Observation and modeling of boundary-layer separation and rotor events

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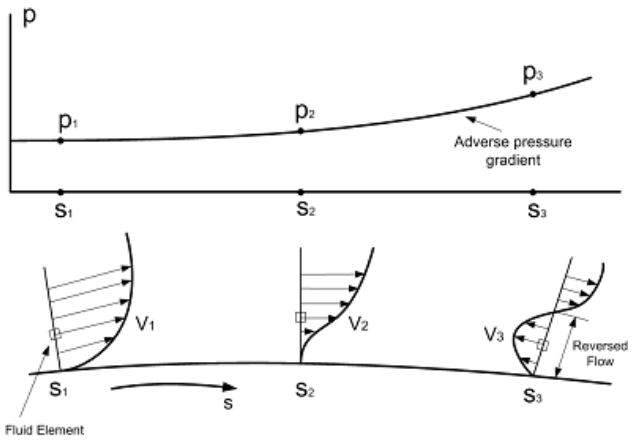
Summary

- Wave-induced boundary-layer separation.
- Medicine Bow Range, Wyoming.
- Granite Peak, Utah.

Wave-induced BLS

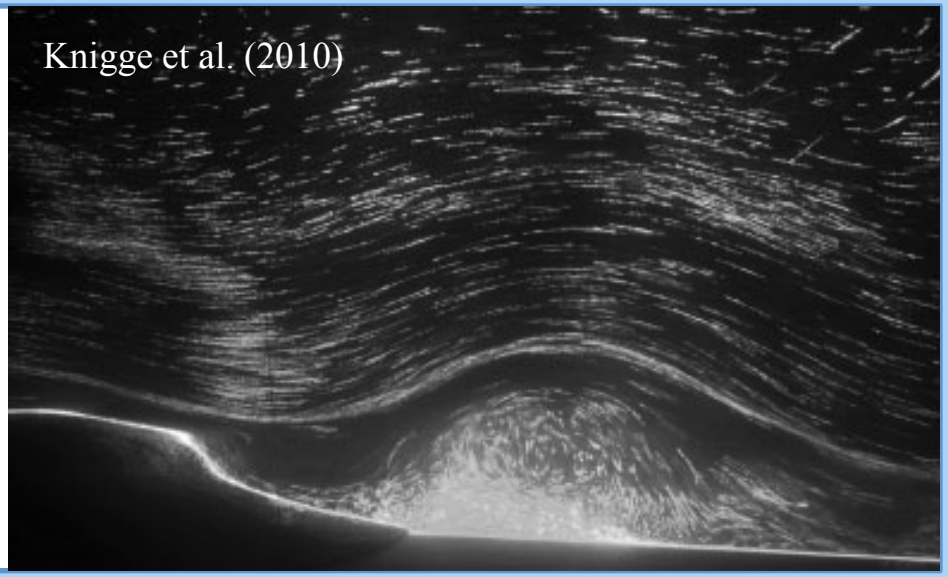
Wave-induced BLS /1



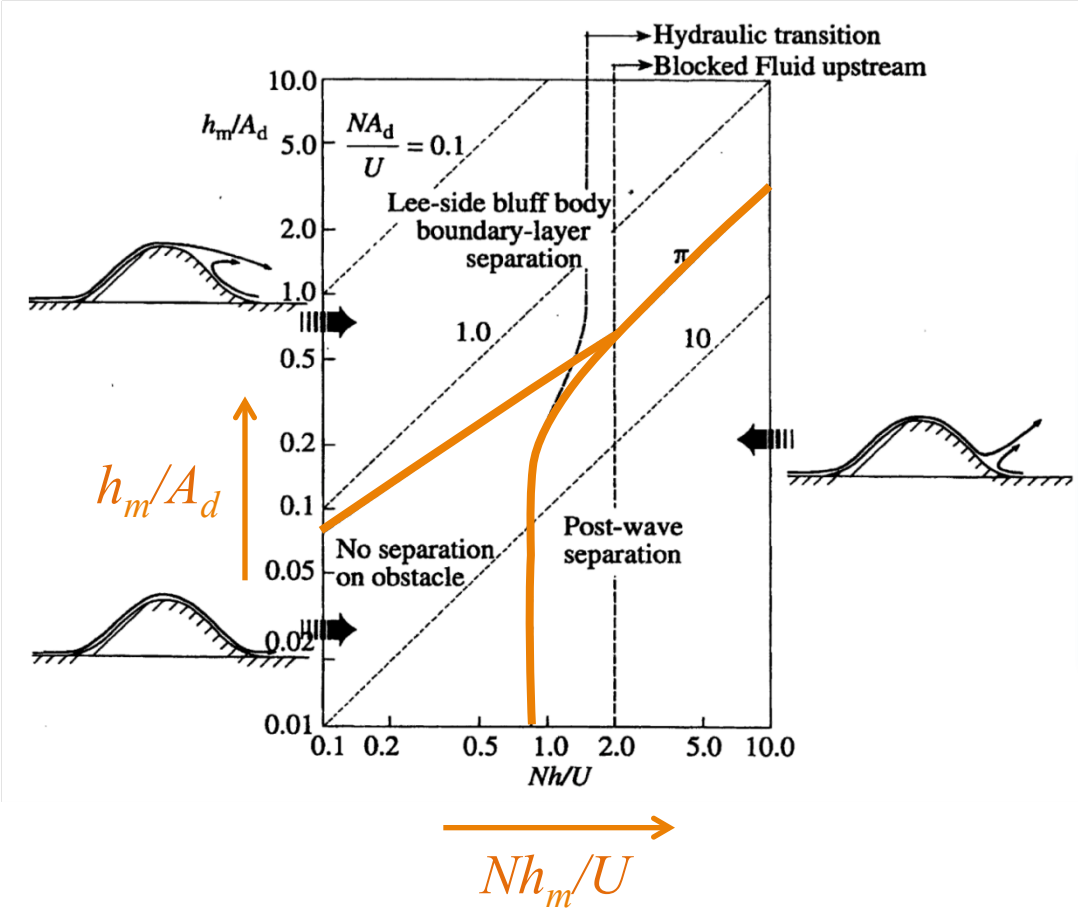
An adverse pressure gradient force acting on boundary-layer flow may cause boundary-layer separation (BLS).

Anderson (1995)

BLS can be wave-induced…



Wave-induced BLS /2



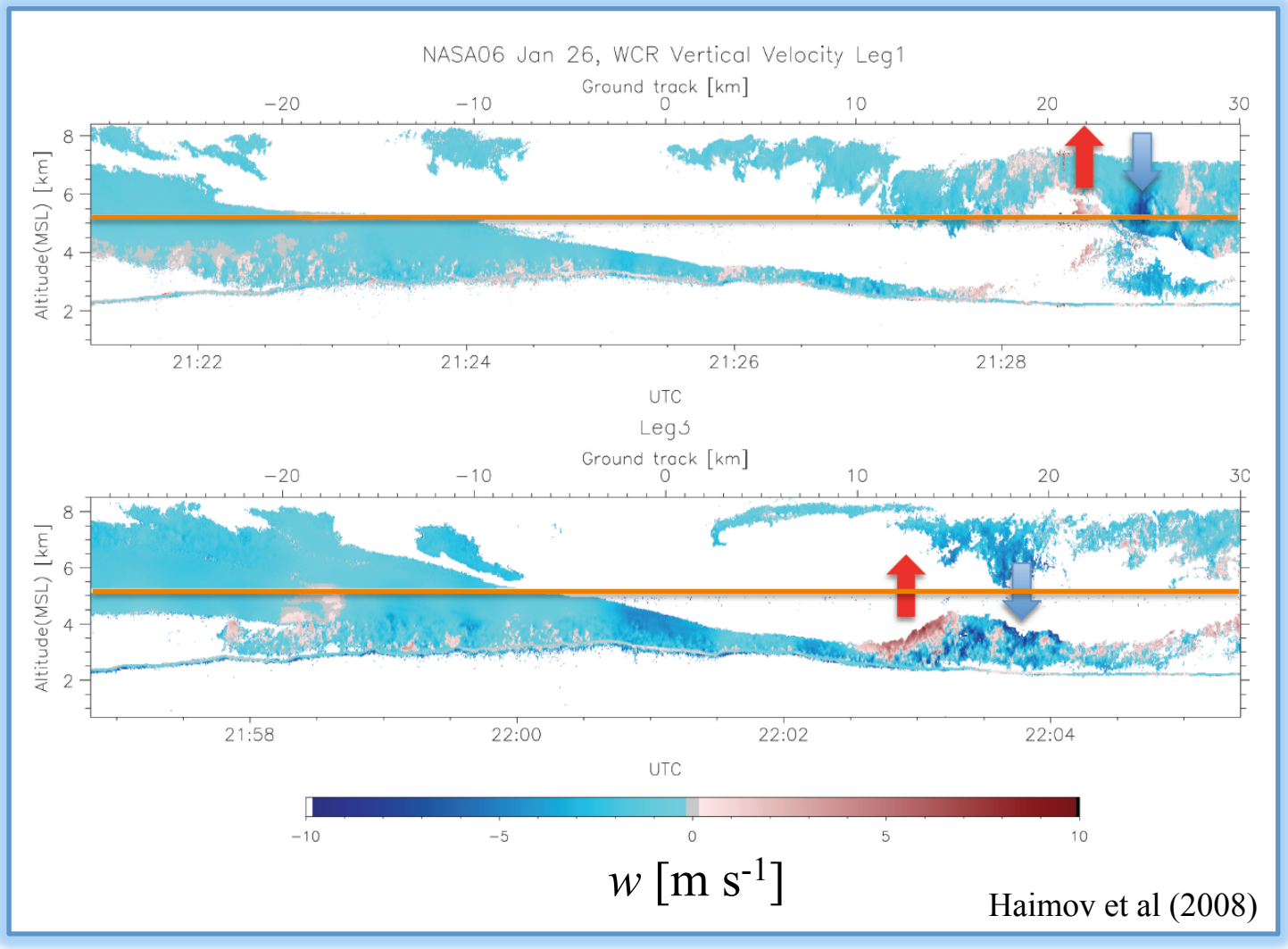
2D flow

h_m	mountain height
A_d	leeside mountain width
N	stability
U	wind
h_m/A_d	steepness
Nh_m/U	nonlinearity
NA_d/U	hydrostaticity

Baines (1995)
Baines and Hoinka (1985)

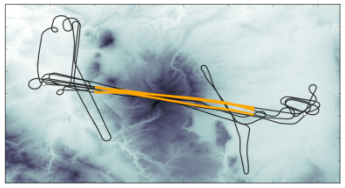
A case study:
Medicine Bow Range

Observations on January 26th, 2006



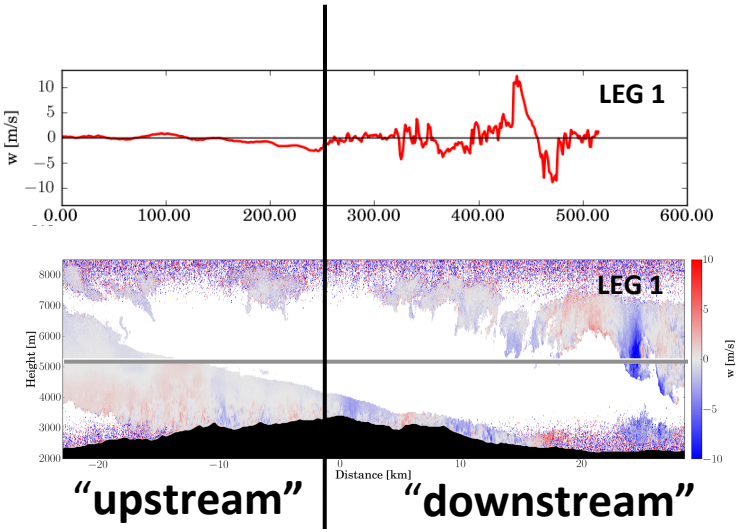
~21:29 UTC

~22:05 UTC

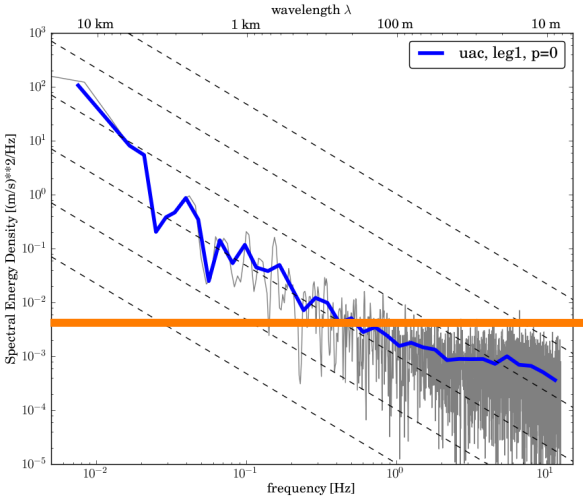


Observations on January 26th, 2006

Dividing a flight leg into parts
“**upstream” (quiescent)** and
“**downstream” (turbulent)**
of the mountain



Fourier spectra

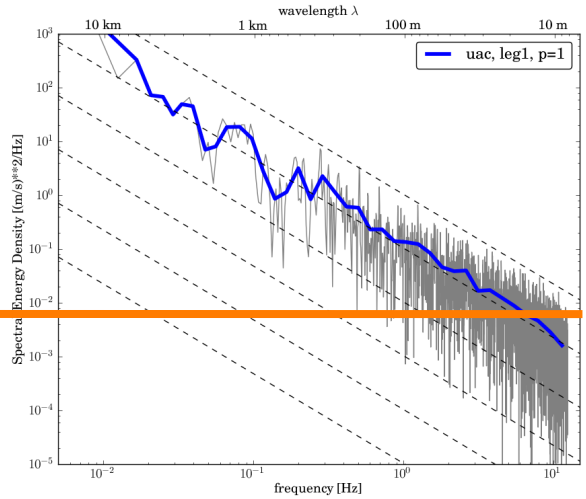


“upstream” – 4 min

u (leg1)

“signal”

“noise”

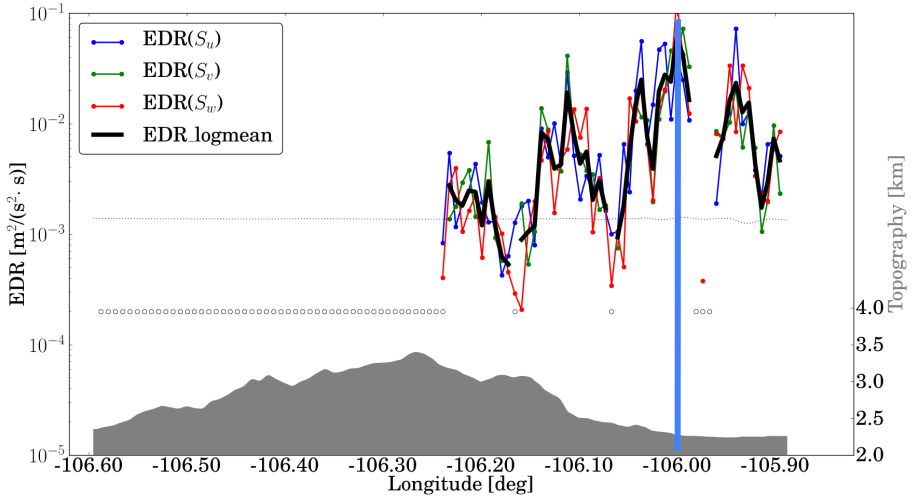


“downstream” – 4 min

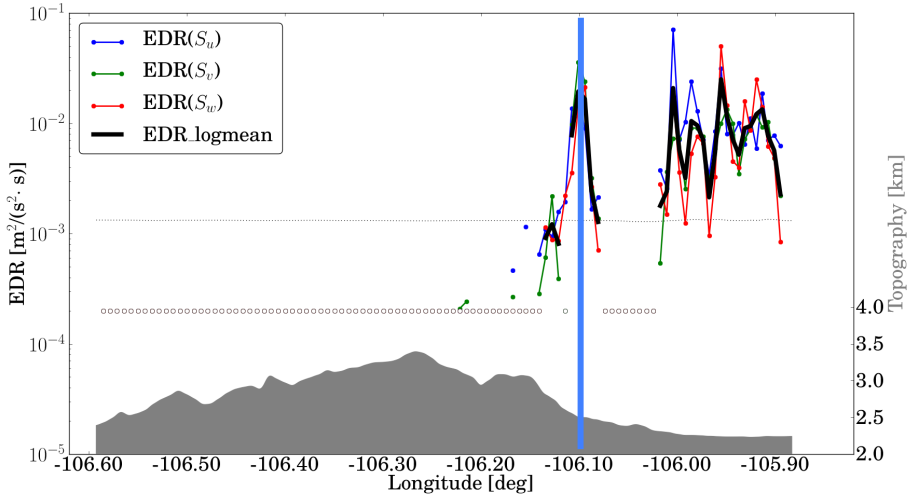
Observations on January 26th, 2006

EDR along flight legs

LEG 1



LEG 3



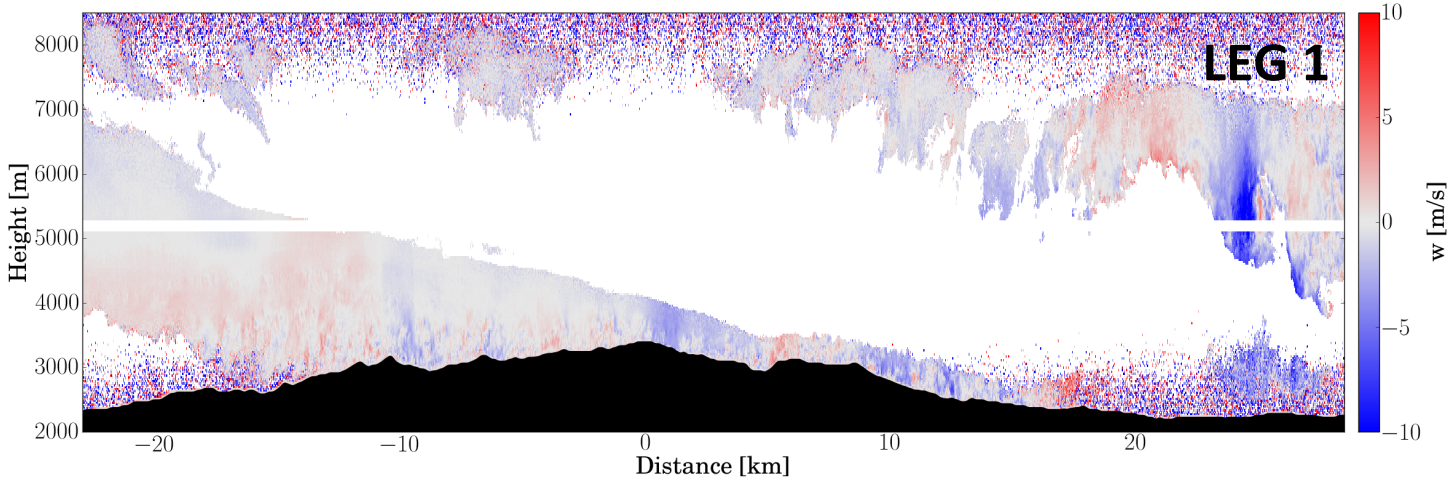
Procedure of applying inertial-dissipation technique:

- Cut time series into 10 s windows (Blackman), sliding interval 5 s
- Compute spectrum and estimate EDR for each window

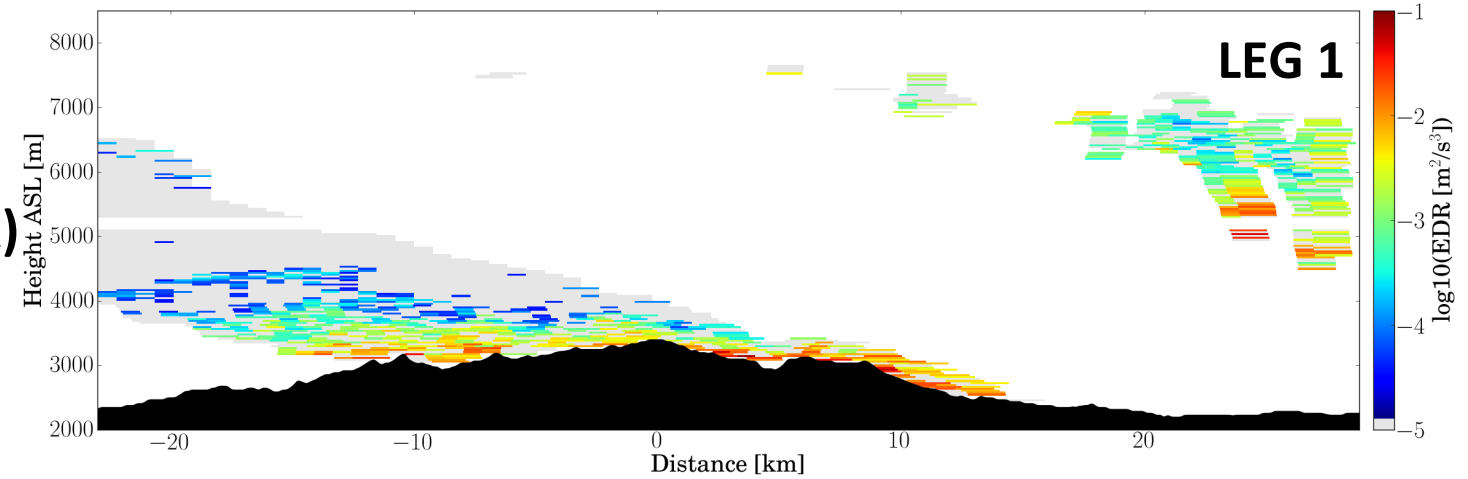
Observations on January 26th, 2006

LEG 1

w



log(EDR)

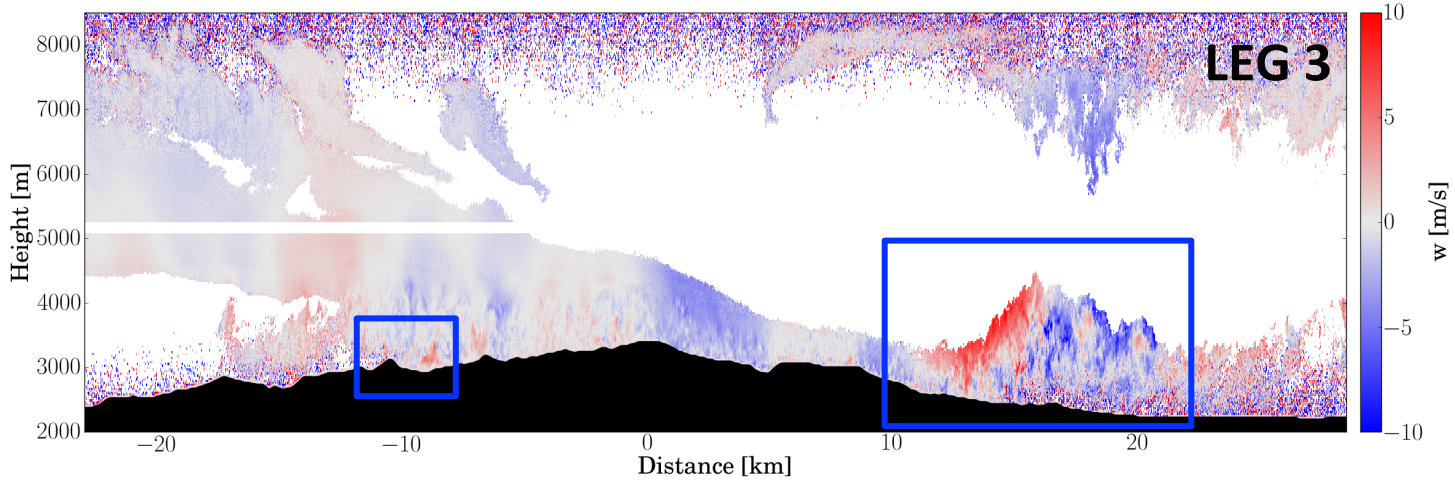


EDR estimation from spectra of 15 s segments, sliding by 7.5 s

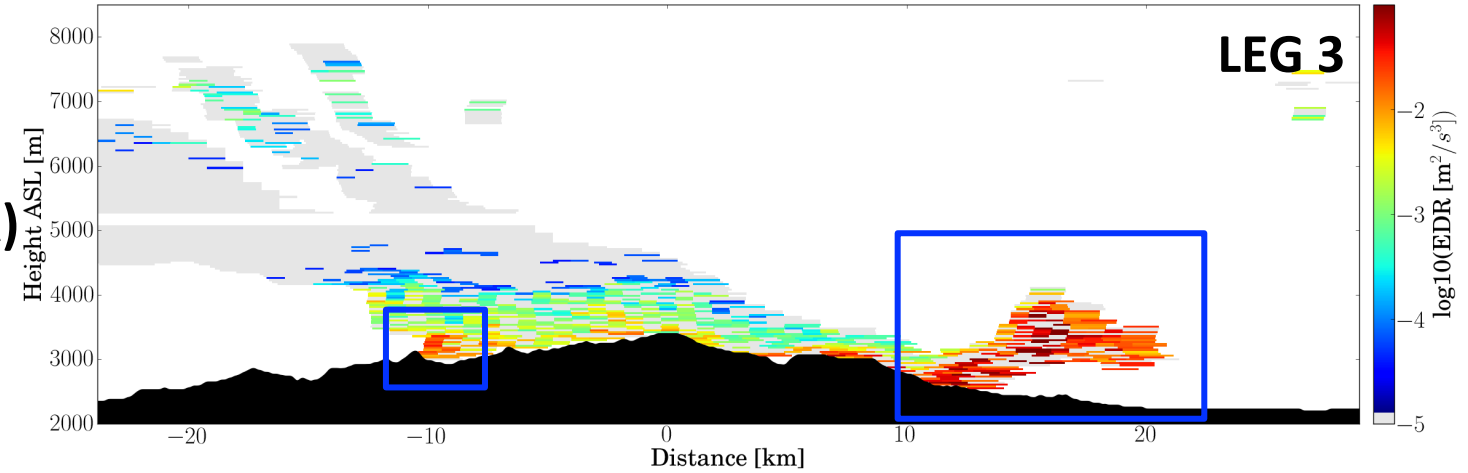
Observations on January 26th, 2006

LEG 3

w

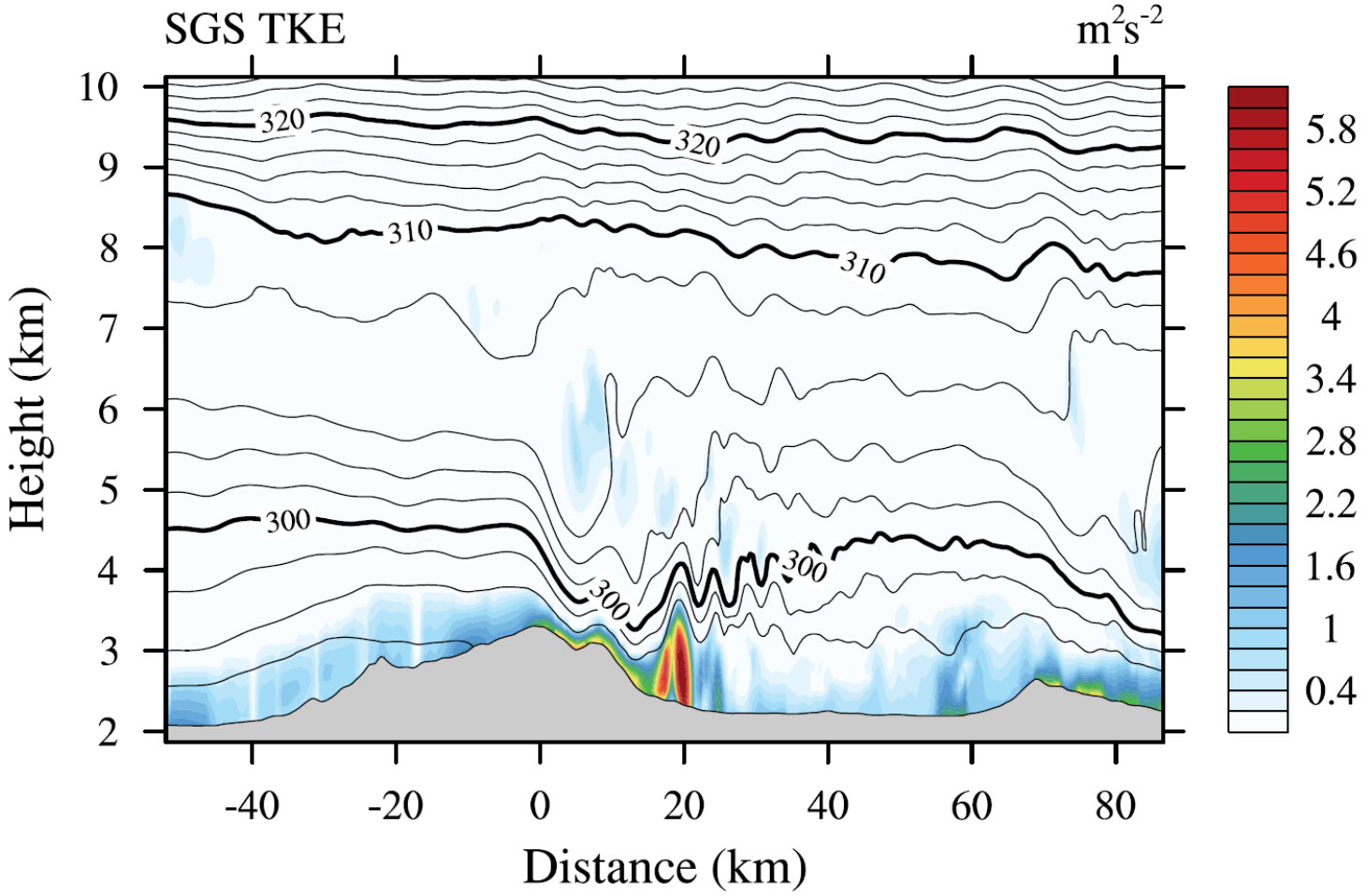


log(EDR)



EDR estimation from spectra of 15 s segments, sliding by 7.5 s

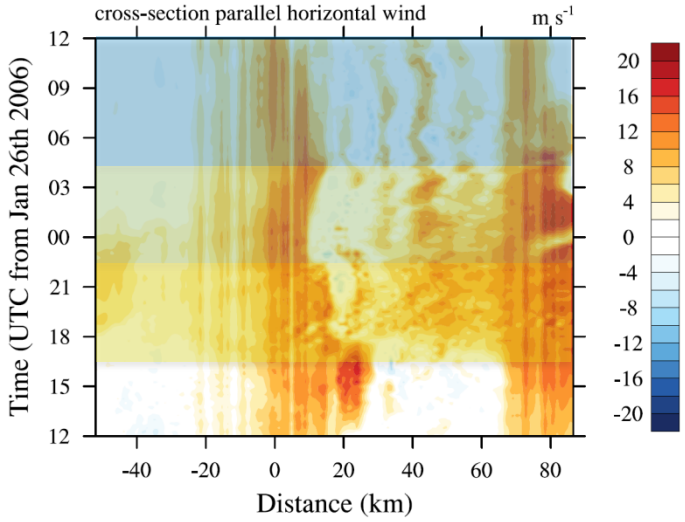
WRF modelling



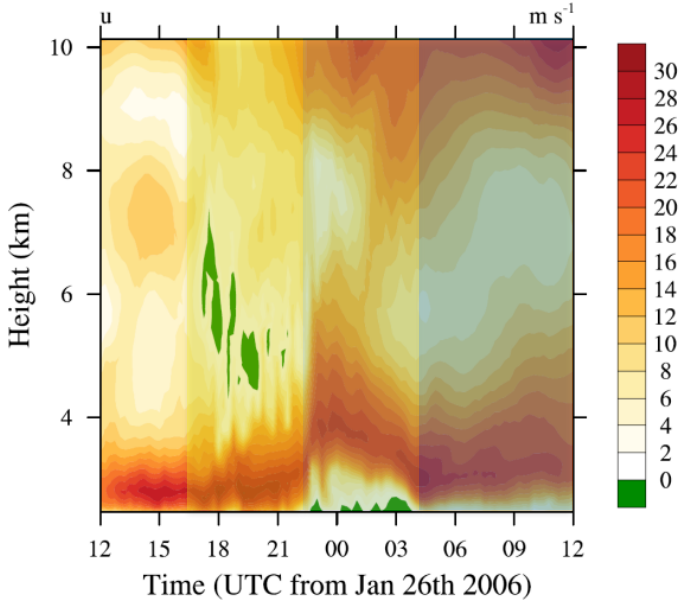
21:45 UTC

WRF modelling

t vs. x



z vs. t

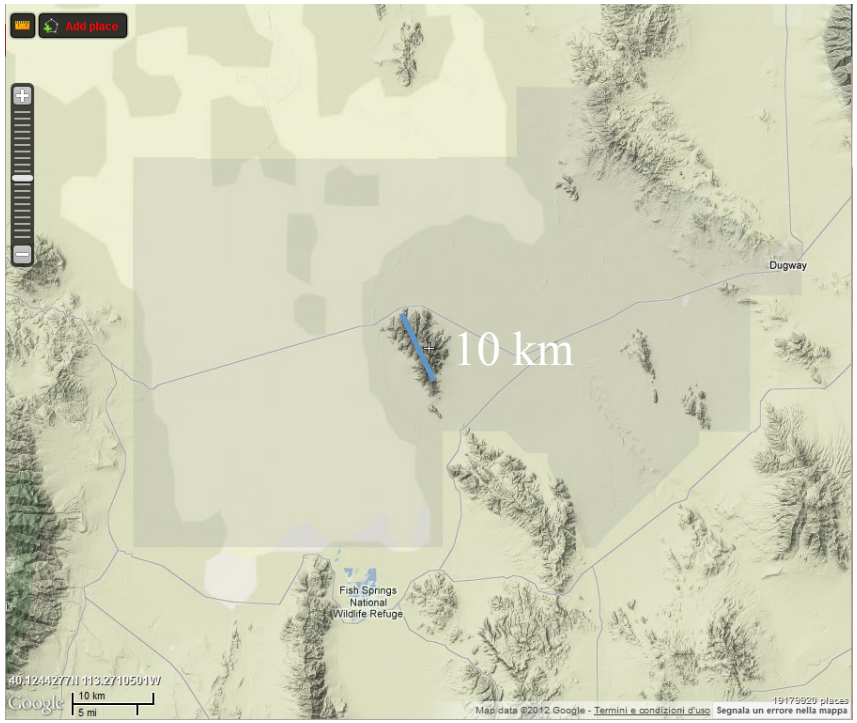


- Phase I:
  - Nonlinear flow regime, wave breaking.
- Phase II:
  - Decreasing nonlinearity upstream, transition.
- Phase III:
  - Neutral layer aloft, trapped lee waves.

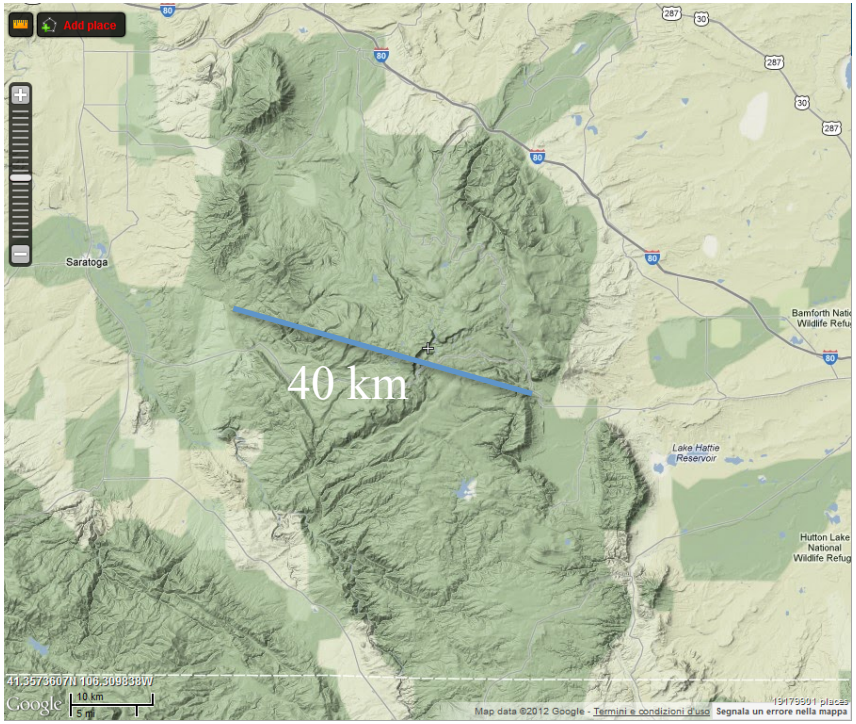
Outlook:
Granite Peak

Comparison to Medicine Bow

Granite Peak

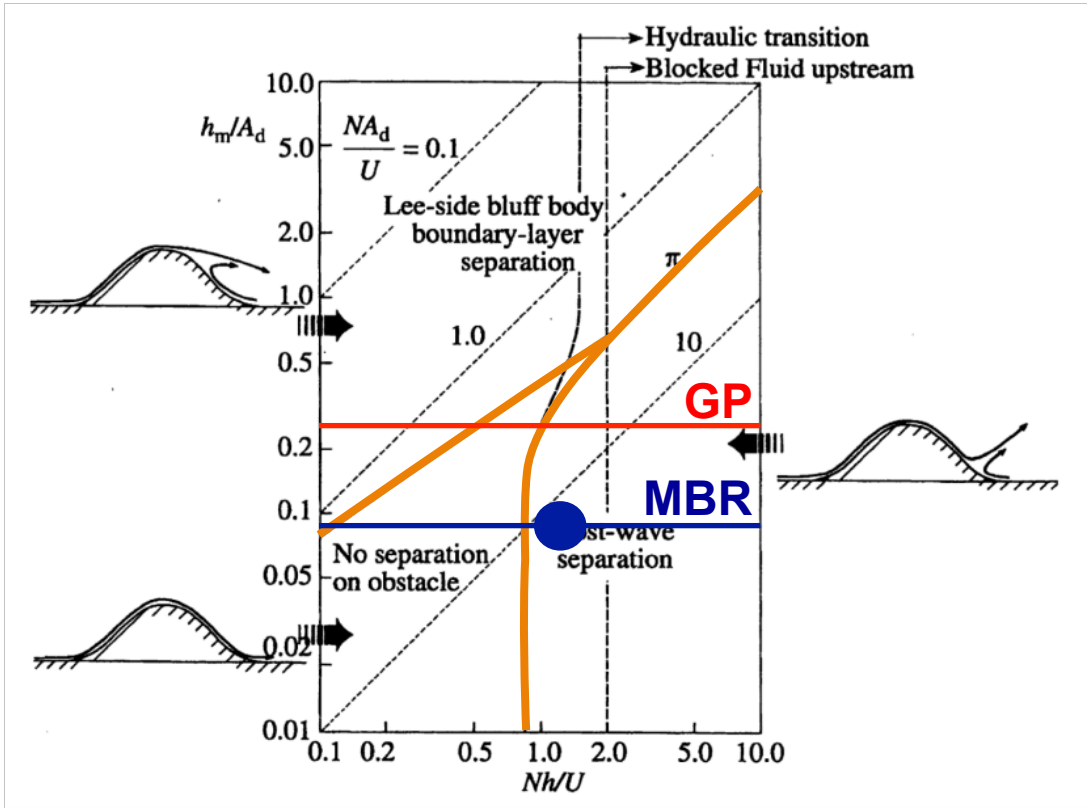


Medicine Bow Range



10 km

Theory

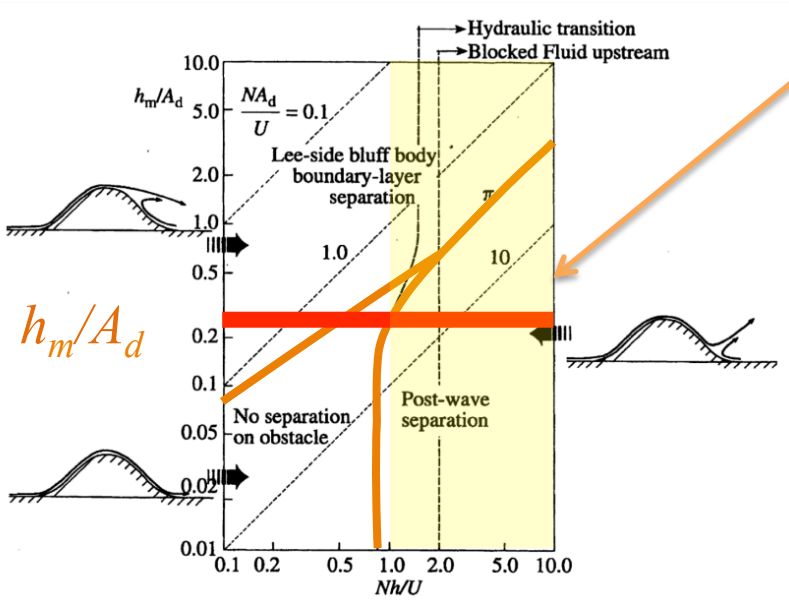


Potentially, all three separation regimes may be observed over Granite Peak, depending on the upstream conditions.

Theory

- Granite Peak is an irregularly shaped 3D obstacle!

2D



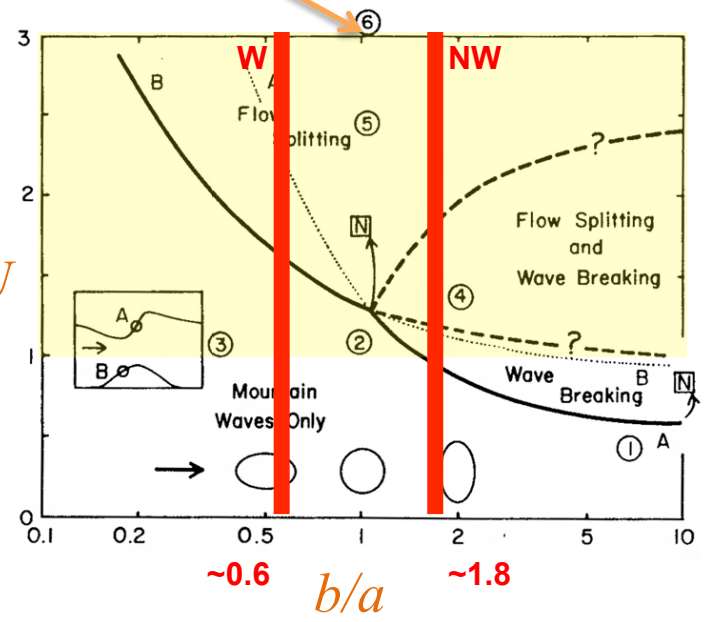
h_m/A_d

Nh_m/U

Baines, 1995

$Nh_m/U>1$

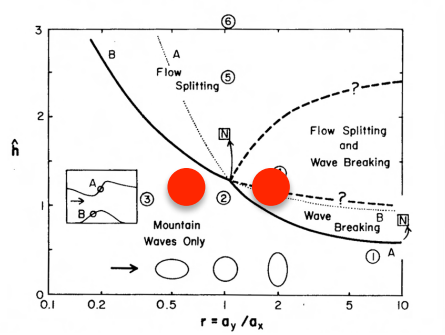
3D



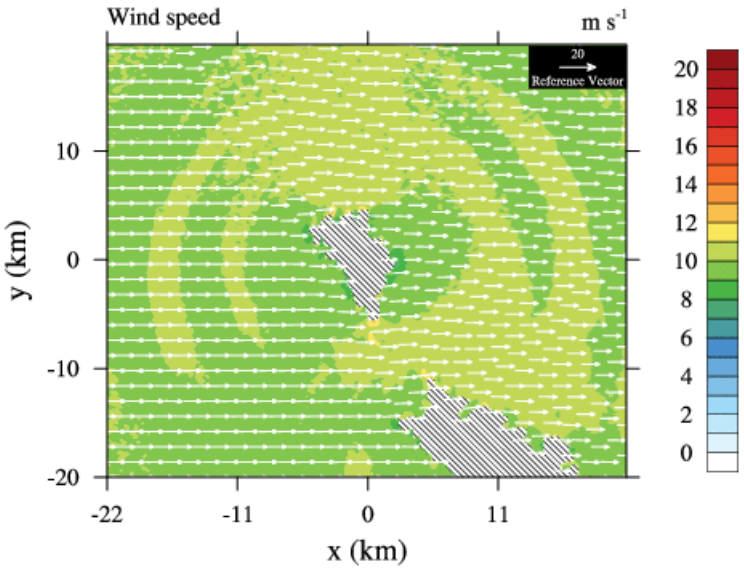
Nh_m/U

Smith, 1989

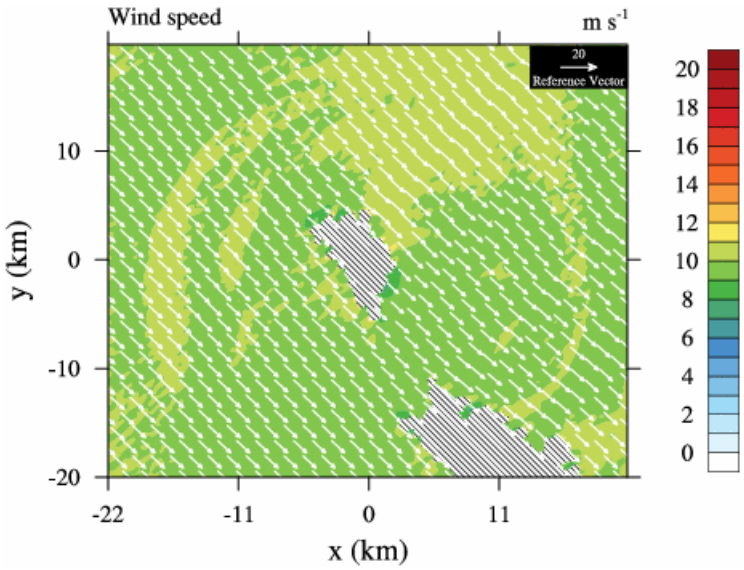
CM1 modelling



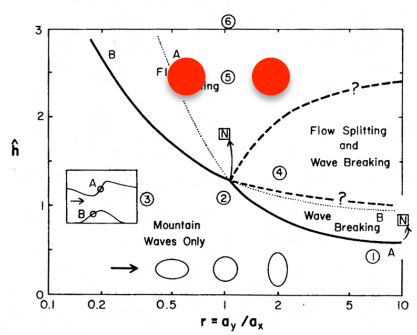
W, 10 m s^{-1}



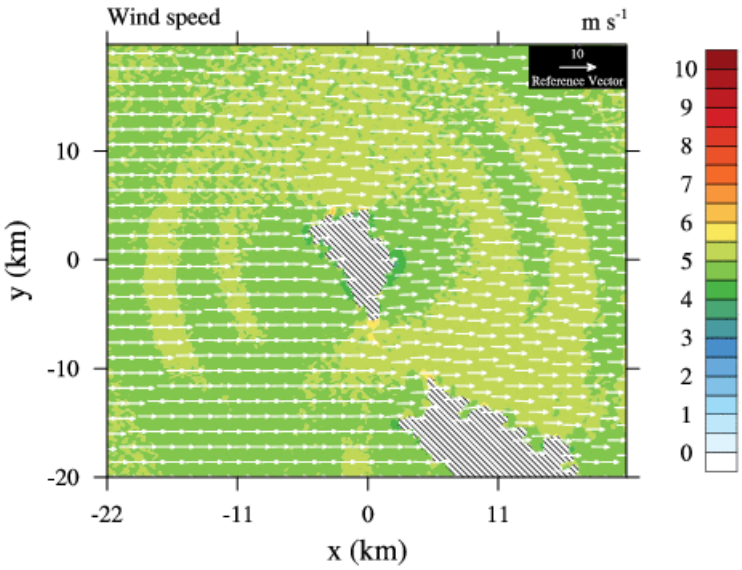
NW, 10 m s^{-1}



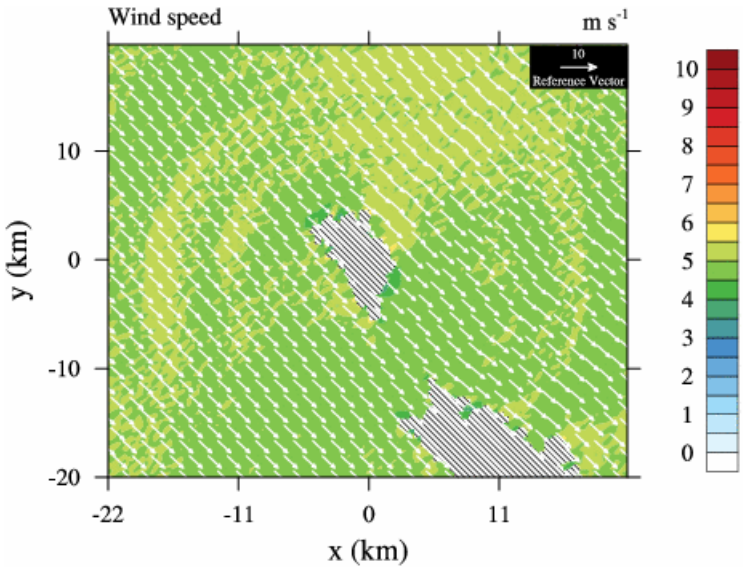
CM1 modelling



W, 5 m s^{-1}



NW, 5 m s^{-1}



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Conclusions

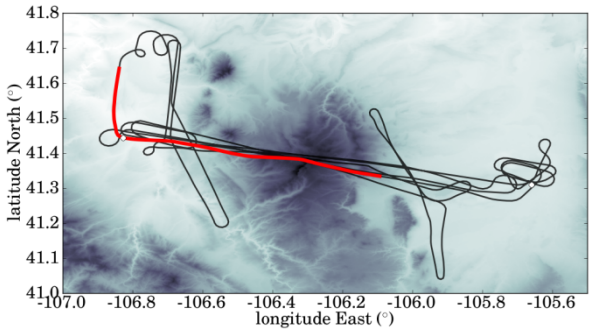
Conclusions

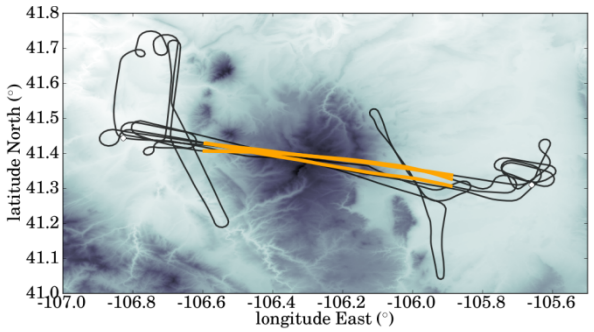
- Expertise in the Vienna Theoretical Meteorology group:
  - Estimation of turbulence parameters from on-board *in situ* and remote sensing measurements.
  - Mesoscale and large-eddy simulations.
- Research focus:
  - BLS, interaction between waves and the atmospheric boundary layer.
  - stable boundary layers.
  - thermally driven flows.

Thank you for your attention

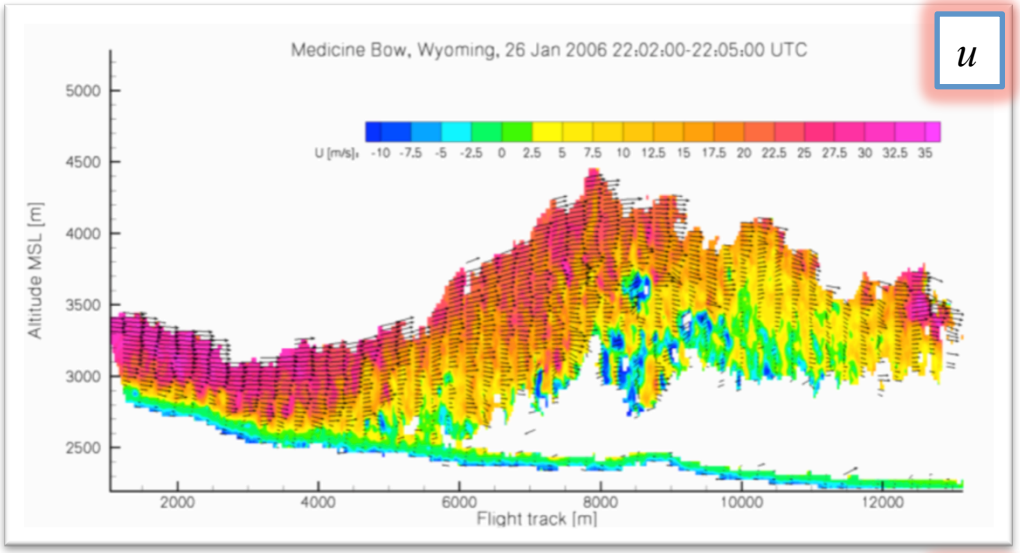
The participation of IMGW staff to the MATERHORN project will be funded from October 2012 by the Austrian Science Funds, FWF, through the project P 24726 – N27: STABLEST – Stable Boundary Layer Separation and Turbulence.

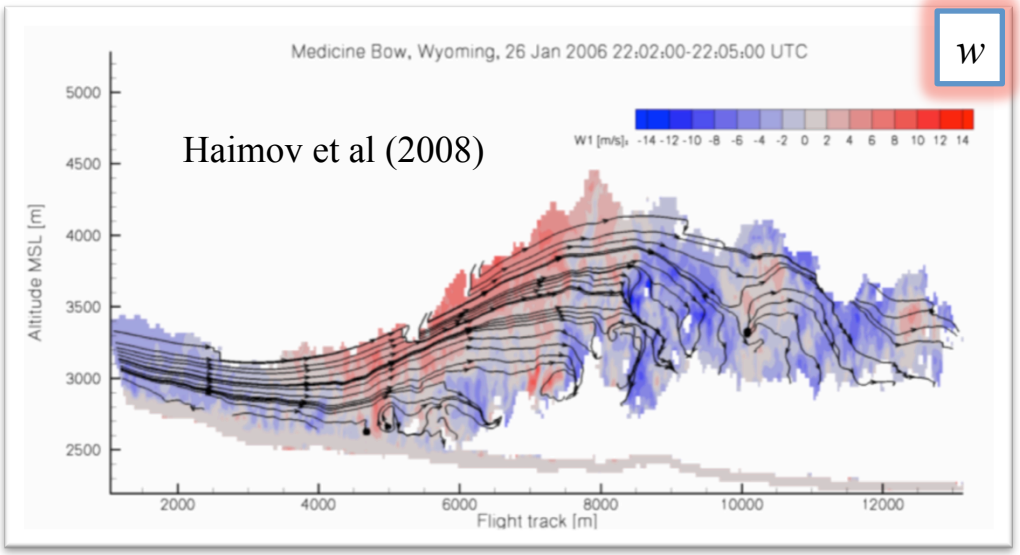
Medicine Bow observations



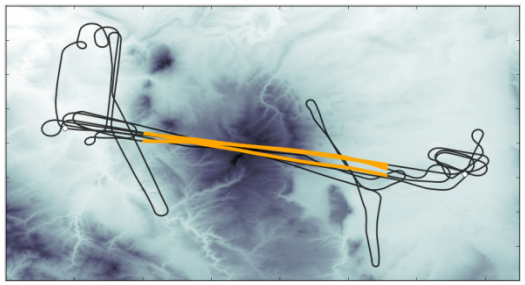


Several flight legs were flown on January 26th 2006, including a ramp sounding and 3 cross-mountain stretches.



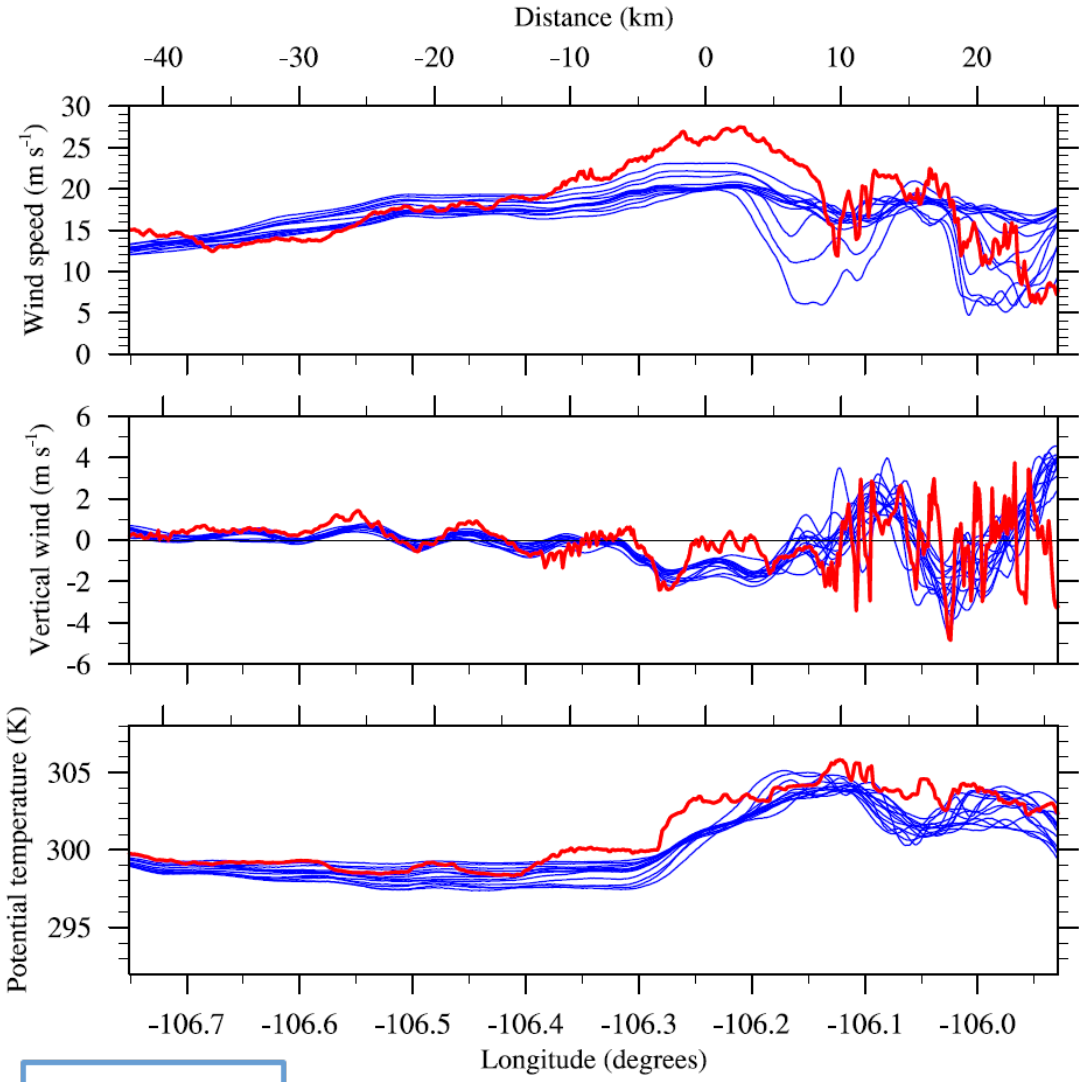


Medicine Bow model verification /1



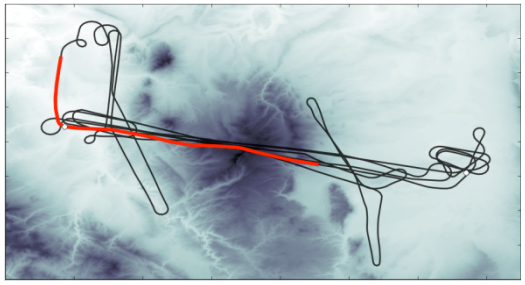
Cross-mountain

Comparison of model output in a time window ± 1.5 h around the actual flight time



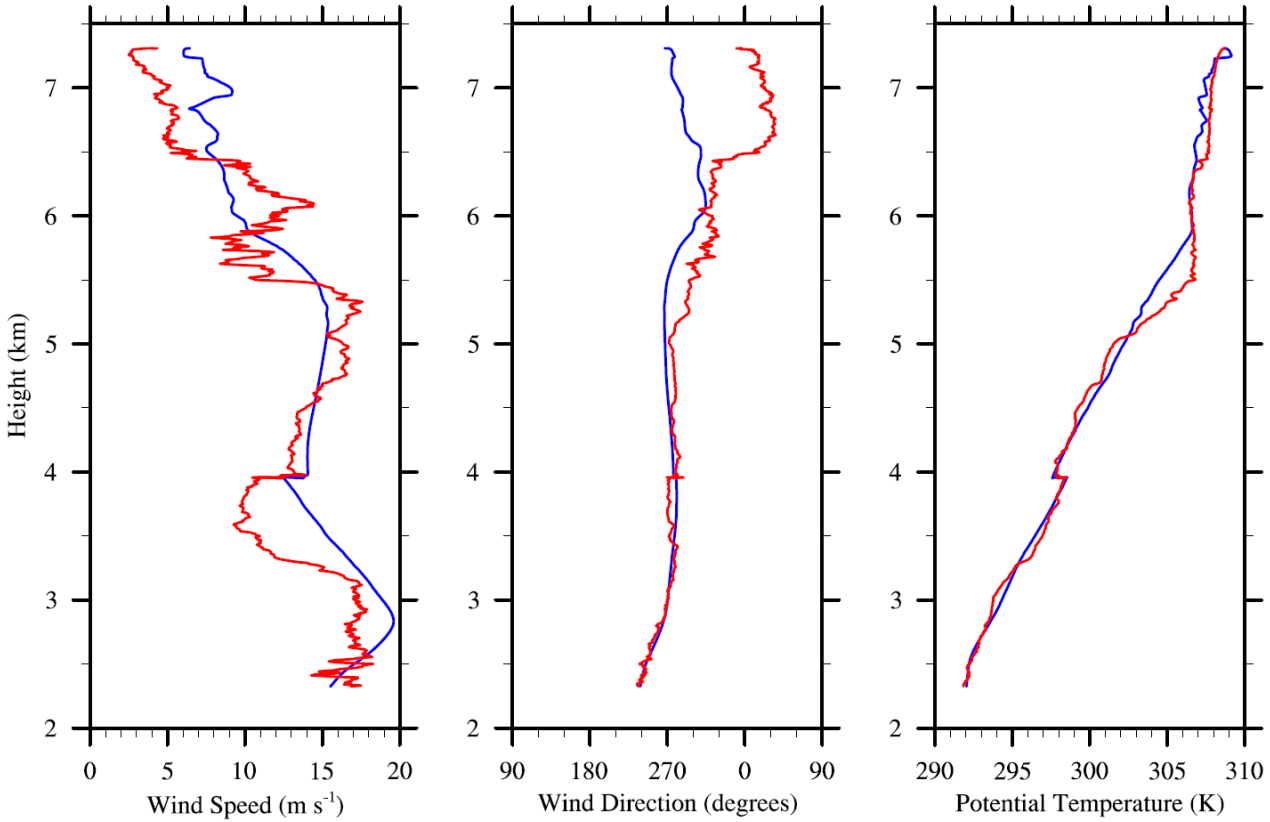
20:20 UTC

Medicine Bow model verification /2



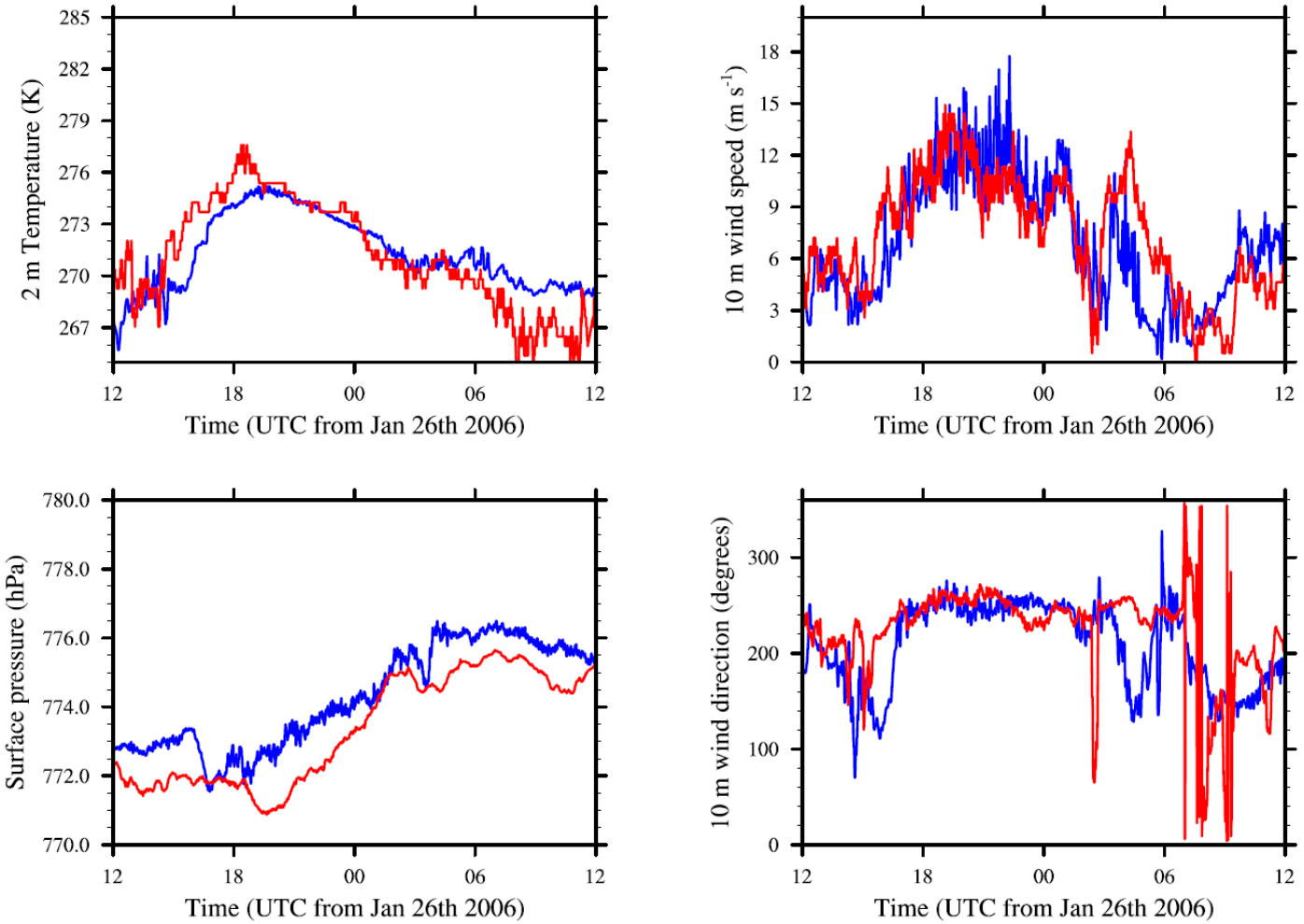
Ramp sounding

Interpolation of model output on the flight trajectory, at the closest output time.



19:30 UTC

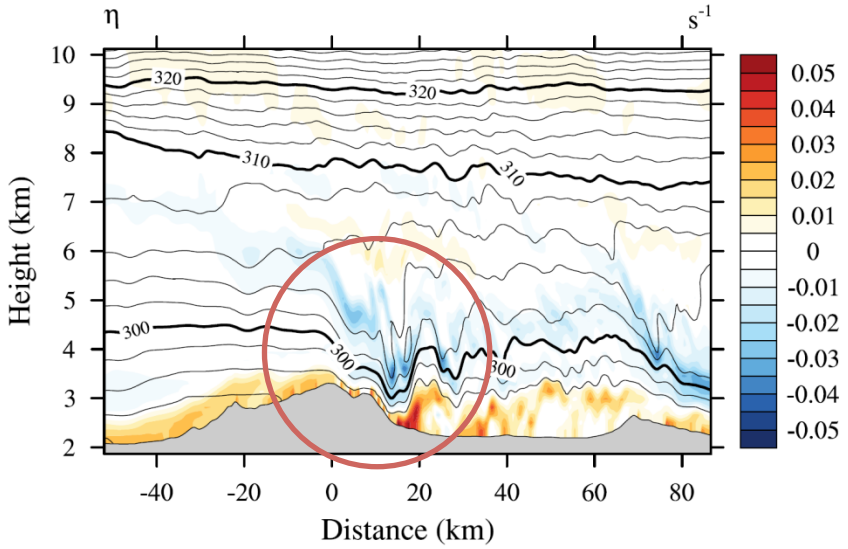
Medicine Bow model verification /3



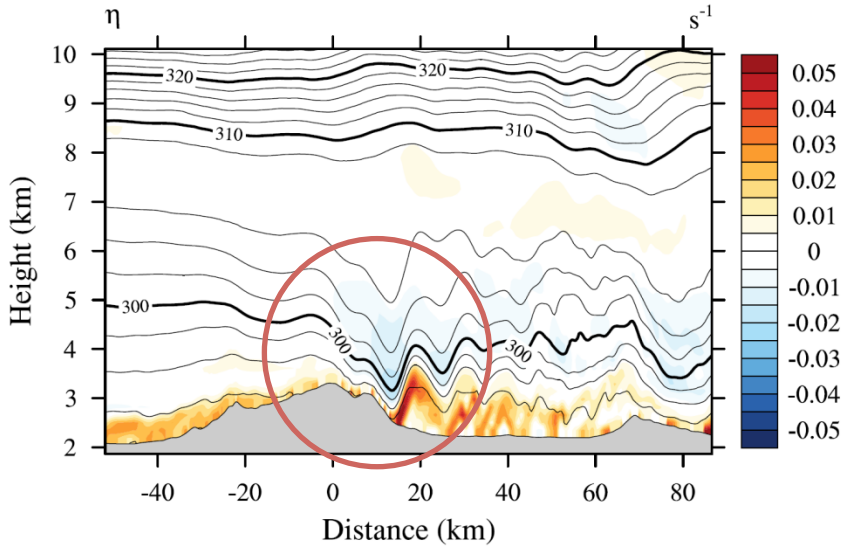
Laramie (WY)

More on BLS /1

20 UTC, Jan 26th

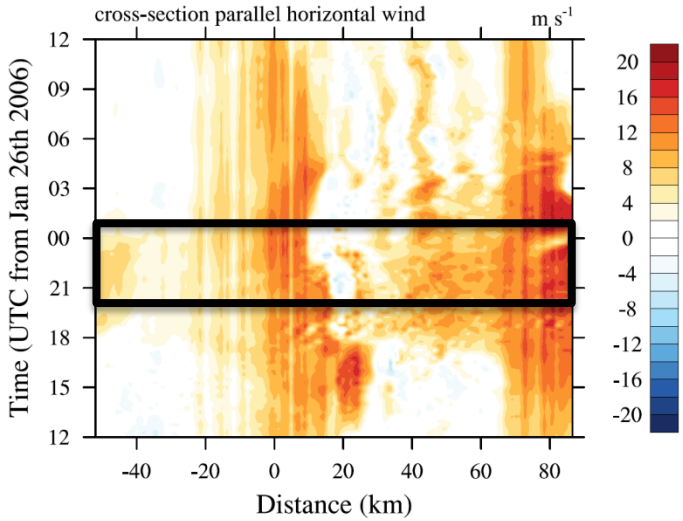


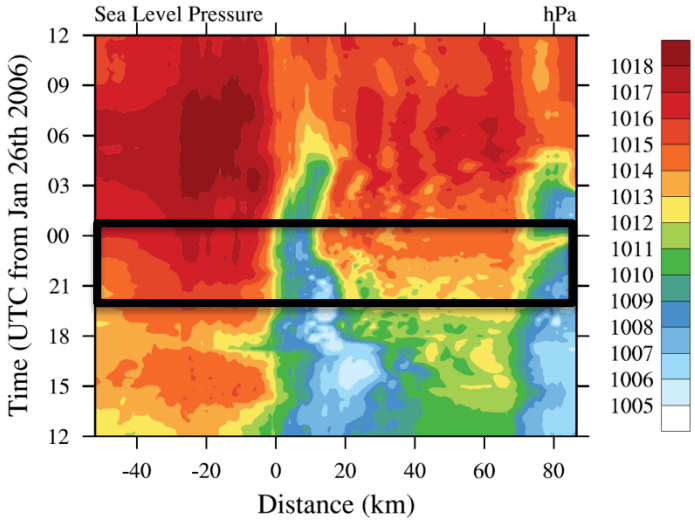
4 UTC, Jan 27th



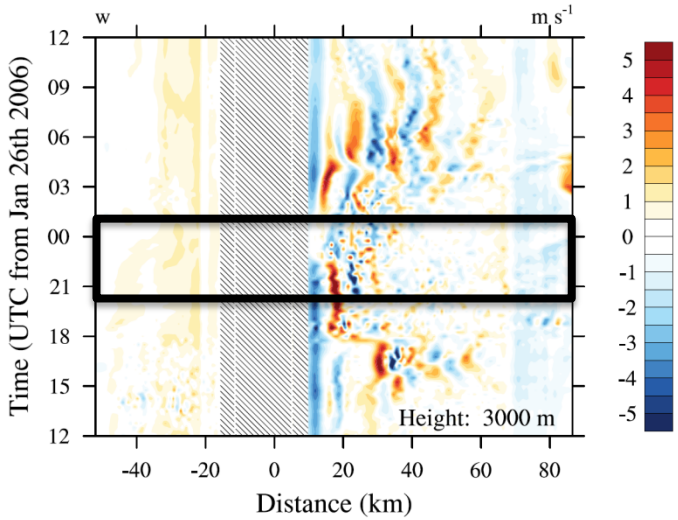
More on BLS /2

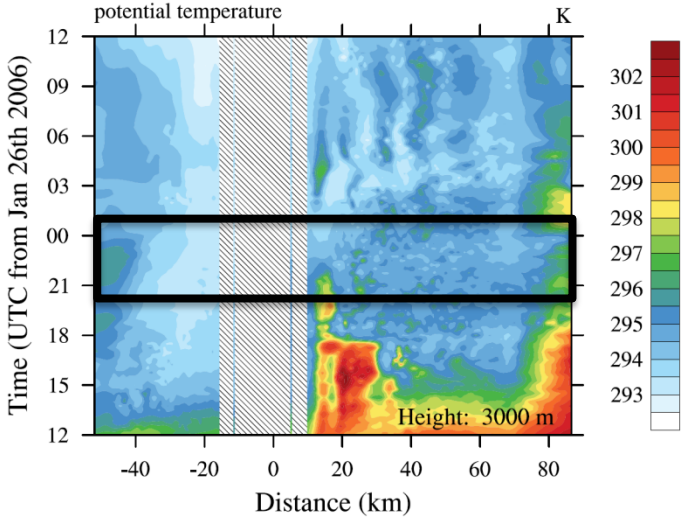
surface





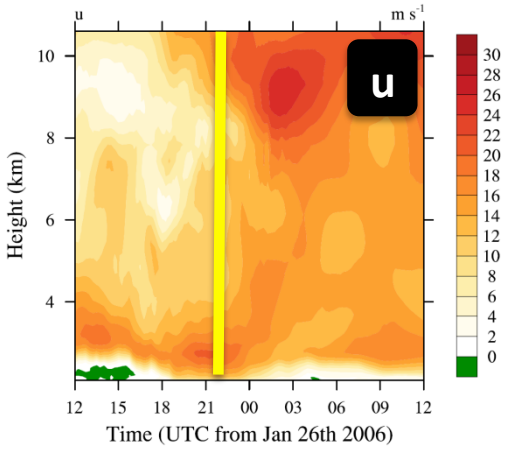
3000 m

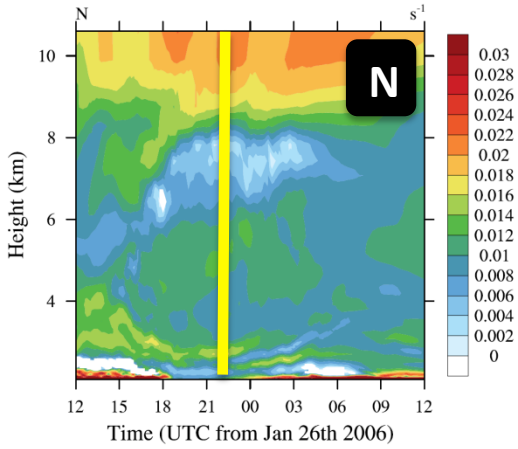


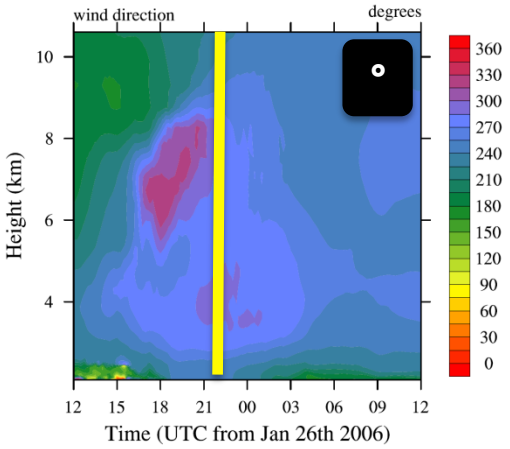


More on BLS /3

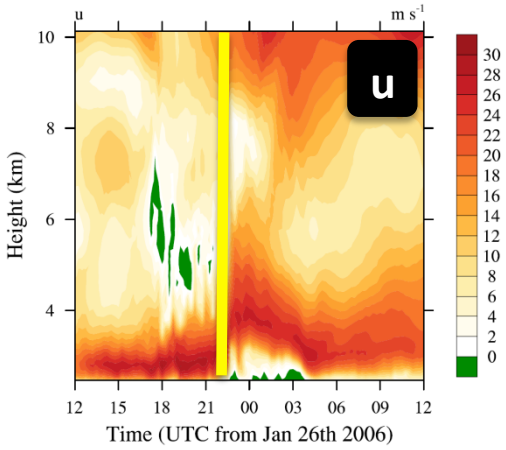
upstream

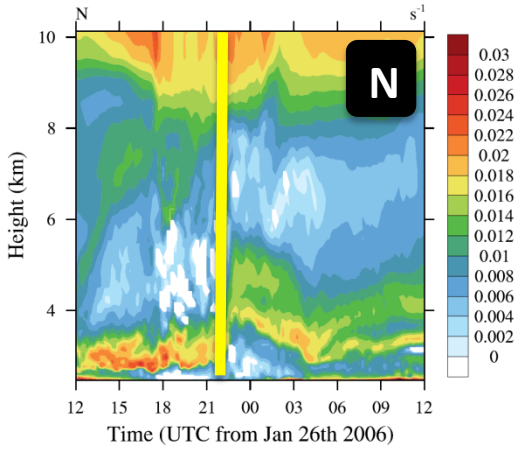


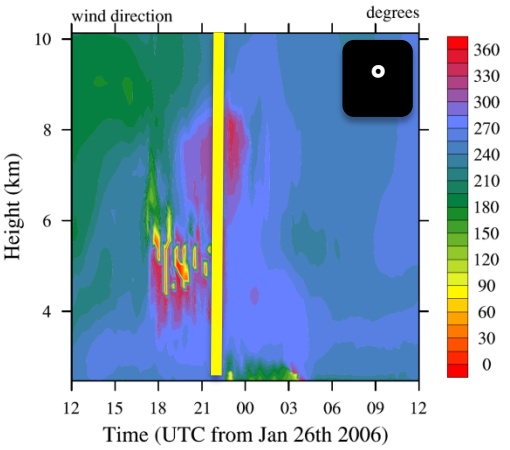




downstream

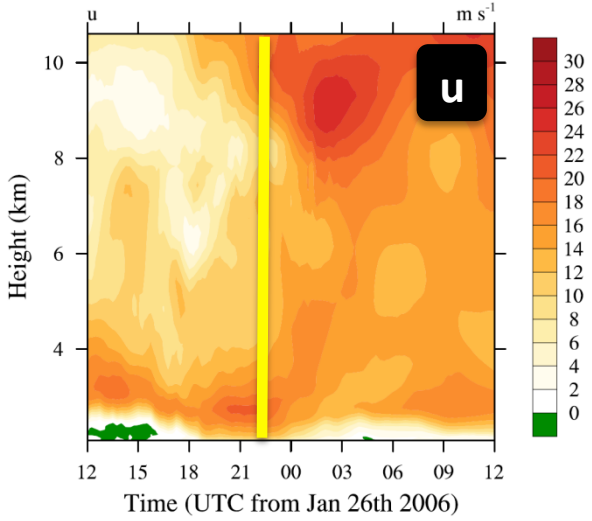


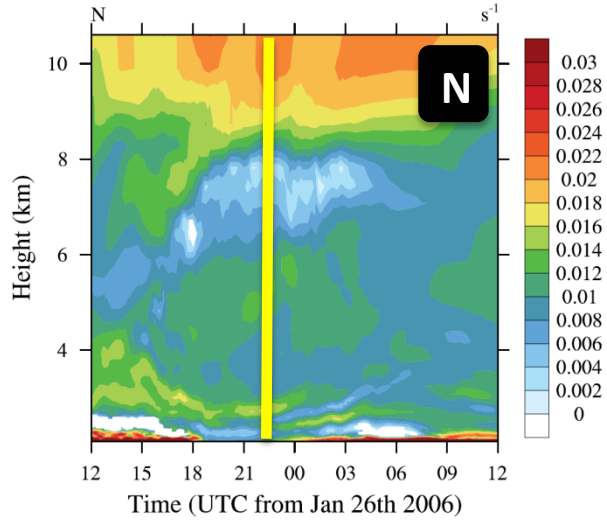


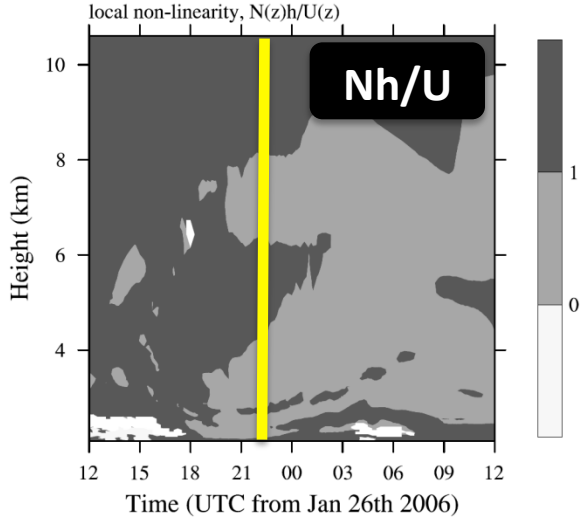


More on BLS /4

Two factors contribute in explaining the rapid motion of the separation line:
(1) Decreasing non-linearity in the inflow conditions;







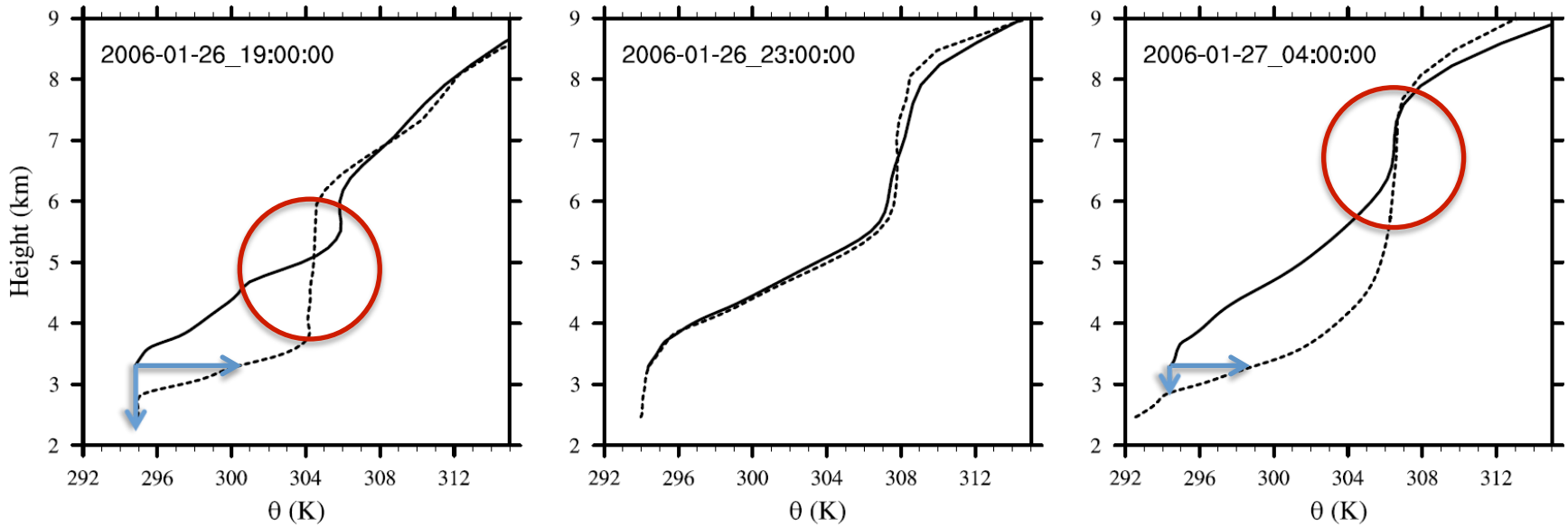
More on BLS /5

Two factors contribute in explaining the rapid motion of the separation line:
(2) Attendant changes in the buoyancy perturbation

Phase I

Phase II

Phase III



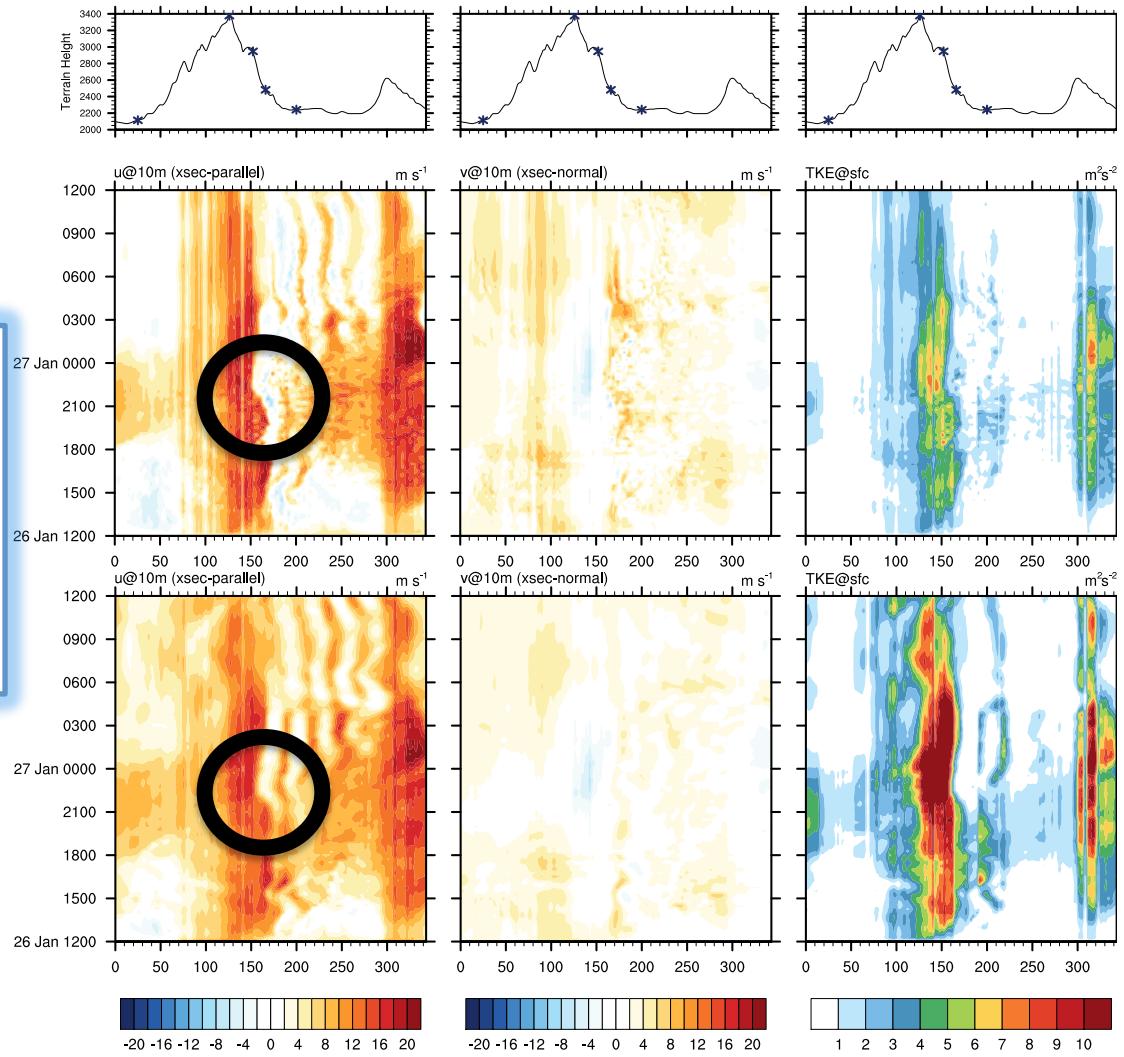
Wave breaking

transition

Lee waves

Sensitivity to BL parameterization

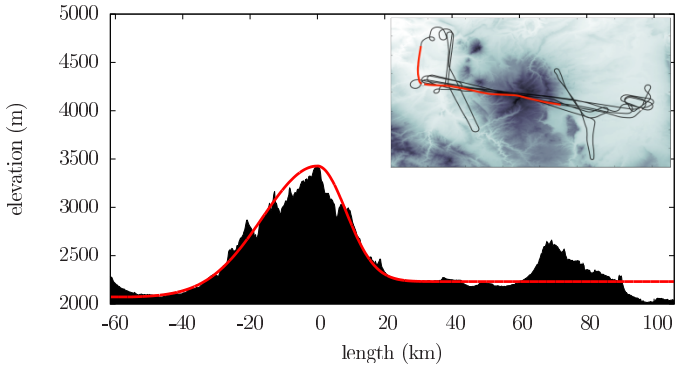
Mellor-Yamada-Janjić (above) vs. Bougeault-Lacarrère (below). The latter creates higher TKE and is therefore much more diffusive. Reverse flow in the rotor region vanishes.

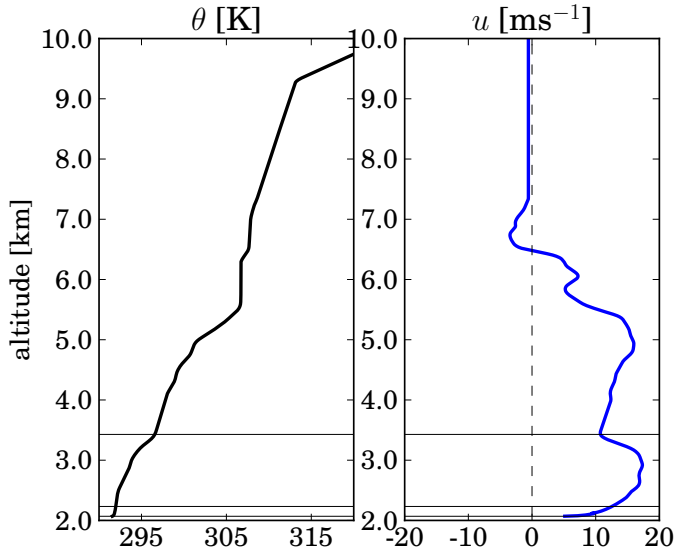


Large-eddy simulation /1

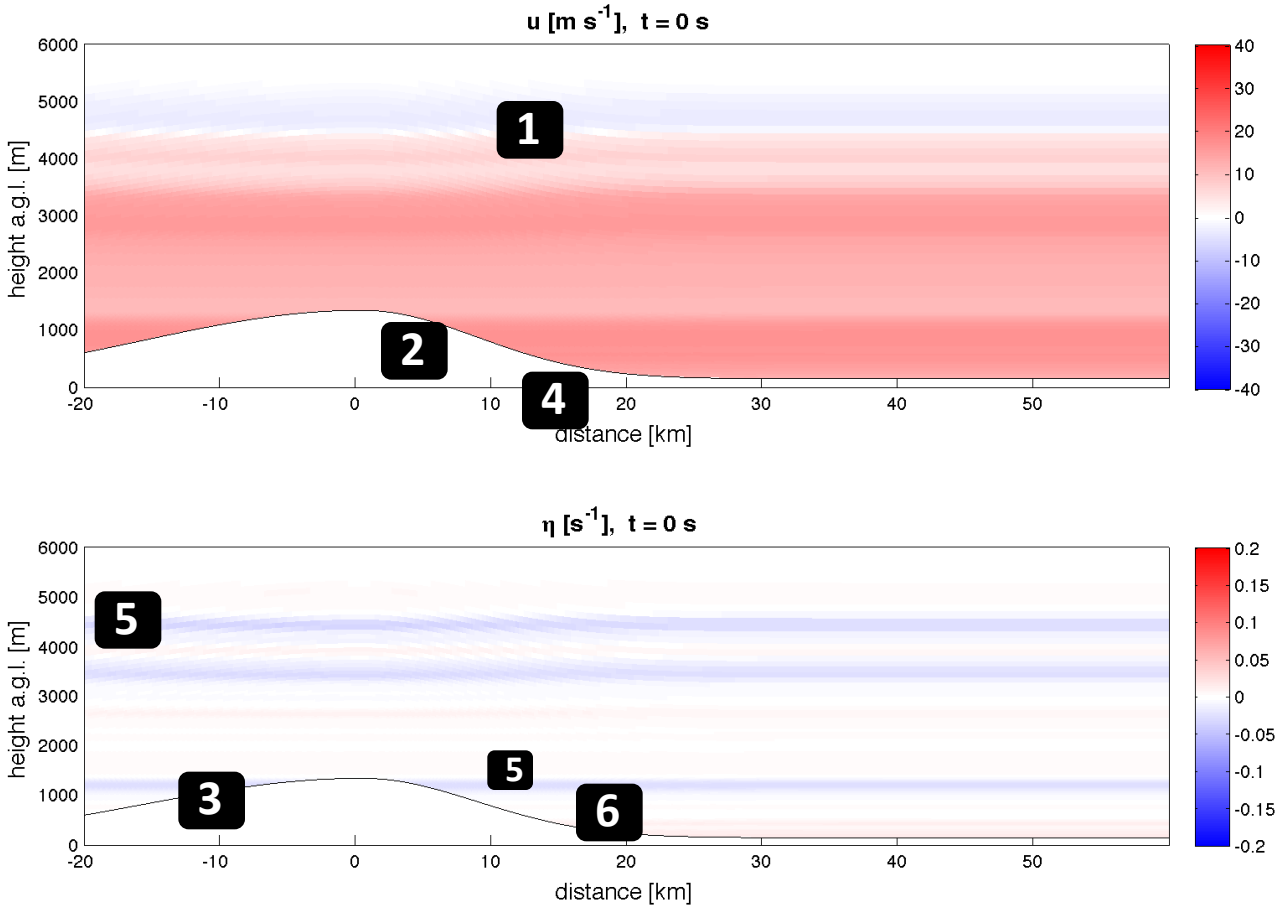
CM1 model

- 3D domain, linear (2D) mountain ridge.
- Domain: 680 (x) × 3 (y) × 12 (z) km.
- Grid spacing: 50 × 50 × 20 m.
- Grid stretching towards boundaries.
- Boundary conditions:
  - Rayleigh damping layer at top, beyond 7000 m.
  - Rayleigh damping layer and open conditions at up- and downstream boundaries.
  - Periodic conditions at lateral boundaries.
- Deardorff (1980) SGS turbulence closure.
- Bottom friction parameterized with bulk drag formulas.
- Initialization with a sounding derived from observations (ramp sounding). Constant inflow.





Large-eddy simulation /2



1 Wave breaking

2 Downslope winds

3 Shear vorticity

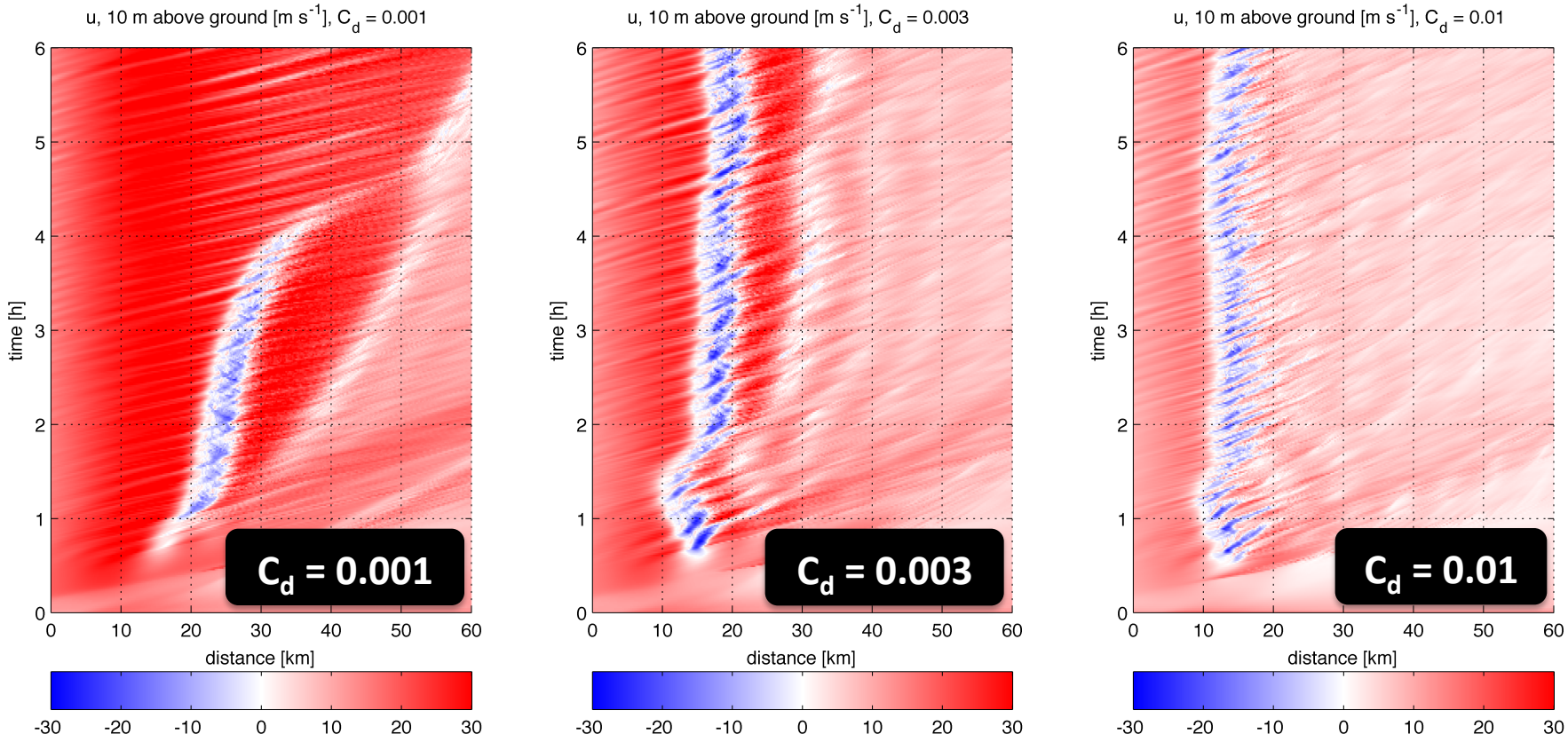
4 Wave-induced BLS

5 KH instability

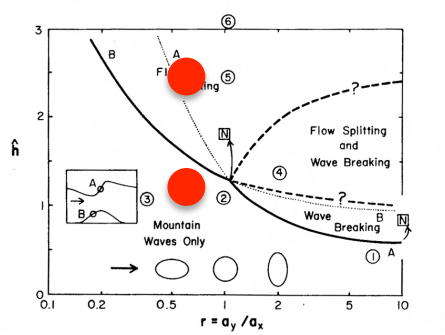
6 Rotors and subrotors

Large-eddy simulation /3

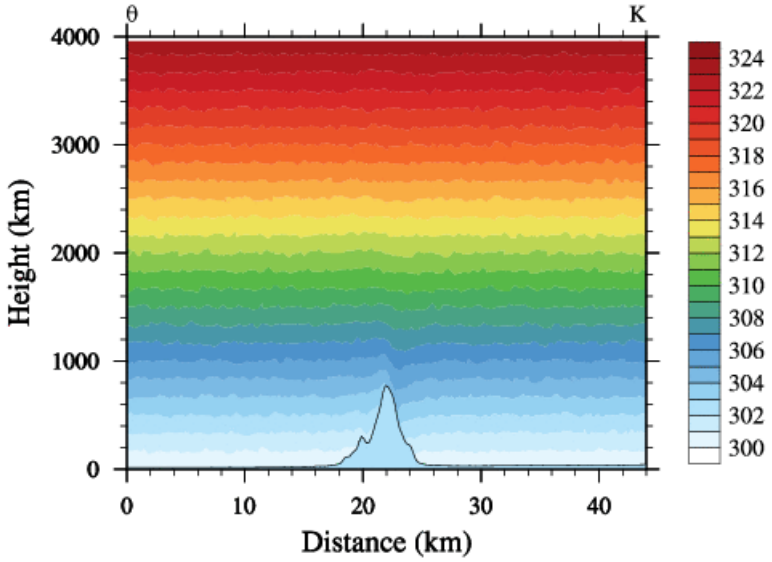
Increasing surface friction: $\langle u'w' \rangle_0 = - C_d U u$, $\langle v'w' \rangle_0 = - C_d U v$



CM1 modelling @ DPG



W, 5 m s^{-1}



W, 10 m s^{-1}