“Estimating the spatial distribution of daily air temperature by Time Series Analysis of MODIS Land Surface Temperature”

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OBJECTIVES

Increase spatial resolution of available air temperature (Ta) data using Land Surface Temperature (LST) time series observed by satellite.

Research questions:

- Are spatial and temporal patterns in LST stable?
- Can we use time series of LST spatial data to capture and characterize such patterns?
- Can we characterize the coupling of Ta with LST using a limited areal density of meteorological stations?

Case study: Telesina Valley, Italy (200 km²)

* Method applied to downscale climate scenario on maximum air temperature at 35 x35 Km
THE APPROACH

Phase 1a: Cloud removal and gap-filling of LST time series

Phase 1b: Characterization of LST spatio-temporal patterns

Phase 1:
- HANTS algorithm
- Gap-filled
- LST/LST_0
- Pixel-wise ratio

Phase 2:
- FFT analysis
- Amplitudes and phases

Phase 3:
- Correlation Analysis
- a1;b1 a0;b0

Phase 4:
- Air temperature calculation

Phase 3.
- Evaluate relationship LST/Ta

Phase 2.
- Evaluate temporal stability of LST ratio
Cloud removal and gap-filling of LST time series

The algorithm handles the Fourier analysis as a curve fitting problem. It works using an iterative procedure, where invalid observations are removed from curve fitting process assigning a weight of zero to them.

### Parameter Setting

- **$N^\circ$ of images**: 365
- **Valid range**: 250 - 350 K
- **Outlier direction**: low
- **Fit Error Tolerance (FET)**: 8
- **Degree of Overdeterminendness (DOD)**: 50
- **$N^\circ$ of Frequency**: 3
- **Harmonic Periods**: 365, 180, 120

**Surface Temperature - MODIS, WA**

Original Data Set

Smoothed Data Set using HANTS

**RECONSTRUCTED LST TIME SERIES**

*Temperature in K*
THE APPROACH

Phase 1a. Cloud removal and gap-filling of LST time serie

Phase 1b. Characterization of LST spatio-temporal patterns

Phase 1. Daily LST MODIS TERRA DAY (2000-2006). LST (x,y)

Phase 2. Evaluate temporal stability of LST ratio

Phase 3. Evaluate relationship LST/Ta

Phase 4. Air temperature calculation

Input

Output

Operation

Final output

HANTS algorithm

Correlation Analysis

FFT analysis

Amplitudes and phases

Gap-filled

LST/LST_o

Pixel-wise ratio

Synthesis

a1:b1

a0:b0

T_{max, station}

T_{max_0}

Air temperature (x,y)
Temporal series of pixel-wise ratio $r$ of LST$(x,y)$ to LST at the reference point show a periodical trend due to seasonality of the allocation of net radiation to sensible and latent heat flux.
THE APPROACH

Phase 1a. Cloud removal and gap-filling of LST time series

Phase 1b. Characterization of LST spatio-temporal patterns

Phase 1
- HANTS algorithm
- Gap-filled
- LST/LST₀
- Pixel-wise ratio

Phase 2
- FFT analysis
- Amplitudes and phases

Phase 3
- Correlation Analysis
- a1;b1
- a0;b0

Phase 3 (1)
- Daily LST MODIS TERRA DAY (2000-2006), LST (x,y)

Phase 3 (2)
- T_max_station
- T_max₀

Phase 4
- Air temperature calculation

Phase 4
- Air temperature (x,y)

Phase 2
- Evaluate temporal stability of LST ratio

Phase 3
- Evaluate relationship LST/Ta
Evaluate temporal stability of LST ratios

Harmonic analysis of pixel wise ratio yearly time series has been performed considering three harmonic components (365, 180, 120 days).

<table>
<thead>
<tr>
<th>Period in days</th>
<th>Area average</th>
<th>std</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean r</td>
<td>0.991</td>
<td>0.01</td>
</tr>
<tr>
<td>365 (A_1)</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>180 (A_2)</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>120 (A_3)</td>
<td>0.003</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Spatial variability negligible

Spatial variability not negligible

$r \approx 1$

$A_1, A_2, A_3 \ll r$
Evaluate temporal stability of LST ratios

The interannual variability of pixel-wise ratio has been evaluated by the calculation of coefficient of variation (cv) of the amplitudes.

Interannual variability of amplitude is not negligible but much smaller than mean $r$

We reconstruct $r(x,y,t)$ taking into account the periodic components but we neglect the interannual variability of the amplitude
THE APPROACH

Phase 1a. Cloud removal and gap-filling of LST time series

Phase 1b. Characterization of LST spatio-temporal patterns

Phase 2. Evaluate temporal stability of LST ratio

Phase 3. Evaluate relationship LST/Ta

Phase 4. Air temperature calculation
Air Temperature calculation

\[ T_{\text{air}}(x,y) = T_{\text{surf}}(x,y) \times a_1 + b_1 \]

\[ T_{\text{surf}}(x,y) = T_{\text{surf}}_{\text{rf}} \times \text{ratio}(x,y) \]

\[ T_{\text{surf}}_{\text{rf}} = T_{\text{air}}_{\text{rf}} \times a_0 + b_0 \]

Ratio\((x,y)\)

Fourier synthesis using mean amplitudes and phases

**a0 b0 estimation**

LST vs Ta
RELATIONSHIP AT REFERENCE LOCATION

**a1 b1 estimation**

Ta vs LST
RELATIONSHIP AT STATIONS

Tair\(_{\text{rf}}\)=Air temperature at reference location.

Tsurf\(_{\text{rf}}\)=Surface temperature at reference location.

Ts=Surface temperature at pixel location.
THE APPROACH

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  - Gap-filled
  - LST/LST₀
  - Pixel-wise ratio

Phase 2
- FFT analysis
- Amplitudes and phases

Phase 3
- Correlation Analysis
  - $a₁;b₁$ $a₀;b₀$
- Synthesis
  - $T_{max\_station}$ $T_{max₀}$

Phase 3. Evaluate relationship LST/Ta

Phase 4
- Air temperature calculation
- Phase 4. Air temperature calculation

Phase 2. Evaluate temporal stability of LST ratio
Ta vs Tsurf RELATIONSHIP AT STATIONS

Tsurf vs Ta RELATIONSHIP AT REFERENCE LOCATION

\[ a_1 = 0.8100 \quad b_1 = 58.7637 \quad R^2 = 0.87 \]

\[ a_0 = 1.18 \quad b_0 = -52.11 \quad R^2 = 0.86 \]
Validation

SAME PERIOD OF LST OBSERVATIONS

PRE – MODIS

Stazione   | anno      | RMSE daily |
------------|-----------|------------|
Benevento   | 1984-1988 | 2.8 K      |
Bucciano    | 1984      | 2.5 K      |
Montesarchio| 1984      | 2.9 K      |
Conclusions

• A procedure to downscale maximum air temperature using satellite land surface temperature has been developed.

• The spatial pattern of LST has a periodic component with limited interannual variability.

• The procedure has been evaluated against observations of air temperature data for the same period as the MODIS LST observations and for few stations in earlier years.

• The RMSE on estimated daily air temperatures was about 3 K and about 2 K for five days moving averages.

• The procedure should be extended to a longer record of LST observations.