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

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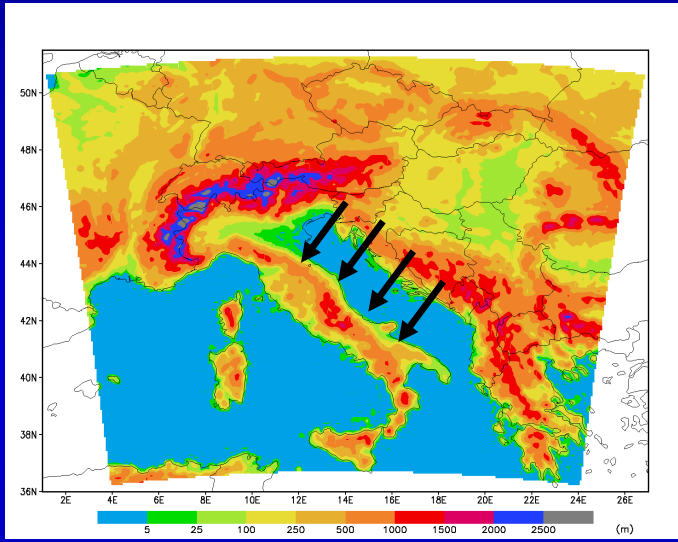
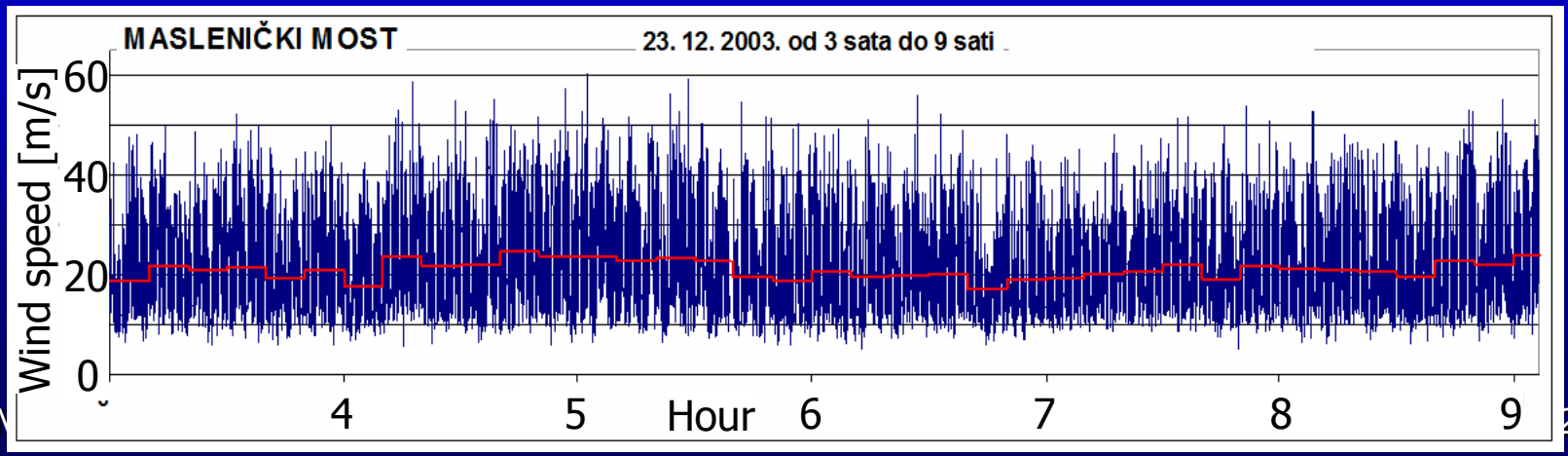
Introduction:: bora winds

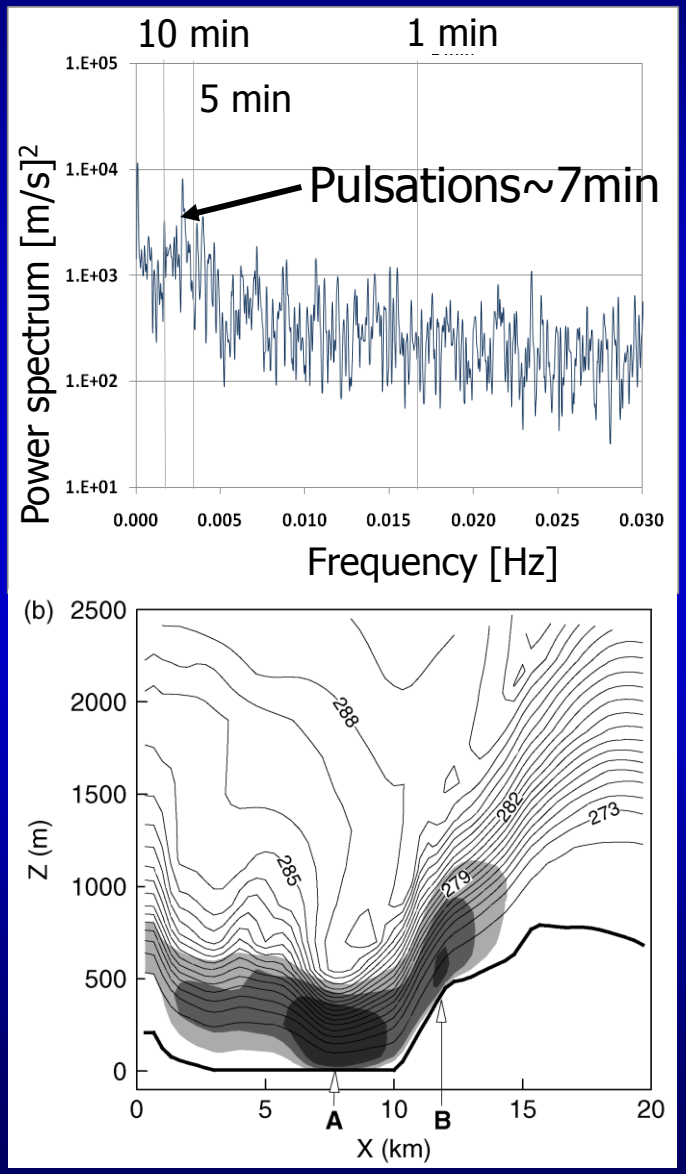
- Bora – gusty NE downslope windstorm along the eastern Adriatic coast
- Wind speeds > 40 m/s
- H5 wind gusts ~ 70 m/s
- Large temporal (and spatial) variability





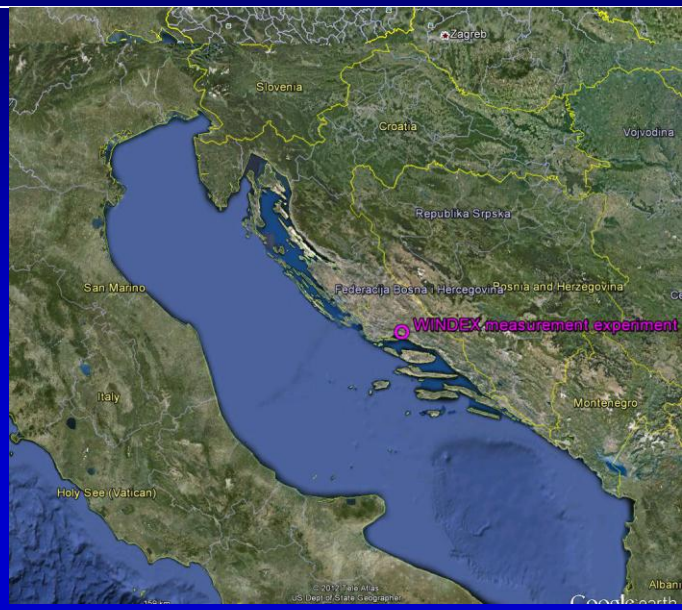
Introduction:: pulsations

- 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)
  - 3. KHI between low-level shooting flow and wave-breaking aloft (Scinocca and Peltier, 1989 .., P&S1990, Smith 1991)
- All 3 mechanisms require wave-breaking (thus non-local)
- In the Adriatic, mechanism of bora pulsations is KHI (Belušić et al., 2007)

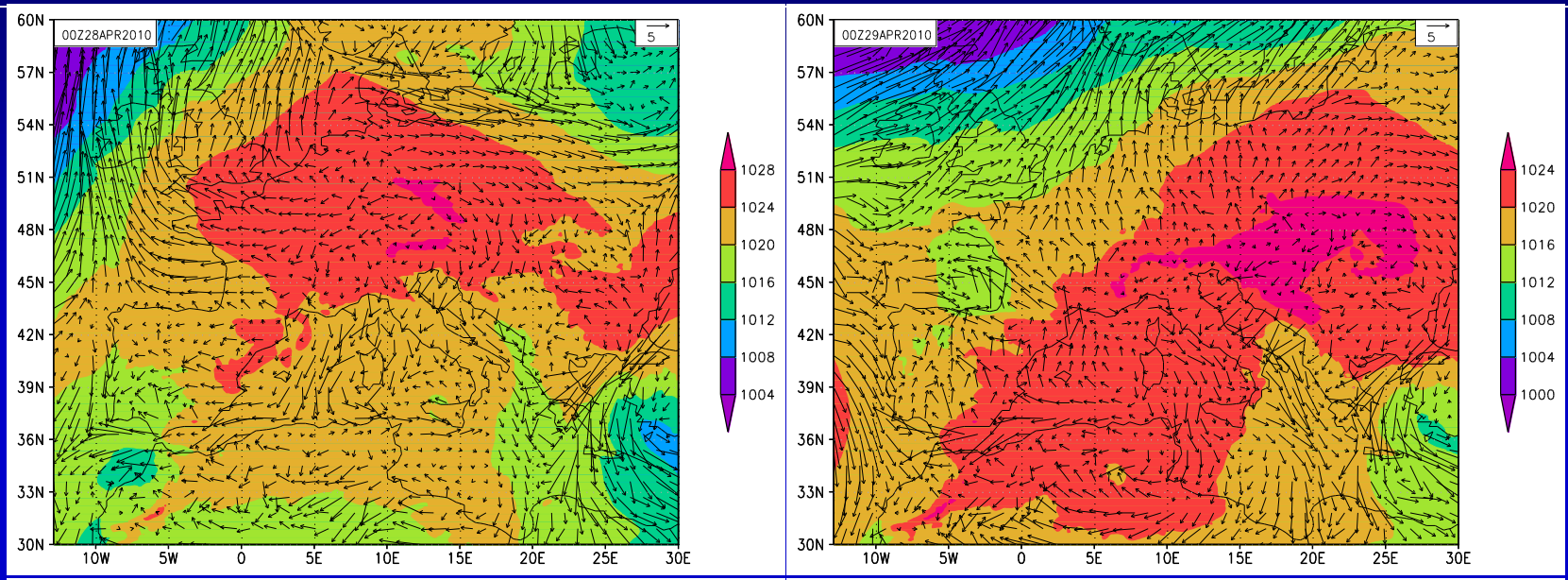


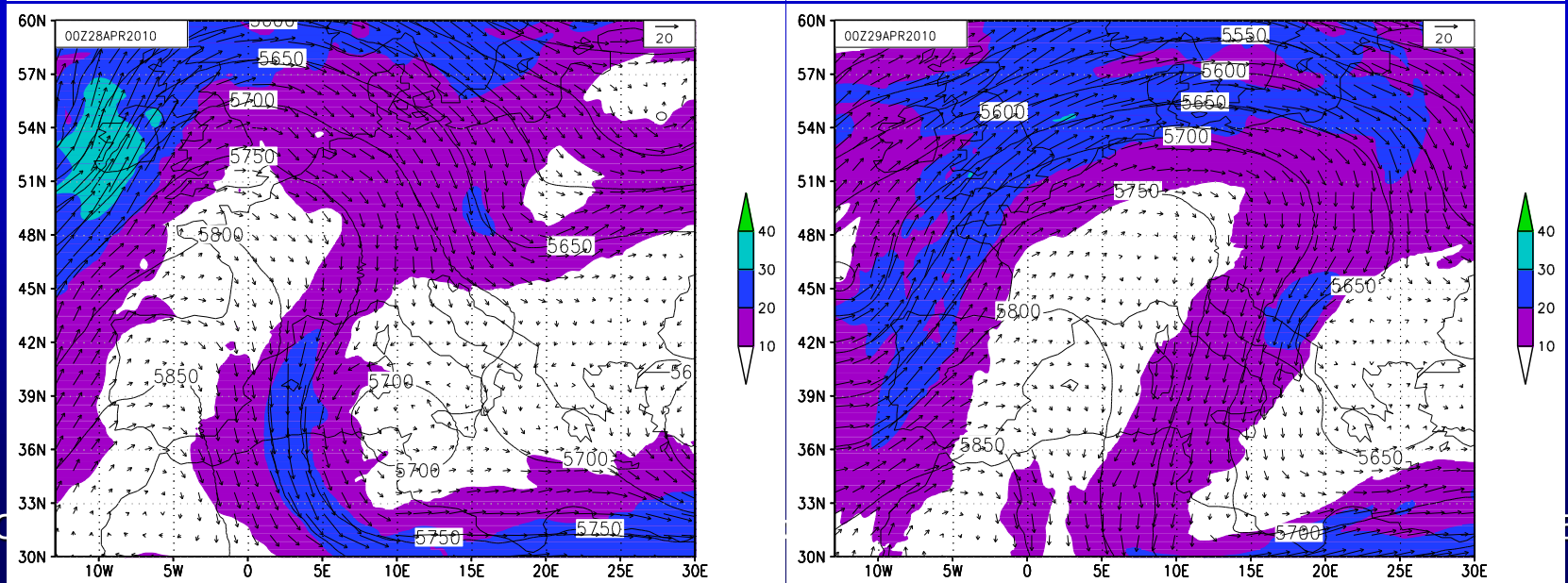
WINDEX measurement campaign

- 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)



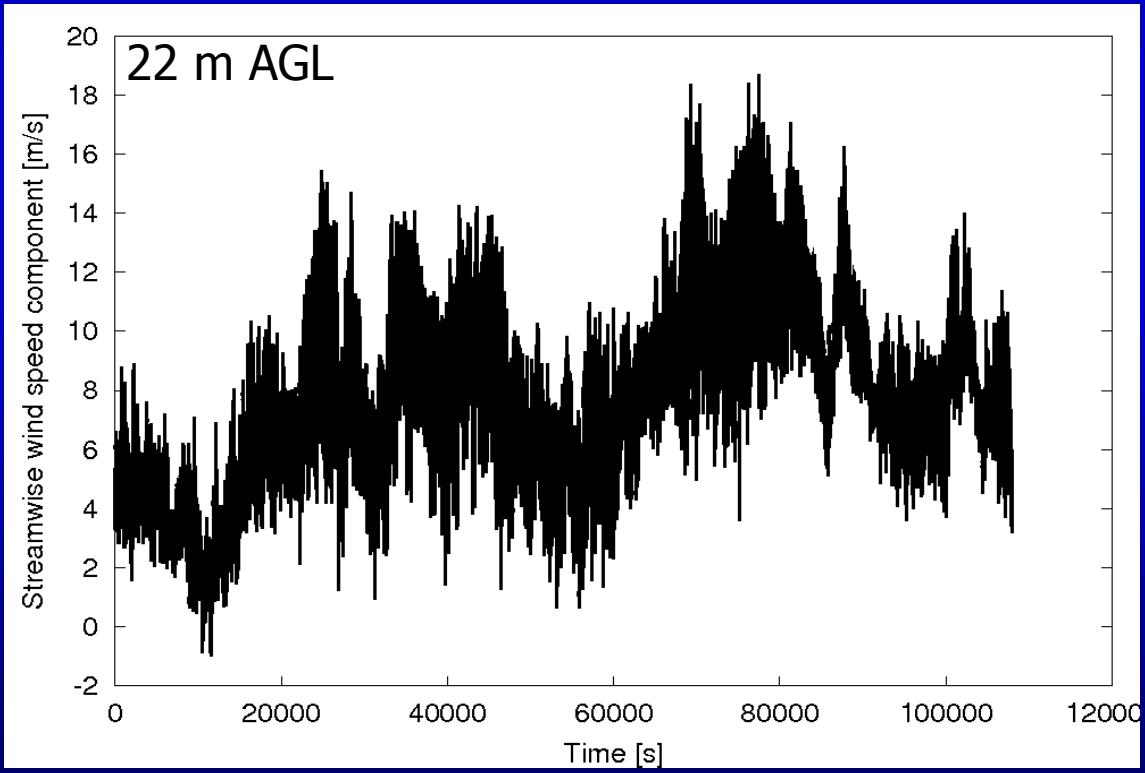
Anticyclonic bora episode 28 Apr 2010





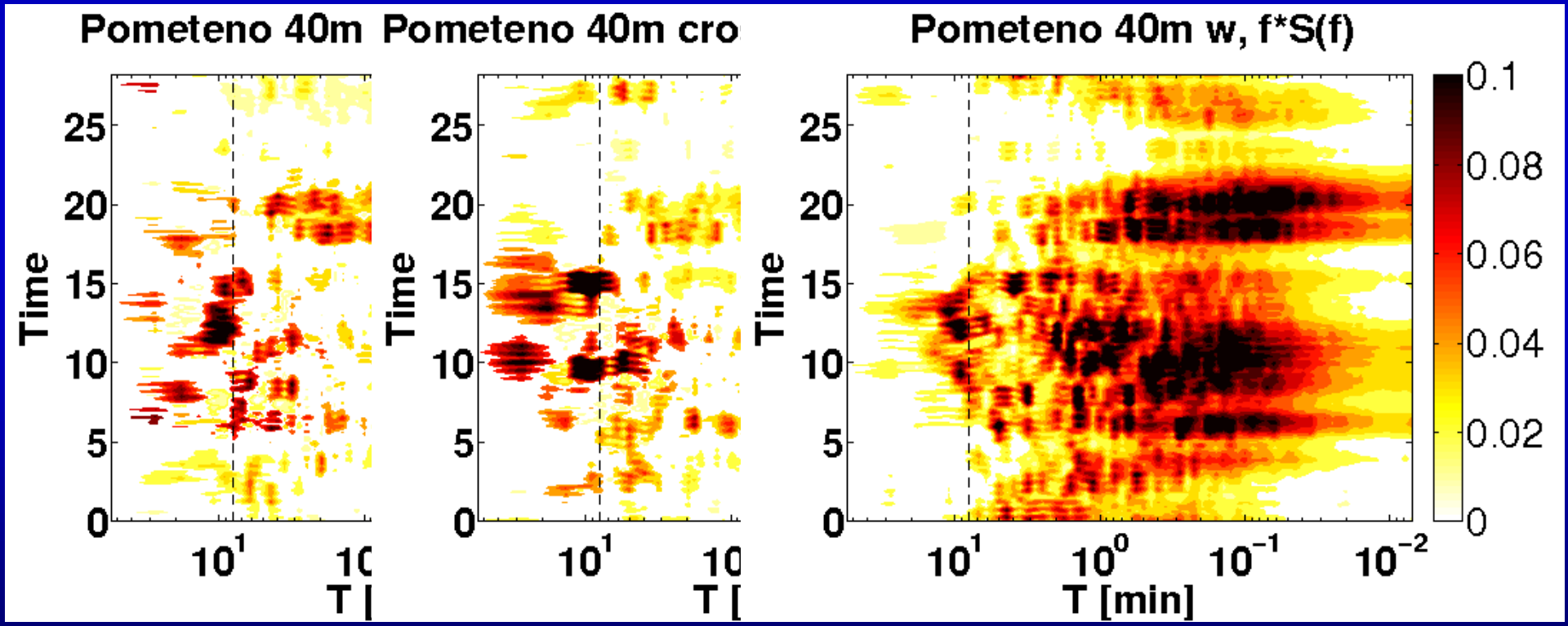
Wind tower measurements on 28 Apr 2010

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



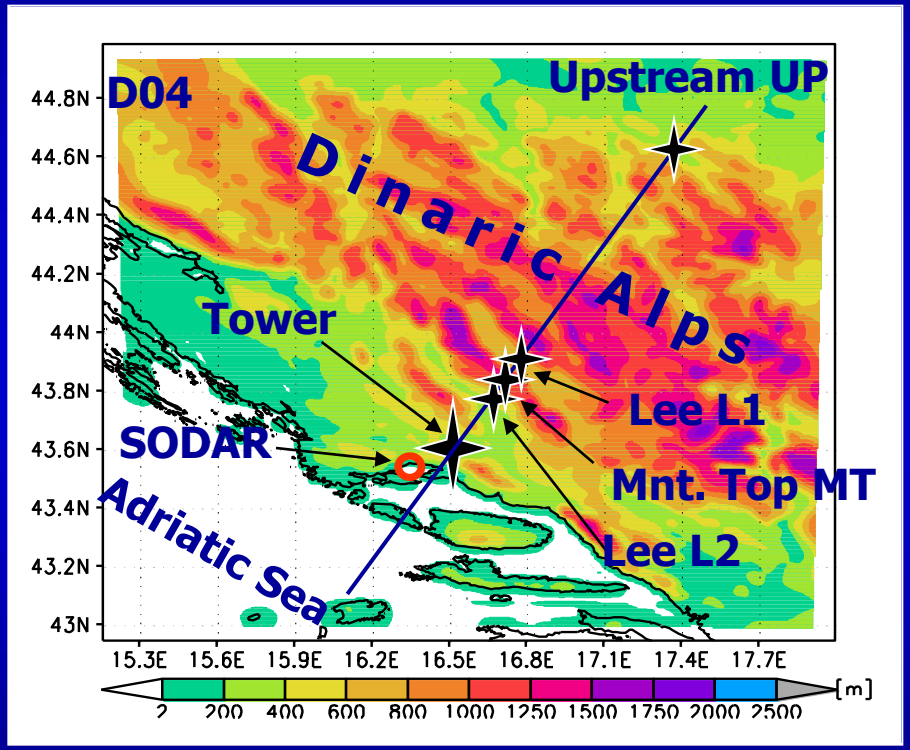
Measurements:: pulsations

- The evolution of pulsations (running spectra)



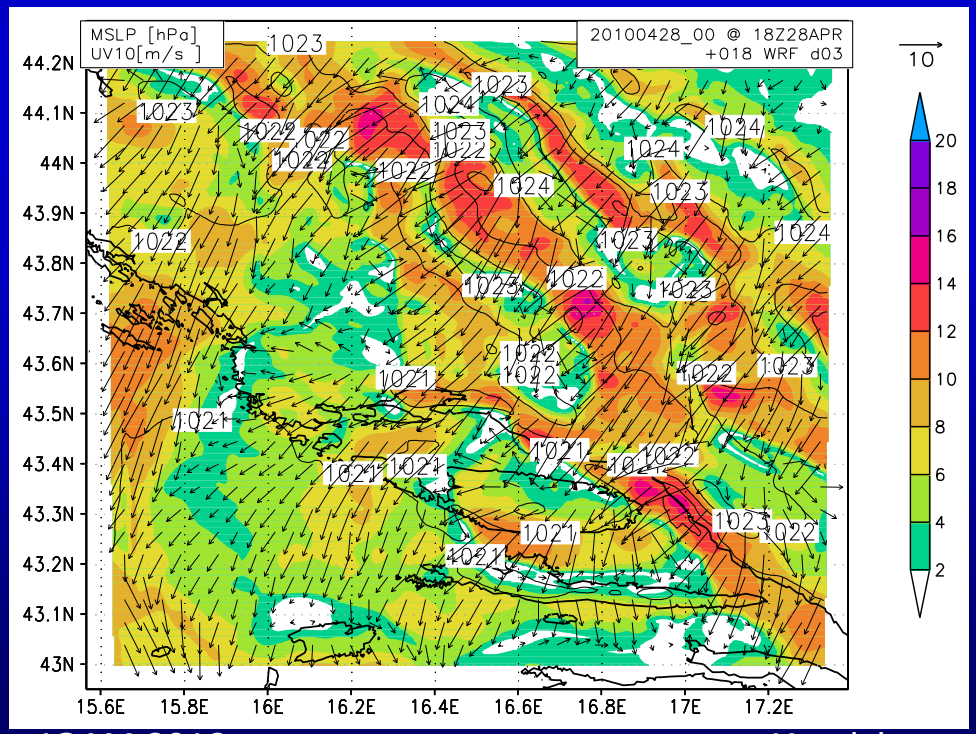
Numerical modeling

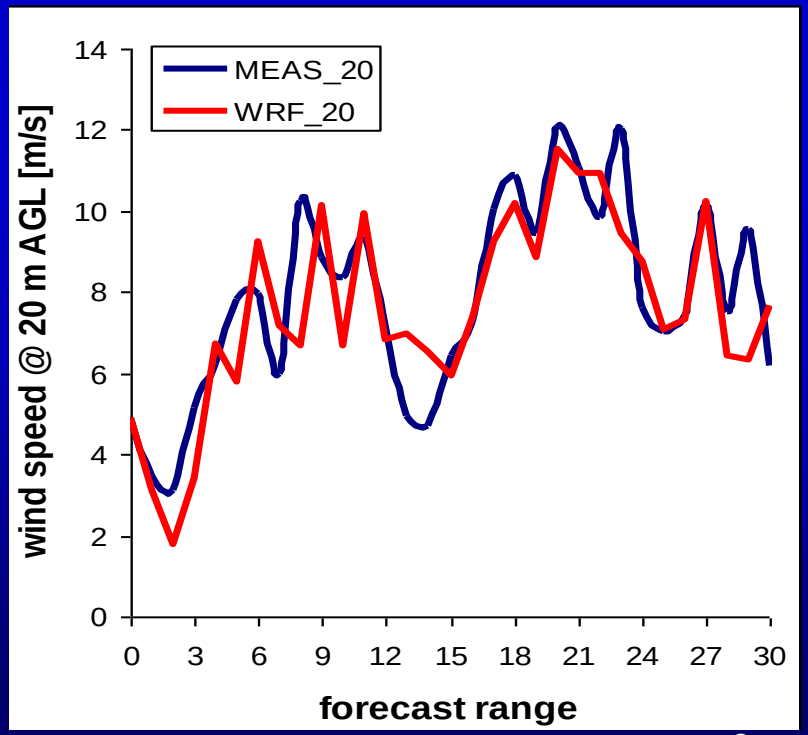
- The WRF model setup:
  - 4 one-way nested domains (dx=9|3|1|0.333 km)
  - 40 vertical levels
  - IC&LBC – ECMWF_OA
  - MYJ, KF, Thompson
  - Noah LSM
  - True horizontal diffusion



Structure and point verification

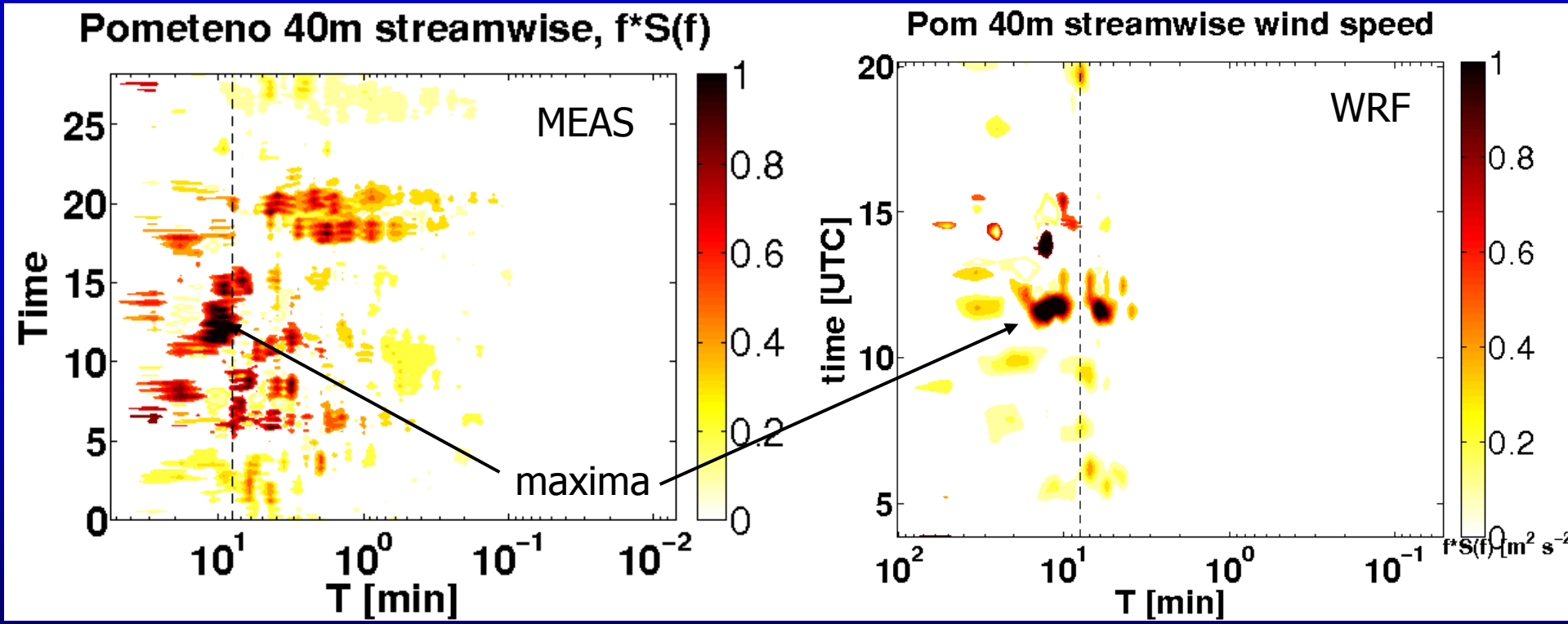
- Large spatial wind speed variability due to individual mountains
- Fair representation of wind speed at tower location





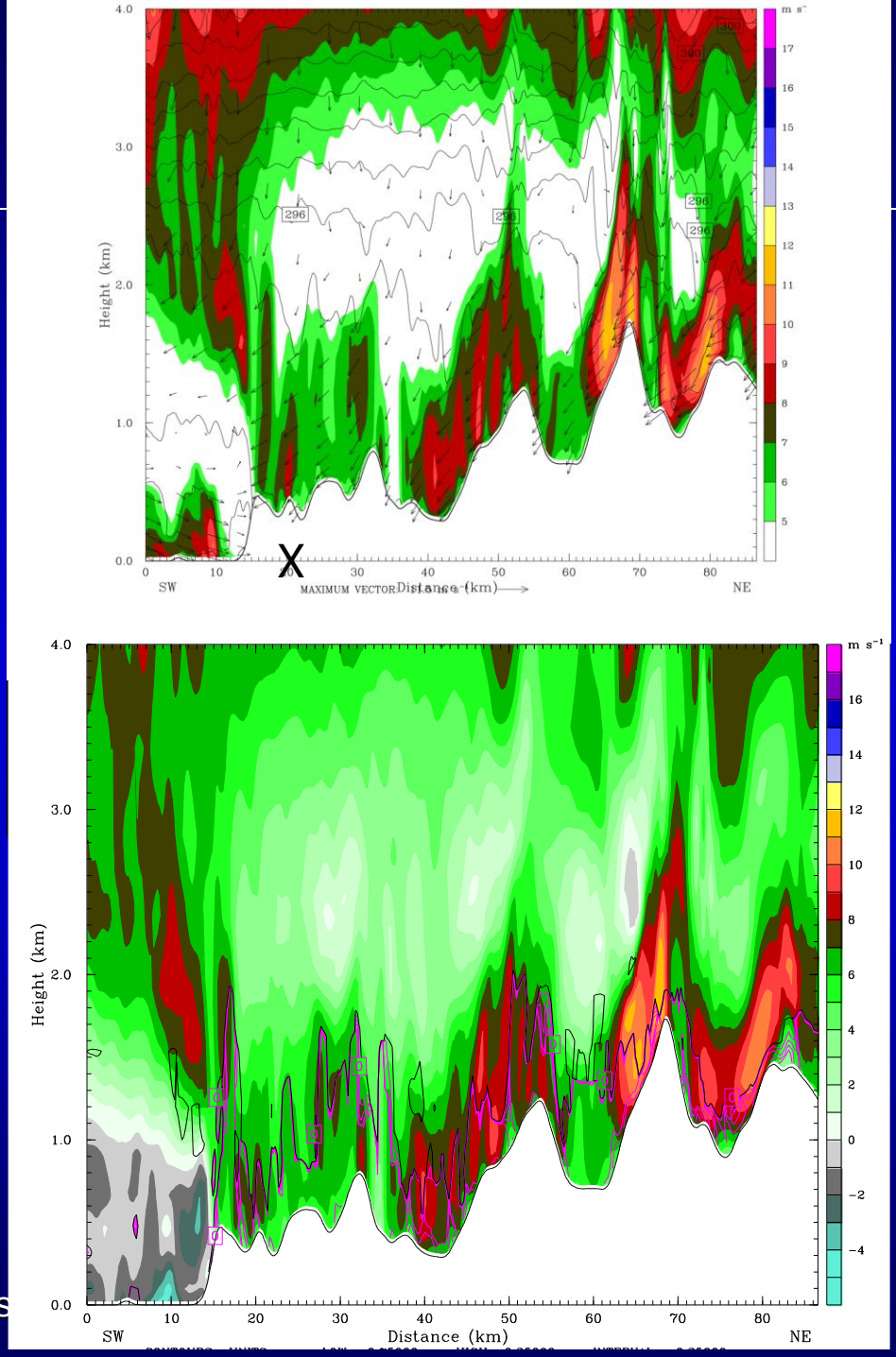
Numerical simulations:: Representation of pulsations

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



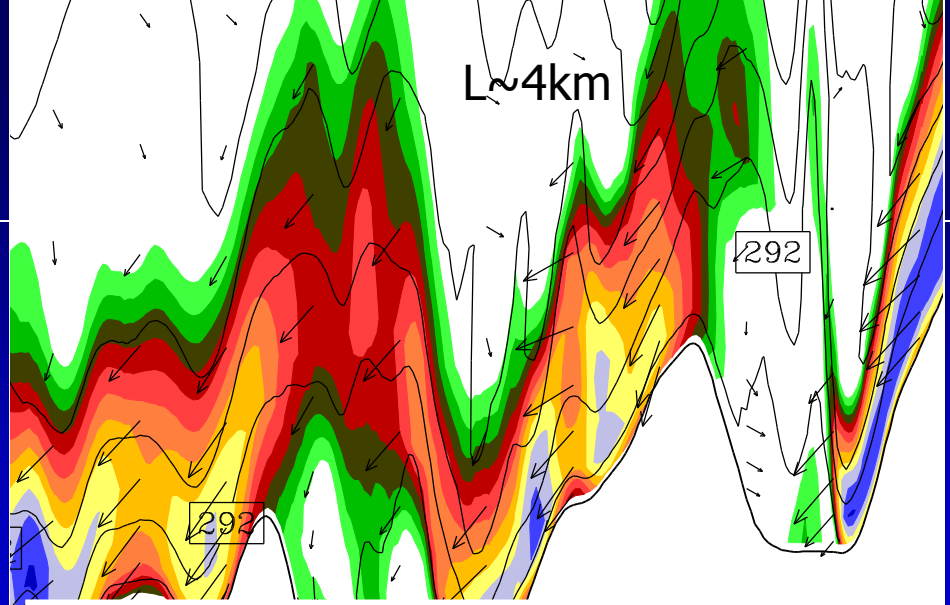
Daytime flow&pulsations

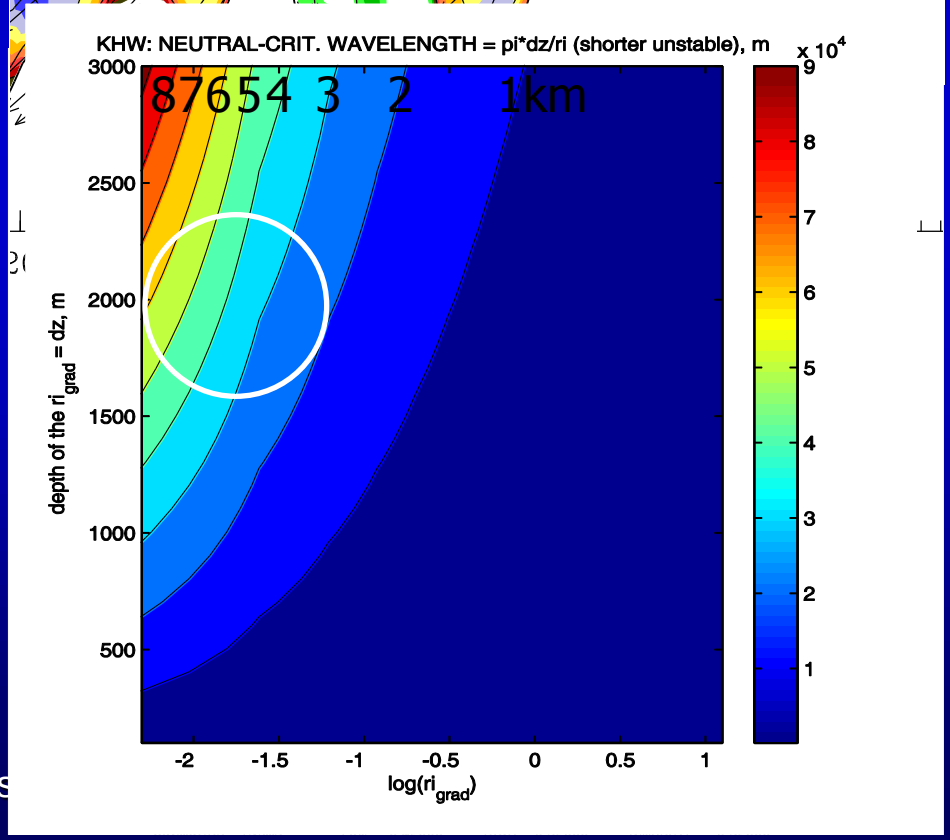
- Daytime flow is unstationary
- Pulsations:
  - The most intensive beneath the primary breaking mountain wave
  - Travel far away from the origin point
  - R<0.25 not always found near the primary gravity-wave breaking region
- KHI mechanism questionable



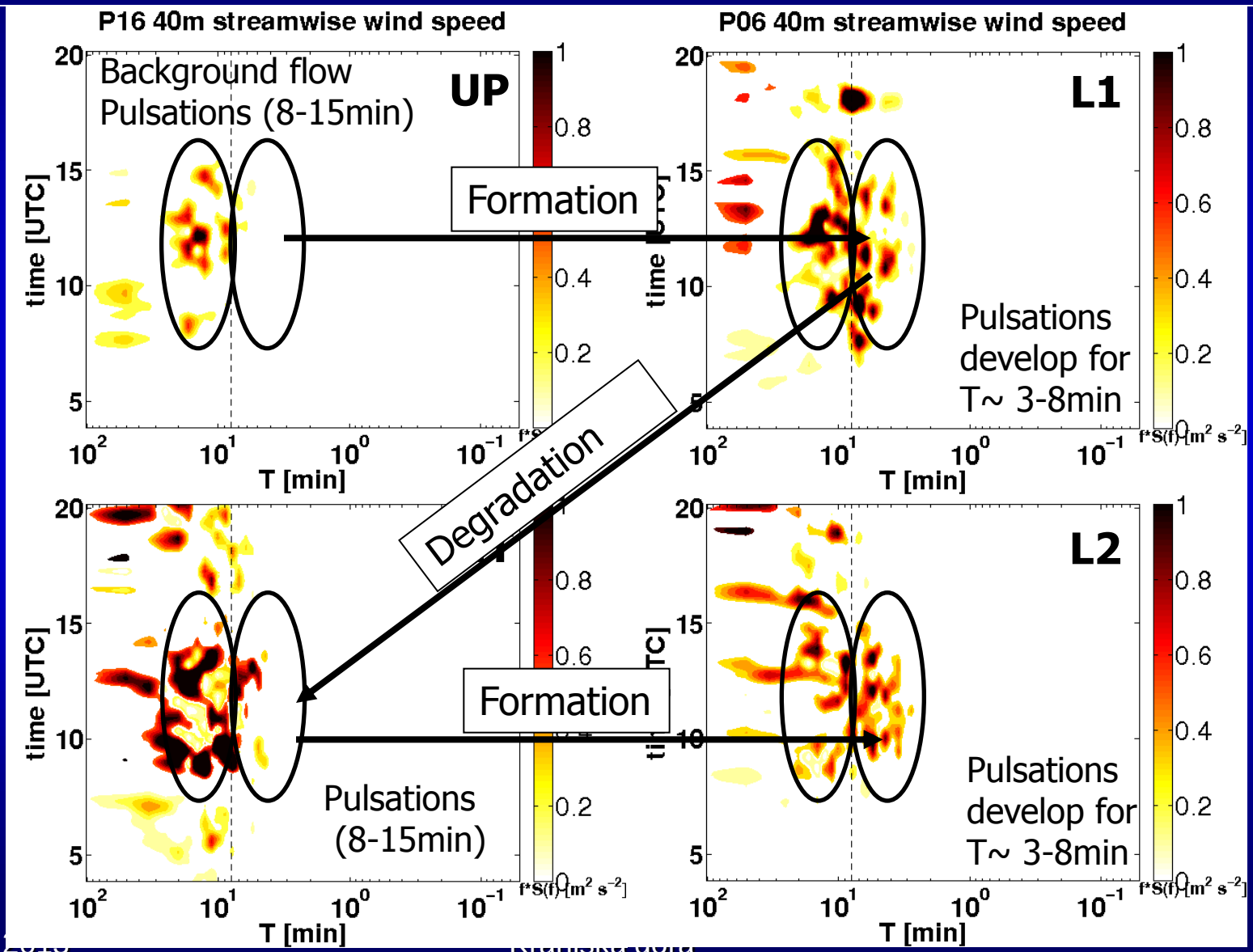
Nighttime flow&pulsations

- 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



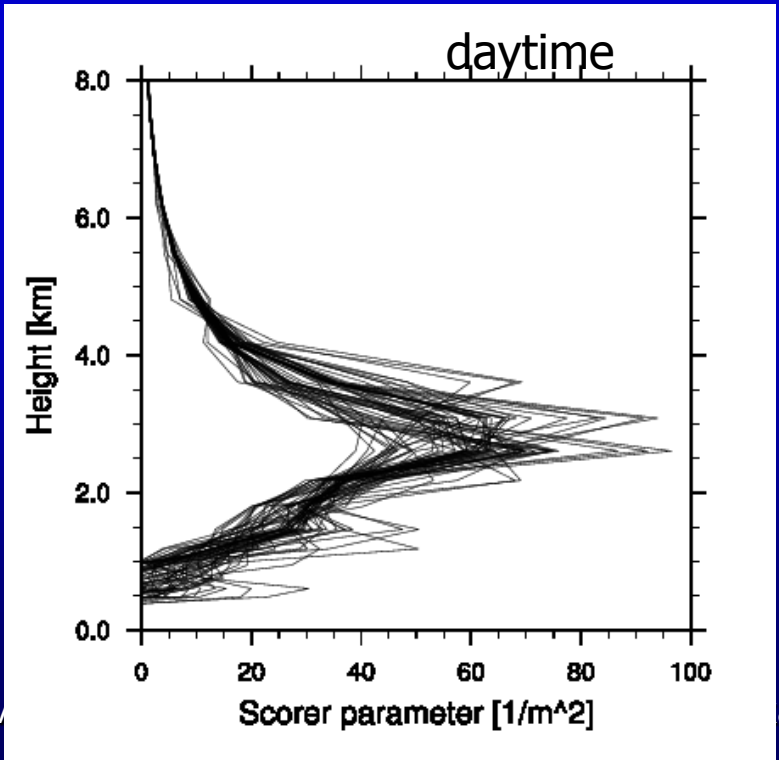


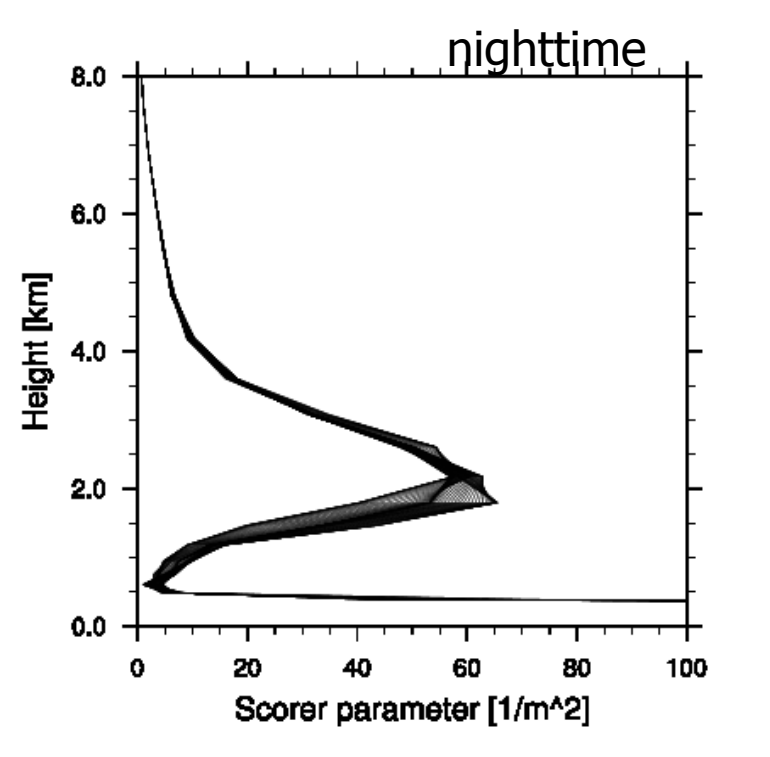
Propagation of pulsations:: large spatial variability



Pulsations:: upstream variability

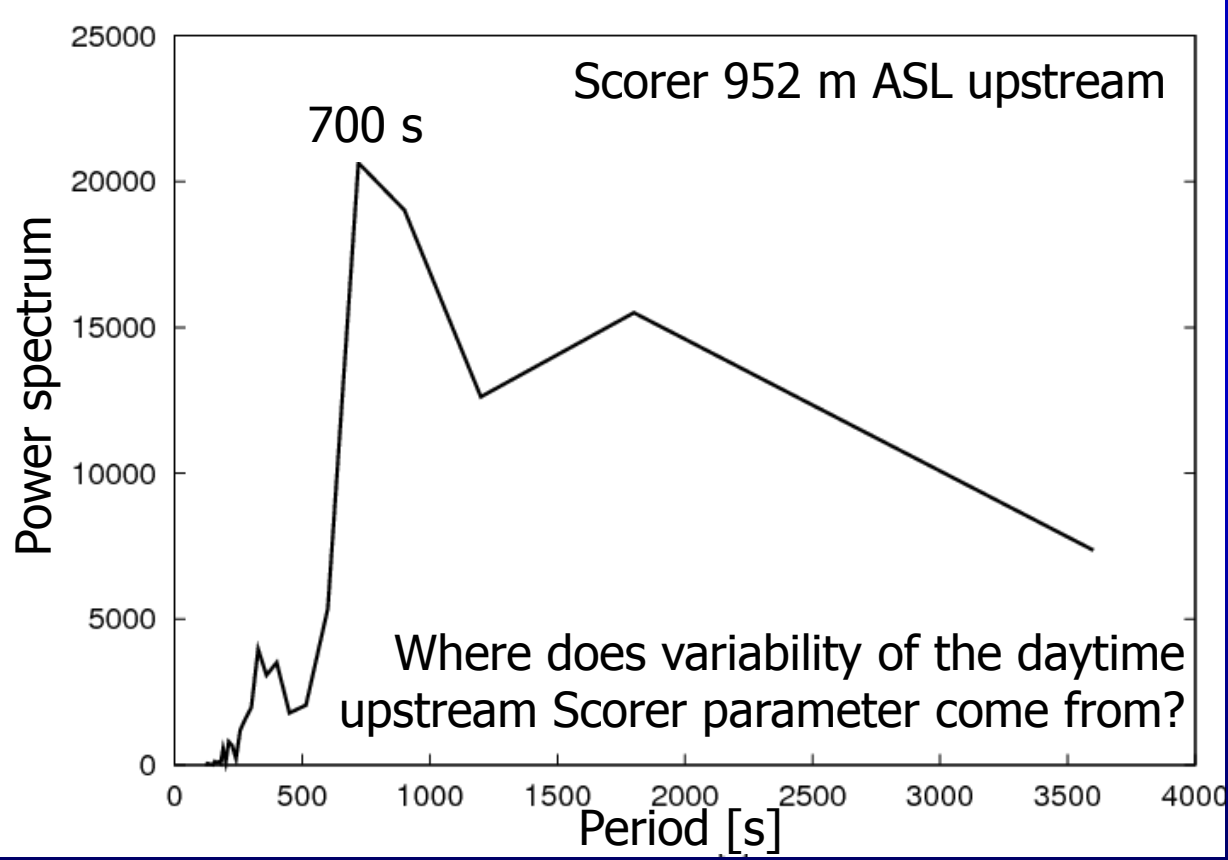
- Daytime pulsations of T~8-15 min are present both upstream and downstream
- Could these daytime pulsations be caused by 1) background flow properties and/or 2) local surface forcing ?





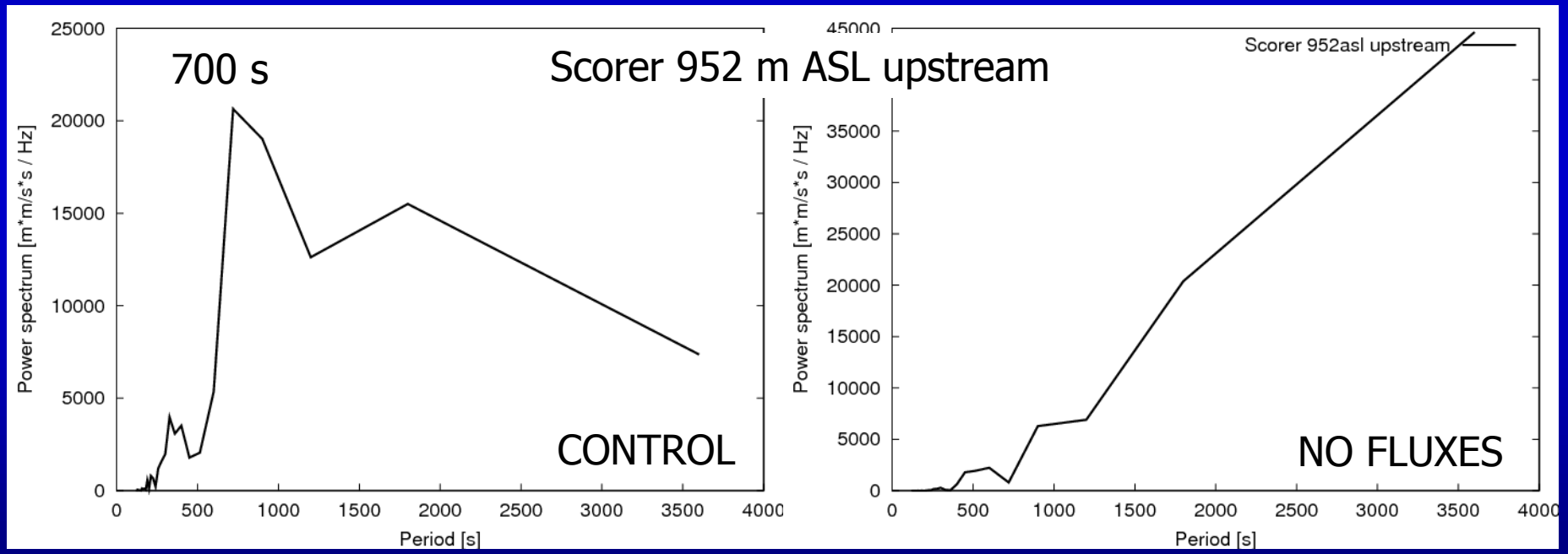
Pulsations:: upstream variability during daytime

- Scorer parameter of the background flow during daytime

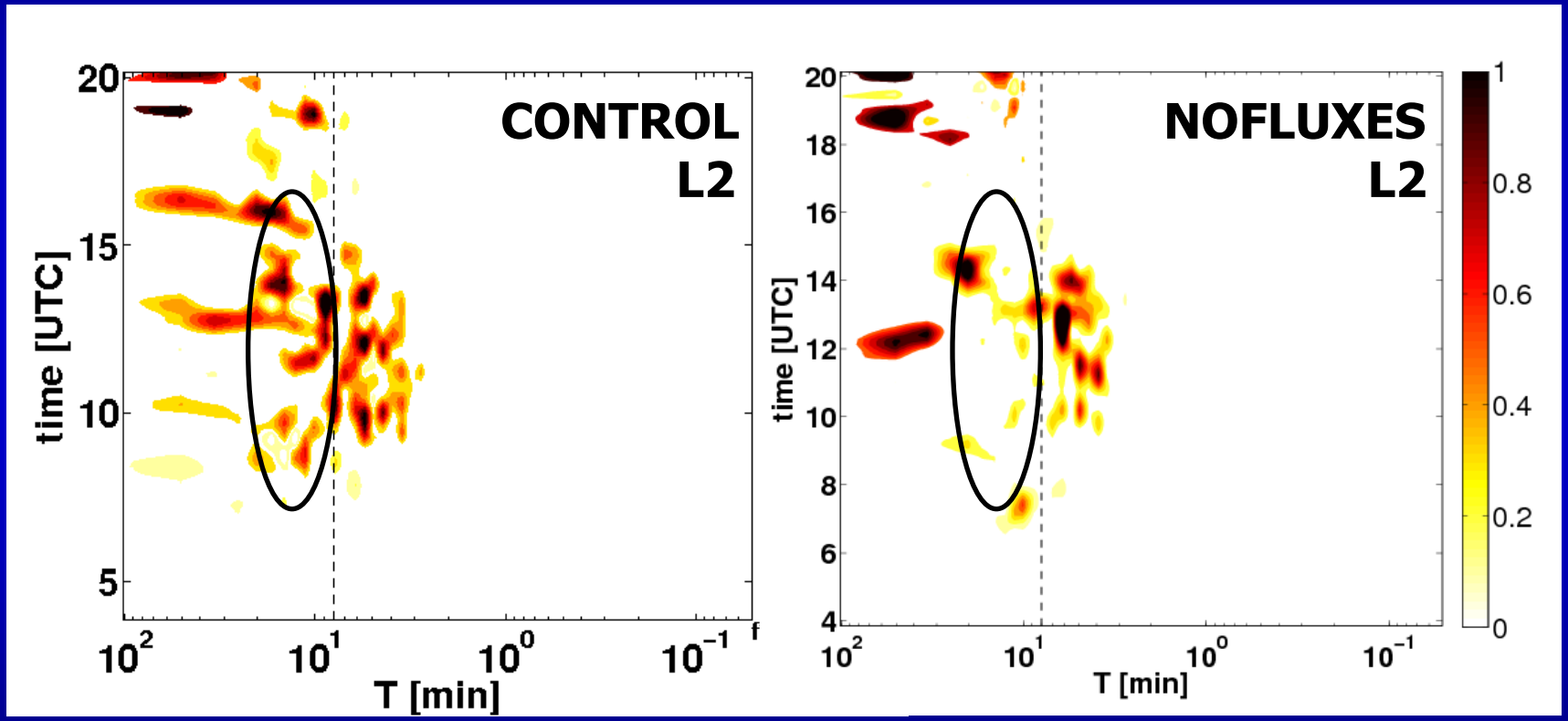


Pulsations:: upstream variability during daytime

- The effect of surface fluxes



Pulsations:: no fluxes from the surface



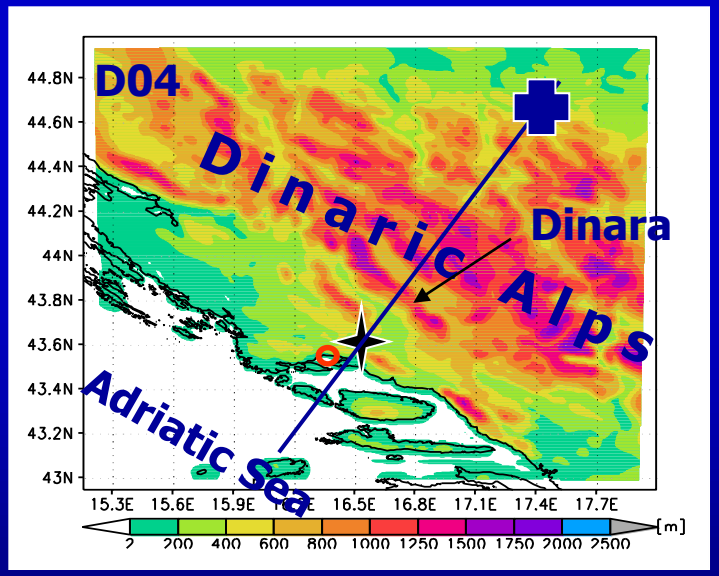
Reduced intensity of pulsations during daytime, primarily for T>~8 min

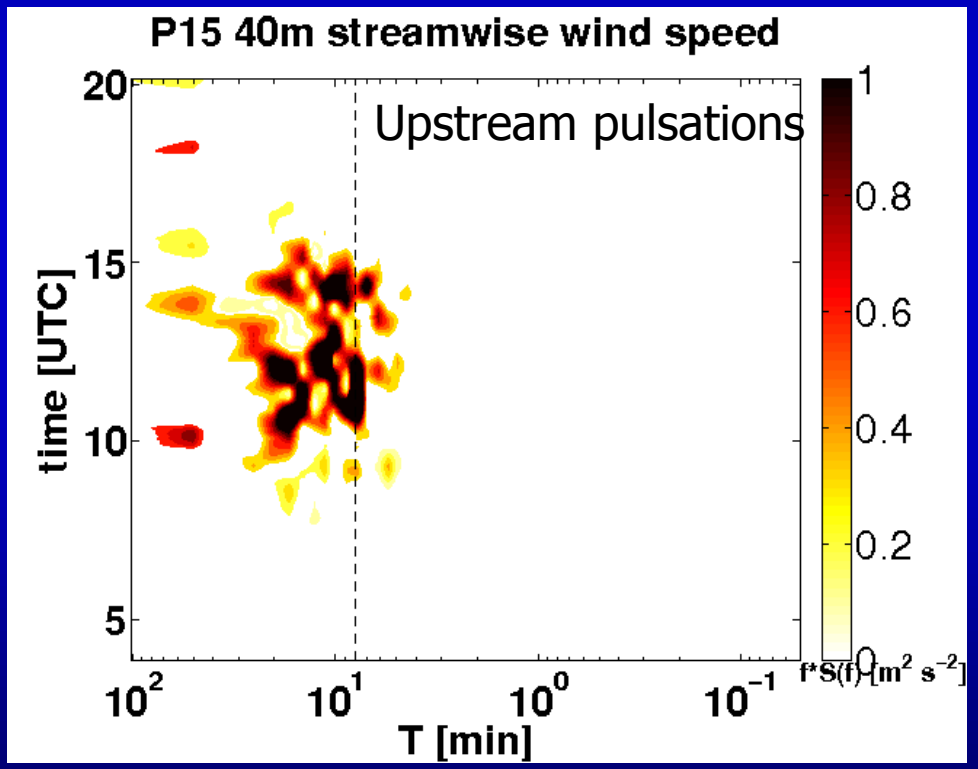
Conclusions

- 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





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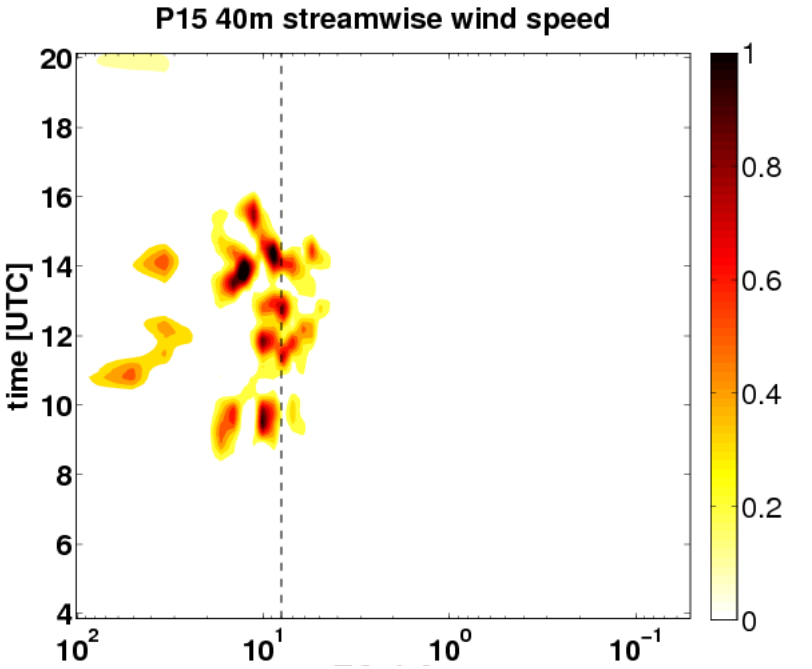
P15 40m streamwise wind speed
time [UTC]
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14
12
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6
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10^{-1}
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0.4
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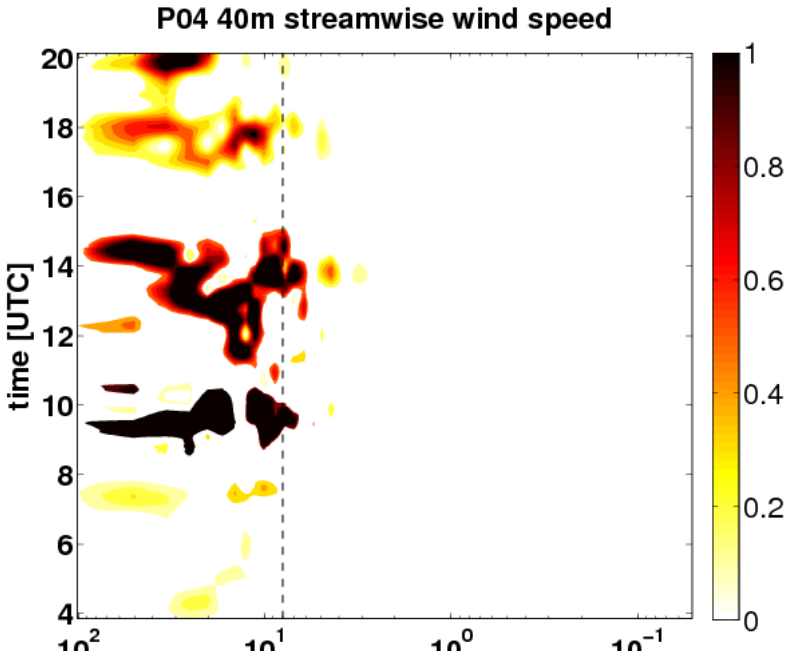
P04 40m streamwise wind speed
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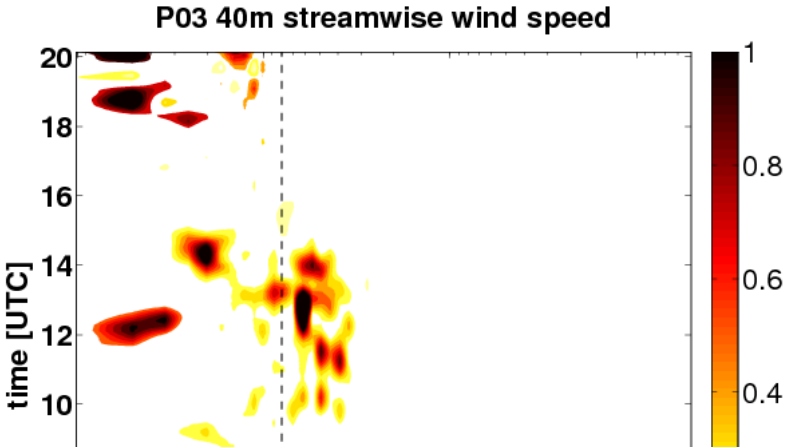
P03 40m streamwise wind speed
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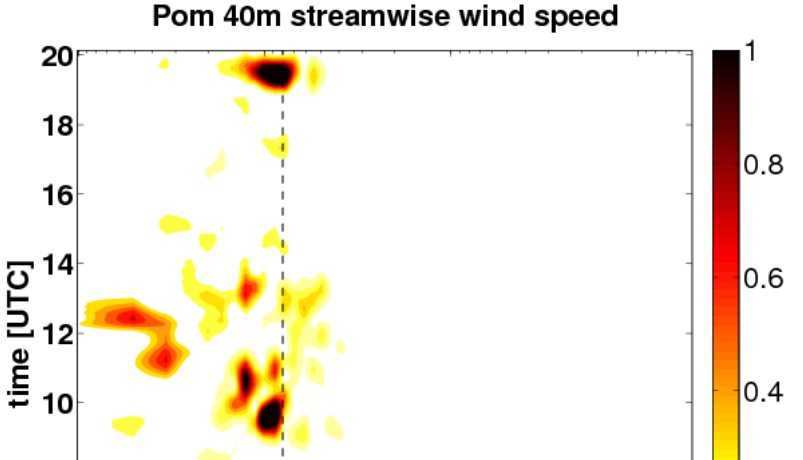
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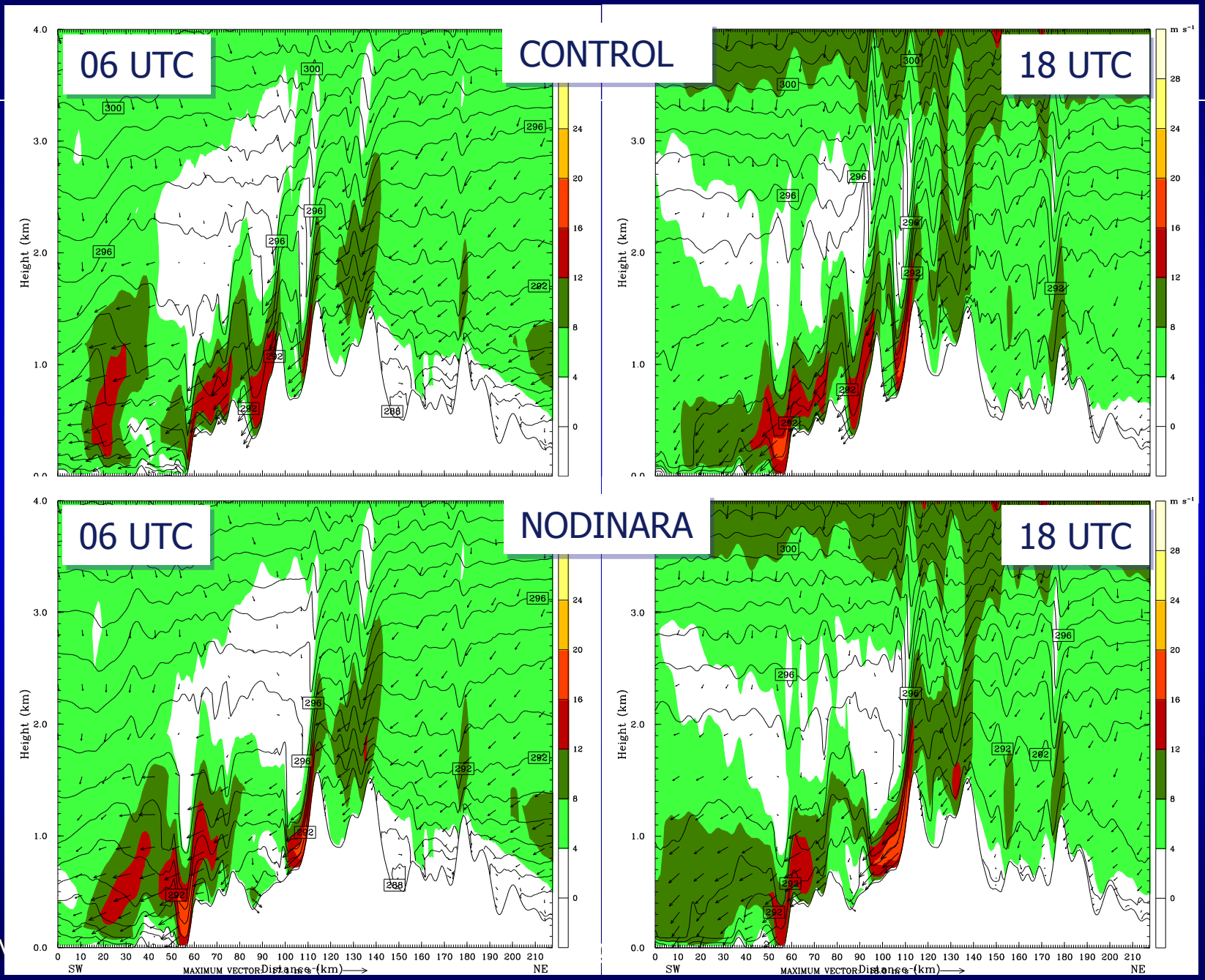
CONTROL
06 UTC
18 UTC
NODINARA
06 UTC
18 UTC
Height (km)
SW
NE
MAXIMUM VECTOR DISTANCE (km)
m s⁻¹