VIDEOSONDE STUDIES OF ICE CRYSTALS IN TROPICAL CLOUDS AND OF PRECIPITATION PARTICLE EVOLUTION IN RAINBANDS AND SQUALL LINES

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1. INTRODUCTION
Videosonde data from East Asian monsoon clouds are used to address two topics. First: between the land and the ocean there are great differences in lightning activity (Christian et al., 2003). This is a consequence of an underlying difference in ice crystal concentrations (Takahashi, 2006). The reason for this difference has been unclear.
Secondly: the defining characteristics of long-lasting, heavy rainfall are rainbands and squall lines. However, the microphysical processes are still unknown because of a lack of direct measurements of precipitation particles in high radar echoes. Precipitation particle analysis relevant to these issues is presented.

2. VIDEOSONDE
The primary purpose for the videosonde (Fig.1, Takahashi, 1990, Takahashi et al. 1999) is the measurement of shapes and electric charges on precipitation particles in the cloud with d>0.5mm. An induction ring is used to measure the charges on falling particles (0.1-200 pC). Some of the videosondes also monitor smaller particles collected on transparent, 16 mm film. In the past 12 years more than 200 videosondes have been launched in East Asia (Takahashi, 2006). Fourteen cases have been selected to investigate ice crystal formation. The videosonde results from the “Hector” case have been selected as a study in the evolution of precipitation particles in a squall line in which electric charge information was essential.

3. RESULTS AND DISCUSSIONS
a. Ice Particle Formation
Details of three typical cases are given. As illustrated in Fig. 2, ice crystal evolution was highly varied with different drop sizes and broadening near the melting level. In the U1 case from Ubon on 7 Aug. 1998, the drops were too small, with a modal size, 18 µm, and freezing was considerably delayed (Fig. 4). In the U5 case from Ubon on 10 Aug. 1998 the drops were too large with modal size 48 µm. The drops froze quickly (Fig.5) but failed to grow ice crystals, an effect that had been reported by Nakaya in 1954. For efficient ice crystal production drops should be 20-40 µm in diameter and of moderate modal size as in the B9 case (Figs. 3,6 from Brunei, 3 Dec. 1996). At these sizes the drops freeze at warmer temperatures and through columnar ice particle formation, grow ice crystals and graupel (Fig.7). As shown in Fig. 6

Fig. 1. Videosonde.

Fig. 2. Peak ice crystal concentration, and modal size and broadening of cloud drops near the melting level.
many frozen spherical particles about 100 µm diameter were occasionally observed in the cold temperature layers (around -40 - -50°C) above thunderstorm.

Cloud drop size distributions are primarily determined by cloud condensation nuclei (CCN) and they are unique in each air mass. The present work suggests that clouds developing over the ocean with low numbers of CCN will grow large cloud drops. Such drops will freeze quickly but ice crystal growth on them will be delayed and is the primary reason for weak lightning activities (Christian et al., 2003).

In contrast to ocean clouds, clouds developed in continental air masses will contain abundant CCN and produce small drops. Drop freezing is delayed and at higher levels in the cloud collisions of fragile graupel eject ice crystals.

Videosonde data analysis showed that in the East Asian monsoon area, ice crystal formation was primarily determined by the drop size distribution near the melting level. There were two modes of ice crystal formation: at warm temperatures columnar crystal growth on moderately-sized frozen drops in mixed air mass and, at colder temperatures, where drops were too small, fragile graupel formation.

Fig. 3. Ice particle number density with height, and cloud drop size distributions near melting level.

Fig. 4. U1 case. (L) Some supercooled drops. (R) Fragile graupel.

Fig. 5. U5 case. Large frozen drops.

Fig. 6. B9 case. Columnar crystal growth from frozen drops, and spherical frozen drops at high levels.
b. Precipitation Particle Evolution in Squall Line

A “Hector” squall line developed over Melville island, Australia into which seven videosondes were successfully launched (Takahashi and Keenan, 2004). With the addition of Doppler radar data, it develops extensive frozen drops at the front at the warmer temperature level, explosive ice crystal and graupel growth in the major precipitation column and many ice crystal in the anvil (Fig. 8).

In this case the analysis was greatly improved by the information on the electrical charges.

1. Raindrops forward in the cloud were primarily positive, of magnitudes nearly the same, irrespective of size (Fig. 9).
2. Below $-20^\circ C$ level in the major convective region there were many supercooled drops (Fig. 10). Although frozen drops were mostly being positively charged, those supercooled drops and raindrops below the melting level were predominantly negative. The amount of charge was similar to that on graupel in the cloud’s upper levels. Ice crystals in the upper levels carried charges of both signs.
3. In the transition layer more ice crystals were positively charged, and graupel and raindrops were predominantly negative.
4. Ice crystals in the anvil were predominantly positive.

Based on these observations the following scenario may be proposed for the evolution of precipitation particles in a squall line (Fig. 11). In the main precipitation region large raindrops, formed by graupel, are lifted up and forward by a low-level rotor and freeze above $0^\circ C$ level. Below $-10^\circ C$ level their positive charge increases through collision with ice crystals and...
they grow by capturing supercooled drops from warm rain. They fall and melt in the forward updraft. In the different way, small, mostly negatively charged raindrops in the main rainfall area are taken up in the main updraft and freeze as they ascend. These negatively charged drops and negative ice crystals are carried upward where the drops may become embryos for new graupel. Surprisingly, in comparison with charged raindrops and supercooled drops, almost half of the particles falling below 0 °C level have been recycled. Recirculation of precipitation particles and the rapid growth of frozen drops through capturing supercooled drops from forward cells must be an efficient precipitation process which may explain the intense rainfall in the leading edge of a squall line.

4. CONCLUSION
The weakness in lightning activity over tropical oceanic areas has been explained by the low numbers of CCNs and the formation of large drops near the melting level. As has been reported in rainbands, frozen drops grow by capturing supercooled drops from warm rain in merging cells and this process also occurs here. However, recirculation of raindrops was extensive and accelerated the accumulation of rain at the leading edge of a squall line.

References

Fig. 11. Model of precipitation particle evolution in squall line.