Parameterisation and calibration of L-MEB in the Level-2 SMOS algorithm

Jean-Pierre Wigneron, Yann H. Kerr, Kauzar Saleh Contell, Philippe Richaume, Patricia de Rosnay, Maria-José Escorihuela, Jean-Christophe Calvet, Aurelio Cano, Andre Chanzy, François Demontoux, et al.

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Outlines:

- SMOS: L-MEB used in the Level-2 algorithm

- Improving L-MEB: key questions?

- recent results for soil:

  -surface roughness

  -effective soil temperature

- Conclusions

2. SMOS (Soil Moisture and Ocean Salinity)

Low spatial resolution: ~ 35-50km
Revisit time: Max. 3 days
Sensitivity ~ 2K over land

Goal of accuracy in SM: ~ 0.04 m3/m3

Launch : 2008

Retrieval algorithm: using multiangular and dual polarization TB

⬇

Soil moisture & vegetation opacity (τ), …

-**Level-2 algorithm completed,** now validation activities

the Expert Support Laboratory (ESL) includes CESBIO, IPSL, TOV-Roma

-**based on L-MEB**, (L-band Microwave Emission of the Biosphere)

L-MEB (L-band Microwave Emission of the Biosphere model)

[Wigneron et al., *in book* 06 , *RSE 07*]

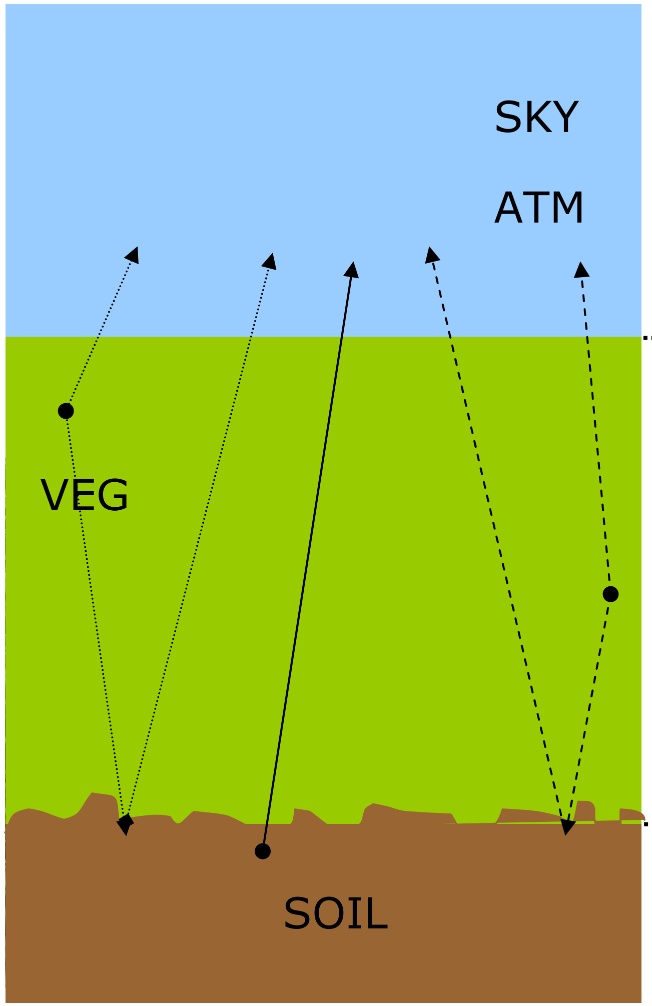
- L-MEB = result of an extensive review of the current knowledge of the microwave emission from vegetation

- Based on based on R.T. modeling ($\tau-\omega$ model for vegetation)
  & specific parametrisations for roughness, T_effective, angular effects, etc.

- Parameter calibration for a variety of soil/vegetation types
  (crops, prairies, shrubs, coniferous, deciduous forests, etc.)

- Valid ~ in the 1- 10 GHz Range (L-, C-, X-MEB)

L-MEB (L-band Microwave Emission of the Biosphere model)



param: HR(SM), NRv, NRh, w0, wb

Zero order solution of radiative transfer equations:

$$TB_{veg}=(1-e^{-\tau/\cos(\theta)})(1-\omega)T_{veg}(1+\Gamma_{soil}e^{-\tau/\cos(\theta)})$$

Accounting for angular effects on τ:

$$\tau(nadir) = b\ VWC = b'LAI+b''$$

$$\tau_p = \tau_0(nadir)\ .\ (\cos^2(\theta)+tt_p \sin^2(\theta))$$

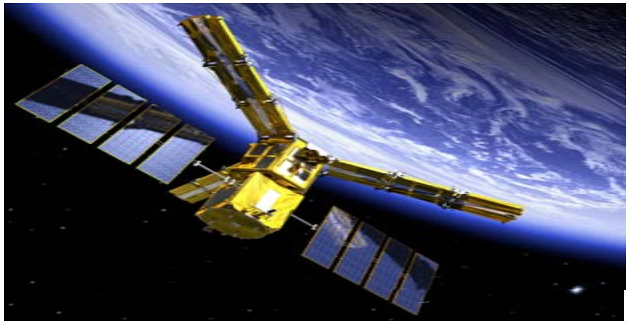
param.: τ_nadir, ω, ttv, tth, b', b''

Roughness, effective temperature:

$$\Gamma_{soil} = \Gamma_{soil\_smooth}\ e^{-HR \cos Np(\theta)} \text{ with } HR\ (SM)$$

$$T_G = T_{depth} + C\ (T_{surf} - T_{depth}),\ C = (SM/W0)^{wb}$$

A few key questions still pending:



- soil emission:
  - -surface roughness: link between NRp, HR, and (STD, Lc, …)?,
  - -HR(SM)?, use of Q ?
  - -effective soil temperature: sensitivity of (W0, b) on the soil type?
  - -model accuracy at rather large angles ($\theta \geq 40°$)?

- soil permittivity:
  - -model accuracy over a large range of soil types (use of Mironov routine for high sand fraction?)

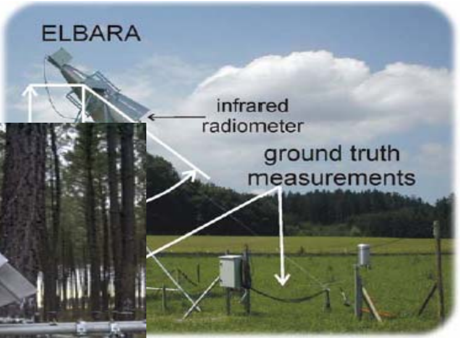
- vegetation
  - -dependence of ω, ttp (p=v, h) on the vegetation structure?
  - -relating optical depth TAU with Veg. Water content, or LAI?
  - -effect of interception (flagged currently using PR)?

- litter, understory in natural environment (forests, prairies, etc.)
  - -several modelling approaches in the literature: -validation ?, -tractable for retrievals ?

Studies: based on experimental activities for a large range of soil and vegetation conditions:

experiments over the last years:

- SMOSREX (CESBIO, CNRM, INRA, ONERA), soil-fallow, Toulouse site, 2003-2008
- BRAY-04-08 (INRA), coniferous forest EMIRAD (TUD), 2004-2008
- MELBEX-1-2 (U. Valencia, INRA), mattoral, vineyards EMIRAD (TUD), 2006-2008
- ELBARA (ETH, U. of Bern), grass, deciduous forest 2004-2006
- REFLEX'05 (Univ. of IOWA),
- …



Modelling Soil TB in L-MEB

$$TB_{soil}=(1 - \Gamma_{soil}).\ T_G$$

Effective soil temperature $T_{G:}$

$$T_{G} = T_{depth} + C\ (T_{surf} - T_{depth}),\ C= (SM/W0)^{wb}$$

Wigneron et al., 2001

Soil roughness effects derived from:

$$\Gamma_{soil\text{-}p} = (Q.\Gamma^{*}_{soil\text{-}p} + (1\text{-}Q).\ \Gamma^{*}_{soil\text{-}q})\ e^{-HR\cos2(\theta)}$$

Wang and Choudhury, 1981

-limited physical basis: meaning of calibrated parameters? site specific calibration ?

-account for ALL complex mechanims at the origin of the soil emission ("geometric" and "dielectric" roughness, inhomogeneities, inclusions, …)

-very good performance and efficiency for retrieval studies at L-band

L-Meb modeling of the effective soil temperature T_G

Wigneron et al., 2008

$T_G = T_{depth} + C\,(T_{surf} - T_{depth})$, Choudhury et al., 1982

T_{depth} at ~ 50cm, T_{surf} at ~ 5 cm, C= 0.246 at L-band

However, the effective depth depends on SM (larger for dry soils)

$T_G = T_{depth} + C\,(T_{surf} - T_{depth})$, $C = (SM/W0)^b$ Wigneron et al., 2001

-W0, and b were calibrated, considering Tdepth & Tsurf at various depths
-W0 = 0.3, b= 0.3; default L-MEB parameters

-modified and validated over SMOSREX (De Rosnay et al.; Holmes et al., 2006)

Sensitivity of W_0 and b to soil texture and density ?

soil texture affects T_G, through:

-relationship between ε and SM
-SM and temperature profiles within soil

Evaluating the effects of soil properties on T_G

Methods:

- building a very large synthetic reference data set:

  -for a large range in soil texture & density, hourly over a 14-day period, 4 initial SM and 5 climatic conditions (winter, summer, etc.)

  -simulating soil temperature & moisture profiles, with a mechanistic soil transfer model (TEC)

  -coupling with a RT model simulating a "reference" T_G

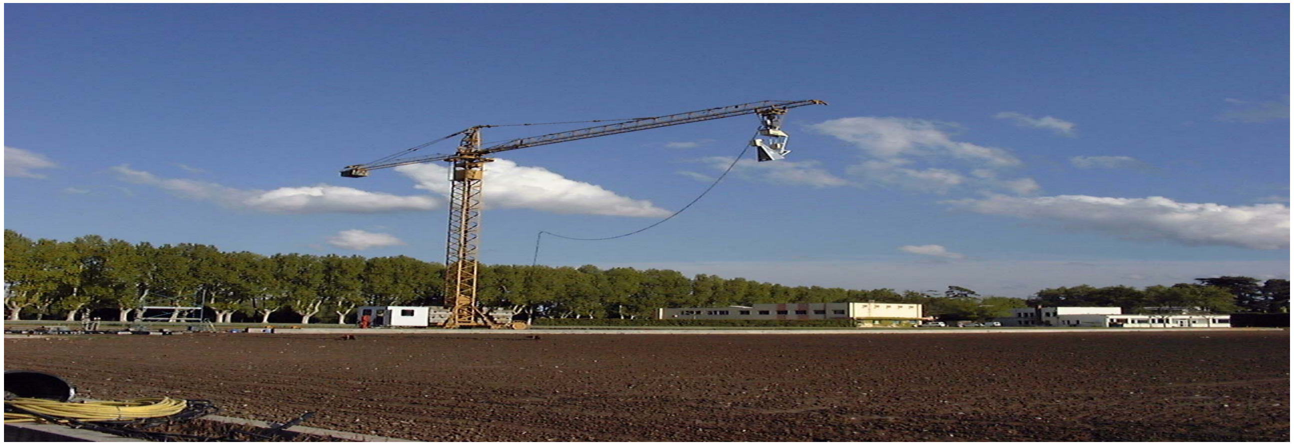
- calibrating model parameters:

  -for Choudhury (Ch): C ; Wigneron, (Wig): W0, b, ..., approaches

  -considering $T_{surf} = T_{air}, T_{0cm}, T_{2cm}, T_{5cm}$, etc., $T_{depth} = T_{10cm}, T_{20cm}, \ldots$

- evaluating the sensitivity of the parameters on texture, density

PORTOS-93 experiment



Soil type	Texture type		SAND S (%)	CLAY C (%)	SILT L(%)	bulk soil density ρ_b (g / cm^3)
1. Poirson	Silty Clay Loam	measured	11	27.2	61.8	1.4
		range	3, 9, 15, 21	21, 24, 27, 30, 33, 36, 39	deduced from L=100-S-C	1, 1.2, 1.4, 1.6, 1.8
2. Collias	Sandy Loam	measured	38.8	10.5	50.6	1.45
		range	30, 37, 44, 51	3, 6, 9, 12, 15, 18, 21	deduced from L=100-S-C	1.4, 1.6, 1.8
3. Vignère	Clay	measured	12.5	47.4	40.1	1.4
		range	3, 9, 15, 21	42, 45, 48, 51, 54, 57, 60	deduced from L=100-S-C	1, 1.2, 1.4, 1.6, 1.8

considered range in soil texture & density:

sand (3 → 51%)
clay (3 → 60%)
bulk density (1 → 1.8 g/cm3)

Main results

- best estimator of T_g are obtained at a depth which depends on the soil type (accuracy ~ 1.5K):

  - ~ 2-5 cm for clay
  - ~ 5 cm for silty clay loam
  - ~ 5-10 cm for sandy soils (drier at surface generally)

- air temperature (T_{air}) is a good estimator of T_g (accuracy ~ 3 K):

  - cannot be improved using information on T_{depth} (using Ch or Wig)

- surface temperature (T_{0cm}~ T_{IRT}) is an estimator of T_g (acc. ~ 4 K):

  - can be improved using information on T_{depth} (acc. ~ 1.8K using Ch)

- using T_{surf} = T_{2cm}, T_{5cm}, etc., information on T_{depth}, with Ch or Wig, provide improvements:

  - acc. 4K -> 1.8K (T_{surf}=T_{0cm})
  - acc. 1.9K -> 1.1K, (T_{surf}=T_{2cm}), etc.

Main results

- using Ch or Wig, results (model parameters, acc.) depend on the soil types:

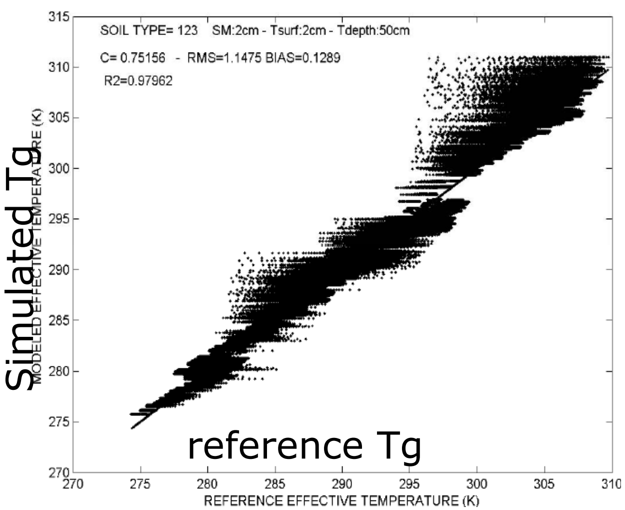
  - for the Ch method (Tsur= 2cm): CT varies 0.82 → 0.65 & RMSE 0.8K → 1.3K (clay and sandy loam)

- investigating the use of additionnal information on soil characteristics: texture (clay, sand) or density (rob)

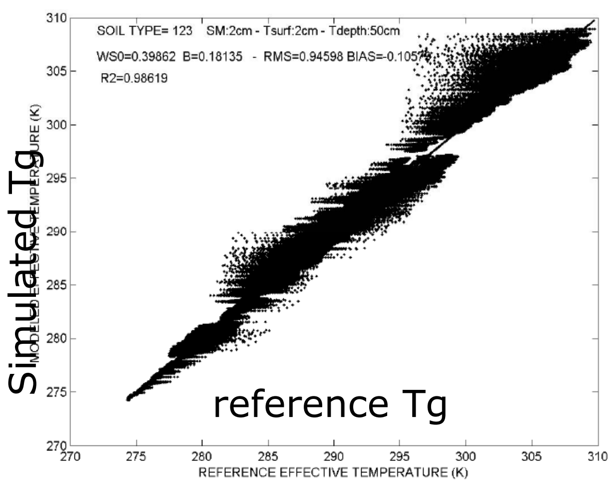
  - a 4P formulation where, W0 = constant; b= a + b. clay + d. rob is the best compromise (accuracy / complexity)

  -the 4P formulation provides ~ a 0.2K improvement (larger for sandy soils)

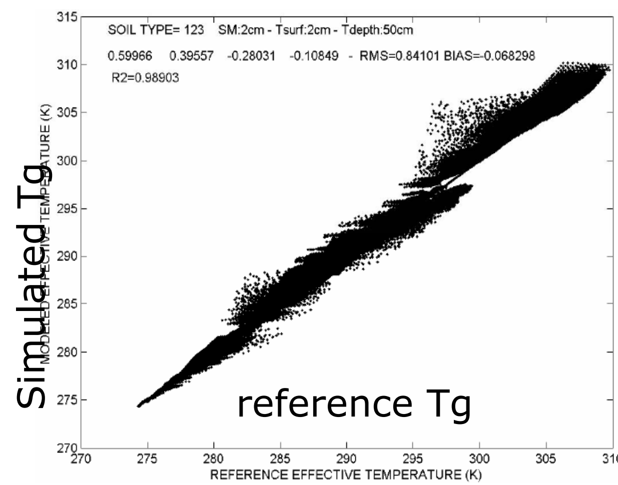
Choudhury



Wigneron 2P



Wigneron 4P



Conclusions (effective Tg)

- effects of soil texture & density on Tg could be evaluated

  -several simplified formulations were developed for a variety of conditions (depending on the availability of ancillary data for: depths for T_{depth}, T_{surf}, texture, density…)

  → possibility to calibrate b & W_0 parameters from available global maps (FAO) (no need for in situ calibration)

  -interest of using Tair or T_0 as proxi of Tg

  -specific effects over sandy soils (much drier in general)

  -studies limited to clay < 60%, sand < 50%

- perspectives

  → accounting for the uncertainties on the ancillary data (on Tair vs T_0, ..)

  → high interest to develop studies over larger ranges of fractions:

  in particular the 'Mironov' routine allows to investigate sandy soils (sand > 80%) corresponding to large fraction of the globe (deserted areas).

Soil roughness modelling in L-MEB

$\Gamma_{soil\text{-}p} = (Q.\Gamma^*_{soil\text{-}p} + (1\text{-}Q).\,\Gamma^*_{soil\text{-}q})\, e^{-HR\,\cos 2(\theta)}$ Wang and Choudhury, 1981

Regular improvements:

$\Gamma_{soil\text{-}p} = (Q.\Gamma^*_{soil\text{-}p} + (1\text{-}Q).\,\Gamma^*_{soil\text{-}q})\, e^{-HR\,\cos NRp(\theta)}$ used in L-MEB

with

-Q ~0 at L-band, increases with frequency Wang et al., 1983, Wign. et al., 2001

-ev decreases with frequency, at large angles (Q#0 ?) Shi et al, 2002

-exponent NR ~ 0 Wang et al., 1983, Wign. et al., 2001

-HR = f(STD / LC) Mo & Schmugge, 1982; Wign. et al., 2001

-HR = f(SM), accounting for higher "dielectric" roughness over dry soils?
Mo & Schmugge, 1982; Wign. et al., 2001, Escorihuela et al., 2007

-distinguishing NR for the V and H polarization, (NRp, HR) Escorihuela et al., 2007

PORTOS-1993: A Re-analysis

PORTOS 1993, experiment: 7 surface roughness conditions

Field N°	Label	Dry Bulk Density (2-4 cm) ρ_b (g/cm^3)	Roughness Characteristics: Std Deviation of height σ_S (mm) mean	std	Roughness Characteristics: Correlation Length L_C (mm) mean	std	Surface Type
6	SB	1.2*	59.37	*13.77*	67.32	*12.54*	P. (fast)
9	OD	1.35	4.76	*1.89*	63.05	*19.01*	P., R. (slow)
11	SC	1.43	8.39	*1.24*	31.47	*20.14*	P., R., H. (fast)
15	SL	1.3	8.96	*2.84*	71.5	*61.9*	P., R. (fast), H. (slow)
16	SR	1.2*	47.43	*4.76*	61.72	*4.10*	P. (fast)
17	SI	1.42	4.57	*1.98*	206.06	*51.49*	P., R. (slow) . Roadrolled
18	SU	1.1	19.15	*5.08*	65.75	*45.6*	P., P. (fast), H. (slow)

Wigneron, 2001:

-Q= NRV=NRH=0

-HR(SM, slope M = STD/Lc)

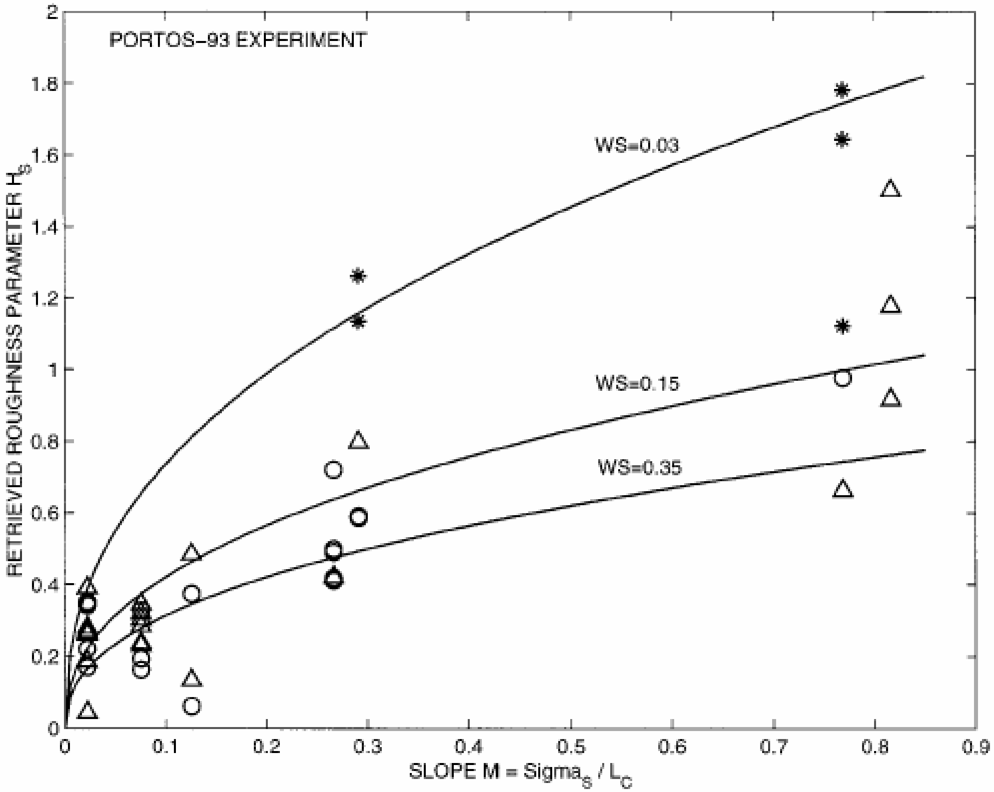
$$\Gamma_{soil-p} = \Gamma^*_{soil-p}\, e^{-HR}$$

PORTOS-1993: Main results

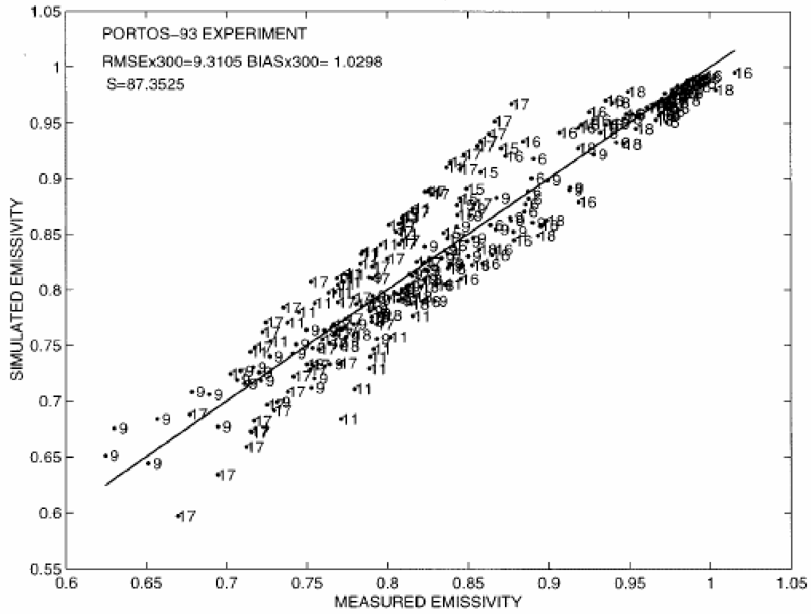
(Wigneron et al., IEEE-GE, 2001)

-Q= NRv=NRh=0

-HR = a. SM^b + (STD/Lc)^c



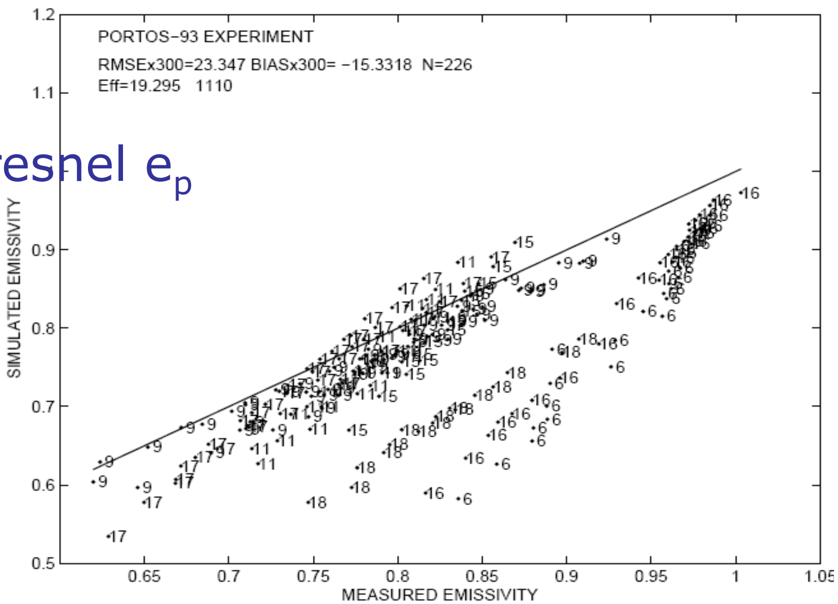
-RMSE (TB) ~ 10K
simulated and measured TB



Since then , new results (Shi et al. 2002-2006, Escorihuela et al., 2007)

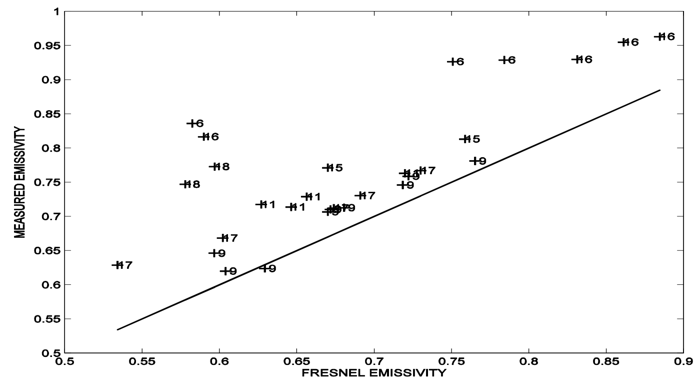
PORTOS-1993: Comparing measured and Fresnel reflectivities

Fresnel e_p

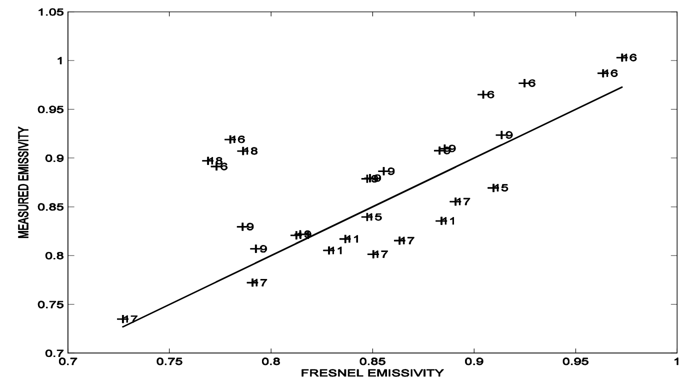


measured e_p

H-pol 40°



V-pol 40°



→ V-pol, 40°: emissivity ↓ as roughness ↑ for 3 fields (11, 15, 17) as predicted by Shi et al., 2002

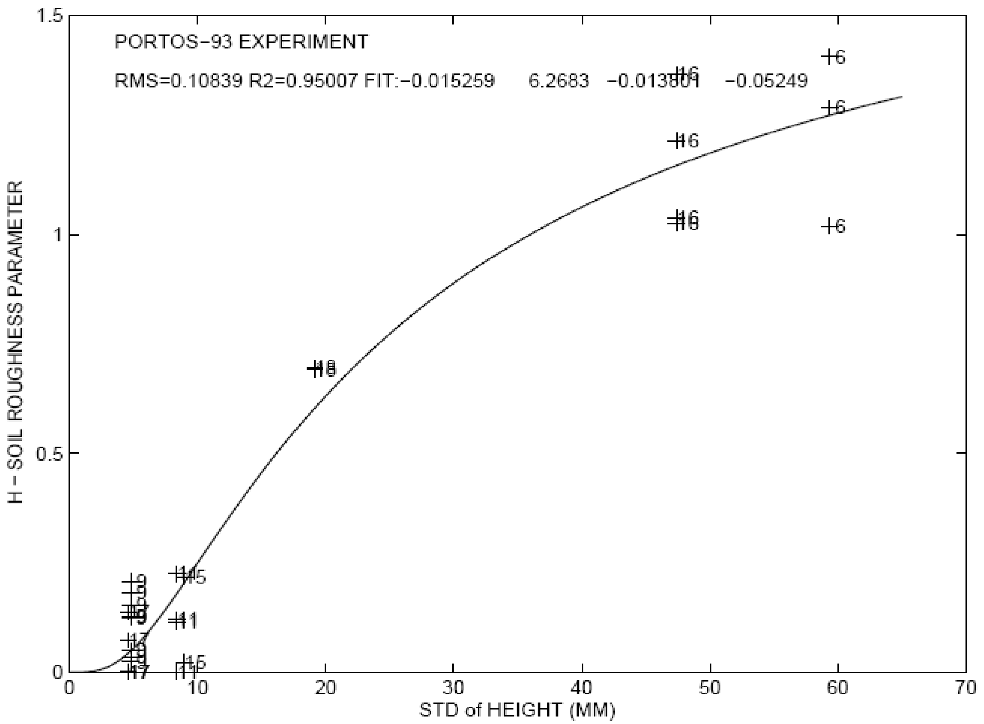
→ Simulations for these fields require the use of the additional Q parameter

PORTOS-1993: a re-analysis accounting for new results by Shi et al., Escorihuela et al.

- Considering Q, NRv and NRh

$$\Gamma_{soil\text{-}p} = (Q.\Gamma^*_{soil\text{-}p} + (1\text{-}Q).\,\Gamma^*_{soil\text{-}q})\, e^{-HR\,\cos Np(\theta)}$$

- Filtering data more accurately (accounting for days with strong diurnal variations in SM, roughness, etc.)



HR = f(STD)

→ HR = (a.STD /(c.STD+d))^b;
R2 = 0.95,

→ no improvement using information about SM or Lc

→ Q ~ 0.2 for fields 11, 15, 17
Q = 0, for the others

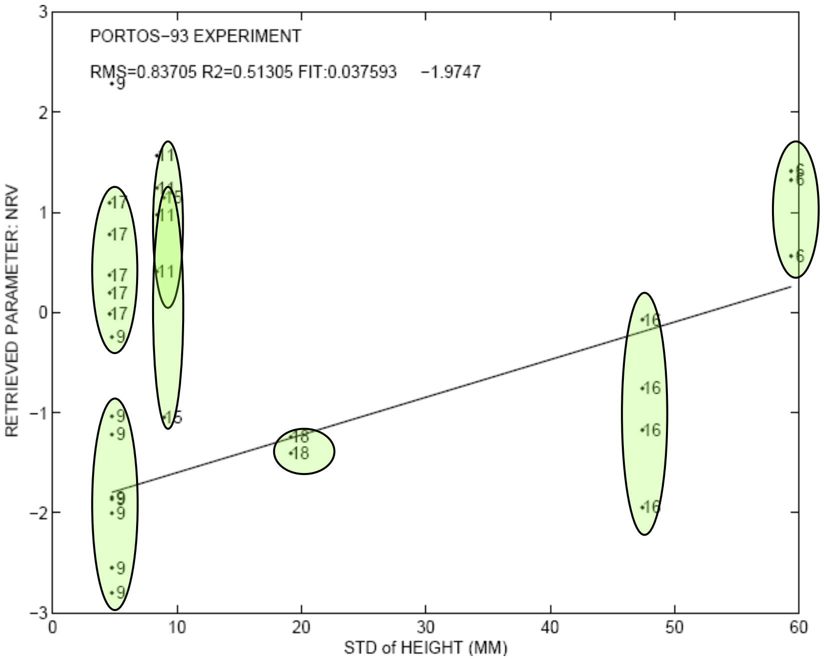
PORTOS-1993: a Re-analysis

-clear values of NRv and NRh can be associated to each field

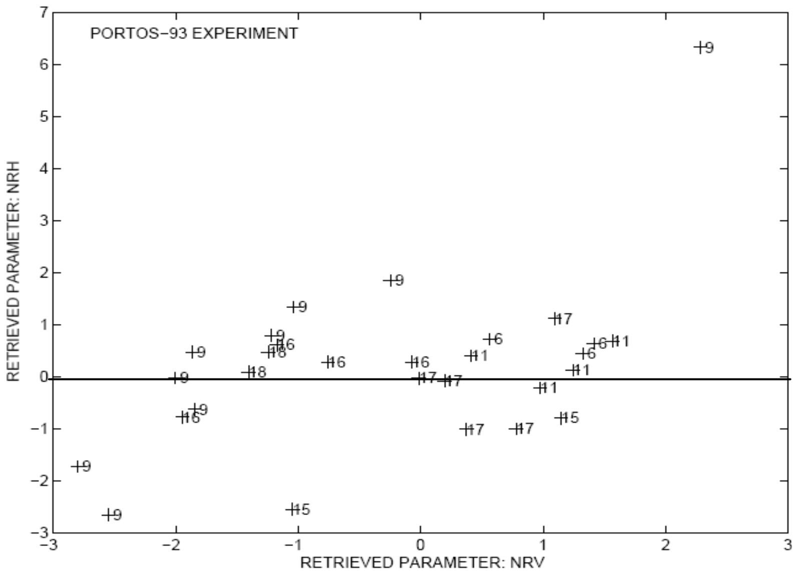
-NRh ≈0

-NRv: could not be clearly related to geophys. param. (STd, Lc, etc.)

NRv = f(STD)



NRh = f(STD)



PORTOS-1993: a re-analysis

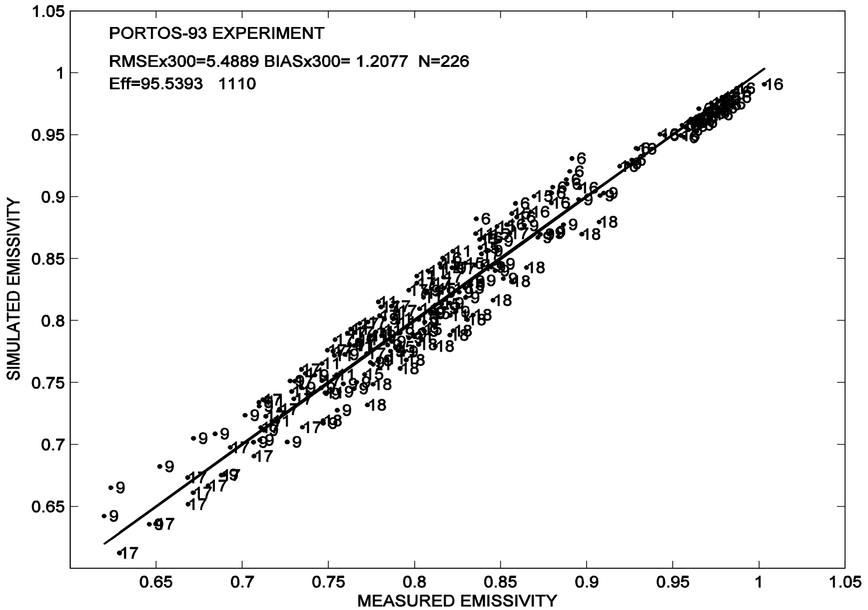
$$\Gamma_{soil-p} = (Q.\Gamma^*_{soil-p} + (1-Q).\,\Gamma^*_{soil-q})\ e^{-HR\ \cos Np(\theta)}$$

→ $HR = (a.STD /(c.STD+d))^b$;

→ Q ~ 0.2 for fields 11, 15, 17
Q = 0, for the others

→ NRh= 0

→ NRv= f(field), between [-2 .. 1]



Comparing measured and simulated reflectivities

RMSE ~5.5 K

Good agreement with other studies:

-REBEX HR ~0.7 for STD = 28mm

-SMOSREX: NRv=-2, NRh=0

L-meb calibration over vegetated fields

Wigneron et al., 2007

Good agreement with results obtained from P93:

	HR	NR_V	NR_H	tt_H	tt_V	ω_H	ω_V	Number of observation dates	RMSE on SM (m^3/m^3)
PORTOS-91, soybean	0.1	0	0	1	2	0	0	32	0.044
BARC, soybean ⊥ //	0.2	-1	0	1	1	0	0	11 11	0.029 0.053
PORTOS-93, wheat	0.1	0	0	1	8	0	0	45	0.061
for DOY<161								30	0.042
EMIRAD-2001, corn ⊥	0.1	0	0	2	1	0.05	0.05	33	0.042
corn //								30	0.044
REBEX, corn	0.7	-1	0.5	2	1	0.05	0.05	5	0.025
BARC, corn ⊥ corn //	0.6	-1	0.5	2	1	0.05	0.05	14 14	0.035 0.023

PORTOS-1993: a re-analysis, conclusions

→ Calibration of the L-MEB parameters (HR, Q, NRv and NRh) was evaluated against the P93 & other (vegetetated) data sets (Wign. et al., 2007, 2008)

- HR could be parameterized as a function of STD
- Q, NRh, NRv could be calibrated for each field
    - -NRh ~0
    - -NRv ~ [-2, 0.5]

-use of Q ? decrease of TBv at high roughness?

→ improved results were obtained (RMSE(TB) : 10K → 5K):

interest to use NRp at rather high angles (θ≥30°)

→ Link between the L-MEB parameters and surface characteristics ??

- no sensitivity of L-MEB parameters to SM & Lc could be revealed