Precipitation, Moisture Sources and Transport Pathways associated with Summertime North Atlantic Deep Cyclones
egusphere-2025-1752

This paper aims to evaluate the moisture sources for summertime extratropical cyclones. It employs a Lagrangian back trajectory method to determine the sources and sinks of moisture for parcels that result in precipitation at the centre of cyclones. Overall, the paper is well written, the analysis interesting and conclusions a valuable contribution to the literature. I have made quite a lot of specific comments, but they are largely points of clarification rather than extensive requests for further analysis. I recommend that this paper would be suitable for publication in WCD if the points below are addressed.

General comments

1. Throughout the paper the authors refer to moisture being 'transported from remote regions to the centre of the cyclone' or the 'delivery' of moisture to the cyclone. These phrases imply that the cyclone is stationary, and that moisture is transported towards it. How good is the approximation of a stationary cyclone? If the cyclone is not stationary, then moisture may remain 'local' to the cyclone centre, but still undergo 'long-range transport' as it moves with the cyclone. Please could the authors be more specific with their phrasing and define what they mean by local and remote.
2. Q2 states that cyclone-relative moisture sources will be determined. While cyclone-relative evaporation is shown (figure 11) I could not find any cyclone relative moisture source analysis in the paper. In a cyclone-relative frame of reference, it would be necessary to subtract the cyclone motion from that of the Lagrangian trajectories. However, since many of the cyclones will not exist for 8-days I'm not sure how this would be performed. As noted in comment 56, simply showing cyclone-relative streamlines or wind vectors overlaid in figure 11 would go some way to answering the question, but as it is, I do not think the authors have answered part of Q2.

Specific comments

3. Line 14: The data source should be referred to here, i.e. ERA5
4. Line 17: Do the authors mean 'beneath the warm conveyor belt', rather than 'in the WCB' or are they suggesting that some precipitation associated with the WCB evaporates within the airflow?
5. Line 24: It is not clear what the authors mean by remote and localised sources. Are they referring to distance relative to the cyclone position at some fixed point along its track, or relative to a moving cyclone?
6. Line 32: The authors refer to moisture 'coming from' specific source regions. This suggests somehow that the atmosphere is stationary, and that the moisture is transported through that stationary atmosphere. Perhaps 'originate' would be more specific term to use?
7. Line 38: There are many earlier papers that describe the role of extratropical cyclones in redistributing energy, moisture and momentum. Please refer to original sources where possible.
8. Line 63: This sentence seems strangely worded to me since it implies that the convergence on the warm side of the cold front is coincidentally co-located with the WCB. In reality, the cross-front ageostrophic circulation causing convergence near the surface increases frontogenesis along the cold front strengthening the horizontal part of the WCB. The convergence also leads to ascent strengthening the vertical part of the WCB. Thus, there is no coincidence but direct cause and effect (see Dacre and Clark, 2025)
   Dacre, H.F. and Clark, P.A., 2025. A kinematic analysis of extratropical cyclones, warm conveyor belts and atmospheric rivers. *npj Climate and Atmospheric Science*, *8*(1), p.97.
9. Line 65: Here it is stated that large-scale vertical motion lifts the WCB above the warm front. What is causing the large-scale vertical motion? Are the authors referring to divergence aloft downstream of a planetary-scale Rossby wave or some other mechanism?
10. Line 71: I do not see follow the logic here. The fact that WCB ascend from the boundary layer to the upper-troposphere in 2-days does not imply that they transport more moisture to the upper troposphere than shallow convective processes, or that they are the main sink of precipitable water in the atmosphere. Please add more details to explain this sentence.
11. Line 74: The WCB is generated by the same mechanisms that are responsible for the formation of extratropical cyclone fronts, therefore they are 'intrinsically linked' not 'often linked'.

12. Line 78: If you are saying that moisture is ‘transported from remote regions to the centre of the cyclone’ then are you assuming that the cyclone is stationary? If not, you need to consider that the moisture may have remained local to the centre of the cyclone, but that it moved with the cyclone as it travelled.
13. Line 81: ARs are generated by the same processes that create the WCB airflow, thus they do not exist without cyclone airflows. The apparent distinction is merely a matter of choice of threshold and the different methods used to identify them.
14. Line 142: Are there any limitations to using ERA5 precipitation in this study?
15. Line 183: Over what period is the intensification measured? 24 hours or the entire cyclone lifecycle?
16. Line 196: In the figure caption what does the maximum depth refer to? Is this the maximum deepening in 24 hours? Or the total deepening over the cyclone lifecycle?
17. Line 212: Frontal circulations occur within 500km of the cyclone centre, particularly in the developing stages before frontal fracture occurs.
18. Line 214: Without observations, how do you know that the precipitation is allocated to the ‘right’ moisture sources?
19. Line 227: Is the first timestep, the first 3 hours?
20. Line 233: Is the start point of the trajectory the cyclone centre, or the location of the trajectory 8-days earlier?
21. Line 237: Is there sensitivity to this choice of threshold?
22. Line 274: Does the maximum depth refer to a deepening of 35.2 hPa over the entire cyclone period in which case is it a maximum or should it be a total? Or is it the maximum deepening over a 24-hour time window, in which case the time period should be included.
23. Line 293: What is meant by ‘keep the moisture in place’? Typically, the winds near cyclones are relatively strong.
24. Line 295: The authors might be interested in reading Demirdjian et al. (2023) which describes this process very nicely.
    Demirdjian, R., Doyle, J.D., Finocchio, P.M. and Reynolds, C.A., 2023. Preconditioning and intensification of upstream extratropical cyclones through surface fluxes. *Journal of the Atmospheric Sciences*, *80*(6), pp.1499-1517.
25. Line 300: Figure 3 uses a colour scale that makes the fluxes on the warm side of the Gulf Stream appear to be positive. I had to look very carefully to see the ‘sharp transition’ from negative to positive. I suggest using a divergent red-blue colour scale instead.
26. Line 303: What is the surface evaporation elevated with respect to? No climatology of evaporation is shown so it is not clear if this is a climatological response or related to the passage of the cyclone.
27. Line 305: Figure 4 uses a colour scale in which it is difficult to observe the ‘evaporation hotspots’. Perhaps anomalies or normalised anomalies could be shown? I.e. subtract the climatological field and divide by the standard deviation of the climatology at each location. Then it would be possible to see how large anomalies are relative to the climatological mean, i.e. 1 std deviation larger/smaller than climatological mean?
28. Line 318: No evidence is provided to support the statement that the dynamical flow is setup by the primary cyclone, or that significant moisture accumulates ahead of the developing cyclone.
29. Line 326: Here the authors refer to the sources of moisture moving eastward. Presumably this is related to the fact that the cyclone is also moving eastward?
30. Line 332: How are long-range and local defined. Do they refer to a distance travelled by the trajectories over the 8-day period or are they the distance relative to a fixed feature, or the moving cyclone?
31. Figure 5: It is useful to show the cyclone track, but I wonder if the position of the cyclone at 24hr intervals preceding the trajectory start time should be shown instead?
32. Line 351: I don’t think that the trajectory figures 6a-c are very legible. It’s difficult to identify the different pathways. If 80% of the moisture uptake occurs within 4 days of precipitation (line 515), would it be better to show shorter trajectories in figure 6 to make it more legible?
33. Line 354: How do you know the parcels were lifted by convection?
34. Line 355: If the parcels are lifted by convection, how do they converge at the surface?

35. Line 359, 370, 570: Here and elsewhere, the descending trajectories behind the cyclone cold front are known as the dry intrusion. It might be helpful to refer to this term to enable links with previous work.
36. Line 360, 578-9: Likewise, the air behind the primary cyclone cold front which is then 'fed into the secondary cyclone' is known as the feeder-airstream. It might be helpful to refer to this term to enable links with previous work.
37. Line 366: Use of the phrase 'came from' suggests air travelling towards the cyclone from the primary cyclone. Would a better description be that this air was swept up by the secondary cyclone as it travels into the region of enhanced moisture?
38. Line 410: You have not shown evidence that maximum vertical motion occurs before minimum MSLP? I think maximum precipitation typically occurs before maximum dynamical intensity due to limited moisture availability as cyclones travel polewards.
39. Line 29: Can you concentrate precipitation. Perhaps extending would be a better word to describe the shape of the precipitation pattern?
40. Line 438: The precipitation does not significantly drop for Gulf Stream cyclones since the moisture availability remains high, even in the decay phase. By contrast, precipitation drops significantly for the other regions due to reduced dynamical forcing and reduced moisture availability.
41. Figure 7: Much of the precipitation pattern in the decaying phase is outside the domain shown. Could a larger domain be used to capture the full shape of the cyclone precipitation pattern in this phase?
42. Line 469: The authors describe the eastwards shift in the moisture sources as 'slight'. This is a subjective word. Could they calculate the magnitude of the eastward shift? This could then be compared with the eastward shift in the mean cyclone position to see if they are comparable.
43. Line 469: The eastward shift is also evident for the Gulf Stream cyclones.
44. Line 474: Local to what?
45. Figure 8: Would it be possible to show the mean cyclone position at various stages in the cyclone lifecycle.
46. Line 495: Within 1000km of what?
47. Line 513: Would these terrestrial sources be the Great Lakes, or are they more widespread than this?
48. Line 526: Sources 1000-1500km away from what?
49. Line 539: Ascending trajectories ahead of the cold front are part of the WCB airflow. It might be helpful to refer to them as the ascending part of the WCB to enable links with previous work.
50. Line 540: What is the evidence for moisture accumulation near the cyclone centre?
51. Figure 11: These figures correspond well with figures 5 and 6 in Dacre et al. (2020), showing maximum latent heat fluxes behind the cyclone cold front as a result of large vertical gradients in specific humidity.
    Dacre, H.F., Josey, S.A. and Grant, A.L., 2020. Extratropical-cyclone-induced sea surface temperature anomalies in the 2013–2014 winter. *Weather and Climate Dynamics*, *1*(1), pp.27-44.
52. Line 615: What about moisture evaporated in the subtropical high as referred to earlier in the paper?
53. Line 623: Here the authors refer to 'delivery' of moisture to the cyclone. Again, this implies the cyclone is stationary and that moisture is transported towards it from 'remote sources'. Is this really what is happening?
54. Line 630: Source distances from what?
55. Line 650: Dacre et al. (2023) use a very different method to that used here and estimate a mean moisture residence time of 36 hours. Do you think this is due to methodological differences or because they focus on extreme winter cyclones where the ascent rates are typically higher than for summer cyclones?
56. Line 657: You have not included a figure of cyclone-relative low-level winds so it is not possible to determine if a feeder airstream is present in your cyclone composites. Would it be possible to overlay cyclone-relative streamlines to see if the feeder airstream can be identified?
57. Line 671: This sentence suggests there are multiple ascending motions. Are the authors referring to frontal line convection as an alternative to the WCB airflow?
58. Line 676: Similar to what, the precipitation in winter cyclones?

59. Line 680: How are you separating fronts and WCB airflow? They are generated by the same mechanism, so it seems strange to separate the precipitation associated with them. Perhaps you are referring to the horizontal and vertical parts of the WCB? Or to frontal line convection and WCB ascent?

Typographical errors

60. Line 10: Why is the word ‘extreme’ in brackets?
61. Line 42: Why is ‘heavy’ in brackets?
62. Line 97: Here and elsewhere, it is more standard to refer to the singular ‘precipitating water’ rather than the plural ‘precipitating waters’.
63. Line 101: ‘How’ should be ‘whether’ since you haven’t determined this yet.
64. Line 164: You do not need cf.
65. Line 171: The number 2 needs units.
66. Line 216: I think interpolated would be a better description than ‘traced’.