Landsat Land Surface Temperature Product: Global Validation and Cloud Analysis

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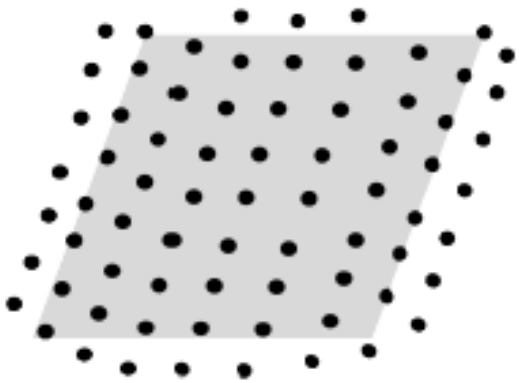
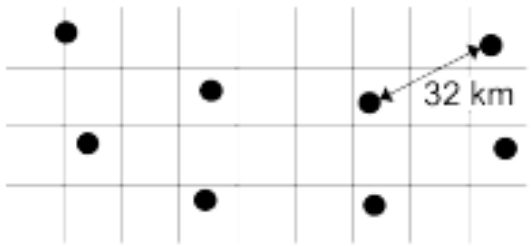
The Basics

- Land Surface Temperature (LST) methodology
- Validation for North America
- Cloud proximity vs. error analysis
- Approaches to global validation

NARR Reanalysis Data

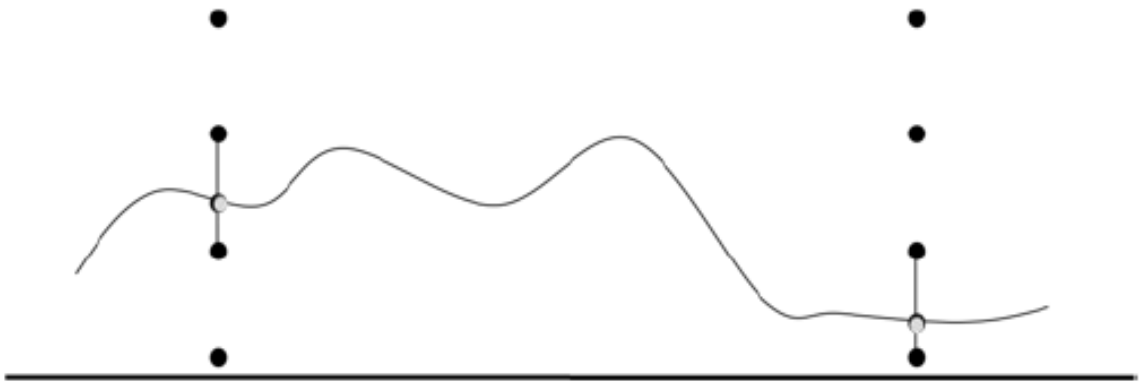
- **N**orth **A**merican **R**egional **R**eanalysis
- Available every 3 hours
- 32 km spacing (0.3 x 0.3 degrees)
- 29 pressure levels (1000 – 100 hPa)
- Lambert Conformal coordinates





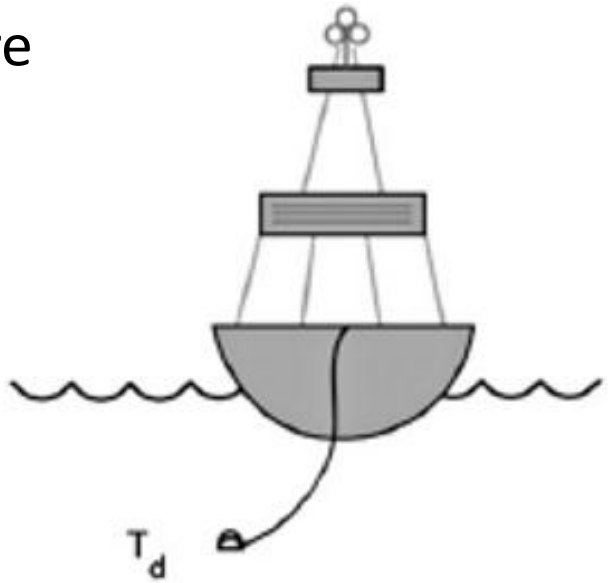
Interpolation

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

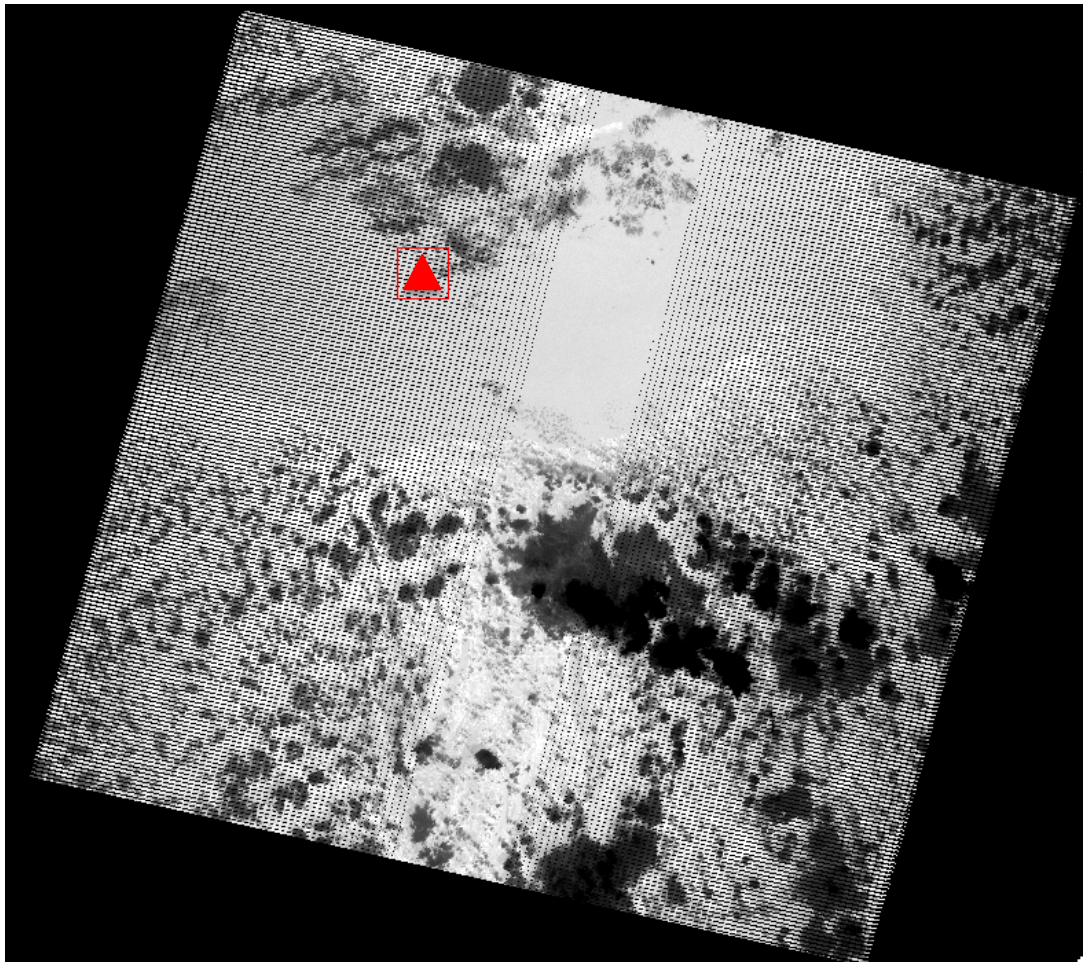


Validation

- Use Landsat scenes over valid buoys
- Correct buoy measurement to skin temperature
- Compare to Landsat predicted temperature

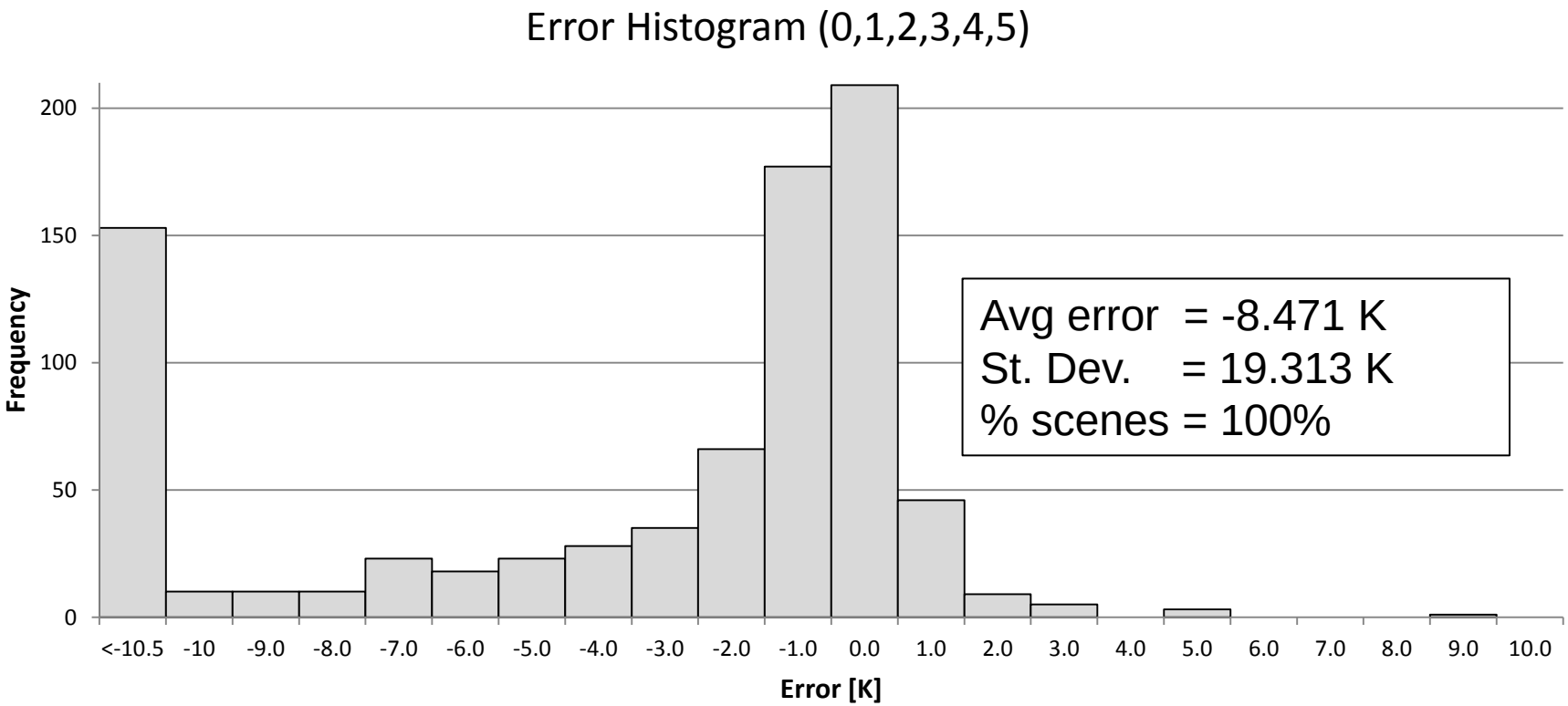


Cloud Analysis

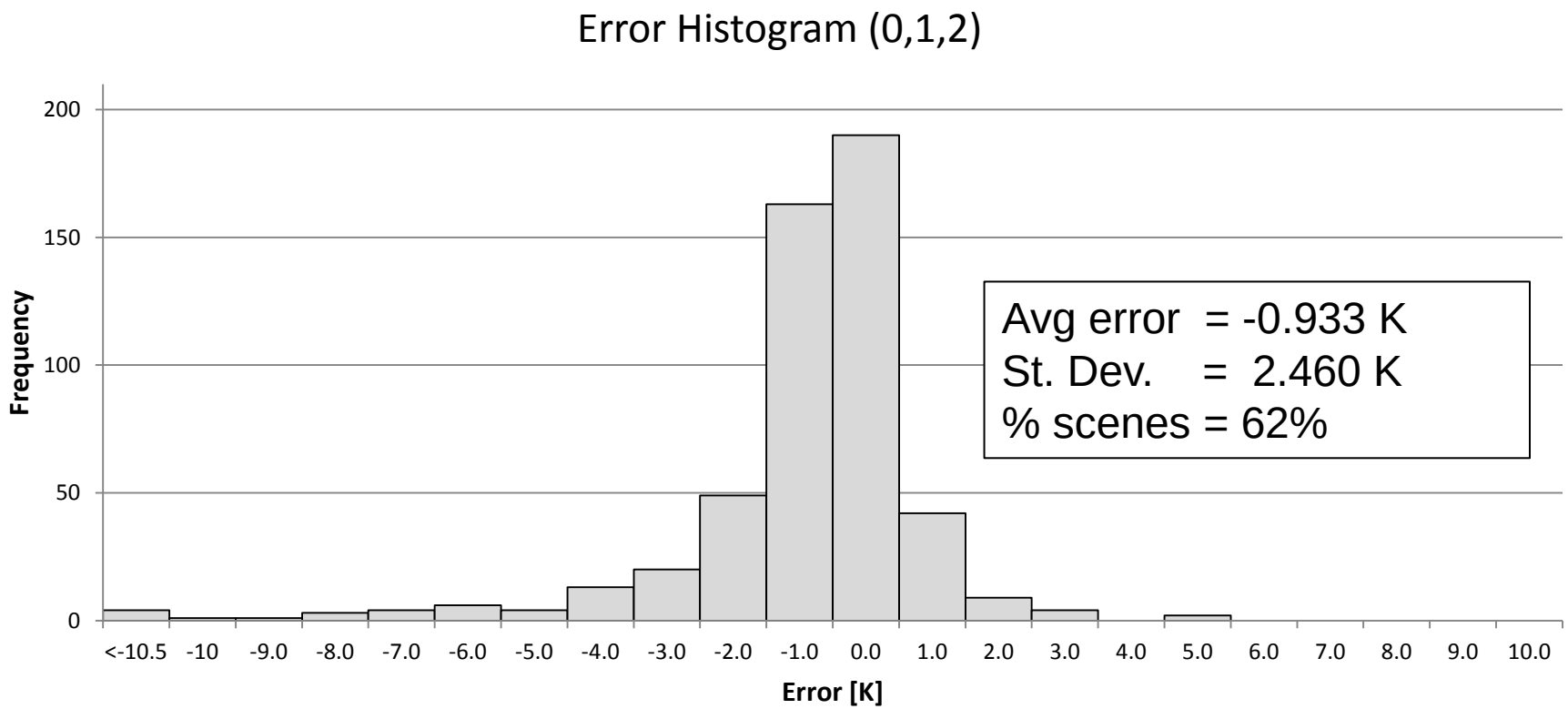


Category	Meaning
0	Cloud free around buoy
1	Cumulus in vicinity
2	Cirrus in vicinity
3	Cumulus over buoy
4	Cirrus over buoy
5	Cloud-covered scene

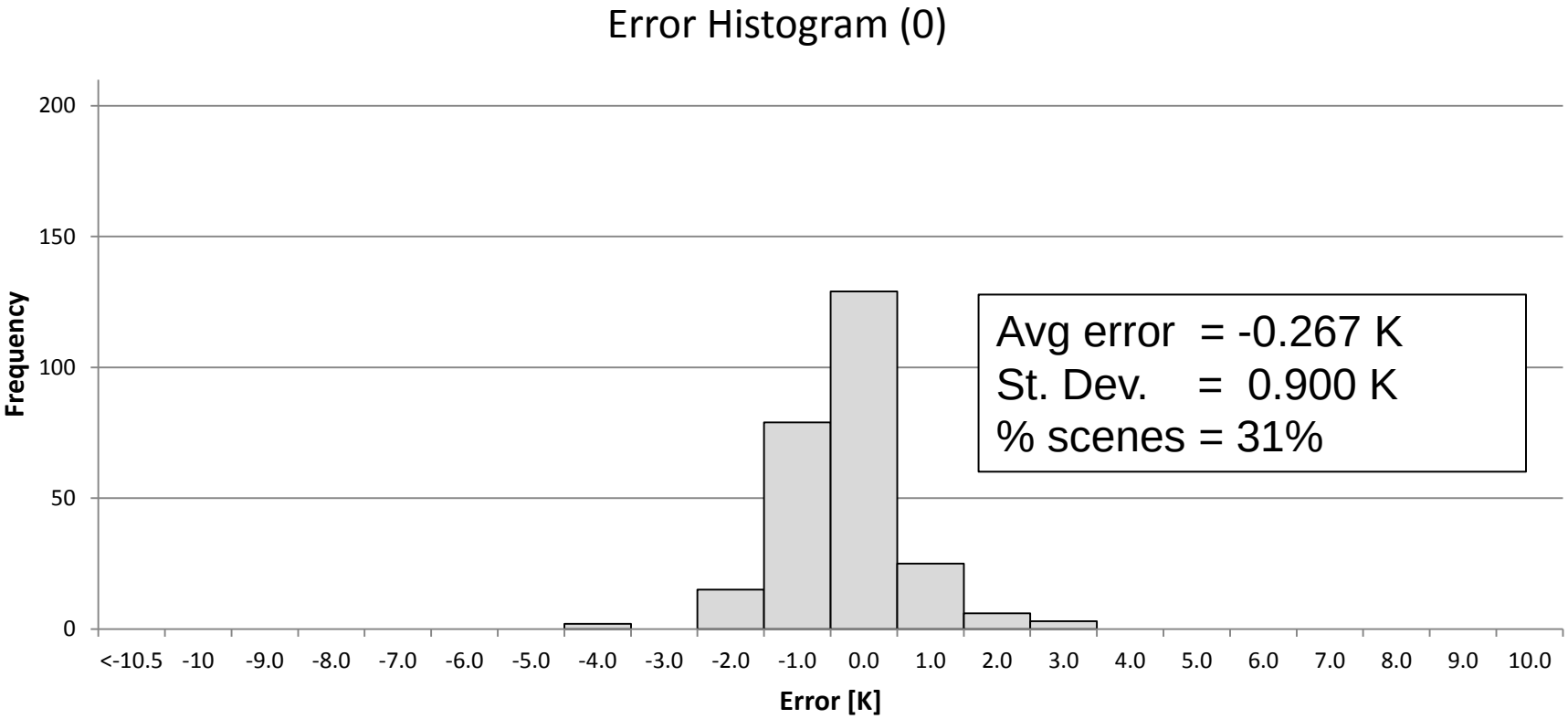
All Cloud Types (826 scenes)



"Clear and Near" Cloud Types (515 scenes)



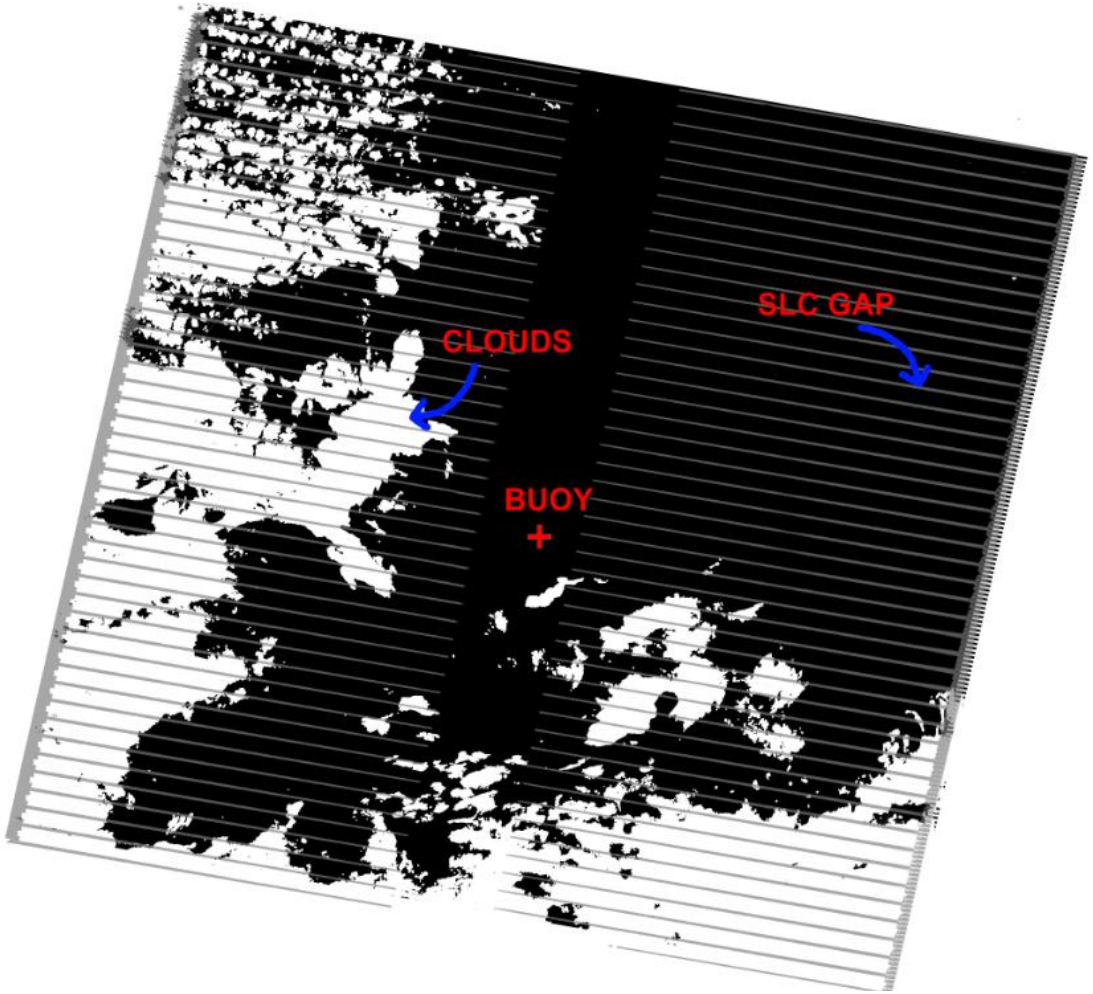
Cloud Free Scenes (259 scenes)



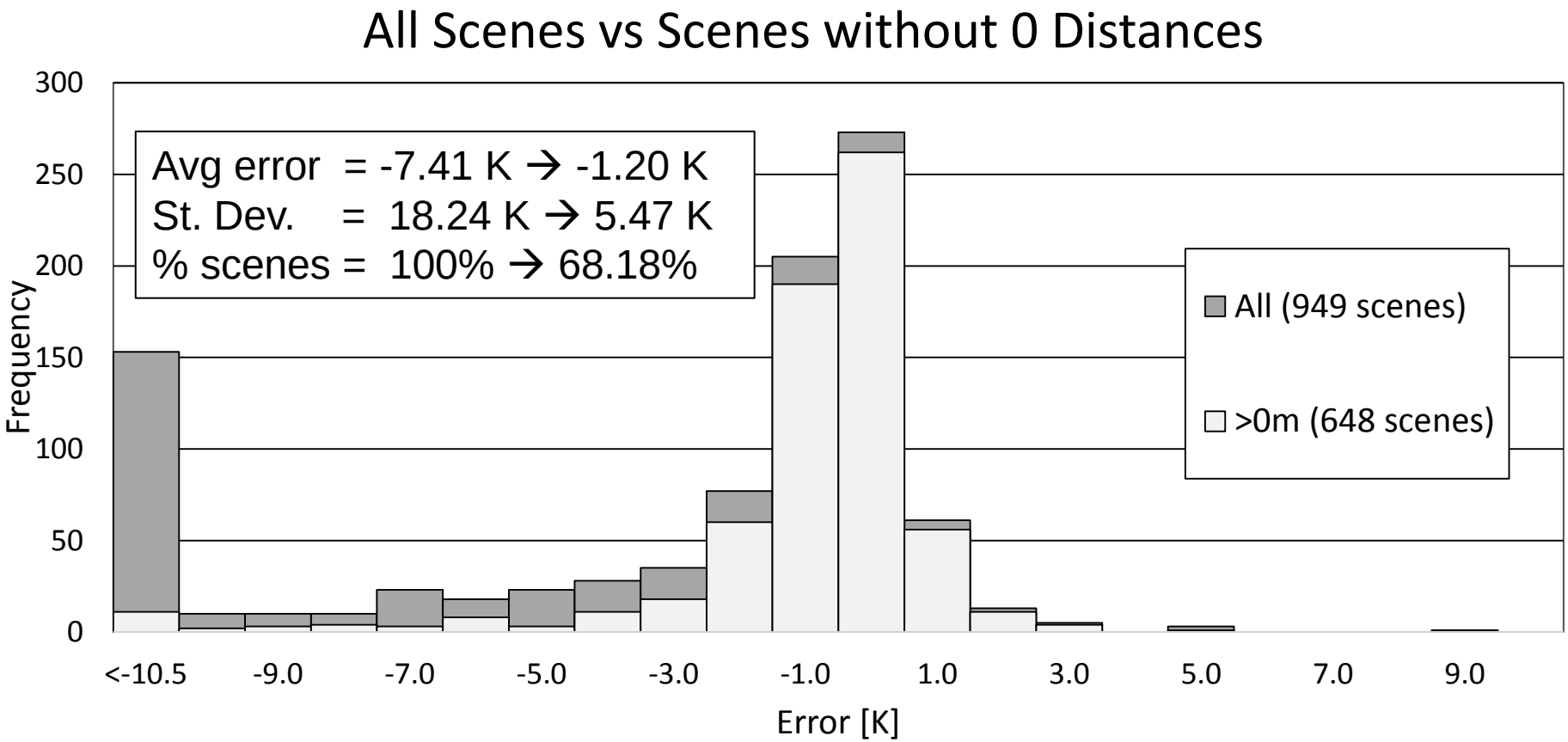
New Method

- 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

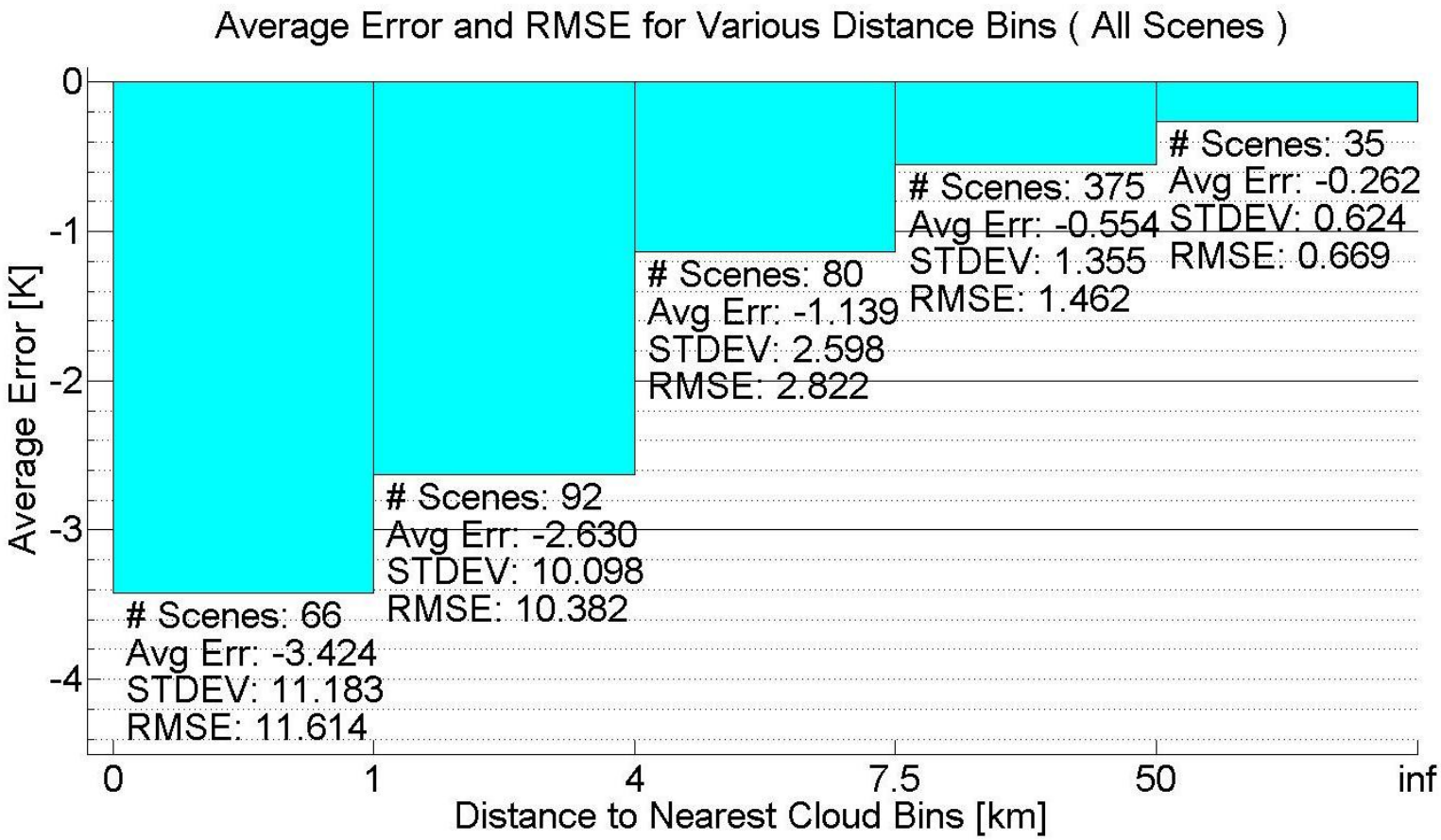
Cloud Mask Example



Removing "0" Distances"



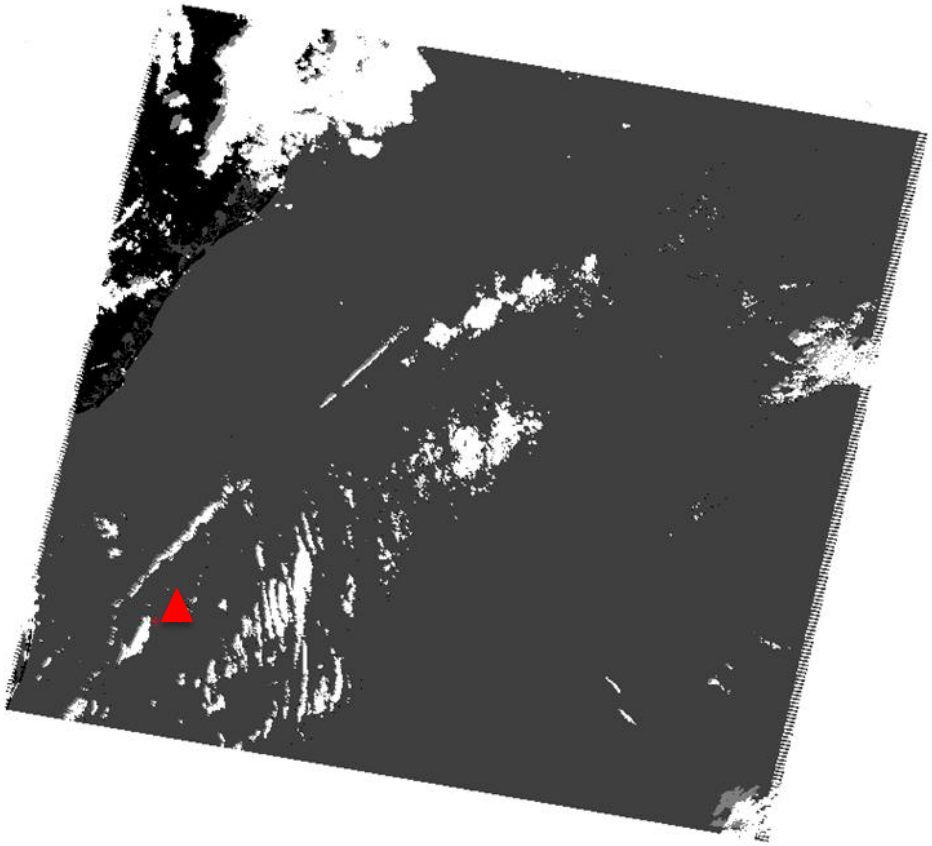
Average Error for Distance Bins



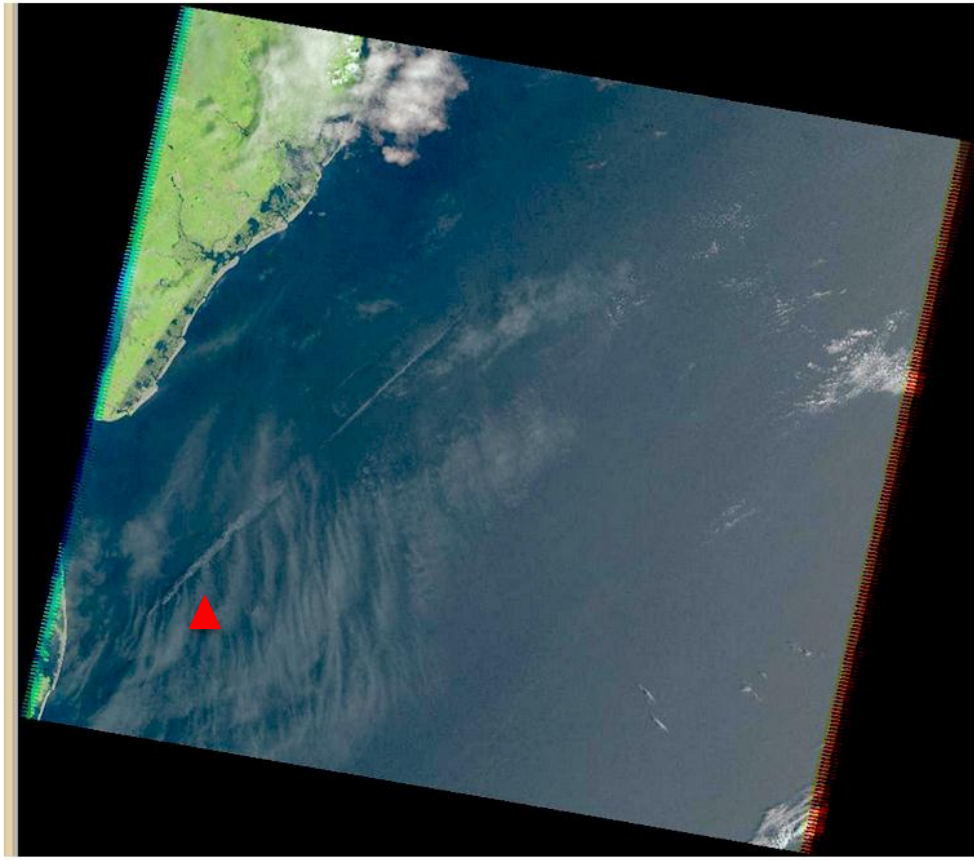
Cirrus Clouds Causing Trouble

Distance to cloud = 1.02 km
Error = -16.34297 K

Cloud mask (clouds are white)

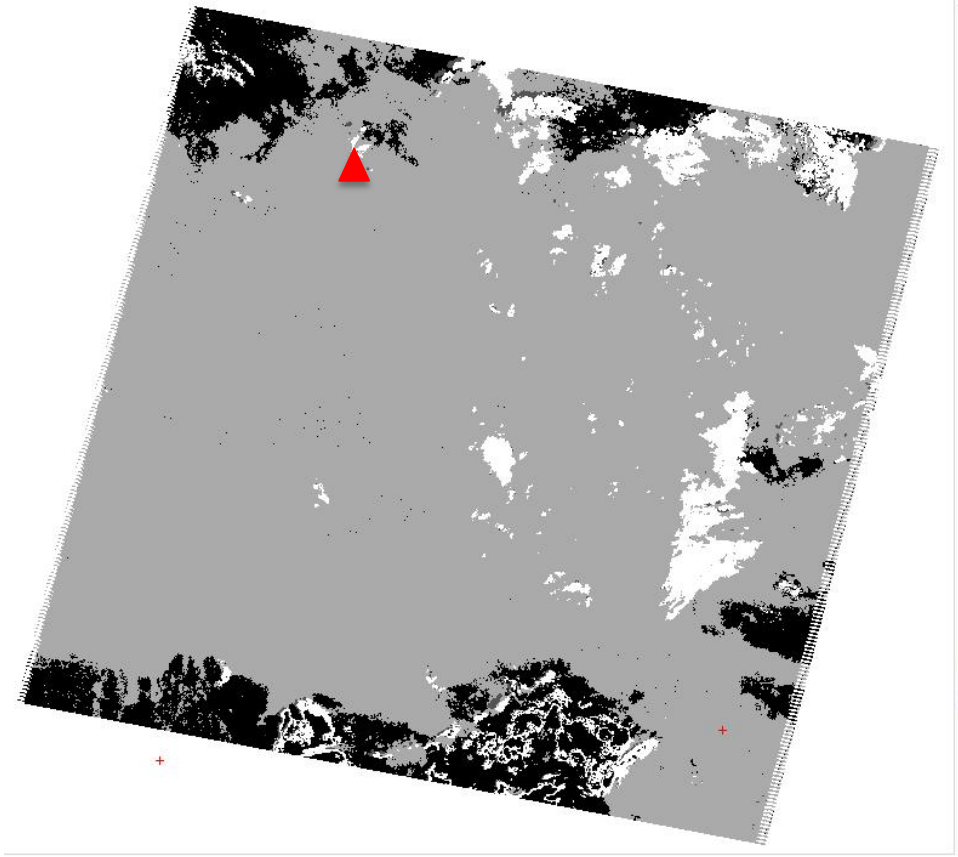


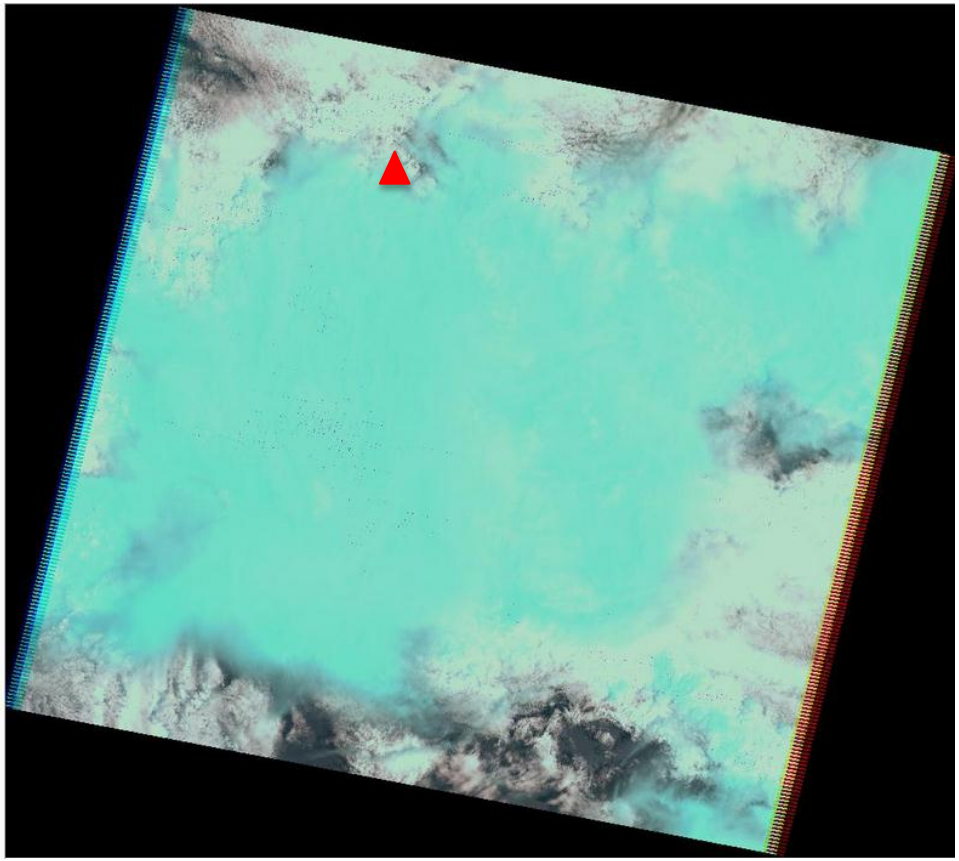
True color image (wispy cirrus)



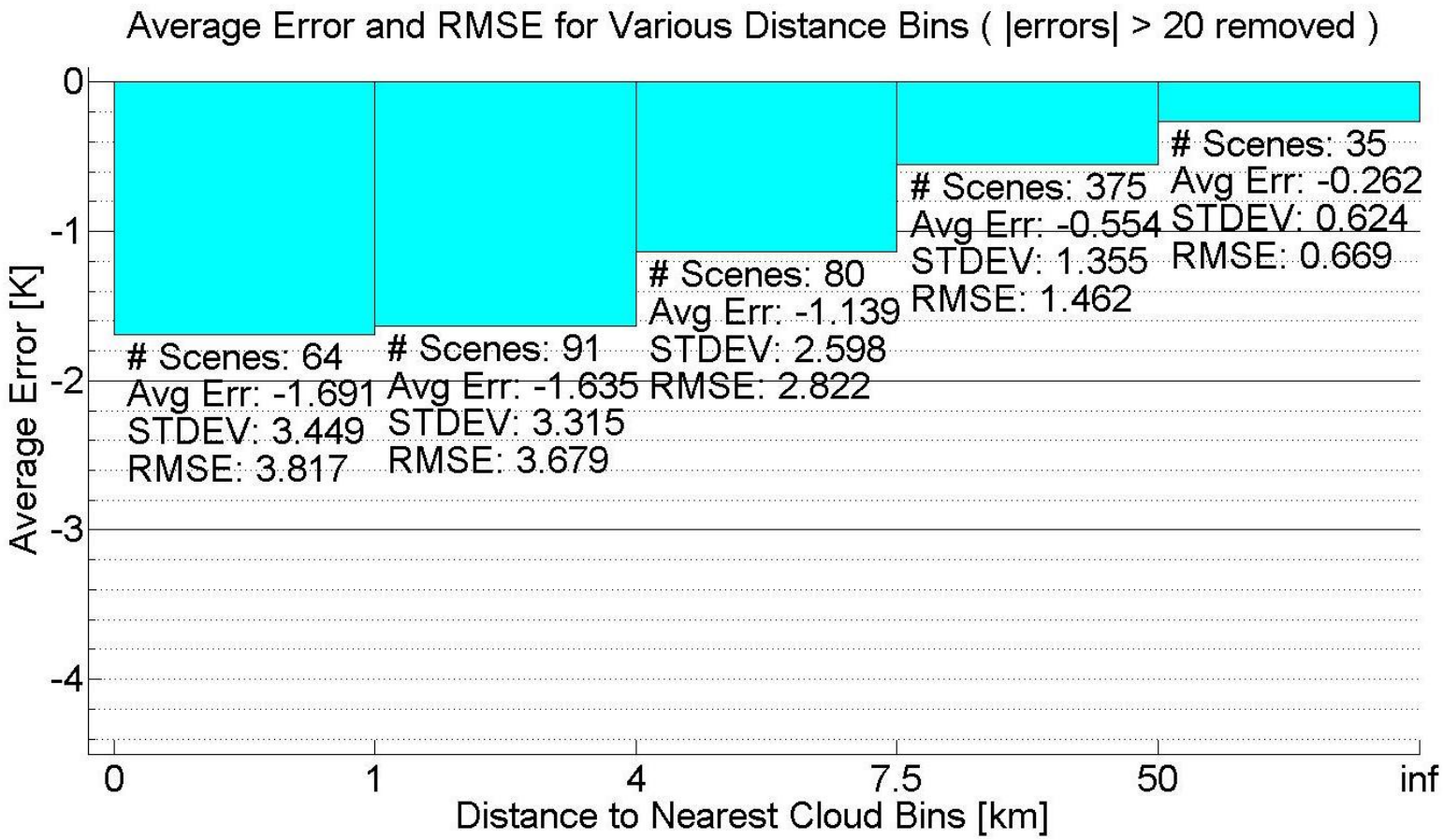
Cloud Mask Failure

Distance to cloud = 2.84 m
Error = -93.1886 K





Removing Bad Scenes



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 (**MOD**erate resolution **I**maging **S**pectroradiometer)

Choosing a New Reanalysis Product

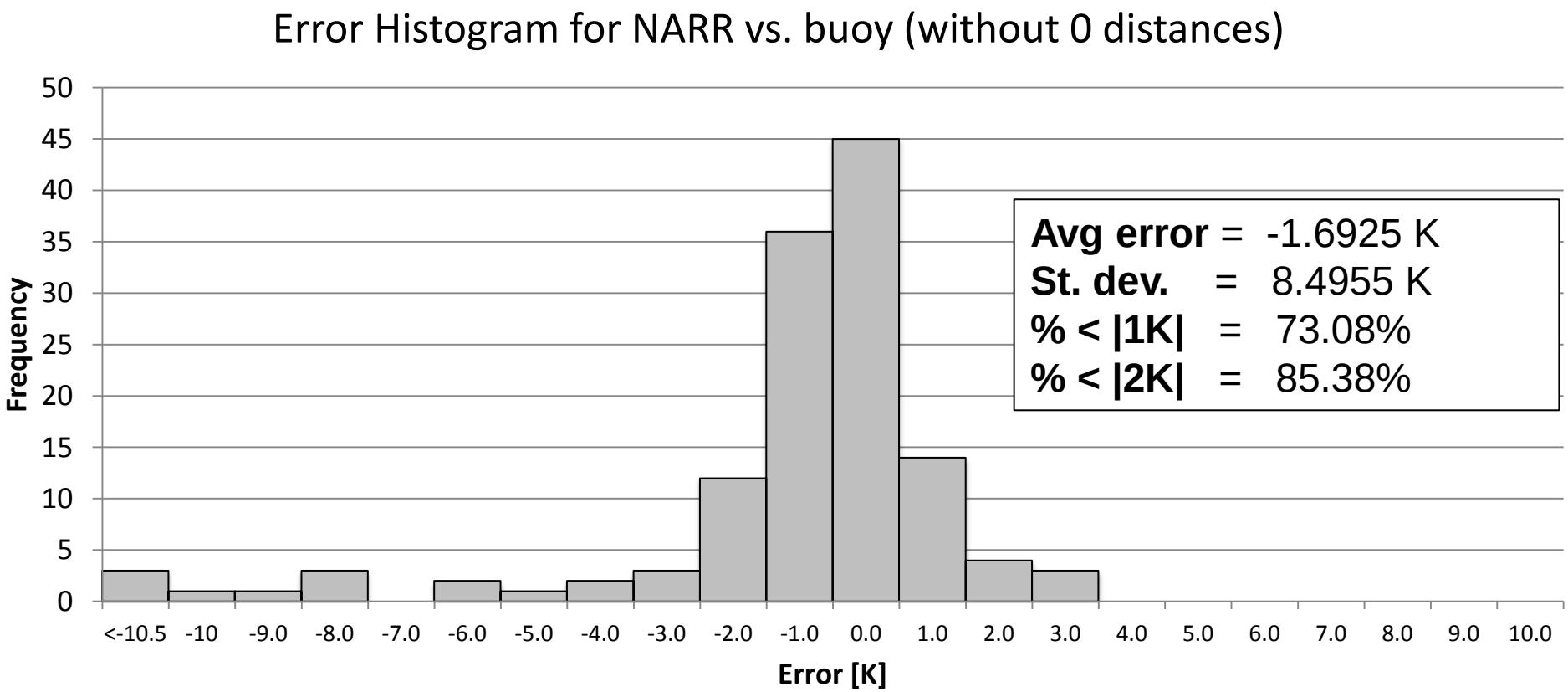
	NARR (NOAA)	MERRA (NASA)	CFSR (NOAA)
Coverage	North America	Global	Global
Spatial	32 km spacing (0.3° at equator) 349x277	1.25° x 1.25° (140 km at equator) 288x144	~38 km spacing (0.5° x 0.5°) 720x361
Temporal	8x daily 3-hr intervals	8x daily 3-hr intervals	4x daily 6-hr intervals
Pressure Levels	29 levels 1000 - 100 hPa	42 levels 1000 - 0.1 hPa	37 levels 1000 - 1 hPa

MERRA vs NARR (397 scenes)

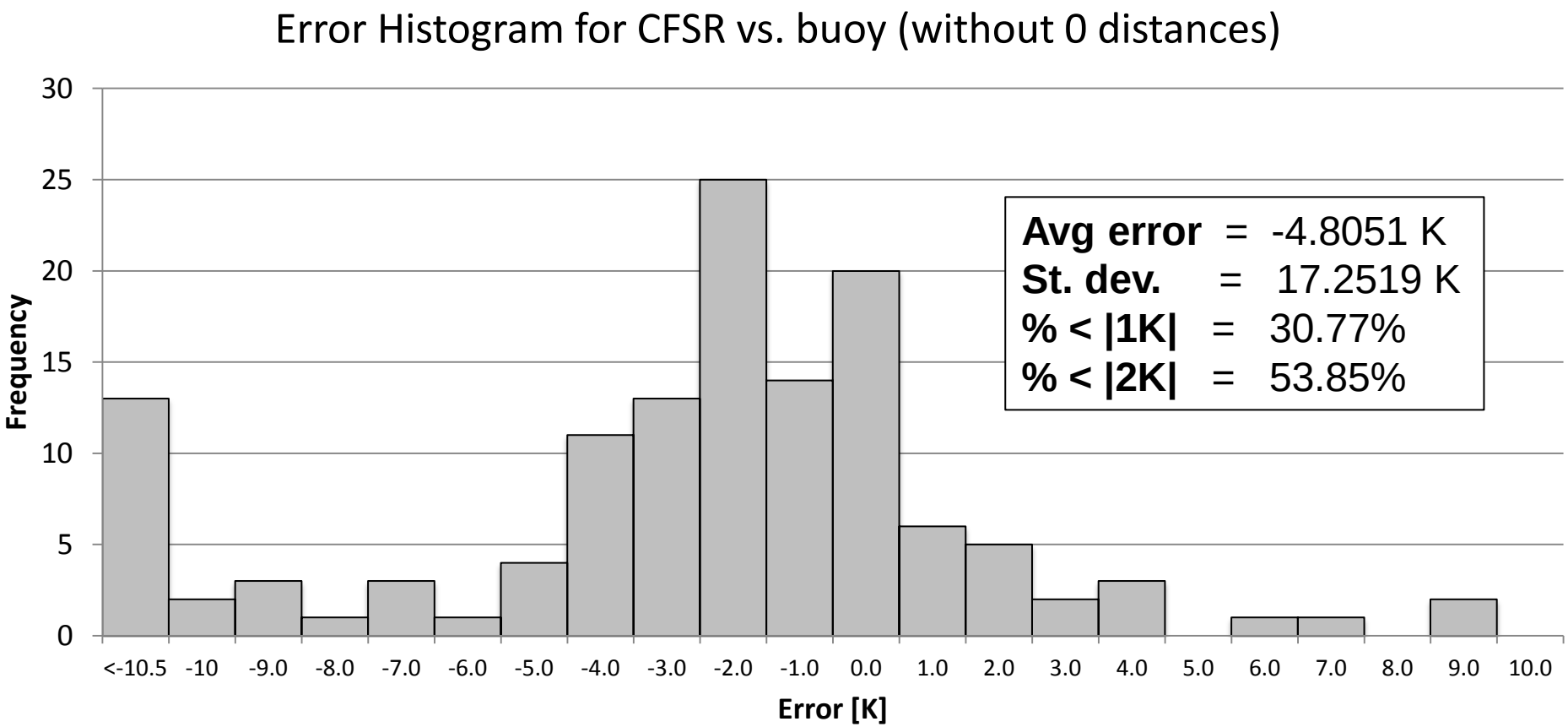
- North American scenes
- Uses old cloud categories

Cloud Category	Mean [K]		Standard Deviation [K]		Number of Scenes [% of Scenes]
	MERRA	NARR	MERRA	NARR	
0,1,2,3,4,5	-8.697	-8.470	18.520	18.190	397 [100%]
0,1,2,3	-1.474	-1.446	3.610	3.724	262 [66%]
0,1,2	-0.954	-1.002	1.846	2.139	239 [60%]
0,1	-0.513	-0.441	1.086	1.471	153 [39%]
0	-0.354	-0.235	0.911	0.921	101 [25%]

CFSR vs NARR (130 scenes)

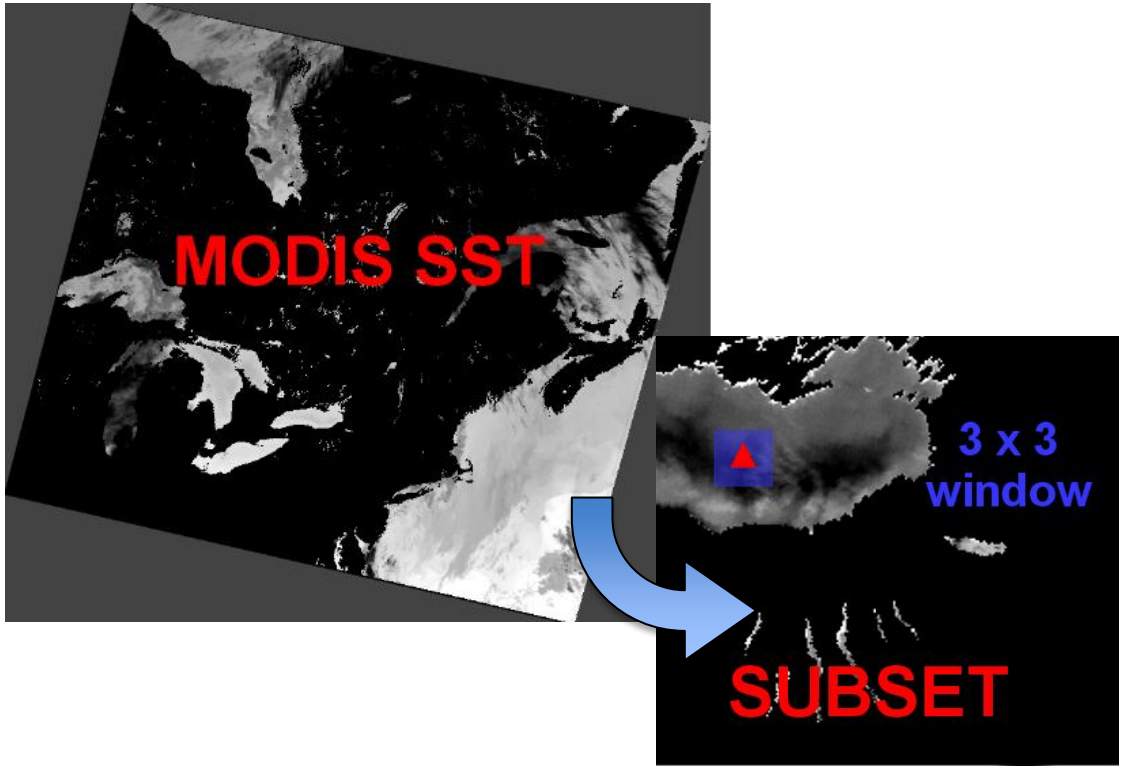


CFSR vs NARR (130 scenes)

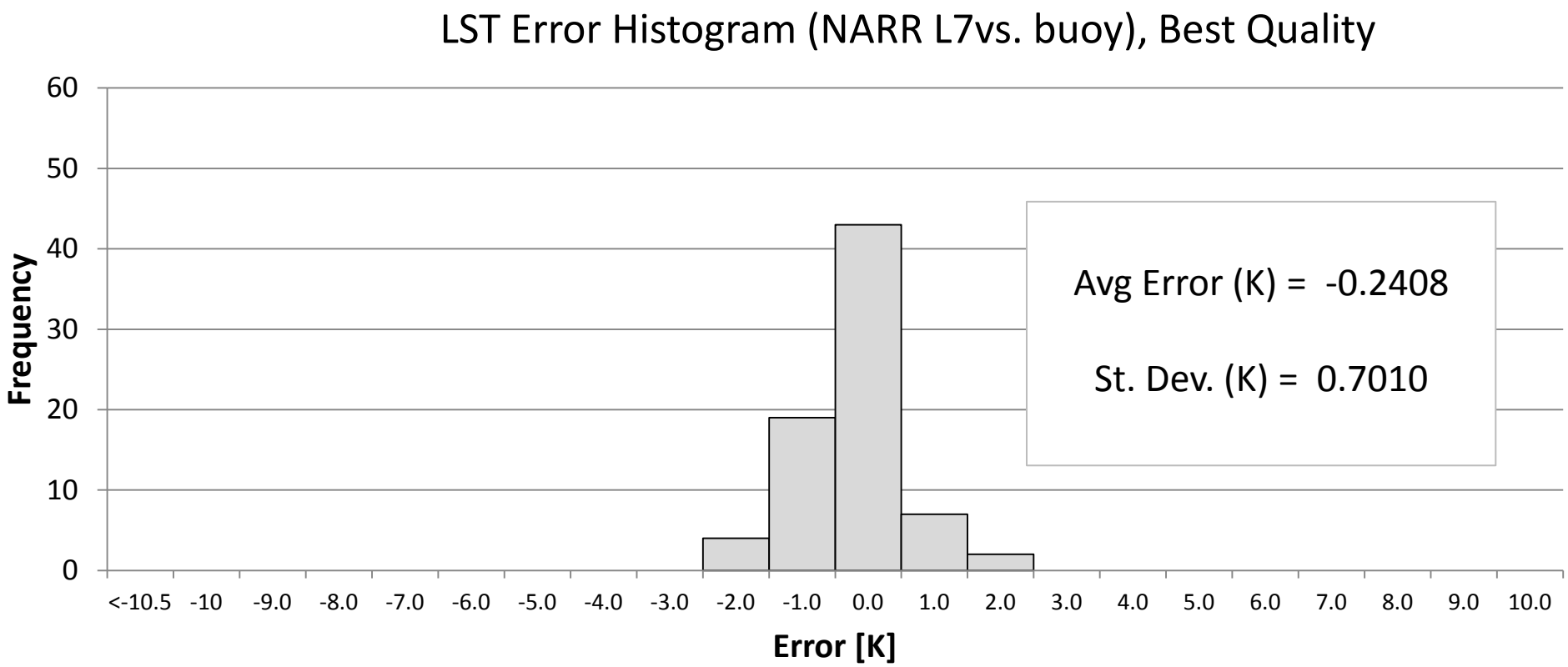


Finding Acceptable Truth Data

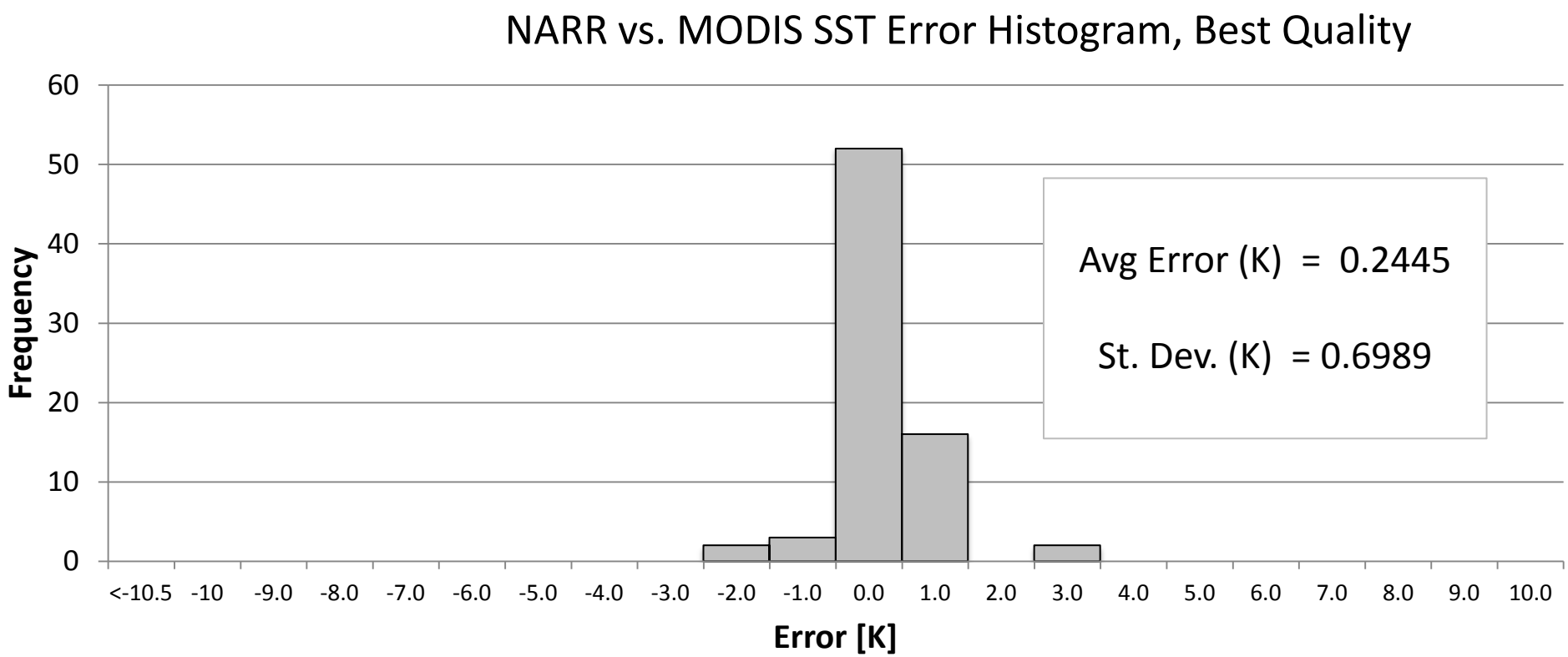
- MODIS Sea Surface Temperature
  - MODIS TERRA has an orbit track similar to Landsat 7 (~20 min behind)
  - Quality band gives each pixel a 0-4 rating, 0 being the best quality



Comparing LST vs. Buoys



Comparing MODIS vs. Buoys



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
  - Use MERRA as reanalysis product
  - Use MODIS SST as truth

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

Extra Slides

Radiance Paths

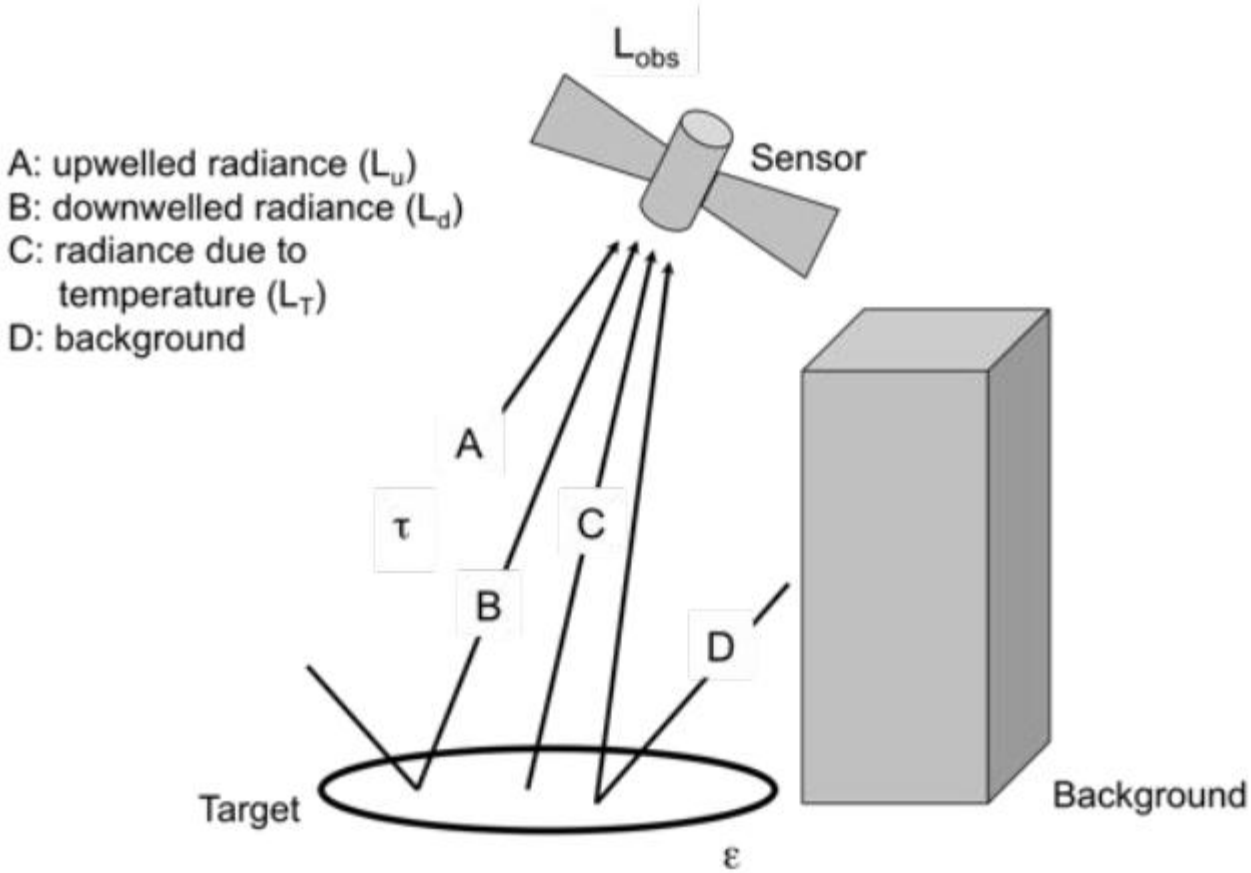


Figure 3.1: Thermal energy paths contributing to the sensor reaching radiance.

Description of Global Sites

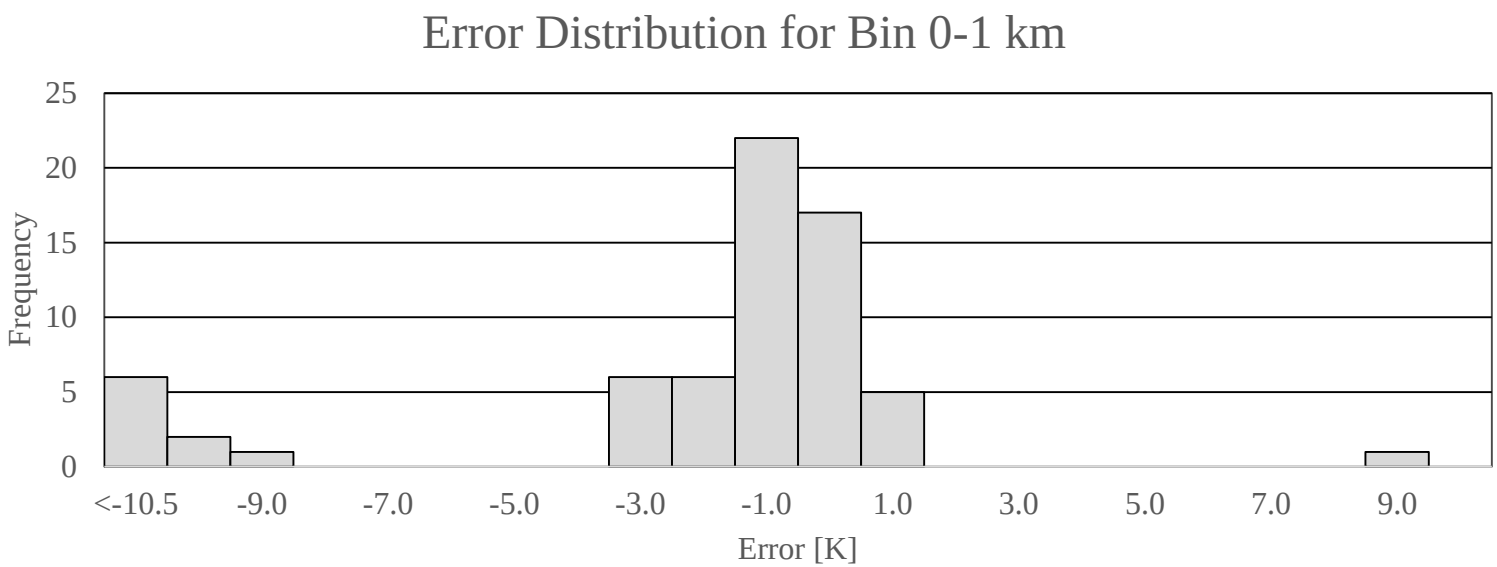
Table 6.4: Descriptions of locations and radiosonde densities for each point selected for global MODIS and Landsat LST comparisons. Note that the radiosonde description refers to the description of the density of input observations to the MERRA product provided in Figure 6.10.

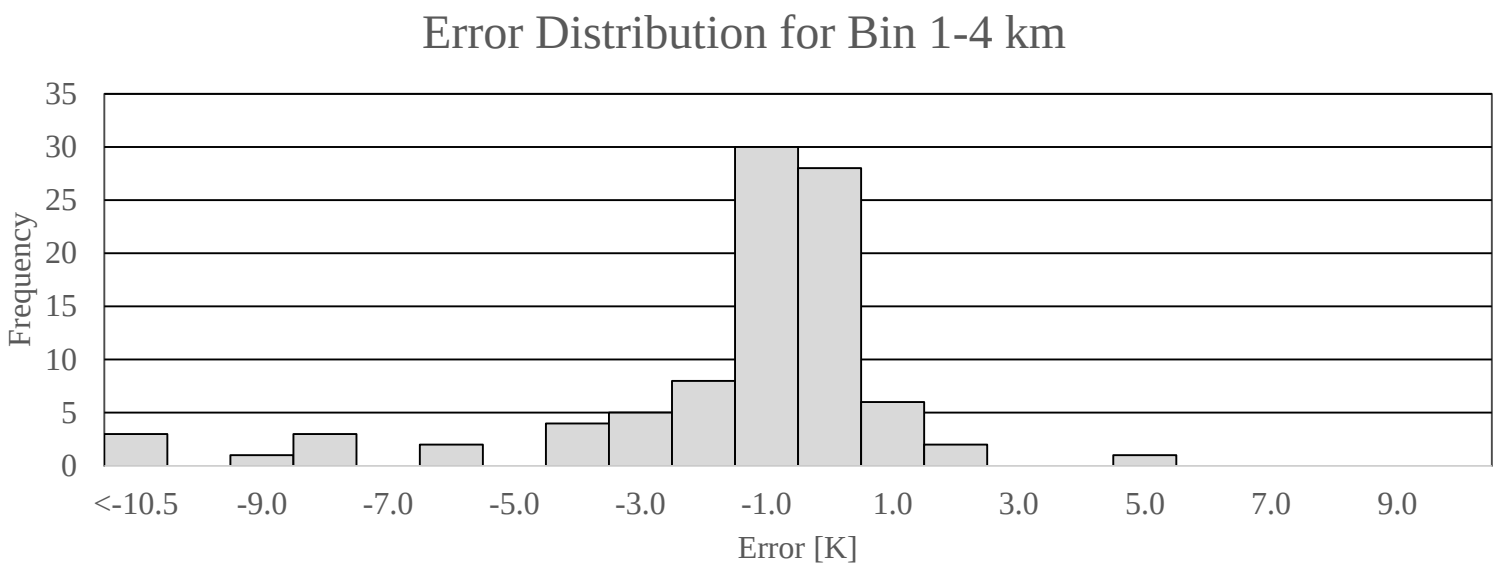
Location	WRS-2 path_row	[lat, lon]	Radiosonde	Description
South America	216_63	[-4.26, -37.7]	1	Tropical
Mediterranean	196_30	[43.3, 4.8]	2	Mid Lat - Northern
Black Sea	174_30	[43.47, 38.91]	2	Mid Lat - Nothern
India	144_54	[9.0, 76.34]	0	Tropical
Hong Kong	121_44	[22.46, 114.9]	2	Low Lat - Northern
Russia	107_19	[58.85, 149.43]	1	High Lat - Northern
Australia	113_82	[-31.9, 114.95]	2	Mid Lat - Southern
Africa	180_75	[-22.0, 14.0]	0	Low Lat - Southern
Greenland	232_17	[61.5, -41.75]	1	High Lat - Nothern
South America	218_77	[-24.045, -45.18]	2	Low Lat - Southern
South America	233_93	[-47.88, -75.45]	1	Mid Lat - Southern

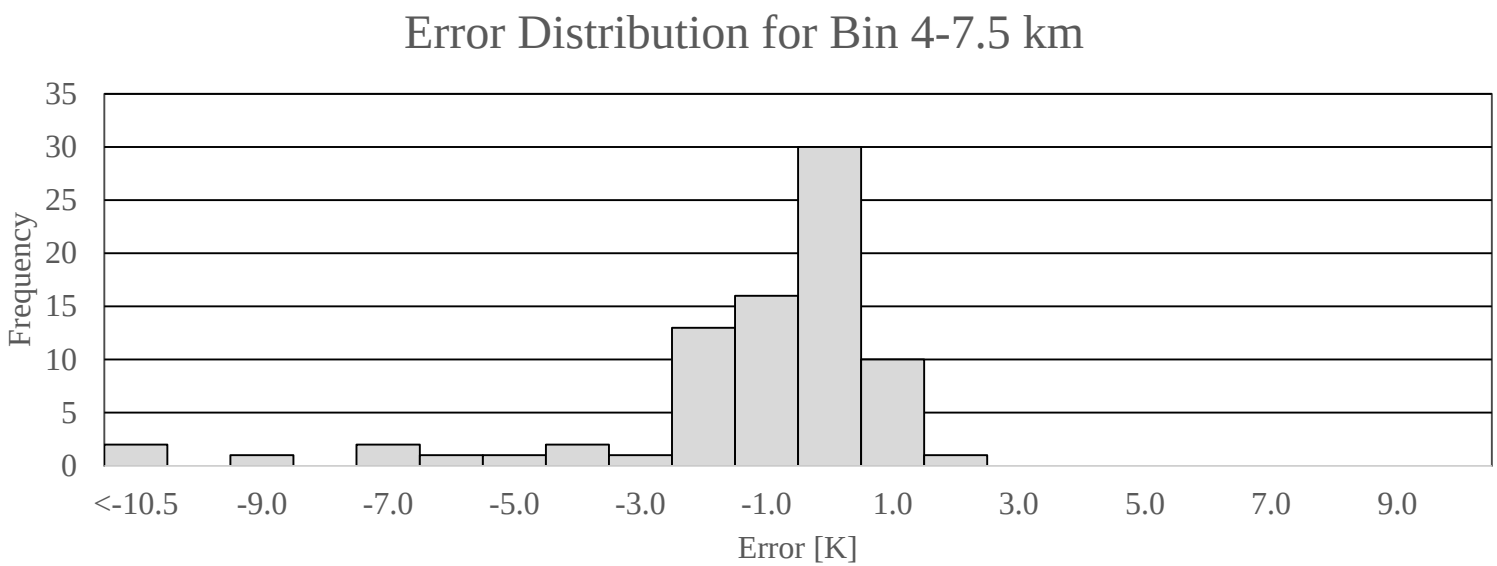
MERRA vs MODIS SST

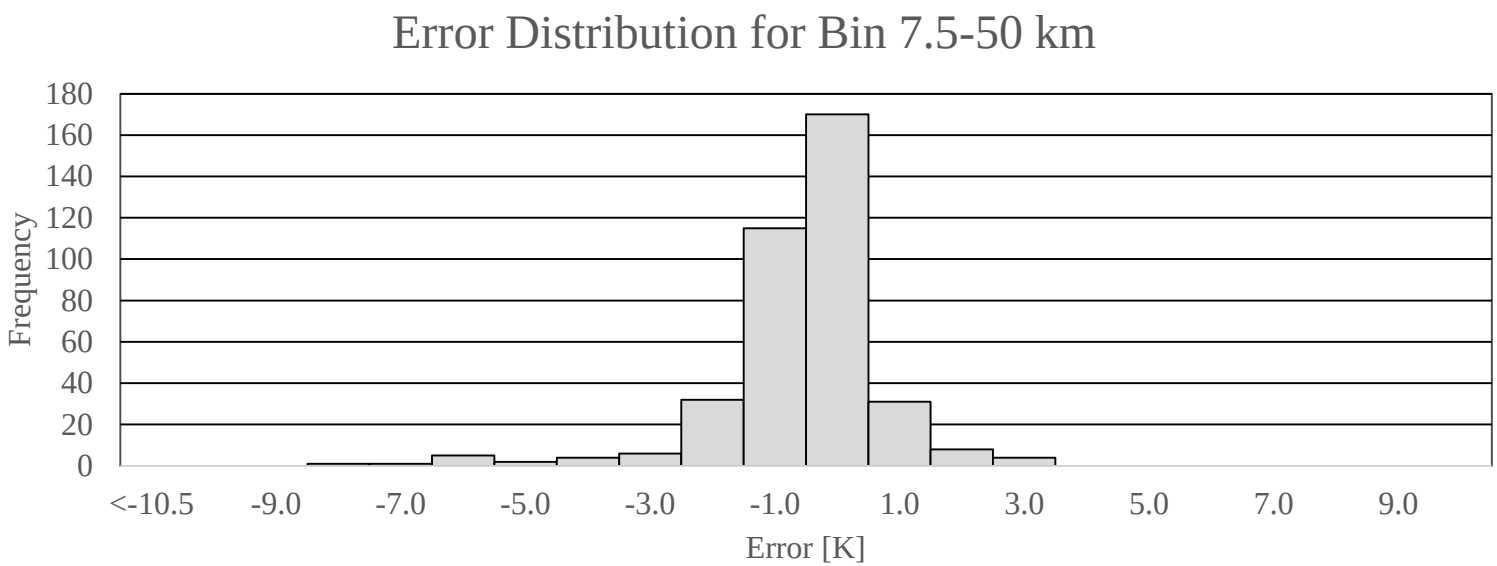
Table 6.5: Statistics of errors for each individual location for MODIS SST and Landsat comparisons. The error is calculated using Equation 6.2, n is the number of scenes analyzed for each location after removing scenes with less than the best quality, and SD is the standard deviation.

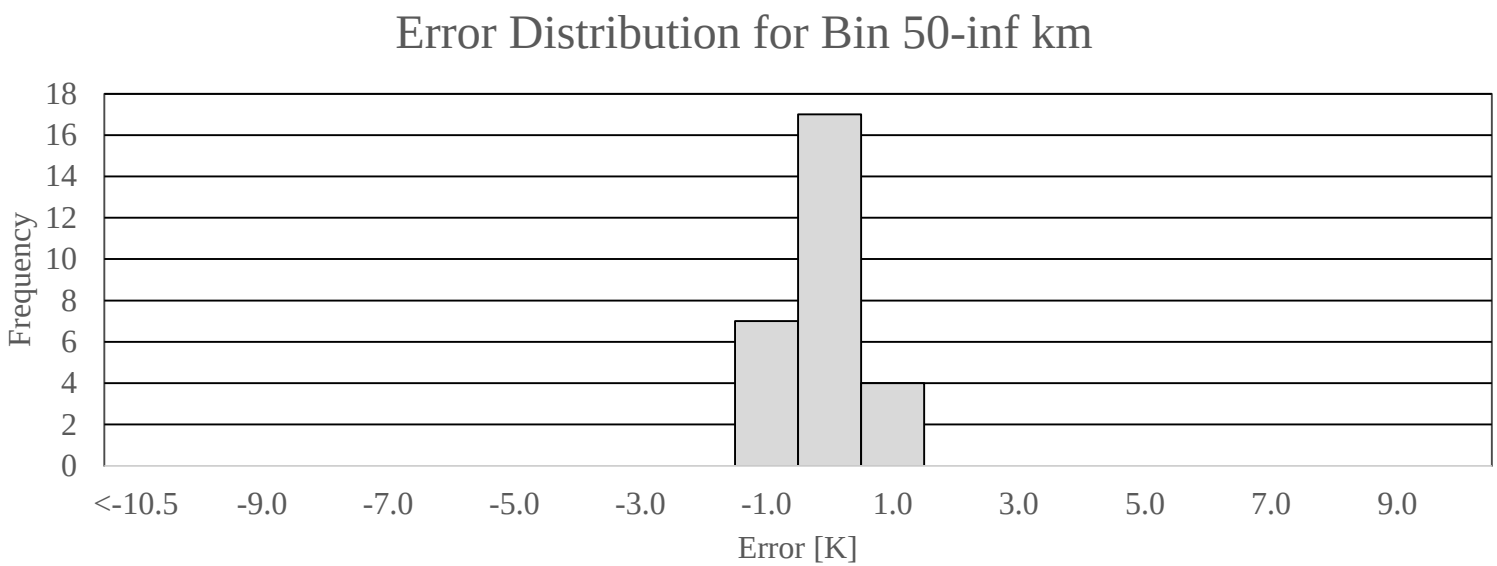
Location	Radiosonde	Description	n	Mean [K]	SD [K]
South America	1	Tropical	4	1.06	0.79
Mediterranean	2	Mid Lat - Northern	4	-0.27	0.28
Black Sea	2	Mid Lat - Northern	6	-0.41	0.45
India	0	Tropical	6	0.82	0.43
Hong Kong	2	Low Lat - Northern	4	0.09	1.31
Russia	1	High Lat - Northern	3	-0.60	0.32
Australia	2	Mid Lat - Southern	8	-0.32	0.43
Africa	0	Low Lat - Southern	4	-0.47	0.27
Greenland	1	High Lat - Nothern	1	-0.24	–
South America	2	Low Lat - Southern	3	0.58	0.29
South America	1	Mid Lat - Southern	5	-0.68	0.25


Error Distribution for Bin 0-1 km
Frequency
25
20
15
10
5
0
<-10.5
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
Error [K]


Error Distribution for Bin 1-4 km
Frequency
35
30
25
20
15
10
5
0
<-10.5
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
Error [K]


Error Distribution for Bin 4-7.5 km
Frequency
35
30
25
20
15
10
5
0
<-10.5
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
Error [K]


Error Distribution for Bin 7.5-50 km
Frequency
180
160
140
120
100
80
60
40
20
0
<-10.5
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
Error [K]


Error Distribution for Bin 50-inf km
Frequency
18
16
14
12
10
8
6
4
2
0
<-10.5
-9.0
-7.0
-5.0
-3.0
-1.0
1.0
3.0
5.0
7.0
9.0
Error [K]

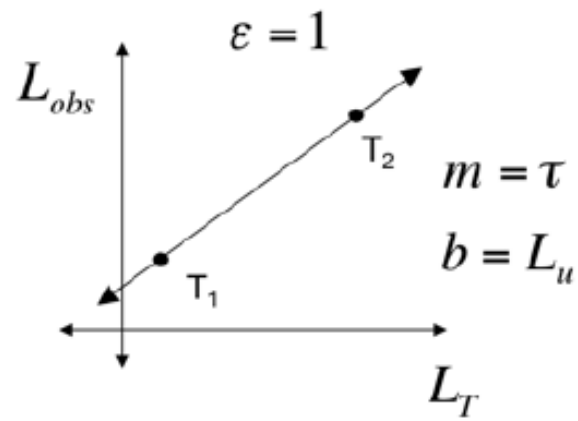
CFSR (Climate Forecast System Reanalysis)

- 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 form January 2011-present
- Data format- WMO GRIB2 (NARR was WMO GRIB1)

Solving for Atmospheric Parameters

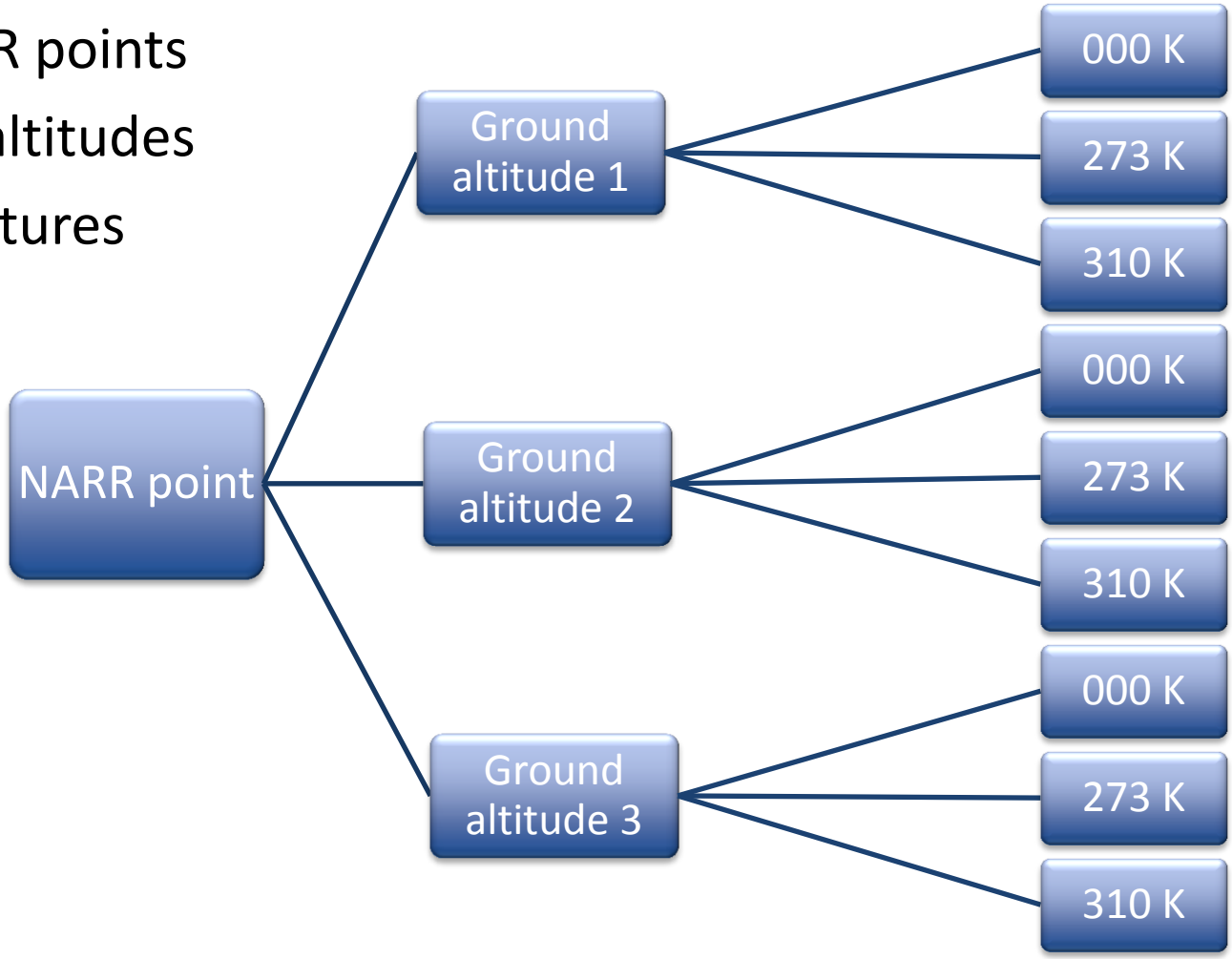
- Finding transmission and upwelled
  - If emissivity ≅ 1, then $L_{obs} = L_T \epsilon \tau + L_u$
  - Slope is transmission and intercept is upwelled

- Finding downwelled
  - If emissivity < 1, then $L_d = \frac{\frac{L_{obs} - L_u}{\tau} - L_T \epsilon}{1 - \epsilon}$
  - Simply solve for L_d



MODTRAN Runs

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



LST Methodology

The "Big Equation"

$$L_{obs} = (L_T \epsilon + (1 - \epsilon) L_d)\tau + L_u$$

L_{obs} = radiance seen by satellite

L_T = radiance emitted from target

ε = emissivity of target

L_d = downwelled radiance

τ = transmission

L_u = upwelled radiance

Landsat 5, North America

- 259, cloud free scenes
- Average error: -0.267 K

Location	Mean [K]	Standard Deviation [K]	Number of Scenes
Salton	-0.12	0.558	11
Tahoe	-0.213	0.713	89
Rochester	-0.068	0.639	20
Delmar	-0.447	1.179	34
Georgia	0.041	1.267	23
Santa Maria	-0.219	0.789	19
Santa Monica	-0.574	1.089	21
Huron	-0.695	0.820	19
Superior	-0.167	0.676	23
Total	-0.267	0.900	259