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

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An Australian Government Initiative

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.

Project Team Members

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End-users

BoM, ACT parks, Tasmania Fire Service, South Australian Country Fire Service, Fire and Emergency Services Authority of Western Australia, Parks and Wildlife Queensland Fire Service

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^o x 0.05^o grids
  - Daily time steps.
  - Forcing data: AWAP.

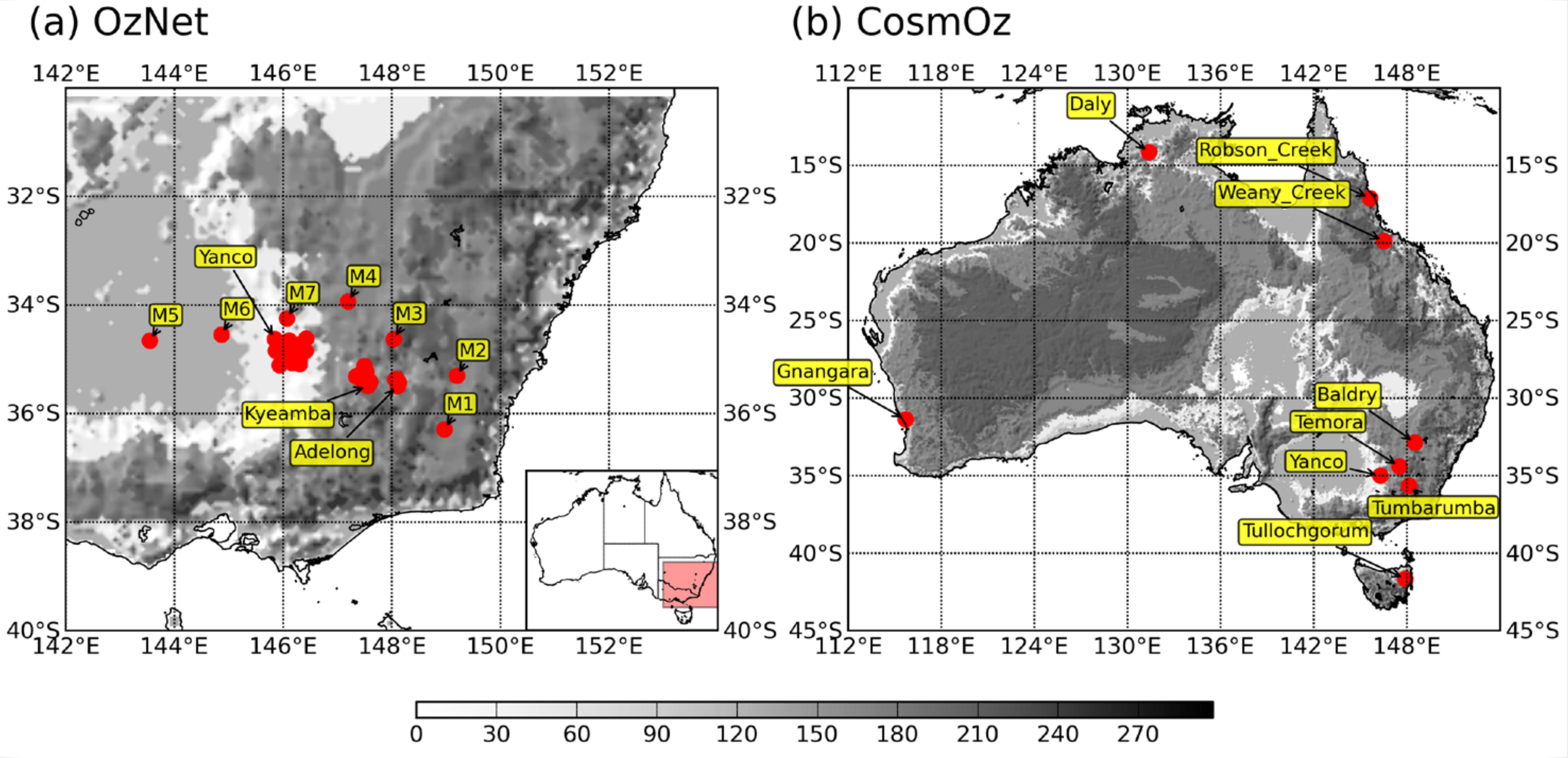
- NWP/LSM
  - ACCESS-Global, ECMWF Operations
  - ACCESS ~80km/~40km/~25km, ECMWF ~25km.
  - ACCESS → Nudging
  - ECMWF → EKF

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

* $API_i = \gamma API_{i-1} + P_i$

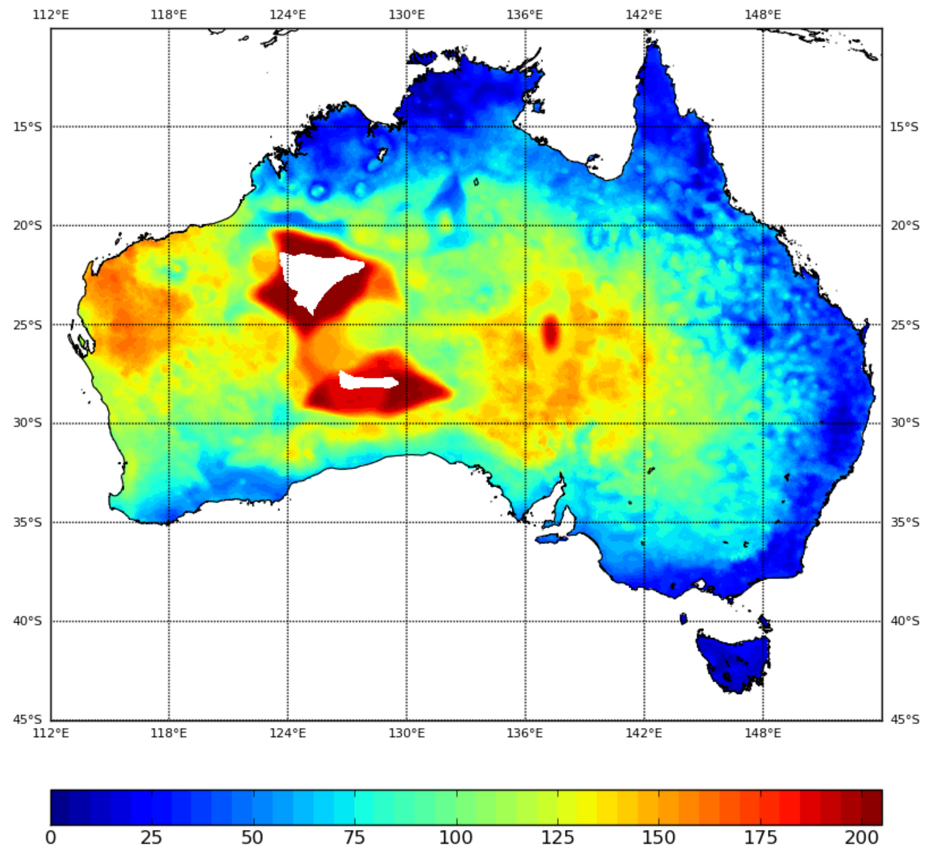
- γ is the recession coefficient
- P is the daily precipitation

In-situ observation locations

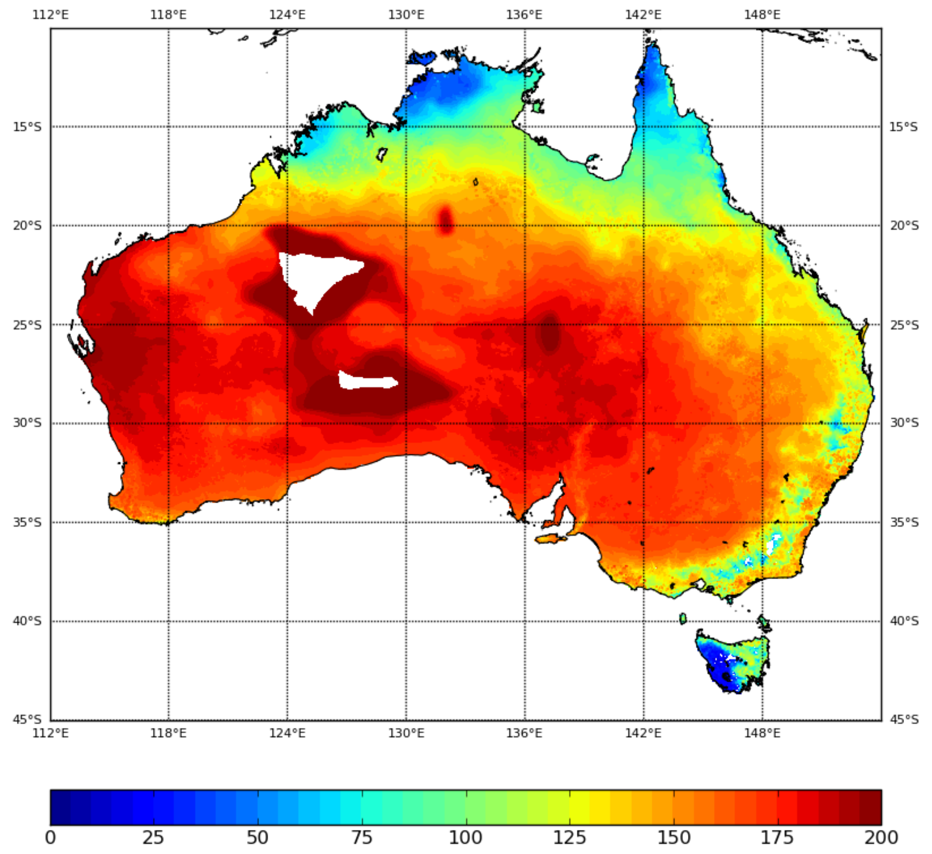


Monthly Mean Values [Using 40 Years of data]

KBDI



MSDI



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
  - $SM_{Norm} = \frac{SM - SM_{Min}}{SM_{Max} - SM_{Min}}$
- 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

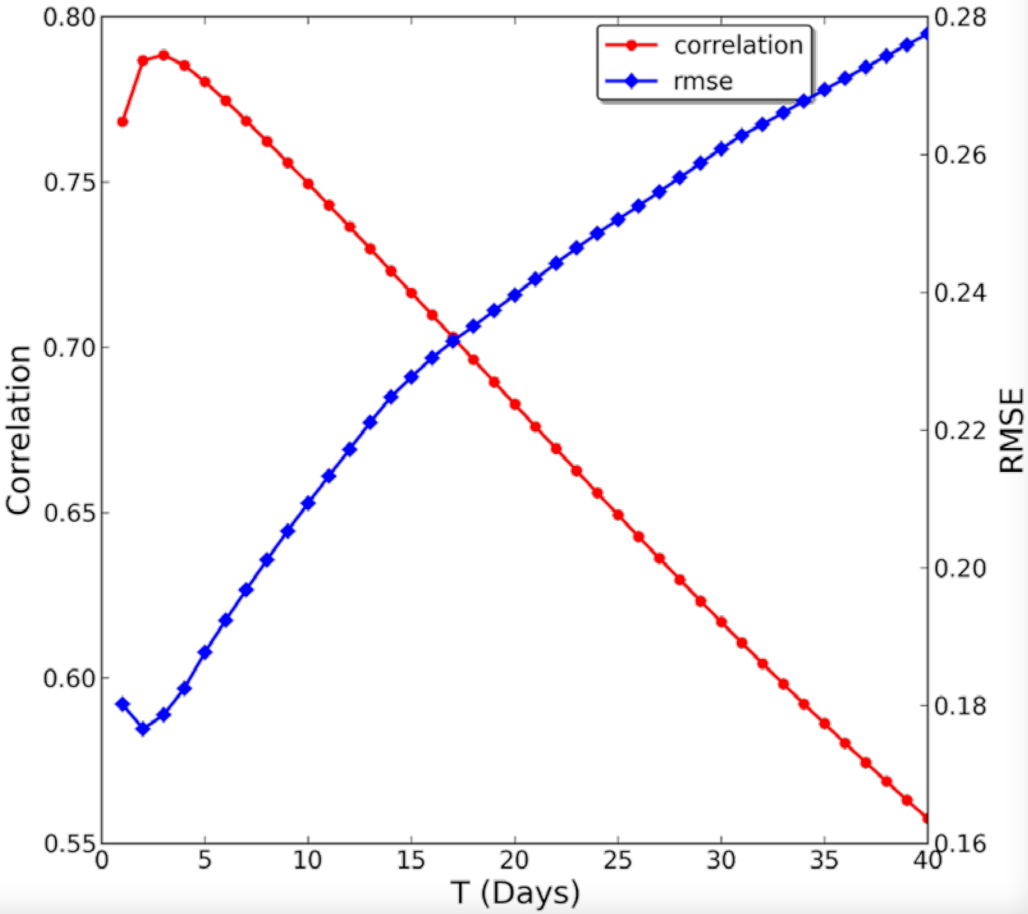
Surface to profile soil moisture

$$SWI_n = SWI_{n-1} + K_n\left((m_s)_n - SWI_{n-1}\right)$$

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:

$$K_n = \frac{K_{n-1}}{K_{n-1} + e^{\frac{(t_n - t_{n-1})}{T}}}$$



Depth weighting of NWP soil moisture

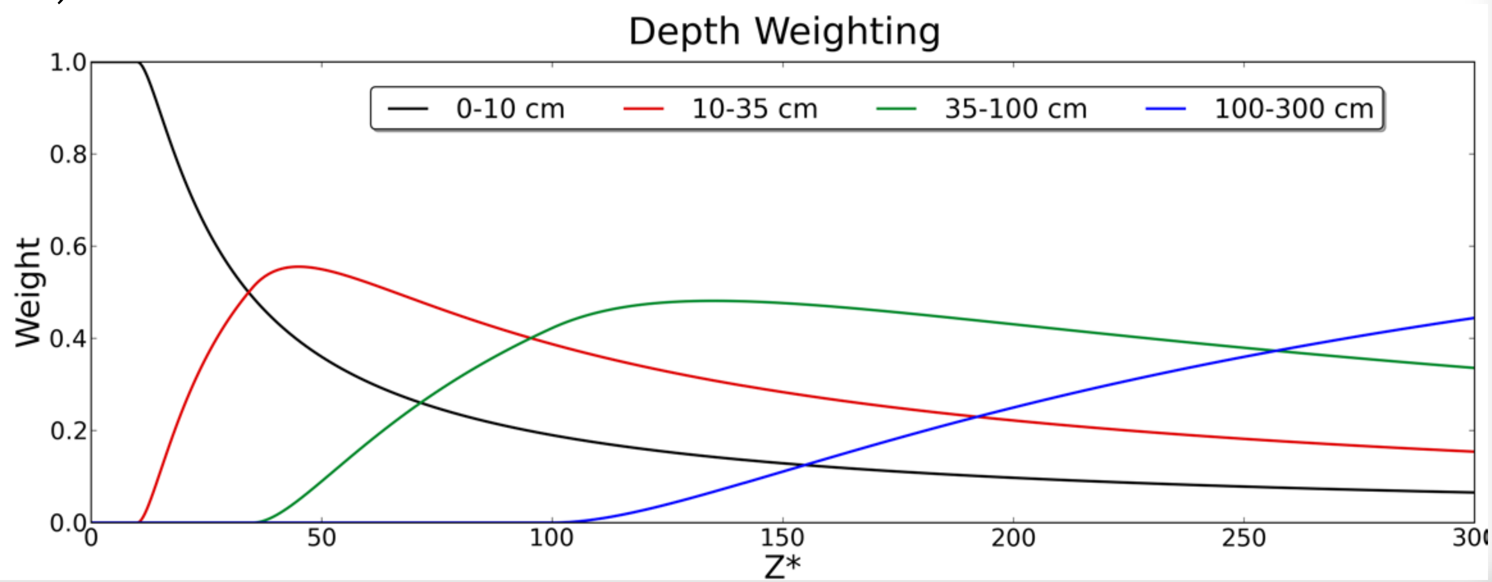
Based on Franz et al., 2012.

$$wt(z) = \int_{Z_{n-1}}^{Z_n} a\left(1 - \left(\frac{z}{z^*}\right)^b\right) dz$$

wt - *Weight*
z^* - CosmOz sensing depth
Z_n - Model soil layer depth at layer n
a,b - Constants

a is defined by:

$$1 = \int_0^{z^*} a\left(1 - \left(\frac{z}{z^*}\right)^b\right) dz$$



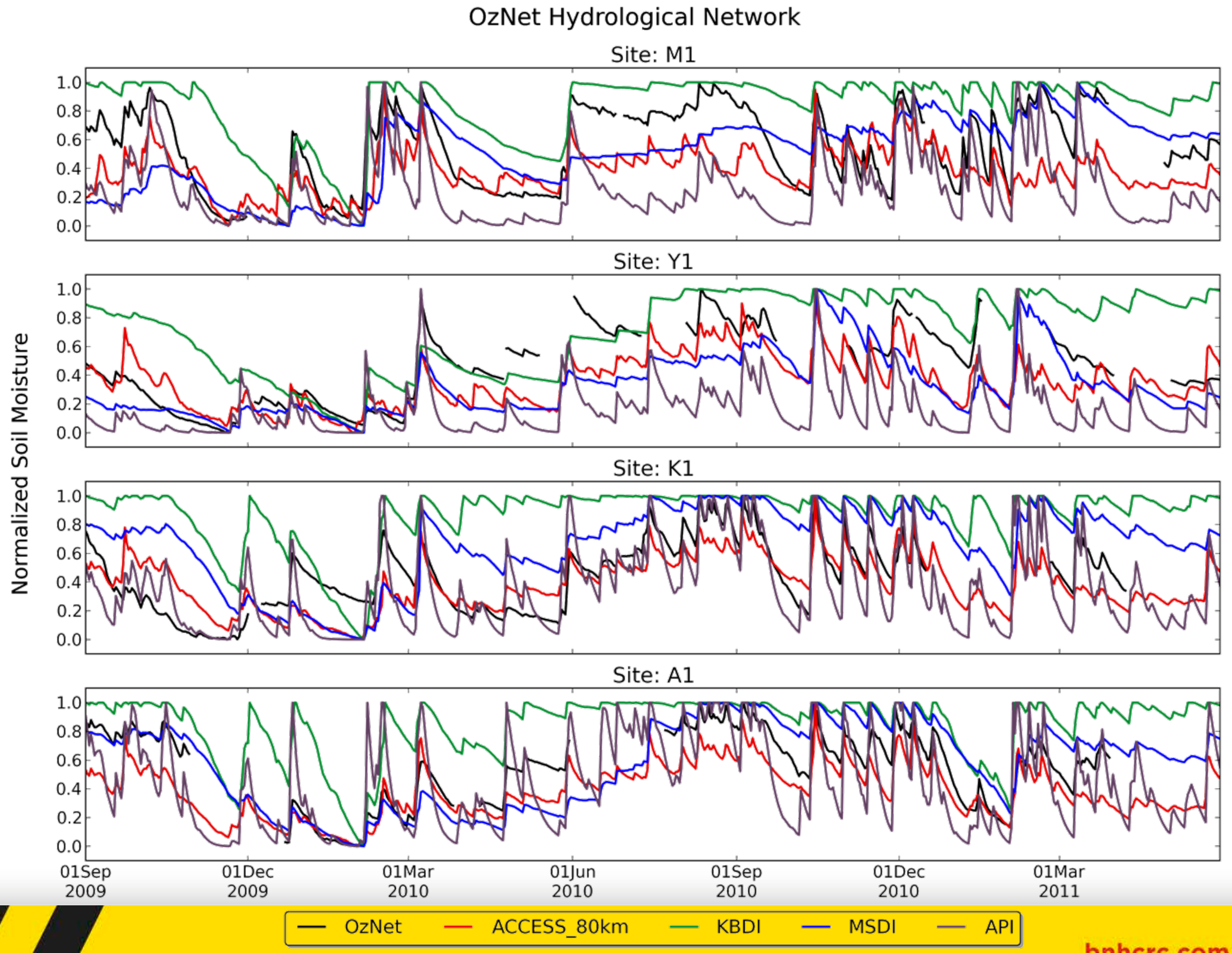
Statically weighted (SW) vs Depth weighted (DW) for ACCESS_40km w.r.t CosmOz

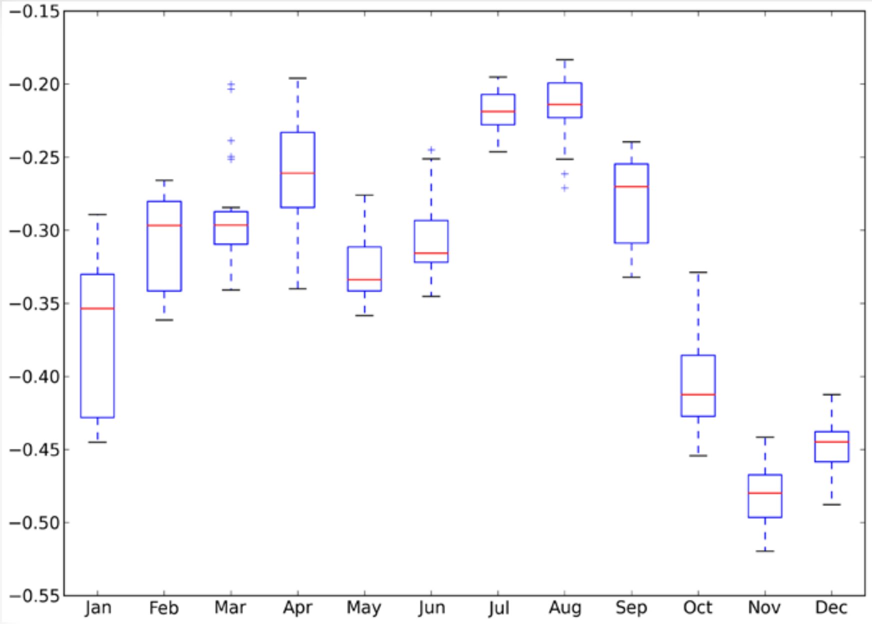
Site	Probing Depth (m)			Correlation [-]		Bias [-]		RMSD [-]	
	Mean	*Max*	*Min*	*LW*	*DW*	*LW*	*DW*	*LW*	*DW*
Baldry	0.22	0.38	0.11	0.89	0.87	0.02	0.01	0.11	0.13
Daly	0.4	0.55	0.16	0.82	0.84	-0.02	-0.03	0.13	0.13
Gnangara	0.4	0.56	0.24	0.57	0.66	-0.07	0.05	0.21	0.19
Robson Creek	0.13	0.21	0.08	0.8	0.82	0.06	-0.06	0.16	0.15
Temora	0.17	0.27	0.09	0.9	0.9	-0.01	-0.05	0.12	0.13
Tullochgorum	0.2	0.47	0.08	0.76	0.75	0.09	0.00	0.18	0.16
Tumbarumba	0.1	0.14	0.06	0.81	0.81	0.04	-0.05	0.16	0.16
Weany Creek	0.23	0.35	0.11	0.74	0.75	-0.02	-0.05	0.15	0.17
Yanco	0.2	0.37	0.08	0.87	0.88	-0.03	-0.05	0.13	0.13
Mean				0.8	0.81	0.01	-0.03	0.15	0.15

Skill scores

Data Set	Normal time series						Anomaly series	
	Correlation [-]		Bias [-]		RMSD [-]		Correlation [-]	
	OzNet	*CosmOz*	*OzNet*	*CosmOz*	*OzNet*	*CosmOz*	*OzNet*	*CosmOz*
ACCESS_80km	**0.72**	–	**0.02**	–	**0.19**	–	0.67	–
ACCESS_40km	–	**0.81**	–	**-0.03**	–	**0.15**	–	0.51
KBDI	**0.6**	**0.63**	**-0.39**	**-0.35**	**0.43**	**0.42**	**0.65**	**0.31**
MSDI	0.71	0.76	**-0.02**	-0.07	0.23	0.2	**0.76**	0.46
API	0.66	0.73	0.14	0.14	0.26	0.23	0.69	**0.61**
ASCAT	–	0.76	–	-0.01	–	0.19	–	0.55

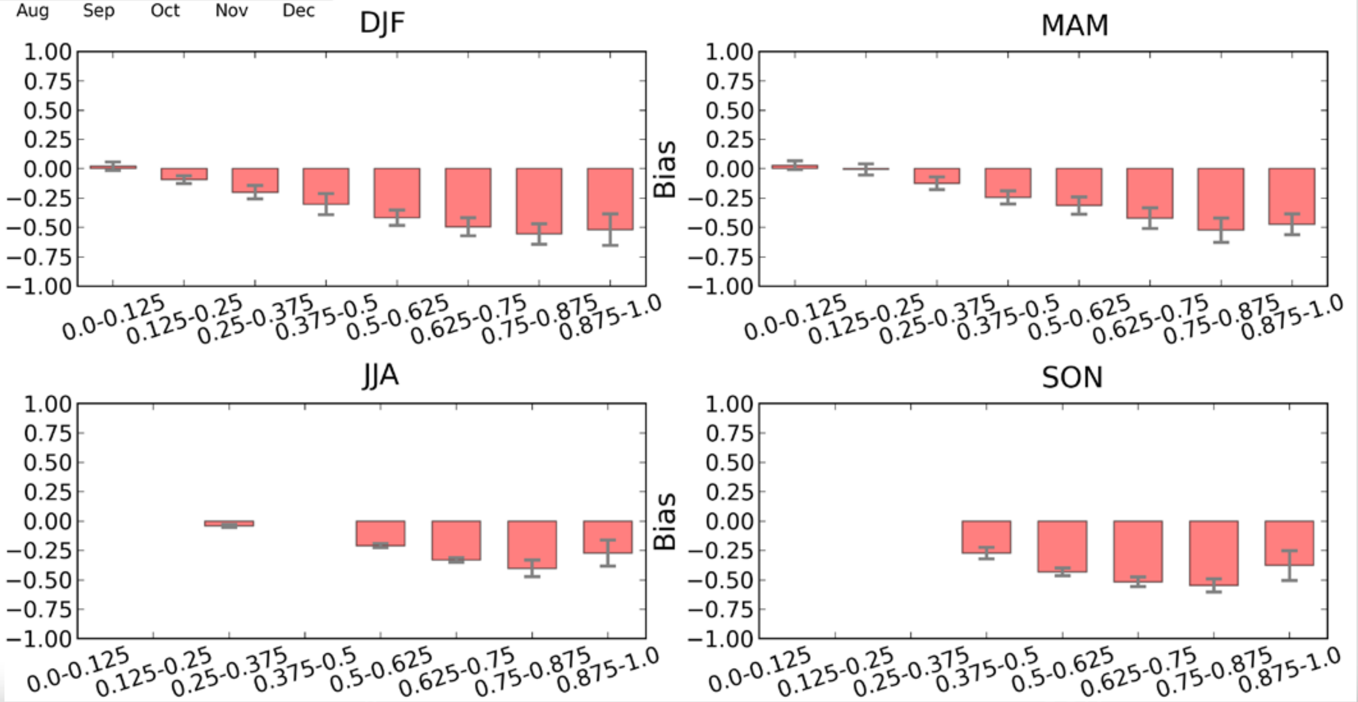
Time series - OzNet

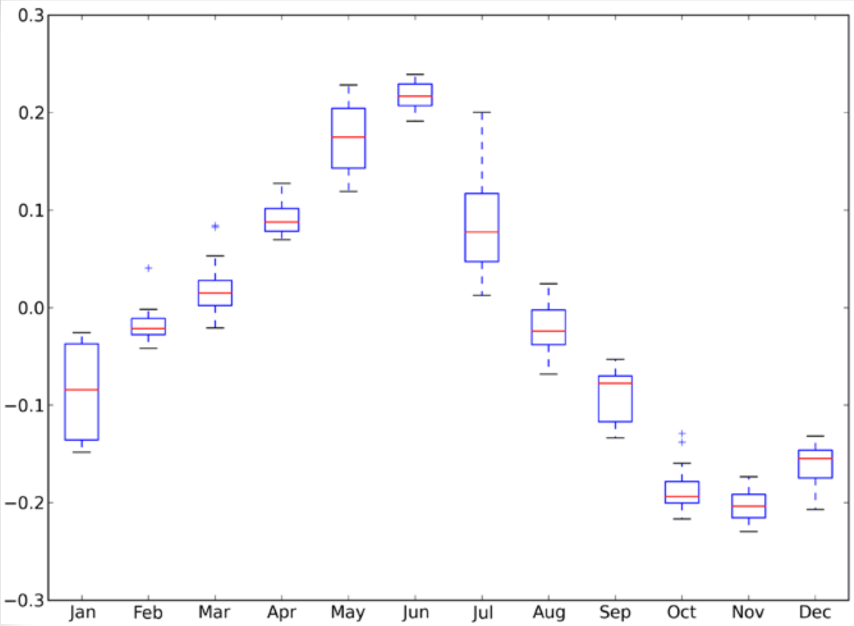




Bias: KBDI vs OzNet @ site A1

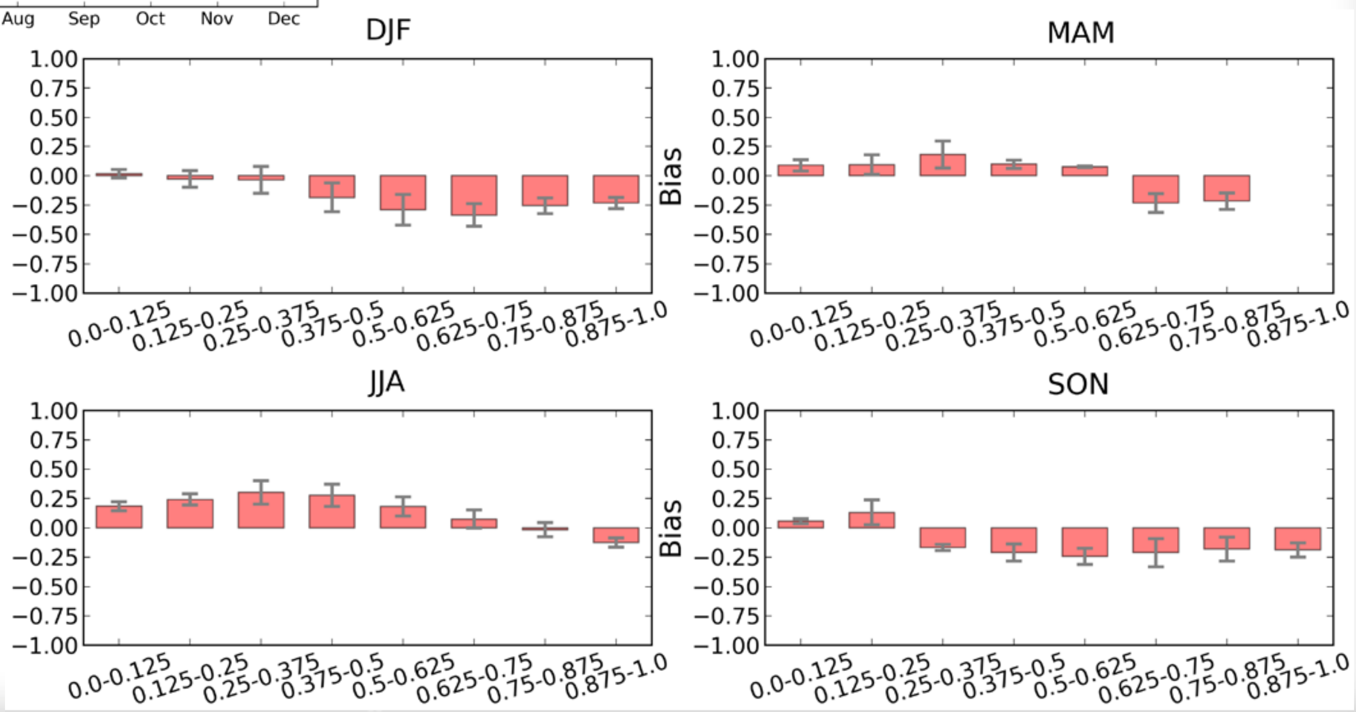
–ve means wetter
+ve means drier



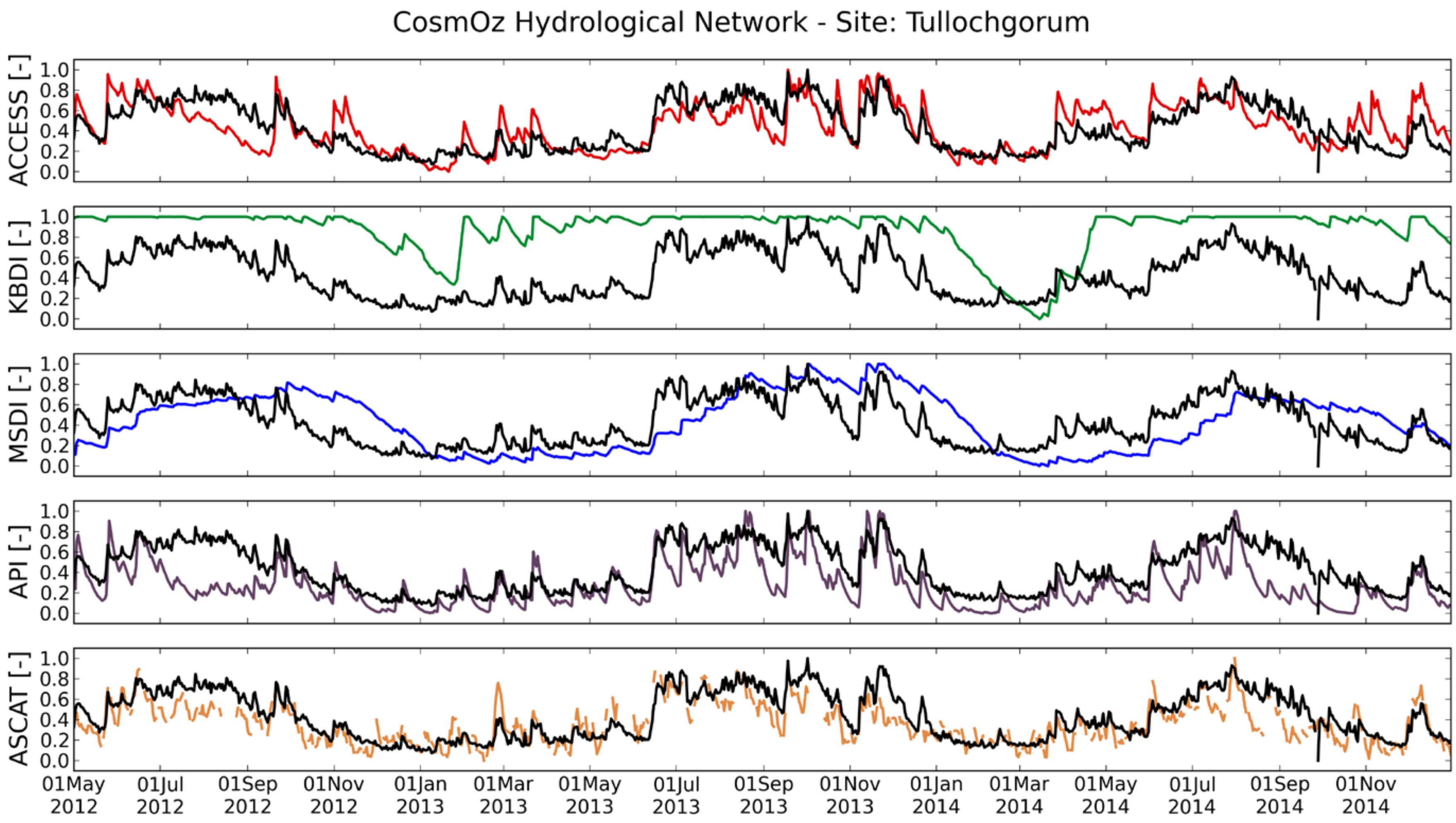


Bias: MSDI vs OzNet @ site A1

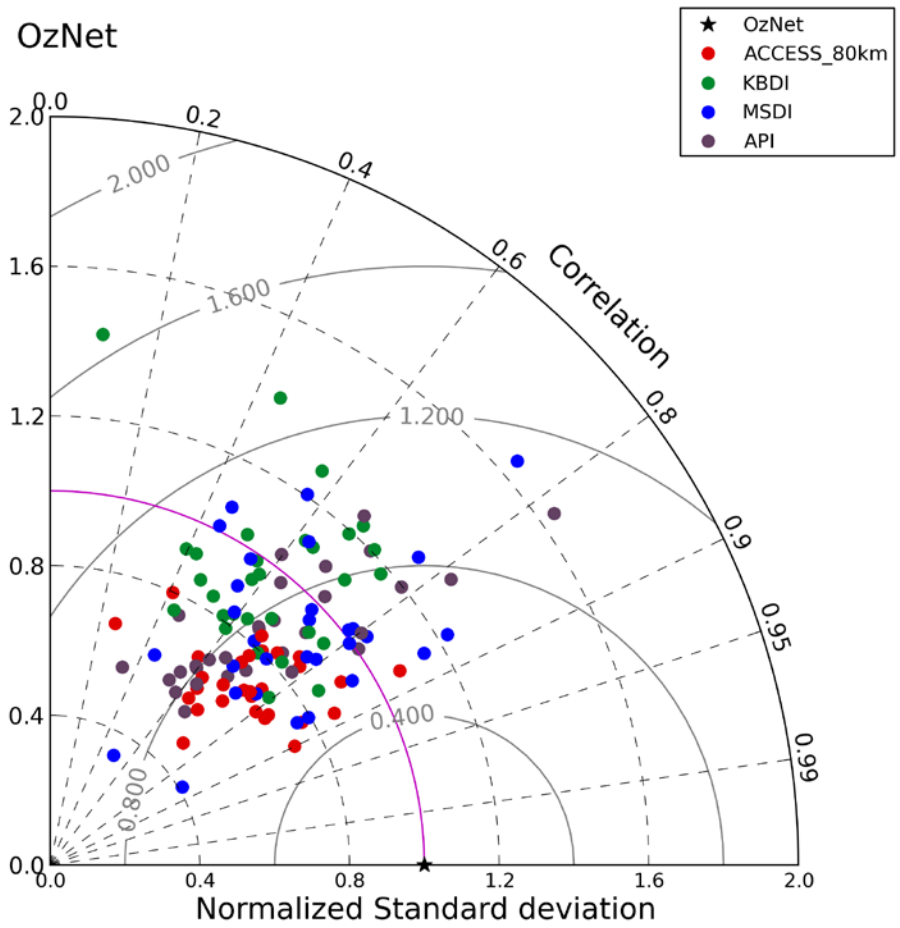
–ve means wetter
+ve means drier

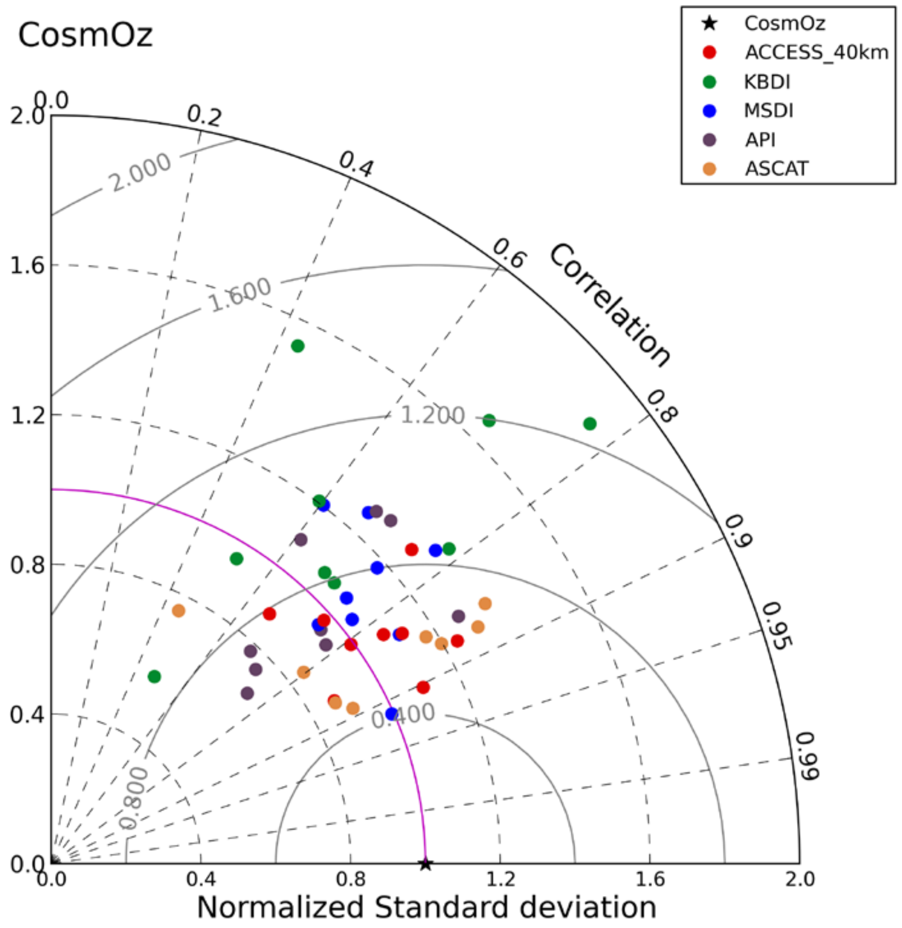


Time series - CosmOz

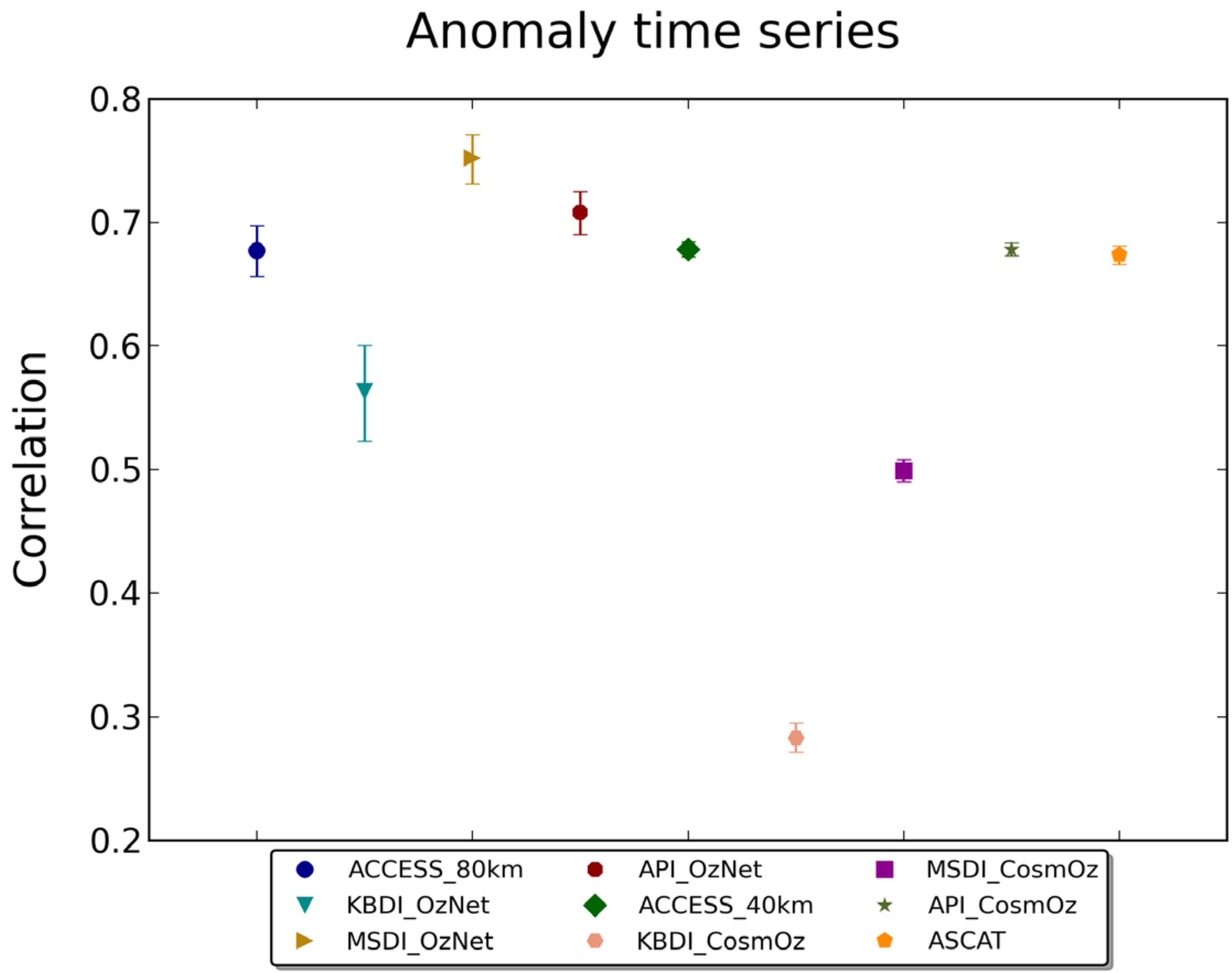


Taylor diagrams





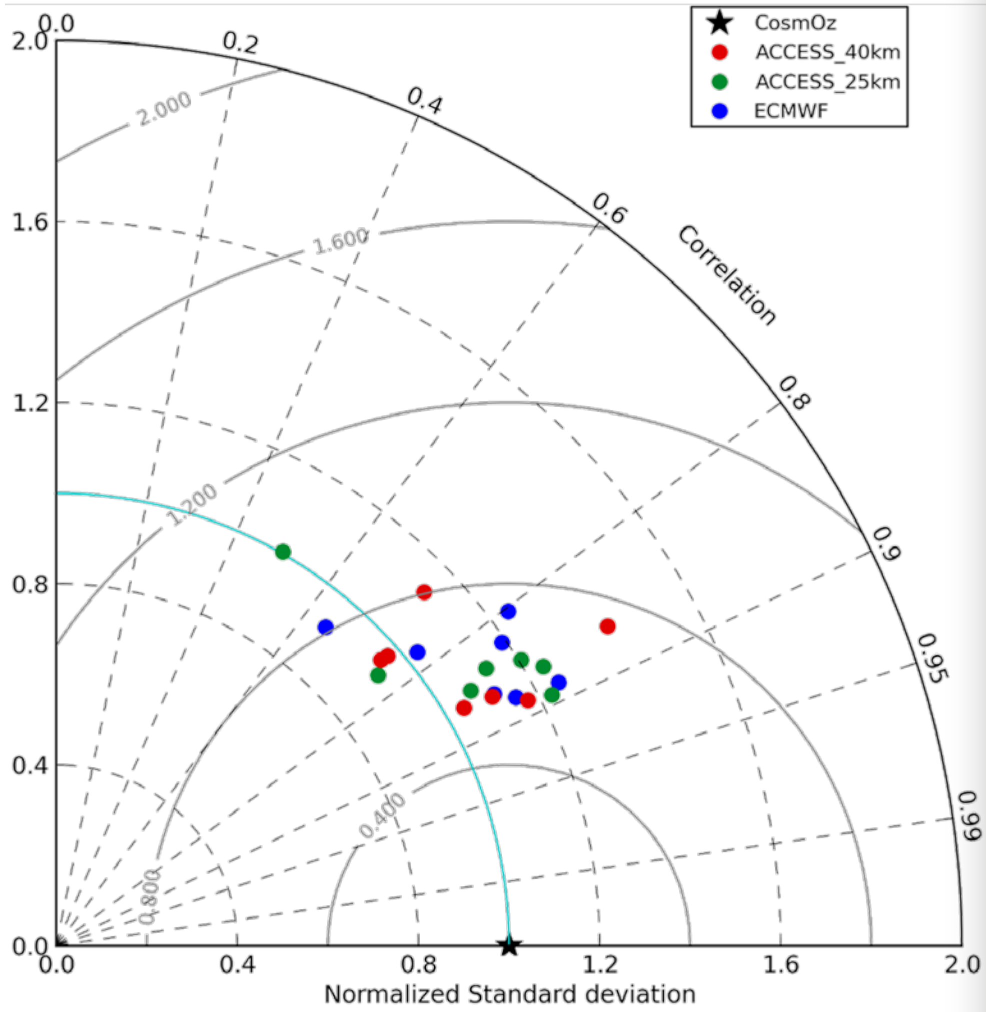
Correlation & CIs



ACCESS_40km/ACCESS_25km/ECMWF

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

Metrics	ACCESS_40 km	ACCESS_ 25km	ECMW F
Correlation [-]	0.82	0.80	0.81
Anomaly Correlation [-]	0.49	0.56	0.58
Bias [-]	-0.04	-0.06	-0.04
RMSD [-]	0.16	0.17	0.17



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.

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THANK YOU

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