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Recommendations on Categorizing Arctic Air Mass Intensity/Coverage and Improving the Monitoring of Arctic Source Regions Across the Northern Hemisphere

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1. Introduction

During the last few decades, the science of meteorology/climatology regarding the discovery, categorizing, monitoring, and prediction of teleconnection patterns influencing atmospheric circulation across the northern hemisphere, originating from both the mid-latitudes and tropics, has been established (Wallace and Gutzler 1981, Barnston and Livezey 1987). The science of categorizing, monitoring, and predicting of cold season arctic air masses over the continental source regions of the northern hemisphere and their advection into lower latitudes, unfortunately, has lagged behind knowledge gained by exploring teleconnections during the corresponding period (Namias 1978, Yarnal 1987).

In an effort to activate research in this mostly unexplored topic, this presentation provided recommendations/proposals regarding: 1) defining arctic air masses by intensity and geographic coverage across northern hemispheric continents, 2) better utilizing the few existing established teleconnections that better correlate to arctic air mass formation and advection, especially over North America, and 3) new arctic (non-teleconnection) indices to better help forecast/monitor the development of arctic air masses over all known northern hemispheric source regions and the potential for advection of these air masses into adjacent lower latitudes. The ultimate future goal is monthly monitoring of arctic air mass frequency, coverage, and intensity similar to what the Climate Prediction Center (CPC) has for ENSO and mid/high latitude teleconnections (Climate Diagnostics Bulletin 2016). Please refer to the power point presentation for details on each of the following recommendations.

2. Recommendations on defining arctic air masses and Northern Hemispheric source regions

Air masses become arctic in character once temperatures at the top of the surface inversion reach -10 degree C or less, since colder surface dew points (or frost points) no longer represent a barrier (via latent heat release) to limit falling surface temps during long clear, cold season arctic/sub-arctic nights under positive (dry) hydro-lapse rate environments and light/calm winds.

Recommendation 1): Standardize monitoring arctic air (-10 degree C and colder) using a standard height of 1 KM above ground level (AGL). One KM AGL temperatures would better depict arctic air masses infiltrating complex high terrain especially where average station pressures are less than 900 hPa. The height of 1 KM AGL surface also corresponds to about halfway between 925 hPa and 850 hPa pressure surfaces meteorologists/ climatologists most frequently use temperature to assess the presence of arctic air over near sea level locations.

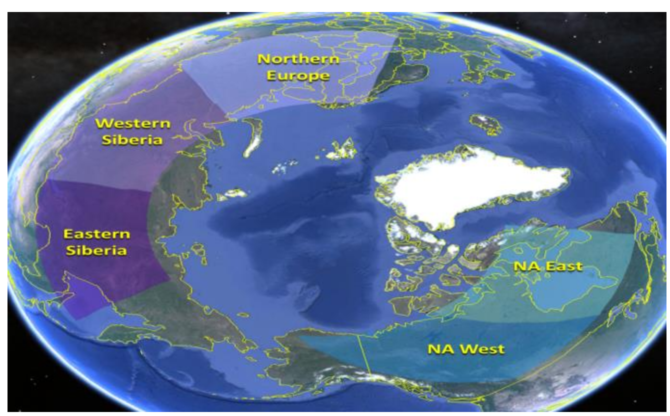

Fig. 1 Recommended Northern Hemispheric Arctic source regions.

Recommendation 2): Define seasonal continental arctic source regions. For the purpose of this

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presentation, we identify five potential source regions: two across North America (NA) and three across Eurasia (EA) based on frequency differences of loading, residence of arctic air masses, and topography - limited to no greater than 45 degrees longitude wide generally from 50 to 70 degrees N latitude (see Fig. 1).

3. Recommendations regarding rating arctic air mass intensity/coverage

The following recommendations are for rating arctic air mass intensity and coverage.

Recommendation 3): Have descriptive arctic air mass intensities based on NA source region return frequencies per winter(s).

Recommendation 4): Define a numerical arctic air mass intensity index for public awareness and historical ranking purposes.

Recommendation 5): Have arctic area indices that measure the area coverage of arctic and deep arctic air across North America.

Recommendation 6): Define a total arctic index combining recommendations 4 and 5 to provide historical comparison of arctic air masses encompassing large continental areas.

Recommendation 7): Measure arctic air mass transport efficiency by comparing the maximum intensity achieved by an air mass in the source region to the later intensity of the air mass reaching the 50, 45, and 40 degree N latitude bands.

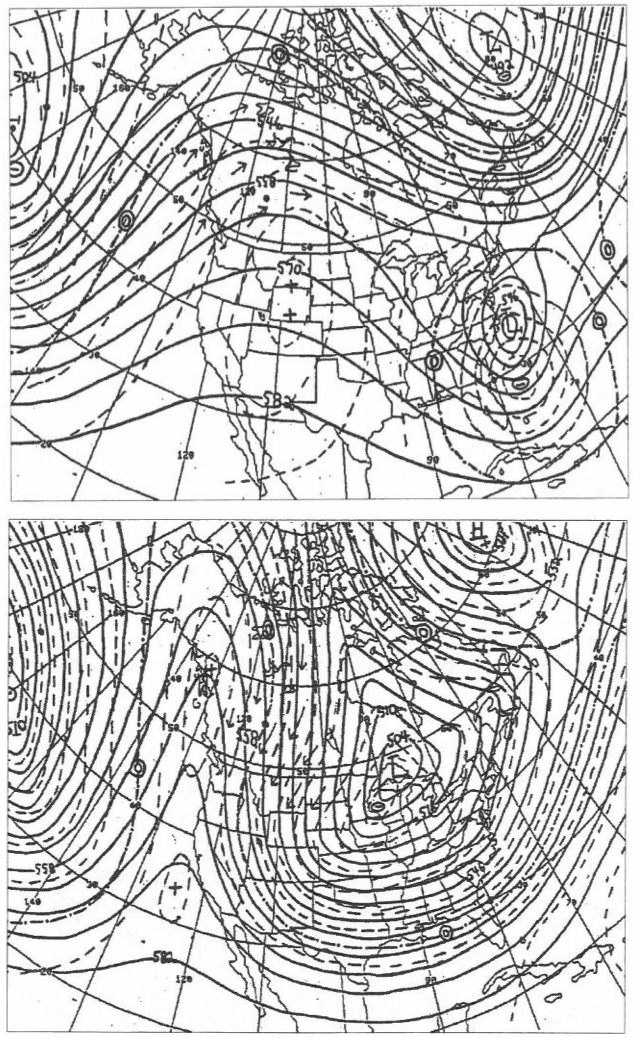

Fig. 2 Examples of 500 hPa North American Pattern with (**a**) positive PNA value and low arctic air mass potential (PNA ++, EP-NP -, TNH-- : NAT--), and (b) positive PNA value and high arctic air mass potential (PNA ++, EP-NP++, TNH++ : NAT++).

4. Northern Hemisphere teleconnection patterns that most reliably correlate to arctic air mass production over northern North America

The following recommendation highlights the use of a new non-teleconnection mid tropospheric pattern by utilizing existing teleconnection patterns that better anticipate the formation and trends of arctic air masses over North America.

Recommendation 8): Combine the EP-NP and TNH teleconnection patterns to produce a single North American Arctic Transition (NAT) Index:

$$\mathrm{NAT} = \frac{x(\mathrm{EP\text{-}NP}) + y(\mathrm{TNH})}{x + y}$$

where x and y are constants that may differ from 1. The reason for the selection of these two patterns for this proposed index is that both are associated with the greatest strength and fetch length of anomalous North to Northeast component mid-tropospheric flow over the NA arctic source region pointing toward the Canadian Rockies Divide. This resultant confluent flow and deep layer cold advection aloft results in rapid formation of deep arctic air masses with strong surface base inversions, since strong and rapid surface anti-cyclogenesis is favored in the lee of the Canadian Rockies when combined with low level barrier blocking (Nouhan 1999). PNA, NAO, and AO are not as consistently reliable indices for arctic air mass formation for various reasons (see Fig. 2, also refer to example winter months in the power point presentation). Lastly, it should be noted that the proposed NAT index and the indices mentioned in the following section do not constitute new teleconnection indices, but rather, indices specific to the potential of loading and advection of arctic air across North America and other Northern Hemispheric source regions.

5. Other proposed mid tropospheric circulation indices to monitor potential of Arctic air masses across all Northern Hemisphere source regions

The following recommendations are for other new circulation indices to better anticipate the formation and trends of arctic air masses over all of the Northern Hemisphere.

Recommendation 9): Sectorize Arctic Oscillation (AO) so that the effects of the ocean domain portions of AO can be minimized by applying the following equation to each corresponding source region from figure 1:

$$\text{AOm} = \frac{500\text{ hPa}(40°\text{-}65°\text{N})\text{S} - 500\text{ hPa}(65°\text{-}90°\text{N})\text{S}}{2}$$

where within the modified Arctic Oscillation (AOm), 500 hPa latitudinal band standardized height anomaly (S) comparisons are reduced to 65°-90°N and 40°-65°N rather than poleward from 20 degrees N (CPC Website) latitude. This contraction of the latitude band comparisons in addition to mostly eliminating ocean domain allows for better correlation to the production of arctic air for each source region. Similar to what is implied by AO, increasing arctic potential is indicated by negative values. In addition to correlating each index to surface temperature anomalies for each source region, indices from neighboring source regions across Eurasia and North America can then be combined or contrasted. Lastly, secular pattern trends can potentially be determined for each source region using re-analysis data.

Recommendation 10): Using the modified sectorized arctic oscillation indices produced from the prior recommendation for the two North America arctic source regions, one can combine centers of action from nearby teleconnection patterns that play a major role in arctic air formation due to topographical impacts on arctic air formation from the Rocky Mountains to improve the potential forecast performance of the indices. For example, one can produce an eastern U.S. version of the NAT index from combining anomalies corresponding to the northwest Canadian Coastline center of action from the EP-NP teleconnection and a western U.S. version of the NAT index by combining anomalies corresponding to the northeast Pacific center of action from the TNH teleconnection pattern. The resultant NATe and NATw indices, which can be used in conjunction with the NAT index would give a better idea of where arctic air is forming and advecting southward over North America without having to compare the corresponding phase of the PNA teleconnection index. Eurasian sectorized arctic oscillations may also benefit from additional modification with nearby teleconnection indices that highlight impacts on arctic air mass potential from adjacent geographical features.

6. Discussion and summary

The proposals/recommendations in the prior sections were given to: 1) provide a common basis as to what qualifies and quantifies as arctic air masses by meteorologists/climatologists, 2) define source regions, and 3) develop specific forecast indices to better anticipate formation and trends of arctic air over each source region. Prior work in this area is limited with a recent work related to monitoring trends of arctic air mass coverage and intensity across North America and Eurasia by Martin 2015 as part of a larger study of monitoring recent trends of both extreme cold and heat by using re-analysis data. Two defining characteristics overlapping with this proposal are: 1) the base definition of arctic air being defined at -10 degrees C, and 2) incorporating intensity by using trends of coverage of the -20 and -30 degree isotherms in addition to the -10 degree isotherm.

This presentation goes further by also proposing new mid tropospheric circulation indices dedicated to the forecasting and monitoring of arctic air masses over each of the Northern Hemispheric source regions. It's important to reiterate that although these new arctic indices were derived from prior existing teleconnection patterns, they no longer constitute what defines teleconnection indices since the arctic indices only gage arctic potential for corresponding limited domain source regions and do not measure explained variance of different mid tropospheric circulation modes defined under Rotated Principle Component Analysis (Barnston and Livezey 1987). In order to maximize predictability, it is recommended that that pressure level that these new indices are calculated on remains close to the level of non-divergence in order to be not so far above from important topographical features that play a role over each source region, with vertical propagation of Rossby waves from the tropics not likely playing a significant factor as in traditional teleconnection patterns such as the PNA (Baxter 2016).

In summary, if these or similar proposals were instituted, seasonal arctic air mass formation and trends would be able to be monitored in a similar format to how CPC monitors tropical (ENSO) and extra-tropical trends in the Climate Diagnostics Bulletin.

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