

A Case Study of Clear-Air Turbulence at Upper Levels

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September 5, 2021



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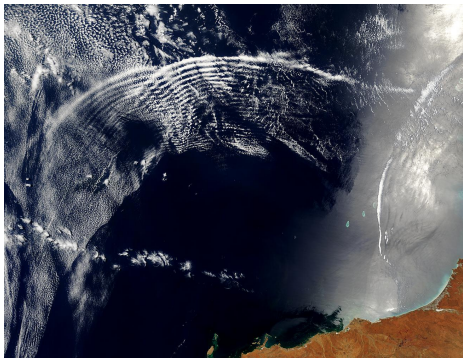
I - CAT phenomena and Implications

II - Case Study : Upper Levels Jet Turbulence

III - Towards High Resolution Simulations of Jet Turbulence

I - CAT phenomena and Implications

Turbulence at tropopausal levels (8-14km)



Atmospheric gravity waves above the Indian ocean. From Mann 2019

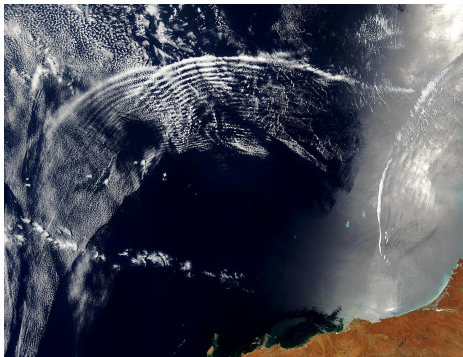
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Coexisting sources¹:

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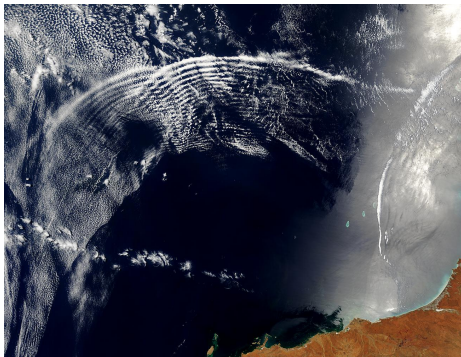
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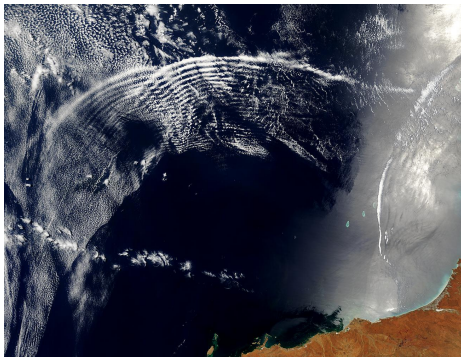
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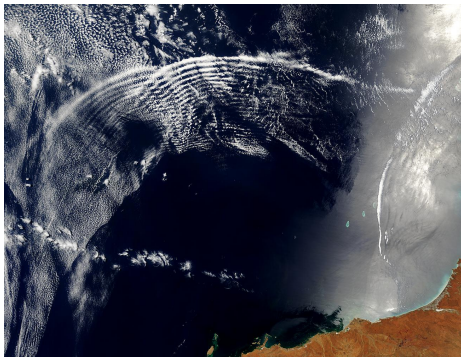
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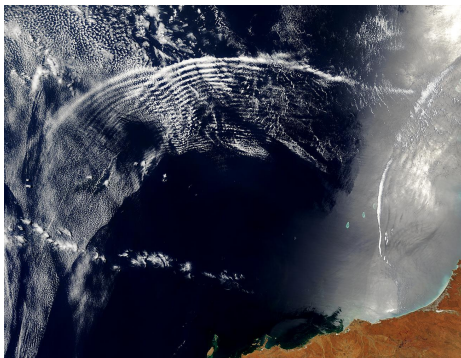
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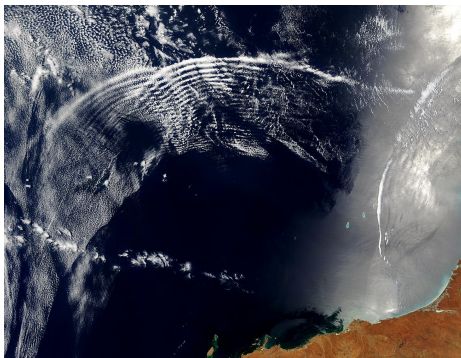
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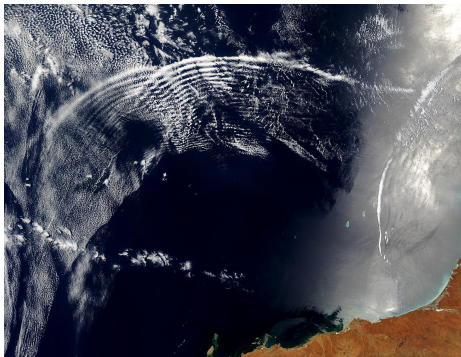
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Improving Turbulence Parameterization $\Rightarrow$ Improving CAT diagnostics

¹Sharman, S. B. Trier, et al. 2012

Study objective

- ▶ Improve the turbulence parameterization for CAT events in upper levels

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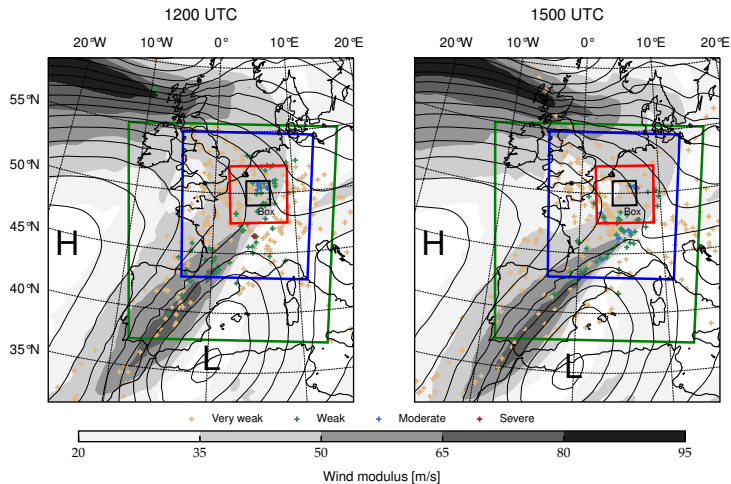
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- ▶ Conduct high resolution (LES) simulations in order to obtain reference turbulent fields
- ▶ Assess, by comparison with coarser fields, which turbulent scheme components need improvements.

II - Case Study : Winterly jet above Luxembourg and Belgium (27/01/2018)

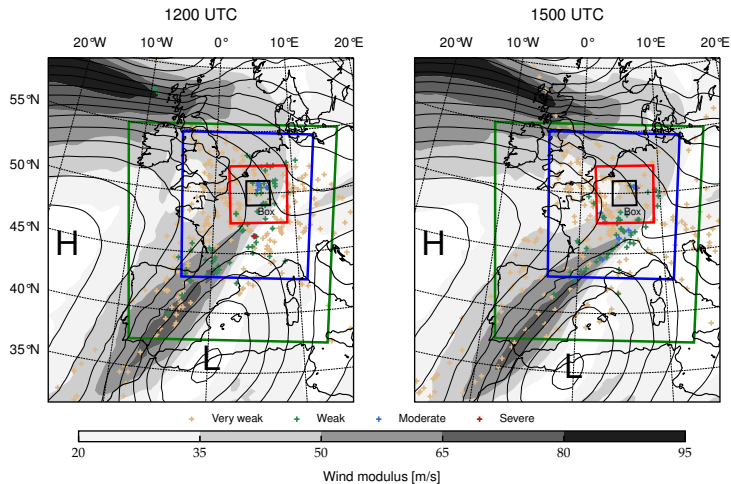
Synoptic analysis, Observations and Models used



300hPa ARPEGE geopotential, wind, EDR available reports above 400hPa

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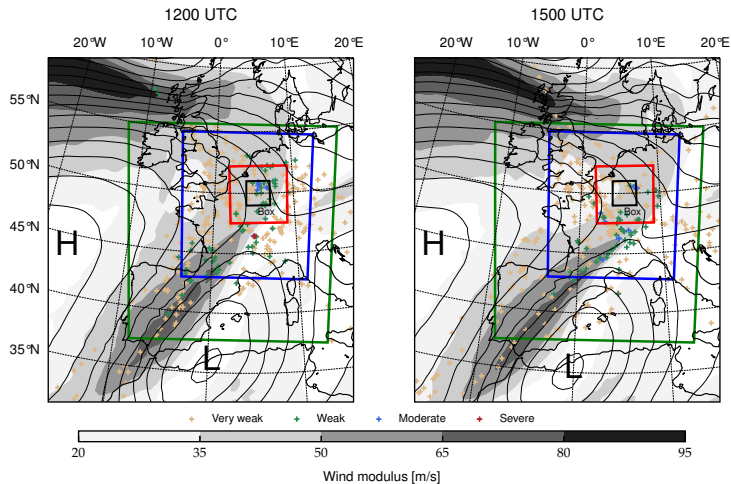
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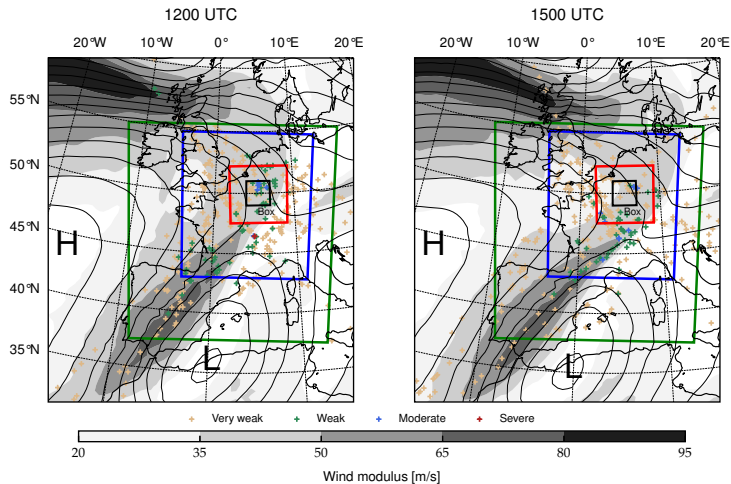
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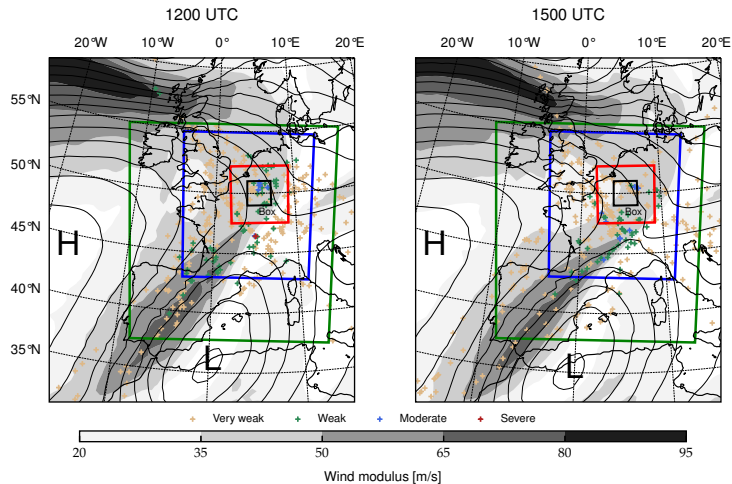
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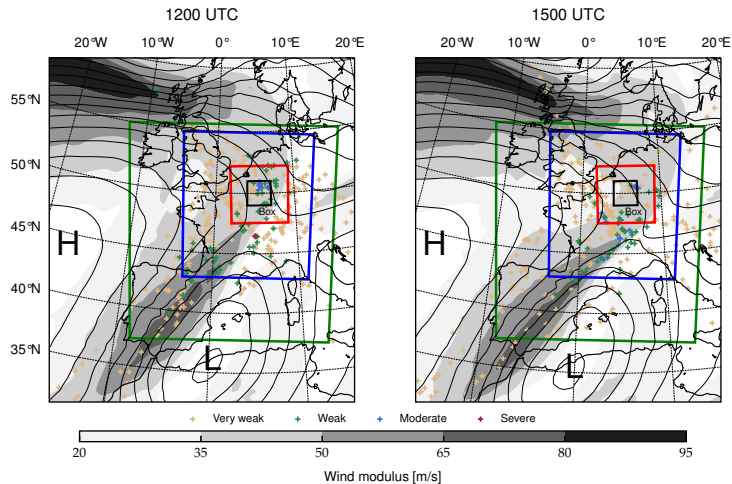
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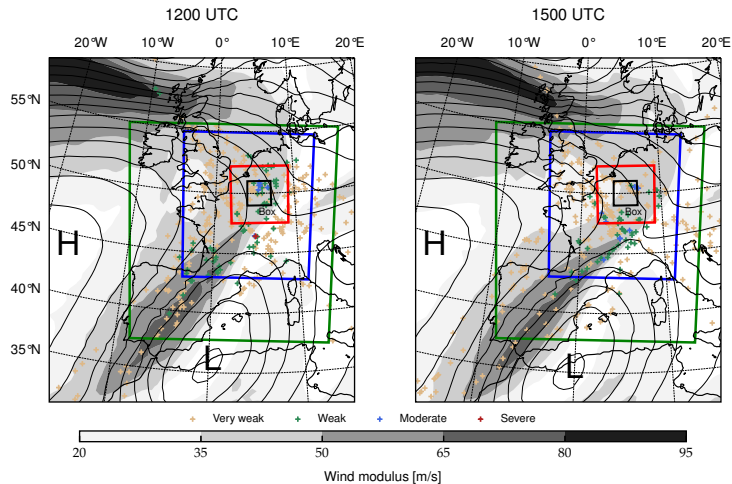
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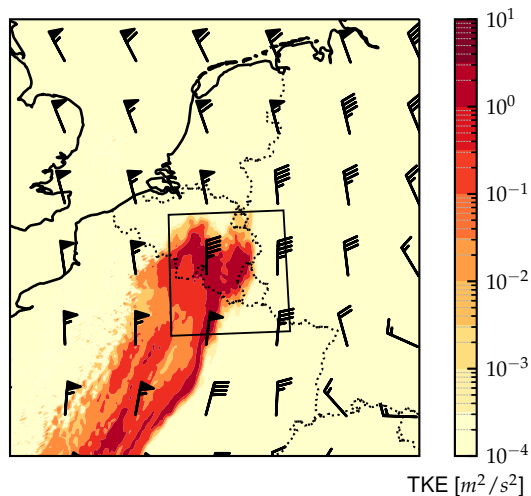
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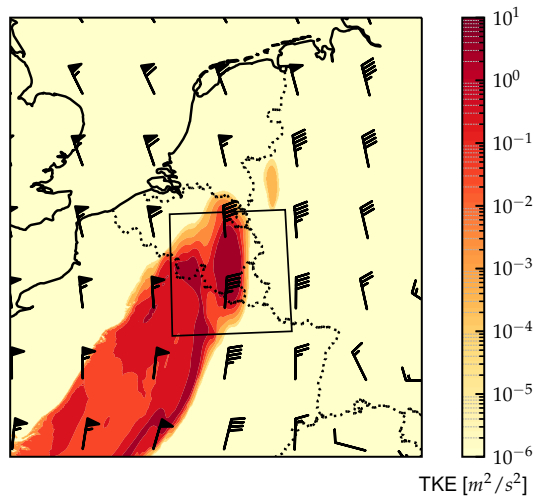
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- ▶ at 260m resolution : MesoNH in LES mode

Results at 1.3km resolution

Wind, TKE 1200 UTC, 11500 m (models levels)

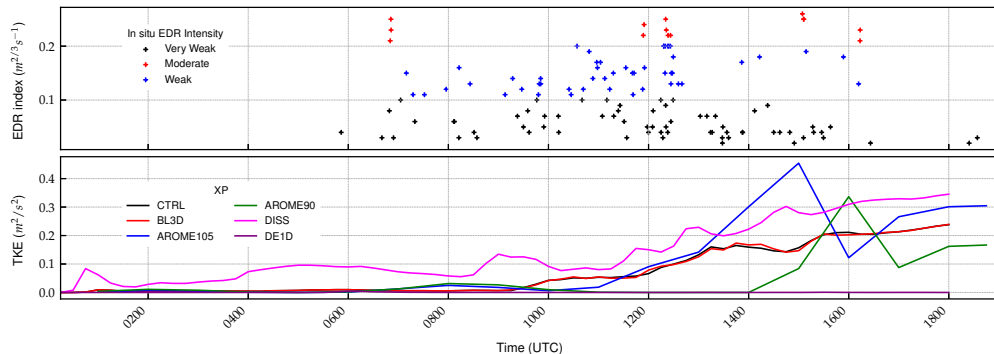


Run CTRL (MesoNH)



Run AROME105 (Arome with increased vertical resolution)

Temporal evolution in upper level box : Sensitivity experiments

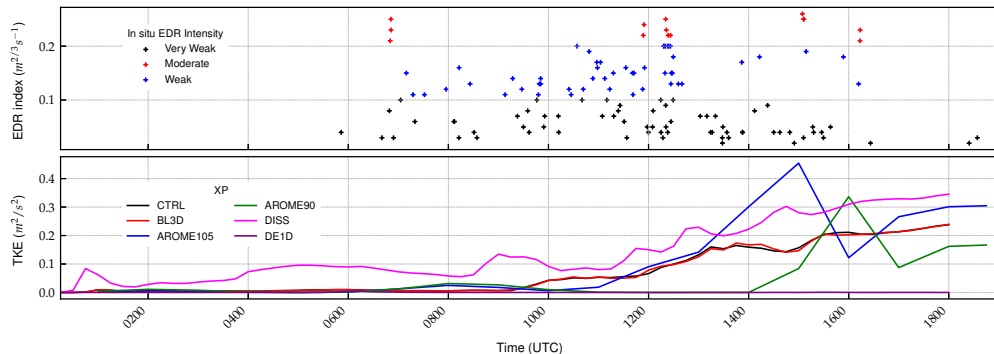


Upper: EDR in situ measurements; Lower: Model TKE

Label	Model	Mixing Length	Turb	Δz (10-12km)	C_ϵ
AROME90	AROME	BL89 ¹	1D	$\sim 400m$ (stretched)	0.84
AROME105	AROME	BL89	1D	$\sim 292m$	—
CTRL	MESONH	BL89	1D	—	—
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DISS	MESONH	BL89	1D	—	0.42

¹Bougeault and Lacarrere 1989

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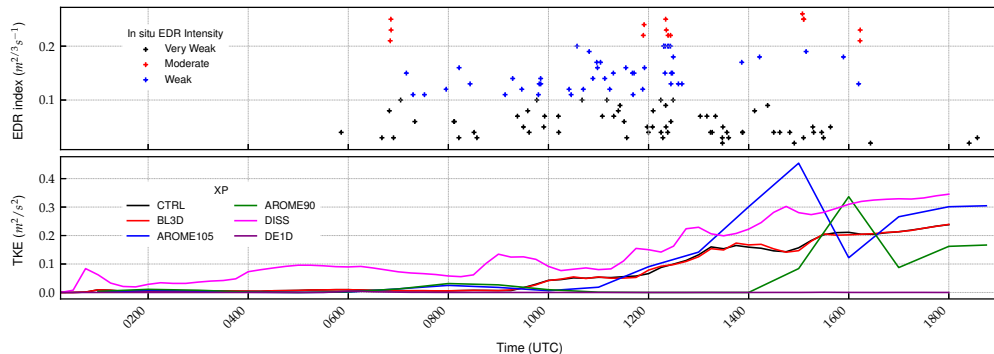
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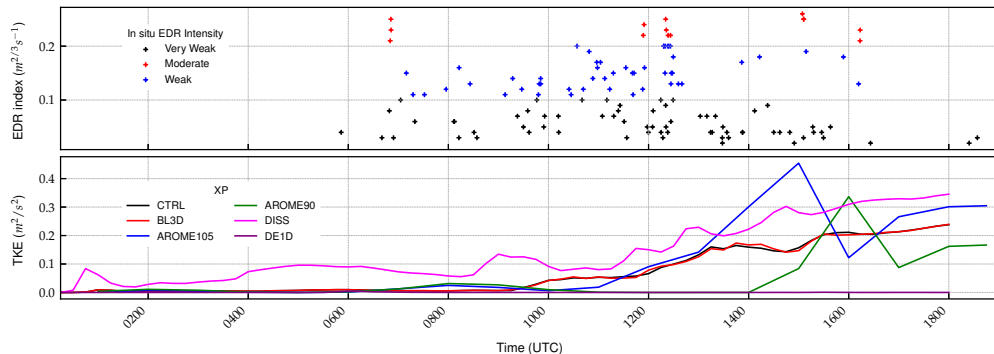
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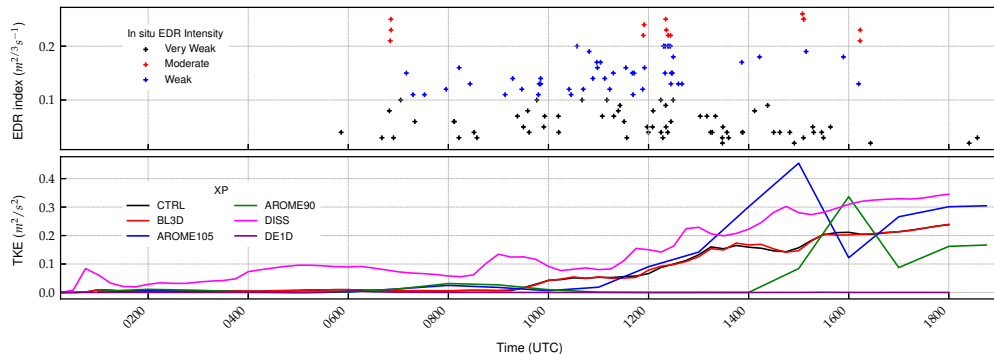
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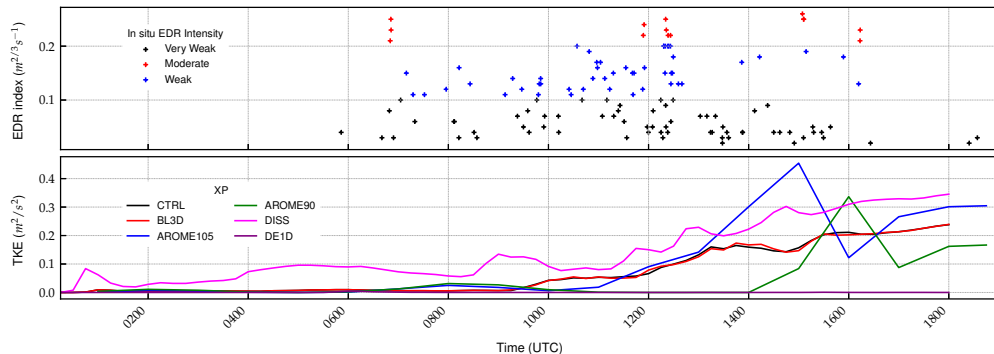
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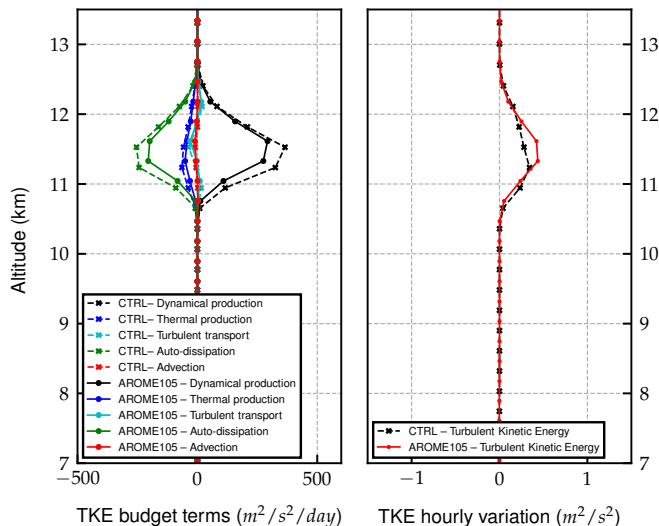
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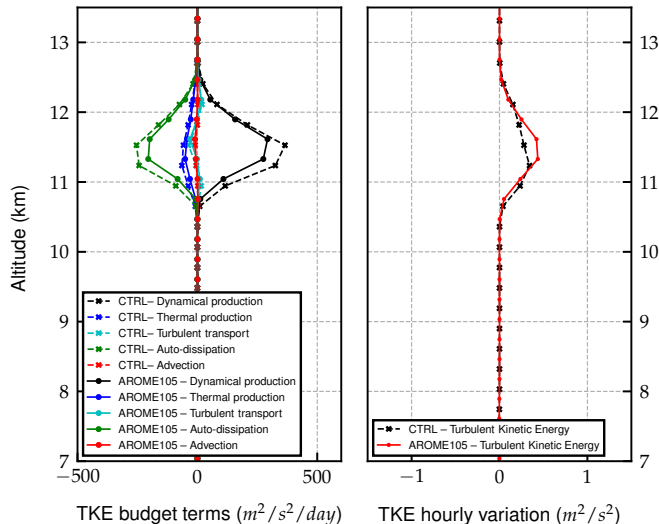
TKE equation Budget



Budgets terms

Budget terms between 1100 and 1200 UTC in box. CTRL : MesoNH ;
 AROME105 : AROME with enhanced vertical resolution

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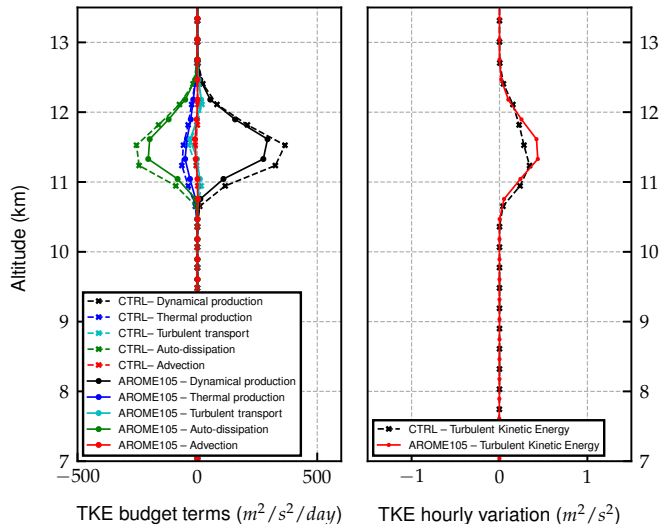


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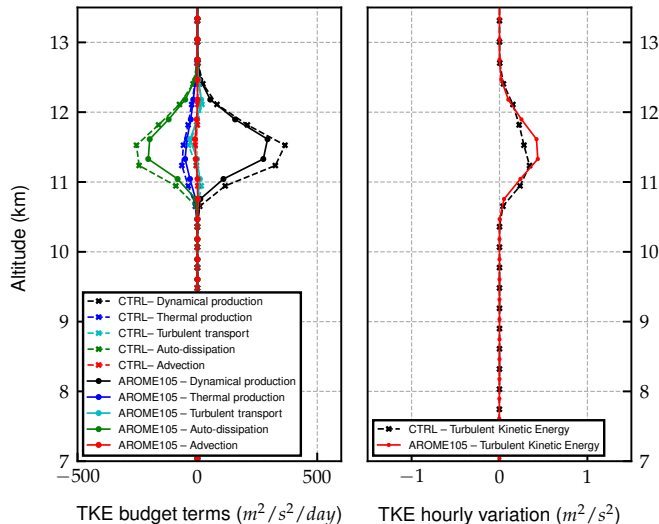


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- ▶ Only dynamic, shear involved TKE production
- ▶ Thermal "destruction" of TKE, characteristic of strongly stable conditions
- ▶ Auto-dissipation of turbulence is the leading TKE sink in the budget

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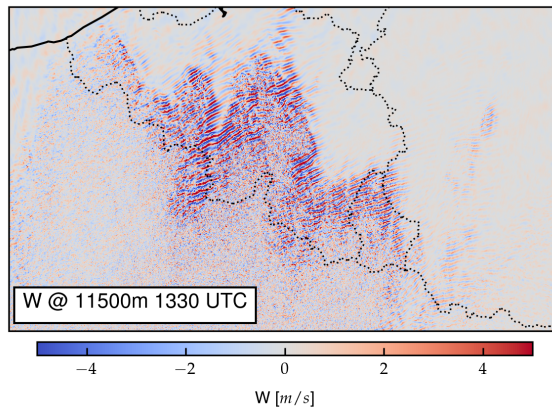
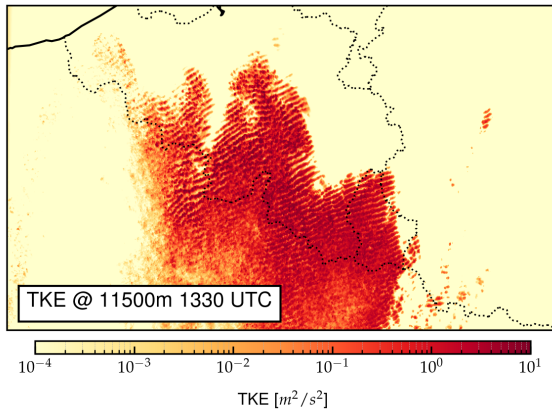
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Experiment setup

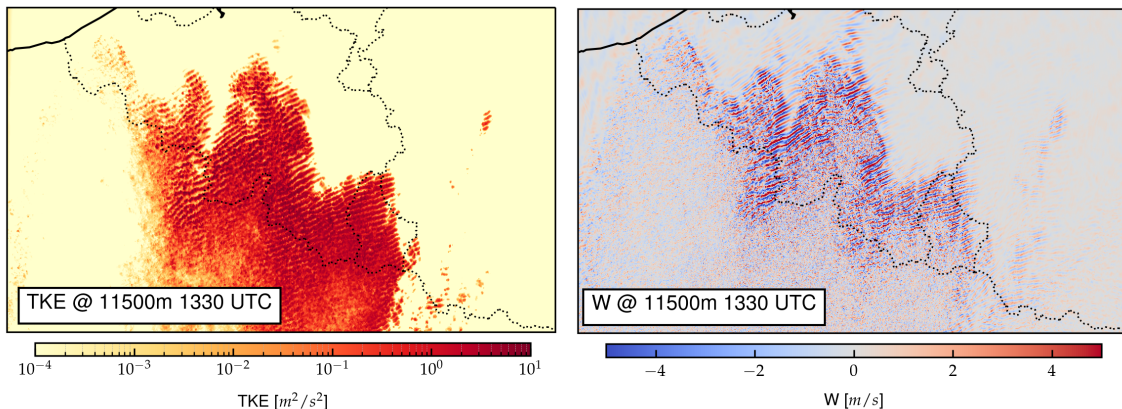
- ▶ Box centered domain 2000×2000 ($\Delta x = 260\text{m}$) and an isotropic grid between 8000m - 14000m
- ▶ 3D formulation, Deardorff mixing length

260m resolution TKE and W fields at 11500m (1330 UTC)



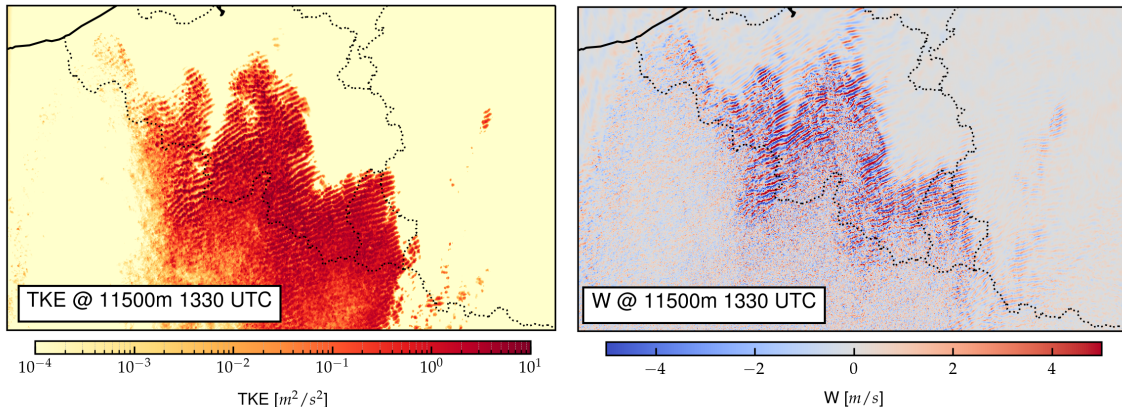
¹Koch et al. 2005

260m resolution TKE and W fields at 11500m (1330 UTC)



- Wave-like structures in vertical wind and TKE fields with $\sim 3.5\text{km}$ horizontal scale

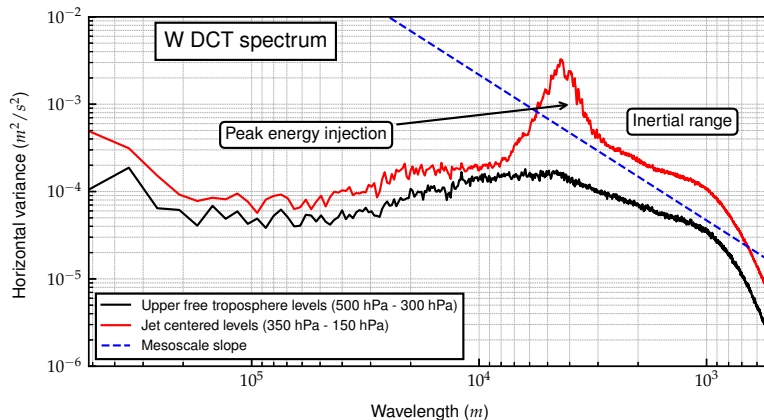
260m resolution TKE and W fields at 11500m (1330 UTC)



- ▶ Wave-like structures in vertical wind and TKE fields with $\sim 3.5\text{km}$ horizontal scale
- ▶ Propagating perturbations locally modifying stability conditions and allowing production of TKE ¹

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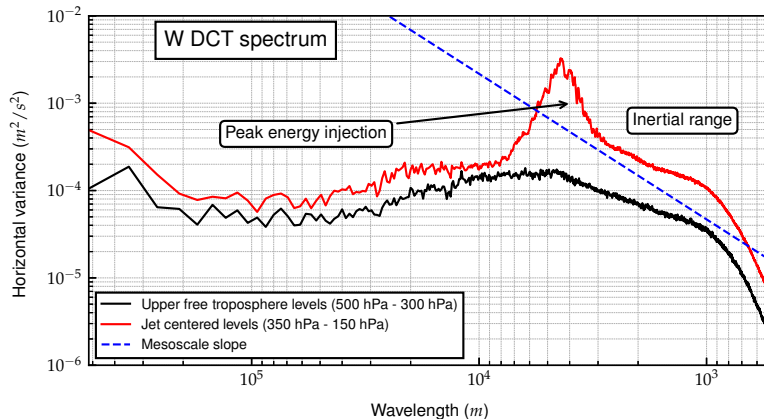
Domain wide horizontal spectra



¹Stanley B. Trier et al. 2020

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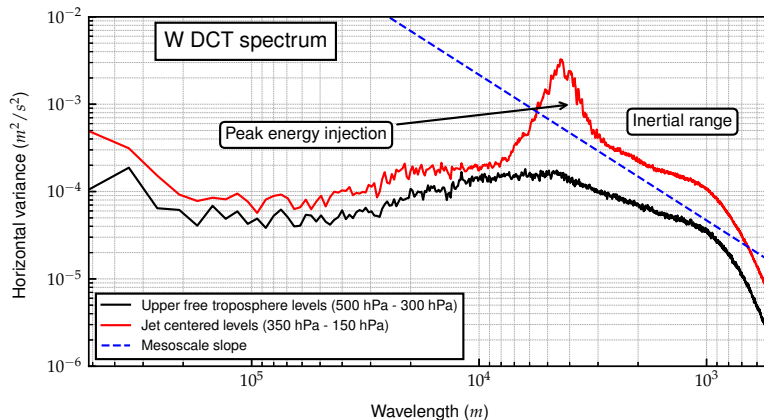


- Peak energy injection at 3-4 km scales → Atmospheric gravity waves consistent with KH instability ¹

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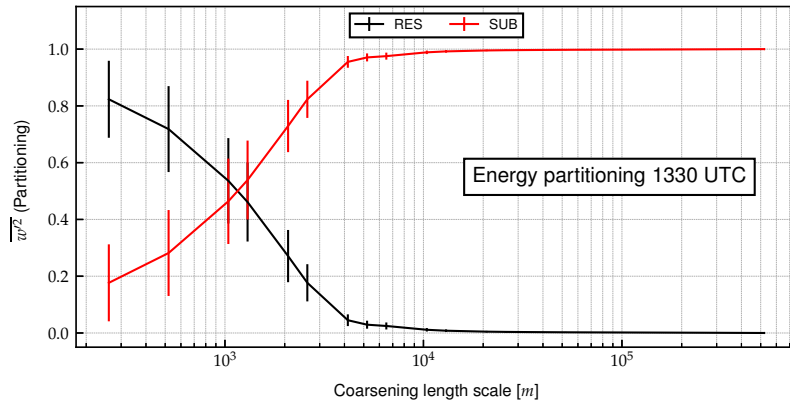


- ▶ Peak energy injection at 3-4 km scales $\rightarrow$ Atmospheric gravity waves consistent with KH instability ¹
- ▶ Kinetic energy spectra for W can be used to diagnose Turbulent Dissipation in the inertial range ², but need sufficient resolution.

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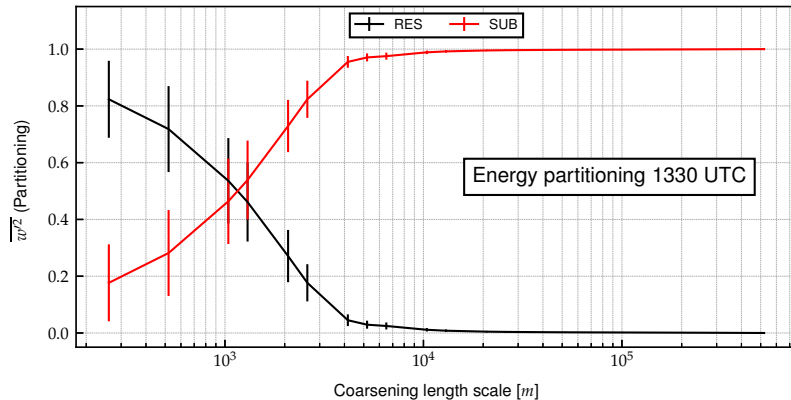
Partitioning between Resolved and Subgrid Energy via Coarse Graining method¹



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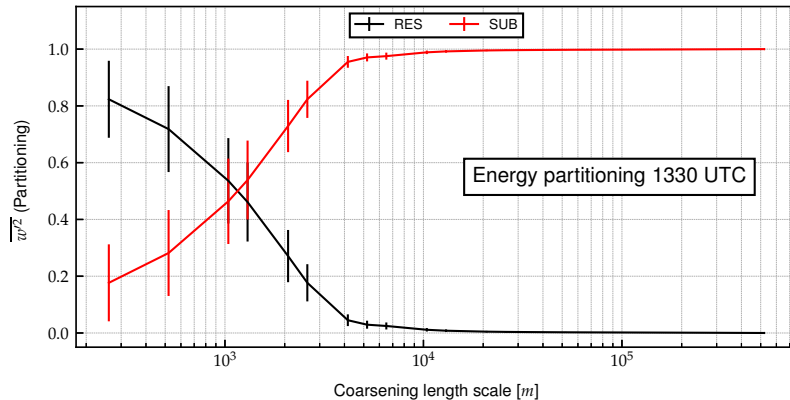


$$\overline{w'\phi'}^{TOT} = \overline{w'\phi'}^{RES(\Delta)} + \overline{w'\phi'}^{SUB(\Delta)}$$

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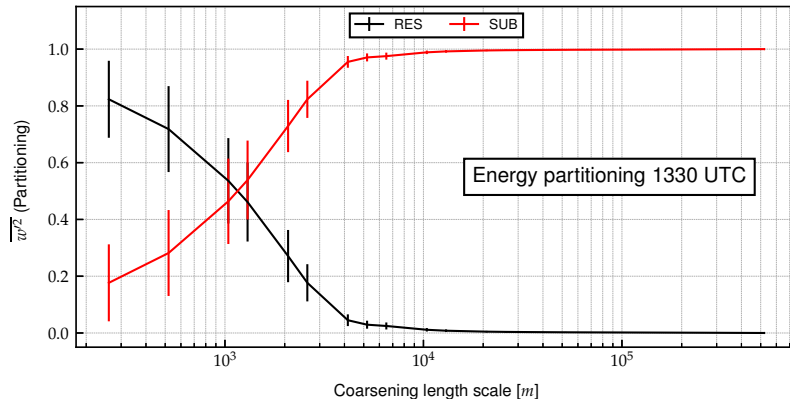
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► W fluctuations resolved at $\sim 82\%$ for 260m resolution

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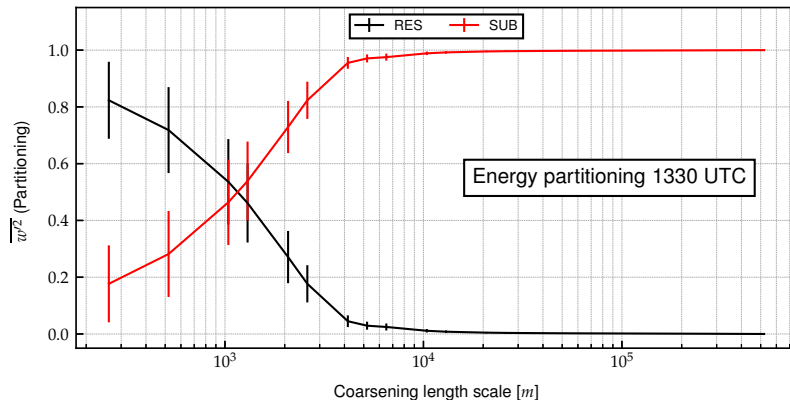
► Gray zone turbulence ² $\Delta x \sim 1100m$

► W fluctuations resolved at $\sim 82\%$ for 260m resolution

¹Honnert, Masson, and Couvreur 2011

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- ▶ Will allow to diagnose source terms from the LES resolution and use these as "truth" fields.

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- ▶ Diagnostic of the turbulent dissipation rate from spectral inertial range.

Complementary material

Turbulence representation in Météo-France NWP operational models

Turbulent fluxes parameterization in Arpege, Arome and MesoNH models

²Cuxart, Bougeault, and Redelsperger 2000.

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General formulation consisting in exchange coefficients for the turbulent flux of quantity ϕ^2 :

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with

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depending on a diagnostic mixing length and the Turbulent Kinetic Energy (e), following the prognostic evolution equation :

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$$\underbrace{\frac{De}{Dt}}_{\text{TKE Variation}} = \underbrace{\frac{\partial}{\partial x_j} \left(C_{TT} L \sqrt{e} \frac{\partial e}{\partial x_j} \right)}_{\text{Turbulent Diffusion}} - \underbrace{\overline{u'_i u'_j} \frac{\partial \bar{u}_i}{\partial x_j}}_{\text{Dynamical production}} + \underbrace{\beta \overline{w' \theta'}}_{\text{Thermal production}} - \underbrace{C_\epsilon \frac{e^{3/2}}{L_\epsilon}}_{\text{Auto-dissipation}}$$

Stability impacts in the thermal term, stability functions and mixing length parameterization.

1.5 order formulation

²Cuxart, Bougeault, and Redelsperger 2000.

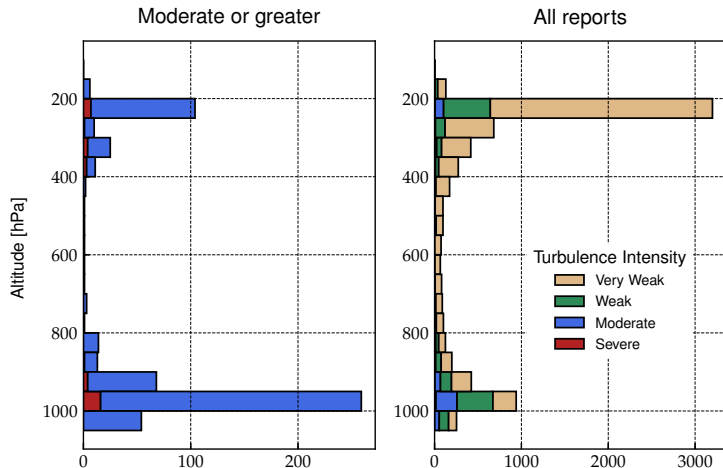
In Situ EDR³ measurements

The EDR index corresponds to

$$EDR = \epsilon^{1/3}$$

and, according to its value, classifies CAT events as :

- ▶ Very Weak : $0 < EDR \leq 0.1$
- ▶ Weak : $0.1 \leq EDR \leq 0.2$
- ▶ Moderate : $0.2 \leq EDR \leq 0.3$
- ▶ Severe : $EDR \geq 0.3$



Available EDR reports classification and altitude repartition, on 01/27/2018

³Sharman and Pearson 2016.

Numerical experiments

Label	Model	Mixing Length	Turb	Δz (10-12km)	Δt	C_ϵ
ARO90	AROME	BL89	1D	$\sim 400m$ (stretched)	50s	0.84
MESONH90	MESONH	BL89	1D	–	2s	0.84
ARO105	AROME	BL89	1D	$\sim 292m$	50s	–
CTRL	MESONH	BL89 ⁴	1D	–	2s	–
BL3D	MESONH	BL89	3D	–	–	–
DE3D	MESONH	Deardorff ⁵	3D	–	–	–
DE1D	MESONH	Deardorff	1D	–	–	–
RM17	MESONH	RM17 ⁶	1D	–	–	0.34
DISS	MESONH	BL89	1D	–	–	0.42

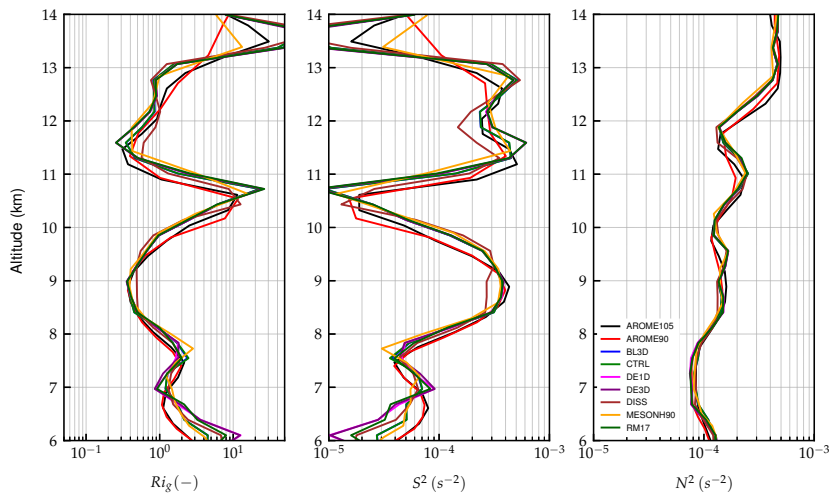
Table: Realized sensitivity experiments at 1.3km resolution

⁴Bougeault and Lacarrere 1989.

⁵Deardorff 1980.

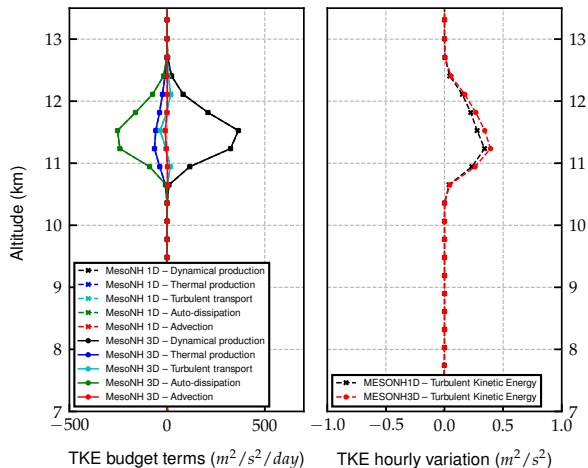
⁶Rodier et al. 2017.

Air layers stability



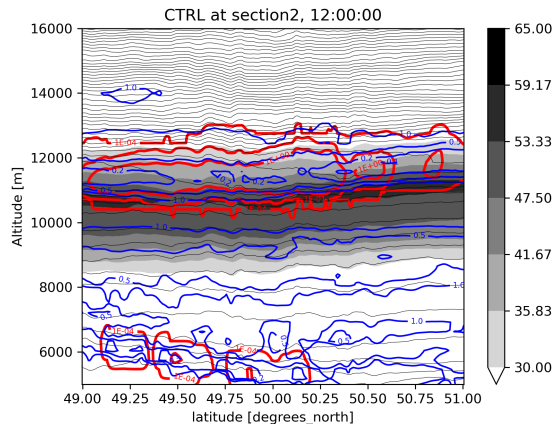
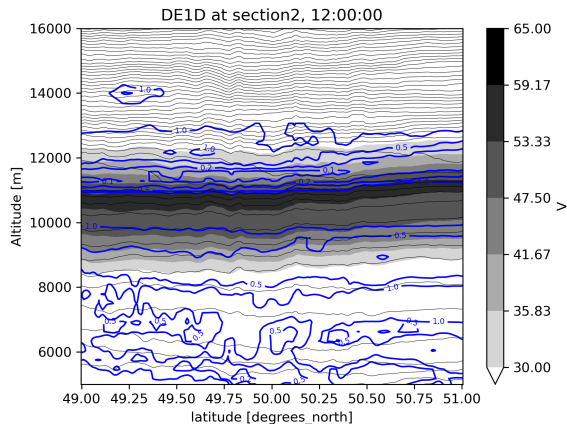
Gradient Richardson (Ri_g), Vertical wind Shear (S^2) and Brünt-Väisälä frequency (N^2) at 1200 UTC

3D turbulence scheme budgets terms



Budget terms between 1100 and 1200 UTC in box. Comparison between 1D and 3D formulations of the CBR turbulence scheme with MesoNH

Vertical wind sections



- TKE spatial localization correlates with low Ri zones. The TKE field induces a decrease for jet wind speeds

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