Atmospheric Motion Vector generation from MTG-IRS

Régis Borde, Olivier Hautecoeur (EUMETSAT)
Patrick Heas (INRIA)
General context
- Horizontal wind product user requirements
- Common AMVs derivation at EUMETSAT
- Current AMVs limitations

Wind profiles extraction from IR sounders
- Background and status of the art
- 3D winds derivation at EUMETSAT (IASI)

Perspectives for MTG-IRS
Why do we care about AMVs?

Main Requirements for winds

- **Main applications:**
  - Global NWP, High Res NWP, Nowcasting.
  - Aeronautical Meteorology.
  - Climate.

- **Timeliness and Observation cycle:**
  - From few minutes (Nowcasting) to max 6 hours (Global NWP)

- **Requested coverage:**
  - Global coverage

Needs important and continuous operation activities

Needs very High level of coordination: CGMS, and IWWG
Extracted from Geostationary satellites (MSG) and Low orbit satellites (Metop AVHRR) following clouds or WV features in consecutives images

Using the channels
- VIS0.8 during daytime, HRV during daytime for low clouds
- IR10.8, WV6.2, WV7.3

Wind product consists of
- Speed, Direction, Altitude
- Quality indicator

Verification against reliable insitu measurements (Radiosonde, aircraft)
AMVs assimilated in ECMWF forecast model, 16 Feb 2016 at 00:00 UTC.

AMVs are the only observation type to provide good coverage of upper tropospheric wind data over large oceans areas and polar regions.
AVHRR winds Examples

Single Metop polar, 17/09/2014, 1:31-1:52

Global AVHRR, 18/09/2014, 9:04-9:46

Hautecoeur, O., and R. Borde, 2015, Derivation of wind vectors from AVHRR Metop at EUMETSAT, to be published in JTECH
DOI: http://dx.doi.org/10.1175/JTECH-D-15-0155.1
So, why extracting winds from IR sounders?

• Current AMVs limitations:
  ✓ AMVs give an information at a single level of the troposphere.
  ✓ Height assignment (HA) is known to be an important problem.
  ✓ Recurrent AMV problems in tropics area (fast speed biases) where important mesoscale phenomena impact the medium range forecast.

• IR sounder AMVs expectations:
  ✓ Vertical wind profiles from IR sounder temperature/humidity fields.
  ✓ HA less a problem.
  ✓ Better information in Tropics (MTG IRS)
MTG-IRS User requirements (EURD Version 2, 2008)

MTG-IRS products

- **Temperature and Humidity Profile Product (THPP):**
  The Temperature and Humidity Profile Product will provide information on the vertical distribution of temperature and humidity. It will include surface temperature and emissivity. It will be derived from IRS observations for clear sky fields of view and for atmospheric layers above selected cloud types. The product will include associated error estimation.

- **Clear Sky Wind Profile (CSWP):**
  The clear sky wind profile product will provide information on the vertical distribution of atmospheric motion in clear sky and for atmospheric layers above selected cloud types. It will be derived from the Humidity Profile Product and will contain information on ozone and CO in broad atmospheric layers.

- **Atmospheric Composition:**
  The atmospheric composition product will be derived from IRS observations for clear sky fields of view and will contain information on ozone and CO in broad atmospheric layers.

- **MTG-Cloud Product (MTG-CP):**
  The MTG Cloud Product will contain micro and macro physical information of clouds within the field of view, like cloud fraction, cloud top height, cloud effective radius. It will be derived from the IRS instrument for all pixels, and will include an error estimation of the various parameters.
State of the art extracting winds from IR sounders

• BACKGROUND

✓ Product recently developed at CIMSS with AIRS (Santek et al., 2016). Presently in demonstration, showed some potential in assimilation experiment in GEOS-5 model (NOAA/NCEP)

✓ EUMETSAT fellow at Met Office, L. Stewart, study done using simulated spectra generated by Met Office UKV 1.5km model.

✓ External study done by DLR for EUMETSAT in 2006. Humidity fields mimicked from Lokall-Modell LM from DWD.
Which strategy?

- **Known difficulties**
  - Cross correlation tracking methods not very efficient considering smooth temperature/humidity fields. Not enough contrast/entropy for good matching.
  - Really difficult to deal with convection.
  - Each layer is considered separately.

- **Present EUMETSAT strategy**
  - Test a 3D optical flow software developed by INRIA (France)  
  - Collaboration with P. Héas (INRIA) started in June 2015.
3D winds algorithm development at Eumetsat

• Use of a 3D optical flow model
  • Optical Flow technique
    • Optical Flow ≜ Interpolator between two images
    • Study 10 years ago (Heas and Memin, 2007) on motion estimation from successive MSG cloud products
    • Collaboration restored with INRIA in 2015
  • Derivation of all pressure levels in one pass
  • Physical regularization introduced
  • Vertical motion is also considered
    • u, v, w retrieved at each level

• “Operational model”
  • Can run in real-time with reasonable computing resources
    • Based on modern mathematics
The concept

Constrained 3D optical flow model

At Time $t$
- WV mixing ratio
- Temperature

At Time $t + \Delta t$
- WV mixing ratio
- Temperature

Model Settings

Basic Conservation Laws
Vorticity and Divergence
Regularization
Minimization algorithm

3D wind field
U,V,W fields derived from observations
Workplan as defined in 2015

- **Proof of concept**
  - Adapt the old code to run on multiple levels
    - Tune the regularization settings
  - Test the AMV derivation on filled (gapless) fields
    - Based on ECMWF forecast temperature and humidity fields
  - Test the AMV derivation on IASI fields
    - Based on operational IASI level 2 products

- **Specification of the new model**
  - Coding and implementation
Test on model forecast data

• Source
  • ECMWF operational data, 21 June 2013
  • Standard pressure levels
  • Parameters
    • T, Q
    • Wind fields (U, V, W)
  • Step = 1 hour

• Grid
  • Polar stereographic projection
  • Dimension: $512 \times 512$
  • Resolution = 20 km
    • (consistent with IASI sampling ~ 25 km)
Forecast temperature experiment

- Grid 512x512 pixels
- 12 levels
- 12:00 ➔ 13:00

P=700 hPa
Wind derived at 700 hPa from forecast temperature

Winds at 700 hPa
Southern Polar Region
on 21 June 2013 at 12:00Z

Derived from temperature fields

No guess used!

Forecast wind field
Wind derived at 700 hPa from forecast humidity

Winds at 700 hPa
Southern Polar Region
on 21 June 2013 at 12:00Z

Derived from humidity fields

No guess used!

Forecast wind field
3D winds derived from humidity fields

Northern hemisphere, 21 June 2013, 12:00 ➔ 13:00 UTC
No guess
<table>
<thead>
<tr>
<th>Pressure (hPa)</th>
<th>Ozone Bias</th>
<th>MBAE</th>
<th>Temperature Bias</th>
<th>MBAE</th>
<th>Water Vapor Bias</th>
<th>MBAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>-2.0</td>
<td>34</td>
<td>1.2</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>-3.4</td>
<td>18</td>
<td>-4.2</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>-5.4</td>
<td>17</td>
<td>-8.6</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>-7.0</td>
<td>21</td>
<td>-9.8</td>
<td>35</td>
<td>-5.8</td>
<td>31</td>
</tr>
<tr>
<td>300</td>
<td>-6.8</td>
<td>22</td>
<td>-8.8</td>
<td>32</td>
<td>-6.0</td>
<td>24</td>
</tr>
<tr>
<td>400</td>
<td>-4.2</td>
<td>20</td>
<td>-5.3</td>
<td>31</td>
<td>-2.1</td>
<td>23</td>
</tr>
<tr>
<td>500</td>
<td>-3.4</td>
<td>38</td>
<td>-0.4</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>-2.3</td>
<td>42</td>
<td>0.1</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>-1.5</td>
<td>44</td>
<td>0.7</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>800</td>
<td>-0.8</td>
<td>46</td>
<td>0.6</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>850</td>
<td>-0.5</td>
<td>46</td>
<td>0.6</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>925</td>
<td>-0.4</td>
<td>50</td>
<td>0.3</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1.2</td>
<td>54</td>
<td>1.6</td>
<td>52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Winds derivation from each parameter, separately

NO GUESS USED
Very preliminary comments

- Wind fields structure retrieved
- Inter-comparison with forecast fields are consistent
- Statistics (mean bias) larger for high levels
  - Temperature field smoother than water vapor content
  - But high atmosphere is dry
  - Ozone is another passive tracker
    - Half-life about one day for mid stratosphere, ten days for low atmosphere
- Q and O3 will be the two main variables tracked
  - With T for consistency.
- No guess means null speed wind
  - Gives negative bias speed for the highest level (highest wind speed)
  - Optical flow technique “doesn’t” like big displacements.
Test on IASI level 2 products

- **Source:**
  IASI_SND_02 products (operational production at Eumetsat)
- **Platform:**
  Metop-A and Metop-B to maximize the overlap between the images
- **Humidity** (water vapor mixing ratio) fields at standard pressure levels
- **Interpolated data** on Polar stereographic grid

Humidity at 500 hPa for successive overpasses
Wind derived from IASI humidity profiles

Derived from IASI humidity fields at 700 hPa

Forecast wind field at 04:00

bias = 0.96

mbae = 44.69
Wind derived from IASI humidity profiles

Derived from IASI humidity fields at 500 hPa

Forecast wind field at 04:00

bias = -0.64

mbae = 36.71
Very preliminary comments

- Feasible but more difficult
- Requires stronger regularization
  - The physical regularization shall be tuned in the vertical profile
- Pixel quality index of IASI level 2 should be considered
- Coverage area should be extended to add constraints
  - The output data are therefore screened to reduce the border effect.

- The algorithm is suitable for operational use
  - Actual implementation is not parallelized but the winds derivation takes only 5 minutes to process about 25 minutes of data.

- ‘Demonstrational product’ available by Q3 2017
Perspectives for MTG-IRS 1/2

• Software can be adapted to MTG-IRS data
  • Dwell of 160x160 pixels (IRS) 2x2 pixel (IASI)
  • Pixel size of 4km (IRS) 12 km (IASI)

• Sparse data not a problem with the new model

• MTG-IRS 3D wind product could be as follow:
  • 4 km resolution
  • Using image pairs (30 min gap) and the current baseline [3-4 3-4 3-4 3-4; 2-4 2-4 2-4 2-4; 1-4 1-4 1-4 1-4] allow a ½ hourly product over Europe (LAC-4) and ~3 series of 3 products per day for LAC-1,2.
Perspectives for MTG-IRS 2/2

• Validation could be done against
  • Radiosonde Observations
  • Common AMVs from MTG-FCI
  • Lidars network and ADM-Aeolus HLOS winds (if still operating)

• User requirements can be potentially discussed for a better coverage
  • Need only image pairs (30 min gap) to derive winds
  • Different baseline than the current baseline can allow a more frequent wind production for LAC-1,2 and 3.

To be discussed !