Estimating Daily Maximum and Minimum Near-Surface Air Temperatures from Satellite Data

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Abstract

Observations of daily minimum and maximum air temperatures, Tmin and Tmax, have traditionally been obtained through in situ observations at meteorological stations. While the station network is extensive, many land masses, such as much of the African continent and polar regions, are poorly observed. Moreover, observations at stations are 'point' observations and may not be representative of air temperatures at neighbouring locations. Satellites provide the means to observe surface skin temperatures at spatial scales of tens of metres to kilometres. But although skin and near-surface air temperatures may be strongly coupled, the two quantities can differ by several degrees over land, where the magnitude of the difference is variable in both space and time. This study describes how satellite data have been used to estimate daily Tmin and Tmax at the pixel scale. A linear regression model is constructed by regressing observed station data against collocated daily minimum and maximum satellite land surface skin temperatures (LST), fraction of green vegetation (FVC), latitude, elevation, urban fraction and distance from coast. The dominant explanatory variable is found to be the satellite LST, which accounts for around 70-80% of the variance in air temperature. The relationships between air temperature and each of the of the explanatory variables show seasonal variability. To account for this variability, a new model is constructed for each day using a moving 11-day temporal window centred on the day in question; this approach also ensures a reasonable pool of data is maintained for the regression since the satellite data suffer from gaps owing to cloud contamination. The example presented in this study is for Europe, where two years of data from the Spinning Enhanced Visible and InfraRed Imager have been used to estimate daily Tmin and Tmax. Analysis of model residuals and evaluation with independent in situ station air temperatures suggests that for most days, more than 50% of the estimated air temperatures are within 3 deg C of collocated station observations, with around 80% within 4 deg C and 90% within 5 deg C. Results for Tmax are slightly better than for Tmin. The mean bias of the satellite-estimated air temperatures oscillates around zero and shows little seasonal variation, although the variance is noted to be lower during summer months.

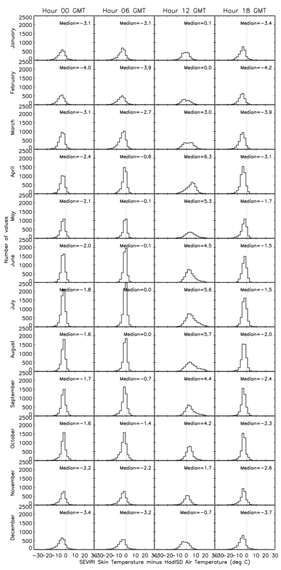


Figure 1: SEVIRI LST minus HadISD station air temps (Dunn et al., 2012) over Europe, 0 to 20 ºE for 2010.

1. Method

Near-surface air temperatures are different from the skin temperature (LST) observed by satellites but the two are closely related (Figure 1). Daily min/max air temperature (Tmin/Tmax) is estimated from LST and other variables through multiple linear regression (Figure 2). Training performed using temporally and spatially collocated station Tmin/Tmax and satellite data:

- LSTmin/LSTmax (Min LST: 23:00-08:00; Max LST: 11:00-16:00 local)
- fraction of green vegetation (FVC)
- latitude (Lat)
- elevation (Z)
- urban fraction (UF)
- distance from coast (DfC)

$$T\min = \alpha_{\min} + \beta_{\min}.LST\min + \chi_{\min}.FVC + \delta_{\min}.Z + \phi_{\min}.UF + \varphi_{\min}.Lat + \gamma_{\min}.DfC$$

$$T\max = \alpha_{\max} + \beta_{\max}.LST\max + \chi_{\max}.FVC + \delta_{\max}.Z + \phi_{\max}.UF + \varphi_{\max}.Lat + \gamma_{\max}.DfC$$

Moving 11-day window for coefficient calculation to capture seasonal effects and maximise number of cloud-free observations (Figure 3).

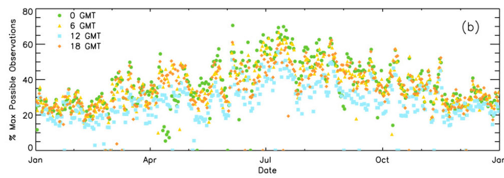


Figure 3: % of cloud-free SEVIRI-HadISD obs for 2010 over Europe.

Data and further information available from
http://www.metoffice.gov.uk/hadobs/msg_tmaxmin/

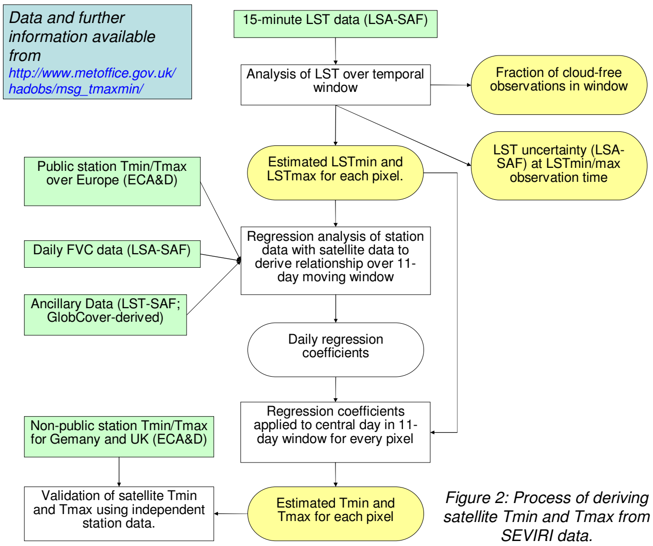


Figure 2: Process of deriving satellite Tmin and Tmax from SEVIRI data.
GREEN = Input data sets
YELLOW = Output data sets

2. Results and Analysis

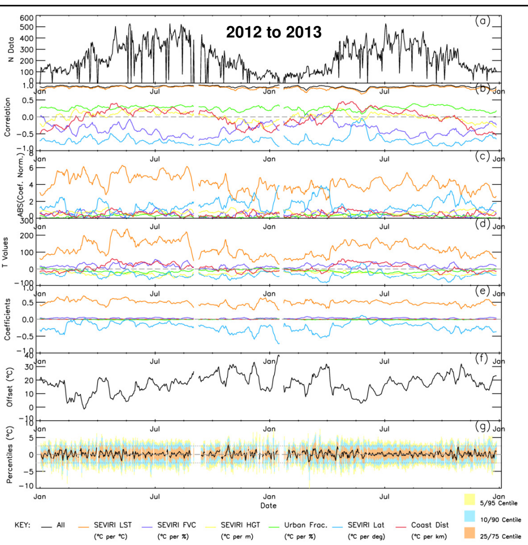
Regression Analysis (Figure 4):

- LSTmin and LSTmax are dominant predictors in regression, followed by latitude. Other predictors have much smaller effects (Fig. 4).
- Effect of distance from coast and elevation in regression may amount to several degrees.
- Urban ΔT component ranges between ±2 ºC in heavily urbanised areas (e.g. capital cities).
- Vegetation fraction ΔT is -5 to +6 ºC for Tmin and -2 to +8 ºC for Tmax.

Performance assessment of Tmin/Tmax:

- Model residuals: most Tmin/Tmax within 3 ºC. No seasonal effects apart from slightly reduced variance in summer months.
- Independent validation with UK and German station data: similar results but slightly noisier than for residuals (not shown).
- Overall: results are slightly better for Tmax than for Tmin (not shown) → attributed to more cloud contamination in Tmin (cloud lowers retrieved LST).

Figure 4: Tmax
*(a) **number** of cloud-free satellite-station matchups on day of observation (i.e. central day in window),*
*(b) **correlation** coefficient between station air temperature and collocated predictor variables (black line indicates multiple linear regression coefficient),*
*(c) **normalised** multiple linear regression **coefficients**,*
*(d) **T-values** for coefficients,*
*(e) **regression coefficients**,*
(f) regression offset, and
*(g) **residuals** (i.e. satellite minus station air temperatures) on day of observation (i.e. central day in window), the solid black line indicates the median.*



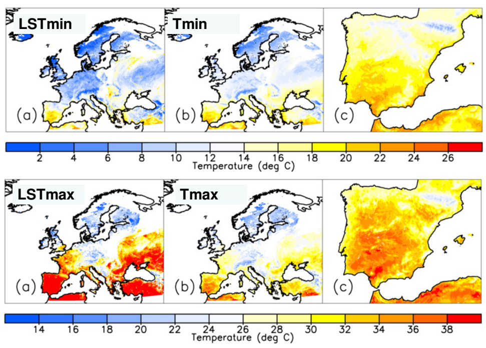


Figure 5: Example of min (top row) and max (bottom row) temperature products over Europe on 21 August 2013.

Discussion points:

Satellite air temps likely to be better than the assessment suggests:

- Point versus area-averaged (several km for SEVIRI)
- Spatio-observational discrepancies because of SEVIRI view angle.
- Undetected cloud.

ACKNOWLEDGEMENTS

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