Accuracy evaluation of near-surface air temperature from ERA-Interim reanalysis and satellite-based data according to elevation

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Abstract : In order to spatially interpolate the near-surface temperature (Ta) values, satellite and reanalysis methods were used from previous studies. Accuracy of reanalysis Ta was generally better than that of satellite-based Ta, but spatial resolution of reanalysis Ta was large to use at local scale studies. Our purpose is to evaluate accuracy of reanalysis Ta and satellite-based Ta according to elevation from April 2011 to March 2012 in Northeast Asia that includes various topographic features. In this study, we used reanalysis data that is ERA-Interim produced by European Centre for Medium-Range Weather Forecasts (ECMWF), and estimated satellite-based Ta using Digital Elevation Meter (DEM), Normalized Difference Vegetation Index (NDVI), difference between brightness temperature of 11 μ m and 12 μ m, and Land Surface Temperature (LST) data. The DEM data was used as auxiliary data, and observed Ta at 470 meteorological stations was used in order to evaluate accuracy. We confirmed that the accuracy of satellite-based Ta was less accurate than that of ERA-Interim Ta for total data. Results of analyzing according to elevation that was divided nine cases, ERA-Interim Ta showed higher accurate than satellite-based Ta at the low elevation (less than 500 m). However, satellite-based Ta was more accurate than ERA-Interim Ta at the higher elevation from 500 to 3500 m. Also, the width of the upper and lower quartile appeared largely from 2500 to 3500 m. It is clear from these results that ERA-Interim Ta do not consider elevation because of large spatial resolution. Therefore, satellite-based Ta was more effective than ERA-Interim Ta in the regions that is range from 500 m to 3500 m, and satellite-based Ta was recommended at a region of above 2500 m.

Key Words : near-surface air temperature, ERA-Interim, elevation

1. Introduction

The near-surface air temperature (Ta), that was defined as temperature of 2m above from the ground of meteorological stations, is one of useful variables in

various research fields such as meteorology, climatology, and hydrology (e.g. Wenbin *et al.*, 2013). Ta is conventionally observed at meteorological stations with high accuracy (Stisen *et al.*, 2007), but these point data cannot consider variation by space

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(Prihodko and Goward, 1997; Wenbin *et al.*, 2013). A lot of studies about spatial interpolation for Ta have been attempted. Reanalysis and satellite are representative methods in order to spatially interpolate Ta values. Reanalysis Ta data, such as ERA-Interim of European Centre for Medium-Range Weather Forecasts (ECMWF), Climatic Research Unit (CRU), and National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR), have been produced. In the previous studies, satellite-based Ta was estimated through empirical and physical method (Prihodko and Goward, 1997; Cresswell *et al.*, 1999; Stisen *et al.*, 2007; Yan *et al.*, 2009; Wenbin *et al.*, 2013). Satellite-based Ta has commonly lower accuracy than reanalysis Ta data. However, reanalysis Ta data have high bias from complex topography and high local elevation (Zhao *et al.*, 2008). Relatively large spatial resolution of reanalysis data can be caused high error values, because Ta is affected by topography (e.g. elevation). In the previous studies, relation of Ta and elevation was analyzed. Ta decreases approximately from 0.55 °C to 0.60 °C per 100 m of elevation change (Rolland, 2003; Frauenfeld *et al.*, 2005). You *et al.* (2010) showed that relationship of elevation, Ta trend magnitude, and mean Ta. Han *et al.* (2005) estimated Ta considering Digital Elevation Meter (DEM) that is related to the moist adiabatic lapse rate.

Our main objective in this study are to perform accuracy evaluation of analysis Ta and satellite-based Ta data according to variance of elevation. We analyzed data quality of analysis Ta and satellite-based Ta data in order to evaluate accuracy according to elevation, and presented optimal elevation threshold of Ta data for reanalysis Ta and satellite-based Ta data.

2. Data & Method

The study area was set to the Northeast Asia region

Fig. 1. Study region in Northeast Asia. The squares mean GTS meteorological stations, and the circles mean KMA meteorological stations.

(Fig. 1). This region included the Taebaek mountains in the Korean Peninsula, Nushan mountains, Taihang mountains in the China, and Kiso mountains in Japan. Observed Ta data from the 64 Korea Meteorological Administration (KMA) and the 406 Global Telecommunication System (GTS) were used to evaluate accuracy of reanalysis Ta and satellite Ta. Data of midday and 15:00 local time were used in order to match with satellite-based Ta data and reanalysis Ta data from April 2011 to March 2012. The satellite-based Ta was estimated using the Communication, Ocean and Meteorological Satellite (COMS) satellite and the Systeme Pour l'Observation de la (SPOT) satellite data. The methodology was considered moisture conditions of surface and atmosphere, and was applied for weighting function for estimating satellite-based Ta (Kim and Han, 2013). This satellite-based algorithm estimated midday Ta, and spatial resolution of satellite-based Ta is 1 km. ERA-Interim reanalysis data at 15:00 local time was used instead of NCEP/NCAR, because NCEP is less reliable than ERA-40 which is previous versions of ERA-Interim (You *et al.*, 2010). The ERA-Interim reanalysis near-surface air temperature (ERA-Interim Ta) data was provided every 6 hours based on UTC. The ERA-Interim Ta was calculated using a bilinear interpolation method (Simmons *et al.*, 2004), and spatial resolution of ERA-Interim Ta data is 0.75 degree. To determine

Table 1. Coefficient of variables for each case

Case	DEM (m)	NDVI	BT ₁₁ -BT ₁₂ (K)	LST (K)	Constant
Case1	-0.0011	4.9763	-0.7875	0.5719	117.3479
Case2	-0.0025	3.2825	0.7681	0.3920	172.9966
Case3	-0.0025	4.8849	1.2763	0.2737	208.7916
Case4	-0.0014	9.2404	1.1254	0.5789	110.6279
Case5	-0.0012	6.8664	1.1219	0.5761	114.4150
Case6	-0.0017	8.4821	1.4664	0.5492	122.1014
Case7	-0.0015	12.7825	-2.2061	0.8099	44.2788
Case8	-0.0011	10.9248	-2.8375	0.8848	25.2093
Case9	-0.0012	10.9466	-3.7676	0.9306	12.8726

elevation, DEM from United States Geological Survey (USGS) was used in Northeast Asia. In this study, USGS 30 ARC-second global elevation data (GTOPO30) was used as auxiliary data. GTOPO30 was retrieved from eight sources of elevation information that consist of raster and vector data (Harding *et al.*, 1999).

Satellite-based T_a was estimated as following equation 1:

$$Ta_k = a_k \cdot DEM + b_k \cdot NDVI + c_k \cdot (BT_{11} - BT_{12}) + d_k \cdot LST + e_k \quad (1)$$

where unit of DEM is m, and Normalized Difference Vegetation Index (NDVI) is vegetation index. BT_{11} and BT_{12} means brightness temperature of $11\mu m$ and $12\mu m$ from COMS satellite, unit of those is degrees Kelvin (K), and unit of LST is degrees Kelvin (K). Table 1 showed coefficients for variables. According to elevation data, we were divided into nine cases to evaluate effects of elevation for ERA-Interim and satellite T_a . The elevation was separated as follows: 0 ~ 500 m, 500 ~ 1000 m, 1000 ~ 1500 m, 1500 ~ 2000 m, 2000 ~ 2500 m, 2500 ~ 3000 m, 3000 ~ 3500 m, 3500 ~ 4000 m, and more than 4000 m.

3. Results

Standard Deviation (SD) of elevation was computed based on spatial resolution of ERA data. SD of

Fig. 2. Standard deviation distribution of elevation based on spatial resolution of ERA data.

elevation was distributed within 300 m in general (Fig. 2). Mean value of SD was 177.97 m, and median value of SD was 149.58 m in Northeast Asia. We estimated satellite-based midday T_a using various variables, and evaluated accuracy of ERA-Interim T_a and satellite-based T_a . The validation results of the accuracy for ERA-Interim T_a and satellite-based T_a using meteorological station data were shown in Fig. 3. The determinant coefficient for between observed T_a and ERA-Interim T_a was 0.9582, and determinant coefficient for between observed T_a and satellite-based T_a was 0.9289. The RMSE was 2.6315 K, and bias was -1.1048 K from ERA-Interim T_a (Fig. 3a), and the RMSE was 3.2279 K, and bias was 0.1575 K from satellite-based T_a (Fig. 3b). The slope of ERA-Interim T_a was close to 1 than the slope of satellite-based T_a , and the intercept of ERA-Interim T_a was close to 0 than the intercept of satellite-based T_a .

Fig. 3. (a) scatter plot about correlation between observed Ta and ERA-Interim Ta, (b) scatter plot about correlation between observed Ta and satellite-based Ta.

Fig. 4. RMSE of ERA-Interim Ta and satellite-based Ta according to elevation.

The distribution for accuracy of classified Ta data depending on elevation was shown in Fig. 4. Low elevation from 0 to 500 m represented that ERA-Interim Ta was better than satellite-based Ta. However, elevation from 500 to 3500 m represented that satellite-based Ta was better than ERA-Interim Ta. ERA-Interim Ta and satellite-based Ta were analyzed depending on elevation (Fig. 5). ERA-Interim Ta had box plot of irregular size from more than 2500 m (Fig. 5a). The upper and lower quartile, and the minimum values of ERA-Interim Ta were better than that of satellite-based Ta within less than 2000 m, but median

Fig. 5. (a) box plot of difference between observed Ta and ERA-Interim Ta depending to elevation, (b) box plot of difference between observed Ta and satellite-based Ta according to elevation.

values were largely located apart the zero point from more than 2500 m as follows: 2500 ~ 3000 m : -6.7212 K, 3000 ~ 3500 m : -3.0674 K, 3500 ~ 4000 m : -2.2709 K, and more than 4000 m : -2.6420 K. The width of the upper and ERA-Interim quartile from 2500 to 3500 m was coarse. On the other hand, satellite-based Ta had box plot of constant range in all cases respectively (Fig. 5b). The maximum and minimum values for difference between observed Ta and satellite-based Ta were located from -10 to 10 K. Although median and mean values were located a little away from the zero point over 2500 m, the median values were a little as follows: 2500 ~ 3000 m : -1.1189 K, 3000 ~ 3500 m : -0.0625 K, 3500 ~ 4000 m : 2.2047 K, and more than 4000 m : 1.7150 K.

4. Discussion

Accuracy of satellite-based Ta and reanalysis Ta were evaluated according to elevation in Northeast Asia. RMSE, Bias, and intercept value of ERA-Interim data were better than that of satellite-based data. These results mean that the accuracy of ERA-Interim Ta was higher than the accuracy of satellite-based Ta, and the ERA-Interim Ta tends to underestimate trends of the ground truth like previous studies (Fauenfeld *et al.*, 2005; You *et al.*, 2010). However, the accuracy of ERA-Interim Ta and satellite-based Ta was different depending on the elevation. Error of ERA-Interim Ta was higher than that of satellite-based Ta from 500 ~ 3500 m. This result indicates that ERA-Interim Ta does not take higher elevation into account, because large spatial resolution of ERA-Interim data is large. When considering elevation of the study area, satellite-based Ta was better than ERA-Interim Ta from 56.12% of study area. Colombi *et al.* (2007) reported that satellite-based Ta was better than the Inverse Distance Weighting (IDW) interpolation method from region of high elevation (more than 2000 m). Therefore, satellite-

based Ta is more effective than ERA-Interim Ta at the region that is range from 500 to 3500 m, and the threshold of elevation for ERA-Interim Ta was established at the region of above 2500 m in the Northeast Asia. Further study is required to evaluate accuracy of satellite-based Ta and reanalysis data considering various climate factors such as wind speed, humidity.

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References

- Colombi, A., C.D. Michele, M. Pepe, and A. Rampini, 2007. Estimation of daily mean air temperature from MODIS LST in Alpine areas, *EARSeL eProceedings*, 6: 38-46.
- Cresswell, M.P., A.P. Morse, M.C. Thomson, and S.J. Connor, 1999. Estimating surface air temperature, from Meteosat land surface temperatures, using an empirical solar zenith angle model, *International Journal of Remote Sensing*, 20: 1125-1132.
- Frauenfeld, O.W., T. Zhang, and M.C. Serreze, 2005. Climate change and variability using European Centre for Medium-Range Weather Forecasts reanalysis (ERA-40) temperatures on the Tibetan Plateau, *Journal of Geophysical Research*, 110: D02101.
- Han, K.S., A.A. Viau, Y.S. Kim, and J.L. Roujean, 2005. Statistical estimate of the hourly near-surface air humidity in eastern Canada in merging NOAA/AVHRR and GOES/IMAGER observations, *International Journal of Remote*

- Sensing*, 26: 4763-4784.
- Harding, D.J., D.B. Gesch, C.C. Carabajal, and S.B. Luthcke, 1999. Application of the shuttle laser altimeter in an accuracy assessment of GTOPO30, a global 1-kilometer digital elevation model, *International Archives of Photogrammetry and Remote Sensing*, 32: 81-85.
- Kim, D.Y., and K.S. Han, 2012. Remotely sensed retrieval of midday air temperature considering atmospheric and surface moisture conditions, *International Journal of Remote Sensing*, 34: 247-263.
- Prihodko, L., and S.N. Goward, 1997. Estimation of air temperature from remotely sensed surface observations, *Remote Sensing of Environment*, 60: 335-346.
- Rolland, C., 2003. Spatial and seasonal variations of air temperature lapse rates in Alpine regions, *Journal of Climate*, 16: 1032-1046.
- Simmons, A.J., P.D. Jones, V. da Costa Bechtold, A.C.M. Beljaars, P.W. Kallberg, S. Saarinen, S.M. Uppala, P. Viterbo, and N. Wedi, 2004. Comparison of trends and low-frequency variability in CRU, ERA-40, and NCEP/NCAR analyses of surface air temperature, *Journal of Geophysical Research: Atmospheres* (1984-2012), 109: D24115.
- Stisen, S., I. Sandholt, A. Nørgaard, R. Fensholt, and L. Eklundh, 2007. Estimation of diurnal air temperature using MSG SEVIRI data in West Africa, *Remote Sensing of Environment*, 110: 262-274.
- Wenbin, Z., L. Aifeng, J. Shaofeng, 2013. Estimation of daily maximum and minimum air temperature using MODIS land surface temperature products, *Remote Sensing of Environment*, 130: 62-73.
- Yan, H., J. Zhang, Y. Hou, and Y. He, 2009. Estimation of air temperature from MODIS data in east China, *International Journal of Remote Sensing*, 30: 6261-6275.
- You, Q., S. Kang, N. Pepin, W.A. Flugel, Y. Yan, H. Behrawan, and J. Huang, 2010. Relationship between temperature trend magnitude, elevation and mean temperature in the Tibetan Plateau from homogenized surface stations and reanalysis data, *Global and Planetary Change*, 71: 124-133.
- Zhao, T., W. Guo, and C. Fu, 2008. Calibrating and evaluating reanalysis surface temperature error by topographic correction, *Journal of Climate*, 21: 1440-1446.