Mitigating the effects of severe fires, floods and heatwaves through the improvements of land dryness measures and forecasts.

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AFAC14

AFTER DISASTER STRIKES

LEARNING FROM ADVERSITY

WELLINGTON 2-5 SEPTEMBER 2014

An Australian Government Initiative

Project Team Members

ACT parks, Tasmania Fire Service, South Australian Country Fire Service, Fire and Emergency Services Authority of Western Australia, Parks and Wildlife Service Tasmania, Monash University, BoM, CAWCR, CSIRO

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- Peter Steinle
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- Ian Grant
- Jeff Kepert
- Claire Yeo
- John Bally
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- Adam Leavesley
- Mark Chladil
- Rob Sandford
- Ralph Smith
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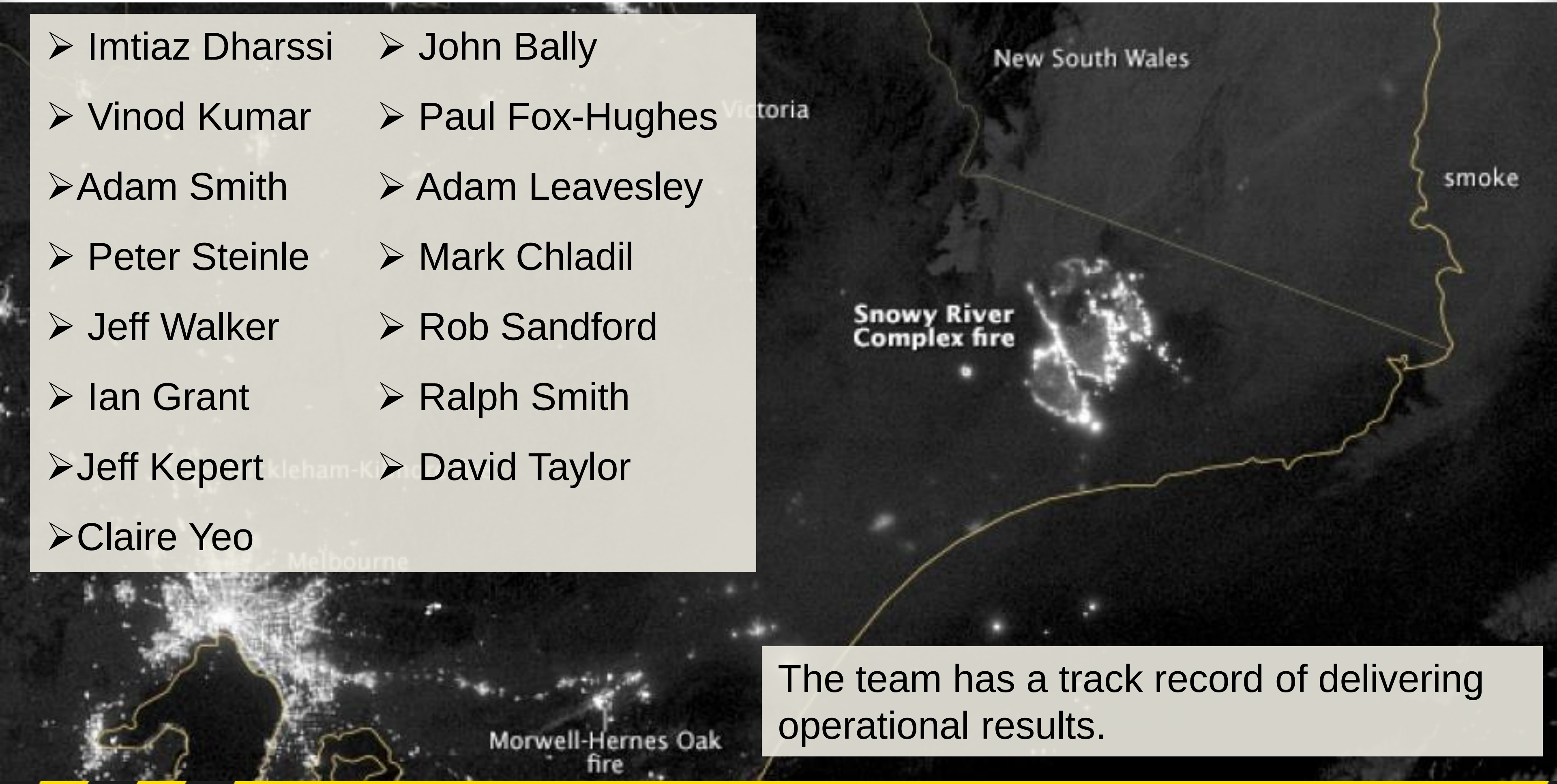


The team has a track record of delivering operational results.

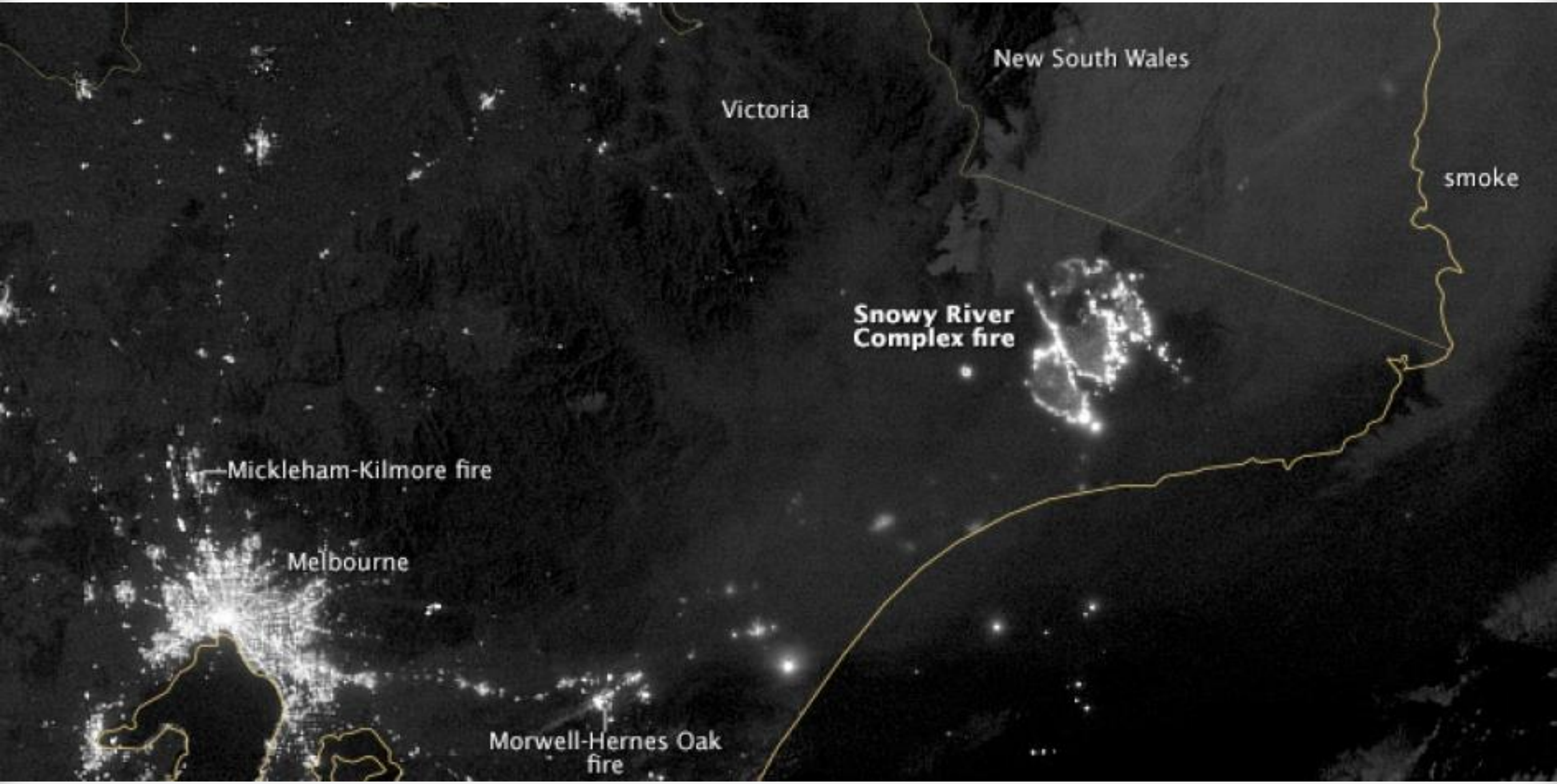
Motivation

- The Australian people, environment and businesses are all vulnerable to extreme weather events such as Bushfires, Droughts, Heatwaves, Floods and Storms

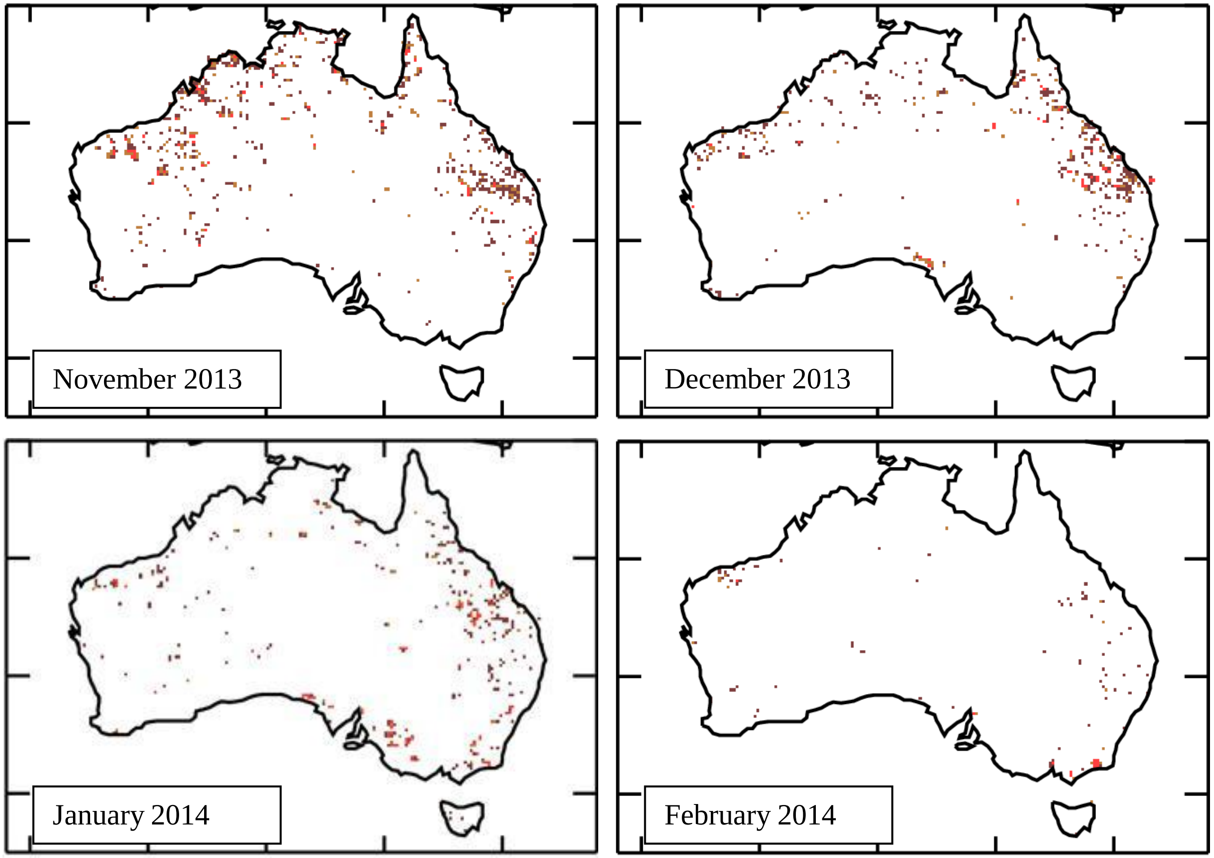
- Extreme weather events cost the Australian economy many billions of Dollars every year
  - Deloitte Access Economics estimate the 2012 total economic cost of natural disasters in Australia exceeded $6 billion

- A recent UK Met Office report concludes that investment in weather services provides an at least seven fold return
  - The Public Weather Service's contribution to the UK economy, 2007

City Sized Fire, February 2014, Victoria, Australia

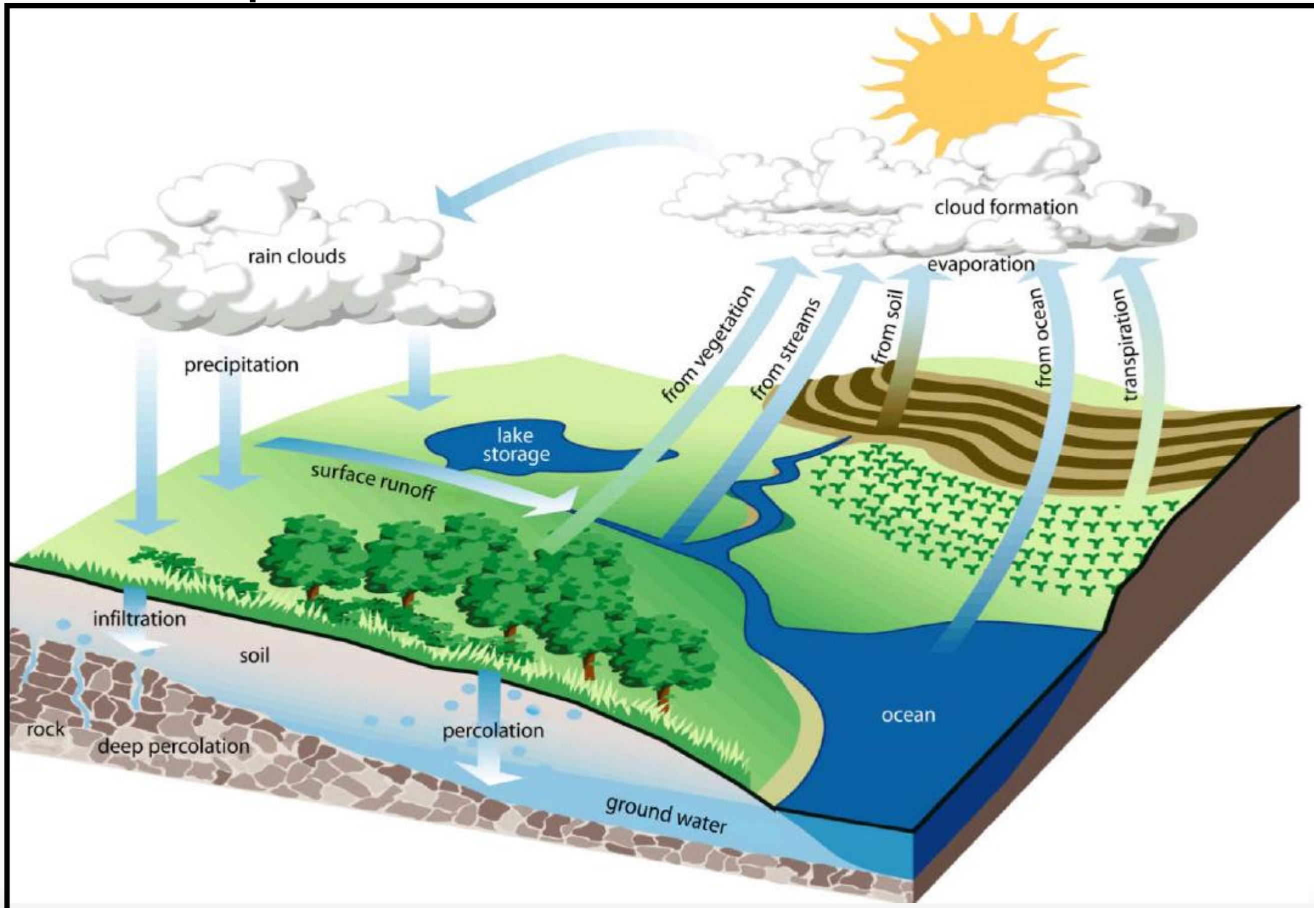


ACTIVE FIRE DETECTED BY THE NASA MODERATE RESOLUTION IMAGING SPECTRORADIOMETER INSTRUMENT.



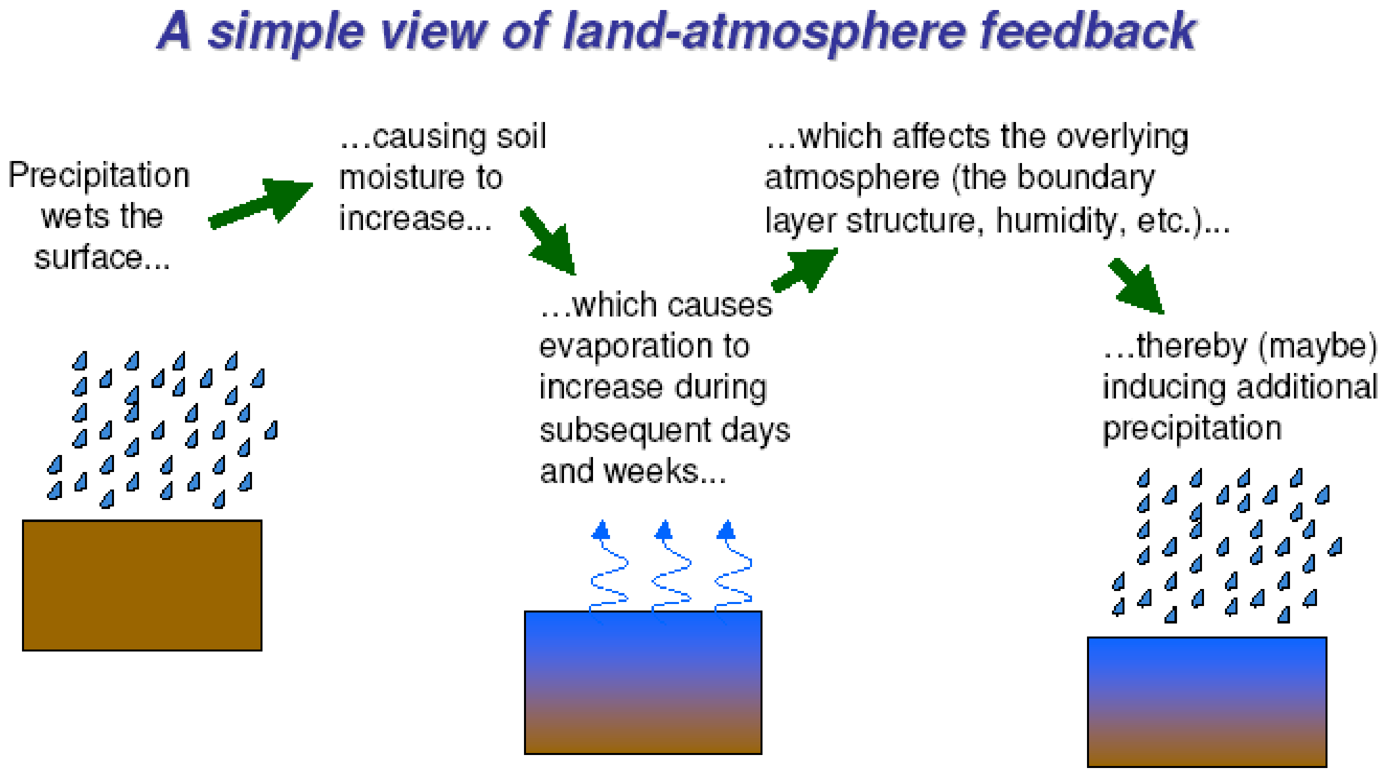
Landscape dryness is important

Knowledge of landscape dryness is critical for the management and warning of fires, floods, heatwaves and landslips.



Strong positive feedbacks between soil moisture and rainfall give the Earth system a long memory allowing extreme conditions to persist for long periods.

Land-atmosphere feedback



From Reichle and Koster:
Land data assimilation and sub-seasonal climate prediction

Landscape Dryness is Currently Calculated Using Simple Methods Developed in the 1960s

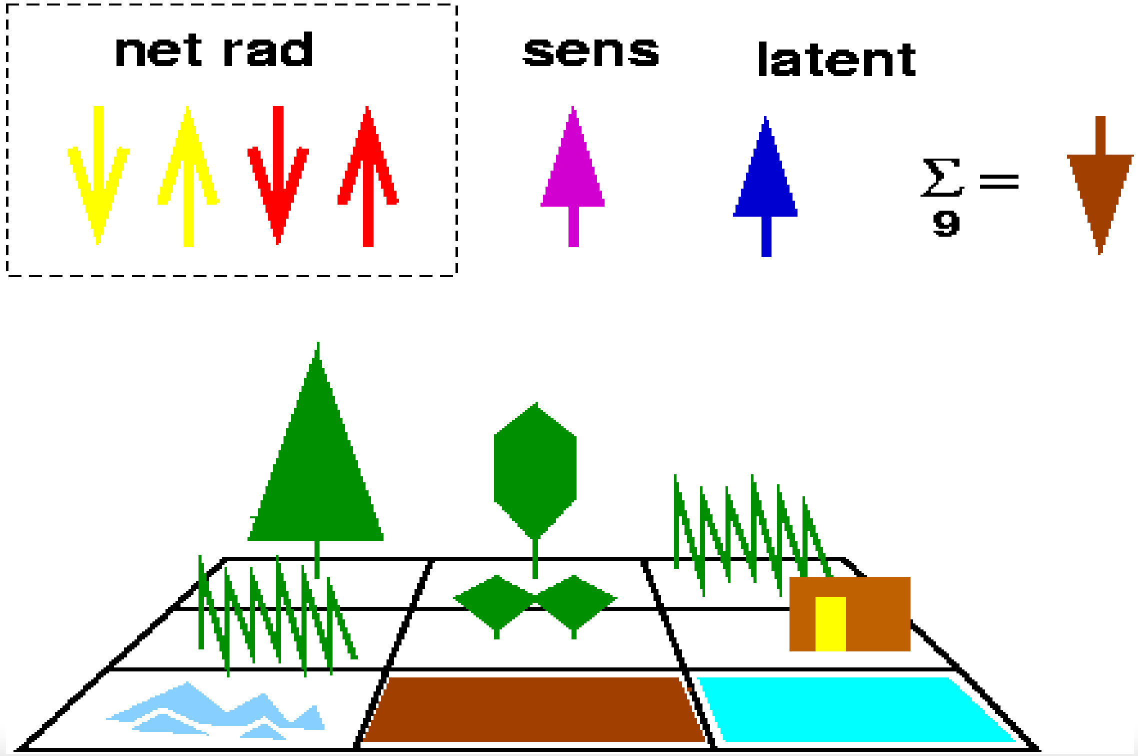
- In Australia the operational McArthur Forest Fire Danger Index uses as landscape dryness input either:
  - The Mount Soil Dryness Index (Mount 1972)
  - The Keetch-Byram Drought Index (Keetch & Byram 1968)

- Current simple landscape dryness methods make simplistic assumptions about
  - Canopy Interception
  - Evaporation and Transpiration
  - Rainfall Runoff

- Current simple landscape dryness methods ignore factors such as
  - Soil Texture
  - Vegetation type and Root depth
  - Solar Insolation
  - Topography and Aspect

Research Strategy

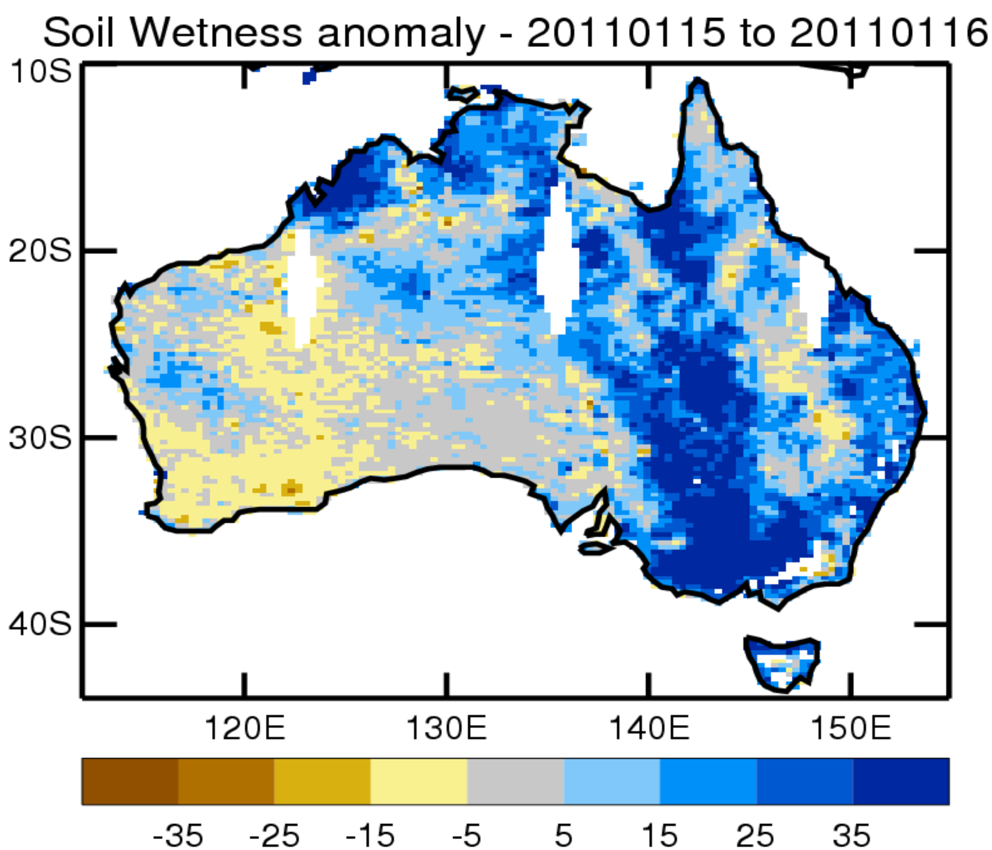
This research will examine the use of detailed land surface models, satellite measurements and ground based observations for the monitoring and prediction of landscape dryness. The new information will be calibrated for use within existing fire and flood forecasting systems.



Modern models calculate landscape dryness with greater sophistication and account for details such as soil texture, solar insolation, root depth, vegetation type and stomatal resistance.

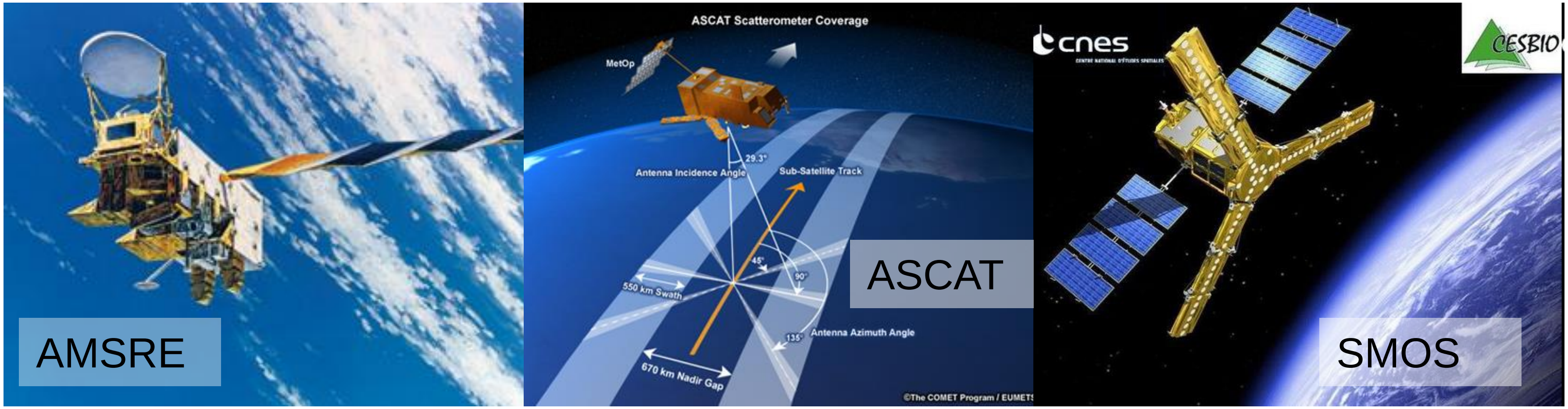
Satellite Systems Provide National Coverage

There are few ground based observations of soil moisture, temperature and vegetation. Satellite systems provide measurements with national coverage on a daily timescale.



New satellite systems provide information about soil moisture, temperature and vegetation properties. Advanced data analysis methods can extract the maximum amount of useful information from the raw measurements.

Soil Moisture from Space



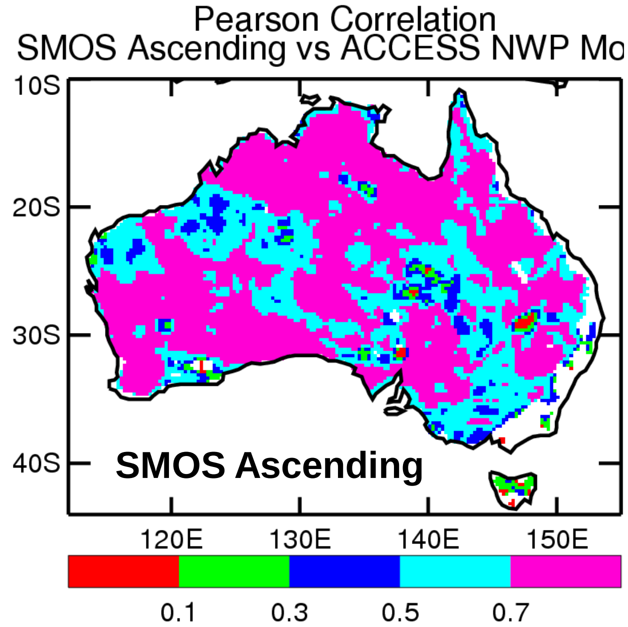
- AMSRE - Advanced Microwave Scanning Radiometer – EOS
  - 2002 to 2011, D pass 1:30 LST, A pass 13:30 LST
  - The AMSR2 follow-on mission was launched in 2012
- ASCAT – Advanced Scatterometer
  - 2006 to present, D pass 9:30 LST, A pass 21:30 LST
- SMOS – Soil Moisture Ocean Salinity
  - 2009 to present, D pass 18:00 LST, A pass 06:00 LST
- SMAP – Soil Moisture Active Passive
  - Launch in late 2014

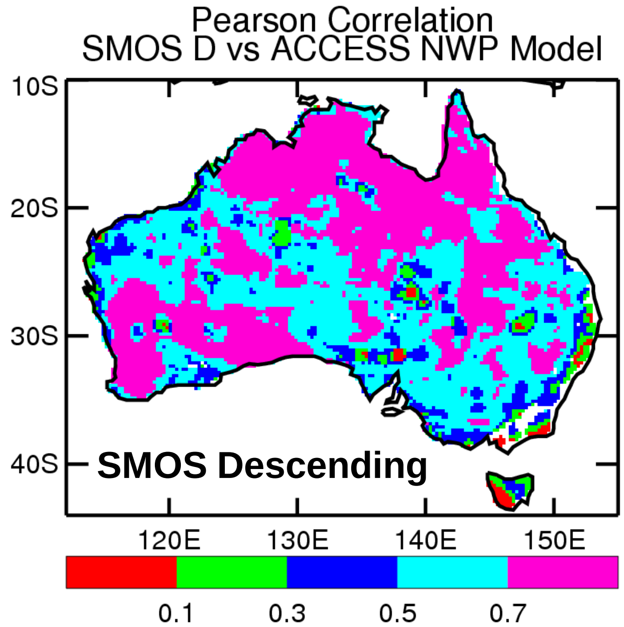
Comparison against OzNet In Situ Soil Moisture, Temporal Correlation (Nov 2010 to May 2011)

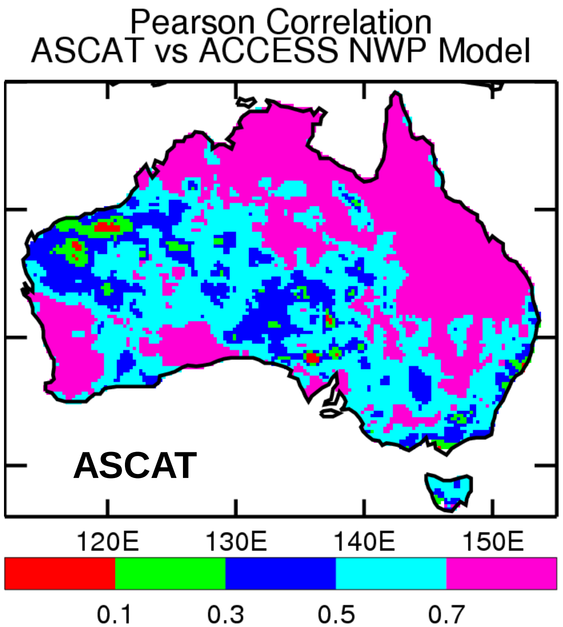
Generally, the model (ACCESS NWP) is most accurate.
SMOS soil moisture retrieved from the ascending pass (6 am) is more accurate than from the descending pass (6 pm) and more accurate than ASCAT.

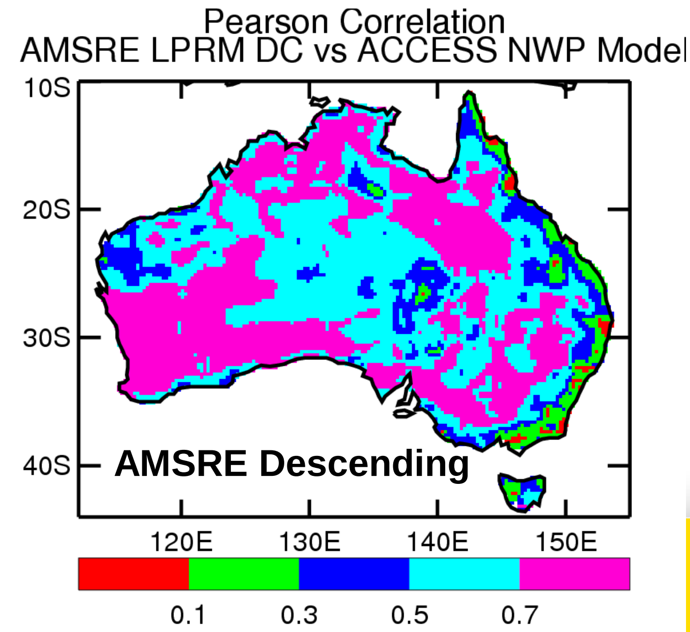
Oznet site	ACCESS NWP	ASCAT	SMOS A pass (Ascending)	SMOS D pass (Descending)
M1	0.599	0.546	**0.740**	0.613
M2	**0.850**	0.702	0.308	0.496
M3	**0.847**	0.498	0.714	0.613
M4	0.763	0.720	**0.849**	0.773
M5	**0.899**	0.813	0.869	0.863
M7	**0.777**	0.704	0.647	0.594

TEMPORAL CORRELATION BETWEEN MODEL & REMOTELY SENSED SOIL MOISTURE (NOV 2010 TO AUG 2011)









TRIPLE COLLOCATION – THEORY

STOFFELEN (1998), SCIPAL ET AL (2008), MIRALLES ET AL (2010), HAIN ET AL (2011), VOGELZANG AND STOFFELEN (2012);

Suppose, we have three separate sources of data that each provides a long timeseries at a given location of soil moisture. Each timeseries contains both biases and random errors.

1) Starting Equations

$$X(t) = a_x + b_x T(t) + \epsilon_x(t) \quad ,$$
$$Y(t) = a_y + b_y T(t) + \epsilon_y(t) \quad ,$$
$$Z(t) = a_z + b_z T(t) + \epsilon_z(t) \quad .$$

a and *b* parameters describe the bias and are unknown.

ε describe the random errors

T(t) is the unknown truth

2) Rescaling Equations

$$Y^* = \langle X \rangle + \frac{b_x}{b_y}(Y - \langle Y \rangle) \quad ,$$
$$Z^* = \langle X \rangle + \frac{b_x}{b_z}(Z - \langle Z \rangle) \quad .$$

There are different methods to estimate b_x/b_y and b_x/b_z. Alternatively, replace steps 2 and 3 with Cumulative Distribution Function (CDF) matching.

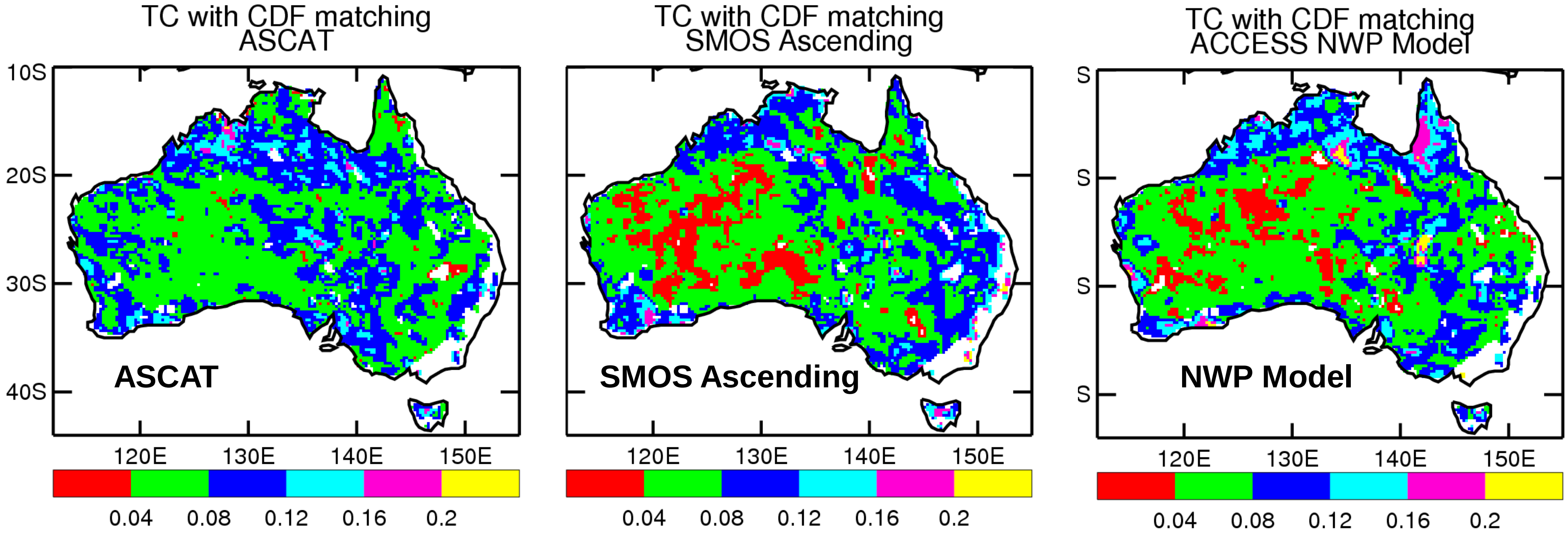
3) Rescaled Time Series

$$X(t) = a_x + b_x T(t) + \epsilon_x(t) \quad ,$$
$$Y^*(t) = a_x + b_x T(t) + \epsilon_y^*(t) \quad ,$$
$$Z^*(t) = a_x + b_x T(t) + \epsilon_z^*(t) \quad .$$

4) Estimated Error Variances

$$\langle(\epsilon_x)^2\rangle_{TC} = \langle(X - Y^*)(X - Z^*)\rangle \quad ,$$
$$\langle(\epsilon_y^*)^2\rangle_{TC} = \langle(Y^* - X)(Y^* - Z^*)\rangle \quad ,$$
$$\langle(\epsilon_z^*)^2\rangle_{TC} = \langle(Z^* - X)(Z^* - Y^*)\rangle \quad ,$$
$$\langle(\epsilon_y)^2\rangle_{TC} = (b_y/b_x)^2 \langle(\epsilon_y^*)^2\rangle_{TC} \quad ,$$
$$\langle(\epsilon_z)^2\rangle_{TC} = (b_z/b_x)^2 \langle(\epsilon_z^*)^2\rangle_{TC} \quad .$$

ESTIMATED STANDARD DEVIATION OF THE ERROR
IN UNITS OF ASCAT SURFACE SOIL WETNESS



Triple Collocation: X=ASCAT, Y=SMOS, Z=Model

Rescaling using CDF matching

Data Assimilation Can Extract the Maximum Amount of Useful Information from Observations

- Satellite systems provide national coverage, but:
  - Satellite data is prone to biases and corruption and can therefore contain large errors
  - Satellite data contain large spatial and temporal gaps
- It is essential to quality control and bias correct the satellite data
- Data assimilation can filter the random errors in the measurements and fill in both the spatial and temporal gaps

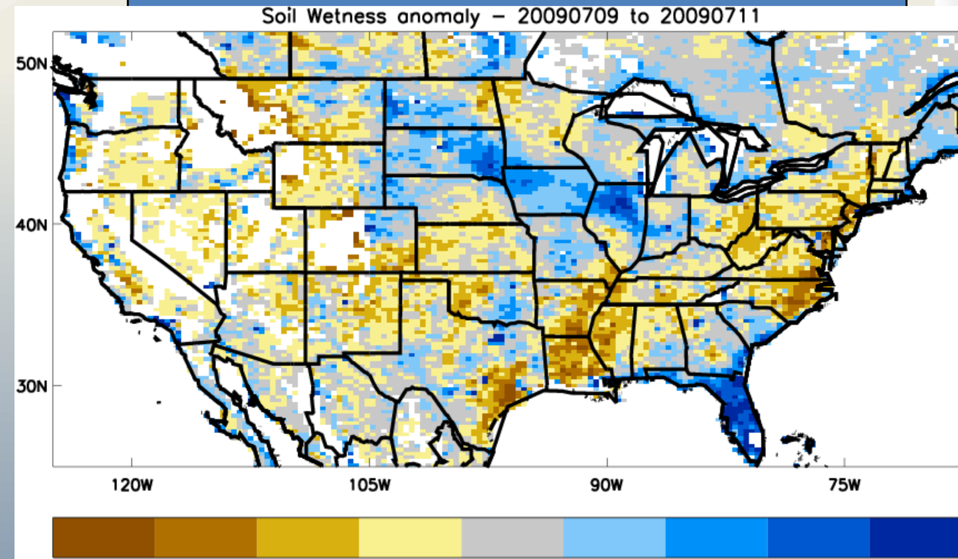
DATA ASSIMILATION EXAMPLE

Assimilation of ASCAT surface soil wetness into a global numerical weather prediction model

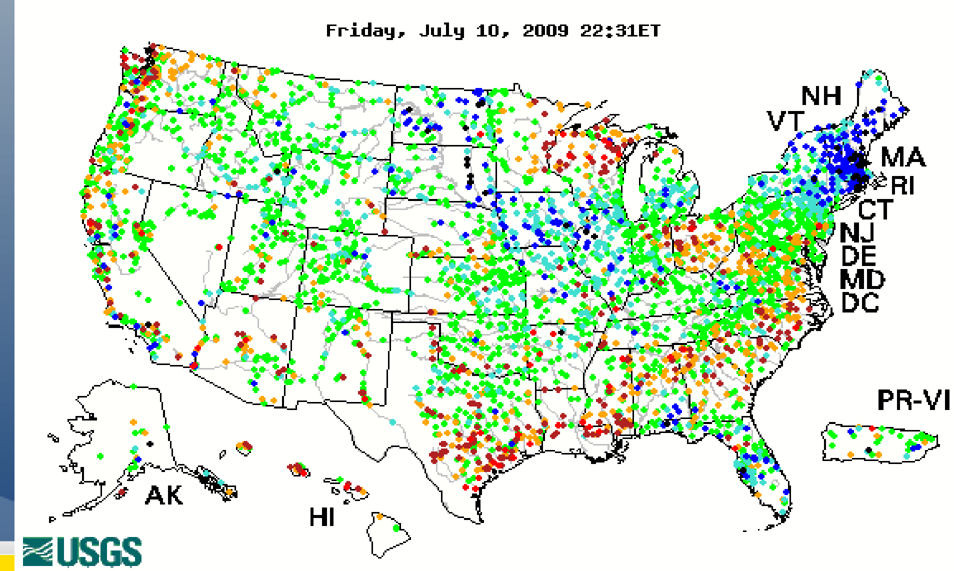
Dharssi, I., Bovis, K. J., Macpherson, B., and Jones, C. P.: Operational assimilation of ASCAT surface soil wetness at the Met Office, Hydrol. Earth Syst. Sci., 15, 2729-2746, doi:10.5194/hess-15-2729-2011, 2011.

WATER ANOMALIES: 9 TO 11 JULY 2009

ASCAT surface soil wetness anomaly



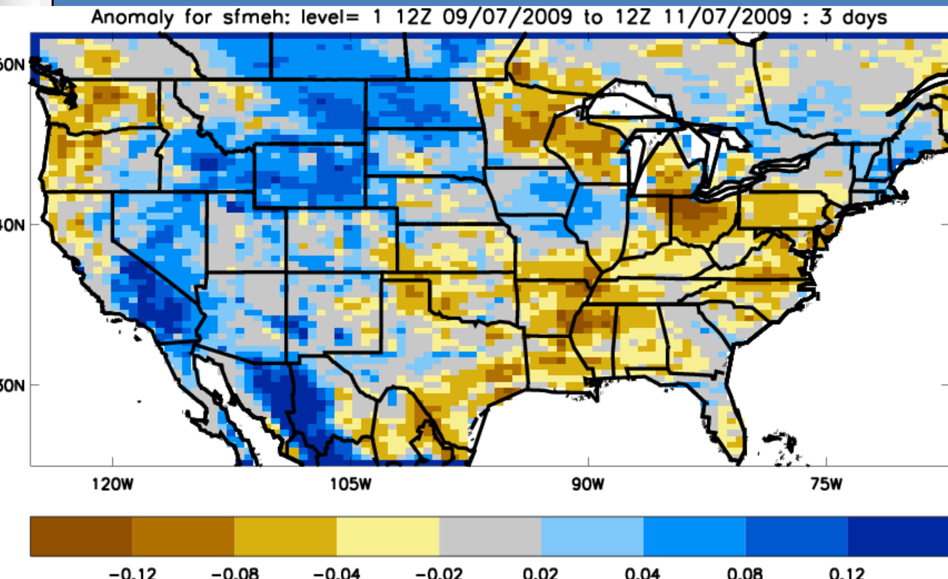
Good qualitative agreement between the two data.



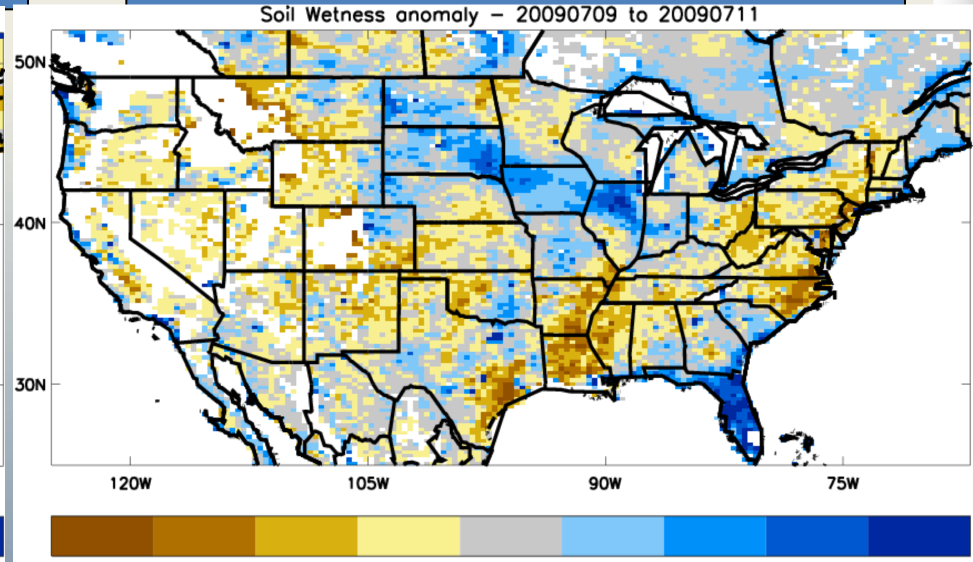
River Flow anomaly

MODEL: 9 TO 11 JULY 2009

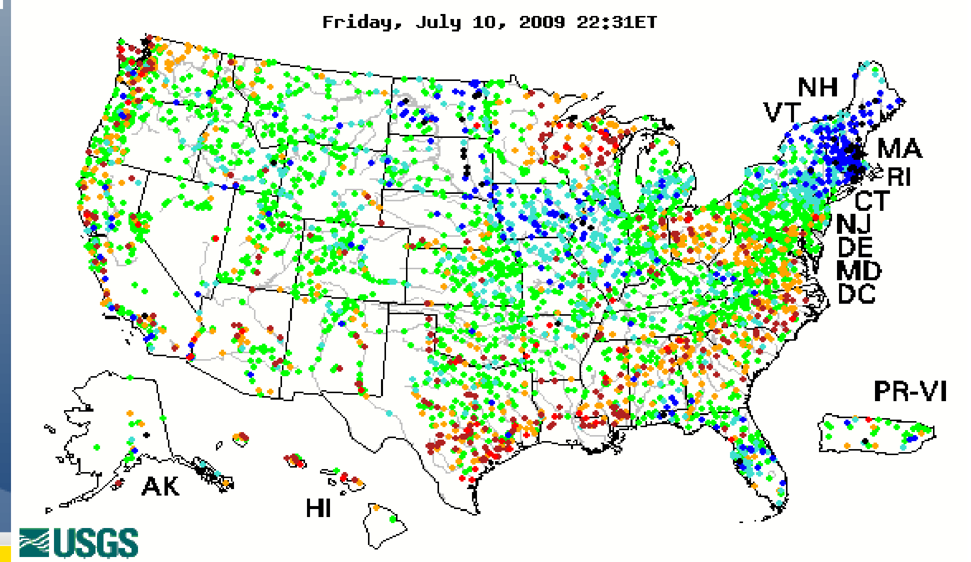
Control run: top 10cm soil moisture anomaly



ASCAT surface soil wetness anomaly



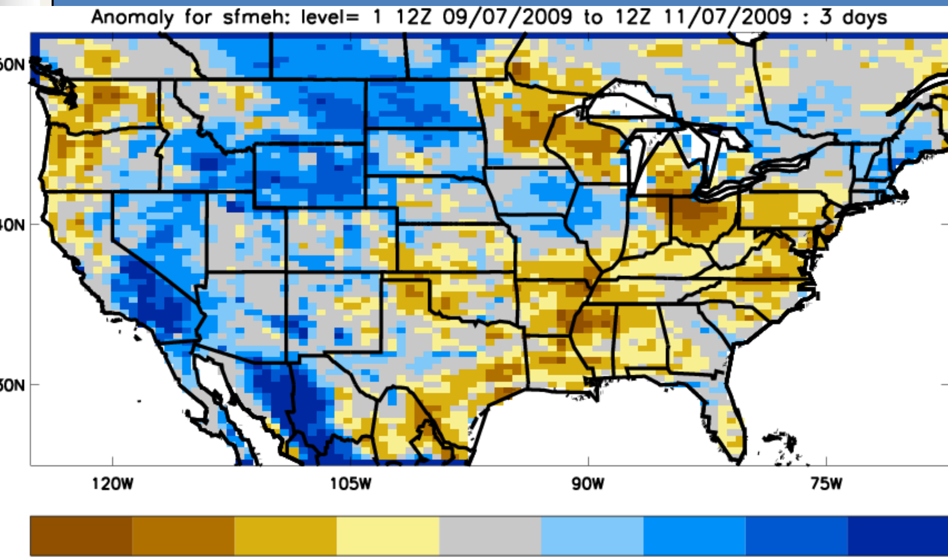
Model soil too wet in the west and possibly too dry in the east (e.g. Florida).



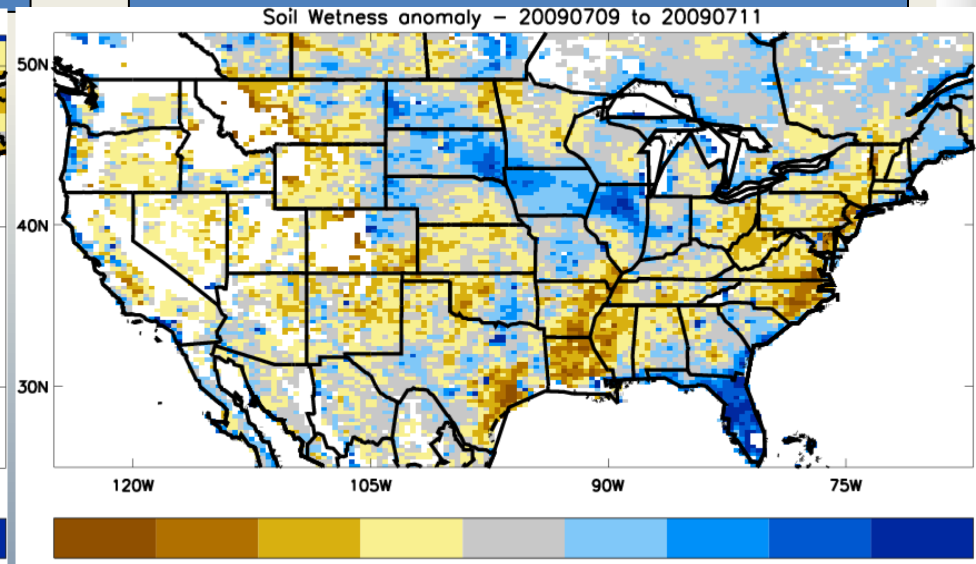
River Flow anomaly

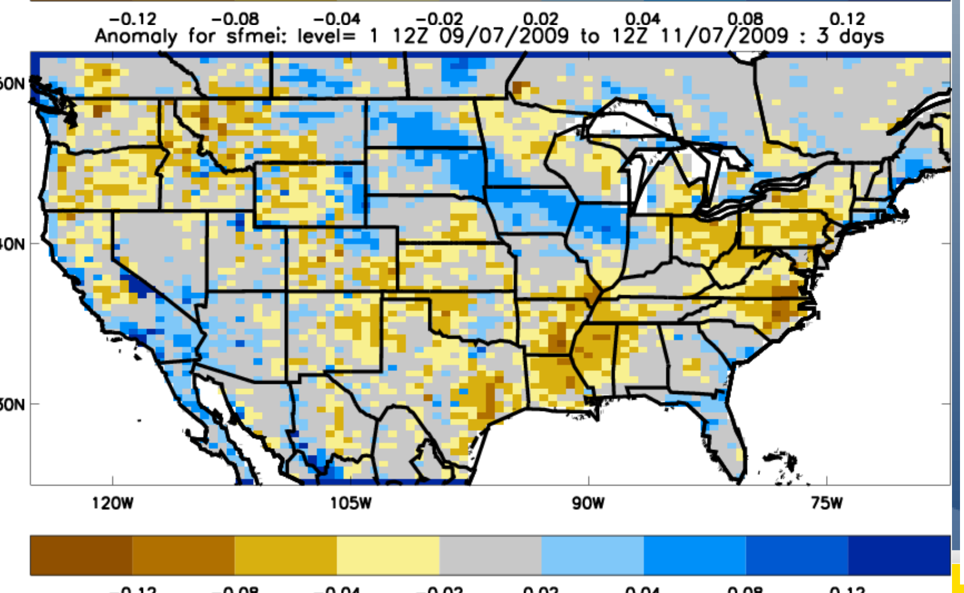
DATA ANALYSIS: 9 TO 11 JULY 2009

Control run: top 10cm soil moisture anomaly

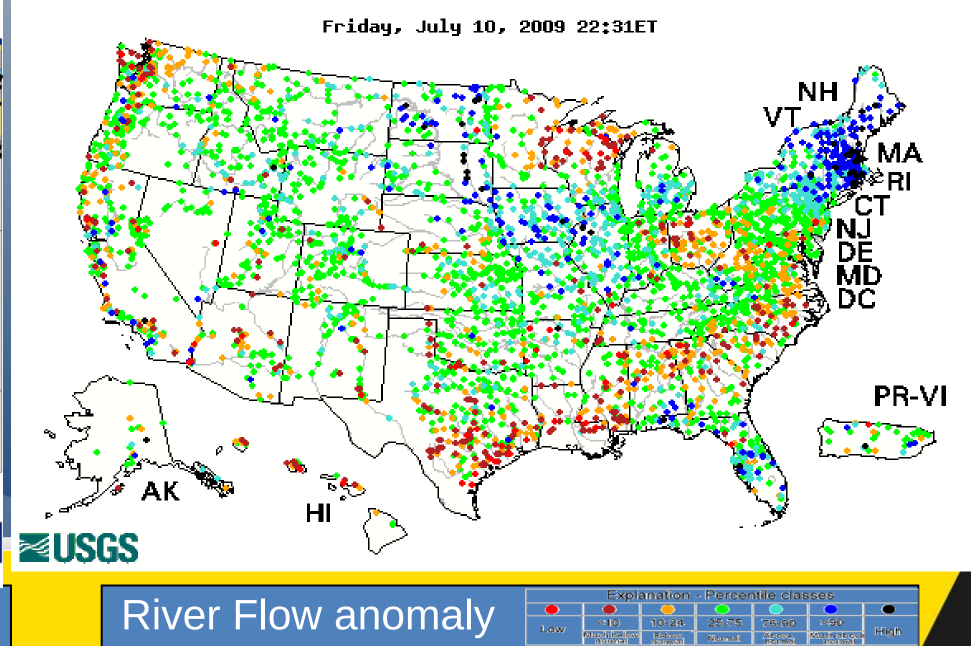


ASCAT surface soil wetness anomaly





Test run: top 10cm soil moisture anomaly

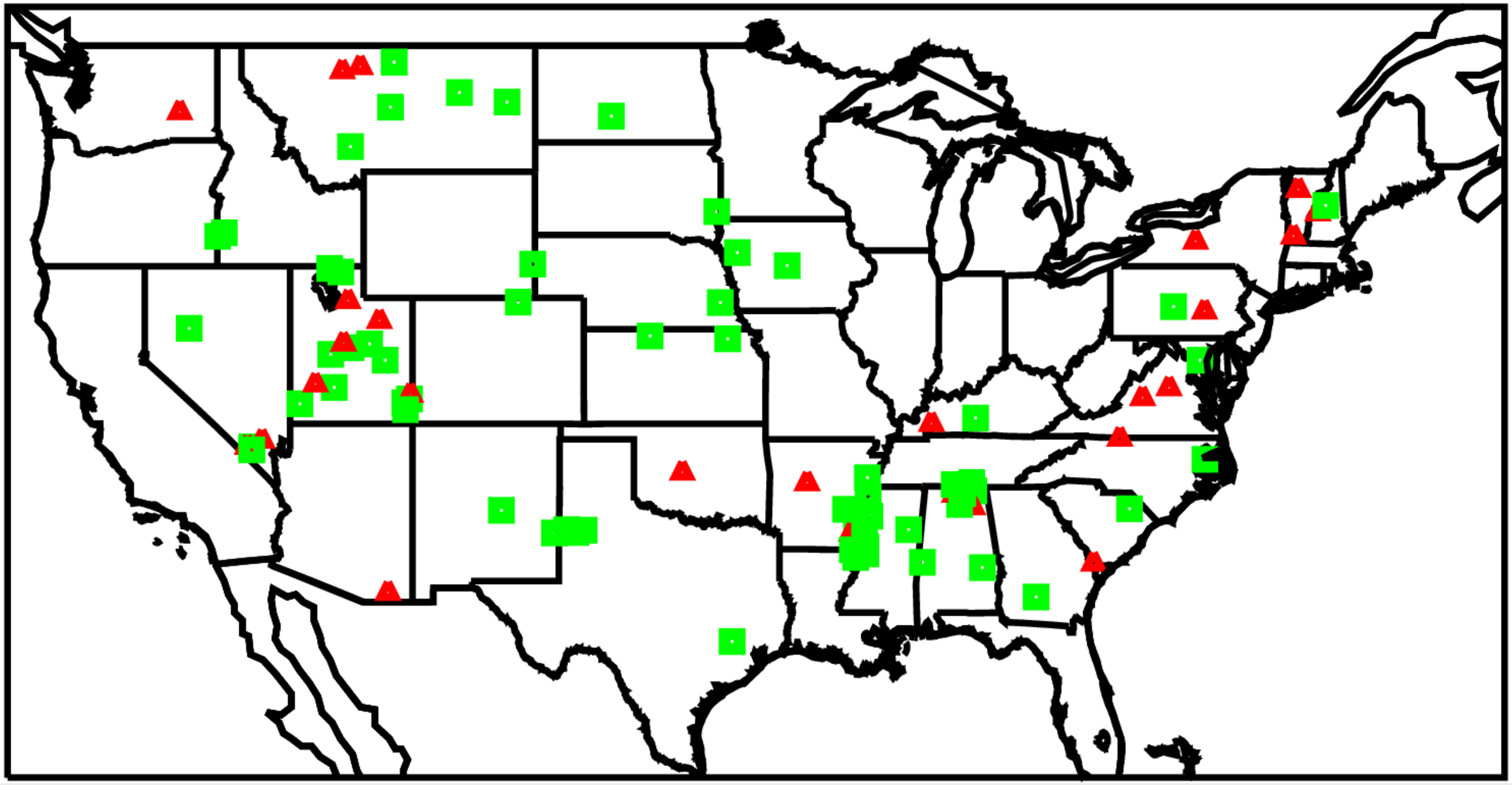


River Flow anomaly

ASSIMILATION OF ASCAT SOIL WETNESS IMPROVES VERIFICATION AGAINST GROUND BASED SOIL MOISTURE MEASUREMENTS

□ Reduction in random errors (Better)

△ Increase in random errors (Worse)



Project News

✓May 2014: Contract between Bureau and BNHCRC signed

✓June 2014: Dr Vinod Kumar recruited to work full time on this project

✓June 2014: Project Management Plan has been finalised

✓July 2014: Soil Moisture workshop held at Monash University

✓August 2014: A teleconference meeting held between scientists and end-users

Expected Outcomes – Big Picture

- ✓ **We will develop an operations-ready system delivering near real-time estimates of landscape dryness on a national scale**
  - ✓ Horizontal resolution will be 5km
  - ✓ Downscaling techniques will be developed to improve the horizontal resolution to 1km

- ✓ We will develop a state of the art, world's best practice, soil moisture analysis system that uses many different sources of observations, cutting edge land surface models and data assimilation techniques.

- ✓ The new information will be calibrated so that it can be used with existing fire and flood prediction systems.

Expected Outcomes: Year One

1. Produce a 20+ years historical dataset of Keetch-Byram Drought Index (KBDI) and Mount Soil Dryness Index (MSDI)
   i. Using 5km gridded daily analyses of Rainfall and maximum Temperature
   ii. Calculate historical dataset of the McArthur Forest Fire Danger Index

   A valuable resource for researchers working on fire climatologies

2. Perform an inter-comparison of the traditional landscape dryness indices (KBDI/MSDI) with data from:
   i. Satellite derived soil moisture estimates
   ii. Ground based observations of soil moisture
   iii. Numerical Weather Prediction models
   iv. Land surface models
   v. Hydrological/Runoff models

3. Perform calibration and rescaling of satellite and model soil moisture measures
   i. To match statistics of traditional landscape dryness indices (KBDI/MSDI) using for example Cumulative Distribution Function Matching

Expected Outcomes: Year Two on

1. **Blending and Merging** of satellite and model data to calculate landscape dryness
2. Use **Data Assimilation** methods to calculate landscape dryness
3. Develop **Downscaling techniques** to estimate landscape dryness at **1km horizontal resolution**
4. Use **Multi-Model Ensembles** to improve accuracy
5. Explore the relationship between soil dryness and litter fuel moisture content. Improve the vegetation and soil parameterisations in models to better match Australian conditions.

Expected Benefits

✓ **Far improved versions of the operational systems** emergency planners are already familiar with.

✓ The outputs will **improve Australia's ability to manage multiple hazard types** and create a more resilient community, **by developing a state of the art, world's best practice in soil moisture analysis** that underpins flood, fire and heatwave forecasting.

✓ Longer term work will **use multiple-models and optimal data analysis to forecast soil dryness indices for operational fire, flood and heat wave applications.** The vegetation and soil parameterisations in models will be developed to match Australian conditions.