2.4 THE MONTHLY SEA LEVEL PRESSURES RECORDS AND THEIR USE IN MESSAGING

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1. INITIAL IDEA

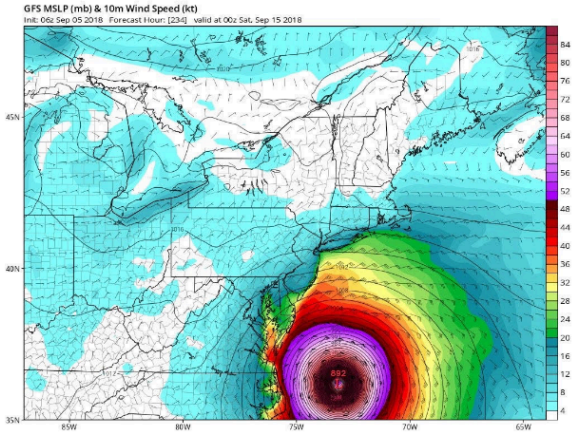
The idea of monthly and all-time sea level pressure (SLP) records for the United States was initially considered in the mid to late 1990's. The National Weather Service (NWS) Lake Charles LA forecast office had such records for Lake Charles itself, which led to the idea. No such maps appeared to be in existence over a broad domain, though notations of such were noted within Weatherwise monthly weather summary articles and in NWS Service Assessments of significant, impactful cyclones.

2. THEIR IMPORTANCE

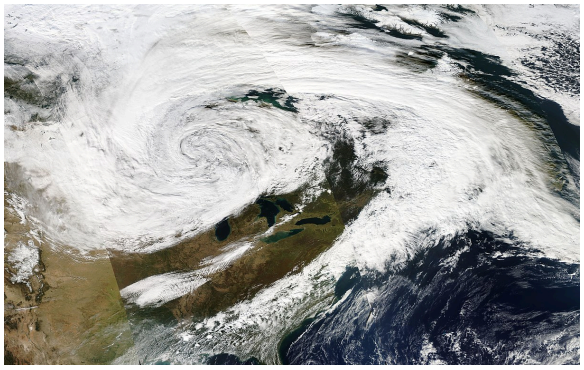
The primary reason to develop monthly SLP record datasets is perspective. Knowing past extremes helps inform the rarity, impact, and frequency of significant events. SLP records also have utility during forecast scenarios. As model guidance remains too strong with cyclones five or more days into the future due to premature phasing aloft – among other reasons – and mesoscale guidance still has issues with overdeepening cyclones within the next 24-48 hours, comparing forecast fields to the records can indicate where guidance might be too strong with both high and low pressure systems. They are also helpful when there are plausible upcoming record events.

3. EXPLORATION

After the record-strong October 2010 cyclone that impacted the Great Plains and Hurricane Sandy in late October 2012, it was apparent that monthly SLP extremes had not been tackled on a national scale. Exploration began as to how to obtain and/or derive such records, initially focusing on low pressure records in order to develop a significant extratropical cyclone database. Some NWS Forecast Offices (WFOs) had such a database for places within their County Warning Areas (CWAs), with most available records residing with NWS Western Region WFO climate publications for their new CWAs dating from the mid to late 1990s. Some NWS websites had monthly or all-time SLP records readily available online. Once publications were searched, outreach was made via social media, via e-mails to webmasters through WFO websites, and through NWS Science and Operation Officers (SOOs) to see if other offices had such information unpublished.



An example of model guidance forecasting an unrealistically strong cyclone (892 hPa) from September 2018, as captured from tropicaltidbits.com.



The October 2010 cyclone in the Upper Midwest

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Several WFOs east of the Rockies had such information (Abilene TX, Great Falls MT, Lake Charles LA, La Crosse WI, Sterling VA, Wakefield VA, and Upton NY). Interaction with other offices stated that they pulled digital data either from the National Centers for Environmental Information (NCEI) or the Weather Underground website, which had harvested NCEI information. The xMACIS database was consulted, though it was determined quickly that SLP was not one of the quantities within the database.

Through research conducted to compile tropical cyclone rainfall spreadsheets and graphics over the years, Roth (2002), it was known that by 2001 keyed in weather data was broadly available through the then National Climatic Data Center (now NCEI) via the Integrated Surface Database (ISD) of global hourly surface weather data, NOAA NCEI (2001). For major sites, Local Climatological Data publications (LCDs) and Form 1001s via NCEI's Environmental Data Access and Display System version 2 (EDADS2) were available to determine monthly SLP extremes prior to 1965 and after June 1996 to make sure that the extremes made the database. Some LCDs from the 1950s and early 1960s stated when a site set a monthly or all-time SLP record.

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.

The February 1960 Oklahoma City, OK LCD showing the indication for an all-time low SLP record being set, U.S. Weather Bureau (1960).

North American and Northern Hemispheric Maps from the Weather Prediction Center (WPC) and its predecessors were scanned at the NOAA Central Library between 2010 and 2015 and used as a form of quality control for the 1965-June 1996 period, as well as other time frames when unusual values were noted in the keyed in data from NCEI. Since 2013, interaction with NCEI led to the utilization of a few different databases in order to develop the record dataset, including EDADS2 in September 2013 and barograph requests for lower elevations since 2023 which required some SLP adjustment as they trace station pressure, not SLP. Thomas Schlatter sent a published all-time SLP list created by Ludlum (1971) while setting up a Weatherwise article about the project and database in late 2015.

4. DEVELOPMENT

Once it became clear that developing monthly high pressure records could be done with little additional effort, the top 5-10 extremes per month were entered for each site's spreadsheet from keyed in NCEI data. The entries were then refined using LCDs, Form 1001s, and occasionally surface weather analyses from the Weather Prediction Center (WPC) and its predecessors. The spreadsheets were initially shared with the WFOs in question either through their SOO, through a listed climate focal point, or through a colleague known at that office.

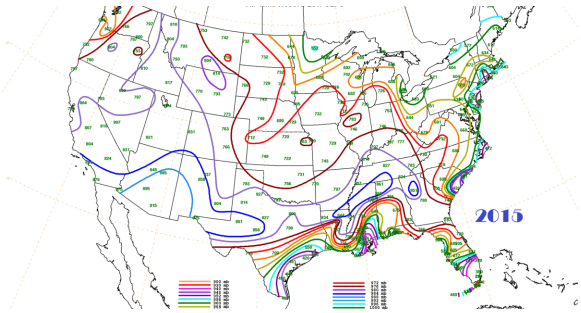
After developing datasets of the Lower 48, Puerto Rico, Hawai'i, and Alaska, it became necessary to develop a Canadian record dataset to bridge in between Alaska and the Lower 48, which involved interaction with Environment Canada as to how to move forward for record development for their country. The Bermuda Weather Service supplied their data, when asked about inclusion. During 2022, a single spreadsheet acting as a master key for the 467 stations was developed, which listed the monthly extremes by site in alphabetical order, indicated the all time extremes in italics, indicated their period of record, and tracked how recently various sites were updated.

Sea Level Pressure Extremes Ma	ster Key	January		February
Location	Station II	Low	High	Low
Miami FL Extremes	KMIA	29.520/23rd in 2017	*30.550/28th in 1988*	29.330/24th in 1942
Midland TX Extremes	KMAF	29.140/17th in 1996	*31.010/10th in 1962*	*29.090/09th in 1960*
Miles City MT Extremes	KMLS	28.970/11th in 1932	31.250/10th in 1962	*28.950/01st in 1963*
Milford UT Extremes	KMLF	*28.960/21st in 2010*	31.021/06th in 1949	28.992/21st in 2023
Milwaukee WI Extremes	KMKE	28.830/24th in 1938	31.000/26th in 1927	28.770/28th in 1902
Minneapolis MN Extremes	KMSP	28.640/10th in 1975	30.990/07th in 2015	28.770/26th in 1971
Minot ND Extremes	KMOT	29.037/17th in 1964	31.137/10th in 1949	28.961/01st in 1963
Missoula MT Extremes	KMSO	*28.950/22nd in 1943*	*31.300/10th in 1962*	29.100/01st in 1963
Moab UT Extremes	KCNY	29.155/22nd in 2010	*30.965/01st in 2008*	*28.927/22nd in 2023*

A portion of the master key SLP record spreadsheet showing its format.

The SLP data was plotted on maps using standard SLP map plotting notation and then contoured. Companion political maps were made as a reference to when the records occurred. The first SLP record maps were done on a monthly basis, with November available during November 2013. The first all-time SLP record maps available by 2015. Separate maps

were available for Alaska in 2016 and for Canada in 2019, with both Alaska and Canada using one unified map.



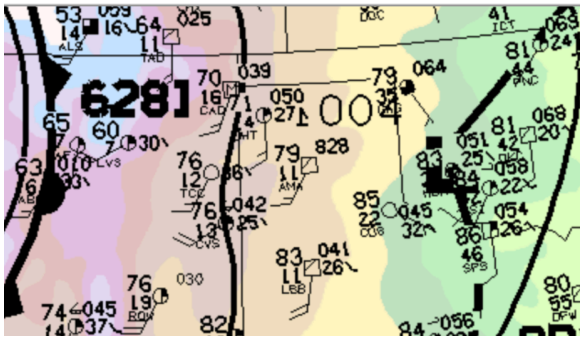
All-time record low SLP map in 2015.

5. LESSONS LEARNED

NCEI data keying historically has left gaps in the individual record sets, which varies by the site. The collapse of the Climate Database Modernization Project, Dupigny-Giroux et. al (2007), circa 2011 led to scanned and keyed in data lying at various universities across the country, available on their individual websites initially. Some of those records have become available through NCEI's EDADS2.

Although the ISD is listed as hourly resolution, a number of sites from the 1970s into the 1990s have data resolution limited to every three hours, what was available at those location's LCDs with the data likely digitized first due to easier availability for those keying in the data, with hourly observations on either side of this temporal window.

Errors within the keyed in data were noted. While some may have been introduced by those that keyed in the information for NCEI, others were introduced at the time of the observation and the errors were missed in real time – these are usually apparent in the real-time surface analyses. Such errors are still being found and quality controlled each time a new record event occurs. In locations with SLP data gaps, altimeter data was used as a proxy at locations at low elevations above sea level (generally under 300 meter elevation). At higher elevations, altimeter cannot be reasonably used as an alternative as its method of reducing to sea level pressure leads to increasing differences between SLP and the altimeter reading. Depending upon the site, the inability to use the



Amarillo TX SLP error on the March 13, 1996 2100 UTC surface analysis via the online WPC North American Surface Analysis Archive.

altimeter reading as an alternative leaves larger gaps in their record.

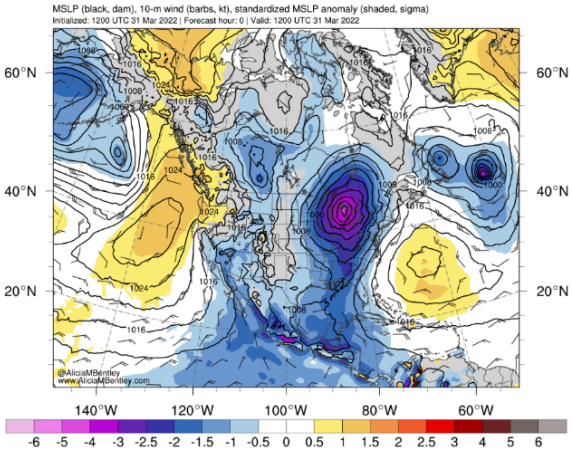
The various spreadsheets were developed over a multi-year period as techniques were being refined to better derive the data and better detect possible error. This has led to random errors still lying in the database, which are checked each time a monthly or all-time SLP record is upcoming or in progress.

6. REANALYSIS GRIDDED DATASETS

Both the European Center for Medium Range Forecasts (ECMWF) and National Centers for Environmental Prediction (NCEP) have developed gridded reanalysis datasets that can be used to detect when monthly SLP record events are possible, and even suggest where errors in the database could exist, but there are caveats. One must keep in mind the period used for those datasets when using them, as monthly or all-time SLP records could have been set prior to the beginning or beyond the end of that database.

When compared to surface observations, model guidance uses the modeled atmosphere, rather than the standard atmosphere, to reduce to SLP. This leads to differences between model forecasts/ verification and what observations indicate, and causes similar issues in reanalysis databases, particularly in the High Plains of North America, generally between the Rockies and the 100th meridian in the United States and the 105th meridian and the Canadian Rockies in Canada.

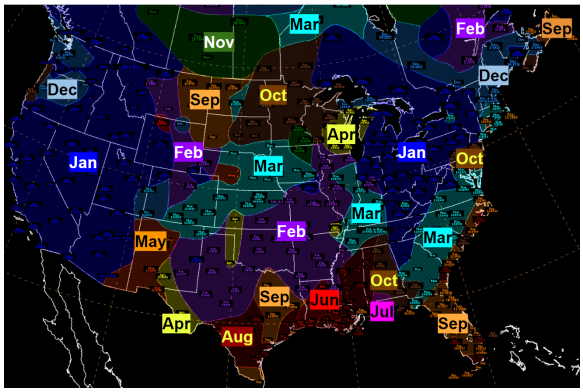
At higher latitudes, a departure of 2.5+ standard deviations from the mean for that time of the year is normally sufficient to imply a SLP record event, while in the subtropics and tropics, departures of 4+ standard deviations from the mean for that time of the year is normally sufficient for implying SLP record events.



Standardized anomalies from March 31, 2022 obtained from Alicia Bentley's real-time maps website. Michigan did approach their March record low SLP.

7. REVELATIONS FROM THE SLP RECORDS

All-time record low SLPs have been possible any month of the year across the northern two-thirds of North America. For the Gulf Coast and portions of the East Coast of the Lower 48 United States, the records were primarily caused by tropical cyclones in the summer and autumn. Tropical cyclones and their post-tropical cyclone evolutions have set the all-time record low SLPs for the United States (Labor Day Hurricane of September 1935) and Canada (Fiona in September 2022). While it is known that pressures with tornadoes likely exceeded the acknowledged United States or North America all-time record SLP in Minneapolis MN in 1904 and Tulia TX in 2007, Blair et. al (2008), coordination with NCEI has led to a constraint of primarily hourly observation sites, such as airports, being used to determine state and national SLP records. Across portions of the Pacific Northwest and Alaska, a few former typhoons led to records during October and November. Interior portions of the continent and portions of New



Months when all-time record low SLPs were set in and near the Lower 48 United States.

England saw records caused by intense extratropical cyclones. Portions of Arizona, Southern Rockies, and westernmost Texas were the wild card, with mid to late spring occurrences. Rather than with the center of surface lows themselves, thermal lows/lee troughs within the warm sector of extratropical cyclones were the primary cause of record low SLPs. During the summer and early autumn, the Desert Southwest sees their monthly record low SLPs caused by thermal lows more so than northeast Pacific tropical cyclone incursions.

The monthly SLP record maps indicate that the deepest cyclones for each month track north to northeast within amplified flow regimes. Surface analyses of the cyclones in question show their isobaric patterns to be round, generally indicating that they are warmer systems with minimal arctic air in their vicinity, even during the colder months. While some produce snowstorms and blizzards as a northern stream shortwave can introduce colder air on their backside after cyclone development ensues, this does not appear to be a common occurrence.

All-time record high SLPs have been documented during a cold season across the United States and Canada between November and April. For portions of northwest Canada and Alaska, the late January-early February 1989 records define the all-time high SLP records for the North American continent as a whole.

8. COLLABORATION AND RECEPTION

During the January 2015 all-time record high pressure event in the northern Plains, information from the Minnesota State Climatologist was passed along by WFO Chanhassen MN, while WFO Omaha NE coordinated records within their CWA; the first time that collaboration had occurred in near real-time for an ongoing event. The Southern Regional Climate Center provided some data for the project for southern Georgia. By late 2015, work had begun on developing an article about the project for Weatherwise, Roth (2016). A couple WFOs expanded the worksheets into all-encompassing spreadsheets for all months. This took over the role of the old green Record books, which had a listing of all extremes for their period of record which were maintained prior to the PC era within NWS WFOs. Others compiled a list of record strong storms in their CWAs, such as the Wilmington, North Carolina WFO.

rank	event name	date	pres. mb	pres. in. Hg.
1	Hurricane Floyd	Sep 16, 1999	959.7	28.34
2	Hurricane Fran	Sep 5, 1996	961.4	28.39
3	Hurricane Donna	Sep 11, 1960	962.1	28.41
4	Hurricane Florence	Sep 14, 2018	965.5	28.51
5	Hurricane Bonnie	Aug 26, 1998	969.9	28.64
6	*1932 nor'easter*	Mar 6, 1932	970.2	28.65
7	Hurricane Hazel	Oct 15, 1954	971.2	28.68
8	1993 Superstorm	Mar 13, 1993	974.6	28.78
9	Hurricane Helene	Sep 27, 1958	975.3	28.80
10	*1873 nor'easter*	Nov 17, 1873	978.0	28.88
11	Hurricane Bertha	Jul 12, 1996	978.7	28.90
12	Hurricane Irene	Aug 27, 2011	979.3	28.92
13	Carolinas Outbreak	Mar 28, 1984	980.4	28.95
14t	1976 Groundhog Day Gale	Feb 1, 1976	983.4	29.04
14t	*1998 nor'easter*	Feb 4, 1998	983.4	29.04
16	*1896 nor'easter*	Feb 6, 1896	984.4	29.07
17	Gale of 1878	Oct 22, 1878	985.1	29.09
18t	Hurricane Connie	Aug 12, 1955	985.4	29.10
18t	Hurricane Ernesto	Sep 1, 2006	985.4	29.10
20	Charleston Hurricane	Oct 13, 1893	986.1	29.12

List of strongest cyclones by lowest SLP for Wilmington NC, from Armstrong (2013).

State mesonets began to inquire about use of their datasets within the project, e.g. the New York State Mesonet. After the March 2019 all-time record low pressure event in eastern CO, in order to add SLP extremes as a quantity to the state records maintained by the State Climate Extremes Committee, Russ Schumacher (the Colorado State Climatologist) reached out to NCEI and the author, with a method bring devised going forward to determine this quantity for other states when they are ready to do so. This use of the database led to a greater spatial observation density in order to ease the development of state records in the future, as the SLP record database was not originally intended to be the ultimate source for state SLP records. Coordination with Environment Canada occurred a bit in 2022 with both the possibility of all-time records being set that spring in Labrador and Newfoundland, and again due to Post-Tropical Cyclone Fiona farther south across Atlantic Canada.

9. UTILIZATION ON SOCIAL MEDIA

Caution is used in the run-up to a monthly or all-time SLP record event. Before WPC posts about it on social media, a best practice has become to coordinate with the impacted WFOs, both as a check to see if it matches their records and matches the messaging they're providing to their local partners, and include the relevant link to the SLP records website. If a WFO wishes to message it themselves, so much the better. The graphics themselves during the past couple of years have the relevant link to their location online and contact information, in case there are questions from any end users of the graphics whose distribution may have spread further afield than the WPC website or WPC social media accounts.

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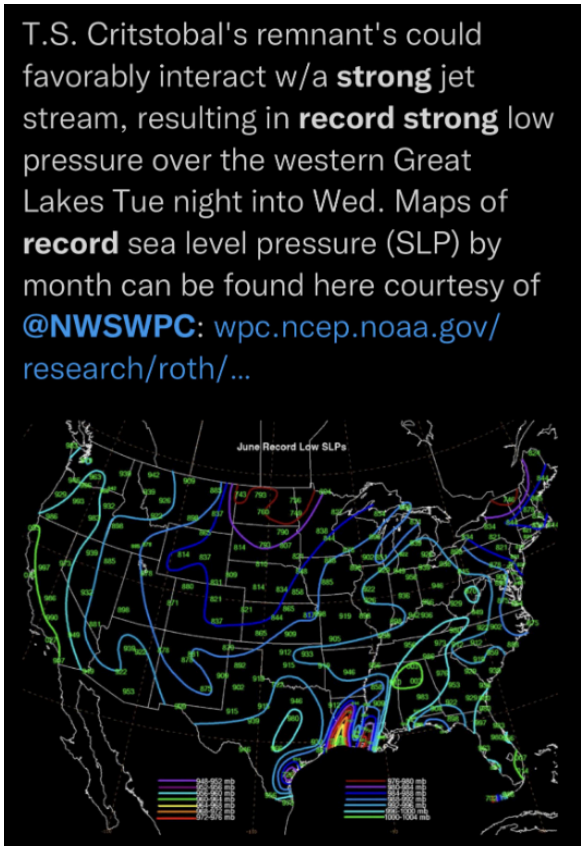

An example from the Chicago IL WFO messaging the possibility of record low June SLPs on June 6, 2020 on Twitter.

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