ボスニアはボーラ風地帯での鉛直風況分布分析：SODARとZephIR LIDARを用いた観測

ANALYSIS OF THE VERTICAL WIND PROFILE AT A BURA-DOMINATED SITE IN BOSNIA BASED ON SODAR AND ZEPHIR LIDAR MEASUREMENTS

Saskia Bourgeois[1], René Cattin[1], Ian Locker[2], Hans Winkelmeier[3]

(1) bourgeois@meteotest.ch, Meteotest, Fabrikstrasse 14, 3012 Bern, Switzerland, Tel. +41 31 307 26 26
(2) The Natural Power Consultants Ltd., Malvern Technology Centre E708, St Andrews Road, Malvern, WR14, U.K.
(3) Verein Energiewerkstatt, Heiligenstatt 24, 5211 Friedburg, Austria

風力開発におけるサ
エネルギー生産予測
鉛直プロファイルを
重要である。リモー
グ技術への挑戦はSO
LIDARといった高度
装置を産み出した。

ABSTRACT

Knowledge of the shape of the vertical wind profile is an important issue particularly for site assessments and energy yield calculations. Strong efforts in the remote sensing technology yielded to state of the art wind measuring instruments like SODARs (SOund Detecting And Ranging) and LIDARs (LIght Detecting And Ranging).

This study presents a wind measurement campaign carried out in Bosnia near Mostar where the terrain was medium complex and the winds were known to be some times very strong and turbulent. A special attention was given to the so called Bora wind, a gusty wind from the north north-east. One goal of the study was to examine the performance of an Aerovironment SODAR and a ZephIR LIDAR under these harsh meteorological conditions in complex terrain. A 30 m mast provided cup anemometer data.

Both, the SODAR and the LIDAR showed a very good performance with high data availability up to 100 m above ground. Measured wind speeds and wind directions agreed well with the 30 m mast data. While the deployment and the data processing of the SODAR was more demanding the LIDAR proved to be more user friendly.

The vertical wind profiles showed almost no increase with height for both prevailing wind directions and the turbulence intensity was only slightly higher during Bora wind events.

この研究はボスニア
程度の複雑地形で、
ばれる北～北東から
季節風地帯での風況
た。SODARとLIDA
を、複雑地形での厳
件下で評価した。カ
は30mの風況タワー
た。

SODARもLiDARも高
で性能を発揮し、風
も30mの観測タワー
よく一致した。SOD
とデータ分析には改
り。一方LiDARは使
とがわかった。

鉛直風速分布は、ど
対しても高度が上が
るという傾向はなか
強度はボーラの時に
る程度であった。

1. INTRODUCTION

の性能向上のため、
での複雑地形帯での
経験を積みたいとの
欧州委員会で策定さ
ラムの一環である。

の検証など風力発電
ントに、風況の鉛直
ルを精査することは
。SODARやLIDAR
モートセンシング技
要な役割を果たすこ
るまでもない。複雑
速プロファイルを扱
グラムは、ボーラの
るその評価までも含
れた。

ら3ヶ月間をかけて
観測を行なった。ア
南東バルカンの陸地
大気圧差から生ずる
観測である。東西に
吹き抜けるデフュー
生した。

The main objective of the project SEEWIND (South East Europe Wind Energy Exploitation) - embedded in the 6th framework program of the European Commission - is to gain experience in wind measurement, site development and operation of large scale wind turbines at sites in complex terrain and especially under the specific geographic and climatic conditions in the West Balkan area with the aim of increasing efficiency and reliability of wind turbine technology. The SEEWIND project started in May 2007 and has a duration of 36 months. It is coordinated by Verein Energiewerkstatt from Austria, the project partners are Meteotest (CH), DEWI and DEWI-OCC (D), Vjetroenergetika (BO), Adria Wind Power (HR), Univerzitet 'Dzemal Bijedic' u Mostar and the Federal Meteorological Institute of Bosnia and Herzegovina (BO).
Knowledge on the shape and the behaviour of the vertical wind profile is crucial for energy yield assessments in such terrain, e.g. for the verification of model simulations. Remote sensing techniques such as SODAR and LIDAR play an important role in this process. Thus, the work package "Vertical wind profile in complex terrain" of the SEEWIND project is dedicated specifically to the evaluation of this question. Within this work package, detailed analysis not only of the average vertical wind profiles but also of the temporal evolution of the vertical wind profile during Bura events were carried out.
A three-month measurement campaign with an Aerovironment 4000mini SODAR was performed at the Podvelez Plateau near the city of Mostar, Bosnia starting in fall 2007. The wind flow at the Podvelez plateau is mainly caused by the Adriatic wind system called "Bora" which is generated by different levels in temperature and air pressure between the Adriatic Sea and mainland of the South-East Balkan area. Additionally, the East-West course of the Neretva valley leads to a strong canalization effect.

測に並行してZephIR
DAR観測も同じ場所
施した。

より複雑な環境下で
スメントにLIDARが
という結論を得た。

In parallel to the SODAR measurement, a three-week measurement campaign with the ZephIR LIDAR system was carried out at the same location. The goal of the measurement campaign was to enhance the knowledge concerning the suitability of LIDAR for wind energy assessments in such complex environment.

2. SITE DESCRIPTION

The measurement site called Maligrad (Figure 1) is located on the high plateau Podvelez approximately 5 km east of the city of Mostar in Bosnia-Herzegovina. The instruments were installed at a height of 730 m asl. To the east there are two other hills reaching up to 880 m asl and 1'060 m asl, respectively. A mountain chain Velez (1'800 m asl) overshadows the site Maligrad further east. To the north north-west, west and south-west, the terrain lowers down to around 50 m asl in Mostar.
The prevailing wind directions are north north-east (Bora) and south. Wind speeds are very variable and can easily reach 20 m/s at 30 m height. Figure 2 shows the wind rose at Maligrad at 30 m as measured at the mast.

観測サイト概要

図１の観測サイトMaligradはBosnia-Herzegovinaの街Mostarから5km東、海抜730mの高原に位置する。東には海抜880mと1060mの別の高原があり、その先の東には1800mのVelez山脈がMaligradに影を落とす。北北西～西～南西にかけ、地形は海抜50mのMostarに向けてなだらかに下る。

主風向は北北東(ボーラ)と南で、風速は変化に富み高度30mで軽く20m/sに至る。図２に風況観測タワーで計測した30m高の風配図を示す。

図１
Miligradのサイト。左がSODAR右がZephIR LIDAR

Figure 1: The measurement site Maligrad with the SODAR (left) and the ZephIR LIDAR (right).

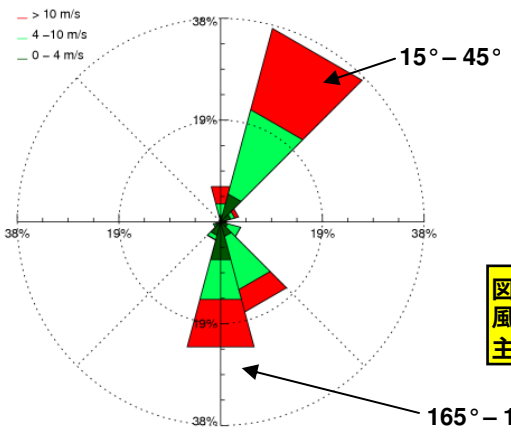


図２
風況マストの高さ30mでの風配図。主風向は15°-45°と165°-195°

Figure 2: Wind rose measured at the met mast at 30 m with the two prevailing wind directions sectors 15°-45° and 165°-195°.

観測内容と期間

3. MEASUREMENT CONFIGURATION

この研究における検討期間は2007年11月22日～12月9日。表1に30m風況タワー、SODAR、LIDARの各観測内容と期間を示す。

The analyzed period for this study started 22 November 2007 and ended 9 December 2007. In table 1 the measurement configuration and measurement periods of the 30 m mast, the SODAR and the LIDAR are shown.

Table 1: Measurement configuration.

	measurement height of wind speed	measurement height of wind direction	measurement period
30 m mast, cup anemometers: Thies Classic (uncalibrated)	12 m; 30 m	30 m	May 2005 – in course
SODAR (Aerovironment 4000 miniSODAR, ASC)	30 m to 150 m with 10 m resolution	30 m to 150 m with 10 m resolution	30 Oct '07 – 4 Feb '08
LIDAR (ZephIR, Natural Power)	30 m; 60 m; 80 m; 100 m; 150 m	30 m; 60 m; 80 m; 100 m; 150 m	21 Nov '07 – 10 Dec '07

検討結果

4. RESULTS

4.1. Comparison of the data availability

While for the SODAR data some obvious outliers were filtered out, all measured data from the LIDAR have been used in this study. The LIDAR data are available only for five levels. At 100 m above ground the data availability is still 85% (Figure 3, left). The SODAR data are available at a vertical resolution of 10 m, however the data availability decreases rapidly with height. At 100 m above ground the data availability is reduced to 54% (Figure 3, right).

データ回収率の比較

SODARの観測データに入っていた明らかに異常なデータは比較材料から除外したが、LIDARの観測データはすべてこの比較材料に加えられた。LIDARの観測は5層に限られる。高度100mでデータ回収率は85%であった(図3左)。SODARは10m間隔で観測できるが、高度とともに回収率は著しく低下し、高度100mで54%

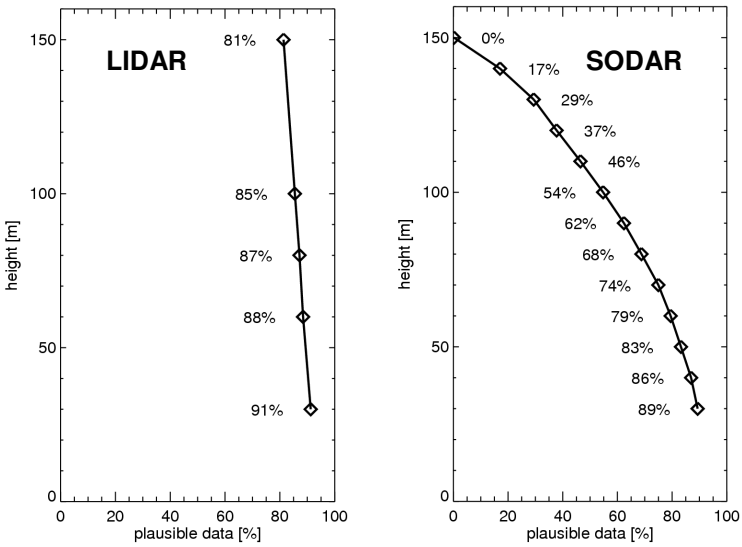


図3
観測高度とデータ回収率の関係
左がLIDAR、右がSODAR

Figure 3: Data availability as a function of the height for the LIDAR (left) and the SODAR (right).

4.2. Comparison of the measured wind speed

A comparison of the measured wind speeds at 30 m is shown in Figure 4 with scatterplots and the evaluated regression and correlation coefficients. The data is displayed for the two prevailing wind direction sectors. Plausible LIDAR data are available for wind speeds well above 20 m/s and show a good correlation to the cup anemometer data (Figure 4, top). The quality of the SODAR data decreases rapidly for wind speeds > 15 m/s and the correlation with the cup anemometer data shows pronounced differences depending on the considered wind sector (Figure 5, bottom).

観測風速の比較

図4に高度30mでの観測風速の比較をプロットし、回帰相関係数を示した。データは2つの主風向別に表示した。
LIDARのデータは高度30mから上でよく回収でき、カップ風速計と良好な相関が認められた(図4上)。
SODARのデータは風速15m/sを超えると急激に精度を失い、また風向によってカップ風速計との明確な差異が現れた(図4下)。

図4
高度30mでの風速データ(10分平均)比較プロット
上：LIDARとカップ風速計
下：SODARとカップ風速計
左：風向セクタ15-45°
右：風向セクタ165-195°

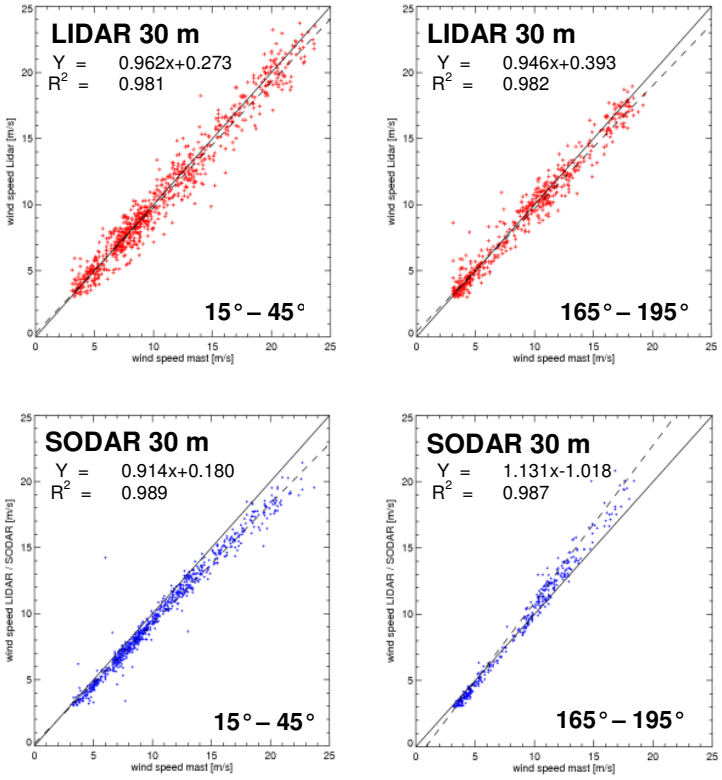
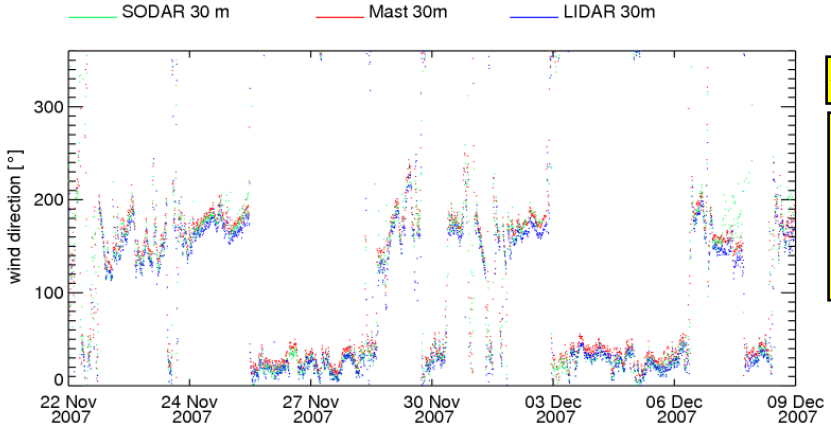


Figure 4: Scatterplot of the 30 m wind speed (10-min averages): cup anemometer – LIDAR (top) and cup anemometer – SODAR (bottom), for the wind sectors 15-45° (left) and 165-195° (right).

4.3. Comparison of the measured wind direction

Figure 5 shows the time series of the measured wind directions for the height of 30 m for the SODAR (green), the mast (red) and the LIDAR (blue).



観測風向の比較

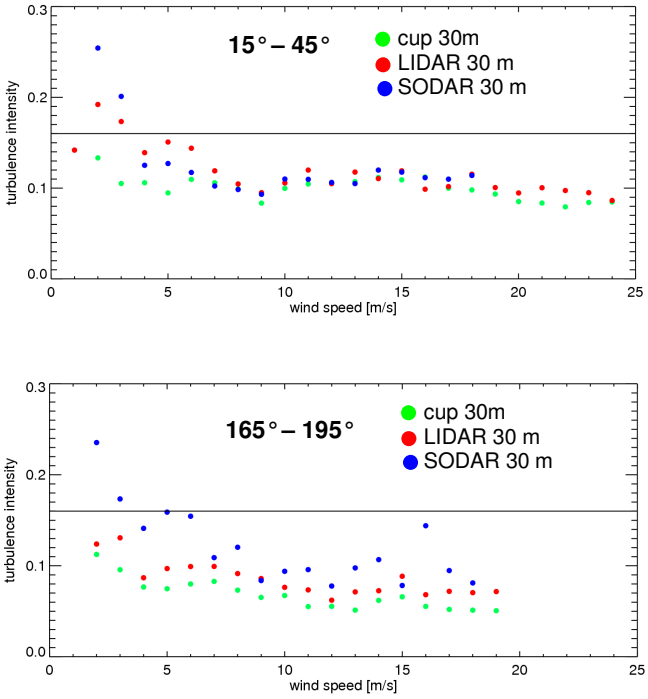
図4で高度30mの風向データ(10分平均)を時系列的に比較した。
緑：SODAR
赤：風況タワー
青：LIDAR

Figure 5: Time series of the 10-min averaged wind direction data for SODAR (green), LIDAR (blue) and mast (red) at 30 m .

4.4. Comparison of the turbulence intensity

As shown in figure 6 the calculated turbulence intensity of cup, LIDAR and SODAR in the sector 15°- 45° agree very well (figure 6, top). For the sector 165°-195° (figure 6, bottom) a shift can be seen between the cup anemometer data and the LIDAR data. Also in this sector the turbulence

intensity from the SODAR data shows strong discrepancies to LIDAR and cup anemometer data.



乱流強度の比較

図6に示すとおり15°- 45°の風向セクタではカップ風速計とLIDAR、SODARのデータはよく一致する(図6上)。165°-195°では3者ともに乖離が見られ、カップ風速計に対しSODARの方がLIDARより乖離していた。

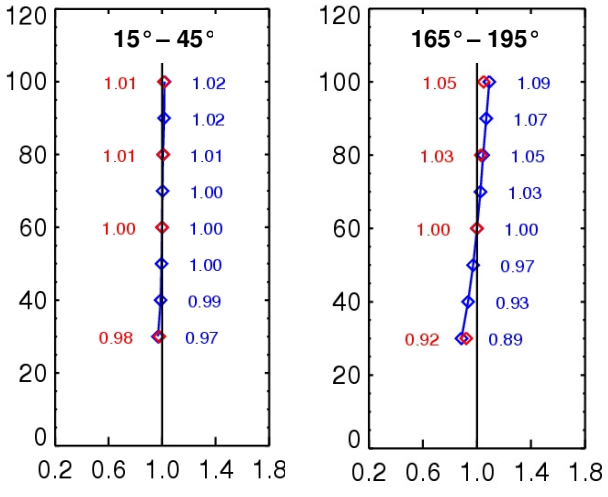
緑：カップ風速計
赤：LIDAR
青：SODAR

上：風向15°- 45°
下：風向165°-195°

Figure 6: Turbulence intensity of cup anemometer data (green), LIDAR data (red) and SODAR data (blue) at the height of 30 m for the sector 15°- 45° (top) and 165°-195°(bottom).

4.5. Vertical profiles of the wind speed

Figure 7 shows the vertical wind profile for the two prevailing wind direction sectors. In general the increase with height is very small and the vertical wind profiles of LIDAR and SODAR agree very well in the sector 15°- 45° (figure 7, left). However, in the south sector 165° - 195° (figure 7, right) the SODAR data shows a stronger increase with height than the LIDAR data.



風速の鉛直プロファイル

図7は2つの主風向における風速の鉛直分布を示す。
風向セクタ15°- 45°で風速の鉛直変化は非常に小さくLIDARとSODARのプロファイルは一致した(図7左)。セクタ165° - 195°ではSODARの方がLIDARよりも強い勾配を観測した。

図7
60mを基準にした鉛直風速プロファイル
赤：LIDAR
青：SODAR
左：風向15°-45°
右：風向165° - 195°

Figure 7: Vertical wind profiles normalized to 60 m of the LIDAR data (red) and the SODAR data (blue) for the prevailing wind direction sectors 15°-45° (left) and 165°-195° (right).

5. SUMMARY AND CONCLUSIONS

Comparison SODAR - LIDAR:

- The LIDAR and the SODAR system showed both a very good performance under the extreme climatic conditions at Maligrad with cold temperatures, heavy rain fall, snow fall and turbulent winds often exceeding 20 m/s.
- The LIDAR has a remarkably higher data availability compared to the SODAR.
- The quality of SODAR data decreases rapidly at wind speeds >15 m/s and for higher levels.
- The transport and installation of the LIDAR is more user friendly compared to the SODAR.
- GSM data transfer of the LIDAR was slow and unstable.

Wind regime at the study site:

- The increase of wind speed with height is very small.
- Turbulence intensities are higher for the sector 15°- 45° (Bora wind) than for the sector 165°-195°. However, the turbulence intensities for both prevailing wind directions are still below class A and B of the IEC.

ACKNOWLEDGEMENTS

The measurement campaign at Maligrad was financed by the 6th framework program of the European Commission (TREN/07/FP6EN/S07.70669/038489) and the local project developer Vjetroenergetika BH. The authors wish to thank Nikola Maric for his excellent technical support at the measurement site.

総括と結論

SODARとLIDARの比較

・Miligradの低温、降雨、降雪、たびたび20m/sを超える強風の厳しい気候にLIDARとSODARともよく耐え、性能を発揮した。

・LIDARはSODARに比べると著しくデータ回収効率が高い。

・SODARの観測データは風速が15m/sを超えると急激に信頼性が低下する。

・SODARに比べLIDARの運搬と設置は容易である。

・LIDARのGSMによるデータ送信は遅く不安定な面がある。

このサイトの風況について

・風速の鉛直勾配は非常に小さい。

・2つの主風向において乱流強度は風向セクタ15°- 45°(**ボーラ風)がセクタ**165°-195°**より大きい。ただし両主風向においても乱流強度はIEC規格のクラス1、クラス2の定義より低い。**