NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Weather Events in NREL's Wind and Solar Datasets

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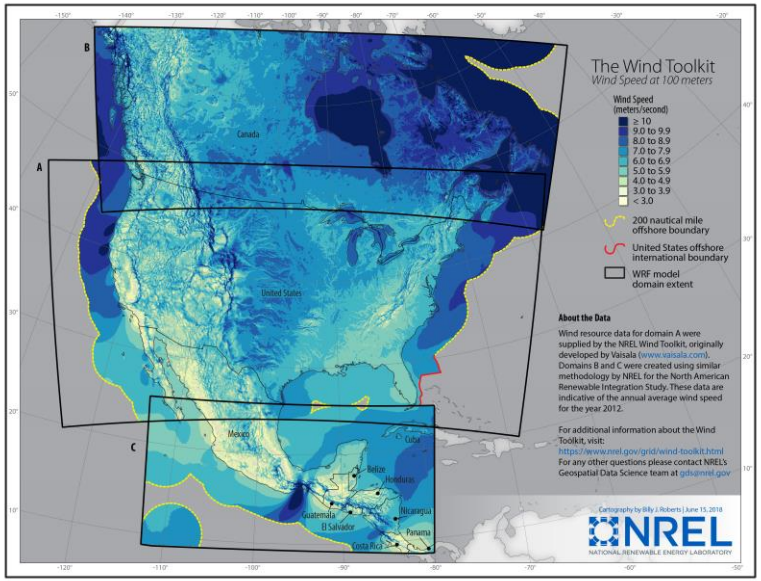
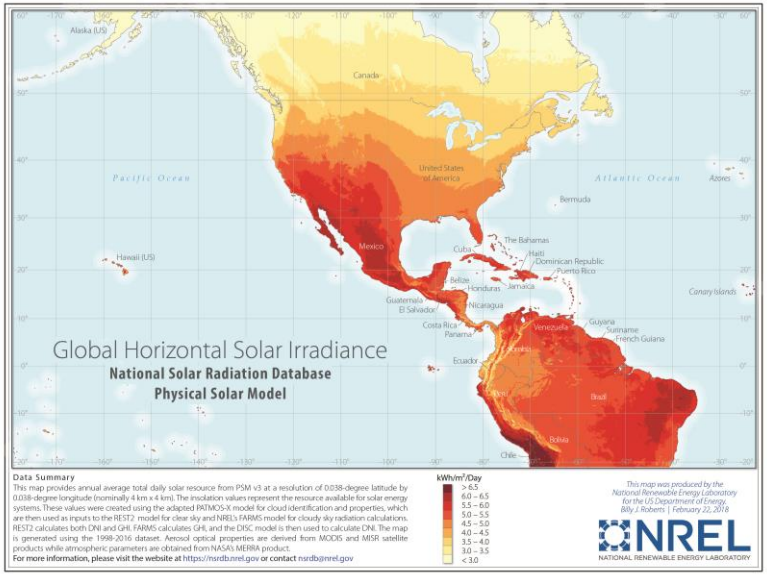
06 June 2019





WIND Toolkit

5-minute resolution

2km x 2km resolution

Domain A

- Vaisala Wind Toolkit
- 2007-2013
- Continuous United States

Domain B

- NREL Created using similar method
- 2010-2013
- Canada

Domain C

- Also NREL created
- 2009-2013
- Southern Mexico

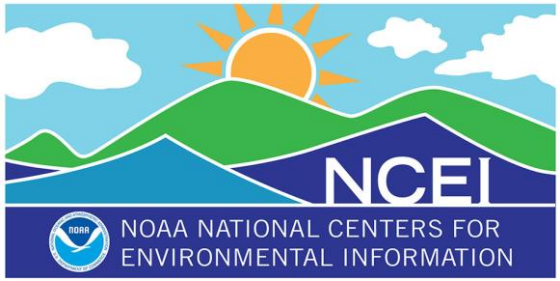
National Solar Radiation Database (NSRDB)

- 1998 – 2014
- 30-minute resolution
- 4km x 4km spatial resolution

Preprocessing Steps

- Extract data into data frames that contain meta-data fields that allow easy selection by lat-lon, state, time etc
- Interpolate to a common 4km x 4km grid
- Limit initial analysis to CONUS

Local Climatological Data (LCD)



- Local Climatological Data (LCD) consist of hourly, daily, and monthly summaries for approximately 1,600 U.S. locations.
- Data are available based on when the station began until present.
- Hourly data includes all major meteorological fields including present weather, sky cover, precipitation amount and type and wind direction, sustained speed and gust.
- Summary of the day includes max and min temperature, deviations from normal, Heating Degree Days and Cooling Degree Days
- Best set for providing ground truth of fields impacting load and renewable resources
- Not the most consistent or easy to process dataset though. Quite a bit of careful post processing needed.

Identifying Extreme Cold/Heat

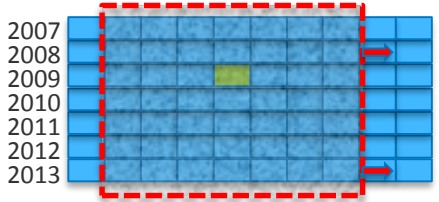
- Use Summary of the Day from LCD to identify periods where weather is likely to drive large load anomalies
- Currently using 28 airport stations in large strategically selected cities
  - Large load centers
  - Well maintained instrumentation

DATE	SEA	PDX	SFO	LAX	SLC	LAS	PHX	DEN	ABQ	ELP	MCI	OKC	DFW	IAH	MSP	ORD	DTW	PIT	BNA	CLT	ATL	MSY	MCO	MIA	BOS	PHL	NYC	IAD
11/30/2013 23:59	6.5	2.9	1.1	2.7	8	2.3	2.4	13.4	3.5	5	7.2	7	1.9	-3	7.9	6.4	0.1	-6.9	-1.8	-8.5	-5.5	-10	2.2	0.1	-12.5	-8.9	-11.2	-12.6
12/1/2013 23:59	8.7	10.1	4.3	8.9	11.3	3.7	3.8	10.8	2.8	3.3	6.6	4.4	9.2	2.3	2.4	2.8	1.5	-1.5	2.5	-4.2	0.8	-1.8	3.4	-0.8	0.9	-1.5	0.2	-8.3
12/2/2013 23:59	-1.1	0.4	1.5	6	18.7	3	1.1	16.1	3.1	2.6	11.1	5.8	4.6	10.6	7.9	4.3	-1.1	4.9	7.8	-0.9	1.2	5.5	0.6	-2.6	-0.8	2.9	2.6	3.1
12/3/2013 23:59	-5.9	-7.4	-1.3	0.2	2	5.3	4.4	2.4	9.4	11.9	13.5	10.2	9.9	12.8	9.4	11.7	-0.7	8.3	9.2	8.4	6.5	10.7	0.8	-1.5	3.6	5.2	3.9	4.4
12/4/2013 23:59	-7.7	-12.1	-6.1	-2.6	-16.6	-10.4	-1.3	-32.3	11.7	17.2	-4.1	-2.5	14.2	15.1	-1.1	16.2	11.7	11.7	23.5	13.7	17.8	17	7	2.6	0.9	4.6	5.3	3.8
12/5/2013 23:59	-12.5	-15.9	-9	-4.5	-17.3	-14.1	-7	-35.1	-10	4.4	-16.6	-18.1	-10.4	1.3	-16.6	-1.4	11.1	14	9.8	18	21.1	19.2	7.2	4.8	8.3	13.9	12.7	22.1
12/6/2013 23:59	-12.4	-14.7	-6.8	-5.4	-15	-13.9	-9.7	-33.8	-14.8	-2.3	-21.3	-25.8	-21.1	-17.4	-24.2	-14	-7.5	-1.6	-8.9	26.3	19.4	6.4	10.4	5.9	7.7	10.3	9	12.5
12/7/2013 23:59	-15.2	-18.5	-6.6	-4.2	-7.7	-6.6	-8.5	-31.6	-11.5	-10.1	-23.9	-28.4	-24.8	-20.2	-27.8	-15.6	-12.1	-10.2	-12.6	14.5	2.7	-14.4	9.6	5.1	-1	-3.4	-3.6	-2.2
12/8/2013 23:59	-13.1	-21.3	-9.5	-8.1	-12.5	-12.4	-3.3	-24.4	-7.3	-3.8	-14.5	-18.1	-18.6	-13	-16.3	-9.2	-9.7	-10.8	-4.3	-3.2	-2	-9.1	10.8	6.2	-7.6	-10	-9.3	-9.8
12/9/2013 23:59	-11.9	-19.1	-7.3	-7	-19.2	-13.2	-10	-19.2	-15.1	-2.6	-23.2	-21.8	-17.3	-10.7	-16.9	-16.8	-7.3	-0.5	-7	-2.9	-0.7	-1.9	10	7.4	-2.3	-4.7	-4.9	-6.5
12/10/2013 23:59	-2.8	-9.9	-8.2	-2.9	-16	-12	-4.8	-4	-13.9	-7.4	-9.8	-18.5	-19.1	-14.5	-13.5	-21.4	-15	-8.1	-7.7	0.3	-4.5	-9.7	7.2	6.5	-3.9	-6.3	-5.5	-7.2
12/11/2013 23:59	-5.7	-6.7	-3	2.2	-14.8	-6.8	1.4	-6.9	-5.7	-1.2	-15.5	-11.2	-12.8	-10.3	-23.2	-18.1	-15.6	-8.8	-7.5	-8.4	-4.2	-8.5	8.4	6.7	-8.6	-11	-9.2	-9.9
12/12/2013 23:59	-3.6	-8.5	-4.9	0.3	-15.6	-3.6	9.5	6.3	-5.5	-3.1	-6.2	-12.9	-10.6	-9.1	-10.8	-20.7	-19.3	-17.5	-13.2	-6.2	-7	-6.3	-1.4	3.8	-13.2	-11.7	-11.9	-12.6
12/13/2013 23:59	5.5	0.6	-3.8	-1.6	-11.4	-1.5	-0.3	7.4	3.6	1.1	0.1	7.3	-3.4	-4.9	-6.4	-5.4	-6.9	-6.2	-7.9	-7.9	-2.7	-2.1	-1.2	1	-12.9	-7.3	-9.5	-8.3

Example of processed deviation from normal SOD data

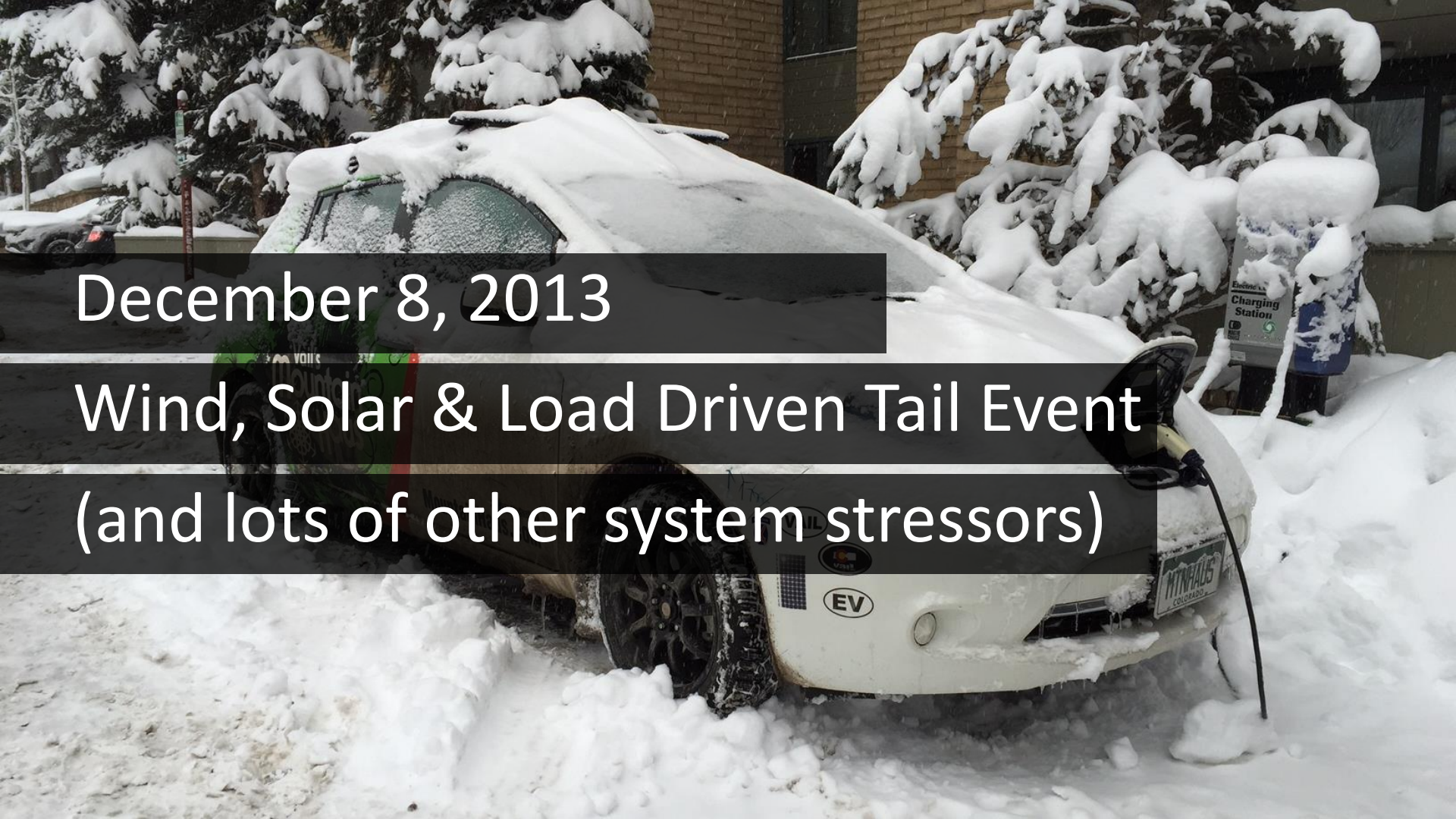
Identifying Extreme Resource Deviation

- Using collocated datasets calculate wind and solar daily CF at every point
  - Assume standardized panel/turbine technologies and losses
- Calculate deviation from seven year, seven day moving window average for every point on every day for wind and solar assuming standard technologies
  - 49 data points per average and deviation
  - Roll deviations up based on regional area masks



- Daily wind deviations will on average be larger due to more production hours, power curve effects and higher capacity factors
- **Arbitrarily chose to scale solar deviations to have the same maximum width**
  - Allows solar to have the same influence on event selection rankings
  - Not a bad assumption based on current pricing trends, but arbitrary none-the-less
- Simple sub-regions: E/W at 105°W, MISO North based on ND, SD, MN, IA, WI, IL, IN, and MI

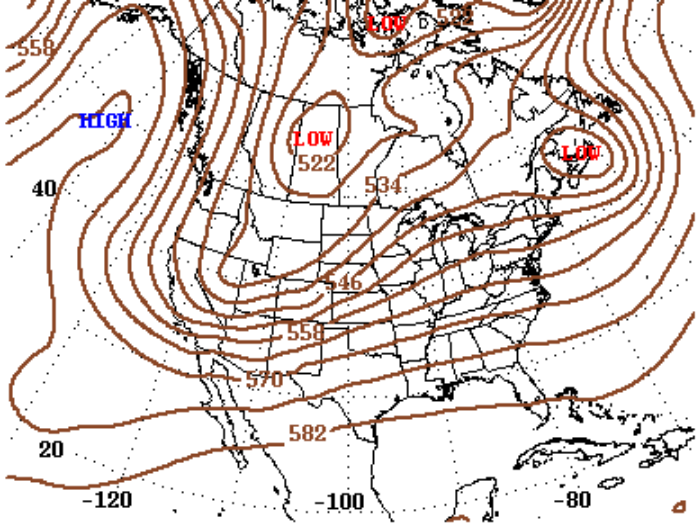
12	3	2013	-0.0288	-0.06883	0.011234	441	178	1582	0.020247	-0.09907	0.139567	1912	171	2486	-0.0565	-0.05205	-0.06096	277	573	418	-0.12761	-0.23065	-0.02457	87	57	1138
12	4	2013	0.039639	-0.00415	0.083431	2281	1167	2420	0.094318	0.086873	0.101762	2535	2359	2407	0.002367	-0.06838	0.073118	1361	419	2231	-0.0967	-0.25501	0.061608	205	32	1866
12	5	2013	0.041257	0.019757	0.062756	2299	1790	2280	-0.01272	0.127064	-0.15251	887	2481	13	0.064753	-0.05436	0.183865	2330	544	2531	0.267705	0.180207	0.355203	2552	2441	2552
12	6	2013	0.00916	0.046668	-0.02835	1623	2175	724	-0.0311	0.070417	-0.13262	439	2254	31	0.031659	0.033008	0.03031	1966	1797	1824	0.091125	0.178344	0.003906	2306	2435	1386
12	7	2013	-0.01491	-0.02334	-0.00647	815	709	1210	-0.04892	-0.12712	0.029283	195	74	1854	0.010737	0.04806	-0.02659	1560	1975	918	0.032092	0.192911	-0.12873	1753	2466	269
12	8	2013	-0.08027	-0.08239	-0.07815	23	122	119	0.013449	-0.01787	0.044765	1743	926	2027	-0.14019	-0.13307	-0.1473	13	120	22	-0.24344	-0.25291	-0.23397	2	35	10
12	9	2013	-0.01445	-0.02874	-0.00016	827	614	1338	0.061315	0.075774	0.046857	2436	2294	2048	-0.06532	-0.10404	-0.02661	202	217	917	0.044016	0.026708	0.061325	1894	1509	1864



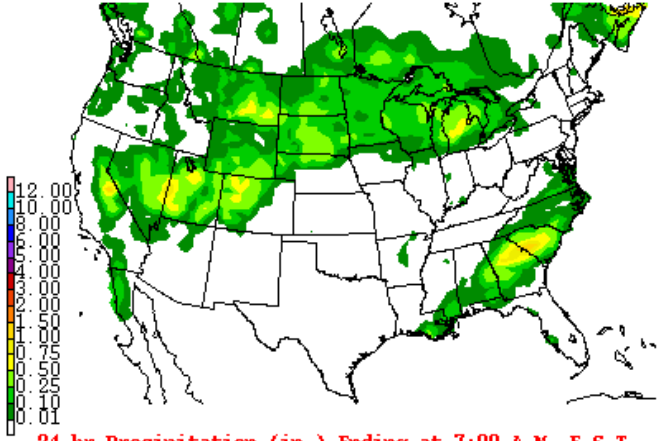
December 8, 2013

Wind, Solar & Load Driven Tail Event

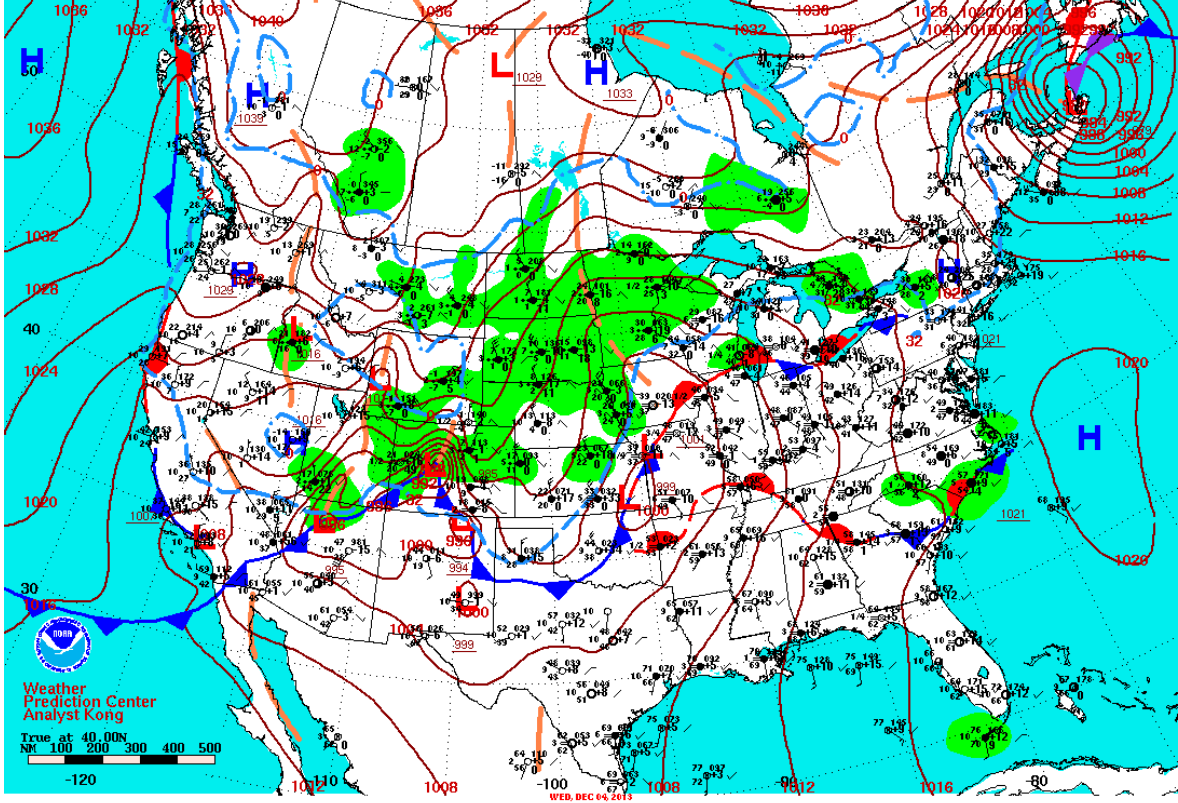
(and lots of other system stressors)



500-Millibar Height Contour at 7:00 A.M. E.S.T.



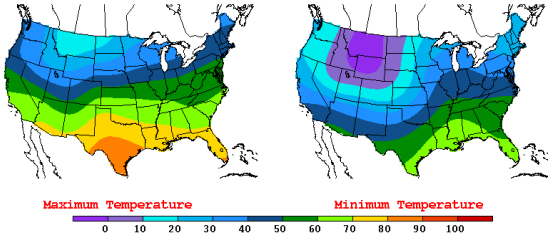
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

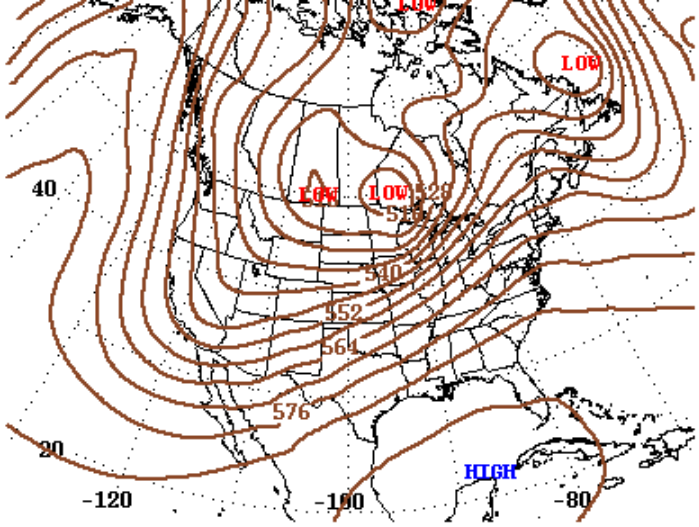


Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

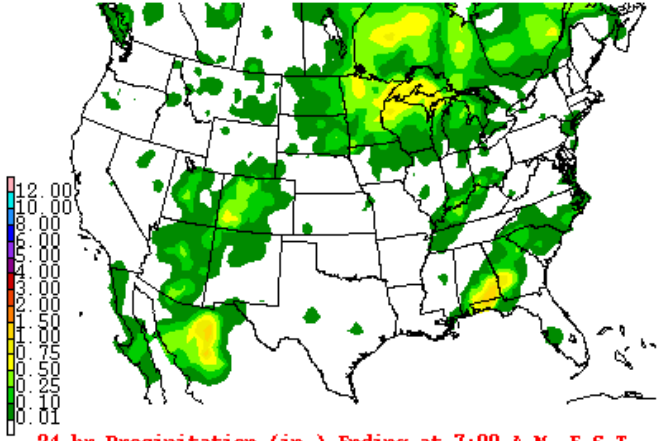
December 4, 2013

Winter Storm Cleon

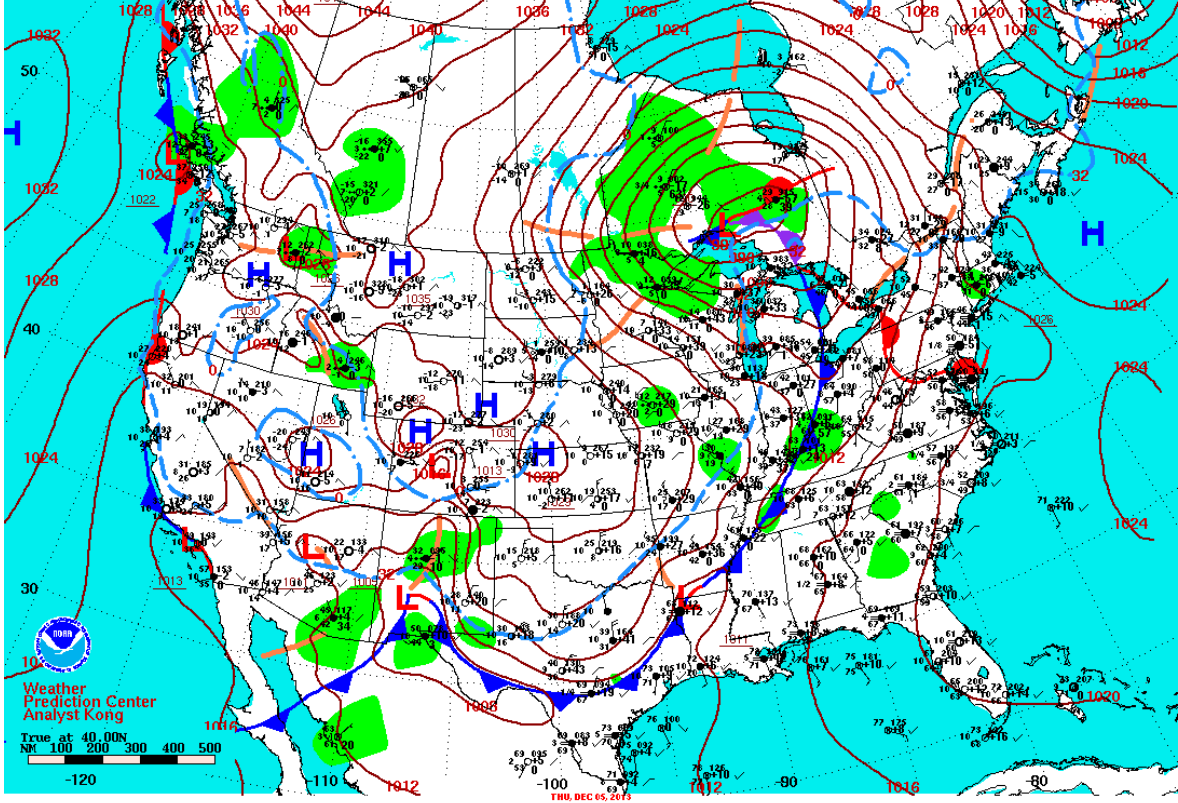




500-Millibar Height Contour at 7:00 A.M. E.S.T.



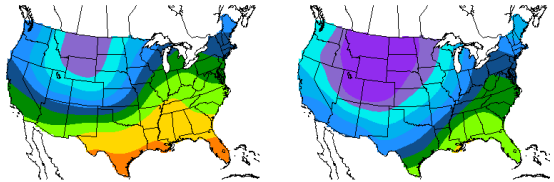
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

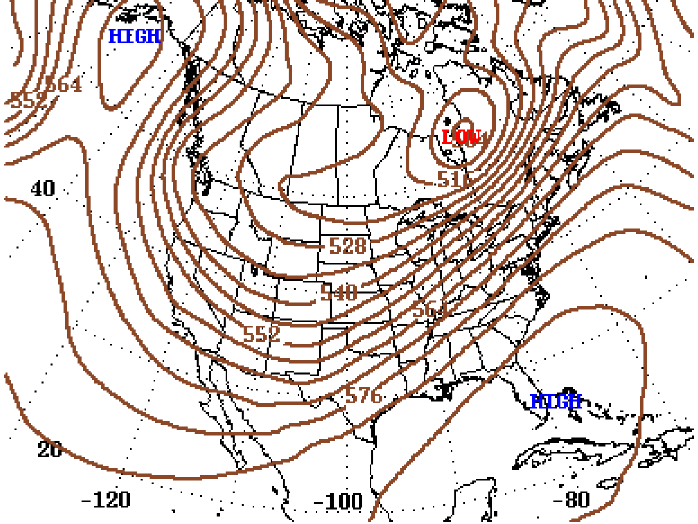


Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

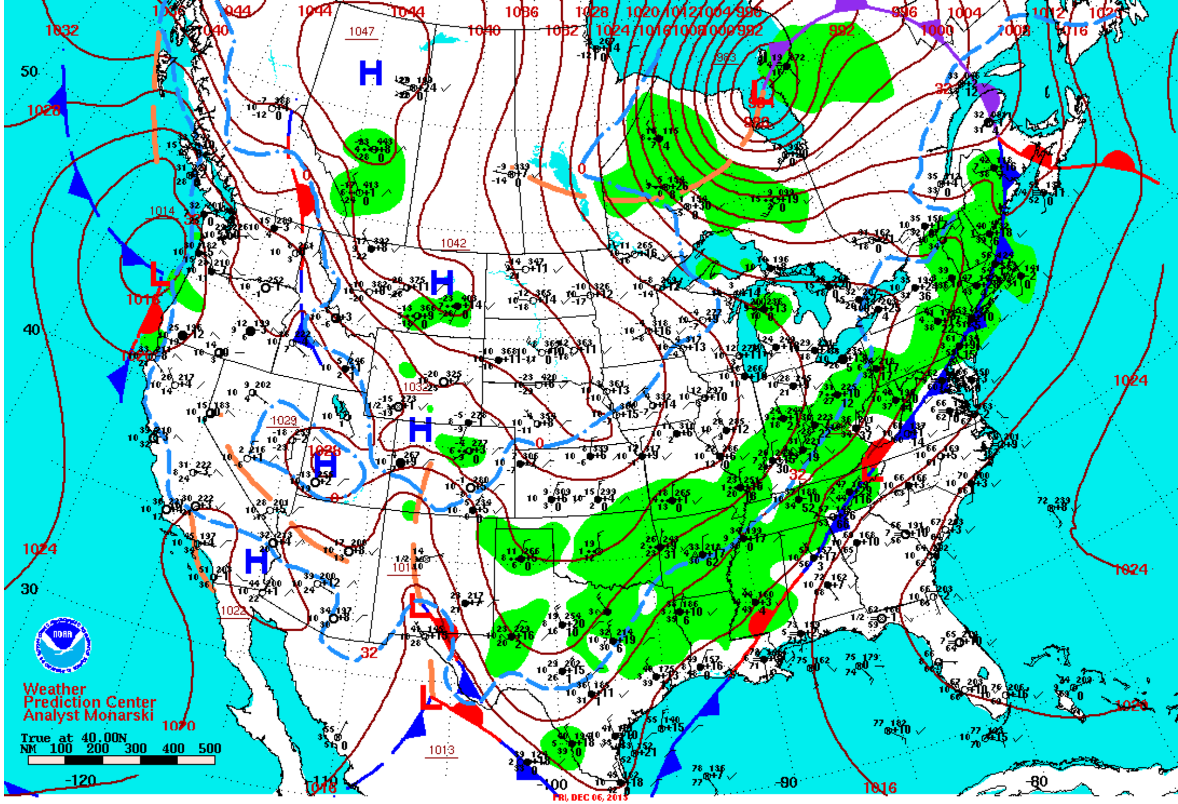
December 5, 2013

(Winter Storm Cleon)

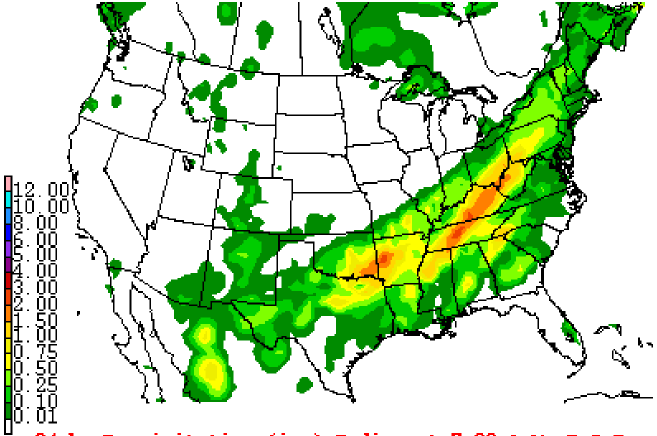




500-Millibar Height Contour at 7:00 A.M. E.S.T.

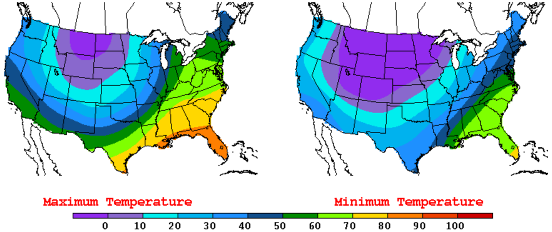


Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.



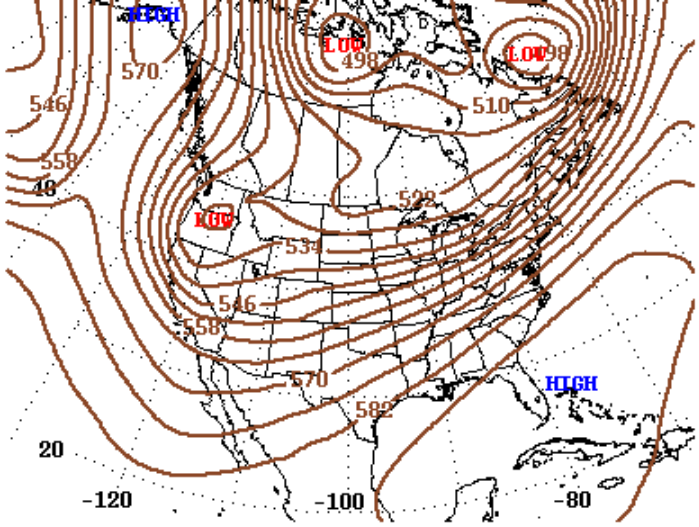
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

December 6, 2013 (Winter Storm Cleon & Winter Storm Dion)

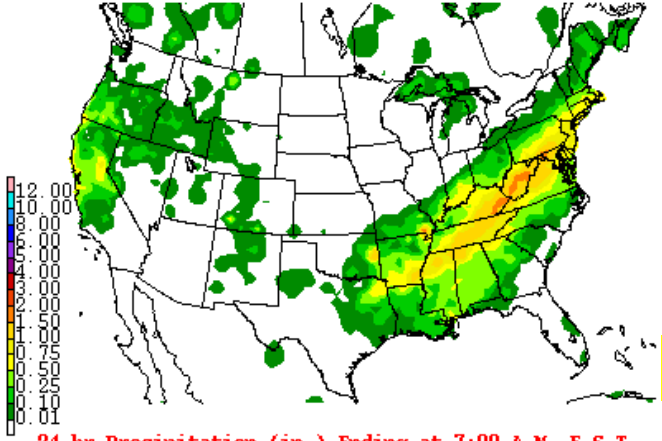


Maximum Temperature

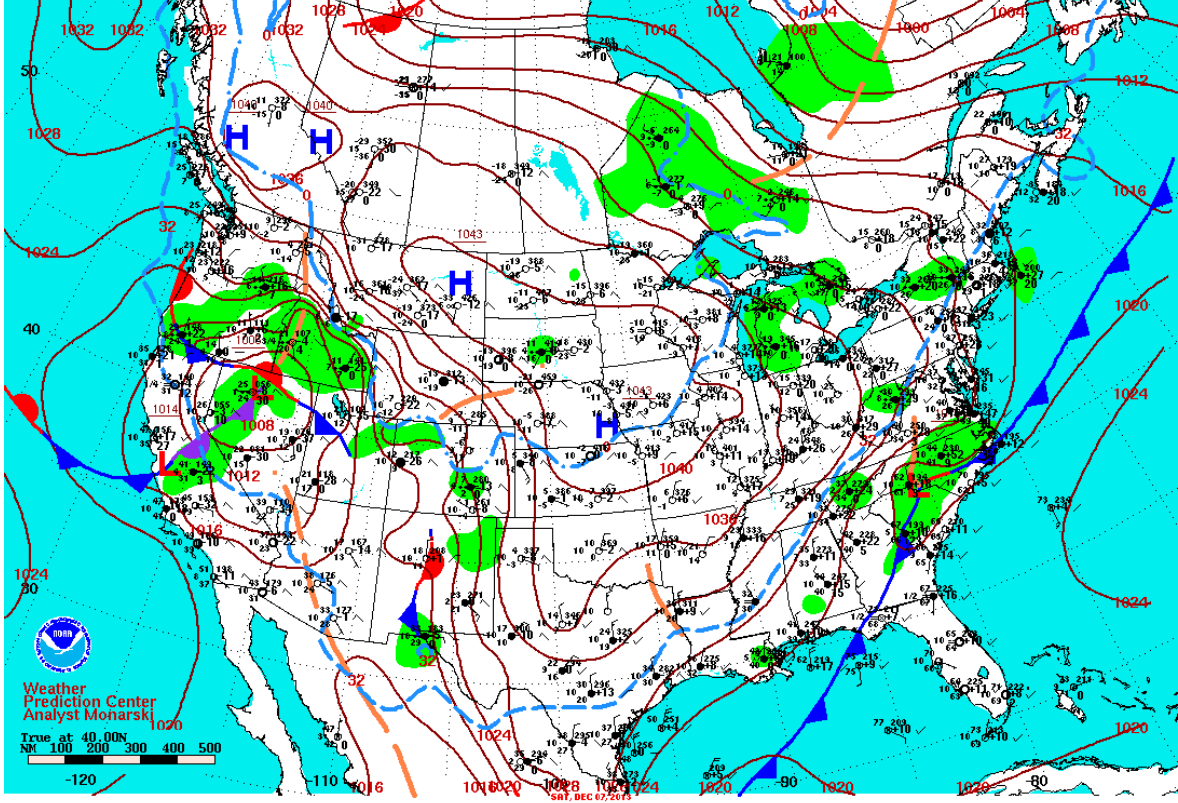
Minimum Temperature



500-Millibar Height Contour at 7:00 A.M. E.S.T.

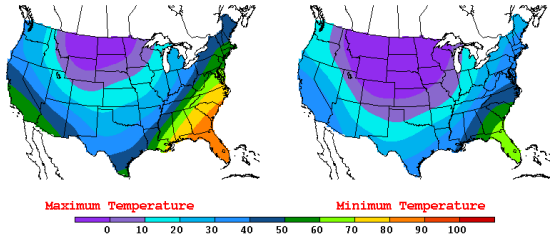


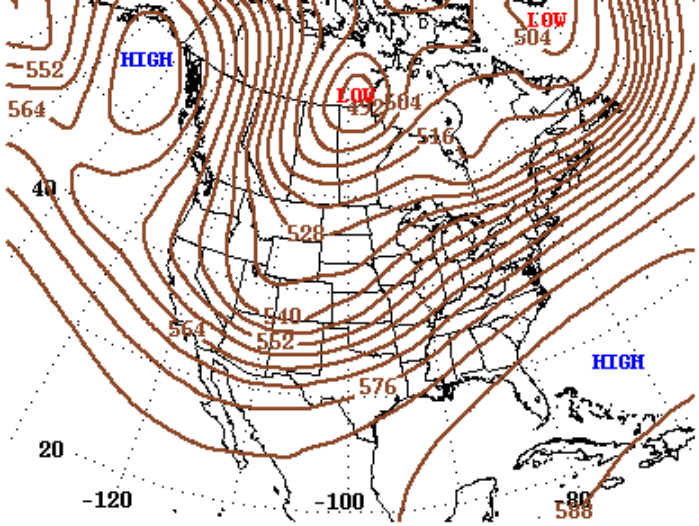
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



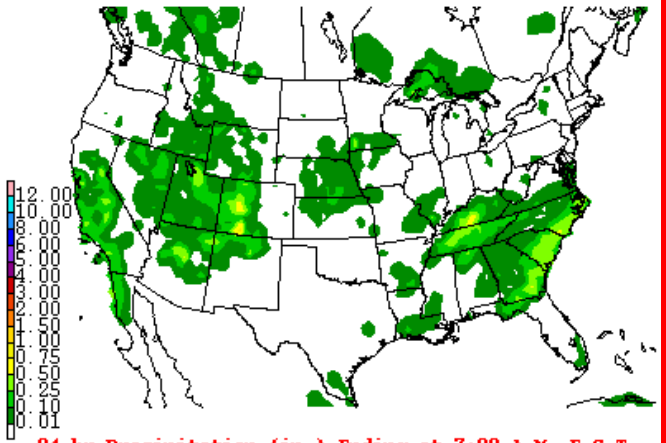
December 7, 2013
(Winter Storm Cleon & Winter Storm Dion)

Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

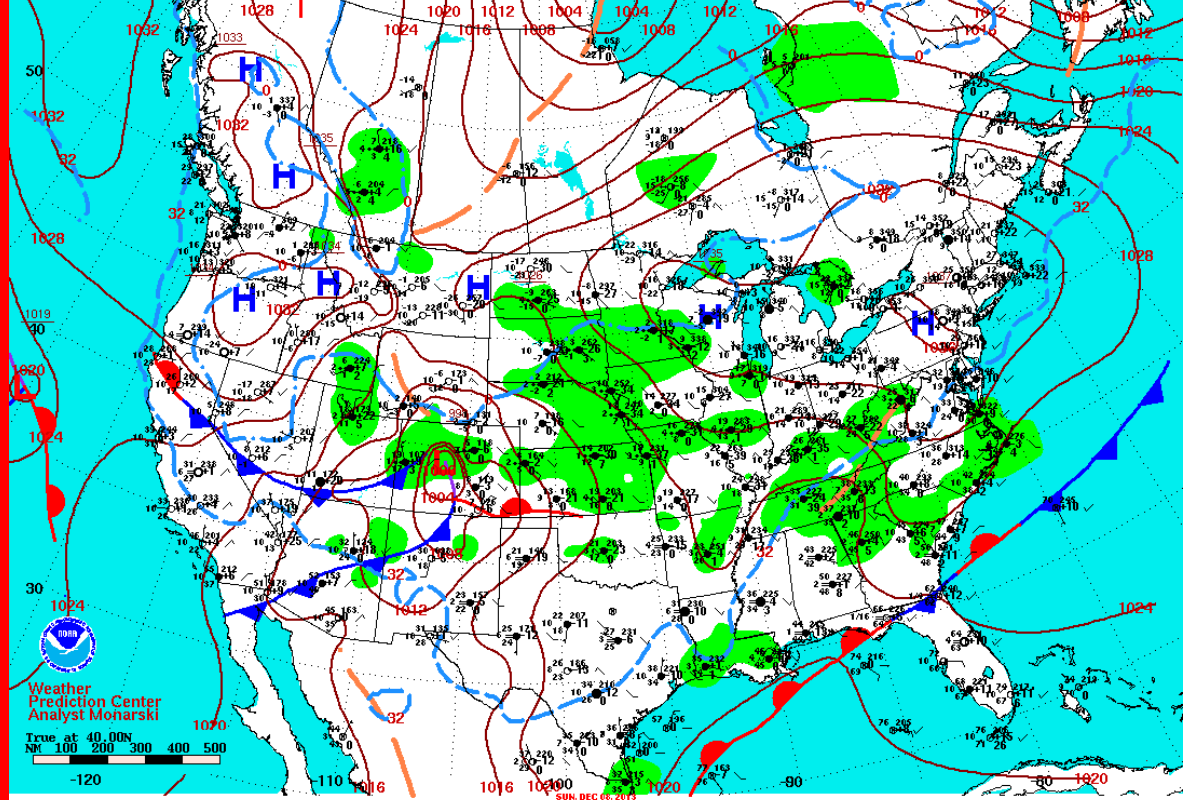




500-Millibar Height Contour at 7:00 A.M. E.S.T.



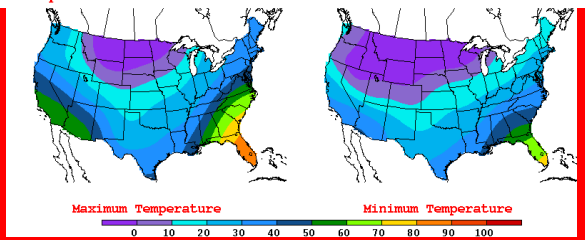
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

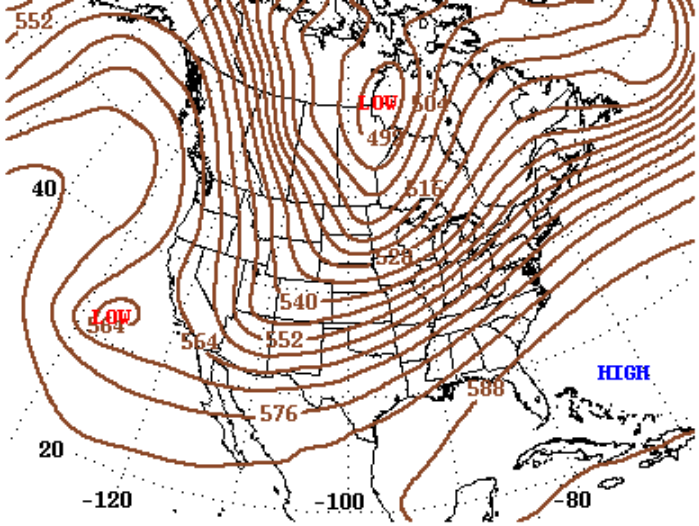


Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

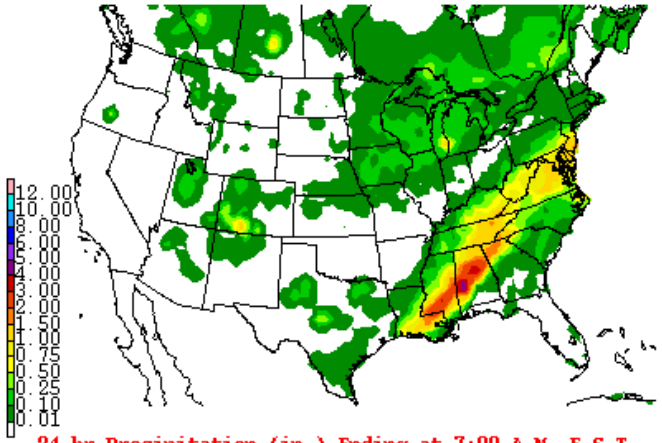
December 8, 2013

(Winter Storm Dion)

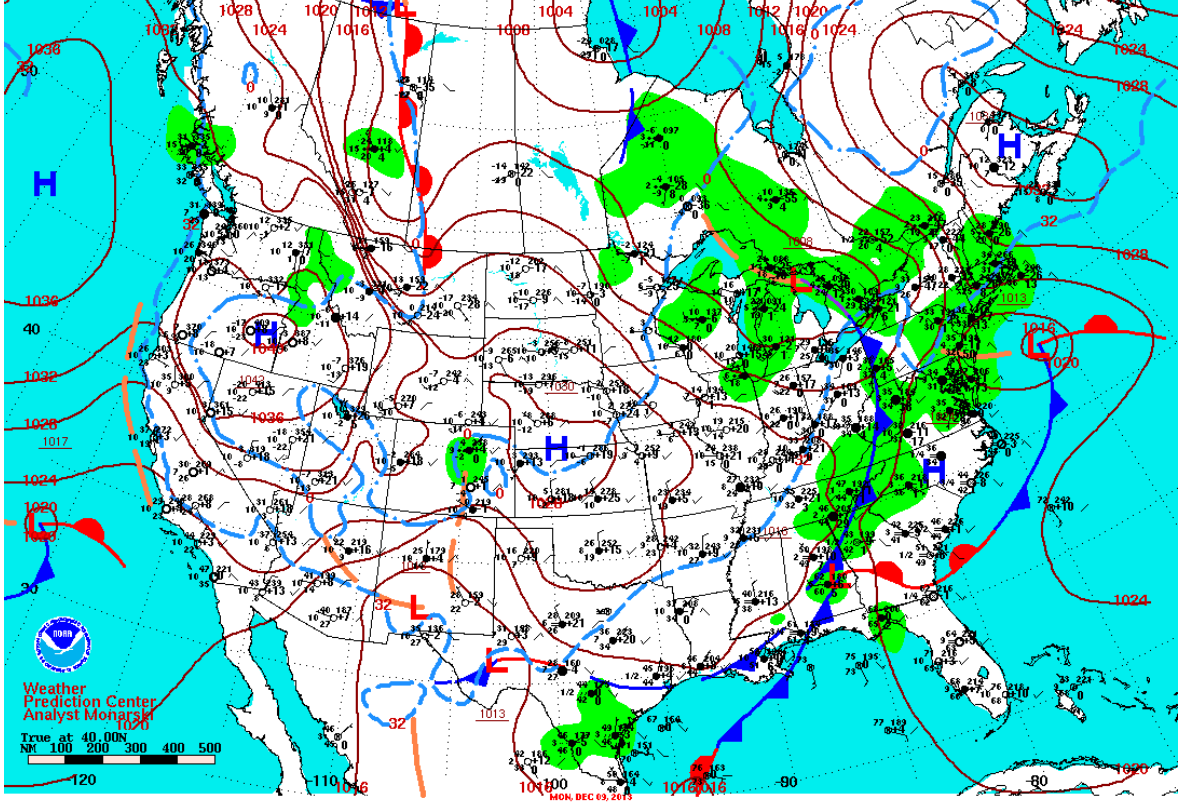




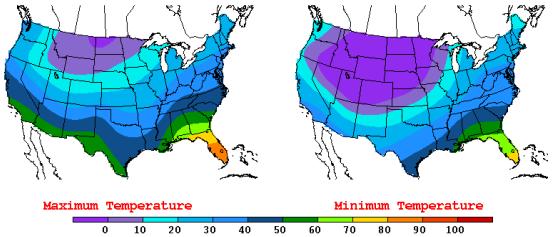
500-Millibar Height Contour at 7:00 A.M. E.S.T.



24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

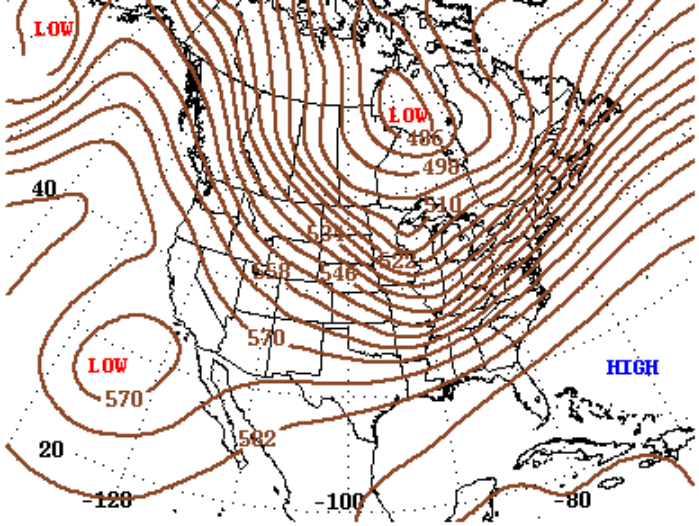


Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

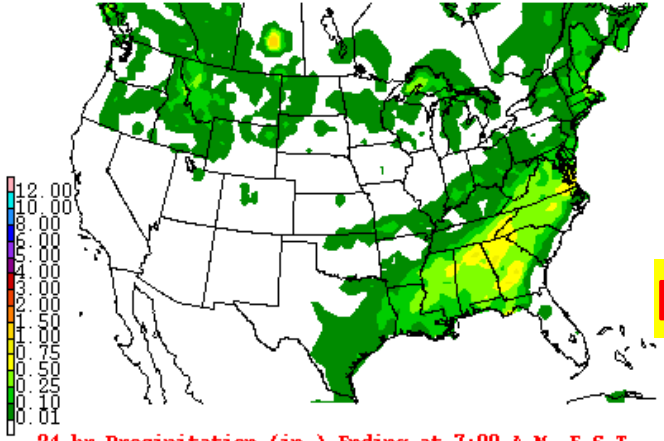


December 9, 2013

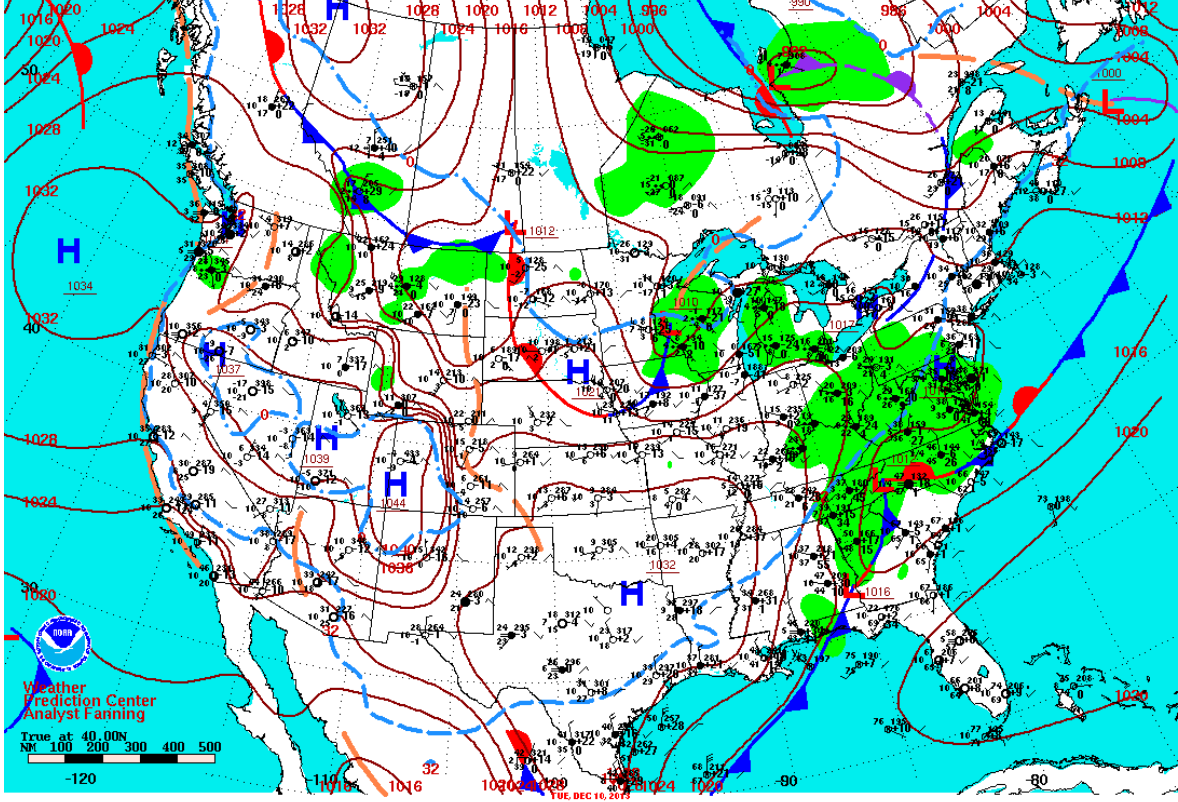
(Winter Storm Dion)



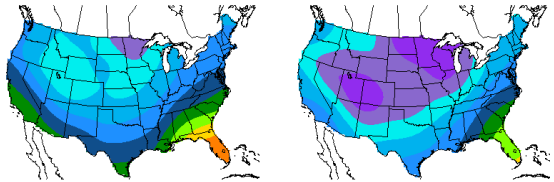
500-Millibar Height Contour at 7:00 A.M. E.S.T.



24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

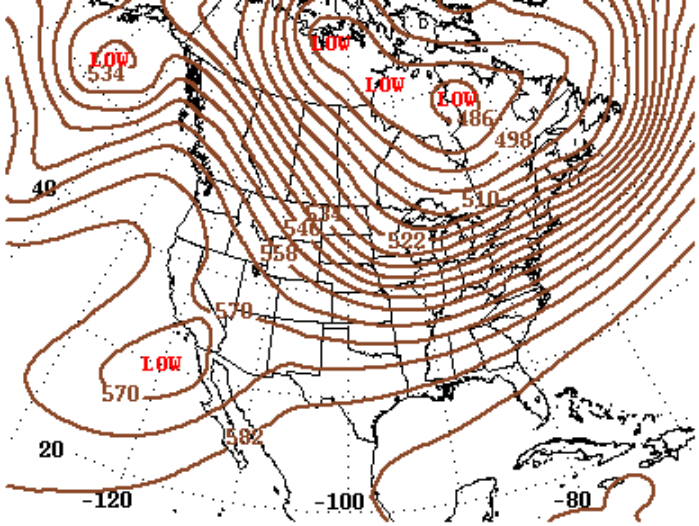


Maximum Temperature — Minimum Temperature

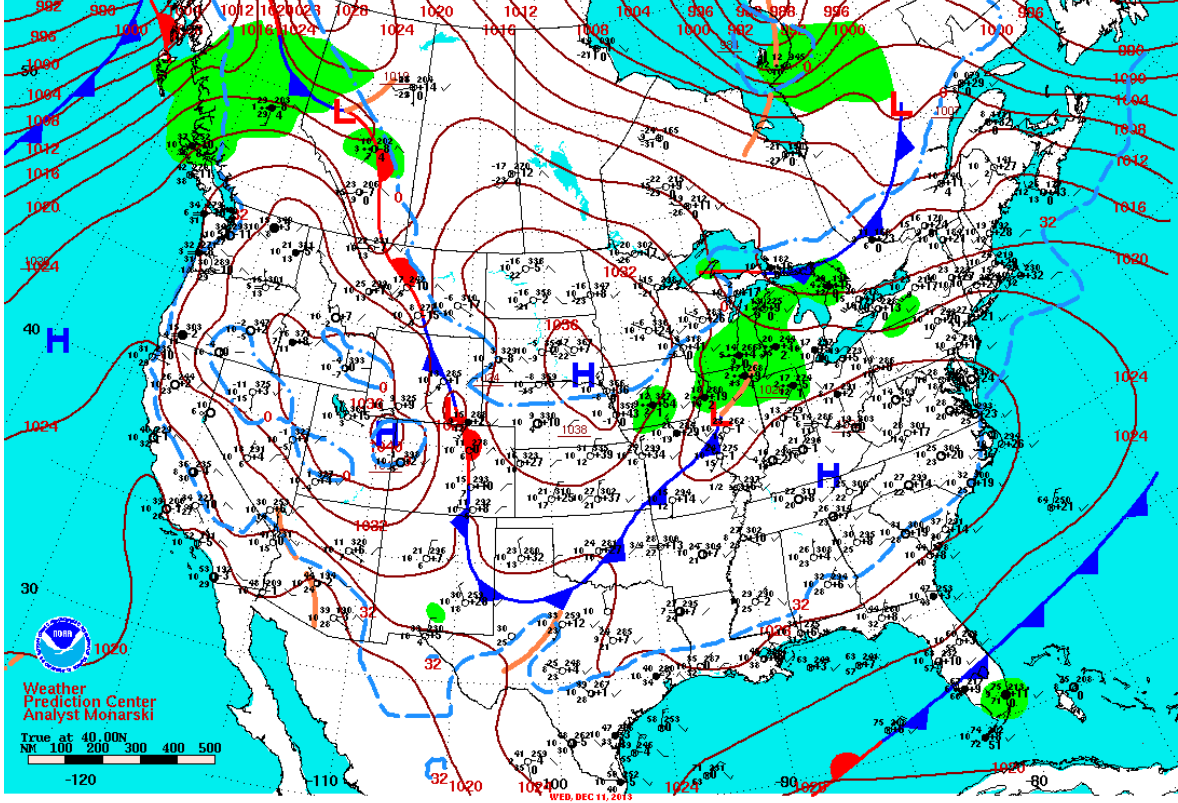
0 10 20 30 40 50 60 70 80 90 100

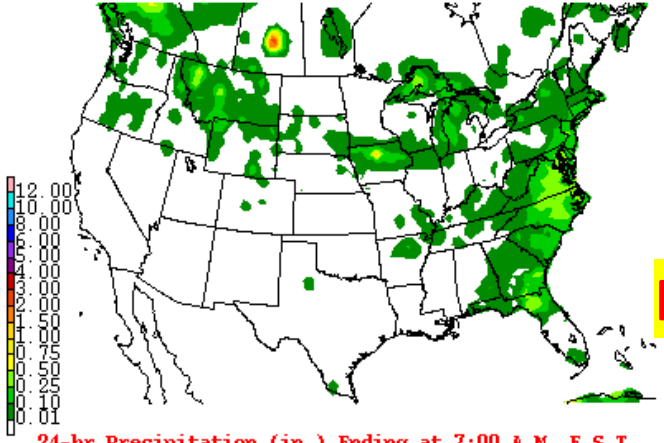
December 10, 2013

(Winter Storm Dion)



500-Millibar Height Contour at 7:00 A.M. E.S.T.

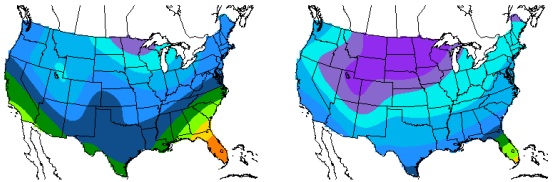




24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

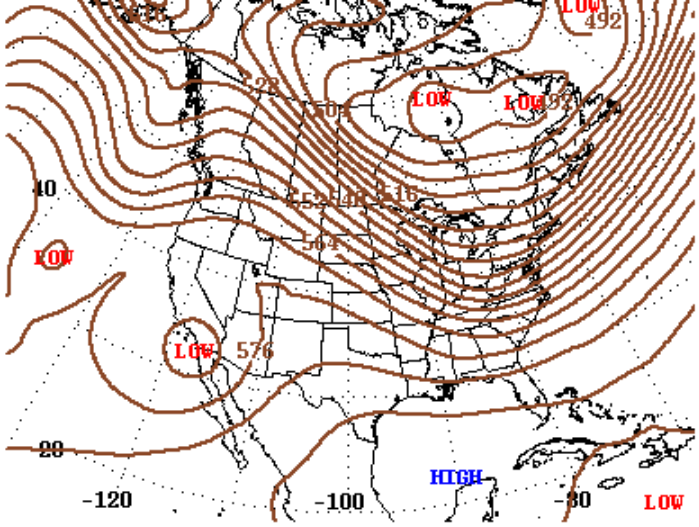
December 11, 2013

Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

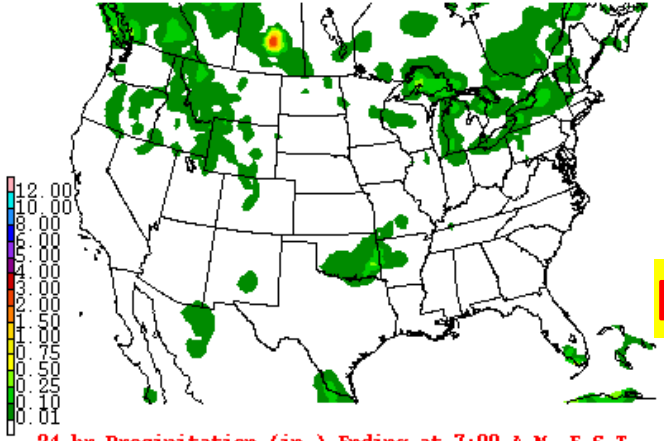


Maximum Temperature Minimum Temperature

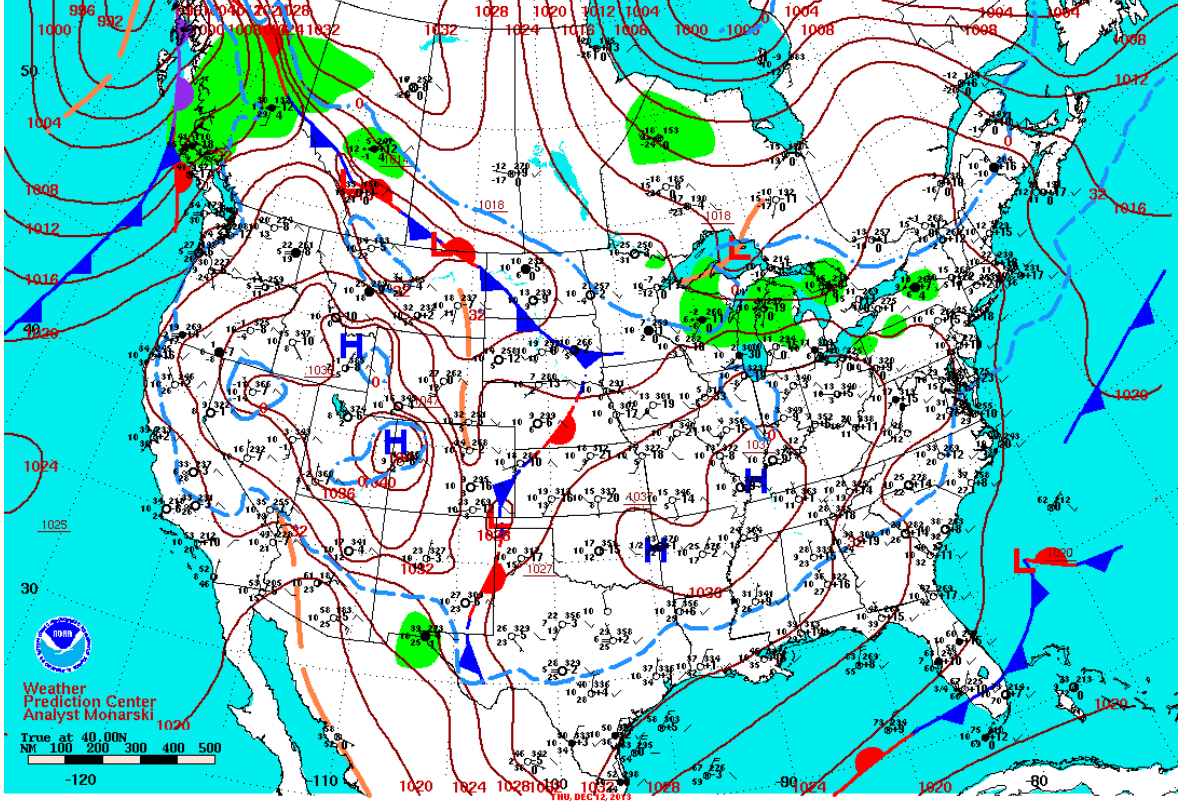
0 10 20 30 40 50 60 70 80 90 100



500-Millibar Height Contour at 7:00 A.M. E.S.T.



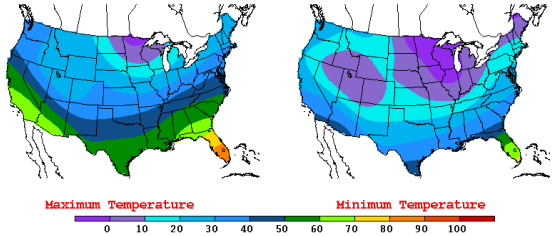
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

December 12, 2013

(Winter Storm Electra)



Winter Storms Cleon, Dion and Electra

- Cleon (Dec 1-7, 2013):
  - 30”+ snow in ID, WY, CO, MN, WI
  - 1 – 1.5” ice in DFW area
  - 4”+ snow in OK, AK, IN, and OH
- Dion (Dec 5-11, 2013)
  - Snow from coast to coast…literally. Newport, OR on Dec 5, Baltimore on Dec 8 and Dec 10.
  - 8”+ in Phili
  - Freezing rain in AK, TN, KY, WV, VA
- Electra
  - Snow from MI to MA, with the Northeast getting the most
  - 4”+ in Saint Louis and Chicago, 5”+ Cleveland, 7”+ Detroit, 11” Albany, NY
- Record lows set in CO, OR, WA and NV


Dec 8, 2013: NFL Game in Phili


Dec 6, 2013: Richardson, TX (AP Photo/LM Otero)


Dec 7, 2013: I-35, TX (AP Photo/LM Otero)

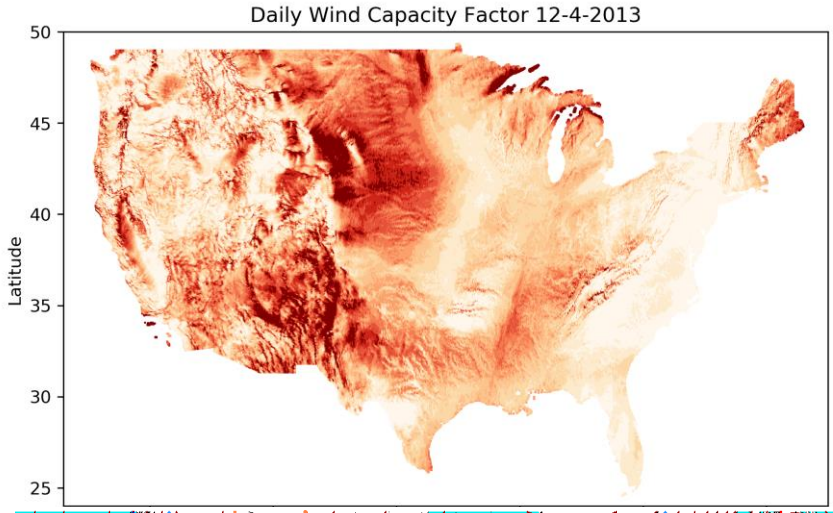
December 2013 Load Driving Temperatures

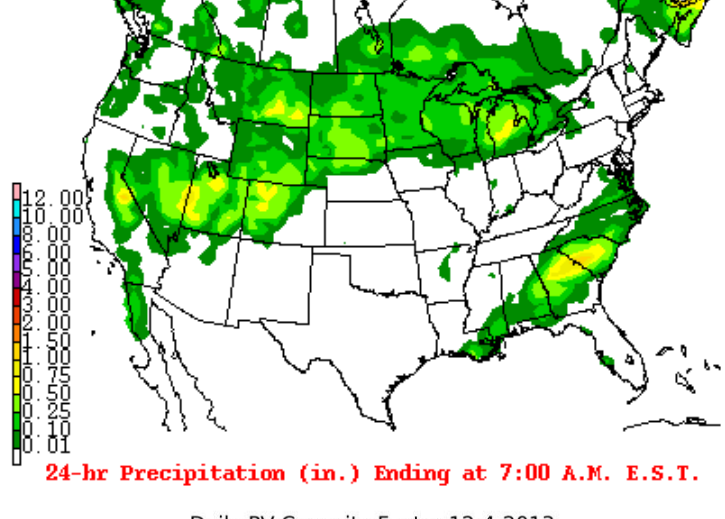
Departures From Normal (°F)

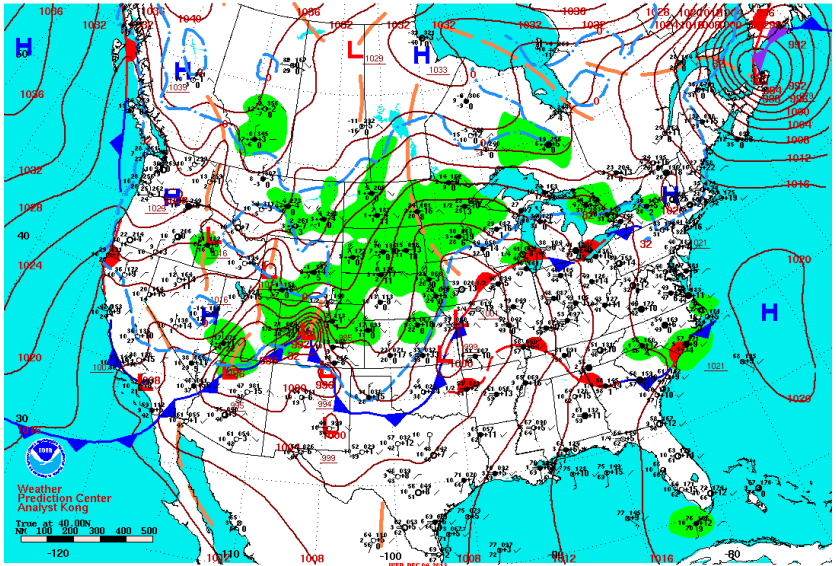
DATE	SEA	PDX	SFO	LAX	SLC	LAS	PHX	DEN	ABQ	ELP	MCI	OKC	DFW	IAH	MSP	ORD	DTW	PIT	BNA	CLT	ATL	MSY	MCO	MIA	BOS	PHL	NYC	IAD
12/3/2013 23:59	-5.9	-7.4	-1.3	0.2	2	5.3	4.4	2.4	9.4	11.9	13.5	10.2	9.9	12.8	9.4	11.7	-0.7	8.3	9.2	8.4	6.5	10.7	0.8	-1.5	3.6	5.2	3.9	4.4
12/4/2013 23:59	-7.7	-12.1	-6.1	-2.6	-16.6	-10.4	-1.3	-32.3	11.7	17.2	-4.1	-2.5	14.2	15.1	-1.1	16.2	11.7	11.7	23.5	13.7	17.8	17	7	2.6	0.9	4.6	5.3	3.8
12/5/2013 23:59	-12.5	-15.9	-9	-4.5	-17.3	-14.1	-7	-35.1	-10	4.4	-16.6	-18.1	-10.4	1.3	-16.6	-1.4	11.1	14	9.8	18	21.1	19.2	7.2	4.8	8.3	13.9	12.7	22.1
12/6/2013 23:59	-12.4	-14.7	-6.8	-5.4	-15	-13.9	-9.7	-33.8	-14.8	-2.3	-21.3	-25.8	-21.1	-17.4	-24.2	-14	-7.5	-1.6	-8.9	26.3	19.4	6.4	10.4	5.9	7.7	10.3	9	12.5
12/7/2013 23:59	-15.2	-18.5	-6.6	-4.2	-7.7	-6.6	-8.5	-31.6	-11.5	-10.1	-23.9	-28.4	-24.8	-20.2	-27.8	-15.6	-12.1	-10.2	-12.6	14.5	2.7	-14.4	9.6	5.1	-1	-3.4	-3.6	-2.2
12/8/2013 23:59	-13.1	-21.3	-9.5	-8.1	-12.5	-12.4	-3.3	-24.4	-7.3	-3.8	-14.5	-18.1	-18.6	-13	-16.3	-9.2	-9.7	-10.8	-4.3	-3.2	-2	-9.1	10.8	6.2	-7.6	-10	-9.3	-9.8
12/9/2013 23:59	-11.9	-19.1	-7.3	-7	-19.2	-13.2	-10	-19.2	-15.1	-2.6	-23.2	-21.8	-17.3	-10.7	-16.9	-16.8	-7.3	-0.5	-7	-2.9	-0.7	-1.9	10	7.4	-2.3	-4.7	-4.9	-6.5
12/10/2013 23:59	-2.8	-9.9	-8.2	-2.9	-16	-12	-4.8	-4	-13.9	-7.4	-9.8	-18.5	-19.1	-14.5	-13.5	-21.4	-15	-8.1	-7.7	0.3	-4.5	-9.7	7.2	6.5	-3.9	-6.3	-5.5	-7.2
12/11/2013 23:59	-5.7	-6.7	-3	2.2	-14.8	-6.8	1.4	-6.9	-5.7	-1.2	-15.5	-11.2	-12.8	-10.3	-23.2	-18.1	-15.6	-8.8	-7.5	-8.4	-4.2	-8.5	8.4	6.7	-8.6	-11	-9.2	-9.9
12/12/2013 23:59	-3.6	-8.5	-4.9	0.3	-15.6	-3.6	9.5	6.3	-5.5	-3.1	-6.2	-12.9	-10.6	-9.1	-10.8	-20.7	-19.3	-17.5	-13.2	-6.2	-7	-6.3	-1.4	3.8	-13.2	-11.7	-11.9	-12.6
12/13/2013 23:59	5.5	0.6	-3.8	-1.6	-11.4	-1.5	-0.3	7.4	3.6	1.1	0.1	7.3	-3.4	-4.9	-6.4	-5.4	-6.9	-6.2	-7.9	-7.9	-2.7	-2.1	-1.2	1	-12.9	-7.3	-9.5	-8.3
12/14/2013 23:59	5.6	-0.2	-0.7	1.5	-4.2	2.6	-0.1	2.5	0.8	-0.7	-5.6	-6.4	-7.2	-4.8	-12.1	-1.1	-9.6	0.2	2.3	1.3	6.5	5.1	9	7.2	-14.5	-6	-10.2	-4
12/15/2013 23:59	9.7	2.9	-0.6	7.5	-8.1	2.8	3	12.5	-0.1	-2.6	-1.4	3.8	-3	-8.6	-17.8	-11.8	-10.3	-3.5	-8.5	0.5	-2.3	-9.8	3.2	9.3	-4.2	0.3	-2.9	1.3
12/16/2013 23:59	4.7	2	3.5	15.6	-9.9	5.9	5.1	17.6	3	-1.5	9.9	11	2.2	-7.4	-7.5	-13.5	-17	-10.2	0.7	-1.3	-2.1	-9.6	-5.6	-0.5	-9.8	-7.4	-8.5	-2.4
12/17/2013 23:59	3.8	-1.9	2.6	11.6	-8.8	7.9	10.2	14.6	8.2	3.6	5.1	9.2	6.4	-1.3	1.8	-2.3	-8.7	-2	7	5.9	5.1	-5.4	-1.5	-0.4	-15.5	-7.1	-9.2	-0.2
12/18/2013 23:59	0.8	-2.8	0.7	6.7	-7.7	6	10.3	24.7	4.3	1.7	13.3	13.4	7.5	-0.1	4.1	-2	-3.4	-6.7	-1.8	1.1	0.3	-2.3	-3.3	0.8	-6.2	-5.9	-6.9	-1.9

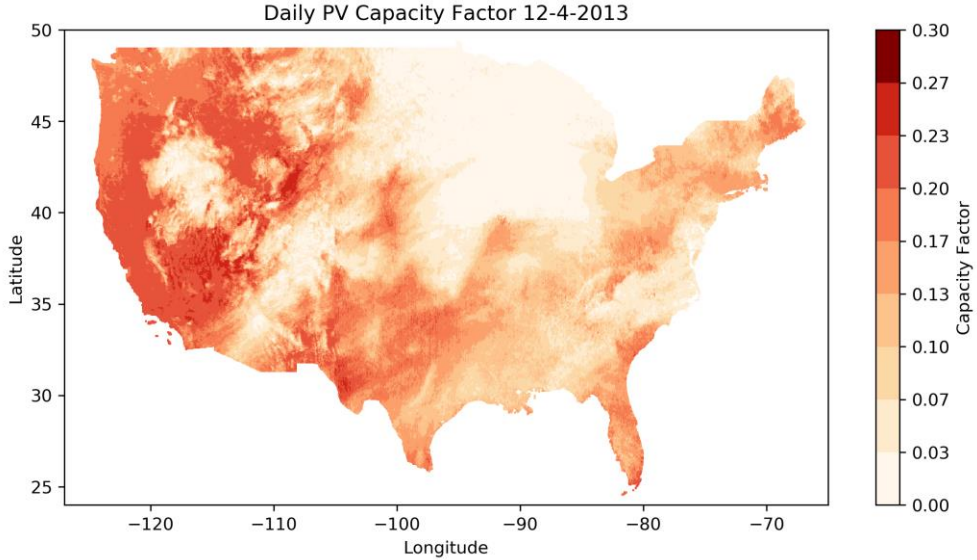
2007-2014 Rank (Rankings includes the Cold Wave of January 2014)

DATE	SEA	PDX	SFO	LAX	SLC	LAS	PHX	DEN	ABQ	ELP	MCI	OKC	DFW	IAH	MSP	ORD	DTW	PIT	BNA	CLT	ATL	MSY	MCO	MIA	BOS	PHL	NYC	IAD
12/3/2013 23:59	288	188	1108	1407	1569	2178	2045	1590	2760	2843	2740	2507	2611	2804	2463	2645	1308	2415	2538	2518	2390	2749	1438	667	1898	2148	1519	2008
12/4/2013 23:59	130	34	86	536	38	109	855	12	2858	2918	891	892	2800	2854	1177	2825	2687	2664	2910	2787	2889	2890	2640	2049	1478	2067	1651	1918
12/5/2013 23:59	27	15	9	230	29	32	210	9	108	1905	115	50	185	1434	125	1184	2661	2745	2587	2882	2915	2915	2658	2512	2459	2805	2034	2899
12/6/2013 23:59	28	20	55	127	65	33	101	10	27	658	43	10	17	78	23	132	435	1116	314	2922	2904	2482	2839	2638	2403	2642	1893	2727
12/7/2013 23:59	14	9	66	281	399	316	135	15	74	99	21	5	6	55	6	89	147	259	136	2810	1752	58	2802	2556	1154	735	653	991
12/8/2013 23:59	25	2	8	23	139	60	569	45	230	479	161	50	26	141	132	330	265	230	690	708	885	214	2854	2681	294	154	248	194
12/9/2013 23:59	36	7	33	49	10	46	94	79	26	617	26	21	36	210	116	69	453	1282	442	751	1102	862	2817	2797	939	573	532	454
12/10/2013 23:59	811	63	18	473	46	63	403	763	38	220	370	45	23	113	187	22	70	399	387	1269	541	185	2658	2706	680	396	488	390
12/11/2013 23:59	308	239	580	1997	70	295	1385	509	333	823	137	208	116	226	31	49	63	344	402	257	577	242	2750	2729	222	110	256	187
12/12/2013 23:59	667	121	204	1434	49	625	2805	2148	362	555	671	155	178	267	289	29	22	49	116	400	339	363	813	2348	64	88	158	97
12/13/2013 23:59	2494	1661	398	818	181	914	1033	2259	1845	1227	1417	2212	693	524	576	669	486	597	375	282	756	832	851	1490	71	313	235	297
12/14/2013 23:59	2504	1467	1304	1804	719	1622	1073	1607	1232	903	720	516	358	534	240	1241	272	1389	1606	1447	2390	2328	2778	2783	45	423	209	717
12/15/2013 23:59	2827	2092	1334	2696	372	1661	1709	2688	1057	617	1221	1758	740	294	101	199	234	902	343	1314	824	180	2146	2889	646	1354	733	1543
12/16/2013 23:59	2382	1942	2345	2907	261	2279	2193	2874	1719	776	2541	2570	1471	360	493	147	46	259	1349	1016	869	189	330	942	164	305	287	966
12/17/2013 23:59	2246	1093	2174	2848	322	2591	2853	2792	2633	1744	2060	2420	2200	943	1579	1056	328	1065	2325	2242	2217	441	788	985	31	331	256	1299
12/18/2013 23:59	1671	885	1699	2639	399	2299	2856	2918	1972	1365	2729	2689	2364	1138	1884	1100	896	525	997	1411	1288	807	517	1417	406	439	380	1045


Daily Wind Capacity Factor 12-4-2013
Latitude
50
45
40
35
30
25
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.
Capacity Factor


12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.


Weather
Prediction Center
Analyst Kong


Daily PV Capacity Factor 12-4-2013
Latitude
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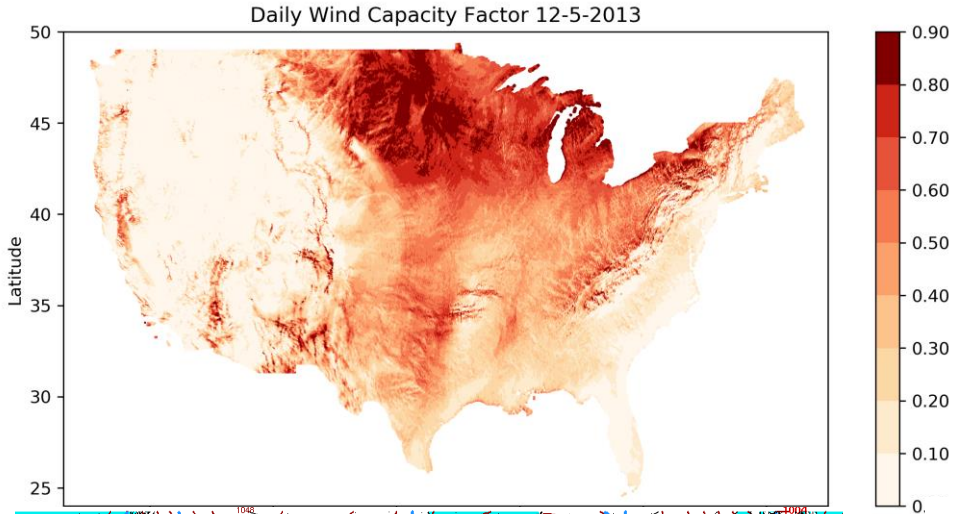
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
Capacity Factor


Daily Wind Capacity Factor 12-5-2013
Latitude
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45
40
35
30
25
Capacity Factor
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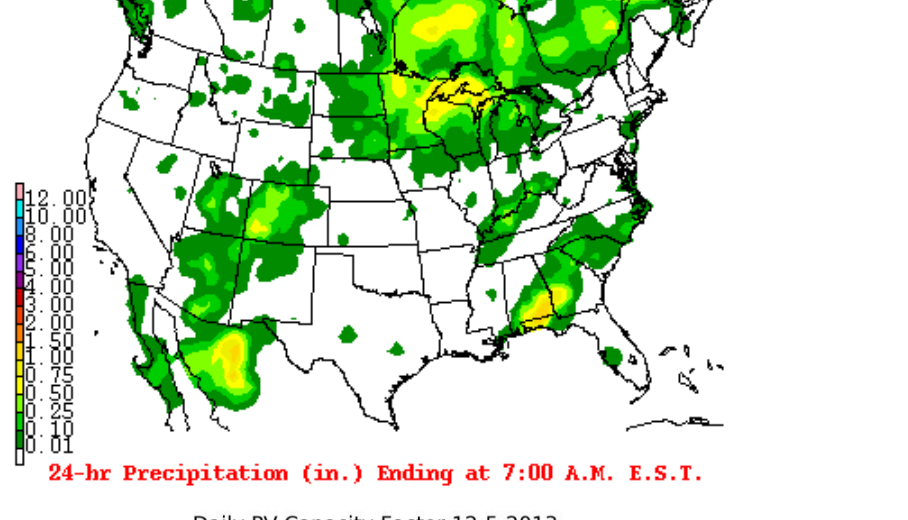
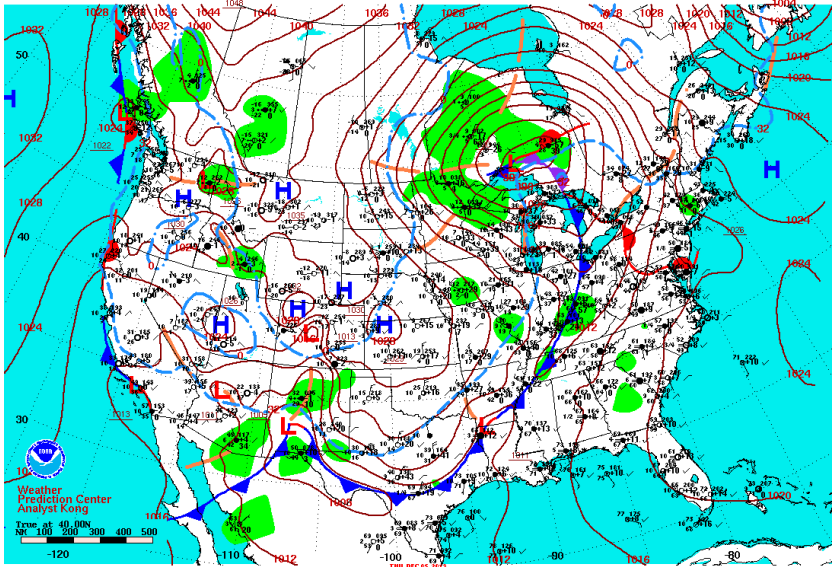
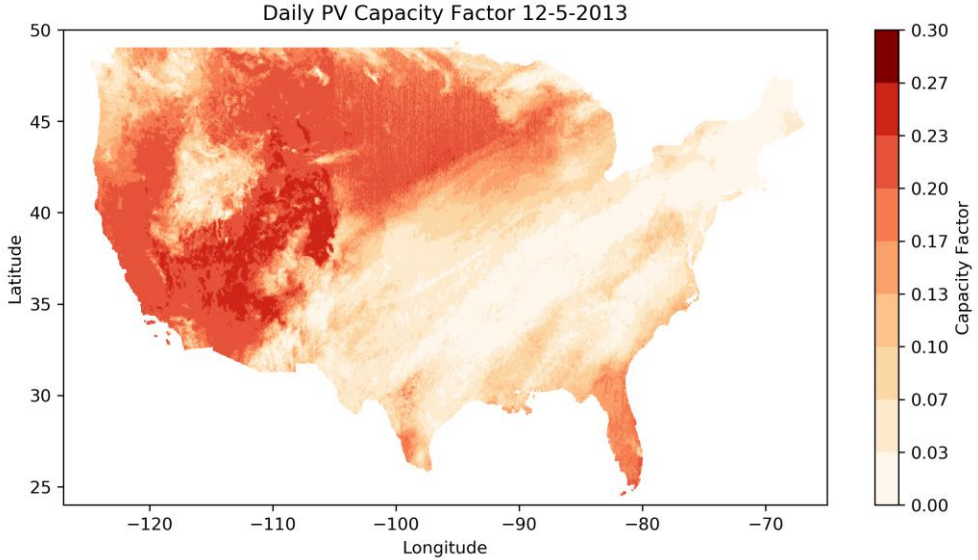
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.


12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.


Weather
Prediction Center
Analyst Kong


Daily PV Capacity Factor 12-5-2013
Latitude
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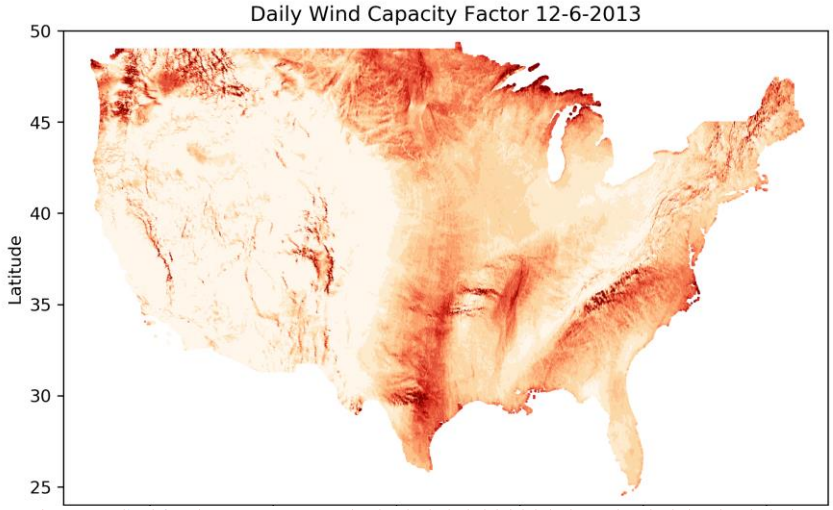
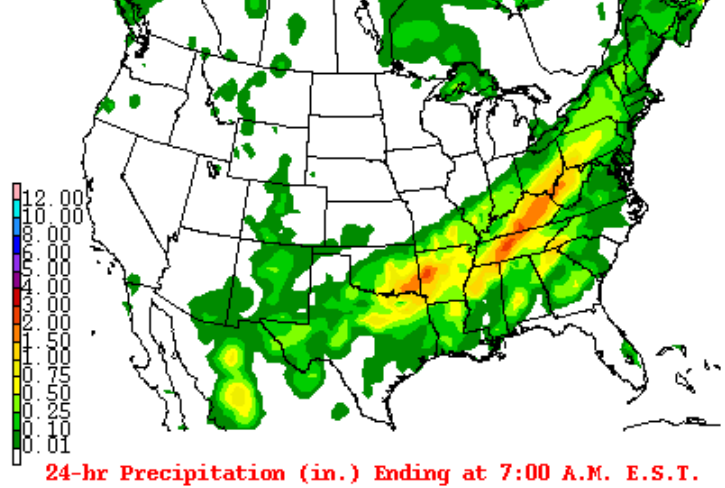
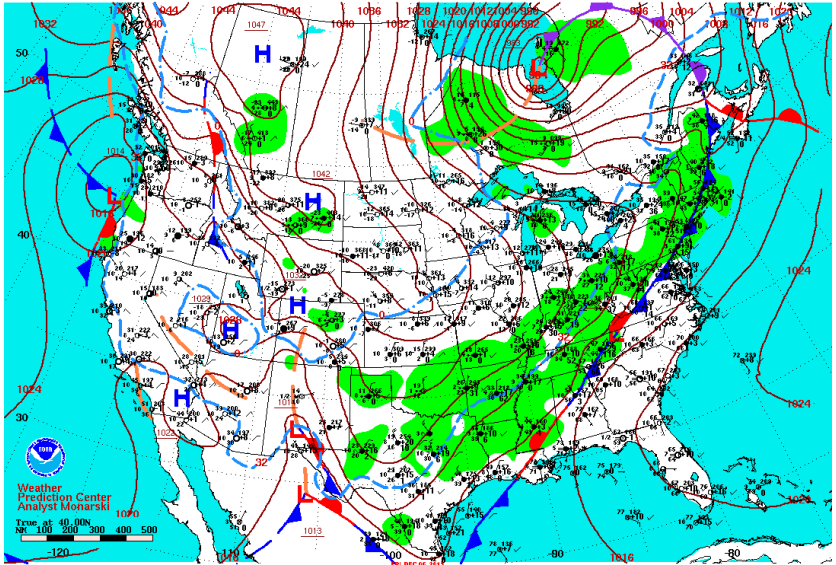
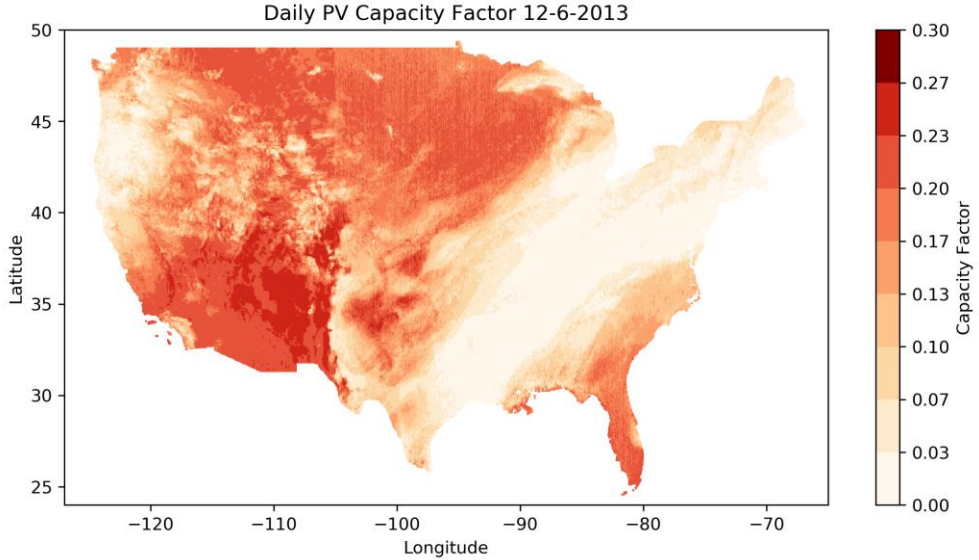
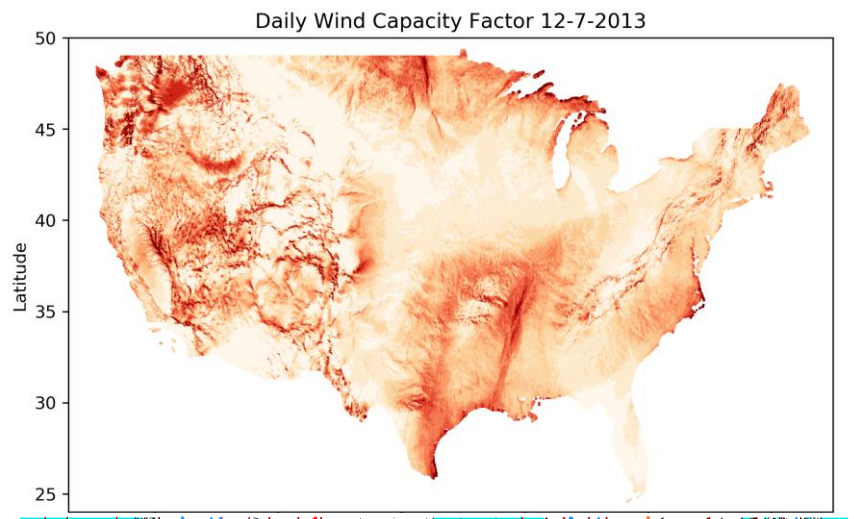
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

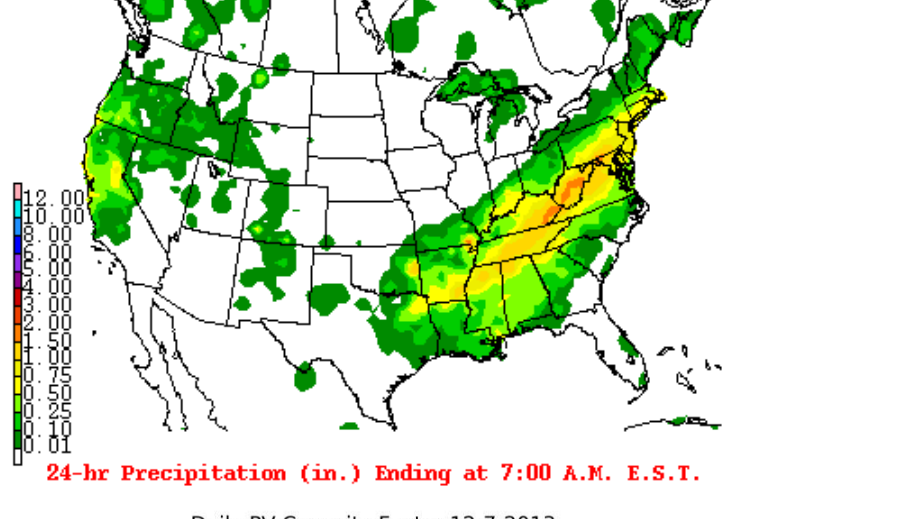

Daily Wind Capacity Factor 12-6-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

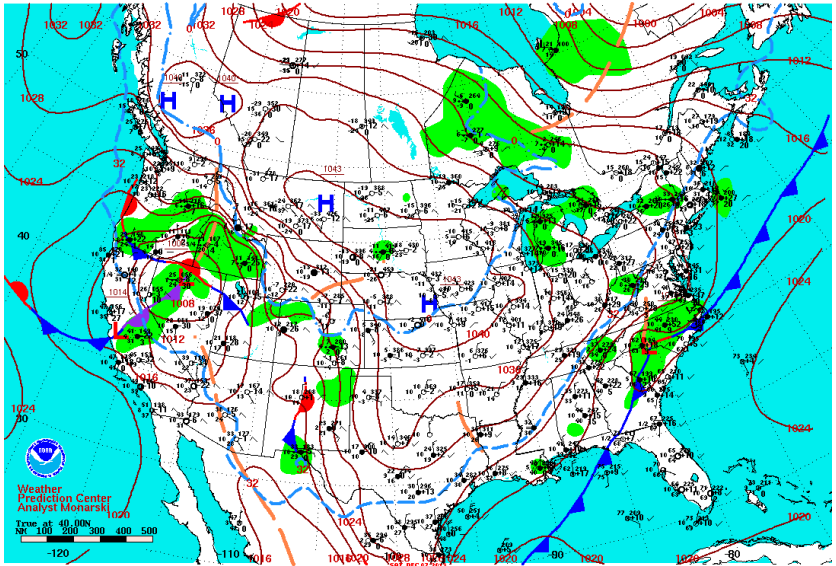

12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.50
1.00
.75
.50
.25
.10
.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

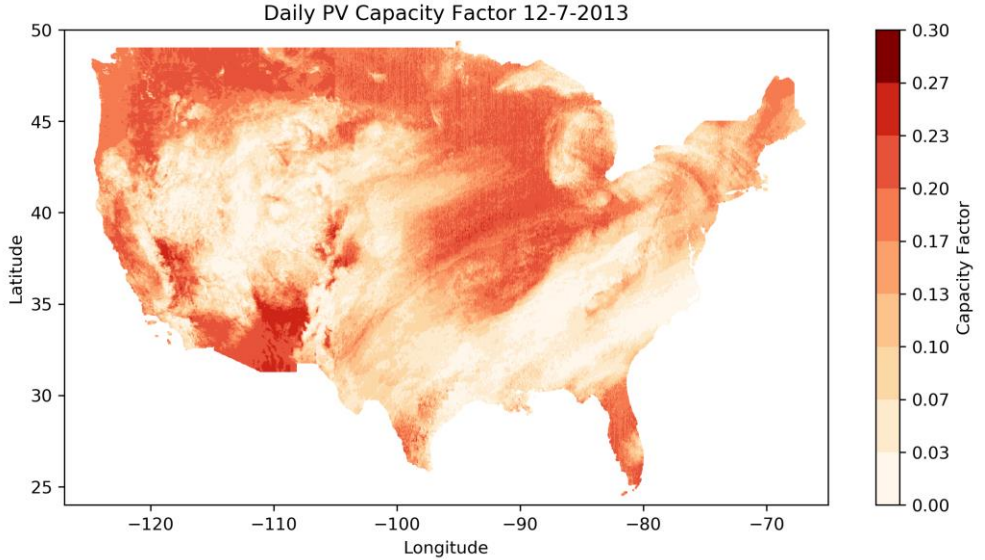

Weather
Prediction Center
Analyst Monarski

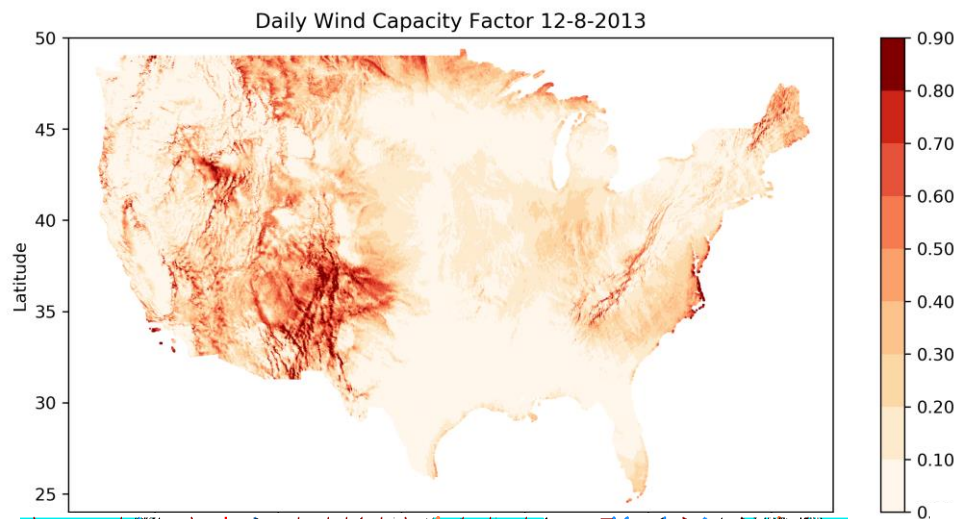

Daily PV Capacity Factor 12-6-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

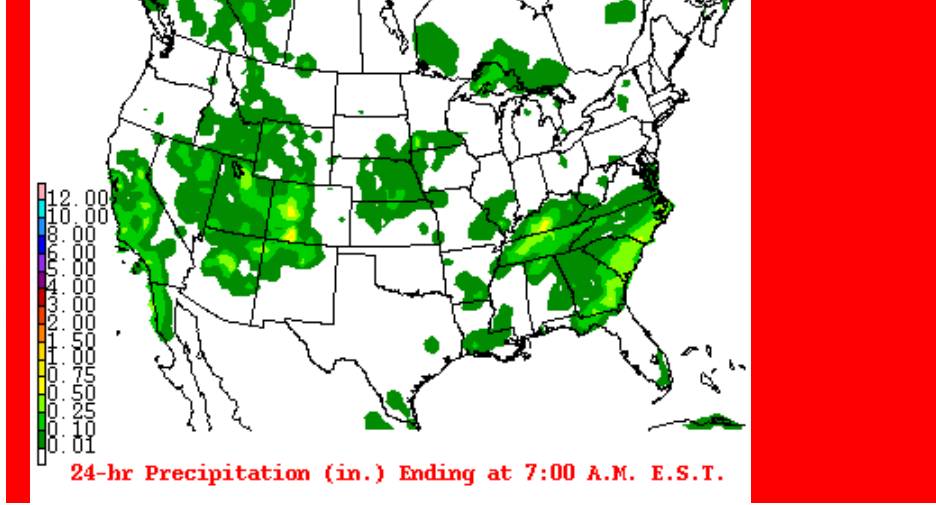

Daily Wind Capacity Factor 12-7-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

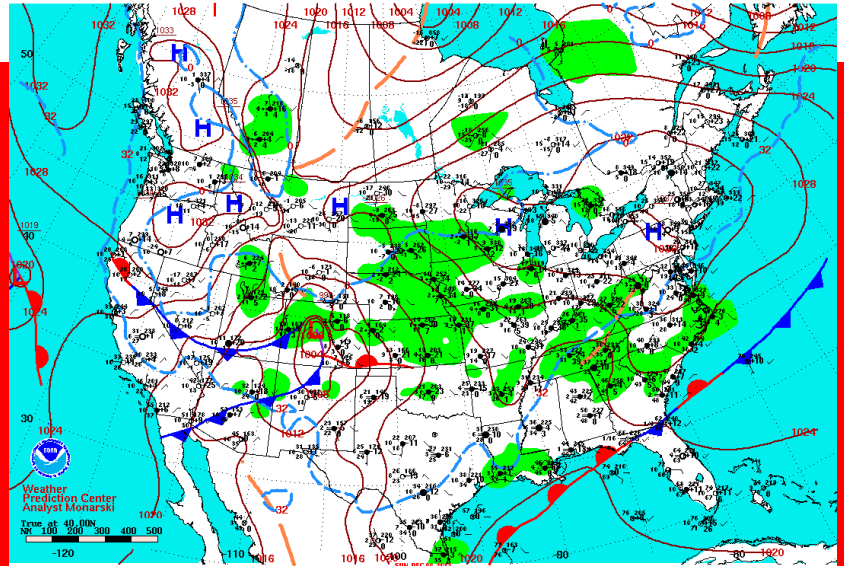

12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.50
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

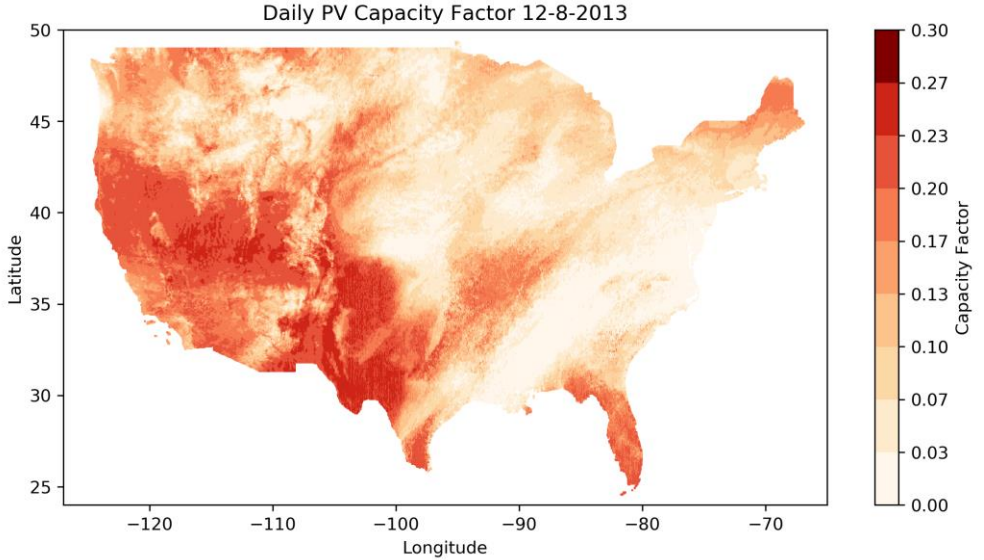

Weather
Prediction Center
Analyst Monarski

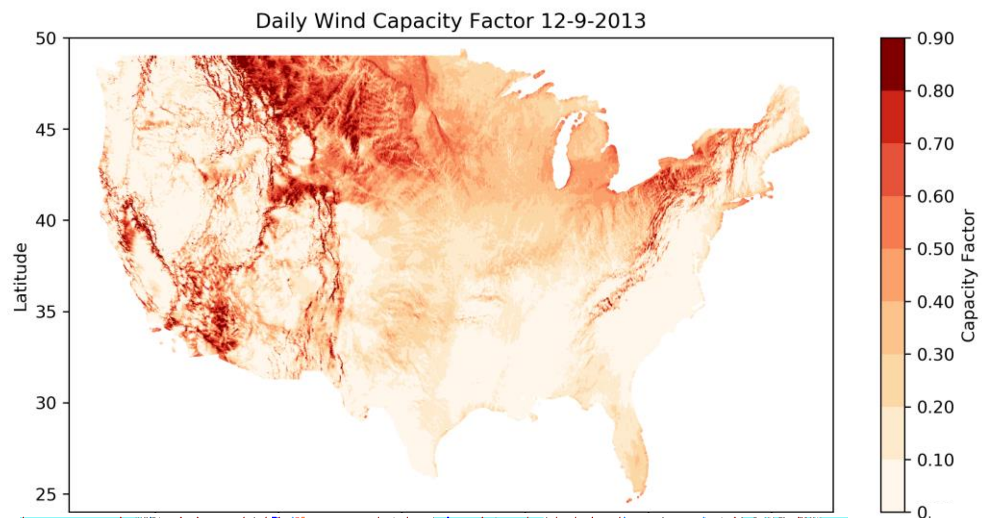

Daily PV Capacity Factor 12-7-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

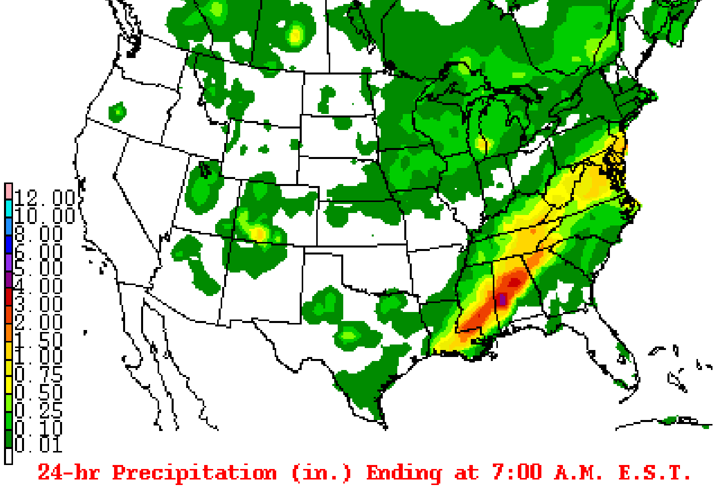

Daily Wind Capacity Factor 12-8-2013
Latitude
Capacity Factor

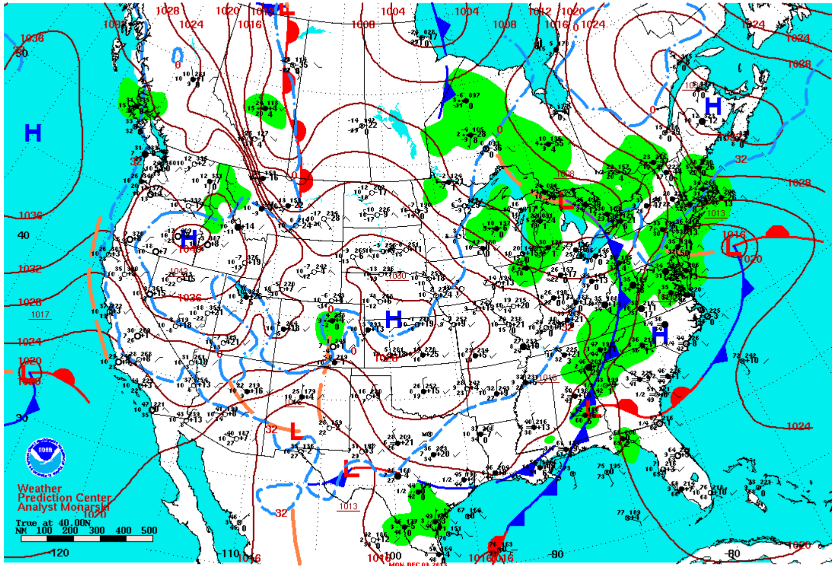

24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

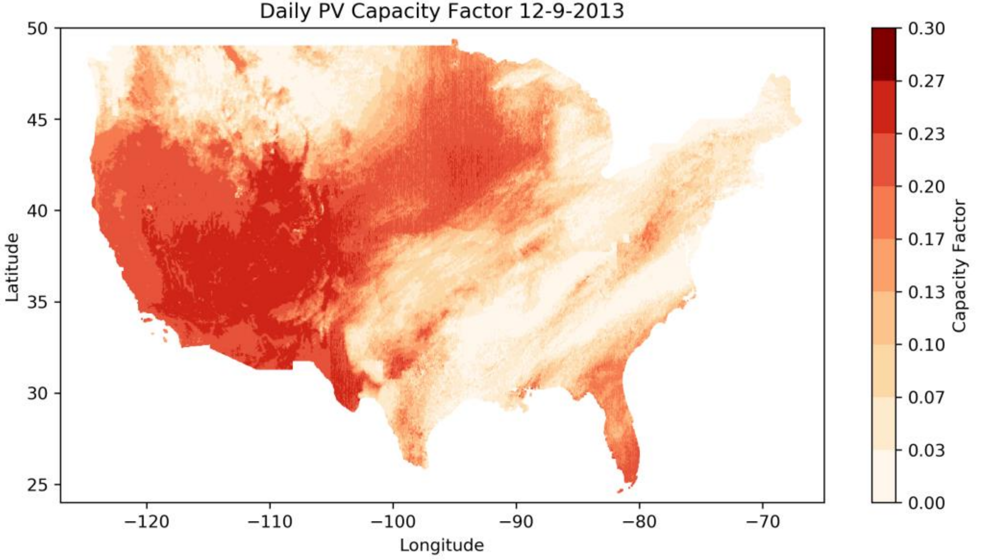

Weather Prediction Center
Analyst Monarski

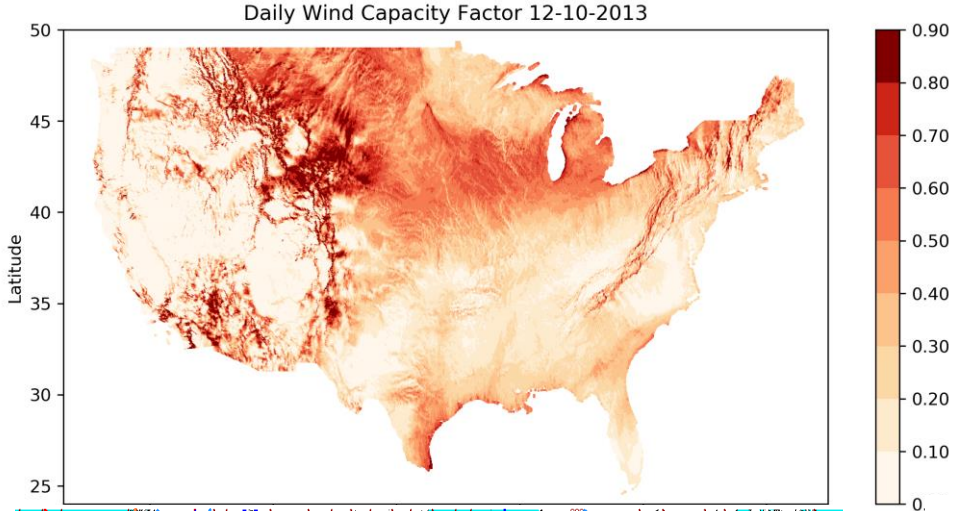

Daily PV Capacity Factor 12-8-2013
Latitude
Longitude
Capacity Factor

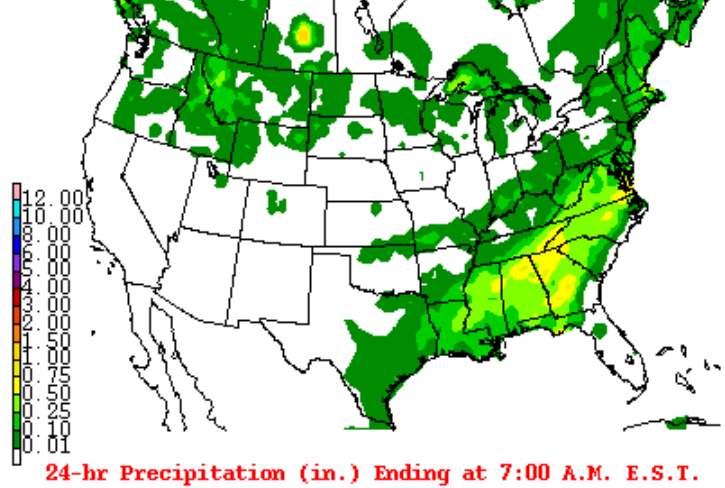

Daily Wind Capacity Factor 12-9-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

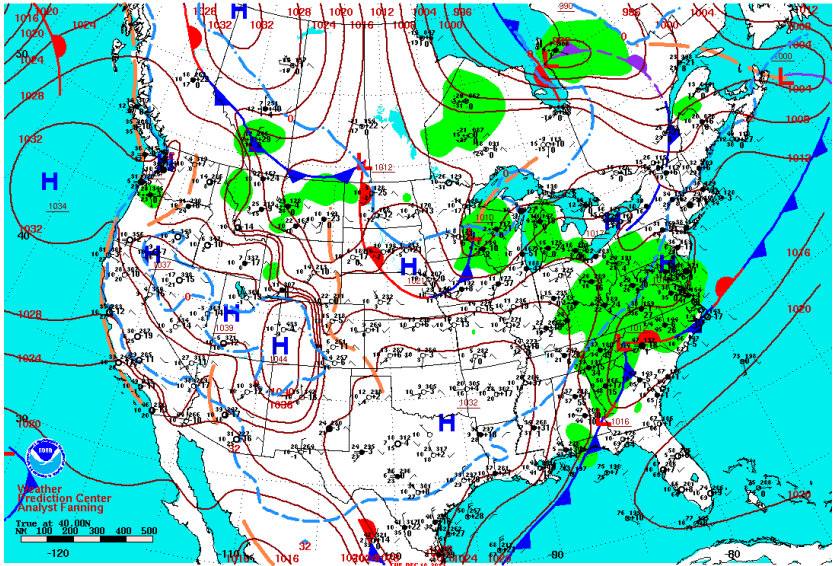

12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

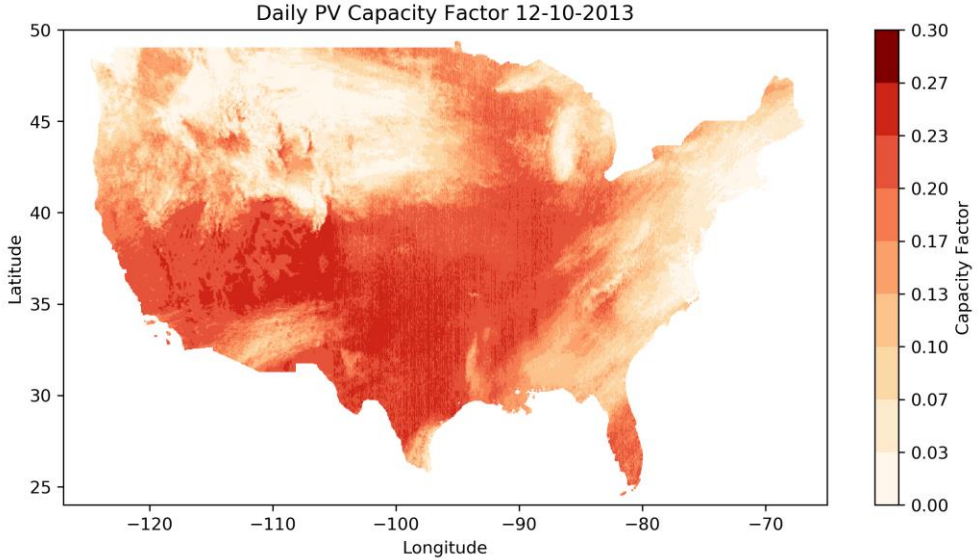

Weather
Prediction Center
Analyst Monarski
True at 40.00N

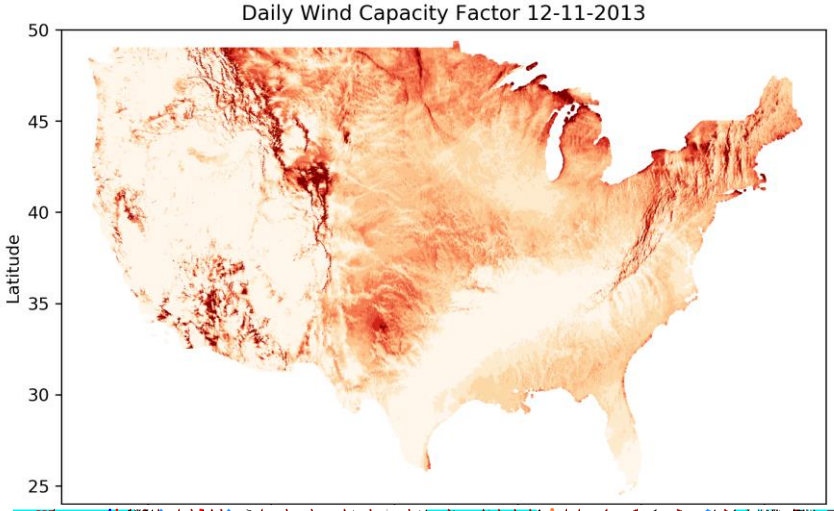

Daily PV Capacity Factor 12-9-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

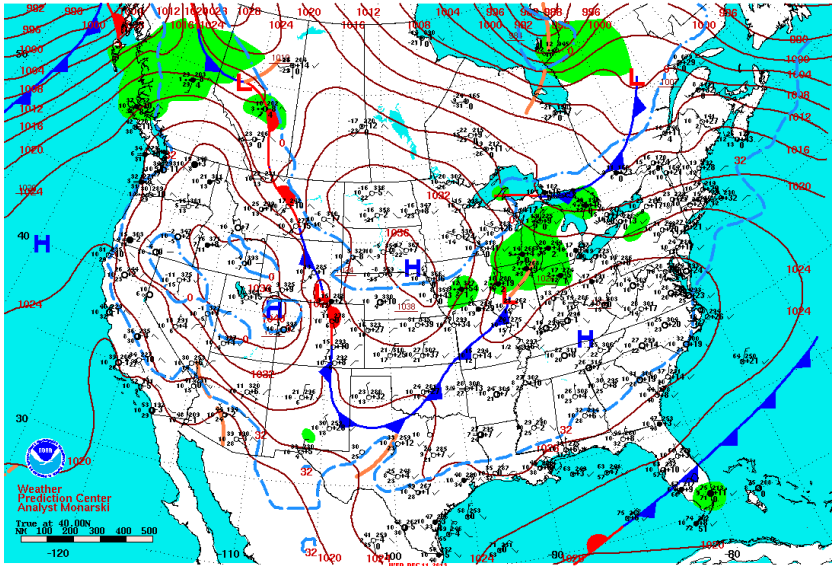

Daily Wind Capacity Factor 12-10-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

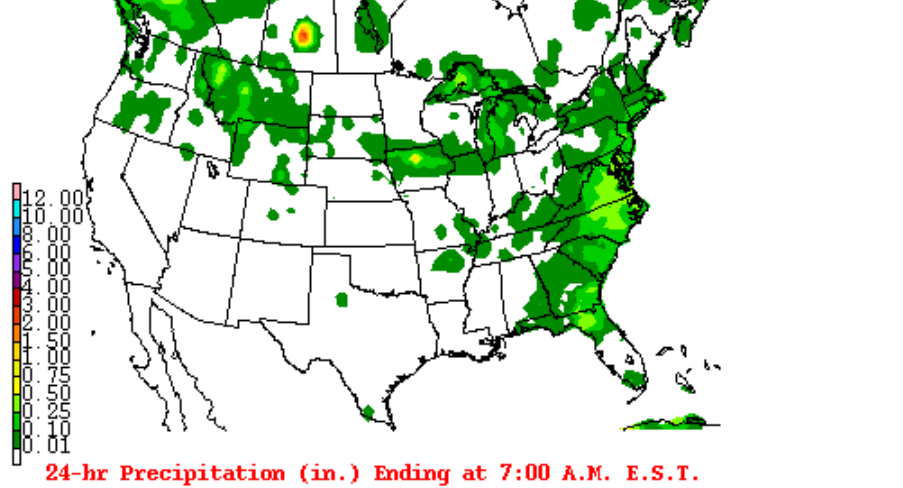

12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

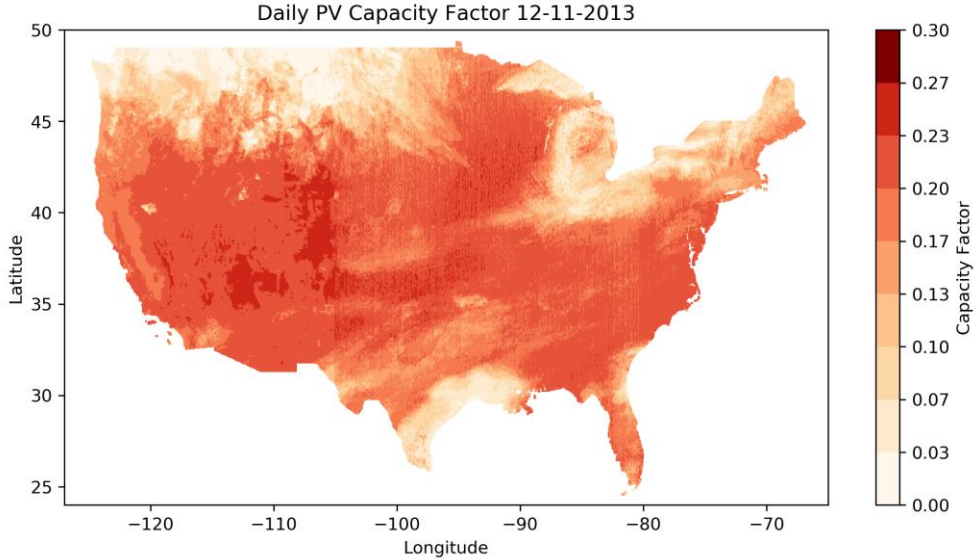

Weather
Prediction Center
Analyst Fanning

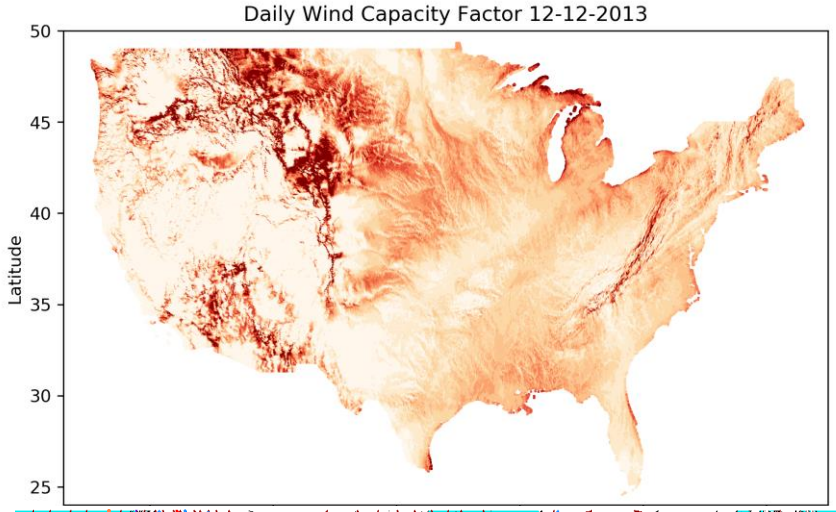

Daily PV Capacity Factor 12-10-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

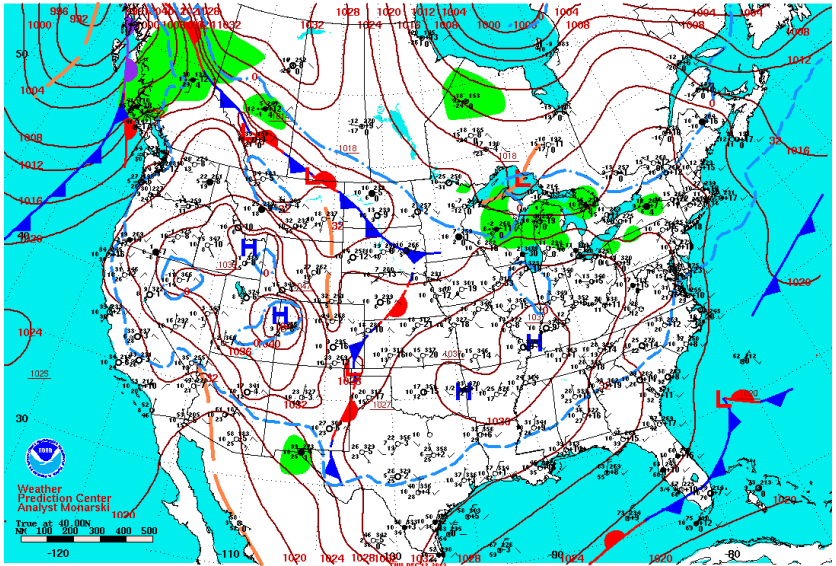

Daily Wind Capacity Factor 12-11-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

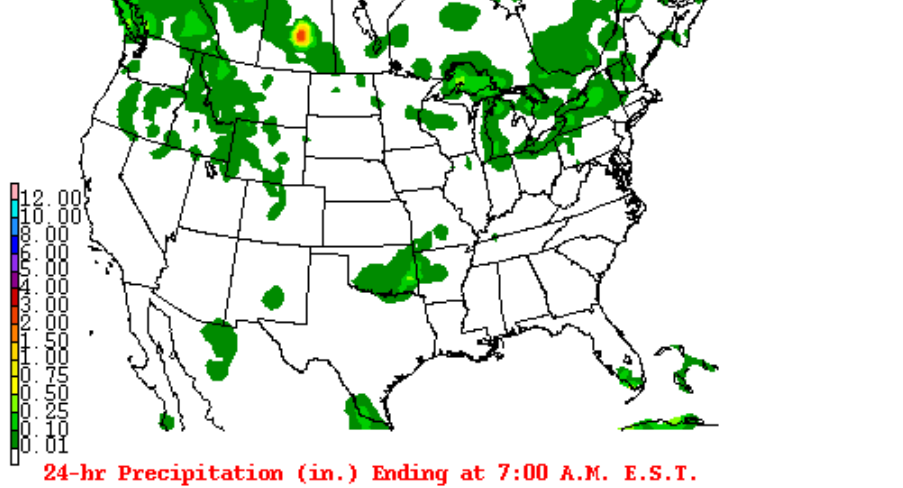

Weather
Prediction Center
Analyst Monarski

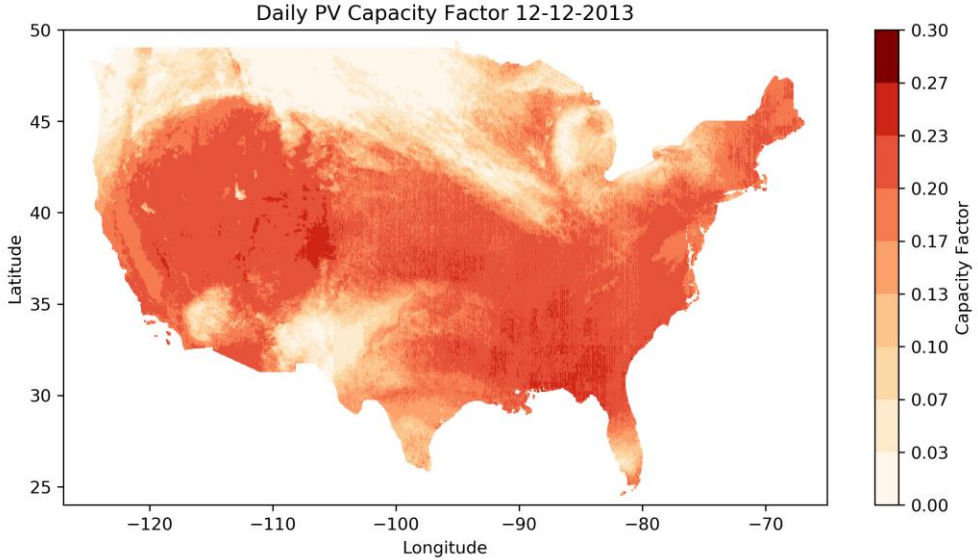

12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

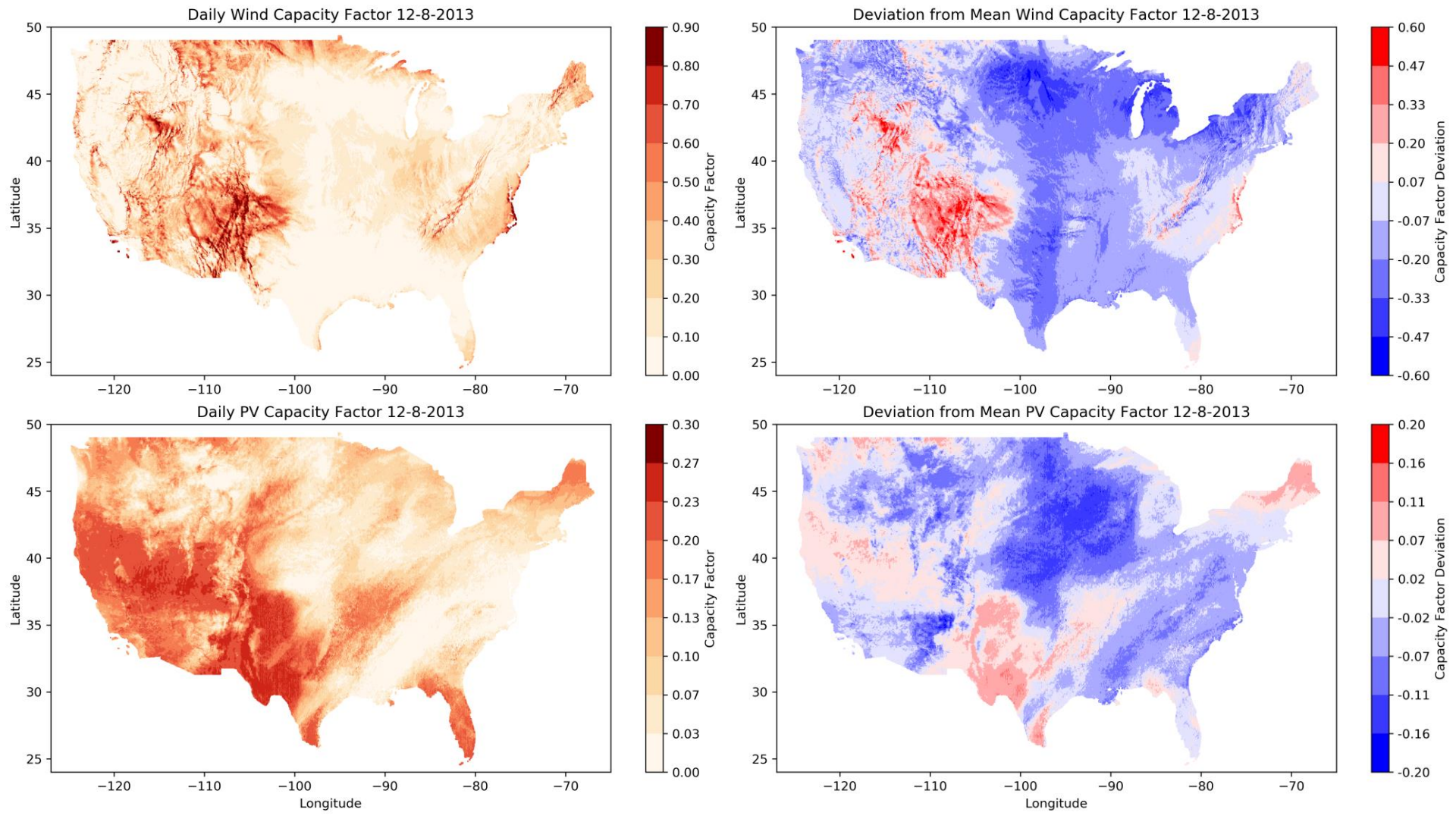

Daily PV Capacity Factor 12-11-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

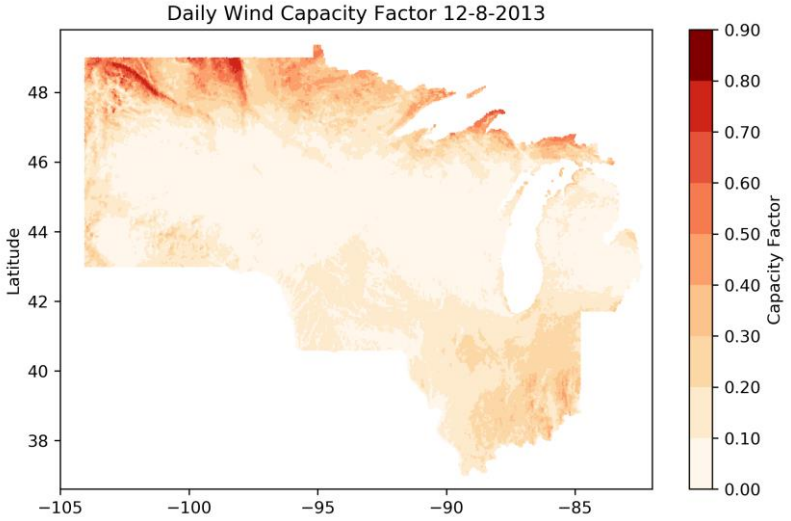

Daily Wind Capacity Factor 12-12-2013
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

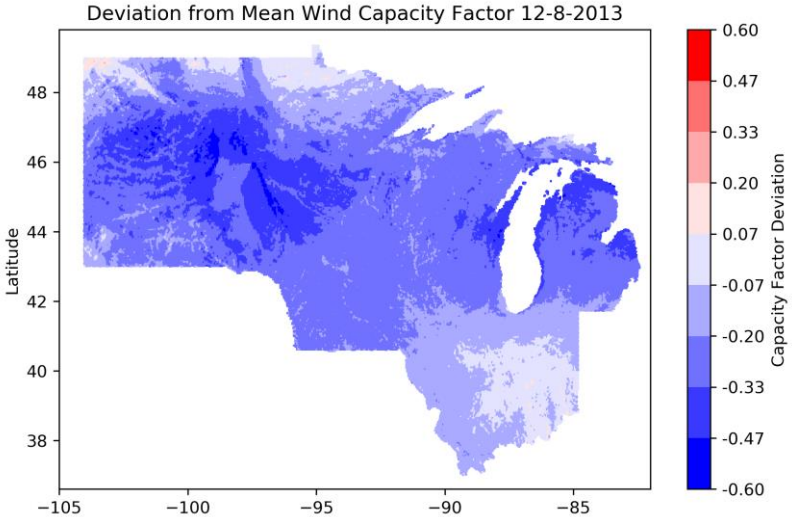

Weather
Prediction Center
Analyst Monarski

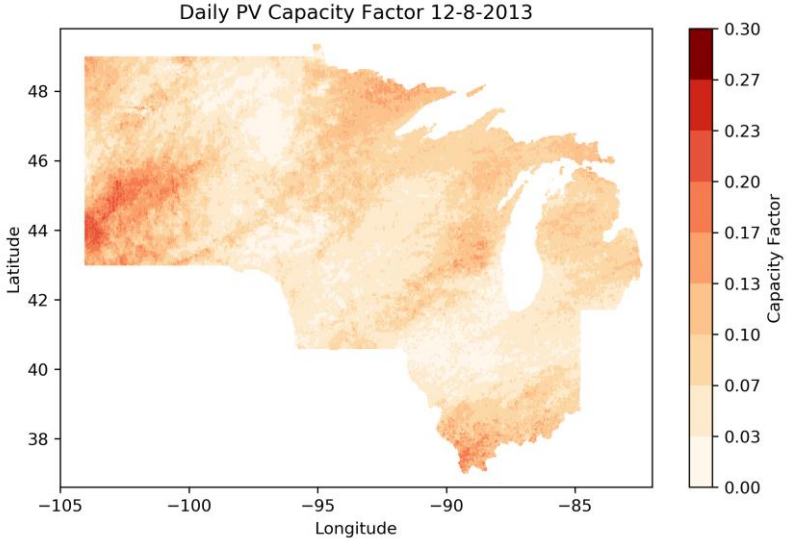

12.00
10.00
8.00
6.00
4.00
3.00
2.50
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

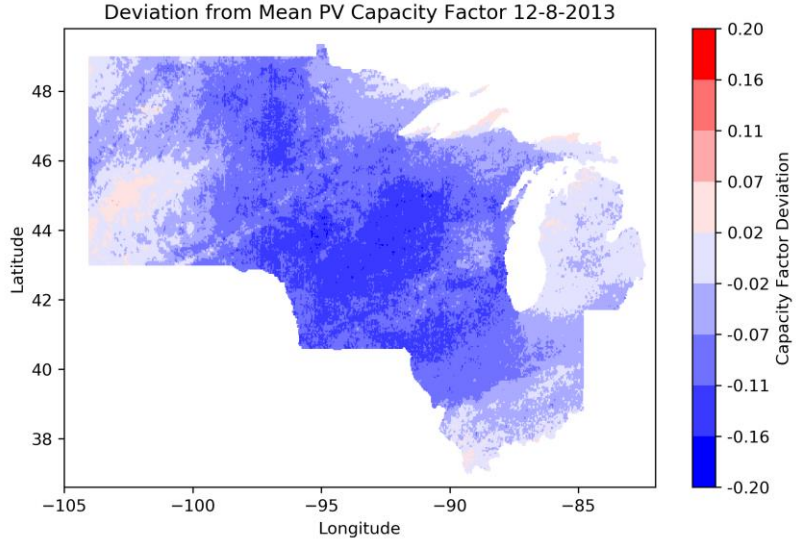

Daily PV Capacity Factor 12-12-2013
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00


Daily Wind Capacity Factor 12-8-2013
Deviation from Mean Wind Capacity Factor 12-8-2013
Daily PV Capacity Factor 12-8-2013
Deviation from Mean PV Capacity Factor 12-8-2013
Latitude
Longitude
Capacity Factor
Capacity Factor Deviation
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.60
0.47
0.33
0.20
0.07
-0.07
-0.20
-0.33
-0.47
-0.60
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
0.20
0.16
0.11
0.07
0.02
-0.02
-0.07
-0.11
-0.16
-0.20


Daily Wind Capacity Factor 12-8-2013
Latitude
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
48
46
44
42
40
38
−105
−100
−95
−90
−85

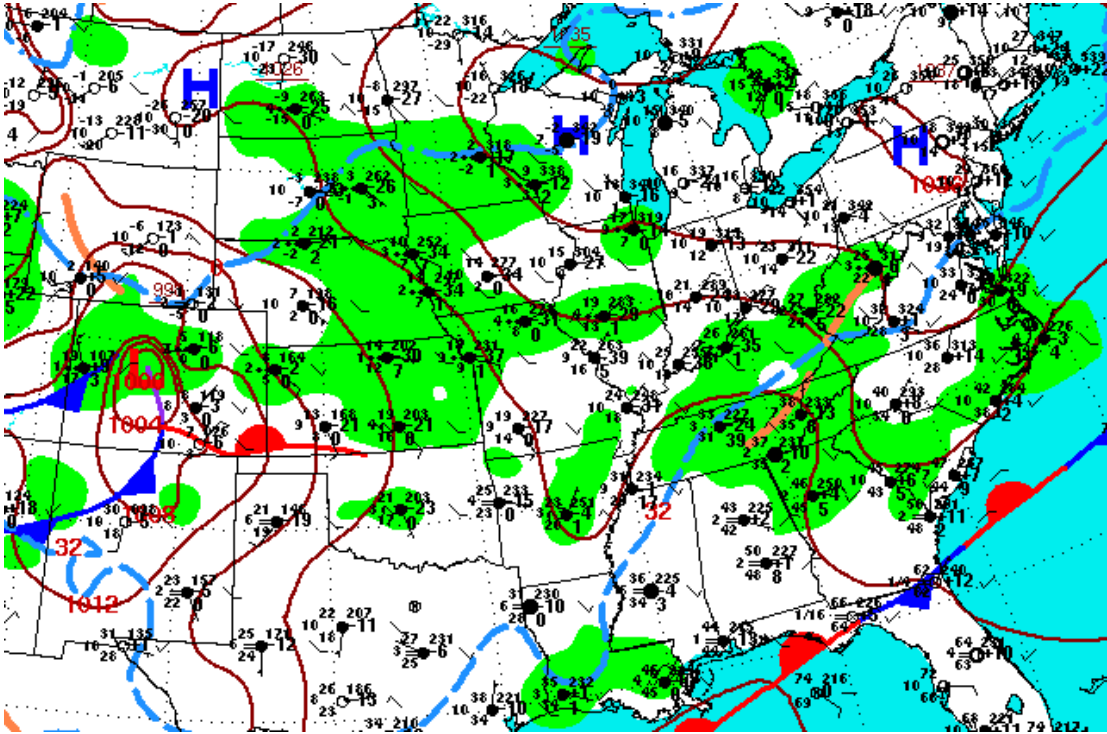

Deviation from Mean Wind Capacity Factor 12-8-2013
Latitude
Capacity Factor Deviation
0.60
0.47
0.33
0.20
0.07
-0.07
-0.20
-0.33
-0.47
-0.60
48
46
44
42
40
38
−105
−100
−95
−90
−85


Daily PV Capacity Factor 12-8-2013
Latitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
48
46
44
42
40
38
−105
−100
−95
−90
−85
Longitude


Deviation from Mean PV Capacity Factor 12-8-2013
Latitude
Capacity Factor Deviation
0.20
0.16
0.11
0.07
0.02
-0.02
-0.07
-0.11
-0.16
-0.20
48
46
44
42
40
38
−105
−100
−95
−90
−85
Longitude

December 8, 2013 - Summary

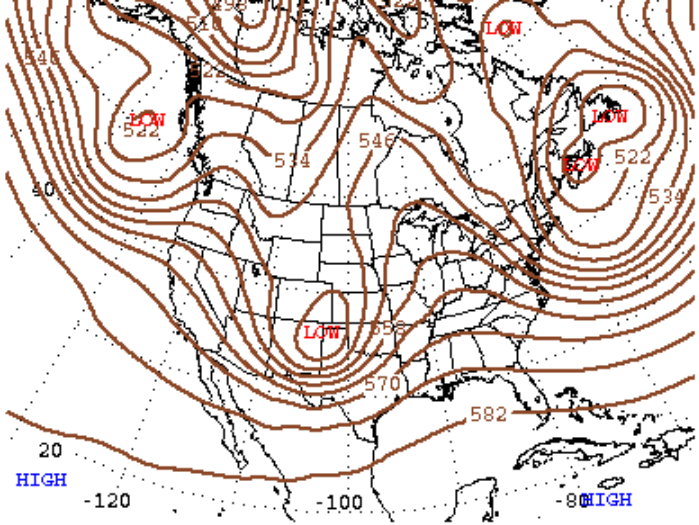
- Second of many cold waves in the 2013-2014 winter
- Combined PV and wind resource saw several lulls over large regions
  - One of lowest 25 days for eastern resource. 13th lowest in MISO
  - 2nd lowest wind/35th lowest solar in dataset for MISO
- Falls during one of the most significant cold periods (duration and intensity) in the dataset for the MISO area
- Period was challenging for T&D due to snow and ice



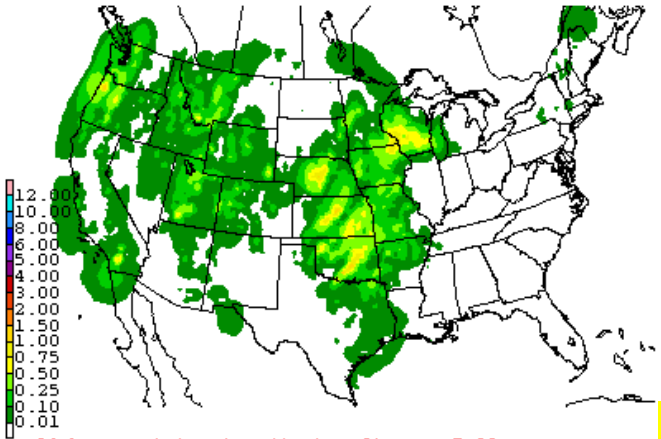
What would the impact have been on a high penetration wind and solar fleet?

Wind Driven Tail Event

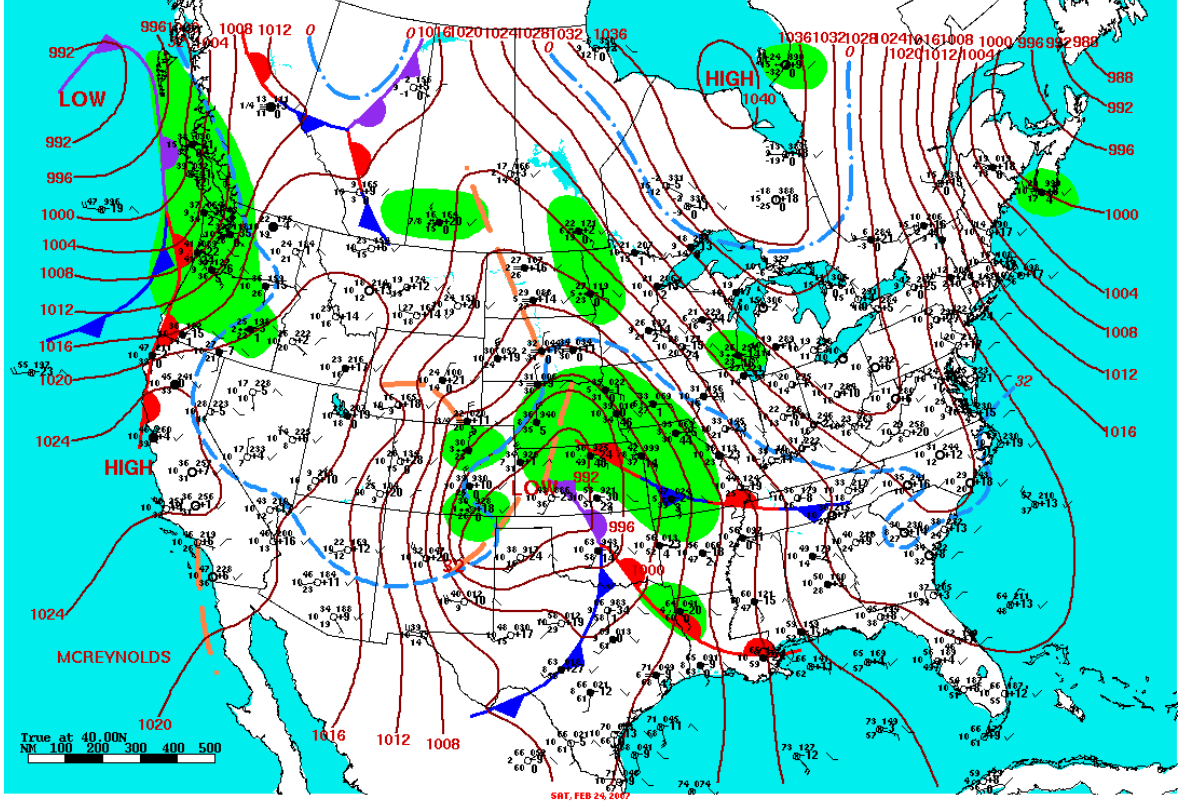
February 27, 2007



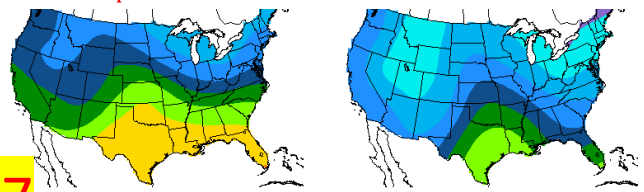
500-Millibar Height Contour at 7:00 A.M. E.S.T.



24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



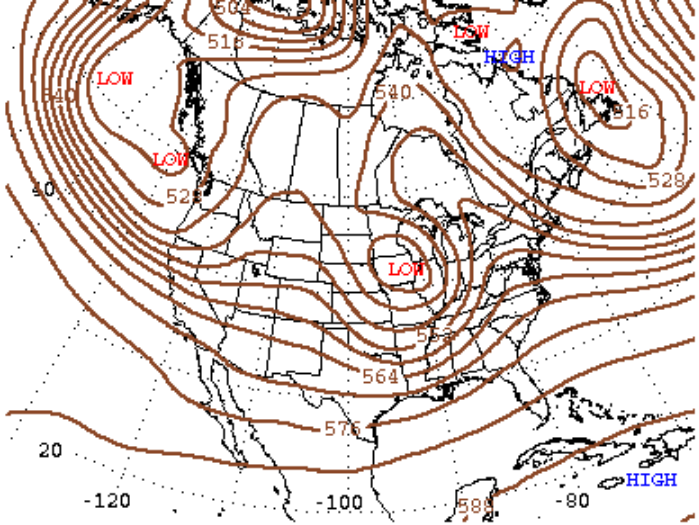
Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.



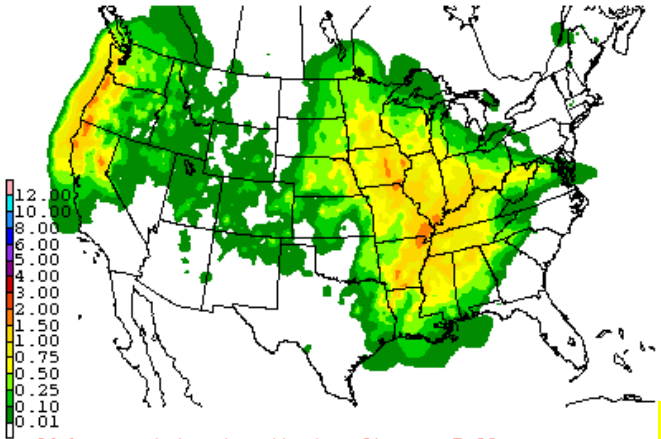
Maximum Temperature Minimum Temperature

0 10 20 30 40 50 60 70 80 90 100

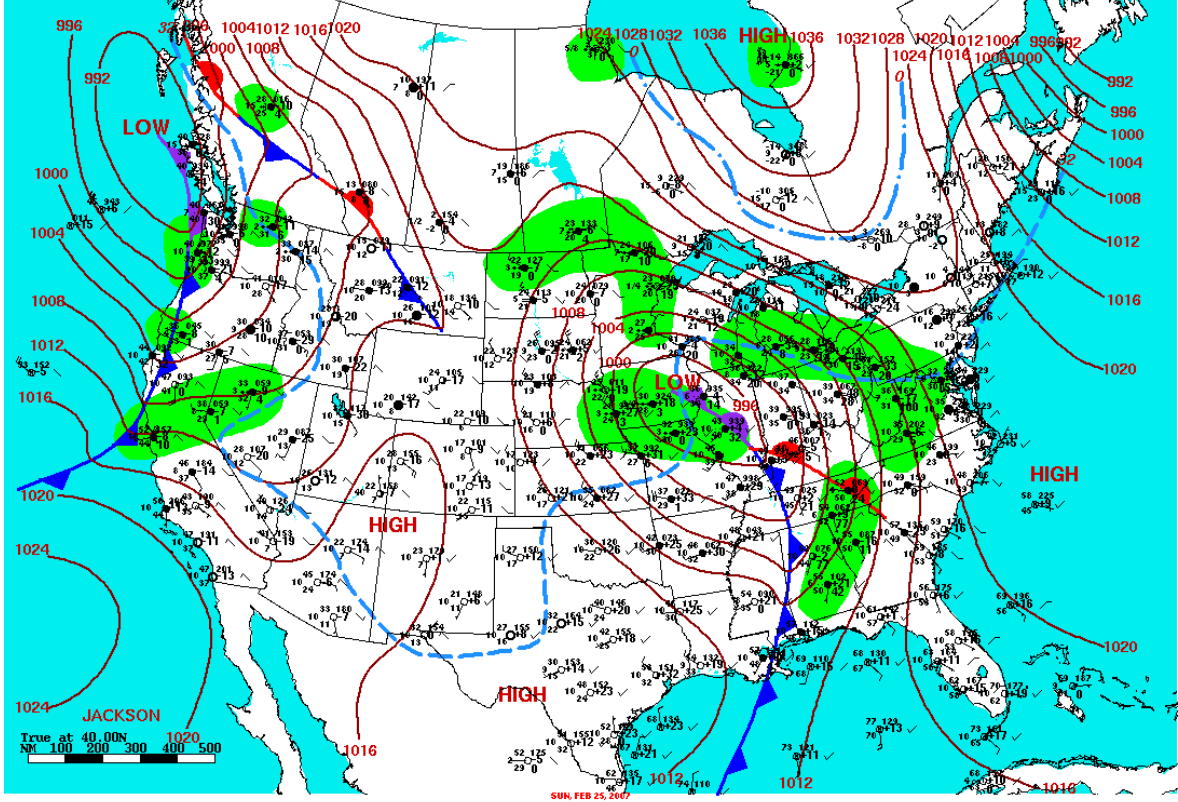
February 24, 2007



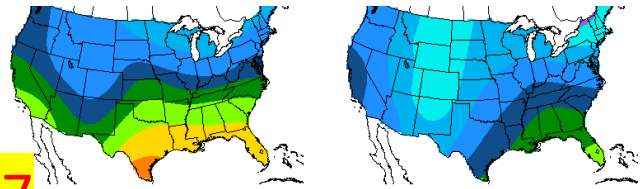
500-Millibar Height Contour at 7:00 A.M. E.S.T.



24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



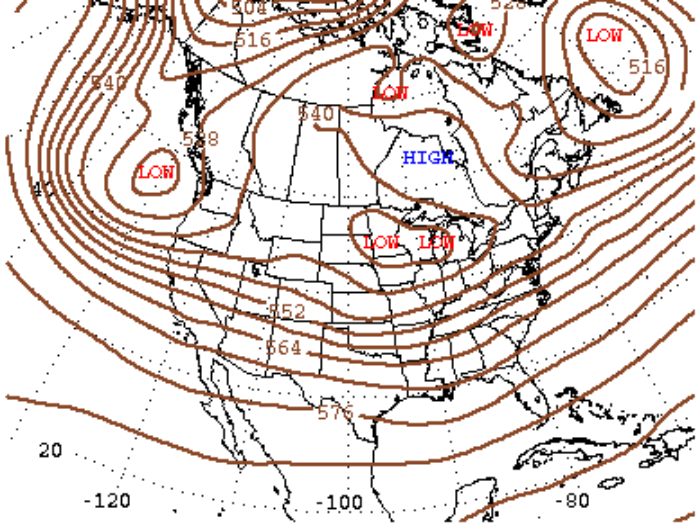
Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

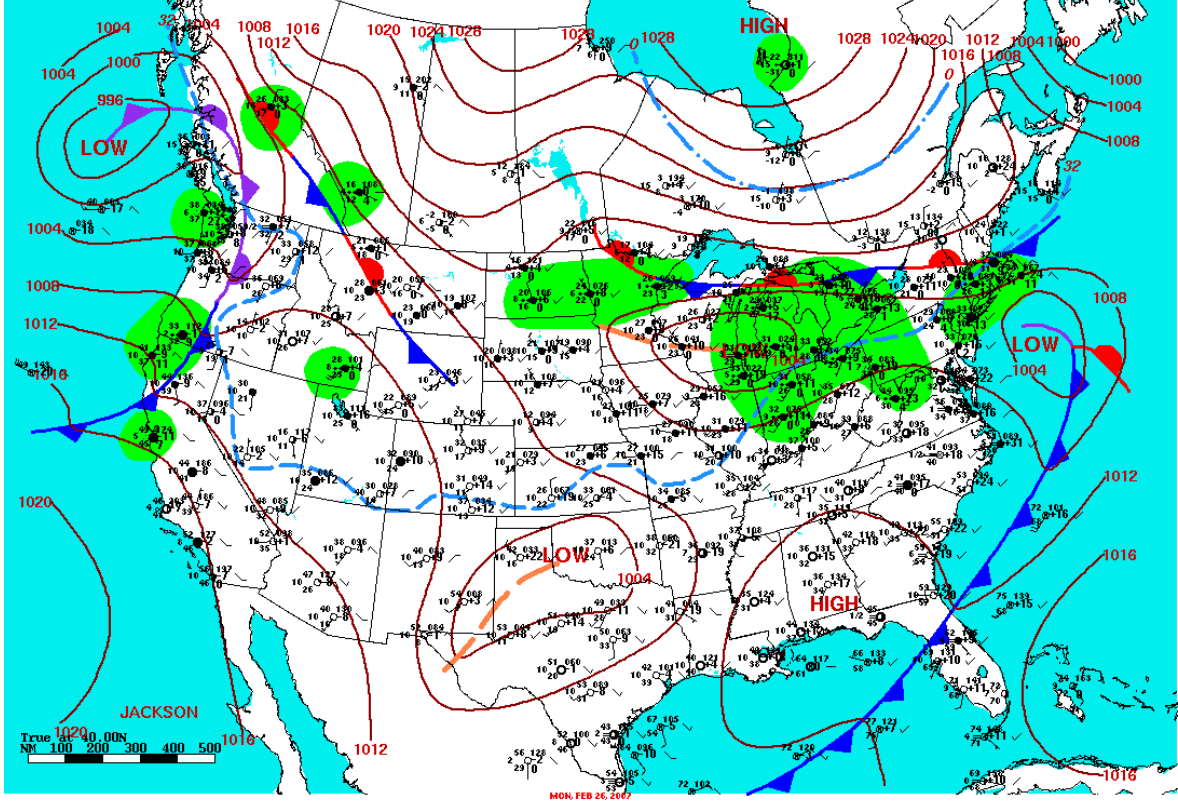


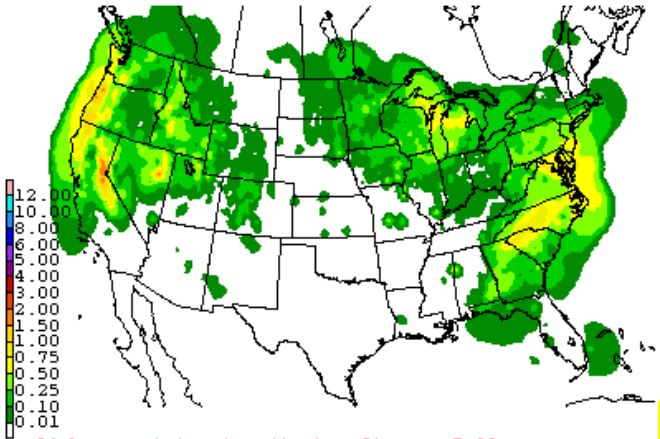
Maximum Temperature — Minimum Temperature

0 10 20 30 40 50 60 70 80 90 100

February 25, 2007

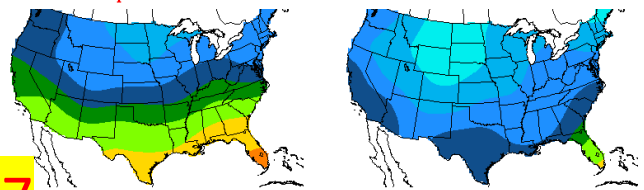






24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

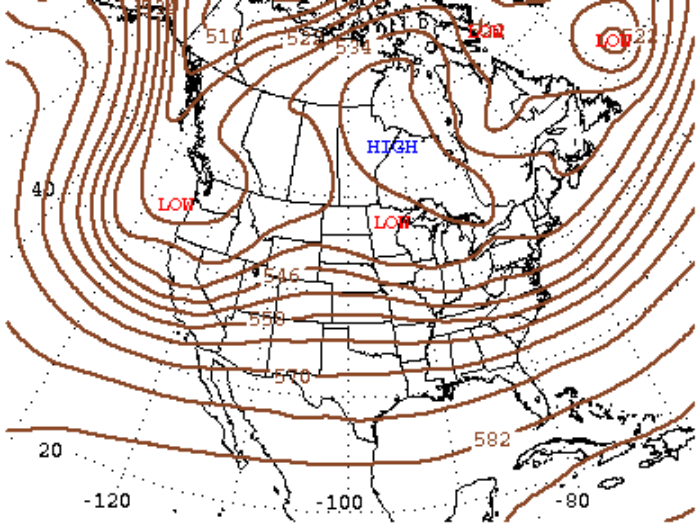


Maximum Temperature

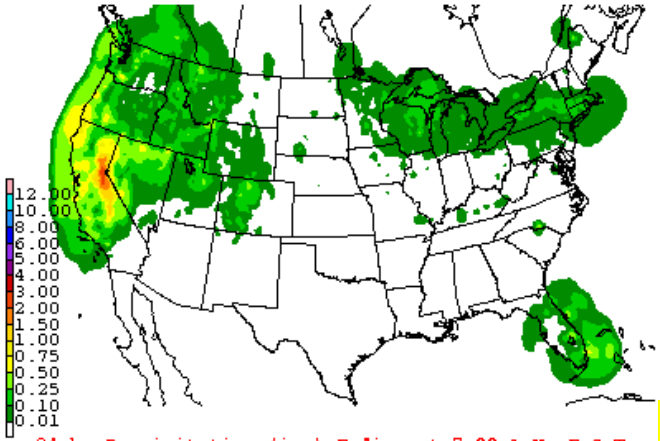
Minimum Temperature

0 10 20 30 40 50 60 70 80 90 100

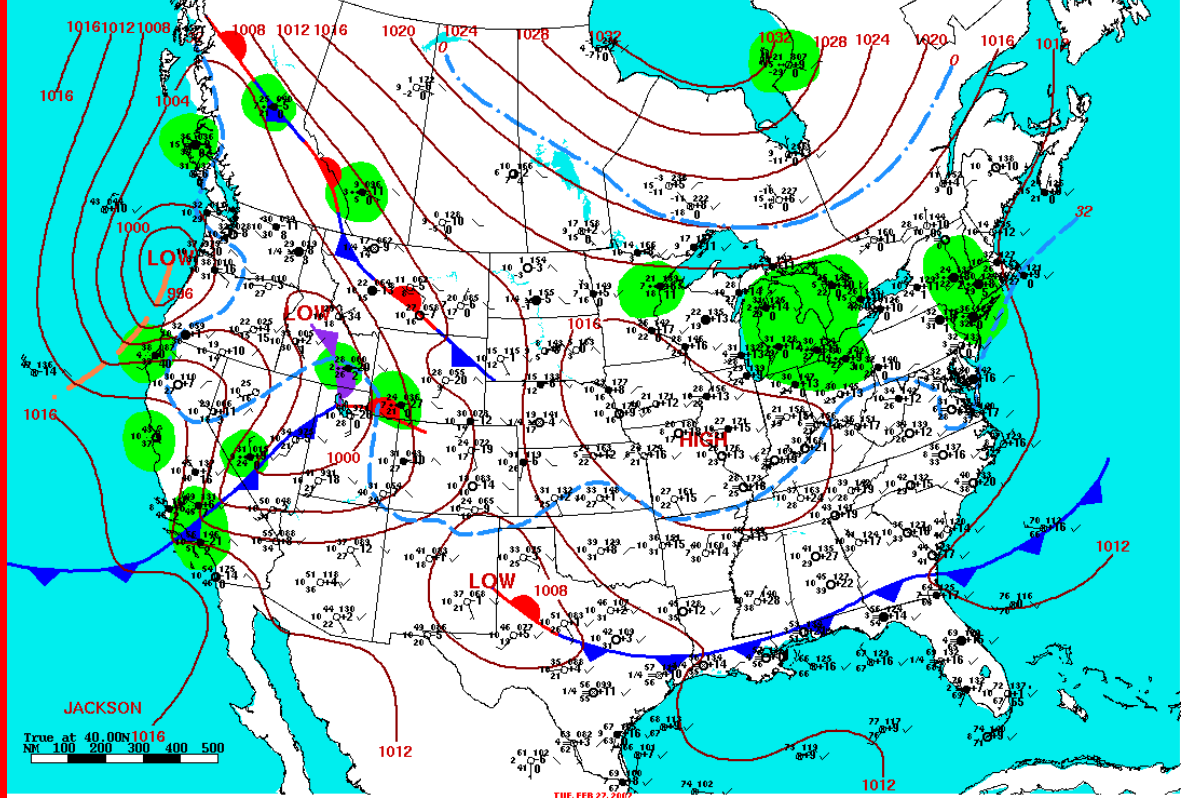
February 26, 2007



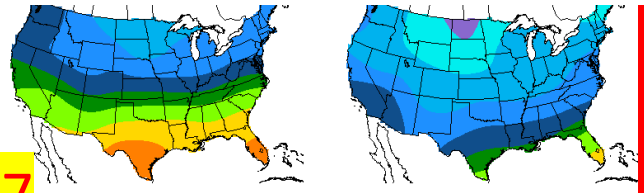
500-Millibar Height Contour at 7:00 A.M. E.S.T.



24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.



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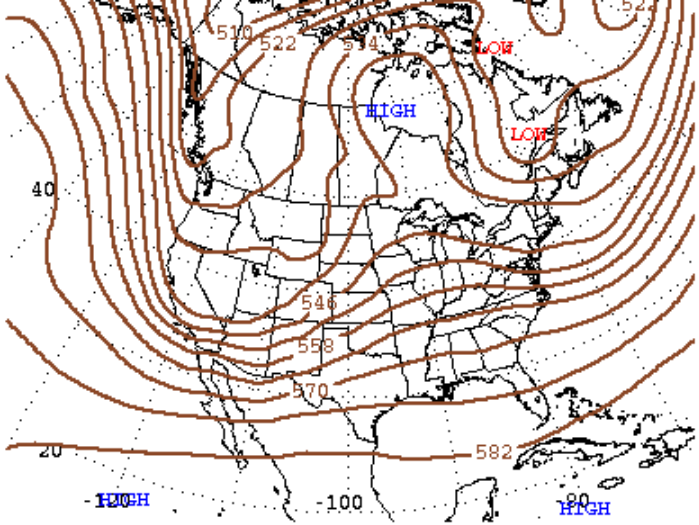

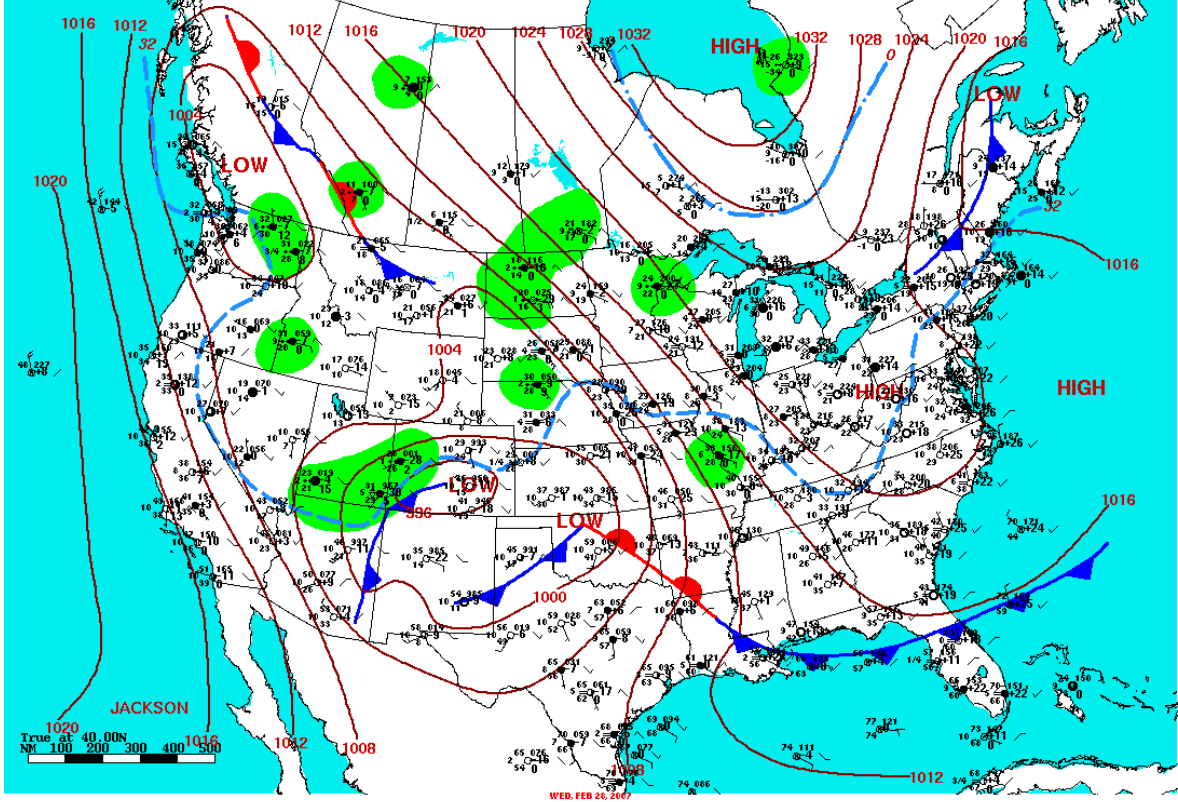

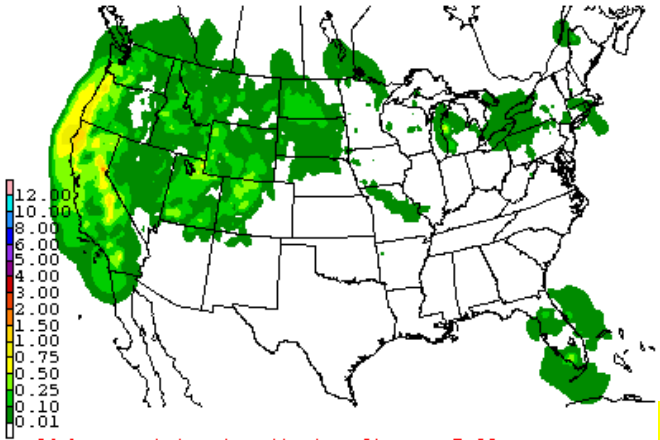

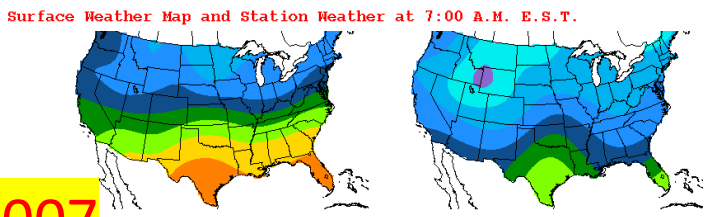

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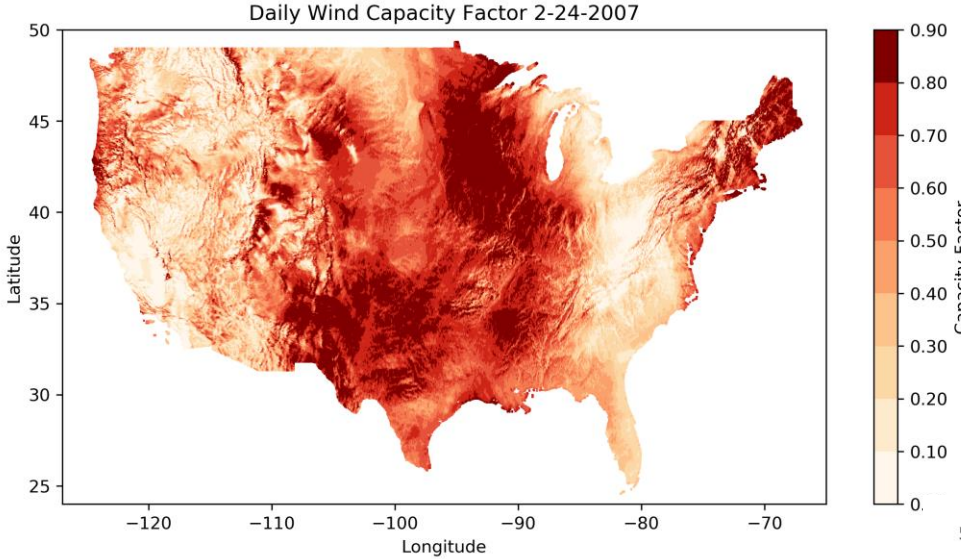
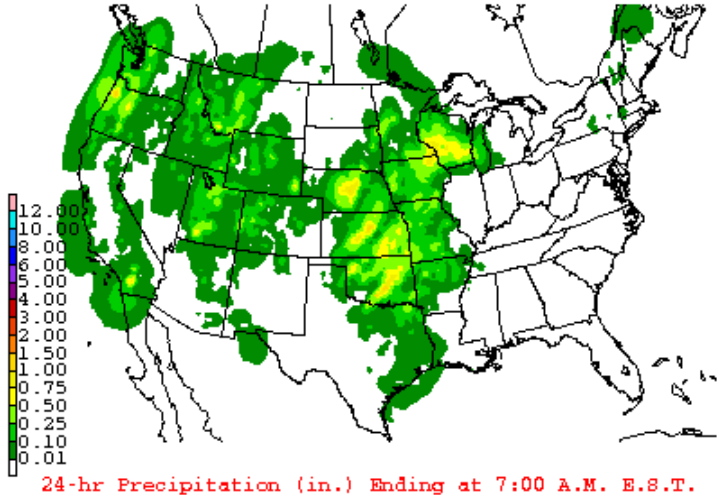
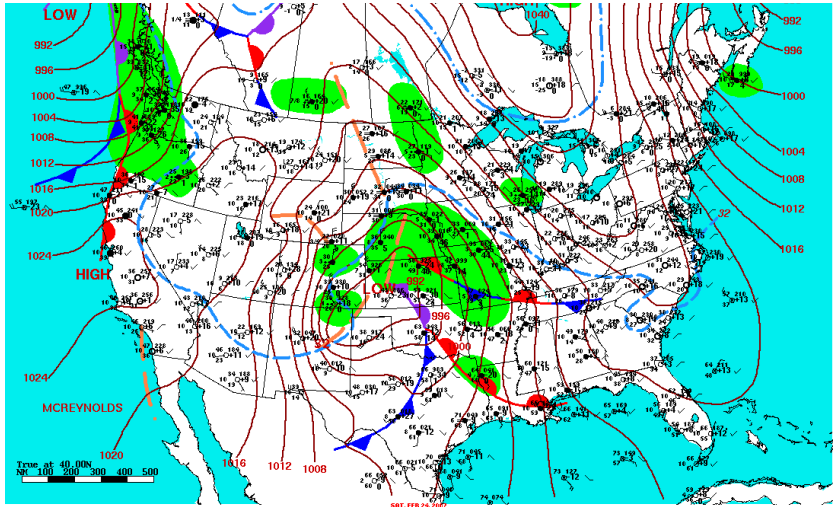
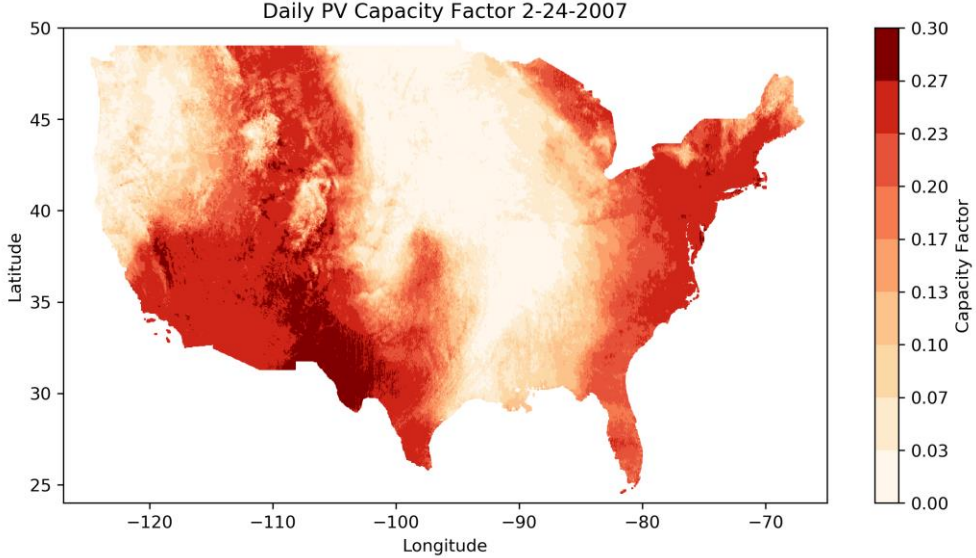
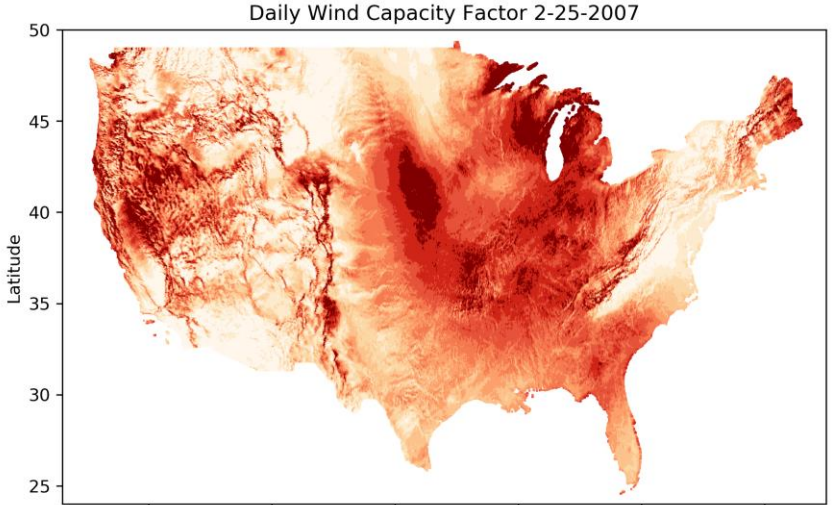
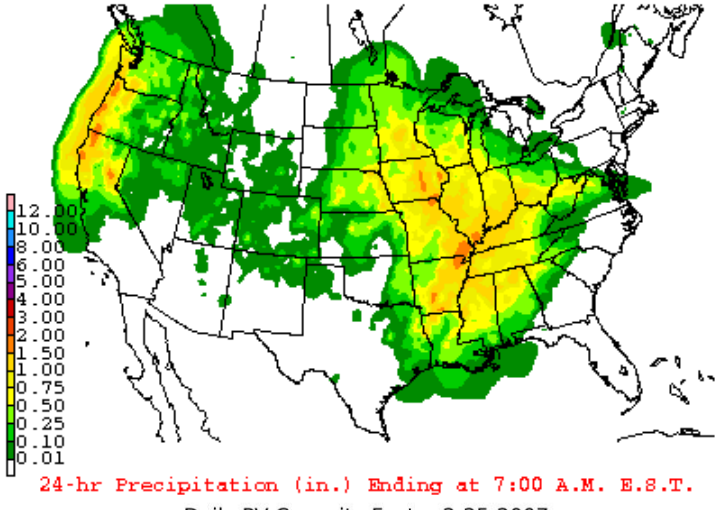

Daily Wind Capacity Factor 2-24-2007
Latitude
Longitude
Capacity Factor

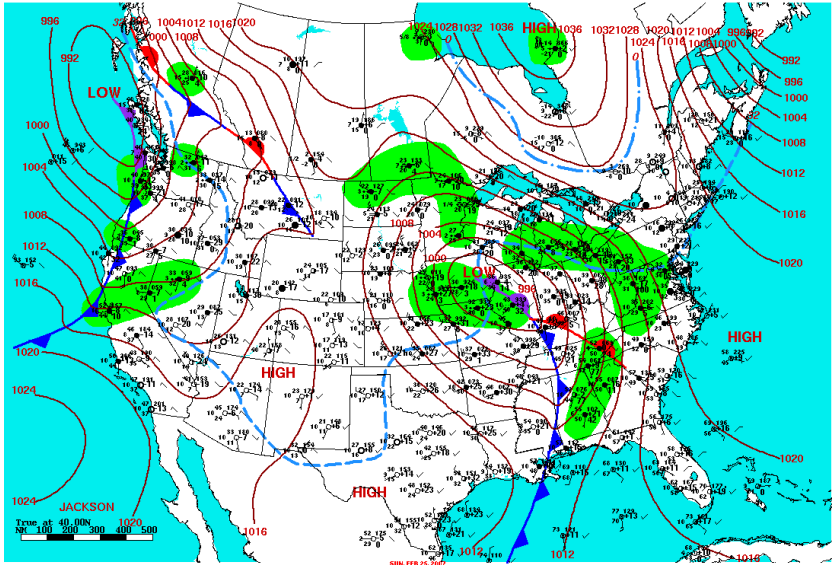

24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

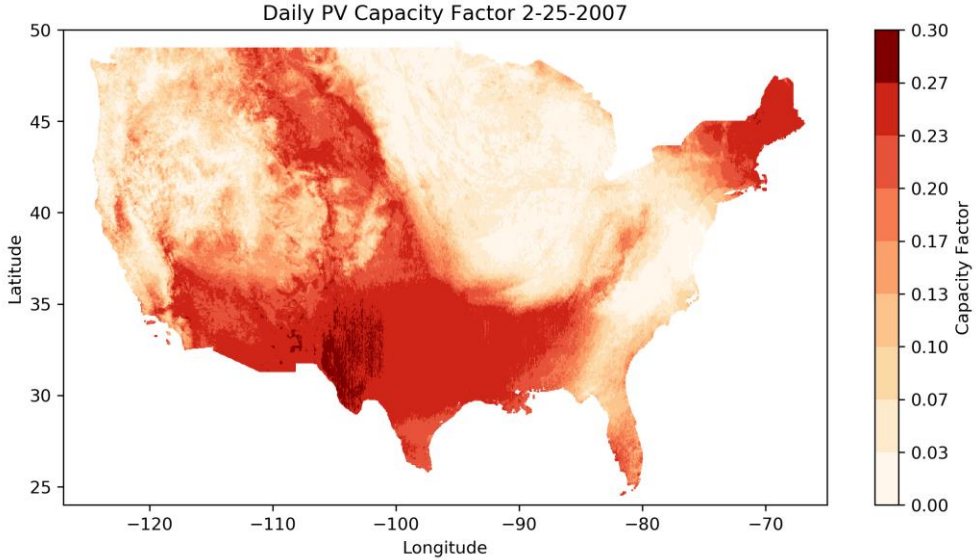

LOW
HIGH
MCREYNOLDS

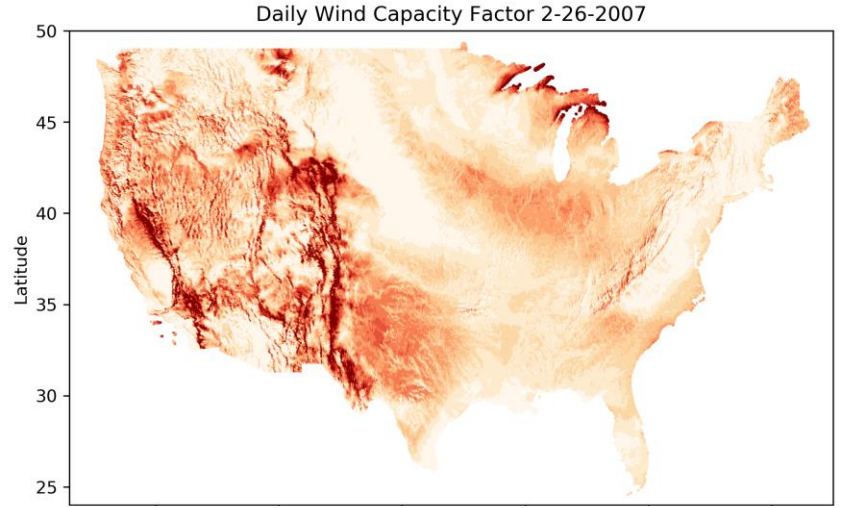

Daily PV Capacity Factor 2-24-2007
Latitude
Longitude
Capacity Factor

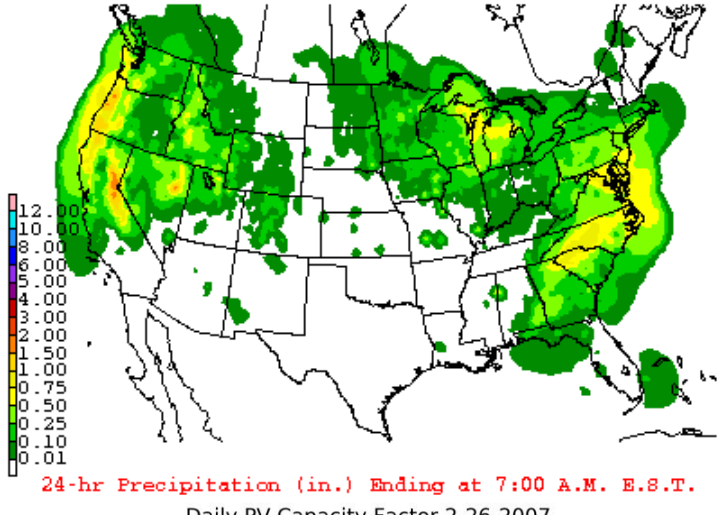

Daily Wind Capacity Factor 2-25-2007
Latitude
50
45
40
35
30
25
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

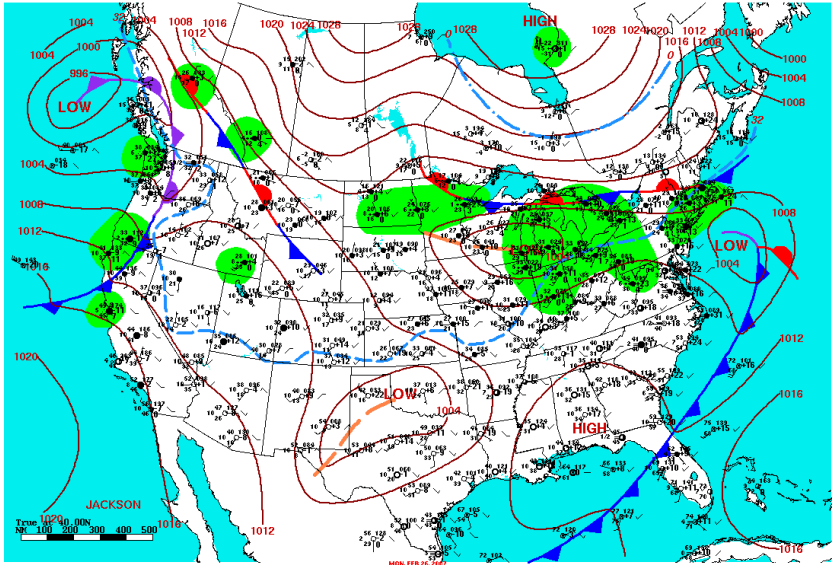

12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

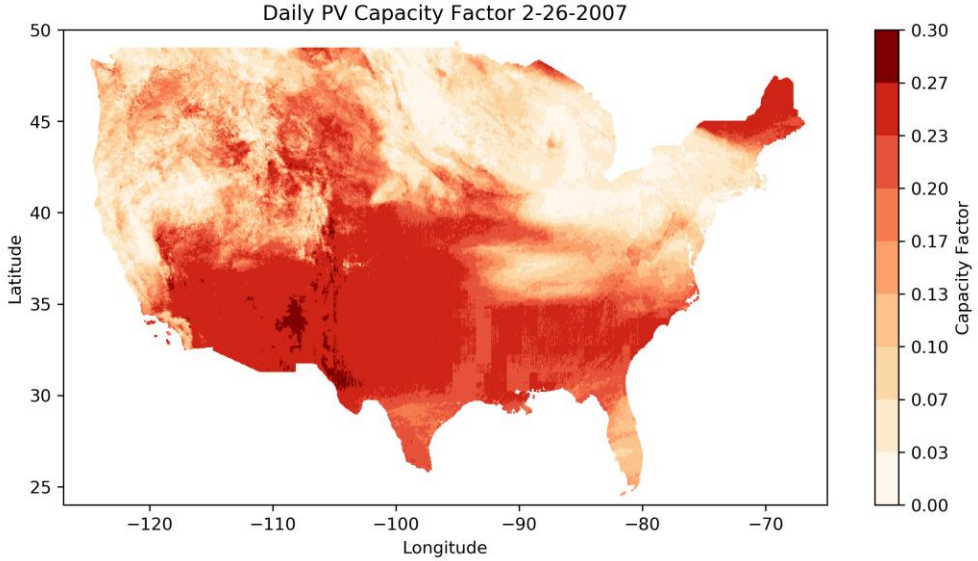

LOW
HIGH
HIGH
LOW
HIGH
HIGH
JACKSON

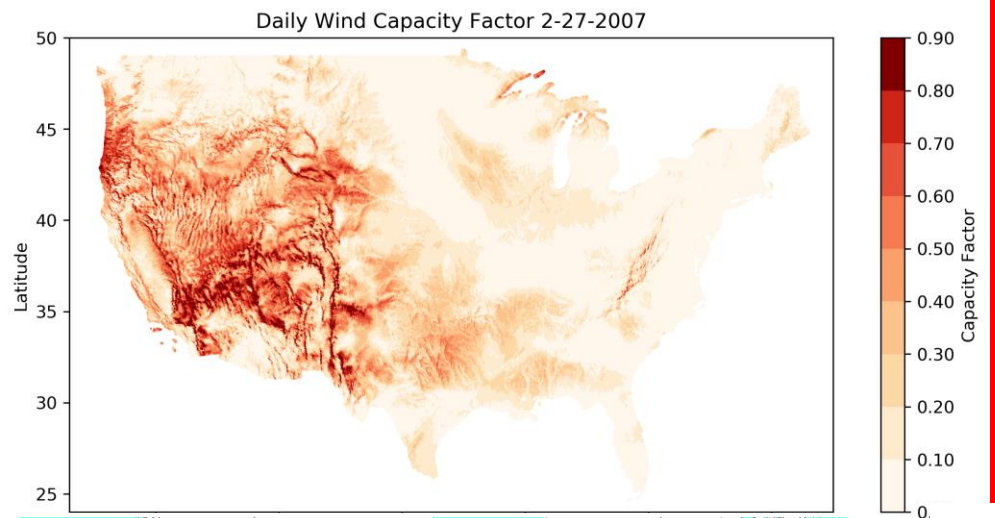

Daily PV Capacity Factor 2-25-2007
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

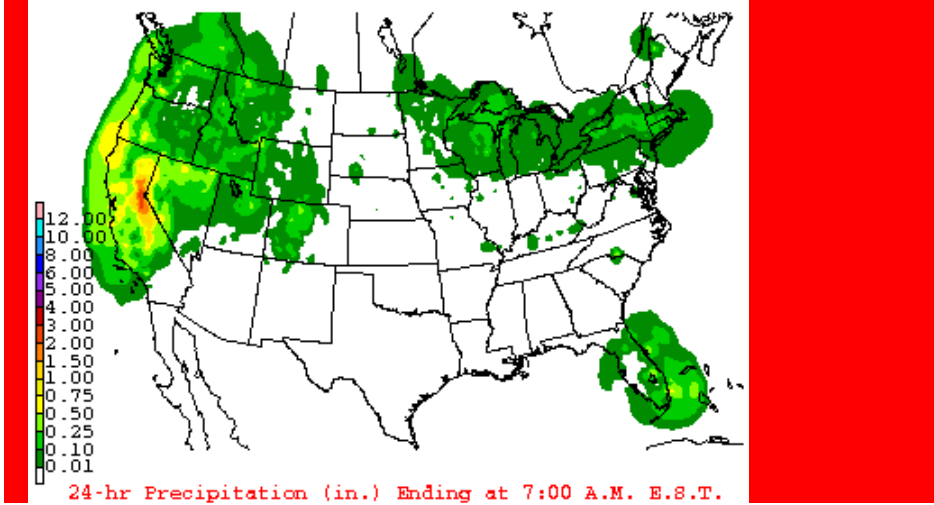

Daily Wind Capacity Factor 2-26-2007
Latitude
50
45
40
35
30
25
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.
Capacity Factor

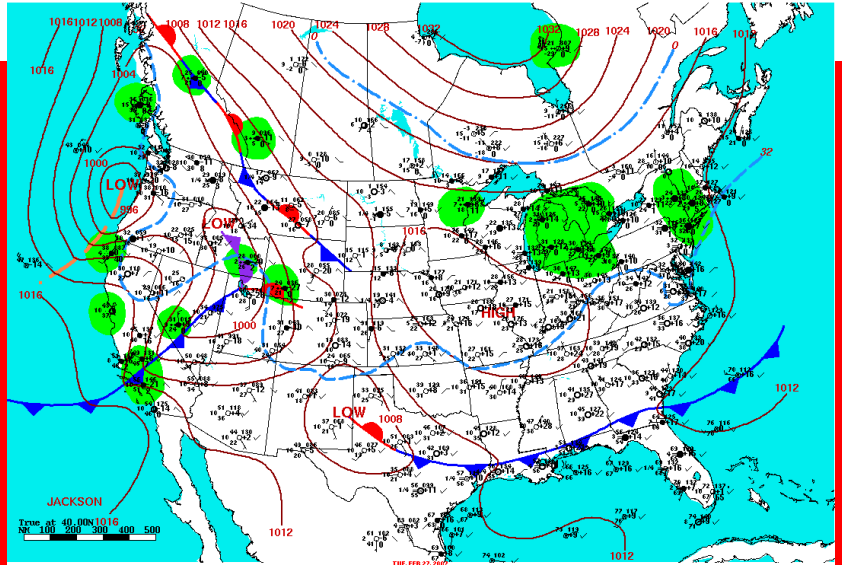

12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

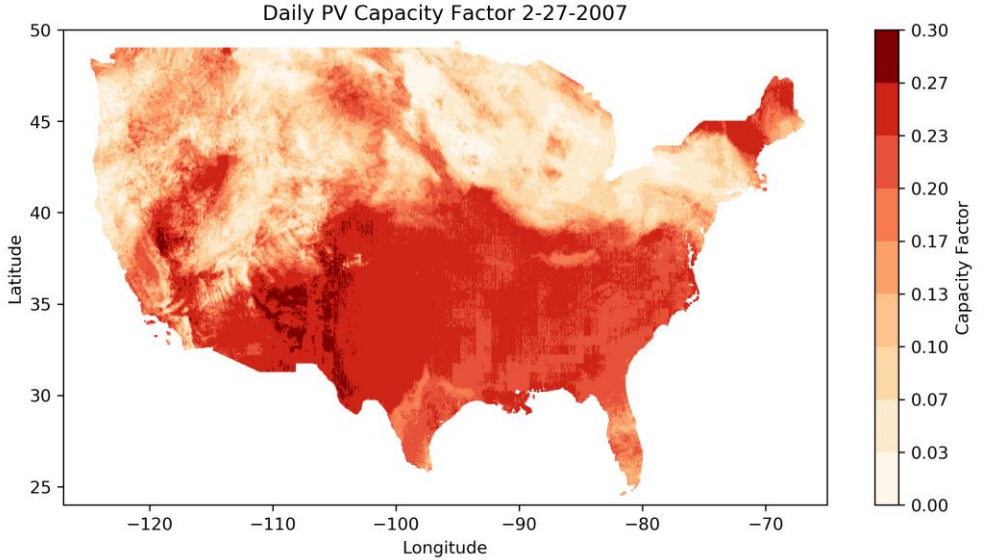

HIGH
LOW
LOW
LOW
HIGH
JACKSON

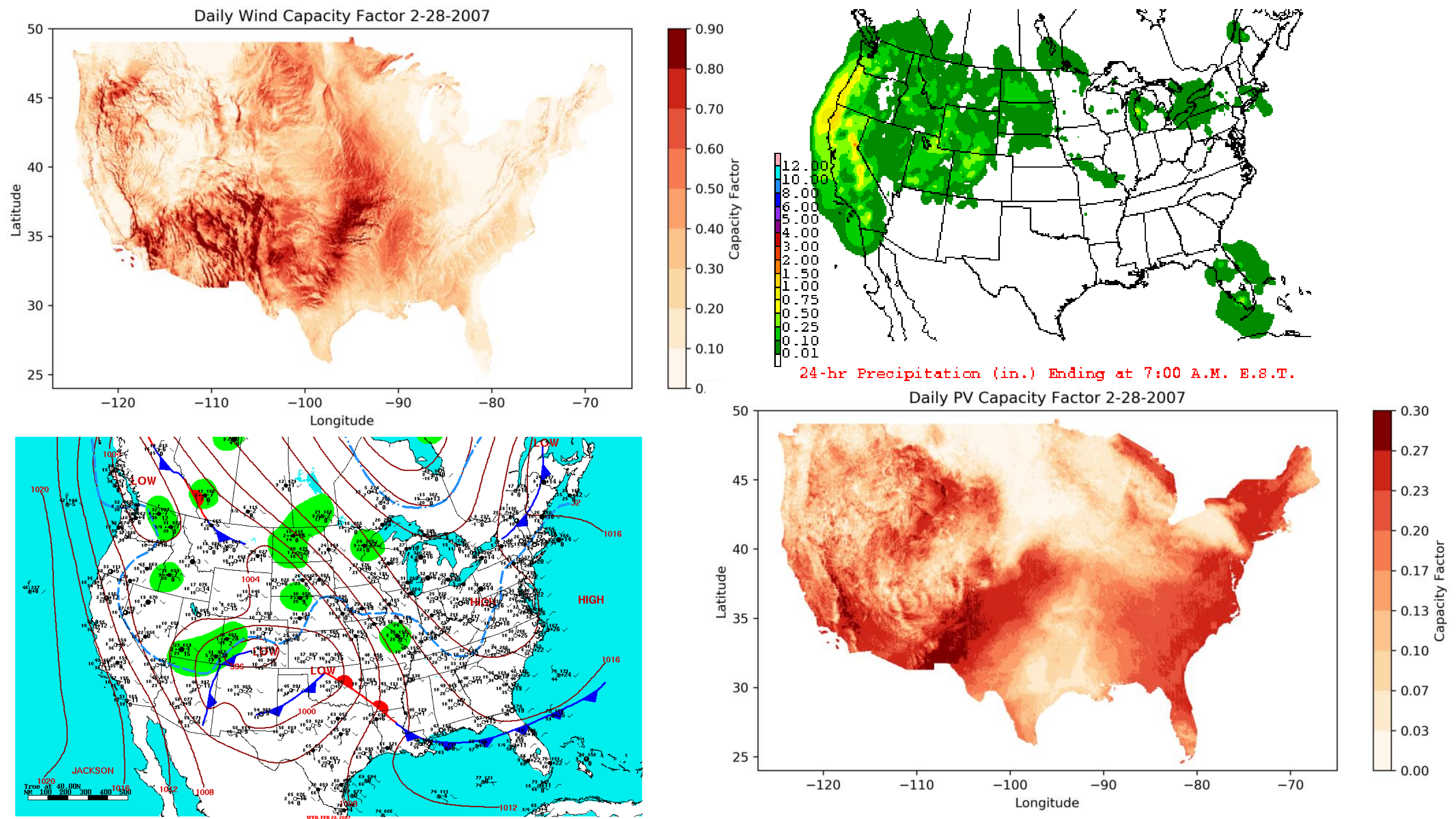

Daily PV Capacity Factor 2-26-2007
Latitude
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
Longitude
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
Capacity Factor


Daily Wind Capacity Factor 2-27-2007
Latitude
Capacity Factor
50
45
40
35
30
25
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.

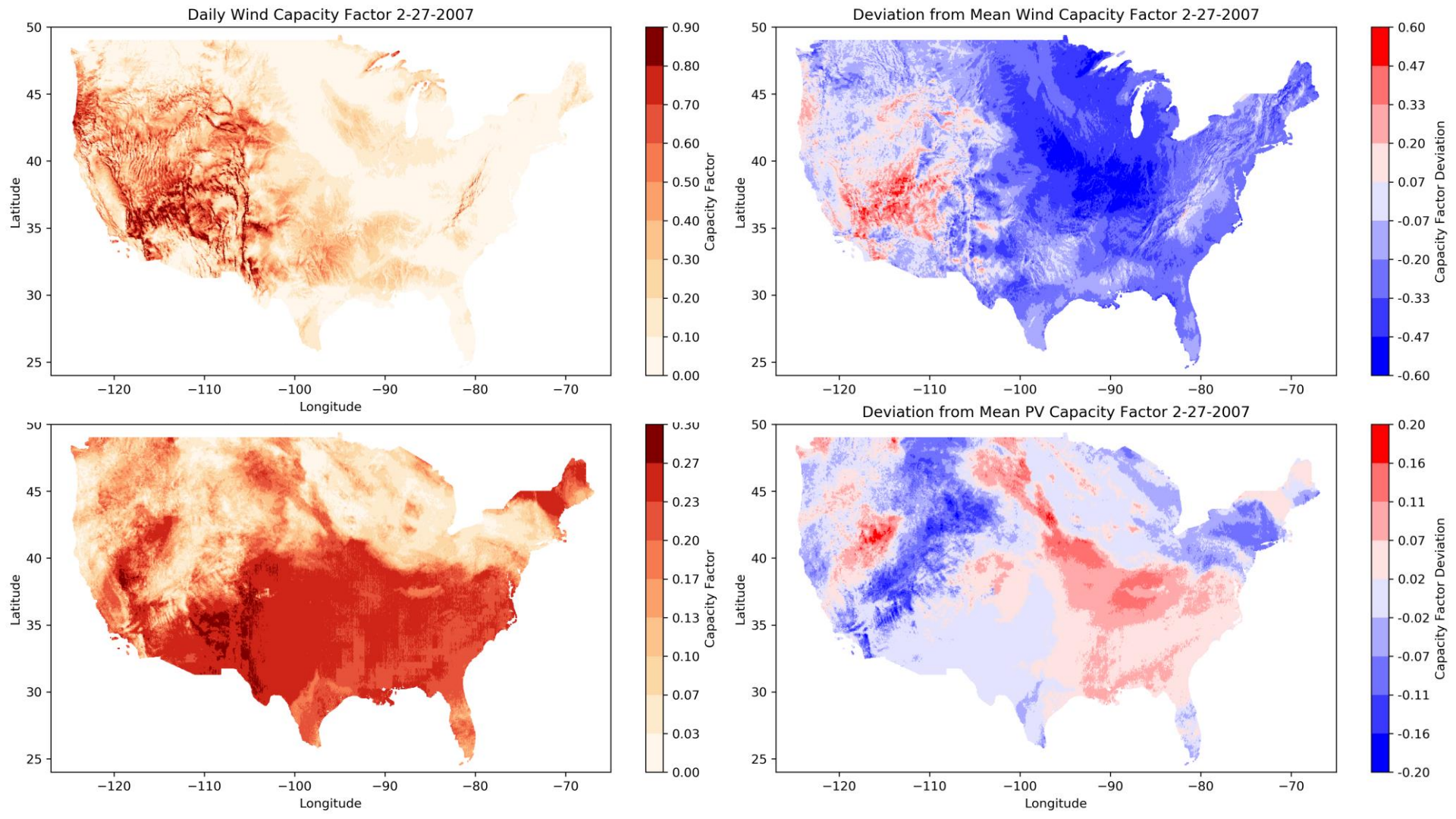

12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

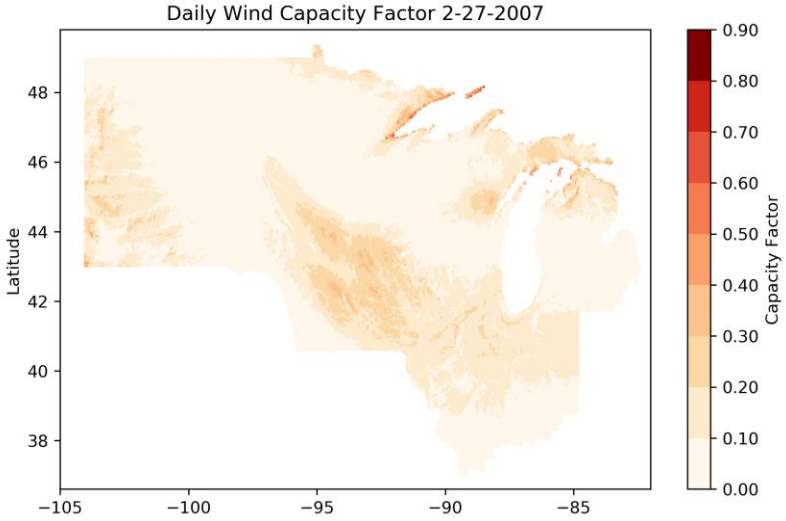

LOW
LOW
LOW
HIGH
JACKSON

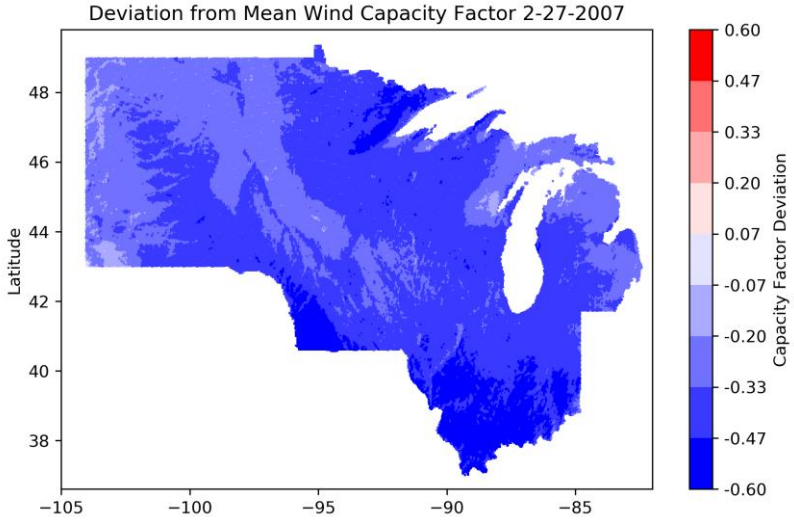

Daily PV Capacity Factor 2-27-2007
Latitude
Longitude
Capacity Factor
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00

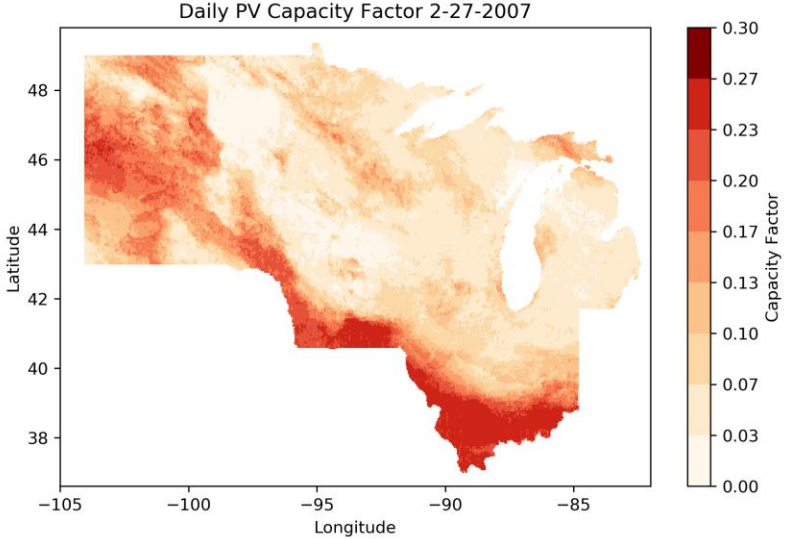


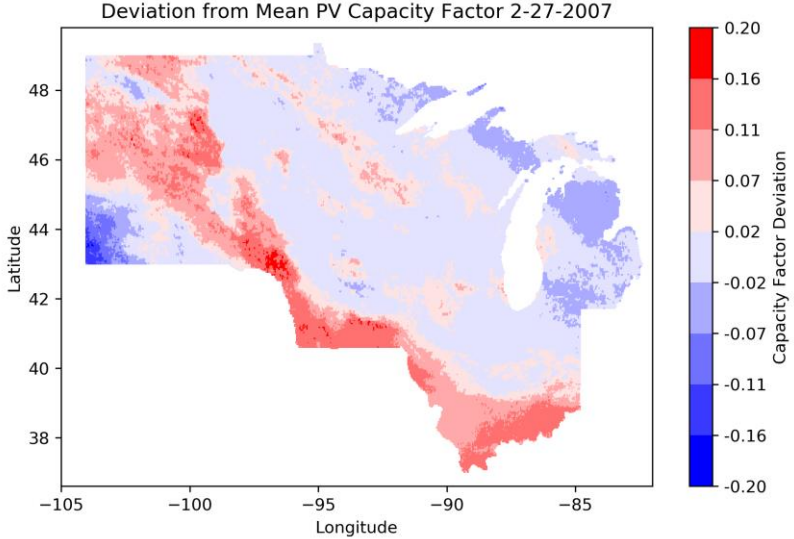
Daily Wind Capacity Factor 2-28-2007
Latitude
Longitude
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
12.00
10.00
8.00
6.00
5.00
4.00
3.00
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.01
24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.
Daily PV Capacity Factor 2-28-2007
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
LOW
HIGH
JACKSON
1020
1016
1012
1008
1004
1000
True at 40.00N
NM 100 200 300 400 500


Daily Wind Capacity Factor 2-27-2007
Deviation from Mean Wind Capacity Factor 2-27-2007
Deviation from Mean PV Capacity Factor 2-27-2007
Latitude
Longitude
Capacity Factor
Capacity Factor Deviation
50
45
40
35
30
25
−120
−110
−100
−90
−80
−70
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.60
0.47
0.33
0.20
0.07
-0.07
-0.20
-0.33
-0.47
-0.60
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
0.16
0.11
0.07
0.02
-0.02
-0.07
-0.11
-0.16
-0.20


Daily Wind Capacity Factor 2-27-2007
Latitude
Capacity Factor
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
48
46
44
42
40
38
−105
−100
−95
−90
−85

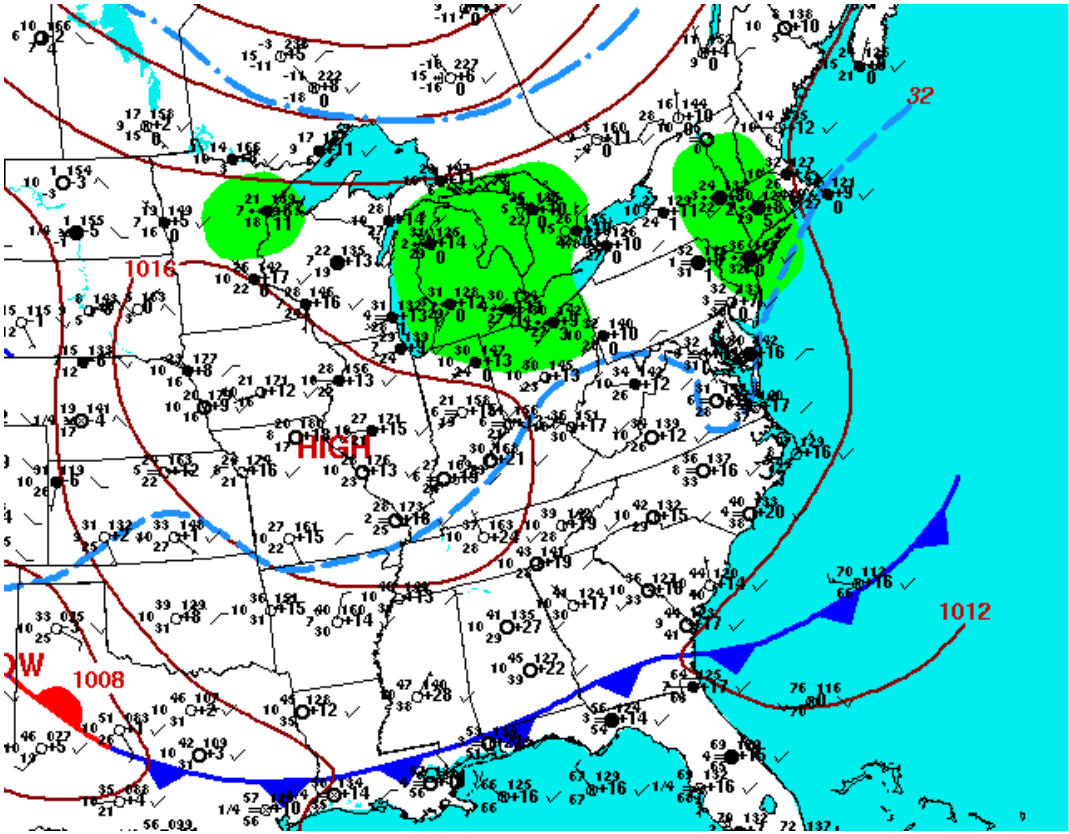

Deviation from Mean Wind Capacity Factor 2-27-2007
Latitude
Capacity Factor Deviation
0.60
0.47
0.33
0.20
0.07
-0.07
-0.20
-0.33
-0.47
-0.60
48
46
44
42
40
38
−105
−100
−95
−90
−85


Daily PV Capacity Factor 2-27-2007
Latitude
Longitude
Capacity Factor
0.30
0.27
0.23
0.20
0.17
0.13
0.10
0.07
0.03
0.00
48
46
44
42
40
38
−105
−100
−95
−90
−85


Deviation from Mean PV Capacity Factor 2-27-2007
Latitude
Longitude
Capacity Factor Deviation
0.20
0.16
0.11
0.07
0.02
-0.02
-0.07
-0.11
-0.16
-0.20
48
46
44
42
40
38
−105
−100
−95
−90
−85

February 27, 2007 - Summary

- Largest nationwide deviation from average wind capacity in the dataset
  - Driven by high pressure east of the Rockies
  - West was actually slightly normal!
- The ENTIRE east is 28 CF points below normal wind capacity
- The northern MISO area was >36 CF points below for wind
- Solar resource was well above normal
- Temperatures were near and slightly above normal east of the Rockies
  - But note the freezing line…it's still winter and plenty cold for robust load



Summary And Next Steps

- Initial analysis of the WIND Toolkit and NSRDB Database indicates that they can mined to discover periods where wind and/or solar resource exhibits tails that may be important to mitigate at high penetrations
- The resource obtained from the datasets exhibits a good qualitative fit with observed weather conditions obtained from public sources
- An initial analysis (not discussed in detail here) suggests that tail events that stress the “traditional” system may occur concurrently with those that stress renewable generation BUT periods that appear benign are also important
- We generated statistics that show geographic and resource diversity are crucial
- Cold season tails are more frequent than warm season ones but warm season resource tails exist too and can be concurrent with high loads
- Next steps include:
  - Producing a detailed catalog of interesting events including high resource, low load tails in shoulder seasons
  - Digging into impacts of weather on renewable operations

Acknowledgements

A big thank you to Michael Rossol and Grant Buster for programming and data sciences support. There help was crucial.

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