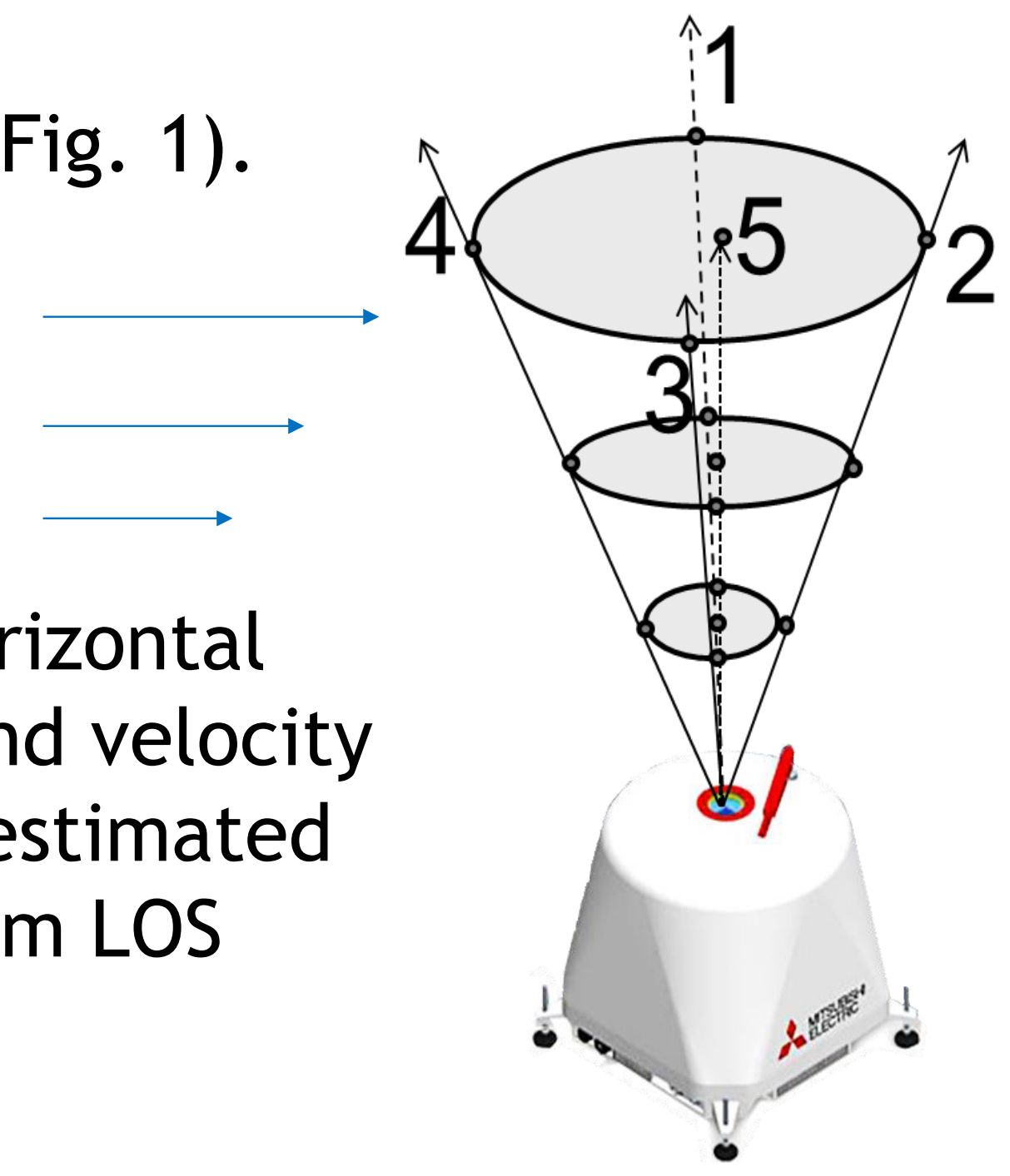
Improving LiDAR performance on a complex terrain using CFD-based correction and direct-adjoint-loop optimization

S Nabi[1], P Grover[1], R Matai[1], Y Kajiyama[3], N Kotake[3], S Kameyama[3], W Yoshiki[3], N Nishio[2,4] and M Iida[2]
[1]Mitsubishi Electric Research Laboratories, Cambridge, USA. [2]University of Tokyo, Tokyo, Japan.
[3]Mitsubishi Electric Corporation, Ofuna, Japan, [4]Electric Power Development Co., Ltd., Tokyo, Japan.

Introduction

- Wind-LiDAR is used for assessment of horizontal wind velocity. In order to do so, it is assumed that the flow remains homogeneous over the sampled volume at a given height (Fig. 1).
- LiDAR performance is excellent on flat terrains [1] but becomes poor on complex terrain.
- The objective is to improve the accuracy of horizontal wind measurement compared to anemometers
- The objective is to present a post-processing algorithm that uses CFD and adjoint optimization [2] tools to reduce such errors in flow retrieval.



Horizontal wind velocity is estimated from LOS

Fig 1. 5 beams Line-of-sight (LOS) velocity

Correction method

- The error is due to the variation of vertical velocity, w (Fig. 2).
- The components u,v, of un-biased velocity at each height z are [3]

$$u = u_L - z\frac{dw}{dx} \qquad v = v_L - z\frac{dw}{dy}$$

u_L, v_L: homogenous velocity components

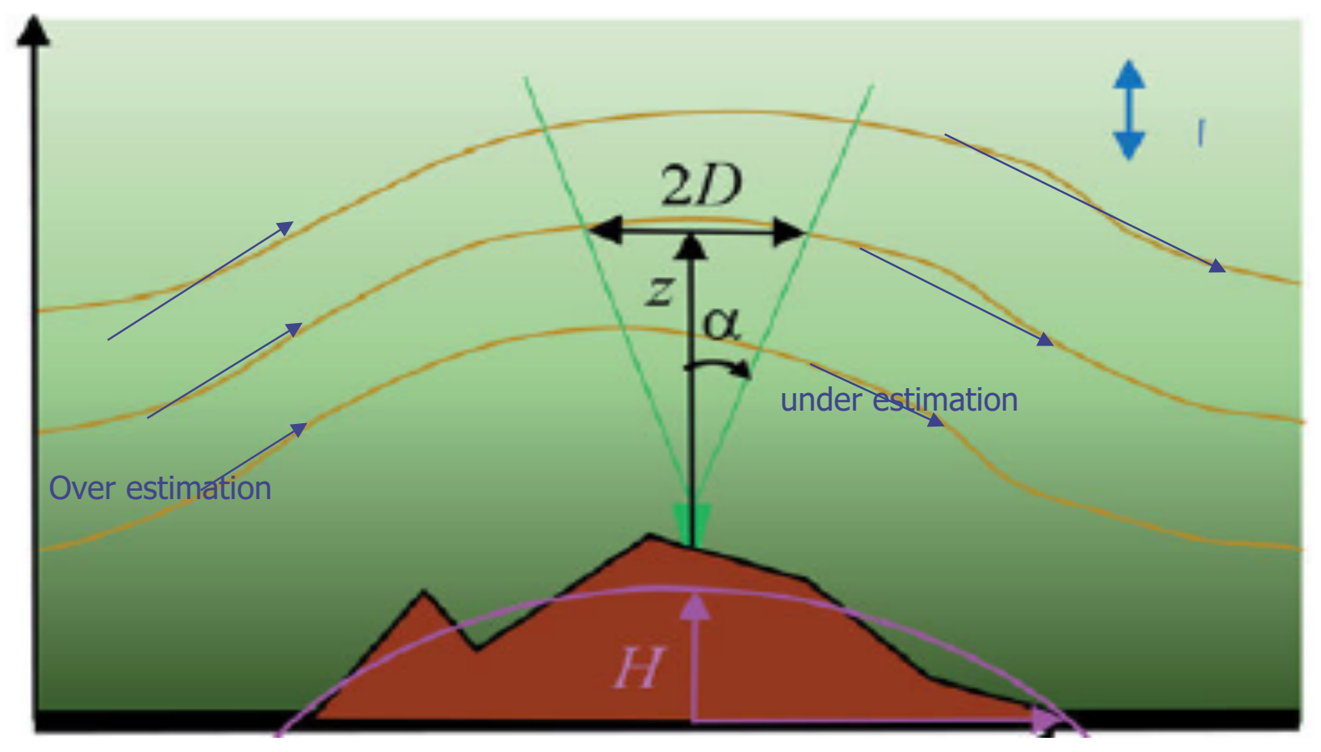


Fig 2. Wind on complex terrain

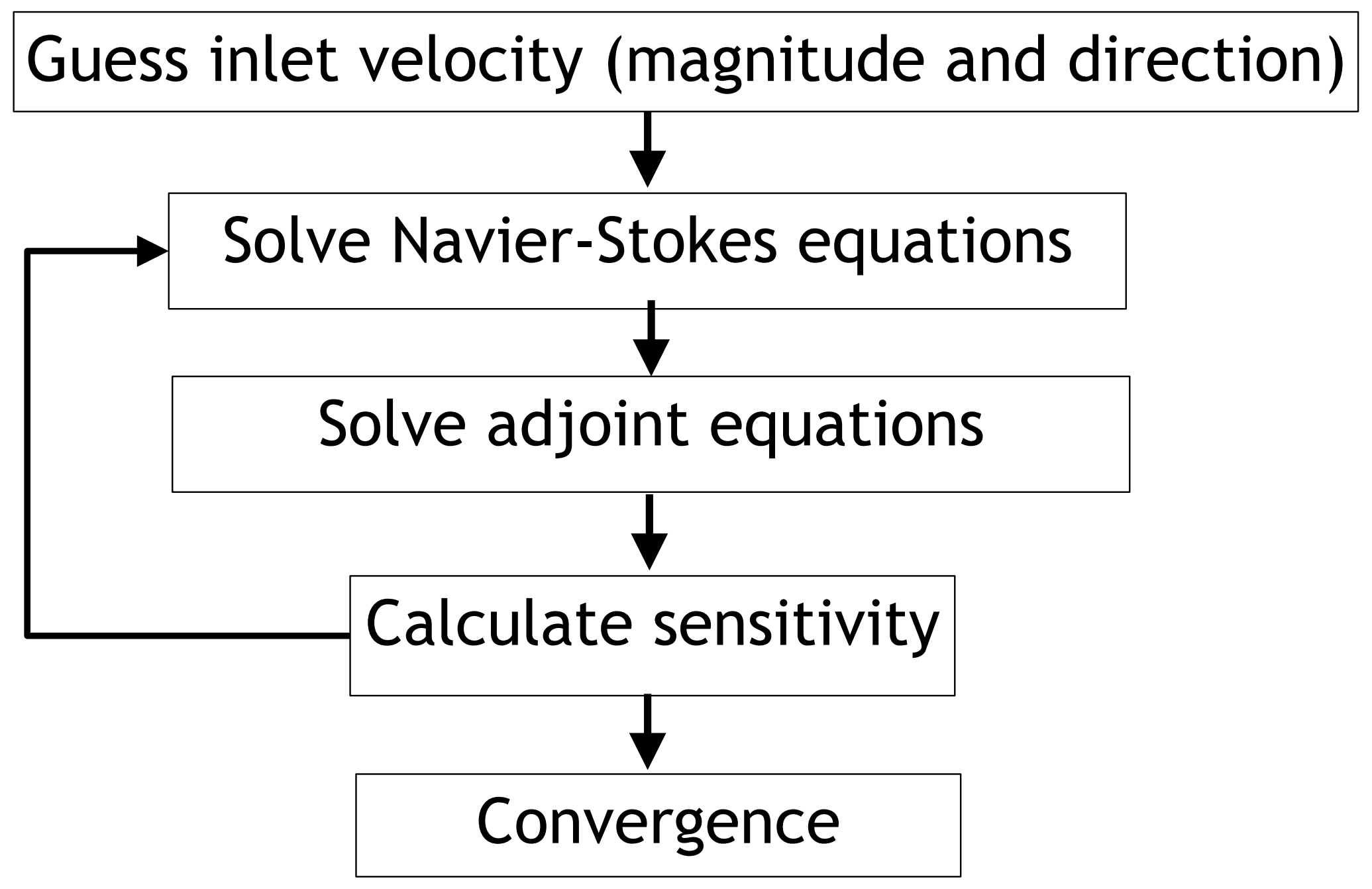
- The inhomogeneity of the vertical component of the wind speed can be simulated by the CFD software OpenFOAM.
- Challenge: there are various unknown parameters for CFD simulation, e.g. inlet velocity profile
- Optimize unknown parameters in CFD models based on LOS data measured by LiDAR (Fig. 3)
- From optimal CFD models we extract horizontal wind velocity
- The cost function is defined as

$$\min_{V_{in}} J = \gamma_i \left(LOS - LOS_{CFD}\right)^2$$

Inlet velocity

weightings

- Result of optimization: i) un-biased velocity retrieval, ii) reconstructed velocity field over terrain



Guess inlet velocity (magnitude and direction)

Solve Navier-Stokes equations

Solve adjoint equations

Calculate sensitivity

Convergence

Fig 3. Optimization algorithm to estimate CFD unknowns, e.g. inlet velocity

Results

- Results are shown for a DIABREZZA LiDAR dataset on complex terrain (Fig. 4, 5).
- Complicated terrain as per IEC 61400-1 since the grade exceeds 10 degrees.
- 10 minute averaged data was used for this calculation.

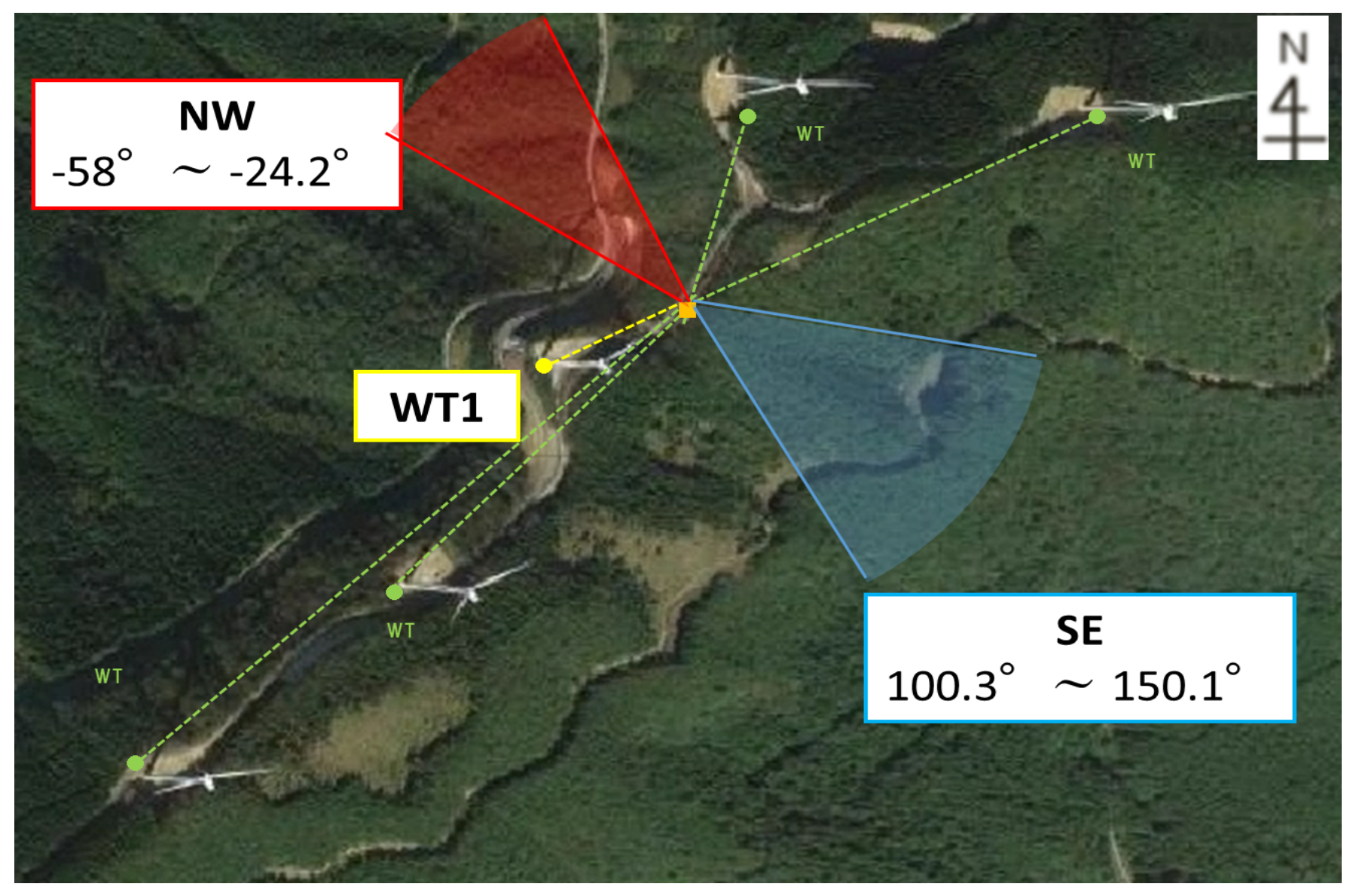


Fig 4. Site map and sector

Fig 5. Photo of DIABREZZA LiDAR

- The slope error in the correlation plot was improved significantly (Fig. 6 and table 1):

Fig 6. red line: 1-1, blue line: before correction (homogenous), black line: after correction with optimization

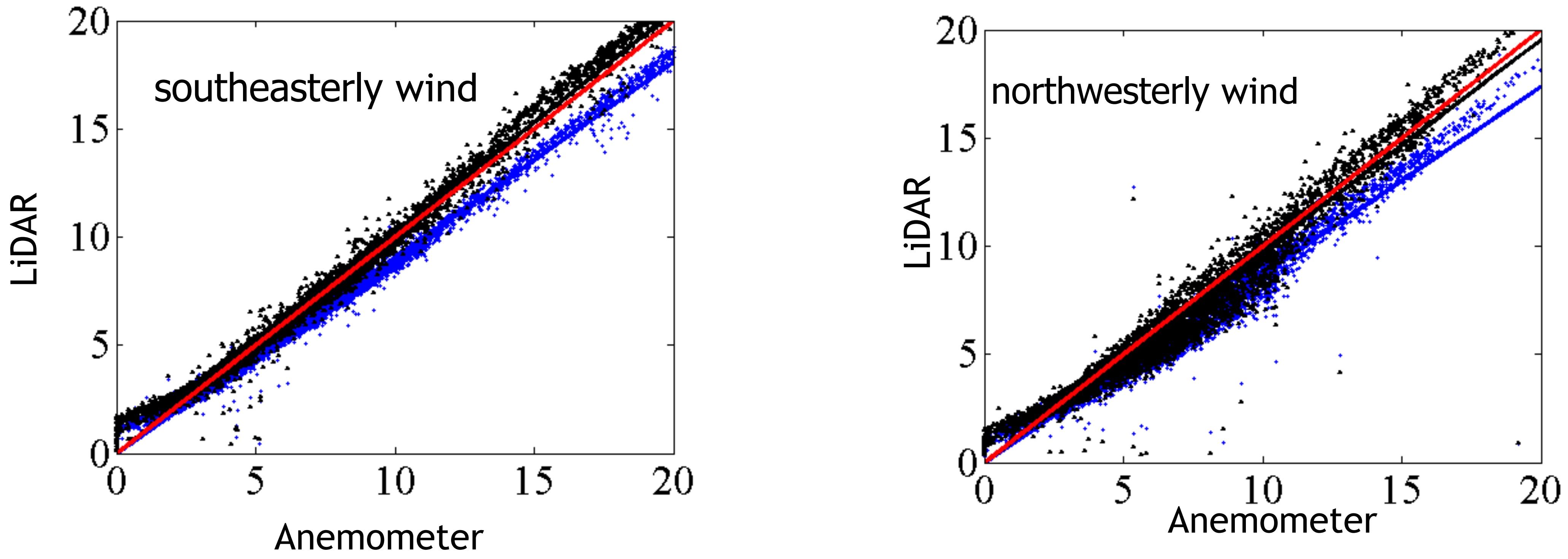


Table 1		Before correction					After correction				
Regression $y = \alpha x + \beta$		2 parameter		3 parameter			2 parameter		3 parameter		
		α	R^2	α	β	R^2	α	R^2	α	β	R^2
NW	4 - 16 m/s	0.861	0.952	0.911	-0.45	0.956	0.963	0.93	1.044	-0.734	0.937
SE	4 - 16 m/s	0.89	0.987	0.913	-0.21	0.988	0.952	0.974	0.976	-0.21	0.972
Uncertainty		12.37 %					4.77 %				

Conclusions

- We presented an optimization based framework for using CFD models in an efficient and accurate manner to improve wind measurement over complex terrain.
- Adjoint-based methods can be used with CFD to efficiently compute the sensitivity of flow with respect to unknown flow conditions.
- The presented algorithm reduced the error due to homogenous assumption for wind direction of northwesterly from -0.09 to +0.04and for southeasterly direction from -0.09 to -0.02.

References

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3. Bingöl, F., Mann, J. and Foussekis, D., 2009. Conically scanning lidar error in complex terrain. Meteorologische Zeitschrift, 18(2), pp.189-195.