Impact of cyclone-cyclone interaction on lake-effect snowstorm: a false alarm

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Motivation and objective

Motivation

- Precipitation has significant impacts on our society and economics, but it is challenging to be predicted accurately in terms of its intensity, timing, and location.
- The location error in predicting precipitation is critical since it can ruin our entire efforts no matter how accurate prediction of the precipitation intensity and timing is.
- The cyclone-cyclone (e.g., two or multiple cyclone) interaction can be an important factor in determining cyclone tracks and associated precipitation.
- This research is motivated by the interactions of two mid-latitude cyclones accounting for a false alarm lake-effect snowstorm, in which the operational model predicted lake-effect snowfall at the lee side of Lake Erie doubles the observed.

Objective

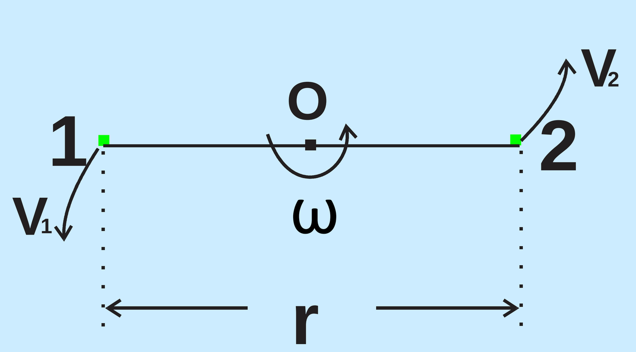
- To diagnose cyclone-cyclone and cyclone-environment interactions and examine their impacts on the lake-effect snowfall event using our newly-developed method;
- To explore possible reasons behind this false-alarm in order to provide physical understanding of why the operational models fail. In particular, the development of CSI and its possible role in forming the lake-effect snowbands are examined.

Methods and data

Methods

- To achieve this goal, the flows induced by a cyclone have to be treated as realistically as possible by including both rotational and divergent flows induced by the vorticity and divergence over in a well-defined vortex core area of the cyclone.
- The classical point vortex model treating a cyclone as a point and not including divergence induced velocity, as described by Fujiwhara (1931), Lamb (1945), Batchelor (1980), and Aref (1983), is not suitable for the above-mentioned purpose.
- CSI index is developed to detect and predict precipitation bands through integrating instability, moisture availability, and lifting conditions. It is the first time that CSI has been applied to lake-effect snow bands.

Limitations of Point Vortex Model

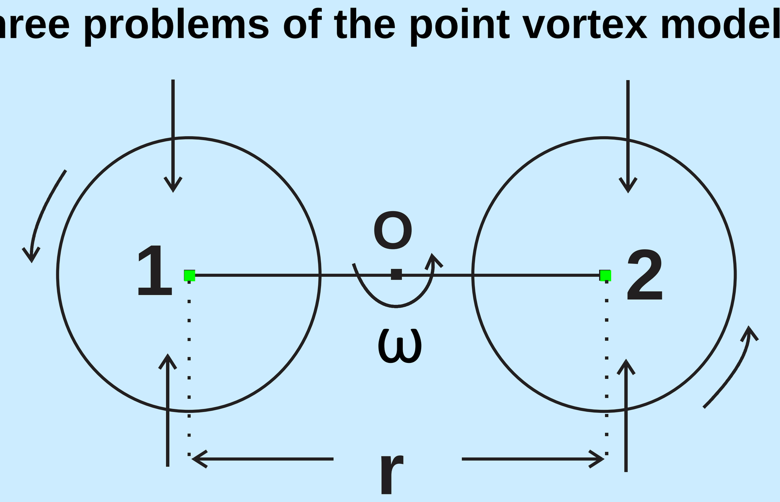


- Singular toward the vortex center
- Purely rotational and not any divergent component
- Not realistically diagnosing the environmental flow

New Model

Induced rotational velocity
$\mathbf{v}_r(\mathbf{x}) = (2\pi)^{-1}\int_s d\mathbf{x}'\zeta(\mathbf{x}')\mathbf{k}\times(\mathbf{x}-\mathbf{x}')/|\mathbf{x}-\mathbf{x}'|^2$
Induced divergent velocity
$\mathbf{v}_d(\mathbf{x}) = (2\pi)^{-1}\int_s d\mathbf{x}' a(\mathbf{x}')(\mathbf{x}-\mathbf{x}')/|\mathbf{x}-\mathbf{x}'|^2$

New model (Cao et al. 2019) overcomes three problems of the point vortex model



- Vortex core area
- Rotational and divergent flows
- Realistic environmental flows

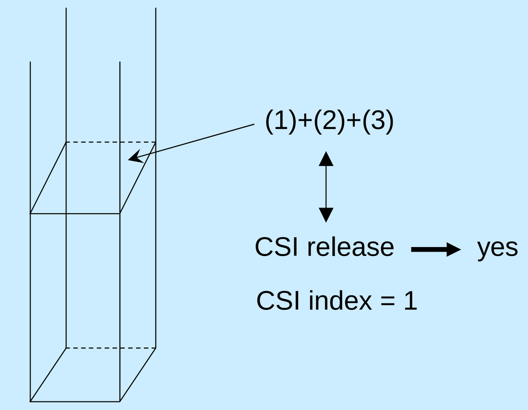
Details for defining vortex core areas at upper and lower levels can be found in

- Cao et al. (2019)
- Cao et al. (2023)

Methods and data (cont)

CSI index for slantwise convection

- (1) $MPV_g < 0$, where $MPV_g = \frac{1}{\rho}(\vec{\zeta}_g \cdot \nabla\theta_e)$
- (2) Relative humidity (RH) > $(RH)_c$
- (3) Vertical motion (w) > 0

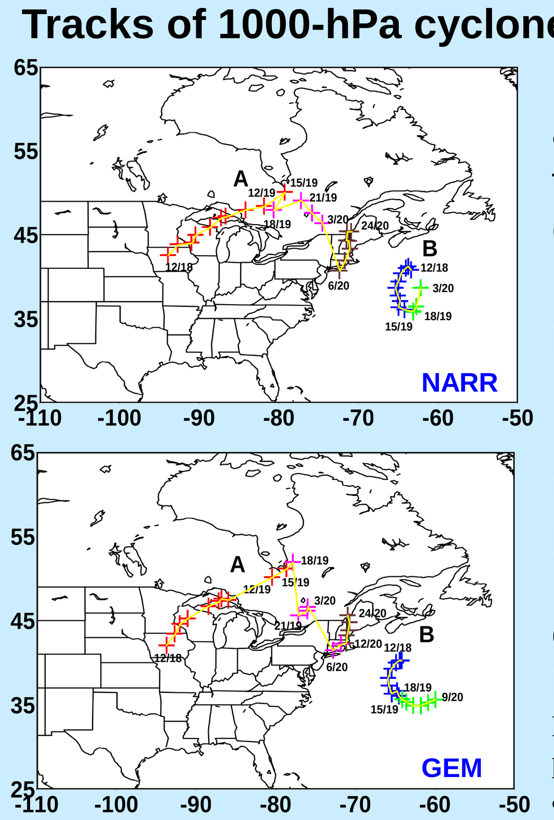


Data

- Hourly operational GEM (Global Environmental Multiscale) regional model (Cote et al., 1998) predictions with a 10-km horizontal grid spacing and 58 vertical levels, retrieved from the archive at the Canadian Meteorological Centre (CMC).
- 3 hourly North American Regional Reanalysis (NARR) with a horizontal grid spacing of 32-km and 29 constant pressure levels that are archived at the National Centers for Environmental Prediction (NCEP) (Mesinger, 2006).
- Canadian Precipitation Analysis (CaPA) data (Mahfouf et al., 2007; Lespinas et al., 2015)

Results and discussions

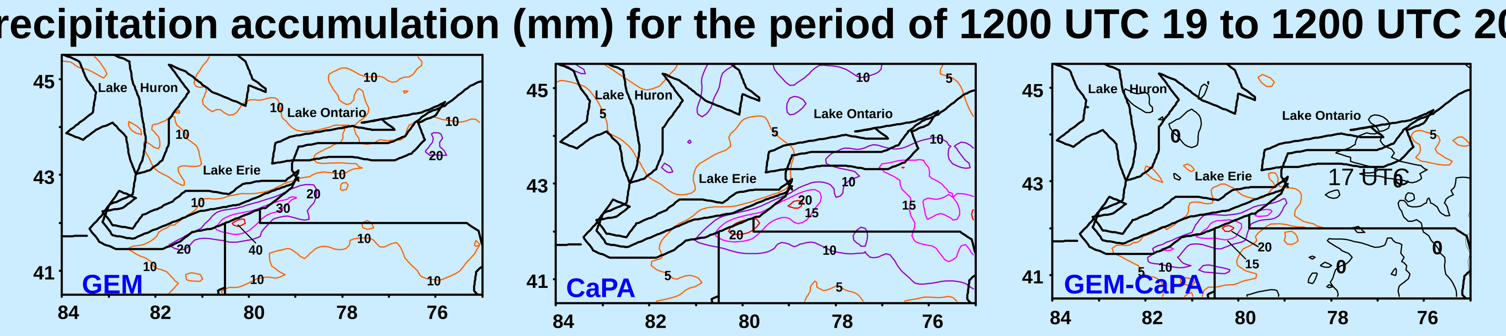
Tracks of 1000-hPa cyclones A and B at hour(UTC)/day labeled along the paths



- Traditionally, a lake-effect snowfall event is defined as one surface low-pressure center tracking from west to east between the Great Lakes and James Bay, Canada.
- Since multiple cyclones often occur in the lake-effect precipitation, it is critical to examine the effects of multiple cyclone interactions on lake-effect precipitation.
- This type of interaction has not previously been taken into consideration in scientific literature and forecast practice (e.g., the current event in 19-21 Nov. 2016).
- Using the recently-developed diagnostic method to examine impacts of two cyclone interactions on the lake-effect snowstorm over the Great Lakes region.

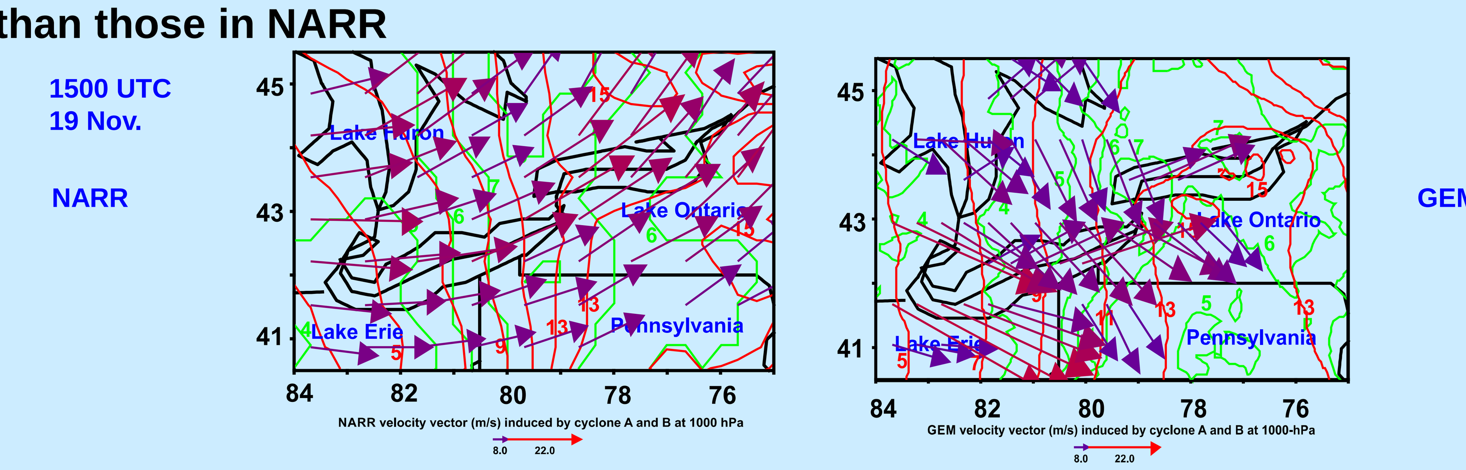
Note: red and blue, pink and green, and brown crosses represent cyclones A and B positions before they merge, after they merge but remain two separate centers, and after they become a single center.

Precipitation accumulation (mm) for the period of 1200 UTC 19 to 1200 UTC 20



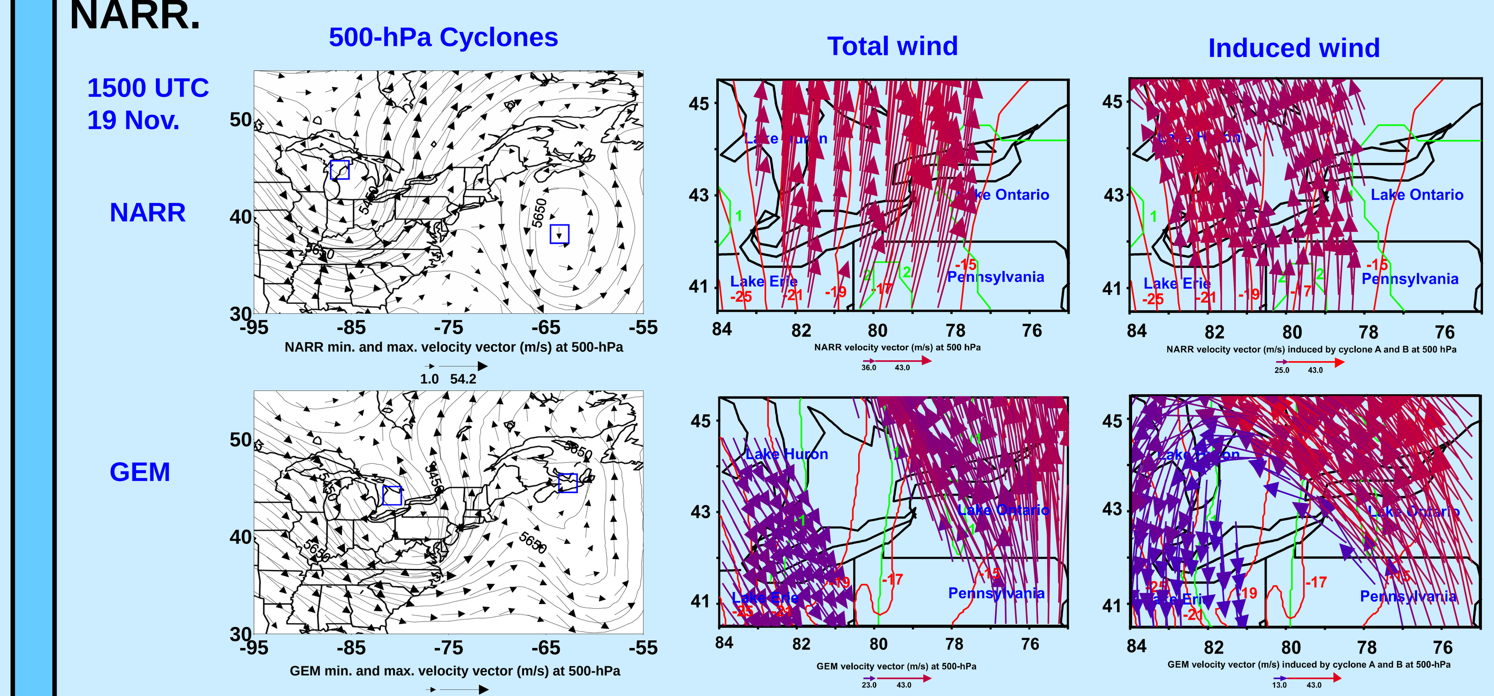
- This winter snowstorm false alarmed by the Canadian operational model, with a prediction of doubled snowfall amount observed over Lake Erie.
- 2004–2005 U.S. FAR for winter storm warnings was 0.31 (e.g., Barnes et al., 2007).

1000-hPa two cyclones induced winds over Lake Erie in GEM are colder & drier than those in NARR

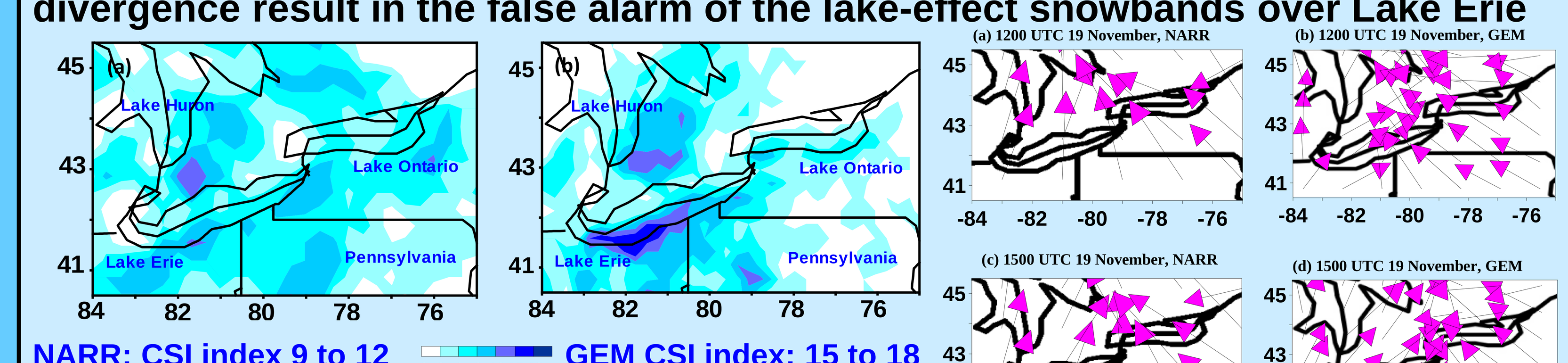


Results and discussions

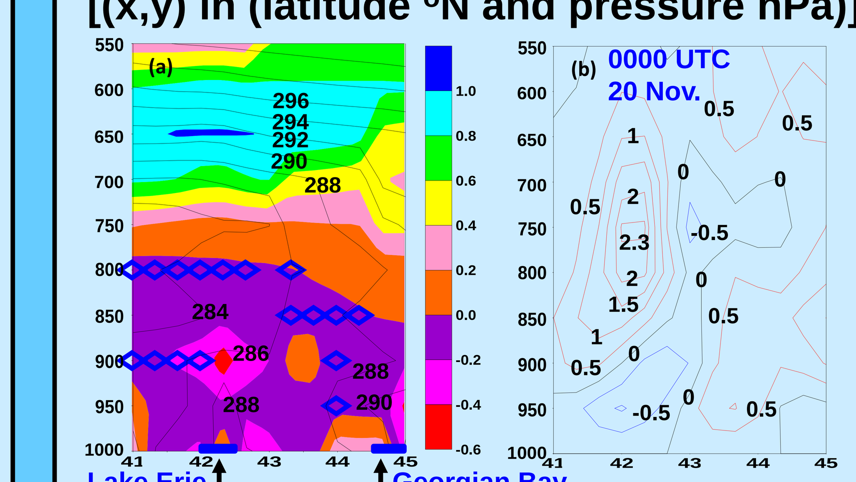
Positions of 500-hPa cyclones are poorly predicted by the operational model, leading to the 500-hPa cyclone A and B induced winds during the intense snowfall period over Lake Erie mainly northerly in the GEM but southerly in the NARR.



Over-predicted CSI index accumulation (1200 UTC/19-1200 UTC/20) and induced divergence result in the false alarm of the lake-effect snowbands over Lake Erie



NARR vertical cross sections along 80.2°W [(x,y) in (latitude °N and pressure hPa)]



- At low levels of Lake Erie both CCI and CSI are present whereas at upper levels and lee side of the lake only CSI is present.
- CSI index is dominant at upper levels and lee side of Lake Erie and over the land.
- CSI release indeed responds for formation of lake-effect snowfall.

Note: right panel: positive for upward motion (W); left panel: blue diamonds for non-zero CSI index, color shading for MPV (at 0.1 PVU intervals), black contours for equivalent potential temperature (K).

Conclusions

- Impacts of cyclone-cyclone interactions on a false alarm with the prediction of doubled snowfall amount over Lake Erie are examined.
- Positions of two cyclones are poorly predicted by the operational model, leading to errors in their induced winds over Lake Erie.
- Over-predictions of conditional symmetric instability result in the false alarm of the lake-effect snowfall over Lake Erie.

References

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