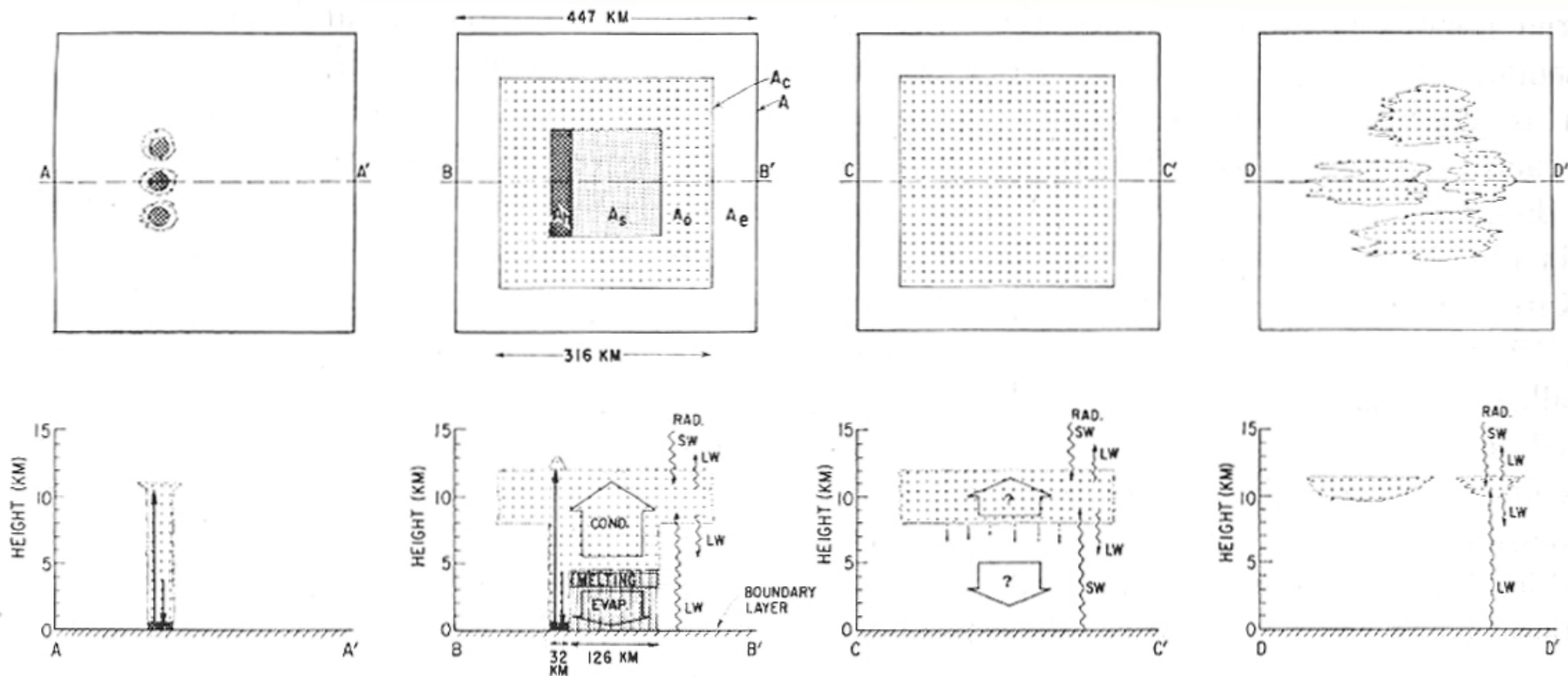


Hydrometeors Injected into the Large-scale Environment by Tropical Cloud Systems

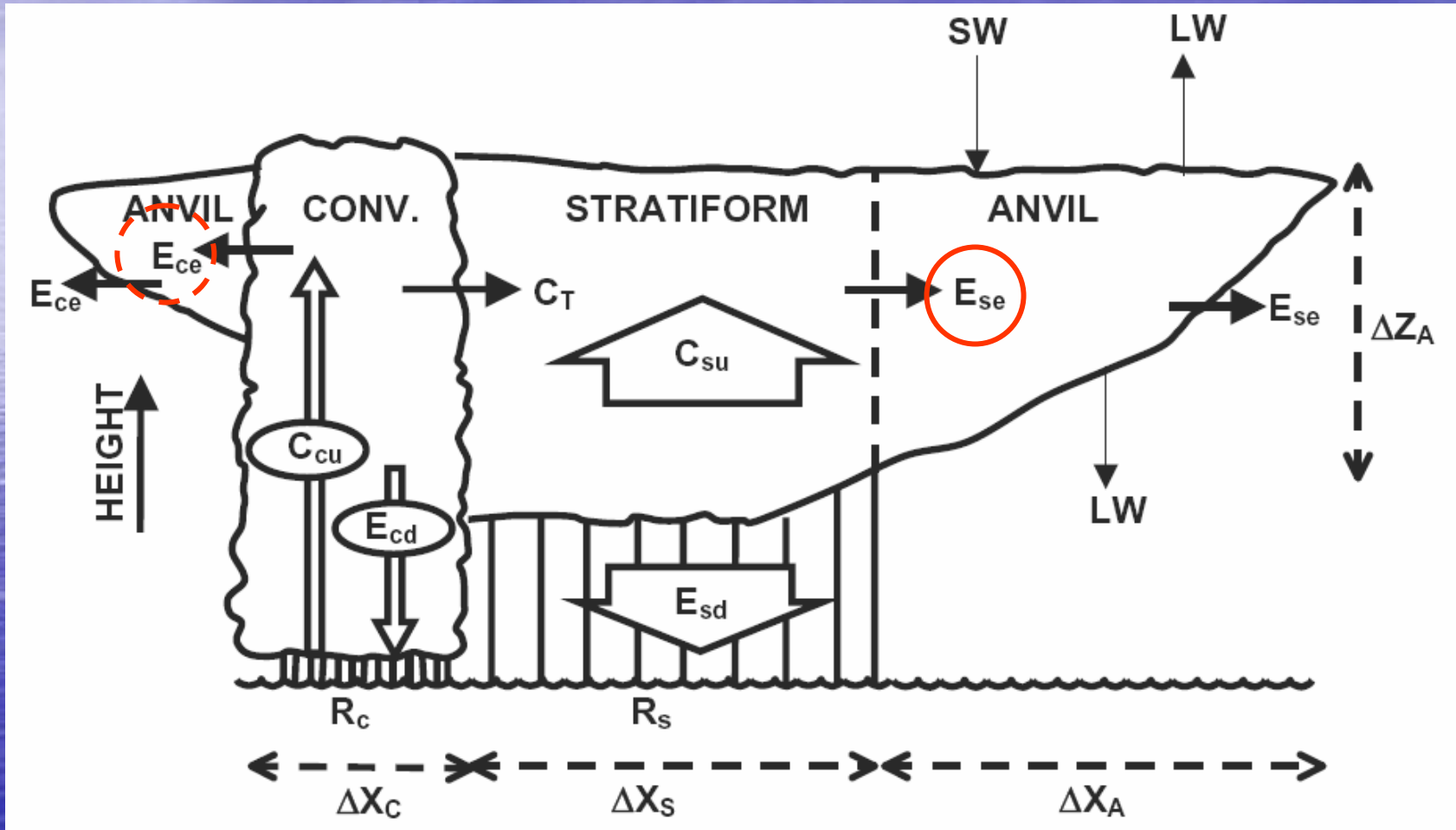
Courtney Schumacher & Robert A. Houze
Co-PIs

Tropical MCSs inject lots of hydrometeors into upper troposphere

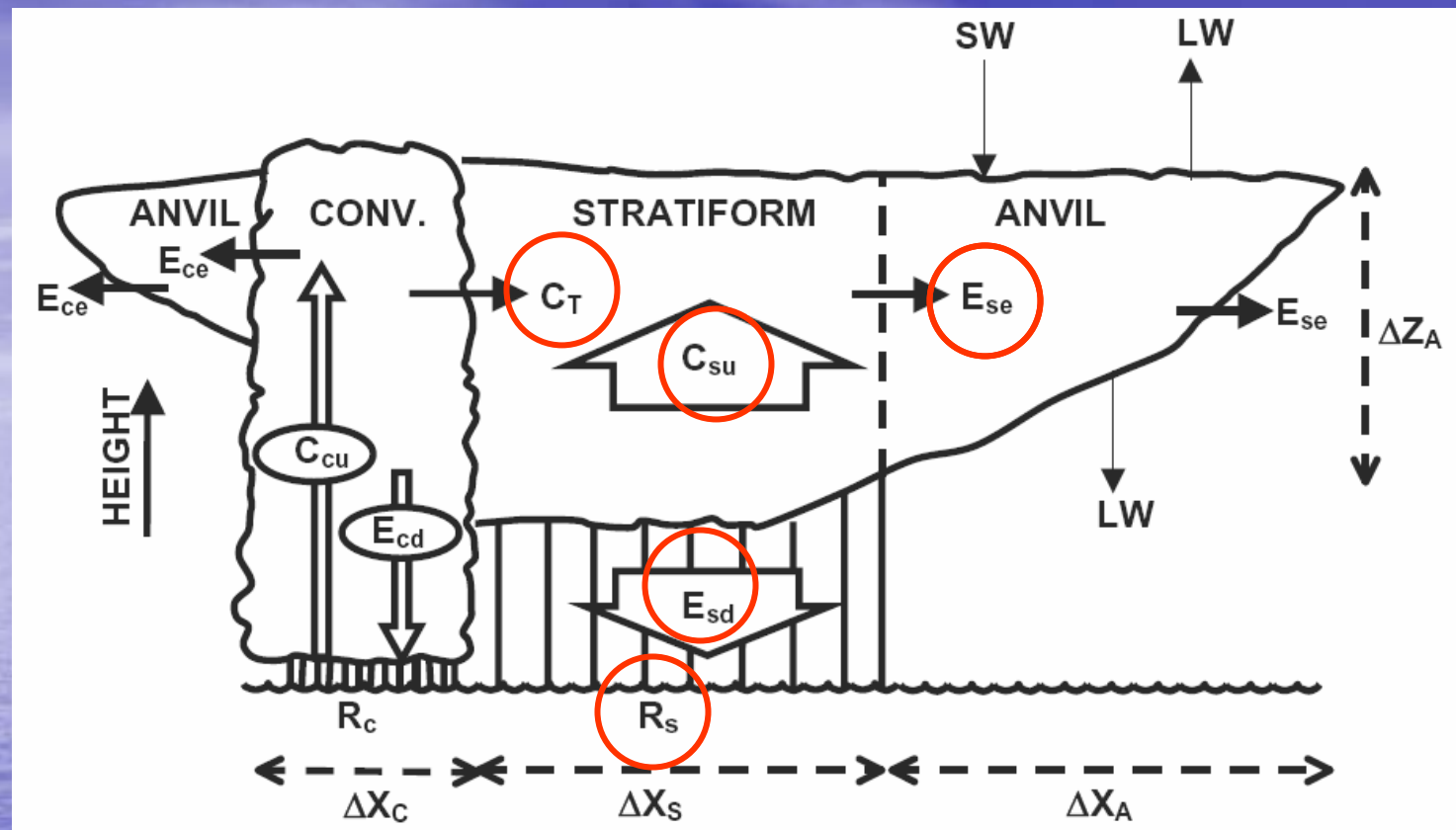


Idealized life cycle of tropical MCS as proposed by Houze 1982

Think of the following schematic as a composite of the water budget of an MCS over its whole life cycle



After Houze et al. (1980)



Stratiform water budget equation

$$C_{su} + C_T = R_s + E_{sd} + E_{se}$$

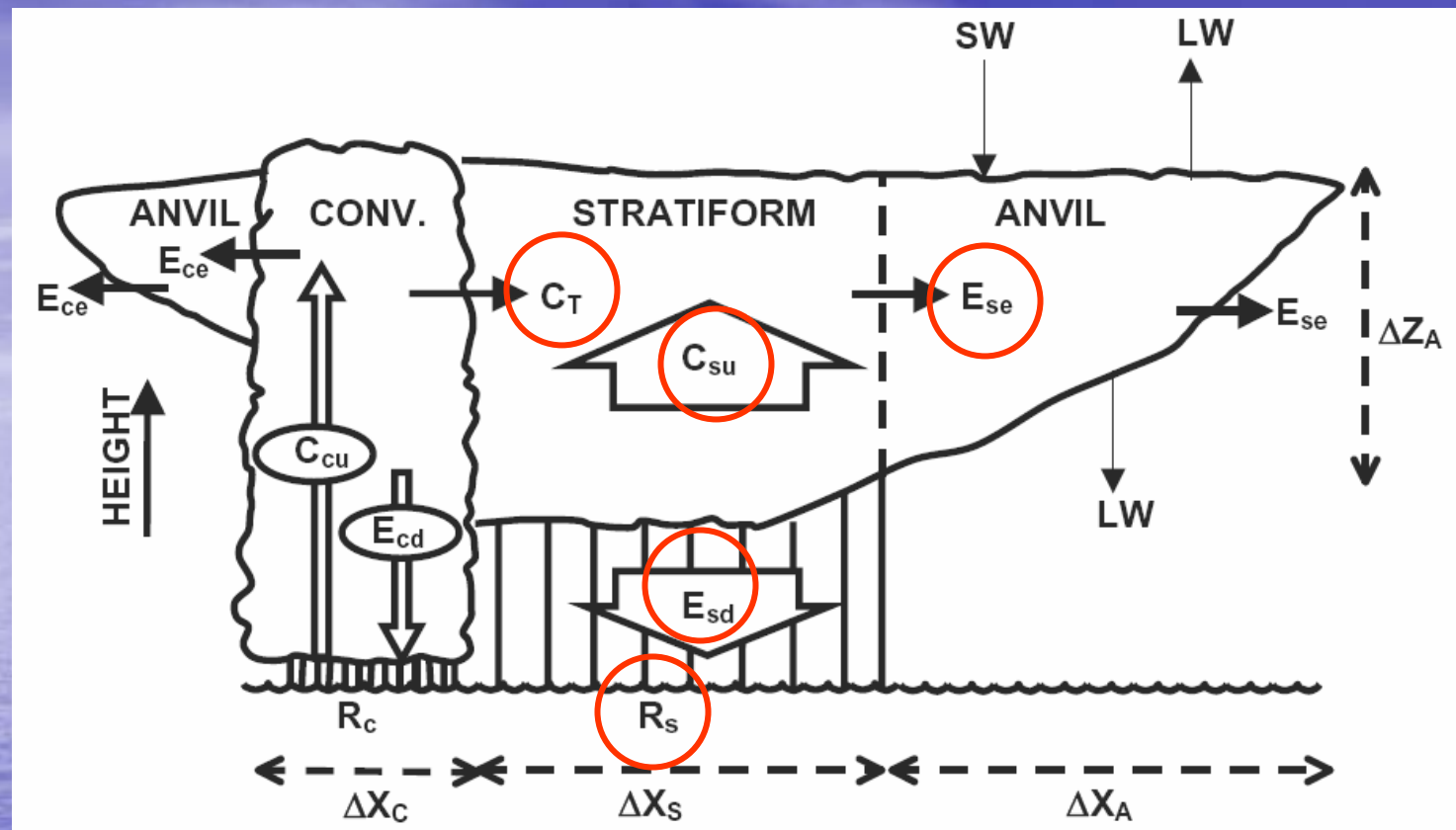
$$R_s = \varepsilon_s (C_{su} + C_T)$$

$$E_{sd} = a (C_{su} + C_T)$$

$$E_{se} = b (C_{su} + C_T)$$

where

$$\varepsilon_s + a + b = 1$$



Measurements

Cloud radar $\rightarrow E_{se}$
 Precip radar $\rightarrow R_s$
 Doppler $\rightarrow E_{sd}, C_{su}, C_T$



$$R_s = \varepsilon_s (C_{su} + C_T)$$

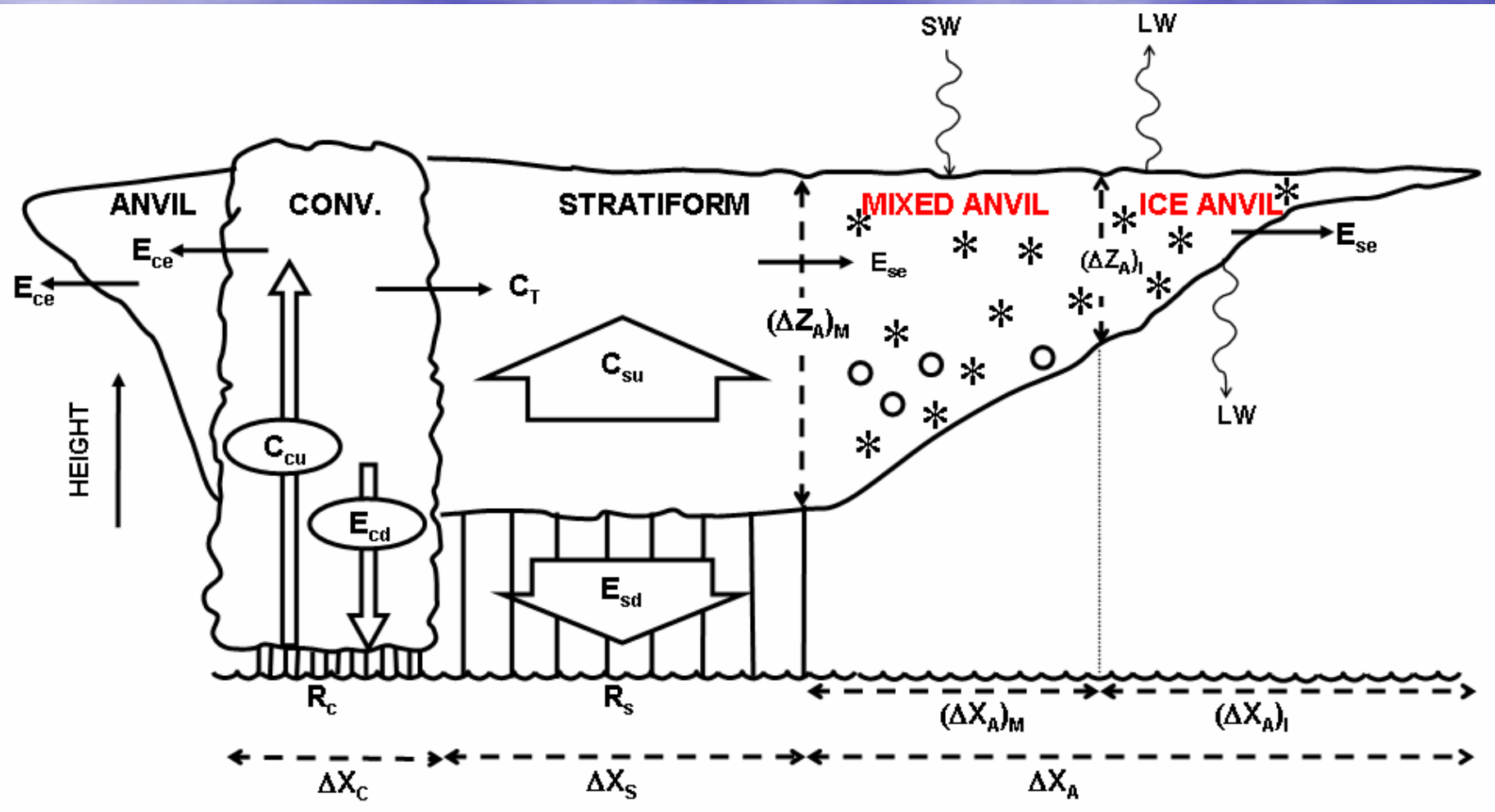
$$E_{sd} = a (C_{su} + C_T)$$

$$E_{se} = b (C_{su} + C_T)$$

where

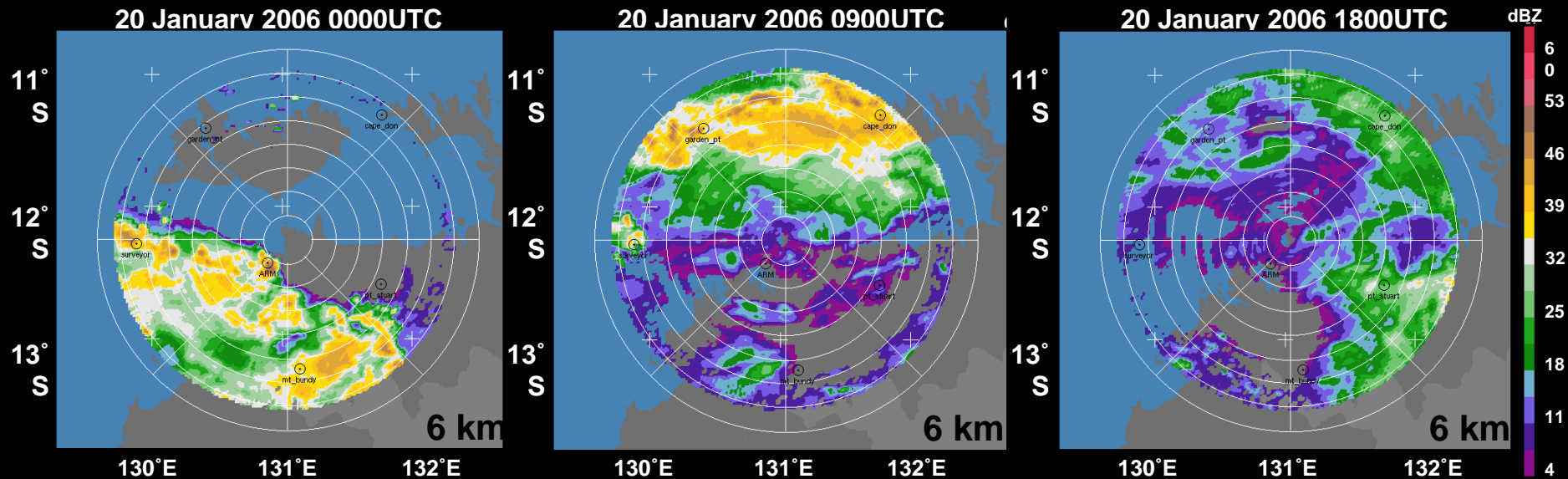
$$\varepsilon_s + a + b = 1 \pm \text{error}$$

In TWP-ICE we are subdividing the anvil into mixed and ice anvils

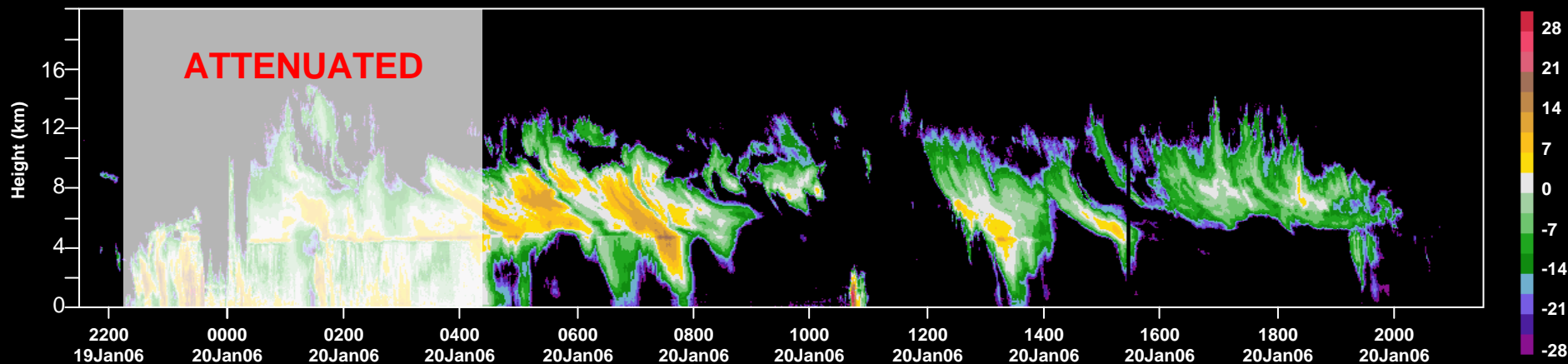


Example from TWP-ICE

Precipitation Radar

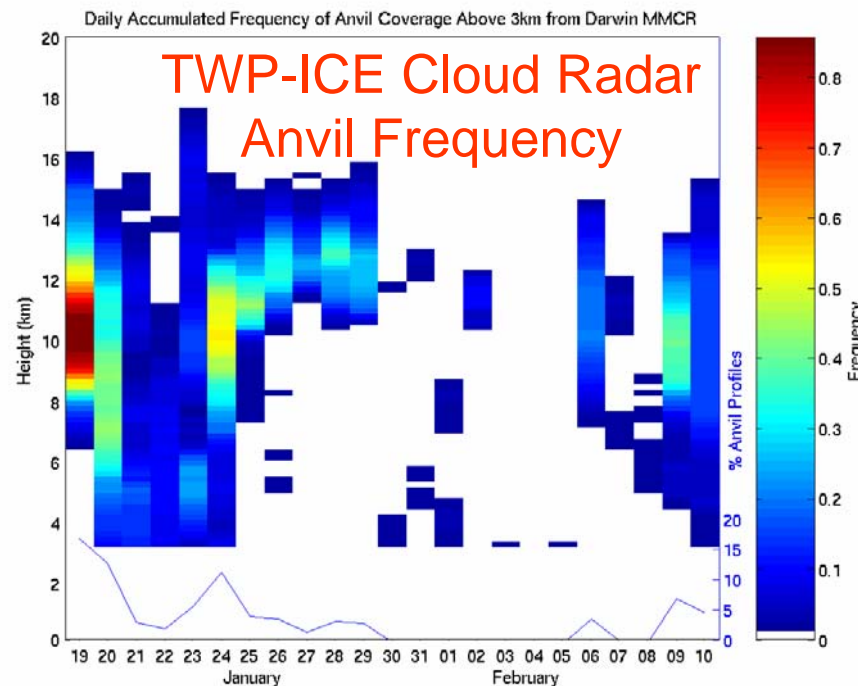
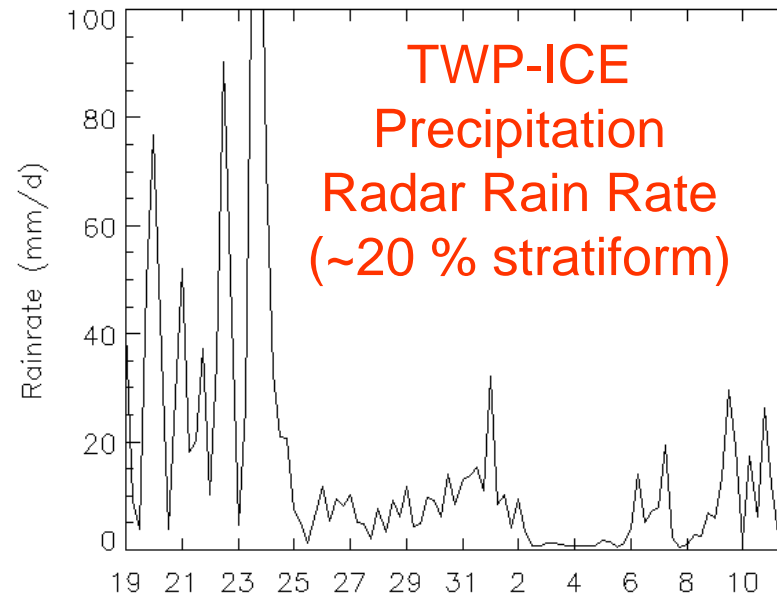


Cloud Radar



Longer-term records of the water budget parameters also are being derived.

Figures here are for duration of TWP-ICE.

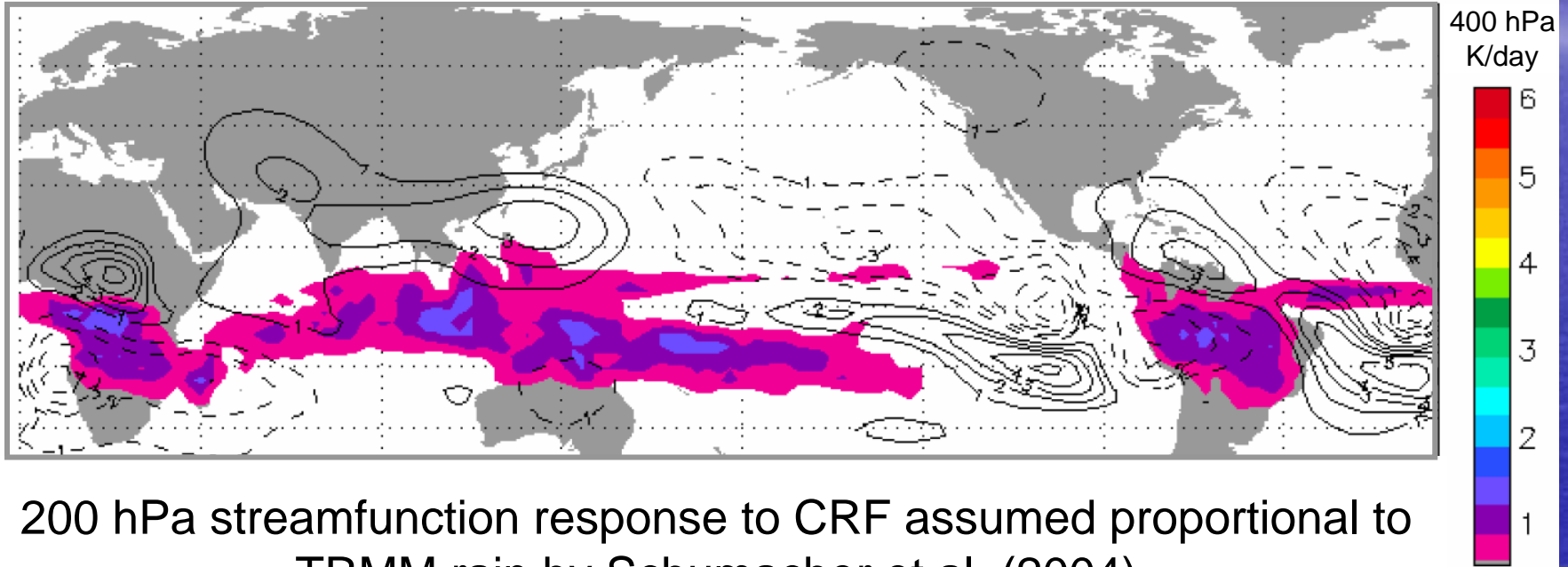


This will also be done for a longer-term climatology.

We will use cloud & precipitation radars permanently located at Darwin.

Using the empirically derived water budget parameters b and ε_s , the stratiform regions' anvil mass is proportional to the stratiform rain

$$E_{se} = (bR_s)/\varepsilon_s$$



200 hPa streamfunction response to CRF assumed proportional to TRMM rain by Schumacher et al. (2004)

The above formula uses the water budget parameters to determine an appropriate amount of anvil mass to accompany the observed stratiform precipitation, which will allow the radiative heating to be added to the latent heating in future studies.

Summary

- Water budget relationships will be used to investigate the magnitude & mechanisms of anvil generation by convective systems
- Cloud & Precipitation Radar will be used to estimate terms in the water budgets, & water budget terms will be checked for internal consistency
- The TWP-ICE dataset is being used to estimate the water budget terms for some representative cases, & for long-term dataset at Darwin
- Will develop formulas for parameterizing the anvil mass in terms of satellite observed rainfall.



Long-term observations at Darwin

Recall--

$$R_s = \varepsilon_s (C_{su} + C_T)$$

$$E_{se} = b (C_{su} + C_T)$$

This implies

$$E_{se} = (b R_s) / \varepsilon_s$$

Values of b & ε_s obtained from TWP-ICE or other experiments will be used to estimate anvil mass E_{se} from precip radar measurement of R_s .

Cloud radar estimate of E_{se} will be an ongoing validation of the rain-estimated anvil mass.

This validation procedure will refine the values of the water budget parameters from field experiment data and provide a longer-term anvil climatology based on Darwin data.