The Greenland tip jet and its effect on the Irminger Sea

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Introduction

Deep convection in the open ocean can occur when a unique set of oceanic and atmospheric conditions - a preconditioned water column, cyclonic circulation and strong atmospheric forcing - are satisfied. Among the few locations where these requirements are met is the Labrador Sea, where the intermediate water mass known as Labrador Sea Water (LSW) originates. Recently the hypothesis that LSW is also formed in the southern Irminger Sea has been rekindled [1]. Regarding the atmospheric forcing, a mechanism capable of enhancing the heat loss from the southern Irminger Sea exists in the form of a strong, but narrow and intermittent wind pattern called the Greenland tip jet [2, Fig. 1]. If a second source of LSW exists, this would influence our understanding of the ventilation of the North Atlantic and its branch of the meridional overturning circulation.

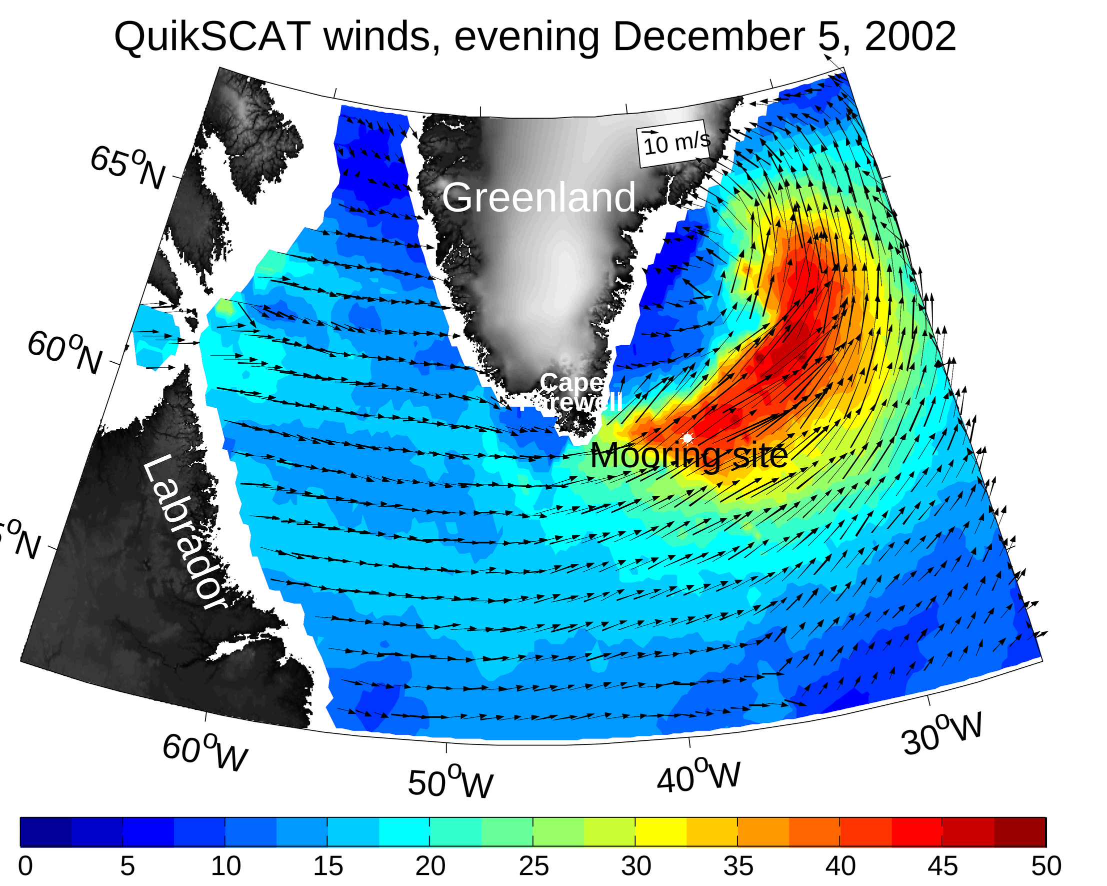

Figure 1: QuikSCAT wind speed (color) and vectors showing a tip jet on 5 December, 2002. The wind speed at the mooring site (white star) during this event was 37 m/s. Orography is rendered in grayscale.

ERA-40 tip jet climatology

Tip jet events were objectively determined using an EOF approach applied to ERA-40 reanalysis data. A total of 586 events were detected during the winters (November-April) of the ERA-40 period (1957-2002). Comparison with high-resolution QuikSCAT data from the period of overlap (1999-2002) indicates that about 90% of the tip jets that took place were detected in the lower resolution ERA-40 data. Both the NAO index and the latitude of the Icelandic Low were significantly correlated with the number of tip jets per winter (0.71 and 0.69 respectively).

Composite averages during the 24 hour period surrounding an event (Fig. 2) portray the tip jet as an intense, short-lived phenomenon. Peak wind speeds approaching 20 m/s (estimated 30 m/s true speed) were sustained for less than a day (top). Each tip jet event was associated with a parent low pressure system, typically occupying the region immediately east of southern Greenland (middle). The turbulent heat fluxes were on average more than 3 times greater during tip jet events compared with background levels (bottom), and the integrated effect of many tip jets during the course of a winter are important for the evolution of the oceanic mixed-layer.

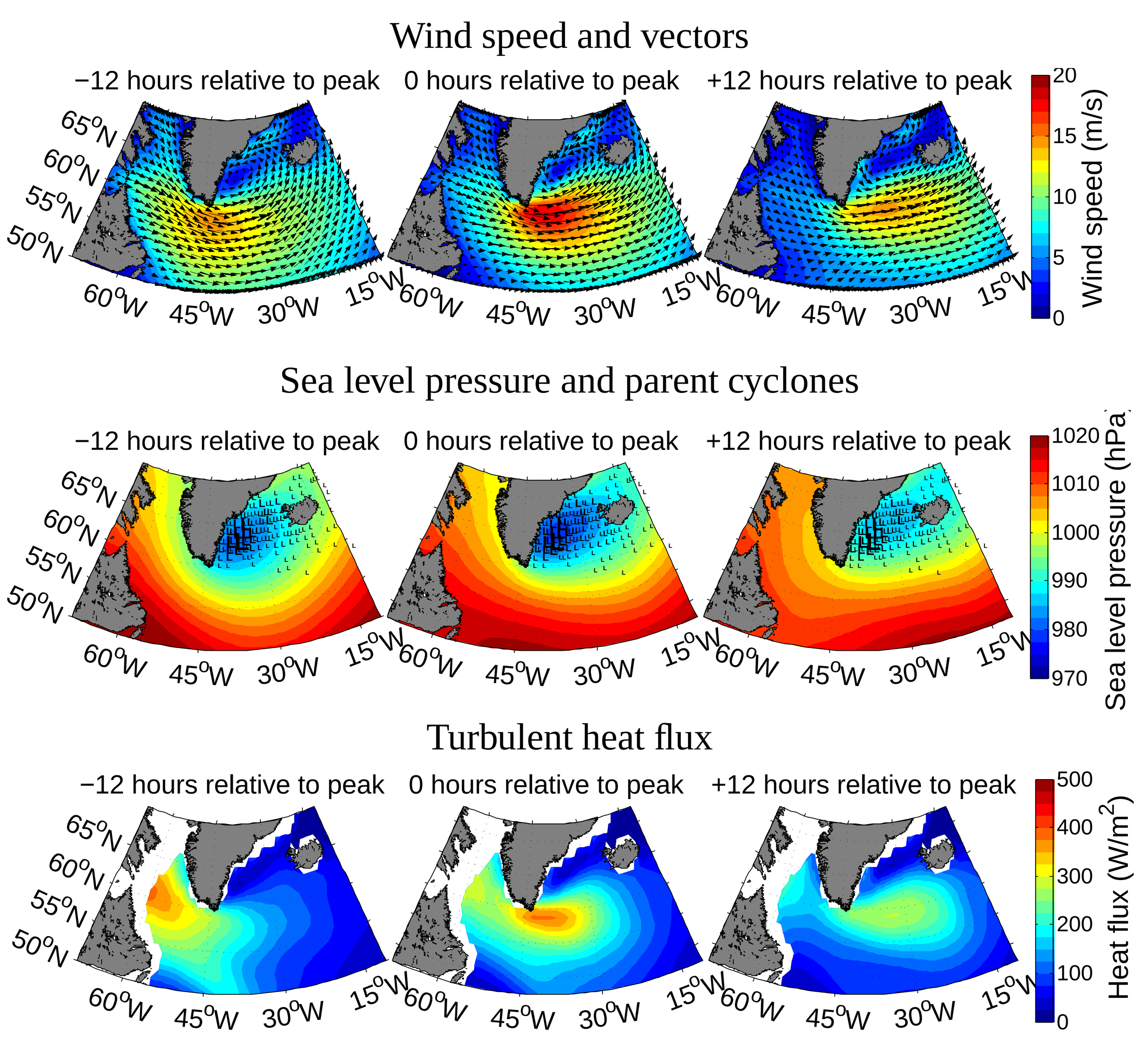

Figure 2: Composites of wind speed, sea level pressure and turbulent heat fluxes showing the evolution of the Greenland tip jet.

Acknowledgements

The authors wish to thank John Toole, Paula Fratantoni, Anna Nikolopoulos, Tom Farrar, Fiamma Straneo, Thomas Spengler, Harald Sodemann, Heini Wernli, Cornelia Schwierz, Christoph Schär, and Nicolas Gruber for very helpful discussions. We also thank Tom Farrar for providing the Matlab version of the PWP model, Heini Wernli and Cornelia Schwierz for providing the cyclone data, and Heini Wernli for providing the jet stream data. We acknowledge Meteo-Swiss, the NOAA Climate Diagnostic Center and Remote Sensing Systems for the ERA-40, NCEP and QuikSCAT data respectively.

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Backward trajectories

The 3D trajectory model Lagranto [3] was applied to compute backwards air parcel trajectories terminating above the southern Irminger Sea. The winters 1994 to 2002 were considered for this analysis, resulting in 2819 trajectories from 101 tip jet events (Fig. 3).

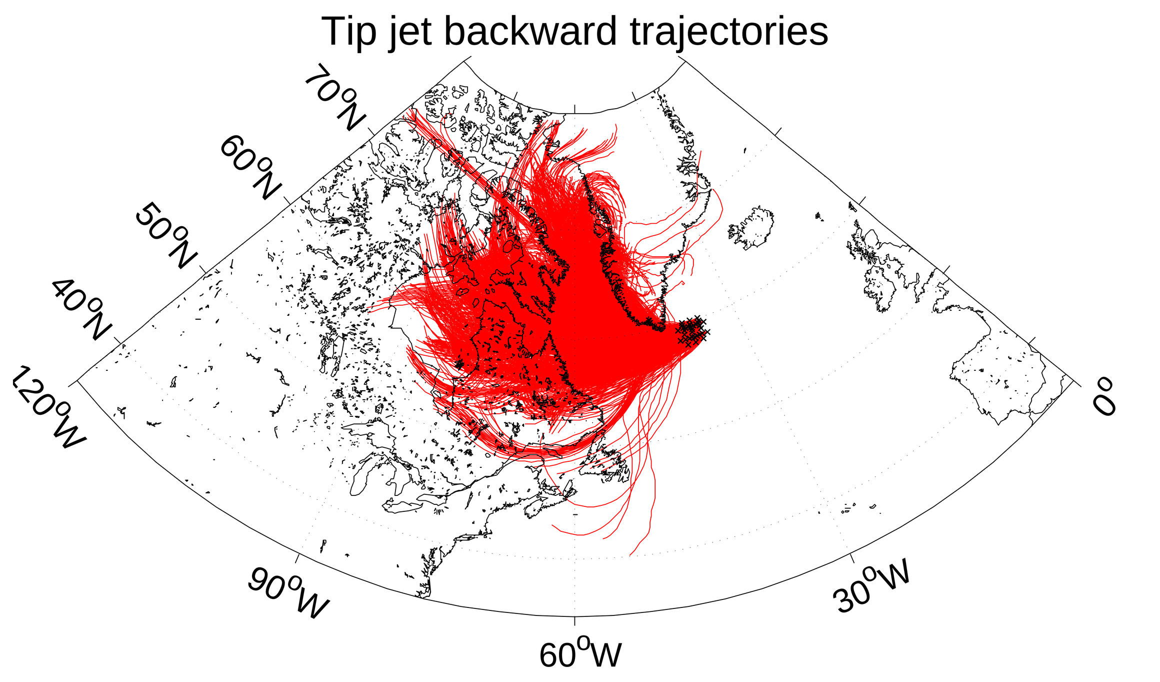

Figure 3: 2-day history of tip jet air parcels terminating at 950 and 900 hPa above the southern Irminger Sea.

The pressure change and velocity were computed along each trajectory, gridded and displayed in Figure 4. The alongtrack pressure change (top, color) indicates that some sinking is occurring over southern Greenland, but the vast majority of trajectories pass south of Cape Farewell (contours). The acceleration associated with deflection around Greenland stands out (bottom, color).

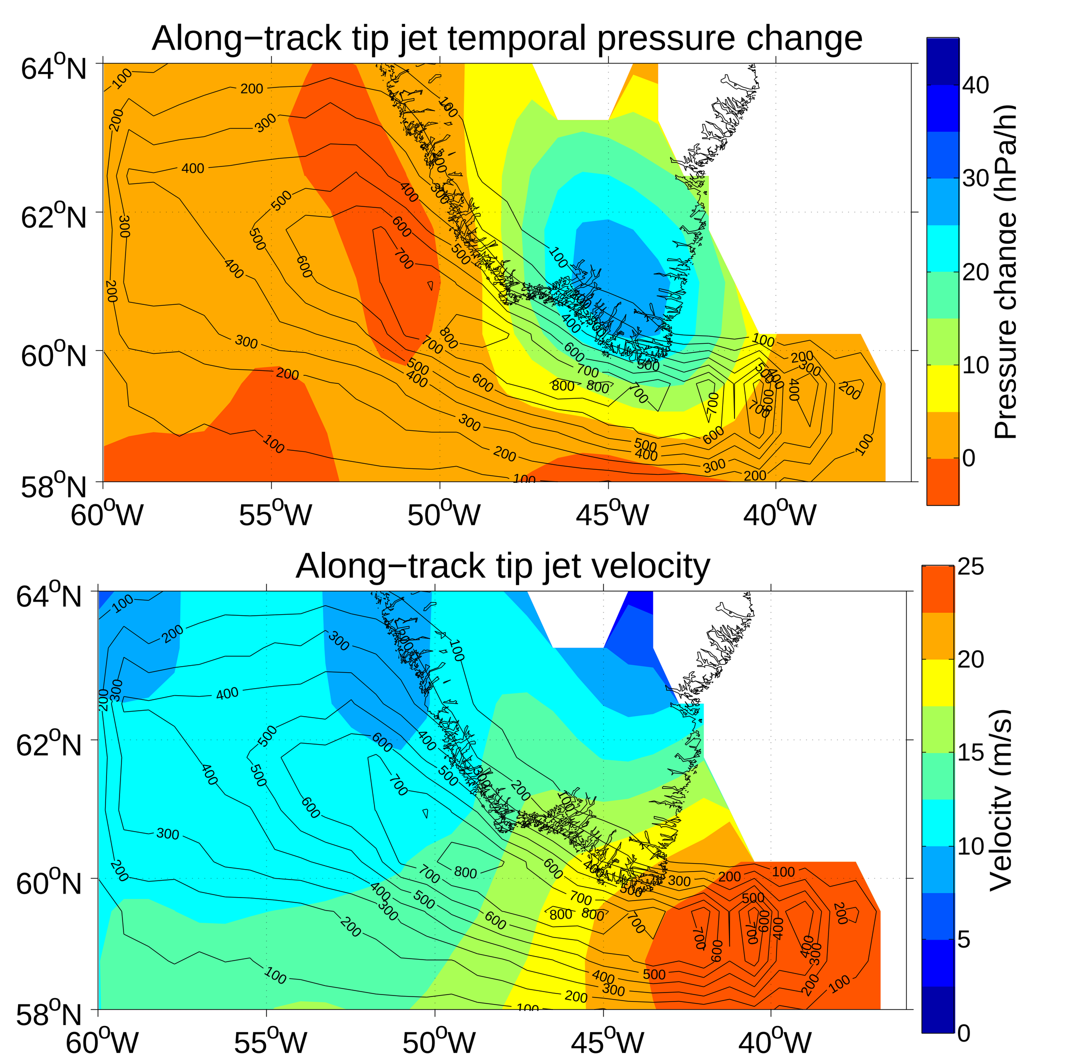

Figure 4: Alongtrack pressure change (top) and velocity (bottom) of tip jet trajectories terminating at 950 and 900 hPa over the southern Irminger Sea.

Mechanism of tip jet generation

A slice across the composite tip jet (not shown) indicates that there is often a vertical coherence with the troposphere-level jet stream, and hence this suggests a connection. The atmospheric conditions in terms of jet stream and cyclone residence during tip jets are contrasted with the mean winter conditions (Fig. 5) using a jet stream [4] and a cyclone [5] data base.

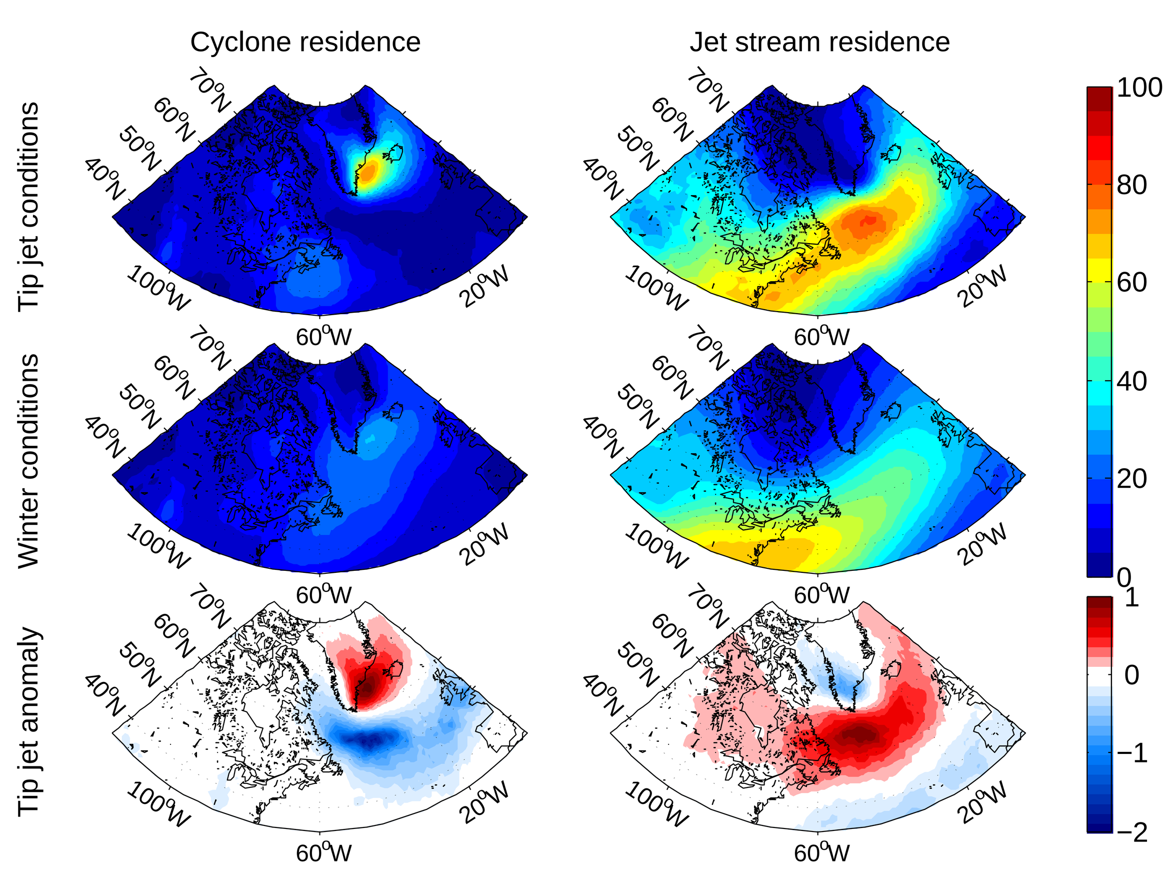

Figure 5: Area occupied by cyclones (left) and jet stream (right) during tip jet events (top) and mean winter conditions (middle). Colors indicate percentage of time. The tip jet anomalies relative to the mean are normalized by the standard deviation (bottom).

The strong positive anomalies of cyclone and jet stream residence during the tip jet events of the ERA-40 climatology (Fig. 5) suggest that the tip jets arise due to an interplay between the high orography of Greenland, a cyclone to the east, and the jet stream to the south. However, the jet stream also acts as an upper-level steering current in which cyclones are embedded and depend upon for sustenance, and it is conceivable that the presence of the jet stream has no impact on the development of the tip jet. The dynamics of this interaction are still under consideration.

Oceanic response

A moored profiler (MP) programmed to obtain twice-daily profiles of temperature and salinity between 60 and 1800 m was deployed in the southwest Irminger Sea (Fig. 1) for the winter of 2002-3. Mixed-layers below 60 m were observed between November and April (Fig. 6). Bulk heat fluxes were computed for the mooring site using timeseries of wind, humidity and air and sea surface temperatures from various sources in order to include the effect of the tip jet events. The resulting "best estimate" turbulent heat flux timeseries were used to force a 1D oceanic mixed-layer model [6, hereafter PWP], to be compared with standard NCEP forcing. Figure 6 shows timeseries of mixed-layer depth from the MP and from the PWP model. Removal of the tip jets from the forcing timeseries resulted in a 20% shallower mixed-layer and indicates that they contributed significantly to its deepening.

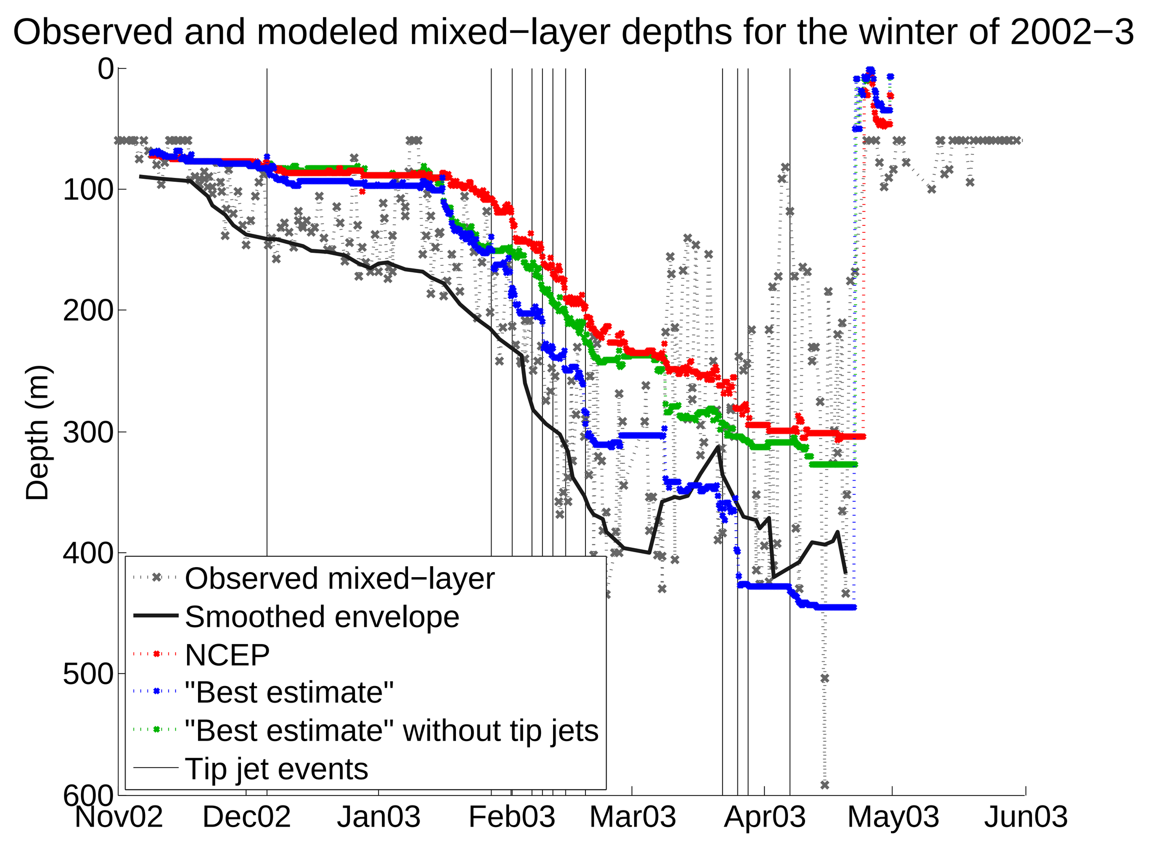

Figure 6: Observations and PWP results for winter 2002-3.

The good agreement between model and data encouraged application of the PWP model to a more robust, high-NAO winter. Deep convection occurred in the Labrador Sea in the winter of 1994-5. Hydrographic data collected in the Irminger Sea the following spring and summer suggests that convection occurred in that basin as well, to a depth of $\sim$1700 m [1]. A best estimate heat flux timeseries was computed for winter 1994-5 and used to force the PWP model (Fig. 7). At the end of the convective season, the mixed-layer had reached a depth exceeding 1700 m.

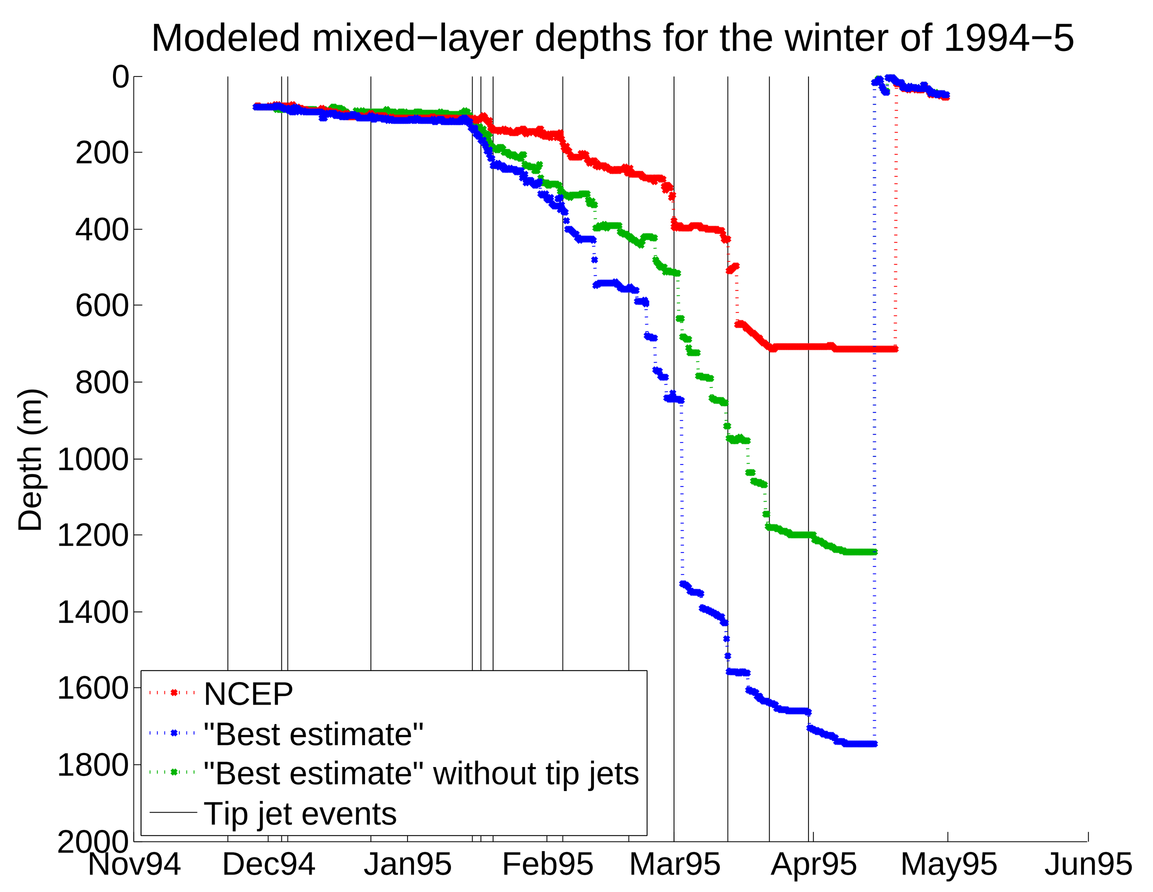

Figure 7: PWP results for winter 1994-5.

Conclusions

- Tip jets are intense, narrow and intermittent wind events east of Cape Farewell that occur on average 13 times per winter.
- Interaction between Greenland's high orography, presence of a cyclone to the east, and the jet stream to the south may generate tip jets.
- Tip jets cause elevated turbulent heat fluxes and are important for the seasonal evolution of the mixed-layer of the southern Irminger Sea.
- 1D mixed-layer model results add to the growing body of studies supporting the hypothesis that deep convection can take place in the Irminger Sea during high-NAO winters.

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