The summer 2018 heat wave in Finland

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Abstract

We study the heatwave of summer 2018 with a focus on Finland using surface observations, radio soundings and reanalysis data. May and July 2018 were exceptionally warm with both months setting new records for the highest national mean temperature. In contrast, June was not abnormally warm. In May 2018, the temperature anomalies were relatively uniform across all of Finland whereas in July the temperature anomalies were most extreme in northern Finland. In both May and July 2018 the anomalous warmth was associated with high pressure and extended throughout the depth of the troposphere. The surface sensible and latent heat fluxes were above climatological average, but the Bowen ratio did not differ notably from the climatological mean. This suggests that surface processes did not play a decisive role in the anomalous warmth.

Introduction

Heat waves do not have a unique, specific definition but are generally accepted to be prolonged periods of time when the near surface temperature is notably warmer than the climatological average. In recent years, Europe has been affected by two exceptional heat waves: the central European heat wave of 2003 (Black et al, 2004), and the Russian heat wave of 2010 (Grumm, 2011). Both of these heat waves led to a large number of excessive deaths: Robine et al (2008) estimate that the 2003 heat wave led to an additional 70,000 deaths and Barriopedro et al (2011) estimate 55,000 extra deaths occurred in 2010. Many studies have analysed the meteorological causes of these two heat waves. Both were associated with prolonged periods of high pressure which remained relatively stationary. Black et al (2004) also analysed the role surface fluxes had on the 2003 heat wave. They showed that as the summer progressed, the latent heat flux changed from a positive anomaly to a negative anomaly as the soil dried whereas the surface heat flux anomaly continued increasing and likely contributed significantly to the 2-m temperature positive anomalies in August 2003.

Despite its northern latitude, ranging from 60 and 70°N, Finland can experience high temperatures during summer (e.g. Kim et al, 2018) due to its relatively continental climate and the relative warmth (given its latitude) of the nearby North Atlantic Ocean. The current 2-m temperature record in Finland is 37.2°C and was set in Joensuu in eastern Finland in July 2010, during the Russian heat wave. In Summer 2018, many parts of Europe again experienced above average temperatures for prolonged periods of time and Finland was no exception to this. Anomalous warmth was recorded across almost all parts of Finland in May and July 2018. In terms of the national monthly mean temperature, May and July were record warm months exceeding previous records by 0.5°C and 0.4°C respectively (FMI, 2018a,b). These observations of 2-m temperature, which are discussed further below, are the main motivation for this study. The first aim of this investigation is therefore to quantify the magnitude of the 2018 heat wave in Finland on a month-by-month basis using standard synop observations. The second aim is to identify the large-scale circulation pattern which was present during the heat wave. The final aim is to use radiosonde soundings to determine the vertical extent of the heat wave over Finland. This last aim is motivated by the fact that most heat wave studies focus on 2-m temperature and that heat waves, for example in 2003, can be strongly influenced by the lack of surface moisture (Fischer et al, 2007) and thus may be constrained within the boundary layer.

Observations of 2-m Temperature

Standard synop observations of 2-m temperature from five sites located throughout Finland (Figure 1) are analysed. The stations are all operated by the Finnish Meteorological Institute (FMI) and the data is freely available from FMI's Open data web page (FMI, 2018c). Two stations in Helsinki are considered: Kaisaniemi which is in the city centre and approximately 1 km from the sea and Vantaa, the airport, which is 20 km inland. The timeseries of daily mean, daily minimum and daily maximum 2-m temperature for each station are shown in Figure 2, along with the climatological daily mean 2-m temperature which was calculated over the standard 30-year averaging period 1981 - 2010. The panels in Figure 2 are ordered so that the most northerly station (Sodankylä, 67.4°N) is at the top and the most southerly (Helsinki Kaisaniemi, 60.1°N) at the bottom.

The first few days of May were characterised by climatologically normal temperatures at all 5 stations (Figure 2). However, the second week of May saw a considerable warming at all five stations. Between the 14th - 16th May, all 5 stations considered here recorded the highest daily maximum temperatures of the month: 27.5°C in Helsinki Kaisaniemi (15th), 29.6°C in Helsinki-Vantaa (15th) , 28.1°C in Jokioinen (15th), 28.6°C in Jyväskylä (14th) and 25.6°C in Sodankylä (16th). The previous May record maximum temperature (27.6, 29.3, 29.2, 29.3 and 28.1°C at the five stations) was only exceeded in Helsinki-Vantaa, but all these records are from the second half of May. At four of the five stations, the nighttime minimum temperatures in the middle of May exceeded the climatological daily mean temperature, indicating the anomalous warmth. The second half of May also had positive temperature anomalies at all stations but the magnitude of these varied from day-to-day. The monthly averaged temperature anomalies for May 2018 were between +4.7°C and +4.9°C for all of the 5 stations except for Helsinki Kaisaniemi which was 4.3°C warmer than average. Three (Helsinki-Vantaa, Jyväskylä and Sodankylä) of these 5 stations also record sunshine hours and all recorded anomalously sunny conditions in May 2018. Helsinki Vantaa recorded 149% of the average sunshine hours, Jyväskylä 159% and Sodankylä 108%. Therefore, it can be concluded that the anomalous warmth of May 2018 affected Finland in a relatively spatially uniform manner but that the sunshine anomalies were larger in south and central Finland compared with the north.

June 2018 was characterised by climatologically average temperatures (Figure 2). Of the 5 stations considered here, Helsinki-Vantaa had the largest positive temperature anomaly (+1.1°C) and Sodankylä had a negative anomaly (-0.6°C). Therefore, in contrast to May 2018, June 2018 was not anomalously warm.

July 2018 saw the return of the anomalous warmth to Finland, particularly after the first week. In Helsinki-Vantaa the maximum temperature of 31.4°C was measured on the 17th July and 21 days in July had a maximum temperature above 25°C. In Sodankylä, a new record maximum temperature of 32.1°C was recorded on 18th July 2018, exceeding the previous record from 1914 by 0.4°C, and 20 days had maximum temperatures exceeding 25°C. Averaged over the whole month, the 2-m temperature anomalies were larger in northern Finland than southern Finland. Sodankylä was on average 5.5°C warmer than average, Jyväskylä (62.4°N - approximately 600 km south of Sodankylä) had a temperature anomaly of +3.8°C whereas Helsinki-Kaisaniemi was 3.3°C warmer than average. In absolute terms, however, the month was slightly warmer in southern than northern Finland, with the mean temperature varying from 20.1°C in Sodankylä to 21.2°C in Helsinki-Vantaa. Positive anomalies of sunshine were also recorded particularly in the north where Sodankylä recorded 404 hours of sunshine which is equivalent to 165% of the climatological average. Smaller sunshine anomalies occurred at Helsinki Vantaa (111%) and Jyväskylä (130%).

Large-scale circulation patterns and spatial extent of 2-m temperature anomalies

ERA-Interim reanalysis data are used to determine the large-scale extent of the heat wave and the circulation pattern it was associated with. Reanalysis data, a blend of observations and model simulation, can be regarded as our best estimate of the atmospheric state. ERA-Interim covers the post-satellite era from 1979 until the present and has a spatial resolution of about 80 km (T255 in spectral resolution). Monthly mean values of mean sea level pressure (MSLP), 2-m temperature and the geopotential height at 1000 and 500 hPa are obtained from ERA-Interim. The 1000 - 500 hPa thickness is calculated (height of 500 hPa surface minus height of 1000 hPa surface) as this gives an indication of the mean temperature of this layer. Warmer layers are thicker / deeper than colder layers with a 1^{o}C warming leading to an increase of thickness of 20 m (neglecting the effect of water vapour on air density). Monthly mean anomalies are also calculated by subtracting the 1981 - 2010 climatological means which were also obtained from ERA-Interim.

The 2-m temperature anomaly for May 2018 from ERA-Interim (Figure 3a) shows that the heat wave was centred on southern Norway and Sweden where the temperatures were 6 - 7^{o}C above average. Above average temperatures are also evident over all of Finland, in agreement with the station observations, and over large parts of Germany, Poland and the Baltic States. In contrast, over western parts of Europe such as the UK and France, temperature anomalies in May 2018 were less than 2^{o}C and in south western Europe there were no positive temperature anomalies.

The average anomaly of mean sea level pressure (MSLP) during May 2018 shows an anomalous high pressure (anticyclonic circulation) over north-eastern Europe and an anomalous low pressure (cyclonic circulation) over Iceland. The high pressure over Fenno-Scandinavia acted as an efficient block which resulted in low pressure systems tracking towards Iceland and leading to record precipitation in Reykjavik. In contrast, Finland was notably drier than average in May 2018: apart from the first 3 days of May, no precipitation was recorded at Helsinki-Kaisaniemi during this month (not shown). By comparing Figure 3a and 3b it is apparent that the positive temperature anomaly over Northern Europe is largely co-located with the positive MSLP anomaly and therefore an anomalous anticyclonic circulation (Figure 3b). The largest MSLP anomalies exceeded 6 hPa and are located over southern Finland and Sweden. This anticyclonic circulation suggests that southern Finland experienced primarily easterly winds in May 2018 which would advect continental air masses from Russia towards southern Finland. The thickness of the 1000 hPa to 500 hPa layer shows the presence of an upper level ridge and a positive thickness anomaly over most southern Norway, Sweden and Finland (Figure 3c). On average, the atmospheric layer between 1000 hPa and 500 hPa (approximately the lowest 5 km of the atmosphere) was 80 - 100 m thicker than average which corresponds to a 4 - 5^{o}C warm anomaly in the layer mean temperature. This indicates that the heat wave was not confined to near the surface.

In June 2018 the large-scale pressure pattern differed considerably from that of May 2018. In June there was no MSLP, 2-m temperature or 1000-500 hPa thickness anomaly located over Finland (Figures 3d-f). The largest positive MSLP anomalies were located to the west of

Ireland and small positive 2m-temperature anomalies were located over large parts of central and western Europe. June 2018 will not be considered further in this study as the focus is on Finland and the reanalysis (and local synop observations) show that June 2018 was not abnormally warm.

July 2018 was again characterized by large positive temperature anomalies over large parts of northern Europe. The 2m-temperature anomalies from ERA-Interim were largest over northern Finland, the Kola peninsula (in north-eastern Russia, directly east of North Finland), and over large parts of Sweden and Norway where they exceeded 5^{o}C (Figure 3g). Smaller positive temperature anomalies were present over northern Germany and France and the south of the UK. The MSLP pattern in July 2018 also differed from May 2018, but in both months the largest positive MSLP anomalies were co-located with the largest 2-m temperature anomalies. In July 2018, the largest MSLP anomaly was located over the Kola peninsula and exceeded 7 hPa, but smaller anomalies extended as far west as the UK (Figure 3h). This anomalous high pressure and anticyclonic circulation resulted in easterly winds over most of Finland. The thickness of the 1000 and 500 hPa layer also had a positive anomaly in July 2018 which was maximized over northern Finland (Figure 3i) and thus co-located with the 2-m temperature and MSLP anomalies. As was the case in May 2018, the thickness shows that all of the lower-to-mid troposphere was, on average, warmer than average.

Anomalies of surface fluxes

ERA-Interim reanalysis data were also used to calculate the monthly mean values of the surface sensible heat flux (H), the surface latent heat flux (LE) and the Bowen ratio which is given by the ratio H/LE. In general, the Bowen ratio increases with decreasing soil moisture. Typical values are 5 over semiarid regions, 0.5 over grasslands and forests, 0.2 over irrigated orchards or grass and 0.1 over the sea (AMS Glossary, 2019). Over Finland, the climatological values of the Bowen ratio range from 0.8 to 1.2 in May with larger values over northern and western Finland, whereas in July typical values are between 0.4 and 0.7 (not shown)

Anomalies of H, LE and the Bowen ratio relative to the 1981-2010 climatology were computed to determine if the surface conditions in summer 2018 were unusual or not. In both May and July 2018, the sensible heat flux was above average in large parts of Finland (Figure 4a, d) and the latent heat fluxes were above average almost everywhere in Finland (Figure 4b, e). These positive anomalies in the surface heat fluxes are consistent with a positive anomaly in the surface radiation. In contrast, the Bowen ratio was close to normal with values slightly below the climatological average in May (Figure 4c) and slightly above average in July excluding northern Lapland and south-western Finland (Figure 4f).

These results suggest that drying of the soil might have slightly enhanced the warm anomaly in July 2018 in some parts of Finland. However, the effect was likely very modest, particularly given that even in July LE was above average and thus evaporation was very likely not substantially water-limited. Therefore, surface processes most probably did not play a decisive role in the anomalous warmth. The same conclusion is supported by the vertical profile of the temperature anomalies, discussed below

Vertical profile of Temperature anomalies

On monthly-to-seasonal timescales the surface is roughly in radiative balance and any excess solar radiation absorbed by the surface must be returned to the atmosphere as a combination of long-wave radiation (due to higher surface temperature), sensible and latent heat fluxes. The partitioning between the sensible and latent heat fluxes (the Bowen ratio) is important as the sensible heat flux only heats the boundary layer whereas heat consumed during evaporation (the latent heat flux) is released during condensation which can occur at any vertical level in the atmosphere. Thus, in the case that the near-surface warmth was substantially amplified by the drying of soil, the resulting increase in Bowen ratio would be expected to make the warm anomaly more constrained to low levels.

Data from two radiosonde stations are used to assess whether the temperature anomalies observed at the surface were constrained to a thin layer of the atmosphere (i.e. the boundary layer) or extended through the depth of the troposphere. In Finland there are two operational sounding stations, Jokioinen (60.81°N, 23.49°E,104 m a.s.l) and Sodankylä (67.36°N, 26.62°E, 179 m a.s.l). Four soundings are made each day at Jokioinen at 00, 06 12 and 18 UTC (here we only consider the 00 and 12 UTC soundings) and two are made at Sodankylä at 00 and 12 UTC, corresponding to 03 and 15 local time during summer. The radiosonde data, on standard pressure levels and in terms of precalculated monthly means, are obtained from the Integrated Global Radiosonde Archive (IGRA, Durre et al, 2006).

The monthly mean soundings for May and July 2018 at 12 UTC from Sodankylä and Jokioinen are shown in Figures 5 - 8 along with the climatological mean sounding calculated over 1981 - 2010. The temperature anomalies in May and July 2018 are computed at selected pressure levels and these are shown in Table 1 in terms of the absolute value and in terms of the standardized anomaly. The standardised anomaly is the number of standard deviations the anomaly represents and is given by $(T - \overline{T})/\sigma_T$ where the overbar represents the climatological mean and σ_T represents the standard deviation of the monthly mean values from 1981 - 2010.

In both May and July, and at both sounding stations, the temperature anomalies were positive at all levels up to 300 hPa (Figures 5 - 8). In May 2018 at Jokioinen at 850, 700 and 500 hPa the temperature anomaly exceeds 5°C (Table 1), which is slightly larger than the 2-m temperature anomaly (4.7°C). The tropopause (visible in Figures 5 to 8 where the temperature starts increasing with height) was slightly higher (250 hPa) in May 2018 compared to climatology (300 hPa). At all pressure levels considered in Table 1, the magnitude of the temperature anomaly in both the 00 and 12 UTC soundings from Jokioinen exceeded 2 standard deviations. Further north at Sodankylä (Figure 6), a similar situation is evident. Warm anomalies are present throughout the troposphere and exceed 1 standard deviation at all levels and 2 standard deviations at most levels (Table 1). However, in comparison with Jokioinen the temperature anomalies are smaller especially at 850 and 700 hPa (Table 1). Therefore, we can conclude that the heatwave in May 2018 extended throughout the depth of the troposphere and was more anomalous at Jokioinen than at Sodankylä.

In July 2018, warm anomalies are evident in the 12 UTC mean sounding from Jokioinen (Figure 7) which are typically of order 3°C. The magnitude of these temperature anomalies also decreases with height (Table 2). However the 850 hPa temperature anomalies of 3.7 and 3.6^{o}C at 00 and 12 UTC respectively are very similar to the July 2-m temperature anomaly (3.5^{o}C). In comparison with May 2018, the temperature anomalies observed in July 2018 at Jokioinen are less anomalous as they only exceed 2 standard deviations at a few pressure levels (Table 2). The temperature anomalies observed at Sodankylä in July 2018 were exceptional: they exceeded 4^{o}C throughout the troposphere and exceeded 3 standard deviations at 850, 700 and 500 hPa (Figure 8, Table 2). These temperature anomalies at Sodankylä were therefore considerably larger and more significant than observed either in Jokioinen in July 2018 or in Sodankylä is May 2018. We can therefore conclude that the most anomalous heat of summer 2018 took place in Northern Finland in July 2018.

Conclusions

May and July 2018 were both anomalously warm in Finland and in both months the heat wave was associated with anomalous high pressure and anticyclonic circulations. In May 2018 the 2-m temperature anomalies were relatively uniform across most of Finland. July 2018 was exceptionally warm, and the heatwave was more extreme in northern Finland compared with southern Finland. This result resonates somewhat with the results of Kim et al (2018) who analysed climate model projections and concluded that the relative change in heat wave duration and occurrence in Finland was larger for northern Finland than southern Finland (they did not consider the magnitude of temperature anomalies). The positive temperature anomalies in May and July 2018 were found to extend throughout the whole depth of the troposphere, from the surface up to ~10 km. The absence of a bottom-heavy temperature anomaly profile, combined with small anomalies in the Bowen ratio, suggests that surface feedbacks and limited soil moisture did not play a decisive role in the extreme heat in Finland in summer 2018. Therefore, this heat wave was most likely driven by an increase in incoming solar radiation allowed by unusually clear skies (cf. Räisänen 2018, who found that variations in the short-wave cloud forcing - i.e. how clouds affect the amount of solar radiation reaching the surface - drive much of the temperature variability in mid-latitude land areas in summer). Ultimately, the anomalous persistent anticyclonic circulation pattern in May and July 2018 was responsible for the lack of clouds and thus at least the largest part of the warm temperature anomalies.

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Figure captions

Figure 1: Map showing the location of Finland and the location of the five synoptic measuring stations used in this study. The two sounding stations (Jokioinen and Sodankylä) are co-located with the synoptic stations of the same name.

Figure 2: Time series of daily mean (grey), minimum (blue) and maximum (red) 2-m temperature observed at the five synoptic stations during May, June and July 2018. The climatological daily mean 2-m temperature from 1981-2010 is shown as a black dashed line. Stations are ordered from the most northerly at the top, to the most southerly at the bottom.

Figure 3: 2-m temperature (a, d, g) , mean sea level pressure (b, e, h) and 500 - 1000 hPa thickness (c, f, i) from ERA-Interim for May, June and July 2018. Shading shows the anomalies relative to the 1981-2010 climatological values calculated from ERA-Interim. Solid black contours in panels b, e and h show the 2018 monthly mean MSLP and in panels c, f and h the 2018 monthly mean 500 - 1000 hPa thickness values.

Figure 4: Monthly mean anomalies of the surface sensible heat flux (a, d), surface latent heat flux (b, e) and the Bowen Ratio (c, f) for May (top row) and July (bottom row) 2018 based on ERA-Interim reanalysis data. Anomalies are calculated relative to the 1981-2010 climatology. In panels c and f, the Bowen ratio has been multiplied by 100 and grid boxes where the climatological mean latent heat flux is less than 20 Wm^{-2} (primarily sea points) are masked out to avoid division by near-zero values.

Figure 5: Mean 12 UTC sounding from Jokioinen in May 2018 (black) and climatological May 12 UTC sounding from 1981 - 2010 (red). Solid lines are temperature, dash-dot lines dew point temperature and dashed red lines show 1 standard deviation of the temperature distribution at each pressure level.

Figure 6: Mean 12 UTC sounding from Sodankylä May 2018 (black) and climatological May 12 UTC sounding from 1981 - 2010 (red). Solid lines are temperature, dash-dot lines dew point temperature and dashed red lines show 1 standard deviation of the temperature distribution at each pressure level.

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Figure 8: Mean 12 UTC sounding from Sodankylä July 2018 (black) and climatological May 12 UTC sounding from 1981 - 2010 (red). Solid lines are temperature, dash-dot lines dew point temperature and dashed red lines show 1 standard deviation of the temperature distribution at each pressure level.

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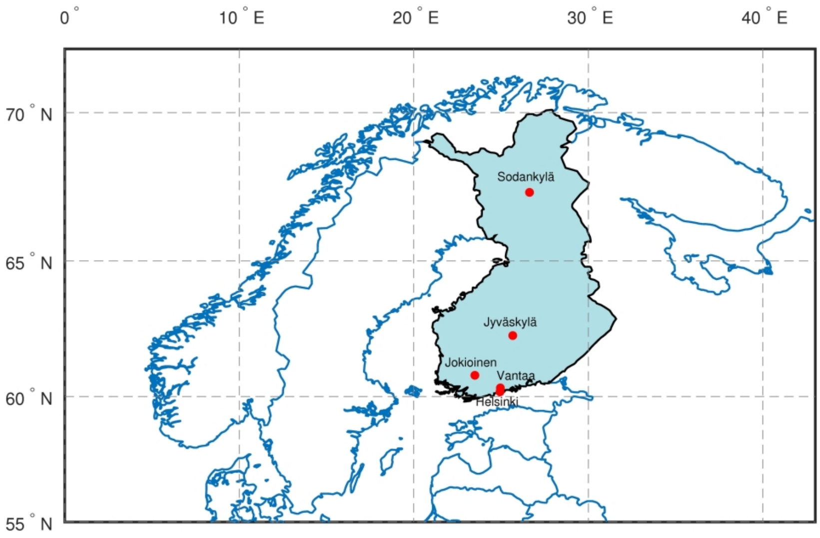
Table 1: May 2018 temperature anomalies (T') relative to 1980 - 2010 climatology at selected pressure levels from radiosonde soundings from Jokioinen and Sodankylä at 00 and 12 UTC. The number of standard deviations (SD, normalised anomaly) are also shown. Values less than 2 SDs are in black, values between 2 and 3 SD are shown in orange, and values greater than 3 SDs in red.

	Jokioinen				Sodankylä			
	00 UTC		12 UTC		00 UTC		12 UTC	
P (hPa)	T' (°C)	T' SD	T' (°C)	T' SD	T' (°C)	T' SD	T' (°C)	T' SD
850	5.7	2.7	5.5	2.7	3.8	1.7	4.7	2.1
700	5.9	2.7	6.0	2.7	4.5	2.2	3.9	1.8
500	5.4	2.9	5.5	2.8	5.7	2.9	5.2	2.8
300	2.9	3.6	2.5	3.1	2.7	2.6	3.3	3.2

Table 2: July 2018 temperature anomalies (T') relative to 1980 - 2010 climatology at selected pressure levels from radiosonde soundings from Jokioinen and Sodankylä at 00 and 12 UTC. The number of standard deviations (SD, normalised anomaly) are also shown. Values less than 2 SDs are in black, values between 2 and 3 SD are shown in orange, and values greater than 3 SDs in red.

	Jokioinen				Sodankylä			
	00 UTC		12 UTC		00 UTC		12 UTC	
P (hPa)	T' (°C)	T' SD	T' (°C)	T' SD	T' (°C)	T' SD	T' (°C)	T' SD
850	3.7	2.2	3.6	2.3	4.9	3.1	5.0	3.3
700	3.1	1.9	2.9	1.9	4.4	3.4	4.6	3.6
500	3.1	1.8	3.3	2.0	4.5	3.1	4.5	3.1
300	2.4	1.6	2.7	1.8	3.3	2.9	3.2	2.7



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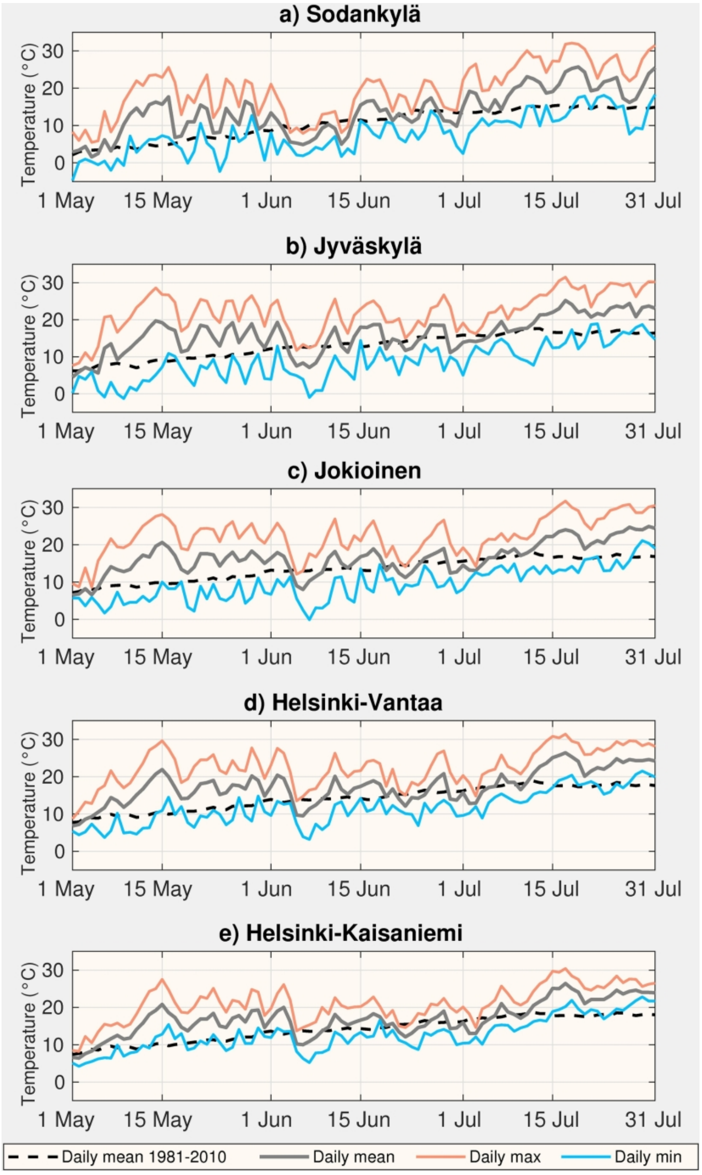

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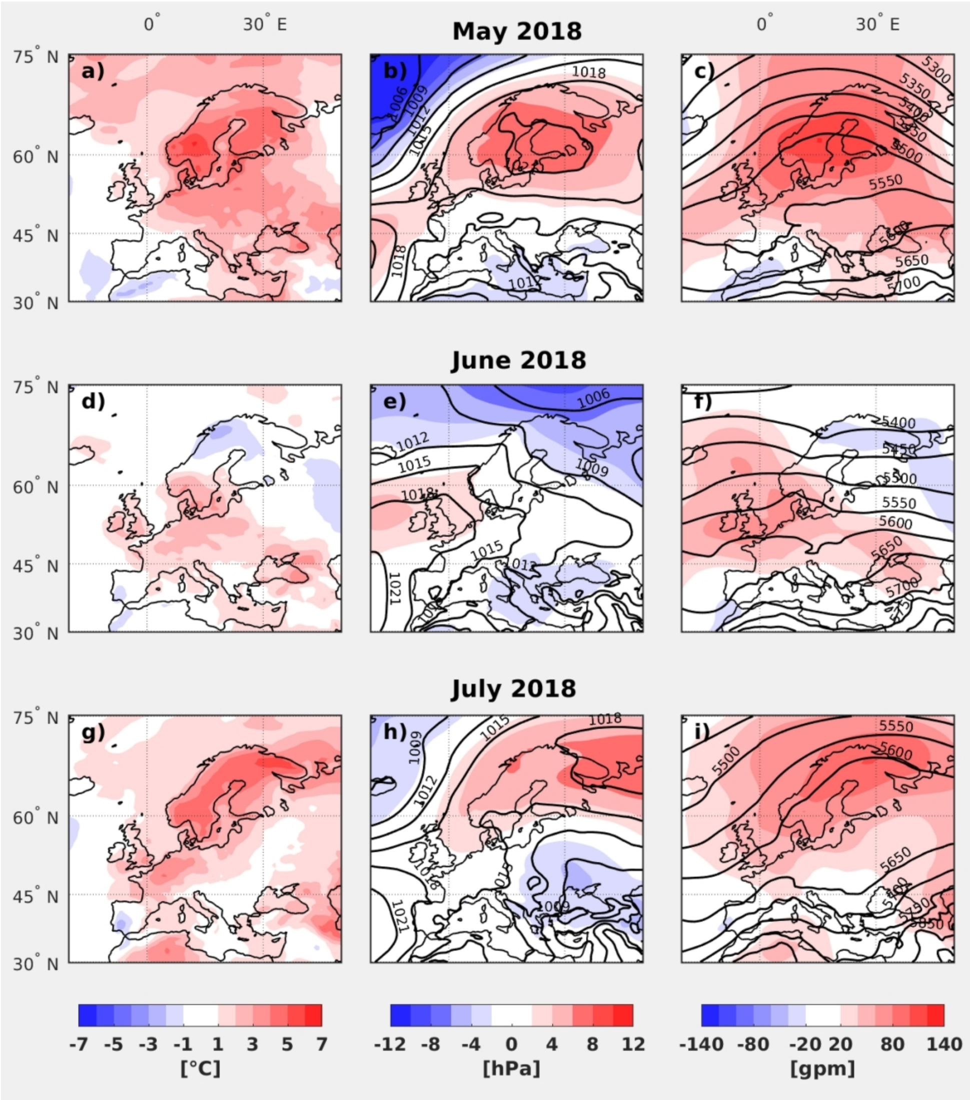

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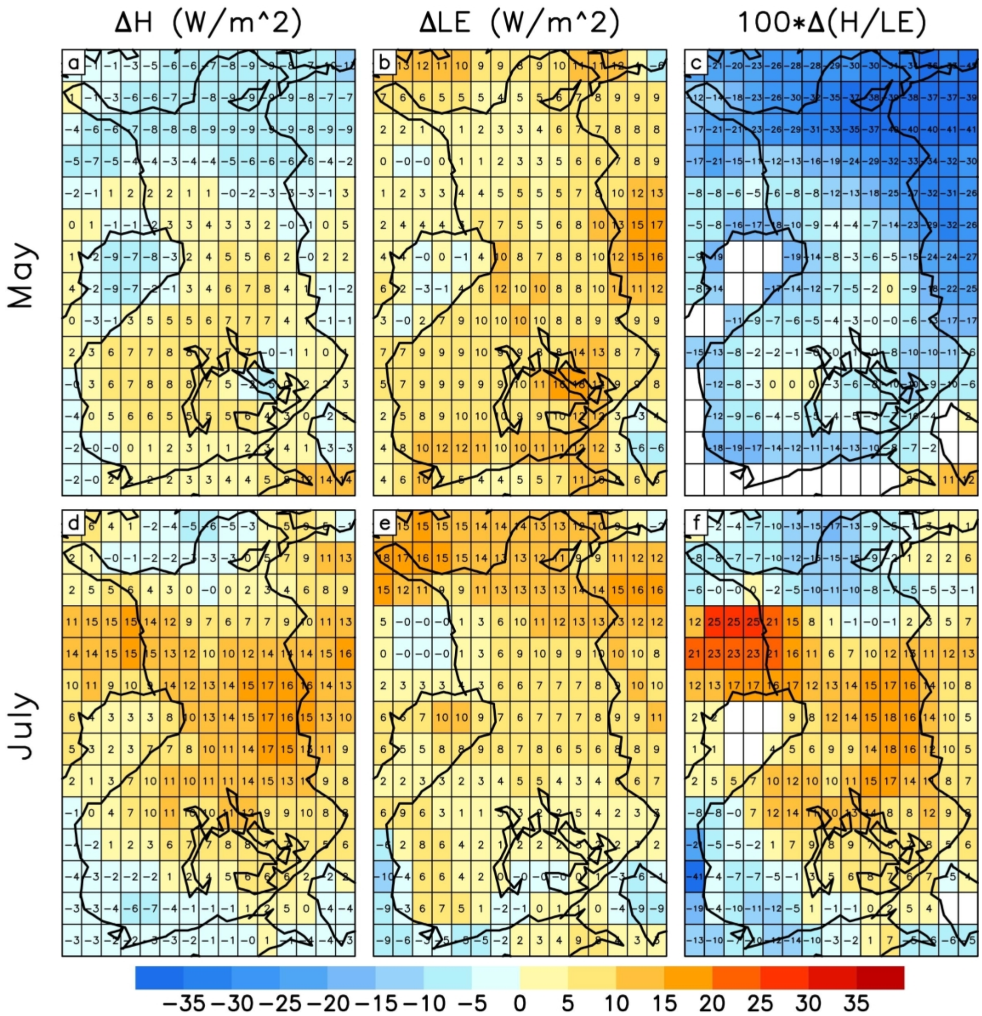

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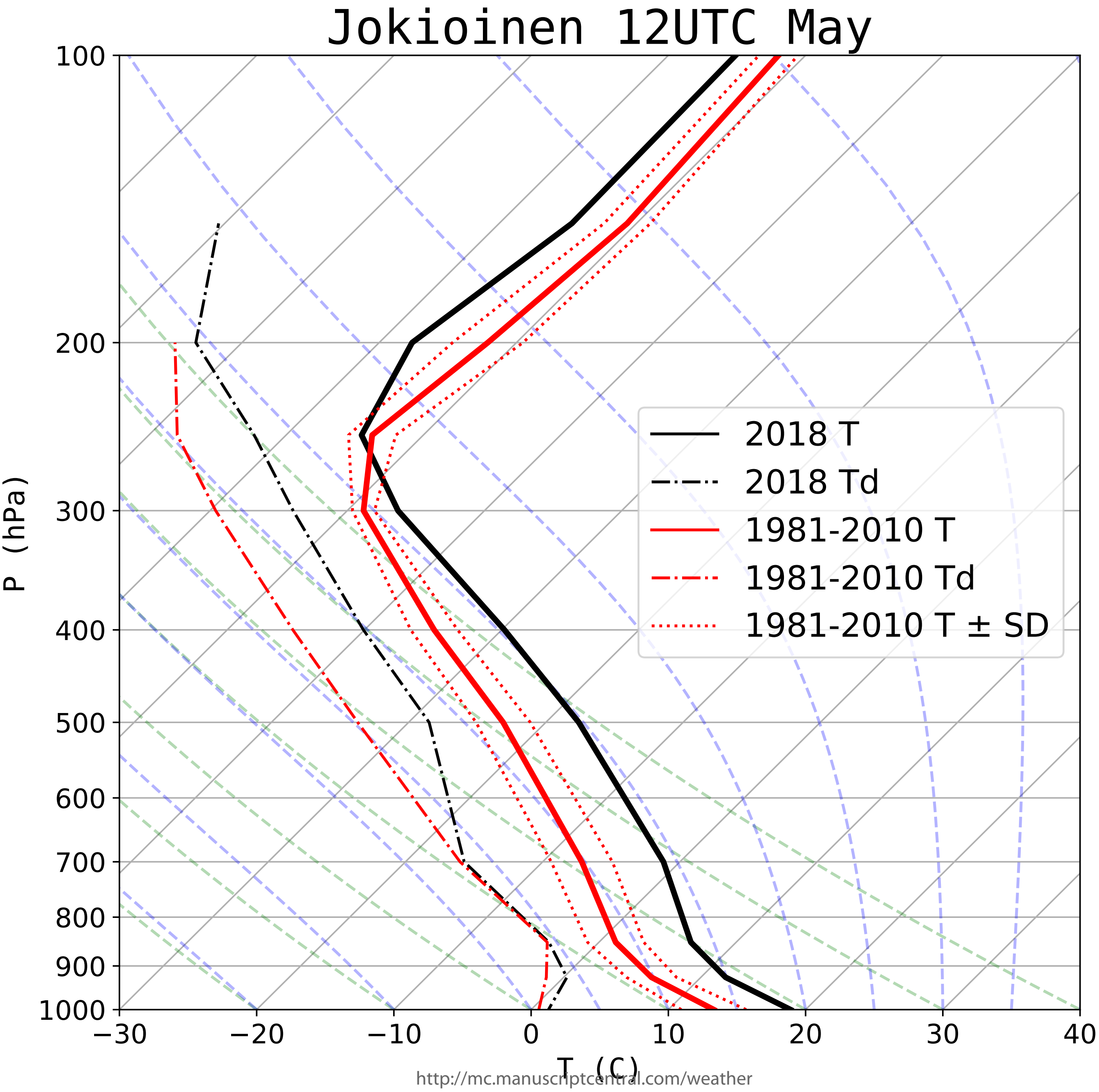
Jokioinen 12UTC May
P (hPa)
100
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700
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40
T (C)
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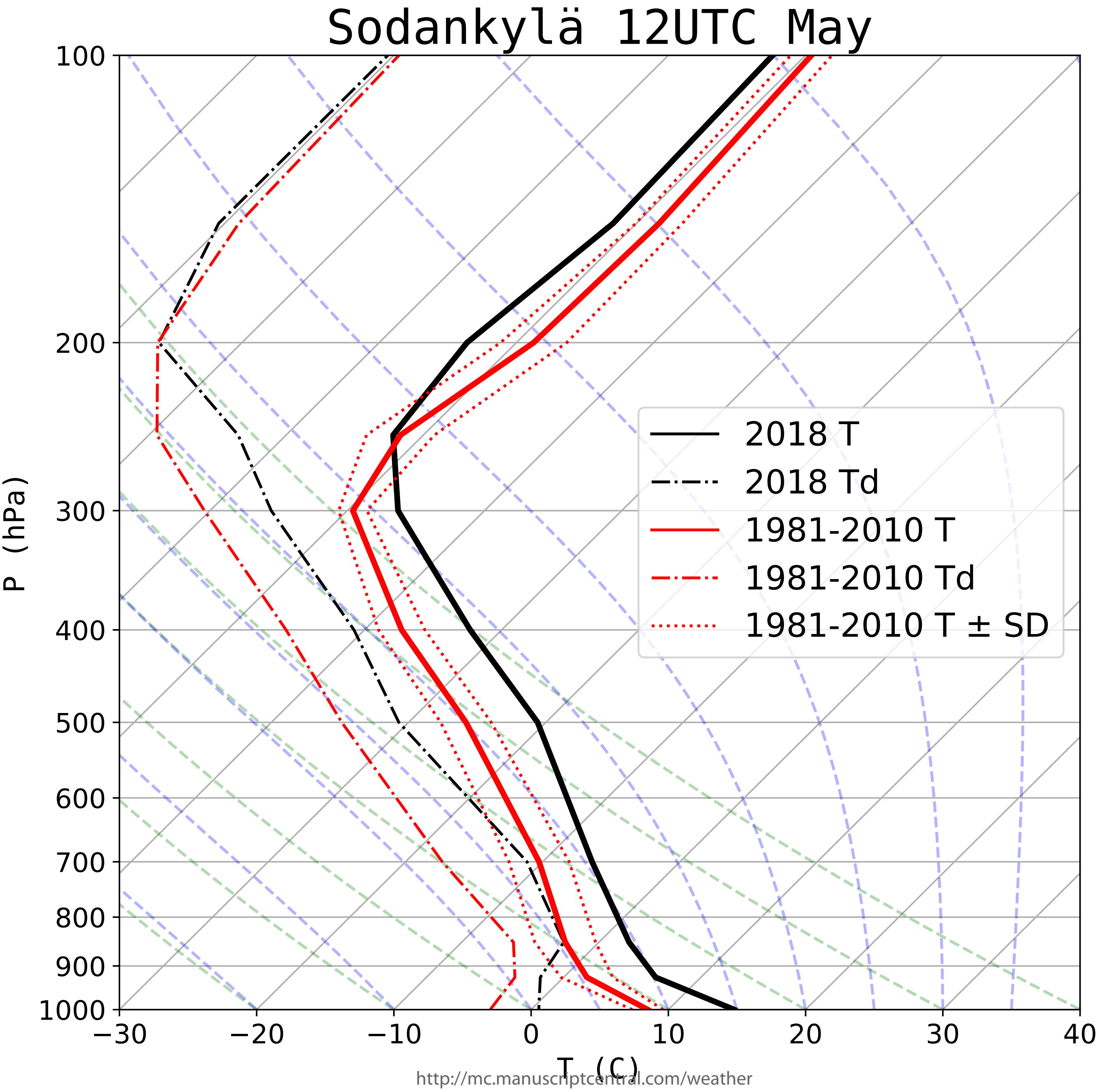
Sodankylä 12UTC May
100
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P (hPa)
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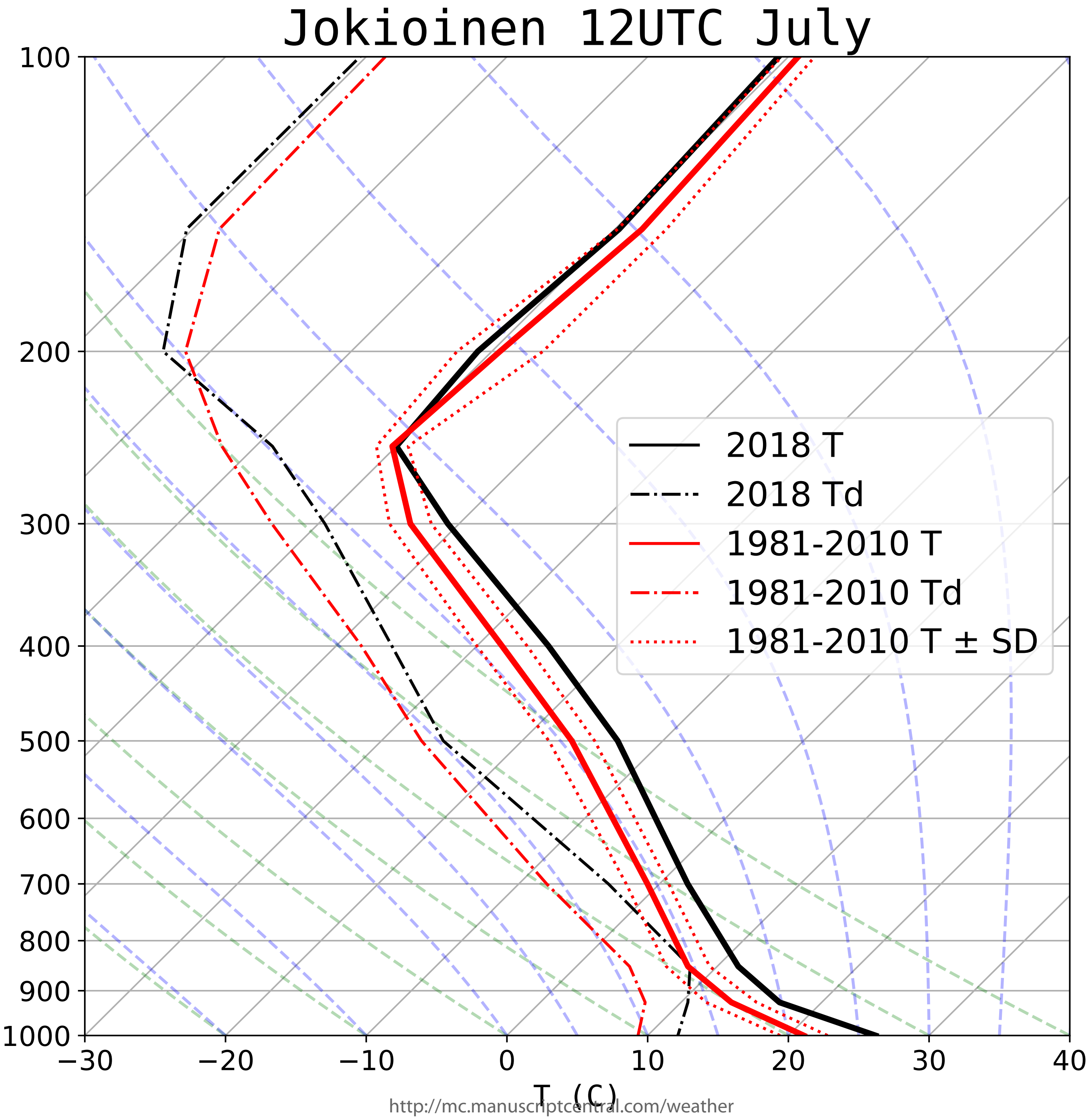
Jokioinen 12UTC July
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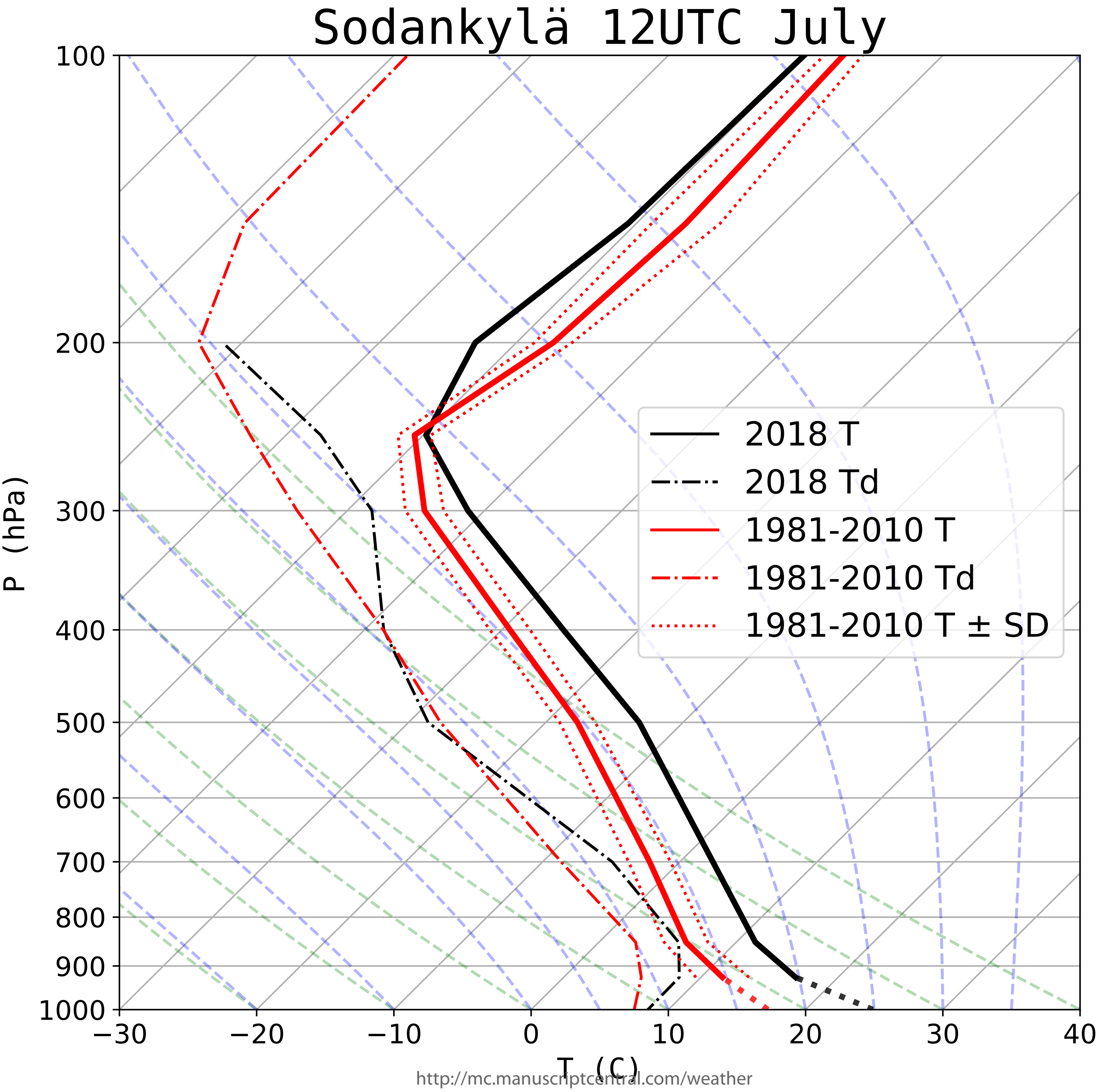
10
20
30
40
2018 T
2018 Td
1981-2010 T
1981-2010 Td
1981-2010 T ± SD


Sodankylä 12UTC July
P (hPa)
T (C)
100
200
300
400
500
600
700
800
900
1000
−30
−20
−10
0
10
20
30
40
2018 T
2018 Td
1981-2010 T
1981-2010 Td
1981-2010 T ± SD

The summer 2018 heat wave in Finland

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May and July 2018 were abnormally warm in Finland as suggested by this photo taken on 13th May 2018 near Helsinki. Surface observations, radiosonde soundings and reanalysis data are analysed to quantify the magnitude of the heat waves at the surface and aloft and to determine the large-scale circulation patterns. Anomalous high pressure was present in both months and the temperature anomalies extended throughout the troposphere indicating that soil moisture feedbacks were likely unimportant.