DETERMINING OPTIMAL CONDITIONS FOR MESOSCALE AMV

Hee-Je Cho, Mi-Lim Ou

National Institute of Meteorological Research,
Korea Meteorological Administration, Seoul, Republic of Korea

Abstract

Atmospheric motion vectors (AMVs) are not local or instantaneous wind information. The temporal and spatial scale of AMV is limited by satellite observation and retrieval algorithm itself. This study aims to make AMVs as smaller scale observations as possible. Based on characteristics of MTSAT-1R data, optimal sizes of target templates are suggested for different temporal and spatial resolution of satellite images.

INTRODUCTION

Wind observations, especially, can have more influence on predicting and understanding shorter and smaller scale phenomena because large scale atmospheric motion is mostly determined by mass field which is well simulated by current numerical models. To answer the needs of nowcasting and short range forecast, meteorological satellites have been developed to provide dense and frequent real-time observations. For the same purpose, AMV producers have made a lot of efforts on wind retrieval algorithm itself to produce AMVs closer to in-situ measurements (e.g. Rawinsonde wind observation).

Most of operational geostationary meteorological satellites offer infrared channel images about 1 to 4 times an hour with horizontal resolution of 3 to 4 kilometers. The scale of AMV is limited by these spatial and temporal characteristics of satellite observation. (1) Horizontal resolution of satellite image and (2) time interval between image pairs can reflect the scale of wind that AMV catches. Also, AMV retrieval algorithm is also assuming certain scale of cloud motion though the (3) horizontal size of target template.

If the time interval between image pairs is short, wind determination can be more stable because AMVs are calculated by tracking movement of cloud or water vapor feature which deforms with time. But it is obvious that frequent observations can degrade the precision of extracted winds with infrared images whose spatial resolution is about a few kilometers. Although the target displacement can have sub-pixel precision with the polynomial regression fitted to pixel-base correlation surface, it still depends on the image resolution and also performance of pixel registration.

This study investigates optimal template size for AMV target. AMVs with different temporal and spatial scale of satellite observations are examined based on QI (quality indicator) statistics as well as comparison to rawinsonde data. All AMVs are produced by KMA (Korea Meteorological Administration) algorithm and MTSAT-1R data.

REDUCING TEMPLATE SIZE

Current operational wind retrieval algorithm of KMA (Korea Meteorological Administration) is employing 32 × 32 pixel size template (128 × 128 kilometer^2 at the sub-satellite point) in the case of AMVs using IRW (infra-red window: 10.8 µm) channel image. It is large enough to neglect mesoscale disturbances within it. But care is needed reducing template size because it can introduce errors in determining winds (Jedlovec and Atkinson, 1998). Sohn and Borde (2008) demonstrated that small target template is effective for slow bias of AMV speed but also increases error vectors.

If reducing template size to half in length scale, error vectors are noticeably increased. Considering cloud deformation in satellite image over 30 minutes, it is too small for appropriate matching of the target template in the next-time image. Bad matching of small target can be ascribed to (1) lack of pixels within template for correlation calculation or (2) inconsistency between size of target template and time interval between images.

MTSAT-1R offers 15 minute interval image triplets four times (around 00, 06, 12, and 18 UTC) a day. These image set allows more stable AMV extraction because of the less deformation of cloud features over shorter time interval. Figure 1 shows the example of AMVs with 16 × 16 pixels (64 × 64 kilometer^2 at the sub-satellite) template and it seems to be too small for 30 minutes interval images. That implies the temporal resolution of satellite observation limits the minimum target size applicable.

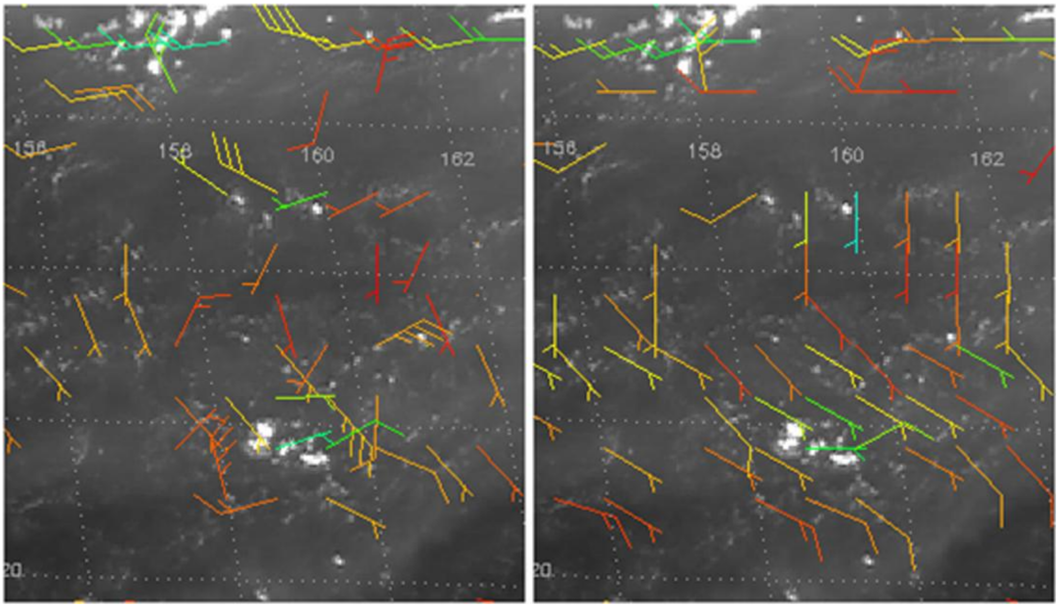


Figure 1: **AMVs with IRW (infra-red window: 10.8 µm) channel image of MTSAT-1R. Target template size is 16 × 16 pixels. Time intervals between images are 30 (left) and 15 (right) minutes.**

PRECISION OF AMV

Precision of AMV is why we have to be careful using frequently observed satellite images. AMV speed precision is determined by the horizontal and temporal resolution of satellite image. With the 30 minutes interval infra-red channel images of MTSAT-1R, one pixel displacement of cloud target corresponds to about 2.2 ms^{-1}(4 kilometer / 30 minutes). 15 minutes image pairs only can produce the AMV with the precision of more than 4.4 ms^{-1}. It becomes worse off the sub-satellite area.

By using HRV (high resolution visible: 0.67 µm) channel images whose spatial resolution is about 1 kilometer at the sub-satellite point, we can expect enough precision of AMV observation. But HRV channel AMV has its own advantage and characteristics different than IRW AMV. Moreover, height assignment of HRV AMV is rather unstable compared to that of IRW AMV.

Using quadratic polynomial regression fitted to pixel-based correlation surface, target displacement of IRW AMV can have sub-grid precision. Examples of AMVs with 'rapid scan' images which can be offered every 7.5 to 1 minutes, confirms it can resolve the target movement by less than a tenth of a pixel.

The successful image navigation and registration (INR) processes can enable the AMV precision to get over the pixel resolution of satellite image. If the regression fit can resolve target displacement by one quarter of a pixel, it is enough for 15 minutes interval infra-red image to provide AMV with about 1 ms^{-1} precision. Figure 2 shows the examples of AMVs observing low level slow winds with or without regression fit. Smooth curvature of slow circular motion cannot be retrieved without sub-pixel scale precision especially for frequently observed low resolution images.

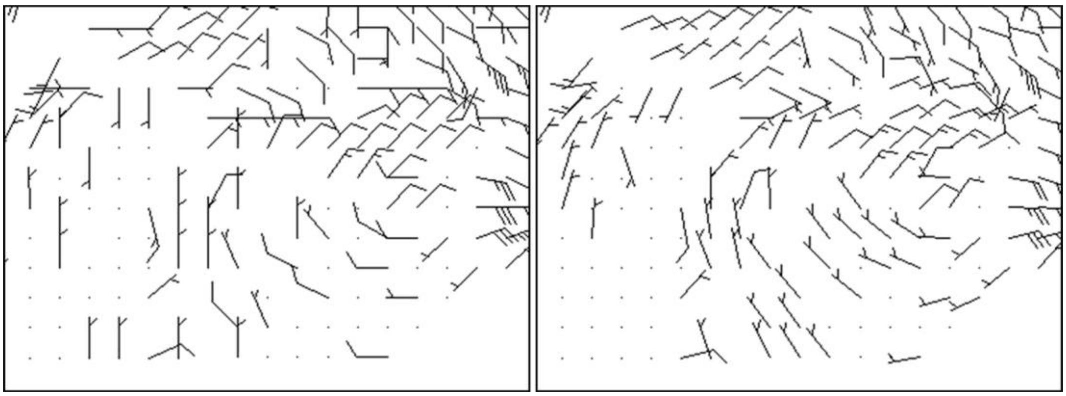
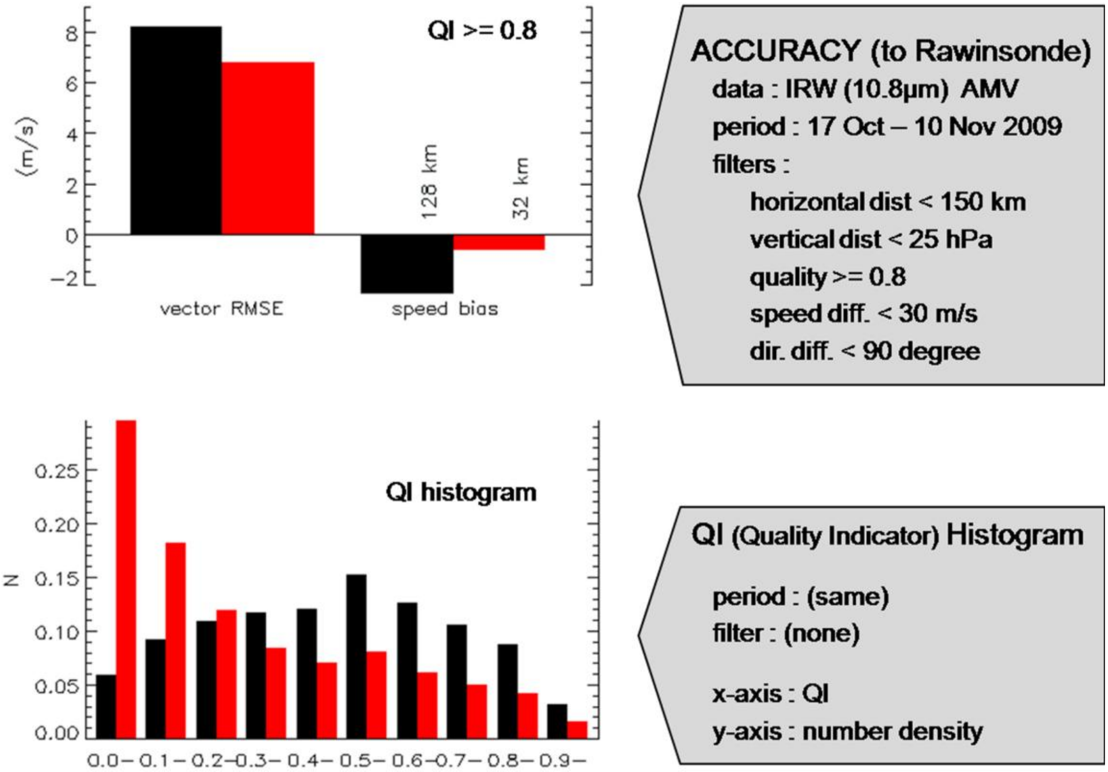


Figure 2: **AMVs with IRW channel image of MTSAT-1R. Time interval between images is 15 minutes. Displacement of target is calculated in pixel unit (left) and in sub-pixel precision by polynomial regression fit (right).**

ACCURACY OR QUALITY

To decide optimal size of target template, we compare the AMVs with rawinsonde wind observations. Figure 3 shows the result for two different target sizes: 32 × 32 (128 × 128 kilometer^2) and 8 × 8 (32 × 32 kilometer^2) pixels with 30 minutes interval infra-red images. Poor quality AMVs are screened out by QI (quality indicators) threshold 0.8. Although the smaller target shows the better agreement with rawinsonde observation, overall quality of AMV is degraded by uncertainty in target matching with too small template for time interval between satellite observations. That means the consensus criteria for AMV quality is not appropriate to evaluate accuracy of different template sizes because screening AMVs by strong quality standard can neglect the increase of overall noise.

By qualitative examination, 0.2 can be considered as a boundary value of QI which excludes computational error in determining target displacement. Ambiguity of this value was tested by demonstrating the same conclusion using similar QI values.



ACCURACY (to Rawinsonde)
data : IRW (10.8μm) AMV
period : 17 Oct – 10 Nov 2009
filters :
horizontal dist < 150 km
vertical dist < 25 hPa
quality >= 0.8
speed diff. < 30 m/s
dir. diff. < 90 degree

QI (Quality Indicator) Histogram
period : (same)
filter : (none)

x-axis : QI
y-axis : number density

Figure 3: **Vector-RMS error and wind speed bias of IRW AMVs compared to collocated rawinsonde wind observations during 17 October to 10 November 2009 (upper). QI histogram of AMVs for the same period (lower). Sizes of target templates are 32 × 32 (black) and 8 × 8 (red) pixels.**

OPTIMAL TEMPLATE SIZE

Optimal template sizes of AMVs using different temporal and spatial resolutions of satellite observation are demonstrated. Among 6 different template sizes varying from 16 × 16 to 128 × 128 kilometer^2 we decided which produces AMVs agreed most with rawinsonde wind observation.

For 15 minutes interval IRW images, 32 × 32 kilometer^2 (8 × 8 pixels) seems to be the most effective template size (Figure 4). Table 1 is the result of same comparison analysis for AMVs with 30 minutes interval IRW images, 15 minutes interval HRV images, and 30 minutes interval HRV images. Obviously, the result confirms that smaller template can be introduced with shorter time interval images.

Despite the advantage of image resolution, optimal template sizes for HRV AMV are similar to those of IRW AMV. This implies that we can ignore the effect of image resolution for the time scale of longer than 15 minutes and also indirectly, assures the enough AMV precision even using infra-red channel images with 4 kilometer resolution.

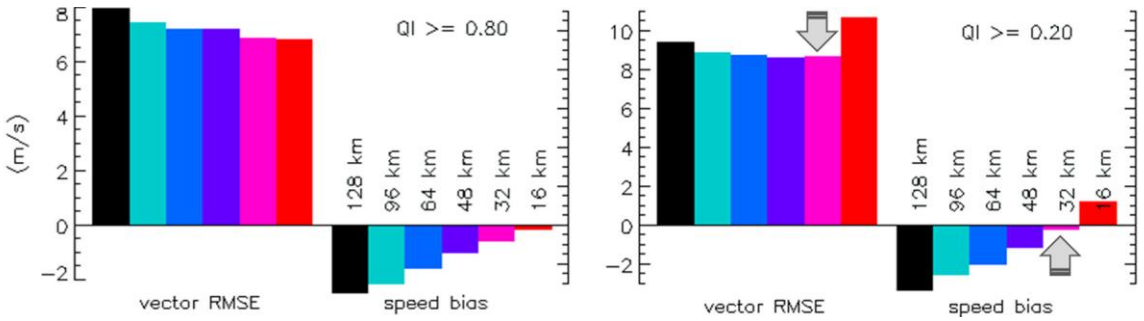


Figure 4: **Vector-RMS error and wind speed bias of IRW AMVs compared to collocated rawinsonde wind observations during 17 October to 10 November 2009. Sizes of target templates are 32 × 32 (black), 24 × 24 (azure), 16 × 16 (blue), 12 × 12 (purple), 8 × 8 (pink), and 4 × 4 (red) pixels. Poor quality AMVs are screened out by QI threshold of 0.8 (left) or 0.2 (right).**

	Image interval: 30 minutes	**Image interval: 15 minutes**
IRW AMV (Image resolution: 4 km)	**96 km – 48 km**	**32 km**
HRV AMV (Image resolution: 4 km)	**64 km**	**64 – 32 km**

Table 1: **Optimal size of target template according to horizontal pixel resolution and temporal resolution of satellite image**

DISCUSSION

Optimal target template sizes for AMVs using current MTSAT-1R observations are suggested. In view of the value of wind observation, optimum can be considered as a minimum size without risking overall quality and accuracy of AMVs. By using rather relaxed QI threshold screening bad AMVs, it was possible to evaluate different template size simultaneously considering not only accuracy but also quality of AMVs. From that the optimal sizes are similar for both IRW and HRV image, target template size seems to be determined by physical deformation scale of cloud image, not by computational stability in target matching.

Because this study deals with observational temporal scale of longer than 15 minutes, it cannot be applied to the AMVs with ‘rapid scan’ images. For those temporal scales less than several minutes, we may have to consider the lacked AMV precision and unstable computation in target matching (lack of enough pixels within extremely small template), both caused by the inconsistency of high temporal resolution than horizontal image resolution.

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