3D and 4D Cloud Lifecycle Investigations Using Innovative Scanning Radar Analysis Methods
Final Report

PI: Pavlos Kollias

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During the last 3 years, our research group several original contributions in innovative use of scanning and profiling radars for the study of clouds and precipitation.

Scanning ARM Cloud Radars – Operational Sampling Strategies

The acquisition of scanning cloud radars by the Atmospheric Radiation Measurement (ARM) program and research institutions around the world generates the need for developing operational scan strategies for cloud radars. Here, the first generation of sampling strategies for the scanning ARM cloud radars (SACRs) is presented. These scan strategies are designed to address the scientific objectives of ARM; however, they introduce an initial framework for operational scanning cloud radars. While the weather community uses scan strategies that are based on a sequence of scans at constant elevations, the SACR scan strategies are based on a sequence of scans at constant azimuth. This is attributed to the cloud geometrical properties, which are vastly different from the rain and snow shafts that are the primary targets of precipitation radars; the need to cover the cone of silence; and the scanning limitations of the SACRs. A “cloud surveillance” scan strategy is introduced that is based on a sequence of horizon-to-horizon range–height indicator (RHI) scans that sample the hemispherical sky (HS) every 30° azimuth (HSRHI). The HSRHI scan strategy is complimented with a low-elevation plan position indicator (PPI) scan. The HSRHI and PPI are repeated every 30 min to provide a static view of the cloud conditions around the SACR location. Between the HSRHI and PPI scan strategies, other scan strategies are introduced depending on the cloud conditions. In the future, information about the atmospheric cloud state will be used in a closed-loop process to optimize the selection of the SACR scan strategy.

Scanning ARM Cloud Radars – Data Quality Control and Processing

The scanning Atmospheric Radiation Measurement (ARM) Program cloud radars (SACRs) are the primary instruments for documenting the four-dimensional structure and evolution of clouds within a 20–30-km radius of the ARM fixed and mobile sites. Here, the postprocessing of the calibrated SACR measurements is discussed. First, a feature mask algorithm that objectively determines the presence of significant radar returns is described. The feature mask algorithm is based on the statistical properties of radar receiver noise. It accounts for atmospheric emission and is applicable even for SACR profiles with few or no signal-free range gates. Using the nearest-in-time atmospheric sounding, the SACR radar reflectivities are corrected for gaseous attenuation (water vapor and oxygen) using a line-by-line absorption model. Despite having a high pulse repetition frequency, the SACR has a narrow Nyquist velocity limit and thus Doppler velocity folding is commonly observed. An unfolding algorithm that makes use of a first guess for the true Doppler velocity using horizontal wind measurements from the nearest sounding is described. The retrieval of the horizontal wind profile from the hemispherical sky range–height indicator SACR scan observations and/or nearest sounding is described. The retrieved horizontal wind profile can be used to adaptively configure SACR scan strategies that depend on wind direction. Several remaining challenges are discussed, including the removal of insect and second-trip echoes. The described algorithms significantly enhance SACR data quality and constitute an important step toward the utilization of SACR measurements for cloud research.

Evaluation of gridded Scanning ARM Cloud Radar reflectivity observations and vertical Doppler velocity retrievals

The scanning Atmospheric Radiation Measurement (ARM) cloud radars (SACRs) provide continuous atmospheric observations aspiring to capture the 3-D cloud-scale structure. Sampling clouds in 3-D is challenging due to their temporal-spatial scales, the need to sample the sky at high elevations and cloud radar limitations. Thus, a suggested scan strategy is to repetitively slice the atmosphere from horizon to horizon as clouds advect over the radar (Cross-Wind Range-Height Indicator - CW-RHI). Here, the processing and gridding of the SACR CW-RHI scans are presented. First, the SACR sample observations from the ARM Southern Great Plains and Cape Cod sites are post-processed (detection mask, gaseous attenuation correction, insect filtering and velocity de-aliasing). The resulting radial Doppler moment fields are then mapped to Cartesian coordinates with time as one of the dimensions. Next the Cartesian-gridded Doppler velocity fields are decomposed into the horizontal wind velocity contribution and the vertical Doppler velocity component. For validation purposes, all gridded and retrieved fields are compared to collocated zenith-pointing ARM cloud radar measurements. We consider that the SACR sensitivity loss with range, the cloud type observed and the research purpose should be considered in determining the gridded domain size. Our results also demonstrate that the gridded SACR observations resolve the main features of low and high stratiform clouds. It is established that the CW-RHI observations complemented with processing techniques could lead to robust 3-D cloud dynamical representations up to 25-30 degrees off zenith. The proposed gridded products are expected to advance our understanding of 3-D cloud morphology, dynamics and anisotropy and lead to more realistic 3-D radiative transfer calculations.

Signal Post-processing and Reflectivity Calibration of the Atmospheric Radiation Measurement Program 915-MHz Wind Profilers

The Department of Energy Atmospheric Radiation Measurement (ARM) Program has recently initiated a new research avenue toward a better characterization of the transition from cloud to precipitation. Dual-wavelength techniques applied to millimeter-wavelength radars and a Rayleigh reference have a great potential for rain-rate retrievals directly from dual-wavelength ratio measurements. In this context, the recent reconfiguration of the ARM 915-MHz wind profilers in a vertically pointing mode makes these instruments the ideal candidate for providing the Rayleigh reflectivity/Doppler velocity reference. Prior to any scientific study, the wind profiler data must be carefully quality checked. This work describes the signal postprocessing steps that are essential for the delivery of high-quality reflectivity and mean Doppler velocity products—that is, the estimation of the noise floor from clear-air echoes, the absolute calibration with a collocated disdrometer, the dealiasing of Doppler velocities, and the merging of the different modes of the wind profiler. The improvement added by the proposed postprocessing is confirmed by comparison with a high-quality S-band profiler deployed at the ARM Southern Great Plains site during the Midlatitude Continental Convective Clouds Experiment. With the addition of a vertically pointing mode and with the postprocessing described in this work in place, besides being a key asset for wind research wind profilers observations may therefore become a centerpiece for rain studies in the years to come.

First Observations of Tracking Clouds Using Scanning ARM Cloud Radars

Tracking clouds using scanning cloud radars can help to document the temporal evolution of cloud properties well before large-drop formation (weather radar “first echo”). These measurements also complement cloud and precipitation tracking using geostationary satellites and weather radars. Here, two-dimensional (2D) along-wind range–height indicator observations of a population of shallow cumuli (with and without precipitation) from the 35-GHz scanning Atmospheric Radiation Measurement Program (ARM) cloud radar (SACR) at the U.S. Department of Energy (DOE)–ARM Southern Great Plains (SGP) site are presented. Observations from the ARM SGP network of scanning precipitation radars are used to provide the larger-scale context of the cloud field and to highlight the advantages of the SACR to detect the numerous small nonprecipitating cloud elements. A new cloud identification and tracking algorithm (CITA) is developed to track cloud elements. In CITA, a cloud element is identified as a region having a contiguous set of pixels exceeding a preset reflectivity and size threshold. The high temporal resolution of the SACR 2D observations (30 s) allows for an area superposition criteria algorithm to match cloud elements at consecutive times. Following CITA, the temporal evolution of cloud-element properties (number, size, and maximum reflectivity) is presented. The vast majority of the designated elements during this cumulus event were short-lived nonprecipitating clouds having an apparent life cycle shorter than 15 min. The advantages and disadvantages of cloud tracking using an SACR are discussed.

Estimation of cloud fraction profile in shallow convection using a scanning cloud radar.

Large spatial heterogeneities in shallow convection result in uncertainties in estimations of domain-averaged cloud fraction profiles (CFP). This issue is addressed by using large eddy simulations of shallow convection over land coupled with a radar simulator. Results indicate that zenith profiling observations are inadequate to provide reliable CFP estimates. Use of scanning cloud radar (SCR), performing a sequence of cross-wind horizon-to-horizon scans, is not straightforward due to the strong dependence of radar sensitivity to target distance. An objective method for estimating domain-averaged CFP is proposed that uses observed statistics of SCR hydrometeor detection with height to estimate optimum sampling regions. This method shows good agreement with the model CFP. Results indicate that CFP estimates require more than 35 min of SCR scans to converge on the model domain average. The proposed technique is expected to improve our ability to compare model output with cloud radar observations in shallow cumulus cloud conditions.

Observations of fair-weather cumuli over land: Dynamical factors controlling cloud size and cover

Comprehensive observations of shallow convection at the Atmospheric Radiation Measurement Southern Great Plains site are carefully analyzed to study the macrophysical and dynamical properties of active and forced cumuli separately and investigate their relationship to the subcloud layer turbulent structure.

Clearly, active clouds possess stronger dynamics and greater horizontal extent than their forced counterpart. As previously reported, upper level stability and relative humidity do control the predominance of active clouds. While cloud cover remains difficult to associate to mixed-layer parameters (small correlation coefficients), mixed-layer top vertical velocity skewness, and coherent updraft fraction most significantly correlate to cumulus cloud cover and especially the portion attributed to active clouds; both of which are not currently considered in shallow cloudiness parameterizations. This study also points to several factors that continue to limit our ability to adequately sample shallow cumuli and suggests that forward models will be necessary to bridge observations and model outputs.

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