Techniques for modelling land, snow and sea ice emission and scattering in support of data assimilation

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Outline

On the need for a good knowledge of emissivity

Variability of emissivity

Emissivity modelling for data assimilation over land, snow, sea-ice

Some assimilation results

Conclusions
Satellites observations: Tbs (no direct measurements of T, Q)

- Simulations of radiative transfer model: atmospheric fields but also surface conditions
- Data quality contrôle: to reject cloudy/rainy data (AMSU-A Ch4: 52.3 GHz, AMSU-B Ch2: 150 GHz, SSMI/S Ch2: 52.3V and Ch8: 150 H)
- Other conditions: bias correction (Dee [2004], Auligné et al. [2007]), good specification of observation and model errors, ….
On the need for a good knowledge of emissivity

AMSU-A/-B Weighting functions (standard atmosphere)

Effect of the surface

Observations in numerical weather prediction, 8-12 September
On the need for a good knowledge of emissivity

To assimilate surface sensitive channels: separate the surface effect from the atmospheric signal

AMSU-A, ch4: 52.8 GHz, 08/04/2010
On the need for a good knowledge of emissivity

Emissivity ~ 0.5: the surface contribution to the measured signal < land surfaces

Assimilation: emissivity model Fastem (English, Hewison [1998], Deblonde, English [2000], Liu et al. [2010]) meets NWP requirements
On the need for a good knowledge of emissivity

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Emissivity ~ 1: Higher contribution of the surface, complexe variations in space/time, surface conditions, type, ...

**Assimilation**: Difficult
On the need for a good knowledge of emissivity

Emissivity $\sim 0.5$: higher contribution of the surface, complex variations in space/time, surface conditions, type, ...

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Emissivity $\sim 1$: the surface contribution to the measured signal < land surfaces

Assimilation: difficult

Emissivity: very high, highly variable

Assimilation: very difficult
On the need for a good knowledge of emissivity

- **In-situ measurements:**
  - Different surface types (bare soils to forests)
  - Calvet et al. (1995), Matzler (1994, 1990), Wigneron et al. (1997) among others

- **Airborne measurements:**
  - Different surface types (forests, snow)
  - Hewison and English (1999), Hewison 2001, ...

- **Satellite estimations:**
  - Regional to global scales, many frequencies, many sensors

- **Modelling approaches:**
  - Limitations:
    - Complexity of interactions between radiation and the large variability of the medium
    - For atmospheric retrievals, need of accurate input parameters (vegetation characteristics, soil moisture, roughness) at a global scale.
  - Grody (1998), Karbou (2005), Isaacs et al. (1989), Weng et al. (2001), ...
Emissivity estimation using the radiative transfer equation

\[ T_b = \varepsilon \cdot T_s \cdot \tau + (1 - \varepsilon) \cdot \tau \cdot T(\downarrow) + T(\uparrow) \]

Under several assumptions

- Ill posed problem: uncertainties about the surface and the atmosphere

- Radiative transfer model (RTTOV) + T/Q profiles (short range forecasts, analyses, reanalyses) + Ts (IR retrievals / short-range forecasts, analyses)

Emissivity estimation:

\[ \varepsilon = \frac{T_b - T(\uparrow) - T(\downarrow) \times \tau}{\tau \times (T_s - T(\downarrow))} \]
Variability of emissivity

AMSU-A 89 GHz, August
Variability of emissivity

AMSU-A 89 GHz, January
Variability of emissivity

SSMI/S, 37 GHz (V+H)/2

AMSU-A, 31 GHz

July 2010

SSMIS 37 GHz, Jul2010

AMSU-A 31 GHz, Jul2010
Variability of emissivity

**SURFEX/ISBA-Crocus snow model:** meteorological forcing from era-interim (Brun et al. 2013); in-situ snow depth data (or SWE) are available for evaluation of the snow model simulations: Crocus did not make use of these data

**SWE Products from NSIDC** (observations AMSR-E ~ 36 GHz), **SWE products from Globsnow** (synop data + observations SSMI, AMSR-E ~ 18.7 & 36 GHz)

\[ \epsilon(89 \text{ GHz}) \]
Variability of emissivity

SURFEX/ISBA-Crocus snow model: meteorological forcing from era-interim (Brun et al. 2013); in-situ snow depth data (or SWE) are available for evaluation of the snow model simulations: Crocus did not make use of these data

SWE Products from NSIDC (observations AMSR-E ~ 36 GHz), SWE products from Globsnow (synop data + observations SSMI, AMSR-E ~ 18.7 & 36 GHz)
Variability of emissivity

Comparison near a synoptic station

\( \epsilon \) versus Crocus

\( \epsilon \) versus Globsnow

\( \epsilon \) versus NSIDC
Variability of emissivity
Variability of emissivity

[Graphs showing daily emissivity differences and daily SWE, temperature, and specific humidity trends over December to May for different datasets like Crocus, Globsnow, AMSRE, Ts-ISBA, T2M-ERA, and Q2M-ERA.]
Variability of emissivity

Effect of the specular assumption over Antarctica following Matzler (2005) study

from Guedj et al. 2010

specular

lambertian
Variability of emissivity

Effect of the specular assumption over Antarctica following Matzler (2005) study

AMSU-A ch5, from Guedj et al. 2010
Variability of emissivity

Very high variability of sea ice emissivity

January 2009

July 2009
Variability of emissivity

Emissivity varies with sea ice types

Ice types from OSISAF

AMSU-A 31 GHz

AMSU-A 50 GHz

AMSU-B 89 GHz

AMSU-B 150 GHz

Emissivity at 31 GHz
Emissivity at 31 GHz
Emissivity at 89 GHz
Emissivity at 150 GHz

05 January 2009, Emissivity at 89 GHz
05 January 2009, Emissivity at 150 GHz

permanent ice
seasonal ice
no ice
ambiguous ice type

January 2009, Emissivity at 50 GHz
Variability of emissivity

Emissivity varies with sea ice types

![Graph showing emissivity variation with sea ice types](image-url)
Some assimilation results

How to use emissivity retrievals in data assimilation?
possible ways for use: « climatology » or « dynamical update of emissivity »

Emissivity climatologies from window channels (one month, two weeks ...)

Estimate the emissivity using one window channel for every atmos. And surface situation

• Take into account the emissivity change with obs. angle (AMSU)
• Uncertainties if the surface conditions change (rain, snow, ...)
• Very useful to estimate the Ts

• choose the best window channel (the most sensitive to the surface or the closest channel, in frequency, to sounding channels ?)
• With this method, we account for the angular dependence of the emissivity and for any change in the surface condition

At ECMWF, a kalman filter was developed to dynamically update atlases (Krzeminski et al. 2008)
Some assimilation results
Effect of a dynamical update of emissivity (without adding more channels)

- Interfaced with RTTOV (Eyre 1991; Saunders et al. 1999; Matricardi et al. 2004)
- Land emissivity is computed from selected surface channels (AMSU-A ch3 (50 GHz) and from AMSU-B ch1 (89 GHz))
Some assimilation results
Effect of a dynamical update of emissivity (without adding more channels)

AMSU-A Ch7 obs. Density (sensitive to Temperature 10 km) during August 2006

CTL

EXP

Densité des observations assimilées (Nombre obs. par cellule de 2.5°×2.5°)
Some assimilation results
Effect of a dynamical update of emissivity (without adding more channels)

Correlations between Obs and RTTOV Sim., AMSU-A ch4, August 2006

CTL

CTL + dynamical emis.

AMSU-A Ch4 52 GHz

CORRELATIONS

0.4 0.5 0.6 0.7 0.8 0.9
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Assimilated AMSU-B Channels over land in ARPEGE operational model (before Apr 2010)
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Assimilated AMSU-B Channels over land in our experiments
Summer 2006

Observations of the boundary layer over land
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Scores geopotential height / Radiosondes, 48h, 1 month

CTL --- BIAS
__ RMSE

EXP --- BIAS
__RMSE

N20

AUS-NZ

S20

TROPIQ
Some assimilation results

Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

TCWV (EXP-CTL)

Similar humidity features with the assimilation of MERIS over land (Bauer 2009)

More humidity in EXP
Some assimilation results

Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

TCWV (EXP-CTL)

Evaluation against GPS measurements

More humidity in EXP

TCWV diurnal cycle, Timbuktu (MALI)
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

TCWV (EXP-CTL)

Evaluation against GPS measurements

TCWV daily time series, Ouagadougou

More humidity in EXP
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Correlations with GPS, 45 days, synoptic times
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Feasability studies to assimilate some SSMI/S sounding channels

SSMI/S:
- Conical scanning: fixed observation angle (53°)
- Polarisation: V and/or H
- Window channels: 19.35 V&H, 22.23 V, 37 V&H, 50.3 V, 91.65 V&H GHz

Over sea

Humidity ch(9,10,11)

Temperature ch (3,4,5)
Some assimilation results
Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Emissivity (~183 GHz) = Emissivity at 91H GHz (ch18)
Emissivity (~54-60 GHz) = Emissivity at 50V GHz (ch1)

Data impact studies for evaluation:

• Period: 01/04/2011 to 29/05/2011
• CTL: the current operational system
• EXP: CTL + assimilation of SSMIS channels 3-5 & 9-11 over sea and land
• Data from DMSP-16 and -17
• Quality control: SSMIS ch2 (52V, 0.7K) and SSMIS ch8 (150H, 2.7K)
• Obs error: 0.5K & 2K
Some assimilation results

Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Fit to observations: SSMI/S

exp:79C2 obstat / ref: 79C3 2011041000-2011042718(06)
SSMIS-1C dmsp-16 SSMIS Tb Tropics
used Tb

Channel Number

RMS

exp -ref nobsexp

-11187 73761
-11206 73761
-11190 73783
-11182 73696
-11112 73623
-11068 73108
+97290 72988
+93900 93900
+94246 94246

BIAS

-0.2 -0.16 -0.12 -0.08 -0.04 0 0.04 0.08 0.12 0.16 0.2

-24 -23 -22 -21 -20 -19 -18 -17 -16 -15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1

-121118 134337
+121118 130735
+134337 134337
+130735 130735
+121118 121118
Some assimilation results

Effect of a dynamical update of emissivity with the assimilation of surface sensitive channels

Fit to observations: Radiosondes

exp:79C2 obstat / ref: 79C3 2011041000-2011042718(06)
TEMP-q N.Hemis
used q

RMS

BIAS

pressure (hPa)

x 0.001

x 0.0001

background departure o-b(ref)
background departure o-b
analysis departure o-a(ref)
analysis departure o-a

bias

x 0.0001

exp - ref
nobsexp

+13 15352
-21 47137
+13 66293
-21 75189
-25 58903
-14 45396
For AMSU-A: use the 50 GHz emissivity for temperature sounding (52-60 Ghz) over sea ice.

AMSU-A channel 5 (53 GHz)
All observations
(One week of data)
Over land & sea-ice: retrieved emissivity at 50 GHz
Over sea: FASTEM model
Some assimilation results
assimilation over sea ice

For AMSU-A: use the 50 GHz emissivity for temperature sounding (52-60 GHz) over sea ice;

AMSU-A channel 5 (53 GHz) assimilated observations
(One week of data)
Over land & sea-ice: retrieved emissivity at 50 GHz
Over sea: FASTEM model
For AMSU-B in particular, can we still use the 89 GHz emissivities for sounding channels without any frequency dependence parameterization?
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Emissivity (~183 GHz) = Emissivity at 89 GHz + f (Tb 89, Tb150, Ts)

Emissivity at 89 GHz = Emissivity at 150 GHz with correction

- seasonal ice
- permanent ice
- ambiguous ice type
Some assimilation results
assimilation over sea ice

For AMSU-B in particular, can we still use the 89 GHz emissivities for sounding channels without any frequency dependence parameterization?

Use of frequency parameterization for sea ice: to describe the emissivity change from 89 GHz to 183.31 GHz

Emissivity (~183 GHz) = Emissivity at 89 GHz + f (Tb 89, Tb150, Ts)
Emissivity (~54-60 GHz) = Emissivity at 50 GHz

Data impact studies for evaluation:

• Period: 15/12/2009 to 04/02/2010
• CTL: the current operational system
• EXP: CTL + emissivity model over sea ice + assimilation of AMSU-A/-B over sea ice
Some assimilation results
assimilation over sea ice

Usage of AMSU-B channel 5 (183.31 ± 7.0 GHz) in ARPEGE
Usage of AMSU-B channel 5 (183.31 ± 7.0 GHz) in ARPEGE

Some assimilation results
assimilation over sea ice
Some assimilation results
assimilation over sea ice

Fit to observations: improvement or neutral effect

RMS errors of AMSU-B departures from Analyses and First-guess (NOAA-17), S. Hemis

RMS

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<tr>
<td>10</td>
<td>6.0</td>
<td>5.7</td>
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</tr>
</tbody>
</table>

~ +28%

CTL --- Analyses  __ First-Guess

EXP --- Analyses  __ First-Guess
Some assimilation results
assimilation over sea ice

Control

Difference in inversion strength brought by a larger warming at 850hPa than at 1000 hPa
Conclusions

• Emissivity retrieval from surface channels is a convenient way to improve the assimilation of data over land

• Method developed for AMSU-A/-B MHS instruments but can be used for SSMI, SSMIS, AMSRE, ATMS, SAPHIR

• Method gives good results over land, sea-ice and improves RTTOV simulations over snow

• Improve the bias correction over land (new predictors ?), Gérard et al. 2010

• Improve the representation of the skin temperature

• Snow, sea ice issues: a specularity parameter ?

• Surface modelling an issue for IR

• Need for increased coupling between land and atmospheric data assimilations
Thank you for your attention