Date: 5/26/2011
To: Lee Robinson
From: Rick Zehner
Subject: Spatial analysis of CIRES' ASTER and LANDSAT thermal anomalies

I have reviewed many of the polygons CIRES provided that have high geothermal potential, based on the satellite thermal imagery as well as other geologic factors as assembled into their GIS as being prospective areas for exploration. My first "read" is that many of the anomalies are much larger and of different shapes than typical geothermal outflow zones, and appear to be correlated with rock type, slope, and aspect. Furthermore, many anomalies occur on ridgetops and not in valleys downslope from range-front faults or other places geothermal systems typically form. This might indicate that the thermal anomalies are mostly solar (not geothermal) in nature.

The purpose of this analysis is to construct some spatial statistics to help understand the viability of the CIRES target model. In this model, ground thermal anomalies in Colorado are detected using either ASTER or LANDSAT thermal infrared spectral bands (among others). Those areas above some anomaly threshold (1 and 2 standard deviations, I believe) were then designated as 'anomalous.' One way to test the viability of their model would be to examine the area spatial statistics make use of the relative area of anomaly versus the total area, and the relative proportion of overlap between ASTER and LANDSAT data. If the area considered anomalous is large compared to the total area, then the infrared imagery would be a "blunt tool" for finding geothermal systems: the search would have to cover too large an area. If there is disagreement between the areas found to be anomalous by ASTER and the areas found to be anomalous by LANDSAT, then the technique might not be robust.

To do this, I used ESRI Spatial Analyst to convert all of the anomaly shapefiles into ESRI grids with a 100m cell size. Then I calculated the total area of the target polygons as well as the areas of ASTER and LANDSAT anomaly. Finally, I calculated the area of overlap between the ASTER and LANDSAT anomalies. Results are shown in the table below.

Total Anomaly Area: The total area considered anomalous varies considerably between polygons. In some of the polygons, thermal anomalies are small <10 km^2 (e.g. Polygons 3, 9, 11, 12) and therefore would appear to narrow the target area sufficiently to imply a robust selection criteria. However, in others (e.g. Polygons 1, 4, 5, 6) the combined ASTER + LANDSAT anomaly area is clearly too large (Polygon 1 anomalies cover 126 km^2) and comprise ~24% of the anomaly area.

ASTER and LANDSAT Agreement: There is very little agreement between what the ASTER data indicates as having anomalous surface temperature versus the LANDSAT data. Polygon 1 has the highest percent of area in which both datasets agree – 5.7%. Over all of the 21 polygons, the ASTER and LANDSAT anomalies are in agreement over only 1.8% of the total anomaly area. This is appallingly low.

POLYGON		LANDSAT ANOM	ASTER ANOM	Intersect L+A	Polygon	LANDSAT ANOM	ASTER ANOM	ADD ANOMs	Intersect L+A	Intersect L+A
NAME	POLY	Area km2	Area km2	Area km2	Area km2	% of Polygon	% of Polygon	% of Polygon	% of Polygon	% Total Anomaly
Eagle 1	1	33.0	93.2	5.7	532.6	6.2%	17.5%	23.7%	1.1%	4.5%
Garfield 2	2	7.4	11.2	0.1	89.1	8.3%	12.5%	20.9%	0.1%	0.5%
Garfield 3	3	6.1	3.5	0.1	80.9	7.5%	4.3%	11.8%	0.1%	0.6%
Garfield 4	4	1.5	21.8	0.2	80.1	1.8%	27.3%	29.1%	0.2%	0.7%
Delta 5	5	2.3	36.7	0.2	164.4	1.4%	22.4%	23.7%	0.1%	0.4%
Delta 6	6	2.6	35.5	0.2	119.5	2.2%	29.7%	31.9%	0.1%	0.4%
Delta 7	7	0.1	12.5	0.0	74.7	0.1%	16.7%	16.9%	0.0%	0.0%
Delta 8	8	0.4	9.7	0.0	61.9	0.7%	15.7%	16.4%	0.0%	0.0%
Delta 9	9	0.0	4.2	0.0	36.1	0.1%	11.6%	11.7%	0.0%	0.0%
Delta 10	10	0.1	19.5	0.0	72.8	0.1%	26.8%	26.9%	0.0%	0.0%
Chaffee 11	11	0.4	0.8	0.0	25.9	1.7%	3.0%	4.6%	0.1%	1.3%
Chaffee 12	12	0.9	2.1	0.0	24.7	3.8%	8.6%	12.4%	0.2%	1.3%
Chaffee 13	13	0.2	13.7	0.0	39.7	0.6%	34.4%	35.0%	0.0%	0.1%
Chaffee 14	14	0.1	2.9	0.0	12.0	0.5%	24.5%	25.0%	0.0%	0.0%
Routte 15	15	0.6	1.6	0.0	40.7	1.5%	3.9%	5.3%	0.1%	1.6%
Routte 16	16	0.9	0.3	0.0	30.4	2.9%	0.8%	3.7%	0.0%	0.1%
Route 17	17	0.4	5.5	0.0	87.4	0.5%	6.3%	6.8%	0.0%	0.5%
Park 18	18	0.5	8.5	0.2	85.7	0.6%	9.9%	10.5%	0.3%	2.5%
Park 19	19	0.2	3.6	0.0	15.2	1.2%	23.6%	24.8%	0.3%	1.2%
Park 20	20	0.3	21.3	0.0	52.0	0.6%	40.9%	41.6%	0.1%	0.2%
Park 21	21	0.1	2.0	0.0	14.7	0.6%	13.5%	14.2%	0.1%	0.4%
TOTAL		58.2	310.1	6.8	1740.6	3.3%	17.8%	21.2%	0.4%	1.8%

I therefore fear that CIRES technique for identifying potential geothermal anomalies using thermal infrared imaging may have problems. Many of the thermal anomalies appear to be solar in nature, too large and of the wrong shape to represent geothermal

outflow zones. Second, the fact that the two thermal imaging techniques have such little area in common may indicate that the surface thermal anomalies are more a function of time of day or other factors unrelated to geothermal systems.