NMOC Operations Bulletin No. 80

Preliminary Information on the Replacement of GASP/LAPS with ACCESS NWP
5 August 2009

1. Overview

In late 2009 the National Meteorological & Oceanographic Centre (NMOC) plans to replace all the existing operational Numerical Weather Prediction (NWP) systems that are run in the Bureau of Meteorology with the new Australian Community Climate and Earth-System Simulator (ACCESS) system, which is based on the UK Met Office Unified Model/Variational Assimilation (UM/VAR) system. The ACCESS NWP systems have been developed and tested by research staff under the leadership of Dr Kamal Puri in the ACCESS Group of the Centre for Australian Weather and Climate Research (CAWCR) and are currently undergoing operational trials and configuration in NMOC coordinated by Jim Fraser.

ACCESS NWP components will be operationally implemented via a progressive rollout schedule, beginning on the Bureau's existing (NEC) supercomputer and ending with implementation of all systems on the new (SUN) supercomputer. Key target dates include:

- August 2009: Initial implementation of global, regional and tropical ACCESS domains on the Bureau's existing NEC supercomputer. These will run in parallel with the pre-existing operational NWP models (GASP, LAPS, TXLAPS, TCLAPS) until December.
- August – October 2009: Parallel trials of new mesoscale and city-based ACCESS domains; development of necessary linkages to all downstream systems; and provision of sample datasets to all existing users. At the same time, work will progress with porting ACCESS systems to the new SUN Constellation supercomputer in conjunction with CAWCR research staff.
- November 2009: Acceptance testing of the full suite of ACCESS systems on the new SUN supercomputer.
- December 2009: Final operational switchover to ACCESS-based systems. Cessation of GASP, LAPS, etc systems and decommissioning of NEC supercomputer.

This Bulletin provides an overview of the ACCESS NWP systems. Not all system details have been finalised, so more detailed information and a discussion of ACCESS forecast performance will be provided in subsequent Operations Bulletins.

2. Background

For many years NMOC has run NWP models to provide a suite of analysis and prediction products to support meteorological, oceanographic and climate services. Until now these systems have been developed in-house by the Bureau of Meteorology Research Centre (now the Centre for Australian Weather and Climate Research, CAWCR). However in recent years the relative performance of these local models has lagged behind improved overseas model guidance, leading to the decision in 2005 to implement the Unified Model/Variational Assimilation (UM/VAR) system developed by the United Kingdom Met Office (UKMO). This NWP forecast system has been made available as part of the ACCESS project - a joint initiative between the Bureau of Meteorology and CSIRO in cooperation with the Australian university community, which aims to provide world-class weather prediction and climate modelling capabilities to Australian users.

Switching to UM/VAR-based ACCESS systems is expected to result in immediate and significant improvement in the Bureau's operational NWP forecast skill (see section 8 for some preliminary verification results), while also providing access to ongoing improvements developed by the UKMO and other meteorological centres that have also adopted the UKMO model.

3. UM model description

Key Features of the Unified Model include:

- The core dynamics of the model are based on a non-hydrostatic formulation.
- The points at which the equations are solved are staggered vertically and horizontally to minimize errors in the numerical solution of the dynamics.
- The vertical levels are "hybrid height" levels. These approximate a constant height above terrain in the low levels, are at constant heights above MSL above approximately 30km, and are a smooth blend in between.

In the current ACCESS configuration the lowest few levels on which wind vectors are output are approximately 10, 50, 130 and 250 m above the terrain. For temperature and most other parameters the bottom few levels are approximately 20, 80, 180 and 320 m above terrain height. Currently all ACCESS models use 50 vertical levels with a top level at 62919m (~0.15 hPa).

Further details of the horizontal and vertical grid structure of the ACCESS model are discussed in the appendix to this Bulletin.

4. Observational data assimilation

The ACCESS system uses a four-dimensional variational data assimilation scheme (4DVAR). This scheme results in a much improved use of observations compared to the scheme used by the GASP and LAPS systems, firstly by using more data and also by making better use of all data. 4DVAR systems take into account time differences between various observations, and also the time differences between the observations and the nominal analysis time in a dynamically consistent way. 4DVAR also allows for multiple reports from the same station to be used, in effect assimilating tendency information as well the full observations. Finally, the variational approach performs a dynamical initialization during the analysis – so that the initialization does not disrupt the fit of the analysis to the observations.

Additional observations which are used by ACCESS and not by GASP and LAPS include:

- Hyperspectral sounders such as AIRS and IASI. These provide much greater vertical detail than the infra-red sounders of the ATOVS instruments that are used by ACCESS, GASP and LAPS.
- Low-level wind data from ASCAT, as well as the QuikSCAT data used by GASP and LAPS.
- Wind speed and precipitable water from the SSM/I instrument aboard the DMSP satellites.
- More aircraft data from AMDAR.
- Winds at 10m from land stations.

5. Main differences

From a user's perspective, the main differences between the current numerical weather prediction systems and the ACCESS systems include:

- Use of a hybrid vertical level structure in ACCESS rather than sigma levels. This will affect any users of raw model data and is discussed further in Section 6 and the appendix.
- The horizontal and vertical staggering of fields on the native model grids, as discussed in Section 3 and the appendix.
- Use of MARS rather than rtdb for forecast storage. For ACCESS the central repository for gridded model output will be the Meteorological Archive and Retrieval System (MARS) rather than the currently used "rtdb" realtime database (for short term storage) and SAM tape archive (for long term storage). ACCESS data will not be stored in rtdb at all under current plans. This will affect any downstream systems that currently retrieve local NWP model input data from rtdb. Methods for the storage, retrieval and distribution of data from MARS have been developed. Maintainers of any downstream systems that currently read local NWP model data from rtdb will need to adapt their systems to use ACCESS data from MARS.
- The initial ACCESS model domains and spatial resolution will generally be very similar to the current GASP/LAPS systems. The only significant changes in domains will be the rationalization of the previous 12.5km MESO_LAPS and the 10km MA_LAPS mesoscale-assimilation models to a single 12km "ACCESS-A" Australian assimilation & forecast system. See section 7 for a brief outline of system domains and resolutions.
- High temporal resolution of model outputs. For example fields from the meso-scale model output will be output at all levels at hourly resolution.
- Accumulated fields output from the ACCESS suite are accumulated from the time of the previous output step to their validity time, except for precipitation fields which are accumulated from the start of the assimilation window (currently set to 3 hours before the analysis base-time). Hence fields such as accumulated precipitation will be non-zero at the analysis output step.
- Vertical velocity (m/s) replaces omega (Pa/s) as the parameter representing vertical motion in the atmosphere although an approximately derived omega will be provided in the short-term for users reliant on omega.
- New fields including accumulated snowfall, screen-level horizontal visibility, fog fraction and 10m wind gusts are slated for eventual inclusion in model outputs (targeted for APS1, although some of these fields may become available during APS0's lifetime – see section 7 for details on APS0 and APS1).

6. Model output data

Model forecast data is written out from the UM in a proprietary UKMO format. These files are then converted to GRIB edition 1 before being stored in MARS. The GRIB files can be converted to NetCDF for external customers if required. For the first year or so, output will also be available in NetCDF and GRIB interpolated to sigma levels similar to the output from the existing systems. However, users should be aware that the conversion of the hybrid height levels to sigma levels introduces interpolation errors. If possible, users of sigma level data should convert their applications to use the hybrid height data instead.

7. Planned operational ACCESS system configurations

It is envisaged that upgrades to ACCESS will be tested via semi-regular parallel test suites before implementation. The initial ACCESS rollout has been designated as “Australian Parallel Suite 0” (APS0) with domains and resolutions chosen to be similar to the existing operational NWP system domains, as shown in Table 1 and Figure 1. The only significant changes in domains compared to the previous GASP/LAPS systems will be the rationalisation of the previous 12.5km MESO_LAPS and the 10km MA_LAPS mesoscale-assimilation models into a single 12km “ACCESS-A” Australian assimilation & forecast system, and also the temporary cessation of global ensemble forecasts until the probable introduction of a new ACCESS-based AGREPS (Australian Global and Regional Ensemble Prediction System) system in the next Parallel Suite APS1 in 2010. The daily schedule will be similar to the existing systems. There have been requests in recent months for changes to the ACCESS-C 5km city-based domains. Unfortunately any changes to model domains will have to wait until the APS1 upgrades in 2010.

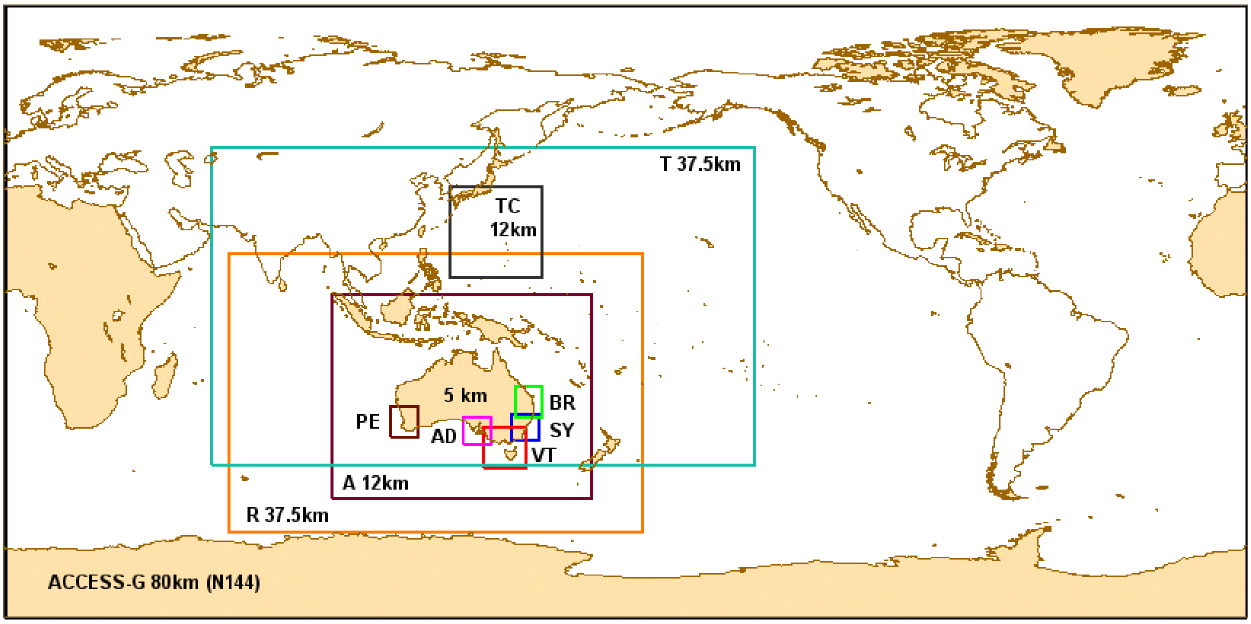

Figure 1: Domains of initial APS0 ACCESS models

NWP system	Domain	Type	Resolution	Domain limits S-N,W-E (lat x lon)	Duration (hours)	Runs (UTC)
ACCESS-G	Global	Assim + Forc	N144 (~80km)	-90.0 to 90.0, 0.00 to 358.75 (217 x 288)	+240	00, 12
ACCESS-R	Regional	Assim + Forc	0.375° (~37.5 km)	-65.00 to 17.125, 65.00 to 184.625 (220x320)	+72	00, 12
ACCESS-T	Tropical	Assim + Forc	0.375° (~37.5 km)	-45.00 to 55.875, 60.00 to 217.125 (270x420)	+72	00, 12
ACCESS-A	Australia	Assim + Forc	0.11° (~12 km)	-55.00 to 4.73, 95.00 to 169.69 (680x544)	+48	00, 06, 12, 18
ACCESS-C	BRISBANE	Forc	0.05° (~5 km)	-31.00,148.00, (158x178)	+36	00, 12
	PERTH	Forc	0.05° (~5 km)	-37.5, 112.00 (158x178)		
	ADELAIDE	Forc	0.05° (~5 km)	-39.5, 132.0 (200x178)		
	VICTAS	Forc	0.05° (~5 km)	-46.0 to -34.05, 139.00 to 150.95 (240x240)		
	SYDNEY	Forc	0.05° (~5 km)	-38.0, 147.00 (160x160)		
ACCESS-TC	Tropical Cyclone	Assim + Forc	0.11° (~12 km)	Relocatable within the ACCESS-T domain: 30°x30°	+72	00, 12

Table 1: Proposed model domains & resolutions.

8. Forecast performance

Detailed testing of the global (ACCESS-G; N144L50) and Australian region systems (ACCESS-R; 37.5kmL50) including 4DVAR has been ongoing since July 2008, initially by CAWCR and more recently by NMOC. Daily full forecast/assimilation cycles for the systems are being run in near real-time. Both systems continue to perform well with a large improvement in skill relative to the Bureau's currently operational global and regional systems (GASP and LAPS). Figure 2a shows verifications from the ACCESS, MetOffice and the Bureau's operational global systems for the period 1 January to 30 June 2009. The differences in performance between ACCESS-G and the MetOffice system are possibly due to a number of factors; namely (i) resolution differences; ACCESS-G is N144 while MetOffice is N320, (ii) differences in the amount of data used in the two systems; ACCESS-G does not currently assimilate IASI and GPS data, and (iii) the MetOffice changes to assimilate cloudy radiances have not been implemented ACCESS yet. Figure 2b shows skill scores from ACCESS-R and LAPS for the period 1 January to 29 June 2009 again confirming the significantly superior performance of the new system.

Subjective comparisons have been made in NMOC of ACCESS MSLP output in comparison to UKMO and ECMWF global models over the Australian Region since January 2009 and have shown that:

- ACCESS-G MSLP forecasts were very similar to UKMO fields to 120 hours with minor differences in the depth of extra-tropical lows and definition of troughs in the westerlies, attributable to differences in horizontal resolution between two models (UKMO ~60 km versus ACCESS-G ~80 km) and also occasional differences in satellite data input.
- ACCESS-G output is compatible with EC forecasts to at least 144 hours, again with differences due to resolution
- Overall performance of ACCESS-G in the Australian region has been very satisfactory. For example, the ACCESS-G forecasts were able to capture several days ahead the extreme conditions of Black Saturday over Victoria.
- ACCESS-R is performing well to 48 hours. However, model performance at 72 hours, while better than LAPS, is generally not as skilful as the equivalent ACCESS-G forecast. The "bomb" cyclogenesis event of late June 2009 over the Tasman Sea was well forecast by ACCESS-R in a sequence of forecasts and was superior to LAPS to 72 hours.

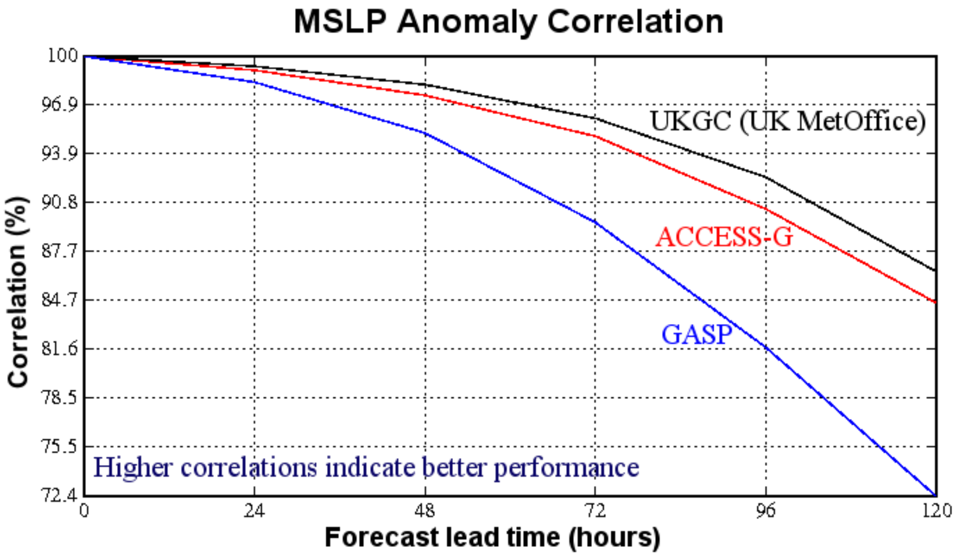

Figure 2a: Anomaly correlations for global model mean sea level pressure forecasts for the Australian region for the period 01 January 2009 to 30 June 2009 for GASP (blue), operational MetOffice (black) and ACCESS-G (red)

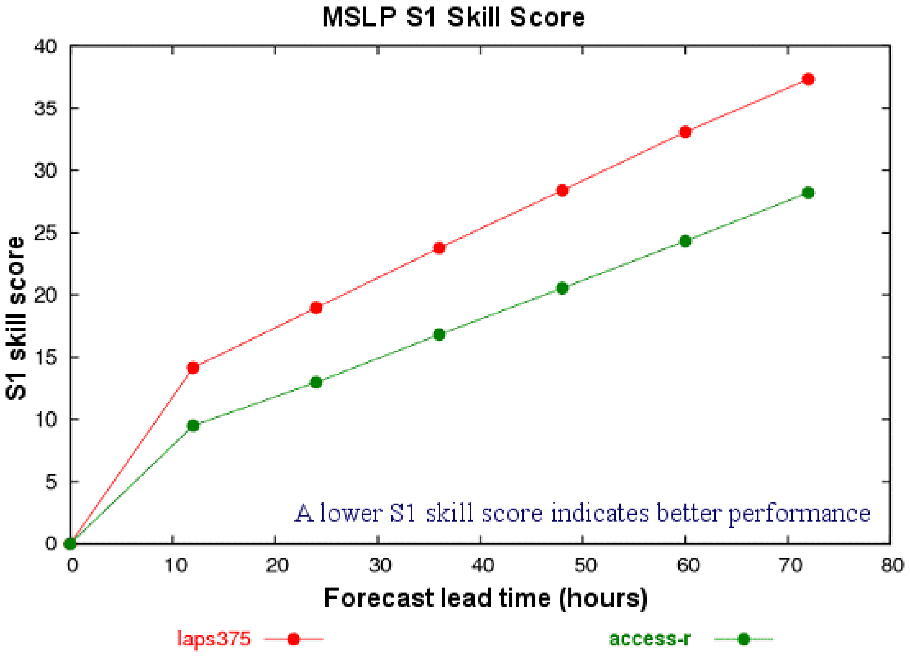

Figure 2b: Verification of regional model mean sea level pressure forecasts (S1 skill score) for the Australian region for the period 1 January 2009 to 29 June 2009 for LAPS (red) and ACCESS-R (green).

9. Sample output product availability

Sample output data from the ACCESS-G, R, & T systems will be available to interested users in early August 2009. Sample output data from the higher resolution models ACCESS-A and ACCESS-C is expected to be available by late August 2009. Sample data will be representative of the routine model outputs and will be available in GRIB-1 and NetCDF formats. Individual files will correspond to collections of data valid at a single forecast time-step and will include:

- All available fields on the native model grids (i.e. staggered - horizontally and vertically)
- Single-level fields interpolated to a single uniform (horizontally destaggered) grid
- Multi-level fields on native hybrid-height vertical coordinates, interpolated to a single uniform (horizontally destaggered) grid
- Multi-level fields interpolated to pressure levels on a single uniform (destaggered) grid
- Multi-level fields interpolated to sigma levels on a single uniform (destaggered) grid (if absolutely required).

The suite of routine gridded and chart products will be recast to reflect the changeover to ACCESS, including new product ID codes. Details of the products and product bundles, together with sample data files and charts will be made available on the Bureau's website at http://www.bom.gov.au/nmoc/ from September 2009. An example chart is shown in figure 3.

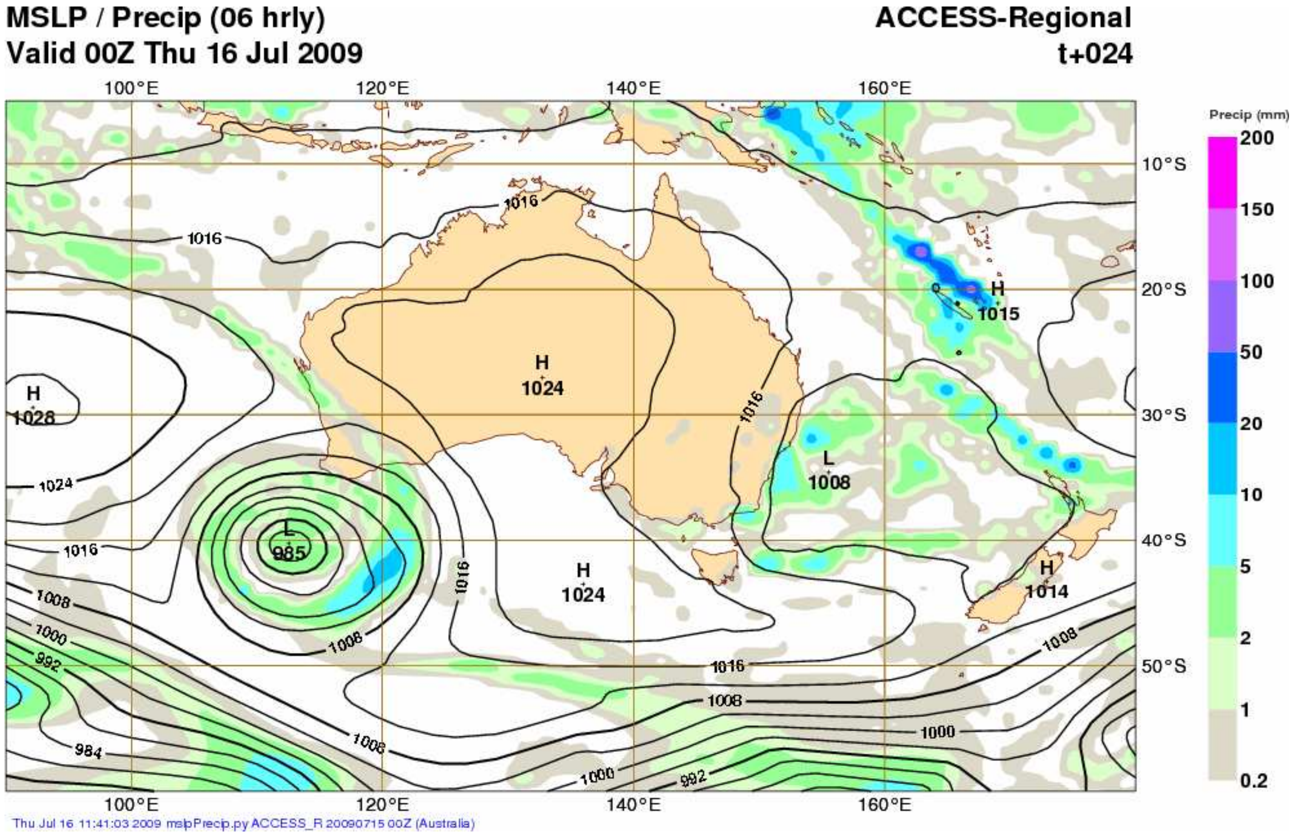

Figure 3: Example plot from ACCESS-R showing mean sea-level pressure (hPa) contoured in black overlain on precipitation (kg/m^2) contoured in colour.

10. Further Information

Further information regarding the operational implementation of ACCESS NWP systems will be made available at http://www.bom.gov.au/nmoc/ as soon as possible.

APPENDIX: Horizontal and vertical grid structure of the ACCESS model

The UM system uses an Arakawa C-grid (Arakawa & Lamb 1977) in the horizontal and a Charney-Phillips grid (Charney & Phillips 1953) in the vertical. This results in fields located on different grids displaced by half a grid spacing in both vertical (height) and horizontal (longitude and latitude) directions. The vertical levels consist of interleaved "theta" and "rho" levels, so named after the main variables stored on them. This staggered arrangement of fields is designed to allow for accurate finite differencing; the exact arrangement is detailed in table 2 and illustrated in figure 4 below.

Variable	**Grid location (longitude, latitude, height)**		
Pressure, Density	i	j	k
Temperature, Humidity, Vertical Wind Speed	i	j	k ± ½
Zonal Wind Speed	i ± ½	j	k
Meridional Wind Speed	i	j ± ½	k

Table 2: Grid positions of variables neighbouring a central point (i, j, k) in grid length units.

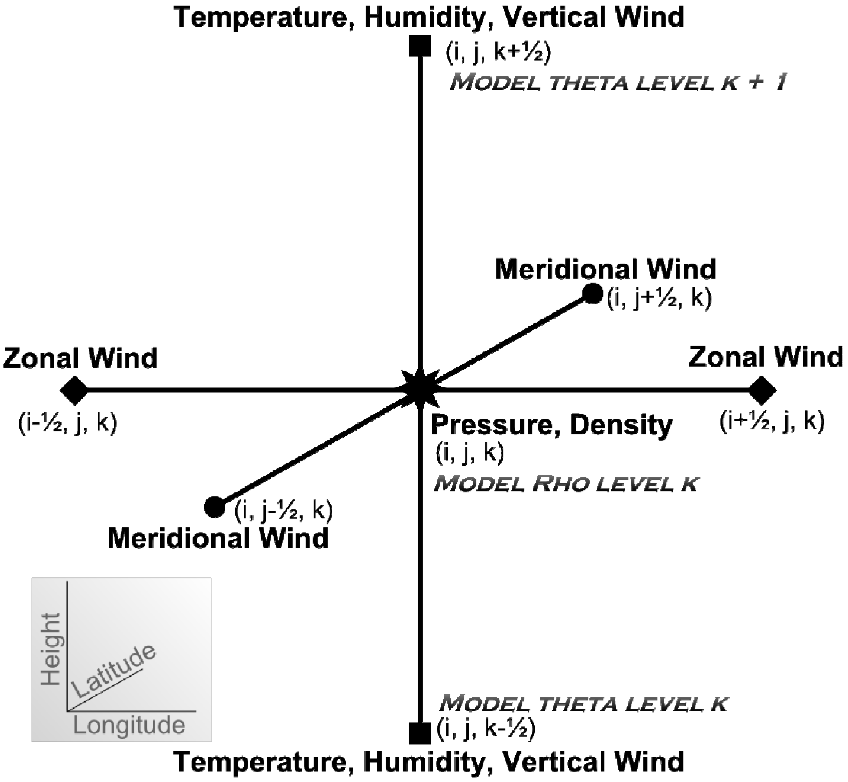

Figure 4: Model grid arrangement as per table 2. This staggered grid pattern has dimensions of one grid unit on all sides and is repeated in all three dimensions to form the entire model grid.

The ACCESS models are configured such that each grid point in the horizontal is spaced a constant latitude and longitude increment apart from adjacent grid points. The vertical levels are constructed in a "hybrid" fashion so they conform to terrain heights near the surface and become constant height surfaces in the upper atmosphere as per equation 1 (illustrated in figure 5).

$$z_i = \left\{ \begin{array}{ll} \eta_i z_T + z_s (1 - \frac{\eta_i}{\eta_{Interface}})^2 & for\ i < Interface \\ \eta_i z_T & for\ i \geq Interface \end{array} \right\}$$

Equation 1

where z_i is the height above mean-sea-level (MSL) of model level i at a particular latitude and longitude, z_T is a constant corresponding to the height above MSL at the top of the model, z_s is the terrain height above MSL at the particular latitude and longitude, η_i is the "eta" value of model level i and $\eta_{Interface}$ is the "rho"-level η value at i = Interface. The current 50-level UM systems running in NMOC have z_T = 62918.64699999984 m, Interface = 30, and η_i values as per table 3. It should also be noted that the UM assumes a spherical earth with radius (to MSL) equal to the mean radius of the planet (6371229 m).

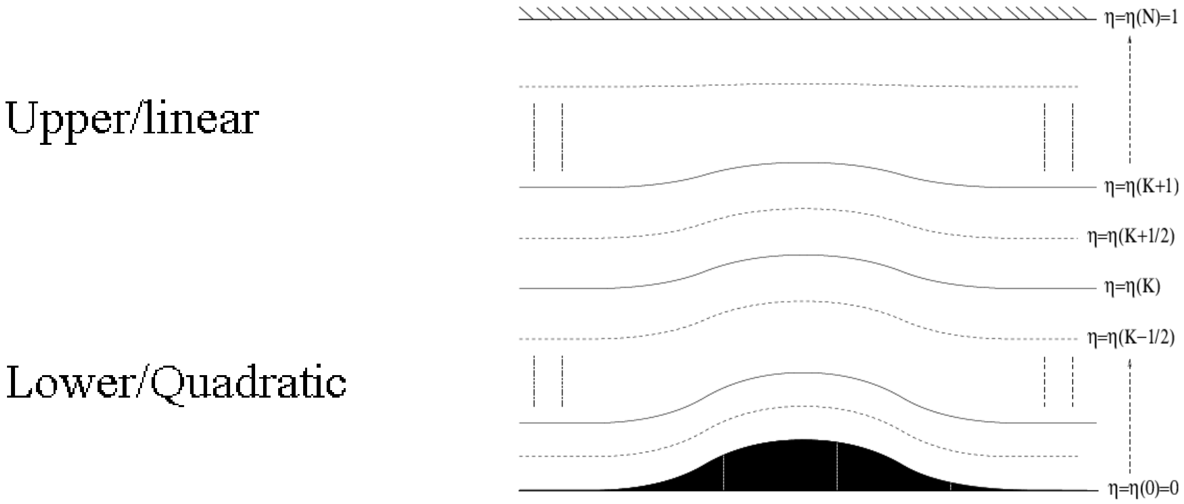

Figure 5: Schematic of hybrid coordinate system used in ACCESS UM models

References

Arakawa, A. & Lamb, V. R. 1977 , Computational design of the basic dynamical processes of the UCLA general circulation model, Methods in Comp. Phys. 17, 174–265.

Charney, J. G. & Phillips, N. A. 1953 , Numerical integration of the quasi-geostrophic equations for barotropic and simple baroclinic flows, J. Meteor. 10, 71–99.

Level index	η (at theta levels)	Height (m)	η (at rho levels)	Height (m)
50	1.0000000	62918	0.9531141	59968
49	.9062281	57018	0.8662998	54506
48	.8263715	51994	0.7923848	49855
47	.7583982	47717	0.7294412	45895
46	.7004842	44073	0.6757434	42516
45	.6510026	40960	0.6297574	39623
44	.6085122	38286	0.5901292	37130
43	.5717462	35973	0.5556734	34962
42	.5396007	33951	0.5253624	33055
41	.5111240	32159	0.4983146	31353
40	.4855051	30547	0.4737836	29810
39	.4620621	29072	0.4511468	28385
38	.4402316	27698	0.4298941	27048
37	.4195567	26398	0.4096167	25772
36	.3996766	25147	0.3899956	24538
35	.3803146	23929	0.3707909	23329
34	.3612672	22730	0.3518300	22136
33	.3423928	21543	0.3329966	20951
32	.3236004	20360	0.3142195	19770
31	.3048386	19180	0.2954611	18590
30	.2860837	18000	0.2767065	17410
29	.2673293	16820	0.2582700	16250
28	.2492107	15680	0.2404693	15130
27	.2317278	14580	0.2233042	14050
26	.2148807	13520	0.2067749	13010
25	.1986692	12500	0.1908814	12010
24	.1830936	11520	0.1756236	11050
23	.1681536	10580	0.1610016	10130
22	.1538495	9680	0.1470152	9250
21	.1401810	8820	0.1336647	8410
20	.1271483	8000	0.1209498	7610
19	.1147514	7220	0.1088707	6850
18	.1029901	6480	0.0974274	6130
17	.0918647	5780	0.0866198	5450
16	.0813749	5120	0.0764479	4810
15	.0715209	4500	0.0669118	4210
14	.0623027	3920	0.0580114	3650
13	.0537202	3380	0.0497468	3130
12	.0457734	2880	0.0421179	2650
11	.0384624	2420	0.0351247	2210
10	.0317871	2000	0.0287673	1810
9	.0257475	1620	0.0230456	1450
8	.0203437	1280	0.0179597	1130
7	.0155757	980	0.0135095	850
6	.0114433	720	0.0096951	610
5	.0079468	500	0.0065164	410
4	.0050859	320	0.0039734	250
3	.0028608	180	0.0020662	130
2	.0012715	80	0.0007947	50
1	.0003179	20	0.0001589	10

Table 3: Model vertical levels and equivalent heights in the absence of topography. The model level structure used in the UM uses a "hybrid" coordinate system which is split between terrain-following quadratic η surfaces near the surface and flat linear η surfaces above a specified level. Currently level 30 is the lowest "constant height" rho level in the UM configuration used in NMOC.