Wave-induced boundary-layer separation

A case study comparing airborne observations and results from a mesoscale model

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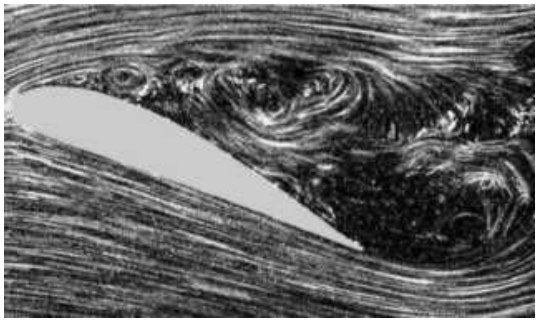
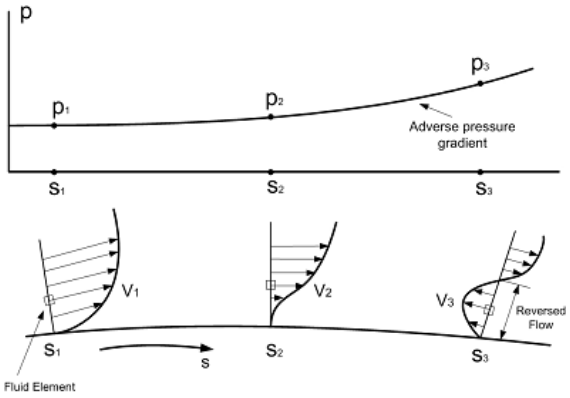
INTRODUCTION

Engineering sciences



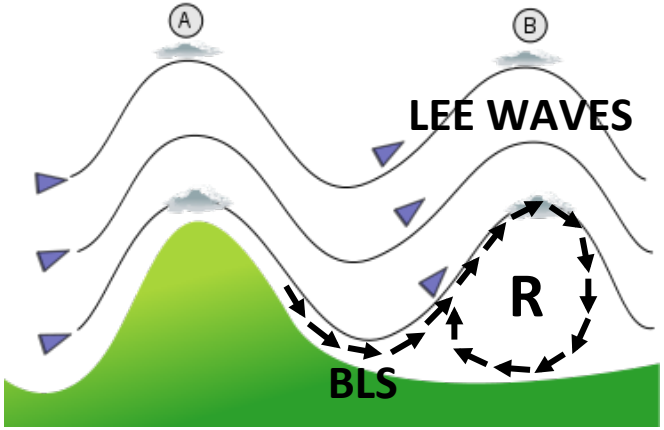


Anderson (1985)

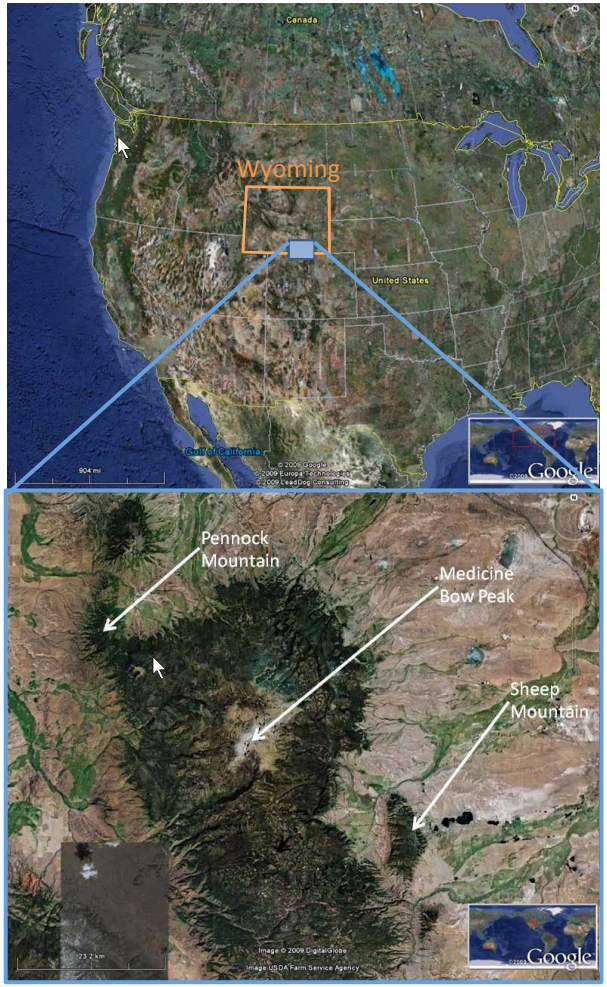
Stratified atmosphere

- Weak stability
  + steep mountain slopes
  … bluff-body separation

- Strong stability
  + moderate mountain slopes
  … wave-induced boundary-layer separation



OBSERVATIONS



January 2006
Medicine Bow Range (SE Wyoming)

Airborne Field Campaign

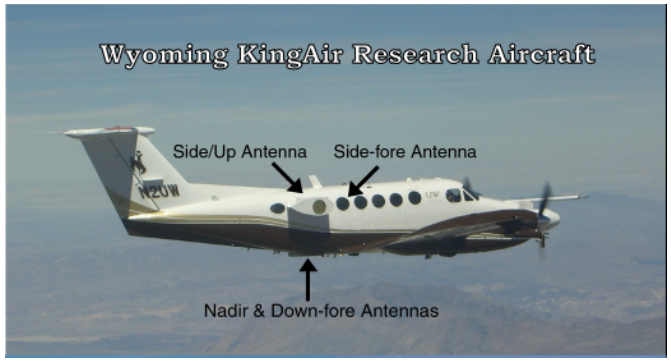
NASA Orographic Clouds Experiment

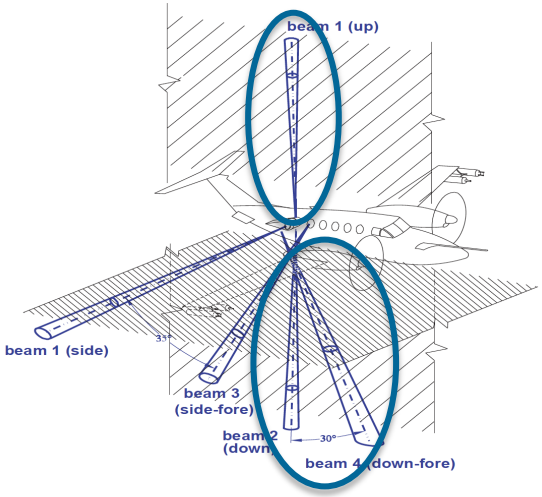
26 January 2006:

- Mountain waves
- Wave breaking
- Wave-induced boundary-layer separation
- Rotors

OBSERVATIONS

Wyoming Cloud Radar (WCR) aboard University of Wyoming King Air (UWKA)





Haimov *et al.* (2008)

UWKA in situ data

- 25 Hz
- u, v, w, θ, q, …

Wyoming Cloud Radar

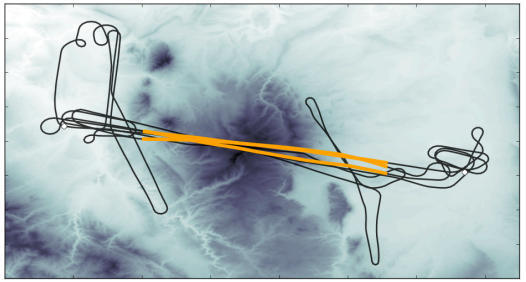
- Dual-Doppler radar
- Sensitive to cloud ice

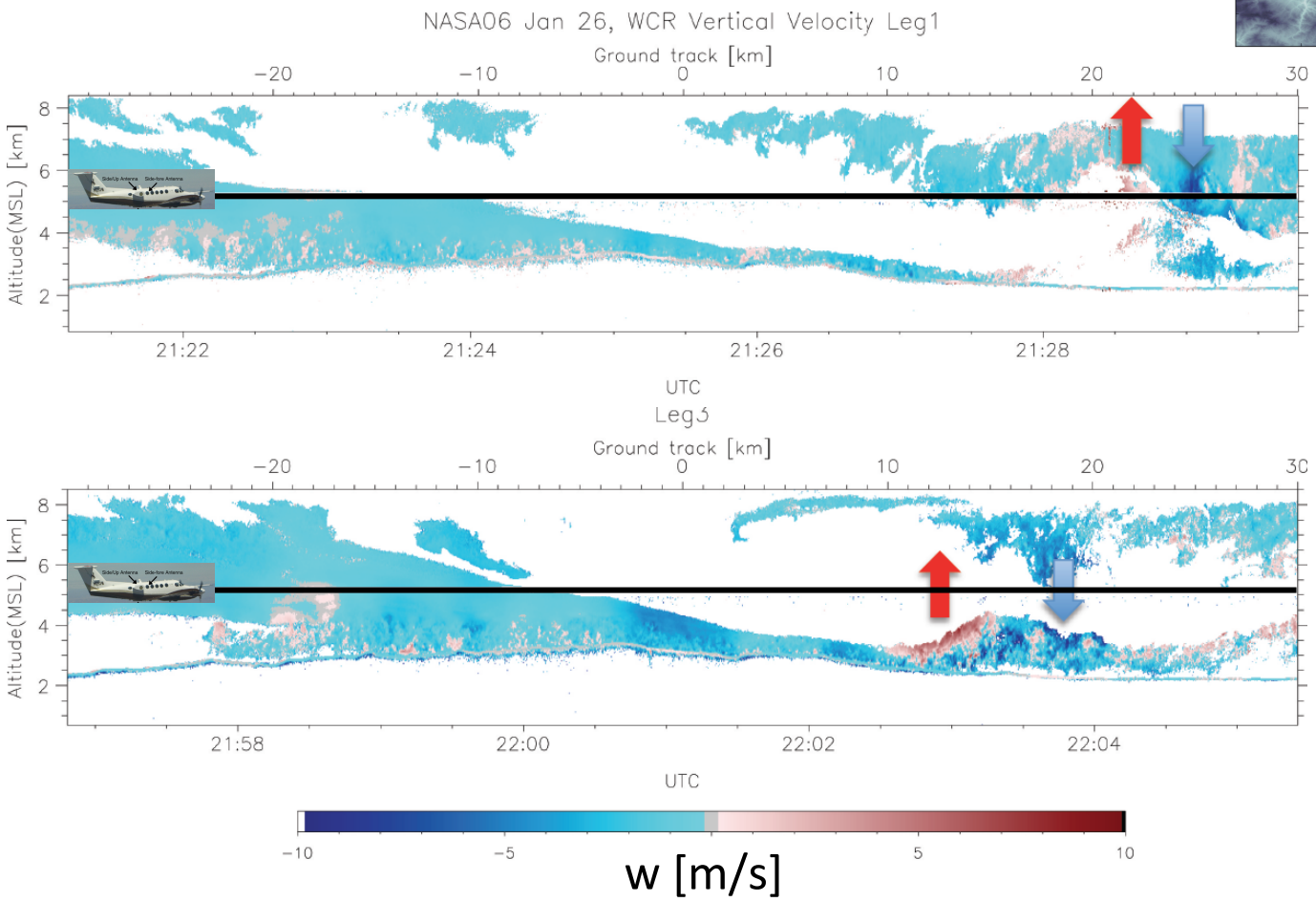
- Resolution of up to 30 x 30 m^2
- Dual-Doppler wind fields in two dimensions (u_{at}, w)

OBSERVATIONS

26 January 2006

strong wave activity, separation, rotor development





Pass 1

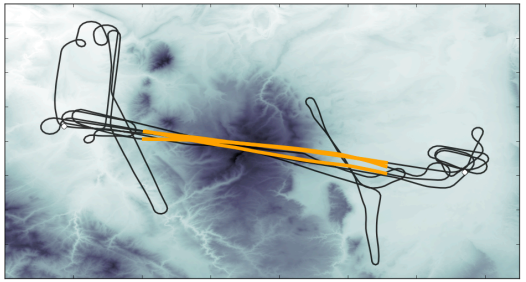
Pass 3

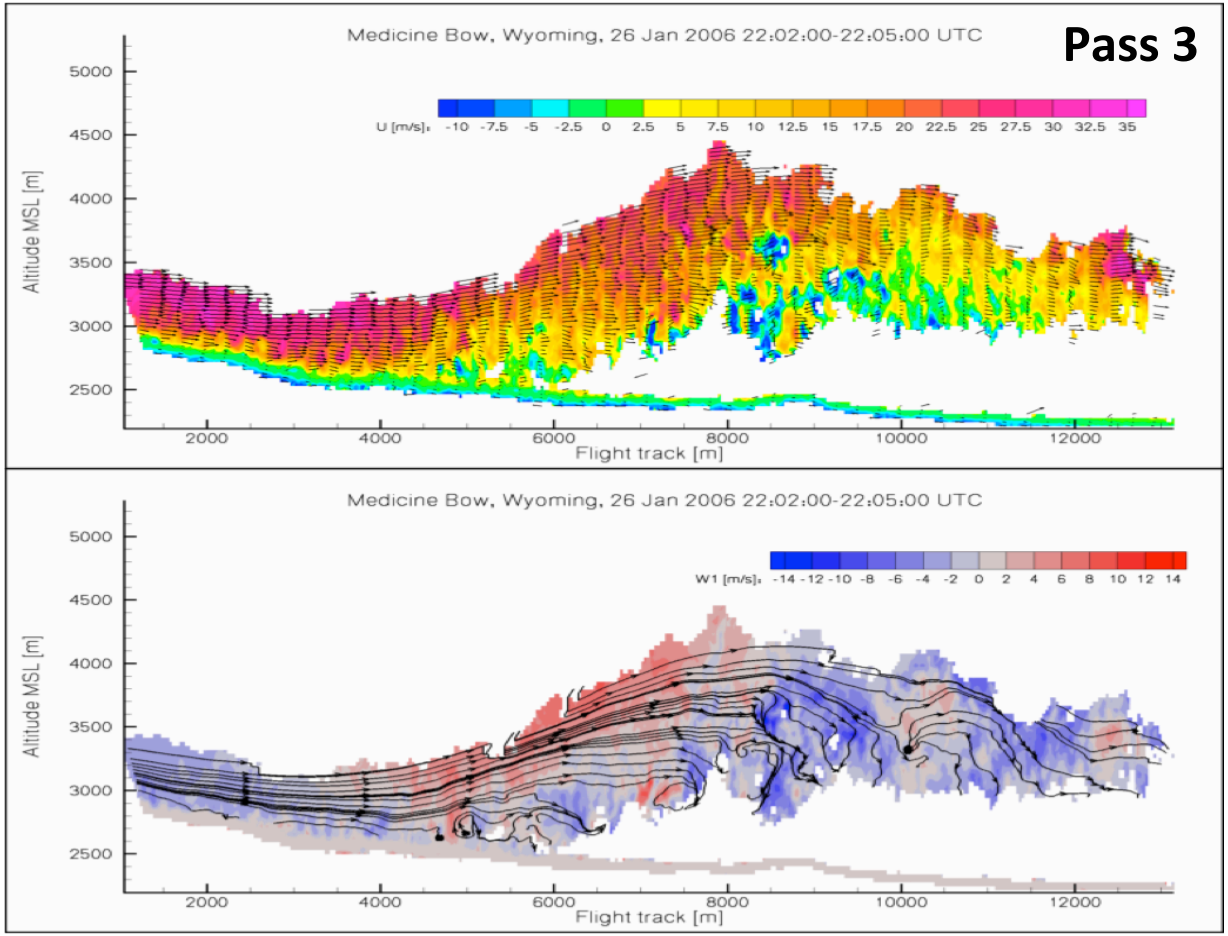
Haimov, Grubišić, French, Oolman (2008)

OBSERVATIONS

26 January 2006

Wind fields retrieved from dual-Doppler reflectivities





u [m/s]

w [m/s]

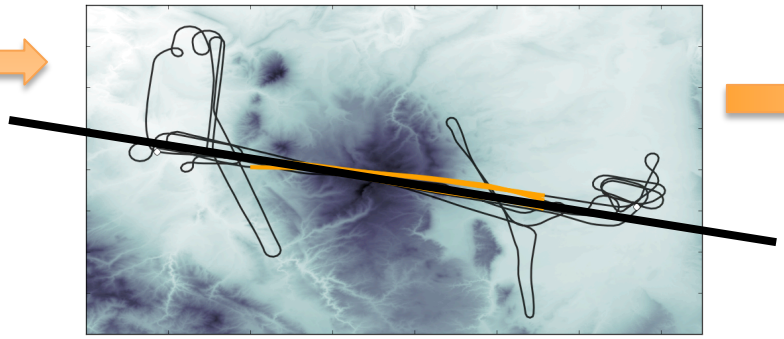
Haimov, Grubišić,
French, Oolman (2008)

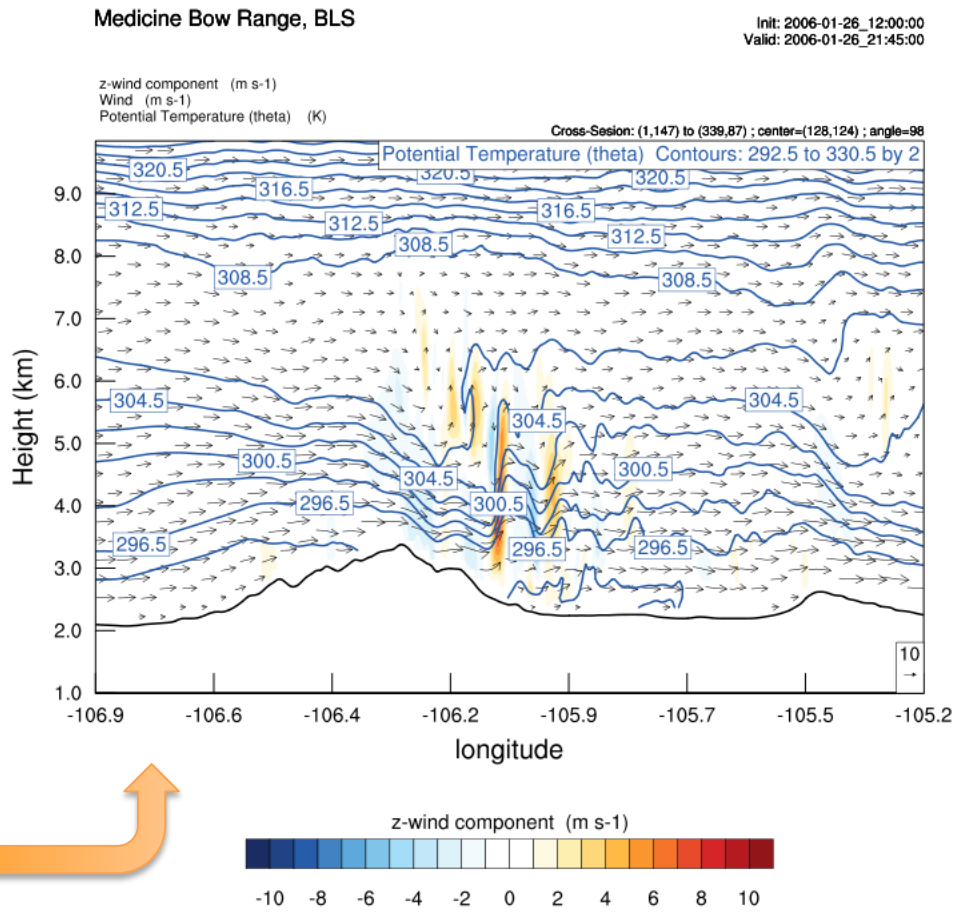
MESOSCALE MODELLING

26 January 2006

WRF simulation

- ECMWF analysis
- Start: 12 UTC 26/01/2006
- Innermost domain:
  dx = dy = 400 m
  dz stretching from 20 to 340 m
- MYJ BL scheme for turbulence
- Morrison for microphysics





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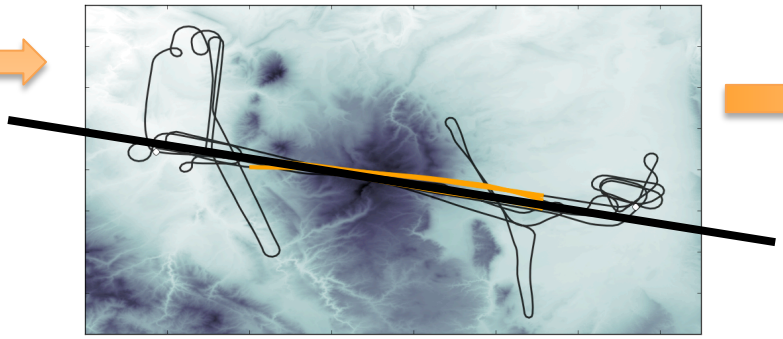

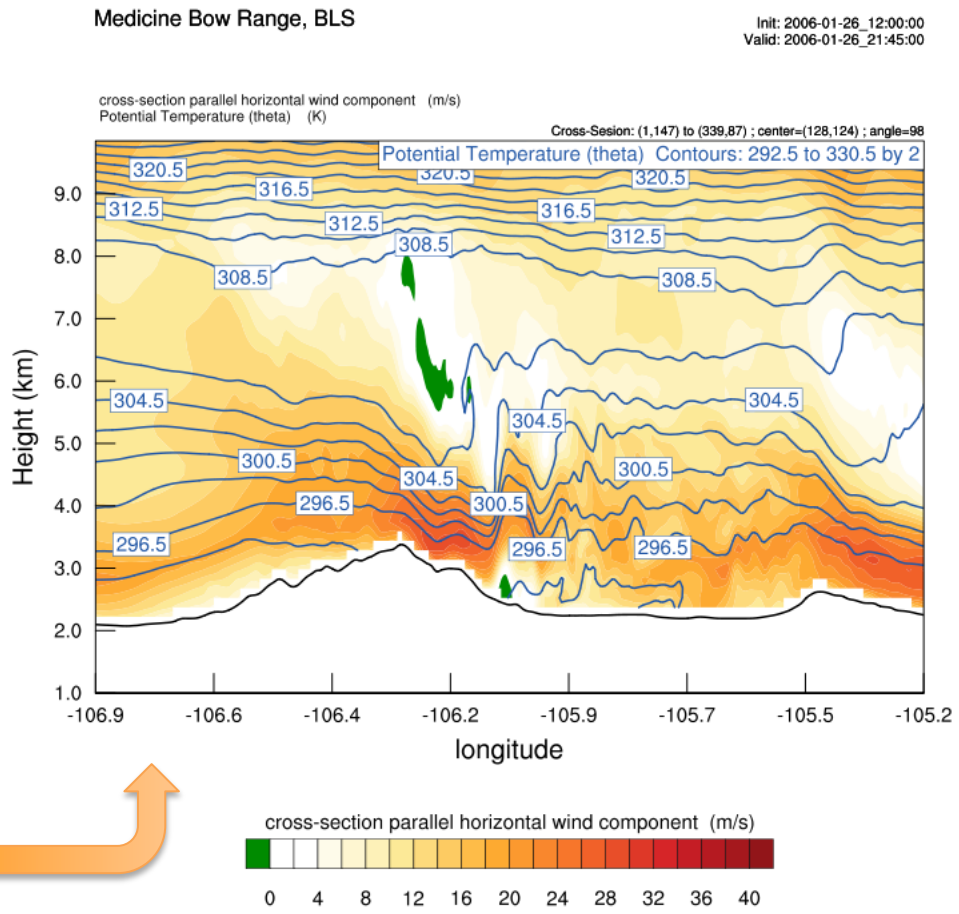

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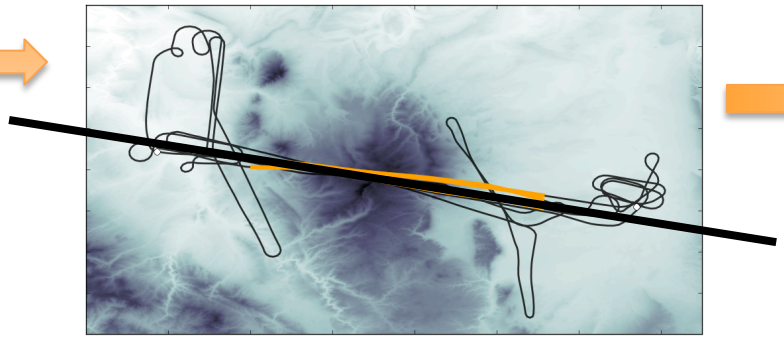
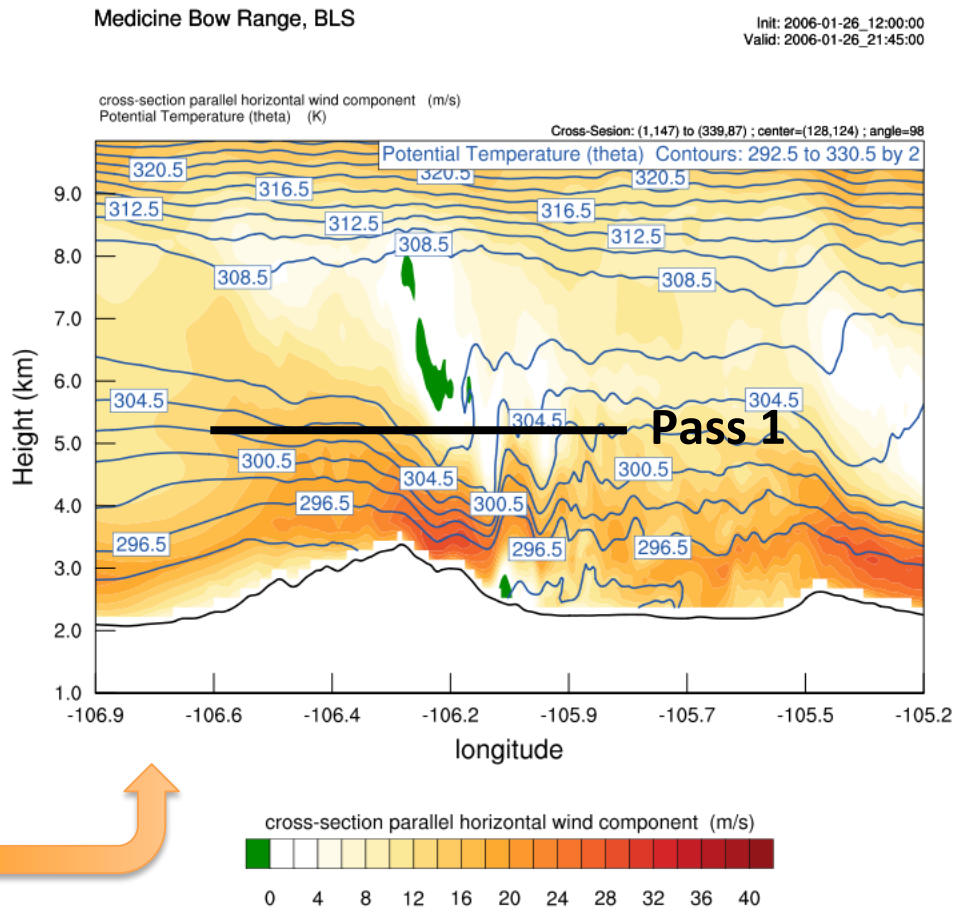
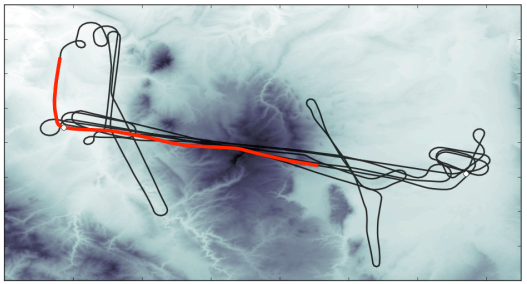


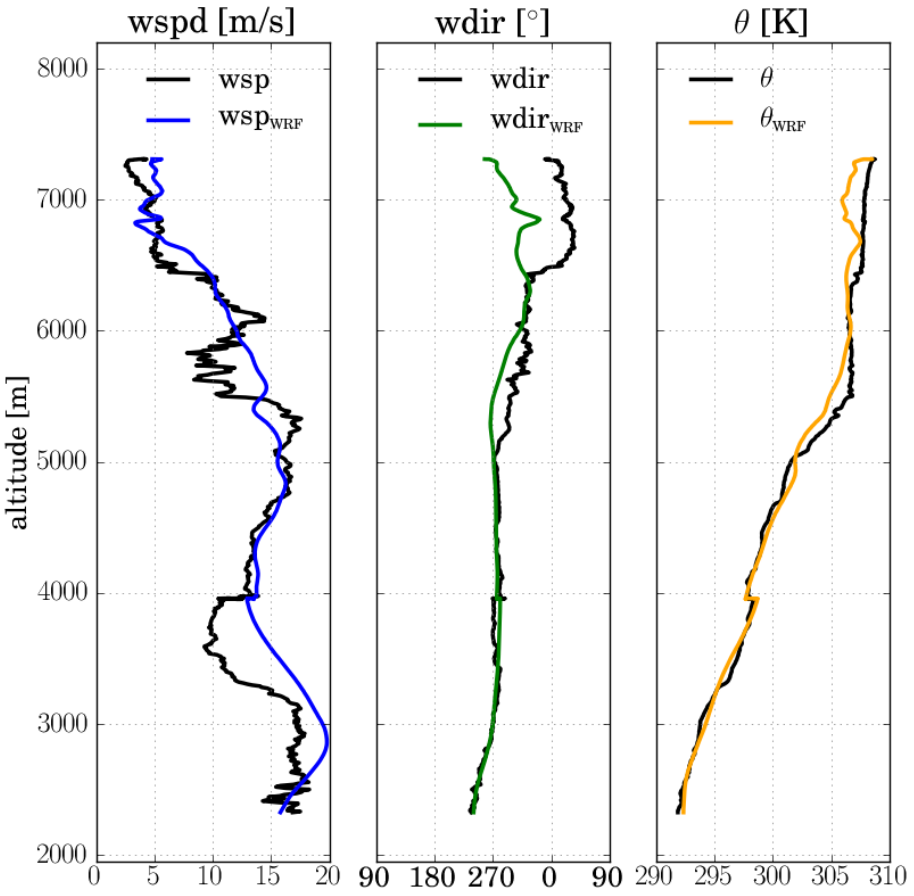


UPSTREAM SOUNDING

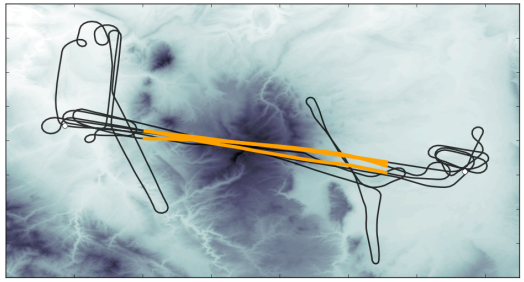


Ramp
Sounding

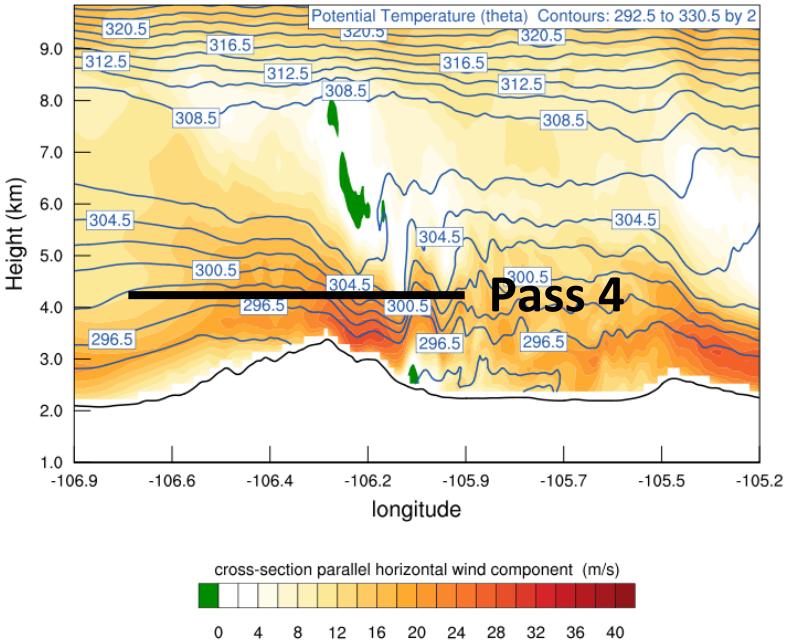
COMPARE
original aircraft sounding
AND
model sounding
at flight time



MODEL VERIFICATION

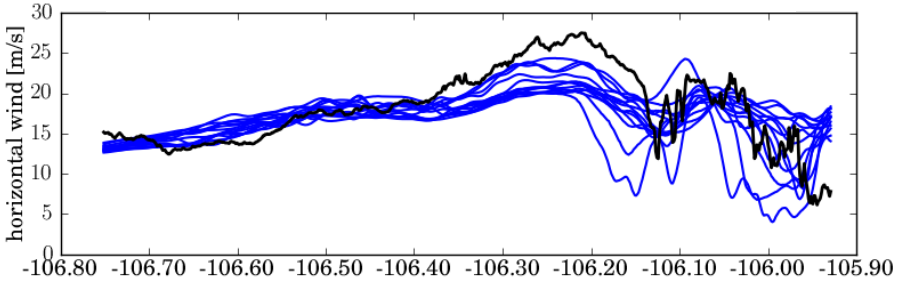


Passes

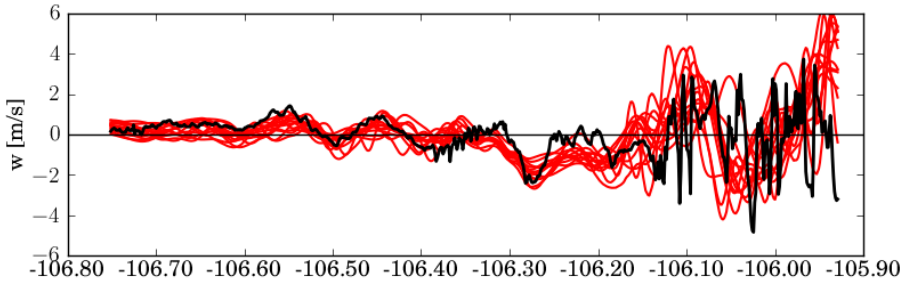


Pass 4

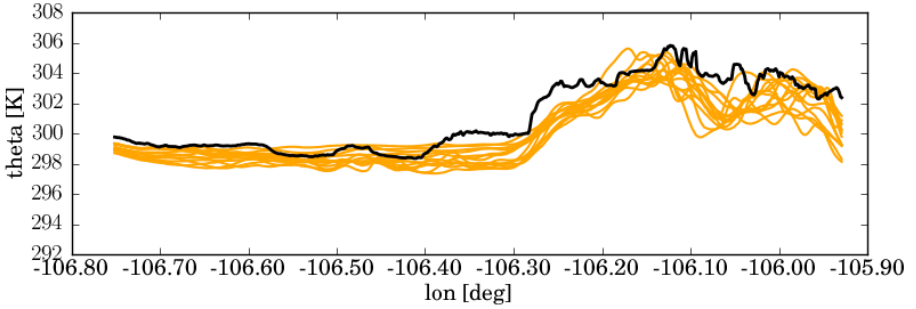
wspd



w

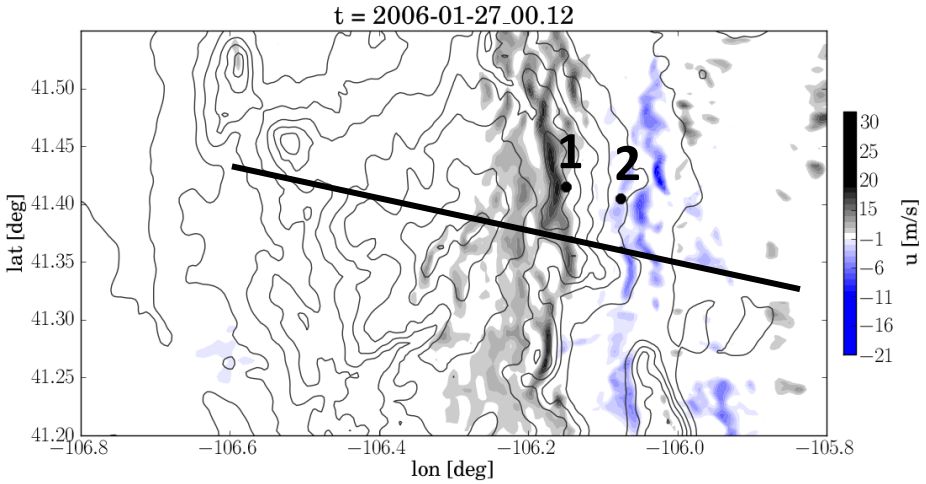


θ



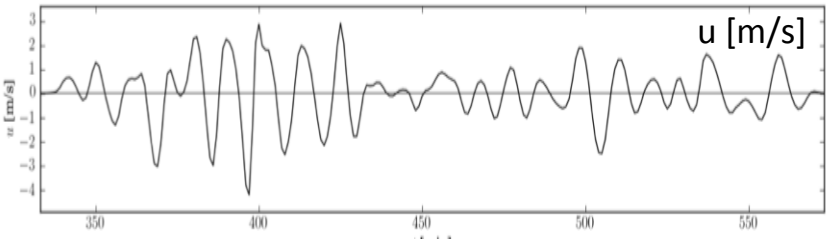
model output for a time window
± 1.5 h around actual flight time

PULSATIONS



1

Pulsations!



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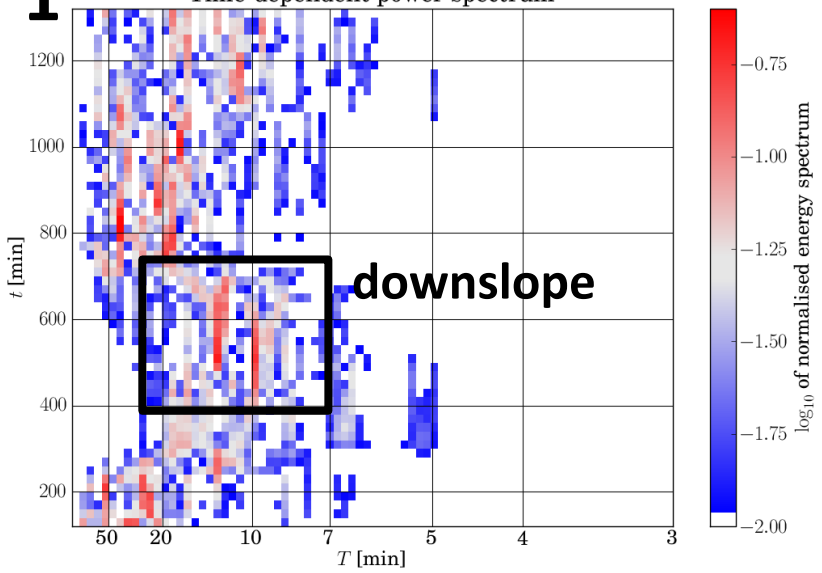

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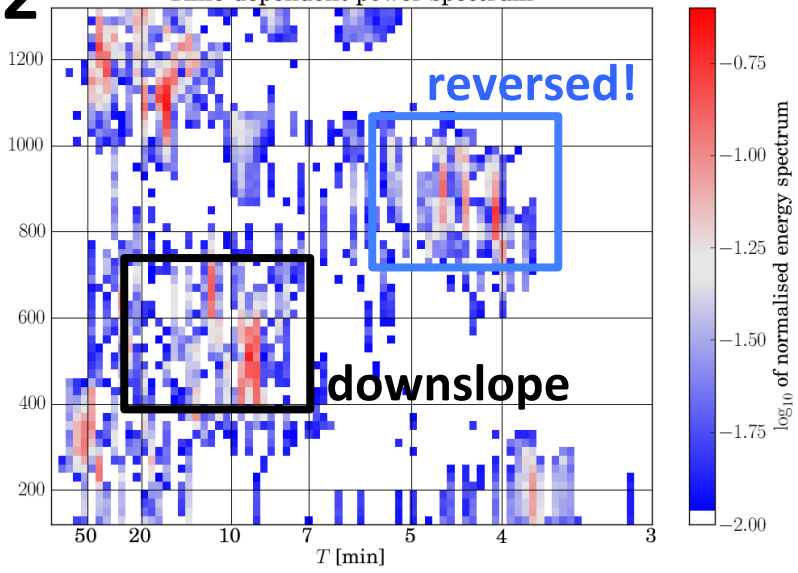
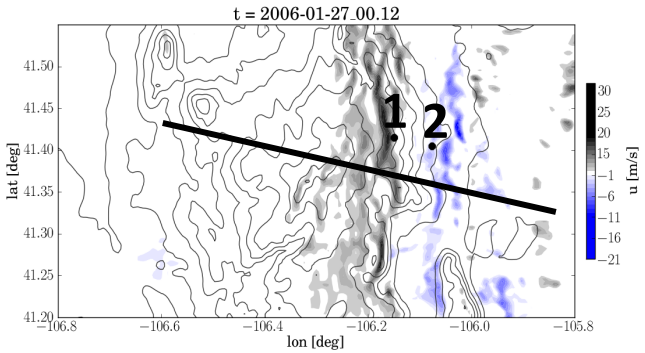


4h window sliding by 20 min

PULSATIONS

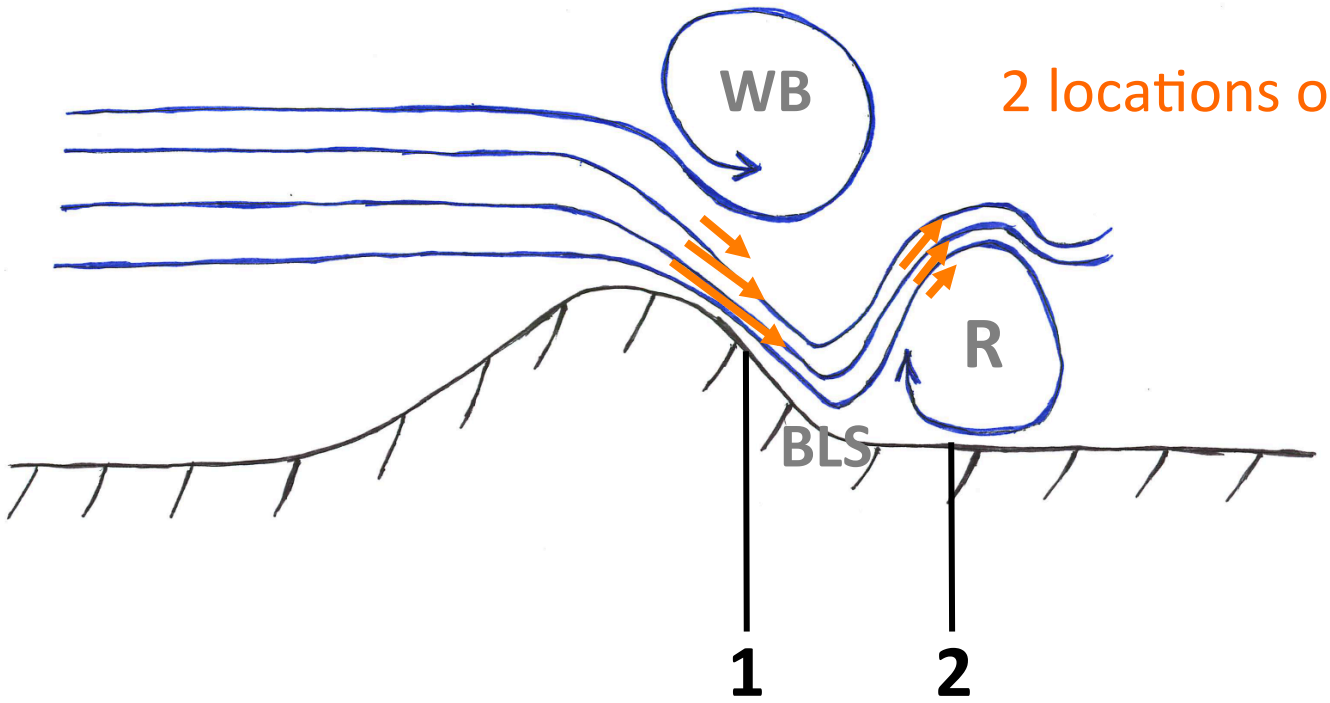


Current working hypothesis

1 … Pulsations like in Bora!?

2 … Advection of subrotor vortices!?

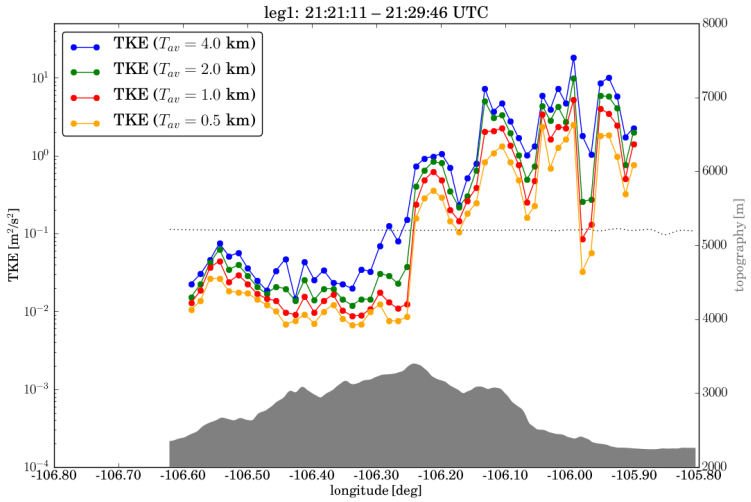
(Doyle and Durran 2007)



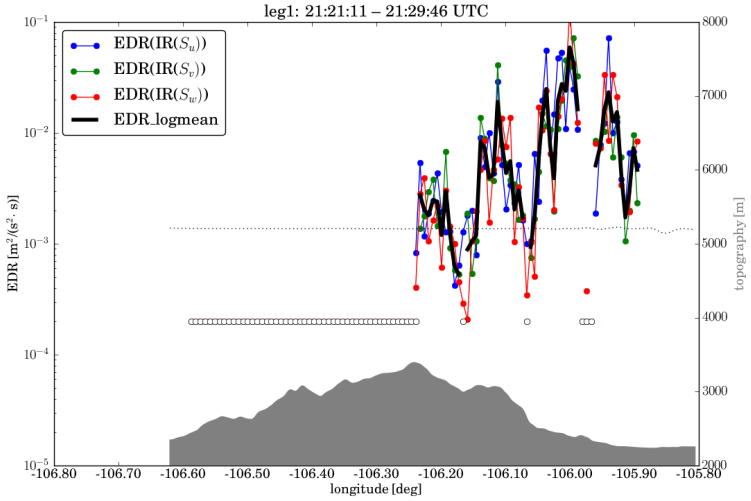
2 locations of KHI ?

TURBULENCE

25-Hz aircraft measurements



Pass 1



TKE

$$\bar{e} = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

… along 1 km segments

EDR… Inertial Dissipation Technique

$$\varepsilon = \left[\frac{k^{5/3} S_i\,(k)}{\alpha_i}\right]^{3/2}$$

… along 1 km segments

SUMMARY

OBSERVATIONS

- airborne observations reveal BL separation and ensuing rotor formation

MODELLING and VERIFICATION

- a mesoscale model (WRF) reproduces the measurements well
- breaking of a large hydrostatic wave, downslope windstorm, BL separation, rotor formation

ONGOING WORK

- pulsations in the downslope windstorm **and** in the reversed flow within the rotor -- **what's their origin?**
- turbulence analysis of in situ and Doppler radar measurements -- a great challenge in flow over complex terrain

Thank you for your attention!

Visit our group's webpage at
img.univie.ac.at/en/research/tm/

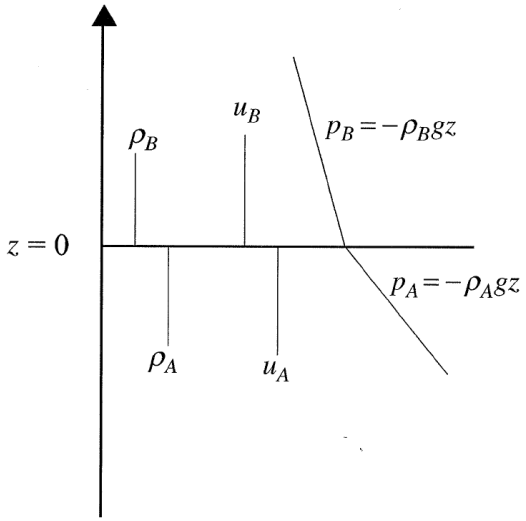
Material

MATERIAL

References:

- Cohn, Grubišić, Brown, 2011: Wind Profiler Observations of Mountain Waves and Rotors during T-REX, JAS
- Doyle and Durran, 2002: The Dynamics of Mountain-Wave-Induced Rotors, JAS
- Doyle and Durran, 2007: Rotor and Subrotor Dynamics in the Lee of Three-Dimensional Terrain, JAS
- Haimov, Grubišić, French, Oolman, 2008: Multi-Doppler measurements of atmospheric rotors and turbulent mountain waves, IGARSS Proc
- Nappo, 2002: An Introduction to Atmospheric Gravity Waves, Elsevier Academic Press

MATERIAL



Helmholtz shear profile

$$k_{crit} = \frac{g}{\rho_A \rho_B} \frac{\rho_A^2 - \rho_B^2}{(u_A - u_B)^2},$$

C.J. Nappo (2002)