Downslope windstorms over very complex orography: formation and development of pulsations

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Introduction:: bora winds

- Bora – gusty NE downslope windstorm along the eastern Adriatic coast
- Wind speeds > 40 m/s
- H5 wind gusts ~ 70 m/s
- Large temporal (and spatial) variability
Introduction:: pulsations

- Quasi-periodic behavior of bora gusts (e.g. Petkovšek, 1976), ~ 3-11 min (e.g. Belušić et al., 2006) = pulsations
- Three mechanisms proposed:
  1. Vortex tilting in the wave-breaking region (Clark and Farley, 1984)
  2. The effect of propagating lee waves (Clark et al., 1994)
- All 3 mechanisms require wave-breaking (thus non-local)
- In the Adriatic, mechanism of bora pulsations is KHI (Belušić et al., 2007)
WINDEX measurement campaign

1) 60-m wind tower on Pometeno brdo
   - 3 sonics at 10 m, 22 m and 40 m (5Hz)
   - 2 cup & vane anems at 30 m and 60 m

2) SODAR on Split Airport
   - 10 m vertical resolution (up to 300 m)

Period: 3 months (Feb-May 2010)
Anticyclonic bora episode 28 Apr 2010
Wind tower measurements on 28 Apr 2010

- Medium to strong bora event: near-surface winds reaching 15 m/s
- Streamwise wind speed component
Measurements:: pulsations

- The evolution of pulsations (running spectra)
Numerical modeling

- The WRF model setup:
  - 4 one-way nested domains (dx=9|3|1|0.333 km)
  - 40 vertical levels
  - IC&LBC – ECMWF_OA
  - MYJ, KF, Thompson
  - Noah LSM
  - True horizontal diffusion

![Map of Dinaric Alps and Adriatic Sea with labeled locations: D04, Upstream UP, Tower, SODAR, Lee L1, Mnt. Top MT, Lee L2](map.png)
Structure and point verification

- Large spatial wind speed variability due to individual mountains
- Fair representation of wind speed at tower location
Numerical simulations: Representation of pulsations

- Pulsations at tower location are represented to an extent, but simulated pulsations have less energy than observed.
Daytime flow & pulsations

- Daytime flow is unstationary
- Pulsations:
  - The most intensive beneath the primary breaking mountain wave
  - Travel far away from the origin point
  - $R<0.25$ not always found near the primary gravity-wave breaking region
- KHI mechanism questionable
Nighttime flow & pulsations

- Nighttime flow more stationary
- Pulsations:
  - More sporadic
  - Appear beneath the breaking mountain wave
  - Dissipate quickly downstream of the origin point
  - Ri<0.25 found near the primary gravity waves
- Pulsations point to Kelvin-Helmholtz instability
Propagation of pulsations:: large spatial variability

Pulsations (8-15min) develop for $T \sim 3-8$ min.

Background flow Pulsations (8-15min) form and degrade over time.

Formation and degradation of pulsations are observed in different regions:
- **P16 40m streamwise wind speed**
  - Formation
  - Degradation

- **P06 40m streamwise wind speed**
  - Formation
  - Pulsations develop for $T \sim 3-8$ min.
Pulsations: upstream variability

- Daytime pulsations of T~8-15 min are present both upstream and downstream
- Could these daytime pulsations be caused by 1) background flow properties and/or 2) local surface forcing?
Pulsations:: upstream variability during daytime

- Scorer parameter of the background flow during daytime

![Power spectrum graph](image)

Where does variability of the daytime upstream Scorer parameter come from?
Pulsations:: upstream variability during daytime

- The effect of surface fluxes

![Graph showing the effect of surface fluxes on pulsations upstream during daytime. The graph compares the Power spectrum [m^2/s/Hertz] for two scenarios: CONTROL and NO FLUXES. The period is given in seconds (s).]
Pulsations:: no fluxes from the surface

Reduced intensity of pulsations during daytime, primarily for $T \approx 8$ min
Conclusions

- 3-dimensional bora flow in the mid-Adriatic is more complex than in the north
- Pulsations found in $u$, $v$ and $w$, but not always at the same time
- Two regimes of pulsations are found:
  - A) Smaller-scale pulsations predominantly point to KHI mechanism. They may occur regardless of the period of day
  - B) Larger-scale pulsations point to effects of upstream variability and surface forcing
- These two regimes of pulsations may act in concert
Pulsations in the background flow

- Daytime pulsations (8-11min) are present in the near-surface daytime background flow.