Weather and Forecasting During Mixed-Phase Arctic Cloud Experiment

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Introduction and Important Events Prior to Mixed-Phase Arctic Cloud Experiment

The Mixed-Phase Arctic Cloud Experiment (MPACE) was conducted across the North Slope of Alaska (NSA) during September 27-October 22, 2004. The experiment was funded by the Department of Energy (DOE)-Atmospheric Radiation Measurement (ARM) with the intention of increasing our knowledge about mixed-phase clouds in the arctic. In addition to radiosonde launches from four sites, lidar provided by the University of Wisconsin and the University of Alaska Fairbanks were used in conjunction with Millimeter Cloud Radar (MMCR), and in situ aircraft measurements taken in the clouds.

Overall, the 2004 fall transition season during MPACE was marked by periods of extreme temperatures, fierce storm systems, and frequent high winds. One of the defining factors that made the fall transition season during MPACE unique was the fact that 2004 was a high-melt year. Historically, pack ice would have advanced to the coastline prior to or during the early stages of MPACE. Instead, the period was marked by the presence of open water along the coastline during the entire period, allowing warm, moist air to be readily available. In fact sea ice did not reach the northern coastline of Alaska until approximately one week after the study ended. Setting the stage for a high-melt transition season was a 2004 summer season that brought anomalously high temperatures to most of Alaska. August was the warmest month of the year at Barrow with a mean temperature of 5.2°F above average. Mean temperatures at Barrow for the three month period spanning June-Aug were 3.6°F above average and by early September the Arctic Ocean was marked by open water to nearly 75°N directly north of Alaska, one of the highest melt years on record. Figure 1 shows the retreat of the pack ice over northern Alaska and the Arctic Ocean during the summer melt season. Figure 2 shows a close up of the NSA with each of the four launch sites labeled. The transition season officially began across the NSA during September 22-25 following criteria set forth by Ivanova et al. (2005). A strong shortwave brought the first major snowfall to the region and transformed the NSA from a dark, low-albedo surface to a snow-covered, high-albedo environment. Cloud tendencies during the various synoptic regimes that occurred during

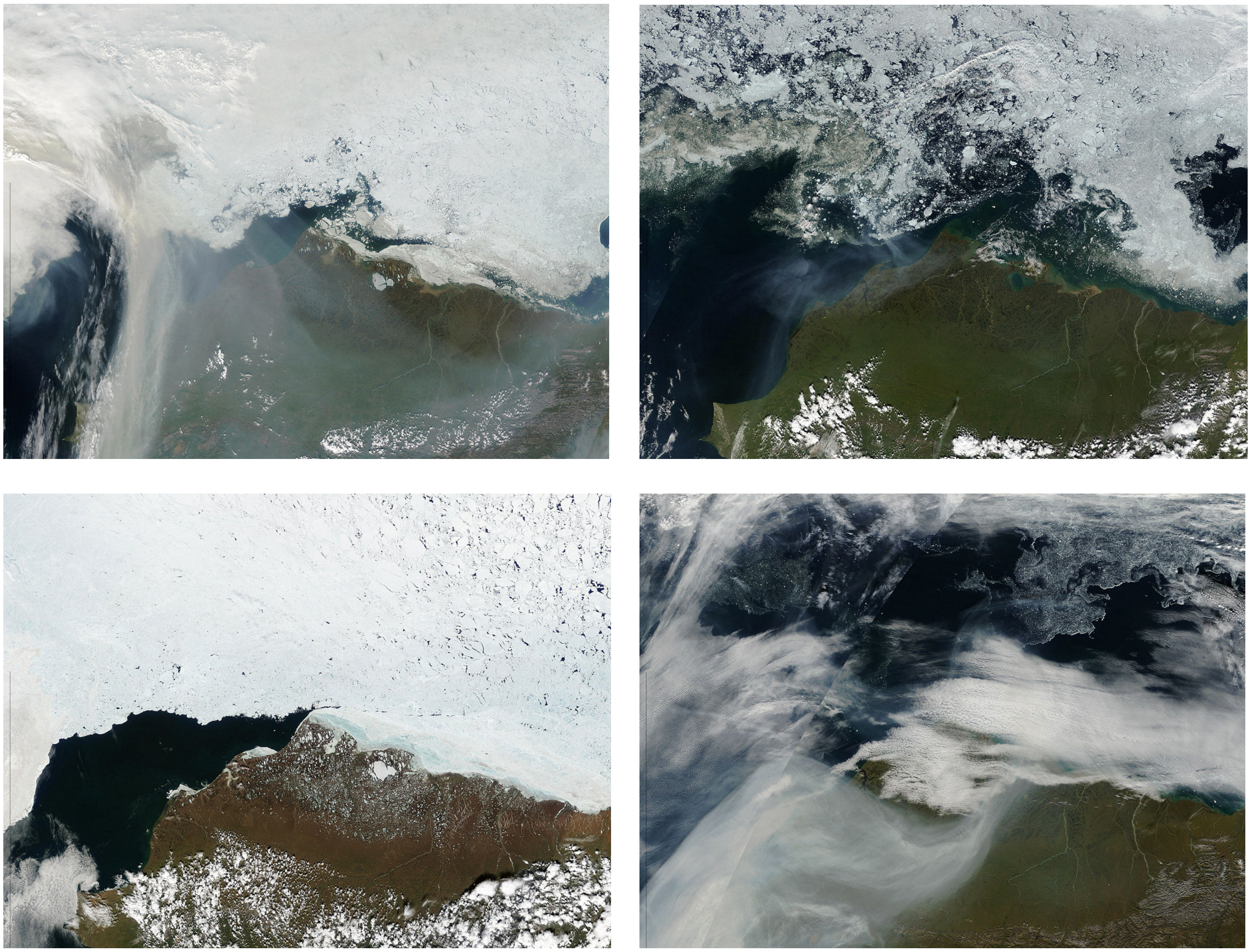


Figure 1. MODIS visible satellite images showing sea ice retreat during 2004 summer season.

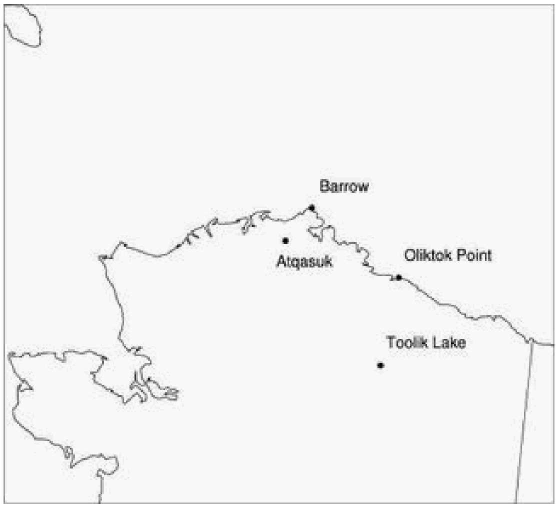


Figure 2. Map of the North Slope of Alaska showing the four experimental sites during MPACE.

MPACE were examined using satellite imagery, MMCR, and Micropulse Lidar (MPL). In previous work, Curry and Herman (1985) found that synoptic conditions had a strong influence on cloud cover and type over the arctic. Klein and Hartmann (1993) correlated low-level stratus clouds with sea-surface temperatures over the Arctic Ocean.

Overview of Weather During Mixed-Phase Arctic Cloud Experiment

During MPACE, the NSA was characterized by three different synoptic regimes with two transition periods. Each regime had significant influence over cloud cover, frequency, and type. The first regime, between September 24 and October 1, was unsettled. Aloft a pronounced trough was in place that funneled several shortwaves into the NSA. During this period, the surface was dominated by three small, weak low pressure systems passing through the area with a large high pressure system northwest of the Alaskan coast over the Arctic Ocean. The first two case days, September 29 and 30, occurred in the heart of this weather regime. September 24-26 was marked by the presence of the first system that moved North along the Canadian/Alaskan border then turned west towards Barrow before dissipating. On September 27, a similar low pressure center tracked west out of northern Canada, stalling to the south of Barrow with deep clouds. Oliktok and Toolik were clear as these regions were in a dry slot. On September 28, the stalled low began to track back eastward bringing with it the first low-level mixed-phase clouds of the experiment. By September 29, the system was exiting the area, making way for the third system that tracked from west to east through the interior near the Brooks Range during October 1. Overall, regime I was characterized by seasonal to slightly above-average temperatures, and gave rise to frequent deep cloud decks in the vicinity of the three synoptic systems (September 24, 27-28, and October 1). Low-level stratus clouds were observed in the short breaks between frontal passages (September 29-30).

October 2-3 marked the transition period between regimes I and II. The upper level pattern began to change dramatically with the trough breaking down and moving off to the east. In its place, a strong, dominant ridge began to build over the NSA, remaining in place through October 9. By October 4, synoptic regime II was firmly in place with high pressure over the pack ice to the northeast of the Alaskan coast. This system dominated the NSA until October 15 and kept several intense storm systems well to the south and west of the NSA. For the majority of the period, winds across the NSA came out of the east or east-northeast with considerable fetch along the Arctic Ocean. In addition, a small low pressure system drifted along the coastline from October 5-7 and dissipated near Deadhorse on October 7, bringing a considerable amount of mid and upper-level moisture to the NSA. This moisture was the source of the cloudiness experienced during the flight operation days of October 5 and 6. By October 8, temperatures over the pack ice had dropped sharply, reaching -20°C with a strengthening of the high. A weak trough moved over the NSA from October 10-13 bringing cooler air to the region. This cooling also was due partly to the advancement of the sea-ice line southward during October 5-10, allowing the flow that reached the Alaskan coast to come directly from the pack ice and, along with it, boundary layer roll clouds. These rolls produced periodic oscillations (~10 hrs) in cloud depth observed at Barrow and Oliktok. This regime was the main driver of cloudiness during the October 8-10 and October 12 case days. Thick, persistent boundary layer stratocumulus clouds coming off the pack ice were present for nearly the entire period (October 4-5, 8-14), and the majority of the MPACE research flights took place during this period. Overall, regime II was marked by above-average temperatures for the first half of the period (October 4-9) and more seasonal temperatures during the second half (October 10-13) associated with the weak trough. Exceptionally low diurnal temperature ranges were present for the entire period with 9 of 11 days having diurnal ranges of 4°F or less.

October 15-17 marked the transition to Regime III. A warm front moved through the area on October 15-16, and a deep ridge moved over the NSA once again as the surface high over the pack ice slowly drifted southeastward. With the block removed, Regime III began on October 18 and lasted for the remainder of the experiment. This period was marked by the influence of an incredibly strong and fast developing low pressure center (940 hPa peak strength with a 42 hPa drop analyzed over 24 hours) that formed near Kamchatka and propagated north through the Bering Strait into the northwestern portion of the Chukchi Sea. The resulting synoptic regime produced southeasterly flow for much of the NSA. Patchy ice also began to form along the arctic coastline, particularly east of Barrow. This formation spawned periods where the NSA was under partially cloudy, or even clear, skies as opposed to the uniform thick boundary layer clouds found throughout regime II. Frontal systems spawned by the low strongly affected the NSA west of a line between Barrow and Oliktok, and deep clouds frequently occurred in their presence. Since the NSA was under the influence of the warm sector in a particularly intense cyclone, temperatures were ~10°F above average, the warmest of the three periods. With the exception of deep clouds in the vicinity of the warm fronts, cloud decks during regime III were erratic and hard to predict. Figure 3 shows an analysis of the MMCR fields from October 20 that exemplify this regime. Clouds are scattered throughout the troposphere with no discernable pattern apparent.

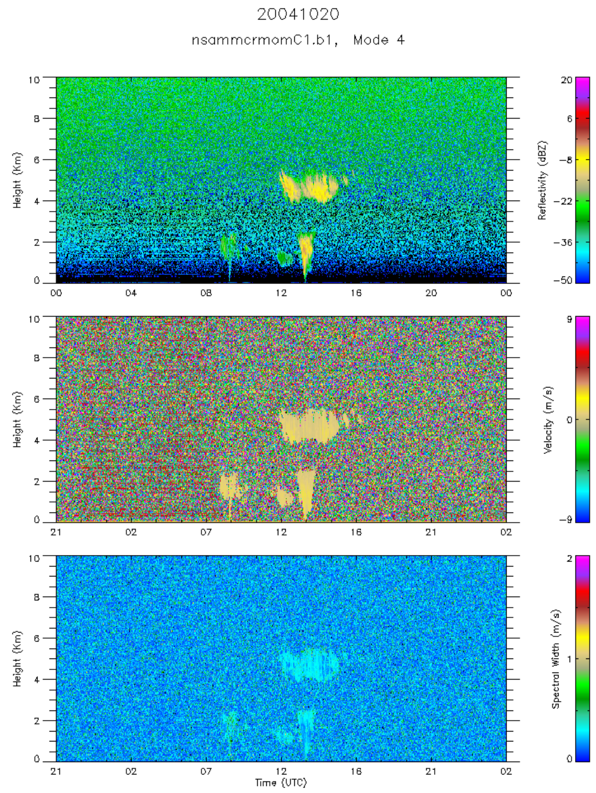
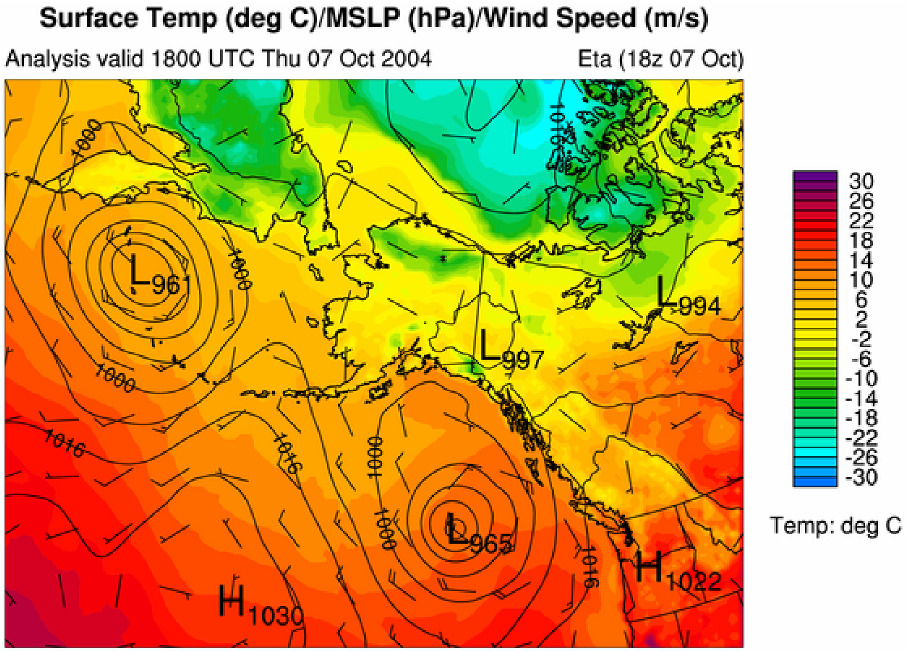


Figure 3. Millimeter Cloud Radar images taken over Barrow, AK on Oct 20, 2004.

Forecasting Issues

Forecasting for Barrow, Alaska and the NSA during MPACE proved to be an arduous task. Overall, the transition season over the NSA is marked by relatively mild ocean waters along the coastline surrounded by a rapidly cooling interior to the south and advancing pack ice from the northeast. Figure 4 shows a typical day in the absence of synoptic-scale disturbances during the middle of the MPACE study period. It is clear that Barrow and the immediate coastline are contained in a small warm yellow tongue surrounded by bitterly cold sea-ice and elevated terrain denoted by green and light blue. This setup can lead to highly variable conditions and makes the accuracy of wind forecasting especially important. Poor temperature forecasts during MPACE were generally accompanied by poor wind forecasts, particularly in direction. The nights spanning October 1-2 and October 21-22 at Barrow were two prime examples. In both instances winds were forecasted to be easterly overnight, but deviated slightly to the southeast, bringing much colder air into the area. In addition, the wind speeds were lower than originally anticipated, and this may have contributed to the unexpected shift in direction and allowed additional radiational cooling to occur. As a result, both cases saw lows that were about 10°F lower than forecasted, a significant difference considering that the average diurnal range at Barrow during MPACE was only 6.5°F. Forecasting cloud deck thickness and heights also proved difficult as radiosonde measurements were often unreliable given the low temperatures and moisture content of the arctic troposphere. In particular, measurements from sonde launches were prone to overestimate dry pockets in the middle and upper troposphere. To exacerbate the problem, measurements in the arctic are quite sparse, with only a handful of observations available across the NSA.



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Summary and Conclusions

The DOE-ARM funded MPACE experiment that took place across the NSA from September 27 – October 22, 2004 was successful at studying mixed-phase boundary layer clouds. Unusually warm summer conditions across the NSA and surrounding areas led to excessive melting of sea-ice in the months leading up to MPACE, and not surprisingly, temperatures as a whole during MPACE were above average. Several aspects of MPACE forecasts left room for improvement, and it is clear that wind forecasting across the NSA is especially important. Clouds forecasts were problematic, with few soundings available and moisture measurements suspect at higher levels.

With the emphasis of the experiment being on mixed-phase boundary layer clouds, it is clear that regime II with relatively undisturbed conditions and east-northeast flow coming off the pack ice produced the best experimental conditions, with thick, mixed-phase boundary layer stratocumulus decks present virtually every day during the period. Conversely, regime III was by far the worst in terms of producing mixed-phase boundary layer clouds. Extremely mild boundary layer temperatures, on the order of 0°C to -5°C, were far too warm to support mixed-phase clouds. In addition, the southerly offshore flow led to scattered irregular cloud decks shown in Figure 3. These decks were difficult to predict and tended to last for only short periods of time. Regime I had conditions that were sometimes conducive to low-level mixed-phase clouds, but only when the atmosphere was undisturbed by synoptic systems which frequently passed through the area during the period.

Acknowledgements

I would like to acknowledge all the people who endured difficult conditions in the field to collect these data and those who spent long hours collecting and assimilating data for research use.

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