VERIFICATION OF SOIL MOISTURE FROM MULTIPLE SOURCES FOR BUSHFIRE DANGER RATING APPLICATIONS

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# Project Background

Bureau researchers were awarded with a project called "**Mitigating the effects of severe fires, floods and heatwaves through the improvements of land dryness measures and forecasts**" by BNHCRC under the '**Monitoring and Prediction**' theme.

<table>
<thead>
<tr>
<th>Project Team Members</th>
<th>End-users</th>
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<tbody>
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<td>Imtiaz Dharssi</td>
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<td>Vinod Kumar</td>
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<td>Peter Steinle</td>
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<td>Jeff Kepert</td>
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<td>Adam Smith</td>
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<td>Ian Grant</td>
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<td>Jeff Walker</td>
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<td>Claire Yeo</td>
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<td>John Bally</td>
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<td>Paul Fox-Hughes</td>
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<td>Adam Leavesley</td>
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<td>Mark Chladil</td>
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<td>Rob Sandford</td>
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<td>Ralph Smith</td>
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<td>David Taylor</td>
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Introduction

- Land (i.e., soil, litter and vegetation) dryness determines the availability of fuel for burning.
- Because fuel availability measures are not always readily available, FDRS include sub-models to estimate it.
- Drought Factor (DF) represent fuel availability in FFDI.
- DF is a combination of seasonal dryness and short-term drying.
- The seasonal dryness is represented using soil moisture deficit (SMD).
- SMD is calculated as either:
  - Mount Soil Dryness Index (MSDI; Mount 1972)
  - Keetch-Byram Drought Index (KBDI; Keetch & Byram 1968)
Introduction: KBDI / MSDI

- KBDI/MSDI make empirical assumptions to moisture depletion in the upper soil layers.

- KBDI is used operationally in the Australian states of Victoria, NSW & Queensland.

- MSDI is used operationally in Tasmania, SA and WA.

- These 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
Motivation of the present study

- KBDI / MSDI models are simple models developed in 1960s.

- Rapid advancements were made in the science of soil moisture since.
  - measurements — satellite remote sensing
  - prediction — physics based land surface models.

- These new techniques potentially provide significantly improved accuracy of the soil moisture fields needed for fire danger rating.

- There are such products already available in some form.
  - E.g. – Numerical weather prediction models, ASCAT

- So the first step is to validate KBDI & MSDI against observations and also against these available "modern day" soil moisture products.
Data sets

In-situ observations
- **OzNet**
  - 0-30 cm profile
  - Murrumbidgee, NSW
  - 2000 - 2011
- **CosmOz**
  - Cosmic ray probes
  - Varying depth profiles
  - 13 sites, 9 calibrated

KBDI / SDI / API*
- For whole of Australia
- 0.05° x 0.05° grids
- Daily time steps.
- Forcing data: AWAP.

NWP/LSM
- ACCESS-Global, ECMWF Operations
- ACCESS ~80km/~40km/~25km, ECMWF ~25km.
- ACCESS → Nudging
- ECMWF → EKF

ASCAT
- On board MetOp-A
- Resolution ~ 12.5km.
- 1-2 pass per day
- ~ top 2cm soil moisture

* $API_i = \gamma API_{i-1} + P_i$
  - $\gamma$ is the recession coefficient
  - $P$ is the daily precipitation
In-situ observation locations

(a) OzNet

(b) CosmOz

bnhcrc.com.au
Monthly Mean Values [Using 40 Years of data]
Data prep. & verification metrics

- **Verification periods:**
  - OzNet  – 01 September 2009 to 31 May 2011 (21 months)
  - CosmOz – 01 May 2012 to 31 December 2014 (32 months)

- **Normalized soil moisture**
  
  \[ SM_{Norm} = \frac{SM_{Max} - SM_{Min}}{SM_{Max} - SM_{Min}} \]

- **Metrics:**
  - Correlation (R), RMSD, Bias.

- **CIs for correlation estimates**
  
  \[ z = 0.5 \ln \left( \frac{1+r}{1-r} \right) \]
  \[ \sigma = \sqrt{1/(N_{eff} - 3)} \]
  \[ N_{eff} = N \frac{(1-r_a r_b)}{(1+r_a r_b)} \]
Exponential Filter

Surface to profile soil moisture

\[ SWI_n = SWI_{n-1} + K_n (m_s)_n - SWI_{n-1} \]

- SWI - Soil water index
- \( M_s \) - Degree of saturation
- \( K_n \) - Gain
- \( n \) - Index of time

The gain \( K_n \) at time \( t_n \) is given by:

\[ K_n = \frac{K_{n-1}}{K_{n-1} + e^{\left(\frac{t_n - t_{n-1}}{T}\right)}} \]
Depth weighting of NWP soil moisture

Based on Franz et al., 2012.

\[ wt(z) = \int_{z_{n-1}}^{z_n} a \left( 1 - \left( \frac{Z}{z^*} \right)^b \right) dz \]

where:
- \( wt \) - Weight
- \( z^* \) - CosmOz sensing depth
- \( Z_n \) - Model soil layer depth at layer n
- \( a, b \) - Constants

\( a \) is defined by:

\[ 1 = \int_{0}^{z^*} a \left( 1 - \left( \frac{z}{z^*} \right)^b \right) dz \]
<table>
<thead>
<tr>
<th>Site</th>
<th>Probing Depth (m)</th>
<th>Correlation [-]</th>
<th>Bias [-]</th>
<th>RMSD [-]</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
<td>Min</td>
<td>LW</td>
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<tr>
<td>Baldry</td>
<td>0.22</td>
<td>0.38</td>
<td>0.11</td>
<td>0.89</td>
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<tr>
<td>Daly</td>
<td>0.4</td>
<td>0.55</td>
<td>0.16</td>
<td>0.82</td>
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<tr>
<td>Gnangara</td>
<td>0.4</td>
<td>0.56</td>
<td>0.24</td>
<td>0.57</td>
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<td>Robson Creek</td>
<td>0.13</td>
<td>0.21</td>
<td>0.08</td>
<td>0.8</td>
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<tr>
<td>Temora</td>
<td>0.17</td>
<td>0.27</td>
<td>0.09</td>
<td>0.9</td>
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<tr>
<td>Tullochgorum</td>
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<td>0.47</td>
<td>0.08</td>
<td>0.76</td>
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<tr>
<td>Tumbarumba</td>
<td>0.1</td>
<td>0.14</td>
<td>0.06</td>
<td>0.81</td>
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<tr>
<td>Weany Creek</td>
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<td>0.35</td>
<td>0.11</td>
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<td>Yanco</td>
<td>0.2</td>
<td>0.37</td>
<td>0.08</td>
<td>0.87</td>
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<tr>
<td>Mean</td>
<td>0.8</td>
<td>0.81</td>
<td>0.01</td>
<td>-0.03</td>
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# Skill scores

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Normal time series</th>
<th>Anomaly series</th>
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<tbody>
<tr>
<td></td>
<td>Correlation [-]</td>
<td>Bias [-]</td>
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<tr>
<td></td>
<td>OzNet</td>
<td>CosmOz</td>
</tr>
<tr>
<td>ACCESS_80km</td>
<td>0.72</td>
<td>-</td>
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<td>ACCESS_40km</td>
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<td>0.81</td>
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<tr>
<td>KBDI</td>
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<tr>
<td>MSDI</td>
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<td>API</td>
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<td>0.73</td>
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<tr>
<td>ASCAT</td>
<td>-</td>
<td>0.76</td>
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</tbody>
</table>
Bias: KBDI vs OzNet @ site A1

-ve means wetter
+ve means drier
Bias: MSDI vs OzNet @ site A1

-ve means wetter
+ve means drier
Taylor diagrams

OzNet

CosmOz

Normalized Standard deviation

Correlation

Normalized Standard deviation

OzNet

ACCESS_80km

KBDI

MSDI

API

CosmOz

ACCESS_40km

KBDI

MSDI

API

ASCAT

bnhcrc.com.au
Correlation & CIs

Anomaly time series

Correlation

ACCESS_80km  API_OzNet  MSDI_CosmOz
KBDI_OzNet  ACCESS_40km  API_CosmOz
MSDI_OzNet  KBDI_CosmOz  ASCAT

bnhcrc.com.au
ACCESS_40km/ACCESS_25km/ECMWF

- Period – 1 Dec 2013 to 28 Feb 2015 (14 months)
- Depth weighed profiles.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>ACCESS_40 km</th>
<th>ACCESS_25km</th>
<th>ECMWF</th>
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<tbody>
<tr>
<td>Correlation [-]</td>
<td>0.82</td>
<td>0.80</td>
<td>0.81</td>
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<td>Anomaly Correlation [-]</td>
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<td>0.56</td>
<td>0.58</td>
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<tr>
<td>Bias [-]</td>
<td>-0.04</td>
<td>-0.06</td>
<td>-0.04</td>
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<td>RMSD [-]</td>
<td>0.16</td>
<td>0.17</td>
<td>0.17</td>
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Conclusions

- In general, ACCESS is better than KBDI or MSDI.
- ACCESS results are encouraging when we consider:
  - Coarser resolution (~40 – ~80 km) of NWP
  - NWP precipitation estimates can be generally erroneous.
  - KBDI and MSDI uses observation based rainfall analyses.
- KBDI soils show large wet bias.
- MSDI is better than KBDI.
- API with a simple formulation matches MSDI and is better than KBDI.
- ASCAT estimates show very good skills.
- ACCESS soil moisture shows similar skill to ECMWF model.
- This study provide an approach to improve FDR.
Future work

- Develop an operational system delivering near real-time estimates of soil dryness for use in FDR.

- Essentially a state of the art soil moisture analysis system that uses many different sources of observations, cutting edge land surface models and data assimilation techniques.

- Planned horizontal resolution is 5km.

- Downscaling techniques will be used to improve the horizontal resolution to about 1km.

- The new information will be calibrated so that it can be used with current operational FDR.

- In addition, the new system provides the capability to be used within dynamic fire weather models.
Acknowledgments

- BNHCRC.
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- CSIRO for CosmOz.
THANK YOU

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