An Atmospheric Correction Parameter Calculator for a Single Thermal Band Earth-Sensing Instrument

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Abstract— **An atmospheric correction tool has been developed for public web site access for the Landsat-5 and Landsat-7 thermal band. The Atmospheric Correction Parameter Calculator uses the National Centers for Environmental Prediction (NCEP) modeled atmospheric global profiles for a particular date, time and location as input. Using commercially-available MODTRAN software and a suite of integration algorithms, the site-specific atmospheric transmission, and upwelling and downwelling radiances are derived. These calculated parameters can be applied to single band thermal imagery from Landsat-5 Thematic Mapper (TM) or Landsat-7 Enhanced Thematic Mapper Plus (ETM+) to infer an at-surface kinetic temperature for all the pixels in the scene. Given the TM and ETM+ Band-6 instrument calibration uncertainties in Top-of-Atmosphere temperature are ±1.0 and ±0.6K, respectively, then the corresponding uncertainties in the inferred surface temperatures are approximately ±2-3K.**

Keywords-atmospheric correction; thermal imagery; LWIR; TIR; Landsat; TM; ETM+; surface temperature

I. BACKGROUND

Since 1984, the systematic collection of Landsat imagery has produced more 60-120m high spatial resolution thermal infrared (TIR) imagery of the Earth's land surfaces than any other satellite system. Yet unlike other NASA Earth Observation System missions, the Landsat production system does not produce derived physical parameters, such as sea surface temperatures, from the calibrated at-satellite radiance data. This paper provides the user with a tool that facilitates the conversion of Landsat TIR calibrated at-satellite data to surface temperature products.

A. Landsat

The Thematic Mapper (TM) on the Landsat-5 satellite, launched March 1, 1984, and the Enhanced Thematic Mapper Plus (ETM+) on the Landsat-7 satellite, launched April 15, 1999, provide a single 10.5-12.5µm TIR band [1]. Table 1 provides selected features of the thermal bands of the two instruments. More information about Landsat is available at the Landsat-7 Science Data Users Handbook (http://ltpwww.gsfc.nasa.gov/IAS/handbook.html). The calibration of TM thermal data has not been rigorously monitored over its history though a recent effort has shown the entire archive of thermal data can be calibrated to ±1K at 300K despite a –0.7K offset error [2]. The ETM+ instrument calibration has been monitored since launch and is calibrated to ±0.6K at 300K [2].

Unlike multi-thermal band systems, the Landsat instruments, each with a single thermal band, provide no opportunity to inherently correct for atmospheric effects. Ancillary atmospheric data are required to make the correction from Top-of-Atmosphere (TOA) radiance or temperature to surface-leaving radiance or temperature. However, with the long history of calibrated data and the current 8-day repeat cycle between the two instruments, there is strong motivation to use these unique data for absolute temperature studies.

B. Atmospheric Correction

Removing the effects of the atmosphere in the thermal region is the essential step necessary to use thermal band imagery for absolute temperature studies. The emitted signal leaving a target on the ground is both attenuated and enhanced by the atmosphere. With appropriate knowledge of the atmosphere, a radiative transfer model can be used to estimate the transmission, and upwelling and downwelling radiance. Once these parameters are known, it is possible to convert the space-reaching radiance to a surface-leaving radiance:

$$L_{TOA} = \tau\varepsilon L_T + L_u + (1-\varepsilon)\, L_d, \qquad (1)$$

where τ is the atmospheric transmission, ε is the emissivity of the surface, L_T is the radiance of a blackbody target of kinetic temperature T, L_u is the upwelling or atmospheric path radiance, L_d is the downwelling or sky radiance, and L_{TOA} is the space-reaching or TOA radiance measured by the instrument. Radiances are in units of W/m^2·ster·µm and the transmission

TABLE I. COMPARISON OF SELECTED FEATURES OF THE THERMAL BANDS OF TM AND ETM+. DUE TO THE BUILD UP OF ICE ON THE LANDSAT-5 DEWAR WINDOW, WHICH EFFECTIVELY DECREASES THE SENSITIVITY OF THE DETECTORS AFTER EACH PERIODIC "DE-ICING", THE LANDSAT-5 NOISE EQUIVALENT CHANGE IN TEMPERATURE (NEΔT) IS SPECIFIED AS A RANGE. THE USEFUL TEMPERATURE RANGE IS BOUNDED BY THE SENSIVITY OF THE DETECTORS AT THE MINIMUM NEΔT AND THE RESCALING FACTORS FOR THE GEOMETRICALLY CORRECTED PRODUCT. LANDSAT-7 HAS NOT EXHIBITED ICING BUT HAS TWO GAINS STATES SO THE SAME MEASURES ARE GIVEN SEPARATELY FOR HIGH (H) AND LOW (L) GAIN SETTINGS [2].

	FWHM (µm)	**Spatial Resolution (m)**	**NEΔT (K at 280K)**	**Useful Temperature Range (K)**
Landsat-5 TM	10.45 - 12.42	120	0.17 - 0.30	min: 230-330 max: 200-340
Landsat-7 ETM+	10.31 - 12.36	60	H: 0.22 L: 0.28	H: 240-320 L: 130-350

and emissivity are unitless. Radiance to temperature conversions can be made using the Planck equation.

The TOA temperature is not a good estimate of surface temperature. Neglecting the atmospheric correction will result in systematic errors in the predicted surface temperature. Fig. 1 illustrates the errors in surface temperature from making no atmospheric correction or using just a MODTRAN standard atmosphere. The surface temperatures predicted by the National Centers for Environmental Prediction (NCEP) modeled atmospheric profiles are truth. With no atmospheric correction, the predicted temperatures are 5-10K low. Using a standard atmosphere, the predicted temperatures are slightly higher then the NCEP temperatures (0-3K). Two variations of the standard atmosphere produced results statistically identical to the standard atmosphere predicted surface temperatures. This illustration provides evidence that any atmospheric correction is better then none.

II. ATMOSPHERIC CORRECTION PARAMETER CALCULATOR

A. *The Web-Based Tool*

Traditionally, calculating the atmospheric transmission and upwelling radiance has been difficult and time consuming. The user had to know where to get the atmospheric data, convert it to the proper format for the radiative transfer model, run the radiative transfer model and integrate the results. The Atmospheric Correction Parameter Calculator facilitates this calculation.

The Atmospheric Correction Parameter Calculator requires a specific date, time and location as input (Fig. 2). The user has the option to select the TM bandpass, the ETM+ bandpass, or no spectral bandpass. Another option allows the user to select how the modeled atmospheric profile is interpolated. If local surface conditions are available, the user can enter them. The local conditions will be used instead of the model predicted surface conditions, and the lower layers of the atmosphere will be smoothed to remove any discontinuities resulting from changing the surface conditions. The calculated results are emailed to the user and output to the web browser. The emailed file contains not only the integrated transmission and upwelling and downwelling radiance for the given site, but also all the atmospheric data used to generate the results. In the case where no spectral band pass is selected, the output is the interpolated atmospheric profiles, for use in a radiative transfer model.

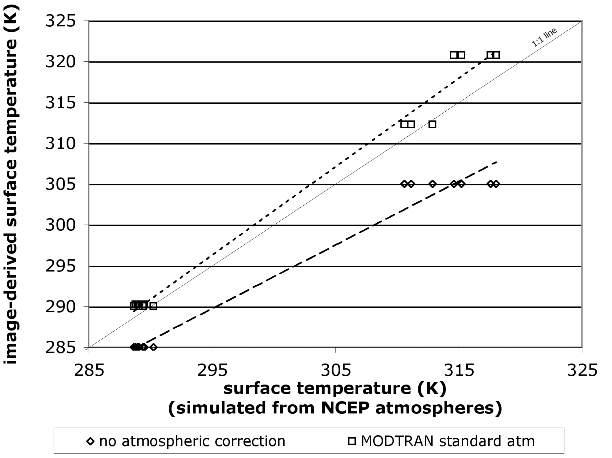
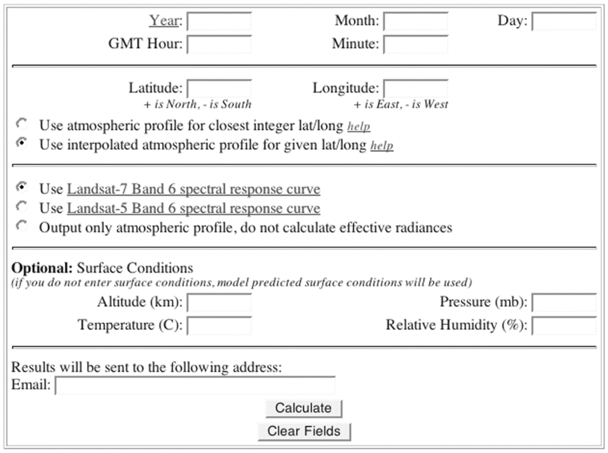


Figure 1. Simulated example using different atmospheric models for atmospheric correction. The surface temperature was predicted for two different TOA temperatures (285 and 305K) for seven cloud-free dates, once per month over the Washington, DC area, from March through October, 2001. The surface temperatures predicted by the National Centers for Environmental Prediction (NCEP) profiles served as truth. This shows that not performing any atmospheric correction will cause biased results, while a basic standard atmospheric model approximates the NCEP model.



Year: ☐ Month: ☐ Day: ☐
GMT Hour: ☐ Minute: ☐

Latitude: ☐ Longitude: ☐
+ is North, - is South *+ is East, - is West*
○ Use atmospheric profile for closest integer lat/long *help*
● Use interpolated atmospheric profile for given lat/long *help*

● Use Landsat-7 Band 6 spectral response curve
○ Use Landsat-5 Band 6 spectral response curve
○ Output only atmospheric profile, do not calculate effective radiances

Optional: Surface Conditions
(if you do not enter surface conditions, model predicted surface conditions will be used)
Altitude (km): ☐ Pressure (mb): ☐
Temperature (C): ☐ Relative Humidity (%): ☐

Results will be sent to the following address:
Email: ☐

Figure 2. User interface of Atmospheric Correction Parameter Calculator. It is located on the web at http://landsat.gsfc.nasa.gov/atm_corr.

The atmospheric profiles are generated by NCEP. They incorporate satellite and surface data to predict a global atmosphere at 28 altitudes. These modeled profiles are sampled on a 1°x1° grid and are generated every six hours. The Calculator provides two methods of resampling the grid for the specific inputted site: “Use atmospheric profile for closest integer lat/long” or “Use interpolated atmospheric profile for given lat/long”. The first extracts the grid corner that is closest to the inputted location for the two time samples bounding the inputted time and then interpolates between the two time samples to the given time. The second option extracts the profiles for the four grid corners surrounding the inputted location for the two times before and after the inputted time. The corner profiles are interpolated for each time, then the resulting time profiles are interpolated (Fig. 3).

The location and time-specific interpolated profile contains pressure, air temperature and water vapor profiles from the surface to about 30km above sea level. In order to predict space-reaching transmission and upwelling radiance, the radiative transfer code, MODTRAN, requires profiles reaching “space”, or 100km above sea level. The upper atmosphere layers (~30-100km) are extracted from a MODTRAN standard atmosphere and pasted onto the site-specific interpolated profile. This results in a surface-to-space profile for air temperature, water vapor, and pressure.

The completed profile is inserted into a MODTRAN 4.0 input file and processed. The spectral transmission and upwelling radiance are extracted from the MODTRAN output files and integrated over the user selected bandpass. The downwelling radiance is generated by running MODTRAN again, placing the sensor just above a target with unit reflectance. The surface radiance in the MODTRAN output file

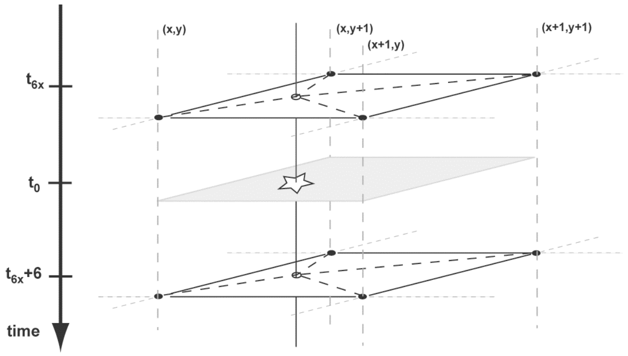


Figure 3. Illustration of the interpolation method between model grid points and time samples for a location and time between NCEP samples. The corners of the grid are interpolated to the given location at both times. The resulting two profiles are interpolated to the given time (t_0).

is taken to be the spectral downwelling radiance and is integrated over the selected bandpass.

The resulting integrated transmission, upwelling and downwelling radiance are output to the browser and emailed to the user for use in removing the effects of the atmosphere with (1). The Atmospheric Correction Parameter Calculator is located at http://landsat.gsfc.nasa.gov/atm_corr.

B. *Expected Errors*

The "Daily analysis and model performance statistics" for the NCEP data show that over the past four years, the NCEP final global predictions are ±2K for air temperature and ±2% for relative humidity for the entire profile based on a comparison to radiosonde observations (http://wwwt.emc.ncep.noaa.gov/gmb/gdas).

The interpolation of the modeled NCEP profiles in time and space adds uncertainty to the site-specific Calculator atmospheric profile. In an illustrative example, the variation around one site, Lake Tahoe, Nevada, is estimated from the variation in the NCEP grid corners (Fig. 4).

In a separate paper [3], the uncertainties in TOA temperatures were simulated for a range of ±2K and ±10% relative humidity (~±0.3K and 1.6%, 1-sigma) and a second range of ±4K and ±20% (~±0.6K and ±3.3% 1-sigma). The results of the simulation were uncertainties of ±0.55K and ±1.1K in TOA temperature for the two cases. Considering the known ±2K NCEP modeling uncertainty and the illustrative interpolation uncertainty ±6% relative humidity, the approximate estimate for the error in inferred surface temperature is extrapolated to be in the range of ±2-3K.

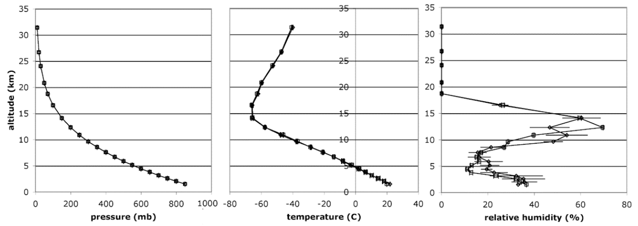


Figure 4. Sample atmospheric profiles of pressure, air temperature and relative humidity from 06-Jun-02 around Lake Tahoe, Nevada for 1200GMT and 1800GMT. The error bars illustrate the variation in a 3°x3° grid about 39N/120W at the two times. The time and altitude averaged standard deviations are ±0mb pressure, ±0.7K air temperature and, ±6% relative humidity.

C. *Limitations*

- There is no automatic check for clouds or discontinuities in the interpolated atmosphere. The user should check the profiles contained in the emailed summary file for problems.
- The user must know the emissivity of the target in order to determine L_T.
- NCEP data are not available for the entire lifetime of Landsat-5 and not all the NCEP data are available to the Atmospheric Correction Parameter Calculator. The dates for which NCEP data are available are listed on the Calculator web-site.
- The interpolation in time and space is linear. This is may not be the most appropriate method for sampling weather fonts or the diurnal heating cycle.
- Currently, only the MODTRAN mid-latitude summer standard atmosphere is available for "space" altitudes.

III. CONCLUSION

With the abundance of Landsat data now available at low cost and without restrictions on distribution, it is important to make the archive of at-satellite thermal data as usable as possible. The Atmospheric Correction Parameter Calculator provides an automated method to derive atmospheric correction parameters needed for generating surface temperatures, large time periods and areas to within ±2-3K.

Landsat-5 and Landsat-7 data are available from the US Geological Survey Eros Data Center at http://earthexplorer.usgs.gov (both –5 and –7) or http://edcimswww.cr.usgs.gov/pub/imswelcome (only -7).

ACKNOWLEDGMENTS

Thanks to the Landsat vicarious calibration teams at Rochester Institute of Technology and NASA/Jet Propulsion Laboratory for use of their data and methods.

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