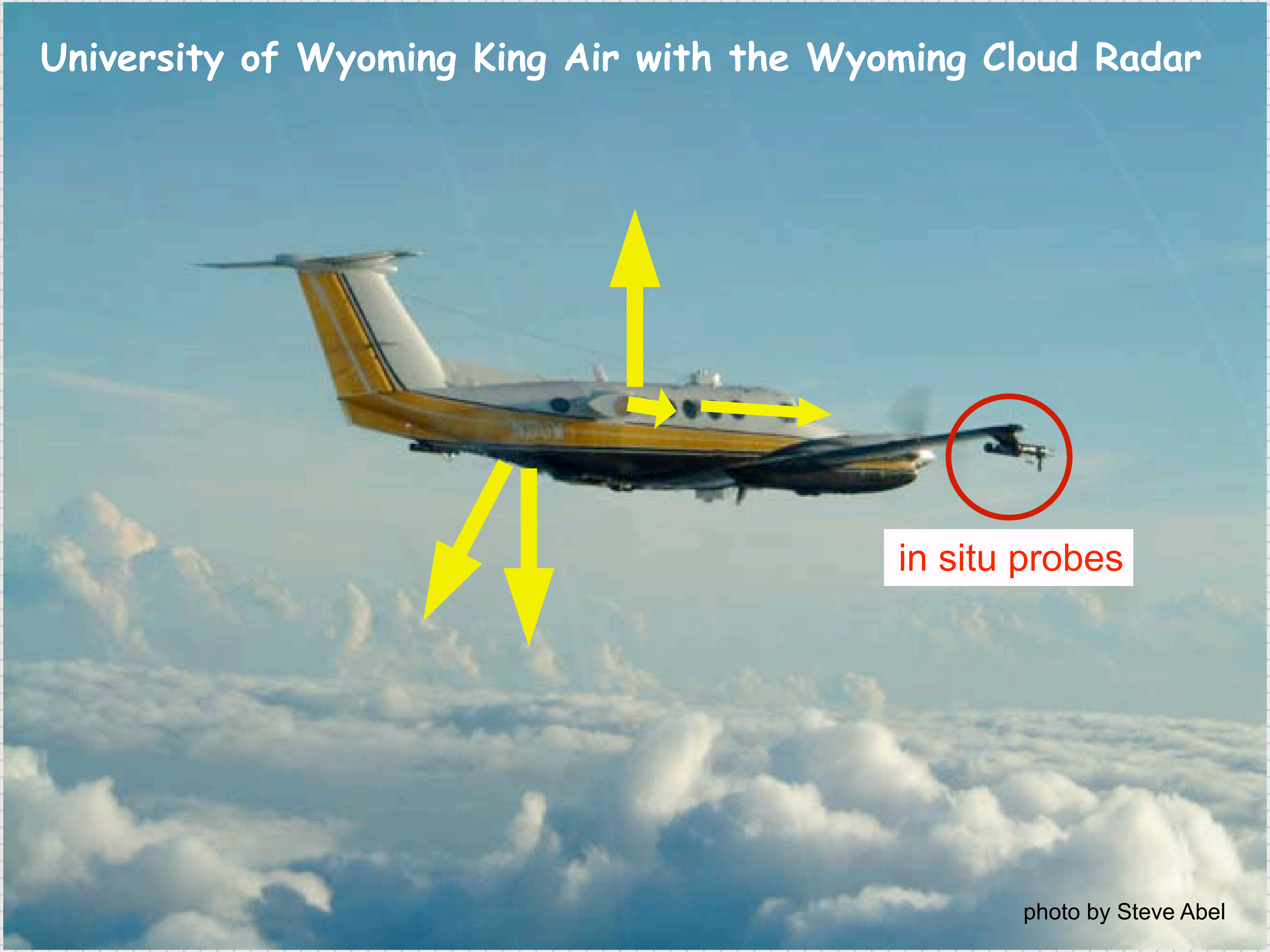
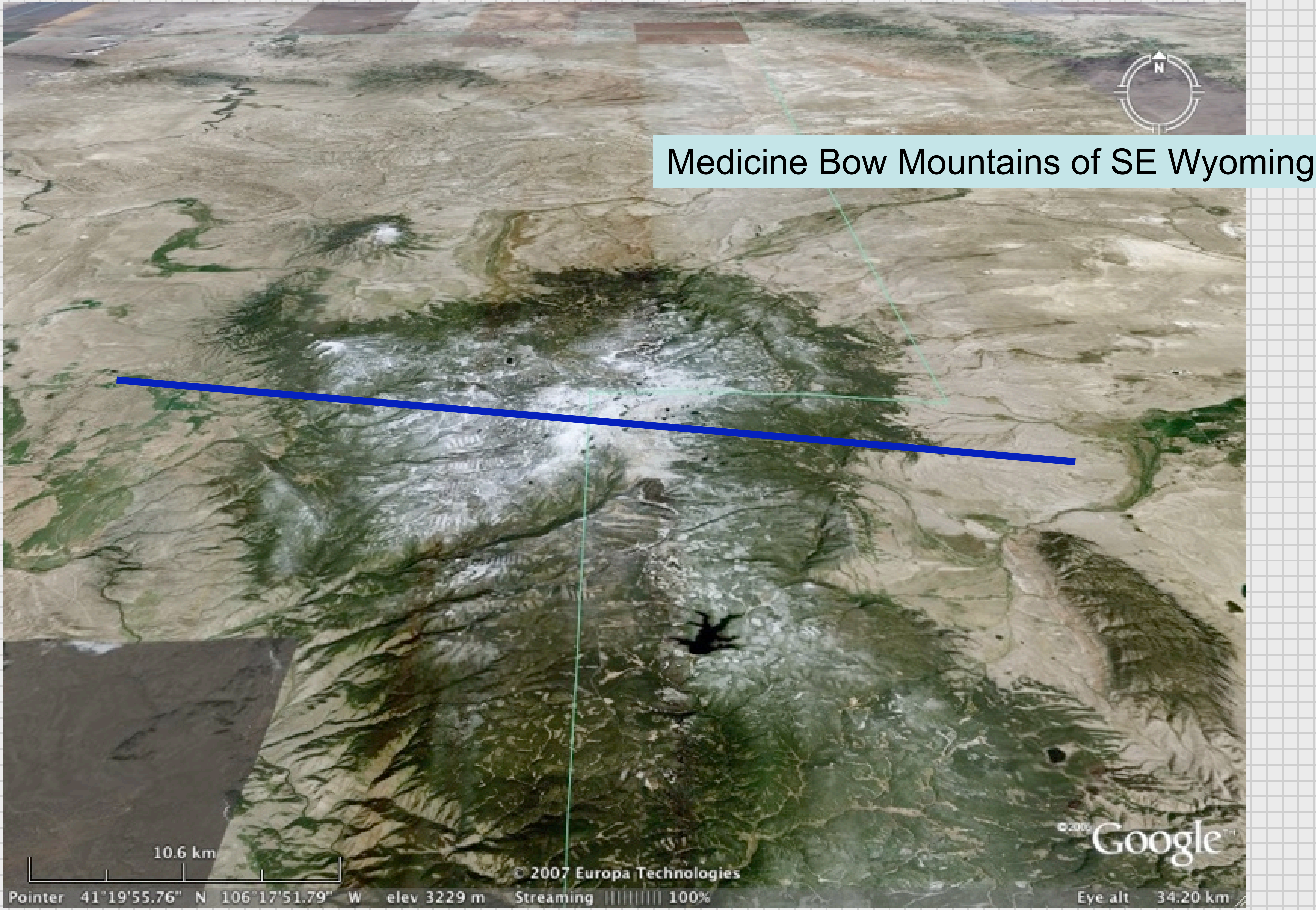
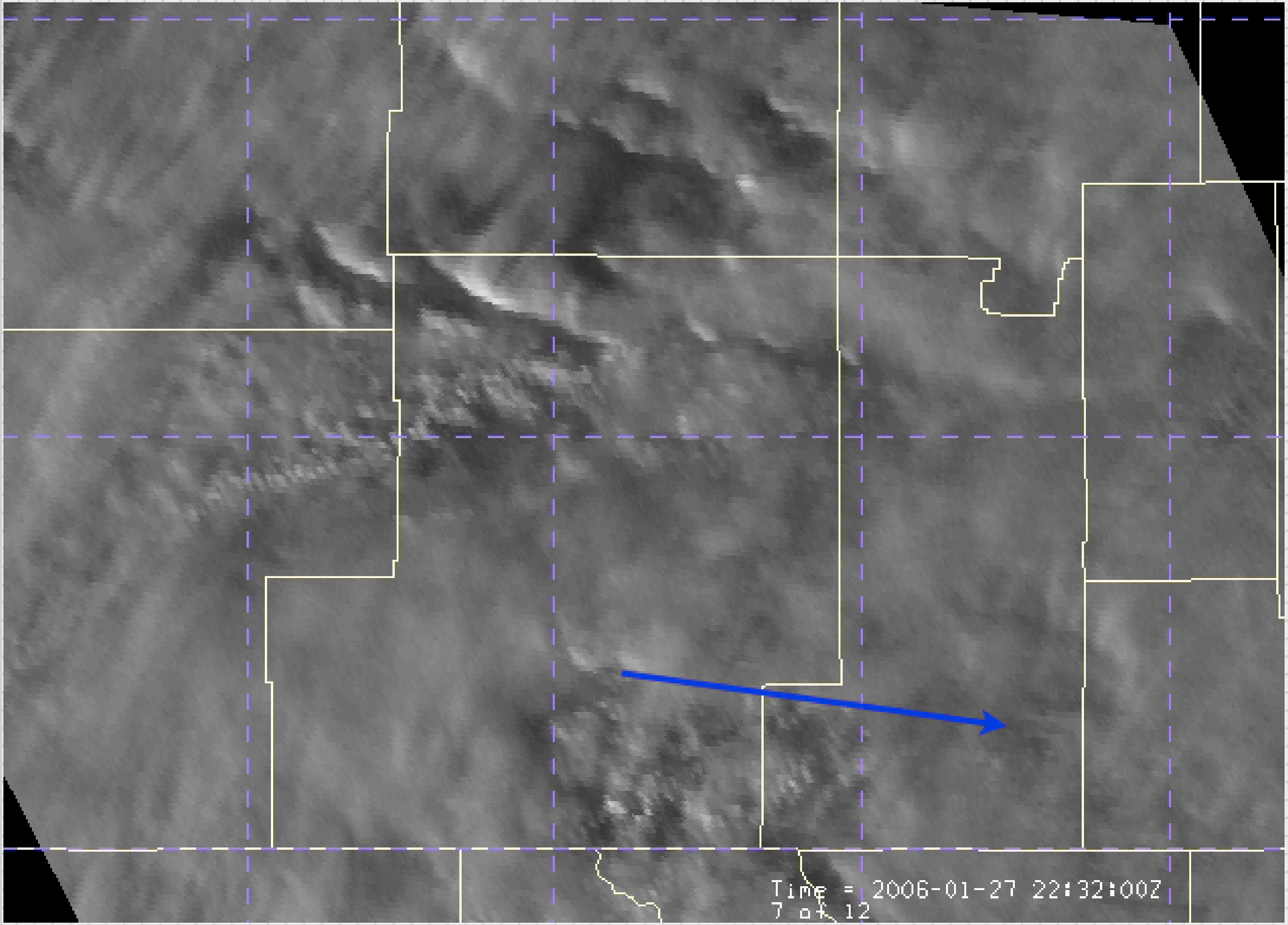
Cloud structure influence on ice formation

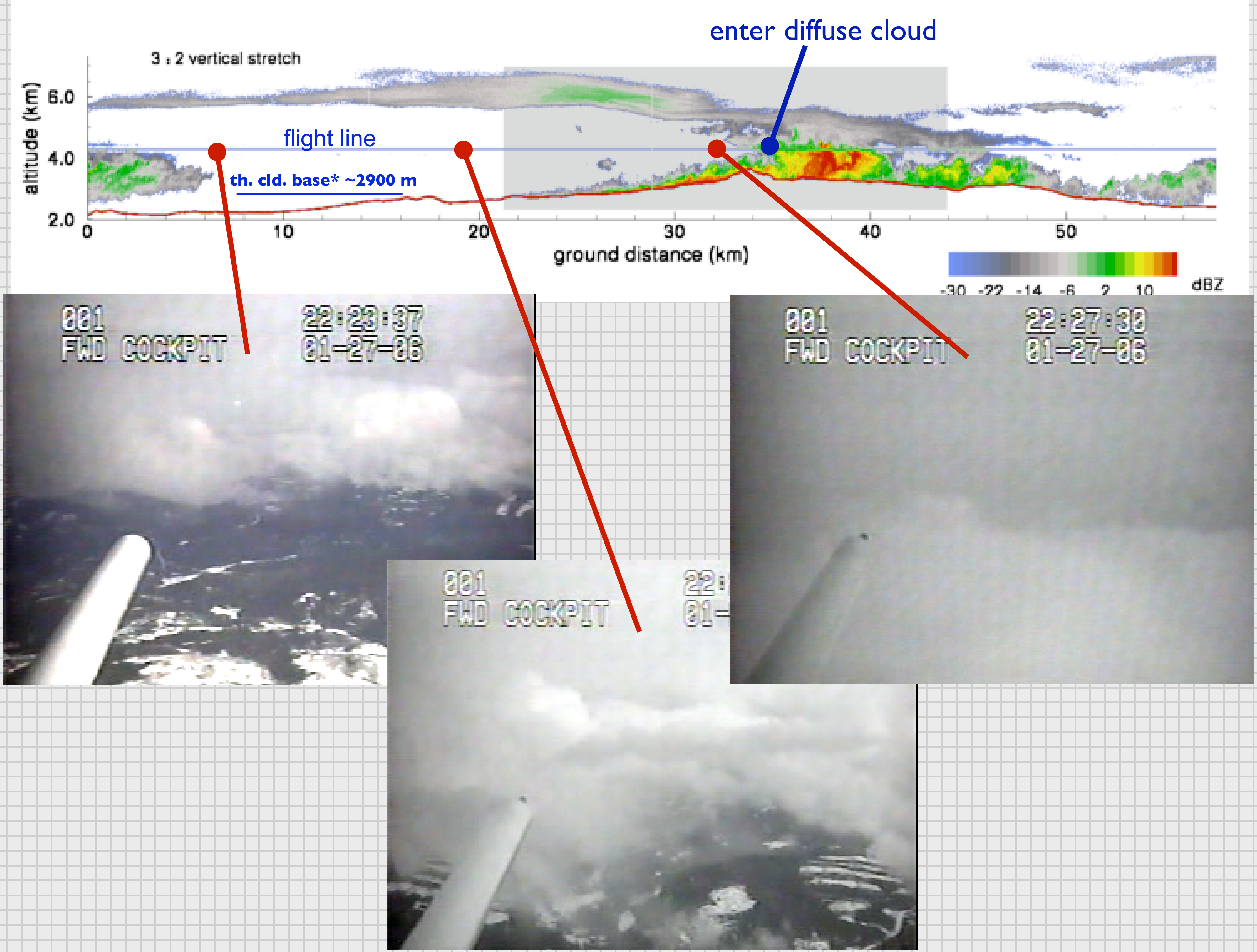
looking deep into clouds with an airborne radar

Gabor Vali, University of Wyoming

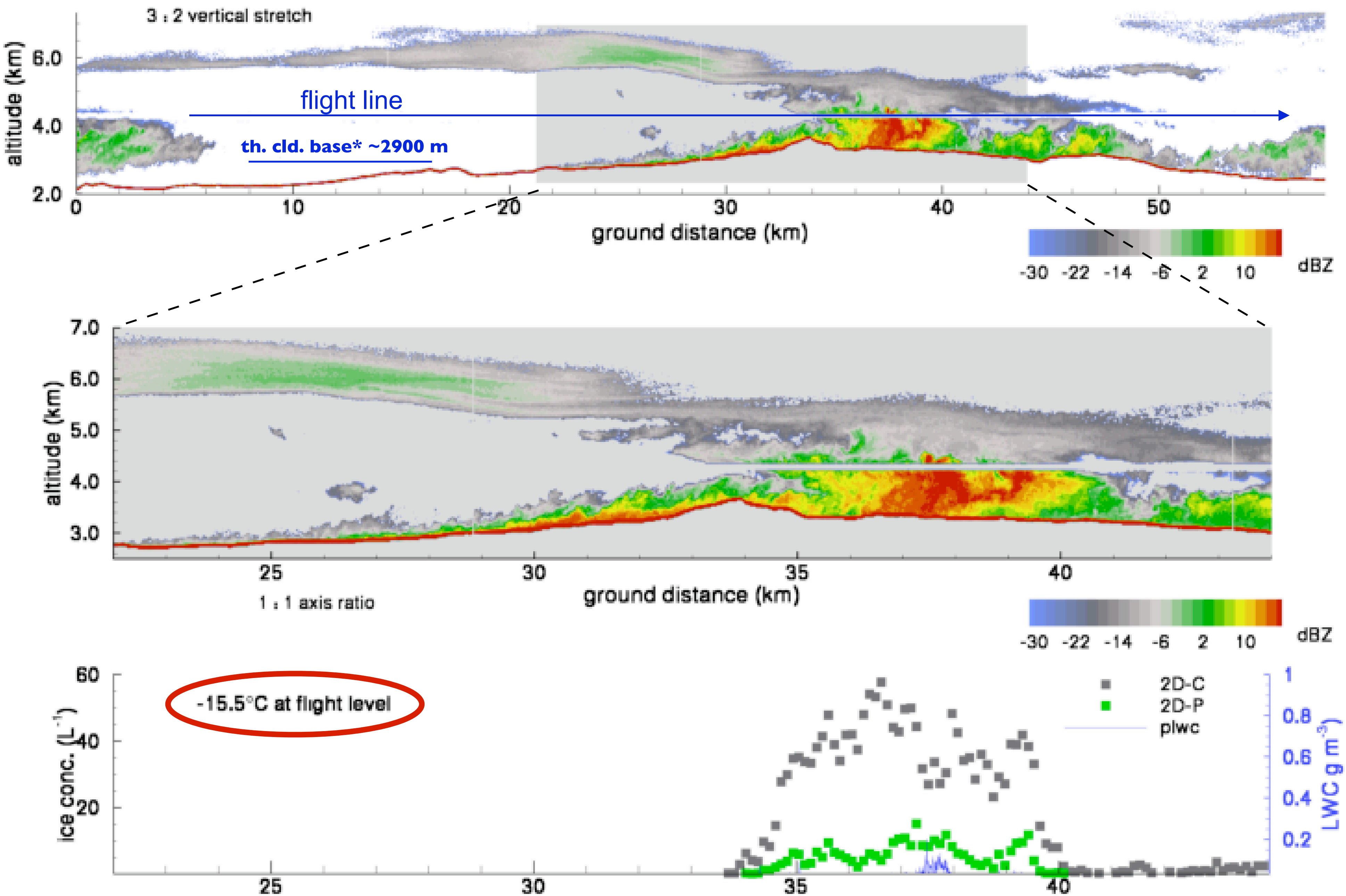

University of Wyoming King Air with the Wyoming Cloud Radar
in situ probes
photo by Steve Abel


Medicine Bow Mountains of SE Wyoming
10.6 km
© 2007 Europa Technologies
Pointer 41°19'55.76" N 106°17'51.79" W elev 3229 m Streaming 100%
Eye alt 34.20 km
Google


Time = 2006-01-27 22:32:00Z
7 of 12

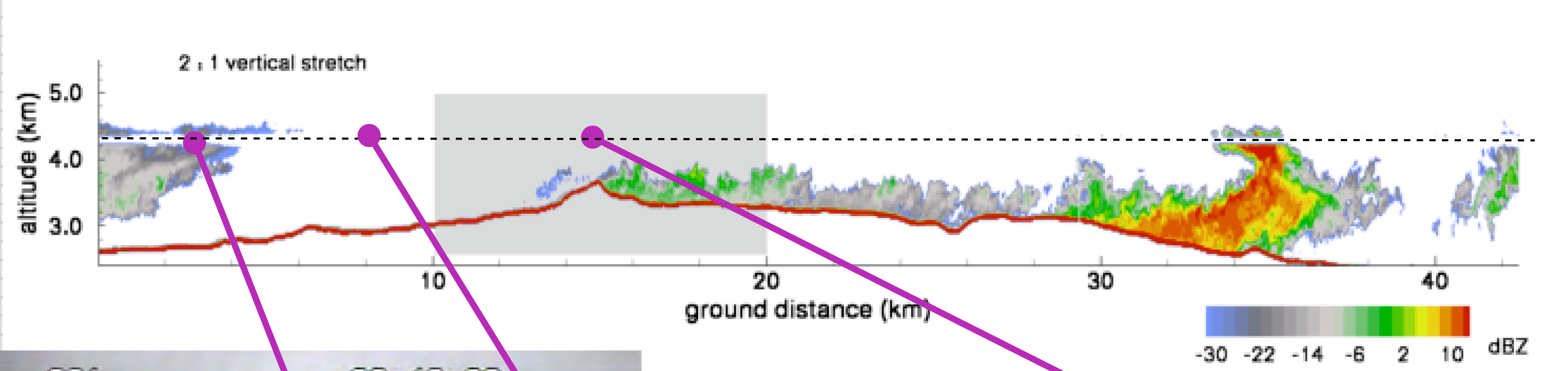


enter diffuse cloud
3 : 2 vertical stretch
altitude (km)
6.0
4.0
2.0
flight line
th. cld. base* ~2900 m
0
10
20
30
40
50
ground distance (km)
-30 -22 -14 -6 2 10
dBZ
001
FWD COCKPIT
22:23:37
01-27-06
001
FWD COCKPIT
001
FWD COCKPIT
22:27:38
01-27-06



* cloud base estimated from 02:25-02:45 SAR sounding

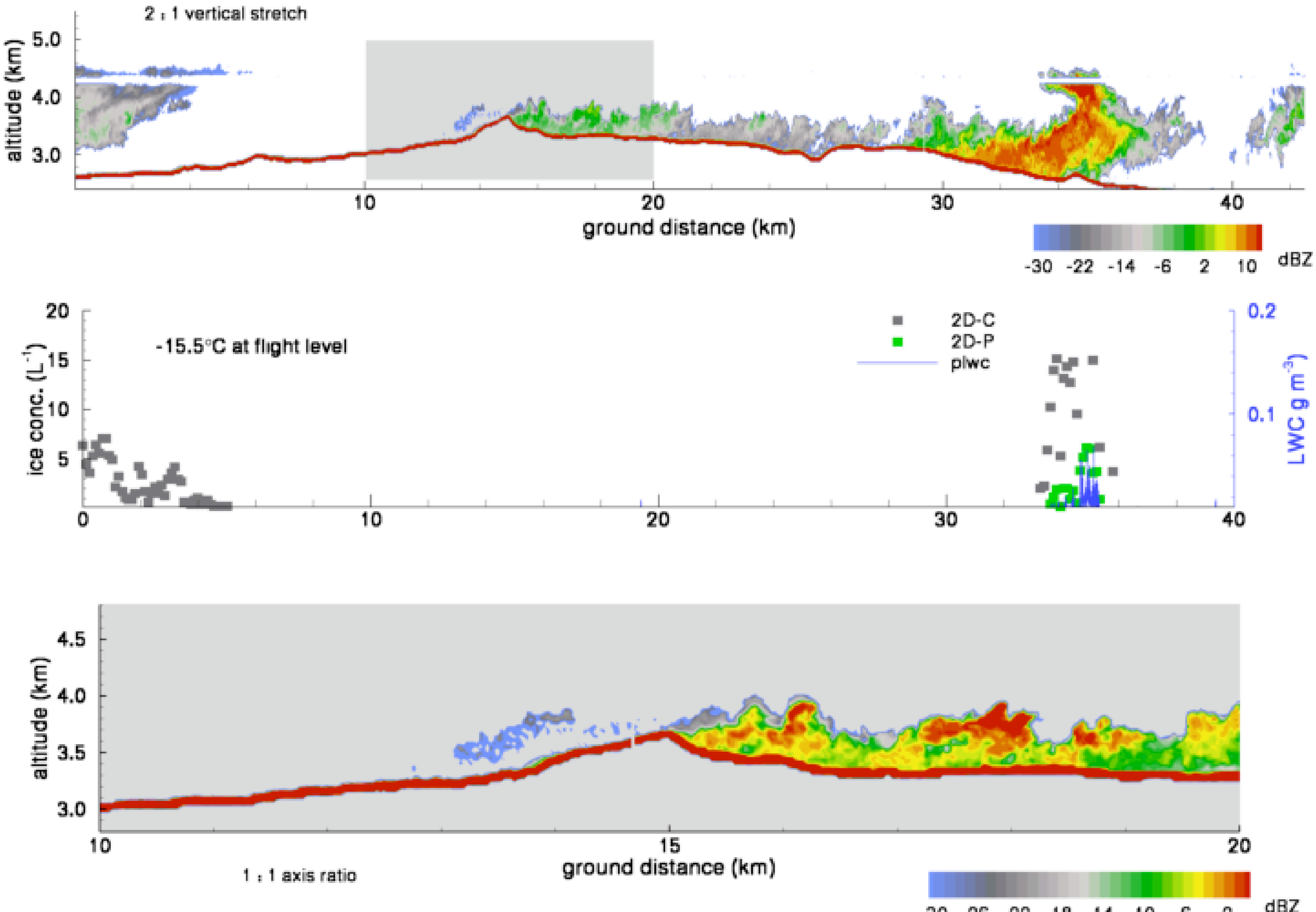
NASA06 jan 27 22:22 - 22:31; across MB Range on 080° heading; winds from 233° at flight level



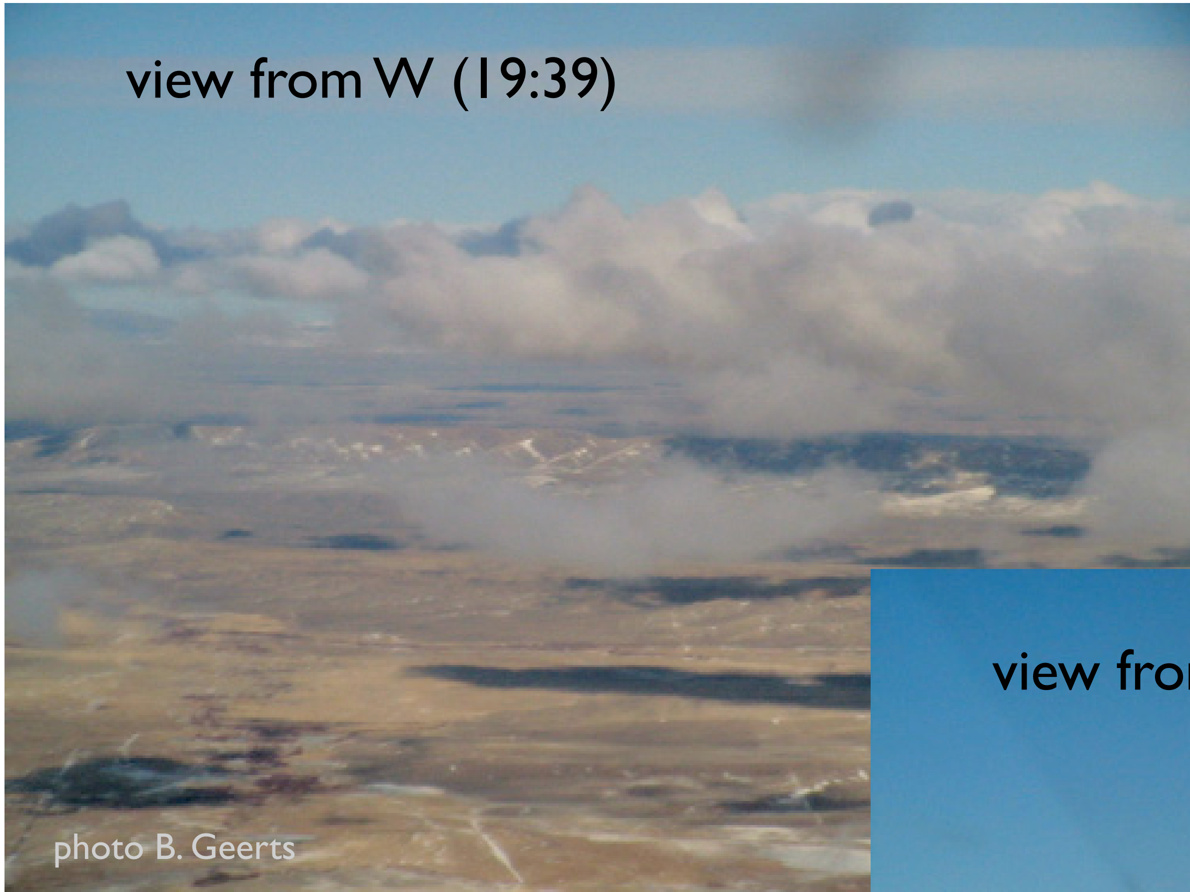
approaching broken cloud field from the West

just about at the leading edge of the cloud field

directly over highest ground; ground visible even though radar shows relatively strong echoes



NASA06 jan 27 22:45 - 22:52; across MB Range on 085° heading; winds from 233° at flight level

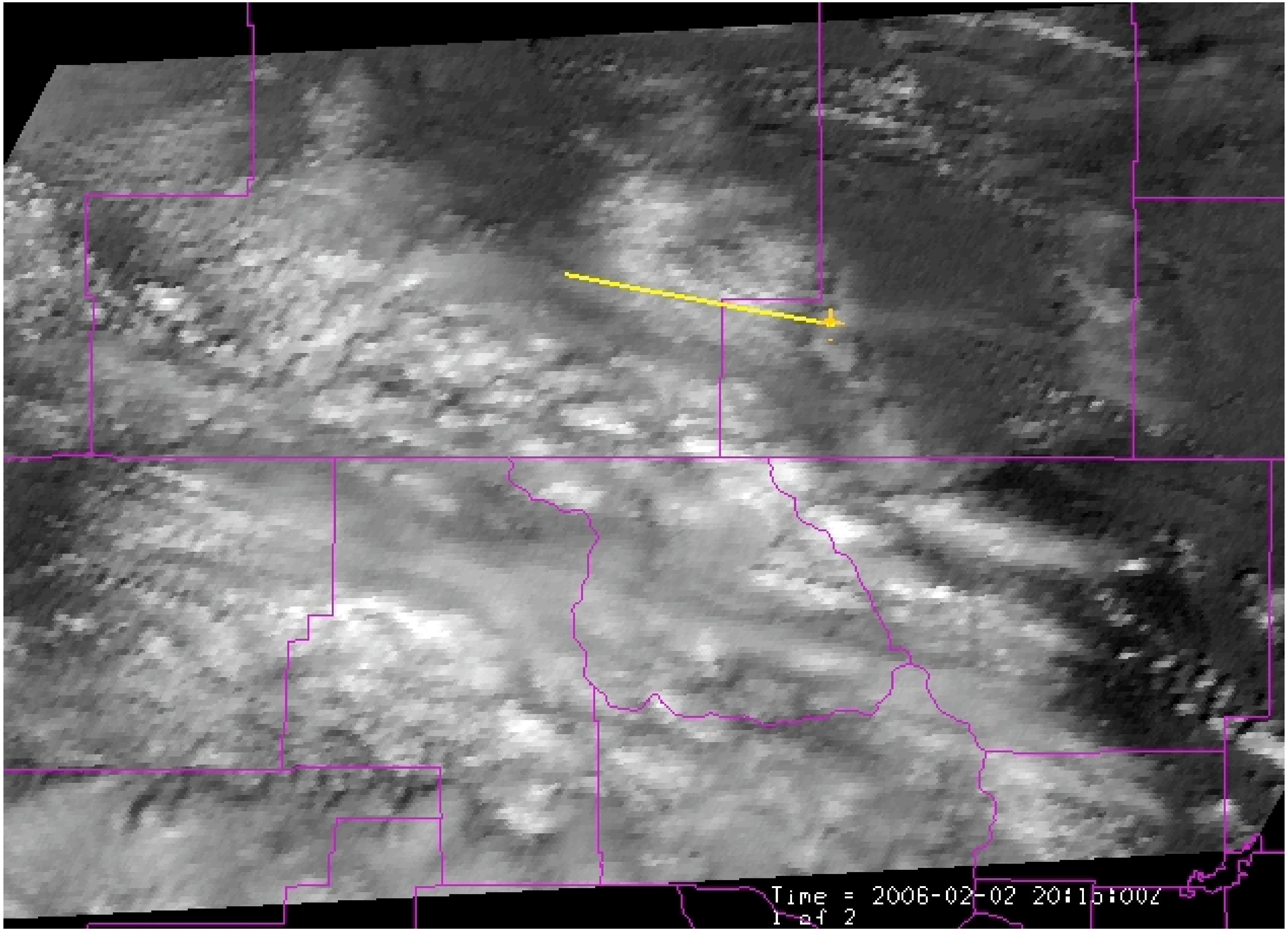


feb 02 - isolated mountain cloud

6 km tops at start of flight, 5 km 2 hours later.

~12-16 m s^{-1} winds

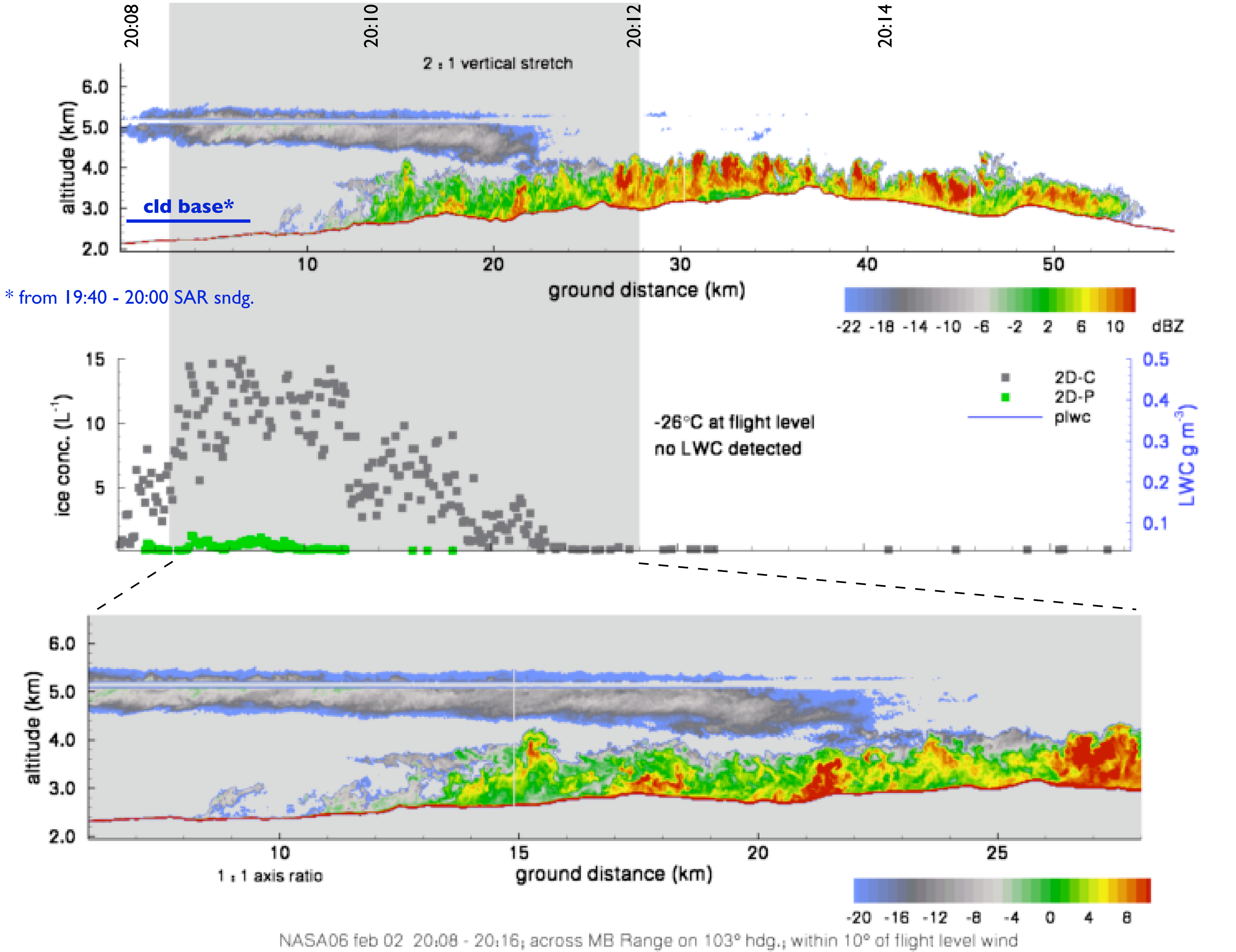
250-280 cm^{-3} drop conc.



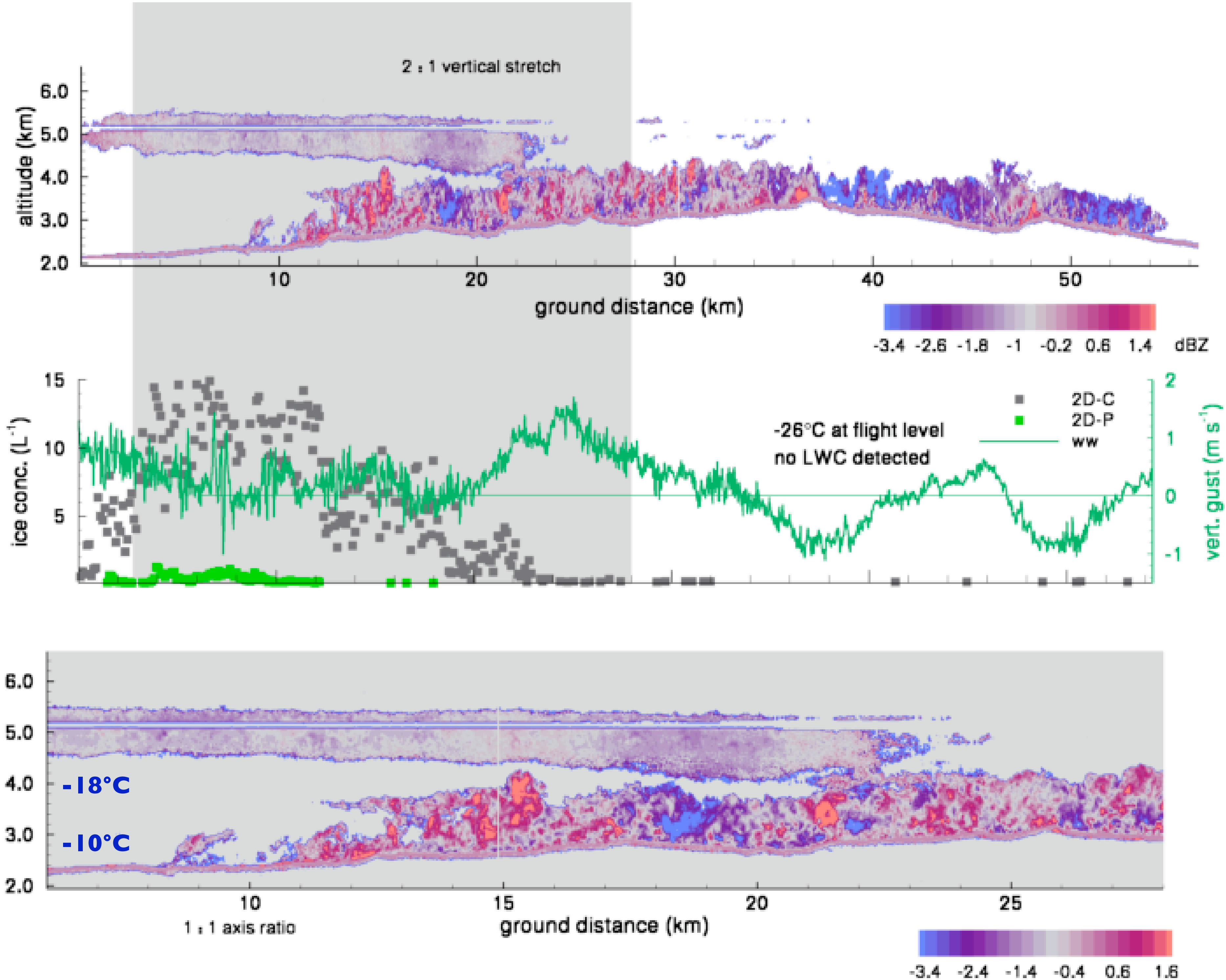
VIS image at 20:15 with flight track 20:08 - 20:16


20:07 approaching
photo B. Geerts

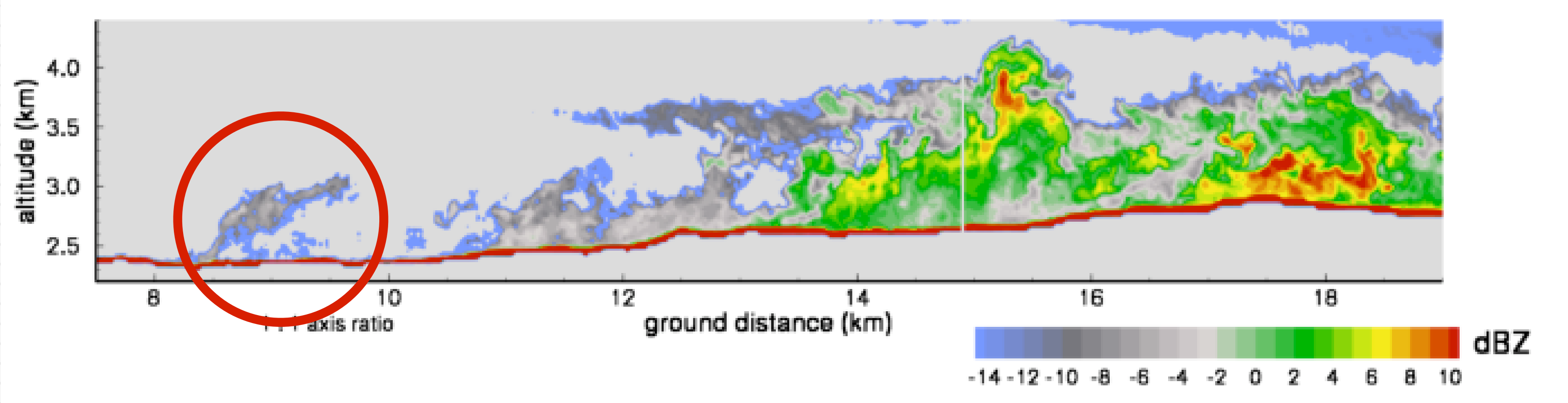

20:11 exiting
photo B. Geerts

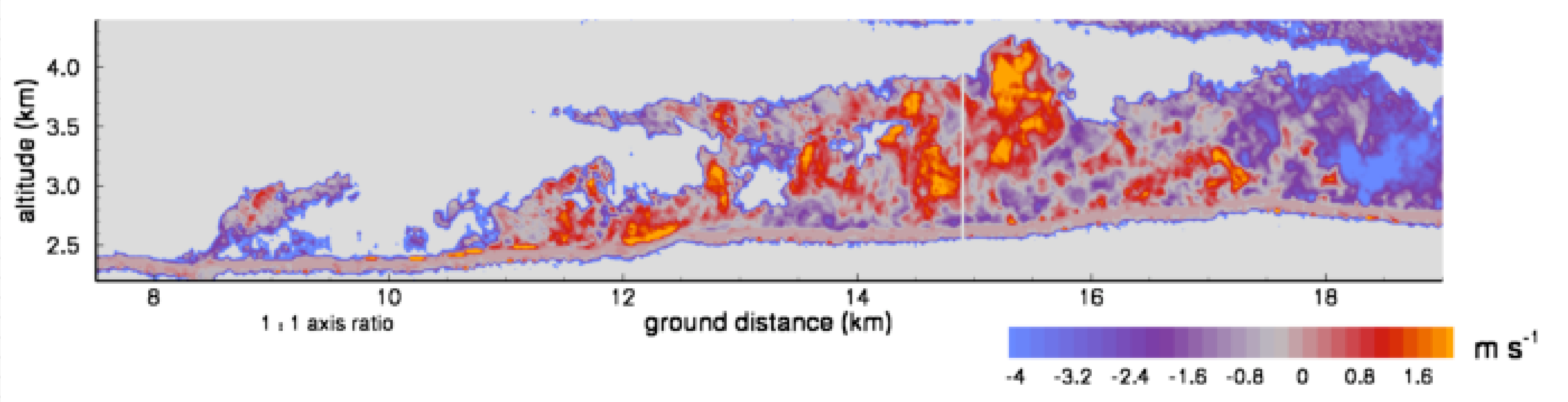


20:08
20:10
20:12
20:14
2 : 1 vertical stretch
altitude (km)
6.0
5.0
4.0
3.0
2.0
cld base*
10
20
30
40
50
ground distance (km)
* from 19:40 - 20:00 SAR sndg.
-22 -18 -14 -10 -6 -2 2 6 10 dBZ
ice conc. (L⁻¹)
15
10
5
-26°C at flight level
no LWC detected
2D-C
2D-P
plwc
0.5
0.4
0.3
0.2
0.1
LWC g m⁻³)
altitude (km)
6.0
5.0
4.0
3.0
2.0
10
15
20
25
1 : 1 axis ratio
ground distance (km)
-20 -16 -12 -8 -4 0 4 8
NASA06 feb 02 20:08 - 20:16; across MB Range on 103° hdg.; within 10° of flight level wind



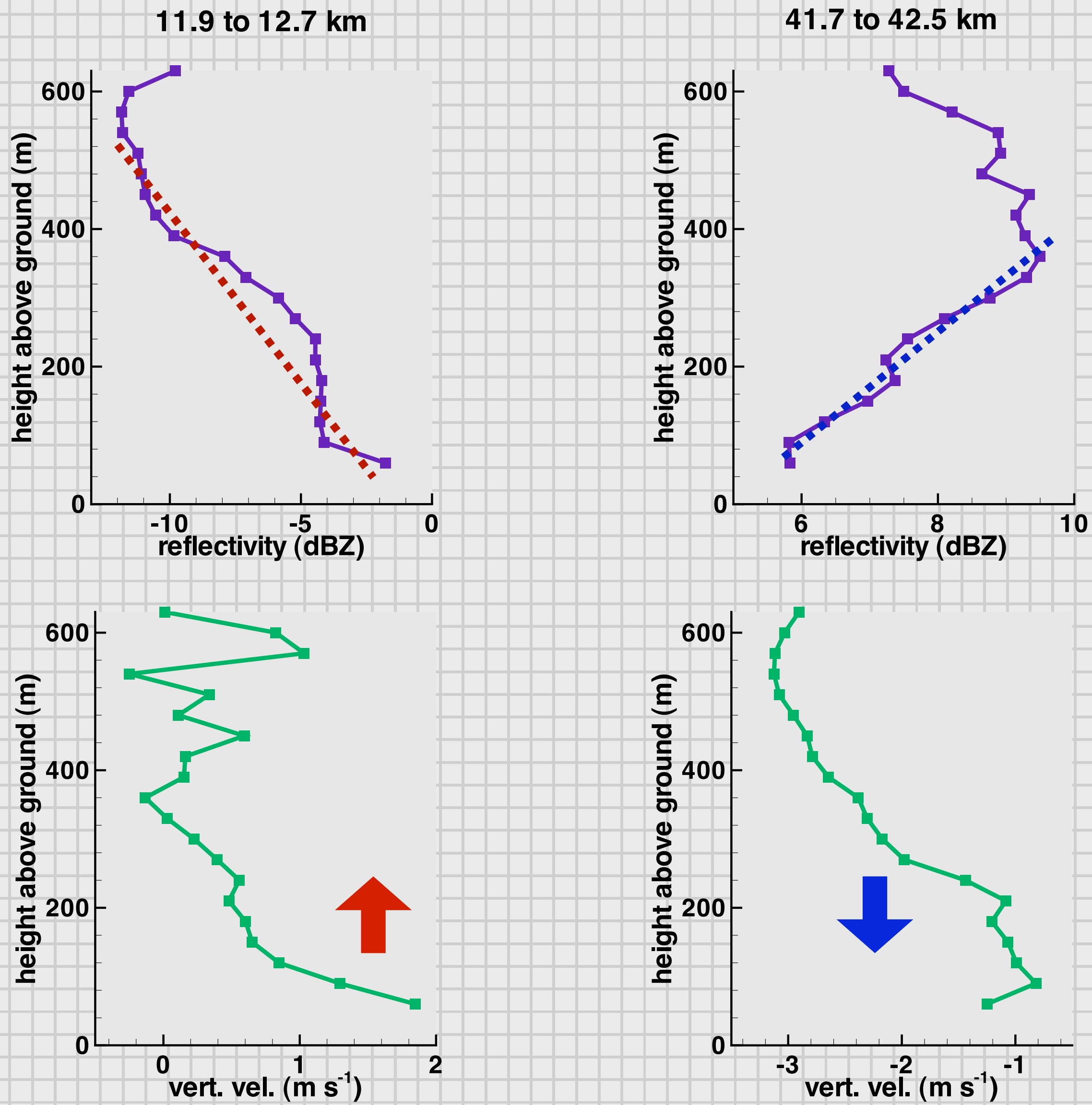
NASA06 feb 02 20:08 - 20:16; across MB Range on 103° hdg.; within 10° of flight level wind


altitude (km)
4.0
3.5
3.0
2.5
8
10
12
14
16
18
axis ratio
ground distance (km)
dBZ
-14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10

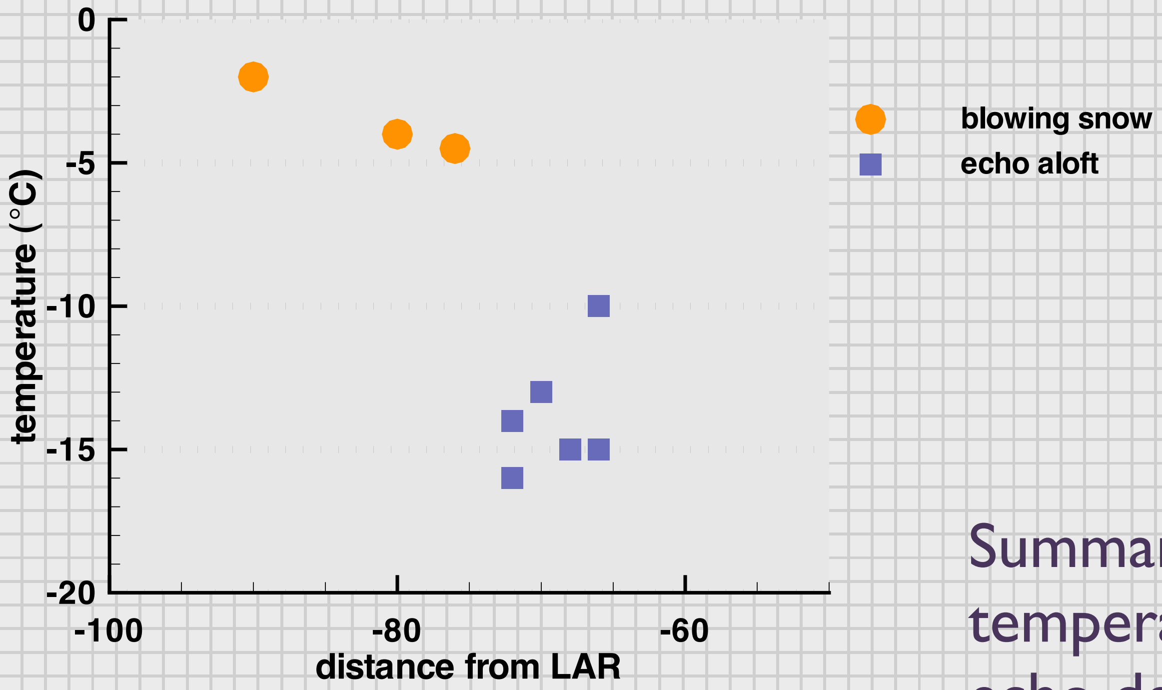

altitude (km)
4.0
3.5
3.0
2.5
8
10
12
14
16
18
1 : 1 axis ratio
ground distance (km)
m s-1
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6

Profiles of the average reflectivity and vertical velocity in boxes of 600 m depth and 750 m length at the indicated positions.

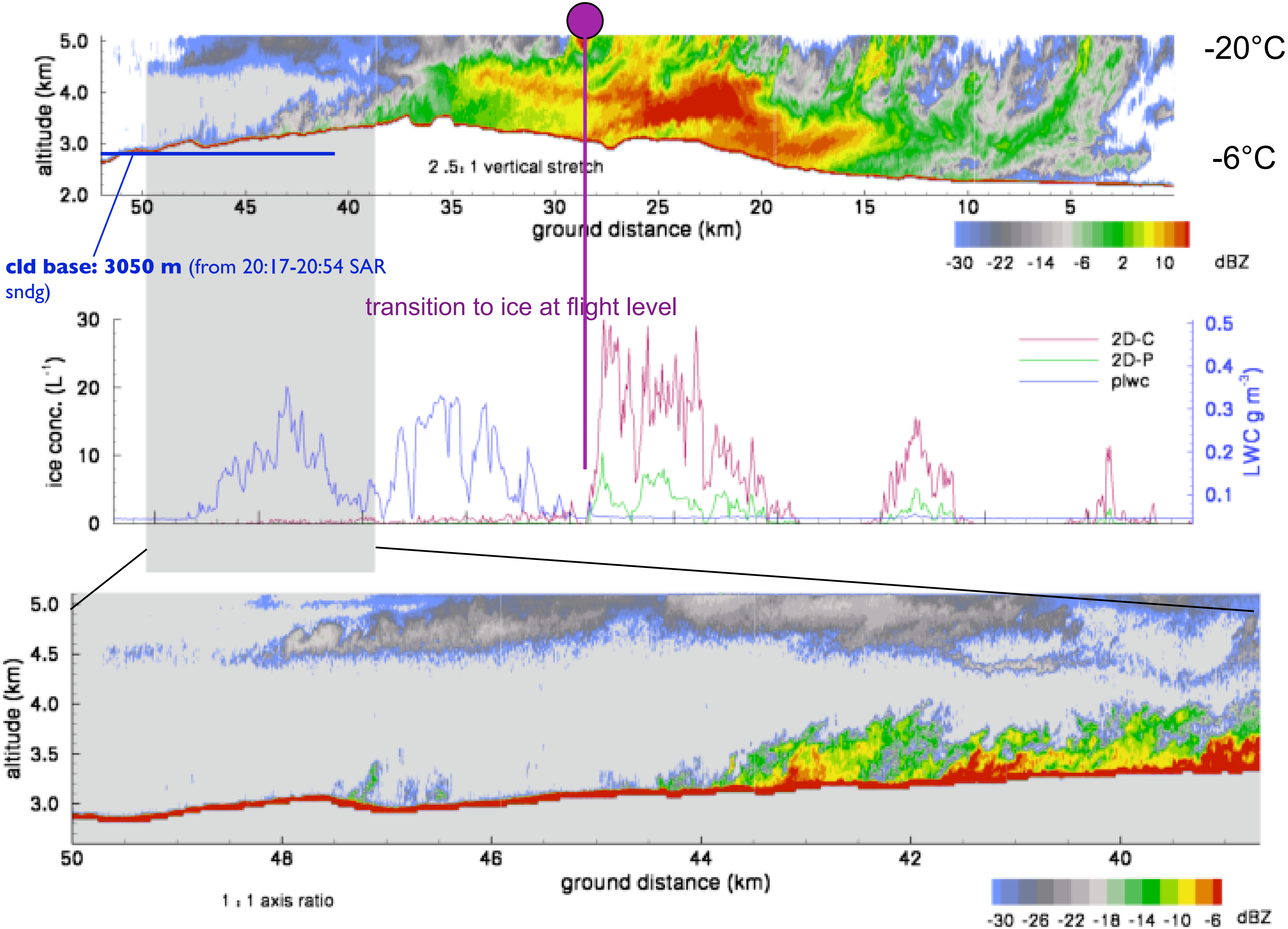
lofted snow with maximum reflectivity and upward velocity near the surface.



falling snow on the downwind side, with downward velocities and positive reflectivity gradients.



Summary of locations and temperatures of earliest echo detected in the lowest cloud layer or near the surface.



NASA06 jan18 22:09 - 22:22; across MB Range on 262° hdg.; into the wind

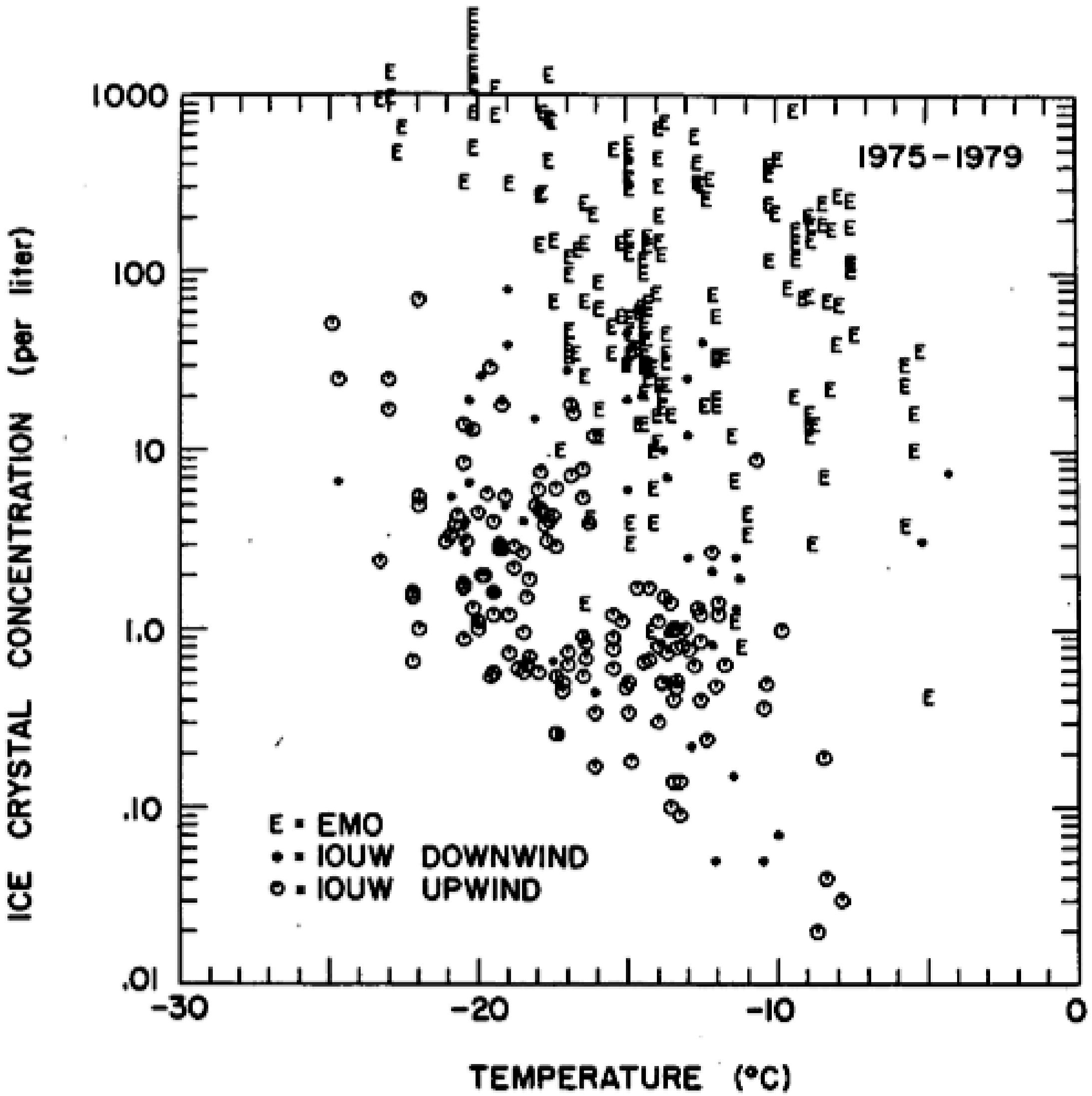


FIG. 11. A summary of ice crystal concentration measurements in Elk Mountain cap clouds. Each aircraft data point represents the geometric mean concentration and arithmetic mean temperature for one cloud pass (open circle) upwind or (closed circle) downwind of the mountain summit. Cloud passes were about 60 s in duration. Typical variabilities for these points are a factor of 2.0 in concentration (geometric standard deviation of the 1 s 2D-C probe counts during the pass) and ±0.5°C in temperature (standard deviation of 1 s values). Each EMO data point (E) is a separate measurement, taken coincidently with the aircraft observations. The data are from 30 different cloud cases on 26 days over the period 1975 to 1979.

Rogers and Vali, 1975

(J. Clim. Appl. Meteor. **26**, 1152 - 1168):

Conditions:

- **cloud and rime**
- **-5° to -25°C**
- **diffusional growth**

Evidence is strong that ice crystals are lofted from, or near, the mountain surface into the cloud. This leads to glaciation of the cloud and a reduction of seeding potential.

Possible mechanisms are:

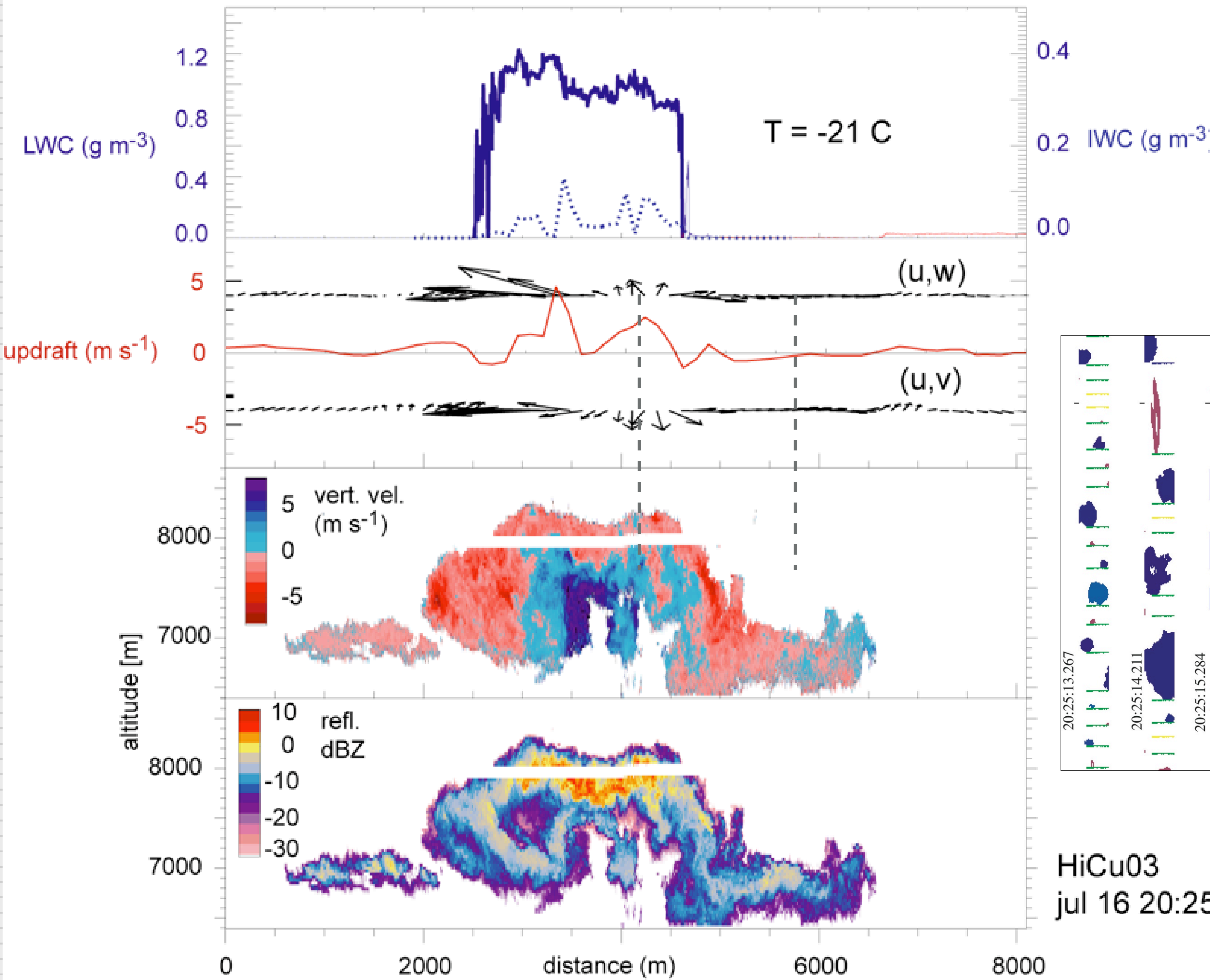
- snow from the surface
- some process involving riming on trees.

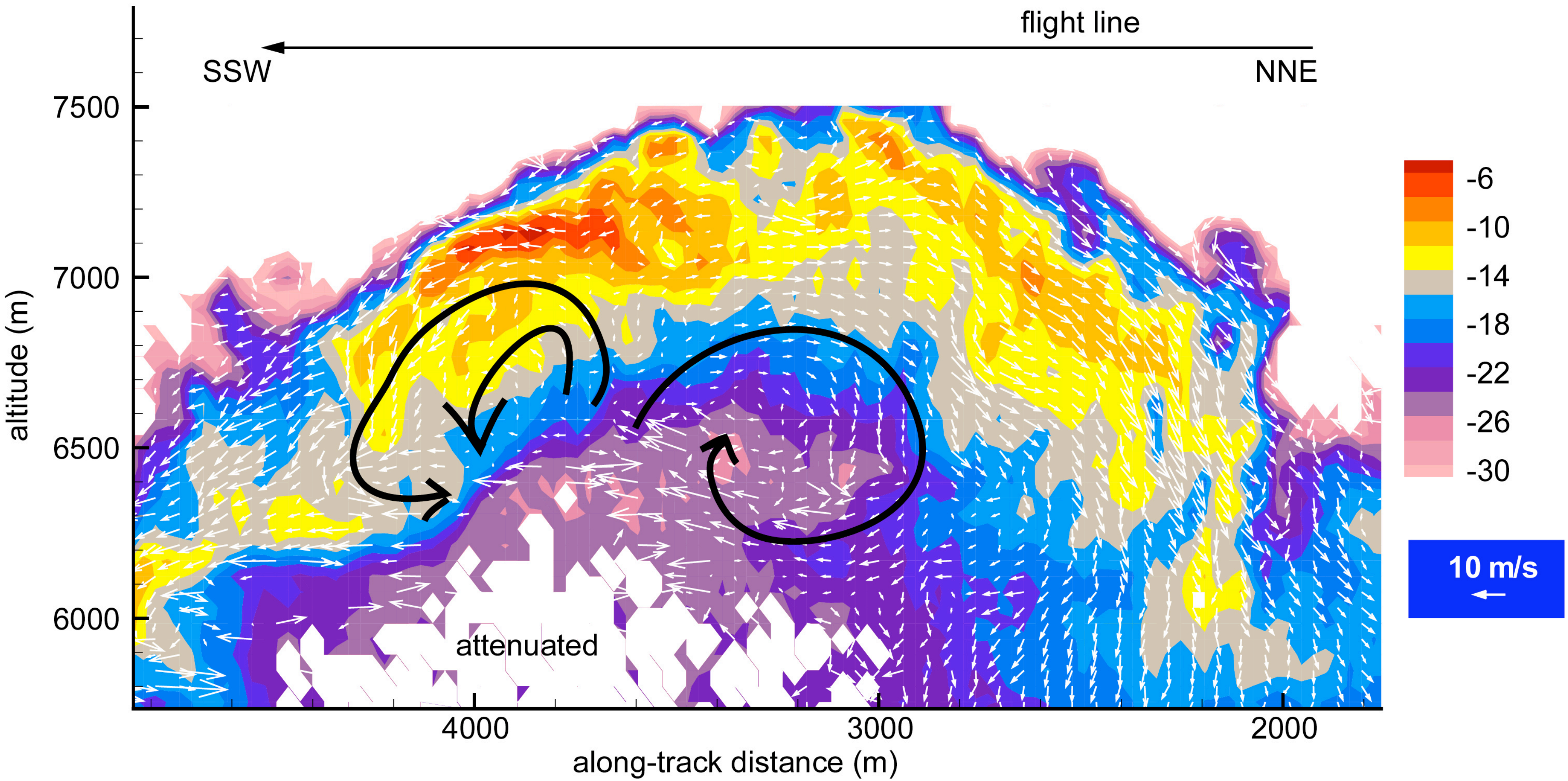
Will not be easy to quantify and to delimit necessary conditions.

Implications for cloud seeding of orographic clouds.

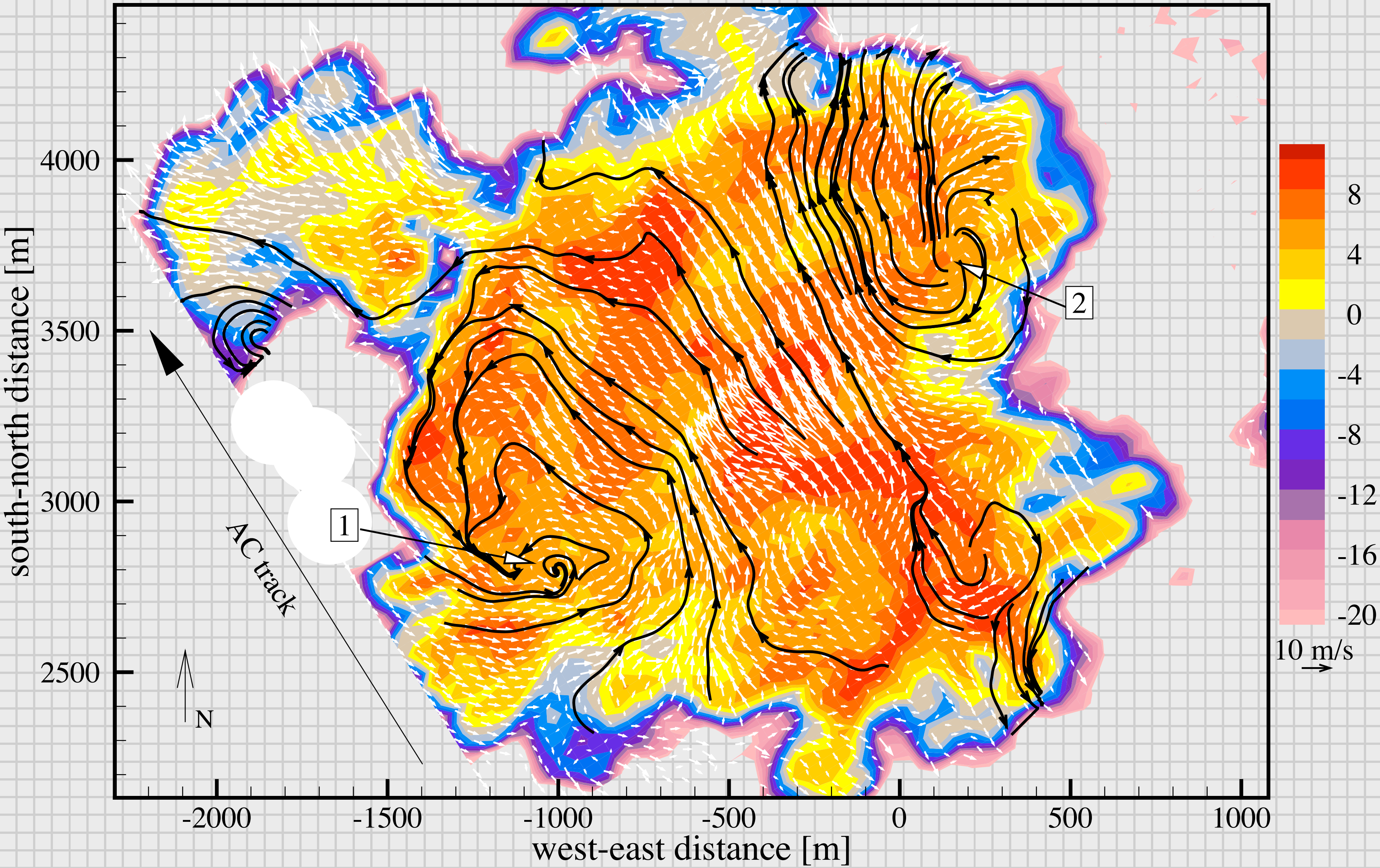
Damiani, Vali and Haimov, 2006
(J. Atmos. Sci. **63**, 1432 - 1450)

Damiani and Vali, 2007
(J. Atmos. Sci. 64, 2045-2060)

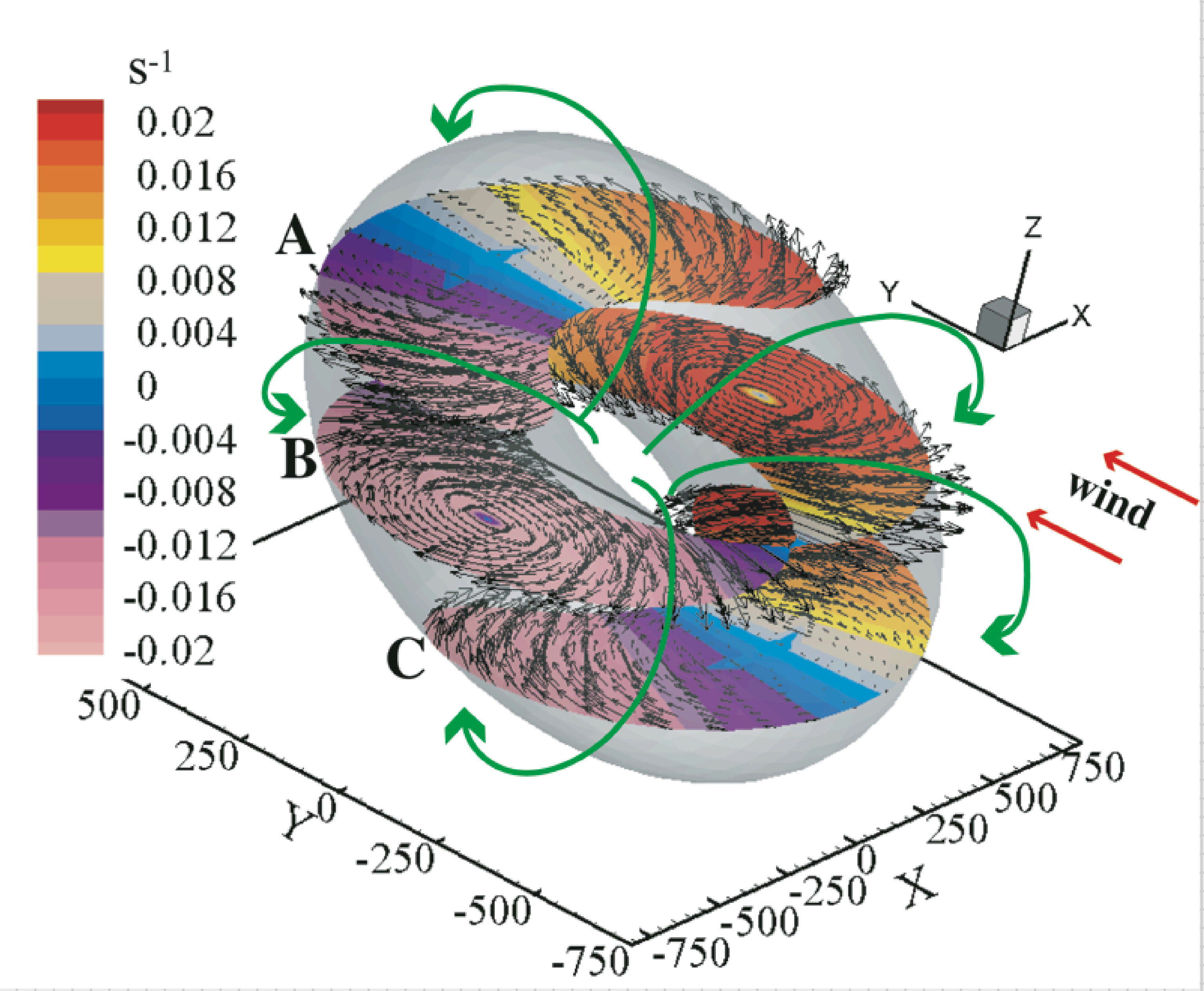

LWC (g m-3)
1.2
0.8
0.4
0.0
0.4
0.2
0.0
IWC (g m-3)
T = -21 C
(u,w)
(u,v)
updraft (m s-1)
5
0
-5
vert. vel.
(m s-1)
5
0
-5
altitude [m]
8000
7000
refl.
dBZ
10
0
-10
-20
-30
8000
7000
0
2000
distance (m)
6000
8000
20:25:13.267
20:25:14.211
20:25:15.284
20:25:16.850
HiCu03
jul 16 20:25

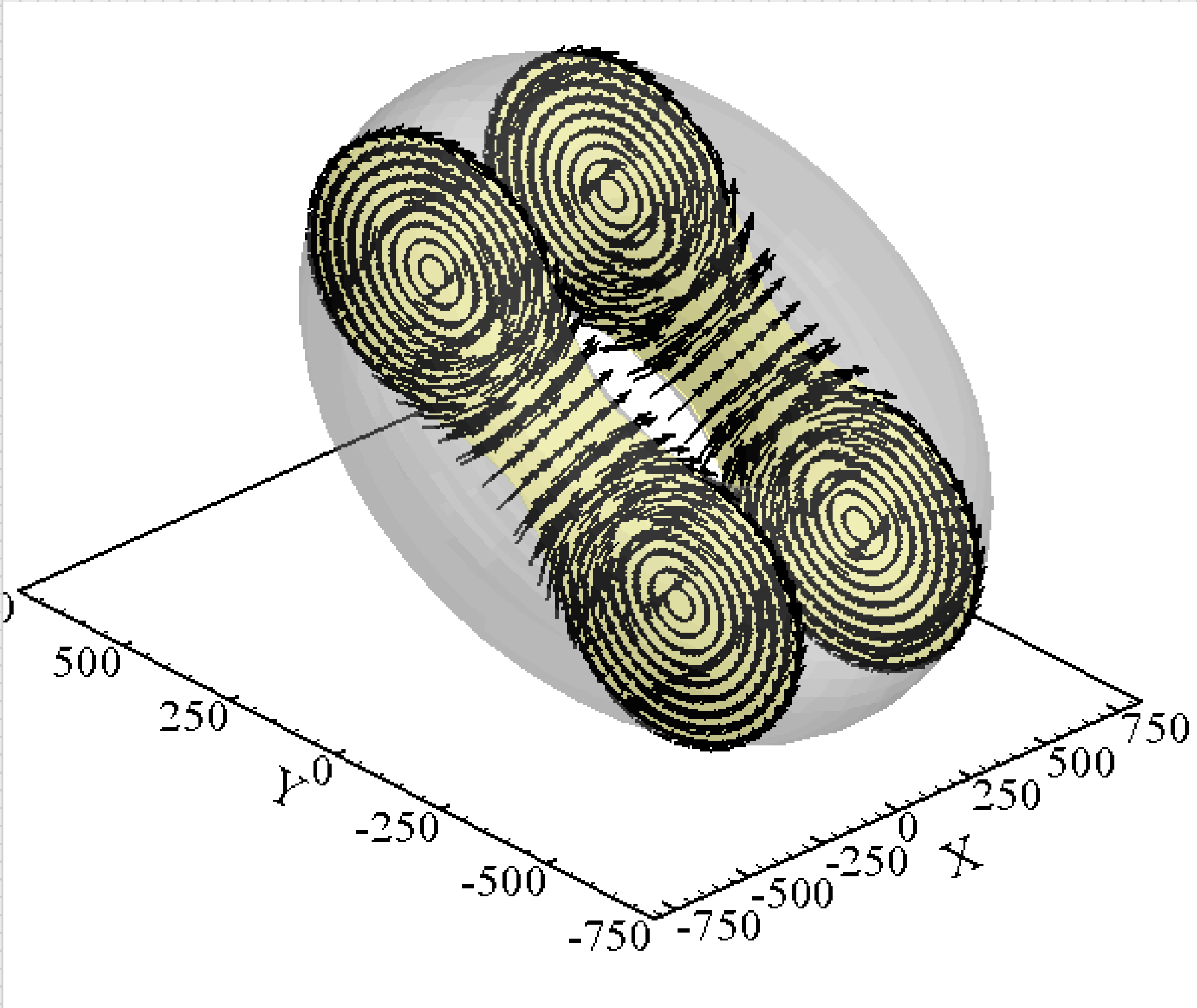


source: R. Damiani

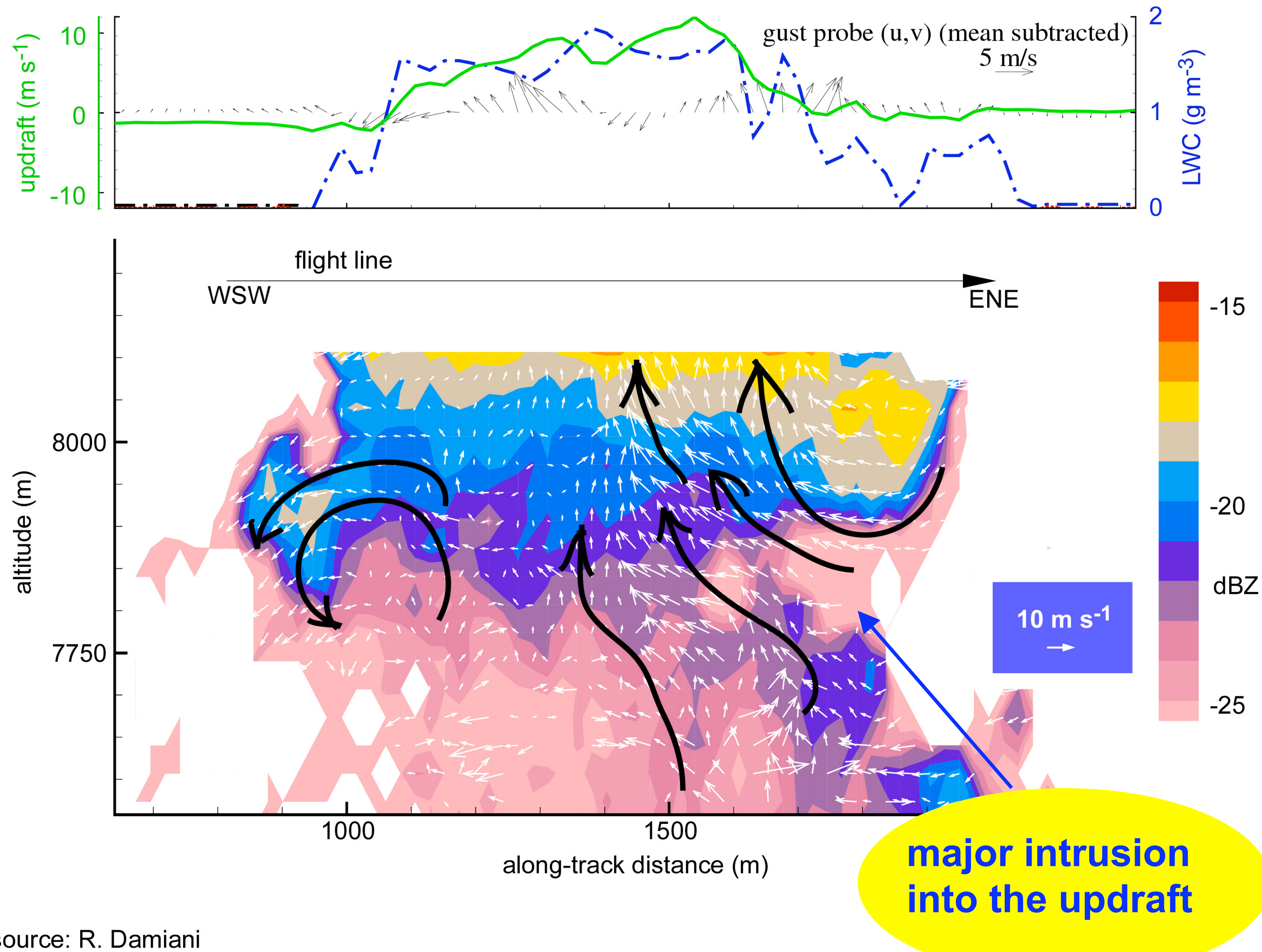


20030712 193510-193600 HBDD scan.wfg=1. sigma=2.5. Advection vel.: E13.39 N-10.19 U0 from wadv=666!.
leg=0 grid cell 35*46 m^2. HDG:330. PALT=7216m. SNR+BSW weighting enabled (vels=0.5-4).


s-1
0.02
0.016
0.012
0.008
0.004
0
-0.004
-0.008
-0.012
-0.016
-0.02
A
B
C
Z
Y
X
wind
500
250
Y 0
-250
-500
-750
-750
-500
-250
0
250
500
750
X



500
250
Y 0
-250
-500
-750
-750
-500
-250
0
250
500
750
X



source: R. Damiani

The toroidal circulation in growing cumulus leads to counter-rotating vortices with horizontal and vertical components.

This circulation results in the injection of ice particles brought down from cloud top into the updraft. It can also lead to major intrusions of dry air into the updraft.

Detailed studies of cloud structures led to the identification of processes that account for some of the large discrepancies reported between ice particle concentrations and ice nucleus measurements.

1. Under what conditions is the "surface effect" active ?

2. Does recirculation of ice from cloud top outweigh ice initiation (natural or seeded) in the updraft?