‘Optimizing’ WindScanner’s turbulence measurements

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Risø wind energy colloquium 2018
DTU, Lyngby, Denmark

April 6, 2018

RECAS
Reduced Assessment Time

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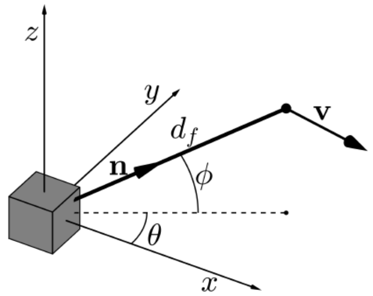
Scanning lidar



$$v_r(\phi, \theta, d_f) = \boldsymbol{n}(\phi, \theta) \cdot \boldsymbol{v}\left[\boldsymbol{n}(\phi, \theta) d_f\right]$$

$$\boldsymbol{n}(\phi, \theta) = (\cos\theta\cos\phi, \sin\theta\cos\phi, \sin\phi)$$

$$\tilde{v}_r(\phi, \theta, d_f) = \int_{-\infty}^{\infty} \varphi(s) \boldsymbol{n}(\phi, \theta) \cdot \boldsymbol{v}\left[\boldsymbol{n}(\phi, \theta)(d_f + s)\right] ds$$

Scanning lidar turbulence

$$
\begin{aligned}
\sigma^2\left[v_r(\phi,\theta,d_f)\right] &= \left\langle \left[\boldsymbol{n}(\phi,\theta)\cdot \boldsymbol{v}'\left(\boldsymbol{n}(\phi,\theta)d_f\right)\right]^2\right\rangle \\
&= \sigma_u^2\cos^2\theta\cos^2\phi + \sigma_v^2\sin^2\theta\cos^2\phi + \sigma_w^2\sin^2\phi \\
&\quad +2\langle u'v'\rangle\cos^2\phi\cos\theta\sin\theta \\
&\quad +2\langle u'w'\rangle\cos\theta\cos\phi\sin\phi \\
&\quad +2\langle v'w'\rangle\sin\theta\cos\phi\sin\phi
\end{aligned}
$$

Assuming $\langle u'v'\rangle = \langle v'w'\rangle = 0$, we only need 4 lidars

$$
\begin{bmatrix} \sigma^2_{v_{r_1}} \\ \sigma^2_{v_{r_2}} \\ \sigma^2_{v_{r_3}} \\ \sigma^2_{v_{r_4}} \end{bmatrix}
=
\underbrace{\begin{bmatrix}
\cos^2\theta_1\cos^2\phi_1 & \sin^2\theta_1\cos^2\phi_1 & \sin^2\phi_1 & \cos\theta_1\cos\phi_1\sin\phi_1 \\
\cos^2\theta_2\cos^2\phi_2 & \sin^2\theta_2\cos^2\phi_2 & \sin^2\phi_2 & \cos\theta_2\cos\phi_2\sin\phi_2 \\
\cos^2\theta_3\cos^2\phi_3 & \sin^2\theta_3\cos^2\phi_3 & \sin^2\phi_3 & \cos\theta_3\cos\phi_3\sin\phi_3 \\
\cos^2\theta_4\cos^2\phi_4 & \sin^2\theta_4\cos^2\phi_4 & \sin^2\phi_4 & \cos\theta_4\cos\phi_4\sin\phi_4
\end{bmatrix}}_{\mathbf{M}}
\begin{bmatrix} \sigma_u^2 \\ \sigma_v^2 \\ \sigma_w^2 \\ 2\langle u'w'\rangle \end{bmatrix}
$$

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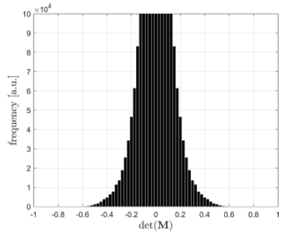
Optimizing the scanning strategy

- Sathe et al. (2014) formulate an objective function for minimizing the random errors of the estimated velocity variances and optimize the objective function
- Here we look at the singularity of $\mathbf{M}$ for different combinations of θs and ϕs for $\min(\phi) = 10$ deg for 3 lidars and assuming 1 lidar at $\theta = 0$ deg and $\phi = 90$ deg



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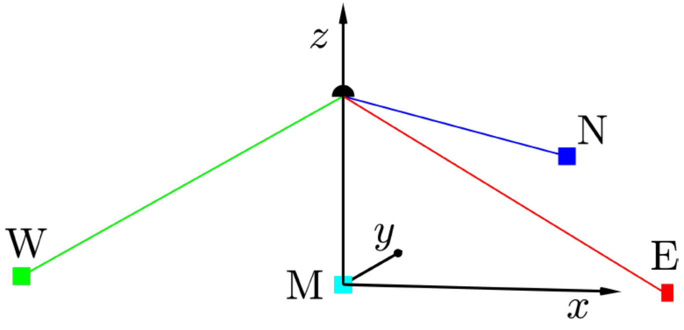
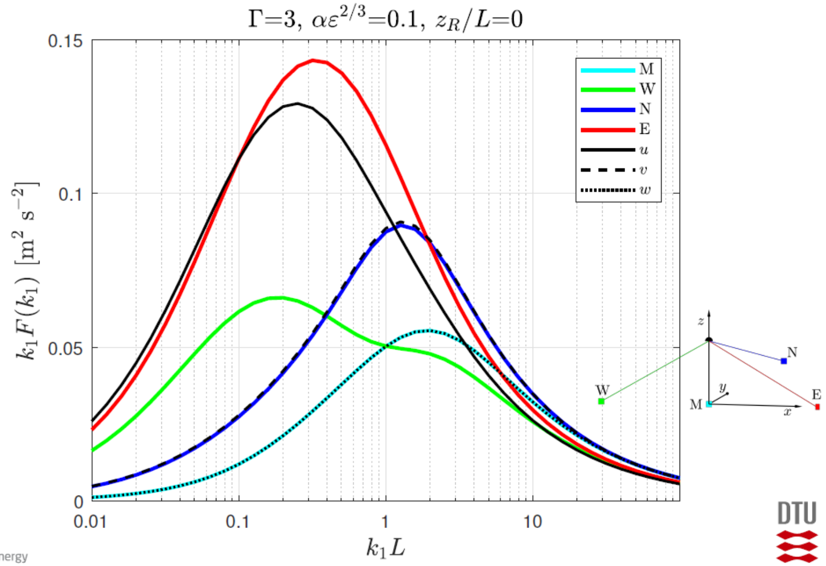
Optimized scanning strategy



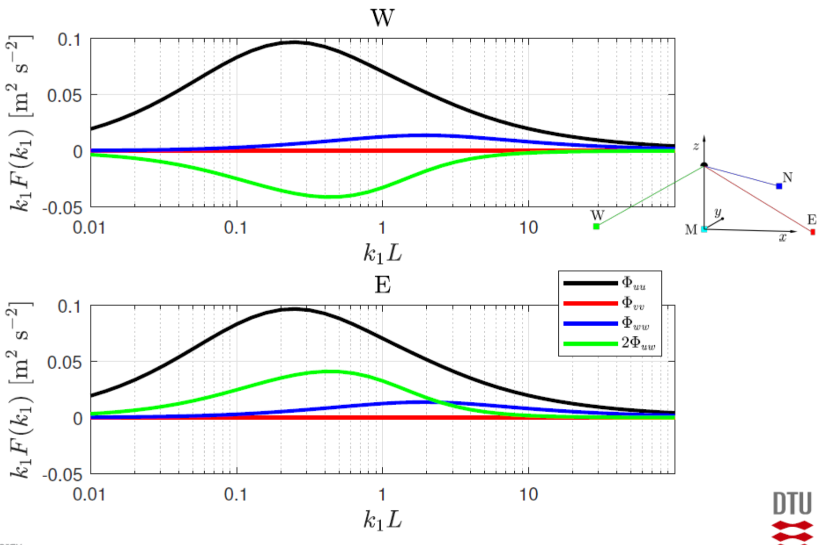
$$F_{v_r}(k_1) = n_i n_j \iint |\hat{\varphi}(\boldsymbol{k}\cdot\boldsymbol{n})|^2 \, \Phi_{ij}(\boldsymbol{k}) dk_2 dk_3$$

$$F_{ij}(k_1) = \iint \Phi_{ij}(\boldsymbol{k}) dk_2 dk_3$$

Optimized spectra and variance check



Optimized spectra components – W and E lidars



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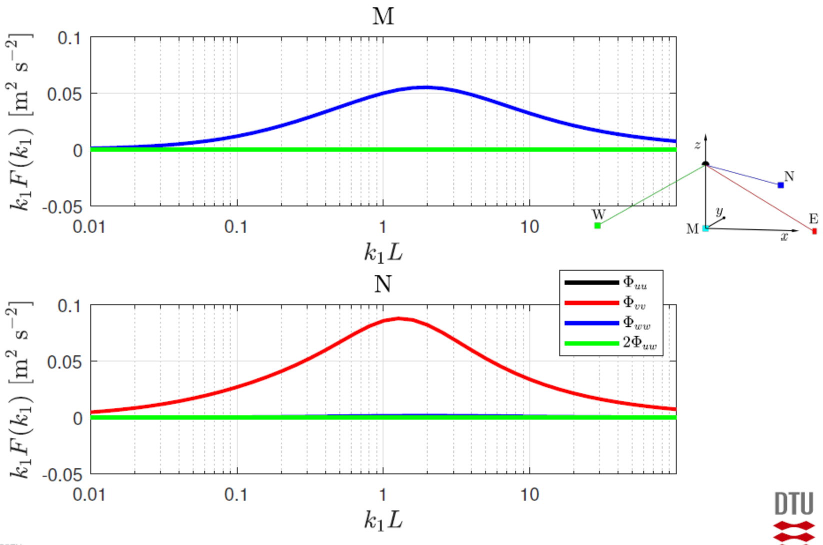
Optimized spectra components – M and N lidars



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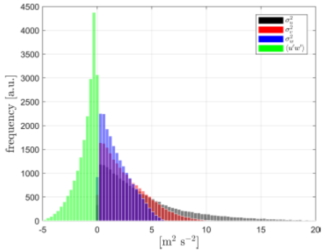
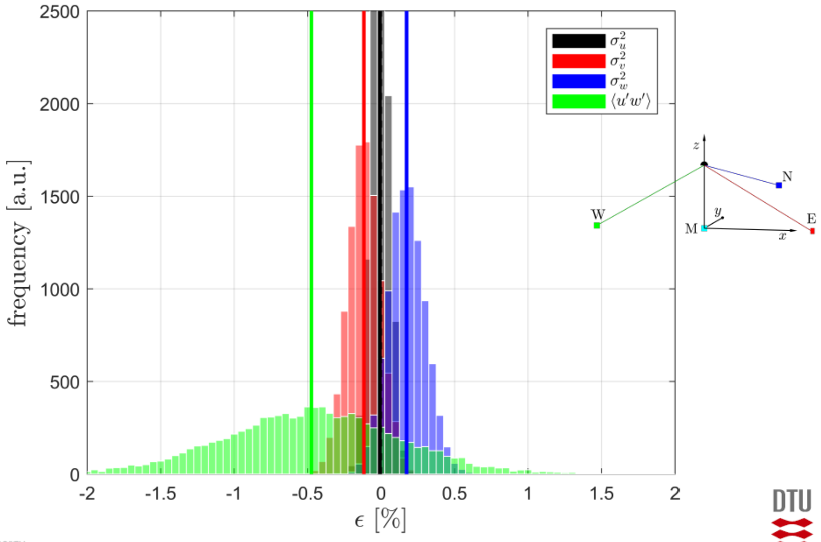
Relative error of a given pattern

- simulate variances for a range of turbulence conditions

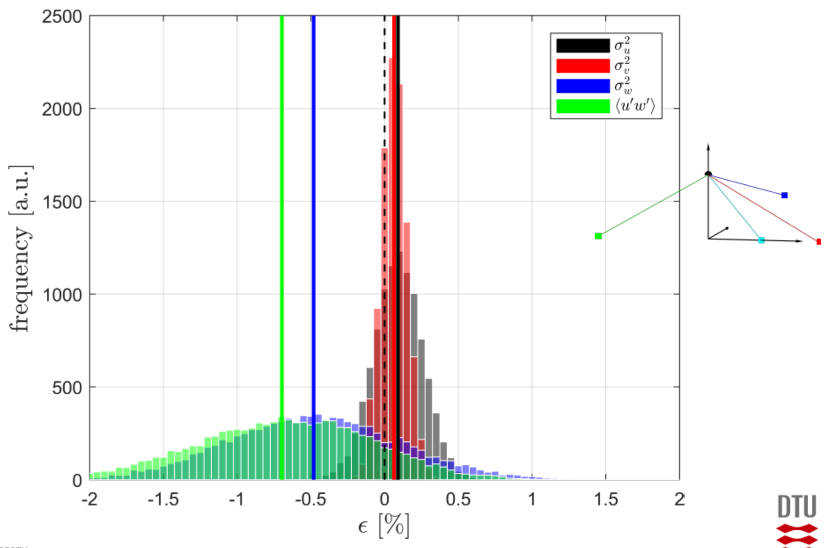


- compute the lidars' radial velocity variances and add random 'error' (mimic observations)
- solve the linear system, i.e., estimate the variances
- bootstrap the difference (simulated vs estimated)

Relative error of the optimized pattern



Relative error of another pattern



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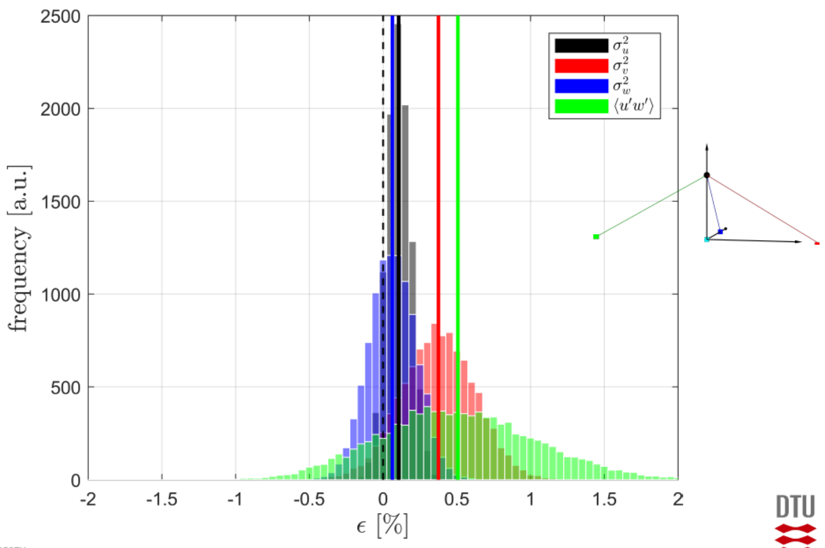
Relative error of yet another pattern



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Thank you for the attention!

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