A global blended drought Index (BDI) from merging satellite observations and land surface model simulations

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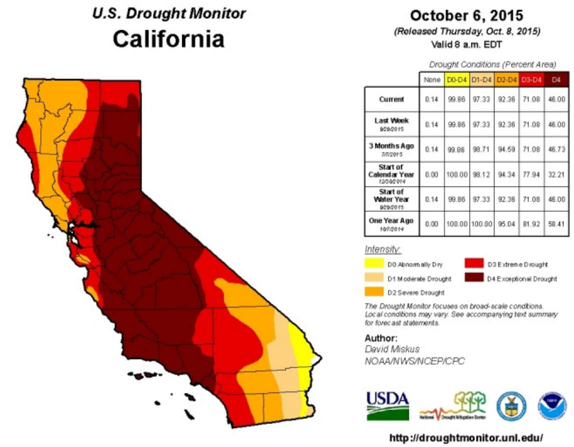
Outline

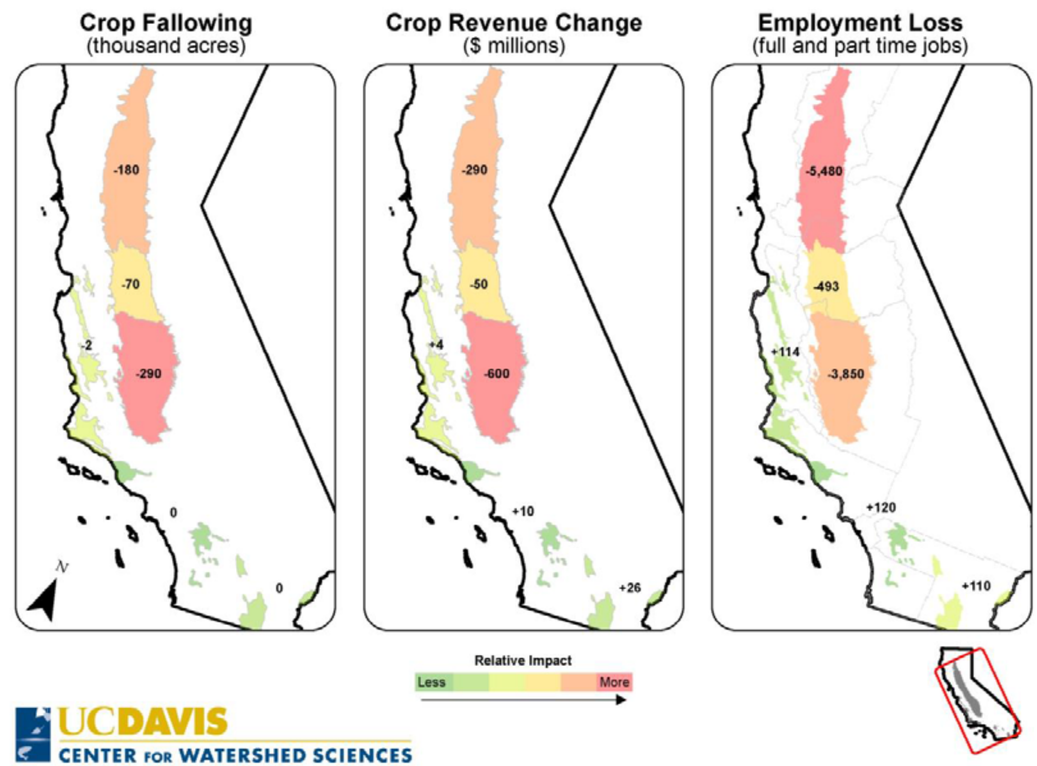
- ***Motivation***
- ***Data Sources***
- ***Triple Collocation Error Model***
- ***Blended Drought Index (BDI)***
- ***Validations***
- ***Drought Evaluations***
- ***summary***

1 Motivation



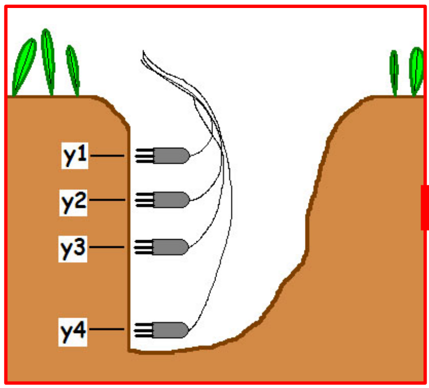
	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.14	99.86	97.33	92.36	71.08	46.00
Last Week 9/29/2015	0.14	99.86	97.33	92.36	71.08	46.00
3 Months Ago 7/7/2015	0.14	99.86	98.71	94.59	71.08	46.73
Start of Calendar Year 12/30/2014	0.00	100.00	98.12	94.34	77.94	32.21
Start of Water Year 9/29/2015	0.14	99.86	97.33	92.36	71.08	46.00
One Year Ago 10/7/2014	0.00	100.00	100.00	95.04	81.92	58.41

Of all natural disasters, the economic and environmental consequences of drought are among the most serious, due to its longevity varying from weeks to decades and widespread spatial extent.

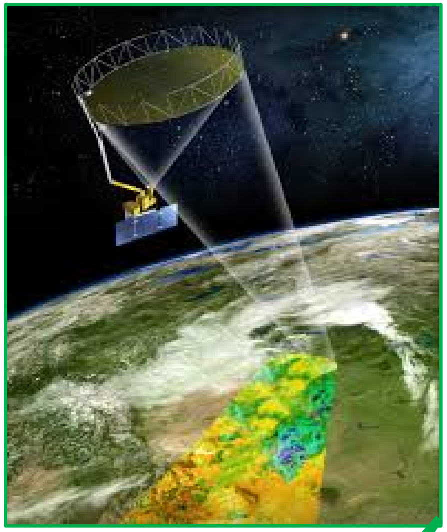


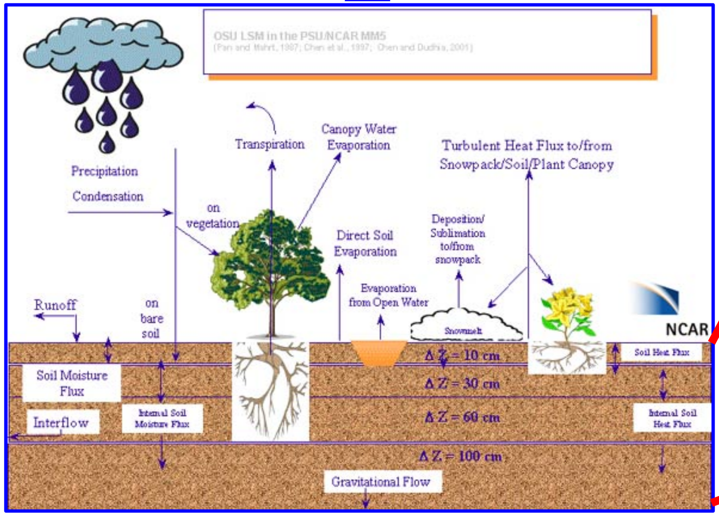
1 Motivation

Agricultural drought is the soil moisture deficit where crop water demands could not be met. The soil moisture statuses at various soil layers are the most important indicator of agricultural drought.



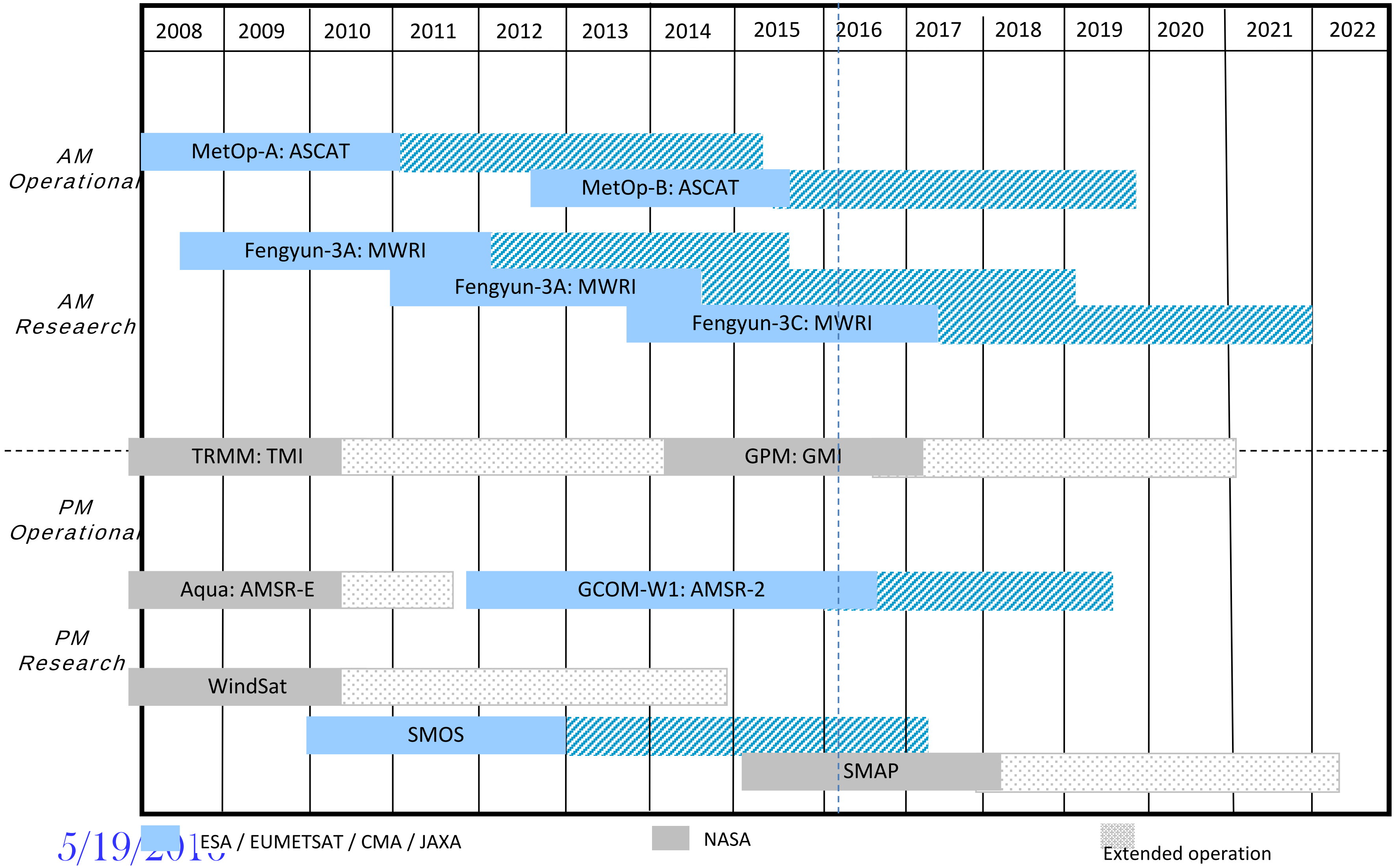
Spatially consistent estimates of the SM state can't be observed





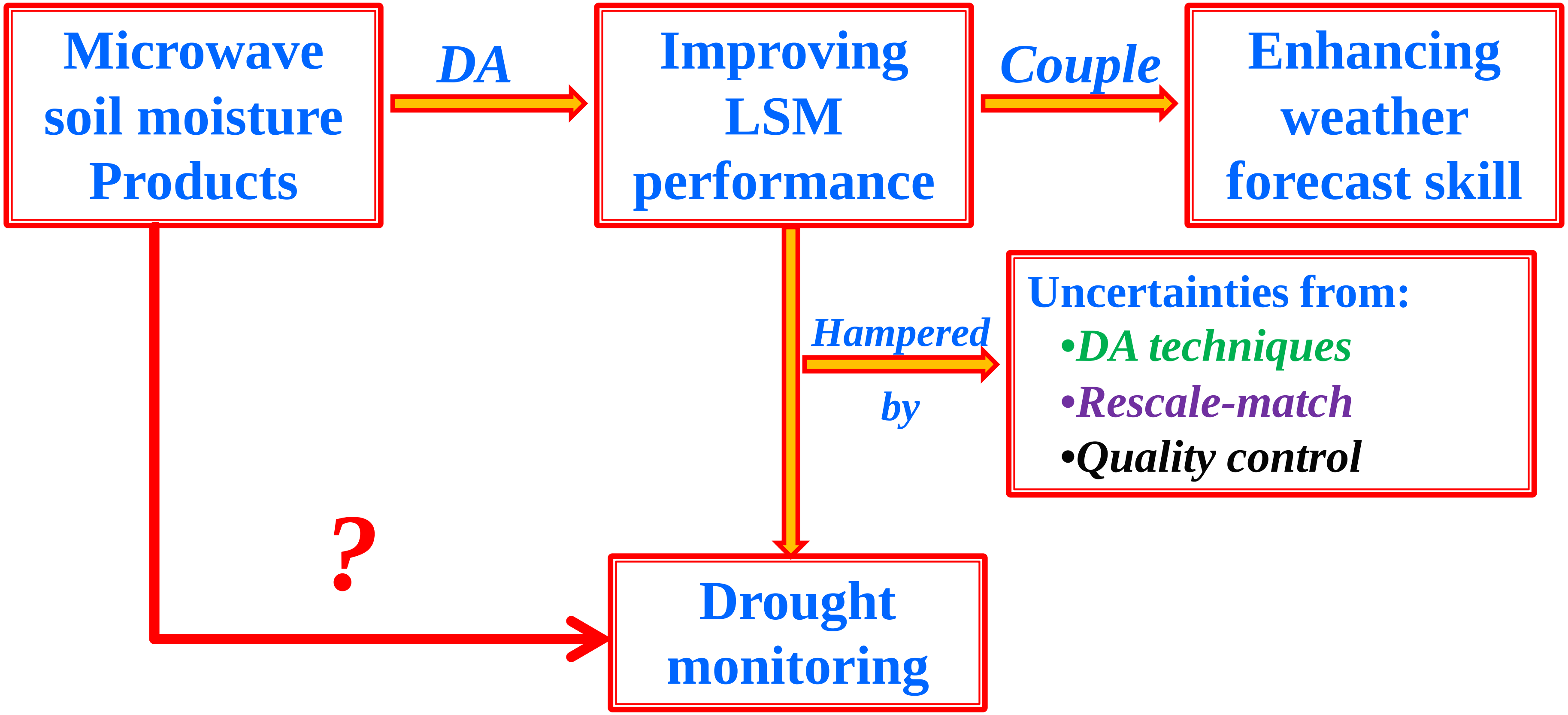
1 Motivation

Current and Future Soil Moisture Satellites:



1 Motivation

How to improve drought monitoring capability using the Remote Sensing Soil Moisture Products?



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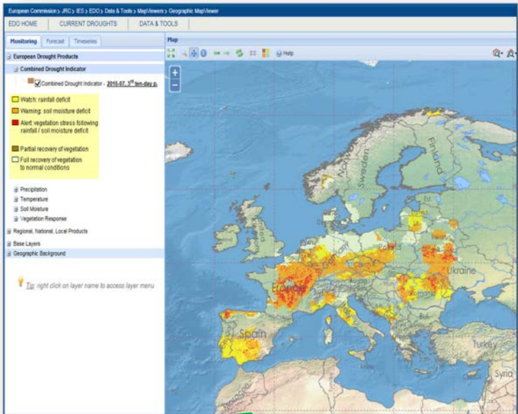
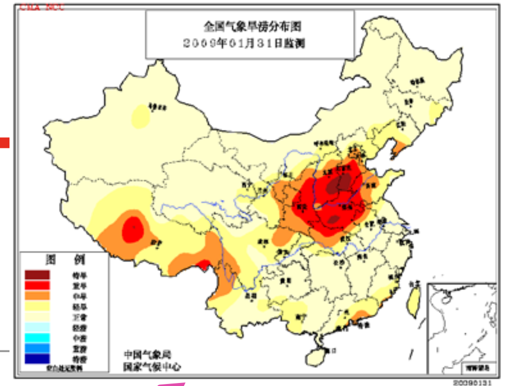
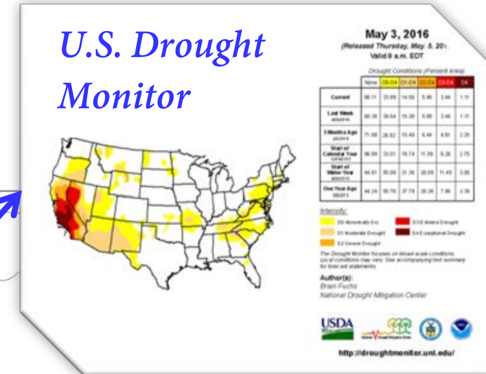


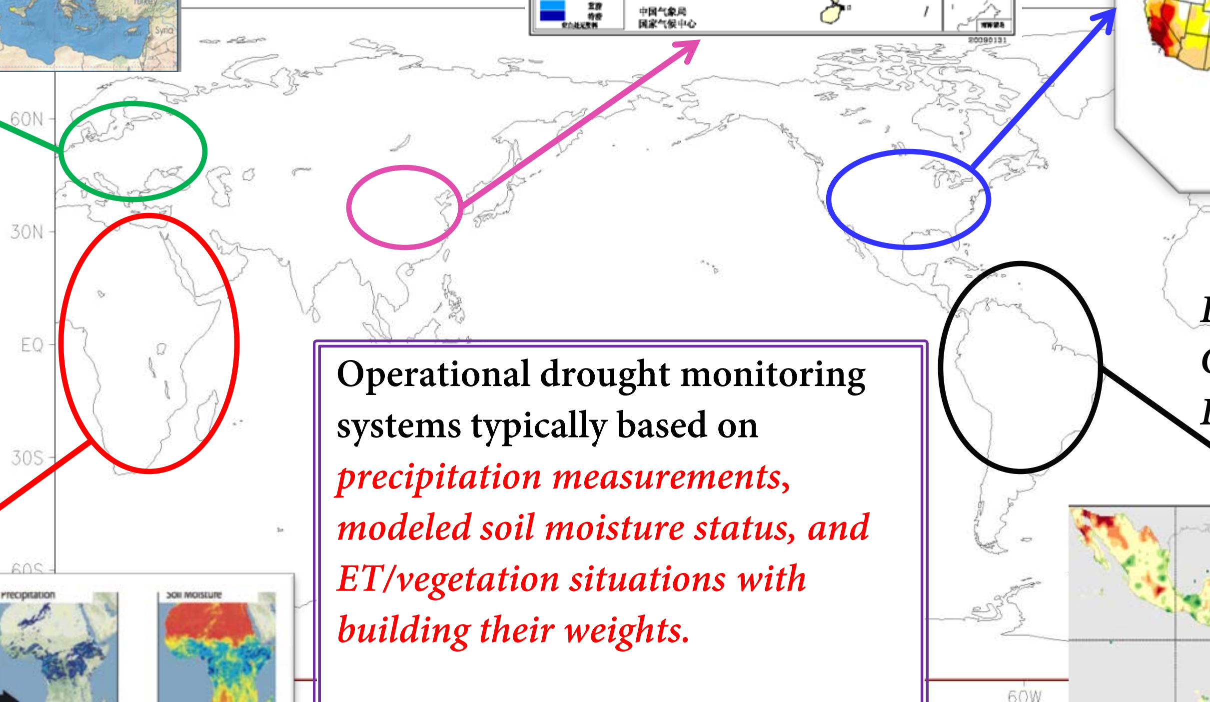
European Drought Observatory

China Drought and Flood Monitor

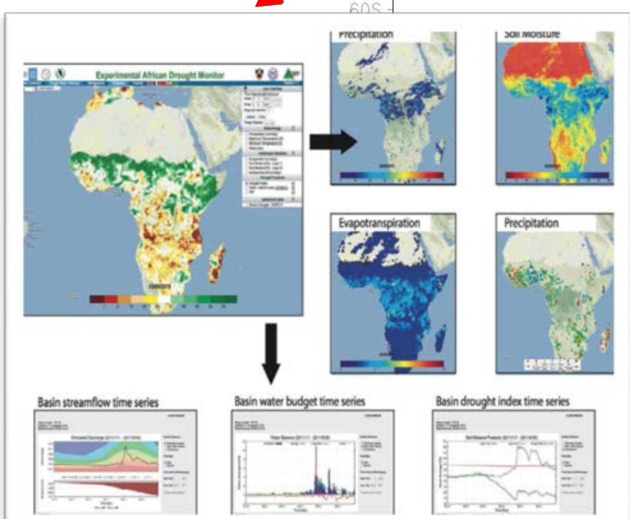


U.S. Drought Monitor





African Drought Monitor and Forecast System

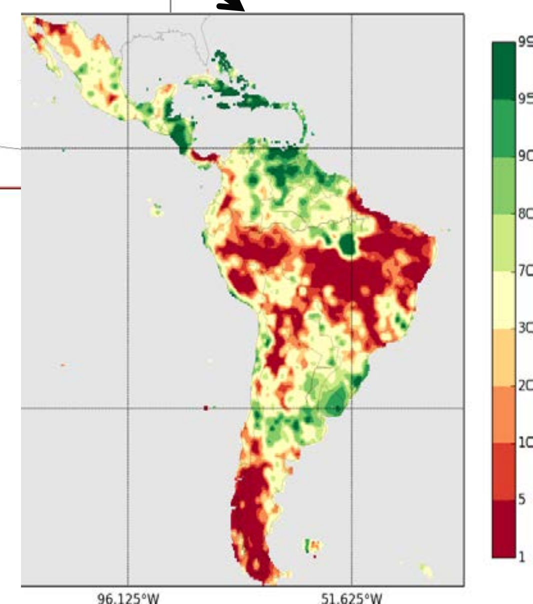


Operational drought monitoring systems typically based on *precipitation measurements, modeled soil moisture status, and ET/vegetation situations with building their weights.*

How to develop a blended drought index:

- ✓ *Merging satellite SM retrievals;*
- ✓ *With optimal information;*
- ✓ *Without rescaling-matching to each other;*
- ✓ *At global scale?*

Latin American and Caribbean Flood and Drought Monitor



2 Data Sources

Noah 3.2 land surface modeling SM (NLSM):

Noah3.2 LSM implemented in LIS 7.1

3-hourly 25 km GDAS:

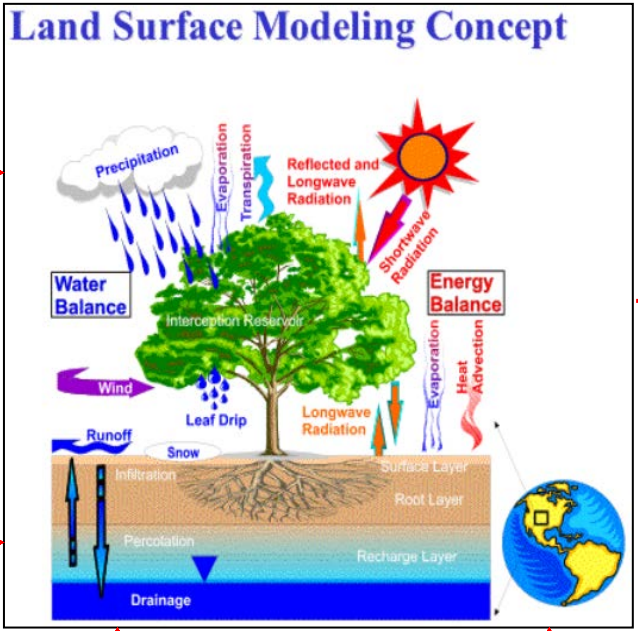
downward SW/LW radiation;

near-surface t_{air} / RH/wind;

surface Pressure.

3-hourly 25 km GLDAS:

Precipitation.



- The model is spun up by cycling 50 times through the period from 2001 to 2014;
- The integrations are conducted over the 2008-2014 period;
- Daily outputs at 25 km spatial resolution;
- Near-global domain (from -60°S, -180°W to 90°N, 180°E);

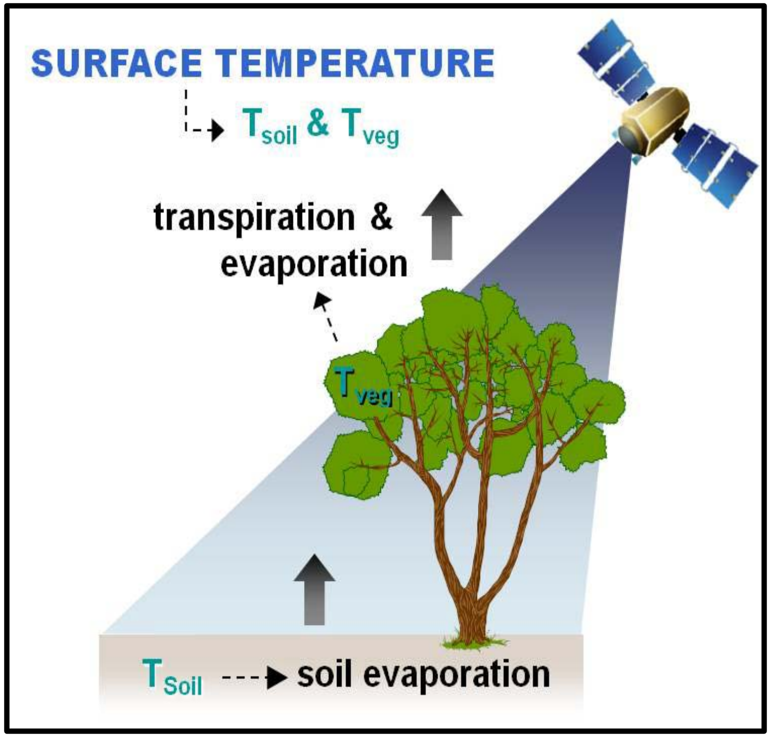
2007-10 MODIS Collection-5 land cover map

8-day MODIS LAI-based green vegetation fraction (GVF)

2 Data Sources

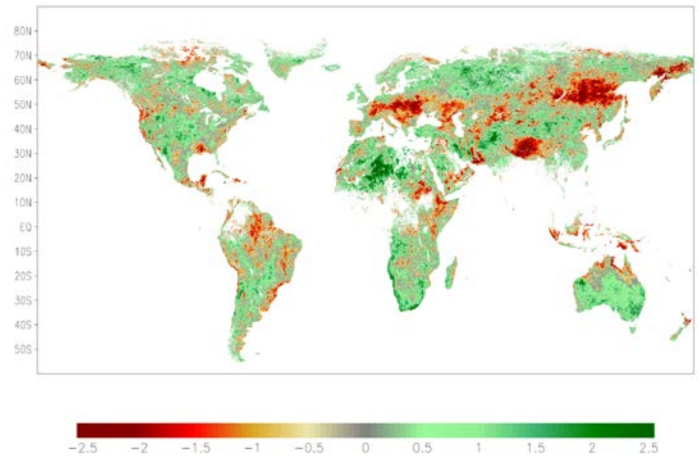
ALEXI model-based Evaporative Stress Index (ESI):

Thermal infrared (TIR) satellite Land Surface Temperature (LST)



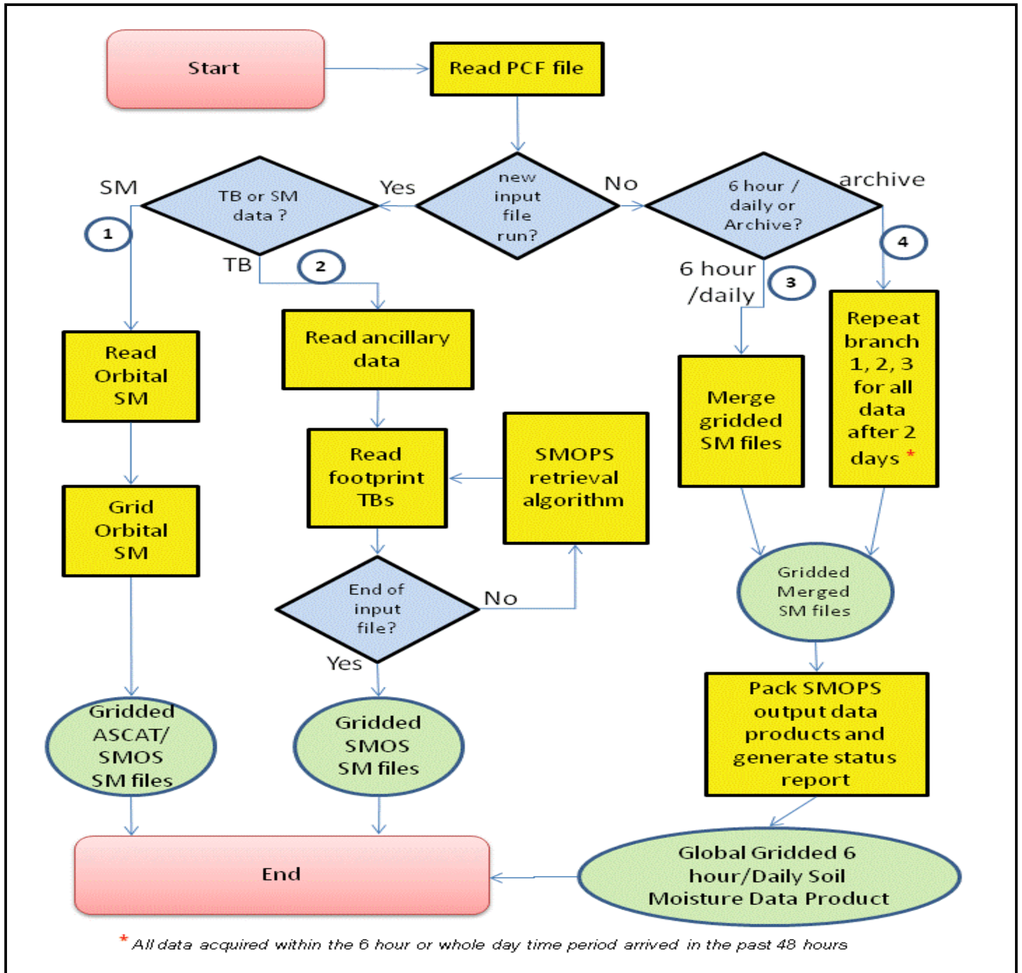
Atmosphere Land Exchange Inverse (ALEXI) model

Weekly 4-week ESI composites on global domain (spatial resolution of 25-km) over 2008-2014 period

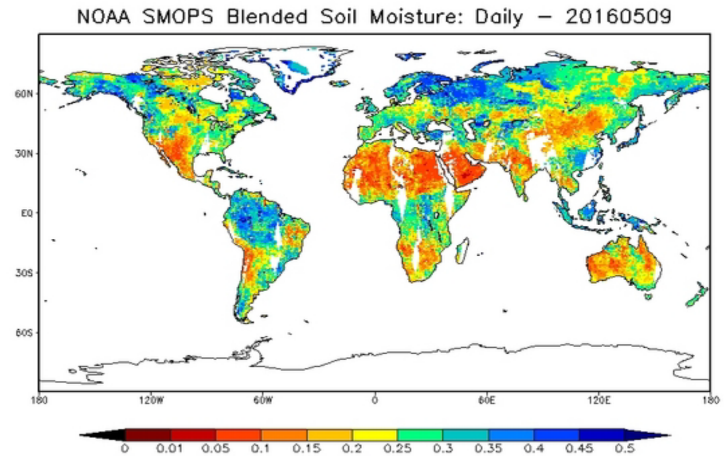


2 Data Sources

Microwave SM products (MWSM):



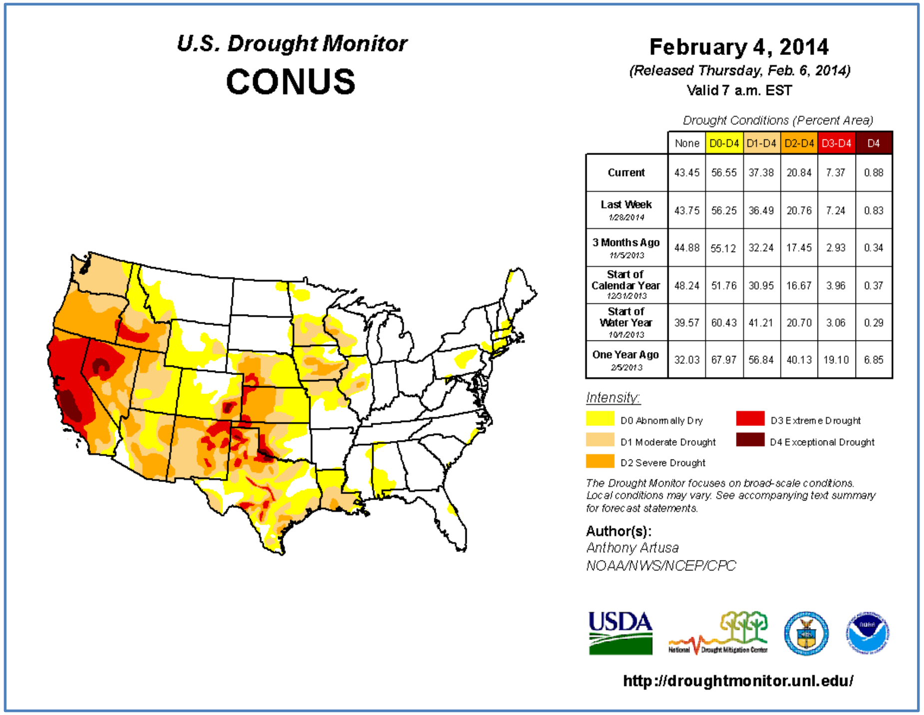
NOAA-NESDIS SMOPS Algorithm Process Flow.



Daily 25 km global microwave SM retrievals include:

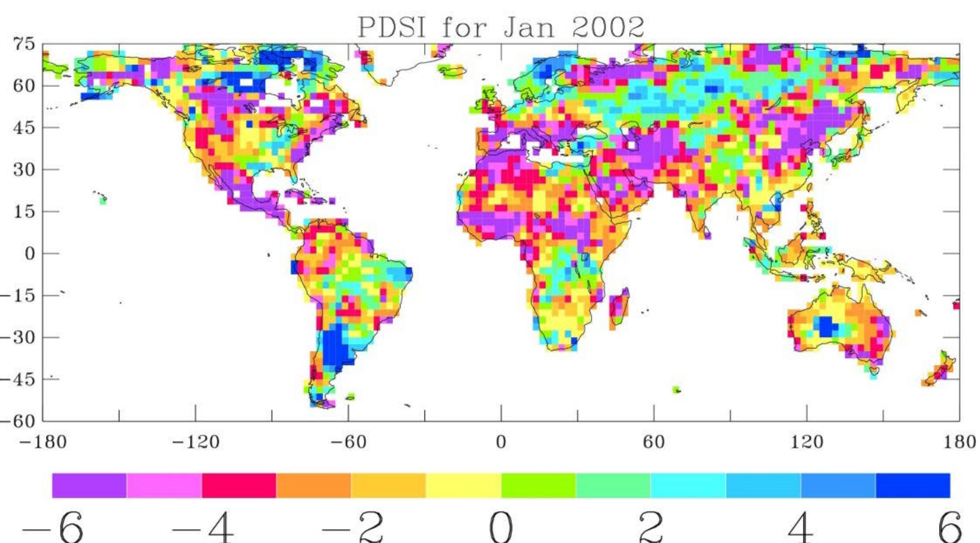
- 2011-2014 Soil Moisture and Ocean Salinity (SMOS);
- 2008-2014 Advanced Scatterometer (ASCAT);
- 2008-2014 WindSat;
- 2008-2014 Soil Moisture Operational Product System–blended (SMOPS).

2 Data Sources



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	43.45	56.55	37.38	20.84	7.37	0.88
Last Week 1/28/2014	43.75	56.25	36.49	20.76	7.24	0.83
3 Months Ago 11/5/2013	44.88	55.12	32.24	17.45	2.93	0.34
Start of Calendar Year 12/31/2013	48.24	51.76	30.95	16.67	3.96	0.37
Start of Water Year 10/1/2013	39.57	60.43	41.21	20.70	3.06	0.29
One Year Ago 2/5/2013	32.03	67.97	56.84	40.13	19.10	6.85

The *weekly United States Drought Monitor* (USDM) data sets from 2008 to 2014 are used to validate the BDI performance on Contiguous United States (CONUS) domain.



The global BDI drought monitoring capabilities are also validated by the *monthly Palmer Drought Severity Index* (PDSI, Dai et al., 2004, 2013) *standard anomalies (against 1985-2014 means)* at 2.5 degree spatial resolution within 2008-2014 period.

3 Triple Collocation Error Model

All of the SM retrievals were processed as:

(1) Temporal composited over 4-week intervals;

(2) The climatology of soil moisture data sets is generated by assembling the variable values for a particular calendar week across all years;

(3) Calculated the standardized anomalies (ψ) for week w, year y, and i, j grid location

$$\psi(w,y,i,j) = \frac{X(w,y,i,j) - \overline{X(w,i,j)}}{\sigma_X(w,i,j)}$$

where $\overline{X}$ and σ_X indicate climatology and climatological standard deviation.

3 Triple Collocation Error Model

The proposed TCEM will only result in meaningful error estimates if the three data sets represent the same physical quantity.

Three separate datasets that provide 25 km grid-scale drought estimations:

(1) the NLSM, which is ***subject to errors in the model representation and in the meteorological forcing data***;

(2) the ALEXI model-based ESI, which ***does not use any precipitation input, but is sensitive to the accuracy of the thermal infrared (TIR) satellite LST and other model inputs*** (e.g., vegetation cover, available energy)

(3) and the MW SM products, which are ***influenced by instrument noise and uncertainty in microwave emission modeling***, especially as vegetation cover increases.

3 Triple Collocation Error Model

According to the previous studies (Janssen et al., 2007; Scipal et al., 2008), we have

$$SA_{MWSM} = \Pi + \mu$$
$$SA_{ESI} = \Pi + \omega$$
$$SA_{NLSM} = \Pi + \rho$$

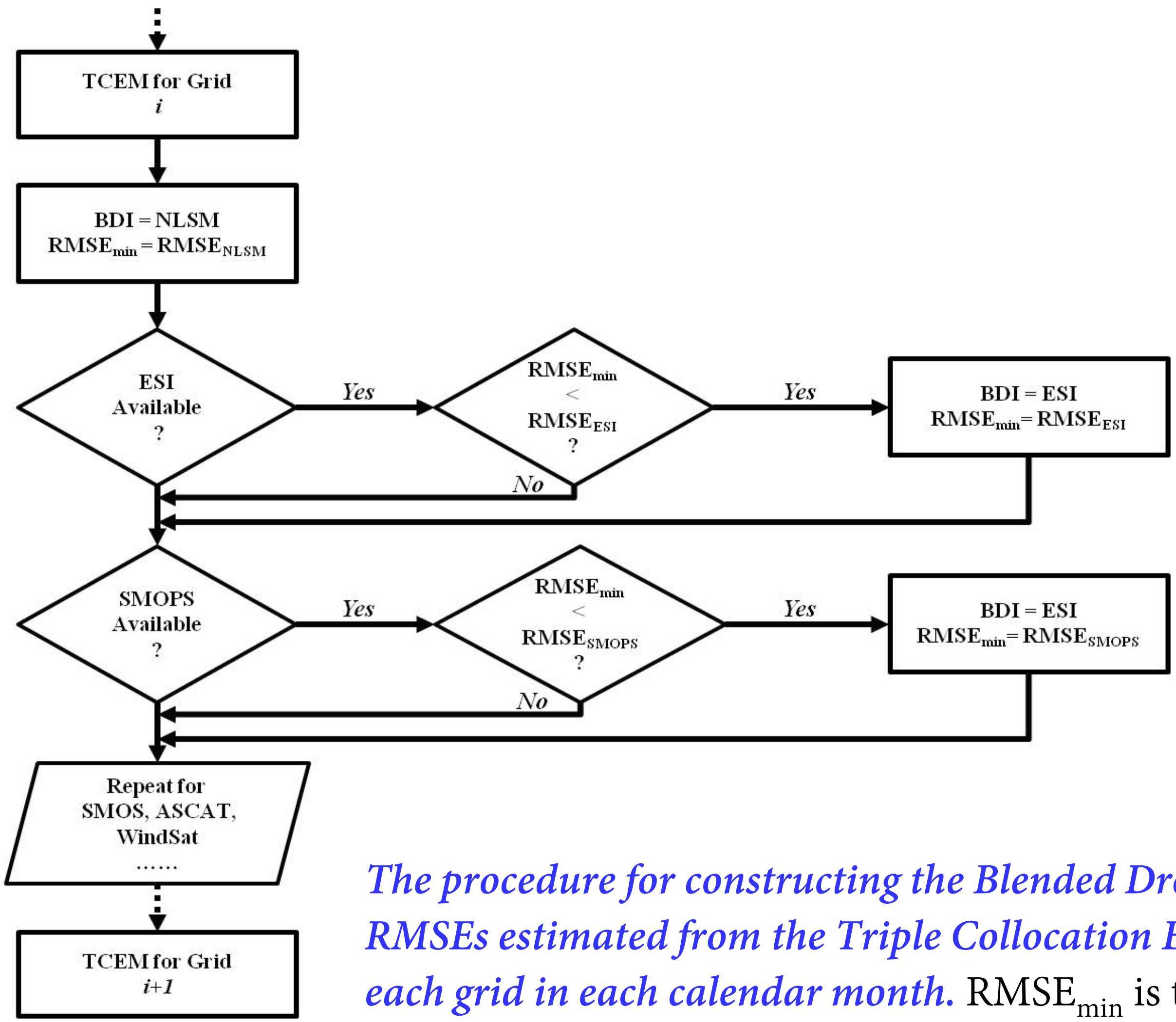
where Π indicates the true SM status, and μ, ω and ρ denotes the unknown errors in the MWSM, ESI and NLSM cases. Then the RMSE values (ξ) for each case are given by (Stoffelen, 1998; Scipal et al., 2008; Miralles et al., 2010)

$$\xi_{MWSM} = (\psi_{MWSM} - \psi_{ESI})(\psi_{MWSM} - \psi_{NLSM}) = \mu^2$$
$$\xi_{NLSM} = (\psi_{NLSM} - \psi_{ESI})(\psi_{NLSM} - \psi_{MWSM}) = \omega^2$$
$$\xi_{ESI} = (\psi_{ESI} - \psi_{NLSM})(\psi_{ESI} - \psi_{MWSM}) = \rho^2$$

under the assumptions that the three data sets don't have any correlations:

$$\mu\rho = 0, \quad \mu\omega = 0, \quad \rho\omega = 0$$

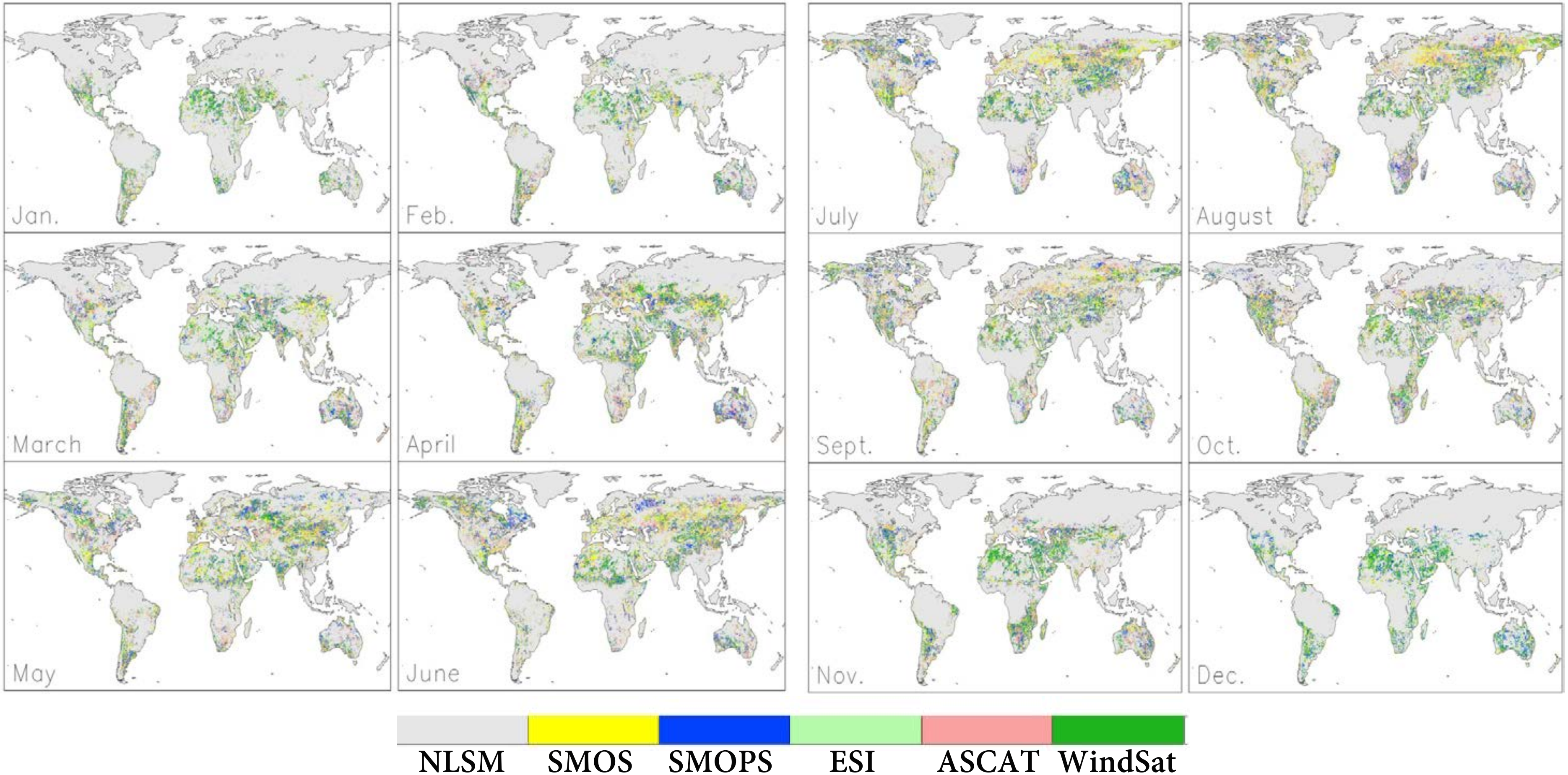
4 Blended Drought Index (BDI)



The procedure for constructing the Blended Drought Index (BDI) using the RMSEs estimated from the Triple Collocation Error Model implemented for each grid in each calendar month. $RMSE_{min}$ is the minimum RMSE for a grid. And $RMSE_{SMOPS}$, $RMSE_{NLSM}$ and $RMSE_{ESI}$ are the monthly RMSE values for soil moisture data sets from SMOPS, NLSM and ESI cases, respectively.

4 Blended Drought Index (BDI)

Spatial distributions of BDI compositions.

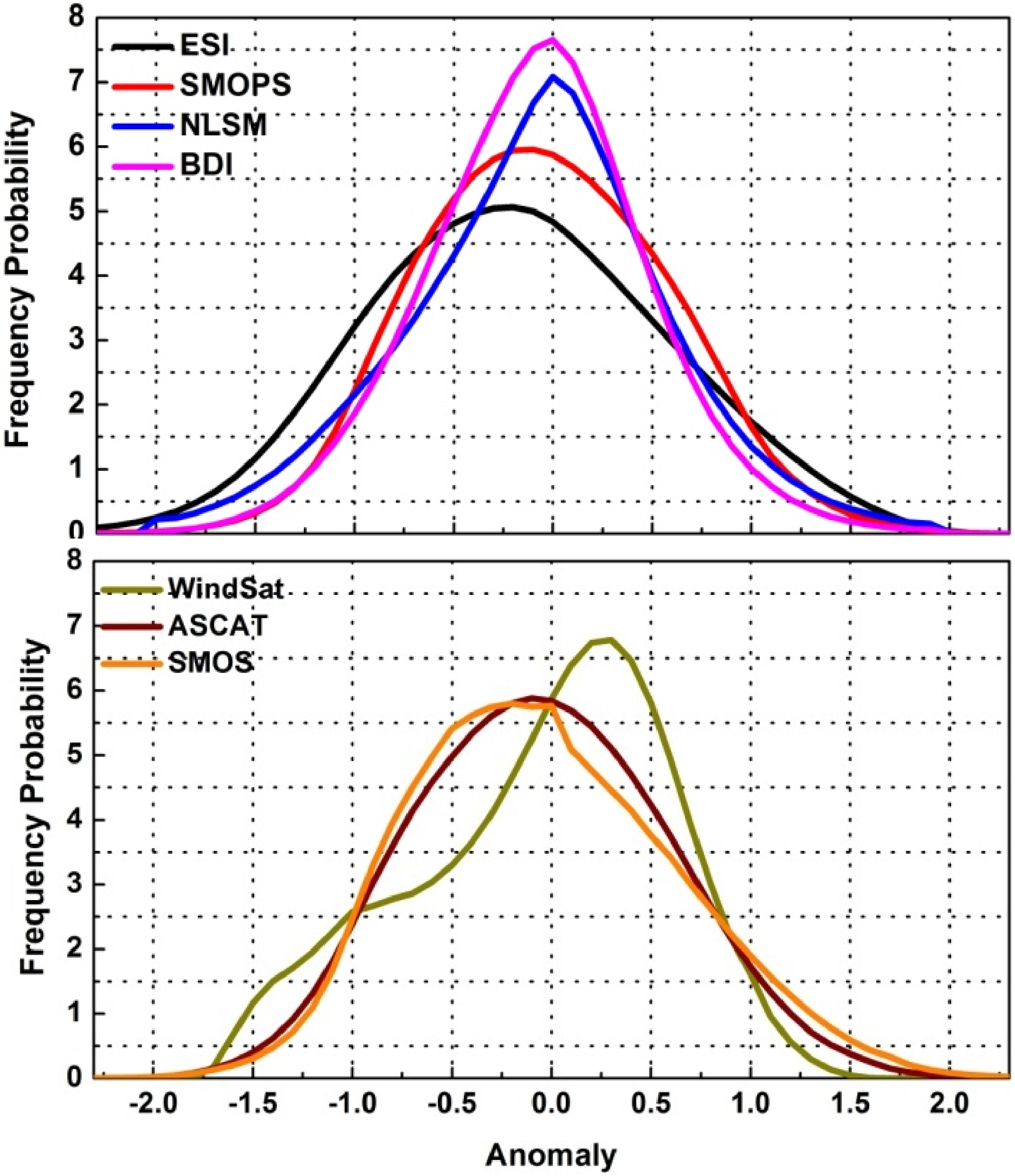


4 Blended Drought Index (BDI)

Based on TCEM-based RMSE, monthly percentage (%) for terrestrial grids filled by the drought estimation signals from each of 6 retrievals.

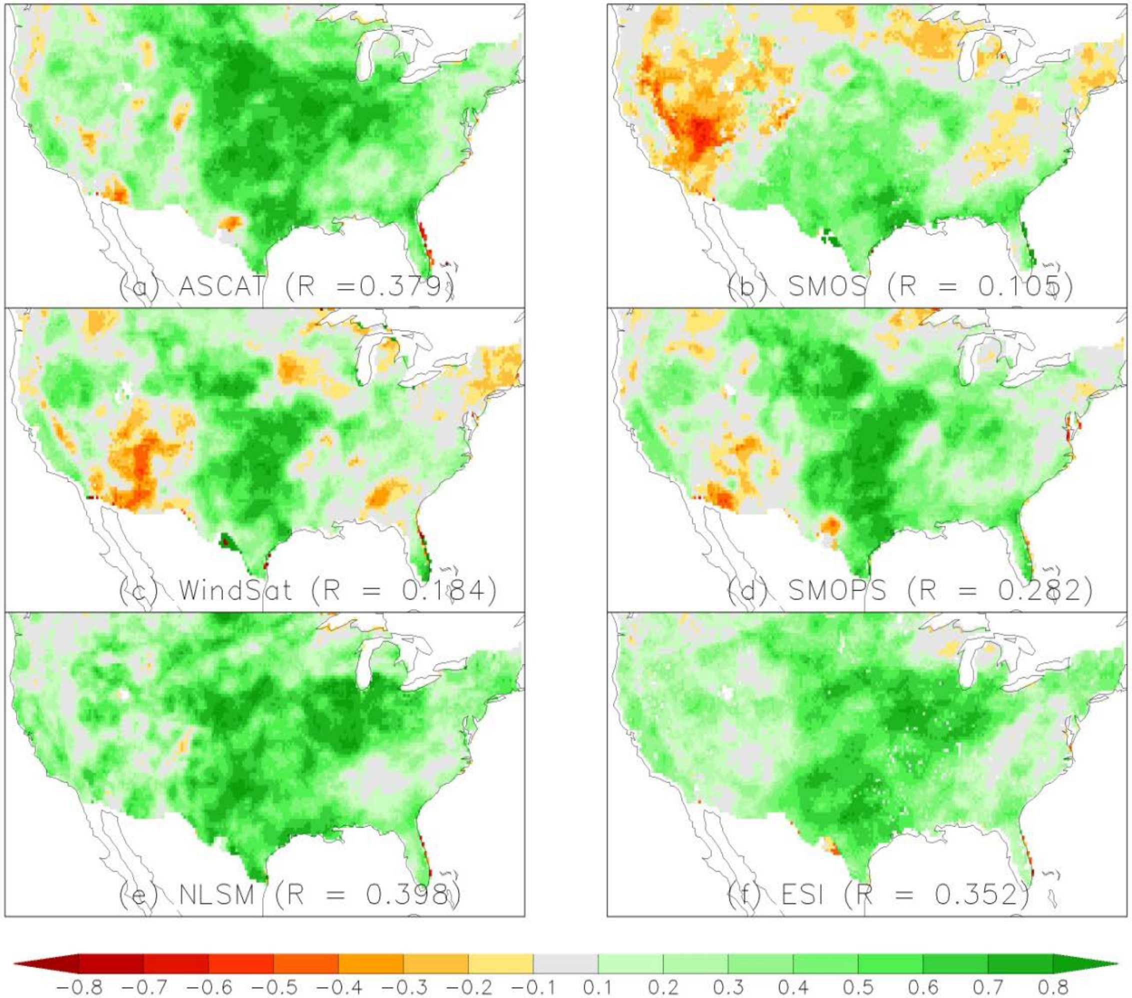
Month	NLSM	ESI	SMOS	SMOPS	ASCAT	WindSat	Sum for MWSM
January	88.01	0.97	2.60	2.68	2.77	2.97	11.02
February	85.50	1.45	2.89	3.10	4.14	2.92	13.05
March	79.37	2.34	4.17	4.46	6.17	3.49	18.29
April	74.99	2.36	5.41	5.51	7.59	4.15	22.65
May	71.29	2.92	6.73	6.64	8.09	4.34	25.79
June	70.14	2.92	6.93	6.61	9.17	4.24	26.94
July	68.35	3.40	7.21	6.30	10.34	4.40	28.25
August	66.49	2.78	7.47	6.60	11.56	5.08	30.72
September	69.51	2.26	6.21	6.43	10.68	4.91	28.23
October	71.36	2.07	5.55	6.64	9.55	4.83	26.57
November	76.85	1.85	4.61	5.55	6.43	4.72	21.30
December	84.86	1.51	4.03	5.26	0.00	4.33	13.63

5 Validations

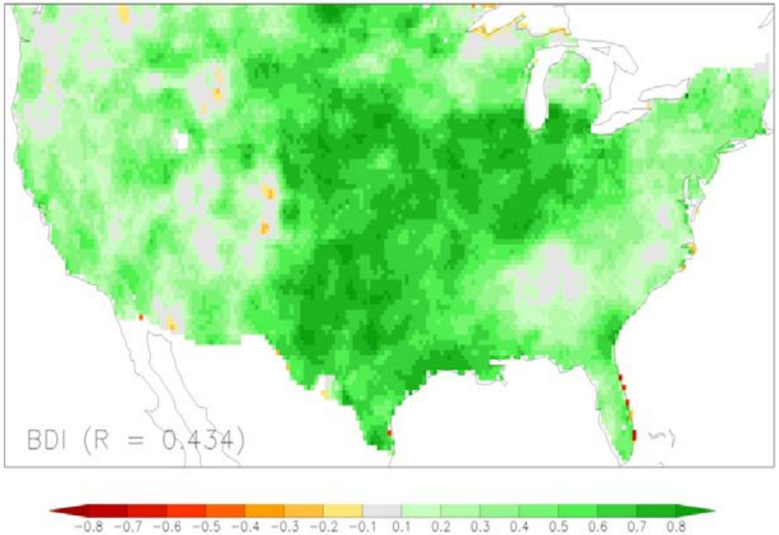


Global domain-averaged frequency probability (%) as a function of drought estimations for the ESI (dark line), NLSM (blue line), BDI (pink line), SMOPS (red line), SMOS (orange line), ASCAT (wine line) and WindSat (blue line) SM products.

5 Validations

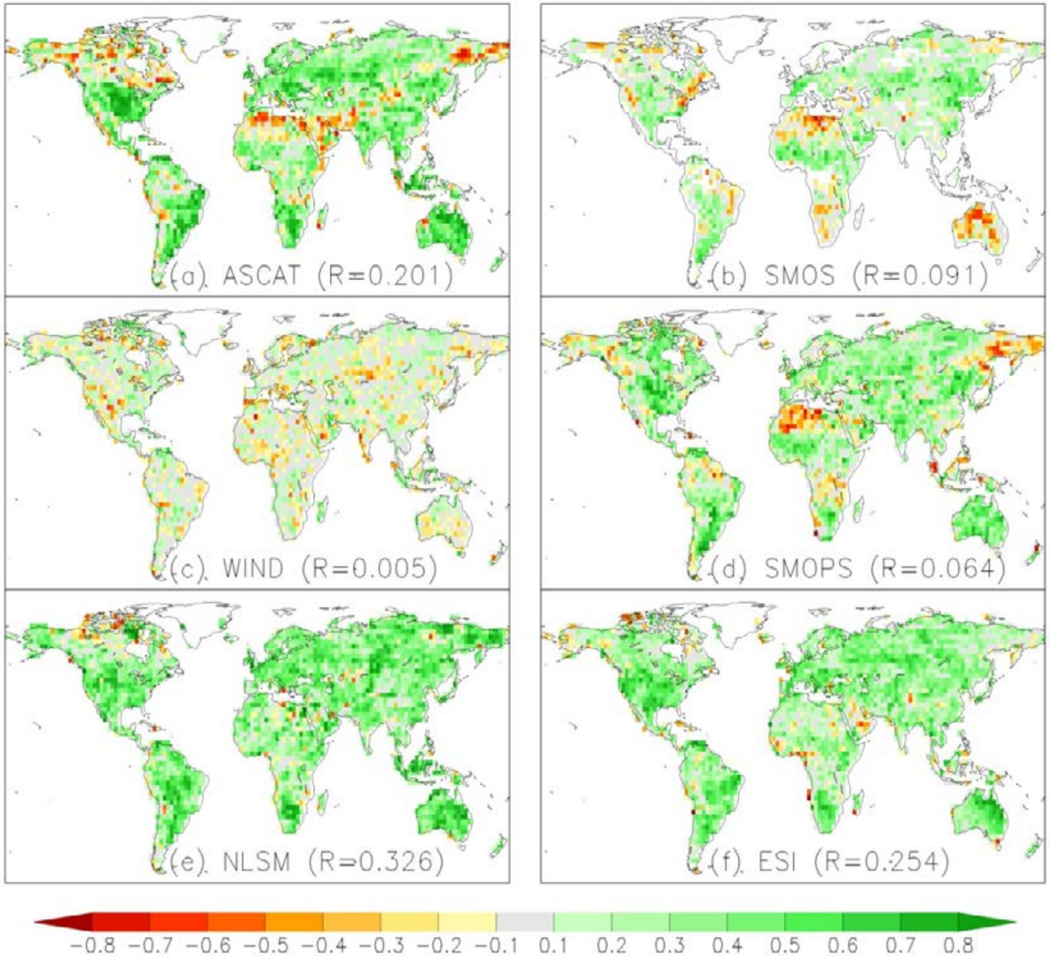


Correlation coefficients (R) between USDM and (a) ASCAT, (b) SMOS, (c) WindSat, (d) SMOPS, (e) NLSM and (f) ESI. The grey color indicates insignificantly.

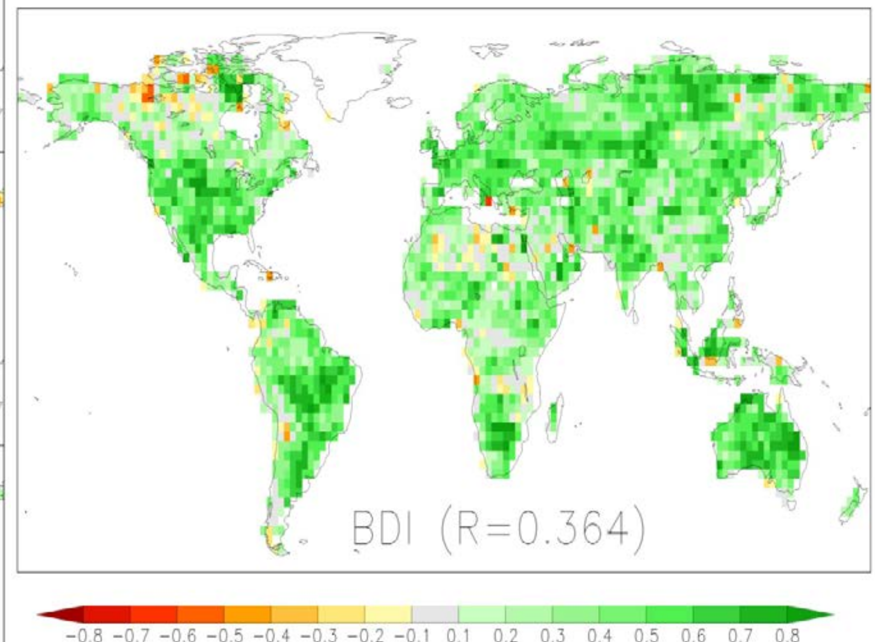


Correlation coefficients (R) between USDM and BDI over 2008-2014 period. The grey color indicates insignificantly.

5 Validations

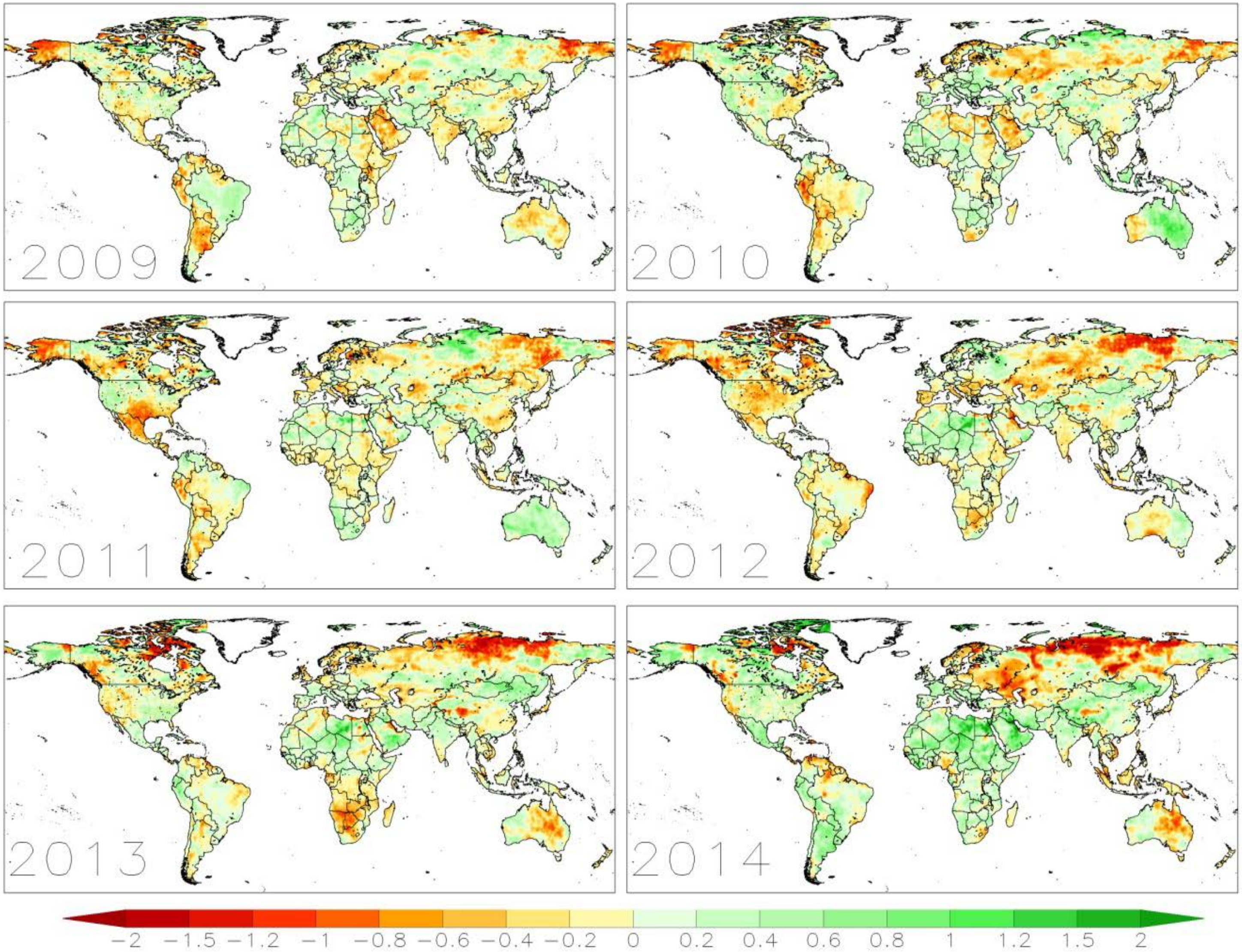


Correlation coefficients (R) between PDSI standard anomalies (against 1985-2014 averages) and drought estimations for (a) ASCAT, (b) SMOS, (c) WindSat, (d) SMOPS, (e) NLSM and (f) ESI cases. The grey color indicates insignificantly.



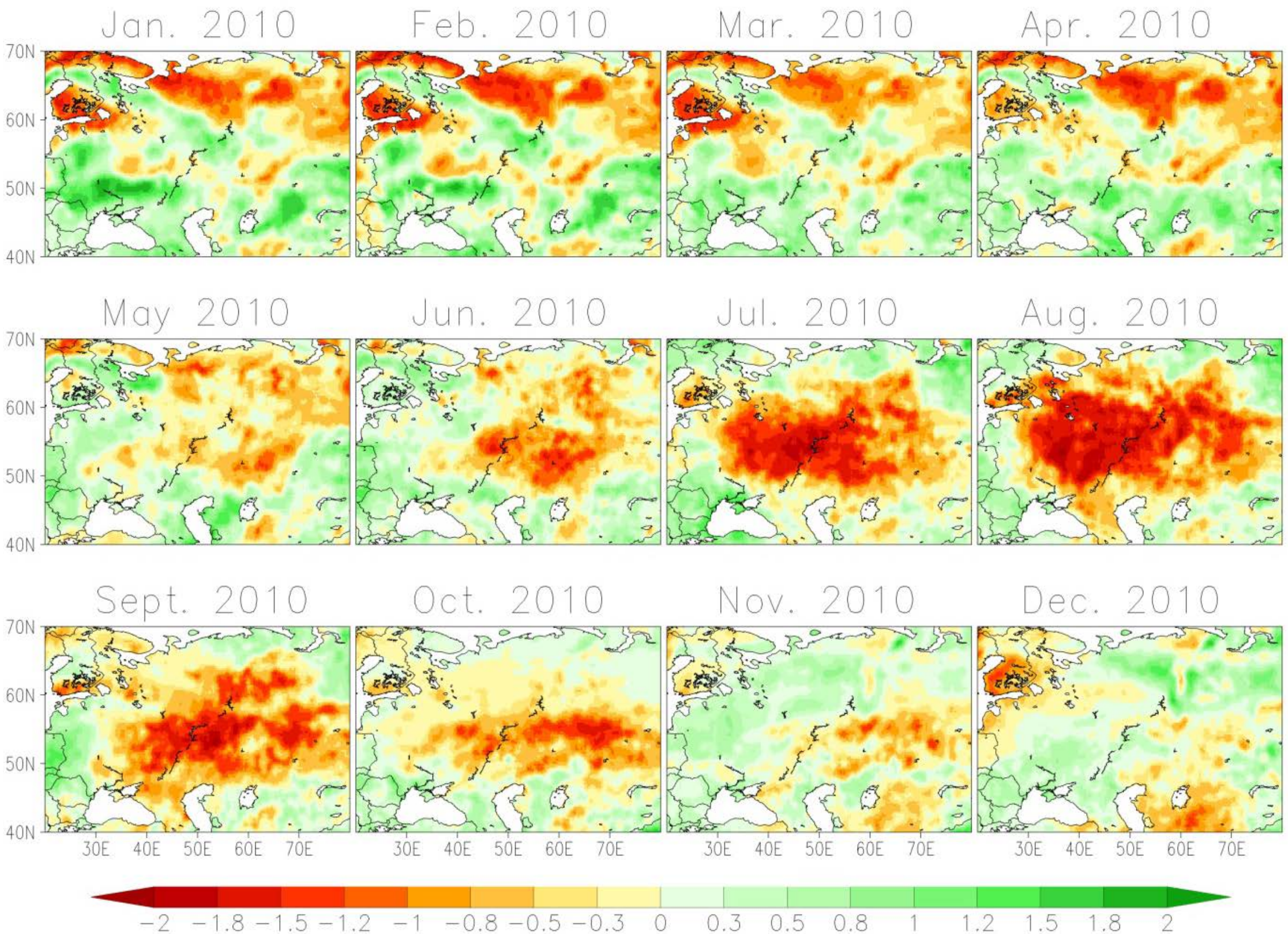
Correlation coefficients (R) between PDSI standard anomalies (against 1985-2014 averages) and BDI over 2008-2014 period. The grey color indicates insignificantly.

6 Drought Evaluations



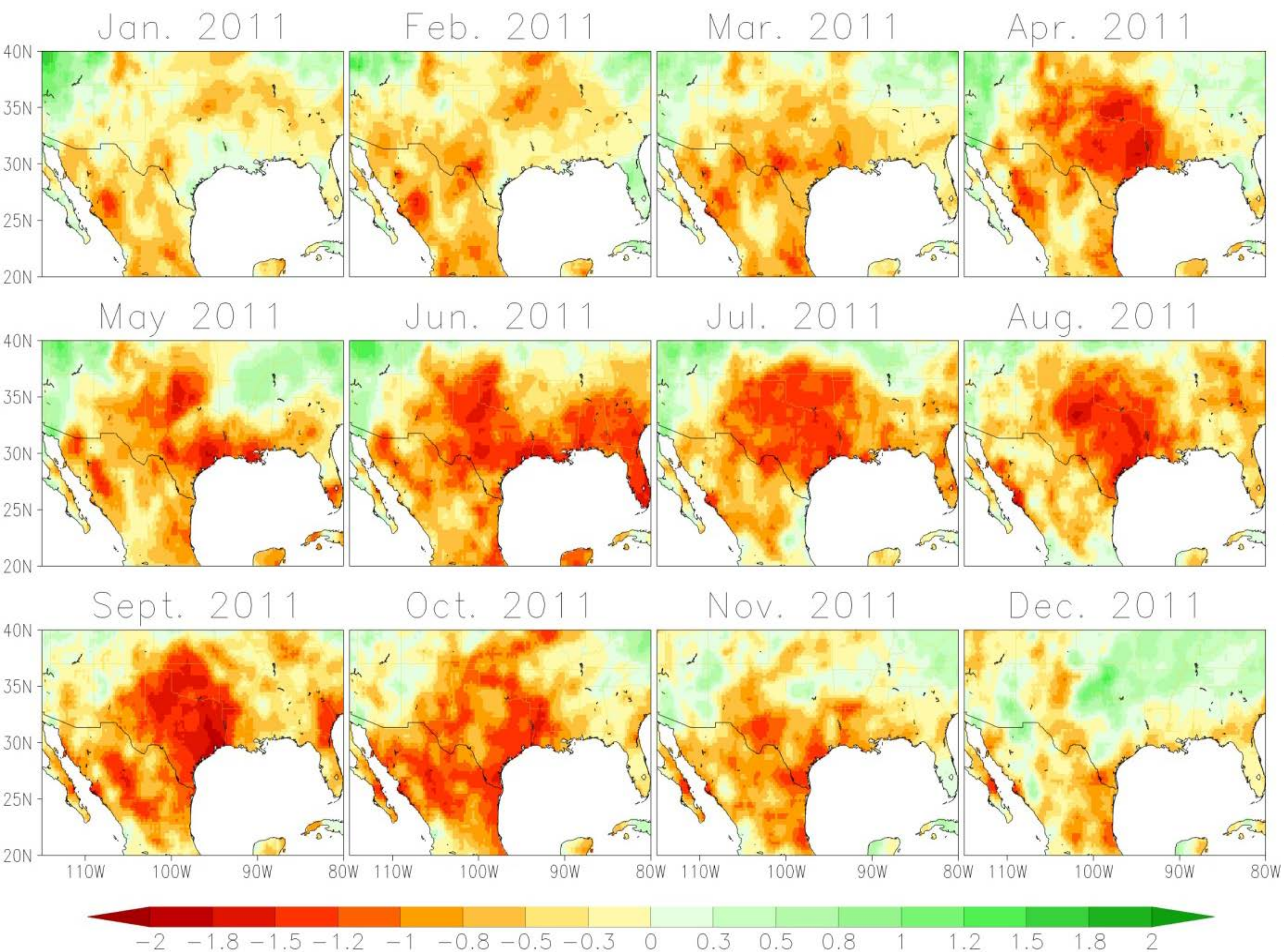
Annual global terrestrial BDI patterns over 2009-2014 period. The BDI ranges from negative (red) to positive (green) values indicate for dry to wet conditions.

6 Drought Evaluations



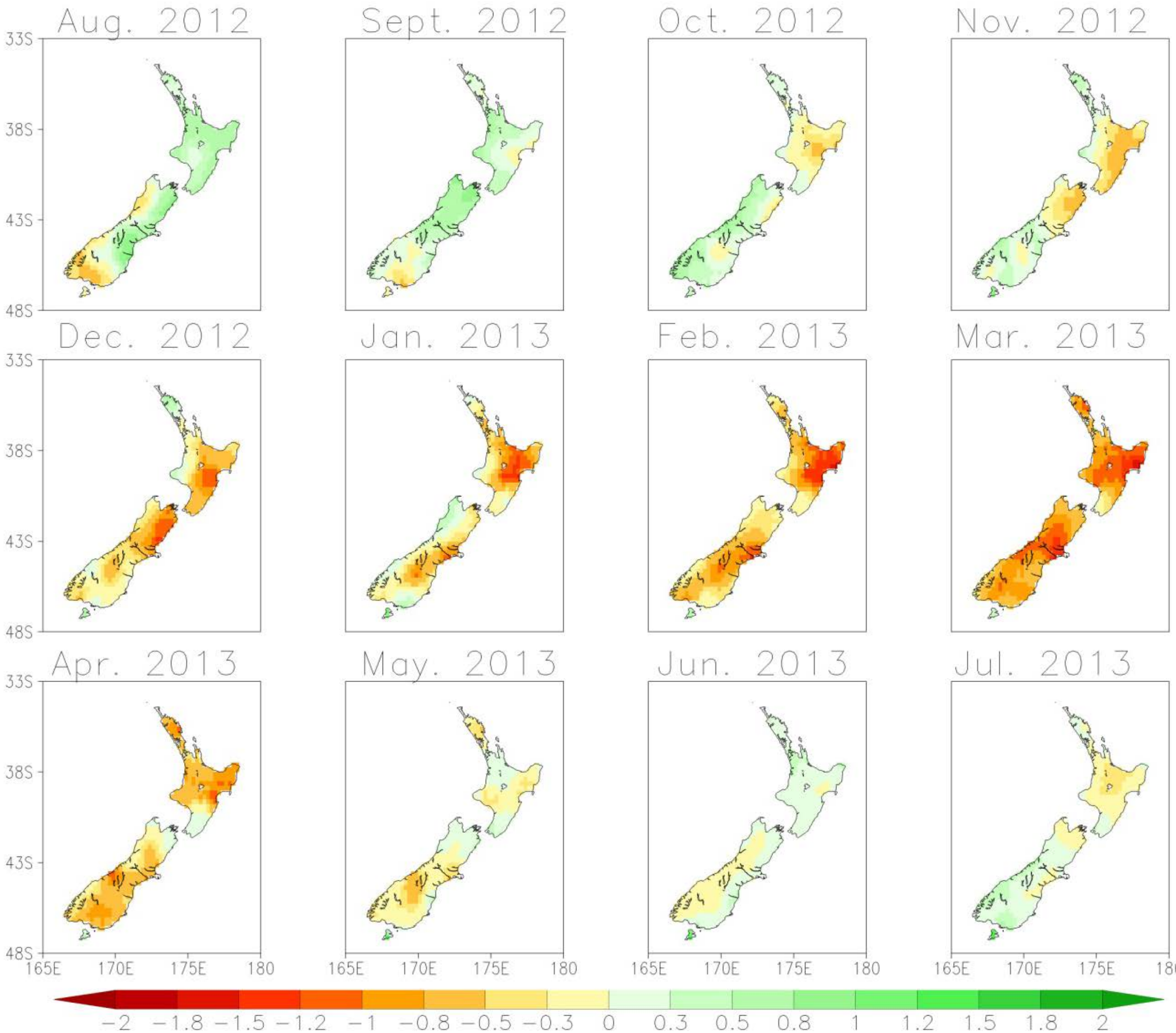
BDI-based monthly drought monitoring on the sub-region (from 40°N, 20°E to 70°N, 80°E) domain in 2010.

6 Drought Evaluations



BDI-based monthly drought monitoring on the sub-region (from 25°N, -115°W to 40°N, -90°W) domain in 2011.

6 Drought Evaluations



BDI-based monthly drought monitoring across the New Zealand (from 48°S, 165°E to -33°S, 180°E) domain from August 2012 to July 2013.

7 summary

- BDI can perform well in comparison with its compositions (such as ASCAT, ESI, NLSM and the like), and ***can reasonably track the time evolution of drought patterns recorded in the USDM and PDSI***.

- In addition to operational insights, ***the BDI is a sustainable developed indicator with merging more available agricultural drought evaluations*** that can respect to the TCEM assumptions.

- Based on the on-line land surface model and real time satellite land surface temperature and soil moisture, ***the BDI can highlight timely drought monitoring, which is essential for decision-making and in turn reducing drought risk and influence***.

- Certainly, ***the BDI can characterize the high spatial resolution monitoring at regional- and global- scales*** using 1 km model output (Yin *et al*, 2015a) and 100 m ESI (Anderson *et al*, 2014) signals.

Thanks!

Questions/Comments ??