2.4 THREE MODES OF RECENT PAN-ARCTIC MULTIVARIATE CHANGE

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1. INTRODUCTION

The Arctic has undergone significant shifts in surface temperatures over the last century (Polyakov et al., 2003) and demonstrable environmental changes have occurred over the previous three decades. These changes have made it difficult for those who live and work in the north to anticipate the course of these changes or at least determine their potential range. There is evidence that changes in midlatitudes are increasingly connected to those in the Arctic. Areal coverage of sea ice has diminished and sea-level pressures in the central Arctic have decreased. Warmer surface temperatures are observed in northern Europe during winter and Alaska and northwest Canada during spring. There is an increase in the frequency of years with colder than normal temperature in the lower stratosphere over high latitudes. Permafrost temperatures have risen in Siberia and Alaska with increased erosion. Satellite estimates of “greening” have increased over both the eastern and western hemispheres, with less snow cover, longer growing seasons and changes in the character of the tundra. The influence of warm Atlantic water in the Arctic Ocean became more widespread and intense in the 1990s, with implications for the upper water column. Many of these changes are noted in Serreze et al. (2000) and Dickson et al. (2000). These changes are robust, and many other biological and physical changes are suggested—increases in cod in the Barents Sea and shrimp off of southern Greenland, caribou populations in North America, and declines and redistributions of marine mammal populations, although the causes for these changes are less certain (Ottersen et al., 2001).

It has been hypothesized that the present changes in the Arctic are interrelated (Morison et al., 2001), and are associated with a rising trend in the Arctic Oscillation (AO) since the 1960s (Thompson and Wallace, 1998). Here the AO phenomenon is used to broadly describe the strengthening and increased zonality of the polar vortex as shown by the AO index and related teleconnection indices. Determining whether the covariability of these changes are coincidental or have a causal link is of major importance. In this paper we examine these changes from a heuristic perspective, based on examination of 86 representative biotic and abiotic time series from the Arctic and subarctic.

The advantage of such a pan-Arctic study which spans multiple scientific disciplines, is that the credibility for analyzing and possibly detecting change in the Arctic is increased by considering multiple lines of evidence. Because Arctic change is poorly understood, each record may project only partially onto the important underlying processes. Thus use of multiple lines of evidence may provide a better representation of change than a single variable or index.

2. THE UNAAMI DATA COLLECTION

The SEARCH Science Plan has given the name Unaami, the Yup’ik word for tomorrow, to the complex of intertwined pan-Arctic changes. Although it appears that many of these changes are interrelated, the causal relation between these changes, their feedbacks and long-term impacts are far from certain. To this end we have selected 86 representative time series for a data collection for further investigation (Appendix). We have chosen data that represent diverse regions and seven data types: climate indices, surface and upper atmosphere, ocean , sea ice, terrestrial, fisheries, and other biological indicators. See http://www.unaami.noaa.gov for complete metadata and time series.

A subset of the data is presented in Fig. 1, with the 1/3 largest values in red and 1/3 lowest values in green; if the time series showed a decrease over time we have inverted the series and noted this with a star. Note the overall shift from green to red over the 30-year period across different data types.

3. INITIAL RESULTS

The primary analysis technique is Principal Component Analysis (PCA), which is used to isolate common modes of variability in the data set. As an initial screening process, we applied PCA to the correlation matrix of the 86 time series for 1965–1995. The percent variance explained by PC mode 1 (23.4%) and PC mode 2 (12.0%) are significant based on the method of North et al. (1982). The first principal component (PC1) for the years 1965–1995 is shown in Fig. 2. It can be interpreted as a trend over these 30 years with an increase in the magnitude of the slope near 1989. Note that the weights of the individual time series contributions can be positive or negative so that the increase in PC1 can represent either an increase or decrease in the individual contributing time series. The correlation of each series with PC1 is shown in the lower part of Fig. 2. Shapes represent data types and colors represent absolute values

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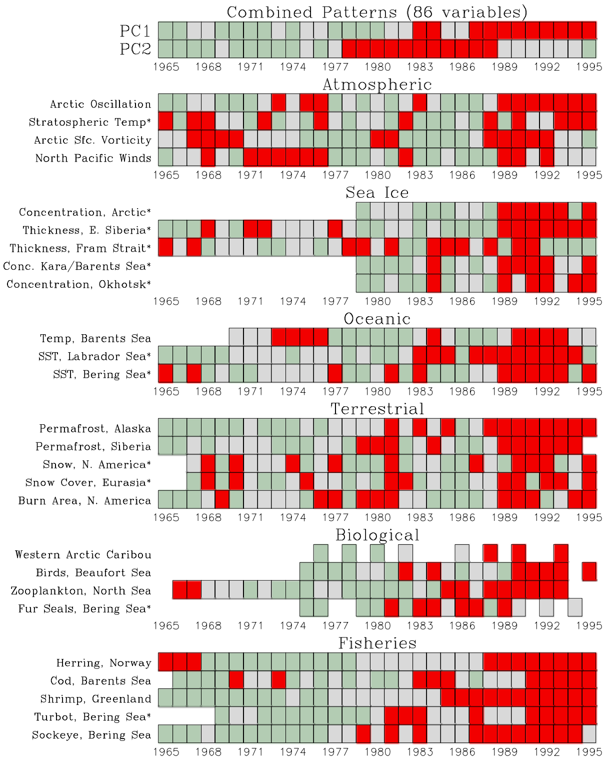

Figure 1. A selection of time series representing six data types that demonstrate Arctic change over the previous three decades. The first two principal components of the larger data set are also shown. Data values are divided into three strata: lowest 1/3 (green), middle (gray), and highest 1/3 (red). To demonstrate covariability over time some series have been inverted as noted by a star. The complete data collection is described at www.unaami.noaa.gov. Note the shift from green to red for many of the series.

of the magnitudes. What is first noted is that every data type and every region of the Arctic has time series which contribute to PC1 with an absolute correlation greater than 0.5. Forty of the 86 series have an ABS(*r*) > 0.5.

The second principal component (PC2) and loading map for the years 1965–1995 is shown in Fig. 3. It shows a minus-plus-minus structure with breaks near the mid 1970s and 1990. Fourteen of the series have an ABS(*r*) > 0.5 with PC2. The shape of PC2 is necessary in understanding the difference in using 20 years of data (1975–1995) and using 30 years (1965–1995). Both PC1 and PC2 have shifts near 1989. Inclusion of the additional 10 years of data is important because it suggests interdecadal shape in PC2 in contrast to the more linear or regime shape of PC1. Both PC1 and PC2 are consistent with a major discontinuity in the late 1980s, while their behavior in the 1970s provides a contrast between the two modes.

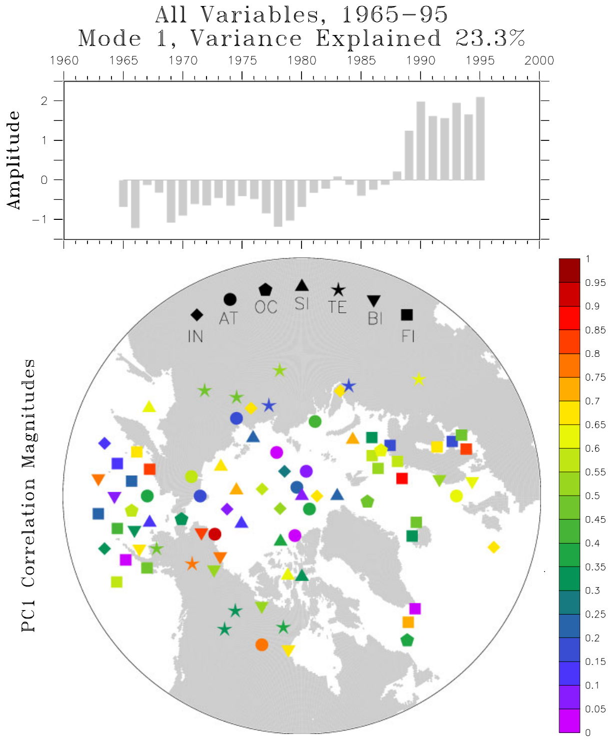

Figure 2. (top) The first principal component time history (PC1) for the entire data collection. Note the single "regime-like" change near 1989. (bottom) The correlation magnitude of each time series with (PC1). Note that a wide variety of data types and locations contribute to PC1.

The structure of time series for land processes has a distinctly different character than other Arctic time series, PC1 or PC2. They represent rather strong linear trends with considerable interannual variability. To this end we have performed PCA on the 11 terrestrial time series for 1965–1995 (Fig. 4); the first mode (TPC1) represents 36% of the variance. The trend, combined with considerable year-to-year fluctuations, is apparent. Eight of the eleven time series strongly project onto TPC1. Examples are permafrost temperatures in both Alaska and Siberia, snow in Eurasia (February mean), greenness in Eurasia and North America (April–October mean), and Siberian river discharge. The major exception to this trend is snow cover extent for North America, which is the largest component of the second principal component for terrestrial time series; it has more the character of PC2 with low values in the 1970s as well as the 1990s.

4. SUMMARY

Our analyses reveal certain commonalities. The two patterns based on PC1 and PC2 (Figs. 1 and 2) have inflection points near 1989. PC1 transitions from a low value to a high value while PC2 has an interdecadal/

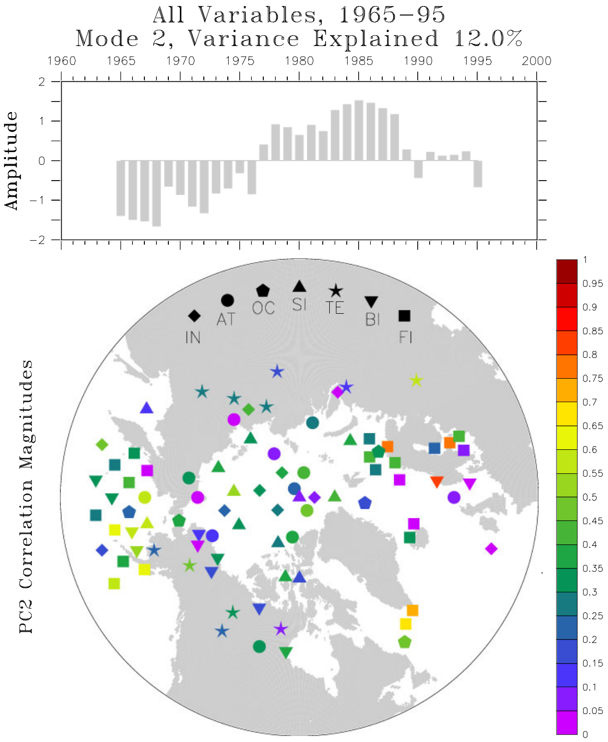

Figure 3. Same as Figure 2, but for the second Principal Component (PC2).

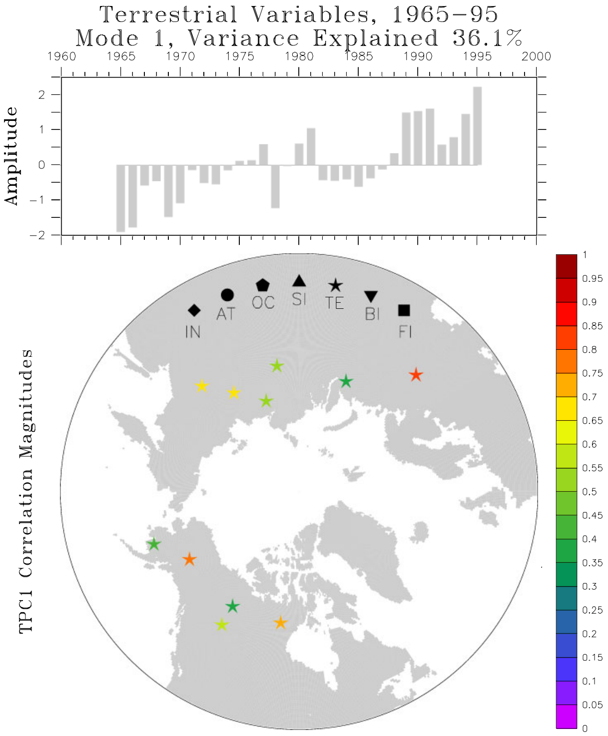

Figure 4. (top) The first Principal Component of the terrestrial time series (TPC1), which shows a linear trend with variability. (bottom) Most of the terrestrial time series project strongly onto TPC1 with correlations greater than 0.5.

decadal character based on the one and one-half cycles spanned by our data collection. The shapes of these patterns are supported by longer records, the AO for PC1 and Fram Strait sea ice efflux for PC2 (Vinje, 2001). The main physical variables associated with PC2 are in the high Arctic. One plausible chain of events is that the physical processes that support PC1, most notably the persistence of a strong polar vortex into spring and the Arctic Oscillation index both of which have influences reaching into mid-latitudes, are manifest in amplifying existing modes of climate variability, most notably the high latitude interdecadal/decadal component.

Land processes show strong temporal and geographic coherence across most variables: snow cover, greenness, permafrost temperatures in both North America and Eurasia, and Siberian runoff. These series have a distinct linear plus interannual variability character in contrast to the primarily regime or interdecadal variability in other time series. The ice cover in the Okhotsk and Kara/Barents Seas also had this linear character. The relation of these trends to the more regime or interdecadal character of other climate indices is uncertain. They do represent spring/summer observations and often indicate accumulated influences over several seasons, for example the increase in shrub abundance (Sturm et al., 2001).

The climate indices supported by many physical and biological time series show coherent changes across the Arctic and subarctic, representing a regime-like pattern after 1989. These changes may be an amplification of high-Arctic interdecadal/decadal oscillation pattern. Many land processes and some sea ice data, which emphasize integrated and springtime/summer values, also show geographic coherence across the Arctic and subarctic, although with a more linear pattern. Many fisheries and other biological time series map onto the principal components of the combined data set, but many do not. More research is needed, especially on the fisheries oceanography to develop regional ecosystem indices of climate change.

Despite their individual character, more than half of the 86 variables in the data collection show considerable projections onto the three Arctic patterns: regime, interdecadal/decadal or linear trend. This suggests that the Arctic is responding to change over the last three decades in a temporal and geographic coherent manner. No single index or class of observations exclusively tracks change in the Arctic, a result of our pan-Arctic, multivariate analysis.

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APPENDIX: UNAAMI TIME SERIES KEY

Atmospheric

1 CO_2 at Barrow, AK
2 Air Temp 925hPa April EOF-1
3 Air Temp 925hPa Dec. EOF-1
4 Air Temp 200hPa March EOF-1
5 Air Temp 925hPa April EOF-2
6 Air Temp 925hPa Dec. EOF-2
7 Air Temp 200hPa March EOF-2
8 Air Temp 925hPa Dec. EOF-3
9 Air Temp 925hPa Dec. EOF-4
10 Siberian High Pressure
11 Ozone, Canada
12 Zonal Wind, 300hPa, N. Atl.
13 Zonal Wind, 300hPa, N. Pacific

Biological

14 Bathurst Caribou, NW Terr.
15 Black Guillimot, Alaska
16 Porcupine Caribou, N. Yukon
17 Red deer, Norway
18 Waterfowl, Old Crow Flats, AK
19 Fur seals, Pribilof Is.
20 Invertebrates, Bering Sea
21 Jellyfish Biomass, Bering Sea
22 “Q” Caribou NW Terr. Canada
23 Western Arctic Caribou, Alaska
24 Zooplankton Biomass, Bering S.
25 Zooplankton, North Sea

Fisheries

26 Arrowtooth Flounder, Bering S.
27 Atka Mackeral, Aleutian Is.
28 Capelin Stock, Barents Sea
29 Chinook salmon, West Alaska
30 Chum salmon, Bering Sea
31 Cod abundance, Baltic Sea
32 Cod abundance, Barents Sea
33 Cod length, Barents Sea
34 Cod recruitment, Iceland
35 Haddock abundance, Barents Sea
36 Halibut index, Greenland
37 Herring, Bering Sea
38 Herring index, Baltic Sea
39 Herring stock, Norway
40 Plaice, Bering Sea
41 Redfish abundance, Barents Sea
42 Saithe recruitment, Iceland
43 Salmon index, Baltic Sea
44 Shrimp, NW Atlantic
45 Sockeye salmon, Bering Sea
46 Sprat index, Baltic Sea
47 Turbot, Bering Sea
48 Yellowfin sole, Bering Sea

Climate Indices

49 Arctic Oscillation
50 “E” Meridional Index, Siberia
51 North Atlantic Oscillation
52 Aleutian Low (NPI) April-May
53 Aleutian Low (NPI) Jan.-March
54 Polar Vortex
55 SLP Wave 1 phase, Arctic
56 Sea level gradient
57 “W” Zonal Index, Siberia
58 Arctic vorticity

Oceanic

59 Ice Flux to North Atlantic
60 SST anomaly, Labrador Sea

61 SST, Pribilof Is. region
62 Kola sea temperature
63 Bering Strait transport

Sea Ice

64 Open water duration, Resolute B.
65 Summer coverage, Arctic
66 Ice Extent, Bering Sea
67 Coverage, Kara-Barents Sea
68 Coverage, Okhotsk Sea
69 Thickness, Beaufort Sea
70 Thickness, Canadian Archipelago
71 Thickness, East Siberia
72 Thickness, Leptev Sea
73 Thickness, N. Fram Strait
74 Thickness, North Pole
75 Max. Thickness, Resolute Bay

Terrestrial

76 Burn area, Alaska/Canada
77 Discharge, Kusk River, AK
78 Discharge, Siberian rivers
79 Greenness, Eurasia
80 Greenness, North America
81 Time of Ice Melt, Ob River
82 Permafrost Temp., Churapcha
83 Permafrost Temp., Zhigansk
84 Permafrost thickness, Alaska
85 Snow cover, Eurasia
86 Snow cover, North America