Some current and future research on Bora wind

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OUTLINE

- **Background,** \( Fr_{\text{vert}} = \frac{U}{Nh} \leq 1 \) (or \( \approx 1 \))

- **Bora and Related (Sub)Structures**

- **Pulsations, Rotors, Turbulence**

- **Future Avenues**
Most of data here by Dept. Geophysics & partly by Met. & Hyd. Serv. Croatia

Other: e.g., Aircraft data MAP’99, Grubišić QJRMS 2004 → Večenaj et al. BLM 2012
Origins of bora gusts: a) atmos. turbulence (mean speed = solid, TKE = dotted, b) eddies due to waves (Mnt, KH, etc.) breaking, rolling down the slope, c) sliding air. Kozmar et al. J. of Wind Eng. & Industrial Aerodyn. 2012, photo by T. Kozmar, 43 km S of Split, Croatia

Left: gap-type of bora, Vratnik Pass & Oštarije Pass | Right: “all-over” wave-breaking transient WB over mnt. flanks severe bora type
TYPICAL BORA EPISODE, SENJ, 08/12/2001; 6TH H EXPANDED – PULSATIONS!
sampling 1 sec, Grisogono & Belušić Tellus 2009
Pulsations: WS > 28m/s shaded, θ by 1K, 09 UTC 08/12/2001, a→d) 650, 750, 850, 950 sec. A, B = individual pulsations, Belušić et al. QJRMS 2007
Redone simulation after Belušić et al. QJRMS 2007 (using COAMPS) now using WRF

Courtesy of Mark Zagar, VESTAS, DK, 2010, submitted to Tellus as Rakovec et al. 2013
Same as the former but vertical x-section (gridpoints): ~ Krk island ← Senj
- **Pulsation cause in this case: 1)** KHI

- **Other possibilities: 2)** eddies from Mnt. Wave-Breaking vortex tilting advected down to sfc.

3) **Propagating lee waves, due to transience in the MWB region; "waveguide" between sfc. & MWB region in the lee**
(a) 4-day raw 4 Hz data near-sfc. time series, 07-11/01/2006, streamwise wind comp. $u$, 1h mean superimposed (b) 4 h with 10 min mean superimposed; Večenaj et al. 2010

$\Leftrightarrow$ $TKE \sim 10 - 20 \text{ m}^2\text{s}^{-2}$, $\varepsilon \sim 0.5 - 1 \text{ m}^2\text{s}^{-3}$; related poster on turb. integral length-scale by Večenaj et al.
Works of K. Horvath, Ž. Večenaj,…
Central Adriatic coast, Dugopolje, upwind from Split

- Related poster on obs. based 1D TKE long-lasting bora case by Babić et al.
- For non-Bora downslope (katabatic) flow, a weakly-nonlinear Prandtl model developed, ICAM2013, Slovenia
Dugopolje: modeled pulsations at noon, > 12 h...

Simulated by Kristian Horvath using WRF (work in progress)

\[
\text{VAR} \equiv 2^{1/2} \sigma_w / [\sigma_u^2 + \sigma_v^2]^{1/2}
\]

**Wind comp. spectra at 3 levels (below)**
Logarithmic law - black

Log. adjustment to the power low - grey

\[ \frac{\bar{u}}{z} = \left( \frac{z_{\text{ref}}}{z_0} \right)^\alpha \]

\( \alpha = 0.189 \pm 0.049 \)

\( u_* = 0.74 \pm 0.31 \text{ m/s} \)

\( z_0 \approx 0.145 \text{ m} \)

\textit{Dugopolje, summertime bora case - continued}

bora wind \( \uparrow \leftrightarrow (\alpha, u_*, z_0) \downarrow \)

bora: moderate \( \leftrightarrow \) strong \( \Rightarrow \) suburban \( \leftrightarrow \) rural \( u(z) \)
Other bora- & its turbulence issues…


- Air-pollution: \(O_3\), VOC, \(NO_x\), Telišman Prtenjak et al. Met. Appl. 2013

- New generalized z-less mixing length-scale: 
  \[ \Lambda = \frac{const \cdot (TKE)^{1/2}}{|S| \left(1 + \frac{Ri}{Pr}\right)^{1/2}} \] 
  (Grisogono QJRMS2010) into mesoscale models

- Fire-protection research, agriculture, traffic, future bora scenarios, etc.
http://www.pmf.unizg.hr/geof
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Figure 12. Schematic diagrams of the two dynamic pressure effects of mountain waves on katabatic flow. The upper diagram shows that, depending on location, katabatic flow can be either strengthened (upper slope case) or weakened (lower slope case), due to the integrated column pressure structure of the mountain wave and the locally induced pressure gradient (arrows). The lower diagram shows that a breaking mountain wave aloft causes rapid pressure fluctuations which, in turn, causes rapid katabatic flow fluctuations.

Poulos et al. JAS 2007
**Daytime pulsations: upstream variability**

- Scorer parameter of the background flow shows an upstream variability during daytime (including unstable sfc. layer)

- Related to lee side pulsations?

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Daytime * $10^7$  

Nighttime * $10^7$
Anomalous refraction of radio-waves during bora

+ diploma work I. Horvat 2013
Near-sfc. $O_3$ & VOC in summer
13.08. no bora $\rightarrow$ 15.08. with bora

ALPEX 1982 ➔ R.B. Smith, JAS ‘85,’87 & J. Klemp & D. Durran, Cont. Atmos. Phys.’87. ➔ Strong(est) Bora is a type of severe downslope windstorm

Mountain wave-breaking usually occurs… \( Fr_v = \frac{U}{(Nh)} \leq 1 \)

3D MODELING of Bora from late ’90s onward… DA (2km) in ALADIN (8km) helps operationally

1 ➔ 5 Hz wind sampling since ~2001…

fine remote sensing data still missing
New info come from MAP – airborne data, PV analysis, fine-scale modeling

Jets & wakes ↔ mountain gaps & peaks

PV banners separate individual bora wakes & jets, $L_x \sim 10 – 25$ km