Model Data Fusion – Atmospheric Issues
(Data Assimilation)

Peter Steinle
Earth System Modelling
Data Assimilation Team Leader
MDF Capability Workshop 10-12th May 2010

www.cawcr.gov.au
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
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
- 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
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)

Tropical Cyclone 12km

City Based 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

• 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
Where to next?

- 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?

• 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.

• 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 $\rightarrow$ 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.
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
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**
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 $\rightarrow$ forecast latency
  ( $\rightarrow$ local reception & processing )

- **Satellite DA drives NWP performance**
2. Precipitation Assimilation

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
  \[ \rightarrow \] 4dVAR + ??
Radar Assimilation

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

<table>
<thead>
<tr>
<th>Met Office</th>
<th>UKV+3dVAR(3hr)</th>
<th>1.5km</th>
<th>36hr x 4</th>
<th>increased freq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteo France</td>
<td>AROME + 3dVAR (3hr)</td>
<td>2.5km</td>
<td>30hr x 4</td>
<td>increased freq.</td>
</tr>
<tr>
<td></td>
<td>→ 4dVAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JMA</td>
<td>MesoScale Model + 4dVAR</td>
<td>5km</td>
<td>15hr x 4 &amp; 33hr x 4</td>
<td></td>
</tr>
<tr>
<td>NOAA/NCEP</td>
<td>RapidRefresh + 3dVAR(1hr)</td>
<td>3km</td>
<td>18hr x 24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>→ 4dVAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DWD</td>
<td>COSMO-DE + 3dVAR</td>
<td>2.8km</td>
<td>18hr x 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>→ EnKF?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1-2km NWP & Radar

+ Initialize precipitation
+ Minimize spinup (nowcasting ↔ NWP)
+ Doppler winds
+ Integration with satellite & in situ data

→ Improved QPE & QPF
3. Land Surface Assimilation

- **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 ?
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
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 Sensitivity
  - Todling
- OEB & WMO
Summary & Issues (1)

• Ongoing commitment if to be “world-class”
  • Development lead-time significant
  • Costly just to keep head above water

• Satellite DA
  • Many areas ready for improvement
  • Capacity ?

• Meso (sub km) scale NWP
  • Hopefully OK for a few years
  • Precipitation from radar+gauges+satellite+NWP
    $\rightarrow$ hydrology ?

• Land Surface
  • Direct importance
  • Satellite data over land
  • Multi-sensor info $\rightarrow$ land surface model parameters

Scope for new developments?

Needs are here & now.
Underpins all future activities

Starting at least…

If start now …
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
  - Some support at least
  - LEARN FROM NWP
Regional Reanalysis

Use NWP info for Calibration & Tuning of:
Land Surface, Carbon Cycle, Hydrology, EPS, Seasonal Prediction, ....
The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

Peter Steinle
Earth System Modelling Data Assimilation Team Leader

Phone: 03 9669 4848
Email: p.steinle@bom.gov.au
Web: www.cawcr.gov.au

Thank you
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

- Techniques must fit within operational windows

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

Global (N320 ~40km)

Tropical Cyclone 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 (+?)
1-2km NWP & Radar

- Quality control
- Calibration
- Cloud modelling
- Error covariances
- Partial coverage
- Predictability
- VERY non-linear obs operators
- Time correlation of obs errors