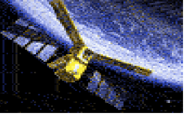


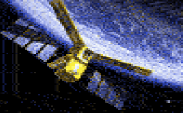
Soil Moisture Remote Sensing for Numerical Weather Prediction: L-band and C-band Emission Modeling over Land Surfaces

The Community Microwave Emission Model (CMEM)

P. de Rosnay[1], M. Drusch[1], J.-P. Wigneron[2], T. Holmes[3], G. Balsamo[1], A. Boone[4], C. Rudiger[4], J.-C. Calvet[4], Y. Kerr[5]

1 - ECMWF
2 - INRA/EPHYSE
3 - Vrije Univ. Amsterdam
4 - Météo-France
5 - CESBIO

ECMWF

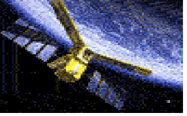


I. CMEM forward operator of surface microwave emission

II. L-band background errors over the SMOSREX site (local scale)

III. AMMA Land Surface Models and Microwave Models inter-comparison and validation with AMSR-E C-band data (regional scale)

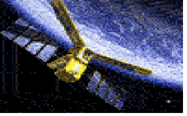
IV. Conclusion



CMEM: Community Microwave Emission Model

- Land surface emission model developed at ECMWF
- Forward operator for computing TOA Brightness Temperature in the operational data assimilation scheme (AMSR-E, SMOS, SMAP …)
- Physical parameterizations based on:
  - LMEB (L-Band Emission of the Biosphere), Wigneron et al., 2007,
  - LSMEM (Land Surface Microwave Emission Model), Drusch et al., 2001
- Modular code: combines different parameterizations for computing surface and atmospheric emissions
- Specifically designed for L-band microwave emission for SMOS
- Also applicable for a large range of Freq: 1 GHz to 20 GHz (to be interfaced with RTTOV-9 by the end of 2008)

(Holmes et al., 2008, Drusch et al., 2008, de Rosnay et al., 2008)



CMEM: flexible portable software

CMEM is coded in Fortran90. It is flexible for:

- **Input / Output file format:**

  Grib, Ascii, Netcdf

- **Input / output file size and variable dimensions**

  Automatic detection of input size and variable allocations.

- **Portable code, for any Linux and Unix systems**

  Requirements: Grib and Netcdf both compiled with fortran 90

  NWP model routines and libraries are externalized (on going)

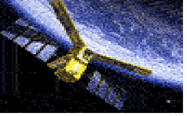
CMEM code: 8300 lines of Fortran (43 subroutines)

Last tagged version of CMEM version 1.3, April 2008

- **CMEM convergence with LMEB ensured at the tile scale**

CMEM Web:

http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html



CMEM: Modular Model

Allows accounting for different parameterizations for each component:

- **Soil dielectric mixing model**

  (Wang & Schmugge / Dobson / Mironov)

- **Effective temperature model**

  (Choudhurry / Wigneron / Holmes)

- **Soil roughness model**

  (None = Smooth / Choudhurry / Wegmuller / Wigneron 01/07)

- **Smooth surface emissivity model**

  (Fresnel / Wilheit)

SOIL

- **Vegetation opacity model**

  (None / Kirdyashev / Wegmuller / Wigneron / Jackson)

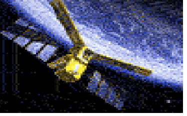
VEGETATION

- **Atmospheric radiative transfer model**

  (None / Pellarin / Liebe / Ulaby)

ATMOSPHERE

In red: options used in LMEB / ESA L2 retrieval algorithm



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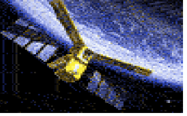


SMOSREX

(Surface Monitoring of Soil Reservoir Experiment)

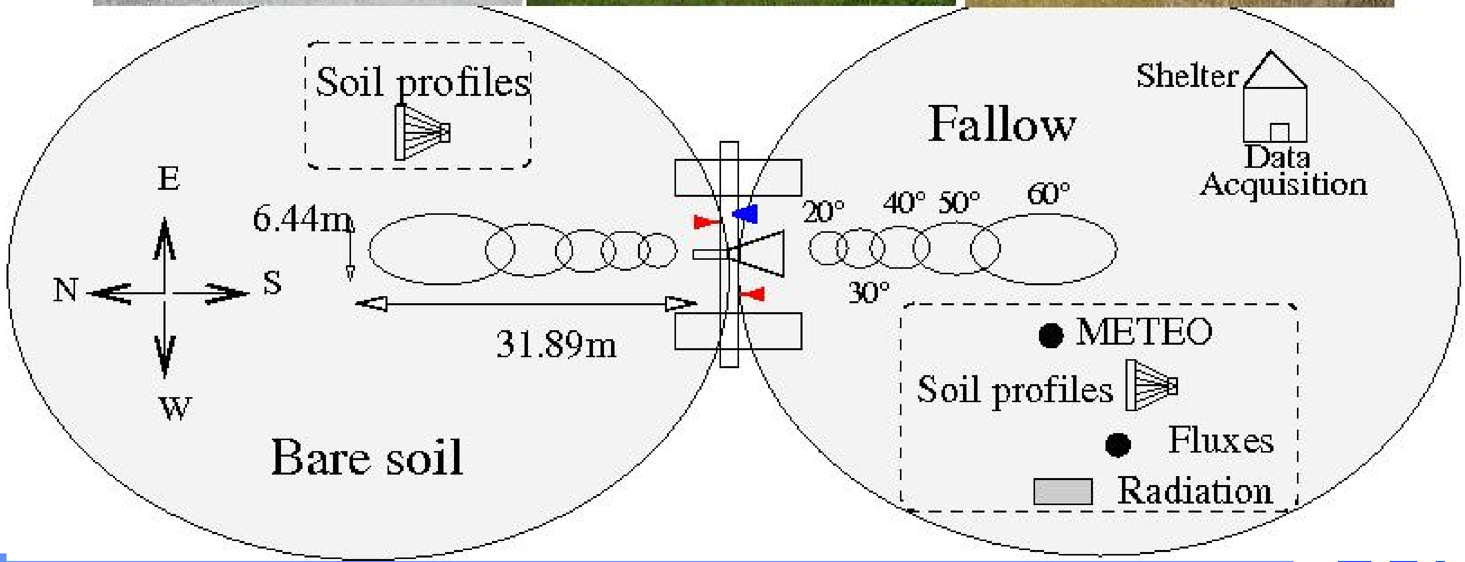
SMOSREX:

Multi–frequency acquisition

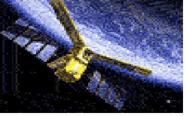
- TIR Pyrometers (KT15): at 40° incidence
- VIS to IR Luminancemeters (Cimel) 5–band: 837(91), 648(53), 549(85), 450(40), 1640(165) nm
- LEWIS: L–band (1.4 GHz) L–band radiometer for Estimating Water In Soils

(de Rosnay et al., 2006)

Multi-angular L-band data 2003-2008



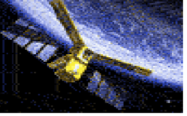
ECMWF



Background errors on simulated TB on SMOSREX pixel

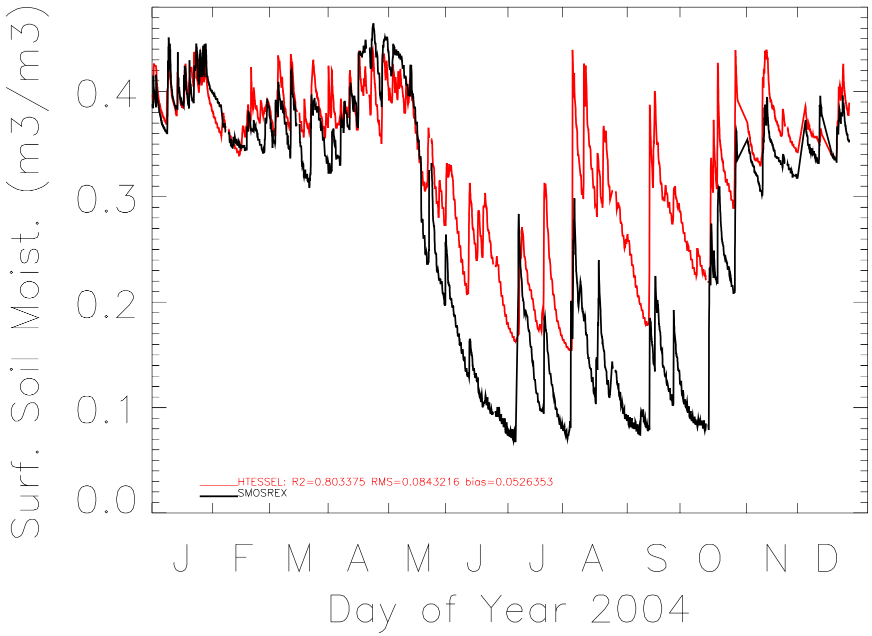
- Operational ECMWF: HTESSEL (ECMWF Land Surface Model) forced by forecast (for 2004 at T799 ~ 25km)
- Coupled to CMEM L-band forward operator on the SMOSREX Pixel
- First guess background error for future operational SMOS assimilation
- Different configurations:
  - **9 CMEM configurations** of soil dielectric and vegetation opacity models
  - **5 incidence angles (20° to 60°)**
- **-> set of 45 1-year experiments** to compare Bg and observed L-band TB on SMOSREX pixel, at two polarizations
- Temporal collocation of first guess TB and Lewis data

ECMWF



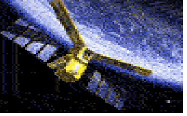
Simulated and observed soil moisture

HTESSEL: R2 = 80.3% ; RMSE = 8.0%



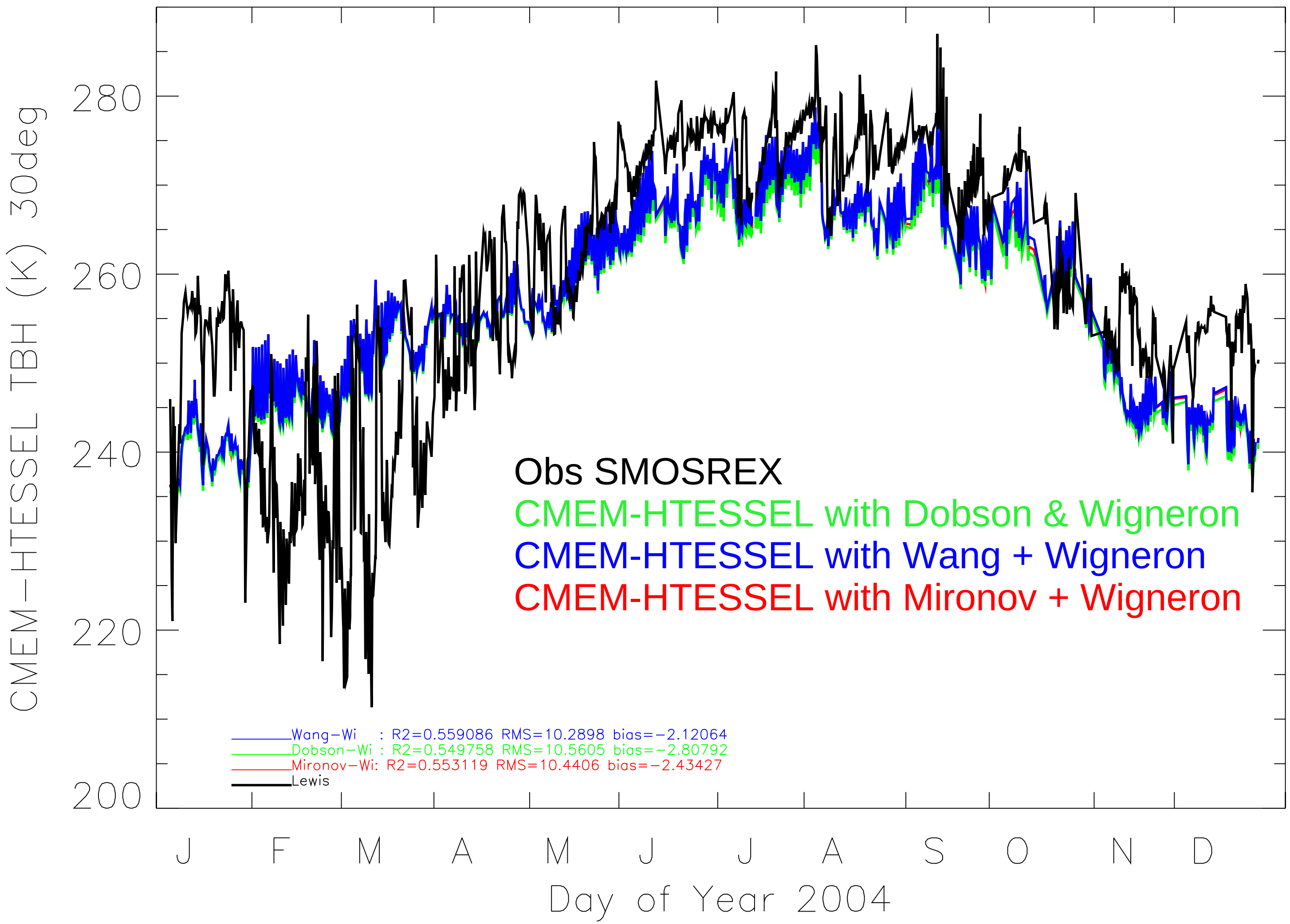
HTESSEL operational (25km)

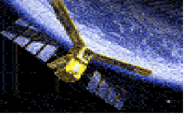
Observations (local)



Best observing and modelling configuration for TBH

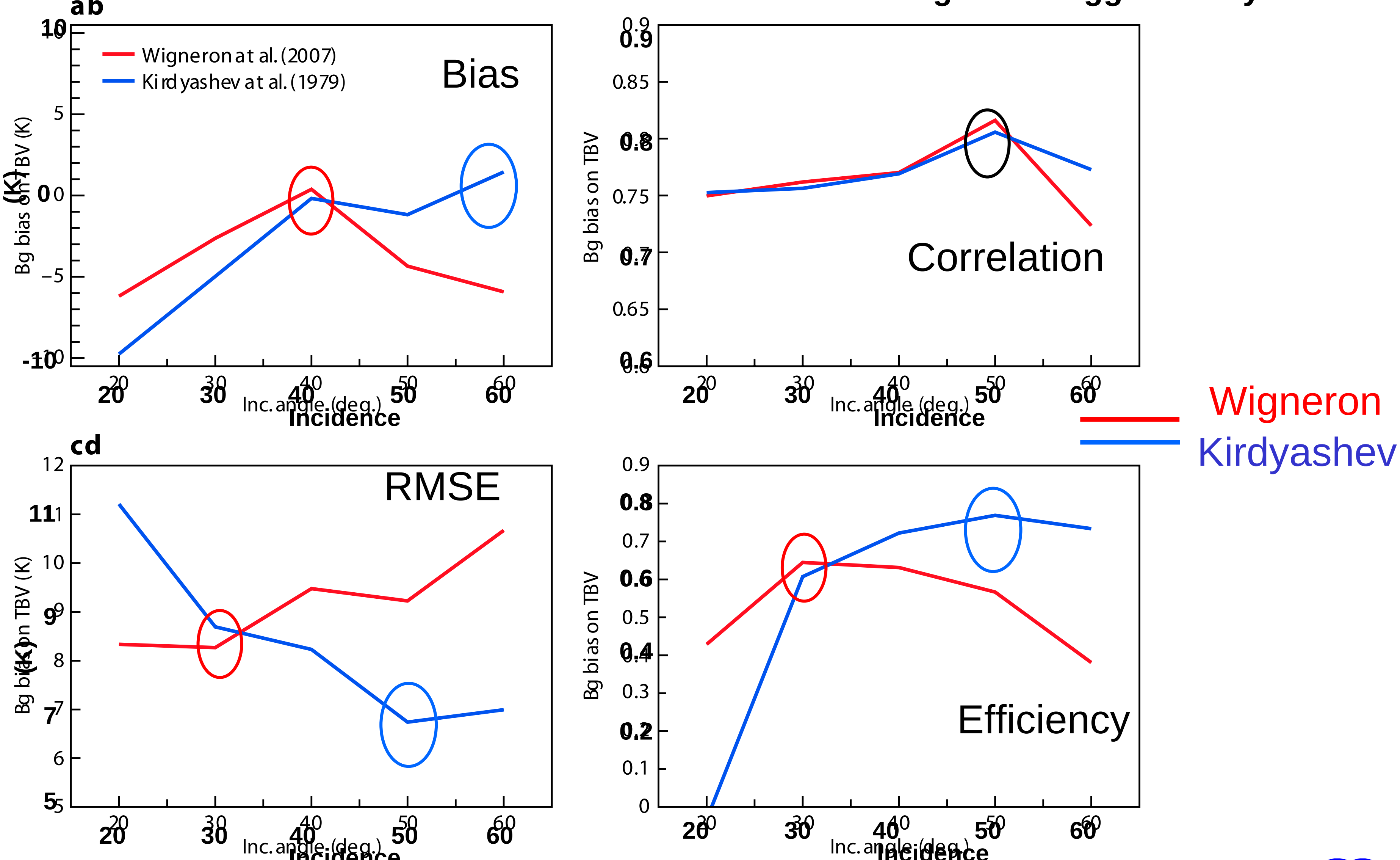
Incidence 30° with Wang&Schmugge dielectric model and Wigneron optical depth model



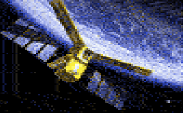


Angular dependency of Background error on CMEM TBv

Best observing/modelling configurations: 30 ° Wang&Schmugge + Wigneron
50 ° Wang&Schmugge + Kirdyashev



ECMWF



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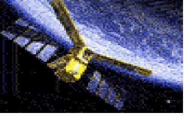


ALMIP-MEM

AMMA Land Surface Model Intercomparison Project – Microwave Emission Model

Context: SMOS / AMMA (African Monsoon Multidisciplinary Analysis)

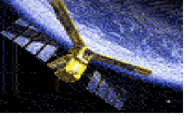
ALMIP (**AMMA Land Surface Model Intercomparison Project**, **Boone & de Rosnay, 2007**)

Concept:

- Combined **8 LSMs and 12 microwave models** inter-comparison
- Coupling **ALMIP** simulations to the Community Microwave Emission Model (**CMEM**)
- Simulation of C-Band Brightness Temperature (TB) for 2006 over West Africa
- Evaluation against AMSR-E (C-band)

Aim:

- Sensitivity of simulated TB to the precipitation forcing
- Scatter C-band TB simulated by a set of LSMs/microwave models at regional scale
- Evaluation of surface soil moisture simulated by LSMs
- Test and validation of different microwave modelling approaches
- **Relative sensitivity of simulated TB to LSMs and Microwave models**



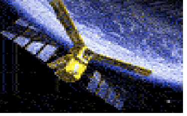
ALMIP-MEM simulations:

- **8 LSMs** (HTESSEL, CTESSEL, TESSEL, JULES, ISBA-FR, ISBA-DF, NOAH, ORCHIDEE)
- **12 Microwave models:**

Vegetation/Dielectric	**Dobson**	**Mironov**	**Wang&Schmugge**
Jackson&O'Neill	**1**	**5**	**9**
Kirdyashev	**2**	**6**	**10**
Wegmueller	**3**	**7**	**11**
Wigneron	**4**	**8**	**12**

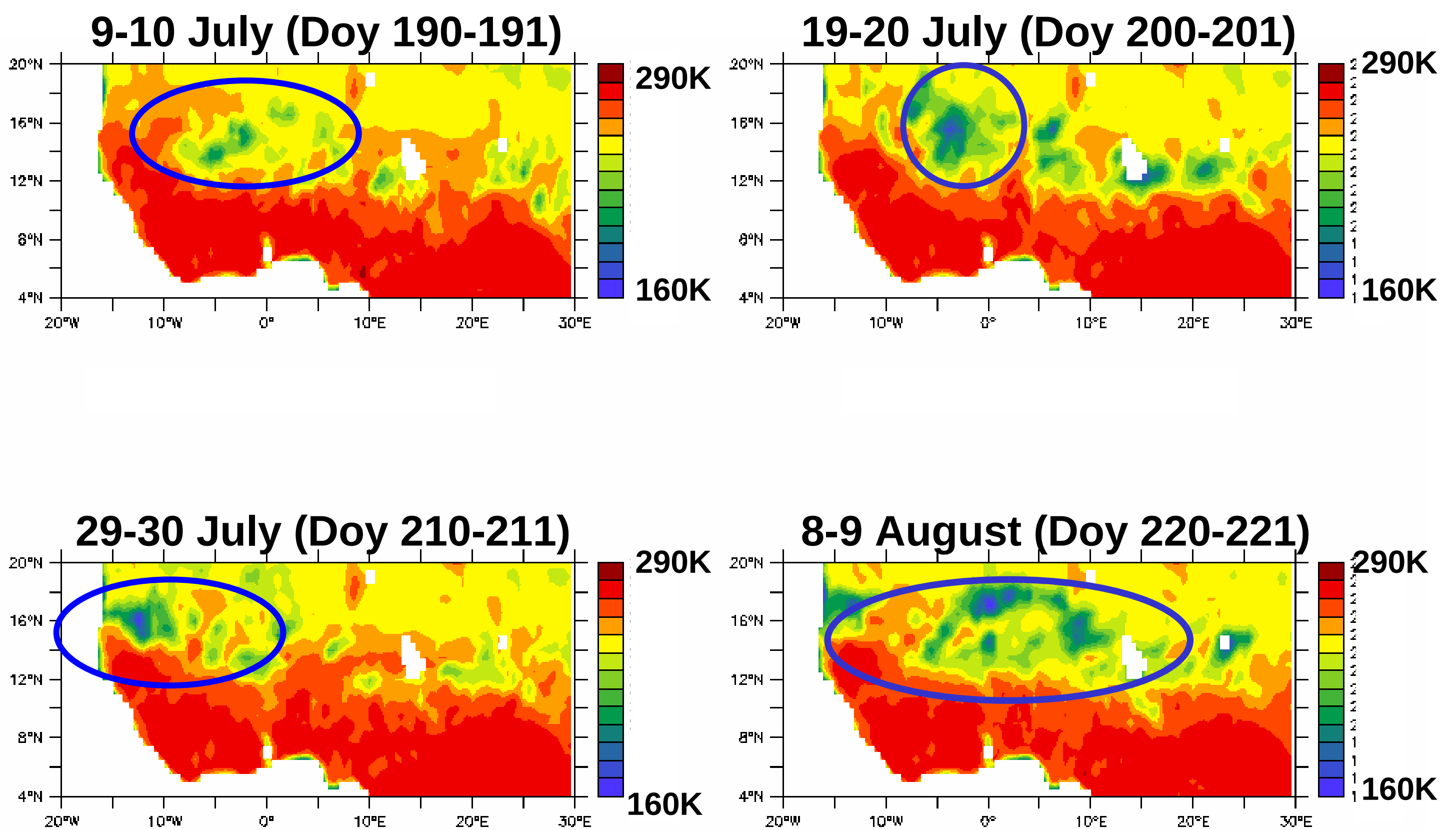
-> 96 1-year (2006) simulations

101x51x365 grid-cells (lon * lat * day)



AMSR-E brightness temperature at horizontal Pol (TBH)

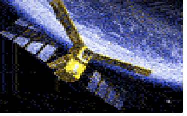
Four case study 2006 (descending orbit)



Wet Patches Shown by lower TB

High vegetation with high TB

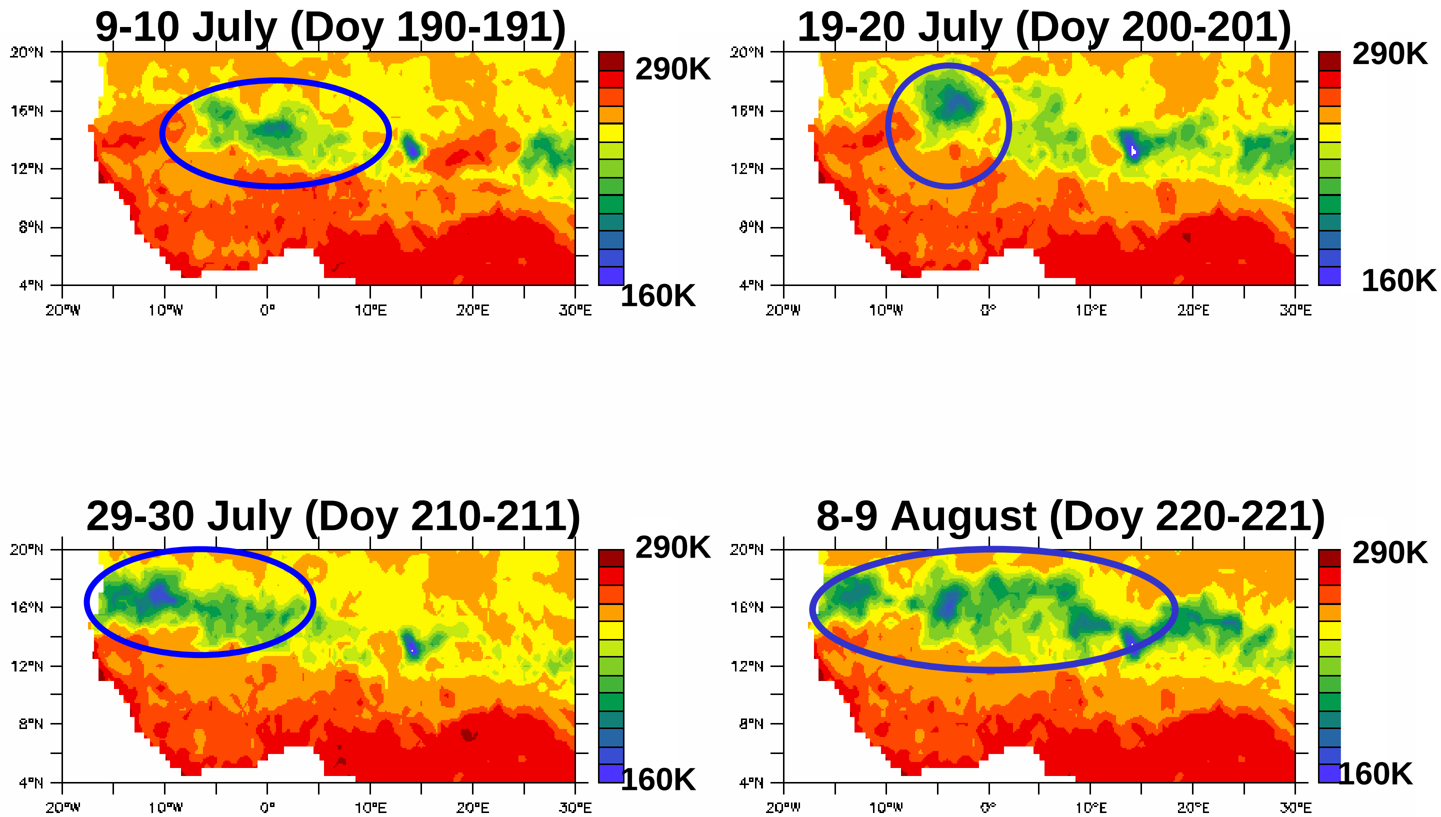
ECMWF



ALMIP-MEM TBH
Four case study 2006

Soil Moisture: ORCHIDEE-CWRR LSM (at 00.00 UTC, 2d ave)

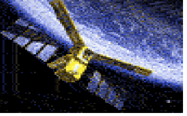
Microwave module: Mironov dielectric and Kirdyashev opacity (CMEM configuration 6)



Corr AMSR-E

Doy	R
190	0.60
200	0.66
210	0.55
220	0.72

Good agreement between ALMIP-MEM and AMSR-E TBH spatial features



Time-latitude TB

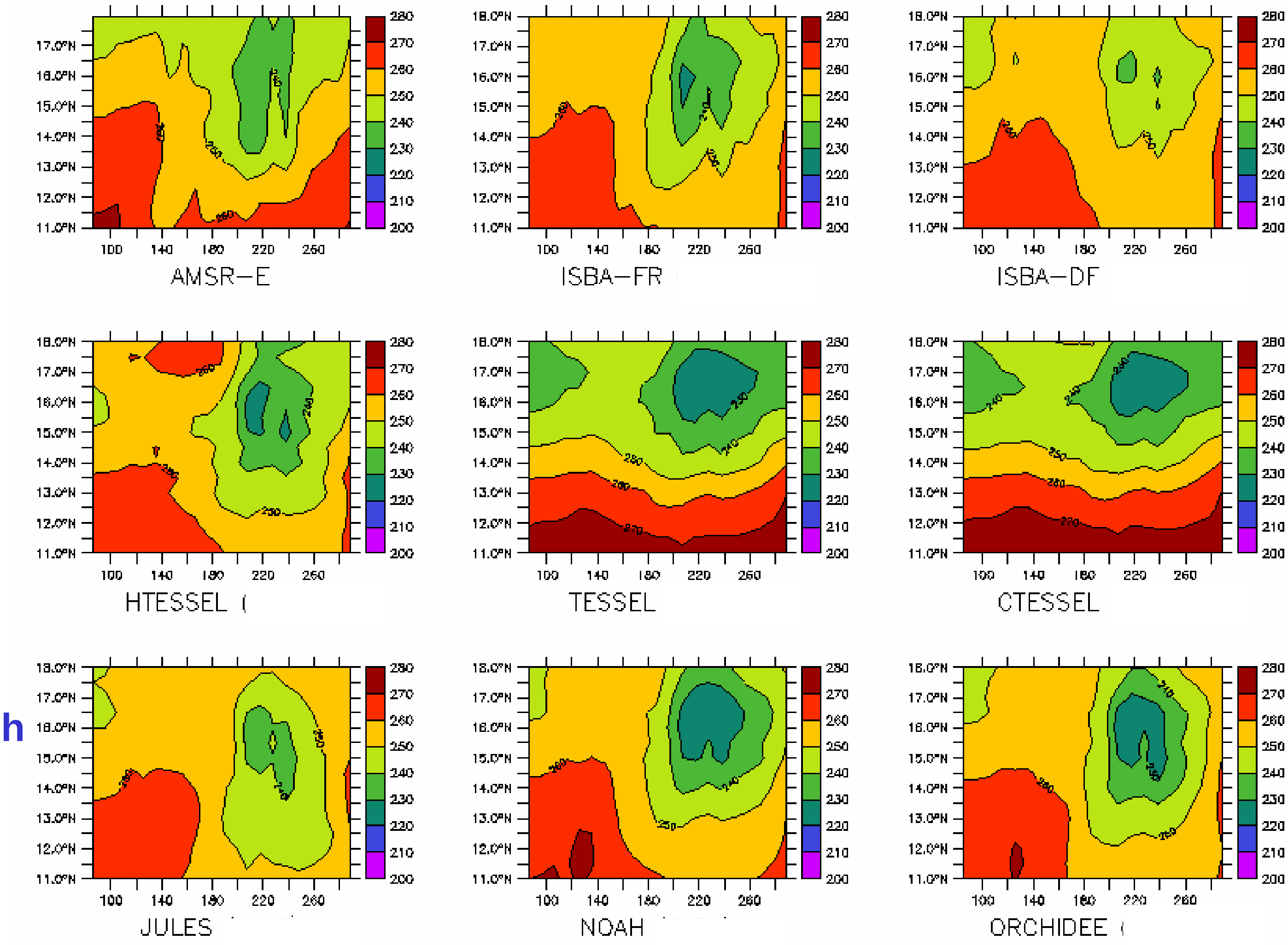
(at horizontal Pol)
Average 10W-10E

AMSR-E
8 ALMIP-MEM LSM

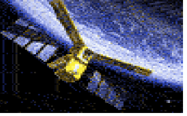
CMEM configuration 10
(Wang&Schmugge
+ Kirdyashev)

Bias correction
Applied for each LSM

- Time-latitude wet Patch
Well captured by most
of the LSMS



ECMWF



Quantitative comparison between ALMIP-MEM simulated and AMSR-E observed TB

- AMSR-E TB interpolated on the ALMIP grid (0.5 degree)

- 3 non-dimensional statistics computed for the window 9-20N and 10W-10E:
    - Correlation coefficient (R) -> evaluate agreement in patterns
    - Normalized SDV (SDV) -> evaluate agreement in amplitude of variations
    - Centred RMSE normalized by observation SDV (E)

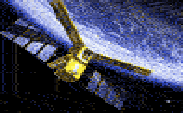
These three statistics are complementary but not independent:

$$E^2 = SDV^2 + 1 - 2 \cdot SDV \cdot R$$

-> Multiple aspects of model performances represented with Taylor diagrams

(Taylor, JGR 2001)

Best performances for R = 1, E=0, SDV=1

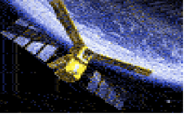


Quantitative comparison

between LSMs, using Wang and Kirdyashev (config 10) for forward modelling:

Model	Correlation	E	SDV
ISBA-FR	0.69	0.74	0.86
ISBA-df	0.73	0.68	0.71
HTESSEL	0.54	0.96	1.01
TESSEL	0.67	1.02	1.36
CTESSEL	0.69	0.98	1.36
JULES	0.63	0.78	0.67
NOAH	0.72	0.72	0.9
ORCHIDEE	0.71	0.75	0.94
AVERAGE	0.67	0.83	0.98

For the window:
- **10W-10E**
- **9N20N**
- **Year 2006**

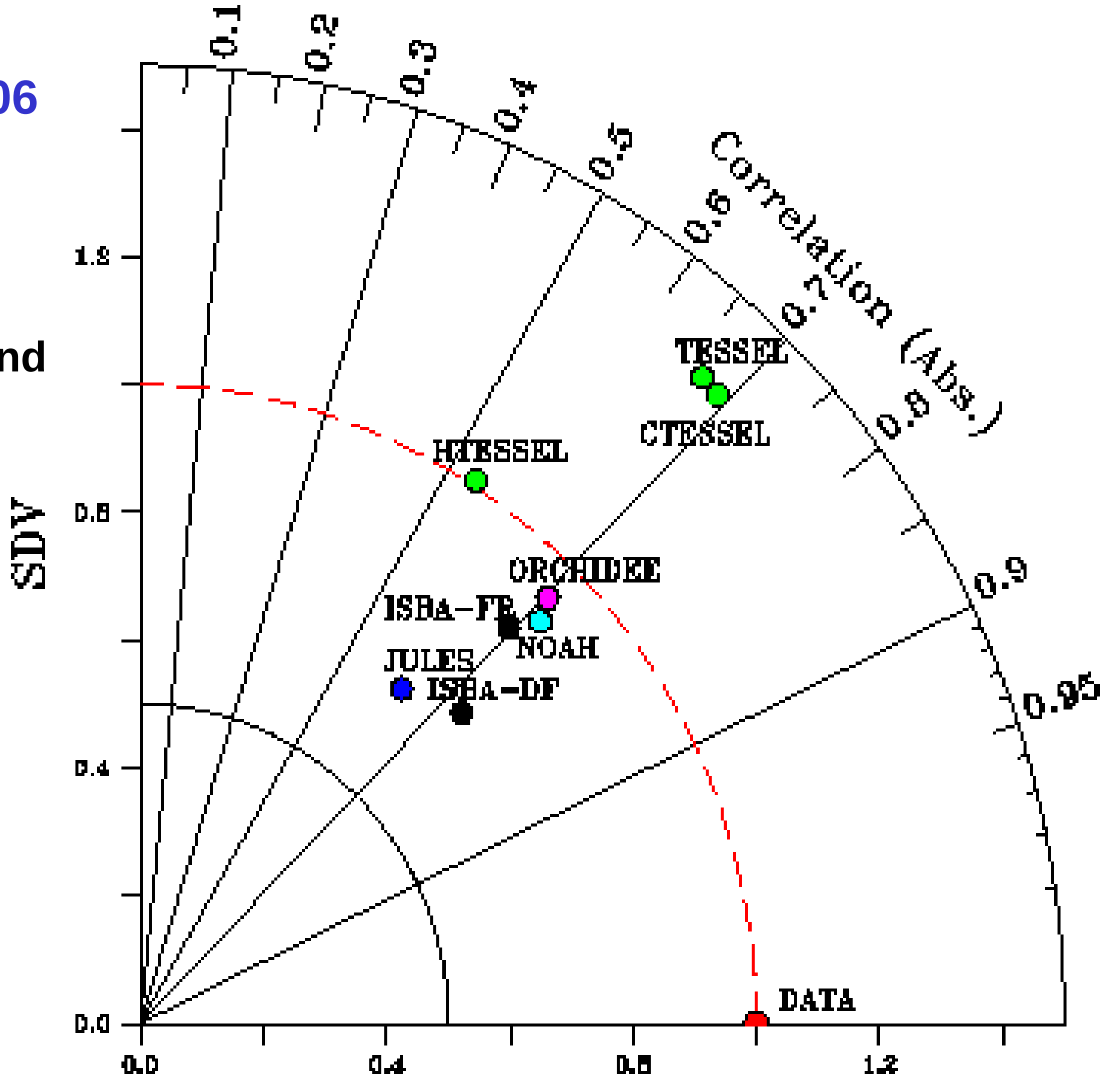


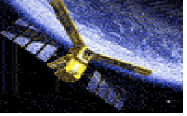
Comparison between simulated and observed TBH over West Africa

Taylor Diagram for the year 2006

Comparison between:
Simulated (8 ALMIP-MEM LSMs) and
AMSR-E C-band TBH

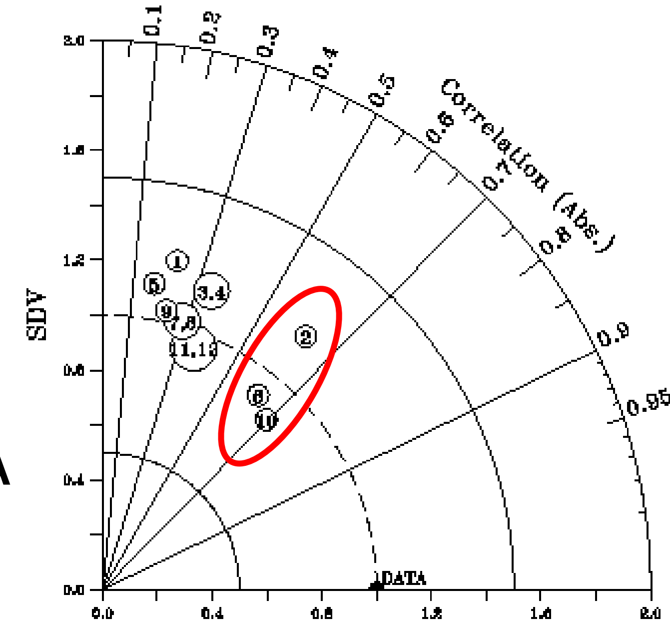
For the case where the
Kirdyashev opacity
Wang and Schmugge
Models are used
(CMEM configuration 10,
Best correlation for all the LSMs)





Taylor Diagrams
Comparison with AMSR-E TB:
For each LSM 12 different MW models

ISBA



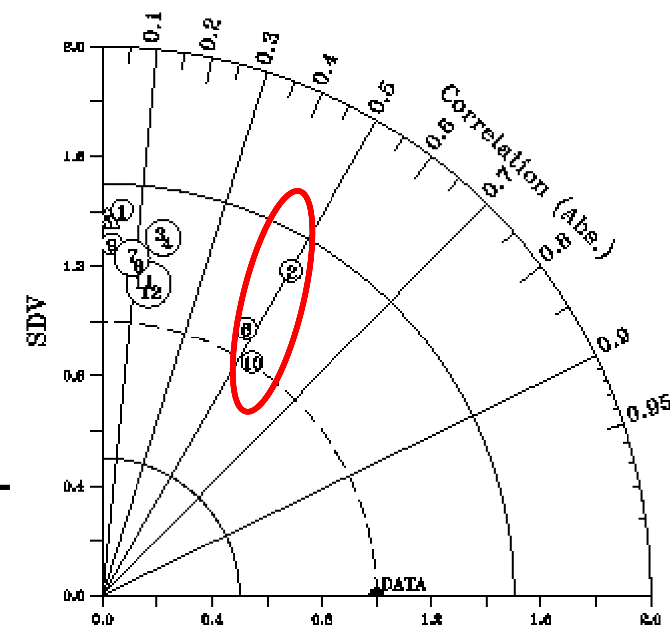
(a) ISBA-FR

Large scatter in Correlation between the MW models

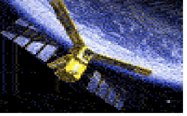
Best results with the Kirdyashev optical depth model (number 2, 6, 10)

Larger SDV with Dobson than with Mironov or Wang&Schmugge models

HTESSEL



(c) HTESSEL



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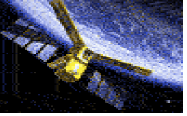


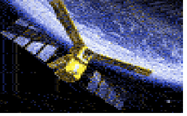
Summary (1/2)

CMEM

- CMEM, portable Fortran90 software to compute microwave emission of land surfaces in NWP models. Flexible to I/O grid-size and format.
- Modularity: various soil and vegetation and atmosphere parameterizations.

SMOSREX: L-band, local

- From HTESSEL-CMEM forced by ECMWF forecast 2004
- **5 observing angles**
- **9 MW modeling configurations** (3 diel. and 3 veg. models)
- Background errors calculated
- Wigneron's optical depth is the best at horizontal polarization while Kirdyashev shows best performances at vertical polarization. Overall best performances are obtained with Kirdyashev model at 50°.
- Wang dielectric model provides best results at both H&V polarizations.



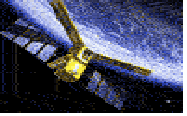
Summary (2/2)

ALMIP-MEM: C-band, regional scale, 55° incidence angle

- Based on LSM community experience in inter-comparison (PILPS, GSWP2), but focus on West Africa and extended to compare different combinations of LSMs and radiative transfer models
- **1st inter-comparison exercise of land surface MW emission models**
- Coupled LSM-CMEM models capture convective system occurrence in Sahel, as well as latitude-time feature of TB
- **Stronger sensitivity of simulated TB to microwave model than to LSM**
- Robustness of the Kirdyashev opacity model to simulate TB in best agreement with AMSR-E measurements, for any LSM.

Consistence between SMOSREX and ALMIP-MEM (different angle, freq, LSM, scale): best modeling configuration Kirdyashev + Wang&Schmugge

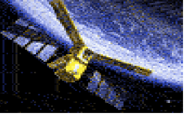
High importance of suitable MW modeling approach for SM retrieval and SM assimilation



Thank You !

CMEM web site:

http://www.ecmwf.int/research/ESA_projects/SMOS/cmem/cmem_index.html



First Guess Error on simulated TBH on SMOSREX

Best observing configuration (20 & 30°)

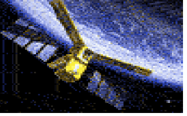
Best modeling configuration (Wang dielectric and Wigneron optical depth)

	RMSE (K)	R^2(%)	Bias (K)
30°	10.4	59.64	-1.3
20°	10.0	68.19	-7.4

First Guess Error on simulated TBV on SMOSREX

Best observing/modelling configurations: 40 ° with Wang and Wigneron
50 ° Wang and Kirdyashev

	RMSE (K)	R^2(%)	Bias (K)
40 ° Wang / Wigneron	9.5	77.0	-0.4
50 ° Wang / Kirdyashev	6.7	80.6	-1.2



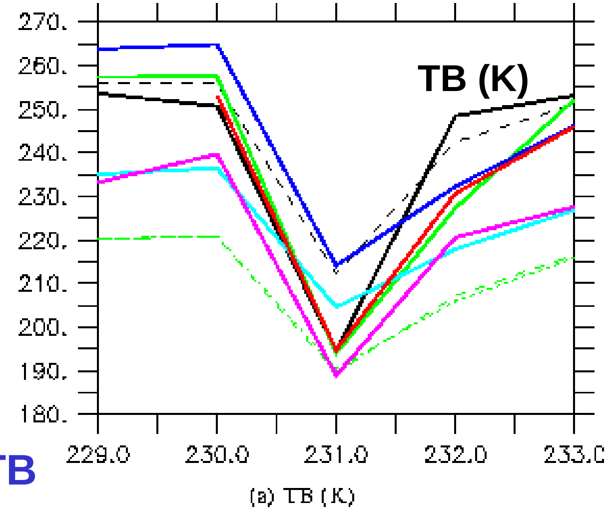
Temporal dynamics

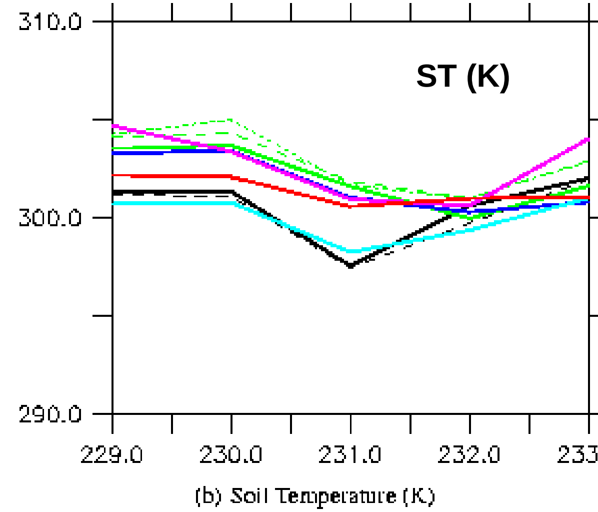
Agoufou site (15.3N,1.5W)
(SMOS vaidation site)

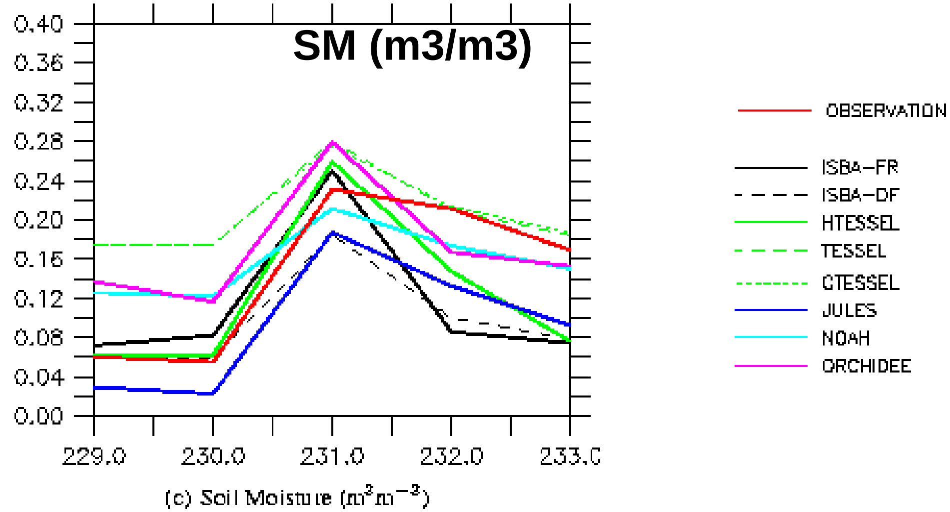
Independent Observations:

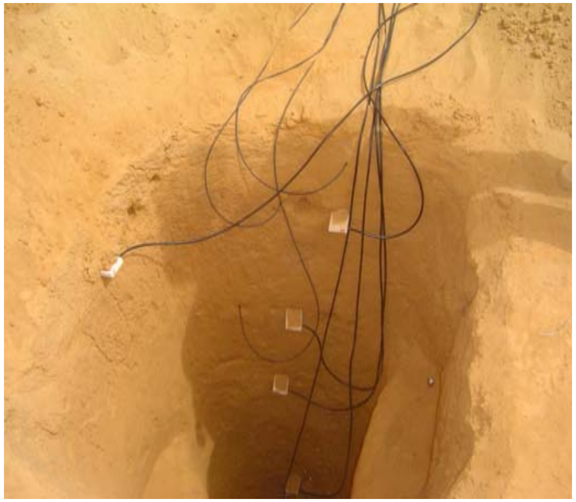
- AMSR-E TB
-Ground Soil Moisture & Temperature

Validation of simulated SM and TB









DoY 229 (17 August) to DoY 233 (21 August)

Field measurements of soil moisture AMMA-EOP (de Rosnay et al., JH 2008)