Cloud Radar Observations made during the Rains of EPIC-2001

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1. Introduction & Summary

The NOAA Research Vessel Ronald H. Brown (RHB) focused on studies of deep convection in the eastern Pacific during September, 2001, as part of the East Pacific Investigation of Climate Processes (EPIC-2001). From September 10-31, the ship remained located at roughly 10N, 95 W.

A cloud radar (Ka-band, 8.66 mm wavelength) was present on the RHB during this time. Although cloud radars are not normally applied within heavily-raining regions, they are potentially of value. The radar's high sensitivity (-40 dBZ at 10 km or -34 dBZ at 15 km, without attenuation) and its high vertical resolution of 45 m means the cloud radar is very sensitive to the presence and structure of upper-level clouds, even when rain is present.

The three weeks of cloud radar data from 10N, 95 W are explored. An examination is made of the diurnal cycle in cloud occurrence, and a quantitative estimate of ice water contents (IWC) made for both precipitating and non-precipitating time periods. This estimate uses an empirical relationship to relate IWC to radar reflectivity, and a relationship relating radar attenuation to rainfall rate, with the surface rain rate serving as a proxy for the entire vertical column of rain rate. The radar data is examined at either a one- or five-minute time resolution.

CONCLUSIONS: We find a diurnal cyle with increased high cloudiness at night for both raining and non-raining time periods. Diurnal changes in cloudiness during convective times are more abrupt. The quantitative estimates of ice water content and particle size seem reasonable but need further tuning and comparison to other data sources. The differences in ice mean particle size and ice water content between raining and non-raining time periods are small.

2. Diurnal Cycle in Cloud Occurrence

A cloud is defined to occur whenever the radar reflectivity in dBZ exceeds -50. A radar scan is considered "raining" if almost all of the range gates below 4.5 km have Doppler velocities exceeding 3 m/s (see raw radar data plots). During the entire Sept. 10-31 time period, 18.2% of the available radar data are classified as precipitating according to this definition. A "non-raining" radar scan also has no radar reflectivities exceeding -5 dBZ between 0-4.5 km.

The mean cloud occurrence by height for radar scans lacking precipitation, shown in Fig. 1, reveals a broad maximum in cloud occurrence between 8 and 12 km. The data were composited into 4 local time periods, encompassing 9 pm-3am LT, 3 am-9 am LT, 9 am-3 pm LT, and 3 pm-9 pm LT. More cloudiness is evident during the nighttime. The maximum cloud top height occurs between 3 am-9 am, consistent with nighttime infrared radiative cooling.

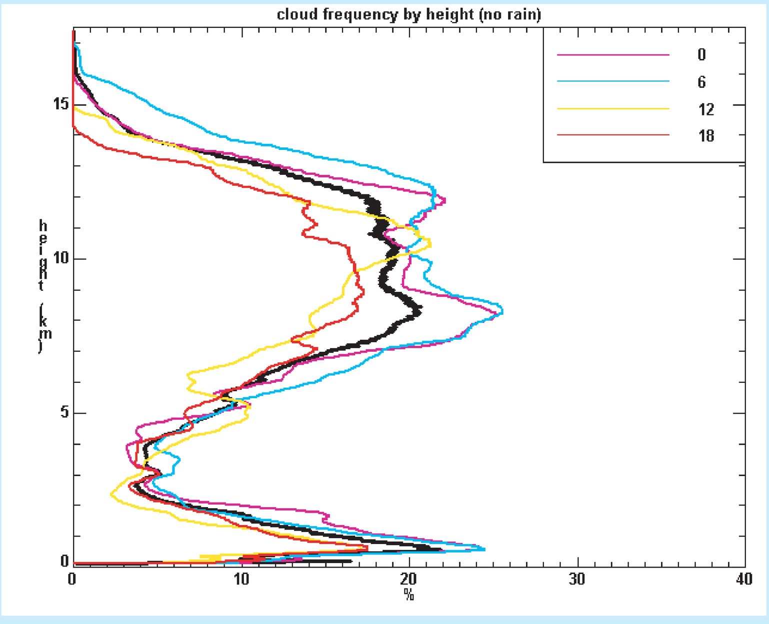

Fig. 1: Cloud frequency by height for radar scans without precipitation below 4.5 km. The black line is the diurnal mean, the fuchsia, blue, yellow, and red lines are averages over, respectively, 9 pm-3am ,3am-9am, 9am-3pm, 3pm-9pm, all in local time.

The mean cloud occurrence by height for radar scans with precipitation below 2 km, shows most of the high cloudiness occurs between 3 am-6 am local time (LT), consistent with a 2 am LT convective peak observed within weather radar data. The convective cloudiness minimum occurs between 3 pm-9pm, and a large jump in convective cloudiness occurs after 3 am. A distinct increase in cloudiness is evident between 5.5-6.0 km, or 1 km above the freezing level. Its cause is not known at this time.

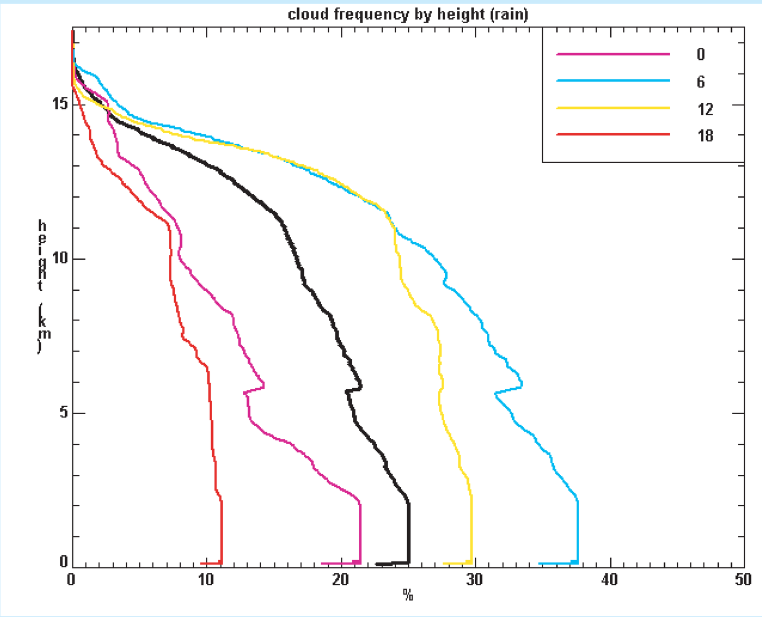

Fig. 2: Cloud frequency by height for radar scans with precipitation below 2 km. The black line is the diurnal mean, colored lines are 6-hour local time averages as defined for Fig. 1.

3. Ice Water Contents & Particle Sizes

Ice water contents (IWC) can be estimated from the radar reflectivities using empirical relationships of the type: *IWC=aZ^b*. Ideally, unique values of the coefficients are determined from other data on the same clouds, such as optical thicknesses derived from an infrared radiometer. For EPIC 2001, aircraft data may provide the best avenue for identifying the most appropriate values for *a* and *b*. In this initial investigation values of a=0.11 and b=0.63 are assumed, consistent with a best fit regression to data from a number of different field programs (Matrosov et al., 1999).

The mean particle size D is then calculated from Z=G*Do^3*IWC, where G is a coefficient that most importantly incorporates a dependence of particle density upon size.

When precipitation occurs, the radar reflectivity is attenuated roughly linearly to the rainfall rate (see Fig. 3) and is roughly independent of temperature and drop size. An estimate is made of the attenuation within the EPIC cloud radar data by assuming the surface rainfall rate measured by the optical rain gauges on RHB (Fig. 8) is representative of the entire vertical column up to the freezing level. This will under-estimate the true attenuation if the surface rainfall rate is less than the precipitation at higher altitudes . Additional attenuation errors can arise from a wet radome, and from increased attenuation at the melting-level.

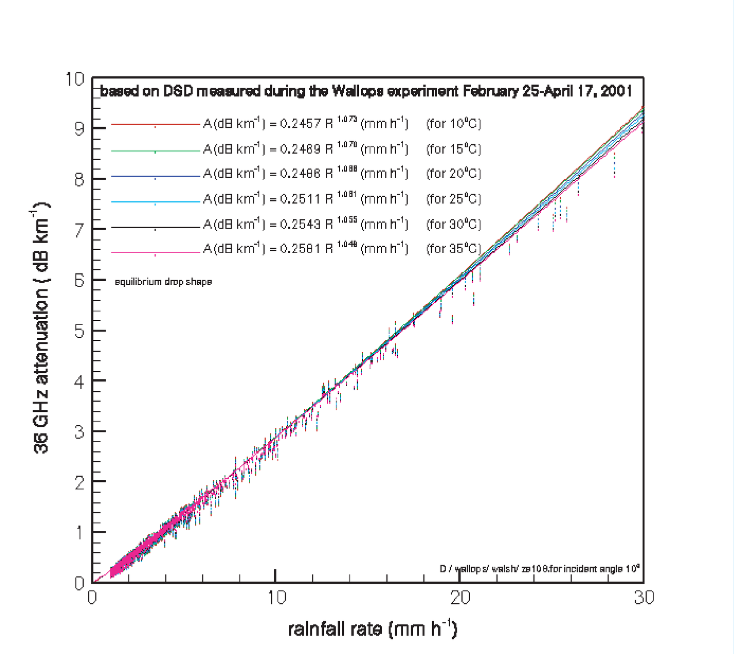

Fig. 3. Attenuation in radar reflectivity as a function of rainfall rate. Plot courtesy of Dr. Sergey Matrosov.

As seen in Fig. 4 and 5, the ice water contents and particle sizes for clouds with and without lower precipitation do not differ strongly, and show differences in vertical structure consistent with the presence of a melting layer or lack thereof. If true, this implies that most of the water vapor ingested into a convective cloud is directly converted into precipitation, and may have useful implications for the modeling of the vapor-cloud phase-precipitation transition within climate and cloud models.

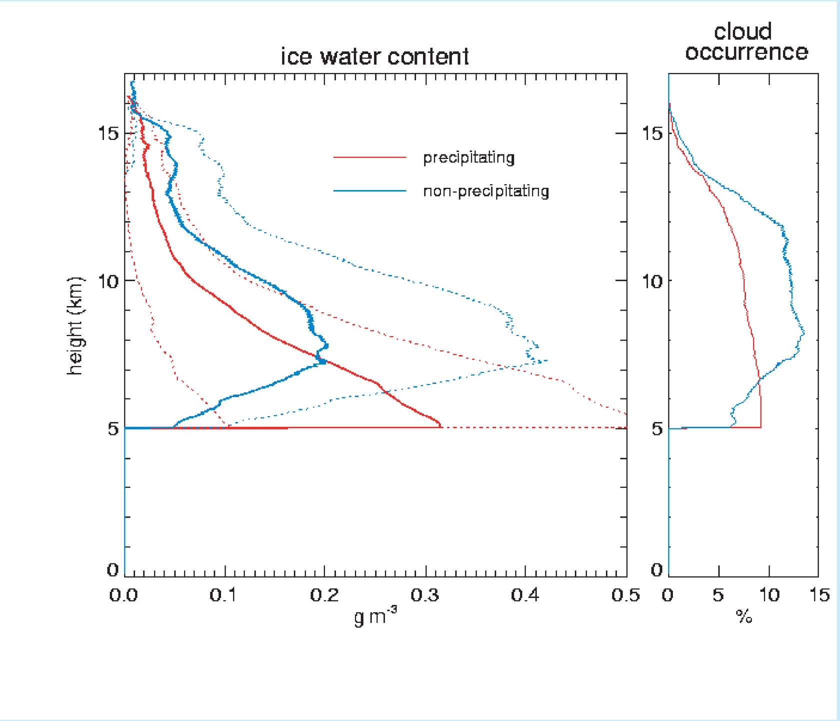

Fig. 4: Mean ice water contents for clouds without precipitation (blue) and with precipitation below 4.5 km (red). Dotted lines indicate the standard deviation.

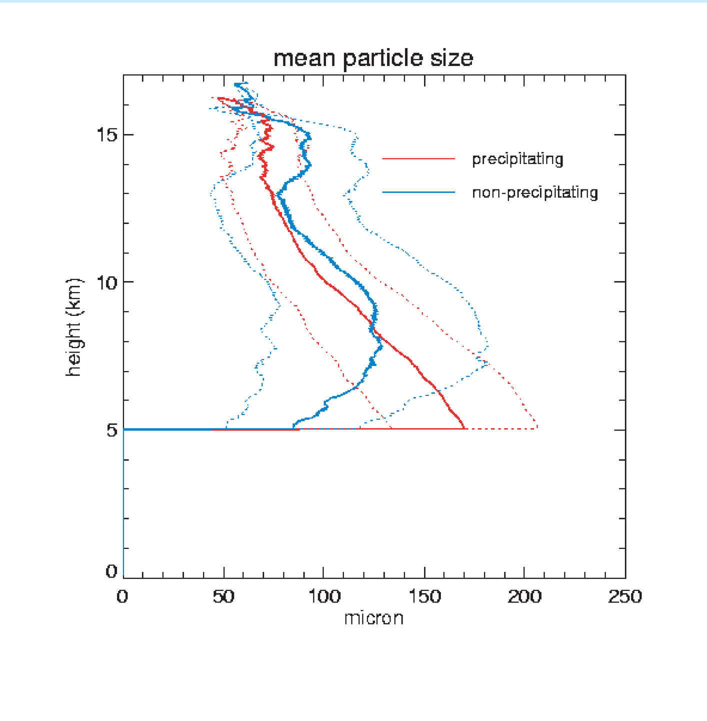

Fig. 5: Same as Fig. 4 but for mean particle size.

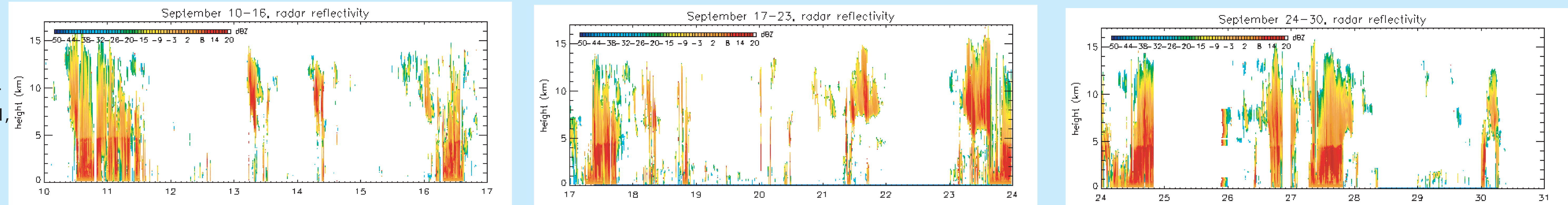

Fig. 6: Measured cloud radar reflectivities from Sept 10-31, 2001, at 95 W and 10 N

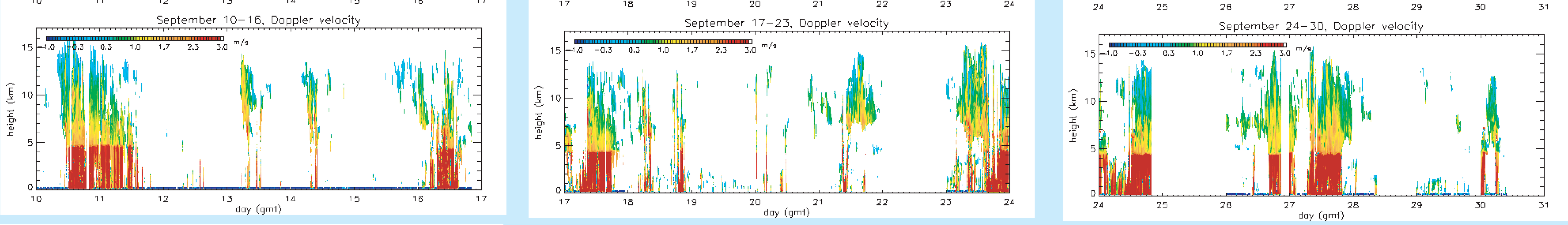

Fig. 7: same as Fig. 5, but for Doppler velocities.

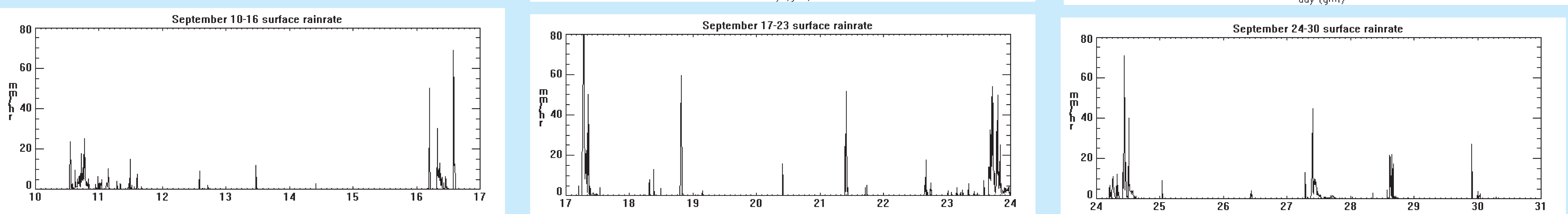

Fig. 8: The surface rainfall rate on the Ronald H. Brown as measured by the optical rain gauges.

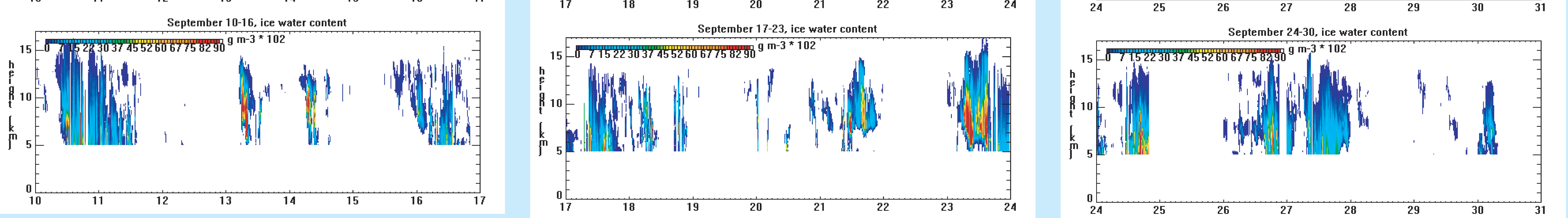

Fig. 9: Derived ice water contents from Sept. 10-31, 2001.