Department of Meteorology

Extratropical cyclone induced sea surface temperature anomalies in the 2013/2014 winter

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1. Introduction

- The 2013/14 winter sea surface temperatures (SSTs) cooled by 2^{o}C more than usual in the mid-North Atlantic region. The 2013/14 winter was also unusually stormy with cyclones passing over the mid-Atlantic approximately every 3 days
- In this study we investigate the SST cooling associated with the passage of multiple cyclones in the 2013/2014 season to determine how significant cyclones were in contributing to the observed cooling anomaly

2. Data

- 6 hourly ERA-Interim net surface heat flux (Q_N) and SST data is used in this analysis. The ECMWF convention for vertical fluxes is positive downwards
- Interannually and monthly varying mixed layer depth (h) from the ECMWF Ocean Reanalysis (ORAS5) is used to calculate the SST tendency due to air–sea interactions (ASIs), ΔSST_{ASI}
- The SST tendency anomaly due to air–sea interactions (ASIs), $\Delta SST'_{ASI}$, for the 2013–2014 season is determined by subtracting the 1989–2015 climatological SST tendency from the 2013–2014 SST tendency.
- $\Delta SST'_{ASI}$ can be separated into the anomaly associated with (i) anomalous Q_N (term 1), (ii) anomalous MLD (term 2) and (iii) anomalous entrainment through the base of the mixed layer, Q_{ENT} (term 3). Since we have no measurements of the entrainment flux anomaly across the ocean boundary layer, it is estimated to be 20% of the surface Q_N anomaly.
- $\Delta SST'_{ASI} = \frac{Q_N^i - \overline{Q_N}}{\rho c_p \bar{h}} + \frac{Q_N^i}{\rho c_p}\left(\frac{1}{h^i} - \frac{1}{\bar{h}}\right) + \frac{Q_{ENT}^i - \overline{Q_{ENT}}}{\rho c_p \bar{h}}$ where ρ is the density of sea water, c_p is the specific heat capacity of sea water and the overbar represents the the climatological value.

3. Cyclone masking method

- The heat flux associated with a cyclone is calculated by creating a 14^o radius mask surrounding the position of the cyclone, and it's position during the previous 30 hours (figure 3a)
- E.g. the synoptic analysis in figure 3b shows a low pressure centre to the west of the UK and a cold front extending across the N Atl. The corresponding cyclone mask captures large negative Q_N surrounding the cyclone centre and the cyclone's cold wake (figure 3c).
- We partition the Q_N anomaly into a part associated with the environmental flow (i.e. outside the cyclone masks) and a part associated with the presence of cyclones (inside the cyclone masks).

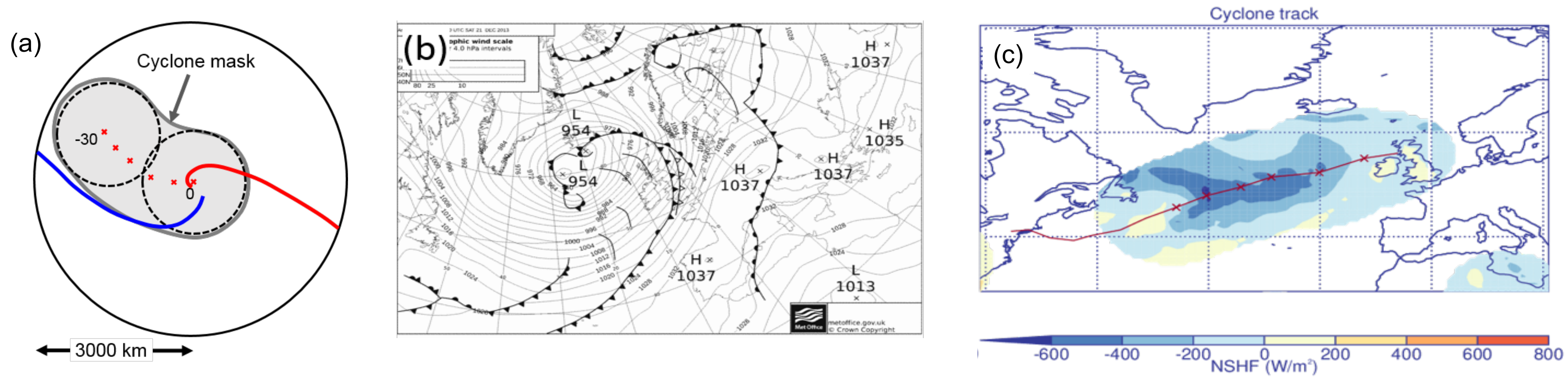

Figure 3. (a) Schematic of cyclone masking method. Red crosses shows the position of the cyclone at time 0 and at 6-hourly intervals up until 30 hours previously. The grey shading shows the extent of the cyclone mask. (b) Met Office synoptic analysis chart, (c) cyclone track and mask for 00 UTC 20 December 2013. Red crosses show the position of cyclones at the analysis time and 30 hours previously.

4a. Results: 2013/14 heat flux anomalies

- In the 2013/2014 winter many cyclones travelled in a zonal direction from the east coast of the US towards the UK (figure 4a)
- Compared to the 1989-2009 climatology, the 2013/14 Q_N was anomalously negative in the mid-N Atl. (figure 4b)
- Both the Q_N anomaly associated with cyclones and the environmental flow (figure 4c) and the environmental flow only (figure 4d) show a tripole pattern, with anomalously negative heat flux in the mid-North Atlantic and positive anomalies in the Norwegian Sea and Gulf Stream regions suggesting that the overall pattern is controlled by the environmental flow.
- In the mid-North Atlantic the negative Q_N anomaly is doubled when cyclones are present. Thus cyclones embedded in the environmental flow pattern increase the negative surface heat flux.

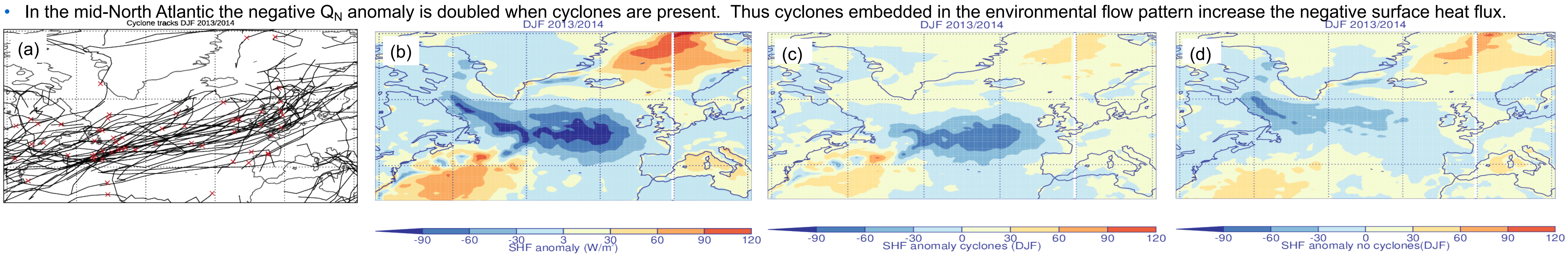

Figure 4: (a) DJF 2013/2014 cyclone tracks (black) with position of maximum intensity (red crosses), (b) Total Q_N anomaly, (c) Q_N anomaly associated with both cyclones and the environmental flow and (d) the environmental flow only.

4b. Results: 2013/14 SST tendency anomalies

- The total SST cooling due to ASI accounts for 68% of the observed cooling anomaly.
- In the mid-North Atlantic region, $\Delta SST'_{ASI}$ is enhanced when cyclones are present but by less than their contribution to the Q_N anomaly because enhanced negative Q_N cools a deeper layer of the ocean than usual, which reduces the direct SST cooling (figure 5a).
- The average SST cooling anomaly due to ASI when cyclones are present was ~1K (figure 5a) which accounts for 41% of the observed anomalous cooling in the mid-North Atlantic (figure 5b)

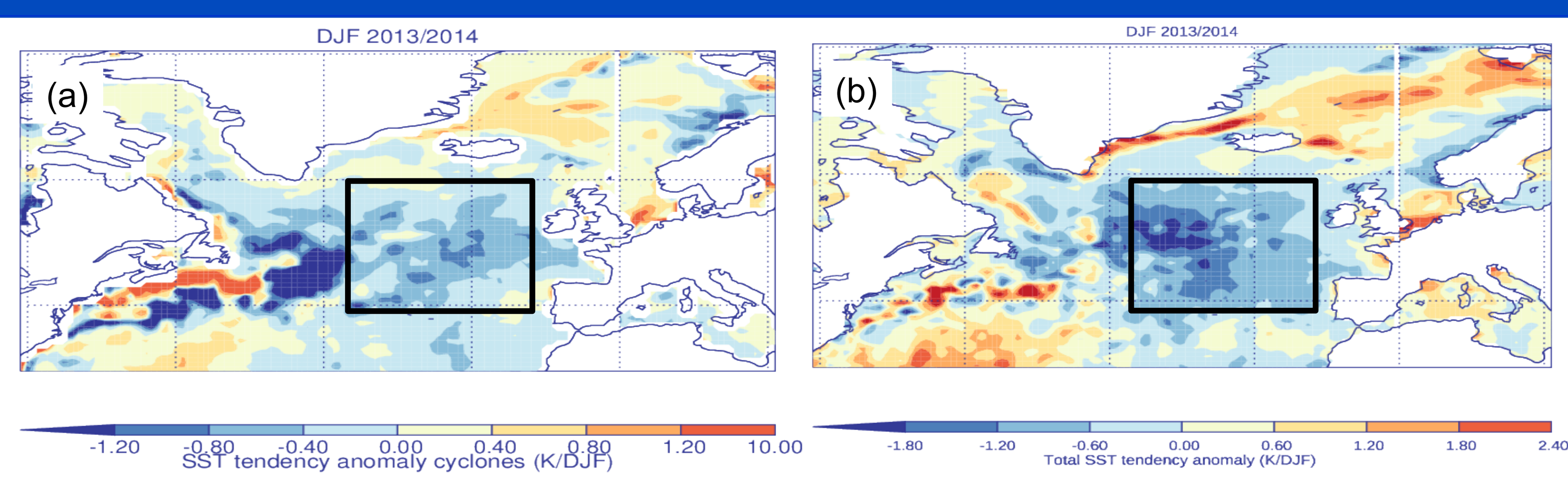

Figure 5: 2013– 2014 (a) $\Delta SST'_{ASI}$ (a) associated with cyclones and the environmental flow. (b) observed $\Delta SST'$. The black boxes show the region over which SST cooling is calculated.

5. Conclusions

- Enhanced exchange of heat and moisture in the cold sector behind the cold front of cyclones can lead to cooling of up to 0.2 K/day for strong cyclones creating a 'cold-wake' in the SSTs.
- During the 2013/2014 DJF season there were a high number of cyclones and their tracks were anomalously zonal. This resulted in anomalously large negative heat flux in a zonal band extending from the east coast of the US towards Europe. The mixed layer depth was also anomalously deep due to enhanced mixing and entrainment of water into the mixed layer from below.
- The anomalous heat flux, MLD and entrainment in the 2013/2014 season accounted for 68% of the observed cooling anomaly in the mid-North Atlantic. Thus, air-sea interactions played a major role in determining the extreme 2013/2014 winter season anomalous SST cooling.
- When cyclones were present, heat flux from the ocean was doubled in the mid-North Atlantic region. This caused a direct cooling of the ocean but also led to increased entrainment and thus a deeper mixed layer. The SST tendency anomaly was thus enhanced by the presence of cyclones but by a smaller amount than might be expected due to a doubling of the heat flux.
- Thus, both the environmental flow and extratropical cyclones embedded within this flow played important roles in determining the extreme 2013-2014 winter season SST cooling.

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