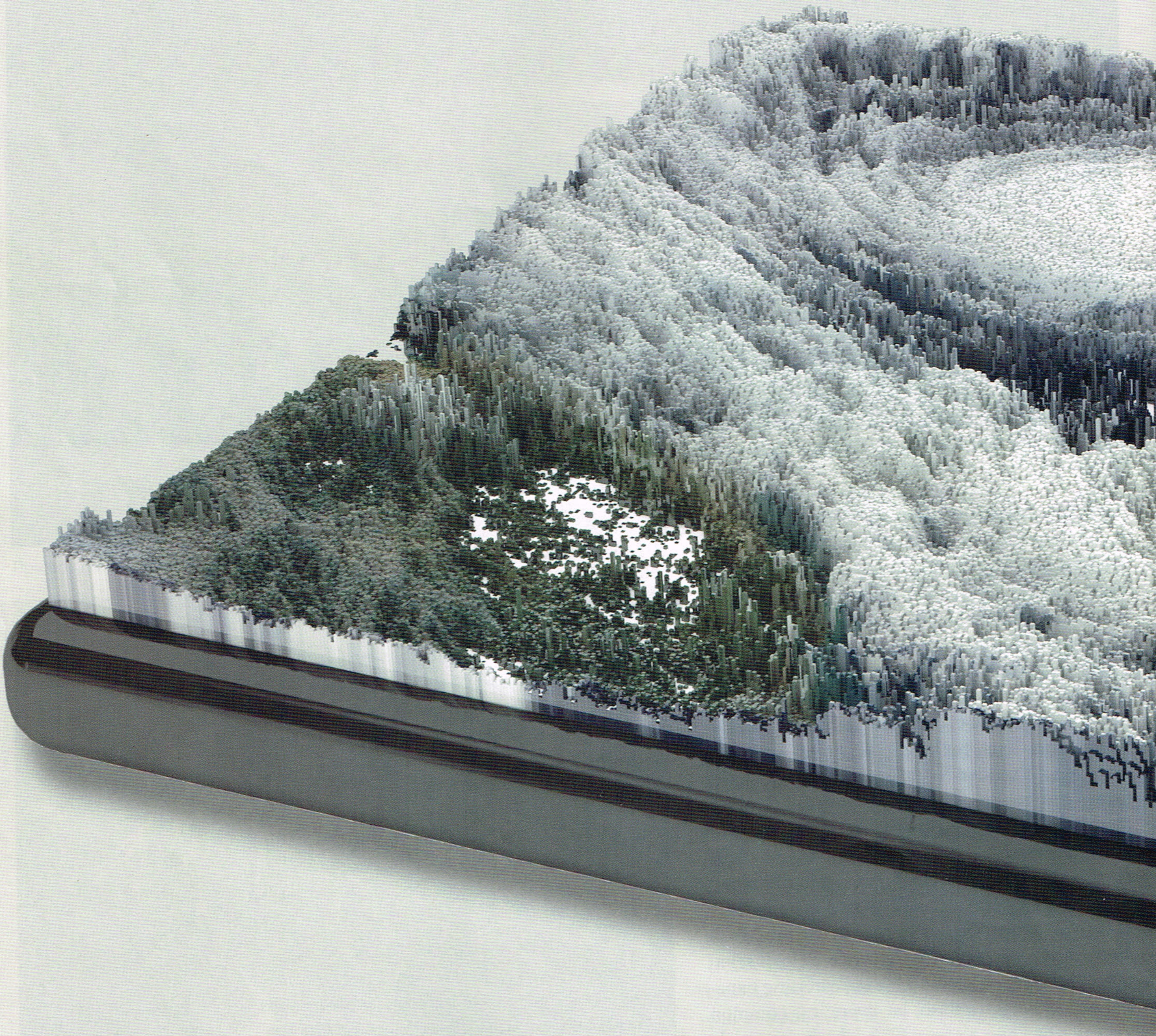
Creating a

DATABASE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# of All-Time Monthly Sea Level Pressure Records for the Lower 48 United States

by David Mark Roth

In recent years, extratropical storms—those associated with temperature and moisture differences within their circulation—have gained unprecedented attention. This is thanks to a record-breaking late October 2010 storm in the northern Plains and Hurricane Sandy's impact, including high winds and a high storm surge near its point of landfall as an extratropical storm on the northern mid-Atlantic states in late October 2012 (see Figure 1). The intensity of these storms—as measured in large part by record-setting low sea level pressures—and the headlines they made added pressure to scientists who were already looking to compile data from extratropical storms to answer questions about climate change.

The strongest extratropical cyclones have central sea level pressures that rival those in some Category 5 hurricanes on the Saffir-Simpson Scale. The October 2010 Northern Plains storm was provisionally declared the strongest extratropical cyclone to affect the Lower 48 United States. This could not be confirmed due to the relative dearth of information regarding sea level pressure extremes for extratropical cyclones. Later, crowd sourcing within the meteorological community determined it was the strongest extratropical storm to affect the United States *between the Rockies and the Appalachians*.

In general, the strongest extratropical cyclones occur during the winter season, when the upper disturbances that spawn them reach their peak strength. This is driven by the temperature differential between the poles and equator, which helps to strengthen the jet stream during the fall, winter, and spring months.

In the wake of this storm and Hurricane Sandy, and to help predict future record-breaking extratropical storms and improve forecasting and warnings, the United

NASA

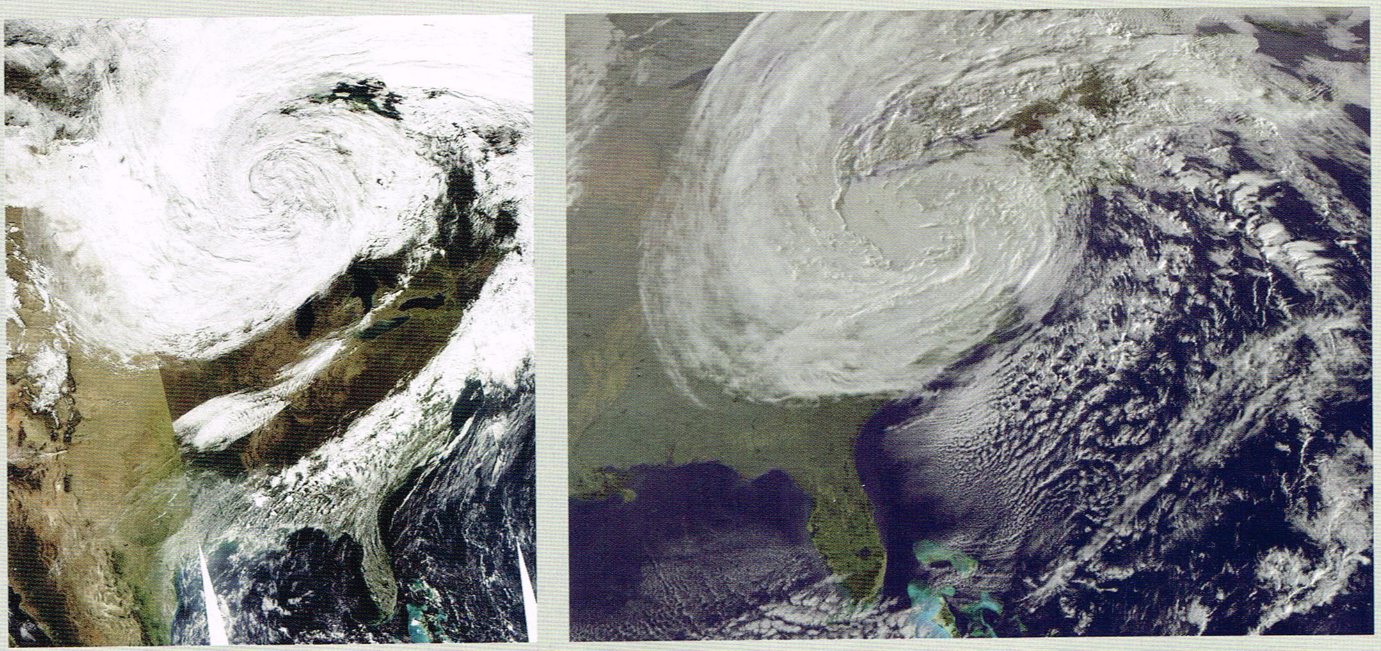


Figure 1. MODIS high resolution satellite imagery courtesy of NASA. The image on the left is the Late October extratropical cyclone on October 27, 2010. The cyclone broke all-time sea level pressure records for portions of Wisconsin and Minnesota as well as producing high winds to its west and north and is the strongest extratropical cyclone to impact the region. On the right is an image of the extratropical cyclone once known as Hurricane Sandy while over Pennsylvania on October 30, 2012, which broke all-time low sea level pressures across portions of the northern Mid-Atlantic States and brought heavy snows to West Virginia.

States Signal Corp, the United States Weather Bureau, and the National Weather Service took the necessary steps to compute sea level pressure data in real-time from 1871 to present, similar to other atmospheric quantities. However, datasets for sea level pressure and other characteristics of extratropical cyclones are neither well organized nor easily accessible, which makes analysis of the data a challenge.

In the absence of such information, I undertook the challenge to develop a series of sea level pressure maps that would help meteorologists gain a better understanding of the strength of extratropical cyclones.

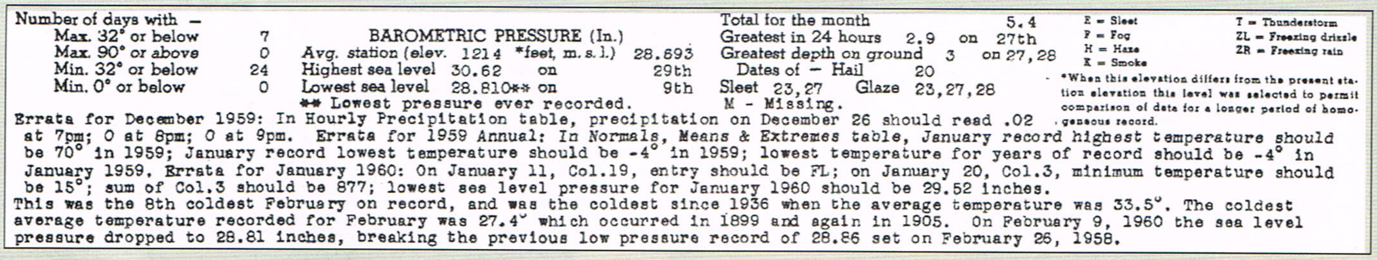
Why So Little Data?

To understand why there is so little organized data on sea-level pressure in extratropical cyclones, and why a database of information would be useful for predicting storm impacts, one must first understand a bit about extratropical cyclones themselves.

One reason a comprehensive extratropical cyclone database does not exist is their high frequency of occurrence. While 86 tropical cyclones (with greater than 39 mph maximum sustained winds) form annually on a global basis, a limited database from the National Center for Environmental Information (NCEI, formerly known as the National Climatic Data Center) from 1965–1975 shows that close to 1,000 extratropical cyclones occur within the Northern Hemisphere annually—more than one order of magnitude greater than their tropical counterparts. They form in the mid-latitudes, between the Tropics of Cancer/Capricorn and the Arctic/Antarctic circles. This area includes the Lower 48 United States, most of Europe, the Middle East, southern Asia, southern South America, and the southern Pacific, southern Atlantic, and southern Indian oceans.

They form near the equatorward edge of the jet stream near wind maxima aloft known as jet streaks along surface frontal boundaries, which causes them to be initially elongated from west to east. As they mature, the cyclones cross the jet stream into colder air masses and occlude as their cold front progresses faster to the east than their associated warm front. Their pressure/wind patterns also become more concentric. A comma-head cloud feature forms, which, during the winter when it is sufficiently cold, helps to focus snowstorms. Strong extratropical cyclones are associated with severe weather outbreaks—usually close to their cold and warm fronts—high winds along their poleward and west sides, and heavy snowfall to the left of their tracks. When a squall line, a line of strong thunderstorms, moves well ahead of its associated cold front, the line can slow down and lead to heavy rainfall and flash flood events.

For the most part, extratropical cyclones move from west to east, guided by the prevailing upper tropospheric westerlies. However, when the jet


Number of days with –
Max. 32° or below 7
Max. 90° or above 0
Min. 32° or below 24
Min. 0° or below 0

BAROMETRIC PRESSURE (In.)
Avg. station (elev. 1214 *feet, m. s. l.) 28.693
Highest sea level 30.62 on 29th
Lowest sea level 28.810** on 9th
** Lowest pressure ever recorded.

Total for the month 5.4
Greatest in 24 hours 2.9 on 27th
Greatest depth on ground 3 on 27,28
Dates of – Hail 20
Sleet 23,27 Glaze 23,27,28
M - Missing.

E = Sleet
F = Fog
H = Haze
K = Smoke
T = Thunderstorm
ZL = Freezing drizzle
ZR = Freezing rain

*When this elevation differs from the present station elevation this level was selected to permit comparison of data for a longer period of homogeneous record.

Errata for December 1959: In Hourly Precipitation table, precipitation on December 26 should read .02 at 7pm; 0 at 8pm; 0 at 9pm. Errata for 1959 Annual: In Normals, Means & Extremes table, January record highest temperature should be 70° in 1959; January record lowest temperature should be -4° in 1959; lowest temperature for years of record should be -4° in January 1959. Errata for January 1960: On January 11, Col.19, entry should be FL; on January 20, Col.3, minimum temperature should be 15°; sum of Col.3 should be 877; lowest sea level pressure for January 1960 should be 29.52 inches.
This was the 8th coldest February on record, and was the coldest since 1936 when the average temperature was 33.5°. The coldest average temperature recorded for February was 27.4° which occurred in 1899 and again in 1905. On February 9, 1960 the sea level pressure dropped to 28.81 inches, breaking the previous low pressure record of 28.86 set on February 26, 1958.

NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION

Figure 2. A segment of the Local Climatological Data publication summary for Oklahoma City, Oklahoma, for February 1960. Note the comments concerning the record low sea level pressure set at the station and when it was set.

stream severely buckles into an amplified upper pattern known as meridional, troughs and ridges become pronounced, and extratropical storms move more poleward.

Winds rotate cyclonically within extratropical cyclones: counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Friction with the earth's surface forces the winds to spiral inward toward their centers. Research by the Ocean Prediction Center indicates that an annual average of 65 non-tropical storms produced hurricane-force winds (74 mph or greater) in the North Atlantic and North Pacific Oceans during the fall, winter, and spring seasons from mid-2001 through mid-2008 , compared to 46 tropical storms per year of equal strength. The strongest extratropical cyclones have central pressures that rival those in some Category 5 hurricanes on the Saffir-Simpson Scale.

Creating Sea-Level Pressure Maps

The purpose of the extreme sea level pressure maps is to develop a comprehensive picture of significant extratropical cyclones stratified by month for the United States, using the record low sea-level pressure maps as a guide. All-time sea-level pressure extremes have been derived over the years by David Ludlum (1971) and Christopher Burt (2007) for the Lower 48, but neither researcher broke down the extremes by month. Since high sea-level pressure records didn't require much additional work, their maps were created as well.

To minimize redundant data collection for this project and maintain greater consistency, I contacted many National Weather Service Forecast Offices to see if monthly sea-level pressure records had already been derived. I also searched the meteorological literature, in part, because there was evidence from the Local Climatological Data publications (LCDs) from the 1950s and early 1960s that monthly pressure records were known for long-term observing sites. (See Figure 2, a snippet from the February 1960 LCD for Oklahoma City, with record pressure data highlighted.) Numerous sites—mostly from the National Weather Service's Western Region—had already determined their extremes. Others had their records in paper format or on their office Web sites.

I began to develop statistics for the other sites between spring 2013 and spring 2015 using the sea-level pressure records from the NCEI's Integrated Surface Database. I then cross-checked these data with Monthly Observation Forms 1001 prior to 1946 (scanned from the originals) and from LCD publications from 1939 onward. Comparing these sources with corresponding surface analyses allowed for the first level of quality control. Finally, I sent most weather forecast offices for which records were derived the associated spreadsheets/worksheets for additional quality control.

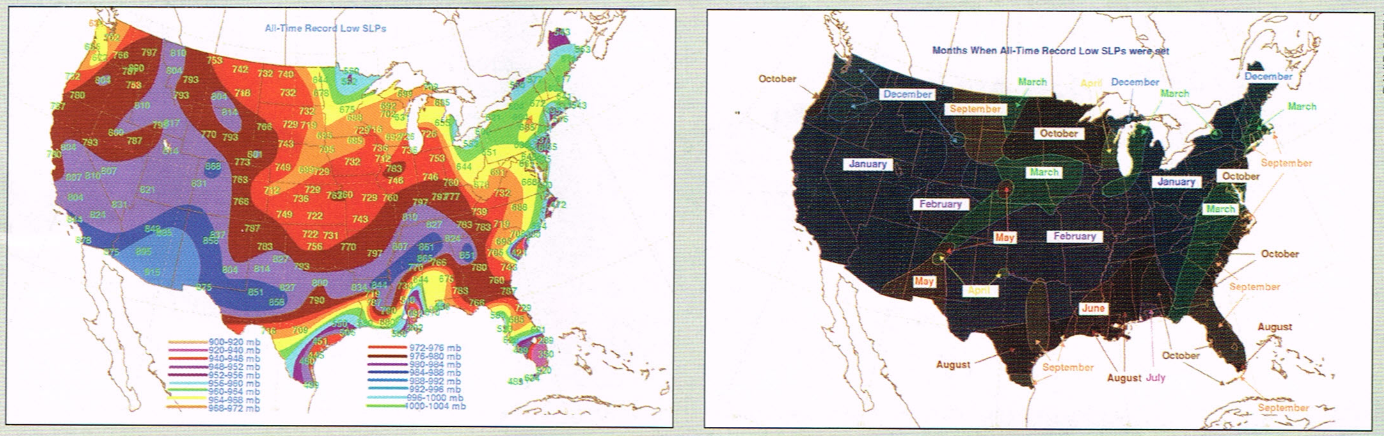


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Figure 3. Above are the all-time low sea level pressure records for the lower 48, with the observed pressure readings (map at left) and the month of occurrence (map at right).

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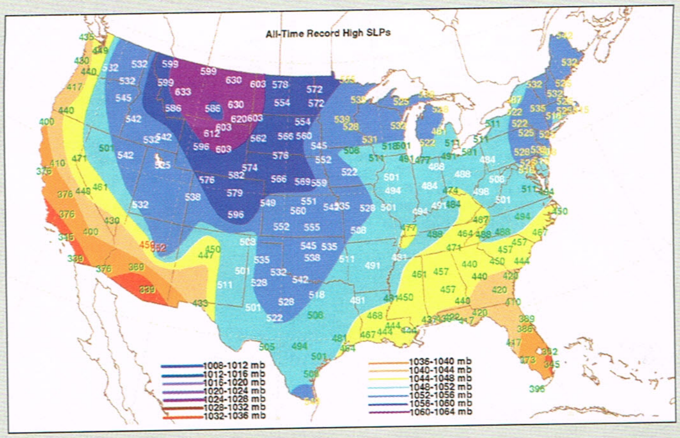

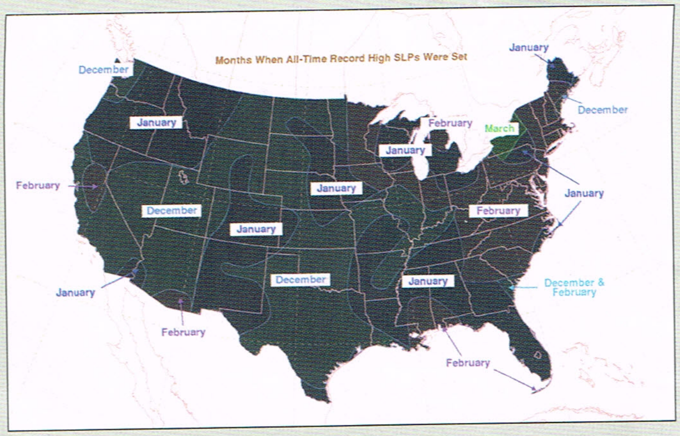

Figure 4. Above are the all-time high sea level pressure records for the lower 48, with the values (map at left) and the month of occurrence (map at right).

The biggest caveat relates to pre-Weather Bureau/Unit States Army Signal Corp observations taken prior to 1893. Though their microfilm records were keyed in by various universities under contract with NCEI, the keyed records are loosely organized in different databases. They are not within the broader digital databases due to the sudden elimination of the Climate Database Modernization Program in 2011.

In more recent years, the digital Integrated Surface Database is potentially more error-prone from January 1965–June 1996 because the LCD publications from this period did not include sea-level pressure extremes. The scanned National Meteorological Center surface analyses and the Weather Prediction Center's Daily Weather Map Series helped to identify inconsistencies within the digital database. For hurricanes, I used National Hurricane Center tropical cyclone reports and Atlantic Hurricane Reanalysis metadata for stronger cyclones to fill gaps between sites within the Southern and Eastern Regions of the National Weather Service.

The development of the sea level pressure record maps took approximately two years; the maps are normally updated within a week after a record event occurs. The development of similar records for Alaska is currently under way.

How Are the Data Used?

Knowledge of monthly sea level pressure records helps us determine when unusually low or high pressure affects portions of the United States, potentially indicating extreme weather in the offing. For example, the Wilmington, North Carolina, forecast office used these records to verify the storms with record low pressure that moved through its county warning area in 2013.

Preferred tracks for major storms stand out in the monthly low sea level pressure extreme maps across the Plains and Midwest, as well as near the Pacific Northwest coast and along the Eastern Seaboard. The records can be used, in conjunction with standardized anomalies, to determine the rarity of such events for any month of the year.

The maps for monthly pressure records have been embraced by climatologists across the Plains/Midwest; they were used to determine that January all-time high pressure records were set across portions of the northern and central Plains on January 7, 2015.

Interpretation of the Records

Much like the temperature pattern, the pressure records across the Intermountain West/Great Basin are tied closely to the solstices, with less variability during June and July at the onset of the North American monsoon and greater variability in December/January. Tropical cyclones can be seen within the southern and eastern portion of maps between June and November, with the larger/stronger tropical cyclones affecting the Lower 48 during August and September. Record high pressures occur during winter, when snow cover and lack of sunlight at high latitudes allow the development of deep and dense cold air masses. Normally, the stronger the high pressure system, the colder the associated air mass is. The stronger the low pressure system, the more extreme the winds are. W

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The website which contains the monthly high and low record sea level pressure graphics is http://www.wpc.ncep.noaa.gov/research/roth/SLPrecords.html.