Climate change is not uniform across the globe and "Arctic Amplification" may well be a cause of increased variability, and extremes, in northern hemisphere mid-latitude weather. While we primarily experience this variability at ground level, within the atmospheric boundary layer, the broad scale atmospheric dynamics are mainly driven from above, where measured data are relatively scarce. Weather prediction models can however provide information and NARR (NCEP North American Regional Reanalysis) model data are a valuable source. Our first step was a comparison of upper level (surface to 15 km height) winds with those measured by our Ontario-Quebec Network of VHF wind profilers. The comparisons were satisfactory and gave us confidence to use NARR winds to analyse variability and trends.
Analyses of upper air winds from NARR data for southern Ontario for the past 36 years are also presented. Annual averages show a slight weakening of 500 hPa zonal wind and a slight increase in the mean of the absolute value of the Meridional Circulation Index (|MCI|). These trends are expected as a result of Arctic Amplification of tropospheric temperature increases but are weak in comparison to inter-annual variability. There are seasonal variations in monthly averaged wind speed and April and October maxima in monthly averaged |MCI|.

Initial results of Wind Profiler vs NARR comparisons are in

500 hPa geopotential heights, Blue (5000m) is low - cold, dense air, max is 5900 m

Sharp gradients correspond to location of jetstream, more intense at 250 hPa
The polar vortex is a large area of low pressure and cold air surrounding both of the Earth's poles. It ALWAYS exists near the poles, but weakens in summer and strengthens in winter. The term "vortex" refers to the counter-clockwise flow of air that helps keep the colder air near the Poles. Many times during winter in the northern hemisphere, the polar vortex will expand, sending cold air southward with the jet stream (see graphic above). This occurs fairly regularly during wintertime and is often associated with large outbreaks of Arctic air in the United States.
http://weather.gc.ca/analysis/index_e.html: 500 hPa + thickness at 12Z, Sat March 4, 2017
500 hPa Sunday 5 March, 2017. Note Toronto is 43.7° N, 79.4° W
Arctic Amplification


Records of the past climates show a wide range of values of the equator-to-pole temperature gradient, with an apparent universal relationship between the temperature gradient and the global mean temperature: relative to a reference climate, if the global-mean temperature is higher (lower), the greatest warming (cooling) occurs at the polar regions. This phenomenon is known as polar amplification.

Arctic amplification dominated by temperature feedbacks in contemporary climate models: Felix Pithan & Thorsten Mauritsen, 2014, Nature Geoscience 7, 181–184

Feedback effects associated with temperature, water vapour and clouds have been suggested to contribute to amplified warming in the Arctic, but the surface albedo feedback—the increase in surface absorption of solar radiation when snow and ice retreat—is often cited as the main contributor.
Meridional Circulation Index

- Arctic amplification leads to a REDUCED equator - pole temperature difference, lower thermal wind effect and lower zonal (E-W) component winds, a slower jet stream. It is argued by some that this slower jet stream is less stable and becomes “wavier” as a result.

- Francis and Vavrus (2015) propose a simple metric to assess the departures from zonal of the upper level winds. Their Meridional Circulation Index or MCI is defined as

  \[
  \text{MCI} = \frac{v|v|}{(u^2 + v^2)} = \frac{\sin(3\pi/2 - \Phi)}{|\sin(3\pi/2 - \Phi)|}
  \]

  where \( \Phi \) is the geographic direction that wind is coming from, Here \( u \) and \( v \) are the zonal and meridional components of the wind. When \( \text{MCI} = 0 \), the wind is purely zonal, and when \( \text{MCI} = 1 \) (−1), the flow is from the South (North). We compute mean values of \(|\text{MCI}|\) as an indicator of “waviness” but have been unable to find other sources with representative values.
Upper-level winds over southern Ontario: O-Q Net and NARR comparisons plus NARR analyses.

Peter Taylor, Wensong Weng and Zheng Qi Wang. ESSE/CRESS

The IPCC (2013) report discusses upper level winds and states, "In contrast to surface winds, winds above the planetary boundary layer have received little attention in AR4 (IPCC, 2007)." It goes on to state, "In the past few years, interest in an accurate depiction of upper air winds has grown, as they are essential for estimating the state and changes of the general atmospheric circulation and for explaining changes in the surface winds."
Upper-level winds are primarily measured by tracking the position of radiosonde balloons as they rise through the atmosphere. Radiosondes are released from a global network at nominal times of 0000 UTC and 1200 UTC each day and data are quickly available to the world's weather services, and to the public. The network is relatively coarse, spatially, and soundings are normally only two per day. In an endeavour to provide better spatial and temporal upper-level regional wind measurements a network of VHF wind profilers, the O-Q Net, has been installed and operated by York, Western and McGill Universities and with support from Mardoc Inc and Environment Canada.
We have made comparisons between winds measured by the O-Q Net profilers and the winds reported by NARR (NCEP North American Regional Reanalysis) analyses. There is good agreement which provides support for the use of NARR data to investigate longer term variations in upper level winds associated with climate change for this region (southern Ontario).
The Ontario-Quebec VHF wind profiler network

[Map showing locations of the VHF wind profiler network in Ontario and Quebec, marked with red dots and labeled cities such as Fraserdale, Markstay, Aumond, McGill, Wilberforce, Negro Creek, Egbert, Walsingham, Harrow, and Gananoque.]
Figure 3. Statistics of comparisons between data from the Aumond VHF wind profiler and radiosondes released from Maniwaki.
NARR: North American Regional Reanalysis

These data sets come from the North American Regional Reanalysis (NARR) project, Mesinger et al (2006), which incorporates assimilated observations and numerical weather prediction model output (NCEP Eta Model).

The availability is every three hours at 0, 3, 6, 9, 12, 15, 18 and 21 UTC, on a 32 km Lambert conformal grid covering North America and surrounding ocean areas.

We interpolate from 4 surrounding grid points to windprofiler locations (plot is Egbert).
Radiosonde is Buffalo, Windprofiler at Egbert. NARR interpolated to Egbert location.
The MCI is a simple metric used by Francis and Vavrus (2015) to assess the departures from zonal of the upper level winds. The index is defined as

\[
MCI = \frac{v|v|}{u^2 + v^2} = \sin(3\pi/2-\Phi)|\sin(3\pi/2-\Phi)
\]

where \( \Phi \) is the geographic direction that wind is coming from. Here \( u \) and \( v \) are the zonal and meridional components of the wind. When MCI = 0, the wind is purely zonal, and when MCI = 1 (-1), the flow is from the South (North). In effect the MCI comparisons provide an indication of the reliability of NARR wind direction information.
Conclusions 1

For climate study purposes a significant contribution of data from the OQ-Net has been to validate the winds produced by the NARR reanalysis. These clearly show that the NARR data on upper-level winds in this region are reliable. Full year comparisons have been made between winds from the VHF profilers and the analyses provided by NARR. These reanalysis data, for locations close to the profiler sites, show good agreement with the observations. They are available on a consistent basis and can provide a means of looking for trends and variability in upper level winds over the past three and a half decades (1980-2015), which will be addressed in a separate paper.
Analyses of upper air winds from NARR (NCEP North American Regional Reanalysis) data for southern Ontario for the past 36 years are presented. Annual averages show a slight weakening of 500 hPa zonal wind and a slight increase in the mean of the absolute value of the Meridional Circulation Index (|MCI|). These trends are expected as a result of Arctic Amplification of tropospheric temperature increases but are weak in comparison to inter-annual variability. There are seasonal variations in monthly averaged wind speed and April and October maxima in monthly averaged |MCI|.
Distributions of Egbert MCI values based on 34 years (1980-2013) of NARR data - values every 3 hours.
Egbert: Annual Average $|\text{MCI}|$ vs Zonal Wind Speed, 250 hPa (+) and 500 hPa (x) with linear regression lines (1980-2013).
Monthly averaged 500 hPa values of |MCI|, based on 3-hourly NARR zonal and meridional winds at the Egbert wind profiler site. 2001-2010 plus 34 year (1980-2013) average.
Comparisons with surface data

Monthly |MCI| - 30 year average

Year, data are monthly averages or totals

-0.2 -0.1 0 0.1 0.2

|MCI| departure from 30 year average

Monthly Precip - 30 Year Average (mm)
Figure 12  Annual values of the correlation between monthly |MCI| perturbations and monthly temperature (♦) and precipitation (+) perturbations relative to their 30 year monthly averages, plus best fit trend lines.
Three hourly comparisons between geostrophically balanced thermal winds and zonal wind speed differences. 250-500 hPa, Egbert site.

Left - February 2010, Right November 2010.
Conclusions so far

Links between upper level zonal winds and $|\text{MCI}|$ and surface temperatures and precipitation are complicated by seasonal variations. Annual averaged values are virtually uncorrelated. Monthly perturbations show stronger correlation on average but annual averages of monthly perturbation correlations have large variability (Figure 12).

The NARR, and other reanalysis data sets are a valuable resource for studies of regional climate change on time scales of several decades. More research on the relationships between upper level winds and surface climate (winds, temperature and precipitation) may lead to useful indications of potential future changes of concern for agriculture, forestry and us all.