Transfert radiatif aux interfaces

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A difficult task

- Frequency variety
- Modes (passive / active)
- Environments (ocean, land, vegetation, soil, snow, and ice)
- Applications (surface characterization, lower- layer atmospheric sounding, research or operational…)

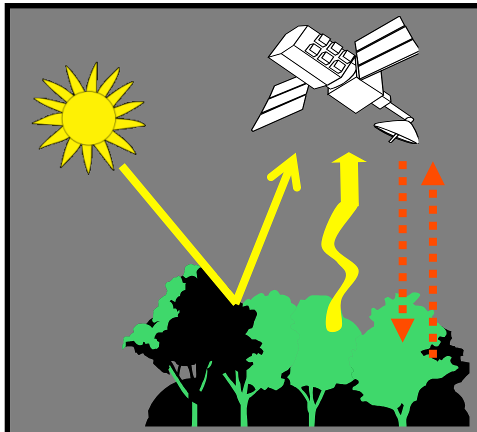
⇒ Will not be exhaustive… Just a flavor…

Outline:

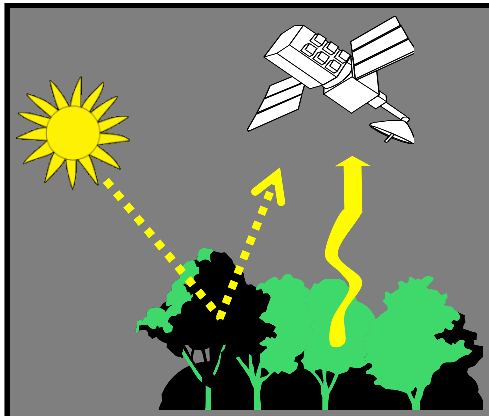
- Visible and near-infrared (prepared by S. Jacquemoud)
- Infrared and microwaves

Soil-vegetation remote sensing

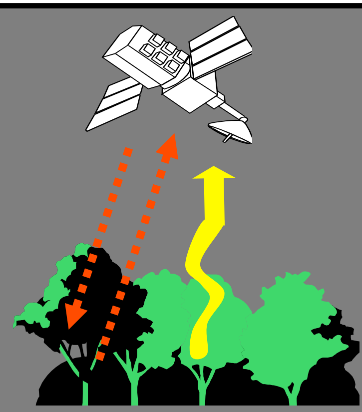
UV-VIS-NIR-SWIR	MWIR-LWIR	Microwaves



Reflectance
Lidar intensity



Brightness temperature

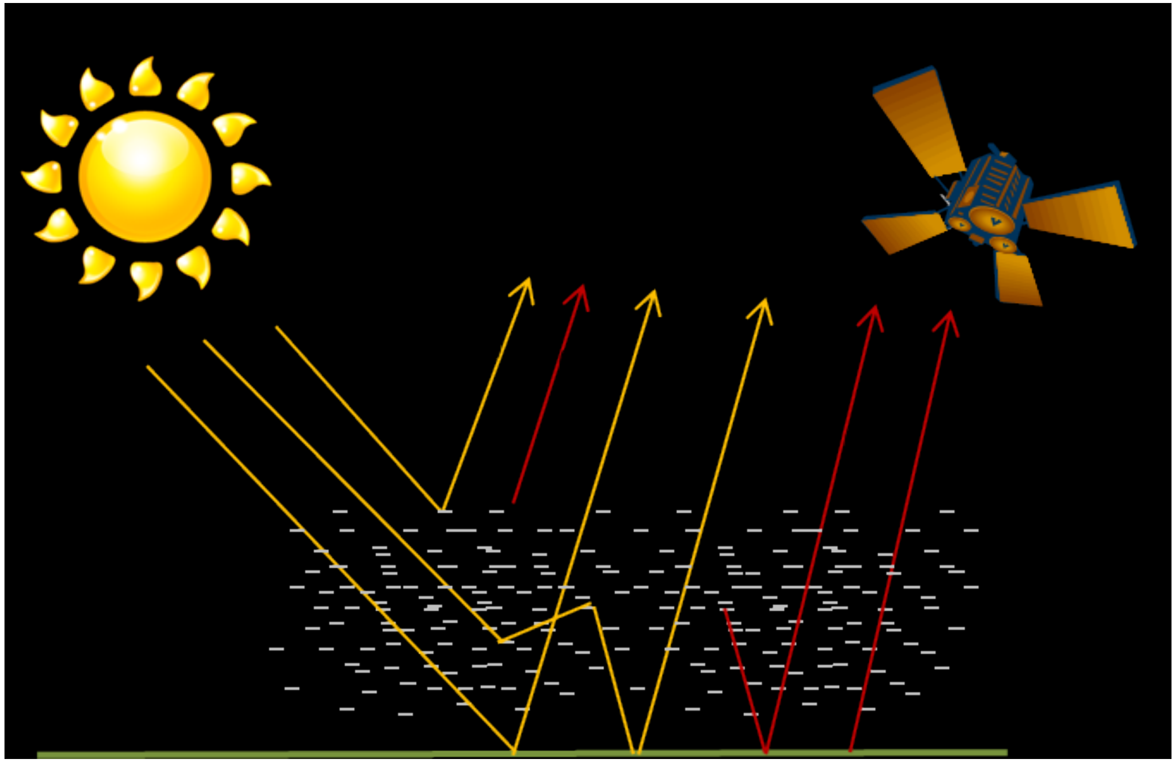


Brightness temperature

Backscattering coef.

Visible and Near-Infrared

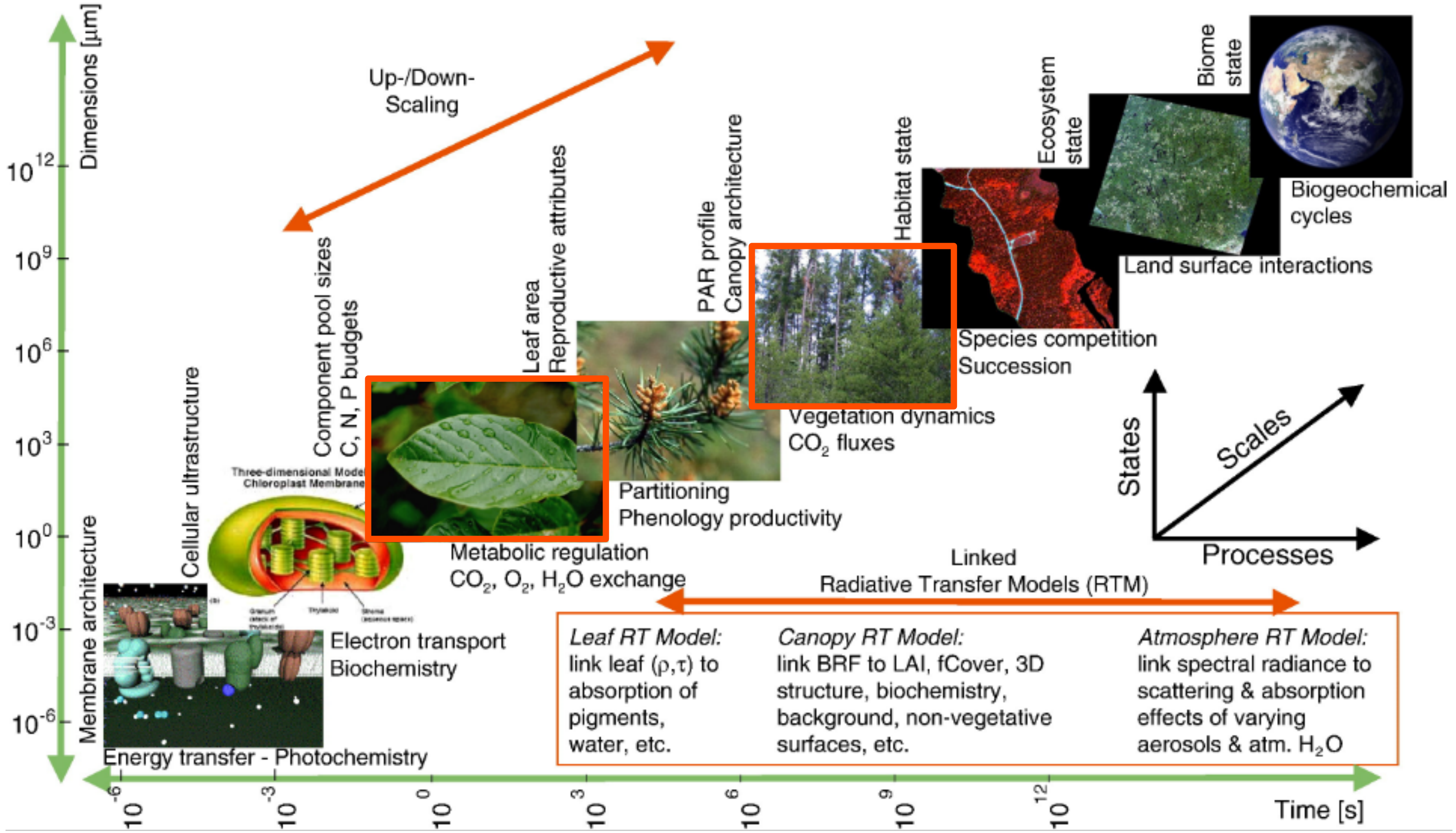
Surface-atmosphere coupling



$$L_\lambda(\theta_v,\varphi_v) = \underbrace{\varepsilon_\lambda(\theta_v,\varphi_v)B_\lambda(T_s)\tau_{atm\uparrow,\lambda}(\theta_v,\varphi_v)}_{\text{1) Thermal emission by the surface}} + \underbrace{L_{atm\uparrow,\lambda}(\theta_v,\varphi_v)}_{\text{2) Atmospheric radiance}}$$

$$\underbrace{+\tau_{atm\uparrow,\lambda}(\theta_v,\varphi_v)\int_0^{2\pi}\int_0^{\pi/2}\rho_\lambda(\theta_i,\varphi_i,\theta_v,\varphi_v)L_{atm\downarrow,\lambda}(\theta_i,\varphi_i)\cos\theta_i\sin\theta_i\,\mathrm{d}\theta_i\,\mathrm{d}\varphi}_{\text{3) Incident radiation reflected by the surface}}$$

Plant canopies: coupled multi-scale processes

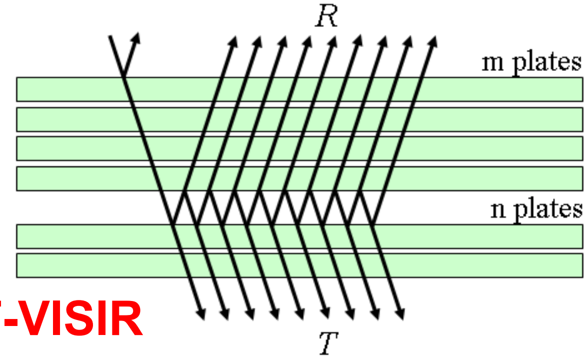


Schaepman et al. (2009), *Remote Sensing of Environment*, 113:S123-S137

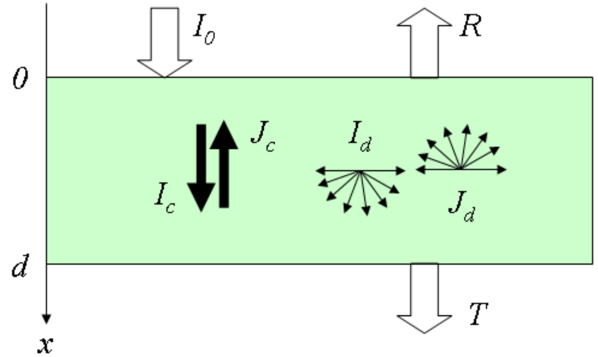
Modeling leaf optical properties

Multilayer models

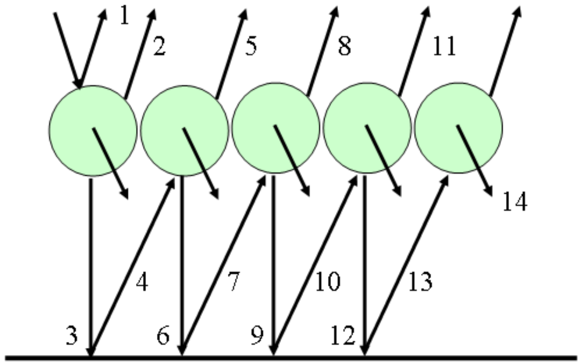
PROSPECT-VISIR



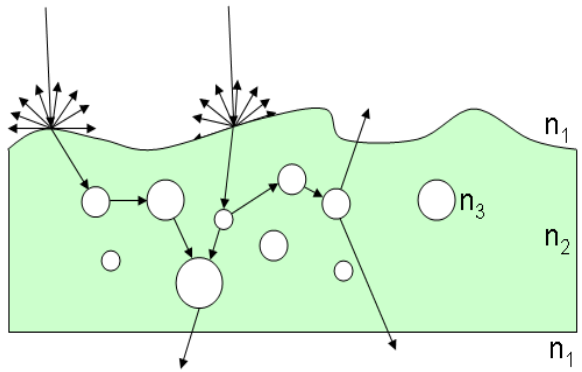
Kubelka-Munk theory



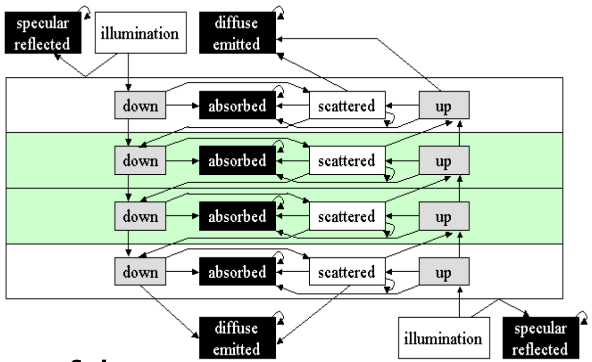
Melamed model



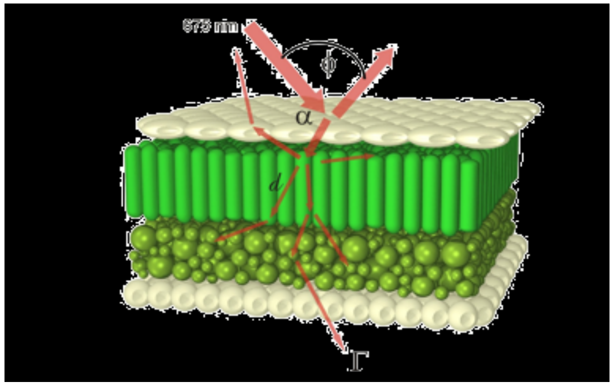
Radiative transfer equation



Stochastic approach



Monte Carlo methods

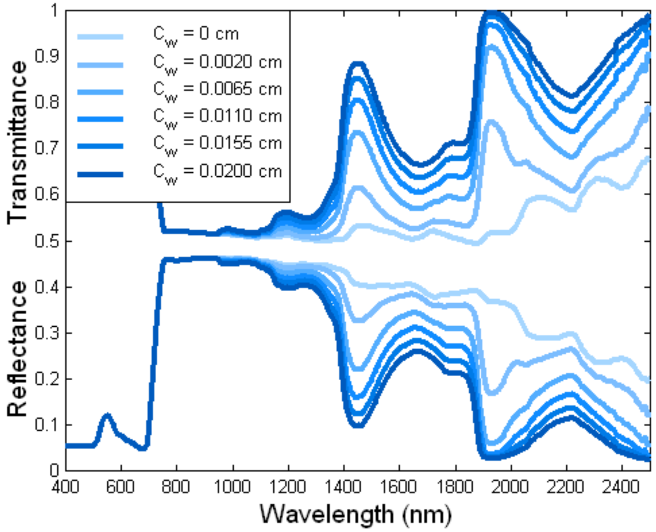


http://opticleaf.ipgp.fr/

http://www.photobiology.info/Jacq_Ustin.html

PROSPECT: sensitivity analysis → water content

« one-factor-at-a-time »



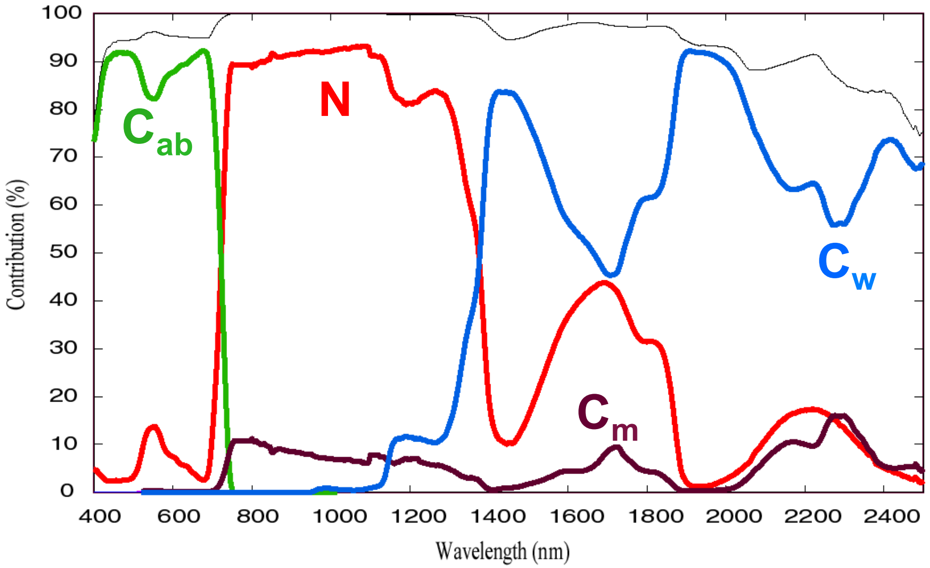
N = leaf structure parameter

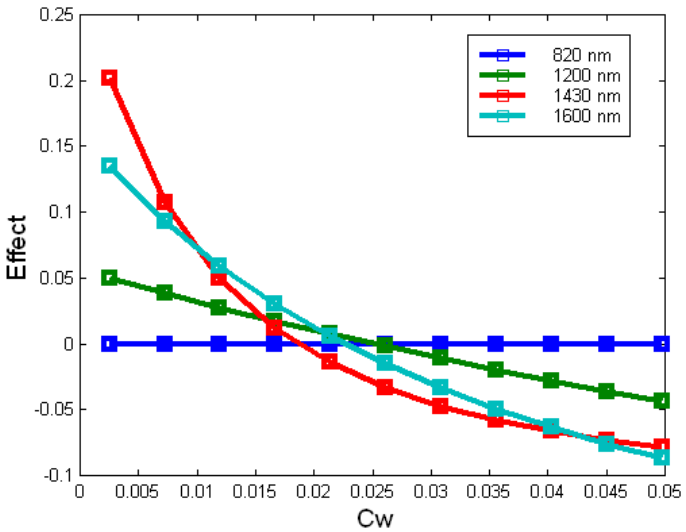
C_{ab} = chlorophyll content

C_w = water content

C_m = dry matter content

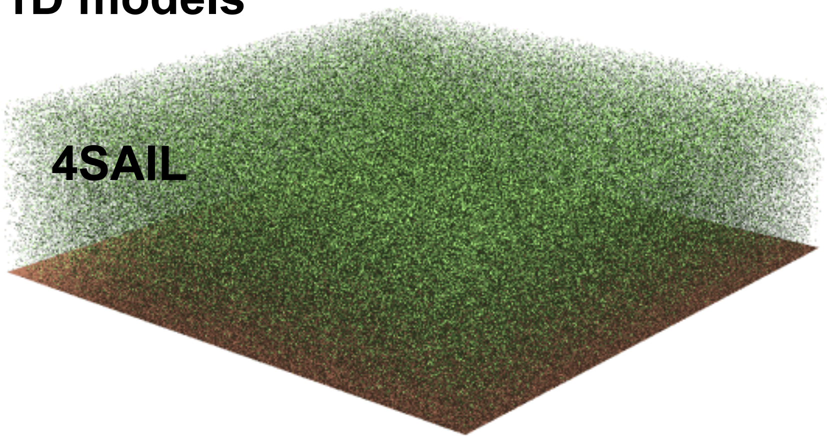
« global »



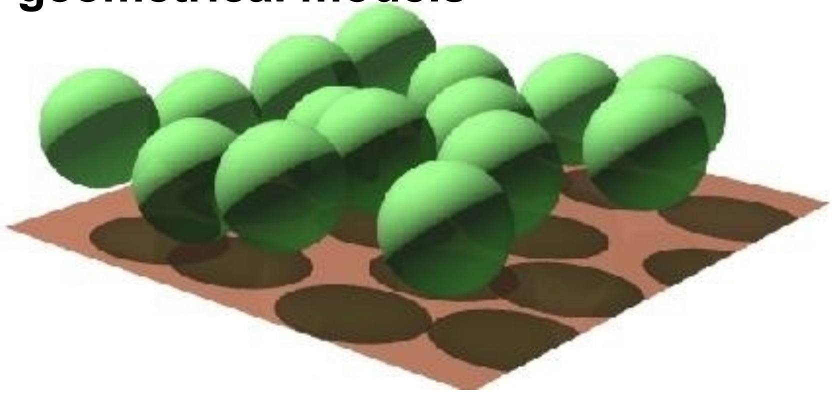


Modeling canopy BRDF

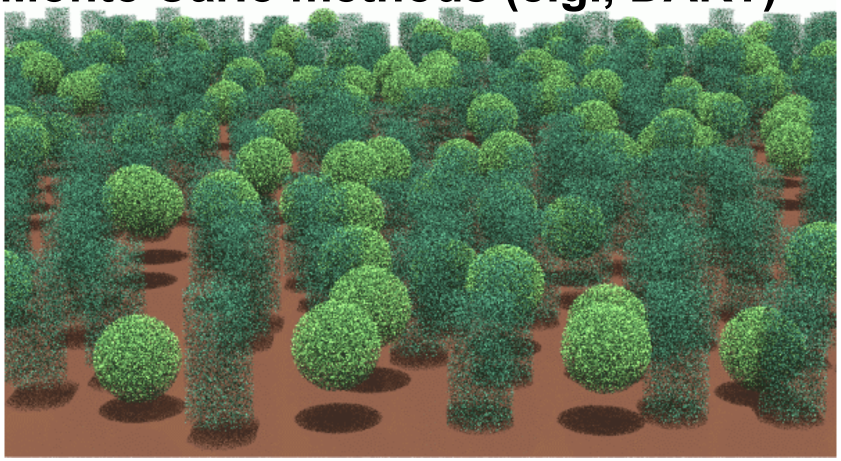
Homogeneous canopies (turbid medium): 1D models



Simple heterogeneous canopies: geometrical models

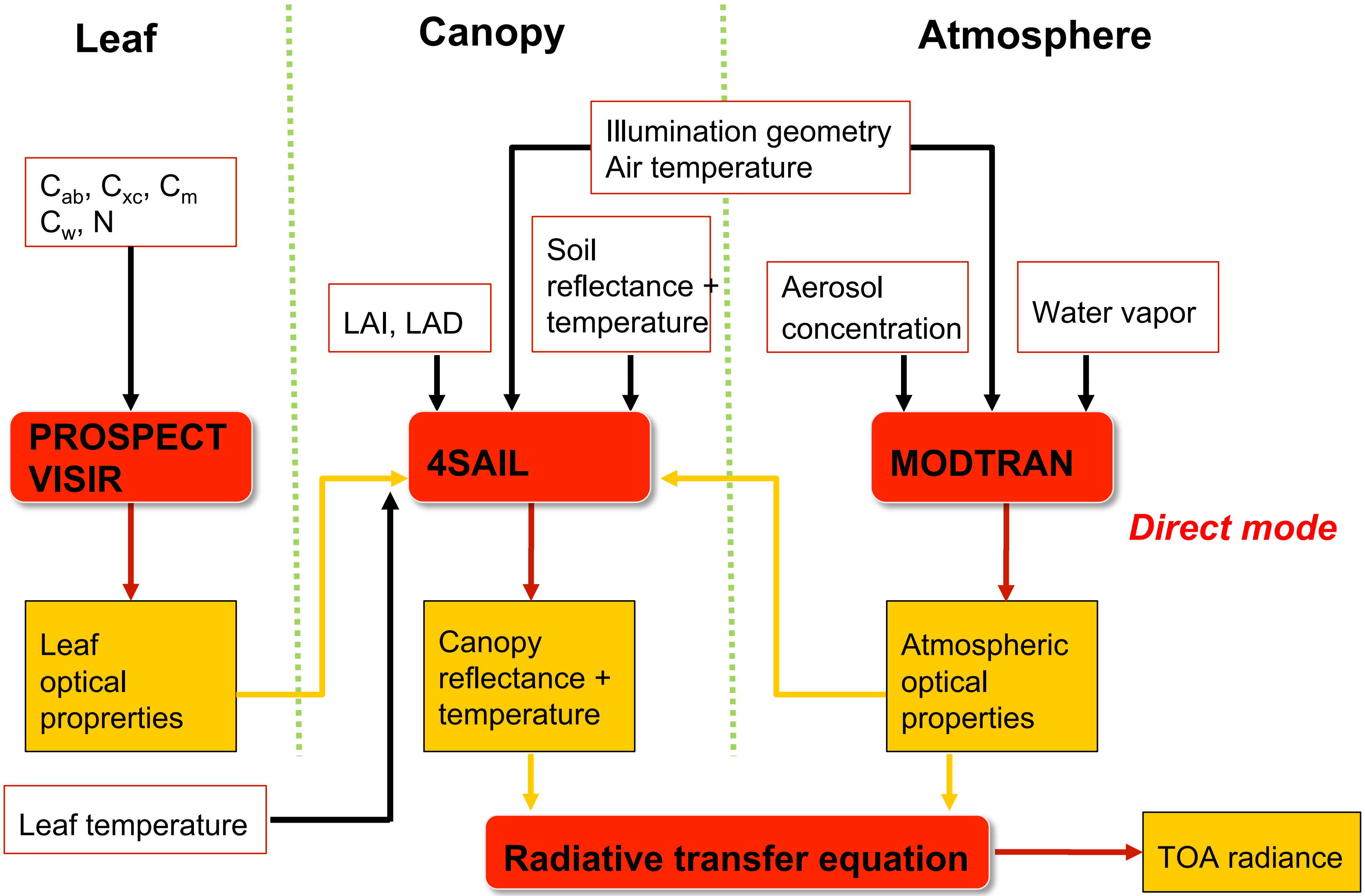


Complex heterogeneous canopies: Monte Carlo methods (e.g., DART)



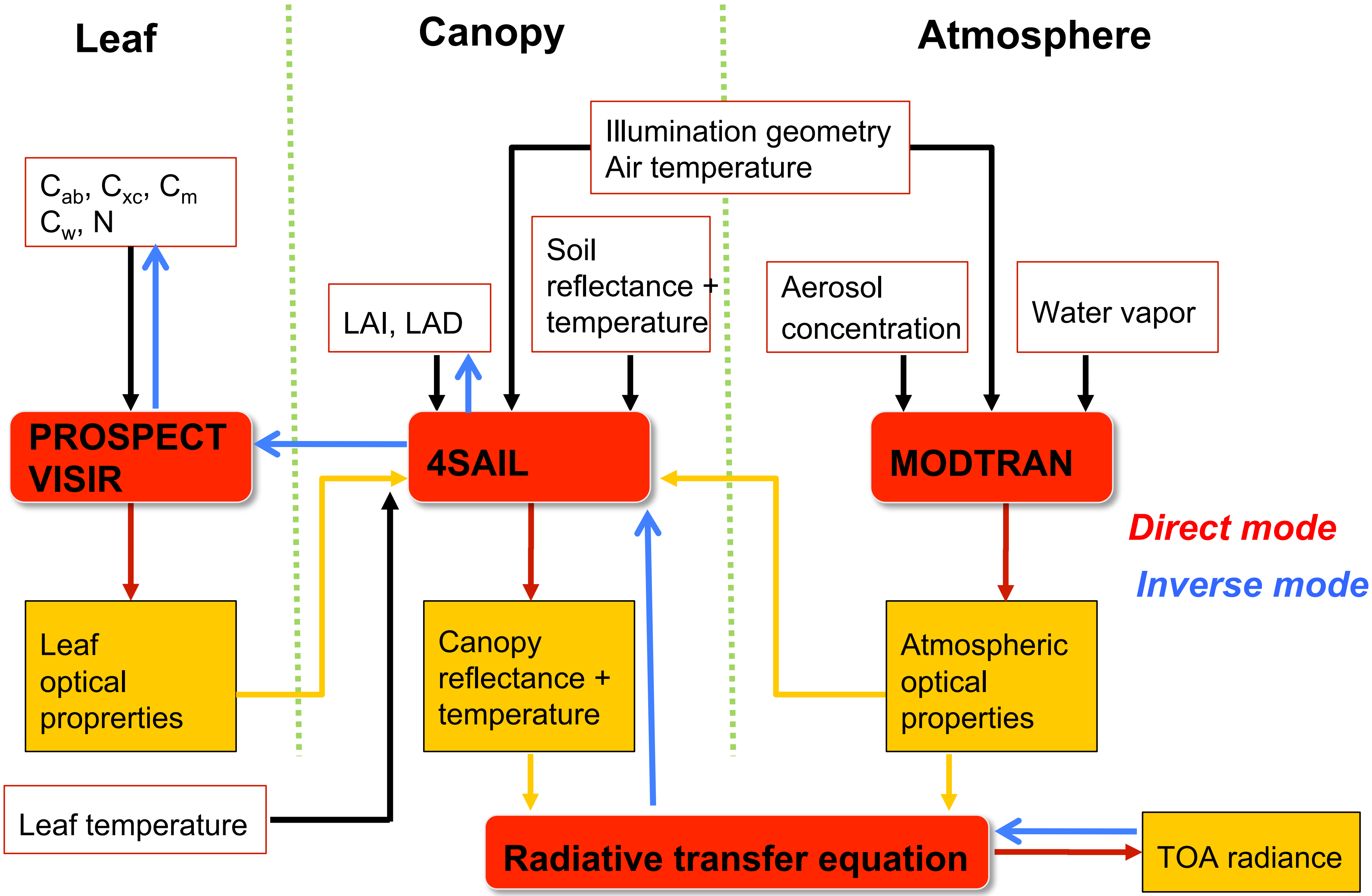
http://rami-benchmark.jrc.ec.europa.eu/

Canopy level: PROSAIL-VISIR



http://teledetection.ipgp.jussieu.fr/prosail/

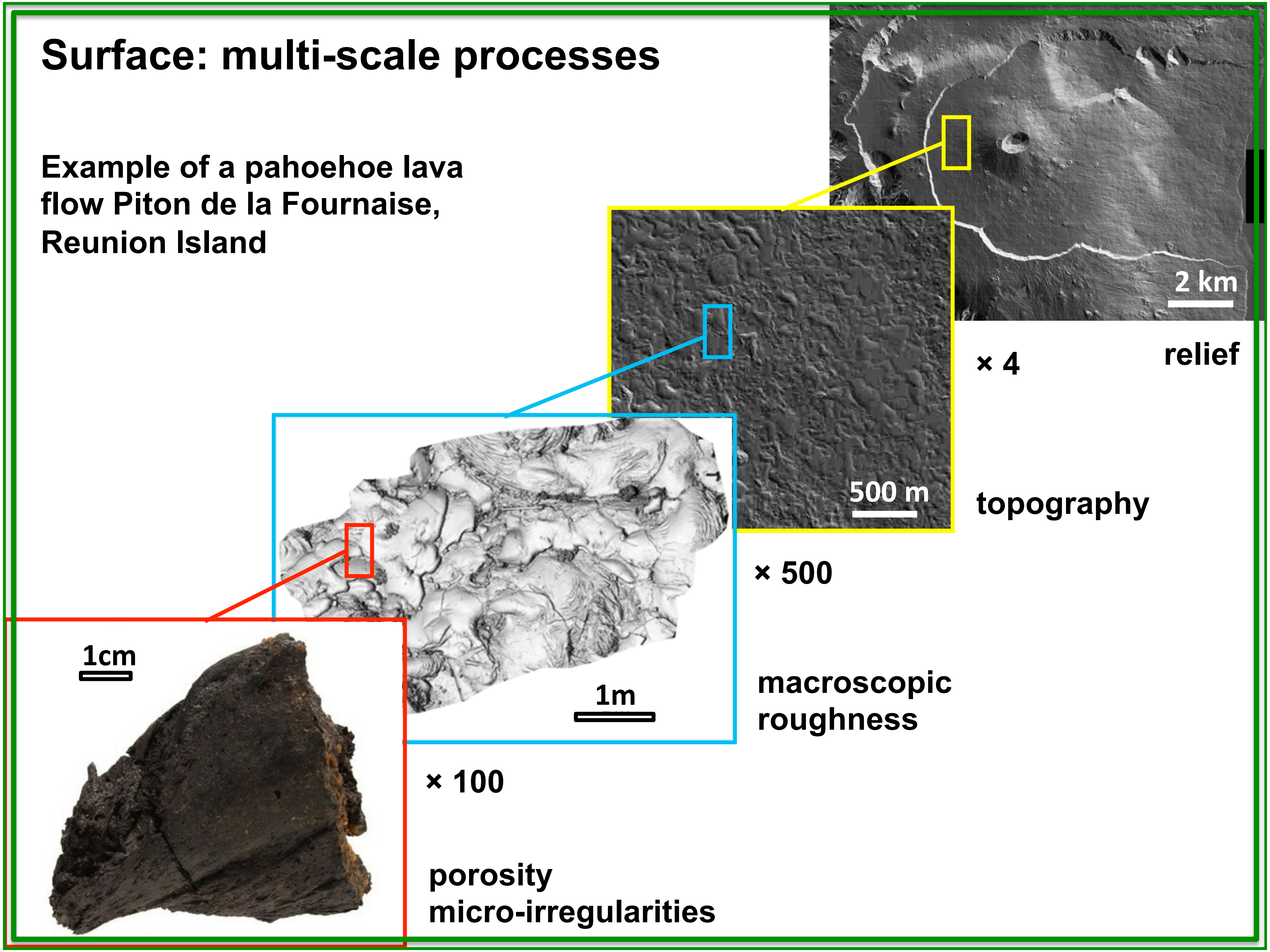
Canopy level: PROSAIL-VISIR



http://teledetection.ipgp.jussieu.fr/prosail/

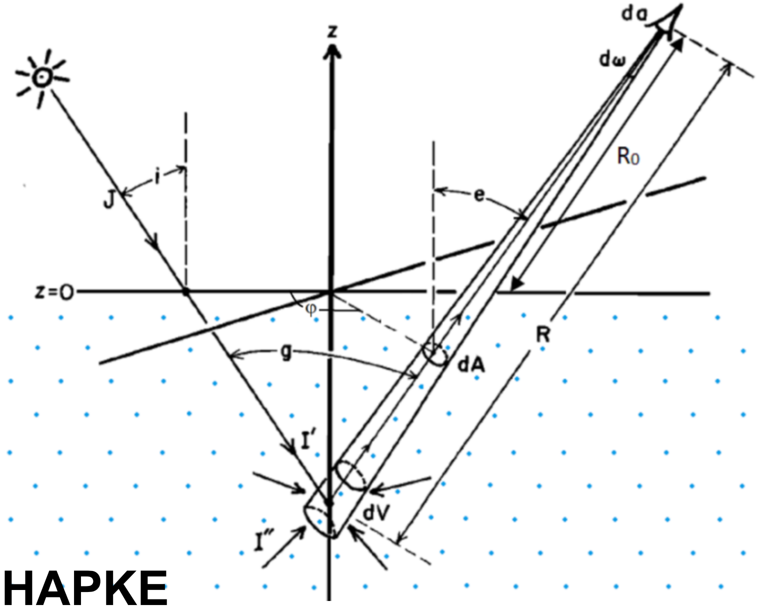
Surface: multi-scale processes

Example of a pahoehoe lava flow Piton de la Fournaise, Reunion Island



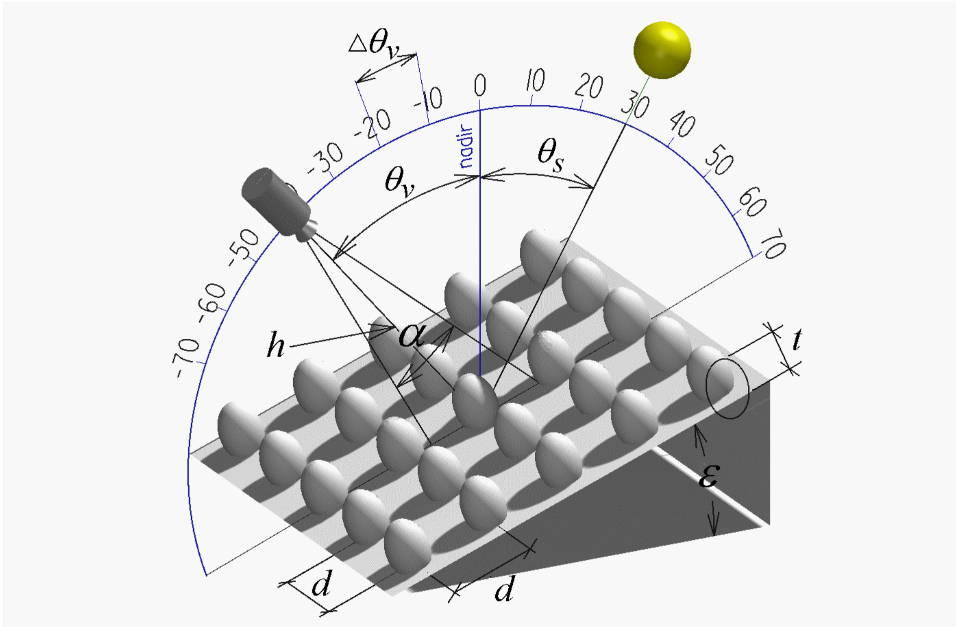
Modelling surface BRDF

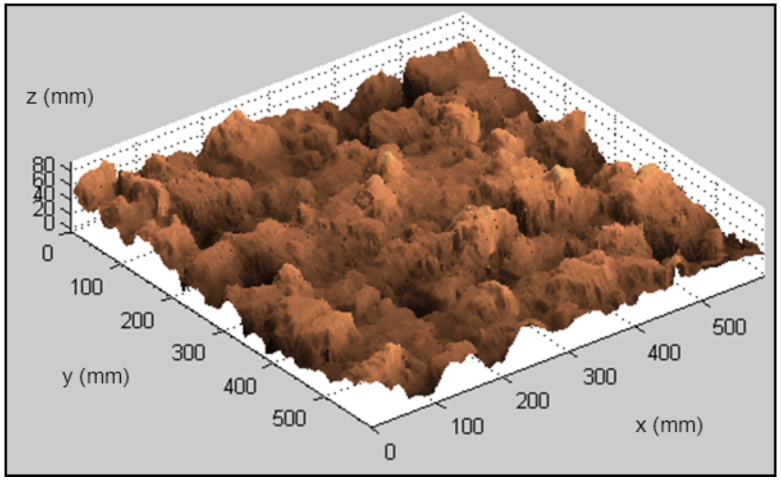
Radiative transfer equation



HAPKE

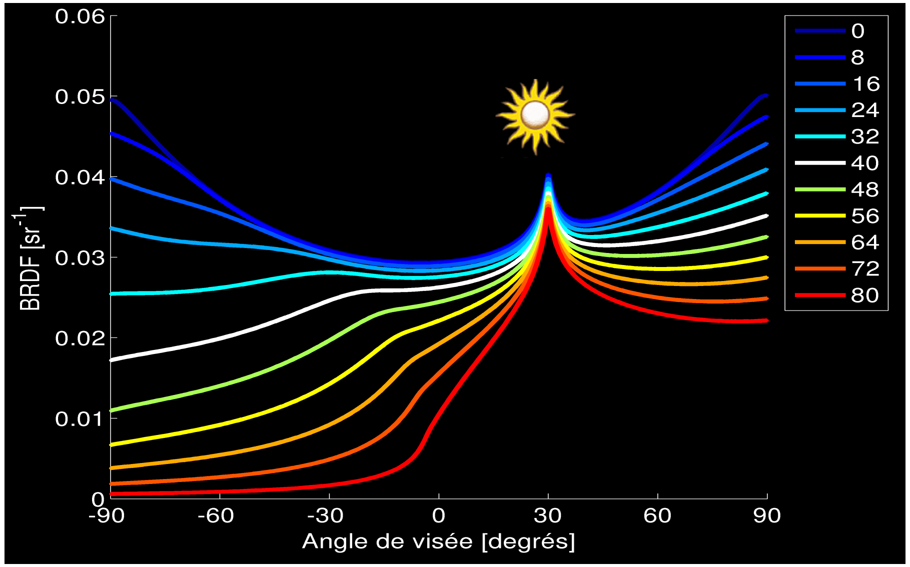
Geometrical models

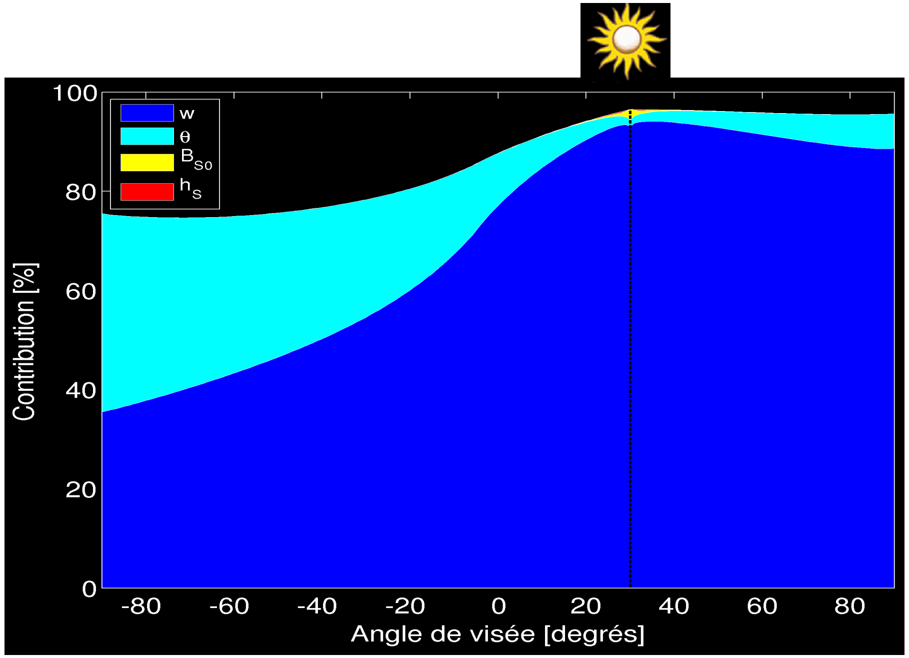




Monte Carlo methods

Hapke: sensitivity analysis → roughness parameter θ



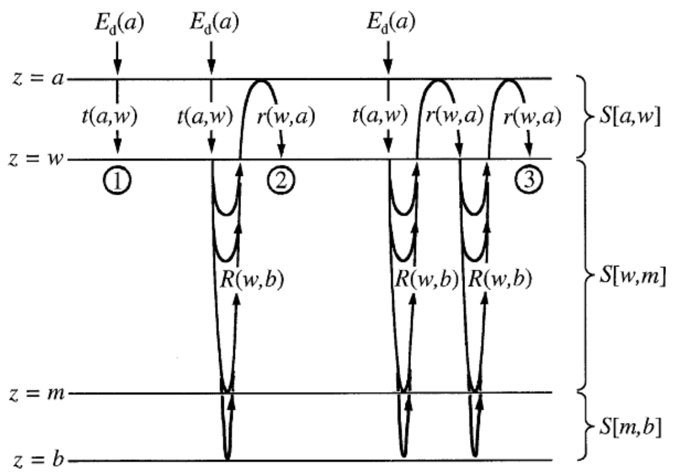


« one-factor-at-a-time »

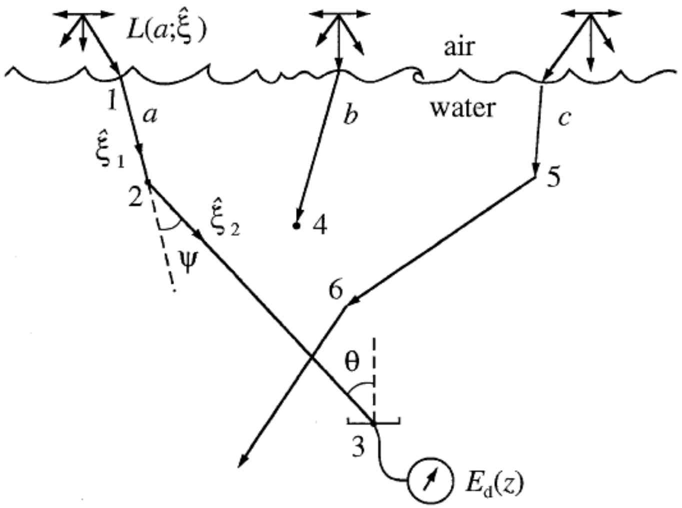
« global »

Modeling water optical properties

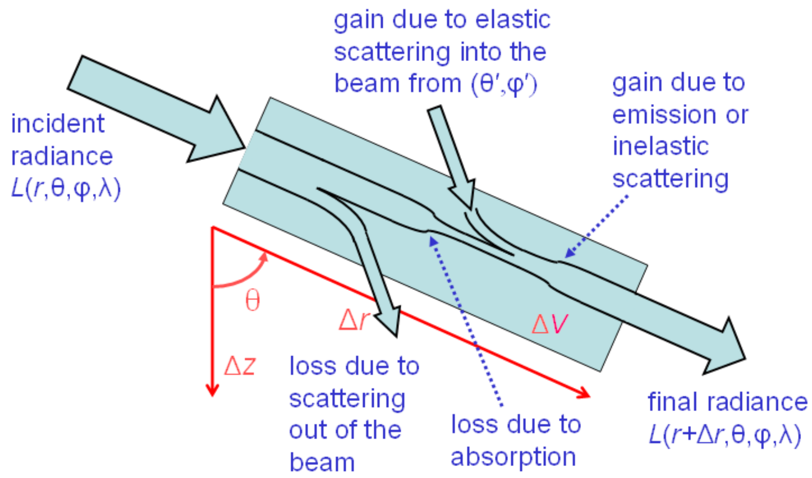
Two-flow problem



Monte Carlo methods



Radiative transfer equation



http://www.oceanopticsbook.info/

Modeling snow optical properties

Two-streAm Radiative TransfEr in Snow model (TARTES):
a fast and easy-to-use optical radiative transfer model to compute spectral albedo of a given snowpack (Libois et al. 2013, Libois et al. 2014)

http://lgge.osug.fr/~picard/tartes/

Resources: databases

http://teledetection.ipgp.fr/prosail/

OPTICLEAF The database on leaf optical properties

http://reflectance.co.uk/

FReD The Floral Reflectance Database

Type search here: Search

http://speclab.cr.usgs.gov/spectral-lib.html

USGS science for a changing world

http://www.onera.fr/dota/memoires

Memoires, base de données thermo-optiques

http://speclib.jpl.nasa.gov/

ASTER Spectral Library

http://www.specchio.ch/

SPECCHIO Online Spectral Database

Resources: radiative transfer models

http://opticleaf.ipgp.fr/

PROSPECT + SAIL = PROSAIL

http://ipl.uv.es/artmo/

ARTMO

http://rami-benchmark.jrc.ec.europa.eu/HTML/

European Commission

RAdiation transfer Model Intercomparison (RAMI)

http://www.cesbio.ups-tlse.fr/us/dart.html

DART

The DART model (Discrete Anisotropic Radiative Transfer)

http://www.npsg.uwaterloo.ca/models.php

Natural Phenomena Simulation Group

University of Waterloo

http://www.oceanopticsbook.info/

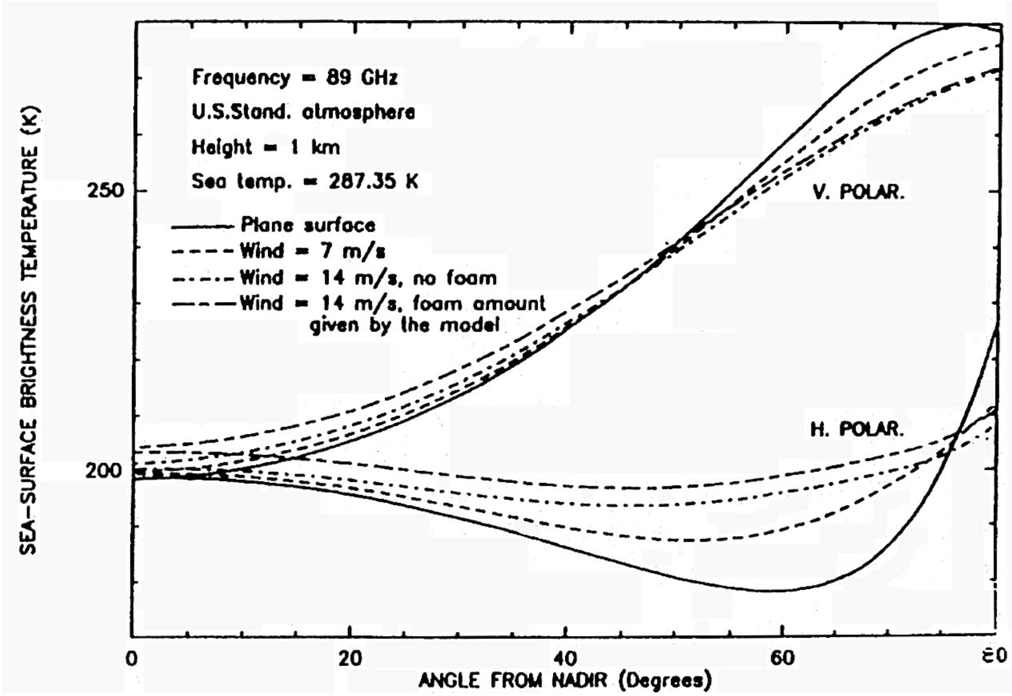
OCEAN OPTICS Web Book

Infrared and Microwave

The ocean emissivity model in the infrared and microwave

- **A function of surface wind speed, surface temperature, salinity**, chlorinity
- **Calculation of the dielectric properties of the ocean water as a function of frequency, surface temperature, salinity**, chlorinity
- **Wind-induced roughness to be taken into account: Large scale geometric optic (wave slope distrib.)** + small scale roughness (ripples)
- **Foam produced when wind increases** (estimation of foam cover and emissivity)
- **Fast models derived**. ISEM in the infrared, FASTEM for the from the two-scale models,

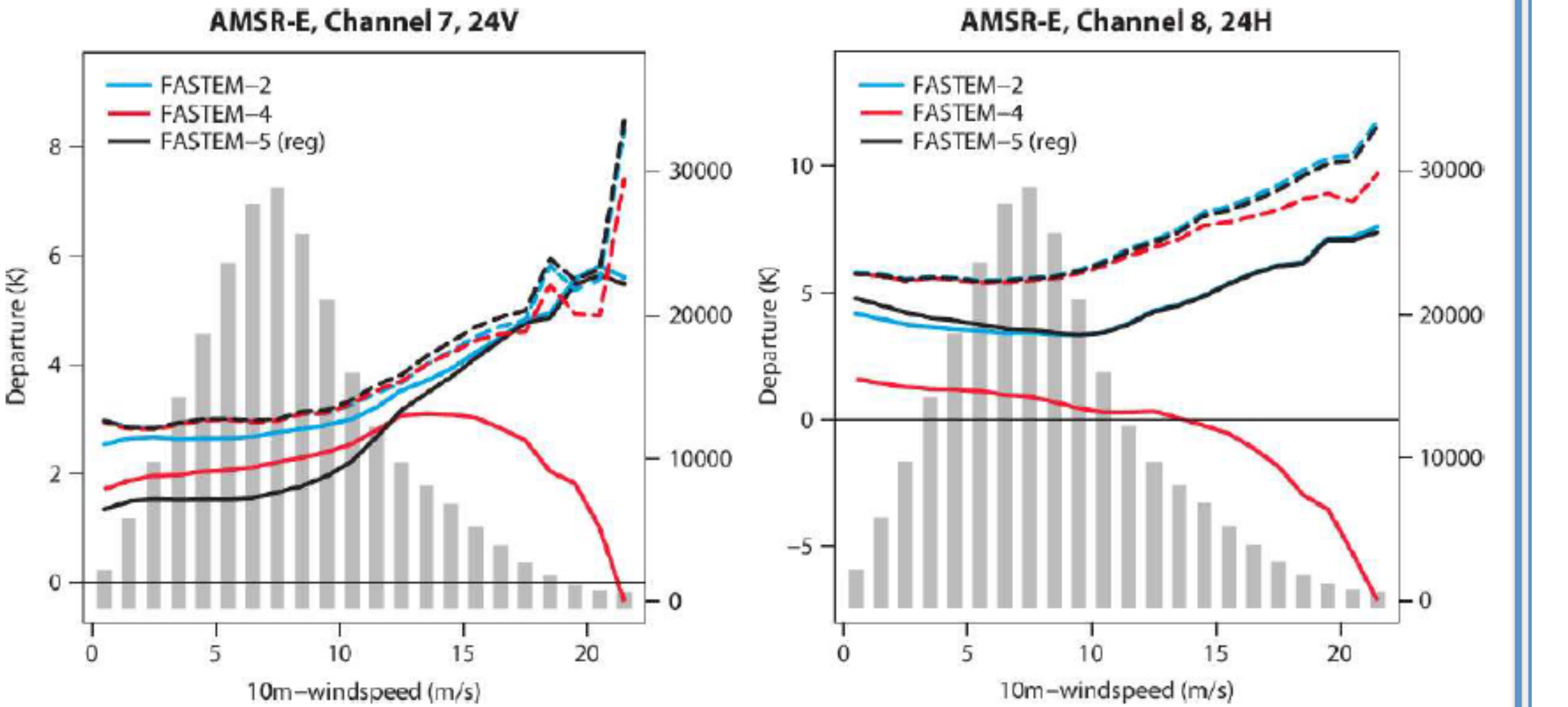
The ocean emissivity model in the microwave



- FASTEM used in RTTOV as well as in CRTM, under permanent development. (English and Hewison, 1998; Liu et al., 2011
  Current questions about foam modeling (cover as well as emissivity).
  FASTEM 6 now.

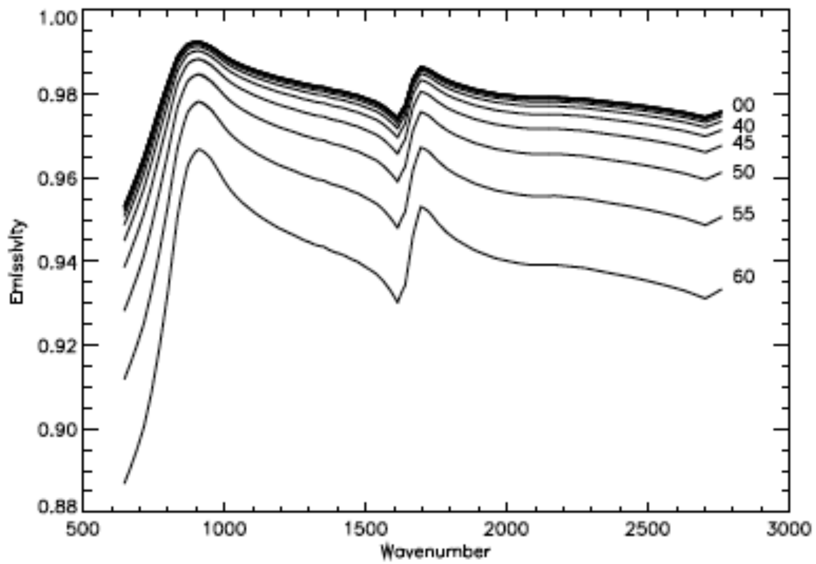
- For special applications such as SMOS, specific developments performed (e.g., Xin et al., IEEE, 2011; Mouche et al., WRCM, 2007)

The ocean emissivity model in the microwave

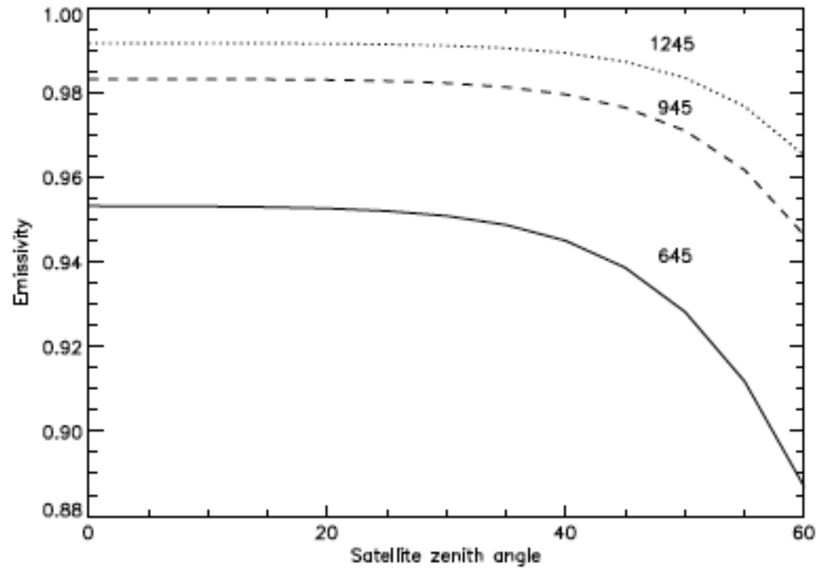


Statistics of the first guess departure (observations minus first guess simulations) for different FASTEM versions at 24 GHz, as a function of the model wind speed at 10 m. The solid line gives the bias and the dashed line the std. The wind population is provided in grey. From Bormann et al., 2014.

The ocean emissivity model in the infrared



(a) Spectral and zenith angle dependence of sea surface emissivity (Masuda, $| u |=0$).



(b) Zenith angle dependence of the sea surface surface at 645, 945, and 1245 cm^{-1}.

ISME: the IR ocean emissivity model.
The spectral and zenith dependence of the ocean surface emissivity in the infrared.
From Sherlock et al., 1999.

Infrared and microwave land surface emissivity model

Two main possibilities

Modeling

- Accuracy depends upon the surface type.
- Number of input parameters and their reliability depend upon the surface type.
  - Efficient models over ocean that can be applied at higher frequency
  - Soil and vegetation likely to have limited frequency dependence
  - Snow and ice modeling very questionable

Parameterization from satellite-derived observations

- Captures well the spatial, temporal, and spectral variability of the emissivities
- Requires satellite observations under similar conditions (frequency, incidence angle, polarizations) or a scheme to extrapolate from a condition to the other

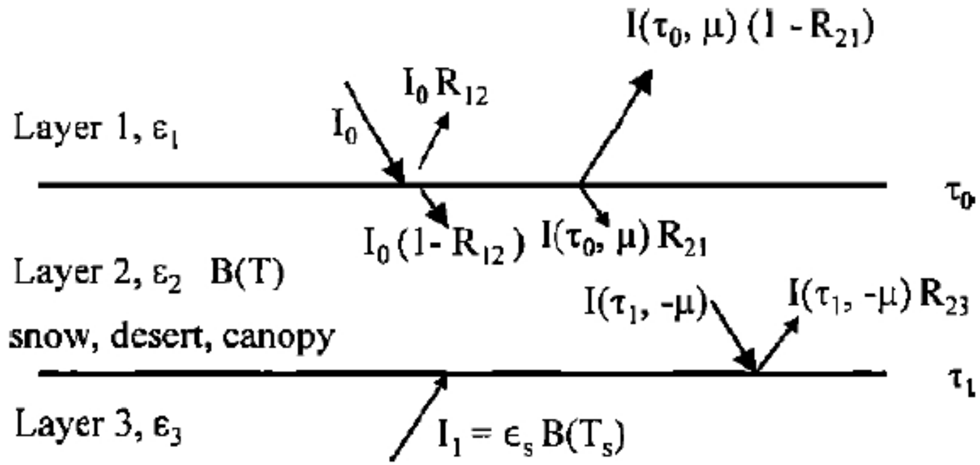
Microwave land surface emissivity model

Many specific models developed for specific environments.

Two major generic model used in NWP centers that can cover the globe:

Microwave Land Emissivity Model (MLEM) in **Community Radiative Transfer Model (CRTM)** developed at NOAA (Weng et al., 2001)

- A three layer model with calculation of the reflection and scattering properties
- For high fractional volume of particles (snow and desert), dense-medium theory
- Modified Fresnel eq. to account for polarization and surface roughness at interface
- Between 5 and 150 GHz for most land conditions.



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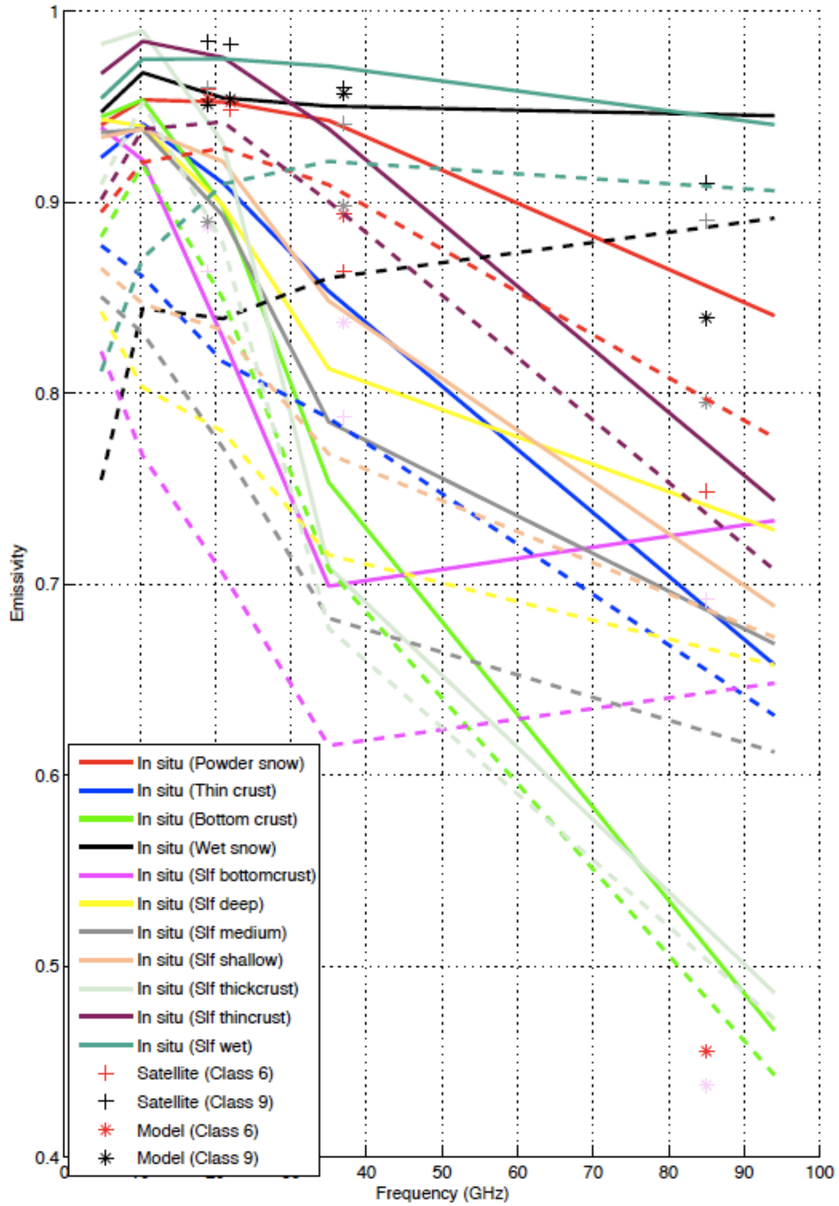
Community Microwave Emission Modelling Platform (CMEM) developed at ECMWF (Holmes et al., 2008)

- Highly modular software package
- Based on the parameterizations used in the L-Band (1.4 GHz) Microwave Emission of the Biosphere (LMEB, Wigneron et al., 2007, Pellarin et al., 2003) and Land Surface Microwave Emission Model (LSMEM, Drusch et al., 2007).
- from 1 GHz to 20 GHz

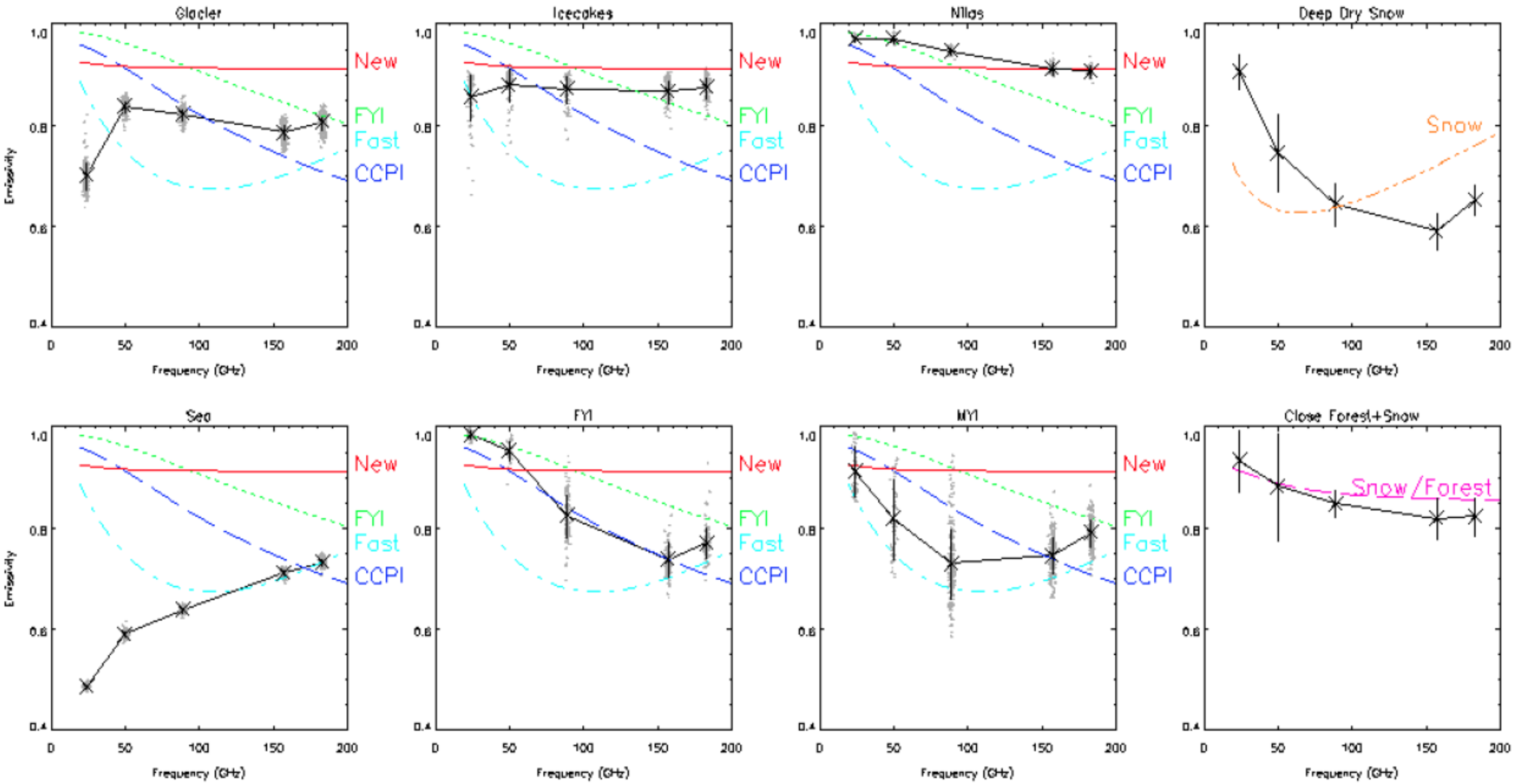
Microwave snow, ice, and sea ice emissivity

From in situ measurements, a very large variability.

Measurements at 4.9, 10.4, 21, 35, and 94 GHz with the PAMIR radiometer (derived from Matzler , MAP, 1994)



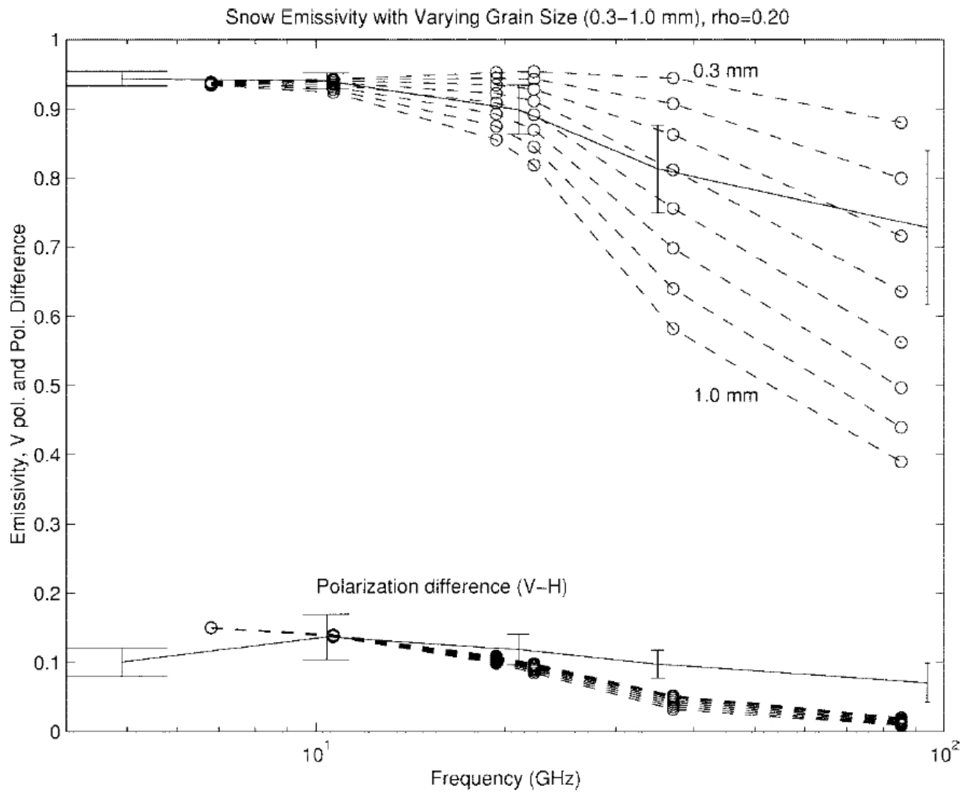
Microwave snow, ice, and sea ice emissivity



Sea-ice emissivity close to nadir, observed from DEIMOS and MARSS instruments on board the UK MetOffice aircraft, over the Barents Sea (black points and lines). Color lines represent previous estimates of the emissivities. From Hewison and English, 2002.

Microwave snow, ice, and sea ice emissivity:

Large sensitivity of the models to the input parameters

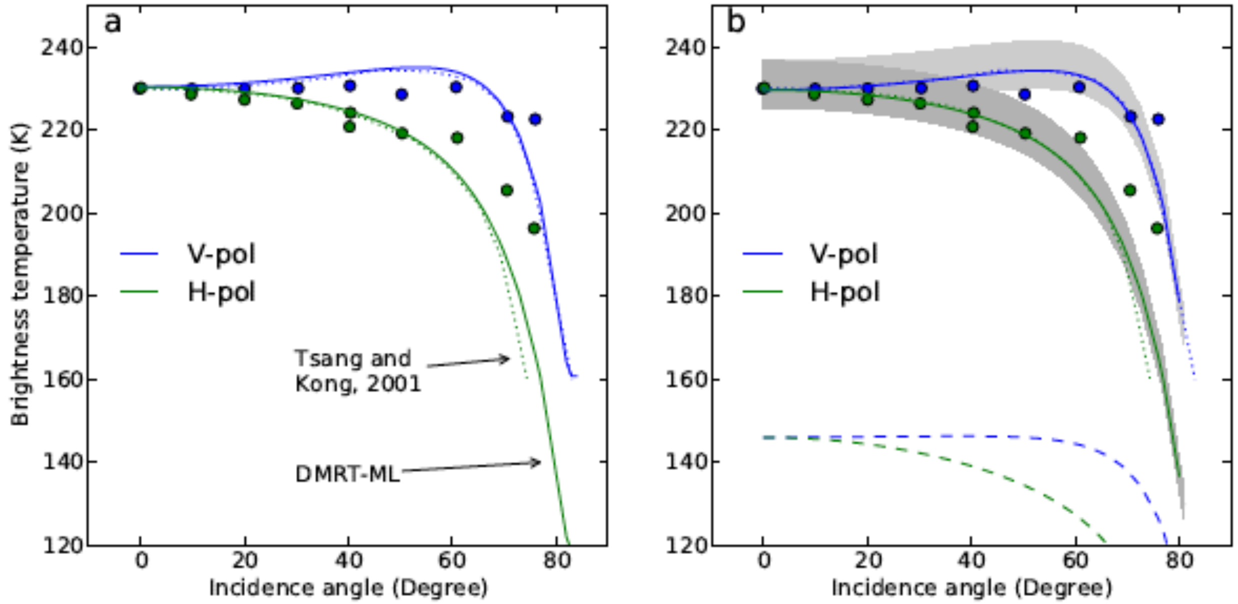


Comparison of the HUT snow emission model with experimental emissivity values in the case of a thick dry snow layer for 50° nadir angle. The bars show the standard deviations of experimental observations. The snow water equivalent is 300 mm, the snow/air and soil/snow boundaries are considered smooth, and the snow density is 0.2. From Pulliainen et al., 1999.

Microwave snow, ice, and sea ice emissivity:

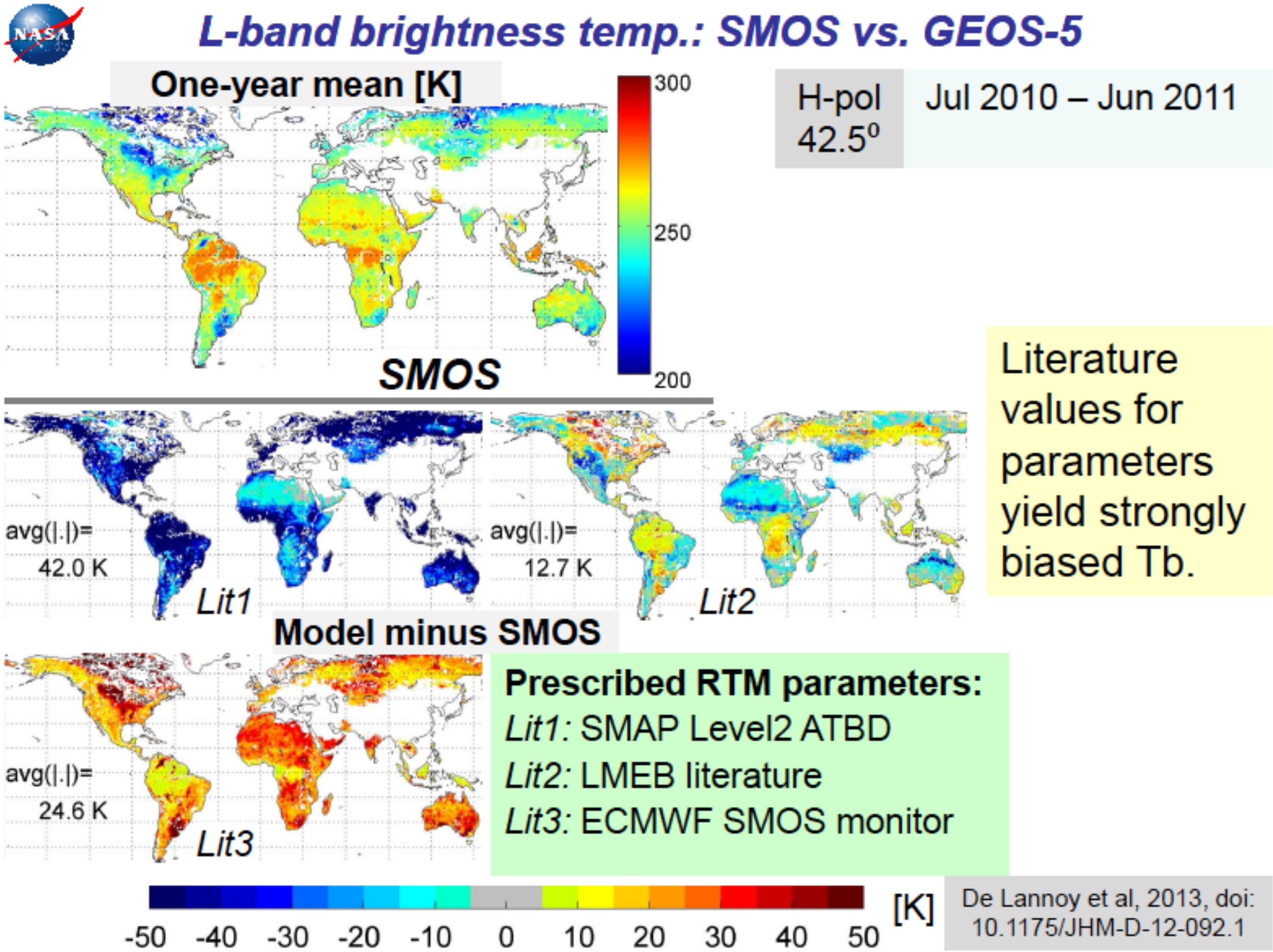
Large sensitivity of the models to the input parameters

The Dense Media Radiative Transfer - Multi Layers model (DMRTML or DMRT-ML): Numerical simulation of the microwave emission of the snowpack using a model based on the DMRT theory (Picard et al., GMD, 2013, http://lgge.osug.fr/~picard/dmrtml/)



Comparison of DMRT-ML simulations (solid line) at 18 GHz with previous calculations (Tsang and Kong, 2001) (dotted curve) and with experimental observations (filled dots). The medium is semi-infinite, with a density of 350 kg m^{-3}, a temperature of 272 K, a grain radius of 1.75mm and an ice dielectric constant of 3.2+ I 0.016. Simulations with a more realistic dielectric constant (Matzler and Wegmuller, 1987) are shown on the right panel with the original radius of 1.75mm (dashed curve) and refitted radius of 0.83mm (solid line). The gray bars represent variations of the dielectric constant imaginary part of ±20% around in the later case. From Picard et al., GMD, 2013.

Microwave soil and vegetation emissivity model:
Difficulty to reproduce the satellite observations

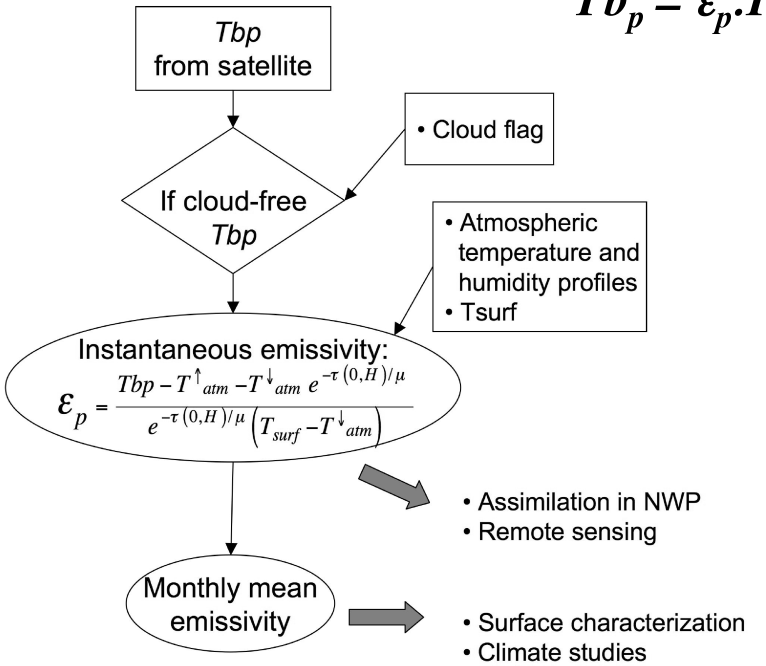


From a presentation by Rolf Riechle (NASA): Drastic calibration needed for the model.

Satellite-derived microwave land emissivity estimates

A generic method to derive land surface emissivity from satellite that can be applied to microwave imager and sounder window channels

$$Tb_p = \varepsilon_p . Ts . \tau + (1-\varepsilon_p) . Tdown . \tau + Tup$$



$$\varepsilon_p = \frac{Tb_p - Tup - Tdown \,.\, \tau}{\tau \,.\, (Ts - Tdown)}$$

Prigent et al., JGR, 1997; BAMS, 2006

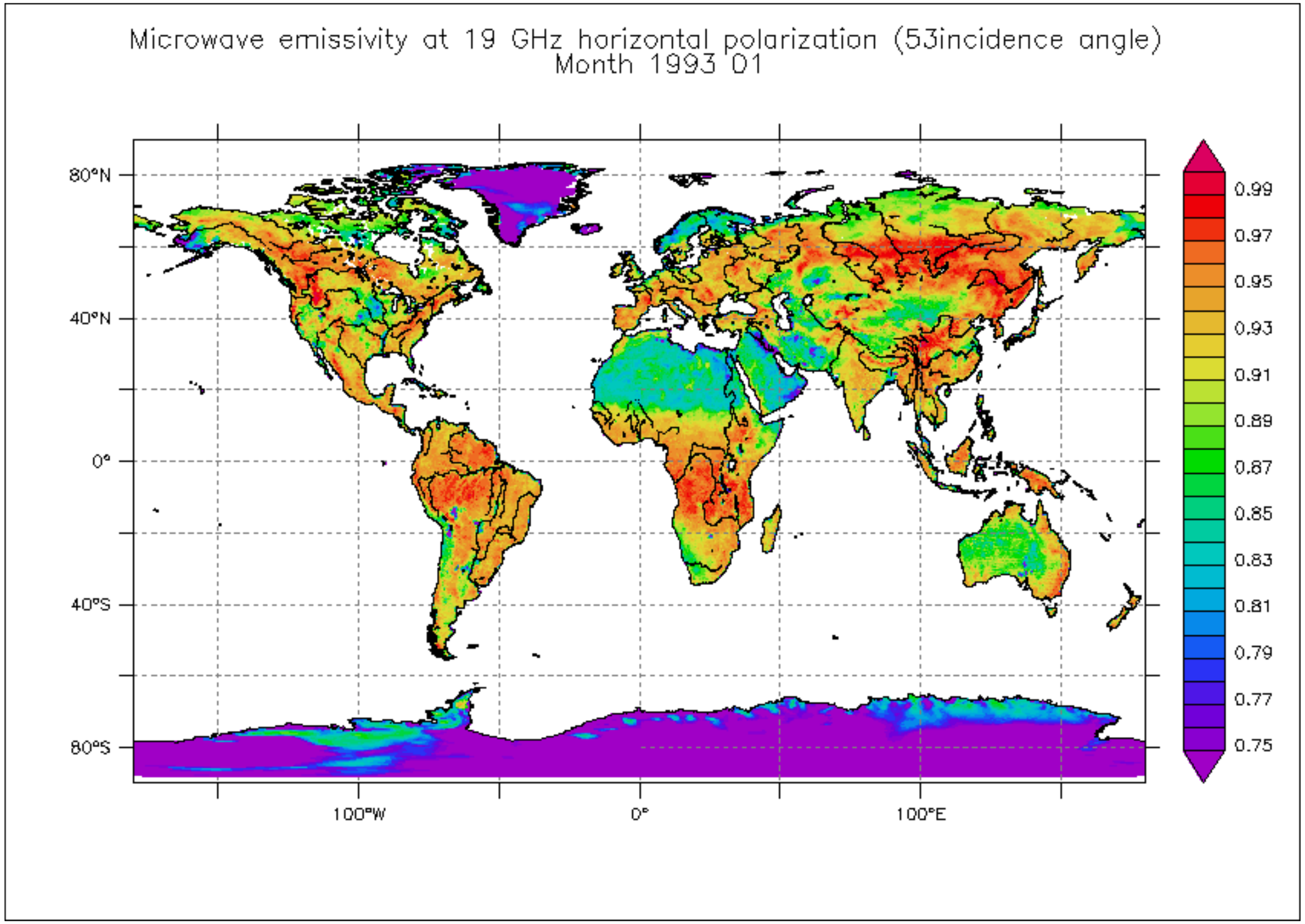
A methodology often used since for other instruments: AMSU (Prigent et al., 2005; Karbou et al., 2005), AMSR-E (Moncet et al. , 2008)

To have a generic estimation, necessity to parameterize the frequency, angular, and polarization dependences.

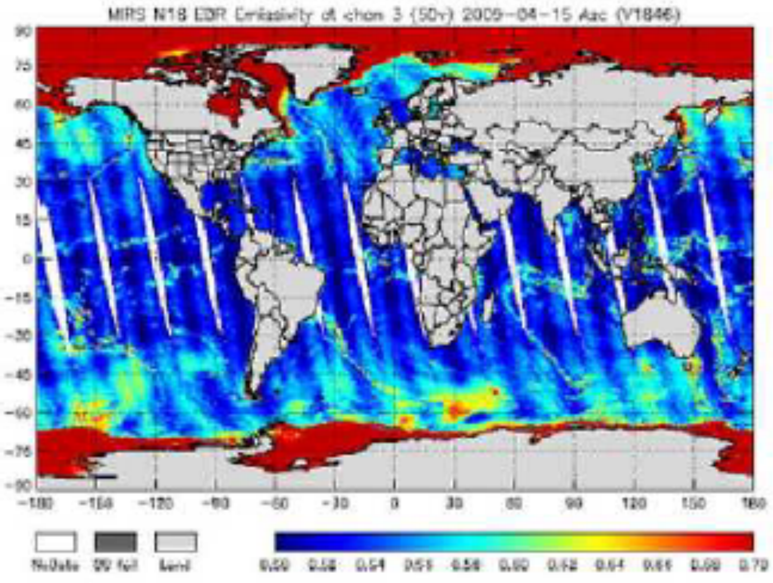
TELSEM: Tool to Estimate Land Surface Emissivities in the Microwaves
(Aires et al., JQSRT, 2011)
Implemented in RTTOV and in CRTM. Mean values + matrix of error correlation

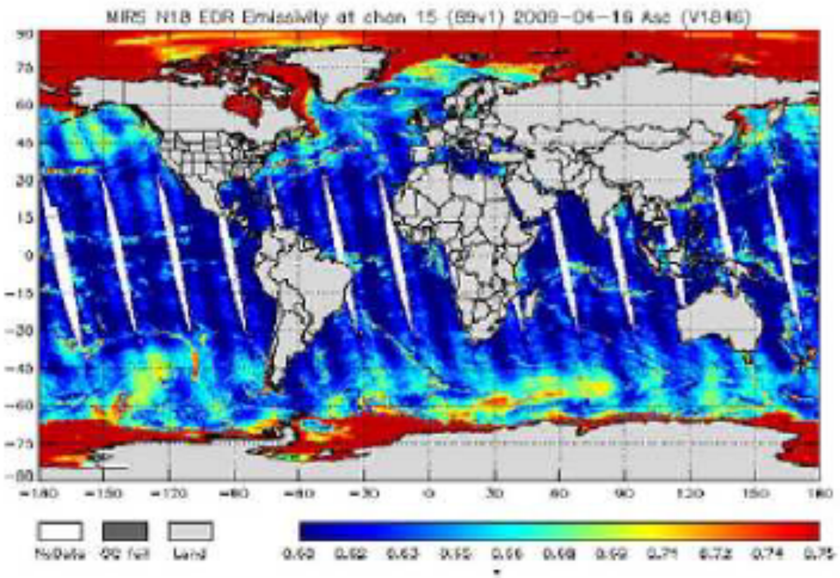
Satellite-derived microwave land emissivity estimates

A database of global daily emissivities over 15 years derived from all the available SSMI instruments, along with a few months of other satellite-derived maps.
A monthly-mean product with a spatial resolution of 0.25°x0.25° at the equator.

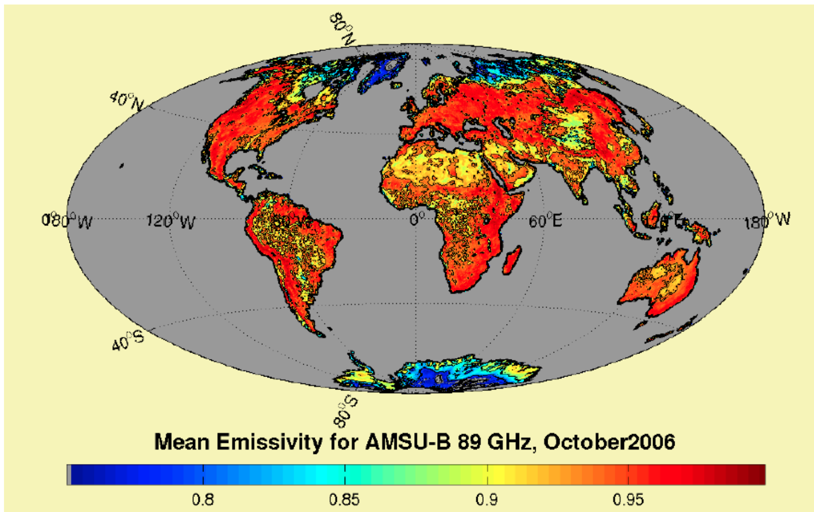


Satellite-derived microwave land emissivity estimates



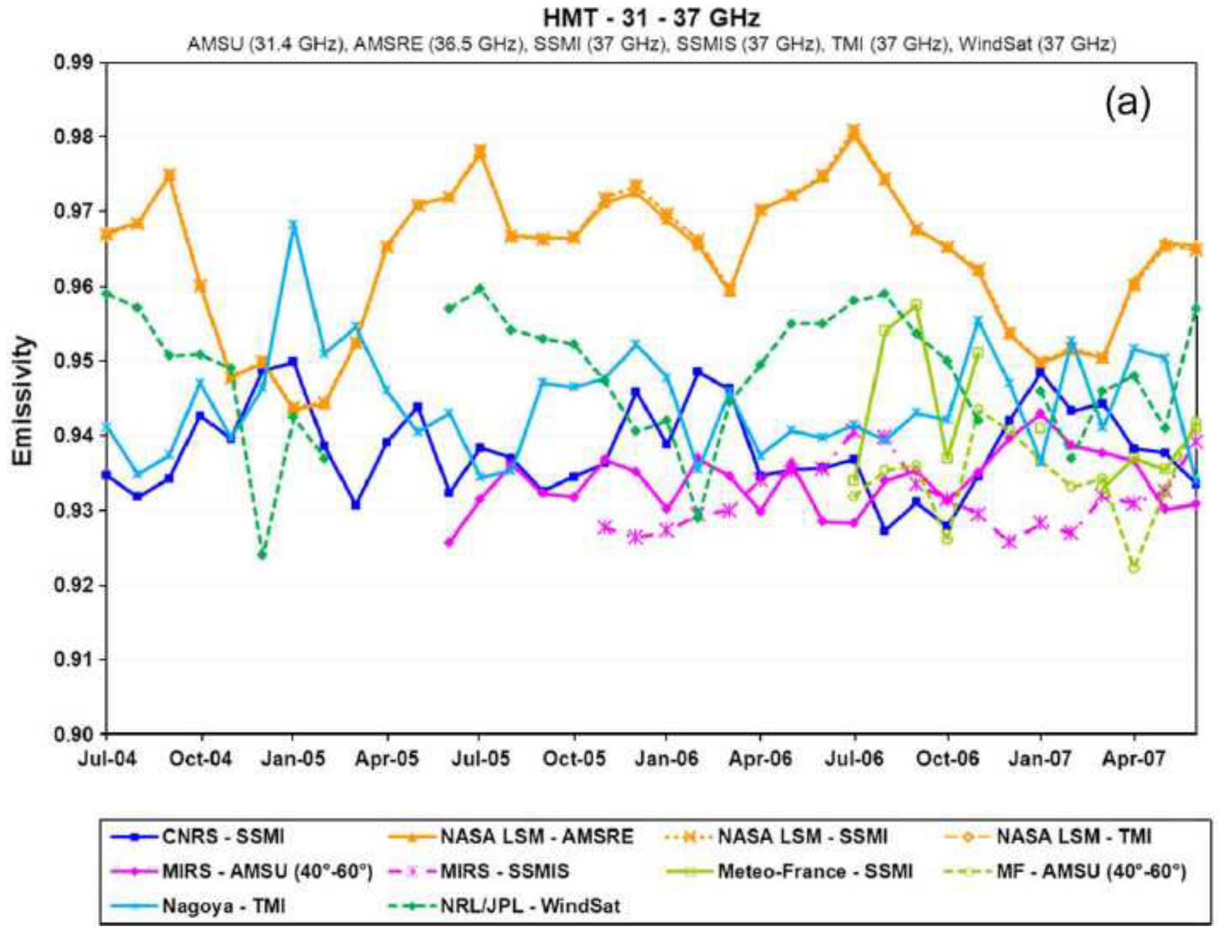


Sea ice emissivity from Kongoli et al., IEEE, 2010



Land surface emissivity from Karbou et al., IEEE, 2005

Satellite-derived microwave land emissivity estimates



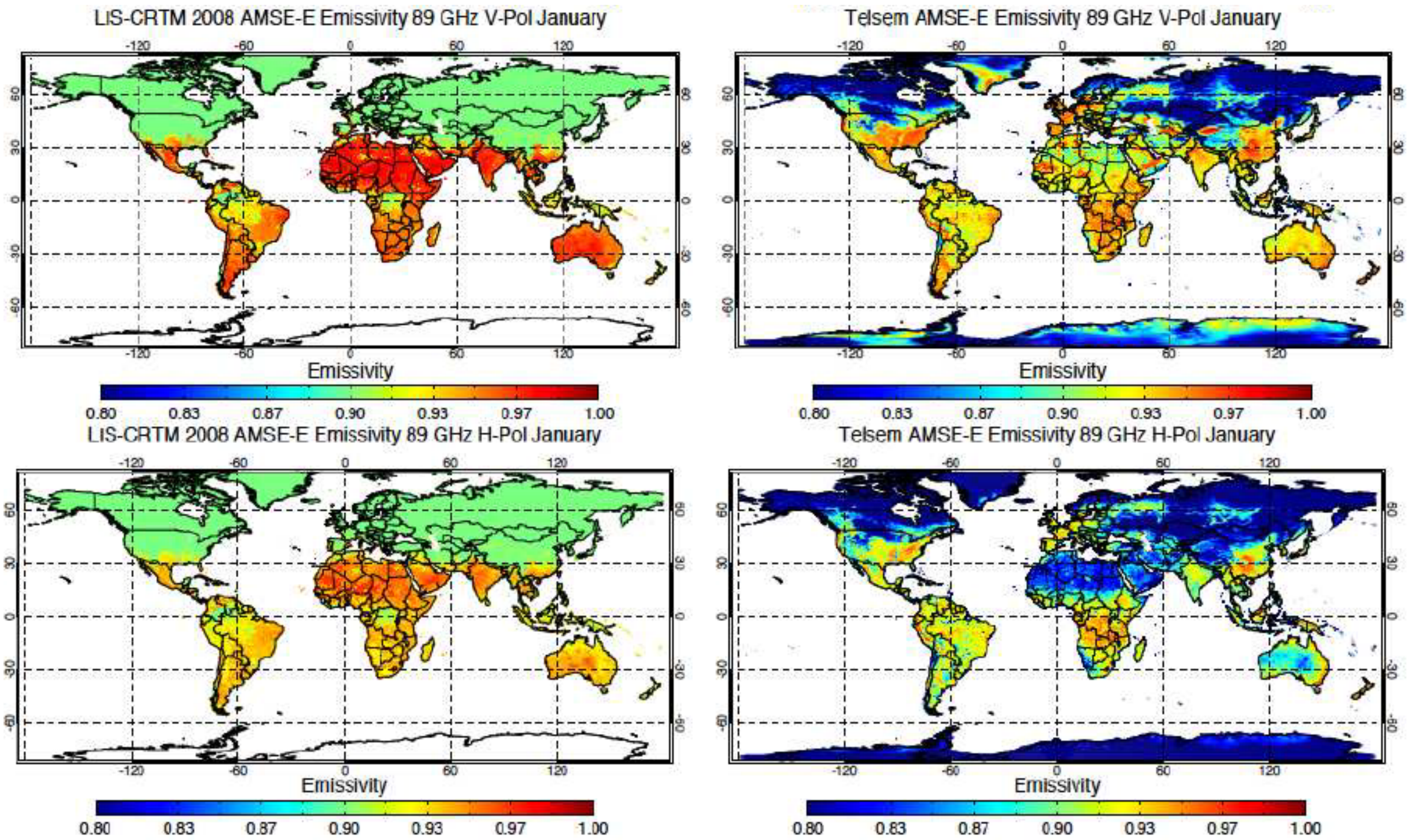
Monthly mean clear-sky emissivity at 31 and 37 GHz (for vertical polarization for imagers and for mixed polarizations for AMSU and MHS), for the South Great Plains site from July 2004 to June 2007. From Ferraro et al., 2013.

Satellite-derived microwave land emissivity estimates

CRTM model | Satellite-derived

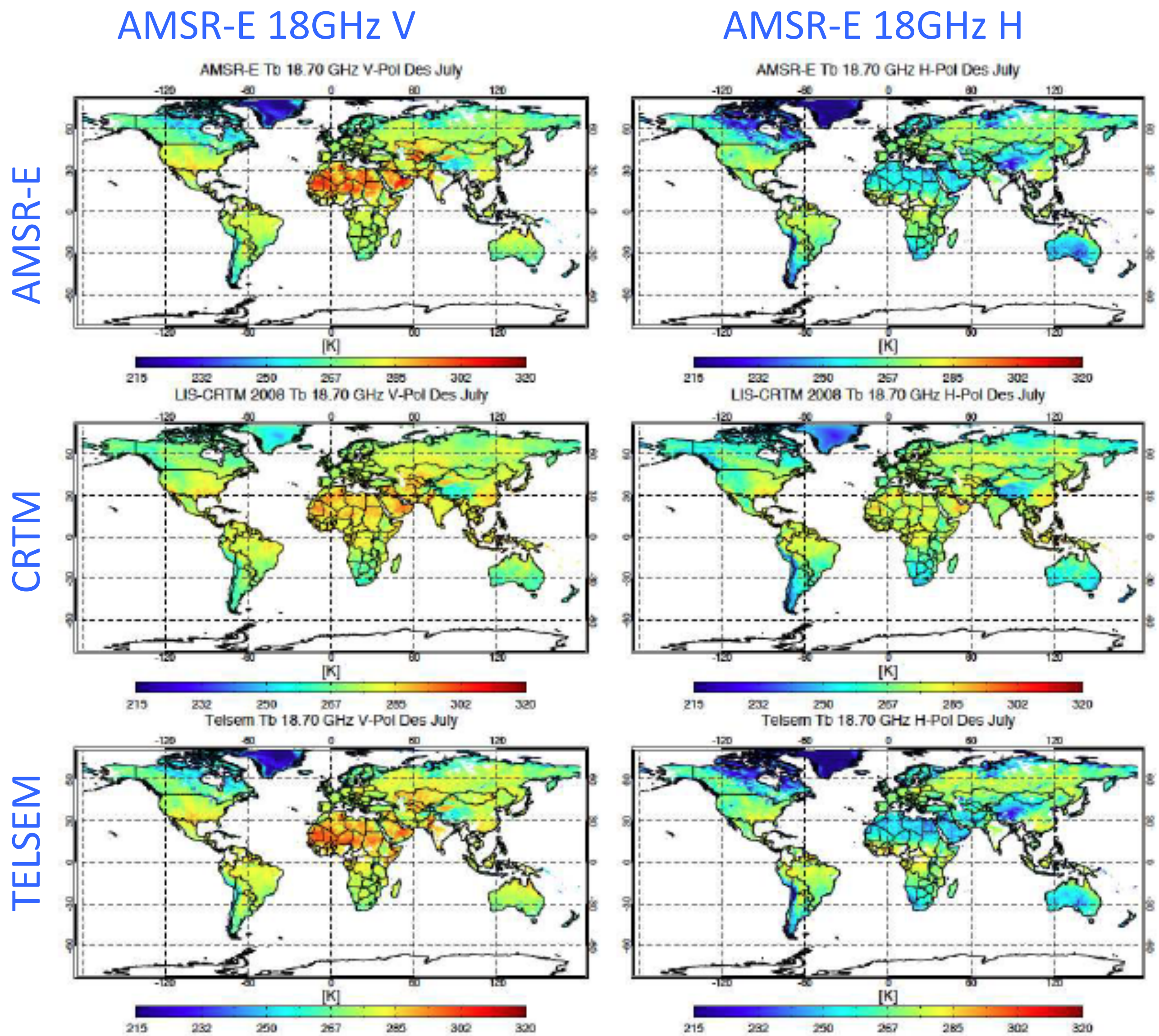
89 GHz V

89 GHz H



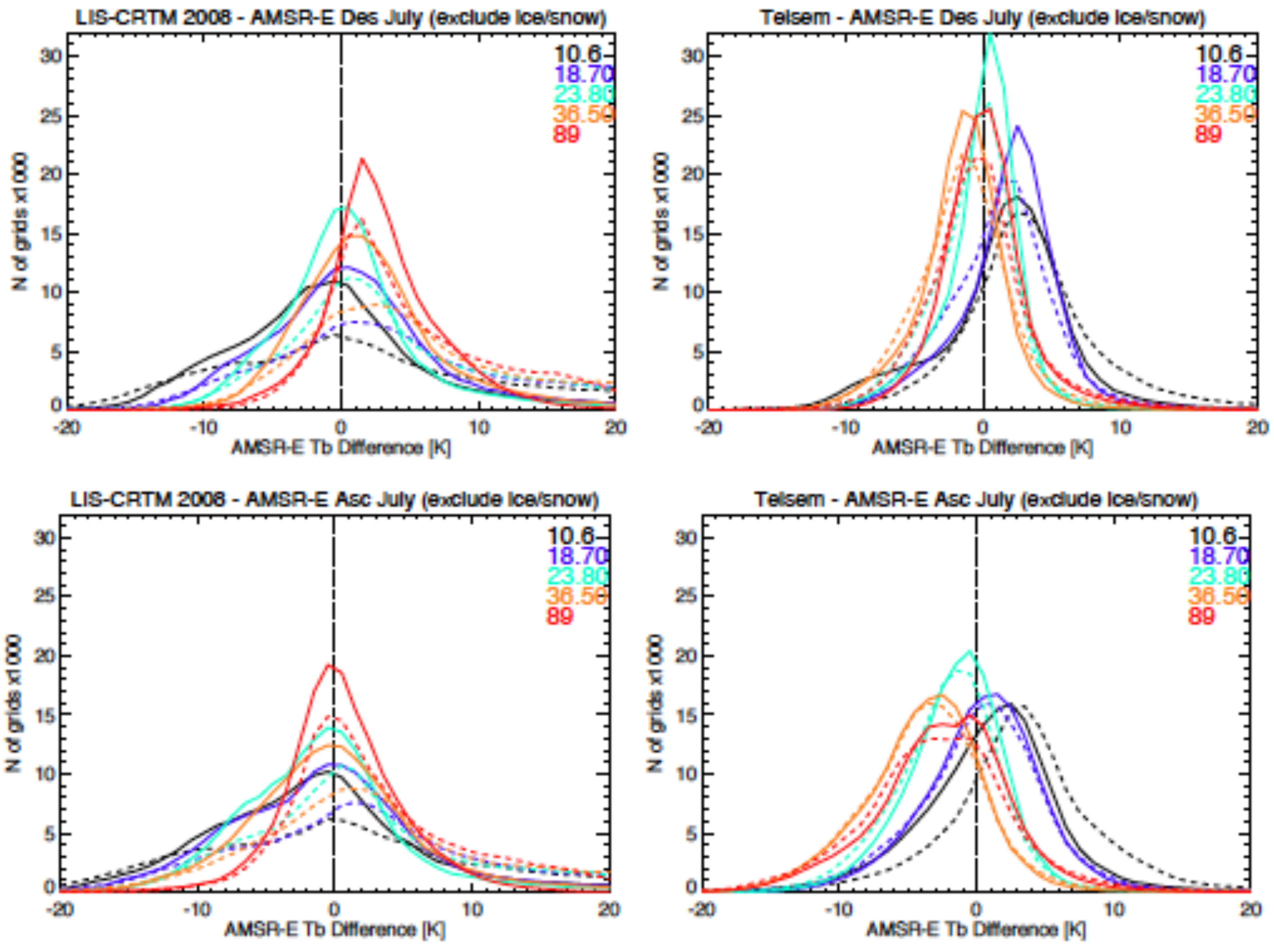
Prigent et al., JGR, 2015

Satellite-derived microwave land emissivity estimates



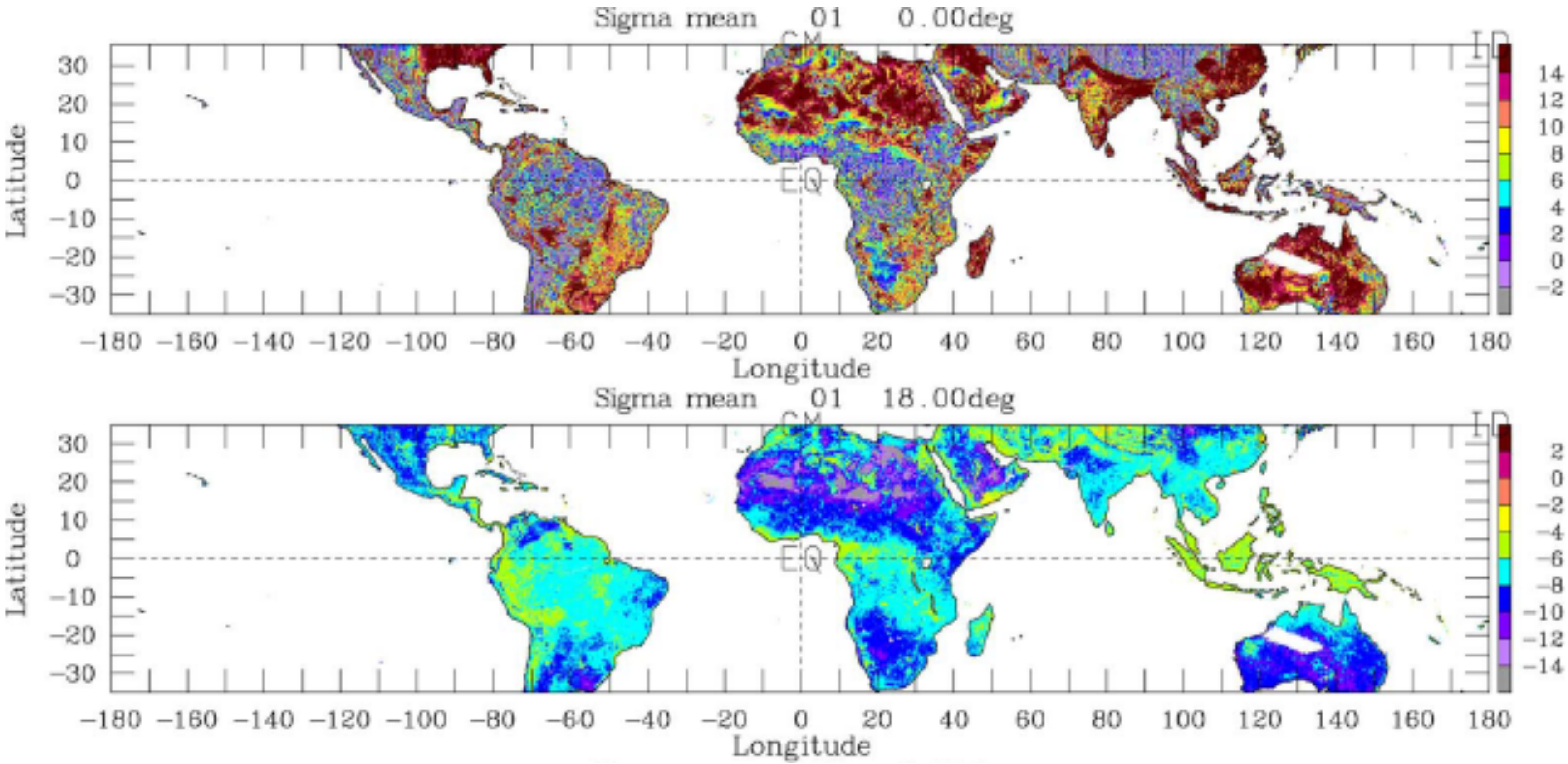
Comparison between satellite observations and radiative transfer model fed with different emissivity sources

Satellite-derived microwave land emissivity estimates



Comparison between satellite observations and radiative transfer model fed with different emissivity sources

Satellite-derived microwave backscattering



Backscattering estimated from the Precipitation Radar (TRMM) at 13GHz, for two different incidence angles, for use in the precipitation retrieval. From Prigent et al., IEEE, 2015

Satellite-derived infrared land surface emissivity

In RTTOV for instance, fixed values:

0.98 for snow and ice free land surfaces,

0.99 for snow and ice.

Now derived from the satellite observations directly.

Additional information from atmospheric contribution and possibly from spectral emissivity data basis such as ASTER database.

- University Wisconsin: Seemans et al., 2008, derived from MODIS.

Monthly mean, 0.05° spatial resolution, 10 freq

- NASA: Zhou et al., 2011, derived from IASI.

Monthly mean, all IASI spectrum

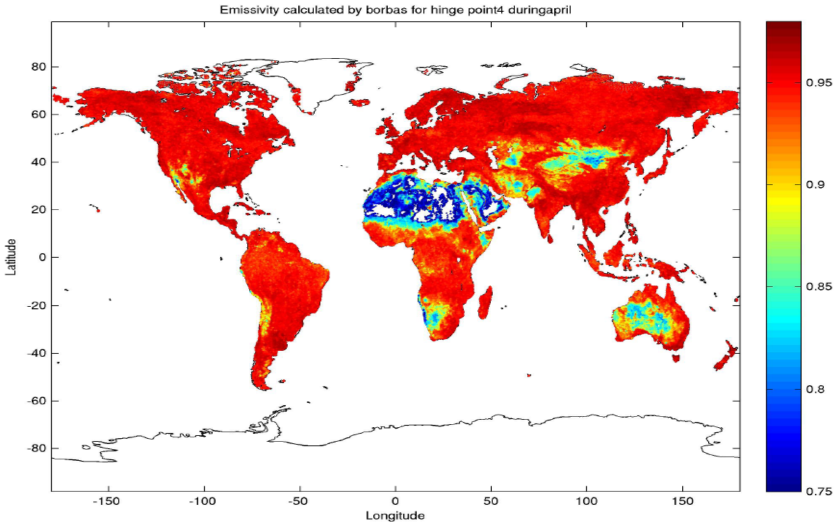
- ARA/LMD: Capelle et al., JAMC, 2012, derived from AIRS

Monthly mean, 0.5° spatial resolution

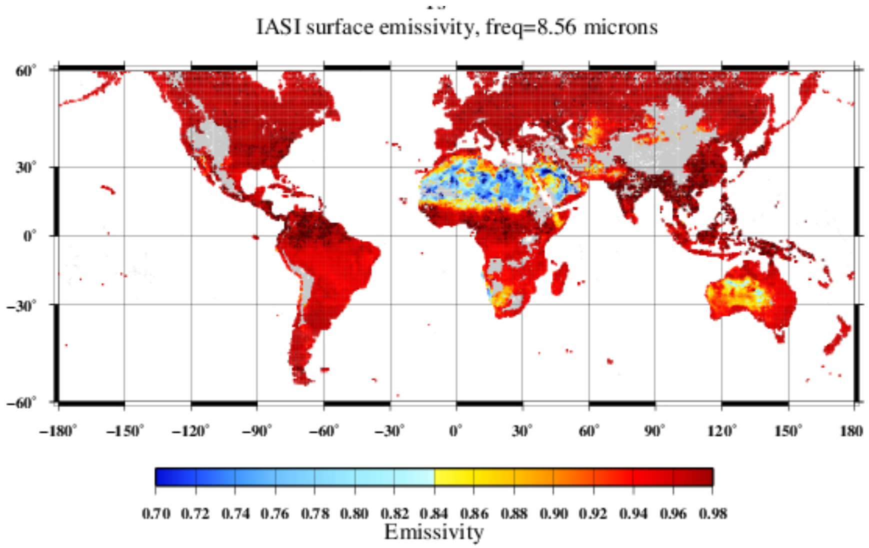
- LERMA: Paul et al, JGR, 2012, derived from IASI

Monthly mean, all IASI spectrum, 0.25° spatial resolution

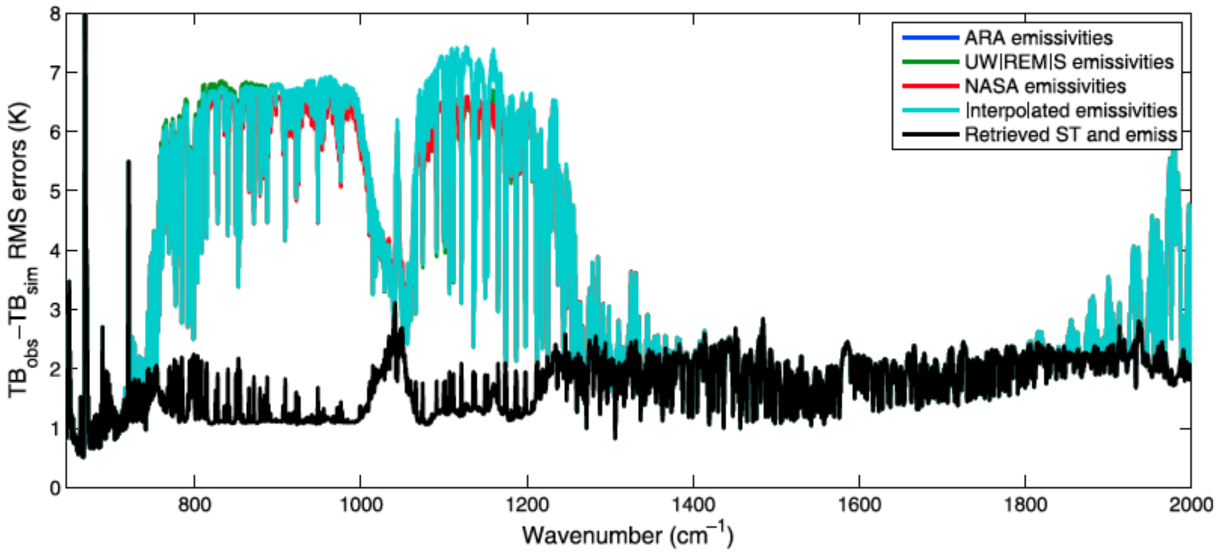
Satellite-derived infrared land surface emissivity



IR emissivity at 8.3μm, Seeman et al., 2008



IR emissivity at 8.56μm, July 2012, Capelle et al., 2012

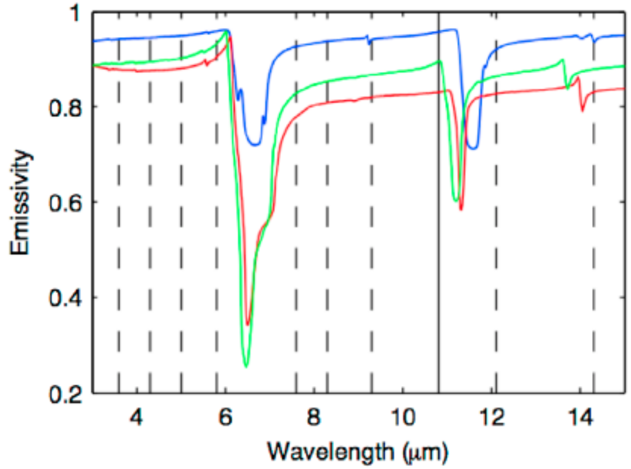


Comparison with the IASI observations, when using different emissivity data bases. Paul et al., JGR, 2012

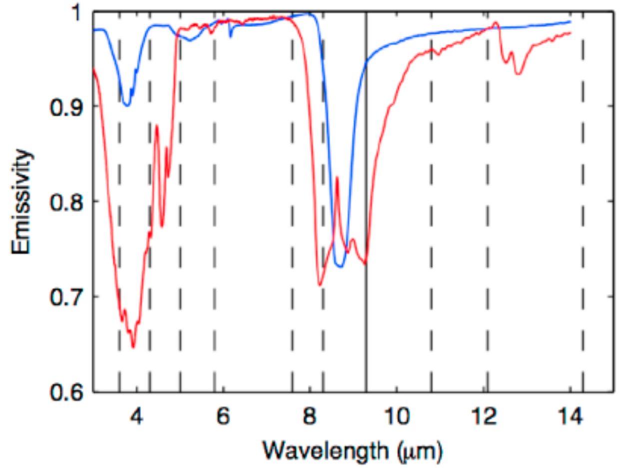
Satellite-derived infrared and microwave land surface emissivity

Infrared emissivity from the ASTER database

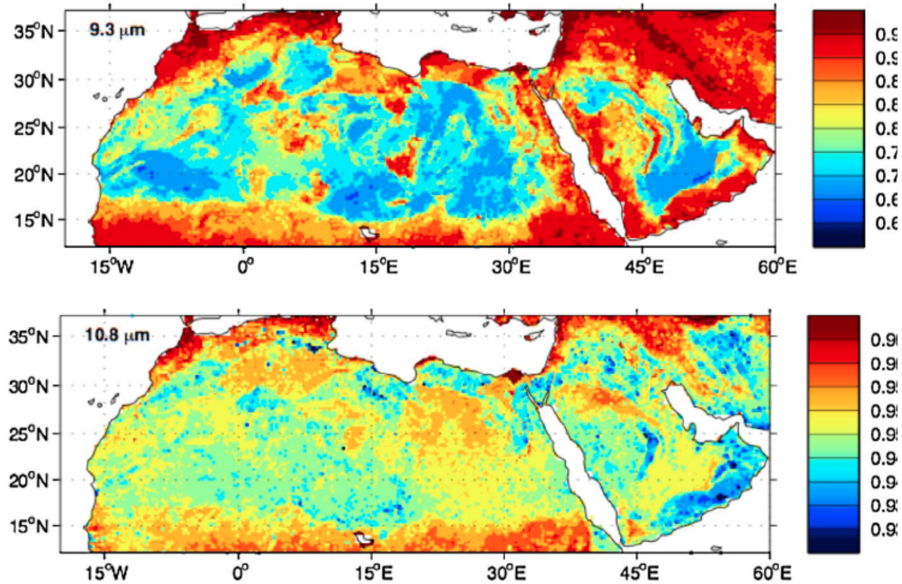
Carbonate



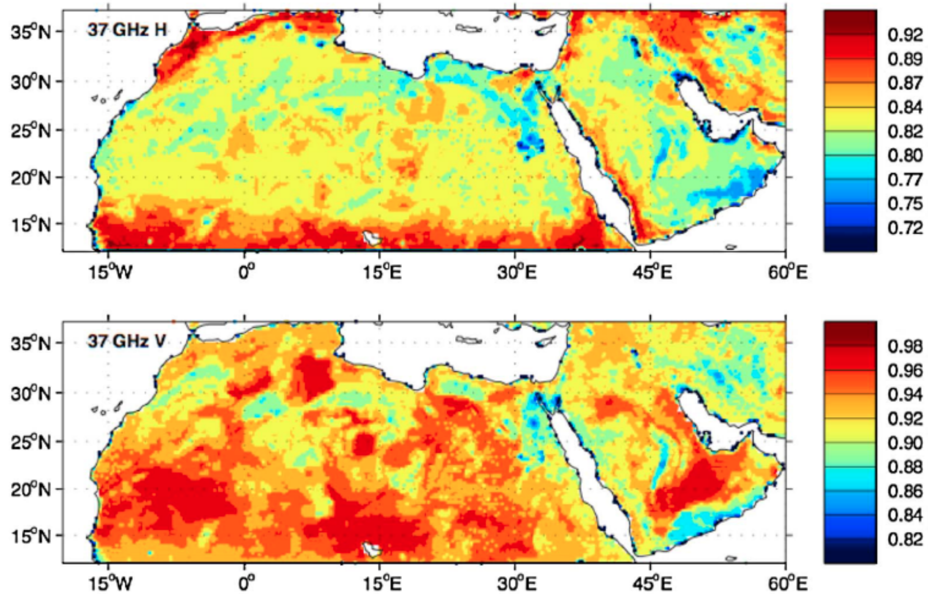
Silicate



Infrared



Microwave



Jimenez et al., JGR, 2010

Conclusion for the infrared and the microwaves

Emissivity model for the ocean rather reliable and applicable globally. Emissivity essentially function of surface wind, temperature, and salinity.

For land, snow, and ice, modeling much more difficult: even if a good model exists, the availability of its inputs at continental or global scale is very questionable.

Radiative transfer models interesting for sensitivity analysis, or fined-tuned for a specific application or environment.

Interest of the satellite-derived land surface emissivity estimates for operational use for application to atmospheric retrieval.

Importance of the role of the surface temperature in the surface contribution; for both infrared and microwave.

What is next?