Model Data Fusion – Atmospheric Issues
(Data Assimilation)

www.cawcr.gov.au

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Earth System Modelling

Data Assimilation Team Leader

MDF Capability Workshop 10-12th May 2010

Australian Government

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NWP summary

- Importance of satellites
  - activities under review

- Precipitation & Ens.Prediction next main projects

- Land Surface
  - Climate/NWP ; CAWCR/WIRADA
  - Uptake of CABLE
  - Across many institutions (many drivers)

- Chemistry & Aerosol
  - Major influences to be resolved

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Reanalysis

- Big $$
  - Lot of organization

- NWP involved
  - Provide technical aspects
  - Not using a "research" version
  - Receive diagnostics & assessment

- Bulk of benefits to rest of community

Collaboration

- **Data availability**
  - Operational NWP data sets available to registered users: cycling 2 weeks
  - Possible to include research data sets

- **Collaborative Projects**
  - Bureau does not have "academic freedom"
  - Require "Business Case" for all new activities
    - Need justification to Exec of what's in it for us
    - Fortunately reasonable requests generally approved
  - CAWCR has signed up for SMOS related project

- **ACCESS-Polar & Ice ?**
- **Oceanic-Atmospheric weather**

Capability / Capacity

- **Outreach to Unis**
  - Maths/Eng Maths in Industry Study Group etc.
  - Next Generation Dynamics
  - Minimization techniques
  - Statistical sampling large systems
  - Error growth & perturbation mechanisms
  - Dynamics & adjoint
  - Physical Parameterizations & DA

- **Centre of Excellence ?**
  - Include Master's Program

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- DA summer school
  - Cost?
  - Will be infrequent
  - Overseas examples of success

- Community test beds etc.
  - Extend UM training sessions as bridge between summer schools
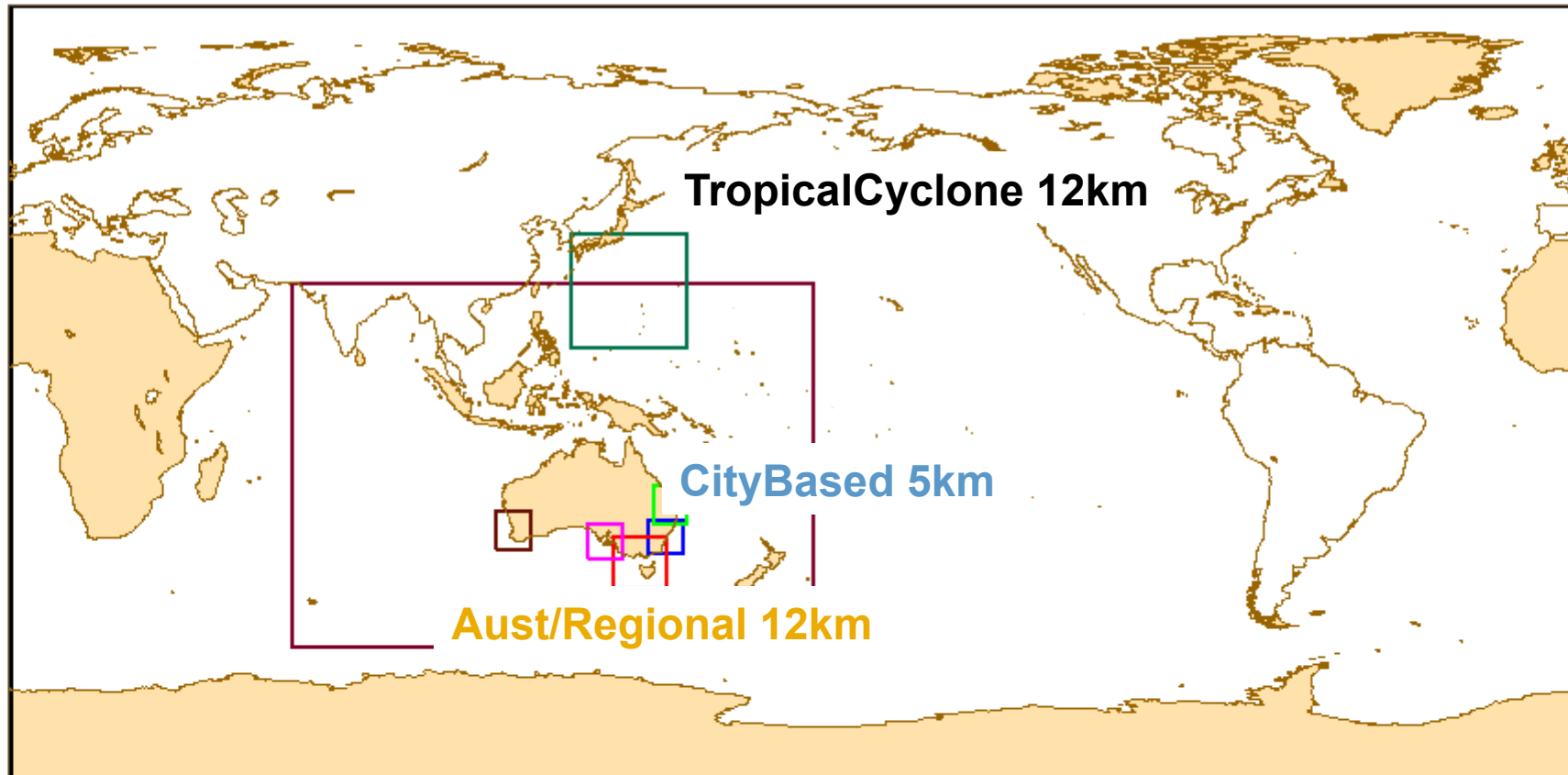 - Link with science workshops

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CAWCR atmospheric projects

- ACCESS NWP

- Global, Regional, City, Relocatable, TC, Polar, Ozone, Coupled & Ensembles
  - 4dVAR
  - Dominated by remote sensing
  - Global ~25km → city based ~2km over next few years
  - (ECMWF already 16km globally)

- Wave Modelling (WaveWatch3)
  - Remotely sensed data
  - NWP time & space scales
    - part of some NWP systems

- POAMA Seasonal → Oscar Alves
  - Atmospheric data from reanalysis grids
  - Start in 1960 (pre-satellite)

ACCESS NWP Domains late 2010

Global (N320 ~40km)

TropicalCyclone 12km

CityBased 5km

Aust/Regional 12km

Uses

- ## Public Weather
  - Detail
  - screen-level elements, UV, air quality, sea state, ….

- ## Disaster Mitigation
  - Precipitation & wind
  - Temperature and moisture for bush-fires

- ## Aviation
  - Upper winds, fog, icing
  - Aerosols: visibility, smoke, volcanic ash, dust

c/o Google Images

- ## Wind & solar energy

- ## Network monitoring

- ## Reanalysis ???

Current Techniques

- 4dVAR
  - Cost of adjoint?
  - Cost of Implementation?
  - Bkg. error covariance modelling
  - Implementations established

- EnKF
  - Avoiding collapse?
  - Localization
    - Non-linear obs operators (satellite moisture channels)
  - Equivalent to 4dVAR

- Particle Filters
  - Dimensionality ??
  - Long way from applications

c/o Google Images

Where to next?

c/o Google Images

- ## Remote sensing
  - New sensors and better use of existing sensors
    - Adaptive thinning
  - Dealing with land, cloud, aerosols & trace gases

- ## Precipitation & mesoscale
  - Non-linearity & non-Gaussianity
  - Modelling convection, complex terrain & surface processes

- ## Coupled DA
  - Differences in time scales & observation density

Where to next?

c/o Google Images

- **DA Techniques**
  - Hybrid Ens/VAR feasible
    - Dynamic background error covariances ← EPS
    - Analysis increments NOT confined to subspace of perturbations
  - Model error?

- **Long window VAR**
  - ~ Kalman Smoother (→ reanalyses)
  - Only at the ECMWF?
  - "model error"

WWRP Strategic Plan: 2009-2017

State of the art in 5-10 years?

- **Aspire to world class systems**
    1. Use more satellite data
    2. Precipitation DA
    3. Land Surface DA
    4. DA Coupled to ocean (+waves)
    5. Advances in DA techniques
        - Hybrid Ens/VAR
    6. Chemistry & Aerosols DA
    7. Observation network optimization etc.

c/o Google Images

- Resolution = COMPUTING GRUNT!   → Tim Pugh

1. Satellites - General

- **Use small percentage of data**
  - Observation error correlation
    - Thin to ~80 or 100km
    - Adaptive thinning?
  - "Contamination"
    - Land surface → emissivity
    - Clouds
  - bias correction – bluntly remove "contamination" (aerosols, trace gases etc.)

- **Generally use radiances**
  - Avoid contamination from retrieval "background"
  - Use all available data in "retrieval"
  - Radiance code provided by satellite operators
    - Small cost relative to cost of sensor.

ATOVS   20100506 0000   719712 obs

146944 METOP   165984 NOAA16   138544 NOAA17   140112 NOAA18   128128 AQUA

AMV   20100505 0000   386751 obs

117248 GOES   38505 ESAC   2650 AUS   33983 JMA   194365 MSG

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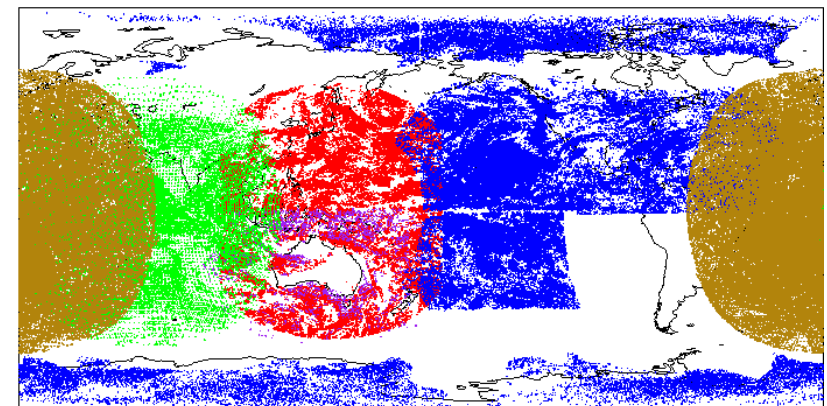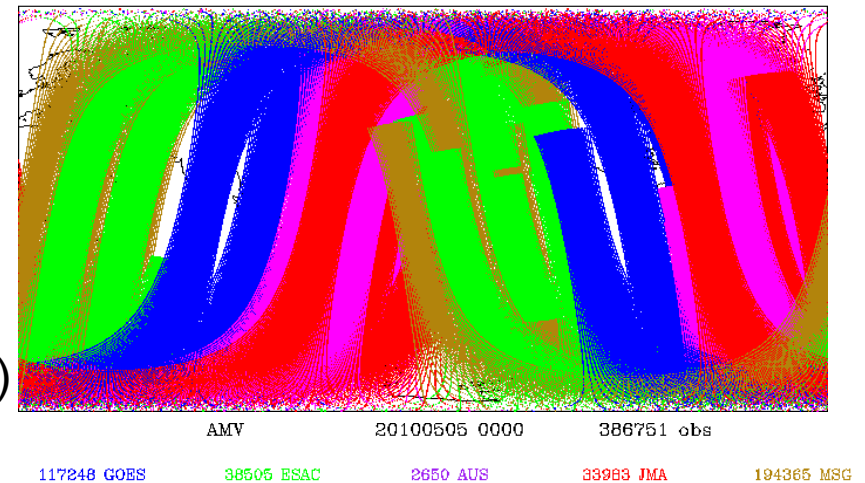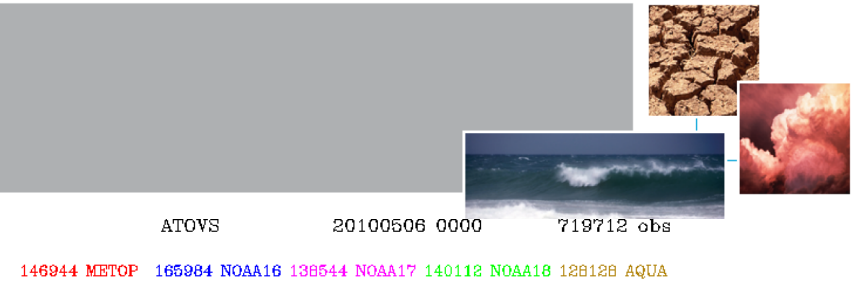
1. Satellites

- **Hyper-spectral IR :**
  - Channel selection: 50-100 channels out of 2000-8000
  - Still single most important sensors

- **Geostationary IR**
  - High time & space resolution
  - Only use AMV's currently in ACCESS
  - IR channels could/should be used
  - Advanced IR imagers (more channels) Can:
    - Suppress incorrect convection
    - Identify "dry slots" → convection & bush fires

HIRS (NOAA 15) Channels 1–10 and Typical IASI Spectrum

c/o Google Images
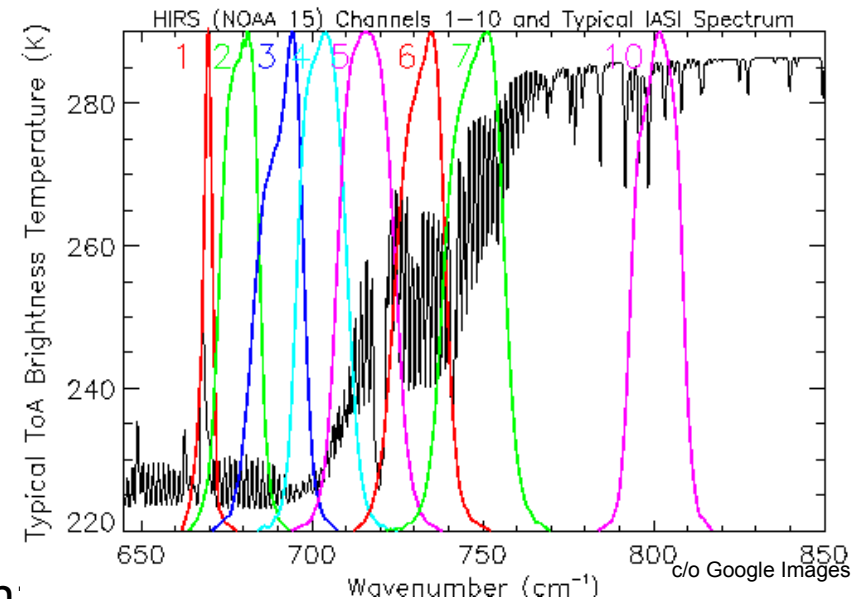
1. Satellites

- **Microwave sounders & imagers**
  - Initialize convection & soil wetness

- **Multi-sensor**
  - Land emissivity & Vegetation

- **Others**
  - GNSS Radio occultation: (~Unbiased) upper atmospheric temperature
  - GNSS zenith delay: High frequency moisture
  - Scatterometer: winds & soil moisture
  - Lidar
  - Cloud radar
  - …

- **Initialize temperature, moisture, wind, clouds, land, aerosols & chemistry**

c/o ESA

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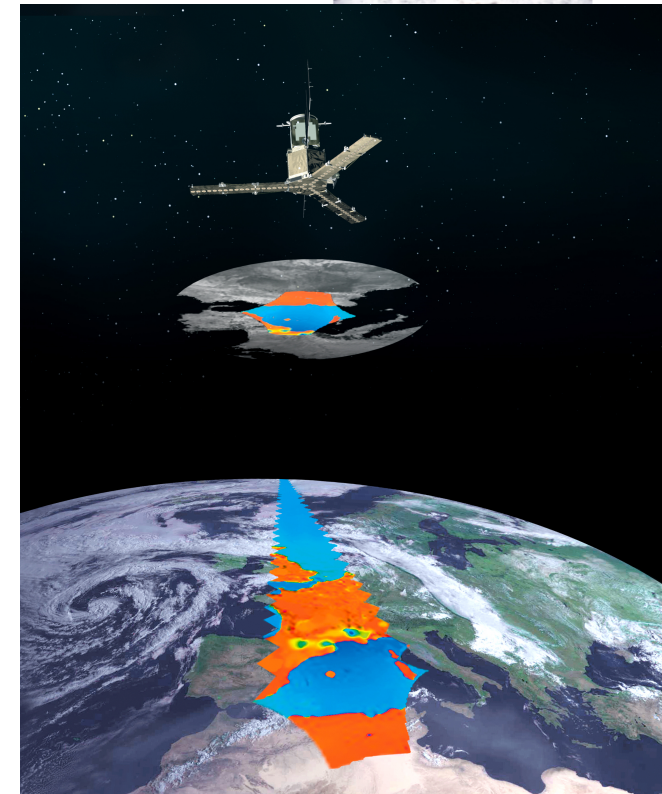
1. Satellite DA - issues

Masses of instruments, but…

- Probability a sensor or local processing askew is high
  - Handful of people to monitor the system (& implement/research/…)

- Experienced / qualified people ??
  - An ongoing capability – age profile?
  - Recruitment / training ?

- Continual improvement in use of data
  - Look to CAWCR for tropics & deserts?
  - Testing (& understanding) upgrades.

- Data Latency → forecast latency
  (→ local reception & processing)

- **Satellite DA drives NWP performance**

Strategic Radar Enhancement Programme

- Advance science of using radar data
    - Bridge nowcasting gap
    - Deterministic
    - Focus on meso-scale
        - Precip & winds

- Operational 2015

- Start with 3dVAR+LH nudging
    → 4dVAR + ??

SREP
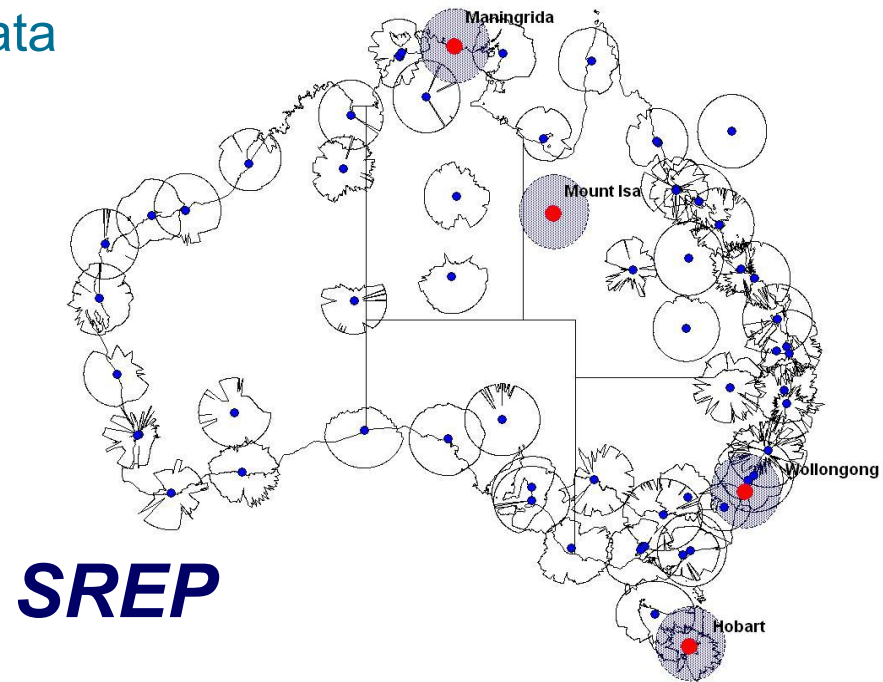
Radar Assimilation

- Developed / Developing at most NWP centres
- Operational ↔ VAR
  - 4dVAR for precip
  - 3dVAR + Latent Heat Nudging (baseline)

Met Office	UKV+3dVAR(3hr) *→ 4dVAR*	1.5km	36hr x 4 *→ increased freq*
Meteo France	AROME + 3dVAR (3hr) *→ 4dVAR*	2.5km	30hr x 4 *→ increased freq.*
JMA	MesoScale Model + 4dVAR	5km	15hr x 4 & 33hr x 4
NOAA/NCEP	RapidRefresh + 3dVAR(1hr) *→ 4dVAR*	3km	18hr x 24
DWD	COSMO-DE + 3dVAR *→ EnKF?*	2.8km	18hr x 8

1-2km NWP & Radar

+ Initialize precipitation

+ Minimize spinup (nowcasting ← NWP)

+ Doppler winds

+ Integration with satellite & in situ data

→ Improved QPE & QPF

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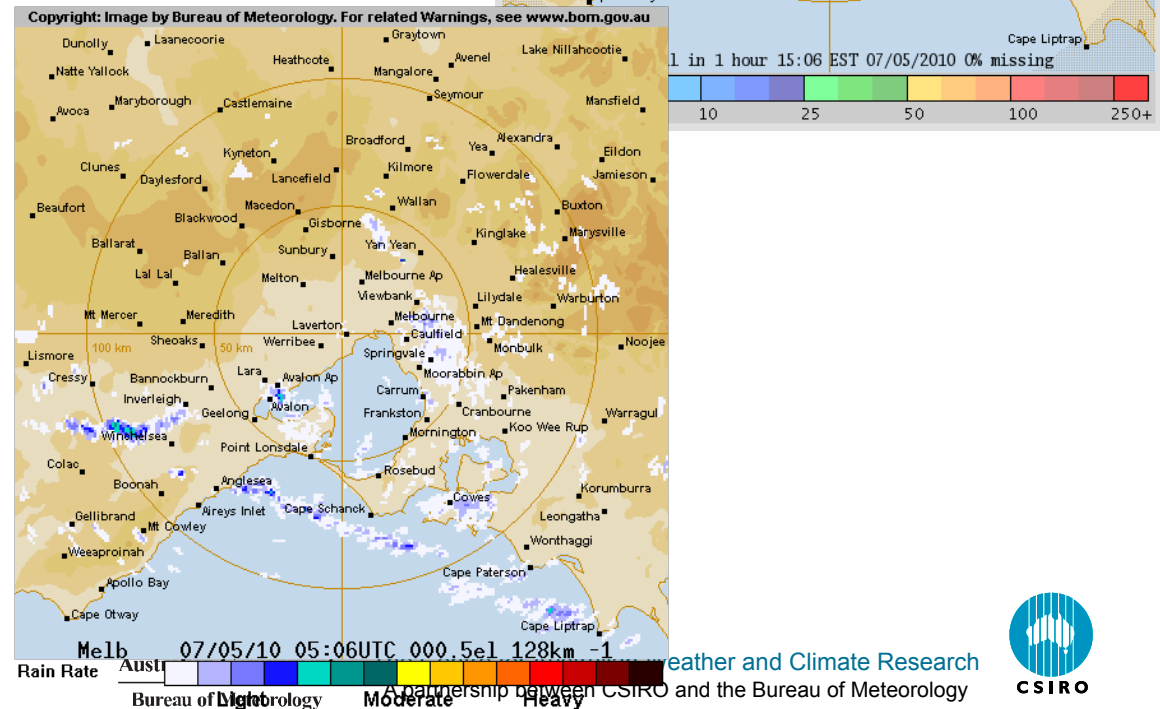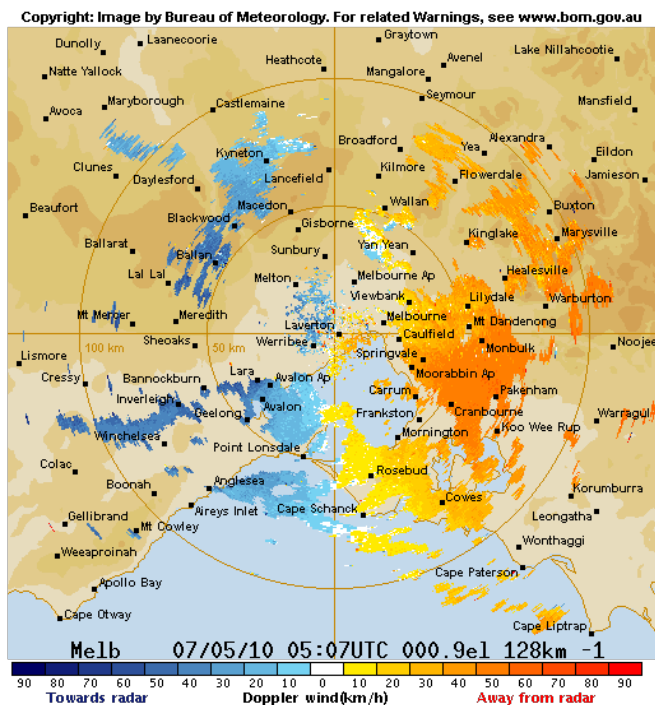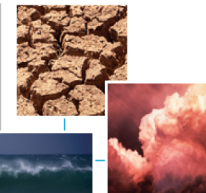
- Advent of new satellites & Advanced LSMs

  - AMSR-E, ASCAT, SMOS etc.

  - Bias/residual → info on LSM calibration

  - Vegetation ?

- Implications of CABLE

  → No longer rely on MetOffice

  - New DA person starting September

  - Model & operational support?

- Impact

  - Significant for NWP & seasonal

  - Emissivity → Satellite use over land

  - Hydrology ?
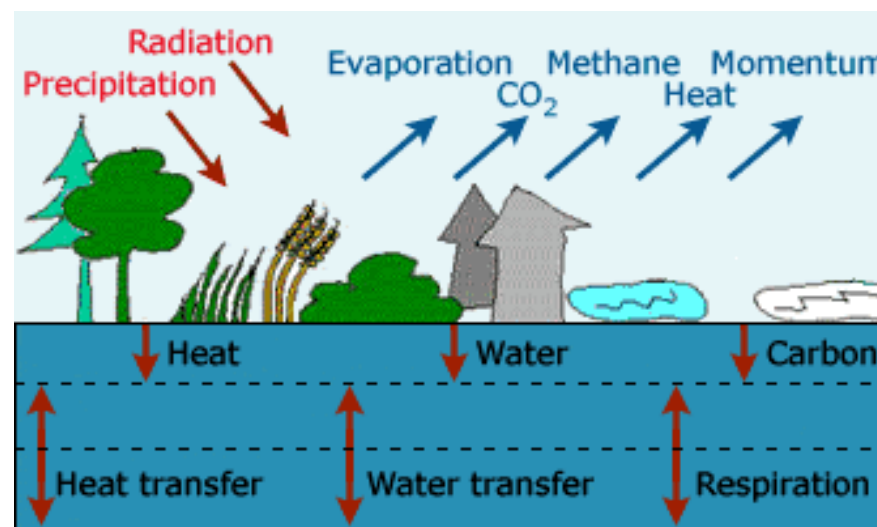
c/o Google Images

4. Coupled Atmosphere / Ocean

- **Improve fluxes to & from NWP**
  - Waves
  - SST & wind stress
  - Short, medium & long range atmosphere
    - TCs & East Coast Lows

- **Impact of "analyzed" SST on NWP**
  - Improved fluxes?
  - Extended prediction?

- **Coupling independent DA & forecast systems**
  - Atmos analyzed/forecast winds → Ocean analysis/forecast
  - Ocean analyzed/forecast SST → Atmos analysis forecast

5. Advances in DA techniques

- Hybrid EnKF / VAR
  - Background error covariances from EPS
  - "centre" of EPS
  - Provides growth-directions outside of ensemble

- Exists
  - Major effort in MetOffice

- Non-Gaussianity
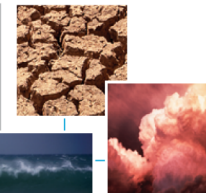 - & model error?
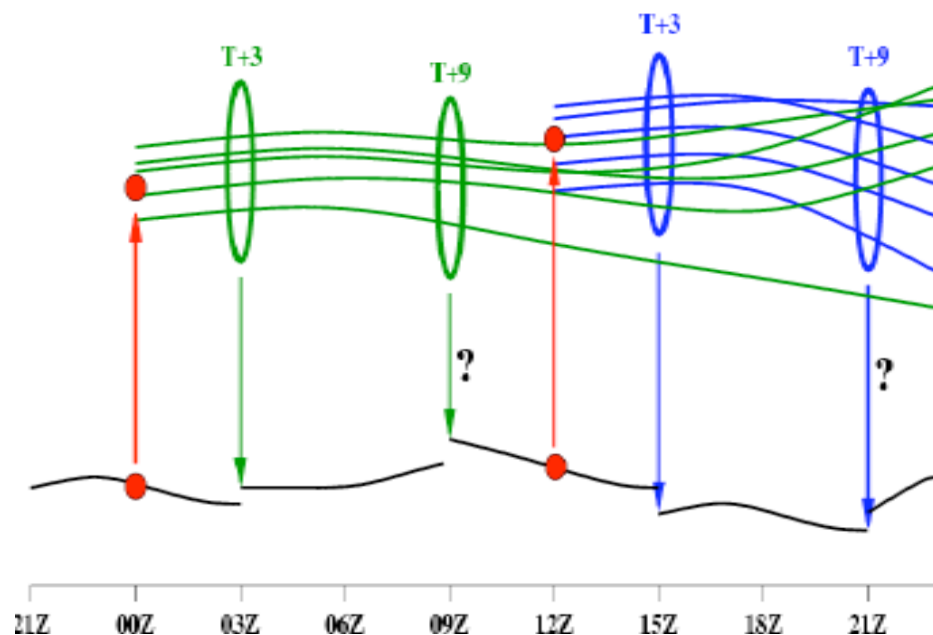
6. Chemistry & Aerosol DA

- **Currently only Ozone**

- **Likely needs :**
  - Improve use of sounders
  - Fog
  - Volcanic Ash (post Iceland)
  - Dust (NE Asia, Aus)

- **Long spin up for development**

- **Emissions accounting & trading**
  - Compare international efforts

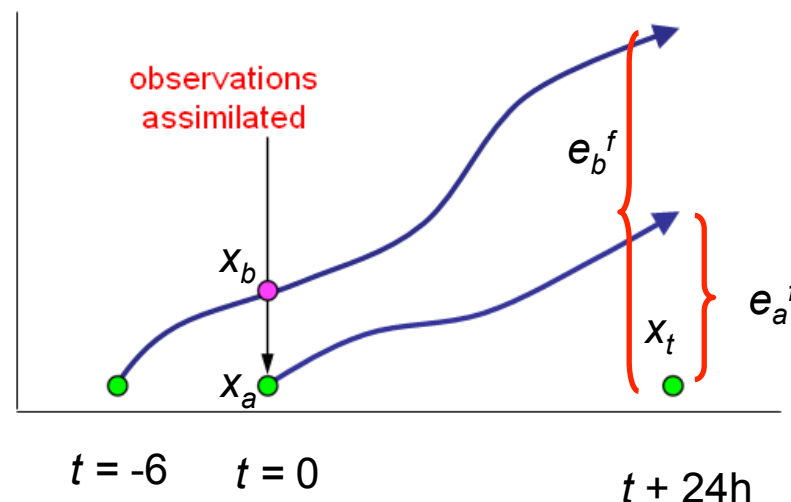FORECAST CLEAR SKY UV INDEX FOR LOCAL NOON FRI 07 MAY 10

SunSmart — Australian Government — Bureau of Meteorology

UV Alert: 9.10 am to 3.20 pm
MAX UV Index: 9

UV INDEX
20
15
11 — EXTREME
8 — VERY HIGH
6 — HIGH
3 — MOD
— LOW

6am 8 10 12 2 4 6 8pm
Cairns   Fri 7 5 2010

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CSIRO
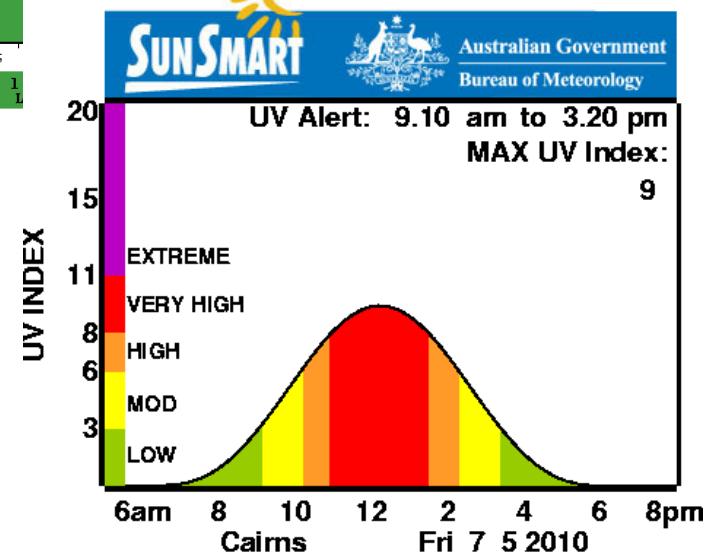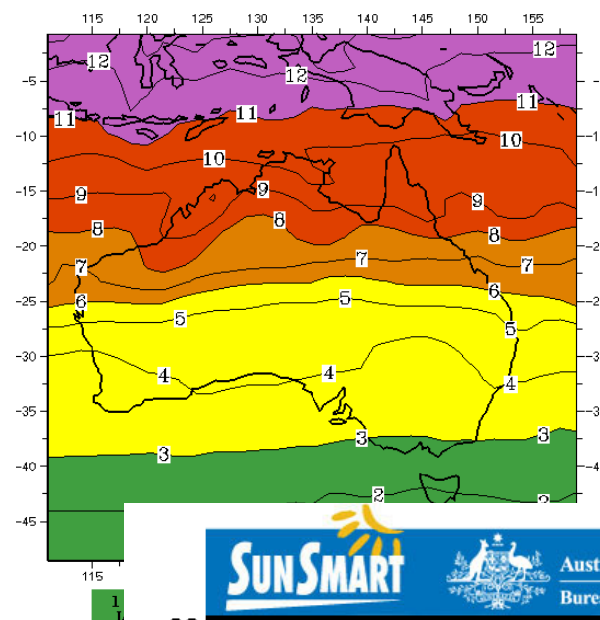
7. Network Design

- Essential to support our essential services
- Obs programs very expensive
  - Always under threat
  - Death by a thousand cuts
- Obs impact calculations
  - OSE
 - OSSE
  - Adjoint Sensitivty
  - Todling
- OEB & WMO

observations assimilated

x_b

x_a

e_b^f

e_a^f

x_t

$t = -6$ $t = 0$ $t + 24h$

NOGAPS 24h Impact Per Ob Jan2007 00+06z

Ships
SatWind
SSMispd
aobDsnd
Qscat
MODIS
LandSfc
Aircraft
AMSUA

-15   -12   -9   -6   -3   0   3

1e-6 J/kg Langland, Cardinali
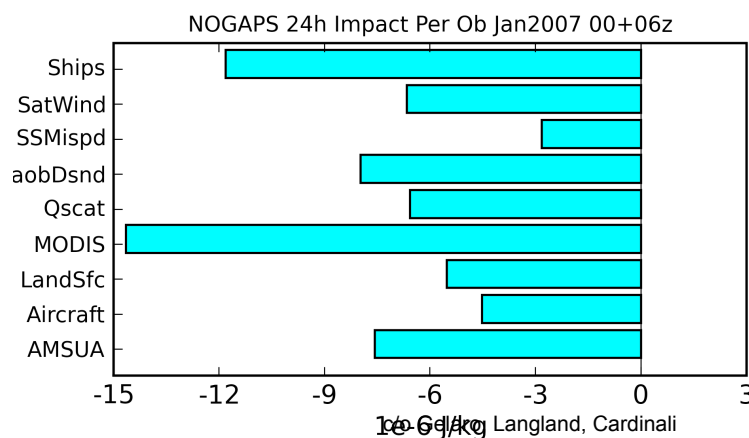
Summary & Issues (1)

- **Ongoing commitment if to be "world-class"**
  - Development lead-time significant
  - Costly just to keep head above water
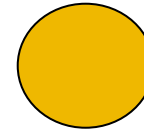
  ○ Scope for new developments?

- **Satellite DA**
  - Many areas ready for improvement
  - Capacity ?
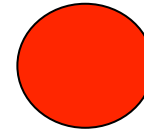
  ● Needs are here & now.
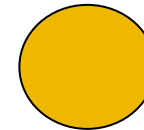 Underpins all future activities

- **Meso (sub km) scale NWP**
  - Hopefully OK for a few years
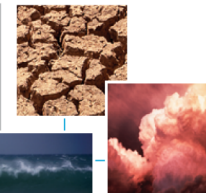 - Precipitation from radar+gauges+satellite+NWP
  → hydrology ?
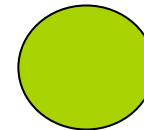
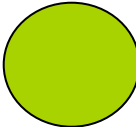 ○ Starting at least…

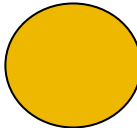 ○ If start now …

- **Land Surface**
  - Direct importance
  - Satellite data over land
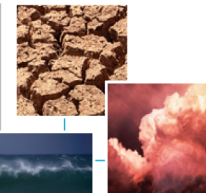 - Multi-sensor info → land surface model parameters

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Summary & Issues (2)

- Atmos/Ocean coupling

  At least under way, but critical mass?

- Future techniques : Hybrid
  - Requires Ensemble Prediction System

  …but need to get started

- Chemistry & Aerosol
  - Needed for fog, visibility & volcanic ash
  - Satellite data usage
  - Emissions accounting & trading !!

  …again

- Support for data networks & models
  - Estimating value of obs << cost of network
  - LEARN FROM NWP

  Some support at least

Regional Reanalysis

Use NWP info for Calibration & Tuning of :

Land Surface, Carbon Cycle, Hydrology, EPS, Seasonal Prediction, ….

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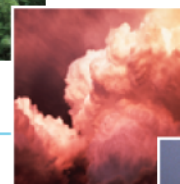
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Thank you

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Atmospheric Prediction Cornerstones

- ## Main errors from initial conditions
  - ## → Data Assimilation

- ## Dominated by remotely sensed data
  - ## Most demanding of resources in NWP

- ## Daily comparison with overseas systems
  ## …. and assessment by forecasters

c/o Google Images

- ## Techniques must fit within operational windows

- ## 4d techniques verging on common
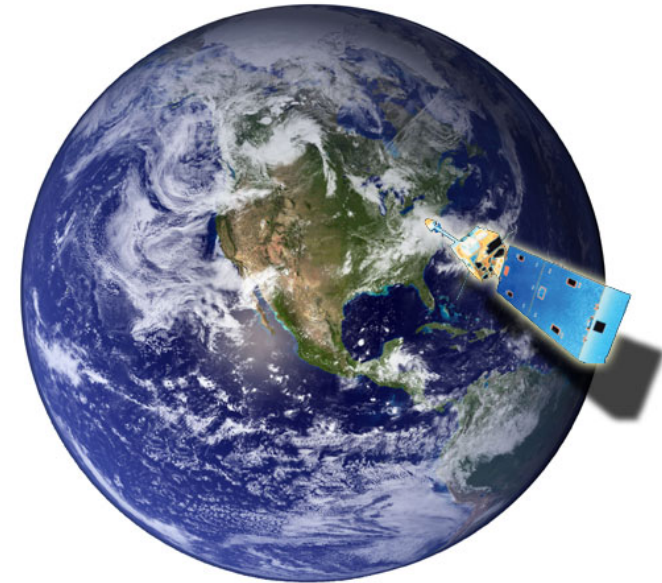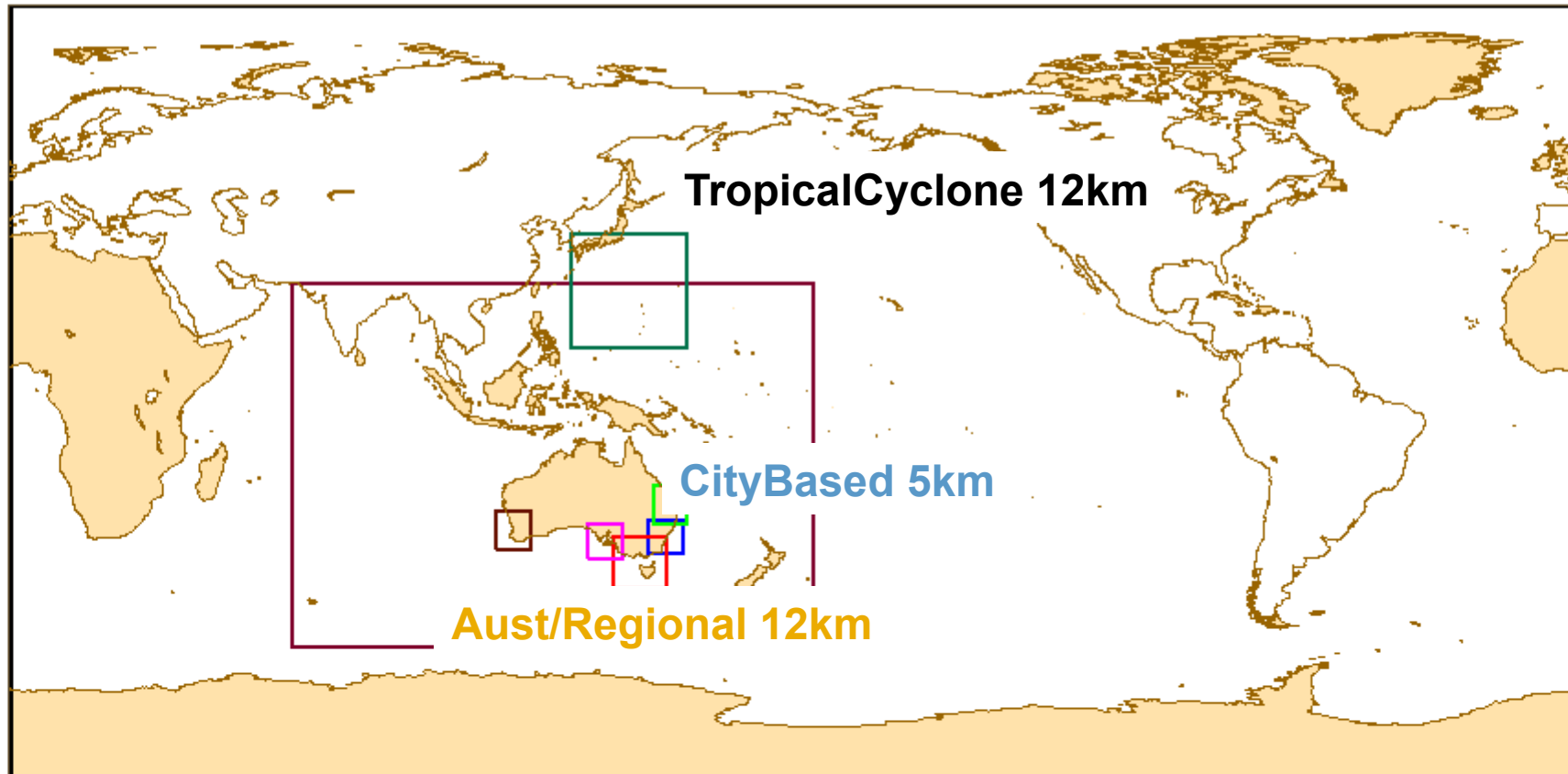
ACCESS NWP Domains late 2010

Global (N320 ~40km)

TropicalCyclone 12km

CityBased 5km

Aust/Regional 12km

Domain / Computation

- 0.02° (2km) Sydney domain (or Brisbane??)
  - Replace current .05° **(160x160)**

- Stretched/Variable rotated grid

- Limited number of domains
  - & coverage
  - Relocatable system *eventually*

- (3dVAR + LH Nudging)
  - vs 4dVAR (+?)

Laps05nsw

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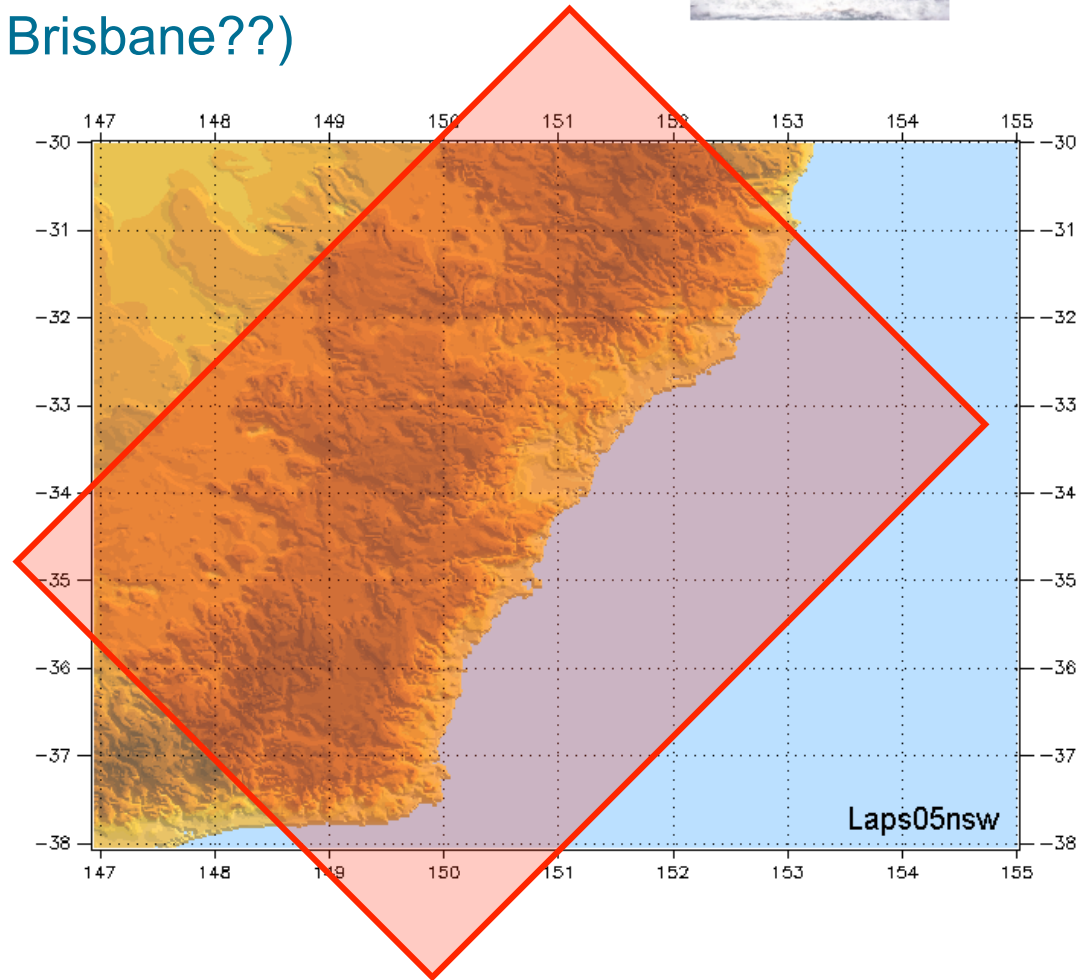
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1-2km NWP & Radar

- Quality control

- Calibration

- Cloud modelling

- Error covariances

- Partial coverage

- Predictability

- VERY non-linear obs operators

- Time correlation of obs errors