# Recent Arctic Summer Sea Ice Albedo Trend and its Relationship to Sea Ice Conditions

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Sea ice extent in the Arctic Ocean has been decreasing an estimated 2-4 % per decade over the course of the satellite record and has reached minimum coverage in recent years. Recent evidence suggests that the ice has also been thinning. The reduction of sea ice extent and thickness is enhanced by the ice-albedo feedback, accelerating the rate of ice melt in the Arctic summer. An assessment of trend in sea ice albedo is therefore critical to determine the processes involved with the recent reduction in sea ice cover.

AVHRR Polar Pathfinder (APP) data is utilized to determine how sea ice albedo varies over the course of the 30-year satellite record. It is observed that Arctic sea ice albedo has been decreasing over this period. This trend is noted for latitudes above 73°N and between 55 and 73°N, although a greater negative trend exists in the farther north latitude region. Recent monthly albedo differences are also observed for April and August, suggesting an increase in the duration of the melt season. The decrease in albedo may is linked to a reduction of multiyear ice concentration, which has also been observed in the APP data, as multiyear ice is generally observed to have a higher albedo than first-year ice. The variability of open water has a weak inverse relationship with observed albedo.

Sea ice extent in the Arctic Ocean has been decreasing an estimated 2-4 % per decade over the course of the satellite record [*Parkinson et al.*, 1999] and has reached minimum coverage in recent years [*Serreze et al.*, 2003; *Comiso*, 2001]. Furthermore, submarine observations in the Central Arctic have found that ice thickness has declined in that region by about 43% in the last 20 years [*Rothrock et al.*, 1999]. These trends have been influenced by the ice-albedo feedback [*Curry et al.*, 1995], which occurs mainly during the summer melt season. Furthermore, the general length of the melt season has also been increasing [*Smith*, 1998]. These findings demonstrate the need to accurately represent the evolution of sea ice albedo during the melt season using observations and modeling.

During the onset of sea ice melt, the ice is transformed from a relatively homogeneous, snow-covered pack to a variegated surface with large spatial variation in albedo. The areally averaged albedo decreases significantly during the summer melt, due to the influence of melting snow, melt ponds, and leads. After melt onset, albedo is reduced significantly and is highly variable (Figure 1). Because this transformation is so profound and so dependent on preceding ice and snow conditions, it is essential to investigate the evolution of sea ice albedo over the melt season, and to assess the relationship between surface albedo and prevailing ice characteristics.

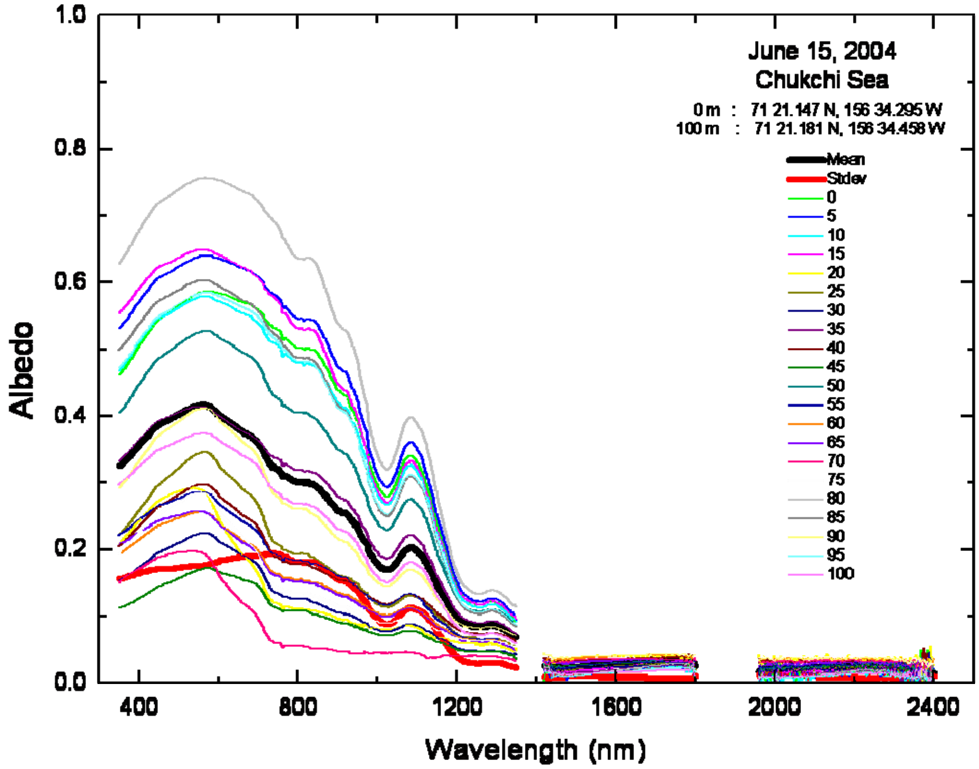


*Figure 1. Spatial variability of sea ice albedo along a 100m albedo line near Barrow, Alaska during June 2004.*

Arctic sea ice albedo has been measured continuously by the Advanced Very High Resolution (AVHRR) satellite-based radiometer for nearly 30 years and has been catalogued as part of the Polar Pathfinder project at the National Snow and Ice Data Center (NSIDC, http://nsidc.org/daac/pathfinder/). Although there is substantial interannual variability, it is evident that summer sea ice albedo has been decreasing over the course of the satellite record, with the greatest fractional decrease occurring in the more northern latitudes (Figure 2).

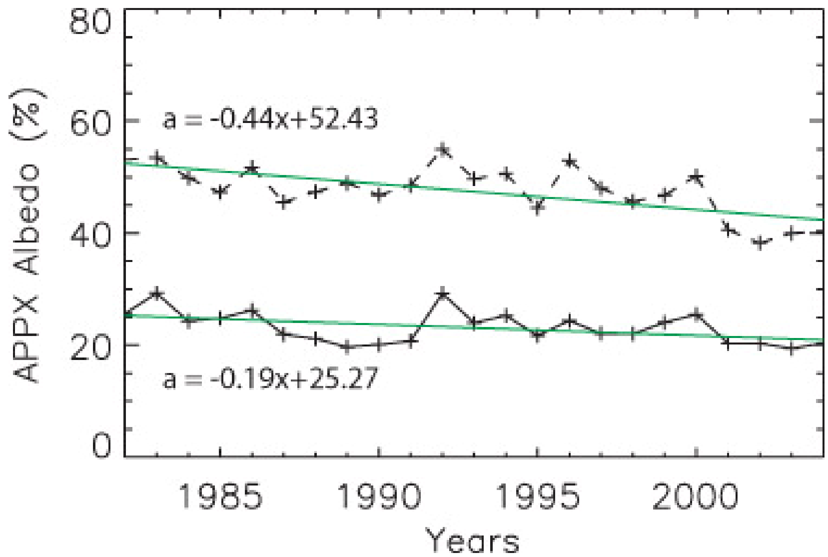


*Figure 2: AVHRR Polar Pathfinder summer albedo for sea ice north of 73°N (dashed line) and between 55 and 73°N (solid line).*

The spectral and broadband albedo of sea ice, particularly ponded ice, is affected by the age of the ice. Ponds on first-year ice are more likely to exhibit a reflectance similar to the underlying ocean, since there is a relatively thin ice layer beneath the pond, or in some cases the pond is partially melted through the ice. On multiyear ice, the pond reflectance is more dependent on the underlying ice properties. Pond characteristics are also affected by the surface topography of the ice, which is a strong function of ice age and roughness. Airborne observations of ponds in the Beaufort Sea found that the majority of ponds over thick multiyear ice exhibited a bluish appearance [*Tschudi et al*., 2001, 1997; *Perovich et al*., 2002]. Pond fraction has been modeled as a function of ice type, varying between 50-90% for first-year ice and 10-25% for multiyear [*Schramm et al*., 1997]. The combination of lower pond albedo and higher pond concentration over first-year ice results in an albedo that is typically lower than multiyear ice.

The contrast in albedo between first-year and multiyear ice (Figure 3) impacts the melt of sea ice during the summer months. Since first-year ice typically has a lower albedo, it allows for more absorption of solar radiation into the underlying ice pack than multiyear ice, leading to enhanced melting. The difference in albedo of the two ice types should influence the observed albedo of the ice pack.

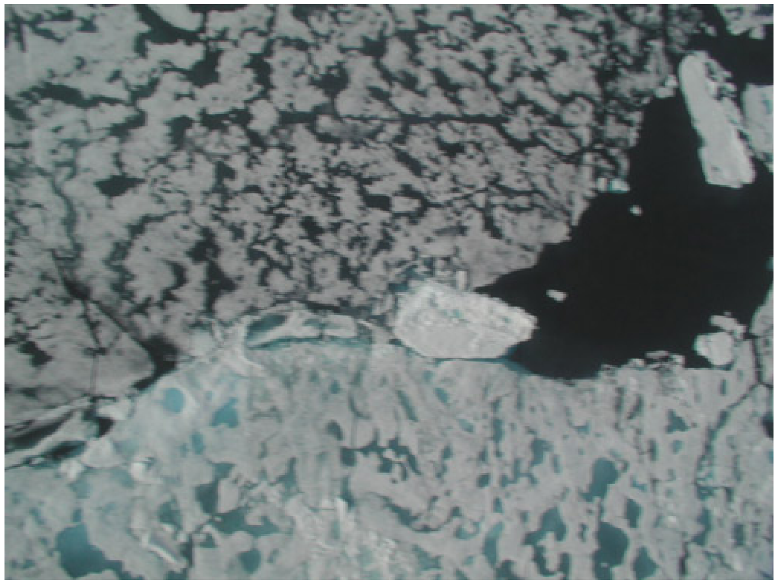

*Figure 3: Airborne photo of first-year (top) and multiyear ice near Barrow, Alaska (June 2004). Photo is about 1 km across.*

The mean summer albedo from 1982-2004 (i.e. all observations shown in Figure 2) are compared to the fraction of the ice pack composed of multiyear ice (Figure 4) and to the amount of open water (Figure 5). The percentage of summer multiyear ice in the pack has a weak positive correlation (0.483) with the summer albedo, but strong enough to suggest that there is an influence. Furthermore, a 3% decline in summer multiyear ice since 1982 appears to influence the 10% decline in summer albedo over the same time period. This significant decline in ice albedo accelerates the melt of the ice through the ice-albedo feedback [*Curry et al*., 1995].

The fractional coverage of summer first-year ice (not shown) does not exhibit a trend over this period.

The albedo of open water is only about 8% [*Pegau and Paulson*, 2001] compared to the approximate 35% albedo observed over summer sea ice. The coverage of summer open water should therefore be inversely related to the observed Arctic albedo, and this relationship exists, although weakly (-0.039). Perhaps this relationship is due to the relatively low concentration (~15%) of water compared to the ice pack coverage. It should be noted that techniques using passive microwave observations generally overestimate amount of open water, as melt ponds may be mistaken for areas of open water. This overestimation was investigated by comparing ice concentrations derived from MODIS (visible) and AMSR (passive microwave) observations in an area where the amount of ponding was known (Figure 6). In this example, a 25.7% pond cover contributed to an ice concentration underestimation (or an open water overestimation) of only 1.5%.  The open water coverage shown in Figure 4 may therefore be 1-2% less than shown, since the 25% pond coverage is a typical mean value for summer pack ice.

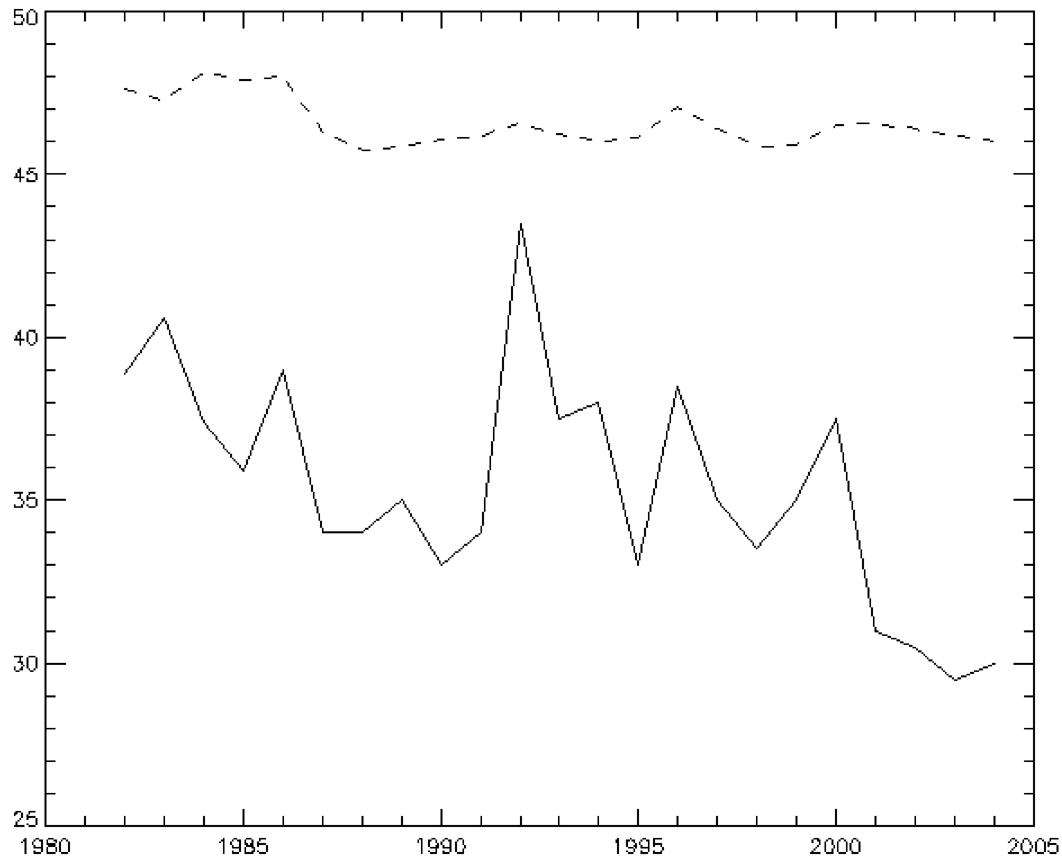


*Figure 4: Arctic summer (JJA) albedo (solid line) and fractional coverage of multiyear ice in the pack (MYI/ total ice, dashed line). From AVHRR Polar Pathfinder.*

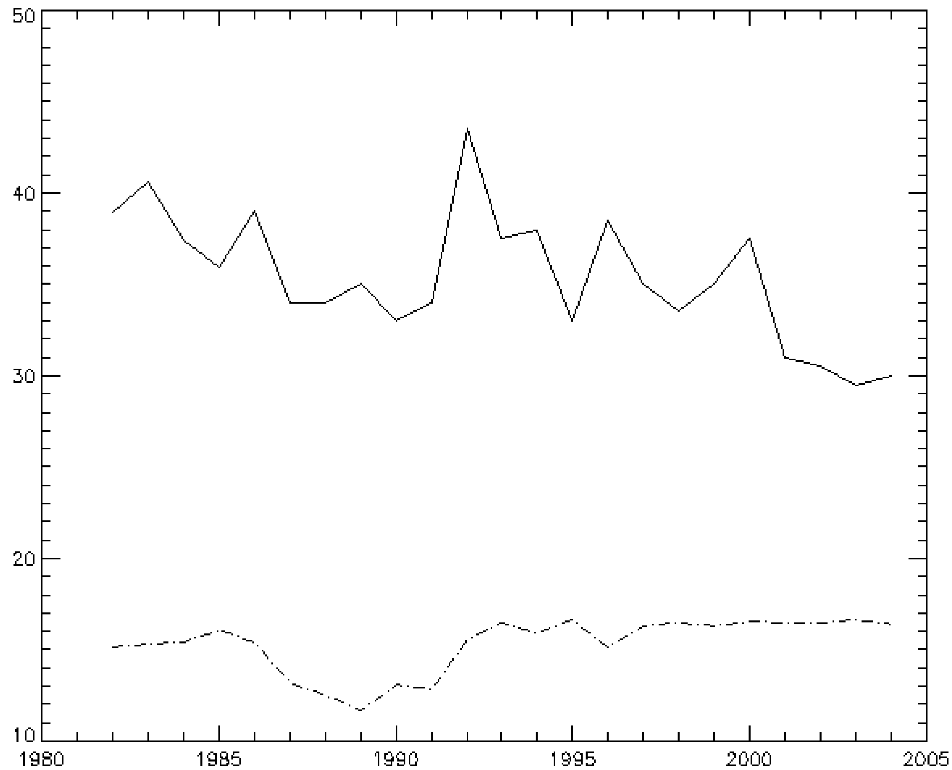


*Figure 5: Arctic summer (JJA) albedo (solid line) and fractional coverage of open water (broken line). From AVHRR Polar Pathfinder.*

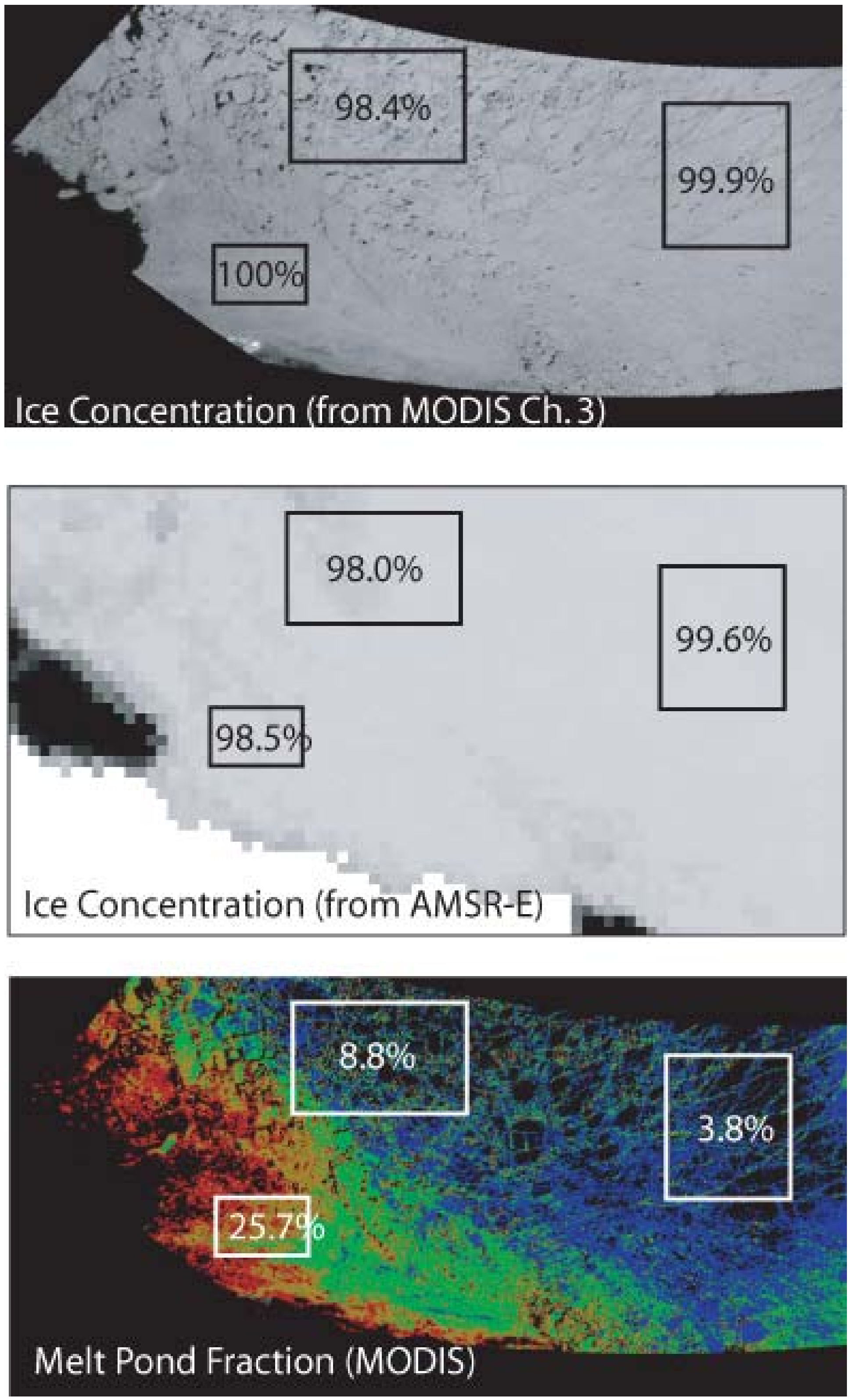


*Figure 6: Ice concentration estimated from MODIS and AMSR. Melt pond fraction estimated from MODIS [Tschudi et al., 2005].*

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