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# A Radar Radial Wind Forward Operator for COSMO

## Implementation and first results

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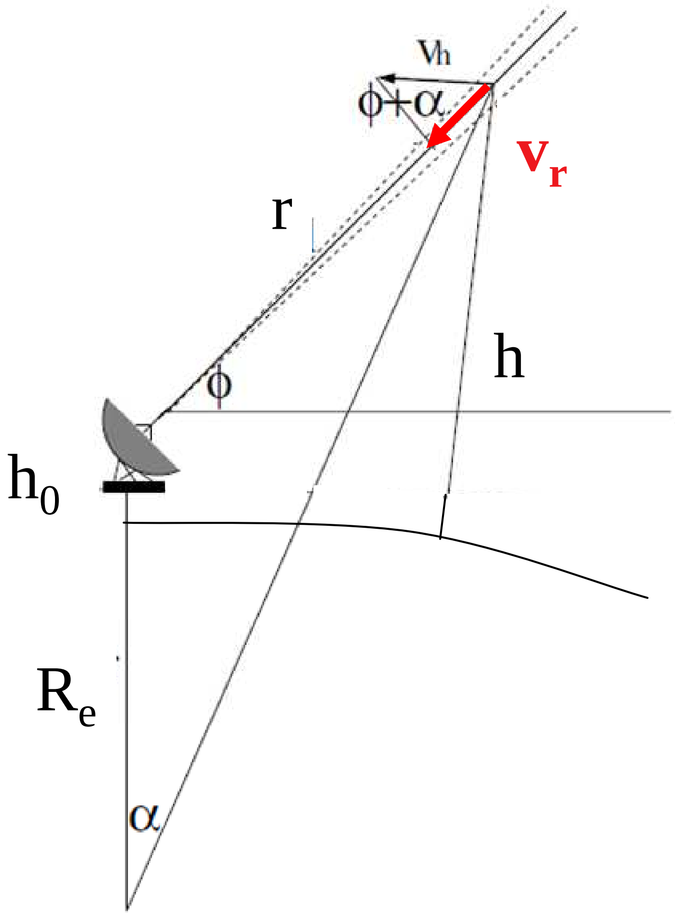
# Introduction

- Implementation of a radar forward operator into COSMO for data assimilation purpose
- Project of Karlsruhe Institute of Technology (Uli Blahak, now@DWD) in cooperation with DWD
- Development of a flexible, modular operator
  - Radial wind, reflectivity and dual polarimetry parameters
  - Comprehensive, full physics included (detailed and expensive)
  - Various simplifications choosable with switches according to application (efficiency)
  - Efficient application on MPP and vector machines
- This contribution: Implementation of first simple radial wind operator

# Doppler radial wind




adapted from Jaervinen et al., 2009

- $v_r$: radial velocity
- $R_e$: earth radius
- r: range
- $\phi$: elevation
- $\theta$: azimuth
- $\alpha$: accounts for earth curvature
- h: height ASL of radar point
- $h_0$: height ASL of radar antenna

# Simple radar operator

- Constant beam propagation, assuming 4/3 earth model
- No consideration of path bending due to variable refractivity
- No consideration of vertical beam broadening (i.e. point measurement)
- No reflectivity weighting
- Neglection of hydrometeor fall speed
- No spatial averaging to match model resolution, i.e. no superobservations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# Radial velocity calculation

- Radial velocity (positive for radial wind towards radar station)

$$v_r(r,\theta,\phi) = -\left[u\sin(\theta) + v\cos(\theta)\right]\cos(\phi+\alpha) - w\sin(\phi+\alpha)$$

$$\alpha = \arctan\left[\frac{r\cos(\phi)}{r\sin(\phi) + \frac{4}{3}R_e + h_0}\right]$$

accounts for earth curvature and beam bending due to refractivity, assuming steady-state standard atmosphere

- Model wind components interpolated trilinearly to radar point $(r,\theta,\phi)$

$$u = u(r,\theta,\phi) \quad v = v(r,\theta,\phi) \quad w = w(r,\theta,\phi)$$

- Rotation to geographical coordinate system

# Implementation in COSMO

- Read in radial wind data and quality information (PE0)
- Distribute meta information about radar stations to all PE‘s (location, radial bins, azimuths, elevations, nyquist velocity, etc.)
- Decide which radar point $(r,\theta,\phi)$ belongs to local subdomain
- Calculate interpolation weights for u,v,w for every local radar point (only once, since static beam propagation)
- Interpolate wind vector (u,v,w) to local radar points, rotate to geographical system and project onto radar beam -> radial wind for each local radar point
- Send model radial wind component of all local beam points to PE0
- PE0: Calculation of difference (obs – model), quality control and output of y and y-H(x) to feedback file

grey: not yet implemented!

# Idealized implementation test

- Set constant model wind (u,v,w) = (0,16.5,0) m/s
- Then the radial wind calculation simplifies to

$$v_r(r,\theta,\phi) = -v\cos(\theta)\cos(\phi+\alpha)$$

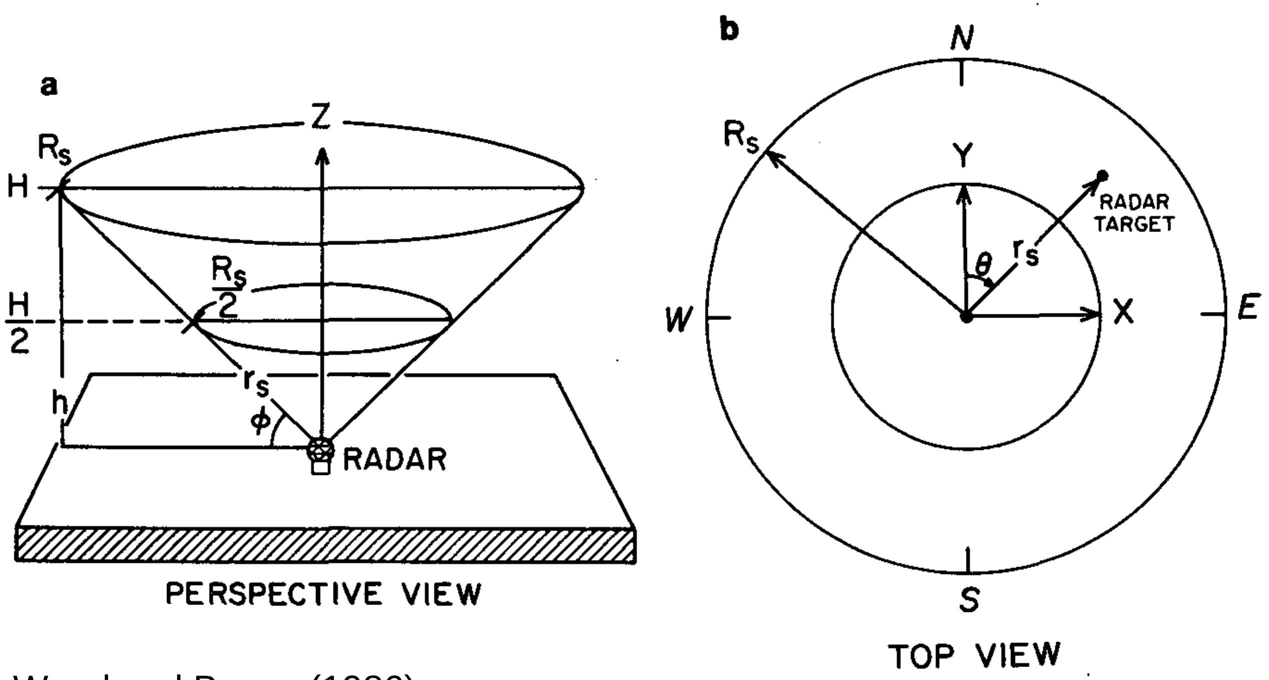
$$\ldots$$

$$v_r(r,\theta,\phi) = \frac{-v\beta\cos(\theta)\cos(\phi)}{\sqrt{r^2+2r\beta\sin(\phi)+\beta^2}} \qquad \beta = \frac{4}{3}R_e + h_0$$

- Result is precise to machine uncertainty

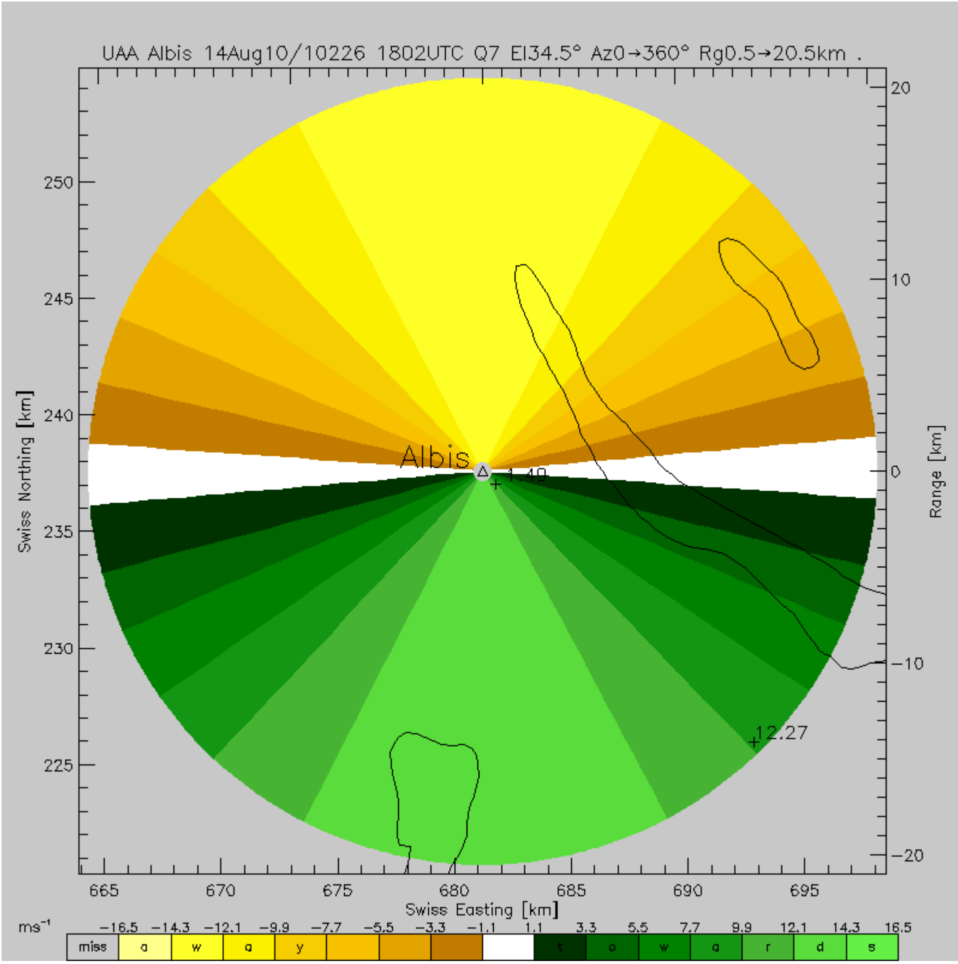
# PPI plots

- PPI: plan position indicator: polar plots in the *(r, θ)* plane for a constant elevation $\phi$
- Increasing height with increasing range *r*




from Wood and Brown (1986)

# Implementation test result



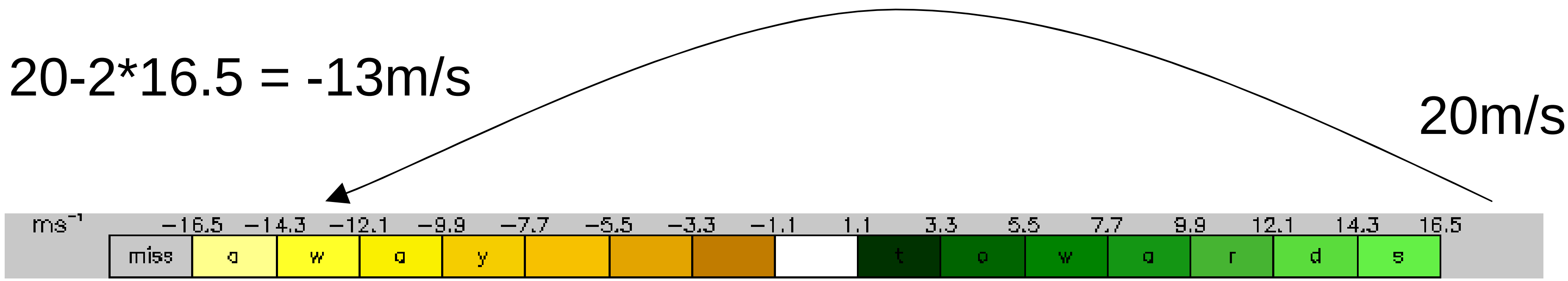

- Albis radar
- Elevation of 34.5°
- r = 0..20km
- h(20km) = 12.27km
- Yellow: away
- Green: towards
- Wind is perpen-dicular to white zero-line
- Indeed shows correct wind (u,v,w)=(0,16.5,0)m/s

# Aliasing and Nyquist velocity

- Doppler radar measures phase shifts
- When phase shifts are less than 180° (one-half wave length), they are clearly detectable.
- Shifts of *180° or more* are ambiguous
- Nyquist velocity: maximum unambiguous velocity
- Velocities larger than the nyquist velocity appear folded into the detectable velocity range.

$$v_r = v_m + 2nv_n$$

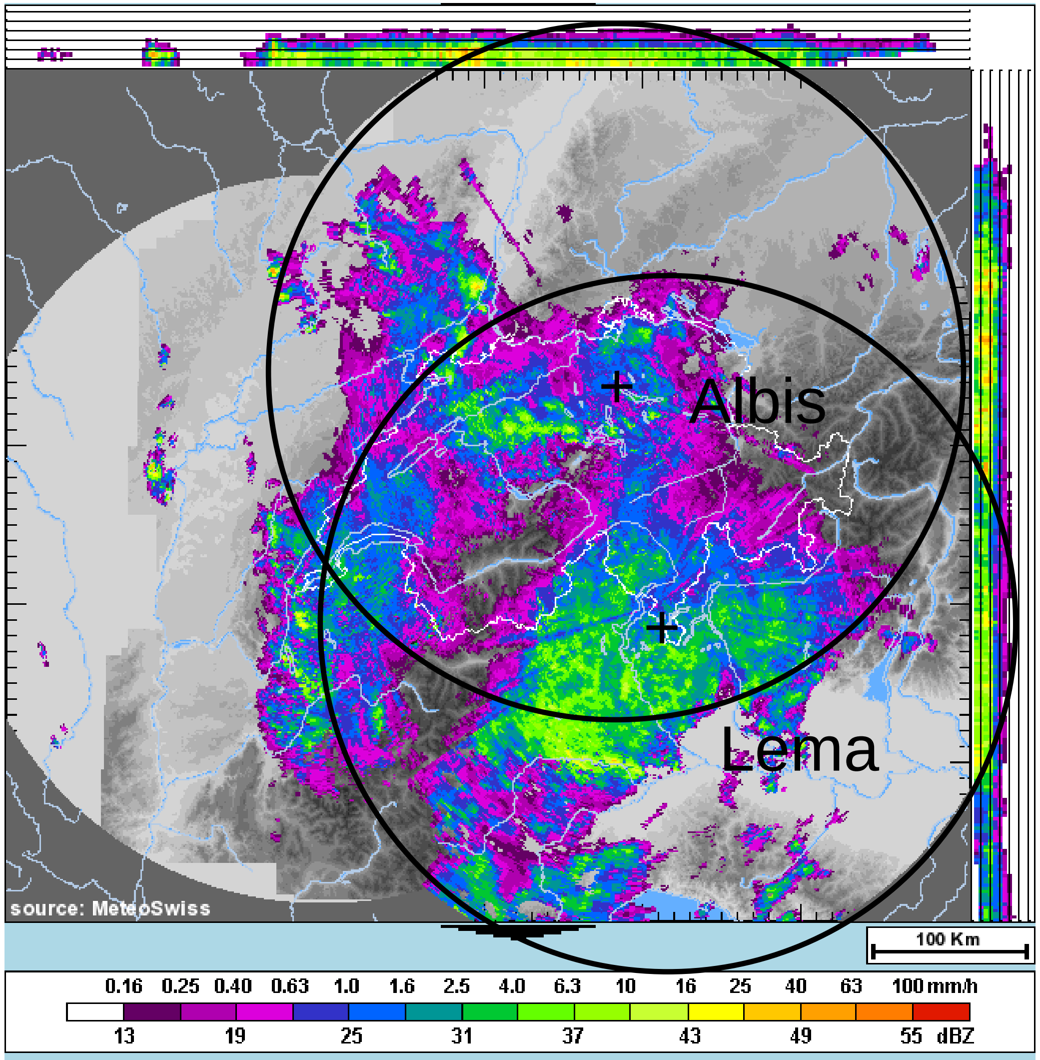
- $v_r$: unaliased radial wind, $v_m$: aliased wind, $v_n$: nyquist velocity
- Light yellow colors adjacent to light green colors: potential aliasing!



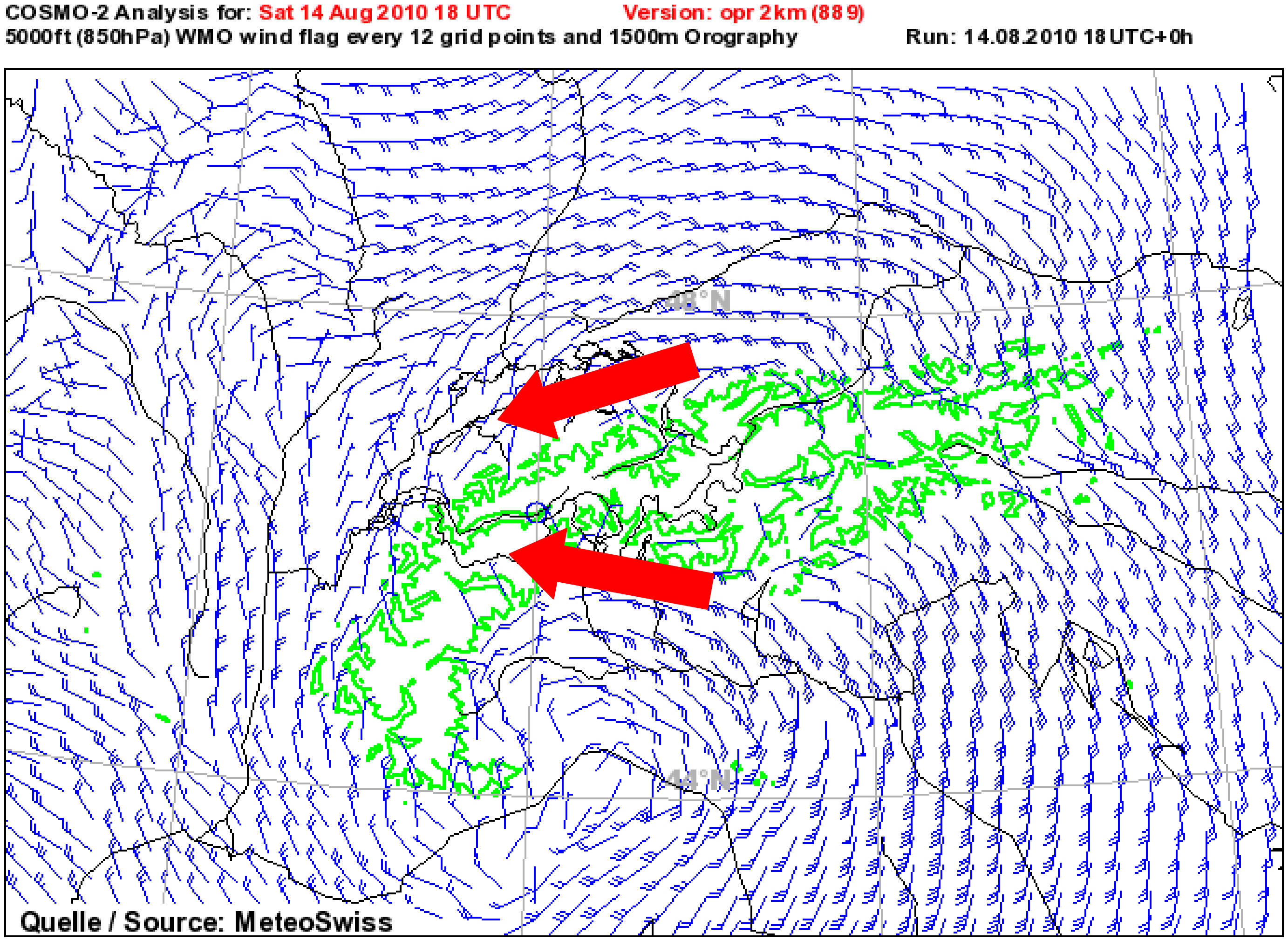
# Real case of 14.8.2010

- Large-scale forced precipitation
- Southerly flow impinging upon the Alps
- Widespread precipitation north and south of the Alps

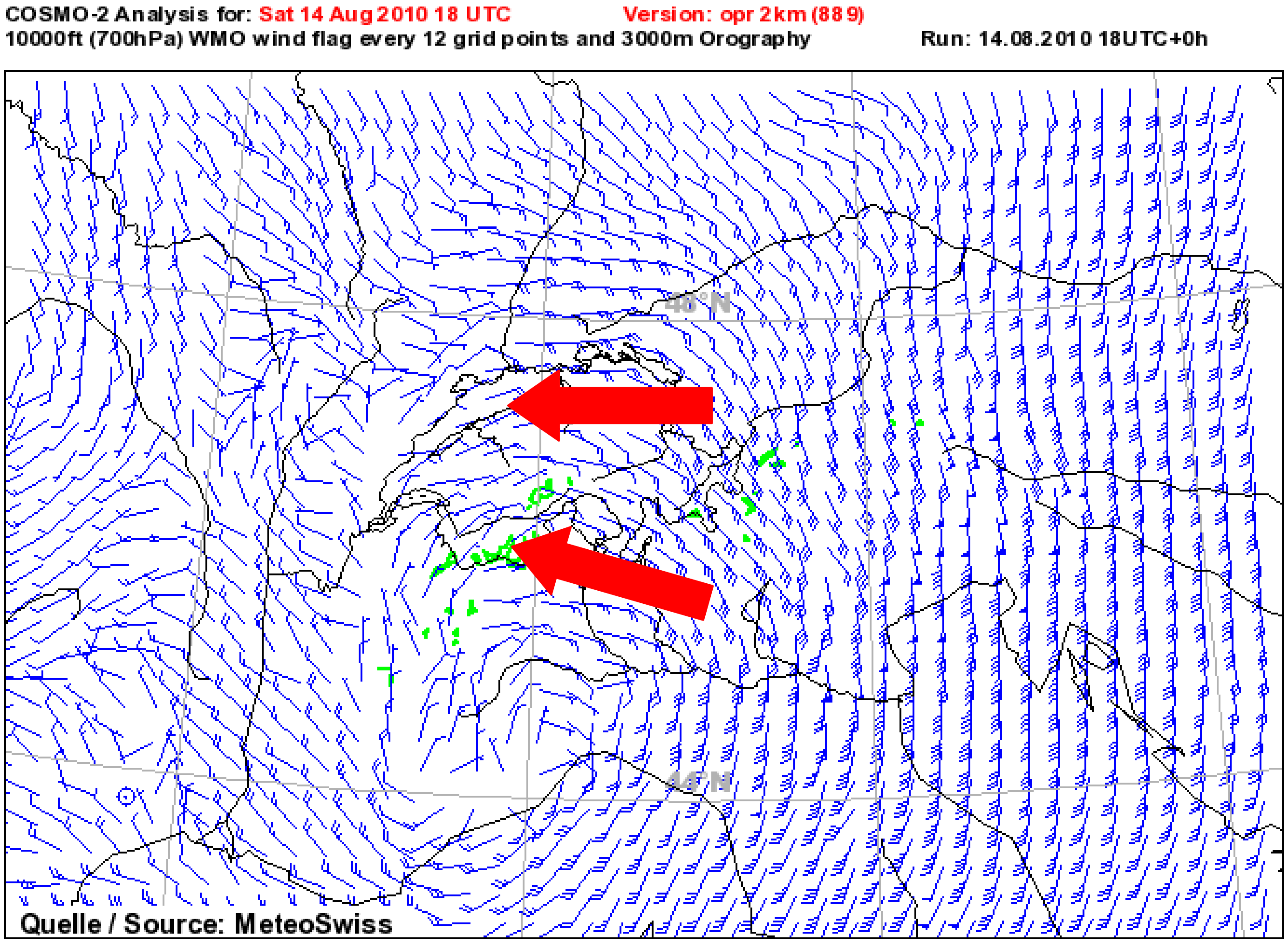
# Reflectivity on 1800 UTC, 14.8.2010



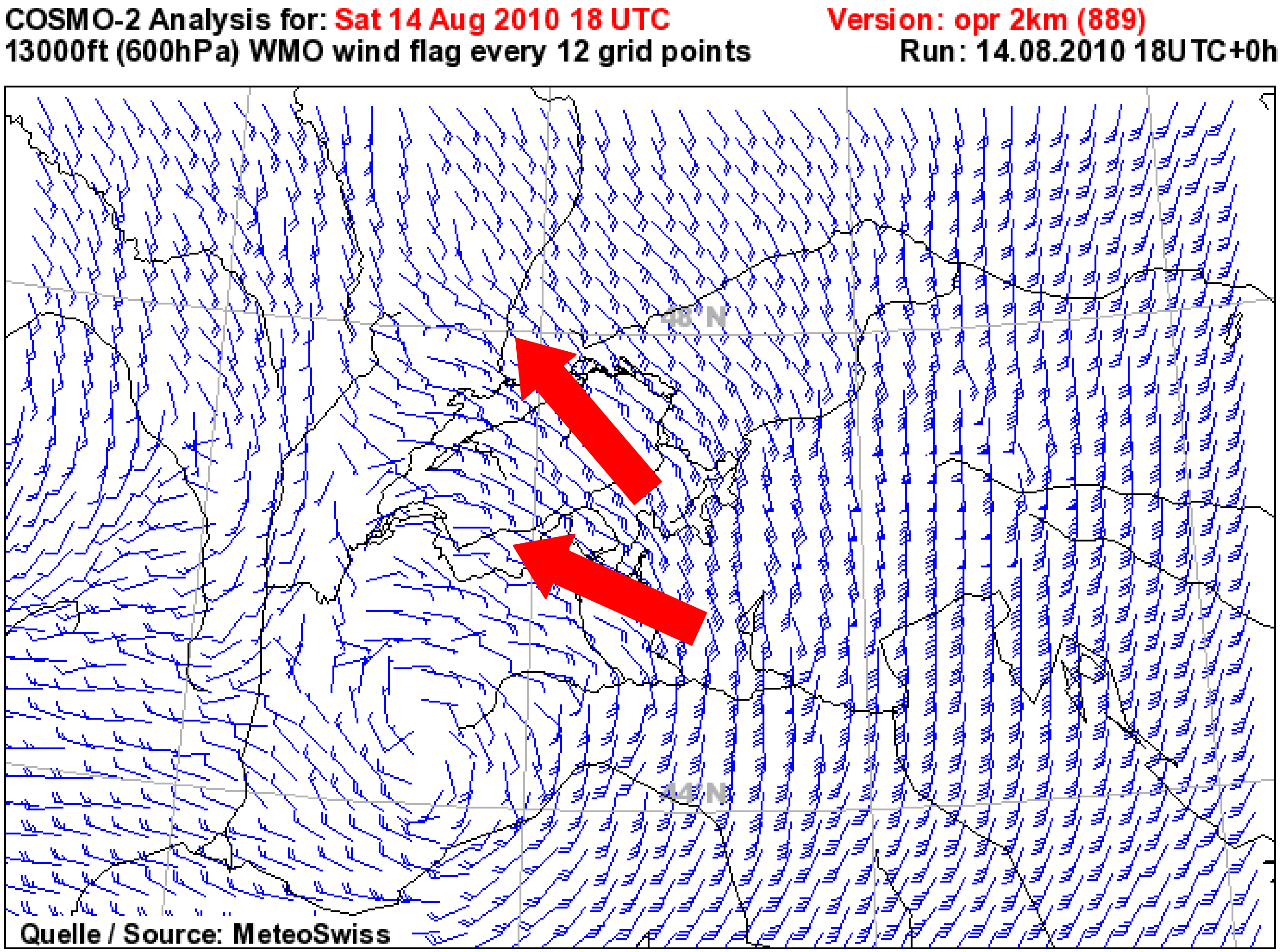
# Wind at 850hPa (ca 1500m)



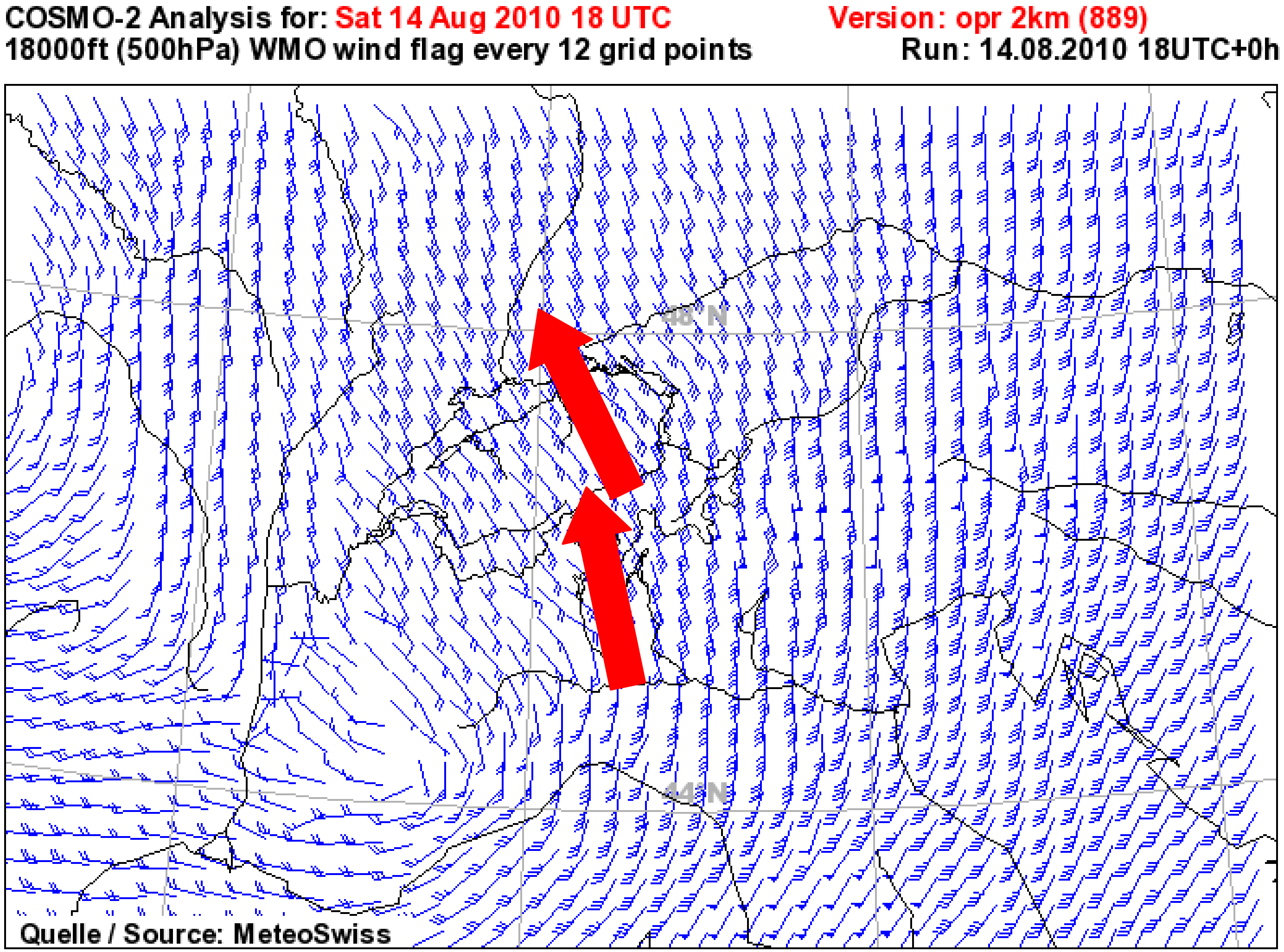
# Wind at 700hPa (ca 3000m)



# Wind at 600hPa (ca 4300m)



# Wind at 500hPa (ca 6000m)



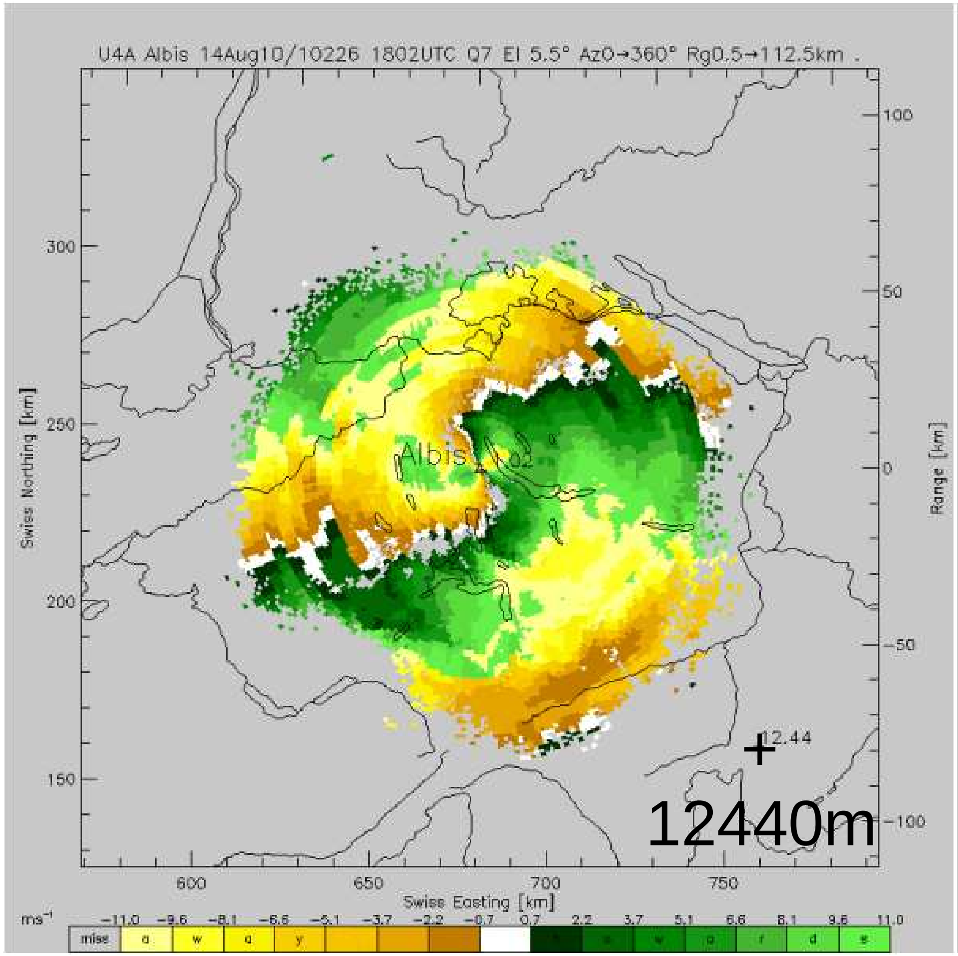
# Modelled and observed radial winds

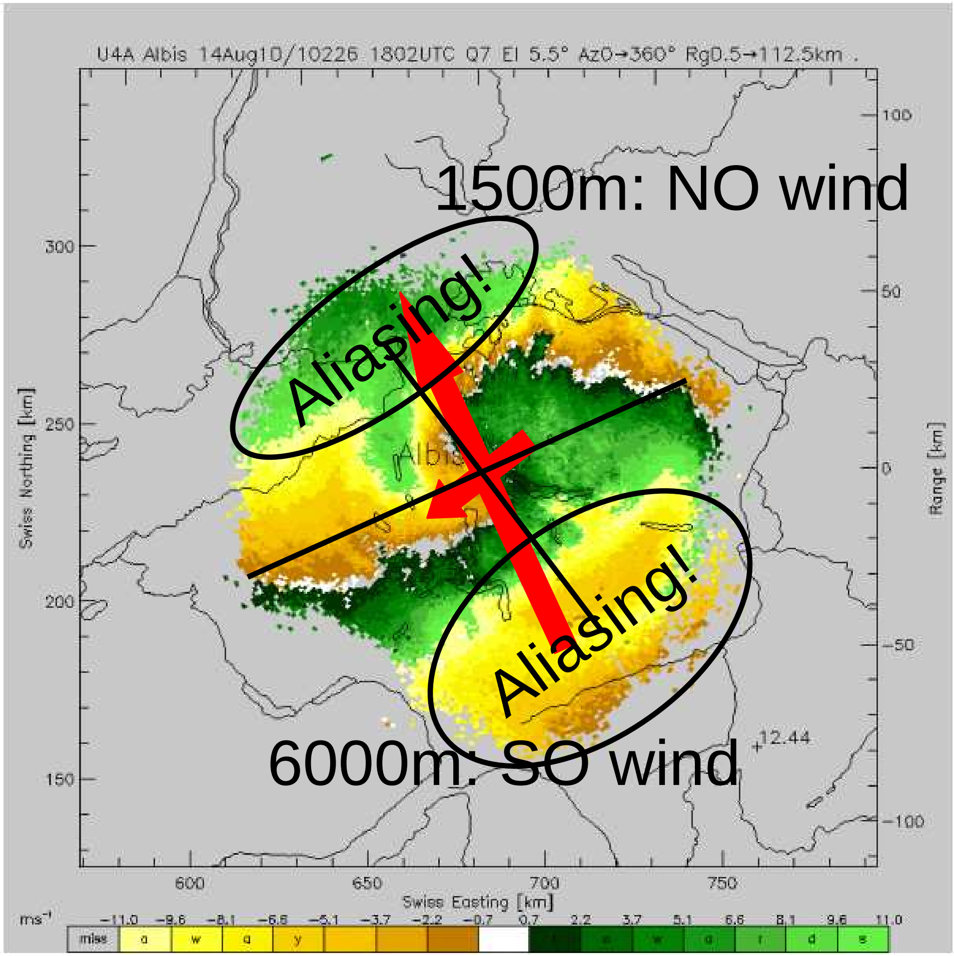
- PPI display of modelled (right panels) and observed (left panel) radial winds are visually compared
- Modelled radial winds, whose observed counterparts are missing, are masked out for ease of comparison
- Modelled radial winds are aliased into unambiguous velocity range for ease of comparison
- Examples from radars Albis and Lema are shown

# PPI Albis, elevation $\phi = 5.5°$

COSMO-2

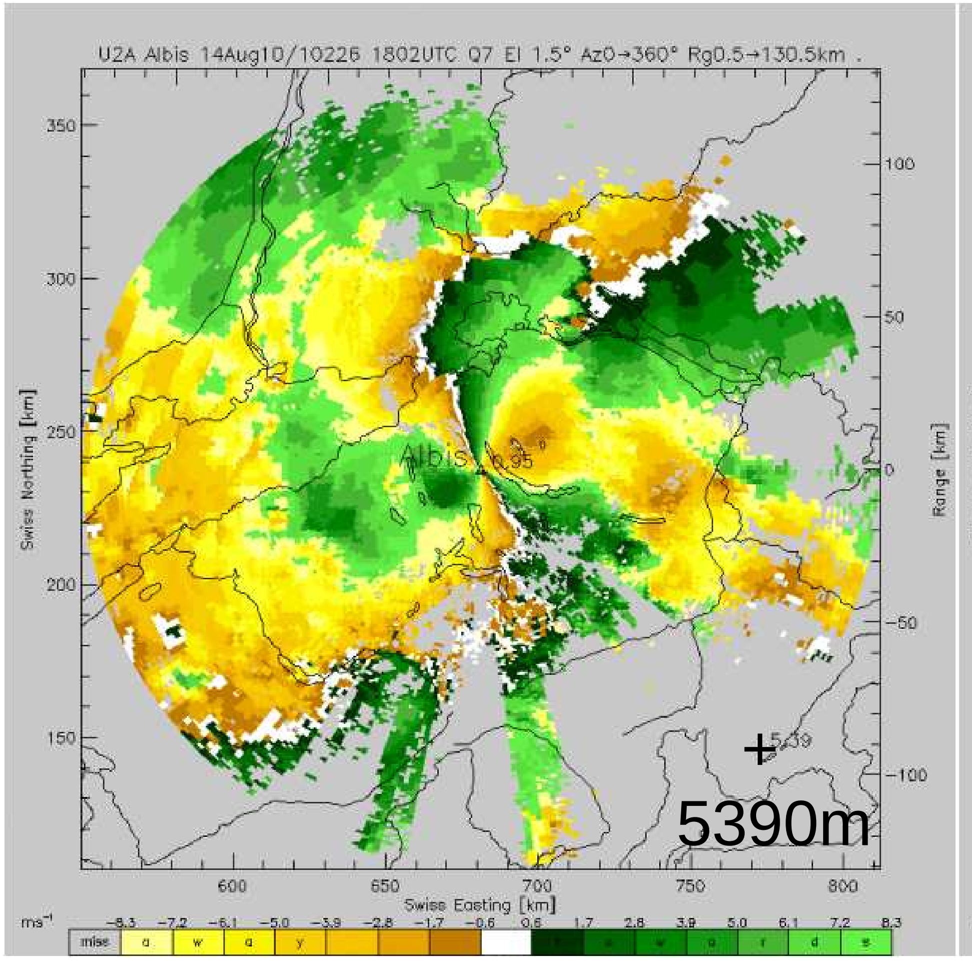
OBS



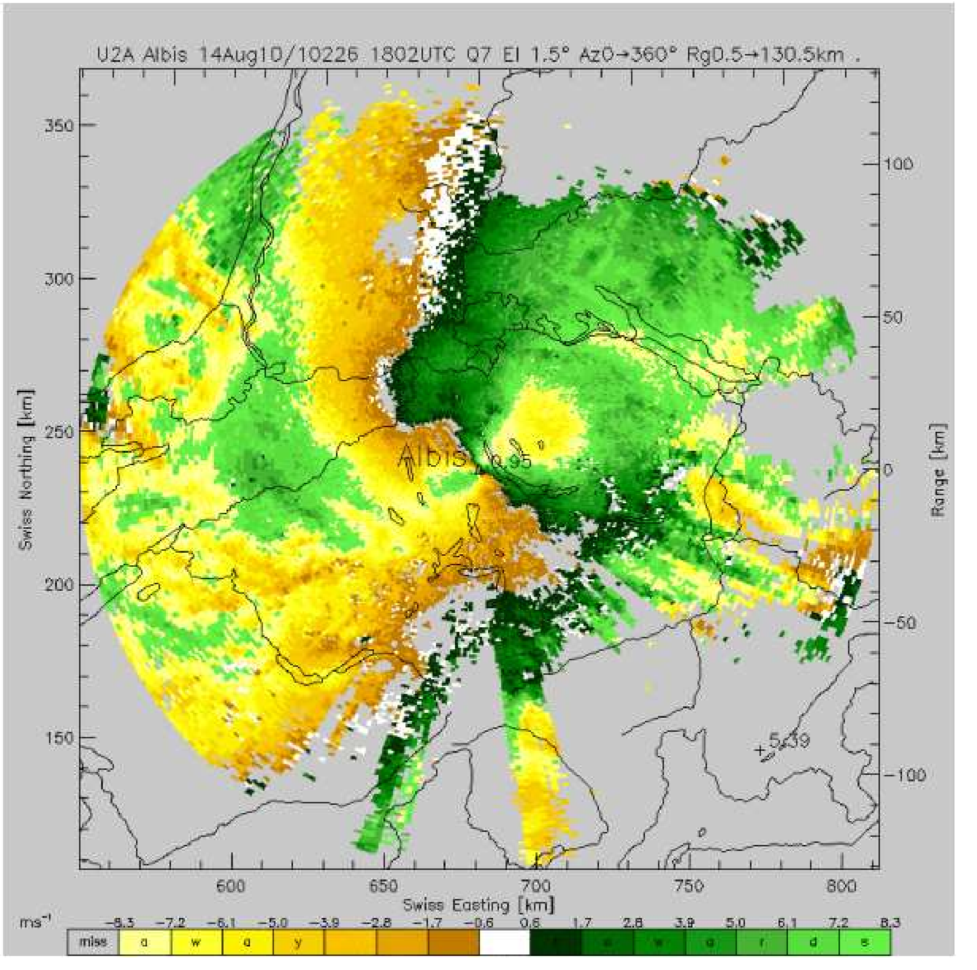



# PPI Albis, elevation $\phi = 1.5°$

COSMO-2

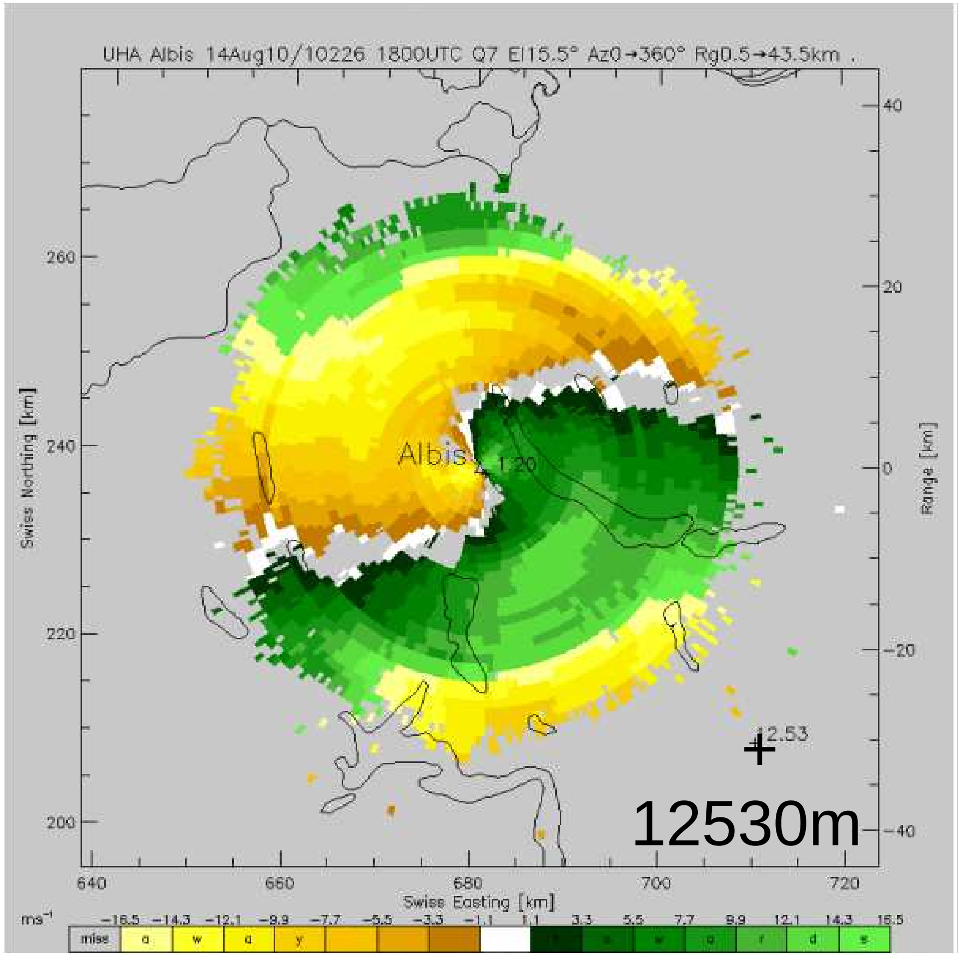



OBS

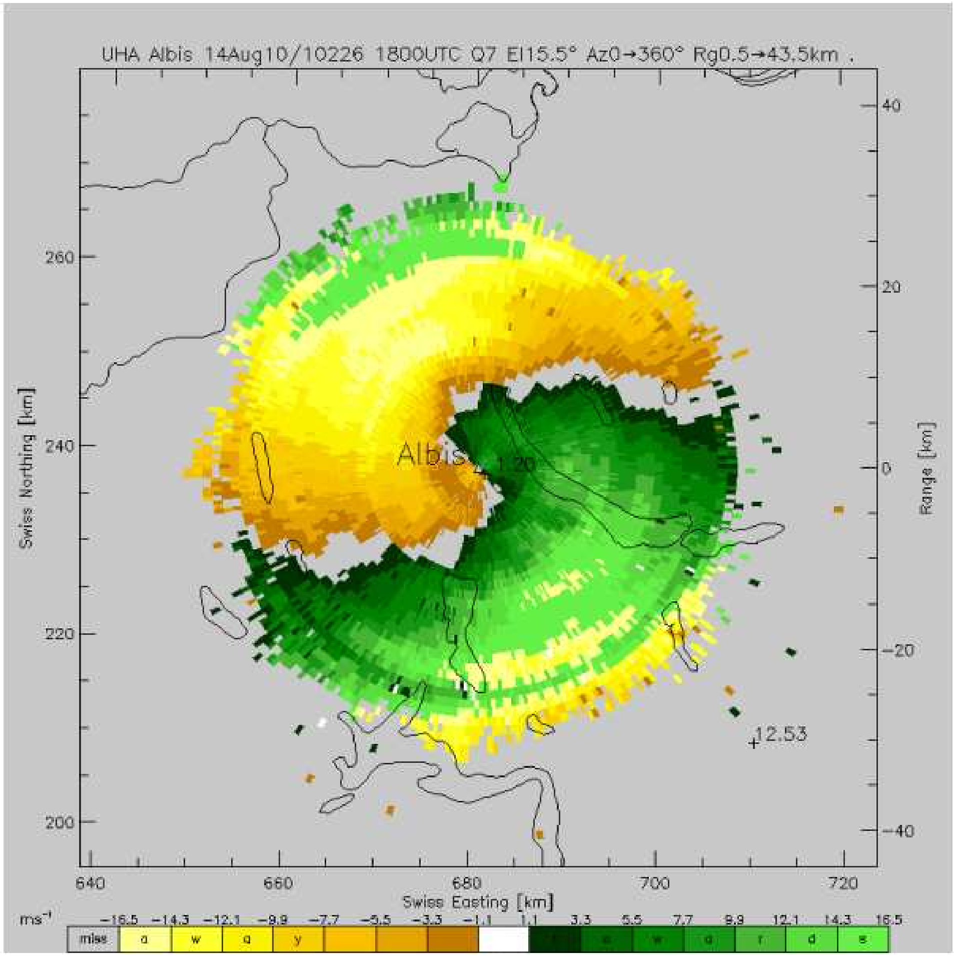


# PPI Albis, elevation $\phi$ = 15.5°

COSMO-2

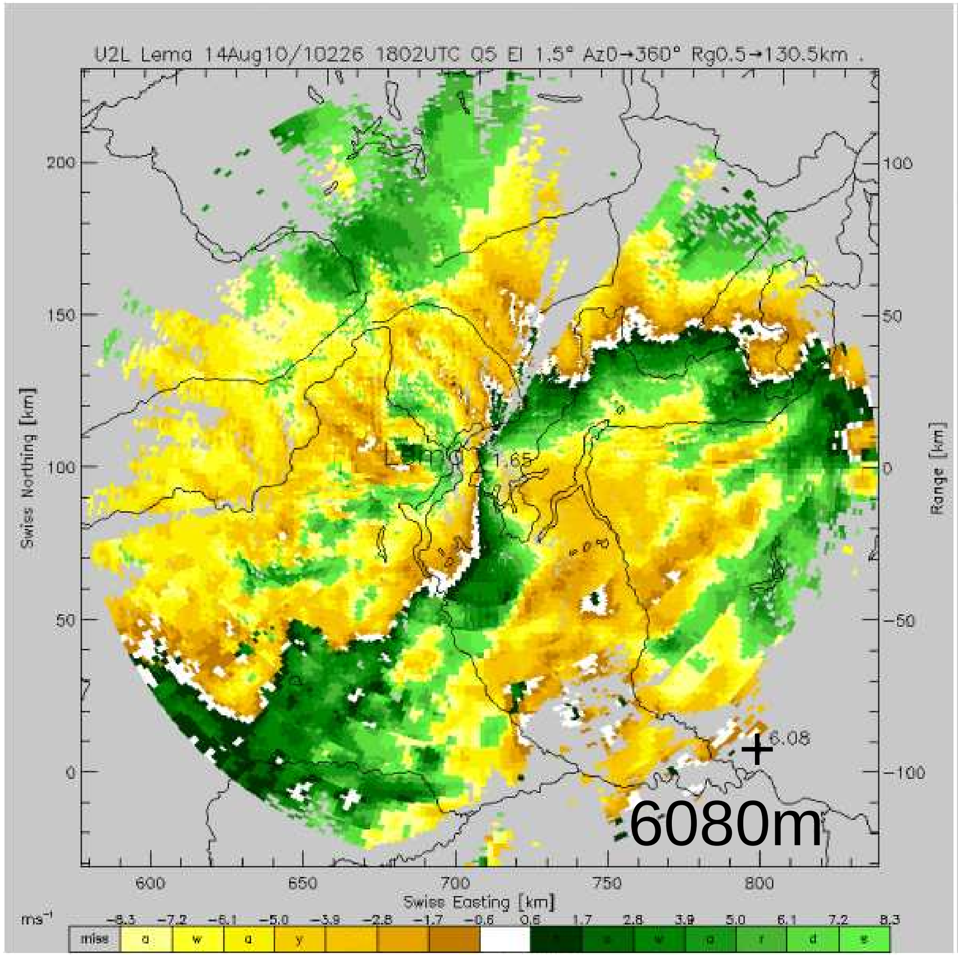



OBS

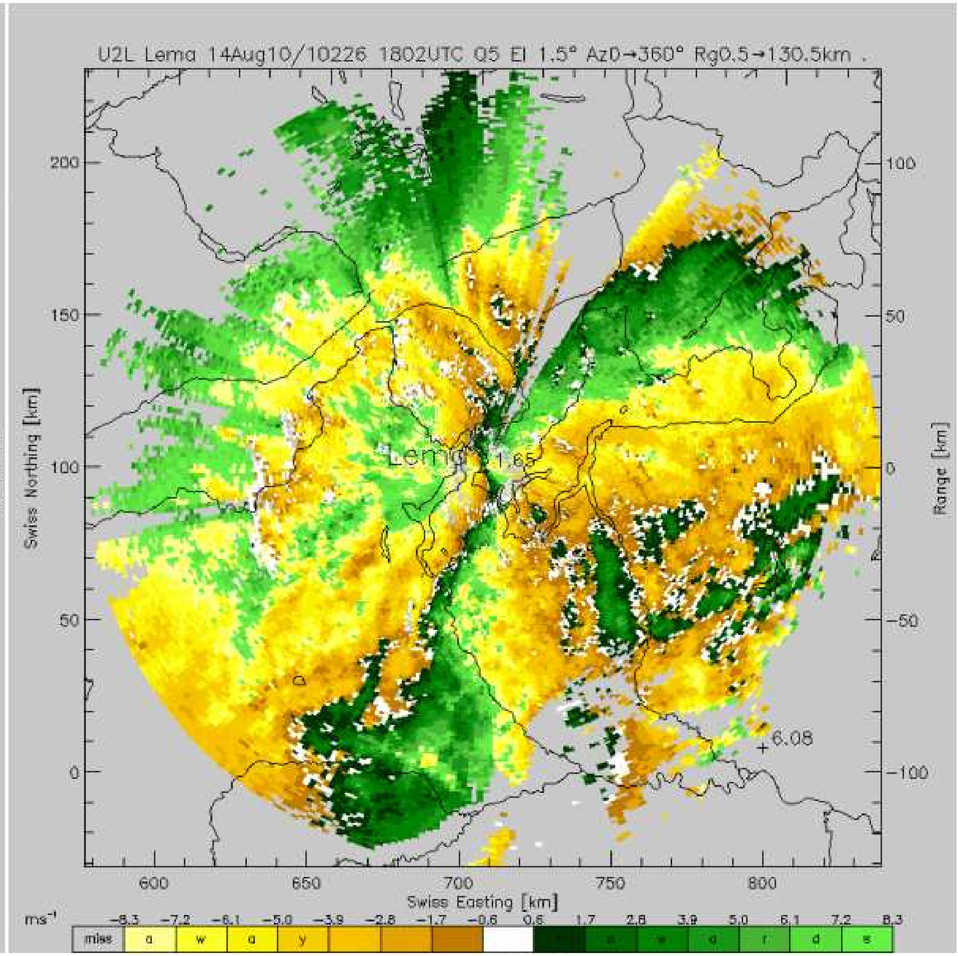


# PPI Lema, elevation $\phi$ = 1.5°

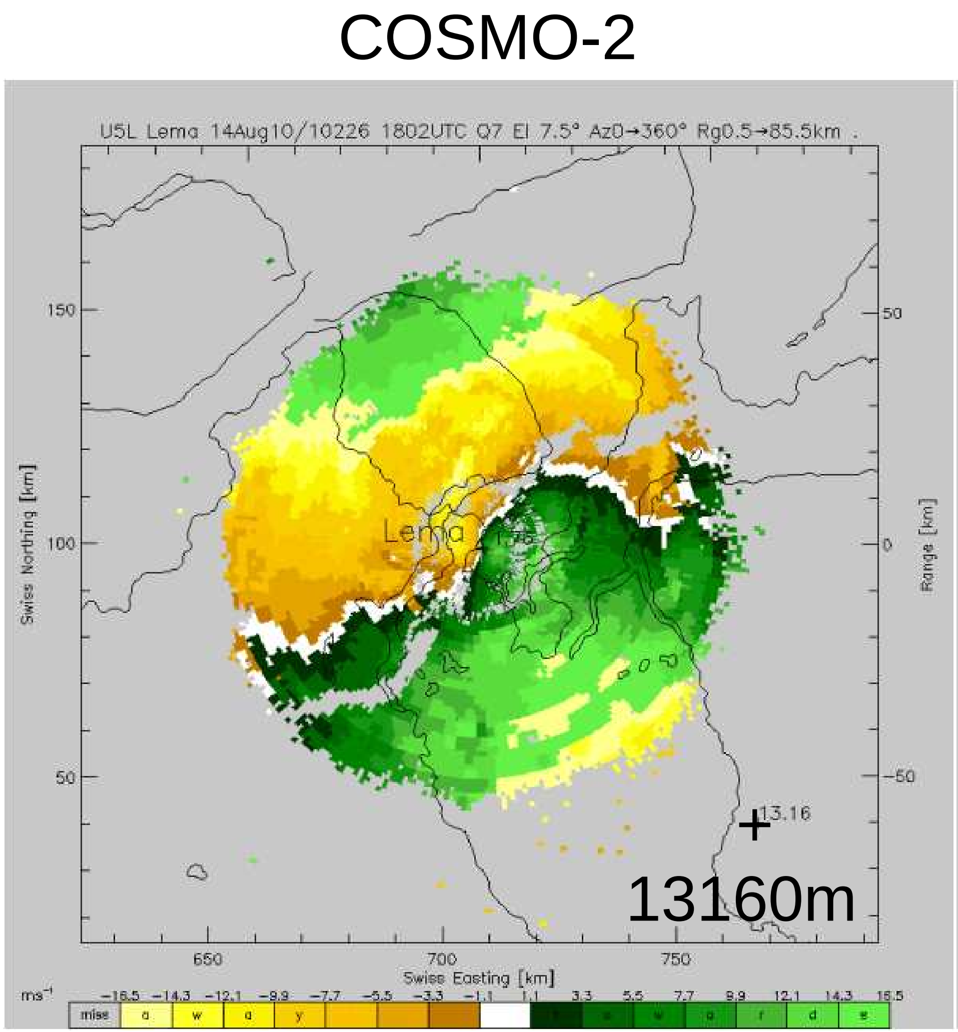
COSMO-2

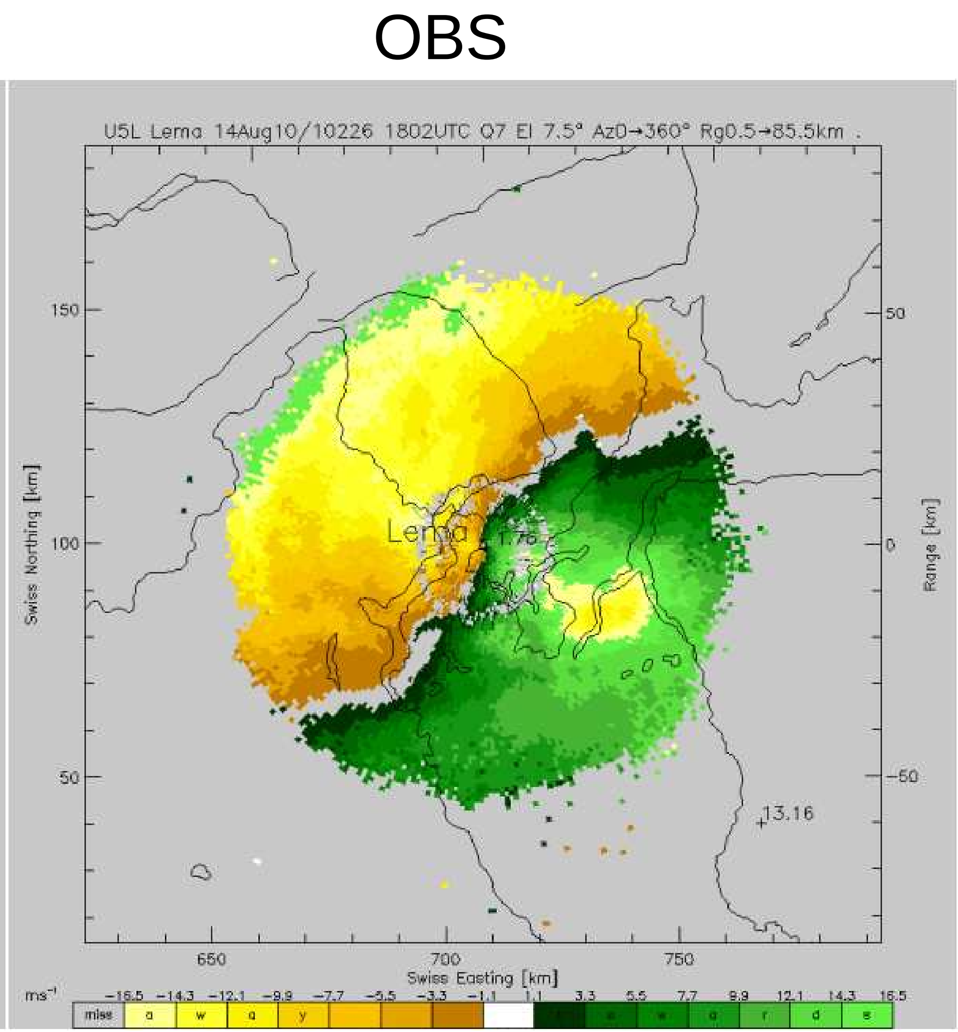



OBS



# PPI Lema, elevation $\phi$ = 7.5°



# Computational aspects

- COSMO-2 setup
  - 26x25=650 PE's
  - 3 radar (Albis, Lema, Dole)
  - r = 1,1,130km, $\theta$=1,1,360°, 20 elevations
  - Computations only on 121 PE's (18.6%) -> bad load balancing!

- COSMO-2 wall clock time
  - 12h forecast, call of operator every 5min (720 times)
  - Without radar operator: 77.75s
  - With radar operator: 78.90s
  - Increase in computer time: +1.15s (+1.47%)
  - Calculations and communication only (output to disk not counted!)

# Summary

- Implementation of simple radial wind operator for COSMO
- Efficient on MPP machine (vectorization?)
- Appears to give meaningful results in a real case study as compared to Swiss radar observations

# Next steps

- Hand out code to Uli Blahak for further development and testing, i.e.:
- Produce and tune super-observations for COSMO resolution
- Test more carefully, evaluate statistics!
- Add more physical features like
  - Vertical (and eventually horizontal) beam broadening
  - Path bending taking into account actual refractivity
  - Reflectivity weighting
  - Hydrometeor fall speed

# Thanks for your attention!


- Jaervinen, H. et al., 2009: Doppler radar radial winds in HIRLAM. Part I: observation modelling and validation. *Tellus* **61A**, 278-287
- Salonen, K. et al., 2009, Doppler radar radial winds in HIRLAM. Part II: optimizing the super-observation processing, *Tellus* **61A**, 288-295
- Salonen, K. et al., 2010, Doppler radar radial wind data in NWP model validation, *Meteorol. Appl,* **15**, 97-102
- Wood, V. and R. Brown, 1986: Single Doppler Velocity Signature Interpretation of Nondivergent Environmental Winds, *J. Atmos. Oceanic Technol.,* **3**, 114-128