Land surface microwave emissivities calculations and applications

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with contributions from
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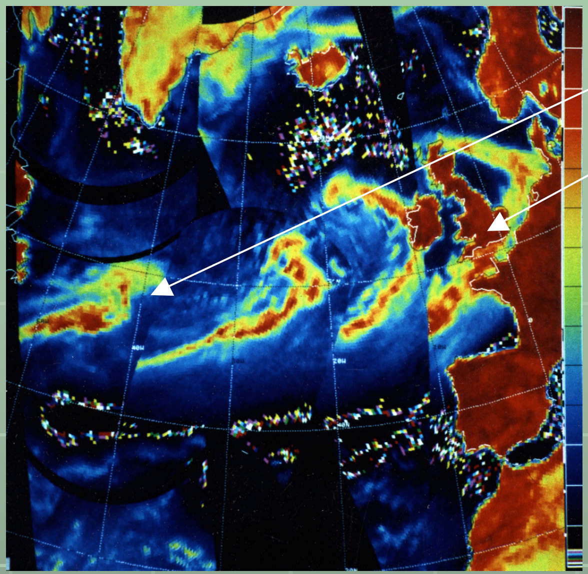
A frontal system observed at 37GHz by SSM/I over the Atlantic (11/10/87-11/11/87)



Over ocean, the front is clearly observed.

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

Good reasons not to use the microwave observations over land:

- emissivity often close to 1 => limited contrast with the atmospheric contribution (ocean emissivity = 0.5)
- high spatial variability (vegetation, humidity, roughness, snow…)
- very difficult to model on a global basis

Good reasons to try:

- can help characterize the land surface
- if the land surface emissivity is accurately estimated, possible to estimate the atmospheric parameters over land

Solution:

To estimate directly the land surface emissivites from satellite observations

This talk :

1- Methodology to calculate the emissivities from the satellite observations

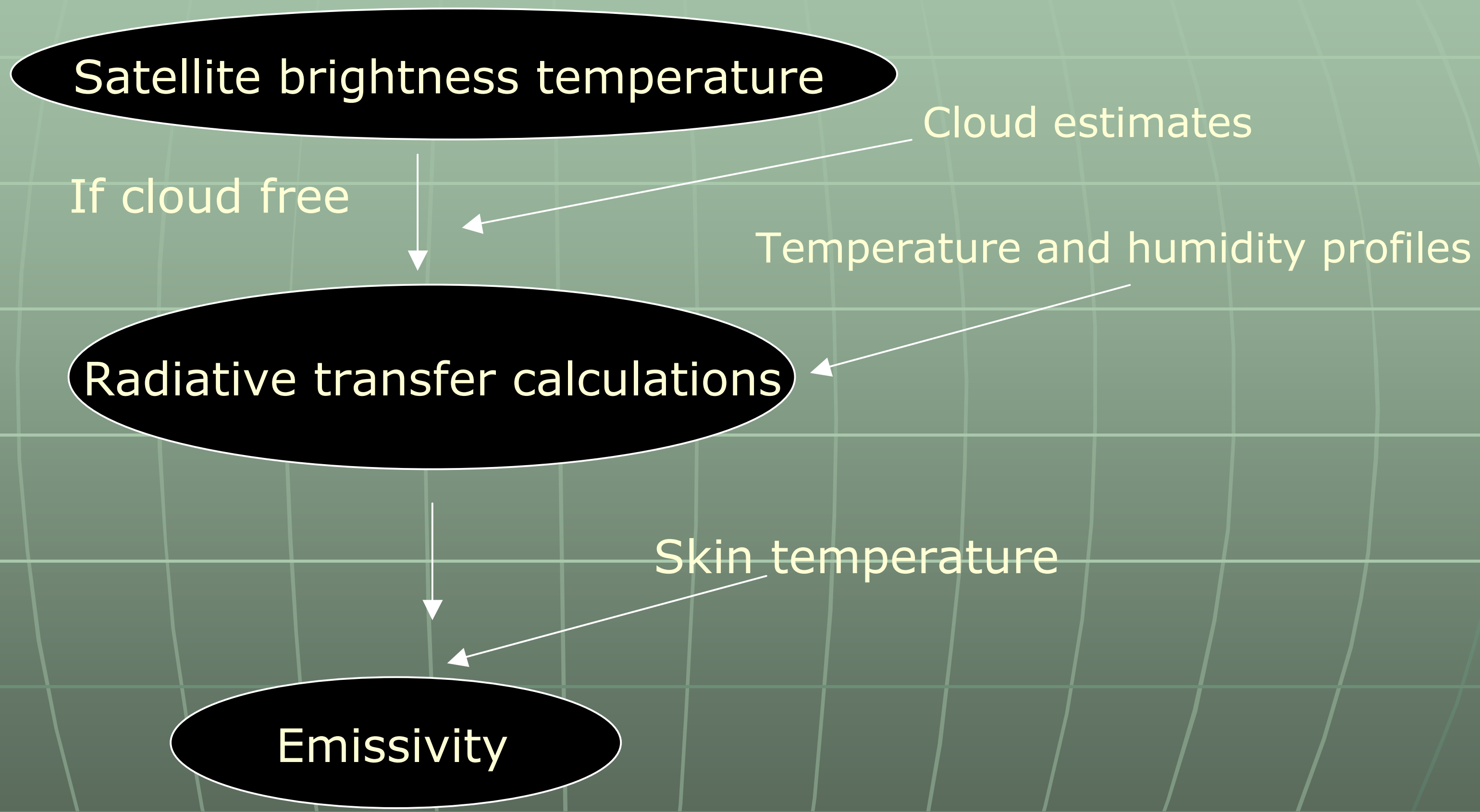
2- Evaluation / comparison

3- Applications to passive microwave retrieval over land (SSM/I,AMSU)

4- Applications to land surface characterization

1-Emissivity estimation (1/4)

A generic method that can be applied to microwave imagers and sounders



$$\varepsilon(p,\upsilon) = \frac{T(p,\upsilon) - T(\upsilon,\uparrow) - T(\upsilon,\downarrow)\times\tau}{\tau\times(Ts - T(\upsilon,\downarrow))}$$

1-Emissivity estimation (2/4)

- uncertainties
  - Ts — **+/- 4 K => 3%**
  - Humidity profiles — **+/- 15 % => 3% at 150 GHz**
  - Temperature profiles — **+/- 1 K => 1% at 50 GHz**
  - Brightness temperature — **+/- 1 K => negligible effect**
  - specular/lambertian surface — **0.9 < E < 1 => < 1%**

=> std for a month within 2%

1-Emissivity estimation (3/4)

- SSM/I: -19, 22, 37, and 85 GHz
  - at 53°, both H and V polarizations
  - 8 years of SSM/I emissivity calculated (06/92-06/00)

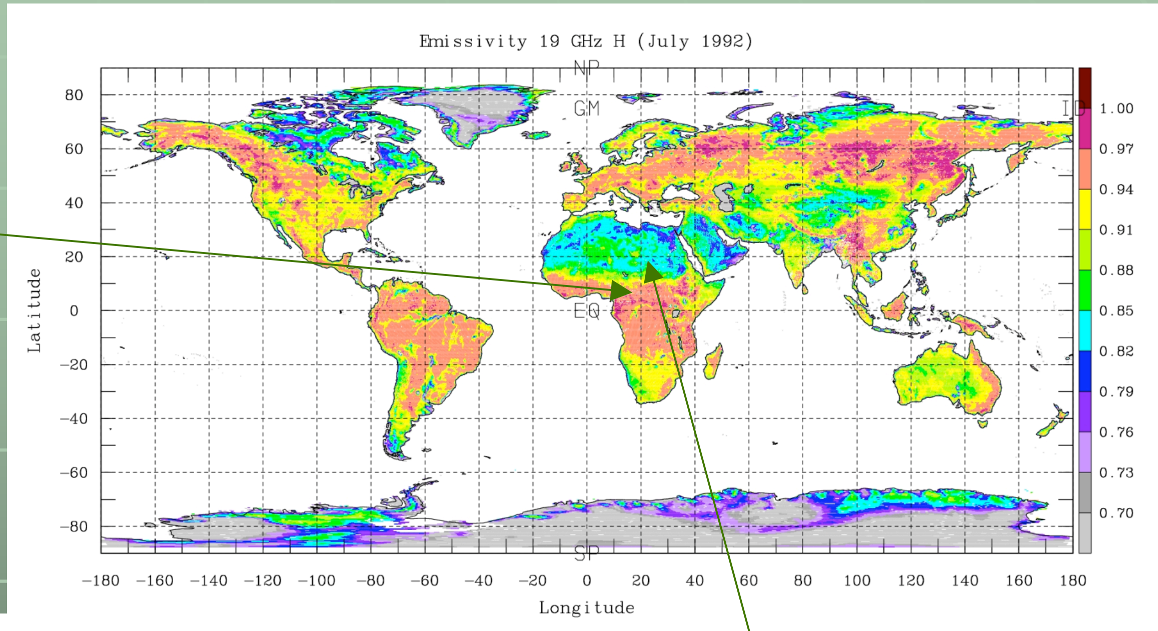
- AMSU: -23, 31, 50, 89, and 150 GHz
  - from 0 to 58°, mixture of H and V polarizations
  - 1 year of AMSU (20000) emissivity calculations (Karbou, Météo France) and several months at ECMWF

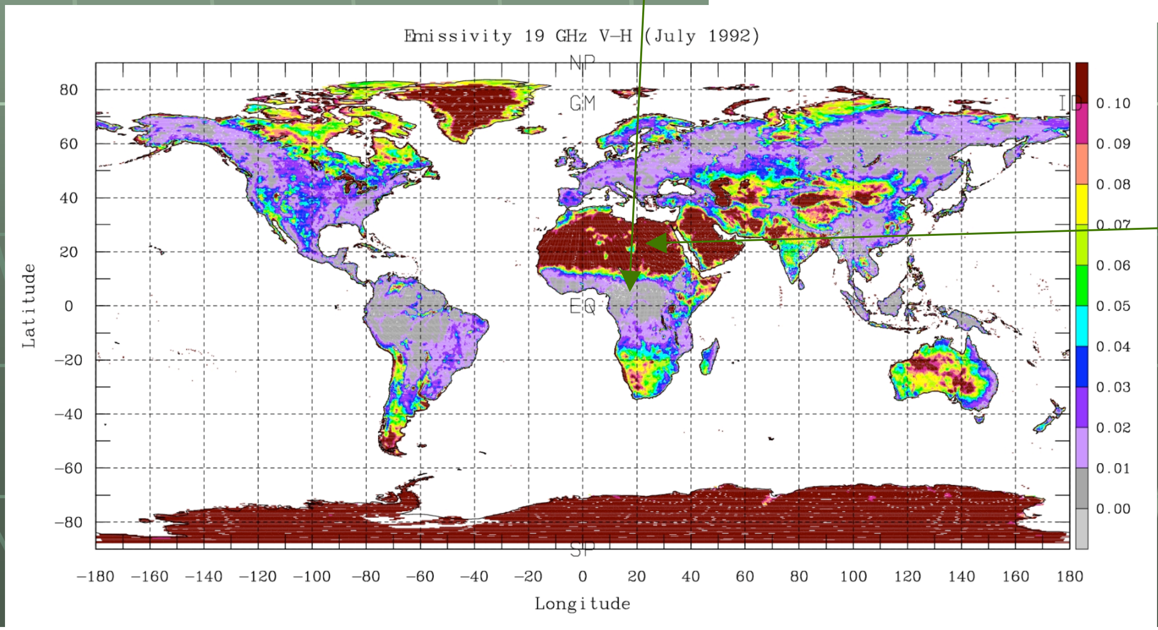
- AMSR: - 6, 10, 19, 22, 37, and 85 GHz
  - at 53°, both H and V polarizations
  - work in progress at AER

1-Emissivity estimation (4/4)

SSM/I emissivity examples

Vegetation:
Large emissivities
Low emissivity polarization differences





Desert:
Low emissivities
Large emissivity polarization differences

2-Emissivity analysis and evaluation (1/4)

No in situ emissivity measurements (beside a few point measurements): one can only check that the expected behaviors are observed.

=> checking of the spatial and temporal consistency with respect to known surface properties (vegetation, topography, standing water…)

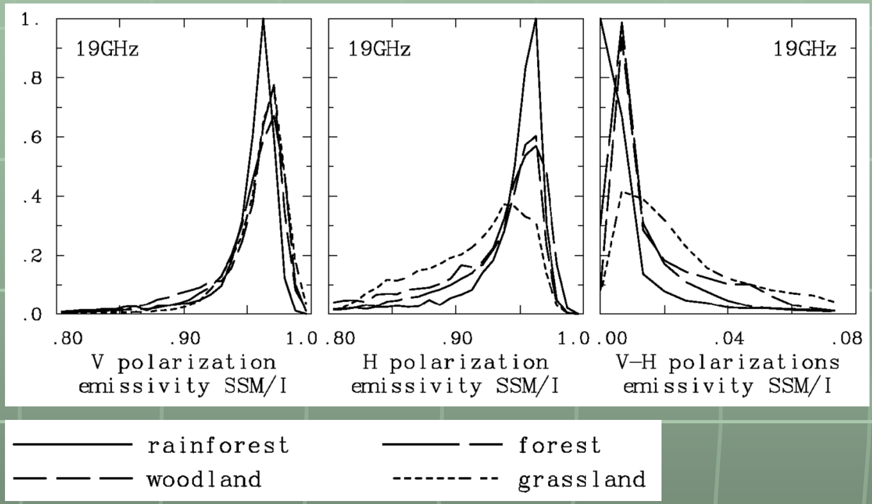
=> checking of the spectral, angular, and polarization variations (for estimates from a given instrument and from different instruments)

=> comparison with emissivity models (but problems with model inputs at global scales)

2-Emissivity analysis and evaluation (2/4)

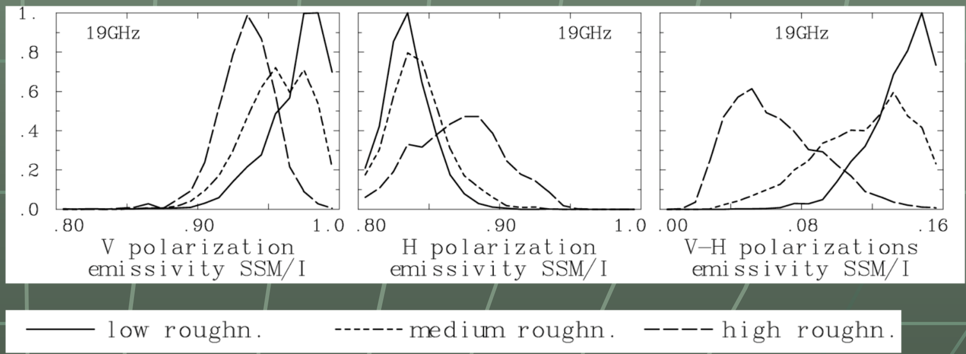
Emissivity dependence with vegetation density:

With increasing vegetation density, emissivity polarization difference decreases.



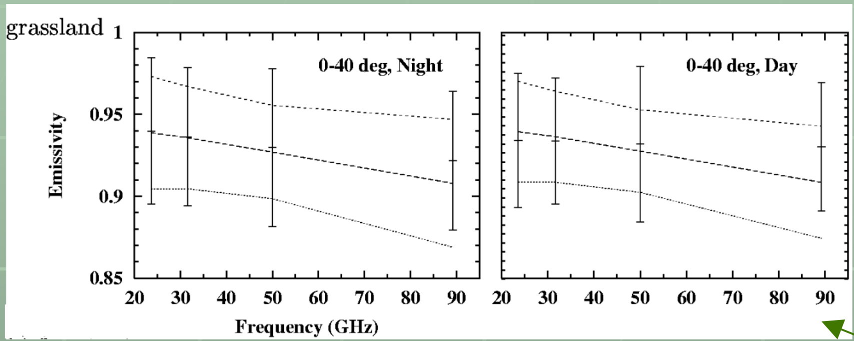
Emissivity dependence with topography:

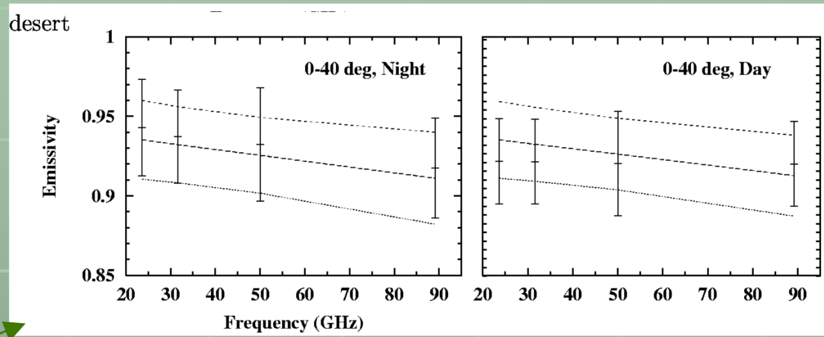
With increasing topography, emissivity polarization difference decreases, especially in arid regions (here North Africa)



2-Emissivity analysis and evaluation (3/4)

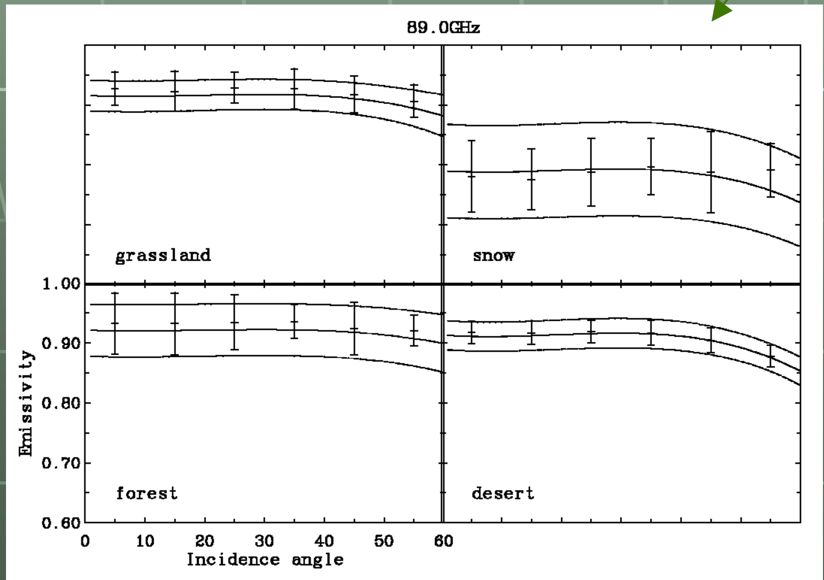
Emissivity spectral dependence:



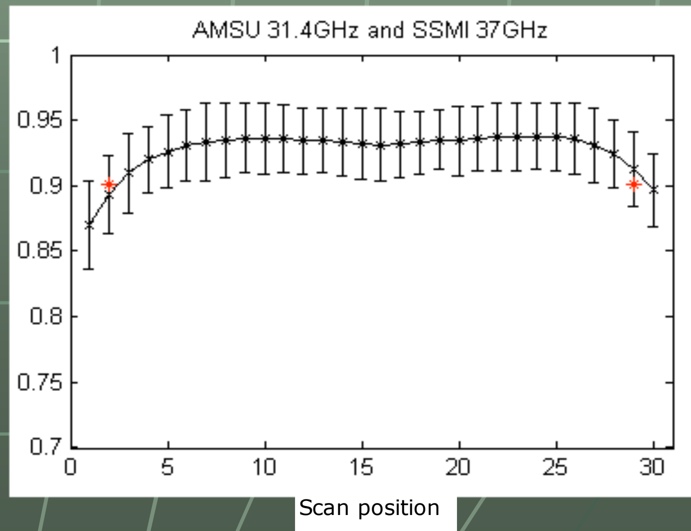


AMSU direct estimates as compared to the values extrapolated/interpolated (in frequency and angle) from SSM/I estimates

Emissivity angular dependence:



!!!! Scan position problem with some AMSU channels !!!



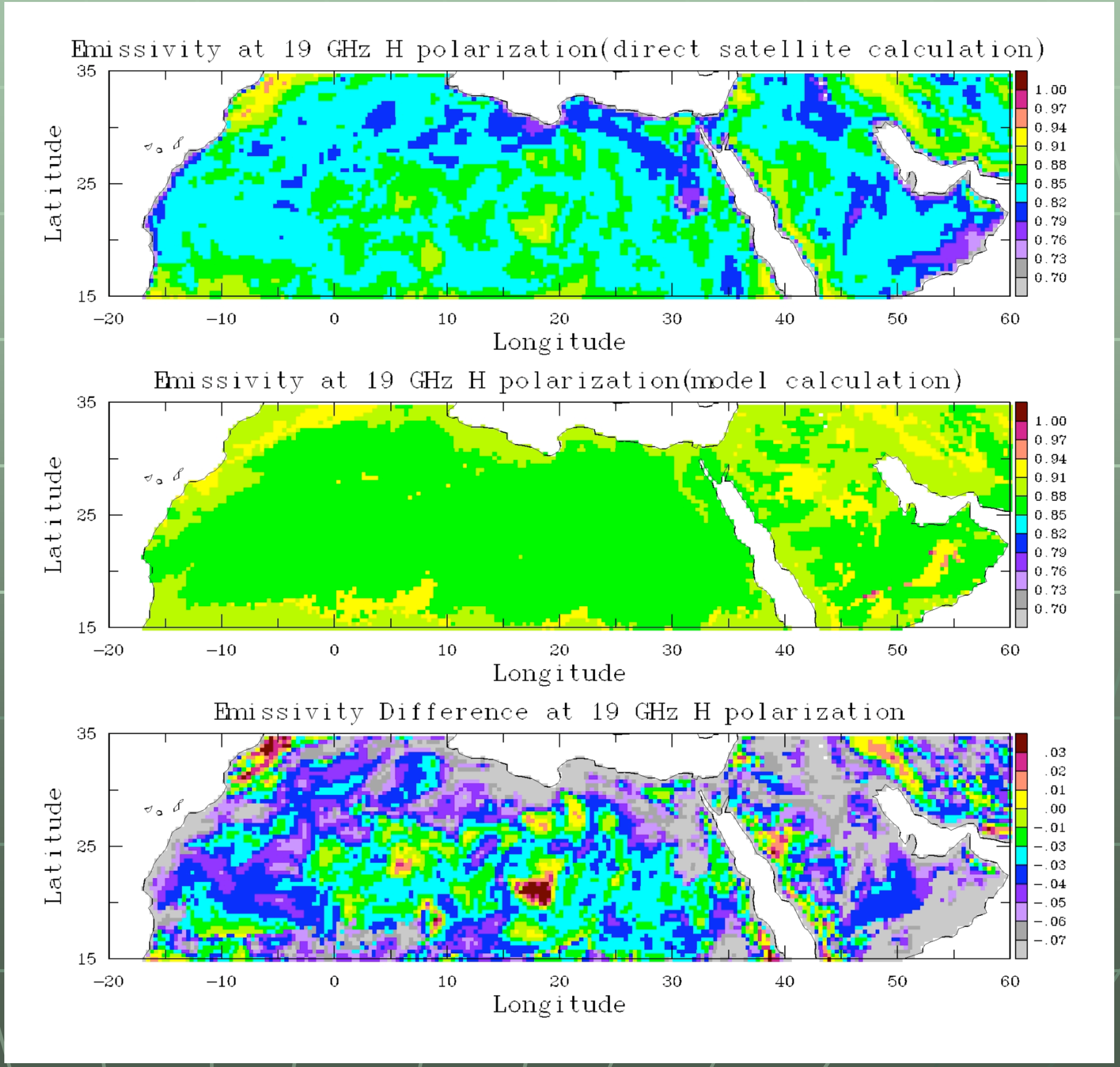
2-Emissivity analysis and evaluation (4/4)

Comparison with emissivity radiative transfer models:

Difficult for the model to correctly reproduce all the spatial structures:

=> complex radiative transfer interactions

=> lack of reliable inputs for the model (soil texture, roughness at different scales…)



3-Application to atmospheric retrievals over land (1/5)

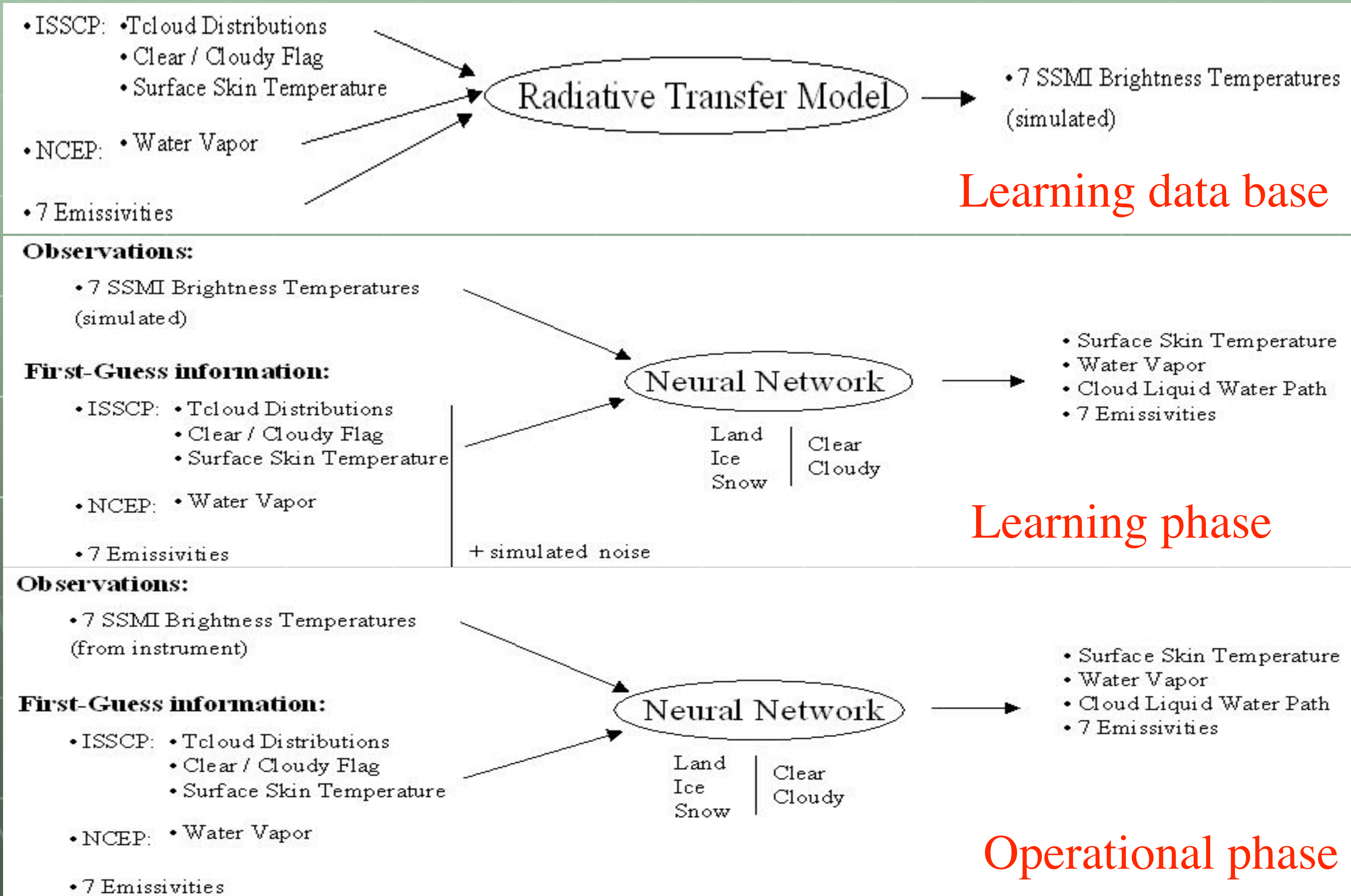
- SSM/I:
  - NN inversion with first guess
  - Simultaneous retrieval of Ts, IWP, ICW, emissivities
  - 8 years of retrieved products
  - 'all weather' Ts estimates

  (Aires et al., JGR, 2001; Prigent et al., JAM, 2003; JGR, 2004)

- AMSU:
  - NN inversion for atmospheric temperature/humidity profiles over land (Karbou et al., JGR, 2005)
  - Assimilation of AMSU-A raw radiance over land in the ECMWF system (Prigent et al., JAM, 2005)
  - Assimilation of AMSU-A and B radiances over land in the Météo-France system (Karbou et al., work in progress)

3-Application to atmospheric retrievals over land: SSMI (2/5)

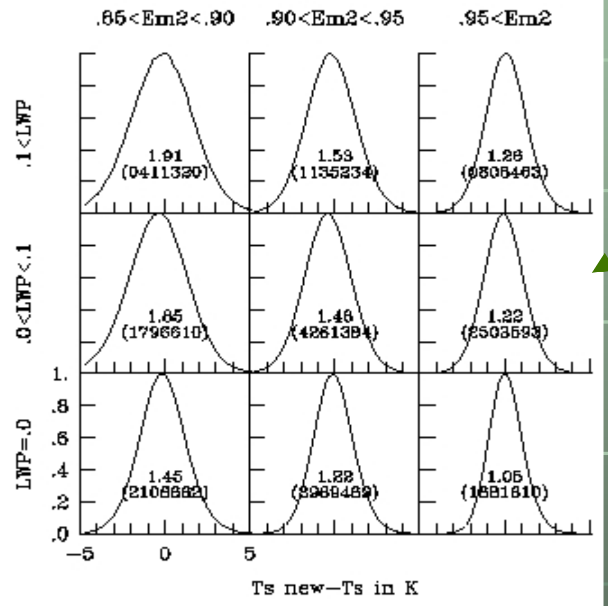
Simultaneous inversion of surface temperature, emissivities, atmospheric water vapor content, and cloud liquid water

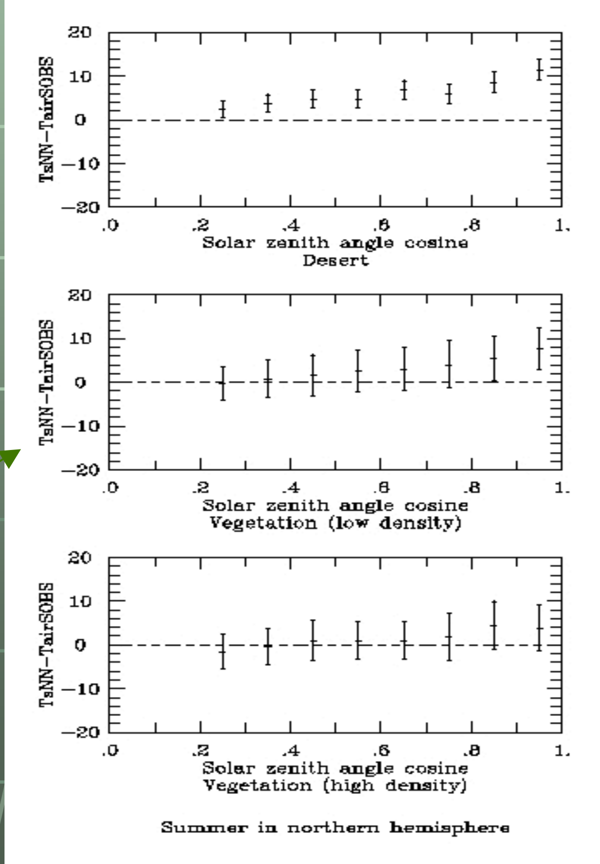


3-Application to atmospheric retrievals over land: SSMI (3/5)

- Systematic calculation of surface temperature from combined SSM/I and IR for an all-weather time record.
- 8 years of data calculated
(Aires et al., JGR, 2001; Prigent et al., JAM, 2003; JGR, 2004)

Theoretical errors for Ts calculated on the data base: no bias related to surface emissivities or cloud cover



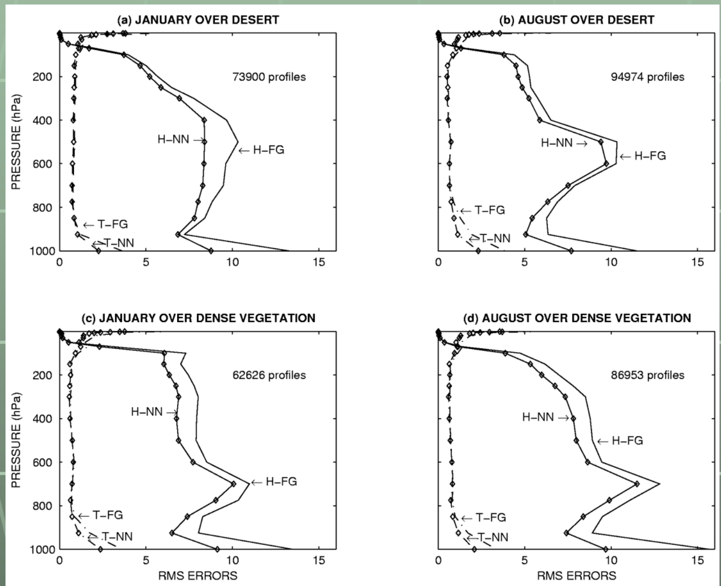


No in situ measurements available for Ts validation: comparison with Tair at 2m.
Check for expected Ts -Tair variations with solar zenith angle, surface humidity, cloud cover.

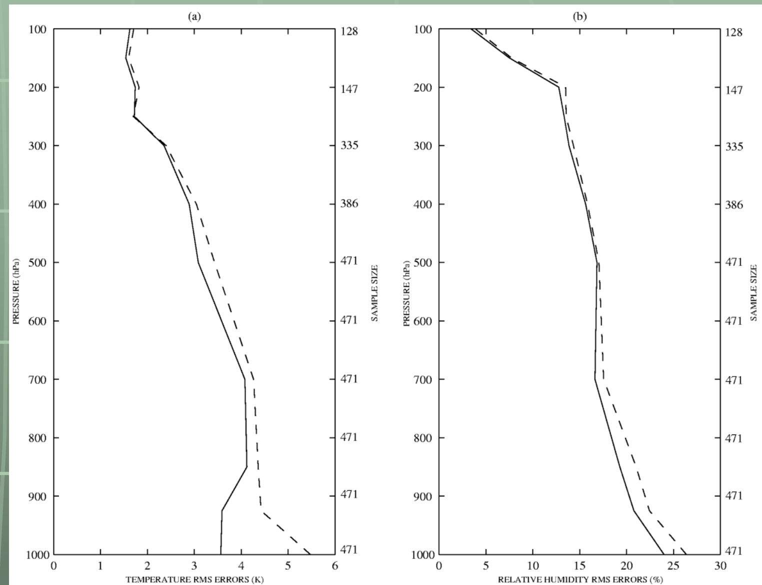
3-Application to atmospheric retrievals over land: AMSU (4/5)

Development of a neural network retrieval for atmospheric and humidity profiling over land using AMSU-A and B (Karbou et al., JGR, 2005)

- reliable surface emissivity estimates
- first guess estimates of Ts (ISCCP) and humidity and temperature profiles (ECMWF reanalysis)



Retrieved RMS error within 2K and 9% for T and H at the surface, regardless of surface type, scanning and atmospheric situations



As compared to radiosonde profiles, results improved by 2K and 2.5% in T and H, respectively.

=> AMSU A and B can bring significant information on the temperature and humidity profiles at lower levels, when accurate surface emissivity information is used

3-Application to atmospheric retrievals over land: AMSU (5/5)

At present, in NWP systems, sounding channels with weighting functions close to the surface not used or used very conservatively

ECMWF experiment:

- calculation of the AMSU-A emissivities in window channels
- evaluation within the assimilation scheme
    - comparison with a control experiment
    - the control experiment: - window channels used to classify the surface type and fixed emissivity for a given surface
      - window channels and channel 4 not used

  => more data to be assimilated with the new emissivity estimates (roughly 20% increase for channel 5 and 6): more data to pass the quality control tests based on observations minus calculation criterion)

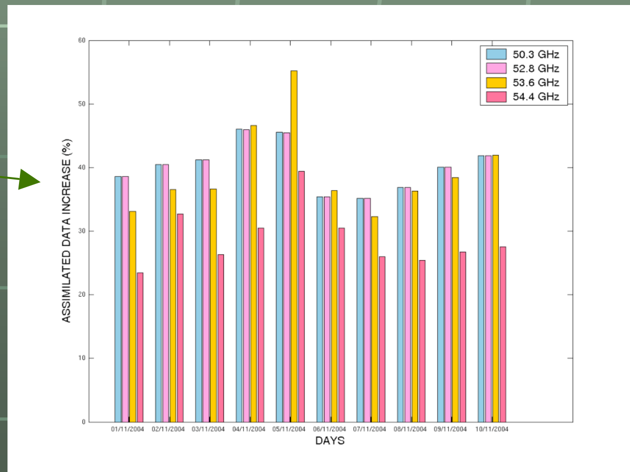
  => on this limited experiment (half a day), neutral impact on the forecast

Météo-France experiment (Karbou et al.):

- similar experimented but with the Arpege model for a two week period.

=> about 40% increase of the assimilated data. Tbs calculated from the background better fit observed Tbs using pre-calculated emissivities.

=> on a global scale, slight improvement in the geopotential height forecast errors.



=> Encouraging results: additional tests to be performed.

4-Application to land surface characterization (1/3)

Systematic analysis of the sensitivity of the microwave land surface emissivities to the surface properties, globally and over long time series

Systematic and objective analysis and comparison of the sensitivity of different satellite observations, from the visible to the microwave, to global land surface characteristics

VIS and N-IR:

NOAA / AVHRR visible (0.58-0.68 mm) and near-infrared reflectances (0.73-1.1μm)

Thermal IR:

NOAA / AVHRR and geostationary (Meteosat, Goes E and W, GMS) thermal IR (~12μm)

Passive microwaves:

SSM/I microwave emissivities (between 19 and 85 GHz)

Active microwaves:

ERS scatterometer (5.25 GHz)
Topex/Poseidon altimeter (5.25 GHz and 13 GHz)

Difficult to disentangle the various parameters that contribute to the surface signal (e. g. , vegetation, soil moisture, snow, soil roughness, and topography) in addition to potential contamination from the atmosphere (gazes, clouds, rain) with a single satellite observation source

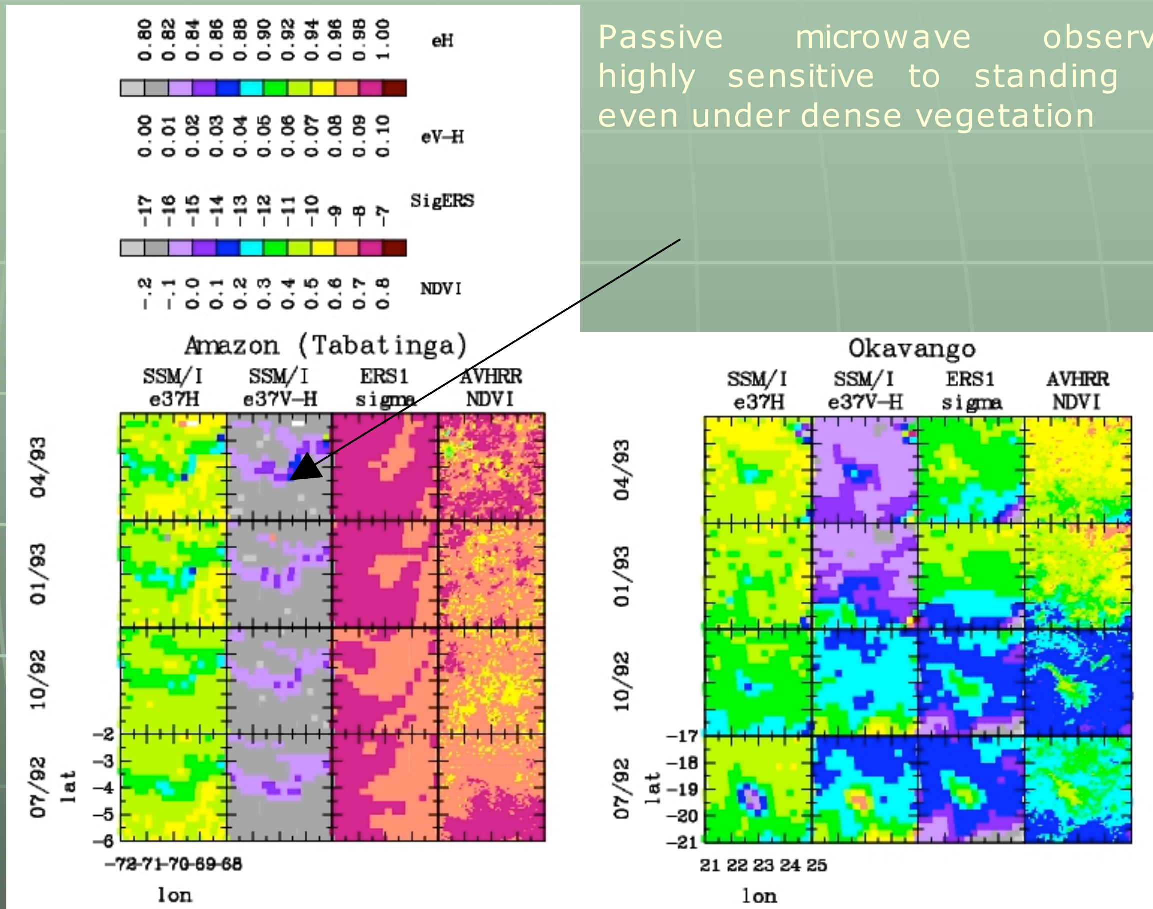
=> Merging of the satellite observations to benefit from their complementary aspects and retrieve surface characteristics.

Applications:

- vegetation monitoring (Prigent et al., JGR, 2001)
- wetland extent and seasonality (Prigent et al., GRL, 2001; Fily et al., RSE, 2003)
- soil moisture estimates (Prigent et al., JGR, 2005; Aires et al., JGR, 2005)
- snow characterization (Prigent et al., JAM, 2003; Cordisco et al., in preparation)

4-Application to land surface characterization (2/3)

Example of the wetland extent and seasonality



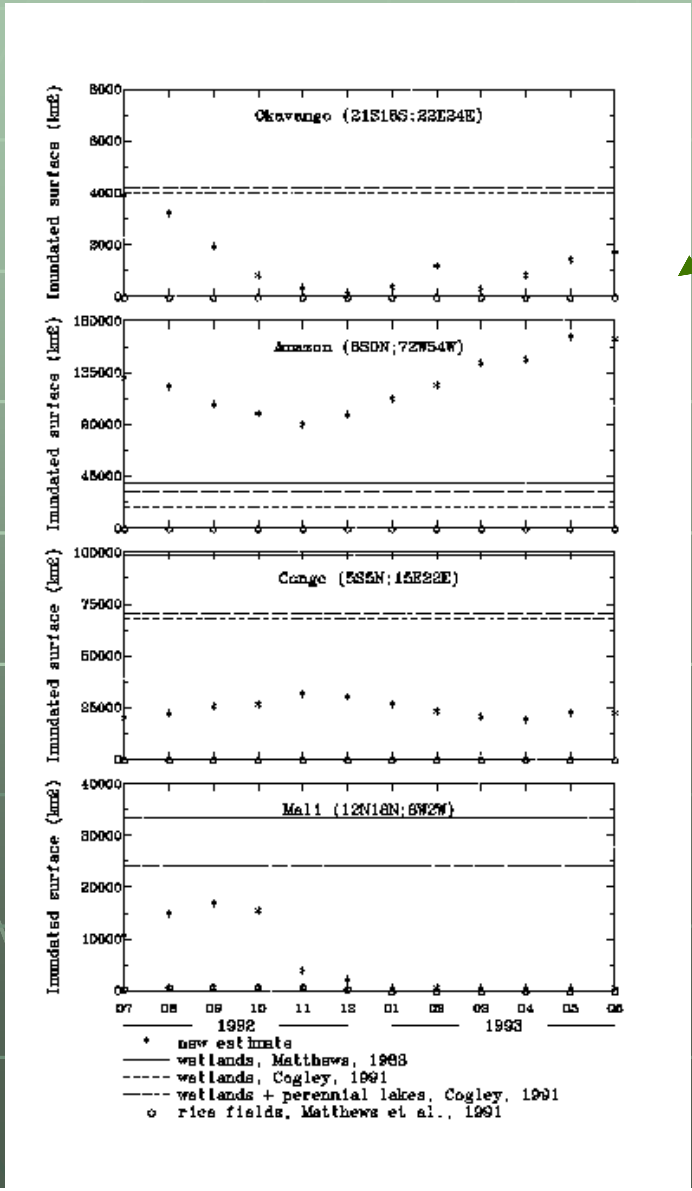
Passive microwave observations highly sensitive to standing water, even under dense vegetation

- clustering of the merged satellite data to detect the inundated pixels
- fractional coverage of flooding then estimated from a linear mixture model with end-members calibrated with radar observations to account for vegetation

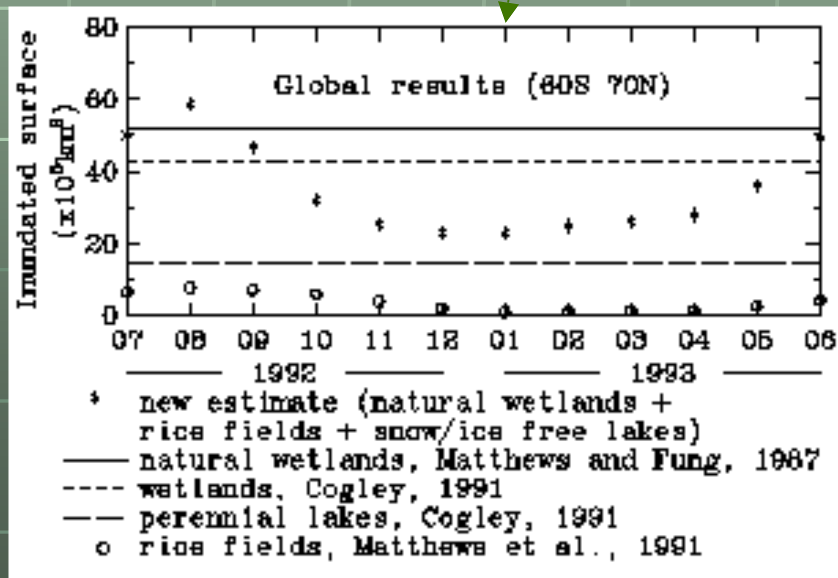
4-Application to land surface characterization (3/3)

Example of the wetland extent and seasonality

Results for specific basin



Global results



Conclusions

Microwave emissivity directly calculated from satellite observations:

- easy and reliable way to estimate microwave land emissivities
- long time record (1992-2000) for the SSM/I emissivities
- thoroughly evaluated
- method directly applicable to AMSR and SSM/IS
- in progress: development of an emissivity model for global application, anchored on the calculated emissivities, for the 10-200 GHz range, all angles, H and V polarizations.

Applications to surface and atmospheric retrievals over land:

- surface and atmospheric retrieval over land possible based on these emissivity estimates from imagers (SSMI) and sounders (AMSU)
- 'all weather' Ts estimates from SSMI
- strong potential for assimilation of AMSU A and B in NWP for temperature and humidity profiling

Applications to land surface characterizations:

- merging with other satellite observations (visible, IR, active microwave)
- various applications (vegetation monitoring, wetland extent and seasonality, soil moisture estimates, snow characterization)

For references, see http://aramis.obspm.fr/~prigent/publication.html