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



J-P Wigneron, Y. Kerr, K. Saleh, P. Richaume, P. de Rosnay, M-J Escorihuela, J-C Calvet, A. Cano, A. Chanzy, F. Demontoux, J. P. Grant, M. Guglielmetti, H. Lawrence, E. Lopez-Baeza, A. Mialon, T. Pellarin, C. Rüdiger, G. Ruffié, M. Schwank, N. Skou, P. Waldteufel, M. Berger, S. Delwart

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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

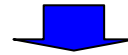
Sensitivity ~ 2K over land

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)

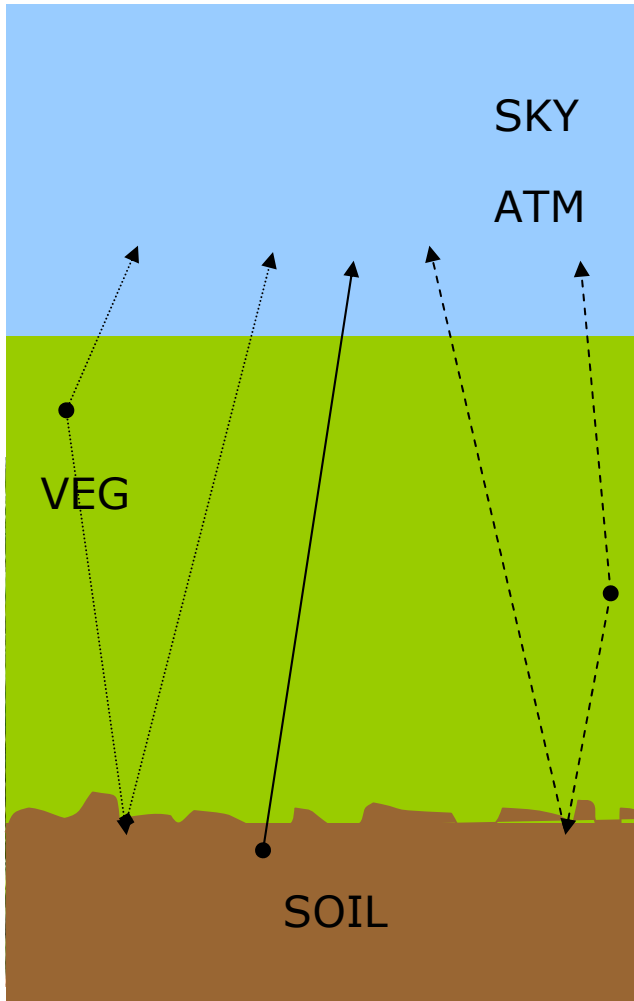
L-MEB (L-band Microwave Emission of the Biosphere model)



[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 (τ - ω model for vegetation)
& specific parametrisations for roughness, $T_{\text{effective}}$, angular effects, etc.
- Parameter calibration for a variety of soil/vegetation types
(crops, prairies, shrubs, coniferous, deciduous forests, etc.)
- Valid \sim in the 1- 10 GHz Range (L-, C-, X-MEB)

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



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 :

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

$$\tau_p = \tau_0(\text{nadir}) \cdot (\cos^2(\theta) + t t_p \sin^2(\theta))$$

param.: τ_{nadir} , ω , $t t_v$, $t t_h$, b' , b''

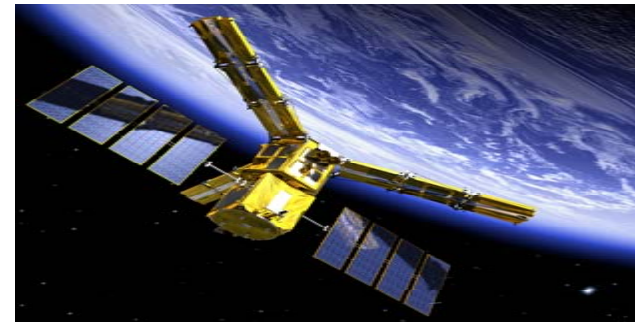
Roughness, effective temperature:

$$\Gamma_{soil} = \Gamma_{soil_smooth} e^{-HR \cos N p(\theta)} \text{ with } HR \text{ (SM)}$$

$$T_{G=} T_{\text{depth}} + C (T_{\text{surf}} - T_{\text{depth}}), \quad C = (SM/W_0)^{wb}$$

param: $HR(SM)$, NR_v , NR_h , w_0 , w_b

A few key questions still pending:



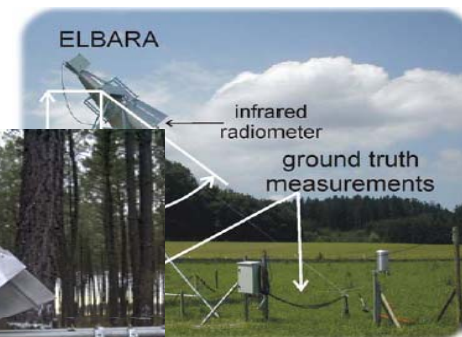
- soil emission:
 - surface roughness: link between NRp, HR, and (STD, Lc, ...)?,
 - HR(SM)?, use of Q ?
 - effective soil temperature: sensitivity of (W0, b) on the soil type?
 - model accuracy at rather large angles ($\theta \geq 40^\circ$)?
- soil permittivity:
 - model accuracy over a large range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

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

Effective soil temperature T_G :

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

Wigneron et al., 2001

Soil roughness effects derived from:

$$\Gamma_{\text{soil-p}} = (Q \cdot \Gamma_{\text{soil-p}}^* + (1-Q) \cdot \Gamma_{\text{soil-q}}^*) e^{-HR \cos^2(\theta)}$$

Wang and Choudhury, 1981

- limited physical basis: meaning of calibrated parameters? site specific calibration ?
- account for ALL complex mechanisms 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

$$T_G = T_{\text{depth}} + C(T_{\text{surf}} - T_{\text{depth}}),$$

Choudhury et al., 1982

T_{depth} at $\sim 50\text{cm}$, T_{surf} at $\sim 5\text{ cm}$, $C = 0.246$ at L-band

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

$$T_G = T_{\text{depth}} + C(T_{\text{surf}} - T_{\text{depth}}), \quad C = (SM/W_0)^b$$

Wigneron et al., 2001

- W_0 , and b were calibrated, considering T_{depth} & T_{surf} at various depths
- $W_0 = 0.3$, $b = 0.3$; 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 ; Wigner, (Wig): W0, b, ..., approaches

- considering
$$\begin{array}{l} T_{\text{surf}} = T_{\text{air}}, T_{0\text{cm}}, T_{2\text{cm}}, T_{5\text{cm}}, \text{etc.}, \\ T_{\text{depth}} = T_{10\text{cm}}, T_{20\text{cm}}, \dots \end{array}$$

- evaluating the sensitivity of the parameters on texture, density

PORTOS-93
experiment



Soil type	Texture type		SAND	CLAY	SILT	bulk soil density ρ_b (g / cm ³)
			S (%)	C (%)	L(%)	
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 $\sim 1.5K$):
 - $\sim 2-5$ cm for clay
 - ~ 5 cm for silty clay loam
 - $\sim 5-10$ 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 ($T_{0cm} \sim T_{IRT}$) is an estimator of T_g (acc. ~ 4 K):
 - can be improved using information on T_{depth} (acc. $\sim 1.8K$ using Ch)
- using $T_{surf} = T_{2cm}, T_{5cm}, \text{etc.}$, information on T_{depth} , with Ch or Wig, provide improvements:
 - acc. $4K \rightarrow 1.8K$ ($T_{surf}=T_{0cm}$)
 - acc. $1.9K \rightarrow 1.1K$, ($T_{surf}=T_{2cm}$), etc.

Main results

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

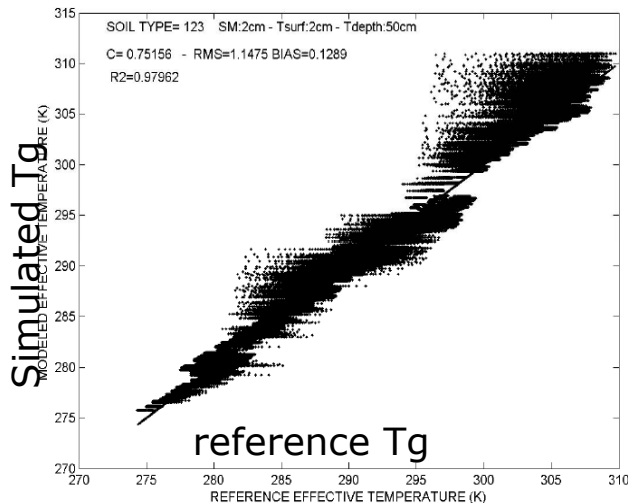
- for the Ch method (Tsurf= 2cm): CT varies 0.82 → 0.65 & RMSE 0.8K → 1.3K (clay and sandy loam)

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

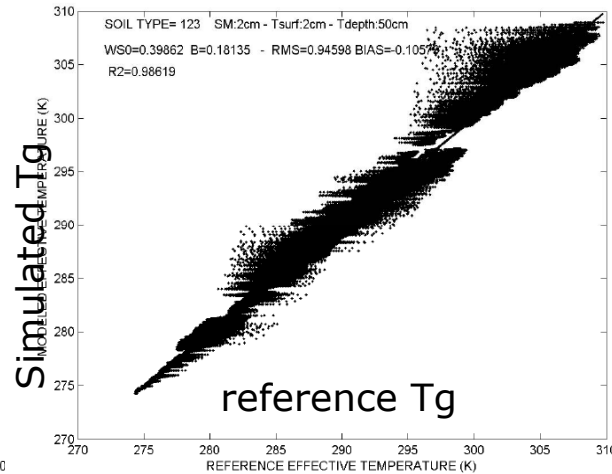
- a 4P formulation where, $W0 = \text{constant}$; $b = a + b \cdot \text{clay} + d \cdot \text{rob}$ is the best compromise (accuracy / complexity)

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

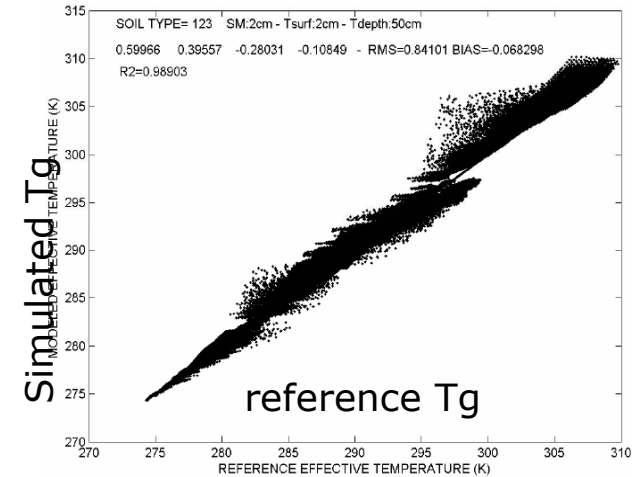
Choudhury



Wigneron 2P



Wigneron 4P



Conclusions (effective T_g)



- effects of soil texture & density on T_g 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 T_{air} or T_0 as proxy of T_g
 - 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 T_{air} 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

$$\Gamma_{\text{soil-p}} = (Q \cdot \Gamma_{\text{soil-p}}^* + (1-Q) \cdot \Gamma_{\text{soil-q}}^*) e^{-HR \cos^2(\theta)}$$

Wang and Choudhury, 1981

Regular improvements:

$$\Gamma_{\text{soil-p}} = (Q \cdot \Gamma_{\text{soil-p}}^* + (1-Q) \cdot \Gamma_{\text{soil-q}}^*) e^{-HR \cos NRp(\theta)}$$

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 $\neq 0$?)

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				Surface Type
			Std Deviation of height σ_S (mm)		Correlation Length L_c (mm)		
			mean	std	mean	std	
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)

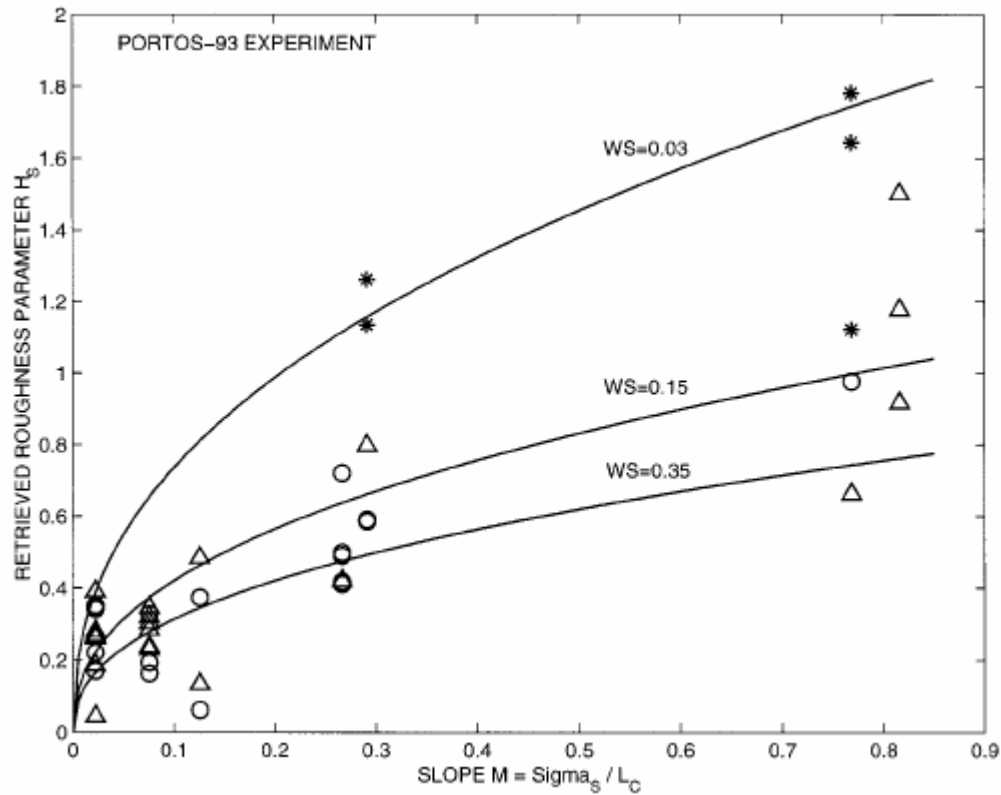
$$\Gamma_{\text{soil-p}} = \Gamma_{\text{soil-p}}^* e^{-HR}$$

PORTOS-1993: Main results

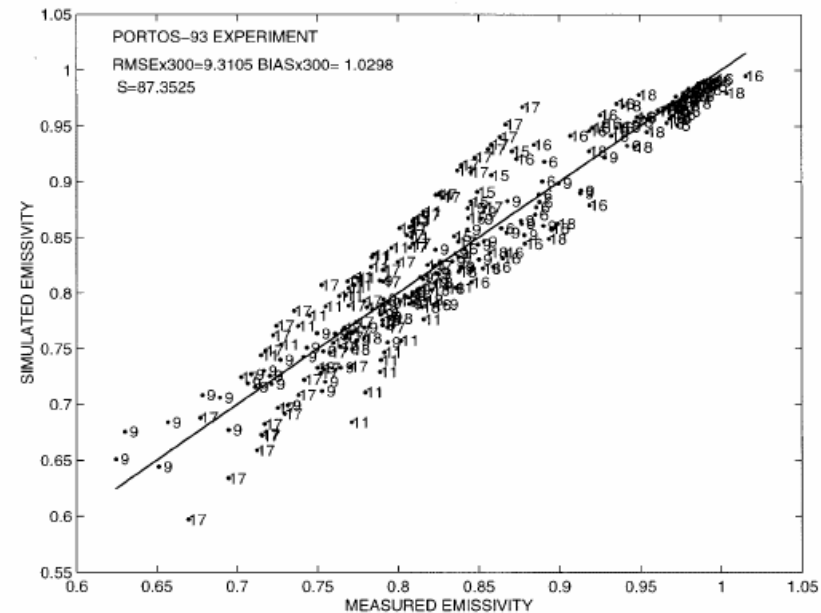
(Wigneron et al., IEEE-GE, 2001)

$$-Q = NRv = NRh = 0$$

$$-HR = a \cdot SM^b + (STD/Lc)^c$$

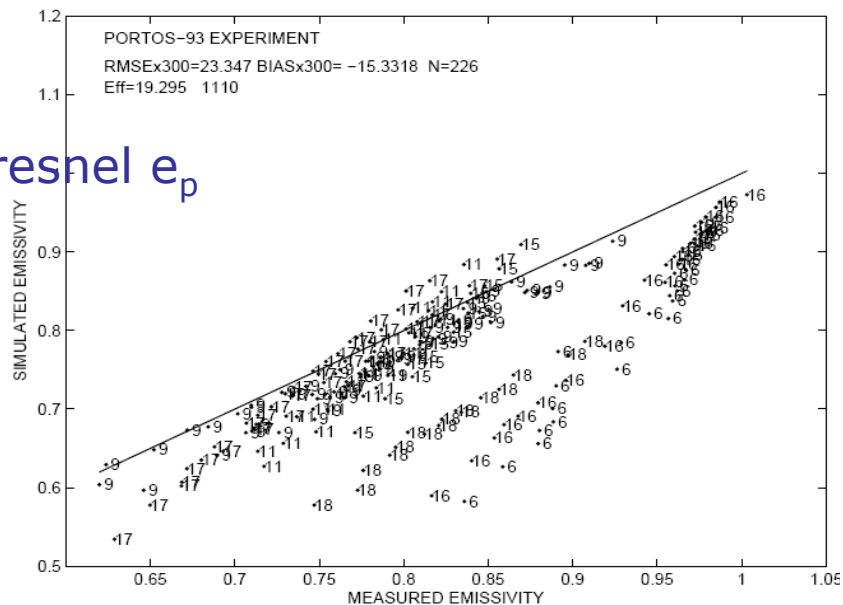


-RMSE (TB) ~ 10K
simulated and measured TB



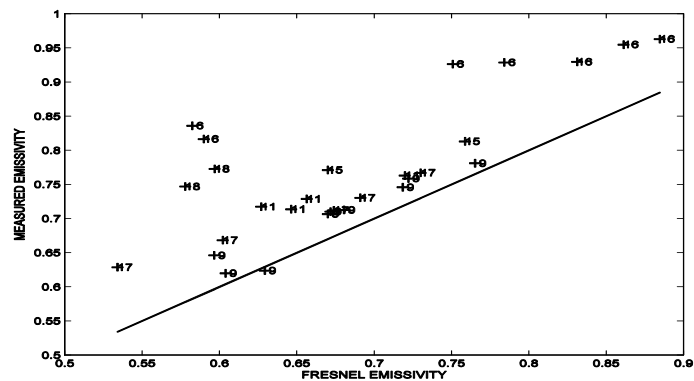
Since then , new results (Shi et al. 2002-2006, Escorihuela et al., 2007)

PORTOS-1993: Comparing measured and Fresnel reflectivities

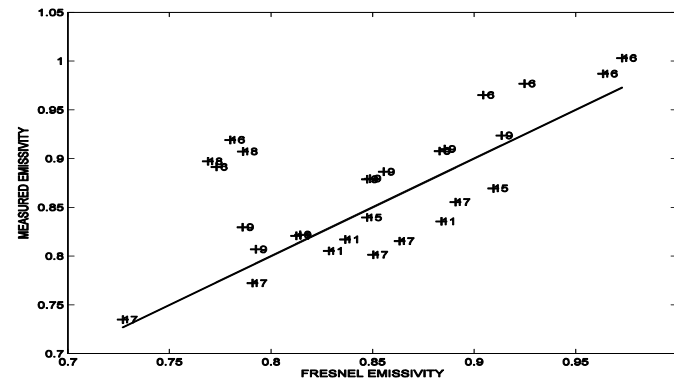


Fresnel e_p

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

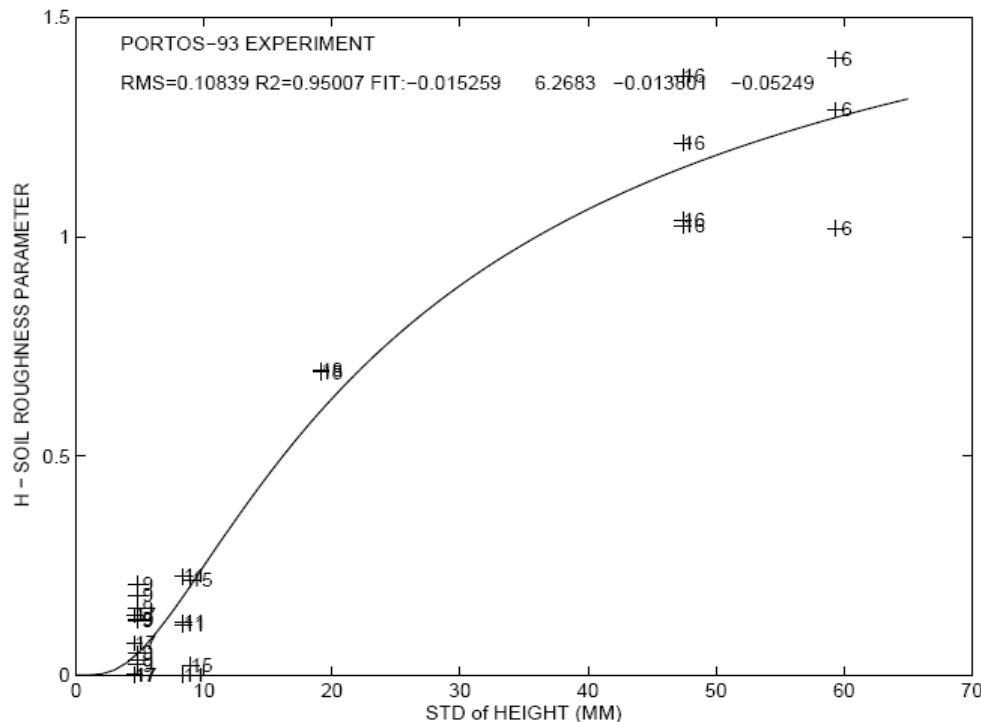
→ Simulations for these fields require the use of the additional Q parameter

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

- Considering Q , NR_v and NR_h

$$\Gamma_{\text{soil-p}} = (Q \cdot \Gamma_{\text{soil-p}}^* + (1-Q) \cdot \Gamma_{\text{soil-q}}^*) e^{-HR \cos N_p(\theta)}$$

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



$$HR = f(\text{STD})$$

$$\rightarrow HR = (a \cdot \text{STD} / (c \cdot \text{STD} + d))^b;$$

$$R^2 = 0.95,$$

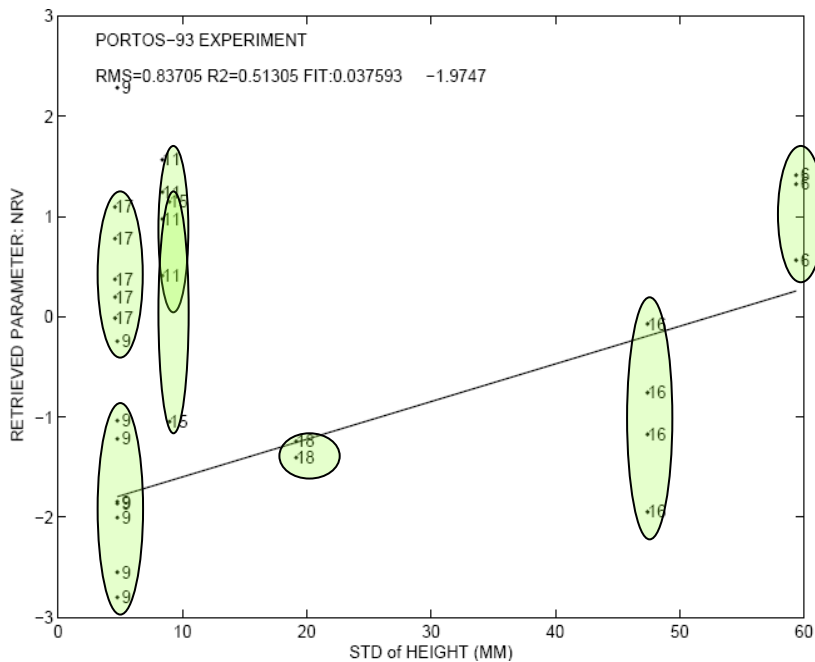
→ no improvement using information about SM or Lc

→ $Q \sim 0.2$ for fields 11, 15, 17
 $Q = 0$, for the others

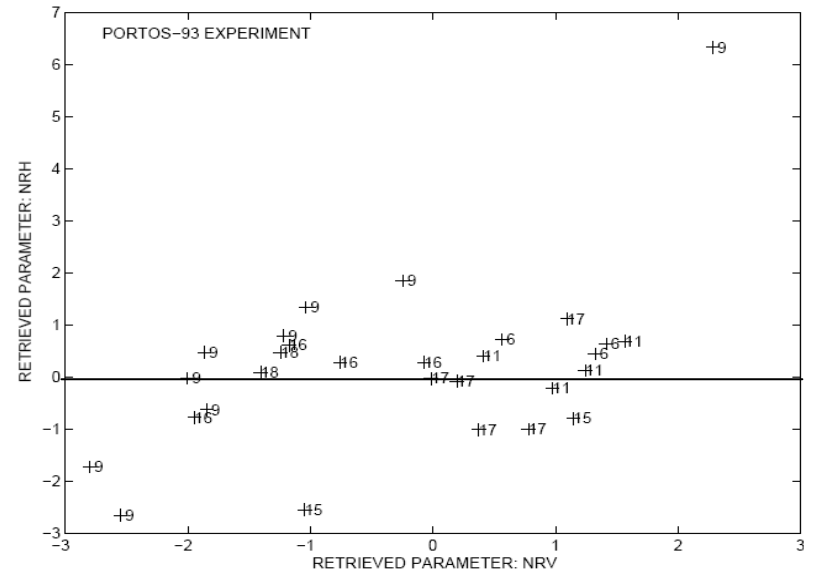
PORTOS-1993: a Re-analysis

- 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.)

$$\text{NRv} = f(\text{STD})$$



$$\text{NRh} = f(\text{STD})$$



PORTOS-1993: a re-analysis

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

→ $\text{HR} = (\text{a.STD} / (\text{c.STD} + \text{d}))^b$;

→ $Q \sim 0.2$ for fields 11, 15, 17
 $Q = 0$, for the others

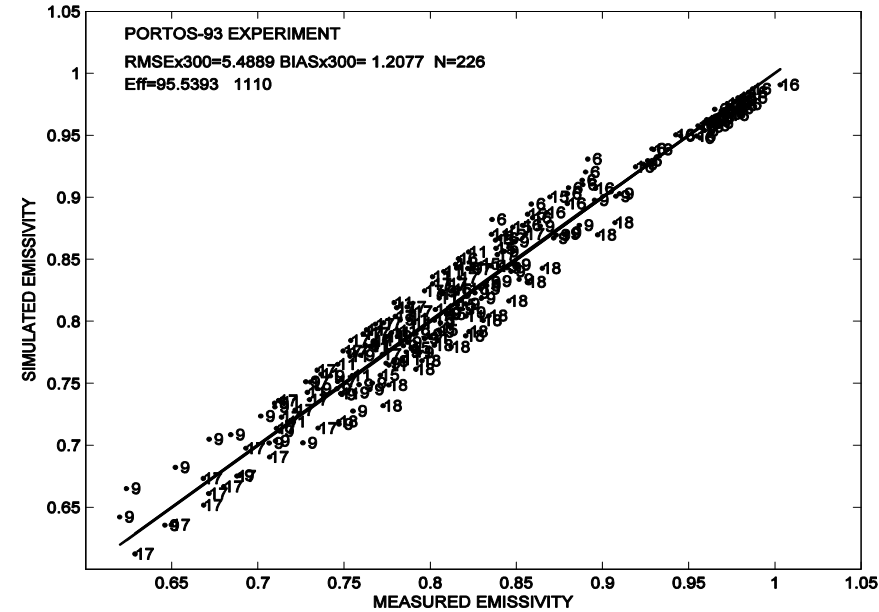
→ $\text{NRh} = 0$

→ $\text{NRv} = f(\text{field})$, between $[-2 .. 1]$

Good agreement with other studies:

-REBEX HR ~ 0.7 for STD = 28mm

-SMOSREX: NRv=-2, NRh=0

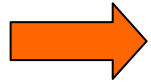


Comparing measured and simulated reflectivities

RMSE ~ 5.5 K

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 (vegetated) 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 $\sim [-2, 0.5]$

-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 ($\theta \geq 30^\circ$)

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

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

