Doppler Wind profiler uncertainty in a turbulent atmosphere

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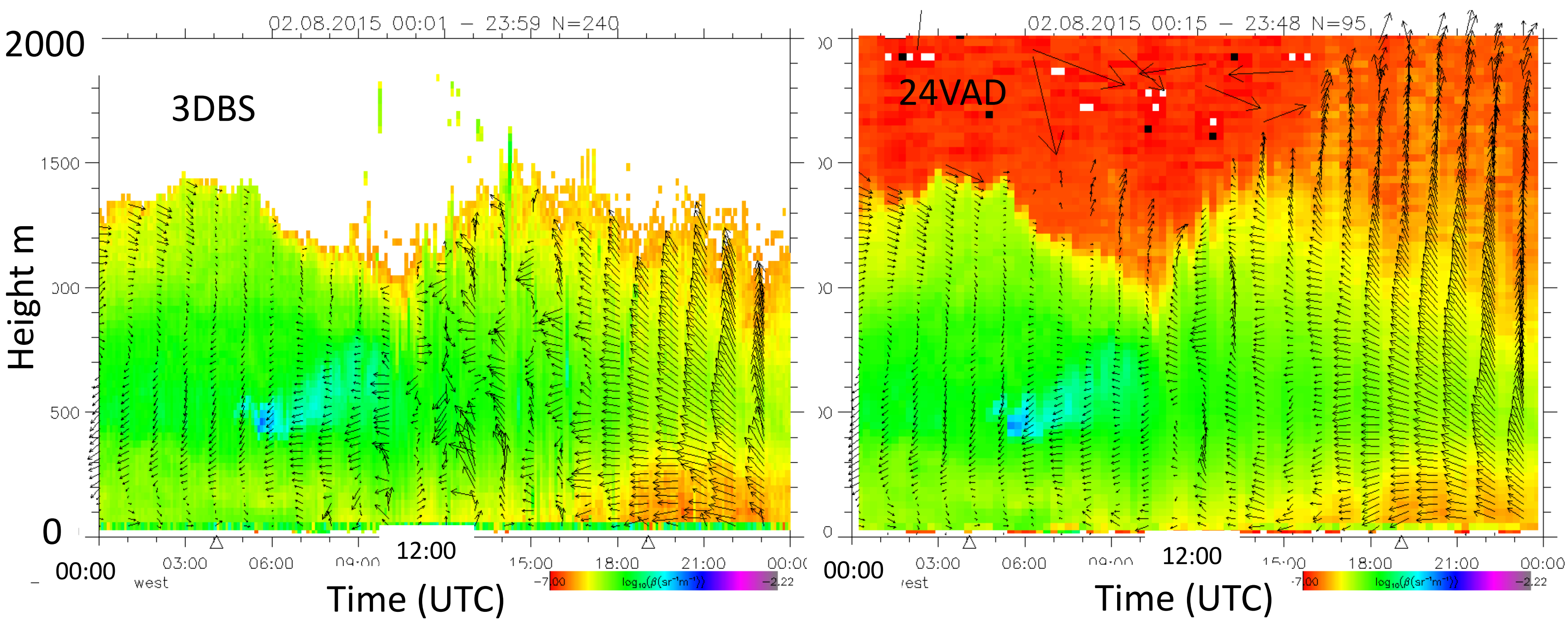
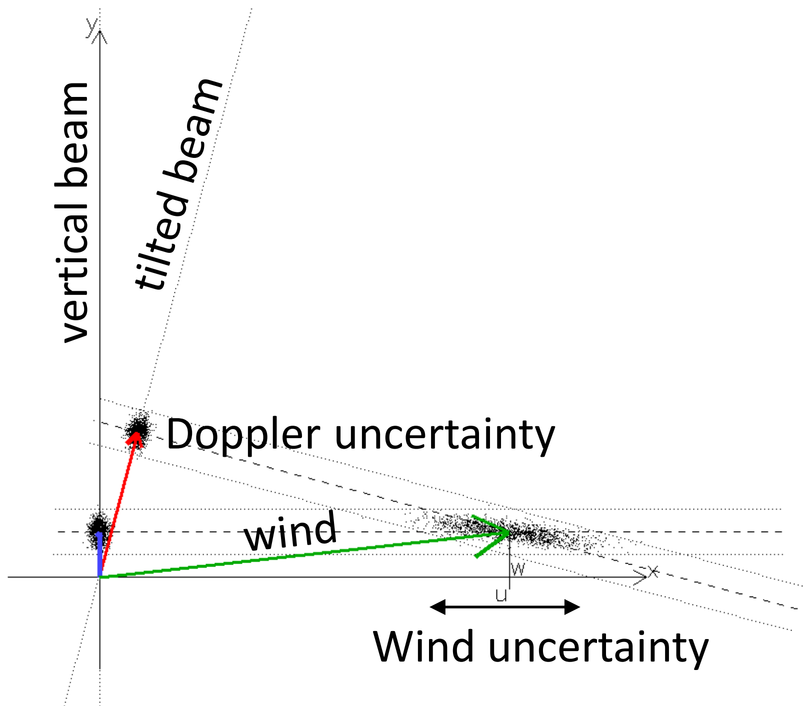
Motivation

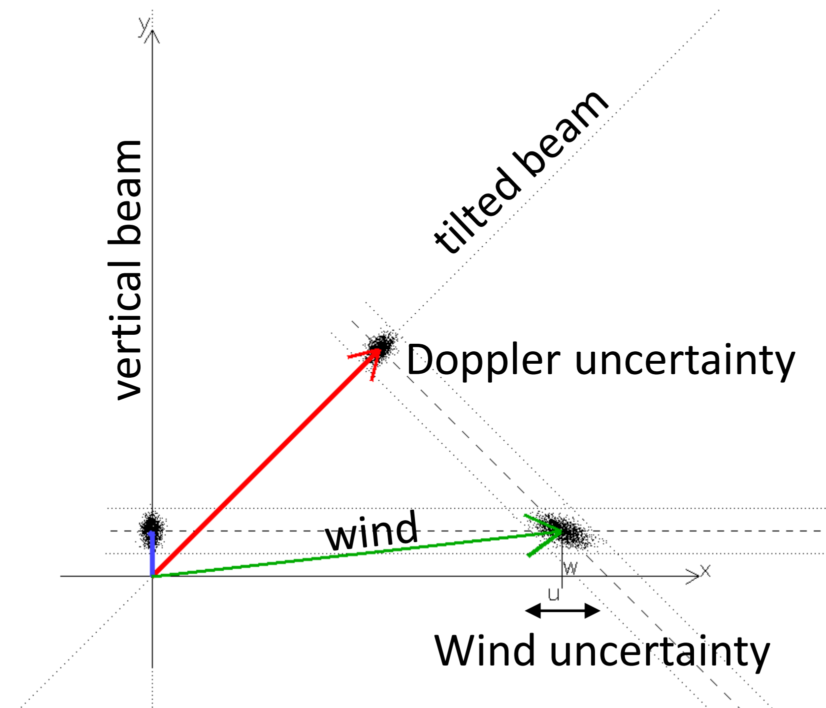
- More and more Doppler wind profiler available (radar, sodar, lidar) -> e-prof
- providing wind data to assimilation requires uncertainty estimates
- Current uncertainty estimate consider only Doppler uncertainty – not turbulence



Motivation: large tilt

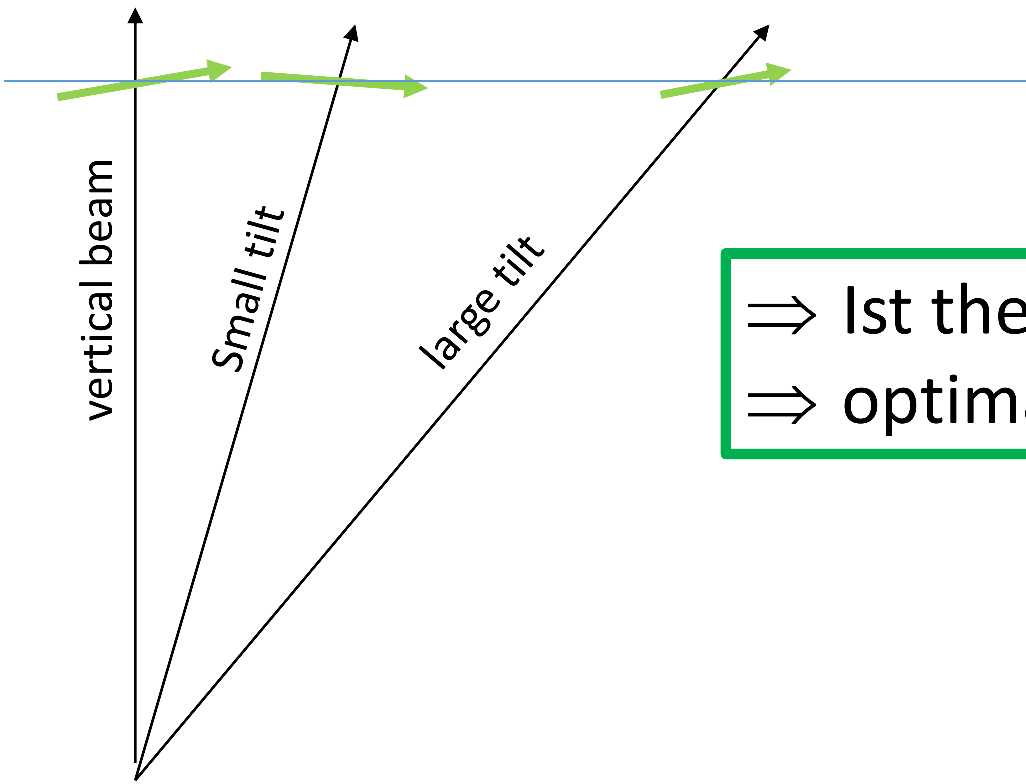
- To get horizontal wind component beams must be tilted
- The larger the tilt the smaller the uncertainty
- => tilt should be large !





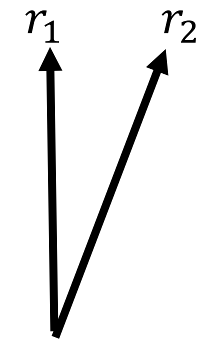
Motivation: small tilt

- Large tilt => large separation => different wind
- Tilt should be small !



$\Rightarrow$ Ist there an optimum tilt ?
$\Rightarrow$ optimal scan ?

Two beams + turbulence



- One vertical and one tilted beam
- Differences in wind speeds due to separation
- Gaussian error propagation
- Separation introduces auto- and cross-covariances between *u*,*u and u,w* etc. at the two locations of the vertical beam (r_1) and the tilted beam (r_2) :
  - If there is upwind at r_1 there might be also upwind at r_2
    =>$C_{ww}(r_1, r_2) \;=\; \overline{w'_{r1} w_{r2}{}'} / \overline{w'^{2}_{r1}}$
  - If there is upwind at r_1 horizontal wind speed at r_1 might be lower
    =>$C_{uw}(r_1, r_2) = \overline{u'_{r1} w'_{r2}} / \overline{u'_{r1} w'_{r1}}$
  - …

assumptions

homogeneity of the turbulent field

=> ... $\overline{u'^2_{s1}} = \overline{u'^2_{s0}} = \overline{u'^2}$ and $\overline{u'_{s1}w'_{s1}} = \overline{u'_{s0}w'_{s0}} = \overline{u'w'}$

- horizontal **isotropy for form** of C_{uu}, C_{uw} etc.
  => depend only on scalar distance

- All normalized auto- and cross-covariances are the **same**:

$$C_{uu}(r) = C_{uw}(r) = C(r)$$

- Especially the last is a very strong assumption.
  But we believe deviations are small enough
  to allow for the use in this *uncertainty estimate*

Two beams: equation

- Equation for one vertical one tilted beam

$$\left(\frac{\Delta u_{rs}}{\sigma_w}\right)^2 = \underbrace{\frac{1}{s_\theta^2}}_{\text{Geometry}} \cdot 2\underbrace{\left[1 - C(r_{01})\right]}_{\text{separation}} \cdot \underbrace{\left(s_\theta^2 \cdot \frac{\overline{u'^2}}{\sigma_w^2} + 2 s_\theta c_\theta \cdot \frac{\overline{u'w'}}{\sigma_w^2} + c_\theta^2\right)}_{\text{Effect of (co-)variances}}$$

$s_\theta = \sin\theta, c_\theta = \cos\ \theta$

- Similar equations can be derived for any arbitrary scan pattern

Two Beams:

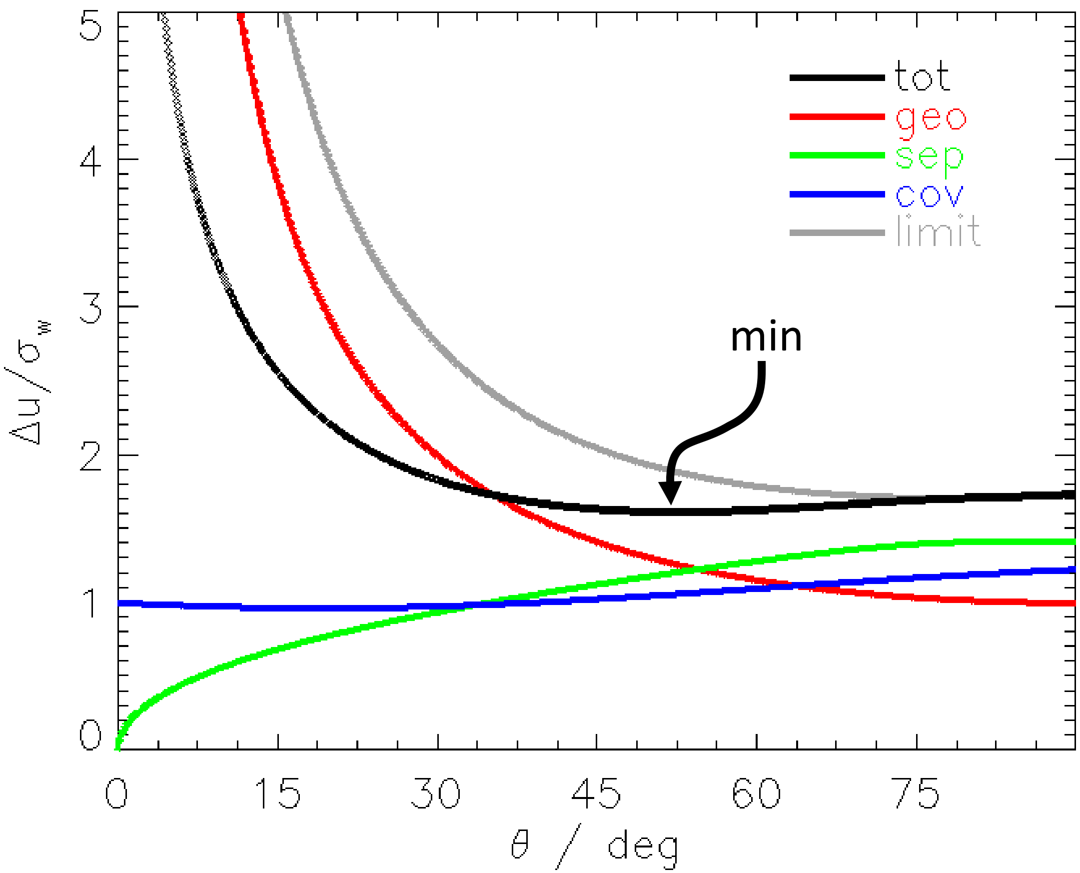
- $C(r)$=exp(-r/L)
  $r = z \cdot \tan\theta$, $z = L$ = 300m,
  uu/σ^2_w=1.2, uw/σ^2_w=-0.2

➢ geometry factor dominates

➢ Efect of (co-)variances is small => we do not need to know *uw* etc. exactly

➢ Weak Minimum at ~50deg

➢ uncertainty of 2-tilted beams is smaller than 1tilt+1vertical



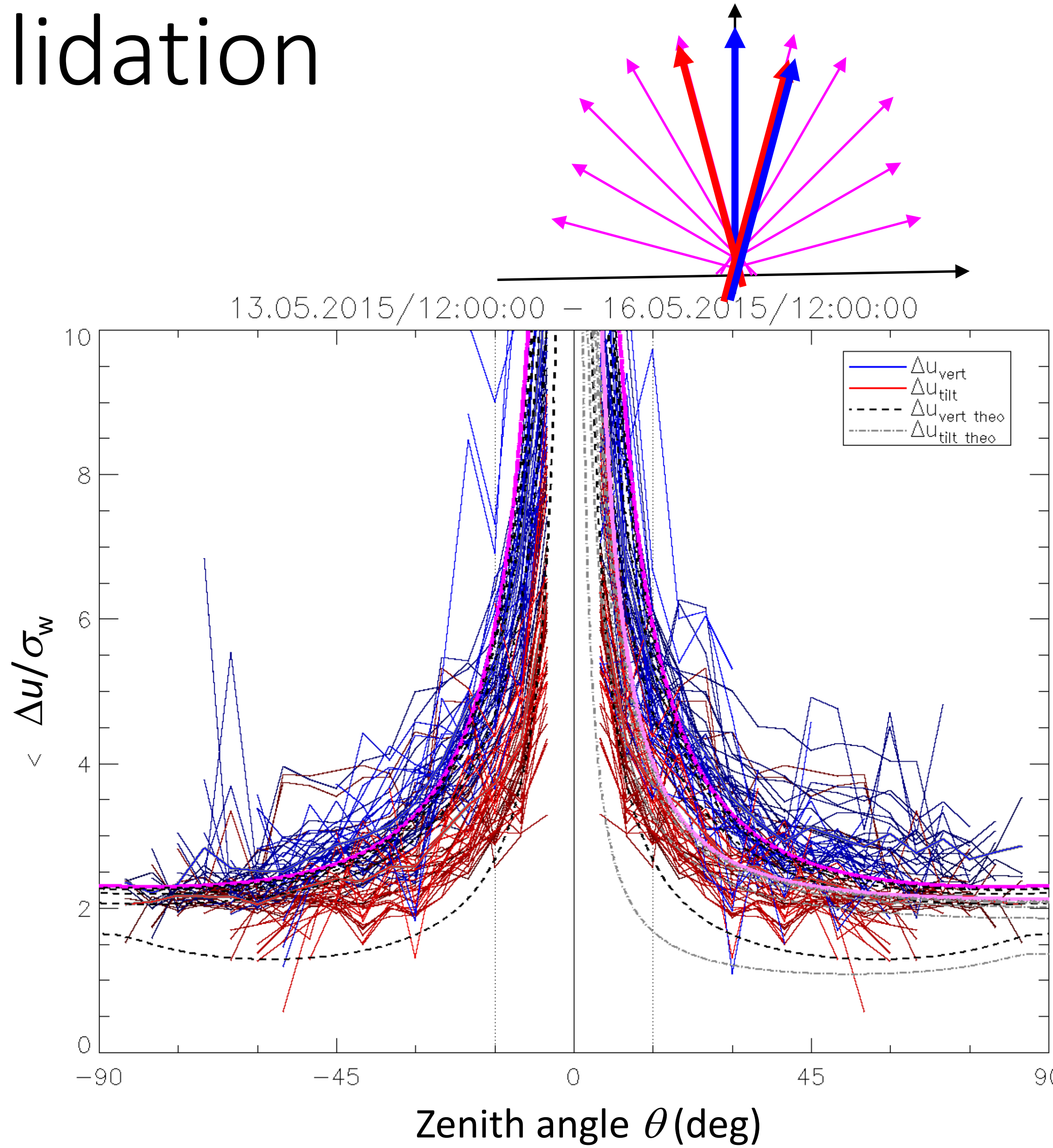
Two Beams: Validation

- RHI-> two beams
  - 1 tilted 1 vertical
  - 2 tilted
  - As a $f(\theta, z)$
  - Difference to VAD-36
  - RMSE over 4days

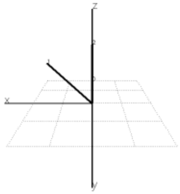
➢ Principal form con-firmed with very large errors at zenith and decay towards low elevations

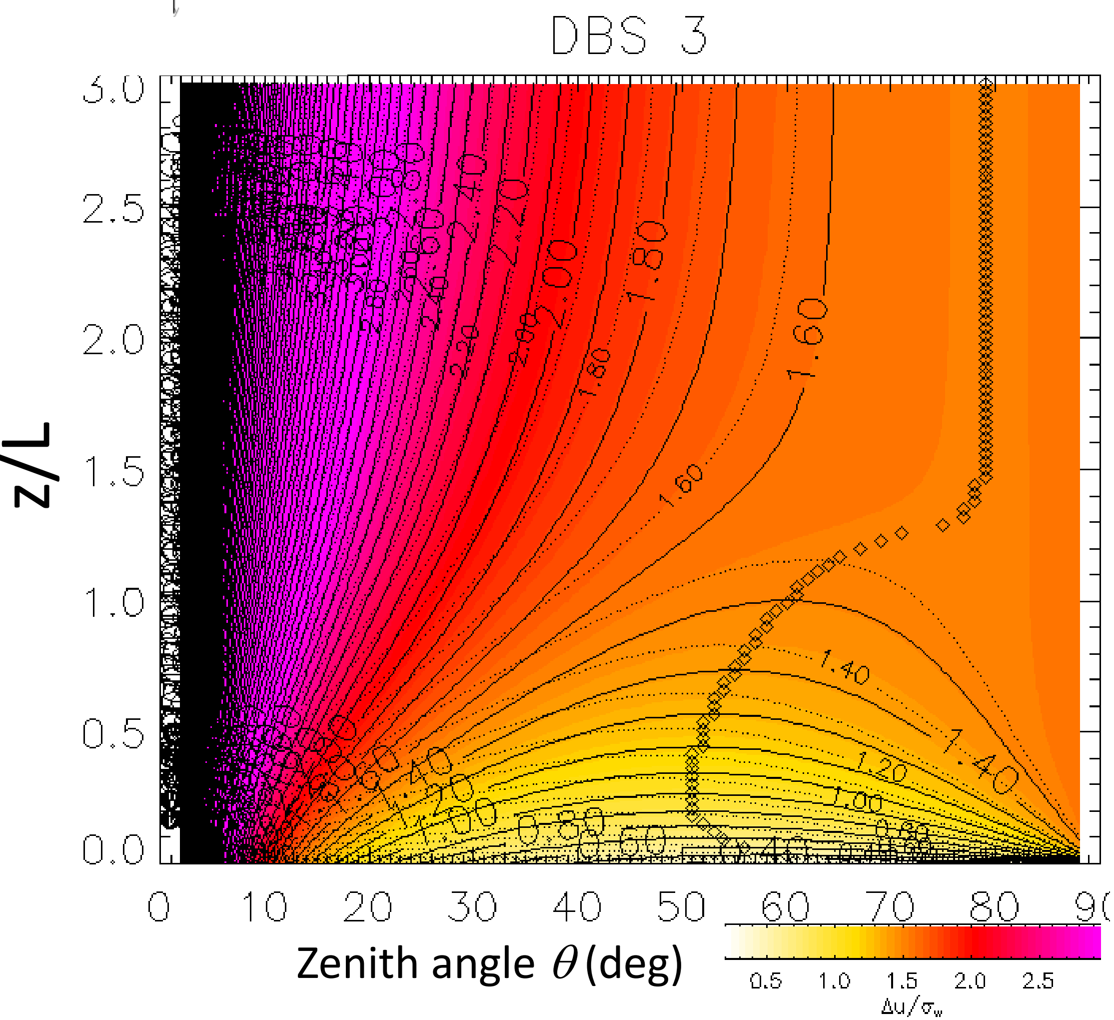
➢ 2 tilted is better than 1tilted

➢ asymmetry for 1tilted beam => inhomogeneity



Many beams: 3 DBS





$\Delta u/\sigma_w$

- With $\Delta D/\sigma_w$=0.25 (Color shading and solid lines)
- No Doppler uncty. (ΔD=0, dotted)
- Elevation of minimum (symbol)

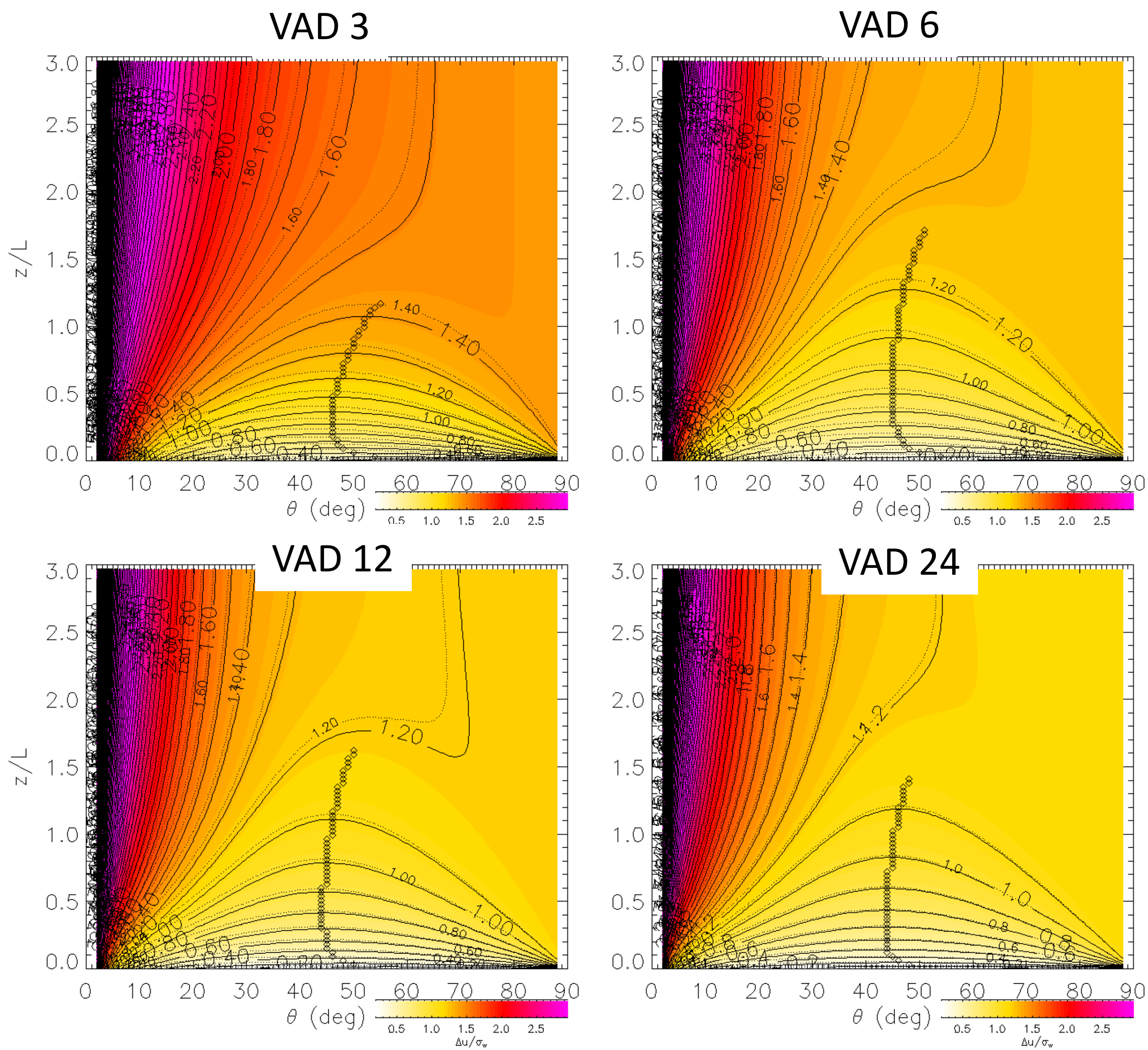
➢ Doppler uncertainty plays only minor role

➢ Minimum at zenith angles around 55deg

➢ But minimum is weak

Many beams: ...

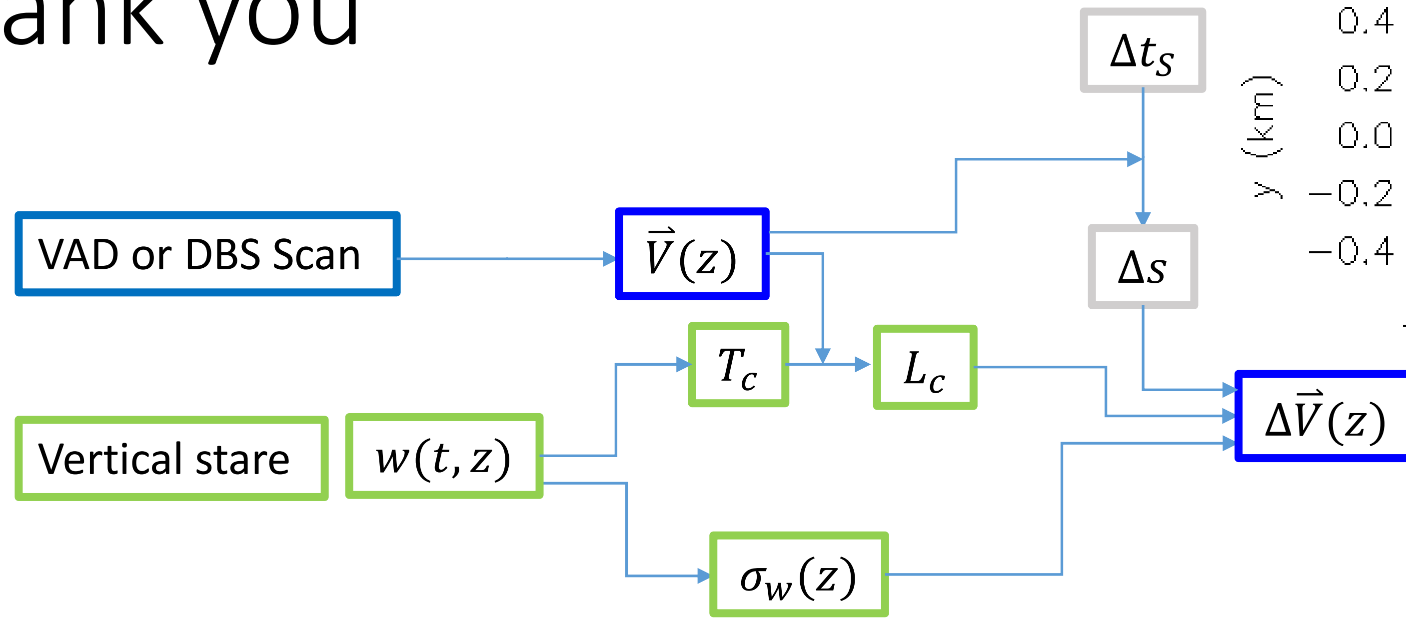
- Increasing the number of beams reduces uncertainty but follows not $1/\sqrt{N}$ law
- Minimum remains at +/- the same place and stays weak
- Larger zenith angle decreases uncty. but effect diminishes above ~30deg.

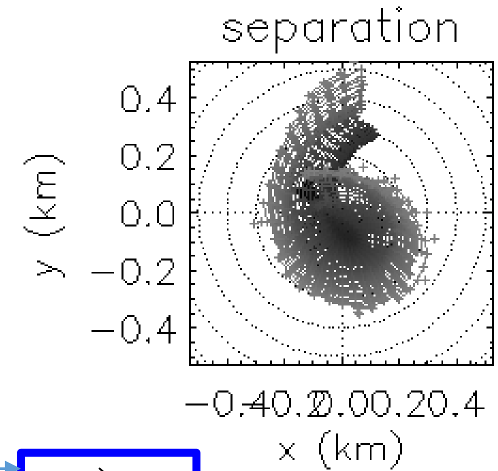


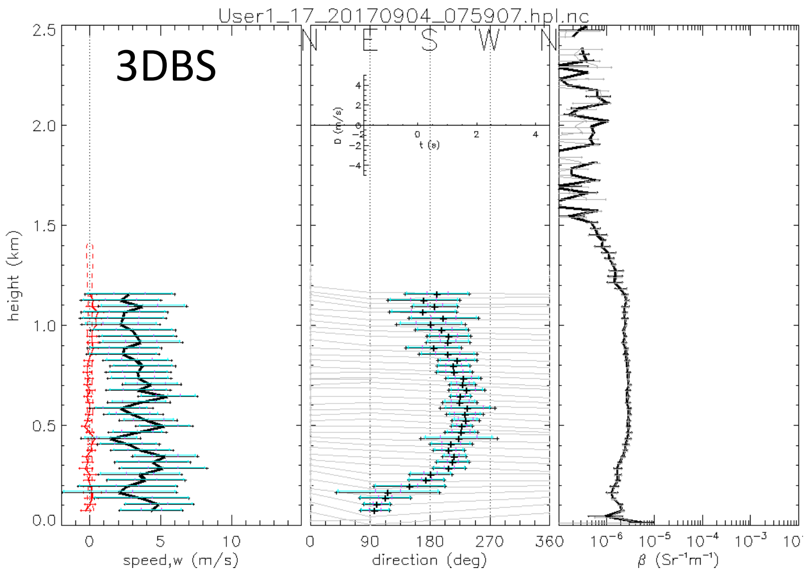
Conclusions

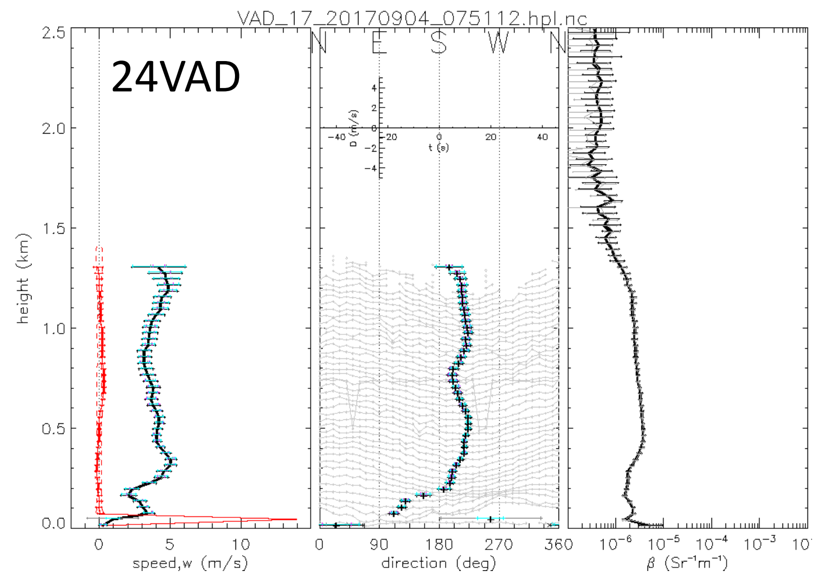
- Uncertrainty estimate requires knowledge of
  - covariance matrix of the wind,
  - spatial auto- and cross-correlations of the wind components
  - we solved this with simplifiactions/assumptions
- DBS-3 scan has larger uncertainty than VAD-3
- More beams decrease uncertainty
  - but effect is less than $1/\sqrt{N}$ law and
  - diminishes with increasing N
  - gain for N>12 is minimal
- Uncertainty decreases with increasing zenith angles
  - effect is for θ>30^o small
  - there is a weak minimum around 55deg at low heights.

Thank you









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