Combination of VIIRS with CrIS toward Extending Data Utilization

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Acknowledgment CrIS SDR Team
Motivation

Combination of CrIS Spectra and VIIRS Products

NWP Data assimilations
Geophysical parameter retrievals

Purpose: Providing sub-pixel information for CrIS observations using collocated high-spatial resolution VIIRS radiances or products
Outline

• CrIS and VIIRS are two independent instruments, though on the same platform
  – Not like IASI and AVHRR on MetOp
  – No alignment requirements
  – Separate geolocation fields

• Fast and accurate collocation algorithm suitable for operational use

• Are CrIS and VIIRS perfect align together?
  – If not, collocated products can introduce errors and uncertainties, making applications even worse.

• Applications
  – Cloud detection
  – Effects of FOV size on the number of clear sky pixels
  – Cluster analysis (on-going)
VIIRS vs. CrIS: Spatially

**VIIRS I5 bands**

- Resolution: 375m (I) or 750m (M)
- Scan Angle: 58.3°
- Sampling: Continuous

**CrIS at 900 cm⁻¹**

- Resolution: 14.0km nadir
- Scan Angle: 48.3°
- Sampling: Sub-sample
Collocation of the measurements from two satellite sensors (either on the same satellite platform or not) involves pairing measurements from two sensors that observe the same location on the Earth but with different spatial resolutions.

It is challenging to do it on the Earth Surface using latitude and longitude.
1) Footprint rotation and distortion off nadir; 2) Searching! Searching! Searching!
Collocation of CrIS with VIIRS Using line-of-sight vector

- It is better to collocate CrIS and VIIRS in space instead of on the Earth Surface

- If we can retrieve line-of-sight vector of CrIS and VIIRS

- The collocation of VIIRS and CrIS can be simplified as examining the angles between two vectors.
  - No worry about FOV distortion
Misalignment between CrIS and VIIRS at the end of scan
Table 2. VIIRS Geolocation Accuracy

<table>
<thead>
<tr>
<th>Residuals</th>
<th>First Update</th>
<th>Second Update</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23 February 2012</td>
<td>18 April 2013</td>
</tr>
<tr>
<td>Track mean</td>
<td>−24 m, −7%</td>
<td>2 m, 1%</td>
</tr>
<tr>
<td>Scan mean</td>
<td>−8 m, −2%</td>
<td>2 m, 1%</td>
</tr>
<tr>
<td>Track RMSE</td>
<td>75 m, 20%</td>
<td>70 m, 19%</td>
</tr>
<tr>
<td>Scan RMSE</td>
<td>62 m, 17%</td>
<td>60 m, 16%</td>
</tr>
</tbody>
</table>

from Wolf et al. 2013
• The misalignment between CrIS and VIIRS can be caused by the CrIS geolocation error.

• Can we use VIIRS as a reference to check CrIS geolocation accuracy?

• The purpose is to identify the error characteristics of CrIS LOS pointing vector by comparing them with the truth.

• Furthermore, if the systematic errors are found, a new set of co-alignment parameters should be retrieved based on assessment results to improve the geolocation accuracy.
Overview of NPP/JPSS Geolocation Algorithms

CrIS (or other instrument)
- Coordinate transformation
- Interferometer
- SSM
- Sensor Isolation system
- Spacecraft

Function call to common geo: `ellipIntersect(outPt, inst2SC, exitVec, dlat, lon, satazm, satzen, range)`

JPSS or any satellite
- COMMON GEO
  - Spacecraft
  - Orbital
  - ECI
  - ECEF(ECR)
  - Geodetic
- SGP4

GEOLOCATION ASSESSMENT
- GCP/Maps/Ground truth
- the other instrument measurements with enough geolocation accuracy
- Comparing the truth and CrIS Geo fields

ADCS
- Pos/Vel/Quaternion (RPY)
- Attitude Determination & Control System (ADCS)
- SGP4

Modified from C. Cao
Inverse Geolocation Computation

Earth's Axis Rotation

Geodetic Nadir

Equator

Spacecraft Orbit

Earth Ellipsoid

Z_{ECF}

X_{orb}

Y_{orb}

Z_{orb}

Earth's Axis Rotation

Los vector in ECI

(satellite velocity and position)

Los vector in ECEF

(lat, lon)

Los vector in S/C

(satellite attitude angles)

Los vector in OCS

Geolocation Fields

(satellite range, azimuth, and zenith angle)

Satellite

Pitch

Roll

Yaw

X_{orb}

Y_{orb}

Z_{orb}
Defining $\alpha$ and $\beta$ angles of CrIS LOS vector in Spacecraft Coordinate

- $\beta = \text{atan}(y/z)$
- $\alpha = \text{atan}(x/z)$

Y: CrossTrack
X: InTrack
Z: from satellite Pointing Earth Surface

P: unit vector of LOS in SBF (x, y, z)
α and β Angles varying with Scan Position (FOV5)
α and β angles are step-by-step perturbed by 21 steps with a angle of $375/833/1000.0$
Using VIIRS to find best collocation position.
Flowchart for VIIRS-CrIS Alignment Check

1. **CrIS Geo. Field**
   - **CrIS LOS Vector in ECEF**
   - **CrIS Sat_P and V in ECEF**
   - **Compute LOS Vector in Orbit Frame**
   - **Compute LOS Vector in S/C Frame**
   - **Perturb α and β angles with small angles**

2. **VIIRS Geo. Field**
   - **VIIRS Vector in ECEF**
   - **Output Collocated Results**
   - **Collocate VIIRS and CrIS**
   - **Convert CrIS LOS Vector into ECEF**
   - **Produce new CrIS LOS vector in SBF**

3. Loop by 21x21 steps
This is root cause of misalignment between CrIS and VIIRS.
New Geometric Parameters

SDR Algorithm Process
1) LOS in IOAR coordinate = ILS parameters (3x3)
2) Convert from IOAR to SSMF coordinate (2 angles)
3) Compute normal to SSM mirror in SSMF (30 Scan Pos) (60 angles)
4) Apply SSM mirror rotation to get LOS in SSMF coordinate
5) Convert from SSMF to SSMR coordinate (3 angles)
6) Convert from SSMR to IAR coordinate (3 angles)
7) Convert from IAR to SAR (3 angles)
8) From SAR=> SBF coordinate (0 angels)
9) From SBF=> Spacecraft (3 angles)

Given the assessment results with 60 angles, the best strategy is to retrieve 60 scan mirror rotation angles.
New SSMF In-track Angles

Values in EngPKT

New Values
Retrieved SSMF Cross-track Angles

Values in EngPKT

New Values

New -EngPKT

FOR Index

Cross_track SSM Angle [uRad]

Xtrack SSM Angle [uRad]

$5 \times 10^5$

$-5 \times 10^5$
Geolocation Performance
(New Parameters)

in-track direction

cross-track direction

Zoom in
Effects of Geolocation Updates
CrIS-VIIRS (M15)

IDPS data

ADL with new mapping angles
Application (I)
Clear Sky Detection Comparison

- Compared to NWP method, the VIIRS method represent the most conservative clear sky detection.

- Differences:
  1. Missed detection of clear sky observations over land by the NWP method
  2. More clear sky observations over sea by NWP method

Blue dots represents the clear pixels identified by both methods
Application (II)

Clear Sky observations change with FOV size

![Graph showing the percentage of clear FOV versus FOV size at nadir for different categories: Total, Over Ocean, Over land. The graph demonstrates a decrease in the percentage of clear FOV as the FOV size increases.](image-url)
The collocated VIIRS pixels are then separated into several classes (7) based on cluster analysis; for each class, the fraction of CrIS FOV coverage, mean radiance value, standard deviation are provided.
Conclusion

- Fast and accurate collocation method of CrIS and VIIRS has been developed, which is suitable for operational use.

- CrIS geolocation has been adjusted to perfectly align with VIIRS.

- Accurate collocation VIIRS products shows some potentials for data assimilation and geophysical parameter retrievals.

• **Wang, L., Y. Chen, and, Y. Han, 2016:** Impacts of Field of View Configuration of Crosstrack Infrared Sounder on Clear Sky Observations, Applied Optics (In Print).

QUESTIONS?
BACKUP SLIDES
Retrieve LOS Vectors

Azimuth, Zenith, Range in Local Spherical Coordinate

(East, North, Up) in meter in Local East, North, Up (ENU) Coordinate

Geodetic Latitude, Longitude, and Altitude (LLA) Coordinate

Earth-centered, earth-fixed (ECEF) Coordinate
CrIS Spatial Response Function

- Ideally, VIIRS images should be convolved with CrIS spatial response function.

- CrIS detector response function: a cutoff value of $\pm 0.963^\circ/2$ (14.0 km at nadir) is about 41.19% to its peak value but already collects 98% of total radiation falling on the detector.

- The box-car spatial response is good enough to represent the real CrIS spatial response.

VIIRS (Box Car Average) - (Spatial Response Convolution): ~0.0023K
In computer science, a *k-d tree* (short for *k-dimensional tree*) is a space-partitioning data structure for organizing points in a *k*-dimensional space.

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Worst case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search</td>
<td>$O(\log n)$</td>
<td>$O(n)$</td>
</tr>
</tbody>
</table>
Two issues can be found that:
1) Land Surface temperate errors during day time make the RTM difficulty to simulate observations over land;
2) NWP method found more clear sky pixels over ocean. It seem warm clouds.
Another Validation Case

Polar Region

CrIS-VIIRS I5 image

IDPS

New Codes + New EngPkt
Zoom-in warm clouds

Some cloud contaminated observations are missed by NWP method.

ggeophysical parameter retrievals

NWP method
VIIRS method