Multichannel PMW for Soil Moisture and Evapotranspiration

Thomas Holmes

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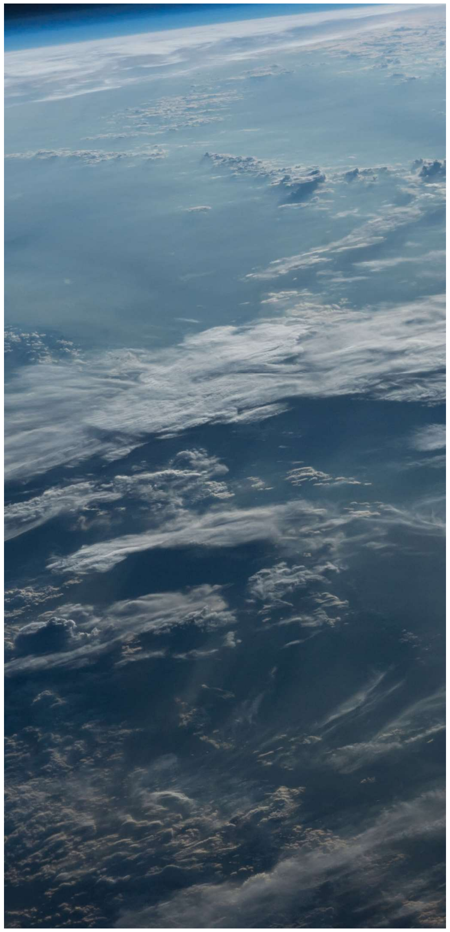
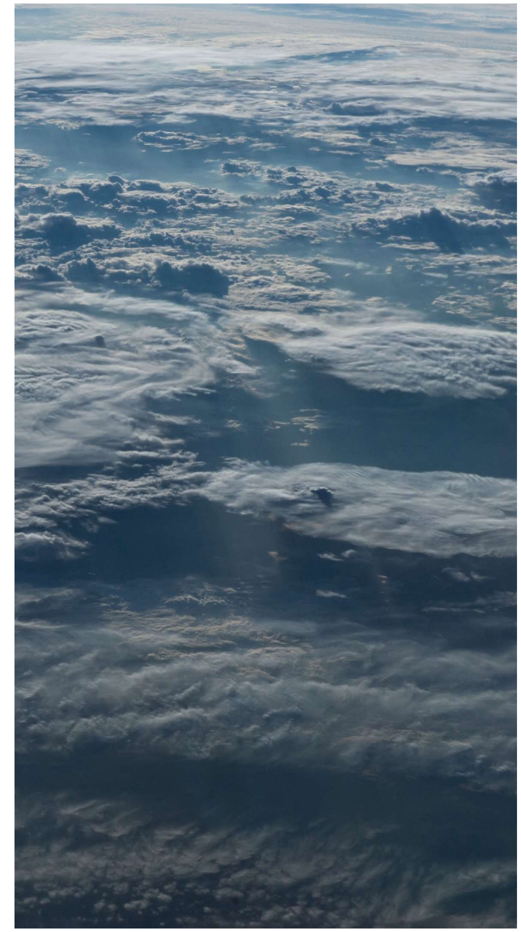
Overview



- Evolution of PMW LST
- Cloud Tolerant Diurnal LST at 5-km resolution
- Impact of Multichannel PMW on the science achievable with 10 km L-band
- Thoughts on SATM



Evolution of PMW LST

Converging Approaches to estimate LST from MW

From a ***global regression analysis***
(e.g. Holmes et al., 2009)

- Single Channel: Ka-band (37 GHz, Vertical)
- Trained on a limited set of in situ data
- Associated biases can be large, especially over bare soil.
- Different overpass-times need new regression equation
- Used in 1st generation soil moisture retrievals

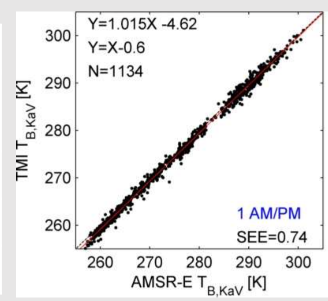
to ***multichannel neural-network analysis***
(Aires & Prigent, 2008)

- Biases controlled by training on global TIR LST data
- Seasonal changes in soil, vegetation, and atmosphere accounted for with higher and lower frequency channels

- A **multi-satellite method** is in between these extremes (Holmes et al., 2015,2016):
    - Single Channel: Ka-band (37 GHz, Vertical)
    - Diurnal resolution with 8 different satellites
    - Sub-daily sampling allows for scaling of diurnal characteristics to match geostationary TIR-LST

Inputs to MW-LST. Many LEO satellites to create a '**virtual constellation**' and mimic the geostationary view of Earth.

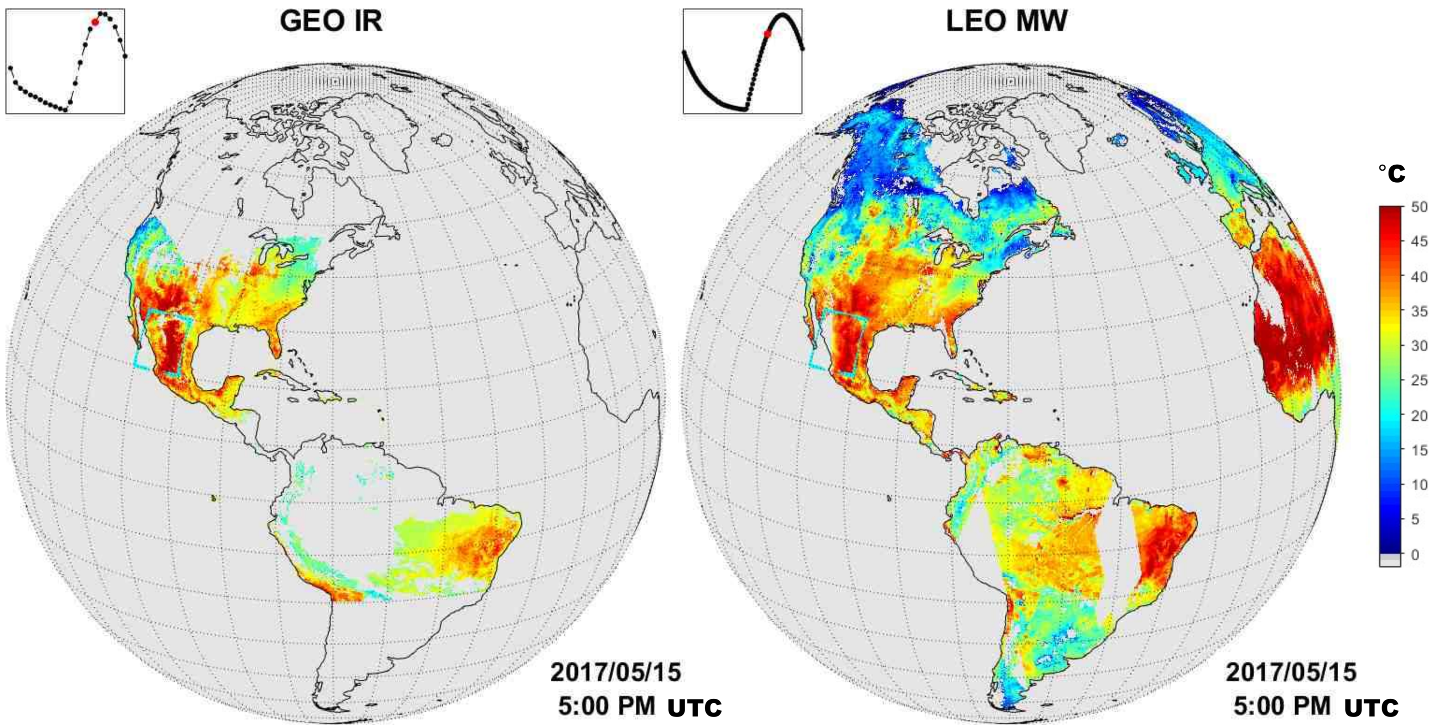
Radiometer	Platform	Overpass	Years
AMSR-E / AMSR2	Aqua / GCOM- W	1:30 AM/PM	2002-2011, 2012-Present
SSM/I, SSMIS	DMSP F13-F18	7-9 AM/PM	2002-2011
WindSat	Coriolis	6 AM/PM	2003-2019
TMI / GPM	TRMM	**Variable**	1997-Present



All satellites inter-calibrated with TMI as transfer reference: IMERG

PMW Land Surface Temperature

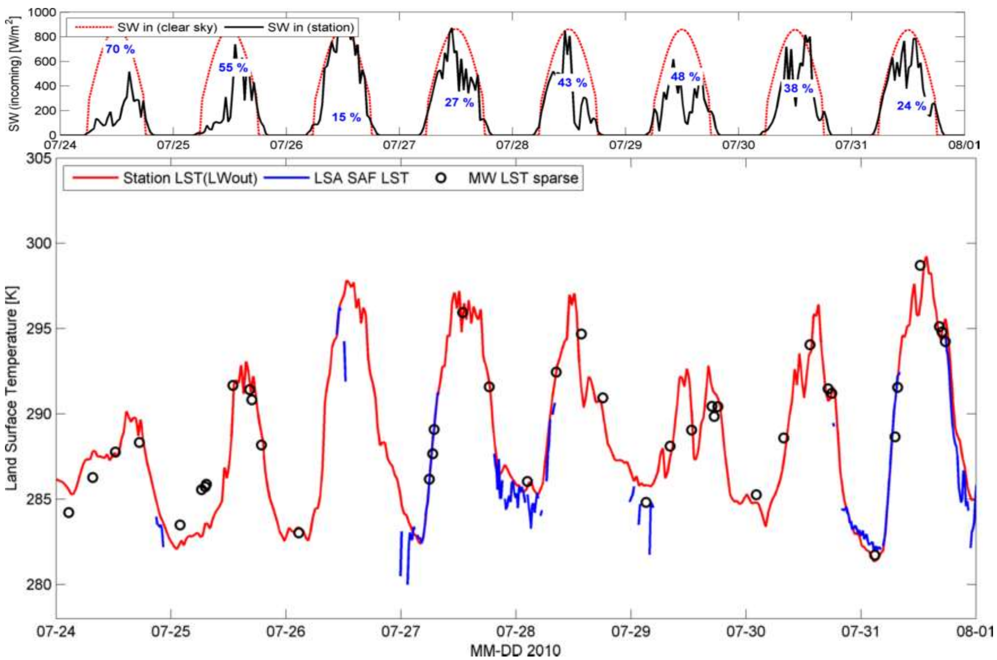
DIURNAL CYCLE RESOLVED



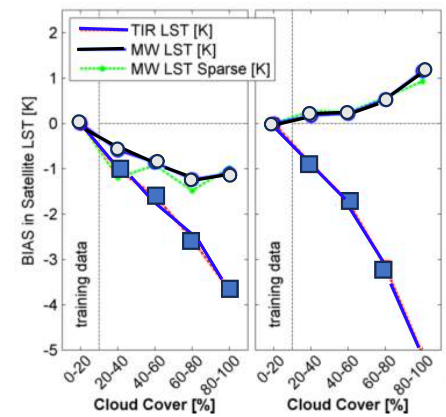
- Geostationary satellites measure diurnal LST, but only for clear skies (On left).
- **Cloud-tolerant diurnal LST** can be obtained by combining passive microwave observations from 6 LEO satellites (On Right).

Holmes, T. R. H., Crow, W. T., Hain, C. R., Anderson, M., and Kustas, W. P.: Diurnal temperature cycle as observed by thermal infrared and microwave radiometers, Remote Sens. Environ., 158C, 110–125, doi:10.1016/j.rse.2014.10.031, 2015.

CLOUD TOLERANT



- In situ LST from LW up: weighted for canopy cover
- TIR-LST: sampling poor due to clouds
- MW-LST: sampling during clear and cloud-covered periods



In Situ validation shows high tolerance to clouds of MW LST (black lines)

MW LST (black circles): sampling during clear and cloud-covered periods where TIR-LST (in blue) is lacking.

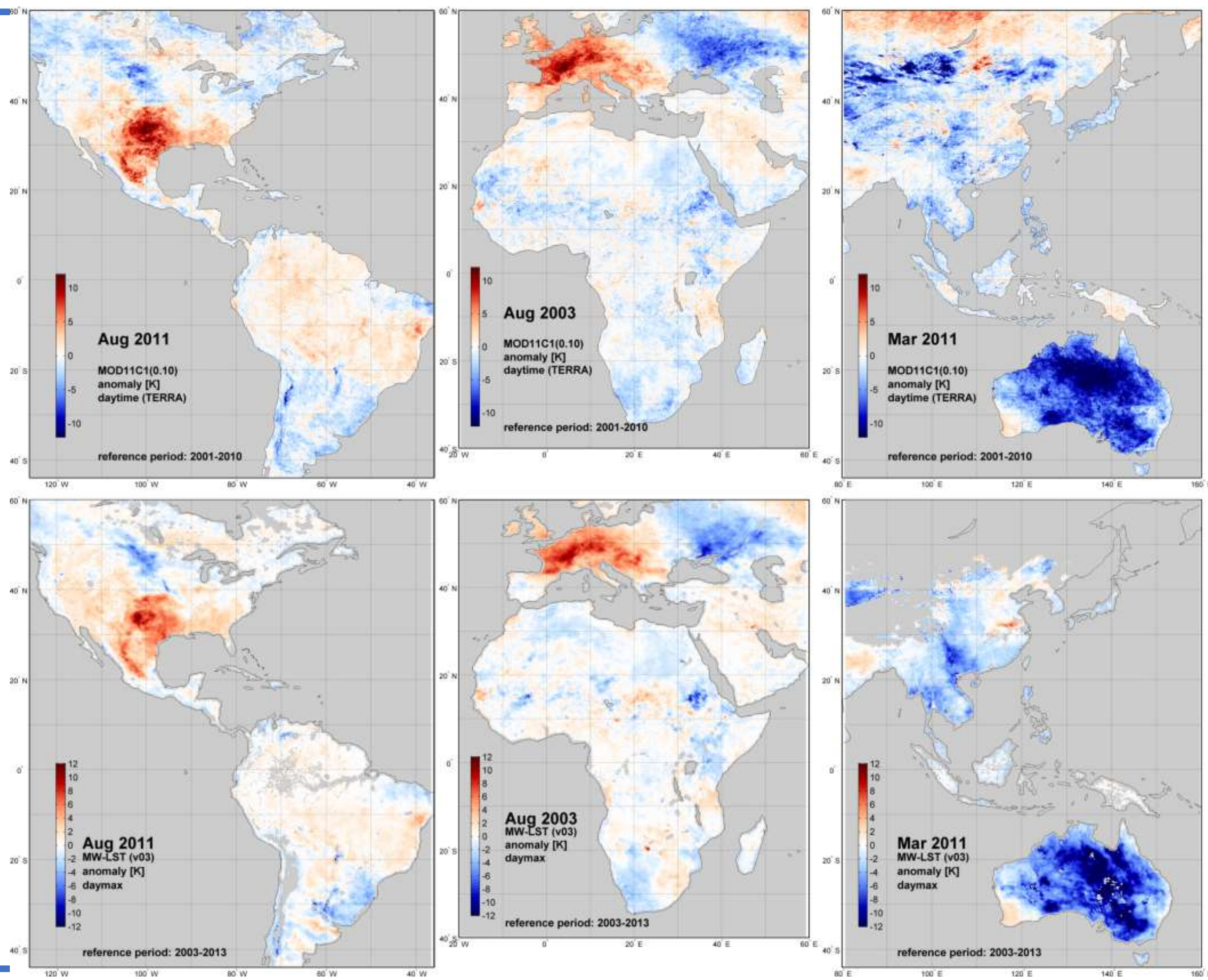
Holmes, T. R. H., Hain, C. R., Anderson, M. C., and Crow, W. T.: Cloud tolerance of remote-sensing technologies to measure land surface temperature, Hydrol. Earth Syst. Sci., 20, 3263–3275, https://doi.org/10.5194/hess-20-3263-2016, 2016

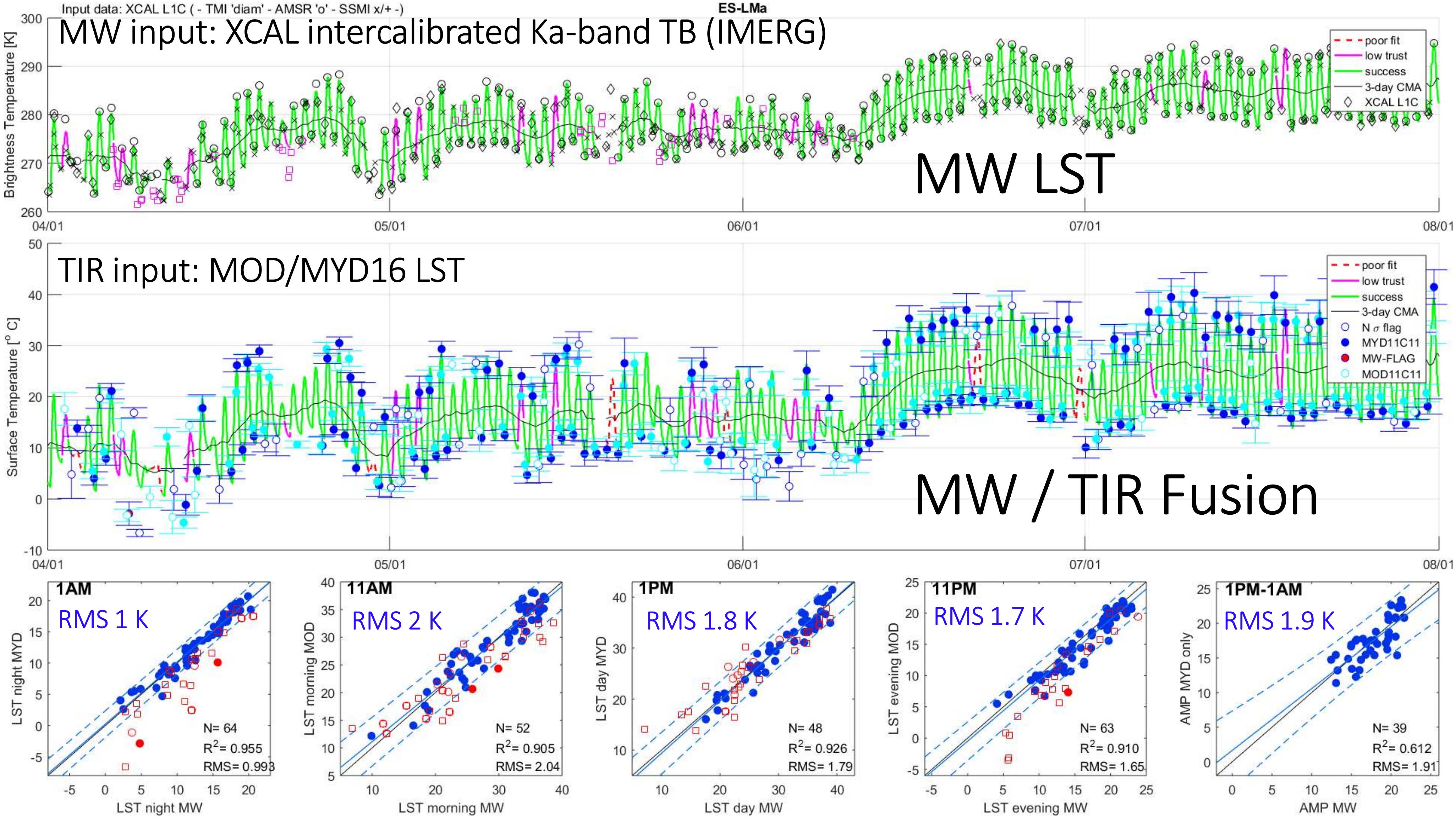
LONG-TERM

MODIS LST MOD11C1 daytime (TERRA) anomaly compared to 2001-2010

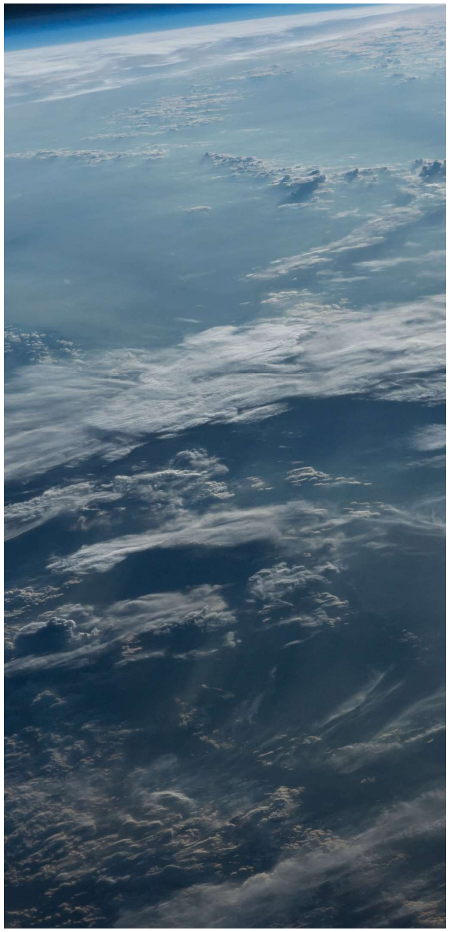
MW LST daily max anomaly compared to 2003-2013

August 2011 Texas | August 2003 Europe | March 2011 Australia




Input data: XCAL L1C (- TMI 'diam' - AMSR 'o' - SSMI x/+ -)
ES-LMa
MW input: XCAL intercalibrated Ka-band TB (IMERG)
Brightness Temperature [K]
poor fit
low trust
success
3-day CMA
XCAL L1C
MW LST
TIR input: MOD/MYD16 LST
Surface Temperature [° C]
N σ flag
MYD11C11
MW-FLAG
MOD11C11
MW / TIR Fusion
04/01
05/01
06/01
07/01
08/01
1AM
RMS 1 K
LST night MYD
LST night MW
N= 64
R2= 0.955
RMS= 0.993
11AM
RMS 2 K
LST morning MOD
LST morning MW
N= 52
R2= 0.905
RMS= 2.04
1PM
RMS 1.8 K
LST day MYD
LST day MW
N= 48
R2= 0.926
RMS= 1.79
11PM
RMS 1.7 K
LST evening MOD
LST evening MW
N= 63
R2= 0.910
RMS= 1.65
1PM-1AM
RMS 1.9 K
AMP MYD only
AMP MW
N= 39
R2= 0.612
RMS= 1.91

Overview



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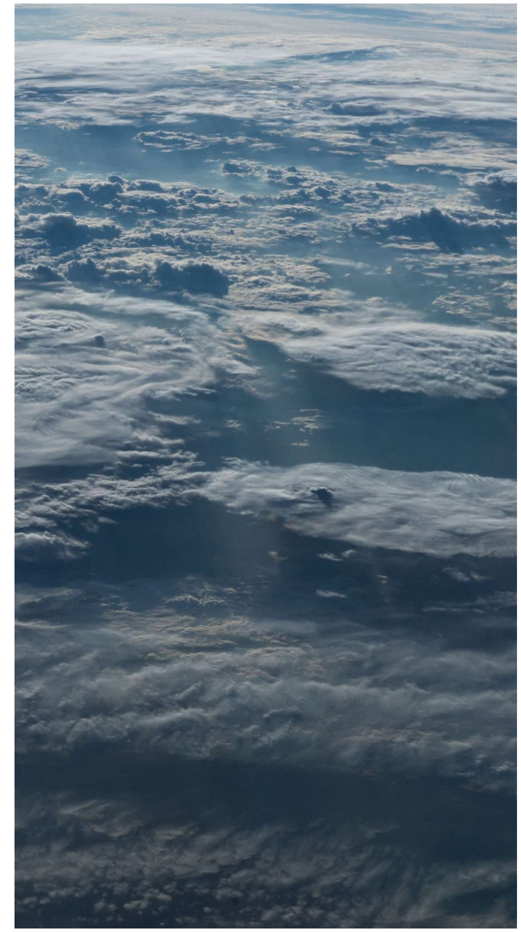


Soil Moisture Retrieval

Alternative (non-model) options for Temperature

- Multi-satellite MW-LST provides options to estimate Tcan and Tsoil:
  - Tcan=MW-LST ubRMSE=2-3.5 K
  - Tsoil=f(MW-LST, dφ) ubRMSE=1.5-2 K
    where dφ is delay in diurnal timing and integrates T-profile and sensing depth
- At 6am, ubRMSE will be on the low side, but estimating dφ for L-band is a challenge

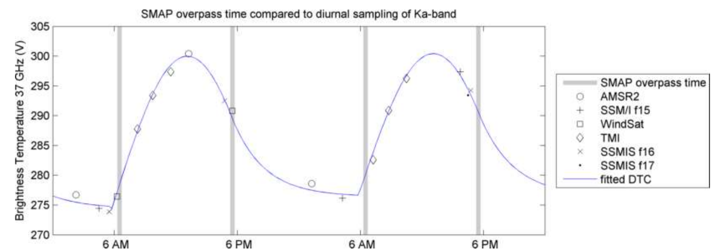


Fig. Example of diurnal sampling for MW-LST based on Ka-band radiometers.

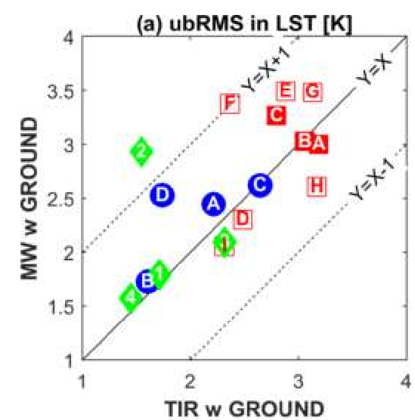
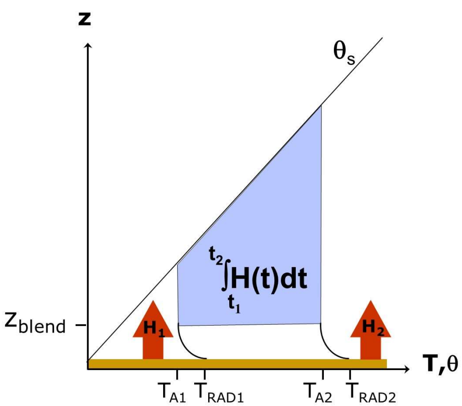
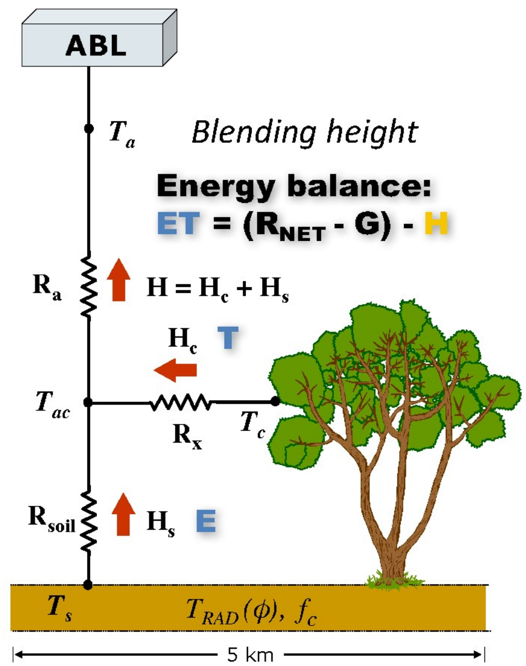


Fig. ubRMS of LST (blue, red) and Tsoil (green).

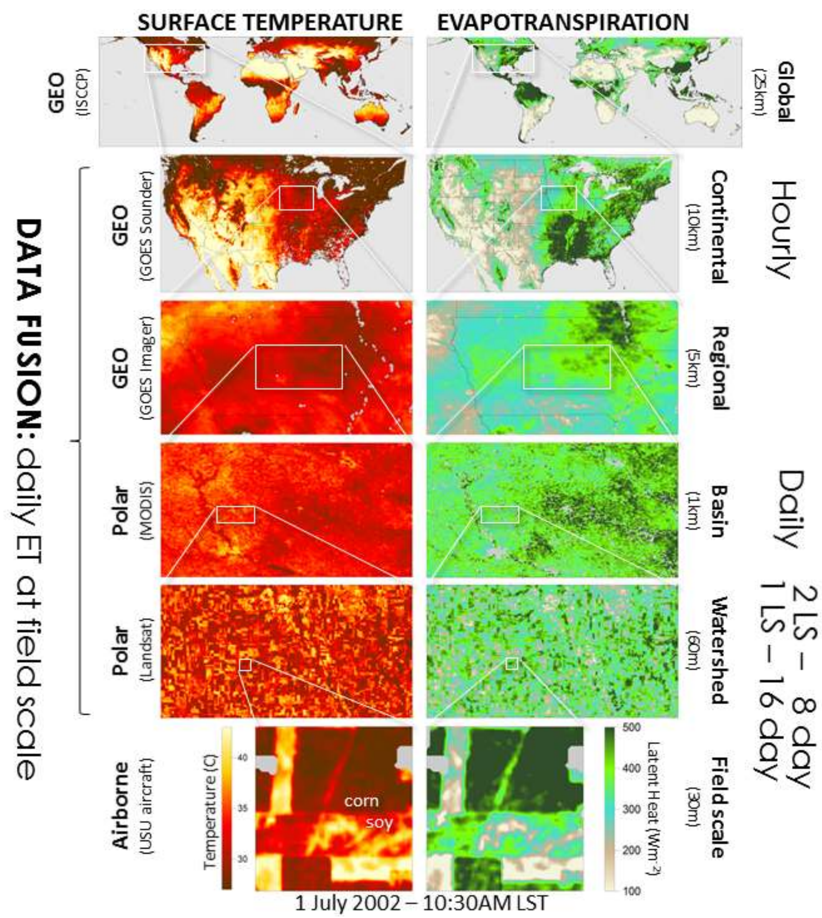
Evapotranspiration



ABL closure

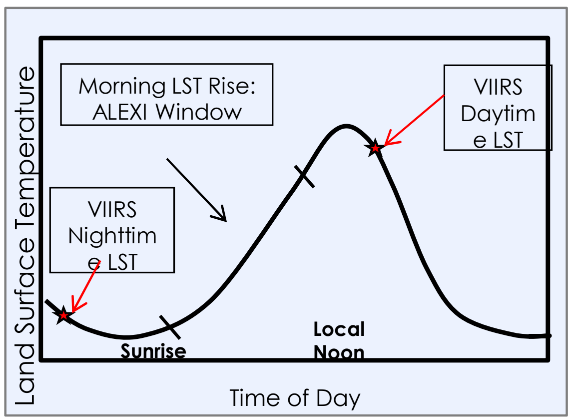


ALEXI
(Atmosphere-Land Exchange Inverse model)

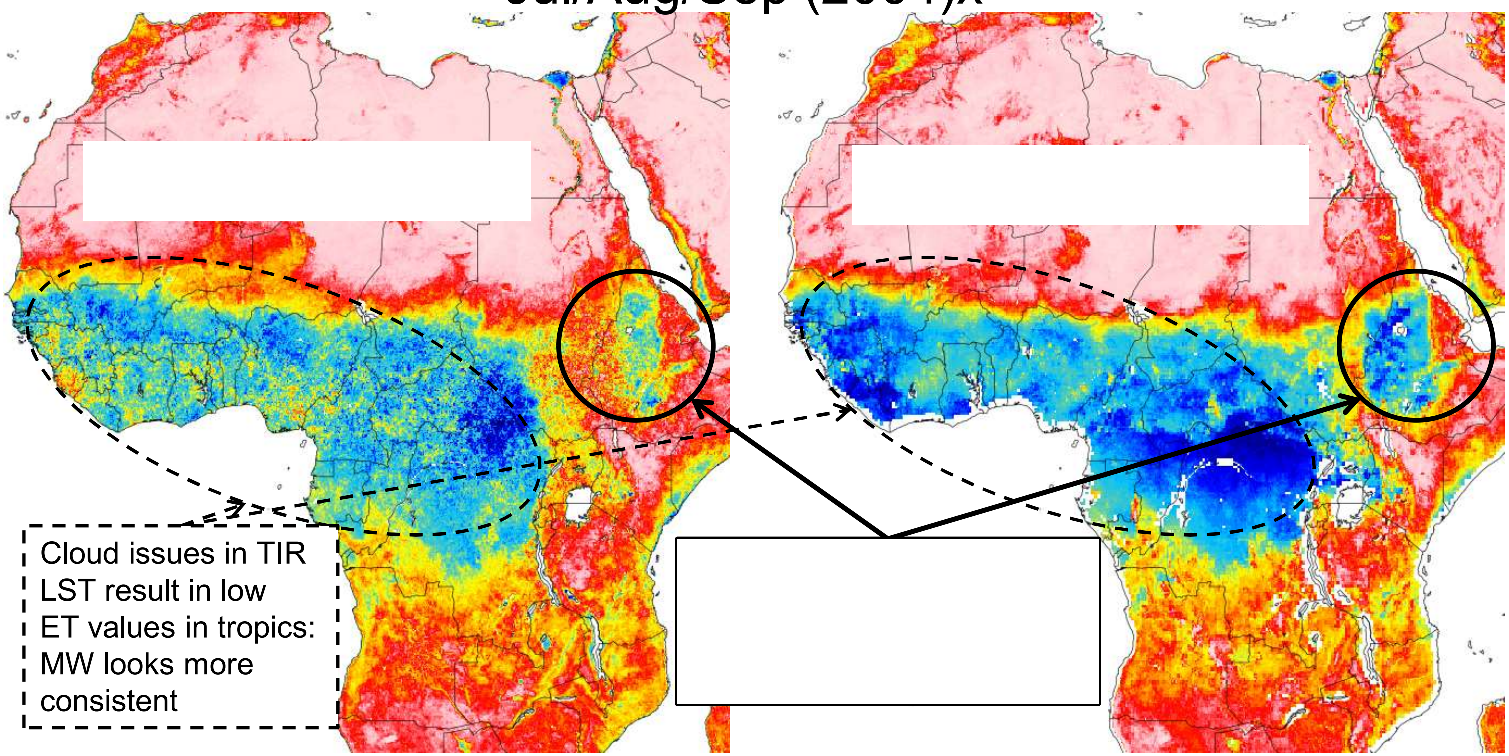


Evapotranspiration

PMW LST substitute for TIR LST as input to surface energy balance approach to ET estimation.



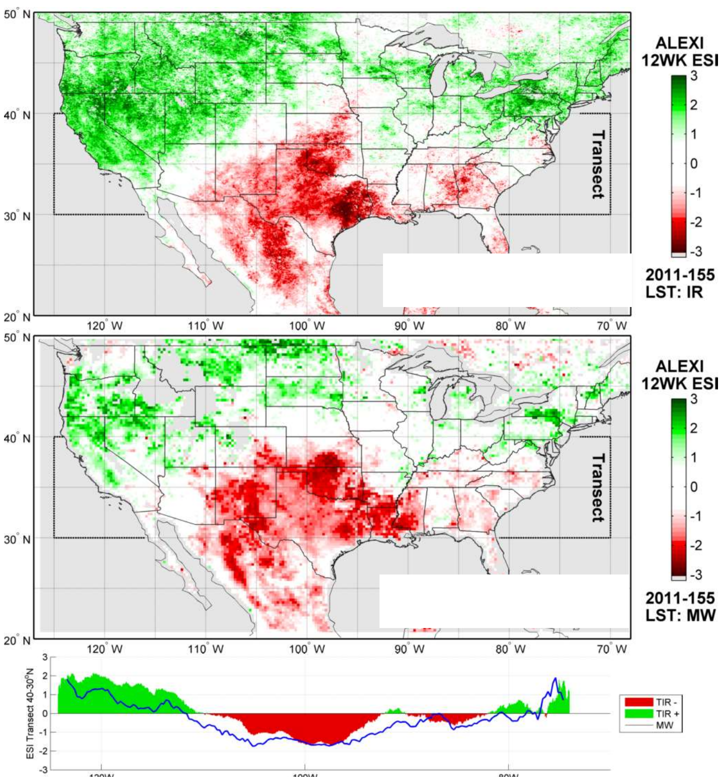
Cumulative - Clear Sky - Evapotranspiration (mm) Jul/Aug/Sep (2004)x



Holmes, T. R. H., Hain, C. R., Crow, W. T., Anderson, M. C., and Kustas, W. P.: Microwave implementation of two-source energy balance approach for estimating evapotranspiration, Hydrol. Earth Syst. Sci., 22, 1351–1369, https://doi.org/10.5194/hess-22-1351-2018, 2018

Drought Monitoring

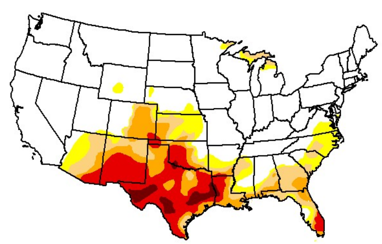
Evaporative Stress Index (ESI) - 12week moving window

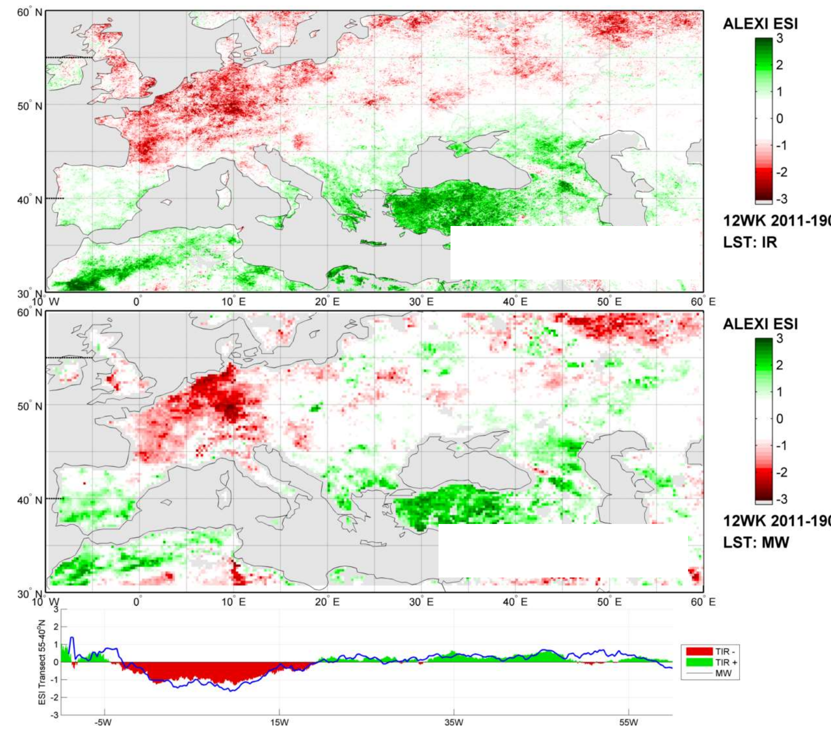


ESI = standardized anomalies in ET/RefET

- Early indicator of agricultural drought
- MW-based ALEXI will increase sampling in cloudy periods, reduce sampling bias

June 7th, 2011
US drought monitor





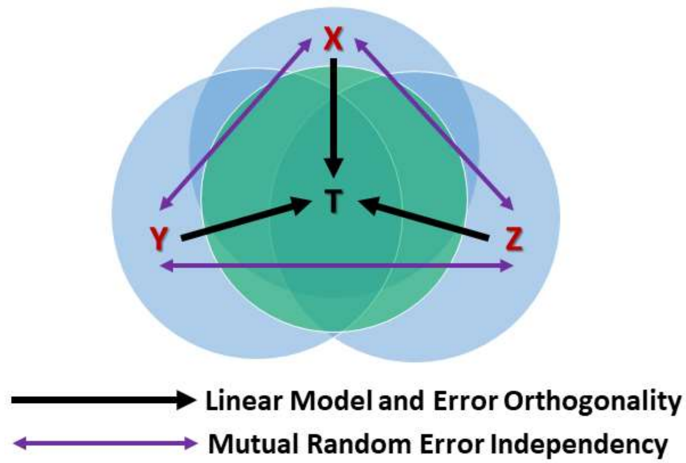
Observational Evidence of L/A Coupling

Triple collocation-based coupling strength metric

Work by Fangni Lei and Wade Crow

Passive L-band Soil Moisture: move to Teff, independent of MODEL

X	PASSIVE
Y	ACTIVE
Z	MODEL



X	ALEXI-TIR
Y	ALEXI-MW
Z	MODEL

Passive Ka-band Diurnal at 5 km is good target to match optimal ALEXI - TIR

Soil Moisture ⟷ **Coupling Metric** ⟷ **Evapotranspiration**

$$R^2[SM_{True}, ET_{True}]_{X,X} \equiv \frac{Cov[SM_X, ET_X]^2 Cov[SM_Y, SM_Z] Cov[ET_Y, ET_Z]}{Cov[SM_X, SM_Y] Cov[SM_X, SM_Z] Cov[ET_X, ET_Y] Cov[ET_X, ET_Z]}$$

[Crow et al., 2015, Lei et al 2018]

Conclusion

Diurnal Passive Microwave LST (from Ka-band)

- *enables all-sky ET retrievals within surface energy balance framework*
- *provides soil temperature profile information to PMW retrievals of soil moisture and vegetation water content*

Thoughts on SATM

- Complex Earth System questions typically require multiple independent observation pathways. To achieve those:
- Data records should minimize temporal sampling bias (e.g. by leveraging cloud-tolerant observations)
- The measurements themselves should be free from temporal or spatial varying bias by utilizing multiple independent retrieval pathways (Active/Passive, TIR/MW).