Improved parameterization of the emissivity of soil surfaces and forests at L-band (L-MEB in the Level-2 SMOS algorithm)

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Toulouse, June 10, 2009, Toulouse

Institut National de la Recherche Agronomique INRA CESBIO vrije Universiteit amsterdam

Outlines:

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

- Improving L-MEB: key questions?

- recent results:
    - -surface roughness
    - -forets:

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 : Sept. 2009

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., RSE 07, *in book* 06]

[Mialon et al., 2009]

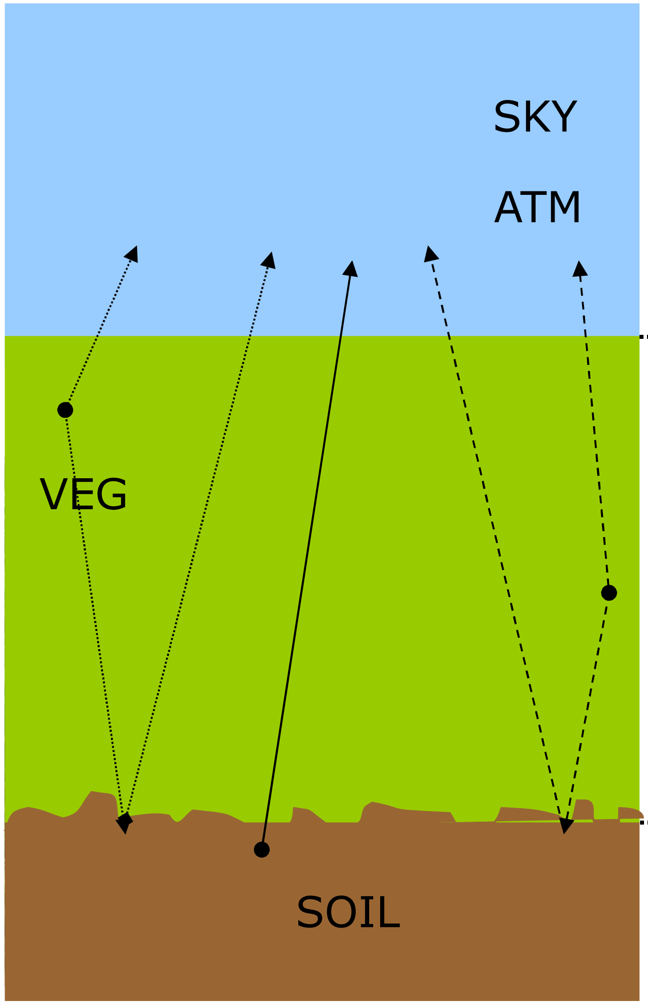
- L-MEB = result of an extensive review of the current knowledge of the microwave emission from vegetation

- 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:

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

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

Key questions still pending:

- soil emission:

  -surface roughness: link between model / geophysical (STD, Lc, …) param.?
  -effective roughness = f(SM)?,
  -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?)

- low vegetation

  -dependence of model parameters on the vegetation structure?
  -relating optical depth TAU with Veg. Water content, or LAI?
  -effect of interception (flagged currently using PR)?

- natural environment (forests, prairies, etc.):

  -modeling litter and interception effects (dry vegetation)
  -optical depth of forest (large variability boreal -> tropical forets?)
  -effect of structure, understory?

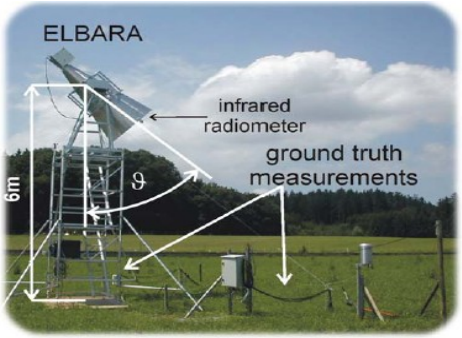
Studies: based on experimental activities for a large range of soil and vegetation conditions:

- SMOSREX (CESBIO, CNRM, INRA, ONERA),
  soil-fallow, Toulouse site, 2003-2009

BRAY - EMIRAD

- BRAY-04-08 (INRA), coniferous forest, Bordeaux
  EMIRAD (TUD), 2004-2008

- ELBARA (ETH, U. of Bern), grass,
  deciduous forest 2004-2006



- …

MELBEX- EMIRAD

Forest emissivity:

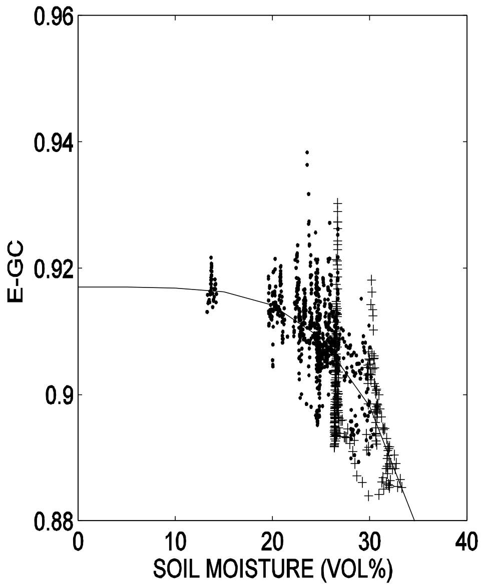
BRAY'2004 experiment: first long term TB exp. over a pine forest (Les Landes, INRA FLUXNET site) **[Grant et al., 2007, 2008, 2009]**

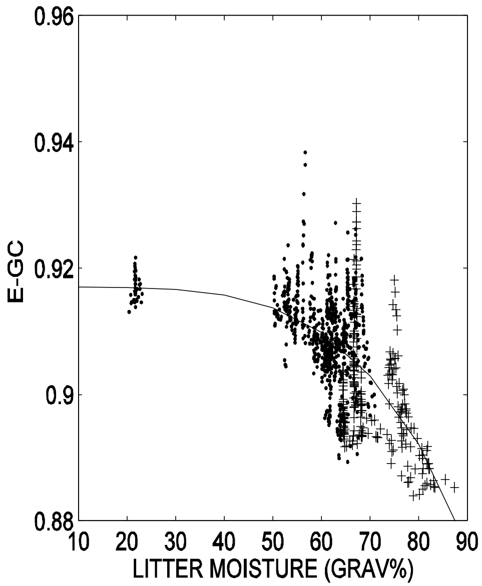
FOSMEX: same over a deciduous forest (JULICH site, ETH Zürich studies) **[Guglielmetti et al., 2007]**

Δ TB ~ 12-15 K between dry / wet conditions

Emissivity = f(SM, LM)

Emirad (TUD, Copenhagen)



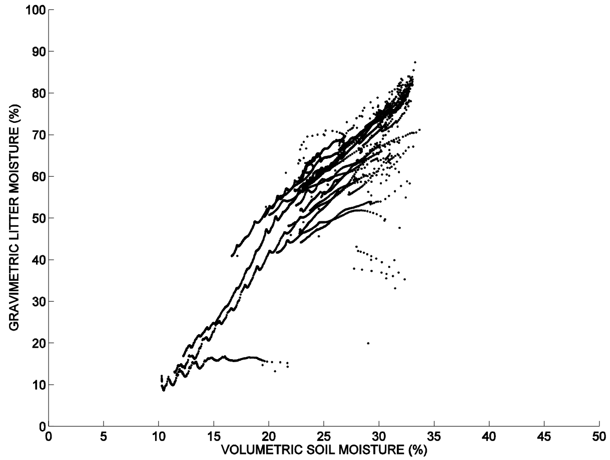


Litter & understory effects

-strong relation between Soil & Litter moisture

-limited emissivity variations due to soil, litter, understory, trees..; ?

Litter Moisture



Soil Moisture

[Grant et al., RSE, 2007]

Bray coniferous forests

Combined analysis of Bray (coniferous, INRA site), FOSMEX (deciduous, Julich site), NAFE'06 (Eucalytus, Australia)

[Grant et al., 2007, 2008]

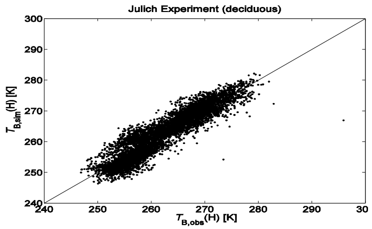
Accuracy of L-MEB: ~ 3K,

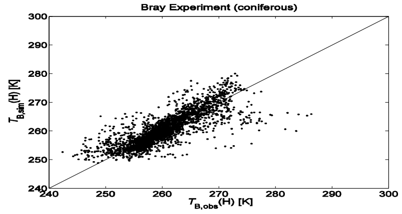
-surface roughness: HR ~ 1 - 1.2 (both sites)
-ω = 0.07

-low angular effects: ttP ~ 0.7 - 1

-tau$_{_NAD}$ ~ 0.4-0.6 (sparse coniferous –eucalyptus forests)

-tau$_{_NAD}$ ~ 1 (dense deciduous forest)

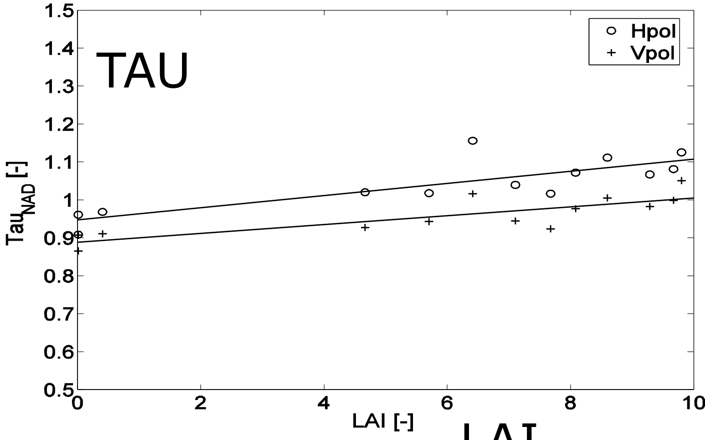




-Transmissivity Γ ~ 0.35 -0.65 at nadir
→ surface effects are strong

-low effects of leaves: 0.03 effects on Γ

-low sensitivity to SM not explained by trees



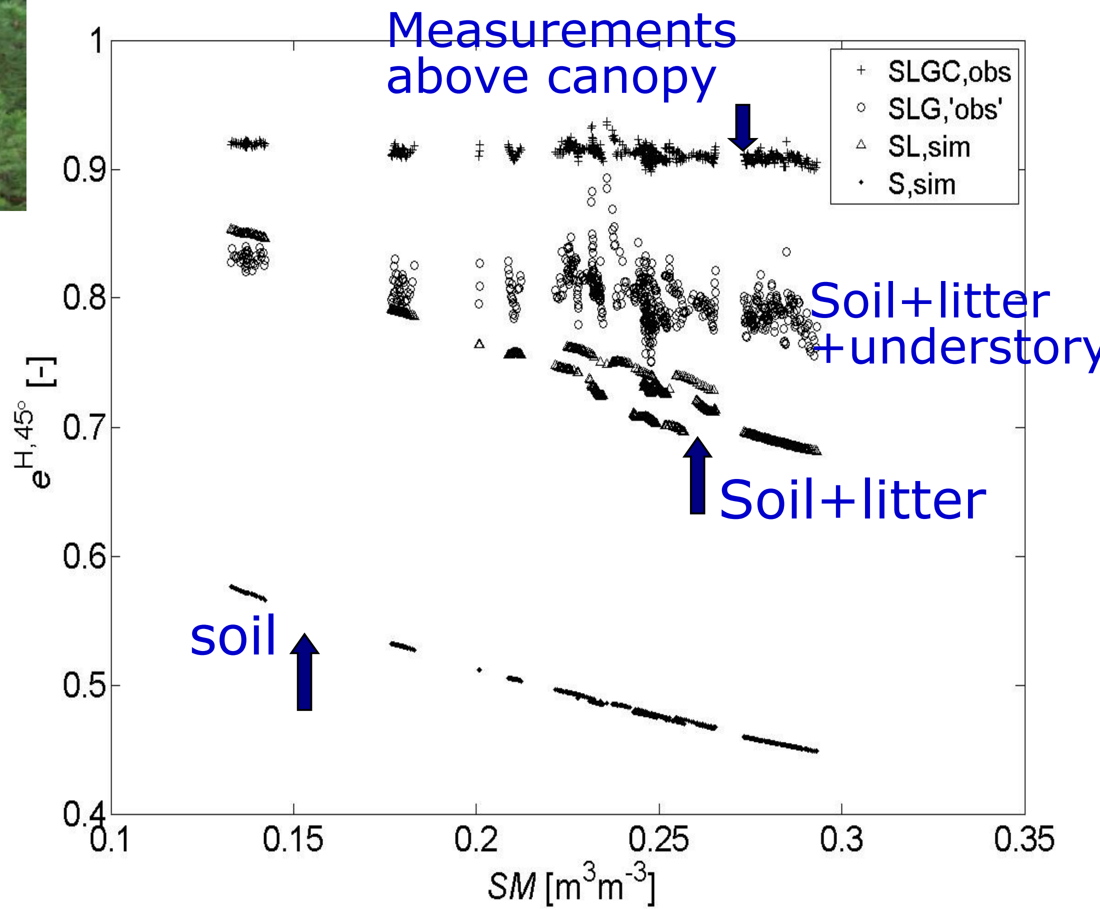
Modelling soil –litter based on a coherent approach (Wilheit model) and dielectric transition model

[Grant et al., 2009]

Over the Bray coniferous site:

→Litter: increase in emissivity, but low effects on sensitivity

→ combined effects of understory and trees on sensitivity



Soil Moisture

Forests signatures - Conclusions

-L-meb: ~3K accuracy for long term experiments over 3 forest sites (coniferous, deciduous, eucalytus)

-low sensitivity to soil moisture (~10-15K change in TB, Δe ~ 0.04) could be related to:

-litter (effects depend a lot on moisture and thickness)

-understory (+ strong interception effects by dead vegetation material)

-trees (transmissivity ~ 035-0.65 over temperate forests)

-generalisation to other forest types…

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

Reflectivity Γ_{soil} = function of Fresnel reflect. Γ^{*}_{soil-p}:

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

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

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

With regular improvements:

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

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

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

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

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

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

Equation used in L-MEB: compromise simplicity/efficiency:

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

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*	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)

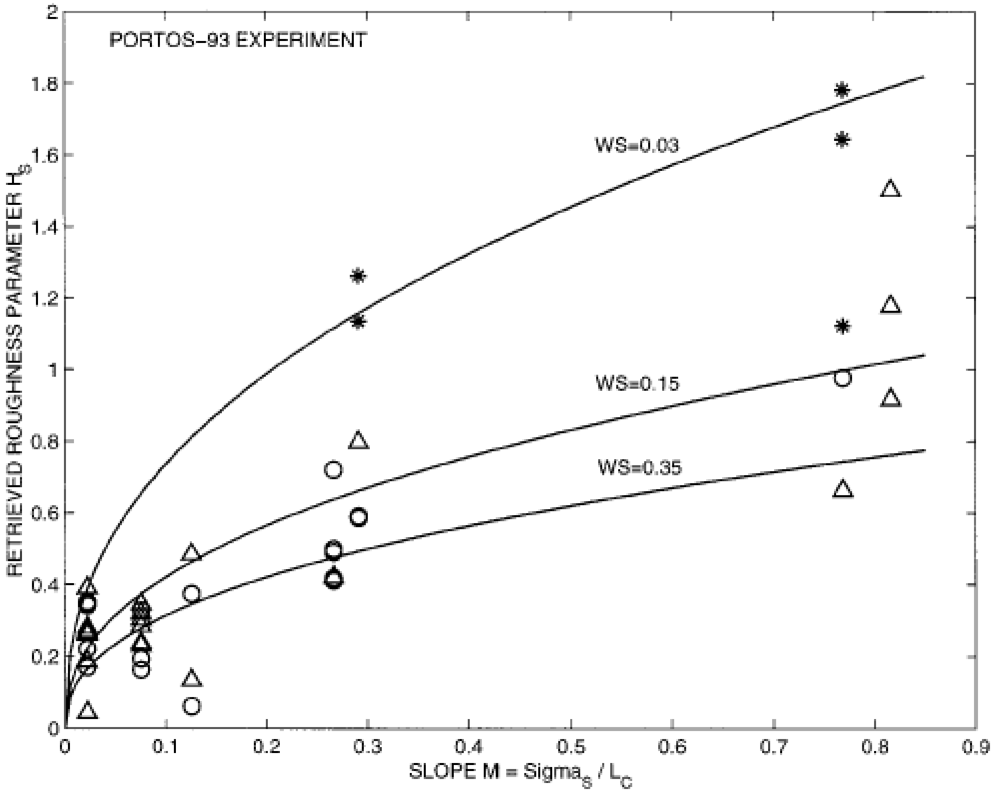
PORTOS-1993: Main results

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

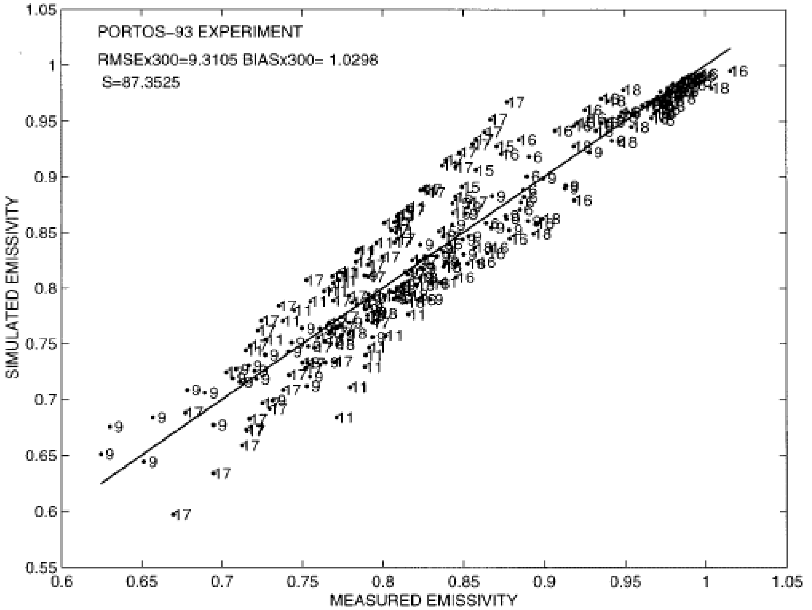
-Q= NRv=NRh=0

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

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



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



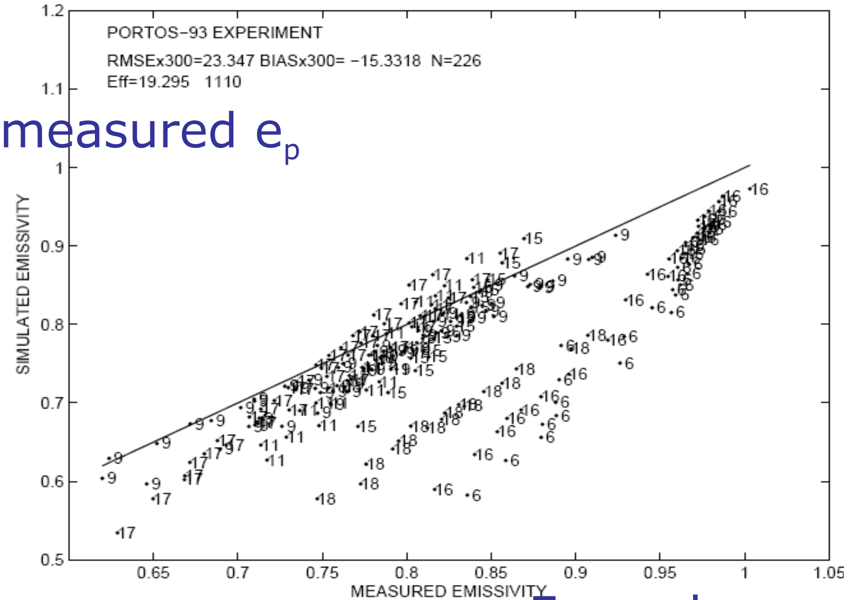
Since then , new results

Shi et al. 2002-2006: ev decreases with roughness at large angles

Escorihuela et al., 2007: distinguishing NRv and NRh

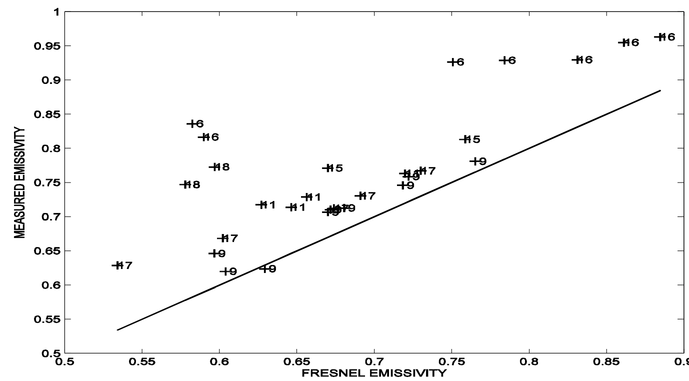
PORTOS-1993: Comparing measured and Fresnel reflectivities

measured e_p

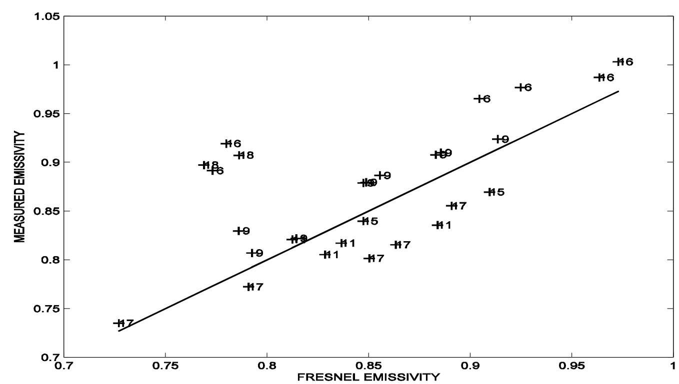


Fresnel e_p

H-pol 40°



V-pol 40°



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

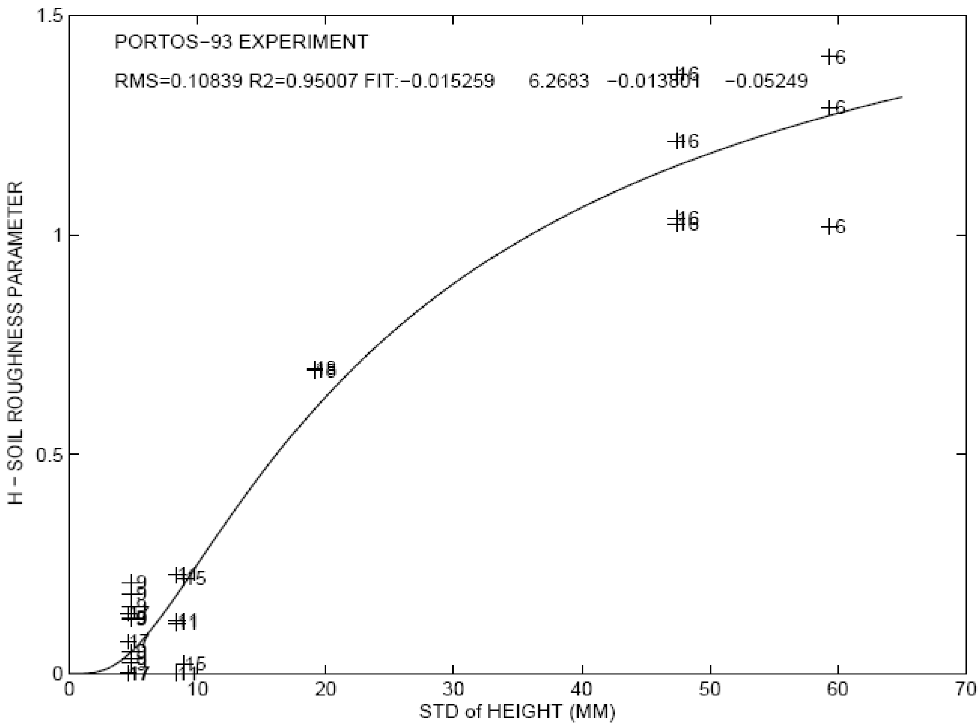
→ Simulations for these fields require the use of the additional Q parameter

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

- Considering Q, NRv and NRh

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

- 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

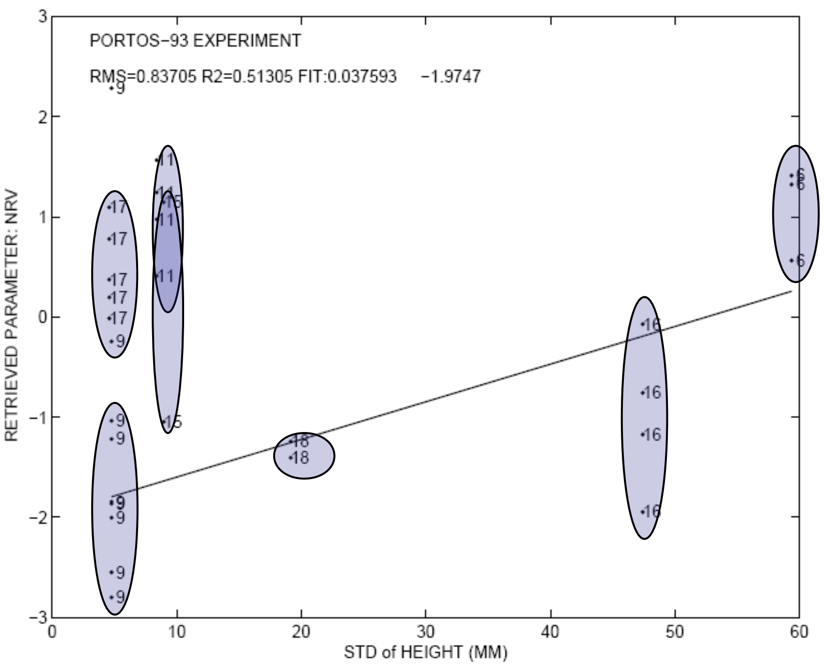
PORTOS-1993: a Re-analysis

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

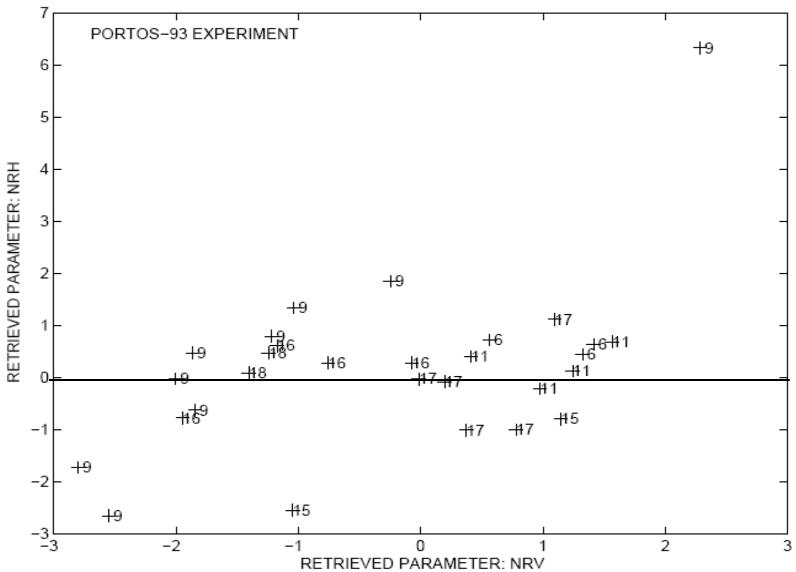
-NRh ≈0

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

NRv = f(STD)



NRh = f(STD)



PORTOS-1993: a re-analysis

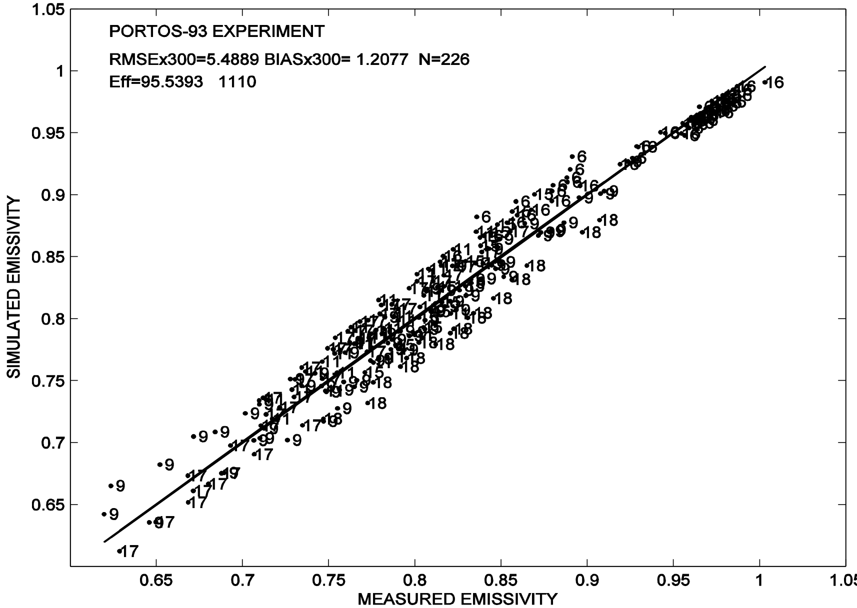
$$\Gamma_{soil\text{-}p} = (Q.\Gamma^{*}_{soil\text{-}p} + (1-Q).\Gamma^{*}_{soil\text{-}q})\, e^{-HR \cos^{Np}(\theta)}$$

→ 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-2005: NRv=-2, NRh=0

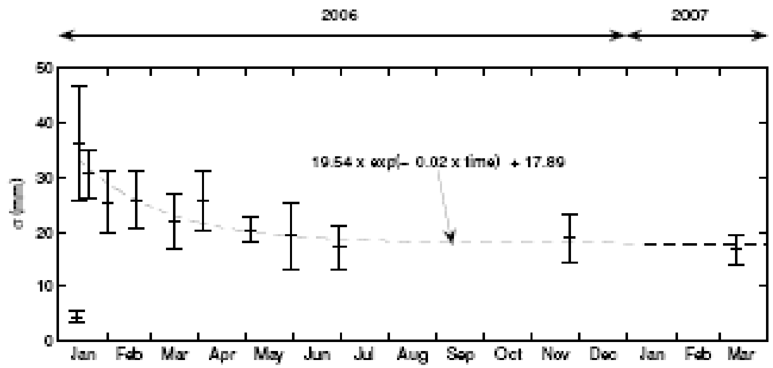
SMOSREX-06 Experiment (Mialon et al., 2009):

One-year decrease of roughness conditions over a plowed bare field left without agricultural practices

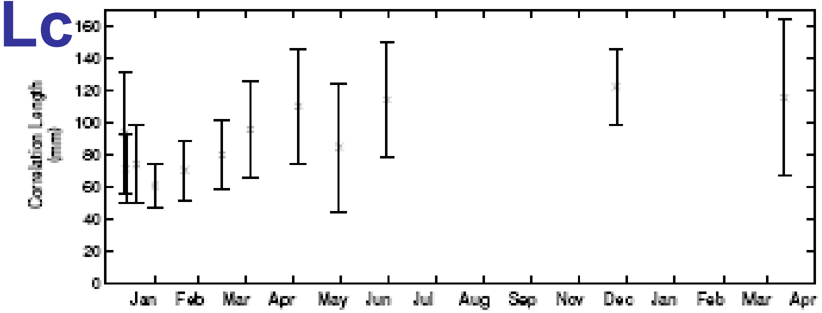
SMOSREX-06 Experiment:

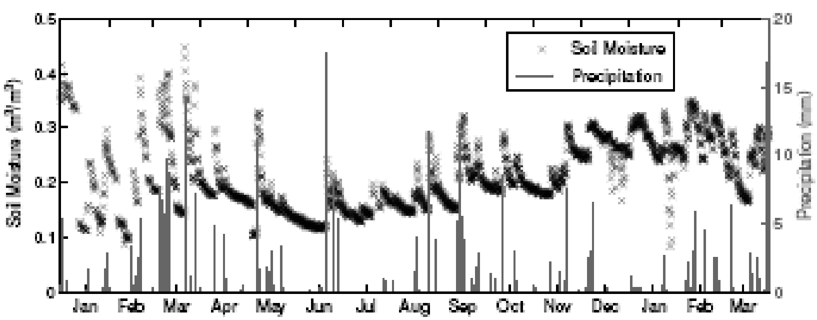
Regular decrease in std of height (σ) and increase in correlation length (Lc), in relation with climatic events

σ



Lc

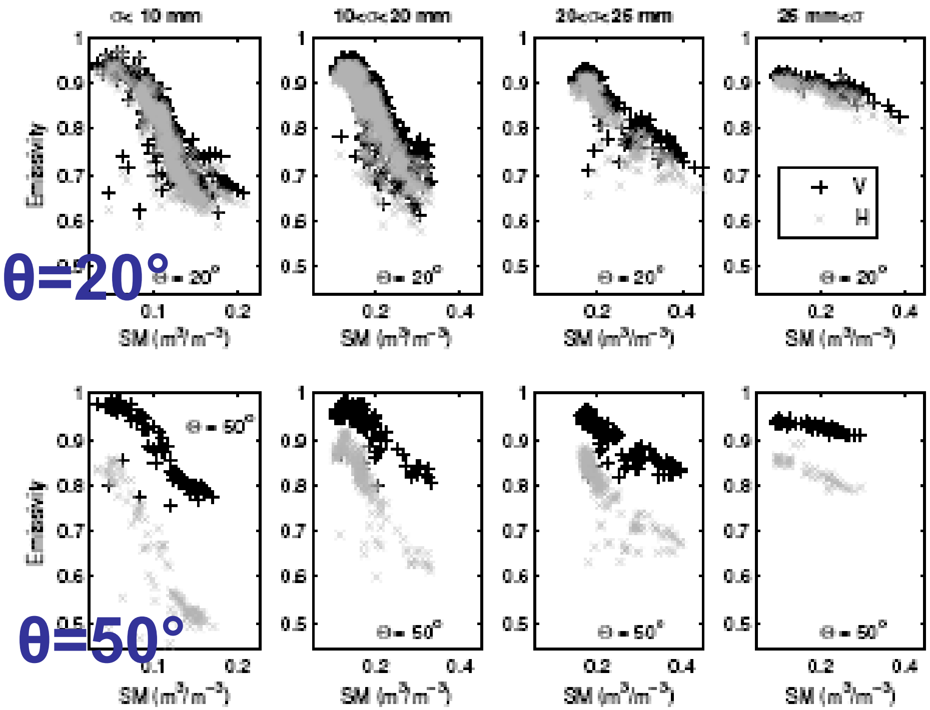




[Mialon et al., 2009]

SMOSREX-06 Exp.: first results

Increasing roughness →



[Mialon et al., 2009]

Shi et al. predicted decrease in ev with increasing roughness

SMOSREX-06: increasing roughness leads to:

-a decrease in ev over dry soils

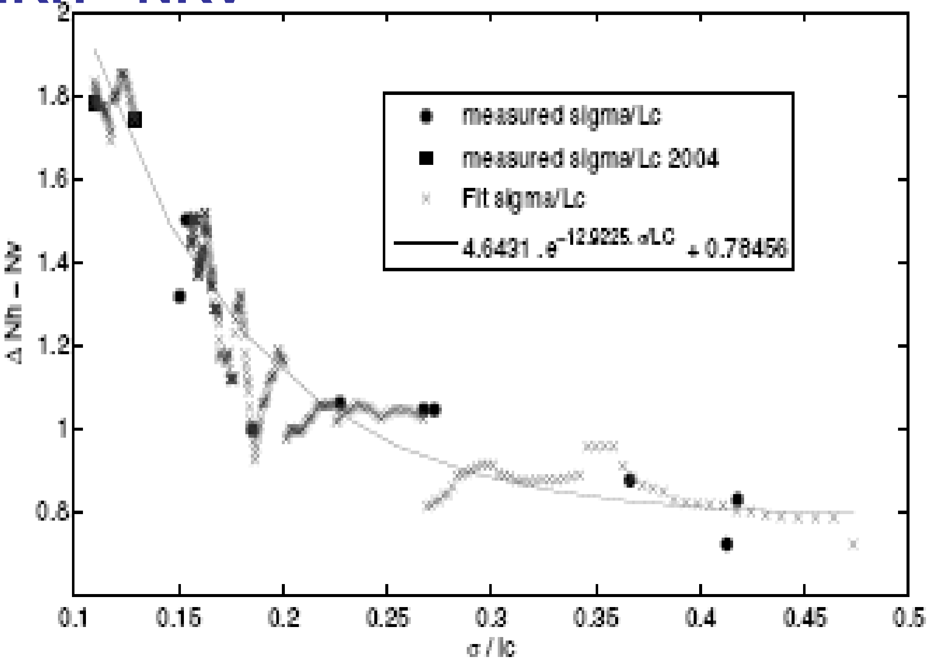
-an increase in ev over wet soils…

SMOSREX-06 Exp.: first results

-Retrieving L-meb parameters: HR, Q, NRv and NRh &

-Investigating relationship with geophysical parameters (σ , Lc, σ /Lc)

NRH - NRV



Increasing roughness (σ / LC) →

[Mialon et al., 2009]

NRV-NRH decreases with roughness (σ / Lc)
(same trend as for PORTOS-93)

L-meb soil modeling conclusions

→ following several recent results (2002-2007) L-MEB modelling of soil could be established based on simple parametrizations of roughness and effective temperature

= very efficient to simulate the signatures of bare soils (multiangular, bi-polarisation) for a large range of conditions

→ relating L-MEB parameters to geophysical parameters (σ , Lc, σ /Lc) is in progress (PORTOS-93, SMOSREX-06-09, etc.)
→ complex theoretical models (AIEM) are still not able to simulate accurately surface/ volume scattering effects
→ studies based on finite elements numerical modelling are carried out currently (INRA/IMS, Bordeaux)