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A CLOUD AND PRECIPITATION RADAR SYSTEM CONCEPT FOR THE ACE MISSION

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1. INTRODUCTION

In 2007, the Aerosol/Cloud/Ecosystem (ACE) mission was recommended for a NASA launch in the next decade by the NRC "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", hereinafter, "Decadal Survey" [1]. One of the primary goals of ACE is to reduce the uncertainty in the impact of clouds and aerosols on climate modeling. This objective requires that cloud-aerosol interaction be better constrained by simultaneous measurement of clouds and aerosols by radar, lidar, polarimeter, and multi-wavelength imager/spectrometer. The Decadal Survey specifically calls for a cloud radar with 94 and possibly 35 GHz channels for cloud droplet size, glaciation height, and cloud height. Doppler capability and cross-track scanning are also indicated in the same document as highly desirable to achieve the scientific goals. In this work we discuss system requirements for a radar called ACERAD that meets the needs of the ACE mission. A concept for the instrument implementation is then presented.

2. ACERAD REQUIREMENTS

Use of W-band (94 GHz) radar for cloud profiling has been proven to be an optimal choice in terms of maximum sensitivity and system compactness for ground-based, airborne and spaceborne radar systems. Key W-band subsystems successfully demonstrated in space by CloudSat [2] and planned for use in EarthCare are high-gain amplifiers (Extended Interaction Klystrons, or EIKs, produced by CPI Canada and generate a 1.8 kW output RF signal); quasi-optical transmission lines (to avoid the about 3dB/m waveguide losses at W-band, and the use of ferrite switches); and low noise amplifiers. However, W-band is affected by substantial atmospheric attenuation, and CloudSat data include evident multiple-scattering contributions in convective cores [3]. Such effects limit the usefulness of W-band radar to light precipitation and only the upper portions of convective cores. The Decadal Survey confirms W-band as the primary choice for ACERAD. Use of a second frequency is also recommended, namely, Ka-band (35 GHz). Ka-band is substantially less affected by attenuation and multiple scattering than W-band. ACERAD's Ka-band channel should allow measurement into moderate precipitation and profiling over a wider range of convective cells. Ka-band will also be used on the dual-frequency radar on the Global Precipitation Measurement (GPM) mission for moderate rain, in combination with the lower frequency channel of 13.4 GHz [4]. Dual-frequency algorithms could also be applied to the ACERAD Ka-/W-band pair in similar fashion to obtain more accurate retrievals of microphysical parameters such as mean particle size [5], [6]. Such dual-frequency retrievals would be possible over a fairly broad range of clouds and precipitation. It would be limited at the low end by clouds too thin to be detected by Ka-band and at the high end by precipitation that is strong enough to completely attenuate the W-band signal.

Two requirements competing against the improved sensitivity are evaluated in the definition of requirements of ACERAD: improved range resolution and cross-track scanning capability. The baseline requirement for range resolution defined for ACERAD at this stage is 250m, sufficient to reduce the ground clutter contamination problem to below the height of cloud-base of low level clouds (although not sufficient for fog formations) and to resolve some of the most important features of cloud systems. Further studies need to be completed to assess whether finer range resolutions are needed. Both CloudSat and EarthCare radars are nadir looking instruments. This choice allows achievement of the required sensitivity by allowing relatively long integration times (and therefore large number of integrated pulses to reduce signal variability). Lack of scanning in the cross-track, however, represents a weakness for cloud monitoring systems. ACERAD will scan at Ka-band and will be nadir-looking at W-band.

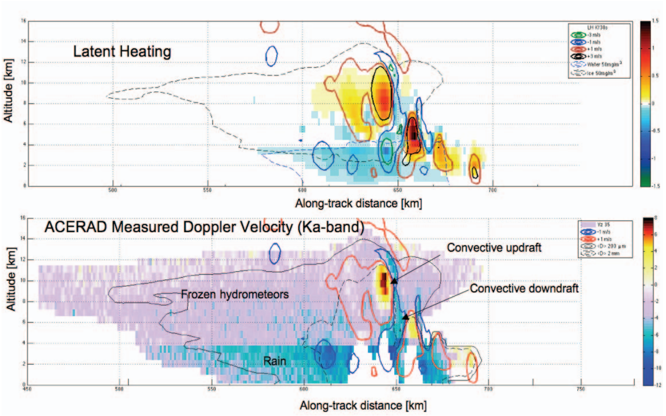

Figure 1. a) Vertical structure of Latent heating (LH) diagnosed by a cloud resolving model, b) simulated ACERAD mean Doppler velocity at Ka-band (V_{Ka}). Classification of precipitating regimes (i.e., convective vs stratiform), and hydrometeor phase states is immediate with V_{Ka}. LH structure can be estimated directly rather than by inference from databases.

The inclusion of Doppler on ACERAD allows measurement of particle motions in clouds, providing better classification of cloud type, direct measure of vertical mass transport and of convective intensity, and it allows estimation of particle size, of air motion, and of latent heat release with higher accuracy than non-Doppler estimates. Figure 1 shows an example of Doppler and latent heat retrieval from a simulation of ACERAD measurement of a convective system.

The requirements on Doppler accuracy for ACERAD are significantly tighter than the ones currently applied for EarthCare. There are two straightforward ways to improve Doppler quality: increase the antenna size or increase the PRF. The latter has already been pushed to the minimum set by the need to avoid second-trip range ambiguities. The only approaches that would allow use of higher PRF are those based on polarization diversity [7] or frequency diversity. Diversity techniques are used in radar to mitigate the constraint imposed by the second-trip ambiguity [8], but they increase system complexity and cost. The ACERAD concept has an along-track antenna dimension of 5 m, sufficient to reduce the Doppler bandwidth due to platform motion (i.e., to maintain coherence between pulses) and to provide high-quality Doppler information at convection-scale in realistic scenarios as demonstrated in [9]. Of more concern is the relatively small maximum unambiguous velocity at W-band. Our solution is to require ACERAD to be fully polarimetric to allow an effectively higher PRF, doubling the maximum unambiguous velocity. Furthermore, this has the added scientific benefit of measurement of depolarization in ice and melting hydrometeors, potentially enhancing classification of particle shapes.

3. ACERAD SYSTEM CONCEPT

ACERAD will take advantage of technology tested in CloudSat wherever possible. While solid-state power amplifiers could potentially be used at Ka-band, their power level at W-band band is still limited. To allow ACERAD to use a common antenna for both frequencies, a reflector antenna fed by high-power vacuum electron devices (EIKs) at both frequencies is used. Scanning at Ka-band presents a serious challenge for the antenna. For an antenna that is larger than the CloudSat antenna, the beamwidth in the scan plane will be less than 0.1 degrees. To get a swath of 25-30 km, considered the minimum useful, ACERAD needs to scan at least 2 degrees off nadir; this is at least 20 beamwidths, which is quite large for a typical parabolic reflector. The problem is that moving the feed far enough off-focus to create a large scan causes phase distortions across the aperture, in turn causing potentially serious degradation of the antenna pattern.

Several antenna concepts have been examined for ACERAD. One promising design is the Dragonian; the initial concept for this type of reflector antenna was reported in [10]. As discussed there, the antenna is based on classical Cassegrain and Gregorian designs but the main reflector and subreflector have been deformed to optimize the field of view. A systematic procedure for designing Dragonian reflectors with circular aperture is reported in [11]. We are modifying this procedure to develop an elongated (in the flight direction) design for ACERAD.

Like CloudSat, ACERAD also uses a quasi-optical transmission line at W-band to connect the transmitter to the antenna and antenna to the receiver. This is implemented with mirrors and free-space propagation, rather than waveguide, significantly reducing losses. Conventional waveguide is used at Ka-band, since losses are lower. The challenge in using quasi-optics for ACERAD is that it must accommodate dual-polarized operation. We have developed a potential way to accomplish this that extends the CloudSat design. It is currently being implemented in laboratory testing.

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