On the Origin of High Altitude High Ice Water Content Regions in Oceanic Deep Convection

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HAIC-HIWC Science Team Meting
Melbourne, 09-12 November 2015

Overview

1. Microphysical properties of HIWC cloud regions
   (a). Effect of dynamics on formation of HIWC
   (b). Extinction coefficient
   (c). Characteristic sizes (MMD, D_{mean}, $D2_{mean}$, $D3_{mean}$)
   (d). Size distributions and its relation to IWC and U_Z
   (e). Integral particle size and phase relaxation time
   (f). Ice particle habits in HIWC and stratiform regions
   (g). Ice particle aggregation

2. Conceptual model of HIWC cloud region formation

Motivation

1. Understand processes resulting in formation of high ice water content cloud regions in MCSs

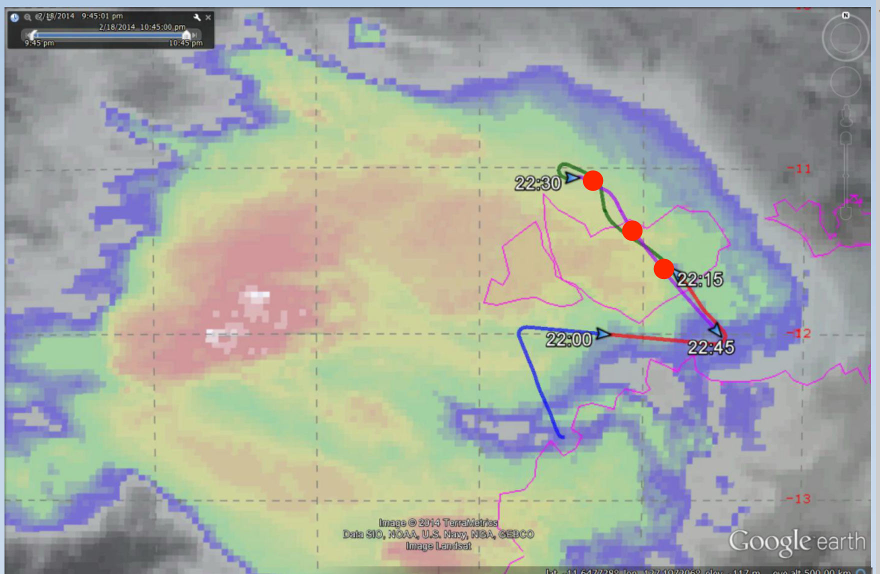
2. Identify main microphysical properties attributed to HIWC cloud regions

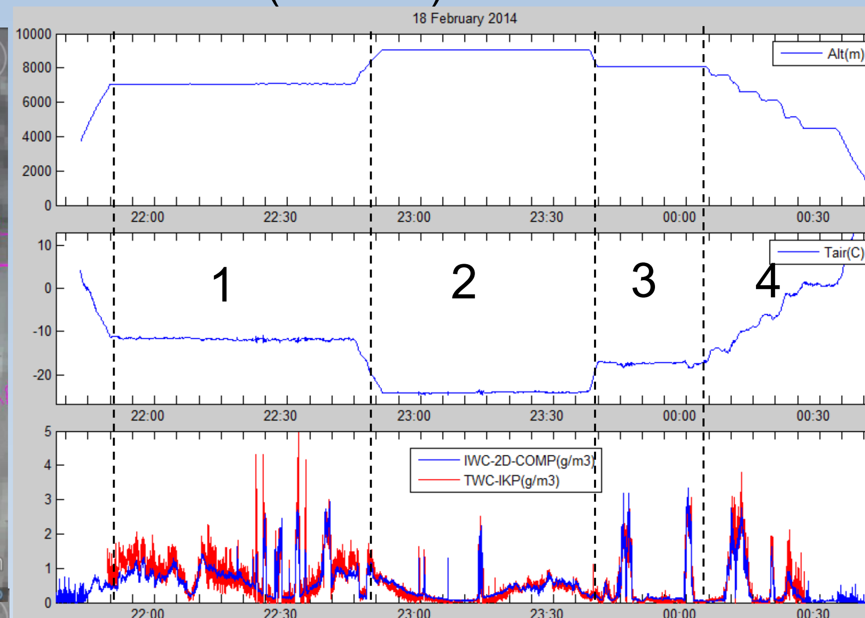
3. Obtain knowledge to support verifications and interpretation of remote sensing tools (satellite, radar) for regulatory objectives

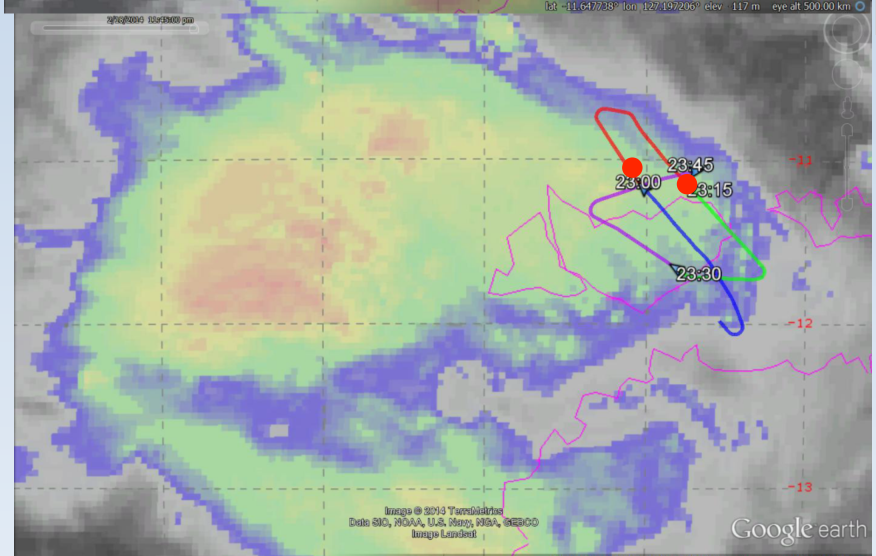
4. Support further development of cloud simulations

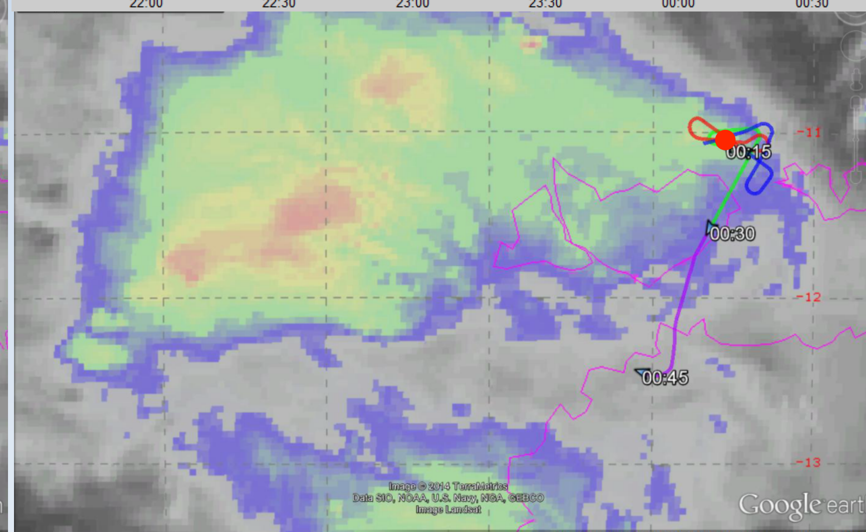
Flight 23 was performed near the north-east size of the MCS

1st part (21:50-22:45) H=7100m; T= -11C
2nd part (22:51-23:38) H=9100m; T= -24C
3rd part (23:45-00:05) H=8100m; T= -17C
4th part (00:07-00:25) 7600>H>5100m; -14C<T<-2C (descent)

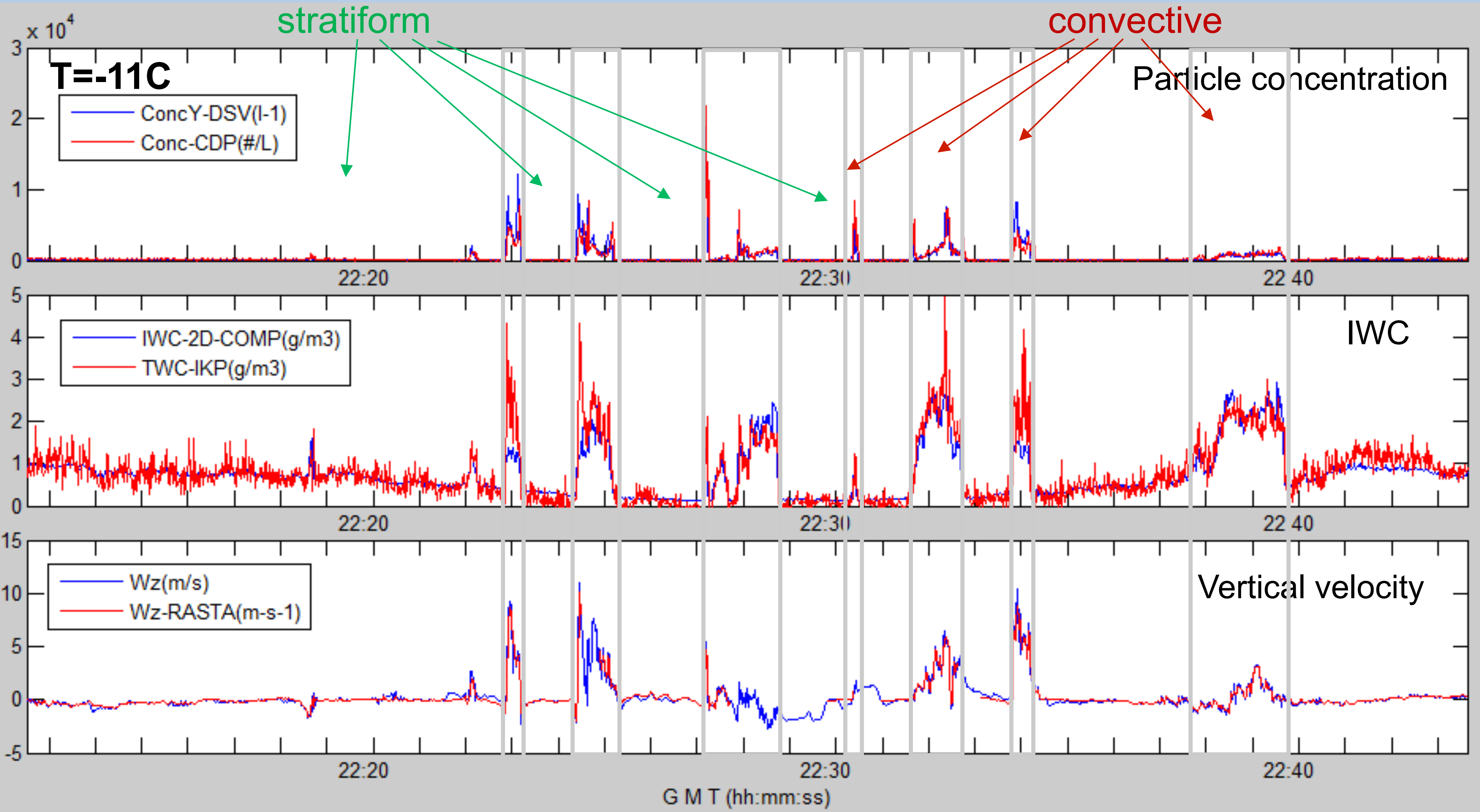




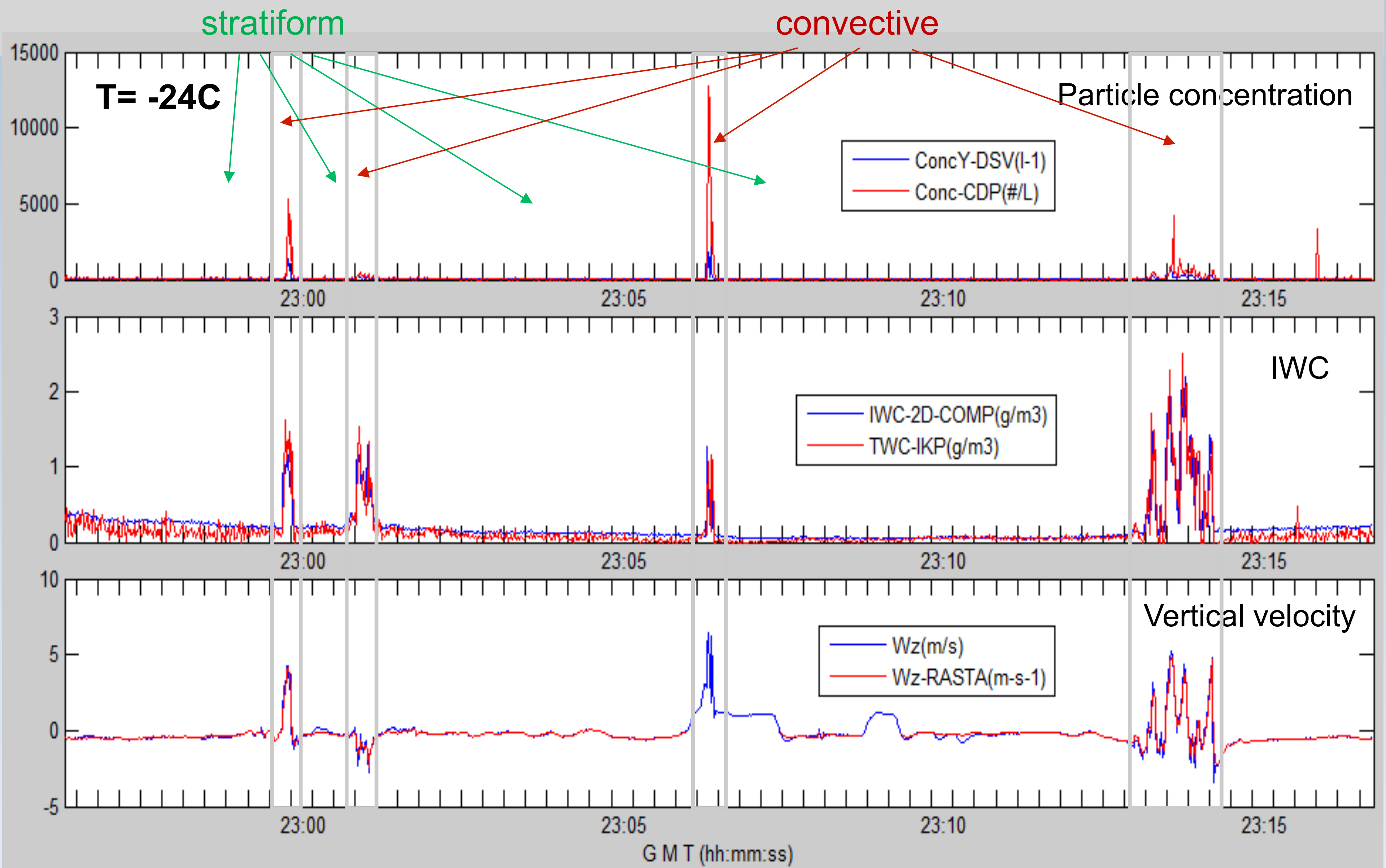




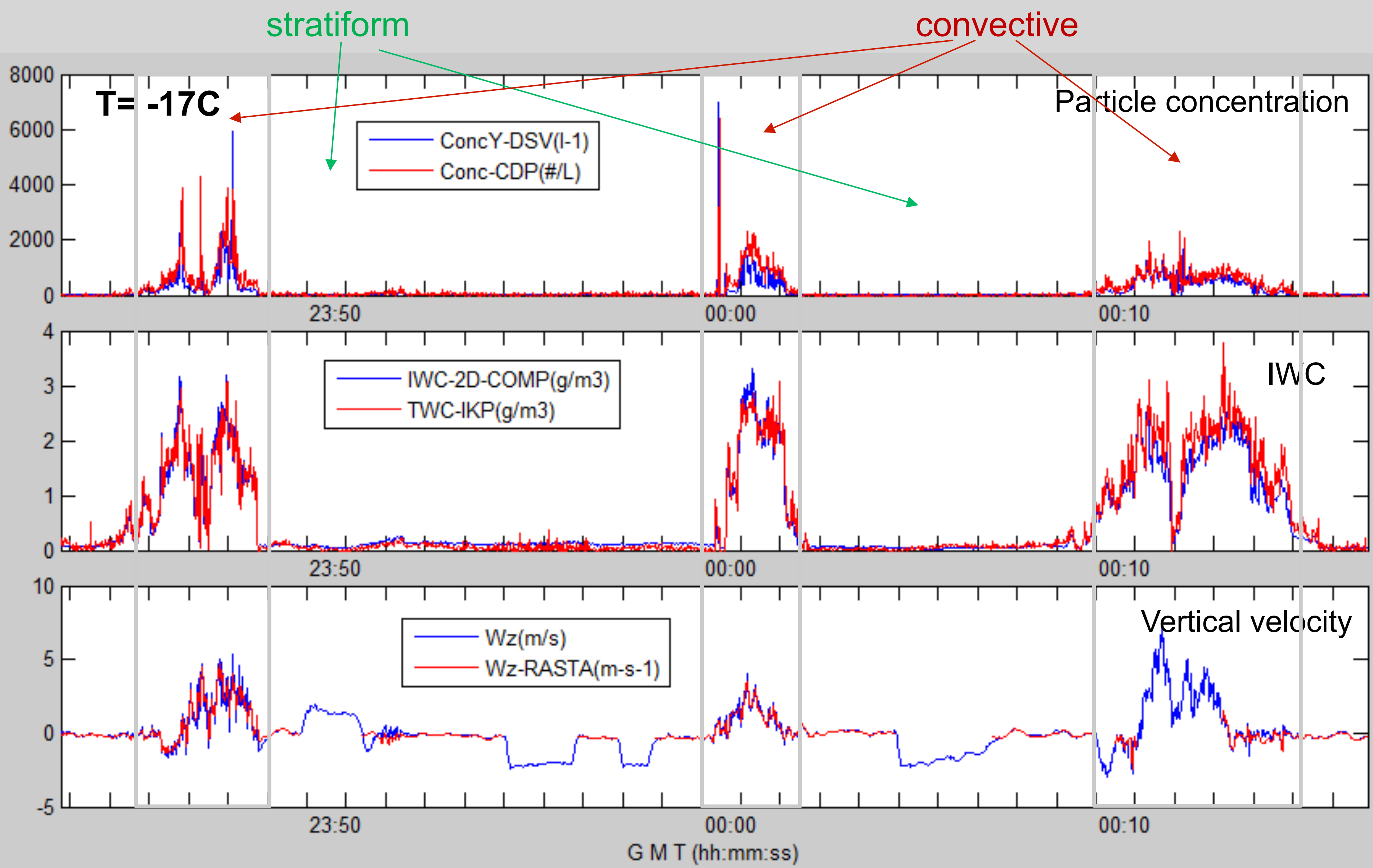
- Correlation between vertical velocity and particle concentration and HIWC cloud regions
- Consistent with previous similar observations
- Stratiform regions: Uz ~ 0m/s, IWC<1g/m^3, N<200L-1
- Convective regions: |Uz| >1m/s, IWC>1÷5g/m^3, N>500L-1
- Characteristic horizontal size of convective regions $\Delta L \sim 10^2$-10^3m



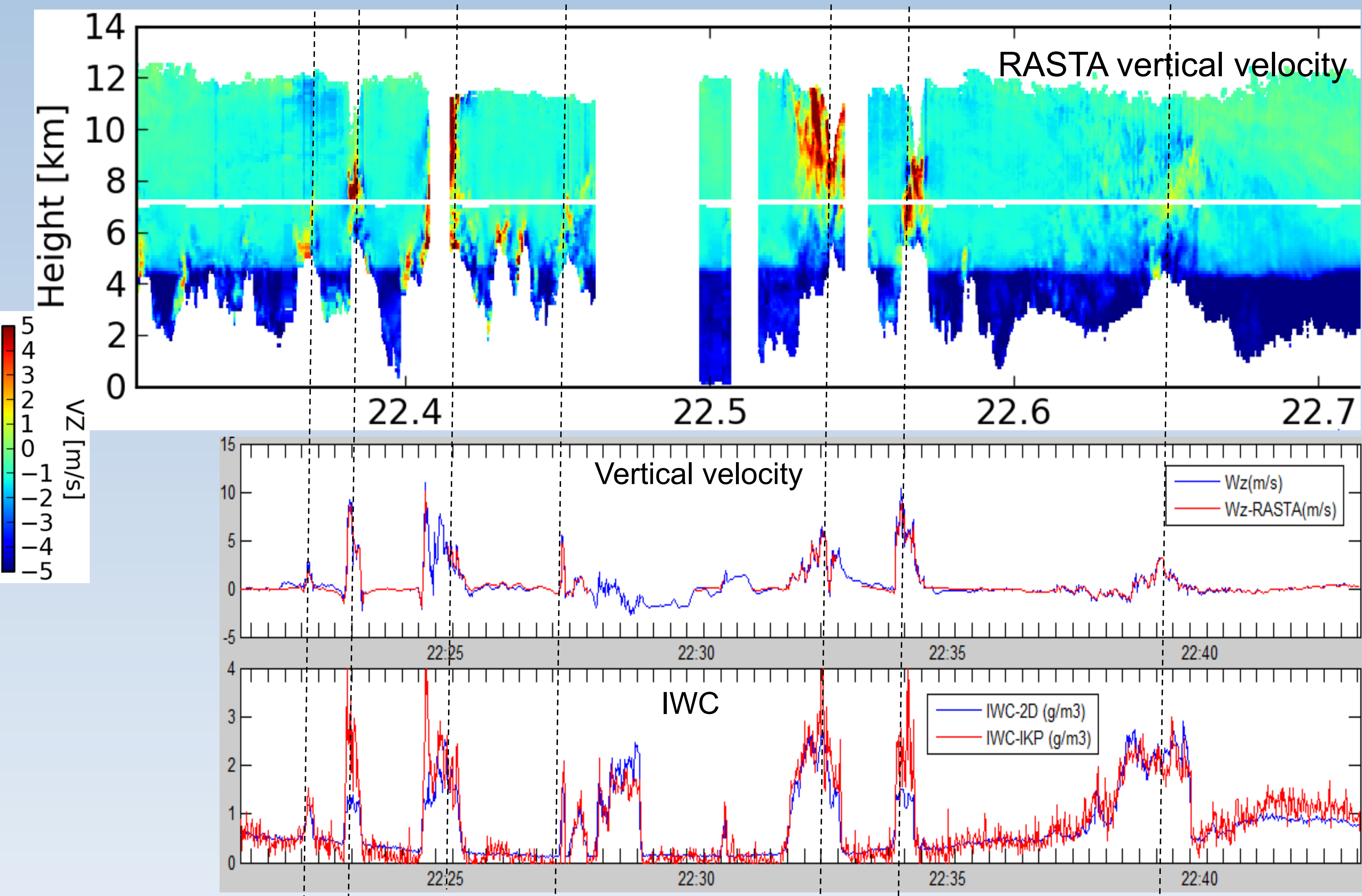
Correlation between U_Z, N and IWC



Correlation between U_Z, N and IWC

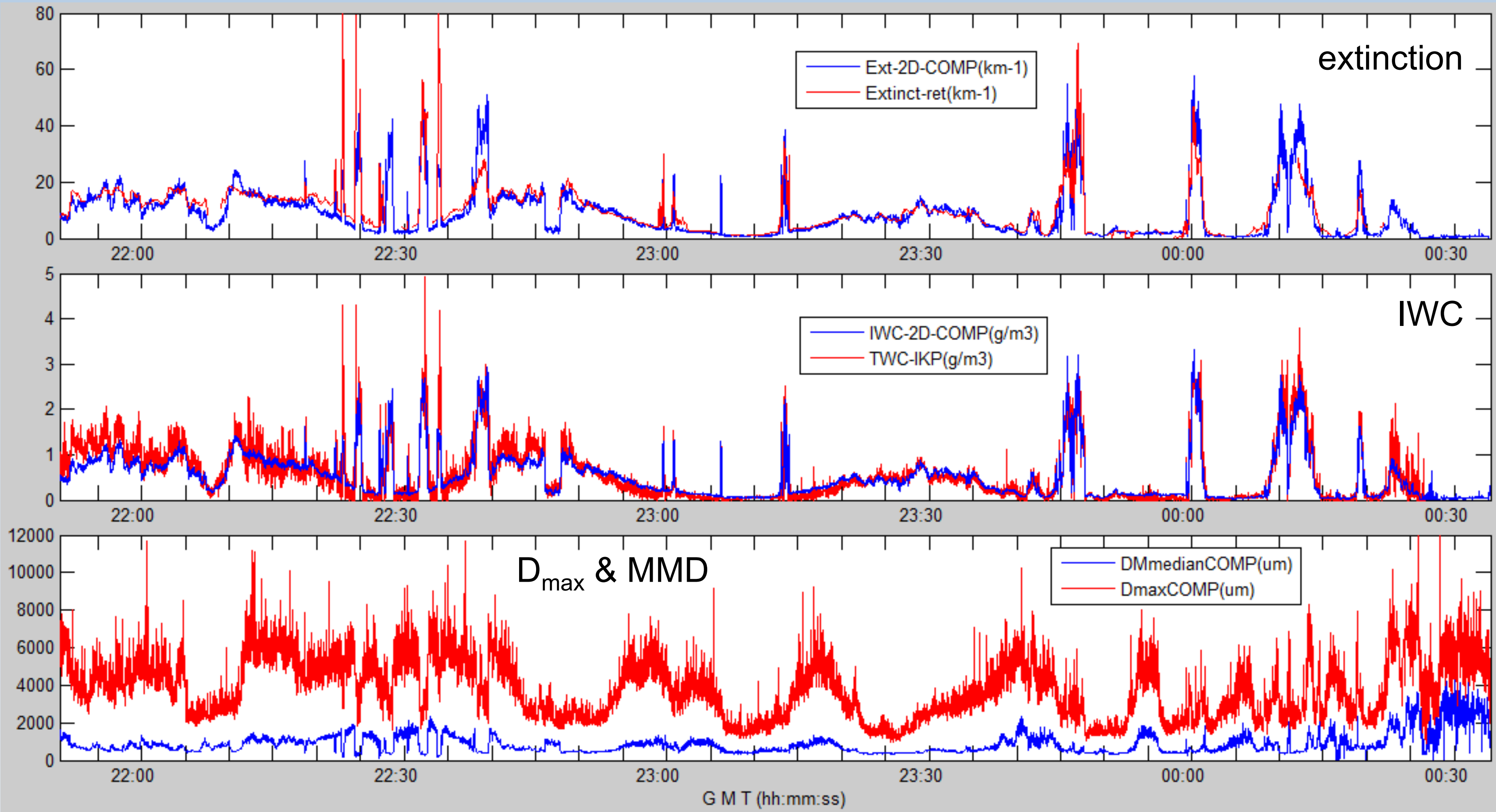


Vertical and horizontal extend of convective cells

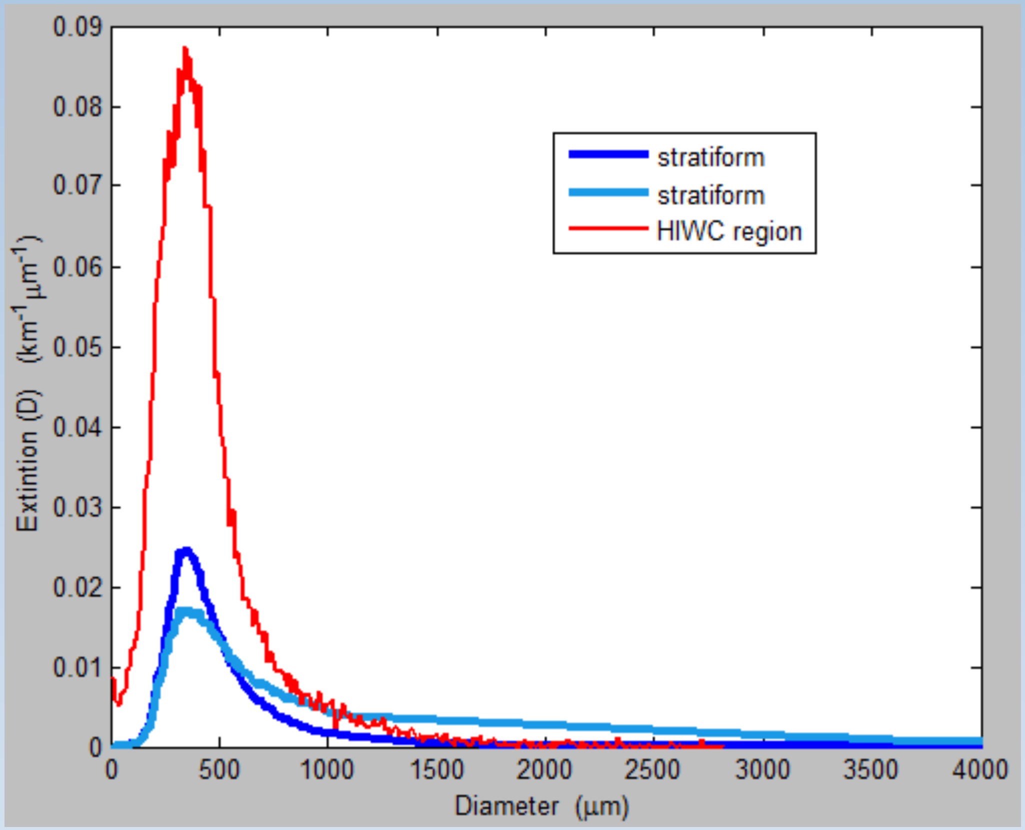


Extinction coefficient (β)

- $1km^{-1} < \beta < 20km^{-1}$ in stratiform regions
- $30km^{-1} < \beta < 80km^{-1}$ in HIWC convective regions



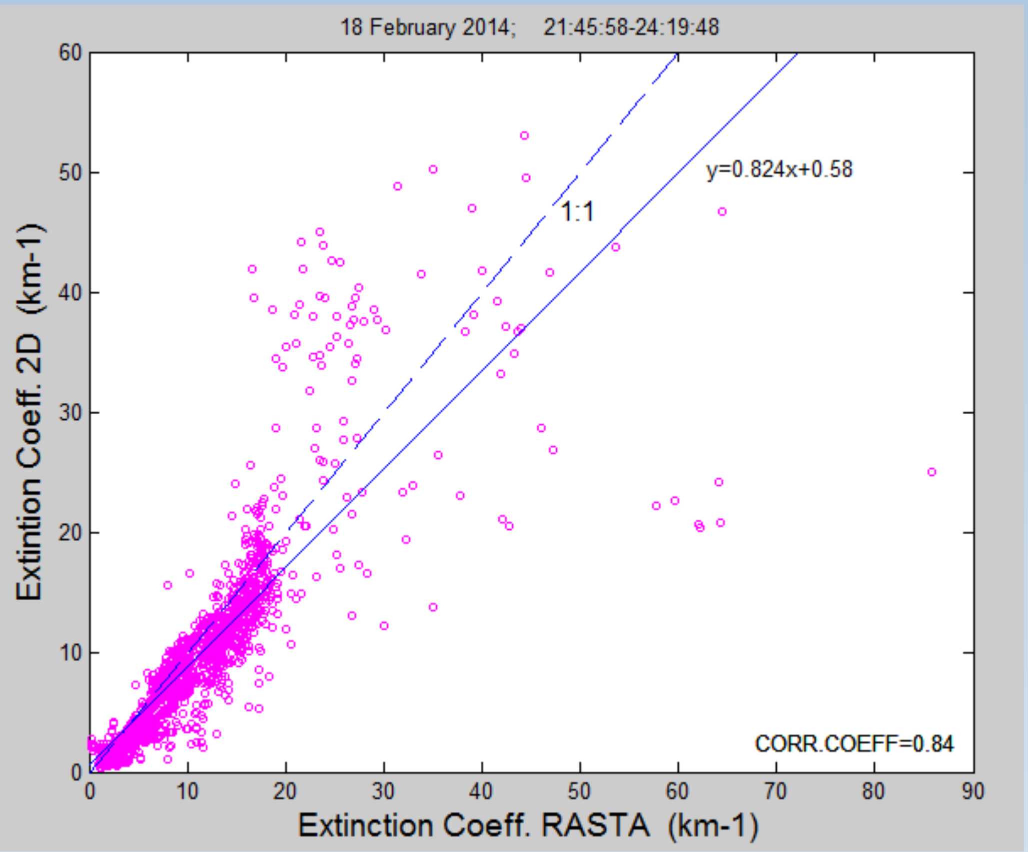
Examples of distributions of extinction coefficient in stratiform and convective cloud regions

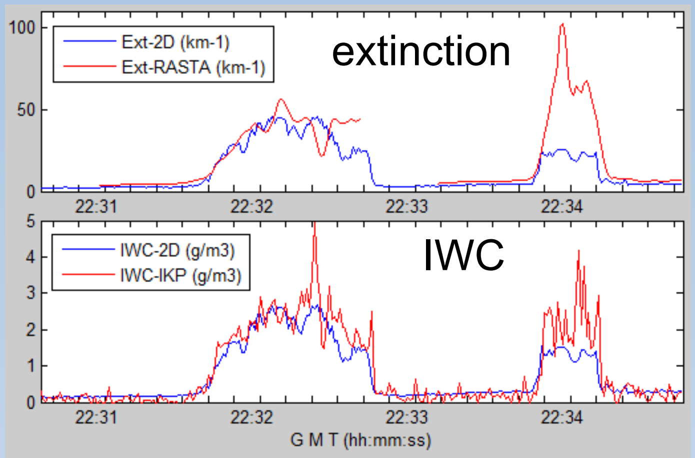


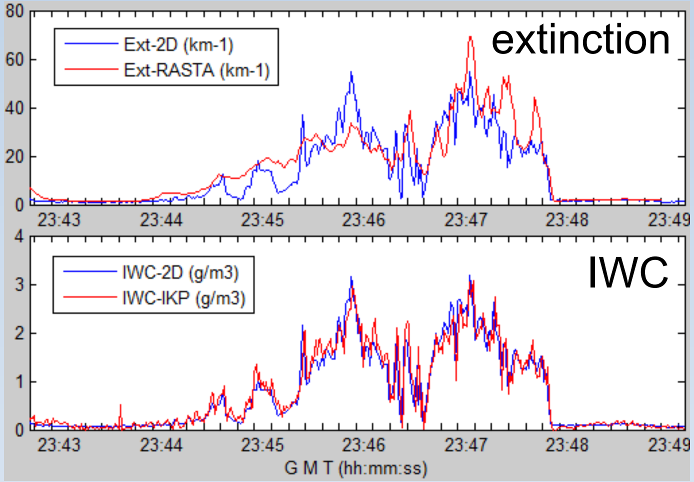
- Both in stratiform and HIWC cloud regions extinction coefficient is mainly contributed by particles from 200<D<600μm size range.

- The distribution β(D) has maximum at D≈300-400μm

Comparisons of extinction coefficient calculated from 2D measurements and that retrieved from the RASTA data





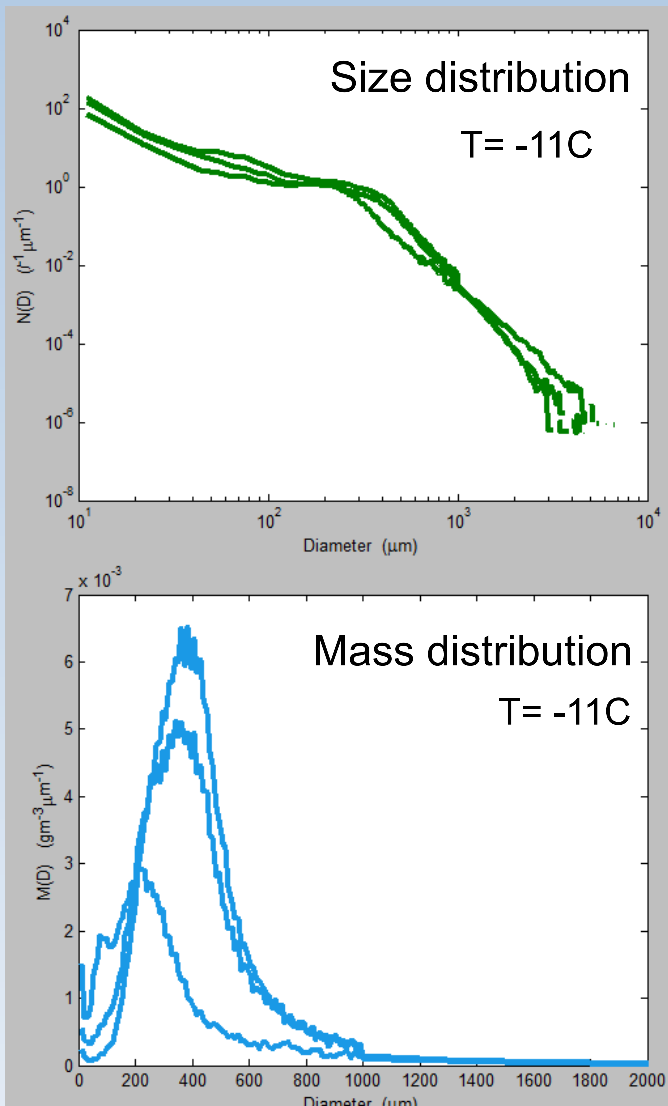


- Good agreement between 2D and RASTA extinction in stratiform regions with $\beta<20km^{-1}$
- For the convective regions with HIWC the separation of β is increasing

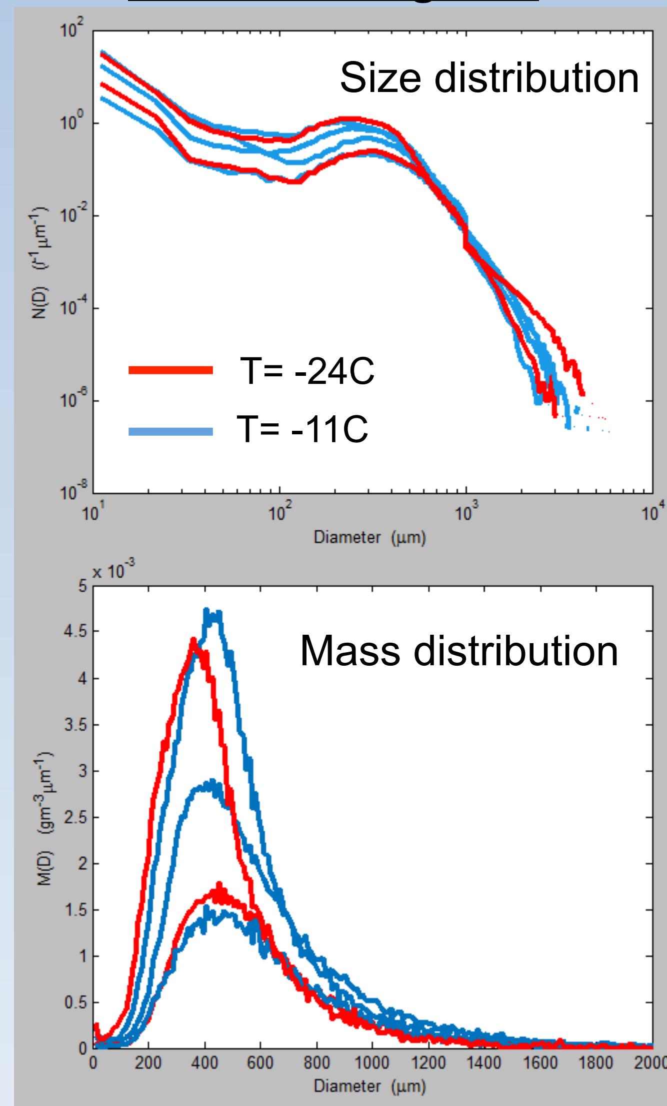
Size and mass distributions

size distribution D_{mod}~200÷300μm both convective & stratiform
mass distribution D_{mod}~200÷400μm both convective & stratiform

convective (HIWC) regions

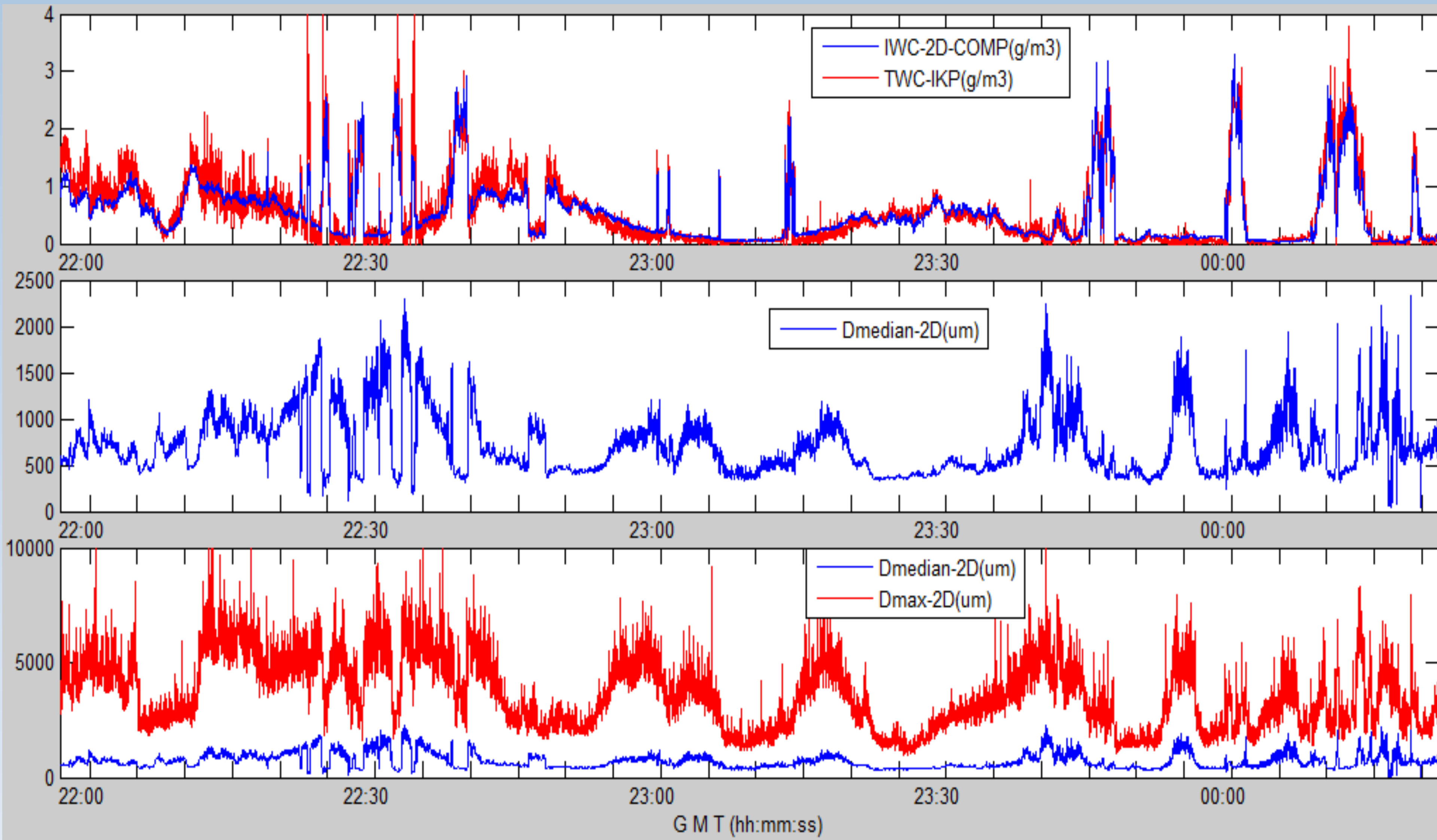


stratiform regions



Median Mass Diameter

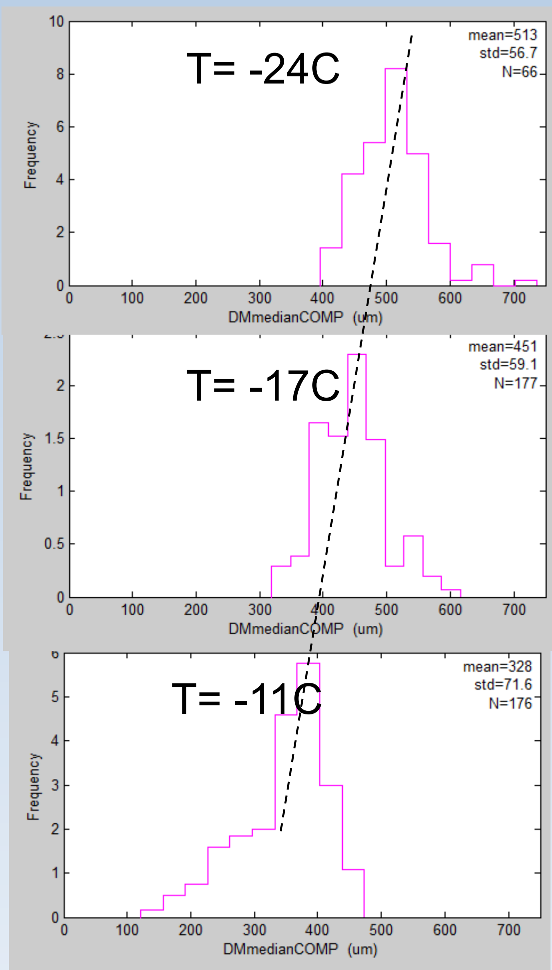
D_{MM} drops down in HIWC cloud regions



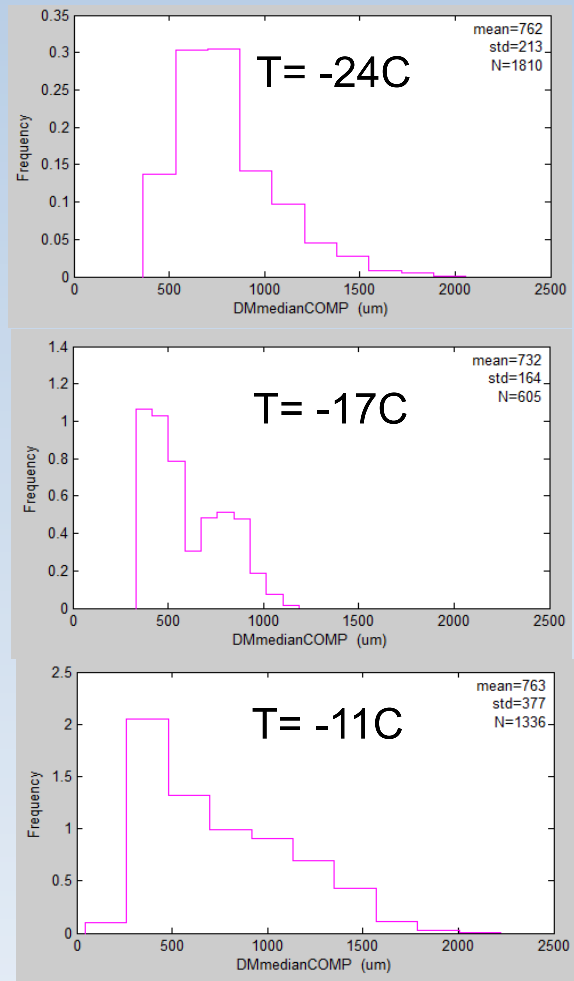
Median Mass Diameter

- $200 < D_{MM} < 600 \mu m$ in HIWC cloud regions
- $300 < D_{MM} < 1500 \mu m$ in stratiform cloud regions
- D_{MM} depends on altitude (or T), cloud dynamics and age

<u>Convective (HIWC) regions</u>



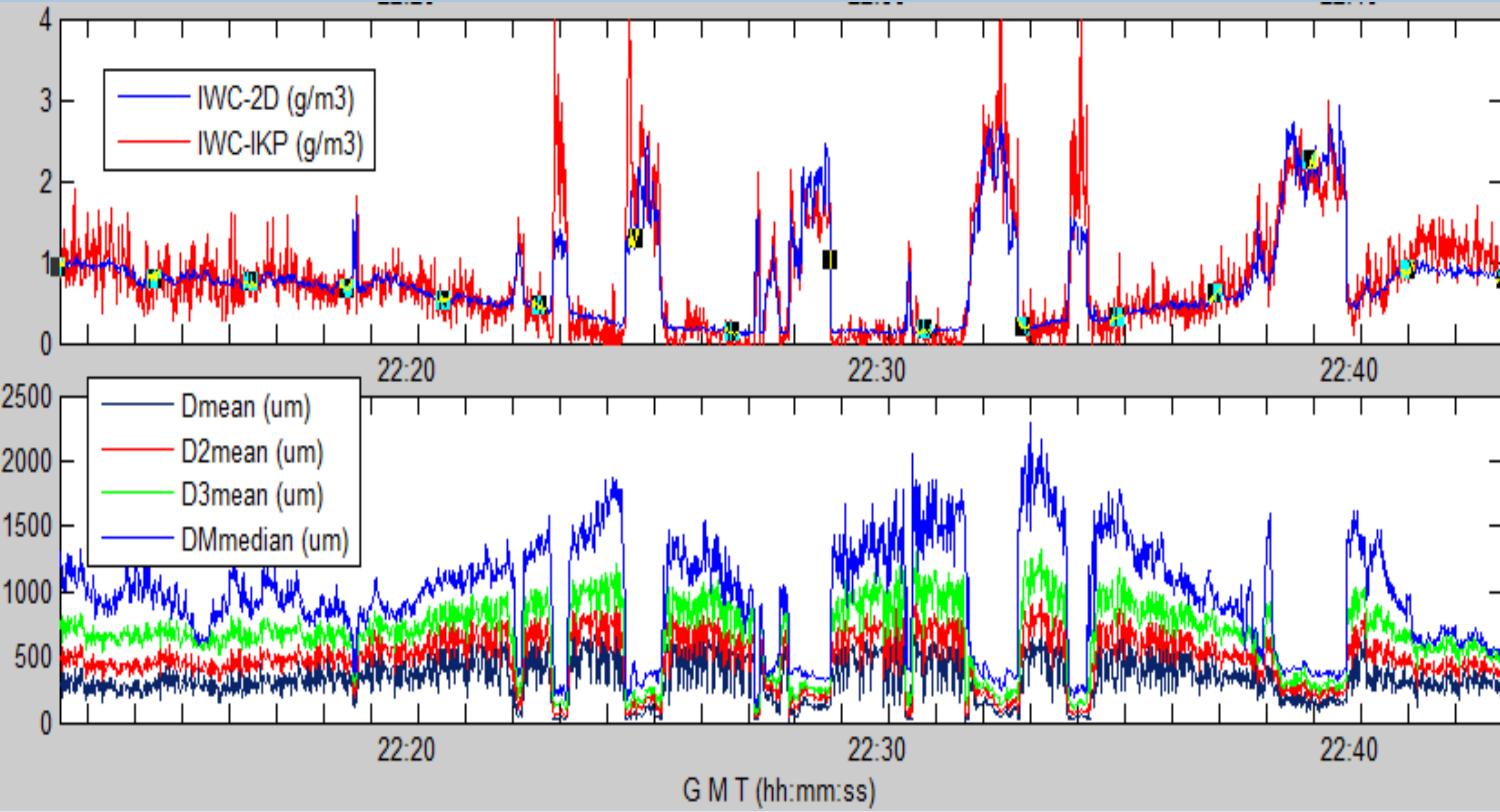
<u>Stratiform regions</u>



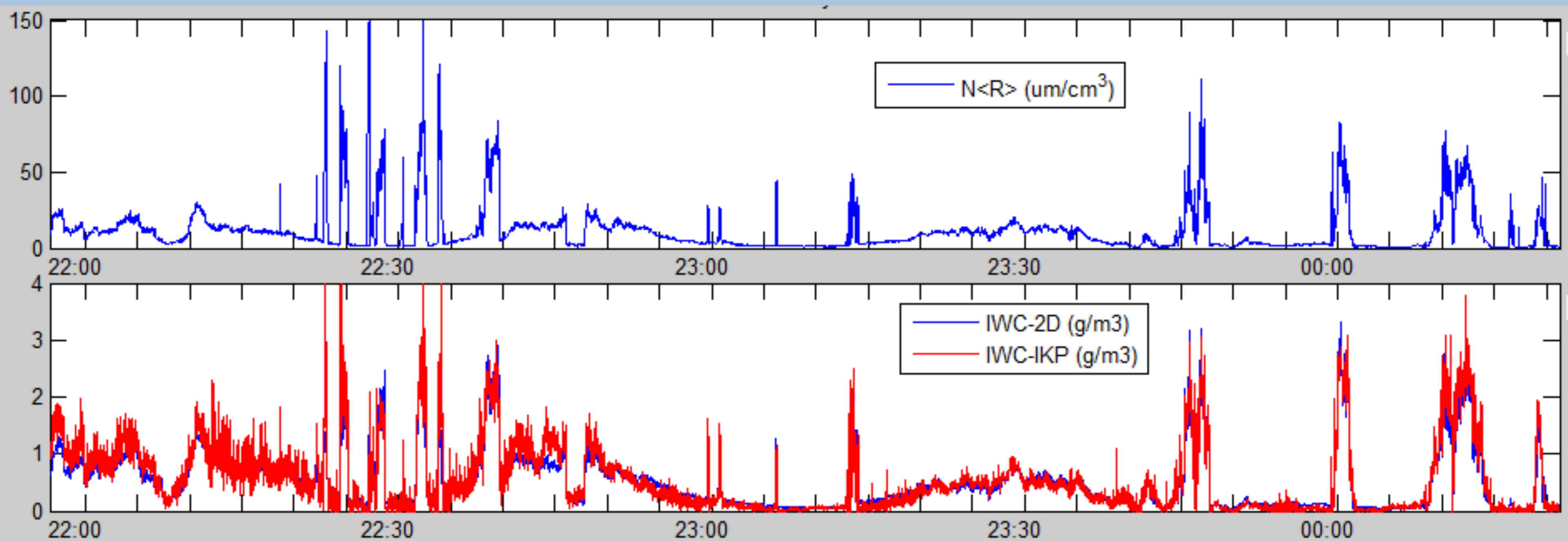
MMD in HIWC convective regions depends on altitude.

However in stratiform regions there is no clear correlation between MMD and altitude (or T)

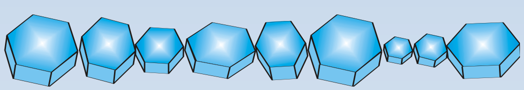
Other characteristic sizes



Integral particle size



$$N_i\bar{r}_i = \int_0^{\infty} f_i(r_i)\, r\, dr_i$$



$2N_i\bar{r}_i$ length of all particles

- $1 < N_i r_i < 30\mu m$ in HIWC cloud regions
- $30 < N_i r_i < 150\mu m$ in stratiform cloud regions

Integral radius $N_i r_i$ determined the rate of the water vapour depletion by ice particles and maintenance of mixed phase

Time of phase relaxation

Korolev & Mazin (JAS, 2003)

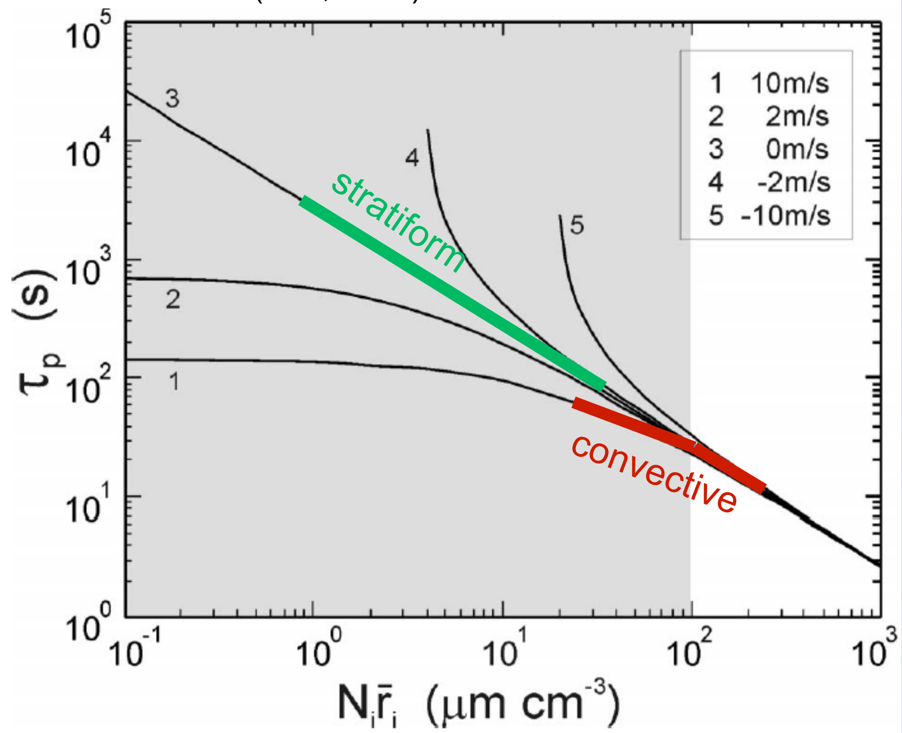


FIG. 6. Time of phase relaxation vs $N_i\bar{r}_i$ in ice clouds for different vertical velocities; $T = -10°C$; $P = 680$ mb. Gray color indicates $N_i\bar{r}_i$ typical for the ice clouds.

$$\tau_p = \frac{1}{a_0 u_z + b_i N_i \bar{r}_i}$$

Time of phase relaxation determines the characteristic time of relative humidity approaching to its equilibrium value S_{qsi}

$$S_{qs\ i} = \frac{a_{0i} u_z}{b_i N_i \bar{r}_i}$$

- $10s < \tau_p < 100s$ convective (HIWC) cloud regions
- $10^2 s < \tau_p < 10^3$ stratiform cloud regions

If $u_Z=0$, then $S_{qsi} \to 0$ i.e. in stratiform region reaching saturation over ice requires minutes to tens of minutes

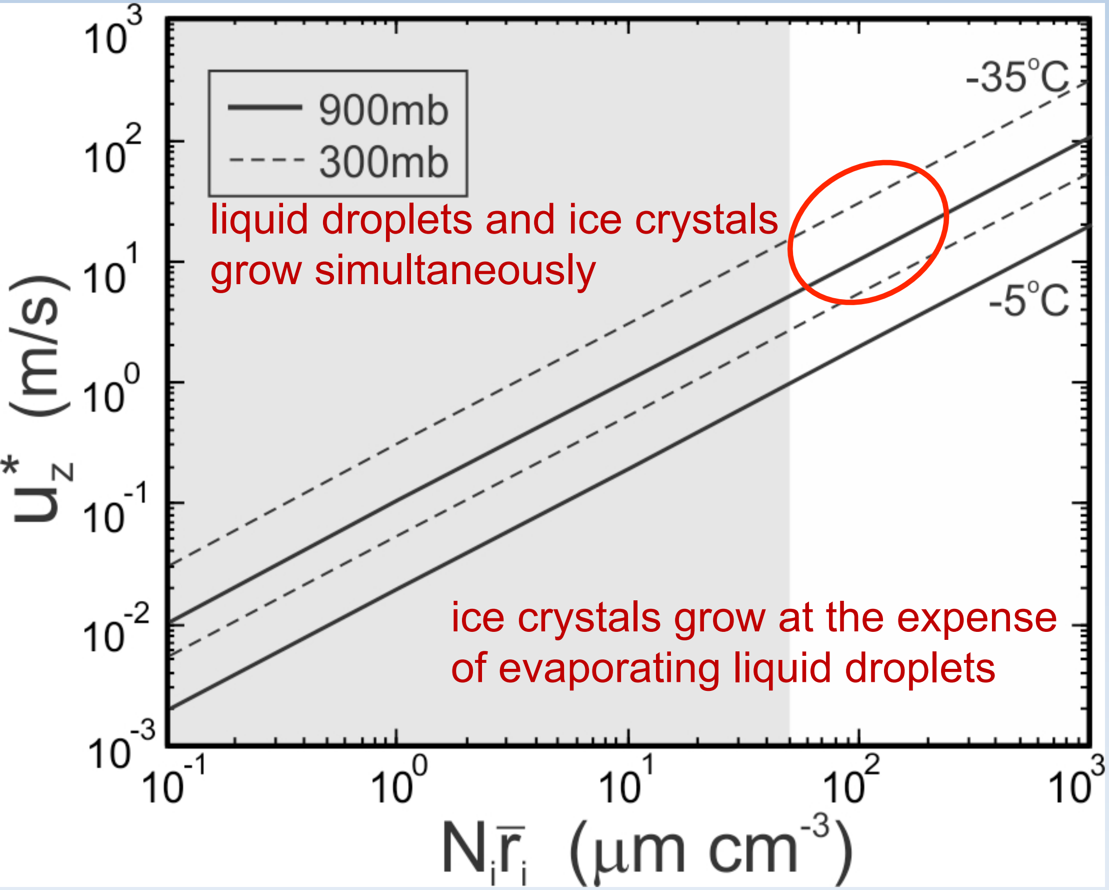
Threshold vertical velocity for activation of liquid in pre-existing ice cloud and maintenance of mixed phase

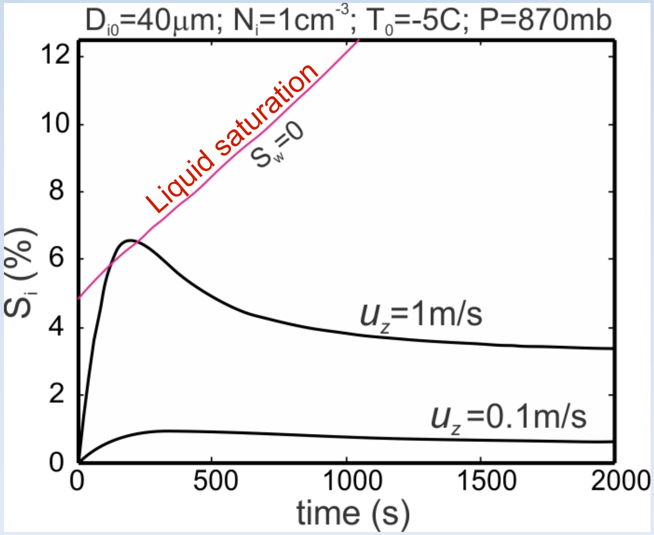
$$\boxed{u_z^* = \frac{b_i^* N_i \bar{r}_i}{a_{0w}}}$$

$u_z > u_z^*$ condition for activation of liquid water in ice cloud

For *Nr* found in convective regions the threshold vertical velocity ranges from few m/s to few tens on m/s. Such high U_z* suggests low probability of finding mixed phase in HIWC regions, unless very high updrafts Uz>15-20m/s

Korolev & Mazin (JAS, 2003)





Modeling of glaciation liquid cloud during ascent

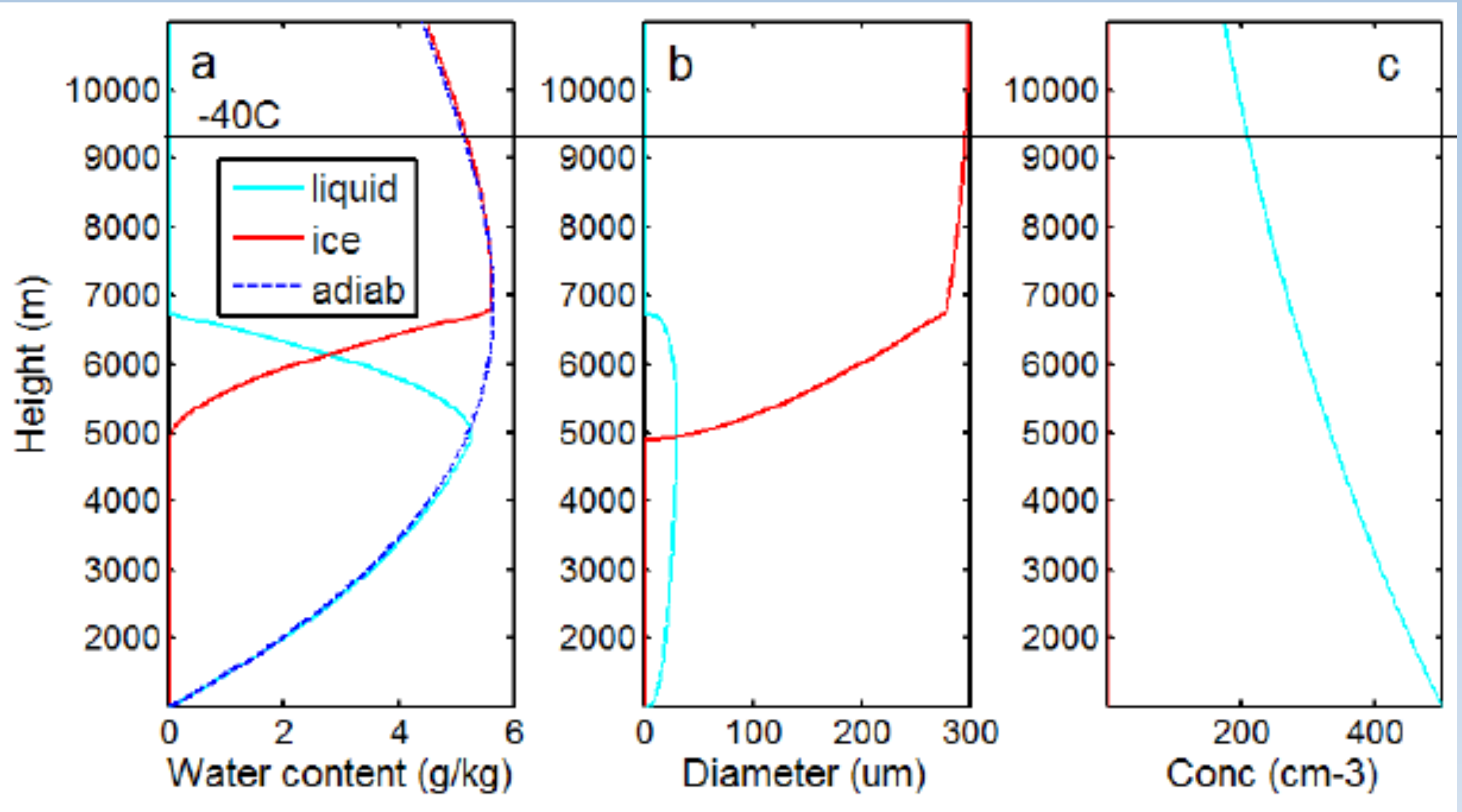
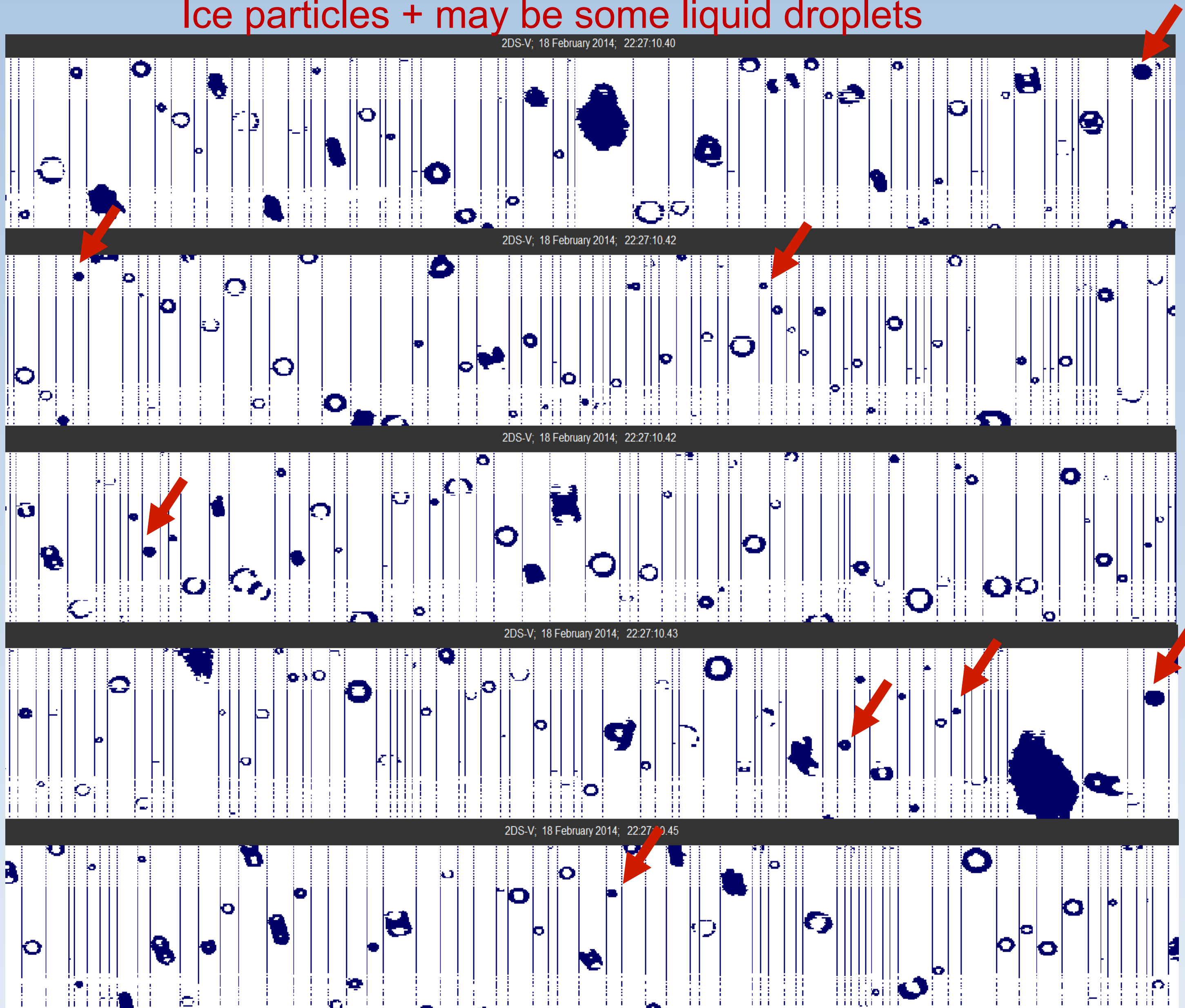


Fig. 3.6. Modeling of changes of (a) LWC and IWC; (b) cloud particle sizes; (c) droplet and ice concentrations; (d) temperature during adiabatic ascent. Ice particles were initiated at T=-5 C, ice particle concentration 1 cm^{-3}, vertical velocity u_z=1 m/s; H_0=500 m, T_0=15 C. Results are for diffusional growth only.

2DS imagery from HIWC convective cloud region

T= -11C; H=7100m

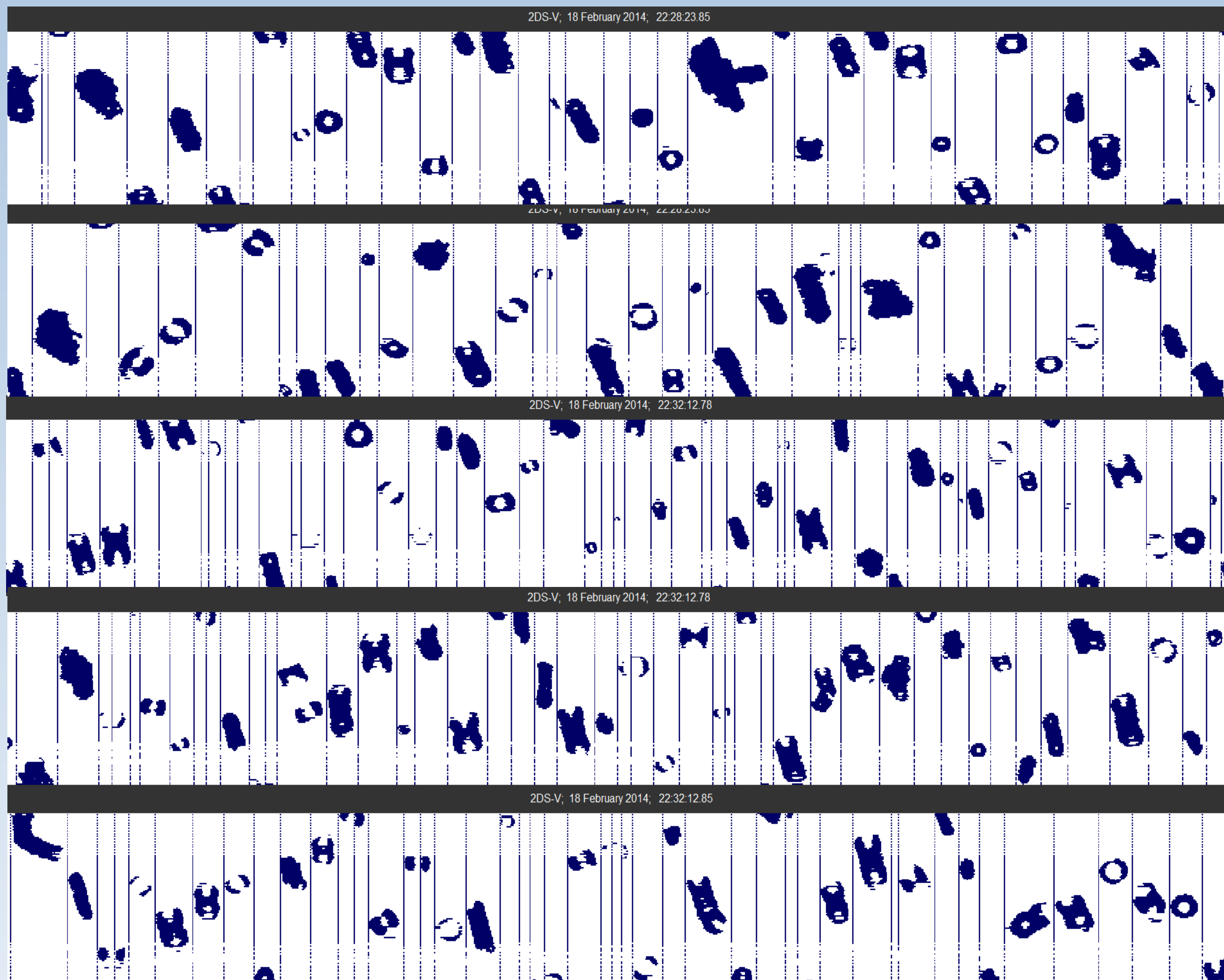
Ice particles + may be some liquid droplets



2DS imagery from HIWC convective cloud region

T= -11C; H=7100m

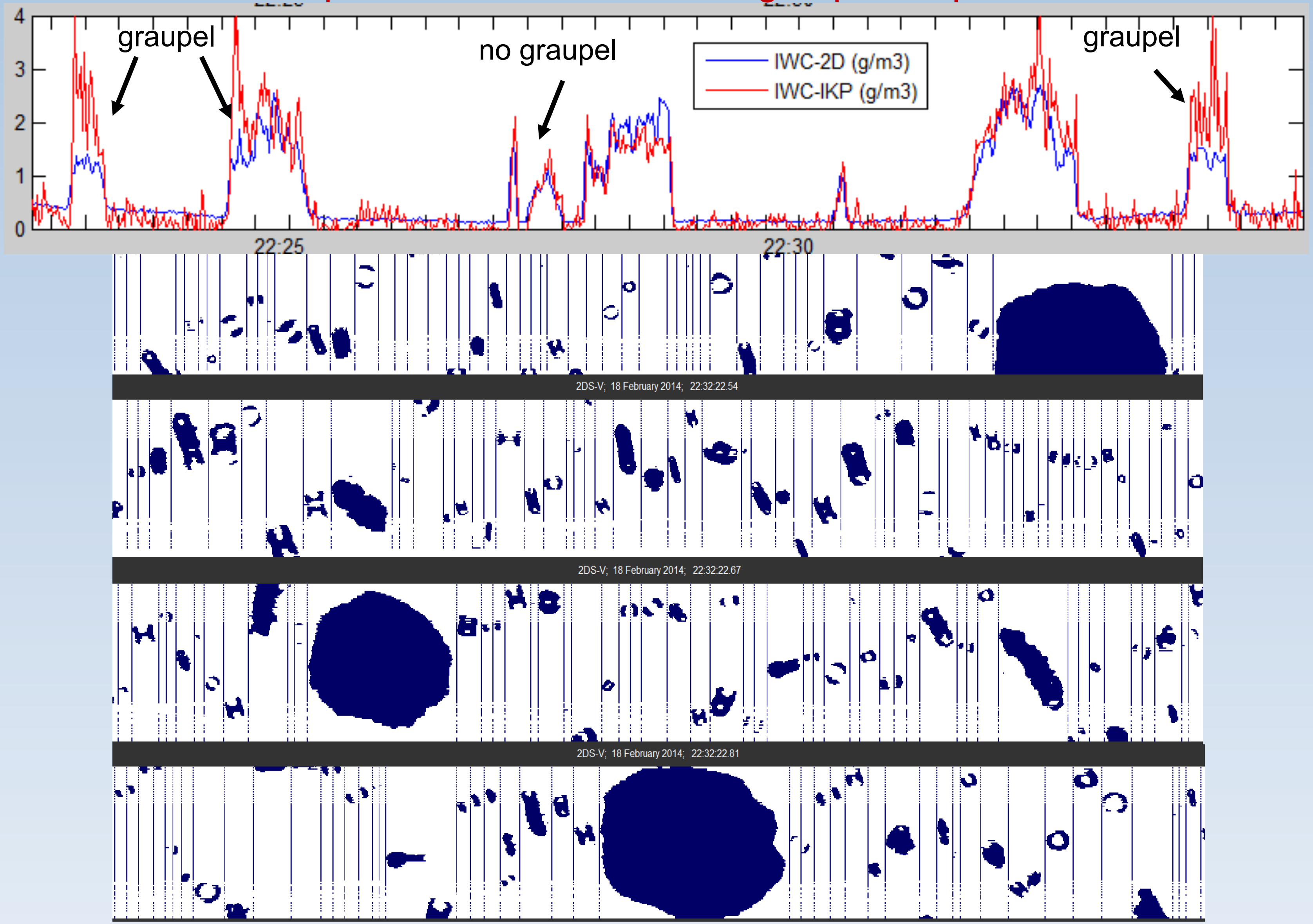
Ice particles: mainly columns, most likely formed due to Hallet-Mossop ice multiplication at lower level, NO AGGREGATES



2DS imagery from HIWC convective cloud region

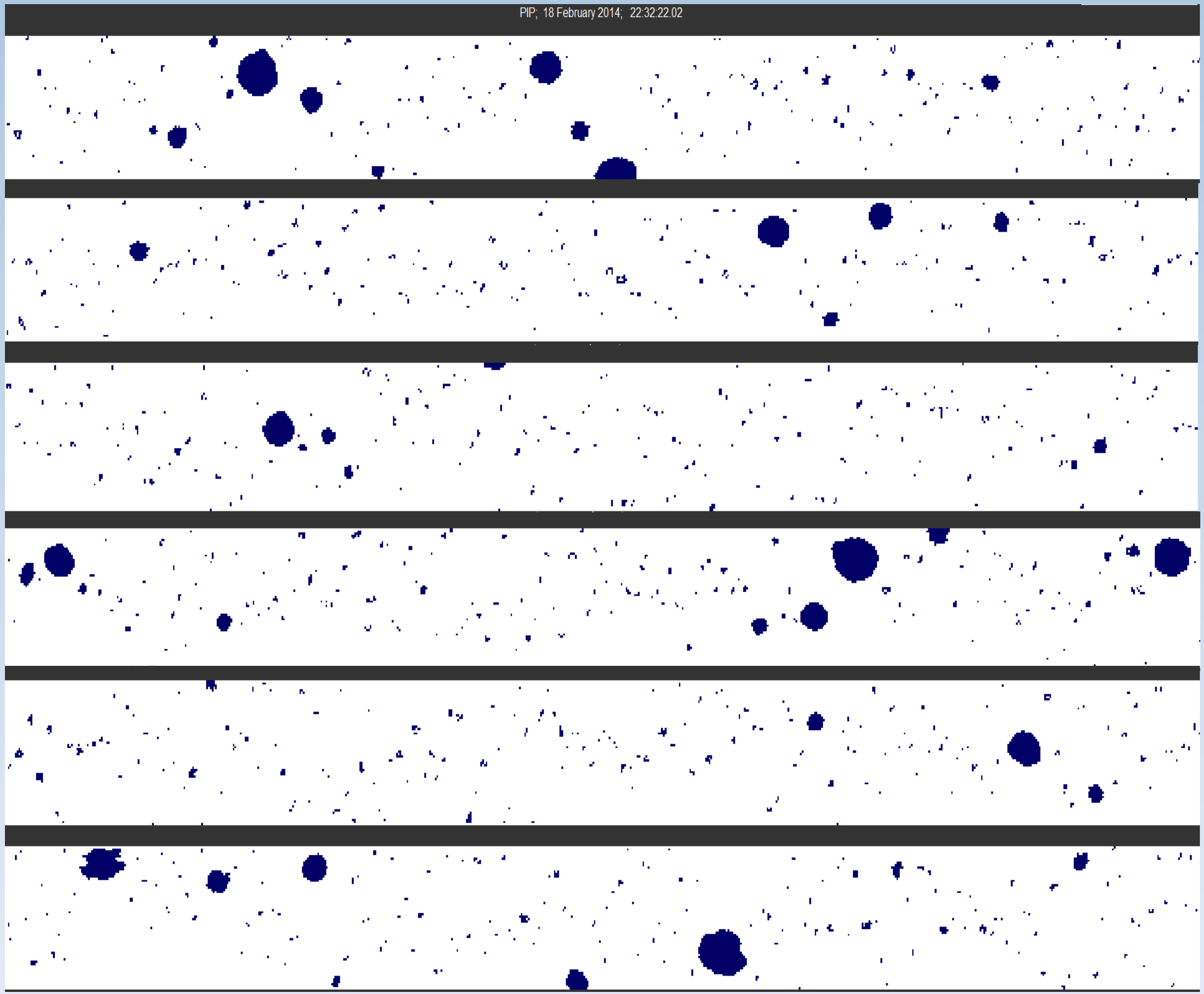
T= -11C; H=7100m

Ice particles: columns + hail/graupel/ice pellet



PIP images from convective (HIWC) cloud regions

Frozen raindrops or hail or graupel or all of them?
NO AGGREGATES

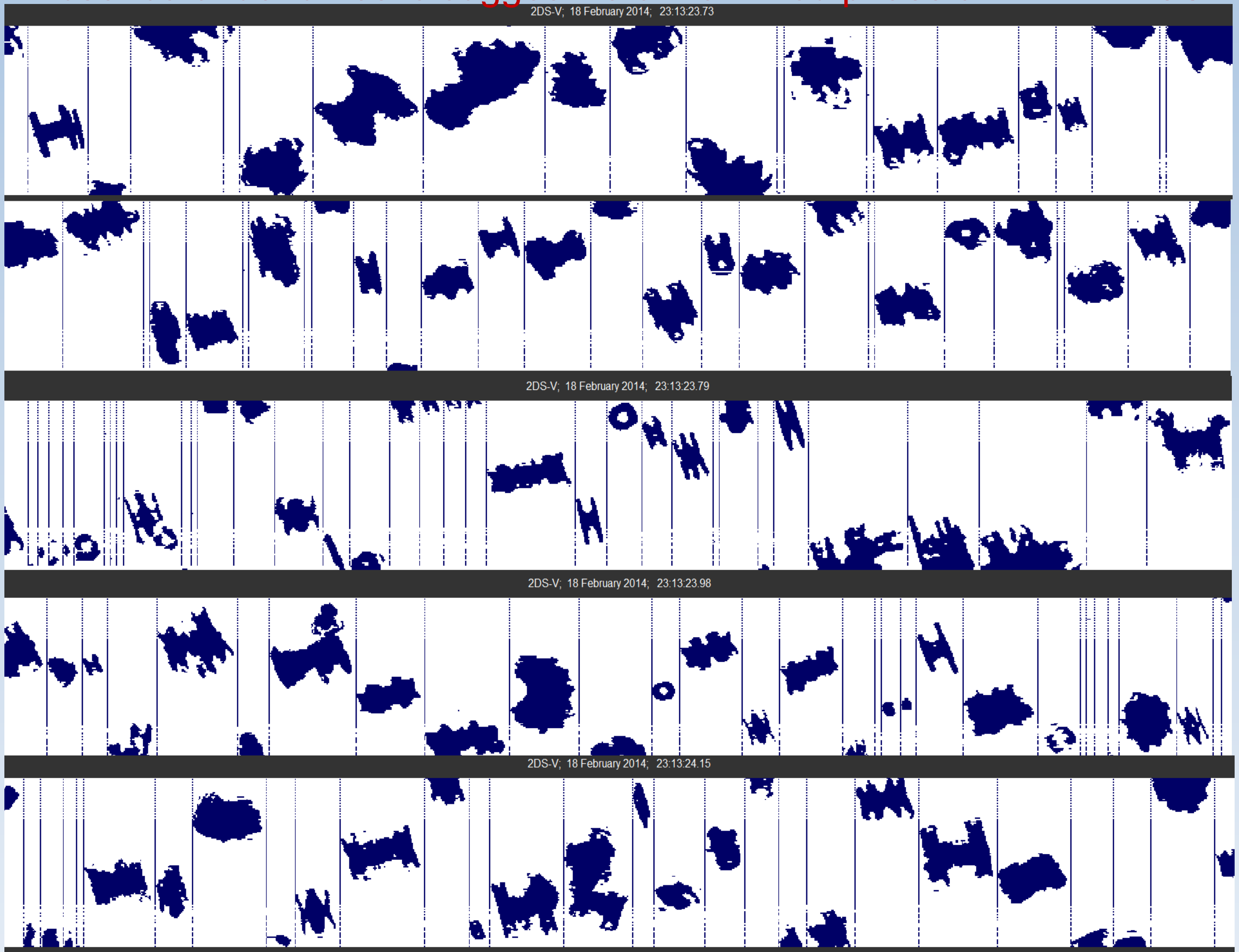


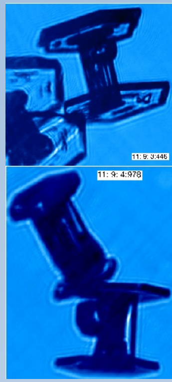
2DS imagery from HIWC convective cloud region

T= -24C; H=9100m

Ice particles: capped columns, no hailstones/graupel

Absence of dendrites is suggestive of no mixed phase at -12<T<-18C





Particle images dominated by capped columns measured by HSI from NRC Convair580 during HAIC-HIWC in Cayenne (Flight 2015-05-15 UTC time 11 30 53)

Bachalo et al., SAE, Prague, 24-June-2015

Ice particle habits formed at different T and RH

plan

colu

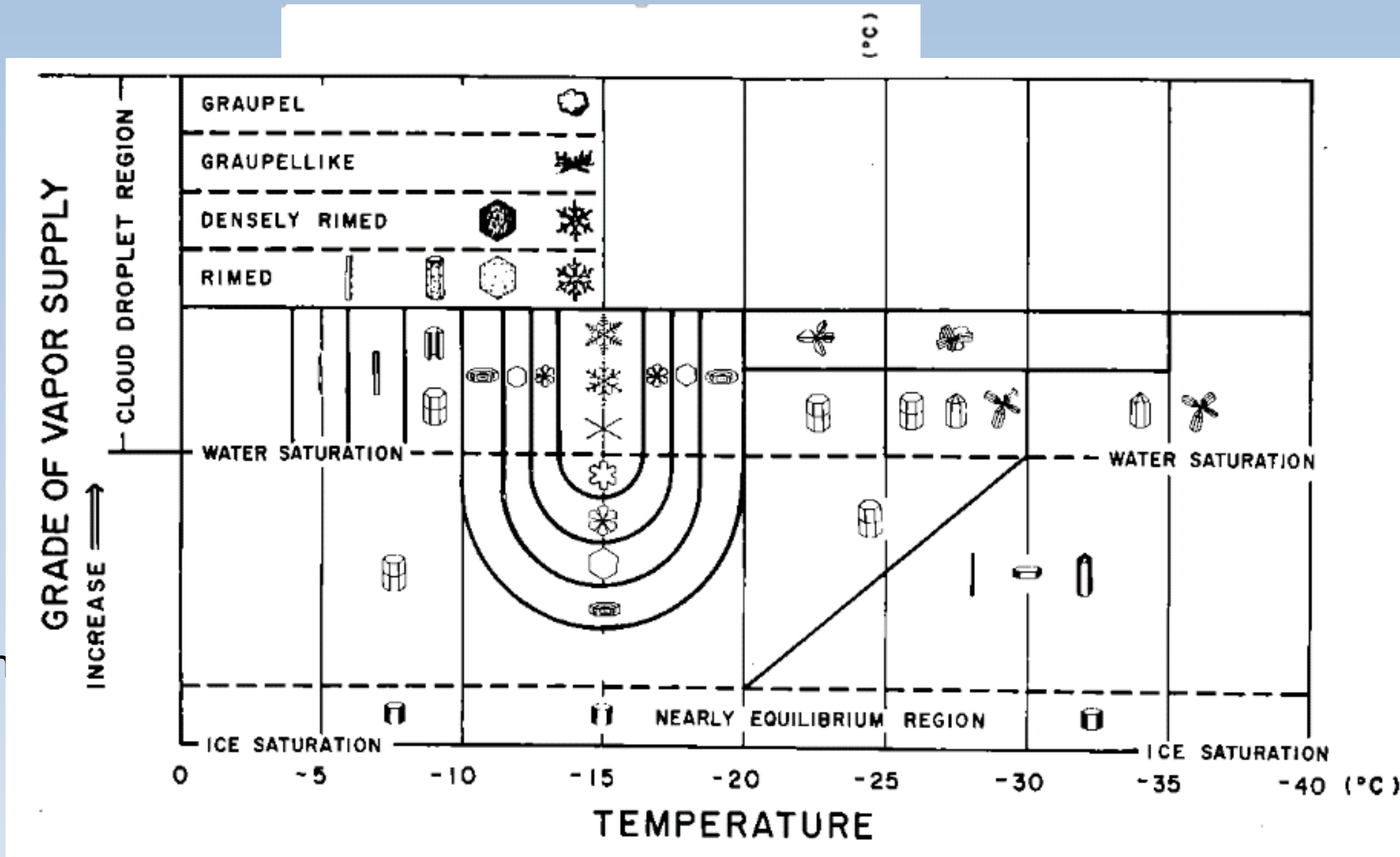
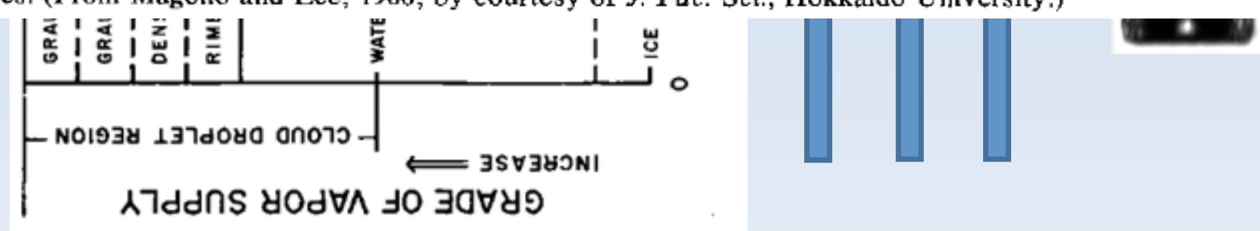


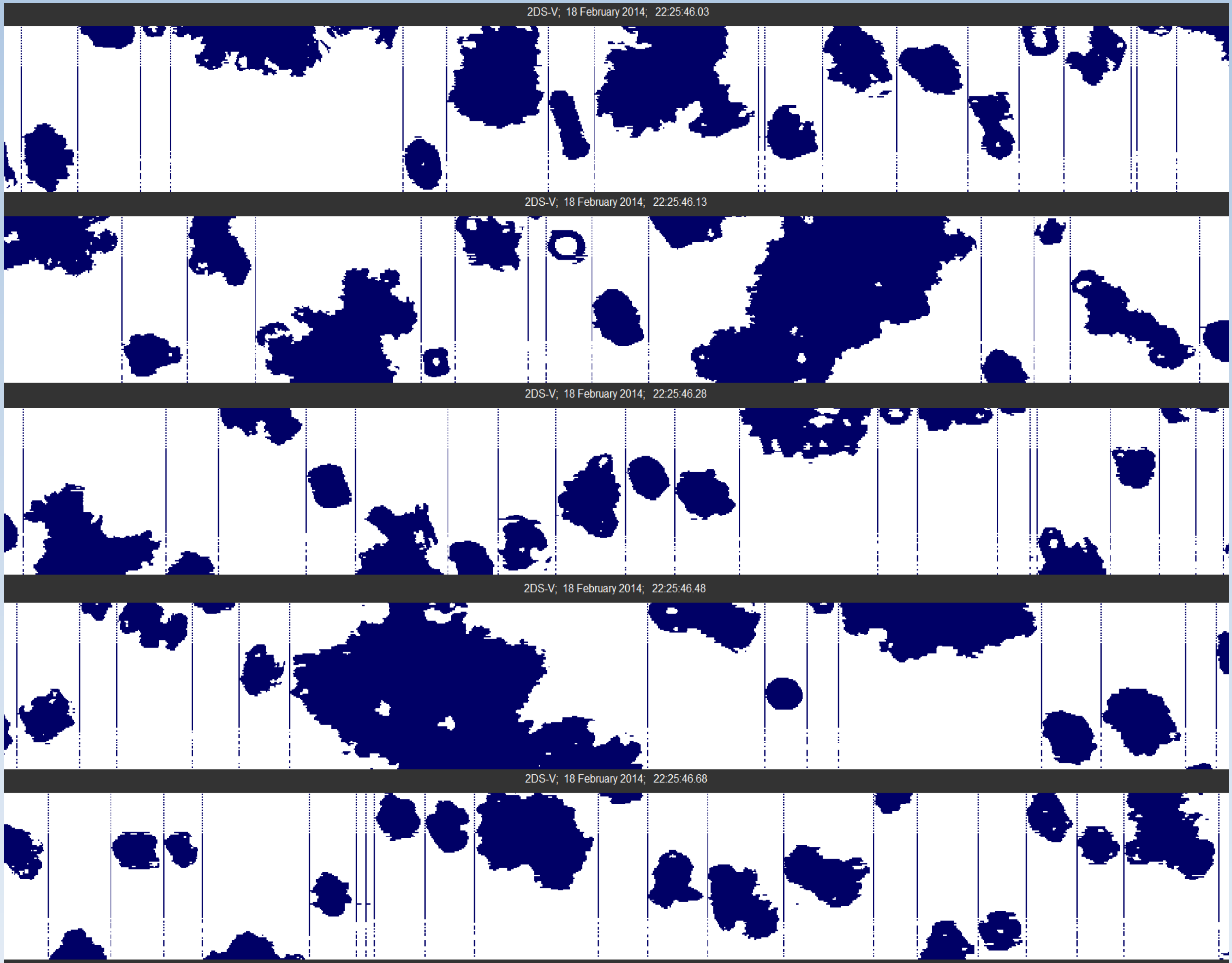
Fig. 2-26. Temperature and humidity conditions for the growth of natural snow crystals of various types. (From Magono and Lee, 1966; by courtesy of *J. Fac. Sci.*, Hokkaido University.)



Ice particle habits in stratiform cloud regions

T= -11C; H=7100m

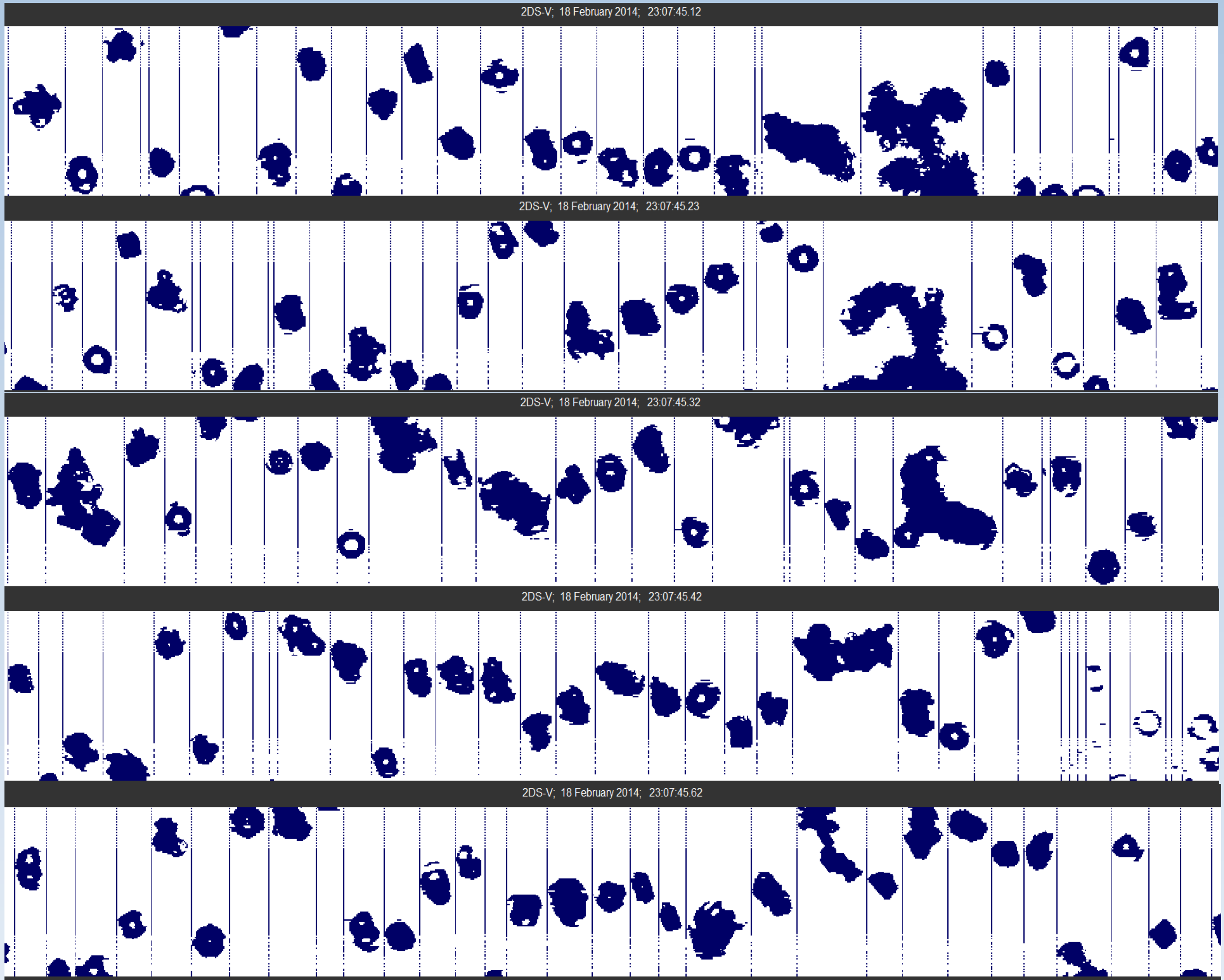
Ice particles: mix of columns, capped columns, compact ice, **aggregates**



Ice particle habits in stratiform cloud regions

T= -24C; H=9100m

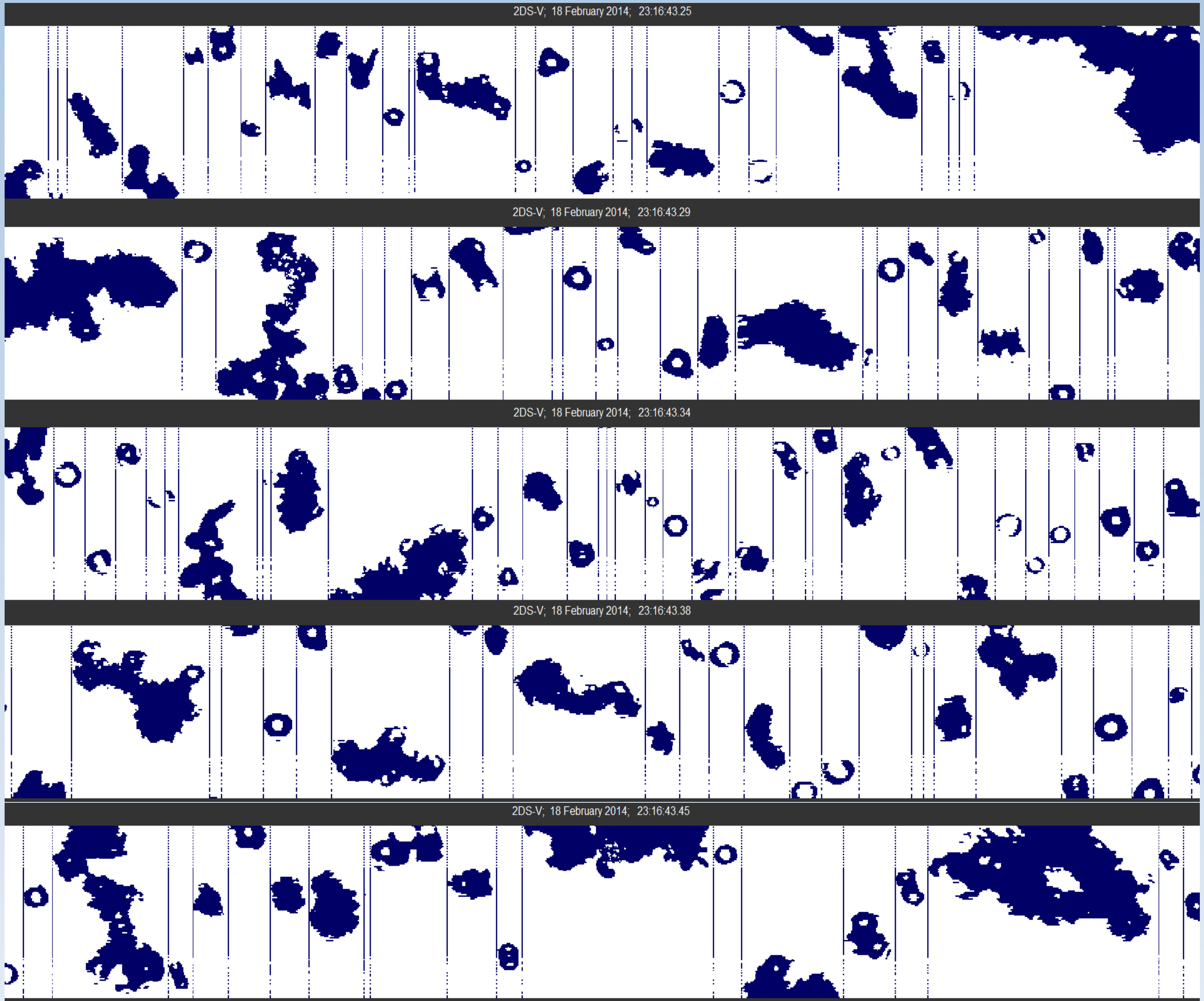
Ice particles: some columns, compact ice, **chained aggregates**



Ice particle habits in stratiform cloud regions

T= -24C; H=9100m

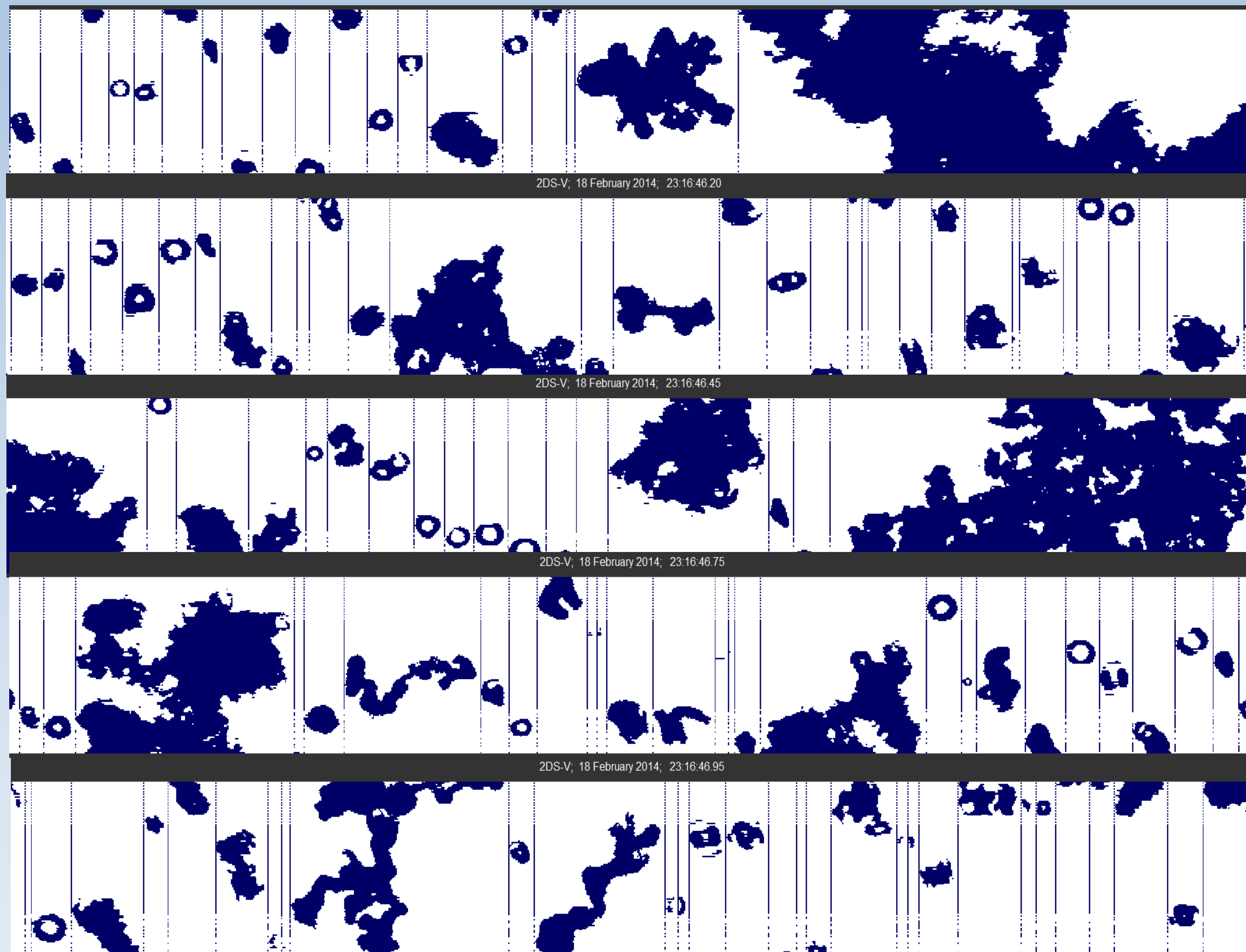
Ice particles: some columns, compact ice, **chained aggregates**



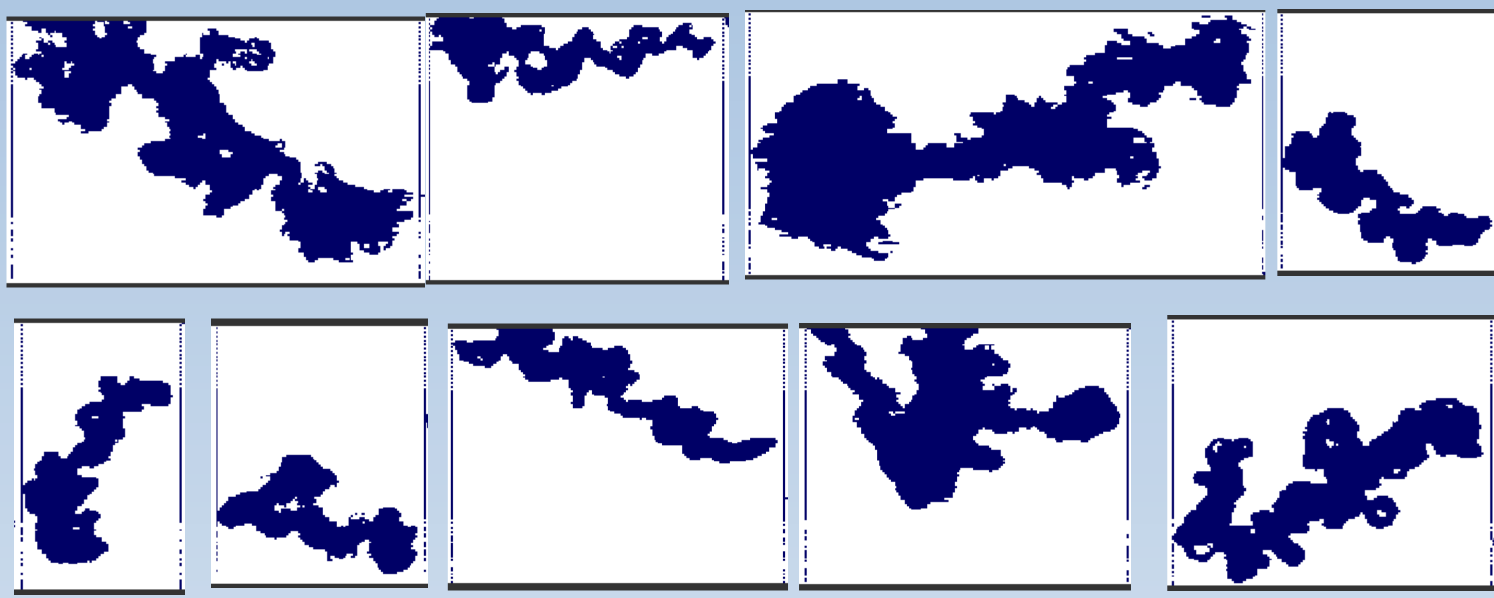
Ice particle habits in stratiform cloud regions

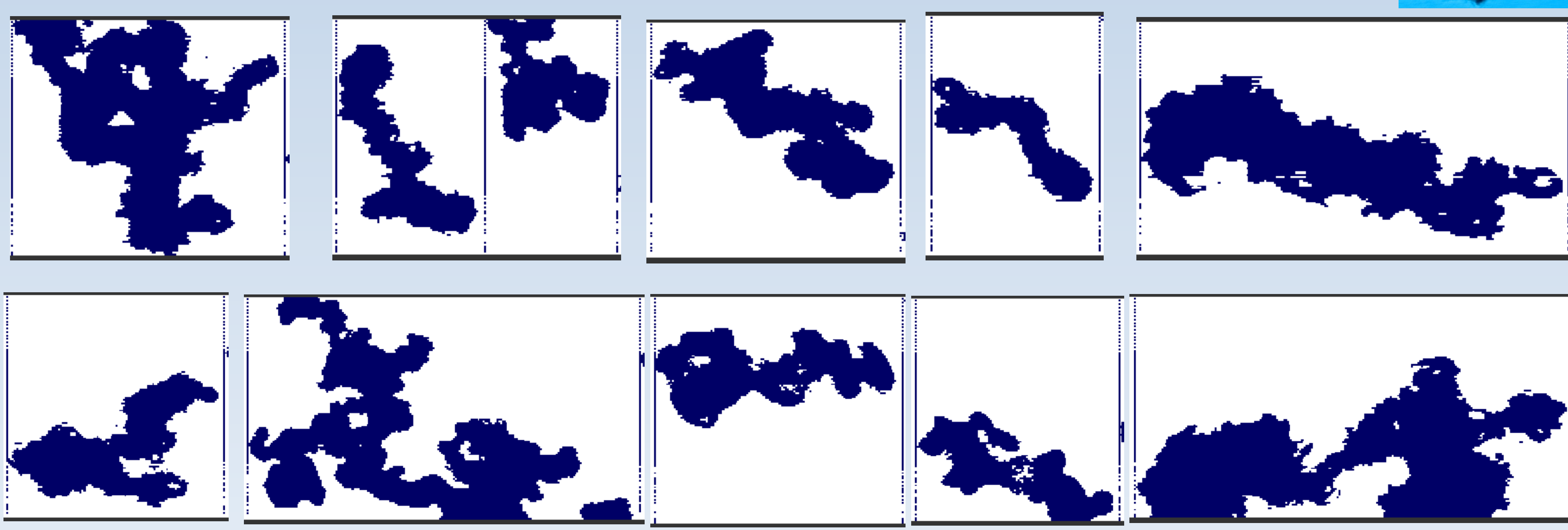
T= -24C; H=9100m

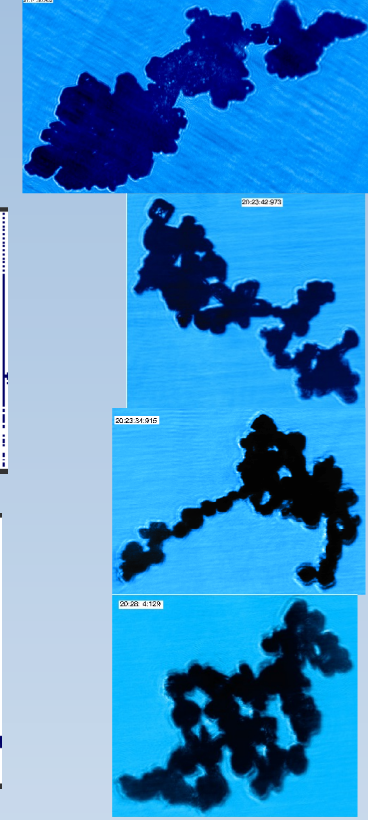
Ice particles: mix of columns, compact ice, compact shape and **chained aggregates**



Aggregated particles at T= -24C level

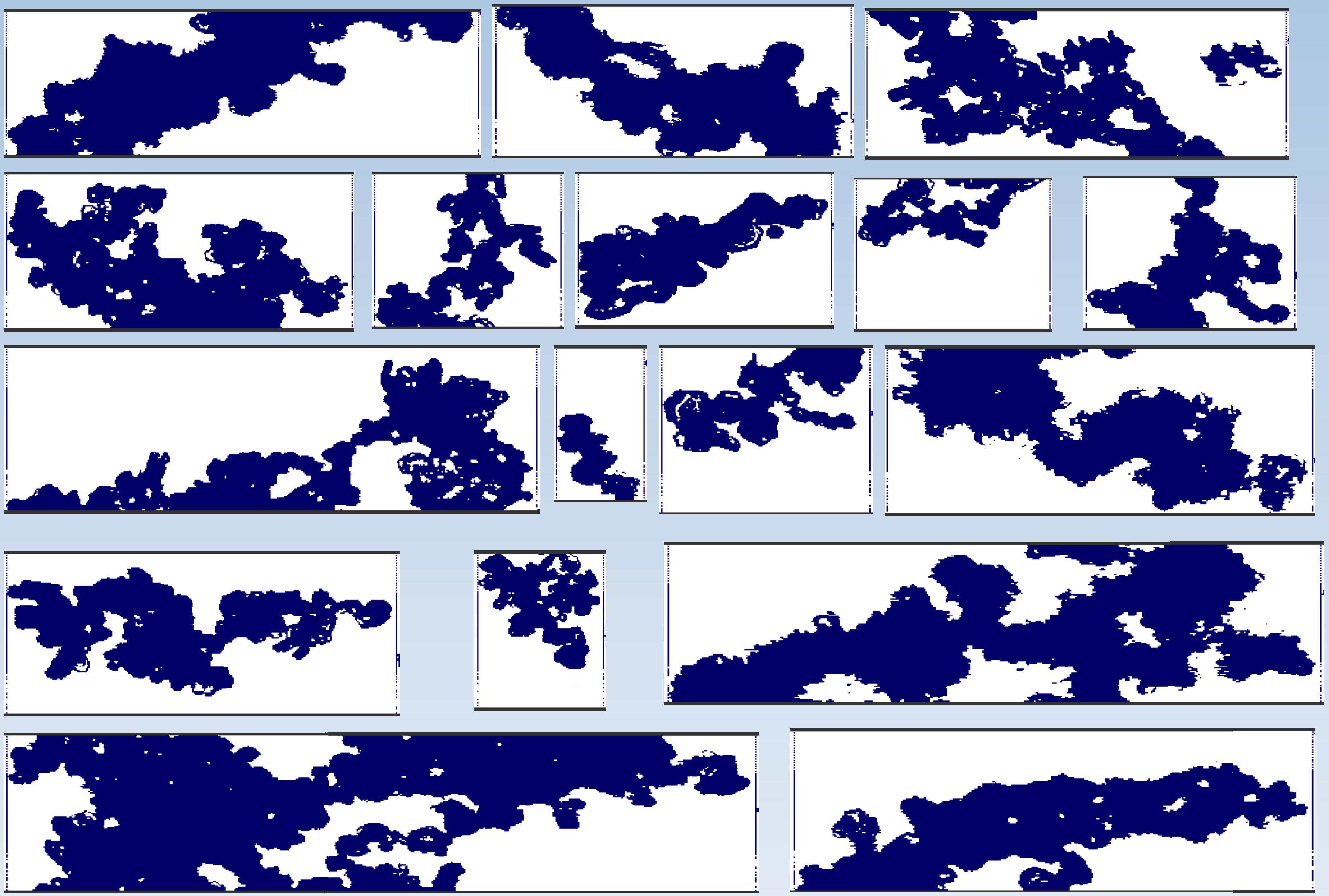






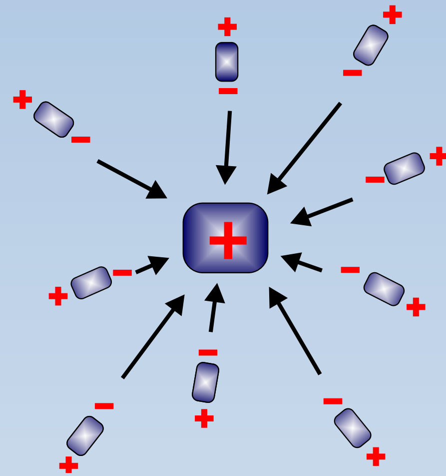
Aggregated particles at T= -11C level

Increase of the aggregates sizes towards ground



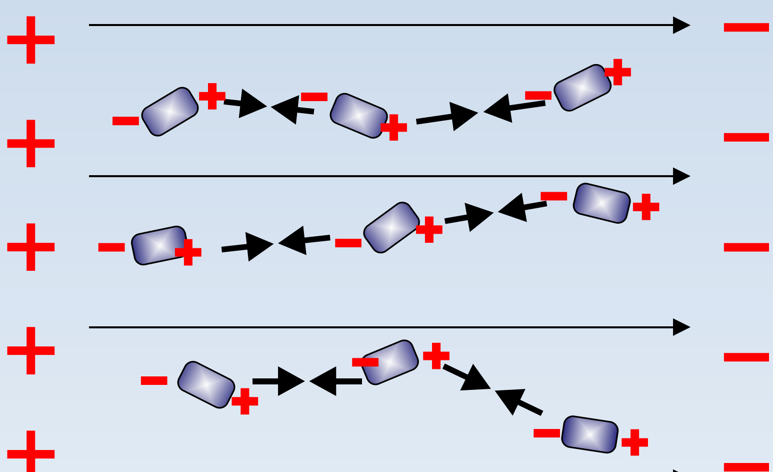
Expected shape of ice particles aggregated in electric field

Aggregation on a charged particle radial field

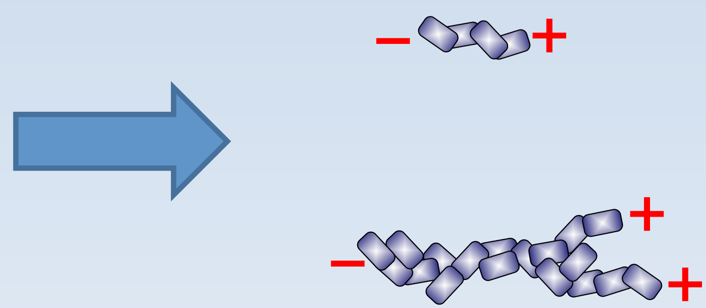


Compact shape aggregates

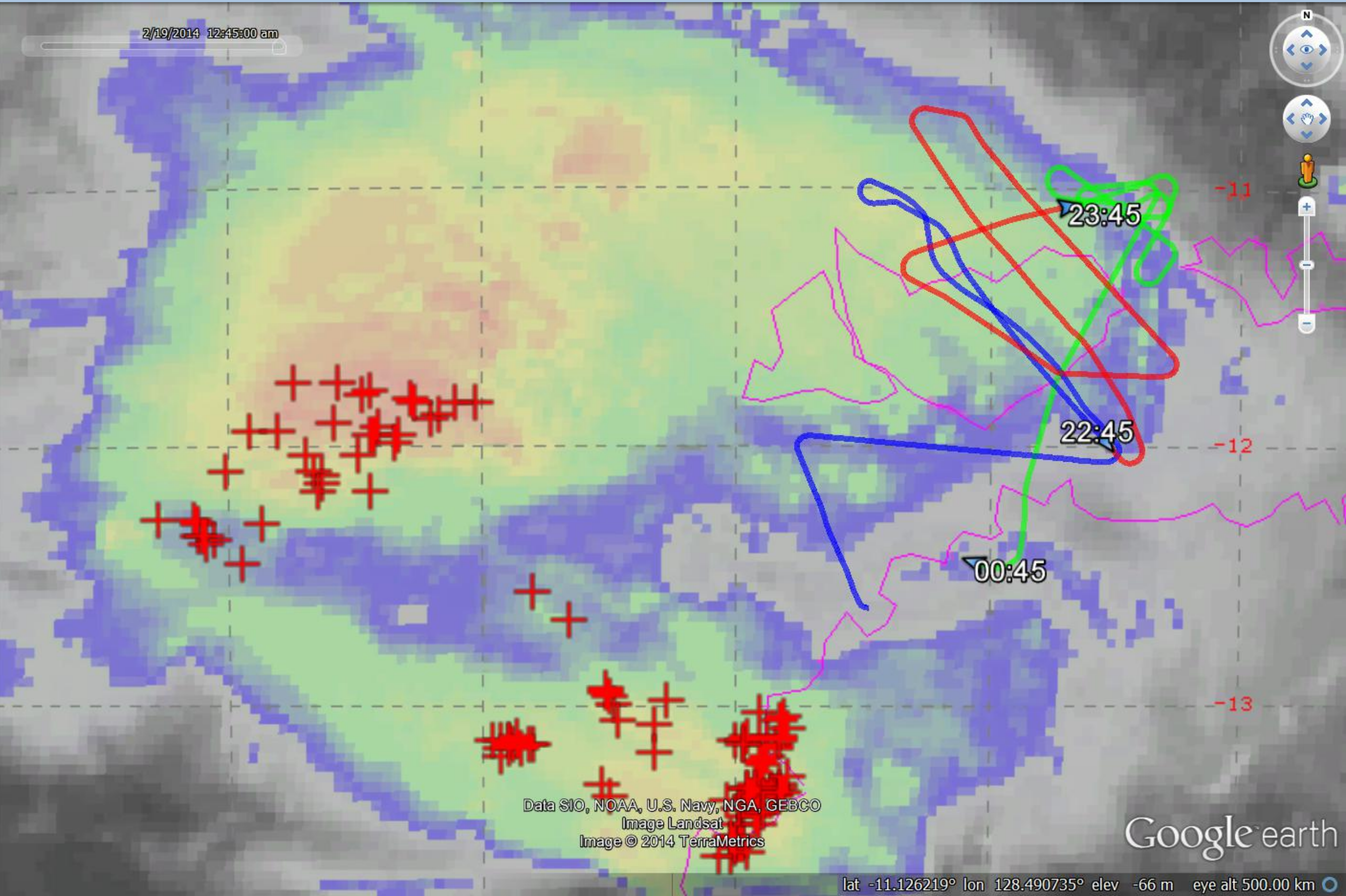
Linear field



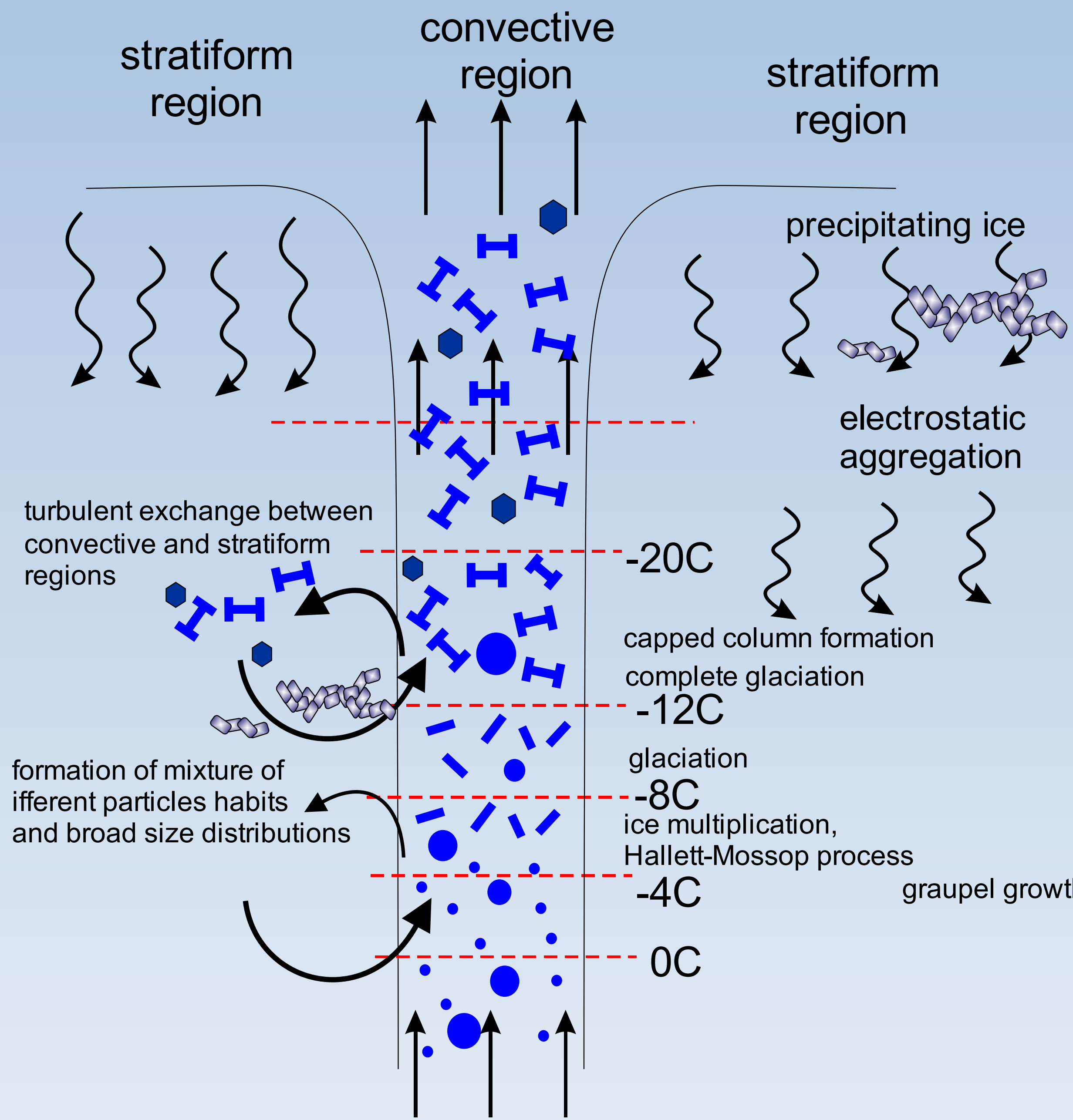
chain type aggregates



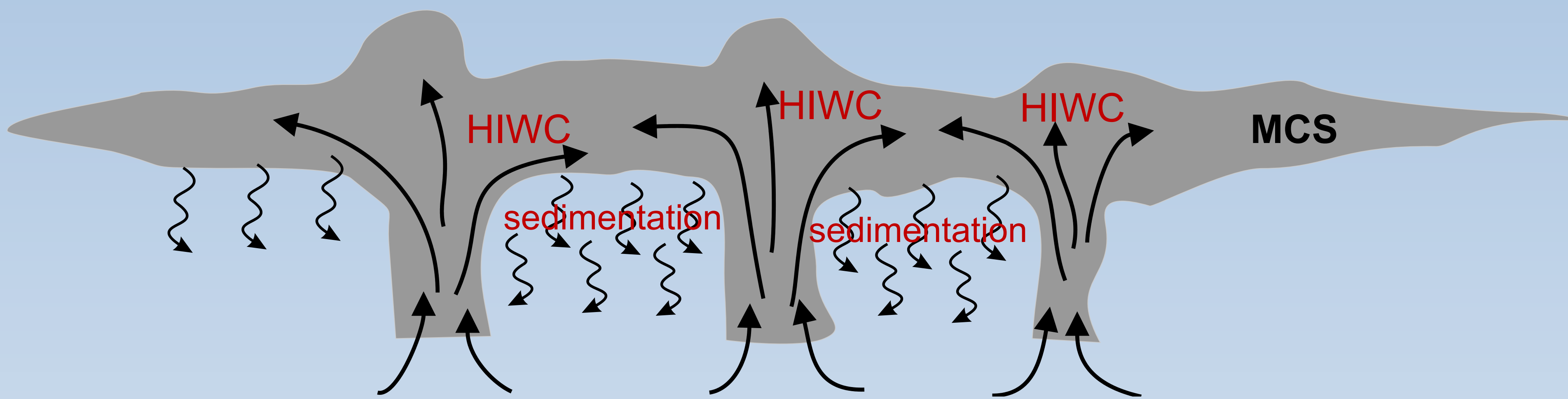
Lightning averaged over the entire flight period



Conceptual model of microstructure formation in MCS (flight 23)



Conceptual model of HIWC formation in MCSs



- HIWC in stratiform reqions are formed as a result of periodic pumping of condensed water in the stratiform regions of MCSs by convective flows (2<Uz<15m/s).
- The convection originate in the warm sector of MSCs at H<5km and may extend to 12km or higher.
- HIWC regions are dynamic objects and they form as a result of balance between particle sedimentation and IWC brought up by convection

Conclusions

- Correlation between U_z and IWC suggests that HIWC is primarily formed in convective updrafts and then spread over stratiform regions of MCSs.
- Electrostatic aggregation seems to play an important role in precipitation formation in MCSs. Most ice aggregation occurs in stratiform regions.
- Conceptual model of HIWC formation is proposed.
- More data analysis is required to adjust the conceptual model.

Acknowledgements:

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