Estimation of instantaneous air temperature at Terra-MODIS satellite overpass Using TVX approach over Andhra Pradesh and Karnataka

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ABSTRACT:

Near-surface air temperature ($T_a$) is a critical variable in the energy and water cycle at earth surface and have immense significance in agro meteorological applications such as crop growth modeling, water requirement mapping, pest-diseases surveillance and climate change studies. Air Temperature is usually obtained from meteorological observatories but paucity of dense network of such met station limit regional applications. Remote Sensing data can help to solve this problem particularly in non-weather station areas at global and regional scale. Over the past few decades, various approaches viz., statistical approach, Energy balance approach, TVX (Temperature and Vegetation) approach and Neural Network approach are being developed with use of satellite observations. In the present study, we explored applicability of TVX (Temperature and Vegetation) approach for estimating air temperature at satellite overpass in Gujarat state. Satellite data comprised combination of 8-day composite of surface reflectance and land surface temperature (LST) products from MODIS on selected seven periods in year (Julian days 032, 129, 265 and 305) of year 2008. Land surface temperature from day-time satellite pass was used in this study. Observed air temperature at satellite pass time from four ISRO AWS station was used for validation purpose. The TVX technique ($T_{air} = a+b*NDVI_{max}$) employed on 9x9 moving window and corresponding intercept and slope of relationship between LST and normalized difference vegetation index was obtained. The relationship obtained for each moving 9x9 window was extrapolated to maximum NDVI ($NDVI_{max}$) obtained for that window in order to compute air temperature. Maps of air temperature at Terra satellite overpass were generated for four Julian day period. For validation, air-temperature values extracted corresponding to geographical coordinates of each of four stations. Overall results on instantaneous air temperature mapping were satisfactory for initial three months i.e. January, February and March owing to presence of
adequate vegetation cover. The error in estimates of air temperature goes high when agricultural crops get harvested in April. Overall comparison between observed and estimated values showed a root mean square error (RMSE) of 1.1°C.

1. INTRODUCTION:

Air surface temperature (Ta) is an important parameter for a wide range of applications such as vector borne disease bionomics, hydrology and climate change studies. Air temperature data is usually obtained from measurements made in meteorological stations, providing only limited information about spatial patterns over wide areas. The use of remote sensing data can help to overcome this problem, particularly in areas with low station density, having the potential to improve the estimation of Ta at both regional and global scales. Air temperature, typically measured at the shelter height 2 m above ground, is a key variable in a wide range of environmental applications including vector-borne disease bionomics (Kuhn et al., 2005) terrestrial hydrology (Chow, n.d.), biosphere processes (Prince and Goward, 1995) and climate change (Solomon et al., 2007).

The types of methods commonly used to estimate air temperature from the Ts can be classified into five groups:

1) **Statistical approaches** (Davis and Tarpley, 1983) (Vancutsem et al., 2010) generally based on regression model, which establish the relationship between Ts and air temperature. This method generally executes well within the region (Stisen et al., 2008).

2) **Empirical solar zenith angle approach** (Cresswell et al., 1999) which is also known as advanced statistical approach. Along with Ts and air temperature, it requires solar zenith angle as proxy for solar energy reaching the earth’s surface. This approach basically performs individual regression analysis for each acquisition time during the day due to the changing interaction between surface and air temperature.

3) **Energy balance approaches** (Sun et al., 2005) that are developed from physically based processes. The major drawback of these approaches is that they require large amount of inputs that cannot be often obtained by remotely sensed observation from satellite-based platform.
4) **TVX approach** (Nemani et al., 1993) (Goward et al., 1994) (Prihodko and Goward, 1997) is based on negative correlation between $T_s$ and NDVI. This approach is contextual in nature and assumes uniform atmospheric forcing and moisture condition within the contextual array.

5) **Neural network approach** (Jang et al., 2004) comparatively new and promising for deriving air temperature. However, this method is empirical in nature and hard to generalize over different regions.

Application of TVX approach on the satellite images to obtain the spatial maps is a challenging task because of the difficulty in estimating regression coefficients of TVX approach through a moving window algorithm. So there is a need to demonstrate the applicability of TVX approach on the satellite images, which is one of the major aims of the present study. A good attempt was made by (Bhowmick et al., 2008) for India to estimate air temperature using K1-VHRR satellite diurnal brightness temperature (BT) and IMD as well as AWS ground observations. However, the drawback of (Bhowmick et al., 2008) study was, they used the BT instead of $T_s$ and BT changes with the active constituents of the atmosphere and many times it does not represent Surface temperature.

Most of the previous studies have focused on estimating daily or instantaneous Air temperature. The TVX method has been widely used for Air Temperature estimation. (Czajkowski et al., 2000) estimated Average Air temperature for a weekly period with associated RMSE between 1.72 and 3.48°C and $R^2 =0.64$. (Stisen et al., 2008) and (Prihodko and Goward, 1997) estimated Air temperature with RMSE higher than 2.5°C and $R^2$ between 0.64 and 0.86. (Cresswell et al., 1999) used a statistical method to derive instantaneous Air temperature with an associated RMSE below 3°C for more than 70% of sampled data. (Zakšek and Schroedter-Homscheidt, 2009) used a more sophisticated method based on the energy balance to estimate instantaneous Air temperature with an RMSE of 2°C. (Vancutsem et al., 2010) used 1 km MODIS data to estimate weekly minimum air temperature and maximum air temperature. They reported correlations between LST and minimum air temperature ranging from 0.01 to 0.96 for several stations and maximum air temperature was estimated with an $R^2=0.92$ and RMSE=1.83°C. In sum, despite of the methods used, previous studies reported errors of about 2–3°C for a variety of target variables and both spatial and temporal resolutions (Zakšek and Schroedter-Homscheidt, 2009).
A study was carried out with an objective to estimate minimum air temperature by regression and maximum air temperature with TVX approach using MODIS data over the Andhra Pradesh and Karnataka. Specifically, we first investigated minimum air temperature using night time MODIS LST data and validated the accuracy of the retrieval. Then, during day time we employed the TVX approach to retrieve maximum air temperature from MODIS LST and NDVI data. Moreover, the study also proposed to estimate the best values of $\text{NDVI}_{\text{max}}$ based on IMD measured Maximum air temperature observation for the study region to improve the accuracy.

2. STUDY AREA:

2.1 Karnataka:

The study area comprises two states namely Karnataka and Andhra Pradesh falling in peninsular India. Karnataka state has three principal geographical zones: the coastal region of Karavali, the hilly Malenadu region comprising the Western Ghats and the Bayaluseeme region comprising the plains of the Deccan plateau. The bulk of the state is in the Bayaluseeme region, the northern part of which is the second-largest arid region in India.

Geographically, Andhra Pradesh is bestowed with two mighty river systems of Krishna and Godavari. Its varied topography ranging from the hills of Eastern Ghats and Nallamallas to the shores of Bay of Bengal supports varied ecotypes, rich diversity of flora and fauna. The state has two regions Coastal Andhra and Rayalaseema he plains to the east of Eastern Ghats form the Eastern coastal plains. The coastal plains are for the most part of delta regions formed by the Godavari, Krishna, and Penna rivers. The Eastern Ghats are discontinuous and individual sections have local names. The Eastern Ghats are a major dividing line in the state's geography. The Kadapa Basin formed by two arching branches of the Eastern Ghats is a mineral-rich area. The Ghats become more pronounced towards the south and extreme north of the coast. Most of the coastal plains are put to intense agricultural use. The Rayalaseema region has semi-arid conditions.
Figure 2.1. The study area Andhra Pradesh and Karnataka is shown in the above figure with the location of IMD meteorological stations, are marked along with the different State Boundary and AWiFS Land Use map by NRSC.
3. MATERIALS and METHODOLOGY:

3.1 Overall methodology for estimating air temperature:

![Methodology flow chart for estimating air temperature](image)

Figure 3.1 Methodology flow chart for estimating air temperature

3.2 MODIS LST IMAGES:

The Terra MOD11 product is similar to the Aqua MOD11 product. It contains Level 2 and 3 LST and emissivity retrieved from Aqua MODIS data at spatial resolutions of 1 km and 5 km over global land surfaces under clear-sky conditions. The generalized split-window LST algorithm will be used to retrieve LST for MODIS pixels with known emissivity in bands 31 and 32. The physics based day/night LST algorithm will be used to simultaneously retrieve surface band emissivity and temperatures from a pair of daytime and nighttime MODIS observations in bands 20, 22, 23, 29, and 31-33 over all types of land cover.
3.3. MODIS REFLECTANCE IMAGES:

The MODIS Surface-Reflectance Product (MOD 09) is computed from the MODIS Level 1B land bands 1, 2, 3, 4, 5, 6, and 7 (centered at 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm, respectively). The product is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level if there were no atmospheric scattering or absorption. NDVI is calculated from the reflectance images using the formula of NDVI \(\frac{(\text{band2}-\text{band1})}{(\text{band2}+\text{band1})}\).

3.4. AUTOMATIC WEATHER STATIONS DATA (AWS):

Automatic Weather Stations for Agrimet-Industrial, Environmental Monitoring Station, Pollution Monitoring Stations and Rain Fall Monitoring Stations with Data logger with Variable Data Scanning and averaging and user friendly system to meet most environmental demanding situation and with uninterrupted power supply with solar power panel with batteries and also mains operated with fully backed with efficient software for analysis and data presentation and supplied with following sensor:


3.4 SOFTWARE:

ArcGIS 10, ERDAS IMAGINE 9.2, ENVI 4.3, Python IDLE GUI 2.6.5, MS-Excel.

3.5. TVX Approach (Temperature/ Vegetation Index):

The empirical TVX algorithm is based on the linear regression relationship between the observed Land Surface Temperature (LST) and Spectral Vegetation Index (NDVI).

The basic consideration of TVX approach for air temperature estimation is the surface temperatures of a dense and thick vegetation cover, measured by a thermal sensor, is very close to the ambient air temperature (Goward et al., 1994) Such a dense vegetation cover is described by maximum NDVI (NDVI\(_{\text{max}}\)). Further, during daytime observations, a strong, negative correlation is typically found between surface temperatures and NDVI in local
spatial arrays of observations (Prihodko and Goward, 1997). Example is presented in figure 1 for MODIS Aqua \( T_s \)-NDVI correlation for \( 9 \times 9 \) pixel window around Delhi PLM IMD station. A linear regression for these pixels within the window was used for generation of slope (\( \alpha \)) and intercept (\( \beta \)) of the equation

\[
T_s = \alpha \times \text{NDVI} + \beta
\]  

(1)

After calculating the regression parameter \( \alpha \) and \( \beta \), the canopy temperature can be estimated by allowing the linear relation to intersect with the NDVI of full vegetation cover (NDVI\(_{\text{max}}\)) which is equal to air temperature and calculated using the following equation.

\[
T_c = \alpha \times \text{NDVI}_{\text{max}} + \beta \approx \text{Air temperature} \]  

(2)

Figure 3.2. The basis of TVX approach is shown in the above figure, where the example of \( T_s \)-NDVI correlation for a \( 9 \times 9 \) pixel window around the Andhra Pradesh and Karnataka in Oct31-Nov7. The \( T_{\text{max}} \) is estimated by extending the regression line to an NDVI for effective full vegetation cover.

The slope and intercept between the NDVI and Surface temperature were computed in a \( 9 \times 9 \) moving window. The size of this moving window act in response to a trade-off between being big enough in order to obtain a reasonable number of valid observations even if not all pixels within the contextual array can be used like in case they are identified as water (negative NDVI) or cloud (no data). This TVX approach assumes uniform atmospheric forcing and moisture condition within the contextual array because it deforms the straight line
fit to the NDVI-LST scatter plot. Further, in some cases, positive slope was observed because of heterogeneity in landscape or due to presence of residual cloud which cannot be removed by MODIS cloud mask product. Those contextual arrays must be removed because it denies the theoretical consideration of TVX approach. In the process of station wise validation, four statistical measures MAE, RMSE and R Square were also computed to assess the accuracy of the retrieved air temperature.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Station</th>
<th>LAT</th>
<th>LON</th>
<th>Landuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ISRO124_15F07C(AICRP AGR.. UAS GKVK BANGALORE)</td>
<td>13.09</td>
<td>77.57</td>
<td>Khariff</td>
</tr>
<tr>
<td>2</td>
<td>ISRO015_15F00F(MCF  Hasan)</td>
<td>13.07</td>
<td>76.08</td>
<td>Double Crop</td>
</tr>
<tr>
<td>3</td>
<td>ISRO018_15F012(IISc.  Bangalore)</td>
<td>13.03</td>
<td>77.56</td>
<td>Built up</td>
</tr>
<tr>
<td>4</td>
<td>ISRO123_15F07B(RV COLLEGE OF ENGG. BANGALORE)</td>
<td>12.92</td>
<td>77.50</td>
<td>Fallow</td>
</tr>
<tr>
<td>5</td>
<td>ISRO216_15F0D8(AF Stn. YELAHANKA. BANGALORE)</td>
<td>13.13</td>
<td>77.61</td>
<td>Fallow</td>
</tr>
<tr>
<td>6</td>
<td>ISRO222_15F0DE(LPSC  ISRO  Banglore)</td>
<td>12.97</td>
<td>77.58</td>
<td>Built up</td>
</tr>
<tr>
<td>7</td>
<td>ISRO223_15F0DF(ISRO HQ  Banglore)</td>
<td>13.04</td>
<td>77.57</td>
<td>Built up</td>
</tr>
<tr>
<td>8</td>
<td>ISRO244_15F0F4(AF Stn. BIDAR)</td>
<td>17.90</td>
<td>77.50</td>
<td>Fallow</td>
</tr>
<tr>
<td>9</td>
<td>ISRO269_15F10D(INS Kadamba. Karwar)</td>
<td>14.76</td>
<td>74.14</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>ISRO001_15F001(Gadanki (NARL))</td>
<td>13.46</td>
<td>79.18</td>
<td>Deciduous Forest</td>
</tr>
<tr>
<td>11</td>
<td>ISRO002_15F002(METSITE. SHAR)</td>
<td>13.69</td>
<td>80.23</td>
<td>Waste Land</td>
</tr>
<tr>
<td>12</td>
<td>ISRO003_15F003(LPSF. SHAR)</td>
<td>13.77</td>
<td>80.24</td>
<td>Fallow</td>
</tr>
<tr>
<td>13</td>
<td>ISRO004_15F004(PULICAT NAGAR SHAR-OLD)</td>
<td>13.70</td>
<td>80.05</td>
<td>Fallow</td>
</tr>
<tr>
<td>14</td>
<td>ISRO005_15F005(NRSA  Shadnagar)</td>
<td>17.02</td>
<td>78.18</td>
<td>Khariff</td>
</tr>
<tr>
<td>15</td>
<td>ISRO006_15F006(TIFR  Balloon facility Hyderabad)</td>
<td>17.47</td>
<td>78.58</td>
<td>Builtup</td>
</tr>
<tr>
<td>16</td>
<td>ISRO007_15F007(SKDR University  Anantapur)</td>
<td>14.62</td>
<td>77.65</td>
<td>Fallow</td>
</tr>
<tr>
<td>17</td>
<td>ISRO008_15F008(A.U -Visakhapatnam)</td>
<td>17.72</td>
<td>83.23</td>
<td>Built up</td>
</tr>
<tr>
<td>18</td>
<td>ISRO017_15F011(NRSA  Hyderabad)</td>
<td>17.47</td>
<td>78.44</td>
<td>Water Bodies</td>
</tr>
<tr>
<td>19</td>
<td>ISRO120_15F078(SVUC  Tirupati AP)</td>
<td>13.62</td>
<td>79.53</td>
<td>ScrubLand</td>
</tr>
<tr>
<td>20</td>
<td>ISRO121_15F079(SPGS  Puttur Chittor AP)</td>
<td>13.48</td>
<td>79.57</td>
<td>Double Crop</td>
</tr>
<tr>
<td>21</td>
<td>ISRO220_15F0DC(AF ACADAMY.DUNDIGUL.HYDERABAD)</td>
<td>17.63</td>
<td>78.40</td>
<td>Khariff</td>
</tr>
<tr>
<td>22</td>
<td>ISRO221_15F0DD  (AF Stn. HAKIMPET. SECUNDERabad)</td>
<td>17.50</td>
<td>78.50</td>
<td>Builtup</td>
</tr>
</tbody>
</table>
Table 3.1. IMD station name, latitude, longitude and land cover for 24 IMD stations used in the study.

<table>
<thead>
<tr>
<th>ISRO Code</th>
<th>IMD Station Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Land Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISRO247_15F0F7</td>
<td>NIO.RC.Visakhapatnam</td>
<td>17.72</td>
<td>83.23</td>
<td>Built up</td>
</tr>
<tr>
<td>ISRO272_15F110</td>
<td>INS Dega.Visakhapatnam</td>
<td>17.72</td>
<td>83.23</td>
<td>Built up</td>
</tr>
</tbody>
</table>

4. RESULTS and DISCUSSION:

The results (Maximum Air Temperature) are derived from MODIS LST (Terra MODIS-Orbital Time-10.30) and NDVI images using TVX approach. The outputs are validated with IMD datasets which are available at 10.30 IST. Results and validation are shown 90 percent over all accuracy between observed and estimated datasets. The $T_{max}$ data derived from the 24 IMD stations were compared with MODIS air temperature day time data derived from $9 \times 9$ pixel average located over stations. Figure 4.2 (a, b, c, d) shows the linear regression for various periods of observed and estimated air temperature located in different parts of the study region confirming that both $T_{s}$ and air temperature have seasonal cycles. During night time, good temporal agreements will be there (Shah et al., 2013). But differences were found during day time depending upon the land cover type and seasonality.

Figure 4.1 Spatial distribution of air temperature images over Andhra Pradesh and Karnataka for the periods of Julian Days 032, 129, 265 and 305 respectively.
Figure 4.1 shown spatial distribution of air temperature over Andhra Pradesh and Karnataka for the four different time periods. In figure 4.1 the first map is shown air temperature of Julian day 32, month of February. Because of the winter season in this period we can identify low temperature than other maps. The second map is in the month of May. Due to summer this shows high temperature than other maps. Third fourth maps are September and October respectively. This is the monsoon season so, we can identify average temperature in both images.

<table>
<thead>
<tr>
<th>Periods</th>
<th>RMSE</th>
<th>MAPE</th>
<th>MSE</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Julian Day 032</td>
<td>0.985</td>
<td>2.595</td>
<td>0.971</td>
<td>0.922</td>
</tr>
<tr>
<td>Julian Day 129</td>
<td>1.236</td>
<td>3.183</td>
<td>1.528</td>
<td>0.890</td>
</tr>
<tr>
<td>Julian Day 265</td>
<td>0.925</td>
<td>2.637</td>
<td>0.856</td>
<td>0.910</td>
</tr>
<tr>
<td>Julian Day 305</td>
<td>0.781</td>
<td>1.972</td>
<td>0.611</td>
<td>0.923</td>
</tr>
<tr>
<td>Overall</td>
<td>1.090</td>
<td>3.163</td>
<td>1.188</td>
<td>0.915</td>
</tr>
</tbody>
</table>

Table 4.1 Statistical details between observed and estimated air temperature

\[ y = 0.8267x + 5.1232 \]

$R^2 = 0.9248$

\[ y = 0.9393x + 1.8509 \]

$R^2 = 0.894$
Figure 4.1 Linear Regression between observed and estimated air temperature for Julian Days – 32, 129, 265, 305

The graph (a) indicates the linear regression between observed and estimated air temperature of the period February (Julian day 32). This is showing around 92% accuracy between observed and estimated air temperature. Winter season might be a reason for high correlation between the observed and estimated air temperature. Because there will be a less evapotranspiration at the time of winter. So, there will be not much interaction of landcover for this approach. This linear regression indicates the RMSE = 0.985, MAPE = 2.595, MSE = 0.971 and $R^2 = 0.922$.

The graph (b) indicates the linear regression between observed and estimated air temperature of the period May (Julian day 129). This is showing around 89% accuracy between observed and estimated air temperature. This is lesser than the winter season. Summer season might be a reason for this correlation between the observed and estimated air temperature. Because there will be a high evapotranspiration at the time of summer. So, there will be much interaction of landcover for this approach. This linear regression indicates the RMSE = 1.236, MAPE = 3.183, MSE = 1.528 and $R^2 = 0.890$.

The graph (c) indicates the linear regression between observed and estimated air temperature of the period May (Julian day 265). This is showing around 91% accuracy between observed and estimated air temperature. This is higher than the summer season and lesser than the winter season. This is the monsoon season. So, there we can expect less
evapotranspiration So, there will be not much interaction of landcover for this approach. This linear regression indicates the values of RMSE = 0.925, MAPE = 2.673, MSE = 0.856 and $R^2 = 0.910$.

The graph (d) indicates the linear regression between observed and estimated air temperature of the period may (julian day 305). This is showing around 92% accuracy between observed and estimated air temperature. This is aslo a monsoon time. So, there will be not much interaction of landcover for this approach. This linear regression indicates the values of RMSE = 0.781, MAPE = 1.972, MSE = 0.611 and $R^2 = 0.923$. 
5. CONCLUSION:

A study was carried out to estimate maximum air temperature over the Andhra Pradesh and Karnataka using MODIS LST and IMD measured maximum air temperature observation from 24 stations. From the statistical analysis between day time MODIS terra LST and IMD maximum air temperature measured at 24 stations represented a good agreement with the RMSE of 1.090°C. Hence, MODIS Terra LST products were found to be accurate enough to spatially represent maximum air temperature in an operational way with an 8-day frequency. A methodology of computing NDVI\textsubscript{max} was developed to estimate T\textsubscript{max} using the TVX approach. This kind of methods will be very useful in the INSAT-3D satellite time frame where diurnal estimates of LST will be available over India.

6. REFERENCES:


