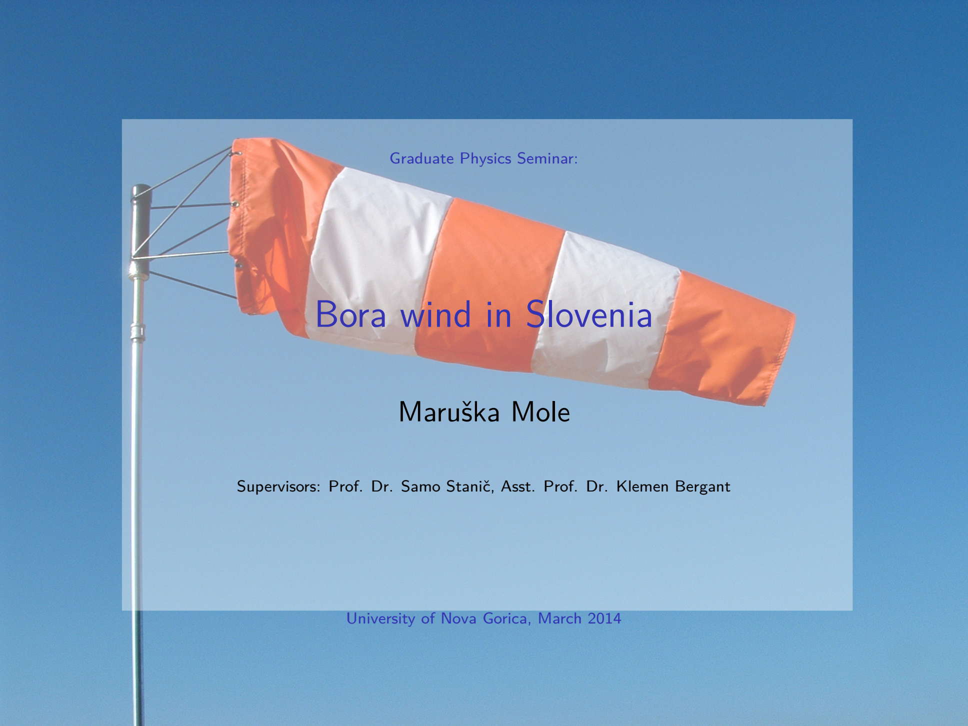


Graduate Physics Seminar:

Bora wind in Slovenia

Maruška Mole

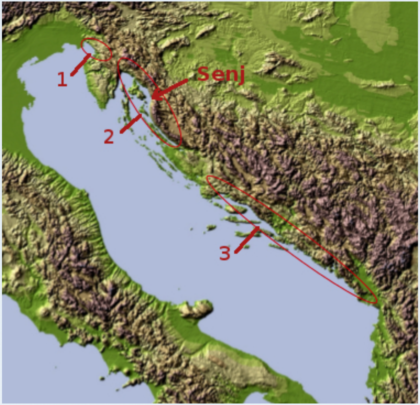
Supervisors: Prof. Dr. Samo Stanič, Asst. Prof. Dr. Klemen Bergant

University of Nova Gorica, March 2014

Outline

What is Bora wind?

- North-eastern or East-north-eastern wind
- Caused by the flow over orographic barrier
- Cold lee-side/downslope wind
- Strong wind gusts – over 50 m/s



Source: `http://www.treehouse-maps.com/`

Effects of strong Bora wind

Source: www.tic-ajdovscina.si, www.siol.net, www.24ur.com

Classification of Bora wind events

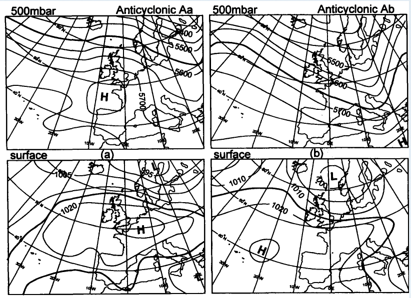
- Historic classifications (tree deformation, local measurements,. . .)
- Synoptic classification:

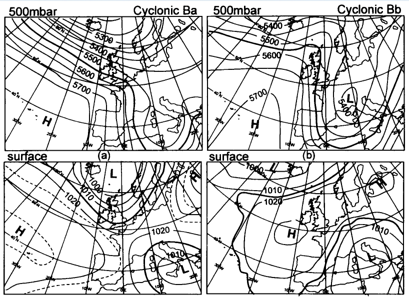
Anticyclonic (Light) Bora:

- planetary through over West Europe
- high pressure over Central Europe

Cyclonic (Dark) Bora:

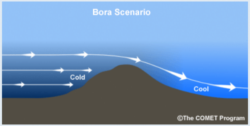
- cyclone in the North Adriatic
- anticyclone over Central Europe

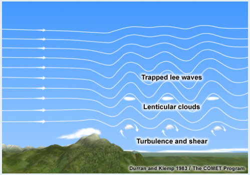




Source: Menezes, A., Tabeaud, M., 2000: Variations in Bora weather type in the north Adriatic See, 1866 - 1998. *Weather*, vol. 55, 2000, 452-458. University Press.

Downslope winds





1. Stably stratified cold air is forced to rise over a topographic barrier
2. The air on the lee-side oscillates and forms the so-called mountain waves – inner gravity waves
3. Consequences:
   - a drag to the upper level of atmosphere
   - possible clear-air turbulence (CAT)
   - strong surface winds at the lee side of the mountains

Airmass motion - basic set of equations

- Continuity equation:

  $\frac{D\rho}{Dt} + \rho\nabla\vec{u} = 0 \quad \rightarrow$ no airmass sources or sinks

- Ideal gas equation:

  $p = \rho RT = \frac{1}{\alpha}RT \quad \rightarrow$ we assume the air to be ideal gas

- Equations of motion:

$$\frac{Du}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + F_{rx}$$
$$\frac{Dv}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + F_{ry} \quad \rightarrow$$
$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

  air parcels affected by basic Newtonian mechanics – Newton's 2nd Law

- Thermodynamic equation:

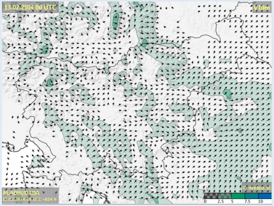
  $\frac{1}{\theta_0}\left(\frac{\partial\theta}{\partial t} + u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y}\right) + w\frac{d\ln\theta_0}{dz} = \frac{J}{c_pT} \rightarrow$ describes energy sources and sinks

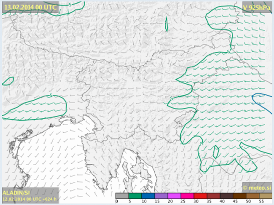
Solutions of basic equations

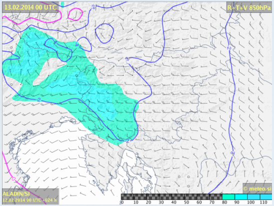
- Basic equations form a system of non-linear partial differential equations
- Possible approaches to solutions of the system of partial equations:
    - Numerical solution of equations $\rightarrow$ weather forecast
    - Linearization of equations $\rightarrow$ analytical solution, yielding the properties of gravity waves with different wavelengths

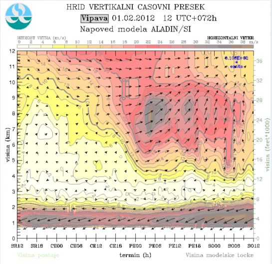
Numerical solutions - Weather prediction

- Spectral method – finite series of orthogonal functions to represent the spatial variations (ALADIN)







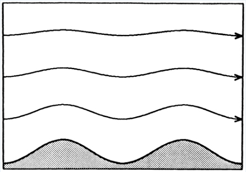


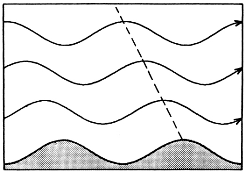
- Finite difference method – simple discretization, derivatives of the variable are approximated by finite differences

Source: http://meteo.arso.gov.si/

Analytical solution for Bora wind case - Wave forms

- Linearization of partial differential equations with perturbation method
- Solutions can be written in wave form
- Special case – inertia-gravity waves over sinusoidal topography:
  $\left(\frac{\partial^2 w'}{\partial x^2} + \frac{\partial^2 w'}{\partial z^2}\right) + \frac{N^2}{\bar{u}^2} w' = 0 \rightarrow$ harmonic oscilator



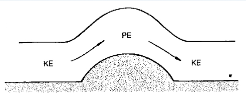


Source: Holton, J. R., 2004: *An Introduction to Dynamic Meteorology, Fourth Edition*. Oxford: Elsevier Academic Press.

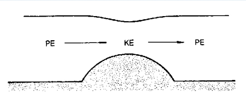
Mountain waves - Downslope windstorm

- Reflection of vertically propagating linear gravity waves in lower layer from the upper layer
- Nonlinear processes have to be taken into account
- Froude number $(\mathrm{Fr}^2 = \bar{u}^2/c^2)$ – the ratio between mean-flow speed and wave speed

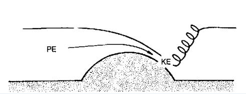
Supercritical case $(\mathrm{Fr} > 1)$



Subcritical case $(\mathrm{Fr} < 1)$



Downslope windstorm

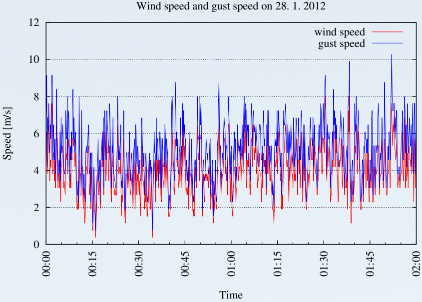


Source: Holton, J. R., 2004: *An Introduction to Dynamic Meteorology, Fourth Edition*. Oxford: Elsevier Academic Press.

- Critical flow at the crest of the mountain, supercritical flow down the lee side of the mountain, subcritical conditions in the valley $\rightarrow$ downslope windstorm

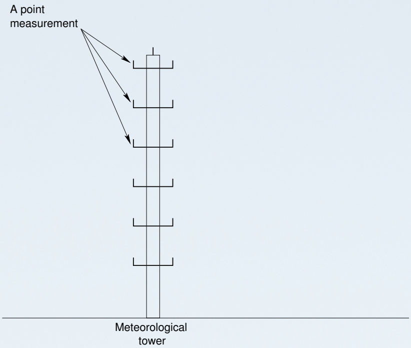
Wind field measurements

- Changes in wind speed often abrupt:
  - High sampling rate – analysis of wind gusts
  - Averaged values of wind speed – input for numerical models (initial conditions)
- Measurements of vertical wind profiles, 2D and 3D wind field $\rightarrow$ verification of numerical models



Measurements obtained by Honzak, L., Rakovec, J., Skok, G., Žabkar, R., University of Ljubljana, Faculty of Mathematics and Physics.

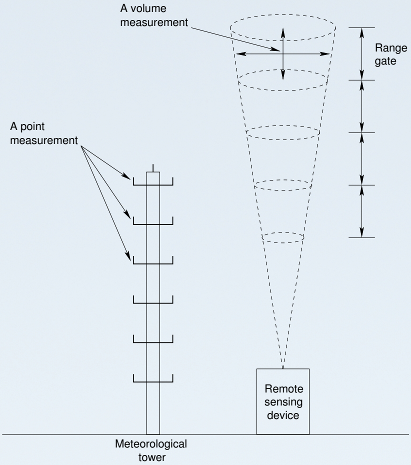
In-situ measurements vs. remote sensing



Measuring techniques:

- In-situ methods:
  - Measurements at or near the ground
  - Sensors measure the properties of atmosphere directly
  - Point measurements
  - Wind speed – averaged value over a period of time
  - Gust speed – maximum value in the same period

In-situ measurements vs. remote sensing

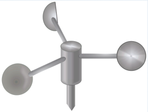


Measuring techniques:

- Remote sensing methods:
  - Detection of a signal scattered on atmospheric features (clouds, aerosols, molecules)
  - Passive methods – scattering of natural radiation (i. e. sunlight) on objects
  - Active methods – system emits the signal and observes the return
  - Volume measurements

In-situ instruments for wind field measurements

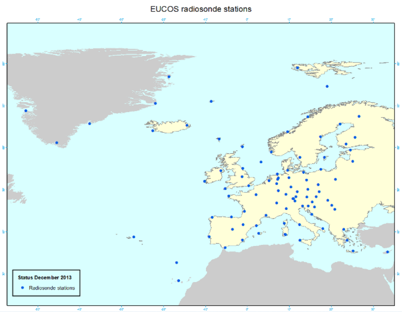
- Cup anemometer
- Propeller anemometer
- Hot-wire anemometer
- Wind vane – wind direction
- Ultrasonic anemometer – 2D or 3D wind vector (measures the time of flight of acoustic signal)




Sources: Cup anemometer – `http://www.logotronic.at`, Propeller anemometer – `http://www.tes.com.tw`, Hot-wire anemometer `http://www.test-equipment.com.au`, Wind vane –`http://www.geographylwc.org.uk`, Ultrasonic anemometer – `http://www.wikipedia.org`.

In-situ instruments for wind field measurements

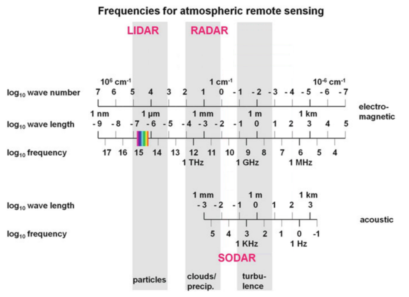
- Radiosondes:
  - vertical profile of 2D wind vector
  - poor temporal resolution – two launches per day
  - poor spatial resolution



Sources: Radiosonde – `http://radiosondemuseum.org`, Radiosonde stations – `http://www.eumetnet.eu/`.

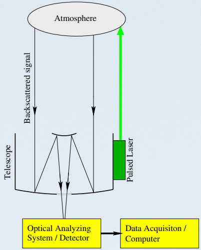
Remote sensing systems for wind field measurements

- Remote sensing systems:
  - SOund Detecting And Ranging – SODAR
  - RAdio Detecting And Ranging – RADAR
    - Synthetic Aperture Radar – SAR
  - LIght Detecting And Ranging – LIDAR



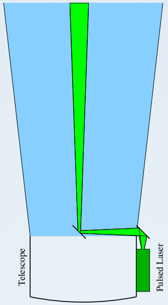
Source: Emeis, S., 2011: *Surface-Based Remote Sensing of the Atmospheric Boundary Layer*. London: Springer.

Basic lidar configuration

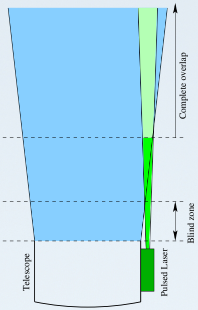


Lidar device:

- Transmitter – high energy light source
- Receiver – optical system and photomultiplier



Co–axial configuration

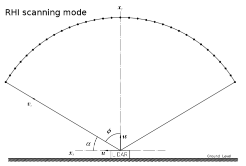


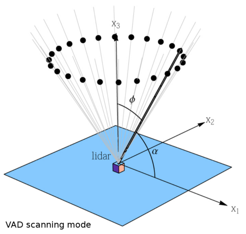
Bi–axial configuration

Transmitter - receiver configuration:

- Co-axial – axis of transmitter and receiver coincide
- Bi-axial – axis of transmitter and receiver are separated

Wind lidar measurements





Possible lidar system configurations:

- Doppler lidar
- Fast scanning elastic-backscatter lidar

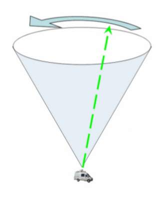
Types of scans used to obtain wind field:

- Time-to-Height Indicator (THI) mode
- Range Height Indicator (RHI) mode
- Velocity Azimuth Display (VAD) mode
- Plan Position Indicator (PPI) mode

Source: Sathe, A., Mann, J., 2013: A review of turbulence measurements using ground-based wind lidars. *Atmospheric Measurement Techniques Discussions*, vol. 6, no. 4, 2013, 6815 - 6871.

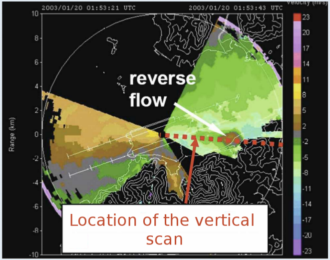
Doppler lidar

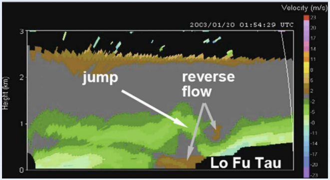
- Scattering on molecules → frequency shift of the backscattered signal
- Frequency shift → wind speed:
  - Radial component of wind → directly from the Doppler shift of the signal
  - 3D wind field → scanning at various azimuth angles



- Direction of the largest frequency shift → wind direction
- Frequency evaluation:
  - Coherent detection – measuring the beat frequency of the signal
  - Direct (incoherent) detection – the frequency change determined by transmission change

Wind field measurements – Doppler lidar





An example of measurements Doppler lidar:

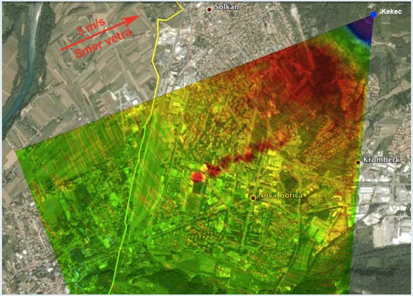
- Spatial resolution: 100 m
- Range: from 400 m to 10 km
- Maximum detectable wind speed: 40 m/s

The system is capable of detecting:

- the terrain-induced wind shear
- hydraulic jumps
- vortexes

Source: Shun, C. M., Chan, P. W., 2007: Applications of an Infrared Doppler Lidar in Detection of Wind Shear. *Journal of Atmospheric and Oceanic Technology*, vol. 25, May 2008, 637 - 655.

Fast scanning elastic-backscatter lidar



- Correlation method → aerosol features identified and followed while drifting with the wind
- Aerosols small and light enough to be assumed they drift with the wind speed

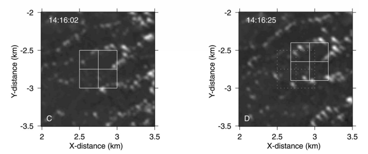
- Measurements strongly dependent on the aerosol concentrations:
  - Low concentrations – weak return signal
  - Low clouds, fog or precipitation – information about the speed of raindrops instead of wind speed

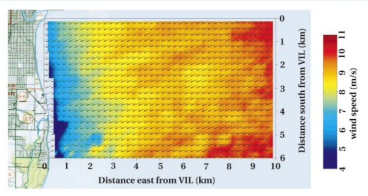
Source: He, T.-Y., Stanič, S., Gao, F., Bergant, K., Veberič, D., Song, X.-Q., and Dolžan, A, 2012: Tracking of urban aerosols using combined LIDAR-based remote sensing and ground-based measurements. *Atmospheric Measuring Techniques*, vol. 5, 2012, 891 - 900.

Wind field measurements – fast scanning lidar

An example of measurements of a 2D vector wind fields:

- Scanning speed: 3.75 °/s for 90 ° PPI scan
- Range: 18 km
- Resolution: 15 m

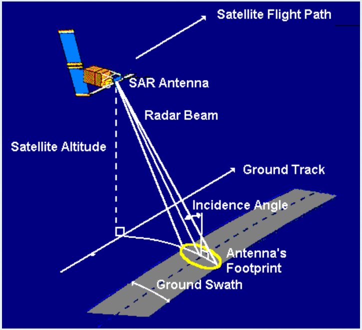


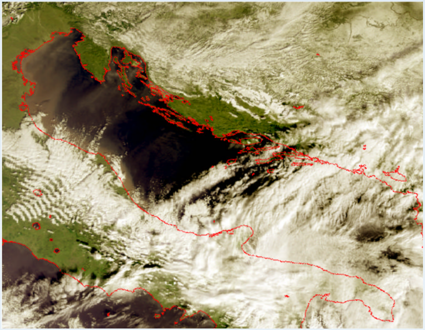


Source: Mayor, S. D., Eloranta, E. W., 2001: Two-Dimensional Vector Wind Fields from Volume Imaging Lidar Data. *Journal of Applied Meteorology*, vol. 40, August 2001, 1331 - 1346.

Synthetic Aperture Radar

- Coherent sidelooking radar system
- Airborne or spaceborne
- Using the flight path to simulate extremely large antenna
- High-resolution imagery
- Wind field obtained by wind scatterometer model



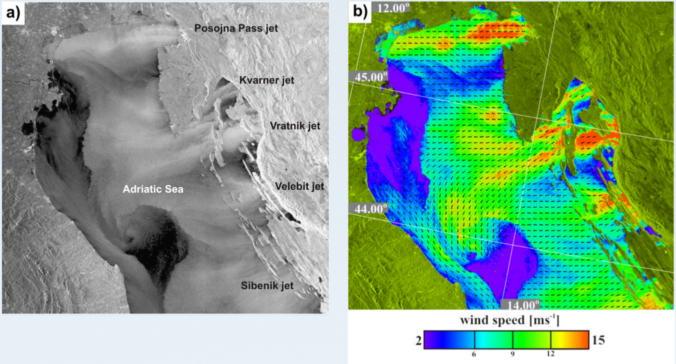


Source: Measuring scheme – `http://www.crisp.nus.edu.sg`, Satellite image – Alpers, W., Ivanov, A., Horstmann, J., 2008: Observations of Bora Events over Adriatic Sea and Black Sea by Spaceborne Synthetic Aperture Radar. *Monthly Weather Review*.

Wind field measurements – synthetic aperture radar

An example of measurements of wind field with SAR:

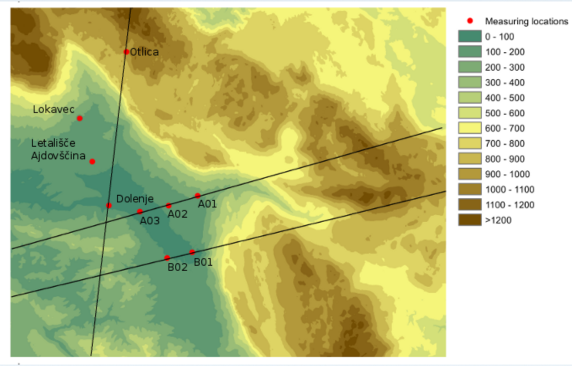
- cloud patterns – gravity waves, wave-induced rotors
- visible flows through the cols
- wind jets and wakes



Source: Alpers, W., Ivanov, A., Horstmann, J., 2008: Observations of Bora Events over Adriatic Sea and Black Sea by Spaceborne Synthetic Aperture Radar. *Monthly Weather Review*.

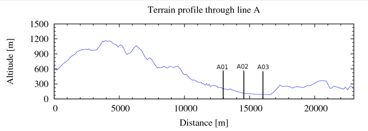
Case study of Bora wind

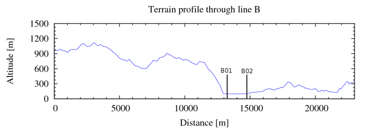
- Period: 27 January - 24 April 2012
- Wind and gust speed measured at 7 locations:
  - 5 locations arranged in two lines perpendicular to the barrier (sampling rate 10 s)
  - 2 meteorlogical stations – Otlica and Dolenje (SR 0.5 h)

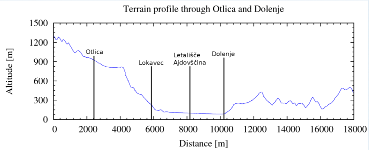


Measurements for lines A and B obtained by Honzak, L., Rakovec, J., Skok, G., Žabkar, R., University of Ljubljana, Faculty of Mathematics and Physics.

Vertical profiles through measuring locations





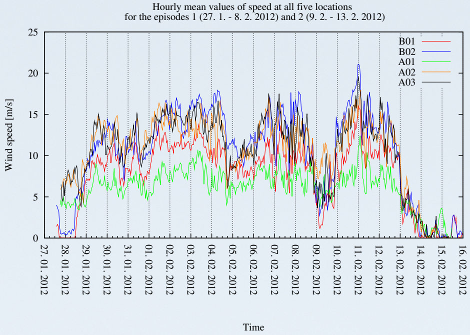


The aim of positioning the sensors in perpedicular lines → capturing the downslope acceleration of the air-masses

Orographic features of the area:

- 900 - 1200 m a.s.l. – Trnovski gozd plateau
- ∼100 m a.s.l. – Vipava valley
- ∼300 m a.s.l. – Karst plateau

Statistics of Bora wind events



- Larger wind speed values for locations in the valley (A02, A03, B02) than on the slope (A01, B01)
- Lowest wind speed at A01
- Peaks of hourly-mean wind speed coincide for all the measuring points

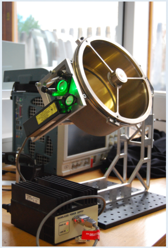
Measurements for lines A and B obtained by Honzak, L., Rakovec, J., Skok, G., Žabkar, R., University of Ljubljana, Faculty of Mathematics and Physics.

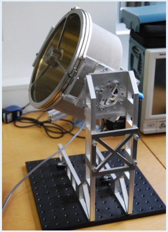
Limitations of measuring system and possible solutions

- Spatial and temporal dynamics of the processes – numerical models
- Verification of numerical models:
  - In-situ measurements – low spatial and temporal resolution
  - Lidar system – spatial resolution of a few meters and temporal resolution of a few seconds

- Requirements for the lidar system:
  - small device – mobility
  - scanning in two directions (zenith and azimuth angle)
  - fast scanning
  - fast data acquisition

Future work





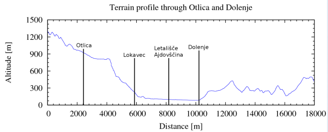
A small rapid scanning lidar system:

- Transmitter – Nd:YAG pulsed laser (532 nm, 5 kHz repetition rate, energy 3 μJ/pulse)
- Receiver – Ritchey-Crétien optic system with two hyperbolic mirrors
- Bi-axial configuration of transmitter and receiver
- Support frame – movements in alt-azimuthal direction
- Light return collection – photomultiplier
- Fast data acquisition – custom made electronics

Conclusions

Retrieval of wind information at high frequency and at different heights:

- Ultrasonic anemometers → better insight into the frequency and eventual periodicity of the wind gusts



- Fast scanning elastic lidar:
  - vertical wind profiles → depth of the Bora wind flow
  - 2D wind profiles → structure of the Bora wind flow