Land Surface Thermal-IR Emissivity Modeling

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JCSDA 6th Workshop on Satellite Data Assimilation
June 10-11, 2008
Land surface thermal infrared emissivity $\varepsilon$ is a critical variable in surface longwave radiation budget.

However, it has been treated very approximately by various operational models.
Noah LSM sets $\varepsilon = 1$ for all land surfaces except for snow.

ECMWF model sets $\varepsilon$ as a constant.

Radiative Transfer for TOVS sets $\varepsilon = 0.98$ for all land surfaces, and $\varepsilon = 0.99$ for sea ice.

Actually, emissivity have a very large spatial variation. It may be as low as 0.7-0.8, which will results in 10% error in surface longwave radiation budget (Jin and Liang, J. Climate, 2006).
MODIS monthly emissivity
(June 2002, version 5)
Our overall objectives

- Develop a high-resolution emissivity database from multiple satellite sensors (e.g., MODIS, ASTER) using a data fusion approach.
- Establish the empirical relations between emissivity and various land surface biogeophysical variables.
- Assess, calibrate and improve existing radiative transfer emissivity models.
Accuracy of MODIS emissivity
Evaluation of emissivity

- It is the first step to evaluate the accuracy of the current available emissivity retrievals before data fusion.
- However, *in-situ* land surface emissivity measurements are not available.
- Land surface longwave radiation including information on land surface temperature (LST) and emissivity can be used to evaluate satellite emissivity retrievals.
Relationship longwave radiation and emissivity can be written as (Wang et al., JGR, 2005, Liang, 2004):

\[ T_s = \left( \frac{L_\uparrow - (1 - \varepsilon_b) \cdot L_\downarrow}{\varepsilon_b \cdot \sigma} \right)^{1/4} \]

\[ L_\uparrow = \varepsilon_b \cdot \sigma \cdot T_s^4 + (1 - \varepsilon_b) \cdot L_\downarrow \]

Broad band emissivity \( \varepsilon_b \) can be estimate from MODIS narrowband retrievals in thermal-IR region (Wang et al., J.G. R., 2005):

\[ \varepsilon_b = 0.2122 \cdot \varepsilon_{29} + 0.3859 \cdot \varepsilon_{31} + 0.4029 \cdot \varepsilon_{32} \]
Method

- First, estimate broadband emissivity from satellite narrowband retrievals (MODIS day/night LST algorithm).
- Second, estimate LST from longwave radiation measurements.
- Third, compare LST from ground-based measurements and satellite retrievals from independent algorithm (split-window algorithm).
- Studies have shown that there is no bias in the MODIS LST from split-window algorithm. We can infer: If the ground-based LST is larger, it seems that the emissivity is underestimated, and vice versa.
Validation MODIS version 4 LST at FLUXNET sites (Wang et al., RSE, 2008)

Fort Peck
Bias: -2.19
RMSE: 2.51
Slope: 0.97

Hainich
Bias: -2.21
RMSE: 2.51
Slope: 0.96

Tharandt
Bias: -3.23
RMSE: 3.44
Slope: 0.98

Bondville
Bias: -3.09
RMSE: 3.41
Slope: 0.99
Validation of $L^\uparrow$ from MODIS version 4 emissivity at SURFRAD sites
Validation of $L_\uparrow$ from MODIS version 4 emissivity at SURFRAD sites (Wang et al., TGRS, 2008, in press)
Validation of Emissivity at Tibetan Plateau
(Wang et al., Int. J. Remote Sens., 2007)
Validation of version 4 emissivity at Tibetan Plateau
(Wang et al., Int. J. Remote Sens., 2007)

MODIS band 29

MODIS band 31

MODIS band 32
MODIS emissivity improvement
(version 5, Wang et al., Int. J. Remote Sens., 2007; Wan, RSE, 2008)
Comparison of MODIS version 4 and 5 broadband emissivity at
SURFRAD sites  (Wang and Liang, RSE, 2008, under review)

Bondville

Boulder
Comparison of MODIS version 4 and 5 broadband emissivity at SURFRAD sites (Wang and Liang, RSE, 2008, under review)

Desert Rock

Fort Peck
Comparison of MODIS version 4 and 5 broadband emissivity at SURFRAD sites (Wang and Liang, RSE, 2008, under review)
Relationship longwave radiation and emissivity can be written as (Wang et al., J.G. R., 2005, Liang, 2004):

\[
T_s = \left[ \frac{L_{\uparrow} - (1 - \varepsilon_b) \cdot L_{\downarrow}}{\varepsilon_b \cdot \sigma} \right]^{\frac{1}{4}} \quad \text{and} \quad L_{\uparrow} = \varepsilon_b \cdot \sigma \cdot T_s^4 + (1 - \varepsilon_b) \cdot L_{\downarrow}
\]

Broad band emissivity \( \varepsilon_b \) can be estimate from MODIS narrowband retrievals in thermal-IR region (Wang et al., J.G.R., 2005):

\[
\varepsilon_b = 0.2122 \cdot \varepsilon_{29} + 0.3859 \cdot \varepsilon_{31} + 0.4029 \cdot \varepsilon_{32}
\]
Comparison of LST calculated from MODIS version 5 emissivity and LST from split-window algorithm at SURFRAD sites (Wang and Liang, RSE., 2008, under review)

Averaged bias over the six sites is about 0.2 K
Accuracy of ASTER emissivity
Comparison of MODIS and ASTER broadband emissivity at SURFRAD sites (Wang and Liang, 2008, under review)
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Summary

- Longwave radiation is helpful to evaluate satellite emissivity products.
- MODIS version 5 emissivity corrects the underestimations of MODIS version 4 for vegetated surfaces.
- ASTER product tends to underestimate emissivity, especially for summer time.
Accomplishments in first year

- Downloading satellite emissivity products from multiple sensors, such as MODIS, ASTER, SEVIRI, AIRS, etc.
- Developing data fusion algorithms to integrate multiple emissivity products.
- Developing a consistent parametric emissivity modeling scheme for different land cover types.
Future plan

- Processing and analyzing different emissivity products and developing an integrated land surface emissivity database;
- Continuing to develop the emissivity models
Reference (1)


Thank You!