Near record anticyclone over southern UK. An investigation.

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Late on the 19th January 2020, most if not all locations in the southern half of the UK recorded their highest MSL pressure in over 100 years. Here in Wokingham a maximum value of 1050.0 hpa was recorded at 2314 GMT on the 19th. The synoptic chart for 0000 GMT on the 20th showed that MSL pressure exceeded 1048 hpa over an area covering the whole of Wales, southern England and the English Channel. The upper air station of Camborne in Cornwall (03808) was near the centre of the anticyclone, and it is instructive to examine a sequence of their 12 hourly ascents covering the 48 hour period between 0000 GMT on the 18th to 0000 GMT on the 20th.

The Thickness Budget.

In order to gain an insight into the thermal structure of the anticyclone, changes in the geopotential thickness of selected layers between fixed pressure surfaces can be employed. This method I call a thickness budget, and its use can show at which level in the atmosphere thermal changes have led to the observed changes in surface pressure.

To this end, values of geopotential from the Camborne ascents at the constant pressure levels of 10, 30, 100, 300, 500 and 1000 hpa were tabulated, and the geopotential thickness between the layers calculated. The 12 hour changes in thickness were then calculated, and are shown in Table 1.

Table 1. Thickness changes for selected layers over Camborne in the 48 hours to 0000 GMT on 20th January 2020, units are geopotential decametres (dam). The 12 hour thickness change estimate due to advection is shown in parenthesis.

Layer hpa	18/00 to 18/12	18/12 to 19/00	19/00 to 19/12	19/12 to 20/00	18/00 to 20/00
Above 10	-1	-4	0	-4	-9
10 to 30	0	0	-2	+2	0
30 to 100	-4	-7	-6	-2	-19
100 to 300	-3	-8	-12	-5	-28
300 to 500	+2 (-3)	+11 (+3)	+5 (+8)	+2 (+5)	+20 (+13)
500 to 1000	+2 (-0.4)	0 (-0.6)	+8 (-2.3)	+5 (-2.3)	+15 (-6)
Net	-4	-8	-7	-2	-21

At 1000 hpa, the geopotential increased from 19 dam at 18/00 to 40 dam at 20/00, a change of +21 dam. The surface pressure at Camborne rose from 1023.4 hpa to 1049.8 hpa in the same period.

The significance of the values in table1 can be appreciated if it is bourne in mind that at any level in the atmosphere, the pressure exerted under the influence of the earth's gravity depends on the mass of air above that level, and that this mass is proportional to its mean temperature. The mean temperature of any layer between fixed pressure surfaces in the atmosphere is proportional to the thickness of the layer. The lower the mean temperature, the smaller the thickness, and vice-versa. Looked at from the point of view of the pressure the earth's surface, its instantaneous value at any location depends on the mean temperature of the entire atmosphere above that location. The MSL pressure at any location will remain steady unless and until there is a change in the mean temperature of the air column above that location. But note that this does not preclude temperature changes taking place, only that the mean remains unchanged.

In the present instance of an anticyclone of unusual intensity over the UK, the changes in thickness for the layers shown in Table1 can be summed over the the atmospheric column for a given period to show how the change in geopotential at 1000 hpa (as a proxy for the MSL pressure) has been produced. It just needs to be recognised that a decrease in thickness will produce a rise in the 1000 hpa geopotential, and MSL pressure, and an increase in thickness will produce a fall in MSL pressure. In any time interval, the total change in thickness in the atmospheric column will be reflected by a change in the 1000 hpa geopotential of opposite sign but of identical amount.

The Data.

In this example, from the 18th January at 0000 to the 20th January 0000, table1 shows the 48 hour net change in thickness to have decreased by 21 decametres (dam), thus the 1000 hpa geopotential can be seen to have responded by increasing from 19 dam at 18/00 to 40 dam 48 hours later, where 19 dam equates to a MSL pressure of 1023.4 hpa, and 40 dam equates to 1049.8 hpa. Using table1, we are able to ascertain at what level or levels in the atmosphere the significant necessary cooling took place, and it is evident that the layer between 30 and 300 hpa, which approximately equates to the lower stratosphere, cools in the 48 hours by 47 dam. It is significant that in the 30 to 300 hpa layer, the 30 to 100 hpa sub-layer played a very large part, cooling by 19 dam, the contributions of the 30 to 100 hpa and 100 to 300 hpa layers being in the ratio of 2:3. Of the 19 dam cooling in the 30 to 100 hpa layer, there was cooling of 5 dam in the 30 to 50 hpa sub-layer, and 14 dam in the 50 to 100 hpa sub-layer (not shown in table1). The entire atmosphere above 30 hpa is also seen to have cooled by 9 dam in the same period, although there was zero change in the 10 to 30 hpa layer. This cooling is offset by 35 dam of warming in the 300 to 1000 hpa layer, which equates to the troposphere in this instance. The sum of these changes, +35 – 56 dam, equals -21 dam and produces a rise in 1000 hpa geopotental by +21 dam.

As table1 shows, in both the lower stratosphere and troposphere, the 12 hour rate of change in thickness proceeded in such a way as to increase up to 1200 on 19th, then decrease. When the values for the 30 to 100 and 100 to 300 hpa are summed, and also the 300 to 500 and 500 to 1000 hpa are summed, the thickness in the lower stratosphere decreased by 7, 15, 18 and 7 dam over each subsequent 12 hour period, while the troposphere thickness increased by 4, 11, 13 and 7 dam in the same period. In both cases the greatest 12 hour change was in the period 19th 0000 to 19th 1200. If these were the only thermal changes taking place in the atmosphere, the surface pressure would have peaked at 19th 1200, as in the subsequent 12 hour period changes in the lower stratosphere and troposphere cancelled out. However, we note that the 1000 hpa geopotential increased by a further 2 dam after 19th 1200, reaching a value of 40 dam by 0000 on the 20th. Table1 shows this to have been due to a net cooling in the atmosphere above 30 hpa which amounted to 2 dam, enough to raise the surface pressure to a near record value of 1049.8 hpa at Camborne.

To place these thickness changes on a common footing, the thickness change per vertical km is calculated for the 48 hour period, and is shown as dam/km below:

Layer hpa	dam/km
10 to 30	0.0
30 to 100	-2.48
100 to 300	-4.02
300 to 500	+5.60
500 to 1000	+2.82

Causes.

So what were the causes of the observed thickness changes? Among the possible affects that can lead to changes in layer thickness, there is advection, dynamically induced vertical displacements, condensation/evaporation, turbulent mixing, heat conduction, radiation and changes in relative humidity. While some of these effects will probably lead to only small changes over the 48 hour period, advection and dynamically induced vertical displacements are expected to dominate. Heating/cooling by change of state would be confined to the troposphere, but there was little or no cloud in this time period. Radiation could have led to some minor changes in the thickness of the atmospheric column, but in the absence of cloud in the troposphere, and being in the winter period in the stratosphere, these would have been very small. Turbulent mixing and heat conduction may also have been present, but the former would probably have been confined to thin layers (compared to the layers selected for table1) having only minor influence on total thickness changes in the troposphere and lower stratosphere. Heat conduction is unquantifiable in this study, but is thought to also have had minimal effect. Changes in relative humidity will produce a hardly noticeable effect on thickness and in just the lowest layers of the troposphere. Advection and dynamical vertical displacements are likely to have been present in both the troposphere and lower stratosphere.

Advection in the troposphere is likely to have played a part in the thickness changes here, also the anticyclone is likely to have had dynamical subsidence at some levels in this layer, which would also lead to changes in thickness. Advection can be measured using the winds reported on the Camborne ascents to calculate the thermal wind, and its vector change. In the 500 hpa to surface layer, the thermal wind veered from 280/23kt at 18/12 to 010/66kt at 19/00, was 360/52kt at 19/12 and 020/40kt at 20/00. On each ascent, advection was cold and generally small in this layer, 2 to 4 kt except 10kt at 19/12.

In the 300 to 500 hpa layer the thermal winds veered from 280/39kt at 18/12 to 020/42kt at 19/00, to 040/14kt at 19/12 and were 030/18kt at 20/00. Here advection was zero at 18/12 and at 20/00, but was warm 16kt at 19/00 and warm 28kt at 19/12. The thickness changes in the 300 to 500 hpa layer show their largest increase in this period, rising by 16 dam in the 24 hours to 19/12. Dynamic subsidence in the 500 to 1000 hpa layer could easily have led to the +13 dam change there, during a period when steady but slight cold advection was taking place.

As the amount of thickness change due to vertical displacements is proportional to the lapse in potential temperature, being zero if the lapse is zero, and as the lapse is normally far greater, in a negative sense, in the stratosphere than the troposphere, dynamical forcing which spans the tropopause will lead to much greater thickness changes in the stratosphere than troposphere. However, such vertical displacement that causes cooling in the stratosphere will not in itself produce warming in the troposphere. That dynamic ascent was taking, or had taken, place over Camborne can be confirmed by charting the change in the level of isentropic surfaces, this being a conserved parameter for adiabatic changes. The 340° isentrope was chosen here as it was to be found in the lower stratosphere, and will serve to illustrate the magnitude of the dynamic ascent in this region. At 1200 on the 18th it was found at an altitude of 1119 dam, 12 hours later was at 1209 dam, then 1310 dam at 1200 on 19th, finally at 1333 dam at 0000 on the 20th, showing that the air in the lowest part of the lower stratosphere had risen by over 2 km.

Dynamic ascent in the lower stratosphere points to the reason for the 47 dam decrease in thickness over the 48 hours in the 30 to 300 hpa layer. That the dynamic ascent extended well into the stratosphere, with cooling felt even in the 30 to 50 hpa sub-layer, may be a factor, possibly the factor, in enabling the surface pressure to approach record values. While table1 shows that concurrent warming took place in the troposphere, both due to advection and subsidence, in the 300 to 500 hpa layer most of the 48 hour change was probably the result of advection (13 of 20 dam change), while in the 500 to 1000 hpa layer subsidence could have increased the thickness by 21 dam if it had not been for continuous slight cold advection here.

Summary/conclusions.

From table1 the increase in thickness in the 500 to 1000 hpa layer was almost certainly caused by dynamic descent associated with the anticyclone. In the 300 to 500 hpa layer, the increase in thickness was mainly due to advection, subsidence being of secondary importance. In the 30 to 300 hpa layer, all the changes in thickness can be ascribed to dynamic ascent, either ongoing over Camborne during the 48 hours, or having occurred upstream in the recent past. For the atmosphere above 30 hpa, changes in the 10 to 30 hpa layer can be seen to have been neutral, but above 10 hpa cooling was evident for most of the time, amounting to a -9 dam contribution to the net thickness change over the 48 hours.

Over the 48 hour period, all the layers above 300 hpa except the 10 to 30 hpa layer, contributed -56 dam to the net thickness change over Camborne, counterbalanced by a +35 dam change in the 300 to 1000 hpa layer. The result was to lift the 1000 hpa geopotential from +19 dam at 18th 0000 GMT, to +40 dam at 20th 0000 GMT. The associated surface pressure rose from 1023.4 hpa to 1049.8 hpa in the same period. Although this investigation concludes that the strength of the anticyclone in this case was attributable to dynamic ascent in the lower stratosphere, it is probably true to say that the pattern of thickness changes shown in table1 may not be dissimilar over anticyclones of lesser intensity at other times in this region.

Additional Note.

Advection of thickness.. From a knowledge of the wind at different pressure levels, it is possible to calculate the thermal wind by subtracting the wind at the base of a layer from that at the top. This is easily done on a spreadsheet, first splitting the wind direction and speed into components in the north-south and east-west directions, subtracting and then resolving the resulting components into direction and speed again.

The thermal wind in a particular layer comes about due to the thermal gradient in that layer, that is, the spacing of adjacent thickness isopleths, just as the real wind at a particular level arises due to the spacing of adjacent isopleths of geopotential. When the thermal wind magnitude and direction are known, the local thermal gradient can be calculated. The sign and magnitude of thermal advection can then be found by calculating the component of the real wind normal to the thermal gradient. If the thermal wind direction minus the real wind direction is negative, then cold advection is taking place. If the thermal wind direction minus the real wind direction is positive, warm advection is indicated.

In the present case, when the actual thermal advection is known only at 12 hourly intervals, in order to ascribe an estimate of the actual thermal change due to advection over the 12 hours between ascents, the instantaneous rate of change in thickness is assumed to extend for 6 hours either side of the ascent time. Adjacent 6 hour values are then summed to give a value for the 12 hour change due to advection. There is considerable scope for error here, as it assumes a linear rate of change between 12 hour ascents, which need not be the case, and the values for advective change shown in table1 should be viewed as an estimate, not a proven value.

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Synoptic charts.

UK Met Office synoptic charts for the 18th to 20th January can be found at:

http://www.woksat.info/etcacaasxx/indexacaasxx.html