Australian Government
Bureau of Meteorology

ACCESS Numerical Weather Prediction resources for the national research community

Michael Naughton

Bureau of Meteorology
R&D Branch
Earth System Modelling Program
Atmospheric Modelling Team

michael.naughton@bom.gov.au

Reprising talk prepared by Gary Dietachmayer
for last week's Climate and Water Summer Institute

OzEWEX 3rd National Workshop
Canberra, 14-15 December 2016

Australian Government
Bureau of Meteorology

Outline

- "ACCESS": the Australian Community Climate and Earth-System Simulator
  - Focus here is on the NWP components of ACCESS

- Introduction to Numerical Weather Prediction (NWP)
- NWP at the BoM
- NWP and streamflow – WIRADA, Carlisle-flood examples
- Access to NWP data - NCI

Australian Government
Bureau of Meteorology

Intro to NWP – towards an eqn set

- Many physical systems have prognostic equations that allow us to predict a future state from a past one.
  - Driving to Canberra: $dx/dt = v(x,t)$
  - If v is constant (V) : $x(new) = x(old) + V * time$
- A significant component of atmospheric behaviour can be captured if we treat the atmosphere as an ideal gas.
  - Three equations for momentum (u, v, w) - "Euler" / "Navier Stokes"
  - Conservation of mass
  - Conservation of energy
  - Equation of state relating thermodynamic variables
- In atmospheric modelling parlance, this is the "**dynamics**" of the model

Australian Government
Bureau of Meteorology

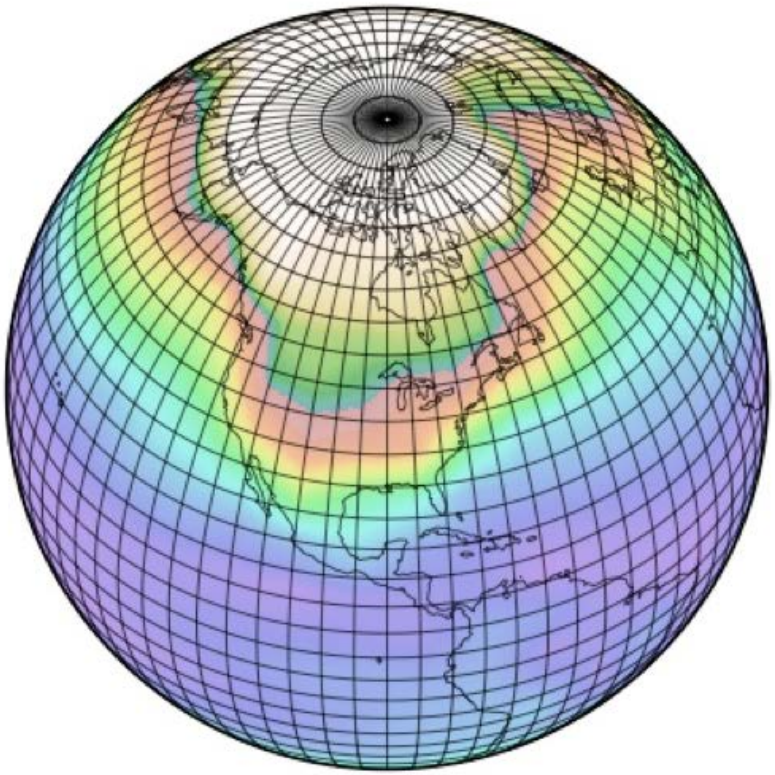
Intro to NWP – the need for discretisation

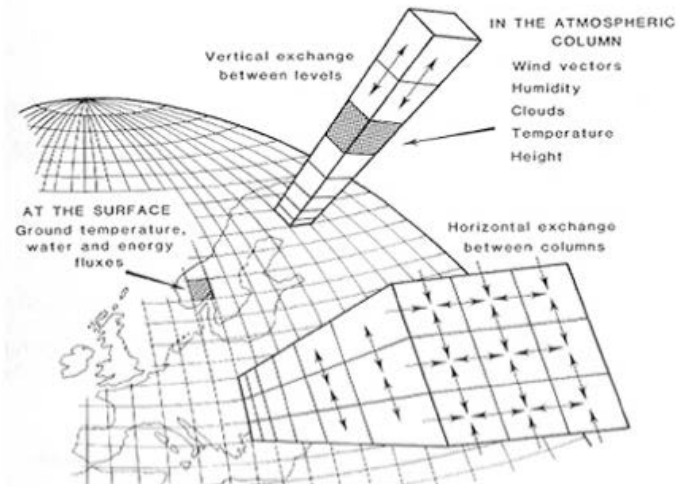
$$\frac{Du}{Dt} = -\frac{uw}{r} - 2\Omega w\cos\phi + \frac{uv\tan\phi}{r} + 2\Omega v\sin\phi - \frac{c_{pd}\theta_v}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} + S^u \qquad \frac{D}{Dt} \equiv \frac{\partial}{\partial t} + \frac{u}{r\cos\phi}\frac{\partial}{\partial\lambda} + \frac{v}{r}\frac{\partial}{\partial\phi} + w\frac{\partial}{\partial r}$$

- Dynamics eqns are a set of coupled, non-linear, partial-differential equations
  - No general analytical solution
- Computers are dumb, but fast – can only do basic algebraic operations, but can do *lots* of them
- *"Discretisation"* is the process of replacing the original continuous equations by a set of algebraic ones whose solution is 'sufficiently close' to the original set.
- Chunk-up space into a regular array of small-volume "grid-cells" – analogous to pixels in an image
  - Replace *derivatives* by *differences*.
- "Resolution" = width of a grid-cell
  - Higher resolution is (mostly!) more accurate, but also more expensive

Australian Government
Bureau of Meteorology

Intro to NWP – Discretisation via a lat/long grid

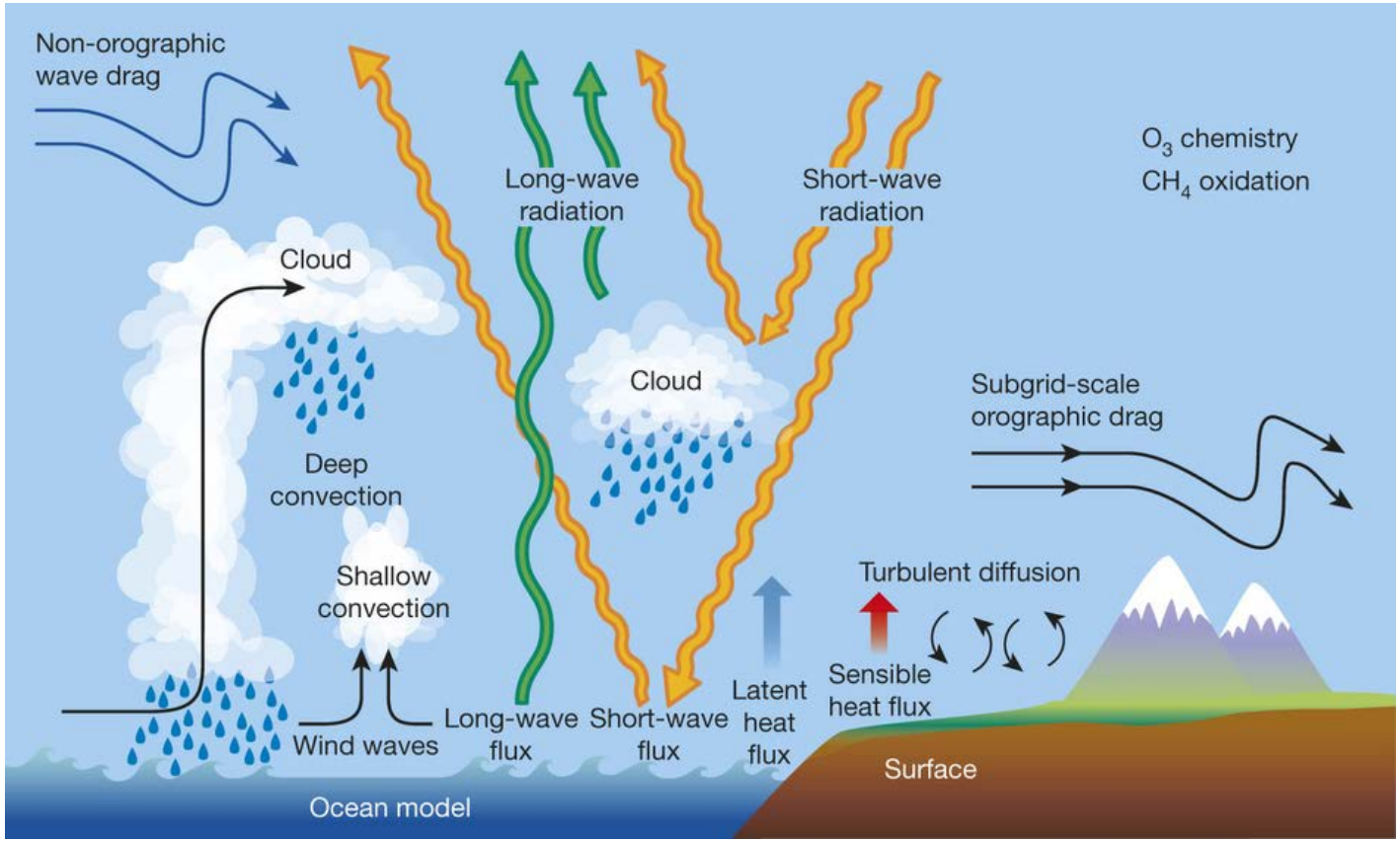




(Henderson-Sellers, 1985)

Australian Government
Bureau of Meteorology

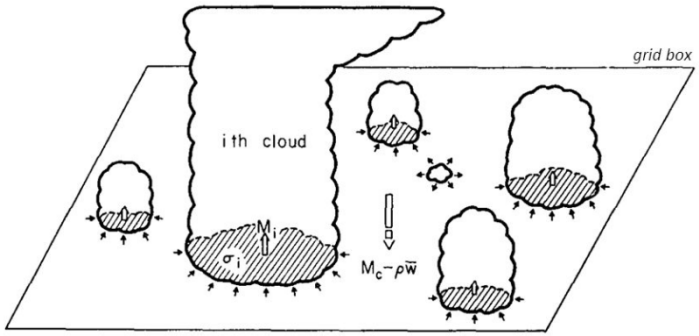
Intro to NWP – beyond N-S (moist processes!)



(Bauer et al, 2015)

Intro to NWP – need for parameterisation

- Many important processes occur at scales of *less than a grid-cell*
- Can't simply ignore them
  - Feed back onto the resolved scales
  - Often very impactful (eg., precip)
- *Parameterise* them – relate their average impact to variables on the model-grid scale
  - E.g., if the model has ascent in an area of moist instability, assume convection will form, (latent) heating will occur, etc
- In modelling parlance, these parameterised processes are referred to as "**physics**"
- "Dynamics" + "Physics" + Big-Computer = ability to project atmosphere forward in time
  - but *from what* ……..



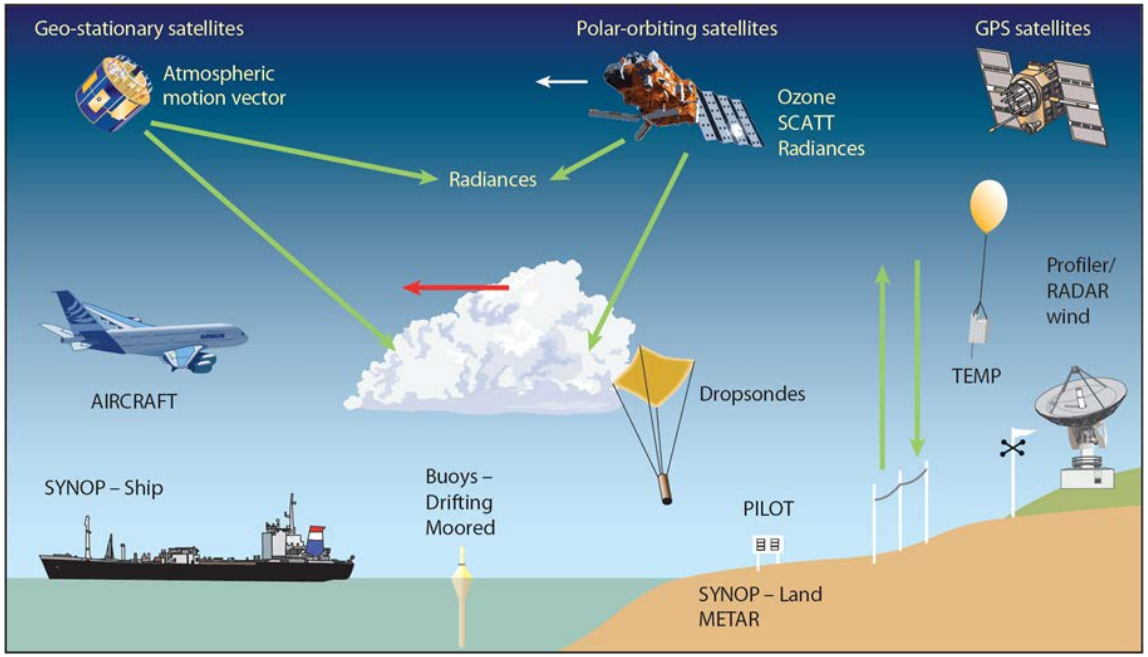
(Arakawa &Schubert, 1974)

Australian Government
Bureau of Meteorology

Intro to NWP – Data Assimilation (Intro)

The problem:

- The model state may consist of ~50 million grid points and 7 meteorological variables at each point - 350 million pieces of information …
- We may actually assimilate "only" 3 – 4 million individual observations
- We don't generally observe model variables (eg., grid-cell temperature versus top-of-cloud radiance)
- Obs coverage varies widely in time/space
- The observations aren't "truth"



Australian Government
Bureau of Meteorology

Intro to NWP – Data Assimilation (Variational)

General idea is to minimise:

$$J(\mathbf{x}_a) = (\mathbf{x}_a - \mathbf{x}_f)^T \mathbf{B}^{-1} (\mathbf{x}_a - \mathbf{x}_f) + (\mathcal{H}(\mathbf{x}_a) - \mathbf{y})^T \mathbf{R}^{-1} (\mathcal{H}(\mathbf{x}_a) - \mathbf{y})$$

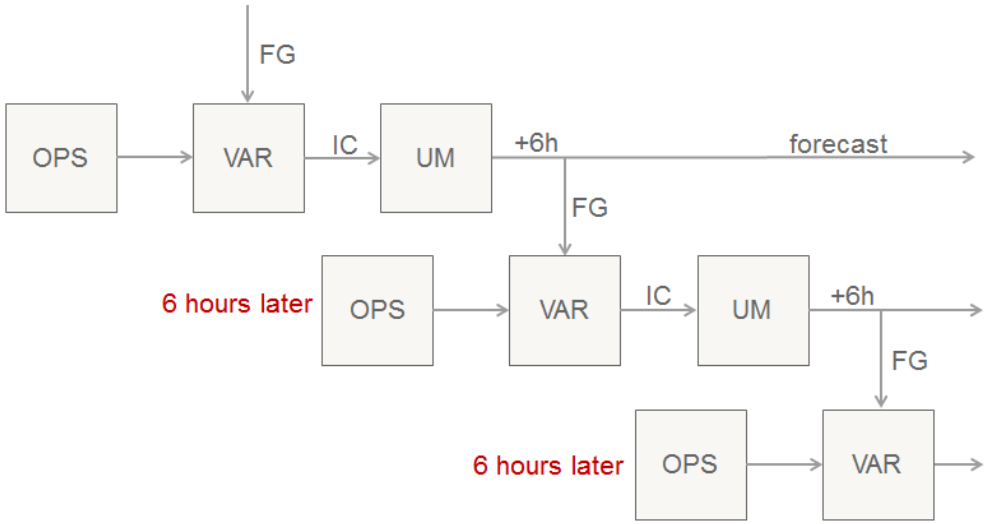
where

- x_a is the "analysis" (model IC), x_f is the short-term forecast ("background")
- y are the observations, *H* maps from observed to analysis (model) space
- B and R are forecast and observation error covariances

Lots of "tricks" applied here:

- Minimisation, with B term, resolves the insufficient data problem
  - and effectively carries obs forward from previous times
- Use a descent method, based on grad-J
- Rescale/filter B term

Intro to NWP – Data Assimilation (the NWP cycle)



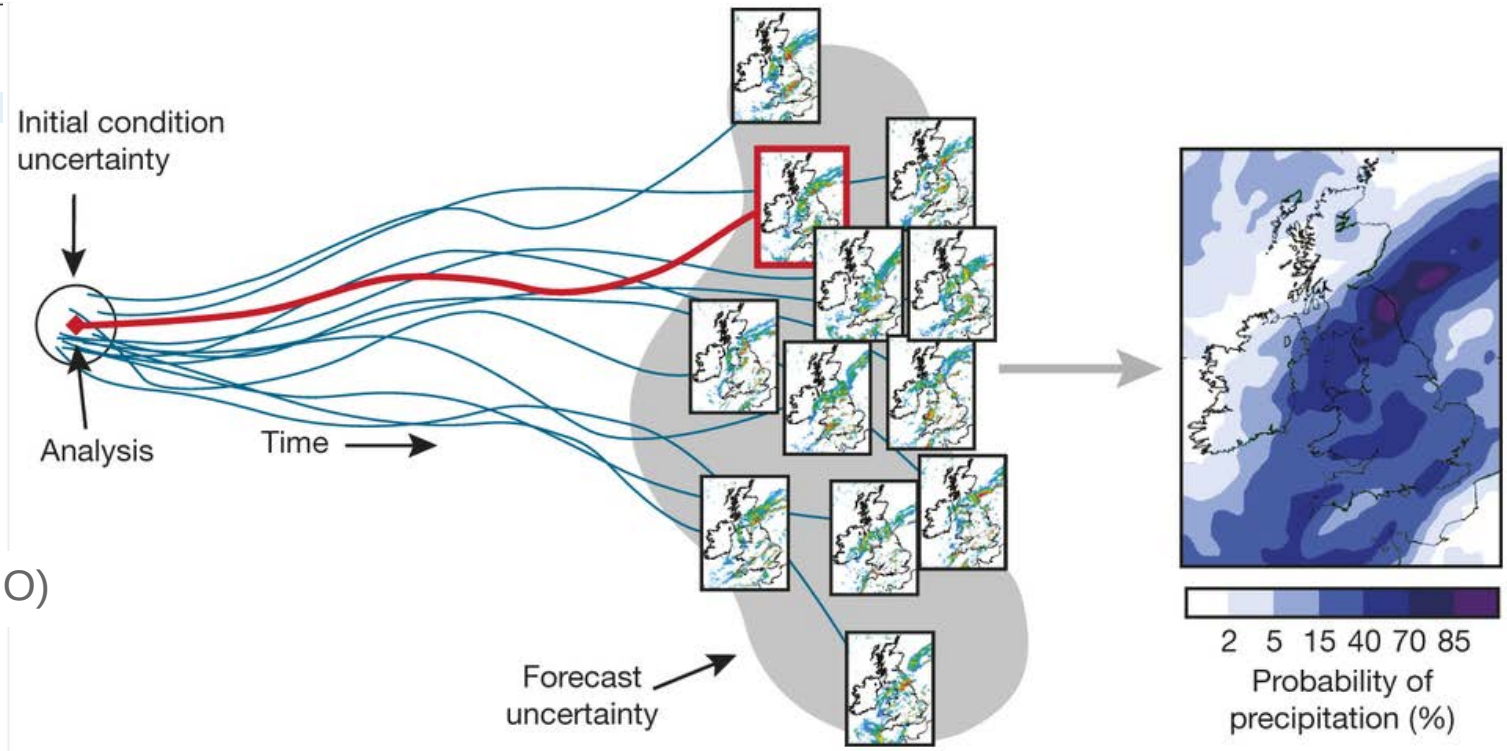
- OPS = Obs-processing
- VAR = DA step
- UM = model-forecast
- FG = First-Guess = Background
- *Analysis is now a blend of model and observations*

At this point we have established a good model to allow us to project forward in time, and a sound method to establish an initial-state to project forward from.

What could possibly be missing ……..

Intro to NWP – Uncertainty and Ensembles

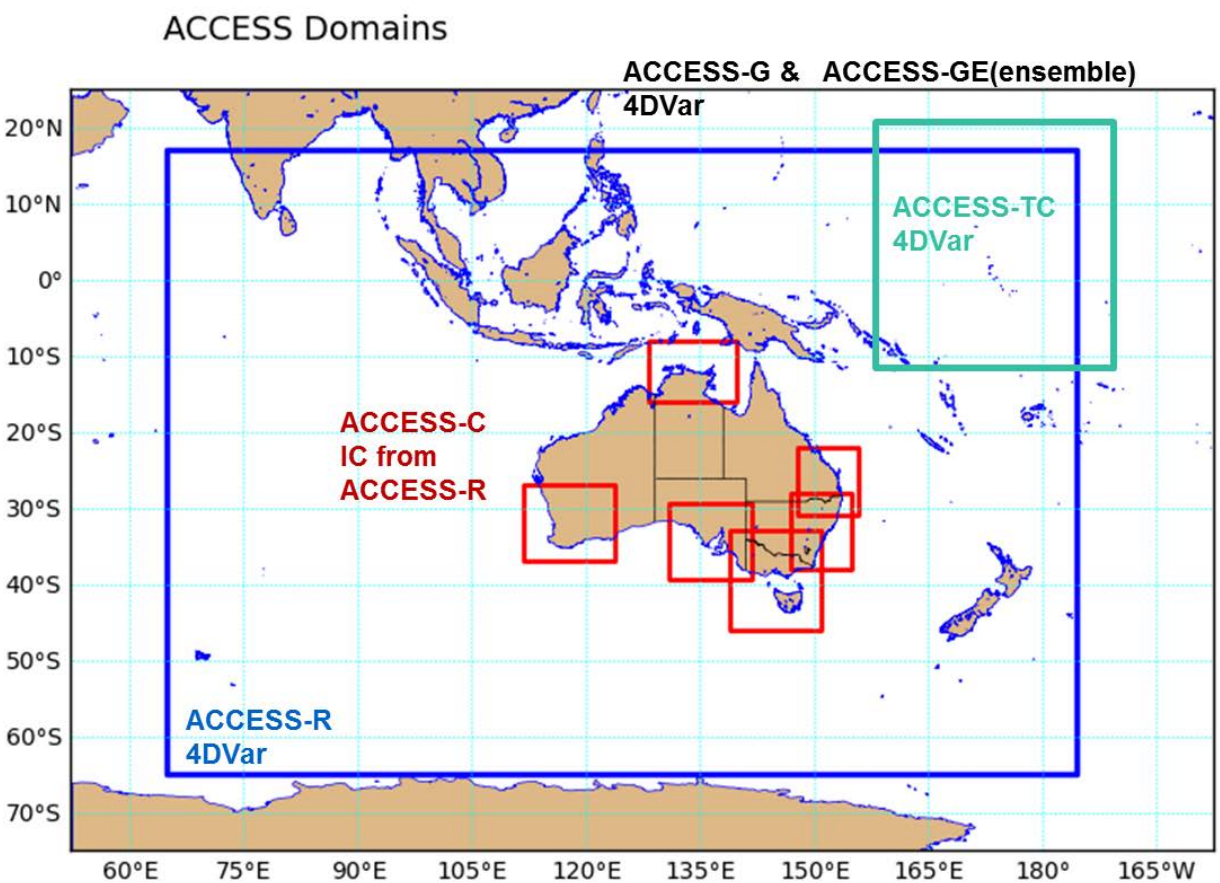
Australian Government
Bureau of Meteorology



(K. Mylne, UKMO)

- The famous "butterfly effect" – even *small* differences in the initial-state can grow into significant differences in the forecast.
- Varies in space & time.
- Running an *ensemble* of FCs off perturbed initial-conditions, enables us to forecast forecast-accuracy (useful information!) or forecast *probabilities*

BoM NWP – Suite Configuration



Grid size (km)

	APS1	APS2
G	40	25
R	12	12
TC	12	12
C	4	1.5

70 vertical levels

Even with a Super-Computer, forecast timeliness demands a balance between: FC-length, model-domain, and resolution

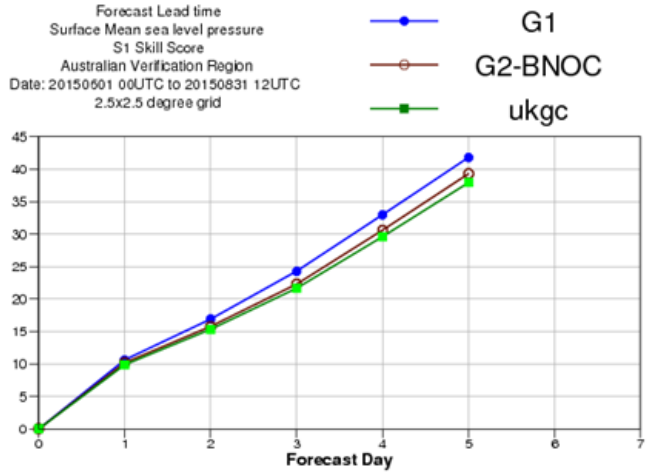
- "APS" = Australian Parallel Suite
- "G2" = ACCESS-**G**, in APS**2**
- Darwin domain in C2

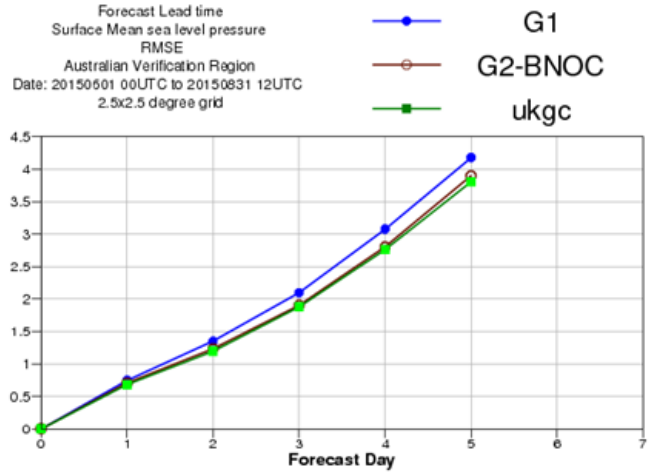
BoM NWP – APS2 Increased Observations

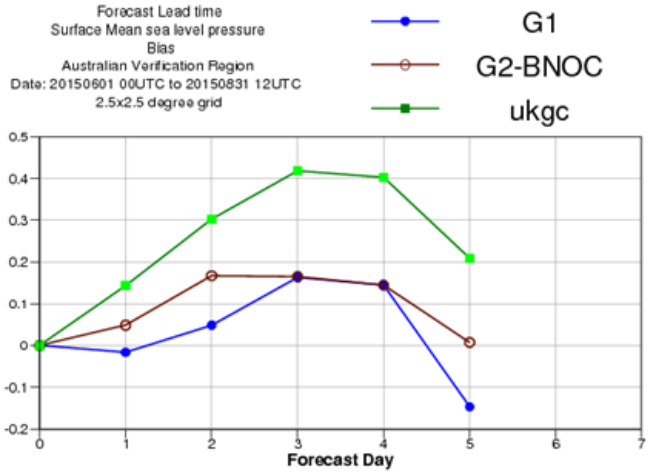
APS2	Surface: synops, ships, buoys Sondes, extra wind profilers Aircraft: AIREPS, AMDARS	
	Satellite observations (I) Wind: Scatterometer surface winds (ASCAT), AMVs from GEOS & POES GNSS-RO: bending angle observations	
	Satellite observations (II): IR and MW radiances **reduced thinning**	
	Platform	**Instrument**
	NOAA-18	AMSU-A/B
	NOAA-19	AMSU-A/B
	MetOp-A	AMSU-A/B + HIRS IASI (138 channels)
	MetOp-B	AMSU-A/B + HIRS IASI (138 channels)
	EOS: Aqua	AIRS (139 channels)
	Suomi-NPP	CrIS (134 channels) ATMS
	MTSAT-2 (Himawari-8)	Clear Sky Radiances

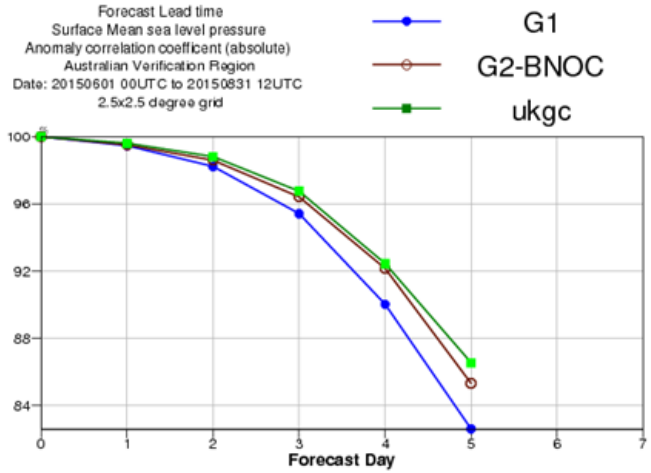
Australian Government
Bureau of Meteorology

BoM NWP – APS2 ACCESS-G Verification









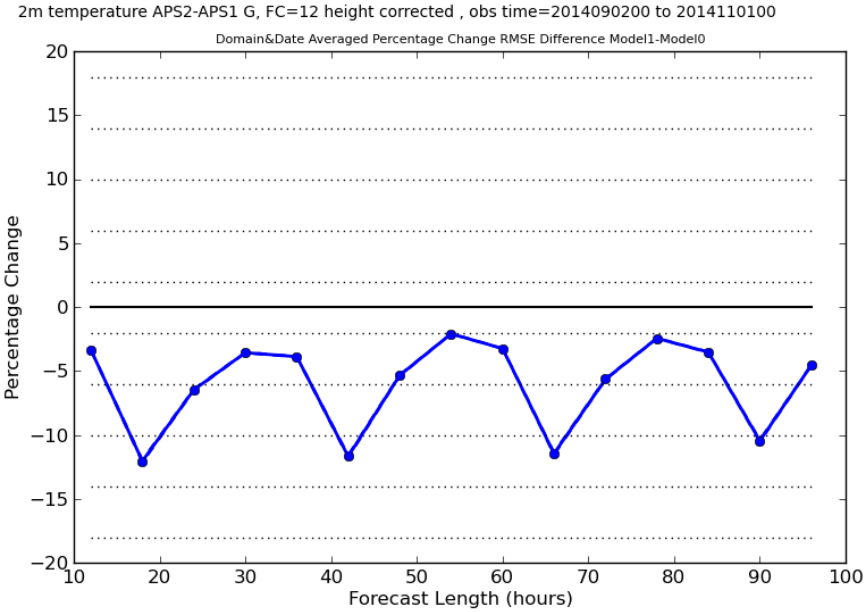
- Aust-region
- Winter
- MSLP
- Verif against own analysis

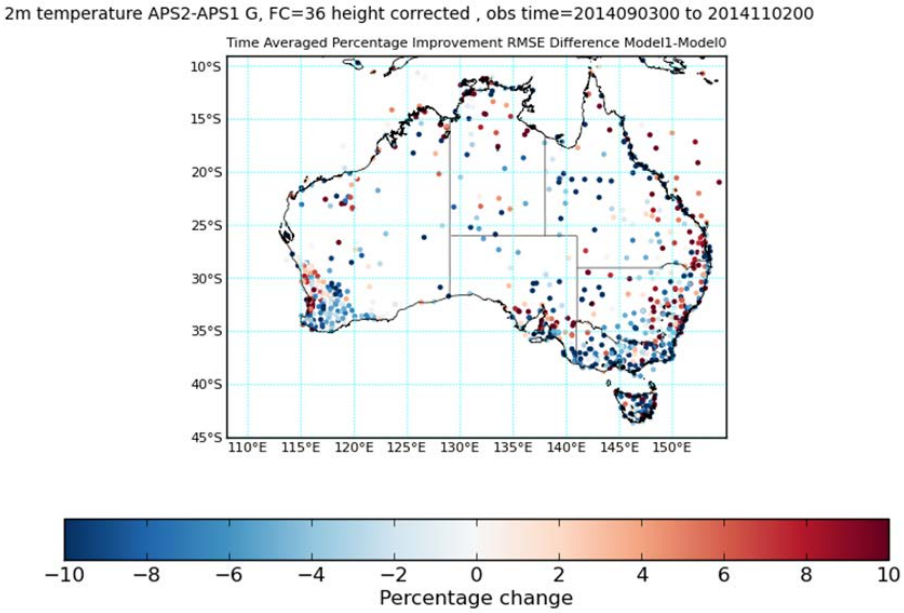
- Comparable to UKMO
- G2 provides 6-8 hours more lead-time than G1

BoM NWP – Performance of APS2 ACCESS-G

Caveats:

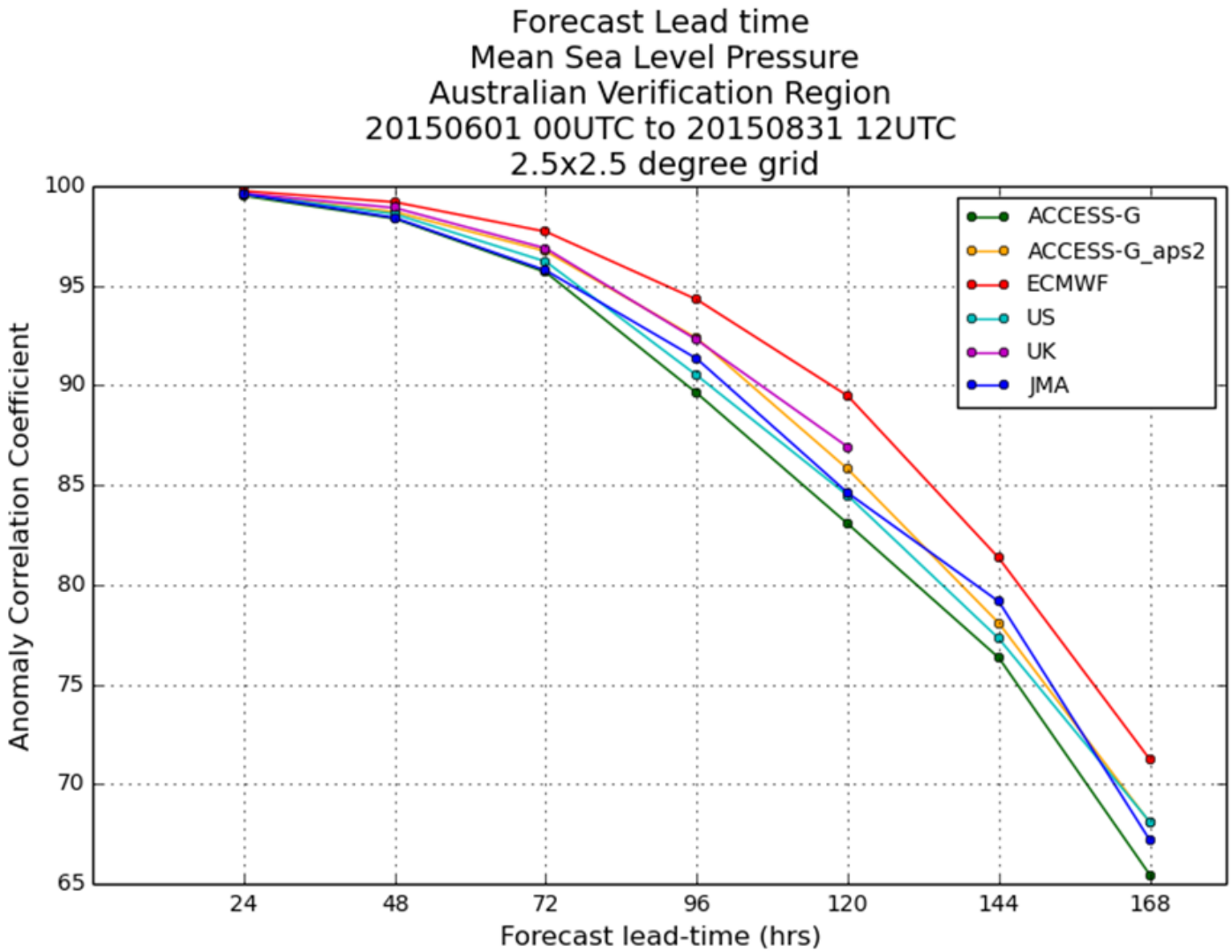
- In summer, G1, G2, UKMO are very similar.
- Tropical performance of G2 is arguably worse *but*,
  - Tropical analyses are not as reliable as mid-latitude
  - Australian *surface-obs* verif is very positive
    - (Spring, G2 – G1 error, ie., *negative* is better, G2 much better at forecasting T-max)





BoM NWP – APS2 ACCESS-G Verification

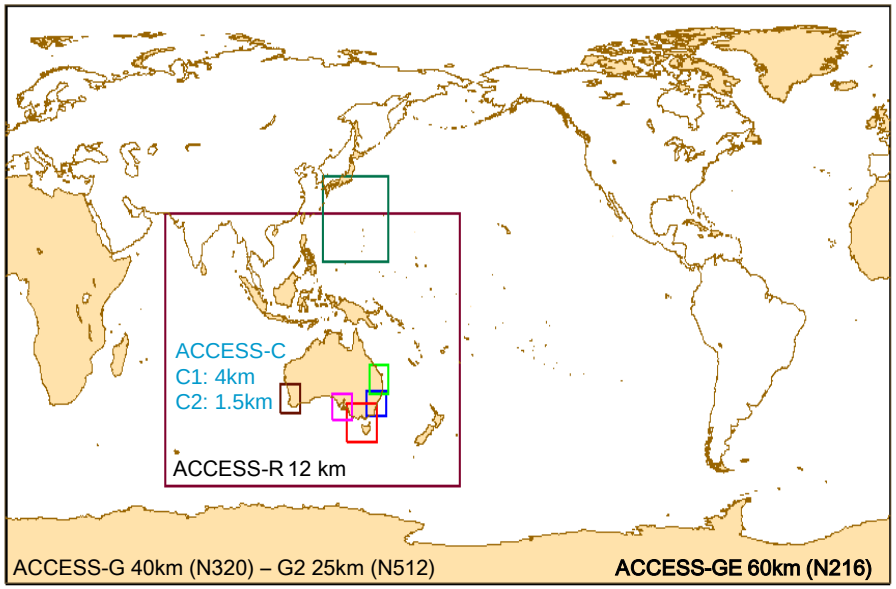
International Comparison: G1, G2, ECMWF, UKMO, US, JMA



BoM NWP – Global Ensemble, "GE2"

24-member ensemble designed for medium-range forecasting

- Based on UKMO MOGREPS
- Global ensemble to 10 days
- Global ETKF for initial condition perts
- *Stochastic model perturbations*



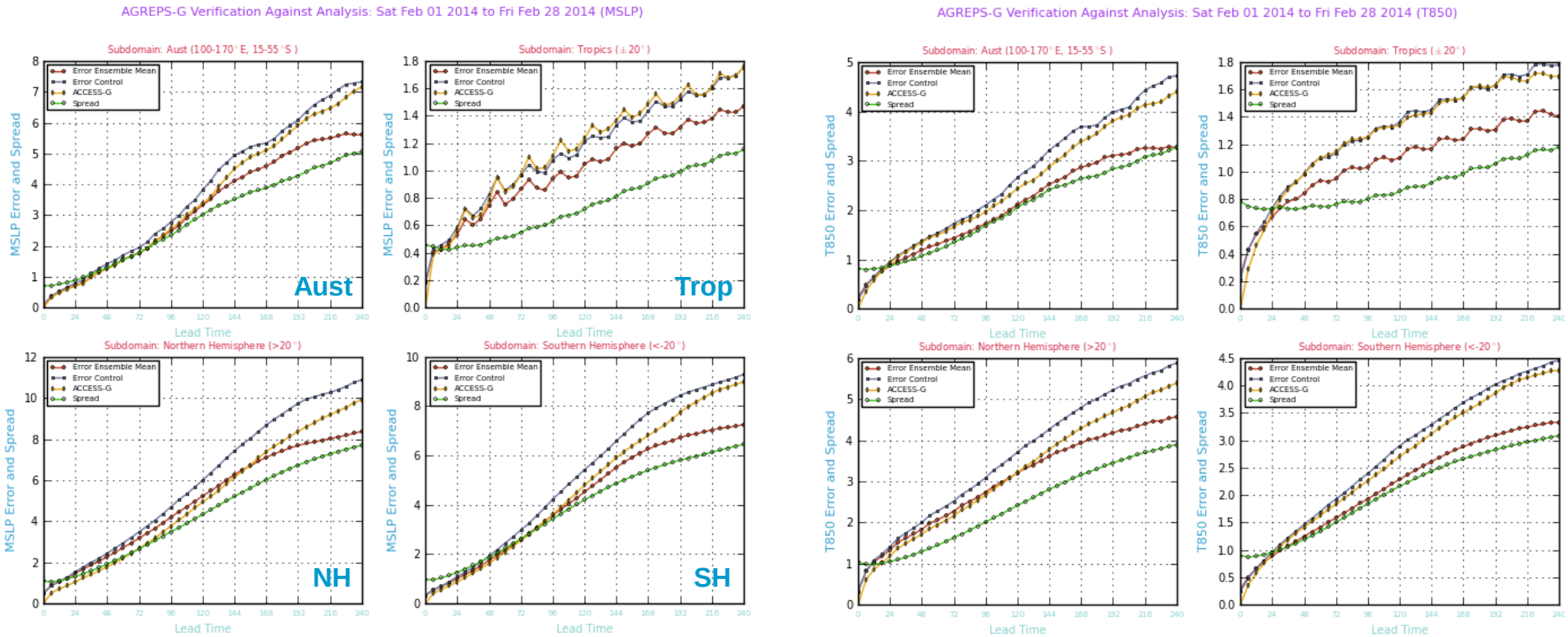
Currently running 12Z daily at 60 km, 70 levels (N216L70)

Scheduled for "limited" (mostly in terms of products) operational implementation in APS2.

Australian Government
Bureau of Meteorology

BoM NWP – GE2 Verification

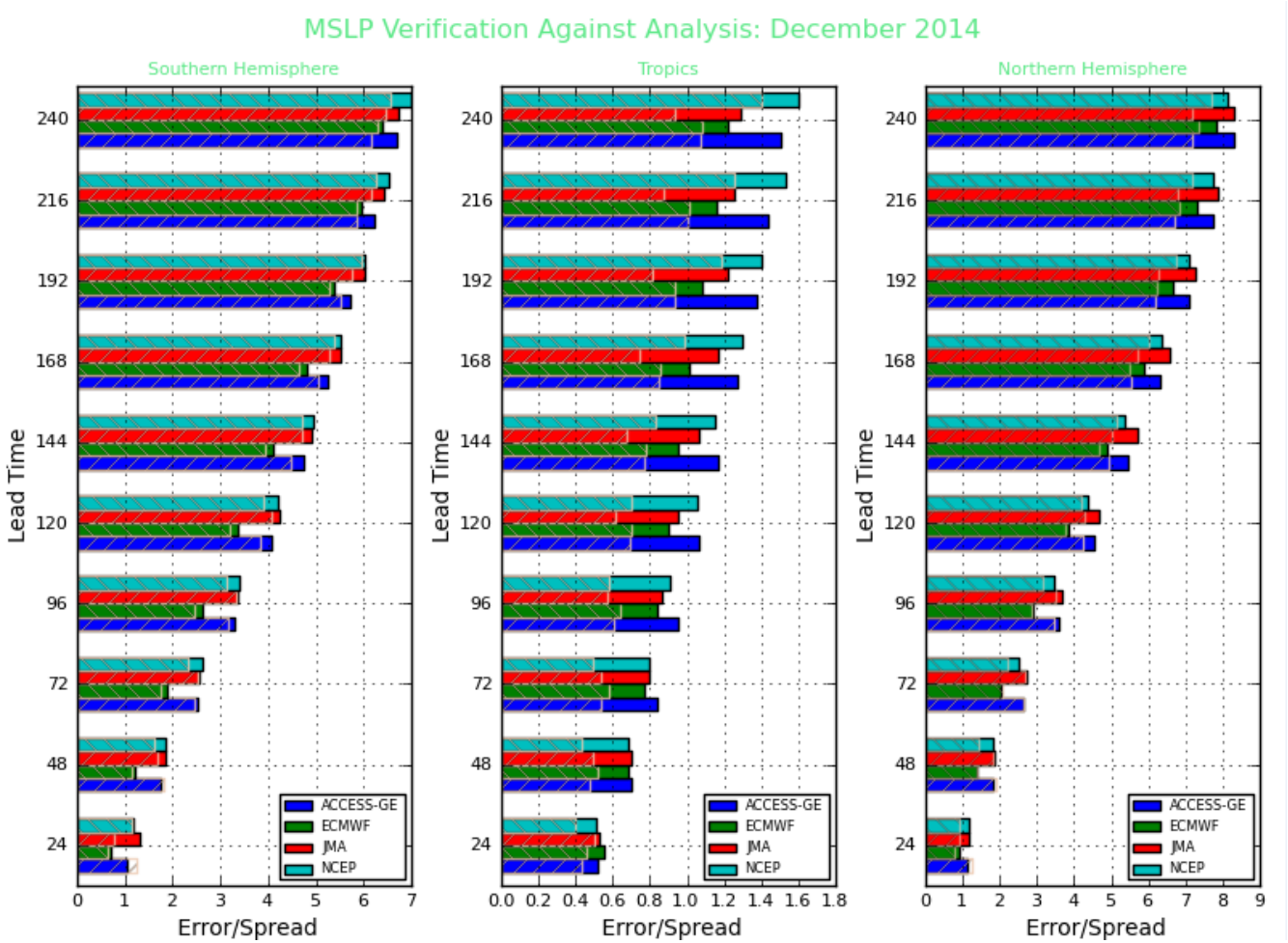
MSLP **T850**



- ACCESS-G
- E-Control
- E-Mean
- E-Spread

Ensemble mean skill better than deterministic ACCESS-G after first couple/few days

BoM NWP – GE2 Verification

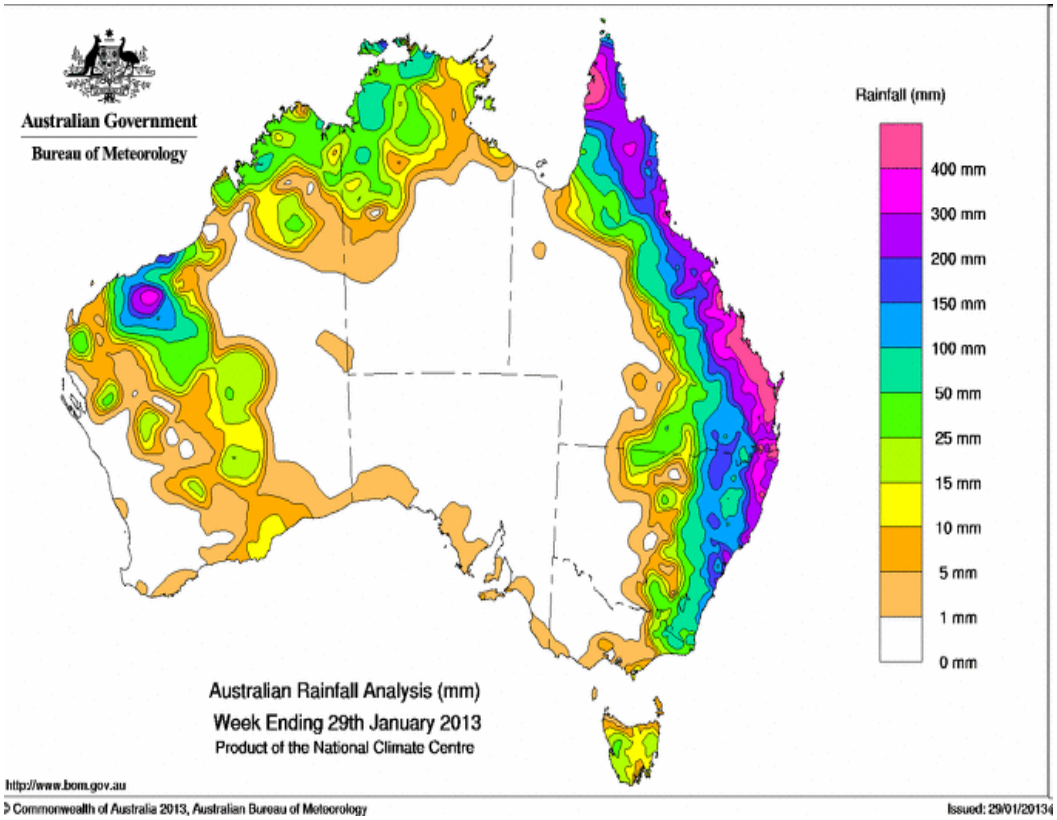


SHEM TROP NHEM

ACCESS-GE
ECMWF
JMA
NCEP

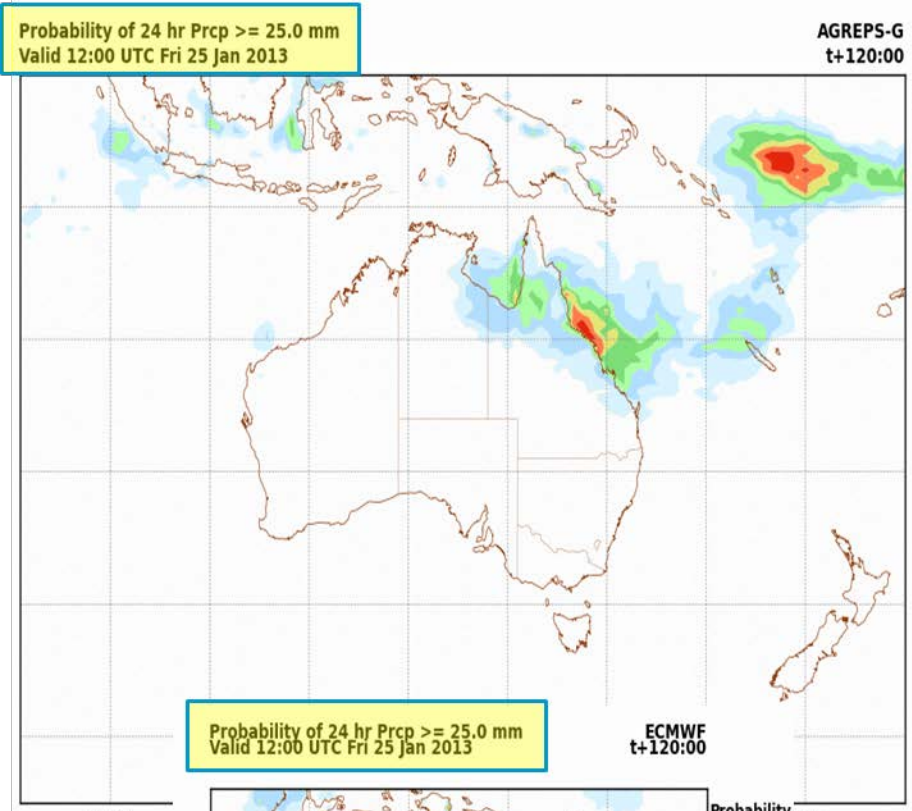
MSLP
December 2014

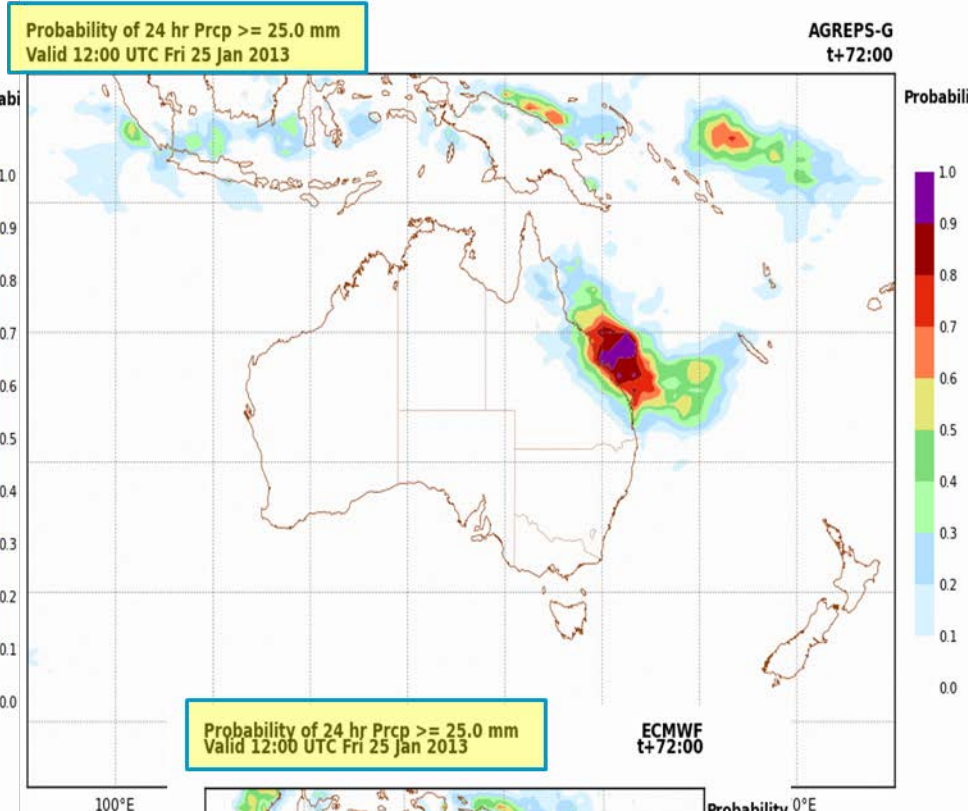
BoM NWP – GE2 case-study ex-TC Oswald

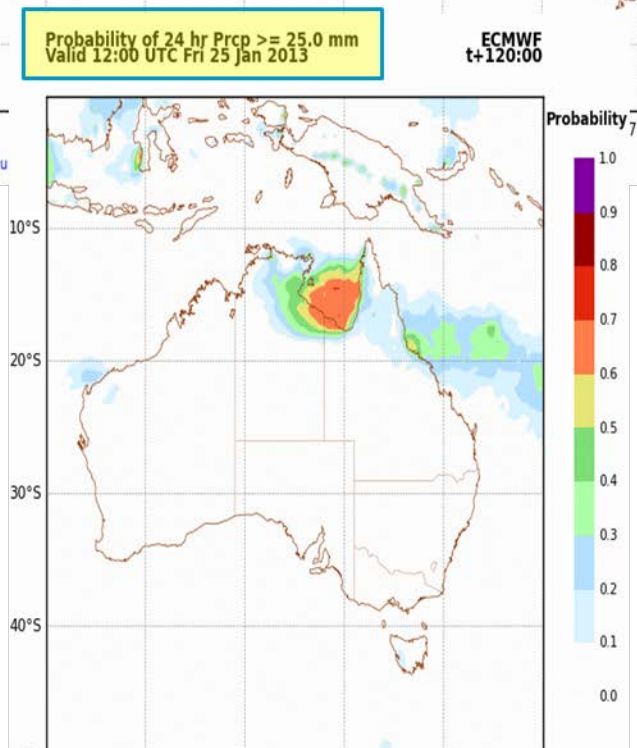


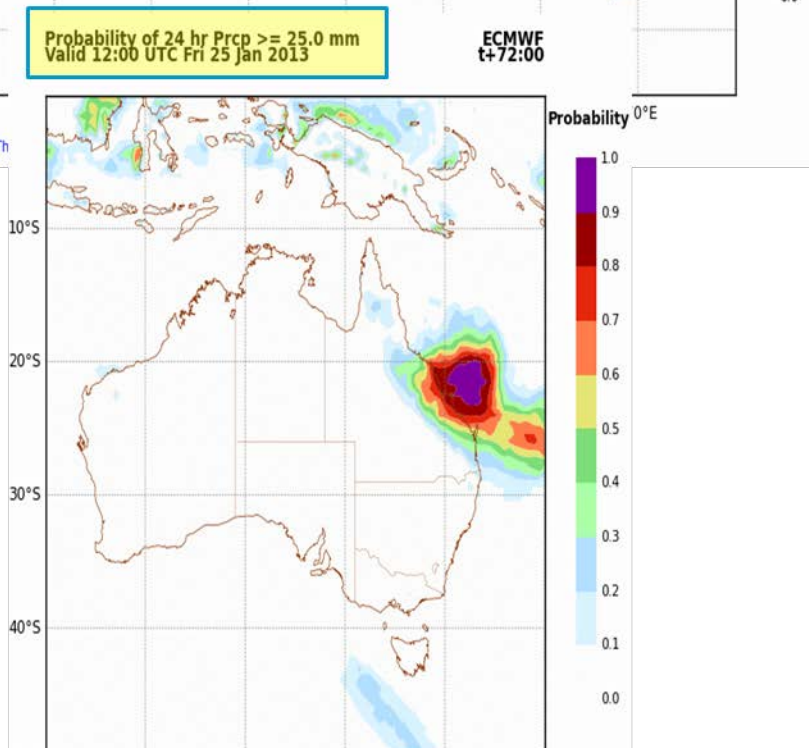
This event followed the monsoon onset in mid-January. TC Oswald formed in the western part of Gulf of Carpentaria around 20 January. It existed briefly as TC until it made landfall and moved across the Cape York peninsula as a tropical low.

Ex-TC Oswald then progressed over the following week down the Queensland coast and through to the northern NSW as far as the Sydney region, before moving off to the east on 29 January.


Probability of 24 hr Prcp >= 25.0 mm
Valid 12:00 UTC Fri 25 Jan 2013
AGREPS-G
t+120:00
Probabi
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100°E
Plot produced at UTC Thu

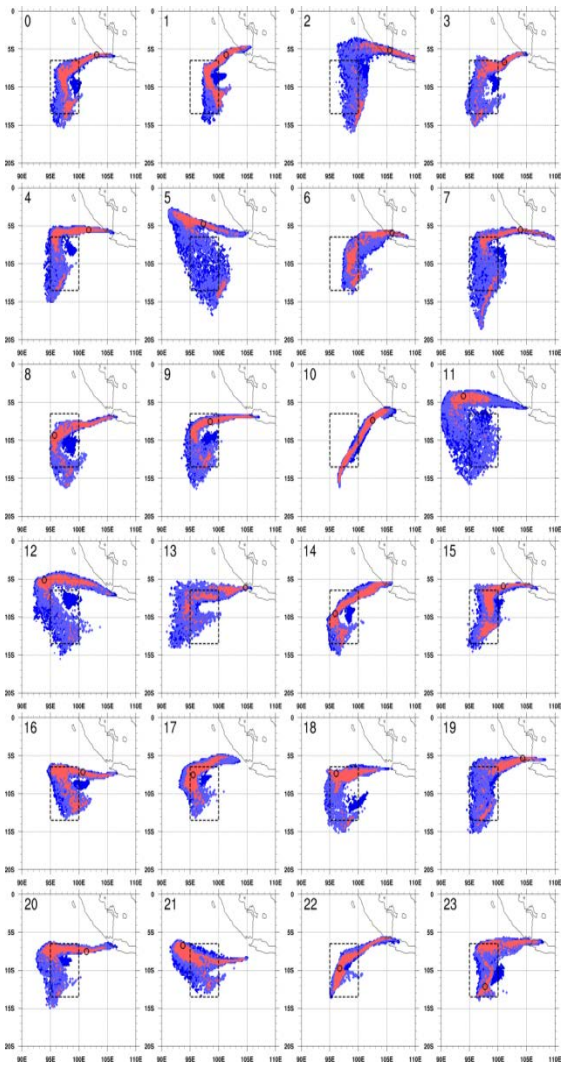

Probability of 24 hr Prcp >= 25.0 mm
Valid 12:00 UTC Fri 25 Jan 2013
AGREPS-G
t+72:00
Probabili
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100°E
Plot produced at UTC Th


Probability of 24 hr Prcp >= 25.0 mm
Valid 12:00 UTC Fri 25 Jan 2013
ECMWF
t+120:00
Probability
70°E
10°S
20°S
30°S
40°S
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


Probability of 24 hr Prcp >= 25.0 mm
Valid 12:00 UTC Fri 25 Jan 2013
ECMWF
t+72:00
Probability
0°E
10°S
20°S
30°S
40°S
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

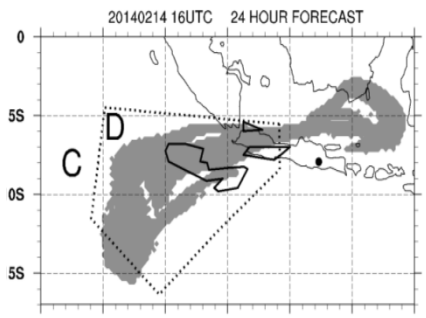
Australian Government
Bureau of Meteorology

BoM NWP – GE2 application example

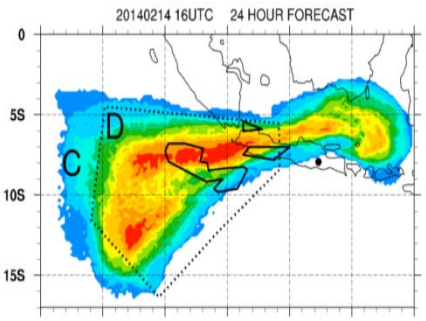


Volcanic ash dispersion

- HYSPLIT dispersion model run from 24 ACCESS-GE ensemble members



Single control member



Ensemble probability

Individual member 24-hour forecasts of ash concentration in the 10-15 km layer.

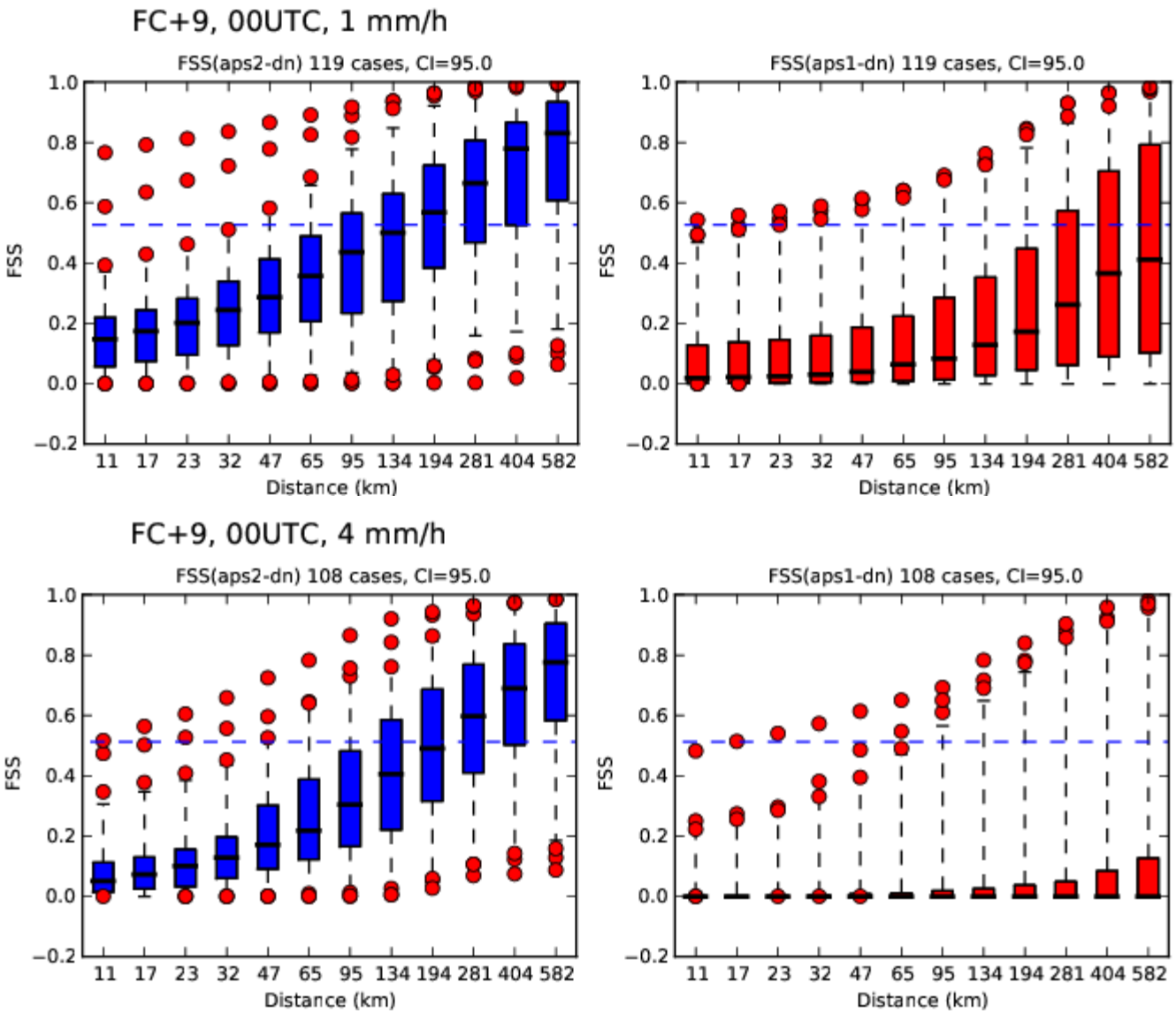
Courtesy Richard Dare

Australian Government
Bureau of Meteorology

BoM NWP – C2 (City) Upgrade Intro

- Inclusion of Darwin domain
- Upgraded components (UM, etc)
- Large increase in resolution (4.0km -> 1.5km), allows us to *drop the grid-cell-bound convection-parameterisation* – model now runs in "convection-permitting" mode
- *Like C1, remains a down-scaler only* – no DA of its own

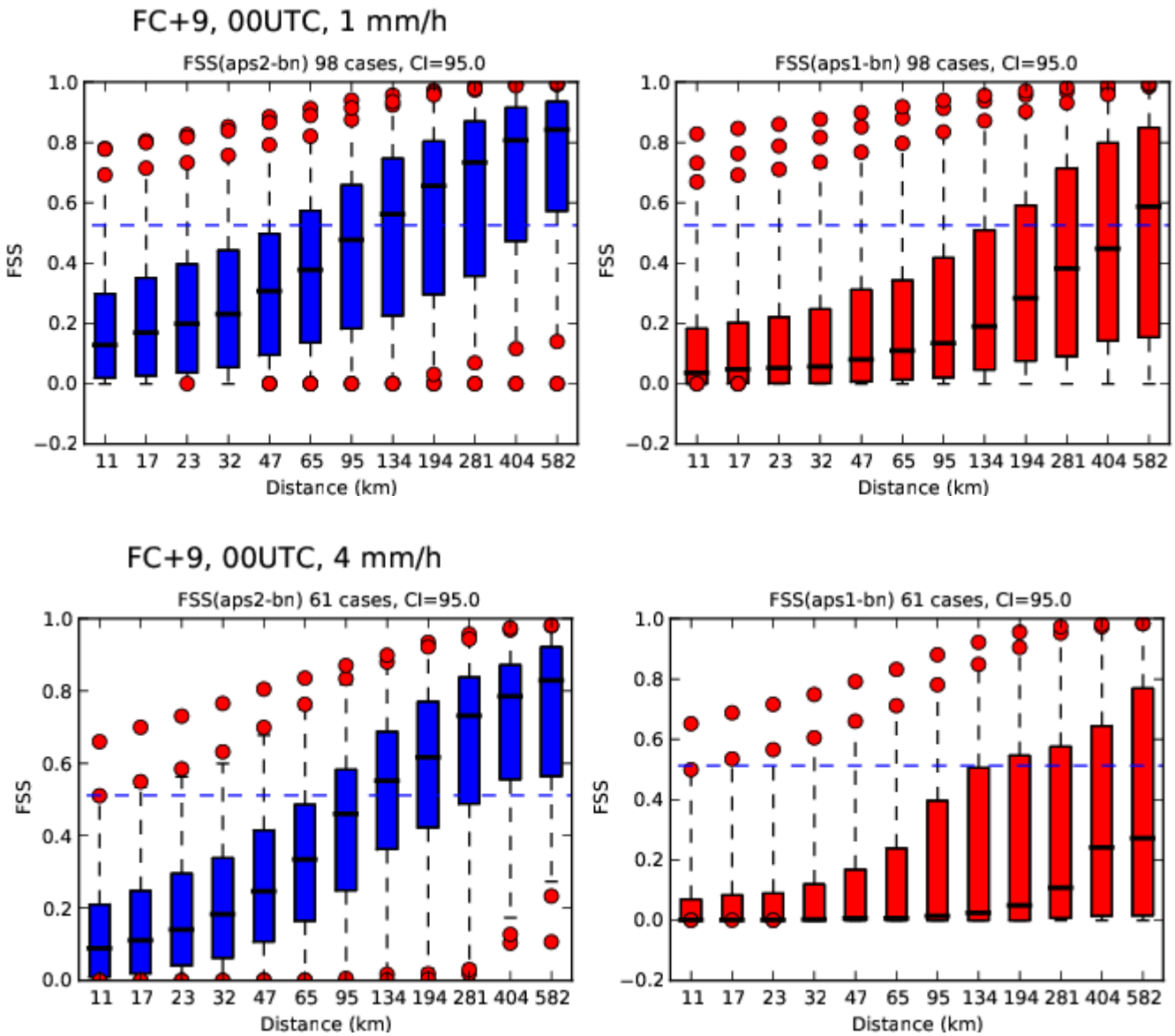
BoM NWP – C2 Darwin Precip Stats



(Focussing on 00Z run to capture initiation)

C2 – left
C1 – right
Light-rain: top
Heavy-rain: bottom

BoM NWP – C2 Brisbane Precip Stats



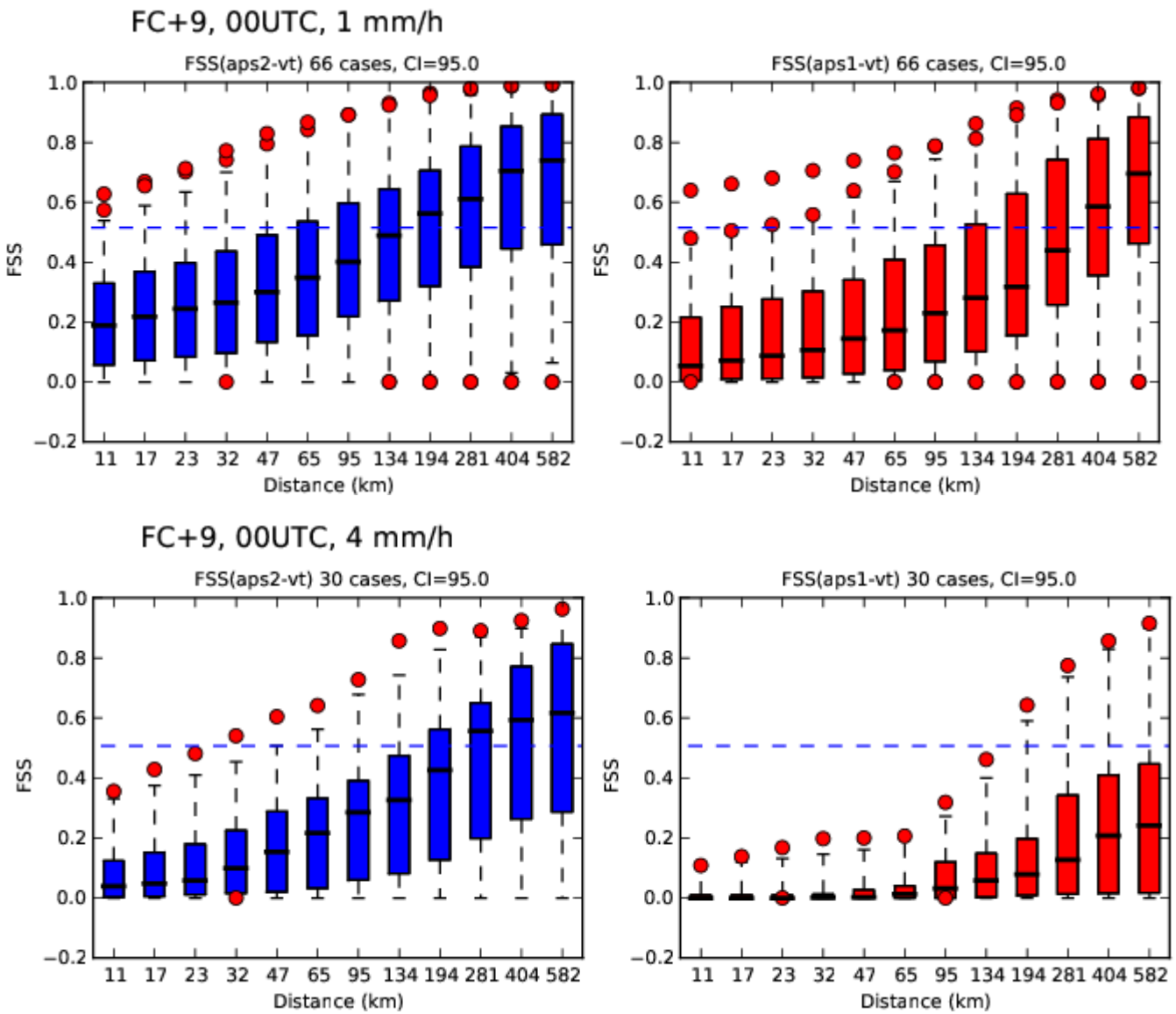
C2 – left

C1 – right

Light-rain: top

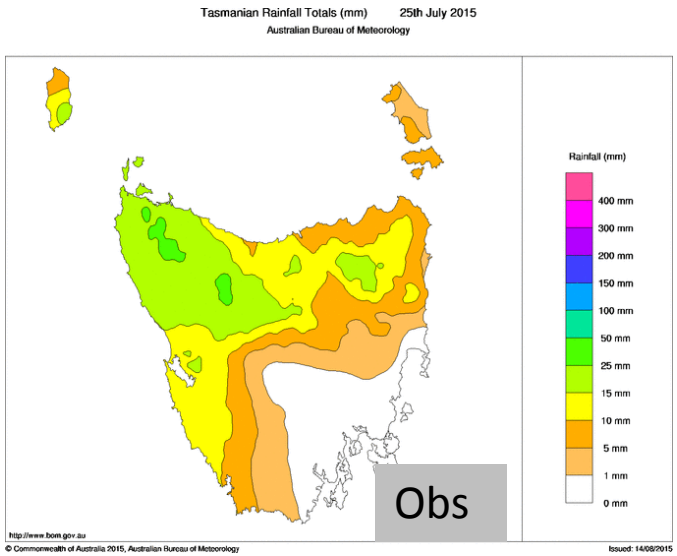
Heavy-rain: bottom

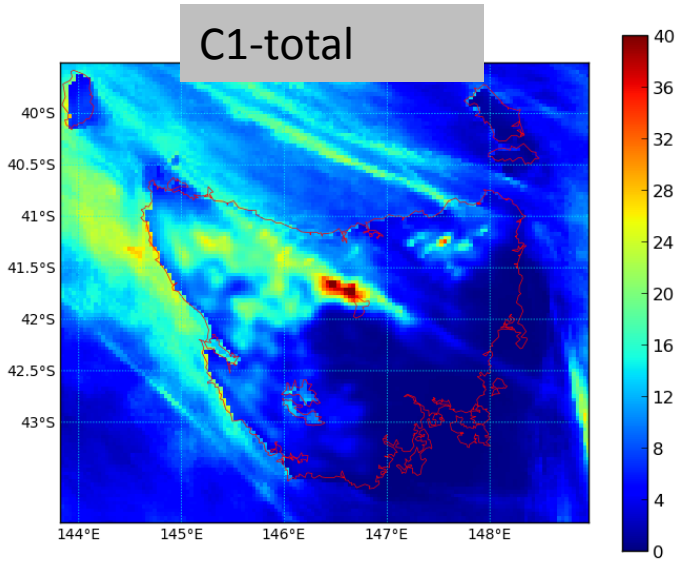
BoM NWP – C2 VicTas Precip Stats



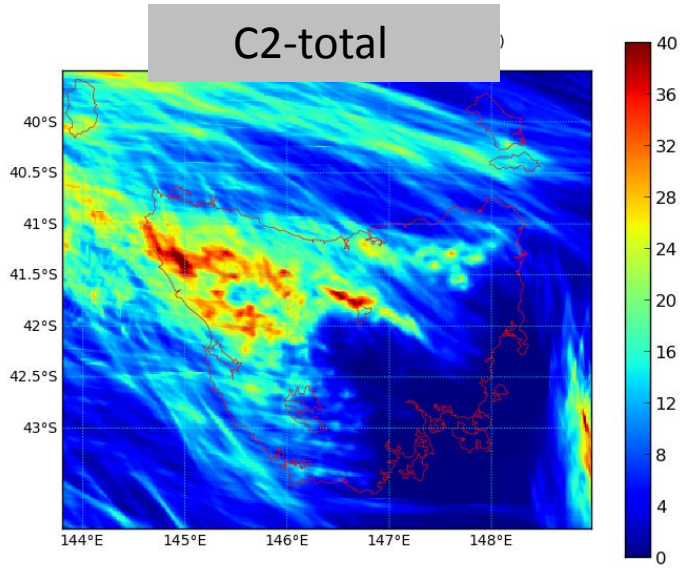
C2 – left
C1 – right
Light-rain: top
Heavy-rain: bottom

BoM NWP – C1 rain "coastal locking"





(Jul-25, 2015: 24 hrc FC)



BoM NWP – Extreme rain event: Darwin, Nov-4 2013

105.7 ABC Darwin ▸ visit another location

Home | Programs | News | Weather | Emergencies | Sport | Events | Promotions | Recipes | Photos & Videos

Rainfall records tumble in dark and stormy night

Print page Email this Permalink Share

Updated November 05, 2013 16:50:49

The weather bureau says a storm that hit Darwin last night was record breaking.

The bureau says six sites across the Top End broke 24-hour November rainfall records overnight.

At Darwin Airport, 105 mm of rain was recorded, the most in 73 years.

The highest recorded fall was at Stokes Hill Wharf in the city, with 117mm.

Forecaster Dave Matthews says the downpour left water over the road at several places near Rapid Creek.

An electrical storm accompanied the downpour but there were no reports of damage.

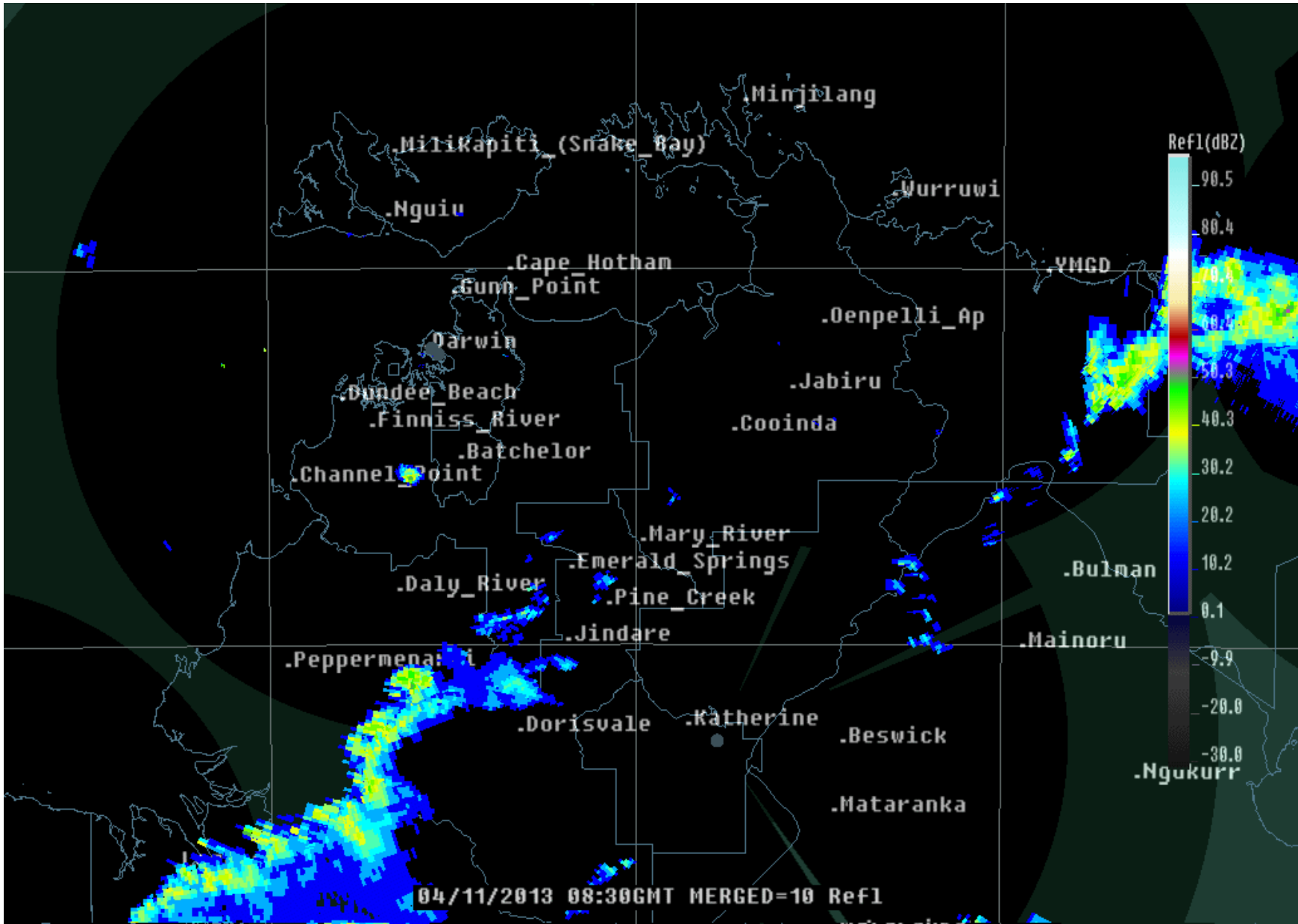
Map: Darwin

An electrical storm accompanied the downpour but there were no reports of damage.

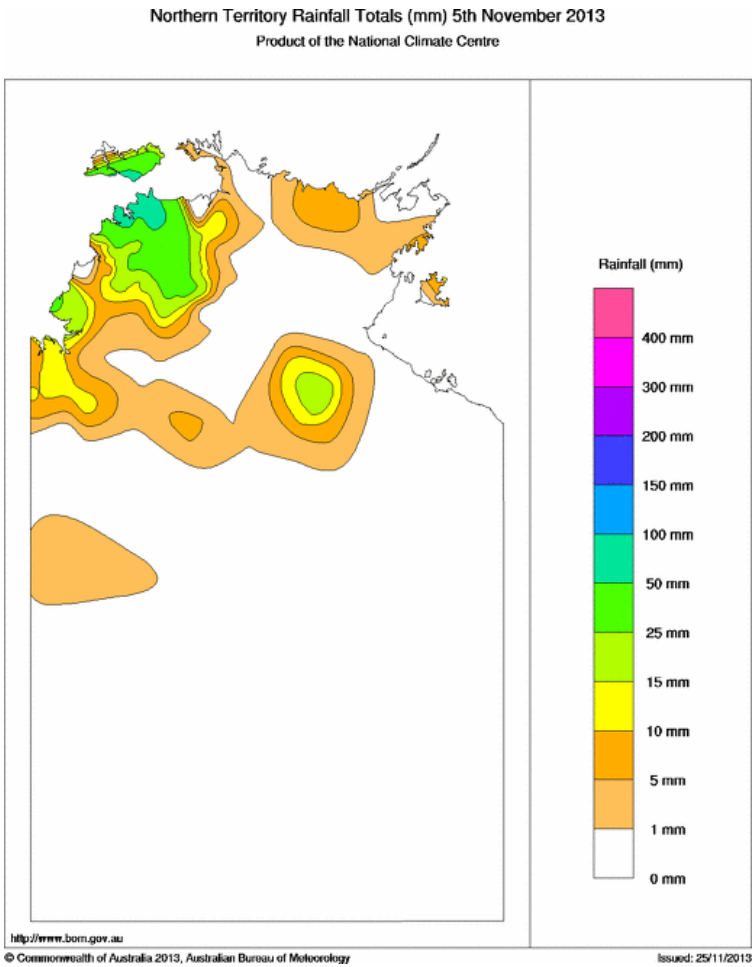
BoM NWP – Extreme rain event: Darwin, Nov-4 2013

12-hr

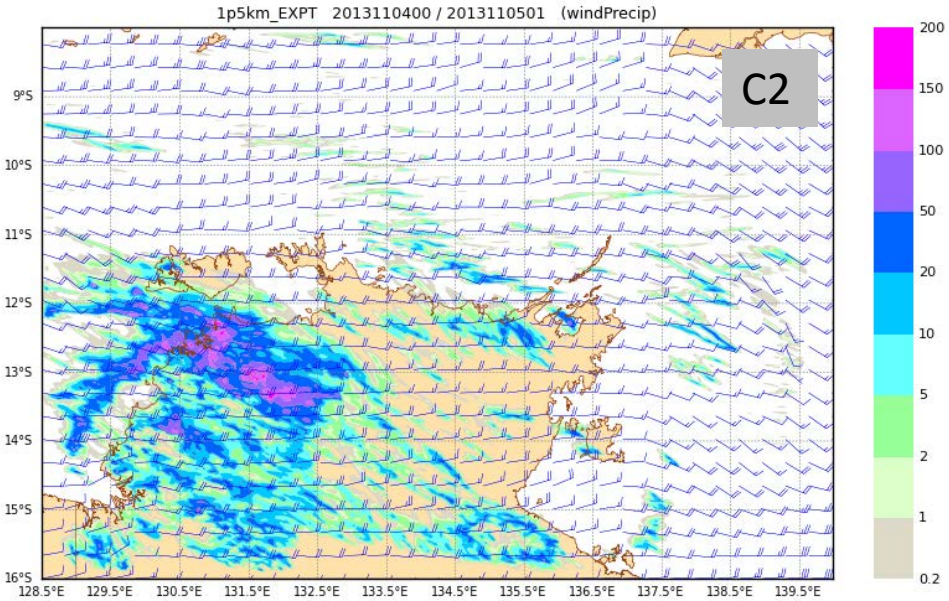
Start:
7:00pm

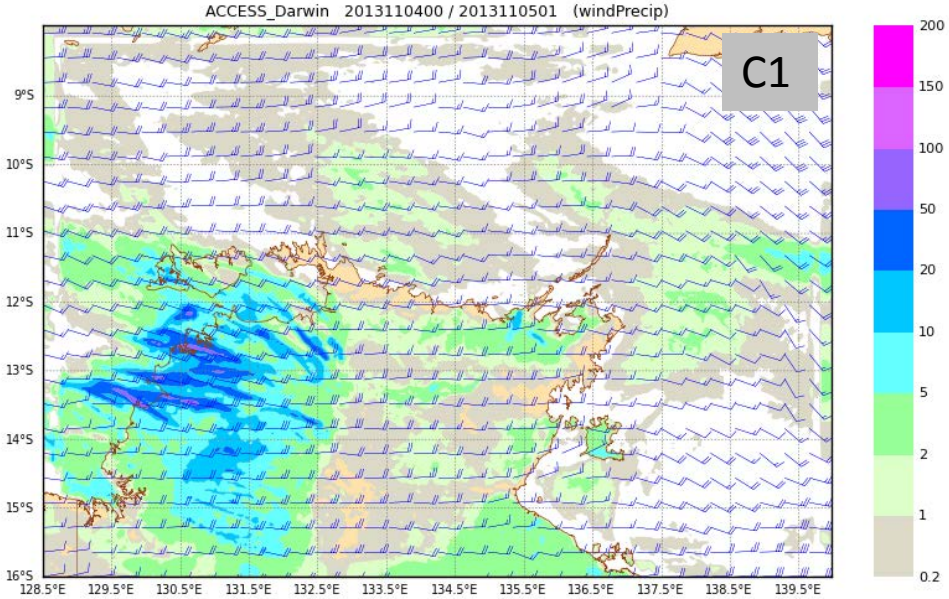


BoM NWP – Extreme rain event: Darwin, Nov-4 2013

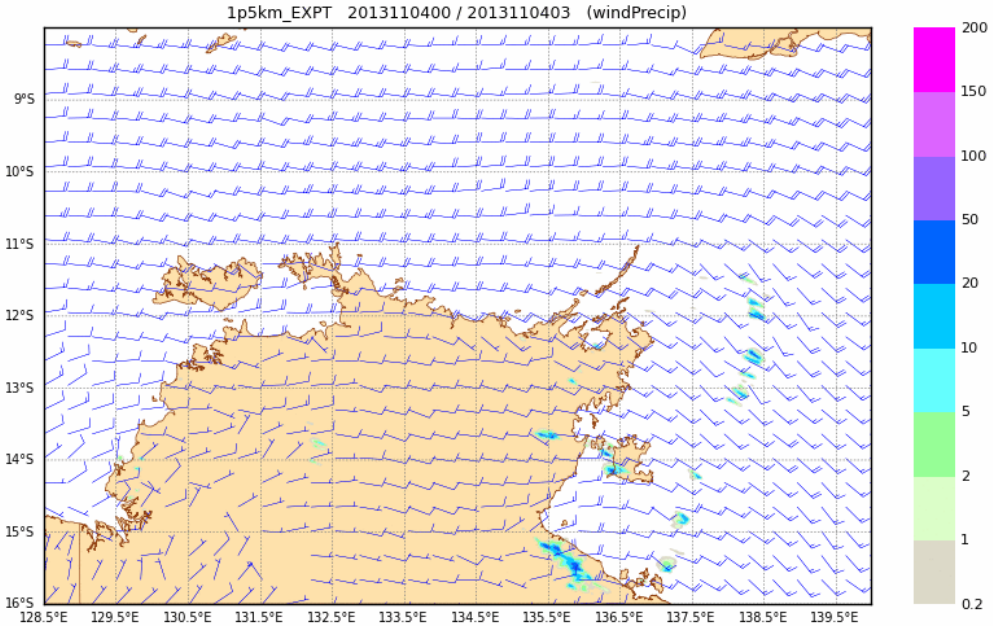


24 Hr accum





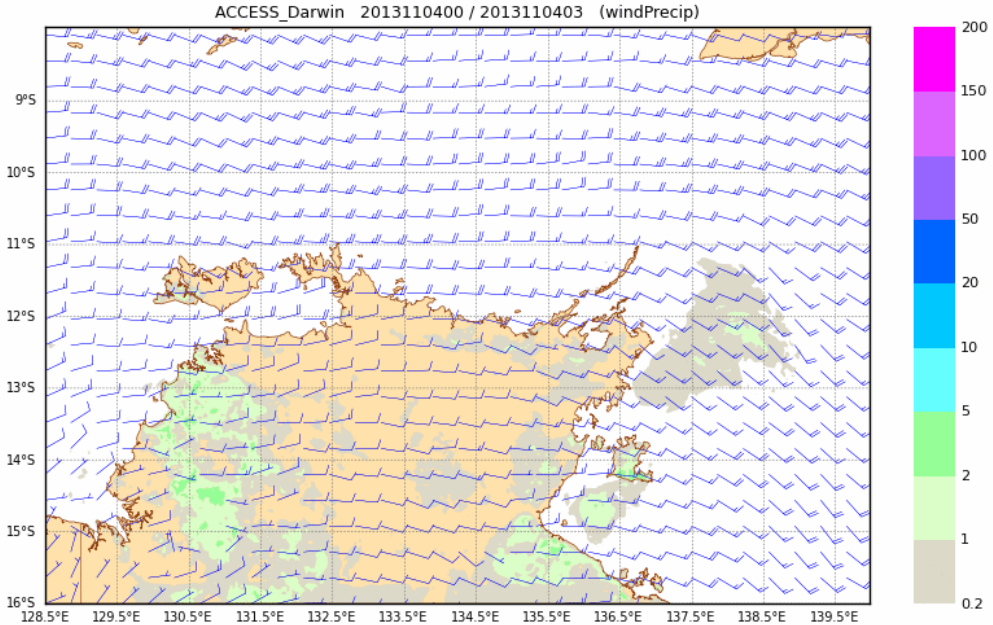
C2



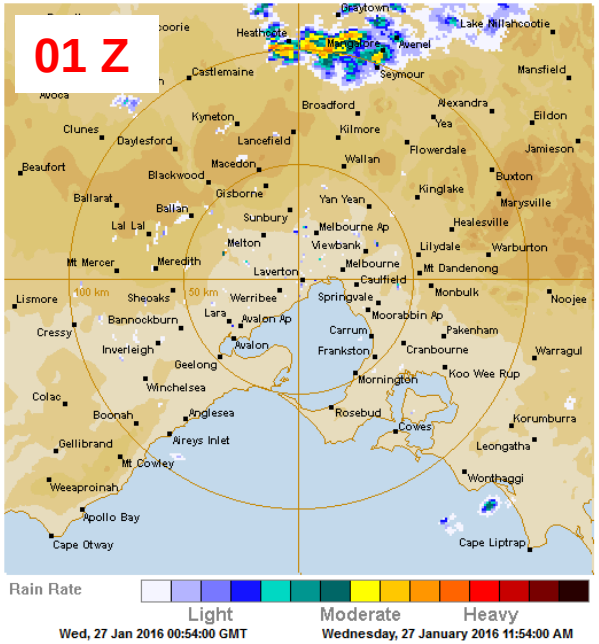
33-hr

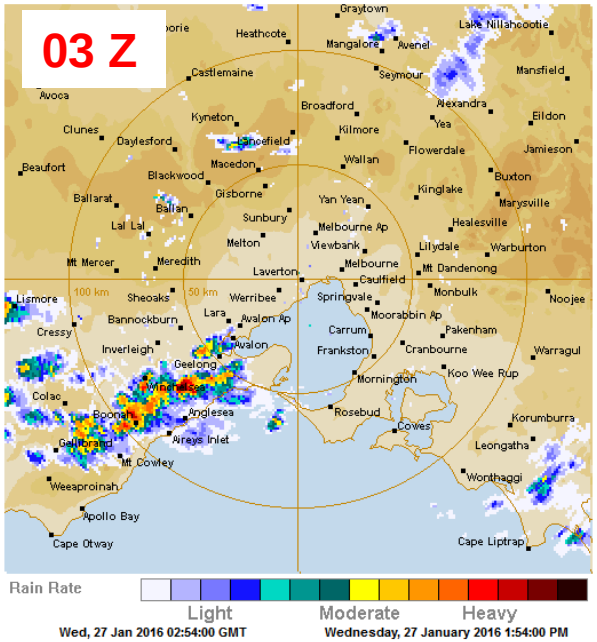
Start:
1:30 pm

C1

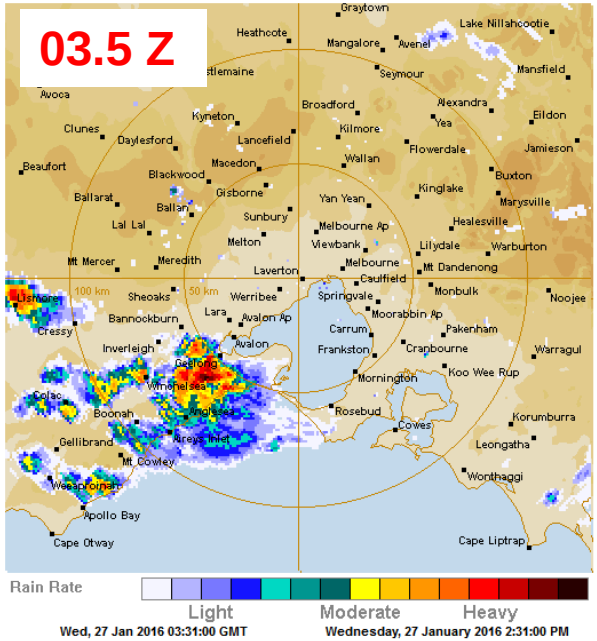


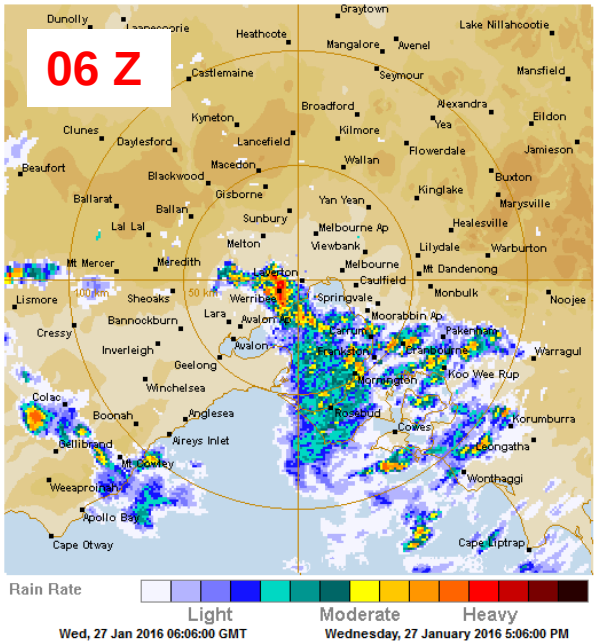
BoM NWP – Geelong Storm, Jan-27 2016





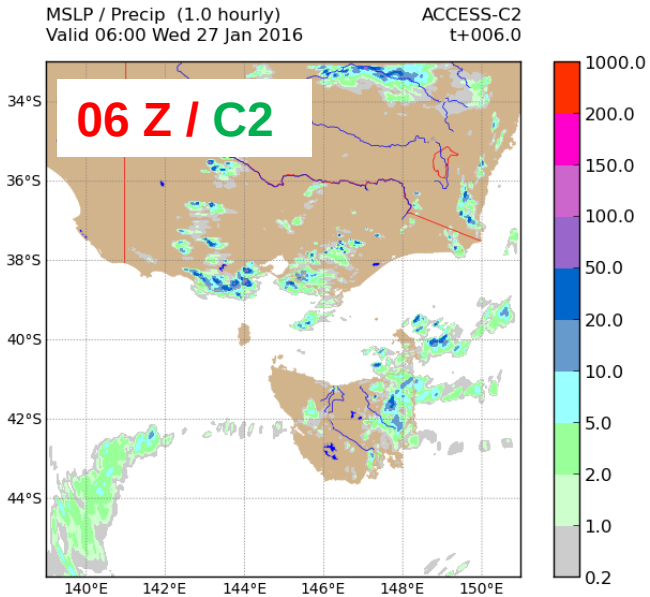
Melbourne Radar

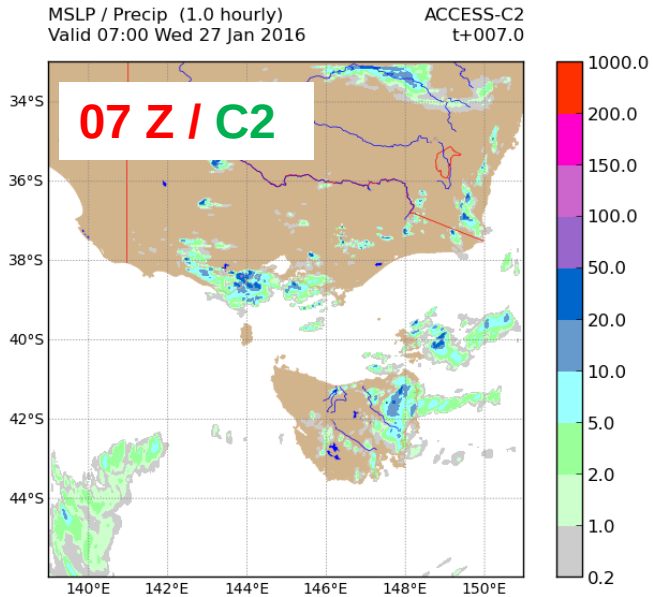




- 01 Z – Geelong region quiet
- 03 Z – Convection along coastline to SW of Geelong
- 03.5 Z – Consolidation, approaching Geelong
- 06 Z – Subsequent propagation to NE

BoM NWP – Geelong Storm, Jan-27 2016

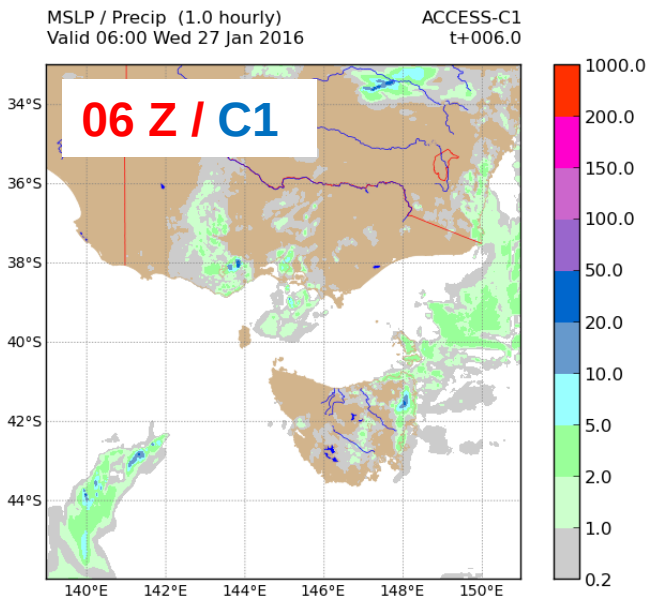


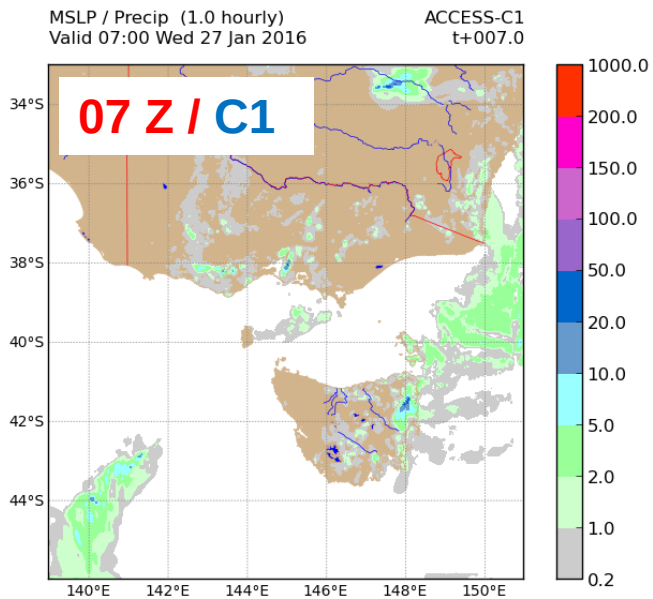


ACCESS-C

Geelong Storm, Jan-27 2016

Delayed timing – but this is forecast-only, no DA





Operational ("C1", 4.5km, param), against APS2 ("C2", 1.5km, conv-perm)

Australian Government
Bureau of Meteorology

BoM NWP – Timelines and Future

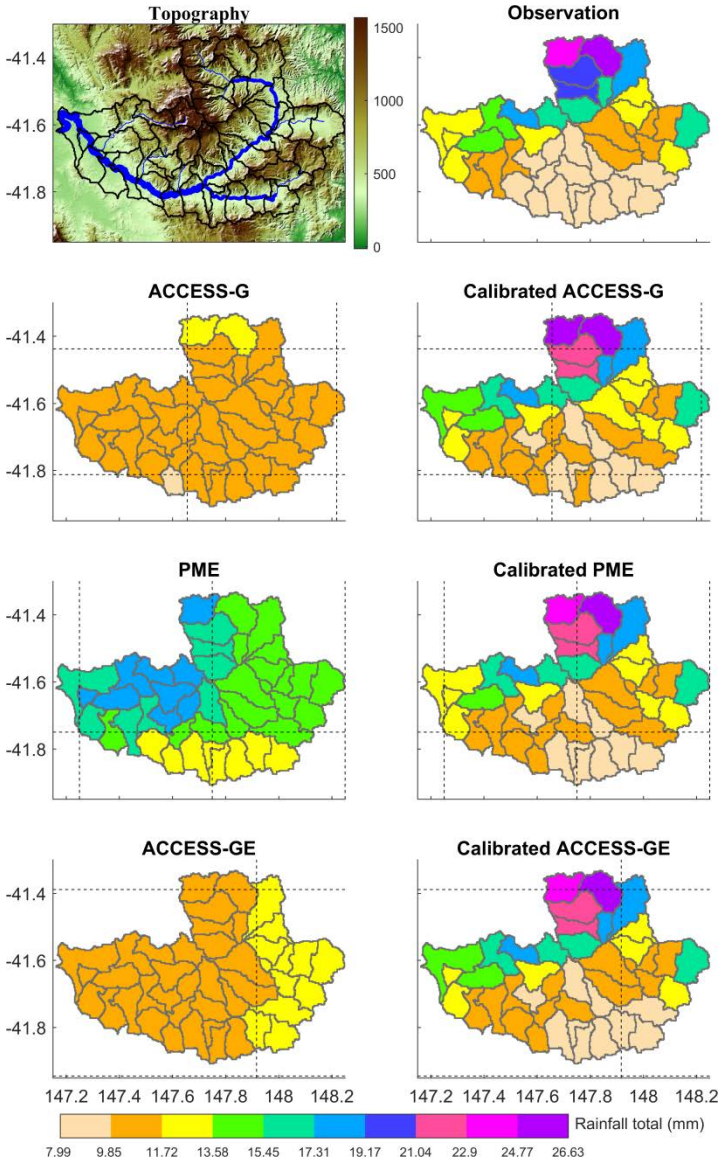
DRAFT ONLY

	APS-2	APS-3' (Opern: Mid-2018)	APS-4' (Opern: End-2020)
ACCESS-G	25km {4dV}	12km {4dVH}	12km {4dVH/En}
ACCESS-R	12km {4dV}	8km {4dVH}	4.5km {4dVH/En}
ACCESS-TC	12km {4dV}	4.5km {4dVH}	4.5km {4dVH}
ACCESS-GE	60km (lim)	30km	30km
ACCESS-C	1.5km {FC}	1.5km {4dVH}	1.5km {4dVH/En}
ACCESS-CE	-	2.2km (lim)	1.5km
ACCESS-X	-	1.5km {4dVH}	1.5km {4dVH/En}
ACCESS-XE	-	-	1.5km

- Need to constantly upgrade NWP to remain world-competitive
- Improved DA ("hybrid-VAR") for APS3+ - requires ensembles
- C3 includes RUC with radar-DA (*ala* SREP)
- City-ensembles (CE3) in APS3
- Flexible domain, "on-demand" systems – X and XE

Australian Government
Bureau of Meteorology

NWP & Streamflow – large-scale



David Robertson – CSIRO/WIRADA

The horizontal resolutions of NWP models are too coarse to resolve the small scale catchment variability

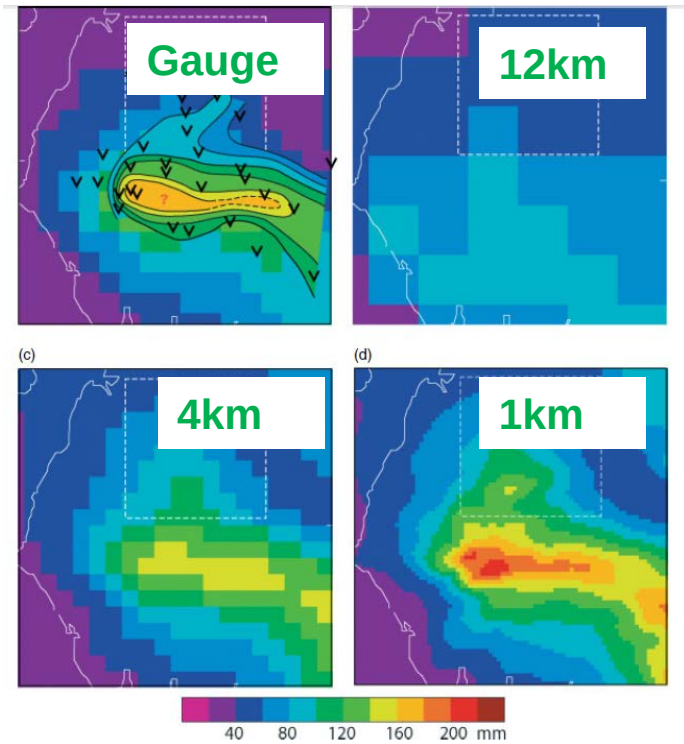
The post-processing is able to reproduce the spatial variation in mean rainfall

Rainfall total for
period 12 h to 216 h

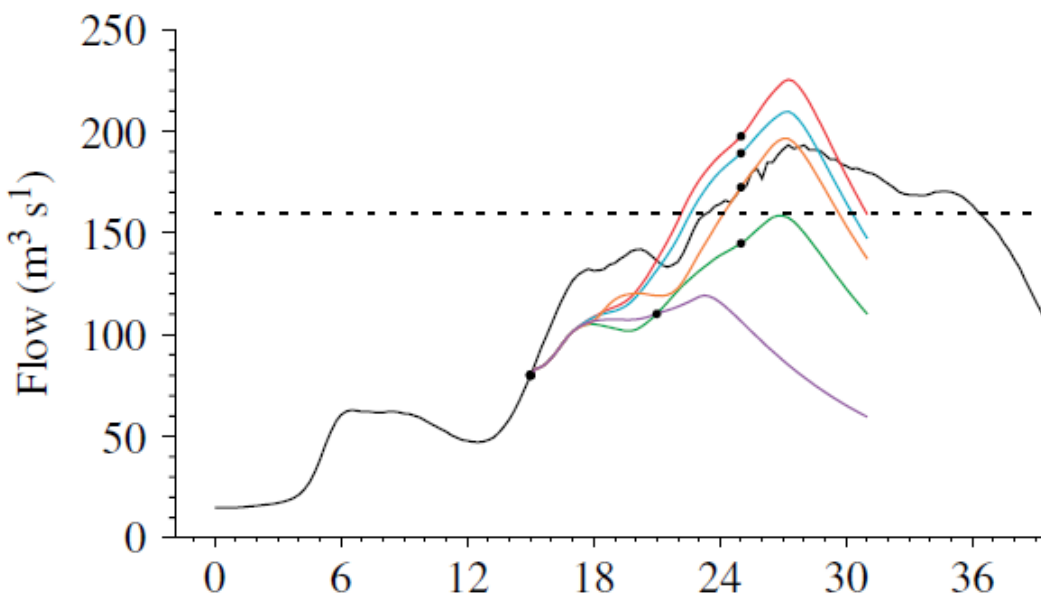
NWP & Streamflow – Direct/High-res NWP

Roberts et al UKMO, 2009

Carlisle Flood, 2005



24-hour rain accumulations



- PDM riverflow FCs for a range of precip-sources
- dashed line – flood warning level
- 1km (red), 4km (blue), 12km (green)
- nowcasting (purple) , rain-gauge (orange)
- observed flow (black)
- note termination of precip sources

Australian Government
Bureau of Meteorology

Access to BoM NWP data - NCI

- Bureau has a strong commitment to computing at the National Computational Infrastructure (NCI) in Canberra
  - New NWP (and other) model systems are prototyped at NCI
  - Part of the "C for community" in "ACCESS"
    - Provision of supported-experiments
    - ACCESS training courses and training materials
    - Supported by NeCTAR CWSLab funding

- Also contributes operational and near-operational NWP data to NCI, as a "nationally significant" dataset, in the RDS archive facility.
- Format of NWP data is steadily improving – from opaque grib to reasonably self-describing netCDF, and OPeNDAP is the goal in the future.
- Currently (Dec-2016) in the process of restructuring the data across multiple NCI projects.

Australian Government
Bureau of Meteorology

Access to BoM NWP data - NCI

http://nci.org.au/data-collections

NCI PROVIDING AUSTRALIAN RESEARCHERS WITH WORLD-CLASS HIGH-END COMPUTING SERVICES

MyNCI

ABOUT NCI | ACCESS | SYSTEMS AND SERVICES | USER SUPPORT | DATA COLLECTIONS | VIRTUAL LABORATORIES | RESEARCH & NEWS

Home / Data Collections / The NCI National Research...

THE NCI NATIONAL RESEARCH DATA COLLECTION

The NCI National Research Data Collection is Australia's largest collection of research data, encompassing more than 10 PB of nationally and internationally significant datasets. For more information, including how to access the dataset, click on the dataset name. You can also browse the entire NCI National Research Data Collection at https://geonetwork.nci.org.au/. For help email datacollections@nci.org.au

Data Collection Name	Description	Organisation
3D Geological Models of Australia	A unique collection of 3D structural and geological models and model inputs for Australia and its near shore regions	GA
ACCESS-CM 0.25 degrees Simulations	Initial spin-up simulations from the new high (ocean) resolution coupled version of ACCESS	ANU, UNSW
ACCESS Numerical Weather Prediction Models	Meteorological weather analysis and forecast model output from NMOC using the ACCESS Prediction System since 2009; represents BoM's daily weather predictions.	BoM
ARC Centre of Excellence for Climate System Science Datasets Collection	This collection includes all the datasets produced and published by the ARC Centre of Excellence for Climate System Science (ARCCSS) during its existence (2011-2018), with the exclusion of datasets which are part of cooperation projects (for example CMIP5 experiments).	ARCCSS
Atmospheric Forcing Products	Atmospheric Forcing Products	BoM
Atmospheric Re-analysis Products	Atmospheric reanalysis and observation data from local Australian and international sources such as NCEP1, NCEP2, ERA40, ERA40c and gridded observation data sets such as AWAP for weather and climate research.	BoM, ARCCSS

Australian Government
Bureau of Meteorology

Access to BoM NWP data - NCI

Australian Community Climate and Earth System Simulator (ACCESS) Numerical Weather Prediction (NWP)

Updated: 11 days ago

Collection of meteorological weather analysis and forecast model output from the Bureau of Meteorology using the Australian Community Climate and Earth System Simulator (ACCESS) numerical weather prediction for various domains, such as global, regional, and city/state. The data collection comes from the Bureau's daily operational numerical weather prediction analyses and forecasts from the period since the ACCESS system became operational in 2009, as well as significant ACCESS NWP research experiments. The analyses are output from the ACCESS version of the UK Met Office 4DVAR software and the forecast data is output from the ACCESS version of the UK Met Office Unified Model software. Data are in the same formats that are used internally in the Bureau's operational systems. For analyses and forecasts, the data are in grib or netCDF formats; model-specific formats are used for observations, model initial and boundary conditions and other associated files.

This collection includes the following subsets:

ACCESS NWP APS2 Operational datasets

Child record

Reference analysis and forecast data from ACCESS NWP APS2 systems including Global, Regional and City based. Includes long development runs and...

Australian Government
Bureau of Meteorology

Access to BoM NWP data - NCI

About this resource

Categories	
Keywords	• Meteorology • National Computational Infrastructure (NCI) • Environment
Language	• English
Resource identifier	• lb4

- "lb4" is an NCI *project*
- Head to **https://my.nci.org.au** and log-on to make a request to be added to that project.

Australian Government
Bureau of Meteorology

Access to BoM NWP data - NCI

- Overview
- About me
- Change password
- **Projects and groups**
- Propose a project

My memberships | Find project or group

Your project and group memberships

Project memberships for **gsd548**		Project
Researcher	**dp9: BoM ESM research at NCI**	**dp9**
Researcher	**fj8: National Water Data Assets**	**fj8**
Researcher	**ig2: NWP Bureau restricted data**	**ig2**
Researcher	**ja4: ACCESS NWP APS3 reference data**	**ja4**
Researcher	**lb4: ACCESS NWP APS2 reference data**	**lb4**
Researcher	**rr4: ACCESS model reference data**	**rr4**
Researcher	**rr5: Bureau of Meteorology Observations reference data**	**rr5**
Researcher	**rr6: Bureau of Meteorology Ocean-Marine reference data**	**rr6**
Researcher	**rr7: Reanalysis Reference Data**	**rr7**
Researcher	**rr8: Bureau of Meteorology Seasonal Climate reference data**	**rr8**

Software group memberships for **gsd548**		Software group
Researcher	**access: ACCESS software sharing**	**access**

Access to BoM NWP data - NCI

Australian Government
Bureau of Meteorology

Operational, APS2, ACCESS-G model output, for a FC starting at 12Z on Dec-4, 2016. Surface ("sfc") fields shown.

```
raijin1
pl  sfc
/g/data/rr4/ops_APS2/access-g/1/20161204/1200/fc> cd sfc
/g/data/rr4/ops_APS2/access-g/1/20161204/1200/fc/sfc> ls
abl_ht.nc            av_swsfcdown.nc       hi_cld.nc             soil_temp.nc
accum_conv_prcp.nc   av_temp_scrn.nc       lat_hflx.nc           soil_temp2.nc
accum_conv_snow.nc   av_ttl_cld.nc         lnd_mask.nc           soil_temp3.nc
accum_evap.nc        av_uwnd10m.nc         low_cld.nc            soil_temp4.nc
accum_evap_sea.nc    av_uwnd_strs.nc       mid_cld.nc            temp_scrn.nc
accum_ls_prcp.nc     av_vwnd10m.nc         mslp.nc               tmax_scrn.nc
accum_ls_snow.nc     av_vwnd_strs.nc       prob_vis_1km_ppt.nc   tmin_scrn.nc
accum_prcp.nc        canopy_wtr_cont.nc    prob_vis_5km_ppt.nc   topog.nc
av_lat_hflx.nc       cld_base_gt0p1.nc     qsair_scrn.nc         ttl_cld.nc
av_lwsfcdown.nc      cld_base_gt1p5.nc     seaice.nc             uwnd10m.nc
av_mslp.nc           cld_base_gt2p5.nc     sens_hflx.nc          uwnd_strs.nc
av_netlwsfc.nc       cld_base_gt3p5.nc     sfc_mois_flx.nc       veg_ruff.nc
av_netswsfc.nc       cld_base_gt4p5.nc     sfc_pres.nc           vis_conv_pptn.nc
av_olr.nc            cld_base_gt5p5.nc     sfc_temp.nc           vis_ls_pptn.nc
av_oswrad_flx.nc     cld_base_gt6p5.nc     snow_amt_lnd.nc       vis_precip.nc
av_qsair_scrn.nc     cld_base_gt7p9.nc     soil_mois.nc          vis_prob.nc
av_sens_hflx.nc      conv_cldbase_pres.nc  soil_mois2.nc         visibility.nc
av_sfc_sw_dif.nc     conv_cldtop_pres.nc   soil_mois3.nc         vwnd10m.nc
av_sfc_sw_dir.nc     dewpt_scrn.nc         soil_mois4.nc         vwnd_strs.nc
av_swirrtop.nc       fog_fraction.nc       soil_mois_cont.nc     wndgust10m.nc
/g/data/rr4/ops_APS2/access-g/1/20161204/1200/fc/sfc>
```

netCDF files, one file per model variable, all forecast-times in the one file

float accum_prcp(time, lat, lon)

```
tten" ;
                wrtn_date:WARNING = "DEPRECATED, DO NOT USE" ;
        int wrtn_time(time) ;
                wrtn_time:long_name = "time (HHMM) that this segment was written
" ;
                wrtn_time:WARNING = "DEPRECATED, DO NOT USE" ;
        float accum_prcp(time, lat, lon) ;
                accum_prcp:grid_type = "spatial" ;
                accum_prcp:level_type = "single" ;
                accum_prcp:units = "kg m-2" ;
                accum_prcp:long_name = "accumulated precipitation" ;
                accum_prcp:stash_code = 5226 ;
                accum_prcp:accum_type = "accumulative" ;
                accum_prcp:accum_units = "hrs" ;
                accum_prcp:accum_value = 4 ;
                accum_prcp:missing_value = 1.e+36f ;
                accum_prcp:_FillValue = 1.e+36f ;

// global attributes:
                :Conventions = "CF-1.5,ACDD-1.3" ;
                :institution = "Australian Bureau of Meteorology" ;
```

Australian Government
Bureau of Meteorology

Summary

- NWP is built upon:
  - *Discretisation*
  - *Parameterisation*
  - *Data Assimilation*
  - *Uncertainty and Ensembles*
  - All the above requiring very large obs/data, and very large computing
- BoM runs a suite of NWP systems covering a range of time/length-scales
  - BoM systems are generally world-competitive
  - Underpin much of the Bureau's weather forecasting capability
  - Systems are continually improved, with convection-permitting and global-ensemble systems imminent
- NWP feeds many downstream systems, including hydrological ones
  - But care must be taken to mitigate NWP limitations too
- NCI is the first port of call for external users interested in BoM NWP data

Australian Government
Bureau of Meteorology

Thank you…

Michael Naughton
03-9669-4411
michael.naughton@bom.gov.au