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IMPACTS OF SPATIAL OBSERVATION ERROR CORRELATION IN ATMOSPHERIC MOTION VECTORS ON DATA ASSIMILATION

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Abstract

This study investigates spatial error correlations in the Atmospheric Motion Vectors (AMVs) derived from geostationary satellite imagery over the East Asia. A good characterization for the systematic errors of observation is essential in order to extract information from the observation during assimilation process. The spatial structure of the AMV error correlations is identified based on monthly datasets of AMVs and sonde observations collocated for July in 2015. Results for AMVs from infrared (IR; 10.8 µm) and water vapour (6.7 µm) channels of the Multifunction Transport Satellite (MTSAT-2) and the Korean geostationary Communication, Ocean and Meteorological Satellite (COMS) are presented. Winds from two datasets show statistically significant spatial error correlations depending on distance with little difference between satellites and channels. Especially, the length sacale of correlation for MTSAT AMVs is longer than that of COMS AMVs, which is connected to the observation error inflation of each satellite.

INTRODUCTION

AMVs from geostationary satellites provide excellent temporal and spatial coverages, and therefore AMVs are an important input to most global data assimilation systems (Bouttier and Kelly, 2001). In data assimilation system, observations are assumed to be unbiased and uncorrelated. However, quality control procedures tend to favor winds that are consistent with neighboring winds, which is enhancing the chance of correlated errors. Generally, AMVs possess spatially correlated errors and thus invalidate the assumption on uncorrelated observation errors (Rohn et al., 2001). As current data assimilation systems do not account for such correlated errors, AMVs are thinned or observation errors are inflated to avoid overfitting.

In East-Asia, AMVs are derived by tracking clouds in the IR, WV and visible channels of the Korean Meteorological Agency (KMA) and the Japan Meteorological Agency (JMA) from two geostationary satellites: COMS and MTSAT-2. The forecast impact of COMS AMVs is broadly comparable to that of operational MTSAT AMVs (Lee et al., 2015). This paper characterizes statistically the spatial structure of observation errors in AMVs by analyzing pairs of AMV-sonde collocations for one month from July 1 to 31, 2015. The spatial correlations of COMS and MTSAT AMV errors give background independent estimates of AMV errors, and it can provide important guidance for the use of AMVs in data assimilation system. The results are an important towards the use of spatially correlated observation errors, or the improvement of thinning schemes or observation errors used for AMVs. In this study, it is discussed how AMVs (i.e., observation; O) and model winds (i.e., background; B) are used to characterize the spatial error correlation structure and to estimate the spatially correlated error in the satellite winds. We then present our results on the error correlations and estimates of the inflated AMV observation error.

METHOD

Collocations between AMV and sonde

The calculations presented in this study use a large number of pairs of collocations between AMV and sonde (including windprofiler) to validate spatially correlated AMV errors. Also, same calculations with pairs of collocations between background wind and sonde are performed to estimate spatially correlated model wind errors. Note, two datasets of background winds are selected from collocated pixels of sonde-COMS AMV and sonde-MTSAT AMV, respectively. We use the AMVs with a quality indicator (QI) threshold of 80% to filter out poor-quality data. Compared to AMV errors, KIAPS Integrated Model version 2.3 (Hong et al., 2015) is used for spatial correlation error of background.

Figure 1 shows the sonde collocated AMVs of COMS and MTSAT. Although horizontal coverage of both satellites is different, this study is focusing on characterizing the spatially correlated AMV error for each satellite. The collocation criteria are as follows: One AMV and one sonde are collocated if they are less than 150 km apart, have less than 25 hPa separation in the vertical, and are separated less than 18 m/s in vector difference. These criteria follow recommendations of the Coordination Group for Meteorological Satellites (Velden and Holmlund, 1998) and previous study (Bormann et al., 2003). As shown in Figure 1, the vertical coverage of COMS is deeper than that of MTSAT, but AMVs of high-level (WV and IR channels) are used to compare the spatial correlation error for both satellites. For your guidance, AMVs of visible channel are excluded in this study because COMS and MTSAT AMVs in the operational numerical weather prediction (NWP) systems are masked for land, so collocated sonde-AMV dataset is nearly few. Then, total samples of high-level COMS and MTSAT AMVs are 134,808 and 163,286, respectively (see Table 1).

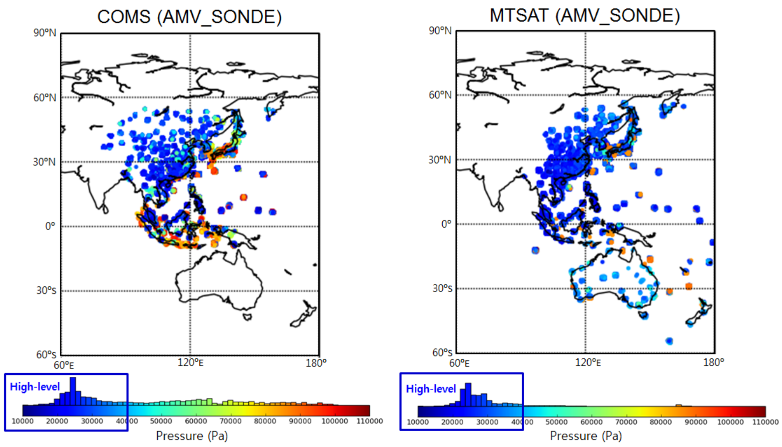

Figure 1: **Collocated sonde-COMS AMVs (left) and sonde-MTSAT AMVs(right). AMVs are used for WV and IR winds of both satellites.**

Likewise Bormann et al. (2003), we calculated first departure-correlations for the both satellites as follows: 1/2(<△u, △u>)+(<△v, △v>). For each pair, wind observations from two sonde stations have been collocated with a different satellite wind. It is based on the assumption that observation errors from sondes are spatially uncorrelated. Therefore, any correlation between the AMV-sonde differences of two stations are attributed to spatially correlated AMV errors, which is done in an isotropic way. Next, we derived a least squares fit of a correlation function to our empirical correlation data.

$$R(r) = R_0\left(1+\frac{r}{L}\right)e^{-r/L}$$

Where, R is a correlation function of the station distance r with the intercept R_0 and the length scale L as fitting parameters. The function is used to extrapolate the correlation data in a statistically reasonable way to zero separation to estimate the AMV errors.

RESULTS AND DISCUSSION

Isotropic error correlations

Figure 2 shows the departure correlation of sonde and AMVs as a function of station distances for the different satellites. Compared to correlation length scale of COMS AMVs (L_{COMS}), the length scale of MTSAT AMVs (L_{MTSAT}) with spatial correlation error is about twice longer (see Table 1). Although AMVs of both satellites are derived same channel with same wavelength, image scanning interval and target box size are different. Target selection to estimate AMVs use 24 x 24 pixels (i.e., 96 x 96 km at the sub–satellite point) and 16 x 16 km pixels (i.e., 64 x 64 km at the sub–satellite point) for COMS and MTSAT, respectively. Additionally, we should note that the spatial coverage of MTSAT is up to the Southern Hemisphere. The correlations tend to be flatter and broader over the Tropics for most winds (Bormann et al., 2003). On the other hand, it is interesting AMVs derived from high-level WV shows L is longer than that from high-level IR for both satellites (see Table 1). Generally, IR AMVs retrieved by small-scale clouds but WV AMVs are retrieved by large-scale clouds. It is probably related to spatial correlation errors of each channel.

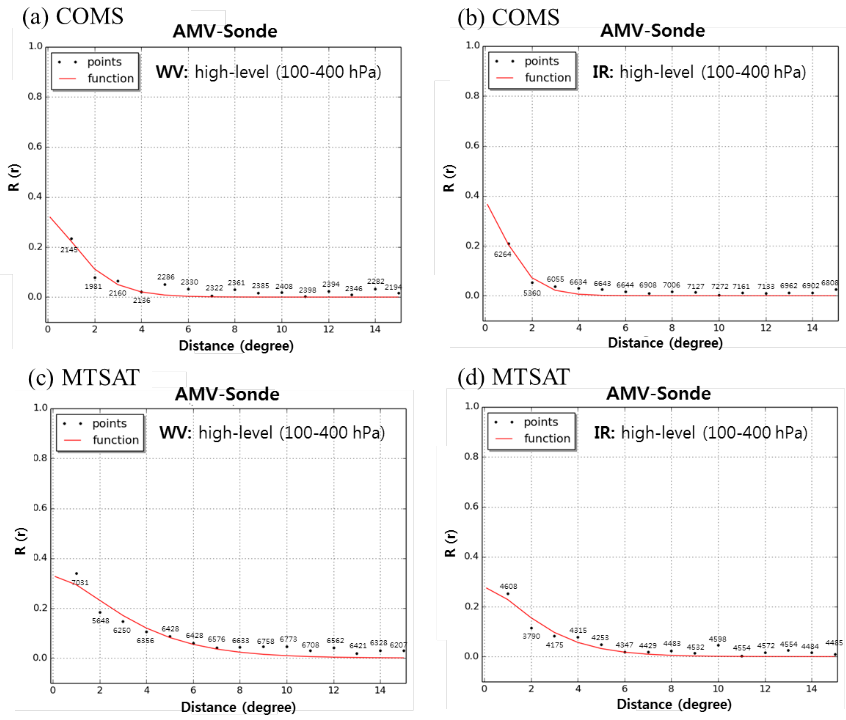

Figure 2: **Departure correlation (R) of AMVs and sondes as a function of station separation. COMS and MTSAT AMVs are used in the high-level IR and WV. Black dots are the statistics of AMV-sonde correlation and red line is the fitting plot. The number is pairs of the collocations used per data point.**

Table 1 is the statistics of the correlation functions for COMS and MTSAT AMVs in Figure 2. It is strange that the number of MTSAT AMVs in high-level WV is about 3 times larger than that of COMS AMVs (but the number of data in IR channel is opposite), even though AMV retrieval algorithms of WV and IR channels in both satellites are same (Sohn et al., 2012). As mentioned before, fitting parameters show larger spatially correlated error in the MTSAT AMVs: e.g., L_{MTSAT} of WV and IR channels are 1.86 and 1.36 degrees, respectively. Especially, the variance of AMVs in observation space is larger for the MTSAT: 19.91 and 18.16 m/s for WV and IR channels, respectively (compare the variances of COMS AMVs).

Error correlation structures for different channels do not differ significantly, in the sense that the correlation scales of the fitted correlation function are usually not significantly different (Figure 2). Nevertheless, the correlations of the AMV-sonde differences of both channels tend to be slightly larger for winds derived WV channel (L_{COMS} = 0.90 and L_{MTSAT} = 1.86 degrees) compared to winds derived IR channel (L_{COMS} = 0.66 and L_{MTSAT} = 1.36 degrees). This indicates a different partitioning of the correlated and uncorrelated error contributions in the AMV-sonde differences, with slightly stronger spatially correlated contributions at different channels.

	No. Sample	R_0	L (degree)	Variance (σ_{AMV}^2) (m/s)
COMS				
WV, high-level	34,128	0.32	0.90	14.59
IR, high-level	100,680	0.37	0.66	13.98
MTSAT				
WV, high-level	97,107	0.33	1.86	19.91
IR, high-level	66,179	0.28	1.36	18.16

Table 1: **Sample numbers of COMS and MTSAT AMVs derived by high-level WV and IR channels, fitting parameters R_0 and L for the isotropic part of the correlations, and the variance of the AMVs with collocated sonde data.**

In Figure 3, the background winds in collocated COMS and MTSAT AMVs give similar error correlations with relatively consistent pattern. It is interesting that COMS AMVs have shorter *L* than that of background winds, but MTSAT AMVs show longer *L* in observation space (compare Figures 2 and 3, and Tables 1 and 2). These characteristics of COMS and MTSAT AMVs can be reflected the inflated observation error with considering spatial correlation errors.

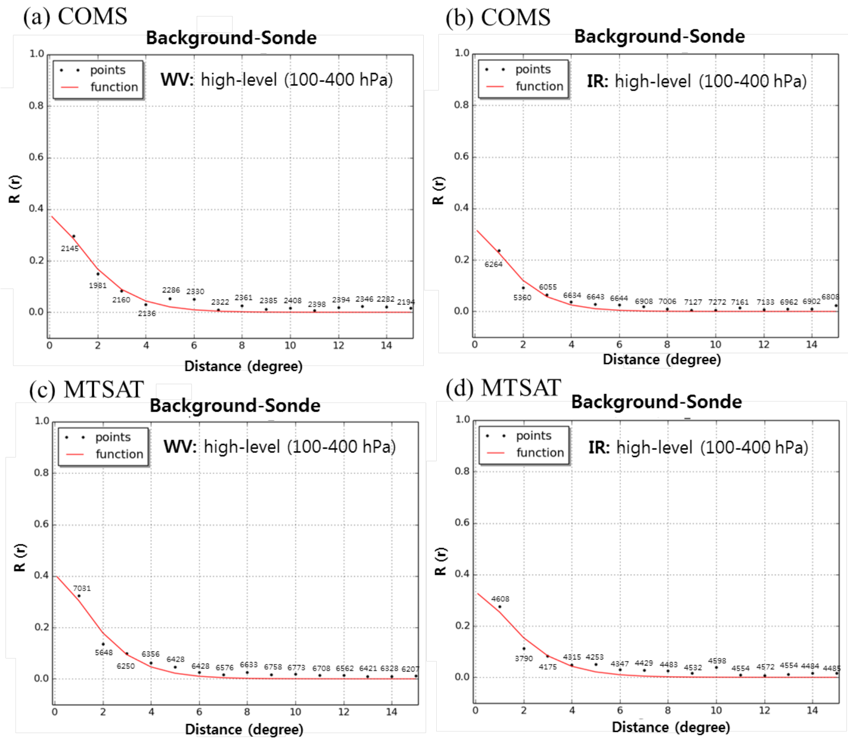

Figure 3: **Same as Figure 2, but for background and sonde.**

Table 2 is the statistics of correlation fitting plot for background winds. The variances of background winds at collocated pixels for both satellites are in the similar values in the range of 9.71 to 10.84 m/s. Also, error correlation structures derived from background winds do not differ significantly. It means the background error of winds is relatively consistent, compared to the observation error of AMVs.

	No. Sample	R_0	*L* (degree)	Variance ($\sigma_{Background}^2$) (m/s)
COMS				
WV, high-level	34,128	0.37	1.09	10.84
IR, high-level	100,680	0.32	0.96	9.71
MTSAT				
WV, high-level	97,107	0.40	1.08	10.50
IR, high-level	66,179	0.33	1.13	10.28

Table 2: **Same as the Table 1, but for background statistics.**

Spatially correlated error in eigenmode

Figure 4 shows the governing eigenvectors of correlation matrices for COMS and MTSAT AMVs. The MTSAT with longer *L* illustrates longer-wavelength structures for the same eigenmode while the COMS with smaller *L* does relatively shorter-wavelength structures. This wavelength scale difference reflects the distinction in the correlation length-scales of both AMV observations in physical space (Figure 2).

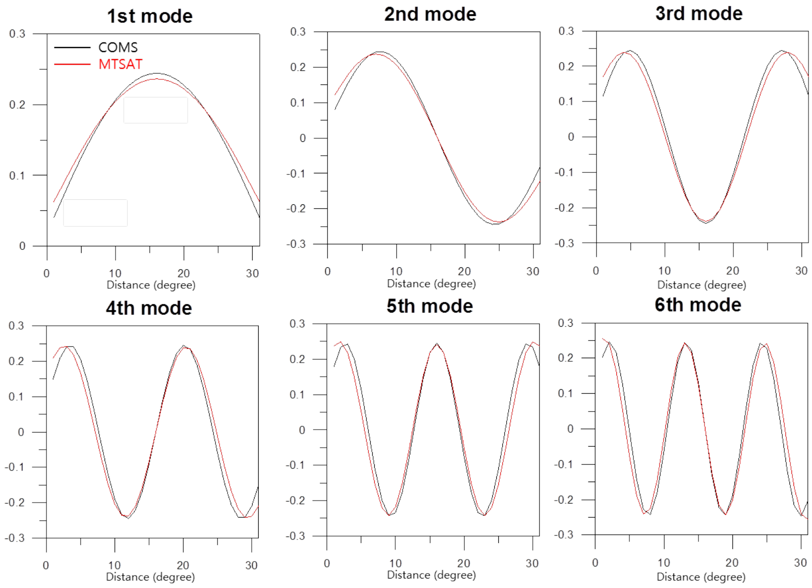

Figure 4: **Leading six eigenvectors of the error correlation matrix for COMS and MTSAT AMVs.**

The error of longer-wavelength structures associated with the leading eigenvector is significantly increased in eigenmode space due to correlation of observation errors (Bormann et al., 2003). Large-scale structures therefore have large errors in the case of correlated errors, and an analysis system that uses these correlated errors should put less weight on these observational structures than one that assumes uncorrelated errors.

Figure 5 illustrates that the ratio of projection of error variance in physical space onto governing eigenmode depends on the correlation length-scale. In eigenmode space, MTSAT AMV errors are mainly projected on the governing mode, because the longer spatial correlation length-scale of MTSAT observation (Figures 2c,d) helps the error variance in physical space to be projected on leading eigenvectors (Figures 4 and 5c,d). However, correlation error shapes of the COMS AMVs are relatively sharper (Figures 2a,b) and thus COMS AMV observation error variance spread more evenly in eigenmode space (Figures 5a,b) as compared to MTSAT AMV. In this comparison between the error variance ratio changes of MTSAT and COMS, the background error having mid-level correlation length-scale is shown as a reference in terms of the error variance distribution along eigenmodes. As a result, we know that the variance ratio of spatially correlated MTSAT high-level WV AMVs to background winds is 3 times larger in the governing eigenmode, compared to that in observation space without considering spatial error correlation (the dashed line in Figure 6c).

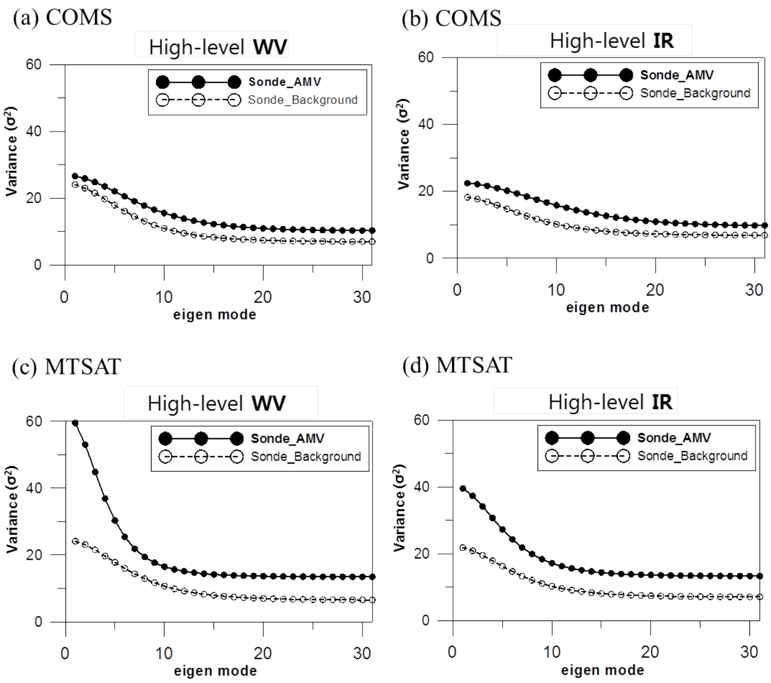

Figure 5: **Variance ratios of spatially correlated AMVs (closed circle with solid line) and background winds (open circle with dash line) in the eigenmode space.**

Inflation factor derived from spatially correlated error

Compared to observation space, the variance ratio of AMV-sonde differences to background-sonde differences is amplified in eigen space due to the spatial error correlation (Figure 6). The correlation length-scales found in this study are much larger than the thinning scales typically applied to AMVs; If we insist to use a diagonal observation error covariance matrix in data assimilation systems, we therefore need to inflate the AMV observation error variance to consider the enlarged error variance in a view of eigenmode space.

We assume that the inflation factor of AMVs derived from both satellites is able to be defined as the maximum of the observation-background variance ratios in eigenmode space divided by those in physical observation space. Following this definition of the inflation factor, observation error of high-level AMVs of both satellites should be inflated about 1.06 to 1.30 times to consider spatial error correlations in a data assimilation frame using a diagonal form of observation error covariance (Figure 6). MTSAT AMVs have the maximum inflation factor (1.3) in the governing mode, but maximum inflation factor (1.1) of COMS AMVs shows smaller eigenmode, which is related to the distinction between correlation length-scales of AMV-sonde difference and background-sonde difference (Figures 3 and 5).

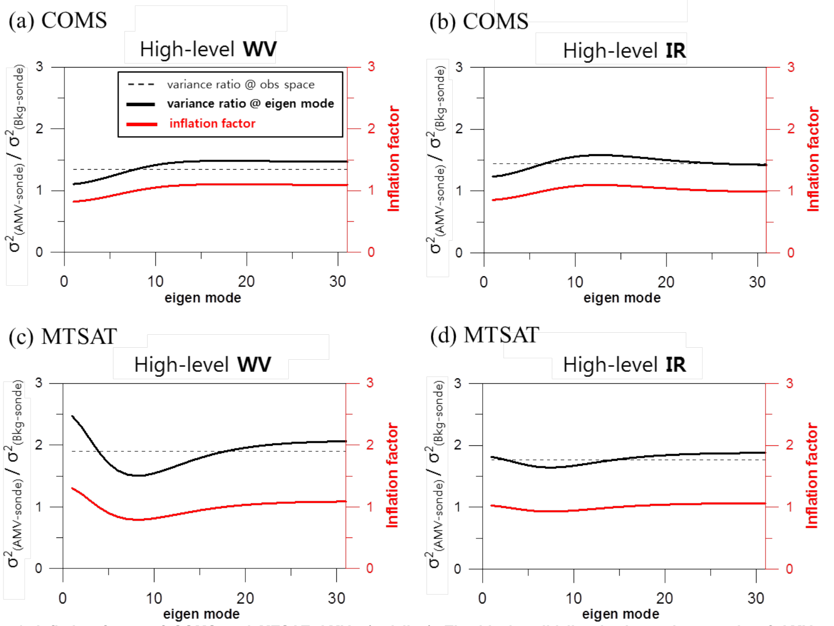

Figure 6: **Inflation factor of COMS and MTSAT AMVs (red line). The black solid line is the variance ratio of AMV-sonde difference to background-sonde difference in eigenmode space, and the black dash line is the same as the black solid line but for physical (observation) space.**

SUMMARY

We have characterized the spatial structure of errors in COMS and MTSAT AMVs by analysing one month of pairs of collocations of AMVs and sondes and assuming spatially uncorrelated errors in the sonde observations. The main findings are:

The ratio of AMV-sonde difference and background-sonde difference variances is amplified in eigenmode space where considering the spatial error correlation error.

COMS and MTSAT AMVs show statistically significant spatial error correlations. In high-level, the correlation length scales of MTMSAT AMVs are longer than those of COMS AMVs. It reflects advantage of COMS in retrieval algorithms.

Spatial error correlations motivated to inflate observation error variance of MTSAT high-level WV channel 1.3 times, while high-level COMS WV 1.1 times.

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