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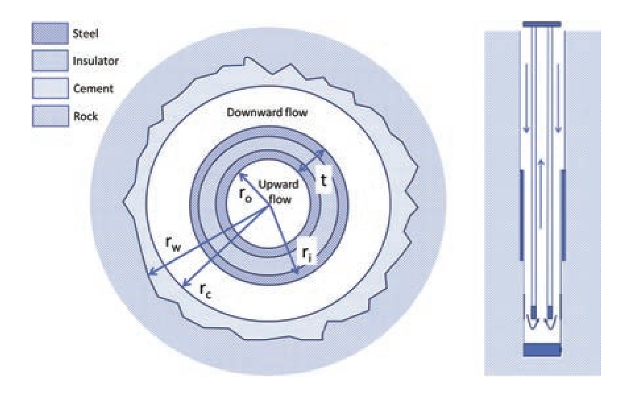
Geothermal Energy Potential of Oil & Gas Wells: Geospatial Distribution Analysis Utilizing NGDS Data

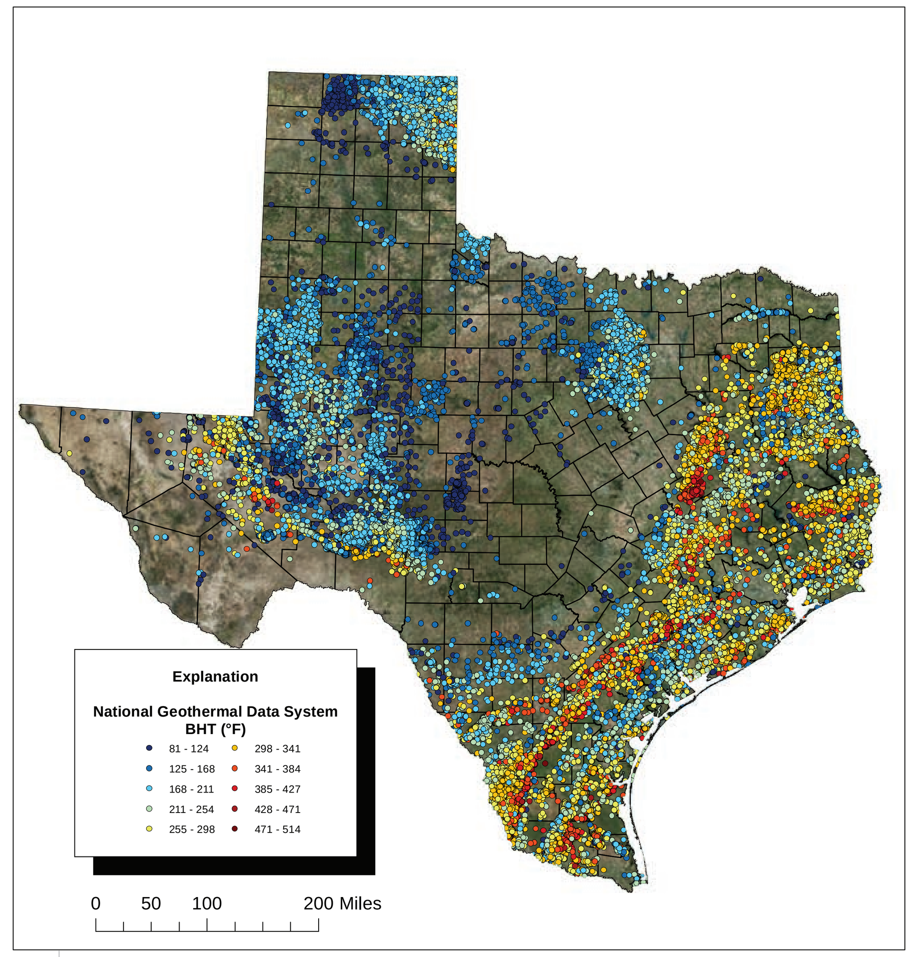
Michael Jones
University of Texas, Austin

THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Retrofitting unproductive hydrocarbon wells into geothermal production systems known as **well-bore heat exchangers (WBHX)** has been a focus of many recent numerical modeling studies (Kujawa et al., 2006; Davis and Michaelides, 2009; Bu et al., 2012; Cheng et al., 2013; Templeton et al., 2014; Alimonti and Soldo, 2016). These hypothetical systems operate by extracting subsurface heat via conduction through the perimeter of a well bore. A circulating fluid is injected through the annular space of the well, reaches a maximum temperature at the wellbottom, and is carried to the surface through an insulated production tubing.



Alimonti and Soldo, 2016



The amount of heat extracted by the circulating fluid is dependent upon the thermal characteristics of both the casing and formation, as well as the fluid circulation rate.

Bottom hole temperature data from **42,601 wells** were obtained from the National Geothermal Data System and are displayed to the left. Using ArcMap Spatial Statistics and Analysis tools, areas containing high concentrations of oil and gas wells with exceptionally high bottom hole temperatures (BHT) were delineated. Identifying statistically significant clusters of hot wells could lead to the necessary increases in economic viability and system efficiency needed for this resource is to be utilized at scale (Cheng et al., 2013).

These benefits would be a result of the ability to select clusters near existing power distribution infrastructure and an overall increase in generation capacity resulting from the ability to connect multiple clustered WBHX systems in series.

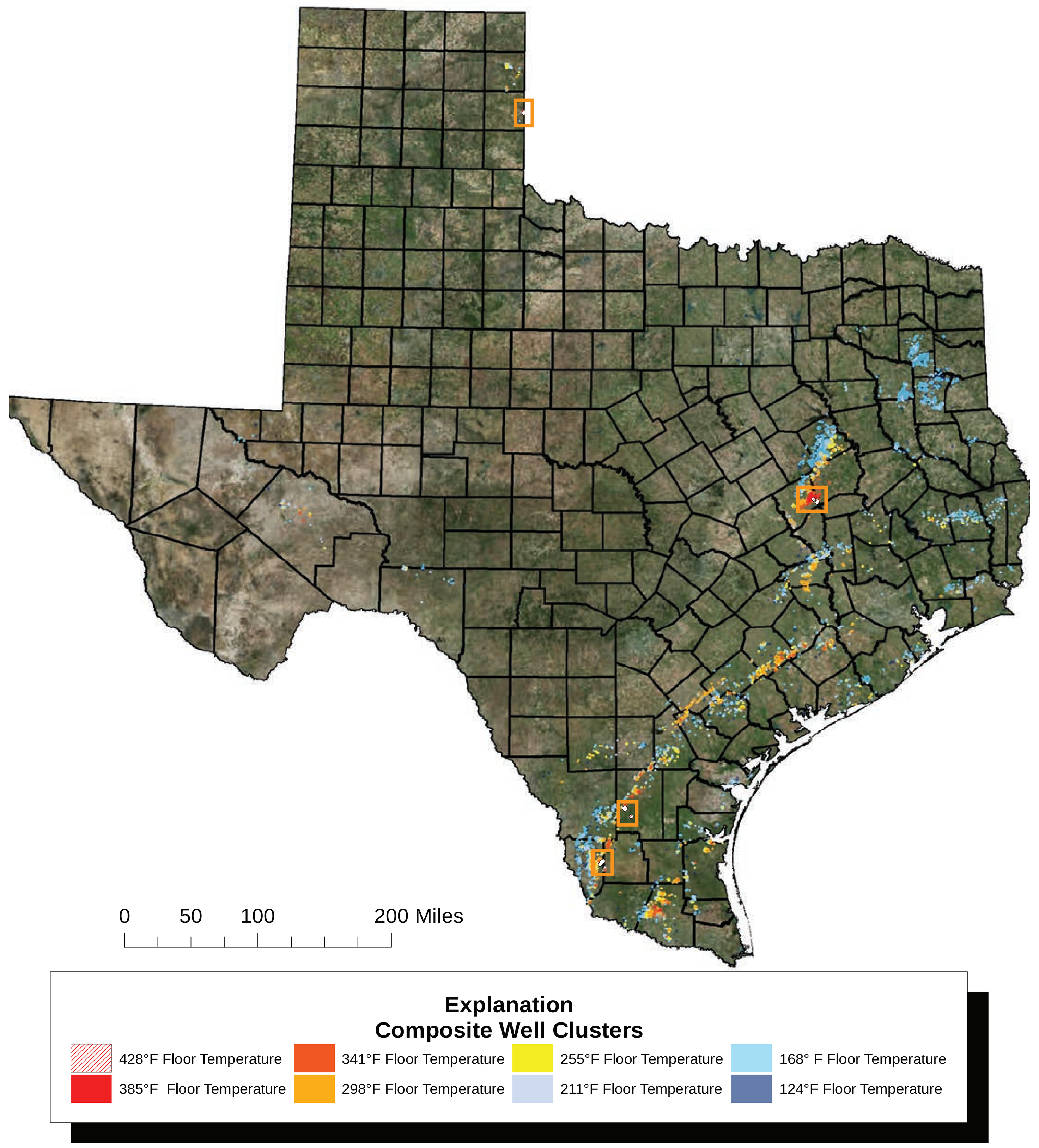
The Cluster and Outlier Analysis tool, which solves for the **Anselin Local Moran's I** statistic of spatial association, was used to identify concentrations of wells with high bottom hole temperatures.

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j}(x_i - \bar{X})$$

where:

I_i *is the statistic of spatial association*
x_i *is the selected attribute of feature i (bottom hole temperature)*
$\bar{X}$ *is the mean value of the selected attribute (mean bottom hole temperature)*
w is the spatial weight between feature i and j
n is the total number of features

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} w_{i,j}}{n-1} - \bar{X}^2$$



References

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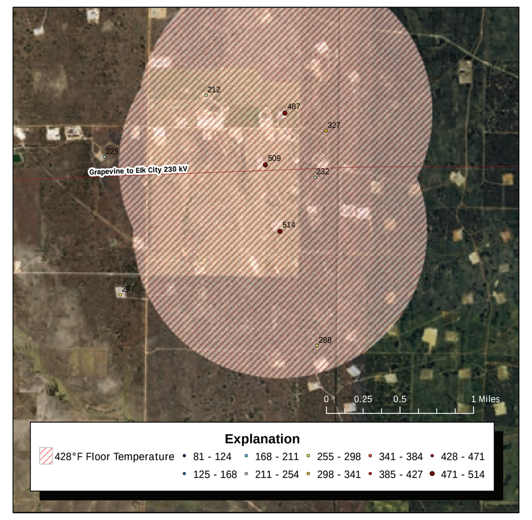
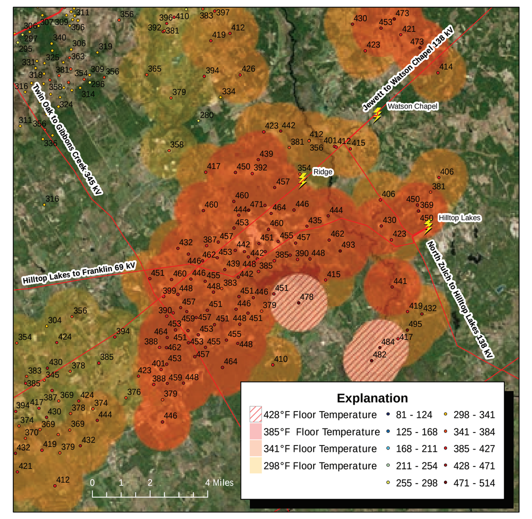
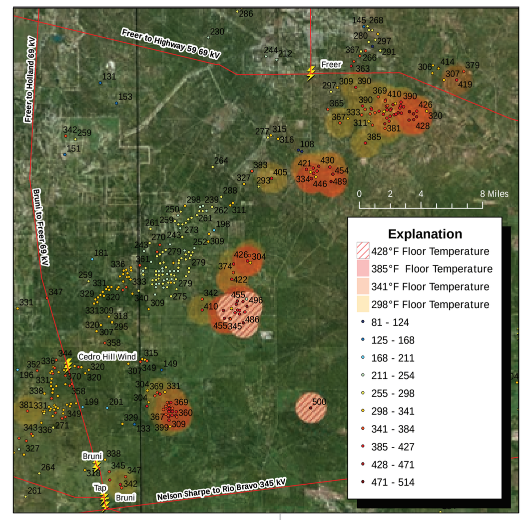


When a given feature (i.e. well) is surrounded by other features with similar attribute values (i.e. bottom hole temperatures) the value of *I* in the aforementioned equation is positive. Collective features with positive *I* values are considered **clusters**. Selecting the conceptualization of spatial relationships determines the spatial weight input (*w*) between two or more features. Common spatial relationships selected for this type of analysis include **inverse distance**, **fixed distance**, and **k nearest neighbors**, among others. **Delaunay triangulation** allows the distribution pattern of the data to determine how many neighbors are considered for each feature and was selected due to the large volume of unevenly distributed features.

As a result of the selected spatial conceptualization and the size of the dataset, initial runs of this analysis resulted in clusters that contained many neighboring features and failed to provide insight into ideal WBHX cluster locations. Thus, it became necessary to institute a lower bound or "**floor**" on the bottom hole temperature attribute in order to produce a more insightful spatial pattern. This floor was raised incrementally over several iterations based on the same equal interval classification scheme shown in the initial dataset. The resulting outputs, when stacked in order of higher floor bounds overlying lower, created a "**composite cluster overlay**," displaying a heat-map-like pattern showing discretized clusters of increasing temperature values.





Final results of this composite cluster analysis are displayed geographically by a **1-mile buffer** around the clustered feature points. This buffer distance was arbitrarily chosen and allows for interpretation of composite clustering trends from both a state wide and regional basis. The state map in the middle panel displays the composite cluster overlay for the entire NGDS Texas dataset and outlines the regional areas displayed in this panel. These higher resolution maps display clusters calculated at the highest floor values and are accompanied by each well's BHT value and nearby **transmission lines** and **substations**.

The northern-most region outlined (top) shows three wells in Wheeler County tapping the **Atoka Formation** in the Anadarko Basin. These isolated wells are separated from one another by less than 0.5 miles. The middle-right map shows wells tapping the tight **Bossier Formation** in Robertson and Leon Counties. The unincorporated resort community of Hilltop Lakes lies just east of these clusters and could serve as a potential small scale off-take. The remaining two maps show well clusters producing from the **Wilcox Group** in Duval (middle-left) and Zapata (bottom) counties.