Glenda Project – Atmospheric Stability – Sigma Theta Overview

The Glenda Project recently procured and deployed a Coastal Environmental WeatherPak 400 wireless mobile weather station.

One of the datasets collected by the WeatherPak is called “Sigma Theta” and is a measurement of Atmospheric Stability.

Atmospheric Stability can be defined as the resistance of the atmosphere to vertical motion. Vertical motion is directly correlated to different types of weather systems and their severity. Atmospheric vertical motion can be either ascending, or descending and are commonly called updrafts, or downdrafts.

Often under calm conditions, and especially over flat terrain, heated air parcels do not rise immediately. They have inertia and remain on the surface until some disturbance permits cooler surrounding air to flow in beneath and provide the needed buoyancy. This disturbance is the trigger for atmospheric in-stability.

Thunderstorms with strong updrafts and downdrafts develop when the atmosphere is unstable and contains sufficient heat, and moisture.

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As air rises, it cools and serves as an indicator of atmospheric stability. The term for the rate of this cooling is called the “Adiabatic Lapse Rate”, and is the traditional method for determining atmospheric stability.

In mountainous terrain, temperature and humidity measurements taken at mountaintop and valley-bottom ground stations provide reasonable estimates of the lapse rate and moisture conditions in the air layer between the two levels.

Adiabatic Lapse Rates (under “baseline” conditions):
Dry: 5.5 degrees F decrease per 1,000 feet elevation increase.
Moist: 3 degrees F decrease per 1,000 feet elevation increase.

A large decrease in temperature with height indicates an unstable condition which promotes up and down wind currents. A small decrease with height indicates a stable condition which inhibits vertical motion. Where the temperature increases with height, through an inversion, the atmosphere is extremely stable. (ie capping)

Lapse rate data is typically collected using balloon carried radiosondes, or rocket launched capsules, as the data is not attainable using conventional ground stations.

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“Sigma Theta” (ST) is a compound term with its origins coming from both the Statistical / Mathematic community and the Physical Sciences.

The term “Sigma” comes from the Statistical community and is a mathematical term used to define the concept / process called “standard deviation”. Standard Deviation is a process used to explain the amount of variability within a data set with the higher the deviation, the higher the level of variability within the data set.

“Theta” comes from the Physical Sciences / Weather community as the term defining the angle of wind direction.

“Sigma Theta” translated means the amount of variability of the changes in wind direction within a dataset.

Robert Yamartino developed the “standard” ST model back in the 1980’s and it has been adopted by the HazMat / EPA community as their preferred model for measuring atmospheric stability using ground based sensors and is based off of the following equations:

Step 1: Compute the average sine of wind direction, the average cosine, and epsilon

$$S = \frac{1}{N} \sum_{i=1}^{N} \sin \theta_i \qquad C = \frac{1}{N} \sum_{i=1}^{N} \cos \theta_i \qquad \varepsilon = \sqrt{1-(S^2 + C^2)}$$

Step 2: Compute sigma theta as the arcsine of epsilon, and apply a correction factor

$$\sigma_\theta = \text{arcsine}(\varepsilon) \left[1 + \left(\frac{2}{\sqrt{3}} - 1 \right) \varepsilon^3 \right]$$

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Frank Pasquill took the next step, and determined levels of Sigma Theta for differing degrees of atmospheric stability. He created a seven tiered system from “A” to “G”, where Class “G” reflects the most stable atmospheric condition, to Class “A” which reflects the highest level of atmospheric in-stability.

His results are shown in the table below:

Stability Class		Description	Definition
1	A	Extremely Unstable	$22.5 \leq \sigma_\theta$
2	B	Moderately Unstable	$17.5 \leq \sigma_\theta < 22.5$
3	C	Slightly Unstable	$12.5 \leq \sigma_\theta < 17.5$
4	D	Neutral	$7.5 \leq \sigma_\theta < 12.5$
5	E	Slightly Stable	$3.8 \leq \sigma_\theta < 7.5$
6	F	Moderately Stable	$2.1 \leq \sigma_\theta < 3.8$
7	G	Extremely Stable	$\sigma_\theta < 2.1$

Based on this Stability Class table, we can now make determinations of atmospheric stability based on ground station data and not have to rely on radiosonde, or rocket launch payloads.

The Sigma Theta data collected at the May 19, 2012 BMR launch is displayed on the following slide.

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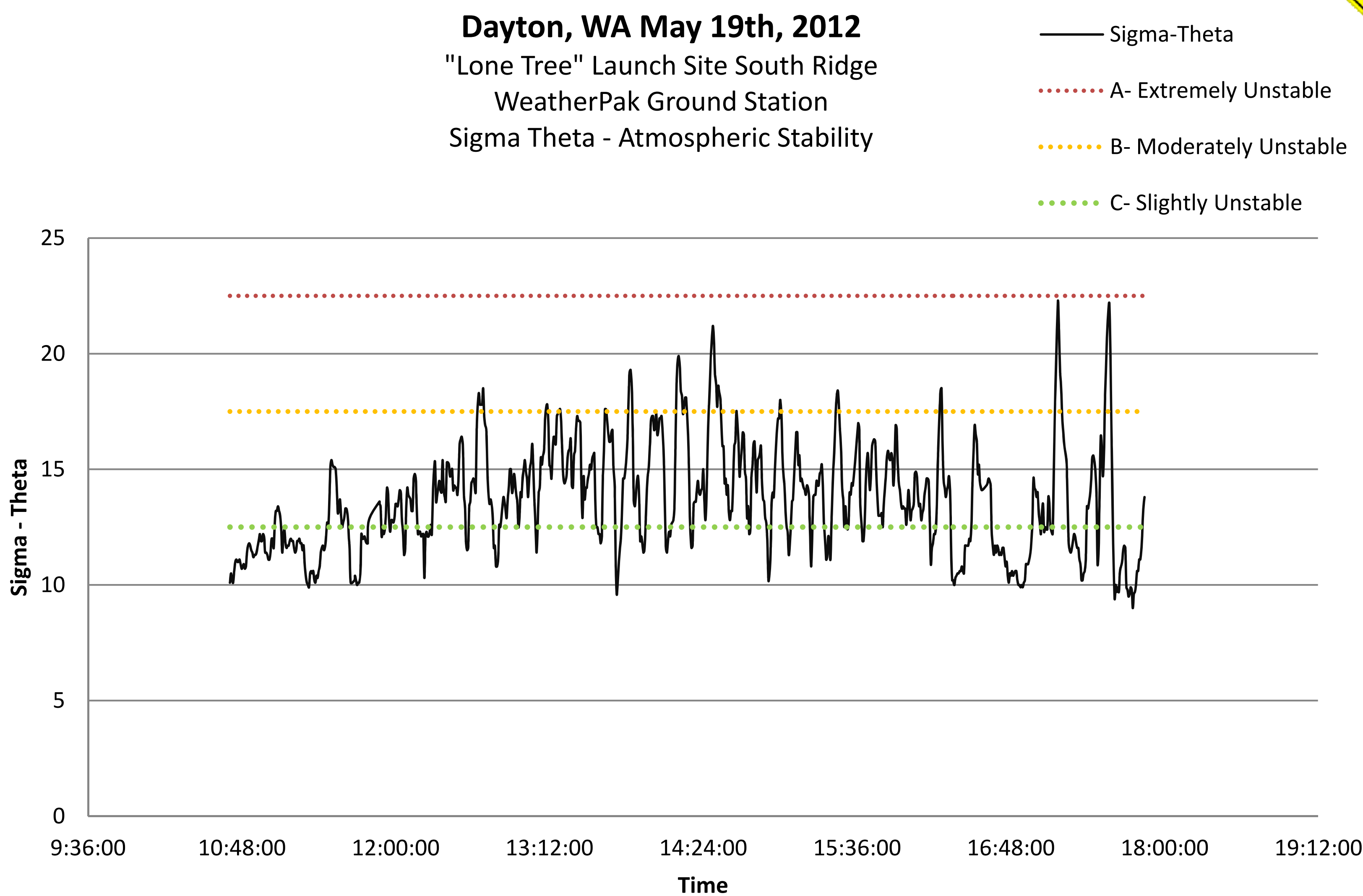

Note that the bulk of the ST data falls in the “Slightly Unstable” range with several points falling into the “Moderately Unstable” band. This implies that atmosphere instability is occurring. However, not severe.

Note also, that atmospheric instability is independent from wind speed as you can have strong winds in a stable atmosphere and calm winds in an unstable atmosphere.

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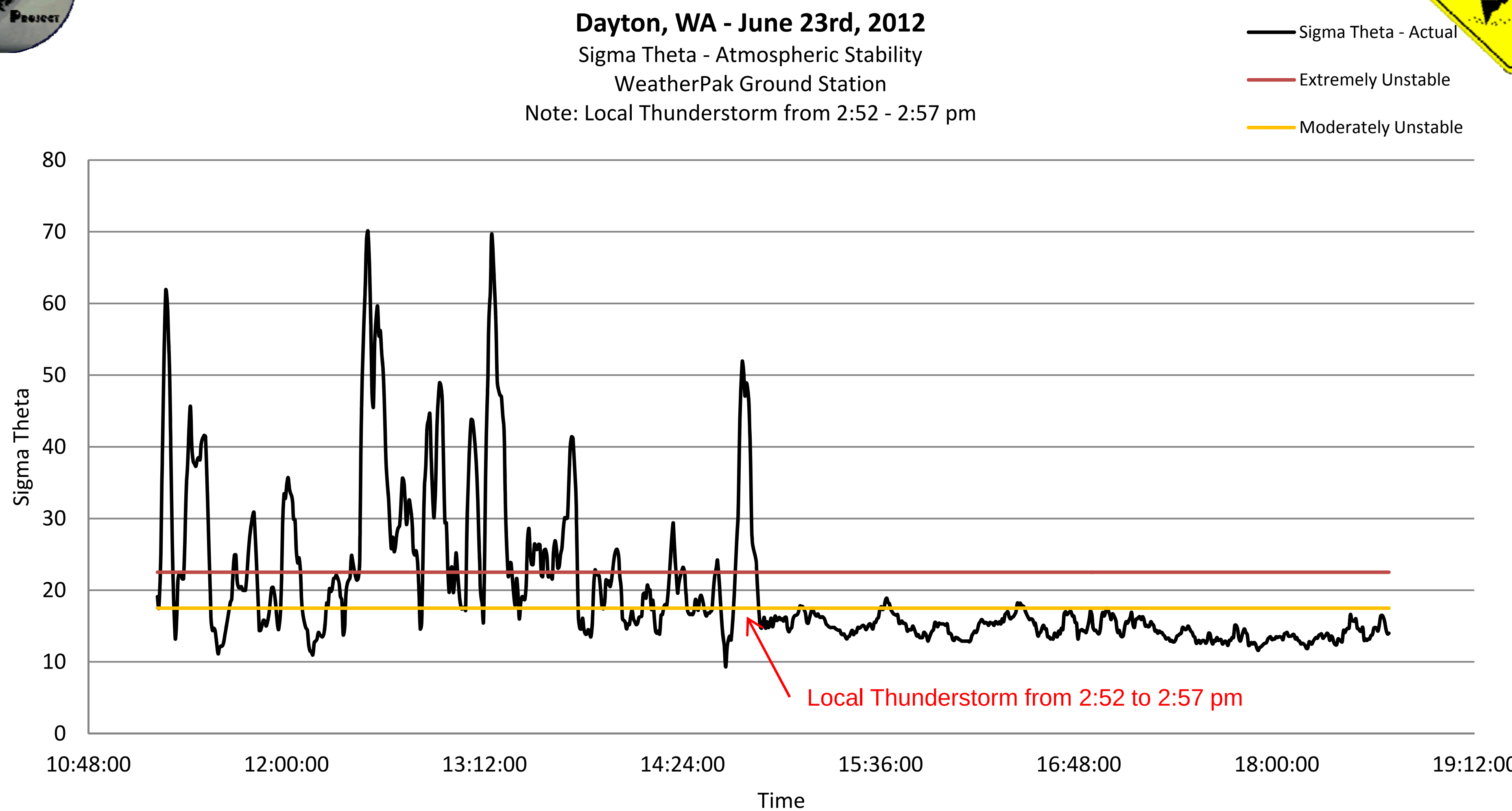

On June 23rd, the WeatherPak was again deployed on the south ridgeline above the BMR “Lone Tree” launch site.

Sigma Theta values reflected “Extremely Unstable” conditions until the passage of a local thunderstorm from 2:52 to 2:57 pm where the Sigma Theta values returned to normal limits.

A case can now be made that Sigma Theta values can be used as a severe weather pre-cursor, and continued deployment opportunities are expected.

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Conclusions

Sigma Theta provides us a tool to measure atmospheric stability using ground based sensors in a mobile environment.

Our new WeatherPak ground station provides us with the capability to measure Sigma Theta in real time with a wireless system and long range.

The June deployment has proven that Sigma Theta values can be used as a severe weather pre-cursor determinate.

Having a wireless system now provides us an additional tool to deploy multiple ground stations around a severe weather system and collect data from multiple paths and directions.