Instantaneous Emissivities Estimation Using AMSR-E Measurements over Land

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Outline

[Introduction]
- General View of Radiative Transfer Process
- Microwave Atmosphere Influence

[Emissivity Estimation Theoretical Background and Dataset]
- Method
- Input Data Description and Estimation Scheme

[Result and Evaluation]
- Estimation Result Analysis
- Comparison with the Previous Result

[Time Series and Frequency Dependency Analysis]
- Time Series
- Frequency Dependency Analysis
- Discrepancy with Simulation?
- Emissivity estimation under cloudy condition…

[Conclusion]
Introduction - Physical fundamental (1/3)

General View of Radiative Transfer Process

**Microwave Spectrum...**
Penetrate Cloud, Rain...
Work all day and night - all weather

Snow pack
Microwave Spectrum
Cosmic Background
Atmosphere Emission
Atmosphere Attenuation
Surface Emission
Bare

Snow, Vegetation, Soil, and Precipitation Patterns

Water and energy move in vertical (layered) soil columns
Introduction - Physical fundamental (2/3)

For a non-scattering plane-parallel atmosphere, the integrated radiative transfer equation (RTE) in the Rayleigh-Jeans approximation over a flat lossy surface can be expressed in terms of the total brightness temperature observed by satellite radiometer at certain frequency, polarization and incidence angle at the top of atmosphere (TOA).

\[ T_{bp}(v, \theta) = e_{s,p}(v, \theta) \cdot T_s \cdot \Gamma(v, \theta) + T_{a,atmos}(v, \theta) + \]

\[ T_{a,atmos}(v, \theta) \cdot (1 - e_{s,p}(v, \theta)) \cdot \Gamma(v, \theta) + \]

\[ T_{CB}(1 - e_{s,p}(v, \theta)) \cdot (\Gamma(v, \theta))^2 \]

- molecular oxygen, water vapor, cloud liquid water
- Rosenkranz (1998) – water continuums absorption

For a scattering plane-parallel

- rain, snow, ice and graupel
- \( \gamma_{s_{-}hydro}(v,z) = \sum_{h=1}^{H} \gamma_{s_{-}h}(v,z) \) \( \gamma_{a_{-}hydro}(v,z) = \sum_{h=1}^{H} \gamma_{a_{-}h}(v,z) \)
- Mie (1908)
- RTE - Eddington-based (Kummerow 1993, Olson, 2001) – 1-D Atm. Mod.

\( \gamma(v,z)=\gamma_{a_{-}h2o}(v,z)+\gamma_{a_{-}o2}(v,z)+\gamma_{a_{-}hydro}(v,z)+\gamma_{s_{-}hydro}(v,z) \)
AMSR-E frequency configuration and the atmospheric absorption curve

Microwave spectral range

Parameter | AMSR-E (Aqua)
---|---
Time Period | Beginning 2002
Frequencies (GHz) | 6.9, 10.7, 18.7, 23.8, 36.5, 89

MODIS / AMSR-E provide the synchronous earth observation
Introduction - Microwave Atmosphere Influence

✓ The retrievals of many geophysical parameters from microwave radiometry pay emphasis on the effect of soil moisture, snow cover and vegetation by quantitative methods, while the effect of the atmosphere (PWV, cloudy-CLW) is generally assumed to be ignored, especially in the low frequency (< 40GHz).

✓ The brightness temperature observed by Satellite at TOA is a function of frequency, the water vapor content, liquid water (cloud), oxygen, hydrometers, atmospheric temperature and underlying surface parameters.
  • Atmosphere absorption and scattering to microwave spectrum
  • With frequency increasing, the atmospheric contribution to the signal of sensor becomes more important.
AMSRE and MODIS/Aqua correction even clear sky-conditions much

Atmosphere influences the low brightness temperature much

By Yubao Qiu, 2008
other findings

Many researchers have mentioned that the atmospheric impact on microwave spectrum is an undeniable factor in microwave propagation.

Simulation work Yubao Qiu, 2007, Taiwan

Simulation work Sodankylä, Finland - subarctic-winter with HUT-SNOW model with clear-sky condition (no cloud or precipitation)

Simulation work 2008 (Amstrong, 2004)
Motivation

The motivation is to **improve the surface presentations.**

Based on what mentioned above, try to understand that:

- How the effective (**intrinsic**) instantaneous surface emissivity (polarization difference, frequency / time dependency under difference surface types) relationship.

To do...

- ... to do the atmospheric correction..., then try to improve the surface parameters retrieval...
- ... to upgrade the NWP models... improve understanding of the surface emissivity, especially over land - i.e. to assimilation...

Also need to study the **intrinsic emissivity** in a “effective” pixel (mixture) instead of the model description (theoretical).
Fundament – derive from the radiative transfer model directly

\[ e_{s,p}(\nu, \theta) = \frac{T_{bp}(\nu, \theta) - T_{atm}^{\uparrow}(\nu, \theta) - T_{CB} \cdot \Gamma^2(\nu, \theta)}{T_s \cdot \Gamma(\nu, \theta) - T_{atm}^{\downarrow}(\nu, \theta) \cdot \Gamma(\nu, \theta) - T_{CB} \cdot \Gamma^2(\nu, \theta)} \]

\( e_{s,p}(\nu, \theta) \) can be readily estimated from above equation, with inputs from AMSR-E measured \( T_{bp}(\nu, \theta) \) and MODIS-derived \( T_s \) and atmosphere parameters.

- The atmosphere correction under clear-sky condition – using the MODIS Atmosphere parameters (the atmosphere 20 layered profiles)
- and can provide the instantaneous emissivities result under clear-sky condition at 6.9Ghz ~ 89.0Ghz.

The former work can be traced via Prigent C. and Karbou, F.’s work.
Emissivity Estimation

Estimation scheme - operational

Atmosphere radiative transfer (reverse) - *Eddington-based* (Kummerow, 1993, Olson, 2001) - 1-D Atm. Mod. - clear-sky

1. AMSR-E L2A - brightness temperature
2. MODIS LST, mask out the cloudy and rainy pixels
3. atmosphere parameters from *MODIS*

Ancillary input:

4. Water body - mask out the inland water body and ocean >80%
5. Gtopo30 *DEM* - consider the atmosphere thickness

- AMSR-E L2A
- Clear-Sky MYD07_L2/Atm.
- Clear-Sky MYD11_L2/LST
- EASE-GRID Projection
- GTOPO30 +Water body
- Emissivity Radiative Transfer Calculation

Operational scheme for the emissivity calculation
Result Quick View

Land surface Emissivity over clear sky condition for the Day of 2006-7-26

18.7V
Ascending orbit

Cloud cover... influence the coverage

18.7V
Descending orbit
These emissivity maps show the expected spatial structure with different surface types.

Small open water (lakes, rivers) exhibits low emissivities with high polarization differences. The major river systems (Amazon, Yangtze and Yellow River) and their associated wetlands and river branches appear clearly on the maps.

Sample: 12~25/08/2006
36.5GHz average for half a month, V-pol
In the coastal areas where an AMSR-E pixel include ocean area may display low 's associated with high polarization Areas - Desert or Snow, Ice - show a large difference.

The Emissivity in V-pol is bigger than that in H-pol., which agrees with the model description.
Instantaneous emissivity histogram

Average emissivity histogram for half a month

MODIS-based result
A Statistic of Minimum, Maximum and Mean Microwave Surface Emissivity with The Abnormal Value Percentage from Instantaneous and Average Emissivity. A is Average Result for Half a Month, B is the Instantaneous Result for 12-08-2006 (Ascending)

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>&gt;1.0 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>6.9V</td>
<td>0.5475</td>
<td>0.5632</td>
<td>1.2133</td>
<td>1.1501</td>
</tr>
<tr>
<td>6.9H</td>
<td>0.2681</td>
<td>0.2801</td>
<td>1.3692</td>
<td>1.1532</td>
</tr>
<tr>
<td>10.7V</td>
<td>0.5746</td>
<td>0.5770</td>
<td>1.2074</td>
<td>1.1257</td>
</tr>
<tr>
<td>10.7H</td>
<td>0.0008</td>
<td>-0.2356</td>
<td>1.2492</td>
<td>1.1097</td>
</tr>
<tr>
<td>18.7V</td>
<td>0.6371</td>
<td>0.6351</td>
<td>1.1352</td>
<td>1.1084</td>
</tr>
<tr>
<td>18.7H</td>
<td>0.3574</td>
<td>0.3784</td>
<td>1.1330</td>
<td>1.0822</td>
</tr>
<tr>
<td>23.8V</td>
<td>0.6514</td>
<td>0.6559</td>
<td>1.1336</td>
<td>1.1102</td>
</tr>
<tr>
<td>23.8H</td>
<td>0.4410</td>
<td>0.4503</td>
<td>1.1287</td>
<td>1.0885</td>
</tr>
<tr>
<td>36.5V</td>
<td>0.6651</td>
<td>0.6638</td>
<td>1.1143</td>
<td>1.1078</td>
</tr>
<tr>
<td>36.5H</td>
<td>0.4350</td>
<td>0.4180</td>
<td>1.1061</td>
<td>1.0827</td>
</tr>
<tr>
<td>89.0V</td>
<td>0.6597</td>
<td>0.6312</td>
<td>1.1214</td>
<td>1.1194</td>
</tr>
<tr>
<td>89.0H</td>
<td>0.5928</td>
<td>0.5865</td>
<td>1.1168</td>
<td>1.1052</td>
</tr>
</tbody>
</table>
A close examination of the emissivity maps, particularly over the continental USA, reveals that areas with emissivity > 1.0 are closely associated with the AMSR-E RFI index map. This helps explain higher percentages of emissivity > 1.0 at lower frequencies.

Comparison between the abnormal Emissivity (6.9 GHz V-pol) and RFI index map.
Fatima (2005)

ISCCP LST
ECWMF
AMSR-E

RTTOV Radiative Transfer Equation

Comparison with other result in different method, but the same time-span

It shows the same pattern.

http://www.cnrm.meteo.fr/gmap/mwemis/mwemis.html
## Comparison

Statistical Characters of Global Emissivities on V-pol, **M** Denotes the MODIS-based Results and F.K. is Fatima Karbou’s Result.

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>25th%</th>
<th>75th%</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9 V</td>
<td>M</td>
<td>0.9365</td>
<td>0.9511</td>
<td>0.0581</td>
<td>0.9322</td>
</tr>
<tr>
<td></td>
<td>F.K.</td>
<td>0.9336</td>
<td>0.9480</td>
<td>0.0449</td>
<td>0.9221</td>
</tr>
<tr>
<td>10.7V</td>
<td>M</td>
<td>0.9346</td>
<td>0.9495</td>
<td>0.0554</td>
<td>0.9311</td>
</tr>
<tr>
<td></td>
<td>F.K.</td>
<td>0.9294</td>
<td>0.9425</td>
<td>0.0405</td>
<td>0.9175</td>
</tr>
<tr>
<td>18.7V</td>
<td>M</td>
<td>0.9418</td>
<td>0.9564</td>
<td>0.0488</td>
<td>0.9380</td>
</tr>
<tr>
<td></td>
<td>F.K.</td>
<td>0.9387</td>
<td>0.9518</td>
<td>0.0415</td>
<td>0.9284</td>
</tr>
<tr>
<td>23.8V</td>
<td>M</td>
<td>0.9450</td>
<td>0.9567</td>
<td><strong>0.2167</strong></td>
<td>0.9407</td>
</tr>
<tr>
<td></td>
<td>F.K.</td>
<td>0.9320</td>
<td>0.9437</td>
<td>0.0410</td>
<td>0.9212</td>
</tr>
<tr>
<td>36.5V</td>
<td>M</td>
<td>0.9379</td>
<td>0.9502</td>
<td>0.0417</td>
<td>0.9345</td>
</tr>
<tr>
<td></td>
<td>F.K.</td>
<td>0.9222</td>
<td>0.9340</td>
<td>0.0423</td>
<td>0.9141</td>
</tr>
<tr>
<td>89.0V</td>
<td>M</td>
<td>0.9540</td>
<td>0.9638</td>
<td>0.0341</td>
<td>0.9504</td>
</tr>
</tbody>
</table>

Quite Consistency. F.K.’s is a little bit smaller than that of M’s, the difference is no more than 0.02, mostly.
## MODIS-IGBP-Based IGBP classification index

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>INDEX</th>
<th>COLOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Majority Land Cover Type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>water</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>evergreen needle leaf forests</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>evergreen broadleaf forests</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>deciduous needle leaf forests</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>deciduous broadleaf forests</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>mixed forests</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>closed shrublands</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>open shrublands</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>woody savannas</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>savannas</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>grasslands</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>permanent wetlands</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>croplands</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>urban and built-up</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>cropland/natural vegetation mosaic</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>snow and ice</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>barren or sparsely vegetated</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>
Comparison - over different Freq. and Land covers

MODIS-based Work

Fatima Karbou's result

Comparison – over different Freq. and Land covers

Wet-land

Snow-Ice

Emissivity vs. Frequency (GHz)

Emissivity vs. Land cover classification

Fatima Karbou's result

Wet-land

Snow-Ice

Emissivity vs. Frequency (GHz)

Emissivity vs. Land cover classification

Fatima Karbou's result

Wet-land

Snow-Ice

Emissivity vs. Frequency (GHz)

Emissivity vs. Land cover classification

Fatima Karbou's result

Wet-land

Snow-Ice

Emissivity vs. Frequency (GHz)

Emissivity vs. Land cover classification
Time Series Analysis - half a year for summer and winter time

- 3 months for summer time and 3 months for the winter time (in the year of 2003~2004)

![Graph showing average emissivity (V-Pol) for evergreen needle leaf forests with data points for summer and winter time. The graph includes data points for various dates between 2003 and 2004.]
Time Series Analysis - half a year for summer and winter time

- 3 months for summer time and 3 month for the winter time (in the year of 2003~2004)

Deciduous needle leaf forests

Average Emissivity V-Pol

the pure pixels (100% cover by single land cover)
Time Series Analysis - half a year for summer and winter time

- 3 months for summer time and 3 month for the winter time (in the year of 2003~2004)

Open shrub

Average Emissivity V-Pol
the pure pixels (100% cover by single land cover)
Time Series Analysis - half a year for summer and winter time

- 3 months for summer time and 3 month for the winter time (in the year of 2003~2004)

Thaw/Refrozen

Snow and Ice

Average Emissivity V-Pol

the pure pixels (100% cover by single land cover)
A preliminary summary

- Summer is stable, while in winter time, the snow or frozen phenomena drivers the emissivity viability (most pixels over the northern hemisphere).

- While over snow/ice, reversely..., because of the Thaw/Refrozen process...in summer time, and winter time has a increasing snow or ice trend...

- The emissivity is increasing as the frequency increasing. Some of them fit well with the model result, but there are also some discrepancy, this should be more work...
Frequency Dependency Analysis over different land cover

Average Emissivity Dependency over different land cover

- Evergreen needleleaf forests
  - Sample number: 653
- Evergreen broadleaf forests
  - Sample number: 2431
- Deciduous needleleaf forests
  - Sample number: 232
- Deciduous broadleaf forests
  - Sample number: 6
- Mixed forests
  - Sample number: 273
- Closed shrublands
  - Sample number: 7
Frequency Dependency Analysis over different land cover

Average Emissivity Dependency over different land cover

- Open shrublands
- Woody savannas
- Savannas
- Grasslands
- Permanent wetlands
- Croplands
Frequency Dependency Analysis over different land cover

Average Emissivity Dependency over different land cover

2. The emissivity at 19.0GHz are higher than the that of its sideward Frequencies.
   ...Unstable behalves...
Frequency Dependency Analysis over different land cover

- Instantaneous Emissivity Dependency over different land cover

Quite OK
Frequency Dependency Analysis over different land cover

- Instantaneous Emissivity Dependency over different land cover

Quite OK

![Graphs showing frequency dependency analysis over different land cover types.](image-url)
Frequency Dependency Analysis over different land cover

- Instantaneous Emissivity Dependency over different land cover

Show the same result with the average

Some of them are quite well with the common knowledge

The PDs are in same trend.
Discrepancy? - bare soil

Mean emissivity for the F.K.'s result

Estimation result
Discrepancy?

Mean emissivity of MODIS-based work

Estimation result

2nd Workshop on Modeling of Surface Properties
9-11 June 2009, Toulouse, France

Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Mixed Forest
Open Shrubland
Woody Savannas
Grasslands
Croplands
Barren or Sparsely Vegetated

H-Pol

V-Pol
Discrepancy?

Theory result

H-pol

H-Pol is ok, but the V-Pol has a Discrepancy, but the MODIS-based and F.K. are the same trend.

Simulation result
Another concern is the global instantaneous emissivity: How the emissivities could be estimated from the cloudy sky.

\[
\text{MPDI} = \frac{(T_{bv} - T_{bh})}{(T_{bv} + T_{bh})}
\]

\[
\text{MPDI} = \frac{(e_v - e_h)}{(e_v + e_h + g)}
\]

\[
g = \frac{2(T\uparrow + T\downarrow \cdot \Gamma)}{(T_s - T\downarrow \cdot \Gamma)}
\]

Assume: \( T_s = T_a \) and \( T\uparrow = T\downarrow = T_a \cdot (1 - \Gamma) \)
Atmosphere influence to MPDI

At low frequencies, MPDI is decided almost by the emissivity, with little atmosphere influence.
We get...from experiment result

Avoid the influence from surface temperature and atmosphere effective temperature, we get:

$$MPDI = \frac{(e_v - e_h)}{(e_v + e_h + 1/\Gamma - 1)}$$
We get... from experiment result

MPDI based H-pol emissivity prediction over different land cover
Grassland, sample 505  
Cropland, sample 107

\[
e_h = B_0 + B_1 \cdot \frac{PR}{MPDI_{6.9}} + B_2 \cdot \frac{PR}{MPDI_{10.7}} + B_3 \cdot \frac{PR}{MPDI_{18.7}}
\]
Estimation of 18.7GHz and 10.7GHz

Grasslands Sample number = 505
- RMSE = 0.0141
- R = 0.95721
- Frequency: 10.7GHz

Croplands Sample number = 157
- RMSE = 0.00874
- R = 0.99608
- Frequency: 10.7GHz
A try to global estimation for 10.7GHz and 18.7GHz
Statistical analysis – evaluation for 10.7GHz

Prediction result globally  All clear sky – calculated directly

Histogram difference between instantaneous emissivity and average
Statistical analysis – evaluation for 18.7Gz

Prediction result globally

All clear sky – calculated directly

Histogram difference between instantaneous emissivity and average
Conclusion

We have got the instantaneous emissivity daily and through comparison evaluation, it shows,

- The average result agree well with the previous result
- The long time series result express meaningful indicator of surface evolution
- And appear some disagreement with the theory result, show discrepancy.

A emissivity prediction method has been provide via the relationship between the MPDI and H-pol emissivity

- The statistical evaluation seems that the result is relatively good.
- These result could be used to do the atmosphere correction for parameters over land, to support the atmosphere retrieval.

More detailed sensitivity analysis work of different input parameters should be conducted in the near future

- Validation? Comparison?
End

Thank you very much!

Any questions?