Introduction to the Himawari-8 Atmospheric Motion Vector Algorithm

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Abstract

Meteorological Satellite Center of the Japan Meteorological Agency (JMA/MSC) began operation of its third-generation geostationary meteorological satellite Himawari-8 at July 2015, and derivation algorithm of an Atmospheric Motion Vector (AMV) is also modified to suit the upgrade to the Himawari-8. Target assignment process is re-designed for avoiding correlated error of AMVs. Noise reduction method to average multiple correlation surfaces from different settings is newly applied for tracking process. Optimal estimation approach was further applied for wind height estimation. Himawari-8 IR AMVs errors are mostly 4-6m/s in terms of root mean square vector difference and the absolute value wind speed bias is less than 1m/s for all height level and area.

1. Introduction

AMV is a satellite-derived product that is to estimate the altitude and motion vector of clouds from satellite imagery. The product utilized for numerical weather prediction as wind observation data under the assumption that the motion vectors cloud matches the wind vector. It plays a certain role in the accuracy of the numerical weather prediction especially over little observation area by the sonde, such as over remote areas and maritime. AMV is a product that has been present from the time of the first-generation meteorological satellite that the observed performance was in a rudimentary stage (infrared and visible bands only). Third generation geostationary meteorological satellite Himawari-8 started its operation from July 2015. Time and spatial resolution and observation wavelength band of the Himawari-8 was greatly improved. However, the legacy AMV derivation algorithm is not expected to show enough performance from the Himawari-8 because the heritage AMV algorithm is designed for the second generation geostationary meteorological satellites which temporal and spectral resolutions are less than that of the Himawari-8. Therefore, Meteorological Satellite Center, to bring out the performance of the third generation geostationary meteorological satellite, has developed a new AMV calculation algorithm. In this document, a description will be given of the AMV calculation

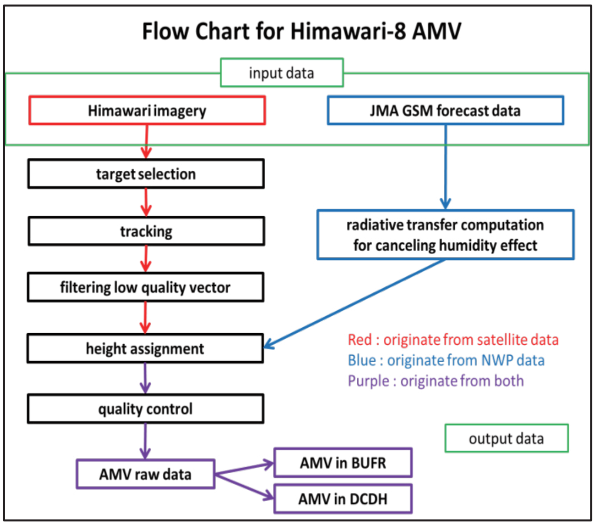

Figure1 : Himawari-8 AMV derivation algorithm flow

AMV is derived by analyzing cloud motion from animated satellite imagery. However, estimation of wind height is required for practical use. And quality control process is also important for avoiding harmful data to users.

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2. AMV derivation system overview

Figure 1 shows overview of flow chart of the AMV derivation system. This document highlights the basic concepts for the target selection, tracking, height assignment and quality control processes are illustrated. AMV data are provided to users in BUFR and DCDH format but this documents focus on only derivation algorithm.

3. Target assignment processing

AMV data are computed on grid points defined in pixel-line space on satellite imagery. Distance between neighboring grid points is set to appropriate value not only for generating high-density winds but also avoiding overlap of targets. Because the overlap of targets generate correlated error which is difficult to consider accurately. In target assignment process, the grid interval is set to exceeding the length of the square side of smaller target box used in the tracking process.

4. Tracking process

The Himawari-8 AMV motion detection method is based on a cross-correlation method. But the difference between the legacy algorithm and the Himawari-8 AMV derivation algorithm is that multiple cross-correlation surfaces derived from different settings are averaged and its surface is used for motion vector estimation. Four cross-correlation surfaces are derived from the following four settings, and adopted for the Himawari-8 AMV.

A) Small target box and timely forward matching
B) Large target box and timely forward matching
C) Small target box and timely backward matching
D) Large target box and timely backward matching

Surfaces C and D are spatially reversed for uniformity with A and B before averaging is performed.

For QI computation, forward and backward motion vectors are derived from average of A and B, C and D respectively. Figure 2 shows example correlation surfaces computed in tracking process. Number of peaks which is considered to be source of tracking error is mitigated on averaged surfaces. 7x7 and 33x33 pixels of target box sizes are used for AMV derivation at November 2016.

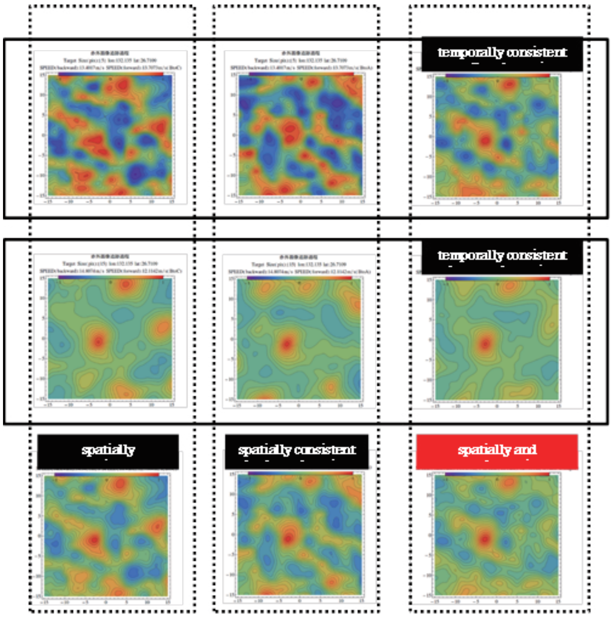

Figure 2 : Correlation surfaces computed in tracking process
Warm color corresponds to high correlation, cold color means low correlation. In Himawari-8 AMV, three motion vectors are computed from three correlation surfaces. First vector is derived from averaged surfaces based on small and large target box in forward matching. Second vector is also same but in backward matching. Those two vectors are used for quality control. Last vector as final output is derived from average of those two averaged surfaces previously computed for first and second vectors. Surface on bottom left is for forward motion, bottom middle is for backward motion and bottom right corresponds to surface for final vector used as output. In reference, averaged surfaces of forward and backward matching to each target box size are shown on right side column. Spurious maxima are mitigated especially in case using small target box.

5. Cloud height estimation

AMV height is estimated by adopting optimal estimation approach using differential evolution method. Optimal latent variables giving observed radiance and motion vector through forward model are computed by searching the optimal latent variables which maximize likelihood function. Likelihood function to be maximized is as follows. h_1, h_2, h_3 of optimal latent variables are interpreted as clouds pressure heights for first, second and third cloud layer. Layer which give best fit to first guess winds are chosen for pressure height for wind vector.

$$\begin{aligned} L_{rad}(\theta_1, p_1, h_1, \theta_2, p_2, h_2, \theta_3, p_3, h_3) \times \\ L_{wind}(h_1, h_2, h_3) \times \\ L_{constraint}^{gap}(h_1, h_2) \times \\ L_{constraint}^{gap}(h_2, h_3) \times \\ L_{constraint}^{gap}(h_1, h_3) \times \\ L_{constraint}^{ordering}(h_1, h_2) \times \\ L_{constraint}^{ordering}(h_2, h_3) \times \\ L_{constraint}^{ordering}(h_1, h_3) \end{aligned}$$

Definitions of each element of in the above production are defined here. The hyper parameters σ are determined by prior information of satellite instruments and residual analysis between observables and optimal radiance. h_{gap} is set to 25 hPa. This is required for regularization.

$$L_{rad}(\theta_1, p_1, h_1, \theta_2, p_2, h_2, \theta_3, p_3, h_3) \equiv$$

$$\prod_{ch}^{IR\ bands} \frac{\sigma_{rad}(ch)^2}{|\,Log(R_{model}^{ch}(\theta_1, p_1, h_1, \theta_2, p_2, h_2, \theta_3, p_3, h_3) - Log(R_{obs}^{ch})|^2 + \sigma_{rad}(ch)^2}$$

$$L_{wind}(h_1, h_2, h_3)$$

$$\equiv \prod_{ch}^{tracked\ bands} \left(1 - \prod_{n=1}^{3} \left(1 - \frac{\sigma_{wind}(ch)^2}{\left|u_{FG}(h_n) - u_{obs}^{ch}\right|^2 + \left|v_{FG}(h_n) - v_{obs}^{ch}\right|^2 + \sigma_{wind}(ch)^2}\right)\right)$$

$$L_{constraint}^{gap}(h_i, h_j) \equiv \frac{1}{\pi} \mathrm{ARCTAN}\left(\frac{\left|h_i - h_j\right| - h_{gap}}{\sigma_{height}}\right) + \frac{1}{2}$$

$$L_{constraint}^{ordering}(h_i, h_j) \equiv \frac{1}{\pi} \mathrm{ARCTAN}\left(\frac{h_i - h_j}{\sigma_{height}}\right) + \frac{1}{2}$$

The radiance forward model is based on the assumption that the satellite observes mixture radiances coming from the ground and three cloud layers. $R(h)$ represents radiance considered to be observed by satellite from black body placed at pressure height h. R_g is also same but from ground or sea surface. The $R(h)$ and R_g are computed by appropriate radiance transfer model for consideration of atmospheric effects with the first-guess vertical profile.

$$\begin{aligned} R_{model}^{ch}(\theta_1, p_1, h_1, \theta_2, p_2, h_2, \theta_3, p_3, h_3) \equiv \\ \rho_g \varepsilon_g R_g + \rho_1 \varepsilon(p_1) R(h_1) + \\ \rho_2 \varepsilon(p_2) R(h_2) + \rho_3 \varepsilon(p_3) R(h_3) \end{aligned}$$

Definitions for ρ and ε are given as below. These parameters are interpreted as radiance ratios from each layers and cloud emissivity depending on cloud phase.

$$\begin{aligned} \rho_g &\equiv (\mathrm{SIN}(\theta_1)\mathrm{SIN}(\theta_2))^2 \\ \rho_1 &\equiv (\mathrm{SIN}(\theta_1)\mathrm{COS}(\theta_2))^2 \\ \rho_2 &\equiv (\mathrm{COS}(\theta_1)\mathrm{SIN}(\theta_3))^2 \\ \rho_3 &\equiv (\mathrm{COS}(\theta_1)\mathrm{COS}(\theta_3))^2 \end{aligned}$$

$$\varepsilon(p) \equiv \begin{cases} emissivity\ of\ ice\ cloud, & 0 \le p < 1 \\ emissivity\ of\ water\ cloud, & 1 \le p < 2 \end{cases}$$

One IR (10.4um) , three WV (6.2, 6.4 and 7.0um) and one CO2 (13.3um) bands are used for L_{rad}. And motion vectors from IR (10.4um), VIS (0.64um) and WV (7.0um) are used for L_{wind}.

6. Quality control process

For the quality control process in Himawari-8 AMV, QI is calculated as in the legacy algorithm. Beside this fundamental quality control, a number of checks are performed to filter out low-quality vectors as outlined below.

Minimum wind speed check
・Wind speed less than 2.5m/s
・Over-land wind speed exceeding 6.7m/s near the surface within 200hPa from ground pressure

Maximum wind speed check

・Wind speed exceeding 100m/s

Zenith angle check

・Target satellite zenith angle exceeding 65 degrees

・(For 3.9um only) Sun zenith angle between 75 and 100 degrees

・(For 0.64um only) in case that sun zenith angle exceeding 85 degrees

Maximum cross-correlation coefficient check

・correlation value of less than 0.75 at the peak position of the averaged matching surface

Radiance likelihood check

・Geometric mean of radiance likelihood term less than 0.5. This check is omitted when optimal radiance and observed radiance are significantly different.

Stripe noise check

・Presence of stripe noise in target imagery

Navigation error check

・Median of all specially computed QI (average of vector, wind speed and wind direction consistency QI) value of 10.4um AMV less than 0.6 . If this check is positive, all AMVs (rather than only those for 10.4um) are rejected and are not disseminated.

Navigation error checking is most important for quality control in Himawari-8 AMV. The other checks are conducted on individual vectors independently, but the navigation error check is based on statistical analysis to all vectors. This check enable to discard all vectors expected to impair NWP operation.

7. Statistical property of Himawari-8 AMV

Following tables are sonde vs Himawari-8 IR AMV statistics. Element of the sonde statistic is mean of motion vector difference (MVD), root mean square vector difference (RMSVD), wind speed bias (BIAS), mean wind speed (SPD) and number of collocation (NC). BIAS means mean wind speed difference between AMV and sonde wind speed (AMV speed minus sonde speed). Filters to AMVs are as follows.

- Within a radius of 150km from the sonde observation point
- Height difference between sonde and AMV height within 50hPa for over 700 hPa pressure height; for lower pressure height, within 35hPa is compared.
- QI (using forecast) exceeding 0.85

IR (B13) upper level (100-400hPa) AMV

(-400hPa)	ALL	NH	TROP	SH
MVD	4.86	5.33	4.22	4.83
RMSVD	5.77	6.26	5.04	5.67
BIAS	-0.2	-0.06	-0.37	-0.64
SPD	22.52	28.12	14.7	28.11
NC	430079	146859	205038	78182

IR (B13) middle level (400-700hPa) AMV

(400-700hPa)	ALL	NH	TROP	SH
MVD	4.09	4.43	3.44	4.41
RMSVD	4.86	5.27	3.95	5.25
BIAS	0.02	0.19	-0.34	0.28
SPD	12.8	15.47	7.96	14.31
NC	5689	3204	1933	552

IR (B13) low level (700-1100hPa) AMV

(700-1100hPa)	ALL	NH	TROP	SH
MVD	3.14	3.05	3.03	3.54
RMSVD	3.86	4.14	3.67	4.15
BIAS	0.68	0.54	0.86	0.25
SPD	9.23	7.79	9.17	10.88
NC	4238	840	2571	827

The RMSVD of Himawari-8 AMV vs sonde is around 4m/s for low level (700-1100hPa), and 4-6m/s for high and mid-level (100-700hPa). The absolute value of BIAS is less than 1m/s for all level and areas, but some negative wind speed bias is seen around high levels.

8. Summary

This report outlines target selection, the tracking method, height estimation and quality control for the Himawari-8 AMV derivation system. Target assignment process is designed to avoid correlated AMV errors, and averaging of similarity surfaces is utilized for noise reduction in the tracking process. The height assignment method is based on optimal estimation to find the optimal solution for the explanation of observed radiance and motion vectors. Quality control for navigation error is based on statistical analysis for QIs of all AMVs. RMSVD of Himawari-8 IR (10.4um) AMV vs sonde is around 4-6m/s and BIAS is between -1 and 1 m/s.

9. References

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ひまわり8号大気追跡風アルゴリズムの紹介

下地　和希*

要旨

気象庁・気象衛星センターは２０１５年７月よりひまわり８号の運用を開始した。ひまわり８号への切替に伴い、大気追跡風の算出アルゴリズムも変更された。ターゲット指定処理は大気追跡風の誤差相関を避けるように再設計された。追跡処理では複数の相関係数曲面を平均化することで、追跡結果のノイズを抑制する処理が追加された。高度推定処理では最適化手法が導入された。ひまわり８号赤外大気追跡風の誤差は4-6m/sで、風速バイアスは全ての高度と領域で1m/s以下であった。

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