NESDIS’ Atmospheric Motion Vector (AMV) Nested Tracking Algorithm: Exploring its Performance

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Topics

• Some GOES-R Information

• Review of Nested Tracking Approach

• Some Examples: Application to an Assortment of Imagers
  - Using Available ABI Proxy Data…

• Performance
  - Overall, individual cases, experimentation with new ideas

• Ongoing Activities and Plans

• Summary
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Continuity of GOES Mission

Fiscal Year

09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

As of June 2014

GOES-13 GOES East

GOES-14 On-orbit spare

GOES-15 GOES West

GOES-R

GOES-S

GOES-T

GOES-U

Approved: Mary E. Land
Assistant Administrator for Satellite and Information Services

JUN 06 2014

GOES: Geostationary Operational Environmental Satellite

- On-orbit storage
- Operational

GOES-R Launch Date: No later than March 31, 2016
## The Advanced Baseline Imager

<table>
<thead>
<tr>
<th>Feature</th>
<th>ABI</th>
<th>Current GOES Imager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Coverage</td>
<td>16 bands</td>
<td>5 bands</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.64 µm Visible</td>
<td>0.5 km</td>
<td>Approx. 1 km</td>
</tr>
<tr>
<td>Other Visible/near-IR 1.0 km</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Bands (&gt;2 µm)</td>
<td>2 km</td>
<td>Approx. 4 km</td>
</tr>
<tr>
<td>Spatial coverage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full disk</td>
<td>Scan Mode 3</td>
<td>Scan Mode 4</td>
</tr>
<tr>
<td>4 per hour</td>
<td>12 per hour</td>
<td>Scheduled (3 hrly)</td>
</tr>
<tr>
<td>12 per hour</td>
<td></td>
<td>~4 per hour</td>
</tr>
<tr>
<td>Every 30 sec</td>
<td></td>
<td>n/a</td>
</tr>
<tr>
<td>CONUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesoscale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible (reflective bands)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-orbit calibration</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>On-orbit calibration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**June 16-20, 2014**

**IWW12 Copenhagen, Denmark**
## ABI Visible/Near-IR Bands

<table>
<thead>
<tr>
<th>Future GOES imager (ABI) band</th>
<th>Wavelength range (μm)</th>
<th>Central wavelength (μm)</th>
<th>Nominal subsatellite IGFOV (km)</th>
<th>Sample use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45–0.49</td>
<td>0.47</td>
<td>1</td>
<td>Daytime aerosol over land, coastal water mapping</td>
</tr>
<tr>
<td>2</td>
<td>0.59–0.69</td>
<td>0.64</td>
<td>0.5</td>
<td>Daytime clouds fog, isolation, winds</td>
</tr>
<tr>
<td>3</td>
<td>0.846–0.885</td>
<td>0.865</td>
<td>1</td>
<td>Daytime vegetation/burn scar and aerosol over water, winds</td>
</tr>
<tr>
<td>4</td>
<td>1.371–1.386</td>
<td>1.378</td>
<td>2</td>
<td>Daytime cirrus cloud</td>
</tr>
<tr>
<td>5</td>
<td>1.58–1.64</td>
<td>1.61</td>
<td>1</td>
<td>Daytime cloud-top phase and particle size, snow</td>
</tr>
<tr>
<td>6</td>
<td>2.225–2.275</td>
<td>2.25</td>
<td>2</td>
<td>Daytime land/cloud properties, particle size, vegetation, snow</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Nominal subsatellite IGFOV (km)</th>
<th>Sample use</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3.80–4.00</td>
<td>3.90</td>
<td>2</td>
<td>Surface and cloud, fog at night, fire, winds</td>
</tr>
<tr>
<td>8</td>
<td>5.77–6.6</td>
<td>6.19</td>
<td>2</td>
<td>High-level atmospheric water vapor, winds, rainfall</td>
</tr>
<tr>
<td>9</td>
<td>6.75–7.15</td>
<td>6.95</td>
<td>2</td>
<td>Midlevel atmospheric water vapor, winds, rainfall</td>
</tr>
<tr>
<td>10</td>
<td>7.24–7.44</td>
<td>7.34</td>
<td>2</td>
<td>Lower-level water vapor, winds, and SO₂</td>
</tr>
<tr>
<td>11</td>
<td>8.3–8.7</td>
<td>8.5</td>
<td>2</td>
<td>Total water for stability, cloud phase, dust, SO₂, rainfall</td>
</tr>
<tr>
<td>12</td>
<td>9.42–9.8</td>
<td>9.61</td>
<td>2</td>
<td>Total ozone, turbulence, and winds</td>
</tr>
<tr>
<td>13</td>
<td>10.1–10.6</td>
<td>10.35</td>
<td>2</td>
<td>Surface and cloud</td>
</tr>
<tr>
<td>14</td>
<td>10.8–11.6</td>
<td>11.2</td>
<td>2</td>
<td>Imagery, SST, clouds, rainfall</td>
</tr>
<tr>
<td>15</td>
<td>11.8–12.8</td>
<td>12.3</td>
<td>2</td>
<td>Total water, ash, and SST</td>
</tr>
<tr>
<td>16</td>
<td>13.0–13.6</td>
<td>13.3</td>
<td>2</td>
<td>Air temperature, cloud heights and amounts</td>
</tr>
</tbody>
</table>
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Nested Tracking Approach

- Designed to minimize observed slow speed bias of satellite winds; a long standing concern of the NWP community.
- Computes local motions (nested) within a larger target scene, together with a clustering algorithm, to arrive at a motion solution(s).
- Potential for determination of motion at different levels and/or different scales.
- Cloud heights at pixels belonging to the largest cluster are used to assign a representative height to the derived motion wind.

GOES-12 Satwinds vs. Rawinsonde (100-400 hPa)

- Mean Vector Difference
- Speed Bias

Motion of entire box
SPD: 22.3 m/s

Average of largest cluster
SPD: 27.6 m/s

Before clustering
After clustering
Nested Tracking Approach*

- Use local motion vectors to extract dominant motion(s)
  - Perform cluster analysis of line and element displacements
  - Use a density-based cluster analysis scheme (DBSCAN**)

- Link pixels driving tracking solution(s) to final height assignment
  - Use the median of pixel level cloud heights associated with each cluster.


Clustering is done on displacements in line/element space:

- **X** – Average displacement of points in cluster
- **X** – Displacement from tracking the entire 15x15 target scene
Nested Tracking & Clustering Details

- **Size of outer target scene is 19x19 pixels**
  - 2-pixel offset is used that yields a maximum of 225 possible local motion estimates derived from nested 5x5 target scenes

- **An initial sample of local motion vectors is filtered by imposing a 0.8 correlation threshold**

- **Clustering (via DBSCAN)**
  - *Specification of two parameters to start*
    - Minimum number of points in a cluster (4)
    - Radius about each point to search for neighboring points (1/2 pixel)
  - *Each point (ie., displacement) is processed and given a classification based on nearby points*
    - **“Core” cluster point:** Has at least 4 points in neighborhood (radius)
    - **“Boundary” point:** Has fewer than 4 neighbors, but connected to neighborhood by at least one other point
    - **“Noise”:** Point does not belong to any cluster
Cloud Height Algorithm Highlights

- Algorithm uses the 11, 12 and 13.3mm channels to retrieve cloud temperature, cloud emissivity and a cloud microphysics.
- Algorithm uses an optimal estimation approach (Rogers, 1976) that provides error estimates ($T_c$).
- NWP forecast temperature profiles used to compute cloud-top pressure and height.
- For pixels typed as containing multi-layer clouds, a multi-layer solution is performed.
- Special processing occurs in the presence of low level temperature inversions.

References


Please visit Andy Heidinger (NOAA/NESDIS) at his poster to learn more about this cloud height algorithm!!
Impact is to push AMV height assignments lower in the atmosphere

**Heritage Approach:**
Coldest 20% of pixels in target box used to compute AMV height assignment

**Nested Tracking Approach:**
Median of cloud-top pressure of points in largest cluster is assigned AMV height assignment

**DISTRIBUTION**

**Frequency** vs. **Pressure**

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**IWW12 Copenhagen, Denmark**

June 16-20, 2014
Nested tracking reduces slow speed bias of AMVs when compared to radiosonde winds!

Expect this to be beneficial to NWP…

Test distribution shifted right
- Due to faster AMVs and/or lower heights
Nested Tracking Output

- **Standard deviation of displacements (in pixels) in largest cluster**
  - Sample 1 (reverse vector), Sample 2 (forward vector)

- **Standard deviation of displacements divided by magnitude of average displacement**
  - Sample 1 (reverse vector), Sample 2 (forward vector)

- **Size of largest cluster**
  - Sample 1 (reverse vector), Sample 2 (forward vector)

- **Median, Minimum, and Maximum cloud-top pressure (hPa) in largest cluster**
- **Median, Minimum, and Maximum cloud-top temperature (K) in largest cluster**
- **Median, Minimum, and Maximum cloud optical depth in largest cluster**

- **Dominant cloud phase of target scene**
- **Dominant cloud type of target scene**

- **Standard deviation of cloud top pressure values in target scene (hPa)**

*Sharon will talk about the parameters she tested with and found useful. These variables are part of the new proposed winds BUFR sequence*
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The GOES-R Winds Team continues to routinely generate and validate ABI proxy winds from GOES-13, GOES-15, Meteosat-10/SEVIRI, and NPP/VIIRS using the GOES-R winds algorithm.
Application to Current GOES

Cloud-drift winds derived from 15-min GOES-15 imagery over the East Pacific

High-Level 100-400 mb  Mid-Level 400-700 mb  Low-Level >700 mb
Using SEVIRI as a Proxy for the Future GOES-R ABI

Loop of winds derived from hourly Full Disk Meteosat-9 SEVIRI 10.8 µm imagery (22 UTC Apr 24 - 08 UTC Apr 25, 2012)

Application to Meteosat/SEVIRI
Application to Simulated ABI Imagery

High-Level 100-400 mb
Mid-Level 400-700 mb
Low-Level >700 mb
Application to Simulated ABI Imagery
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Validation

Speed Bias...

Meteosat-10/SEVIRI (10.8um) AMVs (March 20 - June 2, 2014)

Histogram of speed bias (OBS–RAOB) values

Pressure 100–400 hPa
Latitude 90S – 90N
Speed Bias: -0.68

Start date: 201407900
End date: 201415212

Histogram of speed bias (OBS–RAOB) values

Pressure 400–700 hPa
Latitude 90S – 90N
Speed Bias: -0.10

Start date: 201407900
End date: 201415212

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**Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes**

QI > 80;
PCT1, PCT2 = 0.05 – 0.50

**Nested Tracking Used**

- **Overall Stats for Period:**
  - **MVD** = 4.84 m/s
  - **NRMS** = 0.37
  - **Speed Bias** = -0.72 m/s
  - Avg Speed = 16.12 m/s
  - N = 23,400

**Graph Details:**
- Layer: 100 – 400 MB
- June 16-20, 2014
Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes

Overall Stats for Period:

- MVD = 4.62 m/s
- NRMS = 0.19
- Speed Bias = -0.19 m/s
- Avg Speed = 13.31 m/s
- N = 10,573
Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes

P > 700 mb

QI > 80; PCT1, PCT2 = 0.05 – 0.50

Overall Stats for Period:

MVD = 2.94 m/s
NRMS = 0.40
Speed Bias = -0.04 m/s
Avg Speed = 8.68 m/s
N = 9349
Validation
Height Assignment (Level-of-Best-Fit)...

Meteosat-10/SEVIRI (10.8um) AMVs (22 March 2014 – 02 June 2014)

Speed Bias, RMSE

AMVs at 200 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 200 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 200 mb

Speed Bias, RMSE

AMVs at 300 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 300 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 300 mb

Speed Bias, RMSE

AMVs at 500 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 500 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 500 mb

Speed Bias, RMSE

AMVs at 700 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 700 mb

Input File: ISWITCH1000
Error (m/s) AMV Level: 700 mb

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IWW12 Copenhagen, Denmark
New vs. Heritage AMV Algorithm
Comparing Performance...

Meteosat-8, 11 um
Aug 2006 and Feb 2007

Nested Tracking
Heritage
## Testing EUMETSAT’s CC$_{ij}$ Approach

<table>
<thead>
<tr>
<th>Meteosat-8 11 micron winds Feb 1-28, 2007</th>
<th>Comparisons to Radiosondes (QI &gt; 80)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100–400 hPa</strong></td>
<td><strong>Nested tracking</strong></td>
</tr>
<tr>
<td></td>
<td>23x23 box</td>
</tr>
<tr>
<td></td>
<td>Median pressure of largest motion cluster</td>
</tr>
<tr>
<td></td>
<td>23x23 box</td>
</tr>
<tr>
<td></td>
<td><strong>CC$_{ij}$ height assignment</strong></td>
</tr>
<tr>
<td>Vector RMSE (m/s)</td>
<td>7.76</td>
</tr>
<tr>
<td>Speed Bias (m/s)</td>
<td>-1.37</td>
</tr>
<tr>
<td>Mean speed (m/s)</td>
<td>22.85</td>
</tr>
<tr>
<td>Mean AMV Height (hPa)</td>
<td>277</td>
</tr>
<tr>
<td>Sample Size</td>
<td>3268</td>
</tr>
</tbody>
</table>

- **CC$_{ij}$ approach** tested in GOES-R AMV algorithm for 1 month (Feb 2007)
- **Result:** Higher heights and slightly slower winds; increased slow bias
### Testing EUMETSAT’s \( \text{CC}_{ij} \) Approach

<table>
<thead>
<tr>
<th>Meteosat-8 11 micron winds Feb 1-28, 2007 400–650 hPa</th>
<th>Comparisons to Radiosondes ( \text{QI} &gt; 80 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nested tracking 23x23 box Median pressure of largest motion cluster</td>
<td>Traditional tracking 23x23 box ( \text{CC}_{ij} ) height assignment</td>
</tr>
<tr>
<td>Vector RMSE (m/s)</td>
<td>7.02</td>
</tr>
<tr>
<td>Speed Bias (m/s)</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean speed (m/s)</td>
<td>18.30</td>
</tr>
<tr>
<td>Mean AMV Height (hPa)</td>
<td>480</td>
</tr>
<tr>
<td>Sample Size</td>
<td>951</td>
</tr>
</tbody>
</table>

- \( \text{CC}_{ij} \) approach tested in GOES-R AMV algorithm for 1 month (Feb 2007)

- **Result:** Higher heights and slightly slower winds; increased slow bias
Testing EUMETSAT’s $CC_{ij}$ Approach

Meteosat-8, 11 um
Feb 2007

Nested Tracking

- $CC_{ij}$ approach tested in GOES-R AMV algorithm for 1 month (Feb 2007)
- Result: Higher heights and slightly slower winds; increased slow bias
Feature Tracking
WV band vs. LWIR Window...

Tracking Clouds with the **6.2um** band

Avg speed: 32 m/s

Tracking Clouds with the **10.8um** band

Avg speed: 24 m/s

- WVCT wind (6.2um) almost always faster than IR (10.8um) cloud-drift wind
- LWIR channel tracking features over greater depth of the atmosphere
  - Greater shear evident leading to more smoothing and slower wind estimate
Height Assignment
WV band vs. LWIR Window...

Histograms of cloud top pressure

- Black histogram is for entire scene, green histogram is largest motion cluster
- 10.8um channel tracking more points over greater depth of the atmosphere

Note the interesting fact that for this case we have two AMVs within 10 hPa of each other, but with very different speeds.
Which AMV is more correct?

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Testing the Idea of Combining the Displacements of Each Time Step

Compute sub-vector for the Reverse Time Step

Before clustering | After clustering

Average sub-vectors

Sub-vector 1  Sub-vector 2

This is our current implementation

Final Vector

Compute sub-vector for the Forward Time Step

Before clustering | After clustering
Testing the Idea of Combining the Displacements of Each Time Step

Reverse Time Step

Before clustering

Forward Time Step

Before clustering

Apply clustering to local displacements from both time steps

Final Vector
Testing the Idea of Combining the Displacements of Each Time Step

U1 vs U2

Points from each time step when analyzed *separately*

Points from both time steps when analyzed *together*
Testing the Idea of Combined Displacements

- Small, but consistent improvement in vector RMSE
- No real change in mean speeds, so no change in speed bias
- 5-6% increase in good wind counts when combining the displacements before clustering.
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Ongoing Activities and Plans

• Supporting industry’s implementation of GOES-R Winds algorithm into the GOES-R core ground system

• Continuing our Validation Related Activities Using Available ABI Proxy Data
  – Meteosat-9/10/SEVIRI imagery, GOES-13/15, NPP/VIIRS, and Himawari-8
    • Case studies: Search for outliers, analyze, and understand
    • Develop, test, and validate algorithm adjustments
    • Validation tool development

• Supporting development of a new BUFR sequence for satellite winds (Thurs morning discussion)
  – Our routine (ie., hourly) experimental GOES-13/15 winds (all types) are placed in latest version of this new BUFR sequence and made available on our ftp server.

• Assessing Impact of Nested Tracking Winds in the NCEP GFS Data Assimilation System
  – Meteosat/SEVIRI (Sharon Nebuda will talk more about this Tues afternoon)
  – GOES-13/15 (Iliana Genkova is working on this at NCEP)

• Latest information on transition of nested tracking algorithm into NESDIS operations:
  – NPP/VIIRS: Operational as of May 8, 2014 (Jeff Key will talk more about this later today)
  – GOES-13/15: September 2014 – running in operations in parallel with existing GOES winds for a 9 month period to help ensure a smooth transition for NWP users
  – MODIS: November 2015
  – AVHRR: November 2015
  – GOES-R/ABI: Late 2016/Early 2017
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Summary

- Developed, tested, and validated nested tracking approach using a variety of available ABI proxy data (*Meteosat/SEVIRI, GOES-13/15, NPP/VIIRS, and Himawari-8, when available*)

- **Nested tracking approach effectively minimizes the slow speed bias**
  - Most speed “adjustments” are small, but some can exceed 10 m/s
  - Smaller bias a result of lower heights and faster winds
  - Improvement over heritage approach
  - Expected to benefit NWP

- **Opportunities with the nested tracking approach**
  - Additional clusters may contain useful wind information in the target scene
  - Clustering output enables new quality control to be employed in NWP data assimilation

- **Nested tracking being implemented in NESDIS operations:**
  - GOES-13/15 (soon), VIIRS (now), Terra/Aqua/MODIS (soon), AVHRR (soon), and GOES-R/ABI

- **Impact testing of nested tracking winds in NCEP’s GFS System in progress**
Questions
Backup Slides
Setup of Study

- Winds were generated using Meteosat-8 rapid scan imagery for the period June 1 – 8, 2008.
- Target locations were fixed while box size and time interval varied.

**Target Box Sizes:**
- 5x5, 9x9, 15x15, 21x21

**Time Intervals:**
- 5, 10, 15, 30 minutes
Impact of Box Size and Time Interval on Magnitude of the Speed Bias

Results – *relative to control run (15x15 box, 15-minute loop interval)*

- A larger box yields a larger slow bias – consistent with Sohn and Borde (2008)
  - Argues for using a small target box to reduce speed bias
- Larger time interval also reduces slow bias
  - Believed to be resolution related
Results – relative to control run (15x15 box, 15-minute loop interval)

- A larger box reduces the RMS – largest box tested was 21x21 pixels
  - Argues against using a small box