

Microwave signatures over carbonate sedimentary platforms in arid areas: potential geological applications of passive microwave observations?

Catherine Prigent, Jean Marie Munier, Bertrand Thomas, Gilles Ruffié

► To cite this version:

Catherine Prigent, Jean Marie Munier, Bertrand Thomas, Gilles Ruffié. Microwave signatures over carbonate sedimentary platforms in arid areas: potential geological applications of passive microwave observations?. Geophysical Research Letters, 2005, 32 (L23405), pp.1-4. 10.1029/2005GL024691. hal-00305755

HAL Id: hal-00305755 https://hal.science/hal-00305755

Submitted on 18 Feb 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Microwave signatures over carbonate sedimentary platforms in arid areas: Potential geological applications of passive microwave observations?

Catherine Prigent, Jean-Marie Munier, and Bertrand Thomas

Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique, Centre National de la Recherche Scientifique, Observatoire de Paris, Paris, France

Gilles Ruffié

Physique des Interaction Ondes-Matière, Pessac, France

Received 23 September 2005; revised 21 October 2005; accepted 3 November 2005; published 15 December 2005.

[1] Microwave emissivities have been calculated over the globe from satellite observations between 19 and 85 GHz with the Special Sensor Microwave/Imager (SSM/I). Unusually low and stable microwave emissivities are observed in Oman and Egypt over large regions. Spatial patterns of low emissivities are well correlated with the distribution of tertiary sediments. Dielectric measurements have been performed and confirm that carbonate rocks have high permittivities (higher than 8 as compared to typical values of 5 for other rocks or 2.5 for silicate sands) and this explains the observed low emissivities. Citation: Prigent, C., J.-M. Munier, B. Thomas, and G. Ruffié (2005), Microwave signatures over carbonate sedimentary platforms in arid areas: Potential geological applications of passive microwave observations?, Geophys. Res. Lett., 32, L23405, doi:10.1029/ 2005GL024691.

1. Introduction

[2] Satellite observations at a variety of wavelengths are used for geological applications. The emissivity and reflectance derived from measurements in the short wave infrared provide information on the nature of the minerals in arid regions. For instance, the Advanced Spaceborne Thermal Emission and Reflection Radiometer on board TERRA gives high resolution land surface temperature, emissivity, and reflectance from which desert surface mapping can be derived [e.g., Ogawa et al., 2003]. At much longer wavelengths, radar techniques are used for terrestrial and planetologic applications to explore the surface and subsurface in arid areas. For instance, RADARSAT and the ERS SAR both observing in C-band with high spatial resolution provide geological information (see, e.g., Special issue on radar geology, Canadian Journal of Remote Sensing, 20, 1994).

[3] Satellite passive microwave remote sensing provides valuable information on the state of the atmosphere over ocean (water vapor, temperature, liquid water content, precipitation), on the ocean itself (surface wind speed) and on going research over land essentially concerns soil moisture estimates and snow characterization. However, passive microwave measurements have not been considered for geological applications: firstly, the spatial resolution,

Copyright 2005 by the American Geophysical Union. 0094-8276/05/2005GL024691

typically tens of kilometers, is not supposed to be adequate, secondly the observed wavelengths are not deemed to provide specific information on the geology of the surface. Passive microwave emissivity atlases have been calculated from observations of the Special Sensor Microwave Imager (SSM/I) on board the Defense Meteorological Satellite Program [Prigent et al., 1997]. The first objective was to estimate the land surface contribution in the total signal observed over land by passive microwave satellite, in order to subtract it from the atmospheric signal and estimate the atmospheric parameters over land. In addition, the land surface emissivities derived from microwave satellite measurements can be used to monitor variations of surface and vegetation properties at regional and continental scales and a number of applications have been developed [e.g., Prigent et al., 2001; Aires et al., 2005].

[4] Persistently low emissivities are observed over specific areas in arid regions in North Africa and Arabia. In this study, these particular signatures are described and an explanation is suggested. Section 2 presents the passive microwave observations. A geologic analysis is conducted and good spatial correspondences between the tertiary sedimentary outcrops and the microwave signatures are observed (section 3). Section 4 proposes an interpretation in terms of dielectric properties of the carbonate sedimentary rocks. Section 5 concludes this study.

2. The Passive Microwave Satellite Observations

[5] The SSM/I instruments on board the DMSP polar orbiters observe the Earth twice daily at 19.35, 22.235, 37.0, and 85.5 GHz with both vertical and horizontal polarizations, with the exception of 22 GHz which is vertical polarization only [Hollinger et al., 1987]. The observing incident angle is close to 53°, and the elliptical fields of view decrease in size with frequency, from 43×69 to $13 \times$ 15 km². Microwave emissivities of land surfaces have been estimated from SSM/I observations by removing contributions from the atmosphere, clouds, and rain using ancillary data from the International Satellite Cloud Climatology Project (ISCCP) and the National Centers for Environmental Prediction (NCEP analyses). Cloud-free SSM/I observations are first isolated using collocated visible/infrared satellite observations (ISCCP data). The cloud-free atmospheric contribution is then calculated from an estimate of



Figure 1. Monthly-mean emissivity maps at 19 GHz for July 1992 estimated from SSM/I at 53° incidence. (top) Emissivity horizontal polarization. (bottom) Emissivity polarization difference (Vertical-Horizontal).

the local atmospheric temperature-humidity profile from NCEP reanalysis. Finally, with the surface skin temperature derived from IR observations (ISCCP estimate), the surface emissivity is calculated for all SSM/I channels. The standard deviation of day-to-day variations of the emissivities retrieved over a month are typically 0.013 which is a measure of the precision of these estimates. Monthly mean values are calculated with a spatial resolution of 0.25° at the equator. See *Prigent et al.* [1997] for more details.

[6] Monthly-mean maps of the emissivity at 19 GHz horizontal polarization, along with the polarization difference (vertical-horizontal) are presented for July 1992 over North Africa and Arabia (Figure 1). Low emissivities are observed over South Arabia and in Northeast Egypt around the Nile river. They are very stable on long time periods (several years of data have been examined) and are observable at all SSM/I frequencies, with limited spectral dependence. Low emissivities are usually associated with the presence of standing water: Compared to the other materials, water has high dielectric values that translate into low emissivities. This particular water signature is exploited for the detection of wetland extent and seasonality [Prigent et al., 2001]. Except for some permanent wetlands, most wetland areas are characterized by large seasonal cycle and their microwave emissivities undergo significant variability during the year. The region with low emissivities in Iraq is such an example: the Tiger and the Euphrates rivers regularly flood and this translates into low emissivities. By the same token, the coastal areas are associated with low emissivities due to ocean contamination in the antenna side lobes of the instrument. The regions of concern in South Arabia and Egypt are particularly arid areas with very limited precipitation all year long and their low emissivity cannot be explained by the presence of standing water. On the emissivity polarization difference map at 19 GHz for the same region (Figure 1, bottom), smooth bare soils have a

quasi-specular reflection, producing high polarization emissivity differences around 53° incidence. When the terrain gets rougher or vegetation appears, surface scattering causes the emissivity in horizontal polarization to increase and the polarization difference to decrease. As a consequence, mountainous regions appear with a low polarization difference on the map whereas flat areas are characterized by high polarization differences. It could also be noted that these regions do not correspond to sandy deserts where large penetration depths have been observed [*Prigent et al.*, 1999].

[7] In order to understand the observed passive microwave signatures, other satellite observations covering the same regions have been checked. The visible $(0.58-0.68 \ \mu\text{m})$ and near infrared $(0.73-1.1 \ \mu\text{m})$ reflectances measured by the Advanced Very High Resolution Radiometer do not show any specific structures in these regions: the reflectances are rather high, similar to what is observed in other arid areas. Nothing special has been observed either with the ERS scatterometer that measures the backscattering signal at 5.25 GHz in the vertical polarization.

3. Geology of the Regions and Correspondences With the Microwaves

3.1. Geological Description of the Regions

[8] The Geological Map of Egypt [*Egyptian Geological Survey and Mining Authority*, 1981] covers the Egyptian



Figure 2. Correspondence between the emissivities and the paleogene sedimentary outcrops (top) in Egypt and (bottom) in South Arabia for July 1992. Contours delineate pixels covered by more than 50% by paleogene outcrops.

territory with a 1:2 000 000 resolution. The Geological Map of the Middle East [*Aghanabati*, 1993] provides information with 1:5 000 000 resolution. These two maps have been digitized on a 0.25° grid for comparison with the satellite observations. Other geological sources have been analyzed to have further details on specific regions.

[9] Egypt is characterized by rather low topography. Tertiary carbonate sediments (limestone) cover large regions of modern Egypt, below which lies sandstone, and this earlier sandstone is the surface rock in Nubia and southern Upper Egypt, as far north as the area between Edfu and Luxor. The paleogene carbonate outcrop presents a 'Y' shape that is very similar to the low microwave emissivities observed in the area. The surrounding areas are from the pre-Cambrian period in the East, from the quaternary in the South, and the great sand sea (quaternary) to the West.

[10] The western and southern edges of the Arabian plate, where the Triassic and Jurassic layers were thrust upwards, are evinced by major mountain ranges along the Red Sea and the Indian Ocean. The great central deserts are enclosed by these two formations. East of Yemen and South of Oman are composed of a mostly barren plateau, underlain by tertiary sediments that dip northward toward the Rub al Khali basin. The tertiary ocean sediments are rich in fossils, remains of animals that lived in shallow marine and reef conditions on the continental shelf at the end of the Precambrian era.

3.2. Correspondences With the Microwave Signatures

[11] Examination of the geological maps revealed that the regions of low microwave emissivities coincide with the outcrops from the paleogene. In Figure 2 (top and bottom), in Egypt and in South Arabia, the contours of the paleogene outcrops from the tertiary era have been superimposed on the microwave emissivities at 19 GHz horizontal polarizations. In addition, in Oman and Yemen, the regions with significant relief have been indicated. In Egypt, a very good correspondence is observed between the low emissivities and the sedimentary outcrops. In Oman and Yemen as well, the similarities between the geographical extent of low emissivity and the geological structure is obvious in the region that is relatively flat. In the South West part however, the emissivities are higher: this is due to the large scale roughness associated to the topography that increases in the emissivity for horizontal polarization. This increase in emissivity related to the topographic roughness counter balances the effect of the particular behavior of the sedimentary outcrops. Examination of the vertical polarization (not shown) confirms this interpretation: for the vertical polarization, increasing roughness decreases the emissivity and the two effects add up to yield an even lower emissivities in the mountainous section of the sedimentary outcrops in the South West.

[12] For a more quantitative examination of the correspondences, Figure 3 represents the normalized histograms of the emissivities (top in Egypt and bottom in South Arabia) separately depending on the percentage of coverage of the pixels by the sedimentary outcrops. For South Arabia, the areas with high topography have been excluded. For both regions and especially for South Arabia, the histograms are well separated, meaning that the observed passive microwave signatures are clearly related to the percentage of sedimentary cover in a given pixel.

4. Dielectric Properties of Carbonate Rocks and Emissivity Simulations

[13] Differences in the dielectric properties of carbonate rocks as compared to other rocks and sands could explain observed low emissivities. Measurements of the dielectric properties of rocks and sands above 1 GHz are scarce. *Campbell and Ulrichs* [1969] provided a catalog of dielectric properties of rocks and powders, with measurements at 450 MHz and 35 GHz, but they did not test carbonate rocks. More recent measurements are due to *Nelson et al.* [1989], *Robinson and Friedman* [2003], or *Lebron et al.* [2004], and include carbonate sedimentary rocks. Using different techniques up to 22 GHz, these measurements are performed around 25°C on natural materials, eventually pulverized. They indicate that the emissivity of rocks increases with their carbonate contents, reaching 9.1 for Iceland Spar calcite.

[14] Samples of rocks and soil have also been collected by collaborators in the areas of concern in North Africa and Arabia. Measurements of the dielectric properties of these samples have been performed between 1 and 170 GHz, as well as direct measurements of their emissivity [*Thomas*, 2005]. Our results confirm that lower emissivities are obtained for carbonate rocks, with typical permittivity values ranging from 7.5 to 8.9, depending on the samples. Silicate rocks show lower permittivity, typically around 5.

[15] The microwave emissivities of the surface are simulated using typical dielectric properties derived from the literature review and our own measurements. The Integral Equation Model (IEM) from *Shi et al.* [2002] is adopted. Simulations are performed at 19 GHz, for two surface roughnesses: a smooth surface that has a specular



Figure 3. Normalized histograms of the emissivities separately depending on the percentage of coverage of the pixels by the paleogene outcrops (top) in Egypt and (bottom) in South Arabia (July 1992).



Figure 4. Simulated emissivities at 19 GHz versus the incidence angle, for both polarizations using a IEM model [*Shi et al.*, 2002]. Calculations are presented for two surface roughnesses and three permittivities. Permittivity = 2.5: quartz sands; permittivity = 5: granite; permittivity = 8.5: carbonate rocks.

behavior and a more realistic rougher surface (with RMS height of 0.4 cm and correlation length of 2 cm). The calculations are conducted for three dielectric media: quartz sands (permittivity = 2.5), granite (permittivity = 5) and carbonate rocks (permittivity = 8.5). The imaginary part of the dielectric constant is 0.01 for the quartz sand and 0.1 for the other materials, following typical values found in the literature and confirmed by our measurements (the imaginary part has a limited impact on the simulations). As seen in Figure 4, the emissivity horizontal polarization increases with decreasing permittivity, for both specular and rougher surfaces. For a given permittivity, the emissivity in horizontal polarization increases with surface roughness and the polarization difference decreases. At 53° (the SSM/I observation angle), for realistic natural surfaces with some roughness, materials with high permittivities are needed to generate emissivity values below 0.8, as observed on the satellite images.

5. Conclusions and Perspectives

[16] Unusually low emissivities have been observed over arid regions in North Africa and Arabia. These particular signatures are carefully examined and show very good correspondences with geology structures. The low emissivities coincide well with carbonate outcrops from the paleogene and contrast with the surrounding silicate rich regions. From a literature review and from measurements in the lab, it is shown that the permittivity of carbonate rocks is significantly higher than the values measured for other rocks. Simulated emissivities using these permittivities are consistent with the observations. As a consequence, a direct and strong relationship is evidenced between passive microwave satellite observations and the surface geology.

[17] This analysis can have important applications for microwave remote sensing. Firstly, for missions that are directly related to the characterization of the continental surface, it is crucial to have an accurate understanding of the dielectric properties of the surface and their impact on the observations. The ESA Soil Moisture and Ocean Salinity (SMOS) mission or the NASA Hydros mission are such examples. Determination of the soil moisture from these missions requires accurate estimates of the dielectric properties of the soil and rocks. Secondly, for atmospheric applications (temperature and water vapor profiling, cloud and precipitation monitoring), it is important to quantify the surface contribution, in order to subtract it from the measurements. Lastly, geological applications of passive microwave observations could be extended to planetology exploration, especially for Mars where carbonate components are expected.

[18] Acknowledgments. We express thanks to T. Deschamps and J. Benoit for their involvement at the initial stage of this study. We thank J. Roger (BRGM, France), B. Beaudoin (ENSMP, Paris), A. Karnieli (Univ. Negev, Israel), S. Leroy (Univ. Paris VI), C. Engrand (IN2P3, France) for fruitful discussions on desert geology, and B. Rossow (NASA/GISS) for suggestions on the manuscript. Parts of the dielectric measurements were performed at the IAP (Bern) thanks to C. Matzler. We also thank two anonymous reviewers for their careful reading of the manuscript.

References

- Aghanabati, A. (1993), Geological map of the Middle East, 1:5,000,000, Geol. Surv. of Iran, Teheran.
- Aires, F., C. Prigent, and W. B. Rossow (2005), Sensitivity of microwave and infrared satellite observations to soil moisture at a global scale: 2. Global statistical relationships, *J. Geophys. Res.*, 110, D11103, doi:10.1029/2004JD005094.
- Campbell, M. J., and J. Ulrichs (1969), Electrical properties of rocks and their significance for lunar radar observations, J. Geophys. Res., 74, 5867–5881.
- Egyptian Geological Survey and Mining Authority (1981), Geological Map of Egypt, 1:2,000,000, Cairo.
- Hollinger, J. P., R. Lo, G. Poe, R. Savage, and J. Pierce (1987), Special Sensor Microwave/Imager user's guide, Nav. Res. Lab., Washington, D. C.
- Lebron, I., D. A. Robinson, S. Goldberg, and S. M. Lesch (2004), The dielectric permittivity of calcite and arid zone soils with carbonate minerals, *Soil Sci. Soc. Am. J.*, 68, 1549–1559.
- Nelson, S. O., D. P. Lindroth, and R. L. Blake (1989), Dielectric properties of selected minerals at 1 to 22 GHz, *Geophysics*, 54, 1344–1349.
- Ogawa, K., T. Schmugge, F. Jacob, and A. French (2003), Estimation of land surface window (8–12 μm) emissivity from multi-spectral thermal infrared remote sensing: A case study in a part of Sahara Desert, *Geophys. Res. Lett.*, 30(2), 1067, doi:10.1029/2002GL016354.
- Prigent, C., W. B. Rossow, and E. Matthews (1997), Microwave land surface emissivities estimated from SSM/I observations, *J. Geophys. Res.*, 102, 21,867–21,890.
- Prigent, C., W. B. Rossow, and E. Matthews (1999), Microwave radiometric signatures over different surface types in deserts, *J. Geophys. Res.*, 104, 12,147–12,158.
- Prigent, C., E. Matthews, F. Aires, and W. B. Rossow (2001), Remote sensing of global wetland dynamics with multiple satellite data sets, *Geophys. Res. Lett.*, 28, 4631–4634.
- Robinson, D. A., and S. P. Friedman (2003), A method for measuring the solid particle permittivity or electrical conductivity of rocks, sediments, and granular materials, *J. Geophys. Res.*, 108(B2), 2076, doi:10.1029/ 2001JB000691.
- Shi, J., K. S. Chen, Q. Lin, T. J. Jackson, P. E. O'Neill, and L. Tsang (2002), A parameterized surface reflectivity model and estimation of bare-surface soil moisture with L-band radiometer, *IEEE Trans. Geosci. Remote Sens.*, 40, 2674–2686.
- Thomas, B. (2005), Microwave dielectric properties of minerals and rocks, in *Thermal Microwave Radiation: Applications for Remote Sensing, IEE Electromagn. Waves Ser.*, edited by C. Matzler et al., Inst. of Electr. Eng., London, in press.

J.-M. Munier, C. Prigent, and B. Thomas, Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique, CNRS, Observatoire de Paris, 61, avenue de l'Observatoire, F-75014 Paris, France. (catherine. prigent@obspm.fr)

G. Ruffié, Physique des Interaction Ondes-Matière, Pessac F-33607, France.