Bora flow over the complex terrain of the mid-Adriatic area

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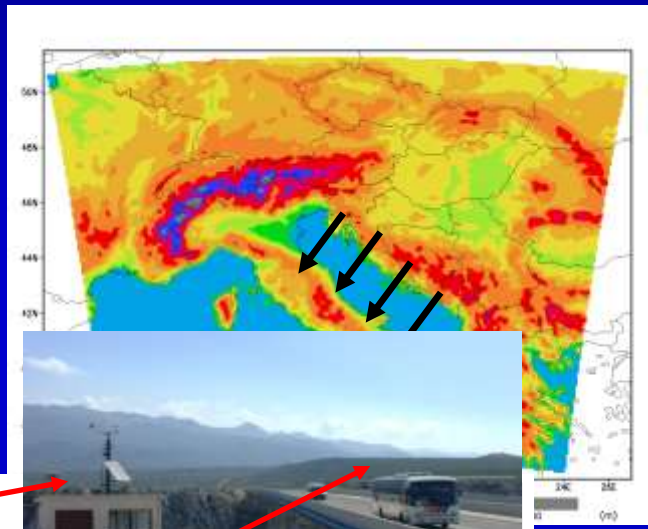
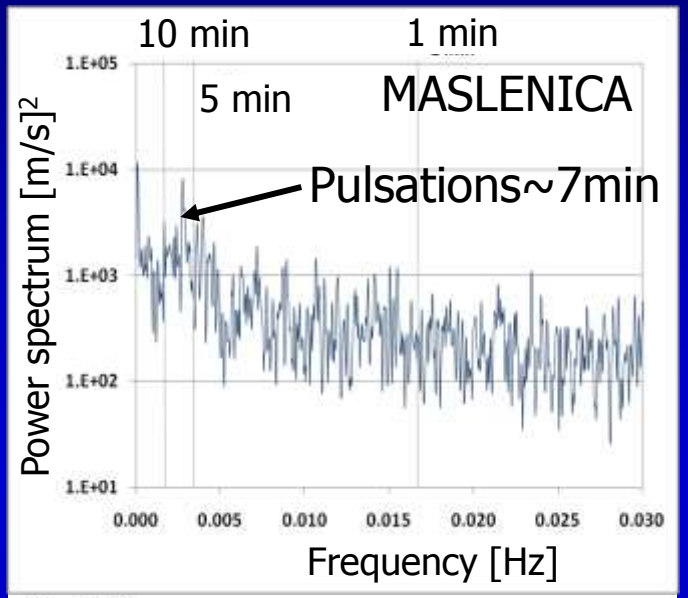
Introduction:: bora winds

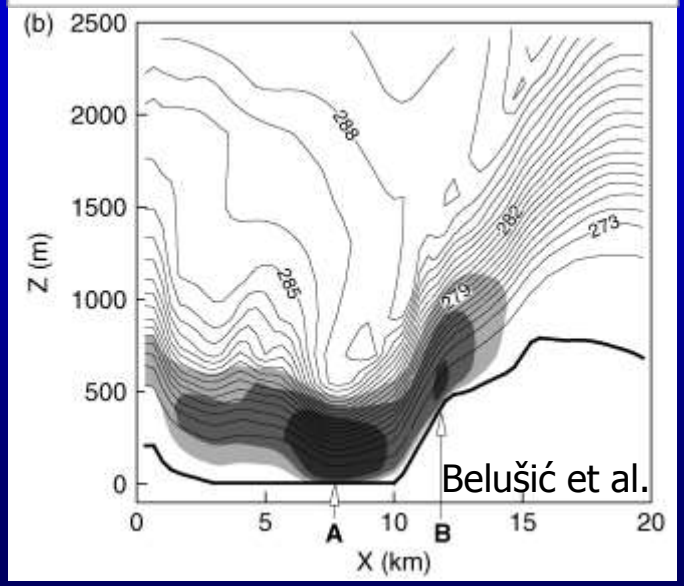
- Bora – gusty NE downslope windstorm all along the eastern Adriatic coast
- Hurricane wind speeds/gusts: 40/70 m/s
- Large temporal (GF~3) and spatial variability
- Cross-cutting issue: hard to measure, simulate and predict



Introduction:: pulsations

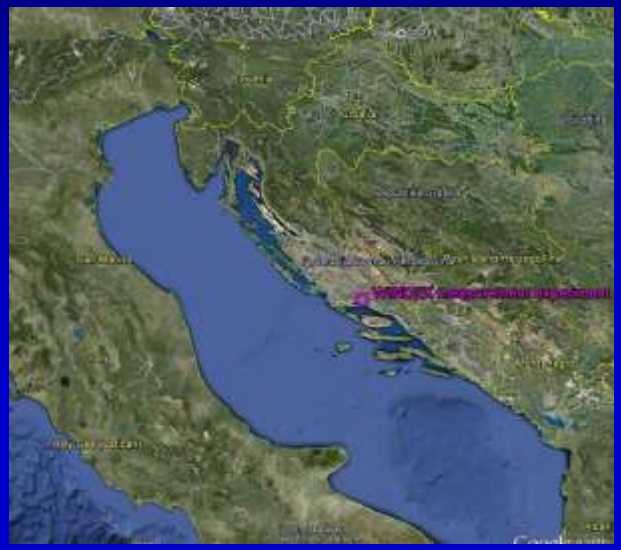
- Downslope windstorms: quasi-periodic behavior, so-called pulsations
- Three mechanisms proposed:
  - 1. *Vortex tilting* in the wave-breaking region (Clark and Farley, 1984)
  - 2. The effect of *propagating lee waves* (Clark et al., 1994)
  - 3. *Kelvin-Helmholtz instability* (KHI) between low-level shooting flow and wave-breaking aloft (Scinocca and Peltier, 1989, P&S1990, Smith 1991)
- Pulsations in bora (e.g. Petkovšek, 1976; Belušić et al., 2006)
- Proposed mechanism of bora pulsations in the n. Adriatic is KHI (Belušić et al., 2007)



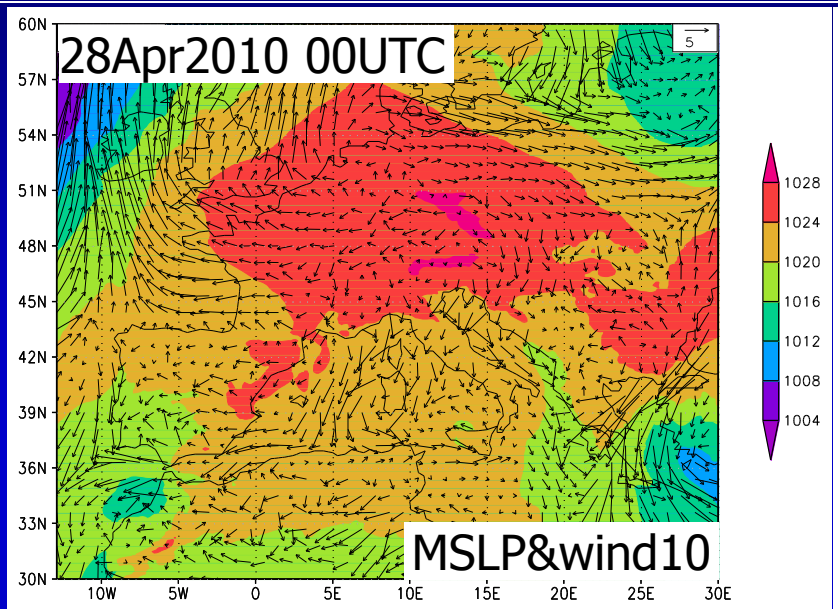


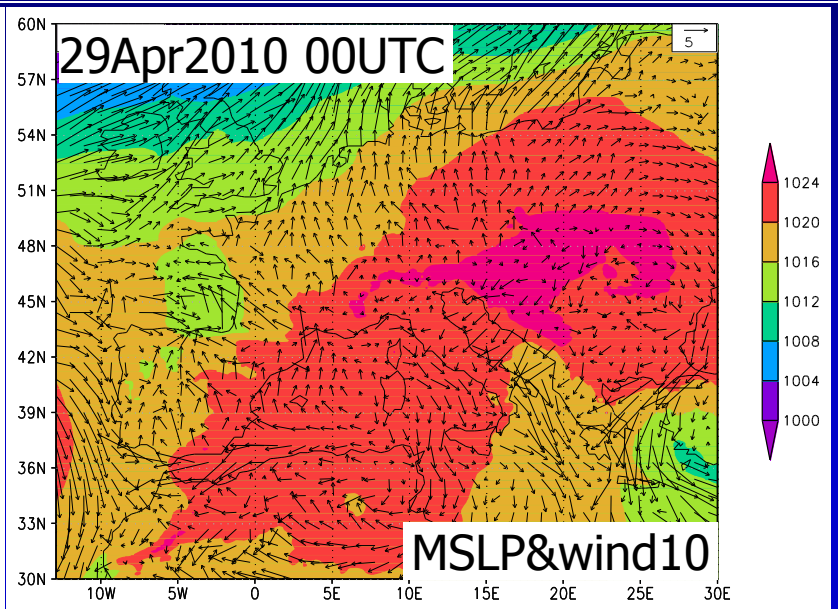
WINDEX feat. BORA measurement campaign

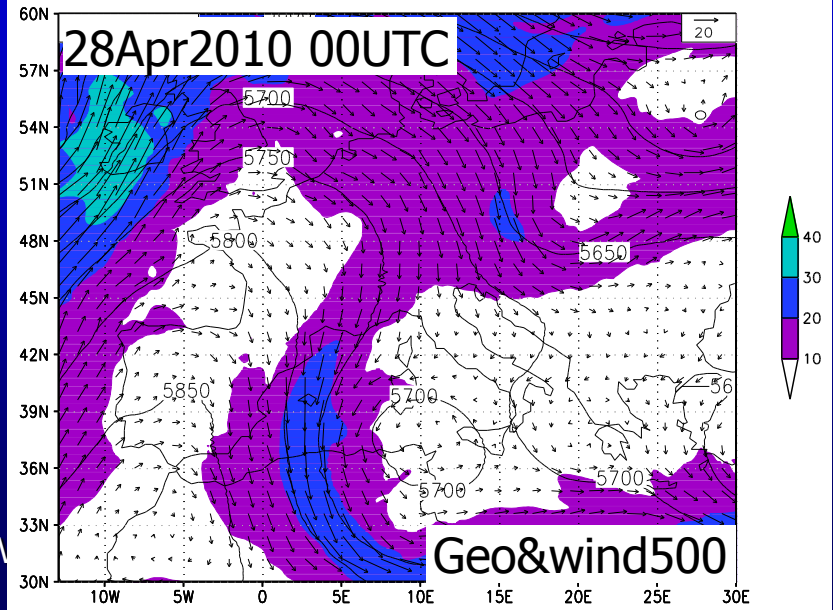
- 1) 60-m wind tower on Pometeno brdo
  - 3 sonics at 10 m, 22 m and 40 m (5Hz)
  - 2 cup & vanes at 30 m and 60 m
- 2) SODAR on Split Airport
  - 10 m vertical resolution (up to 300 m)
- Period: 3 months (Feb-May 2010, extended May 2011)

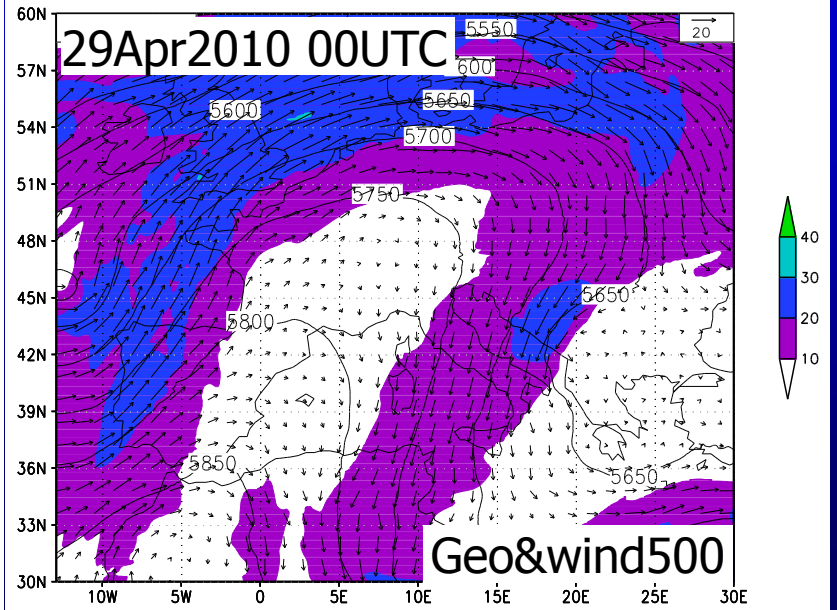


Anticyclonic bora episode 28 Apr 2010



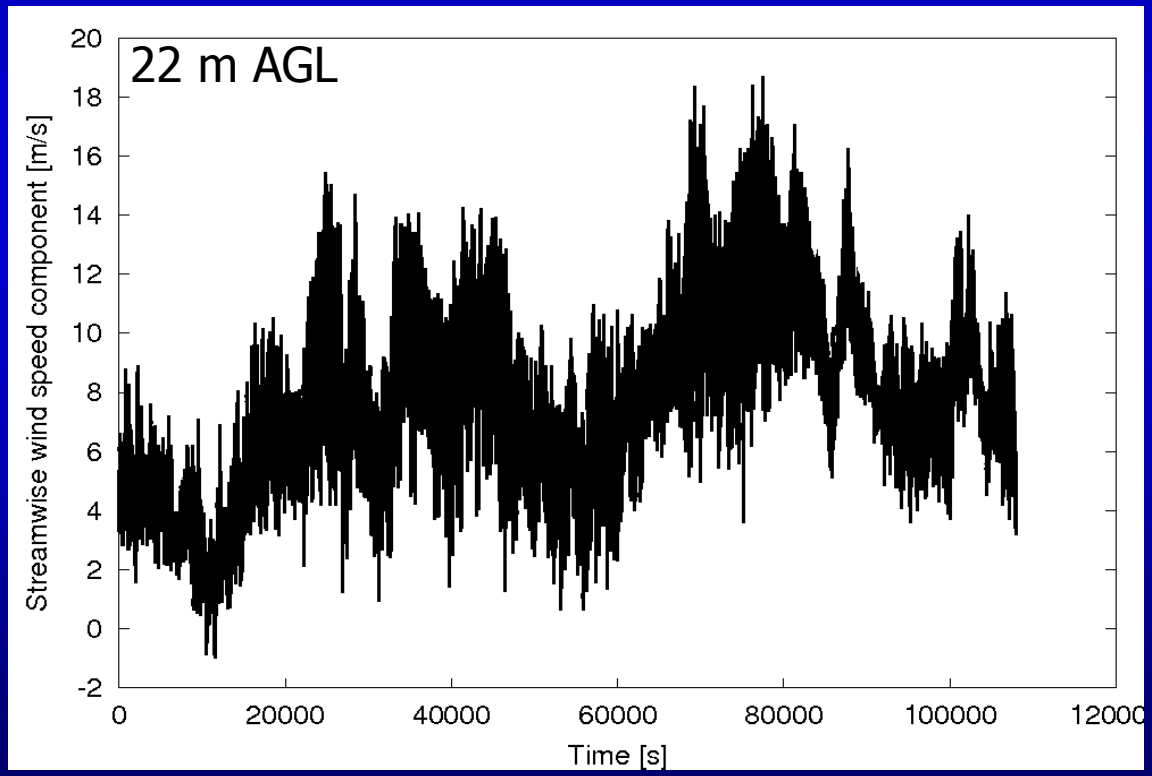






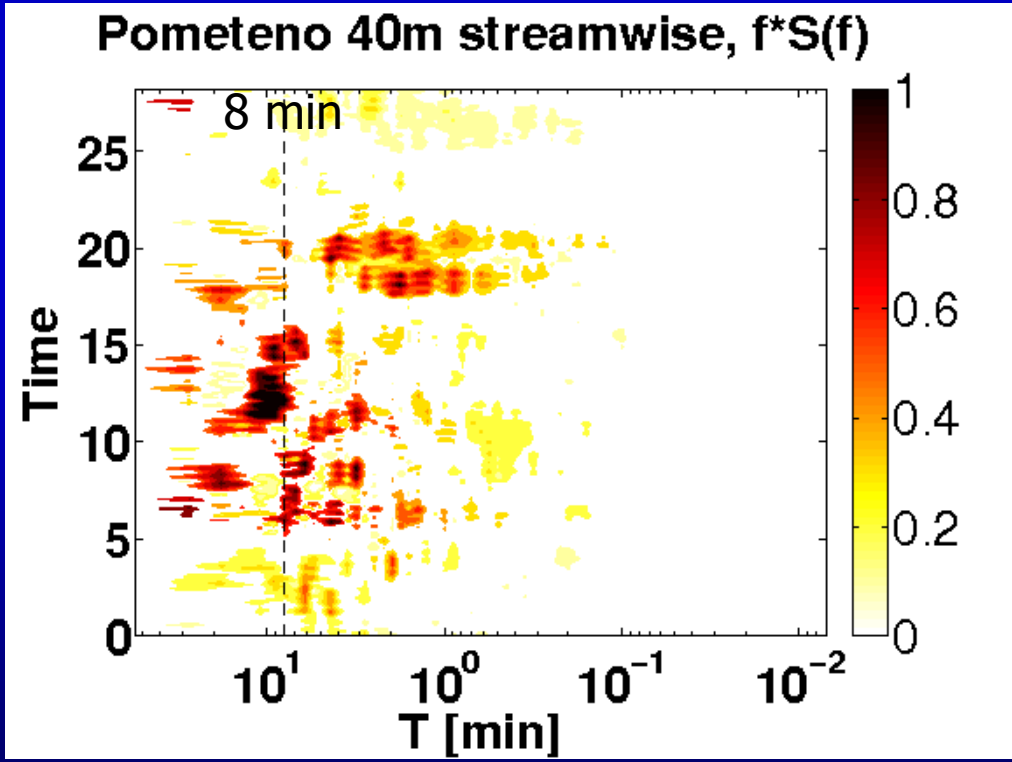
Wind tower measurements on 28 Apr 2010

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



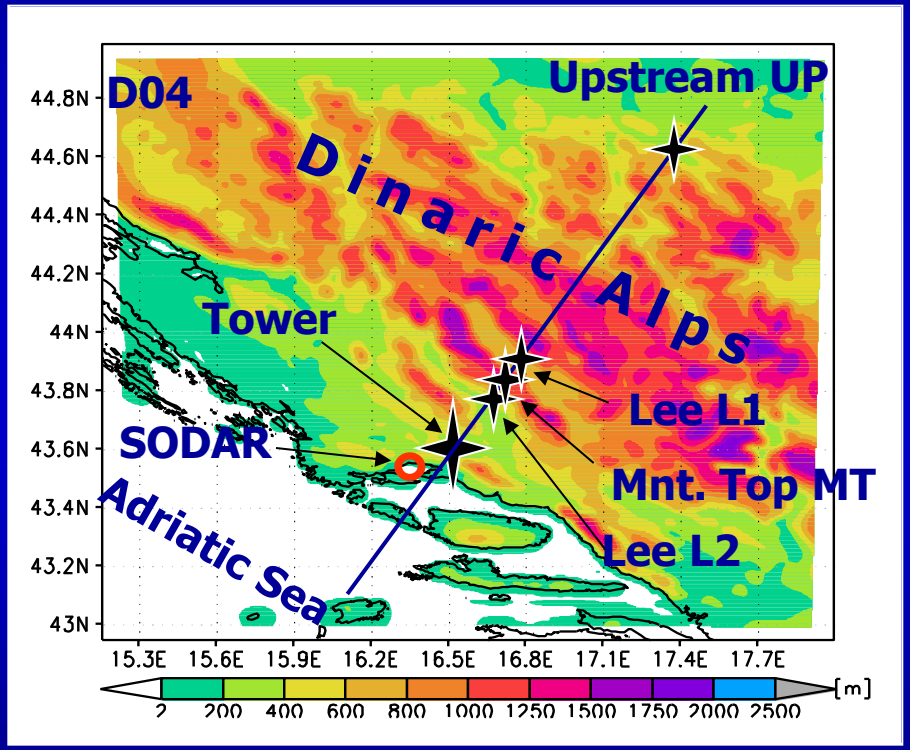
Measurements:: pulsations

- The evolution of pulsations (running spectra)
- Different temporal scales, far from periodic!



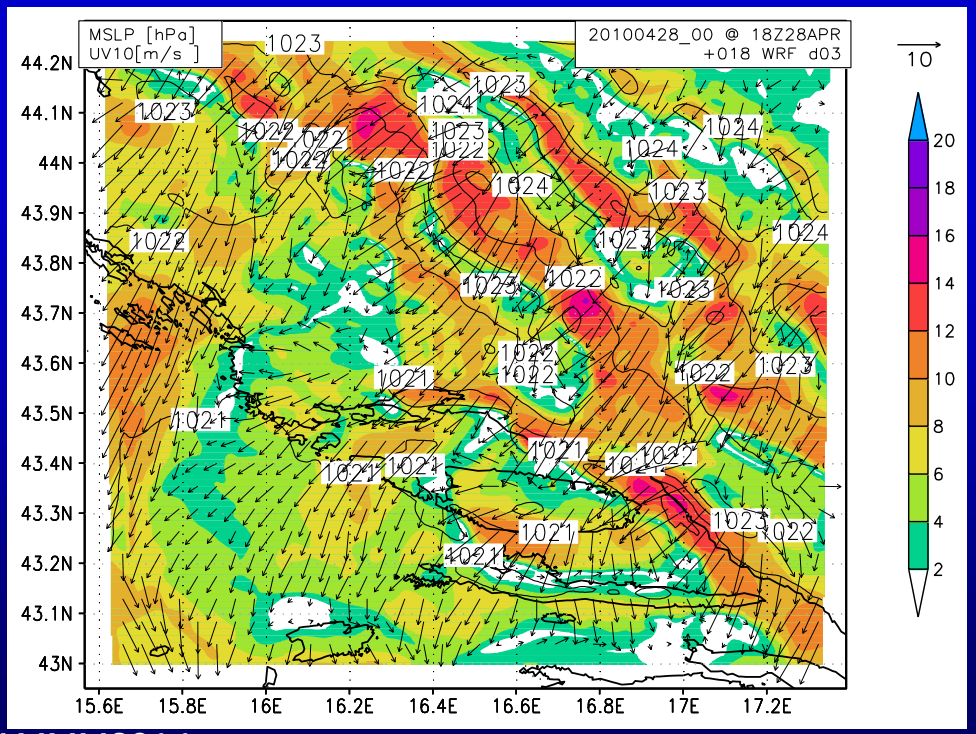
Numerical modeling

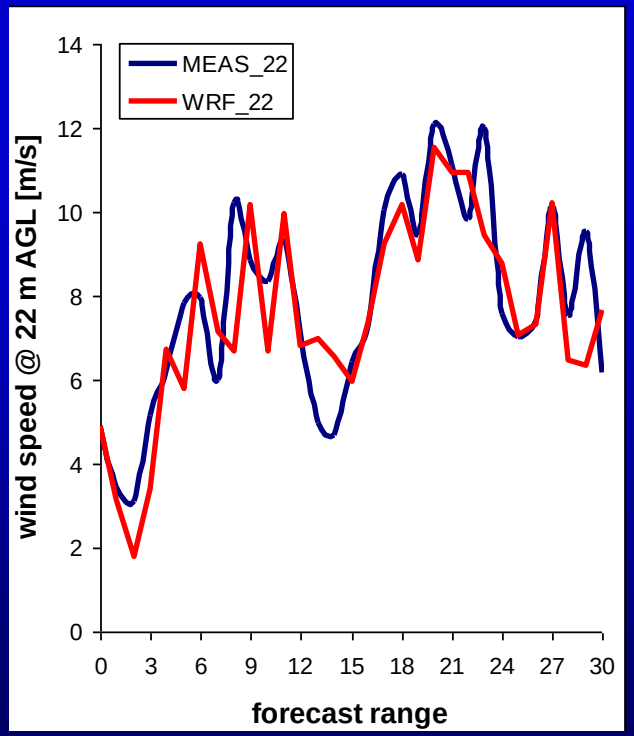
- The WRF model setup:
  - 4 one-way nested domains (dx=9|3|1|0.333 km)
  - 40 vertical levels
  - IC&LBC – ECMWF_OA
  - MYJ, KF, Thompson
  - Noah LSM
  - True horizontal diffusion



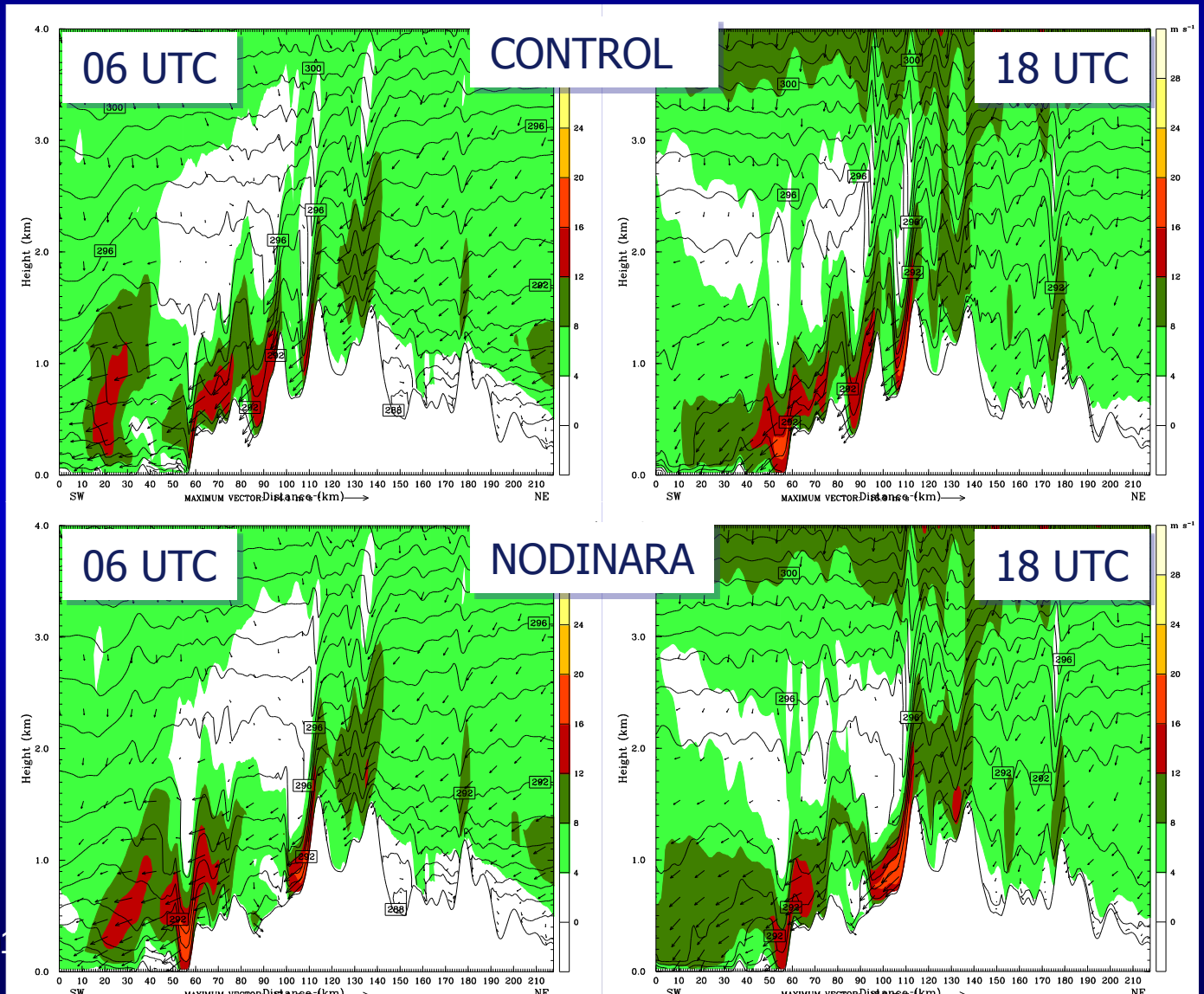
Structure and point verification

- Large spatial wind speed variability due to individual mountains
- Fair representation of wind speed at tower location



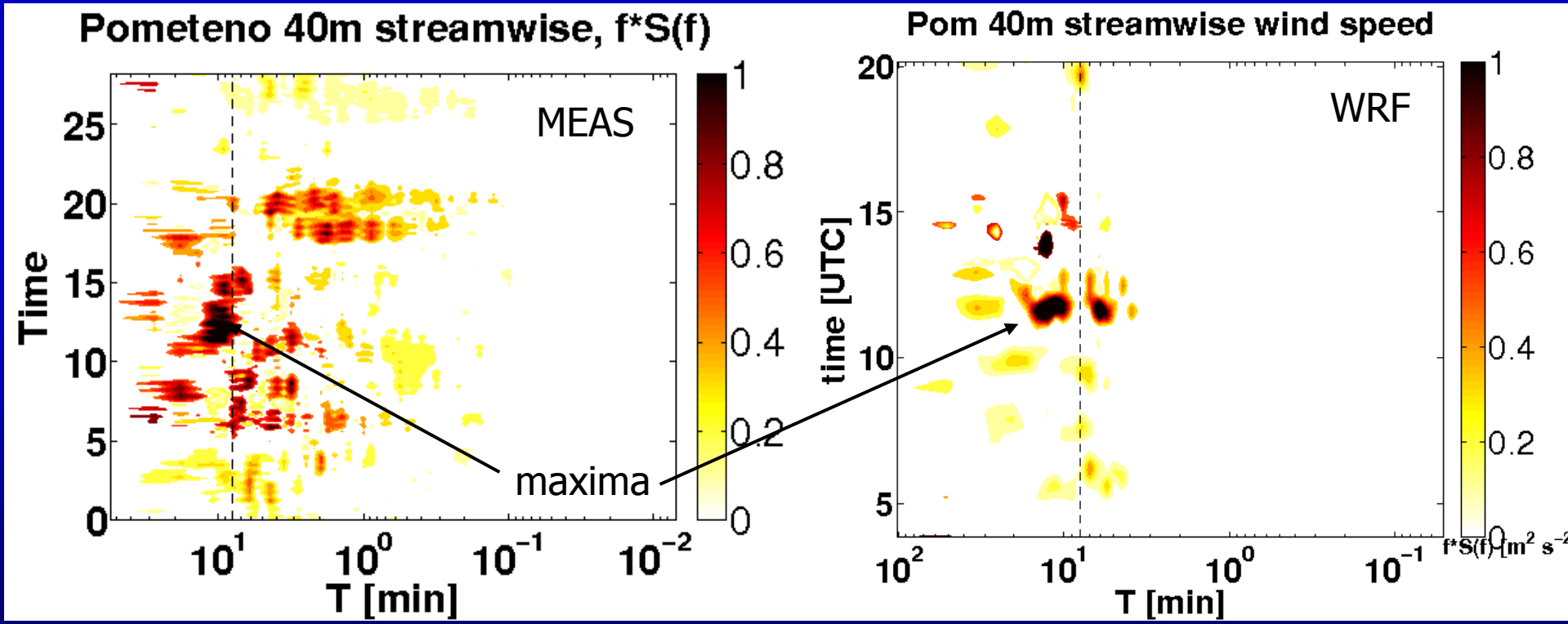


Vertical structure



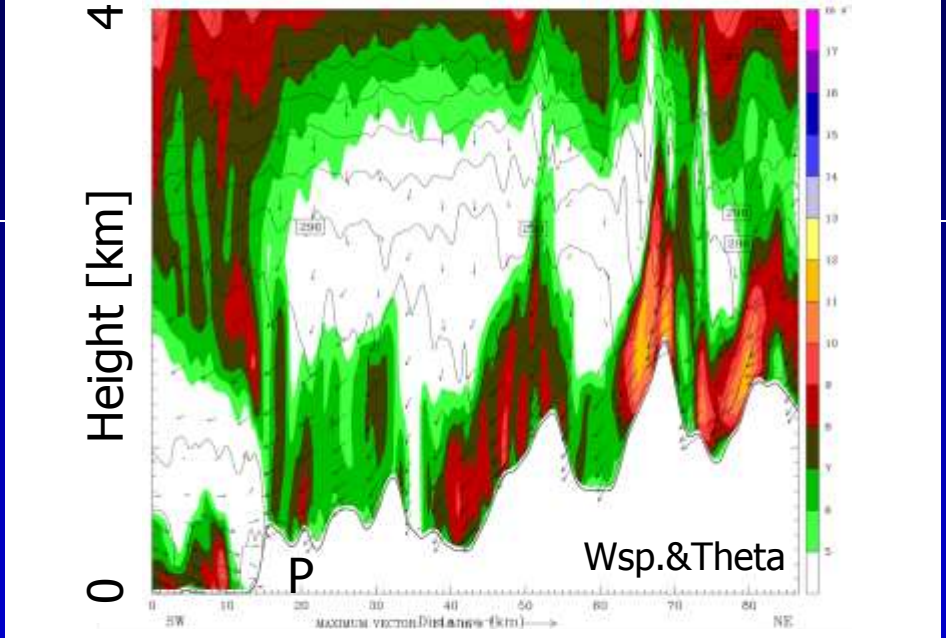
Numerical simulations:: Representation of pulsations

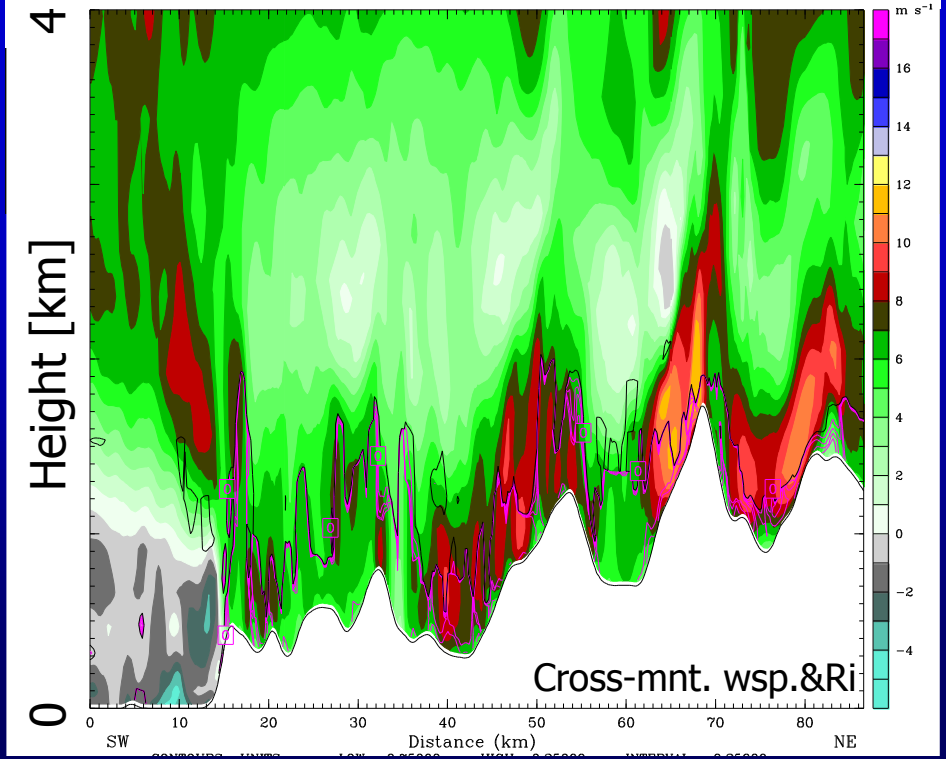
- Pulsations at tower location are represented to an extent, but simulated pulsations have less energy than observed



Daytime flow&pulsations

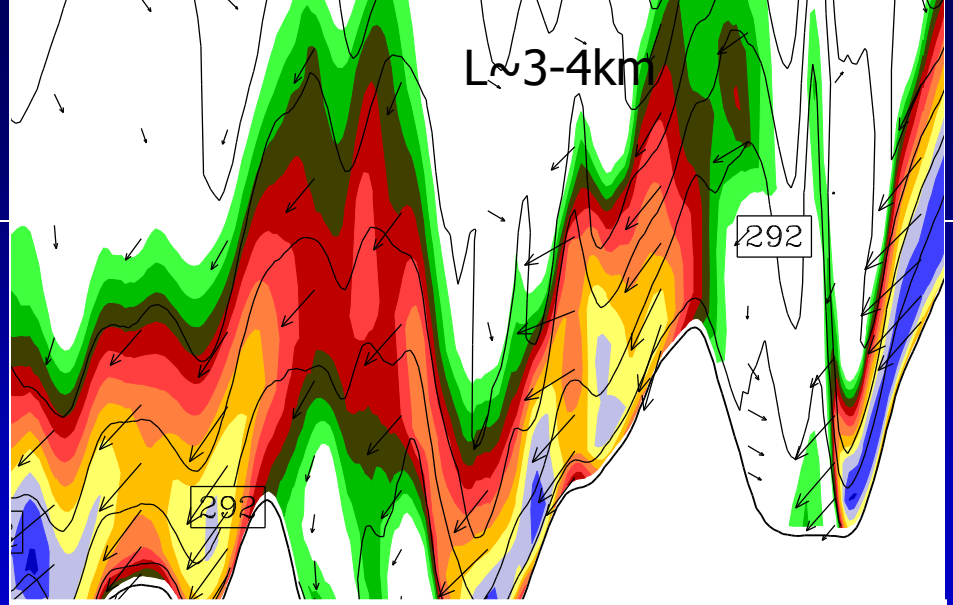
- Daytime flow is unstationary
- Pulsations:
  - Non-local
  - The most intensive beneath the primary breaking mountain wave
  - Travel far away from the origin
  - R<0.25 generally not found near the primary gravity-wave breaking region
- KHI mechanism questionable

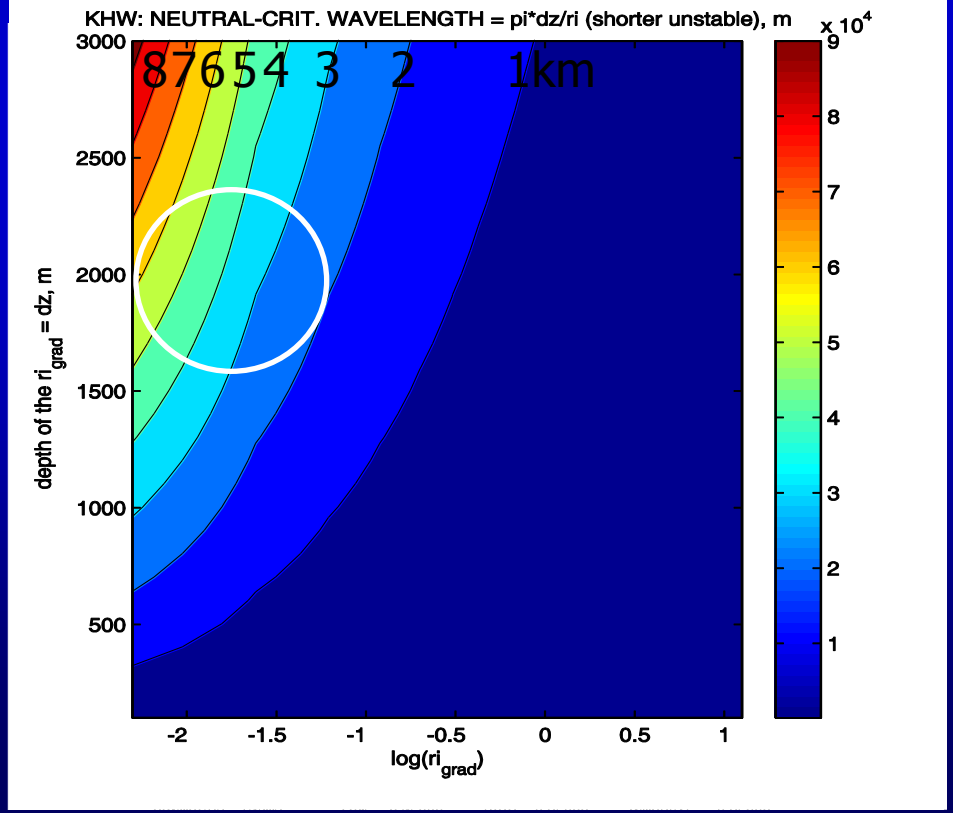




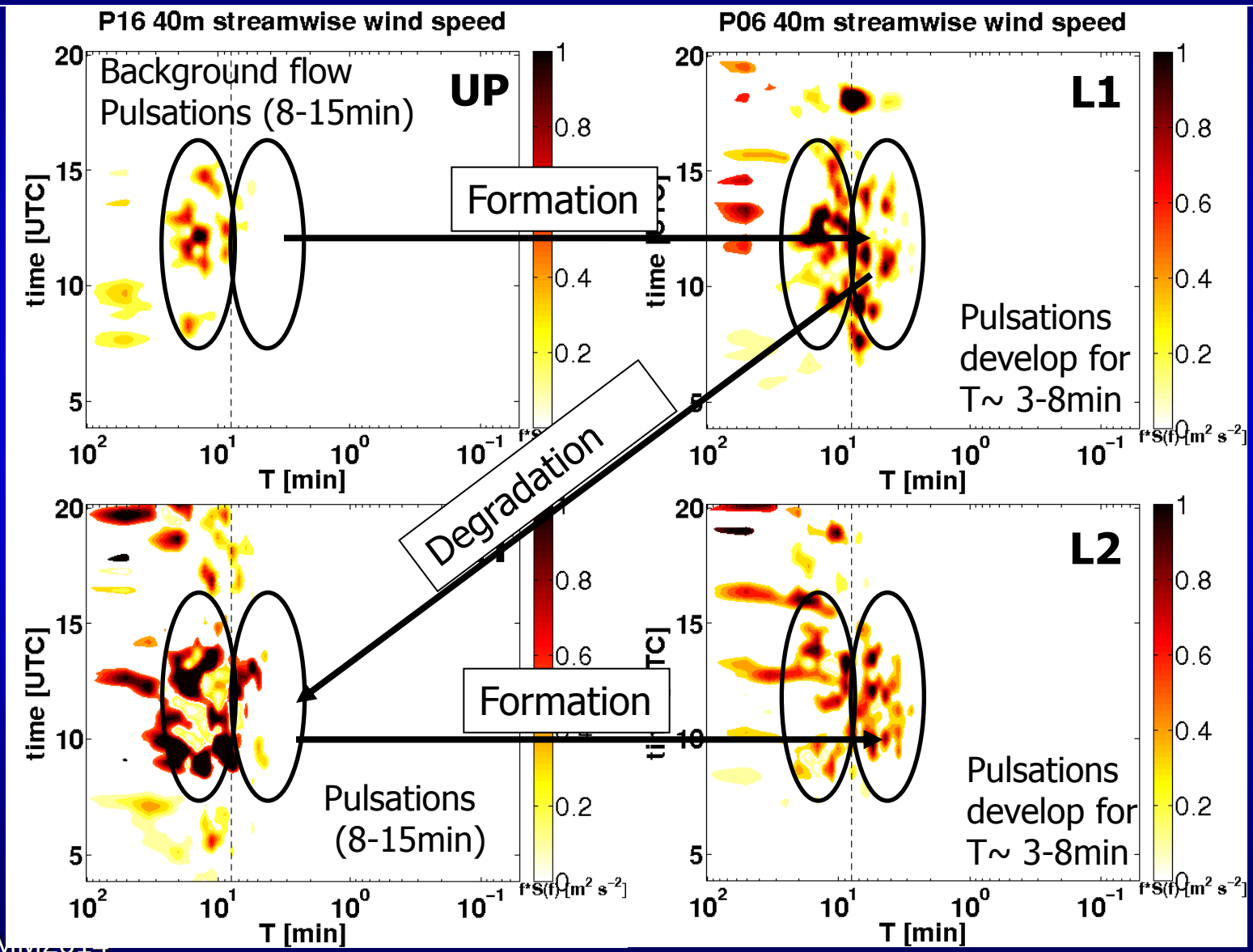
Nighttime flow&pulsations

- Nighttime flow more stationary
- More frequent flow separation
- Pulsations:
  - Non-local
  - 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 KHI



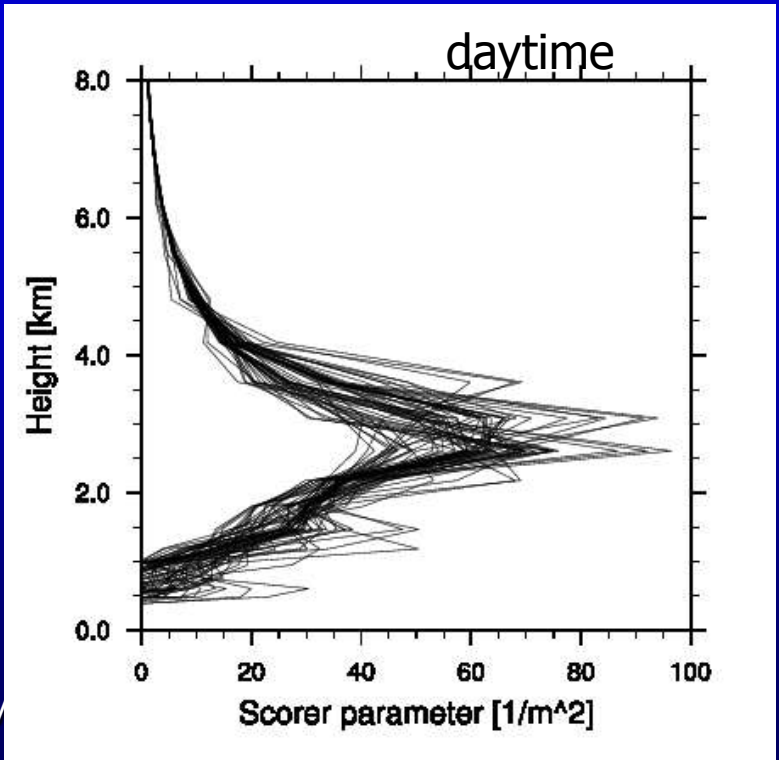


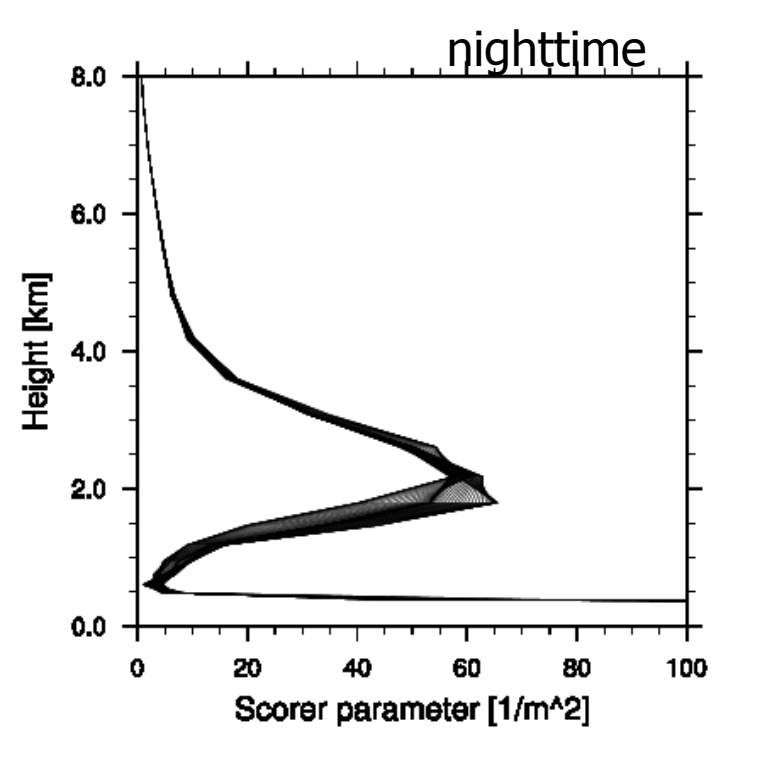
Propagation of pulsations:: large spatial variability



Pulsations:: upstream variability

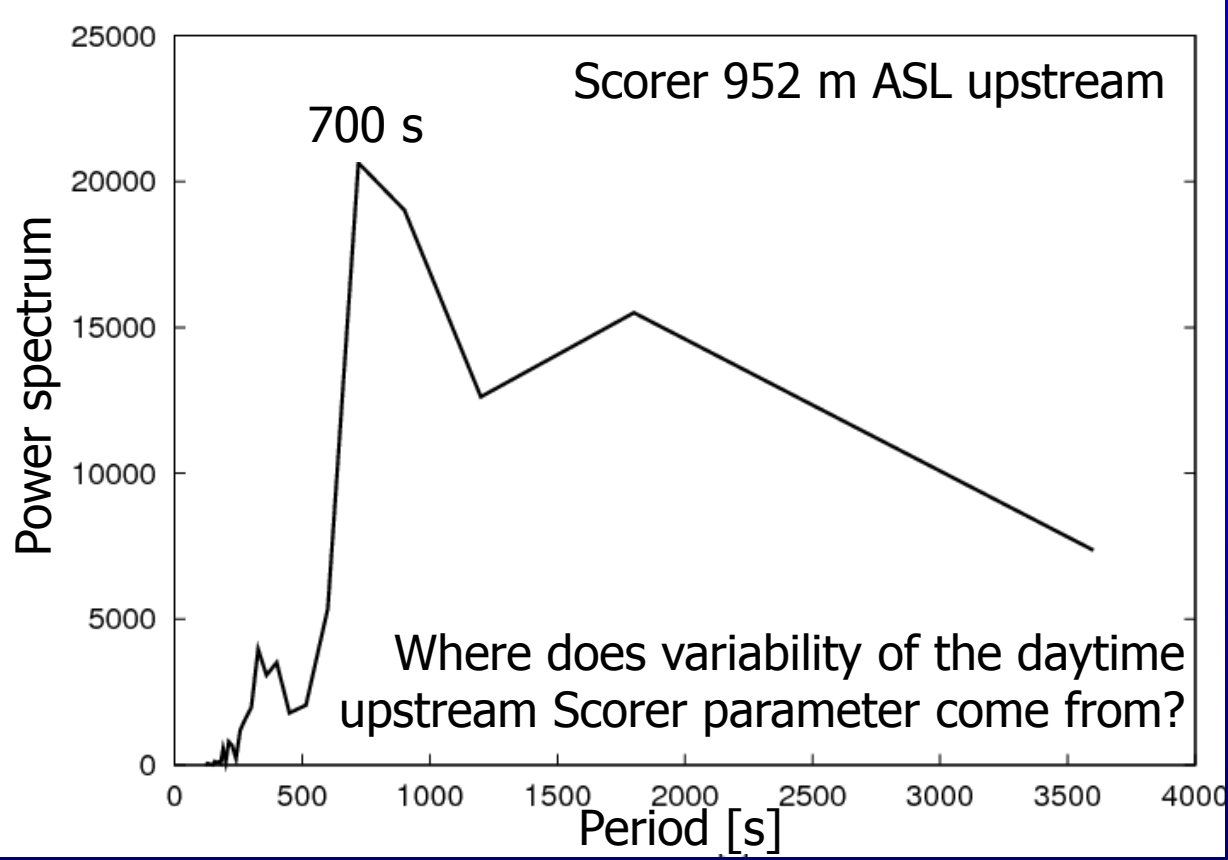
- Less certaity on the origin of non-local daytime pulsations of T~8-15 min
- Are these daytime pulsations caused by background flow properties?





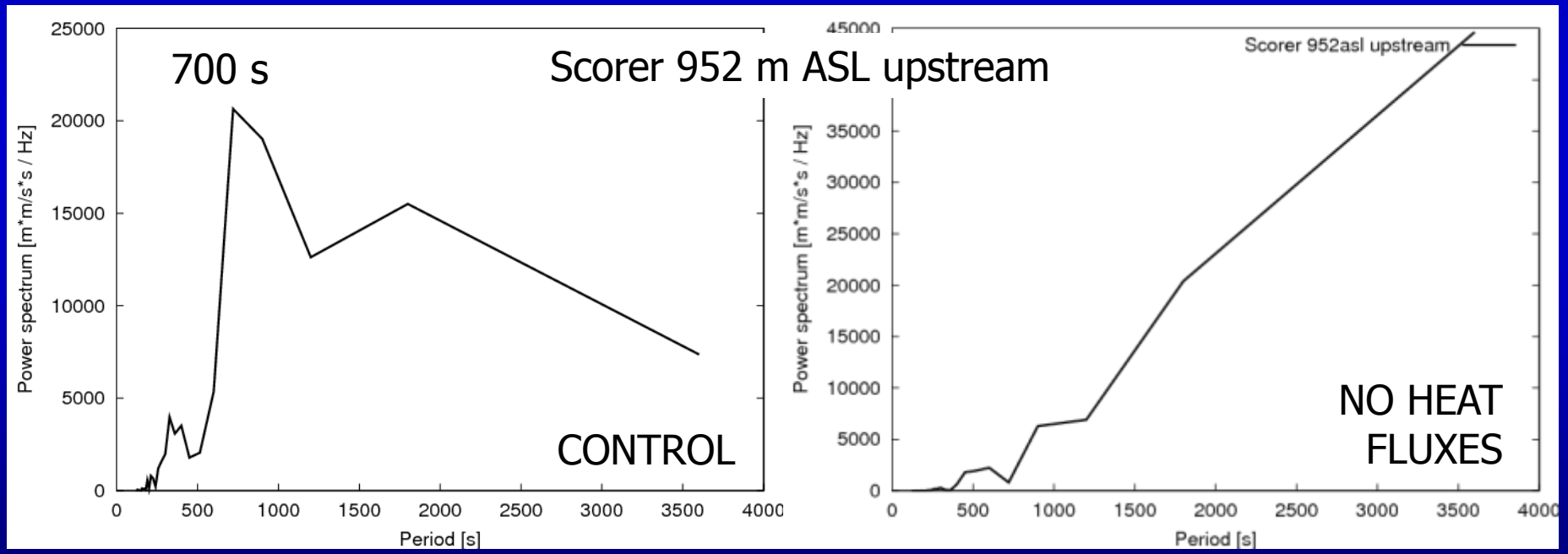
Pulsations:: upstream variability during daytime

- Scorer parameter of the background flow during daytime

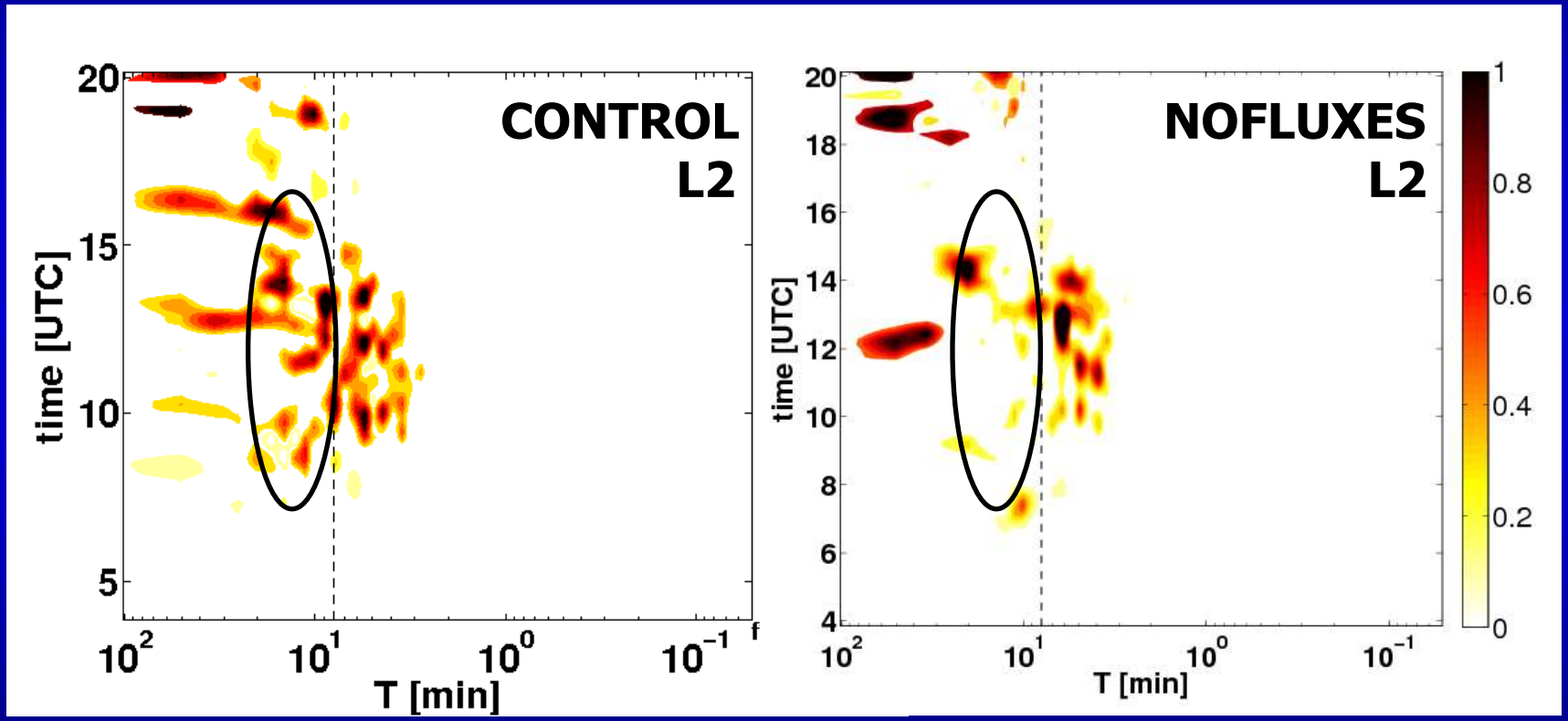


Pulsations:: upstream variability during daytime

- The effect of surface fluxes



Pulsations:: no fluxes from the surface



Reduced intensity of pulsations during daytime, primarily for T>~8 min

Conclusions

- Bora flow in the mid-Adriatic more complex than in the north (effects of the primary and secondary orography, 3D,…)
- Two modes of bora streamwise pulsations are found:
- A) Shorter pulsations (T<8 min) predominantly point to KHI and may occur regardless of the period of day
- B) Longer pulsations (8-15 min) point to effects of upstream variability and occur predominantly during the daytime
- Future: analyze cross-streamwise pulsations, perform multi-scale WRF simulations, study TKE budget