Radiation transfer modeling and land surface parameter inversion from multi source remote sensing data

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Brief introduction of SKLRSS and IRSA

1. Research Background

2. Recent advances on radiation transfer modeling

3. Land surface parameters inversion based on multi-source remote sensing data

4. Multi-scale field experiment system design

5. Product generation Software system development

6. Discussion
0. Brief introduction of SKLRSS and IRSA

- IRSA: Institute of Remote Sensing Applications, Chinese Academy of Sciences
- SKLRSS: State Key Laboratory of Remote Sensing Science
- Division of Remote Sensing Radiation Transfer Modeling and Inversion
(1) IRSA Milestone

1979 **IRSA established:** There are 4 academicians, 58 senior researchers, 200+ staffs, 167+ contractors, 200+ PhD students and post doctors, 100+ MS students

- **1986** Airborne Remote Sensing Centre established
- **1994** Laboratory of Remote Sensing Information Science
- **1997** National Engineering Research Center for Geoinformatics
- **2003** National Demonstration Center for Spaceborne Remote Sensing / National Space Administration
- **2004** State Key Lab of Remote Sensing Science
**IRSA Organization Structure**

- **research units:**
  - Remote Sensing Radiation Transfer Modeling and inversion
  - Environmental Remote Sensing application technology
  - Hyperspectral Remote Sensing
  - Microwave Remote Sensing
  - Remote Sensing Calibration and Validation
  - Remote Sensing Image processing
  - Agriculture and Ecological Remote Sensing
  - Disaster and Emergency Remote Sensing
  - Land Resource Remote Sensing
  - Non-Renewable Remote Sensing
  - Spatial Information System
  - Digital Earth and Navigation Positioning
  - Environment Protection Remote Sensing
(2) Brief Introduction of SLRSS

- **1994**, Key Laboratory of Remote Sensing Information Science, Institute of Remote Sensing Applications, Chinese Academy of Sciences
- **1999**, Centre for Remote Sensing, Beijing Normal University
- **2003**, State Key Laboratory of Remote Sensing Science was approved to be jointly established.
53 fixed researchers, including 46 researchers (28 professors and 9 associate professors) and 7 staff members.

Among adjunct members, there are 7 visiting professors, 8 associate professors, 18 lecturers and 27 post-doctors.
State Key Laboratory of Remote Sensing Science

Sensor

Platform

Basic Theory: EM radiation transfer

Information extraction

Parameter inversion

Earth Science

Water Cycle

Radiation

CO2, Ecosystem

Applications
Radiative transfer mechanism and inversion theory

- improve radiative transfer models in RS
- integrate multi-scale remote sensing models
- synergistic inversion of multi-sensor data
- assimilate multi-scale data and land surface process models.
Technologies for RS data acquisition and processing

- remote sensing detection, data processing and information extraction techniques
- such as multiangle, polarization, full polarization multi-band microwave, hyper-spectral, LIDAR, high spatial resolution imaging, and wireless sensor networks.
Geospatial information integration and applications

- communication networks, integration and information services, simulation and visualization
- monitoring & simulation platforms for land surface radiation, energy balance studies and key element cycle (Carbon, Water,…).
- conduct exemplary applications of agriculture, resources, disaster, environment and health
Research Areas

- Remote sensing experiment
- Information integration, Visualization
- Radiation Transfer Modeling
  - NIR/NIR
  - TIR
  - Micro W

- Parameter inversion
  - Albedo
  - LST
  - LAI
  - Moisture
  - Aerosol

- Remote sensing Application
  - Wet Land Map
  - Atlantic map
  - Crop Monitor
  - Disaster Mon.
  - Environmental
  - Earth System

Wireless Network Technology

Earth System Radiation Transfer Modeling
Parameter inversion
Remote sensing Application
Information integration, Visualization
Remote sensing experiment
1. Research Background
2. Recent advances on radiation transfer modeling
3. Land surface parameters inversion based on multi-source remote sensing data
4. Multi-scale field experiment system design and field experiment campaign
5. Software system development and product generation
6. Discussion
Research Background

Earth system

- Hydrosystem, Water cycle
- Radiation balance
- Ecosystem C cycle

Atmosphere

- Ice, Snow

Biosphere

- hydrosphere
- lithosphere
Control effects for global system

Churkina & Running, 1998
Radiation and energy balance

Key parameters:
- Atmospheric optical depth
- Solar Radiation
- Albedo
- Land surface temperature
- Emissivity
- Latent Heat Flux
- Sensible Heat Flux
- Classification
- Leaf Area Index
- Soil Moisture
Land surface process model scale issues

Land surface process model need different spatial scale observation: 1KM, 5KM, 10KM, 100KM

Vegetation Maps from Satellite Images at three resolutions
Traditional observation system

1. Ground observation station: sparsely distributed
2. Ground station observation doesn’t agree with model scales
3. Remote sensing can provide spatially distribution information

Soil moisture at 25 km x 25 km
New observation system wanted

Remote sensing + ground station observation
EM radiation transfer modeling and inversion

\[ L = f(\lambda, s_{x,y,z}, t, \theta, P, \Omega) \]

- \( \lambda \): WaveLength
- \( s_{x,y,z} \): Location
- \( t \): Time
- \( \theta \): ViewAngle
- \( P \): LandParameter
- \( \Omega \): SensorParameter

Units: m

- Ultraviolet: \( 0.01 \times 10^{-6} \)
- VIS: \( 0.4 \times 10^{-6} \)
- NIR: \( 0.7 \times 10^{-6} \)
- MIR: \( 10^{-6} \)
- TIR: \( 10^{-5} \)
- MIC W: \( 10^{-4} \)
- THz: \( 10^{-3} \)
- NIR: \( 10^{-2} \)
- Unit: m
2. Recent advances on radiation transfer modeling

- The angular effect and scaling effect of remote sensing data due to the earth surface heterogeneity and 3-D structure;
- The Bi-directional reflectance Distribution Function modelling and Thermal emission directionality modelling are the basic issues for quantitative remote sensing.

(1) Basic Principle

(2) Recent Advances
Radiance $L$

Radiation Flux at unit area, unit wavelength, unit solid angle:

$$L = \frac{\partial^3 \Phi}{\partial A \partial \lambda \partial \Omega}$$

($W/m^2 \cdot \mu m \cdot Sr$)
Bi-directional Reflectance Distribution Function (BRDF)

\[ f = \frac{dL(\theta, \varphi, \lambda)}{dE(\theta_0, \varphi_0, \lambda)} \]
Multi-scales of remote sensing radiation transfer

Vegetation canopy: 3D structure

Leaf: Component Spectrum

Mixed pixel, terrain effect

Urban

Forest

crop

road

soil

Image: earth surface—atmosphere—sensor
Recent advances:

1. d-Prospect model for leaf spectrum
2. Radiosity-Graphic combined model on large scale (LRGM)
3. TIR emission directionality modeling
4. Topographic effect modeling
5. Remote Sensing Image simulation system
Leaf Spectrum Model:

- Flat layer models: PROSPECT (Jacquemoud and Baret, 1990)
- Needle leaf models: LIBERTY (Dawson, et. al., 1998)
- Ray tracing model
- Stochastic model
- Hybrid medium model

PROSPECT model is one of the most popular leaf spectrum models.
① d-Prospect model for leaf spectrum

A Model to Simulate Optical Properties Spectra of Double Leaf Surfaces

Experiment Measurement results:
The both side reflectance of crop leaves are not equal as the prospect model predicted.

Thus the assumption that leaf upper and lower surfaces have the same reflectance is not always true, especially for some dicotyledonous leaves.
A typical dicotyledonous leaf has an obvious layer structure. It includes four layers of upper epidermis, palisade mesophyll, spongy mesophyll, and lower epidermis. The water, chlorophyll and pigment features distribute in the palisade mesophyll and spongy mesophyll.

The distribution of chlorophyll and leaf water can not be well-proportioned within the leaf structure of dicotyledonous leaf.
Asymmetric Biochemical material distribution  

\[
\rho^+ = \rho_1 + \frac{\tau_1^2 \rho_2}{1 - \rho_1 \rho_2}
\]

\[
\tau^+ = \frac{\tau_1 \tau_2}{1 - \rho_1 \rho_2}
\]

Optic property asymmetry

\[
\rho^- = \rho_2 + \frac{\tau_2^2 \rho_1}{1 - \rho_1 \rho_2}
\]

\[
\tau^- = \frac{\tau_1 \tau_2}{1 - \rho_1 \rho_2}
\]

Up and bottom side reflectance are equal?

Analyze with plat model

It is found out that the biochemical material asymmetric distribution cause to Up and bottom side reflectance are equal
**PROSPECT**

- $\rho_\alpha, T_\alpha$
- $R_{N-1,90}, T_{N-1,90}$

**dPROSPECT**

- $\rho_1, T_1$
- $\rho_2, T_2$
- $N-1 L$

**Chlorophyll asymmetric distribution ratio**

$$k_1(\lambda) = (K_{C_{ab}}(\lambda) * (1 + W_{C_{ab}})) * Cab + K_{C_{w}}(\lambda) * (1 + W_{C_{w}}) * C_{w} + \sum K_i(\lambda) / 2 * N + k_e(\lambda)$$

$$k_2(\lambda) = (K_{C_{ab}}(\lambda) * (1 - W_{C_{ab}})) * Cab + K_{C_{w}}(\lambda) * (1 - W_{C_{w}}) * C_{w} + \sum K_i(\lambda) / 2 * N + k_e(\lambda)$$

Leaf up surface reflectance $\rho^+$, and bottom surface reflectance $\rho^-$

Jing Li, Qinhuo Liu, and Qiang Liu, D-PROSPECT: A Model to Simulate Optical Properties Spectra of Double Leaf Surfaces
SAIL model to SAILE model

Replace $\rho^+, \rho^-$ in Sail Model, new scattering coefficients are deduced

$=>$ SAILE
Brief summery

Double $N$-layer structure assumption is suggested here, different from the assumption of a pile of $N$ homogeneous layers in PROSPECT model. Two new parameters, $W_{ab}$ and $W_w$ are introduced to represent the vertical distribution fraction of leaf chlorophyll and water contents. The sensitivity analysis proves that D-PROSPECT model has the capability to simulate the spectra reflectance of both leaf sides fitted with the experiment results well.
Vegetation Canopy BRDF models:

- **Physical models**
  - Radiation transfer models: SAIL model (Verhoef, 1984, …)
  - Geometrical Optical models: Li-Strahler GO model (Li, et al., 1986)
  - Hybrid Models: GORT (Li, et al., 1995)、5 Scale model (J.M. Chen)
  - Computer simulation models: MC model, RGM

- **Statistical (empirical) models**: Walthall (Walthall, et al., 1985)
The radiosity-graphics model (RGM) is an important branch of computer simulation modelling for the vegetation BRDF;

As the radiosity method is based on a global solving technique, the RGM can only deal with limited numbers of polygons, and has only been used for small-scale flat terrain scenes.

However, the land surface is generally rugged, so it is necessary to extend the RGM to simulate the remote sensing pixel leaving radiance of the vegetation canopy at a large scale with complex topography.
We have developed a new methodology (Huaguo HUANG, Min CHEN, Qinhuo LIU, et. al., IJRS V. 30, No. 20, 2009, 5421–5439):

(1) virtual forest scene generation combined with a digital elevation model;

(2) scene division method, shadowing effect correction and multiple scattering calculation;

(3) merging the simulated sub-scene bidirectional reflectance factors (BRFs) to get the whole-scene BRF.

(4) We have compared this new method with other models by choosing a large-scale conifer forest scene with a GAUSS terrain from RAMI3 (http://rami-benchmark.jrc.it).

(5) Multi-angle imaging spectroradiometer (MISR) data are used to validate the extended RGM in a Picea crassifolia forest area at a satellite pixel scale in the field campaign in Gansu Province, China.
Spruce forest: (a) sample plot (white cross points) in an MISR pixel (white square box), (b) aerial photos of the spruce trees, (c) real trees, (d) virtual trees, (e) real-tree, (f) simplified virtual tree and (g) virtual branches and needles.
Model validation using multi-angle imaging spectroradiometer (MISR) data

\[
\text{RMSE} = 0.018 \\
R^2 = 0.98
\]
Conifer forest scenes: (a) from RAMI-3; (b) our simulated large forest scene; (c) The subdivision strategy for the whole forest scene; there are 36 sub-scenes, each (187.5m × 187.5m) contains nine boxes with around 1400 trees in it; (d) a sample sub-scene and a single cone tree with leaf scatterers in it.
BRF comparisons between our extended RGM and other 3D radiative transfer models in RAM3

(a) the red band; (b) the NIR band.
A sub-scene division algorithm based on RGM (Qin et al. 2000) as well as a method to generate large-scale virtual forest scenes is developed to simulate forest radiosity for large-scale forests under complex topographic conditions. The extended RGM sub-divides the whole forest landscapes into several smaller scenes, which can overcome the limitation of the maximum polygon number found in the original version of RGM.
Remote sensing Land surface temperature

- Instantaneous observation with continuous variation
- Directional effect (depends on view angle)
- Uncertainty (LST+Emissivity: ill-posed inversion problem)

Difficulties of TIR experiment

- Temporal scale effect (observation time)
- Heterogeneous surface (view field)
- Spatial scale different with satellite
TIR emission directionality observations

The vegetation TIR emission directionality is significant that have been observed by lots of field experiments (Fuchs et al. 1967).

- Bare soil (Lagouarde, 1995)
- Grassland (Chehbouni et al. 2001)
- Sunflower (Paw U, 1989)
- Cotton (Kimes et al. 1980; Kustas, 1990)
- Corn (Lagouarde et al. 1995)
- Winter wheat (Qinhuo Liu, 2001)
- Soybean (Fuchs et al. 1967, Nielsen, 1984)
- Needle leaf forest (Balick et al. 1986, Lagouarde, 2000)
- Broad leaf forest (McGuire, 1989)
- Urban surface (Lagouarde et al. 2004)

The observed directional brightness temperature can vary up to 10K depending on the view angle.
Directional measurement system is designed to observe the TIR emission directionality

- Coniometer system
- Computer control system
- ASD Spectrum Radiometer, Thermal Infrared Camera
- Date processing
Directional Brightness temperature distribution

“Hot Spot” Center varies as solar view angle
a. Soil-leaf-Ear canopy model (SLEC) for Thermal Emission Directionality

Experiment results:

• the sunlit and shaded ear have more than 3K temperature differences
• The directional emission brightness temperature of wheat canopy at tasseling stage can be more than 3-5K;
SLEC DBT model development:
How to calculate the view factor of ear;
How to calculate the thermal radiation from ear, leaf and soil layers and the coupling effects;
How to express the directional emission characteristics of wheat canopy at tasseling stage.

RGM to TRGM

- Expand RGM to TRGM by adding the thermal emission term in the model;
- Describe the relationship of DBT with the canopy structure, component temperature and emissivity;
- To calculate the multi-scattering effect to Thermal emission directionality;
- Coupling the TRGM and CUPID model to analyze the thermal emission directionality variation with the meteorological condition at different spatial and temporal scale, et.

RGM (Qin, 2000) to TRGM (Liu, 2007)

( Radiosity + Computer Graphics )

Multi-scattering

BRF (Visual/NIR)

Thermal Emission

Multi-scattering

new

DBT calculation

Directional Brightness temperature Distribution
TRGM model

Model simulation

measurement
Remote sensing radiation model for flat surface may have a significant error on radiation calculation, up to 900 W m$^{-2}$ when used at mountains area (Hansen et al. 2002).

There are about 2/3 land of China is mountains area.
Topographic effects at mountains areas due to: elevation, pixel slope, in pixel slope;

The interaction of radiation transfer in mountains area: Atmospheric radiation, multi-scattering, shadow effects

Existing models: solar radiation cosine correction, Lambertian radiation transfer models…

Reflectance is over corrected!
BRDF model for mountains area

\[ \rho_H(\theta_s, \phi_s, \theta_v, \phi_v) = \frac{\pi(L - L_p)e^{\tau / \cos(\theta_i)}}{\Theta \left( E_s^h + E_d^h K \cos i_s \right)} \frac{\Omega(i_s, \phi_s, i_v, \phi_v)}{\Omega(\theta_s, \phi_s, \theta_v, \phi_v)} + \frac{[E_d^h (1 - K)V_d + E_d]}{2\pi} \int \int \Omega(i_s, \phi_s, i_v, \phi_v) d\Omega_{i_v} \]

- **BRDF effect**
- **H-D effect**

Solar radiation

Diffuse radiation

Neighbor effect

Atmos. correction

Radiation model

New model

Remote sensing image simulation based on radiation transfer model coupling: land surface—atmosphere—sensor
## RS Image simulation technology development

<table>
<thead>
<tr>
<th>phase</th>
<th>time</th>
<th>character</th>
<th>software</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1960s</td>
<td>Physical simulation</td>
<td>ISF, Itek, USA</td>
</tr>
<tr>
<td>2</td>
<td>1990s</td>
<td>Software: image to image simulation</td>
<td>PATCOD, LaRC</td>
</tr>
<tr>
<td>3</td>
<td>2000s</td>
<td>Simulation based on models</td>
<td>SENSOR, DIRSIG</td>
</tr>
</tbody>
</table>

Remote sensing image simulation systems are widely used in satellite remote sensing, including sensor design, system development and application demonstration:

- **NEMO, OrbView-4, EO-1**
- **WASP, MISI**
- **FIRES**
An optical remote sensing image simulation system has been developed:

Coupling the land surface radiation transfer models, atmospheric radiation transfer models, Remote sensor imaging models, and satellite orbiting models;

Ma, JW; Li, XW; et. al. IEEE TGRS 2006, Yang, GJ; Liu, QH; et. al. IJRS 2009
HJ1、CBERS03/04

- HJ-1A: CCD
- HJ-1B: CCD, IRMSS
- CBERS-03/04: Pan, Multi-spectrum, IR, WFI, MUX
Simulated images at different view angles:
3. Land surface parameters inversion based on multi-source remote sensing data

(1) Introduction to HJ-1 Constellation
(2) Parameter Inversion algorithm development
(3) Model Assimilation for Environmental monitoring
Not only in China, but also in the Asia and Pacific region or from the globe view:

Environment pollution and ecological destruction seriously affected sustainable development of economy and society: air, water, …

Natural disasters occur with great frequency, injuring or killing thousands and thousands of people and inflicting huge economic losses: earth quakes, volcano, floods, droughts, and forest fires.
The application of remote sensing technology for disaster mitigation and environment protection is urgently needed both in China and in the world.
The requirements of monitoring of environment and disaster are very complicated. Although existing satellites have played an important role in the monitoring, but they cannot meet all the requirements.

- spatial resolution
- spectral bands
- revisit interval.

Only one satellite is not able to meet all the requirements.
<table>
<thead>
<tr>
<th>Event</th>
<th>Revisit interval</th>
<th>Resolution (m)</th>
<th>Spectral bands (μm)</th>
<th>All weather need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood</td>
<td>12h~2d</td>
<td>3~100</td>
<td>0.4<del>14, 3</del>21</td>
<td>need</td>
</tr>
<tr>
<td>Drought</td>
<td>1d~20d</td>
<td>3~100</td>
<td>0.4<del>14, 3</del>21</td>
<td></td>
</tr>
<tr>
<td>Forest fire</td>
<td>6h~2d</td>
<td>3~300</td>
<td>3<del>5, 8</del>14</td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td>6h~2d</td>
<td>3~100</td>
<td>0.4<del>1.1, 10</del>12.5</td>
<td>need</td>
</tr>
<tr>
<td>Sand storm</td>
<td>12h~2d</td>
<td>3~300</td>
<td>0.4<del>2.76, 8.0</del>14.0</td>
<td></td>
</tr>
<tr>
<td>Storm tide</td>
<td>6h~2d</td>
<td>10~1000</td>
<td>0.4~1.1</td>
<td>need</td>
</tr>
<tr>
<td>Sparry flow</td>
<td>12h~2d</td>
<td>3~100</td>
<td></td>
<td>need</td>
</tr>
<tr>
<td>Bio-disaster</td>
<td>6h~10d</td>
<td>20~100</td>
<td>0.4<del>2.5, 8</del>14</td>
<td></td>
</tr>
<tr>
<td>Environment pollution</td>
<td>1d~5d</td>
<td>3~500</td>
<td>0.4<del>0.9 high spectrum resolution, 3.5</del>14</td>
<td></td>
</tr>
<tr>
<td>Environment event</td>
<td>4h~1d</td>
<td>3~100</td>
<td>0.4<del>0.9 high spectrum resolution, 3.5</del>14</td>
<td></td>
</tr>
<tr>
<td>Red tide</td>
<td>4h~5d</td>
<td>20~50</td>
<td>0.52<del>0.6, 8.0</del>14.0</td>
<td></td>
</tr>
<tr>
<td>Ecology</td>
<td>5d~60d</td>
<td>10~100</td>
<td>0.4<del>0.76, 1.55</del>1.75, 8.0~14.0</td>
<td>63</td>
</tr>
</tbody>
</table>
a. **Spatial resolution:**
Although some large-scale phenomena observation can be monitored with low resolution remote sensor, most disaster and environment monitoring need middle-high resolution remote sensing data: from 3 to 100m will be needed.

b. **Revisit interval:**
The revisit interval needed for monitoring of disaster and environment are from hours to many days: flood, earthquake, forest and grass fire, plant diseases, and insect pests and pollution accident.

c. **Large-scale:**
Natural disasters and environment pollution often occur in a very large area: the wide swath is needed for most applications.
d. **Multi-spectrum bands:**
Multi-spectrum bands with high spectral resolution are needed to sense different surface characteristics of objects. Besides optical observation, microwave remote sensing is very important as well.

e. **All weather observation:**
Many natural disasters occur under clouds and at night. Visible optical observation only is not enough for monitoring of disaster and environment. Infrared remote sensing will be used day and night and microwave sensor will be very useful for observation through clouds and at night.
The Environmental Monitoring and Disaster mitigation small satellite constellation

The first stage (baseline) includes three satellites (two optical satellites and one SAR satellites): HJ1-1A, HJ-1B was launched on Sept. 6th, 2008, HJ1-C is to be launched on 2010.

And it is expected to expand to the second stage of eight satellites (four optical satellites and four SAR satellites): international cooperation.
Payload on HJ-1

a. **Wide field multi-spectrum camera (WFC) on HJ1—a/B**
Four bands from 0.43~0.90μm. The pixel resolution is 30m, the swath is about 720km.

b. **Infrared scanner (IRS) on HJ1A**
Four IR bands (from 0.75 ~12.5μm), three with 150m resolution, and the fourth 300m (10.5μm~12.5μm). The swath is 720km.

c. **Hyper-spectrum imager (HSI) on HJ1B**
118 bands (from 0.4 ~0.9μm), 100m resolution, the swath is 50km.
<table>
<thead>
<tr>
<th>Item</th>
<th>Sub-item</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Orbit</strong></td>
<td>Type</td>
<td>Sun synchronous orbit</td>
</tr>
<tr>
<td></td>
<td>Average altitude</td>
<td>~650km</td>
</tr>
<tr>
<td></td>
<td>Local time at descending node</td>
<td>~10:45</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>Total mass</td>
<td>~450kg/460kg</td>
</tr>
<tr>
<td></td>
<td>Payloads</td>
<td>147kg/157kg</td>
</tr>
<tr>
<td><strong>Satellite body size</strong></td>
<td>Satellite body size</td>
<td>1200×1100×980mm³</td>
</tr>
<tr>
<td></td>
<td>Maximal envelope</td>
<td>Φ1900mm×1200mm</td>
</tr>
<tr>
<td><strong>WFC</strong></td>
<td>Spectral band</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Ground pixel resolution</td>
<td>30m</td>
</tr>
<tr>
<td></td>
<td>Swath width</td>
<td>720km</td>
</tr>
<tr>
<td><strong>IRS</strong></td>
<td>Number of spectral band</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Ground pixel resolution</td>
<td>150m/300m</td>
</tr>
<tr>
<td></td>
<td>Swath width</td>
<td>720km</td>
</tr>
<tr>
<td><strong>HSI</strong></td>
<td>Number of Spectral band</td>
<td>118</td>
</tr>
<tr>
<td></td>
<td>Resolution/Swath</td>
<td>100m/50KM</td>
</tr>
<tr>
<td><strong>Data transmission</strong></td>
<td>Frequency band</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Storage capacity</td>
<td>8Gbit</td>
</tr>
<tr>
<td></td>
<td>Data rate</td>
<td>~70Mbps or 57Mbps</td>
</tr>
<tr>
<td><strong>AOCS</strong></td>
<td>Three-axis stabilization</td>
<td></td>
</tr>
<tr>
<td><strong>TT&amp;C</strong></td>
<td>System</td>
<td>S-band unified system</td>
</tr>
<tr>
<td></td>
<td>orbit measurement system</td>
<td>GPS</td>
</tr>
<tr>
<td><strong>OBDH</strong></td>
<td>Solar array area</td>
<td>5.66m</td>
</tr>
<tr>
<td></td>
<td>Output power</td>
<td>BOL 618W/ EOL 554W</td>
</tr>
<tr>
<td><strong>Thermal control</strong></td>
<td>Mode</td>
<td>Passive thermal control accompanied with active</td>
</tr>
<tr>
<td></td>
<td>Inside the module</td>
<td>0~+45°C</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td></td>
<td>3 years</td>
</tr>
</tbody>
</table>
**e. Synthetic aperture radar (SAR) on HJ-1C**

### Main Payload Specification of SAR

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation mode:</td>
<td>single mode</td>
</tr>
<tr>
<td>Ground resolution:</td>
<td>30m</td>
</tr>
<tr>
<td>Imaging Width:</td>
<td>100km</td>
</tr>
<tr>
<td>Operation band:</td>
<td>S</td>
</tr>
<tr>
<td>Polarization:</td>
<td>HH or VV</td>
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<tr>
<td>Angle of incidence:</td>
<td>25°-47°</td>
</tr>
<tr>
<td>Size of antenna:</td>
<td>6m×2.8m</td>
</tr>
<tr>
<td>Bit rate:</td>
<td>280Mbps</td>
</tr>
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<td>Onboard operation time:</td>
<td>10min/orbit</td>
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</table>
Environment Application System

To establish national satellite monitoring and forecasting center and form the capacity to produce environmental remote sensing products and process all kinds of environmental data from disaster and environment monitoring satellite constellation and other satellite system.

To provide remote sensing information service, remote sensing data products and decision-making support.
Concluding Remarks

Disaster mitigation and environment protection is urgently needed in the world.

A small satellite constellation composed of optical satellites and synthetic aperture radar satellite(s) can meet the basic requirement of monitoring of disaster and environment.

Although the Baseline will be constructed by China, the international cooperation is the best way for construction and utilization of the whole constellation.
(2) Parameter Inversion algorithm development

Preprocessing
↓
Qualitative application: Classification and identification
↓
Quantitative Monitoring: Inversion
↓
Prediction : assimilation

Information extraction

Calibration correction
Geometric correction
Cloudy mask
Atmospheric correction
Product design

5 class

- atmosphere
- Radiation
- Bio-physics
- Geo-physics
- classification

19 type

- Aerosol Optical depth
- Water vapor
- Cloud
- Reflectance
- Brightness temperature
- VI, VC
- LAI
- AGB
- FPAR
- GPP, NPP
- Leaf water
- Chlorophyll
- BRDF/ALBEDO
- LST
- Emissivity
- Soil Moisture
- ET, HF
- VCI, WDI, CWSI
- Land use/Land cover

2007—2010, National Key Project of Scientific and Technical Supporting Programs(2008BAC34B03, 4.44 million Yuan) : Environmental Parameter Inversion and Assimilation using Environmental and Natural Disaster Monitoring Small Satellite Constellation and other multi-source data
① Pre-processing

calibration

Atmospheric correction

Azimuth angle

View zenith angle
② Classification for land use

1. Land cover classification
   7 classes, 23 sub-classes.

2. Ecological system classification
   6 class ecosystems

<table>
<thead>
<tr>
<th>一级类型</th>
<th>一级编码</th>
<th>二级类型</th>
<th>二级编码</th>
<th>含义</th>
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<tr>
<td>森林</td>
<td>1</td>
<td>常绿针叶林</td>
<td>11</td>
<td>郁闭度&gt;30%，高度&gt;2米的常绿针叶天然林和人工林</td>
</tr>
<tr>
<td></td>
<td></td>
<td>常绿阔叶林</td>
<td>12</td>
<td>郁闭度&gt;30%，高度&gt;2米的常绿阔叶天然林和人工林</td>
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<td></td>
<td>落叶针叶林</td>
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<td>郁闭度&gt;30%，高度&gt;2米的落叶针叶天然林和人工林</td>
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<td>落叶阔叶林</td>
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<td>针阔混交林</td>
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<td>郁闭度&gt;30%，高度&gt;2米的针阔混交天然林和人工林</td>
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<td></td>
<td></td>
<td>湿丛</td>
<td>16</td>
<td>郁闭度&gt;40%，高度&gt;2米的湿丛和矮林</td>
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<table>
<thead>
<tr>
<th>一级类型</th>
<th>编码</th>
<th>含义</th>
</tr>
</thead>
<tbody>
<tr>
<td>森林生态系统</td>
<td>1</td>
<td>森林（主要有热带雨林、常绿阔叶林、落叶阔叶林、针叶林等）生态系统分布在湿润或较湿润的地区，其主要特点是动植物种类繁多，群落的结构复杂，种群的密度和群落的结构能够长期处于较稳定的状态，尤其是热带雨林生态系统。森林中的植物以乔木为主，也有灌木和草本植物。</td>
</tr>
<tr>
<td>草原生态系统</td>
<td>2</td>
<td>草原生态系统分布在中纬度的大陆内部，半干旱、半湿润气候下的浅漠地区，面积大约占全球陆地总面积的1/5。动植物的种类比森林少，植物以多年生草本植物为主，其中以禾本科、豆科和莎草科植物占优势；</td>
</tr>
</tbody>
</table>


Change detection software development

Change detection based on the existing land use map and new remote sensing Image
③ aerosol optical depth inversion algorithm

a. MODIS aerosol optical depth （500m）
b. HJ-1 AOD algorithm supported by MODIS
a. MODIS Aerosol Optical Depth product (500m)
# MODIS AOD ACCURACY

<table>
<thead>
<tr>
<th>date</th>
<th>Beijing AERONET</th>
<th>Beijing MODIS</th>
<th>error</th>
<th>xianghe AERONET</th>
<th>xianghe MODIS</th>
<th>error</th>
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<tbody>
<tr>
<td>2006253</td>
<td>0.2015</td>
<td>0.3268</td>
<td>0.1253</td>
<td>0.2425</td>
<td>0.2292</td>
<td>0.0133</td>
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<tr>
<td>2007129</td>
<td>0.3255</td>
<td>0.4696</td>
<td><strong>0.1441</strong></td>
<td>0.3253</td>
<td>0.4039</td>
<td>0.0786</td>
</tr>
<tr>
<td>2007134</td>
<td>0.1979</td>
<td>0.2914</td>
<td>0.0935</td>
<td>0.1655</td>
<td>0.2508</td>
<td>0.0853</td>
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<tr>
<td>2007149</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.4744</td>
<td>0.6008</td>
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</tr>
<tr>
<td>2007289</td>
<td>0.1528</td>
<td>0.1928</td>
<td>0.0400</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2007305</td>
<td>0.0991</td>
<td>0.1582</td>
<td>0.0591</td>
<td>0.1515</td>
<td>0.1010</td>
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<td>2007307</td>
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<td>0.1083</td>
<td>0.0258</td>
<td>0.1448</td>
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<td>0.1722</td>
<td><strong>0.0074</strong></td>
<td>0.0949</td>
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<tr>
<td>2007330</td>
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<td>0.0238</td>
<td>0.1746</td>
<td>0.1419</td>
<td>0.0327</td>
</tr>
</tbody>
</table>

The accuracy is about 0.1.
HJ-1 CCD AOD supported by the MOD09

Reflectance (MOD09) -> projection -> MODIS Reflectance (500 m) -> inversion -> HJ-1 CCD AOD (500m)

HJ-1 CCD

Reflectance of HJ-1 CCD (500m)
HJ-1 CCD AOD of Beijing

2008.12.25

2008.12.22

2008.12.20

2008.12.18
HJ-1 CCD AOD accuracy

<table>
<thead>
<tr>
<th>AERONET</th>
<th>HJ-1 CCD</th>
<th>error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3054</td>
<td>0.3602</td>
<td>-0.0548</td>
</tr>
<tr>
<td>0.1885</td>
<td>0.08</td>
<td>0.1085</td>
</tr>
<tr>
<td>0.2298</td>
<td>0.1849</td>
<td>0.0449</td>
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<td>0.1526</td>
<td>0.1637</td>
<td>-0.0111</td>
</tr>
<tr>
<td>0.1347</td>
<td>0.0748</td>
<td>0.0599</td>
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</tbody>
</table>

HJ-1 CCD AOD error is about 0.1。
(a) Empirical algorithm for HJ-1 Albedo estimation

(b) Albedo inversion combining MODIS/BRDF and HJ-1/CCD data to get higher resolution product
(a) Empirical algorithm for HJ-1 Albedo estimation

HJ-1 black sky albedo and white sky albedo by date on 051909, 052209

HJ-1 black sky albedo and white sky albedo by date on 062009, 062409, 062809
(b) Albedo inversion combining MODIS/BRDF and HJ-1/CCD data to get higher resolution product

HJ+MODIS: Spatial and Temporal resolution improved

HJ+MODISGA09 inversed black sky and white sky albedo (062009)

Sihan Liu, Qiang Liu, Qinhuo Liu, et. al., IEEE JSTARS, VOL. 3, NO. 3, 2010
HJ+MODIS albedo

June 20, 2009
HJ and MODIS combined to retrieve LAI

- Simulation data set
- SAIL MODEL
- 5SCALE MODEL

1. LUT generation program
2. LUT sorting program
3. LUT
4. LUT sorting program at inversion
5. MODIS surface reflectance
6. MODIS mixing pixel separating program
7. HJ surface reflectance
8. LUT jointly inversion with MODIS and HJ data
9. 30m HJ LAI product
10. HJ classification may

- 5m HJ LAI product
6 Land temperature retrieval algorithm

- single-channel algorithms for Polar-Orbit Satellite:
  - Qin et al. (2001) mono-window algorithm
- Problem: Angular effect was not considered
- Simulation results indicate the LST errors are increased with view angle and water vapor content.
  - 30° would lead more than 1K error on LST.

- angular-dependent single-channel algorithms for HJ-1B wanted:
  - Parametric model based algorithm
Ellicott et al. (2009) proposed a parametric model for atmospheric correction of MODIS TIR data based on NCEP reanalysis data, which can calculate the atmospheric transmittance, upwelling and downwelling radiance with almost the same accuracy as MODTRAN but less computational time.

Is it adaptable to HJ-1B/IRS data? Three parameters with angular effect are needed:
- Layer Transmittance
- Layer Upwelling and Downwelling Radiances
- Total Transmittance and Radiances
Layer Transmittance

In the TIR, the optical thickness for layer $l$ in channel $i$ can be described as the sum of three components for water vapor, water-vapor continuum, and other gases:

$$\tau_{l,i} = \tau_{l,i}^{H_2O} + \tau_{l,i}^{H_2Oc} + \tau_{l,i}^{\text{other}}$$

The layer optical thickness of water vapor:

$$\tau_{l,i}^{H_2O} = \exp(a_{0,H_2O,i} + a_{1,H_2O,i} \rho_{H_2O} + a_{2,H_2O,i} \rho_{H_2O}^2)$$

$$\rho_{H_2O} = \log\left(\frac{\rho_{0,H_2O}}{\cos(\theta_v)}\right)$$

Where $\rho_{0,H_2O}$ is the water vapor content of the layer (g/m$^2$)

$\theta_v$ is the view angle, $a_0$, $a_1$, $a_2$ are band coefficients that depend on $T_l$ (equivalent temperature) and $P_l$ (equivalent pressure).
Layer Transmittance

The layer optical thickness of other gases

\[ \tau_{l,i}^{\text{other}} = \exp(a_{0,\text{other},i} \rho_{\text{other}}^{a_1,\text{other}}) \quad \rho_{\text{other}} = \frac{D}{\cos(\theta_v)} \]

where \( D \) is the layer depth in km, \( a_0, a_1 \) are band coefficients that depend on \( T_l \) and \( P_l \)

The layer optical thickness of water vapor continuum use the CKD model integrated in MODTRAN directly.

The layer transmittance is

\[ t_{l,i} = \exp(-\tau_{l,i}^{\text{H}_2\text{O}} - \tau_{l,i}^{\text{H}_2\text{Oc}} - \tau_{l,i}^{\text{other}}) \]
The **layer atmospheric upwelling radiance** is computed using

\[
L_{l, \text{atm} \uparrow i} = (1 - t_{l, i}) L_i (T_{l, \text{atm}_\text{eq}})
\]

\[
T_{l, \text{atm}_\text{eq}} = w T_{l, \text{bot}} + (1 - w) T_{l, \text{top}}
\]

where \( w \) is weighted factor = 0.5, \( T_{l, \text{bot}} \) and \( T_{l, \text{top}} \) is bottom and top layer temperature

The **layer atmospheric downwelling radiance** is computed using

\[
L_{l, \text{atm} \downarrow i} = (1 - t_{l, i} (\theta_{\text{emis} \downarrow})) L_i (T_{l, \text{atm}_\text{eq}})
\]

where \( \theta_{\text{emis} \downarrow} = 53^\circ \)
Total Transmittance and Radiances

The atmosphere is sliced in $L$ layer with 1 at low altitude and layer $L$ at top of atmosphere. The band atmospheric transmittance $t_i$ along the optical path is derived from the layer transmittance $t_{l,i}$

$$t_i = \prod_{l=1}^{L} t_{l,i}$$

For the upwelling radiance, layer contributions are summed

$$L_{\text{atm} \uparrow i} = \sum_{l=1}^{L} t_{l+1 \rightarrow L,i} L_{l,\text{atm} \uparrow i} \quad t_{l+1 \rightarrow L,i} = \prod_{k=l+1}^{L} t_{k,i}$$

Where $t_{l+1 \rightarrow L,i}$ is transmittance along the path from top of layer $l$ to top of the atmosphere

In parallel, the downwelling radiance is

$$L_{\text{atm} \downarrow i} = \sum_{l=1}^{L} t_{1 \rightarrow l-1,i} (\theta_{\text{emis} \downarrow}) L_{l,\text{atm} \downarrow i}$$
Retrieving the land surface temperature

Planck function

\[ B_\lambda(T) = \frac{c_1\lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1} \]

Channel Radiance

\[ B_i(T_i) = \frac{\int_{\lambda_1}^{\lambda_2} B_\lambda(T_i)f(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} f(\lambda)d\lambda} \]

Regression function

\[ B_i(T_i) = aT_i^2 + bT_i + c \]

\[ T_s = \frac{-b + \sqrt{b^2 - 4a[c - B_i(T_s)]}}{2a} \]
Validation

- Algorithm validation using simulated data
  - TIGR3 database (2311 profiles) + MODTRAN 4

- Algorithm validation using remote sensing data
  - In-situ ground LST measurements with pixel scale are unavailable by now
  - MODIS LST product has high accuracy (1K), so we compare HJ1B with MODIS LST product
Algorithm validation using RS data

- **Validation site:** Heihe river basin
- **Area:** $285 \times 285$ pixels (HJ-1B band4)
- **Land cover type:** farmland, Gobi, and desert
- **6 days** HJ-1B and MODIS images
- **Overpass time difference** of IRS and MODIS are less than 10 minutes
- **Water vapor content** ($w$) was provided by MOD05 product
- **Land surface emissivity** calculated using NDVI Threshold method (Sorbino et al, 2008)
- **Air temperature** was obtained from Yingke automatic weather station
- **NCEP** ($N39^\circ$, $E100^\circ$ and $N39^\circ$, $E101^\circ$)
Algorithm validation using RS data

<table>
<thead>
<tr>
<th>Date (day/month/year)</th>
<th>w*(g/cm²)</th>
<th>Overpass Time (UTC)</th>
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</thead>
<tbody>
<tr>
<td>22/05/2009</td>
<td>0.62</td>
<td>04:13</td>
</tr>
<tr>
<td>07/06/2009</td>
<td>0.96</td>
<td>04:24</td>
</tr>
<tr>
<td>30/06/2009</td>
<td>1.63</td>
<td>04:17</td>
</tr>
<tr>
<td>27/07/2009</td>
<td>1.42</td>
<td>04:12</td>
</tr>
<tr>
<td>19/08/2009</td>
<td>1.36</td>
<td>04:04</td>
</tr>
<tr>
<td>27/09/2009</td>
<td>1.27</td>
<td>04:07</td>
</tr>
</tbody>
</table>

w* is the mean value of water vapor content of the study region.

- The HJ-1B/IRS and MODIS images have been geo-referenced to the Universal Transverse Mercator (UTM) coordinate system.
- HJ-1B/IRS LST results are re-sampled to 1km pixel size to match with MODIS LST product.
- MODIS LST product have been subtracted to HJ-1B/IRS LST images obtained by our algorithm to compare the results.
Algorithm validation using RS data

Values of difference between HJ1B and MODIS LST product

<table>
<thead>
<tr>
<th>Date</th>
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<th></th>
<th>Parametric model based algorithm</th>
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<tr>
<td></td>
<td>Bias (K)</td>
<td>RMSE (K)</td>
<td>Percentage (%) (&lt;±6K)</td>
<td>Bias (K)</td>
</tr>
<tr>
<td>22/05/2009</td>
<td>1.327</td>
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<td>96.763</td>
<td>0.078</td>
</tr>
<tr>
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<td>2.115</td>
<td>97.78</td>
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</tr>
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<td>30/06/2009</td>
<td>1.657</td>
<td>2.726</td>
<td>88.175</td>
<td>-0.815</td>
</tr>
<tr>
<td>27/07/2009</td>
<td>1.871</td>
<td>2.722</td>
<td>93.156</td>
<td>1.331</td>
</tr>
<tr>
<td>19/08/2009</td>
<td>0.831</td>
<td>1.834</td>
<td>96.486</td>
<td>-0.377</td>
</tr>
<tr>
<td>27/09/2009</td>
<td>1.111</td>
<td>1.732</td>
<td>95.812</td>
<td>0.091</td>
</tr>
<tr>
<td>Average</td>
<td>1.390</td>
<td>2.216</td>
<td>94.695</td>
<td>0.025</td>
</tr>
</tbody>
</table>
Algorithm validation using RS data

LST images of the study area on May 22, 2009
(a) HJ-1B/IRS LST image (b) MOIDS LST product
(MOIDS product is re-sampled to a resolution of 300m)
(3) Model Assimilation for Environmental monitoring

a. Assimilation for evapotranspiration

b. Assimilation for ecological model
a. evapotranspiration

Land surface Evapotranspiration estimation flow chat
ET distribution in Heihe Basin, Gansu Province, China, on May 22, 2009 (Wm-2)
b. Assimilation for ecological model

To generate LAI product

Provided by Prof. Shunlin Liang et. al.
Bondville, IL validation

![Graph showing LAI (m^2/m^2) over time with blue, green, and red markers representing retrieved LAI, MODIS LAI, and field LAI respectively. The graph spans from day 1 to 361 of the year 2001.]
4. Multi-scale field experiment system design

(1) Field observation stations

The comprehensive experiment station in Huailai, Hebei Province

The super monitoring station for air quality in Beijing
- **Field observation stations**

  The comprehensive experiment station in Huailai, Hebei Province

  The super monitoring station for air quality in Beijing
- **Field observation station**

  - The comprehensive experiment station in Huailai, Hebei Province
  - The super monitoring station for air quality in Beijing
  - The long-term flux observation station of typical underlying surface around Beijing
  - The ecological observation station for environment and health at Poyang Lake
(2) **Wireless system design for pixel “true value”**

- **1KM*1KM area:**
- **soil moisture, temperature for 18 point**
- **LST, LAI, ALBEDO and Radiation at several points**
- **Wireless network automatically record and transfer**
(3) Heat flux/ Latent Flux observation at pixel scale with LAS

Provided by Prof. Shaoming Liu
5. Software system development and product generation
5. Product generation Software system development

Quantitative Remote Sensing Producing System Based On Multi-source Remote Sensing Data

This system takes advantages of multi-source remote sensing data, including moderate and low resolution data, such as EOS/MODIS, NOAA/AVHRR, FY3/MERSI, FY3/VIRR etc. and high resolution data, such as Landsat/TM/ETM+ and HJ-1, as well as stationary satellite data and high spectral resolution data, to produce quantitative remote sensing parameters like LAI, albedo and so on. The main functions of this system are as follows:

1. Data management subsystem (DBMS): multi-source remote sensing data (MSRSD), auxiliary data (AD), and quantitative remote sensing products (QRSP);
2. Data preprocessing subsystem (DPS): cross-calibration, geometric correction, reprojection and gridding;
3. Quantitative remote sensing parameter producing subsystem (QRSPPS): based on multi-source remote sensing data.
6. Discussion

(1) How to quantitatively describe the directional differences of land surface parameter observed at different scales by different satellites?

Radiation transfer modeling at large scale for complex surface

(2) How to combine accumulated earth observation data to generate the long-term, consistent and accurate land surface products?

Synergic inversion based on information content and error propagation using Multi-scale, multi-spectral (VIS-NIR-TIR-MIR), multi-satellites (Geostationary and polar orbiting, USA, China, European and others)?

(3) How to validate the remote sensing inversed land surface parameters at different scale?

Multi-scale and long term field observation and Scaling transformation?

(4) How to combine remote sensing observation with the land surface process model?

Assimilation?

Sihan Liu, Qiang Liu, Qinhuo Liu, Jianguang Wen, and Xiaowen Li, The Angular and Spectral Kernel Model for BRDF and Albedo Retrieval, IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 3, NO. 3, SEPTEMBER 2010


Yang, GJ; Liu, QH; Liu, Q, et al., 2009, Mid-Infrared Atmosphere Radiation Transfer Analytic Model and Remote Sensing Images Simulation, SPECTROSCOPY AND SPECTRAL ANALYSIS, Vol. 29, No. 3, P. 629-634

Wen, JG; Liu, QH; Liu, Q, et al., 2009, Parametrized BRDF for atmospheric and topographic correction and albedo estimation in Jiangxi rugged terrain, China, INTERNATIONAL JOURNAL OF REMOTE SENSING, Vol. 30, No. 11, P2875-2896


Xin Li, Xiaowen Li, Zengyuan Li, Mingguo Ma, Jian Wang, Qing Xiao, Qiang Liu, Tao Che, Erxue Chen, Guangjian Yan, Zeyong Hu, Lixin Zhang, Rongzhong Chu,1 Peixi Su, Qinhuo Liu, Shaomin Liu, Jindi Wang, Zheng Niu, Yan Chen, Rui Jin, Weizhen Wang, Youhua Ran, Xiaozhou Xin, and Huazhong Ren, 2009, Watershed Allied Telemetry Experimental Research, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, D22103, doi:10.1029/2008JD011590, 2009


Yang, GJ; Liu, QH; Liu, Q, Xiao Q, Gu XF, 2008, Adjacency effect analysis in imaging simulation of high-resolution mid-infrared (3 similar to 5 mu m) remote sensing, JOURNAL OF INFRARED AND MILLIMETER WAVES, Volume: 27, Issue: 3 Pages: 233-240

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