Weather Radar and Snow

Applications of Weather Radar in Aviation Winter Weather Service Provision in Austria

EuMeTrain Snow Event Week

08-12.Feb. 2021

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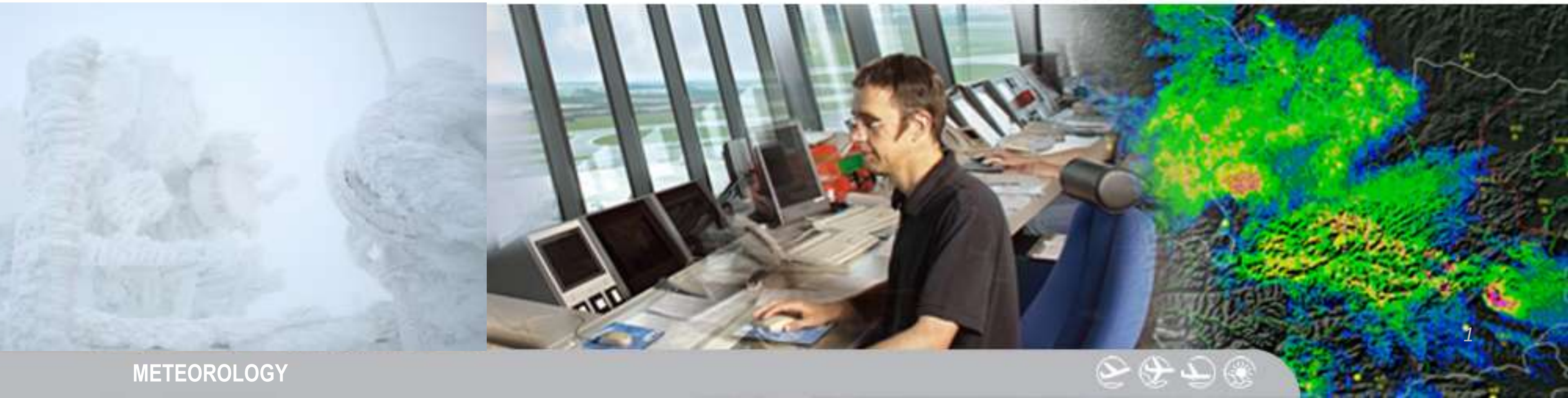
Austro Control, Air Navigation Services - Aeronautical Meteorology , Austria

SAFETY IS IN THE AIR



Outline

weather radar and snow from an operational perspective

- Advantages of Using Weather Radar in Meteorology
  - Winter Weather and Aviation
  - Mesocale Structures
  - Movement of winter squall line
  - Intensity and winter precipitation
- Weather Radar Detection of Snow
  - Weather Radar Principles
  - Radar Moments
  - Z-R, Z-S Relationship
  - Radar Geometry
- Weather Radar Limitations / Advantages of Cold Winter Weather
  - Radar Beam Propagation
  - Quality Control, Data Processing
  - Bright Band
  - Spurious Echoes
- Weather Radar Related Winter Nowcasting Application for Aeronautical Meteorology
  - Nowcasting
  - Assimilation
  - Hydrometeoclassification
  - Quantitative Precitation Estimation
  - Frontal Lines

Outline

Advantages of Using Weather Radar in Meteorology

Advantages of Weather Radars

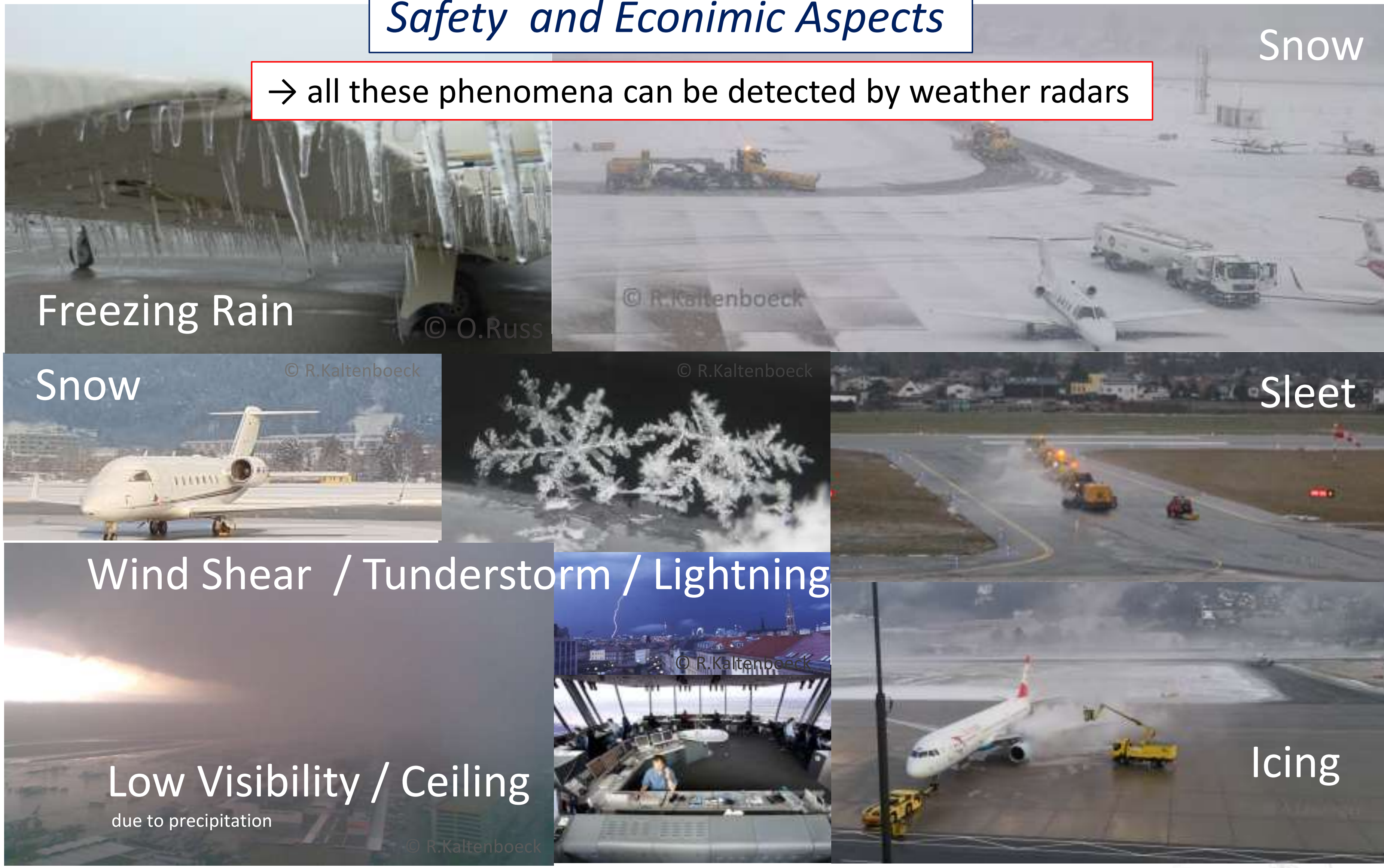
- high spatial and temporal resolution
- up to far ranges /networks
- 3D information of precipitation (horizontal and vertical) + time
- main data source for nowcasting
- detection of
  - cloud droplets and precipitation
  - large/small scale precipitation systems
  - dangerous subscale/mesocale phenomena (even embeded)
  - intensity of precipiation and thunderstorms
  - development of precipitation systems
  - movement of precipitation systems
  - Doppler velocity (e.g. clutter filter, gust fronts, wind shear)
  - Cloud micro physics

→ typically used for **detection** and nowcasting of deep convection, but ….

Winter Weather and Aviation

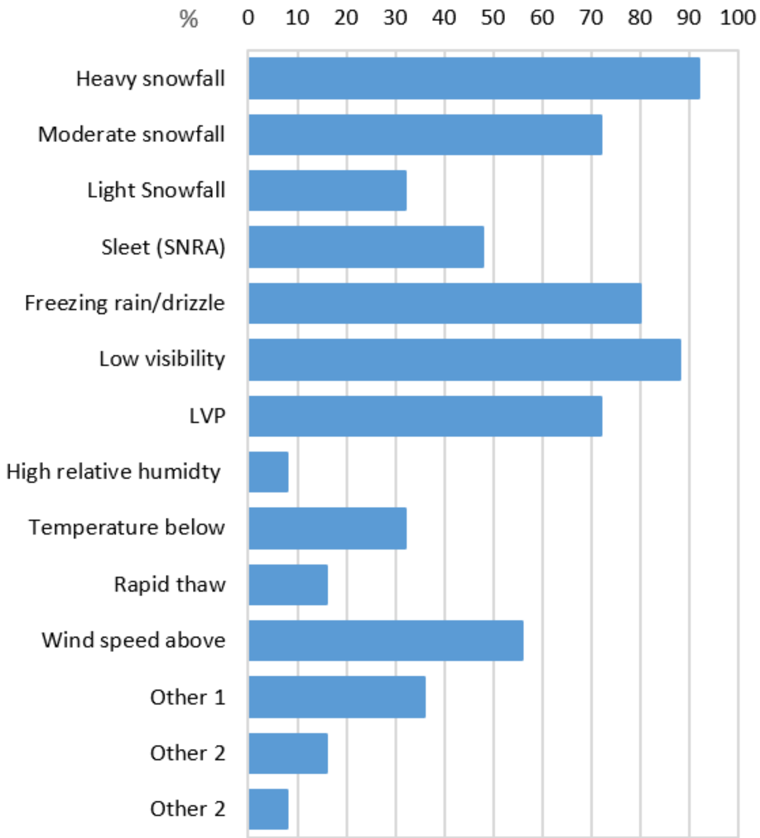
Safety and Econimic Aspects

→ all these phenomena can be detected by weather radars

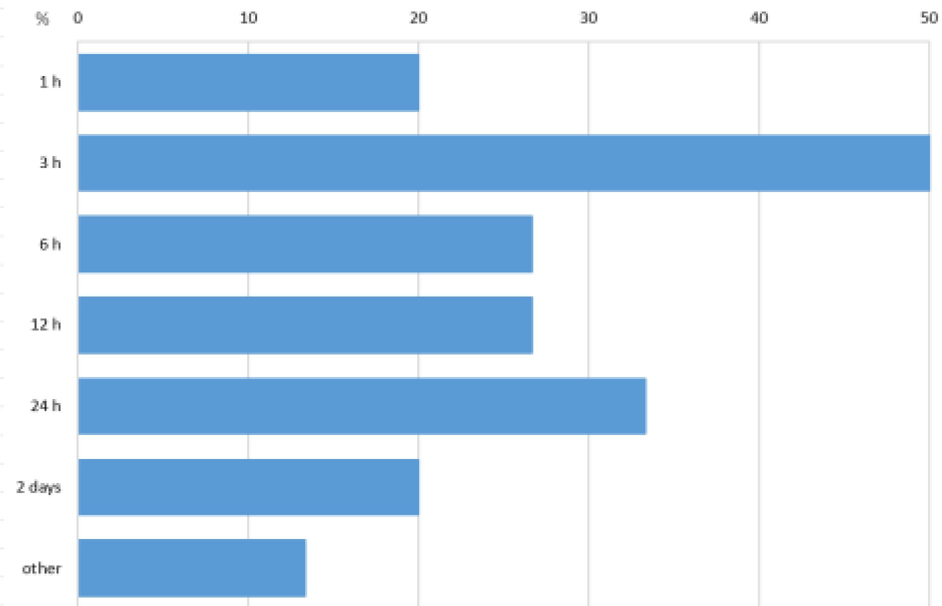


Winter Weather and Aviation

The type of winter weather affecting negatively to airport operation

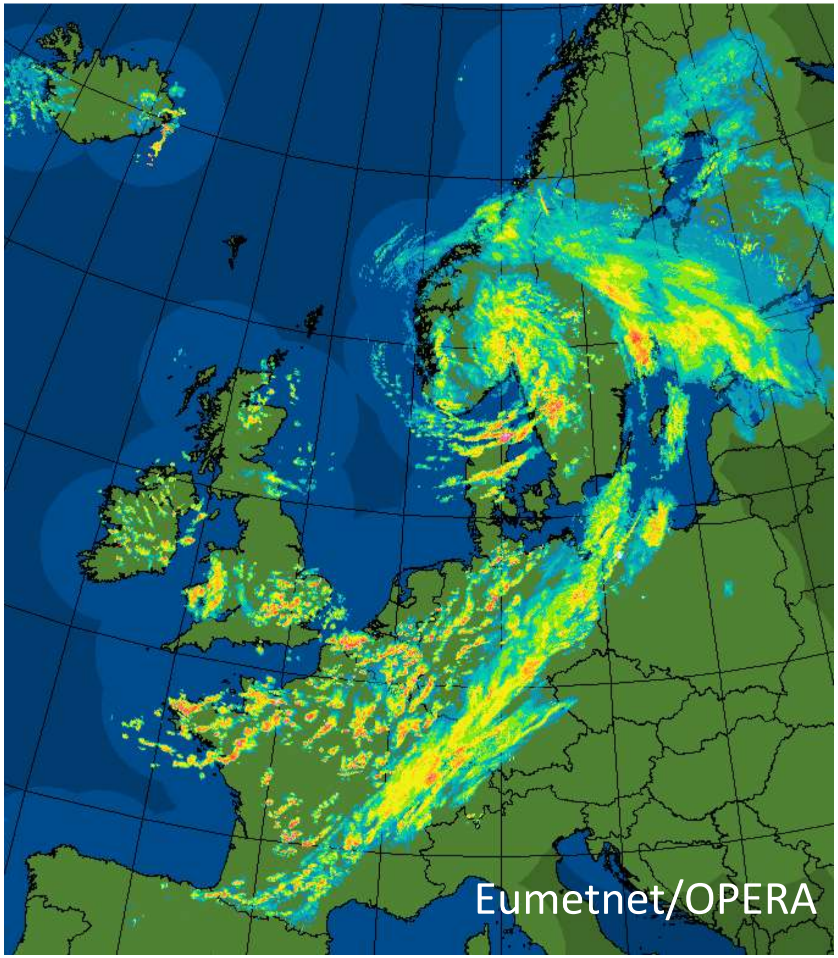


Useful lead time for warning of critical weather for ATM/Airport maintenance group



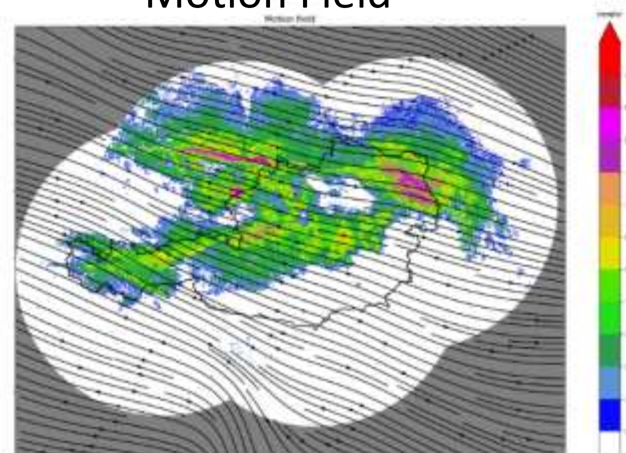
http://pnowwa.fmi.fi

Structures and movement of large and small scale precipitation systems



Cold Front 20190317 13:00 UTC

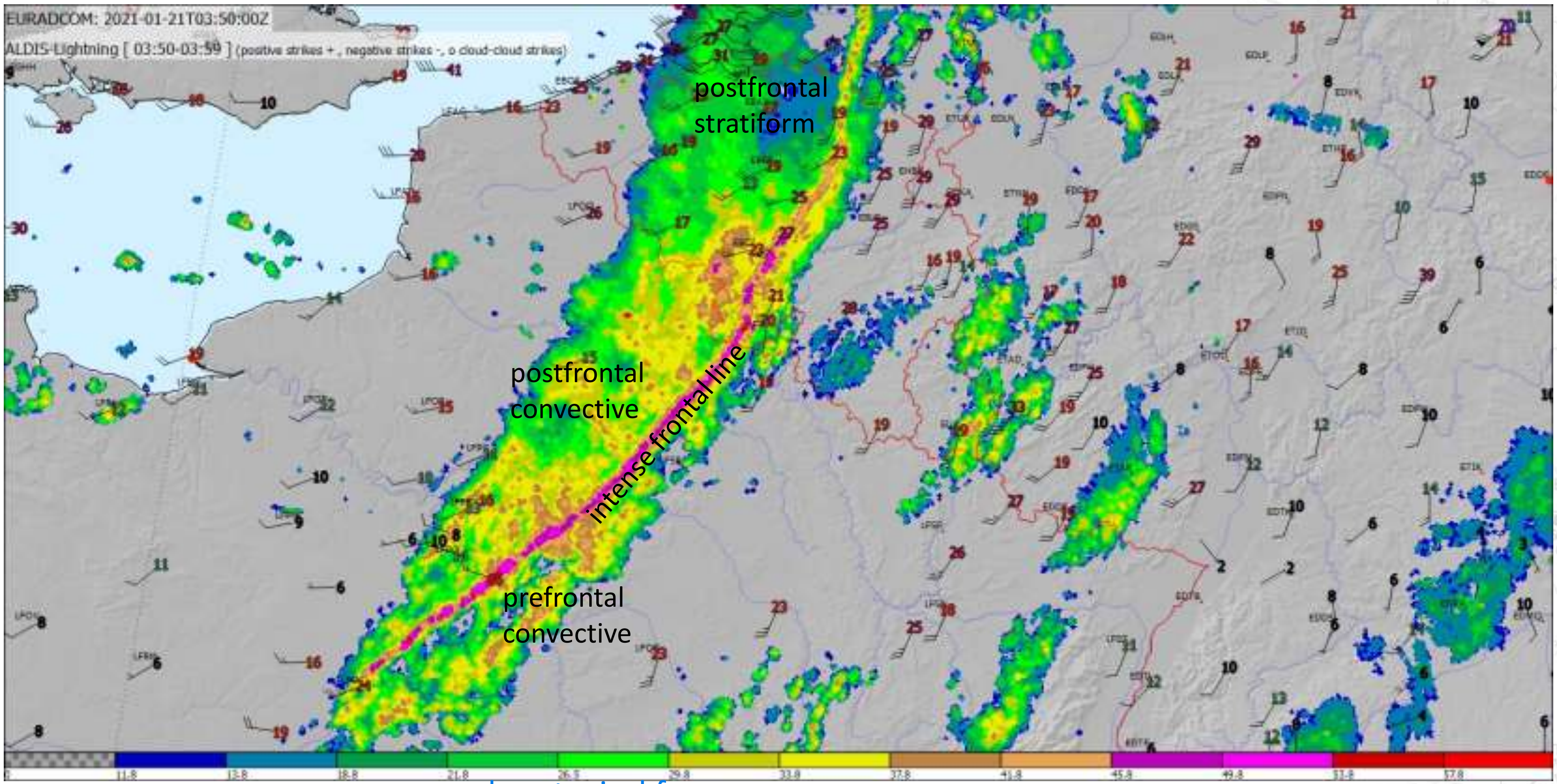
Motion Field



Winter storm 20181224 (+ thunderstorms, wind-shear, gusts 50 kt)

Mesocale Structures

21.Jan 2021 Embeded Mesocale Sub-Structures in Winter Fronts



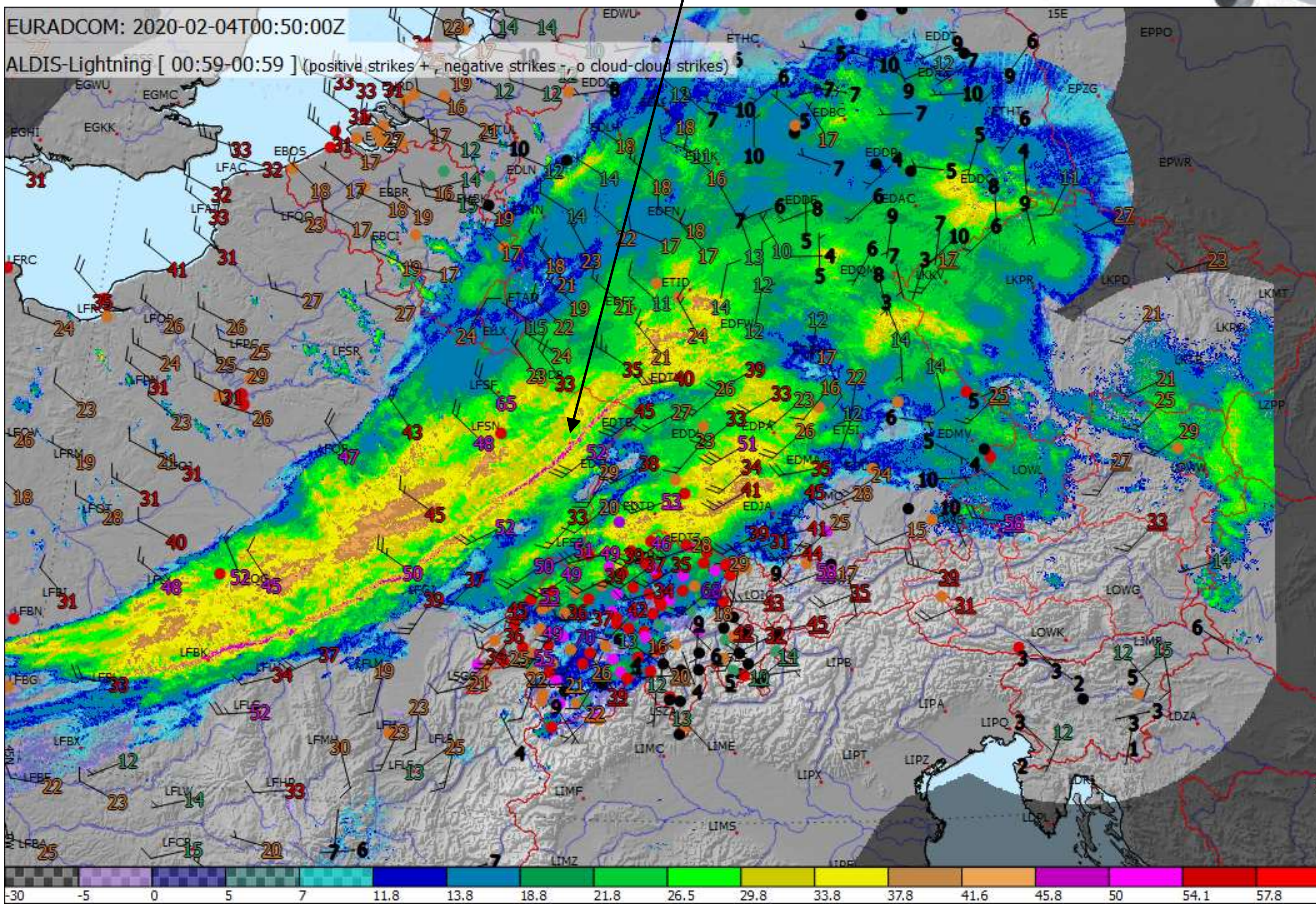
numbers indicate SYNOP wind speed in kt

values typical for snow

leading intense front line accompanied by trailing statiform winter precipitation

Mesocale Structures in Winter Fronts

4th Feb. 2020, wind shift along fine line



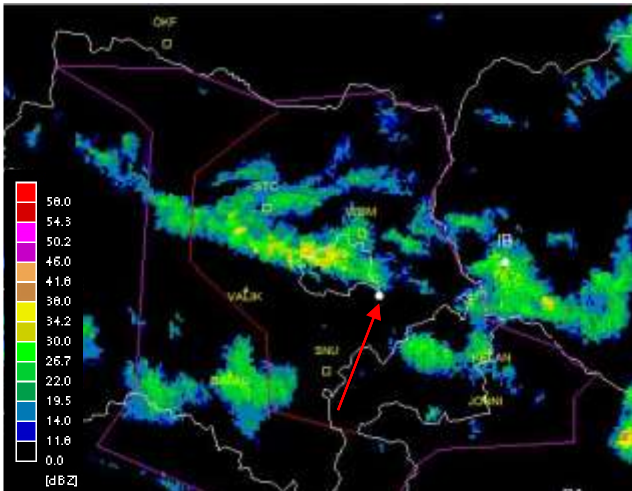
numbers indicate SYNOP gusts in kt

Nowcasting (snowfall, visiblity)

using the weather radar in winter squall line

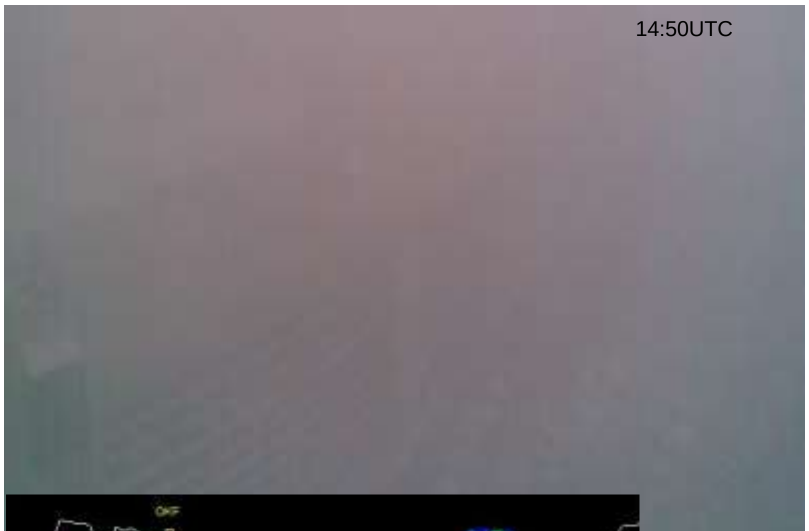
View from Tower Vienna airport

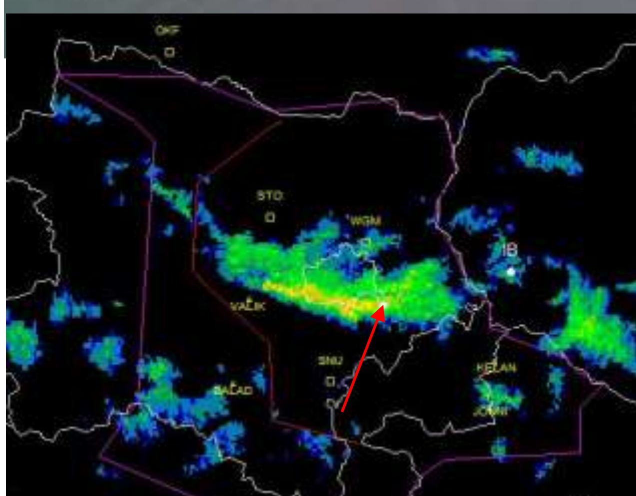
Temperture$_{2m}$: +9 °C



Nowcasting (snowfall, visiblity) using the weather radar in winter squall line

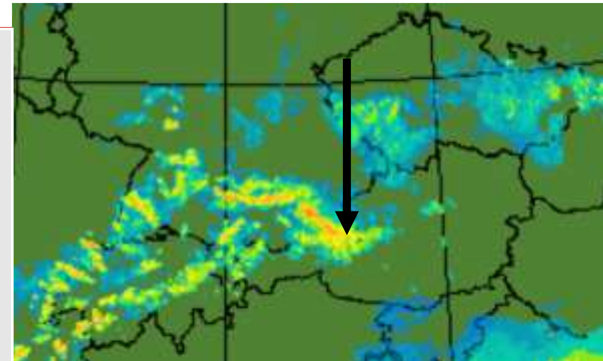
View from Tower Vienna airport

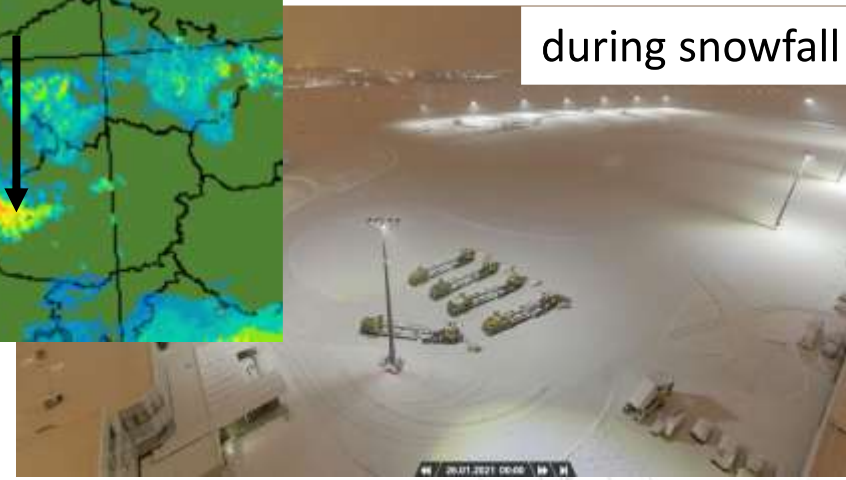




snowfall
drop of visibility

Intensity / Timing of Snowfall





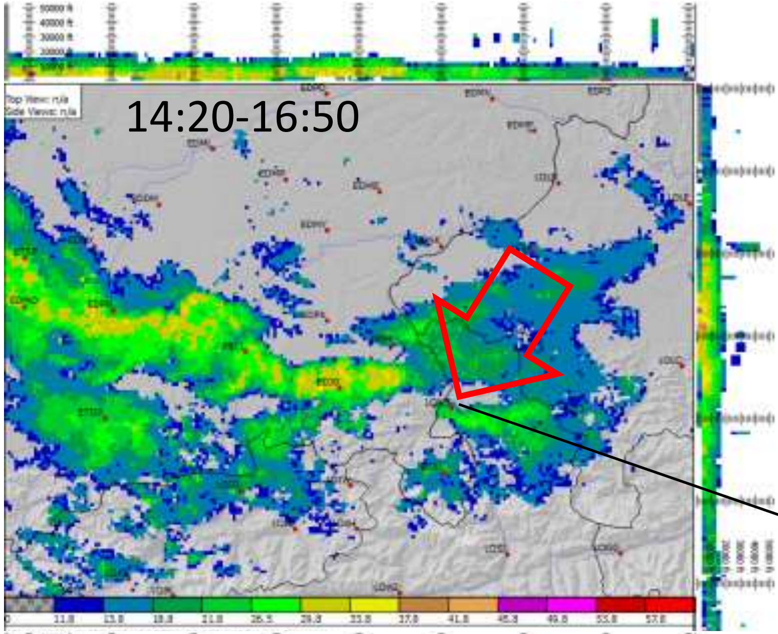
during snowfall

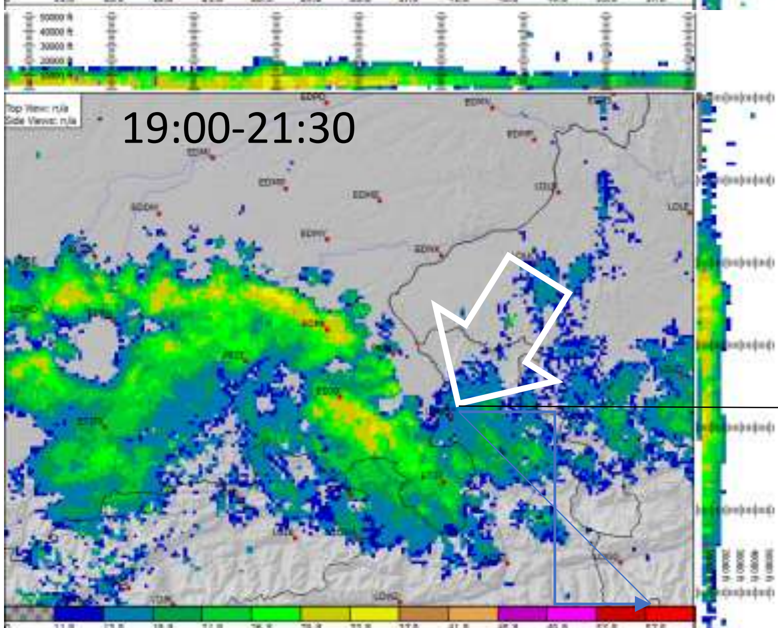
25. Jan. 2021 Salzburg Airport

before

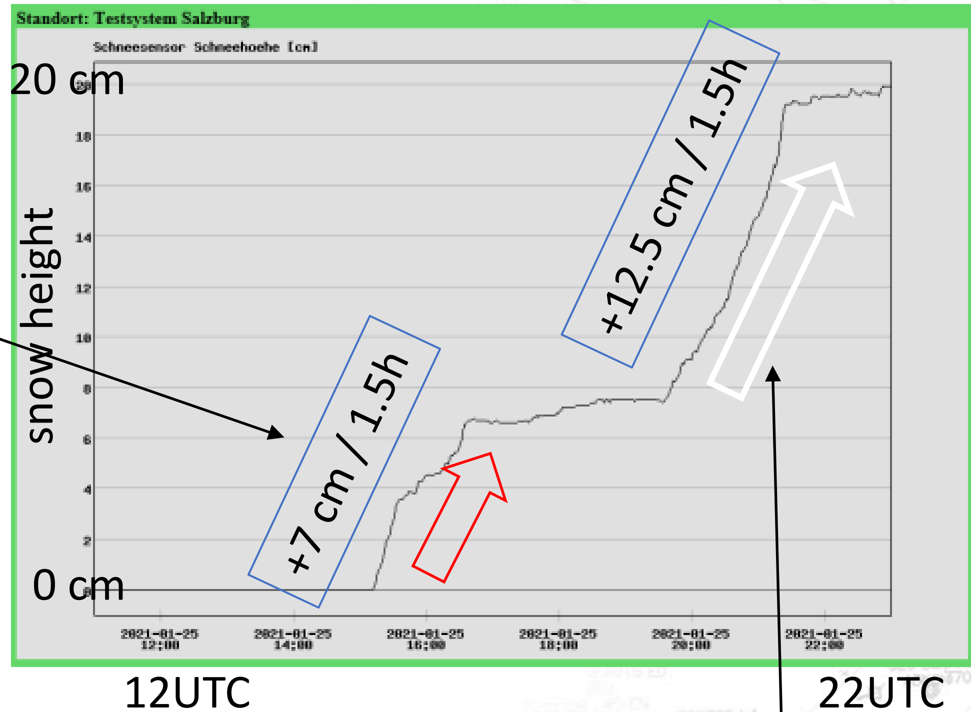
after

Intensity / Timing of Snowfall





25th Jan. 2021
Salzburg Airport



Strong Snowfall ….. Radar Reflectivity > 34 dBZ

Intensity / Timing of Snowfall

25. Jan. 2021 Salzburg Airport

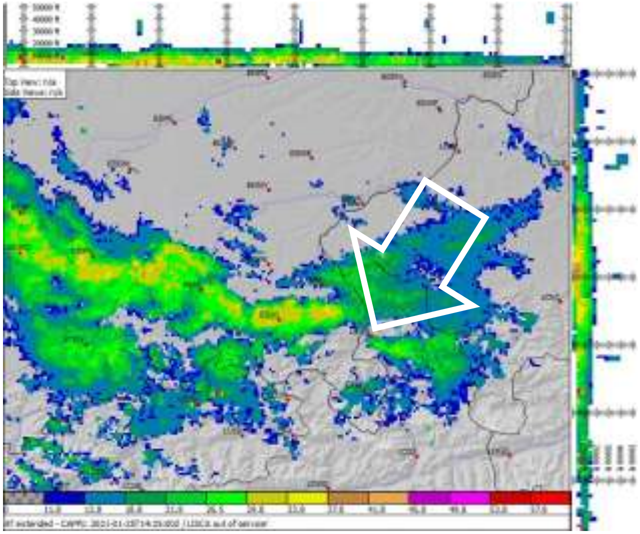
14:40

15:10

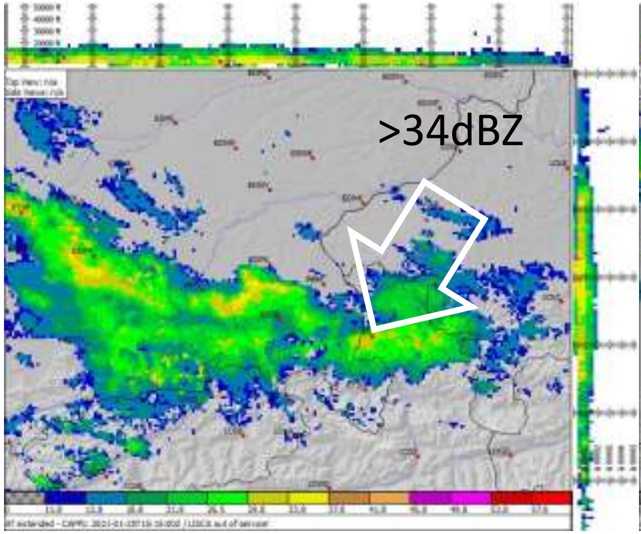
15:20

360° view from tower

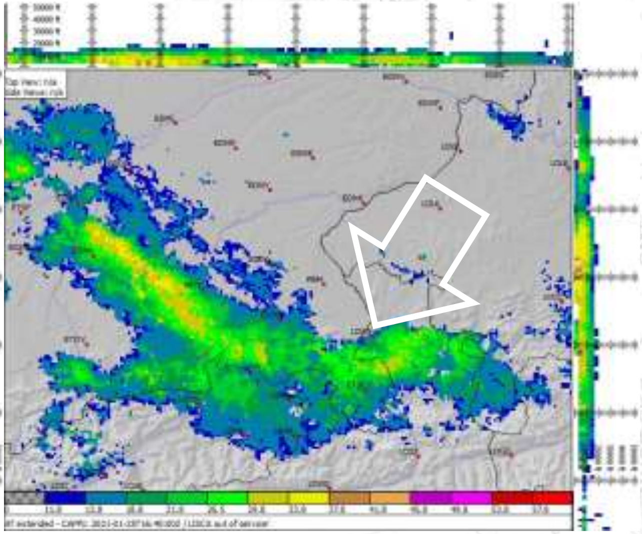
14:25



15:15



16:40



Winter Precipitation Systems

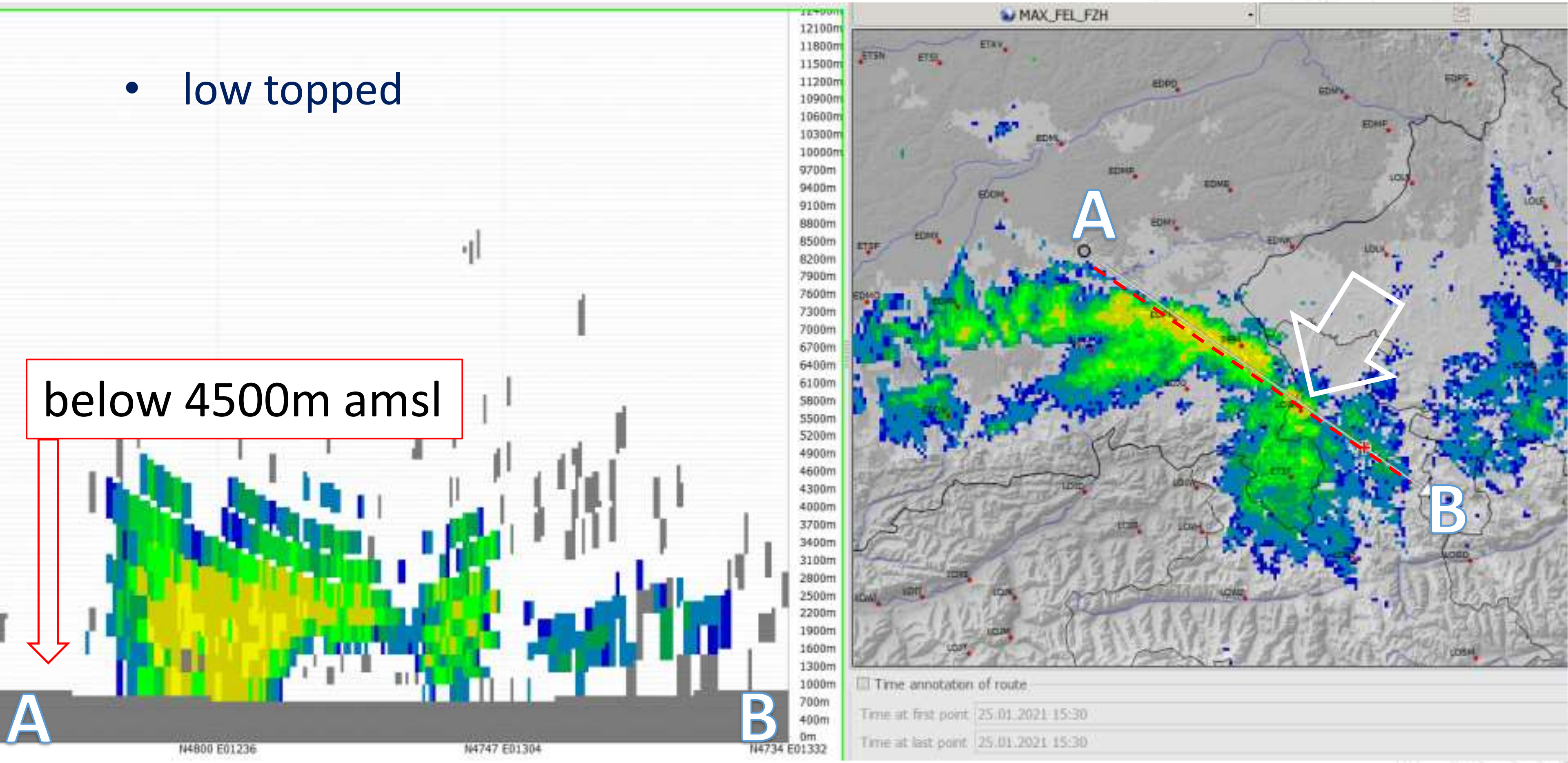
- lower (neg.) temperatures → less humidity
- neg. temperatures → ice → lower dielectric constant
- shallow height (low topped) → radar beam overshooting

weaker radar signals in winter precipitation !

Winter Precipitation – Tops of Snowfall

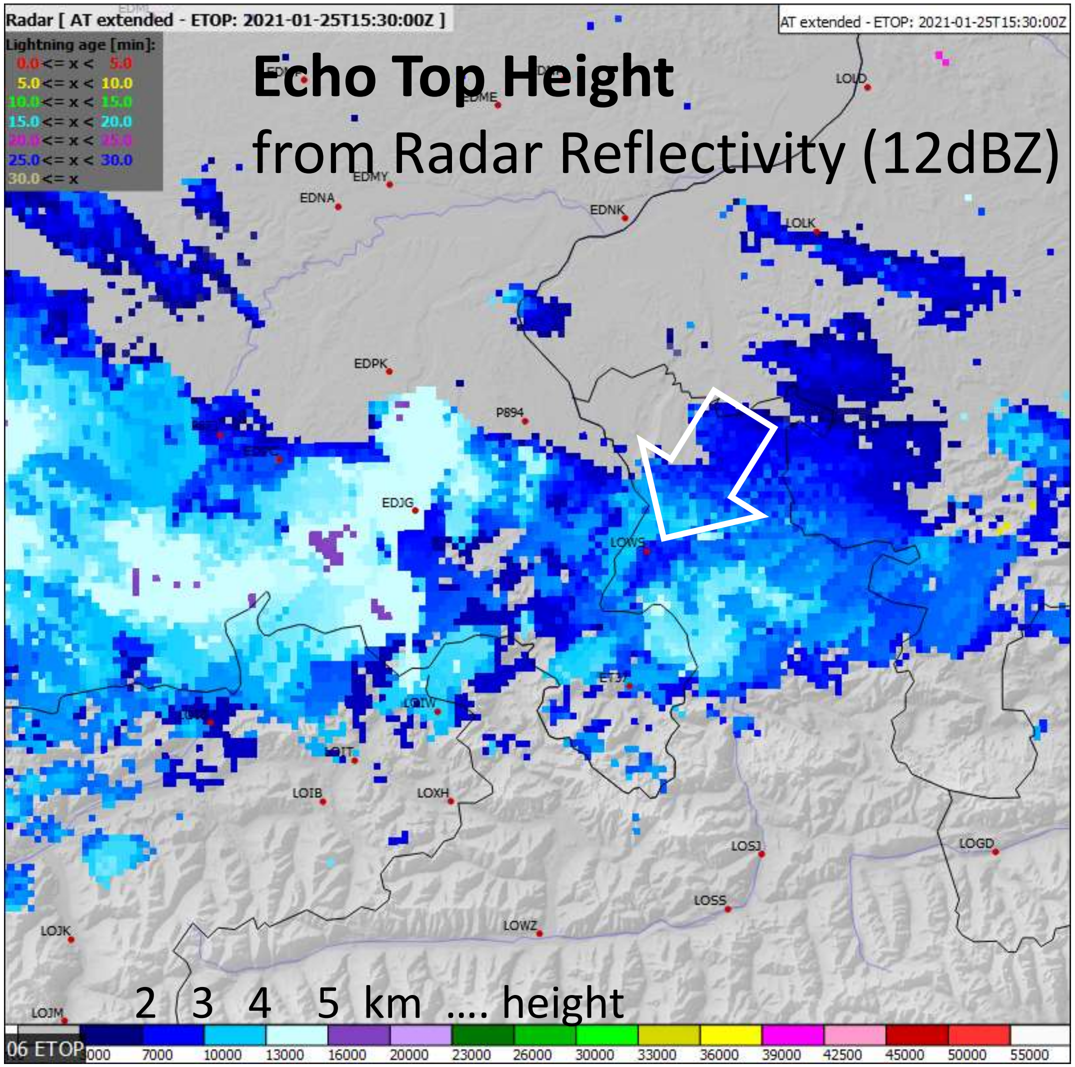
25th Jan. 2021 Salzburg Airport

- low topped

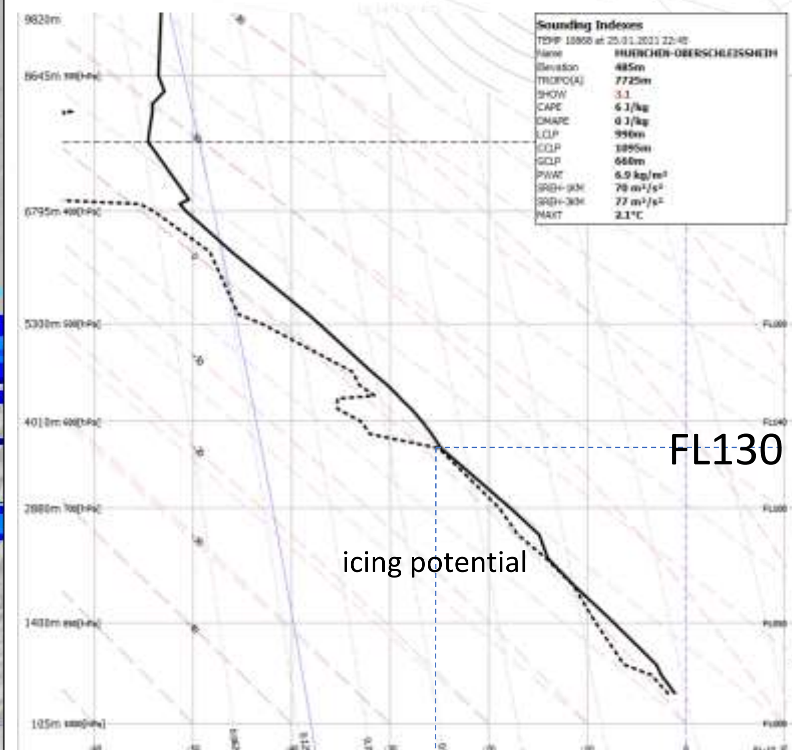


Winter Precipitation – Tops of Snowfall

25th Jan. 2021 Salzburg Airport



in Flight Level / hft



Outline

Advantages of Using Weather Radar in Meteorology

Weather Radar Detection of Snow

Principle of Weather Radar

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Returned Power:

$$P_R(r) = C\,\frac{|K|^2}{r^2}\,z$$

radar properties expressed as radar constant C

range dependency $\frac{1}{r^2}$

Target Properties:

- $|K|^2$ … dielectric constant
  - 0.93 … for **water**
  - 0.197 for **ice**

  difference: factor **5**
- z… linear radar reflectivity factor
  - $\propto$ **Diameter^6** … drop size distribution
  - $\propto \frac{1}{wavelenth^4}$

  ΣnD^6

Radar Reflectivity:

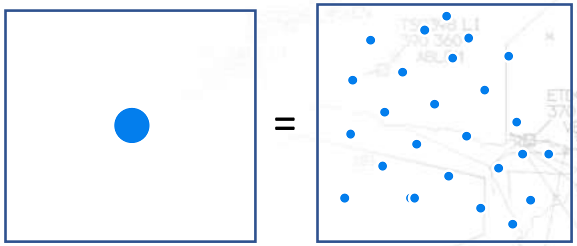
- „equivalent“ due to assumptions (Rayleigh, homogenous beam filling, liquid and we don‘t know the drop size distribution)
- Log scale to avoid several orders of magnitude $Z_H = 10\log_{10}(z/1\,mm^6 m^{-3})$

Principle of Weather Radar


EUMETNET OPERA Database

Radar Reflectivity:

- $\propto \frac{1}{wavelenth^4}$
  - shorter wavelength -> smaller drops sizes can be detected
  - C-band is a good compromise with detection efficiency, attenuation and costs
  - 164 operational C-band radars for Europe in OPERA database
- $\propto$ Diameter^6
  - small increase in drop size diameter →strong increase in reflectivity
  - Large drops results in high reflectivity - but less total water mass as many small drops causing same returned power
  - E.g. equivalent reflectivity values:
    1 drop with diameter 3.0mm
    730 drops with diameter 1.0mm
    46700 drops with diameter 0.5mm



Reflectivity of Snowflakes

- multiple habits in radar volume
    - Snow flakes become large (cm)
    - ice crystals smaller (mm)
    - irregular shape/orientation
- snow flakes – less water content /air inside
- growth – aggregation – riming processes
- errors for snow detection larger than for liquid rain

Principle of Weather Radar

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Radar Moments:

- Reflectivity — Intensity
  - (horizontal, vertical) ZH, ZV
- Radial Doppler Velocity VH — Wind, Shear, Turbulence, Quality
  - including Spectral Width WH
- Polarized Moments
  - using the horizontal and vertical EM wave simultaneously
  - Differenetial Reflectivity ZDR=Z_H-Z_V
  - Cross Correlation Coefficient RHOHV
  - (specific) Differential Phase (KDP) PHIDP
  - Depolarisation (linear or circular)

Quality, Attenuation Correction, Quantitative Precipitation, Hydrometeor-Classification

NOAA: https://www.weather.gov/bmx/radar_dualpol

Quantitative Precipitation Estimation

Z-R Relationship:

- emprical relationship to estimate rainfall rate (surface) from radar reflectivity $Z=aR^b$
- water equivalent
- $Z=200R^{1.6}$ … widley used Marshall/Palmer Stratirom Z-R
- other Examples:
  - $Z=130R^2$ … US Cold Season (East) Stratiform Z-R
  - $Z=300R^{1.4}$ … US Summer Deep Convection
  - $Z=256R^{1.42}$ … DWD
  - $Z=316R^{1.5}$ … Meteo Swiss
- Improvements:
  - real-time radar-rain-gauge merging
  - using additional polarized moments

Z-S Relationship:

- emprical relationship to estimate **snow**fall rate (surface) from radar reflectivity
- equivalent rain rate
- E.g.: $Z=100S^2$ … FMI
- Improvements due to dual pol

Radar Geometry

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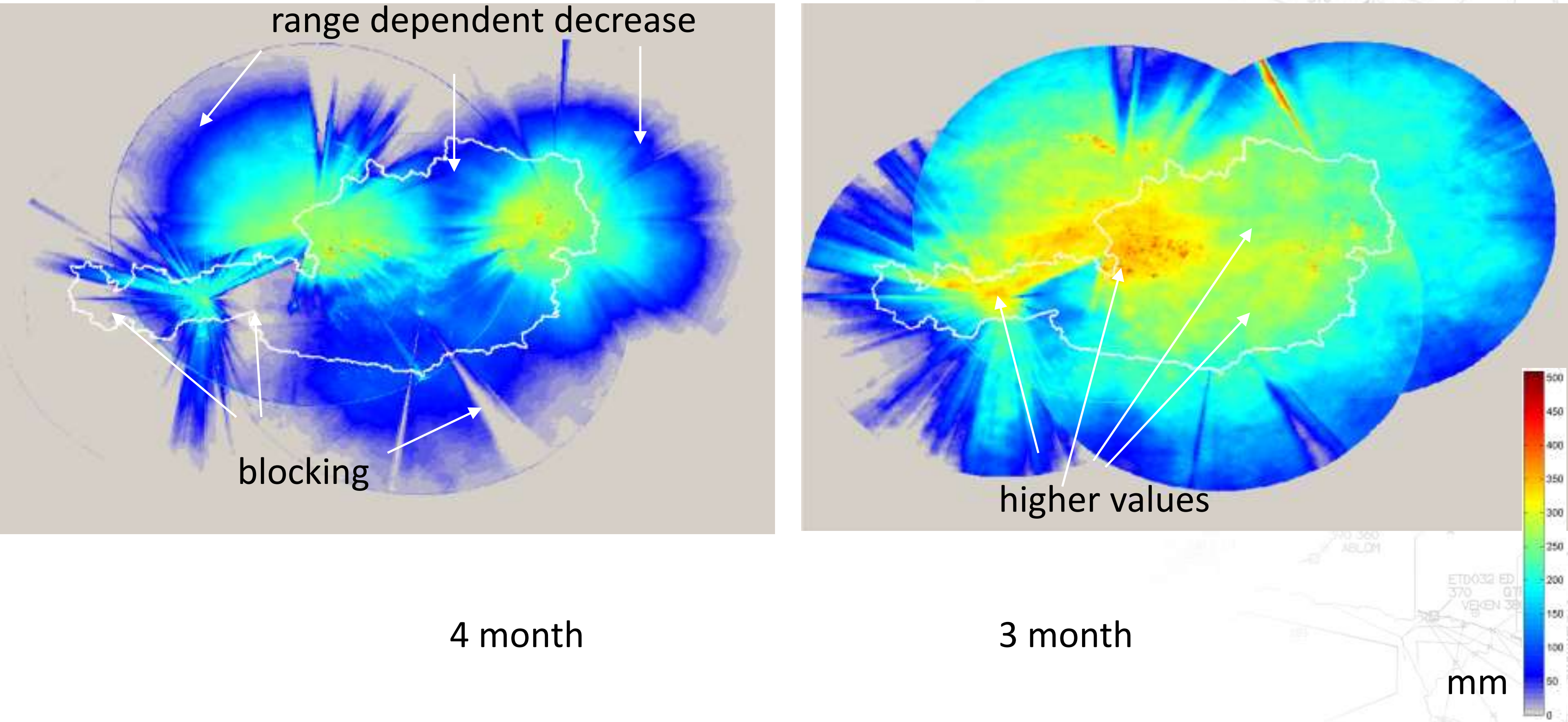
Radar Beam Propagation and Scan Strategy

Know your:

- Scan geometry
- Radar Coverage
- Lowes tilt – height above ground
- Topography
    - Blocking
    - dead zones below radar horizont

Weather Radar Coverage - Austria

Winter Summer



4 month 3 month

mm

Outline

Advantages of Using Weather Radar in Meteorology

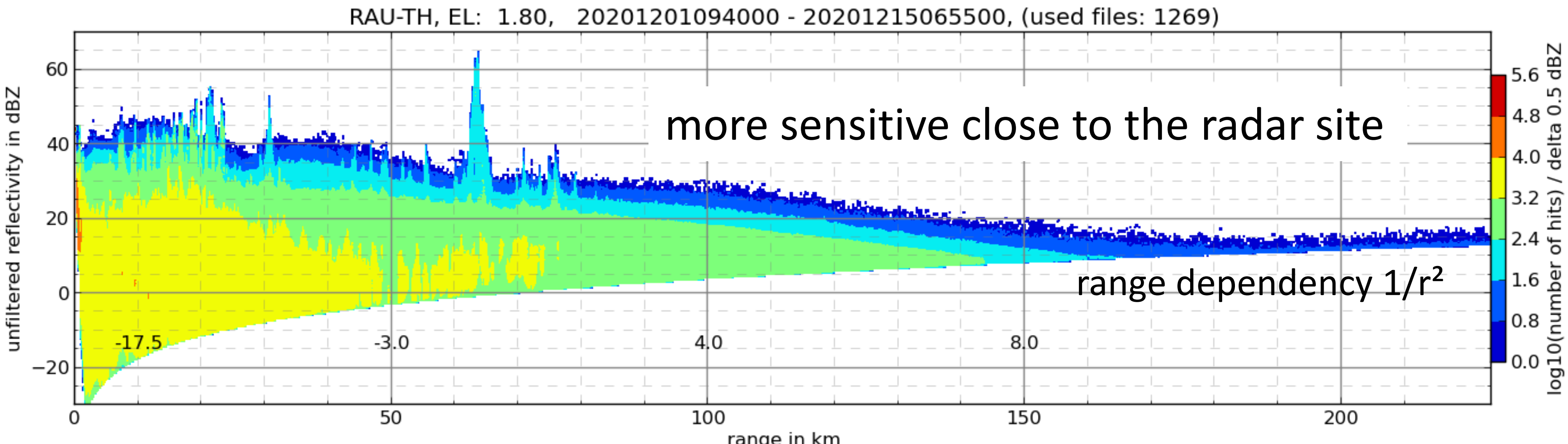
Weather Radar Detection of Snow

Weather Radar Limitations of Cold Winter Weather

Sensitivity

How far can we see snow by using weather radars?

- depends from snow intensity and size
- depends from weather radar (wavelength, antenna size, peak power, scan strategy,…)



in 50 km distance the radar is able to detect -3.0 dBZ
… very weak ….clouds, very weak snowfall

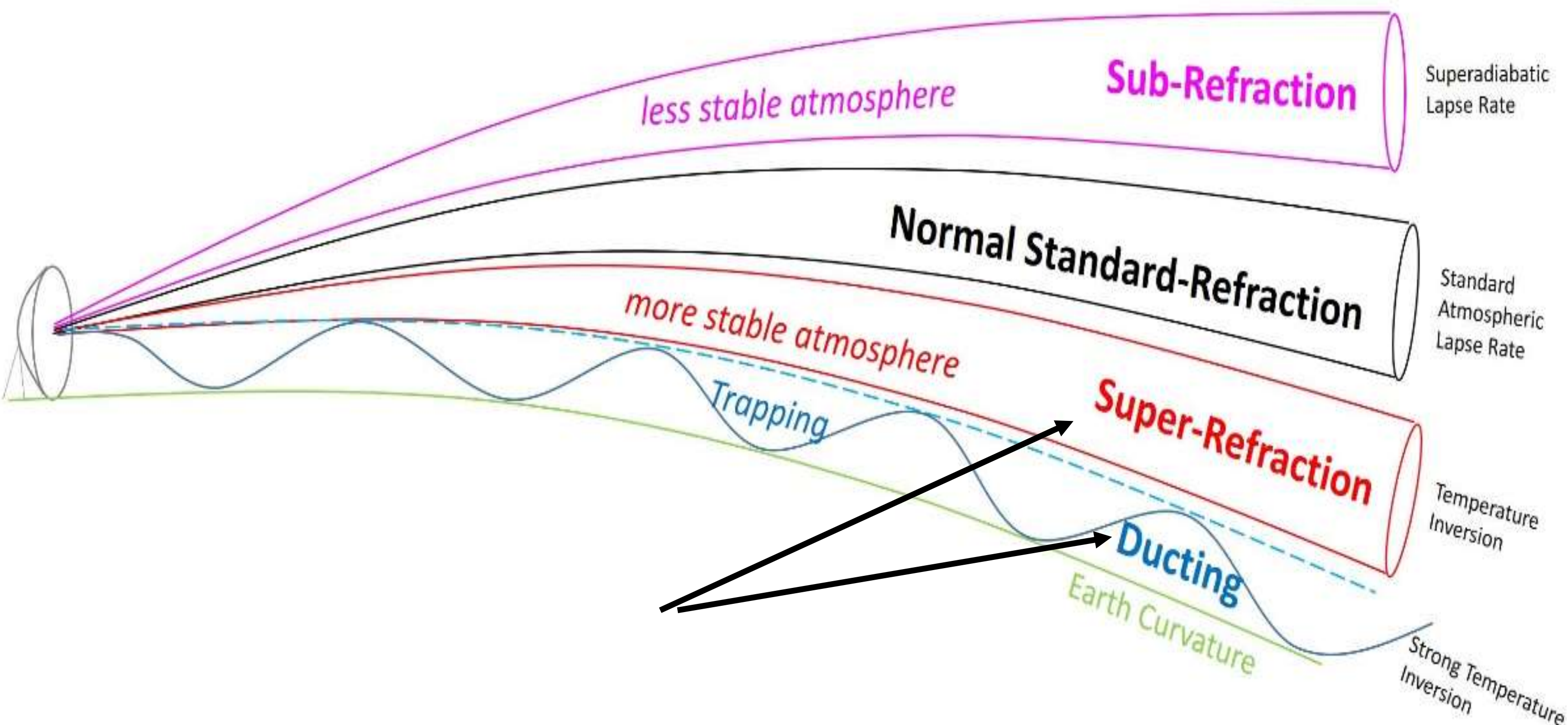
but lowering the detection efficiency due to:

- overshooting radar beam – shallow winter storm
- ice has smaller dielectric constant (factor 5)
- less humity in cold environment

in 150 km distance the radar is able to detect +8.0 dBZ
…. Weak (moderate)…. clouds, moderate snowfall

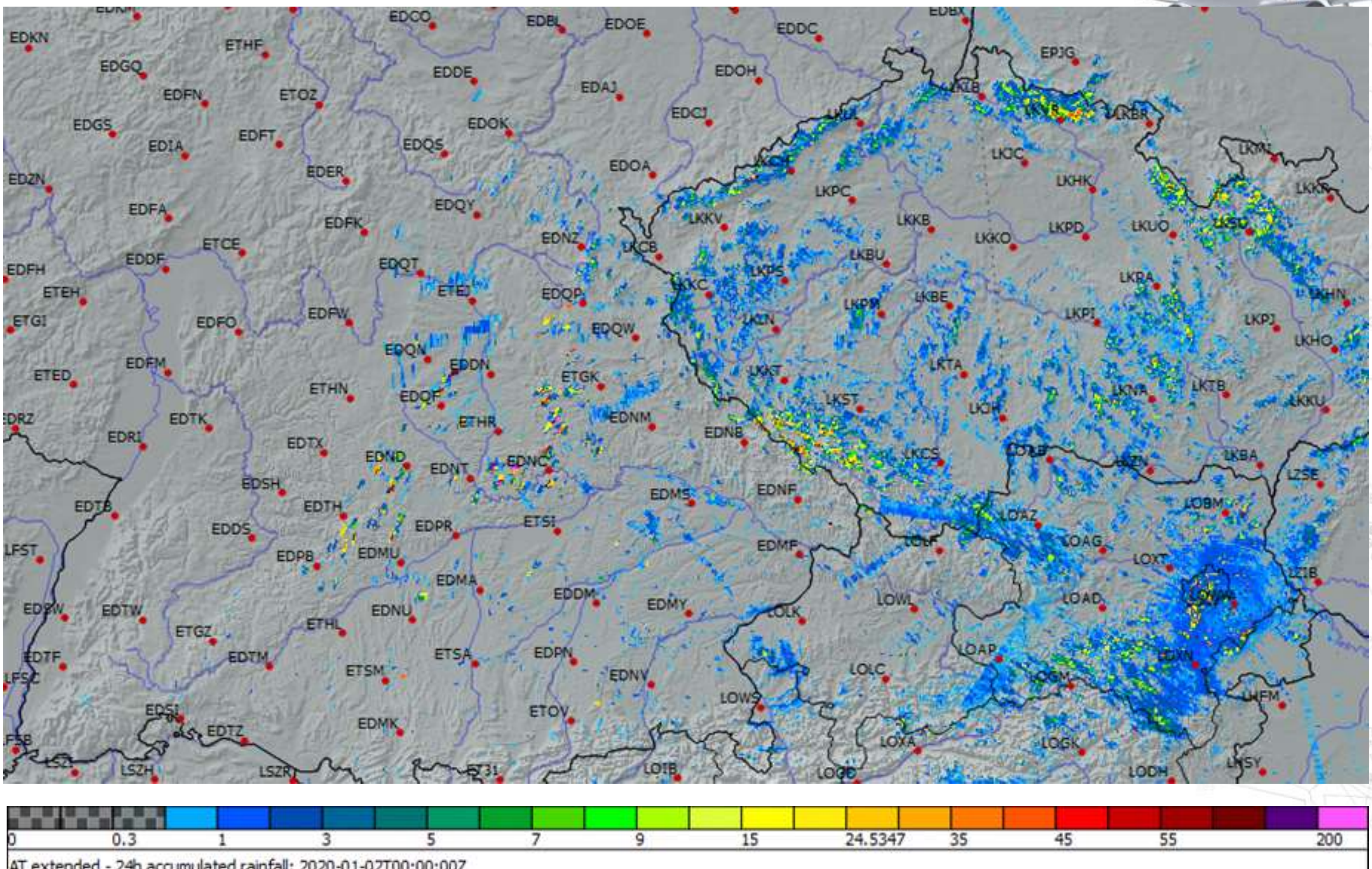
Anomalous Radar Beam Propagation

winter - strong temperature inversion (T, rh)



Anomalous Radar Beam Propagation

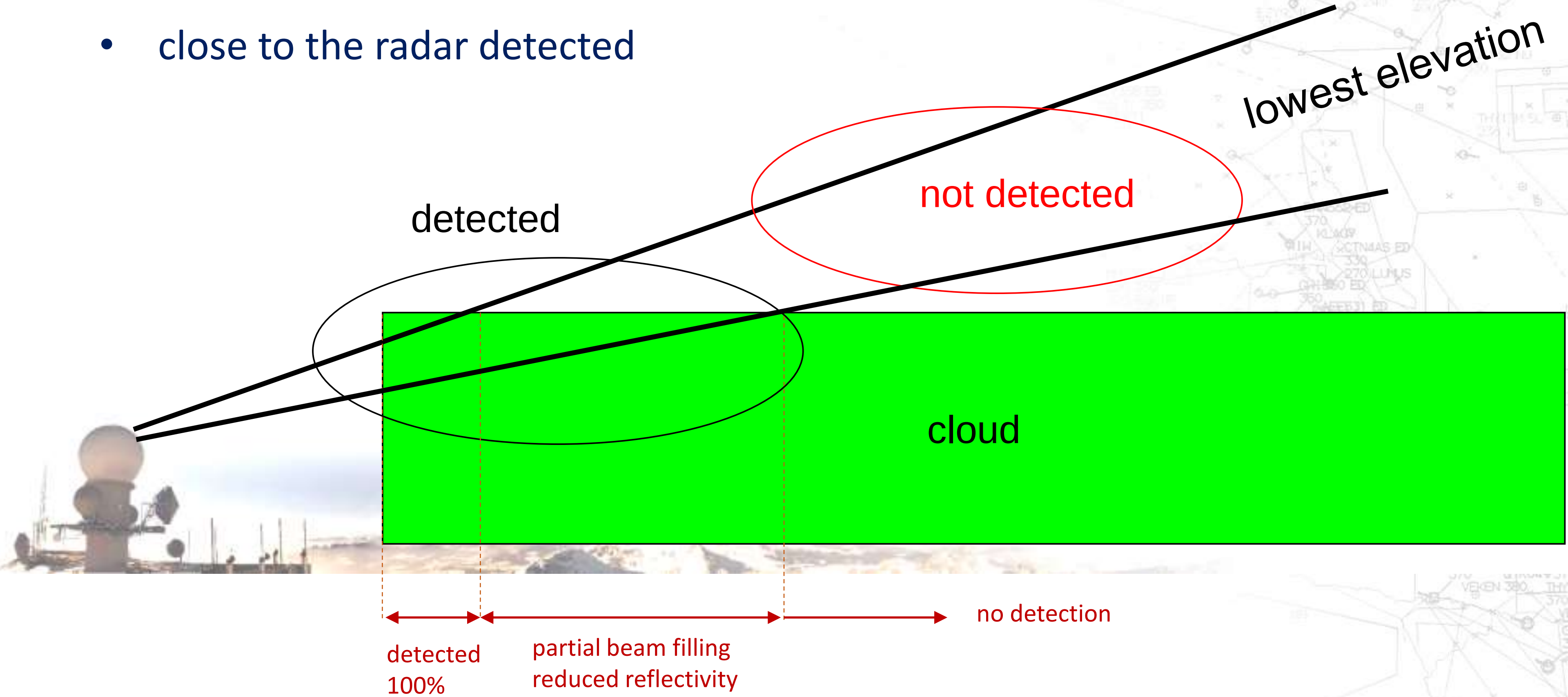
24h accumulated radar precipitation in mm for 1st Jan. 2021



Overhanging Precipitation

low topped/ shallow winter precipitation will:

- not detected at far ranges
- intermediate range with partial beam filling /reduced detecion
- close to the radar detected

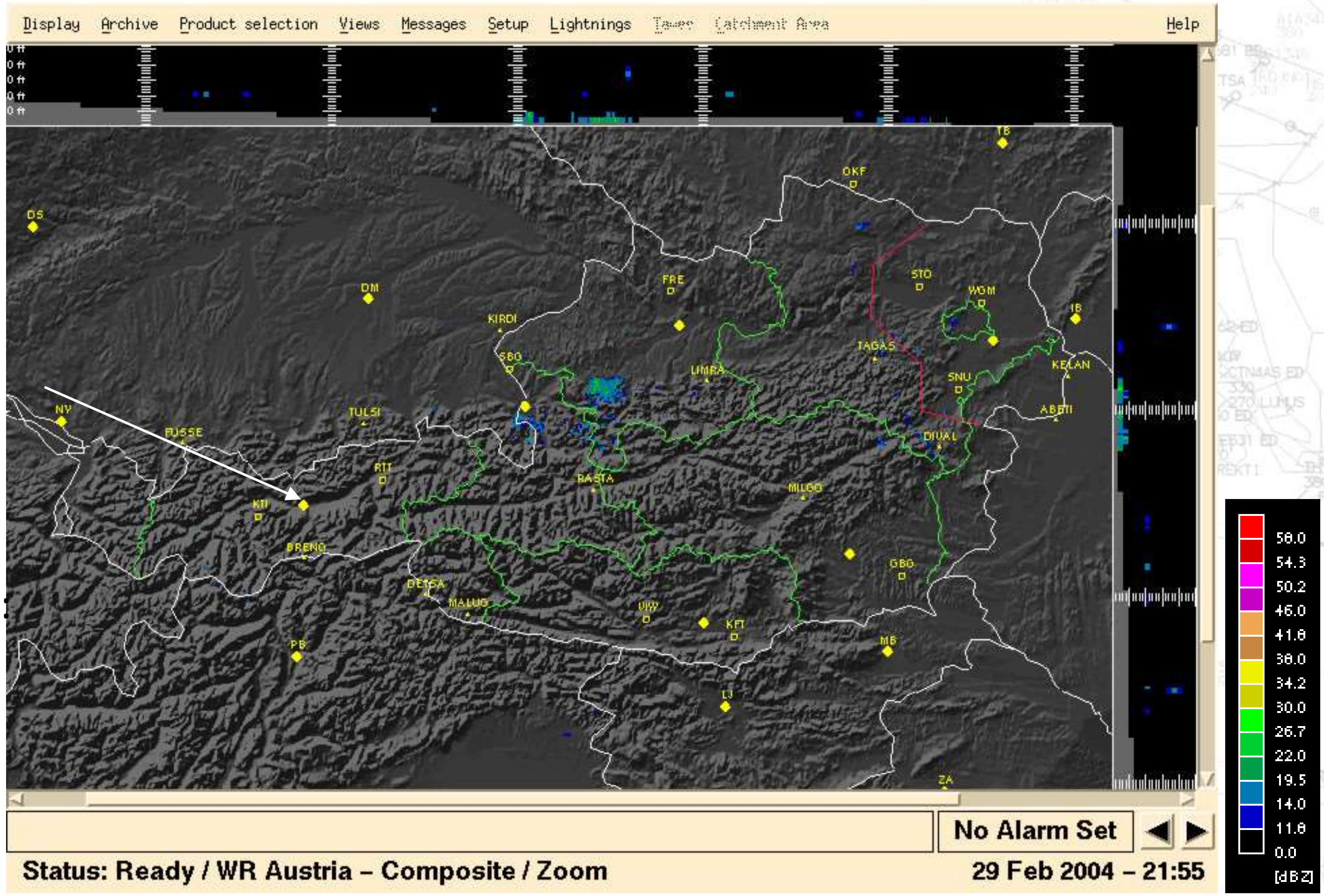


Overhanging Precipitation
moderate snowfall in Innsbruck without radar signal

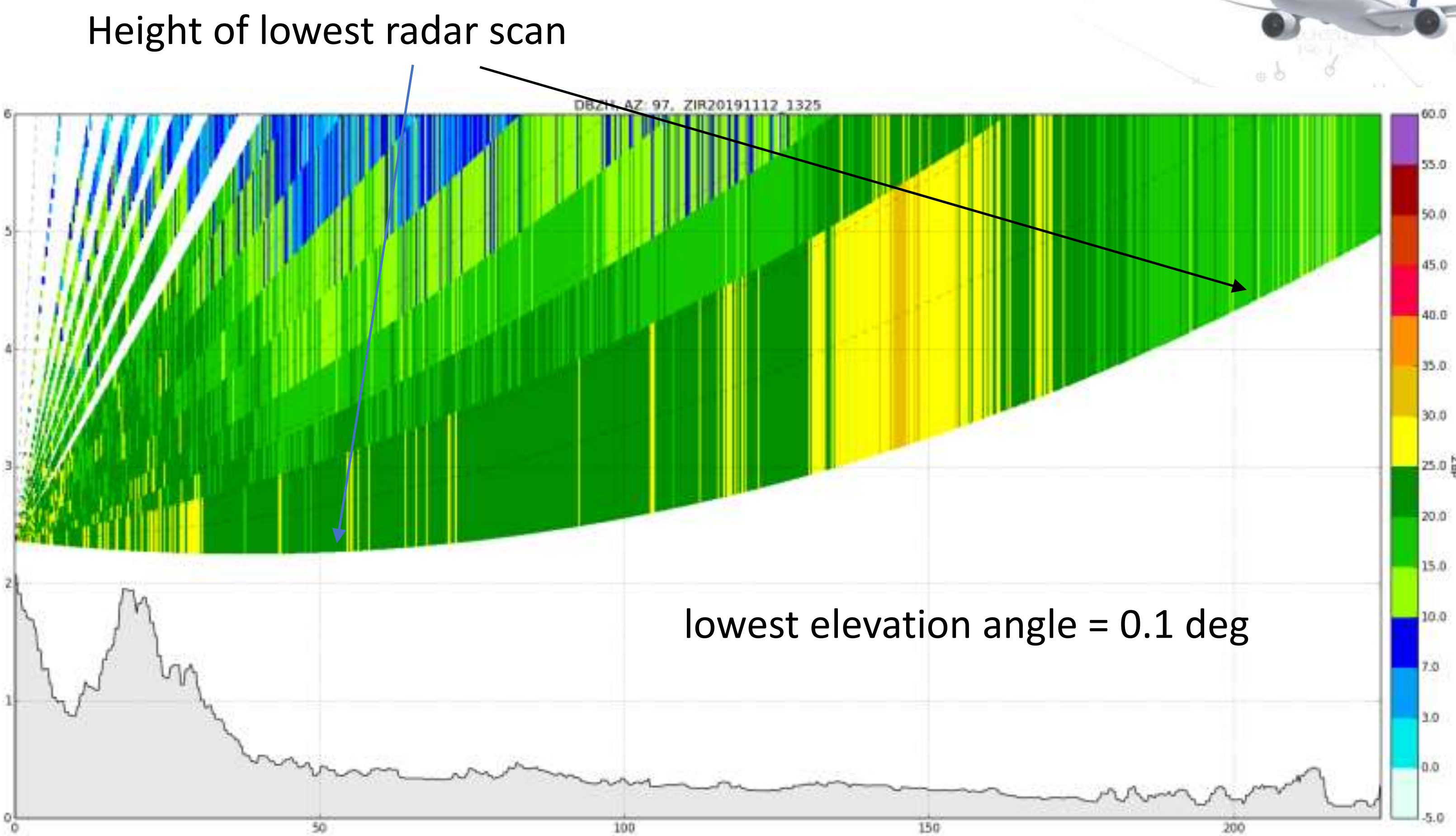
very shallow winter precipitation below radar horizont
(mountain weather radar site at 2300 m msl)

no refectvity below 12dBZ

lowest elevation: 0.5 deg

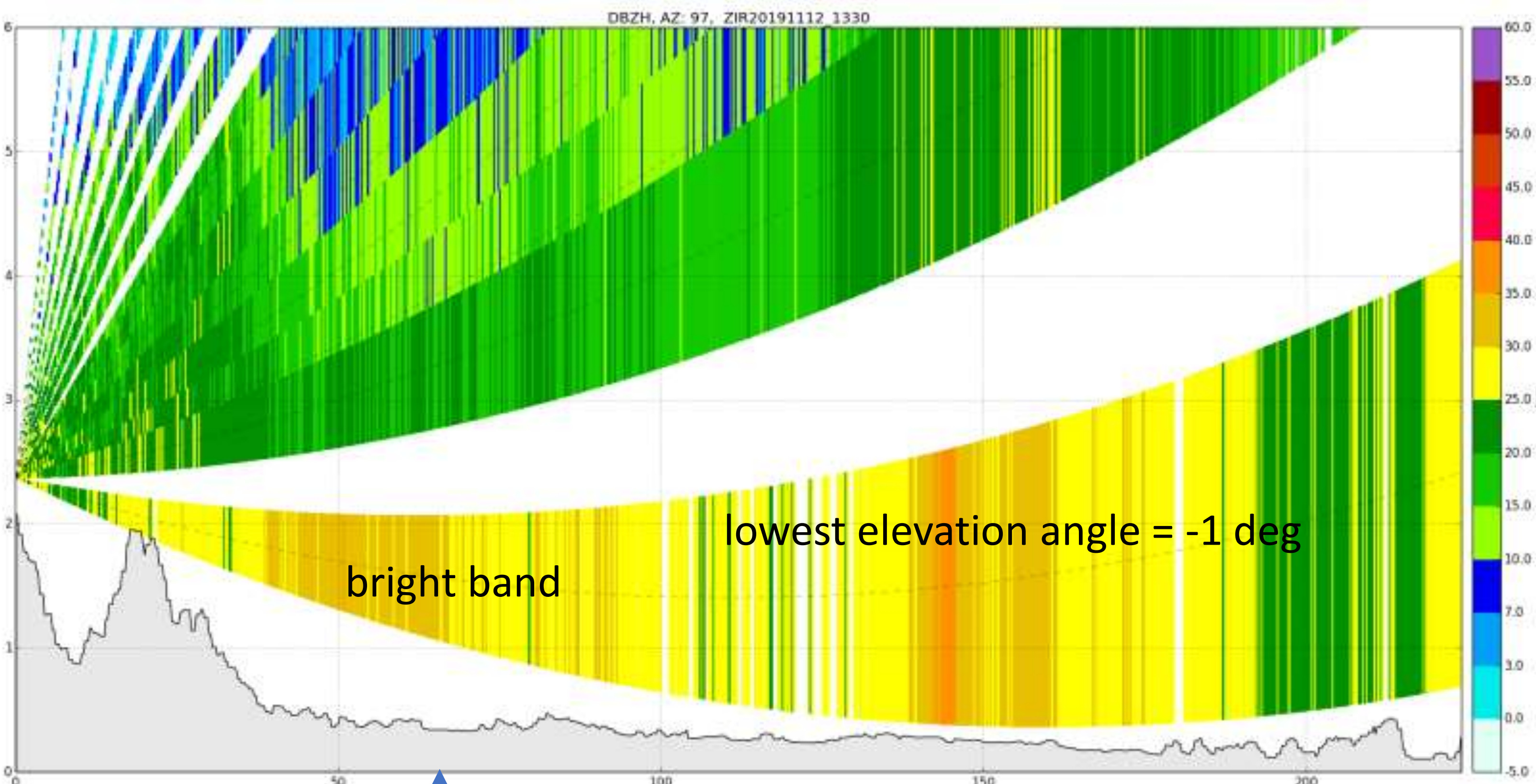


Beam Characteristics



Beam Characteristics

FZ-level … 1900 m msl

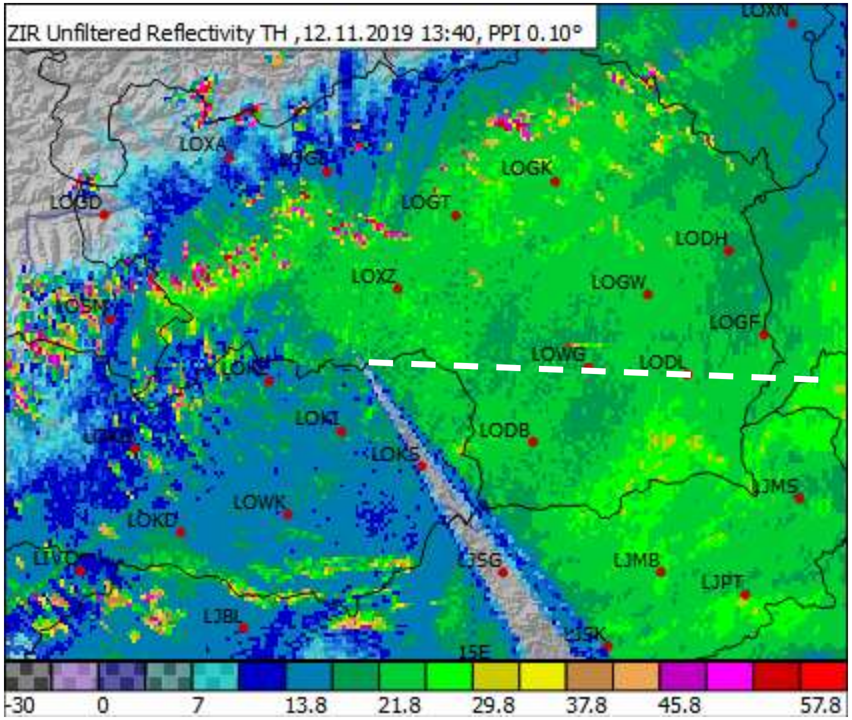


Graz-LOWG: main lobe decends from 2.5km to 1.5km height

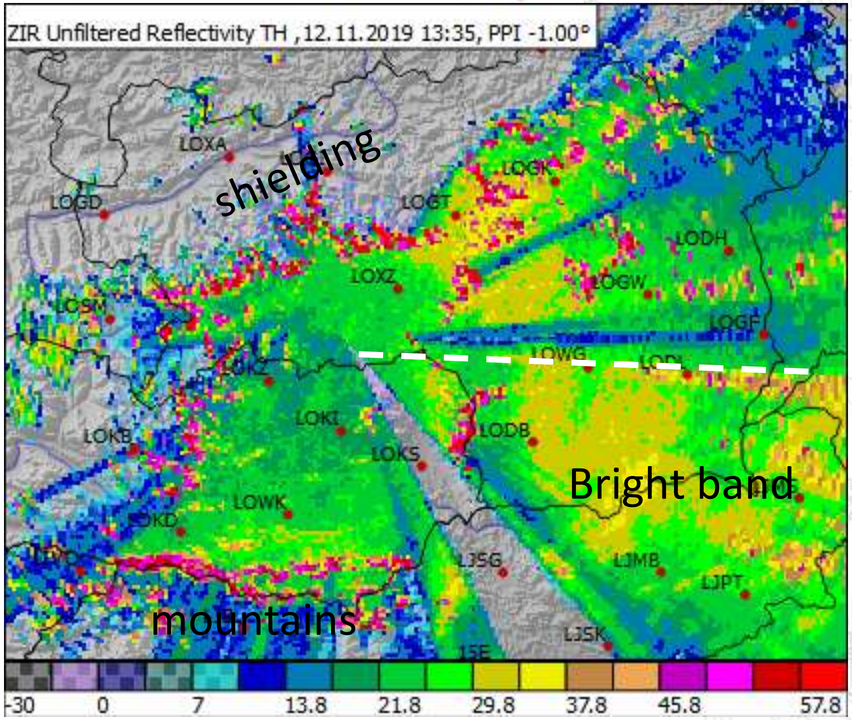
Beam Characteristics

Lowest Scan Elevation:

0.1 deg

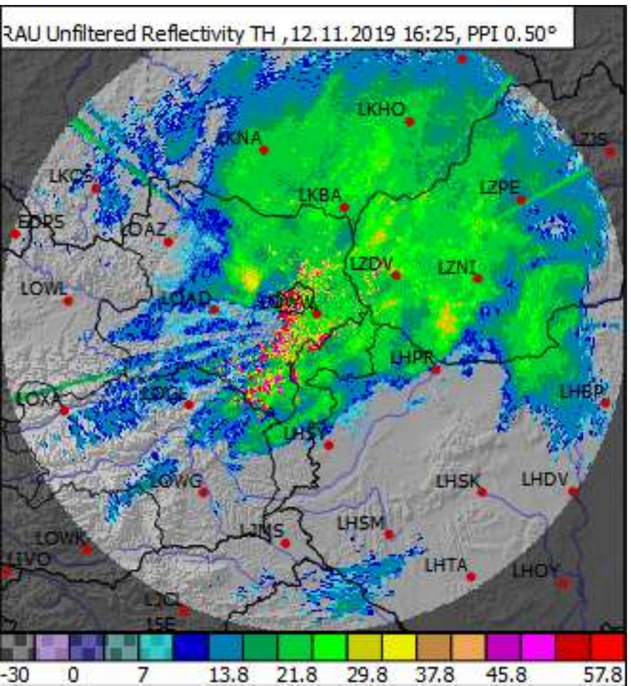


-1.0 deg

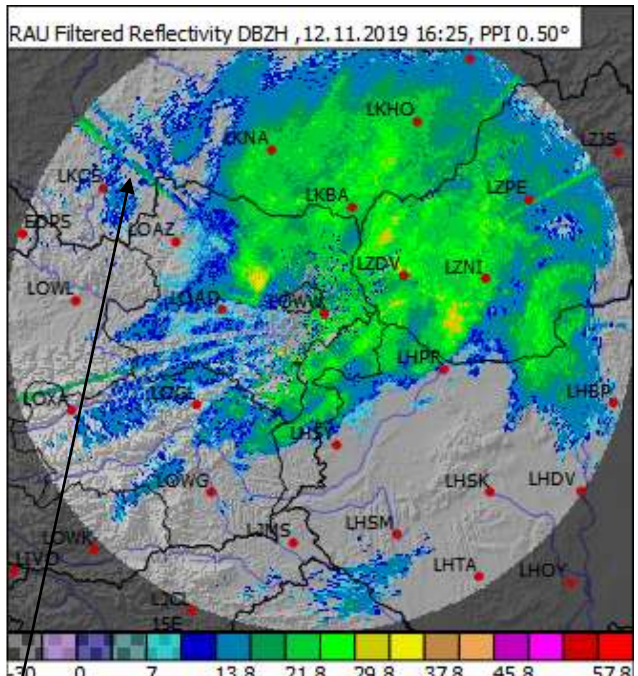


Data Processing - Quality Control

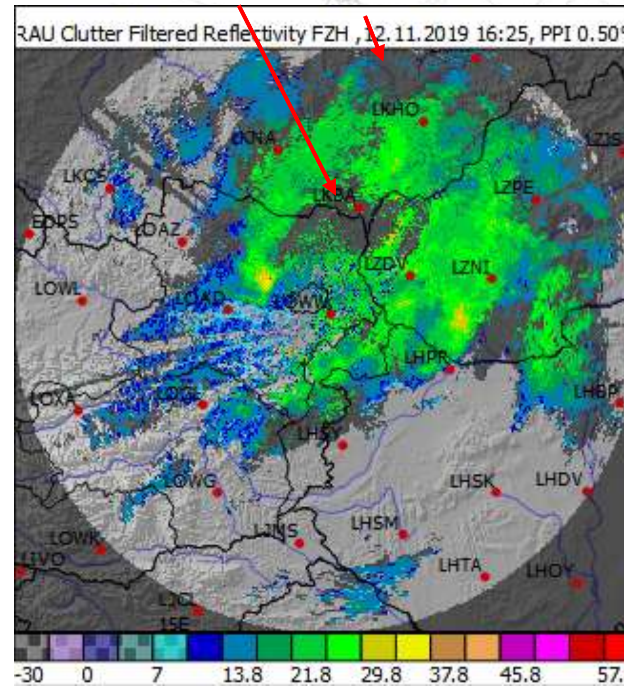
RLAN-filter eliminates weak (noisy) signals like snowfall



unfiltered reflectivity



clutter filtered reflectivity



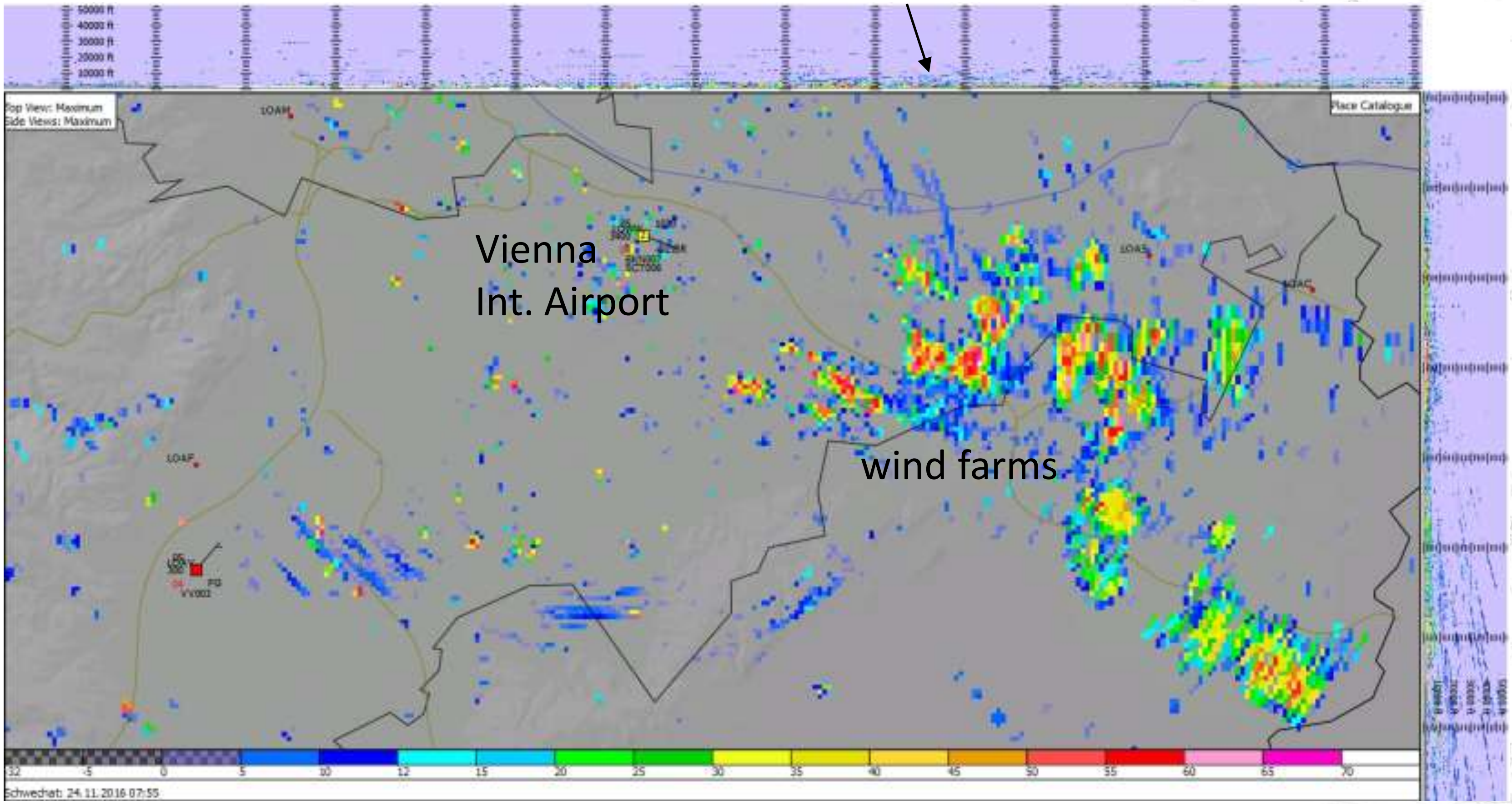
RLAN filter applied

RLAN disturbances still present

Spurious Echoes

no Snow and Rain Showers!

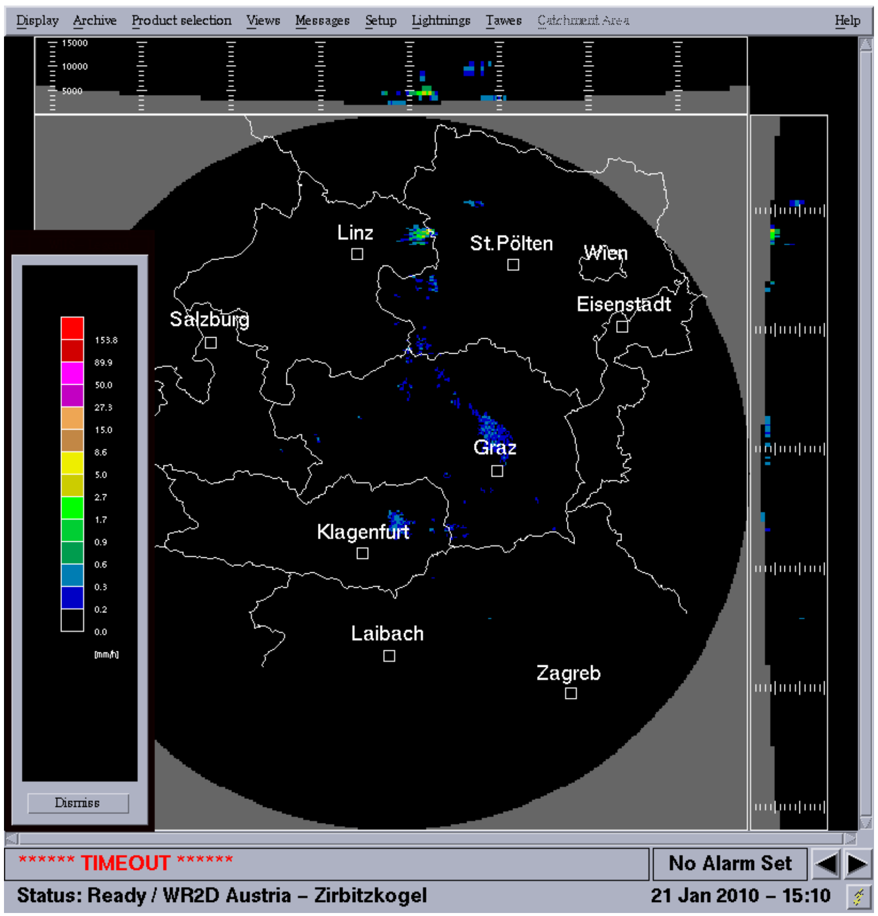
affecting lowest elevations
where winter precipitation occurs

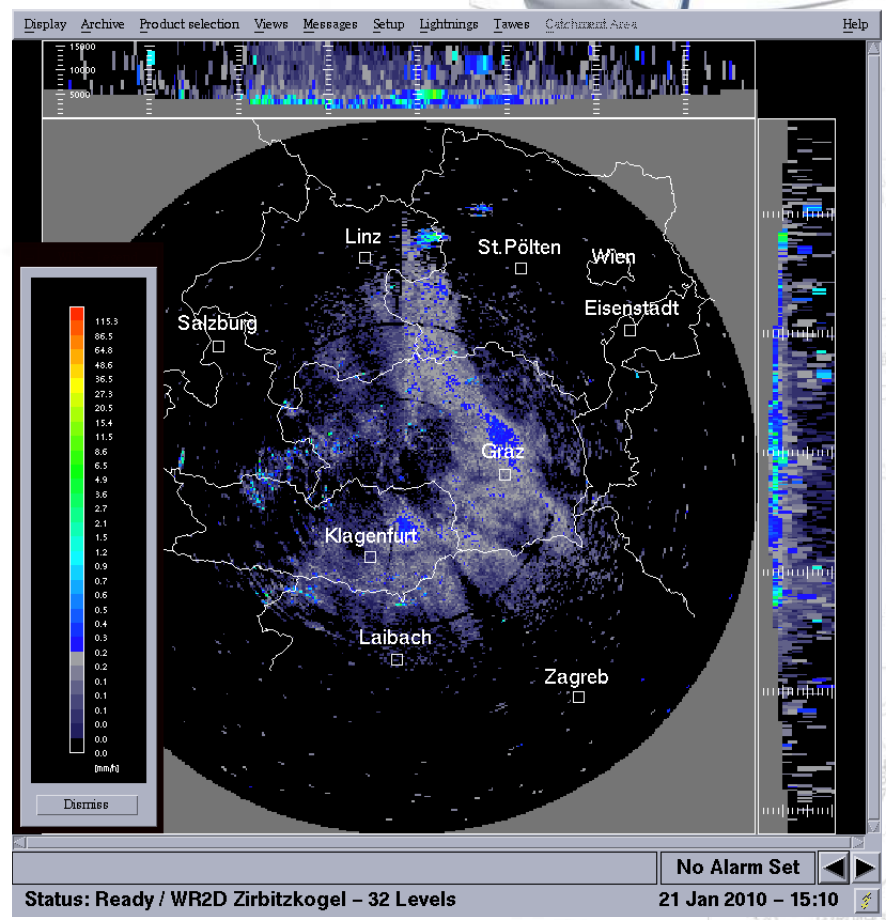


Echoes caused by wind farms in the souronding of Vienna Internat. Airport

Data Thresholding

Graz (LOWG) …. moderate snowfall observed

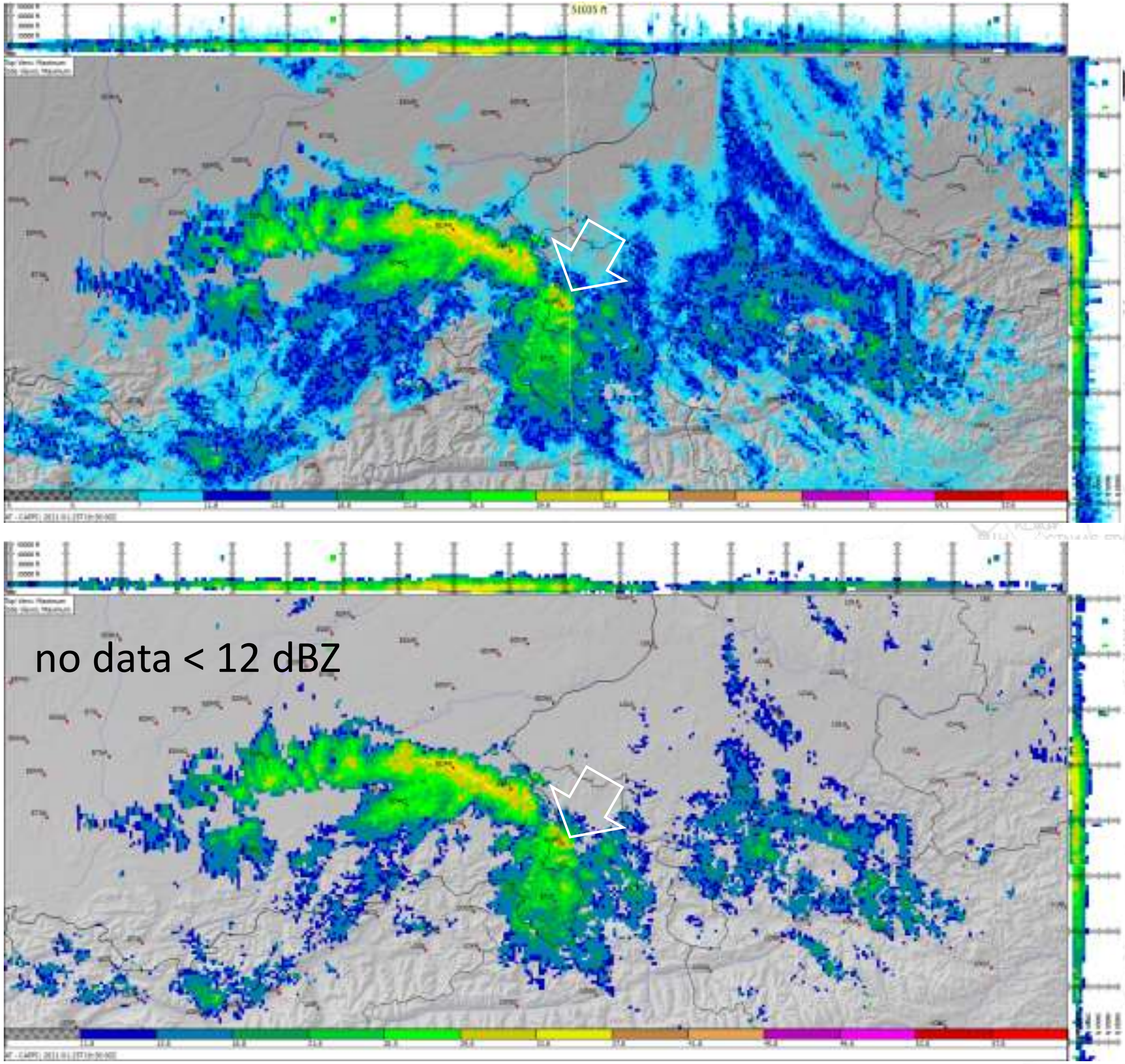




no values below 12 dBZ visualized

Data Thresholding

Snowfall Salzburg
25.1.2021 19:30 UTC



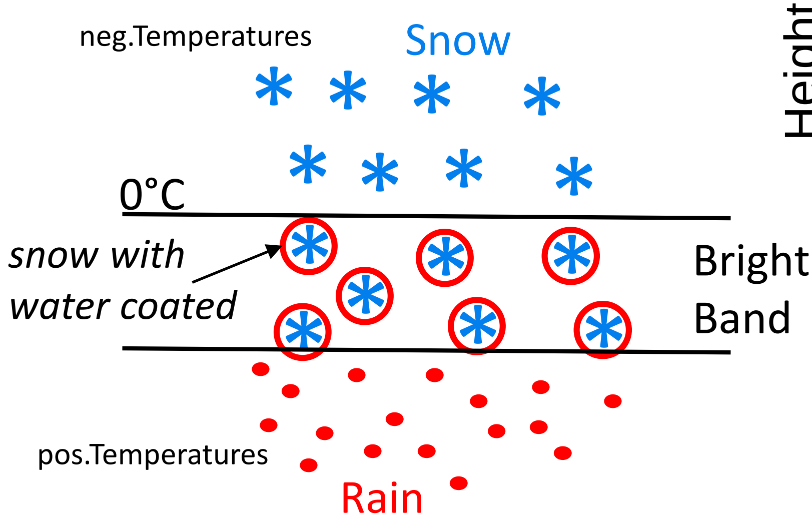
Bright band

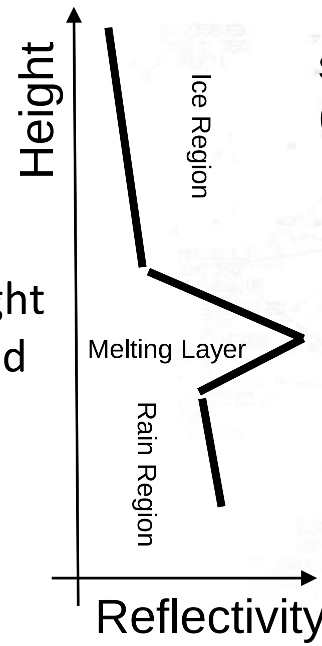
1) when snow falls in areas where the temperature is above 0°C
2) results in large spongy spheres
3) melting snow flakes are large bright radar targets
4) bright reflectivity layer is formed just below 0°C

Dielectricity 0.2
Large Drop Ø

Dielectricity 0.93
Large Drop Ø

Dielectricity 0.93
Small Drop Ø





typical radar reflectivity vertical profile

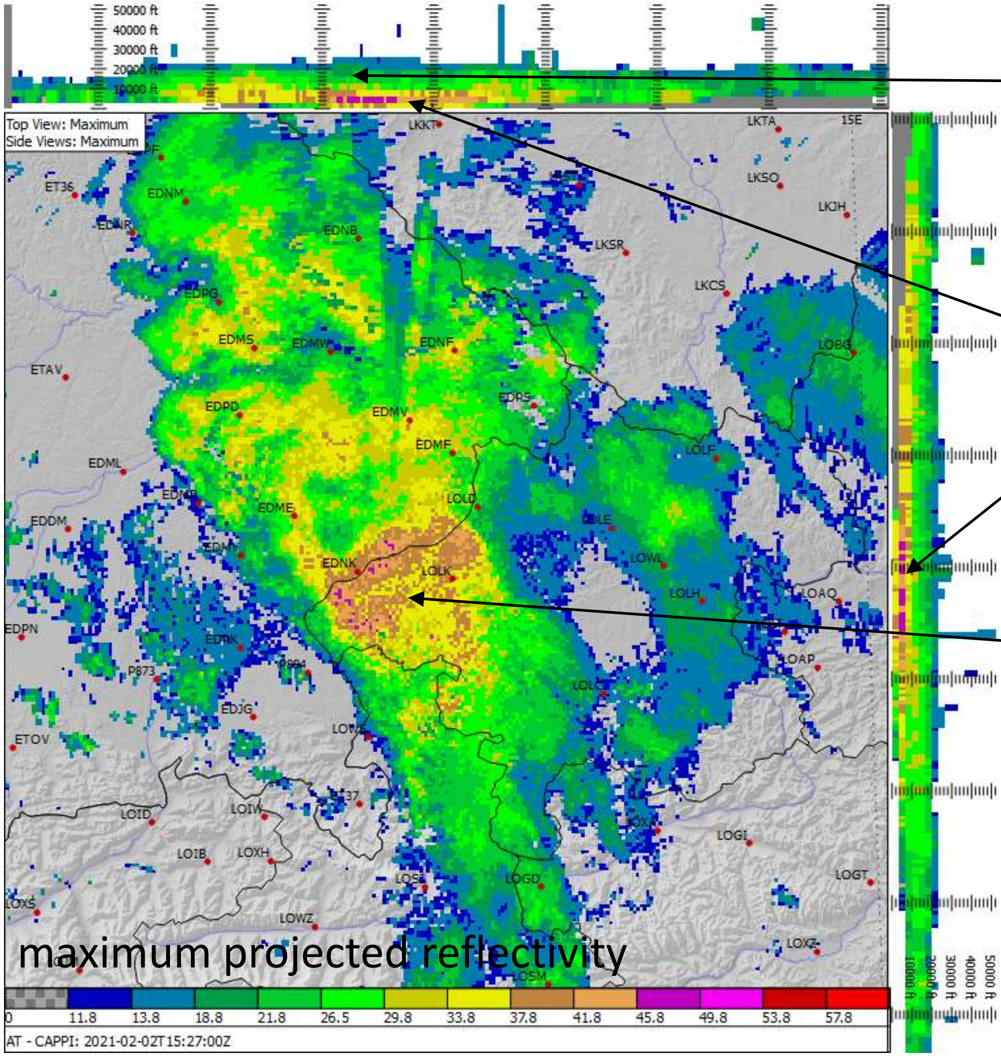
smaller snowflakes (colder, less humid)

lager snowflakes

smaller rain drops

Bright band in standard reflectivity products

2nd Feb 2021 15:27UTC



Icing conditions above

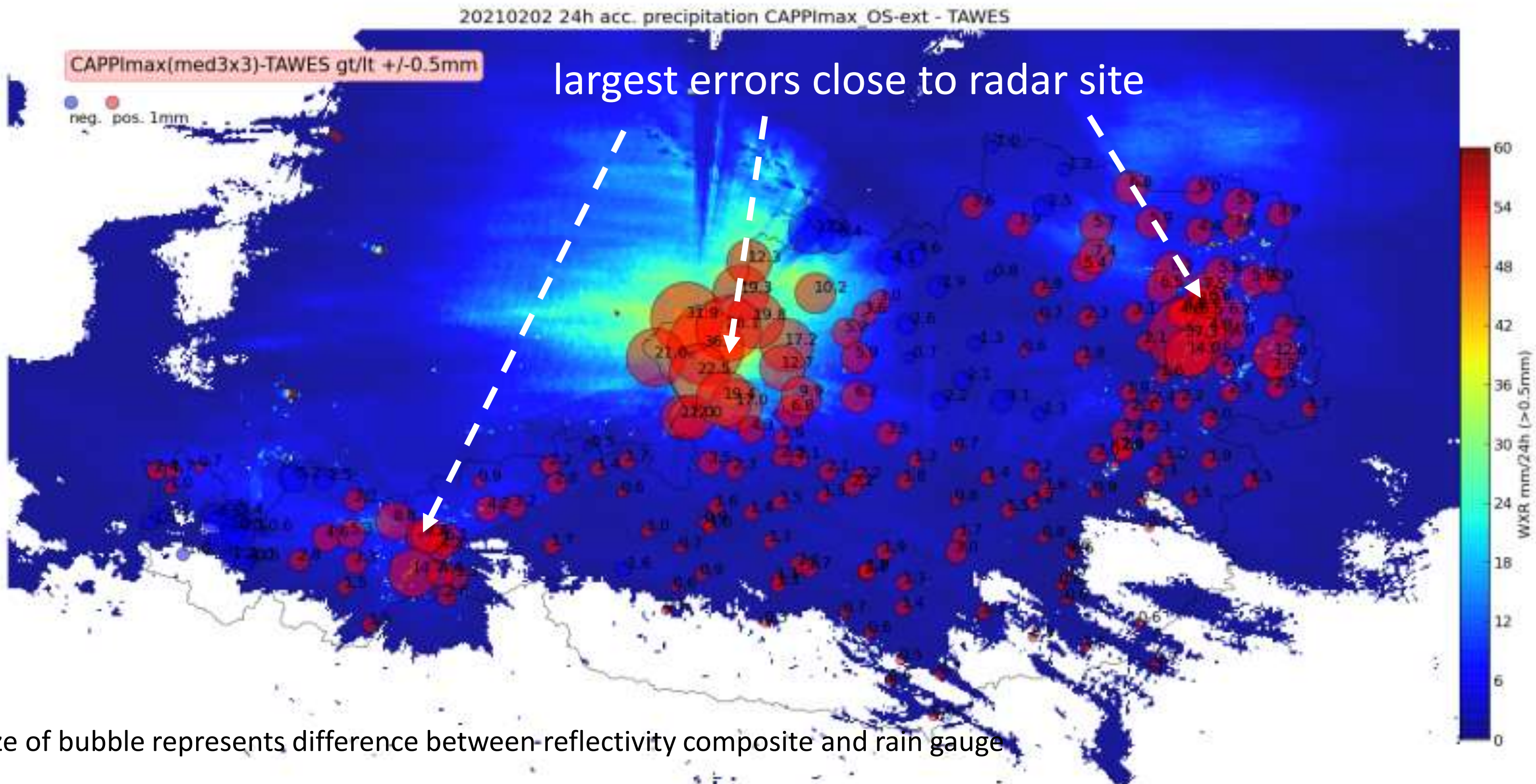
bright band as
line in cross section
Freezing layer detection

bright band as an
area of enhanced reflectivity

Bright band in standard reflectivity products

2nd Feb. 2021

24h accumulated precipitation: radar uncorrected – rain gauge (Austria)



size of bubble represents difference between reflectivity composite and rain gauge

huge error in quantitative precipitation estimation!

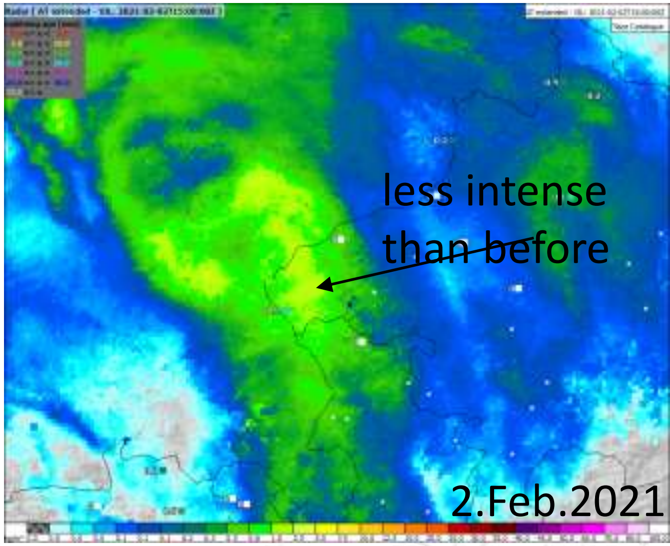
Bright band corrections

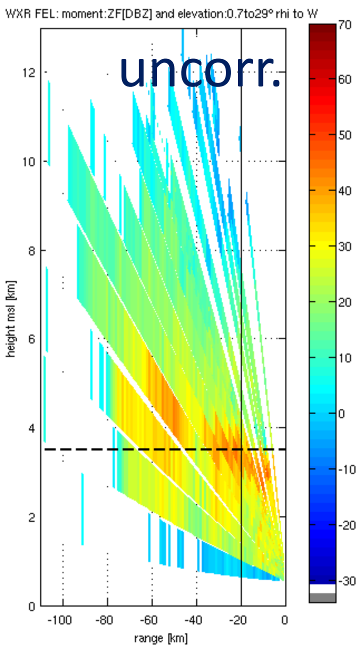
Vertical Integrated Liquid VIL

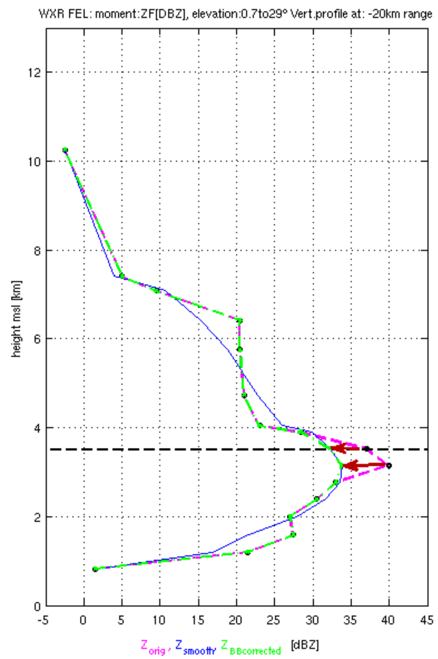
Radar Rain Gauge Adjustment

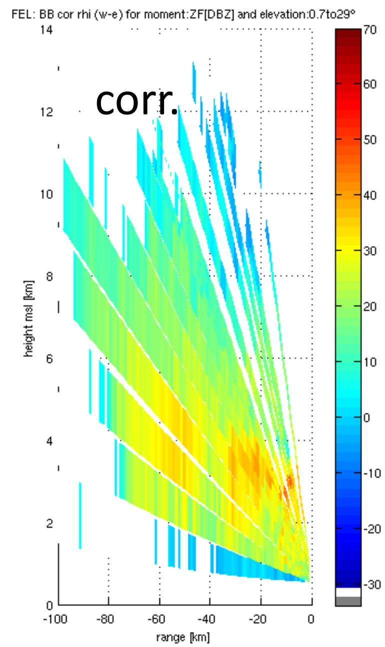
Dual Pol e.g. Hydrometeoclassification

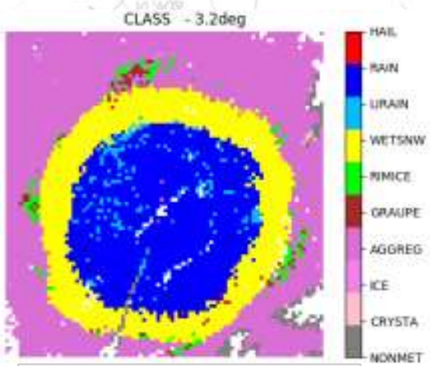
Vertical Profil Correction:







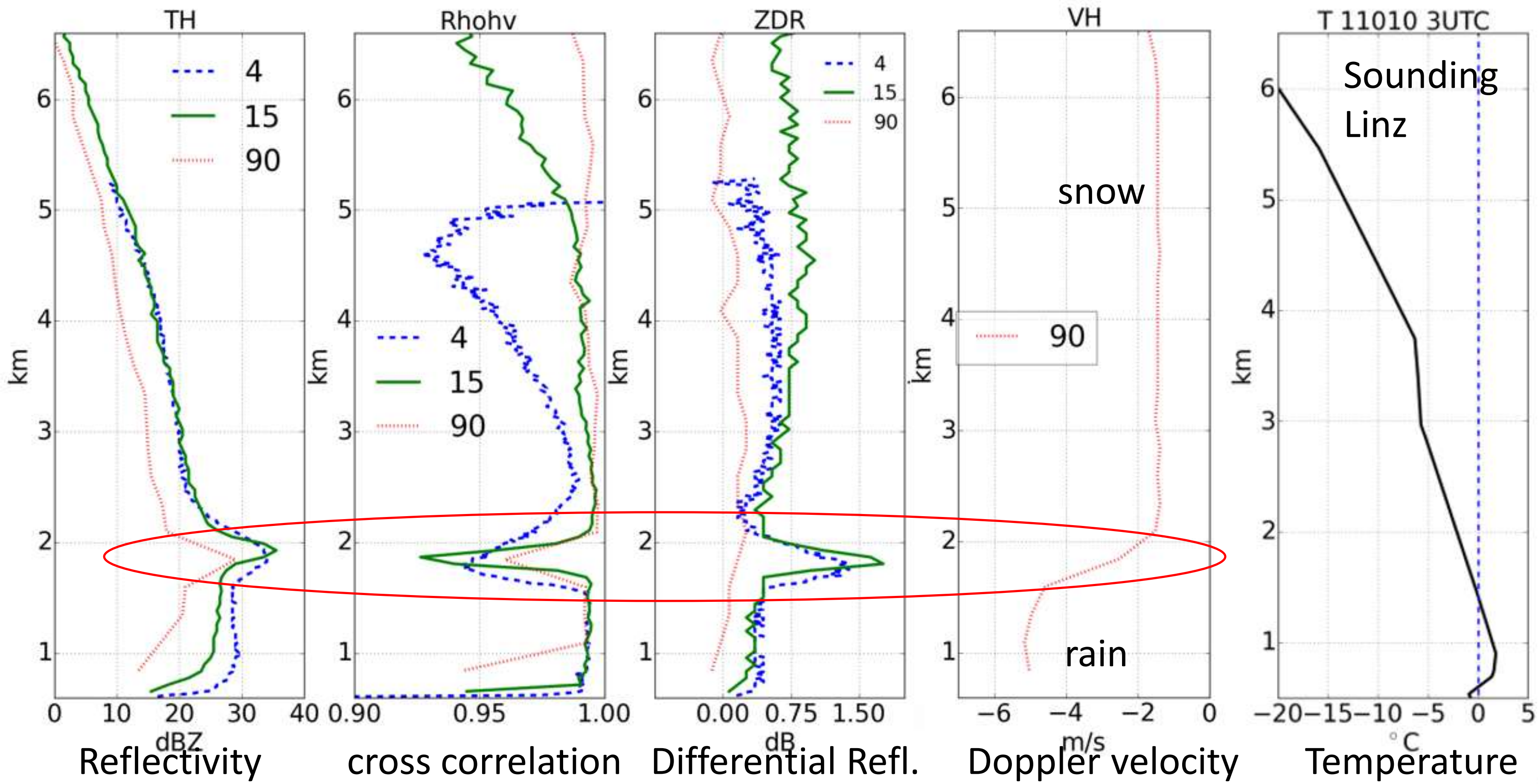




Tüchler, HYMID-Project

Bright Band in dual polarized moments

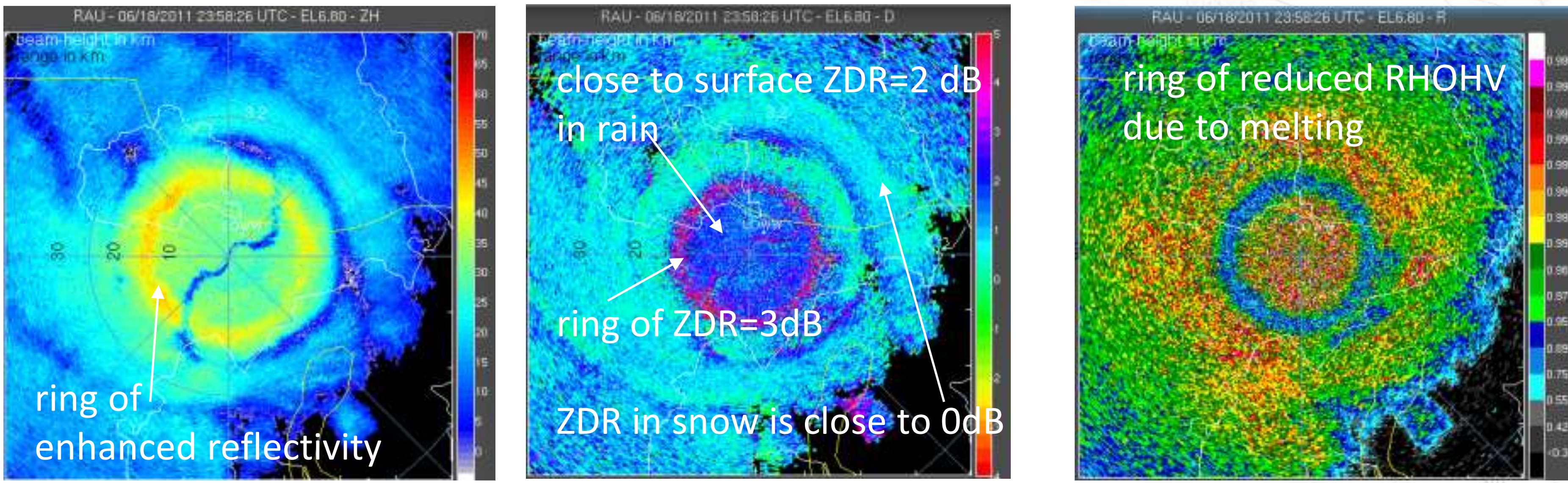
90° **vertical scan** and quasi vertical scans 4° and 15°



https://doi.org/10.1127/metz/2016/0807

Radar Feldkirchen 23.Dec 2012

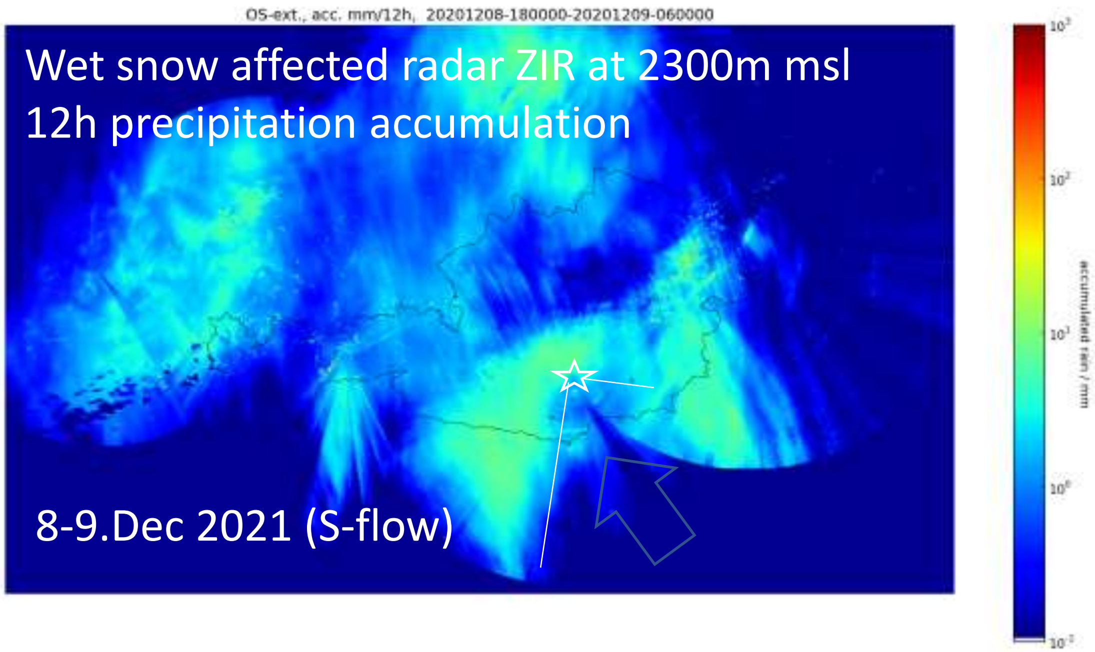
Bright Band in dual polarized moments



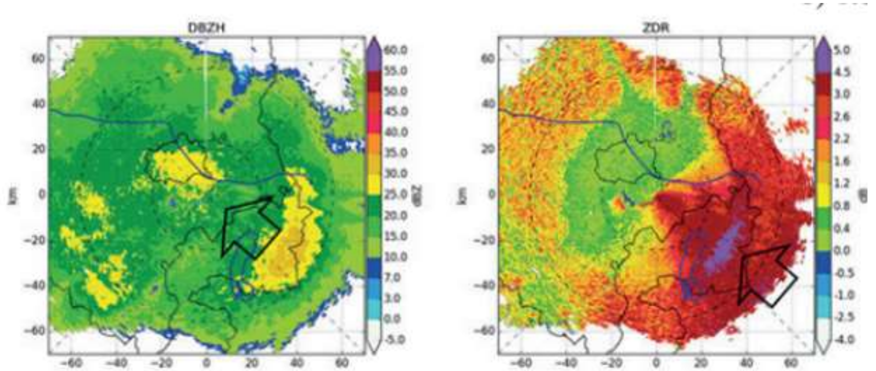
Bright band is embedded in stratiform rain in PPI image with elevation 6.8° from WXR RAU, 18th June 2011 2358 UTC. From left to right, panels show horizontal reflectivity Z_H, differential reflectivity Z_{DR} and cross correlation coeff. ρ_{hv}.

http://www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/NET_166_ext_abs.pdf

Radome influences



long lasting Freezing Rain – SE Flow, 23.Dec 2012 (RAU)

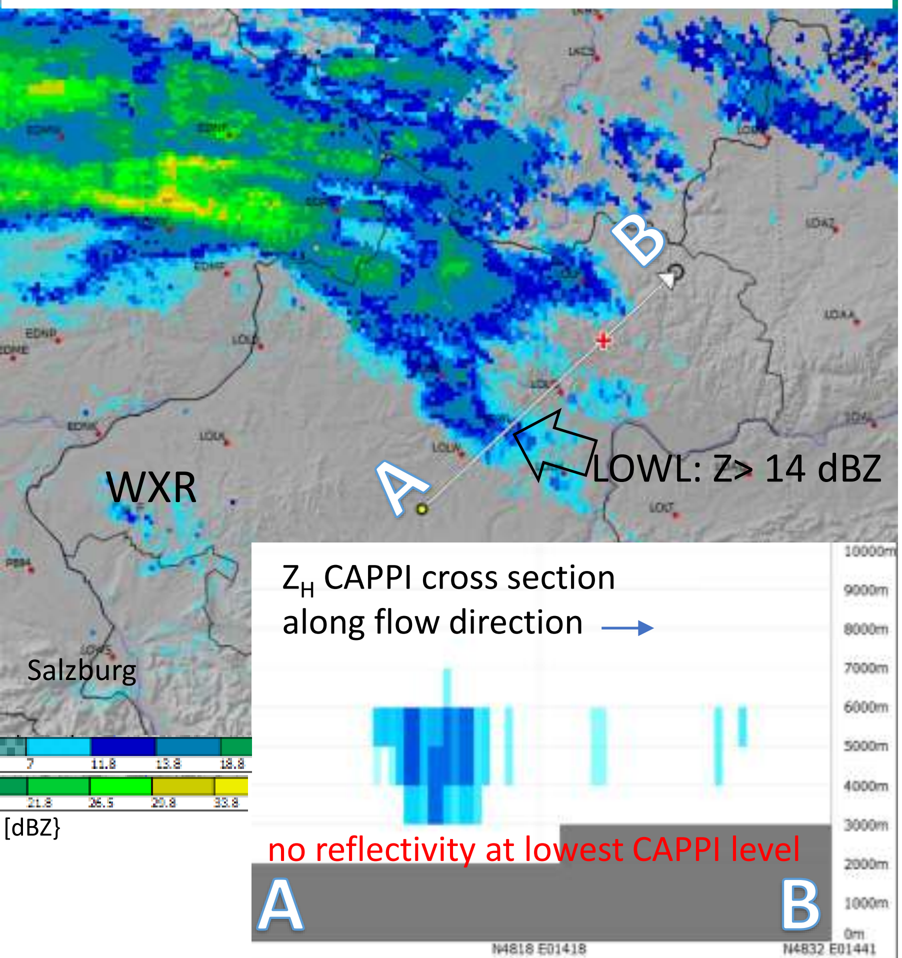


PPI 1.8° Reflectivity and Differential Reflectivy https://doi.org/10.1127/metz/2016/0807

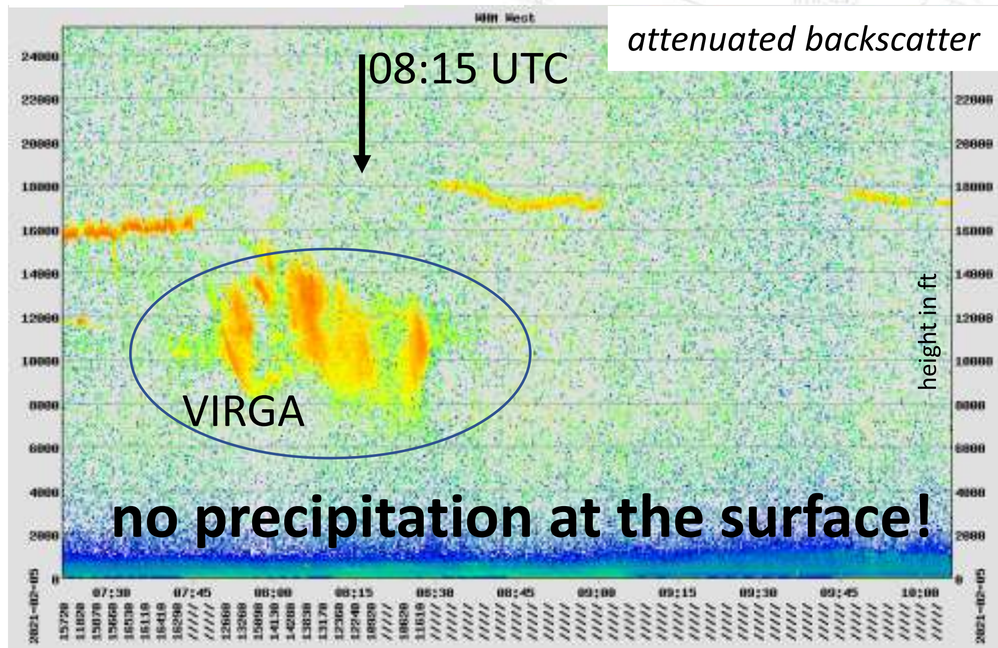
Elevated Echoes: Cloud / Precipitation aloft

5th Feb. 2021 Linz Airport (LOWL)

maximum-projected refelctivity, 08:15 UTC



Ceilometer LOWL:



Outline

Advantages of Using Weather Radar in Meteorology

Weather Radar Detection of Snow

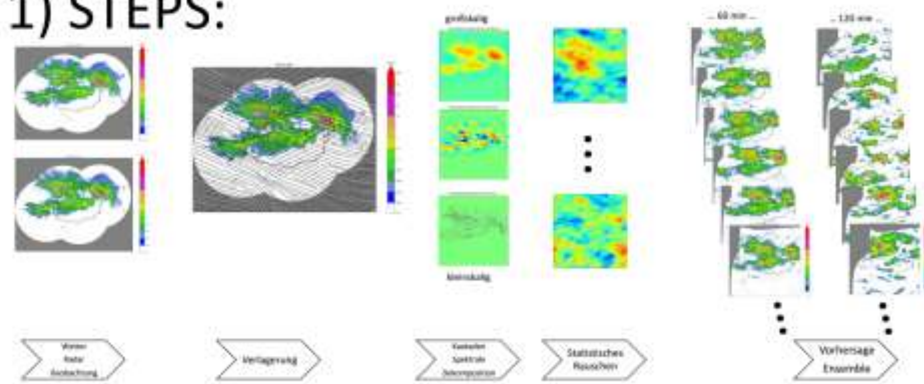
Weather Radar Limitations of Cold Winter Weather

Weather Radar Related Winter Nowcasting Application for Aeronautical Meteorology

Weather Radar for Winter Nowcasting

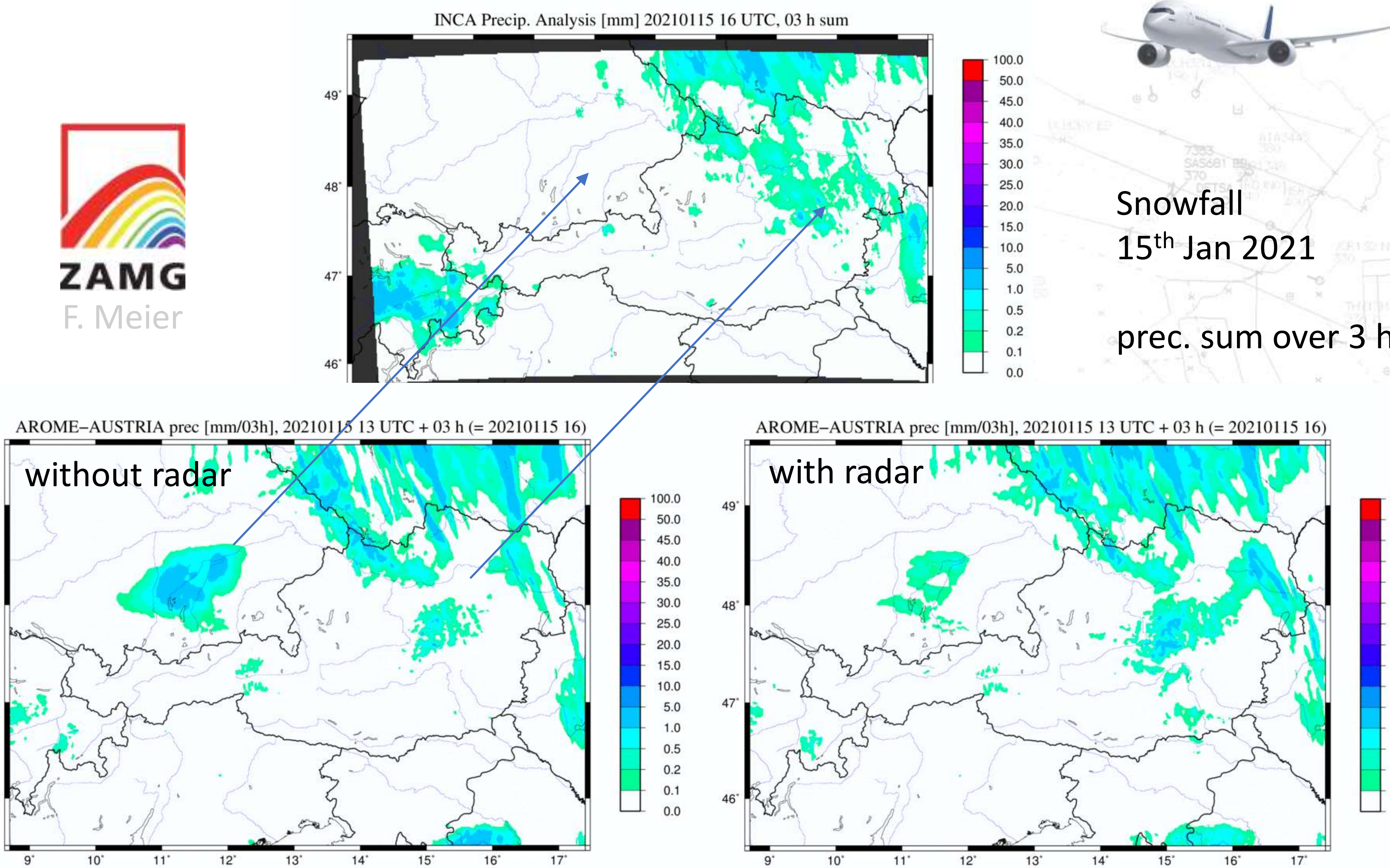
- TREC … Tracking by correlation
- Pysteps … generation of ensembles
- Blending tracking into model

1) STEPS:



Weather Radar Data Assimilation

ZAMG
F. Meier



Snowfall
15th Jan 2021

prec. sum over 3 h

Quantitative Precipitation Estimation

25.Jan 2021 Snowfall Salzburg

Reflectivity:

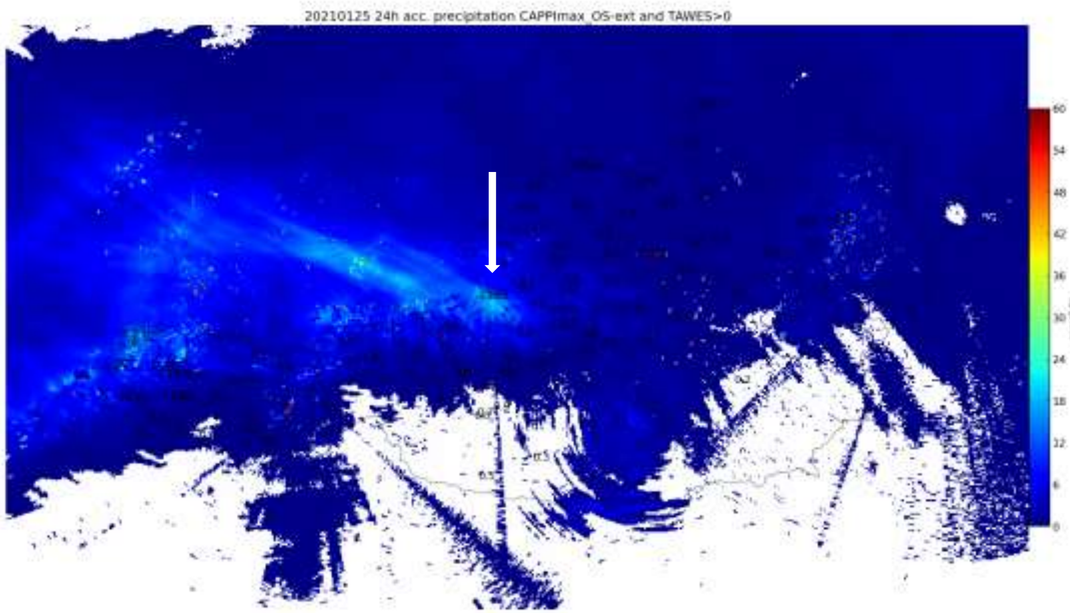
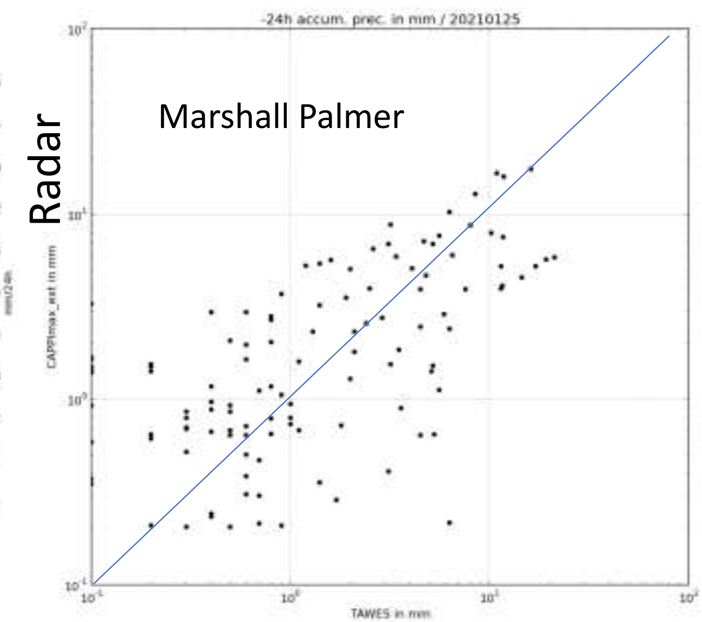


image: accumulated prec. from radar for 24h
numbers: differences in mm from 24h radar-gauge

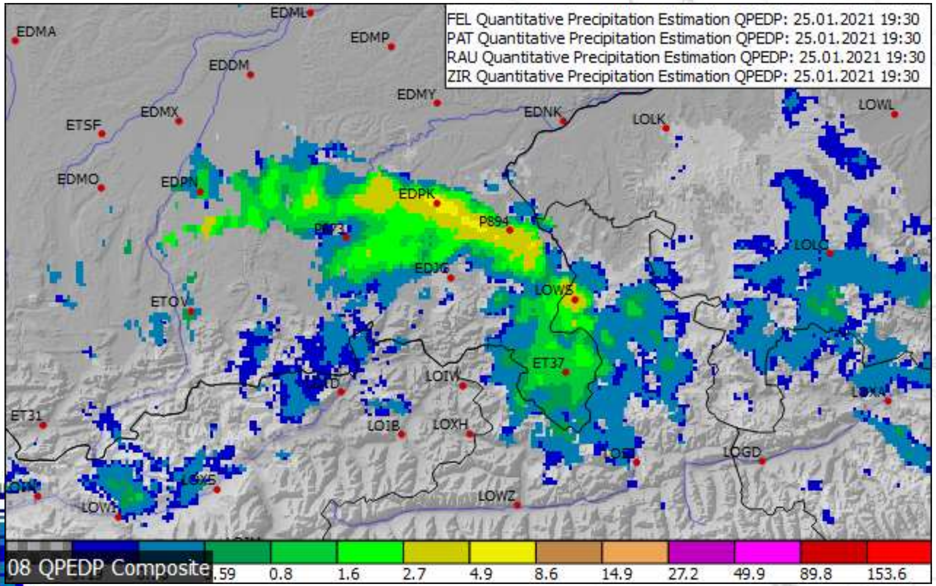


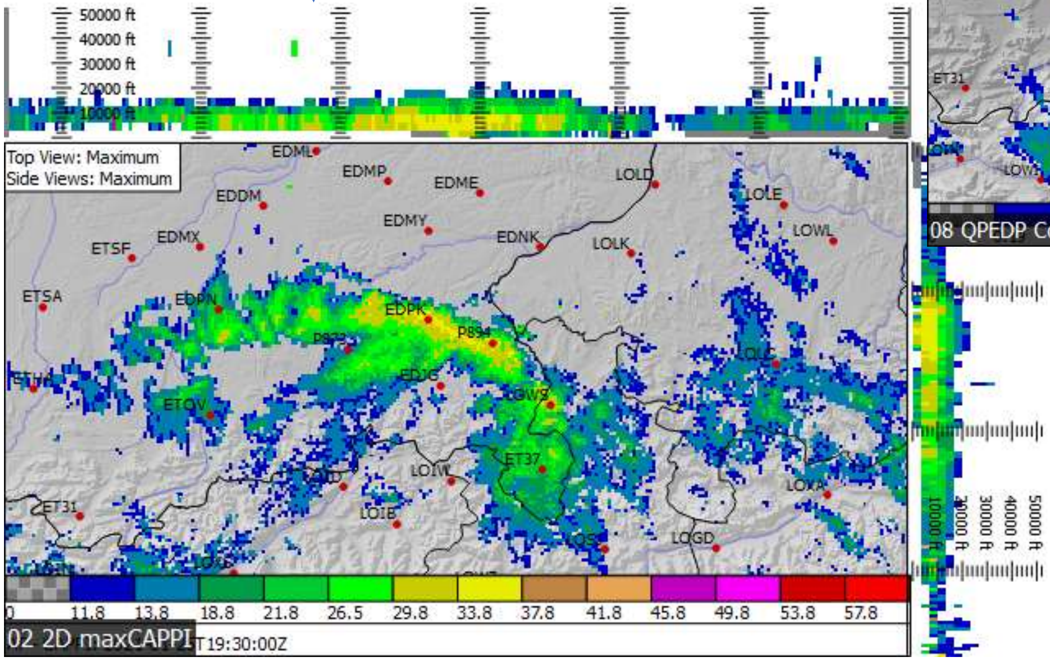
Rain Gauge

Quantitative Precipitation Estimation

25.Jan 2021 Snowfall Salzburg 19:30

Reflectivity + Dual Pol

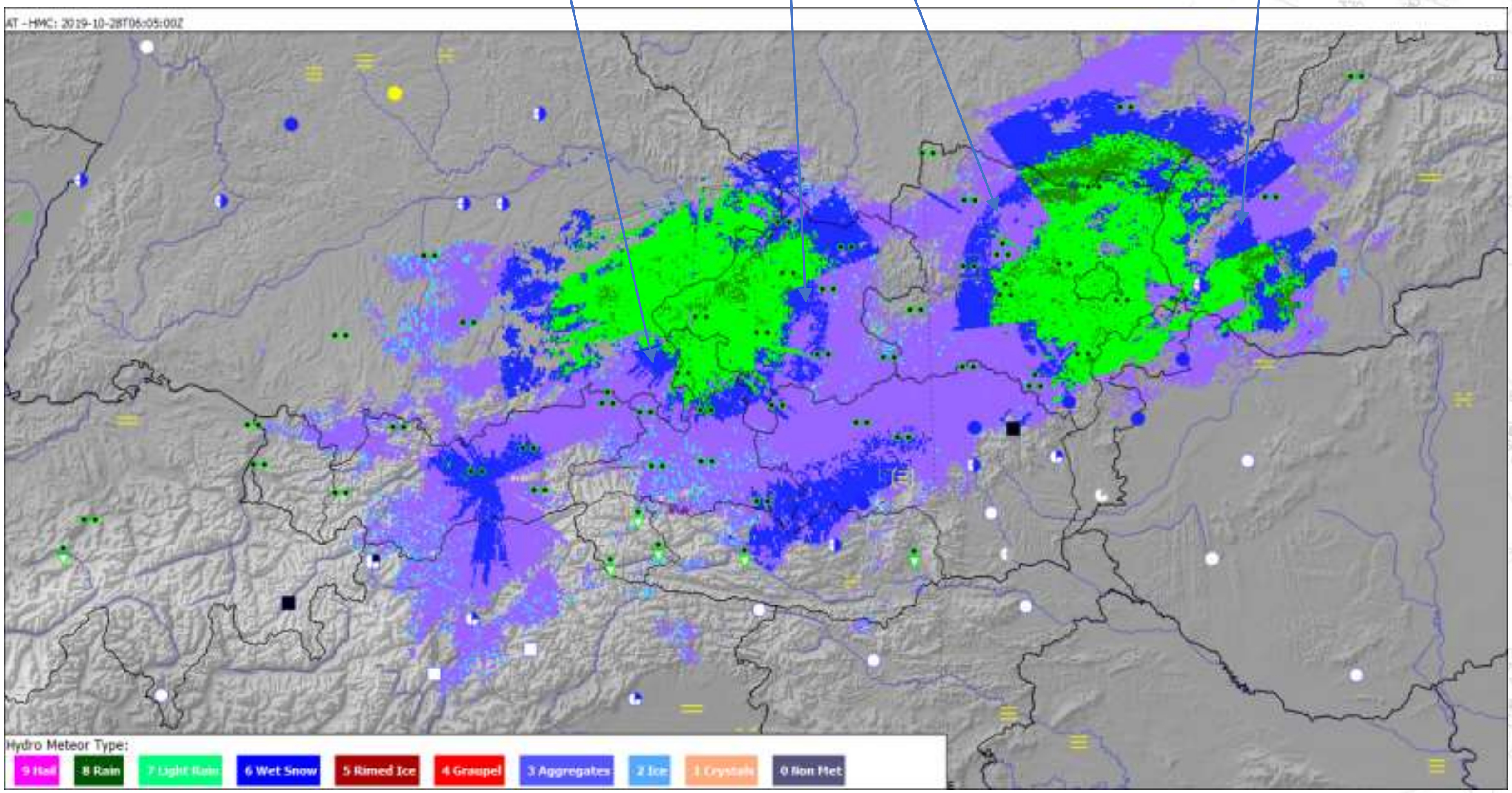




Hydroclassification using dual polarized data

28.Oct 2019 lowest radar coverage

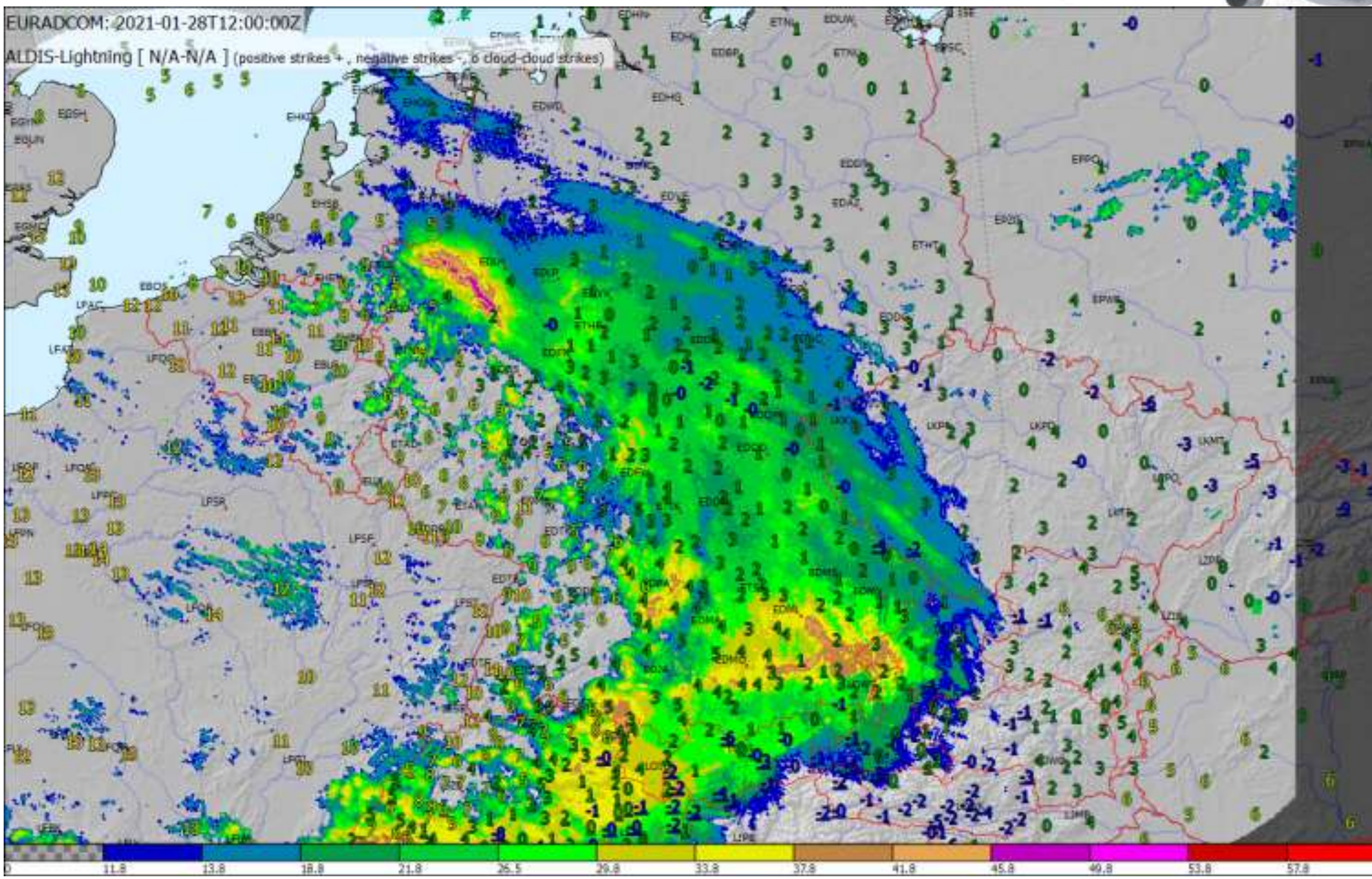
close to the radar site at lower levels rain



Hydroclassification using polarized radar

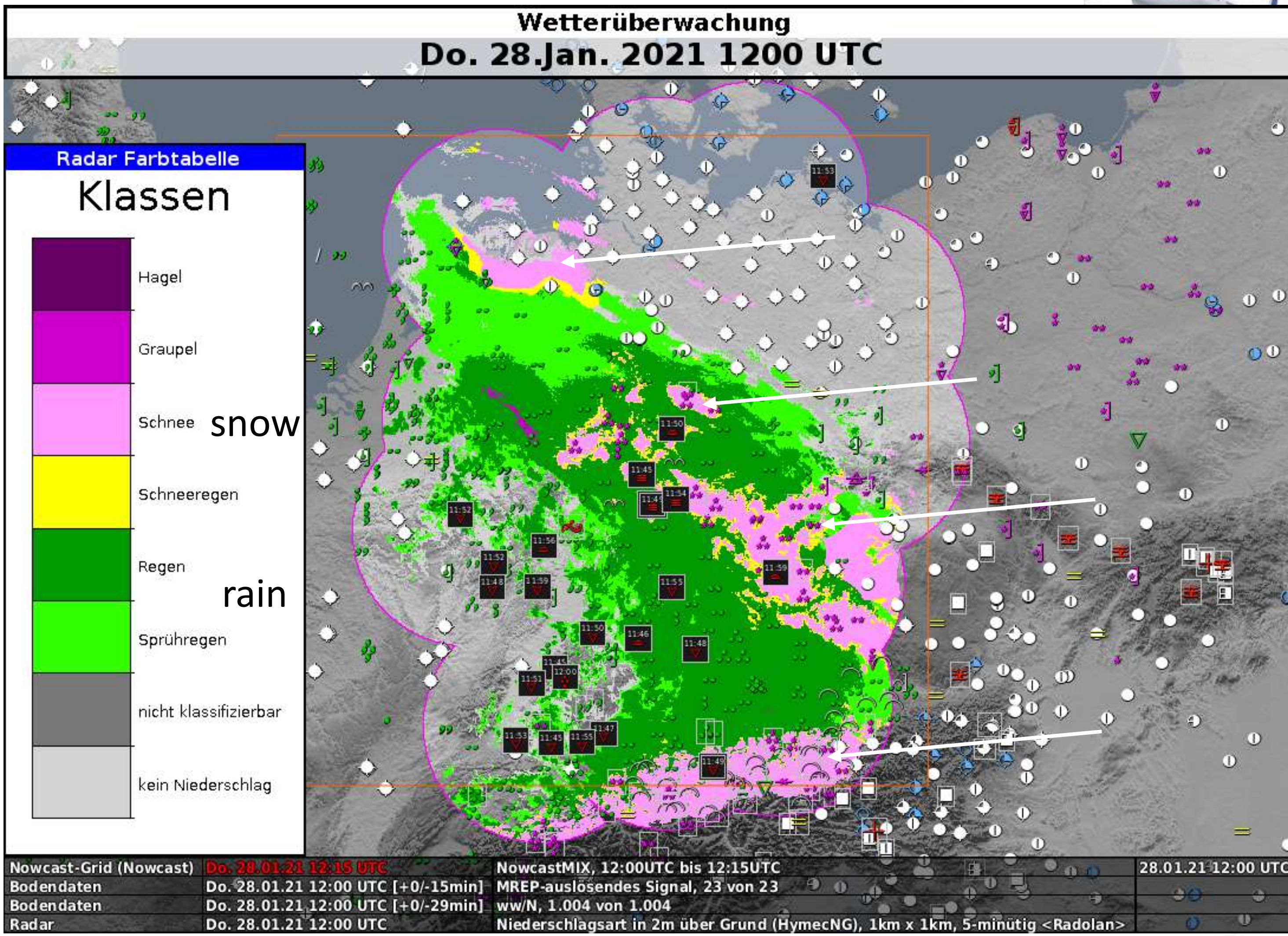
austro CONTROL

28. Jan 2021: start of severe winter episode over Germany



Reflectivity overlaid by surface temperatures

Hydroclassification using polarized radar



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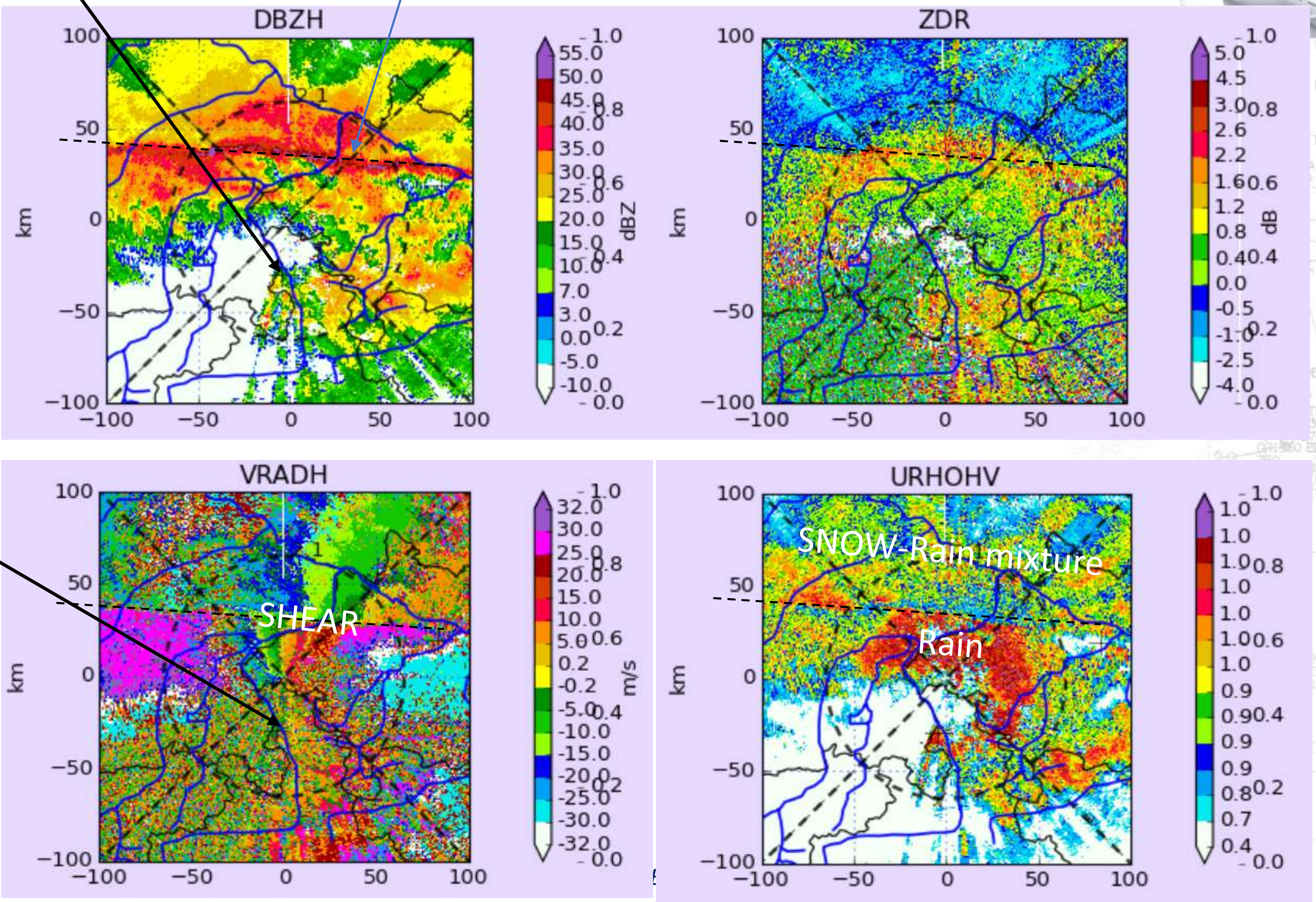
Winter frontal lines

Salzburg

Feldkirchen PPI 1.0deg 20181224_0312UTC

Lightning
Gusts 50 kt



Thank you for your attention.

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SAFETY IS IN THE AIR