Some current and future research on Bora wind

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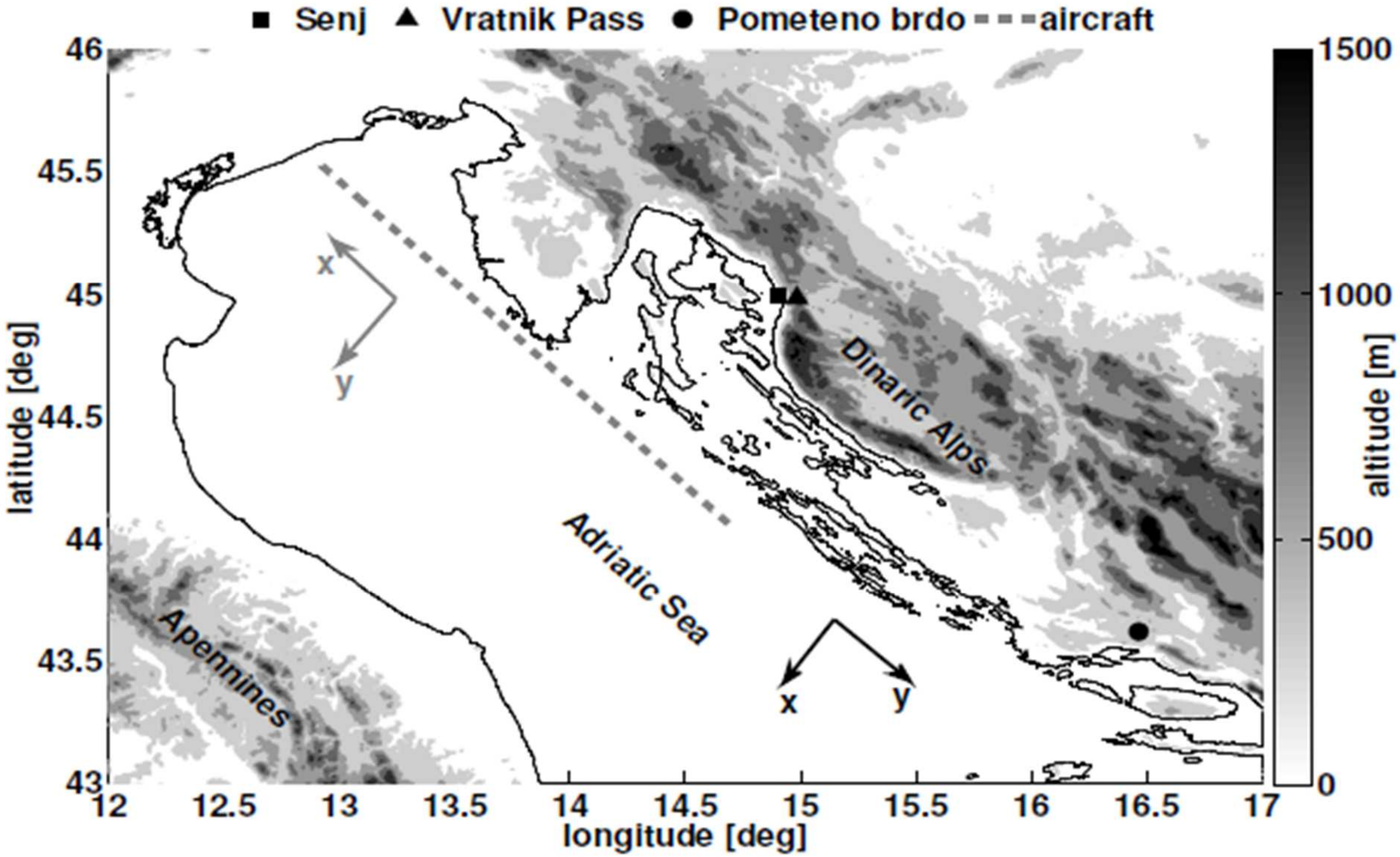
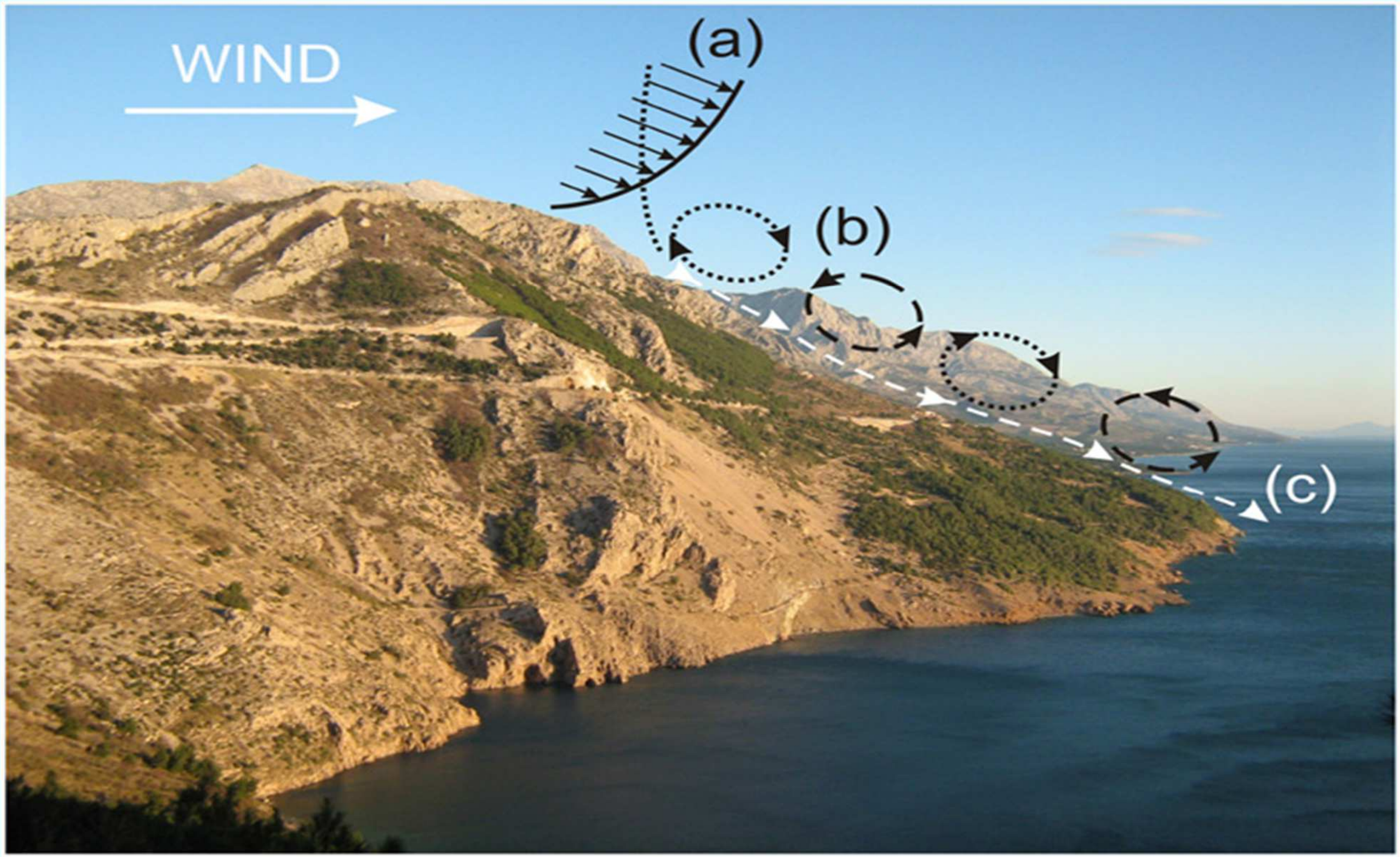
OUTLINE

- **Background,** $Fr_{vert} = U/(Nh) \leq 1$ *(or* ≈ 1*)*
- **Bora and Related (Sub)Structures**
- **Pulsations, Rotors, Turbulence**
- **Future Avenues**

Most of data here by Dept. Geophysics & partly by Met. & Hyd. Serv. Croatia

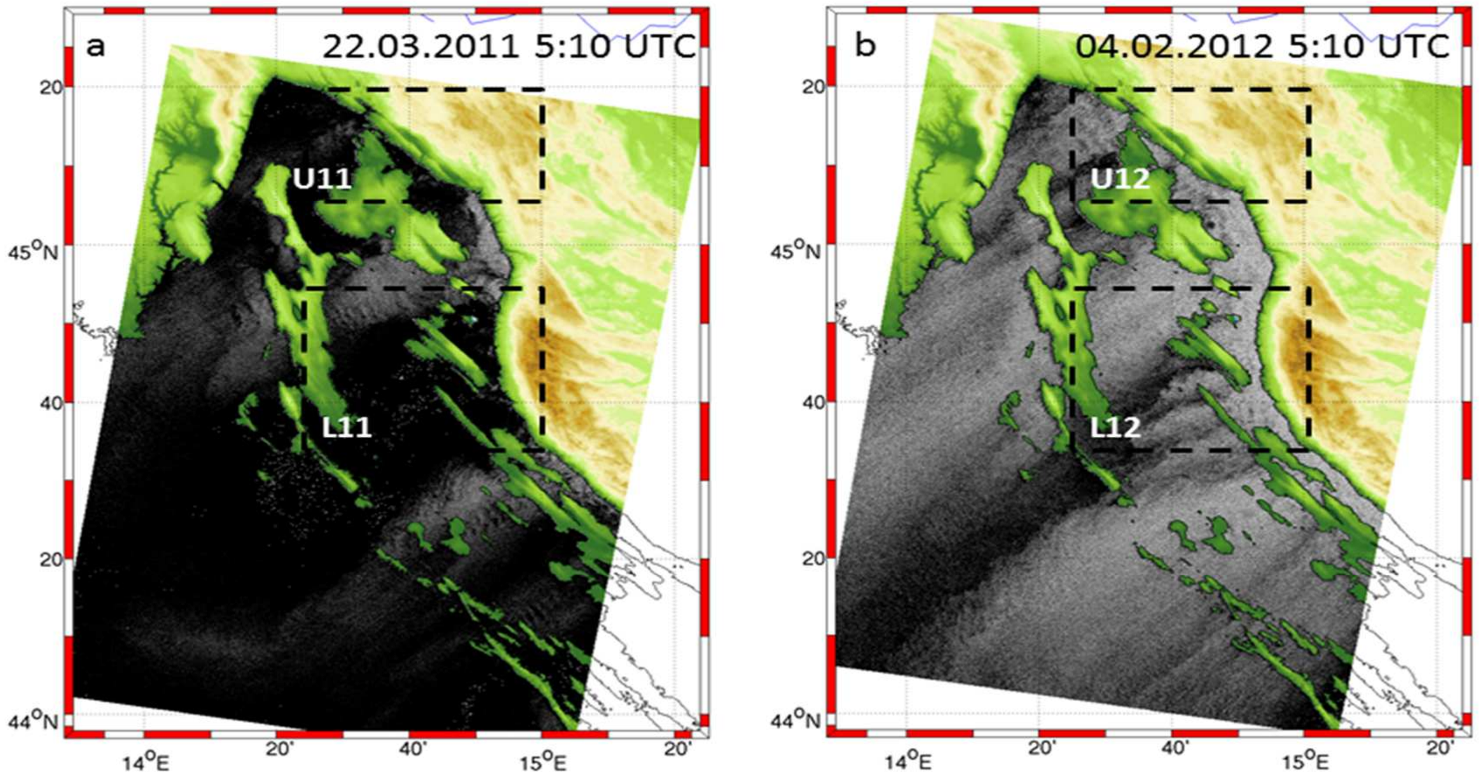
Other: e.g., Aircraft data MAP'99, Grubišić QJRMS 2004 →Večenaj et al. BLM 2012



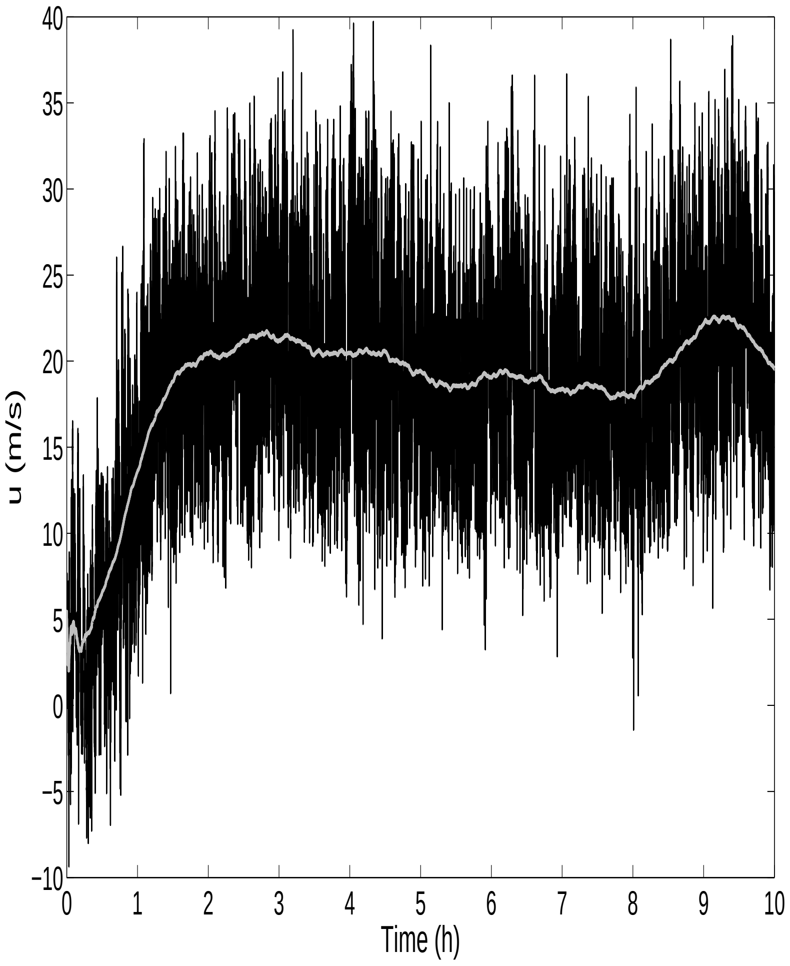


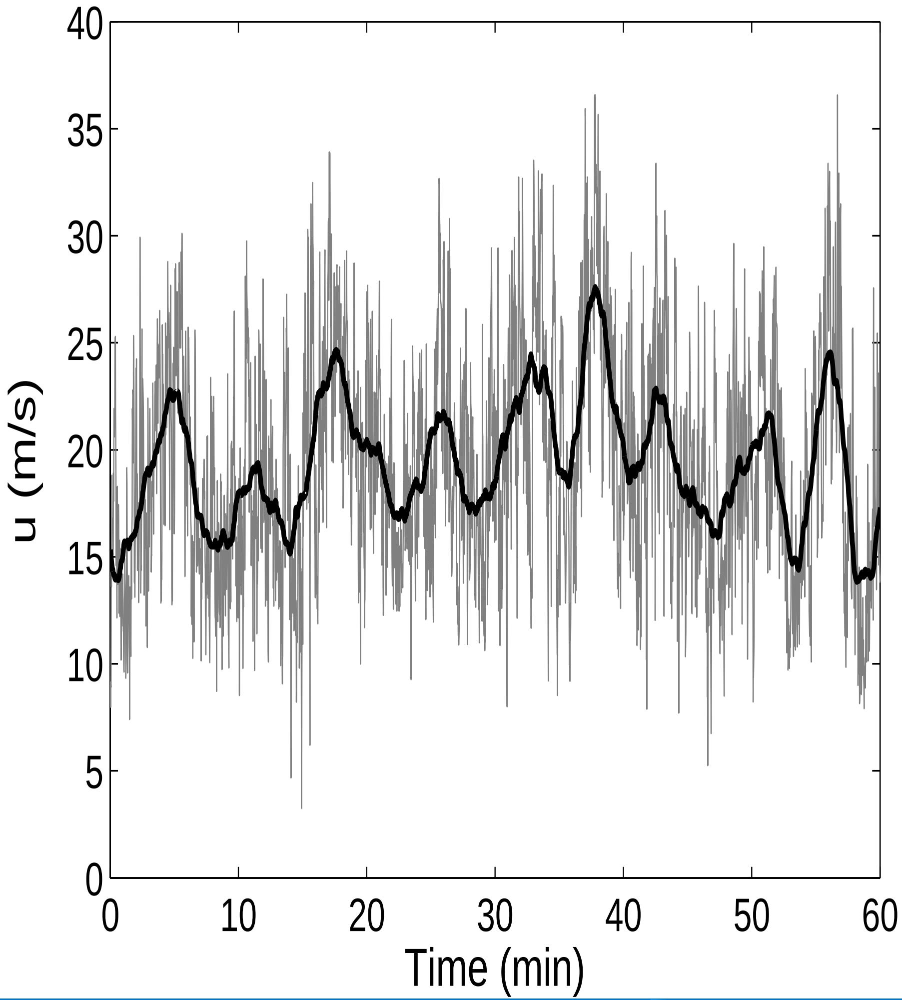
Origins of bora gusts: a) atmos. turbulence (mean speed = solid, TKE = dotted, b) eddies due to waves (Mnt, KH, etc.) breaking, rolling down the slope, c) sliding air.
Kozmar et al. J. of Wind Eng. & Industrial Aerodyn. 2012, photo by T. Kozmar, 43 km S of Split, Croatia

Satellite SAR data, Kuzmić et al. Acta Adriatica, 2013 in press



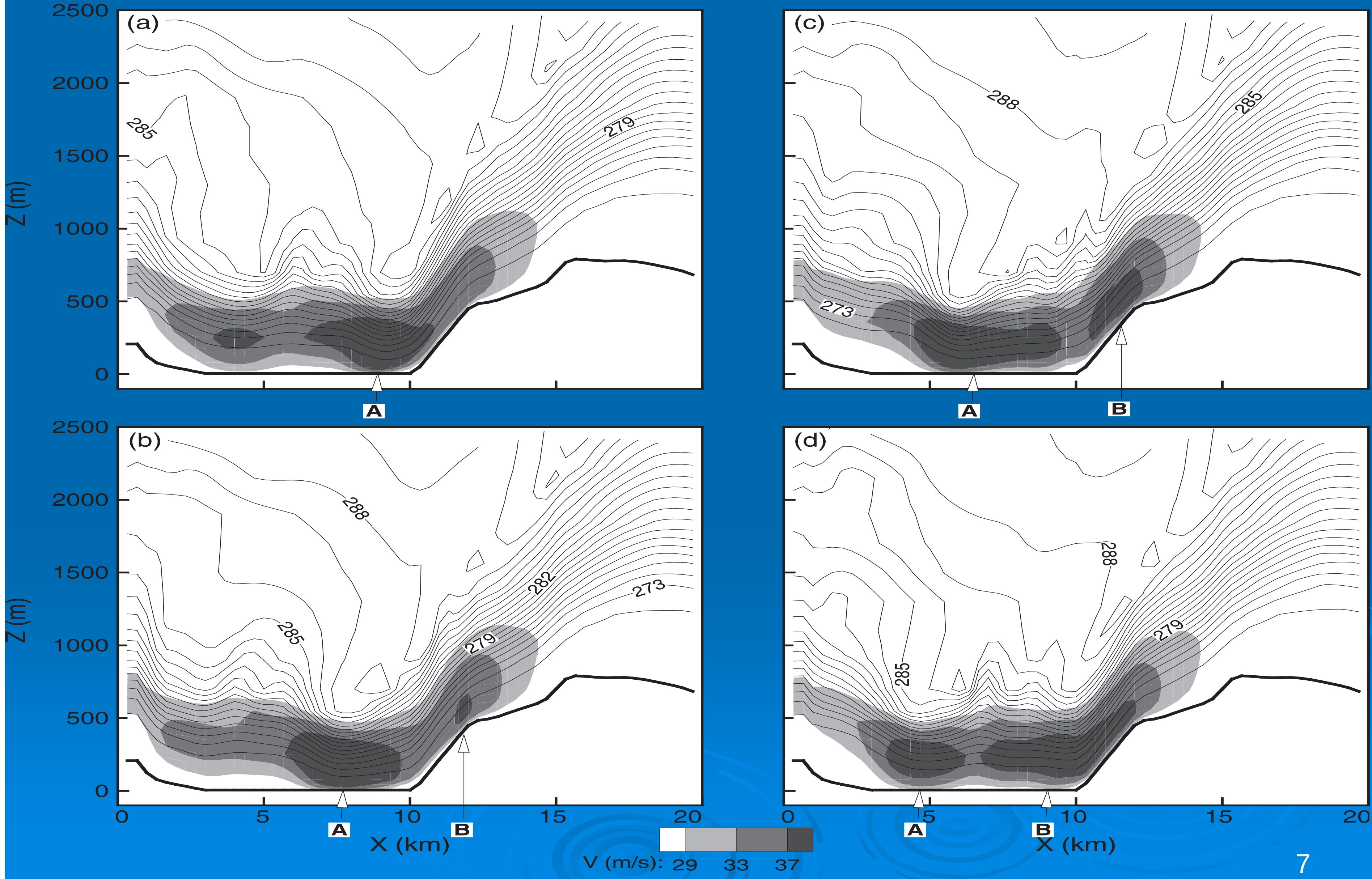
Left: gap-type of bora, Vratnik Pass & Oštarije Pass | Right: "all-over" wave-breaking transient WB over mnt. flanks severe bora type

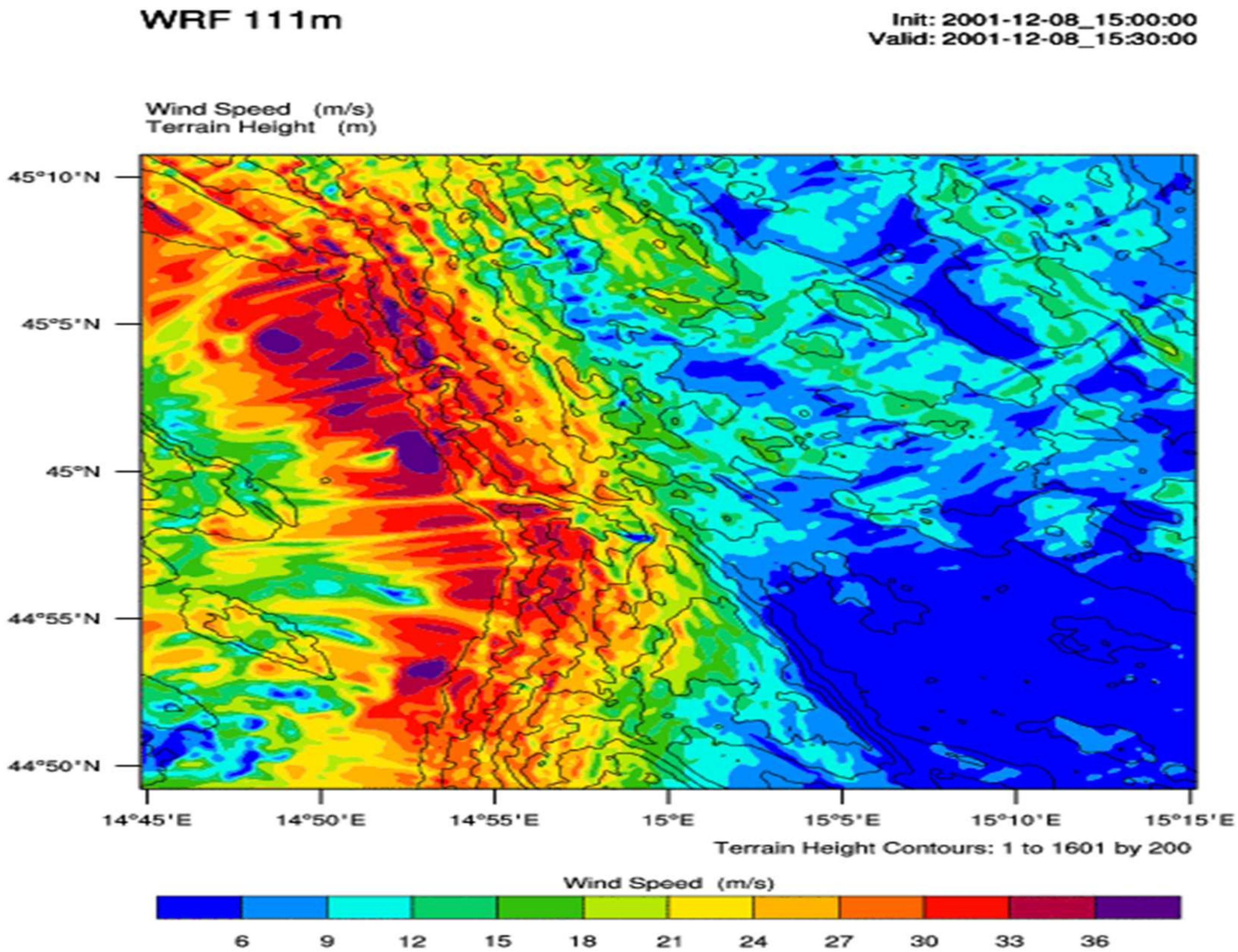




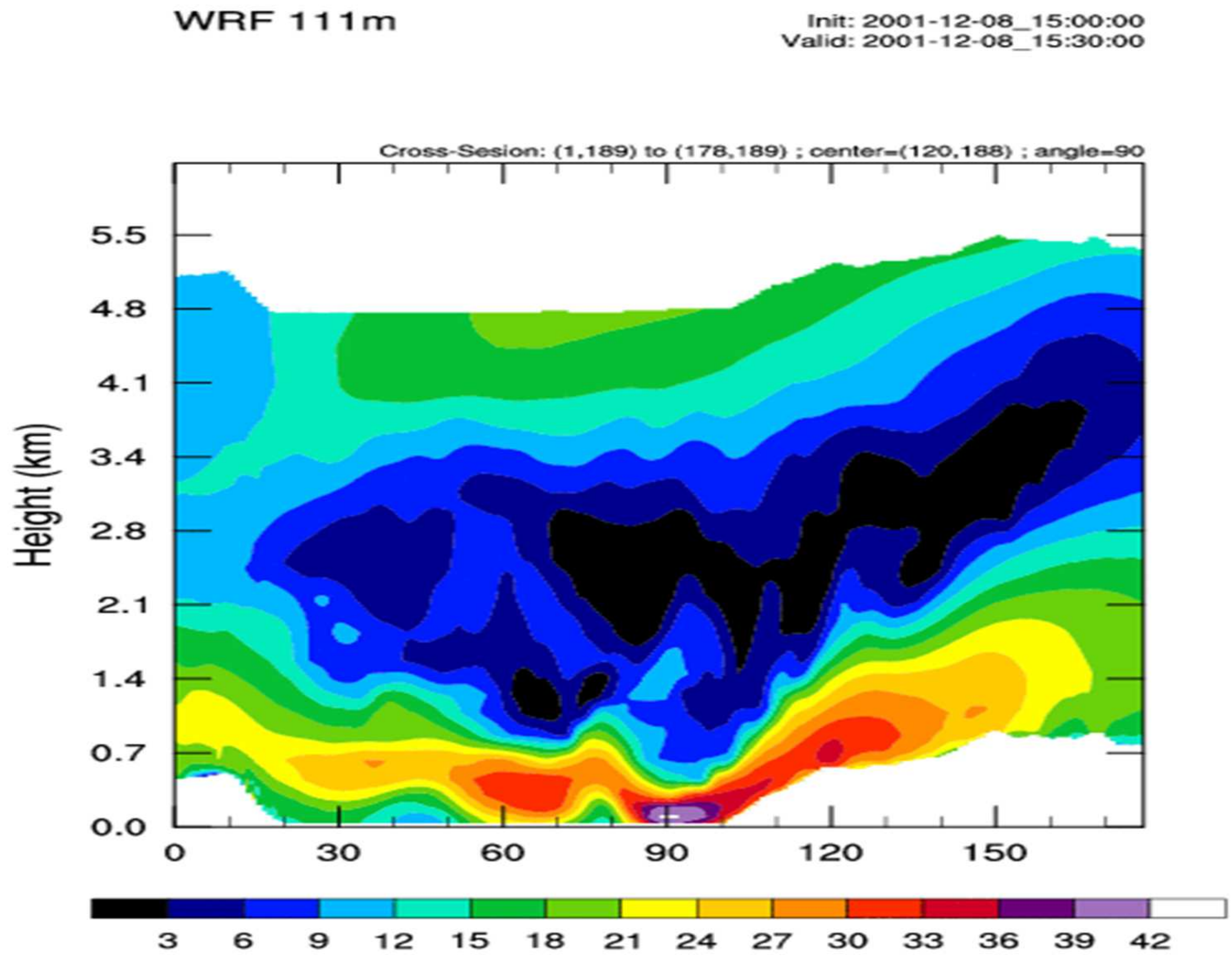
TYPICAL BORA EPISODE, SENJ, 08/12/2001; 6TH H EXPANDED – PULSATIONS!
sampling 1 sec, *Grisogono & Belušić Tellus 2009*

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*

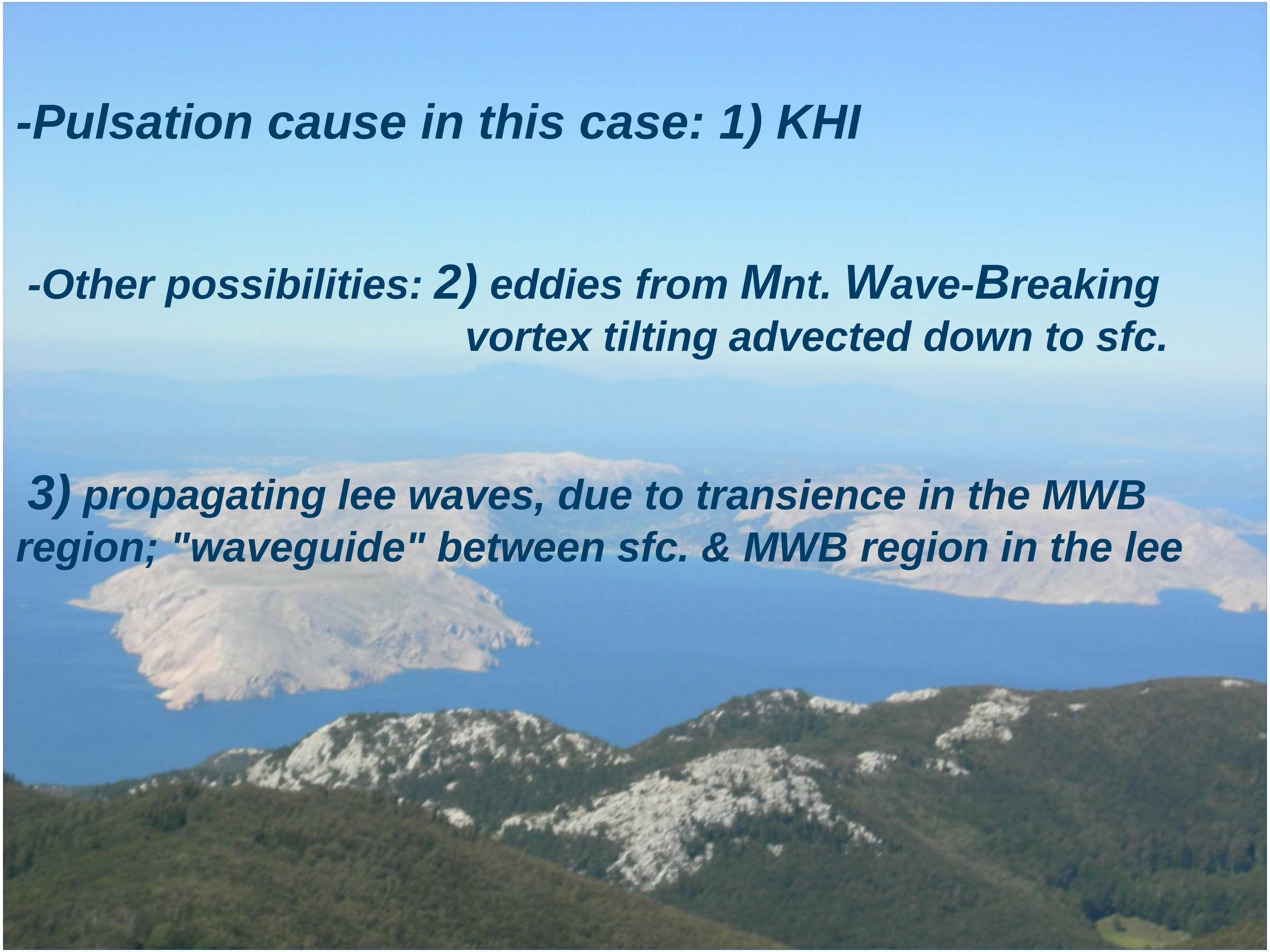




Courtesy of Mark Zagar, VESTAS, DK, 2010, submitted to Tellus as Rakovec et al. 2013
Redone simulation after Belušić et al. QJRMS 2007 (using COAMPS) now using WRF



Same as the former but vertical x-section (gridpoints): ~ Krk island ← Senj

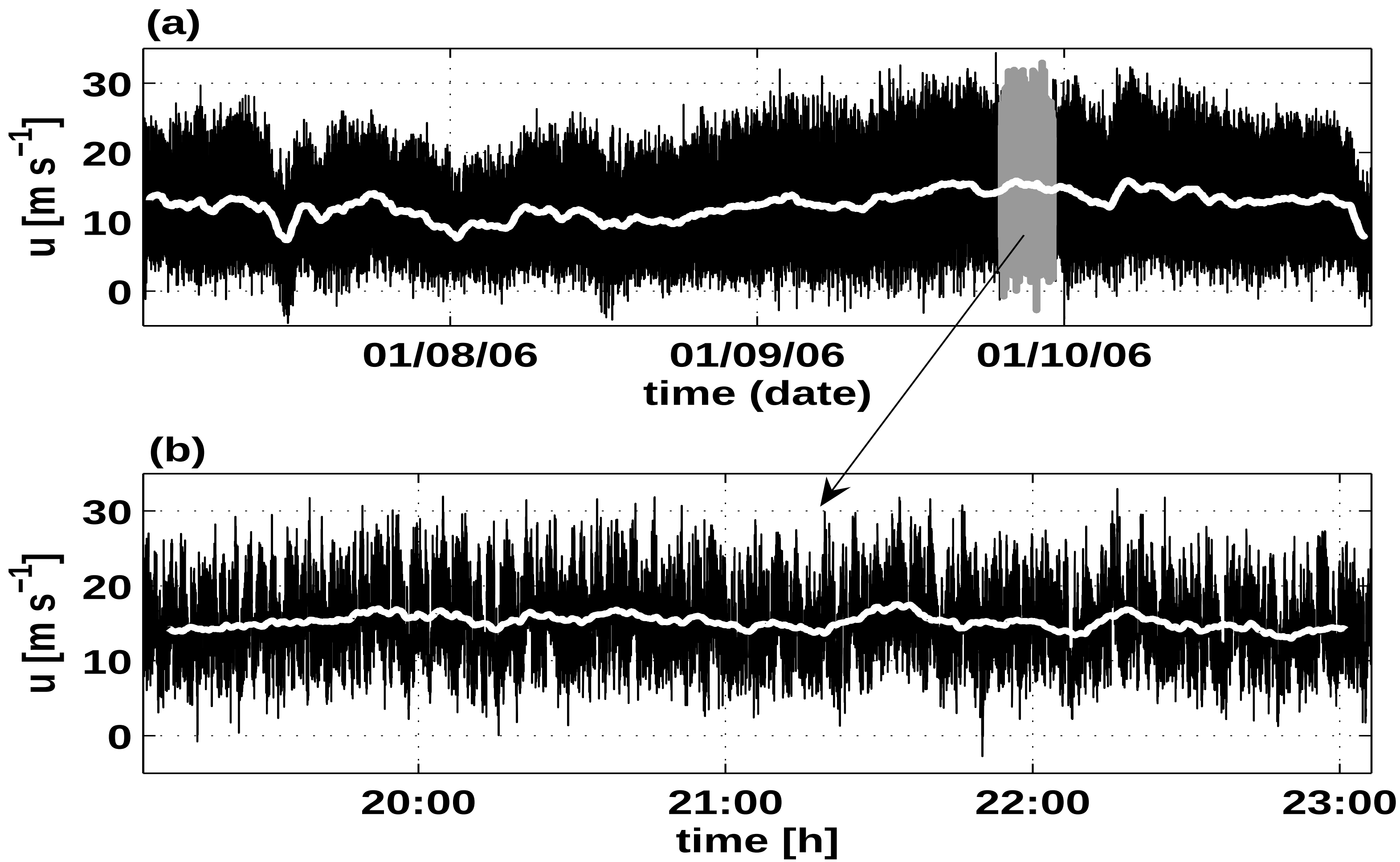


-Pulsation cause in this case: 1) KHI

-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

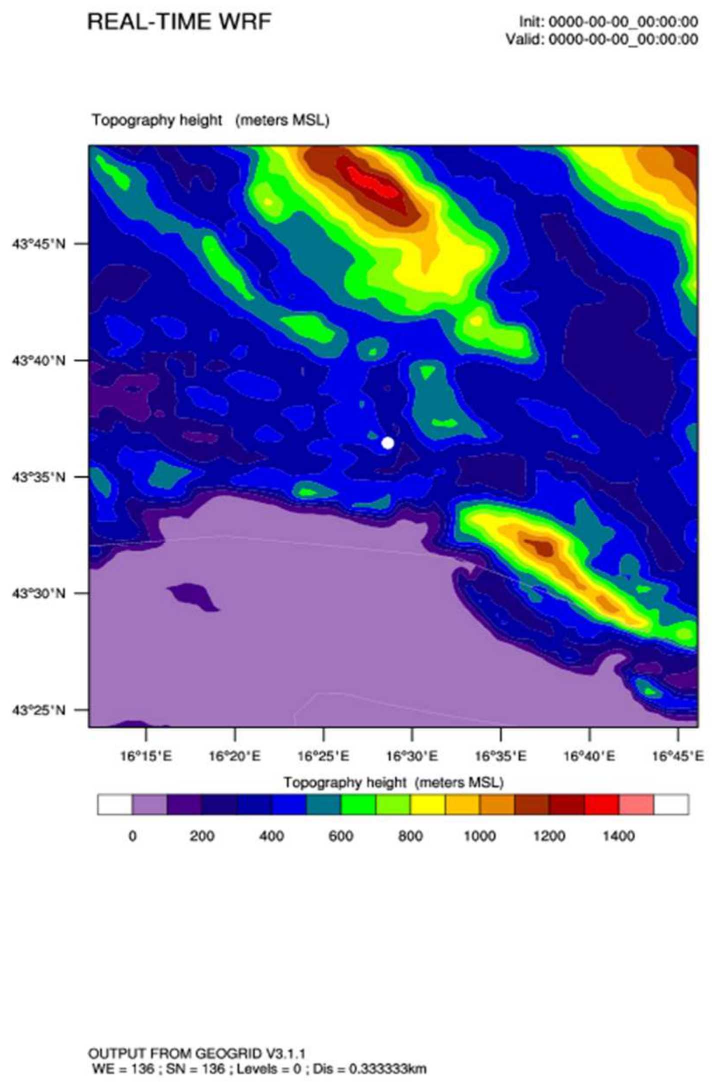
Senj, 2006

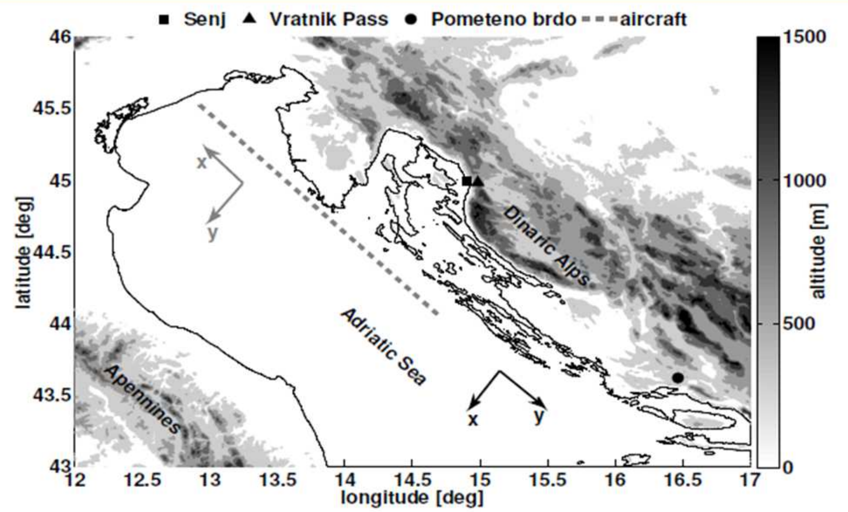


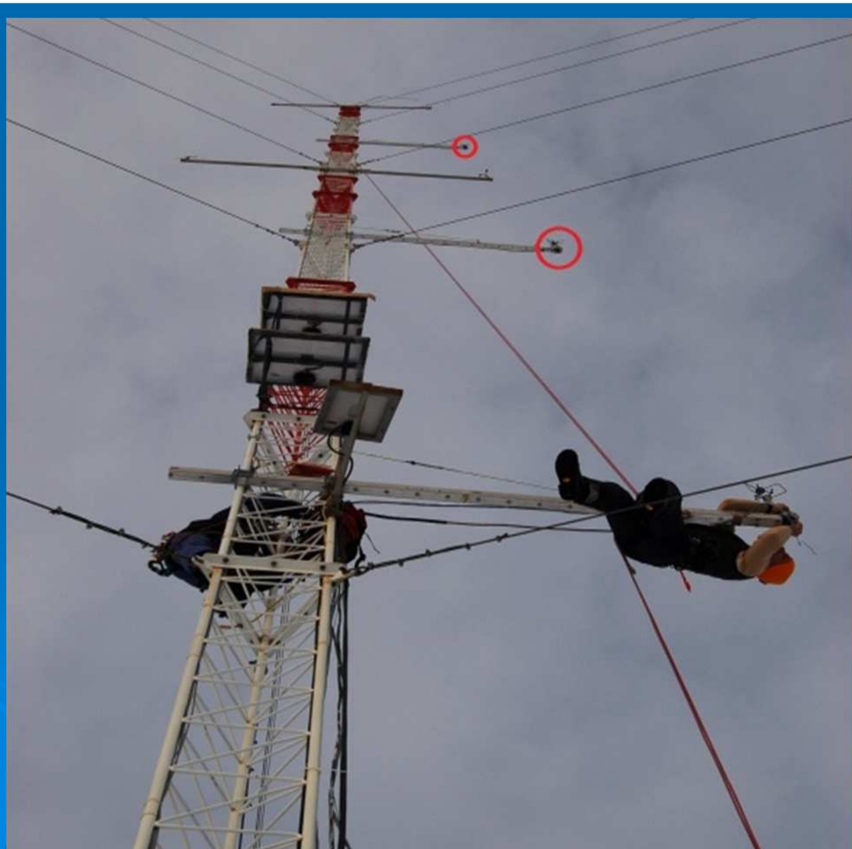
*(**a**) 4-day raw 4 Hz data near-sfc. time series, 07-11/01/2006, streamwise wind comp. **u**, 1h mean superimposed (**b**) 4 h with 10 min mean superimposed; Večenaj et al. 2010*

*⇔**TKE** ~ 10 – 20 m^2s^{-2}, ε ~ 0.5 – 1 m^2s^{-3}; related poster on turb. integral length-scale by Večenaj et al.*

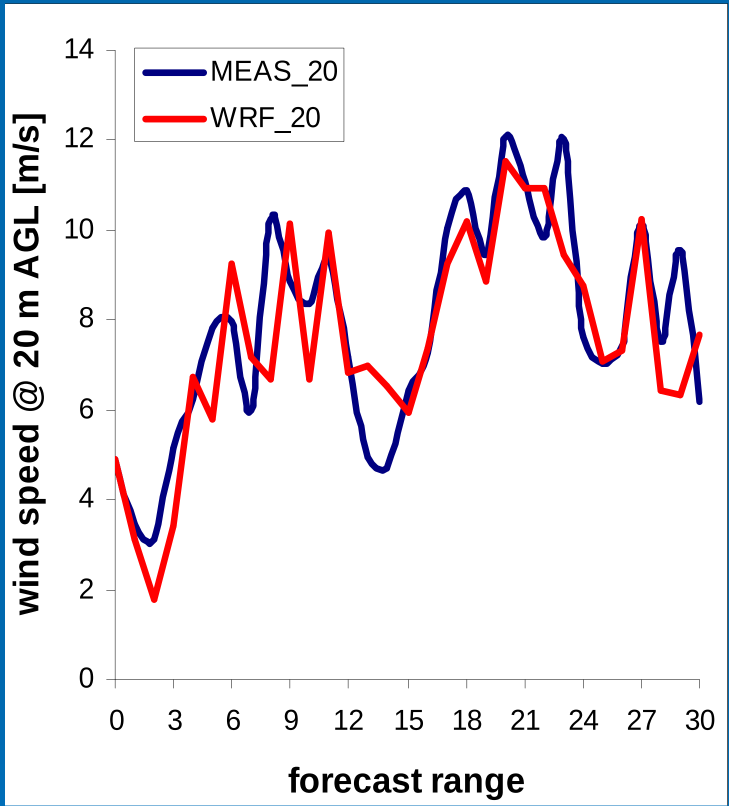
Works of K. Horvath, Ž. Večenaj,…

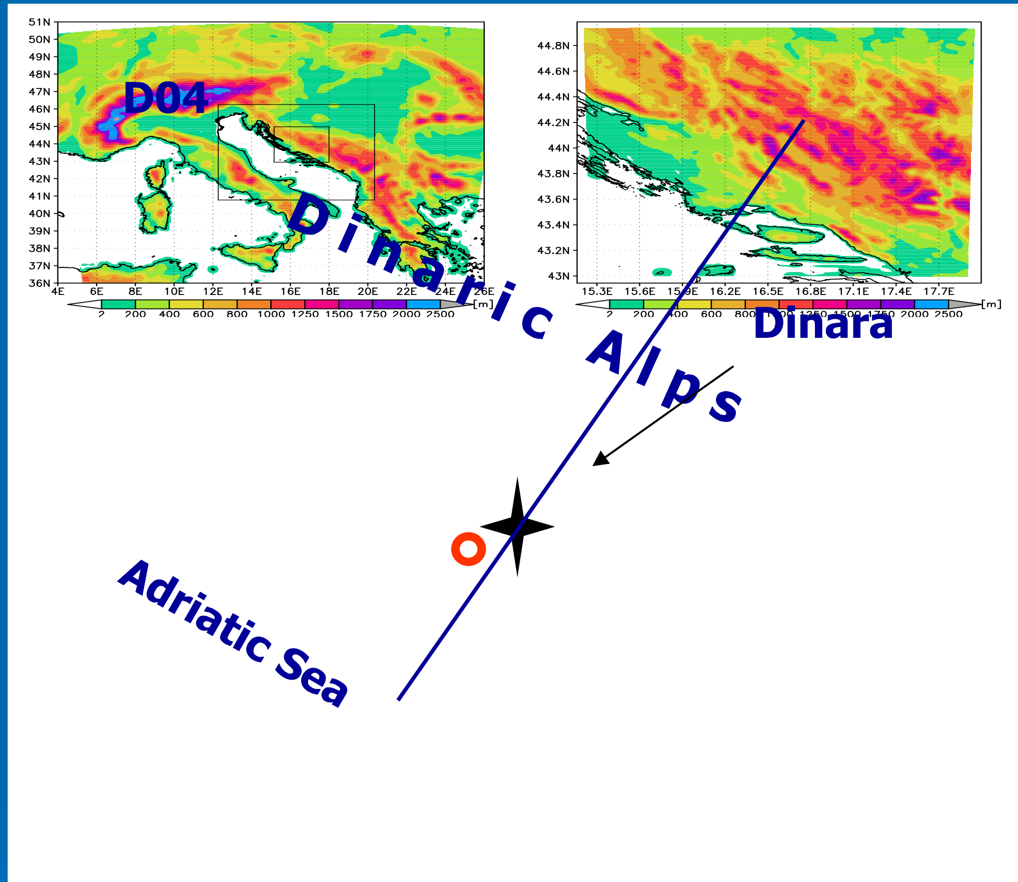






Central Adriatic coast, Dugopolje, upwind from Split

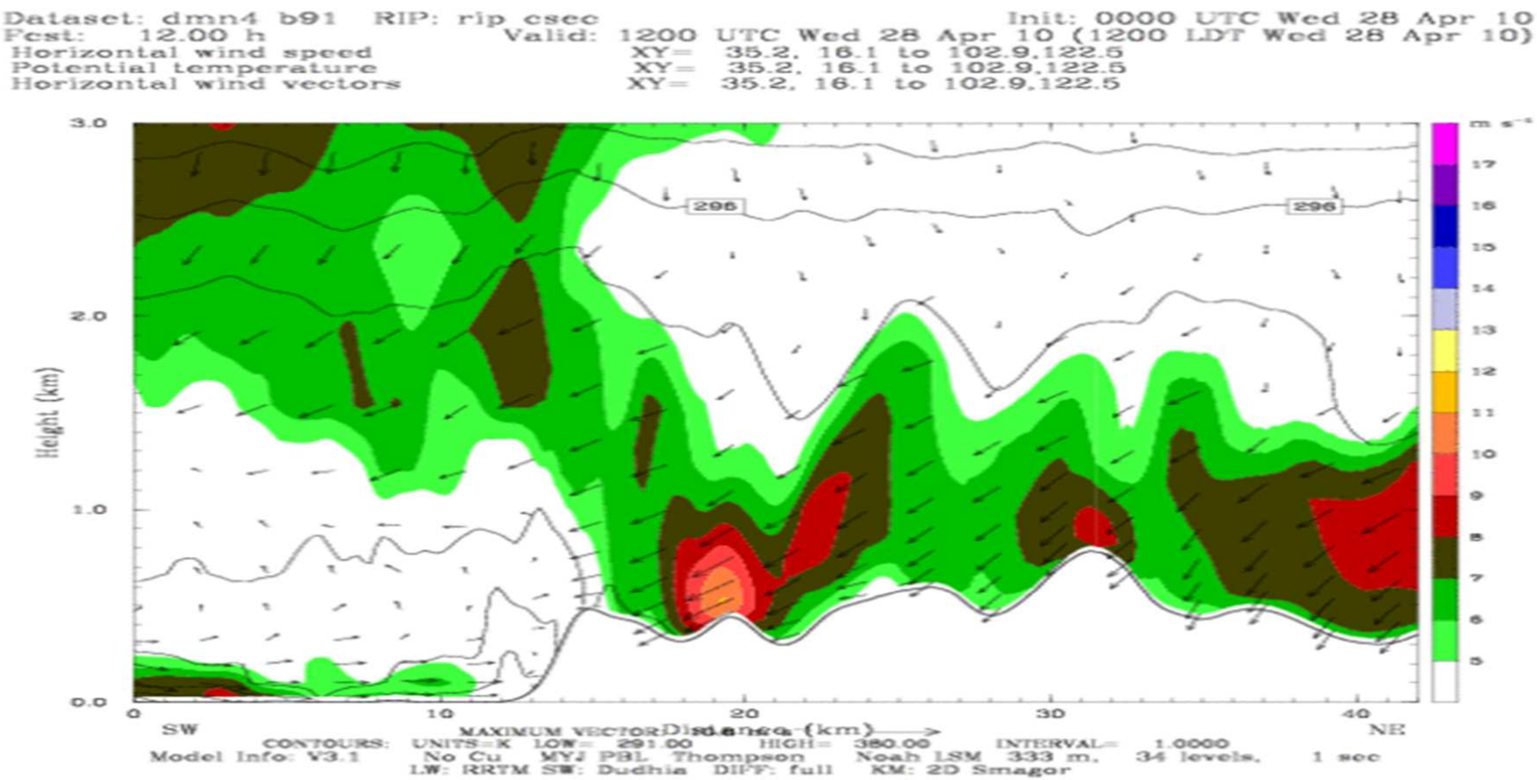




- *Related poster on obs. based 1D TKE long-lasting bora case by Babić et al.*
- *For non-Bora downslope (katabatic) flow, a weakly-nonlinear Prandtl model developed, ICAM2013, Slovenia*

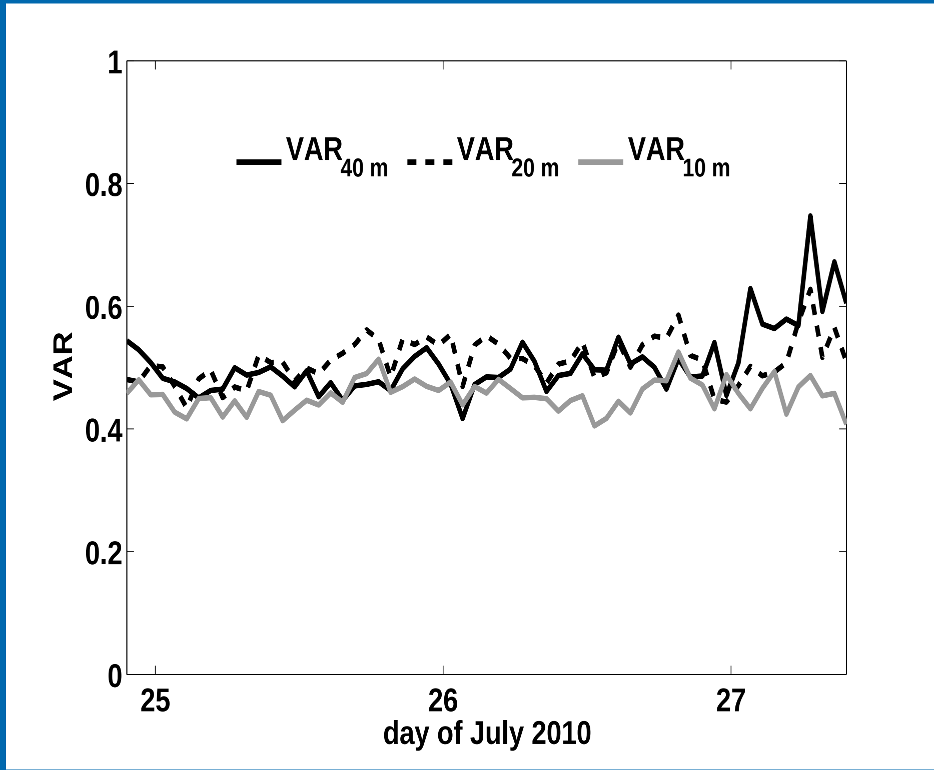
Dugopolje: modeled pulsations at noon, > 12 h…

*Simulated by Kristian Horvath using WRF (*work in progress*)*

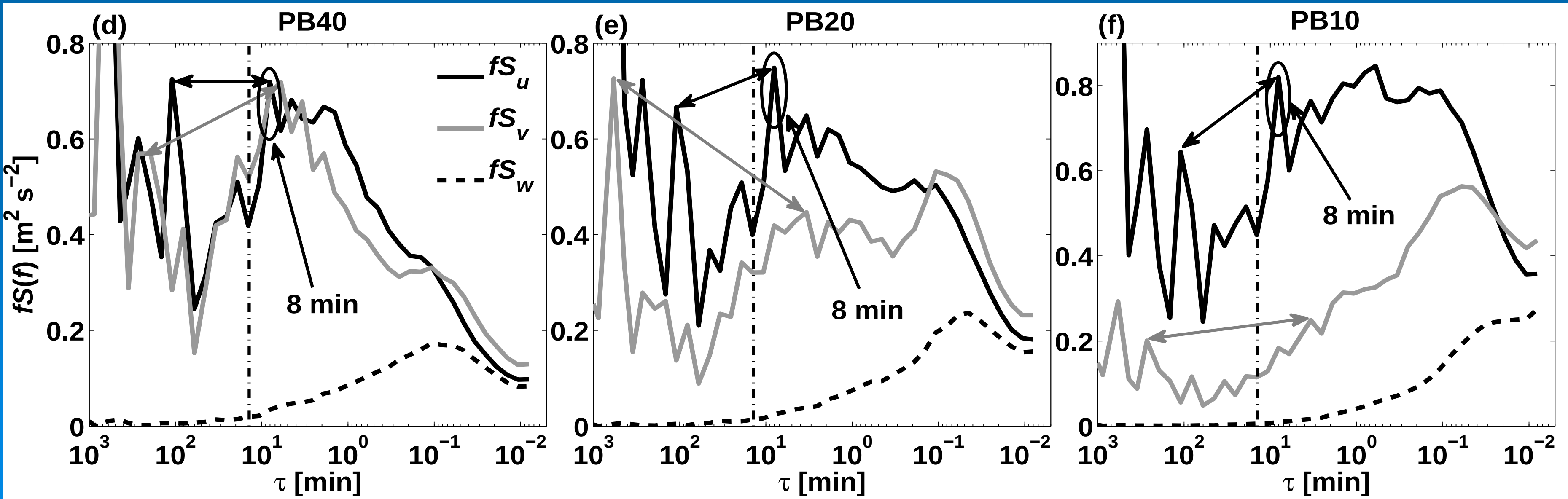


***V**elocity **A**spect **R**atio = anisotropy param.*
= vert/horiz. at Dugopolje, 2010.

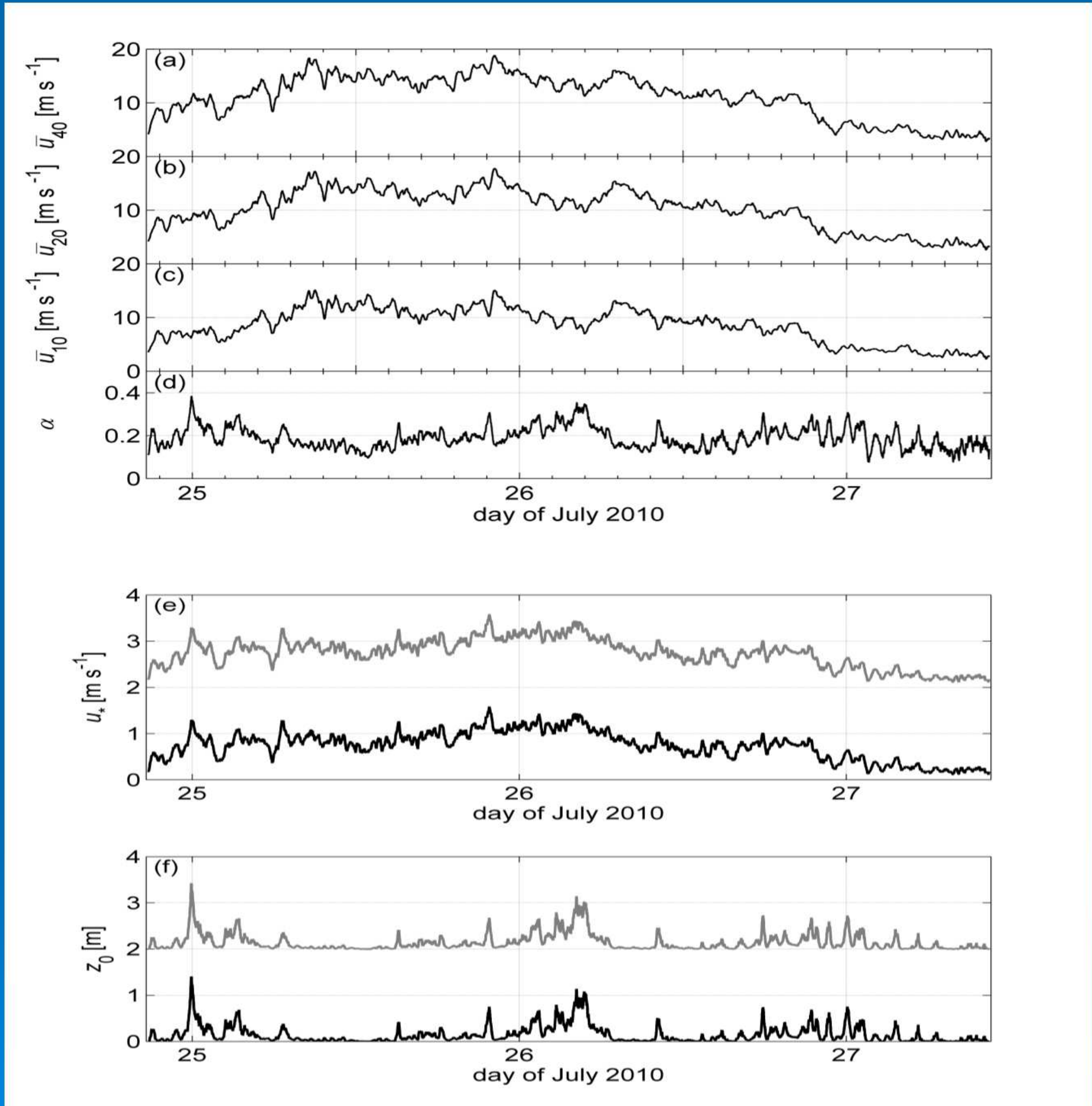
$VAR \equiv 2^{1/2}\sigma_w/[\sigma^2_u + \sigma^2_v]^{1/2}$ →



Wind comp. spectra at 3 levels (below)



Dugopolje, summertime bora case - continued



$$\frac{\bar{u}_z}{\bar{u}_{ref}} = \left(\frac{z_z}{z_{ref}}\right)^{\alpha}$$

Logarithmic law - black

Log. adjustment to the power low - grey

$\alpha = 0.189 \pm 0.049$

$u_* = 0.74 \pm 0.31$ m/s

$z_0 \approx 0.145$ m

bora wind ↑ ↔ (α, u_*, z_0)↓ bora: moderate ↔ strong => suburban ↔ rural u(z)

Other bora- & its turbulence issues…

- *Anomalous refraction of radio-waves, Viher et al. J. Atmos. Sol. Ter. Phys. 2013*

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

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

- *Fire-protection research, agriculture, traffic, future bora scenarios, etc.*

http://www.pmf.unizg.hr/geof
bgrisog@gfz.hr

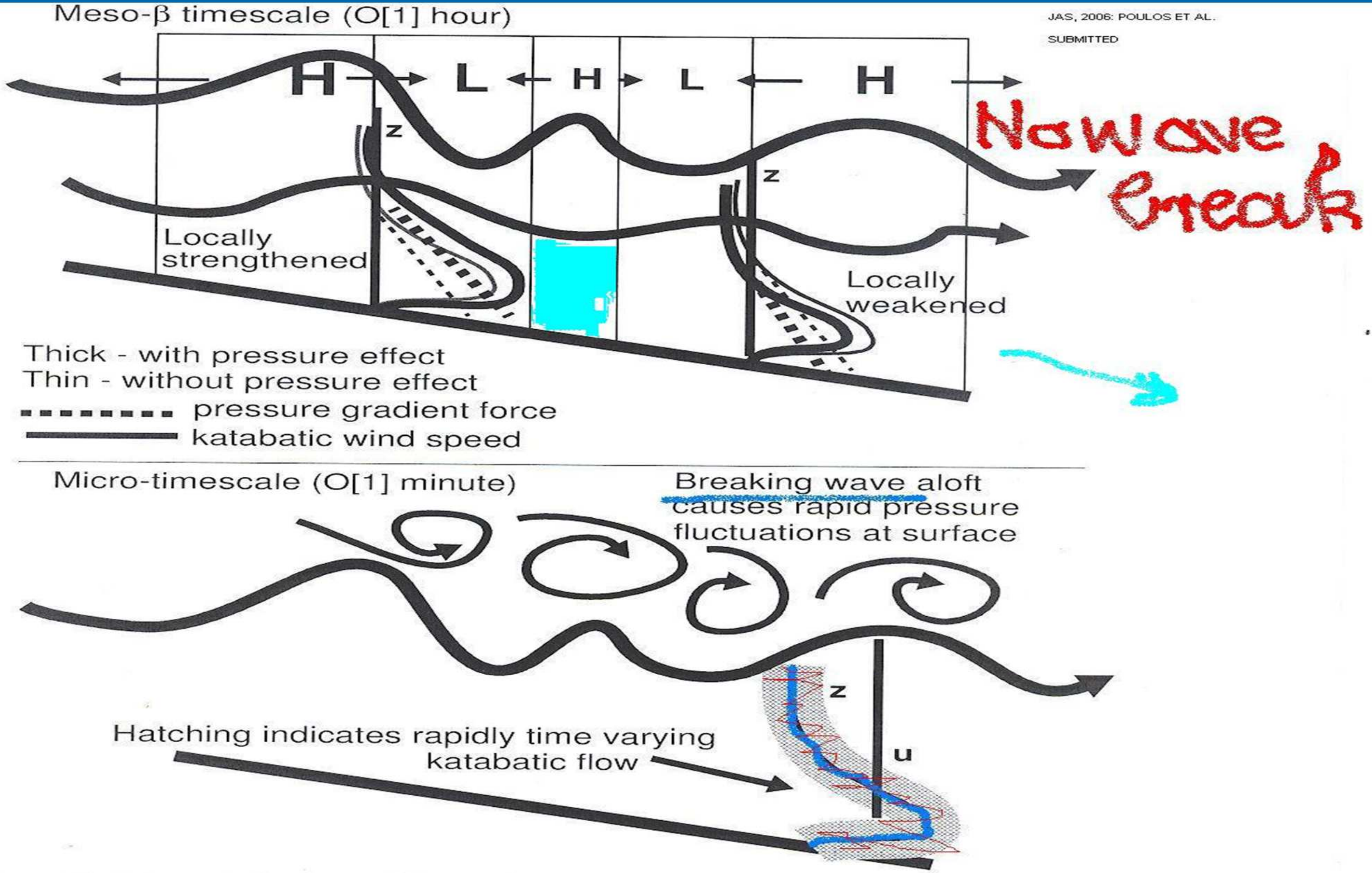


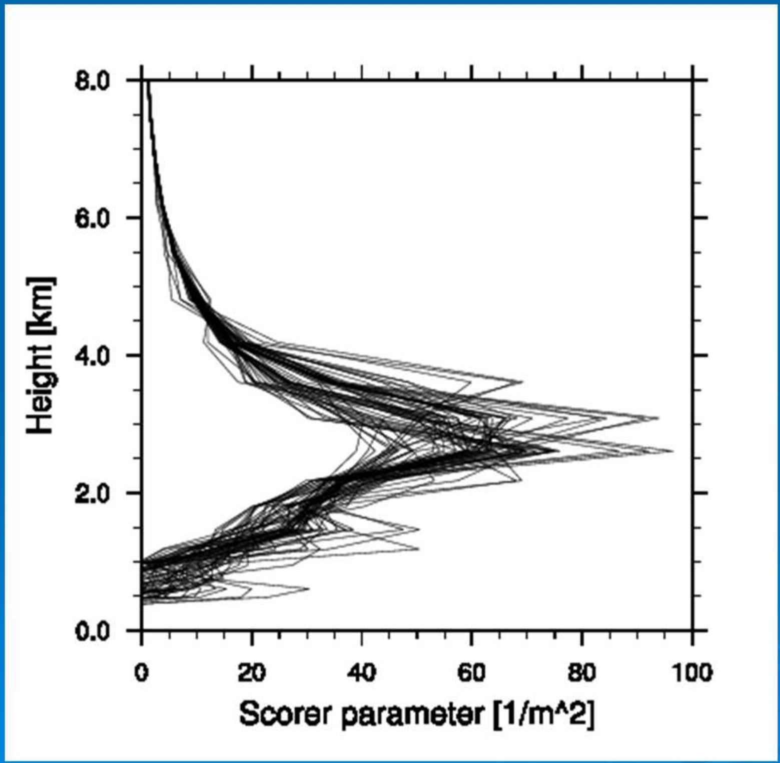
Figure 12. Schematic diagrams of the two dynamic pressure effects of mountain waves on katabatic flow. The upper diagram shows that, depending on location, katabatic flow can be either strengthened (upper slope case) or weakened (lower slope case), due to the integrated column pressure structure of the 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

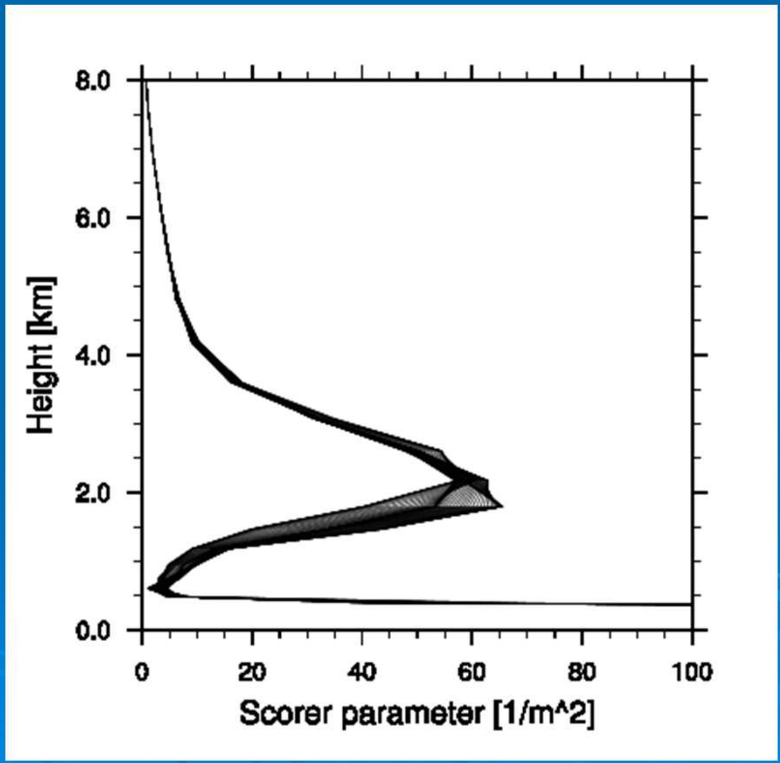
Daytime pulsations: upstream variability

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

- Related to lee side pulsations?



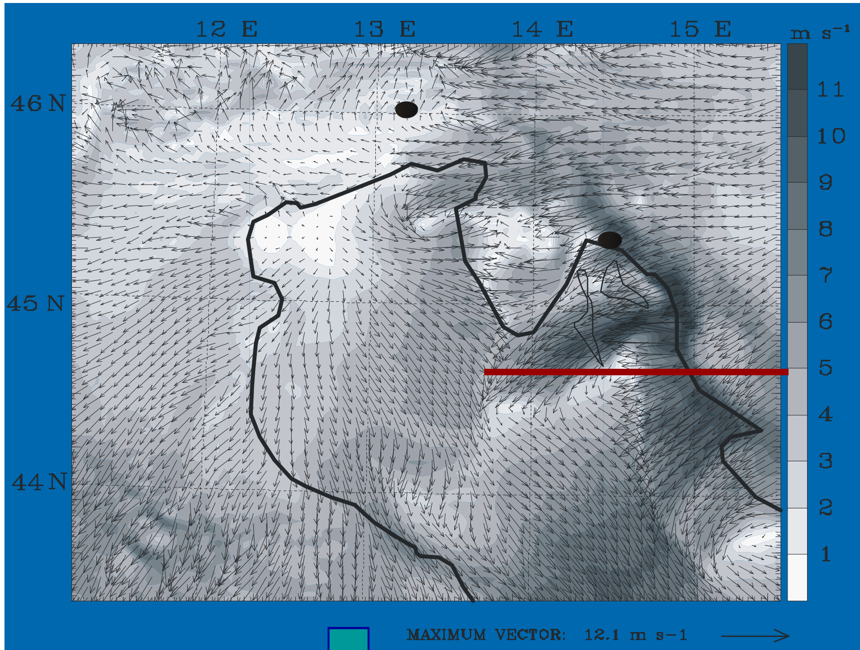
*Daytime * 10^7*

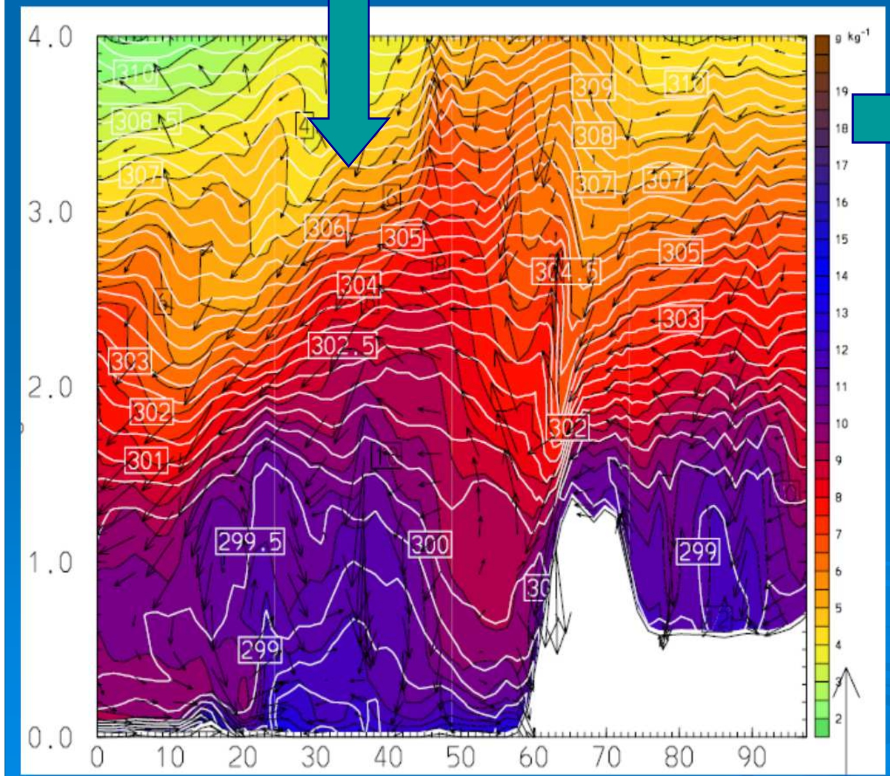


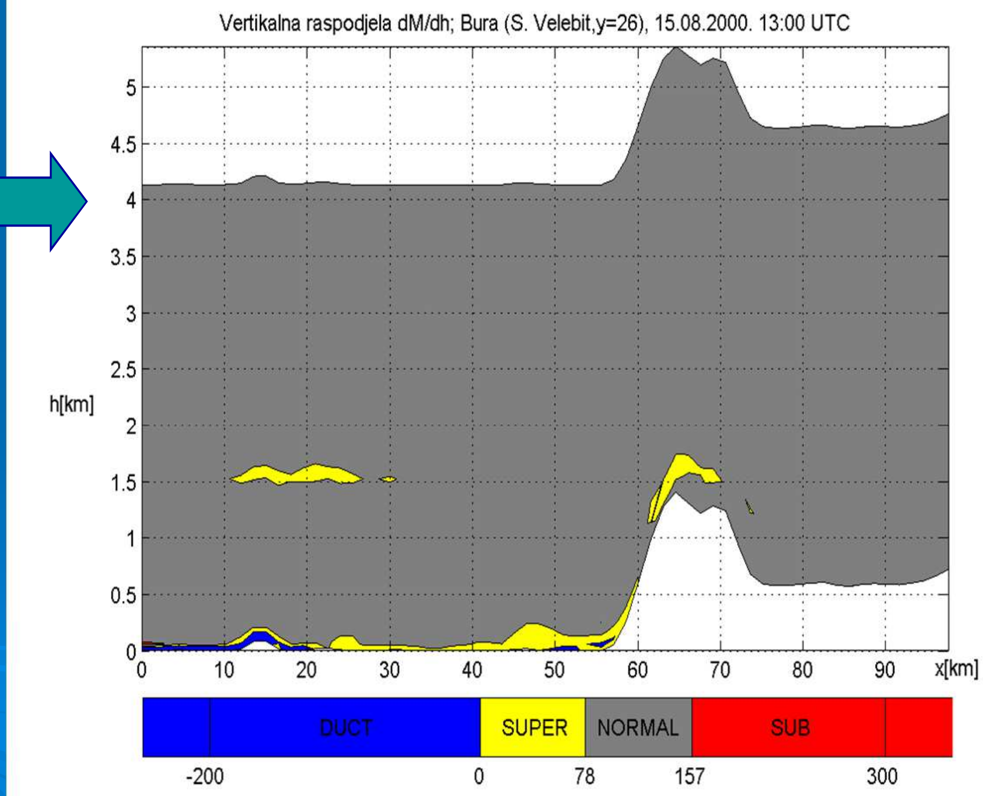
*Nighttime * 10^7*

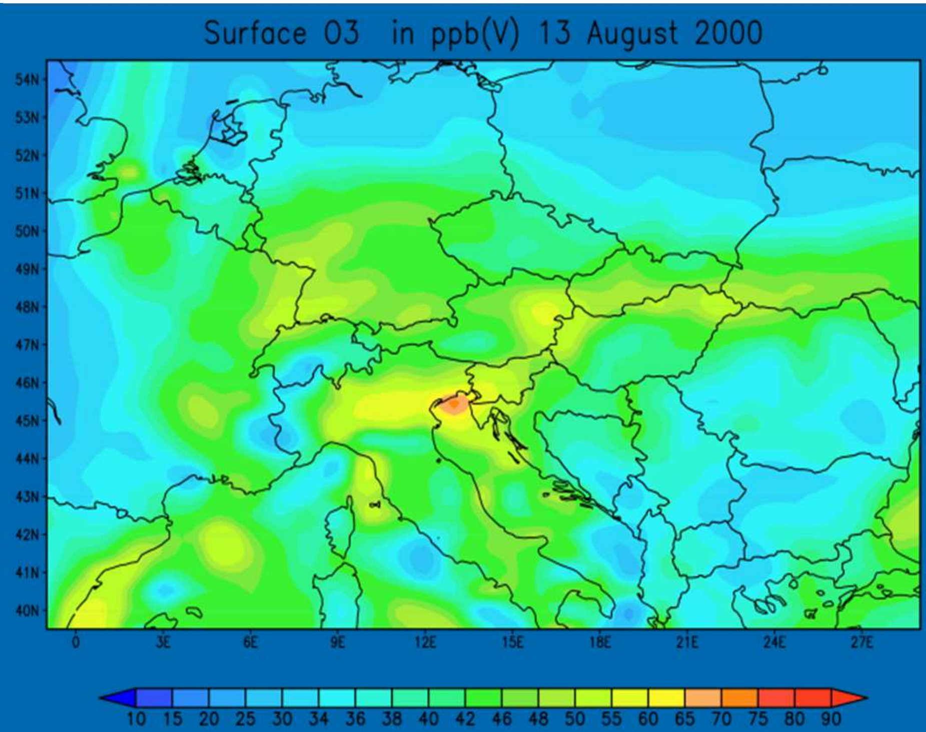
Anomalous refraction of radio-waves during bora

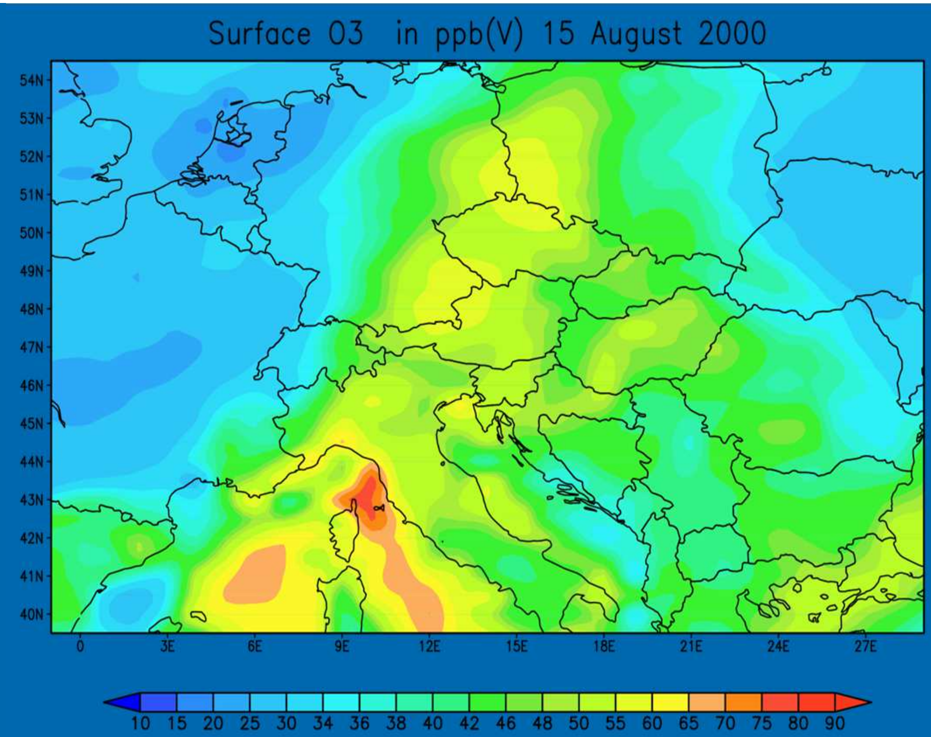
M. Viher et al. J. Atmos. Sol. Ter. Phys. 2013
+ diploma work I. Horvat 2013



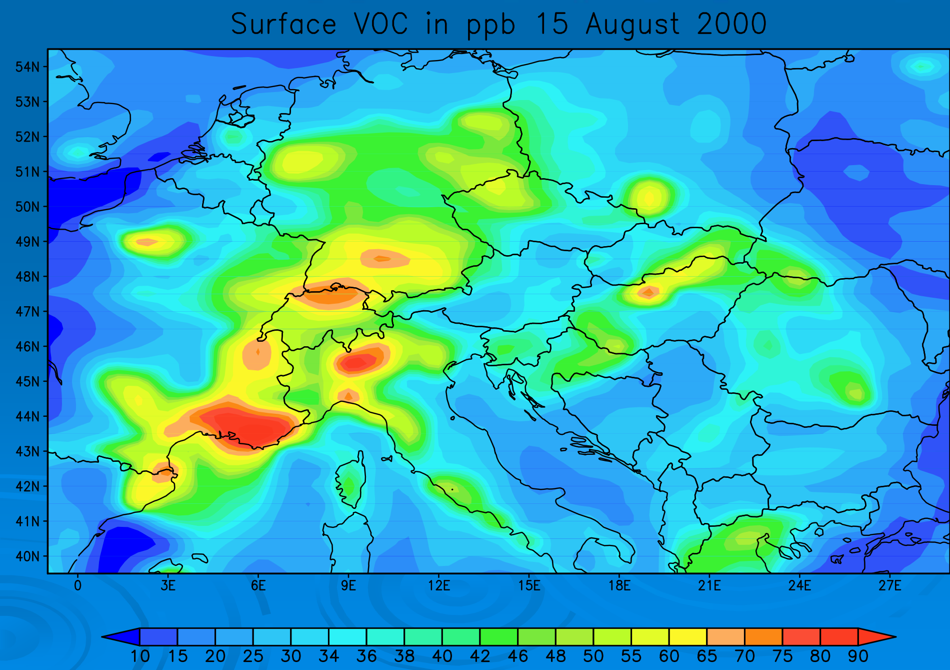




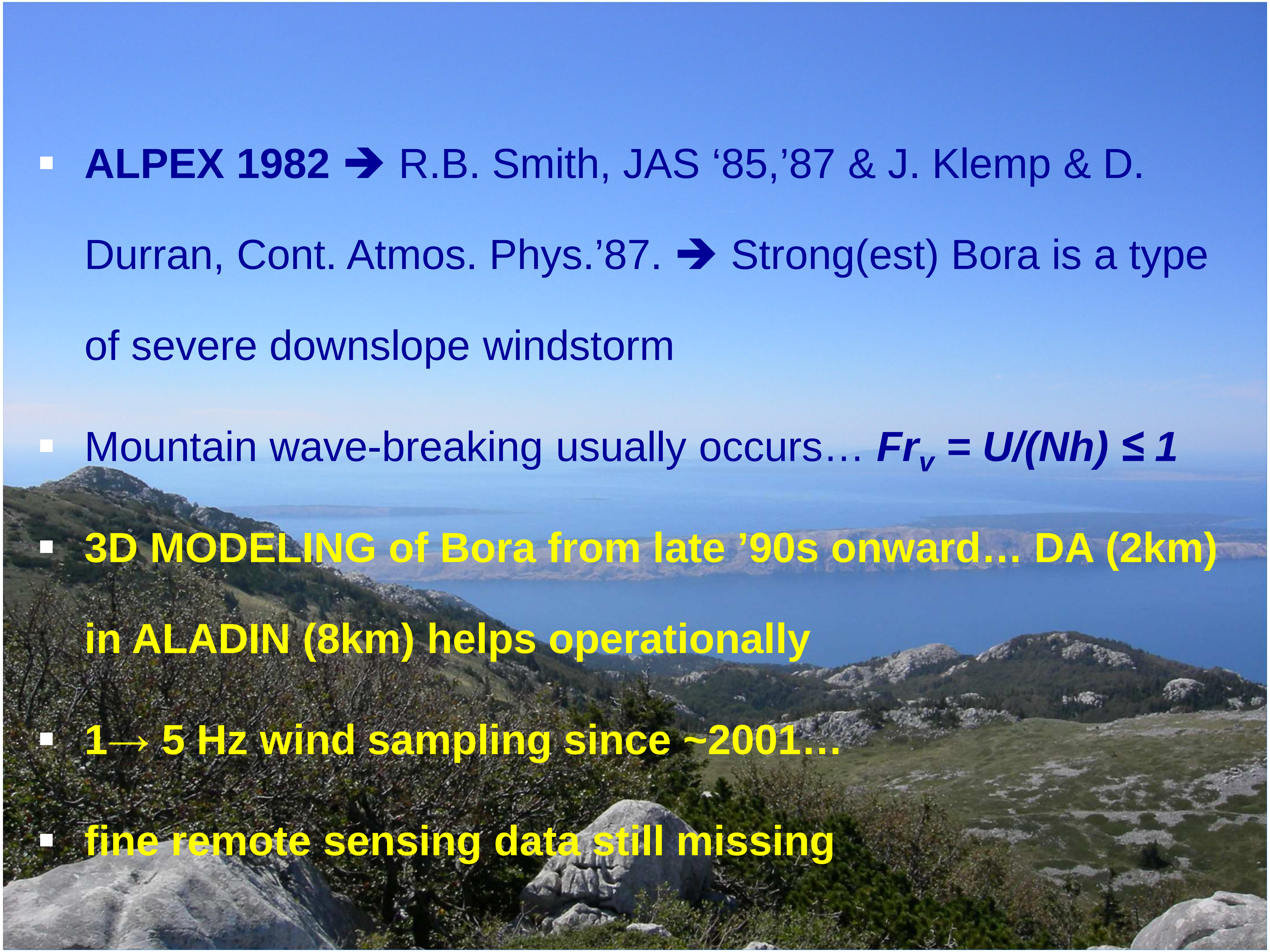




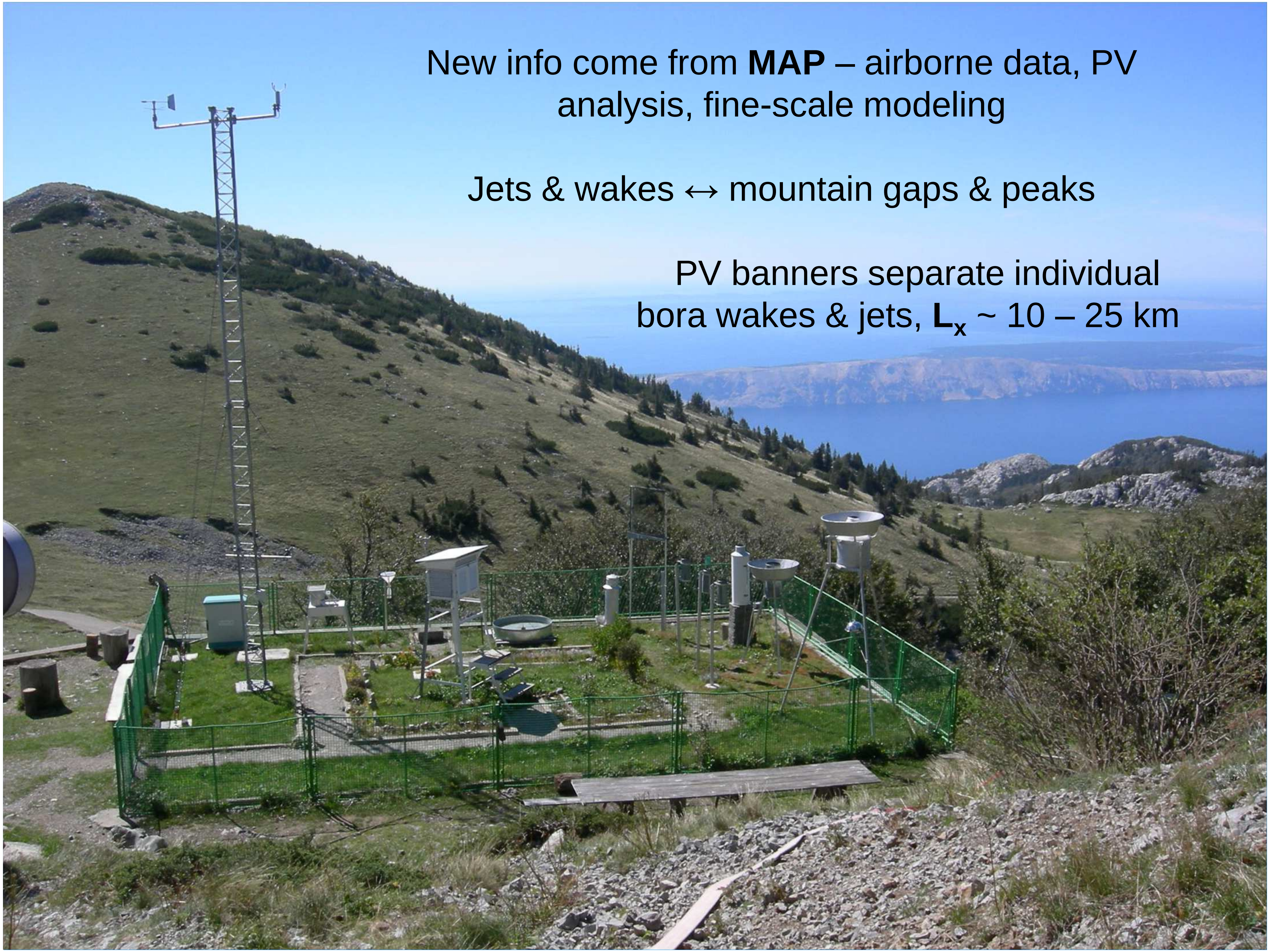
Near-sfc. O_3 & VOC in summer
13.08. no bora → 15.08. with bora



M.Telišman Prtenjak et al. Met. Appl. 2013 in press



- **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… $\boldsymbol{Fr_v = U/(Nh) \leq 1}$
- **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, $\mathbf{L_x}$ ~ 10 – 25 km