AVHRR-derived Land Surface Temperature Maps, Africa, 1995-2000

Abstract

Land Surface Temperature (LST) is a key indicator of land surface states, and can provide information on surface-atmosphere heat and mass fluxes, vegetation water stress and soil moisture. A daily, day and night, LST data set for continental Africa, including Madagascar, was derived from Advanced Very High Resolution Radiometer (AVHRR) Global Area Coverage (GAC; 4 km resolution) data for the 6-year lifetime of the NOAA-14 satellite (from 1995 to 2000) using a modified version of the Global Inventory Mapping and Monitoring System (GIMMS) (Tucker et al., 1994). The data were projected into Albers Equal Area and aggregated to 8-km spatial resolution. The data were cloud-filtered with CLAVR-1 algorithm (Stowe et al., 1999). The LST values were estimated with a split-window technique (Ulivieri et al., 1994) that takes advantage of differential absorption of the thermal infrared signal in bands 4 and 5. The emissivity of the surface was generated using a landcover classification map (Hansen et al., 2000) combined with the FAO soil map of Africa (FAO-UNESCO, 1977), and additional maps of tree, herbaceous, and bare soil percent cover (DeFries et al., 2000). Collateral products include cloud masks and time-of-scan files.

Background Information

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Data File Information:

The data consist of a unique daily gridded land surface temperature map of continental Africa and Madagascar for each day and each night of the 6-year NOAA-14 lifetime. The data files are organized by year, with separate folders for daytime and nighttime data (e.g., AVHRR_1995_DAY and AVHRR_1995_NIGHT). Each folder contains a compressed (.zip) data file, a compressed cloud mask file, and a compressed local solar time file for each satellite overpass of that year. The data files uncompress to flat binary files.

Each data file contains 1152 columns and 1152 rows, in signed integer format (2 bytes), with 8 km by 8 km spatial resolution.

Data in the LST_UL files correspond to land surface temperature retrieved using the Ulivieri et al. (1994) split-window algorithm, in units of degrees Kelvin. A value of -999 is used for pixels where channels 4 and/or 5 reach saturation (323 K and 330 K respectively). A value of -888 is assigned if the brightness temperatures in Channels 4 or/and 5 are below a processing threshold (230 K), or for pixels with no data (e.g., at the edge of the image). These data have been scale by a factor of 10.

Data in CLD files correspond to a cloud mask generated using the CLAVR algorithm (Stowe et al., 1999). No scaling factor is used. The following flags are used in the cloud mask:

Over land:

Cloud Mask Flag	Conditions
3	Clear
4	Clear and DDV (dense dark vegetation)
6	Cloudy or mixed
8	Shadow

Over ocean:

Cloud Mask Flag	Conditions
1	Clear
2	Clear and glint
5	Cloudy or mixed

7	Shadow

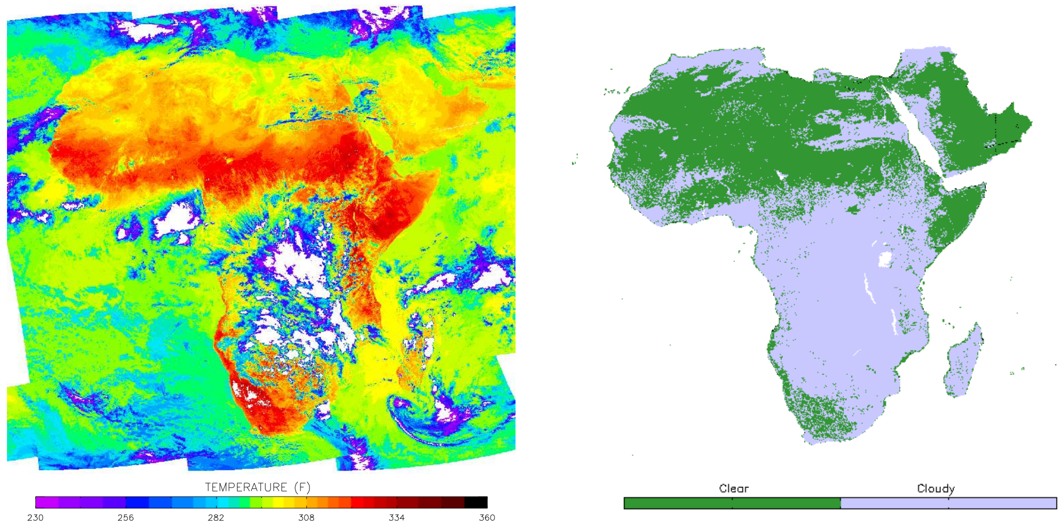
Data in the LSTIME files correspond to local solar time of observation for each pixel, scaled by a factor of 1000.

All data are in Albers Projection. The corner coordinates of the each image are the following:

(x,y)	Coordinates	
(1,1)	LAT: 43.71 N	LON: 24.60 W
(1152,1)	LAT: 43.71 N	LON: 64.52 E
(1,1152)	LAT: 42.24 S	LON: 23.48 W
(1152,1152)	LAT: 42.24 S	LON: 63.41 E

A latitude file (binary, signed integer), a longitude file (binary, signed integer), and a land/water mask file (binary, byte) are also provided with this dataset.

Sample Data Records:



(a) (b)

Figure 1. (a) LST and (b) cloud mask for NOAA-14 AVHRR daytime overpass on January 9th, 1997.

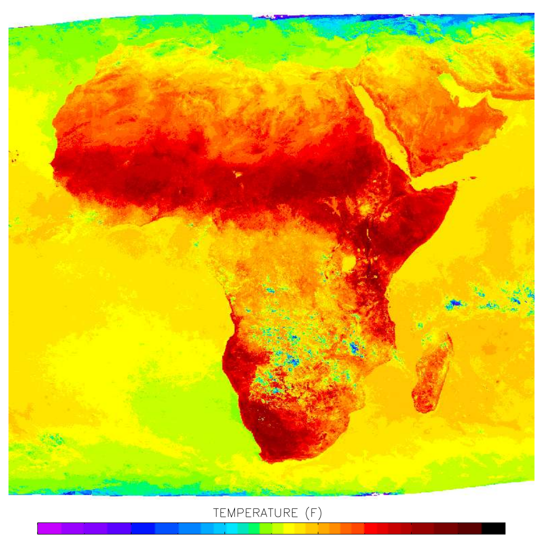


Figure 2. AVHRR LST composite for January 9th through January 16th, 1997 (daytime only).

Methods and Materials:

Theory:

To derive LST, we applied a split-window technique. The method takes advantage of differential absorption in two spectrally close infrared bands to account for the effects of absorption and emission by atmospheric gases. For the AVHRR TIR bands, atmospheric attenuation is greater in channel 5 than in channel 4. This difference increases for increasing water vapor. Since surface emission is assumed to differ negligibly between the bands, the differential shift in sensor measured radiance results almost entirely from atmospheric attenuation and/or emission.

We implemented the split-window algorithm of Ulivieri et al. (1994); i.e.,

$$T = T_4 + 1.8(T_4 - T_5) + 48(1 - \varepsilon) - 75\Delta\varepsilon$$

where T4 and T5 are the brightness temperatures of AVHRR channels 4 and 5, respectively, $\varepsilon = (\varepsilon_4 + \varepsilon_5)/2$, and $\Delta\varepsilon = \varepsilon_4 - \varepsilon_5$. The formulation was developed for cases of total column atmospheric water vapor less than 3.0 g/cm^2, a reasonable condition for much of the semi-arid portions of continental Africa. To account for the spatial variability of the surface emissivity, we created spatial fields of emissivity for channels 4 and 5. We followed a similar method to Snyder et al. (1998) by creating the emissivity maps based on static landcover classification maps (Hansen et al., 2000). In addition to the landcover maps, we used continuous fields of woody, herbaceous, and barren percent cover for the African continent (DeFries et al., 2000) to generate fields of vegetation and soil fractional cover. We assumed that the homogeneous components of each pixel are Lambertian. Emissivity values for the different endmembers were estimated based on the NASA Jet Propulsion Laboratory spectral library using the spectral filter function for AVHRR/2 channels 4 and 5. The spatial variability for the barren soil was considered by using the FAO Soil Map of Africa (FAO-UNESCO, 1977).

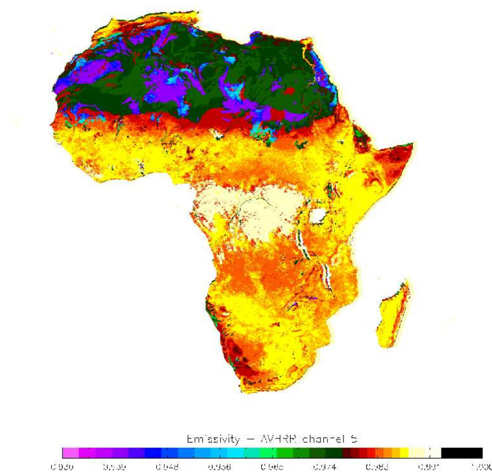


Figure 3: Emissivity for AVHRR channel 5.

Data Collection:

This LST data set is based on NOAA-14 AVHRR/2 Global Area Coverage (GAC; 4 km resolution) data within the Global Inventory Mapping and Monitoring System (GIMMS). The product was generated for each day and night overpass and over the full swath width of the AVHRR scan (±55 degrees). The GAC data were obtained from the NOAA Comprehensive Large Array-data Stewardship System (CLASS) Electronic Library (formerly, NOAA Satellite Active Archive) in level-1b format.

Data Processing:

We processed these data using a modified version of the Global Area Processing System (GAPS). We processed the daily orbits over the operational lifetime of NOAA-14 (1995 to 2000). One of the initial steps involved radiometric calibration; i.e., converting the digital counts to radiance in $mW/(m^2.sr.cm)$, followed by a non-linear calibration of the thermal channels. The radiance was then converted to brightness temperature using the spectral response functions and assuming that the Earth emits as a blackbody in the spectral wavelengths of interest.

Quality control flags produced in the previous steps were analyzed so that pixels with faulty or missing data were identified. We applied the CLAVR-1 cloud algorithm to identify fully and partially cloudy pixels. The products were mapped into Albers Equal Area projection and simultaneously re-binned to 8 km by 8 km pixel size to be compatible with the GIMMS NDVI data set. We re-binned using forward mapping and selecting the maximum brightness temperature in channel 5 (T5).

For additional information please see Pinheiro et al. (2005).

Spatial Coverage:

Continental Africa and Madagascar.

Spatial resolution:

Each pixel represents approximately 8 km x 8 km.

Temporal Coverage:

Years 1995-2000.

Temporal Resolution:

12 hours; i.e., a unique map exists for each day and night of the 6-year NOAA-14 lifetime.

Error Sources:

Probably the two greatest sources of error in this data set are the estimated emissivity and the limitations of the Ulivieri split-window. Our emissivity maps assumed laboratory emissivity data are representative of large natural areas. We also ignored small inland water bodies (e.g., rivers), human settlements, and assumed homogeneity (or well-mixed aggregations) over 8 km pixels. Ulivieri's formulation, like most split-window equations, was derived by fitting a curve to a large set of model output. Further, it is only considered accurate for column water vapor <3 cm. We have not attempted to assess where and when this assumption is met. Moreover, our vegetation structural maps relied extensively on the land cover and continuous fields satellite products, and widely extrapolated site-level vegetation structural characteristics from the literature. Although the regional and continental trends are likely accurate, users are cautioned that pixel-by-pixel errors are likely significant.

Sensor or Instrument Measurement Geometry:

The full width of the AVHRR swath (about 55 degrees from nadir) were used to create the LST maps. Orbit and sensor characteristics can impart temporal and spatial artifacts in the AVHRR data that impair their accuracy, especially as long-term time series. For example, the supposedly sun-synchronous orbit of the NOAA afternoon satellites drifts to later equatorial crossing times as the satellite ages. The drift has averaged approximately 30 minutes per year through their three- to five-year operational life. For NOAA-14 this caused the local solar observation time, at the equator, to drift from 13:30 to later than 16:00.

In addition, some of the AVHRR LST variability can be attributed to angular effects imposed by AVHRR orbit and sensor characteristics, in combination with vegetation structure. These angular effects lead to systematic LST biases, including 'hot spot' effects when no shadows are observed (Pinheiro et al., 2004).

Calibration

The thermal data, used in this study, are calibrated on each mirror rotation (1/6 of a second). These data are ingested with the rest of the satellite data and used in post-processing.

Frequency of Calibration:

Every line of data.

Additional Sources of Information

The AVHRR Land Surface Temperature data sets were funded in part by the PRAXIS Program (MCT, Portugal), the Calouste Gulbenkian Foundation (Portugal), and NASA's GSFC.

Important Notes

LST_UL and CLD data fields for the first 20 days (DOY 1 through DOY 20) of Year 1995 should be discharged. This period corresponds to the beginning of NOAA-14 acquisition and resulted in unreliable data, or no data for those granules.

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