ATMS and CrIS Geolocation

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CrIS/ATMS Instrument Suite (CrIMSS)

- CrIS
- ATMS

±50° Cross Track Scans

0.1 1 10 100 1000
Temperature (K) Pressure (mb)

Co-located

Central or Regional Ground Stations

3x3 Array of CrIS FOVs (each at 14-km diameter)

RDR = Raw Data Record
SDR = Sensor Data Record
EDR = Environmental Data Record

ATMS & CrIS work together to provide soundings in cloudy and clear conditions
Spectral Bands Used for Geolocation

**ATMS**

- Channels used: 1, 2, 3, 16, 17

**CrIS**

- Sub-bands used:
  - LWIR (907-915 cm\(^{-1}\))
  - SWIR (2498 – 2535 cm\(^{-1}\))
VIIRS Instrument Overview

Multispectral, cross-track-scanning, imaging instrument

22 spectral bands 0.4 – 12.5 μm

- Single ~20 cm diameter, rotating, all-reflective telescope
- Day-night band, VisNIR, S/MWIR, & LWIR focal plane assemblies
- Solar reflective and IR emissive on-board calibration sources
- 5 imagery bands at ~375 m nadir resolution
- 16 radiometric quality bands ~750 m nadir resolution
- 1 day / night band 750 m resolution
Three Geolocation Methods

- **Cross Comparison Method (*Likun Wang NOAA/STAR)**
  - Cross compare low spatial resolution sensor with high spatial resolution sensor
  - Shift high spatial resolution image to achieve best match with low resolution image
  - Requires availability of well calibrated, high spatial resolution sensor

- **Shoreline Crossing Method**
  - Fit a cubic polynomial to shoreline crossing points
  - Relies on contrast in radiance between land and sea
  - Inflection point is taken as shoreline crossing point

- **Land-Sea Fraction Method**
  - Determine fraction of land and sea in each pixel footprint using digital shoreline map
  - Model expected radiance from land/sea fraction in each sensor pixel
  - Use simple radiance model with a single temperature and emissivity for land and for sea

Cross Comparison Method

Histogram of VIIRS M16 in CrIS FOV

VIIRS Pixels

CrIS FOV Spatial Response
Shoreline Crossing Method

- **Method Summary**
  - Fit a cubic polynomial through four point in the in-track or cross-track direction
  - The inflection point is taken as the shore crossing point
  - Least-squares-fit to coastlines to minimize total error for scene
Land-Sea Fraction Method

• Method Summary
  – Place a rectangle around each CrIS FOV footprint
  – Divide the rectangle into a grid of equally spaced points
    • Points are represented by the small blue circles in the right hand panel (grid point spacing < 1 km)
  – Shift shoreline position used in calculation in x and y directions until differences between observed and modeled radiances are minimized
Land-Sea Fraction Method Details

$$\chi^2 = \sum_{FOVs} (R_{CrISFOV} - R_{calFOV})^2$$

Minimize chi-squared for best fit

$$R_{calFOV} = (R_{land} - R_{sea})lfrac + R_{sea}$$

Linear radiance model

Where:

- \( R_{CrISFOV} \) = Observed CrIS FOV radiance
- \( R_{calFOV} \) = Calculated CrIS FOV radiance
- \( lfrac \) = Land fraction in a CrIS FOV
- \( R_{land} \) = Land radiance
- \( R_{sea} \) = Sea radiance

**Note:** Shorelines from GSHHG (A Global Self-consistent, Hierarchical, High-resolution Geography Database)

Coordinate System Convention

- North/east coordinate system used to measure error
- Geolocation errors expected to be constant in in-track/cross-track coordinate system
- Measured error rotated to in-track/cross-track coordinates through a rotation matrix
- Used for both shoreline crossing and land fraction method
Land-Sea Fraction Method Example

• Measurement Details
  – 900 cm⁻¹ (11 µm)
  – June 17, 2012 orbit 03307 IDPS SDRs
  – Coastlines from GSHHS (1 km) used to model shoreline
  – Improved coastline accuracy with more sensor pixels

Difference between observed and modeled CrIS brightness temperatures

Gulf of Suez
Method Comparison

• Cross comparison method
  – Results in highest accuracy
  – Can use any scene with spatial structure, not just coastlines
  – Not adversely affected by atmospherics effects (clouds, temperature gradients, indistinct coastlines, etc.)
  – Relies on other high spatial resolution sensor with matching bandwidth
  – Only applied to near nadir measurements
    • 30 degree off-nadir angle due to VIIRS imaging model (CrIS FORs 7 – 24)

• Shoreline crossing method
  – Doesn’t depend on details of footprint
  – Subject to problems with excessive coastline structure
  – Nearest coastline is not necessarily the correct coastline

• Land-sea fraction method
  – Works well on complex coastlines
  – Can be used off nadir
  – Depends on accuracy of land/sea model
• Box shows section used for geolocation case
• Box centered on approximately FOR 25 (FOR range 1 - 30)
• A ~4 km north and east shift required for consistent results between truth (GHHS) and reported (CrIS) results
Software Optimization to Improve Efficiency

- Algorithm optimization
  - Optimize coastline gridding
    - Efficiently determine if given point is inside or outside a polynomial representing coastlines
  - Optimize regions of interest to keep sampling as small as possible
- Implemented selected function in C++
  - Optimized several functions using mex interface
  - Execution times dropped from hours to minutes per geolocation case
- Programming language efficiency
  - Marginal additional improvement in speed
    - Total C++ implementation vs. MATLAB (original implementation)

Execution times dropped from hours to minutes per geolocation case
Example of Poor Choice of Sampling Region

- Vertical shoreline determination not well defined in this test
- Coastlines need structure for unambiguous fits
- Not easy to automate sampling regions
Location of CrIS Geolocation Scenes

- Coastlines by hot dry deserts generally work well
Effects of CrIS Geolocation Patch Detectable

- In October 2012 a bug was fixed in the CrIS SDR geolocation software.
- Results are clearly seen.

![Error vs time graph]

Time of geolocation patch

- In October 2012 a bug was fixed in the CrIS SDR geolocation software.
- Results are clearly seen.
CrIS Results After Geolocation Patch

- Consistent results between organizations (SDL and NOAA/STAR)
- Opposite sign convention for cross-track error
- FORs 7-24
CrIS Geolocation Summary

- Land-sea fraction method works better than shoreline crossing method for CrIS because of unequal ground footprint spacing
- Patch to geolocation software provides opportunities to verify software
  - Average cross-track location increased by nearly 4 km
  - Average in-track location increased by slightly more than 2 km
- Atmospheric window regions used for geolocation analysis
  - LWIR (907-915 cm\(^{-1}\))
  - SWIR (2498–2535 cm\(^{-1}\))
  - No significant difference between results from the two bands
- Results consistent between different organization
  - Geolocation results consistent with NOAA/STAR results
ATMS Geolocation

- ATMS has five bands with separate geolocation
  - K band  – channel 1  – beam diameter 5.2 degrees
  - Ka band  – channel 2  – beam diameter 5.2 degrees
  - V band  – channels 3-15  – beam diameter 2.2 degrees
  - W band  – channel 16  – beam diameter 2.2 degrees
  - G band  – channel 17-22  – beam diameter 1.2 degrees
- Geolocation analysis performed for bands 1, 2, 3, 16, 17
- Bands 1, 2, 3, 16 are window bands
- Bands 17 is sensitive to water vapor but under dry conditions, shorelines are visible
- Accuracy specifications: 5.2° beams < 0.3 degrees, 2.2° beams < 0.2 degrees, and 1.2° beams < 0.1 degrees
Two channels that should give the same results were compared
Both are V band window channels
Land fraction method – 185 cases
Land-Sea Fraction vs. Shoreline Crossing Method Comparison

- Two methods in general give similar results
- Land fraction method shows larger geolocation error
- Land fraction method seems more consistent
Channel 1 Land-Sea Fraction Results

- Number of cases: 183
- In-track mean: -3.4 km, std: 3.8 km
- Cross-track mean: -0.6 km, std: 3.3 km
Channel 2 Land-Sea Fraction Results

- Number of cases: 185
- In-track mean: -5.8 km, std: 3.1 km
- Cross-track mean: 1.6 km, std: 2.6 km
Channel 3 Land-Sea Fraction Results

- Number of cases: 185
- In-track mean: -2.8 km, std: 2.2 km
- Cross-track mean: -3.1 km, std: 2.2 km
Channel 16 Land-Sea Fraction Results

- Number of cases: 185
- In-track mean: 1.1 km, std: 2.2 km
- Cross-track mean: -1.2 km, std: 2.7 km
Channel 17 Land-Sea Fraction Results

- Only using cases with greater than 12 K land/sea brightness temperature difference
- Number of cases: 84
- In-track mean: 1.1 km, std: 2.7 km
- Cross-track mean: 0.4 km, std: 2.6 km
Simulated Effects of Sensor Alignment Error

- Geolocation error simulation created from spacecraft and earth viewing geometry
- Yaw error affects in-track geolocation
- WGS 84 earth model
Simulated Roll and Pitch Error Sensitivity

- Roll error affects cross-track geolocation
- Pitch error affects in-track geolocation
- Observed geolocation errors don’t correspond to simple sensor rotations

0.3 degree roll error

0.3 degree pitch error
Conclusions

• Results consistent between multiple organizations
  – SDL CrIS results consistent with NOAA/STAR except for cross-track sign convention

• Geolocation results consistent between similar window bands
  – Scatter in geolocation results not due to sensor noise

• Shoreline crossing method produces smaller error than land-sea fraction method
  – Probably due to initial guess being zero
  – Additional analysis is needed

• Some adjustments to the ATMS pointing coefficients may be warranted

• More work needed on correlating ATMS geolocation errors with sensor alignment angles
BACKUP
Channel 4 Land Fraction

- Number of cases: 185
- In-track mean: -2.8 km, std: 2.4 km
- Cross-track mean: -3.2 km, std: 2.3 km
Channel 1 Shoreline Crossing

- Number of cases: 184
- In-track mean: -1.9 km, std: 2.3 km
- Cross-track mean: -0.3 km, std: 2.6 km
Channel 2 Shoreline Crossing

- Number of cases: 184
- In-track mean: -2.2 km, std: 2.6 km
- Cross-track mean: 0.8 km, std: 2.5 km
Channel 3 Shoreline Crossing

- Number of cases: 185
- In-track mean: -2.2 km, std: 1.7 km
- Cross-track mean: -2.7 km, std: 1.6 km
Channel 4 Shoreline Crossing

- Number of cases: 185
- In-track mean: -2.4 km, std: 1.6 km
- Cross-track mean: -2.9 km, std: 1.6 km
Channel 16 Shoreline Crossing

- Number of cases: 185
- In-track mean: 0.7 km, std: 1.3 km
- Cross-track mean: -1.0 km, std: 1.6 km