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Utilization of MODIS Surface Reflectance to Generate Air Temperature Information in East Java - Indonesia

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Abstract: *Ambient air temperature is the main variable in the climatological and hydrological analysis. However, Indonesia's limited number of meteorological stations was becoming a problem to provide air temperature data for large areas. This study aims to generate air temperature using the relationship of land surface temperature and vegetation index. A total of 6 climatological stations and 84 MODIS Images for three years (2015 to 2017) were used for the analysis. Research methods include image georeferencing, band extraction from MODIS, derivation of NDVI, generating ambient air temperature, calibrating using the local meteorological station, and image interpretation. Results show that the MODIS Surface Reflectance product's accuracy in generating ambient air temperature in East Java at any period is 86,37%. So MODIS Surface Reflectance product can be used as an alternative solution to generate ambient air temperature.*

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1. INTRODUCTION

Land air surface temperature or ambient-temperature is the main variable in the climatological and environmental-related analysis. Usually, air temperature used as input for calculating evapotranspiration, crop water requirement, and water allocation for irrigation purposes, such as the work of Allen et al. (1998), Huntington & Allen (2009), Bachour (2013), Paparrizos et al. (2014), Faisol (2015), Faisol (2016), and Faisol et al. (2017). Conventionally, this data is obtained from a ground based climatological station. Based on The Meteorology, Climatology, and Geophysics Agency (BMKG), Indonesia's number of climatological stations in 2018 is 1.197 stations (The Meteorology Climatology and Geophysics Agency, 2018). However, most stations were observed manually, and some of them are no longer operated because the equipment was destroyed and/or no replacement tool. Therefore, measurement of land-air surface temperature by other methods promise one of the possible solutions to provide more data availability.

With the advance of remote sensing technology, some sensors (Landsat, ASTER, MODIS, Sentinel) provide spectral bands to record heat energy reflected or emitted from earth surface features. For example, Landsat 8 is equipped with an OLI sensor that capable of recording land surface temperature maximum and minimum (USGS, 2016 and Laosuwan et al., 2017). ASTER provides a specifics channel to record heat energy refracted from the land surface (Jiménez-Muñoz & Sobrino, 2009). To generate air temperature information, the remote sensing data must have a visible electromagnetic spectrum (0.4 µm - 0.7 m), near-infrared (0.7 µm - 1.3 m), and thermal infrared (8.0 µm - 14.0 m) (Faisol, 2015). Moderate Resolution Imaging Spectroradiometer (MODIS) is one satellite remote sensing data equipped with those electromagnetic spectra (National Aeronautic and Space Administration, 2018a)

MODIS is the first interdisciplinary instrument that can be used to monitor land, ocean, and atmosphere. Its instrument operates on both the Terra and Aqua spacecraft with a viewing swath width of

2,330 km and views the entire surface of the Earth every one to two days. Its detectors measure 36 spectral bands between 0.405 and 14.385 µm, and it acquires data at three spatial resolutions; 250m, 500m, and 1.000m (National Aeronautic and Space Administration, 2018b). MODIS provides more than 150 science data products to support various studies in agriculture, climatology, marine, forestry, and others (Savtchenko et al., 2004).

MODIS surface reflectance (MOD09) is one of MODIS science data product that computed from MODIS Level 1B land bands 1 (620-670 nm), 2 (841-876 nm), 3 (459-479), 4 (545-565 nm), 5 (1230-1250 nm), 6 (1628-1652 nm), and 7 (2105-2155 nm). The product estimates the surface spectral reflectance for each band as it would have been measured at ground level as if there were no atmospheric scattering or absorption. It corrects for the effects of atmospheric gases and aerosols (National Aeronautic and Space Administration, 2018a). Besides, MODIS surface reflectance has been equipped with the thermal band that is band 31 (10,78 – 11,284 µm) and band 32 (11,77 – 12,27 µm) (Vermote et al., 2015).

A lot of studies have been using MODIS to generate air temperature. Flores & Lillo (2010) using MODIS to estimate air temperature on a regional scale in Chile, Yao & Zhang (2012) estimating air temperature in The Southeastern Tibetan Plateau based on MODIS satellite image, Shen & Leptoukh (2011) using MODIS Land Surface Temperature to estimate surface air temperature in Eastern Eurasia, Zeng et al. (2015) using MODIS Land Surface Temperature Product to estimate daily air temperature in the US, and Noi et al. (2016) using MODIS Land Surface Temperature Product to estimating daily maximum and minimum air surface temperature in Vietnam. Those studies show that the accuracy of MODIS to generate air temperature up to 92% compared with measured and air temperature records from meteorological stations. After seeing the gap, this study contributes to generate air temperature information in East Java, Indonesia.

2. DATA AND METHODS

2.1. Data

The data that used in this research is MODIS surface reflectance (MOD09) image as many 84 scenes for three years (2015 to 2017), MODIS Geolocation (MOD03) that corresponding with MOD09 image, and daily air temperature data from 6 meteorological stations. MOD09 and MOD03 accessed from NASA website and daily temperature accessed from The Meteorology, Climatology and Geophysics Agency (BMKG) website.

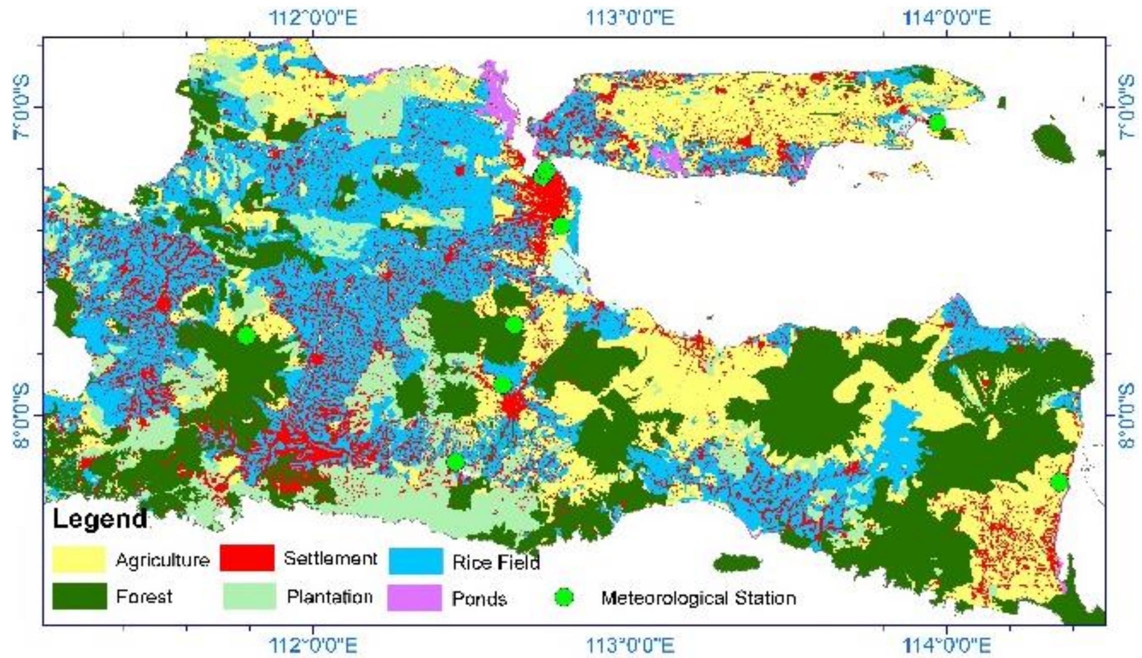

Figure 1. The Landuse Maps of East Java (Indonesian Geospatial Information Agency, 2018)

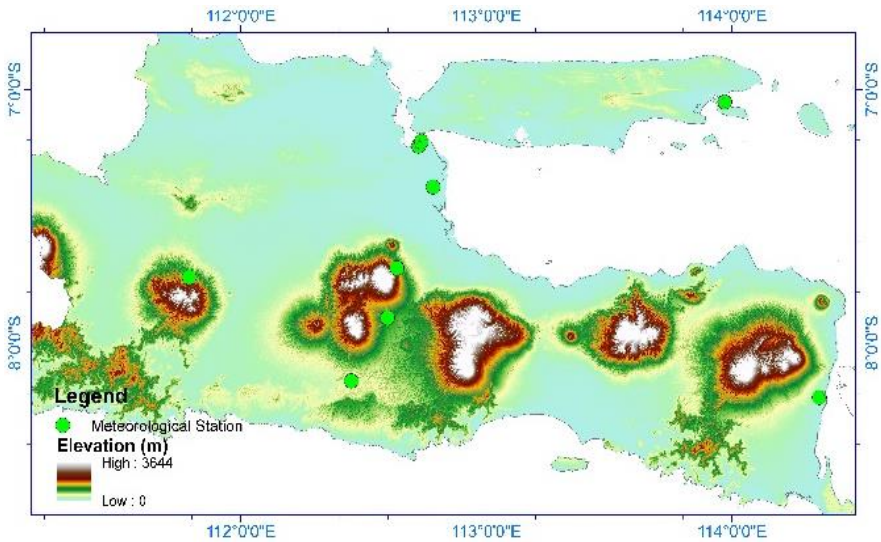

Figure 2. The Topography Maps of East Java (Shuttle Radar Topography Mission, 2018)

2.2. Methods

Generally, the main stages of data processing to generate air temperature information from MODIS Surface Reflectance is:

1. Image georeferencing

   Image georeferencing is to georeferencing MODIS surface reflectance by associated with MODIS Geolocation. MODIS Geolocation is the MODIS data equipped with information about geodetic latitude, longitude, surface height above the geoid, solar zenith and azimuth angles, satellite zenith and azimuth angles, and a land/sea mask for each 1 km sample. This information is included in the header to enable calculating the approximate location of the center of the detectors of any of the 36 MODIS bands.

2. MODIS bands extraction

   The purpose of this stage is to extract the MODIS bands that are used for generating air temperature. There is surface reflectance red bands (ρ band 1), surface reflectance near-infrared bands (ρ band 2), brightness temperature (band 31 and band 32), and solar zenith. This stage is done simultaneously with image georeferencing.

3. Derivation of Normalized Difference Vegetation Index (NDVI)

   NDVI is a measure of the degree of vegetation cover for an area. NDVI of MODIS imagery calculated with the following equation (Vermote & Vermeulen, 1999):

   $$NDVI = \frac{\rho_{Band\ 2} - \rho_{Band\ 1}}{\rho_{Band\ 2} + \rho_{Band\ 1}} \quad [1]$$

   Where:

   NDVI = Normalized Difference Vegetation Index

   $\rho_{Band\ 1}$ = Surface reflectance band 1 (red)

   $\rho_{Band\ 2}$ = Surface reflectance band 2 (near-infrared)

4. Generating air temperature

   The air temperature was generated using the relationship of land surface temperature and vegetation index with the following equation (Hong, 2008):

Ta = 0,9731 Ts + 7,5878. $NDVI$ − 5,0638.cos θ − 2,7233 [2]

Where:

Ta = Air temperature (°K)

Ts = Land surface temperature (°K)

NDVI = Normalized Difference Vegetation Index

θ = Solar zenith angle (radians)

Solar zenith angle (θ) is the angle between the zenith and the center of the Sun's disc and extracted from MODIS Geolocation. Land surface temperature (Ts) calculated with the following equation (Hong, 2008):

$$T_s = \frac{T_b}{\varepsilon_0^{0,25}} \quad [3]$$

Where:

Ts = Land surface temperature (°K)

Tb = Brightness temperature (°K)

ε_0 = Surface emissivity

Brightness temperature extracted from MODIS surface reflectance. Surface emissivity (ε_0) calculated with the following equation (Bastiaanssen et al., 2002):

$$\varepsilon_0 = 1{,}009 + 0.47.\ln(NDVI) \quad [4]$$

Where:

ε_0 = Surface emissivity

NDVI = Normalized Difference Vegetation Index

5. Calibrating using local meteorological station

   This process is to know the accuracy of air temperature generated from MODIS surface reflectance by comparing it with local meteorological station data. The methods used in calibrating is Root Mean Square Error (RMSE) with the following equation:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i - y_i}{x_i}\right)^2} \quad [5]$$

   Where:

   RMSE = Root mean square error

   x_i = Air temperature data from meteorological stations (°C)

   y_i = Air temperature that generated from MODIS surface reflectance (°C)

   n = Amount of data

6. Image interpretation

   This stage aims to create air temperature distribution maps at any period.

Flowchart to generating air temperature using MODIS Surface Reflectance product shown in Figure 3.

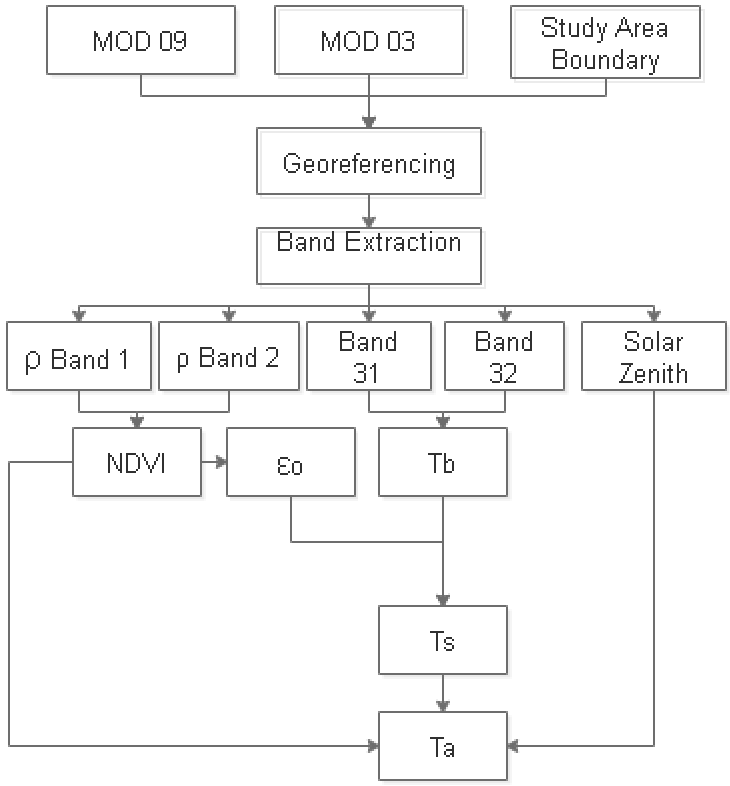

Figure 3. Flowchart to generate air temperature from MODIS Surface Reflectance (Authors, 2018)

3. RESULTS AND DISCUSSION

From MODIS surface reflectance interpretation, air temperature in the study area during 2015 – 2017 is 17.37 °C – 37.09 °C. Generally, air temperature in residential and lowland areas higher than in agriculture and plateau area. Air temperature distribution in the study area shows in Figure 4 to Figure 6. The comparison between air temperature generated from MODIS surface reflectance and meteorological stations data recording is shown in Figure 7 to Figure 12.

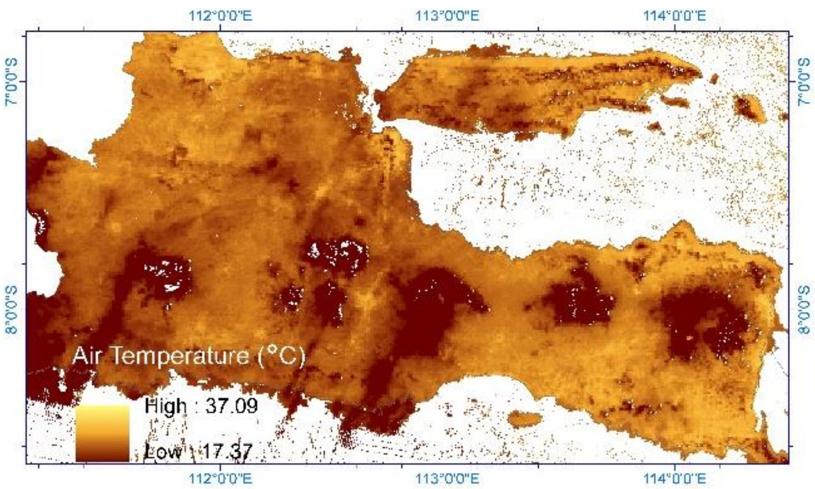

Figure 4. Air temperature distribution in East Java on 29 March 2015 (analysis, 2018)

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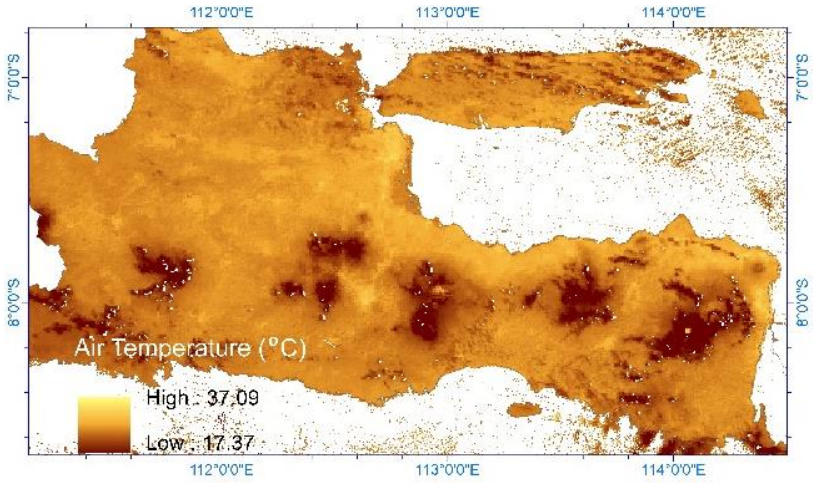

Figure 5. Air temperature distribution in East Java on 12 June 2016 (analysis, 2018)

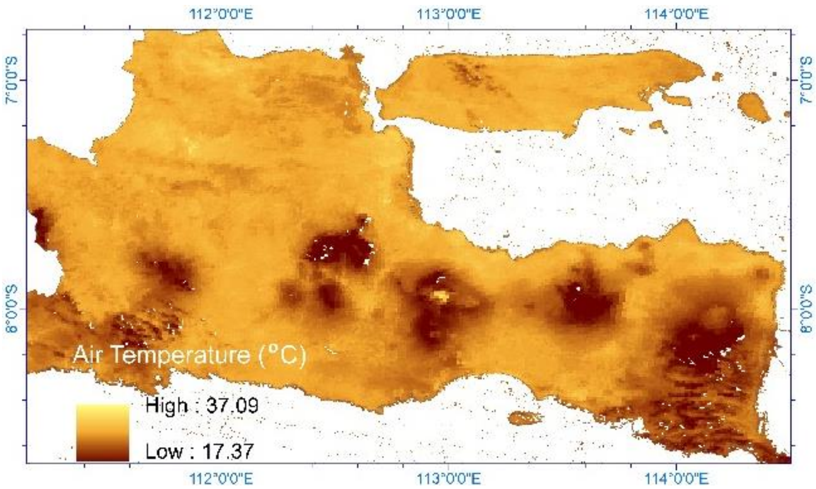

Figure 6. Air temperature distribution in East Java on 24 May 2017 (analysis, 2018)

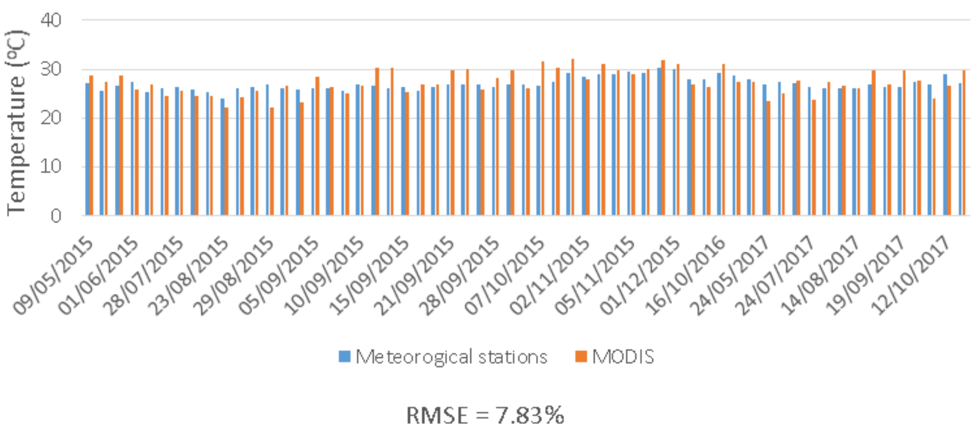

Figure 7. Air temperature comparison between MODIS surface reflectance processing with Banyuwangi meteorological stations (analysis, 2018)

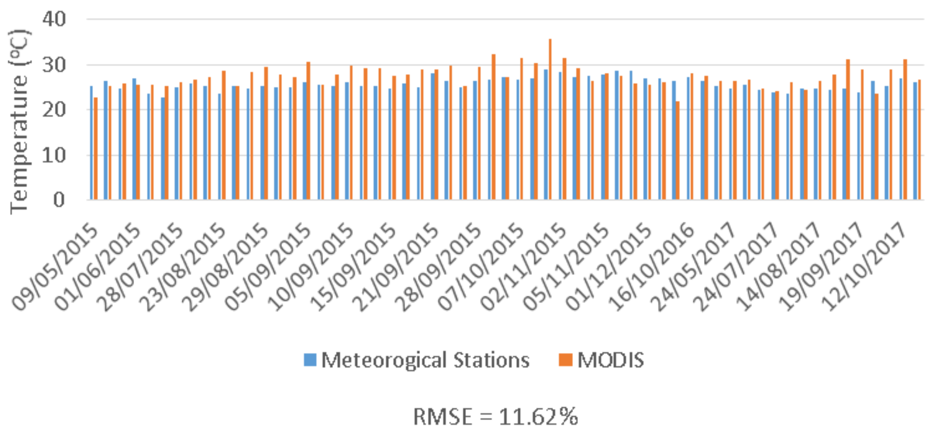

Figure 8. Air temperature comparison between MODIS surface reflectance processing with Malang meteorological stations (analysis, 2018)

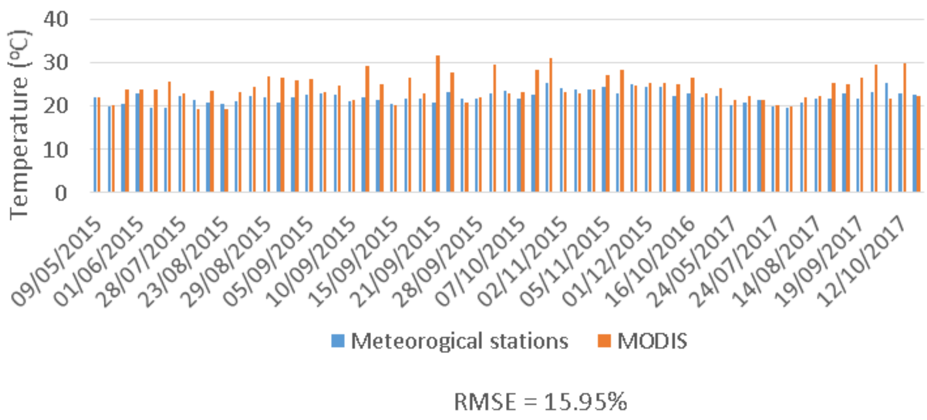

Figure 9. Air temperature comparison between MODIS surface reflectance processing with Pasuruan meteorological stations (analysis, 2018)

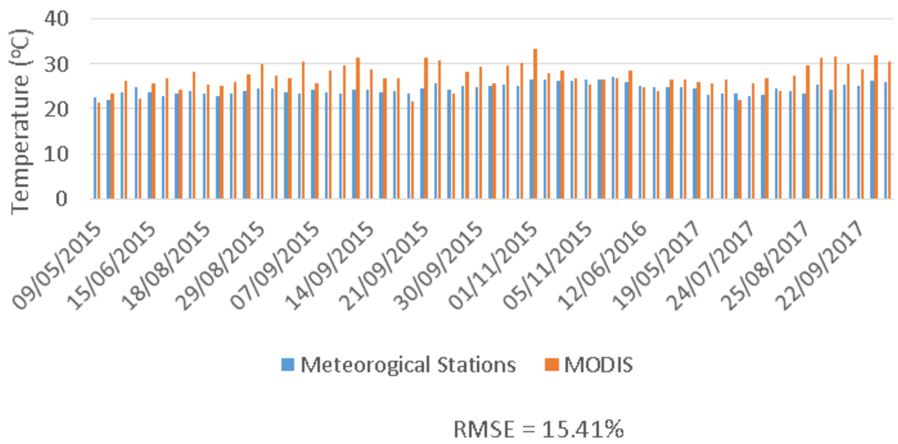

Figure 10. Air temperature comparison between MODIS surface reflectance processing with Nganjuk meteorological stations (analysis, 2018)

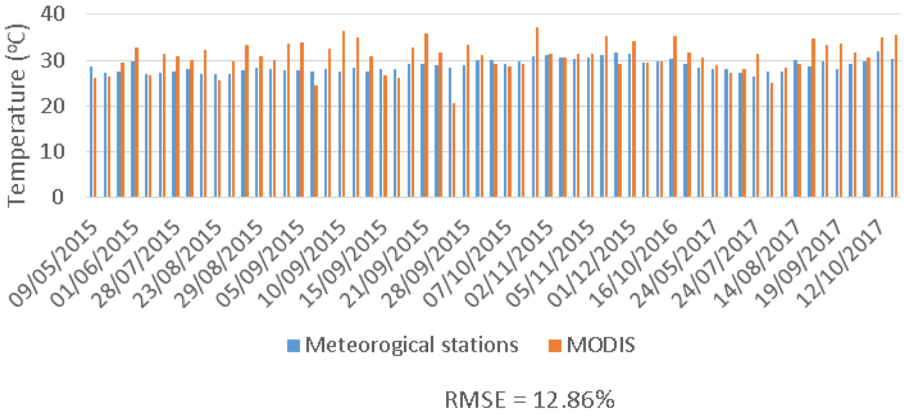

Figure 11. Air temperature comparison between MODIS surface reflectance processing with Surabaya meteorological stations (analysis, 2018)

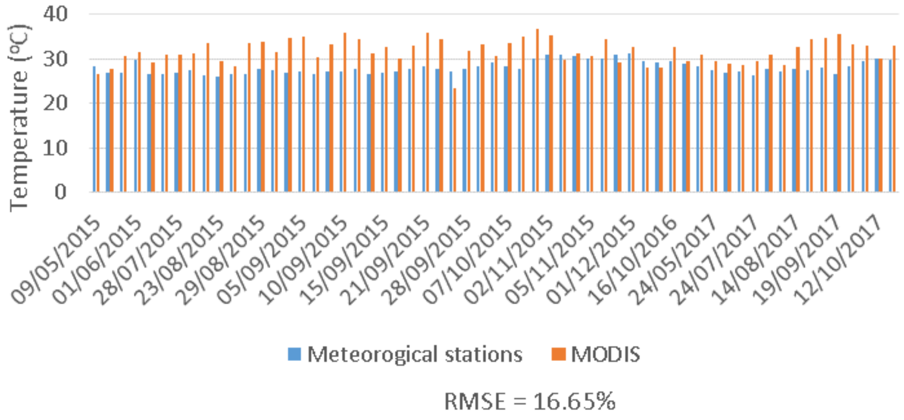

Figure 12. Air temperature comparison between MODIS surface reflectance processing with Sidoarjo meteorological stations (analysis, 2018)

Previous research has shown MODIS accuracy for generating air temperatures up to 92% compared to air temperature records and measurements from meteorological stations (Flores & Lillo, 2010; Noi et al., 2016; Shen & Leptoukh, 2011; Yao & Zhang, 2012; Zeng et al., 2015). In this study, air temperature generated from MODIS surface reflectance is higher than data recording from meteorological stations with an average accuracy of 86.37%. Several factors cause the difference in air temperature generated from MODIS surface reflectance and meteorological stations data recording, e.g., (1) The air temperature generated from MODIS surface reflectance is the air temperature at imagery acquisition time. In contrast, air temperature from meteorological stations is the average temperature recording in the morning, daytime, and afternoon; (2) Air temperature generated from MODIS surface reflectance depends on weather conditions during recording, while air temperature from meteorological stations is based on weather conditions throughout the day; (3) MODIS acquisition time for East – Java is 09.10 am – 10.20 am, so it caused air temperature higher than data recording from meteorological stations.

4. CONCLUSION

This study has successfully modeled air temperature with MODIS so that it provides the view that MODIS images can be used for air temperature in fast growing regions on a regional scale. Generally, MODIS surface reflectance can be used to generate air temperature. With 86.37% accuracy, MODIS surface reflectance can be used as an alternative solution to get air temperature data due to limited climatological stations.

For detailing the analysis, future work needs to be done by using better satellite resolution. If it possible, the results of this study would be better by combining some of satellite imagery and data about air temperature.

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6. REFERENCES

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements. *Fao, Rome*, *300*(9), D05109.

Bachour, R. (2013). *Evapotranspiration modeling and forecasting for efficient management of irrigation command areas*. Utah State University.

Bastiaanssen, W., Ralf, W., Richard, A., Masahiro, T., & Ricardo, T. (2002). *SEBAL: Surface Energy Balance Algorithms for Land, version 1.0. The Idaho Department of Water Resource*. University of Idaho, Kimberly, USA.

Faisol, A. (2015). *An Application of Remote Sensing to Analysis Crop Water Requirement*. Gadjah Mada University.

Faisol, A. (2016). An Application of Moderate Resolution Imaging Spektroradiometer to Optimize Water Allocation in Irrigation Area. *Proceedings of AESAP*, 136–139. Bogor, Indonesia: The 1st International Conference on the Role of Agricultural Engineering for Sustainable Agriculture Production.

Faisol, A., Indarto, I., Novita, E., & Budiyono, B. (2017). Utilization of MODIS Surface Reflectance to Generate Air Temperature Information in East Java-Indonesia. *Geoplanning: Journal of Geomatics and Planning*, *7*(1).

Flores, F., & Lillo, M. (2010). Simple air temperature estimation method from MODIS satellite images on a regional scale. *Chilean Journal of Agricultural Research*, *70*(3), 436–445. [Crossref]

Hong, S. (2008). *Mapping regional distributions of energy balance components using optical remotely sensed imagery*. New Mexico Institute of Mining and Technology Socorro, New Mexico.

Huntington, J. L., & Allen, R. G. (2009). Evapotranspiration and Net Irrigation Water Requirements for Nevada. *World Environmental and Water Resources Congress 2009: Great Rivers*, 1–15. [Crossref]

Indonesian Geospatial Information Agency. (2018). Retrieved March 10, 2018, from http://tanahair.indonesia.go.id/portal-web

Jiménez-Muñoz, J. C., & Sobrino, J. A. (2009). A single-channel algorithm for land-surface temperature retrieval from ASTER data. *IEEE Geoscience and Remote Sensing Letters*, *7*(1), 176–179. [Crossref]

Laosuwan, T., Gomasathit, T., & Rotjanakusol, T. (2017). Application of remote sensing for temperature monitoring: The technique for land surface temperature analysis. *Journal of Ecological Engineering*, *18*(3). [Crossref]

National Aeronautic and Space Administration. (2018a). Retrieved March 30, 2018, from https://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=09

National Aeronautic and Space Administration. (2018b). Retrieved March 9, 2018, from https://lpdaac.usgs.gov/

Noi, P. T., Kappas, M., & Degener, J. (2016). Estimating daily maximum and minimum land air surface temperature using MODIS land surface temperature data and ground truth data in Northern Vietnam. *Remote Sensing*, *8*(12), 1002. [Crossref]

Paparrizos, S., Maris, F., & Matzarakis, A. (2014). Estimation and comparison of potential evapotranspiration based on daily and monthly data from sperchios valley in central Greece. *Global NEST Journal*, *16*(1), 204–217. [Crossref]

Savtchenko, A., Ouzounov, D., Ahmad, S., Acker, J., Leptoukh, G., Koziana, J., & Nickless, D. (2004). Terra and Aqua MODIS products available from NASA GES DAAC. *Advances in Space Research*, *34*(4), 710–714. [Crossref]

Shen, S., & Leptoukh, G. G. (2011). Estimation of surface air temperature over central and eastern Eurasia from MODIS land surface temperature. *Environmental Research Letters*, *6*(4), 45206. [Crossref]

Shuttle Radar Topography Mission. (2018). No Title. Retrieved March 5, 2018, from https://earthexplorer.usgs.gov/

The Meteorology Climatology and Geophysics Agency. (2018). Retrieved March 5, 2018, from http://www.bmkg.go.id/

U.S. Geological Survey. (2016). *Data Users Handbook version 2.0. Earth Resources Observation and Sciences, Greenbelt, Maryland*.

Vermote, E. F., Kotchenova, S. Y., & Ray, J. P. (2015). *MODIS Surface Reflectance User's Guide, version 1.4*. USA: NASA.

Vermote, E. F., & Vermeulen, A. (1999). Atmospheric correction algorithm: spectral reflectances (MOD09). *ATBD Version*, *4*, 1–107.

Yao, Y., & Zhang, B. (2012). MODIS-based air temperature estimation in the southeastern Tibetan Plateau and neighboring areas. *Journal of Geographical Sciences*, *22*(1), 152–166. [Crossref]

Zeng, L., Wardlow, B. D., Tadesse, T., Shan, J., Hayes, M. J., Li, D., & Xiang, D. (2015). Estimation of daily air temperature based on MODIS land surface temperature products over the corn belt in the US. *Remote Sensing*, *7*(1), 951–970. [Crossref]