Model-Data Fusion in Water Balance Modelling: Examples from Water for a Healthy Country Flagship

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Overview some of the different flavours of MDF work tried / tested / used in research under CSIRO’s Water for a Healthy Country Flagship & WIRADA

Model development, optimisation, parameter selection/estimation, calibration, tuning, fitting; data assimilation, state updating; model-data integration, image fusion; statistical blending; data merging; model selection, …

- **Talk outline**
  - Choice of MDF Techniques for Water Balance studies
  - Some examples from WfHC Flagship & WIRADA
  - Issues for Water Balance MDF
  - Conclusions & Recommendations
Choice of MDF Techniques

1. Nature of the systems we are modelling governs the appropriateness of the MDF techniques employed
   • System dynamics: e.g. stochastic dynamic, deterministic static, ...

2. Use of Observations
   “Observations” includes measured direct / indirect (retrieved) or modelled quantities
   • Constraint e.g. sequentially update model trajectory; batch parameter estimation for time series of data
   • Model development & evaluation e.g. inferring model structure, parameterisation, model selection/development, verification
   • Model forcing & input e.g. driver data propagating model from one time step to next; spatially varying land surface variable

3. Application space & time frames
   • Real-time e.g. flash flood forecasting,
   • Retrospective / historical e.g. medium- and long-term predictions, climate change studies
Some examples from WfHC and WIRADA

<table>
<thead>
<tr>
<th>Real time</th>
<th>Retrospective</th>
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| **• Rainfall-runoff modelling**  
Parameter estimation, state updating & forcing adjustment using stream gauges observations | **• Landscape water balance model development**  
Using flux tower & stream flow observations to determine optimal level of model complexity |
| **• Open water fraction**  
Integrating multiple sources of remotely-sensed observations to map extent of flooding | **• Spatial modelling of water stores & fluxes**  
Spatial water balance estimation constrained by remote sensing in reanalysis |
| **• Precipitation blending**  
Statistical blending of gridded estimates & point measurements of precipitation |  |
Real-time flow forecast on the Condamine-Balonne

- **System**
  - 6 hourly
  - 20 forecasting points
  - Total area of 80 000 km²

- **Models**
  - Rainfall-runoff
  - River Routing
  - Data Assimilation to update Routing
Real-time flow forecast on the Condamine-Balonne

- **Variational DA**
  - Assimilation window of 7 days
  - Updating correction factors on
    - rainfall
    - model states

- **Issues**
  - Raw input data
  - DA not compensating structural errors
Estimating flooded area by blending satellite imagery

Flood extent estimation

MODIS
- 500 m resolution
- cloud affected
- twice daily

AMSR
- 14x8 km resolution
- affected by rain
- 1-2 times daily
Estimating flooded area by blending satellite imagery

Weight of sensor based on cloud cover fraction
The Australian Water Resources Assessment (AWRA) system

• AWRA model development

• Surface obs from **flux** towers & **stream flow** observations were used to derive a model of Australian water balance of optimal complexity.
The Australian Water Resources Assessment (AWRA) system
Data assimilation: MODIS EVI

Howard Springs savanna

Kyemba grassland

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MODIS greenness (EVI) observations
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prior parameter estimates
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parameter fitting followed by EnKF LAI

Data courtesy Lindsay Hutley, Jason Beringer, Jeff Walker and Robert Pipunic
Result: comparison against flux tower ET

- Prior parameters reproduce ET patterns reasonably well.
- Ensemble Kalman filter to update LAI occasionally leads to improvements, but also degradation at times.
- Much of the recalcitrant differences can be attributed to errors in rainfall (kriging product).
Total water storage
1 February 2010
Total soil and ground water storage combined, compared to average for this day for 1980-2009 (so-called “anomaly”)

Example AWRA reports
Blending gauge and satellite-based precipitation

Statistical blending of gauge & gridded precipitation data (Li & Shao, *J Hydrol*. 2010)

TRMM Multi-satellite Precipitation Analysis
3B42 precipitation product

NCC Daily rainfall observations

Blended satellite-gauge daily rainfall

2003-04-12
1200 UTC

2003-04-13
Daily Rainfall Estimates (24 hr to 9am local time)
Historical blended gauge and satellite-based precipitation

- Historical archives of rain gauge obs & satellite (TMPA 3B42) retrievals

- Displayed are time series of monthly precip average for 13 drainage divisions

- Trend in annual precipitation from the blended product for Jan 1998 – Dec 2008

**Note**

- Number of gauge obs ~6000 per day
  (as opposed to ~1000 per day in Real Time)
- Satellite image history to short for most climate studies
Near real-time blended gauge and satellite-based precipitation

- Sequences of daily rainfall for 1-24 March 2010
- Blended satellite and NRT gauge generated ~9pm on day of interest

- **Some issues**
  * Not very “real-time” – but is 12 hr latency acceptable for most applications? (probably not for flood warning)
  * Alternative blending approaches & data sets need to be tried
  * Needs objective quantitative assessment of accuracy
Issues

• Nature of the systems
  • Modelling states difficult/impossible
    • e.g. Ground water dynamics
  • Makes development of observation operator challenging
    • Conceptualisation
  • No connection in space (e.g. adjacent catchments)

• Observations
  • Quality control – what/where are the error bars on the observations?
  • Timeliness – what level of latency is acceptable/unacceptable?

• ...
Conclusions & recommendations

• “Models without observations are misguided; observations without models are uninteresting…”

• Observations are essential for determining appropriate level of model complexity, constraining model estimates & evaluating model performance

• Better characterisation of observation errors is needed
  • Obs error needed for assimilation; ensemble modelling; model verification
  • Greater support for field campaigns

• Ask the questions:
  • Are we making the most of the data we currently have?
  • What more data would we like to have & where?
Conclusions & recommendations

- MDF techniques abound – not all techniques appropriate for certain applications
  - “When all you have is a hammer, all problems start to look like a nail”
- However, some challenges are ubiquitous to all field
  - Encourage dialogue between the communities gathered here
- What would be good to have is …
  - Access to toolsets/existing algorithms
    - LIS, OpenDA tools, software libraries, …
  - Access to expertise/capabilities
    - Tap into this community; foster linkages & promote cross-divisional/institutional collaborations
  - Performance testing infrastructure
    - e.g. web-based interface to submit algorithms / outputs to be objectively assessed against alternative approaches. (ET-ICE)
  - Ability to interrogate / develop model structure
    - e.g. revisit rainfall-runoff model paradigm