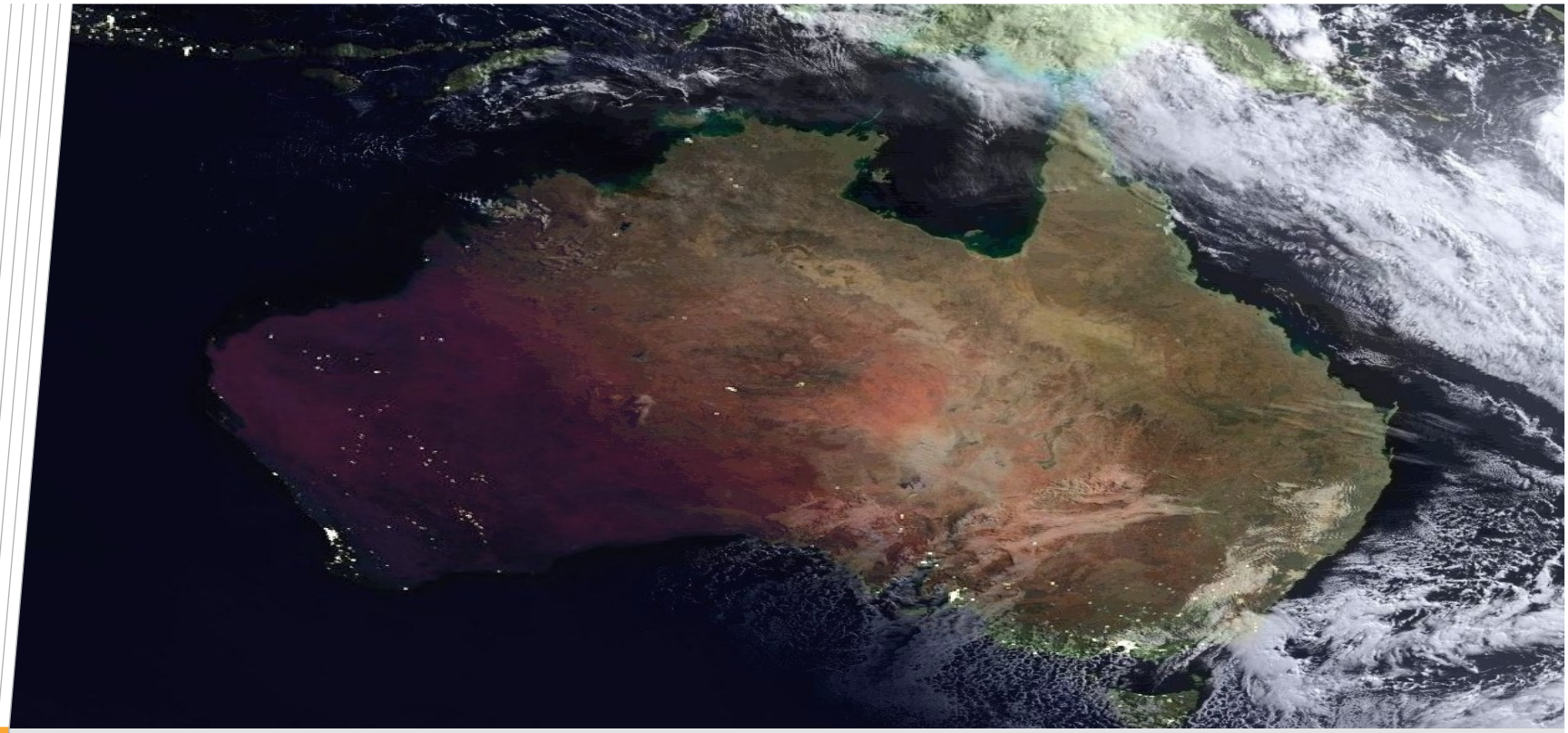

www.csiro.au

# Earth Observation perspectives over a large, dry, flat continent

**Tim Malthus, CSIRO Land and Water, but mainly WIRADA stream members:**

Albert Van Dijk, Luigi Renzullo, Juan Pablo Guerschman, Tim McVicar, Randall Donohue

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# Outline

- Context and motivation
  - The need for continental water information
  - Limitation of existing water information sources
- Addressing the challenges
  - Water information R & D alliance
  - Model data fusion
- The Australian Water Resources Assessment (AWRA) model
  - Evaluation examples
- Continental precipitation estimation
- Fractional vegetation cover estimation
- Conclusions



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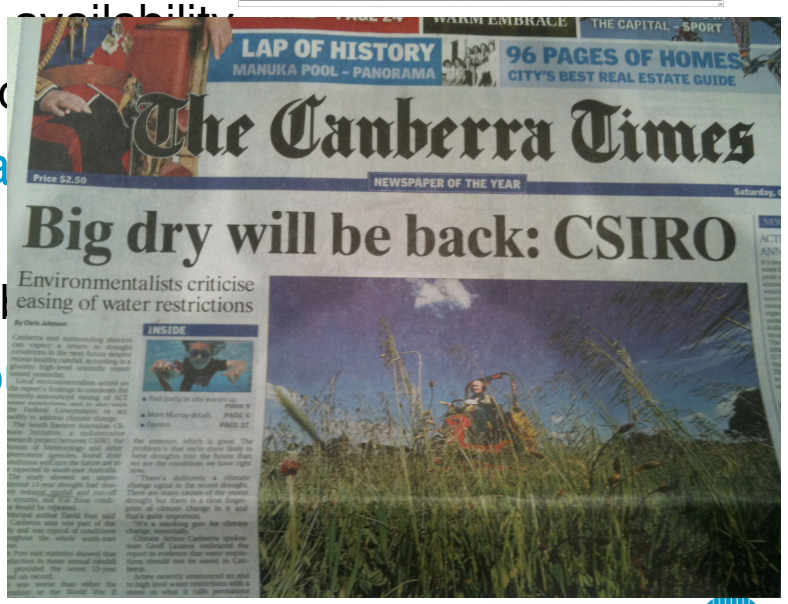
# Context

- 10 to 15 years of drought (1990's to 2009)
- Water Act 2007 (Federal)
- Federal Government charges the Bureau of M … op continental water information services:
  - Annual national water account
  - Scheduled water resources assessments
  - Interpretations of current and future availabilit…
  - Forecasts of availability from days t…
- Federal 'takeover' of the Murray-Da… Darling Basin Authority
  - To set new limits on water that can l…
- Discussion over 'big' Australia (pop… immigration? – from ~21 M today)



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# Murray-Darling river system

- Iconic
- 23 major river valleys, covers 1 M km$^2$ across four states
- One of the largest and driest catchments in the world, 16 Ramsar wetlands
- Home to 2 M people
- Fundamental to Australian economy - produces 39% of Australia's total agricultural production ($15 B per annum)
- 65% of Australia's irrigated land area and around 40% of Australia's farms
- 20/23 major river valleys are in poor to very poor ecological condition
- Over-abstraction due to oversubscription of water rights



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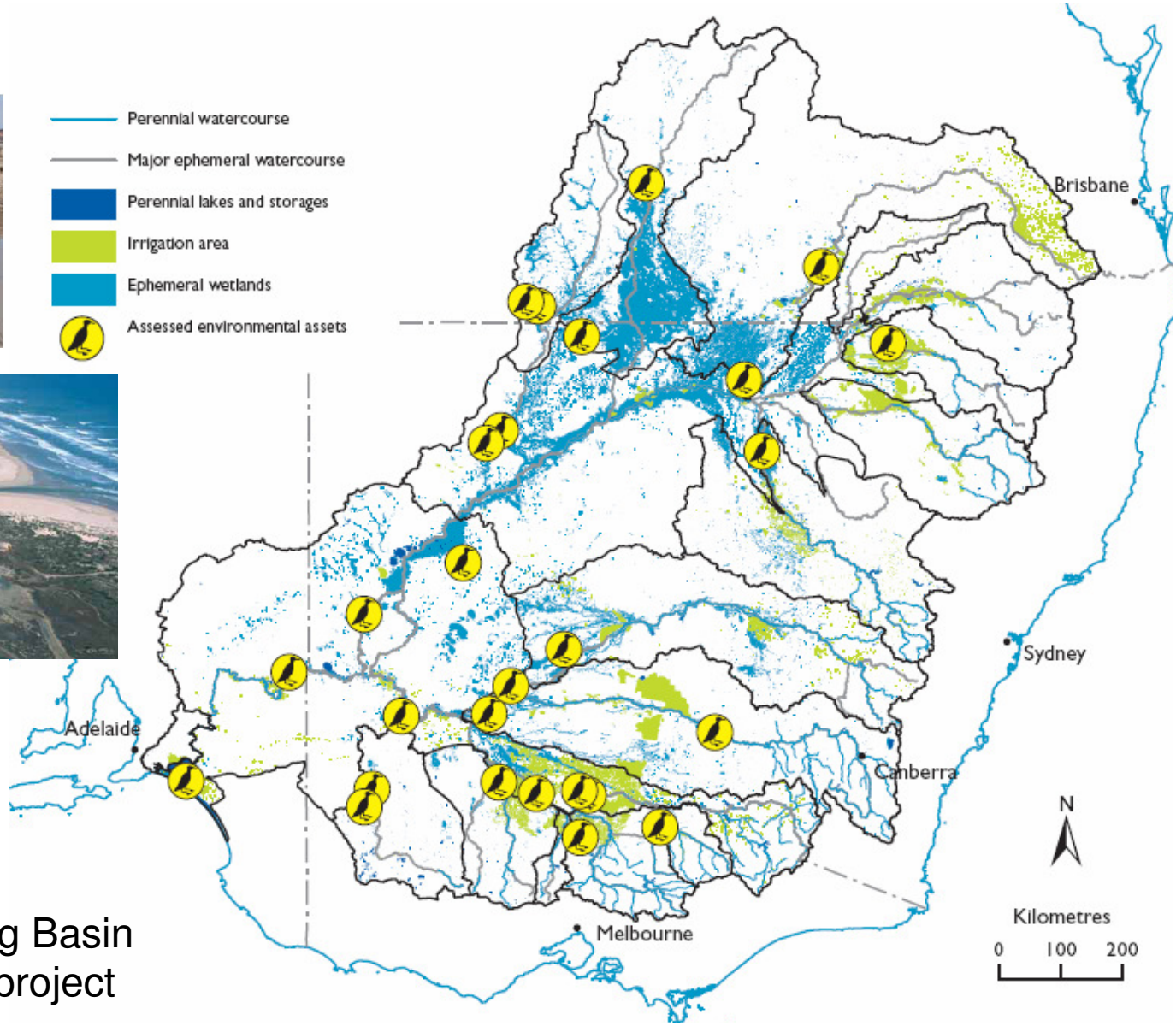
# M-D Basin

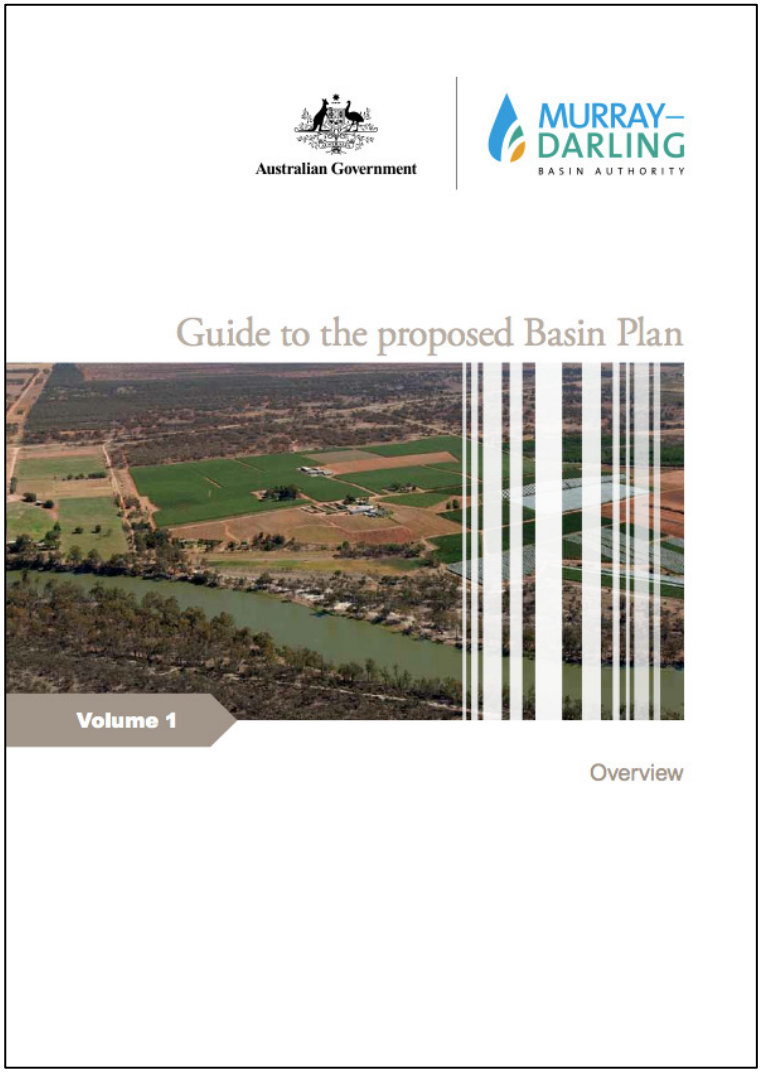
Murray River mouth in 2003




from: Murray-Darling Basin Sustainable Yields project

# MDBA Guide to the Plan – October 2010

- Released 8 October 2010
- To a storm of controversy
- Argues for increased allocations for environmental flows (i.e. less abstraction)



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# Why do we need continental water information?

***Managing water resources for security & efficiency of use requires deep insight & accurate monitoring & forecasting***

## Some questions asked:

- How much water was added to and taken from our rivers, dams and groundwater? How much is left?
- Who used water, for what, and were they entitled to it?
- How and why has our water situation changed?
- What is the effect of particular events and activities? (e.g. bush fires, plantation forestry, farm dams)
- How much new resource will become available over the weeks to decades ahead?

## Require reliable estimates of all water budget terms:

- water in the soil, groundwater, rivers, lakes, dams
- water use by dry land and irrigated agriculture, forestry, environment, mining, industry and households
- water losses to inefficiencies (evaporation)
- Inputs from precipitation

## Information needs to be provided:

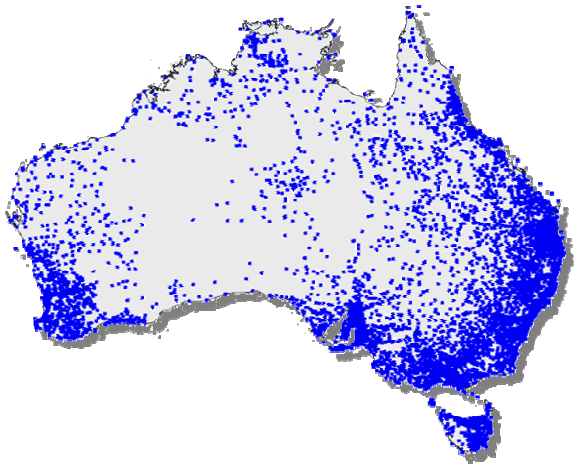
- nationally, but with local credibility and relevance
- best possible quality, with understood and minimised uncertainty
- without delay (near-real time)

# Why is this information not already there?

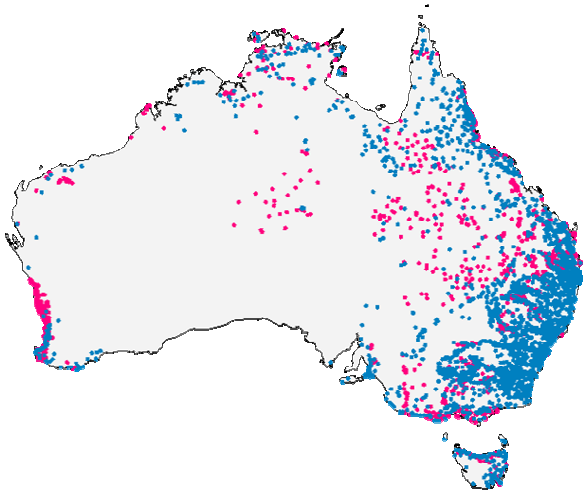
***Currently, this level of information does not exist anywhere in the world – for several reasons.***

**In Australia, until a few years ago:**

- Water resource crises were mostly local and domain of state agencies.
- Research focused on scenario and design questions, not resource monitoring.
- On-ground networks very sparse and run by >200 different organisations.
- Earth observation immature and underutilised for water resources monitoring.
- Models and observation data treated largely separately (calibration only).



Rainfall gauging network



Surface and ground water gauging networks

# Can we now address this challenge?

**Pathway:**

- Bureau of Meteorology Water Information division was created.
- collates all relevant observations and delivers information services.

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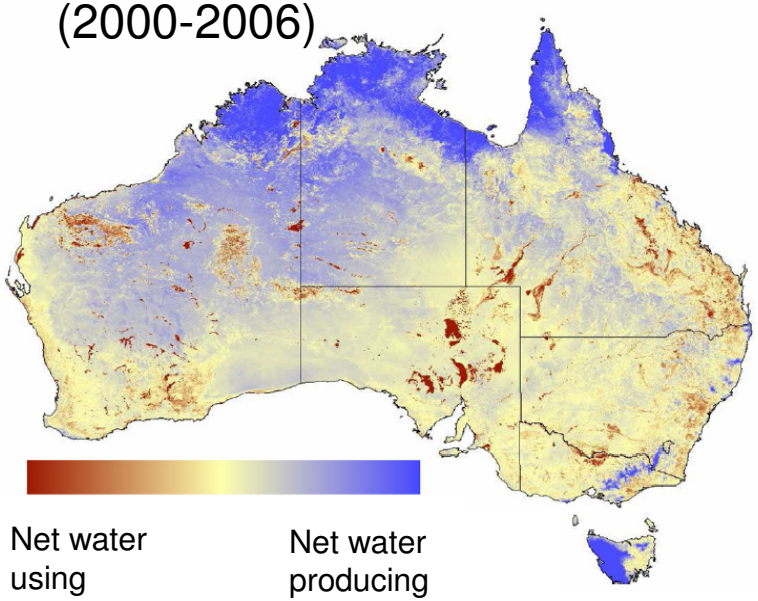
*//www.bom.gov.au/water/*

**Science:**

- *satellite observation* has matured sufficiently for water monitoring.
- advances in combining models with observations: *model-data fusion*.

Water balance across Australia (2000-2006)




**Resourcing**:

- 40 FTE, 5-year ***water information research and development alliance (WIRADA)*** between Bureau and WfHC.

*www.csiro.au/partnerships/WIRADA.html*

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# Water Information R & D Alliance (WIRADA)
# Four project areas

1. **Water Informatics**
   - Hydrologist workbench
   - Australian Hydrological Geospatial Fabric Design
   - Water Data Transfer Standards
2. **Foundation data**
   - SRTM Digital Elevation Model
   - Precipitation and Actual Evapotranspiration Products *
3. **Water Resources Assessment and Accounting ***
4. **Water Forecasting**
   - Flood and short-term water forecasting
   - Seasonal and long-term forecasting

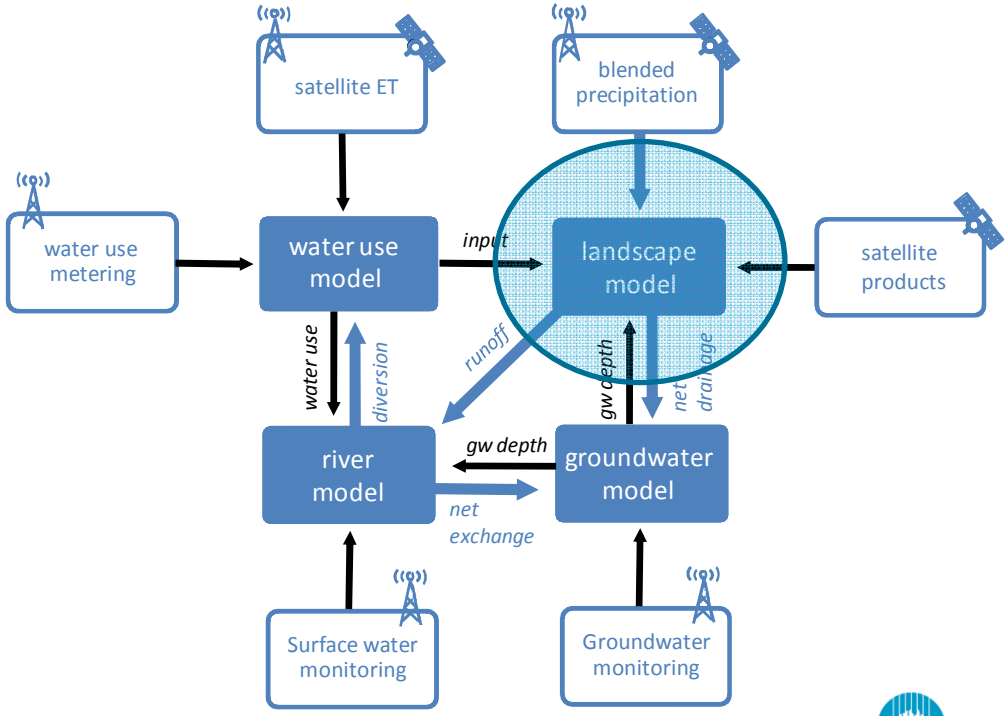
# Australian Water Resources Assessment (AWRA) model development

## Aim

***To reconstruct entire water balance for the whole of Australia with an accuracy acceptable for water resource management***

## System specifications

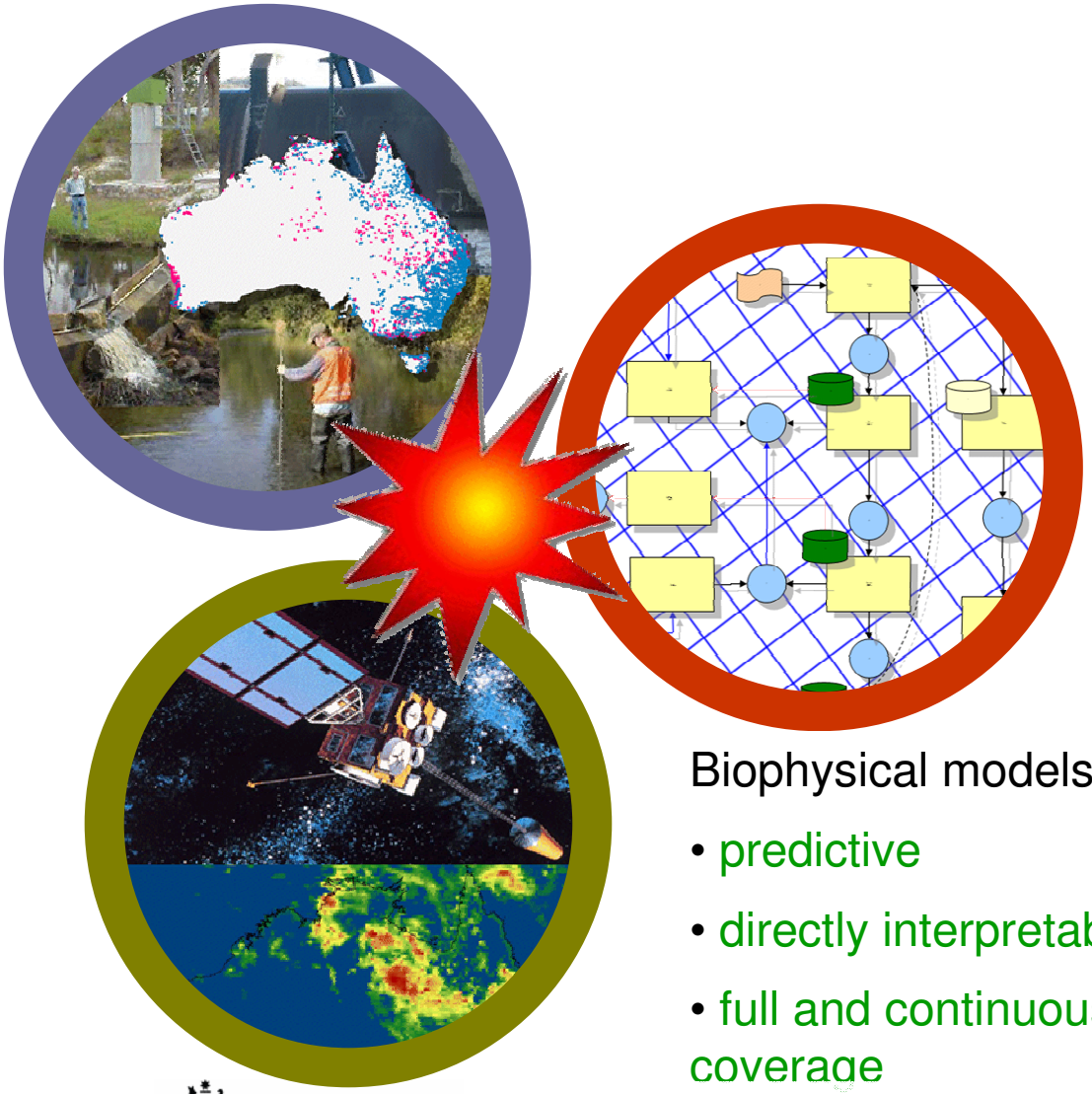
- Continental coverage
- Local accuracy and relevance
- Confidence through using all relevant observations
- Up to date and insightful information
- Technology and theory that is robust, benchmarked and evolving
- Integrates ground and satellite observations from the outset



# Model-data fusion – best of three worlds

On-ground observations

- *relatively* direct
- sparse and/or infrequent
- not predictive



Satellite observations

- full and frequent coverage
- *relatively* indirect
- not predictive

Biophysical models

- predictive
- directly interpretable
- full and continuous coverage
- unhindered by reality

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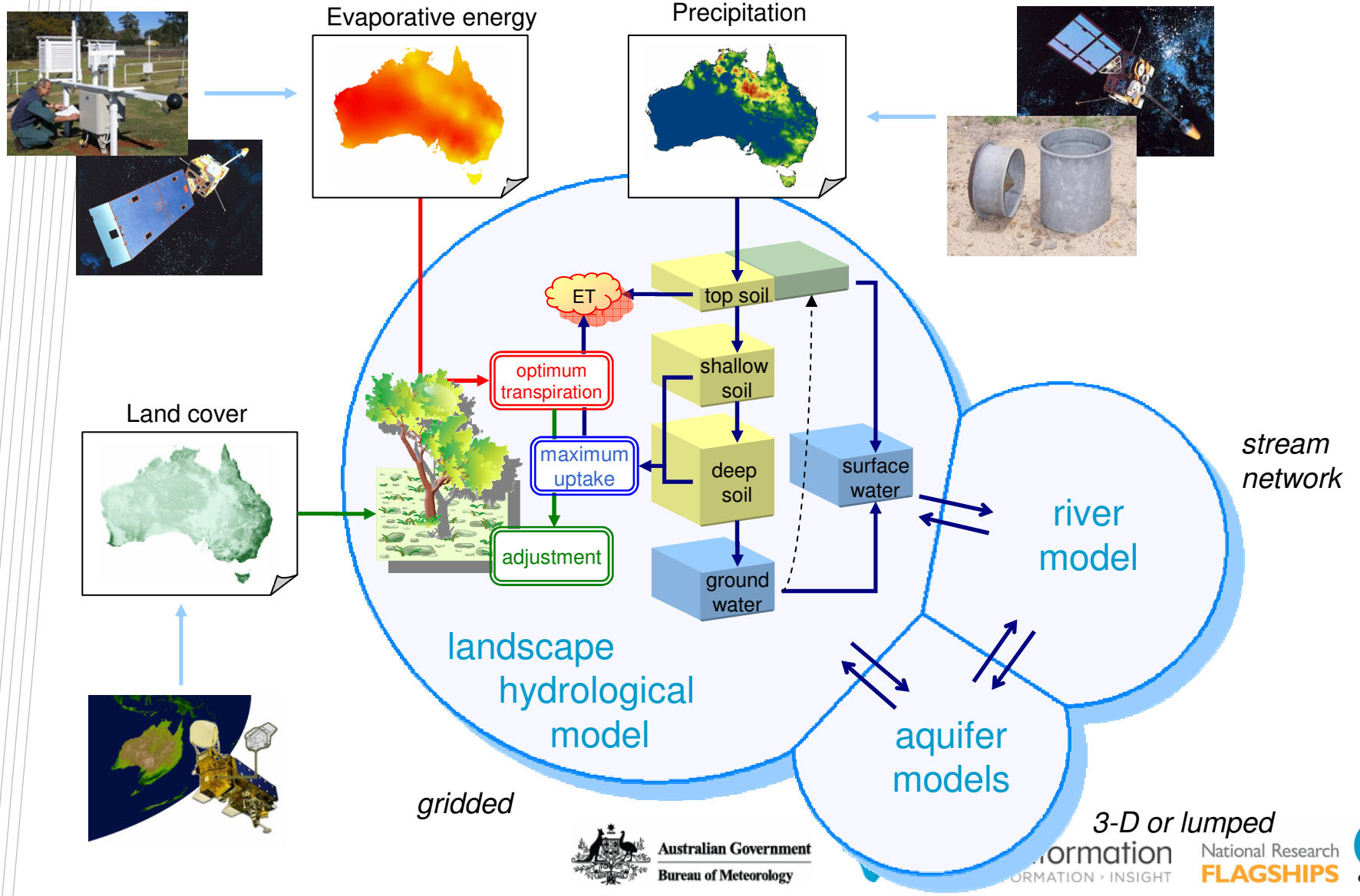
# AWRA system *version* 0.5

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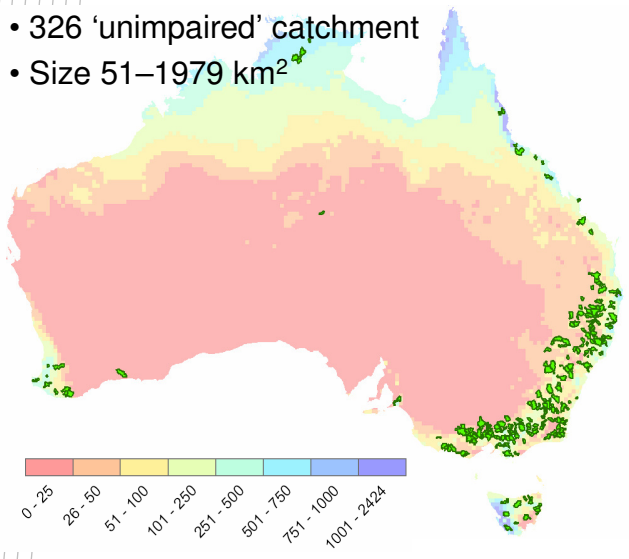
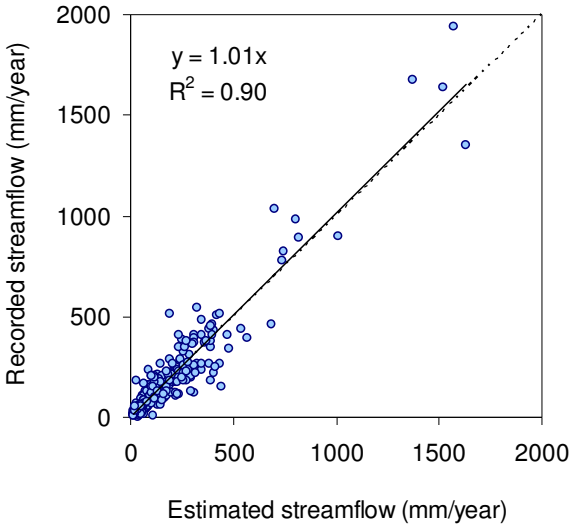
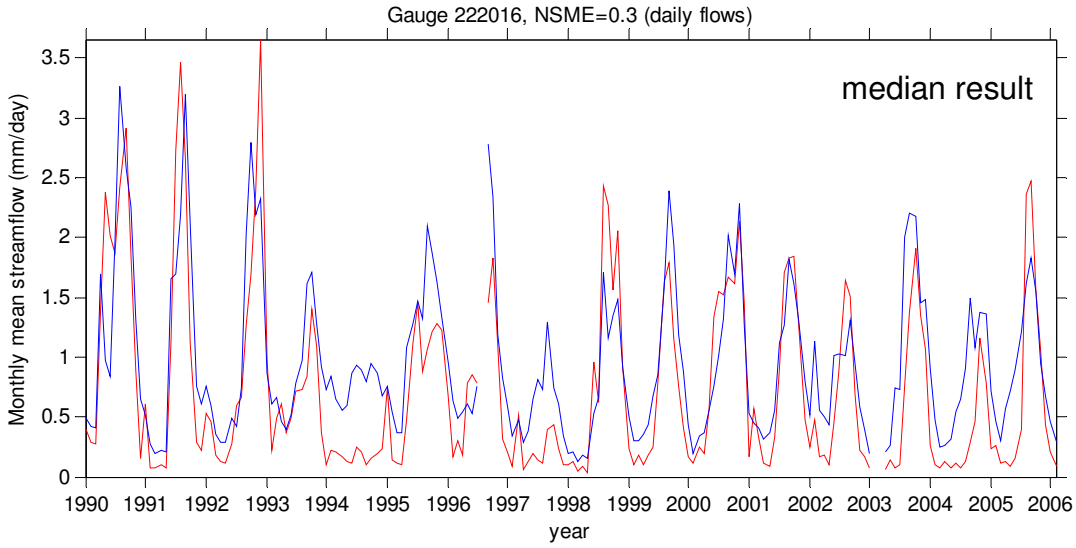
# Example 1: Streamflow from test catchments

- 326 'unimpaired' catchment
- Size 51–1979 km$^2$



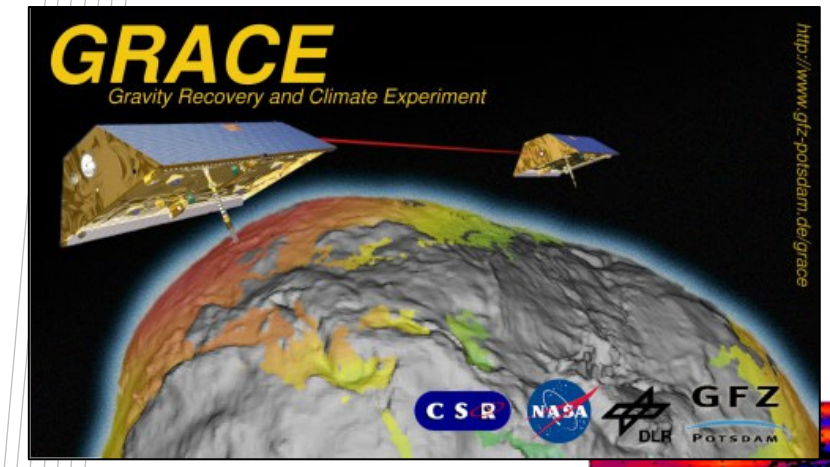




**Results (without parameter optimisation):**

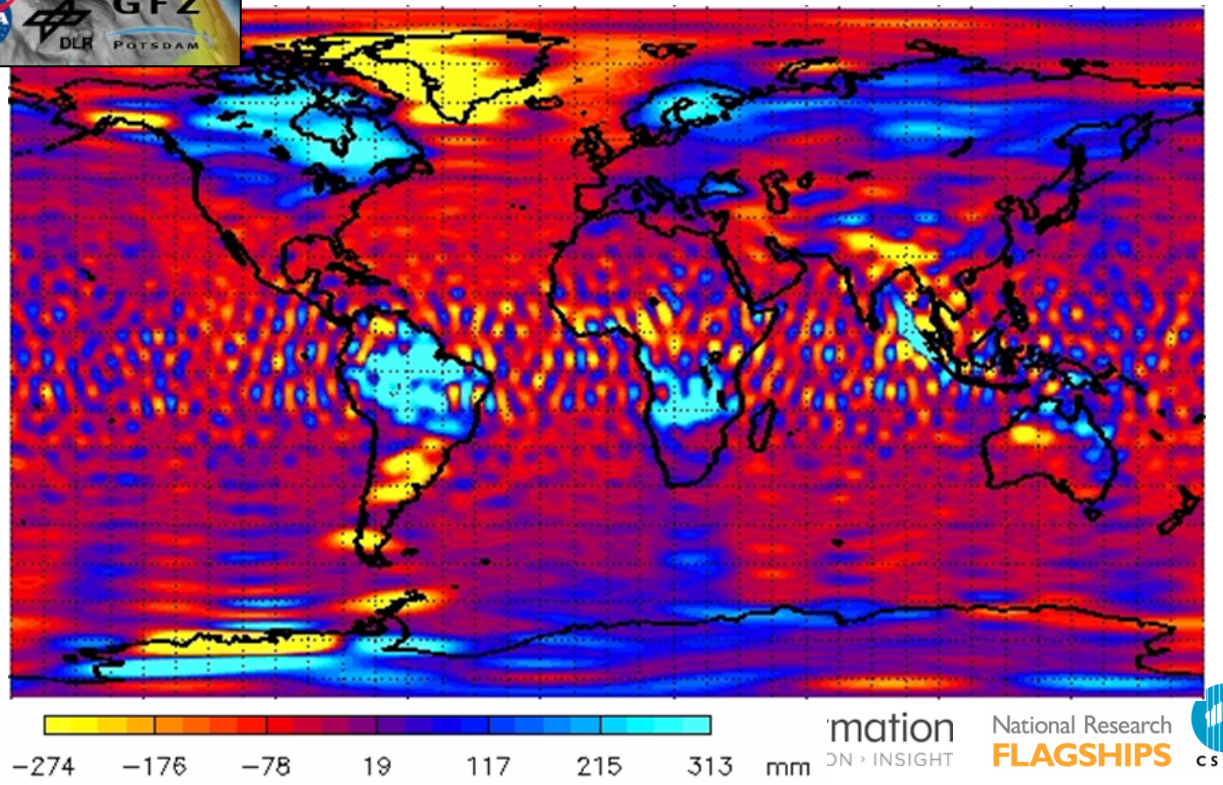
- No bias in the estimates
- Relative and absolute agreement for years and means as good or better (±20%) than achieved previously (e.g. MDBSY)
- Suitable for use in accounting and assessment
- Daily to monthly patterns can be improved through more elaborate 'regionalisation'
- Formal benchmarking experiment underway that involves other rainfall-runoff models

# Example 2:
# **G**ravity **R**ecovery **A**nd **C**limate **E**xperiment




Satellite mission that can measure total terrestrial water storage over large areas

Anomaly for April 2009




*source://geoid.colorado.edu/grace/grace.php*

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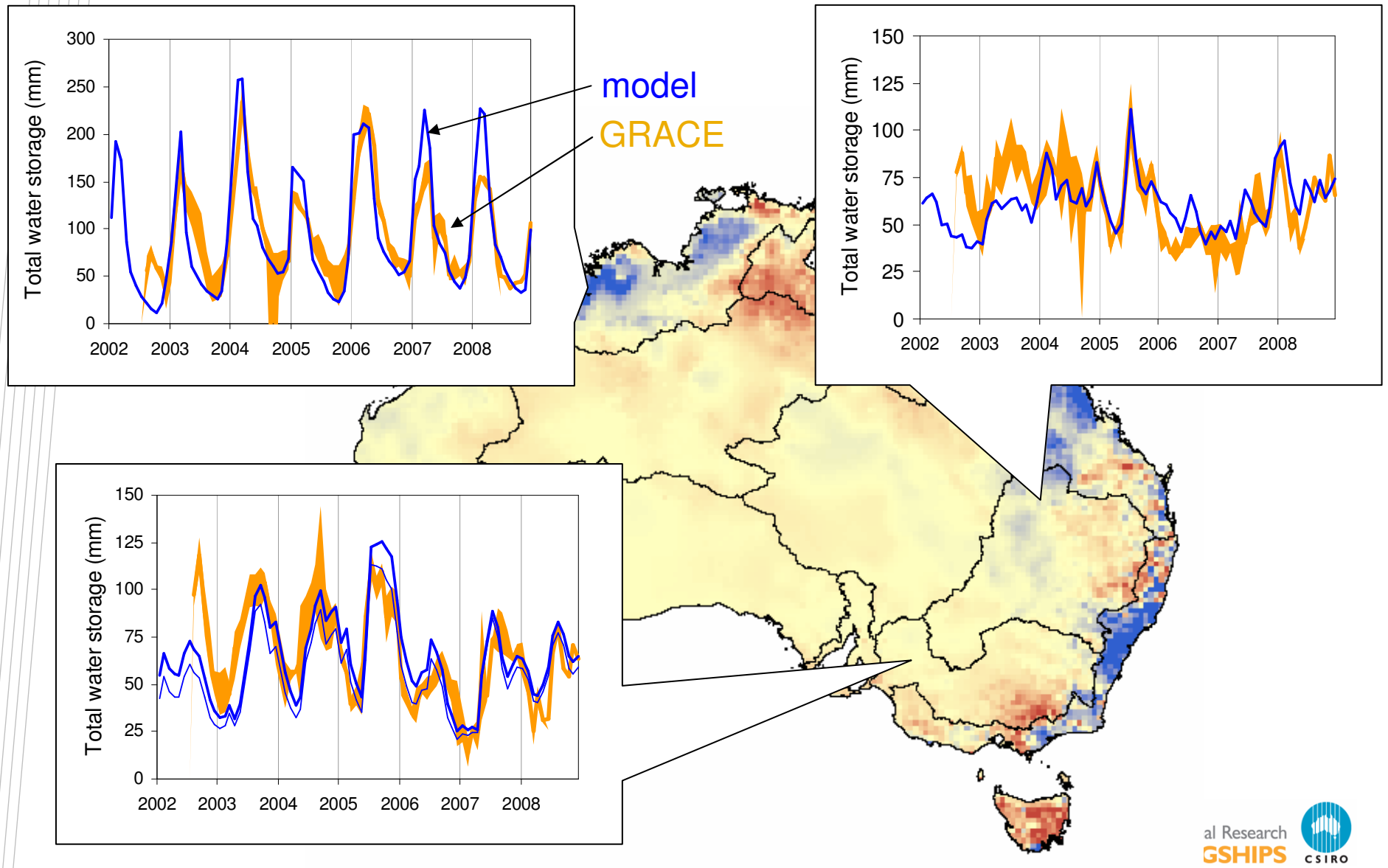
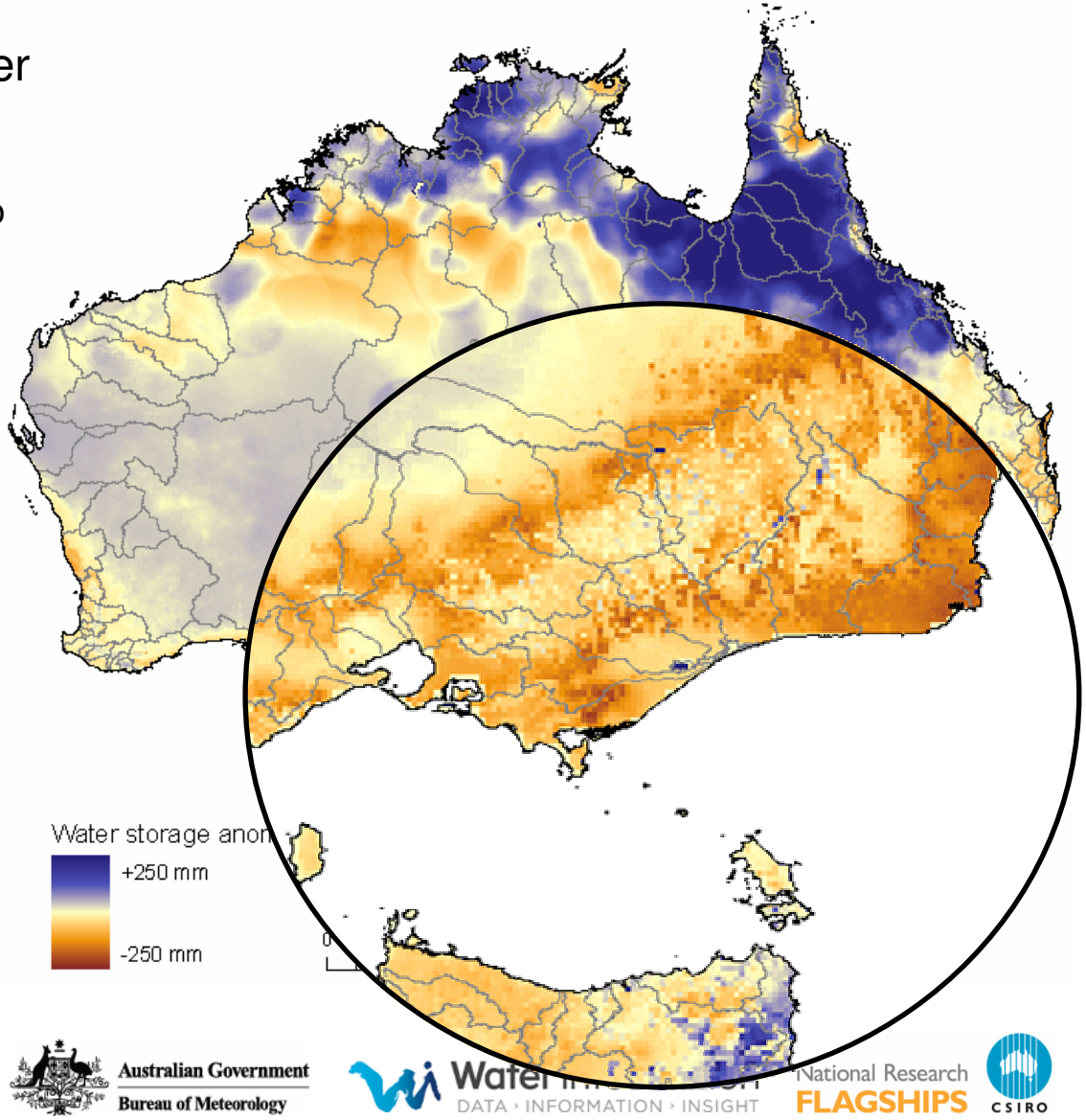
# Example 2:
# **G**ravity **R**ecovery **A**nd **C**limate **E**xperiment



# Example report: Current total water storage

1 February 2010 - total water storage

Total soil and ground water storage combined, as anomaly compared to average for this day for 1980-2008

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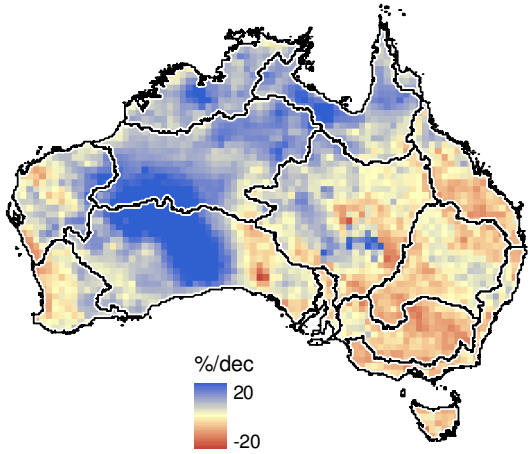
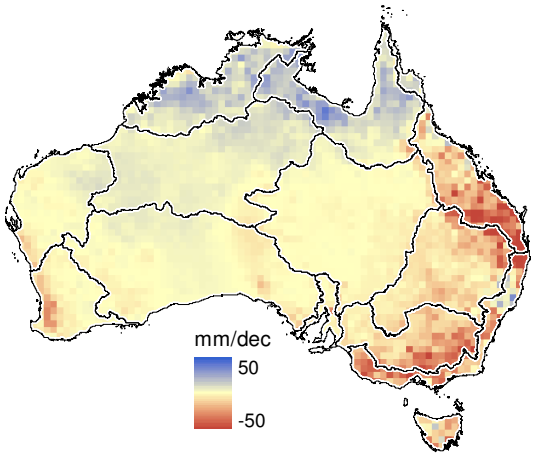
# Example output: hydrological trends (AWRA, 1980-2008)

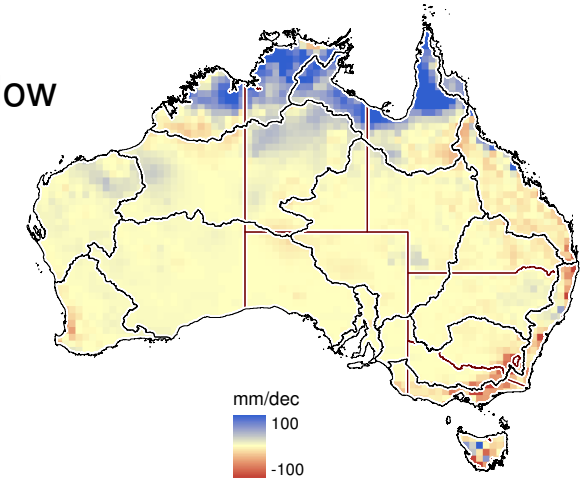
Rainfall (input)

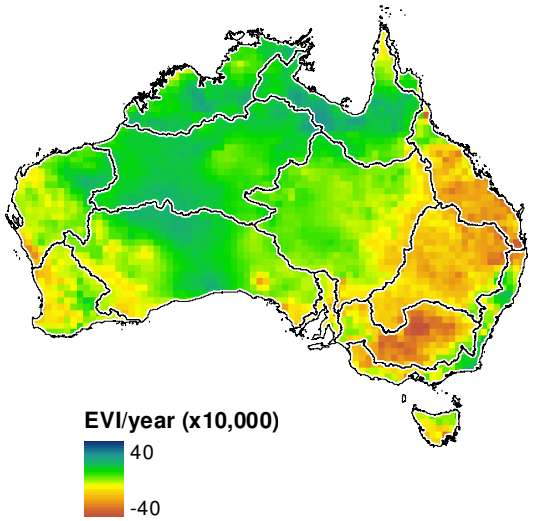



Soil & ground-water storage

Streamflow




Vegetation greenness (Enhanced Vegetation Index, EVI)

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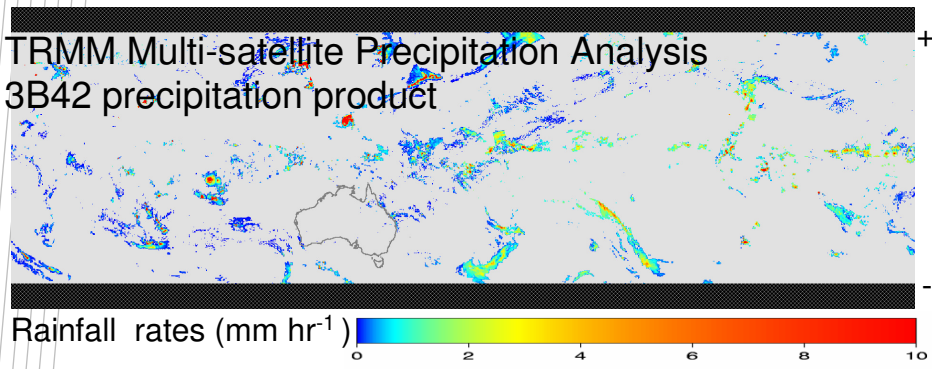
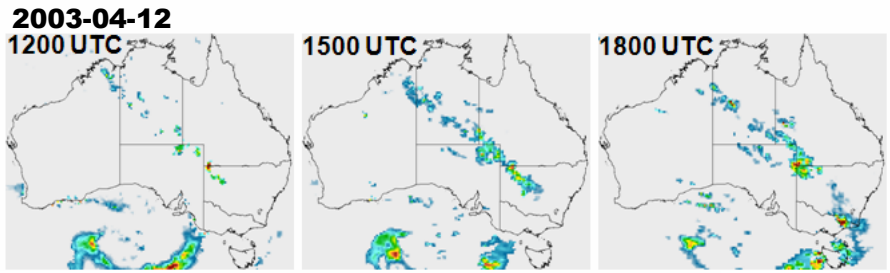
# Blending gauge and satellite-based precipitation for continental water (& energy) balance modelling

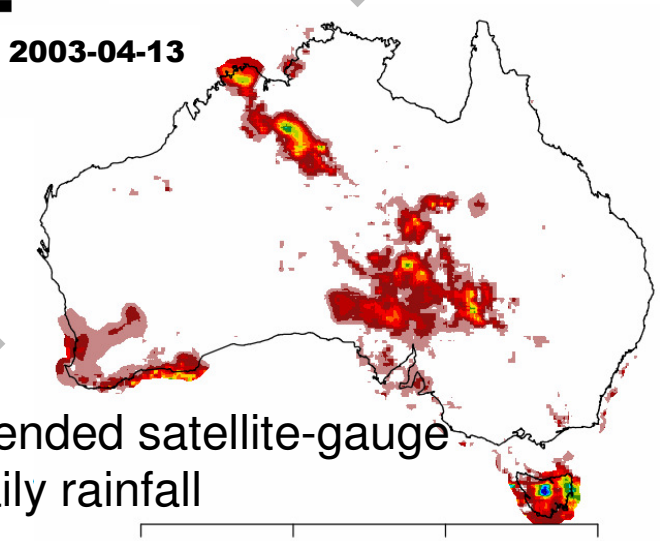
Quasi-global satellite-based precipitation products

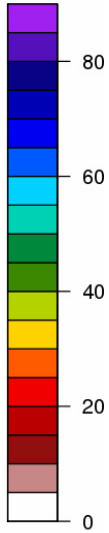


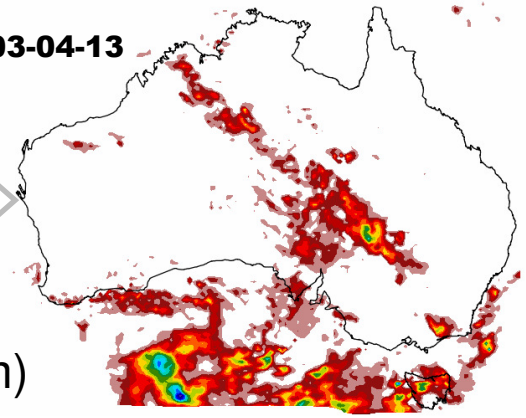

NCC Daily rainfall observations

Australian subset




Daily rainfall estimates (24 hr to 9am)

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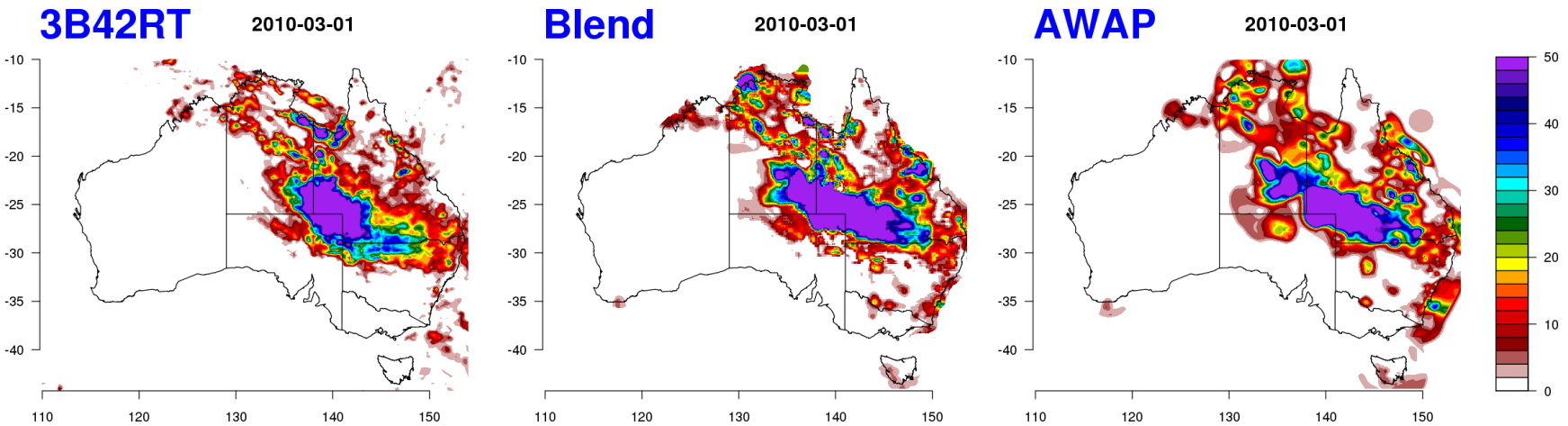
Blended satellite-gauge daily rainfall

# Near real-time implementation of Li & Shao Blending algorithm

- 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 (TMPA, CMORPH)
  - * Needs objective quantitative assessment of accuracy

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# Vegetation Fractional Cover products

- Vegetation fractional cover
  - Knowledge of cover, important for a range of applications:
    - Water use, wind and water erosion
    - Management practices
  - Previous work focused on the discrimination of **tree** and **grass** proportions by decomposing greenness
  - Ignored non-photosynthetic vegetation component, which is dynamic in space and in time and important
    - Carbon, water, energy modeling
    - Fire risk
    - Soil erosion
    - Grazing management

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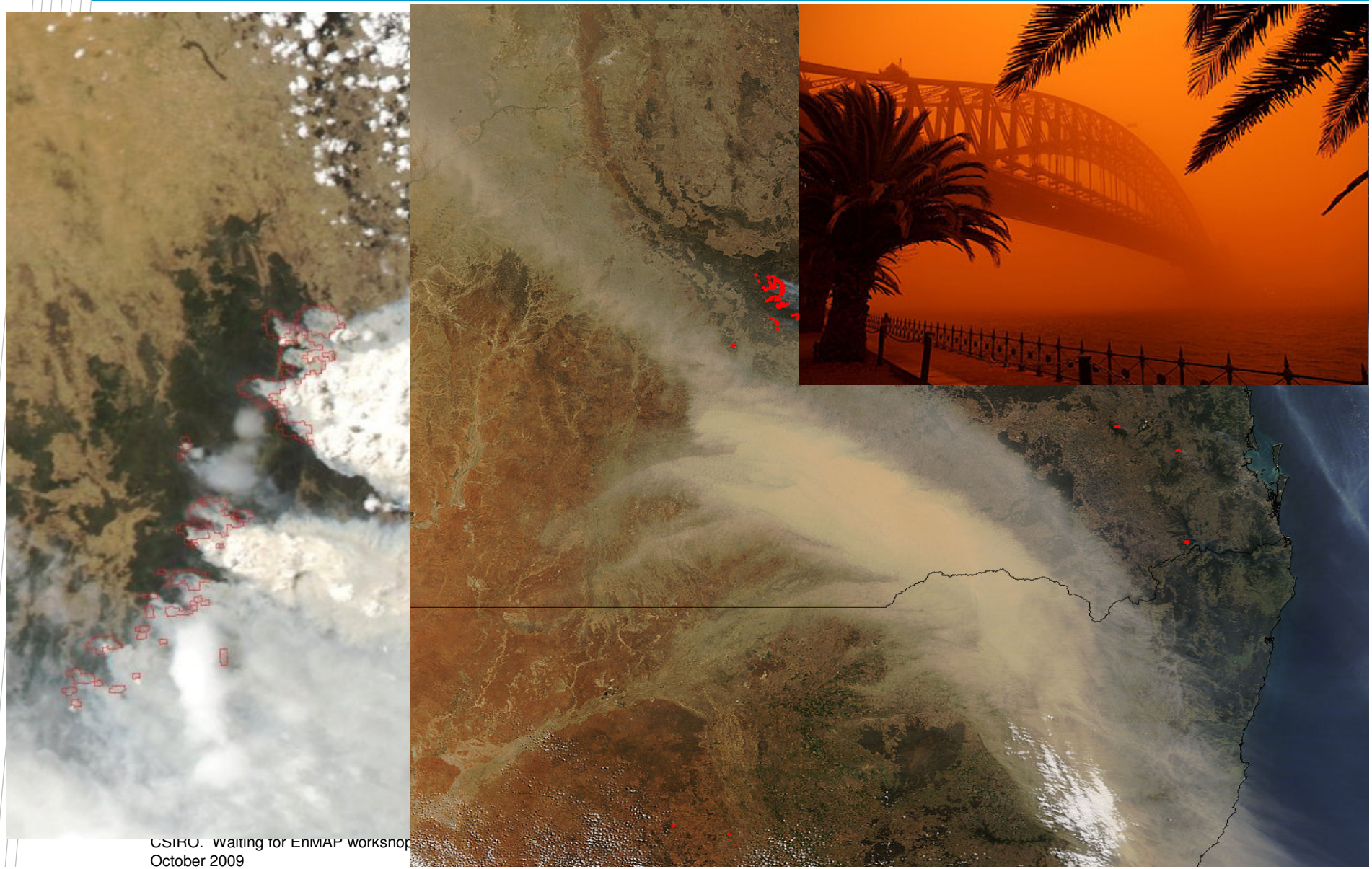
# Links between state of surface cover and major events, effects on water

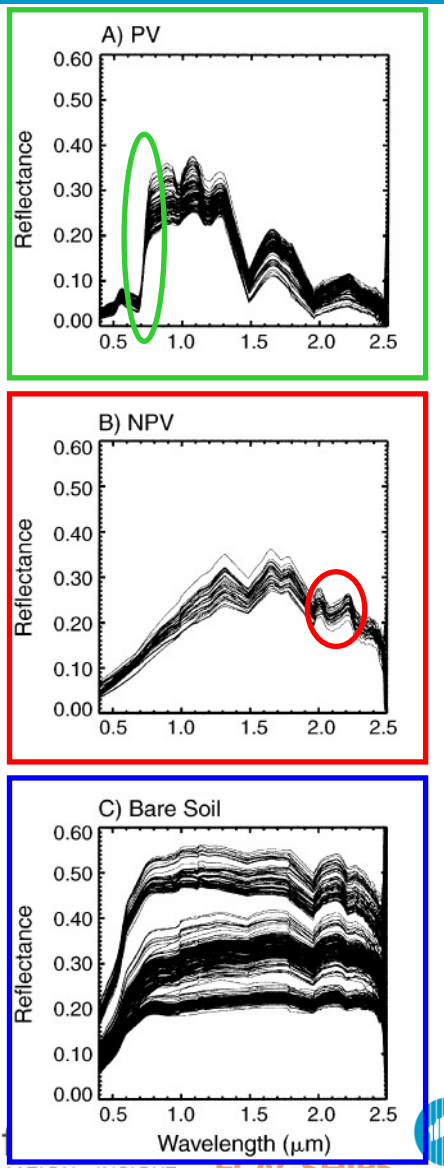


# Background - theory

- Spectral characteristics of PV, NPV and BS

  - **Photosynthetic Vegetation**: has an spectral feature at 600-800 nm (chlorophyll)
    **Non-Photosynthetic Vegetation**: has a feature at 2000-2200 nm (cellulose and lignin)
    **Bare Soil**: does not have any of the above

  - Two indices can quantify these features:
    - Normalised Difference Vegetation Index
      NDVI= ( ρ800 − ρ680 ) / ( ρ800 + ρ680 )
    - Cellulose Absorption Index
      CAI= 0.5·( ρ2000 + ρ2200 ) − ρ2100




Asner et al. 2003



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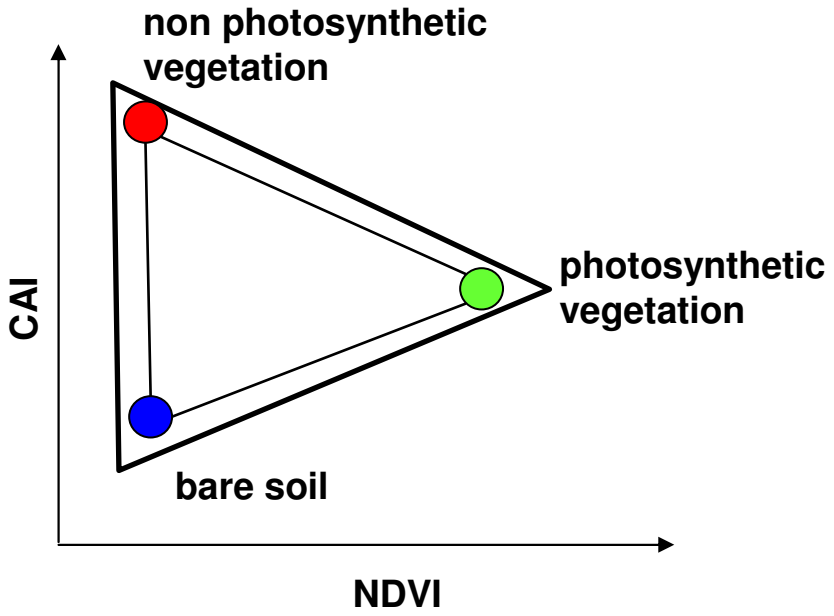
# Background - hypothesis

- Hypothesis:
  - The fractional cover of PV, NPV and Bare Soil in a “pixel” can be determined according to the position of its spectra in the space defined by the CAI and the NDVI. “Pure” pixels will be located close to the vertices of the triangle while “mixed” pixels will be located inside the triangle.
  - The vertices of the triangle can be considered “endmembers” and a linear unmixing can resolve the relative proportions of PV, NPV and S for the pixels contained in the triangle.



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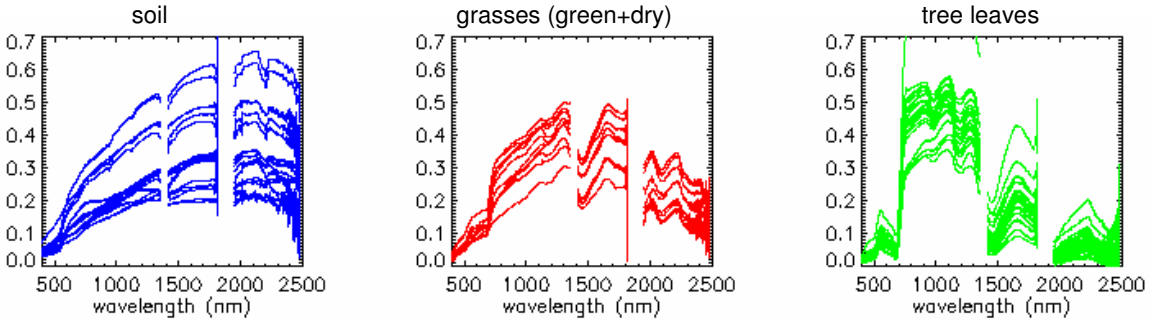
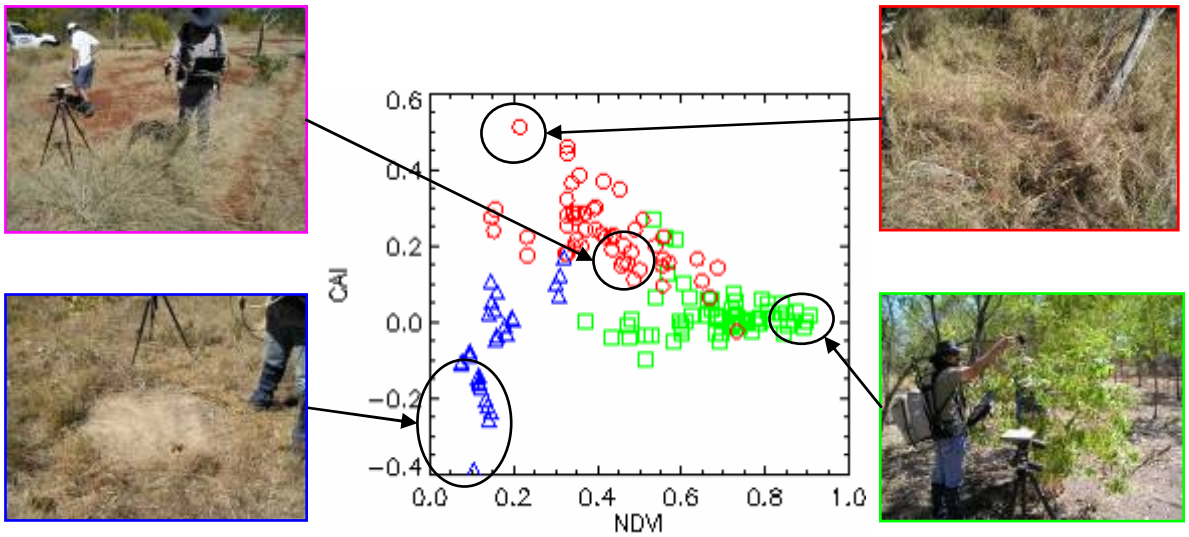
# Field measurements

- July 2005 NT data supports the idea that using NDVI and CAI allows to separate the PV, NPV and BS components



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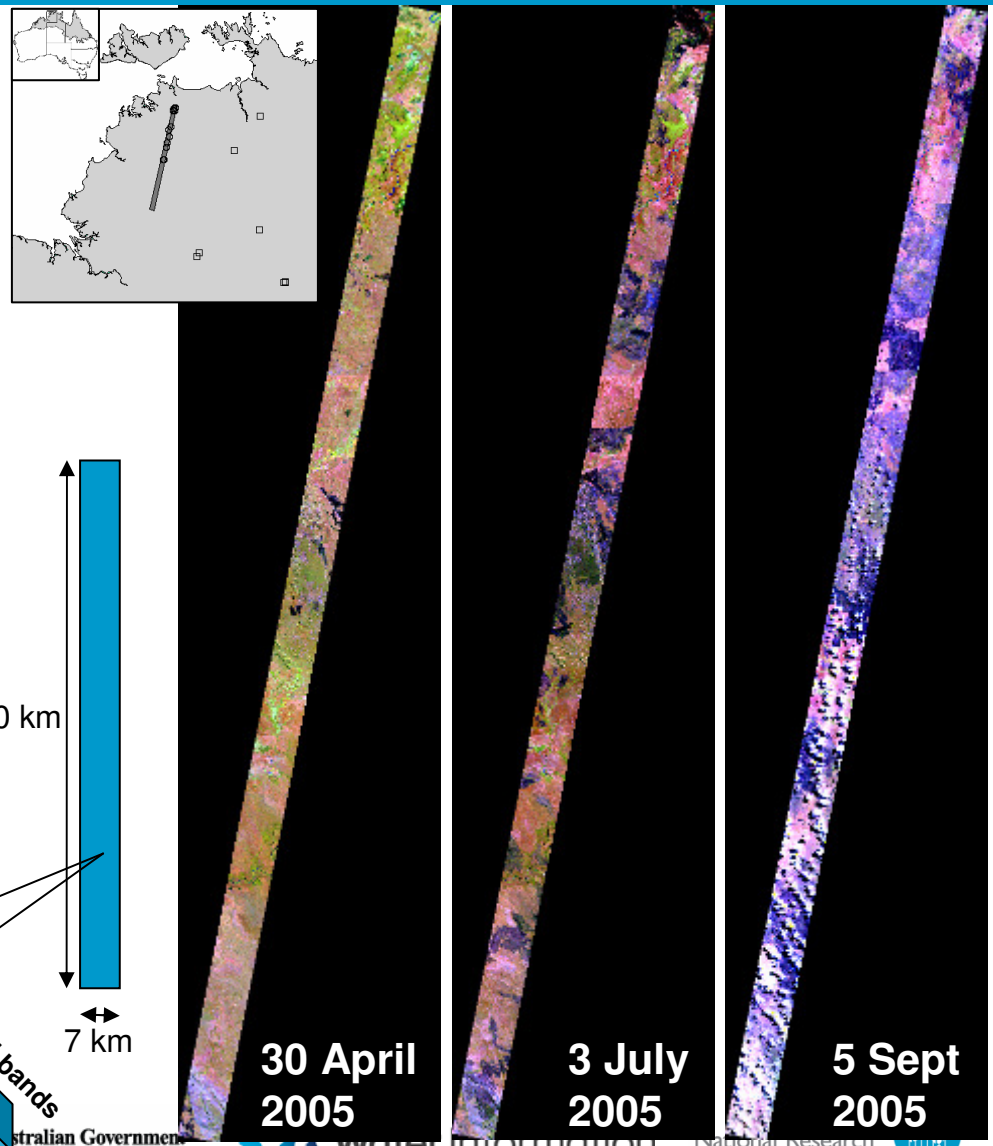
# Scaled to Hyperion data

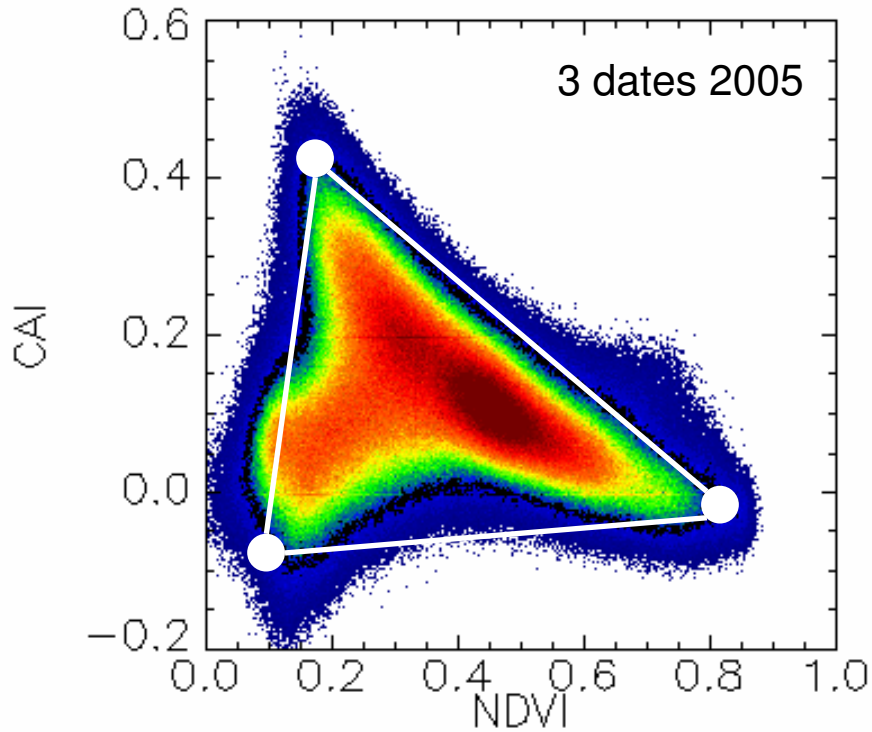
- Hyperion imagery:
  - 3 EO-1 Hyperion images acquired in 2005
  - 30 meters, 149 spectral bands (400-2400 nm)
  - ACORN Atmospheric correction
  - Rectification and geolocation
  - Manually masked clouds (Sept image)
  - calculated NDVI and CAI



# Scaled to Hyperion data (cont)

- **Spectra from Hyperion, the effect of season:**
  - The distribution of the Hyperion pixels in the NDVI/CAI space form a “triangle”.
  - As the dry season advances, the pixels move to lower NDVI and increase their range in CAI.
  - NDVI and CAI values for the endmembers (“pure pixels”) derived from the images

    PV: NDVI=0.8, CAI=0
    NPV: NDVI=0.175, CAI=0.4
    S: NDVI=0.1, CAI=-0.1
    We applied a linear unmixing and forced those pixels falling outside the triangle to be equal to 0 (or 1)



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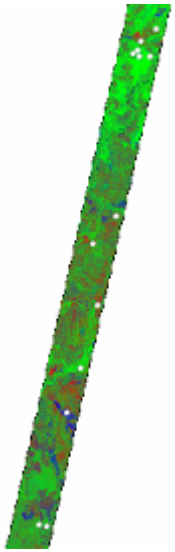
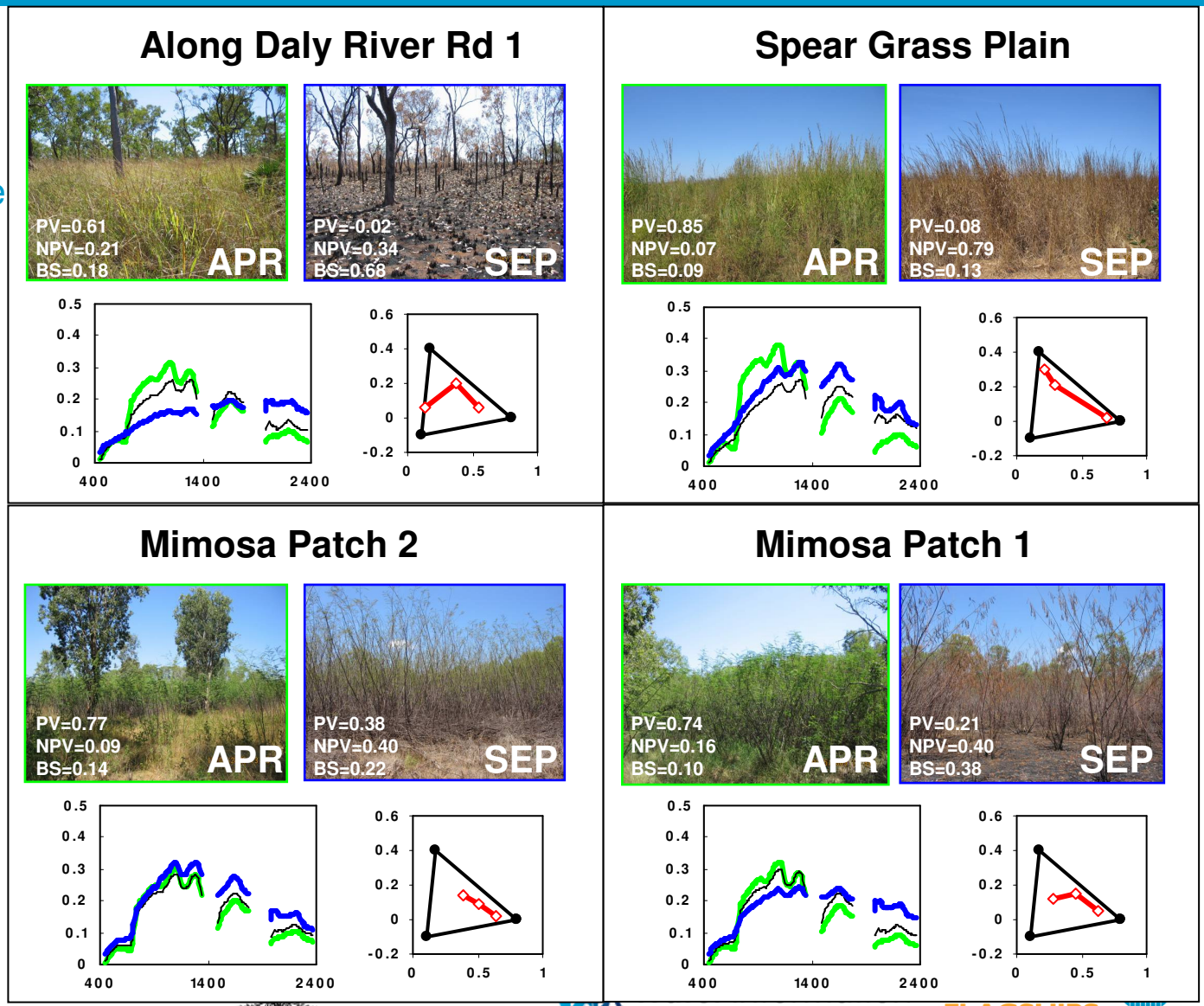
# Scaled to Hyperion data (cont)

Qualitative validation:

pictures taken at 12 sites concurrent with the Hyperion images. Four examples shown here





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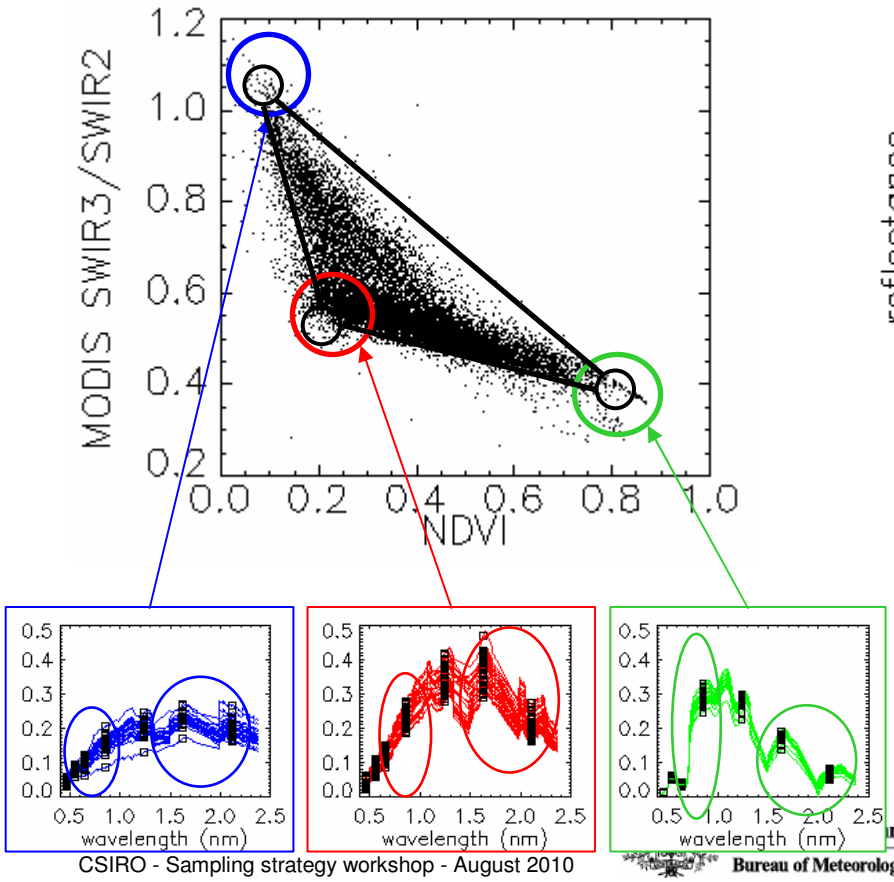
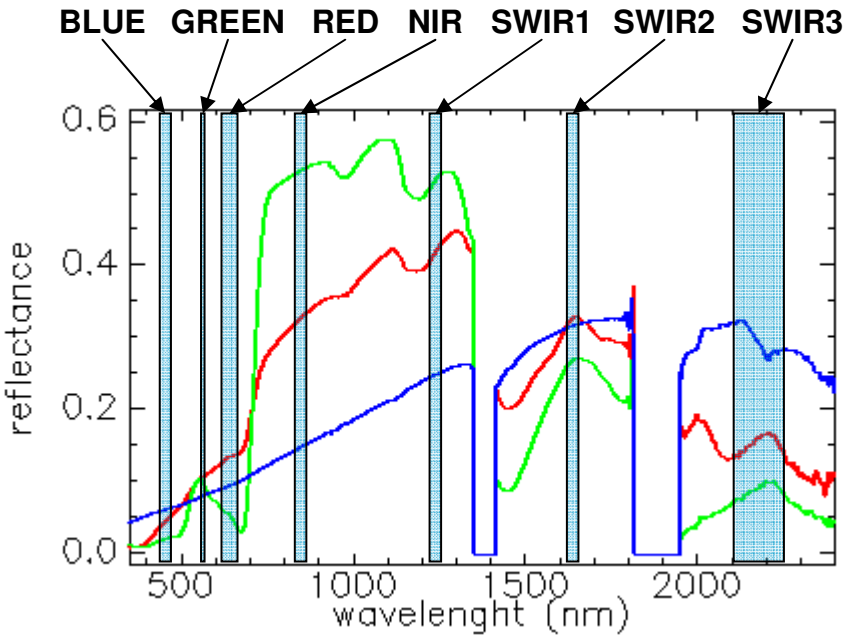
# Scaled to MODIS / Continent scale

- Needed to monitor fractional cover on a regular basis (weekly, monthly)
- MODIS can't measure CAI, need substitute for it



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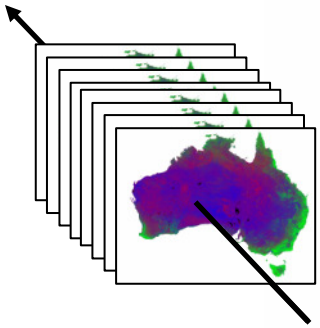
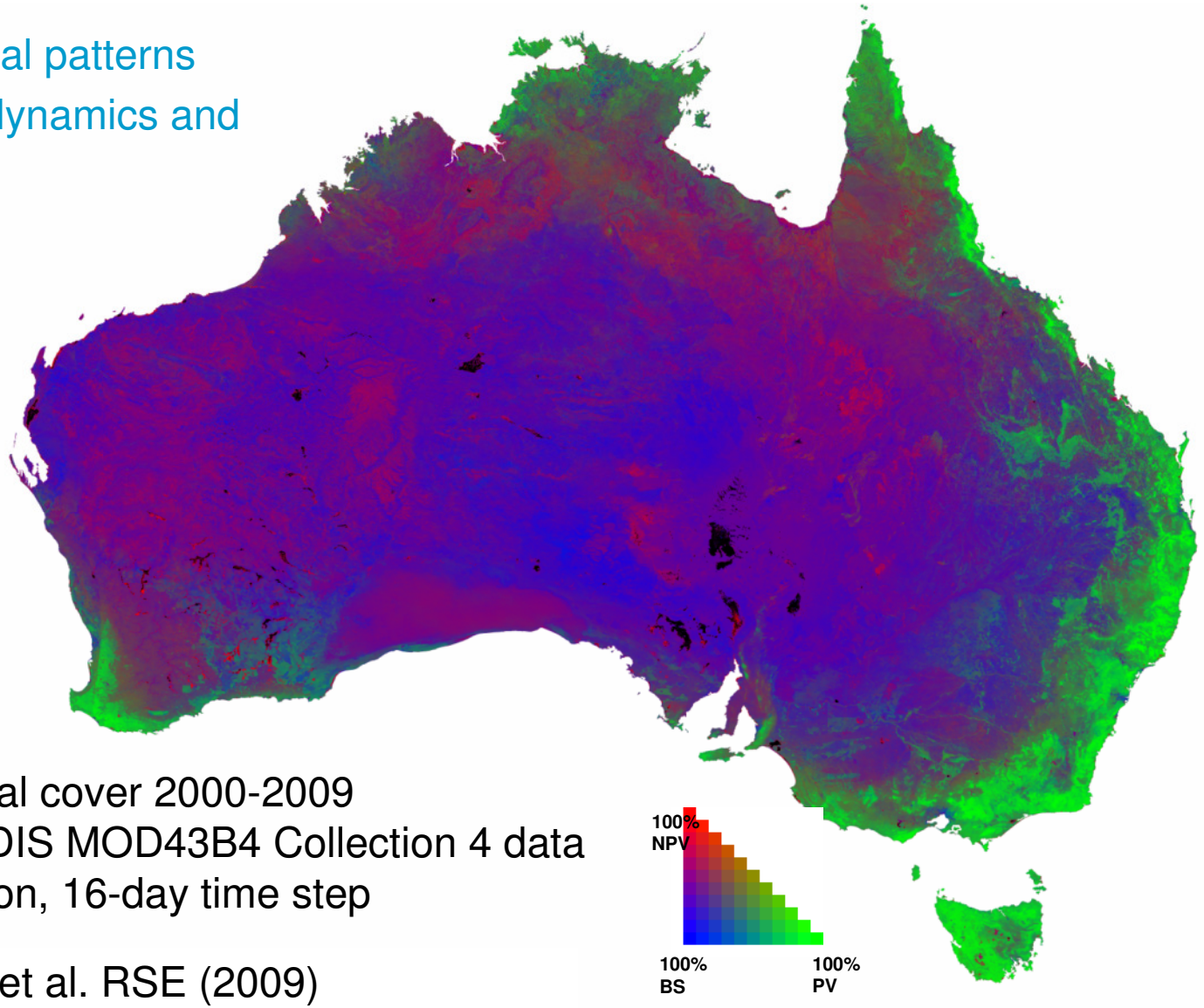
# Prototype operational product

- Mean spatial patterns
- Seasonal dynamics and trends



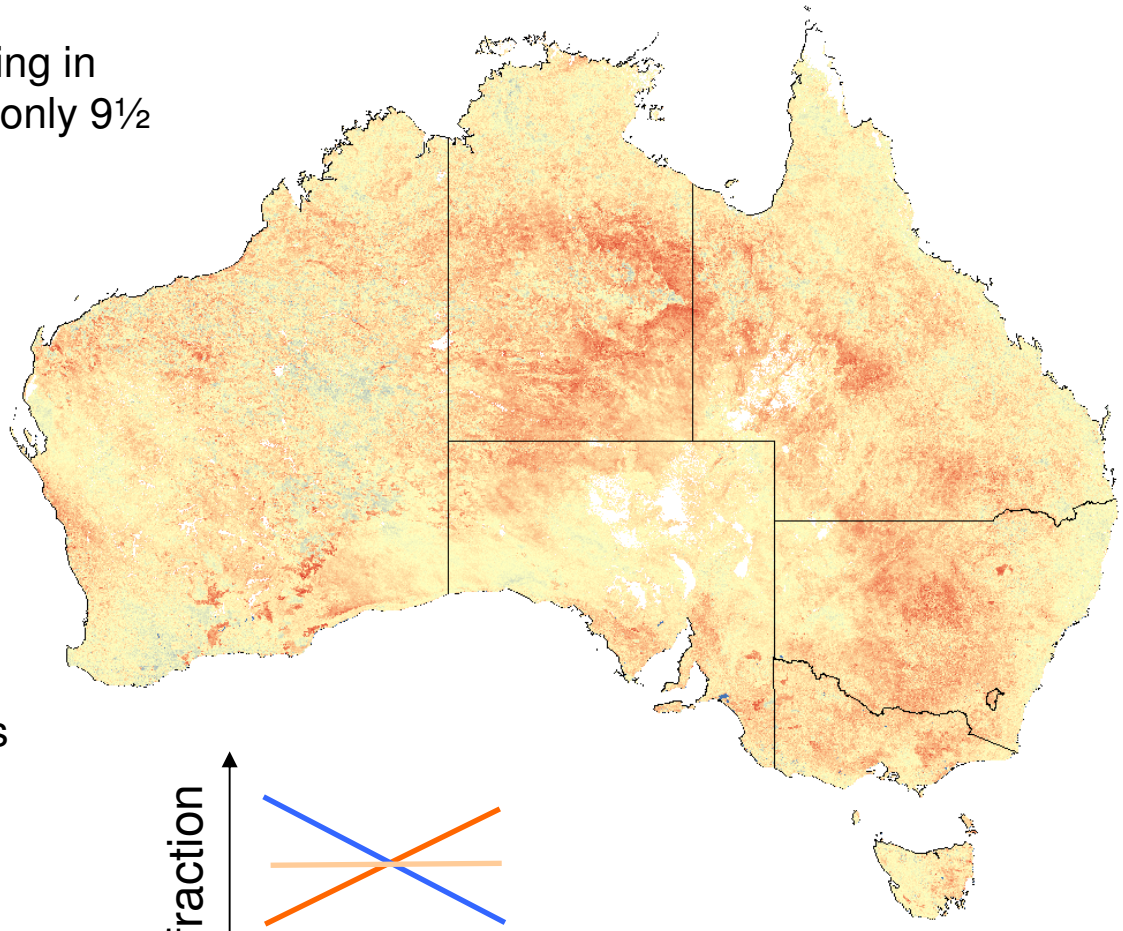


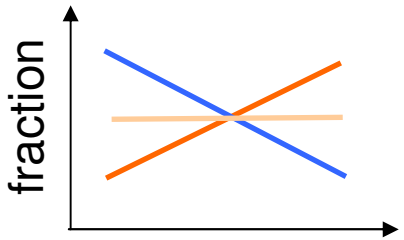

Mean Fractional cover 2000-2009
Based on MODIS MOD43B4 Collection 4 data
500 m resolution, 16-day time step

Guerschman et al. RSE (2009)

# Continental trends in fractional cover

- Linear slope of BS
  - Fractions of BS increasing in most of the continent? (only 9½ years here)
- Attributing changes in ground cover
  - Land management?
  - Wind/ water erosion?
  - Climate change?
  - $CO_2$ fertilisation?
  - Disturbances (fire)?
  - And all their interactions





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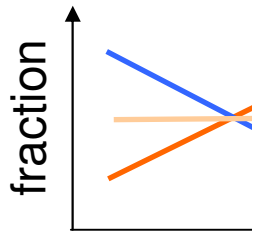
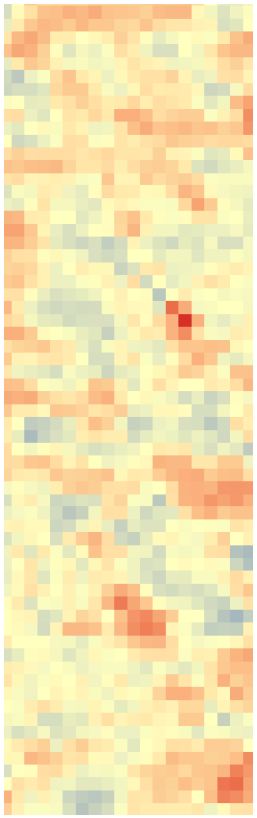
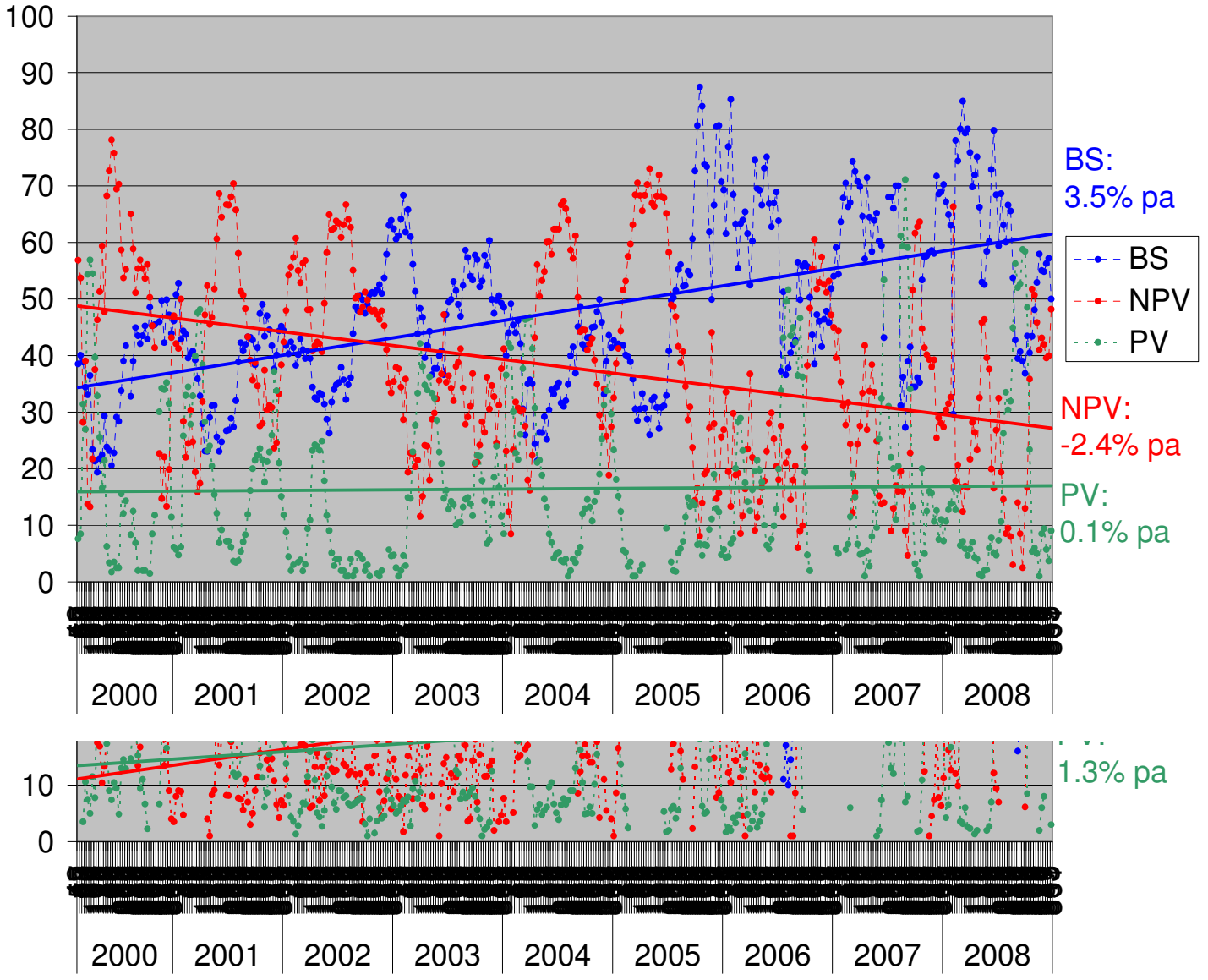
# Zooming in - Trends in bare soil fraction

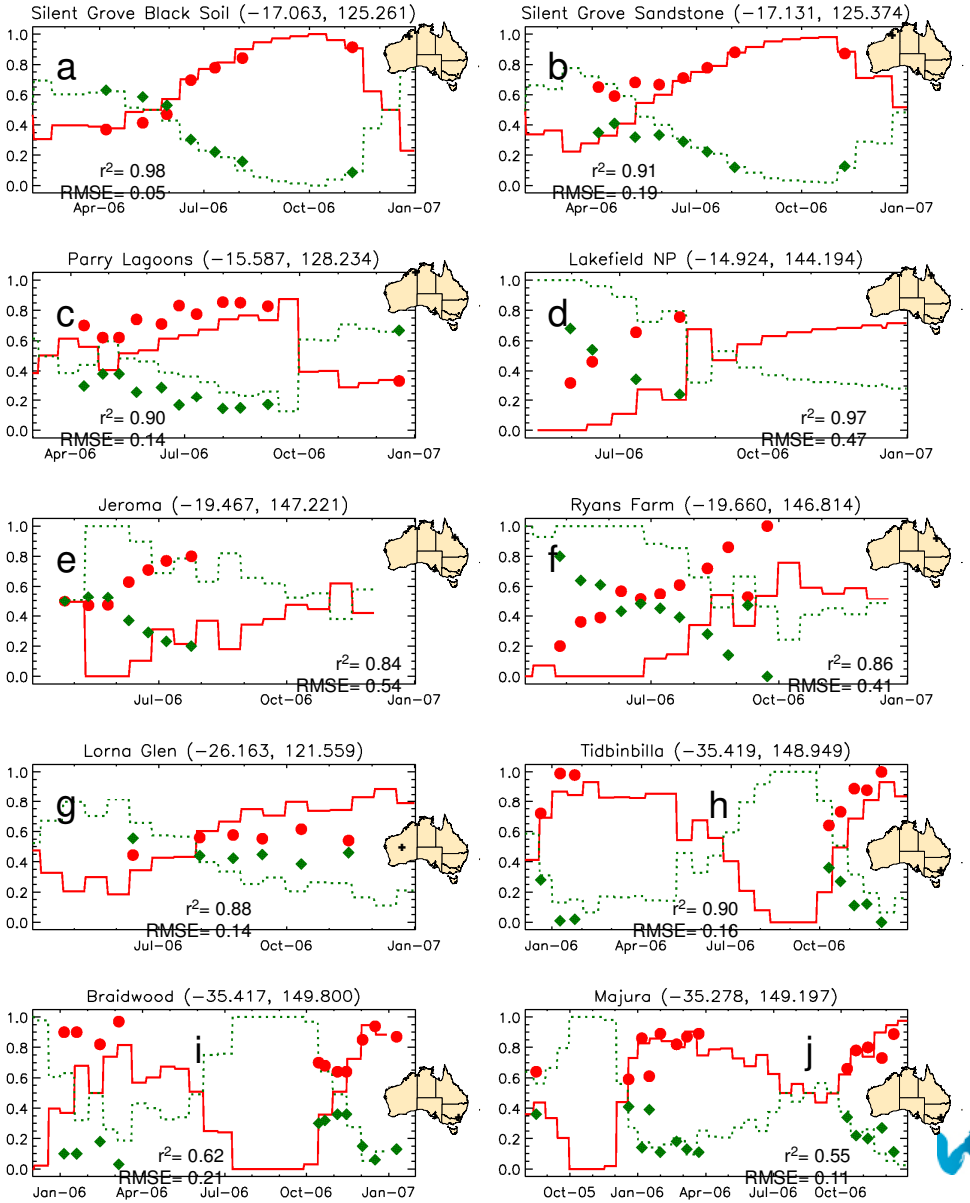


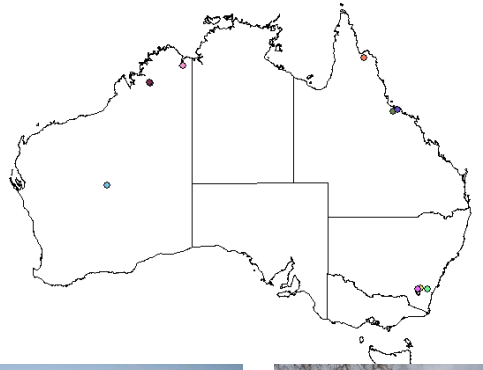



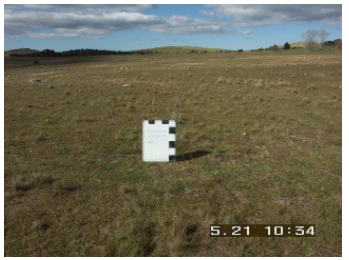
Fractional Cover – Juan

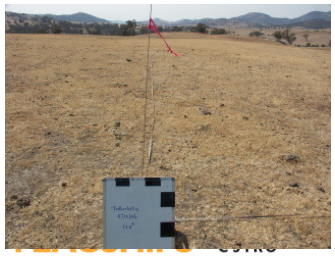


# Initial validation







# Further validation required

- What confidence can we apply to the product across the continent?
- Needs separate targeted quantitative validiation (beginning November 2010)
- What other factors might affect the algorithm?
  - Soil colour and moisture content
  - Vegetation colour
  - Canopy vertical structure (biomass, LAI)
  - Tree density?
- Research towards the development of a second version of the product



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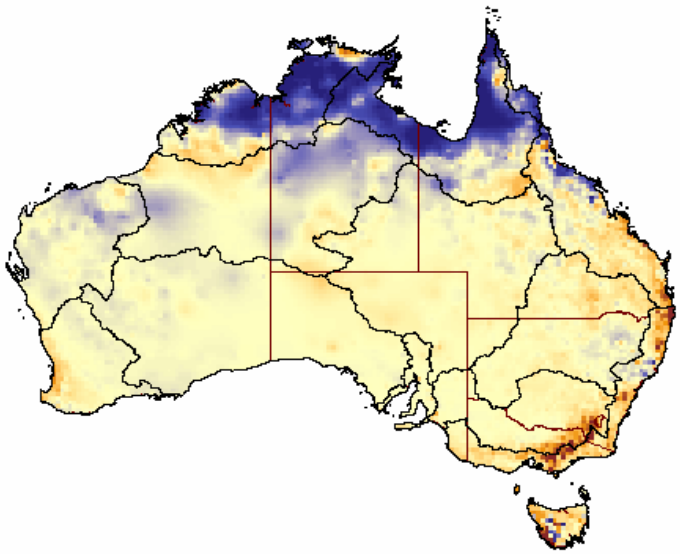
# Conclusions

- AWRA system combines on-ground and satellite observations with models to monitor the continental water balance, reproduces satellite and on-ground observations satisfactorily
- Model selection and decisions on appropriate complexity are guided by comparative performance testing
- Higher level system design allows for ongoing evolution (e.g. modular ICT, benchmark tests)
- More observations do not necessarily reduce uncertainty, much depends on the observational model
- Computational efficiency is still an important factor in operational MDF



# Conclusions (RS / Political perspectives)

- Reliance on optical data
- Under-reliance on other remote sensing approaches, especially SAR and Radar altimetry, Soil moisture

- Succession planning (MODIS and Landsat focus)
- MODIS will cease 2013? (NPOESS/VIIRS is a poor replacement)
- Landsat focus for higher resolution landscape products (data gap looming? LDCM?)

- Australia is wholly reliant on other countries for its RS data (and typically doesn't pay for it)
- Offers little in return (e.g. calibration)

**CSIRO Land & Water**
Dr Tim Malthus, Program Leader
Environmental Earth Observation
Email: Tim.Malthus@csiro.au

Dr Albert van Dijk, Stream Leader & Research Team Leader
Email: Albert.Vandijk@csiro.au

Dr Luigi Renzullo, Research Scientist
Email: Luigi.Renzullo@csiro.au

www.csiro.au

# Thank you

**Contact Us**
**Phone:** 1300 363 400 **or** +61 3 9545 2176
**Email:** Enquiries@csiro.au **Web:** www.csiro.au

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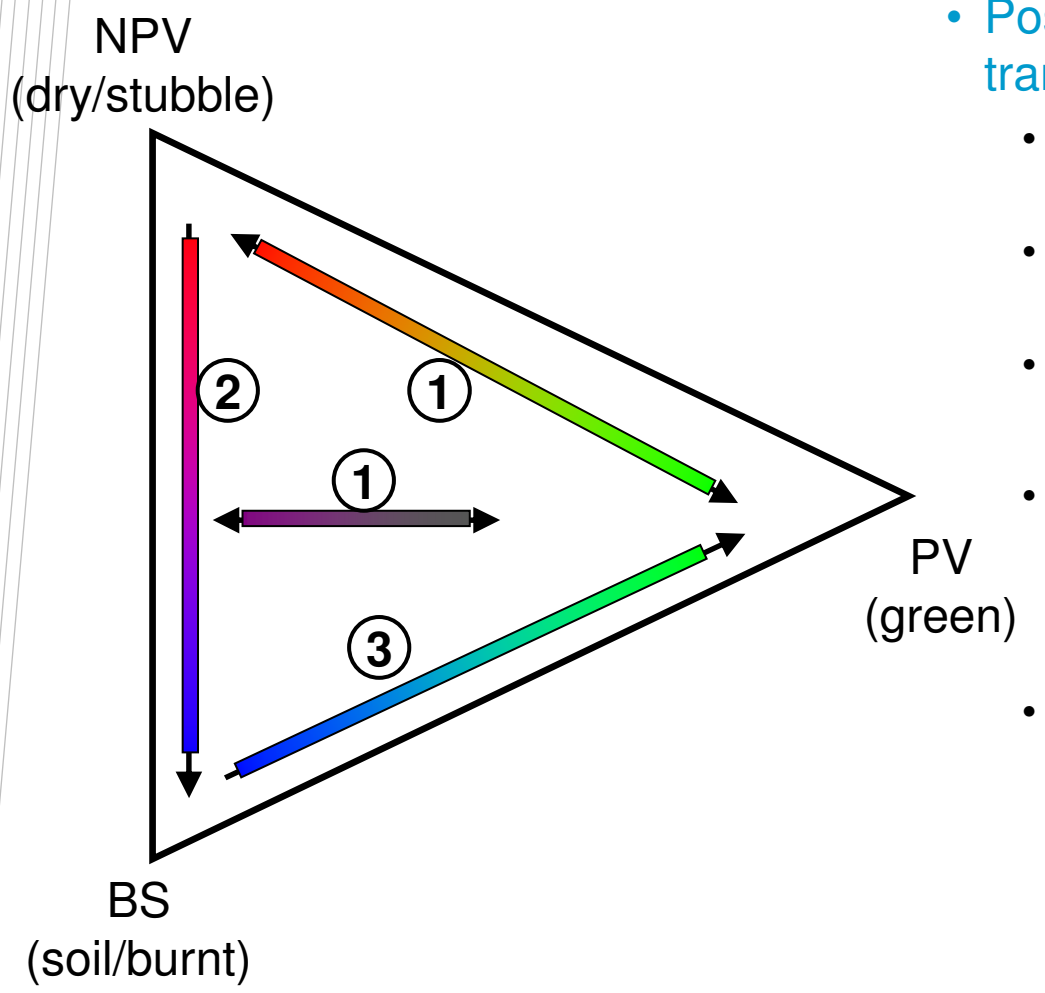
# Fractional cover transitions




- Possible fractional cover transitions.
  - 1: seasonal changes driven by climate (2-way)
  - 2: abrupt change due to fire (only 1-way)
  - 3: vegetation regrowth after fire
- Typical annual transitions in the savannas: from PV to NPV to BS (if burnt) (1-2-3)
- Unlikely transitions which could indicate a failure in the algorithm: from BS to NPV.



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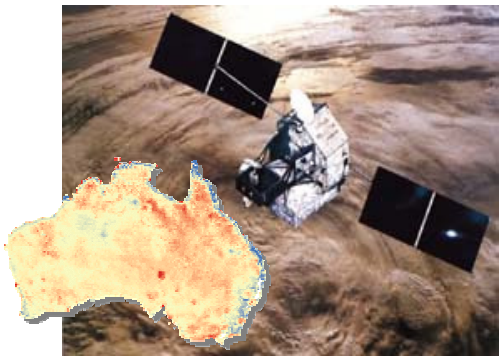
# Types of model-data fusion

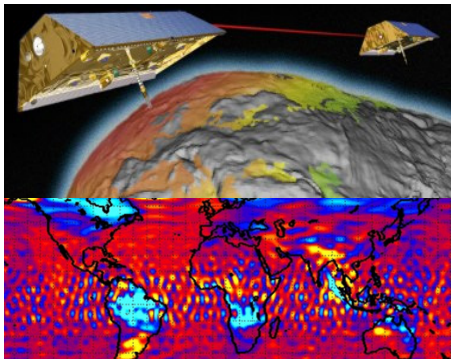
1. **Observation blending** (off-line, before model run)
   - Precipitation
   - ET drivers (radiation, atmospheric variables)
   - Land cover & terrain properties

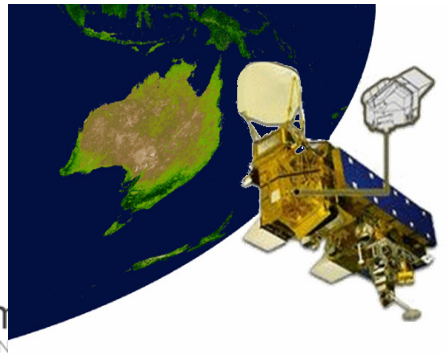
2. **Data assimilation** (on line or off line, using model)
   - Non-sequential: parameter calibration
   - Sequential: state / flux updating (variational, Kalman and particle filters)

3. **Model evaluation** (off line, after model run)
   - Performance statistics, error stats
   - Build confidence in model estimates
   - Benchmark for improvement

4. **Data blending** (off line, after model run)
   - Bias correction
   - Data reconciliation



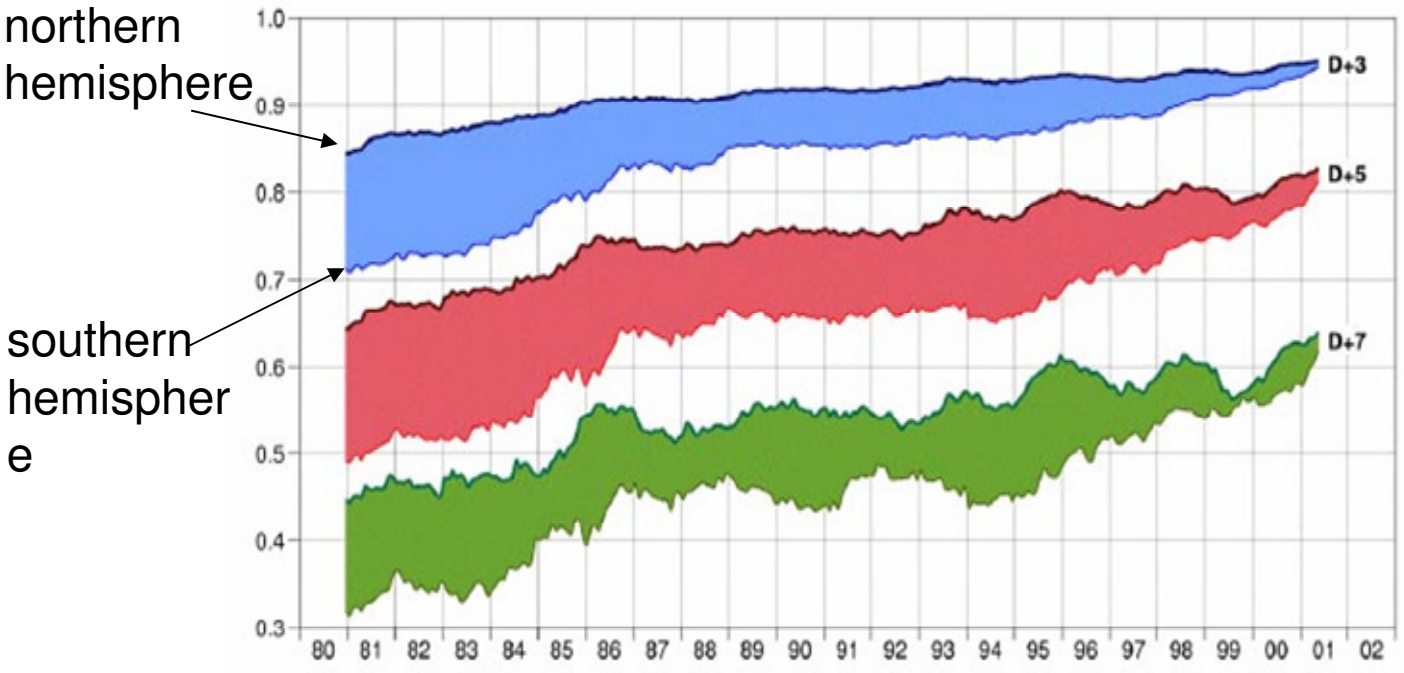




# Model-data fusion

Model-data fusion with satellite observations has already revolutionised weather forecasting

Measure of skill in weather forecasts (Simmons & Hollingsworth, 2002)



# Roadmap for evidence based modelling

**Evaluate**

new observations

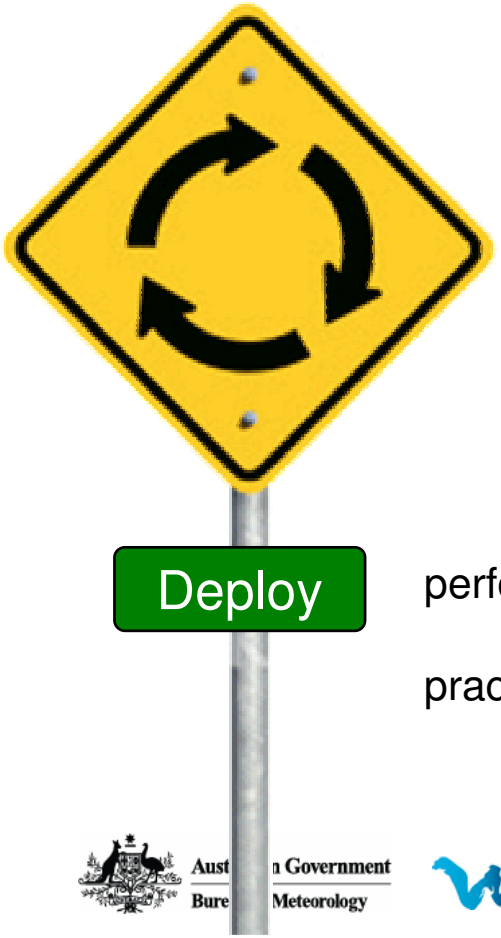
new theory

**Develop**

Occam's Razor

Adopt, Adapt, Invent

data-driven model development



**Deploy**

performance benchmark testing

practical feasibility

***Also requires a modular and flexible ICT infrastructure***

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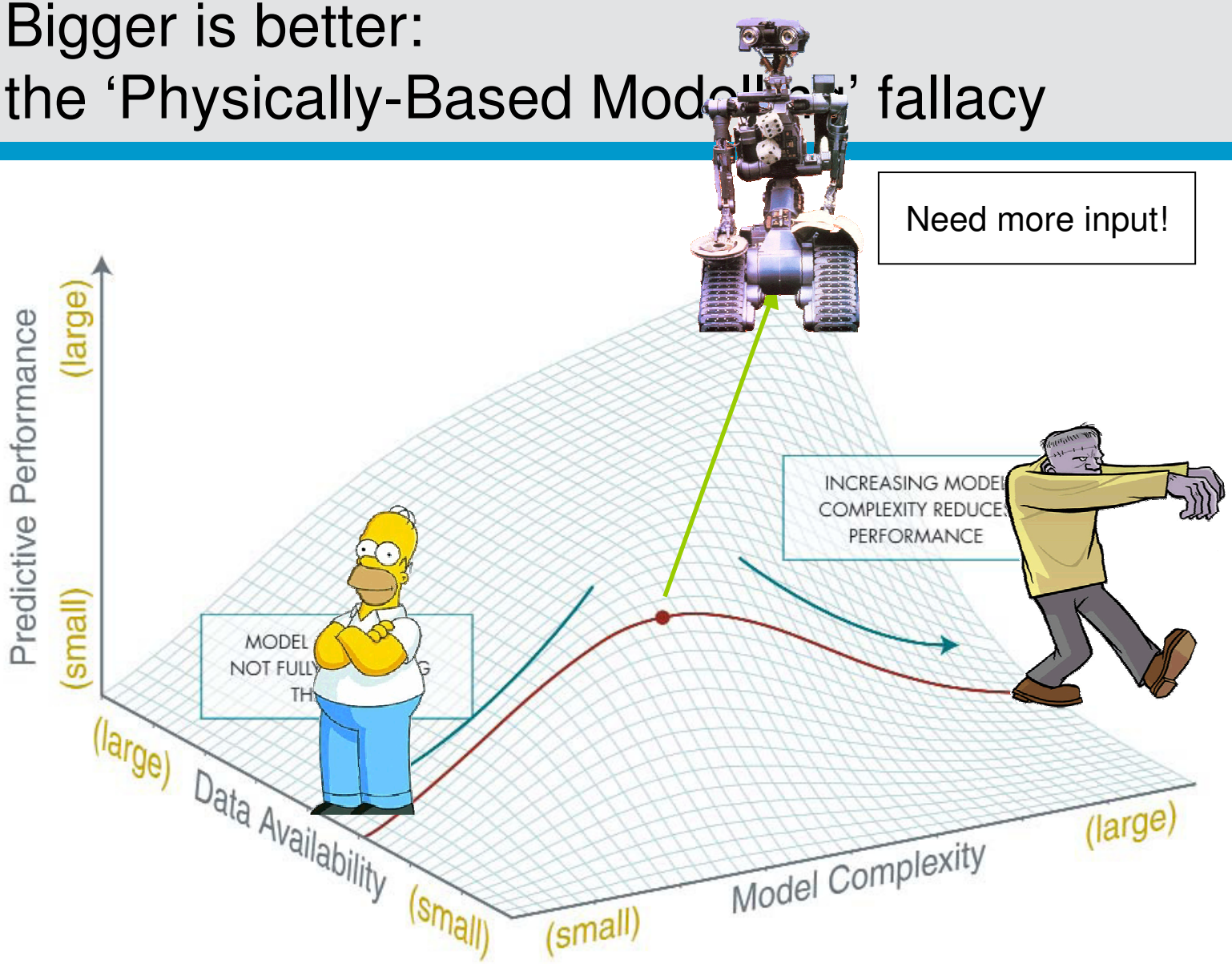
# Bigger is better: the 'Physically-Based Modelling' fallacy




(*http://www.toolkit.net.au/modelchoice/*, after Grayson & Blöschl, 2000)

# Conclusions

Focus on continental scale monitoring and forecasting (CSIRO)

AWRA model - Continental water balance modelling across Australia reproduces satellite and on-ground observations satisfactorily

Future development focused on model selection/development and operational model-data fusion (MDF) techniques.

- MDF techniques required include 2-4 dimensional data blending and dynamic model-data assimilation

Blending satellite and gauge precipitation - Satellite-based estimates of rainfall are useful covariate in reducing estimation variance, especially in ungauged areas of the continent

- How much of an improvement over gauge-only analyses is the satellite-gauge blended product remains to be fully assessed.

Fractional Cover – useful prototype product undergoing wider validation

# Activity 2b: Blending high-frequency and high-resolution remotely sensed data

- How to best extract hydrological relevant information from various remotely sensed sensors?

- Applications include: (1) high-resolution mapping of ETa; (2) estimating irrigation area; and (3) assessing water body dynamics. All three can improve accountability of rural water use

- There are 3 primary domains that information is extracted from remotely sensed imagery
  - Spectral (e.g., riparian tree health: green veg = while yellow veg = 'not happy Jan')
  - Spatial (e.g., upscaling LAI-NDVI relationship: upscale from field to TM, develop LAI-TM scene, upscale from LAI-TM scene to AVHRR/MODIS scale and extent)
  - Temporal (e.g., irrigation efficiency: is ETa decreasing for same crop yield over the last 10 years?)

- There are a range of approaches that use 2 of the above 3 domains to extract more information from remotely sensed imagery (very few methods combine all 3 domains – either in parallel or sequence)

- Two widely used optical sensors include MODIS and Landsat-ETM
  - MODIS: daily, resolution 250m, 500m and 1000m, ~15 spectral bands useful for land applications
  - Landsat-ETM: 16-day, resolution 25m (60m thermal), 7 spectral bands useful for land applications