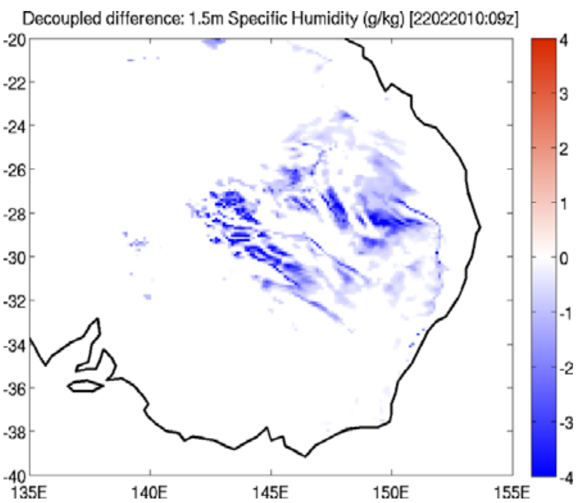


Figure 4 *Difference between original and revised parameterisation for 22/2/2010 (09Z) for 1.5m specific humidity (g/kg).*

Figure 4 illustrates the differences in screen level humidity and temperature stretching across northern New South Wales. The new parameterization introduces a decrease in specific humidity and a subtle increase in temperature reflecting a decoupling of screen level diagnostics from the surface.

Time-height sections of specific humidity using the decoupled surface layer scheme show a marked weakening of the evolution of screen-level humidity at the local maximum location (Figure 3b). Similarly, the forecast time series of temperature and specific humidity for Bourke show the differences in temperature and humidity introduced by the revised parameterization with slight warming and drying at screen level (black lines, Figure 2). Whilst illustrating the effect of the surface layer decoupling, it is difficult to note a specific improvement to the forecast in this instance as Bourke was not itself located at a point where the model was in greatest error. A clearer illustration of the improvement made by the new scheme is by noting the removal of many isolated 'bullseye' maxima in q1.5 (Figure 1b). Despite this, some local areas across NSW continue to show a weak 'spotting' of humidity maxima. With sparse observational coverage however, it is difficult to establish the extent to which the forecast may still be departing from reality.

4. Operational testing

4.1 Effect upon model skill

Before introduction into the operational forecast system, the new parameterization required testing to check for any deleterious effects upon the model and changes to forecast skill. In a trial applying the change to the forecast model only, data were tested against observations for the control and the revised model configurations. Overall, the impact of the new parameterization was found to be minimal in terms of forecasts of temperature, humidity, wind speed and mean sea level pressure.

4.2 Limitations of revised parameterization

The major limitation upon version 1 of the decoupling diagnostic in the operational ACCESS NWP system was that it introduced separate definitions of screen level temperature and humidity between the forecast model and the VAR data assimilation system. Purely from a diagnostic point of view the parameterization of decoupling made an improvement by inhibiting the prediction of excessive values of temperature and humidity under strongly stable conditions. At the Met Office, the implementation of this version of the parameterization was also extended to the Perturbation Forecast (PF) model of the VAR system in order that the definitions at screen level remained consistent. The effect of this was an overall cooling bias during assimilation as it was applying smaller warming increments due to the diagnosis of warmer screen level temperatures. It was found that the forecast skill was reduced in this instance. Because of this, a second version of the decoupling diagnostic was developed that took account of the assimilation cycles (Edwards, pers. comm.) and is now operational in the UK. This has yet to be applied to ACCESS-A.

5. Conclusion

The representation of the boundary layer under stable conditions remains a particularly difficult problem in NWP models. The decoupling of the screen level from the surface during the evening transition was poorly represented in the existing operational version of ACCESS-A due to the breakdown of Monin-Obukhov similarity under clear, calm conditions. A new parameterization of surface layer decoupling was applied to the calculation of surface scalar variables in the operational ACCESS NWP system. Although devised for improving forecasts of temperature, the addition of decoupling also had a desired effect upon moisture, inhibiting the tendency of the model to predict excessive values of specific humidity under strongly stable conditions. Operational testing showed that the new parameterization had a negligible effect upon the forecast skill, but importantly there were no deleterious effects found.

The addition of a parameterization for surface layer decoupling has had a positive effect upon predictions of low level specific humidity. This has removed an unrealistic feature in the screen level diagnostic under clear and calm conditions. The improved representation of near-surface moisture is of special importance in NWP over Australia, particularly in regard to the forecasting of fire weather conditions. However, it is acknowledged that there are limitations upon the application of version 1 of the decoupling parameterization. Firstly, there is a difference in the calculation of screen level diagnostics between the forecast model and the VAR data assimilation system. Secondly, the new parameterization has been 'tuned' to address errors in screen level temperature, not moisture. The validity of this approach will be the subject of further investigation.

The formulation described here has been deemed viable for the present, however further testing of the second version of the decoupling parameterization will be undertaken as part of the next upgrade of the operational NWP suite.

Acknowledgments

The authors would like to acknowledge John Edwards at the UK Met Office for valuable discussion regarding the decoupled parameterization. Thanks also to Ivor Blockley and Jim Fraser of the National Meteorological and Oceanographic Centre and the forecasters in the NSW Regional Office in the identification of the problem. Thanks also to Chris Tingwell, Tomasz Glowacki, Les Logan and Martin Dix at the Bureau of Meteorology for their assistance model setup, testing and integration of the code the NWP repository.

References

Acevedo, O.G., and D.R. Fitzjarrald, 2001: The early evening surface-layer transition: temporal and spatial variability, *J. Atmos. Sci.*, **58**, 2650-2667.

Cuxart, J., et al., 2006: Single-column model intercomparison for a stably stratified atmospheric boundary layer, *Boundary-Layer Meteorol.*, **118**, 273-303.

Edwards, J.M., J.R. McGregor, M.R. Bush, and F.J. Bornemann, 2010: Assessment of numerical weather forecasts against surface observations, *Q. J. R. Meteorol. Soc.*, (in press)

Fitzjarrald, D.R., and G.G. Lala, 1989: Hudson Valley fog environments, *J. Appl. Meteor.*, **28**, 1303-1328.

Garratt, J.R., 1992: The atmospheric boundary layer, Cambridge University Press, Cambridge, UK.

Holtslag, B., 2006: GEWEX atmospheric boundary-layer study (GABLS) on stable boundary layers, *Boundary-Layer Meteorol*., **118**, 243-246.

Lock, A.P., 2007: The parameterization of turbulent fluxes in the boundary layer, *UM Documentation Paper 24 – section 3, 50pp.*

Mahrt, L., 1999: Stratified atmospheric boundary layers, *Boundary-Layer Meteorol.*, **90**, 375-396.

Puri, K., et al., 2010: The Australian Community Climate and Earth System Simulator (ACCESS), (in preparation).

Svensson, G., and B. Holtslag, 2007: The diurnal cycle – GABLS second intercomparison project. *GEWEX News*, 17 (1), 9-10.

Preliminary results from Numerical Weather Prediction implementation of ACCESS

Kamal Puri, Yi Xiao, Xudong Sun, Jin Lee, Chermelle Engel, Peter Steinle, Tan Le, Ilia Bermous, Les Logan, Robin Bowen, Zhian Sun, Michael Naughton, Gregory Roff, Gary Dietachmayer, Asri Sulaiman, Martin Dix, Lawrie Rikus, Hongyan Zhu, Vaughan Barras, Holly Sims, Chris Tingwell, Brett Harris, Tomasz Glowacki, Mohar Chattopadhyay, Lilia Deschamps, John Le Marshall

Centre for Australian Weather and Climate Research
Bureau of Meteorology, Melbourne, Australia

Jim Fraser, Joan Fernon, Ivor Blockley, Charles Sanders, Lixin Qi, Arnold Mavromatis, Aurelio Turco, Karen Sonntag, David Howard, Alan Wain, Graham Warren, Xinmei Huang, Aihong Zhong, Mikhail Entel, Xiaoxi Wu, Chris Bridge, Terry Skinner

National Meteorological and Oceanographic Centre
Bureau of Meteorology, Melbourne, Australia

Corresponding author: Kamal Puri
CAWCR, Bureau of Meteorology
GPO Box 1289 Melbourne, 3001 Australia
e-mail: k.puri@bom.gov.au

Introduction

The Australian Community Climate and Earth System Simulator (ACCESS) is a fully coupled earth system model (ESM) being jointly developed by the Bureau of Meteorology and CSIRO, with help from the Australian Universities. A key aim of ACCESS is to develop a system that enables a national approach to climate and weather prediction model development, and will also provide the Bureau and CSIRO the capability to underpin Australia's basic weather and climate services and to conduct the best possible science for use in analysing climate impacts and adaptation. ACCESS will also enable Australian scientists to contribute to major international model intercomparison projects and provide opportunities for scientists to share knowledge, form collaborations and initiate new projects.

ACCESS planning started in 2005 with the development of two key documents (available at http://www.accessimulator.org.au/report/index.html), namely:

“Blueprint for ACCESS”, K. Puri, June 2005
“Project Plan for ACCESS”, K. Puri, September 2005.

The Blueprint provided an analysis of ACCESS stakeholder requirements and developed the scope for ACCESS, based on these requirements and an analysis of Earth System Models in use at a number of key international Centres. The Project Plan, provided the scientific justification for ACCESS and recommendations for the preferred options for the components, together with an estimate of the level of investment required for ACCESS to achieve its required objectives. Development of ACCESS has followed the recommendations made in the Project Plan with significant collaboration with international partners, particularly the United Kingdom Met Office.

ACCESS is designed to provide a seamless modelling system, based on the concept of a continuum of prediction problems, with a blurring of the distinction between shorter-term predictions and longer-term climate predictions, and brings together multi-disciplinary strengths across disciplines ranging from modelling, data assimilation and software engineering. Key components of the ACCESS ESM include the modules shown in Table 1. The atmosphere and ocean/sea-ice models are coupled using the

OASIS coupler.

The fully coupled ACCESS has now been technically assembled and detailed testing/tuning is in progress in preparation for submitting runs to be considered for the Intergovernmental Panel for Climate Change's (IPCC's) Fifth Assessment Report. A major milestone in the ACCESS development was reached in September 2009 when the numerical weather prediction component of ACCESS (atmospheric model + data assimilation) was implemented operationally by the Bureau of Meteorology.

This research letter presents some results to provide an indication of the performance of the ACCESS NWP system. A more detailed paper is being prepared.

Table 1 *Modules of the ACCESS ESM*

Module	Name	Source
Atmosphere	Met Office Unified Model (UM)	MetOffice
Ocean	Modular Ocean Model version 4 (MOM4)	NOAA Geophysical Fluid Dynamics Laboratory
Sea-ice	The Los Alamos Sea Ice Model version 4 (CICE4)	DoE Lawrence Livermore National Laboratory
Land surface/Carbon cycle	The CSIRO Atmosphere Biosphere Land Exchange model (CABLE)	CSIRO
Chemistry and Aerosols	United Kingdom Chemistry and Aerosol model (UKCA)	MetOffice, Leeds and Cambridge universities
Data Assimilation - atmosphere	4-dimensional variational assimilation (4DVAR)	MetOffice
Data Assimilation - ocean	Ensemble Kalman Filter	Bureau/CSIRO
Coupler	OASIS	CERFACS (Centre Européen de Recherche et de Formation **A**vancée en Calcul Scientifique)

Brief description of NWP component

Two key recommendations made by Puri (Project Plan for ACCESS, September 2005) were:

"ACCESS should import the Met Office atmospheric model HadGAM1 to provide the initial atmospheric model for ACCESS"

"The Met Office 4DVAR scheme should be imported to form the atmospheric data assimilation module in ACCESS. Work on EnKF formulation should be continued to provide an extension to the VAR scheme"

The Met Office unified model (UM) (Davies et al., 2005) and data assimilation system (OPS/VAR) (Rawlins et al., 2007) have been obtained under a research licence signed between the Bureau, CSIRO and the Met Office. ACCESS implementation has subsequently proceeded along these recommendations.

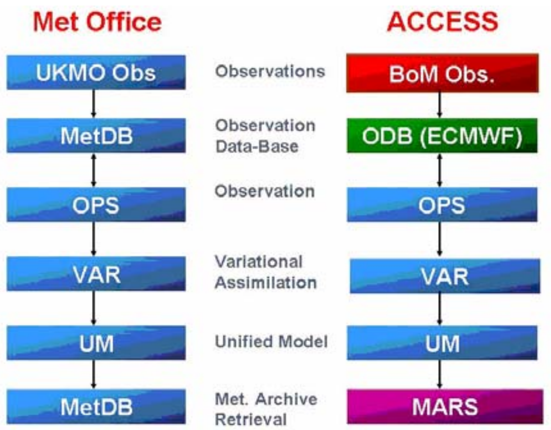


Figure 1 *Differences between the ACCESS and Met Office data assimilation systems.*

Figure 1 shows a schematic of the NWP component of ACCESS and the key differences between the Met Office and ACCESS NWP implementation. The key difference in the initial implementation of the ACCESS NWP system is the different computing environment, in particular the source of observational data, and the archive of forecast products. The ACCESS system has been interfaced into the Bureau's real time stream of meteorological observations using the Observation Data Base (ODB) from the European Centre for Medium-range Weather Forecasts. This system provides a new set of files for each assimilation period that also generates a record of the observations presented to the operational suite. The ODB was chosen as it provides an efficient and flexible method for handling large amounts of data from a wide variety of sources, can store feedback statistics from assimilation, and has been implemented at a number of NWP centres. The operational archive of forecast products was also moved to the Meteorological Archive and Retrieval System (MARS), also from the ECMWF. This system has been shown to be an efficient archive and retrieval system well suited to use by modern NWP systems.

As shown in Table 2, the initial operational ACCESS implementation (APS0 – Australian Parallel Suite 0) retained the same model resolutions and configurations as the Bureau's previous global and regional NWP systems GASP and LAPS.

Table 2 *Model domains and resolutions for initial ACCESS implementation.*

NWP system	Domain	Resolution
ACCESS-G	Global	N144 (80 km), L50
ACCESS-R	Regional	37.5 km L50
ACCESS-A	Australia	12.0 km L50
ACCESS-T	Tropical	37.5 km L50
ACCESS-C	Cities	5 km L50
ACCESS-TC	TC	15 km L50

Some Verifications

As noted above, both global (ACCESS-G) and regional (ACCESS-R) systems became operational on the NEC SX6 supercomputer in September 2009. The tropical region system (ACCESS-T, 0.375°x0.375°x50 levels) became operational in October 2009, and the high resolution Australian region version (ACCESS-A) was run in real time since September 2009. Operational implementation of ACCESS-A occurred on the Bureau's new Oracle Constellation supercomputer (Solar) when it was declared operational in August 2010. In another key milestone, final operational switchover to ACCESS-based systems occurred on Solar on 17 August 2010 with cessation of the Bureau's previous operational global and regional NWP systems, GASP (Seaman et al., 1995; Bourke et al., 1995) and LAPS (Puri et al., 1998), followed by decommissioning of the NEC SX6 supercomputer.

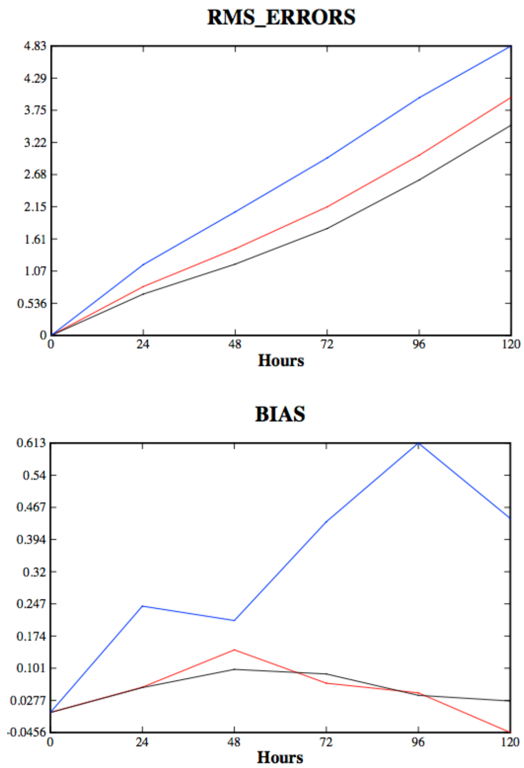


Figure 2a *Mean sea level pressure rms error and mean error (bias) in the Australian region as a function of forecast time for the period 1 September 2009 to 30 June 2010 for GASP (blue) and ACCESS-G (red) and MetOffice (black).*

The ACCESS-based global and regional systems have resulted in a large improvement in skill relative to the Bureau's previously operational systems (GASP and LAPS). An example to illustrate this is presented in Figures 2a and 2b which show verifications of sea level pressure from the ACCESS-G, GASP and the Met Office for the period 1 September 2009 to 30 June 2010. ACCESS-G lags in performance relative to the Met Office system. This is likely due to a number of factors, namely (i) resolution differences – ACCESS-G is N144(80km) 50 levels while MetOffice is N512 (25km) 70 levels, (ii) differences in the amount of data used in the two systems - ACCESS-G does not currently assimilate IASI and GPS-radio occultation data, (iii) recent Met Office changes (assimilation of cloudy radiances) have not been implemented in ACCESS, and (iv) use of older 2005 background covariances in the ACCESS systems.

Figures 3a and 3b show verifications for ACCESS-R and LAPS for the period 1 January 2010 to 30 June 2010, again showing major gains both at the surface and in the vertical with the ACCESS system (~1 day improvement in 3-day forecasts).

Verifications for ACCESS-A and ACCESS-T shown in Figures 4a and 4b again show significant gains in performance relative to the mesoLAPS, MALAPS and TXLAPS systems they replaced.

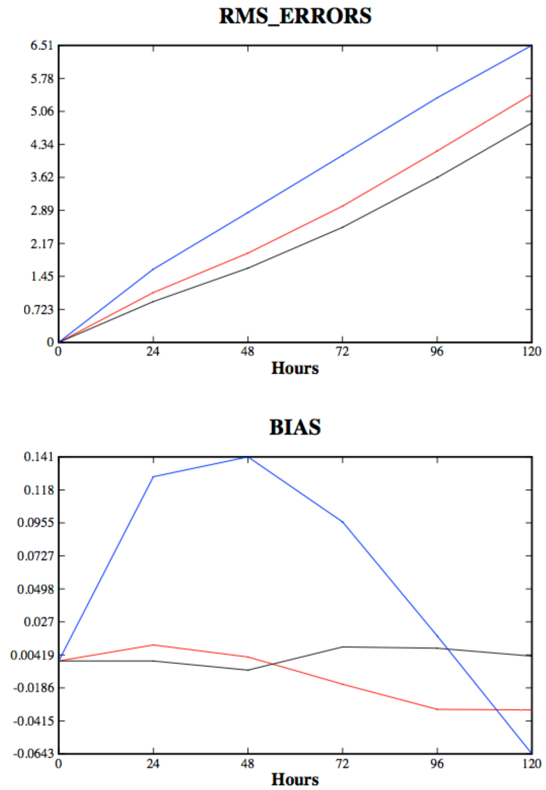


Figure 2b *As in Figure 2a but for the southern hemisphere annulus.*

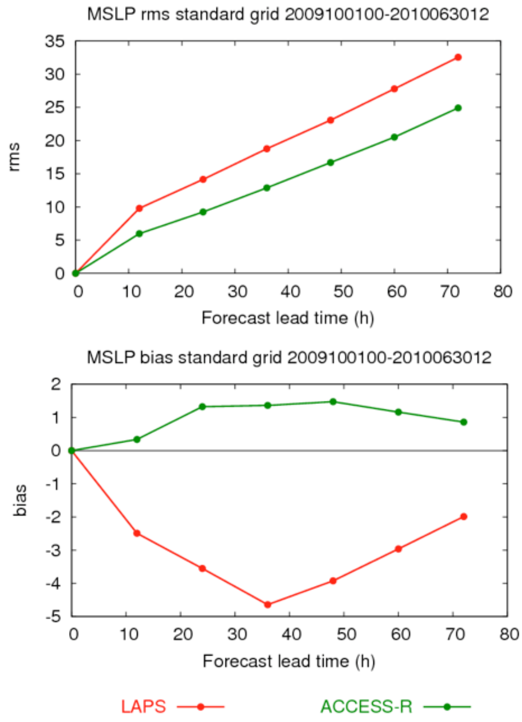


Figure 3a *Verification of ACCESS-R mean sea level pressure forecasts (rms error and bias as function of forecast time) for the Australian region for the period 1 January 2010 to 30 June 2010 for LAPS (red) and ACCESS-R (green).*

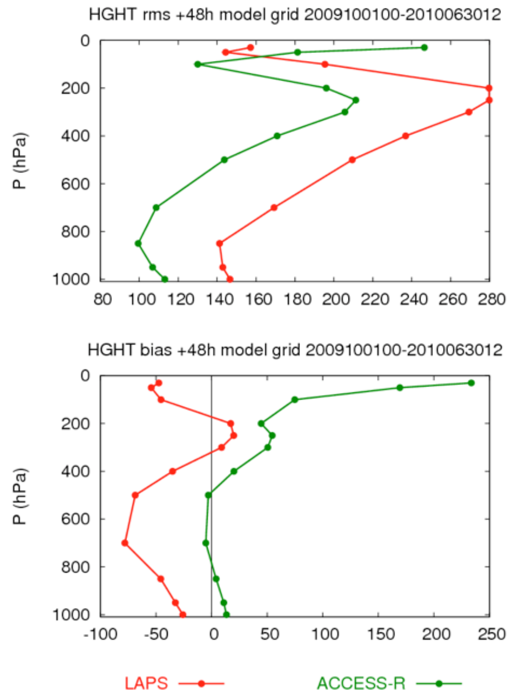


Figure 3b *Verification of 48h ACCESS-R mean height forecasts (rms error and bias as a function of height) for the Australian region for the period 1 January 2010 to 30 June 2010 for LAPS (red) and ACCESS-R (green).*

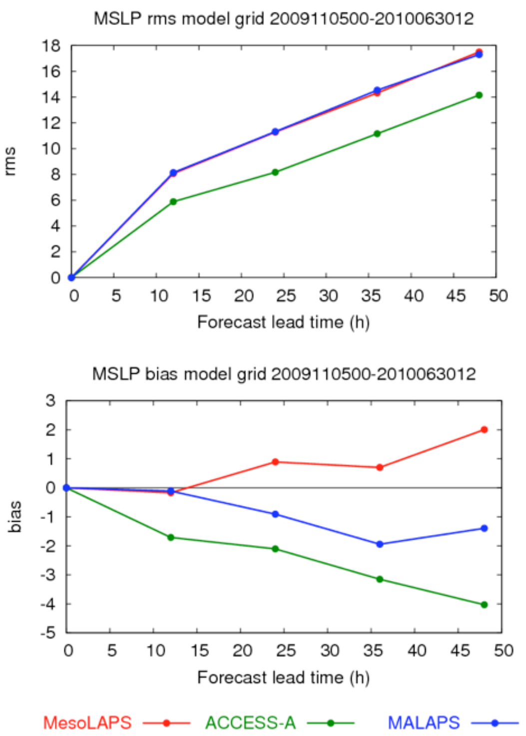


Figure 4a *As in Figure 3a but for ACCESS-A.*

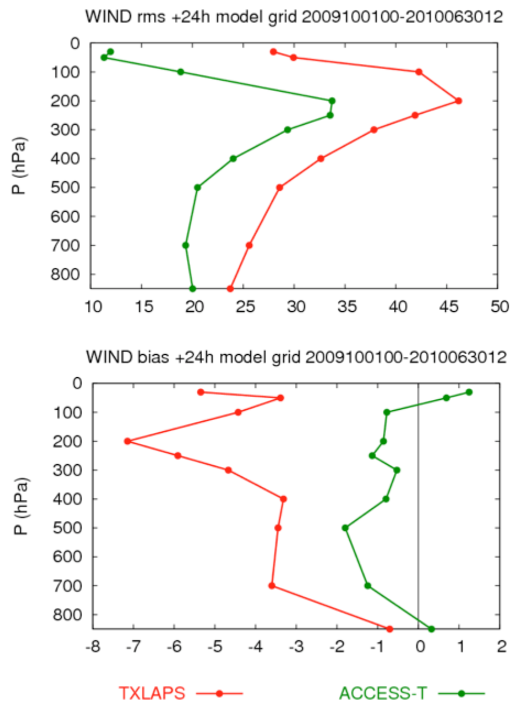


Figure 4b *As in Figure 3b but for ACCESS-T winds*

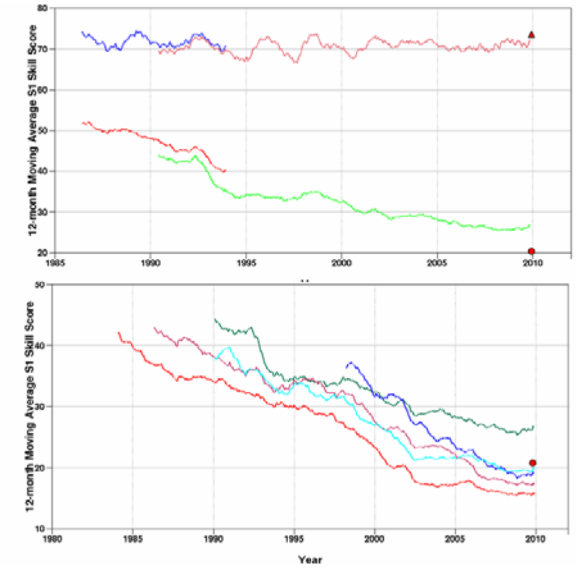


Figure 5 *History of performance of 48h forecasts from the Bureau's regional (top panel) and global (bottom panel) systems. The top panel includes LAPS (green) and ACCESS-R (red dot); the upper curve is for persistence. The bottom panel includes GASP (green), ACCESS-G (red dot) and global models from key operational international centres. The skill scores are for the Australian verification region.*

Figure 5 shows a history of the performance of the Bureau's regional and global systems in terms of 12-month running mean of S1 skill score as a function of years. The global figure includes operational models from other international operational centres (ECMWF, MetOffice, NCEP and JMA). The figure shows a continuing improvement in the Bureau models with large gains obtained through the implementation of LAPS and now ACCESS-R and ACCESS-G. Over the past few years the performance of GASP had fallen significantly relative to the international global models. This performance gap has now been largely filled with the introduction of ACCESS-G. The slightly lower level of performance of ACCESS-G can be attributed to its lower resolution relative to the other global models and the current usage of fewer satellite instruments.

Daily precipitation forecasts are of considerable interest to the public and pose considerable challenges for the forecasters. Tables 3 and 4 respectively show objective verifications for various measures of precipitation forecasts from ACCESS-R and ACCESS-SY (Sydney region). The ACCESS-R verifications cover the period 1 September 2009 to 5 April 2009 while the ACCESS-SY cover a shorter period from 21 May 2010 to 19 June 2010.

Table 3 *Mean verification scores for precipitation forecasts (0 – 24h and 24 – 48h) from LAPS and ACCESS-R (blue=ACCESS better, red=ACCESS worse).*

	OBSERVED	LAPS	ACCESS-R	LAPS	ACCESS-R
		00 24	00 24	24 48	24 48
Rain Area (km^2 * 10^3)	1204	1273	1297	1283	1261
Avg Intensity (mm/d)	11.14	11.82	8.21	11.14	8.07
Rain Volume (km^3)	13.40	15.0	10.7	14.3	10.2
Max Intensity (mm/d)	74.36	86.16	81.95	84.37	78.45
Mean Abs Error (mm/d)		2.29	1.88	2.53	2.03
Average RMSE (mm/d)		6.34	5.51	6.92	5.93
Average Correlation		0.54	0.55	0.45	0.50
Bias Score		1.06	1.08	1.07	1.05
Probability of Detection		0.72	0.74	0.68	0.70
False Alarm Ratio		0.32	0.31	0.36	0.33
Critical Success Index		0.54	0.55	0.49	0.52
Hanssen & Kuipers Score		0.63	0.65	0.58	0.61
Equitable Threat Score		0.45	0.47	0.39	0.43

Overall ACCESS-R is comparable or slightly better than LAPS in most scores for both time ranges, although ACCESS-R tends to under-do the average intensity and rain volumes whereas LAPS tends to overdo these. ACCESS-SY is comparable to or better than its LAPS counterpart (LAPS-SY) on most scores for both time ranges.

Table 4 *Mean verification scores for precipitation forecasts (0 – 24h and 24 – 48h) from LAPS-SY and ACCESS-SY (blue=ACCESS better, red=ACCESS worse).*

	OBSERVED	LAPS-SY	ACCESS-SY	LAPS-SY	ACCESS-SY
		00 24	00 24	24 36	24 36
Rain Area (km^2 * 10^3)	120	81	106	86	103
Avg Intensity (mm/d)	8.58	10.18	7.97	10.89	8.29
Rain Volume (km^3)	1.03	0.82	0.84	0.94	0.86
Max Intensity (mm/d)	24.33	72.02	60.56	71.65	70.09
Mean Abs Error (mm/d)		2.37	1.87	2.48	2.09
Average RMSE (mm/d)		5.00	3.69	5.23	4.10
Average Correlation		0.43	0.55	0.44	0.52
Bias Score		0.67	0.89	0.72	0.87
Probability of Detection		0.62	0.77	0.65	0.75
False Alarm Ratio		0.08	0.13	0.10	0.13
Critical Success Index		0.59	0.69	0.45	0.68
Hanssen & Kuipers Score		0.59	0.70	0.61	0.69
Equitable Threat Score		0.47	0.57	0.48	0.56

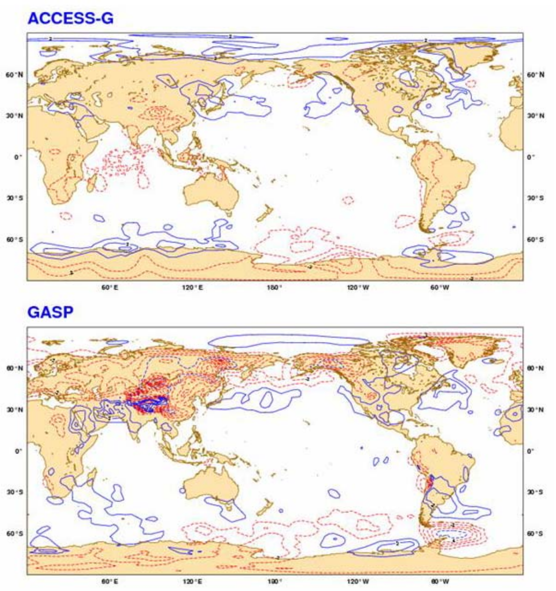


Figure 6a *Mean January MSLP 48 hr forecast errors for ACCESS-G and GASP. Contour interval is 1hPa, full (dashed) contour lines denote positive (negative) values.*

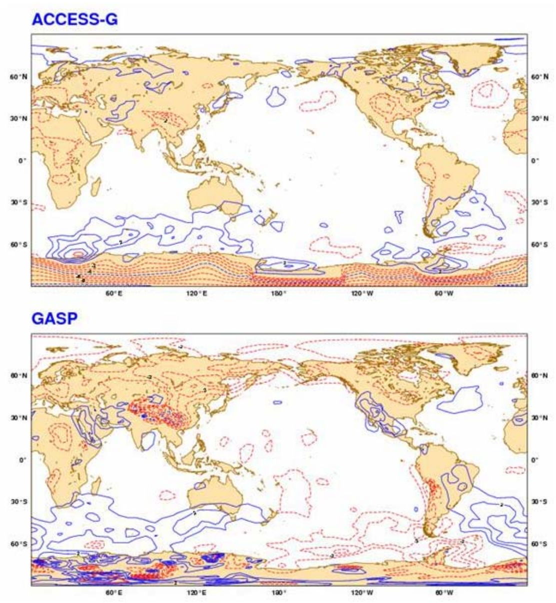


Figure 6b *As in Figure 6a but for mean June MSLP errors.*

Figures 6a and 6b show the mean January 2010 and June 2010 mslp errors for ACCESS-G and GASP. A key feature to note is the significantly lower biases over land areas (except over Antarctica, which involves large extrapolations below the elevated Antarctic land-mass) for ACCESS-G. The ACCESS system, however, appears to have a systematic bias over the narrow sea-ice belt around Antarctica in June.

Future Development

The design of ACCESS, which is consistent with seamless prediction, provides a platform that allows the flexibility needed to implement major upgrades and new applications. Thus for example the non-hydrostatic formulation readily allows increased resolutions and 4DVAR allows assimilation of data from a wide variety of platforms including significantly enhanced sounders planned for new satellite launches.

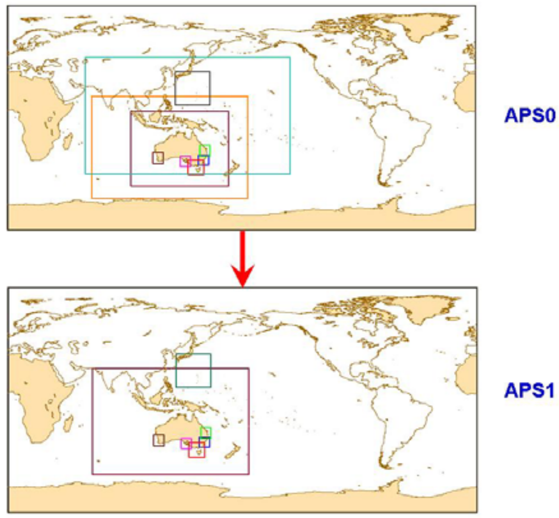


Figure 7 *ACCESS NWP domains for suites APS0 and APS1.*

An ongoing activity at major operational centres is regular upgrades to the operational systems. The upgrades include improved numerics, improved physical parametrisations, developments in analysis formulations, and assimilation of new sources of data particularly from new satellite sounders. This ongoing work has been essential to realise the major improvements in numerical weather prediction over the past decade. The ACCESS NWP system will need to follow this practice of regular upgrades if its forecast performance is to remain competitive with that of other international centres. Accordingly, planning for the next upgrades (APS1 and APS2) has commenced. The first upgrade, APS1, planned for implementation early in 2011 will include increased resolutions (N320 (40km) 70 levels for ACCESS-G and 12km 70 levels for ACCESS-R) while the second upgrade, APS2, planned for later in 2011 will include further increases in resolution (N512 (25km) 70-90 levels for ACCESS-G, and 2-3km for ACCESS-C). The upgrades will also include improvements to physical parametrisations, assimilation of wider variety of satellite sounders (e.g. IASI and GPS data and use of cloudy radiances), and a rationalisation of the regional domains (see Figure 7). The upgrades to the NWP suite will also include routine experimental running of the 24-member ACCESS global and regional ensemble prediction systems, AGREPS.

A major challenge facing weather prediction centres is reduction and mitigation of adverse effects of weather. In response to this there has been a major shift in emphasis towards severe weather prediction. Australia is vulnerable to the ravages of adverse weather such as tropical cyclones, high rainfall, high winds, fire-weather conditions, etc. Tropical cyclones, for example, represent the most regular major natural meteorological disaster affecting the tropical regions of the Southern Hemisphere. The socio-economic impact of tropical cyclones is major. Thus, a major emphasis in the future development of ACCESS NWP must be in severe weather prediction. This development will be closely tied to the ACCESS Global and Regional Ensemble Prediction System (AGREPS) that is currently under development, and the recently commenced Strategic Radar Enhancement Project (SREP), which involves a new research effort in high resolution NWP assimilation of radar precipitation and wind data, as well as the installation of four Doppler radars.

Conclusions

ACCESS has made significant progress since its start in 2005, with operational implementation of the ACCESS-based NWP systems by the Bureau, successful assembly of the fully coupled ACCESS earth system model, and commencement of detailed testing and tuning in preparation for submitting runs to be considered for the IPCC's Fifth Assessment Report. Significant progress has been made with ACCESS infrastructure. Examples include successful porting to both Solar (Bureau) and Vayu (National Computational Infrastructure, NCI) machines, development of infrastructure to allow ready usage by University researchers, and setting up of a unified inventory based at NCI. A pleasing aspect is the increasing use of ACCESS by researchers, including experimentation with physical parametrisations, tropical cyclone studies, impact of enhanced stratospheric resolution, use of idealised limited area version of ACCESS, and atmospheric tracer mass conservation in the UM.

As noted above the design of ACCESS provides a platform which has the flexibility needed to implement major upgrades and new applications. The results obtained from the initial operational implementation, including major performance gains relative to the Bureau's previously operational systems (GASP and LAPS), provide considerable confidence that future upgrades will deliver continuing substantial improvements in the Bureau's ability to provide forecasts of increasing precision and reliability.

Acknowledgements

The continuing and timely support and advice on UM and 4DVAR by Met Office staff is gratefully acknowledged. ACCESS NWP implementations would not have been possible without this support.

References

Bourke, W.P., Hart, T., Steinle, P., Seaman, R., Embery, G., Naughton, M. and Rikus, L. 1995: Evolution of the Bureau of Meteorology's Global Assimilation and Prediction System. Part 2: Resolution enhancements and case studies. *Australian Meteorological Magazine*, **44**, 19 - 40.

Davies, T., Cullen, M. J. P., Malcolm, A. J., Mawson, M. H., Staniforth, A., White, A. A. and Wood, N. 2005: A new dynamical core for the Met Office's global and regional modelling of the atmosphere. *Quarterly Journal of the Royal Meteorological Society*, **131**, 1759–1782.

Puri, K., Dietachmeyer, G., Mills, G.A., Davidson, N.E., Bowen, R.M. and Logan L.W. 1998: The new BMRC Limited Area Prediction System, LAPS. *Australian Meteorological Magazine*, **47**, 203 - 23.

Rawlins, F., Ballard, S. P., Bovis, K. J., Clayton, A. M., Li, D., Inverarity, G. W., Lorenc, A. C. and Payne, T. J. 2007: The Met Office global four-dimensional variational data assimilation scheme. *Quarterly Journal of the Royal Meteorological Society*, **133**, 347–362.

Seaman, R., Bourke, W., Steinle, P., Hart, T., Embery, G., Naughton, M. and Rikus, L. 1995: Evolution of the Bureau of Meteorology's Global Assimilation and Prediction system. Part 1: analysis and initialisation. *Australian Meteorological Magazine*, **44**, 1 - 18.