Retrieving number of activated CCN from satellite-retrieved vertical Re profiles of convective clouds

Tal Halevi, Daniel Rosenfeld, Eyal Freud
Institute of Earth Sciences, The Hebrew University of Jerusalem, 91 904 Jerusalem, Israel halevital@gmail.com

INTRODUCTION

Here we present a possible solution for the challenge of global measurements of cloud condensation nuclei (CCN) in the cloudy boundary layer from space.

The idea is to use the clouds themselves as natural CCN chambers by retrieving simultaneously the number of activated aerosols at cloud base, N_a, which is obtained by analyzing the distribution of the cloud droplet effective radius, r_e, in convective elements as a function distance above cloud base, D. This is based on satellite retrievals of cloud top temperature, T, and r_e. The variations of the retrieved r_e at a given T (or D) are caused by 3-D effects, mixing properties and cloud-base updraft variability.

METHODS

We assume that (a) entrained sub-saturated air is mixed with the cloud in homogeneously (Freud et al., 2011) and that (b) there is no significant droplet coalescence or precipitation, and no secondary nucleation of cloud droplets (i.e. all droplets activate at cloud base). These assumptions were shown to cause overestimation of ~30% in the derived N_a, based on in-situ measurements with an instrumented aircraft. We use the following steps to derive N_a:

1. Retrieve the vertical profile of cloud drop effective radius, as a function of vertical distance above cloud base, $r_e(D)$, using satellite-retrieved mid-IR (3.7 μm) reflectance. D is inferred from the difference between the retrieved cloud top 10.8 μm brightness temperature (T) and cloud base temperature (the cloudy pixels with highest T).

The errors due to 3-D effects, mixing and cloud base updraft variability are bracketed by obtaining a set of $r_e(D)$ for different percentiles (30%, 50%, 70% and 90%) of r_e that are associated with the same T (figure 1).

2. Convert the satellite-retrieved r_e to r_v, the mean cloud droplet volume radius, using the relation r_e=1.08r_v

(Freud and Rosenfeld, 2012).

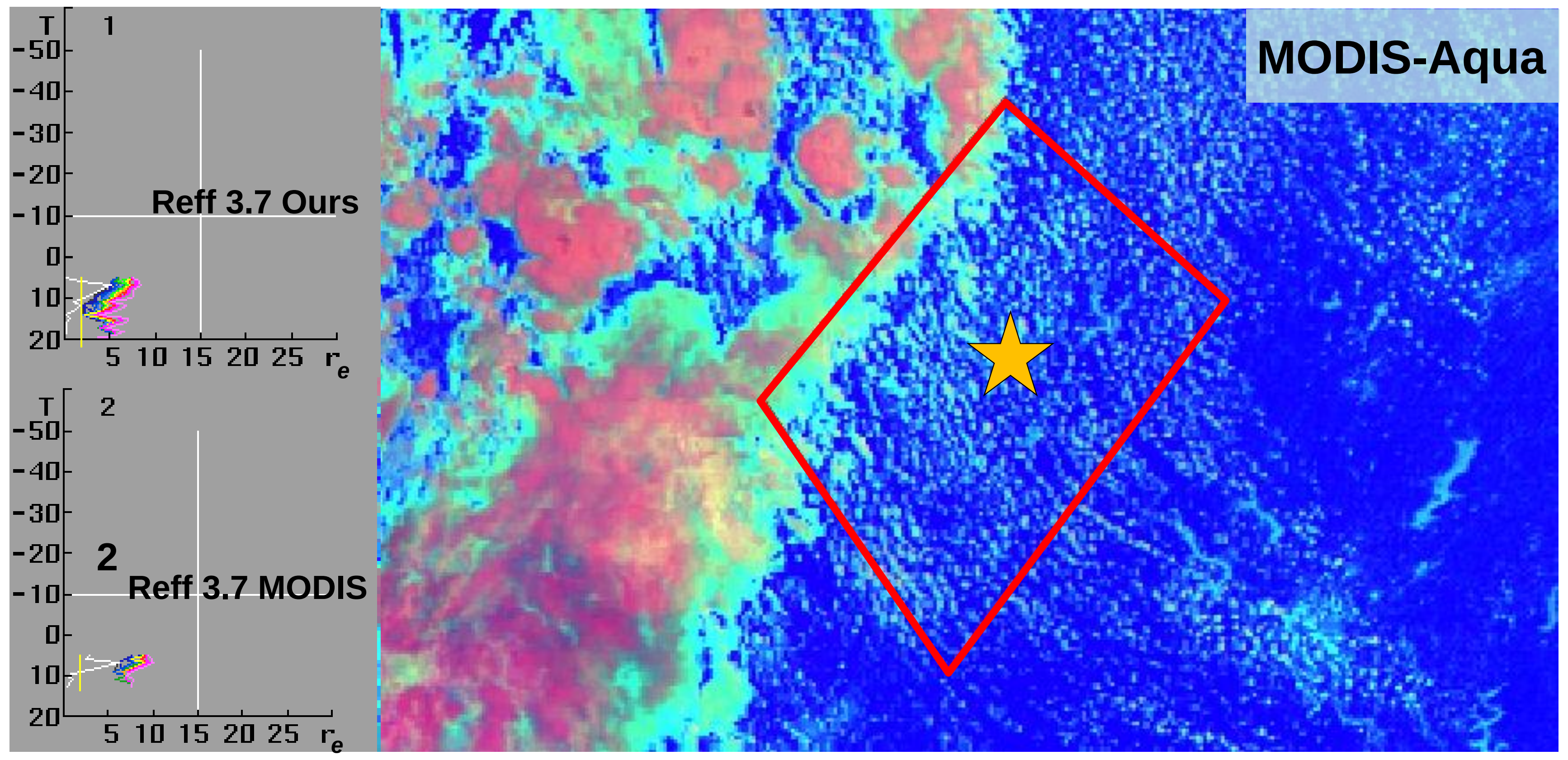
3. Assume inhomogeneous mixing, which allows the equality r_v=r_{va}, and calculate N_a by:

$$N_a = 10^6 * 3 * q_{La} / 4 * \rho_L * \Pi * r_{va}^3$$

Where $q_{L\alpha}$ is adiabatic cloud liquid water content (mixing ratio) and ρ_L is the water density (figure 2).

4. Compare the satellite-retrieved N_a to the CCN measured on the ground in order to obtain the possible super-saturation variability at cloud base.

Case Study: Southern Great Plains, July 1 2010, 19:25



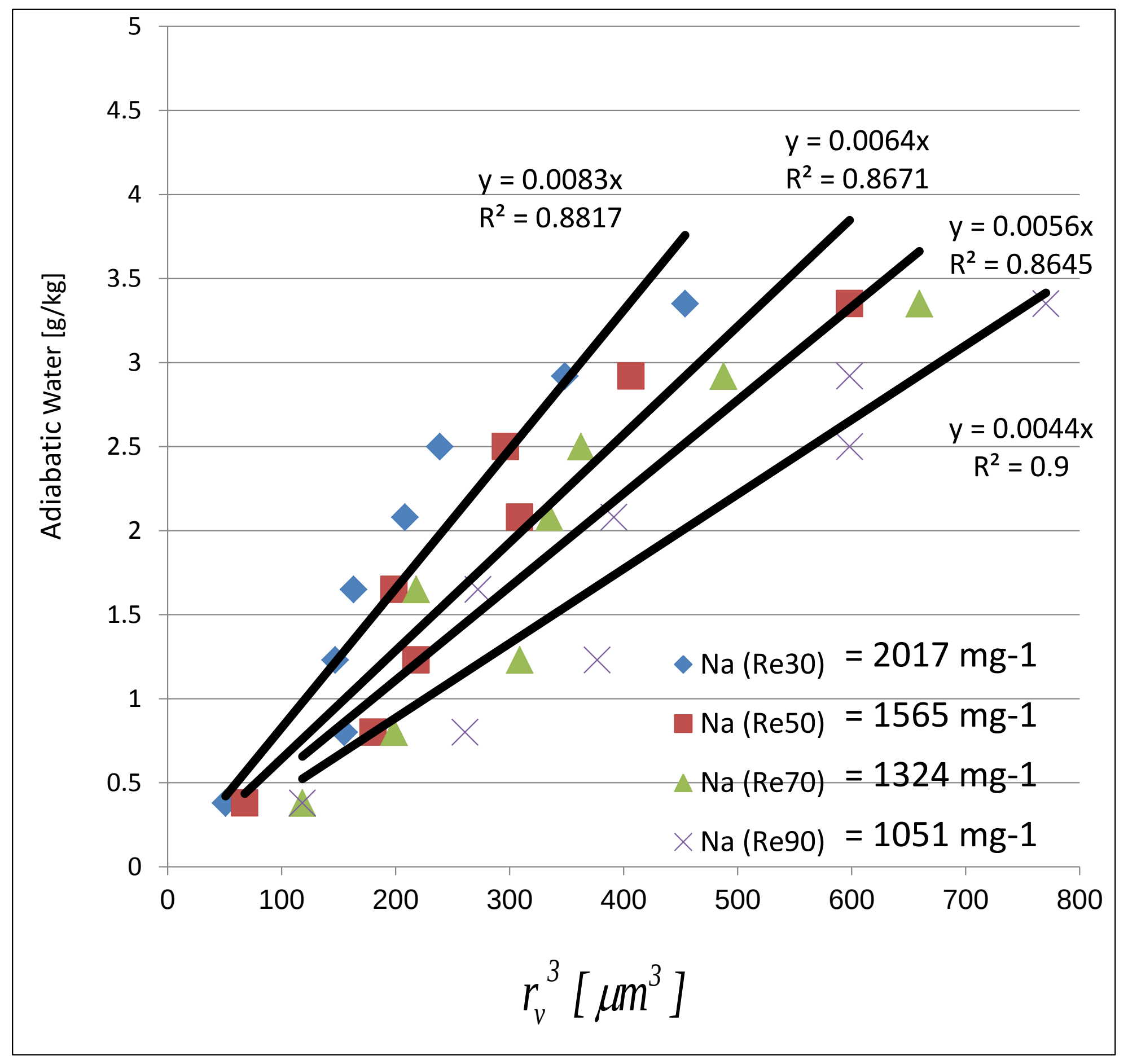
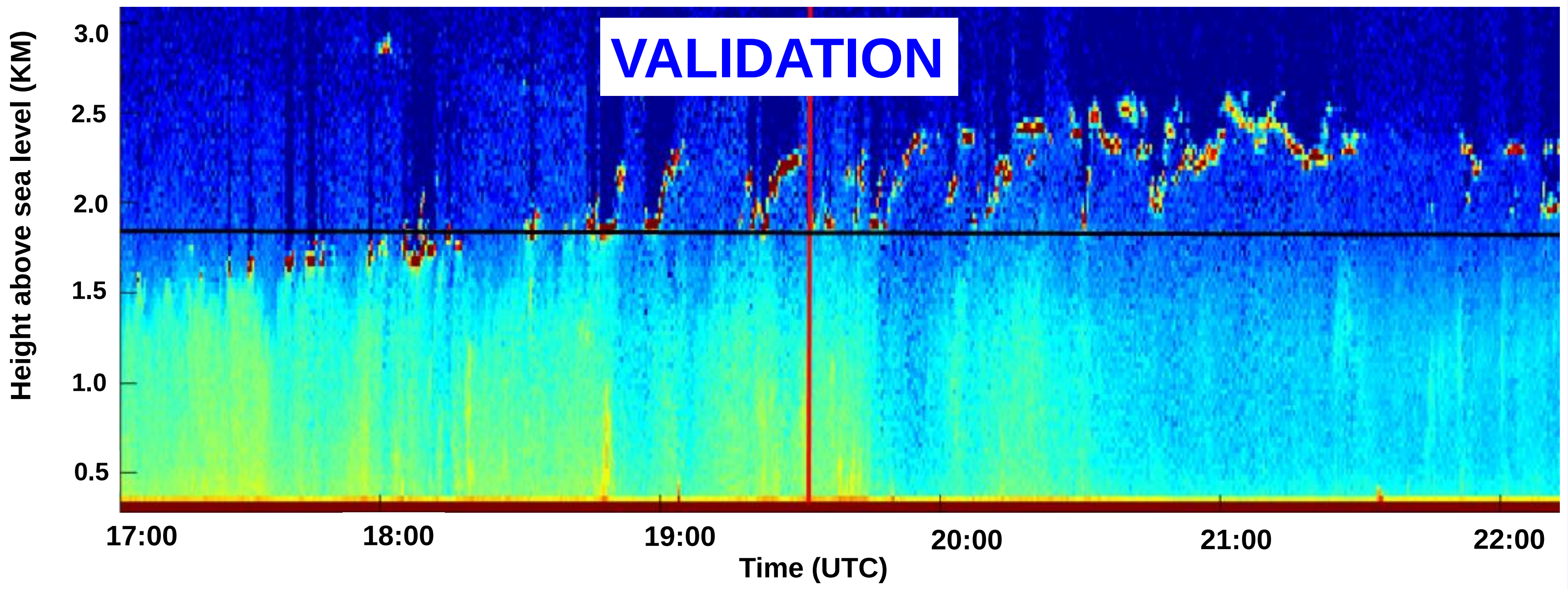


Figure 1 (top): An RGB composite, where the visible channel modulates the red, 3.7 μm reflectance modulates the green, and 10.8 μm brightness temperature modulates the blue (after Rosenfeld and Lensky, 1998). The data in the enclosed area were used to calculate the *T*-r_e relations from which N_a is calculated. We use the 3.7 μm retrieved r_e by us, after bias correction from MODIS products.

Figure 2 (left): The mean droplet volume radius, r_v (scaled to r_v^3) vs. the adiabatic water mixing ratio (q_{La}) for different r_v percentiles (see legend). q_{La} is calculated with an adiabatic parcel model, whose inputs are the cloud base pressure and temperature (taken from the nearest sounding). N_a is derived from the slope of the linear best fit (Eq. 1) for each *T*-r_e percentile.

VALIDATION



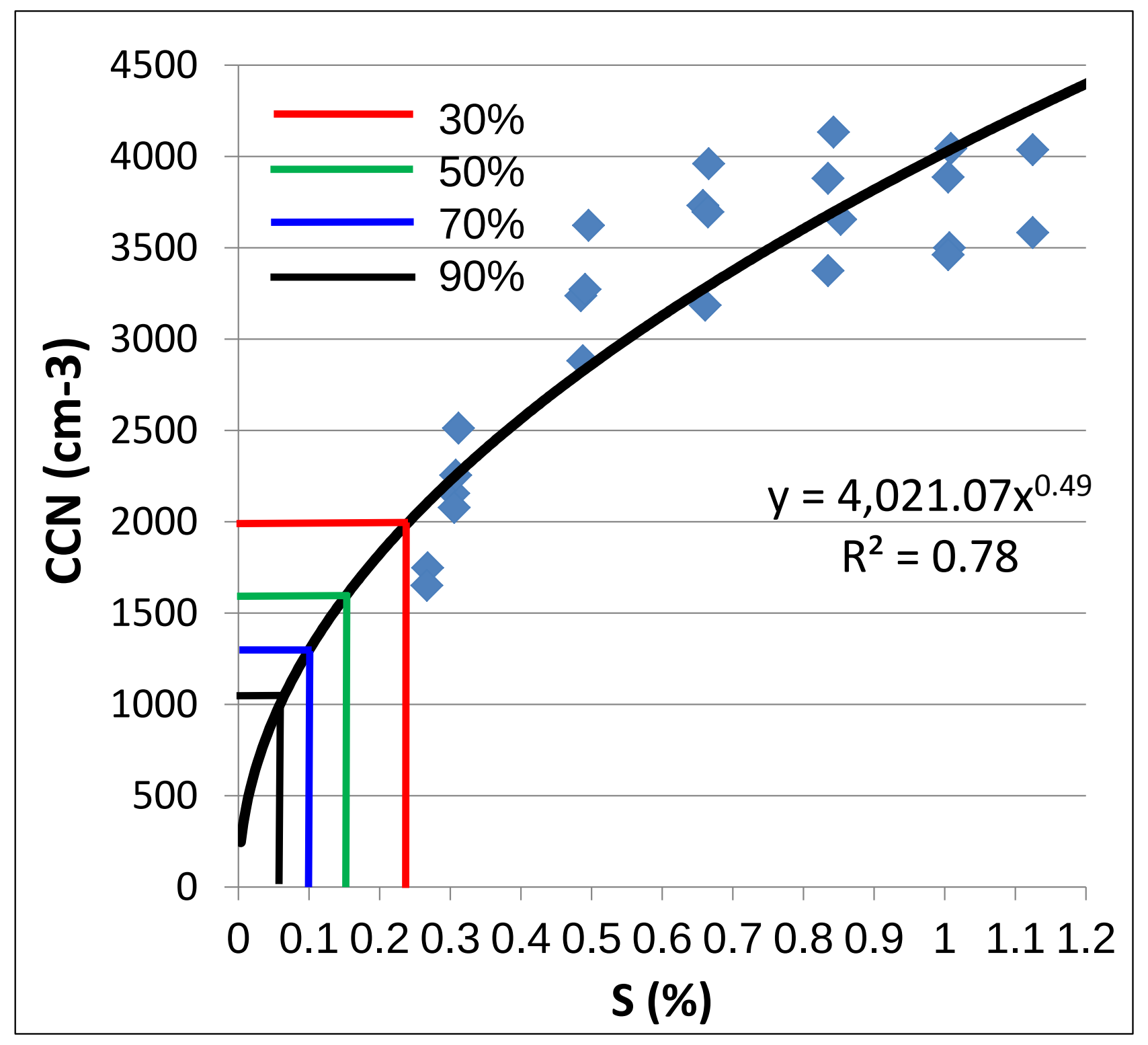


Figure 3 (top): Time series of microwave backscatter measured with a Micro-pulse Lidar (MPL) on 1 July 2010 in **SGP**. The derived cloud base altitude at 19:25 UTC (the time of MODIS-Aqua overpass - Fig. 1) is ~1.85 km MSL.

The sounding LCL height is 1.86 km where T equals 14.7°C.

Figure 4: CCN activation spectrum measured at the SGP site on July 1, 2010 between 18:25 to 20:25 UTC. The satellite-retrieved N_a that have the same values as the SGP-measured CCN were used to extract the super-saturation (S) values, at which the CCN were activated. The retrieval uncertainty due to 3-D effects is likely bracketed between the 30% and 70% percentiles of *T*-r_e retrievals.

RESULTS

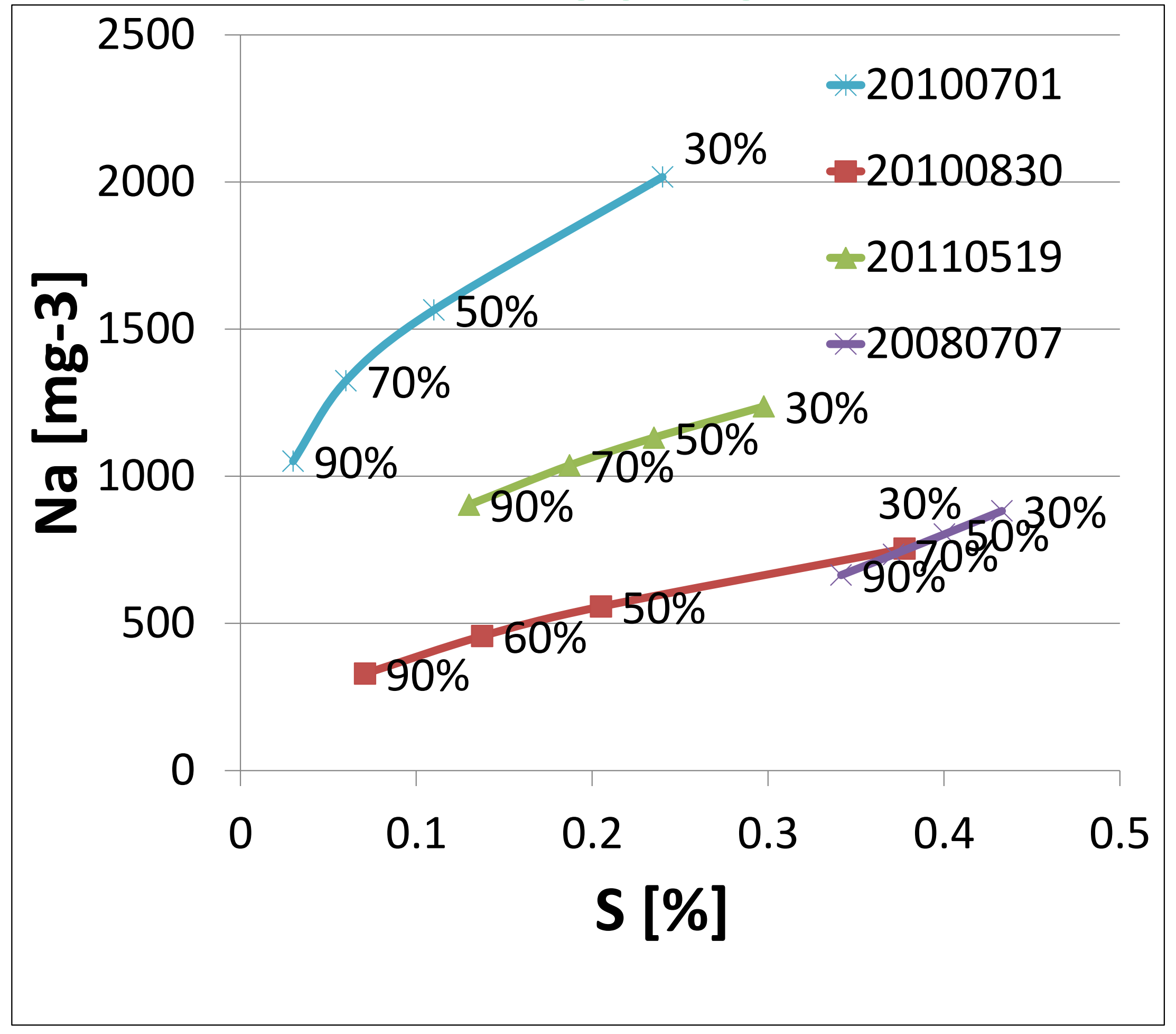


Figure 5: The super-saturation, S, for which the retrieved N_a and ground-based measured CCN are the same, for the different percentiles of *T*-r_e relations and for four case studies at different days.
Due to mixing, the actual N_a should be ~30% smaller than the retrieved N_a. The uncertainty due to 3-D effects is probably bracketed by the percentiles of 30-70%.

SUMMARY AND OUTLOOK

- ✓ We have shown that the concept of retrieving N_a from satellite retrieved *T*-r_e relations can work.
- ✓ In order to infer CCN spectra from N_a derivations, the cloud base updrafts (*w*) are required and the following equation applied: $S_{\max} = C w^{3/4} N_a^{-1/2}$ From the companion poster of A. Khain. Also Pinsky and Khain, 2012.
- ✓ The updrafts can be parameterized from the difference between satellite-measured surface skin and reanalysis based surface air temperatures and cloud base height above ground. This is subject of future research. So far we are only 9 month into the first year (out of 3) of this study.

REFERENCES AND ACKNOWLEDGEMENTS

Freud E., D. Rosenfeld, and J. R. Kulkarni, 2011: Resolving both entrainment-mixing and number of activated CCN in deep convective clouds. Atmos. Chem. Phys., 11, 12887-12900.

Freud E., and D. Rosenfeld, 2012: Linear relation between convective cloud drop number concentration and depth for rain initiation. J. Geophys. Res., 117, D02207.

Pinsky M., and Khain A., 2012: Analytical estimation of droplet concentration at cloud base. Submitted.

Rosenfeld D. and I. M. Lensky, 1998: Satellite-based insights into precipitation formation processes in continental and maritime convective clouds. The *Bulletin of American Meteorological Society*, **79**, 2457-2476.

This project is funded by the ASR program.