# The Role of Albedo as a Forcing in the Formation and Evolution of Melt Ponds on Undeformed First Year Sea Ice

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## Introduction

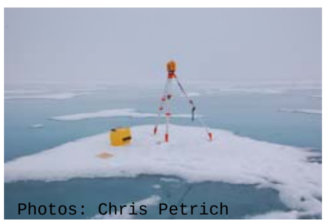
As spring progresses in the arctic, warm temperatures and solar energy input eventually begin melting snow on the surface of the sea ice. The sea ice is initially impermeable and the melt water pools on the surface in ponds. The development of these melt ponds dramatically changes the albedo of the underlying ice, and therefore the energy balance of the ice. The melt ponds are highly dynamic, expanding and shrinking over the course of a melt season with behavior which also varies from one melt season to the next. The effect ponding has on surface albedo is dramatic. Ponded ice albedo can drop as low as 0.15 and unponded ice ranges near 0.65. The uncertainty in pond area evolution, therefore, leads to a large uncertainty in shortwave energy flux and in turn total energy balance. This study tracks the evolution of melt ponds on a flat pan of first year ice near Barrow, AK and correlates their behavior to other measureable parameters in an effort to better understand which factors are responsible for determining melt pond location and movement. It is hoped that a greater understanding will help us narrow in on the the factors which determine behavior of areal fraction over time in future studies.

## Methods

We selected a test site on a pan of flat, un-deformed pan of first year ice which was representative of a common surface type in the pack. The site was beyond major dust pollution from Barrow roads and logistically readily accessible. At the site we laid out a 200 meter line along which all measurements would be taken, setting one side for walking on and the other for measurements. We took time series photographs and tracked surface type, snow and melt pond depth, wavelength-integrated and spectral shortwave albedo, and absolute surface elevation. With the exception of surface elevation, which was measured only twice, data were taken at 5 meter intervals daily from 5/28/2008-6/17/2008 (except 6/2). This period spanned from the beginning of snow melt until melt was well advanced, melt ponds had formed and drained, and the ice became logistically difficult to access. For energy flux analysis we utilize incoming solar data collected at the ARM site roughly 4 km from our measurement location.

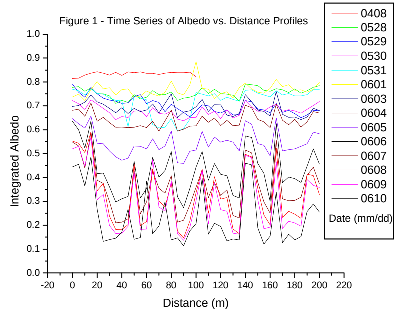
Measuring albedo early in melt

Pond depth and surface characterization, late melt



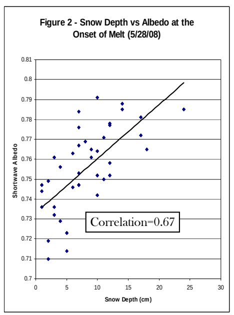

Finding surface elevation using a laser level

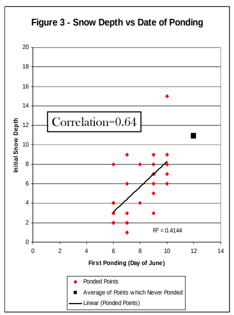
## Observations and Correlations

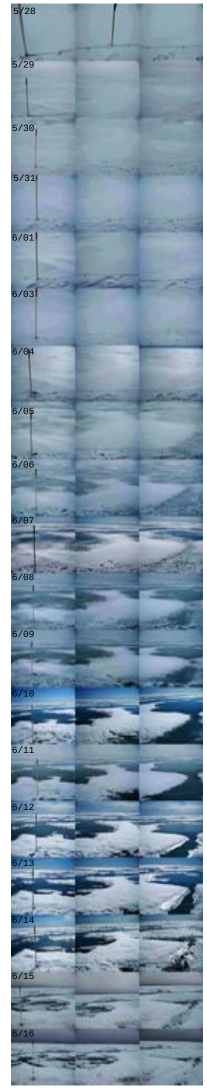



As the melt season progressed, we observed that the date an area became ponded appeared to be anti-correlated with snow depth (Figure 2), and areas which became ponded first remained the deepest melt ponds throughout the season. Tracking the outline of a melt pond from its formation around 6/7/08 in the time series photographs at right through the end of our field campaign illustrates both phenomena. The area which does not become ponded coincides with a dune of deeper snow prior to the onset of melt and though the melt pond area increases and decreases, the location where the melt pond first developed remains the center of the melt pond through the season.

We also observed that albedo profiles remained very similar as the melt season progressed (Figure 1). Since melt ponds featured a lower albedo than bare ice, we hypothesized that the melt ponds locations were maintained by a positive feedback due to their greater shortwave absorption and higher melt rate. Further extending the hypothesis, we ventured that the original formation of the melt pond was forced by the lower albedo of the shallow snow between the dunes at the beginning of the melt season (Figure 3) absorbing more energy and melting both earlier and more rapidly than their surroundings.



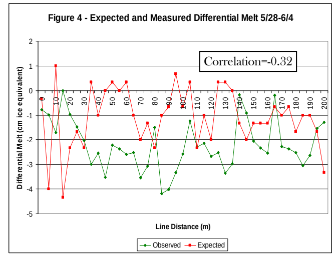



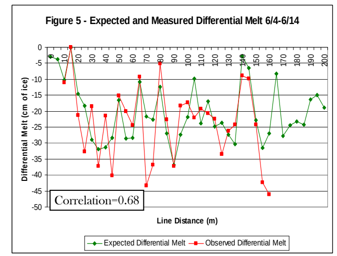

## Exploring Causation

Of the major heat flux variables in the surface energy balance, only outgoing shortwave radiation, determined by the albedo, should have a sufficient variability to force strong differential melting on a spatial scale of several meters. Using shortwave influx data and our albedo measurements, we calculated this differential energy flux. Assuming that the differential energy will all go into ice melt we then converted to expected daily ice melt.

In order to test the theory that the pre-melt snow albedo differences were sufficient to determine the location of melt ponds, we correlated the expected differential melt at each sample location with the snow melt observed prior to pond formation. Not only is the absolute differential melt expected roughly half that observed, Figure 4 shows that correlation between observed and expected differential turns out to be weak, and opposite of expected.

The second part of the theory, that melt pond location is maintained by an albedo feedback, was tested by carrying out the same calculation for the dates after melt pond formation began. Figure 5 shows that albedo variations did have the capability to cause a large enough differential melting, and that this amount correlates quite well with the observed differential melting.




## Conclusions

We have observed strong correlations between pre-melt snow depth and melt pond locations, as well as strong correlation between pre melt albedo and snow thickness, however greater melt in thin snow areas is not observed and shortwave energy flux due to albedo differences in the snow does not appear to cause the initial melt pond development. Once the ice surface becomes slushy and melt ponds begin to be established, however, differential energy flux is sufficient to cause significant differential melting. Incoming energy flux differential correlates well with observed melt differentials supporting the hypothesis that a shortwave albedo positive feedback is responsible for maintaining melt pond locations after the onset of melt.

Future work should examine whether the slushy layer which initiates the differential melting is present beneath thicker snow dunes a the same time it becomes apparent between them, as well as other potential causes of the correlation between snow thickness and initial melt pond formation, including the potential for superimposed ice topography beneath dunes to guide melt water to inter-dune spaces.

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