Final Report

Quantifying the Impact of ACE Radar Specifications on Precipitation Microphysics and Process Rate Retrievals with Ground-based and Airborne Radar Observations

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I Project Statement

This Aerosol-Cloud-Ecosystems (ACE) preparatory study utilizes a combination of ground-based and airborne radar observations to document the trade space between vertical resolution, spatial resolution, and sensitivity for the ACE radar.

II Accomplishments

Over the course of this 1 year project, we successfully completed our primary objective of performing a comprehensive observation-based description of the trade-space between ACE radar vertical resolution and sensitivity requirements and quantifying their implications for detecting ice-phase hydrometeors. This capability is absolutely essential to address ACE goals of documenting the signatures of aerosol influences on ice microphysical processes. We also made significant progress developing the tools required to analyze airborne radar observations from the RADEX campaigns to understanding the implications of spatial resolution, vertical resolution, and sensitivity on our ability to distinguish ice processes above and within the melting layer and evaporation below it.

I Influences of Vertical Resolution and Sensitivity on Observing Ice Phase Processes

The primary objective of our work was to document how chosen ACE radar vertical resolution and sensitivity requirements affect its ability to detect and characterize differences in ice-phase regions of precipitating clouds. Given the need for dual-frequency algorithms to reduce ambiguity in ice microphysical property retrievals, it is essential that both frequencies have sufficient sensitivity to frozen hydrometeors if ACE is to fulfil its objective of documenting the signatures of aerosols on precipitation processes. To these ends, we conducted a comprehensive analysis of more than 10 years of vertically-pointing ground-based radar observations from the DOE ARM North Slope of Alaska site to map out the impacts of minimum detectable signal and ground-clutter on snowfall detection capabilities. Various combinations of sensitivity and vertical resolution that span the range of ACE radar configurations being proposed were simulated by degrading the resolution of the Millimeter-wavelength Cloud Radar (MMCR) observations and imposing artificial reflectivity cutoffs to represent reduced sensitivity and ground clutter. Figure 1 shows two key result from this analysis. The left-hand side shows the degree to which reflectivities at higher levels begin to decorrelate from that near the surface as one moves higher into the cloud. The implication here is that in order to provide a reasonable proxy for a majority of snow events (say 80% correlation), the ACE radar should have sufficient vertical resolution to limit the ground-clutter to 500 m or less. The right-hand side illustrates the combined effects of sensitivity and ground-clutter on snowfall detection suggesting that most (> 90%) snow events at Barrow are sufficiently deep to be detected by a radar with less than 750 m of ground clutter. However, few of such systems have reflectivities that exceed 0 dBZ suggesting that the ACE radar would require a sensitivity of least -5 dBZ to detect them. The regime-dependence of these findings has been assessed by applying similar tests for distinct environmental conditions including stratifying by sea-level pressure, temperature, and wind speed as well as distinguishing open water and ice-covered conditions.

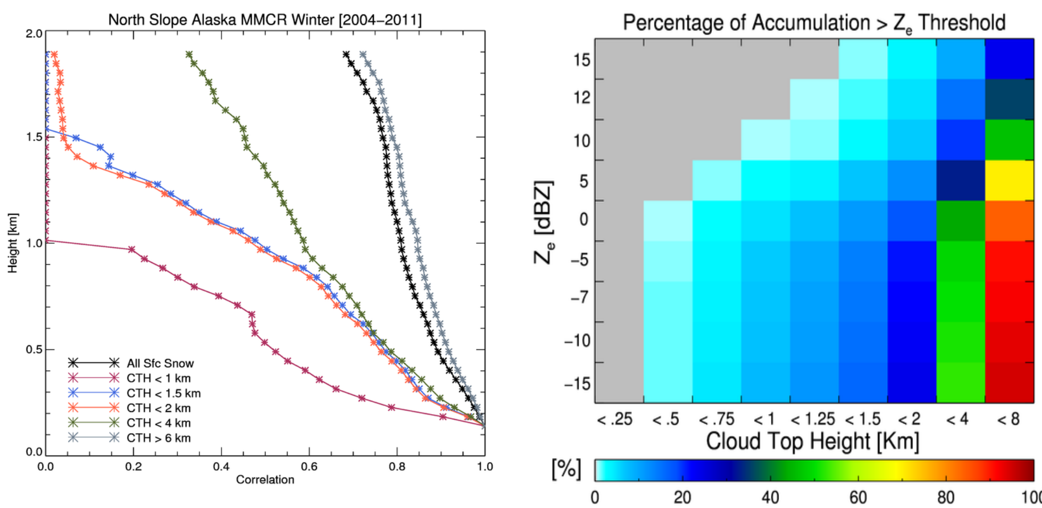

Figure 1: Left: correlation between reflectivity aloft and near-surface reflectivity for snowfall systems of varying depths. Right: fraction of snowfall accumulation from reflectivities larger and cloud top heights higher than the indicated thresholds.

II Analysis of Airborne Radar Observations from RADEX

To connect requirements developed from surface-based measurements to ice processes aloft and in different precipitation regimes, we have developed a toolkit for analyzing multi-frequency radar observations collected during the RADEX deployments during the IPHEx and OLYMPEX field campaigns. These tools allow radar observations at X-, Ku-, Ka-, and W-band to be degraded to arbitrary spatial and vertical resolution to establish the impacts of ACERAD sensitivity resolution on the interpretation of liquid and ice microphysical process signatures. By degrading the native horizontal and vertical radar resolution of the data, we are capable of simulating numerous proposed ACE radar configurations to establish the impact on multi-wavelength radar signatures, both above the melting-layer and near the surface. An extensive and time-consuming first step involved preprocessing the data at native resolution to determine reference precipitation statistics. This required identifying level flight, surface type and elevation, and the first clutter-free bin above the surface.

A RADEX trade-space analysis toolkit was then developed to degrade the resulting quality-controlled data to any desired resolution, apply sensitivity thresholds to one or more frequencies, and examine the effects different degrees of ground-clutter contamination. Rudimentary algorithms for identify surface precipitation and the depth of the raining column above have also been developed. Examples of preliminary experiments aimed at examining trade-offs between instrument resolution and sensitivity are shown in Figures 2 and 3. Degrading the spatial and vertical resolution to values characteristic of spaceborne radars has a noticeable impact on the ability to identify key features like the bright-band within the storm. Panels (b) and (c) represent two possible configurations for ACE and demonstrate the information lost should a lower spatial resolution of 5km be adopted. Figure 3 illustrates the loss of ice phase process information above the melting layer and sensitivity to light rain as Ka-band sensitivity is reduced. Since simultaneous observations at both ACERAD frequencies will be required to quantify aerosol influences on process rates, it is essential that the lower frequency have sufficient sensitivity to detect hydrometeors aloft. We anticipate these datasets and the accompanying tools will form the basis of a comprehensive study of instrument studies for a redefined ACE cloud and precipitation process mission after the release of the NSF Decadal Survey.

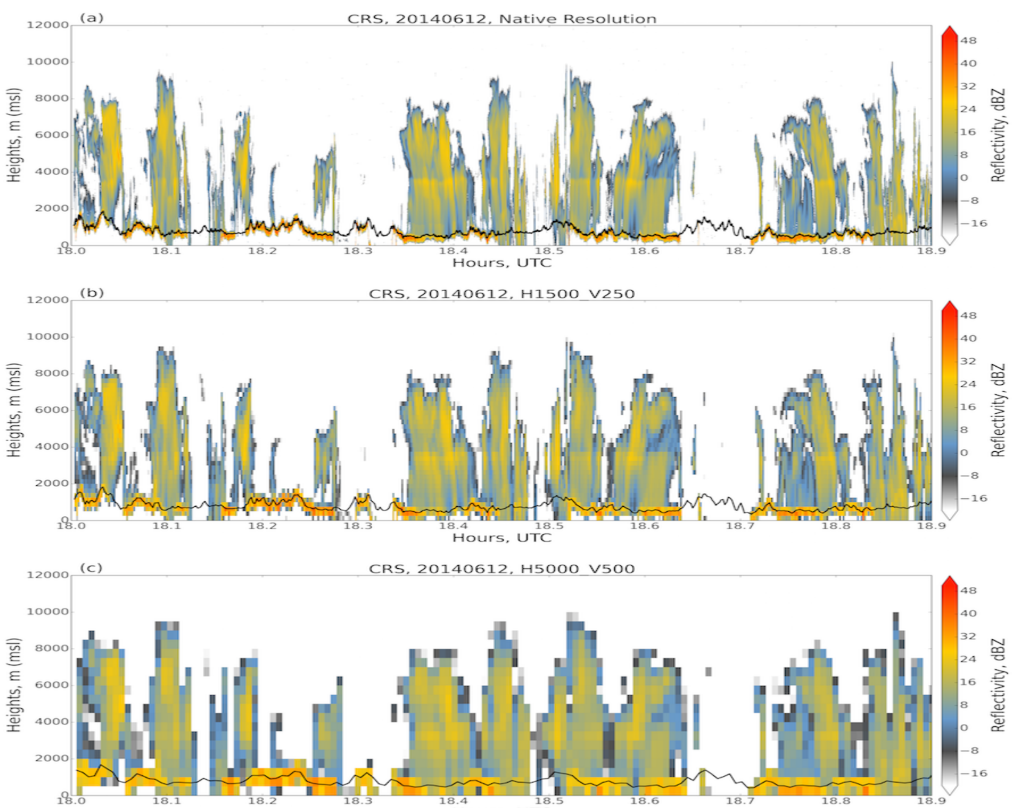

Figure 2: CRS reflectivity cross-section observed during the IPHEx campaign at native resolution (top), 1.5 km horizontal and 250m vertical resolution (middle), and 5 km horizontal and 500m vertical resolution (bottom). These degraded resolution images enable the impacts of ACERAD resolution choices to be quantified.

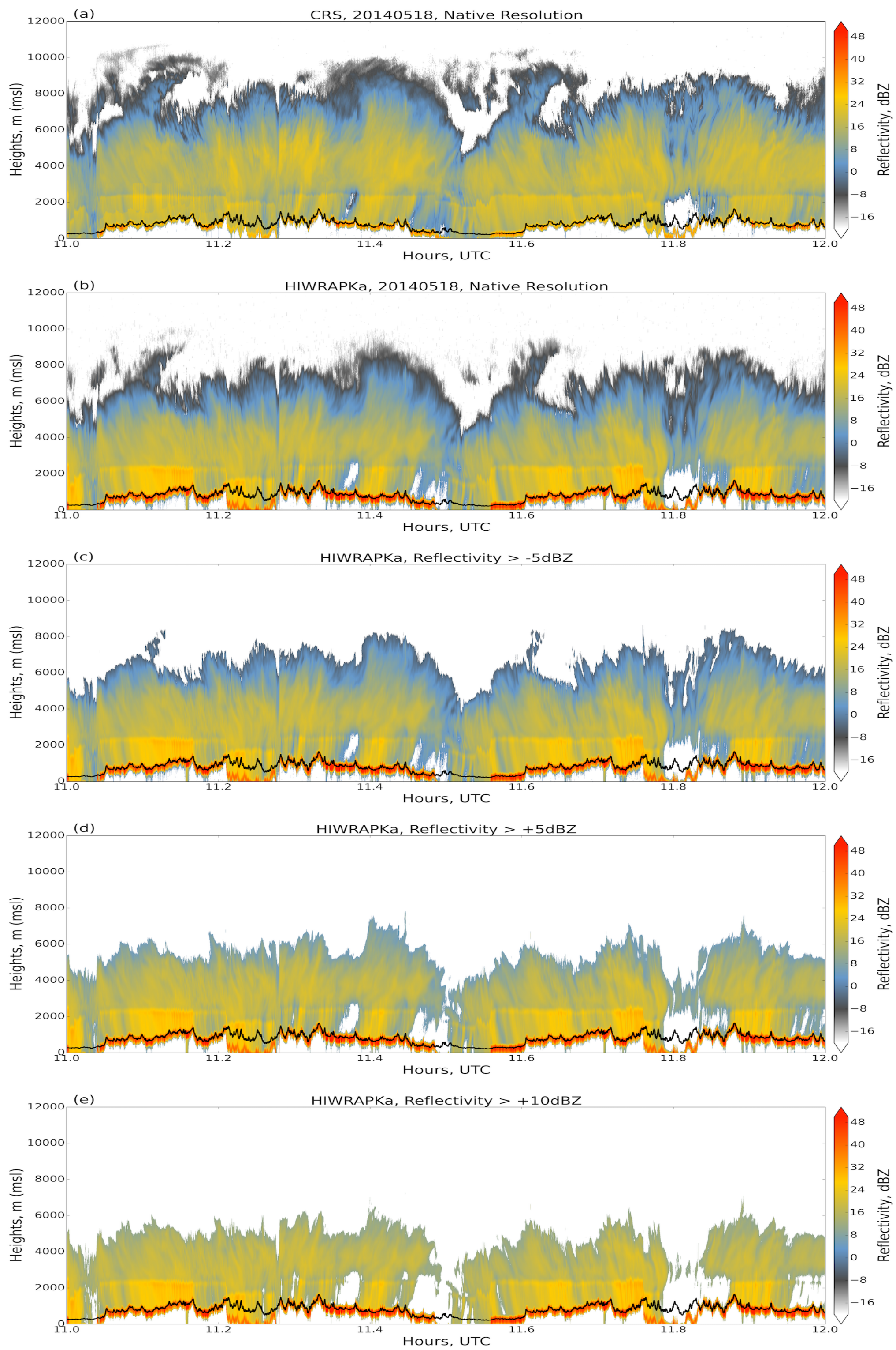

Figure 3: HIWRAP native resolution Ka-band reflectivity cross-section from the IPHEx campaign with various sensitivity thresholds applied. Panel (b) depicts the scene at the original HIWRAP sensitivity. Panels (c), (d), and (e) correspond to -5, +5, and +15 dBZ sensitivity thresholds, respectively. CRS W-band reflectivities are shown in panel (a) for comparison.

III Manuscript Preparation

A significant effort is underway to complete a manuscript distilling the results from our original analyses of the influence of radar sensitivity and spatial resolution on the potential for the ACE radar to resolve precipitation responses to aerosol changes using existing CloudSat observations. While these analyses concluded a year ago, we have continued to refine our portrayal of the results over the past year to improve the clarity of the associated manuscript. Figure 4 presents a new key figure from that manuscript that illustrates the impacts of sensitivity and field of view on the ability of ACE to distinguish convective and stratiform precipitation processes (based on the current CloudSat convective/stratiform rainfall partitioning algorithm). In addition to the more straight-forward result that decreased radar sensitivity (MDS) leads causes precipitation occurrence to be under-estimated, the figure shows that decreasing spatial resolution causes raining area to be artificially over-estimated due to 'smearing'. Contrasting the left and right hand sides of these figures, we see that this effect is more pronounced when all raining pixels are considered and somewhat muted when convective area is considered. This difference implies that the smearing effect of large fields of view also reduces the fraction of pixels that are considered convective and increases the fraction of stratiform precipitation retrieved by the radar. This has important implications for ACE objectives centering on quantifying the influence of aerosols on the partitioning of convective vs. stratiform precipitation processes.

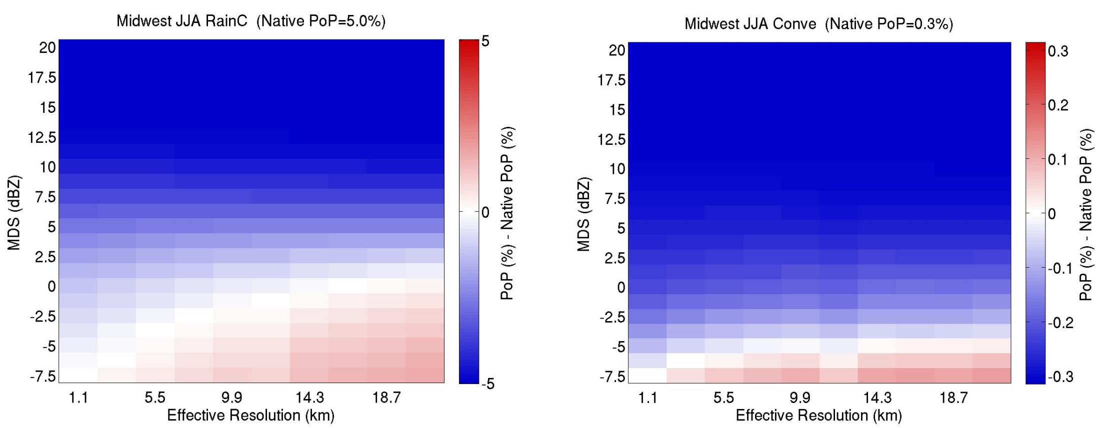

Figure 4: Left: Trade-offs between rainfall detection capabilities, sensitivity, and spatial resolution for different possible configurations of the ACE radar. Right: As on the left but for the ability to distinguish convective from stratiform rain. Statistics are drawn from a 15x15 degree region in the Midwestern United States.