Landsat Land Surface Temperature Product: Global Validation and Cloud Analysis

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LST Goals

• Develop an automated method to obtain per-pixel LST results for Landsat scenes

• Determine how accurate the method is for North American regions

• Determine how accurate the method is globally and for all Landsat sensors

• Develop a way to estimate expected LST errors in order to make a quality map
The “Big Equation”

\[ L_{\text{obs}} = \left( \varepsilon L_T + (1-\varepsilon)L_d \right)\tau + L_u \]

- \( L_{\text{obs}} \) = radiance seen by satellite
- \( L_T \) = radiance emitted from target
- \( \varepsilon \) = emissivity of target
- \( L_d \) = downwelled radiance
- \( \tau \) = transmission
- \( L_u \) = upwelled radiance
EMISSIVITY
• Extract Bare Earth Emissivity from the North American Aster Land Surface Emissivity Database (NAALSED)-Soon available globally!
  – Emissivities \((\varepsilon_{13}, \varepsilon_{14})\) and regression coefficients (JPL)
    \[
    \varepsilon_{\text{landsat}} = C_{13} \varepsilon_{13} + C_{14} \varepsilon_{14} + C
    \]
LANDSAT 5 derived emissivity from NAALSED bands 13 & 14 over the Salton Sea and Imperial Valley, CA. (JPL)
Correct Emissivity for High NDVI conditions
Note: an error in emissivity of 0.01 corresponds to 0.7K error in temperature in these bands.

Fig. 3. Average emissivity spectra for different soil samples included in the ASTER spectral library (http://speclib.jpl.nasa.gov). ‘Inceptisol’ refers to the mean value for all the soil samples included in the ASTER library and classified as Inceptisol (7 samples). These values have been chosen as soil emissivities in the NDVI method. ‘All soils’ refers to the mean value for all the soil samples included in the ASTERlib (49 samples). Error bars refer to the standard deviation of the mean values. The emissivity spectrum obtained from field measurements (Field) and the one measured in the JPL are also given for comparison.[Munoz et al. (2006) RSofE V.103,#4, pp. 474-487].

\[
\begin{align*}
\varepsilon_{13} &= 0.968 + 0.022 \, P_V \\
\varepsilon_{14} &= 0.970 + 0.020 \, P_V \\

P_V &= \left( \frac{\text{NDVI} - \text{NDVI}_s}{\text{NDVI}_v - \text{NDVI}_s} \right)^2
\end{align*}
\]
Lake Tahoe
5 Class Classification Map

Aster Band 13
Lake Tahoe Emissivity Data

<table>
<thead>
<tr>
<th>Class</th>
<th>Average Emissivity</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>0.988</td>
<td>0.00736</td>
</tr>
<tr>
<td>Class 2</td>
<td>0.976</td>
<td>0.00698</td>
</tr>
<tr>
<td>Class 3</td>
<td>0.975</td>
<td>0.00748</td>
</tr>
<tr>
<td>Class 4</td>
<td>0.975</td>
<td>0.00681</td>
</tr>
<tr>
<td>Class 5</td>
<td>0.972</td>
<td>0.00890</td>
</tr>
</tbody>
</table>
Lake Tahoe
5 Class Classification Map

Aster Band 14
Lake Tahoe Emissivity Data

Class 1  Average Emissivity 0.988  SD 0.00644
Class 2  Average Emissivity 0.974  SD 0.00476
Class 3  Average Emissivity 0.974  SD 0.00477
Class 4  Average Emissivity 0.974  SD 0.00472
Class 5  Average Emissivity 0.972  SD 0.00572
A Land Surface Temperature Product

Validation of atmospheric component

- Use calibration sites – Atm. Compensation
  - Salton Sea (below sea level and hot)
  - East & West Coast (sea level – wide range of atmosphere)
  - Great Lakes (≈ 0.2 km)
  - Lake Tahoe (≈ 1.4 km)
- Covers all dates, all instruments
- Only tests atmospheric compensation since all targets are water
NARR Reanalysis Data

- **North American Regional Reanalysis**
- Available every 3 hours
- 32 km spacing (0.3 x 0.3 degrees)
- 29 pressure levels (1000 – 100 hPa)
- Lambert Conformal coordinates

Need to interpolate in time, elevation and location
Final Output

- Landsat sized array
- 5 parameters total
- Use parameters around buoy location to get estimated temperature

\[ L_{\text{obs}} = [\varepsilon L_T + (1-\varepsilon)L_d]\tau + L_u \]
Validation

- Use Landsat scenes over valid buoys
- Correct buoy measurement to skin temperature
- Compare to Landsat predicted temperature
Landsat 5, North America

- 259, cloud free scenes

<table>
<thead>
<tr>
<th>Location</th>
<th>Path_Row</th>
<th>Mean Error [K]</th>
<th>Standard Deviation [K]</th>
<th>RMSE [K]</th>
<th>No. of Scenes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salton Sea</td>
<td>39_37</td>
<td>-0.12</td>
<td>0.558</td>
<td>0.545</td>
<td>11</td>
</tr>
<tr>
<td>Lake Tahoe</td>
<td>43_33</td>
<td>-0.213</td>
<td>0.713</td>
<td>0.740</td>
<td>89</td>
</tr>
<tr>
<td>Lake Ontario</td>
<td>16_30</td>
<td>-0.068</td>
<td>0.639</td>
<td>0.626</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>17_30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delaware Bay</td>
<td>13_33</td>
<td>-0.447</td>
<td>1.179</td>
<td>1.245</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>14_33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia (coast)</td>
<td>16_38</td>
<td>0.041</td>
<td>1.267</td>
<td>1.239</td>
<td>23</td>
</tr>
<tr>
<td>Santa Maria (coast)</td>
<td>43_36</td>
<td>-0.219</td>
<td>0.789</td>
<td>0.799</td>
<td>19</td>
</tr>
<tr>
<td>Santa Monica (coast)</td>
<td>41_37</td>
<td>-0.574</td>
<td>1.089</td>
<td>1.208</td>
<td>21</td>
</tr>
<tr>
<td>Lake Huron</td>
<td>20_29</td>
<td>-0.695</td>
<td>0.820</td>
<td>1.059</td>
<td>19</td>
</tr>
<tr>
<td>Lake Superior</td>
<td>24_27</td>
<td>-0.167</td>
<td>0.676</td>
<td>0.682</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>—</td>
<td>-0.267</td>
<td>0.900</td>
<td>0.905</td>
<td>259</td>
</tr>
</tbody>
</table>
Landsat 5, North America

LST Error (259 cloud free scenes)
Don’t want to restrict product to cloud free scenes: Development of Quality Metric for cloud in scene

• Use reflectance product to get cloud mask for Landsat scene

• Calculate distance from buoy to nearest cloud pixel

• See how cloud proximity relates to LST error
Cloud Mask Example
Removing “0” Distances

All Scenes vs Scenes without 0 Distances

- Avg error = -7.41 K → -1.20 K
- St. Dev. = 18.24 K → 5.47 K
- RMSE = 19.679 → 5.597 K
- % scenes = 100% → 68.18%

Frequency

Error [K]

< -10.5 | -9.0 | -7.0 | -5.0 | -3.0 | -1.0 | 1.0 | 3.0 | 5.0 | 7.0 | 9.0

All (949 scenes)

>0m (648 scenes)
Average Error for Distance Bins

Average Error and RMSE for Various Distance Bins (All Scenes)

Distance to Nearest Cloud Bins [km]

Average Error [K]

-4
-3
-2
-1
0

# Scenes: 66
Avg Err: -3.424
STDEV: 11.183
RMSE: 11.614

# Scenes: 92
Avg Err: -2.630
STDEV: 10.098
RMSE: 10.382

# Scenes: 80
Avg Err: -1.139
STDEV: 2.598
RMSE: 2.822

# Scenes: 375
Avg Err: -0.554
STDEV: 0.624
RMSE: 0.669

# Scenes: 35
Avg Err: -0.262
STDEV: 1.355
RMSE: 1.462

inf
Removing Bad Scenes

Average Error and RMSE for Various Distance Bins (|errors| > 20 removed)

- **Distance to Nearest Cloud Bins [km]**
  - 0
  - 1
  - 2
  - 3
  - 4
  - 50
  - inf

- **Average Error [K]**
  - 0
  - -1
  - -2
  - -3
  - -4

- **# Scenes**
  - 64
  - 91
  - 375
  - 35

- **Avg Err**
  - -1.691
  - -1.139
  - -0.262

- **STDEV**
  - 3.449
  - 1.355
  - 0.624

- **RMSE**
  - 3.817
  - 1.462
  - 0.669
Global Validation Problems

• Problems
  – NARR is only available for North America
  – Buoys unavailable on a global scale

• Solutions
  – Compare LST NARR results to LST results using global reanalysis products
  – For truth, use MODIS (MODerate resolution Imaging Spectroradiometer)
Choosing a New Reanalysis Product

<table>
<thead>
<tr>
<th></th>
<th>NARR (NOAA)</th>
<th>MERRA (NASA)</th>
<th>CFSR (NOAA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coverage</strong></td>
<td>North America</td>
<td>Global</td>
<td>Global</td>
</tr>
<tr>
<td><strong>Spatial</strong></td>
<td>32 km spacing</td>
<td>1.25° x 1.25°</td>
<td>~38 km spacing</td>
</tr>
<tr>
<td></td>
<td>(0.3° at equator)</td>
<td>(140 km at equator)</td>
<td>(0.5° x 0.5°)</td>
</tr>
<tr>
<td></td>
<td>349x277</td>
<td>288x144</td>
<td>720x361</td>
</tr>
<tr>
<td><strong>Temporal</strong></td>
<td>8x daily 3-hr intervals</td>
<td>8x daily 3-hr intervals</td>
<td>4x daily 6-hr intervals</td>
</tr>
<tr>
<td><strong>Pressure Levels</strong></td>
<td>29 levels 1000 - 100 hPa</td>
<td>42 levels 1000 - 0.1 hPa</td>
<td>37 levels 1000 - 1 hPa</td>
</tr>
</tbody>
</table>
Finding Acceptable Truth Data

• MODIS Sea Surface Temperature
  – MODIS TERRA has an orbit track similar to Landsat 7 (~20 min behind)
  – Quality band gives each pixel a 0-4 rating, 0 being the best quality
Comparing LST vs. Buoys

LST Error Histogram (NARR L7), Best Quality

Avg Error = -0.2408 K
St. Dev. = 0.7010 K
RMSE = 0.737 K
Comparing MODIS vs. Buoys

MODIS SST Error Histogram, Best Quality

- Frequency
- Error [K]

Avg Error = 0.2445 K
St. Dev. = 0.6989 K
RMSE = 0.736 K
Preliminary Global Validation of Landsat 7

- Compared MODIS SST product to LST results using MERRA
  - 63 scenes globally, 11 sites
  - Errors range from -0.68 to 1.06 K
Steps Forward

• Run LST process for hundreds of global scenes for Landsat 7
  – Use MERRA as reanalysis product
  – Use MODIS SST as truth

• Perform Landsat 4 and Landsat 8 validation: Using Buoys

• Continue to utilize the “distance to nearest cloud” metric

• Merge emissivity error, atmospheric error propagation error estimate and cloud proximity errors into confidence metric????????????????
Error Propagation
Error Propagation
Multilevel Confidence Estimation

Calculated without clouds (398 scenes total, 332 without clouds)

Best: $\tau > 0.9$

Good: $0.8 < \tau < 0.9$

Bad: $\tau < 0.8$

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean</th>
<th>SD</th>
<th># scenes</th>
<th>% of cloud free data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>0.868 K</td>
<td>1.083 K</td>
<td>95</td>
<td>28.6%</td>
</tr>
<tr>
<td>Good</td>
<td>1.500 K</td>
<td>2.828 K</td>
<td>93</td>
<td>28.0%</td>
</tr>
<tr>
<td>Bad</td>
<td>2.318 K</td>
<td>2.867 K</td>
<td>144</td>
<td>43.4%</td>
</tr>
</tbody>
</table>
Estimating LST Error

• $S_a = \text{Error due to atmosphere } (\tau, L_u, L_d)$
  - Determine using error propagation for cloud free scenes
• $S_c = \text{Error due to presence of clouds}$
  - Develop relationship between cloud proximity and LST error
• $S_e = \text{Error due to emissivity}$
  - Obtained from JPL

• $S_{TOTAL} = \sqrt{S_a^2 + S_c^2 + S_e^2}$
  - For cloud free cases, $S_a$ will dominate
  - As clouds get closer, $S_c$ will dominate
INPUT?
Extra Slides
Further Explanation
Radiance Paths

Figure 3.1: Thermal energy paths contributing to the sensor reaching radiance.
Skin Correction

\[ z = \text{sensor depth} \]
\[ T_z = 24 \text{ hr avg at } z \]
\[ T_s = 24 \text{ hr avg at skin} \]
\[ a = \text{thermal gradient} \]
\[ d = \text{cool skin effect} = 0.17 \text{ K} \]
\[ \mu_m = 24 \text{ hr avg wind speed} \]
\[ c = \text{phase constant} \]
\[ b = \text{damping constant} \]

\[
\langle T_s \rangle = \langle T_z \rangle - az - d
\]
\[
a = 0.05 - \frac{0.6}{\mu_m} + 0.03 \ln(\mu_m)
\]
\[
f(t - cz) = \frac{T(z, t) - \langle T_z \rangle}{e^{-bz}}
\]
\[
c = 1.32 - 0.64 \ln(\mu_m)
\]
\[
b = 0.35 + 0.018e^{0.4\mu_m}
\]

\[ T_s = T(0, t) = \langle T_s \rangle + f(t) \]
Shepard’s method

Figure 4.19: caption

\[ d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \]

\[ w_i = \frac{d_i^{-p}}{\sum_{j=1}^{n} d_j^{-p}} \]

\[ F(x, y) = \sum_{i=1}^{n} w_i f_i \]
Spatial Interpolation
CFSR (Climate Forecast System Reanalysis)

- Global, high resolution, coupled atmosphere-ocean-land surface-sea ice system
- Initialized 4x daily (0000, 0600, 1200, 1800 UTC)
- Time series products available at 0.3, 0.5, 1.0, and 2.5° horizontal resolutions
- Available from January 1979 to December 2010
- CFSRv2 is available from January 2011-present
- Data format- WMO GRIB2 (NARR was WMO GRIB1)
**Description of Global Sites**

Table 6.4: Descriptions of locations and radiosonde densities for each point selected for global MODIS and Landsat LST comparisons. Note that the radiosonde description refers to the description of the density of input observations to the MERRA product provided in Figure 6.10.

<table>
<thead>
<tr>
<th>Location</th>
<th>WRS-2 path_row</th>
<th>[lat, lon]</th>
<th>Radiosonde</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>216.63</td>
<td>[-4.26, -37.7]</td>
<td>1</td>
<td>Tropical</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>196.30</td>
<td>[43.3, 4.8]</td>
<td>2</td>
<td>Mid Lat - Northern</td>
</tr>
<tr>
<td>Black Sea</td>
<td>174.30</td>
<td>[43.47, 38.91]</td>
<td>2</td>
<td>Mid Lat - Northern</td>
</tr>
<tr>
<td>India</td>
<td>144.54</td>
<td>[9.0, 76.34]</td>
<td>0</td>
<td>Tropical</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>121.44</td>
<td>[22.46, 114.9]</td>
<td>2</td>
<td>Low Lat - Northern</td>
</tr>
<tr>
<td>Russia</td>
<td>107_19</td>
<td>[58.85, 149.43]</td>
<td>1</td>
<td>High Lat - Northern</td>
</tr>
<tr>
<td>Australia</td>
<td>113.82</td>
<td>[-31.9, 114.95]</td>
<td>2</td>
<td>Mid Lat - Southern</td>
</tr>
<tr>
<td>Africa</td>
<td>180_75</td>
<td>[-22.0, 14.0]</td>
<td>0</td>
<td>Low Lat - Southern</td>
</tr>
<tr>
<td>Greenland</td>
<td>232_17</td>
<td>[61.5, -41.75]</td>
<td>1</td>
<td>High Lat - Northern</td>
</tr>
<tr>
<td>South America</td>
<td>218_77</td>
<td>[-24.045, -45.18]</td>
<td>2</td>
<td>Low Lat - Southern</td>
</tr>
<tr>
<td>South America</td>
<td>233_93</td>
<td>[-47.88, -75.45]</td>
<td>1</td>
<td>Mid Lat - Southern</td>
</tr>
</tbody>
</table>
MERRA vs MODIS SST

Table 6.5: Statistics of errors for each individual location for MODIS SST and Landsat comparisons. The error is calculated using Equation 6.2, n is the number of scenes analyzed for each location after removing scenes with less than the best quality, and SD is the standard deviation.

<table>
<thead>
<tr>
<th>Location</th>
<th>Radiosonde</th>
<th>Description</th>
<th>n</th>
<th>Mean [K]</th>
<th>SD [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>1</td>
<td>Tropical</td>
<td>4</td>
<td>1.06</td>
<td>0.79</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>2</td>
<td>Mid Lat - Northern</td>
<td>4</td>
<td>-0.27</td>
<td>0.28</td>
</tr>
<tr>
<td>Black Sea</td>
<td>2</td>
<td>Mid Lat - Northern</td>
<td>6</td>
<td>-0.41</td>
<td>0.45</td>
</tr>
<tr>
<td>India</td>
<td>0</td>
<td>Tropical</td>
<td>6</td>
<td>0.82</td>
<td>0.43</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2</td>
<td>Low Lat - Northern</td>
<td>4</td>
<td>0.09</td>
<td>1.31</td>
</tr>
<tr>
<td>Russia</td>
<td>1</td>
<td>High Lat - Northern</td>
<td>3</td>
<td>-0.60</td>
<td>0.32</td>
</tr>
<tr>
<td>Australia</td>
<td>2</td>
<td>Mid Lat - Southern</td>
<td>8</td>
<td>-0.32</td>
<td>0.43</td>
</tr>
<tr>
<td>Africa</td>
<td>0</td>
<td>Low Lat - Southern</td>
<td>4</td>
<td>-0.47</td>
<td>0.27</td>
</tr>
<tr>
<td>Greenland</td>
<td>1</td>
<td>High Lat - Nothern</td>
<td>1</td>
<td>-0.24</td>
<td>-</td>
</tr>
<tr>
<td>South America</td>
<td>2</td>
<td>Low Lat - Southern</td>
<td>3</td>
<td>0.58</td>
<td>0.29</td>
</tr>
<tr>
<td>South America</td>
<td>1</td>
<td>Mid Lat - Southern</td>
<td>5</td>
<td>-0.68</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Monica’s Cloud Free Histograms
The Salton Sea (0)
Lake Tahoe (0)
Rochester (0)
Delmar (0)

Frequency

Error [K]
Georgia (0)
Santa Maria (0)
Santa Monica (0)
Lake Huron (0)

Frequency

Error [K]
Lake Superior (0)

Error [K] vs. Frequency
Distance Bin Histograms
Error Distribution for Bin 0-1 km

Frequency

Error [K]

-10.5 -9.0 -7.0 -5.0 -3.0 -1.0 1.0 3.0 5.0 7.0 9.0
Error Distribution for Bin 1-4 km
Error Distribution for Bin 4-7.5 km
Error Distribution for Bin 7.5-50 km
Error Distribution for Bin 50-inf km

Frequency

Error Distribution

Error [K]

Frequency

< -10.5  -9.0  -7.0  -5.0  -3.0  -1.0  1.0  3.0  5.0  7.0  9.0
Distance to Nearest Cloud vs Error vs Percent Clouds in 2 km Annulus

Error [K]

Percent Clouds in Annulus

Distance to Nearest Cloud [km]
The Basics

• Land Surface Temperature (LST) methodology

• Review of Monica’s work

• Development of a quality metric

• Approaches to global validation
Solving for Atmospheric Parameters

• Finding transmission and upwelled
  – If emissivity \( \cong 1 \), then \( L_{obs} = L_T \epsilon \tau + L_u \)
  – Slope is transmission and intercept is upwelled

• Finding downwelled
  – If emissivity < 1, then \( L_d = \frac{L_{obs} - L_u}{\tau} - L_T \epsilon \frac{1}{1-\epsilon} \)
  – Simply solve for \( L_d \)
MODTRAN Runs

- ~100 NARR points
- 9 ground altitudes
- 3 temperatures
Interpolation

- Temporal (to get NARR data at proper time)
- Height (to get parameters at appropriate pixel height)
- Spatial (to get parameters at a per-pixel level)
Cook’s Validation Results

- Landsat 5, North American Scenes
  - 9 sites, 259 cloud free scenes
  - 9 sites, 827 scenes with varying types/amounts of clouds
Cloud Analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Cloud free around buoy</td>
</tr>
<tr>
<td>1</td>
<td>Cumulus in vicinity</td>
</tr>
<tr>
<td>2</td>
<td>Cirrus in vicinity</td>
</tr>
<tr>
<td>3</td>
<td>Cumulus over buoy</td>
</tr>
<tr>
<td>4</td>
<td>Cirrus over buoy</td>
</tr>
<tr>
<td>5</td>
<td>Cloud-covered scene</td>
</tr>
</tbody>
</table>
All Cloud Types (826 scenes)

Error Histogram (0,1,2,3,4,5)

- Avg error = -8.471 K
- St. Dev. = 19.313 K
- RMSE = 21.078 K
- % scenes = 100%
“Clear and Near” Cloud Types (515 scenes)

Error Histogram (0,1,2)

Avg error = -0.933 K
St. Dev. = 2.460 K
RMSE = 2.629 K
% scenes = 62%
Cloud Free Scenes (259 scenes)

Error Histogram (0)

Avg error  = -0.267 K
St. Dev.    = 0.900 K
RMSE       = 0.927 K
% scenes   = 31%
Cloud Mask Failure

Distance to cloud = 2.84 km
Error = -93.1886 K
Cirrus Clouds Causing Trouble

Distance to cloud = 1.02 km
Error = -16.34297 K

Cloud mask (clouds are white)

True color image (wispy cirrus)
MERRA vs NARR (397 scenes)

LST Error Using NARR (without 0 distances)

Avg error = -2.362 K
St. dev. = 8.509 K
RMSE = 8.815 K
% < |1K| = 69.47%
MERRA vs NARR (397 scenes)

LST Error Using MERRA (without 0 distances)

Avg error = -2.344 K
St. dev. = 8.290 K
RMSE = 8.600 K
% < |1K| = 69.85%
CFSR vs NARR (130 scenes)

Error Histogram for NARR (without 0 distances)

Avg error = -1.6925 K  
St. dev. = 8.4955 K  
RMSE = 8.630 K  
% < |1K| = 73.08%
CFSR vs NARR (130 scenes)

Error Histogram for CFSR (without 0 distances)

Avg error = -4.8051 K
St. dev. = 17.2519 K
RMSE = 17.844 K
% < |1K| = 30.77%
Spectral Response Functions
TIRS and the Future

![Spectral Response Functions Graph]

- Landsat 5
- Landsat 7
- ASTER
- TIRS1
- TIRS2

Wavelength [μm]

Spectral Response

Data from Digital Imaging and Remote Sensing Lab
Initial Results

Distance to nearest cloud
vs
Percent clouds within 5 km annulus
vs
LST error
Cloud Summary & Steps Forward

• Distance to nearest cloud method showed a general trend between cloud proximity and LST error

• This may not be the best method (doesn’t consider the amount of clouds nearby)

• One option is to look at the fraction of clouds in “ring” areas around the buoy (see next slide)
“Clouds in Rings” Method

• Each scene has an error associated with it (at the buoy location)

• For each ring of a defined size, calculate the percent of pixels that are clouds

• Observe relationship between rings, cloud coverage, and error.
All data, reversed x-axis
Errors vs percent clouds in different rings

- Errors vs Percent Clouds in 0 to 5 km Annulus
- Errors vs Percent Clouds in 5 to 15 km Annulus