# 3.10 AN ANALYSIS OF STATIC STABILITY IN THE ARCTIC ATMOSPHERE

Richard I. Cullather* and Amanda H. Lynch
Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

## 1. INTRODUCTION

The static stability of the atmospheric column is of fundamental meteorological significance as an indicator of vertical motion and in the prediction of cloud cover and severe weather. Changes to atmospheric stability over long periods of time are also of interest in understanding variability in climate. In northern high latitudes, measures of static stability are by definition a proxy for the strength of the pervasive near-surface temperature inversion, a principal climatic structure of the autumn and wintertime Arctic atmosphere (Sverdrup 1933). Serreze et al. (1992) notes that the Arctic inversion is a complex feature involving radiative cooling, warm air advection, subsidence, surface properties, and topography. Kahl and Martinez (1996) have found evidence for a strengthening and an increase in the elevation of the inversion layer over the period 1950-1990 based on radiosonde data from drifting ice stations and dropsondes from U.S. Air Force aircraft. Over land surfaces the temperature changes throughout the atmospheric column are not as well documented.

A more striking motivation is the need to document trends in summertime atmospheric instability in the Arctic, which has not received major scientific attention. Reap (1991) has computed spatial distributions of thunderstorm activity over Alaska using a lightning detection network. Regression analysis using the National Weather Service Nested Grid Model (NGM) indicated that large-scale static instability was the primary prerequisite for the formation of thunderstorms over the state's interior region, mainly in June and July. There are a large number of studies using indigenous or traditional knowledge which indicate increasingly frequent and severe thunderstorms and lightning in the Arctic (Riedlinger and Berkes 2001, Kofinas 2002). In many cases, interviews with native elders indicated the recent occurrence of thunderstorms where few or none had been observed previously. These studies indicate a phenomenon that has not been extensively studied in the past but may serve as an indicator of high latitude climate variability.

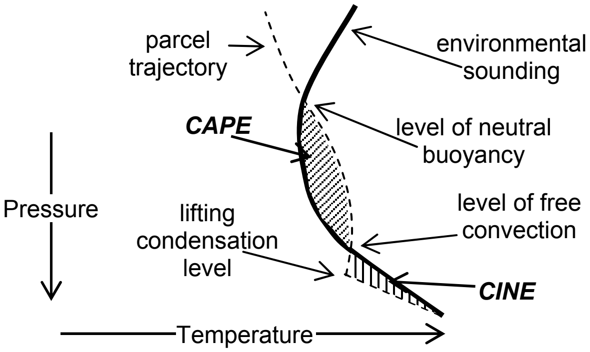

Figure 1. Schematic of the parcel method and computational definitions.

## 2. DATA AND METHOD

Convective available potential energy (*CAPE*, Moncrief and Miller 1976) is defined as the integrated quantity of energy available for the upward acceleration of an air parcel raised adiabatically from the surface. Generally, the

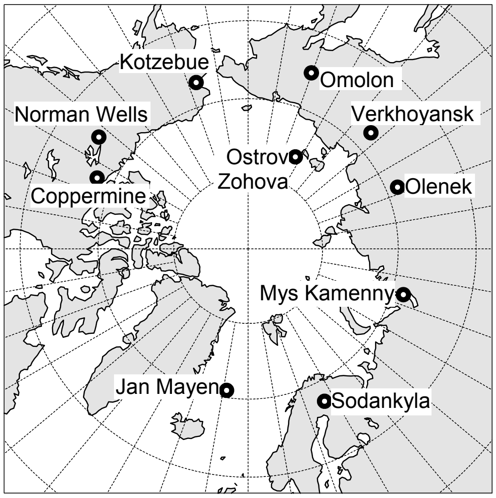

Figure 2. Upper air station network used in this study.

---

* *Corresponding author address:* Richard I. Cullather, Climate and Global Dynamics Division, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000; email: cullat@ucar.edu.

energy of convective inhibition (*CINE*) is defined only for that region of the profile that is below the level of free convection (LFC). If the profile has no LFC, then *CINE* is infinite (Fig. 1). Here, *CINE* is evaluated up to 500 hPa. This provides a finite quantity that may be assessed in the absence of *CAPE*. A subset of 10 upper-air stations from the Historical Arctic Rawinsonde Archive (HARA, Serreze et al. (1995) is used and shown in Fig. 2. The entire archive of HARA stations was examined for one year. Subsampled stations shown were selected for highlighting features of interest and examination of interannual variability. Archives of the stations shown contain data covering a large fraction of the period 1955-1996.

## 3. MEAN STATISTICS OF *CINE*

Shown in Fig. 3, the yearly march of stability indices at each station is generally indicative of the regional circulation conditions. Largest wintertime mean values of *CINE* are associated with Siberian land surfaces inland of the Laptev Sea. The *CINE* annual cycle for Verkhoyansk station reflects the strong continentality of the temperature regime and is characterized by an extraordinary range of monthly mean values. Serreze et al. (1992) estimated the median temperature difference across the wintertime inversion to be about 20°C for Verkhoyansk. The station is located at relatively low elevations in the Yana River Basin and is regarded as having the coldest surface temperatures in Asia. On the opposite side of the Arctic Ocean Basin, Coppermine station is located in close proximity to the Canadian Archipelago but has similar continentality. These stations may be contrasted with stations located farther eastward in Eurasia, and oceanic stations. The continual progression of storms in the North Atlantic results in a small annual cycle for Jan Mayen.

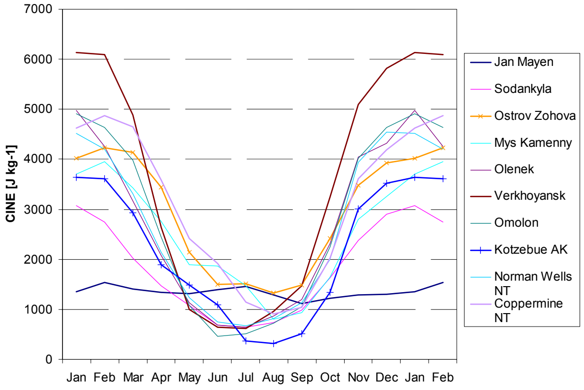

Figure 3. Monthly mean values of *CINE* computed from available rawinsonde data, 1955-1996.

On interannual time scales there is an expected influence of the storm track on the atmospheric stability in the North Atlantic. Comparison of DJF *CINE* values with corresponding values of the North Atlantic Oscillation Index (Hurrell 1995) indicates a weak anticorrelation with a Spearman rank correlation coefficient of 0.43 over the period 1958-1996. Beyond the immediate vicinity of the North Atlantic, discernible trends are not apparent from 1971 to the present. For the Siberian stations, strict quality control eliminates many soundings prior to 1971, primarily due to a lack of near-surface observation points. These difficulties are similar to those experienced by Serreze et al. (1995), who used data only for the period after 1973. It is apparent that less data is available in winter months than for other times of the year.

## 4. ESTIMATES OF *CAPE*

Monthly frequency distributions of *CAPE* were computed for each station. Bluestein (1993) has indicated threshold values of *CAPE* with application to the midlatitudes. Moderate to strong convection occurs for a range from 1000 to 3000 J kg$^{-1}$. Given the lower tropopause height in the Arctic, it is not clear that these values are applicable to higher latitudes. From the stations surveyed, four repeatedly contain numbers of summertime *CAPE* values above 500 and 1000 J kg$^{-1}$. These stations lie on a zone of baroclinicity identified by Reed and Kunkel (1960) as the Arctic front. The zone approximates the tree line and topography around the periphery of the basin. For the data analyzed, 7.7 percent of the July soundings at Olenek contained *CAPE* values greater than 500 J kg$^{-1}$, and 5 percent were greater than the midlatitude severe weather threshold of 1000 J kg$^{-1}$. For Norman Wells, these values are 4.3 percent and 0.9 percent for July soundings. In general, large *CAPE* values for these stations are confined to July.

Frequency distributions of July *CAPE* are shown for 2 stations in Fig. 4. In general there is no clear trend in the frequency of *CAPE* values greater than 500 J kg$^{-1}$. The frequency of large values for Olenek in July is greater than 10 percent in the early 1970s and after 1990, however in between these episodes there is an extended period where the frequency is less than 5 percent. Norman Wells also shows individual years of a higher frequency in severe *CAPE* values with no discernable trend.

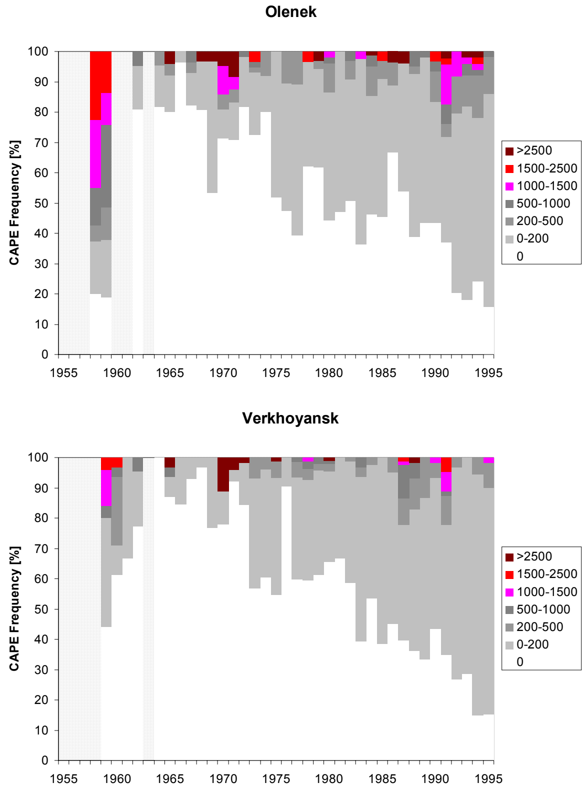

Figure 4. *CAPE* July frequency distribution by year for 2 stations examined. Dotted field indicates months with less than 20 soundings.

The most unusual trend found is in the decrease of the number of soundings where *CAPE* is equal to zero. This is particularly noticeable for the eastern Russian stations. For both Olenek and Verkhoyansk, the number of *CAPE* values that are identically equal to zero was greater than 80 percent in 1965 but less than 20 percent in 1995. There is an indication from the data that the zero fraction was also lower prior to 1965.

## 5. REFERENCES

Kahl, J.D.W., and D.A. Martinez, 1996: Long-term variability in the low-level inversion layer over the Arctic Ocean. *Int. J. Climatol.*, **16**, 1297-1313.

Kofinas, G., 2002: Community contributions to ecological monitoring: Knowledge co-production in the U.S.-Canada Arctic borderlands. *The Earth is Faster Now: Indigenous Observations of Arctic Environmental Change*, I. Krupnik and D. Jolly, Eds., Arctic Research Consortium of the United States, pp. 54-91.

Moncrieff, M.W., and M.J. Miller, 1976: The dynamics and simulation of tropical cumulonimbus and squall lines. *Quart. J. Roy. Meteor. Soc.*, **102**, 373-394.

Reap, R.M., 1991: Climatological characteristics and objective prediction of thunderstorms over Alaska. *Wea. Forecasting*, **6**, 309-319.

Reed, R.J. and B.A. Kunkel, 1960: The Arctic circulation in summer. *J. Meteor.*, **17**, 489-506.

Riedlinger, D., and F. Berkes, 2001: Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record*, **37**, 315-428.

Serreze, M.C., J.D. Kahl, and R.C. Schnell, 1992: Low-level temperature inversions of the Eurasian Arctic and comparisons with Soviet drifting station data. *J. Climate*, **5**, 615-629.

Serreze, M.C., R.G. Barry, and J.E. Walsh, 1995: Atmospheric water vapor characteristics at 70°N. *J. Climate*, **8**, 719-731.

Savelieva, N.I., I.P. Semiletov, L.N. Vasilevskaya, and S.P. Pugach, 2000: A climate shift in seasonal values of meteorological and hydrological parameters for northeastern Asia. *Prog. Oceanogr.*, **47**, 279-297.