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Empirical Determination of the Sea Surface Emissivity at L-band: A contribution to ESA's SMOS Earth Explorer Mission

PhD Dissertation by

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Preface

This thesis was completely carried out in the Department of Signal Theory and Communications of the Technical University of Catalonia (UPC).

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Executive summary

Two important applications in remote sensing have received special attention in the past years: (ocean salinity and soil moisture). This work focuses in the first one. Ocean salinity concentration is related to climate monitoring. Its frequent knowledge at a global scale is important in climate predictions, because it is a tracer of sea surface currents and it is an indicator of the difference between evaporation and precipitation. In May 1999, the European Space Agency (ESA) selected SMOS (Soil Moisture and Ocean Salinity) as the second Earth Explorer Opportunity mission. Its main goals are the study of the soil moisture and the ocean surface salinity. To measure these parameters an L-band dual-polarization radiometer with full polarimetric capability called MIRAS (Microwave Interferometric Radiometer of Aperture Synthesis) will be embarked on a satellite that will be launched at the beginning of 2007.

To improve of the emissivity models at L-band, and to study the retrieval of sea surface salinity using multi-angular radiometric measurements, ESA sponsored two WISE (*WInd and Salinity Experiment*) field experiments that took place during the last two months of 2000 and 2001 at the *Casablanca* oil-rig, 40 km away from the *Ebro* river mouth at the coast of *Tarragona*, *Spain*. Five scientific teams from three different countries (*Spain*, *France* and *US*) participated.

The main parameter measured in these two experiments was the brightness temperature (T_B) to be related to the sea state, wind, foam, swell, etc. To do this, a real aperture fully-polarimetric *Dicke* radiometer was designed and implemented at UPC.

However, the emission of foam and of the sea surface perturbed by rain were difficult to determine, since sea state effects masked them. During the spring of 2003 a new field experiment called Foam, Rain, Oil Slicks and GPS-reflections (FROG) 2003 experiment was sponsored by the Spanish Government to determine the emission these two factors, plus the effects of having an oil film such as in the case of an oil spill. The controlled experiment was performed at the facilities of the Institut de Recerca en Tècniques Agropecuàries (IRTA) at Poble Nou del Delta, in the Ebro river mounth

The main results of the WISE and FROG field experiments can be summarized as follows:

- The sensitivity of the brightness temperature (T_B) to wind speed extrapolated at nadir (θ = 0 °), is ~0.23 K/(m/s) or ~0.25 K/(m/s) depending on the atmospheric stability.
- There is a modulation of the instantaneous T_B due to the wave slopes that increases with a wind speed at a rate of ~0.1-0.15 K/(m/s).
- The impact of the presence of sea foam in the L-band is estimated to be 0.18 K at wind speed of 20 m/s, (WISE field experiments). The foam induced T_B increases at vertical and decreases at horizontal polarization with increasing the incidence angle.
- At L-band the rainfall contribution is smaller than foam contribution and negligible except for the formation of a fresh water layer and the dumping of large waves.

List of Acronyms

ADC	Analog to digital converter
AGC	Automatic Gain Control
CEPT	Centre d'Études Terrestres et Planétaires
CU	Control Unit
DAC	Digital to analog converter
DC	direct current
DCU	Digital Correlator Unit
DDE	Dynamic Data Exchange
DR	Dicke Radiometer
DRM	Data Review Meeting
ESA	European Space Agency
ENSO	El Niño Southern Oscillation
FOV	Field Of View
FROG	Foam Rain Oil and GPS reflectometry
GPS	Global Position System
ICM	Institut de Ciències del Mar
IRTA	Institut de Recerca i Tecnologia Agroalimentàries
KO	Kick-Off meeting
LAURA	L-band AUtomatic RAdiometer
LF	Low Frequency
LNA	Low Noise Amplifier
LO	Local Oscillator
LODYC	Laboratoire d'Oceanographie Dynamique et Climatologie
MBE	Main Beam Efficiency
MC	Motor Controller
MIRAS	Microwave Imaging Radiometer by Aperture Synthesis
OS	Ocean Salinity

PCM	Pre-Campaign Meeting
PM	Progress Meeting
PRM	Preliminary Results Meeting
PSU	Practical Salinity Unit
RF	Radio Frequency
RFI	Radio Frequency Interference
SM	Soil Moisture
SMOS	Soil Moisture Ocean Salinity
SSA	Small Slopes Approximations
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWH	Significant Wave Height
TCU	Thermal Control Unit
UMass	University of Massachusetts
UPC	Universitat Politècnica de Catalunya
UPS	Uninterruptible Power Supply
UTC	Universal Time Coordinate
WISE	WInd and Salinity Experiment
pol	polarization
pdf	probability density function
rms	root mean square

List of symbols

A_t	Total area which radiates electromagnetic energy
A_r	Effective area of the antenna collecting the electromagnetic energy
B	Equivalent pre-detection noise bandwidth
$B(\theta,\phi)$	Brightness
B_{bb}	Brightness of a black-body
$B_f(\theta,\phi)$	Spectral brightness density
E_v	Electric field at vertical polarization
E_h	Electric field at horizontal polarization
$F(U_{10})$	Fractional sea foam coverage as a function of wind speed at 10 m
$F_t(\theta,\phi)$	Antenna radiation pattern
$F_n(\theta,\phi)$	Normalized antenna radiation pattern. Maximum equal to one
G_s	Receiver Front-end's gain
H	Horizontal
I	In-phase signal
K_i	Proportional constant of the PID control
L_a	Atmospheric attenuation
N_T	Digital correlator's total count
P	Power collected by an antenna
P_{bb}	Power collected by an antenna surrounded by a black body
$P(k)$	Slope spectrum as a function of the wavenumber
Q	Quadrature signal
R	Distance between the antenna and the radiating surface
RH_{ext}	External relative humidity (measured from the UPC meteorological station)
RH_{int}	Internal relative humidity (measured from the UPC meteorological station)
S_{ij}	Scattering parameters Matrix
$S(k)$	Surface's height spectrum as a function of the wavenumber
$T_B(\theta,\phi)$	Brightness Temperature

$T_{B_{H,V}}^{Foam}$ Brightness temperature of 100 % foam-covered flat surface

$T_{B_{H,V}}^{Fresnel}$ Brightness temperature of the flat sea surface

$T_{B_{H,V}}^{Water}$ Brightness temperature of 100 % foam-free water surface

$T_{B_{H,V}}^{measured}$ Brightness temperature measured by the radiometer

$\Delta T_{A_{H,V}}^{finite\ beam}$ Brightness temperature error variation due to the finite antenna's beamwidth

$T_{B_{H,V}}^{c}$ Corrected brightness temperature

T_H Brightness temperature at horizontal polarization

T_V Brightness temperature at vertical polarization

T_{AP} Apparent temperature

T_{MB} Main beam apparent temperature

T_{SL} Side lobes apparent temperature

T_o Physical temperature

T_{SC} Atmospheric downward radiation reflected by the surface

T_{UP} Atmospheric upward radiation

T_A Antenna temperature

T_{break} Wave period of the breaking wave

T_{DN} Atmospheric downward emission

T_{ref} Reference-source noise temperature

T_{refH} H-channel reference source physical temperature

T_{refV} V-channel reference source physical temperature

T_{int} Radiometer's physical temperature

T_{ext} External physical temperature

T_{ph_corr} Physical temperature of the digital correlator unit

T_{ph_abs} Physical temperature of the absorber

T_{abs} T_B from the absorber

T_{sky} T_B from the sky

T_{surf} Sea surface temperature

T_{ms_ext}	External Physical temperature (measured from the UPC meteorological station)
T_{ms_int}	Radiometer's Physical temperature (measured from the UPC meteorological station)
T_{REC}	Receiver noise temperature
T_d	Derivative constant of the PID control
T_i	Integrate constant of the PID control
U	3st Stokes parameter in brightness temperature, (also known as T_3)
U_{10}	Wind speed referred to 10 m height
V	4st Stokes parameter in brightness temperature, (also known as T_4)
$V_{B_{H,V}}$	Dicke radiometers output's voltage
V_H	Dicke radiometers output's voltage for the horizontal polarization
V_V	Dicke radiometers output's voltage for the vertical polarization
V	Vertical
WS	Wind speed (measured from the UPC meteorological station)
WD	Wind direction (measured from the UPC meteorological station)
c	speed of the light
d	Foam layer thickness
$e(\theta,\phi)$	Emissivity
e_w	Emissivity of water
$e^c_{H,V}$	Corrected emissivity of the two channels
e_H	Emissivity of the horizontal channel
e_V	Emissivity of the vertical channel
f	Electromagnetic frequency
f_a	Void fraction beneath the foam layer
f_o	Central frequency (f_o = 1,413.5 MHz for LAURA and SMOS)
f_c	Cut-off frequency
f_s	Dicke switching frequency
h	Planck's constant = $6.64 \cdot 10^{-34} J$
k	Boltzmann's constant = $1.38 \cdot 10^{-23} J \cdot K^{-1}$

p	Polarization
r_p	Average bubbles radius
ΔT_o	Physical temperature variations
ΔT_{ref}	Reference-source noise temperature variations
ΔG_s	Gain fluctuations
ΔT	Radiometric sensitivity
$\Delta \mathrm{T}$	The sea-air temperature difference
$\Delta T_{B_{H,V}}$	Induced brightness temperature at H- and V- polarization
$\Delta_F T_B$	Foam-induced brightness temperature change
$\Gamma_{H,V}$	Fresnel reflection coefficient
δ	Bubble's water coating thickness
ε_r	Dielectric permittivity
ε_W	Permittivity of sea water taking into account bubbles
ε_{SW}	Permittivity of sea water
$\varepsilon_{N\alpha}$	Permittivity of the foam layer
ϕ_l	Liquid fraction and the water/foam conductivity
κ	Bubble's packing coefficient stickiness
λ	Wavelength
μ_{xy}	Corrected normalized correlation
η_r	Antenna ohmic efficiency
η_{MBE}	Main beam efficiency
ρ_{xy}	Measured normalized correlation
σ	Foam conductivity, water conductivity ratio
σ_{foam}	Foam conductivity
σ_{water}	Water conductivity
σ_{air}	Air conductivity
θ	Incidence angle ($\theta = 0°$ NADIR)
τ	Radiometer integration time

τ_{foam}	Foam persistence time
Ω_t	Solid angle subtended by the transmitting antenna

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