ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Use of radar data in NWP models

16.6.2006

Kirsti Salonen

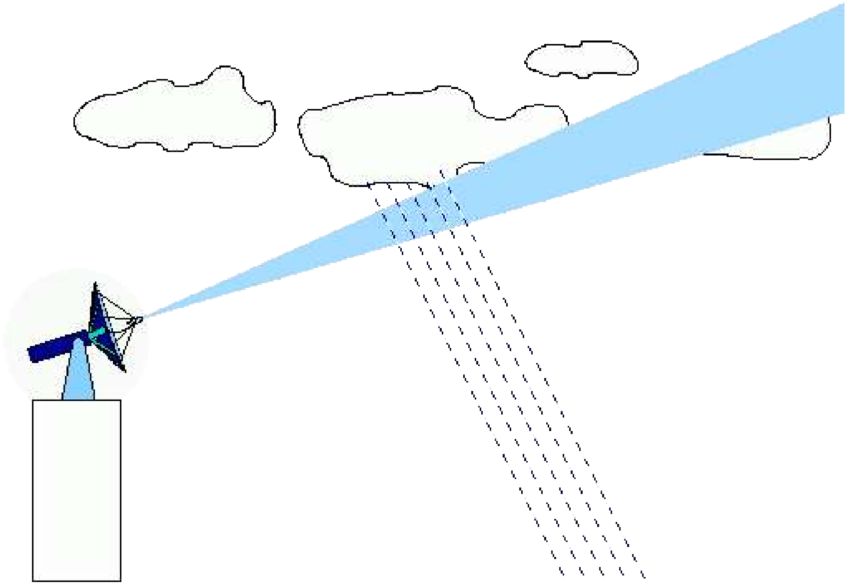
Content

- Introduction – why do we want to use radar data in NWP
- Radar observations, their usage and related problems
    - Wind
    - Reflectivity
    - Refractivity

Introduction

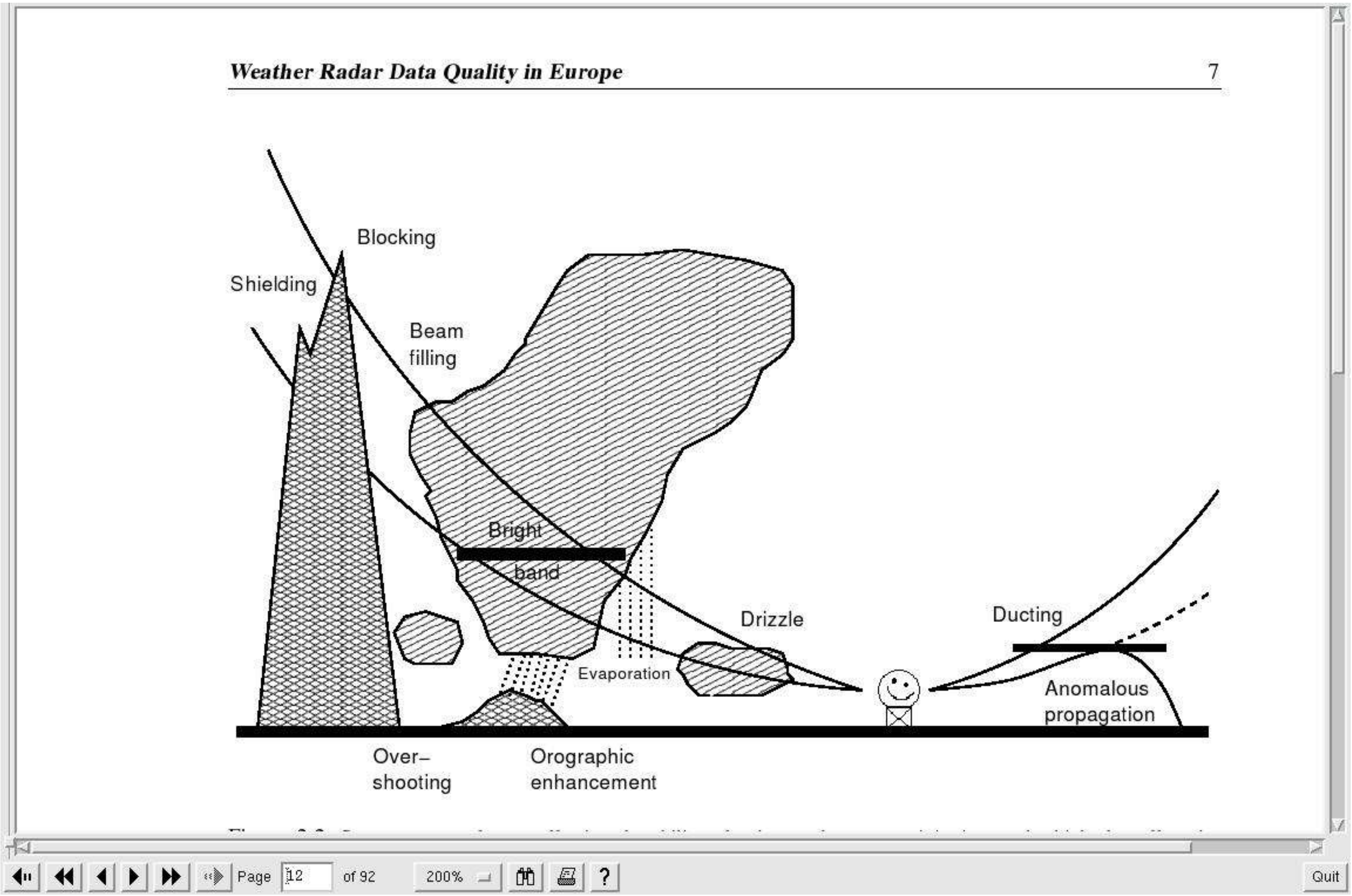
- Radar data have potential for improving NWP model forecasts:
    - In few years operational NWP models will be run with resolutions of order 1-5 km.
    - Such high resolution models require high resolution <u>wind</u> and <u>moisture</u> data for initialisation.
    - DA techniques have developed and are now capable to extract information from observations only indirectly related to prognostic variables.

Radar measurement



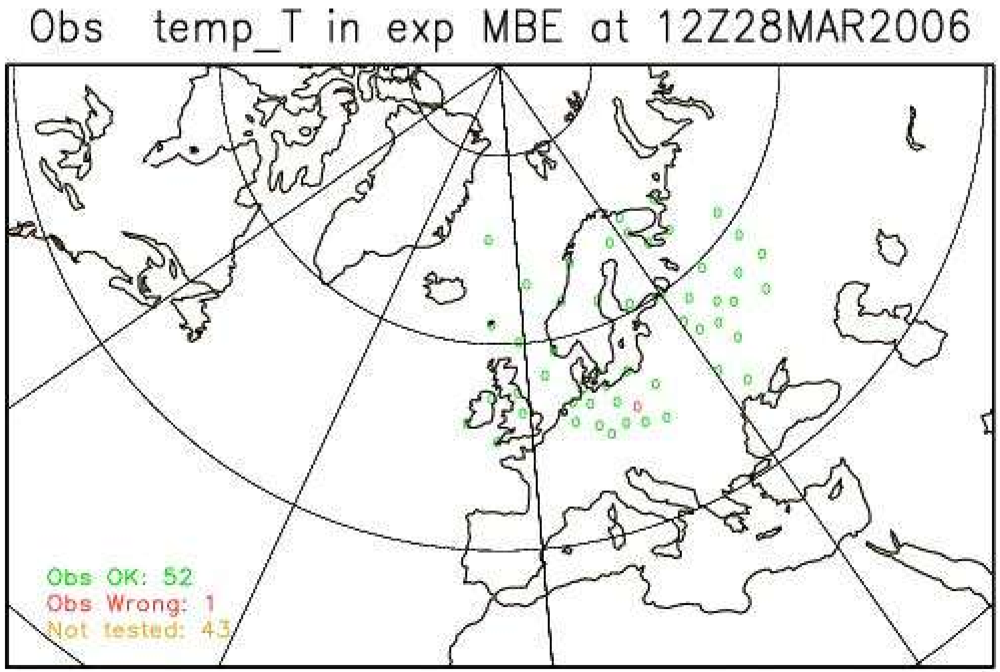
- Doppler radar emits electromagnetic waves to investigate atmospheric properties.
- The amplitude of waves is used to estimate the reflectivity
- The phase of the waves is used to estimate the radar radial wind.
- All radar measurements are volume integrals of atmospheric properties

Error sources



Spatial distribution of observations

Sounding observations

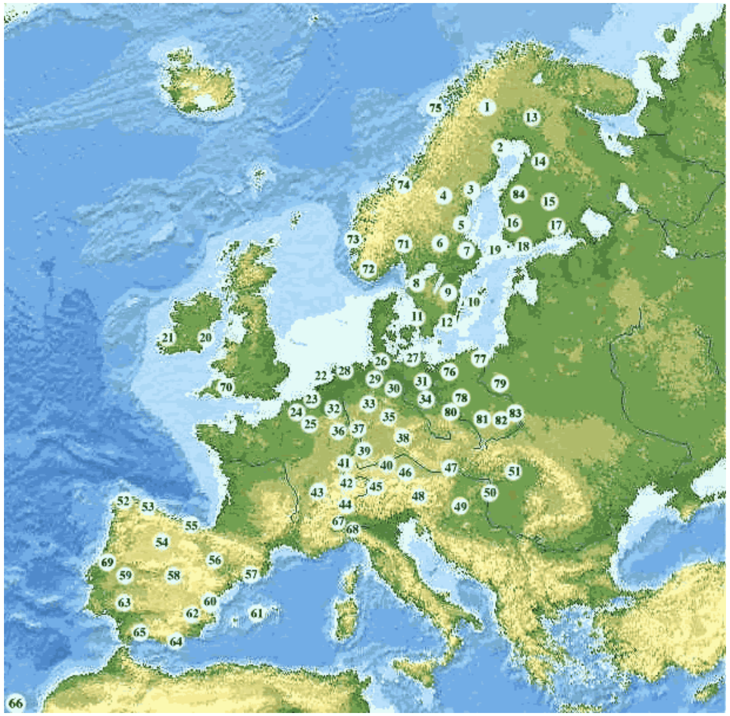


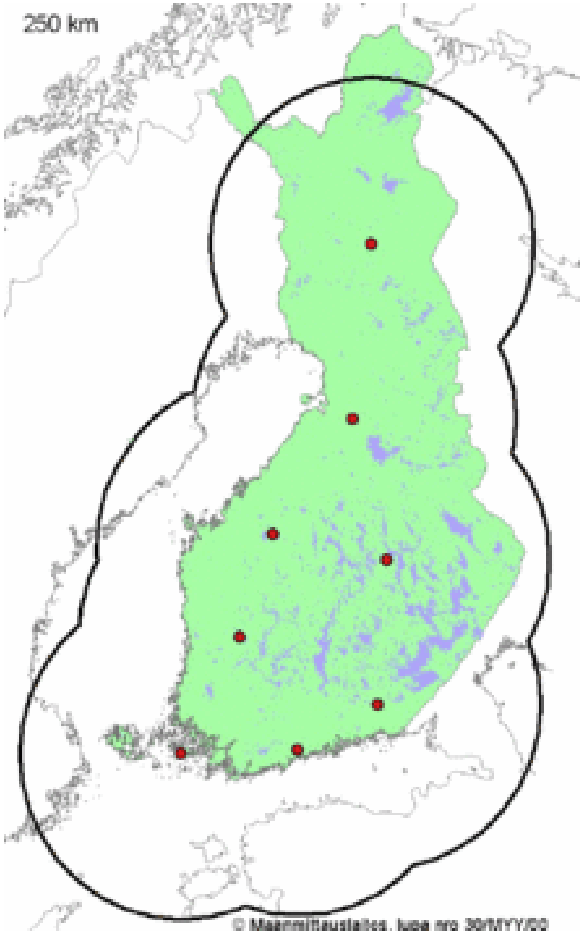
Spatial distribution of observations

Radar network:

spatial resolution: ~1km

time resolution: 5 -15 min





Radar observations

- Radar radial wind component
  - VAD, VVP, superobservations
- Radar reflectivity
  - precipitation
- Refractivity
  - information about atmospheric moisture (+ temperature and pressure)

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Radar radial wind

- The radial velocity is determined from observed phase difference between successive radar pulses.
- Ambiguity problem:
  1. Maximum unambiguous velocity..... $Vn = PRF \frac{\lambda}{4}$
  2. Relation to maximum unambiguous range.............................. $RnVn = c \frac{\lambda}{8}$
  3. True velocity..................................... $Vtrue = Vm + 2nVn$

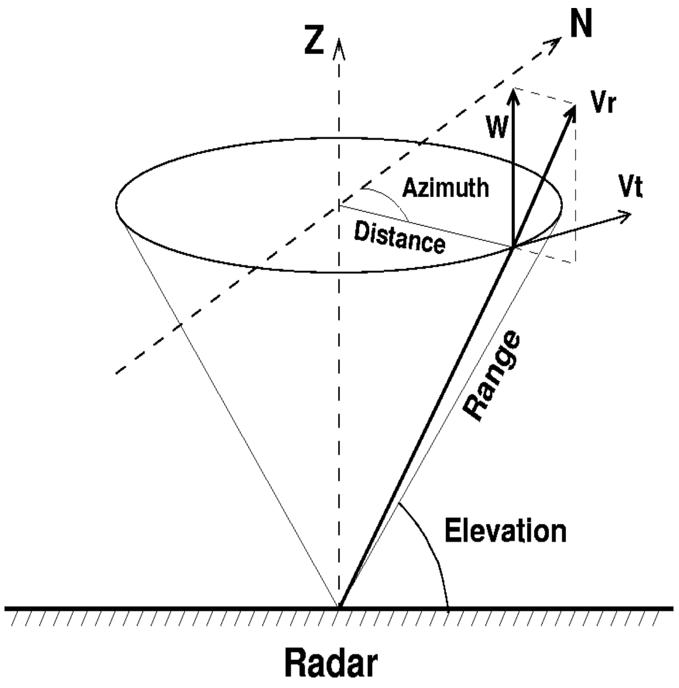
Radar radial wind

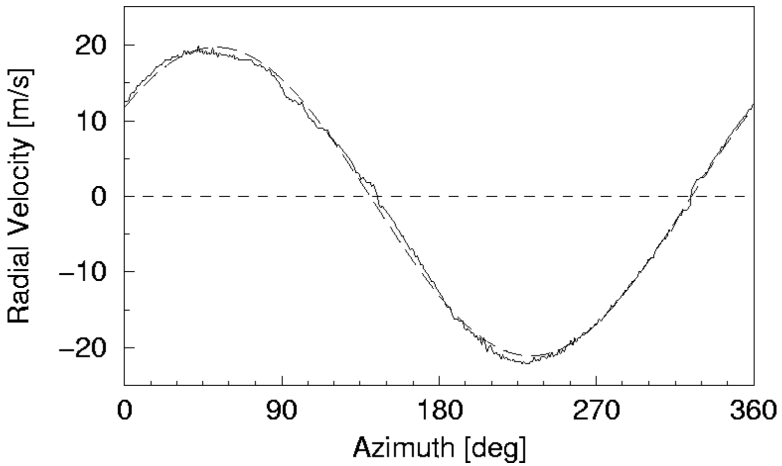
- Two methods to make use of radar radial winds:
  - a) Define u- and v- components of the wind. Simplifying assumptions of the wind field must be made.
  - b) Use an assimilation method where it is possible to use radar radial wind observations directly. Observation is modelled with a so called observation operator.

Wind profiles

- VAD and VVP methods assume linear wind field model.

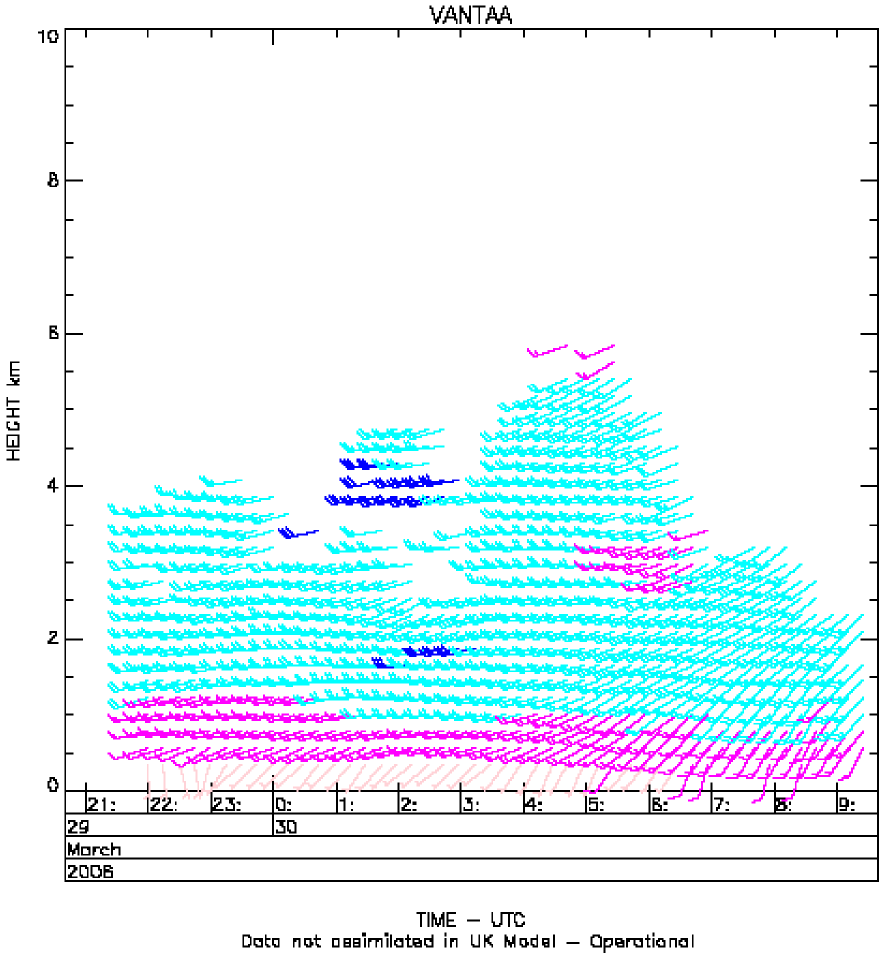
- When radial wind is displayed at constant range and elevation as a function of azimuth angle, it will have a form of sine.





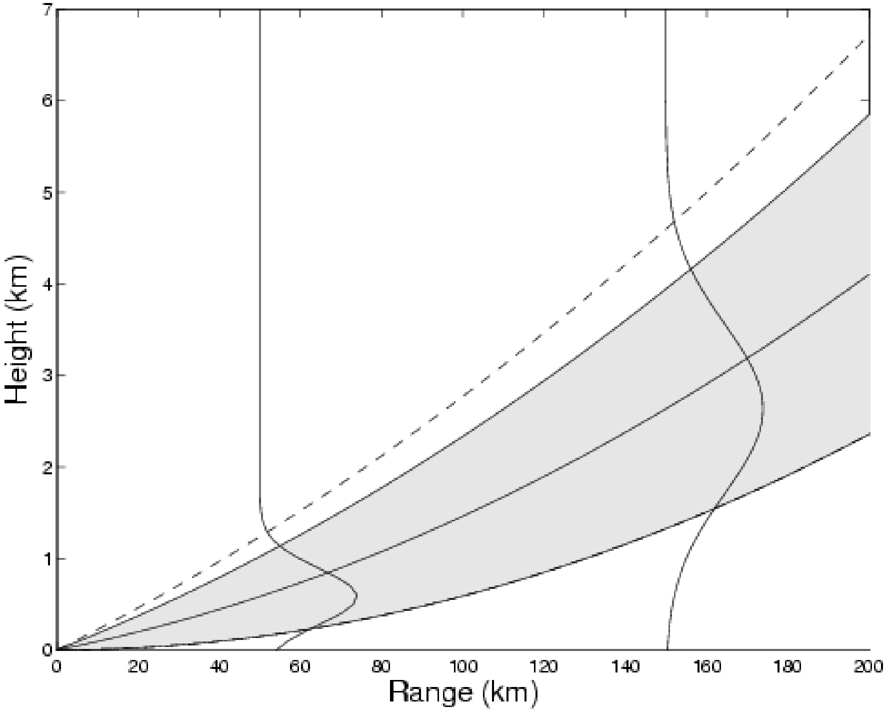
Wind profiles

- With VAD/VVP method from one radar site it is possible to get one vertical profile of horizontal wind.
- Wind profiles are easy to use in all assimilation methods.



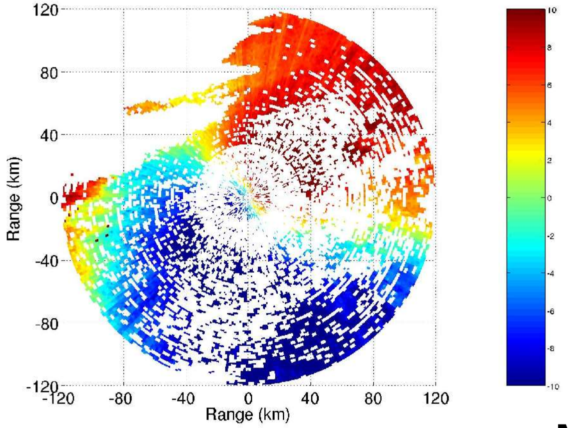
Radar radial wind

- Radar radial wind is not a model variable.
- Variational data assimilation enables use of observations which are not model variables.
- The observation is modelled with a so called observation operator.

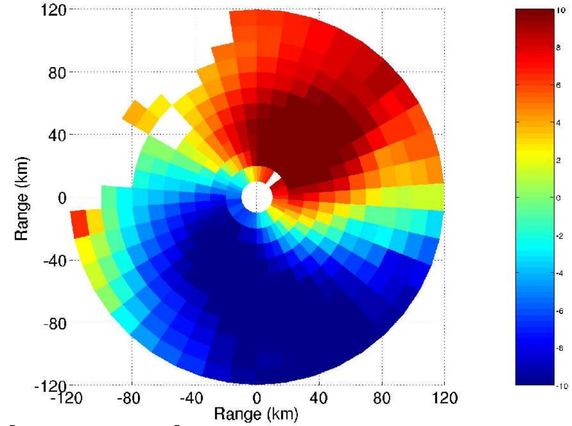


Radar radial wind

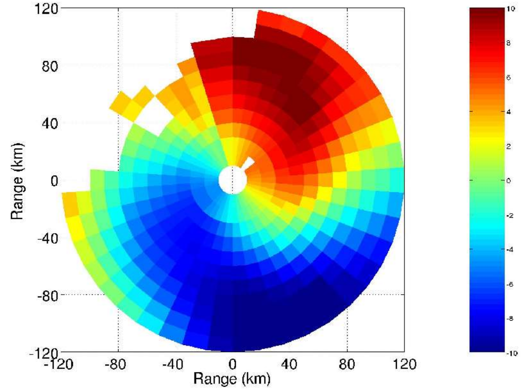
Raw observations



Superobservations



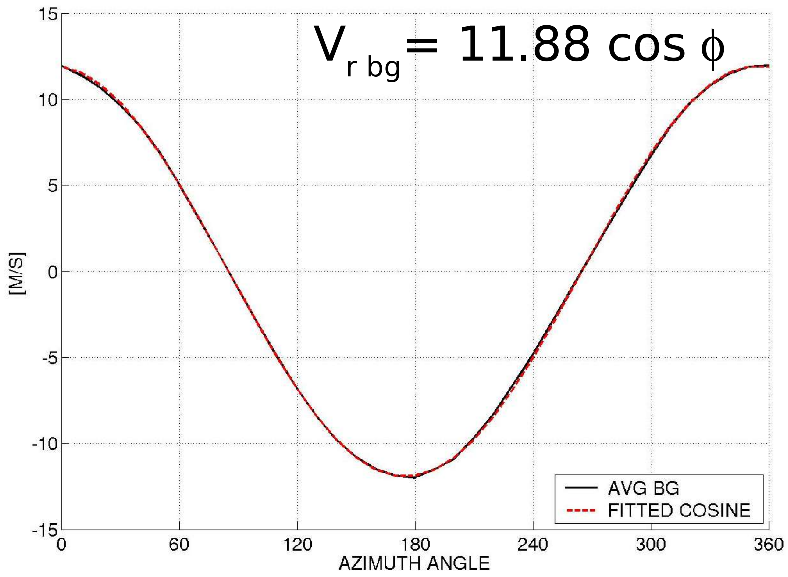
Model counterpart



Average V_r and fitted cosine

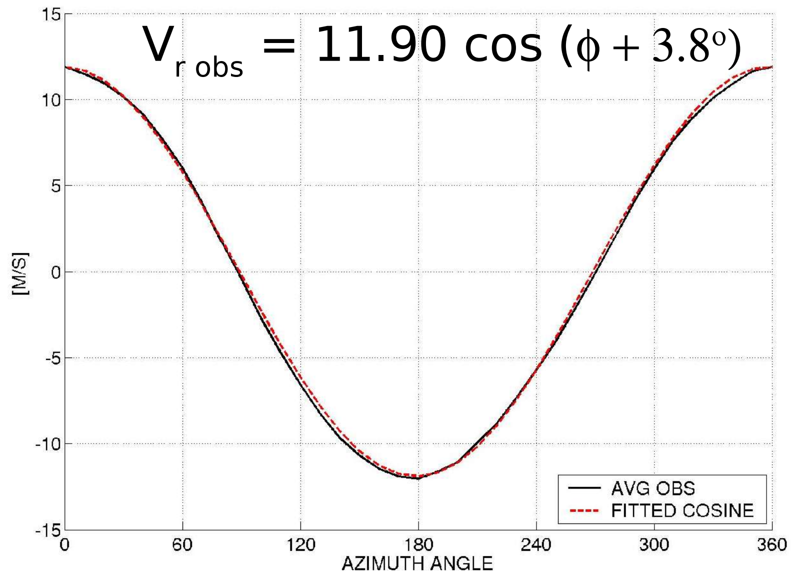
Model Bg

$$V_{r\ bg} = 11.88 \cos \phi$$



Observed

$$V_{r\ obs} = 11.90 \cos (\phi + 3.8^{o})$$



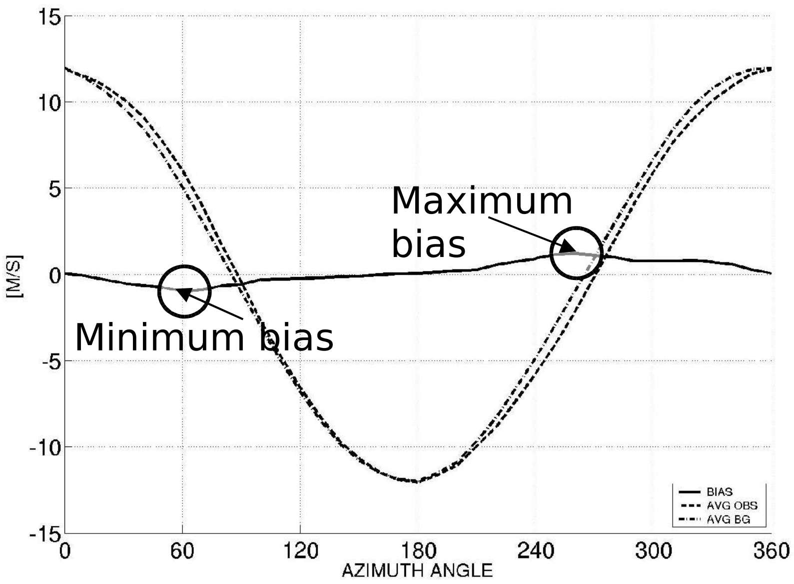
Bias as a function of azimuth angle

- Maximum bias 1.19 m/s
- Minimum bias –0.98 m/s

- Bias estimated from the fitted cos-curves:

  Bias in wind speed 0.02 m/s

  Bias in wind direction 3.8°



Radar reflectivity

- Two methods to make use of radar reflectivity:
    - a) Define precipitation with Z-R-relation.
    - b) Use assimilation method which can make use of radar reflectivity directly. Observation is again modelled with a so called observation operator.

Radar reflectivity – Radar precipitation

- There is no 'universal' Z-R-relation
  - Marshal-Palmer $Z = 200\ R^{1.6}$
  - Laws and Parsons $Z = 400\ R^{1.4}$
  - Joss and Waldvogel $Z = 300\ R^{1.5}$
- Radar precipitation is commonly assimilated with latent heat nudging (LHN).
- Radar reflectivity can be assimilated directly in variational assimilation framework.

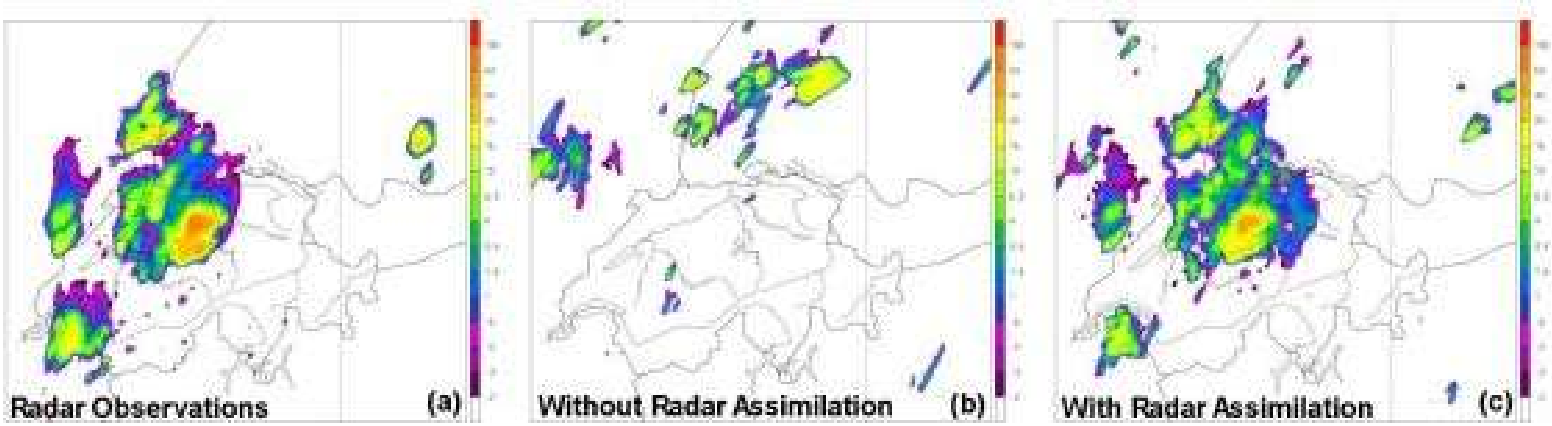
Radar precipitation

- LHN is a method of forcing NWP model towards observed precipitation rates.
- The model's latent heating is corrected at each timestep by amount calculated from the difference between observed and model estimated precipitation.
- Extra heating acts as a source term in the thermodynamic equation, which in turn adjusts the model vertical velocity field and takes the model precipitation rate closer to the observed.

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Radar precipitation

- 1h accumulated rain rates
  - a) Observed by Swiss radar network
  - b) Model simulation with 2.2 km horizontal resolution
  - c) Model simulation where precipitation observed by radars is assimilated with LHN-method.



Figures: D. Leuenberger

Radar reflectivity

- Variational assimilation enables direct use of radar reflectivities.
- Observation operator must take into account:
  - The shape of the radar beam
  - Bending of the radar beam
  - Scattering processes
- Development and testing is ongoing at AROME/ALADIN framework at Meteo France.

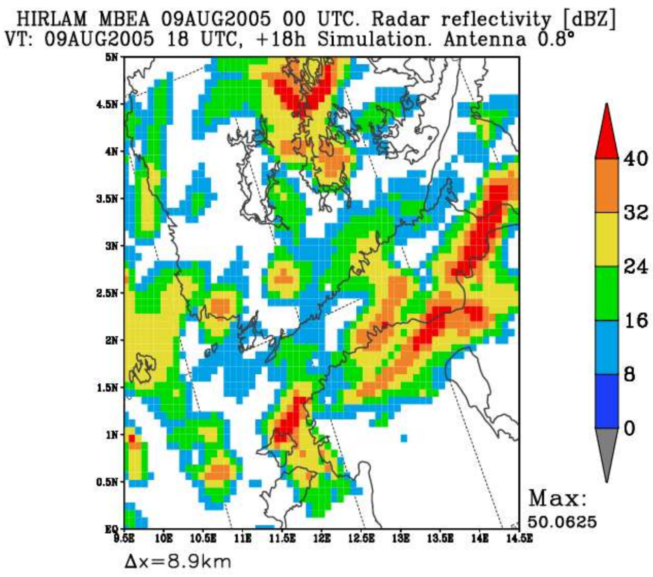
Radar simulation model (RSM)

- Using predicted hydrometeors and state variables from NWP model, the RSM is able to simulate radar reflectivity measurements of any weather radar situated within the model domain.
- The RSM is useful for
  - the validation, and hence improvement of mesoscale models
  - monitoring model forecasts in real time by comparing simulated radar images to real ones
  - estimating some of the errors related to the retrieval of the surface rain rate from radar reflectivity measurements.

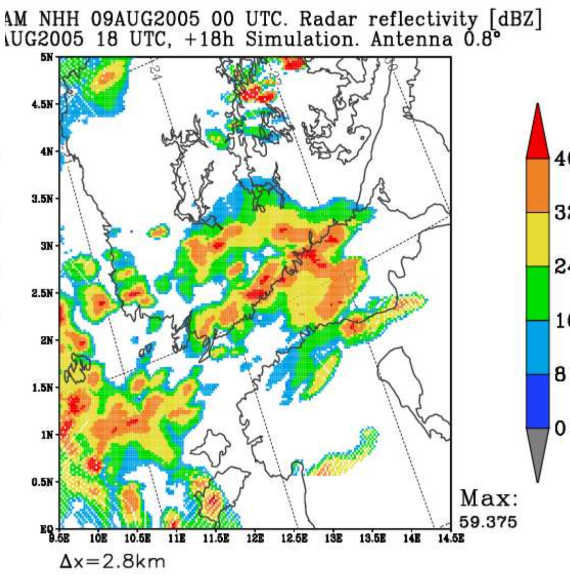
Radar simulation model

Applied in model validation

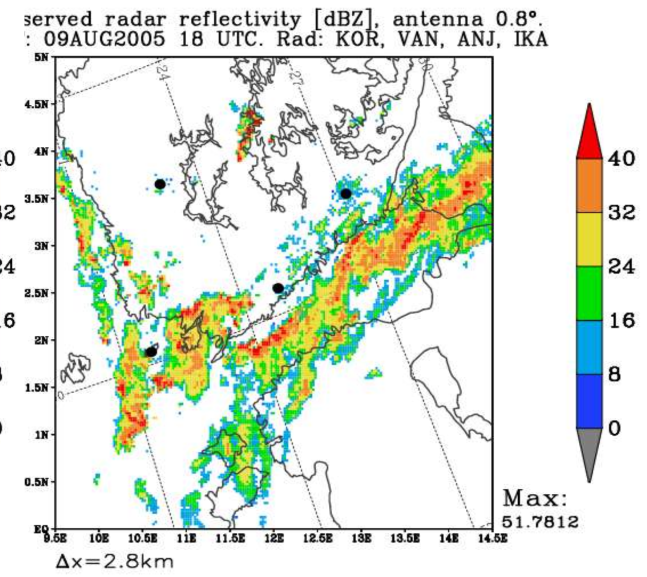
HIRLAM 9 km



HIRLAM 3 km



Observed radar reflectivity



Figures: S. Niemelä

Refractivity *N*

- Refraction index has traditionally been seen as a quantity whose unusual vertical structure causes anomalous propagation of radar waves.
- On the other hand: refraction index is strongly related to atmospheric parameters p, T and q.
- For fixed targets only *n* varies: $t=2r\frac{n}{c}$

Refractivity *N*

- The phase difference to the target's reference phase is related to changes in n:

$$\Delta\Phi = 4\pi f \frac{r}{c} \Delta n$$

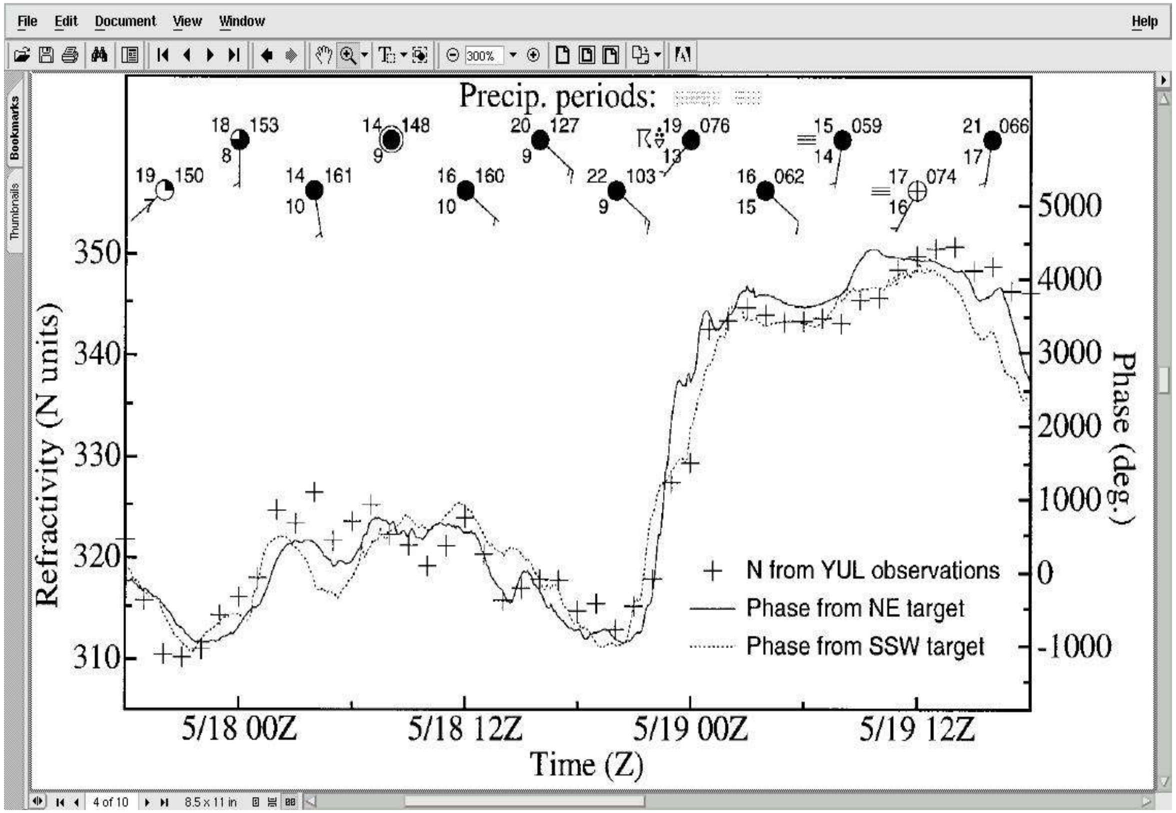
- Refractivity *N* = (*n*-1) x 10^6,

$$N = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2}$$

- At cold temperatures *N* is mostly a funcion of *T*. As the *T* increases, *N* becomes more sensitive to changes in moisture than in temperature.

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

Refractivity *N*



Time evolution of the phase of two targets (solid and dotted line) contrasted with refractivity computed from observations (crosses)

Figure: Fabry et al, 1997

ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

More information:

Alberoni et al, 2003: Quality and assimilation of radar data for NWP. *http://www.smhi.se/cost717/*

Lindskog et al, 2004: Doppler radar wind data assimilation with HIRLAM 3DVAR. MWR **5**, 1081-1092.

Caumont et al, 2005: Towards 1D+3D assimilation of radar reflectivities: ongoing results. *http://ams.confex.com/ams/32Rad11Meso/techprogram/paper_96522.htm*

Fabry et al, 1997: On the extraction of near surface index of refraction using radar phase measurements from ground targets. J. Atmos. Oceanic Technol., **14**, 978-987.