Correcting the View Angle Dependency of Geostationary Satellite Skin Temperature Measurements over Africa

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Introduction

Emission from the surface and, hence, skin temperature (T_s) is viewing-zenith-angle- (VZA-) dependent – varying by 6 K or more with increasing VZA. Although commonly ignored, methodologies for angular normalization of T_s are needed to better understand surface emissivity and reduce errors in T_s retrievals. To develop corrections for the VZA-dependence of T_s from Geostationary Earth Orbit (GEO) satellites, inter-calibrated GEO and MODerate-resolution Imaging Spectroradiometer (MODIS) data are collocated for clear scenes observed at different viewing and illumination angles. The radiances in these temporally and spatially matched datasets are used to derive T_s using similar one-channel retrieval algorithms, by which T_s is computed from the observed 11-µm brightness temperature (*T11*) through application of atmospheric absorption corrections appropriate for that spectral channel. Matches from the two instruments are used to determine the diurnal dependence of T_s on VZA by calculating the surface-leaving IR temperature (T_o) differences between the near-nadir views and off-nadir data. With seasonal *T11* data from Meteosat-9 (Met-9) and Aqua-MODIS over Africa, an adjustment can be computed using matched pairs, for which the Aqua-MODIS VZA is set less than 5°. Applying this correction to the same Met-9 data removes the VZA dependence. The effectiveness of the correction is assessed using independent matched land surface temperature datasets from Terra- and Aqua-MODIS and ground-site measurements. The approach can be used to develop corrections for each GEO, and should also be applicable to Low Earth Orbit (LEO) satellites. These corrections will be valuable for improving estimates of instantaneous surface emissivity, surface radiation, and surface heat exchange in observations and models.

Background

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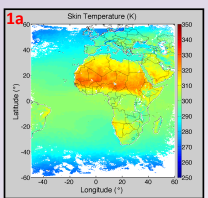
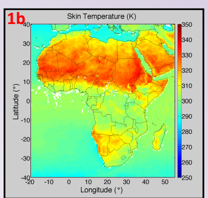
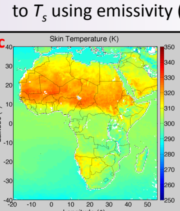


- **Fig 1a)** April 2013 Meteosat-9 daytime T_s averaged to a 0.25°x0.25° grid. Met-9 is one of five GEO satellites used by NASA LaRC that, together, provide hourly near-global high-resolution T_s.
- **Fig 1b)** April 2013 Aqua-MODIS daytime T_s averaged to a 0.50°x0.50° grid. NASA LaRC LEO-based T_s also available historically from NOAA Advanced Very High Resolution Radiometer (AVHRR) instruments.

1b


- Single-Channel T_s General Overview* ($T_s = B^{-1}\{[B(T_o) - (1-\varepsilon_s)L_s]/\varepsilon_s\}$)
  - Start with modeled T_s from MERRA gridded tile data
  - Transfer T_s to top-of-atmosphere (TOA) via correlated k-distribution
  - Adjust modeled T_s and temperature/humidity profiles such that T_s consistent with observed *T11* at TOA
  - Convert T_s and *T11* to radiance (L) and find ratio for each clear tile
  - Apply ratio to pixel-level L_{toa} for all clear pixels within that tile
  - Yields a pixel-level surface L, which is converted, via inverse Planck Function (B^{-1}), to T_s using emissivity (ε_s) model or CERES maps

1c


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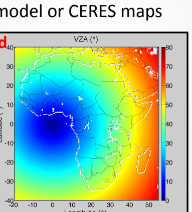

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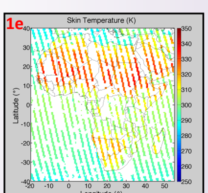


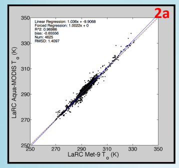
- GEO (Meteosat-9) Dataset Setup
  - African continent and surrounding bodies of water
    - 40°N, 40°S, 55°E, 20°W
  - January, April, July, and October 2013
  - 3-km pixels averaged hourly to a 0.50°x0.50° grid **(Fig 1c)**
    - Standard deviation < 1 K
    - Pixels must be classified 'clear' and non-adjacent to classified 'cloudy'
    - VZA mapped to same grid **(Fig 1d)**
- Aqua-MODIS Dataset Setup
  - Same domain and time period as Met-9
  - 1-km pixels averaged to a 0.50°x0.50° grid
    - Standard deviation < 1 K
    - Pixels must be classified 'clear' and non-adjacent to classified 'cloudy'
    - Only pixels that have VZA < 5° and are within 15-min of Met-9 scan are averaged **(Fig 1e)**

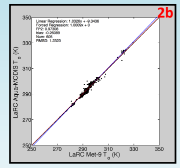
VZA Dependency Model

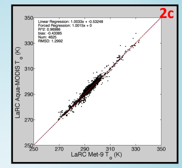
Fig 2a) LaRC Met-9 T_o matched within 15 minutes of LaRC Aqua-MODIS T_o. MODIS data limited to VZAs less than 5° as in **Fig 1e.**

Fig 2b) Same as **Fig 2b,** except VZA and azimuth angle differences between the two instruments held to less than 5°.

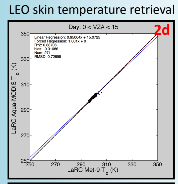
Fig 2c) Same as **Fig 2a,** except has been unbiased based on the ray-matched relationship shown in **Fig 2b.**

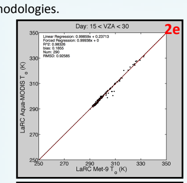


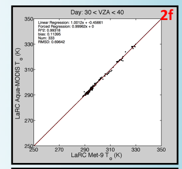


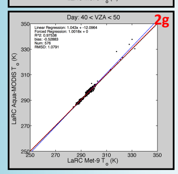


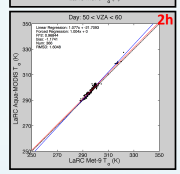
Figs 2d, 2e, 2f, 2g, 2h, and 2i) Same as **Fig 2c,** except limited to solar zenith angles less than 80°, and stratified into VZA groupings of 0° < VZA < 15°, 15° < VZA < 30°, 30° < VZA < 40°, 40° < VZA < 50°, 50° < VZA < 60°, and VZA > 60°. The unbiased scheme (**Fig 2c**) is used rather than the true relationship (**Fig 2a**) because the correction model should be solely dependent on varying viewing and illumination conditions, and should not be influenced by biases introduced by small differences in skill owed to subtle changes between the GEO and LEO skin temperature retrieval methodologies.

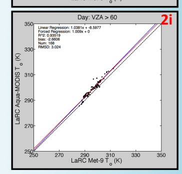




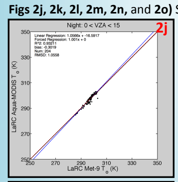


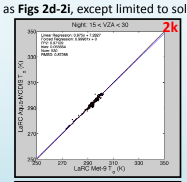


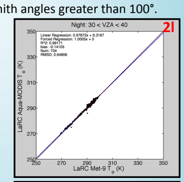


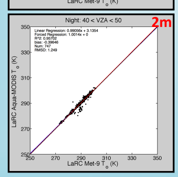


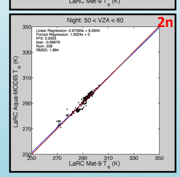
Figs 2j, 2k, 2l, 2m, 2n, and 2o) Same as **Figs 2d-2i**, except limited to solar zenith angles greater than 100°.

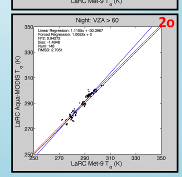




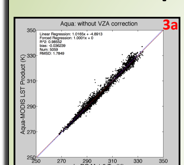


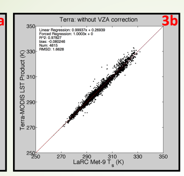




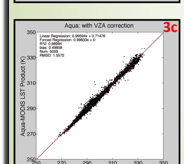


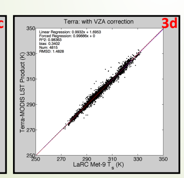
VZA Dependency Model Application Results

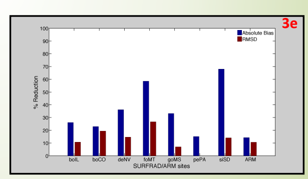




- **Figs 3a** and **3b)** LaRC Met-9 T_s validated with Aqua- and Terra-MODIS Land Surface Temperature (LST) product. Uses MODIS emissivity product. Spectral band difference correction applied.
- **Figs 3c** and **3d)** Same and **Figs 3a** and **3b**, except with VZA dependency corrections (**Figs 2d-2o**) applied.
- **Fig 3e)** Improvements in precision (RMSD) and accuracy (absolute bias) of LaRC GOES-East T_o compared to ground sites, from before to after application of the VZA dependency correction model.







Conclusions/Future Work

- When compared to MODIS LST, the VZA dependency correction reduces the uncertainty of LaRC T_s by 11-13%, while keeping the bias to less than 0.5 K
- Compared to SURFRAD/ARM, applying the correction all but universally results in improvements in both accuracy and precision of the LaRC T_o product (Penn State SURFRAD site excepted)
- Need to build model using at least a full year of data, as larger sample size would improve confidence, allow for finer-resolution VZA bins, and/or allow more flexibility in illumination and azimuthal considerations
- Need to reanalyze SURFRAD/ARM improvements using a VZA dependency model based on GOES-East

*Scarino, B.; Minnis, P.; Palikonda, R.; Reichle, R.H.; Morstad, D.; Yost, C.; Shan, B.; Liu, Q. Retrieving Clear-Sky Surface Skin Temperature for Numerical Weather Prediction Applications from Geostationary Satellite Data. Remote Sensing. 2013; 5(1):342-366.