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

Alexei V. Korolev,
(Environment Canada)

Alfons Schwarzenboeck (CNRS);
Andrew Ackerman, (NASA Goddard Institute for Space Studies);
Julien Delanoe (CNRS);
Fabien Dezitter (Airbus Operations SAS);
Christopher Dumont (Federal Aviation Administration);
Ann Fridlind (NASA Goddard Institute for Space Studies);
Alice Grandin (Airbus);
Lyle Lilie (Science Engineering Associates Inc);
Greg MacFarquhar (U. of Illinois);
Rodney Potts, Alain Protat (BoM);
Adam Varble (University of Utah);
J. Walter Strapp (Met Analytics Inc.);
Edward Zipser, (University of Utah)

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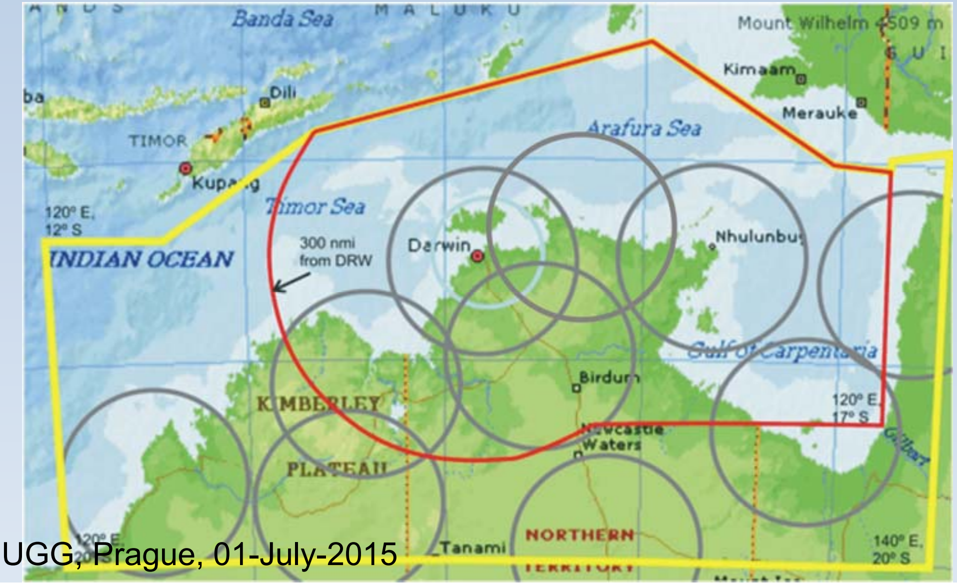
Background

- High Altitude Ice Crystal – High Ice Water Content (**HAIC-HIWC**) is an international field campaign, which was set up to enhance knowledge of ice crystal icing in deep convective clouds, develop tools for avoidance conditions associated with engine power loss events and assess future aviation regulations.

- The flight operation of the 1st HAIC-HIWC were conducted out of Darwin in Jan-Mar 2014 on the French Safire Falcon-20.



Motivation

1. Understand mechanisms of formation of high ice water content (HIWC) cloud regions associated with uncontrolled engine power loss events of commercial aircrafts

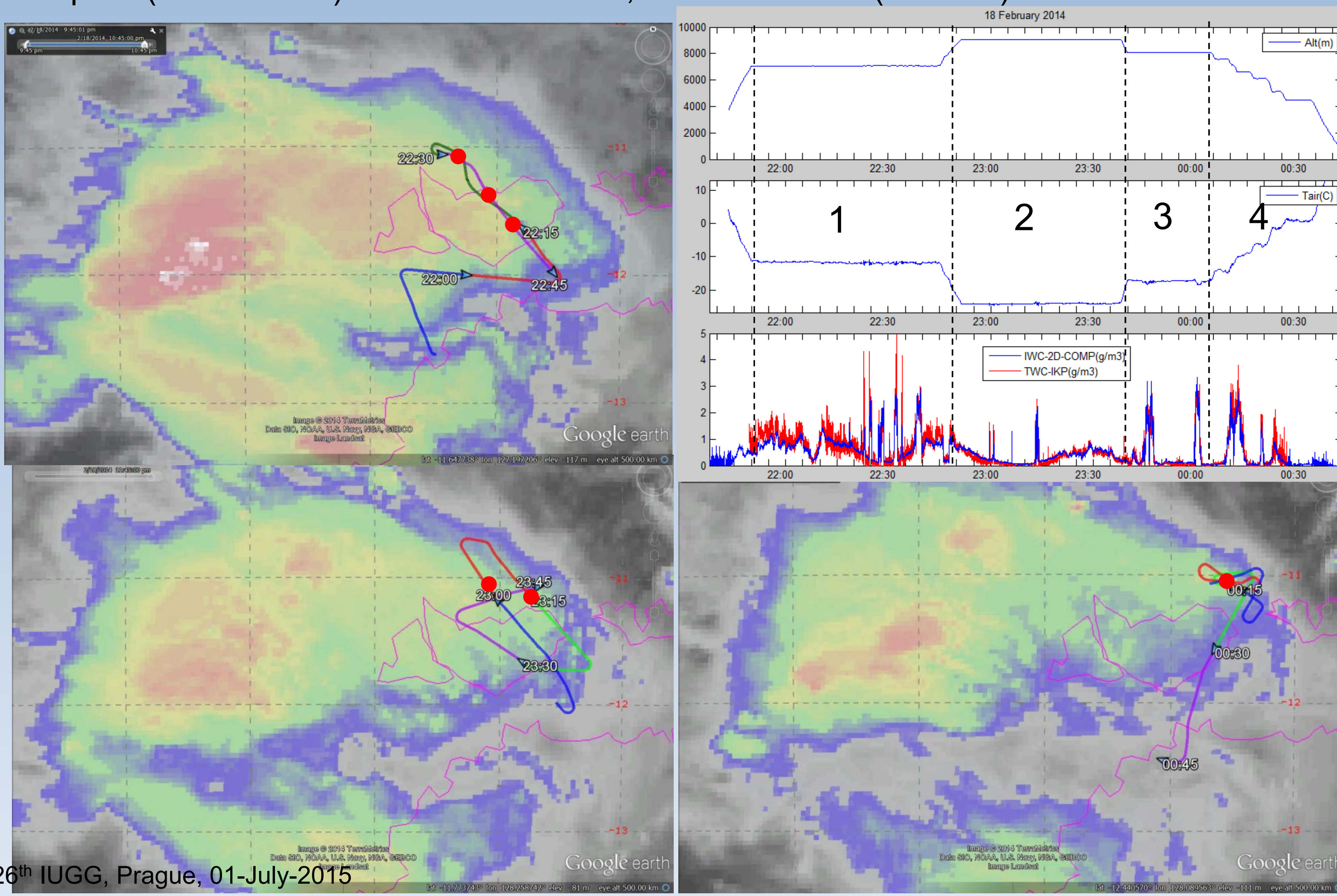
2. Identify main microphysical properties attributed to HIWC cloud regions in MCSs

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

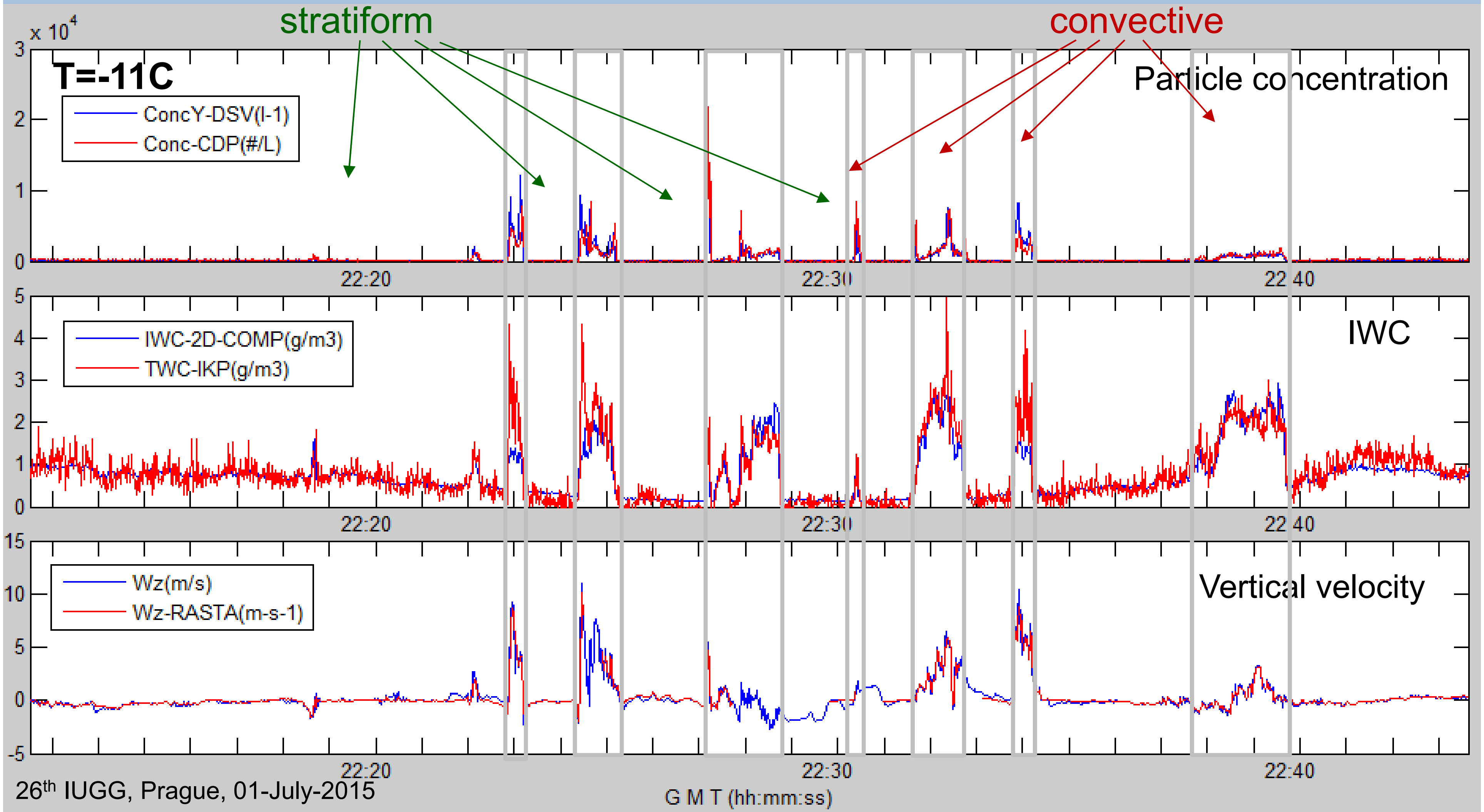
4. Support further development of cloud simulations

Flight 23 (18-Feb-2015) was performed near the north-east size of the MCS

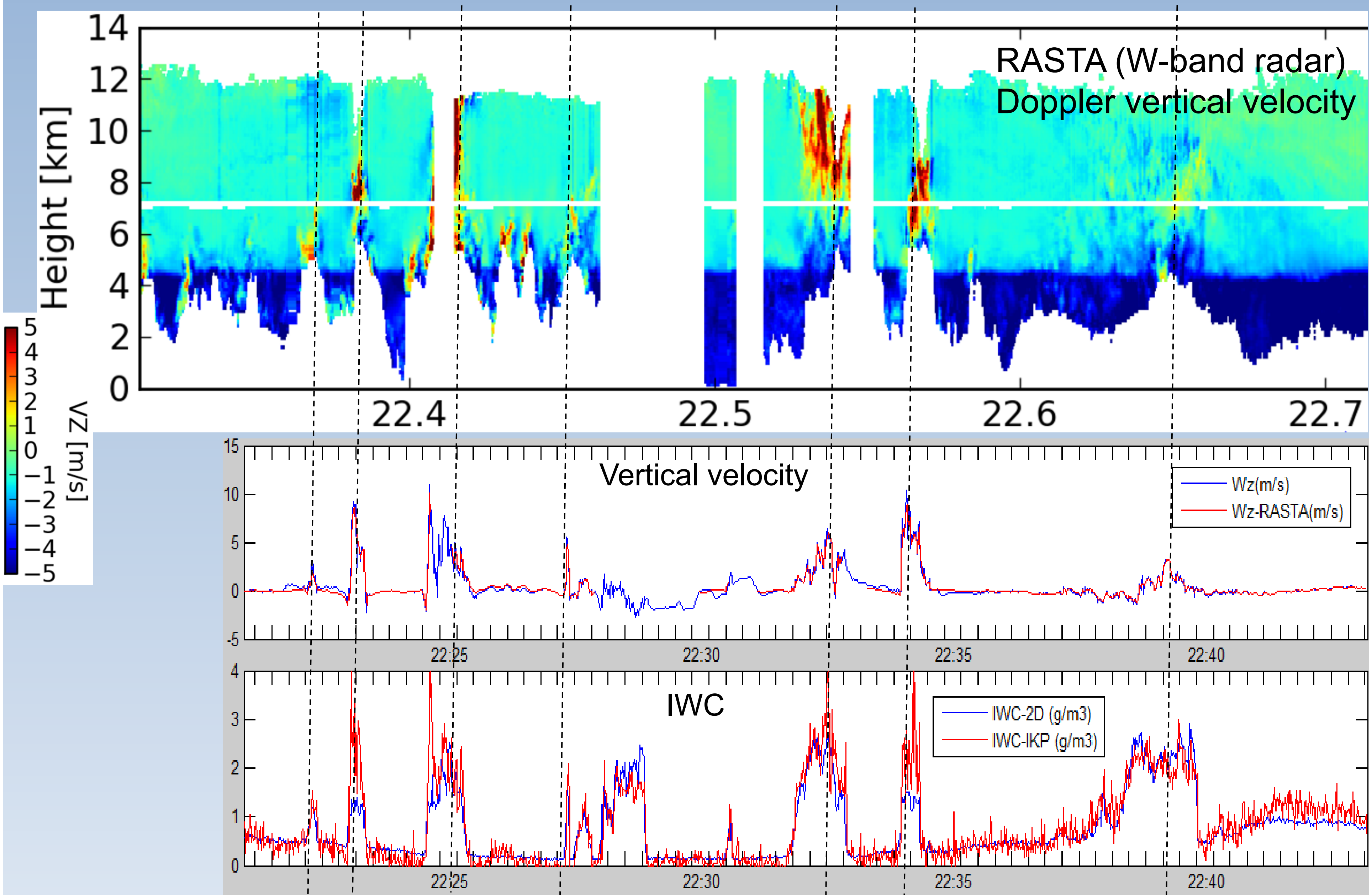
1st part (21:50-22:45) H=7100m; T= -11C
2nd part (22:51-23:38) H=9100m; T= -24C
3rd part (23:45-00:05) H=8100m; T= -17C
4th part (00:07-00:25) 7600>H>5100m; -14C<T<-2C (descent)



- 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

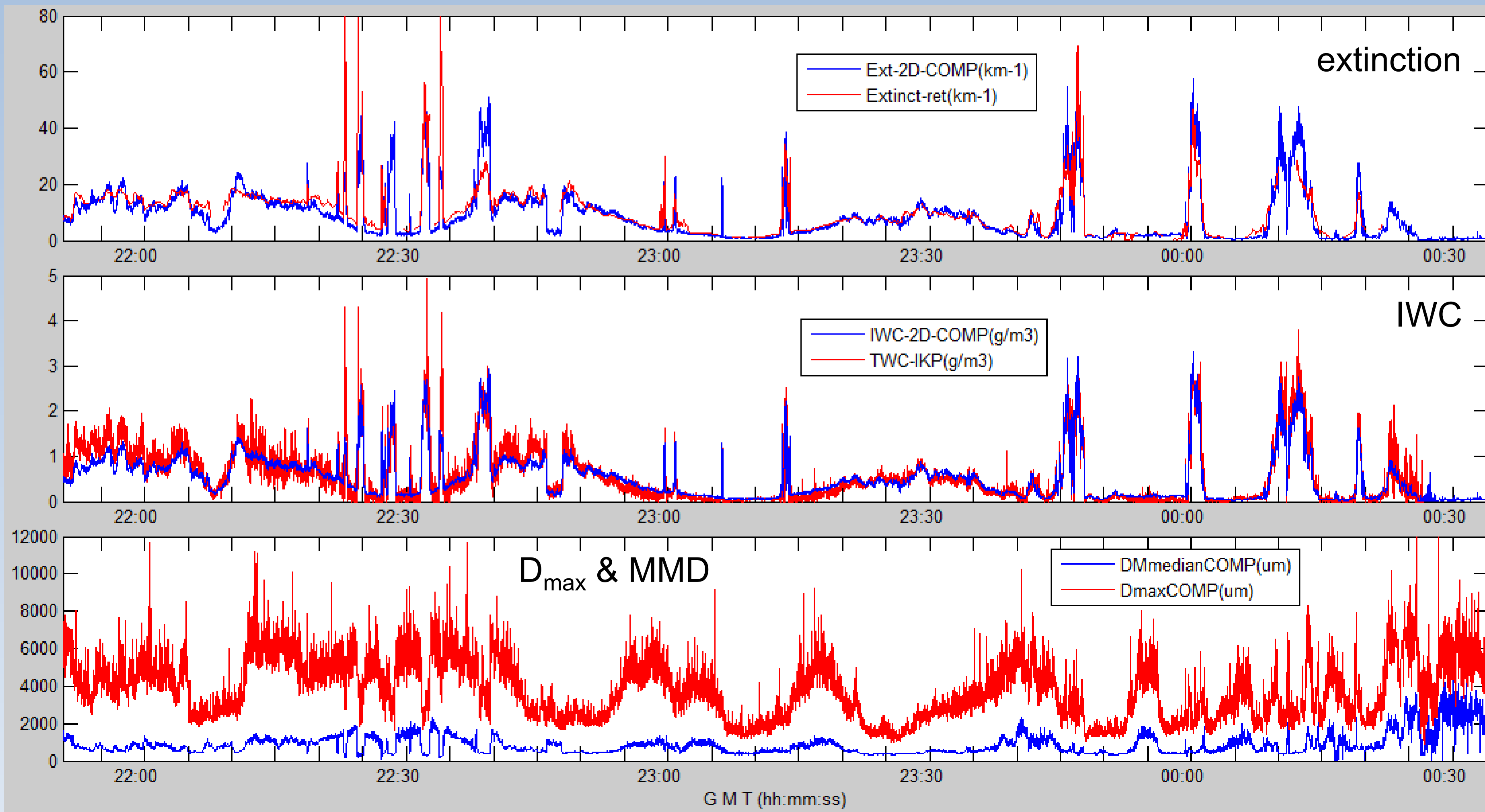


Vertical and horizontal extend of convective cells

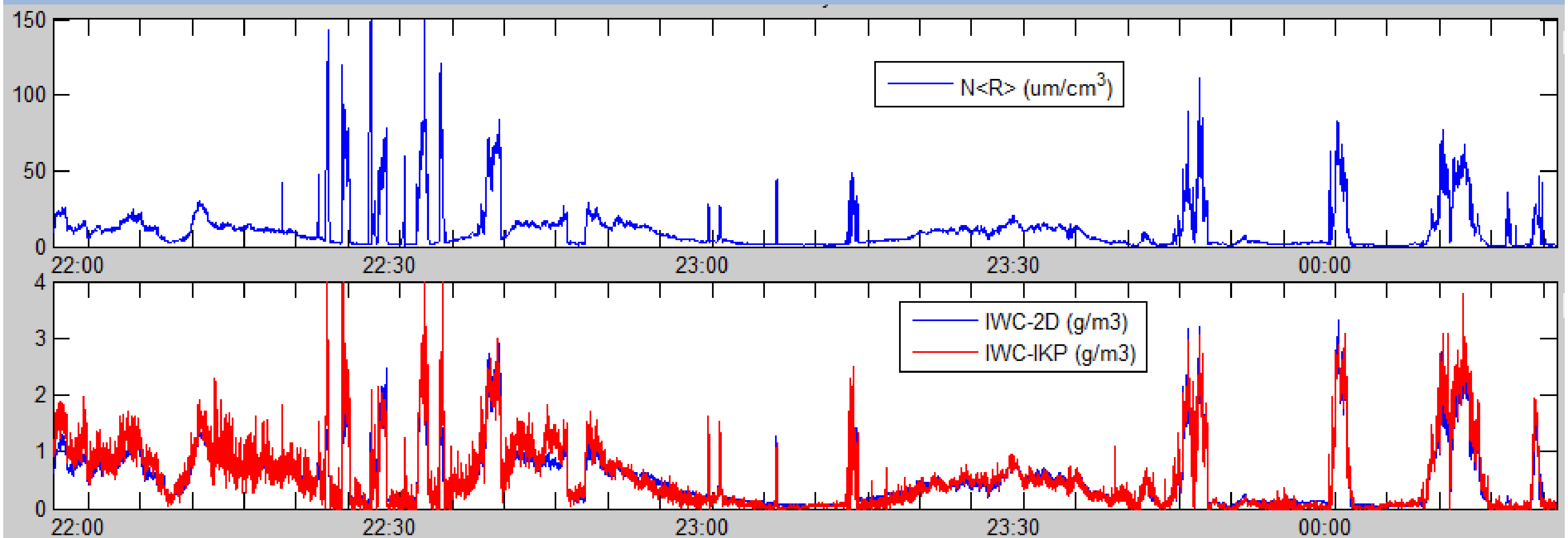


Extinction & MMD coefficient (β)

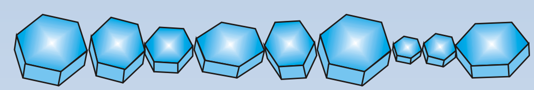
- $1km^{-1} < \beta < 20km^{-1}$ in stratiform regions
- $30km^{-1} < \beta < 80km^{-1}$ in convective convective regions



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 < $N_i r_i$ < 30μm in stratiform cloud regions
- 30 < $N_i r_i$ < 150μm in convective cloud regions

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

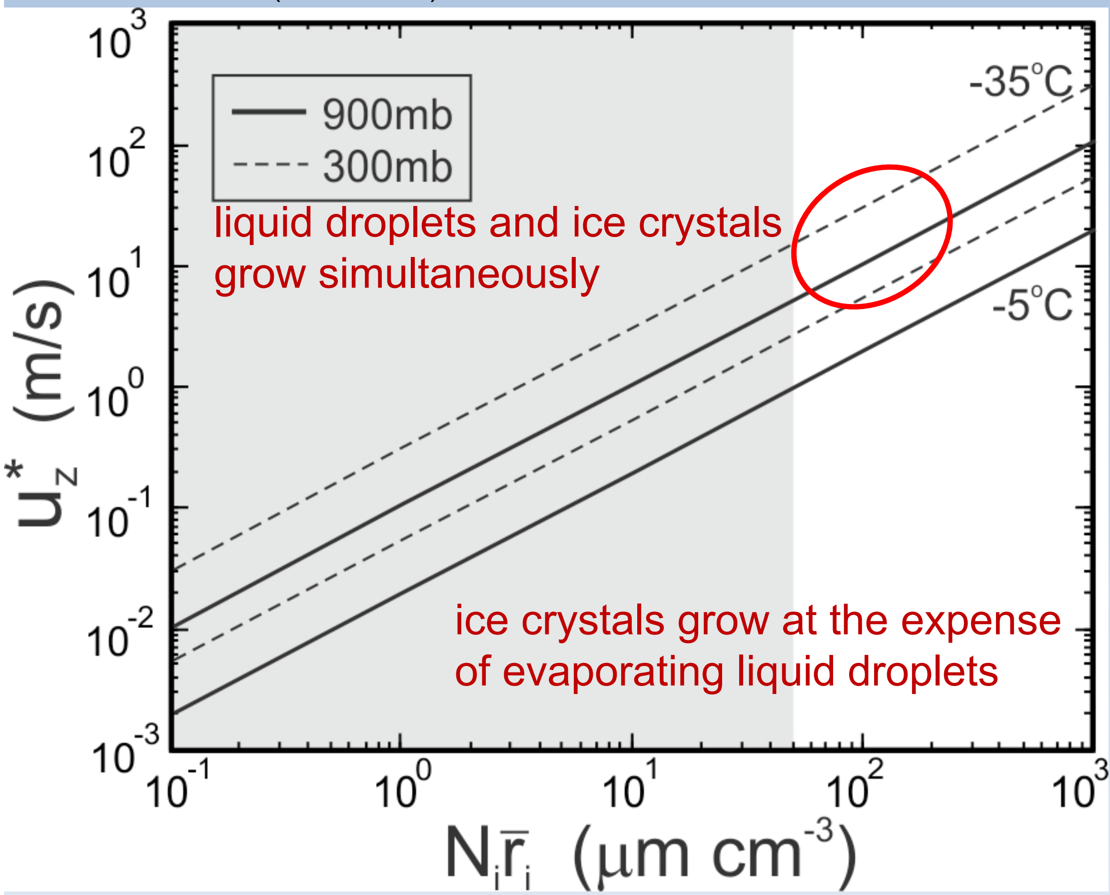
Threshold vertical velocity for activation of liquid in pre-existing ice cloud and maintenance of mixed phase

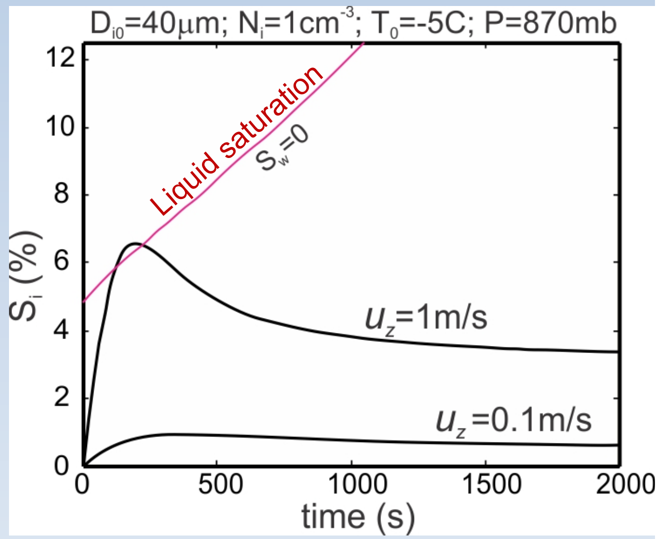
$$u_z^* = \frac{b_i^* N_i \bar{r}_i}{a_{0w}}$$

$u_z > u_z^*$ 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 U_z>15-20m/s

Korolev & Mazin (JAS, 2003)





Modeling of glaciation liquid cloud during ascent

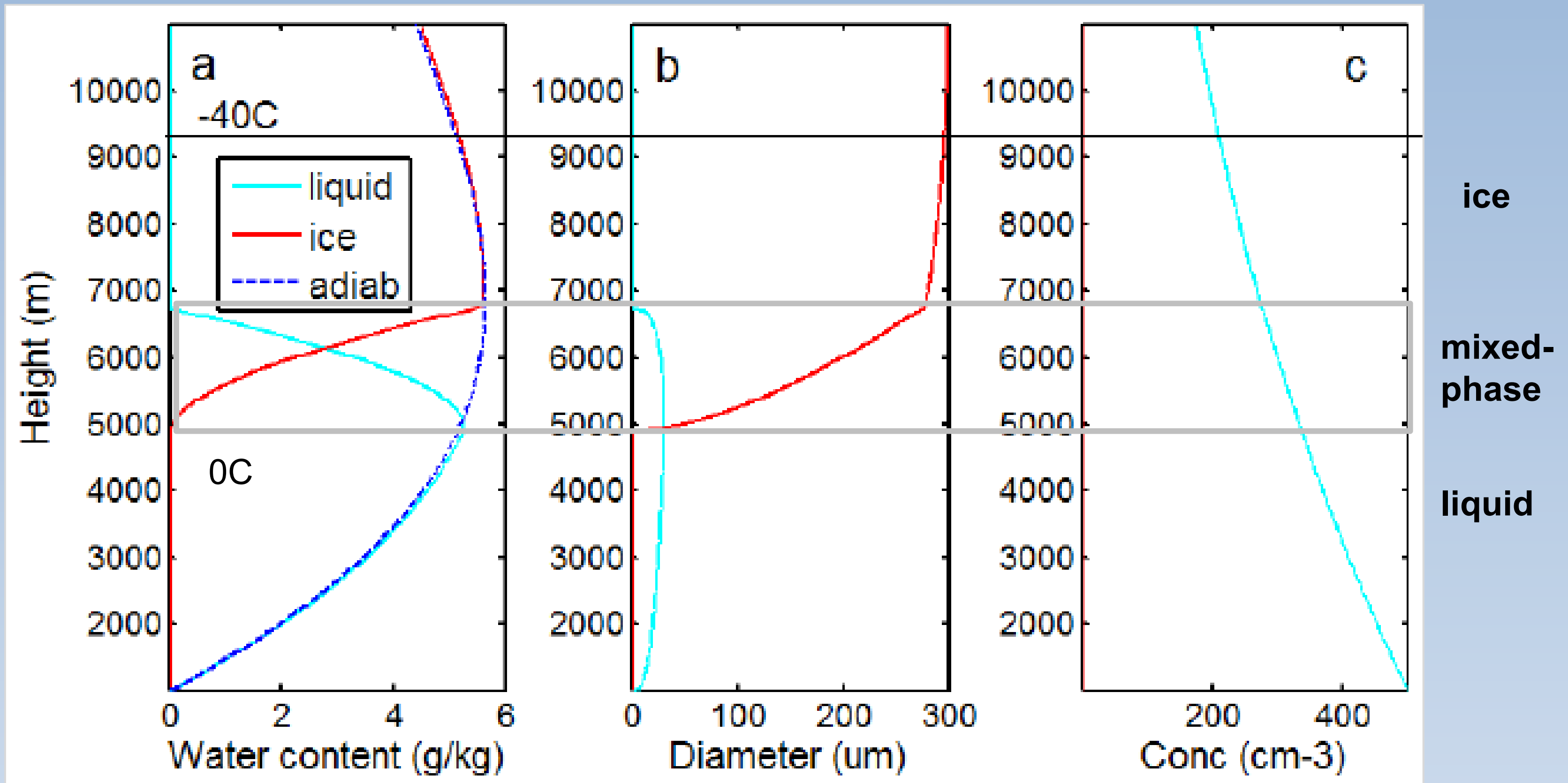


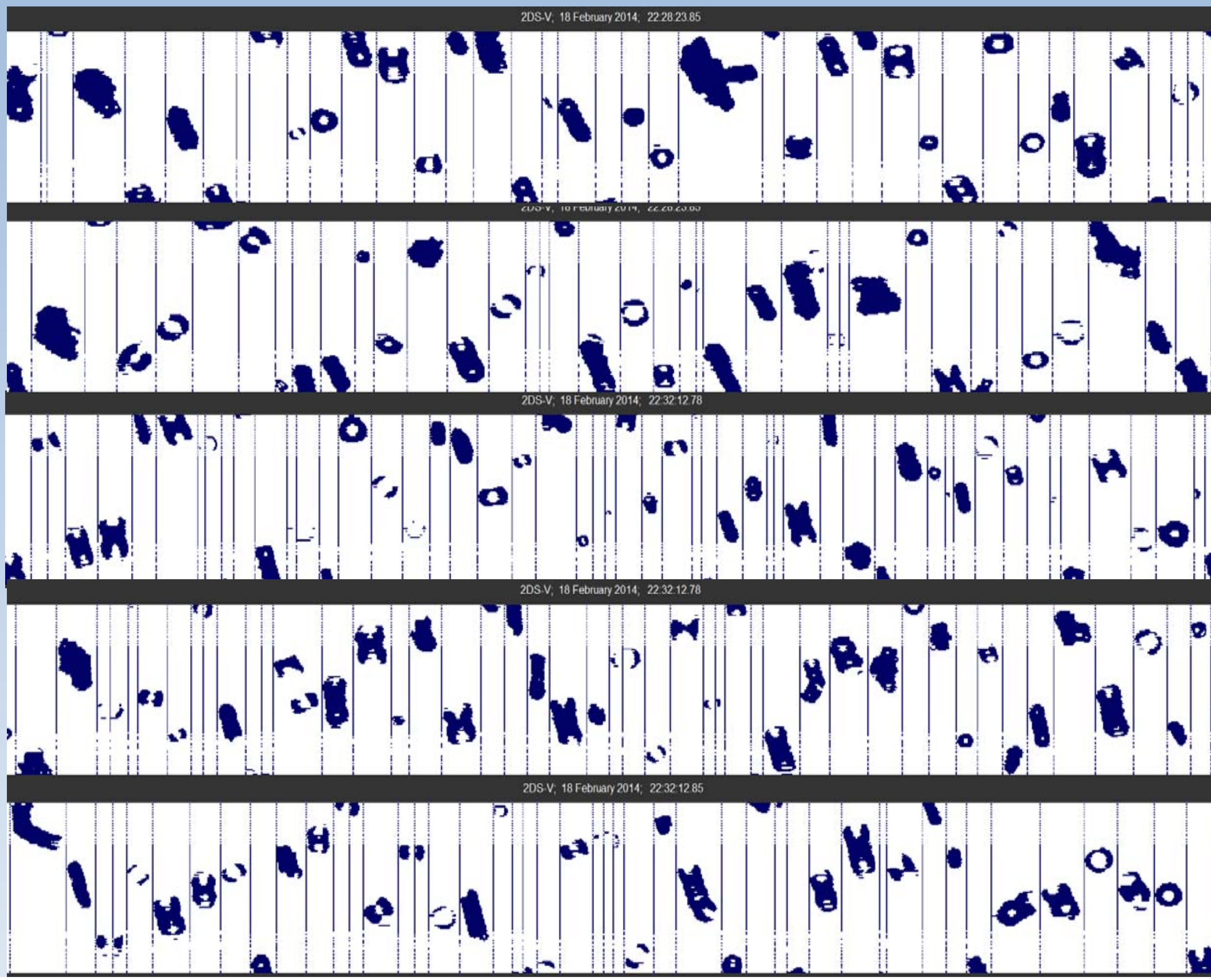
Fig. 3.6. Modeling of changes of (a) LWC and IWC; (b) cloud particle sizes; (c) droplet and ice concentrations; (d) temperature during adiabatic ascent. Ice particles were initiated at T=-5 C, ice particle concentration 1 cm^{-3}, vertical velocity u_z=1 m/s; H_0=500 m, T_0=15 C. Results are for diffusional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

HIWC science plan, 2008

2DS imagery from convective cloud region

T= -11C; H=7100m

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

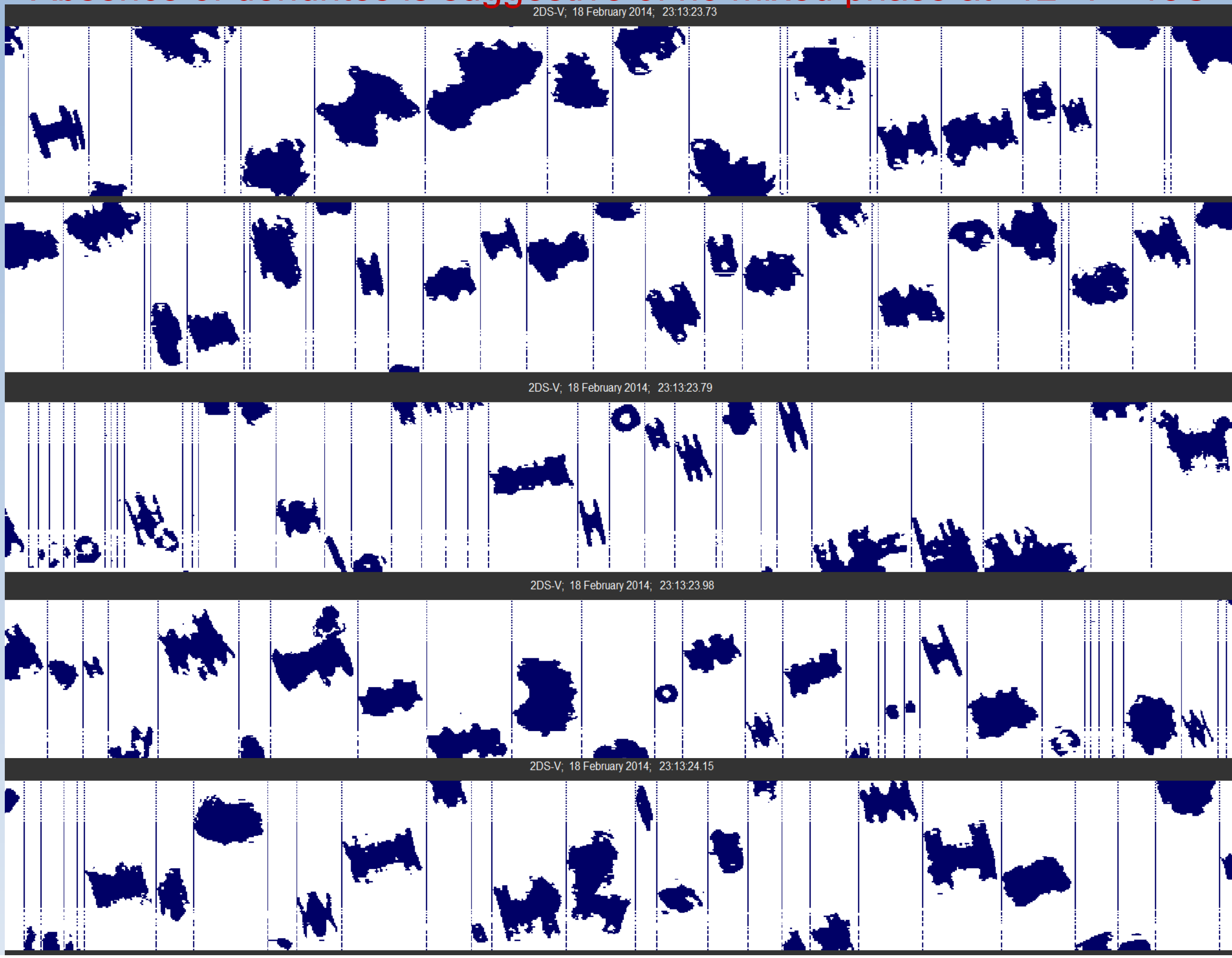


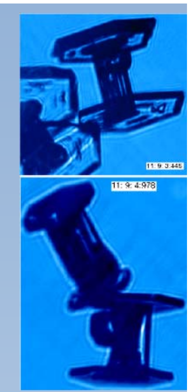
2DS imagery from convective cloud region

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)

Ice particle habits formed at different T and RH

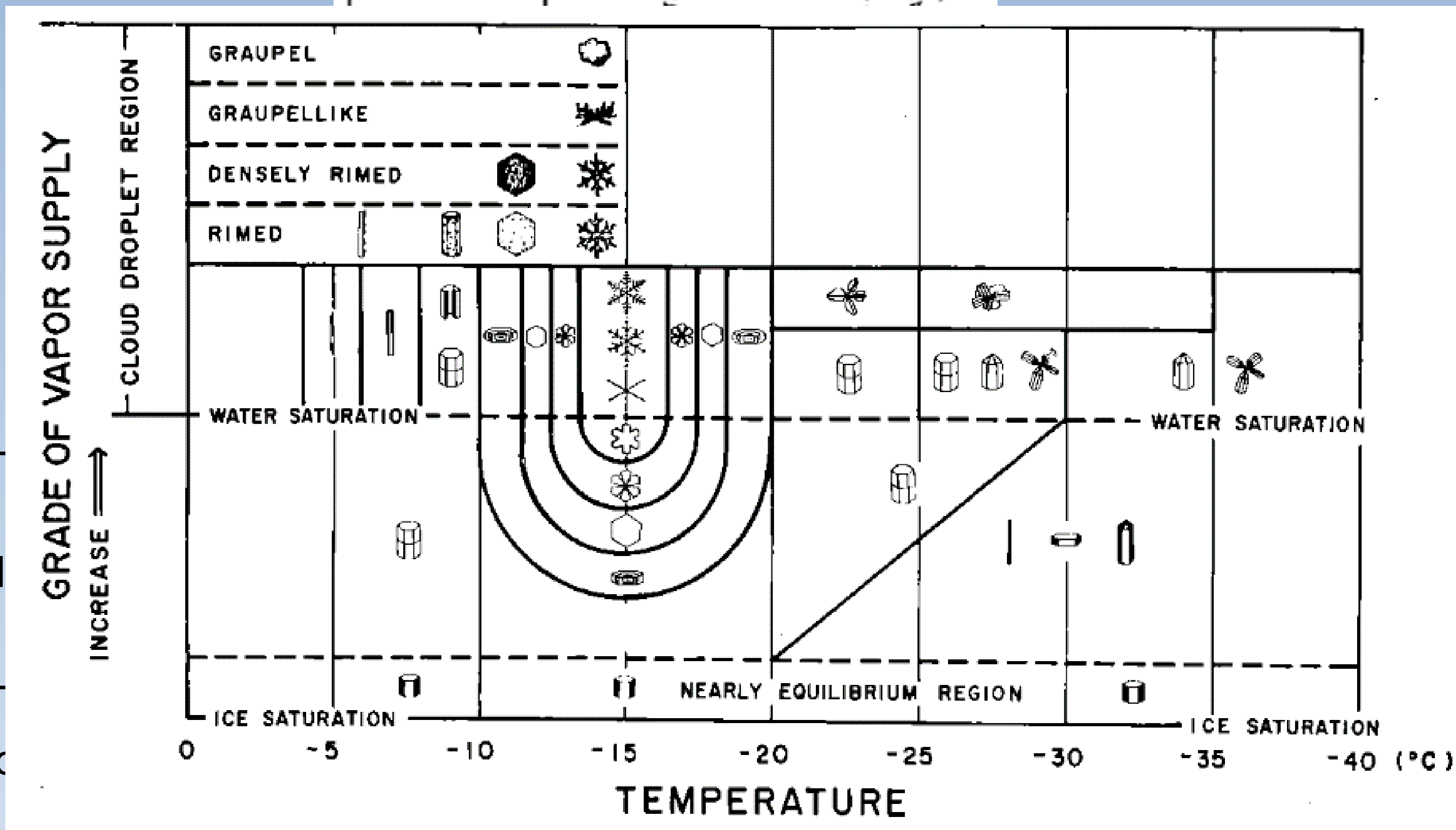


Fig. 2-26. Temperature and humidity conditions for the growth of natural snow crystals of various types. (From Magono and Lee, 1966; by courtesy of *J. Fac. Sci.*, Hokkaido University.)

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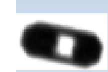
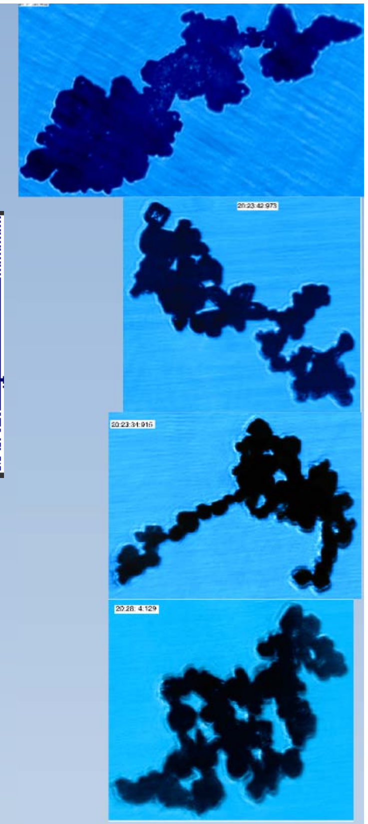
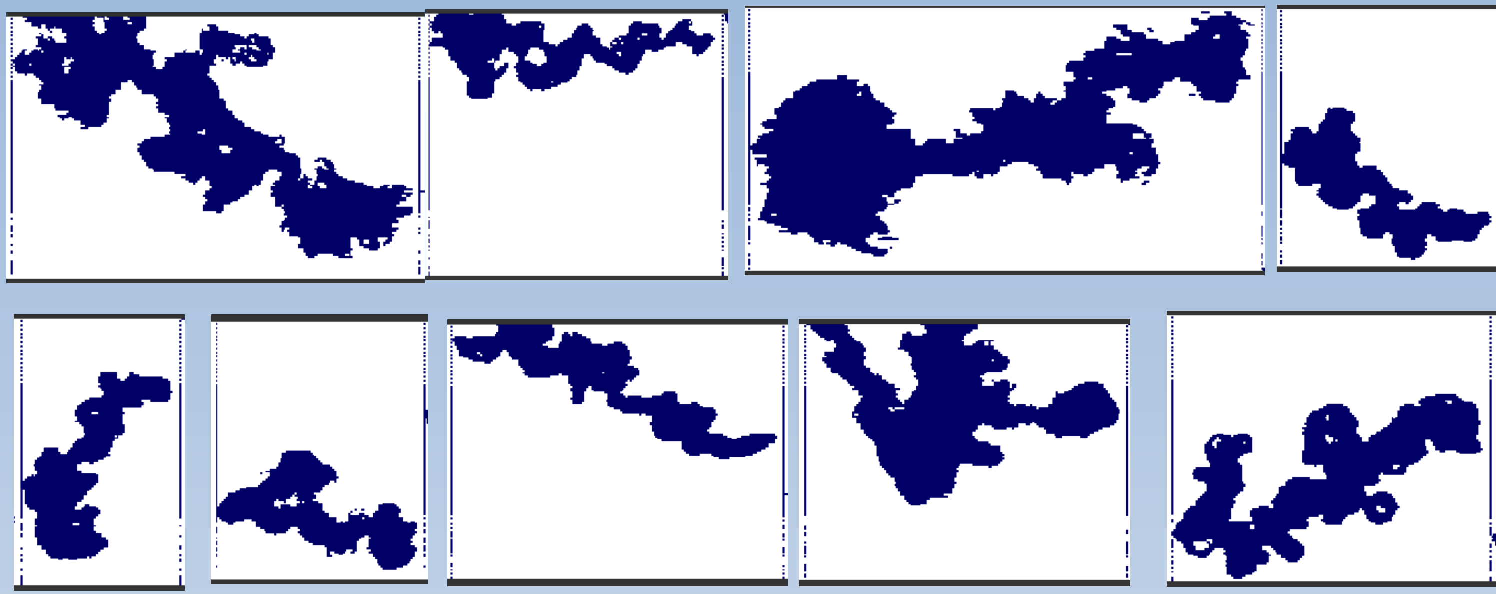
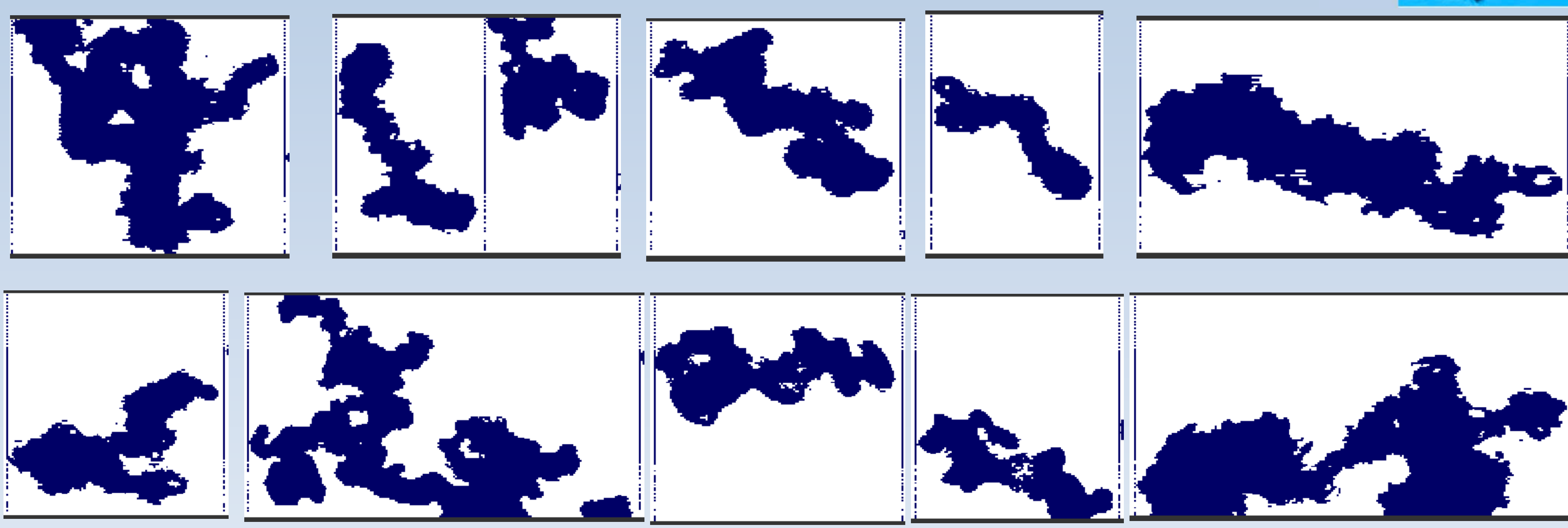


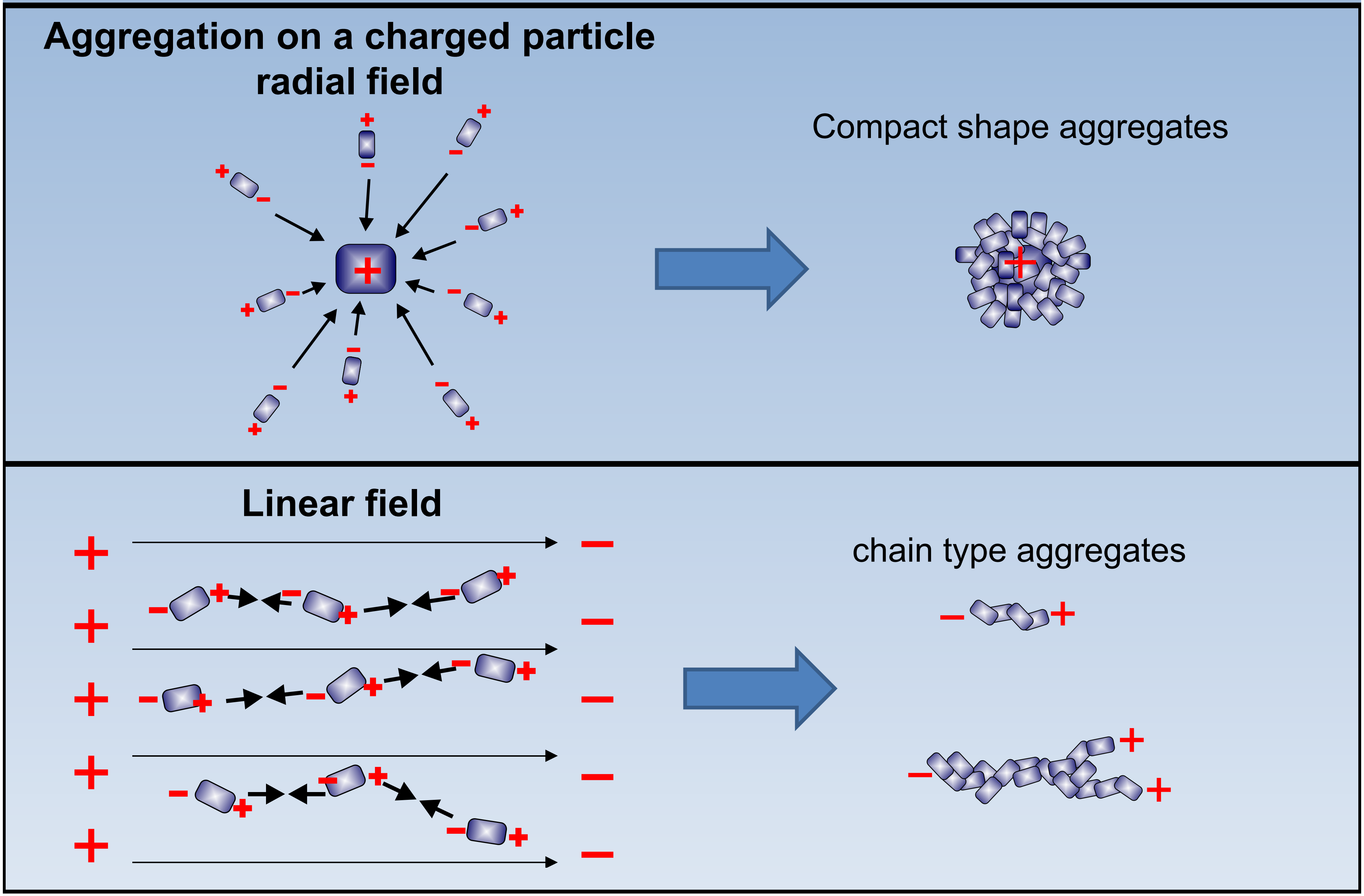
Aggregated particles in stratiform region at T= -24C level



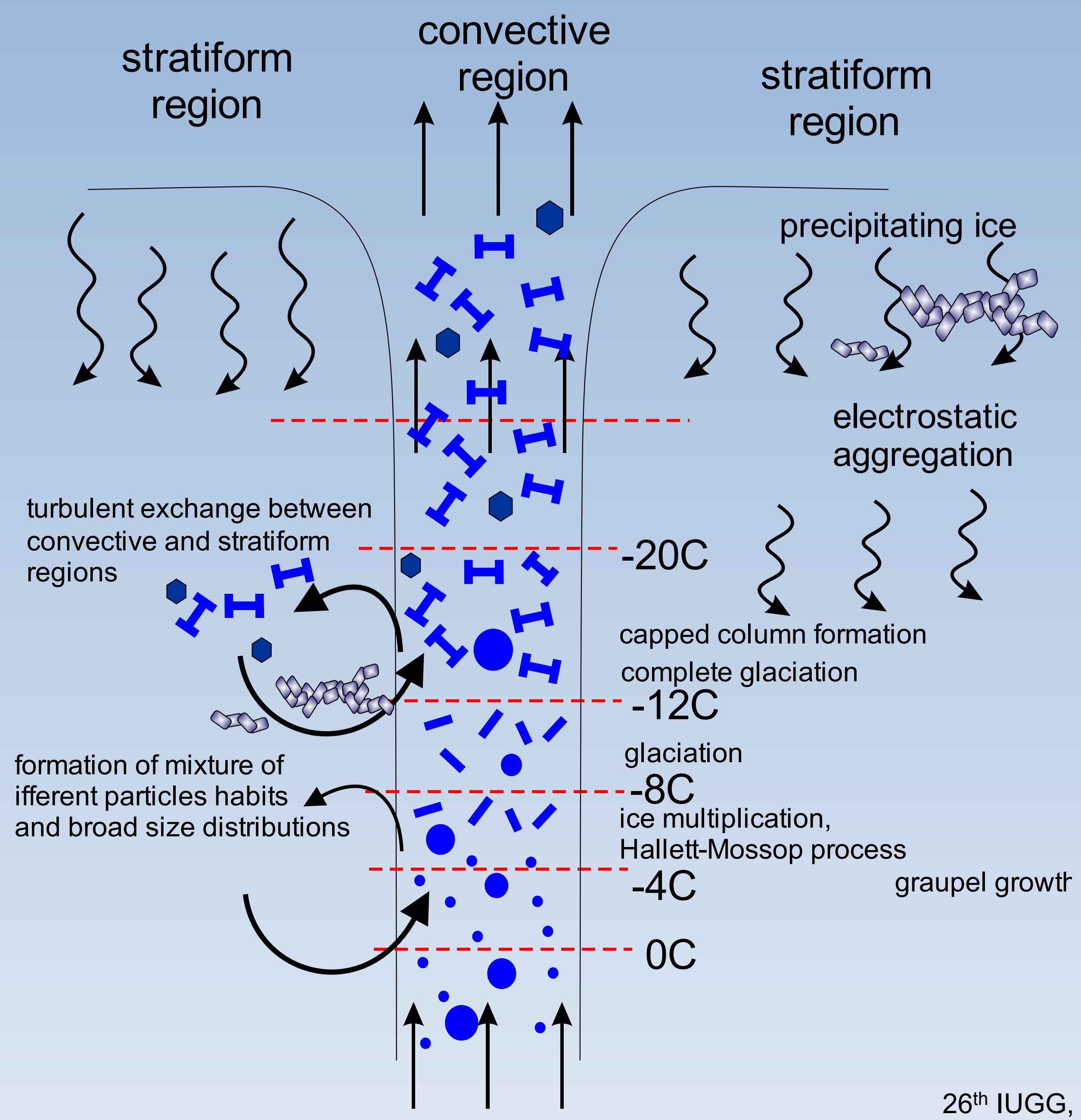




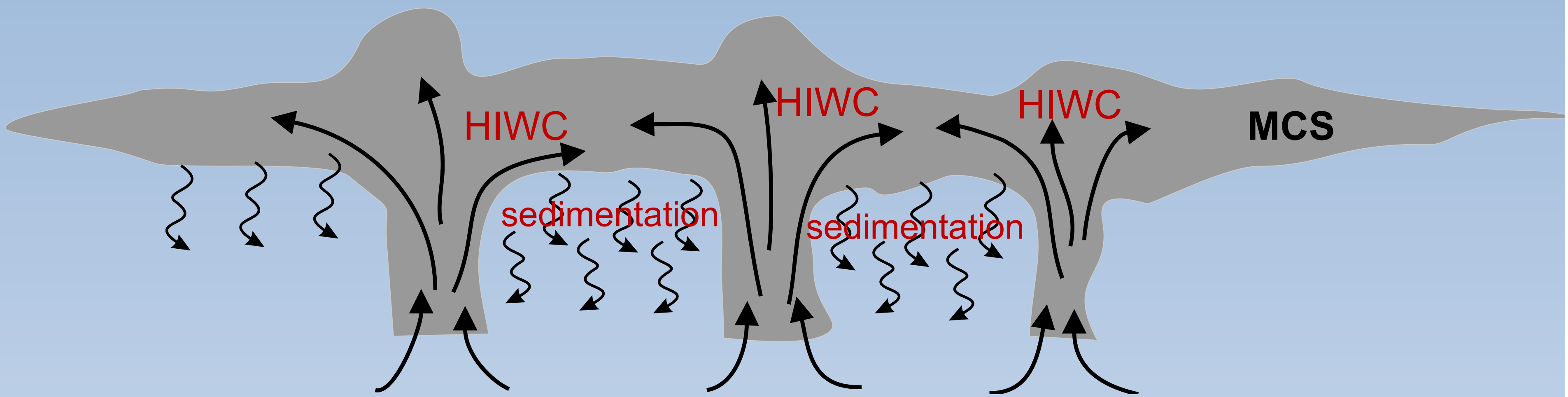
Expected shape of ice particles aggregated in electric field



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 originates 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.
- Ice multiplication (e.g. Hallet-Mossop) appears to be the major mechanism of ice initiation in *mature* MCSs.
- Electrostatic aggregation plays an important role in precipitation formation in MCSs. Most ice aggregation occurs in stratiform regions.

Acknowledgements:

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