bushfire&natural
HAZARDSCRC

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

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An Australian Government Initiative

CRC AUSTRALIA

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.

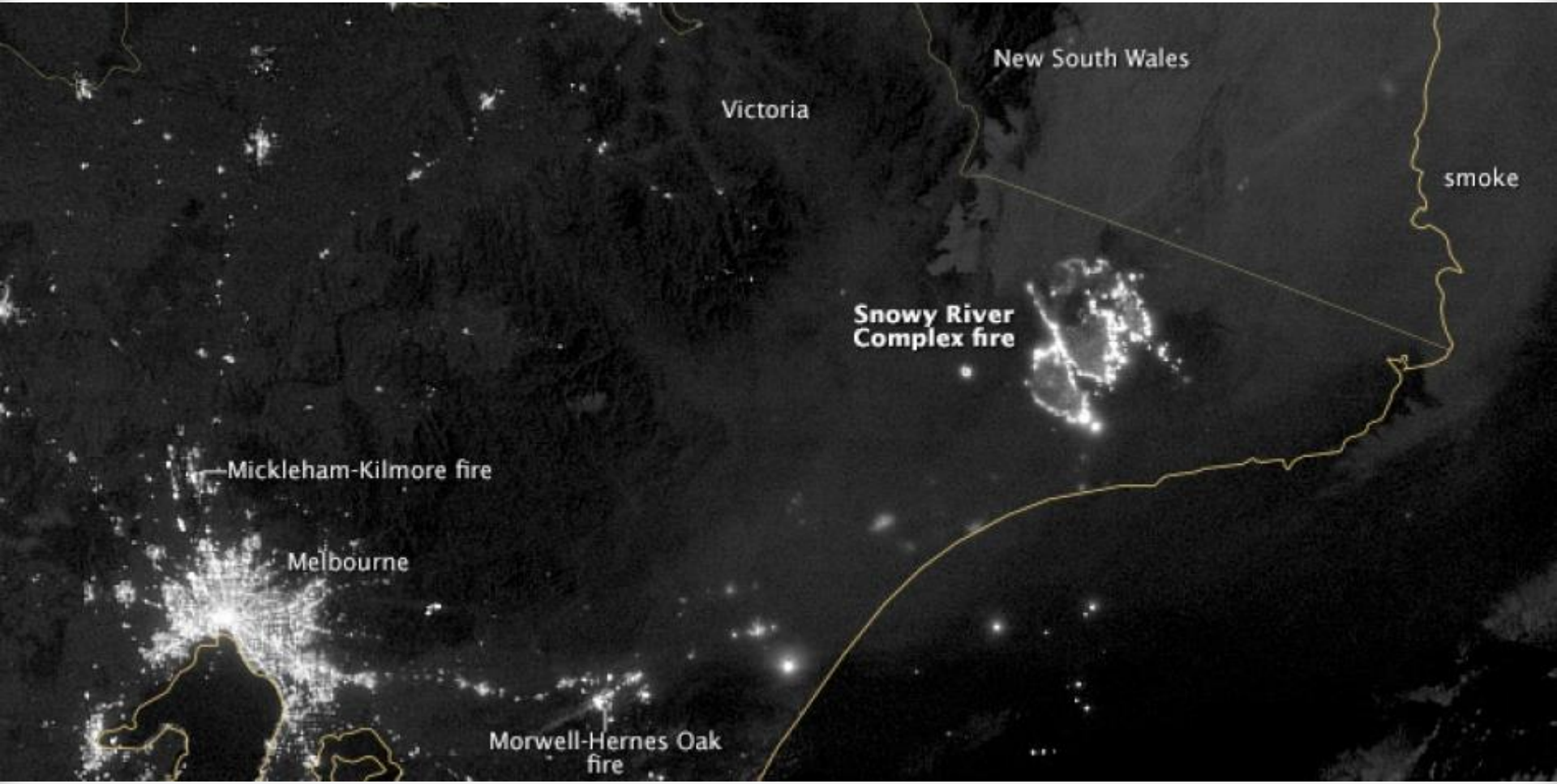
Project Team Members

- Imtiaz Dharssi
- Vinod Kumar
- Peter Steinle
- Jeff Kepert
- Adam Smith
- Ian Grant
- Jeff Walker
- Claire Yeo
- John Bally
- Paul Fox-Hughes
- Adam Leavesley
- Mark Chladil
- Rob Sandford
- Ralph Smith
- David Taylor

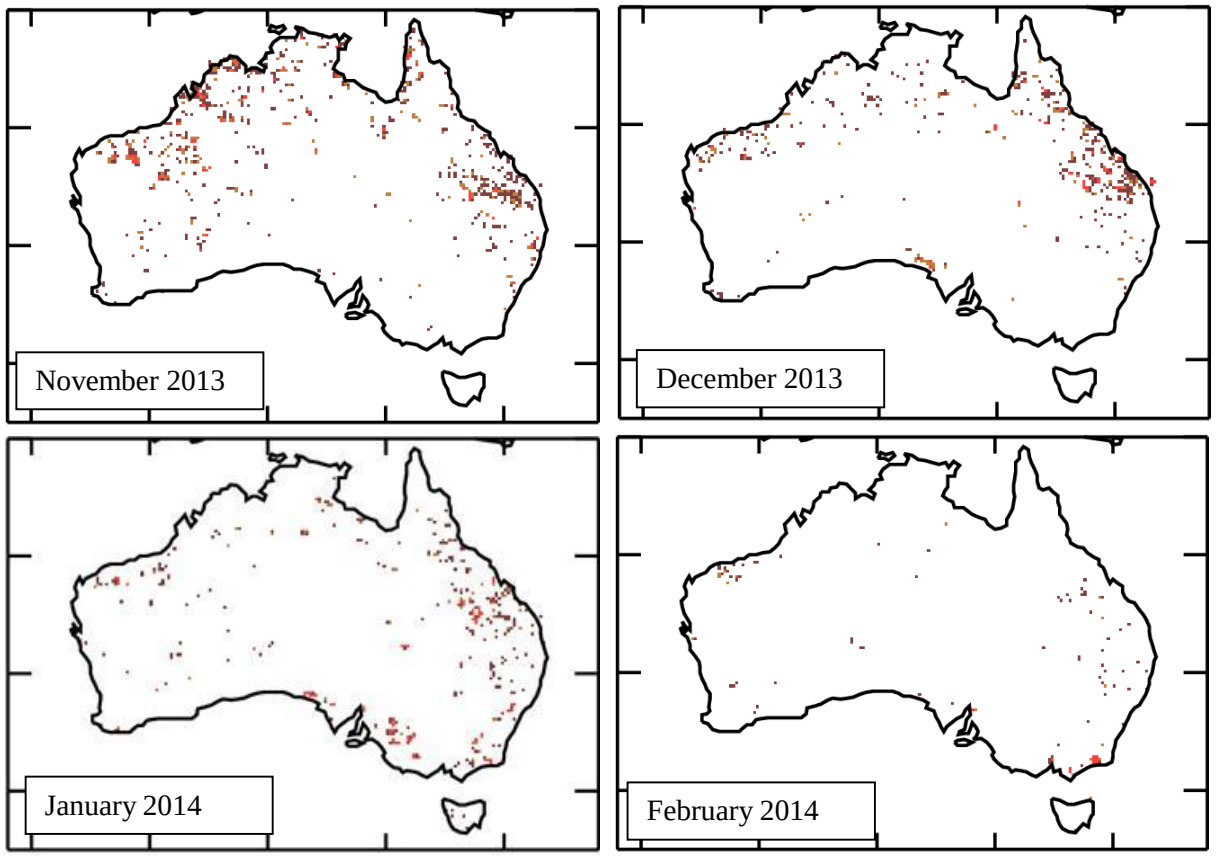
End-users

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

Snowy River Feb. 2014, Victoria



ACTIVE FIRE DETECTED BY MODIS



McArthur's Forest Fire Danger Index

$$FFDI = 2e^{(-0.45+0.987\ln(DF)-0.0345RH+0.0338T+0.0234V)}$$

DF - 'Drought Factor'
T - Temperature (°C)
V - Wind speed (km h^{-1})
RH - Relative humidity (%)

- FFDI was introduced in 1958.
- FFDI is still used operationally.
- Several modifications over the years.

DF and land dryness

- Land (i.e., soil, litter and vegetation) dryness determines the availability of fuel for burning.
- The ignition, spread as well as the short temporal variation of fire depends on fuel availability.
- Because fuel availability measures are not always readily available, FDRS include sub-models to estimate it.
- Drought Factor (DF) represent fuel availability.
- DF is a combination of seasonal dryness and short-term drying.
- The seasonal dryness are represented by drought indices which are cumulative estimates of soil moisture deficit (SMD) at upper soil layers.

Keetch–Byram Drought Index (KBDI)

- Formulated in 1968.
- Used operationally in the Australian states of Victoria, NSW & Queensland.
- ET is a function of vegetation cover density (VCD).
- VCD is an exponential function of mean annual rainfall.
- ET is an exponential function of T_{max}.
- Maximum water available for transpiration is 203.2 mm.

Mount's Soil Dryness Index (MSDI)

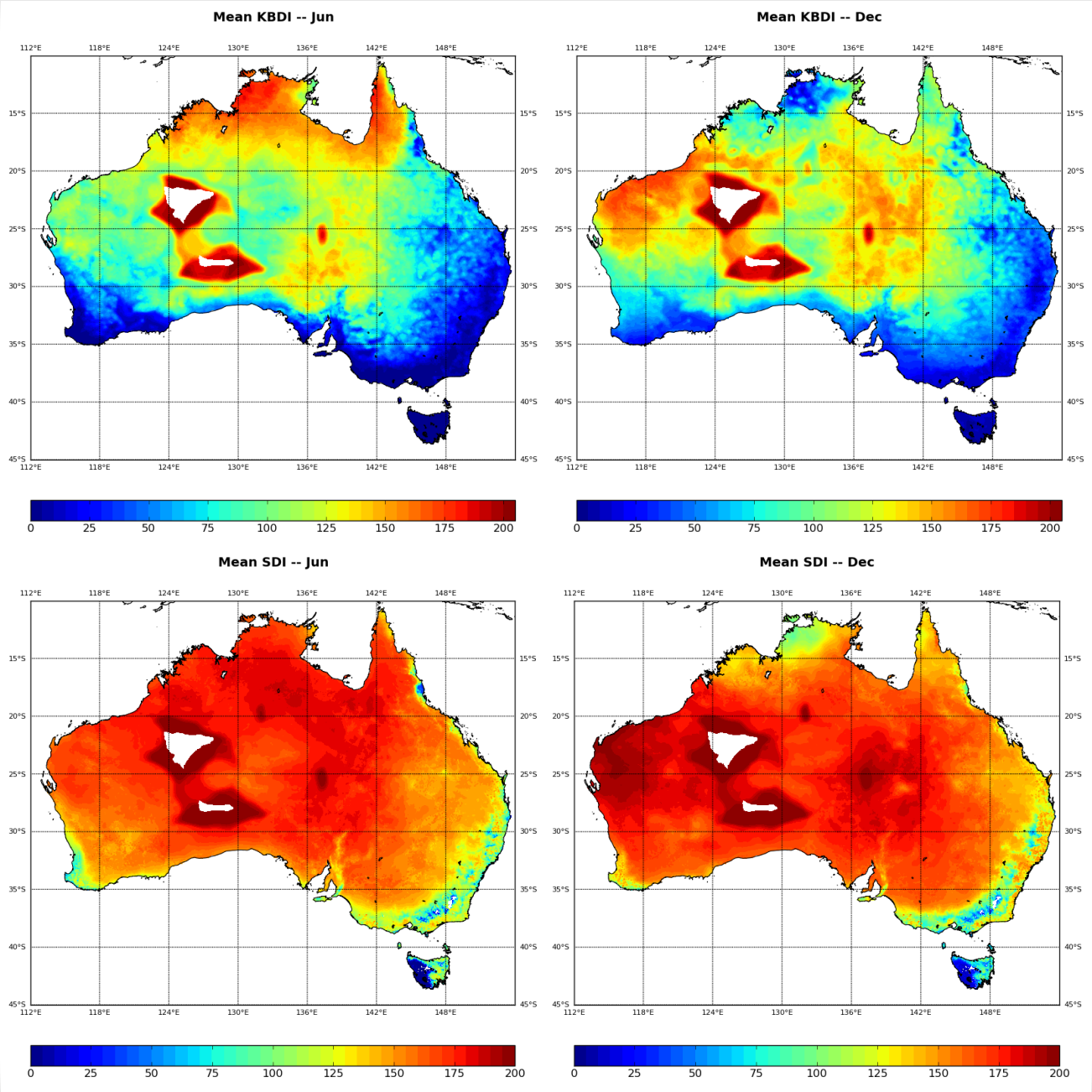
- Formulated in 1972 for Forestry Tasmania
- Used operationally in Tasmania, SA and WA.
- Based on KBDI.
- But interception and runoff are treated separately.
- The interception and runoff is based on seven vegetation categories.
- Numerous parameters for each vegetation class, whose tuning is critical.
- ET is a linear function of T_{max}

Key objectives of BNHCRC research

- Generate a long time series of gridded KBDI & SDI.
- Validate KBDI & SDI against observations and LSM soil moisture products.
- Explore the scope of better soil moisture products from land surface models by using advanced data assimilation techniques.
- Deliver an operations ready system which gives a high-resolution (both temporal and spatial) soil moisture analysis for FDR.

Data sets

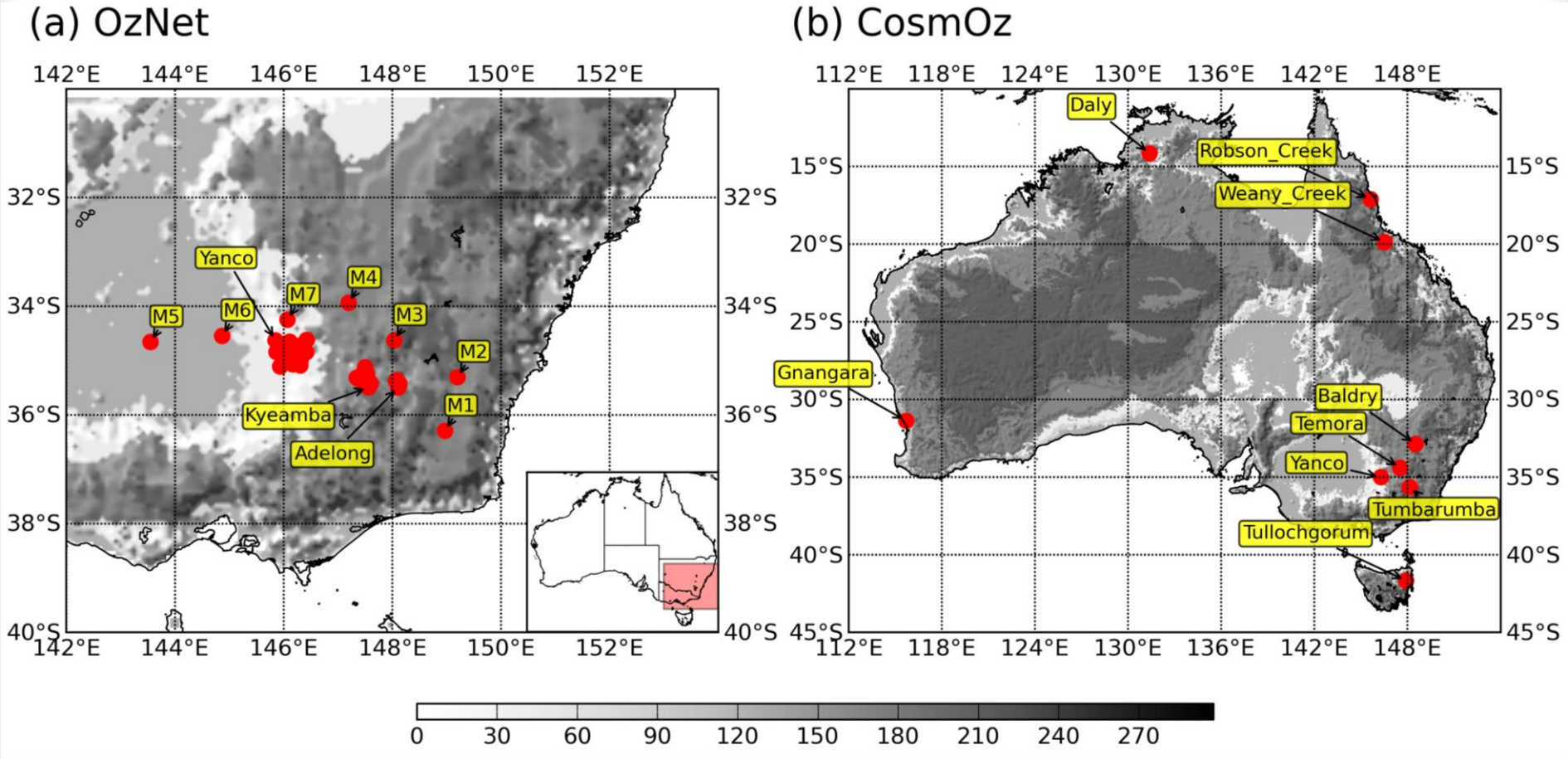
- KBDI / SDI / API
  - For whole of Australia
  - 0.05° x 0.05° grids
  - Daily time steps.
  - Forcing data: AWAP.
- In-situ observations
  - OzNet
    - 0-30 cm profile
    - Murrumbidgee, NSW
    - 2000 - 2011
  - CosmOz
    - Cosmic ray probes
    - Varying depth profiles
    - 13 sites, 9 calibrated
- NWP
  - ACCESS-Global, ECMWF Operations
  - APS0 ~80km, APS1 ~40 km, APS2 ~25km, EC-Op ~25km.
  - ACCESS → Soil moisture nudging
  - ECMWF → EKF
- ASCAT
  - On board MetOp-A
  - Resolution ~ 12.5km.
  - 1-2 pass per day
  - ~ top 5cm soil moisture


Mean KBDI -- Jun
Mean KBDI -- Dec
Mean SDI -- Jun
Mean SDI -- Dec
112°E 118°E 124°E 130°E 136°E 142°E 148°E
15°S 20°S 25°S 30°S 35°S 40°S 45°S
0 25 50 75 100 125 150 175 200

API

- API is a cumulative index representing the soil moisture state.
- It is based on the assumption that, at a given time, amount of moisture in a soil column is related to precipitation at earlier times.
- API for day i is given by:
- $API_i = \gamma API_{i-1} + P_i$
  - γ is the recession coefficient
  - P is the daily precipitation.
- γ represent the memory of soil column, i.e., the amount of moisture that has been retained from the preceding times.
- A long-term API reflects seasonal soil moisture conditions while a short-term API reflects the most recent rainfall intensity.

In-situ observation locations



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.
- Taylor Diagram
  - $\sigma_{Norm} = \frac{\sigma_{Est}}{\sigma_{Obs}}$
  - $uRMSD^2 = {\sigma_{Est}}^2 + {\sigma_{Obs}}^2 - 2\sigma_{Est}\sigma_{Obs}\cos R$

Exponential Filter

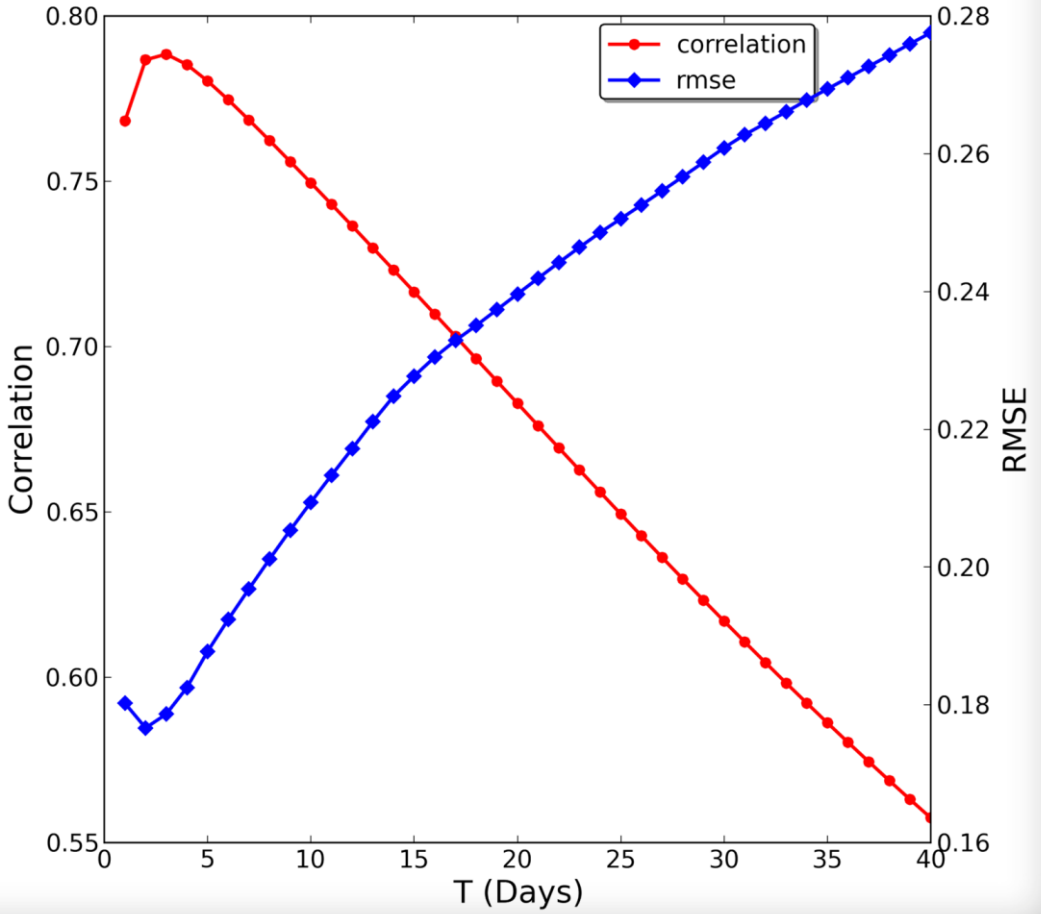
Surface to profile soil moisture

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

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

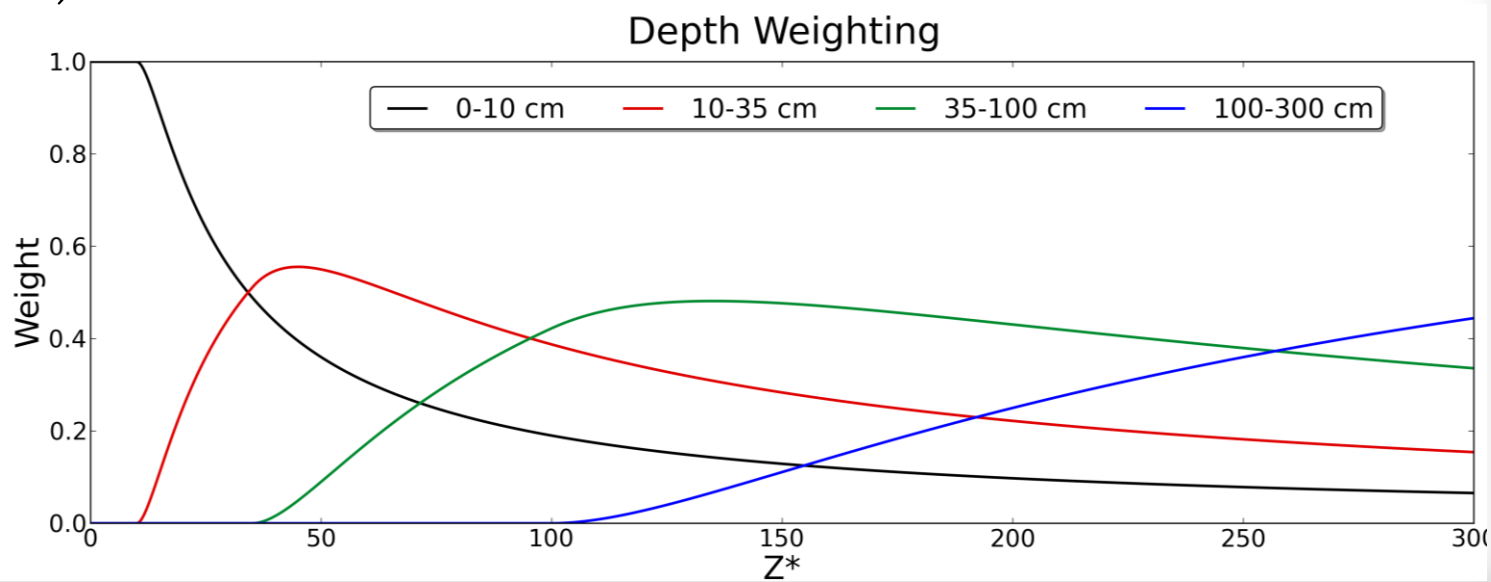
Based on Franz et al., 2012.

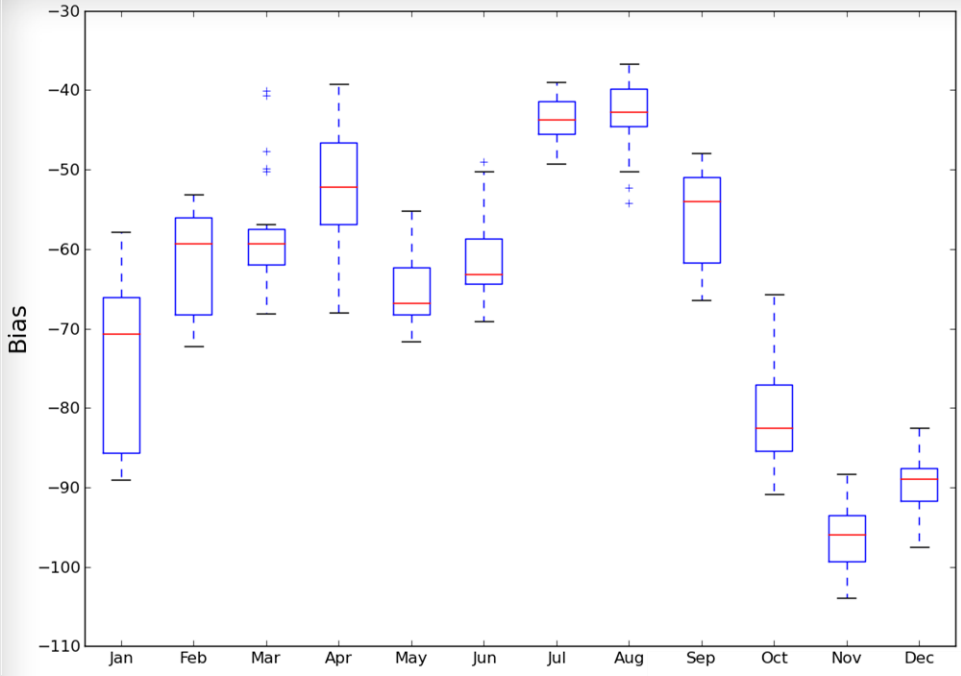
$$wt(z) = \int_{Z_{n-1}}^{Z_n} a\left(1 - \left(\frac{z}{z^*}\right)^b\right) dz$$

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

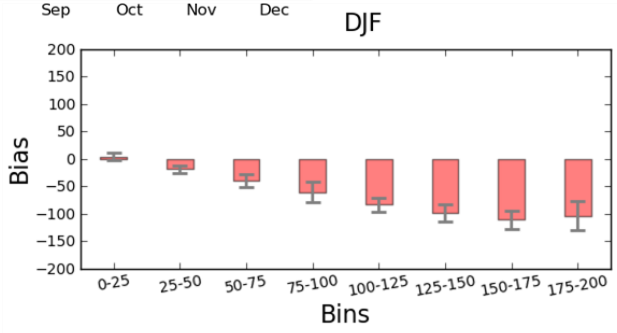
a is defined by:

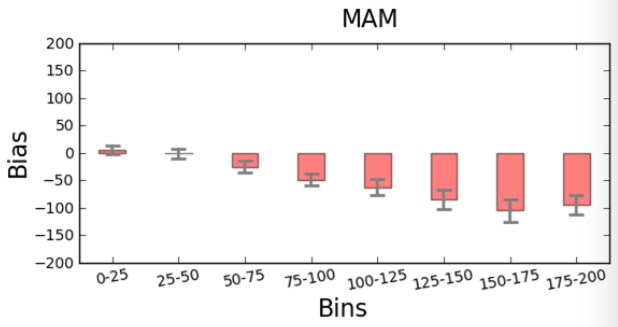
$$1 = \int_0^{z^*} a\left(1 - \left(\frac{z}{z^*}\right)^b\right) dz$$

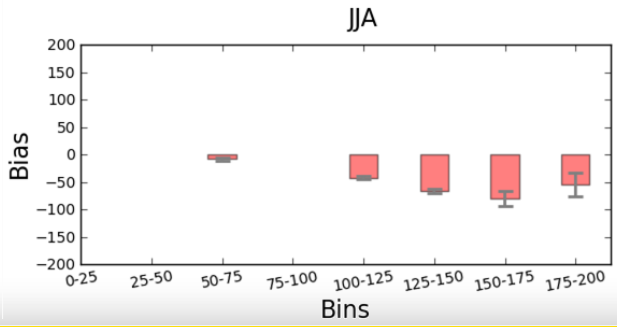


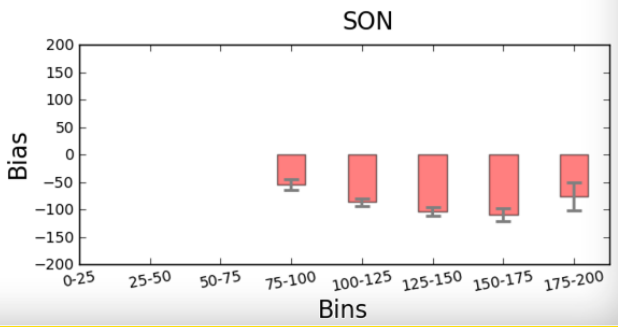


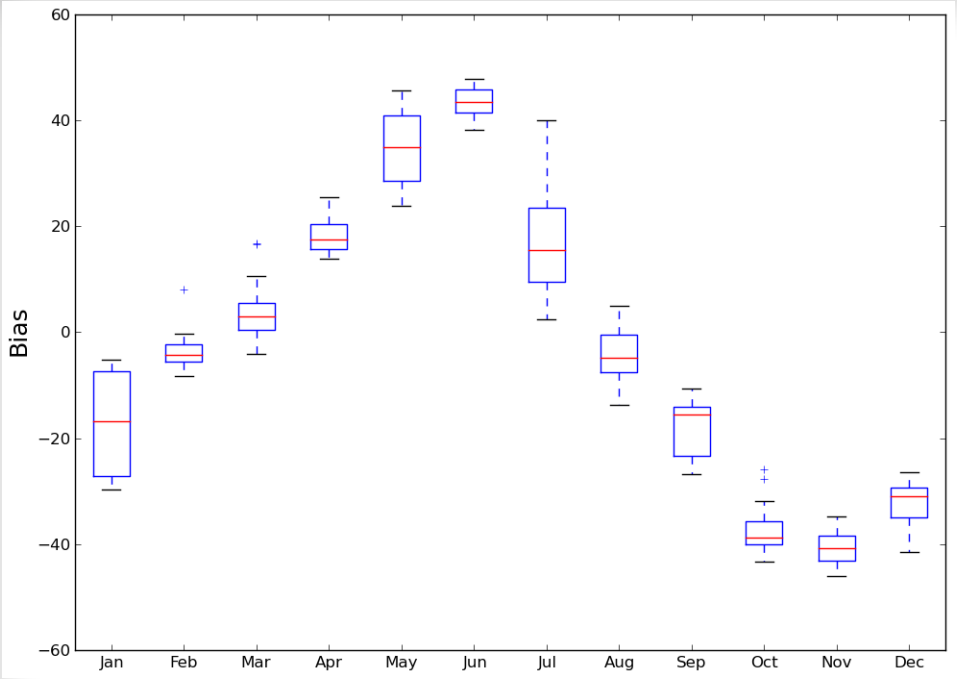
KBDI vs OzNet @ site A1



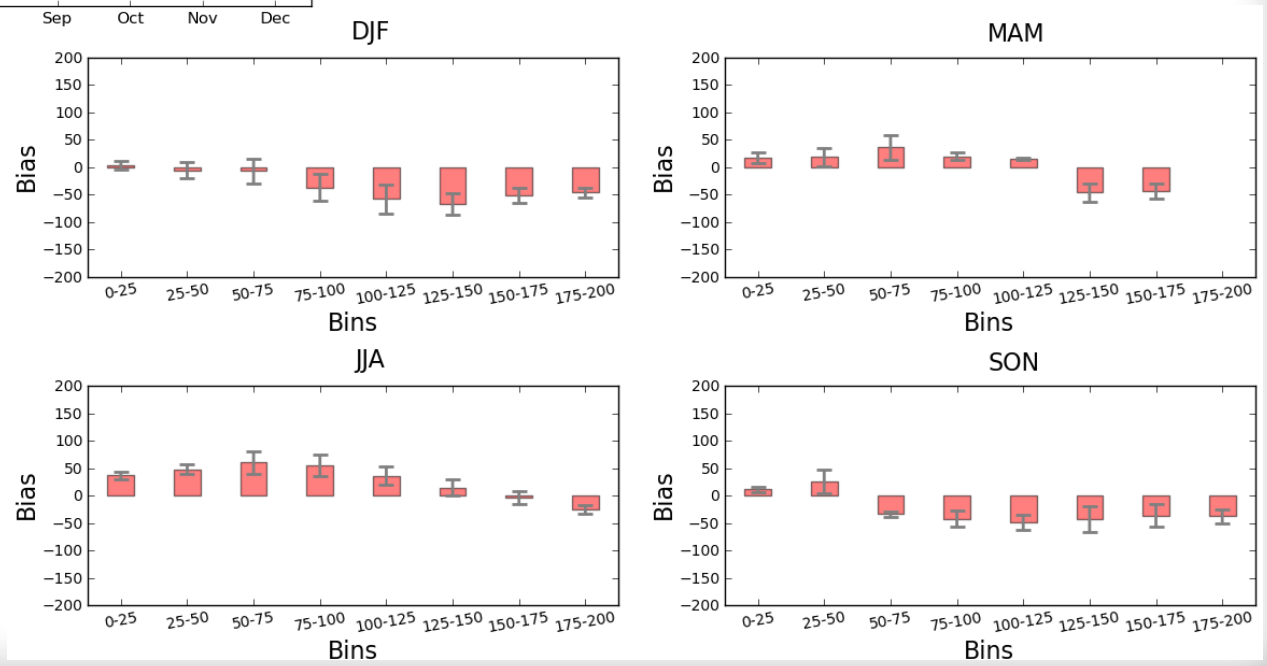








MSDI vs OzNet @ site A1



Skill scores

OzNet vs. Models

Data Set	Correlation [-]	Bias [-]	RMSD [-]
APS0	0.72	0.02	0.19
KBDI	0.6	-0.39	0.43
MSDI	0.71	-0.02	0.23
API	0.66	0.14	0.26

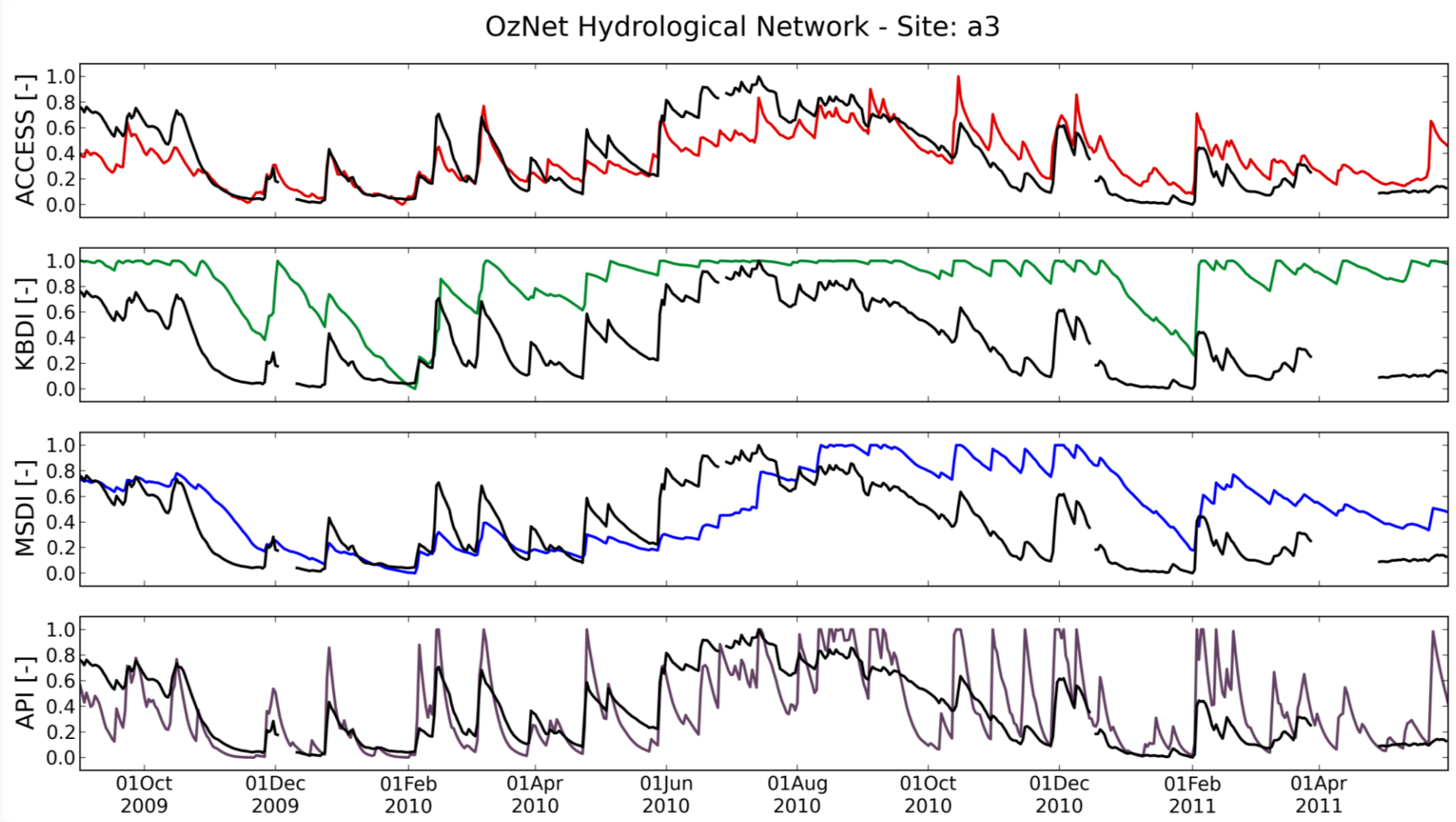
CosmOz vs. Models

Data Set	Correlation [-]	Bias [-]	RMSD [-]
APS1	0.81	-0.03	0.15
KBDI	0.63	-0.35	0.42
MSDI	0.76	-0.07	0.2
API	0.73	0.14	0.23
ASCAT	0.76	-0.01	0.19

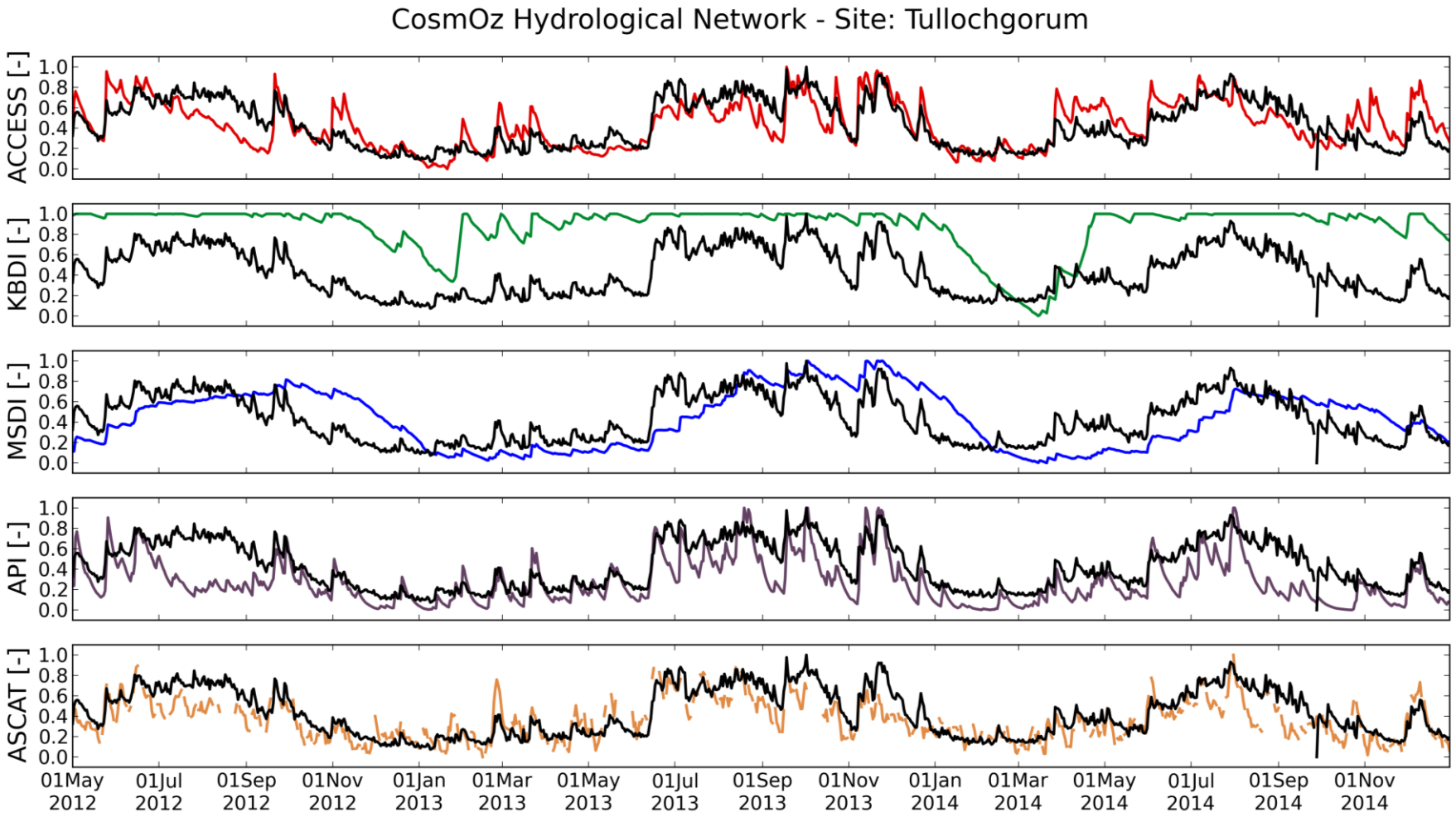
Site	Probing Depth (m)			Correlation [-]		Bias [-]		RMSD [-]	
	Mean	Max	Min	LW	DW	LW	DW	LW	DW
Mean	0.23	0.37	0.11	0.8	0.81	0.01	-0.03	0.15	0.15

LW – Linearly weighed
DW – Depth weighed

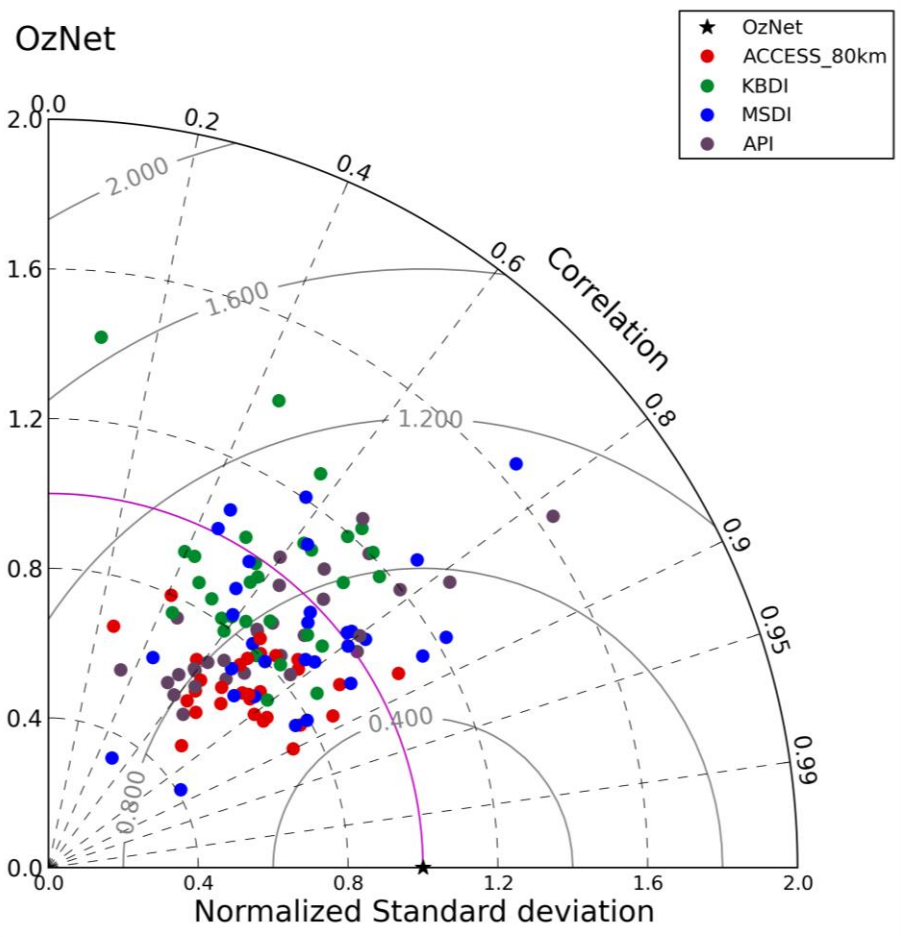
Time series - OzNet

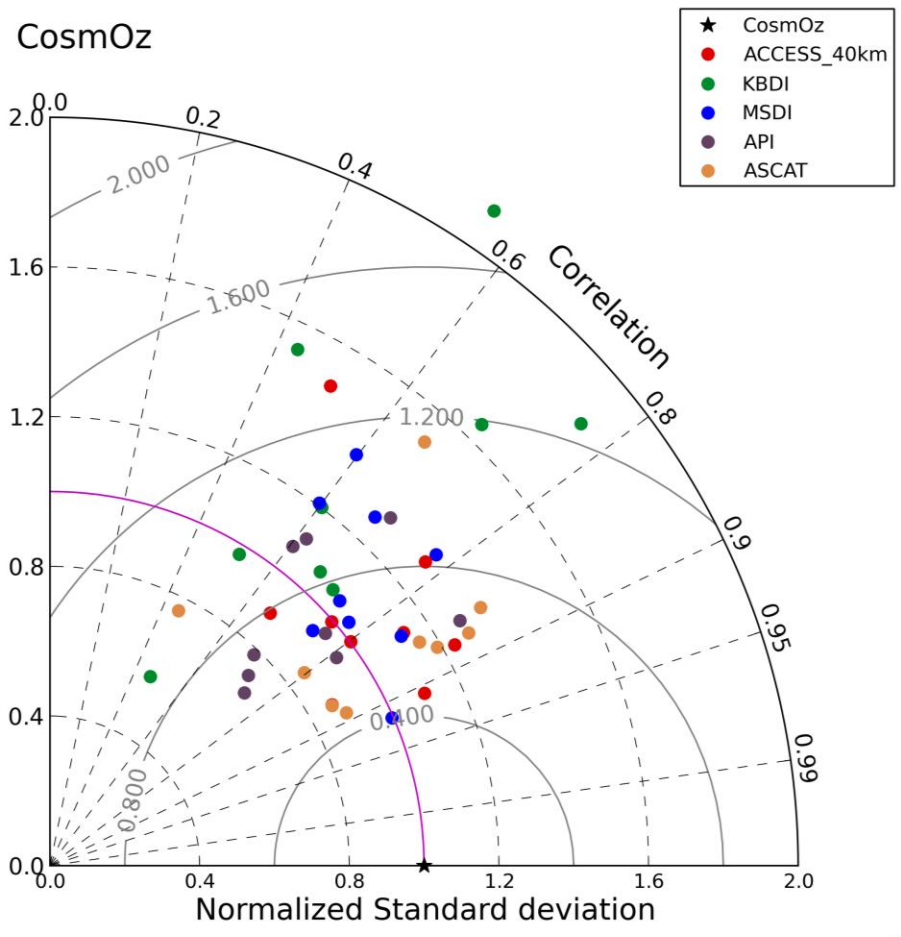


Time series - CosmOz



Taylor diagrams

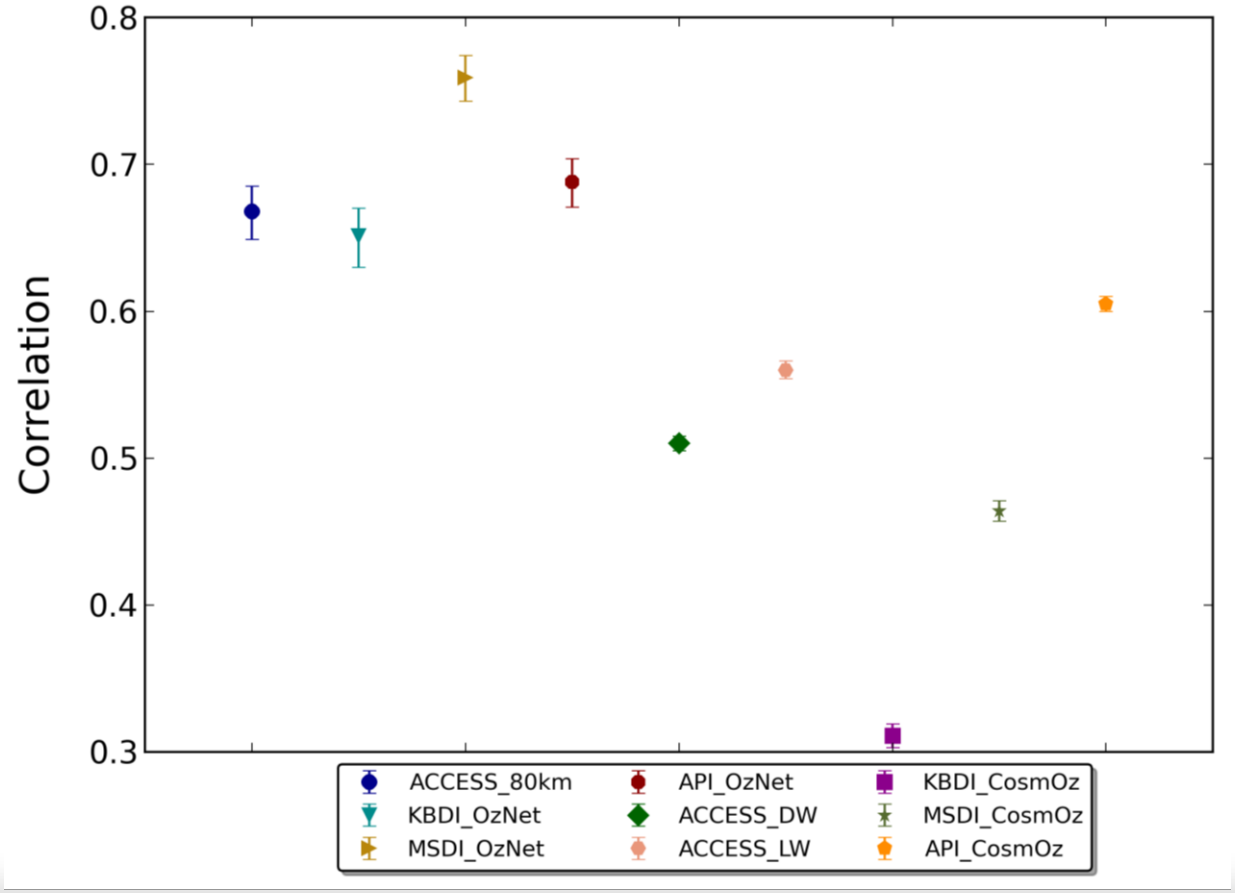




Anomalies

The anomaly (dimensionless) is then given by:

$$A(i) = \frac{SM(i) - \overline{SM(F)}}{\sigma_{SM(F)}}, \qquad \text{where } i \text{ is the day and } F = [i - 15, i + 15]$$



Anomalies

Data Set	Bias [-]		RMSD [-]	
	OzNet	CosmOz	OzNet	CosmOz
APS0	0.06	–	0.17	–
APS1	–	0.02	–	0.18
KBDI	-0.17	-0.18	0.24	0.26
MSDI	-0.04	-0.02	0.15	0.19
API	0.07	0.08	0.17	0.18
ASCAT	–	0.02	–	0.16

APS1/APS2/ECMWF

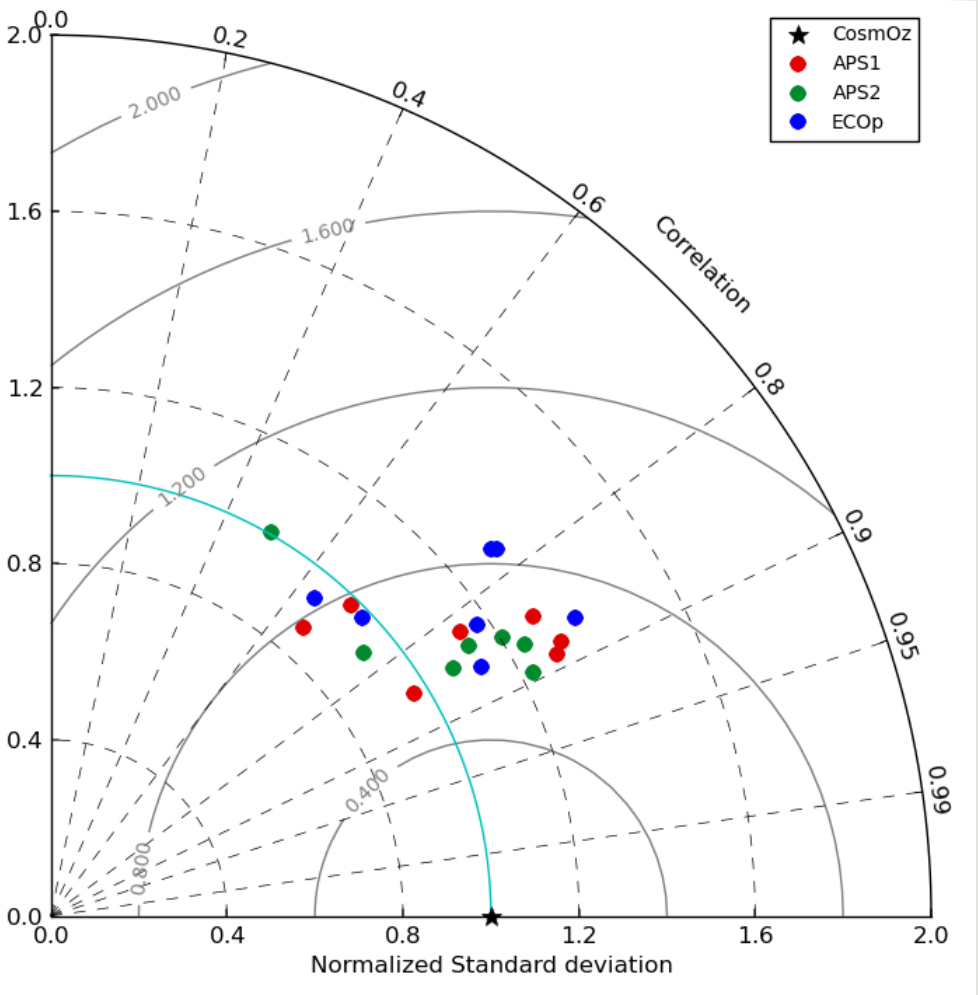
- Period – 1 Dec 2013 to 28 Feb 2015 (14 months)
- Depth weighed profiles.

Normal

Metrics	APS1	APS2	EC-Op
Mean Correlation	0.81	0.80	0.78
Mean Bias	-0.08	-0.06	-0.06
Mean RMSD	0.18	0.17	0.19

Anomalies

Metrics	APS1	APS2	EC-Op
Mean Correlation	0.57	0.57	0.6
Mean Bias	0.0	0.0	0.07
Mean RMSD	0.18	0.18	0.18



Conclusions

- In general, ACCESS is better than KBDI or SDI.
- ACCESS results are encouraging when we consider:
  - Coarser resolution (~40 – ~80 km) of NWP
  - NWP precipitation estimates are generally erroneous.
- KBDI soils show large wet bias.
- SDI 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 developed to improve the horizontal resolution to about 1km.
- The new information will be calibrated so that it can be used with existing fire and flood prediction systems.

Acknowledgments

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- Jeff Walker, Monash University.
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THANK YOU

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