3.2.7. BARROW SNOW MELT DATE

Snow Melt Analysis

An important process that occurs every spring over continental regions of the arctic is the melting of the snow pack. Variability in the date when the tundra becomes snow free is expected to affect the annual net energy budget of the region. As the global mean temperature continues to increase, the arctic is predicted to experience enhanced warming because of a positive radiative feedback caused by decreasing surface albedo in response to accelerated melting of ice and snow. Albedo is derived from the ratio of reflected to downwelling, shortwave, broadband irradiances. Of particular interest to CMDL has been the timing of the spring snowmelt at BRW that has historically been designated as the day when albedo drops below 0.30 [*Dutton and Endres*, 1991]. Fresh snow has an albedo exceeding 0.85, whereas dry tundra has a value of about 0.17 [*Stone et al.*, 1996]. Once the daily average albedo drops below 0.3, it seldom increases again until snow accumulates the following autumn. This fact makes monitoring the melt relatively straightforward and provides an important record for evaluating regional climate change. Figure 3.20 shows daily average albedos spanning the period of melting for 1998 and 1999. Although the final melt typically occurs in a matter of a few days as shown in the figure, the actual timing of this event is highly variable from year to year at any particular location, depending on many factors. Temperature is usually presumed to be a primary factor; however, changes in cloud cover that affect solar intensity or thermal emissions, the stability of the atmosphere, and boundary layer turbulence (winds) are also factors. Another important variable is the amount of snow that accumulates during the preceding months. Any long-term variation in these or other factors may affect the spatial or temporal distribution of snow and lead to a perturbation in the regional energy balance. It is essential that these processes be understood and be parameterized correctly in models to improve climate simulations.

Foster [1989] found that the disappearance of snow in spring at Barrow has occurred progressively earlier since the 1950s and has speculated that this was a manifestation of global warming. His analysis was based on observations of snow cover made at the Barrow NWS station. *Dutton and Endres* [1991] argued that the apparent trend was attributable to local urbanization effects, basing their analysis on the more objective, radiometric determination of melt made at BRW (e.g., Figure 3.20). Because BRW is located on open tundra several kilometers upwind of town, it has not been affected by such development. *Foster et al.* [1992] expanded on these earlier studies using satellite data to show that the earlier melt was regional in scale. In this report, the record from BRW is updated in an attempt to explain the trend and variability of the annual melt there.

Updated time series for NWS and BRW indicate a further divergence as shown in Figure 3.21. It is now known for certain that the NWS record was contaminated because of new construction and a dramatic increase in traffic directly upwind of that site. The development began in the late 1960s in anticipation of developing the North Slope oil reserves. Thus the NWS data subsequent to this time are progressively more suspect. To construct a valid, long-term time series of melt dates for Barrow, the BRW radiometric record was appended onto the early NWS record, bridging the gap of 1966-1985 using proxy data. The proxy data were derived from careful examinations of temperature records that show a distinct seasonal signature related to the melting process. This repeatable feature appears as a period of about 8 days running of near-freezing air temperatures, followed by an abrupt and sustained warming caused when solar radiation is absorbed by the exposed tundra that then releases heat to warm the overlying air.

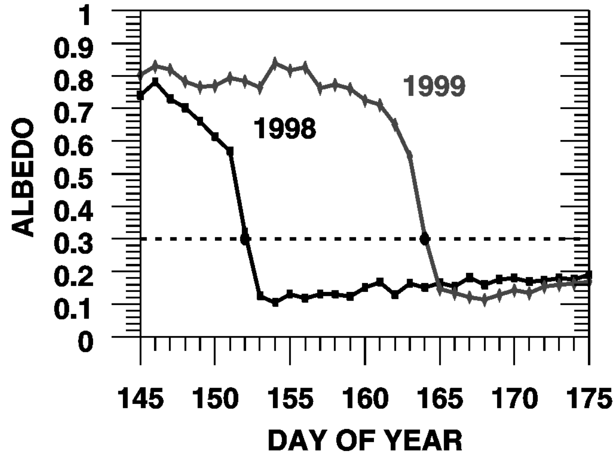

Fig. 3.20. Time series of daily average surface albedo for 1998 and 1999 at BRW. The snowmelt date is determined radiometrically as the date when the surface albedo drops below 0.30 (30%).

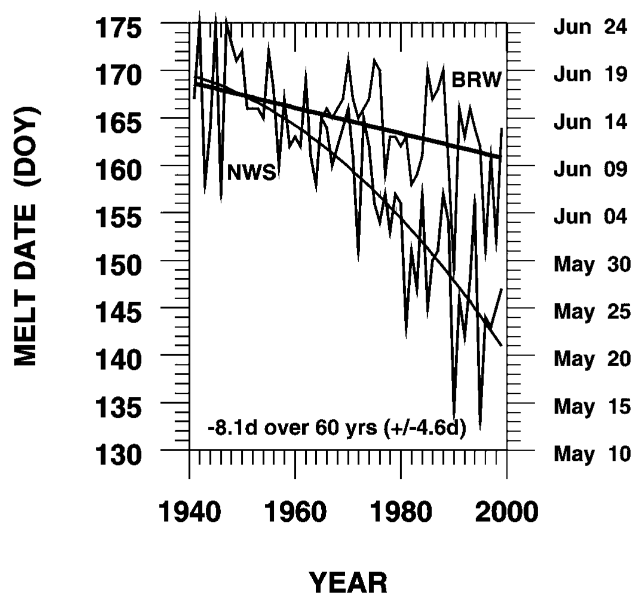

Fig. 3.21. The date of snowmelt in the vicinity of Barrow shows a trend. At the NWS site in town the disappearance of snow is occurring much earlier than at BRW because of local urbanization effects. The linear trend for BRW is given in the legend and is based on a 95% confidence level.

Regression analyses were used to evaluate the time series shown in Figure 3.21. The downturn (quadratic) indicated for the NWS record is now attributed to contamination of that site by nearby development, but the composite BRW time series shows a trend that is statistically significant (–8.1 ±4.6 days over 60 years at the 95% confidence level). It is hypothesized that the earlier melting of the snow pack in the vicinity of Barrow results from less than normal accumulation of snow throughout the winter and/or warmer spring temperatures possibly associated with enhanced thermal emissions from clouds as described by *Stone* [1997]. To explore these possibilities, meteorological records were analyzed dating from the mid-1960s, the period showing the most pronounced trend. Integrated water equivalent precipitation (WEPC) from October through February is used to quantify seasonal snow accumulation because this measure is less prone to error than actual snow depth data. In addition, the temperature (T) and total sky cover (SC) averages for March and April were examined. Although the final phase of melting is obviously dependent on concurrent weather conditions, the analysis suggests that the factors mentioned previously probably condition or "ripen" the snow pack prior to the onset of melt by establishing its maximum depth and its microphysical characteristics. Figure 3.22 displays time series for each of these factors compared with the record of melt. Each time series was analyzed for a trend and was cross-correlated with melt date. The coefficients correlating melt with WEPC, T, and SC are, respectively, +0.39, –0.47, and –0.30. As expected, melt date is positively correlated with snowfall (represented by WEPC) and anti-correlated with temperature, but no one factor explains a significant portion of the variance. However, an empirical model based on a multiple regression using a nonlinear combination of these factors was found to explain >70% of the variance [R. Stone, unpublished results, 2000]. It is concluded that decreasing snowfall during winter, combined with warmer, cloudier spring conditions are primary factors that have led to an earlier melt at BRW.

Overall the melt has advanced by more than a week since the mid-60s but is characterized by significant interannual variability. The most pronounced change occurred during the last decade, with the melt dates of 1990, 1996, and 1998 being particularly early. Figure 3.22 shows that during each of these years little snow accumulated through the winter (minimal WEPC) and the following March and April periods were relatively warm. In contrast, the 1999 melt occurred late because WEPC was much higher and spring temperatures were much colder. Because the melt occurs during the peak of the annual solar cycle [*Stone et al.*, 1996], there is a dramatic increase in net surface radiation when the tundra becomes snow free. It is estimated that the trend indicated in Figure 3.21 represents an increase in the annual net radiation balance at BRW of about 10%. Analyses of melt dates for other North Slope sites (not presented here) show a similar tendency toward an earlier melt suggesting that the region as a whole has experienced an increase in net radiation in recent years. If the area affected covers a large enough region of the artic and this trend is sustained, then the implications of these findings will have even greater significance in the context of global climate change. It is important to understand what processes underlie these observations.

Trajectory Analysis

A previous study showed that shifts in circulation patterns influence northern Alaska climate [*Stone,* 1997]. It is very likely that similar changes underlie the variations in the annual melt at BRW through perturbations in the precipitation and temperature patterns of the region. To a large extent the climate of northern Alaska is influenced by the relative positions and intensities of two dominant pressure systems, the Aleutian Low and the Beaufort Sea anticyclone. This is revealed through analyses of back-trajectories similar to those of *Harris and Kahl* [1994] made in conjunction with an examination of geopotential height fields that highlight these synoptic patterns. Enhanced precipitation during winter was found to occur often when warm moist air reaches northern Alaska from the North Pacific as a result of circulation around the Aleutian Low. Drier conditions prevail there when upper-level winds are generated over the Beaufort Sea and effectively block the southerly flow. Year-to-year variability of these features appears to be associated with natural shifts in planetary wave patterns rather than a response to a general warming of the arctic. It is speculated that these variations are correlated with the phase of the arctic oscillation [e.g., *Thompson and Wallace,* 1998]. This possible connection is a focus of continuing research. Eventually it is hoped to determine to what extent the annual cycle of snow cover over northern Alaska is affected by natural versus anthropogenic factors.

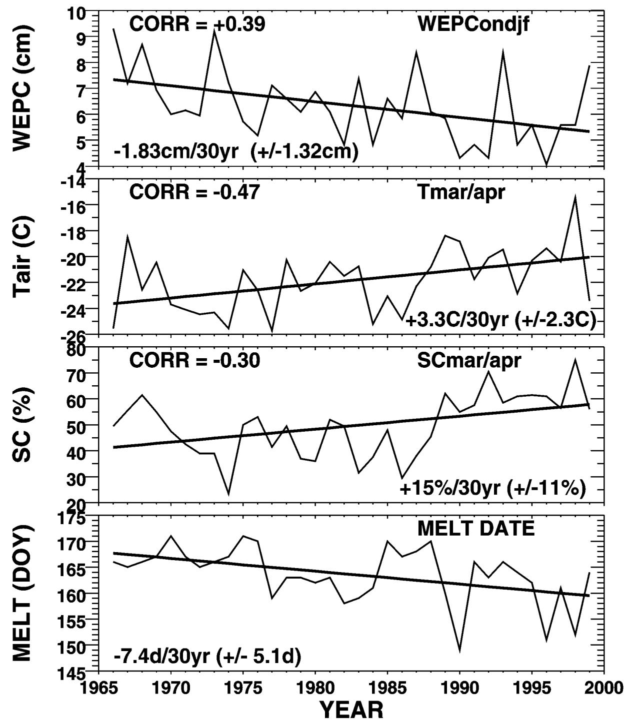

Fig. 3.22. Time series of factors that are believed to affect spring snowmelt at BRW compared with dates of melt. As labeled, top to bottom: integrated water equivalent precipitation for October through February, average March/April 2-meter air temperature, average total sky cover for March/April, and melt date determined from proxy (temperature) data and albedo measurements as described in the text. Each time series has a linear fit to determine trends based on the 95% confidence level given in the lower legends. Also, cross-correlation coefficients relating melt date with each variable are given (upper, left).