Atmospheric Motion Vector (AMV)

Algorithm Theoretical Basis Document

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List of Acronyms

AMV	Atmospheric Motion Vector
CGMS	Coordination Group for Meteorological Satellites
COMS	Communication, Ocean, and Meteorological Satellite
CMDPS	COMS Meteorological Data Processing System
EBBT	Equivalent Black Body Temperature
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellites
IWW	International Wind Workshop
MODIS	Moderate-resolution Imaging Spectroradiometer
MTSAT	Multi-Functional Transport Satellite
NESDIS	National Environmental Satellite, Data and Information Service
NTC	Normalized Total Contribution
NTCC	Normalized Total Cumulative Contribution
OSSE	Observing System Simulation Experiments
QI	Quality Indicator
TBB	Black Body Temperature
WMO	World Meteorological Organization

1. Introduction

Atmospheric Motion Vectors (AMVs) are operationally produced using satellite imagery for all observation regions of satellite including the gap area of low latitudes and ocean, etc. The AMVs improve the weather analysis and prediction ability (Velden and Young 1994). . It is widely in use as data assimilation on Numerical Weather Prediction (NWP) model (LeMarshall et al., 1996 and Goerss et al. 1998, Solden et al. 2001, Xiao et al. 2002) This also contributes to the various parts of atmospheric application such as analysis of tropical low pressure, retrieval of wind shear, position tracking of a jet stream, and analysis of coastal gap wind (Rogers. E. et al., 1979, Velden, C. S. et al., 1992, Velden, C. S. et al., 1998, Velden, C. S. et al., 2005).

In this algorithm, Communication, Ocean, and Meteorological Satellite (COMS) Meteorological Data Processing System (CMDPS) is used to produce meteorological variables using COMS data. It is in charge of AMVs retrieval. There is produced a split window channel (IR1: 10.8㎛) AMVs, water vapor channel (WV: 6.75㎛) AMVs, Shortwave infrared channel (SWIR: 3.75㎛) AMVs, and visible channel (VIS: 0.65㎛) AMVs using observed satellite imagery of each channel.

The AMVs algorithm is composed of four steps: target selection, height assignment, vector retrieval, and quality information. After optimizing target selection to assure stability of vector retrieval, it produces vectors by defining vector displacement the maximum correlation coefficients position by the cross-correlation method.

We assigned the height of vectors using the retrieved radiative simulation data due to temperature and humidity data at pressure level as given by the NWP model. It produced the quality information for each vectors depending on the quality test algorithm of AMVs developed by the European Organization for the Exploitation of Meteorological Satellite (EUMETSAT).

Section 2 describes the background and limitations of AMVs retrieval research. Sectoin 3 describes the AMVs algorithm, including the retrieval processing overview, and validation. Section 4 provides the interpretation methods of the retrieved AMVs results. The last section explains the issues and possibilities for improvement of the current algorithm.

2. Background and purpose

2.1. Retrieval background and limitations of AMVs

2.1.1. Retrieval background

AMVs have been retrieved from all operational geostationary meteorological satellites since the 1960s (Hubert and Whitney, 1971). From the current Geostationary Operational Environmental Satellites (GOES) series and the European Meteosat satellites to former Geostationary Meteorological Satellite (GMS) and Multi-Functional Transport Satellite (MTSAT), the retrieval technique history is almost the same as the history of geostationary meteorological satellites (Velden et al., 1997, 1998, Schemetz et al., 1993, Tokuno, 1996, LeMarshall et al., 1999).

Operational AMVs generation in the National Environmental Satellite, Data and Information Service (NESDIS) is fully automated, generated using GOES-8/GOES-9 observation. The International Wind Workshop was held under the sponsorship of World Meteorological Organization (WMO) from 1994 to the present in order to utilize widly and share international technology. The NMSC is actively participating in this workshop. Past NMSC AMVs were produced through annexed program within Terascan (SeaSpace Co.) software.

This algorithm is retrieved AMVs using an hourly GMS-5 Satellite data in the East Asia region. The height assignment and quality tests were performed, but were not the product for the autonomously developed algorithm. As part of the COMS Meteorological Data Processing System (CMDPS) development research, the AMVs retrieval algorithm was developed from 2003 and coded Standardized AMVs operational module with other CMDPS products depending on the purpose of the project.

2.1.2. Limitations of the AMVs algorithm

● Limitation due to temporal and spatial observation resolution of satellite data

The accuracy and retrieval density of AMVs has improved based on improvement of temporal-spatial resolution and spectral sensitivity of satellite data (Velden et al., 2005). The scale of atmospheric phenomenon reflecting AMVs depends on temporal and spatial resolution of satellite data. The variation of cloud and water vapor shape for a given time (the observation time difference between the satellite images) is slight, so the tracking of image movement is possible by its assumption. Due to the nature of image tracking, it can produce better atmospheric phenomenon on a minute scale scale if use the satellite data of a shorter observation time interval and higher spartial resolution.

● Limitations of height assignment for the vectors using NWP model

The retrieved height of vector from satellite data depends on the vertical temperature and humidity profiles of the Numerical Weather Prediction (NWP) model.

The Equivalent Black-Body Temperature (EBBT) method, is a height assignment algorithm now widely used. It is determined as the level where the infrared channel brightness temperature observed from satellites fits the calculated brightness temperature by RTM. Therefore, AMVs are affected by the accuracy of temperature and humidity predicted field of NWP model used as input data of RTM.

2.2. The importance and utilization of CMDPS AMVs

In certain conditions, including lack of observation in the ocean and Southern hemisphere, and sparse spatial density, it is difficult to make ground observations. AMVs retrieval from satellite data is able to fill in the gaps of ground observation. The main application field of AMVs is NWP. It contributes to rainfall intensity simulations and tracking of central typhoons. It also improves predictability utilized for data assimilation of local and global NWP models. AMVs help the tracking of Convection Initiation (CI) providing comparatively homogeneous wind fields, is used in the field of nowcasting forecast.

● Application of data assimilation for NWP

The impact assessment of satellite products affected on the NWP ability is generally performed by Observing System Simulation Experiments (OSSE) test. In various studies, the use of AMVs show to improve the prediction accuracy of global model

Also, In this study of simulation for rainfall intensity and tropical low using local NWP model, it is know which the distribution of rainfall intensity and the movement of low pressure etc are improved(Cherubini et al., 2006).

● The forecast utilization of the path of a Tropical Cyclone

The immediate data assimilation of AMVs using 3DAR and 4DAR has been performed by numerous studies. Velden et al.(1998) have found for the usefulness of AMVs of Tropical Cyclone tracking study.

Zhang and Wang(1999) used the AMVs when produced the asymmetric Bogers-vorticity data to modify the analyzed wind fields. This method showed that the path forecasting of the tropical low pressure is improved.

● **The forecast utilization of Convective initiative**

The CI derives information of lighting and rainfall occurrence which tracks down the convective development, growth, and extinction steps using infrared channel satellite data. The utilization of a spatio-temperal dense satellite is very helpful in bad weather as it improves accuracy of short-term convective cloud tracking.

In using AMVs, it is possible to track convective clouds 30 to 40 minutes faster than radar measurement (Mecikalski, J. R. et al, 2006).

3. Algorithm

3.1 Theoretical Background

AMVs use continuous observed satellite data at regular intervals. The shape during a given time calculates atmospheric winds through the movement of a two-dimensional target of unchanging size. It can grasp the Cloud's movement through infrared and visible channel imagery, and water vapor movement through the continuous satellite imagery with the human eye. The AMVs are calculated by quantification and automation and assigned the quality information for each vector.

Meteorological satellite agencies such as EUMETSAT, NOAA, and JMA calculate displacement of a target using a cross correlation coefficient with continuous imagery. Each vector is assigned using the simulated results of RTM. The vectors of all channels are fundamentally assigned the EBBT method. These are carried out through comparison between the observed IR brightness temperature from satellites and the calculated brightness temperature using RTM. The AMVs will detect the average movement of a regular size target. The calculated simulation results are used in the height assignment to retrieve smoothly of operational AMVs in real time.

3.2. Methodology

The AMVs of four channels (infrared channels and water vapor channel) AMVs are produced for COMS full disk depending on COMS observation and CMDPS AMVs retrieval schedule. The visible channel AMV is retrieved in daytime pixel area within 80 degree of Sun Zenith Angle (SZA). In the case of SWIR AMV, it is retrieved in the nighttime area over SZA 100 degree, which the scattering element does not affect.

The retrievals of AMVs include as follows; target selection for retrieveing the accurate vector besides vector estimation, the height assignment for retrieveing the vectors and pre-processing for producing RTM simulation, and post-processing for providing RTM simulation.

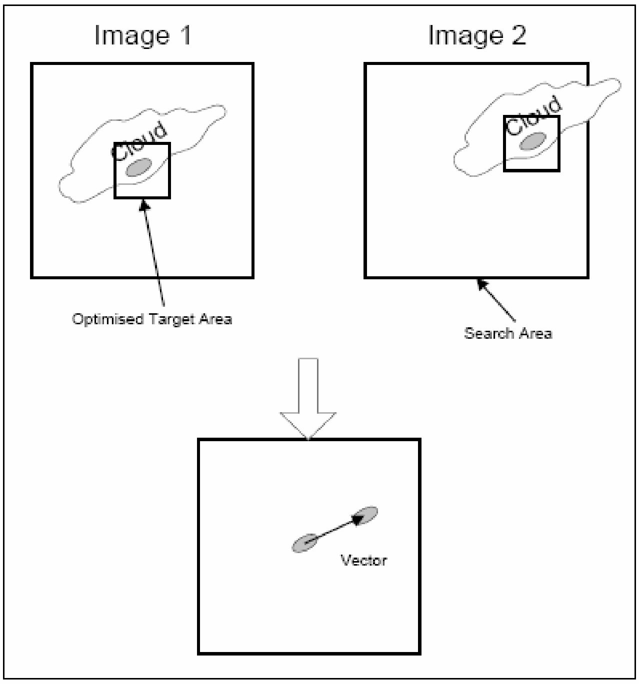
3.2.1. Target selection

As a basic unit of calculating AMVs, target signifies square of regular pixel size in the satellite imagery. This algorithm uses 24x24 pixels pixel size. If size of target changes, the temporal and spatial scales of the observed wind can change. So it requires attention for consistency with other processes (retrieval resolutions, reference pixel ratio in height assignment) in AMVs algorithm. AMVs use in the target analysis real time cloud detection data produced by CMDPS Cloud detection algorithm.

More than 10% (water vapor channel: 80%) of cloudy pixels are cloudy target. Otherwise, they are classified as clear targets. The AMVs (IR, SWIR, and VIS channels) calculate vector in cloudy targets only and WV AMVs calculate both clear and cloudy targets.

The target, In the case of both ocean and land can indiscriminately calculate the vectors between the cloud boundary and the coastline. It can set up the target that does not calculate including the coastline.

Fig. 3.1 Schematics for target and search area



3.2.2. Vector retrieval

If the target is selected, the vector is calculated through the displacement of each target. When the algorithm calculates the displacement of target, this uses cross-correlation coefficients (Nieman et al., 1997, Buche et al., 2006). The target and the highest cross-correlation coefficients decides on the displacement for location of the next time imagery. The size of tracking area and center location of next time imagery for achieving cross-correlation coefficients is automatically calculated within algorithm (refer to section 3.2.4).

The calculated area with cross-correlation coefficients is a square. If the pixel length of one side is NT, total pixels becomes $(NT)^2$ used to obtain one cross-correlation coefficients. The location of pixels in a target denotes (i,j), If (m,n) represents the relative location of pixels within a tracking area in terms of (m, n), each $T_{i,j}$ and $S_{m+i,n+j}$ can be represented by the satellite observation value within a target and tracking area. Therefore, the cross-correlation coefficients are the same as equation (3.2). Then, target pixels are calculated in the entire range included in the tracking area.

$$CC = \frac{E(T-\overline{T}) - E(S-\overline{S})}{\sigma_T \cdot \sigma_S} = \frac{E(T \cdot S) - E(T)E(S)}{\sigma_T \cdot \sigma_S} \tag{3.1}$$

$$CC_{T,S_{m,n}} = \frac{N_T^2 \sum_i^{N_T}\sum_j^{N_T} T_{i,j} S_{m+i,n+j} - \sum_i^{N_T}\sum_j^{N_T} T_{i,j} \sum_i^{N_T}\sum_j^{N_T} S_{m+i,n+j}}{\sqrt{N_T^2 \sum_i^{N_T}\sum_j^{N_T} T_{i,j}^2 - \left(\sum_i^{N_T}\sum_j^{N_T} T_{i,j}\right)^2}\sqrt{N_T^2 \sum_i^{N_T}\sum_j^{N_T} S_{m+i,n+j}^2 - \left(\sum_i^{N_T}\sum_j^{N_T} S_{m+i,n+j}\right)^2}} \tag{3.2}$$

In this algorithm, in order to retrieve the vector, it is used three images from satellites to have a time difference of about 15 or 30 minute intervals. Then, it always decides the target through analysis of the second image. The vector 1 is retrieved using the first and the second image, and the simple average of the vector 2 using the second and the third image is finally retrieved.

Comparative and stable vector extraction is possible through this method. The consistency of Vector 1 and 2 is used to decide on the quality of the final vector. The displacement of each calculated target is converted to physical distance through latitude/longitude information of observed pixels from satellites.

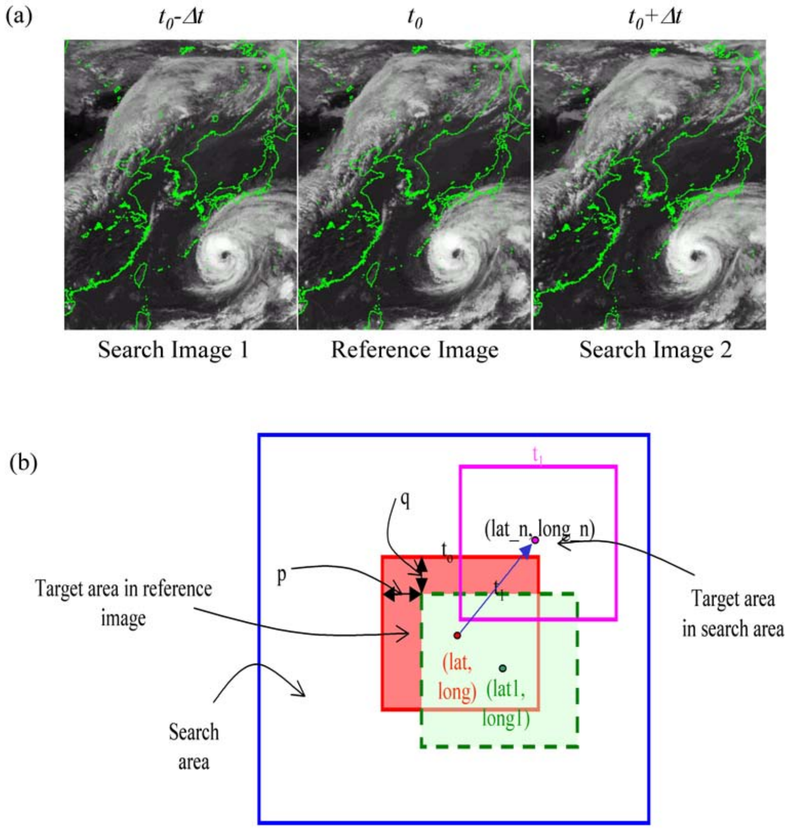
The displacement is calculated by equation 3.3 and 3.4 assuming spherical coordinate system (Φ_1 and Θ_1 are latitude and longitude of each target center. Φ_2 and Θ_2 is latitude and longitude of the location selected with final displacement within the target area.

If the physical displacement of a vector is calculated, we retrieve the wind vector (wind speed/wind direction) divided into the difference of observation time of these images

$$\Delta x = R_E(\Theta_1 - \Theta_2)\cos\left(\frac{\Phi_1 + \Phi_2}{2}\right) \tag{3.3}$$

$$\Delta y = R_E(\Phi_1 - \Phi_2) \quad (3.4)$$

Fig. 3.2 Three (a) sampled images for derivation of target displacement and (b) schematic diagram of target tracking for wind vector estimation. The target area in reference image is moved around within the search area(many dotted line boxes) to calculate cross correlation and select the maximum cross correlation point(the solid line box in t_1).

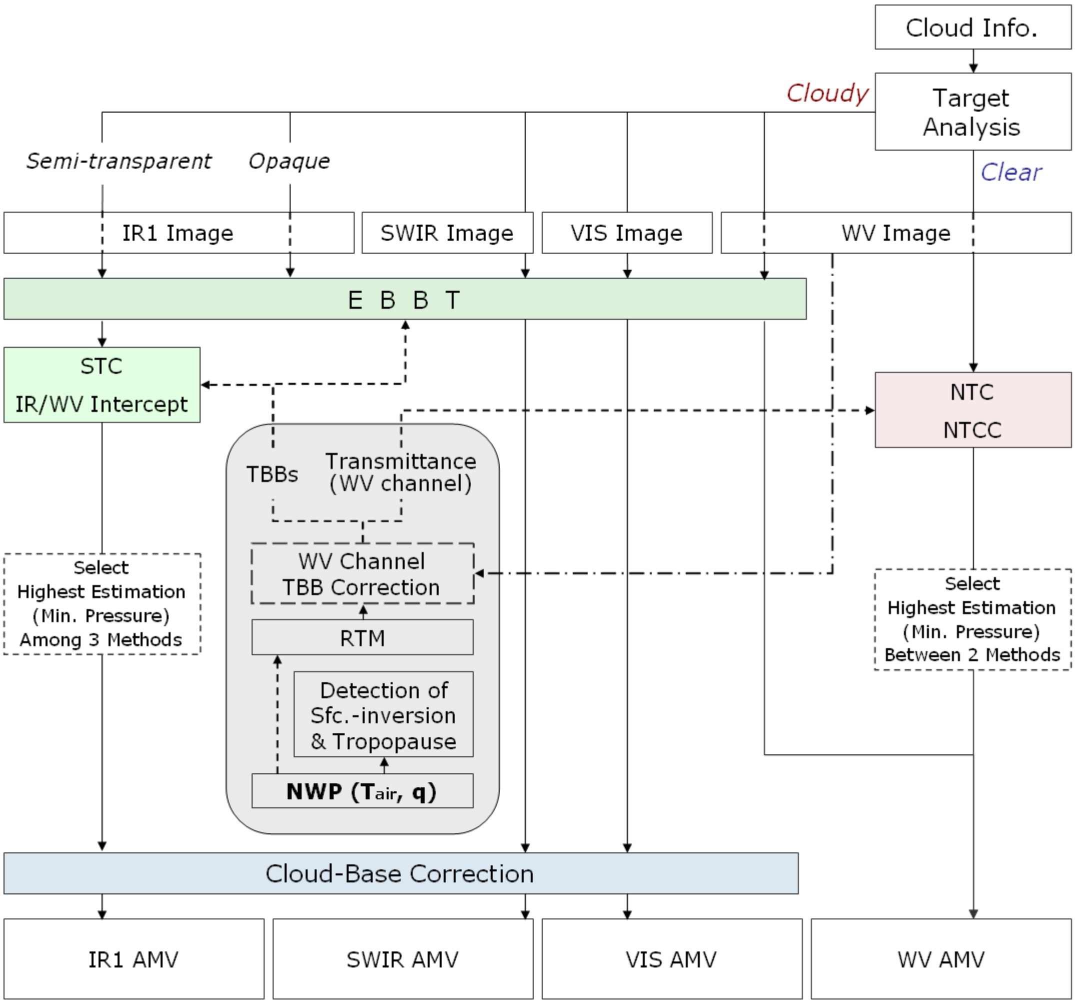


3.2.3. Target Height assignment

The height assignment of vector is globally proceeding for active research as important element to decide the accuracy of AMVs. The height assignment method of AMVs is the Equivalent Black-Body Temperature (EBBT) method using all AMVs, Normalized Total Contribution (NTC) method and Normalized Total Cumulative Contribution (NTCC) using AMVs of clear target of water vapor channel. Meanwhile there are two methods of Semi-Transparent Correlation and IR/WV Intercept performing in IR channel AMVs (Fig. 3.3).

Performing two pre-processing processes before the height assignment, it determines a low level inversion and the tropopause using NWP temperature profiles (all height assignment are processed between a low level inversion and the tropopasue) and corrects the WV clear simulated data using satellite observation data. In the case of IR, SWIR, and VIS channel AMVs, additional cloud base height correction is carried out after the height assignment.

Fig. 3.3 Flow chart of height assignment



• The pre-processing of Height Assignment

A. Low level inversion and tropopause determination

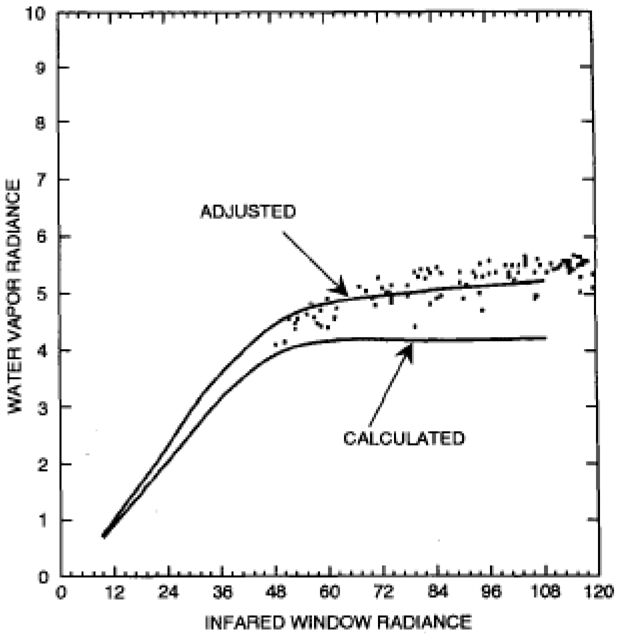
A low level inversion and tropopause is determined using the vertical temperature profile of each pixel in the NWP model. The AMVs of all channels can be assigned between low level inversion and the tropopause. There is determined on the tropopause where appears a bottom level of height for the positive temperature lapse rate in high level over 400 hPa and on a low level inversion where appears a upper level of height for the positive temperature lapse rate in high level below 600 hPa.

B. the Simulation correction for brightness temperature of water vapor channel

RTM corrects the simulated brightness temperature of water vapor channel which is smaller than averaged WV brightness temperature of clear pixels above 2K in the target.

At this time, the correction width is different according to altitude, the simulated value less than a low level inversion is replaced by clear mean brightness temperature observed from satellite, and is not performed which the correction is in higher position than the tropopause, reducing width of correction depending on altitude (Fig. 3.4). This correction can perform when there are more than 10 clear pixels referenced within the pixels. The clear sky simulation of clear sky by RTM than observed brightness temperature from satellite

Fig. 3.4 Example showing the adjustment applied to the forward calculations of the water vapor channel TBBs when calculated and measured values disagree.



● The classification of Clear and Cloud Targets

The AMVs must be classified either clear or cloudy target because it retrieves the vector of cloudy pixels in the IR, SWIR, VIS channels but not in the water vapor channel. The brightness temperature of the IR1 channel in the target area is defined as clear pixels lower than –10℃. These cloudy pixels in the target area are classified as the cloudy and clear pixels (above 10% and below 10%). The water vapor channel is only defined as a cloudy target when the IR1 channel brightness temperature has more than 80 % small cloudy targets below -10℃ in the target area due to the nature of the channel.

● **Height assignment of Cloud target AMVs**

A. EBBT(Equivalent Black-Body Temperature) Method

The basic EBBT method is used to assign a height for all channel AMVs to compare with the representative value of the IR channel brightness temperature within the target and simulated vertical brightness temperature of the RTM. It is performed when an opaque cloud exists in each vertical layer of the model as input temperature / humidity profile of global NWP data.

The representative brightness temperature of the target, IR channel brightness temperature is defined as the 15% below mean of pixels. Not all cloudy pixels within the target are used because the vector calculation is processed using a cross-correlation coefficient to reflect the movement at high level. We selected two layers for simulation having the representative brightness temperature of the calculated target and the most similar simulated data, and determined the height to interpolate vertically based on the brightness temperature with the two cloud heights.

Although The AMVs of IR, SWIR, and VIS channels are performed using all IR channels, but the AMVs of the WV channel uses WV channel data as well. The WV channel observes the water vapor at medium and high levels for non-movement of the nature of its water-droplets or ice crystals. AMV retrieval using WV images reflects the movement of water vapor at medium and high levels. The EBBT method using WV channel AMVs is defined as the representative brightness temperature using the average of all pixels within the target.

The simulation data provided by the CMDPS pre-processing module is performed on the assumption of radiative opaque clouds. The EBBT method may be ineffective in semi-transparent clouds of a dominant target. When the semi-transparent stratus exists particularly at high levels, the IR channel of satellites measure until the radiative emission below the clouds and the assigned height by EBBT method is possible below cloud top height. Therefore, the correction algorithm of two semi transparent clouds is conditionally performed in the case of IR channel AMVs.

B. IR/WV Intercept method

IR/WV intercept method plays the role of correcting the radiative effect below semi-transparent clouds. The WV and IR brightness temperatures influenced by upper tropospheric water vapor for simple cloud layers uses the corrected method (equation 3.5) for cloud height using the linear regression relationship depending on cloud amount.

$$\frac{R(WV) - R_{cl}(WV)}{R(IR1) - R_{cl}(IR1)} = \frac{N\varepsilon(WV)[R_{op}(WV, P_c) - R_{cl}(WV)]}{N\varepsilon(IR1)[R_{op}(IR1, P_c) - R_{cl}(IR1)]} \quad (3.5)$$

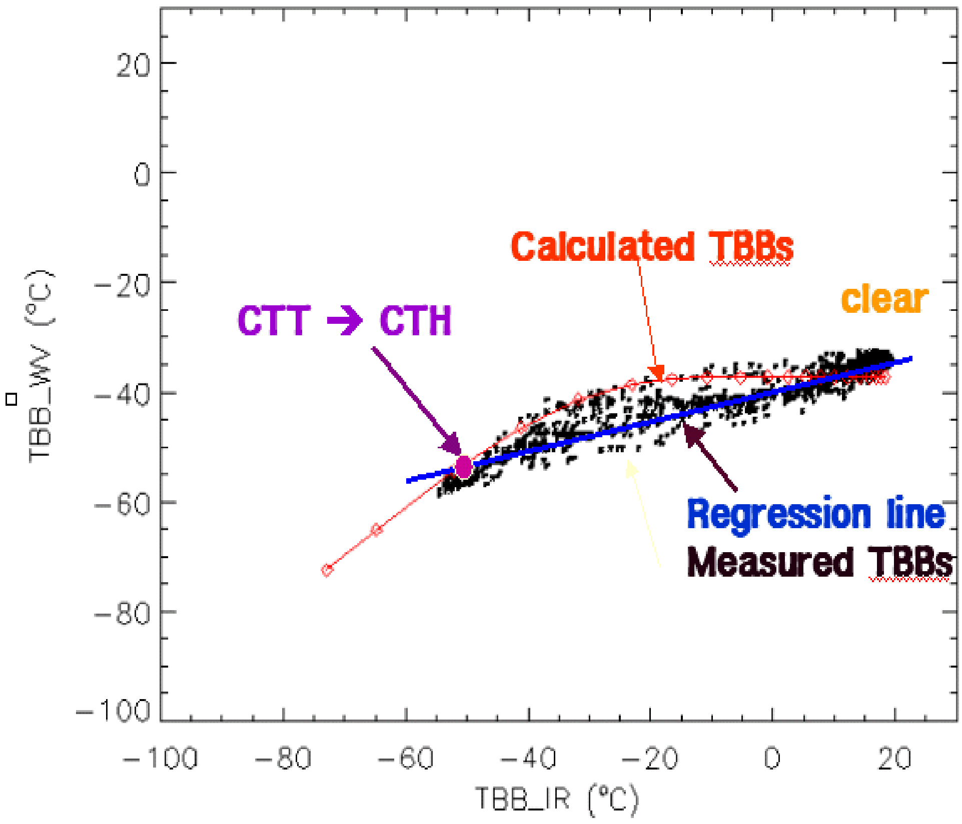
Where, R(WV) and R(IR1) are brightness temperature of WV and IR channels in the target. The subscript op and cl is opaque cloud and clear sky, respectively. If the emissivity Ne of WV and IR channel is almost equal, Equation (3.5) can be written as equation (3.6)

$$\frac{R(WV) - R_{cl}(WV)}{R(IR1) - R_{cl}(IR1)} = \frac{R_c(WV, P_c) - R_{cl}(WV)}{R_c(IR1, P_c) - R_{cl}(IR1)} \quad (3.6)$$

The curved red line in Fig. 3.5 will link up between the simulated brightness temperature of IR and WV channels for opaque clouds of each different cloud top height. The blue line is the linear trend line of IR and WV channel brightness temperatures in the target observed from a satellite. At this time, a straight line observed from satellite brightness temperature and calculated brightness temperature for opaque clouds intersects in the clear and opaque cloud area. As the height of semi-transparent clouds extends the linear trend line for brightness temperature in target, can get a point of intersection with calculated brightness temperature curve.

The existing feature of clouds in a target performs the threshold check to determine the semi-transparent clouds. In case of levels lower than 500 hPa, the height retrieved by IR/WV intercept method is not used.

Fig. 3.5 Measured TBBs within target area partially filled with clouds. The curve represents the forward calculations of TBBs for IR1 and water vapor channels for opaque clouds at different levels in the atmosphere.



C. Semi-transparent Correction (STC) Method

The STC method calculates the height of Semi-transparent clouds of IR channel AMVs on the same principle of the IR/WV intercept method. The IR/WV intercept method obtains a linear trend line using the brightness temperature of all pixels in a target observed from a satellite. The STC method estimates the height to link up with a straight line between points of simulated data and averaged brightness temperature of cloudy pixels in a target observed from a satellite.

This method can correct the simulated brightness temperature of the WV channel which has more than 20 sufficient clear pixels in a target, because this method is sensitive to clear sky simulated data of RTM. The STC method, like the IR/WV intercept method, performs the threshold check to determine for semi-transparent features of the existing clouds in a target. In the case of lower than 500 hPa levels, the height retrieved by the semi-transparent correction method is not used.

● The height assignment of Clear target AMVs

In clear targets, WV channel AMVs are produced. Unlike most IR channels, the radiance observed from the WV channel is determined by the emitted upward radiance in several atmosphere layers and had the greatest weighting value at a height of 400 hPa. If high levels of atmospheric water vapor exist in a dry region, on average, WV channel AMVs can measure the winds between 200 hPa and 400 hPa.

The Simulation data provided in CMDPS pre-processing module is performed on the assumption of opaque clouds of various layers. Then it is calculated with WV channel emissivity existing from Cloud top to atmospheric top level. The atmospheric emissivity of various optical thicknesses with the change of cloud top is calculated and the emissivity of medium value of them is considered a representative value of the atmospheric thickness. The cloud top height associated with the optical thickness of such a representative value assigns to the height of a clear target. It is divided into Normalized Total Contribution (NTC) method and Normalized Total Cumulative Contribution (NTCC) method depending on the method o determine The medium value

The horizontal axis in Fig. 3.6 shows the layer of the NWP model associated with cloud top height. When the red line has each layer at cloud top height, this shows emissivity from cloud top to atmospheric top. The NTCC method is a way to assign a representative height of clear WV channel. The atmospheric emissivity for cloud top height has 0.5 from cloud top to atmospheric top.

If the accumulative emissivity of the red line for the horizontal axis is simple differentiation, the emissivity of each atmospheric layer can be calculated. The NTC method has the highest emissivity, which is a way to assign at a representative height of the thickest in the optical thickness.

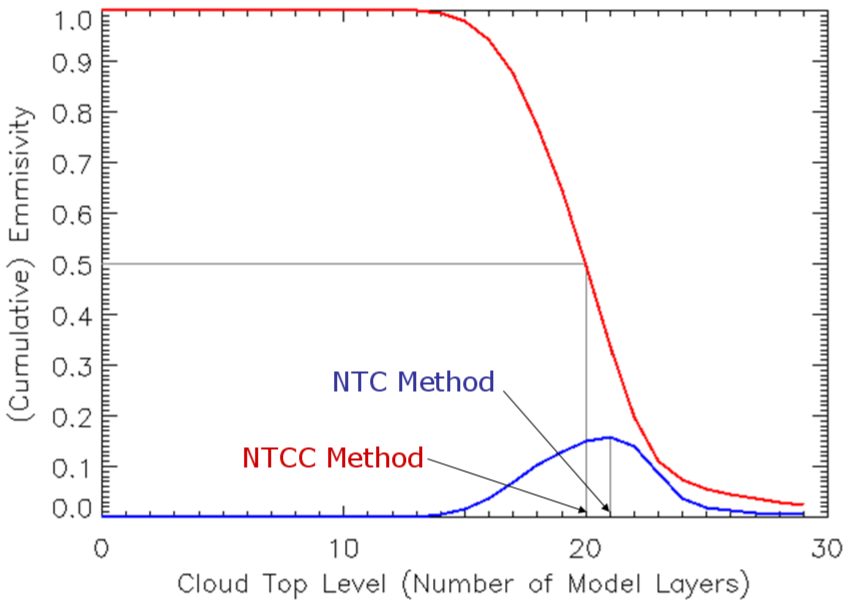
● The post-processing of height assignment

A. Height decision

IR channels AMVs have the three maximum estimation values with each height assignment algorithm (EBBT, IR/WV Intercept, STC method). Clear WV AMVs have two height estimation values with NTC and NTCC method.

The highest height for these methods, namely the pressure is selected the lowest estimation value as final height. Then, the processing of vector retrieval using cross-correlation coefficients are based on the fact that is likely to apply to movements of the highest height.

Fig. 3.6 Simulated water vapor channel emissivity of each layer (blue), and cumulative emissivity from cloud top to top of atmosphere (red).



B. Cloud base correction

Low level cumulus are based on the movement at a velocity of the cloud base. It has a vector lower than 650 hPa taken from the cloud base correction for all assigned vectors.

For the height correction of the cloud base, it estimates the cloud base temperature. This is calculated to add standard deviation multiplied by $\sqrt{2}$ of brightness temperature in a target with a representative brightness temperature of IR channels in a target. The calculated height using simulation data of IR channels from RTM with this cloud base temperature (the same way as EBBT method) is the final height of low level vectors. In case of WV channel AMVs observed for movement of atmospheric medium or high level, the height correction of cloud base is not taken.

3.2.4. Dynamic decision of vector tracking areas

To estimate the vectors, tracking area needs to derive the cross-correlation coefficients within a target. The size of a tracking area decides the maximum winds which AMVs can observe. If it uses the tracking area of 80×80 pixel size, the target of 24×24 pixel size can move as 28 pixels in the east-west direction. This algorithm uses imagery of 4 km resolution every 15 minutes applicable to size which can observe the wind speed of about 124 ㎧ in sub-satellite point. If the size of tracking area become smaller, it retrieves the wrong vectors in strong wind areas. If the tracking area is bigger, the probability of the maximum cross-correlation coefficient on real displacement and irrelevant location increases and slows down the stability of vector retrieval.

To solve these at the same time, dynamic tracking area is adopted to increase general quality of vectors and retrieval stability. It will predict the moving position of a target using NWP wind data if the position of a target is determined and the height is assigned.

If it traces vectors moving in the predicted position at the center of a target, large wind speed in small target areas can be observed, and it can reduce the probability of tracking errors that occur in overlarge areas with small wind speeds. However, if a tracking area is configured in too small of an area, AMVs are generally similar to the predicted wind of NWP or errors in vector tracking are likely to happen. Also, if the wrong height is estimated in the height assignment algorithm, then there is an error in vector tracking, which shows it in the incorrect position. In case of wind speed of NWP less than 20㎧, it do not move the center of a tracking area. The size of a tracking area is configured to have the observation range of ±30㎧ which compared with NWP wind fields both zonal and meridional flow.

3.2.5. Quality control

In the process of checking the quality of final calculated vectors, the quality information of this algorithm uses the applied method (Holmlund, K., 1998) of AMVs at EUMETSAT and consists of five tests in all (Fig. 3.7). Each test is calculated considering the temporal and spatial variation of observed winds. If the temporal and spatial resolution changes, it can be optimized accordingly. This checks temporal direction consistency between two vectors retrieved from the continuous three satellite imagery for QI retrieval.

The next step checks the spatial vector consistency of final vectors and the temporal forecast consistency calculated with the simple average of two vectors. Each check represents the quality from 0 to 1. This weighting average becomes the final quality coefficient and then the weighting value for spatial homogeneity is 2, the weight for the rest elements retrieve with 1.

For mean wind speed, vectors smaller then 2.5 ㎧ are less accurate, and lowers the final quality coefficient multiplied by 0.4 of wind speed. In the case of height of WV channel AMVs observed in high level winds lower than 400 hPa, it lowers the quality coefficient in proportion to the square of vertical distance and all low level vectors less than 500hPa have the quality coefficient of zero. The coefficients of each quality function for the current algorithm shown in Table 1.

Table. 1 Coefficients for calculation of quality indicator

Temporal direction consistency	a_{tdc} = 20. b_{tdc} = 10. c_{tdc} = 10. d_{tdc} = 4.
Temporal speed consistency	a_{tsc} = 0.2 b_{tsc} = 0.01 c_{tsc} = 1. d_{tsc} = 2.5
Temporal vector consistency	a_{tvc} = 0.2 b_{tvc} = 0.01 c_{tvc} = 1. d_{tvc} = 3.
Spatial vector consistency	a_{svc} = 0.2 b_{svc} = 0.01 c_{svc} = 1. d_{svc} = 3.
Temporal forecast consistency	a_{tfc} = 0.2 b_{tfc} = 0.01 c_{tfc} = 1. d_{tfc} = 3.

3.3. The retrieval process

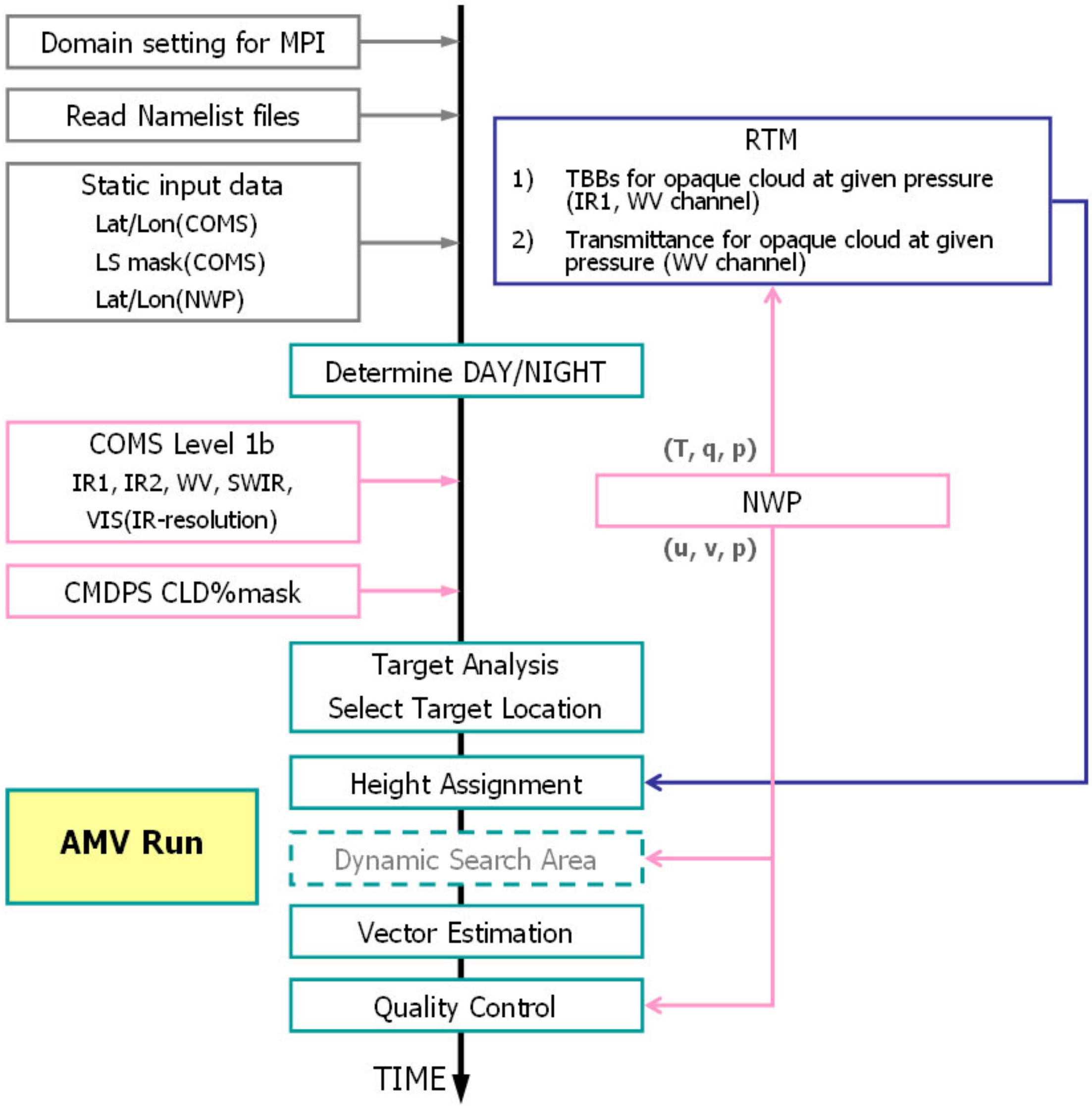
This section is concerned with technical parts which are needed to retrieve the AMVs. This intensively handles to importantly think in operation or require careful items. The basic flow of AMVs module is as follows in Fig. 3.8.

3.3.1. Input data (NWP and RTM data)

The results of the global NWP are used as input data of RTM, also are used on the quality decision and dynamic tracking area of AMVs. The radiative simulation requires considerable calculation, and is prepared in the pre-processing step before satellite imagery is received. Temperature, humidity, wind, and pressure of NWP parameters are used, and IR channel brightness temperature and WV channel emissivity of the RTM simulated results are used.

The NWP data uses forecast fields of standard time (00, 06, 12, 18 UTC) of the global model, RTM use the Radiative Transfer For ATOVS (RTTOV). RTTOV perform the integrals based on 43 isobaric surface (1013-0.1 hPa), vertical temperature, humidity data of GDAPS model creates initial input data of RTM to interpolate/extrapolate in accord with them.

Fig. 3.8 Flow chart of AMV production

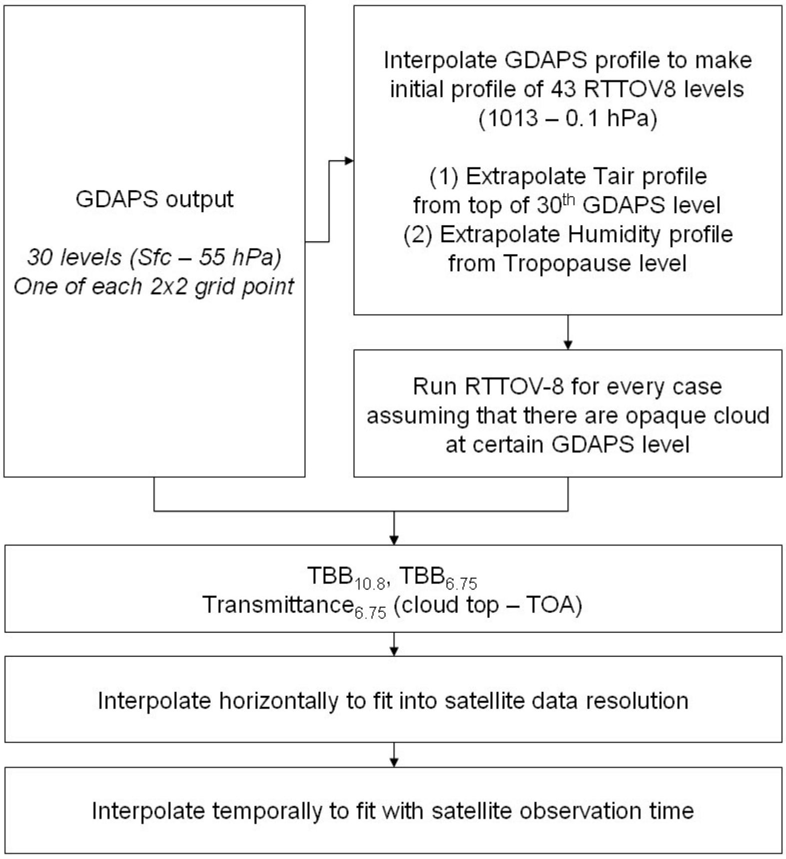


Data higher than the top level of the used global model is made based on the standard atmospheric data built in RTTOV. GDAPS has a feature for overestimated simulation of upper water vapor, the error is open to increase in the case of performing the RTM. Humidity is used until the tropopause and more height is used to transform based on the standard atmospheric data to minimize its effect in the development process. Radiative simulation is performed as total layer of the vertical troposphere for each horizontal pixel of NWP.

Each simulation assumes that the opaque clouds for the emissivity value of 1 exist. Each results of simulation are IR, WV channel brightness temperature and WV channel emissivity. These are considered for radiative simulation only in higher atmosphere than assumed cloud layers.

The NWP model and RTM data is timely interpolated for the retrieval time of AMVs. It is spatially interpolated considering the location of each target in this AMV algorithm. Spatial interpolation uses four locations around each target centers. Temporal interpolation uses data of two hours along the retrieval time in AMVs. The prediction time information of the NWP and RTM models in the setting step of execution is automatically entered into the nwp_time variable of the Namelist file.

Fig. 3.10 Preparation of NWP and RTM data



3.3.2. Input data (Satellite imagery and products)

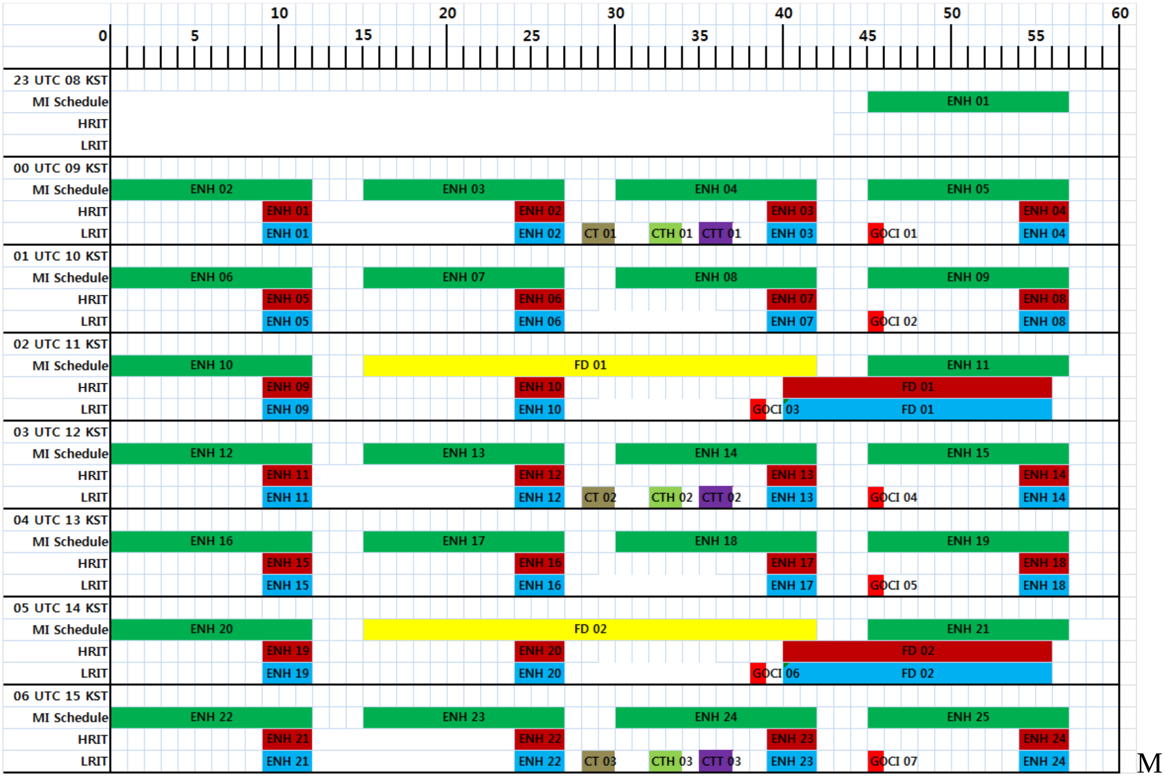
To retrieve AMVs, three images with a know observation time are needed. The visible channel image uses data of 4km resolution provided by CMDPS, not the raw data at 1km resolution.

- A digital count
- Brightness temperature (in the case of visible channel reflectance)
- Observation time
- Day/night information
- Latitude/longitude data (static input data)
- Land/sea information (static input data)
- Cloud mask information (CMDPS cloud mask results)

Three images in satellite observation of the same location, the different time periods need to retrieve one vector. It calculates the vectors using three images from satellites at 15 minute intervals based on an hourly 00 minute depending on the observation schedule of COMS. Namely, it retrieves the vectors using every hour three images of 45, 00, and 15 minutes. However, in time zones observing in global area of eight times a day, at 3-hour intervals from 02 UTC, we do not use additional image data of the global region. It retrieves vectors of the northern hemisphere using three images of satellites at 30, 45, 00 minutes.

For day/night determination, cloud pixel decisions, target analysis, time interpolation of NWP and RTM data, AMV extraction is based on second imagery and observation time in the three images. The difference value of observation time of two images is needed to calculate the size of vectors. For a reliable vector size extraction, exact measurement time of each pixel from satellites is needed. If east/west width utilizes uniform data in all observation modes like COMS, knowing the observation starting time can tell the difference between imagery of all pixels.

Fig. 3.9 COMS MI Observation and H_LRIT Dissemination Schedule



Cloud information is provided by the cloud detection algorithm in CMDPS. Extracting one image of hemisphere AMVs requires cloud detection results of images corresponding to the second time in the three images used.

AMVs modules calculate for the sun zenith angle of each pixel considering the latitude/longitude data and observation time information. The AMVs of visible channel extracts the location of the sun zenith angle less than 80 degree in pixel area during the daytime. SWIR channel AMVs extract for more than 100 degrees during the nighttime.

3.3.3. Configuration for target selection

Target is the basic unit of AMV extraction. It requires attention because the feature of vector extraction can change depending on the attributes of a target. The attributes of the basic target is as follows:

- Target area size (ref_range)

- Vector retrieval resolution (grid_vector)
- target extraction pixel ratio (sampling ratio)

The current AMVs algorithm (Based on HRIT resolution), the target area (ref_range) is 24×24 pixels. The retrieval resolution (grid_vector) is adjusted by 12×12 pixels. The EBBT method in the height assignment algorithm uses the mean IR channel brightness temperature of 15% cold pixels over cloud pixels in a target.

An unsuitable target for retrieving AMVs is excluded through the following threshold values:

- Ratio of cloud pixels (thr_per_cld)
- Occupation ratio of land/ocean (thr_sel_ls_fraction)

For the ratio of cloud pixels in a target, the target below the threshold values is not retrieved if these are unsuitable. WV channel AMVs detecting the current of water vapor instead of cloud is irrelevantly retrieved for the presence of clouds. Target including the coastline may not estimate the valid vectors because radiation effect of land and sea. The ratio of the main portion below threshold among land and sea in target cannot retrieved the vectors

3.3.4. The retrieval control of quality information

In section 3.2.4 the basic idea of quality information extraction for the retrieval method is explained. To retrieve the Quality Indicator (QI), it checks temporal direction consistency between two vectors retrieved in three consecutive satellite images. It also checks spatial vector consistency of final vectors and temporal forecast consistency with NWP wind data calculated in a simple average of two vectors. Each check indicates a quality with values ranging from 0 to 1. Their weighting average is the final quality coefficient and then the weighting value for spatial consistency is 2, the weighting values for the rest of elements is set to 1.

It is decided to set the logical variables of wind direction (l_aqc_temporal_direction_cons), wind speed (l_aqc_temporal_speed_cons), vectors (l_aqc_temporal_vector_cons), temporal consistency with NWP wind data of namelist whether each test is the determination of quality coefficient use or not. The namelist variables for weight value of each check are aqu_tbc_w, aqc_tsc_w, aqc_svc_w, and aqc_tfc_w in CMDPS_AMV_Mod_Postproc.F90 file.

3.3.5. Output data

The attributes and the result variables finally retrieved from AMVs algorithm is shown in Table 4. It is possible to output other variables based on the purpose of the research, but the following variables are basically produced.

Table. 4. Output data for AMV module

OUTPUT DATA							
Parameter	Mnemonic	Unit	Min	Max	Prec	Acc	Res
SATELLITE IDENTIFIER	sat_id	-	-	-	-	-	pixel
IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	id_org_gen_cen	-	-	-	-	-	pixel
SATELLITE CLASSIFICATION	sat_class	-	-	-	-	-	pixel
SEGMENT SIZE AT NADIR IN X DIRECTION	seg_size_x	-	-	-	-	-	pixel
SEGMENT SIZE AT NADIR IN Y DIRECTION	seg_size_y	-	-	-	-	-	pixel
YEAR	sat_time_year2	-	-	-	-	-	pixel
MONTH	sat_time_mon2	-	-	-	-	-	pixel
DAY	sat_time_day2	-	-	-	-	-	pixel
HOUR	sat_time_hour2	-	-	-	-	-	pixel
MINUTE	sat_time_min2	-	-	-	-	-	pixel
SECOND	sat_time_sec	-	-	-	-	-	pixel
LATITUDE	opt_target_lat	°	-	-	-	-	pixel
LONGITUDE	opt_target_lon	°	-	-	-	-	pixel
SATELLITE INSTRUMENT USED IN DATA PROCESSING(6)	sat_istr	-	-	-	-	-	pixel
SATELLITE DERIVED WIND COMPUTATION METHOD	opt_target_amv_mth	-	-	-	-	-	pixel
PRESSURE	pressure	hPa	-	-	-	-	pixel
WIND DIRECTION	fnl_amv_wd3	°	-	-	-	-	pixel

WIND SPEED	fnl_amv_ws3	m/s	-	-	-	-	pixel
SATELLITE CHANNEL CENTRE FREQUENCY	sat_ch_cen_freq	Hz	-	-	-	-	pixel
SATELLITE CHANNEL BAND WIDTH	sat_ch_bnd_wdth	Hz	-	-	-	-	pixel
COLDEST CLUSTER TEMPERATURE	opt_target_cold_temp	K	-	-	-	-	pixel
HEIGHT ASSIGNMENT METHOD	hgt_ass_mth	-	-	-	-	-	pixel
TRACER CORRELATION METHOD	tracer_corr_mth	-	-	-	-	-	pixel
LAND/SEA QUALIFIER	opt_target_lsmask	-	-	-	-	-	pixel
SATELLITE ZENITH ANGLE	opt_target_sat_zen	°	-	-	-	-	pixel

3.4. Validation

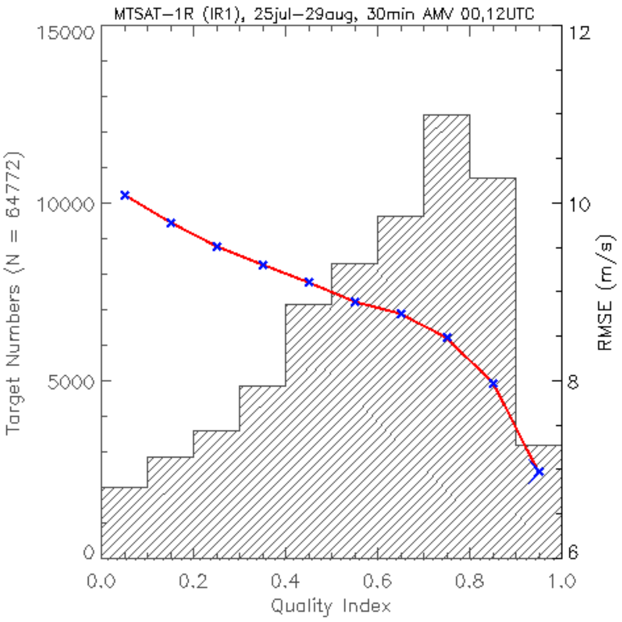
3.4.1. Validation method

The validation of AMVs is performed in comparison to the observed wind data from radiosondes. In case of the accuracy assessment, the quality coefficient is done on the basis of validation using vectors greater than 0.85. The quality coefficient level of the validated AMVs can be established differently depending on the data application field. If the vectors are included which have small quality coefficients, the number of the retrieval vectors increase, but their accuracy decreases.

The bar graph of Fig 3.11 shows the number of vectors included within the range of each quality coefficient. A red line shows the accuracy of all vectors which have a higher quality coefficient value of the horizontal axis. In case of the accuracy assessment, it is done on the basis of including the validation target that the vector is not different from the radiosonde wind speed more than $30ms^{-1}$ and wind direction more than 90 degrees.

The validation index is as follow, the RMSE of vectors and the bias of wind speed is an important validation index. If it standardizes to divide the RMSE into the radiosonde mean wind speed, it is possible to compare the validation indices for other regions and seasons.

Fig. 3.11 Collocation numbers and Vector-RMSEs for each quality criteria



$$(MVD)=\frac{1}{N}\sum_{i=1}^{N}(VD)_i \tag{3.7}$$

$$(VD)_i=\sqrt{(U_i-U_r)^2+(V_i-V_r)^2} \tag{3.8}$$

$$(SD)=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(VD)_i-(MVD)^2} \tag{3.9}$$

$$(RMSE)_i=\sqrt{(MVD)^2+(SD)^2}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(VD)_i^2} \tag{3.10}$$

$$(BIAS)_i=\frac{1}{N}\sum_{i=1}^{N}\left(\sqrt{U_i^2+V_i^2}-\sqrt{U_r^2+V_r^2}\right) \tag{3.11}$$

3.4.2. Validation data

Validation of AMVs using radiosonde data is aimed at all observation data within a satellite's wind extraction area.

3.4.3. Collocation methods

Among satellite winds retrieved based on radiosonde observation time within an hour, AMVs are retrieved accurately within 150km in the horizontal and 20 hPa in the vertical from their matching radiosonde wind data.

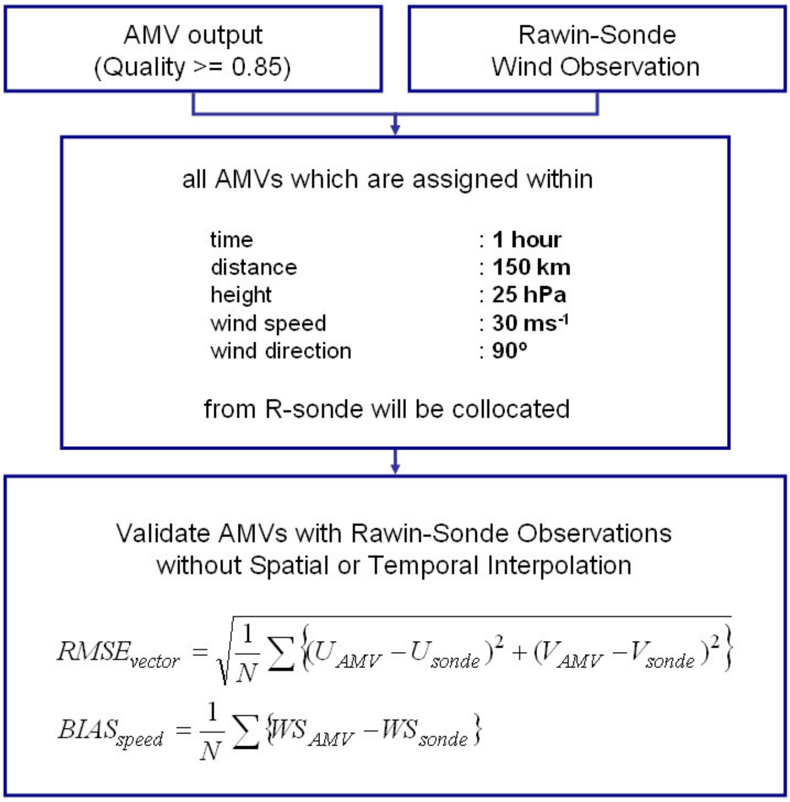


Fig. 3.12 Flow chart of AMV validation using rawinsonde data

3.4.4. Validation result analysis

The AMV algorithm studies and the validation of the retrieved results were performed during the month of February 2012. For vectors with a quality index of greater than 0.85, the RMSE is about 3.83 ㎧ (If it standardizes into observation wind speed, it is about 0.20), The bias showed the value of –

0.73 ㎧Vectors-RMSE and wind speed-Bias reflect the features of wind system changed for the area and season. AMV accuracy reports of collocated Coordination Group for Meteorological Satellites (CGMS) monthly have also disseminated the results of validation for latitude and height.

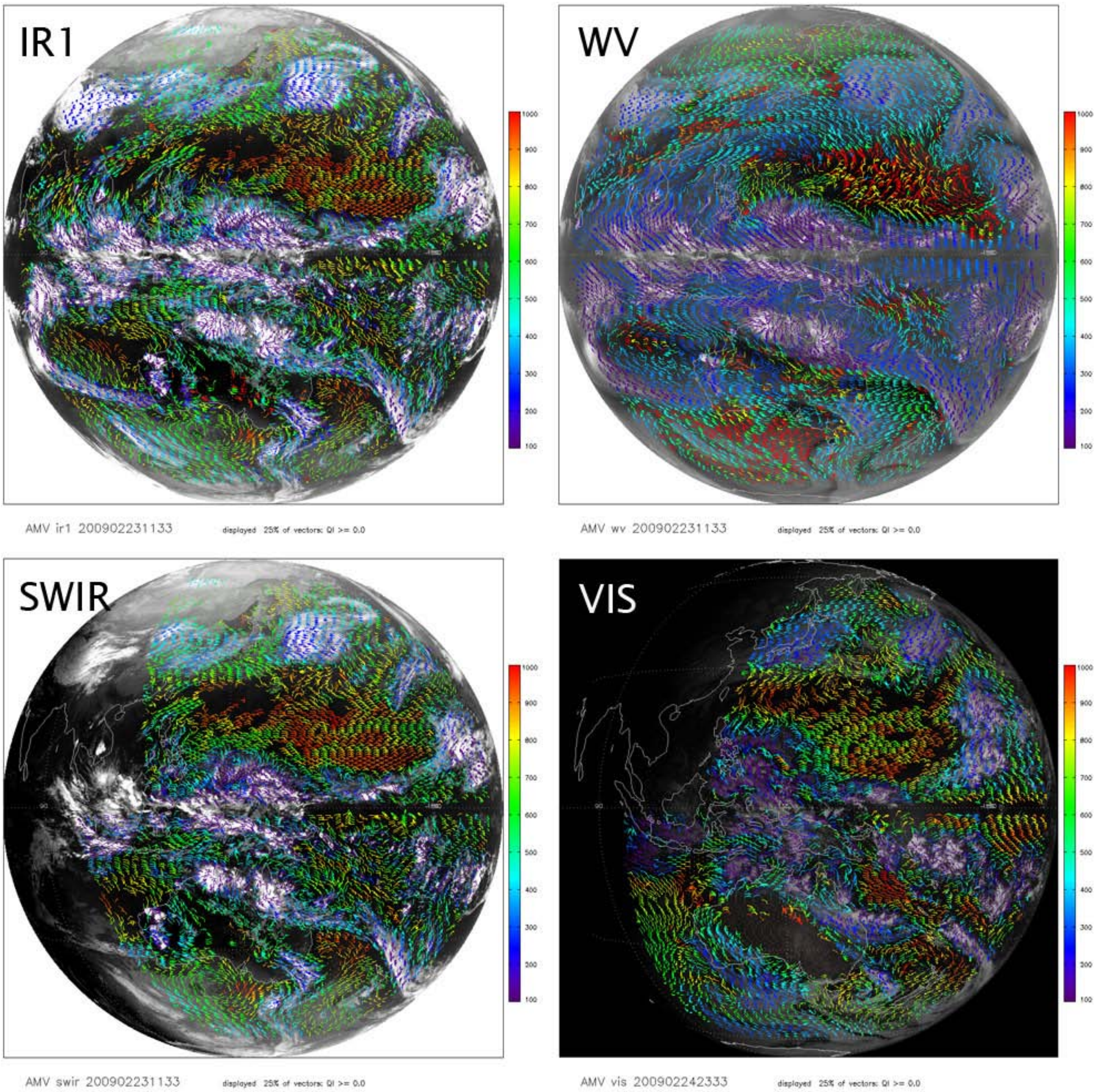
Table. 5 Example of validation table

lat =	-20°S - 50°N
altitude =	0hPa - 1000hPa
period =	01feb2012 - 31feb2012
rmsvd =	3.83
nrmsvd =	0.20
ws(amv-nwp) =	19.58
bias =	-0.73
N =	377135

4. Retrieval result analysis

Basically, AMVs are observation wind field data. Its output can be use to read the values of wind direction, wind speed, and vector height. AMV images use the produced final products closest to the requirement dissemination time. Their images are expressed in wind vectors divided into three heights of low / medium / high level based on images of each channel. The size of images and production / dissemination time can change depending on the observation mode of COMS. It can additionally adjust the number of vector on reference to quality index depending on usage purpose. Fig. 3.13 is an example of AMVs for each channel. For a feature of each channel extraction, VIS channel vector has a low level vector less than 700 hPa. Vectors of cloud targets for WV channels refer to high level vectors more than 400 hPa.

Fig. 3.13 Sample images of AMVs for each channel (displayed only 25%)

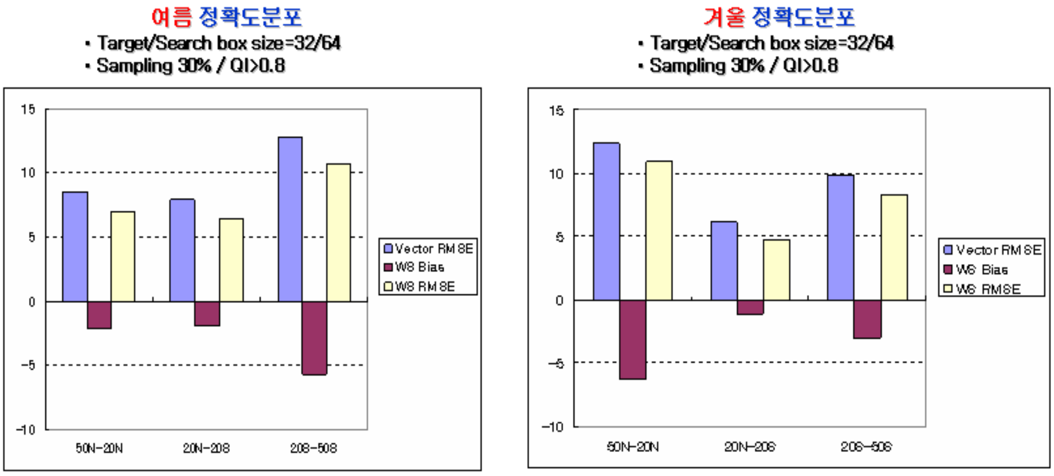


5. Problems and possibilities for improvement

• Wind speed error of AMVs

One of the problem for the current algorithm is that compared with observation, wind speed will have a relatively lower deviation. As can be seen in Fig 3.15, wind speed shows the tendency to be smaller than total observation regardless of season and area. The deviation in the winter hemisphere is bigger. The sensitivity results for size of target area, the deviation of wind speed in smaller target than the present can see to be improved and additional studies need.

Fig. 3.14 Regional validation results for long-term AMVs



● Sensitivity variations by Target size

The retrieval of AMVs handles the movement of a total target. Height assignment is calculated through the representative value of the radiative features of a target. If multi-layered clouds exist within pixels, vectors cannot easily be extracted. If the size of target is different, the scale of atmospheric phenomenon and the radiative distribution features included within a target can be changed. Therefore, in the case of using targets of uniform size, AMVs can exist in which the atmospheric motion is difficult to extract properly.

● Inconsistency of vector tracking and height assignment process

Vector tracking and height assignment algorithm can be calculated in response to other each pixel. It retrieves one representative vector for this target using all pixels within a target area associated with vector tracking. However, the height of a vector is decided by 15% cold pixels within a target area. Buche (2006) derived contribution ratio for vector extraction of each pixel within a target area through cross-correlation coefficients calculated in the processing of vector tracking. This has shown improvement using the height assignment high pixels of contribution ratio. A study on the representative decision of pixels associated with height assignment will be continued.

6. References

Bormann, N., Sami Saarinen, Graeme Kelly, and Jean-Noël Thépaut, 2003, The spatial structure of observation errors in atmospheric motion vectors from geostationary satellite data, *Mon. Wea. Rev.*, **131**, 706-718.

Bűche, G., H. Karbstein, A. Kummer, and H. Fischer, 2006, Water vapour structure displacements from cloud-free Meteosat scenes and their interpretation for the wind field, *J. Appl. Meteorol. Clim.*, **45**, 556-575.

Cherubini, T., S. Businger, C. Velden and R. Ogasawara, 2006: The impact of satellite-derived atmospheric motion vectors on mesoscale forecasts over Hawaii, *Mon. Wea. Rev.*, **134**. 2009-2020.

Goerss, J. S., C. S. Velden, and J. D. Hawkins, 1998: The impact of multispectral GOES-8 wind information on Atlantic tropical cyclone forecasts in 1995. Part II: NOGAPS forecasts. *Mon. Wea. Rev.*, **126**, 1219-1227.

Holmlund, Kenneth, 1998, The utilization of statistical propertied of satellite-derived atmospheric motion vectors to derive quality indicators, *Wea. Forecasting*, **13**, 1093-1104.

——, Christopher S. Velden, and Michael Rohn, 2001, Enhanced automated quality control applied to high-density satellite-derived winds, *Mon. Wea. Rev.*, **129**, 517-529.

Hubert, L. F., and L. F. Whitney JR., 1971, Wind estimation from Geostationary-Satellite pictures, *Mon. Wea. Rev.*, **99**, 665-672.

Key, J., D. Santek, C. S. Veldenn, N. Bormann, J.N. Thepaut, L. P. Riishojgaard, Y. Zhu, and W. P. Menzel, 2002: Cloud drift and water vapor winds in the polar regions from MODIS. *IEEE Trans. Geosci. Remote. Sens.*, **41**, 482-492.

Leese, John A., Charles S. Novak, and Bruce B. Clark, 1971, An automated techniques fro obtaining cloud motion from Geosynchronous satellite data using cross correlation, *J. Appl. Meteorol.*, **10**, 118-132.

Mecikalski, J.R., K.M. Bedka, 2006 : Forecasting Convective Initiation by monitoring the evolution of moving cumulus in daytime GOES imagery. *Mon. Wea. Rev.*,**134**, 49-134.

Nieman, Steven J.. W. Paul Menzel, Christopher M. Hayden, Donald Gray, Steven T. Wanzong, Christopher S. Velden, and Jaime Daniels, 1997, Fully automated cloud-drift winds in NESDIS operations, *Bull, Amer. Metoor. Soc.*, **78**, 1121-1133.

Rao, P. Anil, Christopher S. Velden, and Scott A. Braun, 2002, The vertical error characteristics of

GOES-derived winds : Description and experiments with Numerical Weather Prediction, *J. Appl. Meteorol.*, **41**, 253-271.

Rogers. E. et al., 1979: The benefits of using short-interval satellite images to derive winds for tropical cyclones, *Mon. Wea. Rev.*, **107**, 575-584

Schmetz, J., Kenneth Holmlund, Joel Hoffman, Bernard Strauss, Brian Mason, Volker Gaertner, Arno Koch, and Leo Van De Berg, 1993, Operational cloud-motion winds from Meteosat Infrared images, *J. Appl. Meteorol.*, **28**, 1206-1225.

Solden, B.J., C.S. Velden, and R.E. Tuleya, 2001: The impact of satellite winds on experimental GFDL hurricane model forecasts. *Mon. Wea. Rev.*, **129**, 835-852.

Su, Xiujuan, John Derber, Steve Lord, Christopher S. Velden, and Jaime Daniels, 2003, Toward improved use of GOES satellite-derived winds at the National Centes for Environmental Prediction(NCEP), Office note **440**.

Tokmakian, Robin, P. Ted Strub, and Julie Mcclean-Padman, 1990, Evaluation of the maximum cross-correlation method of estimating sea surface velocities from sequential satellite image, *J. Atmos. Ocean. Tech.*, **7**, 852-865.

Tomassini, M., G. Kelly, and R. Saunders, 1999, Use and impace of satellite atmospheric motion winds on ECMWF analyses and forecasts, *Mon. Wea. Rev.*, **127**, 971-986.

Velden, C. S., C. M. Hyden, W. P. Menzell, J. L. Franklin and J. S. Lynch, 1992: The impact of satellite-derived winds on the hurricane track forecasting. *Wea. Forecasting*, **7**, 107-119.

——, T. L. Olander, and S. Wanzong, 1998: The impact of multispectral GOES-8 wind information on Atalantic tropical cyclone track forecasts in 1995. Part I: Dataset methodology , description, and case analysis, *Mon. Wea. Rev.*, **126**, 1202-1218

—— and Coauthors et al, 2005: Recent innovations in deriveing tropospheric winds from meteorological satellites, *Bull. Amer. Meteo. Sec.*, **86**, 205-223

Xiao, Q., X. Zou, and Y. H. Kuo, 2000: Incorporating the SSM/I-derived precipitable water and rainfall rate into a numberical model: A case study for ERICA IOP-4 cyclone. *Mon. Wea. Rev.*, **128**, 87-108.

Zhang, S.F., and S.W.Wang, 1999: Numerical experiments of the typhoon tracks by using satellite cloud-derived wind. *J. Trop. Meteor.*, **15**, 347-355.