Simulation and SMAP observation of Sun-glint over the land surface at the L-band

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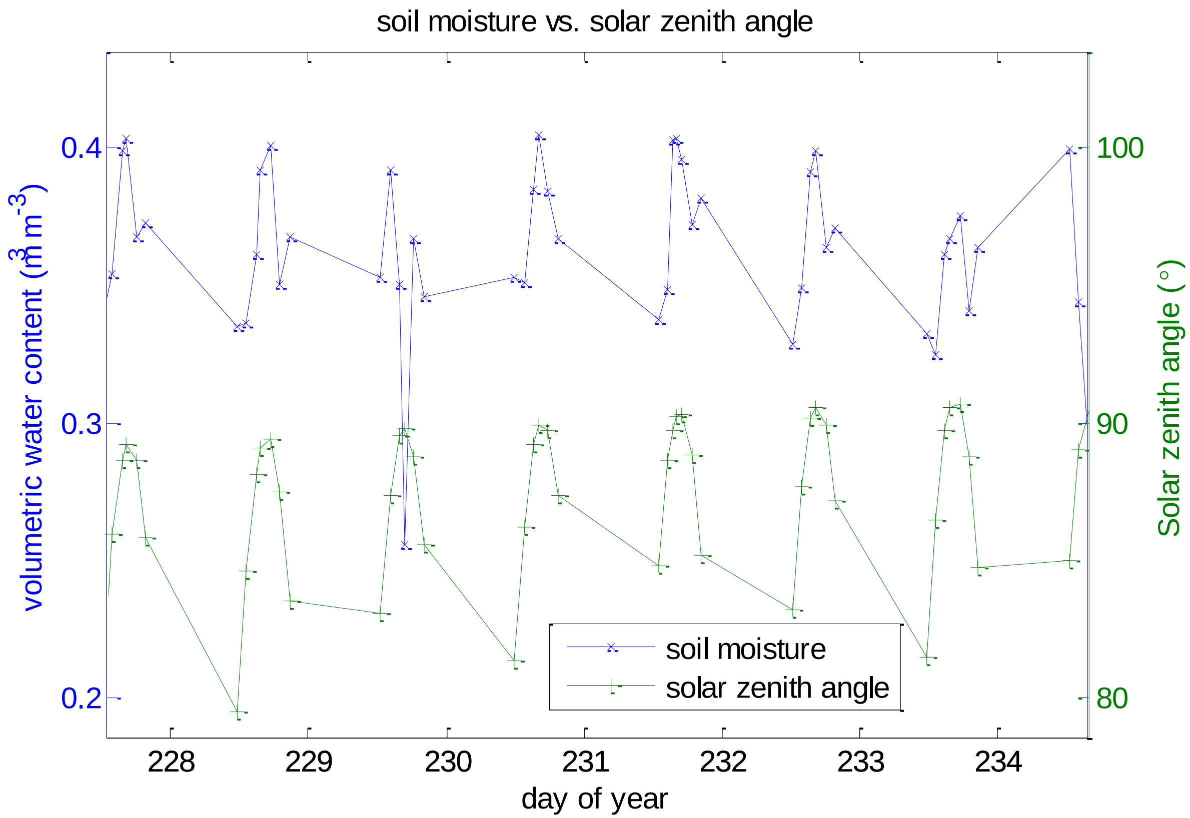
The famous dry bias in SMOS soil moisture

- The recently validations from all over the world show that the SMOS soil moisture has dry (or negative) bias comparing to *in situ* soil moisture measurements (Adams et al., 2014; Al-Yaari et al., 2014; Al Bitar et al., 2012; Albergel et al., 2012; Bircher et al., 2012; Bircher et al., 2013; dall'Amico et al., 2012; Dente et al., 2012; Gherboudj et al., 2012; Jakkila et al., 2014; Lacava et al., 2012; Montzka et al., 2013; Rötzer et al., 2014; Sanchez et al., 2012); the dry bias is dependent on orbits and the wet soil has more dry bias (Gherboudj et al., 2012) from SMOS soil moisture.

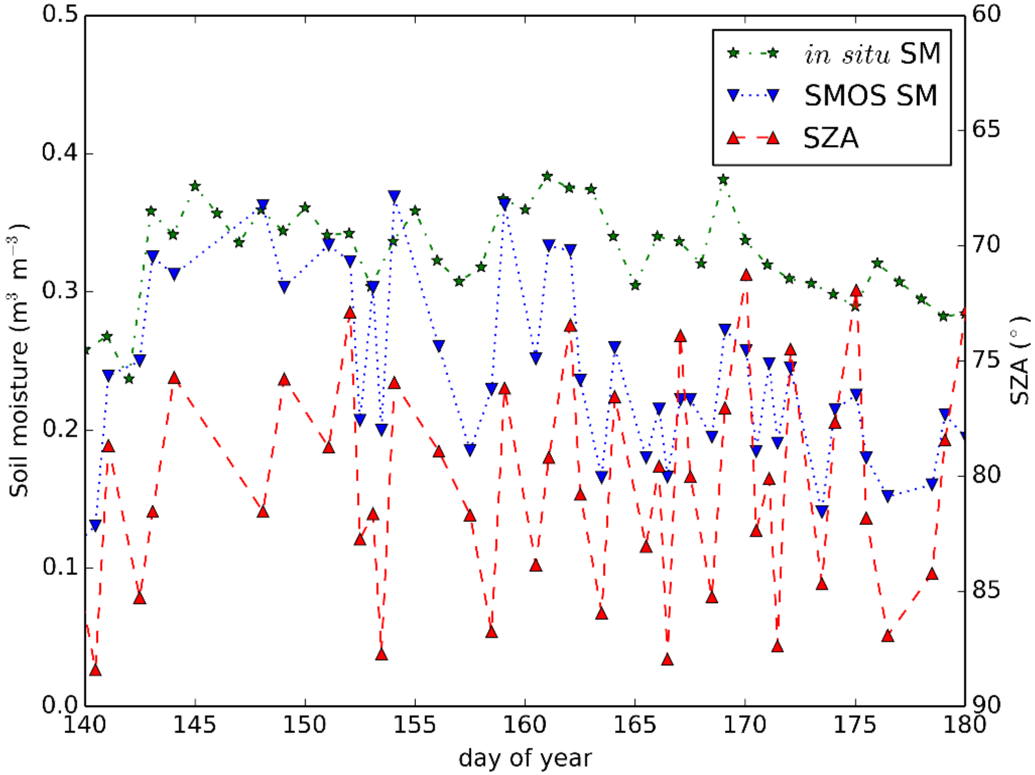
One approach to find the mystery?

SMOS Soil moisture vs. Solar Zenith Angle (1)



- Diurnal cycles of soil moisture from SMOS and solar zenith angle for pixel DGG= 4112533 (latitude: 76.531°, longitude: 110.686°) in 2012. High frequency of SMOS observations (6-7 times per day) in this region captured the diurnal cycles of soil moisture.

SMOS Soil moisture vs. Solar Zenith Angle (2)

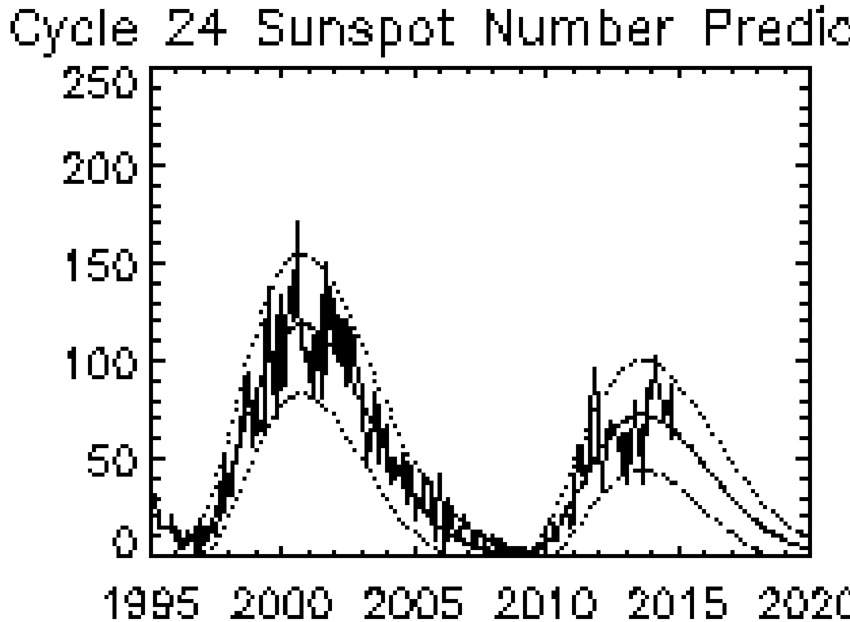


- Soil moisture and solar zenith angles for the DGG grid 147228 at the Kenaston site during the CanEx-SM10 experiment in 2010. In contrast to previous, Sun-glint at higher SZA induced more soil moisture dry bias.

Facts vs opinions

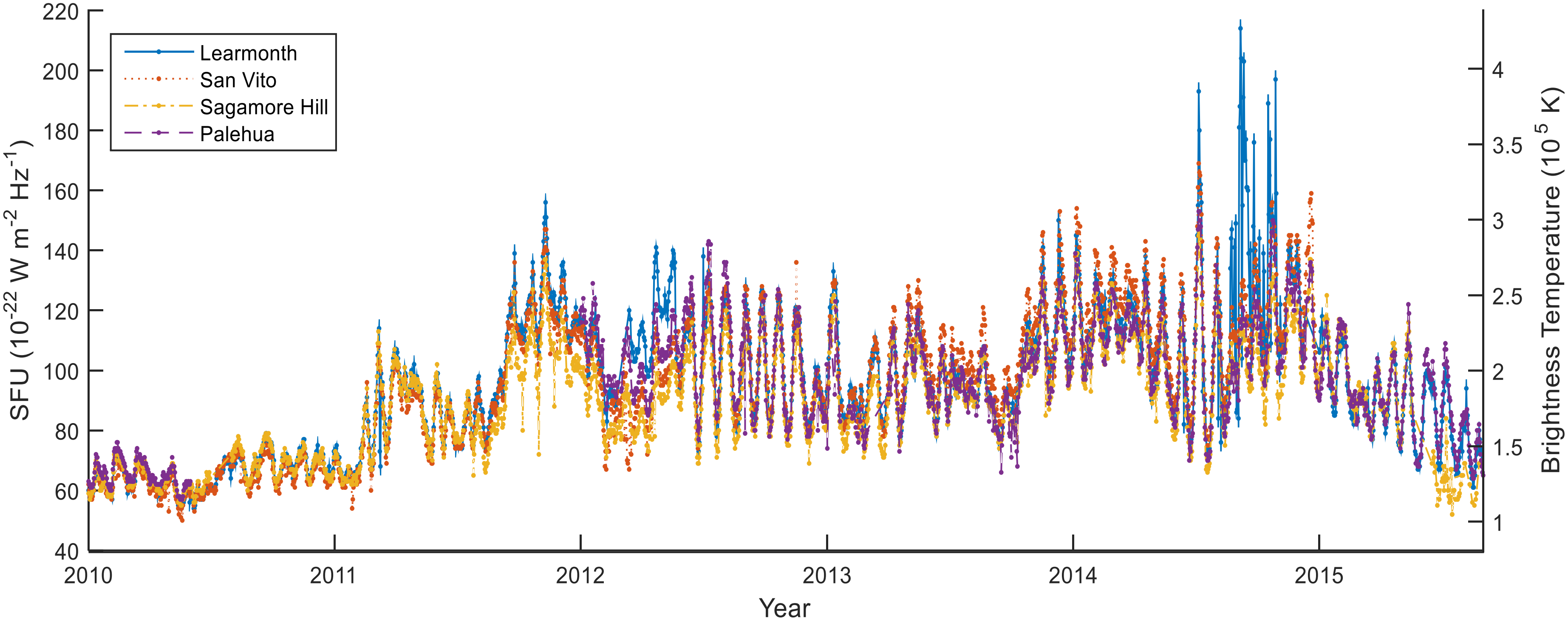
- ***Comments from the reviewers: "… soil surface is less reflective, …, solar elevation angle is low for the dusk/dawn orbit, …, Sun-glint is a specular reflection and cannot be viewed in SMOS's field of view".***
- ***"Spurious signals. On one hand, no significant impact of sun contamination (glint) has been detected, so far, over land but work is in progress," cited from https://earth.esa.int/documents/10174/1854503/SMOS_L2SMv620_release_note (released in March, 2016).***

Solar activities



- SMOS: proposed launch - 2006. xx
- SMOS: launch (2009.11 -)
- SMAP: 2015.01 -

SFU vs solar BT



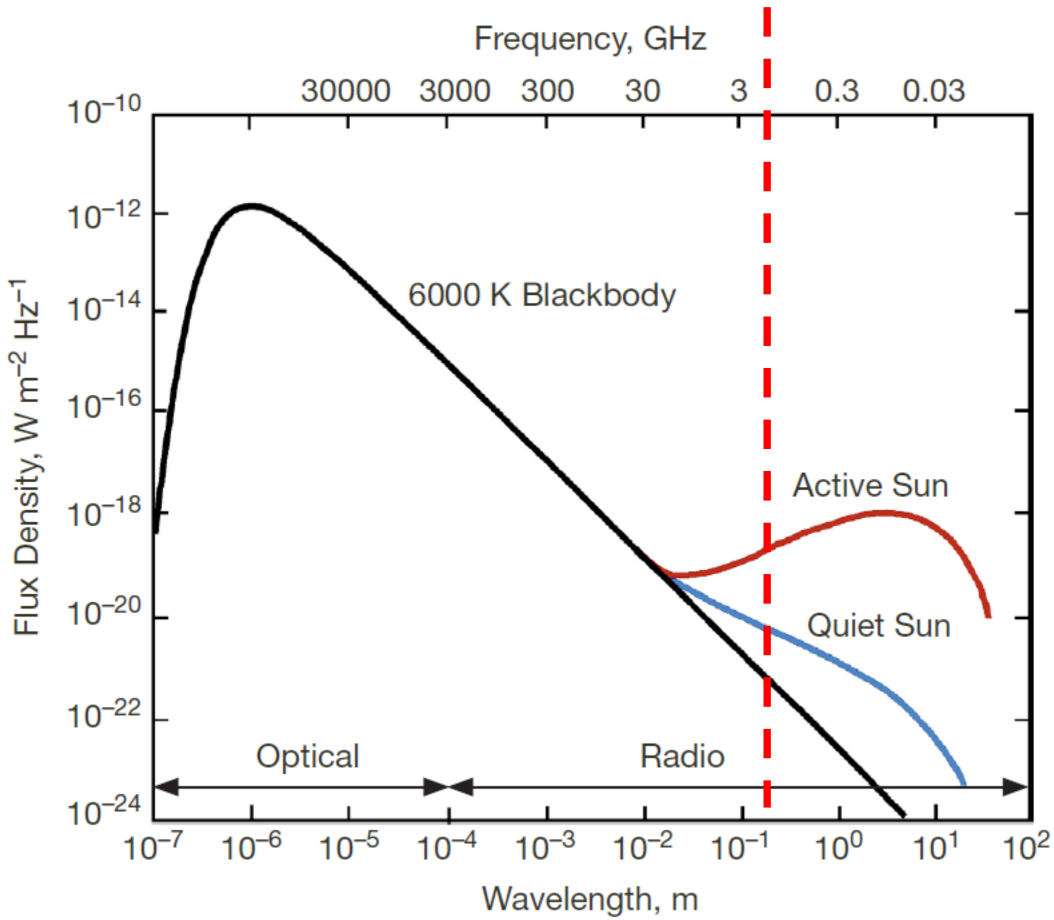


Figure 1. The solar radiation spectrum at optical and radio frequencies. At wavelengths greater than 1 cm, the radiance from an active Sun is much larger than from a quiet Sun and from a blackbody at 6000 K (figure after [1,2]).

At the L band, the blackbody temperature of the Sun ranges between 100 000 (minimum value in quiet period) and several million Kelvins, depending on the solar activity (Reul et al., 2007).

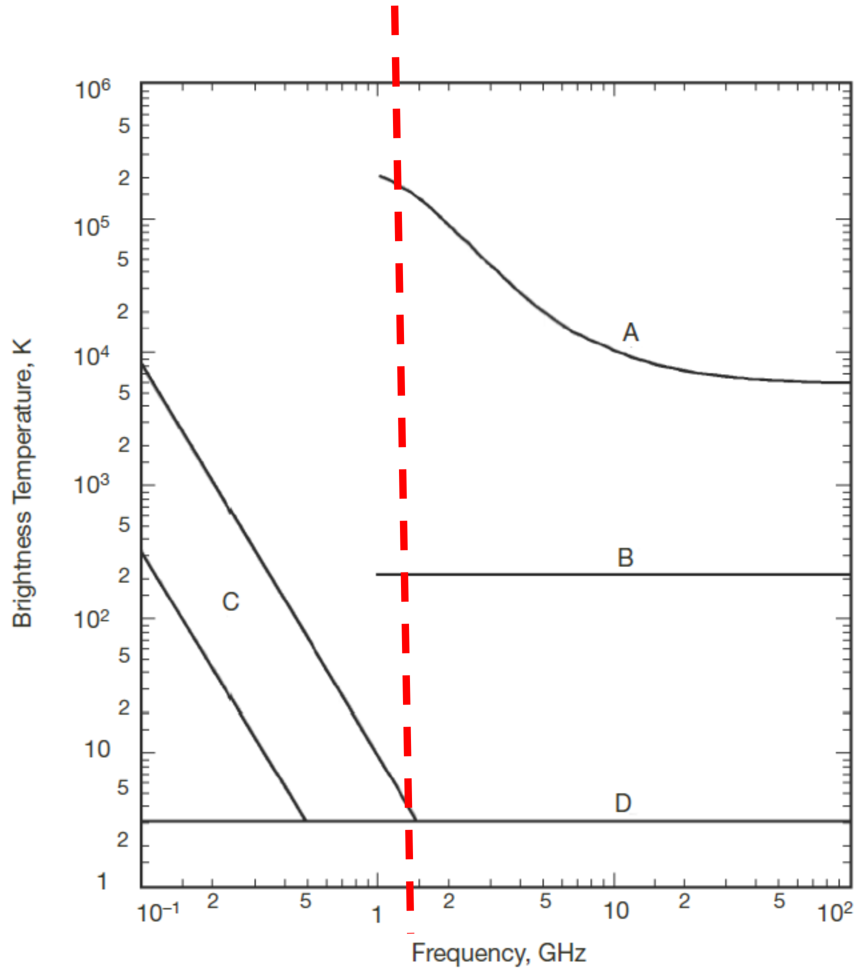


Figure 3. All noises from extraterrestrial sources. Line A is from a quiet Sun, while line B is from the Moon (all with 0.5-deg beamwidth diameter). Galactic noise (C, maximum to minimum) and cosmic background (D) are also shown. Lunar emission is independent of the frequency (figure after [7]).

At Ocean

- The expected contamination to SMOS brightness temperature due to roughness scattering of sun-glint will range between 0 K and about 500 K, depending on the target position, the season, the roughness state at the target, and the level of solar activity at the time of measurements (Reul et al., 2007).

Land surface

- The reflected Sun glint from the land surface is also observed from airplane (Colliander et al., 2012; Saleh et al., 2007).
- Direct observation of the Sun showed an increment of 130 K in brightness temperature during T-REX 2006 experiment (quiet Sun activity period);
- The impact of the reflected Sun glint on radiometric measurements over a grass field and over and agricultural area reaches 25 K (in 2003) and 17 K (in 2006) respectively, as reported in Escorihuela et al. (2008).

- Unfortunately, the few studies on Sun-glint are rather misleading for SMOS applications because
- (1) the above two studies were conducted when solar activity is low (i. e. 2006, see fig. 2 below) while the launch of SMOS was postponed (2009 - now), so the Sun-glint in current SMOS brightness temperature will be a few times stronger than that in 2006;
- (2) the reflected Sun-glint from wet soil with low emissivity (<0.6) (Njoku and Entekhabi, 1996) will be a few times stronger than that from the dry soil with high emissivity (>0.9) where the previous studies were conducted.

The current SMOS SM model

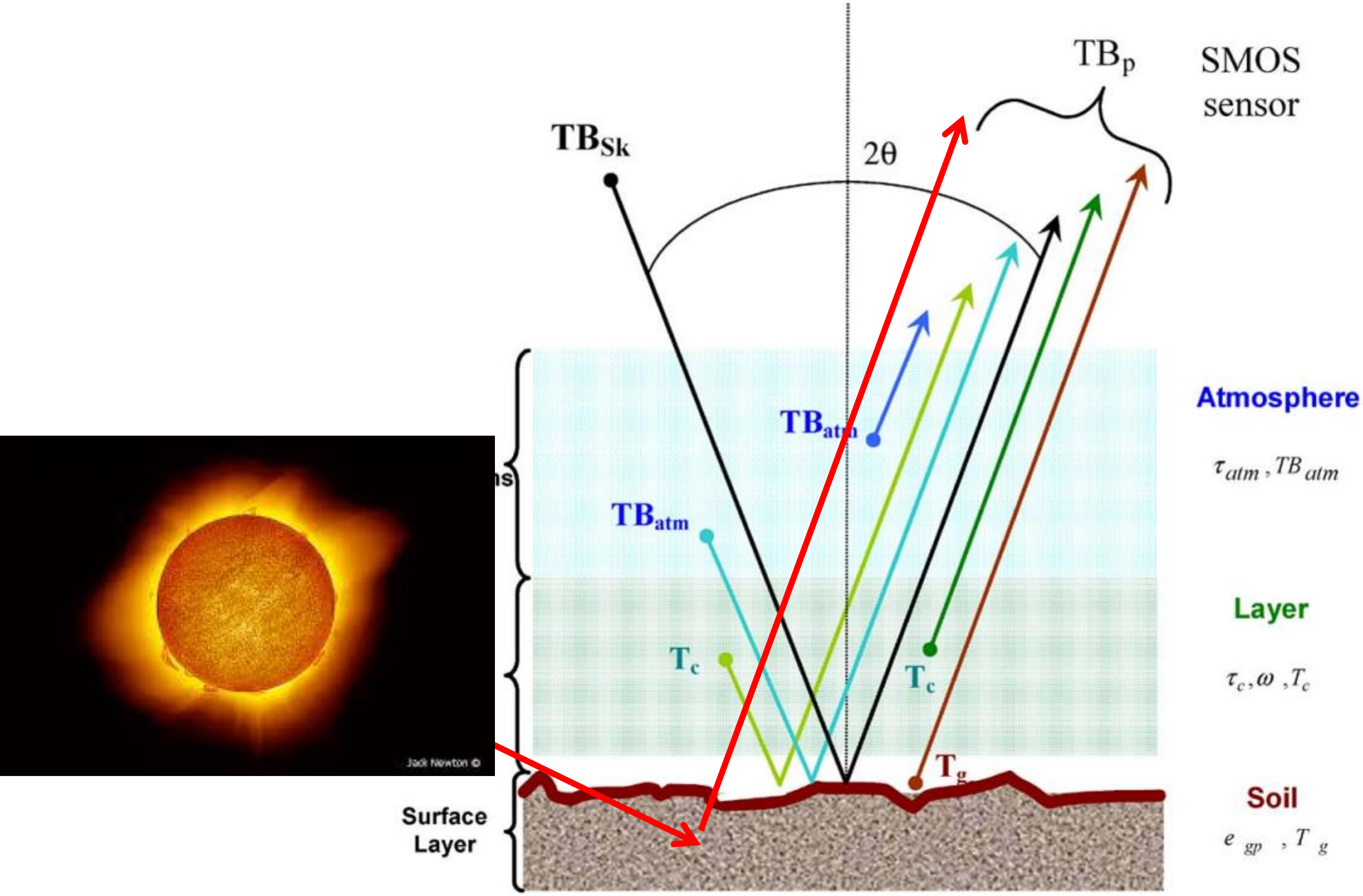


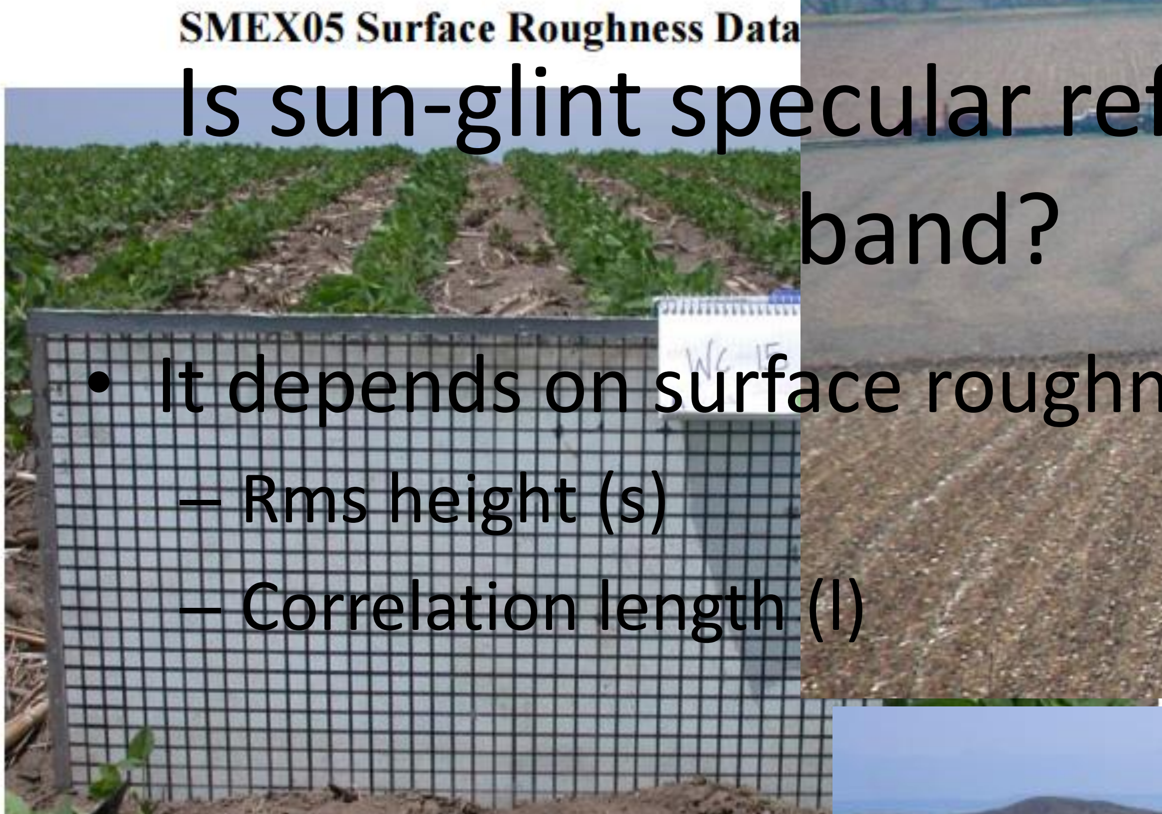
Fig. 2. Contributions to TOA brightness temperature.

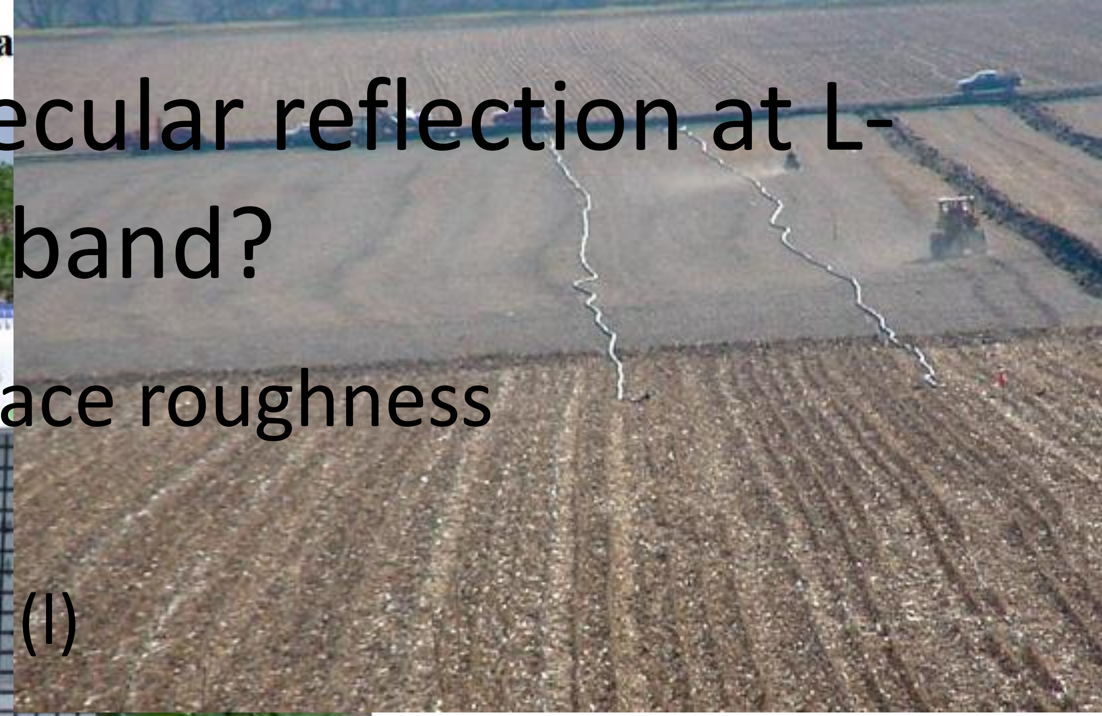
Advanced Integral Equation Model (AIEM)

- Wu, T.D., Chen, K.S., Shi, J.C., Lee, H.W., and Fung, A.K.: 'A study of an AIEM model for bistatic scattering from randomly rough surfaces', Ieee Transactions on Geoscience and Remote Sensing, 2008, 46, (9), pp. 2584-2598

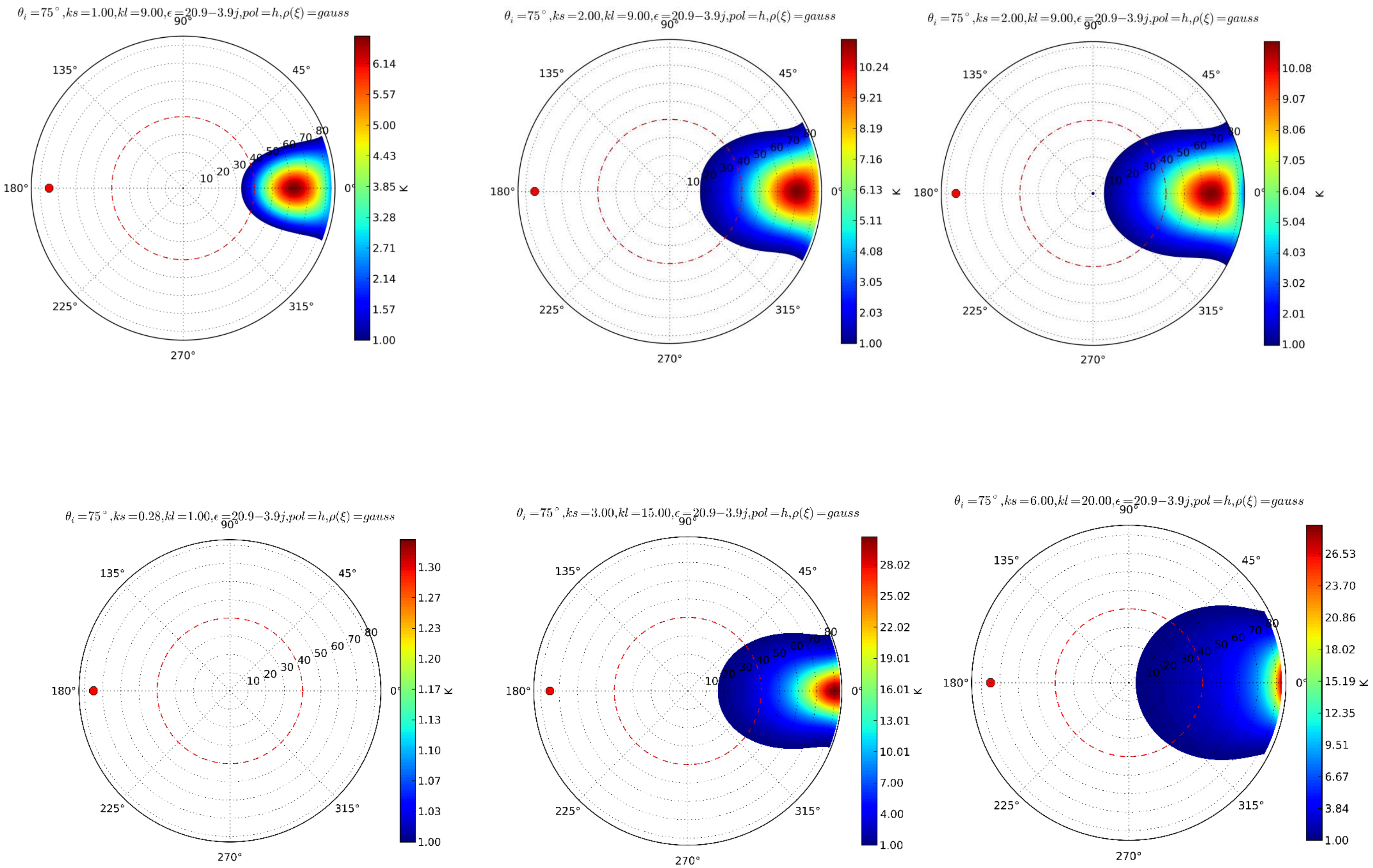
- Sun as an active "Radar" in the AIEM

Is sun-glint specular reflection at L-band?



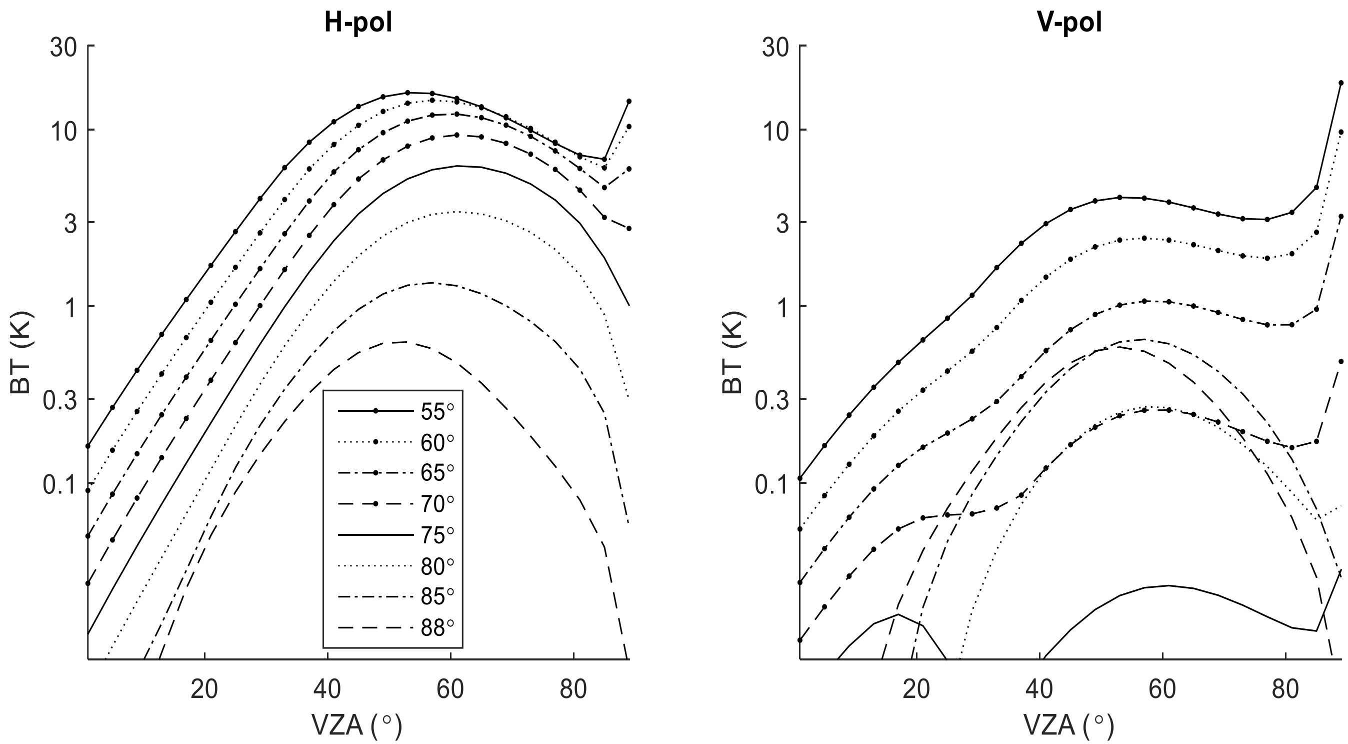


- It depends on surface roughness
  - Rms height (s)
  - Correlation length (l)
- The terrain plays a role
  - DEM

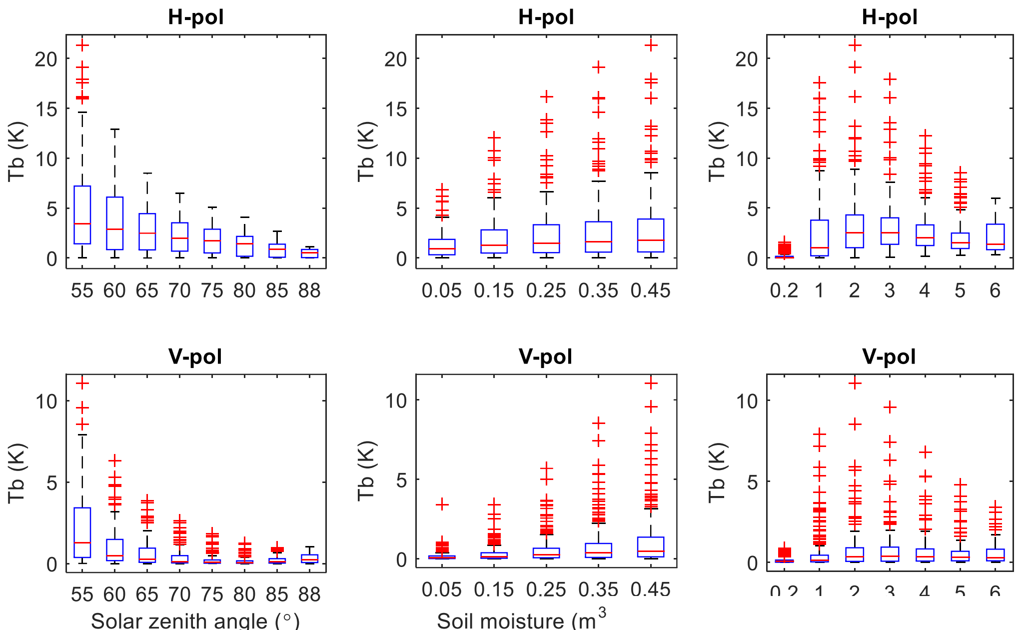


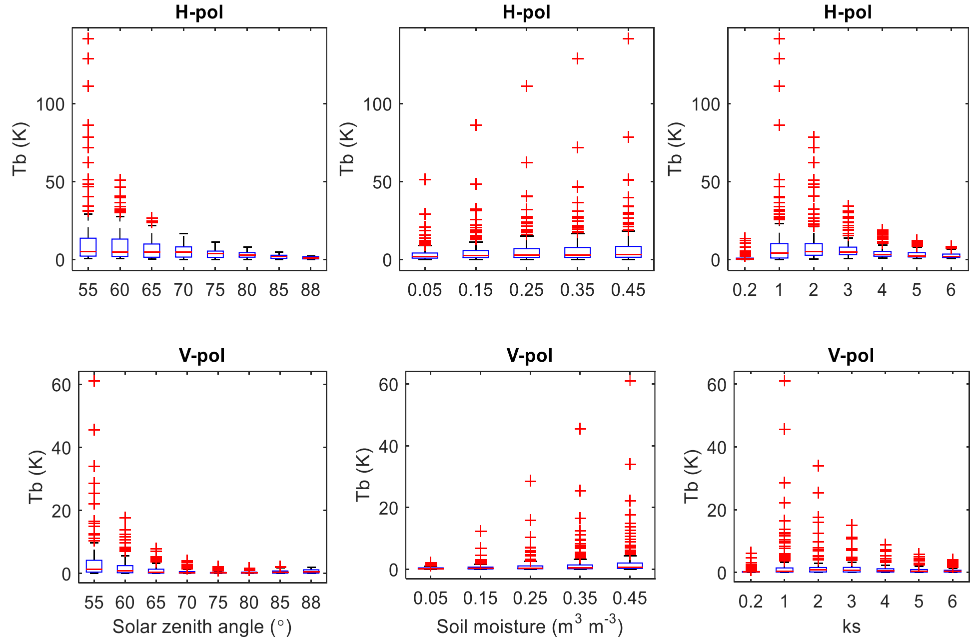
Small Perturbation Model (SPM) -> Physical Optics (PO) model -> Geometric optics (GO) model

Different incidence solar angle ks=1, kl=9, e= 20.93 + 3.89 j



Reflection (v-pol) goes to zero at an angle called the Brewster angle

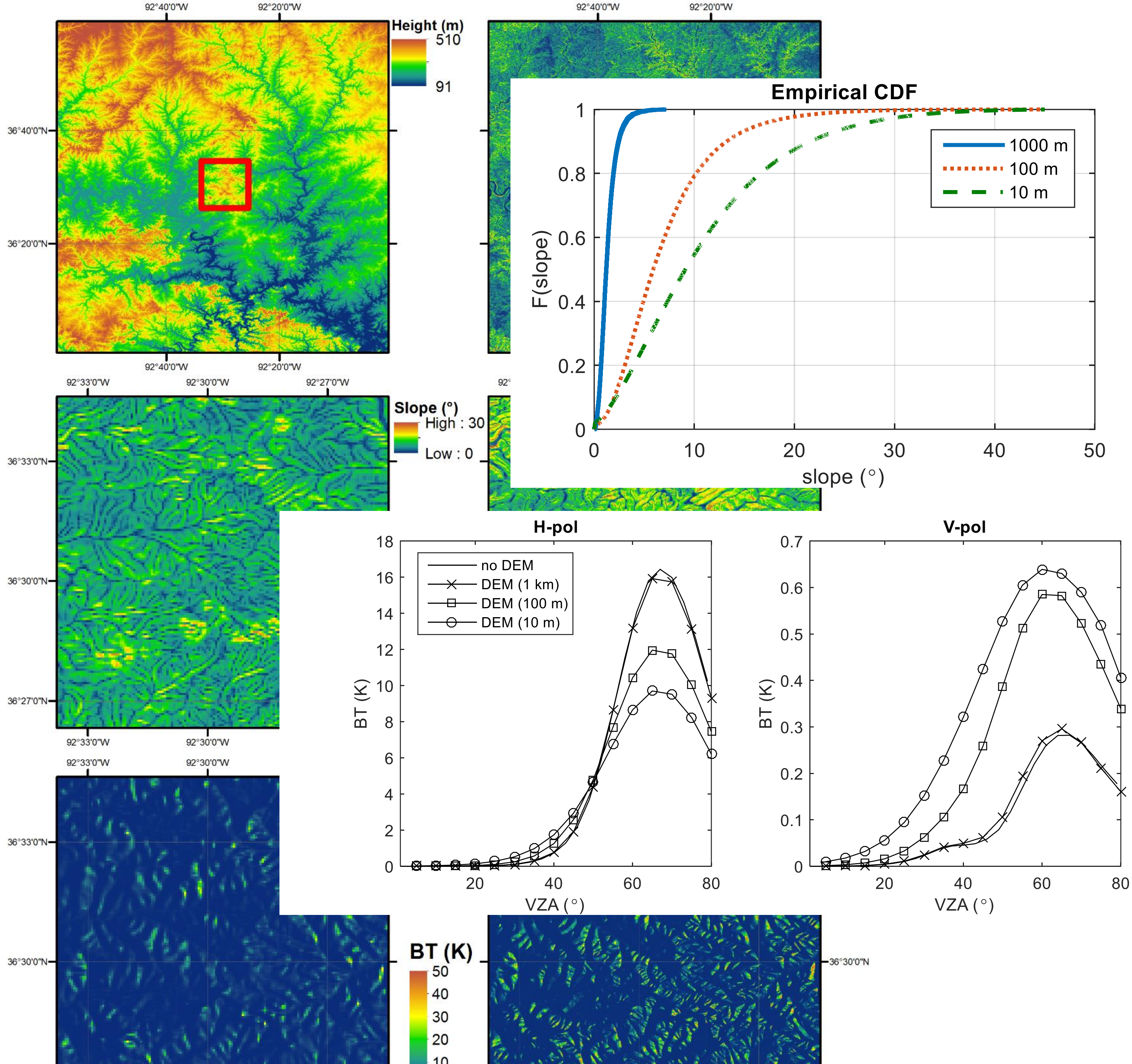

H-pol
V-pol
Tb (K)
Solar zenith angle (°)
Soil moisture (m3


H-pol
V-pol
Tb (K)
Solar zenith angle (°)
Soil moisture (m3 m-3)
ks

SM from V-pol has less dry bias

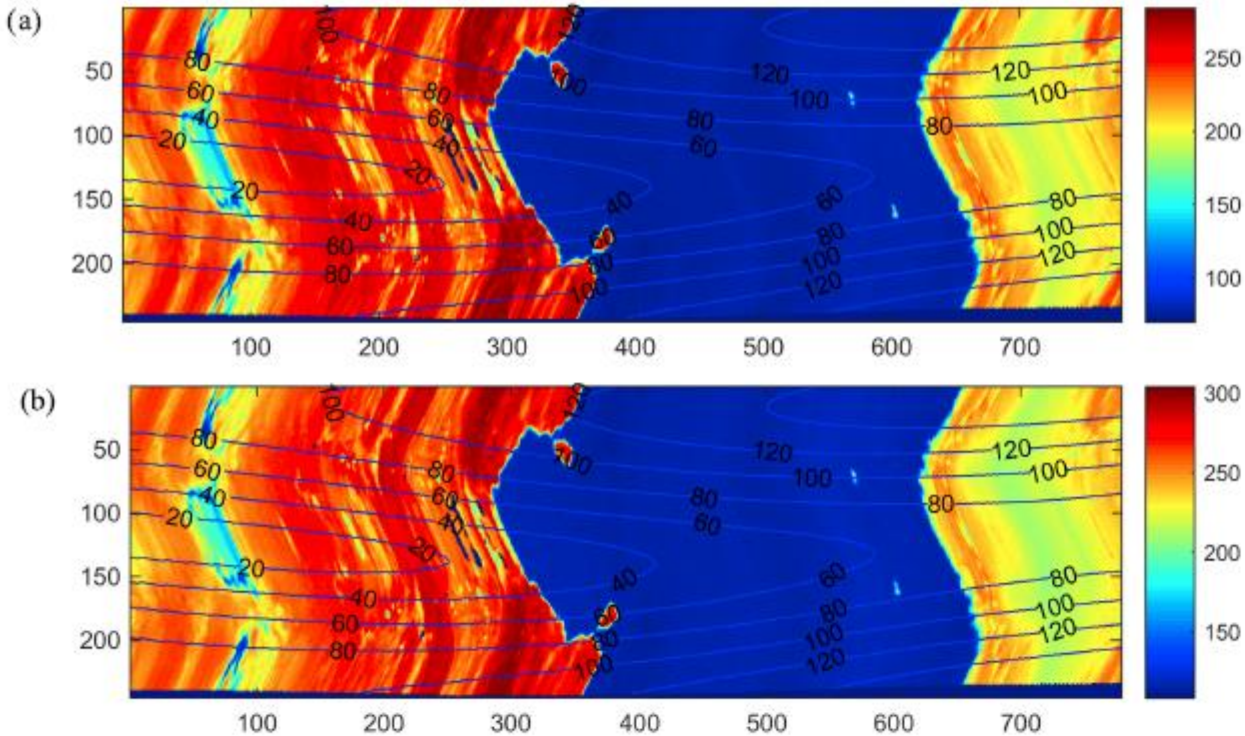
Table 7.2. SMAP L2SMP Beta Release CVS Assessment

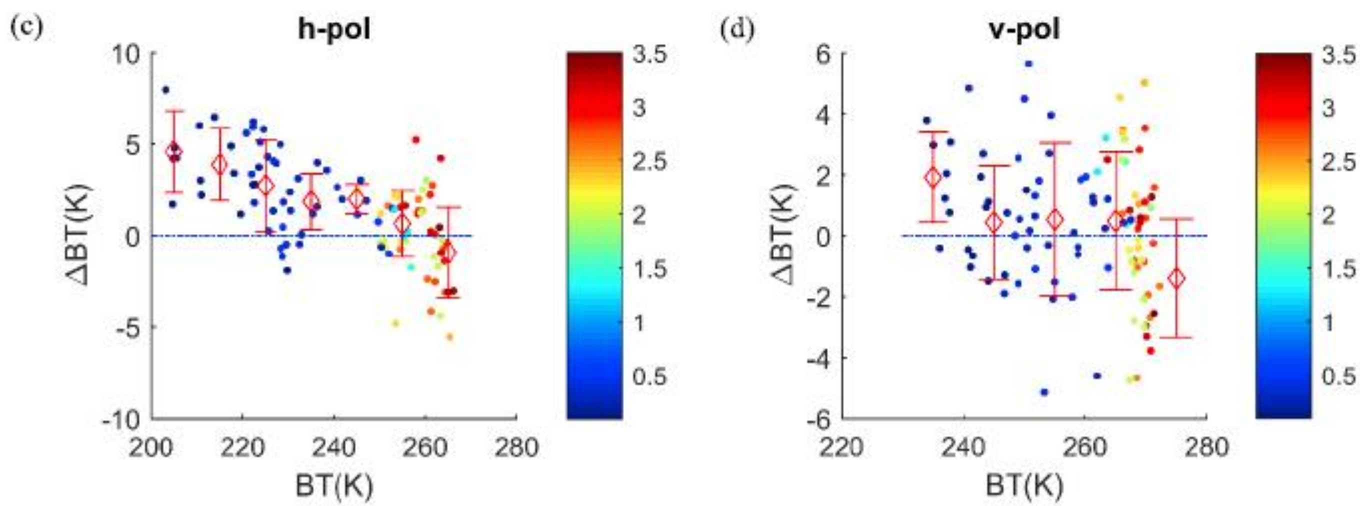
	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R		
Site name	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Walnut Gulch	0.036	0.036	0.053	-0.025	-0.001	0.018	0.044	0.036	0.057	0.183	0.403	0.415
TxSON	0.027	0.022	0.031	-0.076	-0.028	0.040	0.081	0.036	0.050	0.976	0.978	0.934
Fort Cobb	0.046	0.042	0.051	-0.058	-0.043	-0.026	0.074	0.061	0.057	0.733	0.736	0.654
Little Washita	0.044	0.040	0.048	-0.062	-0.043	-0.019	0.076	0.059	0.052	0.738	0.759	0.723
South Fork	0.082	0.079	0.072	-0.055	-0.051	-0.058	0.099	0.095	0.093	0.693	0.718	0.532
Little River	0.028	0.029	0.038	0.029	0.058	0.092	0.041	0.065	0.100	0.865	0.845	0.775
Kenaston	0.022	0.021	0.035	-0.134	-0.109	-0.075	0.136	0.111	0.082	0.813	0.869	0.860
Monte Buey	0.052	0.043	0.046	-0.070	-0.049	-0.017	0.087	0.065	0.049	0.760	0.763	0.665
REMEDHUS	0.040	0.041	0.053	-0.059	-0.042	-0.027	0.071	0.059	0.059	0.690	0.727	0.692
Yanco	0.068	0.058	0.053	0.020	0.031	0.040	0.071	0.066	0.067	0.875	0.862	0.827
Kyeamba	0.043	0.036	0.035	0.001	0.017	0.031	0.043	0.040	0.047	0.948	0.959	0.923
SMAP Average	**0.044**	**0.041**	**0.047**	**-0.044**	**-0.024**	**0.000**	**0.075**	**0.063**	**0.065**	**0.752**	**0.784**	**0.727**
SMOS Average	**0.043**			**-0.014**			**0.065**			**0.796**		
Averages are based on the values reported for each CVS												



92°40'0"W
92°20'0"W
Height (m)
510
91
36°40'0"N
36°20'0"N
Empirical CDF
F(slope)
slope (°)
1000 m
100 m
10 m
92°33'0"W
92°30'0"W
92°27'0"W
Slope (°)
High : 30
Low : 0
36°33'0"N
36°30'0"N
36°27'0"N
H-pol
V-pol
no DEM
DEM (1 km)
DEM (100 m)
DEM (10 m)
BT (K)
VZA (°)
BT (K)
50
40
30
20
10
36°30'0"N

SMAP conical scan for Sun-glint detection: Same view zenith angle, different azimuthal angle





Increase of BT due to Sun-glint (SFU values are 100 and 110 at Learmonth and Palehua, respectively). (a) BT for H-pol overlaid by contours of t angles (θ_g) for file SMAP_L1B_TB_01893_D_20150610T001714_R12170_001. (b) BT for V-pol. (c) Scatter plot of ΔBT for H-pol versus BT for ving $\theta_g < 15°$. (d) Similar to (c) but for V-pol. In (c), the ΔBT explains 40% of variance of BT. In (d), the ΔBT explains 5% of variance of BT.

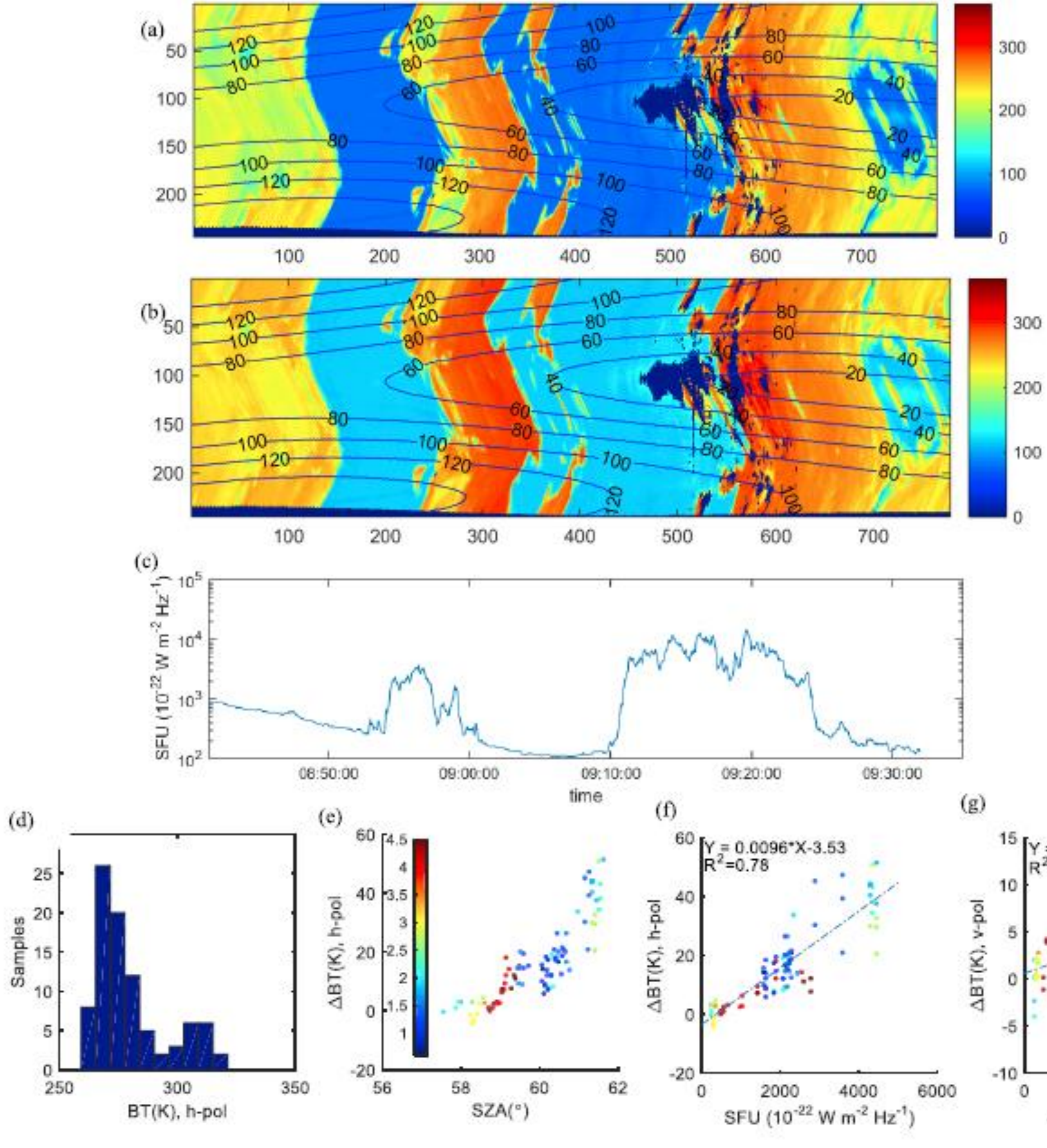
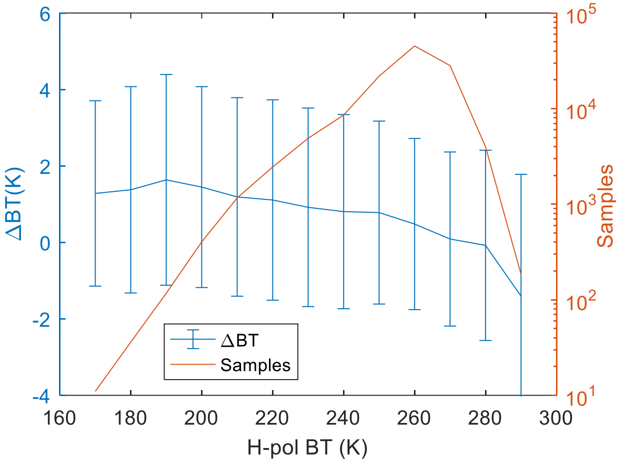
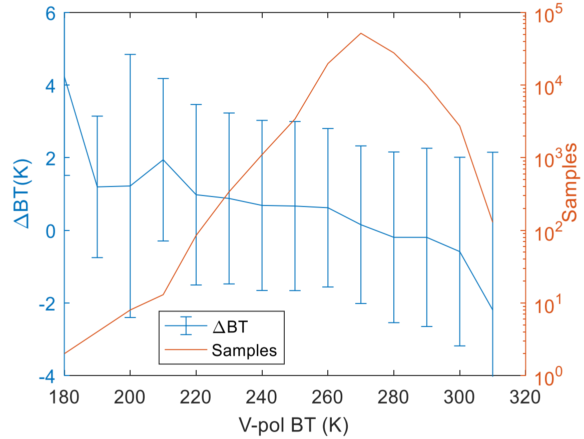
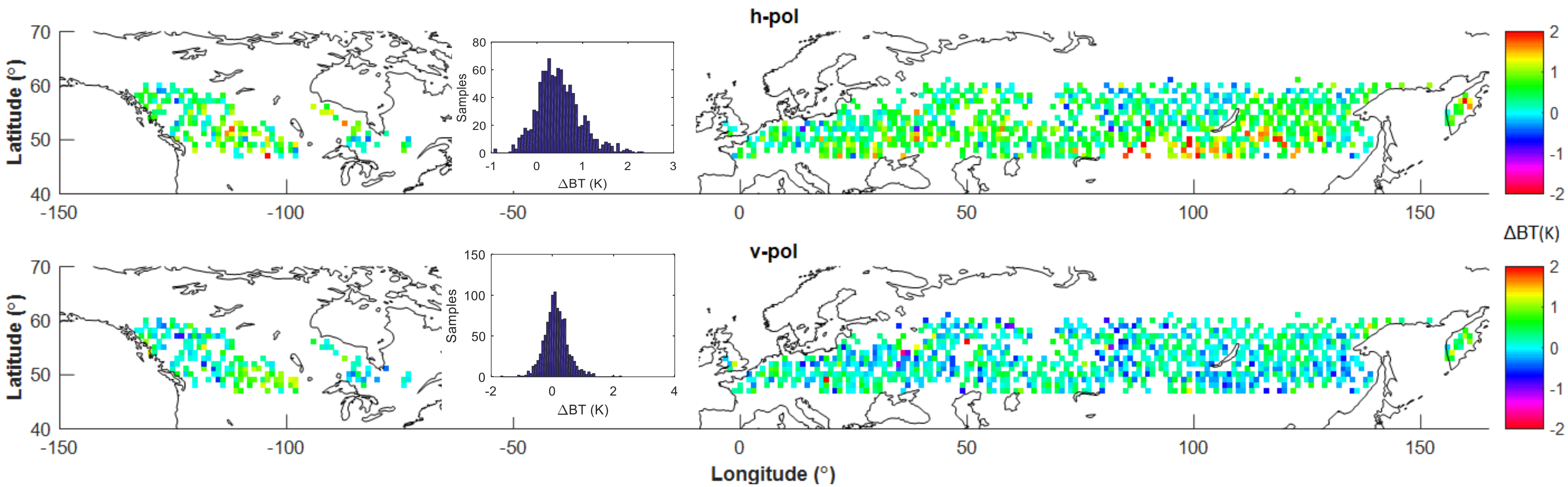


Fig. 12. Increase of BT due to Sun-glint during an intense solar radio burst. (a) BT for H-pol overlaid by contours of Sun-glint angles (θ_g) for file SMAP_L1B_TB_02118_A_20150625T084132_R12170_001. (b) BT for V-pol. The missing data region in dark blue in (a) and (b) are corresponding to the period of the strong solar radio burst (c) in June 25, 2016. The light plumes circled by contour 20° in (a) and (b) are Sun-glint on the sea surface after the Sun-burst. The column numbers in (a) and (b) correspond to the observation time in (c). (d) Histogram of BT in H-pol with $\theta_g > 35°$ filtered by having another BT observation with $\theta_g < 15°$. (e) Scatter plot of ΔBT for H-pol versus SZA for pixels in (d). (f) Scatter plot of ΔBT for H-pol versus SFU for pixels in (d). (g) Scatter plot of ΔBT for V-pol versus SFU for pixels in (d).



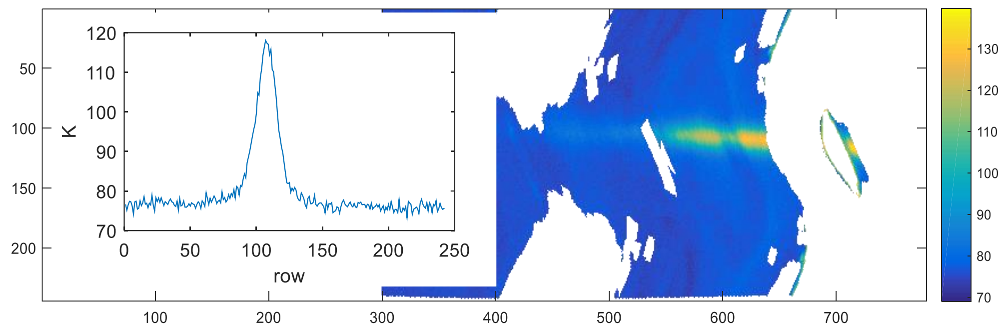


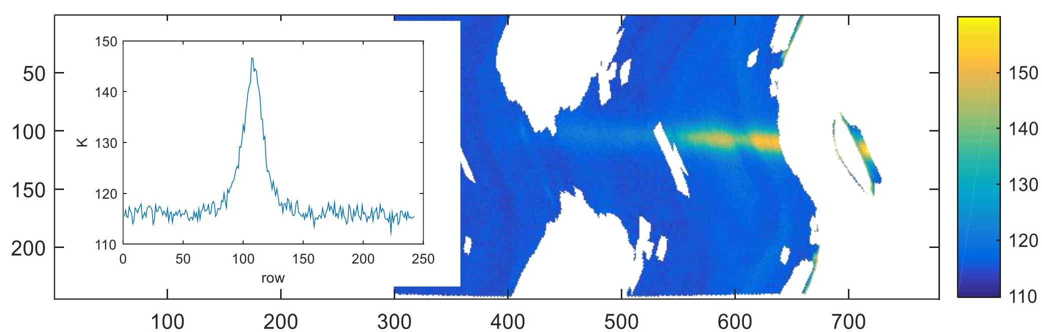
Lower limit of Sun-glint



Azimuthal asymmetry Vegetation "hotspot" effect: 5-10 K between hotspot and dark spot directions

δ^0_{hh} (-5 to -10 dB) would lead to a BT range of 0.54 K to 0.17 K


120
110
100
90
80
70
K
0
50
100
150
200
250
row
50
100
150
200
100
200
300
400
500
600
700
130
120
110
100
90
80
70


150
140
130
120
110
K
0
50
100
150
200
250
row
50
100
150
200
100
200
300
400
500
600
700
150
140
130
120
110

Conclusions

- The role of Sun should not be ignored for L-band soil moisture retrieval
- Explanation of surface roughness at different scales
- SMOS has larger VZA than SMAP and it covers a period with stronger solar activities than that for SMAP
- Instantaneous SFU vs. median values
- Orbit matters, pol (H or V) matters, soil moisture matters
- Higher soil moisture (clay), higher Sun-glint

The mystery?

- $\Delta\theta=0.4 \sim \Delta BT=80$ K vs. 0.01 m^3 m^{-3} vs 2 K
- VWC=2 Kg/m^2, tau=0.34; 1.6 K / *T* (40°) = 2.5 K
- Solar reflection filter is applied to SMAP in April, 2016?
- Azimuthal asymmetry for a two-big-leaf canopy; vegetation backscattering effect…

Thanks!

Questions?

Email: liming.he@utoronto.ca

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