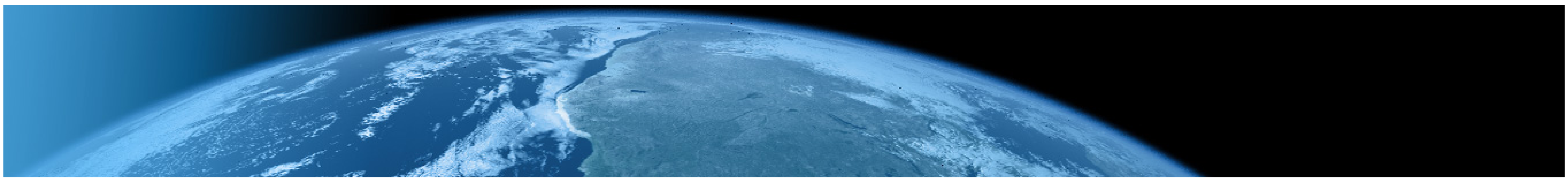

The Greenland Tip Jet and its Effect on the Irminger Sea

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

K. Våge[1, 2], R.S. Pickart[1], G.W.K. Moore[3], M.H. Ribergaard[4] and H.C. Davies[2]

[1]Woods Hole Oceanographic Institution, Massachusetts, USA
[2]Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland
[3]University of Toronto, Ontario, Canada
[4]Danish Meteorological Institute, Copenhagen, Denmark

Woods Hole Oceanographic Institution 1930

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]. Indirect evidence indicates that deep convection may have taken place there during sufficiently strong, high-NAO winters. Cyclonic circulation and a preconditioned water column are features of the Irminger Sea, and a mechanism capable of enhancing the heat fluxes from the southern Irminger Sea exists in the form of a strong, but narrow and intermittent wind pattern called the Greenland tip jet[2;3] (Fig. 1). This study seeks to elucidate the atmospheric conditions leading to tip jet events using the ERA-40 reanalysis data and a trajectory model. The impact of the events in dictating the evolution of the wintertime mixed-layer in the southern Irminger Sea is investigated using in-situ moored profiler data and application of a one-dimensional mixed-layer model. A second source of LSW would influence our understanding of the ventilation of the North Atlantic and its branch of the meridional overturning circulation.

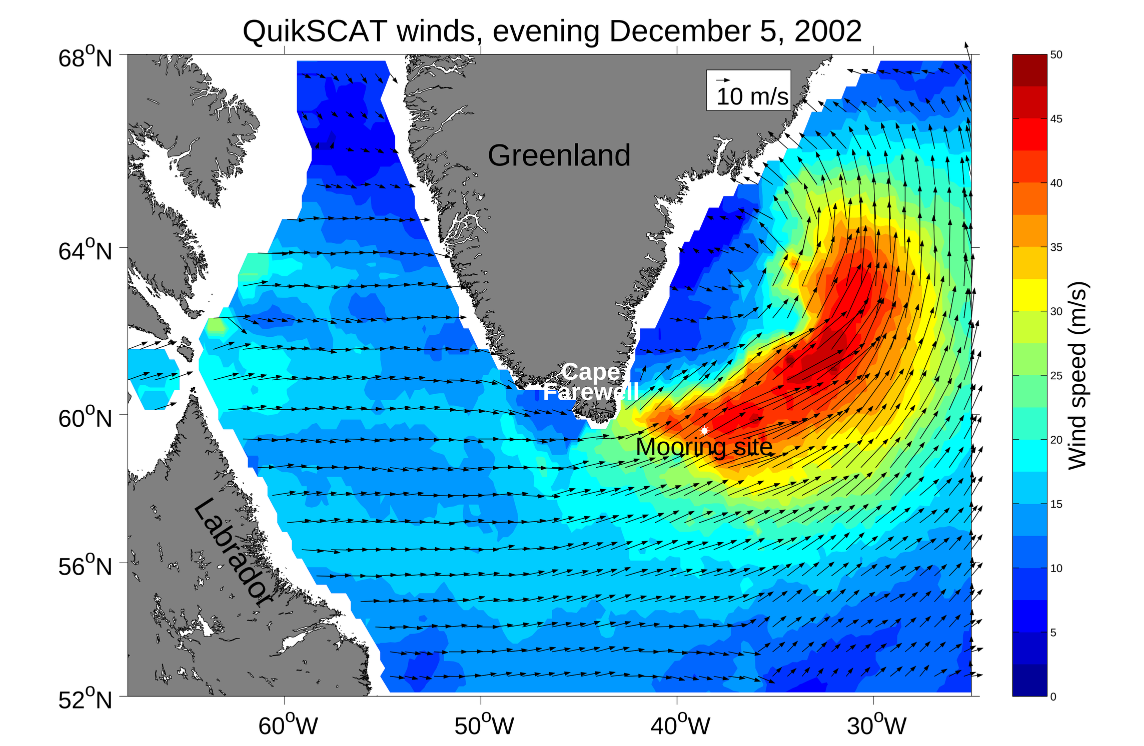

Figure 1: QuikSCAT wind speed (color) and vectors showing a tip jet on 5 December, 2002. The wind speed at the mooring site (white star) during this event was 37 m/s.

ERA-40 tip jet catalog

Tip jet events were objectively determined using an empirical orthogonal function (EOF) approach and a wind speed and direction criterion. A total of 531 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 there were detected in the lower resolution ERA-40 data. No false positives were reported. The ERA-40 and QuikSCAT maximum tip jet winds were highly correlated (0.78), but the satellite data showed that the ERA-40 winds were significantly underestimated. Correlations were also found between the total number of tip jet events per winter and both the NAO index and the latitude of the Icelandic Low (both 0.67).

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 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).

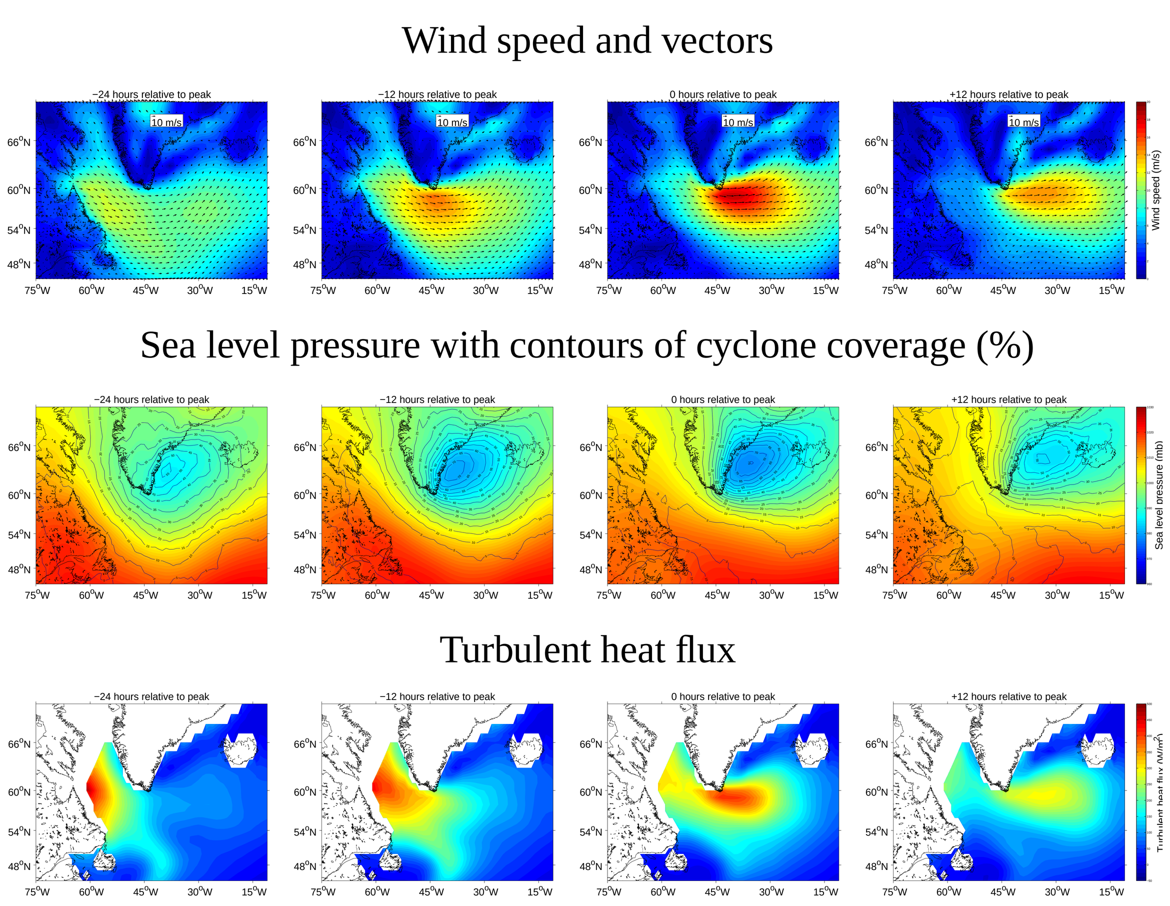

Figure 2: Composites of wind speed, sea level pressure and turbulent heat fluxes showing the evolution of the Greenland tip jet.

Backward trajectories

The 3D trajectory model Lagranto[4] was used to compute backwards air parcel trajectories terminating above the southern Irminger Sea, a region of weak water column stratification where deep convection is believed to occur during high-NAO winters[1]. The winters 1994 to 2002 were considered for this analysis, resulting in 2819 trajectories from 101 tip jet events (Fig. 3).

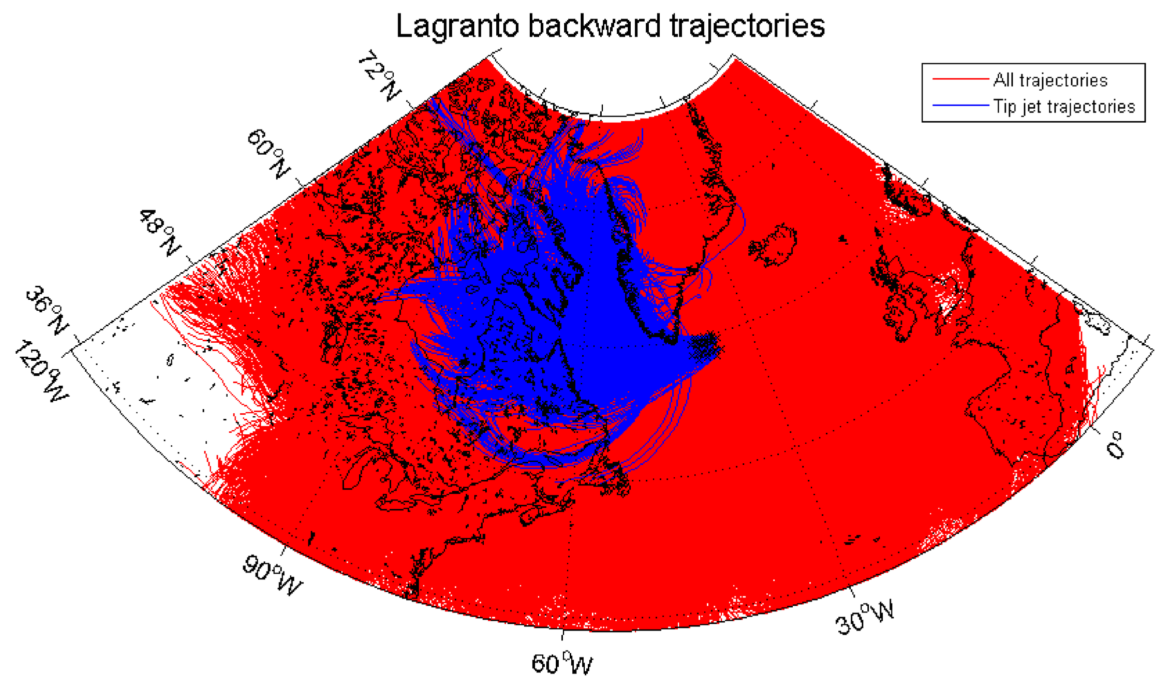

Figure 3: The Lagranto 5-day history of all air parcels terminating at 950 and 900 *hPa* above the southern Irminger Sea during winter 2001-2 (red trajectories) shows that nearly the entire domain is capable of supplying this region. However, during the tip jet events of 1994-2002 all of the air parcels originated from a region west of Greenland (blue trajectories).

The pressure change and velocity were computed along each trajectory, gridded and displayed in Figure 4. Only trajectories with a terminal wind speed greater than 20 m/s and a direction deviating at most 30° from east are included in order to capture the trajectories of those air parcels that actually formed the tip jets. The along-track pressure change (top, color) indicates that some sinking is occurring over southern Greenland, but that the vast majority of trajectories actually pass south of Cape Farewell (contours). The acceleration of air parcels due to the deflection around Greenland stands out (bottom, color).

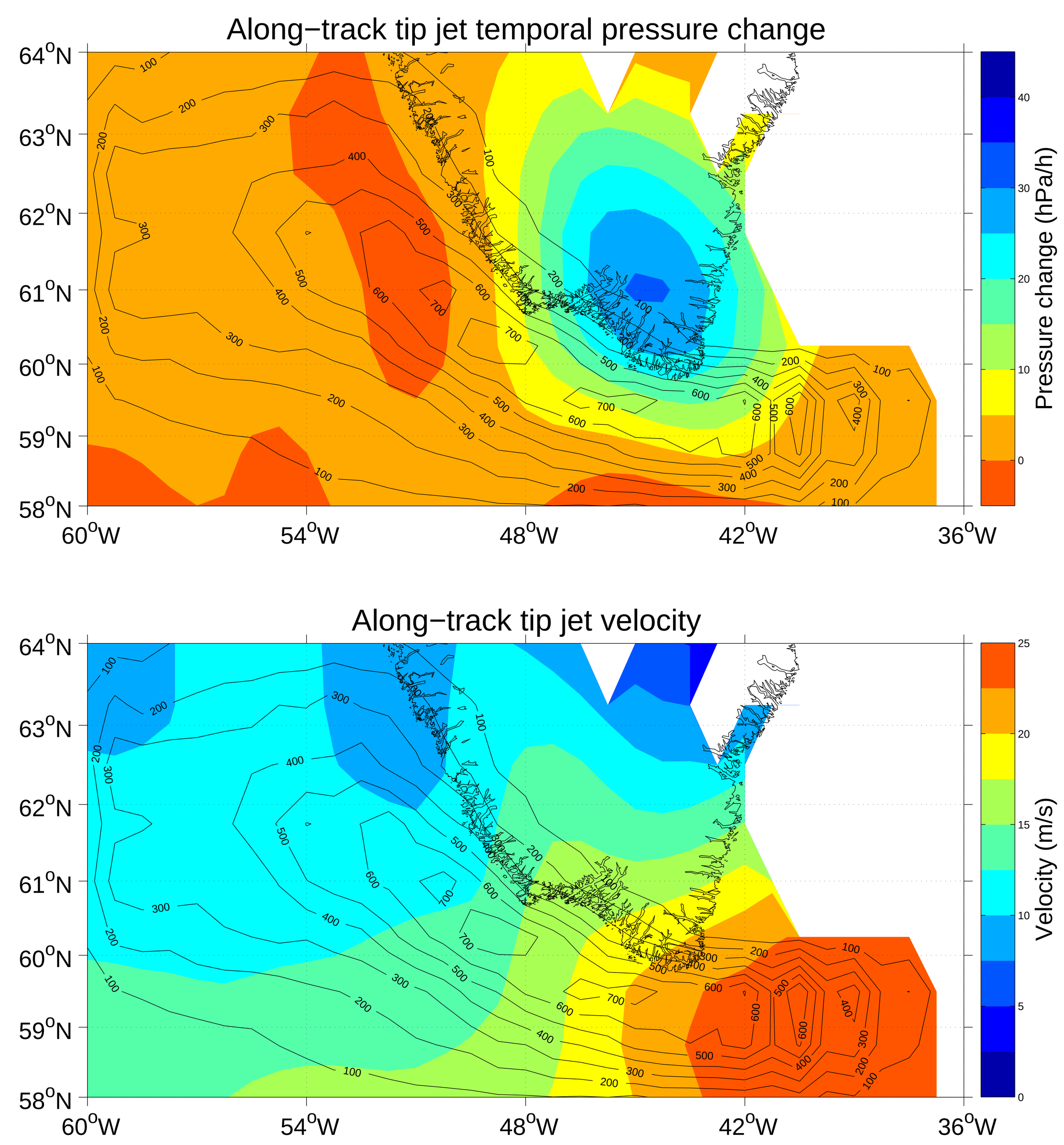

Figure 4: Along-track pressure change (top) and velocity (bottom) of tip jet trajectories terminating at 950 and 900 *hPa* over the southern Irminger Sea.

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. 5).

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[5] (hereafter PWP). Figure 5 shows timeseries of mixed-layer depth from the MP and from the PWP model. For comparison, the model was also forced with NCEP fluxes (green) as well as the best estimate fluxes with the tip jets removed (red). Driven with the best estimate fluxes, the mixed-layer model simulates the envelope of the observed mixed-layer depth fairly well, including the rapid deepening during February associated with the integrated effect of 7 tip jets occurring in quick succession that month. The final depth of convection for the winter of 2002-3 ($\sim$400 *m*) also agrees well with the MP data. 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.

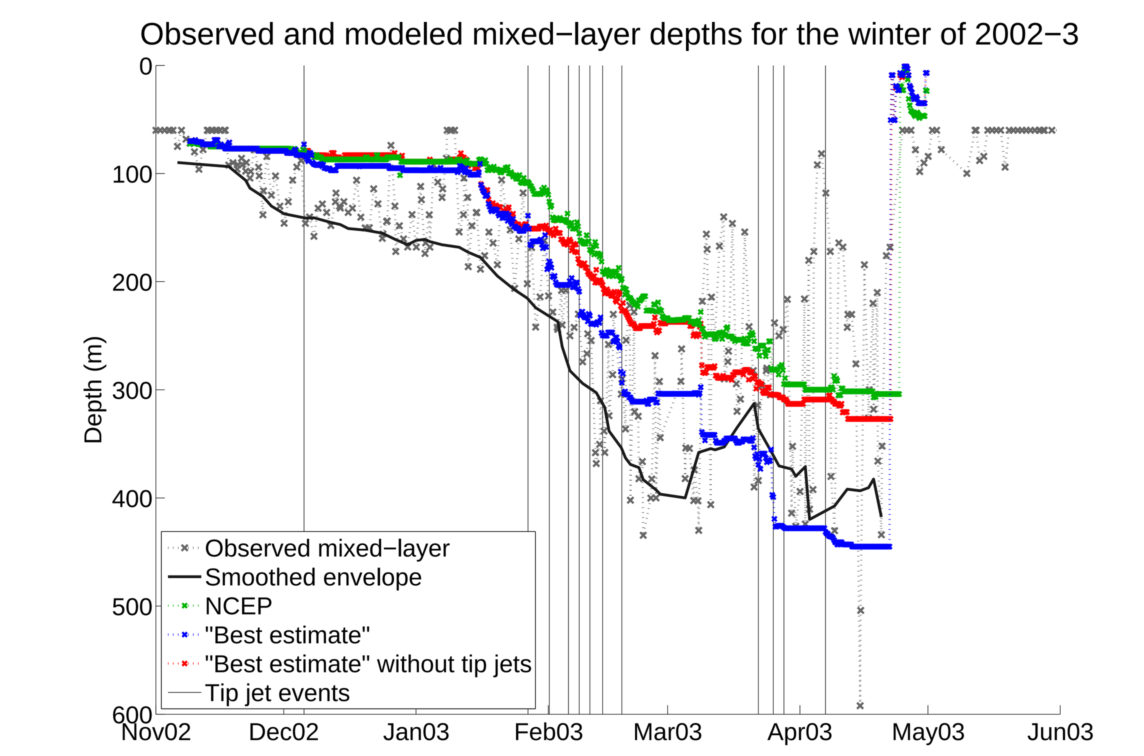

Figure 5: Data and PWP results for winter 2002-3.

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. 6). At the end of the convective season, the mixed-layer had reached a depth exceeding 1700 *m*.

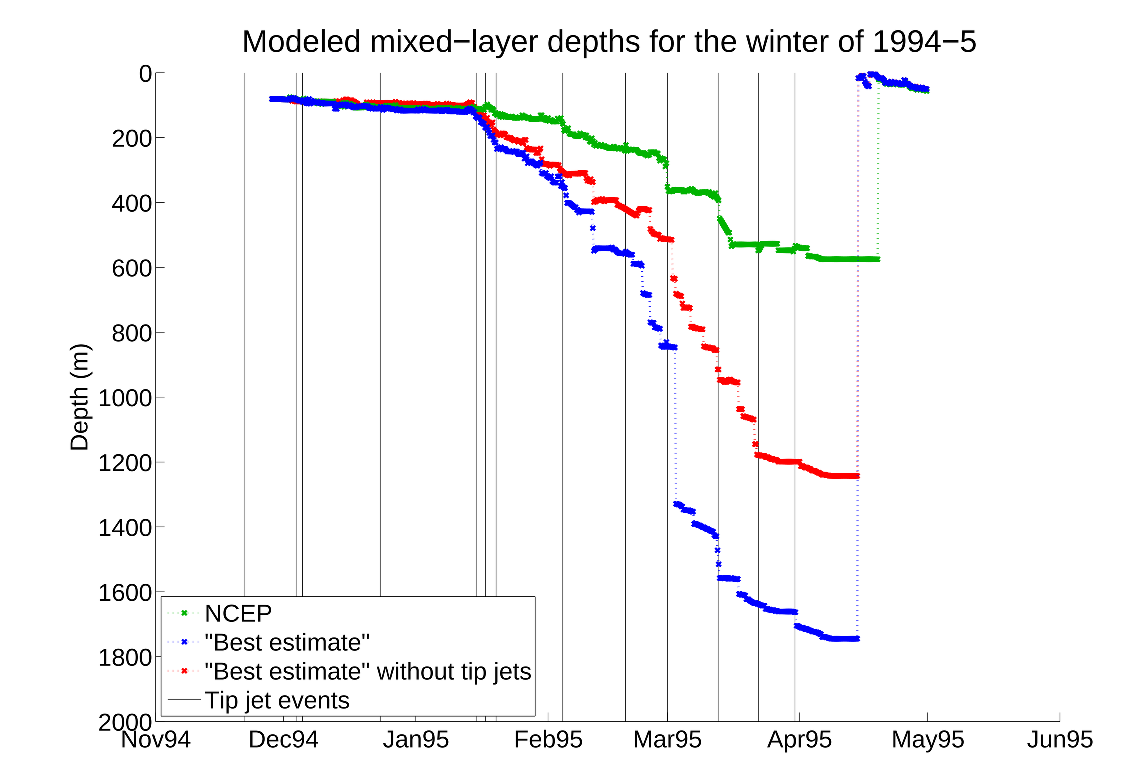

Figure 6: PWP results for winter 1994-5.

Conclusions

- Tip jets are intense, but narrow and intermittent wind phenomena that commonly occur east of Cape Farewell during winter
- 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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Contact information: kjetil@whoi.edu

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