Atmospheric Rivers over eastern Canada: Their seasonality, impact on air mass dynamics, and links to extreme precipitation

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We investigate extremely warm, moist air masses with an analysis of 850-hPa equivalent potential temperature (θ_e) extremes throughout the four seasons at Montreal, Quebec. The utility of using 850-hPa θ_e as the metric is that it represents the thermodynamic property of air that ascends during a precipitation event. It is also the lower boundary of the θ_e coupling index calculation that modulates the strength of vertical circulations.

We compose a monthly climatology of 850-hPa θ_e for the 33-year period from 1979 through 2011. Our trend analysis shows a significant temporal increase in 850-hPa θ_e for all months of the year. No trend in variance is detected.

We produce an analysis of the 40 most extreme cases of positive θ_e, 10 for each season, based upon the standardized anomalies from the 33-year climatology. The analysis showed that the cases are characterized by air masses with distinct subtropical traits for all seasons: reduced static stability, anomalously high precipitable water, and anomalously elevated dynamic tropopause heights. Persistent, slow moving upper- and lower-level features were essential in the build up of high- θ_e air that encompasses much of eastern Canada. The trajectory analysis also showed anticyclonic curvature to all paths in all seasons, implying that the subtropical anticyclone is crucial in the transport of high- θ_e air. These atmospheric rivers during the winter are characterized by trajectories from the subtropical North Atlantic, and over the Gulf Stream current, northward into Montreal. In contrast, the summer anticyclonic trajectories are primarily continental, traveling from Texas north-northeastward into the Great Lakes, and then eastward into Montreal.

The role of the air mass in modulating the strength of a precipitation event is addressed with an analysis of the most basic of expressions, namely $P = RD$, where P is the total precipitation, and R is the precipitation rate, averaged through the duration, D, of the event. Though appearing simple, this expression includes R, which incorporates thermodynamic and dynamic factors driving the air's ascent. This ascent is associated with a change of water vapor mixing ratio, as an air parcel's moisture condenses following a moist adiabat. Thus, the analysis of this deceptively simple expression involves non-linear interactions between the parcel's ascent and its air mass.

We focus on the pertinent aspect of an extreme precipitation event: the details of the associated air mass, and the atmospheric river responsible for its transport. The precipitation rate, R (assumed to be same as condensation, with an efficiency of 1), may be expressed as the product of vertical motion and the change of saturation mixing ratio following a moist adiabat, through the troposphere. This expression for R includes the essential ingredients of lift, air mass temperature, and static stability (implicit in vertical motion). We use this expression for precipitation rate to examine extreme precipitation events in the extratropical latitudes to document the associated air masses and their physical impacts on the precipitation rate.

Implications of this air mass modulation on precipitation rate are discussed in the context of longer-term global climate change.