1.1 Criteria for a Good Weather Observation Site from 1826-2006

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1. INTRODUCTION

The changes in weather observational data induced by changes in the observational site are well documented. Changes in the observation site's location, elevation, exposure, and instrumentation are known to cause anomalies in the observed data. Procedural changes such as time and frequency of observation, methods for calculating means, and exposure requirements induce alteration of data too. The results of testing of new instruments produce constraints that affect site selection that may affect the data themselves.

Basic differences in weather data arise from changes in the criteria used to collect them.. There have been many changes to the criteria used to select a location for the installation of weather observation equipment. At any point in time, the criteria used were considered to be the best available. Nevertheless, those criteria were frequently modified for what were considered to be good reasons.

This paper discusses site selection criteria, how and why they differed from one network to another, and how they have evolved to those currently in use.

1.1 Background

The National Climatic Data Center implemented a Climate Database Modernization Program to scan and index early colonial meteorological records and journals from the 1700's and 1800's and to make them available online. These images include the observational records produced by the networks of the Army Surgeon General, the Navy, the Smithsonian Institution, the Army's Signal Service, the Weather Bureau, and the National Weather Service. Over forty-five million pages of data have been scanned and placed on line so far.

Approximately 160 stations (about 3 per state) were selected for priority digitization of their scanned observational records. The records of other stations will be digitized as funding permits. The digitization process is underway with quality assurance applied to the digitized data to ensure accurate conversion of the data to digital form.

A comprehensive set of metadata is being developed to complement the digital data set. The metadata include digitized information about station location, observers, and instrumentation.

As a supporting part of Climate Data Base Modernization program, narrative station histories are being written for some of the stations that have records extending deep into the nineteenth century. Those narratives necessitated a look at a wide variety of historical information for each of those stations. That look was the inspiration for this paper and presented most of the examples used herein.

1.2 Methodology

The original observational records, related metadata and station histories, and supporting documents were used in this study. They represent the simple and complex, the formal and informal, and the intended and unintended histories of the criteria used to select weather observational sites over the years.

2. DEFINITIONS

One of the difficulties in making this study is that exposure criteria are often used interchangeably with site selection criteria. In this study, site selection refers only to the choice of a geographic location. Exposure refers only to the relationship between instruments and their environment at that location.

3. THE OBSERVATIONAL NETWORKS

National networks have existed since about 1817 and, during some periods, overlapped in time and in spatial distribution.

3.1 Surgeon General Network

The U.S. Army Surgeon General developed the first national climate network in 1814 (U.S. Army, 1855) and used the surgeons at Army Posts as their

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observers (Smart, 1894). The reasons for developing such a network were clearly stated in a Surgeon General report in 1826 (Lovell, 1826). Lovell stated that the network was formed to determine in a series of years if "there be any material change in the climate of a given district of country; and if so, how far it depends upon cultivation of the soil, density of population, etc." He stated that within the United States "…within memory of many now living the face of whole districts of country has been entirely changed; and in several of the States two centuries have effected as much as two thousand years in many parts of Europe."

Surgeon General Lovell wanted the climate network because the opportunity for building baseline data was, like the Indians, "…. fast passing way; and in a few generations, both these sons of the forest and the interminable wilderness they inhabit will, for all useful purposes, be as though they had never been."

Surgeon General Lawson wrote in 1851 that the network was aiding "….in determining the influences of the progress of civilization—that is, the effect of the improvement of a country—on climate, temperature, and atmospheric phenomena generally." Understanding climate change was still the focus.

The Army network followed the expansion of the settlement frontier with observations at the new Army posts and provided the first weather information recorded in many states.

There was a U.S. Navy observational network that began in 1834. It was composed of Naval Stations located along the coasts and its interests were not spatially competitive with the Army network.

3.2 Smithsonian Institution Network

The Smithsonian Institution began receiving observations from their new network in 1849 (Miller, 1931). The observation sites were not selected initially, the observers were. Later efforts considered geographic distribution of the observation sites but most were still near the homes of the observers. There were 616 Smithsonian observers just prior to the Civil War.

The Smithsonian network was a designed to collect information on climate. There were aspirations of developing forecasts using data collected by way of telegraph. There were modest results but for the most part, that aspiration was unfulfilled. Their primary focus remained on climate.

3.3 Signal Service Network

Congress created the Signal Service within the Army Signal Corps with weather forecasting as its primary objective. From the beginning, they were expected to make observations and issue warnings of impending storms. The Signal Corps was selected because their use the telegraph could provide near real time reports of weather observations to a central office in Washington. The first such reports were telegraphed on 1 November 1870 from twenty-eight locations and the first surface weather map was promulgated.

The Signal Service supplanted the Smithsonian network and the primary role changed from the Smithsonian's observations of climate to the Signal Service's observations of weather. Later, the Smithsonian observers were invited to submit their data to the Signal Service as voluntary observers. By 1884, there were 458 stations reporting, most were volunteers (Signal Service, 1884). The Surgeon General network coexisted during the Signal Service years but those data, like those of most of the voluntary observers, were ancillary to their forecasting mission. The Signal Service relied on data from their own sites on which to develop forecasts.

3.4 Weather Bureau Network

A major change in observations occurred when the weather functions of the Signal Service were disestablished in 1891. Its observational network morphed into one that supported agriculture's needs and became part of the new Weather Bureau formed within the Department of Agriculture. Although the emphasis in forecasting shifted to an agricultural interest, the locations and the observers were the same ones used by the Signal Service.

Although their mission was focused on agriculture, the Weather Bureau offices did not move to rural areas away from their Signal Service locations. Instead, an extensive Cooperative Observer Network was developed with numbers eventually exceeding 12,000 observers nationwide.

The Forecast Offices remained downtown until the early 1940's when the rapid development of aviation began to take center stage. The offices were moved to the cities' airports and the downtown sites were, for the most part, abandoned during the next few years.

Subsequently, the Weather Bureau was moved into the Department of Commerce and eventually renamed as the National Weather Service.

3.5 National Weather Service Network

The National Weather Service observational network evolved toward automated observations. Initially, the automated systems were augmented by human observers but that ended about 2001. Over 800 Automated Surface Observation System (ASOS) and over 600 Automated Weather Observing System (AWOS) are now operational.

In the 1980's, over one thousand observing stations were selected for designation as the Historical Climatology Network.

The more recent move of the Forecast Offices away from the airports was a radical change. In many cases, the moves were to locations that had no observational equipment. Some of those locations were rural, some suburban, and some collocated with the radar. Eventually, observations were resumed at the initiative of the local forecasters.

4. SITE SELECTION CRITERIA

The early interest in developing observational networks focused on climate rather than weather. In a letter to C. F. Volney in January 1797, Thomas Jefferson wrote that he wanted to develop a climate network in Virginia,

> …I had once (before our Revolutionary war) a project on the same subject.[winds]. As I had then an extensive acquaintance over this State I meant to have engaged some person in every county of it, giving them each a thermometer, to observe that and the winds twice a day for one year, to wit, at sunrise and at 4 p.m. (the coldest and the warmest point of the twenty-four hours) and to communicate their observations to me at the end of the year.

The recipient of that letter was an early observer of climate and soils (Volney, 1804). He toured Kentucky, Ohio, and New York and wrote that, everywhere he visited, he heard reports that identified climate change.

> … longer summers, later autumns, and also later harvests; shorter winters, snows less deep and of shorter duration, but cold not less intense. And, in all the new settlements these changes have been represented to me not as gradual and progressive, but as rapid and almost sudden, in proportion to the extent to which the land is cleared.

Sixty years later, Lapham (1867) drew similar conclusions about Wisconsin.

> It is quite evident, therefore, that a forest is a great equalizer of temperature, modifying both the extreme heat of summer and the extreme cold in the winter; its removal makes the climate fore excessive; the range of the thermometer being increased...

The selection of observation sites did not place that hypothesis to a test. The networks were established using other principal criteria.

4.1 Surgeon General Network Sites

The military posts were the obvious choice to provide the first national network because of their geographic distribution. The posts at the fringe of the expanding frontier were of particulate interest, areas that as yet were still in the wilderness. The collection of climate data from them was useful to settlers contemplating moves to those frontier areas.

The Army assigned the weather observation function to Post Surgeons. Therefore, posts that had surgeons also took weather observations. The only site selection criterion was where within the Post the observations would be taken. The answer was somewhere near the Surgeon. Most observation sites were near their quarters or near the hospital, if there was one. Although there were no criteria for site selection, there were rules for observations including ones for proper exposure of the instruments.

4.2 Smithsonian Network Sites

The initial Smithsonian network incorporated observers who were already recording and providing information to other collectors such as those in New York and Pennsylvania. The initial network's voluntary nature obviated the need for site selection criteria. Soon thereafter, there was a study (Fendler, 1860) that showed the effects of urbanization. The Smithsonian concluded that country locations were preferable over city ones because the city temperature observations were too high. Standards for exposure of instruments were used.

4.3 Signal Service Network Sites

The Signal Service network that was first operational in 1870 was the first to have site selection criteria. They required access to telegraph and a means to disseminate their forecasts. The telegraph lines followed the railroads and dissemination was visual by forecast flags or postings on bulletin boards. Those requirements limited the site location to downtown in cities. Directions for exposures

exacerbated the effects of the downtown location by stating that wind measurements were best when mounted on the highest buildings.

4.4 Weather Bureau Network Sites

In 1890, the newly created Weather Bureau took over all the Signal Service sites. Most of those sites continued for the next sixty years without significant change. In 1905, the Weather Bureau's Station Regulations stated the site selection criteria.

> In general, the office building should be higher than the surrounding structures, preferably with a flat or gently sloping roof, without towers, gables, or high chimneys, and should afford facilities for the exposure of the instruments as provided in the circulars of the Instrument Division.

Those regulations assured that observations would continue to be taken on top of downtown buildings. Later, the Weather Bureau opened offices in other cities even constructing buildings in several smaller cities. The Cooperative Observer program was expanded and most of those sites were rural or suburban.

In the early 1940's, the Weather Bureau moved their observations to the city airports, usually to the roof of administration buildings. Most of the downtown locations were subsequently abandoned. The airports sites underwent changes in organization (NWS or FAA), equipment (manual or automated), and location (atop buildings or amid runways). As observations changed from observers to recording or automated equipment, site selection became virtually synonymous with equipment exposure.

4.5 National Weather Service Network Sites

The Weather Bureau was renamed the National Weather Service in 1967. In the 1980's, over one thousand NWS stations (mostly cooperative observers) were selected for designation at the Historical Climatology Network. The selection criteria included the length of the period of record, percent of missing data, number of station moves and other station changes that could affect data homogeneity and spatial coverage. Most of those selected were rural cooperative stations but some were NWS first order.

Most recently, the Climate Reference Network became operational. Its site selection criteria required that its sites must remain largely stable for 50 years or more, be located in fairly pristine environments, have clearance from obstructions in clear terrain, have good exposure for instruments, and be separated from micro-climate inducing influences ranging from small ponds to urbanization. The network will have about 110 sites.

5. DISCUSSION

Until the Climate Reference Network was begun, none of the national networks were sited using criteria that were based primarily on climatological considerations. Almost all sites were selected by the availability of the site, the convenience of it, or the influence of its previous location.

5.1 Surgeon General Network Data

Data collected by the Surgeon General Network have several positive attributes. First, all the observers were Physicians, all trained as scientists, and motivated by an interest to discover the relationship between climate and disease. Second, all the observations were taken from closely similar sites: all made on an Army post, located near the Surgeon's office or hospital with similar exposures, and observed at the same times. Third, the data are usually the earliest data in each state, began about 1817 or at the establishment of a post, extend to 1892 or to the closure of the Post, and contain few missing days of data.

5.2 Smithsonian Institution Network Data

The observers who provided the data collected by the Smithsonian were mostly physicians, pharmacists, lawyers, teachers, ministers, or other professionals. Although the observation sites were not selected for climatological reasons, they were very uniform. Most were in the backyards of the observer's home, in rural or in small towns, and observations were made at the same times. The Smithsonian concluded (Fendler, 1860) that country locations were preferable over city ones because the city temperature observations were too high.

The scope of the data collected by the Smithsonian was the most expansive of any of the networks. Data now regarded as surrogate climate data were collected routinely on phenology, well water temperature, and freezing of waterways.

5.3 Signal Service Network Data

Signal Service data were recorded by Observer Sergeants. Those observers were trained for about six weeks in the Signal Service's meteorology school before being assigned to a site. All of the initial Signal Service data come from sites that were new, had prescribed exposures, and frequent inspections to assure conformity. The data collected came from sites that were uniform, if not the

most desirable ones. Typically, the site was in the middle of a city, on the roof of one of the highest buildings with instruments located as far as possible from chimneys.

Voluntary observers were added to the Signal Service network including some who were former Smithsonian observers. Therefore the volunteer's location was typically rural or suburban.

5.4 Weather Bureau and National Weather Service Data

The Weather Bureau observations became a corporate endeavor when hourly observations began that required that several individuals be involved during the course of a month. Only the cooperative observers remained as individuals in the system. The Weather Bureau and National Weather Service also pursued development of recording instruments (triple register, thermograph, weighing rain gage, etc), automated observations (ASOS, AWOS, etc), and remote observations (radar, satellite, etc.). Increasingly, the emphasis was on collecting data useful in forecasting. Data useful in climatology received less interest.

The Climate Reference Network data promises to be the first since the Surgeon General Network to focus primarily on climate.

6. CONCLUSIONS

The datasets from the various networks that extend deep back into the nineteenth century are, or soon will be, available to researchers. It is counterintuitive to believe that those older data may be the better suited to climatological study than those from more recent times. But, that may prove to be true.

There is a continuum using the similar networks of the Surgeon General, the Smithsonian Institution, the Voluntary Observers of the Signal Service, and the Cooperative Observers of the Weather Bureau and the National Weather Service. Their data are from the most uniform sites and originate from areas least contaminated by urbanization or other environmental alterations. Most interesting and most promising, these data cover as much as 180 years of climate observations. If the current cooperative observer program can be sustained, the continuum's baseline can extend that period into the future. The Climate Reference Network provides the verification capability of the continuum's collection of real data to assess climate variability and change.

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