

# 2013 ENGINEERING GUIDE TO SITING PRECIPITATION GAUGES

Siting a Precipitation Gauge to obtain a large area representative sample of spatially random phenomena is not impossible, but nearly impossible. With knowledge of the systematic errors caused by topography, obstructions, and wind you can reduce the site induced errors to a minimum.



# 2013 Engineering Guide to Siting Precipitation Gauges

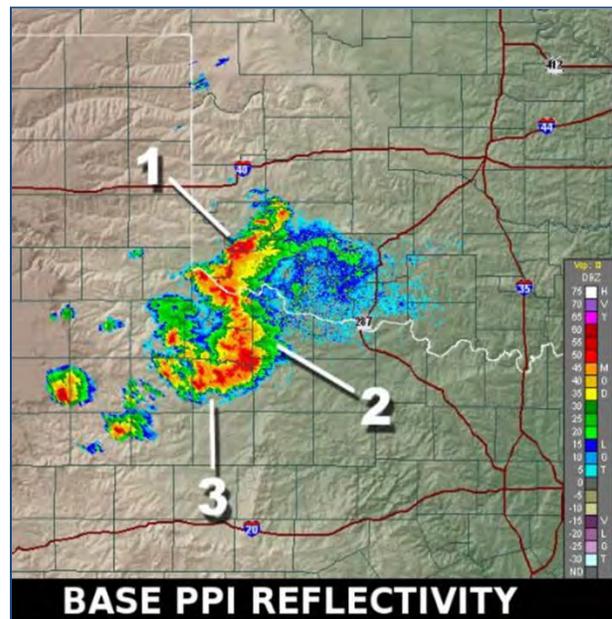
## SITING PRECIPITATION GAUGES TO MINIMIZE MEASUREMENT ERRORS

We are often asking a precipitation gauge that is measuring a 0.2 to 0.32 square meter sample to represent the precipitation of a 1000 square meter or larger geographic area. The spatial distribution of precipitation is spatially non-uniform and often random at the synoptic scale (over 1000 km). It can also be systematically non-uniform at the Meso-alpha scale (200-2000 km), the Meso-beta scale (20-200 km), the Meso-gamma scale (2-20 km), and at the Microscale (1-2 km or less). The real challenge is how to site precipitation gauges in order to obtain representative samples of precipitation events over such wide geographic areas.

### Precipitation is Not Uniformly Distributed

A good example of the non-uniform spatial distribution of precipitation is demonstrated by the radar depiction of a thunderstorm over relatively flat terrain in Oklahoma.

When measuring a randomly distributed phenomenon, a large number of point samples and statistical analysis are required to create an accurate area characterization. A single precipitation measurement slightly north or south of this cell would indicate little or no precipitation in the area. It would take a large network of hundreds of precipitation gauges, separated by as little as 1 or 2 km, to accurately characterize this precipitation event without the aid of Doppler Radar. Economic factors often dictate that the least number of gauges be used to characterize the precipitation over the desired area. Properly locating (siting) these gauges become a critical factor in characterizing the precipitation over such wide areas.



A 70 mile (112 km) wide by 10-30 mile (16-48 km) wide thunderstorm moving to the east, southwest of Oklahoma City, OK as recorded by NOAA radar. Note variation in precipitation intensity of factor of 10 between areas 1 and 3.

## Terrain and Obstacles Can Introduce Systematic Errors to Precipitation Measurements

If a large number of gauges were sited without taking into account the systematic errors introduced by the terrain and other obstacles, a completely erroneous conclusion as to the total area precipitation could result.

For example, on a **Mesoscale** the impact of having more gauges sited on the windward side of a mountain than on the lee side of a mountain could lead to a conclusion that higher than actual total precipitation has occurred over an area inclusive of both sides of the mountain. Having more gauges sited in the lee of a large body of water could give a higher than actual estimate of total area precipitation. Having more gauges sited in the lee of a city complex could give a higher than actual estimate of total area precipitation. Having gauges located on the windward side of river valleys could give a higher than actual indication of total area precipitation. Understanding how Mesoscale obstructions and topography impact precipitation can lead users to site gauges at locations that don't erroneously enhance or diminish precipitation estimates over wide geographic areas.

**Microscale** siting criteria deals primarily with wind as a local source of disturbance of the precipitation measurement. Obstacles of a uniform height that act as an effective wind break, but do not block precipitation, present the best sites for accurate precipitation measurement. One study showed measurably greater precipitation in forest clearings than on adjacent open farmland. Was this because the surrounding trees impacted wind speed and more precipitation fell into the forest gauge than in the open farmland or some other local phenomena? Siting gauges too close to trees, buildings and even small adjacent topographic anomalies may block blowing precipitation and significantly impact the gauges ability to accurately measure representative samples of total area precipitation. Siting gauges in open land without wind shielding can lead to lower than actual estimates of total area precipitation as the wind will blow the precipitation (especially solid precipitation at speeds in excess of 5 m/s) over the top of the gauge's collection orifice. Siting gauges on top of buildings or tall poles where significantly higher wind speeds may occur may also lead to under catchment. Siting gauges in pits, level with the ground, can minimize wind induced errors but introduce over catchment due to measurement of drifting snow or debris. Precise guidelines for Microscale siting of precipitation gauges is essential for representative measurements.

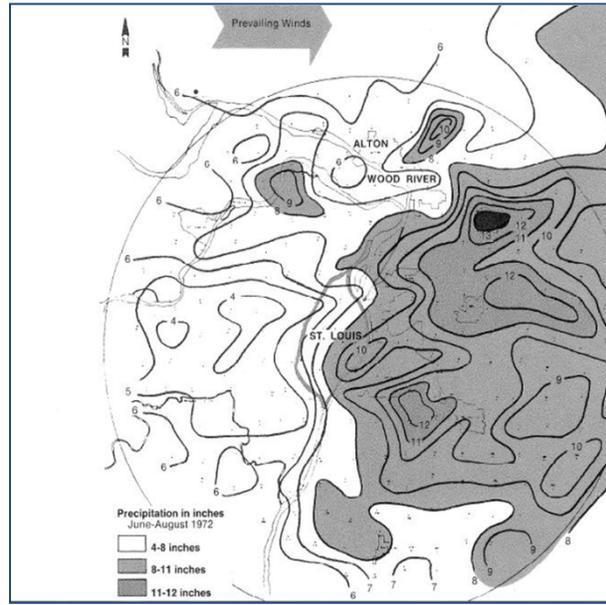
This application note will focus on how these systematic errors introduced by siting choices at the Mesoscale and Microscale level can be minimized to provide representative precipitation gauge data for input into wider area precipitation estimates and analytical models.

## MESOSCALE SITING CONSIDERATIONS

### 1. Cities Influence Distribution of Precipitation:

At the mesoscale, cities can influence the distribution of precipitation. This phenomenon is well documented in the five-year study of precipitation called METROMEX (Metropolitan Meteorological Experiment), which encompassed a 56 mile diameter relatively flat area around St. Louis, Missouri. As much as 300% more precipitation was observed downwind of the St. Louis area as up wind of the area during the July and August growing season as shown in the accumulated precipitation figure.

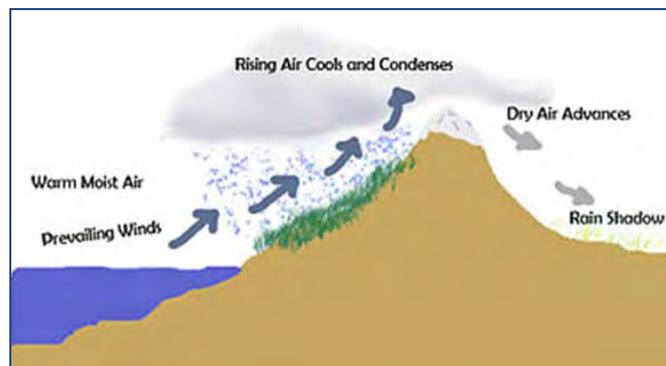
A precipitation measurement at the St. Louis International Airport, which is located 10 miles northwest of the city, would record only half the precipitation that would fall in Eastern St. Louis. Most of this difference is ascribed to urban heat radiation and aerosol pools emanating from the city and must be considered in siting precipitation measuring instruments.



St. Louis, Missouri Accumulated Precipitation

### 2. Mountains and Hills Influence Distribution of Precipitation

Mesoscale orographic phenomena is most often described as mountains blocking rain producing weather systems and casting a shadow of dryness, or a “Rain Shadow,” behind the mountain. This phenomenon occurs when warm moist air is pulled by the prevailing winds towards the top of mountains where it condenses and precipitates before crossing over the top, leaving a rain shadow or dry air on the leeward side of the mountain as shown in the example of a rain shadow.



An example of a rain shadow

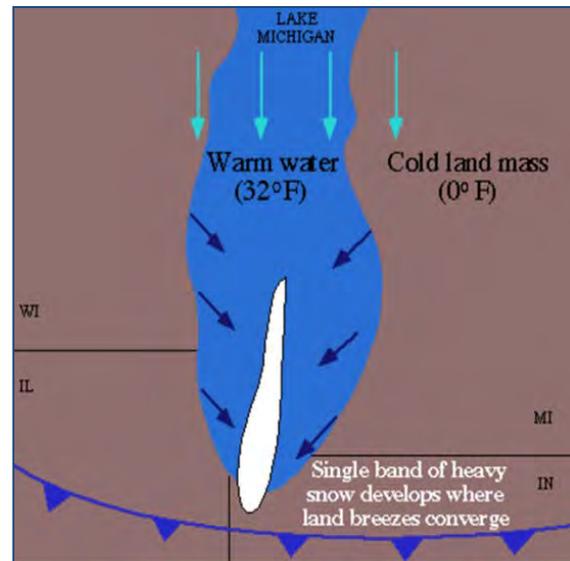
Mountains and rough terrain can impact mesoscale precipitation in many other ways as described in the writings of Robert A. Houze. In his paper *Orographic Effects on Precipitating Clouds*, (#2011RG000365, *Reviews of Geophysics*, 50, RG1001/2012) he provides a more comprehensive perspective of

orographic effects on precipitation and how complex terrain modifies precipitation. He shows how the effect of upslope and downslope winds can increase precipitation on either the windward or leeward side of mountains and how rainfall may be maximized on mountain ridges and minimized in valleys. Siting rain gauges to measure average precipitation over large geographic areas must carefully consider orographic factors on the measurement. We highly recommend a careful study of the referenced Houze paper before siting gauges near hilly or mountainous terrain.

### 3. Lakes Influence Distribution of Precipitation

NOAA describes lake effect snow as heavy bands of snowfall that may be 20 to 30 miles wide and 100 miles inland on the leeward side of a large lake or other body of water. It can “hover over one location for several hours, dropping several feet of snow; however, 10 to 15 miles on either side of that narrow band skies may be sunny with no snow at all.”

This phenomenon is well documented on the leeward side of the Great Lakes, but similar though less dramatic effects have been observed to the lee of smaller warm bodies of water and should be considered when siting precipitation gauges.



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### 4. Valleys Influence Distribution of Precipitation

In the absence of mountains, there is significant evidence that river valleys can significantly affect the spatial distribution of precipitation. One example is the Canadian River valley that runs generally west to east across the northern Texas panhandle and lies 800 to 1000 feet below the surrounding plateau. The snowfall on the windward side of the valley has been recorded at half the level of the leeward side of the valley and twice the level of the valley floor (Chris Kimble, NOAA Amarillo, Texas).

In the complex terrain of southern Germany, the interaction of valleys and circulation patterns on small scale precipitation distribution has been analyzed (M. Liu et. al, Hydrol. Earth Syst. Sci Discuss 9, 14163-14204, 2012). “The results show an interaction of valley orientation and the moisture flow direction of the CPs (circulation patterns) at the intermediate-scale, i.e. when the valley is shielded from the moisture flow, the precipitation amount within the valley is comparable to that on the mountain crest; when the valley is open to the moisture flow, the precipitation within the valley is much less than on the mountain.”

More recently, in an excellent AMS paper presented in 2013, we found the following quote:

“The ageostrophic frontogenesis, acting as a mesoscale ascent-focusing mechanism, helps air parcels to rise above the temperature inversion into a conditionally unstable atmosphere, which results in enhanced precipitation focused along the SLRV (St. Lawrence River Valley)” (Milrad et.al, Precipitation Modulation by the St. Lawrence River Valley in Association with Transitioning Tropical Cyclones, AMS 2013). In other words, more rain falls in the river valley than in the surrounding areas.

Locating precipitation gauges in river valleys, especially those surrounded by high plateaus or mountains could result in measurements not representative of the surrounding area.

When siting precipitation gauges, carefully consider the above mesoscale influences on the spatial distribution of precipitation and the potential for misrepresenting precipitation falling in the wider geographic area to be represented by the measurement.

## MICROSCALE SITING CONSIDERATIONS

According to The World Meteorological Organization Commission for Instruments and Methods of Observation, “Wind is the greatest source of disturbance in precipitation measurement.” As early as 1769, William Heberden wrote about the variation of precipitation with height. He observed over the course of 1 year that a rain gauge on the ground recorded 22.61 inches, on top of a nearby house recorded 18.14 inches, and on top of Westminster Abbey recorded 12.10 inches. We now know that these differences in observations are directly related to the increased velocity of wind with height and gauge under-catch as a function of wind speed. Furthermore, we know that wind speed increases exponentially with height above ground with the exponent a function of ground surface roughness.

The ideal site selection would have trees, shrubs or other objects that act as a wind break surrounding the gauge, but they would not be so tall as to block the normal flow of blowing precipitation. Furthermore, an ideal site would be on relatively flat land to reduce localized eddies caused by terrain. There should be no large obstacles adjacent to the gauge that would block or deflect precipitation around the gauge. Finally, the gauge should be sited in a way that minimizes collection of drifting snow, blowing debris, and splashing rain.

### 1. Forest Site

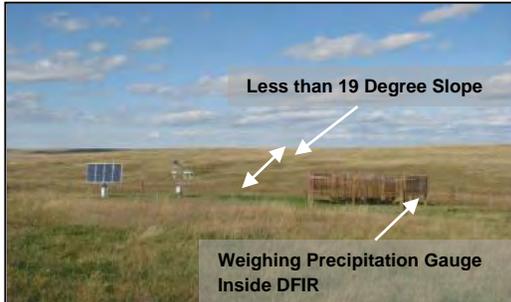
The ideal forest site would have trees cut down so that the nearest trees are at a distance greater than 4 times the height of the remaining trees (US NOAA/CRN criteria). It would have intervening shrubbery and bushes cut to a height not to exceed the height of the gauge inlet orifice. The U.S. Forest Service installation in Howland, Maine, as shown in the precipitation gauge figure, meets these criteria.



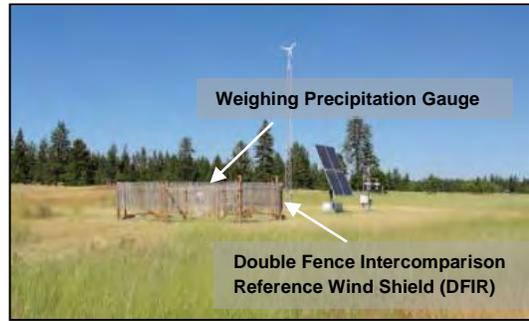
Precipitation Gauge sited in Forest Clearing.  
Belfort Weighing Precipitation Gauge with Belfort Alter Shield in Howland Research Forest as part of U.S. Forest Service Climate Tower Network program

## 2. Open Flat Land Sites

The ideal open flat land site would be surrounded by cleared surfaces with a slope not to exceed 1/3 (an elevation change of 1 unit over a horizontal distance of 3 units) or 19 degrees (NOAA/CRN and WMO specification) as shown in the NOAA CRN sites.



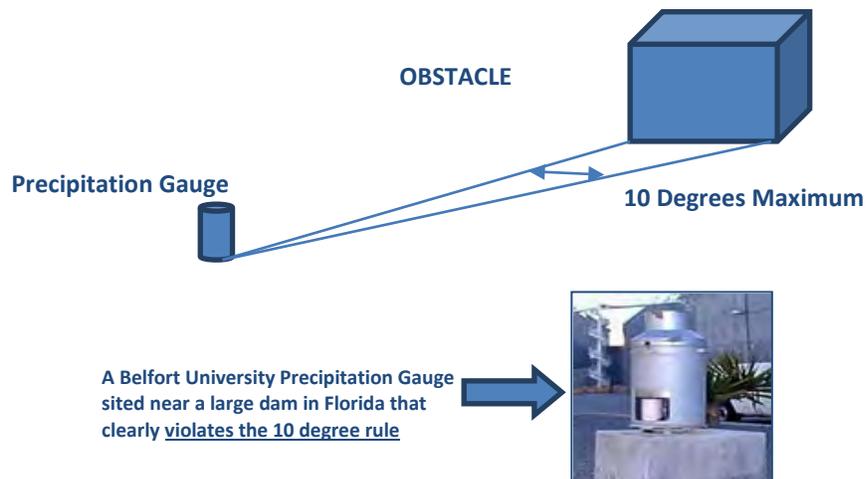
NOAA/Climate Reference Network Site  
Pierre, South Dakota



NOAA/Climate Reference Network Site  
Spokane, Washington

## 3. No Large Obstacles

The ideal precipitation gauge site would not have any obstacles that subtend more than a 10 degree arc when looking from the base of the gauge as it will block precipitation or cause eddies that will impact collection efficiency.



#### 4. Minimize Collection of Drifting Snow, Blowing Debris and Splashing Rain

All precipitation gauges will measure blowing snow as a precipitation event. Weighing type precipitation gauges will weigh leaves and blowing debris from a freshly harvested field as if it were accumulative precipitation. The small diameter inlet orifices used in manual and tipping bucket gauges will become easily fouled by blowing debris and under record precipitation. Gauges sited too close to the ground in hard surface areas can collect rain splashes and record them as precipitation.

- a. Minimizing the effect of blowing snow requires siting your gauge in a way that snow collected on adjacent trees or ridges does not blow into the collection orifice. In areas where there is significant accumulation of snow, the gauge inlet should be at least one meter above the highest amount of historic snow accumulation as shown in the WMO test site in the mountains of Switzerland.



**Belfort Precipitation Gauge and Wind Shield attached to top of mounting pole in Davos, Switzerland**  
Courtesy of World Meteorological Organization SPICE Program



**Mounting pole installation for Belfort Precipitation Gauge in Davos, Switzerland**  
(Note pole height sufficient to position gauge well above level of snow accumulation)

- b. In the spring, blowing seeds and pollen from trees can be anticipated in areas of deciduous trees and some conifers. This debris can be recorded as precipitation in weighing type gauges and can

also foul the inlets of tipping bucket and manual gauges. In the fall, blowing leaves can be a significant source of error for all types of precipitation gauges. Siting gauges away from or above blowing seeds, pollen or leaves will minimize the problem. One of the most common reference gauge site designs is called a "Pit Gauge Site." It is designed to locate the inlet gauge orifice at the surface of the ground as shown and thereby



Pit Site for Precipitation Gauges can be subject to blowing snow and debris, C.E. Duchon et.al 2010, University of Oklahoma

eliminate wind-related catchment errors. However, it must be continuously monitored to remove blowing debris and carefully constructed to prevent splash-back from nearby surfaces.

- c. Siting gauges in areas of low grass will reduce the maximum drop splash to less than 1/3 of a meter. Rocks or other hard surfaces can cause rain drop splashes to reach a height of 1 meter and contribute to errors in precipitation readings. Gauges at the USCRN sites are sited on a 3 foot high pole with the inlet orifice at 1.66 meters (65.35") above ground in areas where snow accumulation does not require additional height. At this height drop splashes from hard surfaces should not affect the accuracy of precipitation measurements.

## MICROSCALE CLASSIFICATION OF PRECIPITATION GAUGE SITES

The World Meteorological Organization (WMO) and the U.S. Climate Reference Network (USCRN) have published general guidelines to classify sites for precipitation gauges such that they are “Regionally and Spatially” representative. This detailed information is available in their online publications WMO-No8 CIMO Guide, 2010 and U.S. Climate Reference Network Site Information Handbook, 2002. The following summarizes the essence of their guidelines:

### **Class 1 Precipitation Measurement Site:**

- Flat horizontal ground with a slope less than  $1/3$  (an elevation change of 1 unit over a horizontal distance of 3 units) or 19 degrees with no impact from surrounding terrain features (such as mountains, etc.).
- Surrounding trees, shrubbery or other obstacles of a uniform height at a distance equal to or greater than 4 times the height of the precipitation gauge inlet.
- Uniformity for the above purpose means that there is less than a factor of 2 difference in lowest and highest obstacle and an obstacle is defined as material that subtends over at least a 10 degree arc as viewed from the gauge.

### **Class 2 Precipitation Measurement Site (Site induced measurement error up to 5%):**

- Same as Class 1 site except the obstacle is located a distance of at least 2 times the height of the precipitation gauge inlet.

### **Class 3 Precipitation Measurement Site (Site induced measurement error of 10% to 20%):**

- Open land surrounding gauge with a slope less than  $1/2$  (30 degrees).
- Obstacles are located at a distance of at least 1 times the height of the precipitation gauge inlet.

### **Class 4 Precipitation Measurement Site (Site induced measurement error over 20%):**

- Land surrounding gauge with a slope greater than  $1/2$  (30 degrees).
- Obstacles are located at a distance of less than 1 times the height of the precipitation gauge inlet.

### **Class 5 Precipitation Measurement Site (Site induced measurement error over 50%):**

- Obstacles overhanging the gauge, such as trees, roof edges, etc.

## SUMMARY

Precipitation gauge siting considerations can lead to significantly reduced errors in the measurement of representative samples of area precipitation with a minimum number of gauges. Knowing that any single precipitation event can be spatially non-uniform introduces a requirement for multiple measurement sites over a wide geographic area. Knowing that cities, mountains, river valleys, and lakes systematically modify the **Mesoscale** level of precipitation introduces a requirement to site gauges in a manner that compensates for these known systematic spatial non-uniformities in order to gather more meaningful area wide data. Knowing that wind modification at the **Microscale** level of precipitation introduces a requirement to locate gauges where wind is reduced to a minimum without blocking blowing precipitation. Proper Mesoscale and Microscale precipitation gauge siting considerations can reduce systematic errors in representation of large area precipitation data by over 50%.

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