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Supplement of

The characteristics and structure of extra-tropical cyclones in a warmer climate

Victoria A. Sinclair et al.

Correspondence to: Victoria A. Sinclair (victoria.sinclair@helsinki.fi)

Supplement

1 Composite of the median cyclones

In addition to creating composites of the 200 strongest cyclones in both experiments, composites were also created of the 200 most average cyclones in each experiment. These average cyclones were identified as the 100 cyclones with maximum vorticity values lower but closest to the median relative vorticity and the 100 cyclones with maximum vorticity values higher than but closest to the median relative vorticity. As the median 850-hPa relative vorticity was slightly lower in SST4 (5.75×10^{-5} s^{-1}) compared to in CNTL (5.94×10^{-5} s^{-1}), the SST4 composite contains slightly weaker cyclones.

Figure S1 shows the temporal evolution of the median composite cyclone in CNTL in terms of the total column water vapour (TCWV) and the mean sea level pressure (MSLP). In comparison to the composite cyclone created from the strongest 200 cyclones, the median cyclone has higher values of MSLP, weaker MSLP gradients, lower TCWV values to the south of the cyclone and higher values to the north indicating a weaker gradient in TCWV.

Figure S2 shows the response of the TCWV to warming for the median composite cyclone. Similar to what was found for the strongest cyclones, TCWV increases everywhere relative to the cyclone centre with the largest absolute increases occuring in the warm sector. However, the magnitude of the absolute increase is approximately 50% smaller in the median cyclone compared to the strongest cyclone.

Figure S3 shows the total precipitation in the median cyclone in the CNTL in black contours. This shows that the precipitation amounts in the median cyclone are much smaller than in the strongest cyclones. For example, at t =-24 h, the maximum precipitation rate in the composite of the strongest 200 cyclone exceeds 7 mm per 6 h whereas the corresponding value for the median cyclone is 2 mm per 6 h. The response of the total precipitation to warming for the median composite cyclone is also shown in Figure S3. In the median cyclone, at t =-48 h, the increase in precipitation is larger than at any other offset time and occurs in two areas - just poleward of the maximum precipitation in the CNTL and also in the warm sector quite far equatorward and downstream of the cyclone centre. At $t = -24$ h and 0 h, the increase in precipitation in the median cyclones is primarily along the cold front region and in the warm sector and as such the spatial pattern is very different to what is found for the strongest 200 cyclones.

Figure S4 shows the change in the 700-hPa vertical velocity of the median cyclone which is closely related to the spatial patterns in the precipitation. At t =-24 h and $t = 0$ h there is weaker ascent co-located with the largest values of ascent and weaker descent near the cold front. The decrease in the ascent may be because in SST4 the median maximum vorticity is weaker than in CNTL which would likely mean the cyclones includes in the SST4 median cyclone are weaker than those in CNTL.

Thus, it can be concluded that although the TCWV and precipitation increase with warming in the median cyclone, the absolute increases are smaller and the changes in the spatial structure of precipitation and ascent of the median cyclone with warming are very different compared to the changes found for the strongest 200 cyclones.

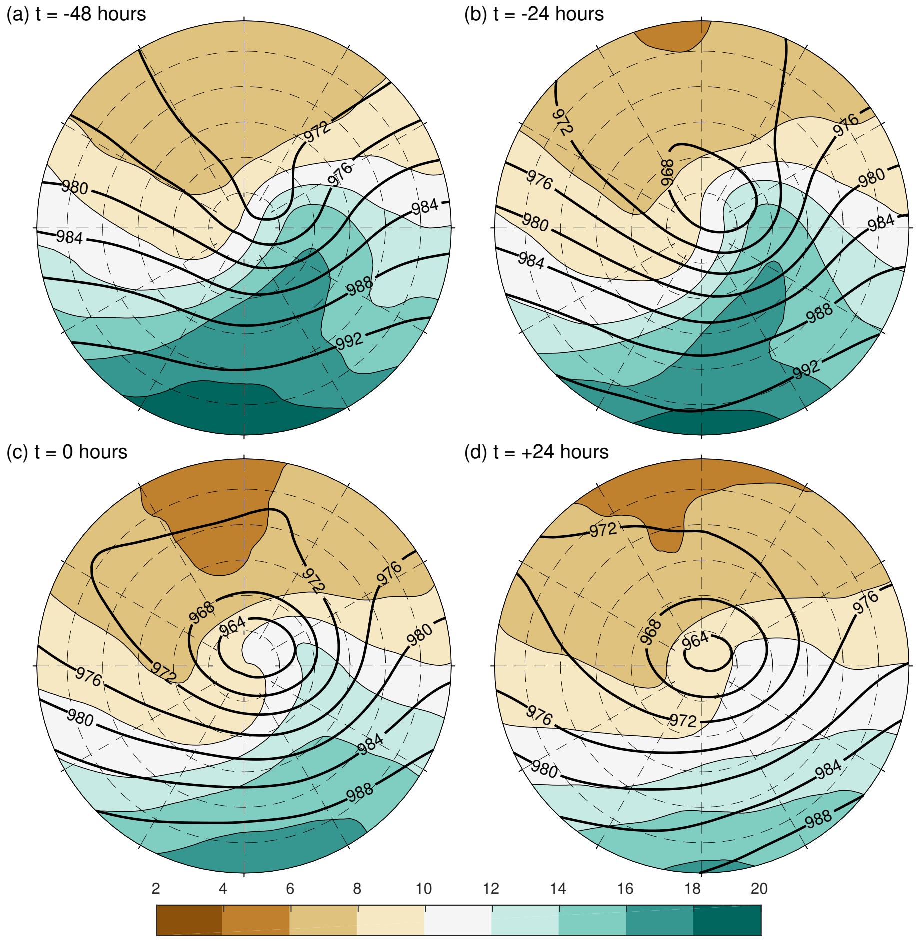

Figure S1: Composite cyclone of the most average 200 extra-tropical cyclones in the CNTL simulation at (a) 48 hours before time of maximum vorticity, (b) 24 hours before time of maximum vorticity, (c) time of maximum vorticity and (d) 24 hours after the time of maximum vorticity. Shading shows the total column water vapour (g kg^{-1}) and black contours show the mean sea level pressure (hPa). The plotted radius is 12 degrees.

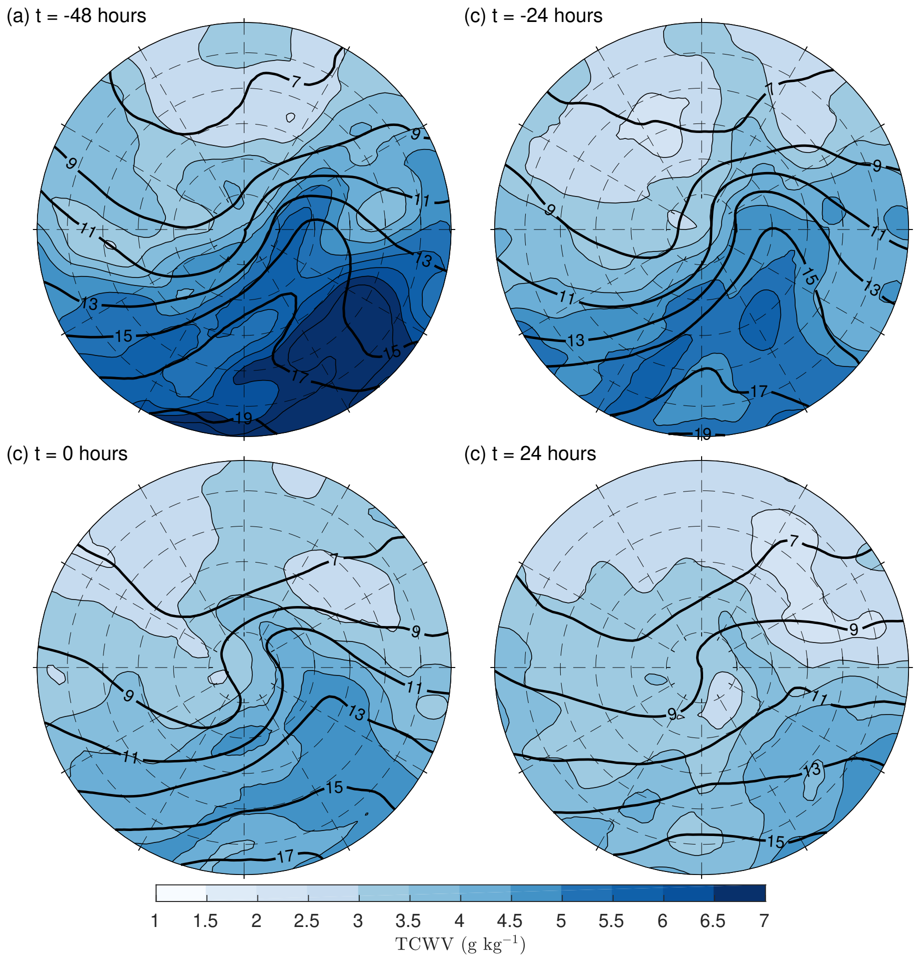

Figure S2: Composite mean of the total column water vapour (TCWV) of the most average 200 extra-tropical cyclones in the CNTL simulation (black contours, every 2 g kg^{-1}) and the difference between SST4 and CNTL (shading) at (a) 48 hours before time of maximum intensity, (b) 24 hours before time of maximum intensity, (c) time of maximum intensity and (d) 24 hours after the time of maximum intensity.

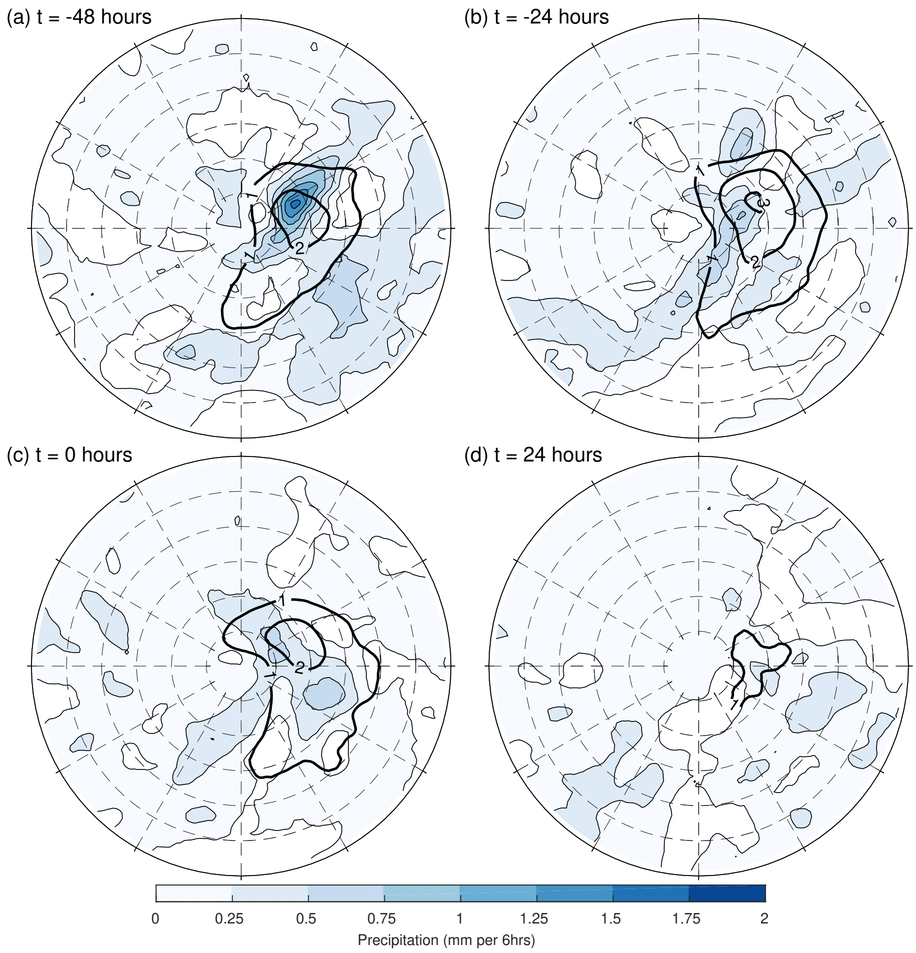

Figure S3: Composites of total precipitation in the CNTL simulation (black contours) and the difference between SST4 and control (shading) for the most average 200 storms at (a) 48 hours before time of maximum intensity, (b) 24 hours before time of maximum intensity, (c) time of maximum intensity and (d) 24 hours after the time of maximum intensity.

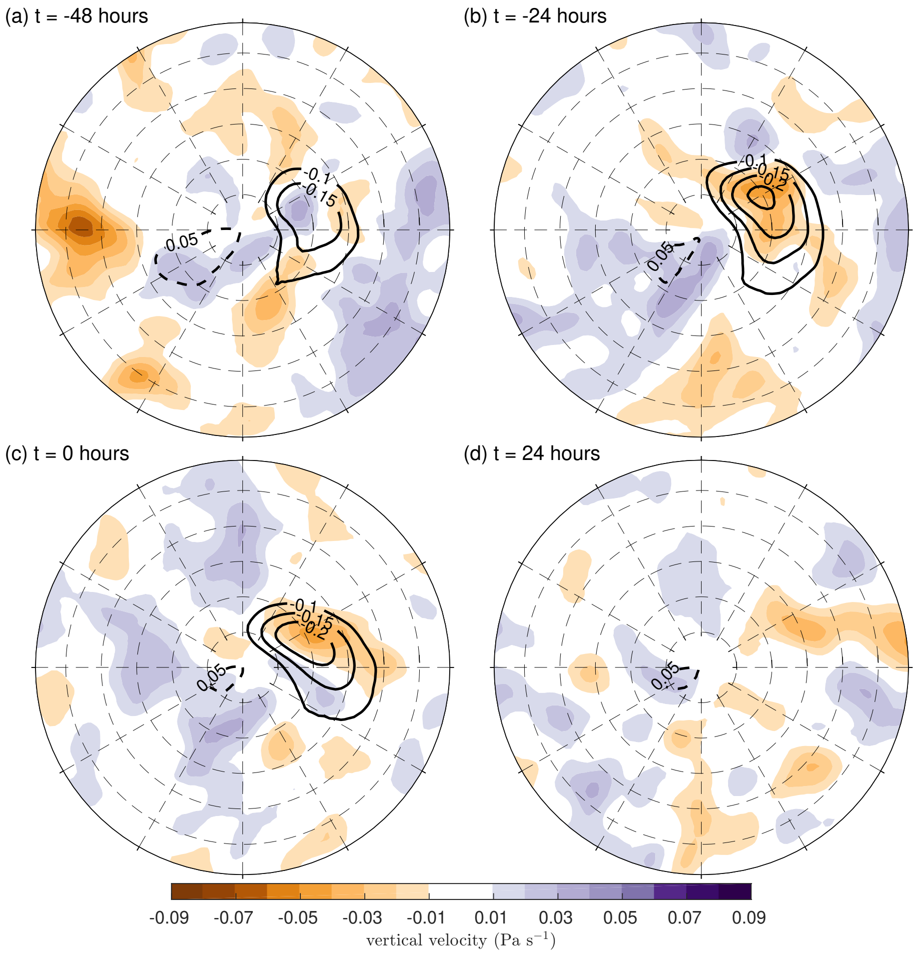

Figure S4: Composite mean of the 700-hPa vertical velocity in pressure coordinates in the CNTL simulation (black contours) and the difference between SST4 and control (shading) for the 200 most average storms at (a) 48 hours before time of maximum intensity, (b) 24 hours before time of maximum intensity, (c) time of maximum intensity and (d) 24 hours after the time of maximum intensity.