Operational AIRS-MODIS Co-location System

AIRS Spatial Response Function &
MODIS IR channel Spectral Response Function

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AIRS-MODIS Collocation Processing in ORA

- Operational Collocation Algorithms: Co-register observations from AIRS and MODIS
- AIRS spatial response function simulation
- Algorithm validation analysis and results
- MODIS IR channel spectral response function
- Summary
Apply AIRS EFOV Spatial Response Function for Collocations

The AIRS radiance is contributed by all the points within the EFOV of the sensor.

In one AIRS EFOV, hundreds of MODIS observations are collocated.

A more realistic AIRS EFOV Spatial Response Function is used to:

1: Select collocated MODIS observations

2: Calculate the weights for each MODIS FOV
AIRS Spatial Response Function
Simulation: Physical Model

- The radiance for each AIRS footprint is a combination of 51 instantaneous fields of view (IFOV)

- IFOV spatial response function:
  - Pre-launch measurements
  - circle, ellipse, rectangle

- The spatial response function of the AIRS EFOV is the convolution product of the spatial response function of each IFOV and the integration time. Other factors that we need to take into account are:
  a: Time integration pattern
  b: Scanning pattern / stepwise or continuous
  c: Reflect mirror rotation / whether mirror is used
  d: Satellite movement
  d: Earth rotation
  e: No spherical earth

- AIRS Sampling model: AIRS scan speed: 8/3; 119 Sampling; 90Earthview
  0.022 Integration Period; 51subsampling
AIRS Spatial Response Function
Simulation Methodology

• Time Integration
  – 0.022 second sampling period
  – Simulate sub sampling IFOV during the EFOV integration period
  – Project all sub sampling IFOV spatial response function on earth
  – Integrate IFOV spatial response function over EFOV sampling time

• Sub sampling
  – 51 times
  – 51 sub scan angles
  – 51 sub satellite positions

• Satellite orbit calculation
  – along track movement, 51 pointing vectors

• Add Reflection mirror

• Use Earth elevation model (WSR84), non spherical

• AIRS EFOV spatial response function in earth surface coordinates:
  – 90 spatial response function for 90 scan angles.
AIRS EFOV Spatial Response Function
Opposite Edge of Scan
Algorithm Validation Results and Analysis

• Validation Method

• AIRS SRF application: AIRS pointing correction

• The problem in validation: MODIS Spectral Response Function
  MODIS Spectral Response Function Retrieval

• Algorithm Validation with real Data:
  • Ocean Case   Land   Case
  • Polar Case   Coastline Case   Desert Coastline Case
AIRS EFOV Spatial Response Function Application

Simple SRF

Realistic SRF
AIRS EFOV Spatial Response Function
Application: Pointing Bias Correction

Bias setting: x: 30 mili degree
     y: 100mili degree

Pointing direction bias from centroid:
In scan direction
In orbit direction
Low Latitude Region (Land) : 4/16/119  Ascending

Radiances  Simple SRF  Realistic SRF
Coastline: 04/17/143

Radiance  Simple SRF  Realistic SRF

With Simulated AIRS SRF
Desert Coastline: 04/17/111

Radiance

Simple SRF

Realistic SRF
MODIS Response Function Retrieval

- Part II MODIS IR channel Spectral Response Function
MODIS Relative Spectral Response Function (RSRF) Problem

For the MODIS infrared channel 20-36, there is no way to monitor the instrument spectral sensitivity. Recent researching about the MODIS observation data show that there may be different instrument spectral response function shifting in these 16 infrared channels.

For AIRS-MODIS co-location processing, an observation data based algorithm is developed to retrieve on-orbit ‘Broad band’ MODIS spectral response function with co-located AIRS high spectral resolution observation data.

The retrieved result provide the information of the ‘real’ MODIS RSRF on the observation system level. Those information can be used to improve the integration quality of different instrument and provide inter-instrument calibrilication ability.
Basic Methodology

• Basic equation: Individual MODIS IR channel

\[ Rad_{MODIS} = \sum_i Rad_{AIRS} W_i \]

• \(Rad_{(MODIS)}\): Low spectrum resolution MODIS observation
• \(Rad_{(AIRS)}\): High spectrum resolution AIRS observation
• \(W_i\): Weighting defined by spectral response function

• To resolve the \(W_i\), a equation group is needed:

\[ A_{ij} X_j = M_i \]

• \(A_{(i,j)}\): AIRS observation matrix
• \(X_{(j)}\): Weighting vector
• \(M_{(ij)}\): MODIS observation vector

• \(I > J\) is required
• Key Assumption: All no-linear behavior is independ of wave length.
AIRS Inter-channel Sampling

MODIS Channel 35 Spectrum Response Function

SPEC35

AIRS Radiance

MODIS IR Channel(35) RSF

MODIS Channel 35 Spectrum

SPEC35
Deficient Matrix inverse Problem

• The X can be solved by multiplying both sides by the pseudo-inverse of A. But A is invariably rank deficient.

• Physically, X is continues with un-limited dimensionality. The A and M are tend to be low dimensionality.

• With rank deficient A, M, Retrieval of X based on matrix inversion are very sensitive to noise.
Retrieval with Simulated Data

Noise Free Data
Retrieval with Simulated Data

Data with Noise
NOISE = [-0.5,0.5]
Improved Methodology: Retrieval with deficient Matrix

Data set Optimization:
- Co-located MODIS–AIRS Date/ Uniform scene.
- Apply the AIRS spatial response function
- Differential equation: Remove system bias.
- Average Equation to reduce the Observation white noise

Deficient Matrix Equation Optimization:
- Regulate Matrix A with Truncated Singular decomposition:
- Noise Reduction: Truncate small singular values

Constraint Retrieval algorithm: Constraint
Retrieval/Selection.

Retrieval average
Simultaneous optimization Retrieval with Physical constraining

Constraints:
1. RSF positivity
   \[ X_j \geq 0 \]
2. RSF smoothness
   \[ |X_j - X_{j+1}| \leq T \]
3. RSF Bounded prediction
   \[ |M_i - \sum_{j=1}^{l} A_{ij} X_j| \leq \varepsilon \]
4. Modality
5. RSF rank constraint
6. RSF border limitation

Smoothness Weighting factor:
\[ f = \left| \left| M_i - \sum_{j=1}^{l} A_{ij} X_j \right| \right|^2 + \lambda X^T D X \]
\[ \Rightarrow \min \left| \begin{array}{c} \frac{\partial f}{\partial x} = 0 \end{array} \right. \]
\[ D \approx \left( \begin{array}{cccc} 1 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 \\ \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 1 \end{array} \right) \]
Retrieval Algorithms Numerical Test

Purpose: Validate the Retrieval algorithms

Validation Method:

Retrieval with simulated AIRS /MODIS Data set to test whether This algorithms can obtain useful retrieval result when observation noise exist.

Data set:
AIRS Data: AIRS Observation data
MODIS Data: AIRS Convolution product With pre-launch measurement MODIS RSRF

Noise Model: Free noise/System Bias/White Noise / Observation related noise

\[
\text{NOISE} = -1.242 + [-1,1] + 0.01 \times \text{Rad(MODIS)} + 0.01 \times \text{Rad(MODIS)} \times [-1,1]
\]
Constrain retrieval with Free noise Data

The smooth constrain will limit the high Frequency Component in retrieval result.

‘Over’ constrain will lead to the ‘under estimate of the high frequency component and thus introduce retrieval Bias between retrieval result and the ‘Truth’.
TSVD & Retrieval Bias

**TSVD Truncated small Singular factor to reduce the Equation Noise sensitivity, It will also lead to the retrieval Result to lost the high frequency component and introduce Retrieval Bias.**
Simulated Data with zero noise to valid algorithms
Pre-launch Measurement

U=0.05 AVE:1 SVD:111
U=0.05 AVE:1 SVD:56
U=0.05 AVE:1 SVD:28
u=0.05 AVD:1 SVD:14

U-0.05
TSVD & Constraint & Retrieval Bias

Simulated Data with zero noise to valid algorithms
U=0.01 AVE:1 SVD:111
U=0.001 AVE:1 SVD:8
U=0.01 AVE:1 SVD:8
U=0.05 AVE:1 SVD:8

SVD:8 will limit the precision
Algorithms Validation
Simulated MODIS observation with noise

Simulated Data with additional noise:
0.02* MODIS* Normal[-1,1]
U=0.01
U=0.04
U=0.08
U=0.1
U=0.2

Pre-launch measurement
RSF smoothness constraint

PS:
Different between simultaneous optimization and low pass filter
 Algorithms Validation with Simulated Data

MODIS Spectral Response Function (CH36)

Retrieval with noise free simulated data: U=0.01 SVD:8
Retrieval with simulated data with noise : U=0.01 SVD:8
Algorithms Validation with Simulated Data

Simulated Data Testing
Retrieved RSF with Noise free simulated MODIS Data with U=0.05 SVD:111
Modis = AIRS x RSF
RSF: Pre-launch Measurement of Spectral Response Function

Retrieved Spectral Function with Simulated Data
Addition MODIS Noise is added to Modis Observation

Single Resolution with Positive/Border/Peak Constrain
F:C16.REAL.UTEST.SA20U.GRF
Algorithms Validation with Simulated Data

Noise = -1.242 + System Bias

[-1,1] + Random Noise

0.01*Rad(MODIS)
Retrieval Result Analysis
Constraint Retrieval with Observation Data
MODIS channel 35 RSRF Retrieval

Single solution: choose with Positive/Border/Peak constraint
F:C16.REAL.UTEST.RA01UA.GRF
MODIS channel 35 RSRF Retrieval

![Graph showing MODIS channel 35 RSRF retrieval with different u values. The graph compares the MODIS RSRF for channel 35 against frequency, with curves for u=0.01, 0.02, and 0.1, labeled as Pre-launched.]
1: Some information we can get with this retrieval
   Shifting and reshape.

2: Strong constraint will lead to detail structure of
   the RSF be to smoothed. When the noise is
   compressed, the high frequency component
   useful information is also depressed.

3: The precision and the compression of the noise, that is a comprise.
Biased Constraint retrieval

With less constraint, more 'high frequency' component can be kept.
Noise sensitivity & Constraint bias

The bias introduced by constraint condition depend on:

- The SRF pattern.

  If In SRF, the high frequency component is small, the bias introduced by constrain is small. The retrieval can be used as SRF.

- Constraint strength.

  Weak constraint mean strong noise sensitivity.

Solution:

1: Limit the noise in data will reduce the requirement of the constraint.

2: High frequency component compensation.
Constrainting bias correction

Simplified correction model basing on the SRF Data and assumption that slight shape change. If the shape change is great, the correct will introduced bias.
Evaluation for channel 36

BIAS = Observation - AIRS \times RSF

RSF: Pre-launched Measurement
Retrieved RSF

Radiance bias between Observation and convolution RSF
Summary

• AIRS spatial response function can be used to improve the collocation accuracy.

• AIRS pointing bias and MODIS spectral change make the collocation problem more complex.

• Constraint retrieval algorithms can be applied to obtain MODIS RSF information with AIRS high spectral resolution information. This application reveal that the inter-instrument Calibratio is possible and useful.

• The multi-sensor remote sensing data integration and inter-calibration will beneficial to retrieval and calibration both.