The Fully Polarimetric Architecture of the Ka-W SACR2

Michele Galletti[1], Mariko Oue[2], Hans Verlinde[2], Alexander Ryzhkov[3]

[1] Radar Science Group, Brookhaven National Laboratory, Upton, NY
[2] Department of Meteorology, Penn State University, State College, PA
[3] NOAA-NSSL, Norman, OK

Introduction

An important focus of the ARM/ASR programs is the understanding of ice and mixed-phase cloud processes.

1) Ice particle habits, and the processes that morph such habits, are detectable by polarimetric radars at all frequencies:
S, C, X, Ka and W

1) To date, ice particle habit identification at mm-wavelengths was experimentally achieved by means of hemispheric RHI scans and use of depolarization ratios (DR) at different polarization bases [4, 5]:

- LDR linear depolarization ratio
- SLDR slant linear depolarization ratio
- CDR circular depolarization ratio
- EDR elliptical depolarization ratio

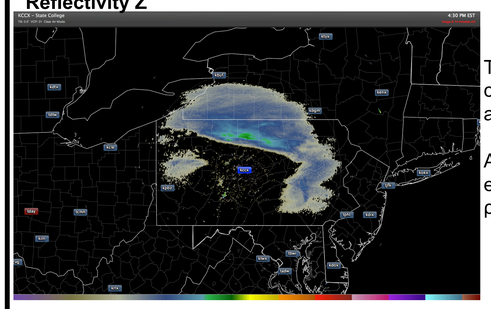
3) Electromagnetic simulations of planar (stellars, dendrites, plates) and columnar (columns, needles) performed in the '90s by Aydin at Penn State [2, 3], point at the utility of specific differential phase KDP at mm-wavelengths Ka and W.

4) The newly developed dual-frequancy (Ka - W) SACR2 slated to be deployed at Oliktok Point and at the Azores sites will feature, for the first time at mm-wavelength, fully polarimetric architecture, making available LDR, SLDR, CDR, EDR, KDP as well as Z_{DR} and ρ_{HV} at the same time.
Besides, obviously, the full Doppler spectrum and its moments:
0^{th} moment reflectivity Z, 1^{st} moment velocity V and 2^{nd} moment spectrum width σ_V.

Dendritic growth at S-band - STSR mode NEXRAD

Dendritic growth and subsequent aggregation was particularly evident from cases captured by NEXRAD operational radars (S-band) during the numerous cold spells occurred this winter (2013-2014).
Dendritic growth is most efficient around -15˚C, in presence of sufficient atmospheric moisture. The "polar vortex" outbreaks occurred this past winter pushed cold air masses southward. East of the Great Lakes, where significant water vapor was injected in the cold air masses, dendritic growth occurred systematically. Here is an example from Jan 1^{st} 2014 from KCCX.

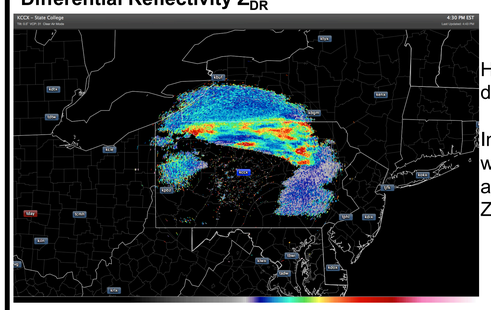
Reflectivity Z



The formation of large dendritic crystals is the precursor of aggregation at lower elevations.

Aggregation is revealed by enhanced Z, lower Z_{DR} and higher ρ_{HV}.

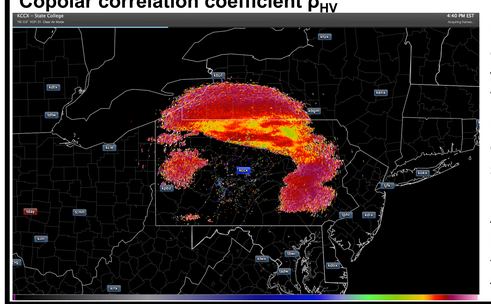
Differential Reflectivity Z_{DR}



High Z_{DR} indicates planar (plates or dendrites) crystal growth aloft.

In this case, we are probably dealing with dendrites, given the high aggregation efficiency shown in the Z field above.

Copolar correlation coefficient ρ_{HV}



High Z_{DR} (large dendritic crystals growing aloft) correlate with low ρ_{HV}.
This is due to the fact that oblate particles flutter as they fall, exposing a large spread in H to V size ratio in the polarization plane.

Aggregates do flutter as they fall, but their H to V size ratio is closer to 1, and ρ_{HV} remains higher than for dendrites

STSR mode: NEXRAD, C-SAPR, X-SAPR

The polarimetric architecture of choice in today's precipitation weather radar systems at S, C and X bands is named STSR mode, where STSR stands for Simultaneous Transmit Simultaneous Receive. Such polarimetric architecture is implemented in the NEXRAD network of S-band weather radar systems, as well as in the ARM line of precipitation radars: X-SAPR and C-SAPR.

Such polarimetric architecture yields the Doppler spectrum and its moments: Reflectivity Z, Velocity V, Spectrum Width σ_V, plus three polarimetric variables:

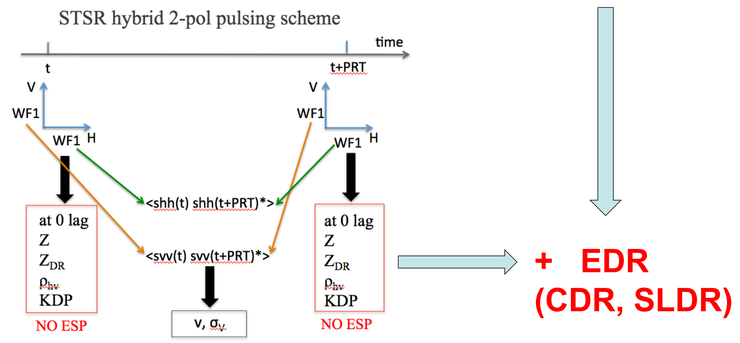
Differential Reflectivity	Z_{DR}
Specific Differential Phase	KDP
Copolar correlation coefficient	ρ_{HV}

Additional signal processing (currently not operationally implemented) could yield the Depolarization Ratio corresponding to the specific transmit polarization state radiated by the antenna (lying on the circular/slant circle of the Poincare sphere), generally named EDR, Elliptical Depolarization Ratio [4].
SLDR and CDR are specific instances of EDR.

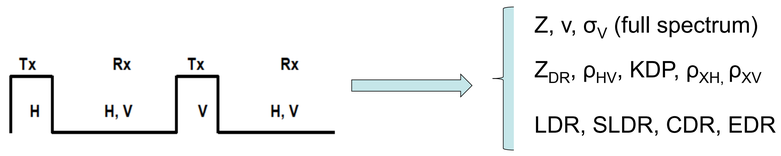
Implementation of EDR is highly recommended in precip radars at STSR mode, especially in radars capable of performing hemispheric RHIs (e.g. ARM X-SAPR).

Control of transmit polarization to exactly circular would yield CDR, the most useful instance of EDR.

Control of transmit polarization at STSR mode to obtain CDR is highly recommended, especially in radars capable of performing hemispheric RHIs.



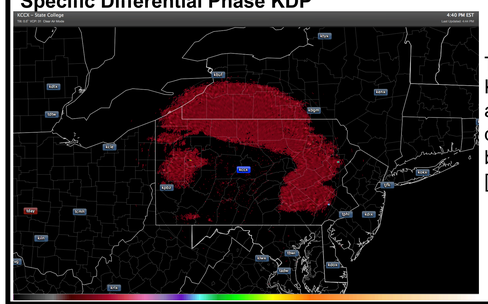
ATSR mode: SACR2 at Ka and W



The new SACR2 will feature fully polarimetric architecture. The H and V transmit channels will not be excited simultaneously, as in the STSR mode, but alternately.
Reception still occurs simultaneously as in the STSR mode.
Such mode is named ATSR mode, which stands for Alternate Transmit Simultaneous Receive.
ATSR mode allows the retrieval of the complete polarimetric information (fully polarimetric), yielding simultaneously Z, Z_{DR}, ρ_{HV}, KDP, LDR, EDR, SLDR and CDR, plus the full spectrum.
Besides the availability of all polarimetric variables at the same time, KDP at millimeter wavelengths is expected to greatly improve ice cloud observations [2, 3].

The dynamic range of Specific Differential Phase KDP at S, C and X bands for dendritic crystals is fairly small. At S-band, it is between 0.15 and 0.4 ˚/km [1]. As a result, the KDP field at S-band in ice appears practically featureless. This prevents effective estimation of oblate ice crystal number concentration and of ice particle density (e.g. plates vs. dendrites).

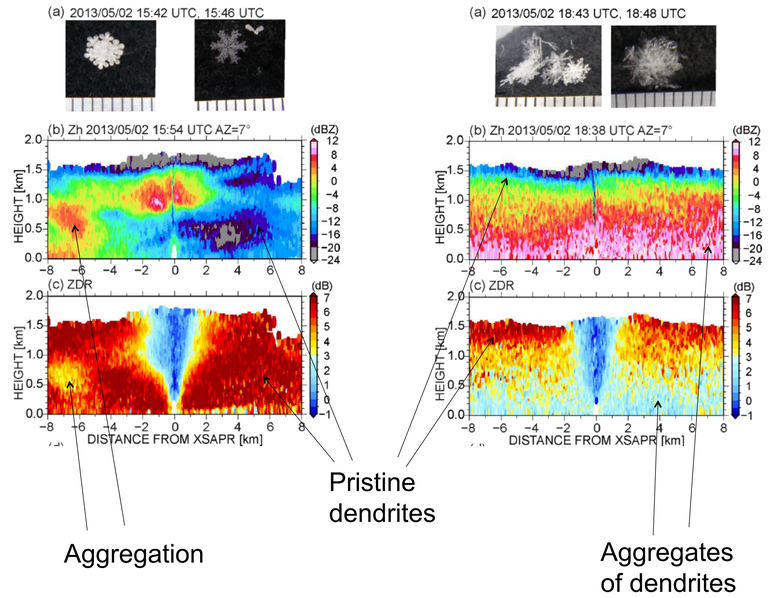
Specific Differential Phase KDP



The most efficient way of improving KDP dynamic range is to measure KDP at Ka and W bands. In this way, the dynamic range is expected to increase by more than one order of magnitude [2].

Dendritic growth at X-band - STSR mode X-SAPR

During the ARM Scanning Radar IOP, in May 2013 in Barrow, AK, the ARM X-SAPR radar performed hemispheric RHIs on shallow boundary layer clouds and deeper frontal clouds. Differential Reflectivity Z_{DR} at X-band was capable of capturing significant dendritic growth in Arctic clouds and the subsequent aggregation process [6].



Don't miss the full story on Thursday Plenary Session at 8:30 – 8:45 am: "X-band polarimetric radar observations of an Arctic shallow boundary layer cloud", by Mariko Oue!!

CONCLUSIONS

- Reflectivity Z and Differential Reflectivity Z_{DR} are very effective in capturing dendritic growth and subsequent aggregation. These cloud processes occur extensively, both in mid-latitude winter storms and in the Arctic, whenever sufficient moisture is available (e.g. east of the Great Lakes, in Arctic BL clouds with layers of supercooled liquid water).
- Copolar correlation coeffiient ρ_{HV} anticorrelates with Differential Reflectivity Z_{DR} due to the width of canting angle distribution of dendritic crystals. Dendrites have high positive Z_{DR} and low ρ_{HV}, aggregates have high ρ_{HV} and low Z_{DR}.
- At S, C and X bands, Z_{DR} and ρ_{HV} are very effective in the detection of dendritic growth and aggregation, but KDP is not very effective for the retrieval of planar ice particle number concentration and planar ice particle density, due to its relatively small dynamic range.
- KDP at millimeter wavelength (Ka-W SACR2) is expected to bridge the gap, paving the way for quantitative retrieval of particle size distribution (PSD) of non-spherical ice crystals (planar, columnar).
- Implementation of EDR (CDR) is recommended in radars at STSR mode

References

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