Evaluation of an emissivity module to improve the simulation of L-band brightness temperature over desert regions with CMEM

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Outline

- Motivation
- Experimental setup and outlined simulations
- Results
- Conclusions

Background for investigation

- DWD runs SMA with screen level observations and aims to use microwave satellite data to improve soil moisture in the model.
- To benefit from ECMWF's development of CMEM a collaboration has been initiated between DWD and ECMWF to gain expertise in the application.
- In the framework of a 2x2 week scientific visit this investigation has been outlined: The implementation and evaluation of a desert module after Grody and Weng (2008) which has been provided in fortran code by Yudong Tian.

Motivation for the study

- Community Microwave Emission Model platform CMEM (de Rosnay et al., 2009), is used in NWP to assimilate low frequency microwave brightness temperature in L-Band as observed by the SMOS and SMAP satellite.
- Large variety of parameterizations available that account for the heterogeneous soil and surface conditions, but no specific parameterization for the emissivity of extremely dry sandy soils which dominate large desert areas, treated as bare soil so far.
- Parameterisation from Grody & Weng (2008), considers scattering at closely spaced particles derived from dense media theory which is appropriate for L-Band wavelength. ⇨

Experimental setup

Brightness temperatures Tb are simulated with CMEM for the 2013 period in offline mode on T 511 reduced Gaussian grid and compared to SMOS observations.

CMEM configuration

- Input from H-TESSEL using ERA-Interim atmospheric forcing (SM, ST, Tair, Tskin, Land cover, LAI, soil texture).
- Faraday rotation is applied to the calculated brightness temperature to account for ionospheric effects on the polarization of the signal.

Experimental setup

SMOS observations (reproc v505)

- Level1 SMOS NRT TB data interpolated at the model resolution (T511) using a bi-linear interpolation.
- Incidence angle 40°, best H-TESSEL/CMEM configuration (De Rosnay, 2015).
- 6:00 UTC ascending path are chosen to have best conditions with respect to minimal daily ionospheric perturbations and moderate vertical surface soil moisture gradients.

Experimental setup

Additional quality control

SMOS Observations

- Water fraction < 5%
- No RFI contamination (flag 1 and 4 of the NRT bufr product)

CMEM Simulations

- No snow covered / frozen ground.
- Only over bare ground and low vegetated areas.

Comparison TBxx, Tbyy, angle=40°

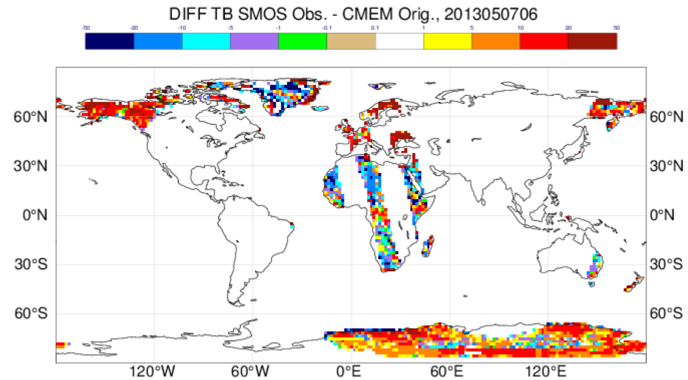
Results

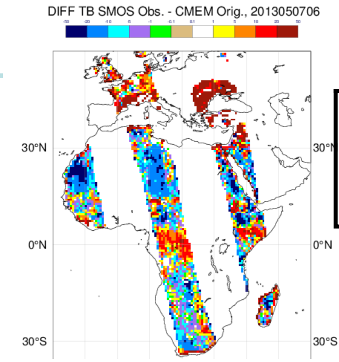
Selection of validation area
- Gridpoint validation
- Validation for Sahara domain (1°x1°)

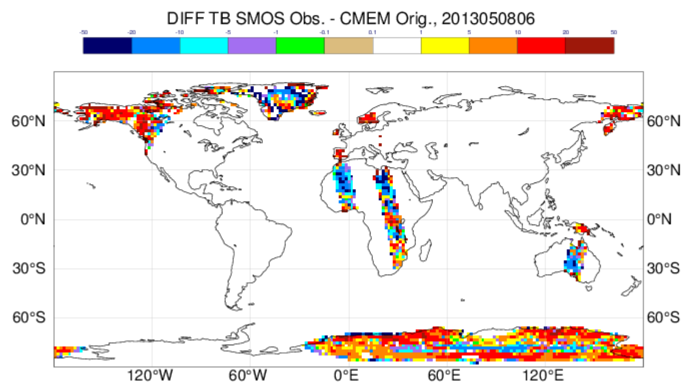
Experiments
- GW for dry conditions (swvl1<0.02), else orig. parametrisation
  - statistics for whole timeserie
  - for dry periods only
- GW for all surface conditions

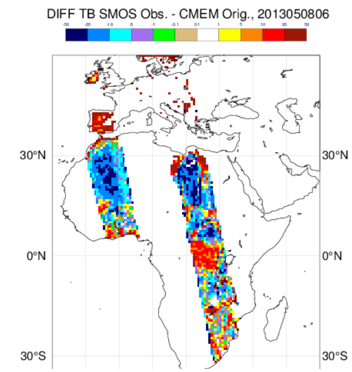
Strong warm bias in simulation for Sahara region

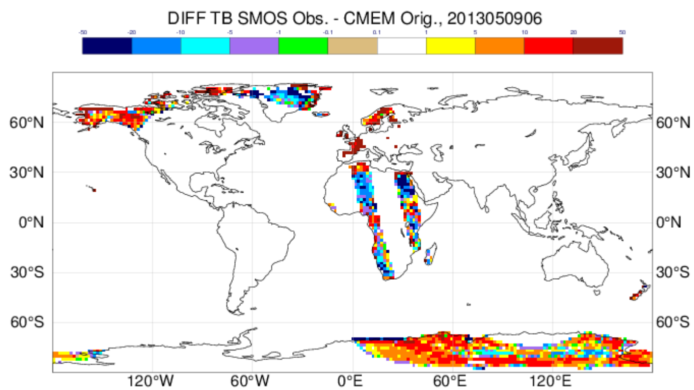
TBxx Obs – Fg,
20130807 - 20130809

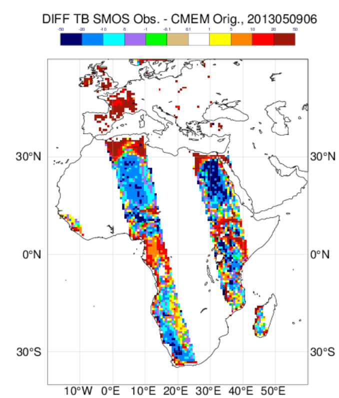




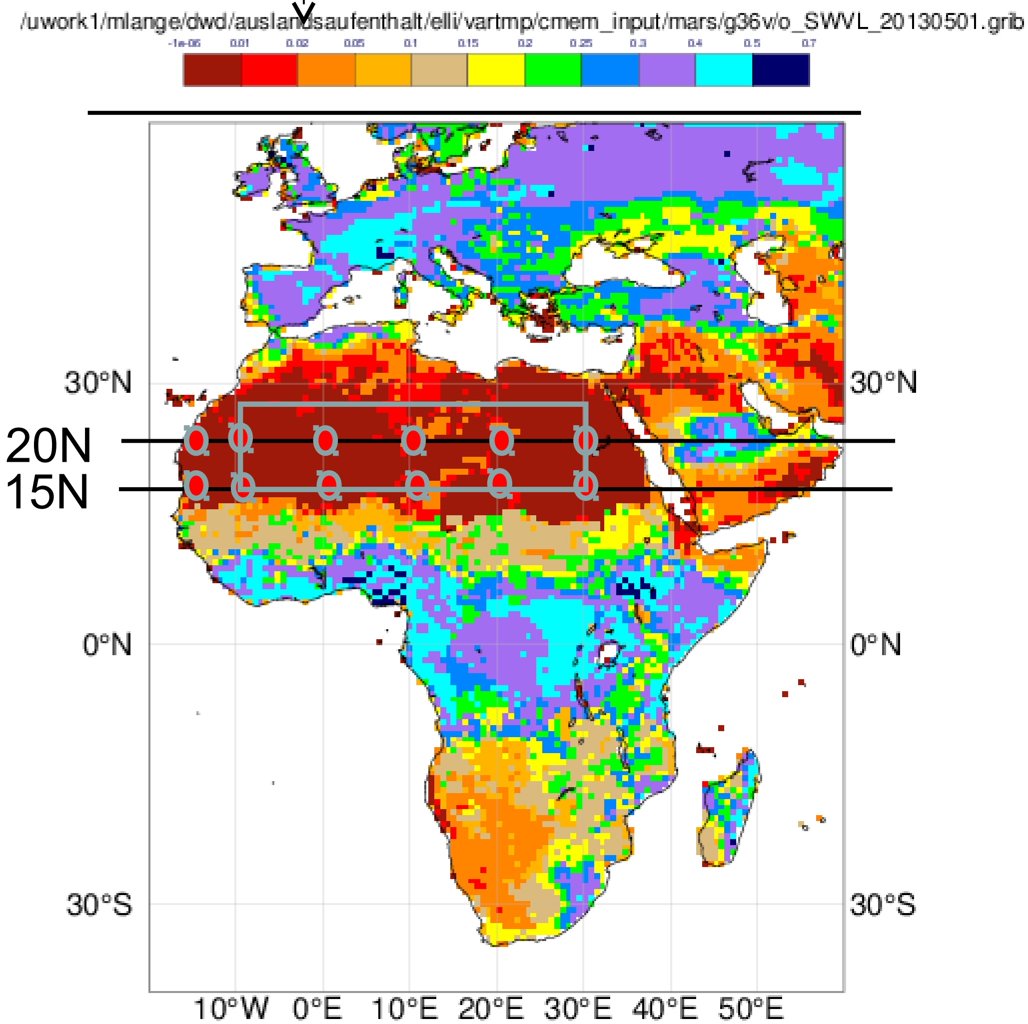


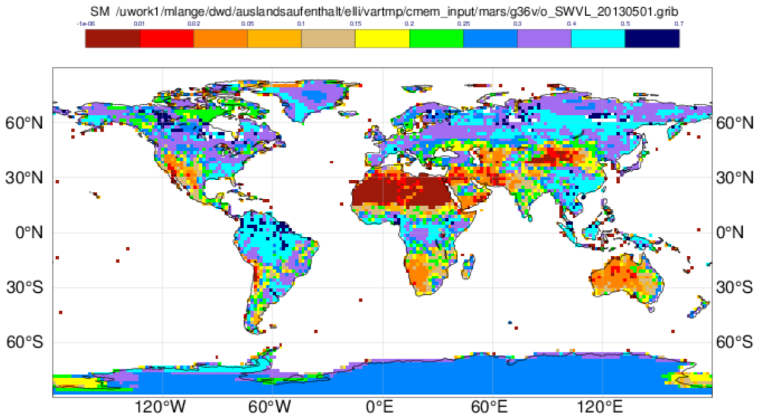






swvl1=0.02 m3/m3





Results

Gridpoint validation

Strong warm-bias for CMEM in x-pol, smaller bias in y-pol

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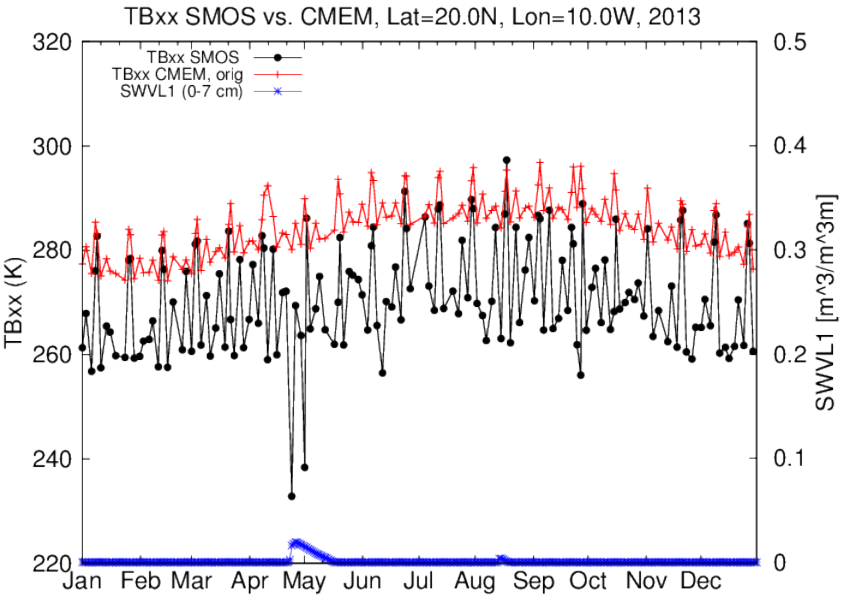
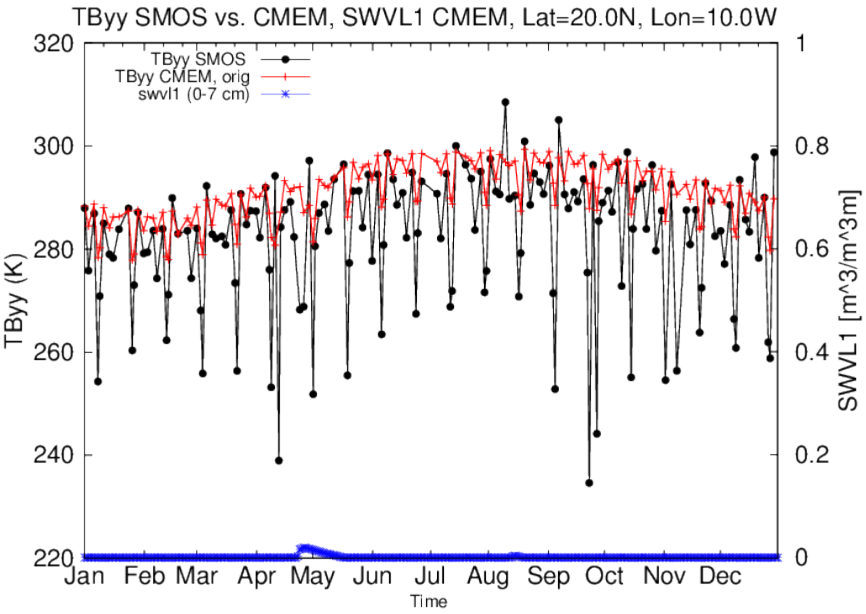
Wetter und Klima aus einer Hand

X-Pol

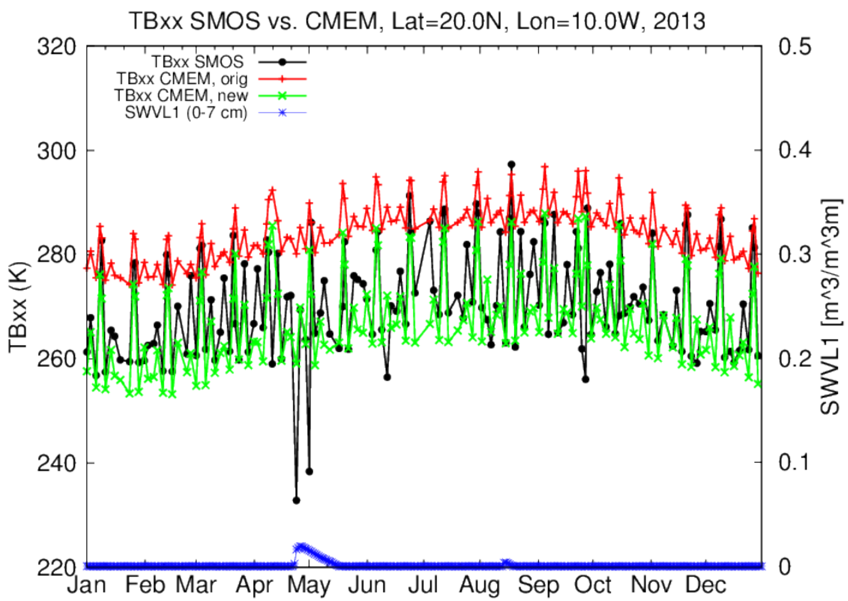


Y-Pol

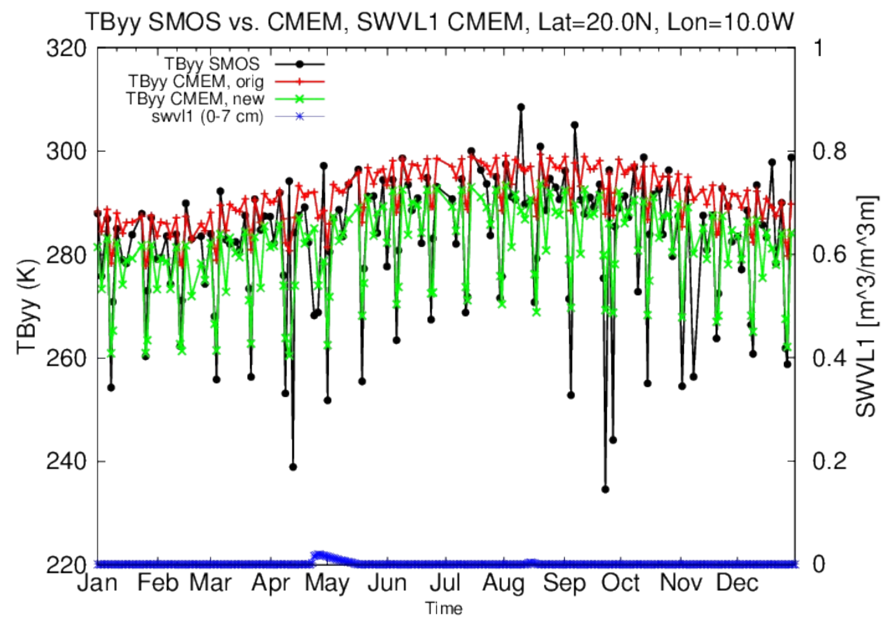


Grody & Wenig parameterisation mostly removes the bias for CMEM in both polarisations

X-Pol



Y-Pol



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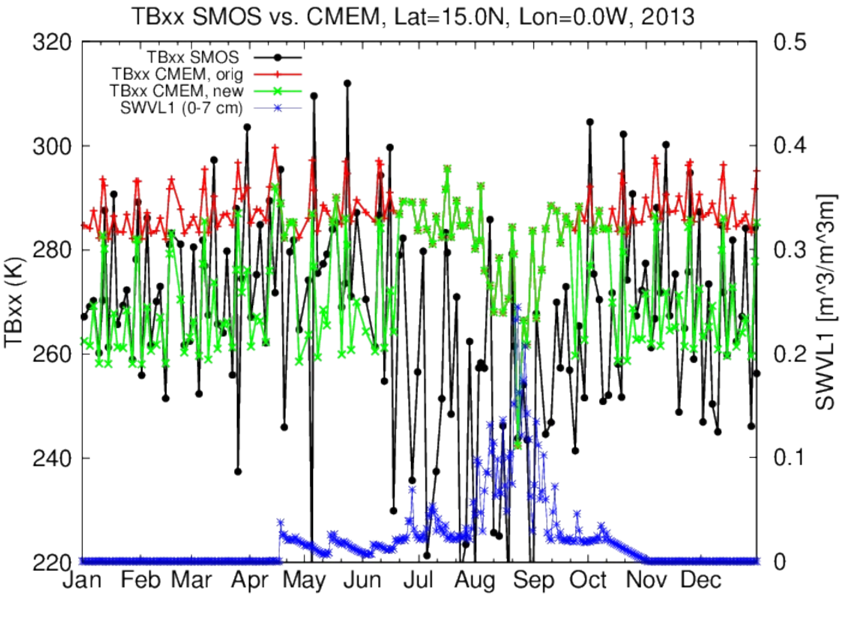
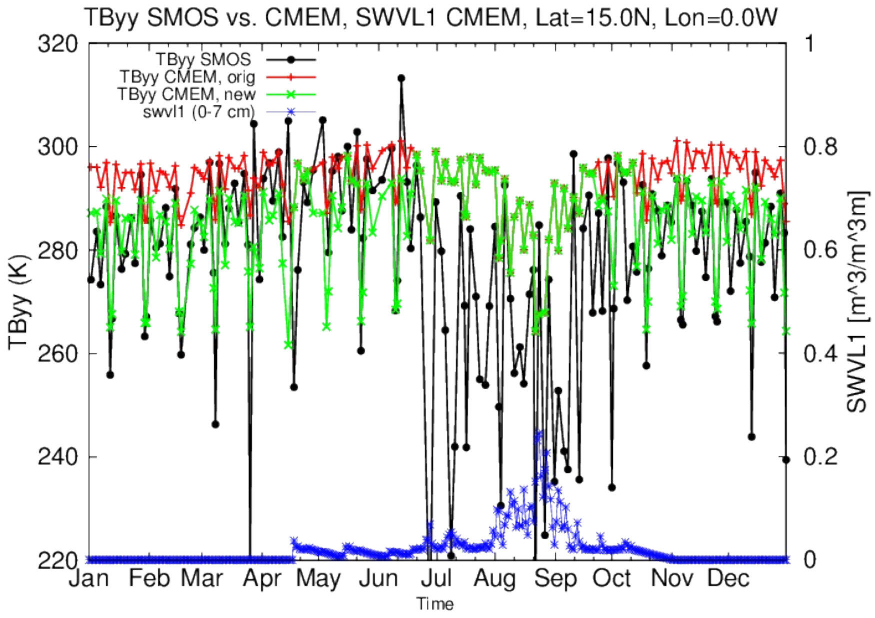


Y-Pol



Bias and Rmsd improved, Degradation in Correlation

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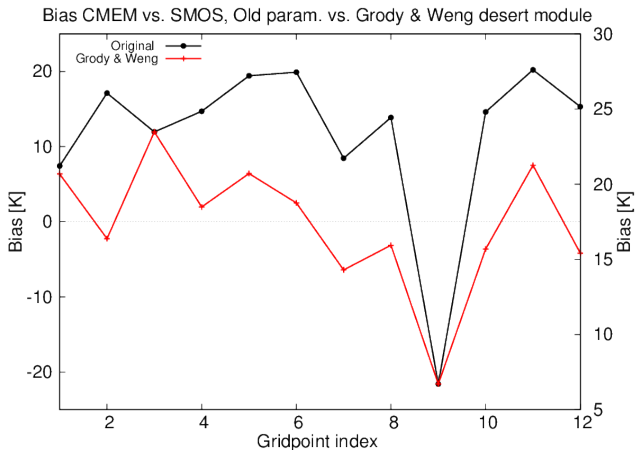
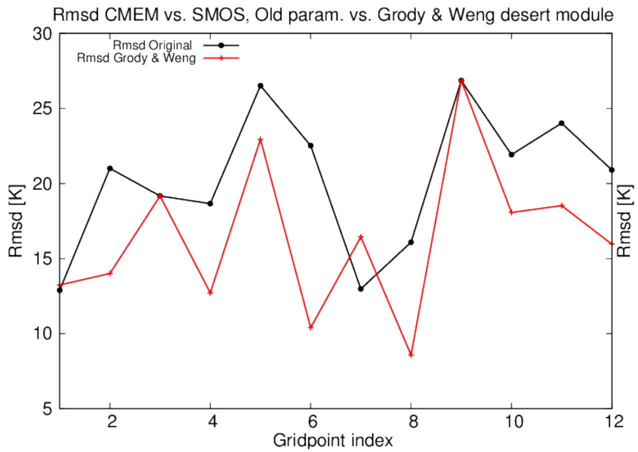
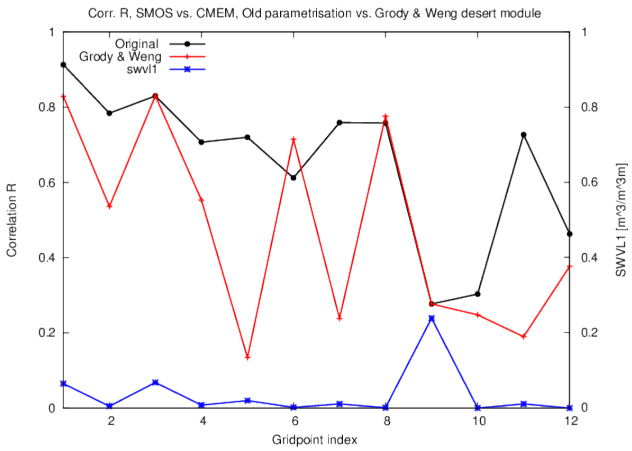
Bias



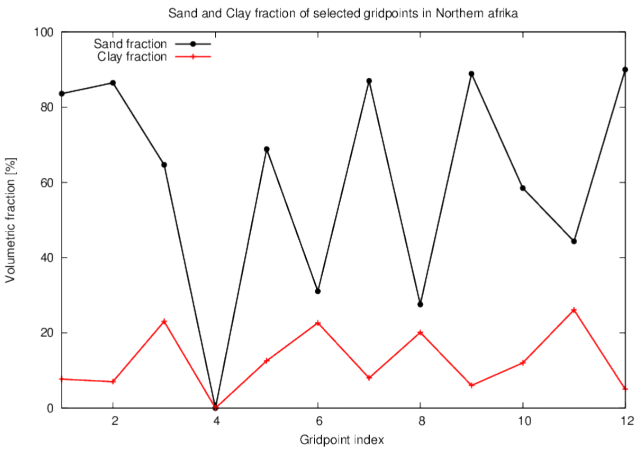
Rmsd



Correlation



Soil texture



Try to improve correlation between SMOS TB and CMEM TB for Grody & Weng

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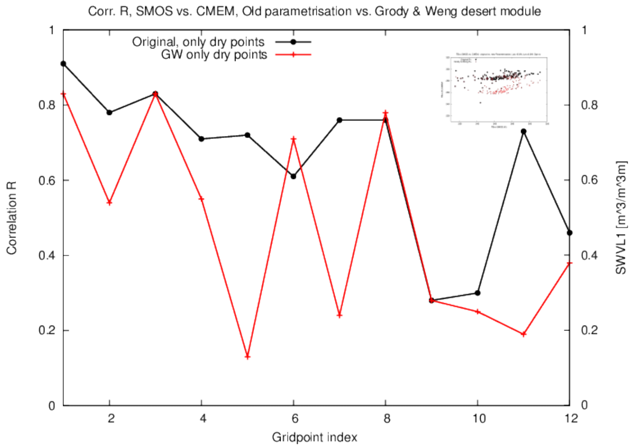
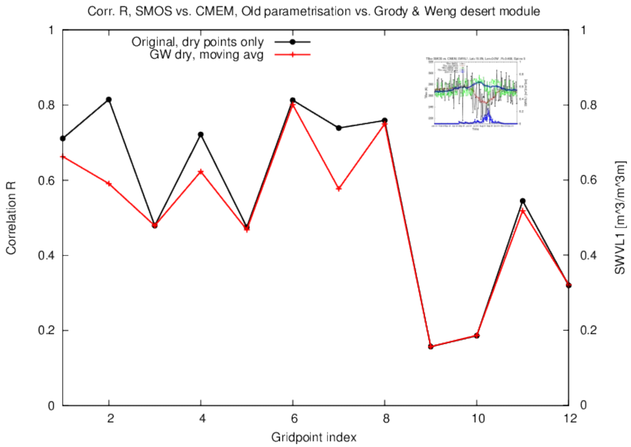
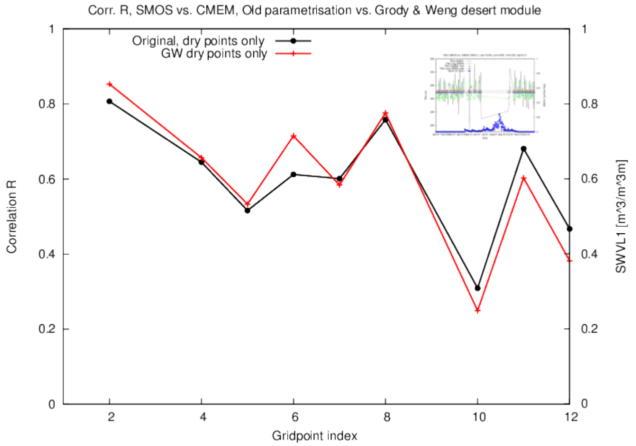
GW dry, orig elsewhere



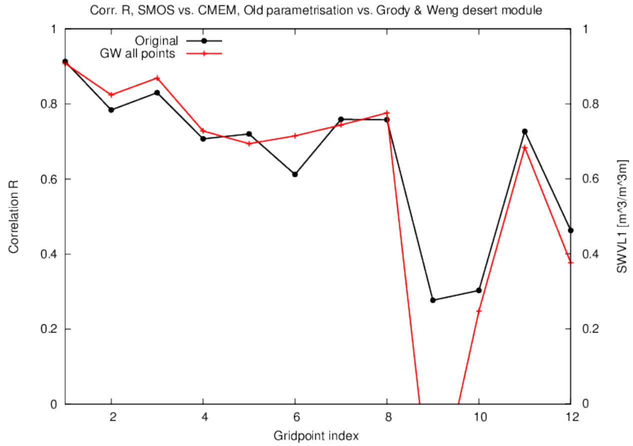
Moving average TB



Dry periods only



GW all conditions



Results

Domain validation (1°x1°)
15N-25N, 10W – 30E

GW performs comparable to Wang & Schmugge
No degradation under moist conditions

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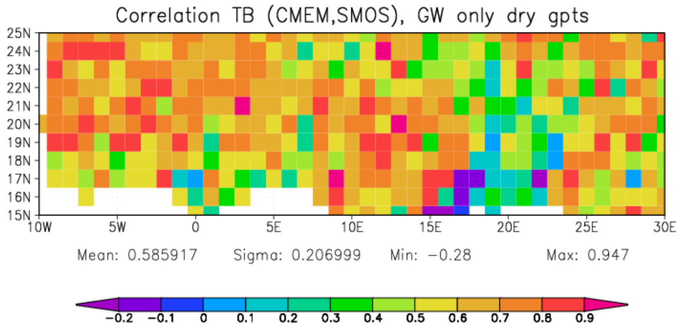
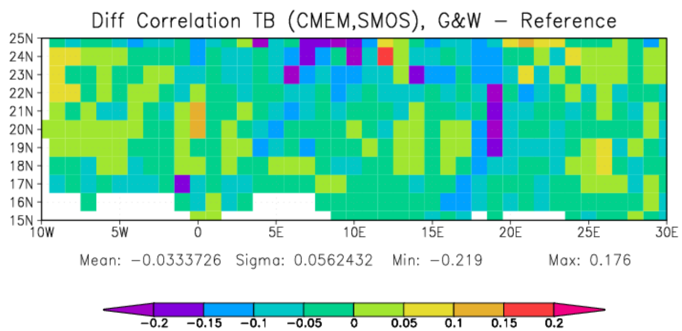
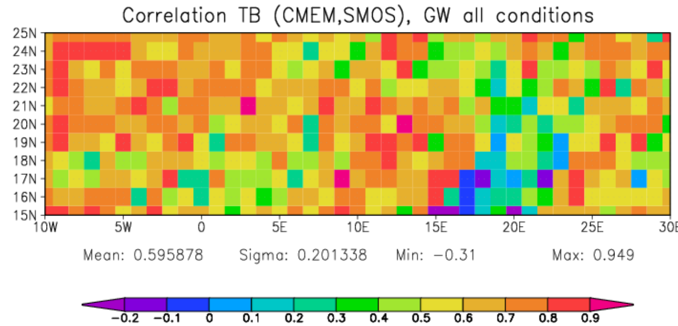
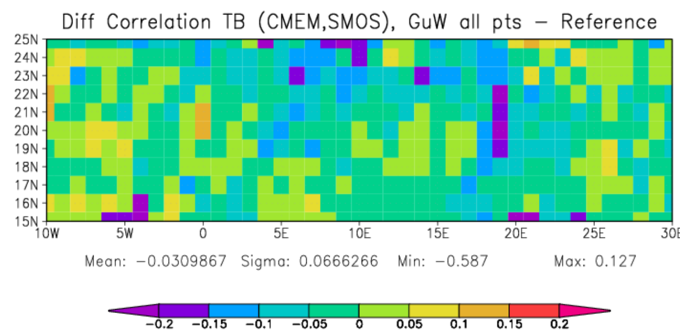
Dry periods only





GW all conditions





Combine CDF matching functions for both parameteristations

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$$Tb'_{cmem} = \overline{Tb}_{smos} + \frac{\sigma_{smos}}{\sigma_{cmem}}(Tb_{cmem} - \overline{Tb}_{cmem})$$

Modify Tb(cmem) to match avg and variance of Tb(smos)

$$Tb'_{cmem} = A + BTb_{cmem}$$

$$A = \overline{Tb}_{smos} - \frac{\sigma_{smos}}{\sigma_{cmem}}\overline{Tb}_{cmem} \qquad B = \frac{\sigma_{smos}}{\sigma_{cmem}}$$

calc. CDF matching coefficients for each parameterisation

$$Tb^*_{cmem} = w_1 Tb'_{cmem}(GW) + w_2 Tb'_{cmem}(old)$$

Combine Tb'(cmem) for both parameterisations for different soil conditions.

dry parameterisation

$$w_1 = \begin{cases} 1 : swv_1 < swv_{dry} \\ \dfrac{swv_1 - swv_{dry}}{swv_{wet} - swv_{dry}} : swv_{dry} \le swv_1 \le swv_{wet} \\ 0 : swv_1 > swv_{wet} \end{cases}$$

moist parameterisation

$$w_2 = 1 - w_1 = \begin{cases} 0 : swv_1 < swv_{dry} \\ \dfrac{swv_1 - swv_{dry}}{swv_{wet} - swv_{dry}} : swv_{dry} \le swv_1 \le swv_{wet} \\ 1 : swv_1 > swv_{wet} \end{cases}$$

Summary and Outlook

- The microwave emissivity module for desert regions after Grody & Weng (2007) has been evaluated for the 2013 period with CMEM.

- The strong warm bias is mostly removed and rmsd is strongly improved.

- Positive impact for correlation compared to the Wang & Schmugge dielectric mixing model is obtained only when data from new parametrisation are seperated, no mixing.

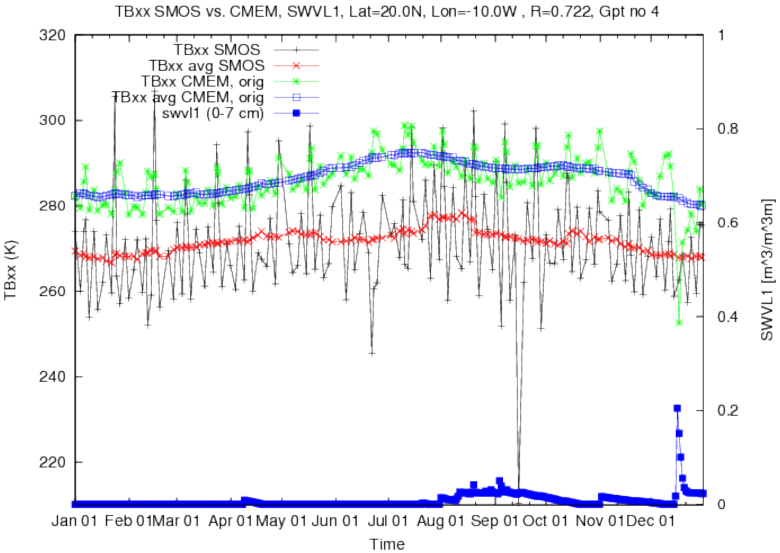
- GW parametrisation shows partly good performance even under non-dry conditions.

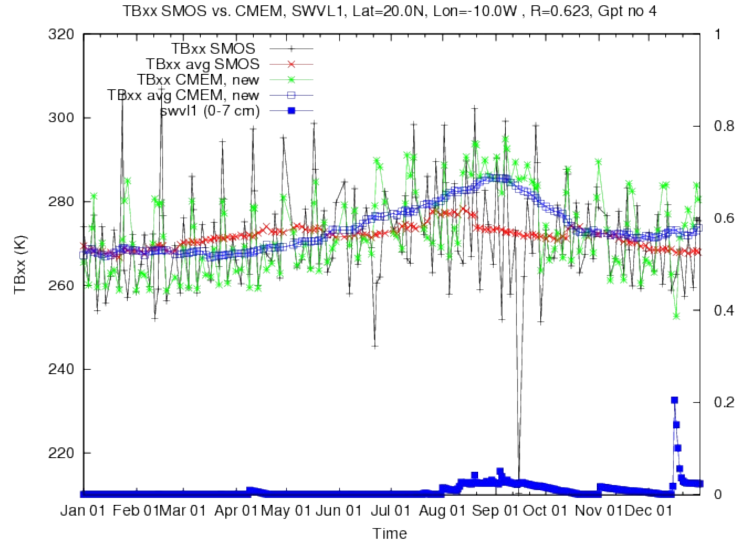
- To make use of the parameterisation for assimilation of SMOS data under dry and wet conditions the combination with the old parameterisation using CDF matching will be further investigated.

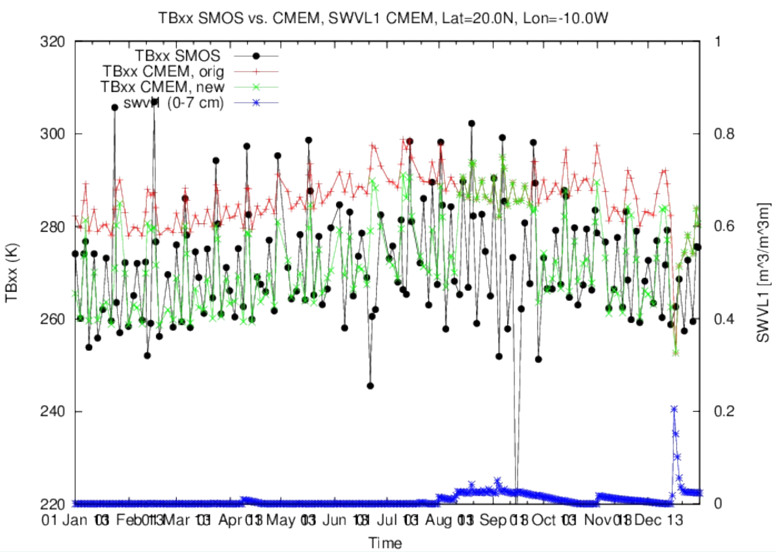
Open question

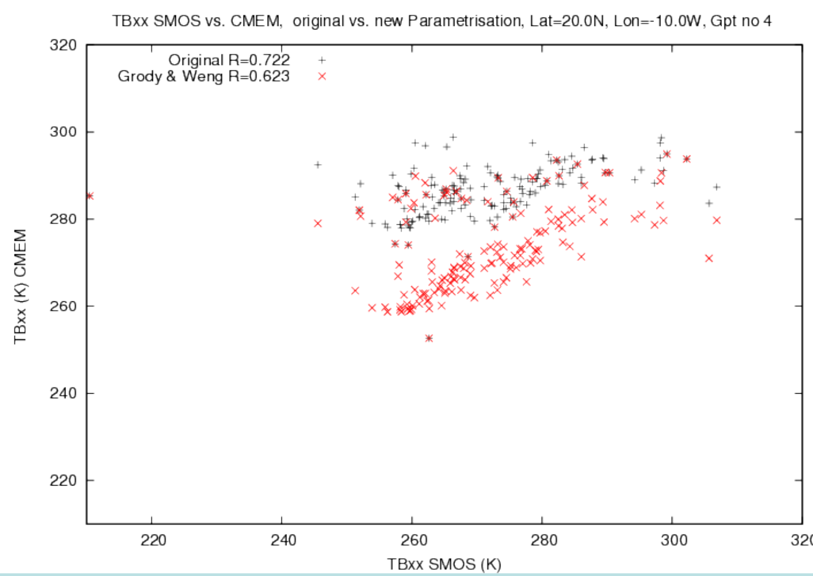
Analyses with respect to soil texture didn‘t reveal clear relation between sand fraction and correlation. So classification with respect to existing soil databases used in NWP is not appropriate to characterize dielectric properties.
Is there any initiative to generate emissivity maps for L-band frequencies? Should we set some focus on this?

Grody & Weng parameterisation mostly removes the bias for CMEM in both polarisations









Switch between parameterisations leads to double penalty for correlation

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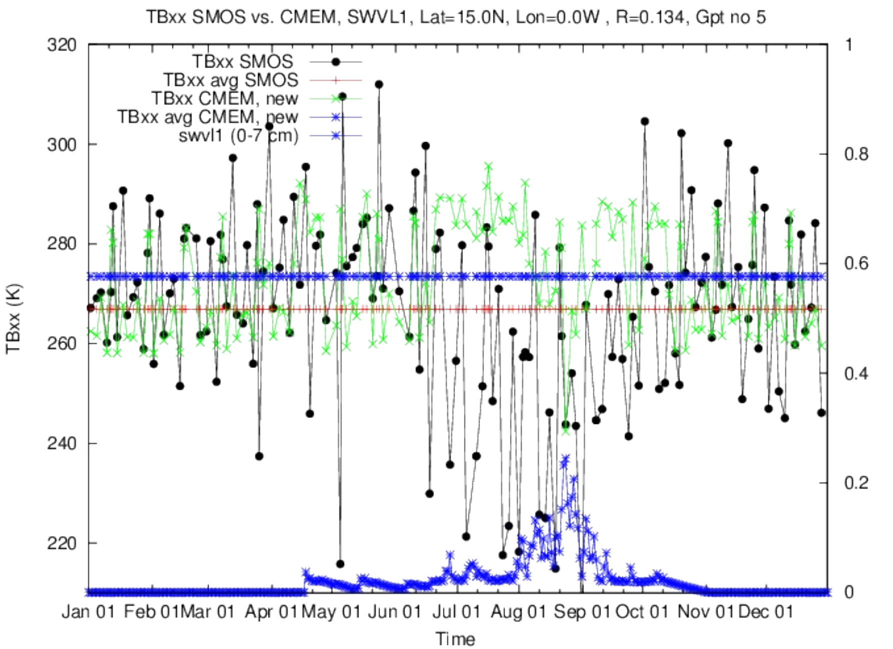
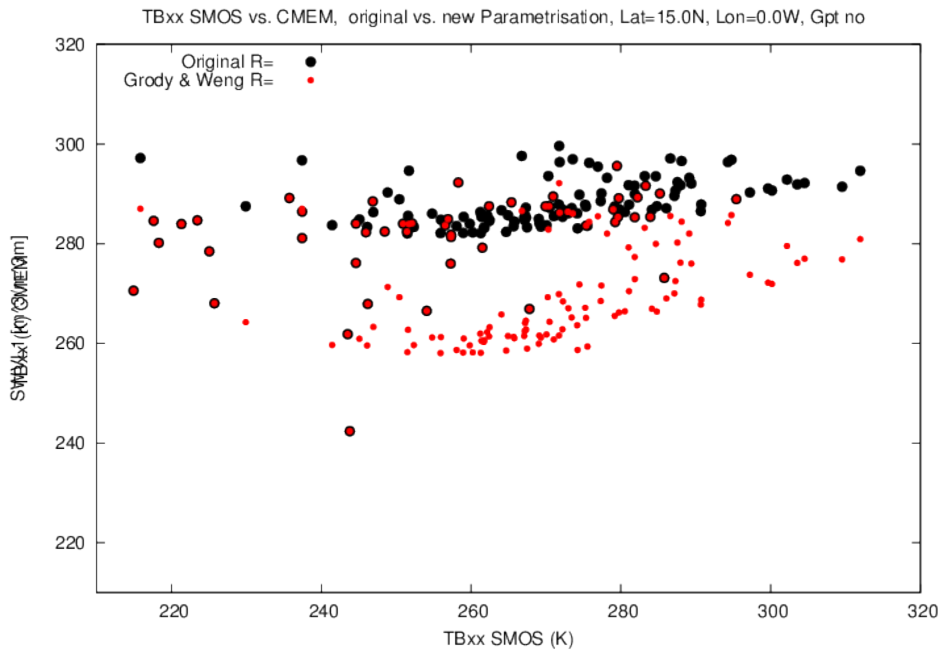
GW dry, orig moist vs SMOS



TB CMEM / SMOS



Moving average TB partly removes offset

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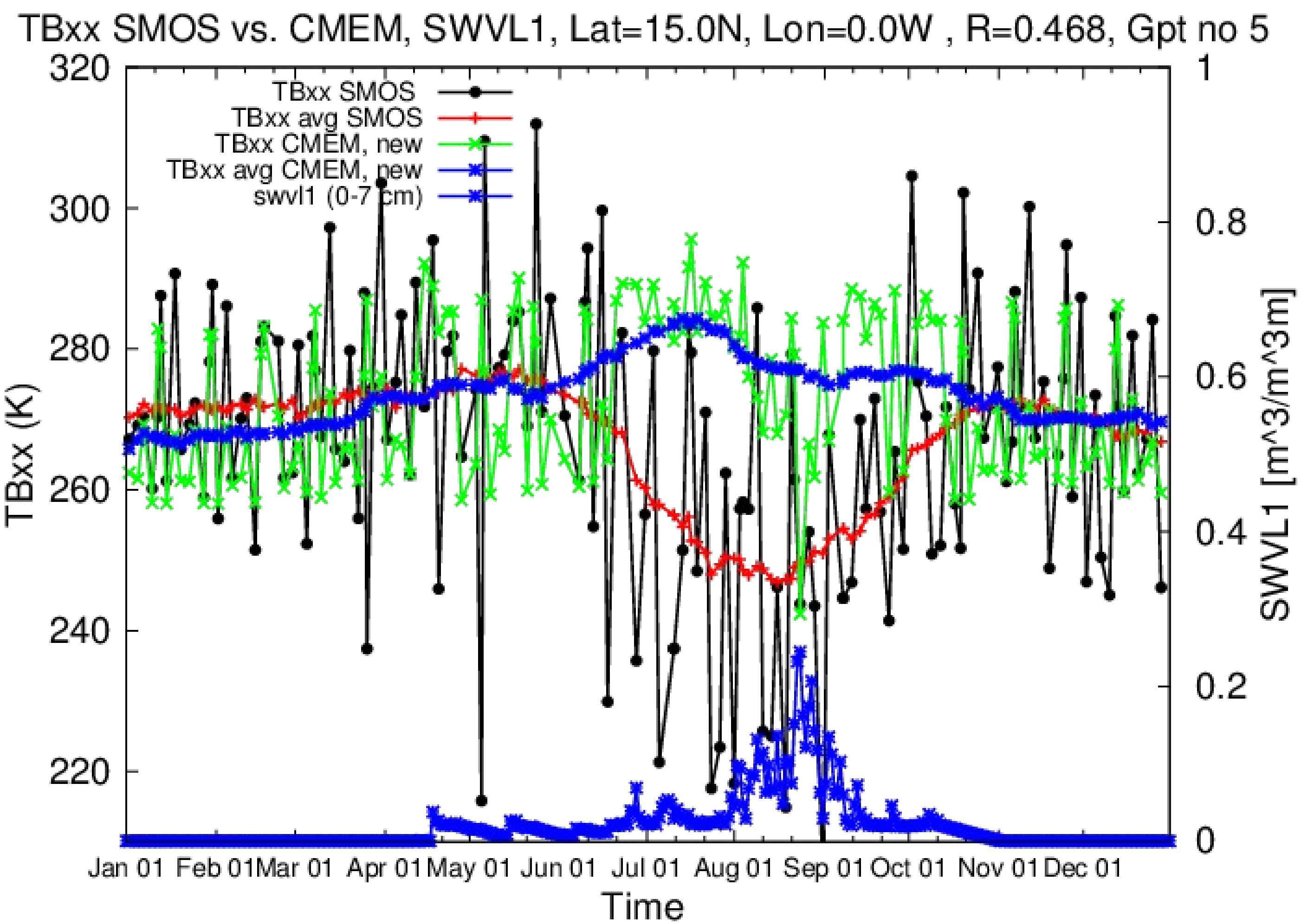
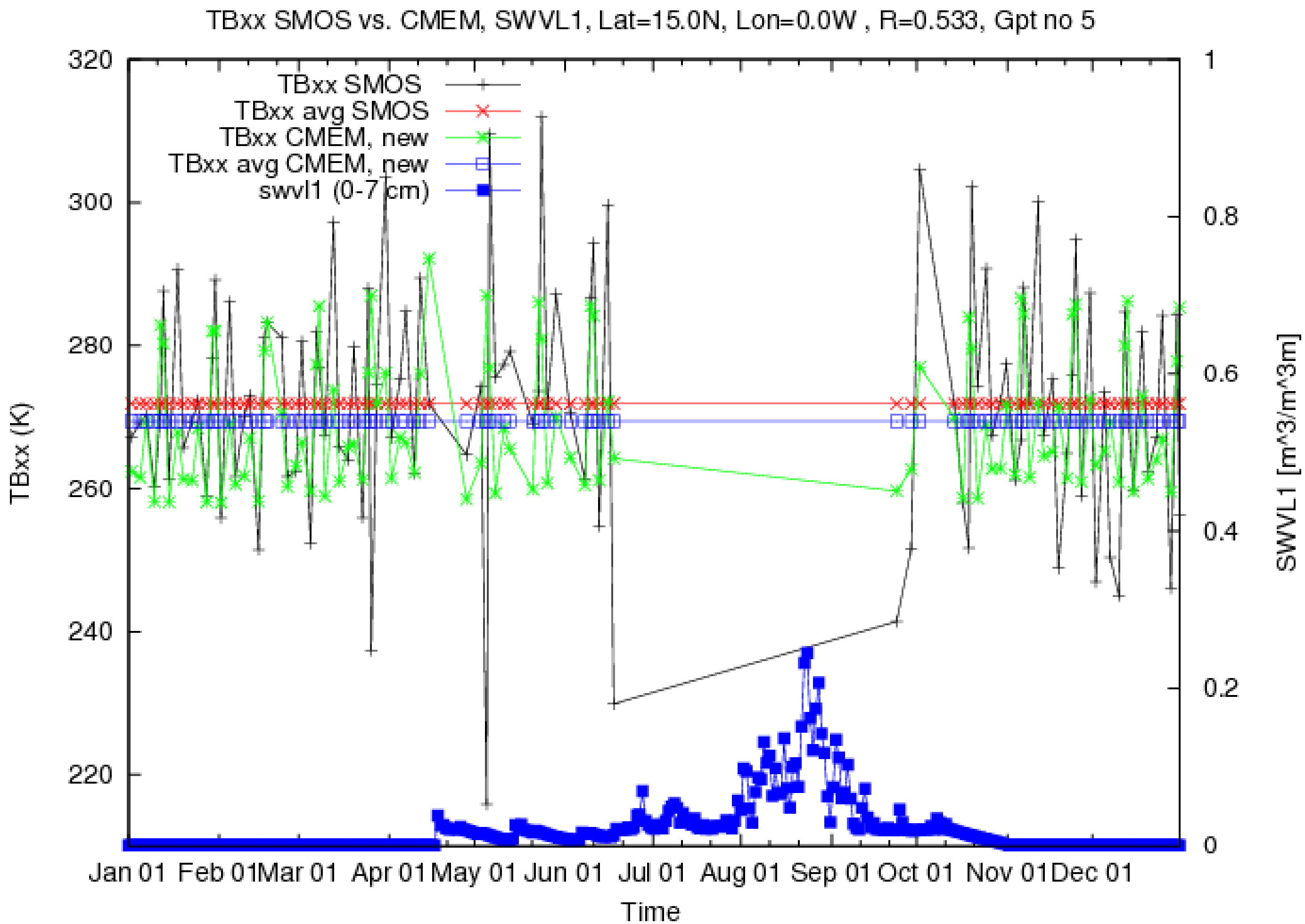


Dry conditions only



2d var (z,t) soil moisture analysis

- Motivation for SMA. Forecast errors in precip can lead to long term trend in soil moisture and biases in screen level temperature and precipitation.
- Kalman filter cycled 2D Var scheme which minimises screen level fc errors in conjunction with deviations from bg soil moisture state.

$$J = (w - w_b)^T B^{-1} (w - w_b) + (T_{2m} - T_{2m}^{obs})^T O^{-1} (T_{2m} - T_{2m}^{obs})$$

$$\nabla J = 0$$

No observation of soil water content!

Analysis depends on T2m forecast error and sensitivity ∂T2m/∂w

$$w_{ana} = w_b + (\Gamma_{T2m}^T O^{-1} \Gamma_{T2m} + B^{-1})^{-1} \Gamma_{T2m}^T O^{-1} \underbrace{(T_{2m}^{obs} - T_{2m}(w_b))}_{T2m\ fc\ error}$$

$$\Gamma_{T2m} = \frac{\partial T_{2m}(12:00, 15:00)}{\partial w(0:00)}$$

Brightness temperature observed by earth viewing radiometer

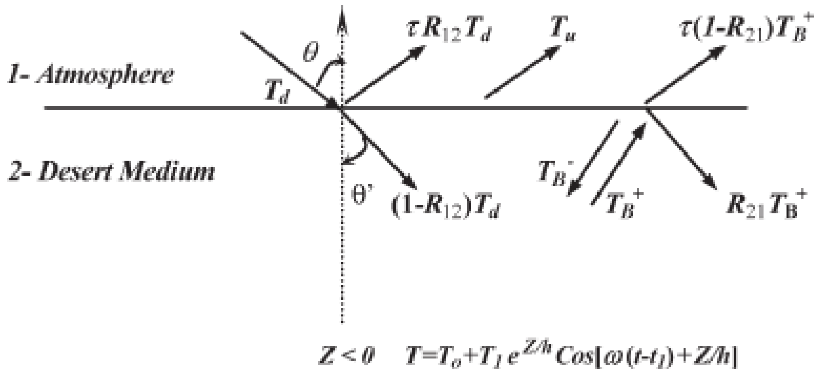


Fig. 3. Schematic representation of desert surfaces. Medium 1 consists of the upward T_u and downward T_d atmospheric radiation, the downward-reflected radiation $R_{12}T_d$, and the radiation transmitted from medium 2 across the interface $(1-R_{21})T_B^+$. Medium 2 consists of the upward T_B^+ and downward T_B^- radiation, the upward-reflected radiation $R_{21}T_B^+$, and the radiation transmitted from medium 1 across the interface $(1-R_{12})T_d$.

$$T_B(\nu,t) = T_u(\nu) + \tau_\nu \left[\varepsilon_S(\nu)T_{\text{eff}}(\nu,t) + \{1-\varepsilon_S(\nu)\}\, T_d(\nu)\right] \qquad (1)$$

$$\varepsilon_S(\nu) = (1-R_S)\left[\frac{2a}{(1+a)-(1-a)R_S}\right] \qquad a = \sqrt{\frac{1-\omega}{1-\omega g}}.$$

Adopted from Grody and Weng, 2008*

* IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 46, NO. 2, FEBRUARY 2008

Two way cooperation

Bias and Rmsd improved, Degredation in Correlation

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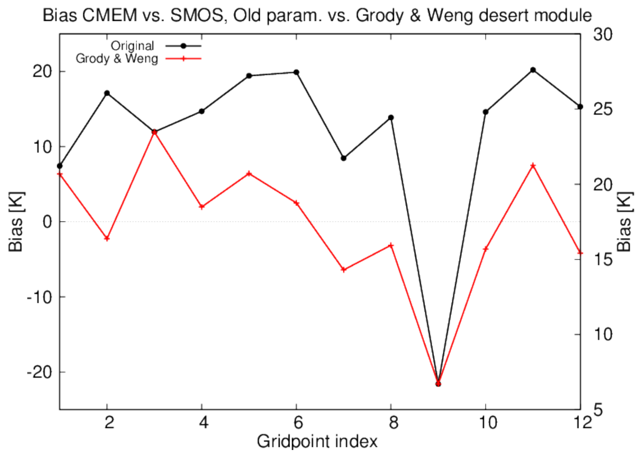
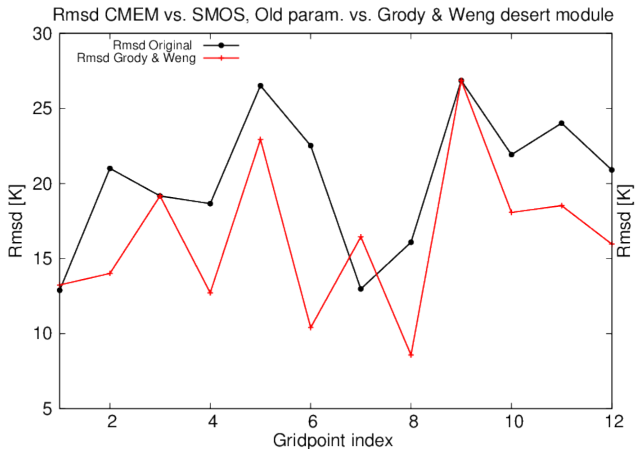
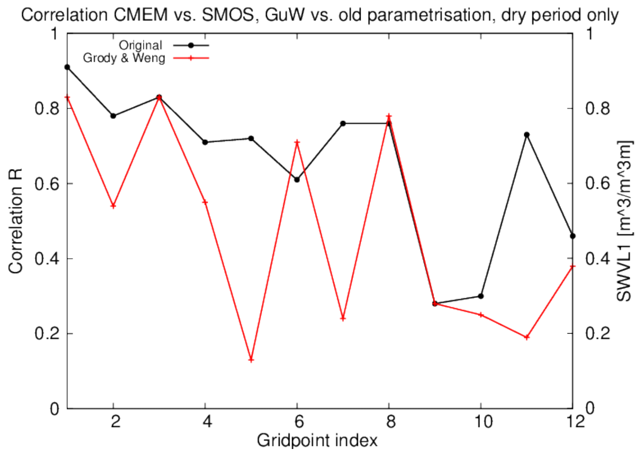
Bias



Rmsd



Correlation

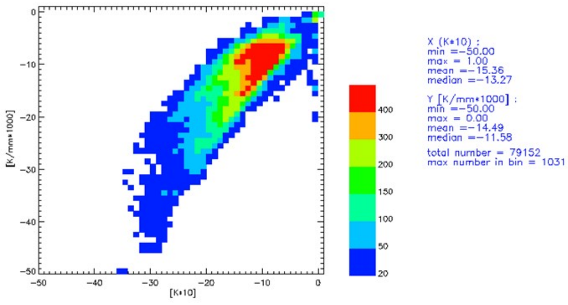


Parameterisation for Sensitivity dT2m/dw

Senstivity as derived from Surface energy balance and Penman type equation

$$\frac{\partial T_{2m}}{\partial w_k} = \frac{\overline{r_a}}{\rho c_p}\left(\frac{\alpha}{1-\alpha}\right)\frac{Lhfl}{(r_a + r_f)}\frac{1}{f_{LAI}}\left(1-\frac{r_s}{r_{s,\max}}\right)\frac{r_s}{w_{root} - w_{pwp}}\frac{dz_{k,root}}{z_{root}}$$

dT2m/dw
Param / explicit variation



No further need for additional model runs!

Combine CDF matching functions for both parameteristations

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Modify Tb(cmem) to match avg and variance of Tb(smos)

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calc. CDF matching coefficients for each parameterisation

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Combine Tb*(cmem) for both parameterisations for different soil conditions.

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moist parameterisation

$$w_2 = 1 - w_1 = \begin{cases} 0 : swv_1 < swv_{dry} \\ \dfrac{swv_1 - swv_{dry}}{swv_{wet} - swv_{dry}} : swv_{dry} \le swv_1 \le swv_{wet} \\ 1 : swv_1 > swv_{wet} \end{cases}$$