A Tool to Estimate Land Surface Emissivities at Microwave frequencies (TELSEM)

Filipe Aires[1,2], Catherine Prigent [3], Fredéric Bernardo[2], **Carlos Jiménez [3]**, Rogers Saunders [4], Pascal Brune [5]

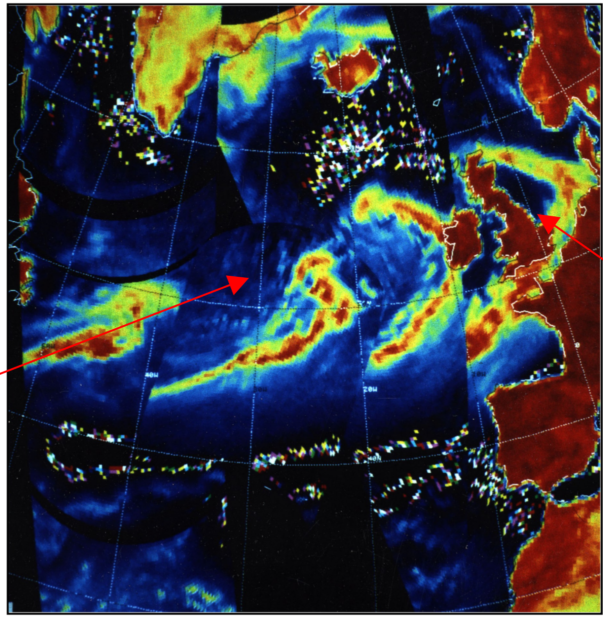
[1] LMD, IPSL, Université Paris VI, France
[2] Estellus, Paris, France
[3] Observatoire de Paris, France
[4] MetOffice, Exeter, England
[5] Metéo-France, Lannion, France

Motivation

• Satellite passive microwave observations have long been used over the **oceans** to estimate atmospheric properties.

• In contrast, over **land** there are not fully exploited because of the large and variable contribution of the land surface to the up-welling radiation.

e.g. SSM/I Tb 37GHz -V



over ocean, the front is clearly observed.

over land, lost of contrast between the land and the atmospheric contribution

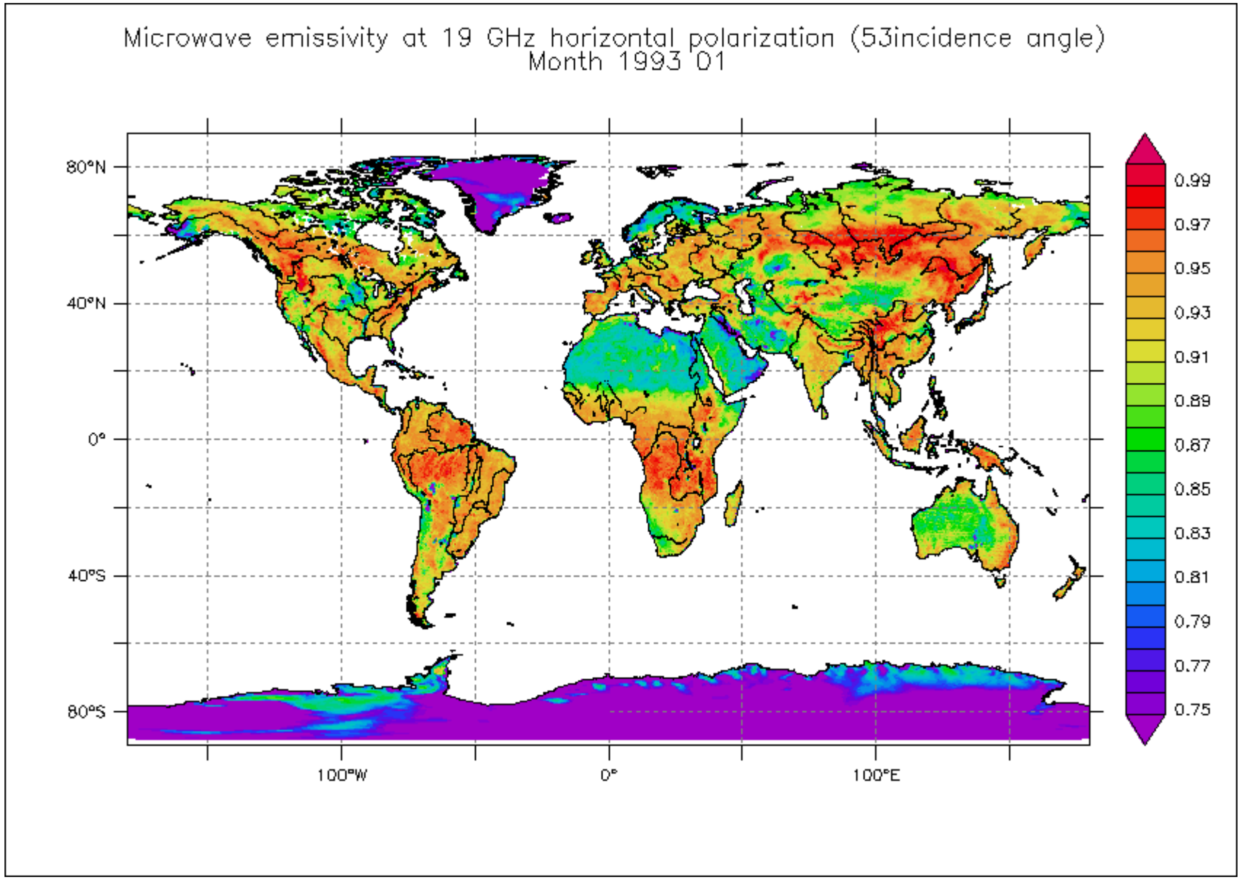
Exploitation of surface sensitive microwave channels requires accurate estimates of land surface **microwave emissivities** (**e**)

<carlos.jimenez@obspm.fr>

LMD/CNRS ESTELLUS l'Observatoire de Paris LERMA METEO FRANCE Met Office

• Not easy! Land surface **e** is spatially **very variable**, being sensitive to many **surface parameters** (e.g. vegetation cover, soil moisture, surface roughness, standing water or snow), and depending on frequency (**freq**), polarization (**pol**) and incident angle (θ).

e.g. SSM/I e



Possibilities to estimate **e:**

(1) Field experiments

- high temporal and spatial resolutions, making possible detailed analysis of surface processes.
- difficult to capture the large spatial and temporal variability of the surfaces measured from the satellites at the global scale.

(2) Models

- developed for various surface conditions using different RT solutions depending on surface characteristics.
- difficult to apply globally due to they complex interaction of the radiation and the surface and the global availability of the required inputs (e.g. soil composition, texture, humidity, or roughness).

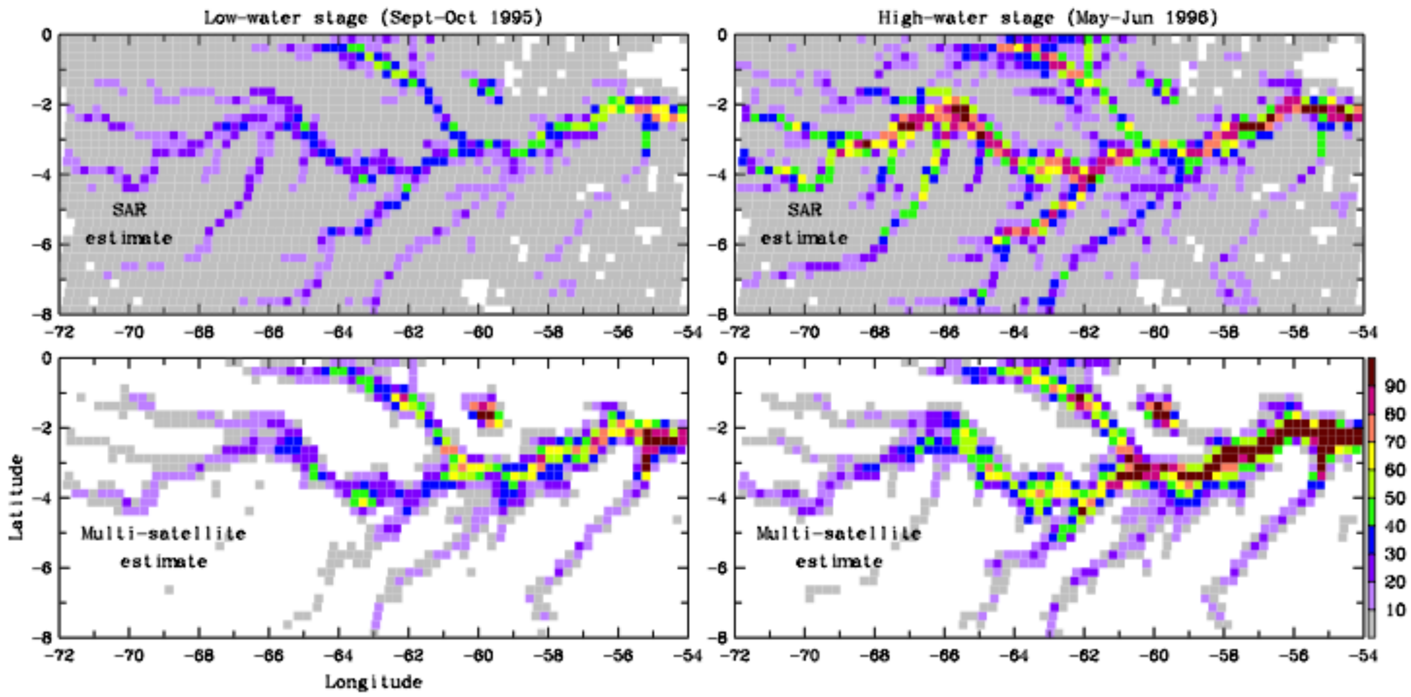
(3) Satellite observations

- produced directly from observations by removing the contribution of the atmosphere and surface temperature using ancillary data.
- limited to the observations conditions of the given satellite (freq, θ, and pol), and requiring good quality ancillary information (especially cloud filtering and surface skin temperature).

• Apart from the applications related to atmospheric retrieval over land, the **e** are useful estimates to help **characterizing the land surface**.

e.g. global estimation of **inundated surfaces** from satellite observations

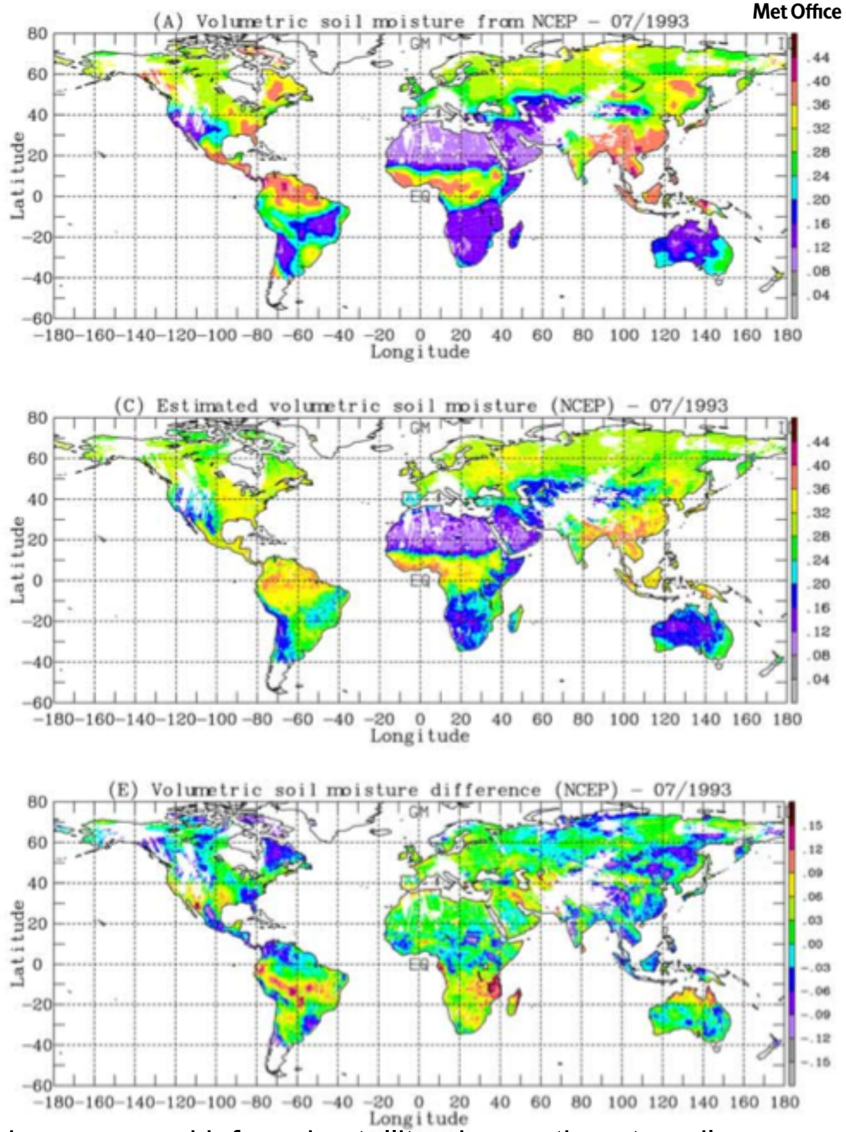
- comparison of mulit-satellite (including SSM/I **e**) and SAR estimates over the Amazon basin



[Prigent, C., et al., Global inundation dynamics inferred from multiple satellite observations, 1993-2000, JGR, 112, 2007]

Motivation

- Characterizing the **land surface**.



e.g. (a) July 93 monthly **soil moisture** from **NCEP**, (c) associated prediction from satellite observations (including SSM/I **e**), and (e) difference .

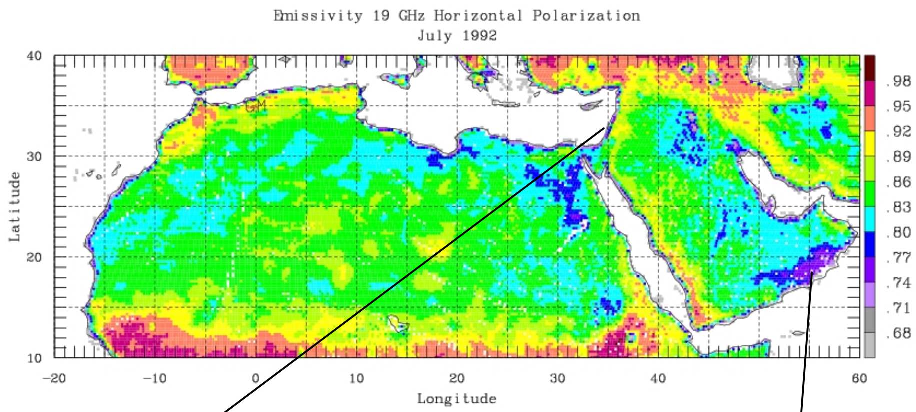
[Aires, F., et al., Sensitivity of microwave and infrared satellite observations to soil moisture at a global scale. II: Global statistical relationships, JGR, 110, 2005]

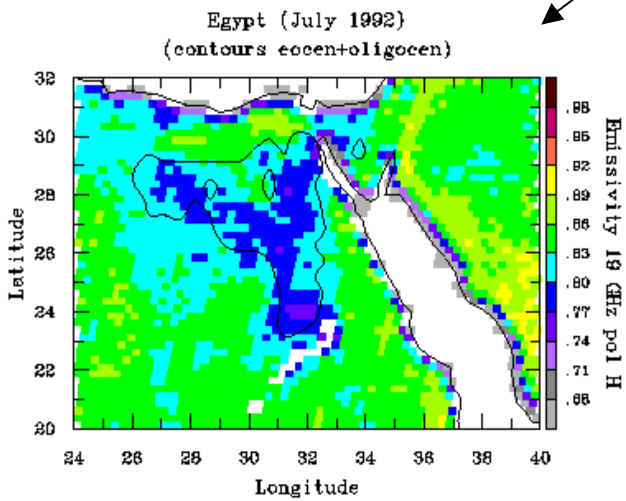
Motivation

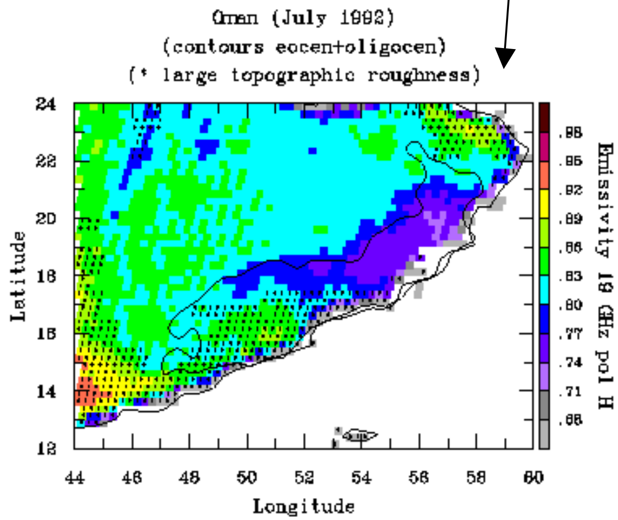
• Characterizing the **land surface**.

e.g. geological applications

- clear detection of the carbonated sedimentary outcrops from the tertiary era







[Prigent, C., et al., Microwave signatures over carbonate sedimentary platforms in arid areas: Potential geological applications of passive microwave observations?, GRL, 32, 2005]

[Jimenez, C., et al., Relations between geological characteristics and satellite-derived infrared and microwave emissivities over deserts in Northern Africa and the Arabian Peninsula, JGR, in review]

1.Motivation

2.Method

3.SMM/I **e**

4.Satellite -derived **e**

5. TELSEM

6. Summary

- Estimation of surface **e** from observations

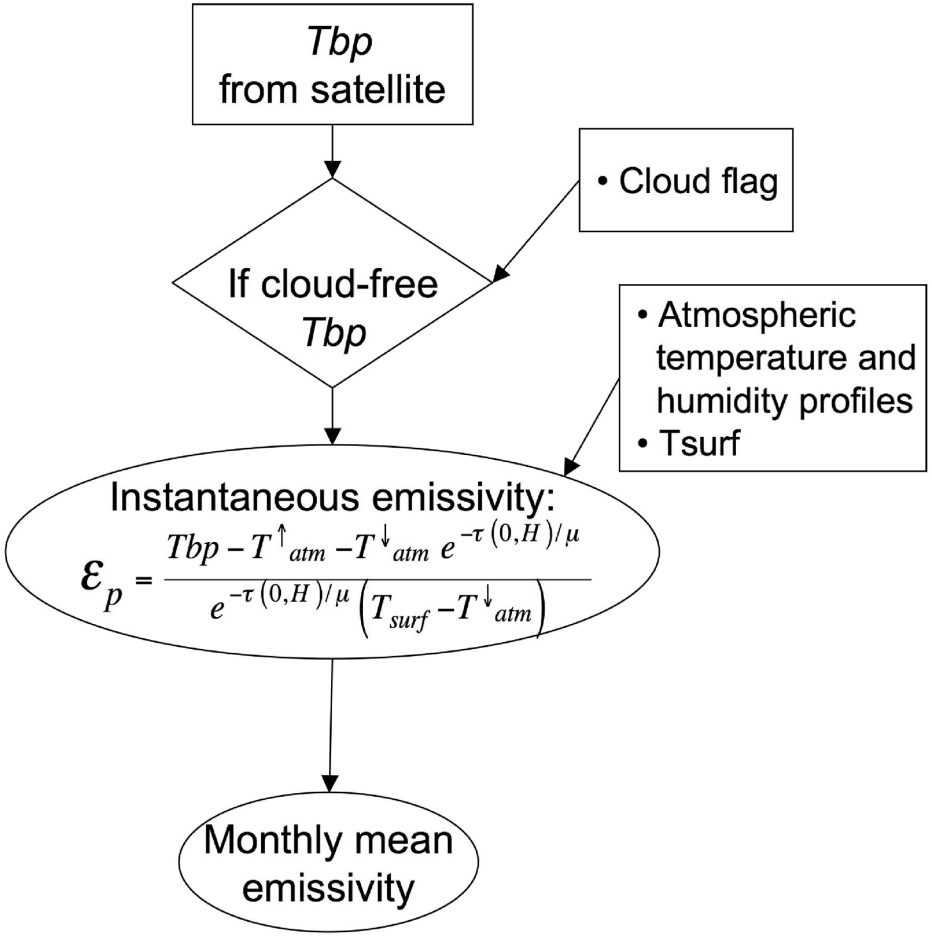
2.1.1. Basic principal. Over a flat lossy surface, the integrated radiative transfer equation in the Rayleigh-Jeans approximation, for a non scattering plane-parallel atmosphere can be expressed in terms of brightness temperature for a given polarization state p:

$$Tb_p = T_{surf} \times \epsilon_p \times e^{-\tau(0,H)/\mu} + T^{\downarrow}_{atm} \times (1 - \epsilon_p) \times e^{-\tau(0,H)/\mu} + T^{\uparrow}_{atm} \quad (1)$$

with $T^{\downarrow}_{atm} = \int_H^0 T(z)\alpha(z)e^{-\tau(z,0)/\mu}dz$ and $T^{\uparrow}_{atm} = \int_0^H T(z)\alpha(z)e^{-\tau(z,H)/\mu}dz$. Tb_p is the brightness temperature measured by the satellite for polarization state p; T_{surf} is the surface "skin" temperature; ϵ_p is the surface emissivity for polarization state p; $\mu = \cos(\theta)$, θ being the incidence angle on the surface; $\alpha(z)$ is the atmospheric absorption by gases at altitude z; $T(z)$ is the atmospheric temperature at altitude z; $\tau(z_0, z_1) = \int_{z_0}^{z_1} \alpha(z)dz$ is the atmospheric extinction from z_0 to z_1; and H is the orbiter height.

Methodology

- Steps involved in the **e** estimation



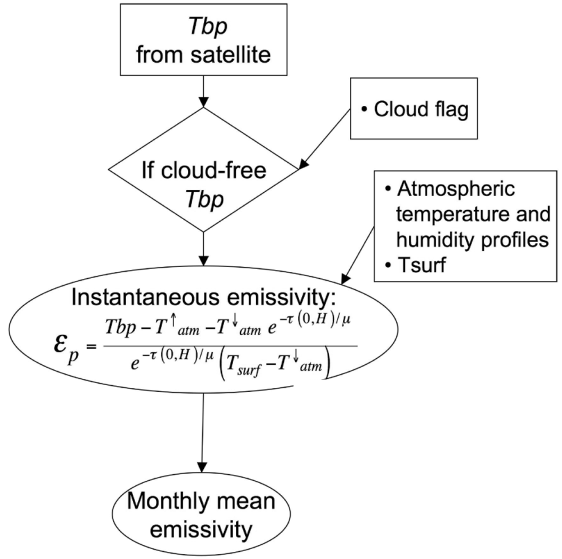
[Prigent, C., et al., Land surface microwave emissivities over the globe from a decade, BAMS, 2006]

Methodology

- Assumptions in the **e** estimation
  - Equation **strictly valid** for flat surfaces (specular reflection) and no volume scattering (surface temperature is the skin temperature).
  - **Not** always the case, e.g:

    - very dry sand, deep vegetation canopies, significant snow layers, **volume scattering** is possible and radiation does not emanate from a thin surface layer.

    - rough terrain where the specular assumption is not valid and **surface scattering** is present.



n

The satellite-derived **e** estimates are an **"effective" e** aggregated over the depth of penetration and the field of view of the instrument.

[Prigent, C., et al., Microwave radiometric signatures of different surface types in deserts, JGR, 104, 1999]

[Karbou, F. & Prigent., C., Calculations of LSE from satellite observations: validity of the specular approximation over snow-free surfaces, IEEE GRS Letters, 2(3), 2005]

- **Lambertian or specular?**

- Comparing **e** estimates assuming Lambertian or specular reflections.

- Error related to the specular approximation typically well within 1% in the case of natural-snow free surfaces.

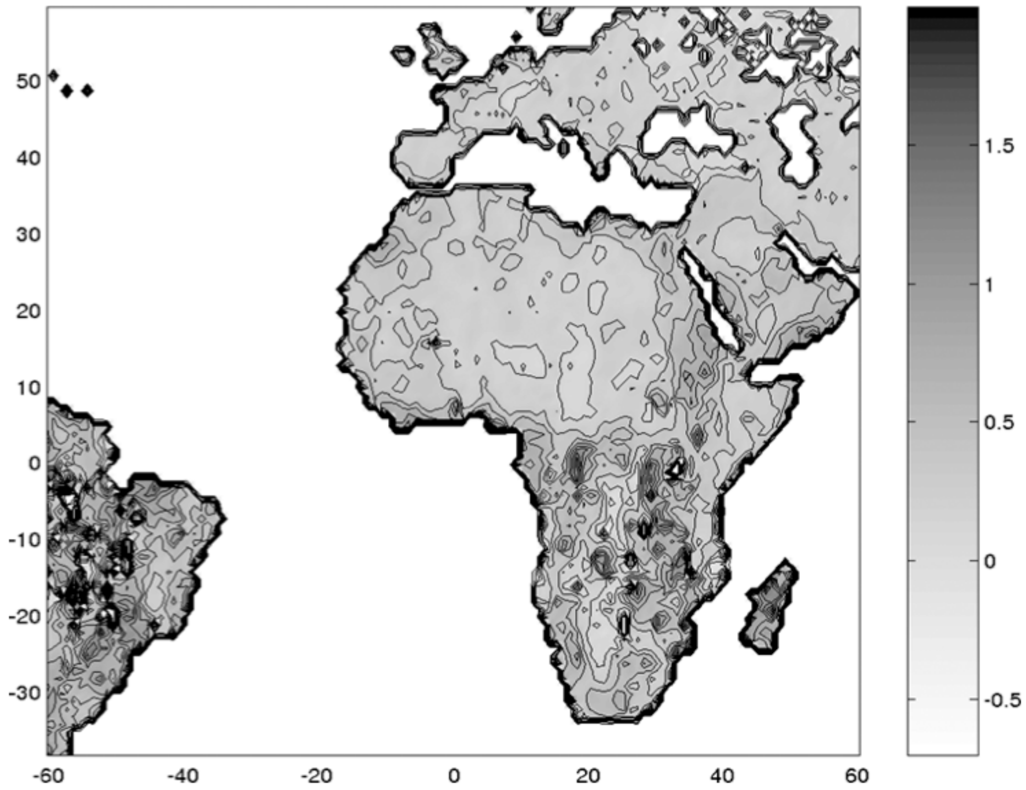


Fig. 5. Mean emissivity difference (in percent) map between the specular and the Lambertian cases using data near nadir from AMSU-A instrument at 23 GHz and during February 2000.

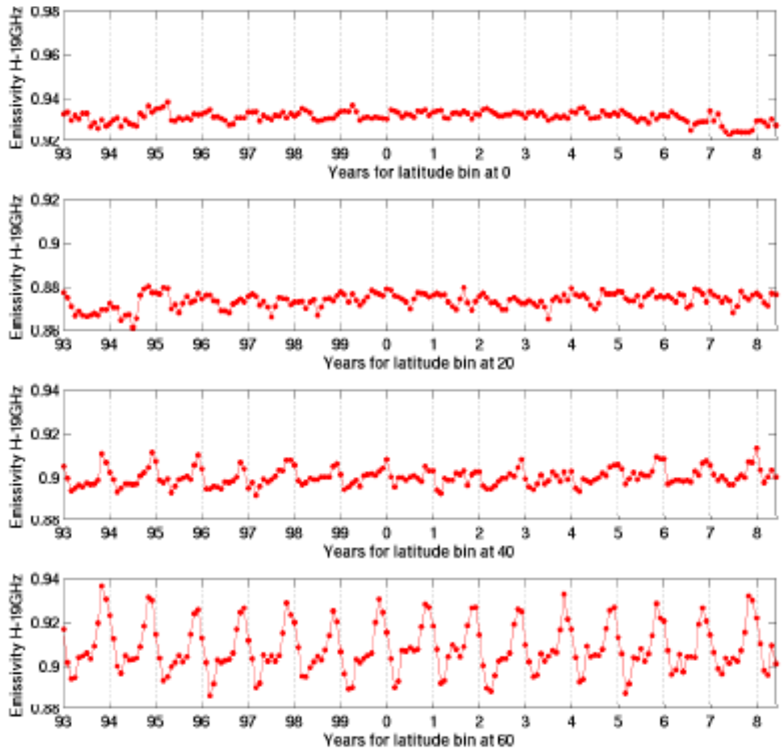
[C. Matzler, On the determination of surface emissivity from satellite observations, IEEE GRSL, 2, 2005]

[Karbou, F. & Prigent, C., Calculations of LSE from satellite observations: validity of the specular approximation over snow-free surfaces, IEEE GRS Letters, 2(3), 2005]

• Estimation of surface emissivity at **19, 22, 37** and **85 GHz**, **V** and **H** polarizations (22 GHz only V), at an incident angle of **53º**.

• For the processing using **ISCCP** cloud flag, ISCCP infrared surface temperature, atmospheric fields from the **NCEP** reanalysis, gaseous absorption from **MPM 93**.

• 16 years of estimates availables, carefully analyzed and monitored over the full time series, with estimated uncertainties within 2% for most surfaces.



e.g. 19 GHz-H e for different latitude bands over 15 years

[Prigent, C., et al., Microwave land surface emissivities estimated from SSM/I observations, JGR, 102, 1997]

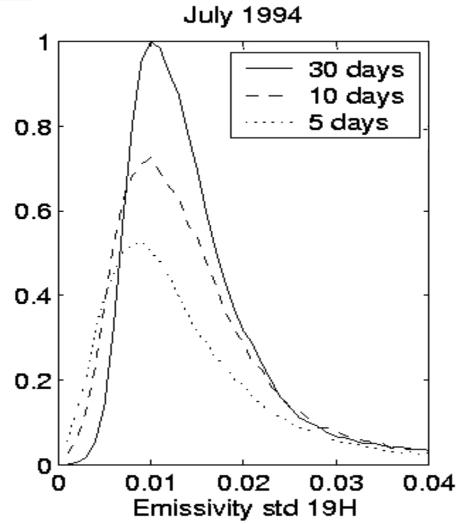
- Estimation errors:

UNCERTAINTIES

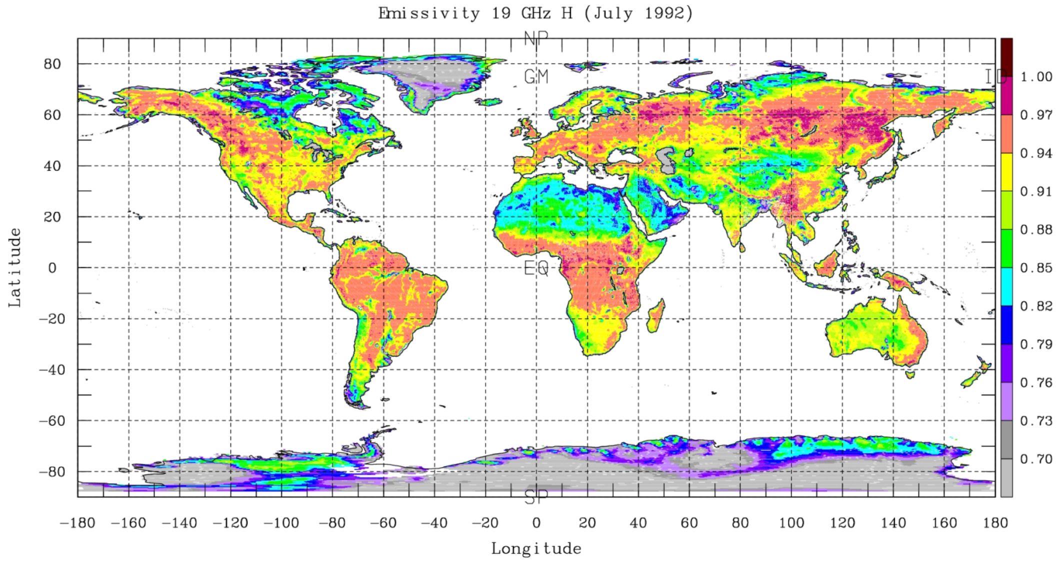
Ts	+/-4 K => 3%
Cloud flag	Drastic effect…
Water vapor content	+/-10 % => 2% at 85 GHz
Brightness temperature	+/-1 K => negligible effect
Spec / Lamb surface	0.9 < e < 1 => < 1%

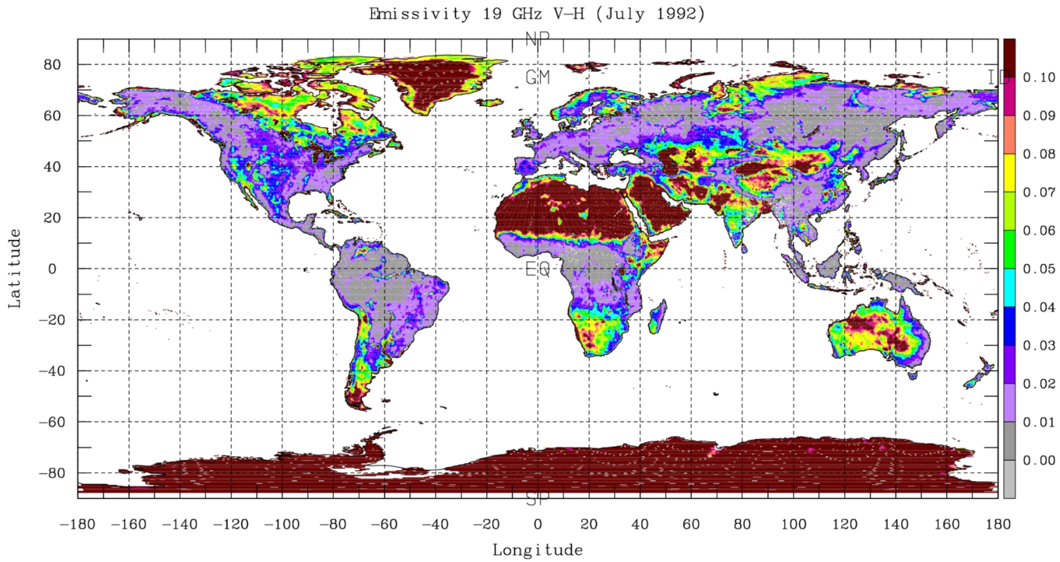
std over a month within 2%

e.g. std over 5-10-30 days
- part of the variability is noise,
- part is related to surface changes



SSM/I e





e.g. **SSM/I e** 19 GHz

Vegetation:
- large emissivities
- low emissivity V-H differences

Deserts:
- low emissivities
- large emissivity V-H differences

Rivers and lakes:
- low emissivities
- large emissivity V-H differences

How can we use these estimates/methods for satellite retrieval schemes over land?

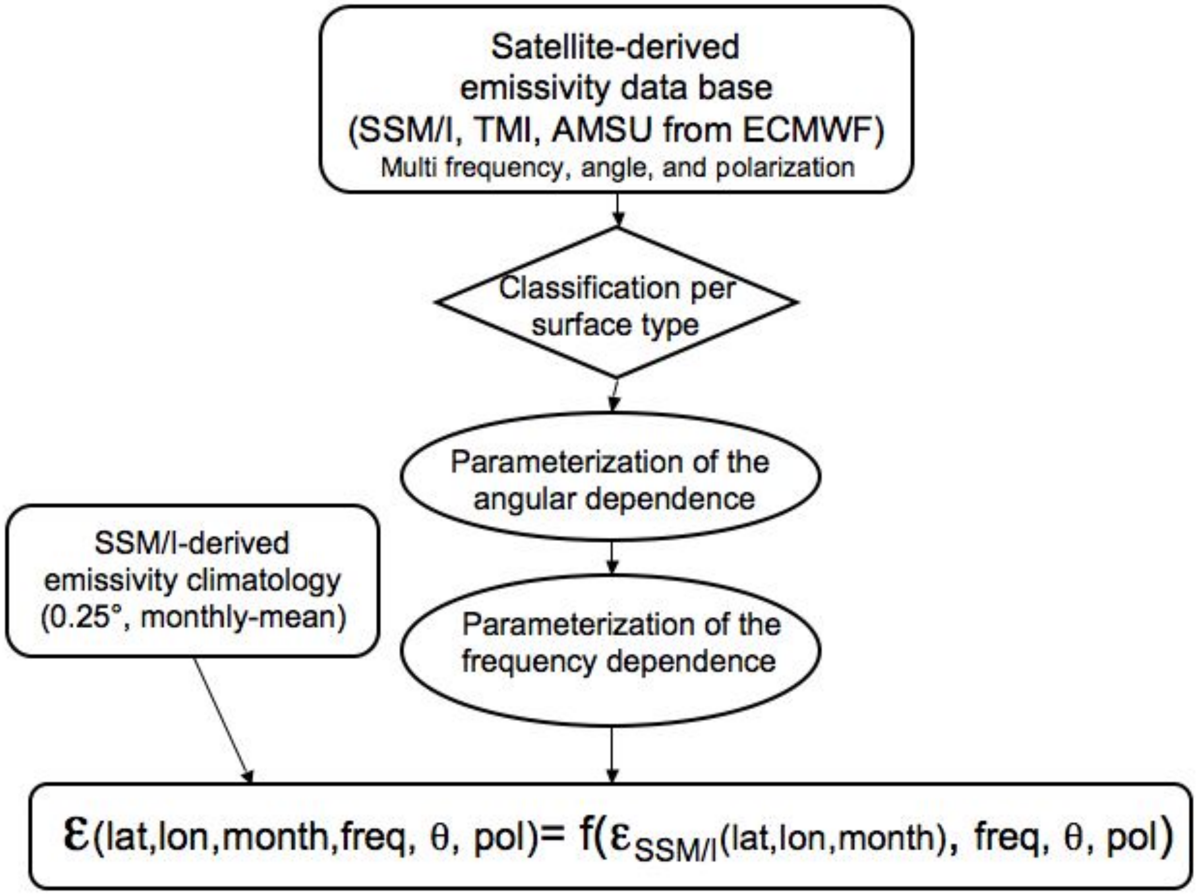
- **Direct estimation** of surface **e** in a retrieval scheme may be difficult to implement:
  - a cloud clearing procedure needed
  - computationally demanding
  - **e** estimates may not be robust for all situations.

- Another strategy is **pre-computed e** atlases providing an **e** first guess that can be adjusted in the inversion or assimilation scheme
  - first-guess need to be as close as possible to the real **e**
  - it needs to take into account frequency, incident angle, and polarization dependencies

A SOLUTION

To derive a parameterization of the **e** frequency, angular, and polarization dependence anchored on a reliable satellite-derived **e** data base.

- **Steps in deriving the parameterization:**



[Prigent, C., et al., A parameterization of the microwave land surface emissivity between 19 and 100 GHz, anchored to satellite-derived estimates, IEEE GRS, 46(2), 2008]

Satellite-derived e-parameterization

1.Motivation

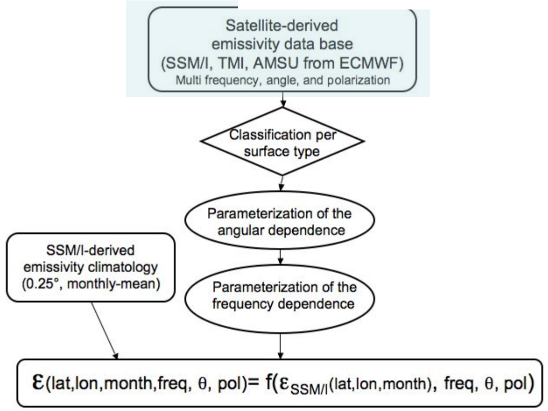
2.Method

3.SMM/I **e**

4.Satellite -derived **e**

5. TELSEM

6. Summary



Emissivity calculation for different frequencies, angles, polarizations

• **e** directly estimated from **satellite observations** under clear sky conditions and averaged over the month (as described before):

SSM/I: 19.35, 22.235, 37.0, 85.5 GHz at 53° for V - H pol. (22V only)
TMI: 10.65, 19.35, 21.3, 37.0, 85.5 GHz at 49° for V - H pol. (21V only)
AMSU-A: 23.8, 31.4, 50.3, 89.0 GHz from 0 to 55°, for a mixture of V - H pol.

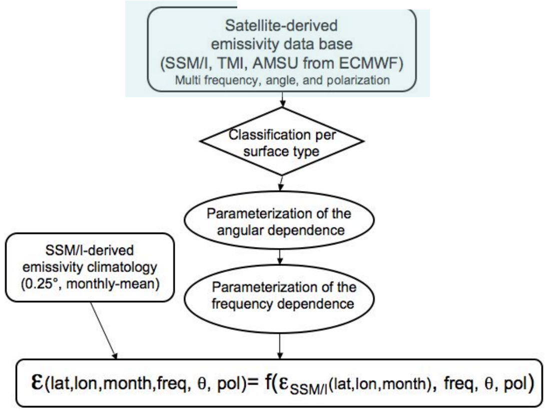
[RTTOVS and atmospheric profiles, clear sky screening, and skin temperature from the **ECMWF forecast**]

• For comparison purposes, **e** also estimated from a **model**:

Weng et al. (2001) radiative transfer model

[ECMWF forecast inputs ro tun the model]

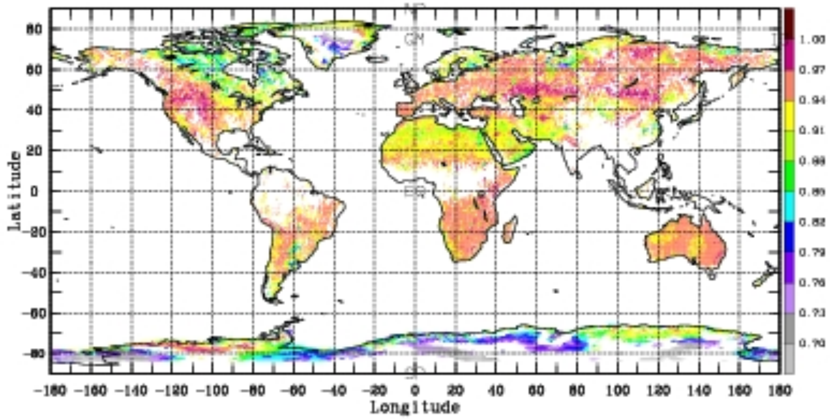
Satellite-derived e-parameterization



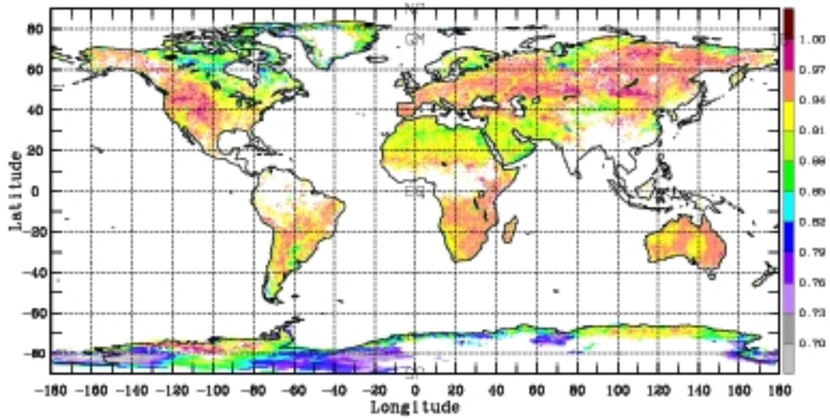
Emissivity calculation for different frequencies, angles, polarizations

e.g. **AMSU-A 31.4 GHz**

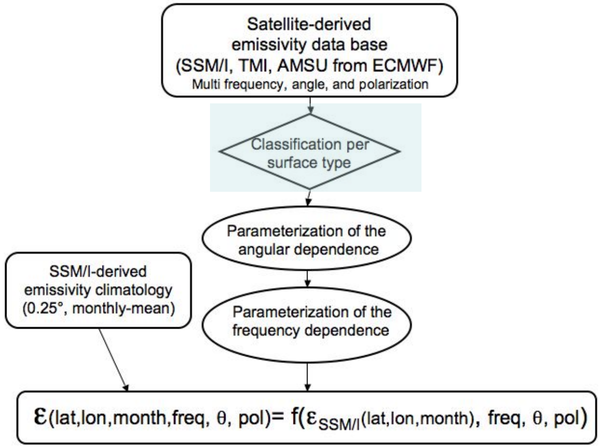
10°-20°



40°-50°



Satellite-derived e-parameterization



• Data set separated in different surface types, using a clustering method applied to the SSM/I emissivity estimates.
• Five classes are isolated, from vegetated regions (class 1) to desert surfaces (class 5).

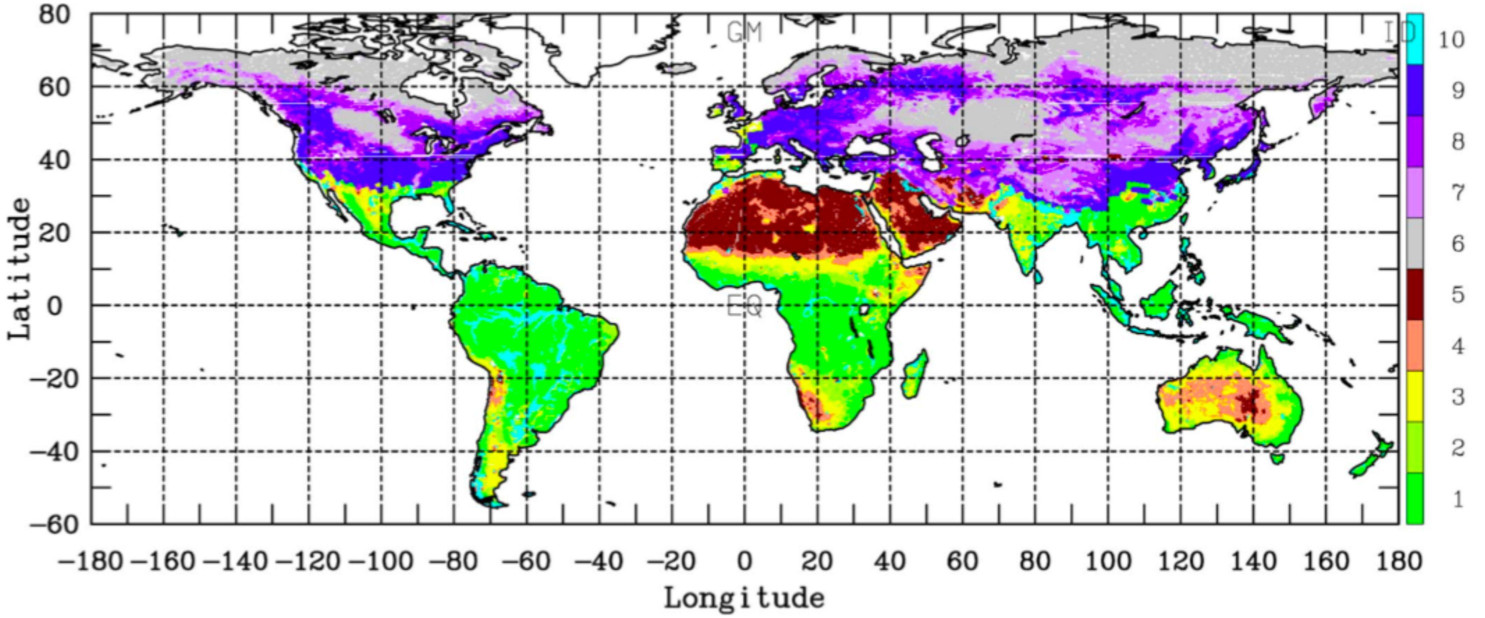


Fig. 2. Result of the classification of SSM/I derived emissivities for January. Classes from 1 to 5 represent continental snow-free regions. Classes 6 to 9 correspond to snow-covered land, and pixels with standing water are grouped in class 10.

<carlos.jimenez@obspm.fr>

Satellite-derived e-parameterization

1.Motivation

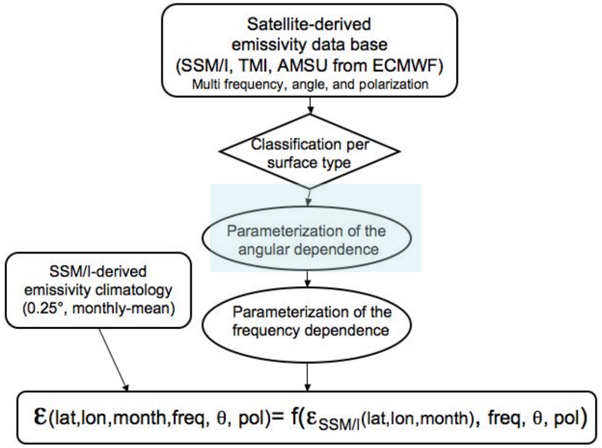
2.Method

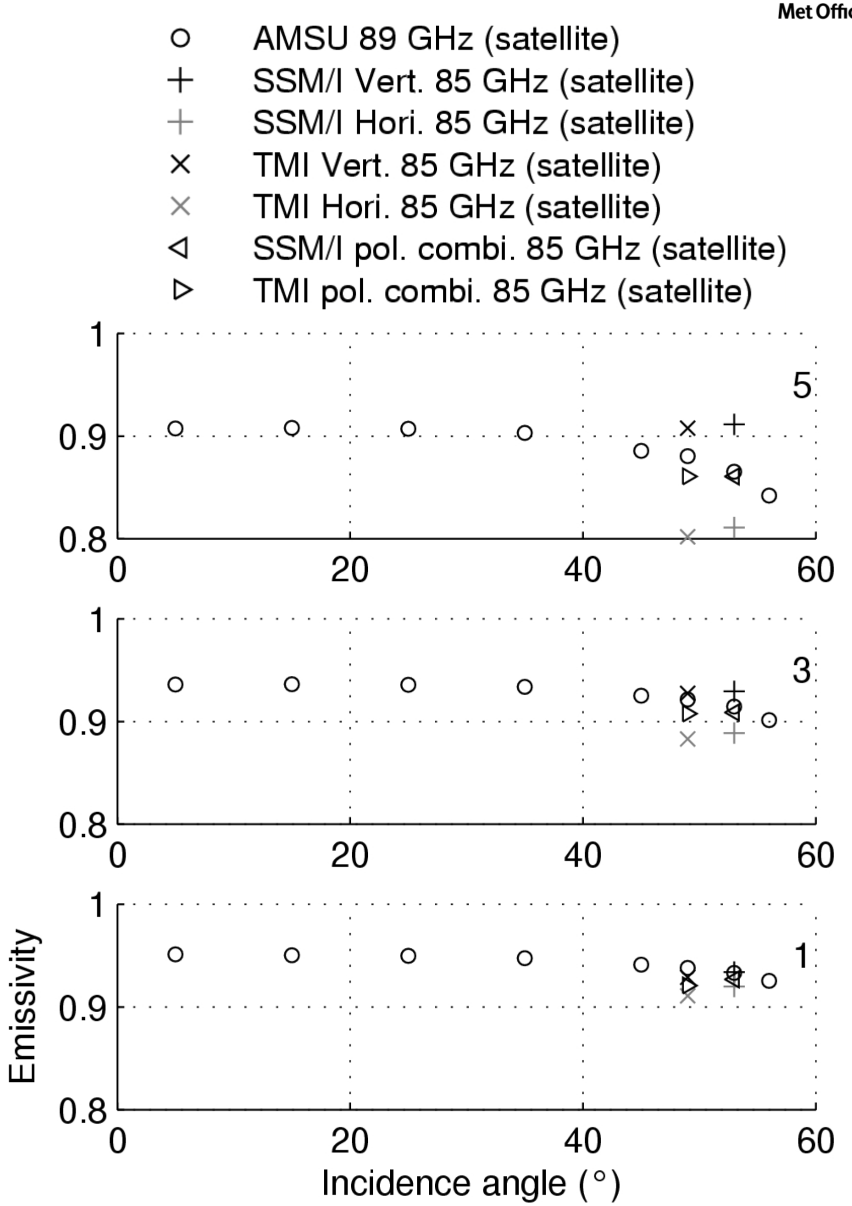
3.SMM/I **e**

4.Satellite -derived **e**

5. TELSEM

6. Summary





- **Smooth angular dependence** of the AMSU derived emissivities

- Very good agreement between the AMSU emissivities at 53° and the V and H SSM/I emissivity combination (with TMI, a calibration issue?)

Satellite-derived e-parameterization

1.Motivation

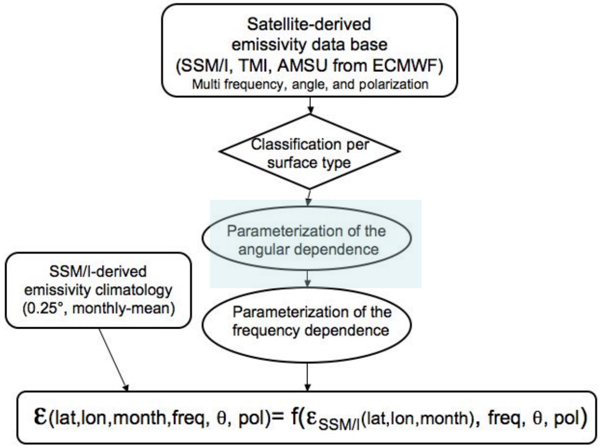
2.Method

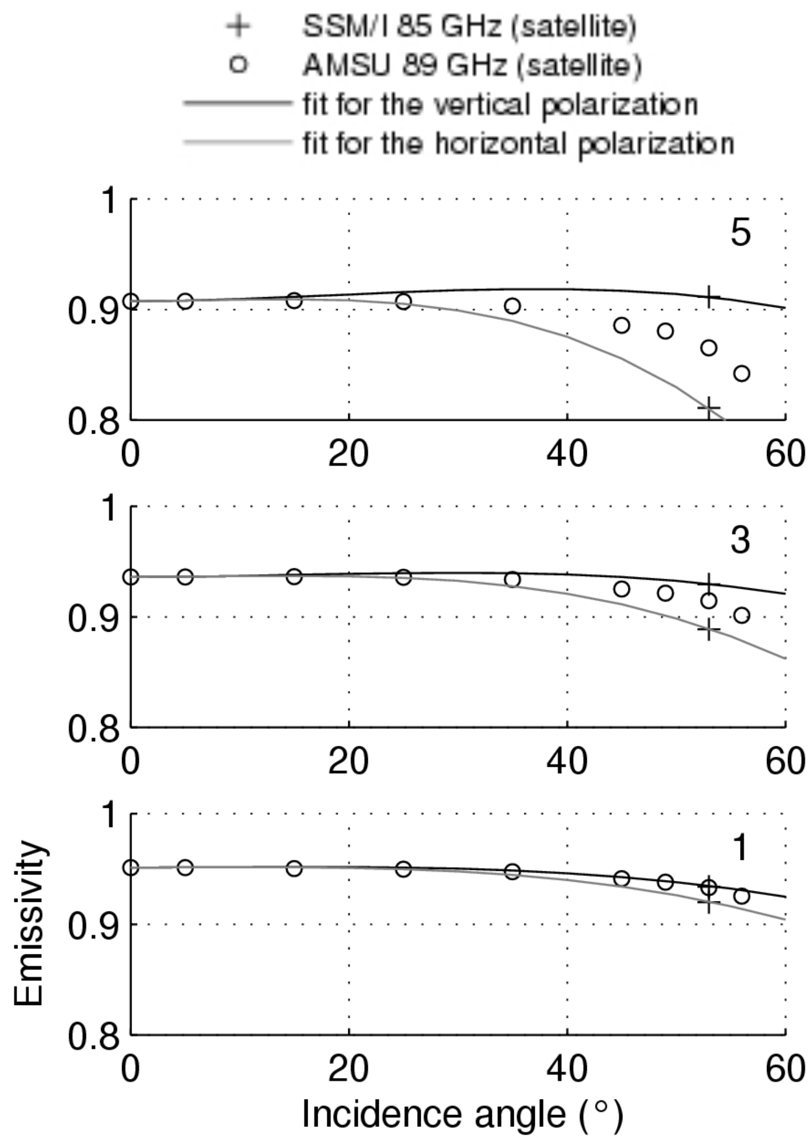
3.SMM/I **e**

4.Satellite -derived **e**

5. TELSEM

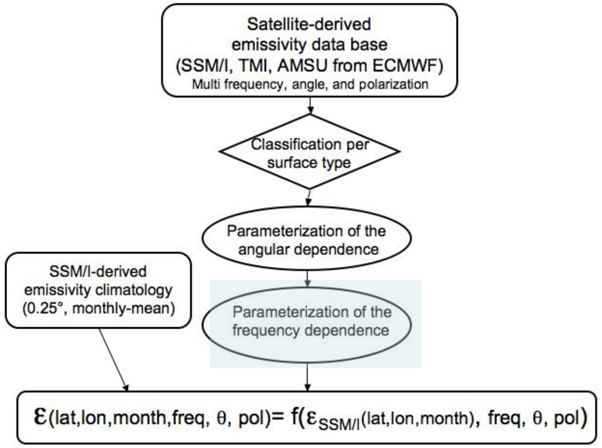
6. Summary

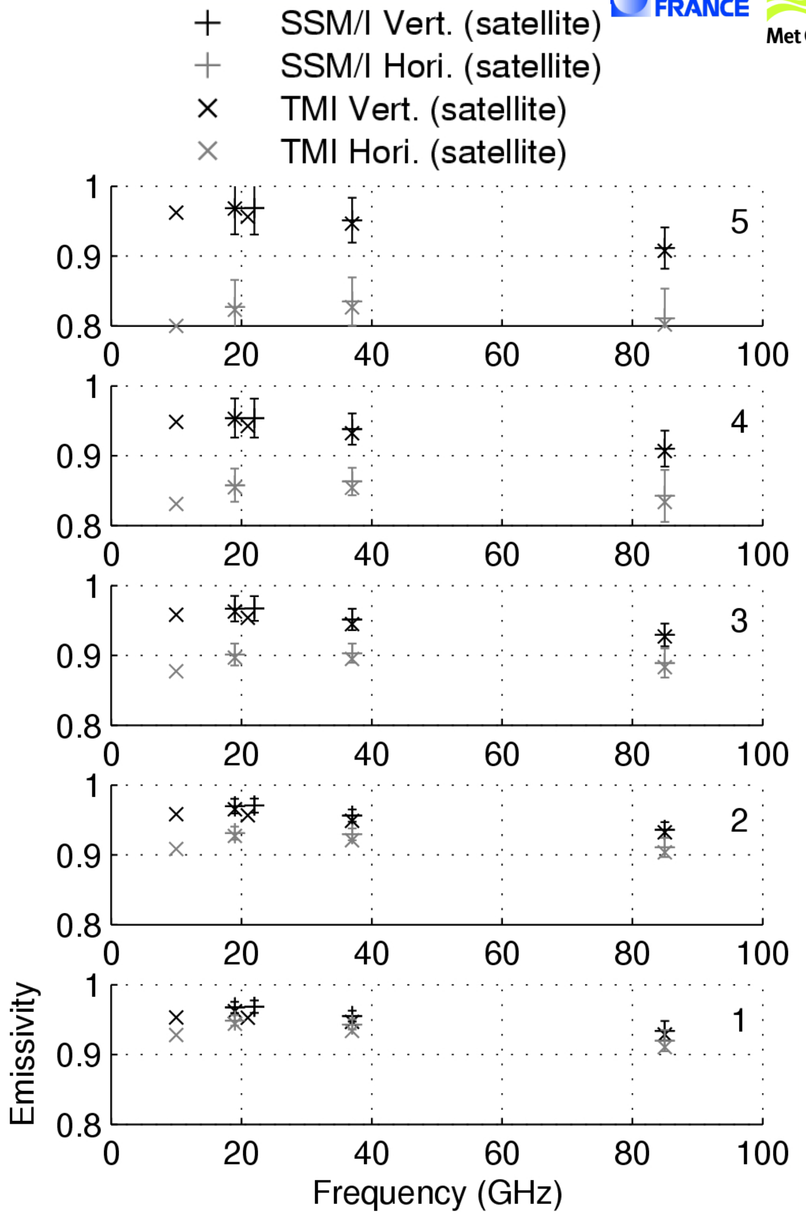




- To describe the emissivity angular dependence, derivation of a **polynomial function** that fits both the SSM/I and AMSU derived estimates, for each surface type.

Satellite-derived e-parameterization



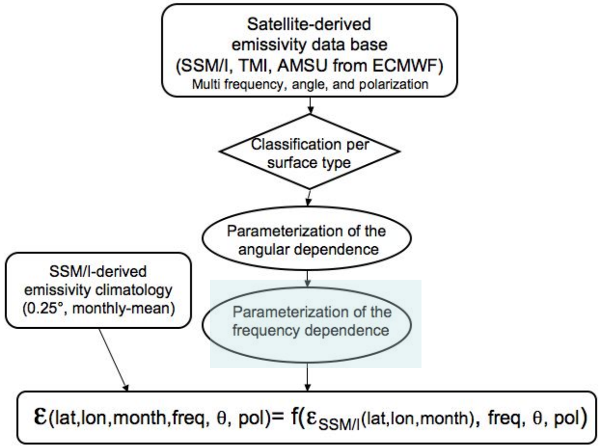


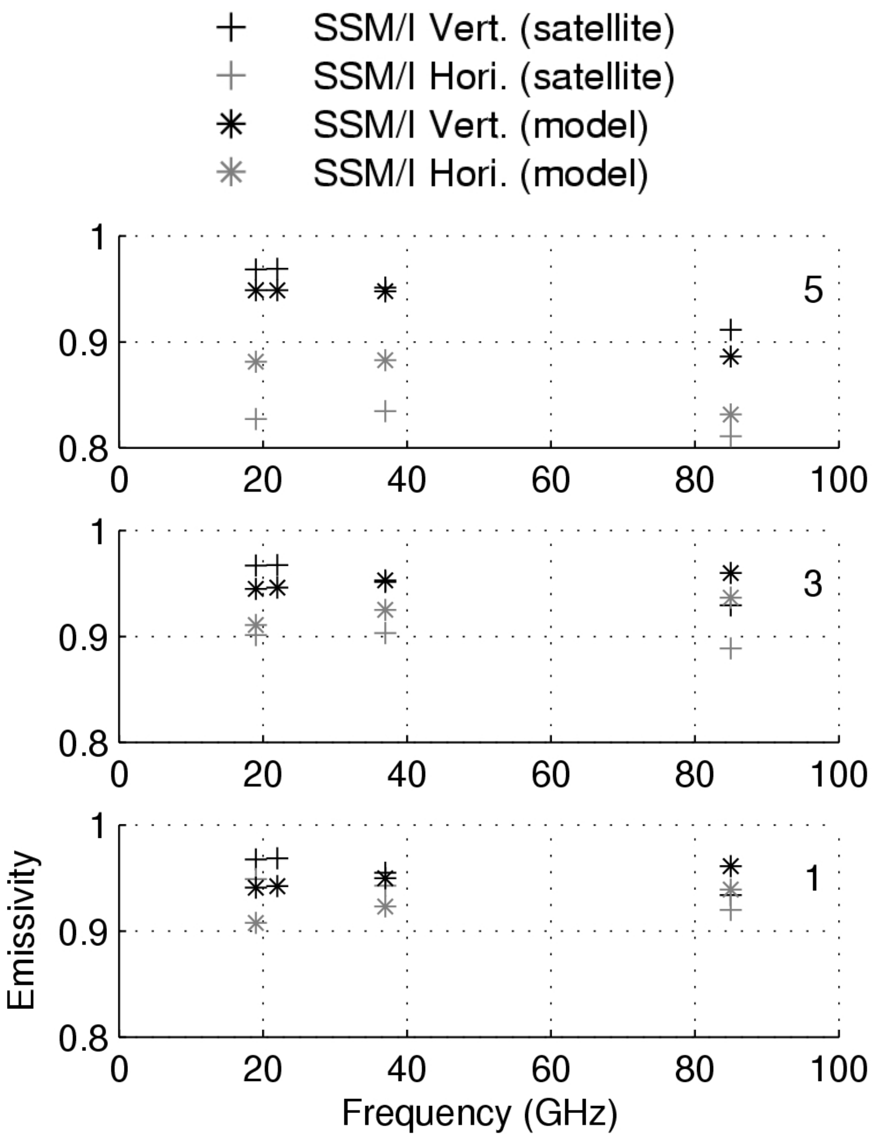
- Emissivities calculated from SSM/I and TMI very similar for a given frequency, except around 22 GHz. Inter-calibration problem?

- **Weak frequency dependence** and close to linear between 19 and 85 GHz.

- The 10 GHz stands apart, especially for H polarization.

Satellite-derived e-parameterization



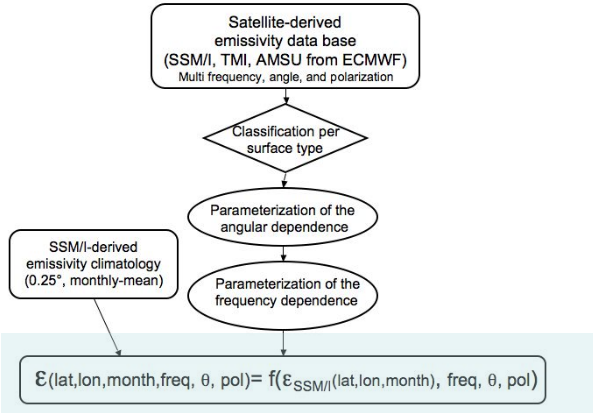


Comparison between satellite-derived and modeled emissivities

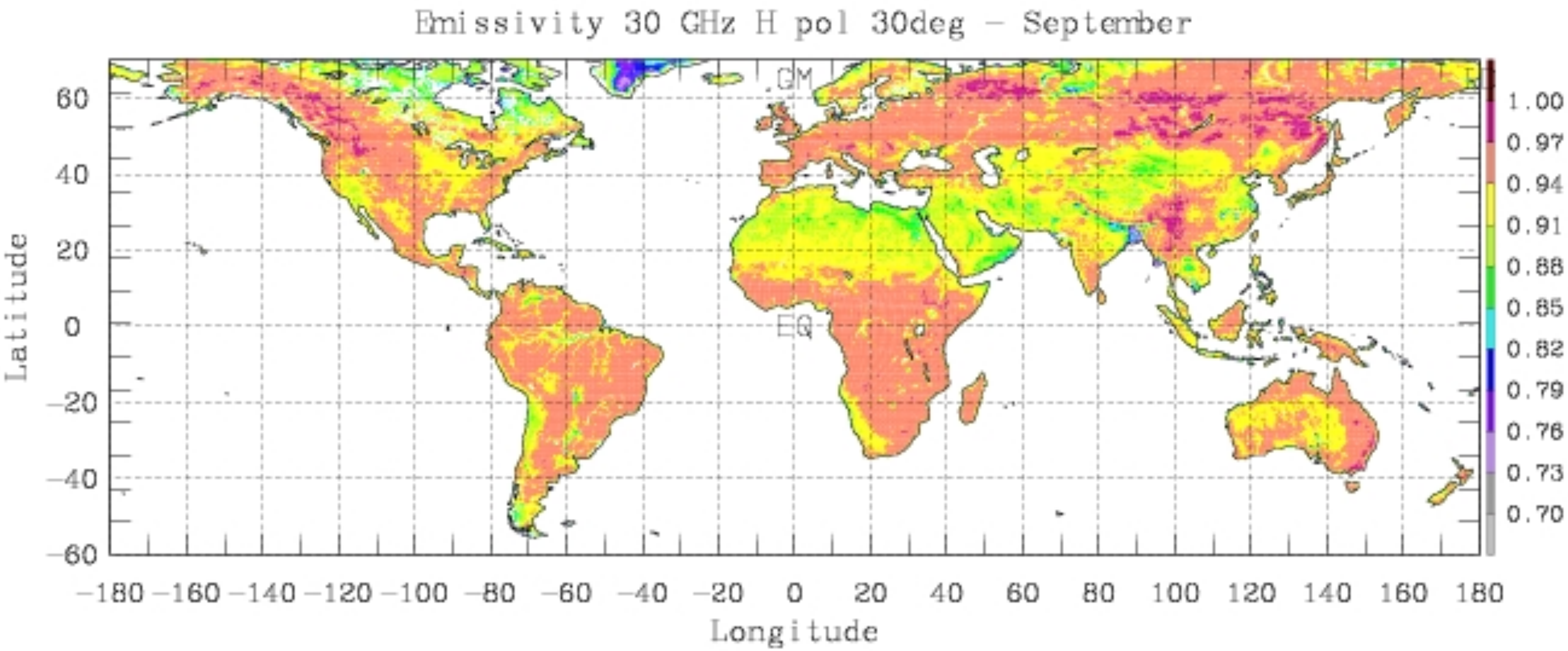
- Much smaller polarization dependence from the model than from the satellite. Too much 'roughness' in the model?

- Less frequency dependence with the model over arid regions than with satellite.

Satellite-derived e-parameterization



e.g. global map **parameterized e**



Satellite-derived e-parameterization

LMD/CNRS · ESTELLUS · l'Observatoire de Paris · LERMA · METEO FRANCE · Met Office

1.Motivation

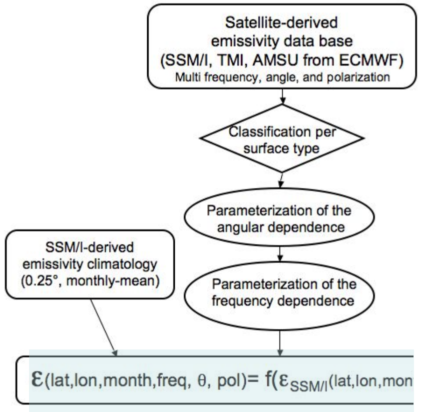
2.Method

3.SMM/I **e**

4.Satellite -derived **e**

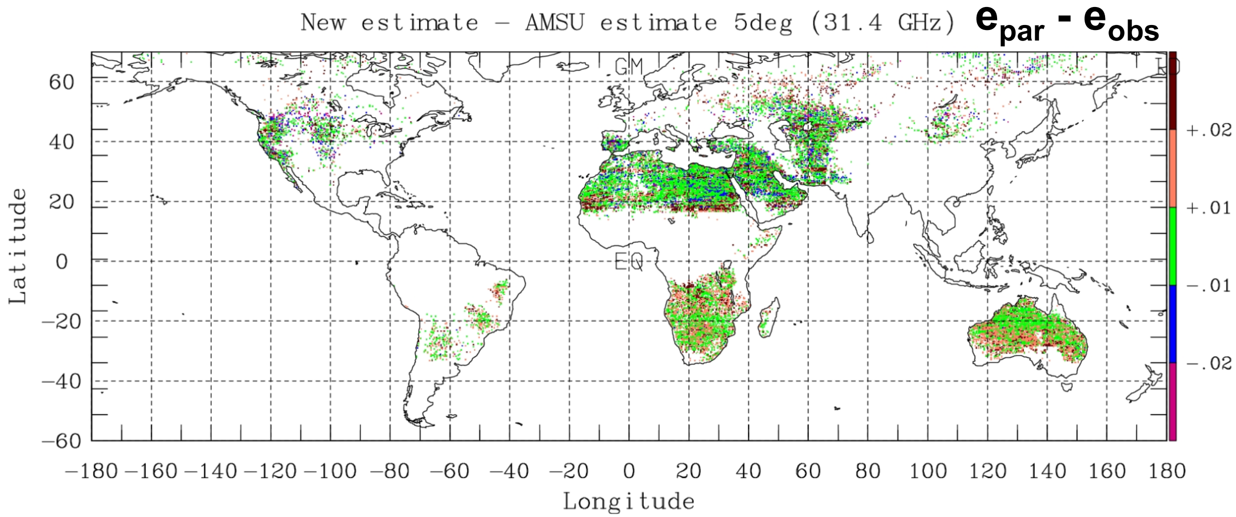
5. TELSEM

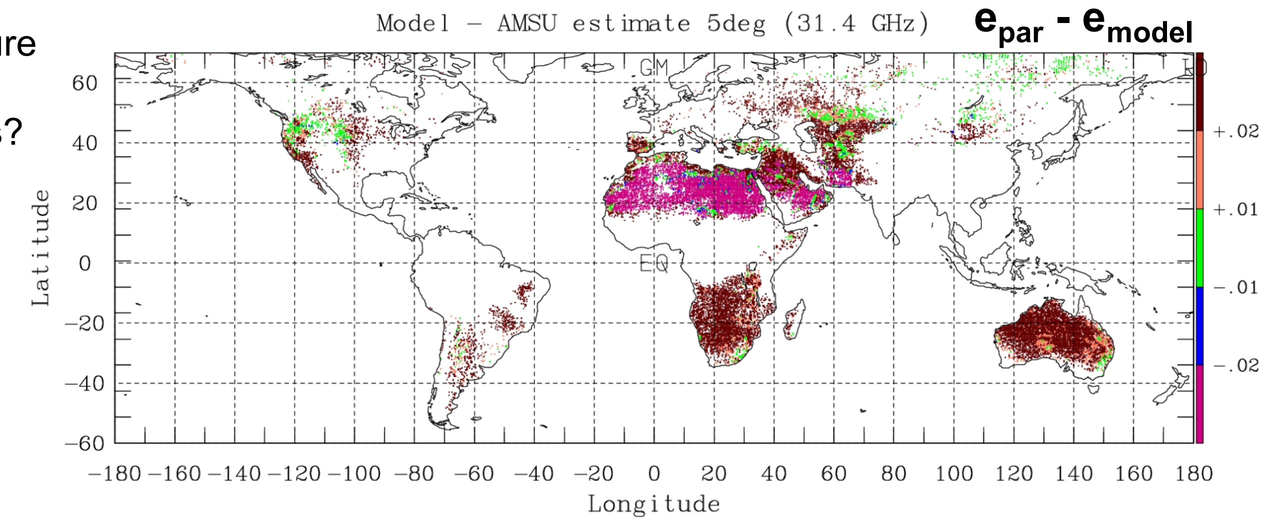
6. Summary



- quality of the model **inputs**?
- model ability to capture the radiation/surface **complex interactions**?

e.g. **parameterized e** and model **e** differences with **e** observations





• Practical **implementation**:

Tool to Estimate Land Surface Emissivities in Microwaves (**TELSEM**), developed within the RTTOV model to provide microwave radiance users (in particular the NWP community) with robust first guess of **e** estimates.

How the algorithm works:

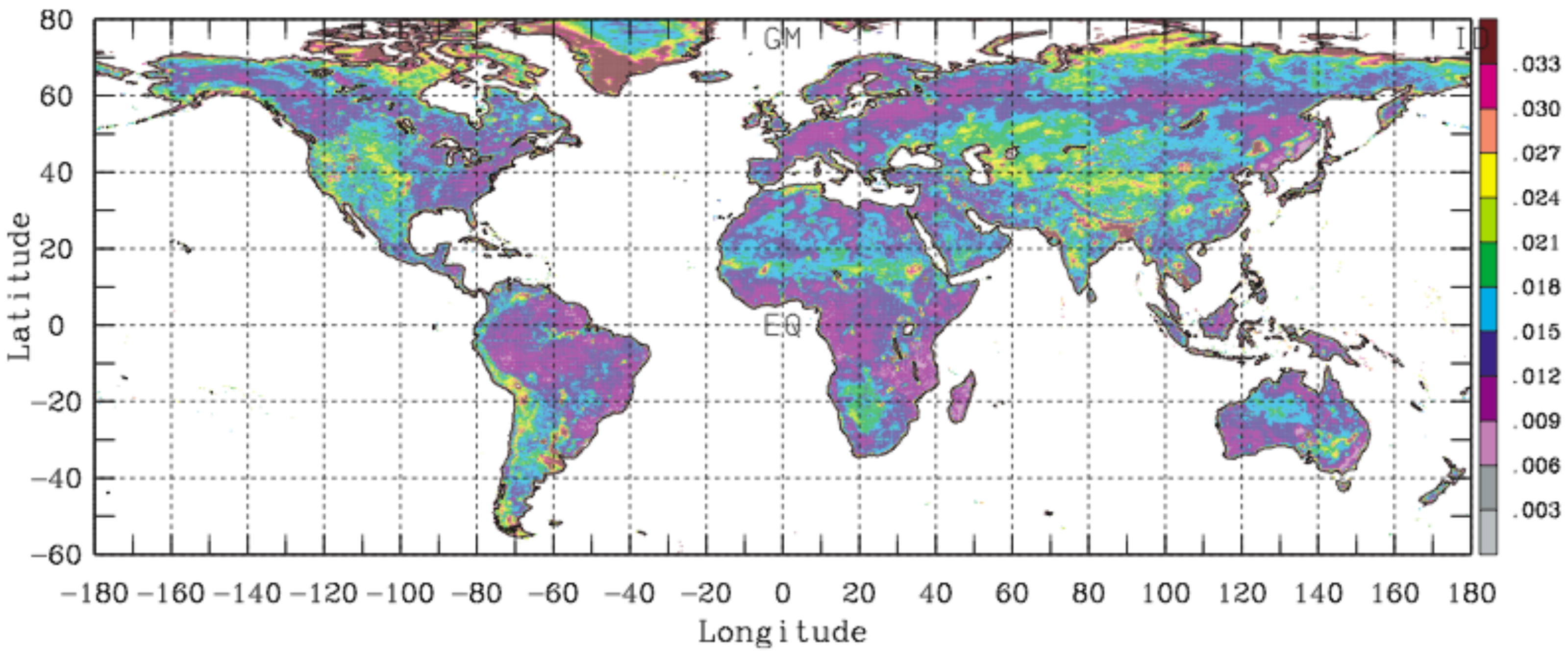
(1) Selection by the user of -a location on the Earth (lat, lon) -a month -a frequency, incidence angle, polarization
(2) Search for the SSM/I **e** in the climatological database for that location and month.
(3) Apply the frequency and angular parameterization to derive the **e** for the observing conditions selected by the user (frequency, angle, and polarization).

- **Errors associated** to estimated **e** provided by TELSEM

  -essential information for most retrieval schemes, especially for assimilation systems.

  - TELSEM provide the **full covariance matrix** of the **e** uncertainties on the new set of channels (freq, θ, and pol)

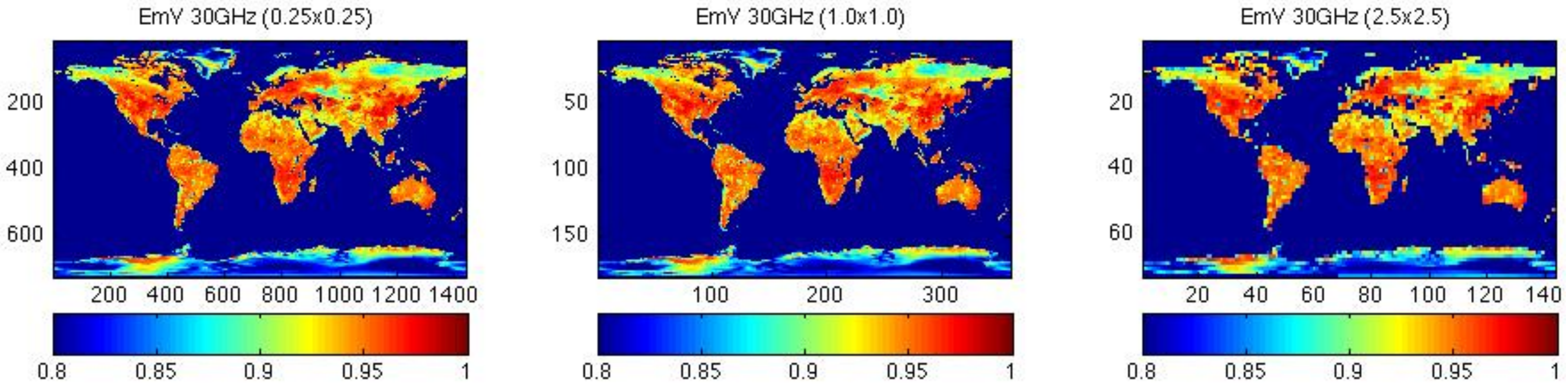
e.g. **e uncertainty** for 31.4 GHz, 15º, V-pol, September



LMD/CNRS · ESTELLUS · l'Observatoire de Paris · LERMA · METEO FRANCE · Met Office

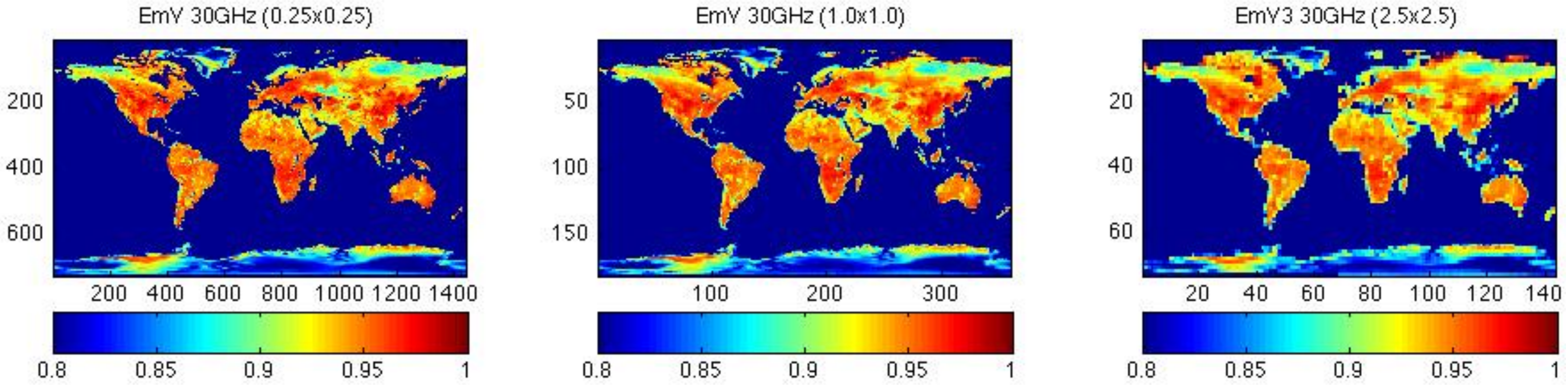
- **Horizontal resolution**:
  - **e** atlas at ~ 0.25ºx0.25º
  - the interpolator tool can be used at any horizontal resolution

closest to **e** atlas pixel



- 2 possibilities to provide estimates at users lat-long grid

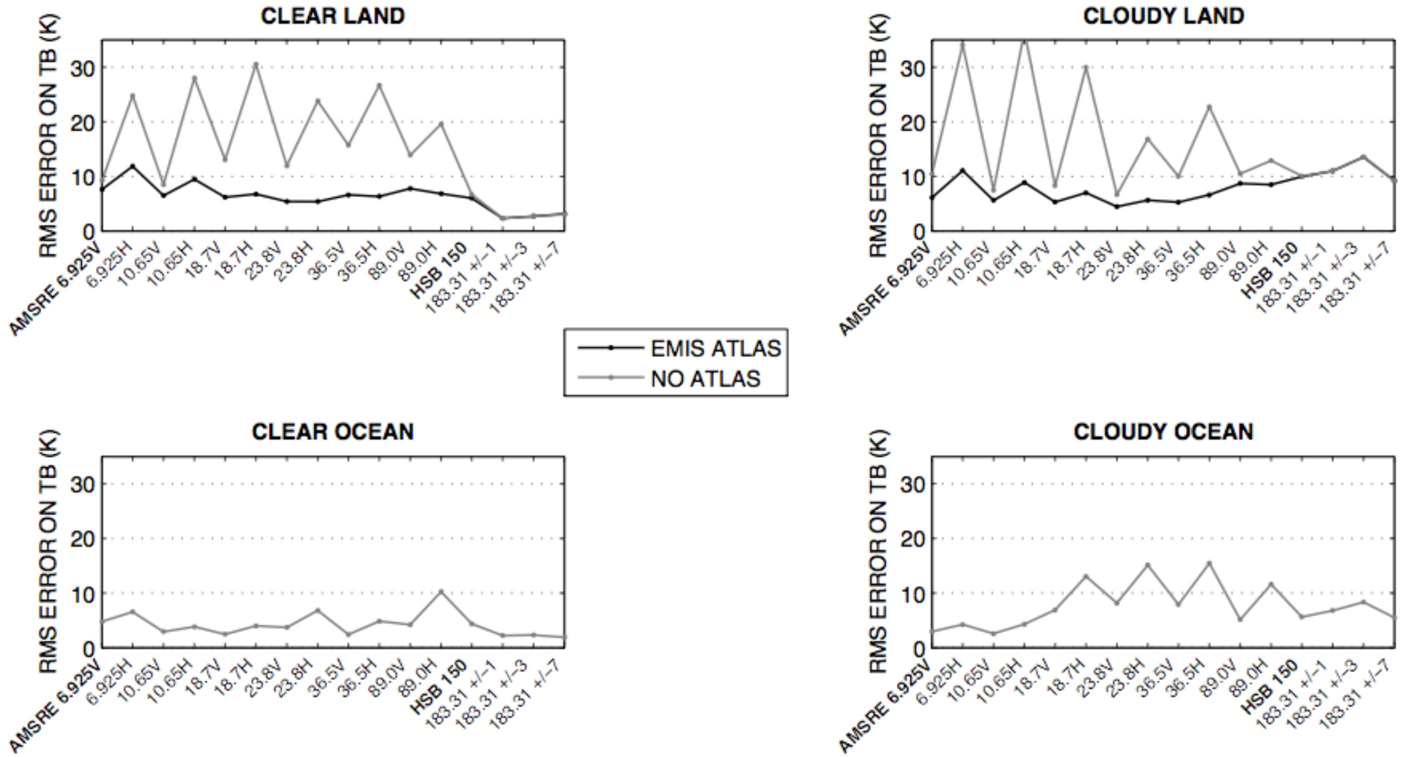
area-average of **e** atlas pixels



TELSEM

• Does it work? **Evaluation** of TELSEM **e [AMSR-E & HSB]**:

• Comparing July-2002 and January-2003 observations with RTTOV and **RTTOV+TELSEM** RT simulations, atmospheric fields and Ts from ECMWF, non precipitating conditions.



• For comparison purposes, also clear and cloudy ocean cases by **RTTOV+FASTEM**.

smaller RMS Tb differences for RTTOV+TELSEM for window channels, specially for H-pol.

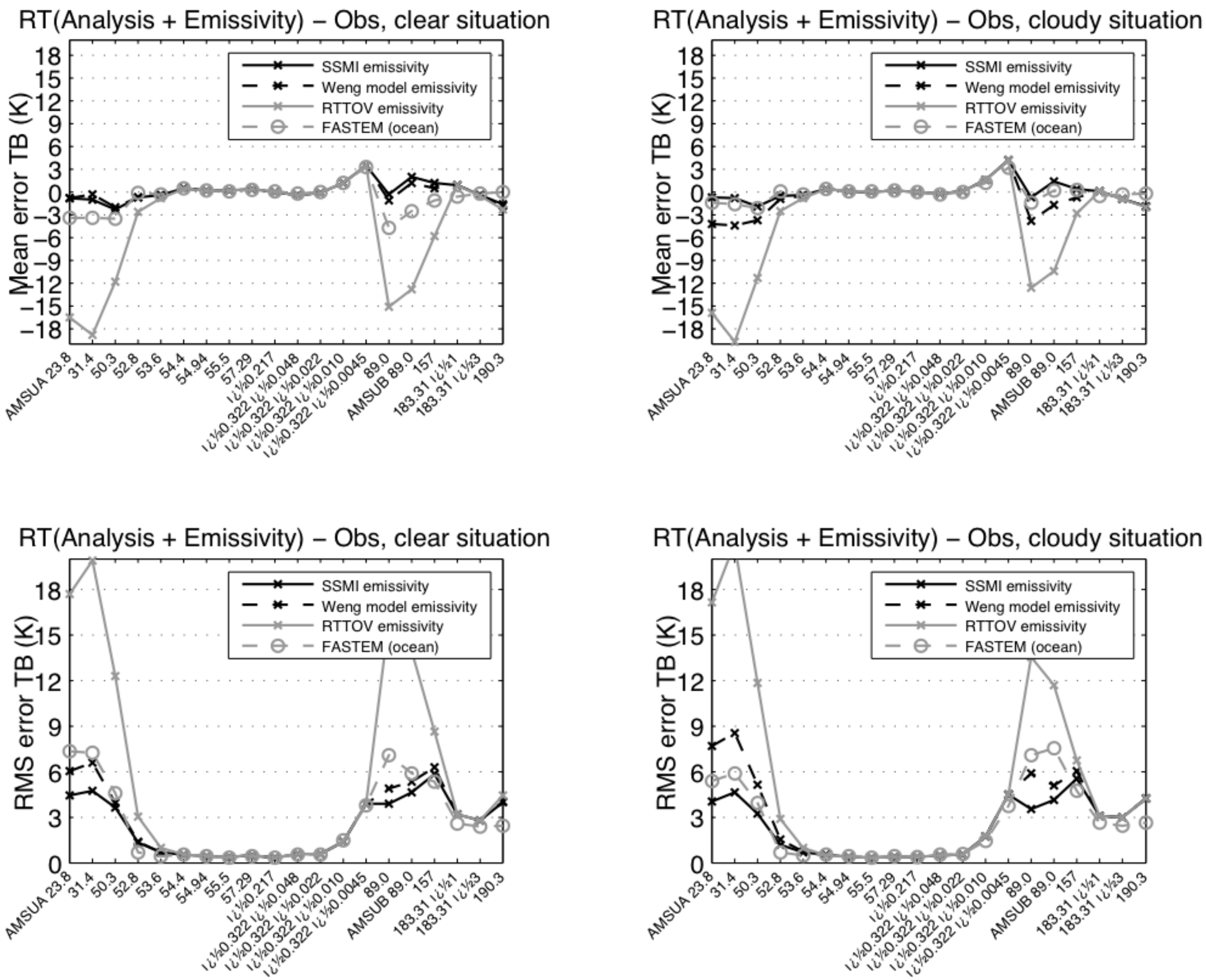
[Aires, F., et al., A Tool to Estimate Land Surface Emissivities at Microwaves frequencies (TELSEM) for use in numerical weather prediction schemes, in review.]

• **Evaluation** of TELSEM **e** [**AMSU**]

• comparing 07/2002 - 01/2003 observations with RT simulations assuming different **e,** non precipitating conditions, lat [-60 +60]

• for comparison purposes, also RT simulations over the oceans

• comparable land and ocean RMS differences for RTTOV+TELSEM



[Aires, F., et al., A Tool to Estimate Land Surface Emissivities at Microwaves frequencies (TELSEM) for use in numerical weather prediction schemes, in review.]

1.Motivation
2.Method
3.SMM/I **e**
4.Satellite -derived **e**
5. TELSEM
6. Summary

• **Practical issues**:

TELSEM: a Tool to Estimate Land Surface Emissivities at Microwave frequencies

Version 1.0

November 2009

EUMETSAT
NWP SAF

Table of Contents

• For related publications:
http://aramis.obspm.fr/~prigent/publication.html

• Monthly mean SSM/I **e** full time record available under request
catherine.prigent@obspm.fr

• TELSEM part of the RTTOV distribution (Fortran90), also under request
filipe.aires@lmd.jussieu.fr

• possible **interfacing** with **ARTS**

The power reflection coefficients are converted to an intensity reflection coefficient as

$$r = |R|^2, \quad (6.11)$$

This leads to that the transformation matrix for a specular surface reflection is (compare to *Liou* [2002, Sec. 5.4.3])

$$\mathbf{R} = \begin{bmatrix} \frac{r_v+r_h}{2} & \frac{r_v-r_h}{2} & 0 & 0 \\ \frac{r_v-r_h}{2} & \frac{r_v+r_h}{2} & 0 & 0 \\ 0 & 0 & \frac{R_hR_v^*+R_vR_h^*}{2} & i\frac{R_hR_v^*-R_vR_h^*}{2} \\ 0 & 0 & i\frac{R_vR_h^*-R_hR_v^*}{2} & \frac{R_hR_v^*+R_vR_h^*}{2} \end{bmatrix}. \quad (6.15)$$

If the downwelling radiation is unpolarised, the reflected part of the upwelling radiation is

$$\mathbf{R}\begin{bmatrix} I \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} I(r_v+r_h)/2 \\ I(r_v-r_h)/2 \\ 0 \\ 0 \end{bmatrix}. \quad (6.16)$$

as expected.

If **R** is given by Equation 6.15, Equation 6.6 gives that the surface emission is

$$\begin{bmatrix} B\left(1-\frac{r_v+r_h}{2}\right) \\ B\frac{r_h-r_v}{2} \\ 0 \\ 0 \end{bmatrix}. \quad (6.17)$$

In the case of specular reflections, `surface_los` shall of course be set to have the length 1. The specular direction is calculated by the internal function `surface_specular_los`[1]. Equations 6.15 and 6.17 give the values to put into `surface_rmatrix` and `surface_emission`.

TELSEM providing **e**$_v$, **e**$_h$ --> **r**$_v$, **r**$_h$ --> **R** (but not **R**$_h$, **R**$_v$)

Summary

• A method developed to estimate **global microwave emissivities** in the 19-90 GHz range (potentially higher frequency), for all incidence angles and both orthogonal polarizations. It is anchored to a monthly-mean emissivity climatology derived from **SSM/I observations** over a decade.

• Possible **applications**:

- for **assimilation** of close-to-the-surface sounding channels
- for **surface background** estimate in precipitation and cloud retrievals
- for skin surface **temperature retrievals**
- for simulation of more realistic responses of **future instruments**.

• First tests performed indicate a **strong positive impact** in reducing the differences between RT simulations for AQUA (AMSRE/HSB) and METOP (ASMUA/MHS) and the corresponding observations.

• **RTTOV implementation** (Fortran90+Atlas) available upon request.