On the errors in satellite microwave radiometric imaging of a terrain with complex topography

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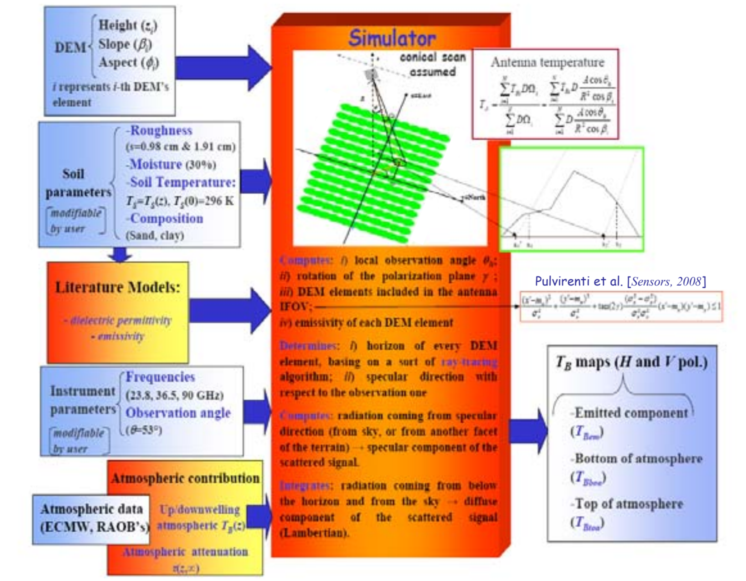
ABSTRACT - A simulation study to evaluate the influence of the topography on the measurements performed by a satellite microwave radiometer is accomplished in this work. The Northern Italy region (including Alps) is considered and the information on the relief, extracted from a digital elevation model (DEM), is exploited. We have developed a simulator of satellite microwave radiometric observations of mountainous scenes. It is able to operate at different frequencies and observation angles and (presently) it assumes bare soil. The simulation shows that the changes in the local incidence angle generally tend to lower the antenna temperature. The effect of the rotation of the polarization plane attenuates (for horizontal polarization) or enlarges (vertical polarization) this decrease. Facets illuminated by radiation from surrounding elevated terrain show an emission which is enhanced with respect to surfaces which scatter atmospheric downward radiation only. At horizontal polarization, this results in a general overestimation of the brightness temperature with respect to that measured observing a flat terrain. At vertical polarization, both under- and overestimation may occur.

1. Introduction

- Spaceborne microwave radiometric observations of land are mainly determined by surface emissivity and temperature. For bare soils, the **emissivity** at a given frequency depends on moisture, surface geometry (at wavelength scale i.e., roughness, and at resolution scale, i.e., ***topography***), composition and density.
- Over **mountainous areas**, ***relief effects*** must be taken into account. At microwave frequencies, the highly inhomogeneous features of the mountainous scenario should be compared with the relatively large antenna footprints.
- The relief effects on the upwelling T_B measured by a spaceborne radiometer are [Mätzler and Standley, *IJRS, 2000*]:
  - ✓modification of the atmospheric contributions due to their dependence on the altitude of the emitting surface;
  - ✓shadowing of the downwelling atmospheric radiation;
  - ✓local modification of the viewing angle with respect to a flat terrain;
  - ✓rotation of the linear polarization plane.

  These effects imply an overall change of the apparent emissivity with respect to the surface characteristics that would be sensed in case of a flat terrain.
- In this work, we perform a simulation study to evaluate the errors due to complex topography in satellite microwave radiometric imaging. We have focused our analysis on Northern Italy (including Alps) and we have used a digital elevation model (DEM) to extract the information about the height, as well as the slope and the aspect angles.
- We have assumed a conical-scanning radiometer flying at 800 km of altitude with an observation angle of 53°. We have considered frequency bands at 23.8 and 90.0 GHz, with resolutions of 60×40 and 15×13 km, respectively.

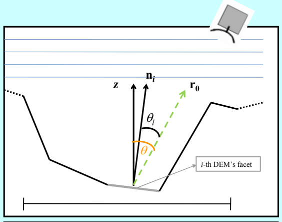
2. Block diagram of the simulator



3. Implementation

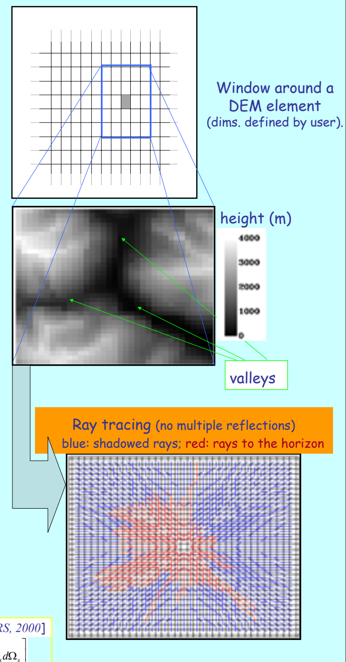
Emitted component

-Dielectric permittivity as in Calvet et al. [*TGRS, 1995*].
-Emissivity $e(\theta_i)$ as in Prigent et al [*TGRS, 2000*]: INRA model.
-Emitted component as in Pulvirenti et al [*Sensors, 2008*]:
Simplifying assumptions for radiometer's antenna: *i)* major lobe efficiency η_{ML} = 1; *ii)* directivity of the major lobe D=constant; *iii)* distance between the radiometer and each DEM facet R=const.

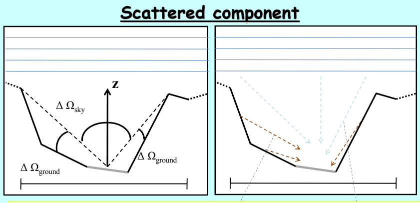


emitted component: $T_{Bem} = e(\theta_i)T_S$

Determination of the horizon



Scattered component



Reflectivity partly specular & partly Lambertian [Mätzler & Standley *IJRS, 2000*]

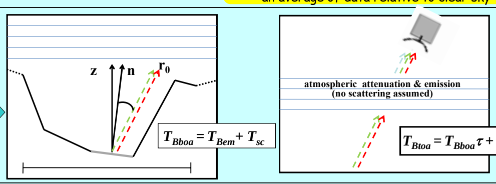
$$T_{sc}(\theta_i,z) = r_{sp}(\theta_i)T_{inc\_sp}(\theta_s,z) + \frac{r_0}{\pi}\left[\iint_{\Delta\Omega_{ground}} T_{inc\_ground}(\theta_s,\varphi_s,z)\cos\theta_s d\Omega_s + \iint_{\Delta\Omega_{sky}} T_{inc\_sky}(\theta_s,\varphi_s,z)\cos\theta_s d\Omega_s\right]$$

Coherent component — Diffuse component

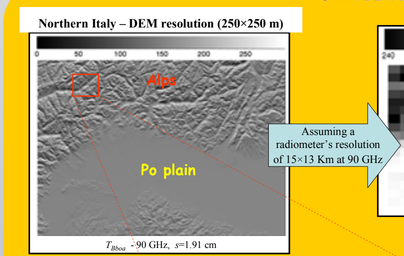
Either from sky or from ground (neighboring pixels)

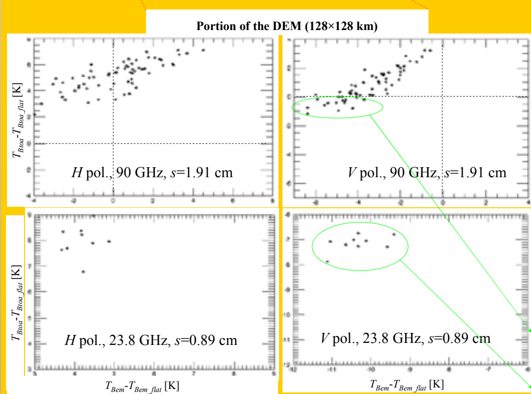
Atmospheric parameters derived from ECMWF data acquired throughout year 2000. Performed an average of data relative to clear sky

Outputs (T_{Bem}, T_{Bboa}, T_{Btoa})



4. Results





Subscript *flat* indicates a terrain without relief whose altitude is the average of DEM heights within the antenna IFOV

Values of T_{Bem}-T_{Bem_flat} mainly determined by:
- -dependence of emissivity on local observation angle:
  high θ_i (> Brewster angle at s=0.89 cm, V pol) → low e(θ_i)
- -rotation of the polarization plane
  V pol: decrease; H pol: increase)
- -antenna integration

H pol: T_{Btoa} > T_{Btoa_flat} since T_{inc_ground} > T_{inc_sky}

V pol: T_{Btoa} < T_{Btoa_flat} since the increase due to T_{inc_ground} > T_{inc_sky} does not compensate the decrease due the coupling with H pol.

For s=0.89: large difference between emissivities at *H* and *V* pol. (according to the INRA model)

	90 GHz, H pol, s=1.91 cm	90 GHz, V pol, s=1.91 cm	23.8 GHz, H pol, s=0.89 cm	23.8 GHz, V pol, s=0.89 cm
mean(T_{Btoa}-T_{Btoa_flat})	~4.5 K	~1 K	~8 K	~ −7 K
range of (T_{Btoa}-T_{Btoa_flat})	2 ÷ 7 K	−1.5 ÷ 3.5 K	6.5 ÷ 9 K	−8 ÷ −6.5 K
mean(T_{Bem}-T_{Bem_flat})	~0.5 K	~−3.5 K	~4 K	~ −10.5 K
range of (T_{Bem}-T_{Bem_flat})	−4 ÷ 4.5 K	−6.5 ÷ −0.5 K	3.5 ÷ 5 K	−11.5 ÷ −9.5 K

Summary and Conclusions

- Developed a simulator of radiometric images of a terrain with complex topography.
- Changes in local observation angle tend to lower the apparent emissivity of a radiometric pixel with respect to the corresponding flat surface characteristics. The effect of the rotation of the polarization plane enlarges (*V* pol), or attenuates (*H* pol) this decrease.
- Facets illuminated by radiation from surrounding elevated terrain has larger T_{sc} with respect to flat surfaces which scatter sky radiation.
- A quantification of the discrepancies between T_{Btoa} and T_{Btoa_flat} has been yielded at 90.0 and 23.8 GHz.