Hi all,

Synoptic-scale and mesoscale aspects of recent clustered cyclogeneis events in the Northeast were the subjects of the 23 March and 6 April Friday map discussions, respectively. Supporting materials can be found here http://www.atmos.albany.edu/mapdisco/20180323/ and here http://www.atmos.albany.edu/mapdisco/20180406/. Tomer Burg and Eric Bunker assisted with map discussion.

I. 23 March 2018: Synoptic overview of the clustered northeastern US cyclogenesis events of 1–21 March 2018:

1. Selected NH mean and anomaly maps for 1–21 March 2018 can be found here:

a) 250-hPa mean and anomalous winds: http://www.atmos.albany.edu/mapdisco/20180323/images/250W_NH_1–21Mar18.gif and http://www.atmos.albany.edu/mapdisco/20180323/images/250WA_NH_1–21Mar18.gif

b) 300-hPa mean and anomalous heights: http://www.atmos.albany.edu/mapdisco/20180323/images/300Z_NH_1–21Mar18.gif and http://www.atmos.albany.edu/mapdisco/20180323/images/300ZA_NH_1–21Mar18.gif

c) 850-hPa mean and anomalous temperature: http://www.atmos.albany.edu/mapdisco/20180323/images/850T_NH_1–21Mar18.gif and http://www.atmos.albany.edu/mapdisco/20180323/images/850TA_NH_1–21Mar18.gif

d) Mean and anomalous SLP: http://www.atmos.albany.edu/mapdisco/20180323/images/SLP_NH_1–21Mar18.gif and http://www.atmos.albany.edu/mapdisco/20180323/images/SLPA_NH_1–21Mar18.gif

2. Clustered cyclogenesis events:

Key features of interest include a retracted North Pacific jet stream, an extensive band of anomalously high 300-hPa heights from North Africa eastward across northern Asia to the North Pacific, and from there northeastward to southern Greenland. Other key features included anomalously low 300-hPa heights from the midlatitude eastern North Pacific eastward across the CONUS, with a pronounced anomalous height minimum near the midAtlantic coast, the North Atlantic, western Europe, and northeastward toward northern

Russia. These large-scale 300-hPa flow anomalies are consistent with an anomalously strong subtropical jet across the North Atlantic and North Africa, and an anomalously strong polar jet from northwestern Europe to northeastern Asia and western Alaska. Positive 300-hPa height anomaly centers near the Aleutians and the Davis Straight are consistent with a blocking pattern in both regions and with the negative phase of the NAO/AO.

The 850-hPa temperature anomaly pattern pretty well mirrors the 300-hPa height anomaly pattern, consistent with an equivalent barotropic atmospheric structure to first order. The SLP anomaly map indicates the presence of anomalous easterlies from northern Russia westward to northeastern Canada and the northeastern U.S. to the south of an anomalous 10–15 hPa anticyclone centered over Greenland, a pattern that is also consistent with the negative phase of the NAO/AO. Veteran East Coast weather weenies will recognize these anomaly patterns as supportive of clustered cyclogenesis events in which warm-air advection from the north and northeast can wrap westward and then southward around deep coastal cyclones with resulting heavy precipitation extending well inland. Tomer Burg's map of total snowfall in the Northeast from 1–21 March shows the broad coverage of snow across the region aside from a notable snow hole near State College and a broader area of minimal snowfall in southern and eastern Ohio (http://www.atmos.albany.edu/mapdisco/20180323/images/MarchSnow.png). Individual storm snowfall maps prepared by Tomer Burg can be found here: http://www.atmos.albany.edu/student/tburg/snow/. The NWS-Albany regional total snowfall map for the 2 March 2018 storm can be found here: http://www.atmos.albany.edu/mapdisco/20180323/images/2marchsnow.png

3. Tomer Burg's surface and upper air maps for the North Pacific, North America, and the CONUS for 1 March–4 April 2018:

Tomer's maps (http://www.atmos.albany.edu/student/tburg/analysis/201803.php) allow interested readers to gain an excellent appreciation of the complex and multiple synoptic-scale trough interactions that governed atmospheric behavior over much of the central and eastern CONUS as well as adjacent Canada and the western Atlantic during the significant snow events of 2, 7, 13, and 21 March 2018. Choose the maps you want to view at the top and use the left and right arrows to move backward and forward.

4. Synoptic-scale science issues and opportunities:

To first order, the predictability horizon for the aforementioned clustered cyclogenesis events was relatively limited. Although we knew 5–7 days in advance that significant snowfall events were likely to occur somewhere in the Northeast, the details of where and when the heaviest snow would fall and where the rain/snow line would be located were often unclear until < 24–48 h before significant precipitation beain to fall even when making full use of ensemble forecasts. Tomer Burg's loop of 500-hPa absolute vorticity, geopotential height, and winds shows that these clustered cyclognesis events where characterized by multiple interacting troughs and individual vorticity maxima.

We hypothesize that Fujiwhara-like trough/vorticity interactions in which individual troughs and vorticity maximum tended to rotate cyclonically around one another helped to draw the deepening coastal storms closer to the coast. We also hypothesize that a persistent blocking cold anticyclone to the north (NAO and AO were < 0) over eastern Canada enabled warm-air advection from the northeast, north, and northwest to wrap cyclonically around the deepening coastal cyclones well to the west of these cyclone centers. These two hypotheses are consistent with the observed heavy snow falling well to the west of the individual coastal cyclones. We suggest that both hypotheses can be tested within the context of a predictability investigation.

Sheldon Kusselson posted great experimental CIRA advected layered PW satellite imagery of the 2, 7, 13, and 21 March 2018 snow events to the map listserv (see below). His imagery nicely shows how high PW corridors (atmospheric rivers) wrap westward and cyclonically around the 2, 7, and 13 March storms, consistent with the above discussion about warm-air advection wrapping around the coastal cyclones from the northeast, north, and northwest. The failure of a high PW corridor to wrap westward and cyclonically around the 21 March cyclone is consistent with the heavy snow forecast failure in the Boston area for this event (see section II below).
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Sheldon Kusselson post from 16 March 2018:

"Hello Map,

With the increasing potential of yet a 4th major March 2018 NE US storm for the Tuesday night into early Thursday time frame, I decided to put together a satellite comparison of the previous three with the Experimental Layered Precipitable Water product. A training session on the product can be found at: http://rammb.cira.colostate.edu/training/visit/training_sessions/advected_layer_precipitable_water_product/ and embedded in that a quick guide at: http://rammb.cira.colostate.edu/training/visit/training_sessions/advected_layer_precipitable_water_product/QuickGuide_LPW_Advected_20180216.pdf .

Attached are images of the four layers of the advected precipitable water near the time of the lowest surface pressure of the storm for each event, along with 24 h precipitation amounts and NCEP WPC surface analysis.

One of many big takeaways of this big picture satellite product is the length of the atmospheric river of moisture or moisture plume at all layers, even at the 500-300 hPa level.

And especially the first event ~ 2 March where precipitable water moisture at the highest levels of 700-500 and 500-300 hPa can be traced way back to the eastern tropical Pacific Ocean.

Though still experimental and having at times missing data swaths in the composite product, the CIRA experimental Layered Precipitable Water product at http://cat.cira.colostate.edu/sport/layered/advected/LPW_alt.htm will be improved over the next three years to fill in gaps as more polar orbiting satellites are used. In the meantime, you are more than welcome to view the 4 layer product for the upcoming storm next week to see how it compares with the previous March 2018 storms.

Sheldon Kusselson
Retired, NOAA/NESDIS"

Addendum posted by Sheldon Kusselson on 21 March 2018:

"I have added this latest storm in the Mid-Atlantic to my comparisons of Northeast US Winter Storms this month...making 4 in a little less than 3 weeks. This latest "March Madness" one does not have as long a fetch of precipitable water moisture at 4 layers as the previous events. As a matter of fact the highest level at 500-300 had no discernible "atmospheric river of moisture. So, in addition to other things, there won't be the bombing low off the coast and excessive precipitation in New England like seen with the previous events.
But don't tell the folks in the DC-Baltimore corridor that. As this will go down as the heaviest snow of the winter in many places and one of the heaviest snows so late in the season."
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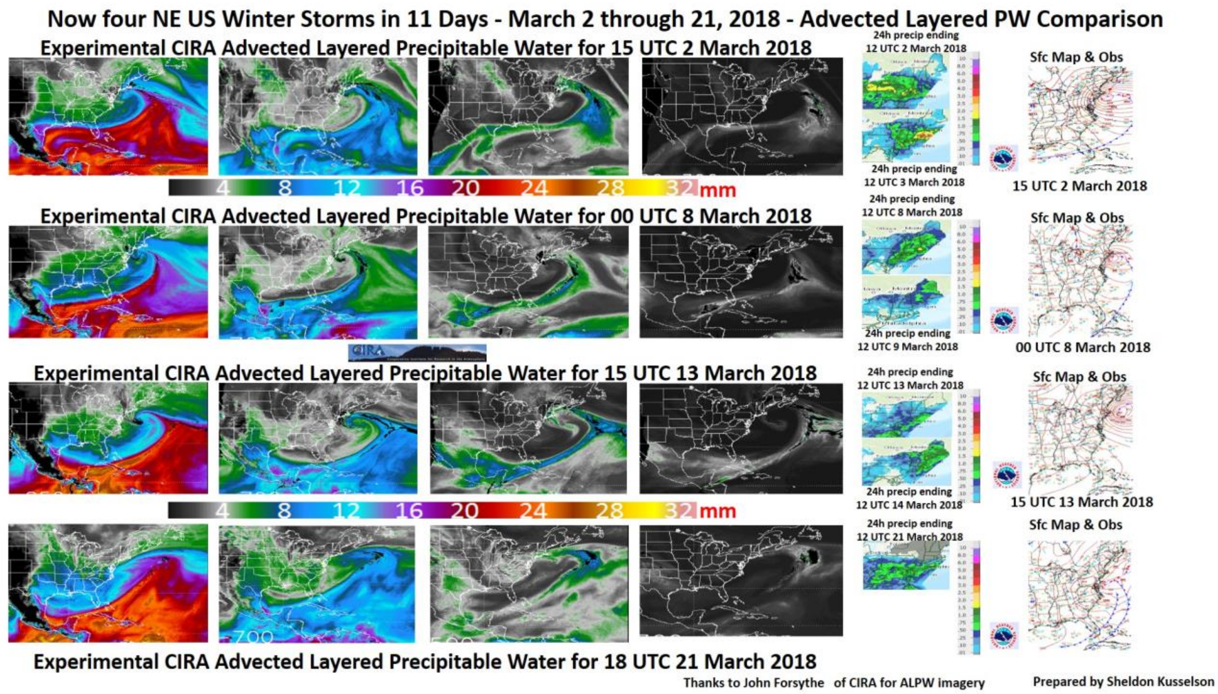

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II. 6 April 2018: Mesoscale aspects of the clustered cyclogenesis events of 1–21 March 2018:

1. Overview:

Mesoscale banded structures are readily evident in Tomer Burg's radar loops of the storms of 2, 7, and 13 March 2018 (http://www.atmos.albany.edu/student/tburg/analysis/radar_20180302.php, http://www.atmos.albany.edu/student/tburg/analysis/radar_20180307.php, and http://www.atmos.albany.edu/student/tburg/analysis/radar_20180313.php (no radar loop is available for the storm of 21 March). The 13 March storm was especially noteworthy for a double banded structure (http://www.atmos.albany.edu/mapdisco/20180406/images/radar.jpg) during which the Berkshires and Worcester highlands received copious snowfall while much of the Connecticut River Valley experienced a relative snowfall minimum. A discussion of the snowfall amount forecast challenge from the Boston perspective (courtesy of David Epstein at the Boston Globe) where heavy snow was forecast but not observed on 21 March can be found here (http://www.bostonglobe.com/metro/2018/03/22/how-did-forecasters-get-this-nor-easter-wrong/i4id17vN9NVT1uEHZXHeCO/story.html?camp=breakingnews:newsletter)

2. Science issues:

a) Banded structures:

Mesoscale snow band structures, evident in all four storms, were especially prominent in the 13 March 2018 event as evidenced by a RadarScopePro base reflectivity image from KOKX at 1437 UTC 13 March (http://www.atmos.albany.edu/mapdisco/20180406/images/radar.jpg). Observed twin heavy snow bands located between Bridgeport-New Haven and along the New London-Norwich corridor at 1437 UTC straddle an elongated snow hole just east of Shirley (Shirley, you are joking). The 1437 UTC radar image is consistent with an observed regional radar loop made by Tomer Burg (http://www.atmos.albany.edu/student/tburg/analysis/radar_20180313.php). A west-east vertical cross section through the aforementioned twin snow bands in the 7-h 3-km NAM from 0600 UTC 13 March and valid 1300 UTC 13 March shows that the twin snow bands are both associated with two-dimensional frontogenesis maxima. A distinguishing feature of the westernmost snow band is it is associated with a frontogenesis maximum between 700–600-hPa that coincides with a dendritic growth zone while the easternmost snow band exhibits equally intense frontogenetical forcing, but is lower in the atmosphere between 850–700 hPa. We hypothesize that the westernmost snow band was linked to mid-level confluent frontogenetical forcing that may have been enhanced by low-level upslope flow along the eastern slopes of the higher terrain over western CT/MA while the easternmost snow band formed in a region of wrap-around warm-air advection frontogenesis north and northwest of the offshore cyclone that may have been further reinforced by surface NNE flow along the coast and more northerly flow inland over the Worcester hills. Sinking motion between the two frontogenetically forced snow bands likely contributed to the snow hole over the Connecticut River Valley. WRF simulations will be needed to test this hypothesis.

b) GFS planetary boundary layer issues in the 2 March 2018 storm:

The observed Albany, NY, sounding for 1200 UTC 2 March (http://www.atmos.albany.edu/mapdisco/20180406/images/ALB.gif) shows a deeply saturated atmosphere with quasi isothermal conditions below ~800 hPa, deep warm-air advection as evidenced by the veering wind profile, and near freezing conditions at the surface consistent with the observed steady snowfall at that time. The corresponding 24 h forecast GFS sounding over Albany (derived from the Tropical Tidbits site) shows a similar warm-air advection wind profile, but with an unsaturated quasi-mixed layer from the surface to 900 hPa. The model forecast surfaceT/Td of 39/33 is inconsistent with the forecast saturated environment above 900 hPa from which precipitation would be falling. There is also enough "north" in the low level wind to avoid downslope warming issues in the Hudson Valley. Something is likely wrong with the GFS planetary boundary layer (PBL) forecast in this case. It is noteworthy that GFS MOS forecast from 1 March had a 47 F maximum temperature on 2 March versus the 33–34 F observed temperature, a remarkably large error that likely reflected the inability of the GFS to maintain an evaporatively and sensibly cooled PBL.

To help uncover the source of the GFS PBL error, Matt Vaughan conducted two WRF runs. He centered WRF over central NY, triple nested it to a resolution of 1.33 km, and initialized the model at 0000 UTC 1 March 2018 using the 0000 UTC 1 March 2018 GFS with forecast boundary conditions (GFS data courtesy of the UCAR Research Data Archive). The simulations were run for 72-h with one run using the YSU PBL scheme, and the other run using the MYJ scheme (and their corresponding surface layer physics schemes). Some results from his simulation can be found here: http://www.atmos.albany.edu/student/mvaughan/WRF/2_March/00z_gfs/Skewt_wrf.html. Use the right and left arrows to change the forecast soundings by 1 h. Use up and down arrows to change between the YSU and MJY runs. The 35 h forecast sounding for Albany, NY, valid 1100 UTC 2 March (closest time to the observed sounding launch) from the MJY scheme shows a much more moist PBL than the GFS operational run forecast. Although the MJY sounding looks to be too cold by 0.5–1.0 C, the forecast temperature, dew point and wind profiles are in pretty good agreement with the observed ALB sounding. The corresponding 35 h forecast ALB sounding from the YSU run is similar to the MYJ run, but is slightly warmer by ~1 C. Both the MJY and YSU forecast soundings suggest that steady stratiform precipitation is occurring, an inference confirmed by the presence of 25–30 dBZ model-simulated based reflectivity values in both runs (use up and down arrows to see the simulated radar reflectivities).

c) Impressions that the Northeast and Midwest has endured an especially cold winter:

The media and the general public have been moaning and groaning for weeks now that parts of the Northeast and Midwest have endured the coldest winter since the invention of sliced bread. Curious, I constructed time series of daily average temperatures and their anomalies as well as daily maximum and minimum temperatures for the last 90 days ending 7 April from this CPC web site (http://www.cpc.ncep.noaa.gov/products/global_monitoring/temperature/global_temp_accum.shtml). I generated 90-day temperature time series plots (see below) for Washington, DC; Caribou, ME; Boston, MA; Columbus, OH; Albany, NY; and Chicago, IL. Thanks to many warm days in the second half of January and an exceptionally warm period in February, all six stations have positive daily average temperature anomalies for the last 90 days. So, why all the moaning and groaning about the cold? I suspect that the answer lies in the failure of the daily mean temperature to change much since the exceptional February warm period. Daily mean temperatures have not increased at anywhere near their climatological seasonal rate of increase over the last two months. People have noticed and they are complaining…..loudly. For perspective purposes, I have appended a four month (Dec 2017, Jan-Feb-Mar 2018) map of 850-hPa temperature anomalies (source: NOAA/ESRL/PSD). The upper Great Lakes and Northern Plains had the largest negative temperature anomalies (-

1.5 to -2.5 C). Overall, the cold December and first few days of January tipped the scales toward below normal temperatures from the Northern Plains eastward to western New England. The real story of the 2017–2018 winter that has been slow to end is not the overall mean temperature anomaly but the large temperature variability about the mean in conjunction with several persistent sub-monthly weather regimes. Welcome to a nice real-time demonstration of the difference between weather and climate. A relevant science question is what role did the sudden stratospheric warming of late January 2018 and the subsequent disruption of the polar vortex play in the evolution of the observed large-scale tropospheric flow patterns in February, March, and now into April.

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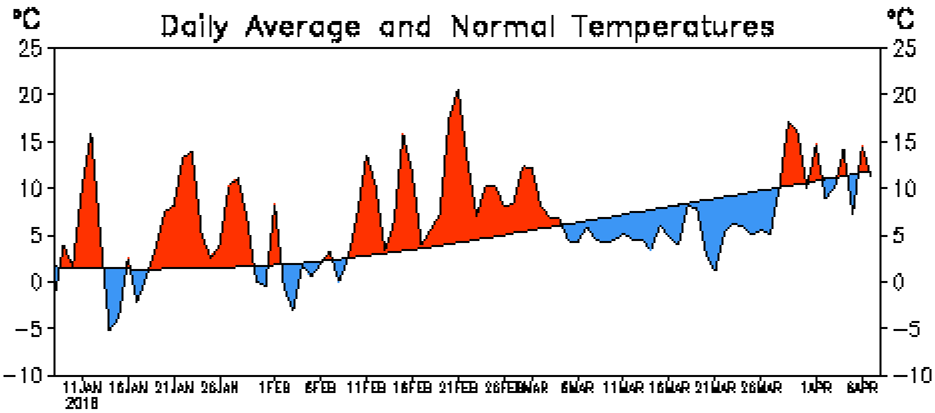
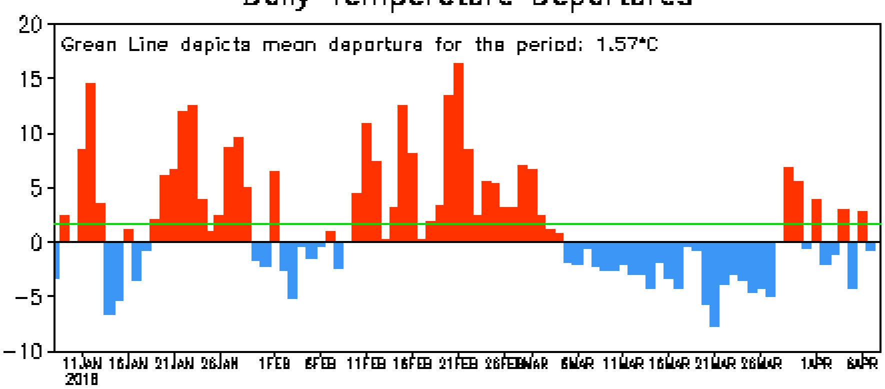
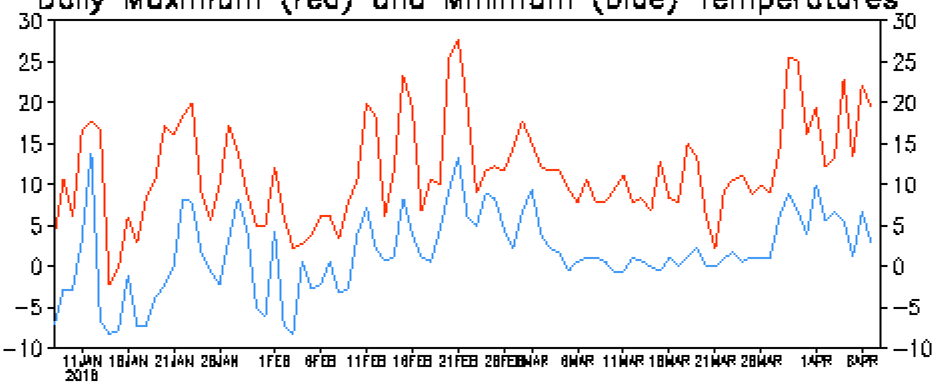
III. Figures:

1. CPC 90-day temperature time series ending 8 April 2018 for selected stations:

WASHINGTON D. C.



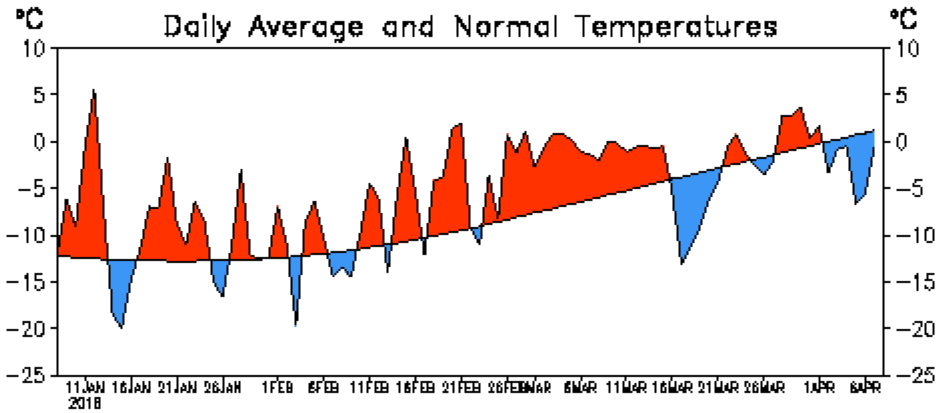


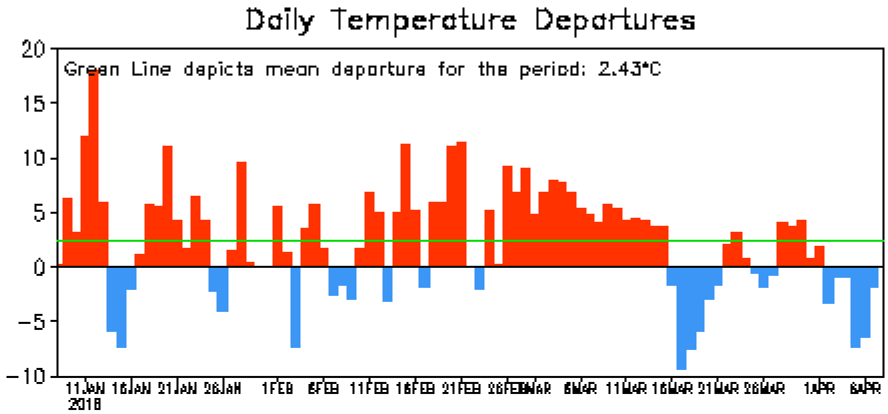


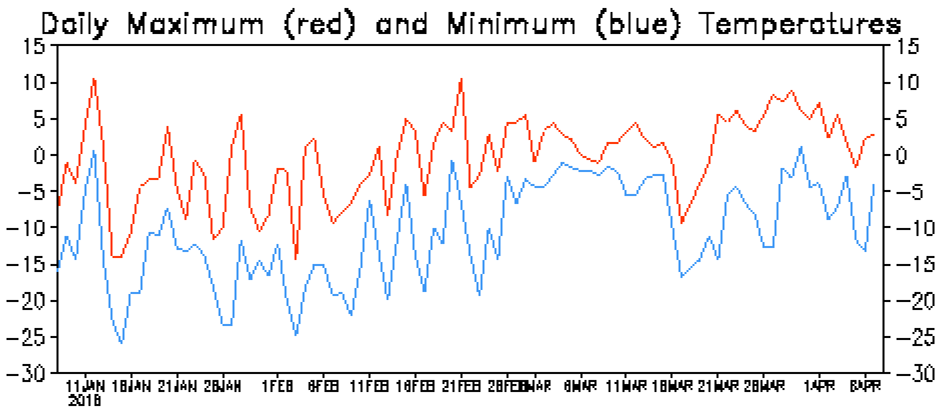
Data updated through 07 APR 2018

CLIMATE PREDICTION CENTER/NCEP

CARIBOU, MAINE





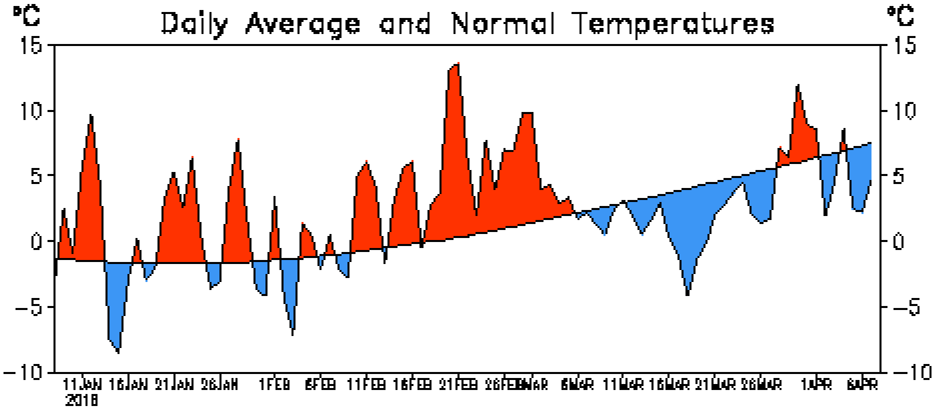


Data updated through 07 APR 2018

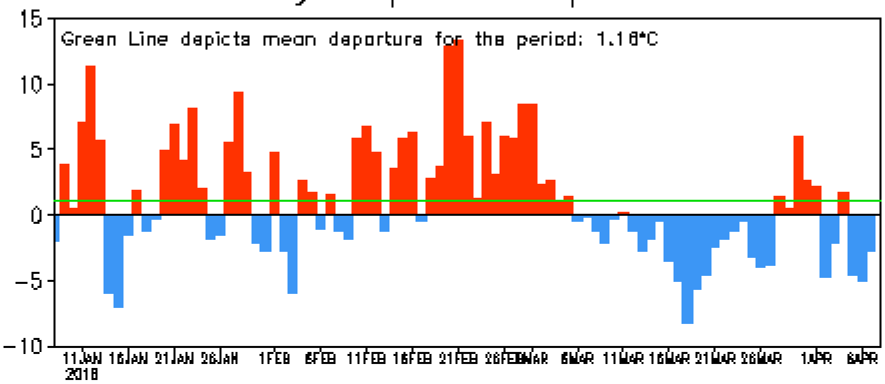
CLIMATE PREDICTION CENTER/NCEP

BOSTON/LOGAN, MASSACHUSETTS

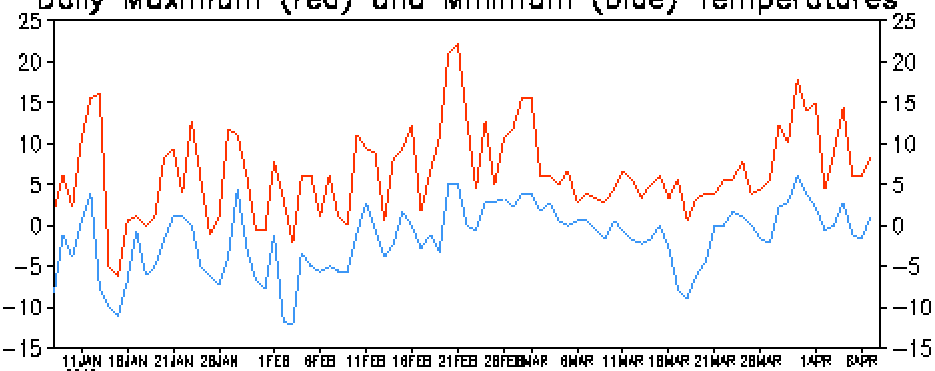
Daily Average and Normal Temperatures



Daily Temperature Departures



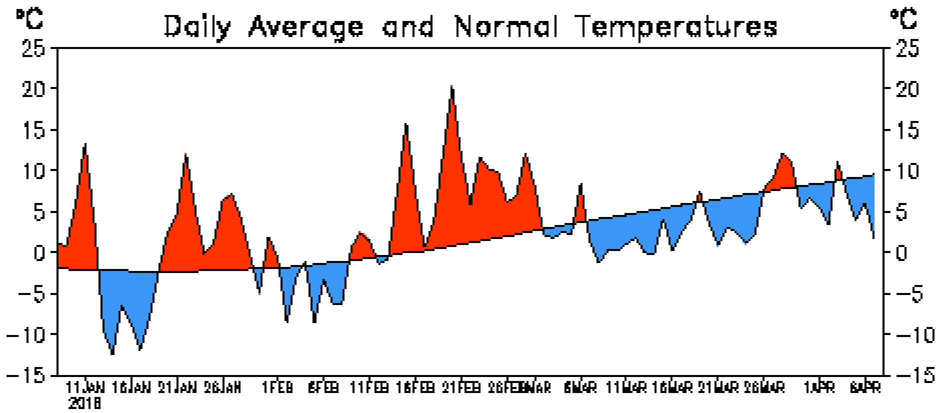
Daily Maximum (red) and Minimum (blue) Temperatures

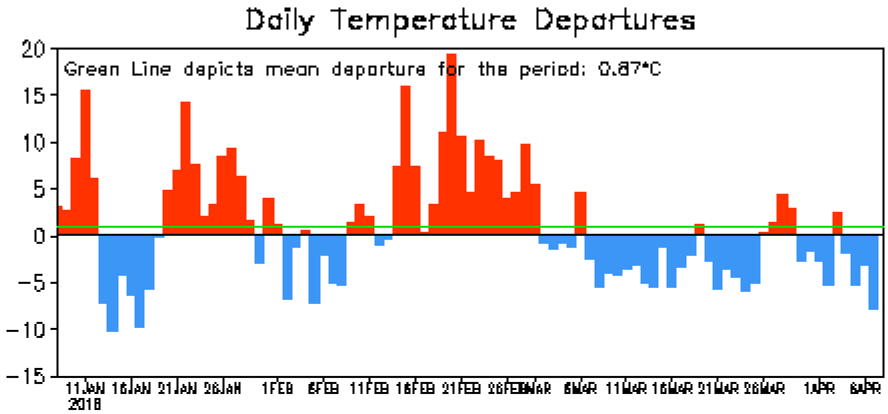


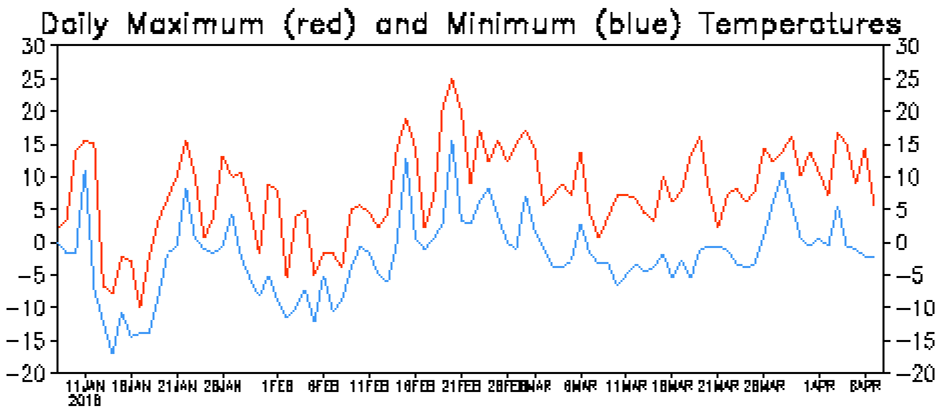
Data updated through 07 APR 2018

CLIMATE PREDICTION CENTER/NCEP

COLUMBUS, OHIO



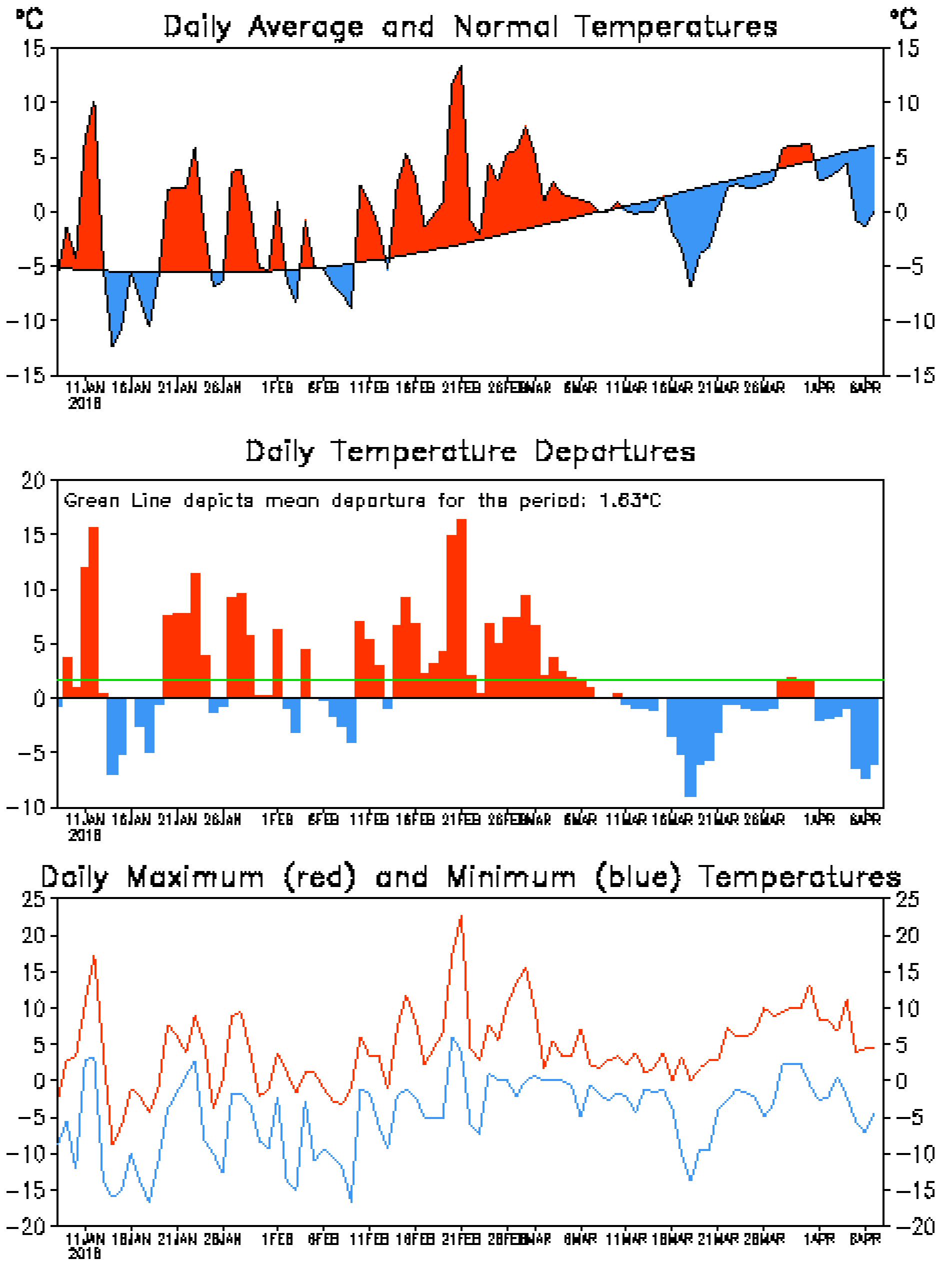




Data updated through 07 APR 2018

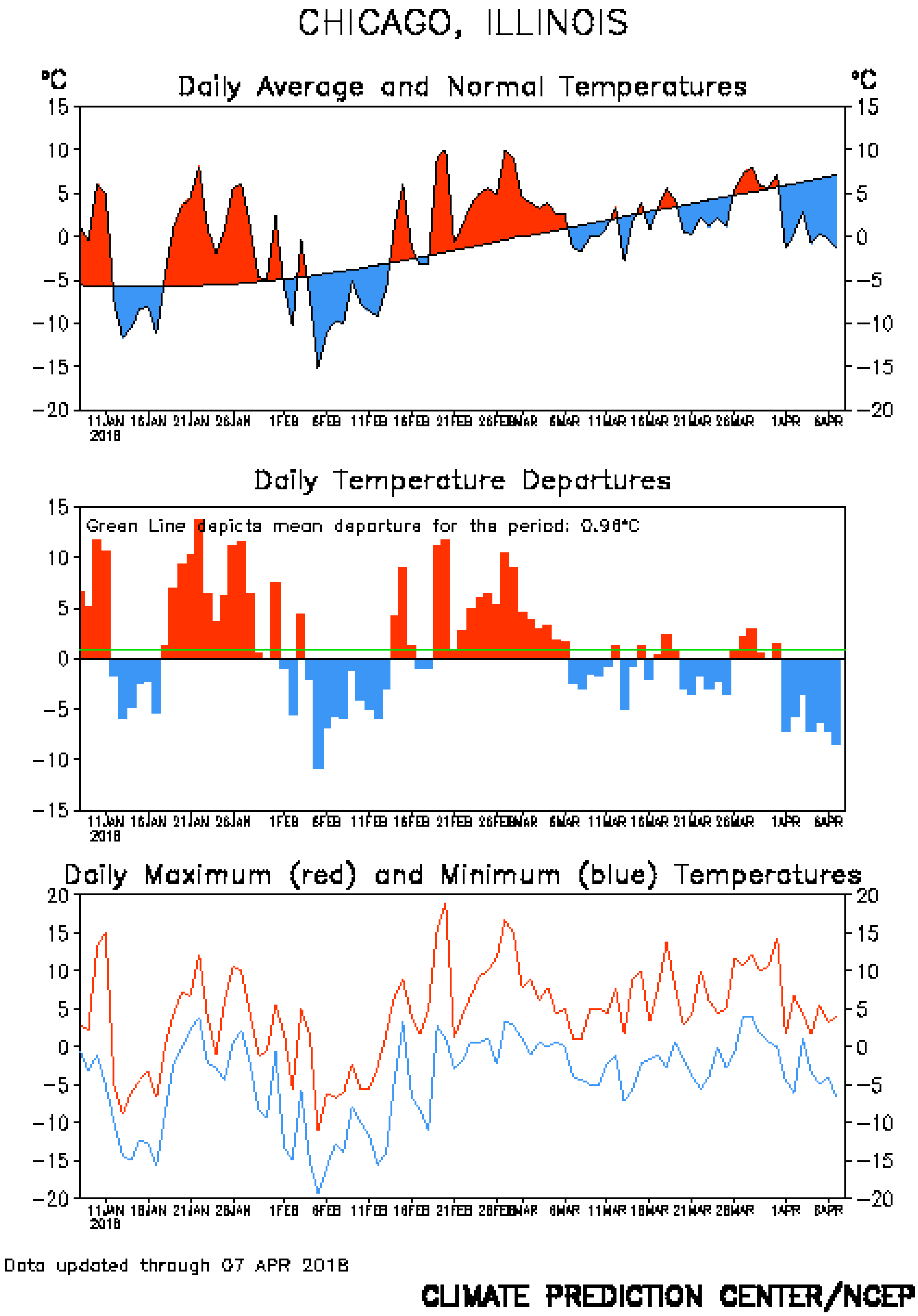
CLIMATE PREDICTION CENTER/NCEP

ALBANY, NEW YORK

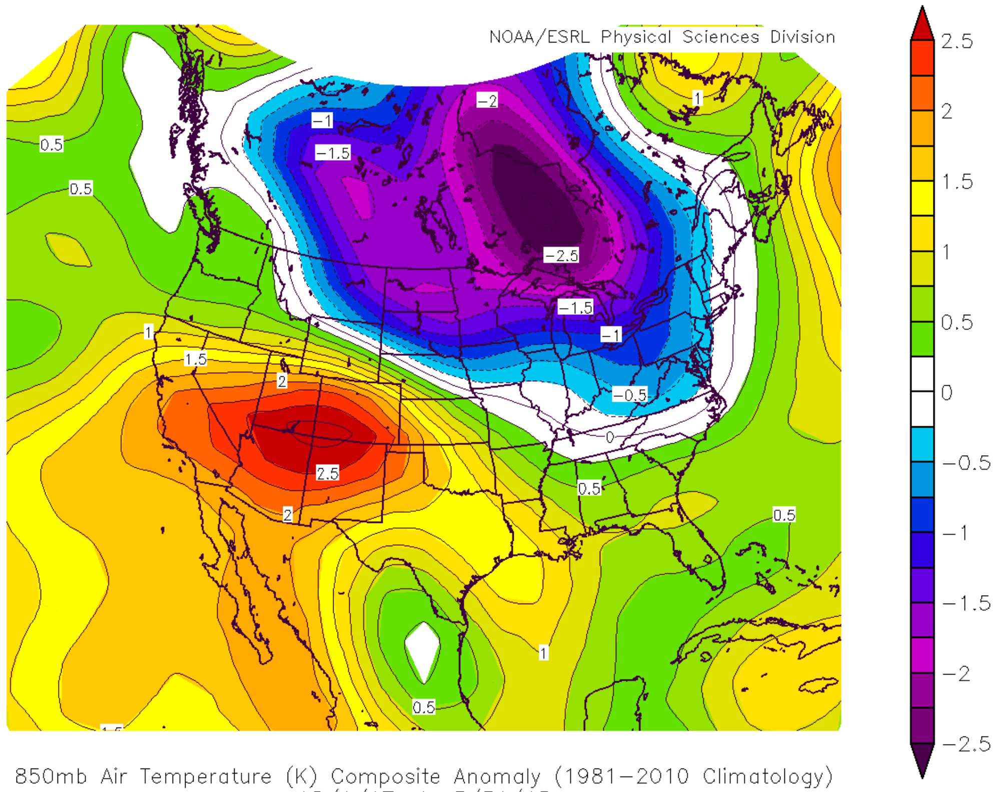


Data updated through 07 APR 2018

CLIMATE PREDICTION CENTER/NCEP



2. NOAA/ESRL/PSD 850-hPa temperature anomaly (deg C) for Dec 2017 through Mar 2018:



850mb Air Temperature (K) Composite Anomaly (1981−2010 Climatology)
12/1/17 to 3/31/18

NCEP/NCAR Reanalysis