Exploring the Sensitivity of Passive Microwave Signatures to Different Surface and Observation Conditions Using the L-band Microwave Emission of the Biosphere (L-MEB) Model

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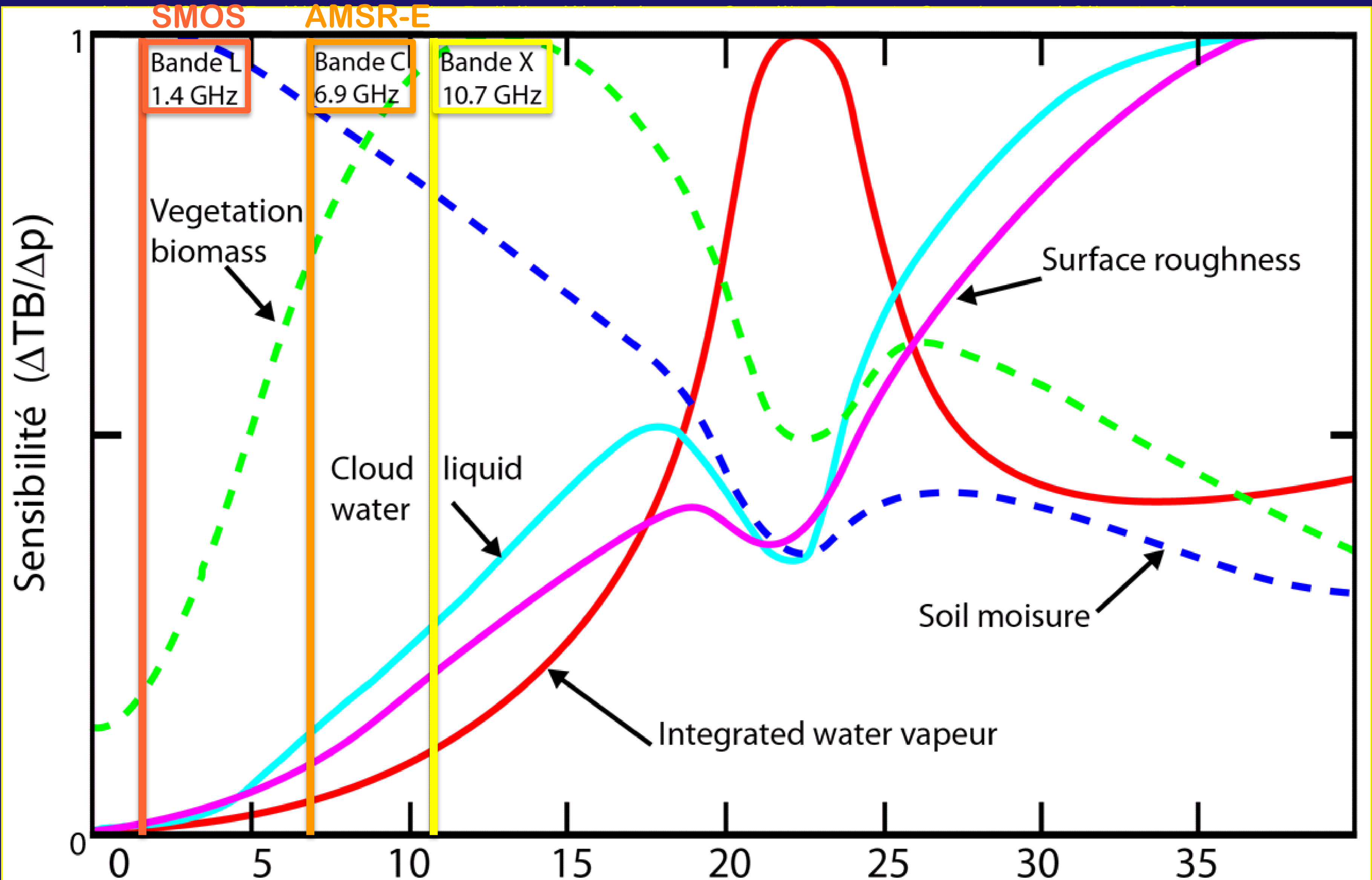
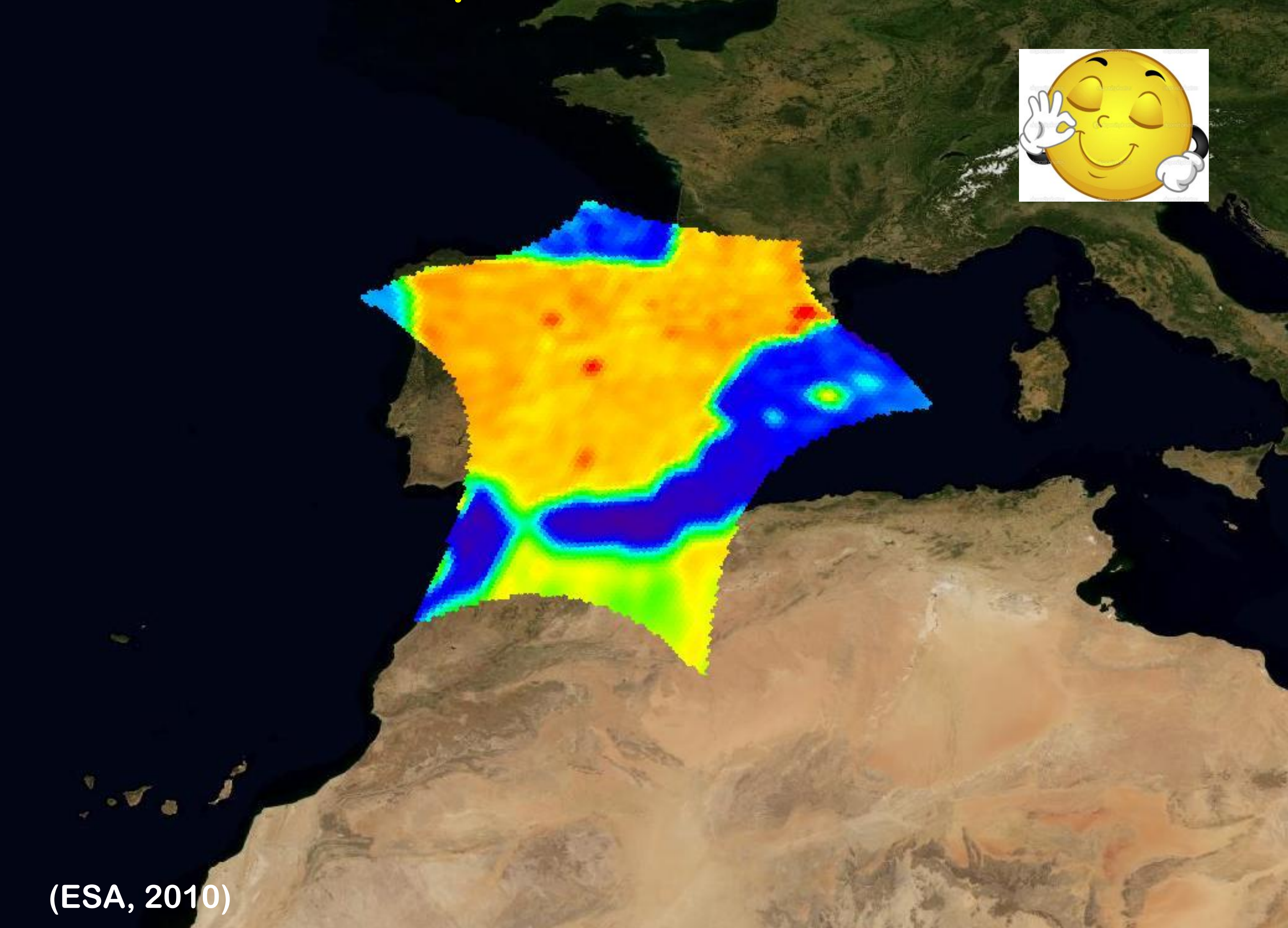


(Berger et al., 2003)

Free RFI over Spain … and over the VAS!!!



(ESA, 2010)

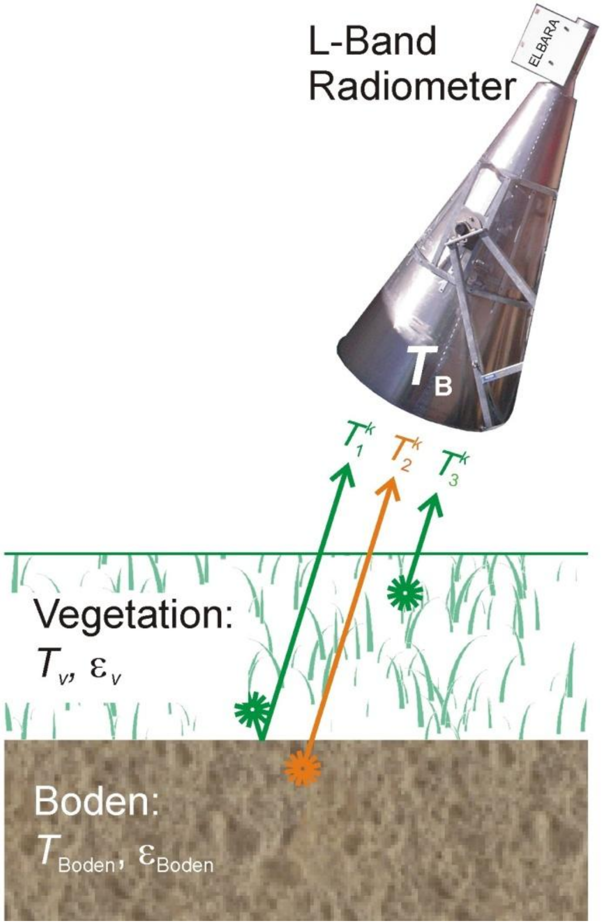
How it works:

The electromagnetic radiance T_B (brightness temperature) of an object is determined by:

Temperature T and emissivity E.

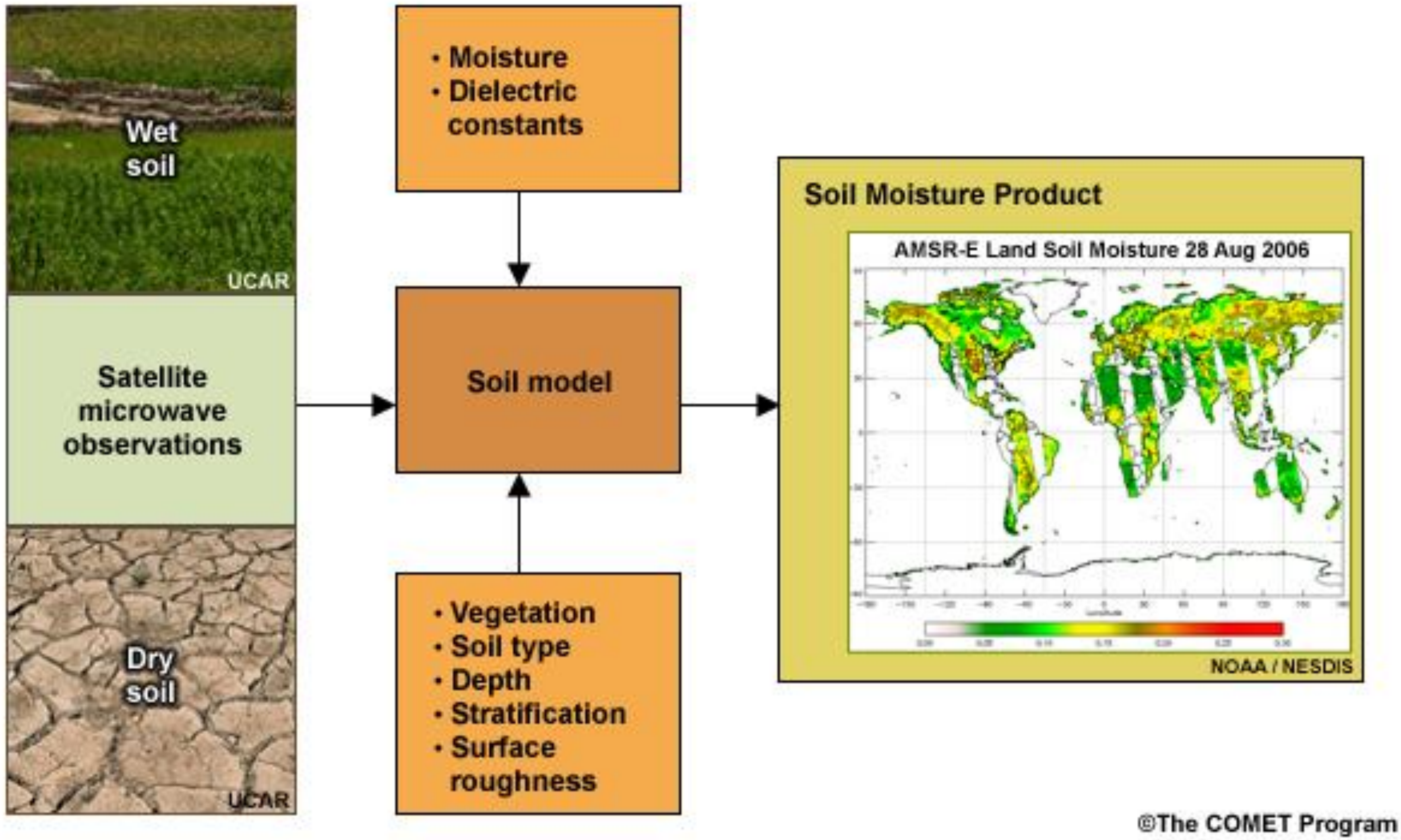
E depends on the dielectric constant ε of the object, and therefore on the water content θ.

measurement:		model:		result:
T_B	⇒	Radiative transfer $T_B = f(T_i,E_i)$ and $E_i = f(\varepsilon_i)$ Dielectric mixing model $\varepsilon = f(\theta)$	⇒	$T_B \Rightarrow \theta$



Radiative components in case of a soil covered with vegetation

Generalized Microwave Soil Moisture Retrieval Process



SMOS

the key point is …

'Brightness temperature' of a specific land surface depends on the vegetation layer optical thickness, the effective surface temperature, and soil type and roughness, as well as soil moisture content. To discriminate among these efects, microwave radiometry offers the possibility of acquiring data at different polarization, different incident angles and, possibly, different frequencies. SMOS can provide dual and full polarization and multi-angle images.

models

A number of models have been developed for the computation of microwave emission from the land surface

- Ulaby et al., 1986
- Wang and Choudhury, 1995
- Njoku and Entekhabi, 1996
- Wigneron et al., 2007
    - Algorithm chosen to retrieve SM from SMOS
        - multi-angular and
        - full-polarization observations
    - *SMOS Level 2 Soil Moisture Processor* is based on the inversion of L-MEB model

with different approximations and parameterizations of the key processes in the radiative transfer equation, depending on the specific application and frequency range.

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

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L-band Microwave Emission of the Biosphere (L-MEB) Model: Description and calibration against experimental data sets over crop fields

J.-P. Wigneron [a,*], Y. Kerr [b], P. Waldteufel [c], K. Saleh [a], M.-J. Escorihuela [b], P. Richaume [b], P. Ferrazzoli [d], P. de Rosnay [b], R. Gurney [e], J.-C. Calvet [f], J.P. Grant [g], M. Guglielmetti [h], B. Hornbuckle [i], C. Mätzler [j], T. Pellarin [k], M. Schwank [h]

The principle of this algorithm is to exploit the multi-angular SMOS observations to simultaneously obtain soil moisture and the radiative characteristics of vegetation over different types of continental covers (Wigneron et al., 2007).

Objectives (1/2)

The main objective of this sensitivity analysis was

- to study the microwave spectral signature of natural surfaces and
- explore the behaviour of L-band brightness temperature as a function of
    - observation angle
    - polarization
        - vertical –V-
        - horizontal –H-
        - normalized difference polarization index
        - polarization ratio

for different conditions

Objectives (2/2)

for different conditions

- Soil type and soil properties
  - texture
  - roughness
- Soil moisture content
- Land use and vegetation type
  - vegetation optical depth –TAU-
  - leaf area index –LAI-
  - biomass
  - For example
    - cereal crops over marl soil
    - grasslands
    - low-vegetation semi-arid zones
    - conifer forests over sandy soil
- Mixed pixel issue (possible presence of water within a land pixel)

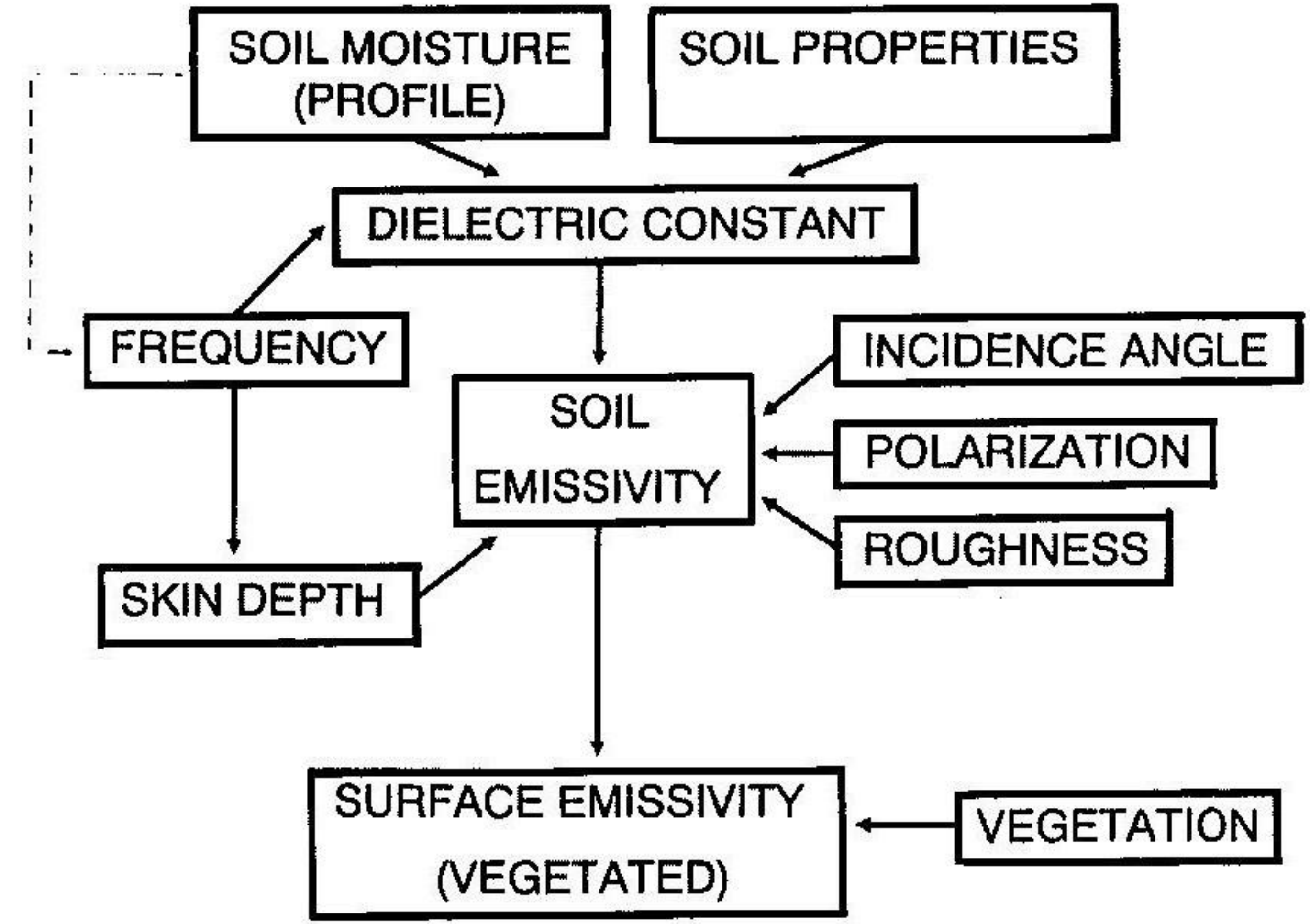


Figure 7

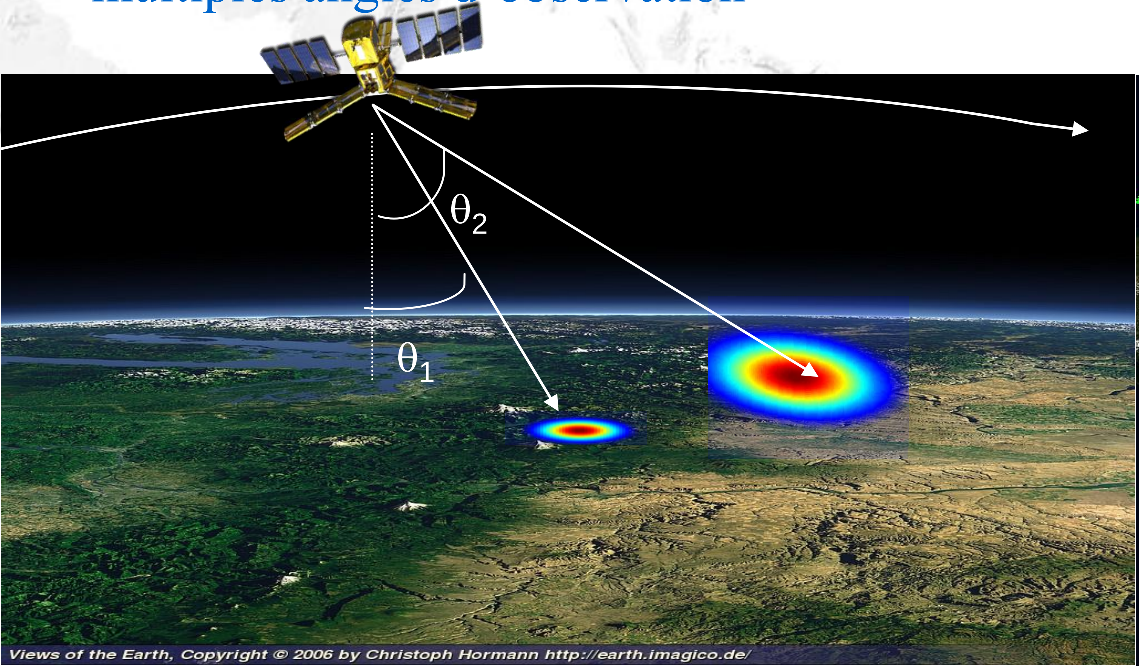
Schematic overview of factors influencing the brightness temperature of a complex, vegetation covered surface (from: Van de Griend and Owe, 1993b).

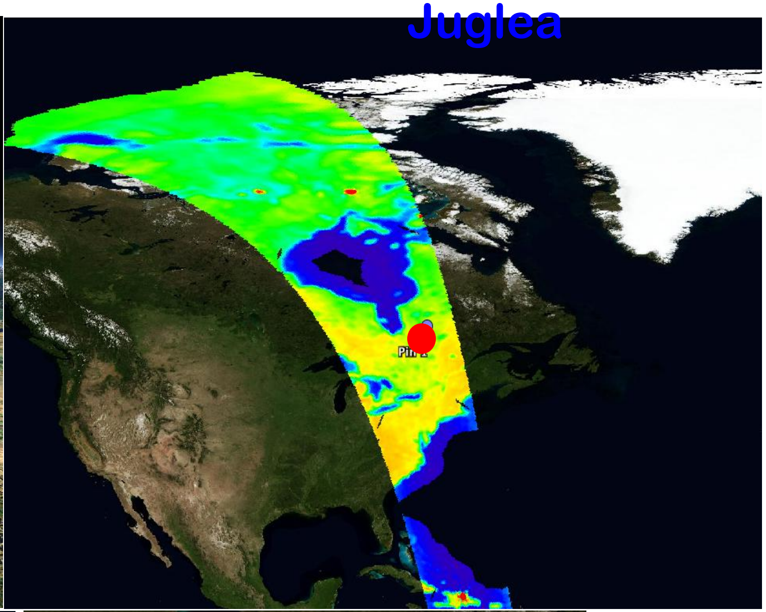
for example … observation angles

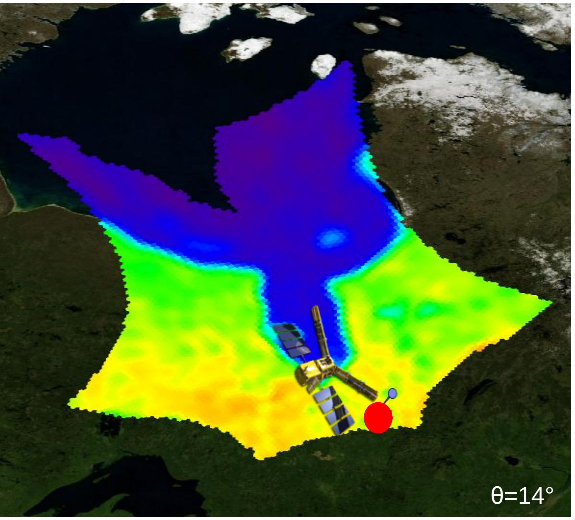
La mission SMOS (Soil Moisture and Ocean Salinity)

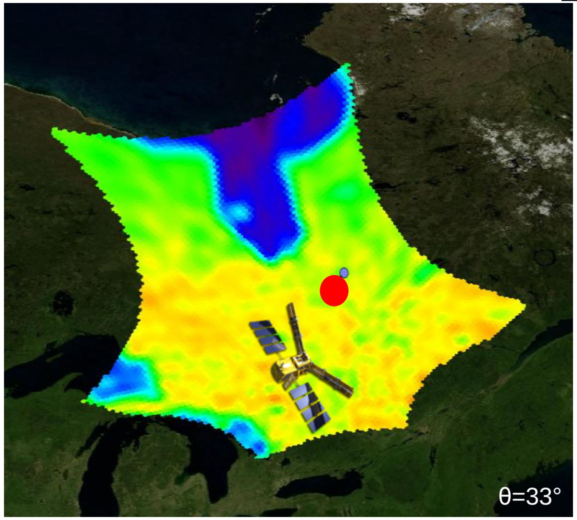
- multiples angles d'observation

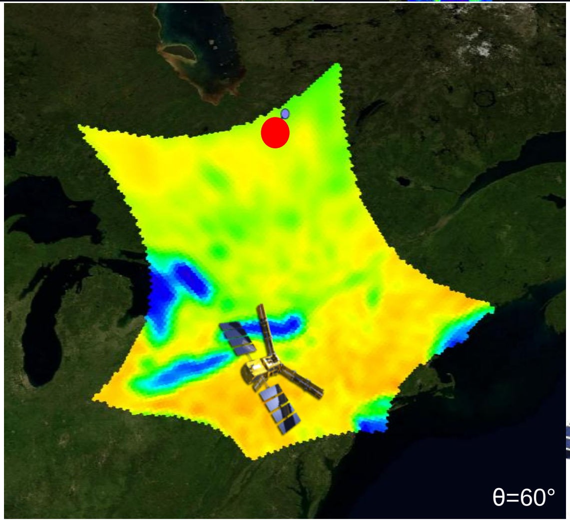
Silvia Juglea











L-MEB Input Variables

Variable Description	Unit
Landmask	-
Sand%	-
Clay%	-
Elevation	m
Vegetation type	-
Air temperature (2m)	K
Leaf Area Index (LAI)	m^2m^{-2}
Surface soil temperature (0 ~ 5cm)	K
Deep soil temperature (50 or 100cm)	K
Vegetation canopy temperature	K
Surface soil moisture	m^3m^{-3}
Surface frozen soil moisture	m^3m^{-3}
Canopy water interception	kgm^{-2}
Snow temperature	K
Snow depth	m
Snow water equivalent	kgm^{-2}
Snow covered fraction	-
Liquid water content of the snow	m^3m^{-3}

L-MEB Model Characteristics/Capabilities

- Brightness temperature simulation for
  - Single frequency (1.4 GHz)
  - Dual polarization (H and V)
  - Multiple incidence angles
  - Various land cover types (and subgrid heterogeneity)
    - Water bodies / Bare soil / Herbaceous canopies / shrubland / forest types
  - A variety of climatological conditions
    - No snow / frozen soil / snow overlaying vegetation

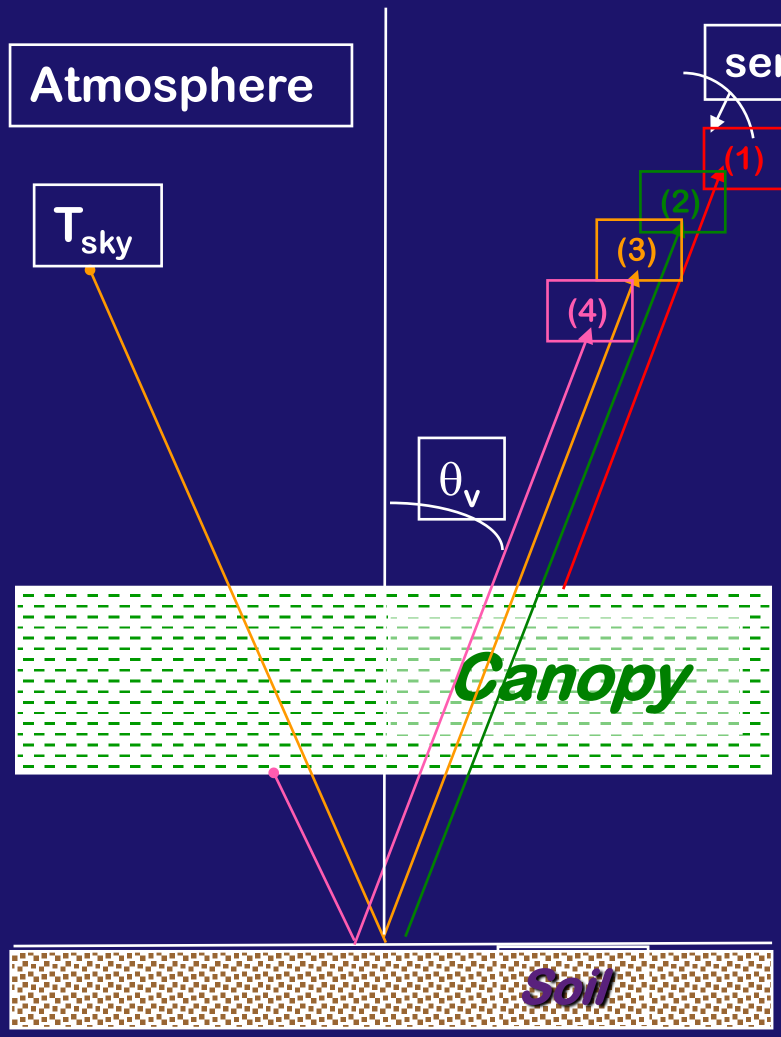
Vegetation Cover Effects (τ-ω Model)

- τ-ω model is based on two parameters
  - Optical depth (τ)
    - To parameterize the vegetation attenuation properties
    - $\tau = b\, W_c$ where W_c is the total vegetation water content.
  - Single scattering albedo (ω)
    - To parameterize the scattering effects within the canopy

τ-ω Model Parameters for common land cover types

Land cover Type	ω	b	Wc
Water bodies		0.0	
Bare soil		0.0	
Crops	0.05	0.15	0.5*LAI
Grasslands	0.05	0.20	0.5*LAI
Shrubland	0.00	0.15	2 kgm^{-2}
Rainforests	0.15	0.33	6 kgm^{-2}
Deciduous forests	0.15	0.33	4 kgm^{-2}
Conifer forests	0.15	0.33	3 kgm^{-2}

τ-ω Model (con’t)



Radiation components in a vegetation layer

- The direct vegetation emission (1)
- Soil-surface emission attenuated by the canopy (2)
- Downward cosmic background and atmospheric radiation attenuated by the canopy (3)
- The vegetation emission reflected by the soil and attenuated by the canopy (4)

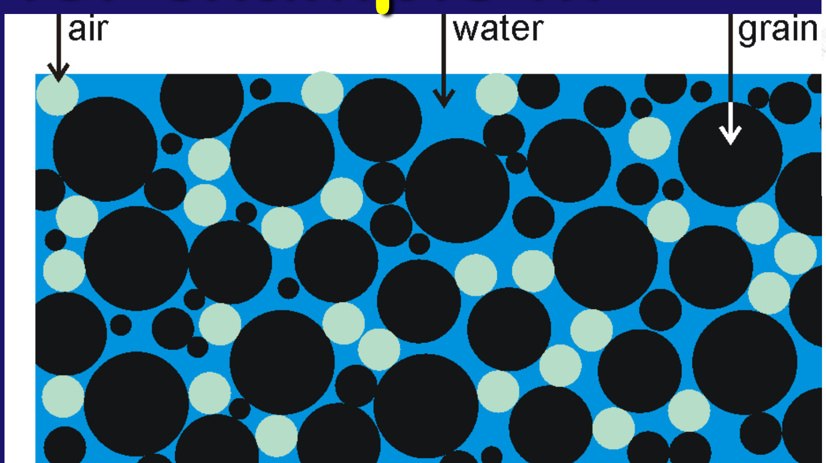
Snow-covered Surface (HUT Snow Model)

- Snow overlaying herbaceous vegetation canopies (soil/vegetation/ snow/atmosphere medium)
  - Soil/vegetation emission (τ-ω model)
  - Soil/vegetation emission is treated as that of the soil which is overlaid by snow (HUT model)
- Snow under forest /shrubland canopies (soil/snow/forest or shrubland/atmosphere medium)
  - Soil/snow cover emission (HUT model)
  - Soil/snow cover emission is treated as that of the soil which is overlaid by forest or shrubland canopies (τ-ω model)

Other Issues

- Subgrid heterogeneity
  - Brightness temperature of the mixed pixel is simulated as a linear combination of each cover fraction and its respective brightness temperature.
- Treat soil as stratified dielectric instead of uniform dielectric.
- Account for topography effects (right now only for atmosphere).
- Some improvements are necessary for the emission simulation over snow-covered surface (HUT model is an approximate approach).

for example …



$$\varepsilon_S = \varepsilon_w + 3\varepsilon_w \frac{(1-\eta)\dfrac{\varepsilon_M-\varepsilon_w}{\varepsilon_M+2\varepsilon_w} + (\eta-\theta)\dfrac{\varepsilon_A-\varepsilon_w}{\varepsilon_A+2\varepsilon_w}}{1-\left[(1-\eta)\dfrac{\varepsilon_M-\varepsilon_w}{\varepsilon_M+2\varepsilon_w} + (\eta-\theta)\dfrac{\varepsilon_A-\varepsilon_w}{\varepsilon_A+2\varepsilon_w}\right]}$$

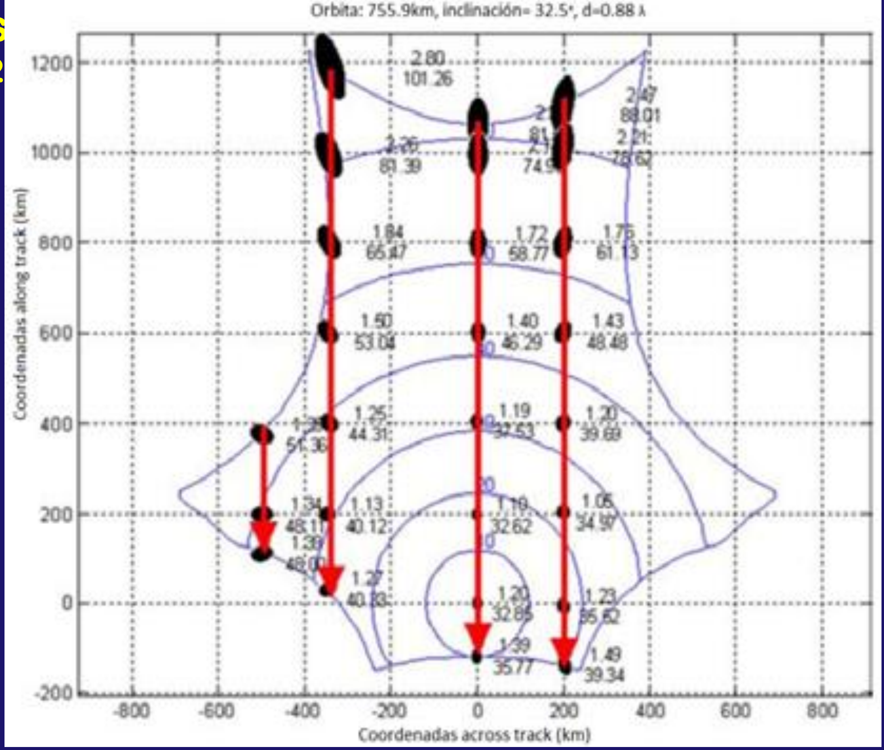
Maxwell-Garnett formula:

η = porosity

θ= volumetric water content

ε_A, ε_W, ε_M, permittivities of air, water, and matrix (grains)

Mike Schwank



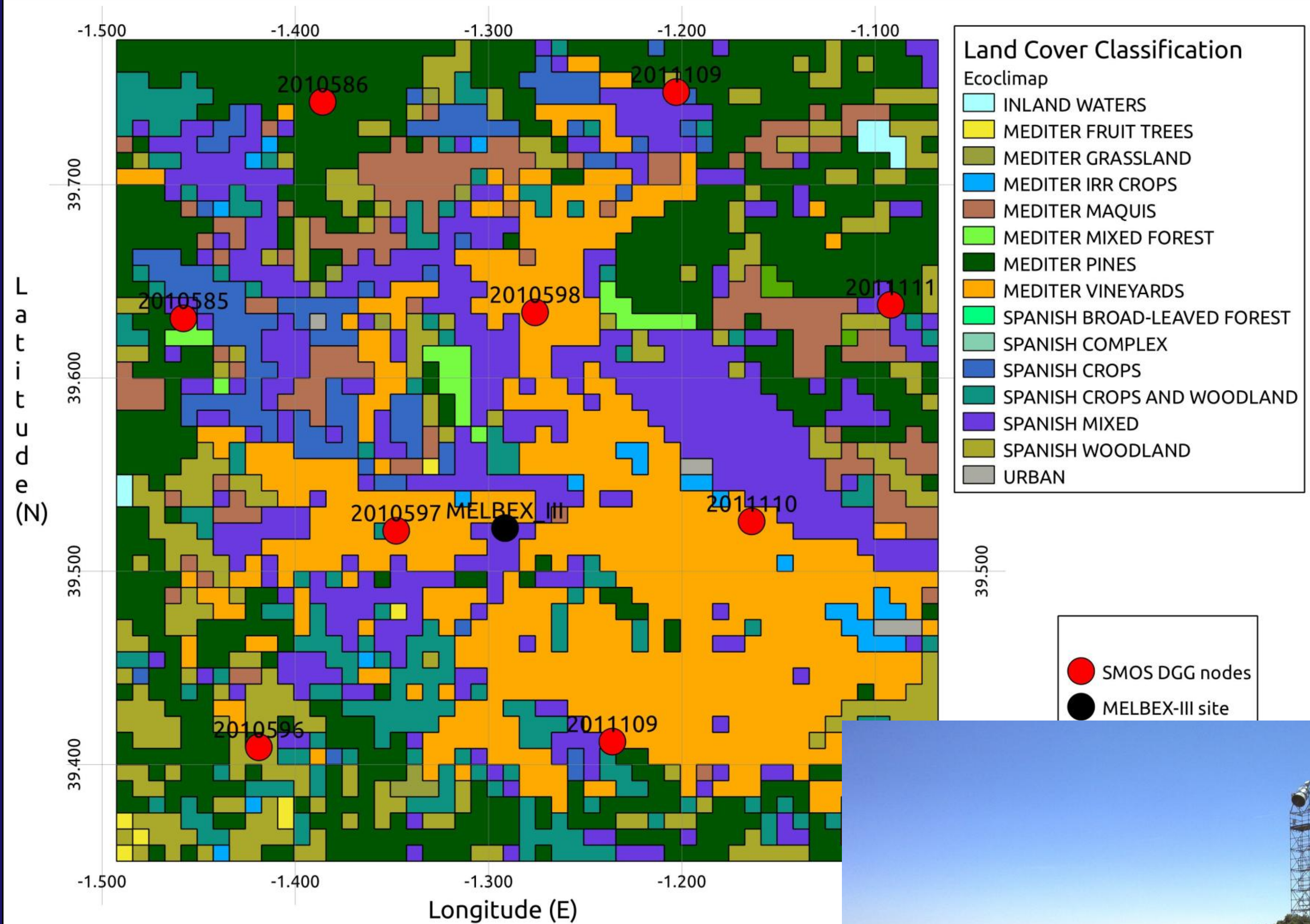
As the satellite moves over the Earth, a given point within the Field Of View (FOV) is observed from **different view angles** by the 2-D interferometer.

The series of **dual-polarized multi-angular measurements allow simultaneous retrievals of several surface parameters including soil moisture and vegetation optical depth** (Wigneron et al., 2001).

As part of the SMOS mission, geophysical products such as **soil moisture (SM) and vegetation opacity (τ) are produced by an operational algorithm.**

In the algorithm, for each incidence angle, the different cover types (bare soil and vegetated area, open water, urban area, etc.) present within the SMOS footprint are estimated from high resolution land use maps.

For low vegetation and forest categories, these maps use a large number of sub-categories corresponding, for instance, to grasslands, crops, scrubs, tropical and boreal forests, which were distinguished for a variety of climatic and geographic conditions. Currently, the ECOCLIMAP data base (Masson et al., 2003) that distinguishes 218 ecosystems at 1 km resolution was selected as the reference landcover map.



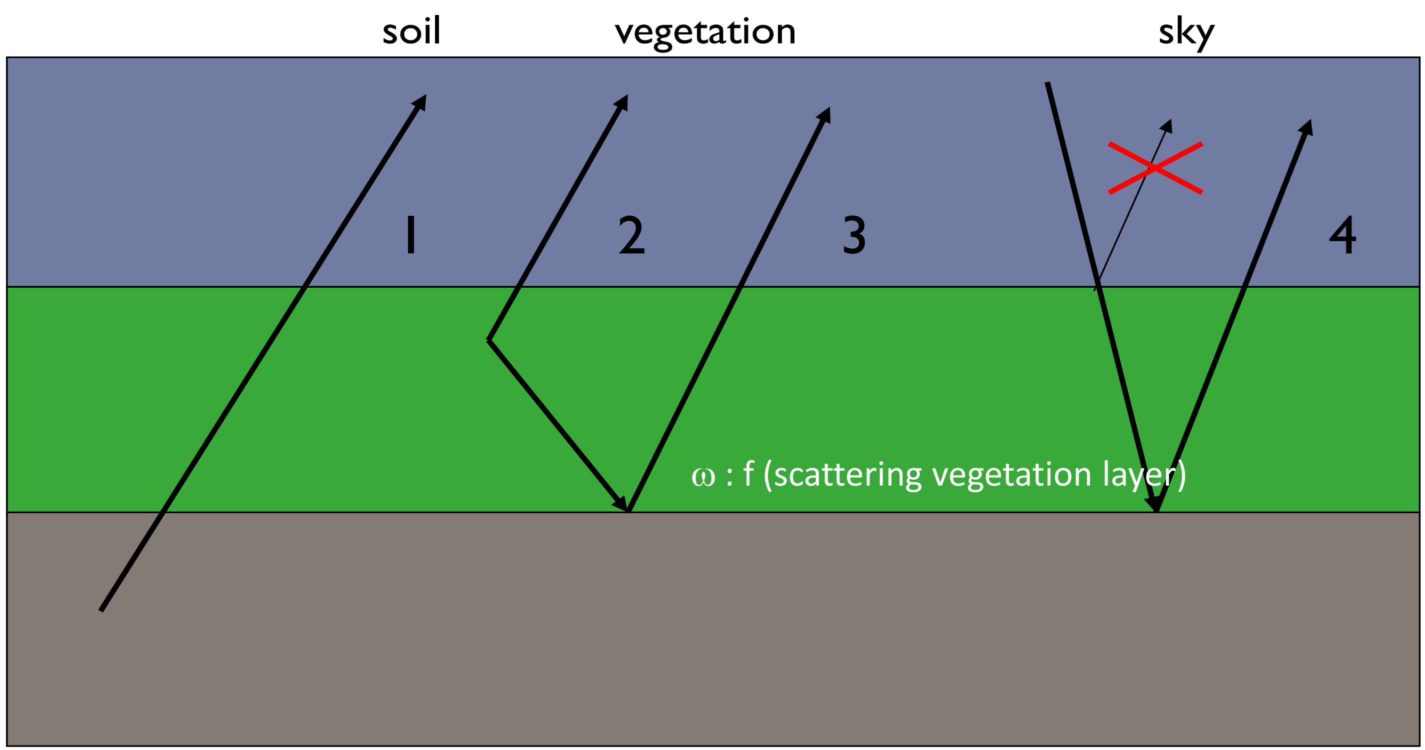
E. Lopez-Baeza. Exploring the Sensitivity of Passive Microwave Signatu

Within each pixel, the brightness temperatures from each cover type are simulated with a forward model and then aggregated, accounting for the SMOS field of view and antenna pattern. Parameters driving the forward model are selected and tabulated based on the selected vegetation classes and on maps of soil properties (for soil texture, roughness and bulk density).

The L-MEB manuscript only describes the forward model used over each homogeneous vegetation type and the description of the whole algorithm and of the aggregation process over heterogeneous pixels is described in Kerr et al. (2006) (SMOS Level 2 ATBD)

$$T_{BP}(\theta) = (1-\omega_P)(1-y_P)(1+y_P r_{GP})T_C + (1-r_{GP})\, y_P T_G$$

$$T_{BP}(\theta) = \underbrace{(1-r_{GP})T_G\, y_P}_{1} + \underbrace{(1-\omega_P)(1-y_P)T_C}_{2} + \underbrace{(1-\omega_P)(1-y_P)\, T_C r_{GP}\, y_P}_{3} + \underbrace{T_{Bsky}\, y_P^2 r_{GP}}_{4}$$



Jennifer Grant

$$T_{BP} = (1 - \omega_P)(1 - \gamma_P)(1 + \gamma_P \rho_{GP}) T_C + (1 - \rho_{GP}) \gamma_P T_G$$

$$\gamma_P = \exp(-\tau_P / \cos(\theta))$$

$$\tau_P = \tau_{SP} + \tau_L + \tau_{IP}$$

$$\tau_{SP} : vegetation \cdot layer$$

$$\tau_L : litter \,\&\, understory$$

$$\tau_{IP} : rain \cdot \mathrm{int}\, erception$$

$$\tau_{SP}$$

$$\tau_{S\_NAD} = b' \cdot LAI + b''_S$$

$$\tau_{SH}(\theta) = \tau_{S\_NAD} \left[\sin^2(\theta) \cdot tt_H + \cos^2(\theta) \right]$$

$$\tau_{SV}(\theta) = \tau_{S\_NAD} \left[\sin^2(\theta) \cdot tt_V + \cos^2(\theta) \right]$$

$$T_{BP-TOA} = T_{BP} \exp\left(\frac{\tau_{ATM}}{\cos(\theta)}\right) + T_{B-SKY-U}$$

$$T_G = T_{soil\_depth} + Ct(T_{soil_{surf}} - T_{soil_{depth}})$$

$$C_t = (SM / w_0)^{bw}$$

$$\mathrm{T_{B-GP}} = \mathrm{e_{GP}} \cdot \mathrm{T_G}$$

$$(e_{GP} = 1 - r_{GP})$$

$$r_{GP}(\theta) = \left[\left(1 - Q_{RP}(\theta)\right) r^*_{GP}(\theta) + Q_{RP}(\theta) r^*_{GP}(\theta)\right]$$

$Q_R = 0$ (low frequencies, Wigneron et al., 2001)

$$\mathrm{r}_{GP}(\theta) = [\mathrm{r}^*_{GP}(\theta)]\exp(-H_{RP}(\theta)\cos^{N_{RP}}(\theta))$$

N_R=0 (for 1.4, 5 &10.7 GHz) (Wang et al. 1983)

H_R= Parameterises intensity of roughness effects

Q_R = Parameterises polarisation effects

N_{RP} (p = H,V) = 0 Parameterises reflectance as f(θ)

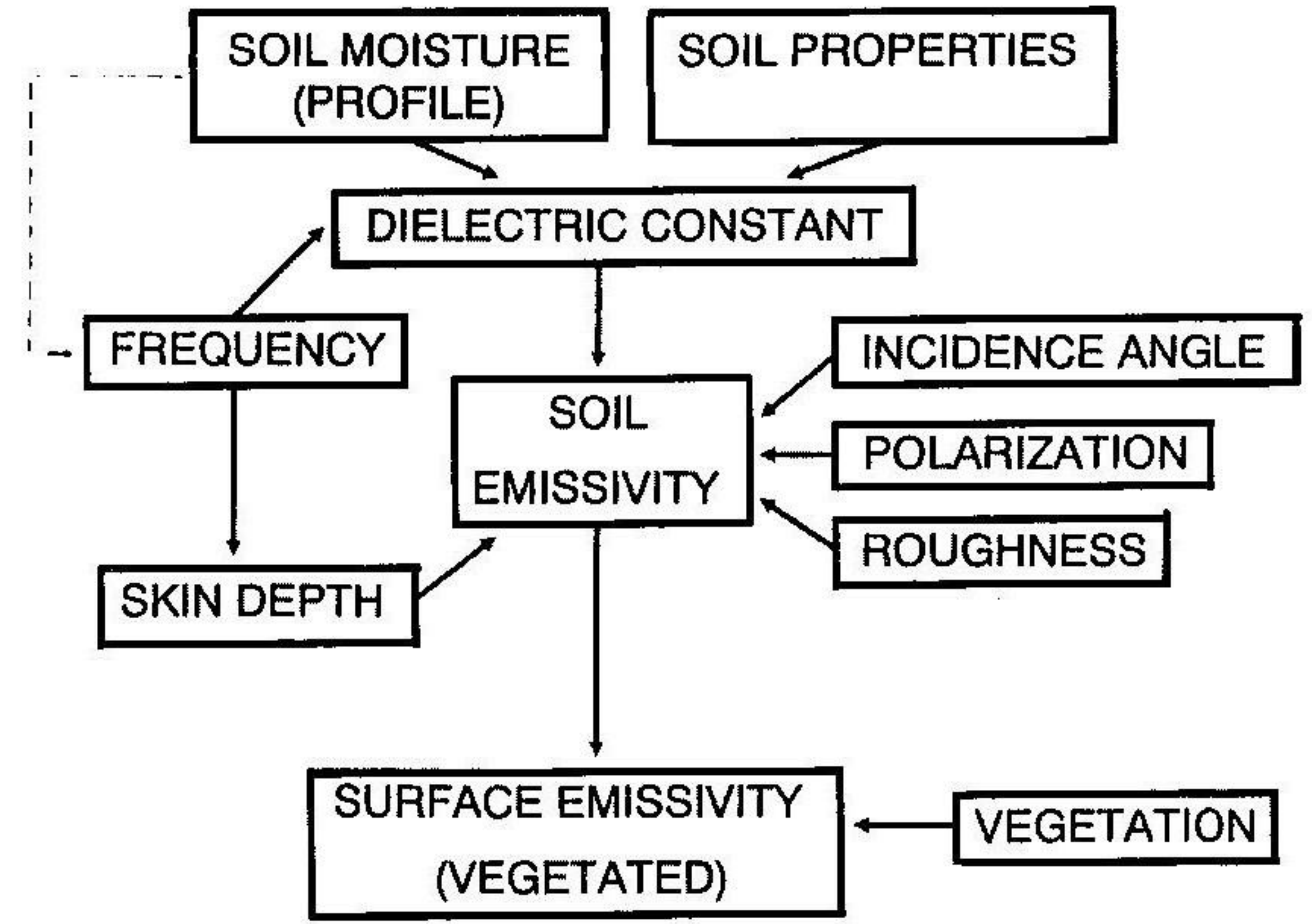
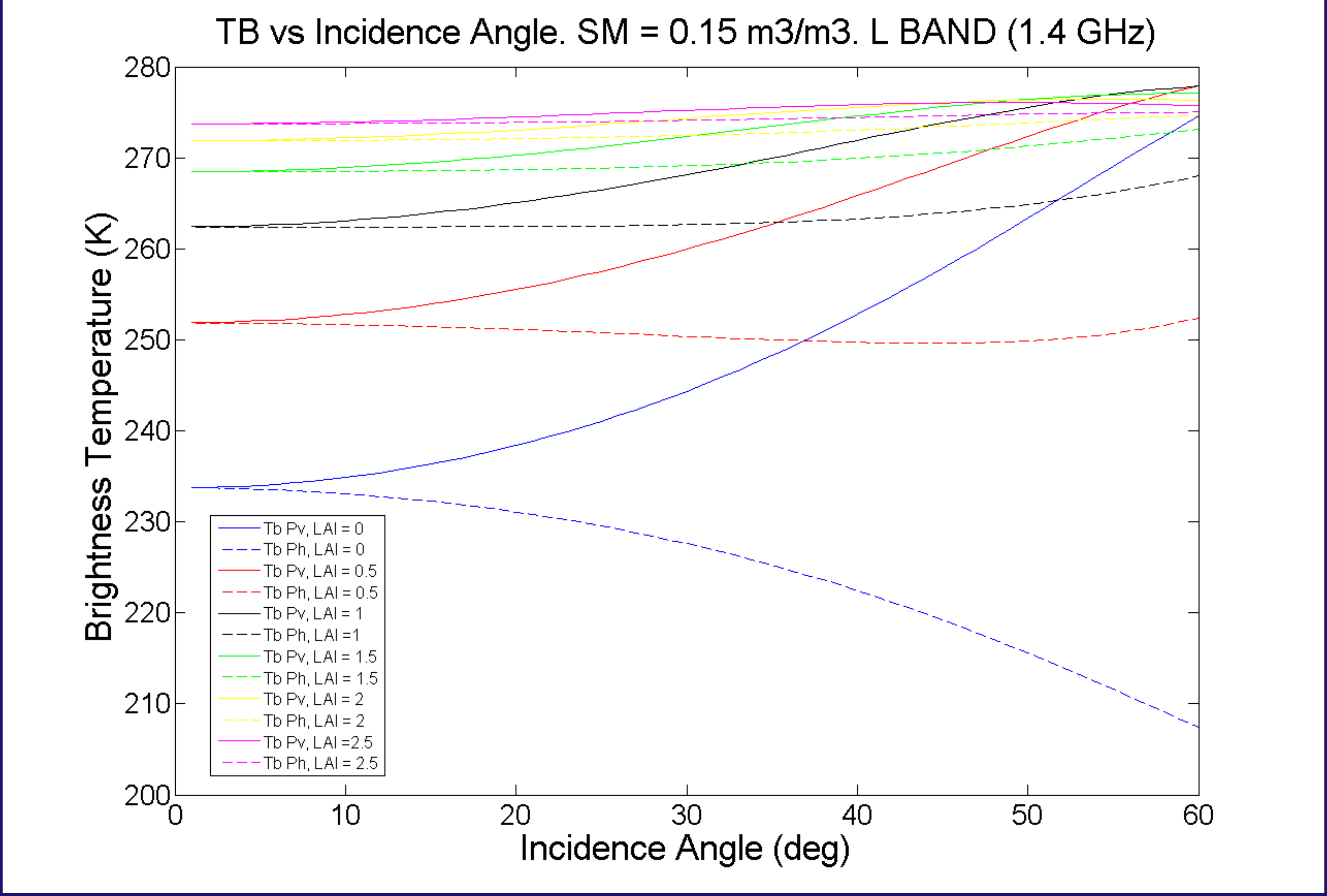
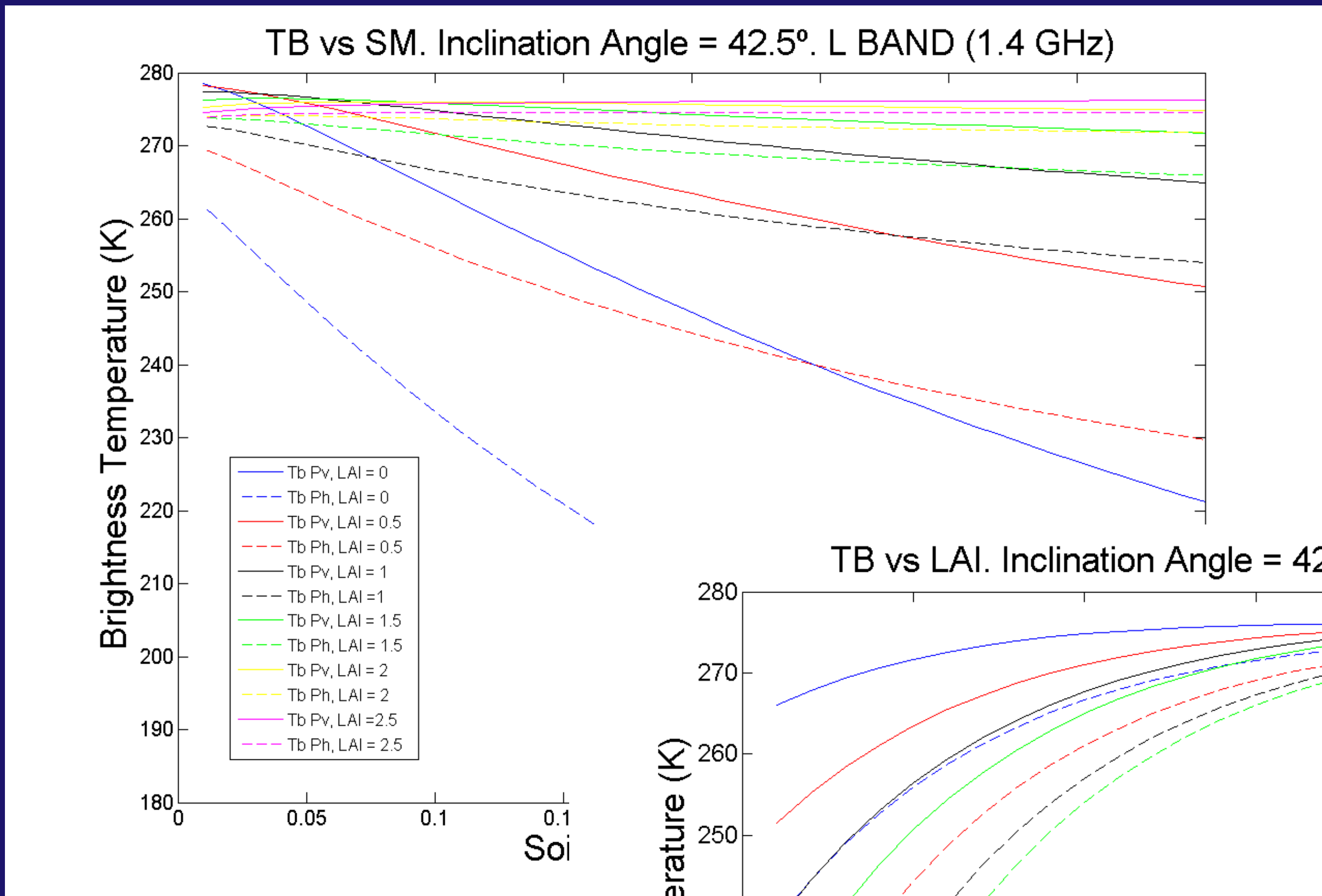
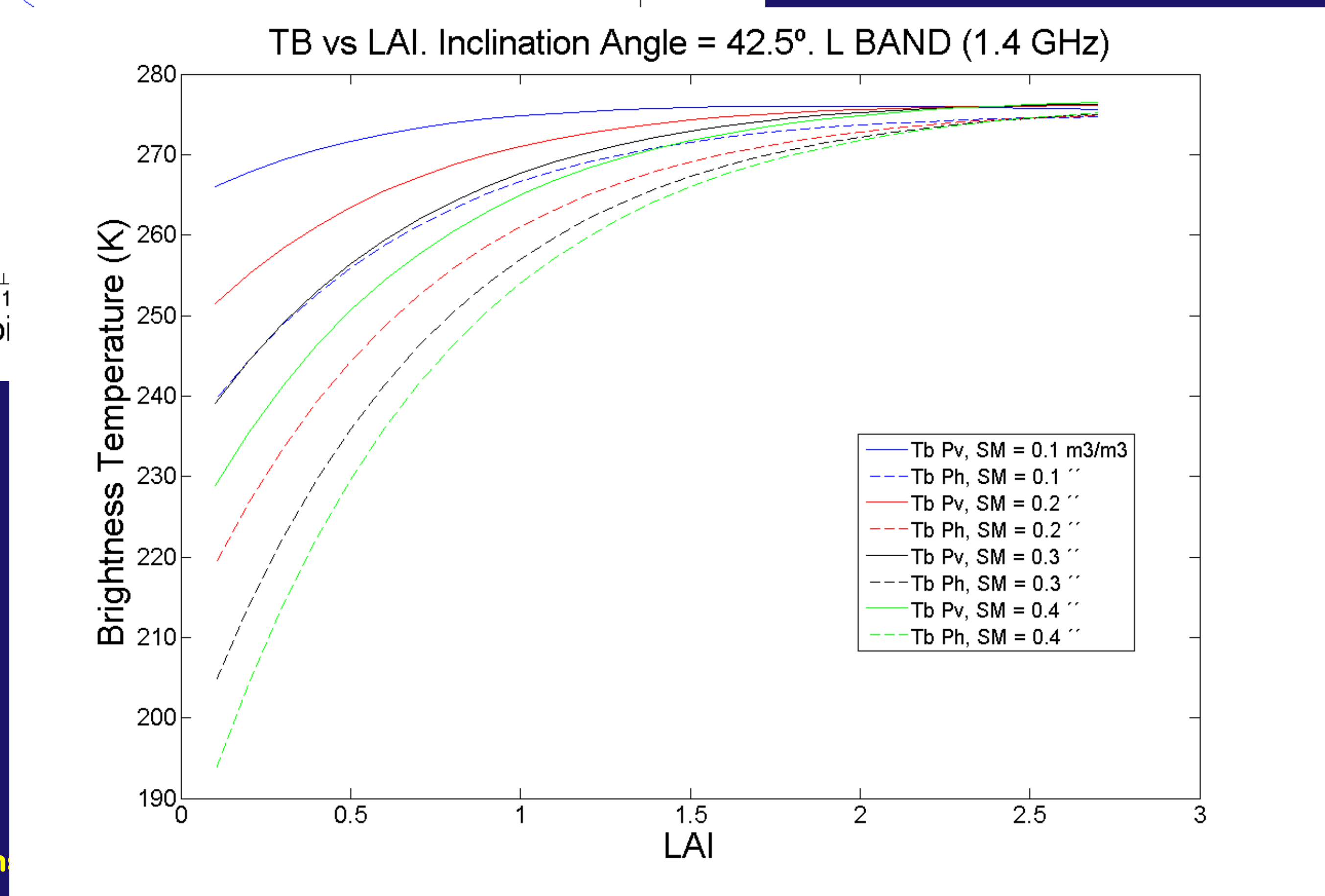


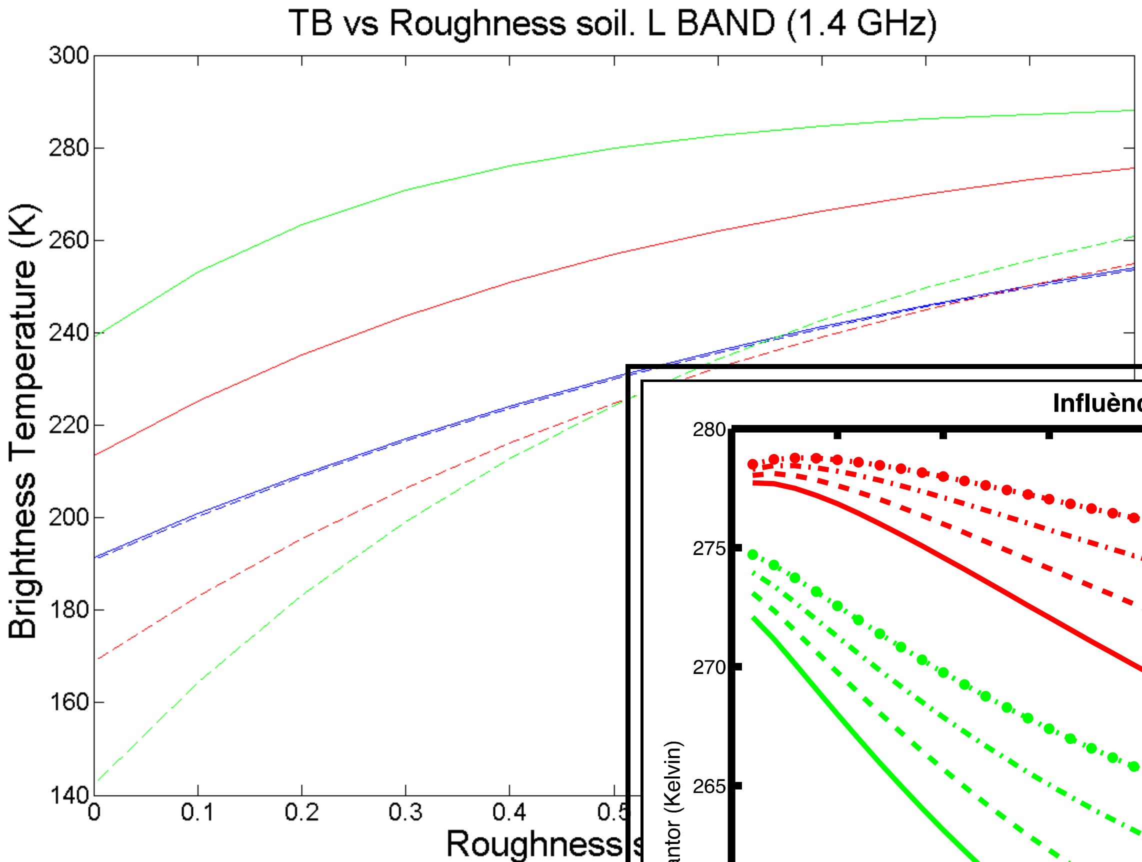
Figure 7

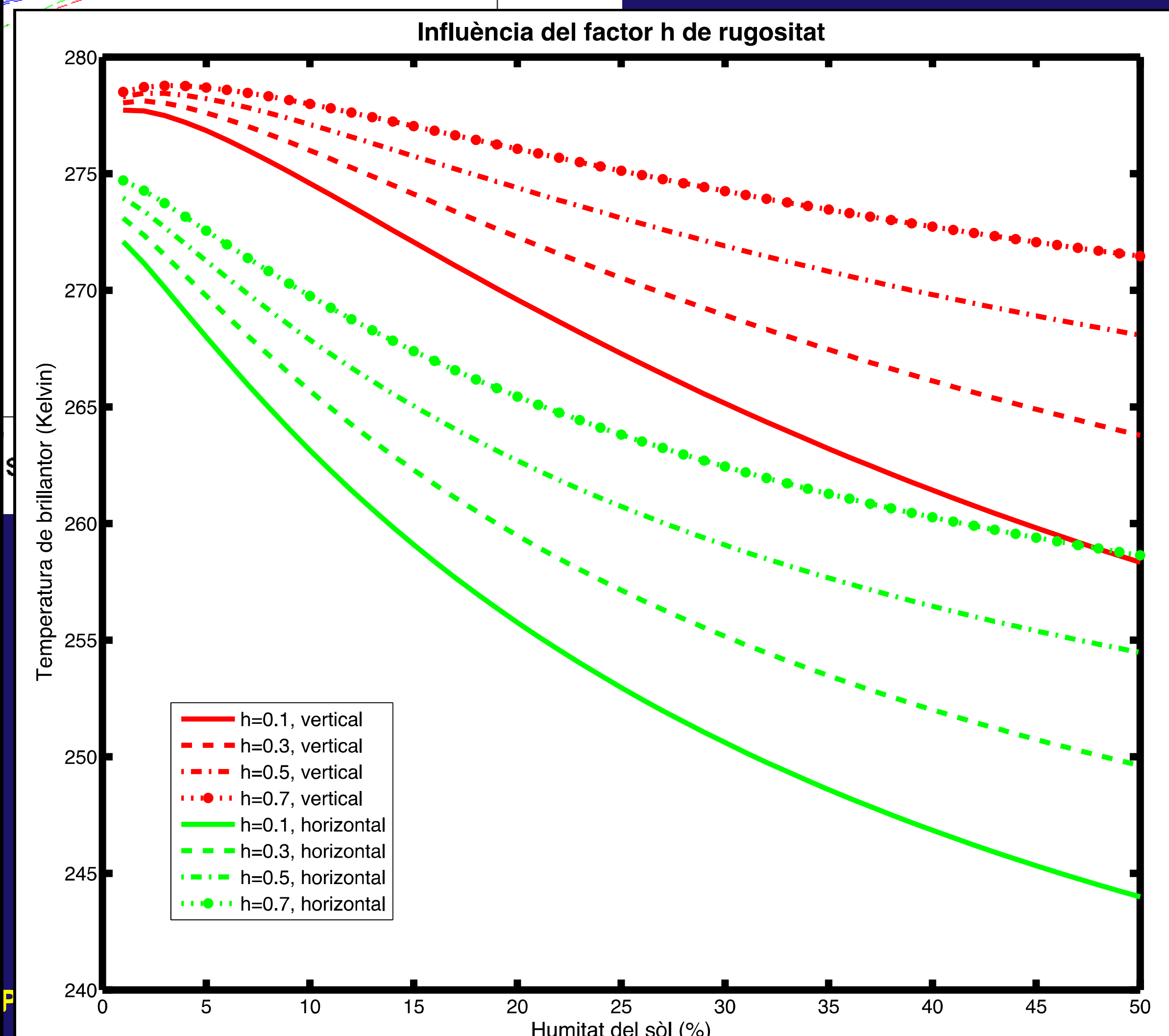
Schematic overview of factors influencing the brightness temperature of a complex, vegetation covered surface (from: Van de Griend and Owe, 1993b).

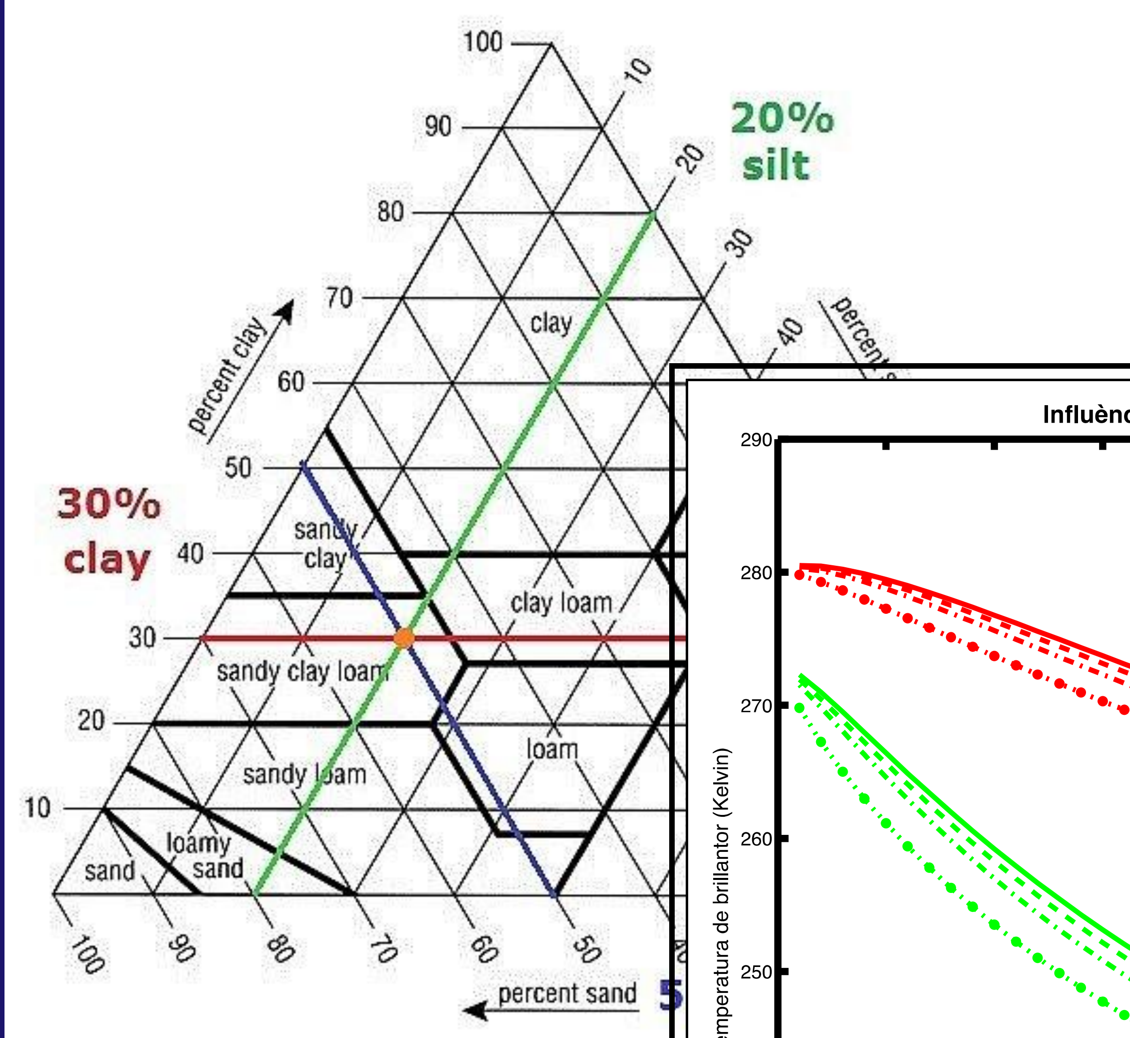

TB vs Incidence Angle. SM = 0.15 m3/m3. L BAND (1.4 GHz)
Brightness Temperature (K)
Incidence Angle (deg)
280
270
260
250
240
230
220
210
200
0
10
20
30
40
50
60
Tb Pv, LAI = 0
Tb Ph, LAI = 0
Tb Pv, LAI = 0.5
Tb Ph, LAI = 0.5
Tb Pv, LAI = 1
Tb Ph, LAI =1
Tb Pv, LAI = 1.5
Tb Ph, LAI = 1.5
Tb Pv, LAI = 2
Tb Ph, LAI = 2
Tb Pv, LAI =2.5
Tb Ph, LAI = 2.5

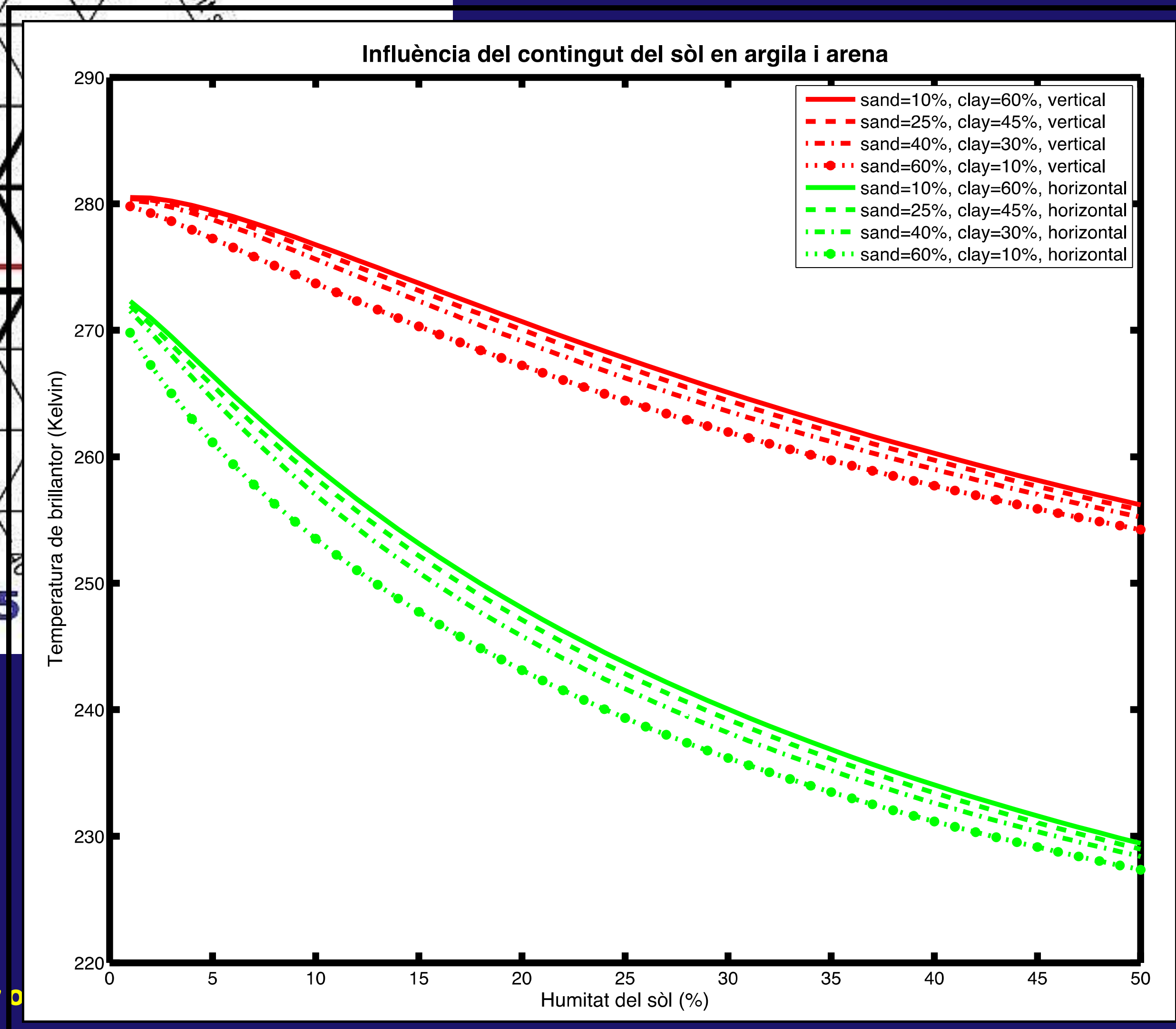

TB vs SM. Inclination Angle = 42.5º. L BAND (1.4 GHz)
Brightness Temperature (K)
280
270
260
250
240
230
220
210
200
190
180
0
0.05
0.1
0.1
Soi
Tb Pv, LAI = 0
Tb Ph, LAI = 0
Tb Pv, LAI = 0.5
Tb Ph, LAI = 0.5
Tb Pv, LAI = 1
Tb Ph, LAI =1
Tb Pv, LAI = 1.5
Tb Ph, LAI = 1.5
Tb Pv, LAI = 2
Tb Ph, LAI = 2
Tb Pv, LAI =2.5
Tb Ph, LAI = 2.5


TB vs LAI. Inclination Angle = 42.5º. L BAND (1.4 GHz)
Brightness Temperature (K)
280
270
260
250
240
230
220
210
200
190
0
0.5
1
1.5
2
2.5
3
LAI
Tb Pv, SM = 0.1 m3/m3
Tb Ph, SM = 0.1 ´´
Tb Pv, SM = 0.2 ´´
Tb Ph, SM = 0.2 ´´
Tb Pv, SM = 0.3 ´´
Tb Ph, SM = 0.3 ´´
Tb Pv, SM = 0.4 ´´
Tb Ph, SM = 0.4 ´´


TB vs Roughness soil. L BAND (1.4 GHz)
Brightness Temperature (K)
300
280
260
240
220
200
180
160
140
0
0.1
0.2
0.3
0.4
0.5
Roughness s


Influència del factor h de rugositat
Temperatura de brillantor (Kelvin)
280
275
270
265
260
255
250
245
240
0
5
10
15
20
25
30
35
40
45
50
Humitat del sòl (%)
h=0.1, vertical
h=0.3, vertical
h=0.5, vertical
h=0.7, vertical
h=0.1, horizontal
h=0.3, horizontal
h=0.5, horizontal
h=0.7, horizontal


20%
silt
30%
clay
percent clay
percent sand
clay
sandy clay
clay loam
sandy clay loam
loam
sandy loam
loamy sand
sand
100
90
80
70
60
50
40
30
20
10


Influència del contingut del sòl en argila i arena
sand=10%, clay=60%, vertical
sand=25%, clay=45%, vertical
sand=40%, clay=30%, vertical
sand=60%, clay=10%, vertical
sand=10%, clay=60%, horizontal
sand=25%, clay=45%, horizontal
sand=40%, clay=30%, horizontal
sand=60%, clay=10%, horizontal
Temperatura de brillantor (Kelvin)
Humitat del sòl (%)
290
280
270
260
250
240
230
220
0
5
10
15
20
25
30
35
40
45
50

Conclusions

- L-MEB allows us to study the dependency of T_B with soil and vegetation parameters and geometry of observation
    - study 1st order parameters
        - observation angle
        - polarisation
        - SM
        - LAI
    - study 2nd order parameters
        - roughness parameters
        - vegettion structure
        - soil texture

- further study the simulations for
    - other bands (L, C, X)
    - polarisation indices
        - pol difference $T_{BV} – T_{BH}$
        - pol ratio T_{BV}/T_{BH}
        - NDPI = $(T_{BV} – T_{BH}) / (T_{BV} + T_{BH})$