A comparison of two nonhydrostatic models for a convective situation using a kinetic energy spectral analysis

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Introduction

- Comparison of two nonhydrostatic models at convective scale:
  - AROME: operational fine-scale NWP model used at METEO-France since 2008
  - MesoNH: research model

- Characterization of diurnal convection

- Analysis using Kinetic Energy spectra

1 - Models

Characteristics of models used in this study

MesoNH (Lafore et al. 1998):

- Aneslatic: pseudo-incompressible equations (Durran)
- Grid point model
- Eulerian advection scheme:
  - PPM for scalar fields
  - 4th order centered scheme for wind
- Explicit leapfrog time scheme
- 4th order diffusion

AROME (Seity et al. 2011):

- Fully compressible system
- Spectral model
- Semi-Lagrangian scheme
- Semi-implicit time scheme
- 4th order spectral diffusion gridpoint SLHD on hydrometeors

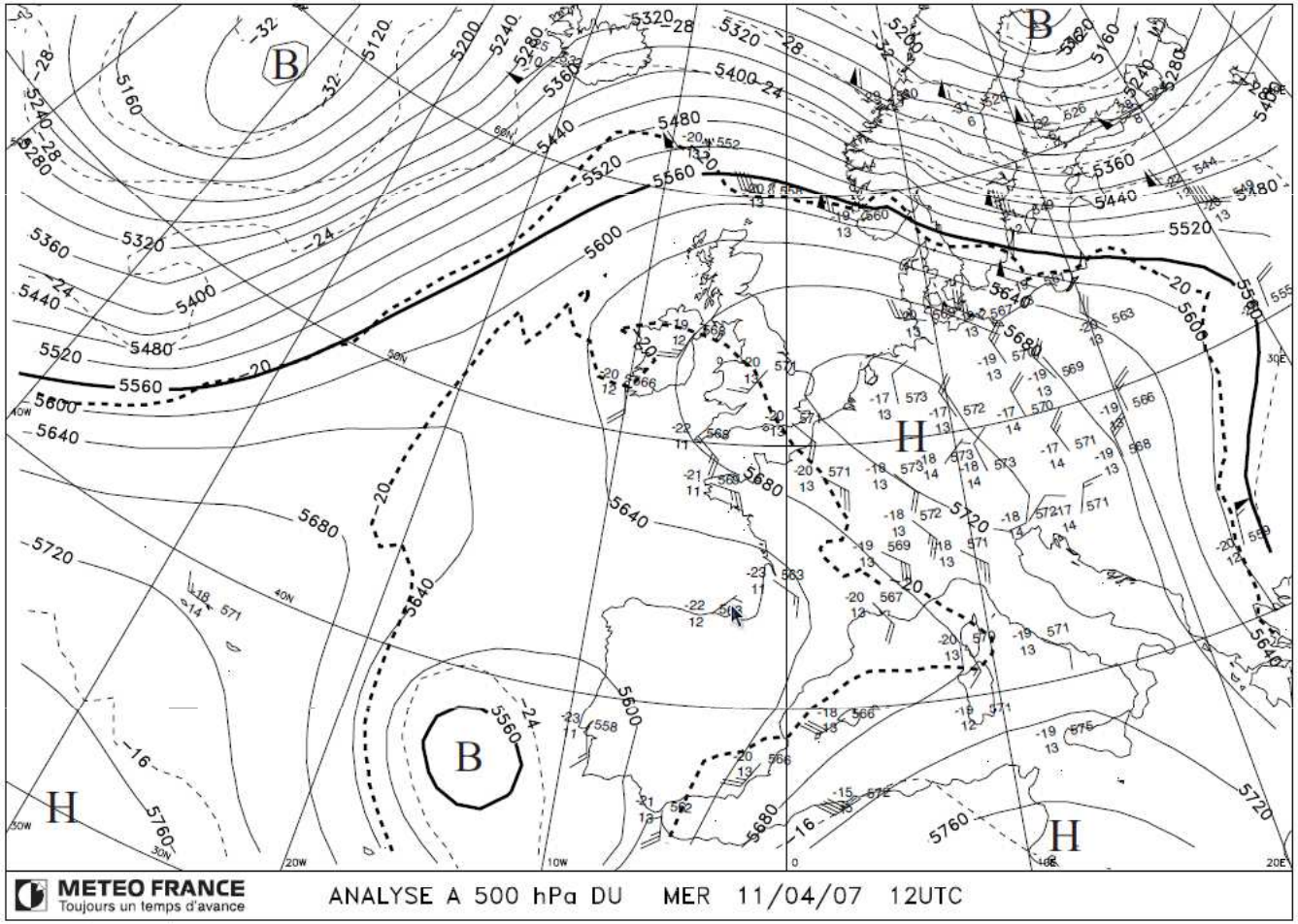
Same physics package (at 2.5 km):

- one moment mixed-phase microphysical scheme: 5 hydrometeor classes
- 1D Turbulence scheme: pronostic TKE equation with a diagnostic mixing length (Bougeault Lacarrere mixing length)
- Surface scheme: SURFEX (ISBA parametrisation, TEB scheme for urban tiles, ECUME for sea tiles)
- Radiation scheme: ECMWF parameterization
- EDMF Shallow convection scheme

Comparison of KE spectra will concern the differences between the two dynamics

2 - Case study: 11 April 2007

Synoptic situation at 12UTC



Analysis: ZT 500

Convection over SW France:

Ridge/ thalweg with geopotential low → SE flux over France

Cold air mass in midtroposphere

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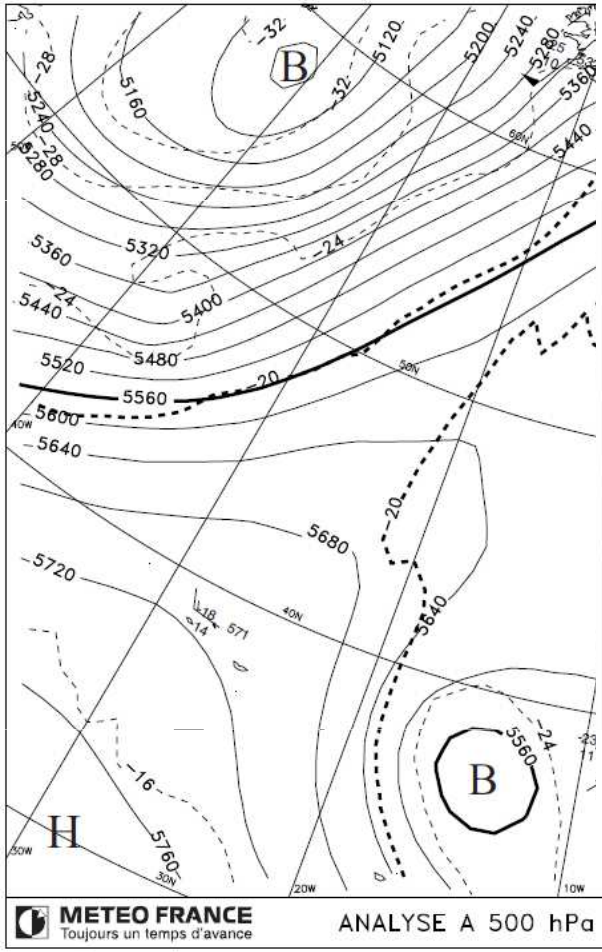
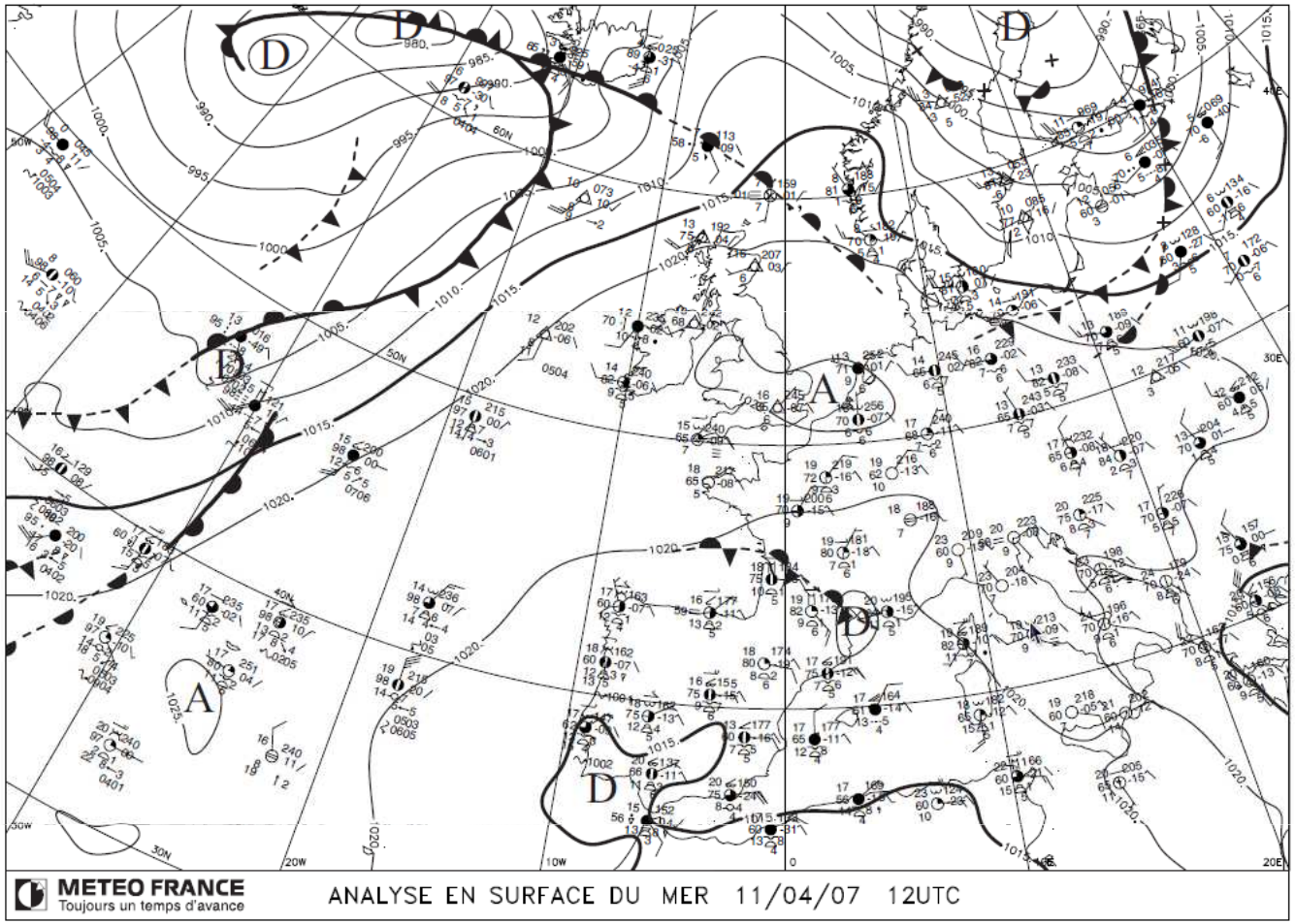
Synoptic situation





Analysis: Surface Pressure

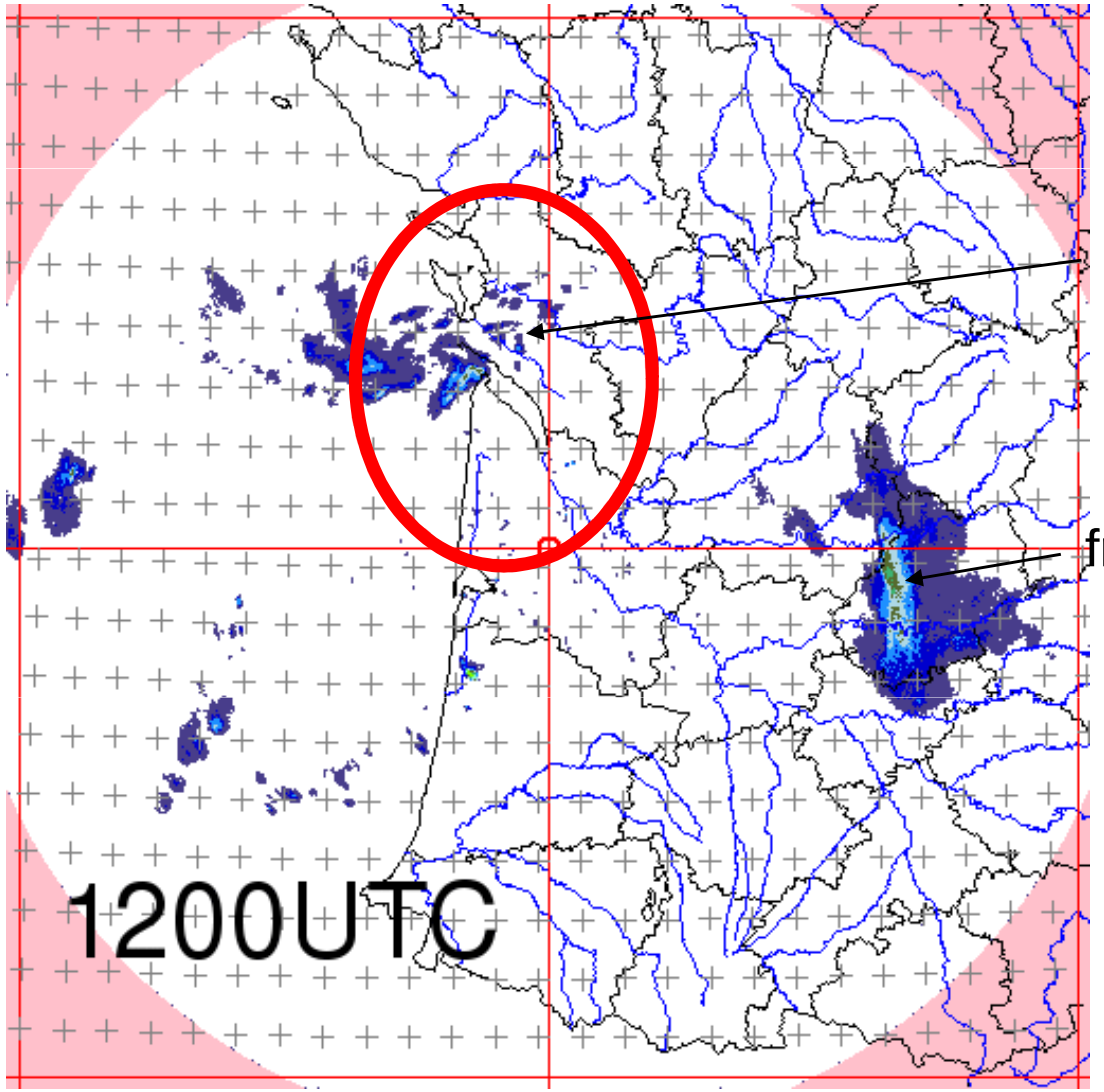
Convection over SW France:

Ridge/ thalweg with geopotential low → SE flux over France

Cold air mass in midtroposphere, front

2 - Case study: 11 avril 2007

Radar reflectivities



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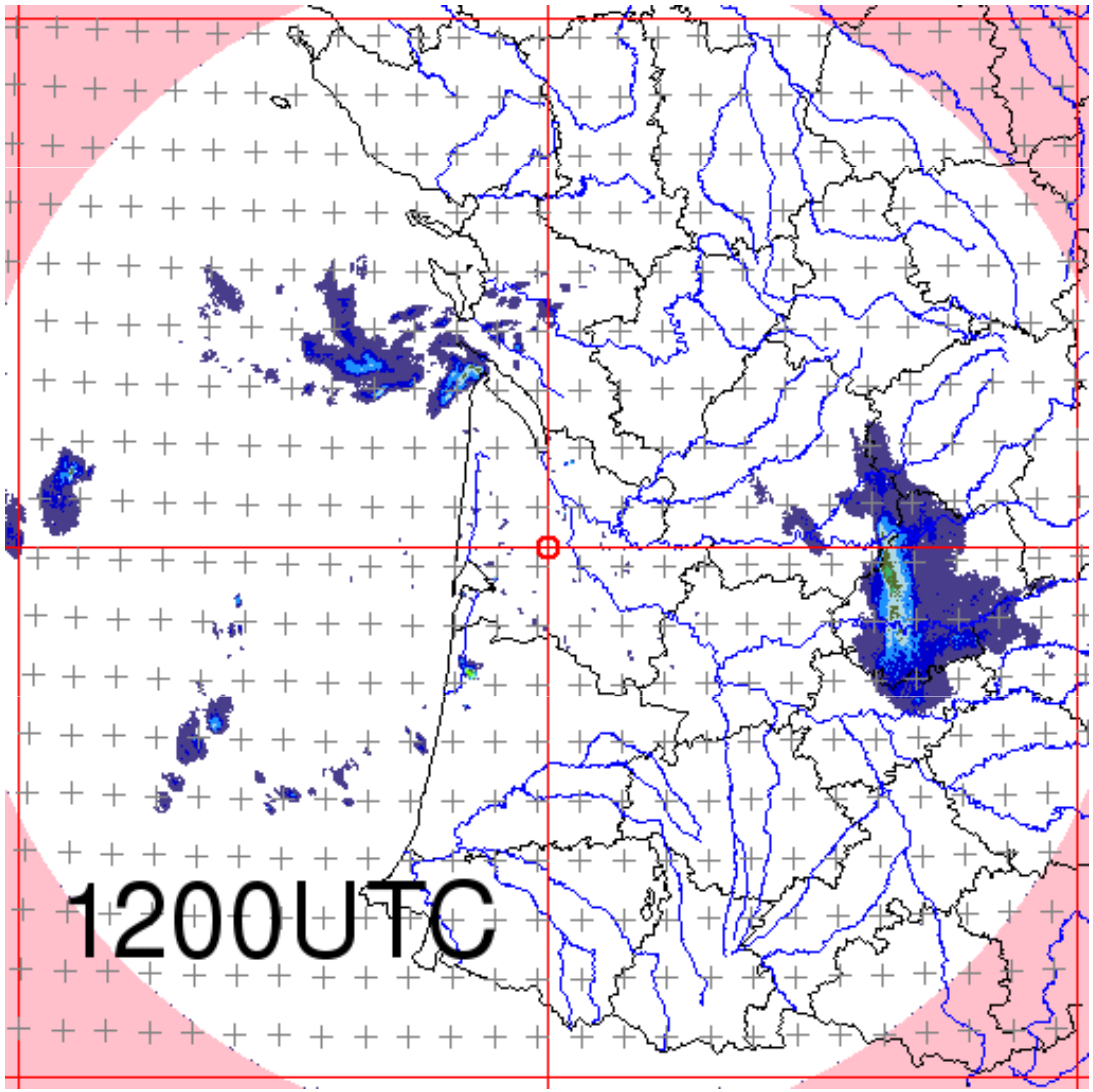

Convective cells over plains during the afternoon

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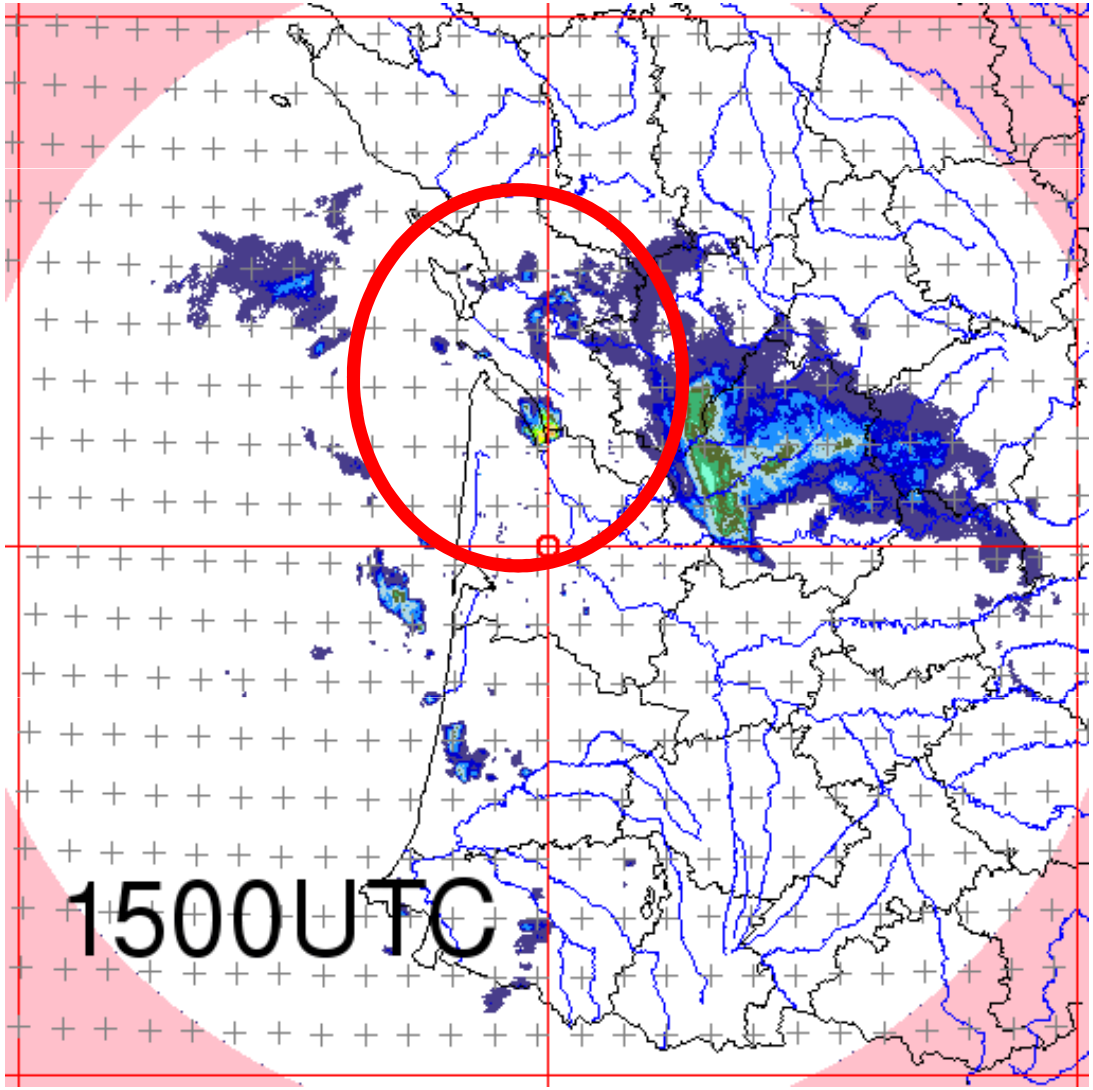
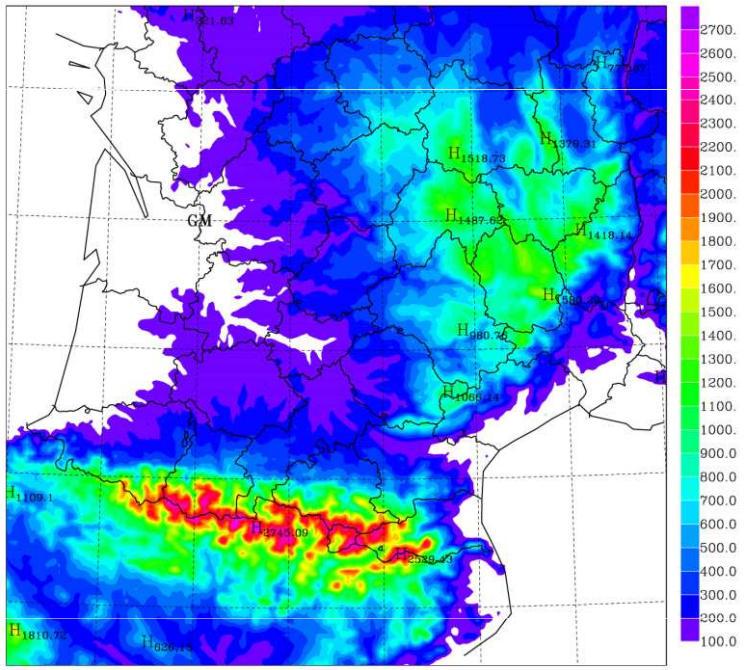


Convective cells over plains during the afternoon

Domain and resolution

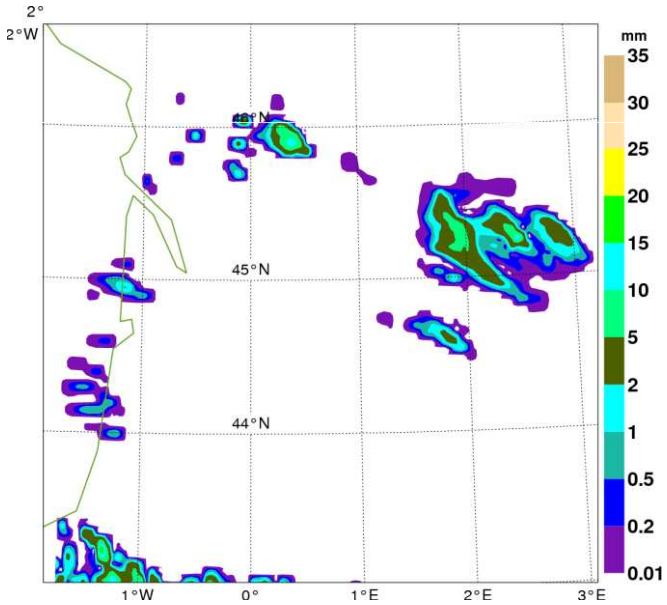


For both models:
- Domain covering southwestern France: 570x570 km²
- Horizontal resolution: 2.5 km
- 41 vertical levels
- Forecast starting at 00UTC from a 10-km ALADIN analysis

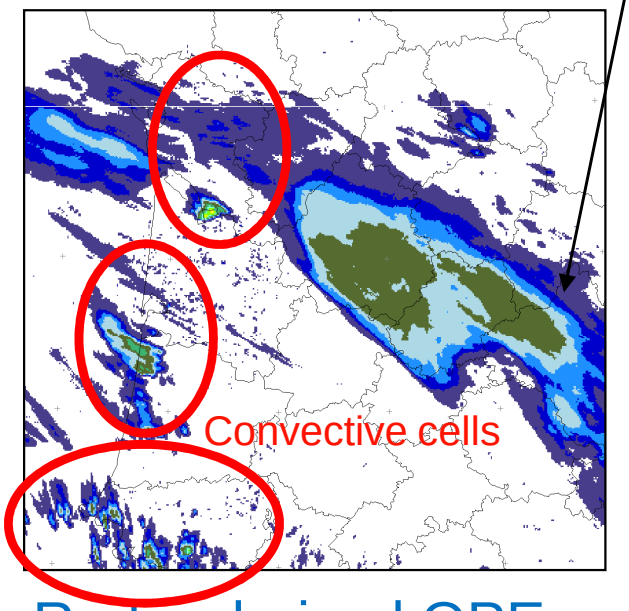
3 - Simulations

Comparison of 3-hour precipitation between 12 and 15 UTC

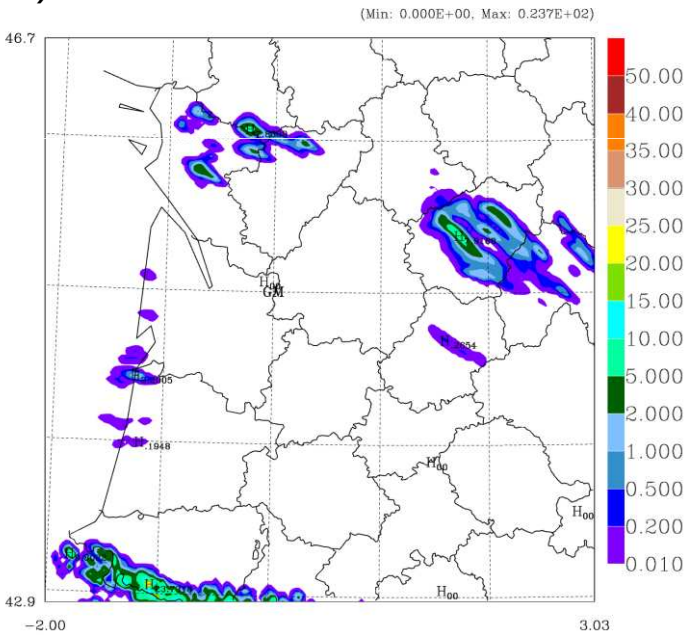
Small precipitation (<5mm) from frontal line



AROME



Radar-derived QPE



MesoNH

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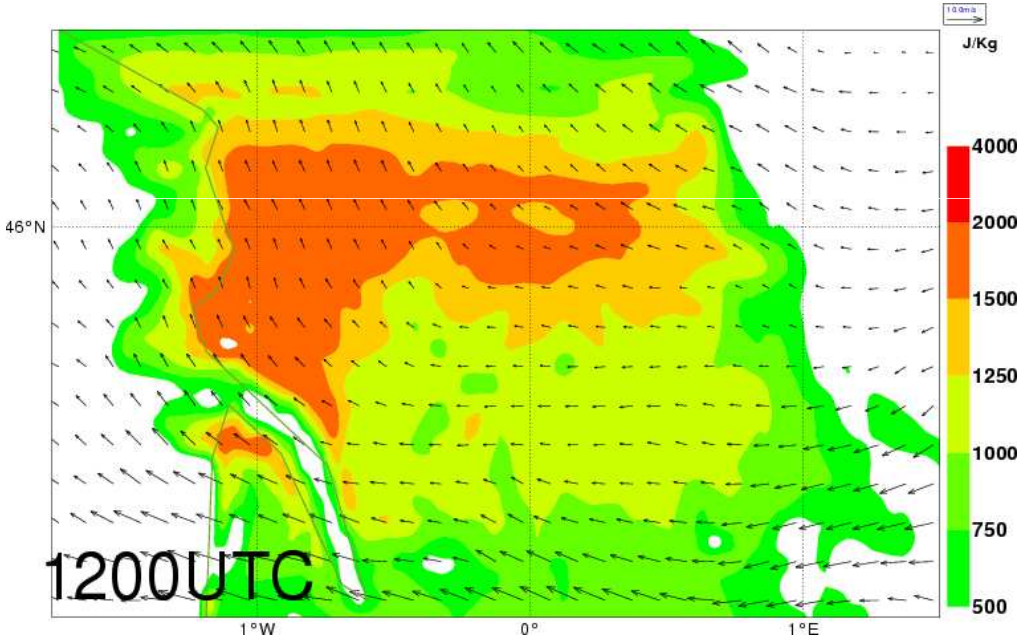
Initiation of convection



CAPE (colour scale)
Cumulated precipitation (1, 2, 5,10, 20 mm, blue lines)
850 hPa Wind (vectors)

AROME

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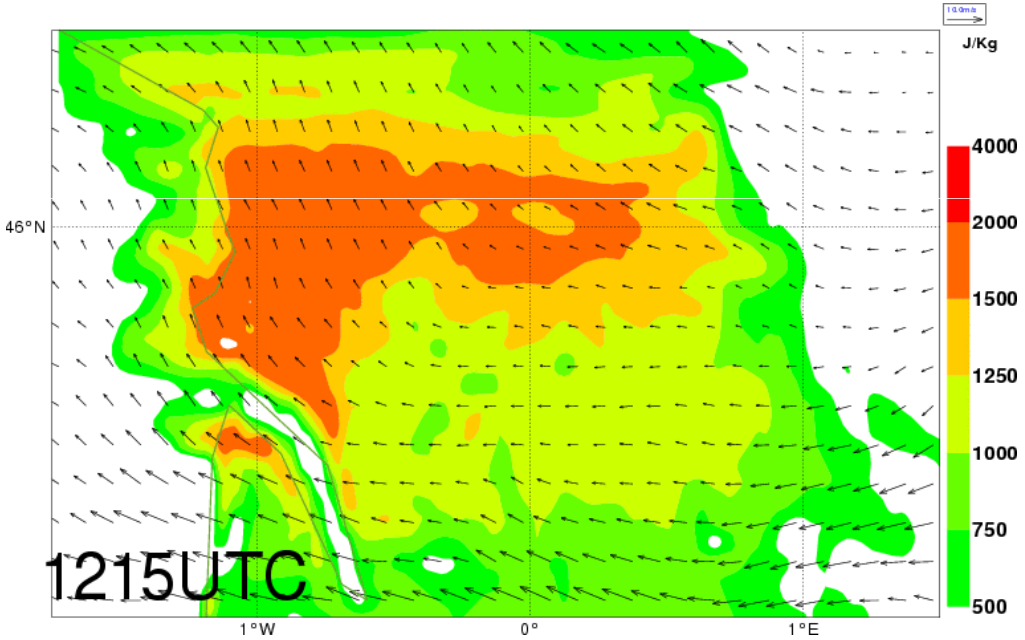

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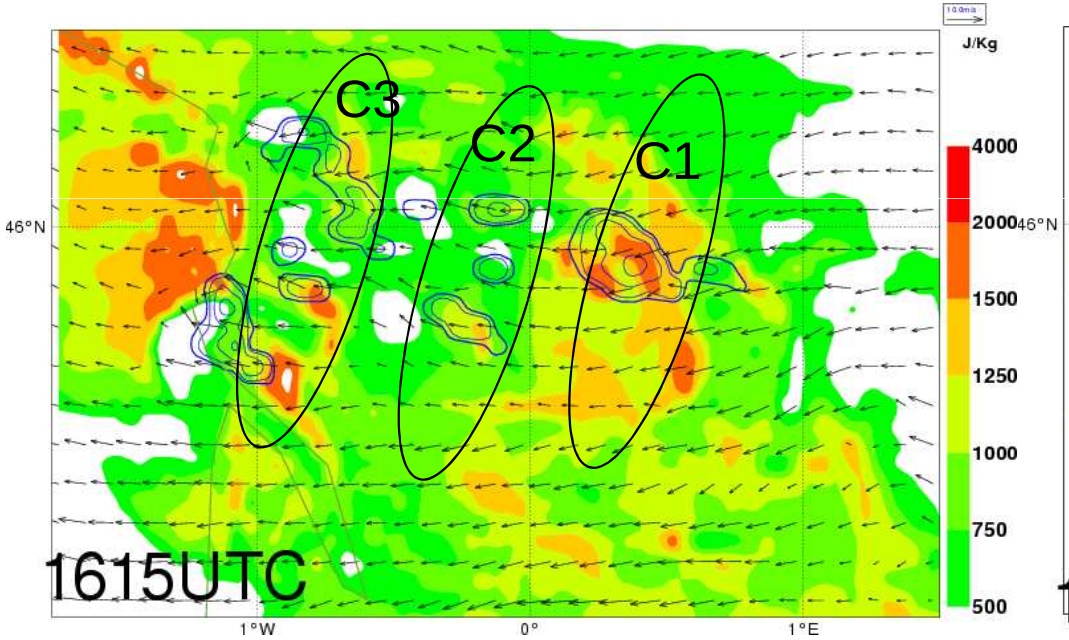

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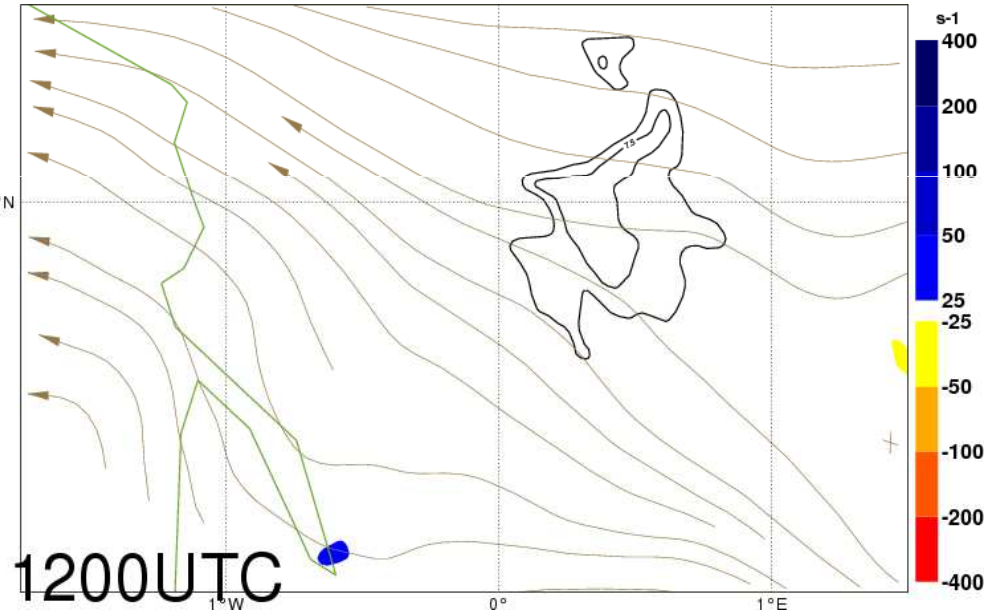

925 hPa Divergence (colour scale)
925 hPa Specific humidity (7,7.5,8,8.5 g/Kg , black lines)
10m Wind (streamlines)

AROME

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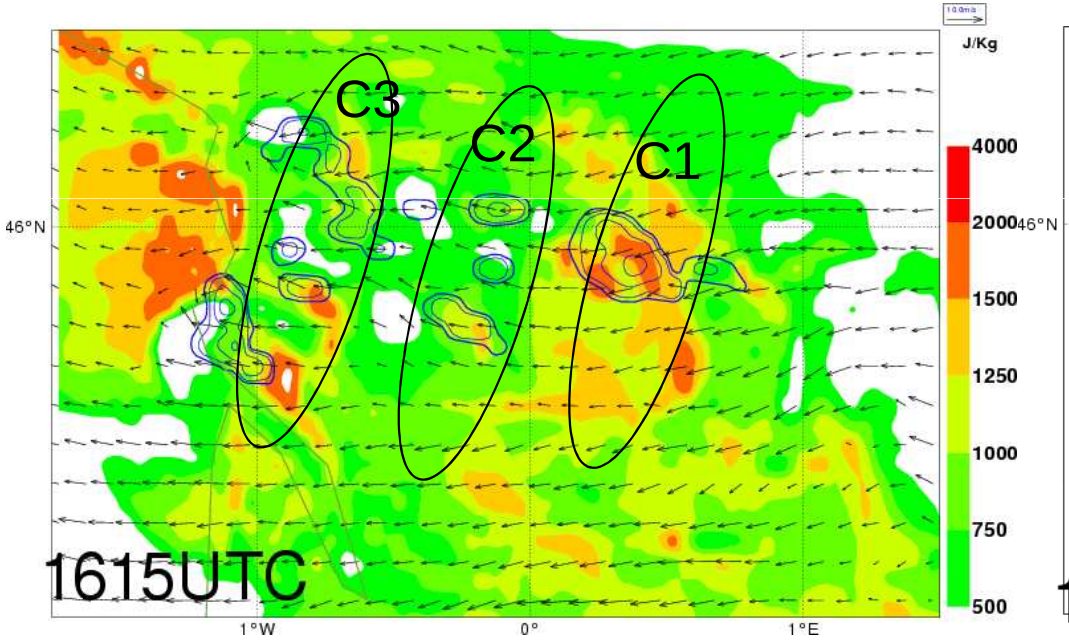

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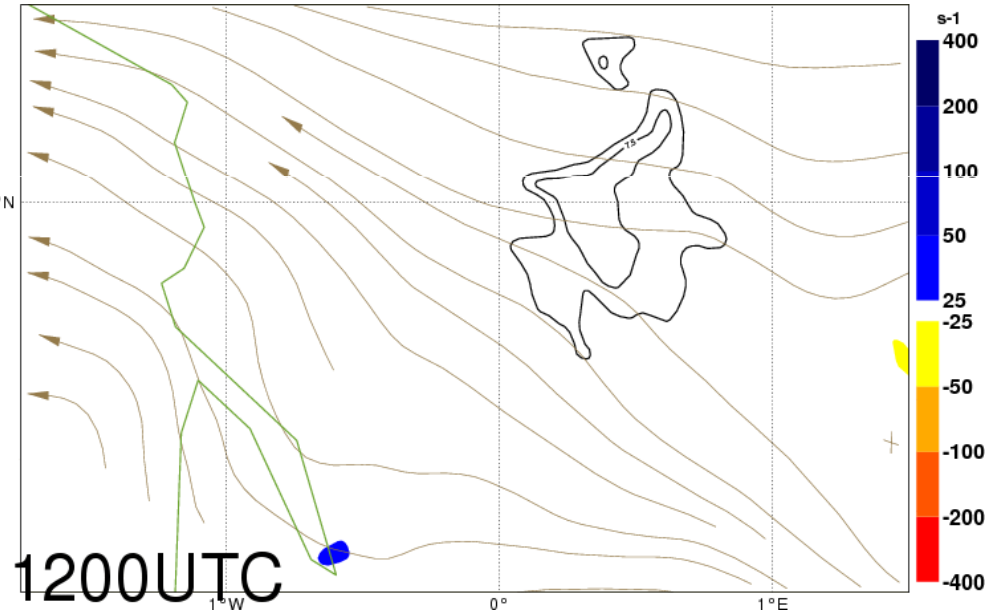

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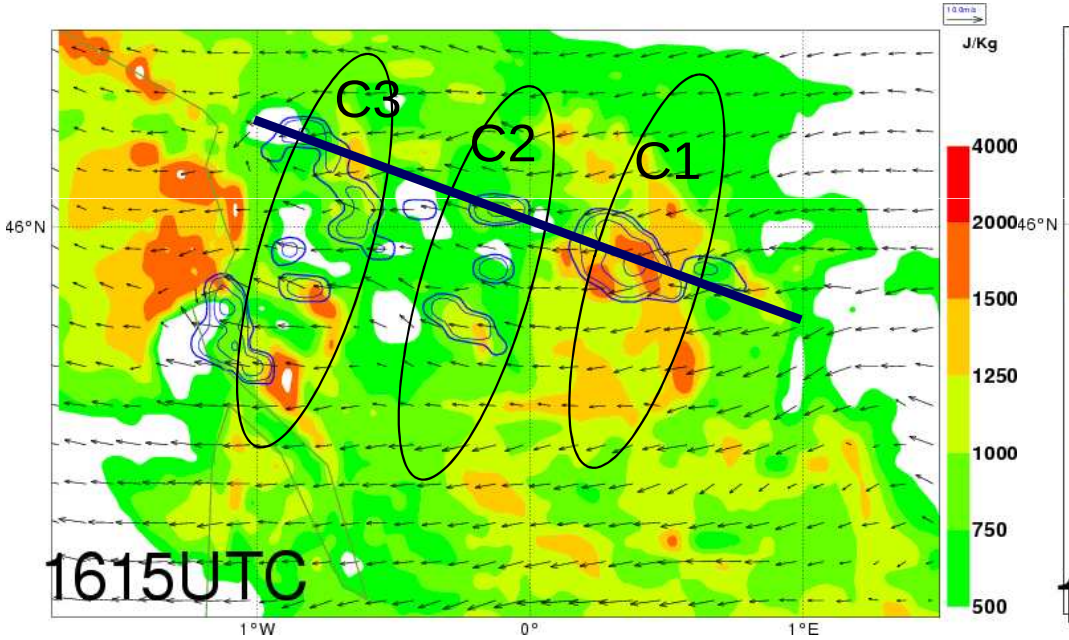

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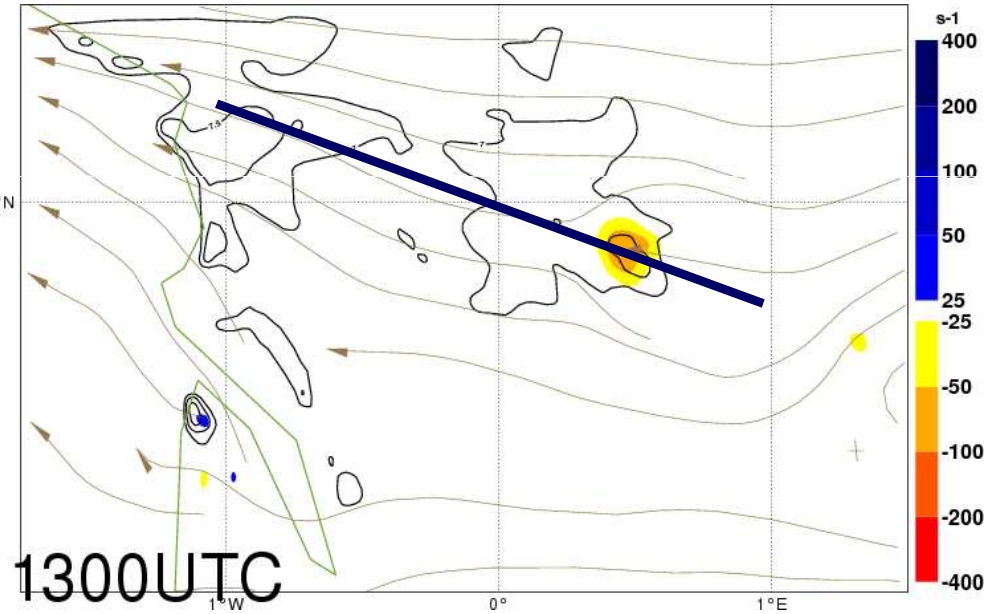

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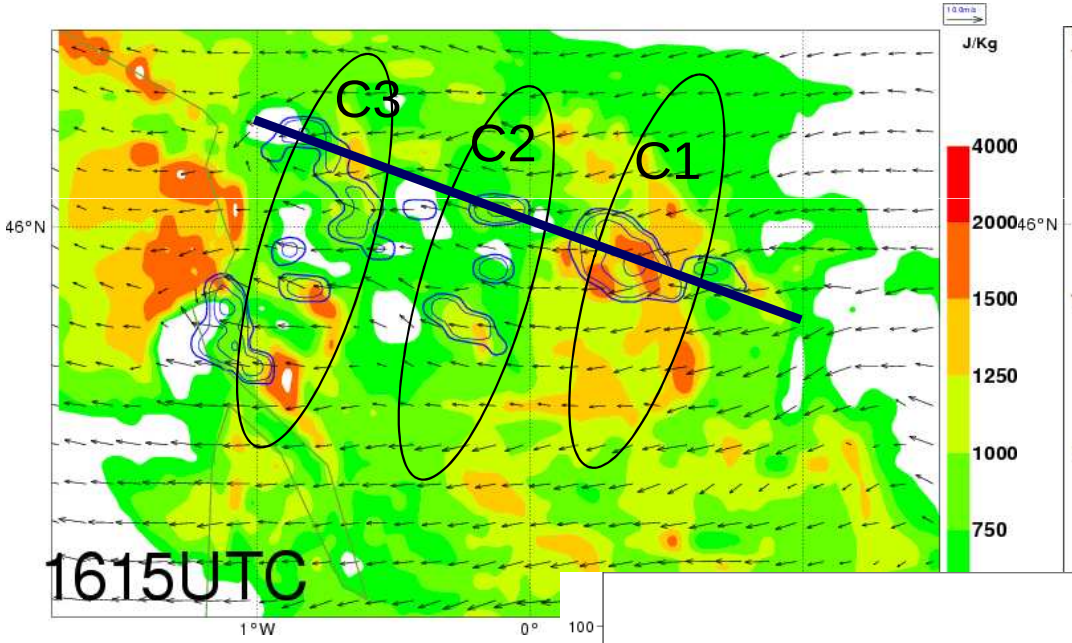
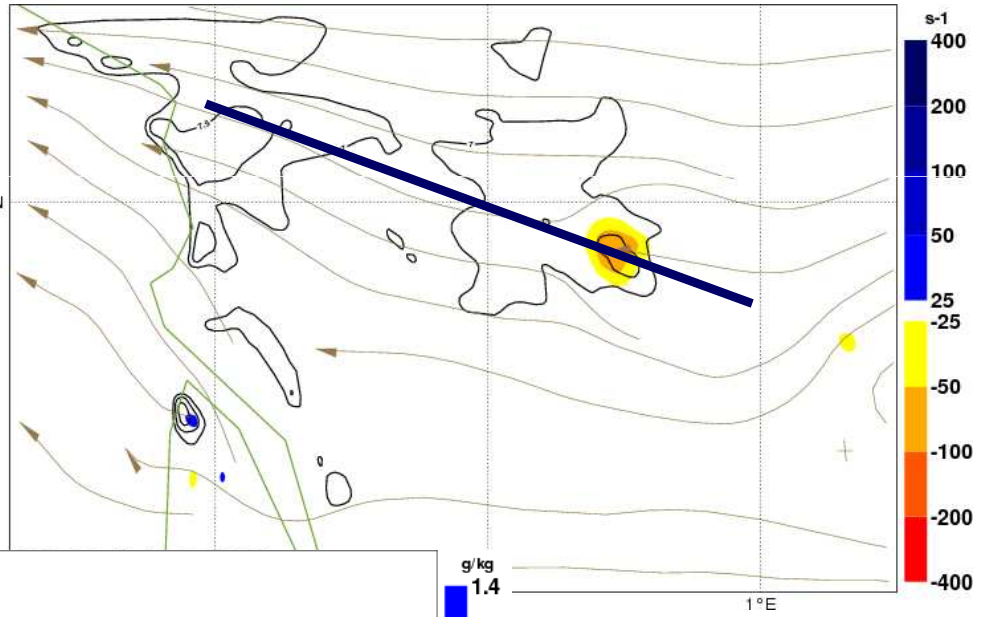
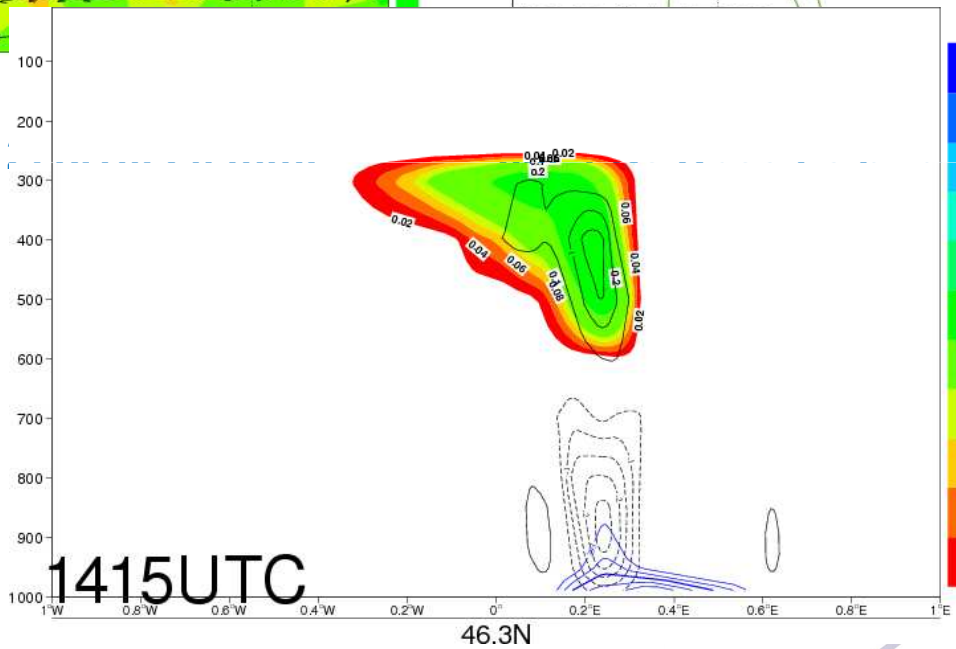




CAPE (colour scale)
Cumulated precipitation (1, blue lines)
850 hPa Wind (vectors)

AROME

Ice Mixing ratio (g/Kg, colour scale)
VV (m/s, black lines)
θv (K, blue lines)



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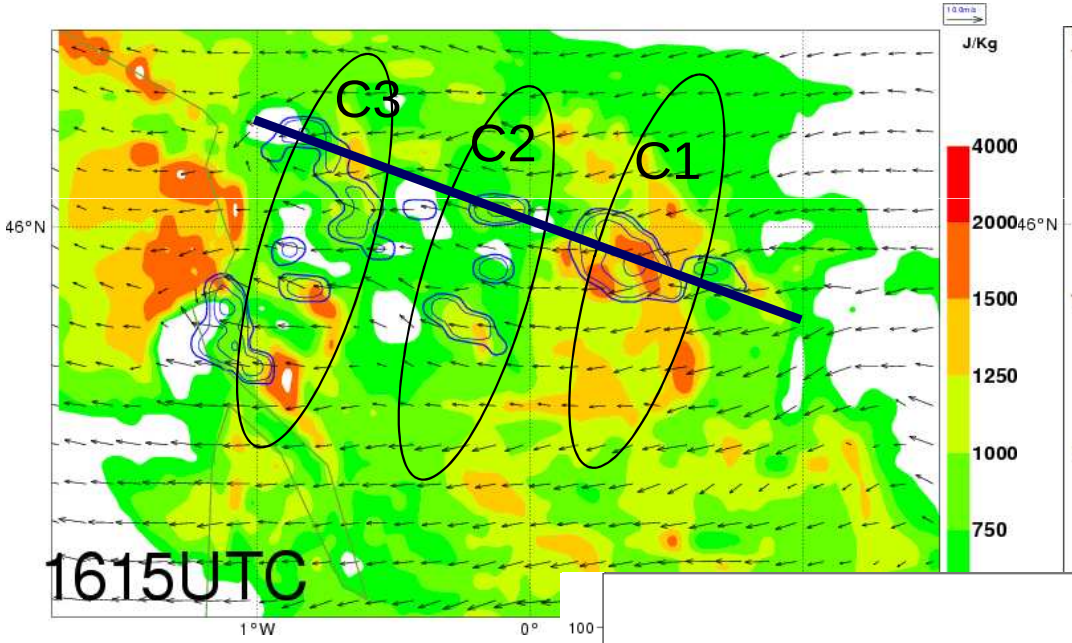
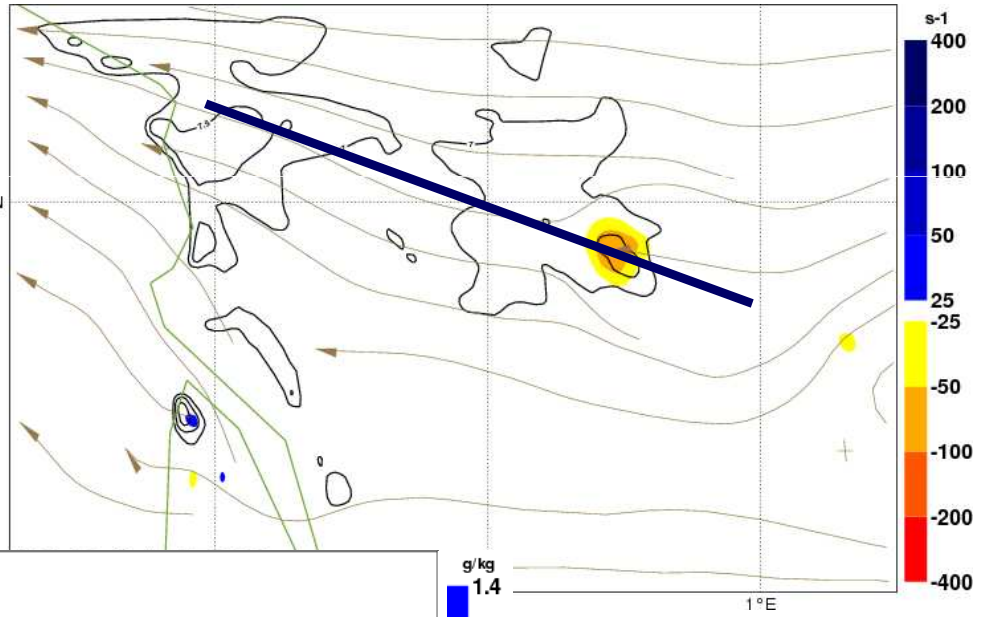
Conditionally unstable atmosphere
Lifting from low-level convergence
Lifting from cold pool
....

Initiation of convection





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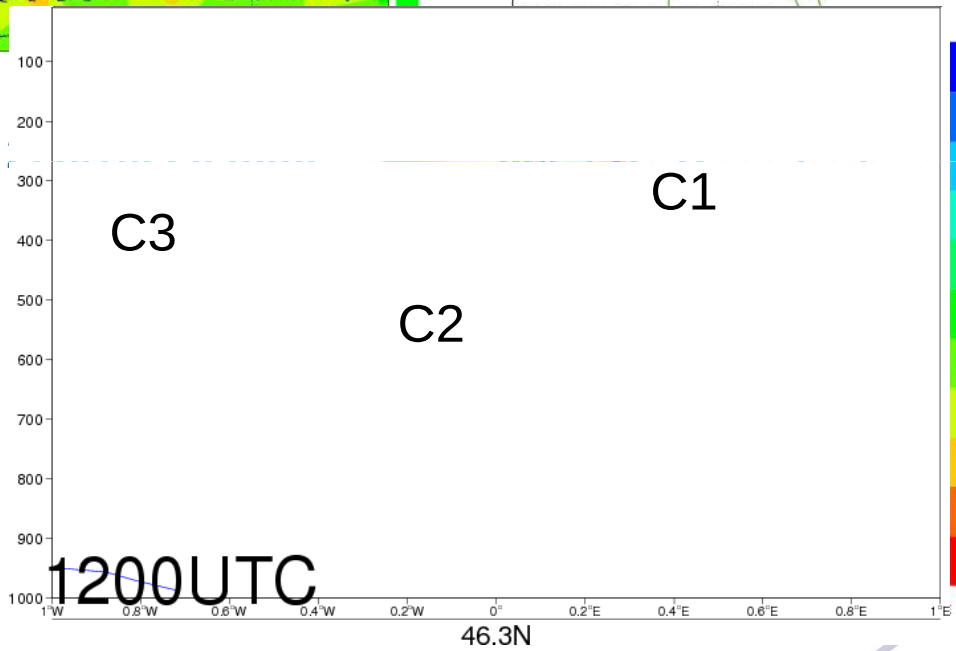

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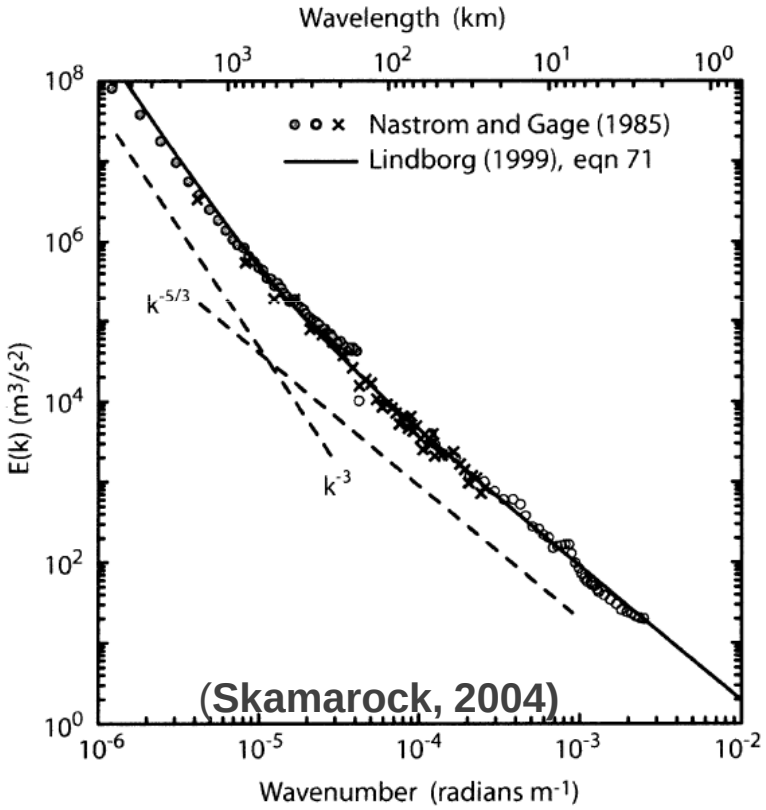
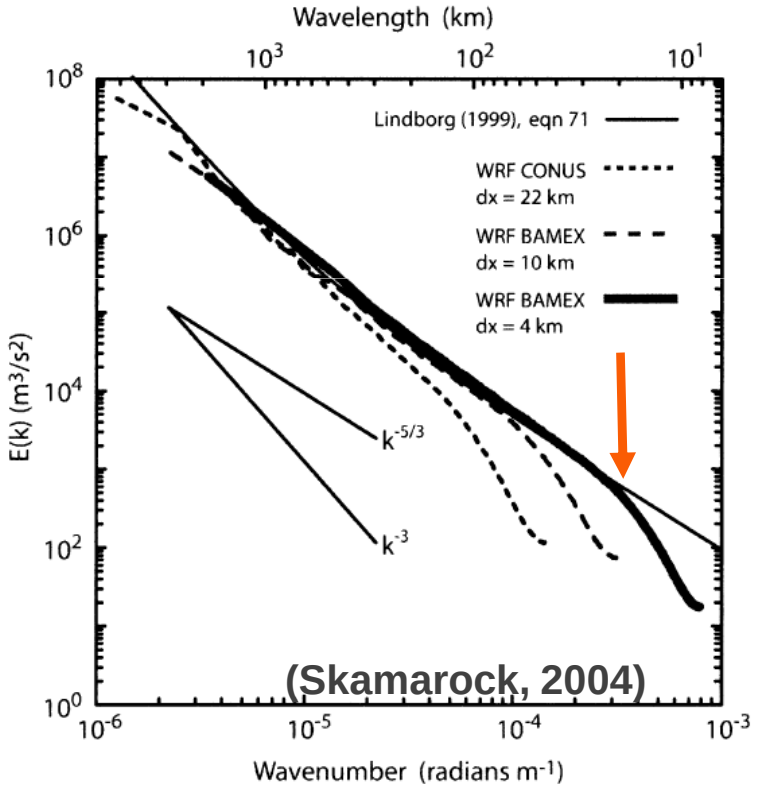
4 – KE spectra

Kinetic energy spectra:

- Distribution of KE according to the spatial scales
- Energy cascade from large scales to small scales
- In observations, KE follows a k^{-3} dependence in the large scales and a $k^{-5/3}$ dependence in the mesoscale part
- Useful tool to assess the ability of models to reproduce the observed slopes, to determine the effective resolution (Skamarock, 2004)



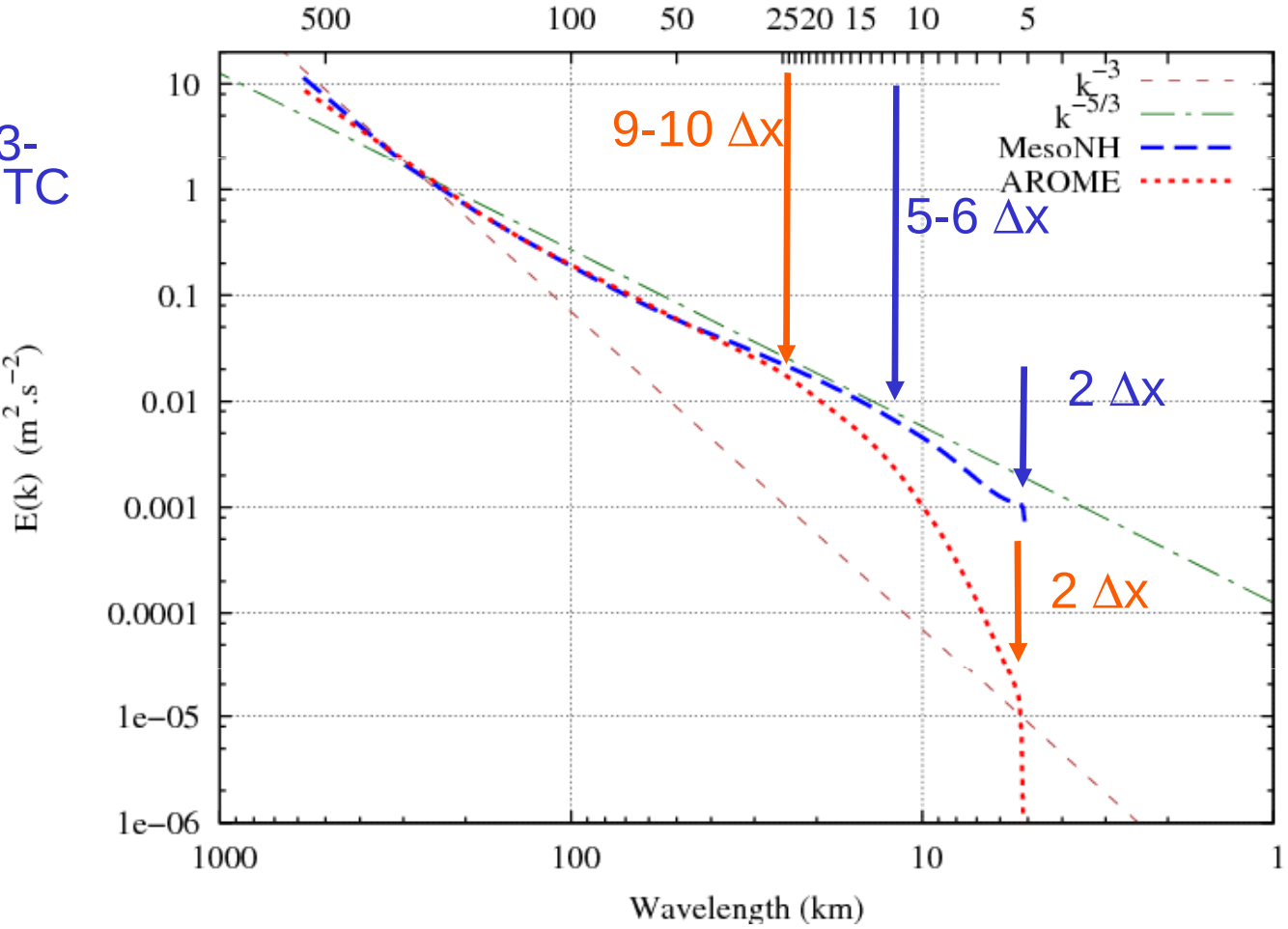


Spectra computation

- Algorithm of spectra computation using a DCT (Denis et al., 2002)
- Computed using 2D decomposition of the velocities (u,v,w)
- Computed every hour and for each model level
- Averaged over selected periods and layers
- Same tool for both models

Comparison between AROME and MesoNH

KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC



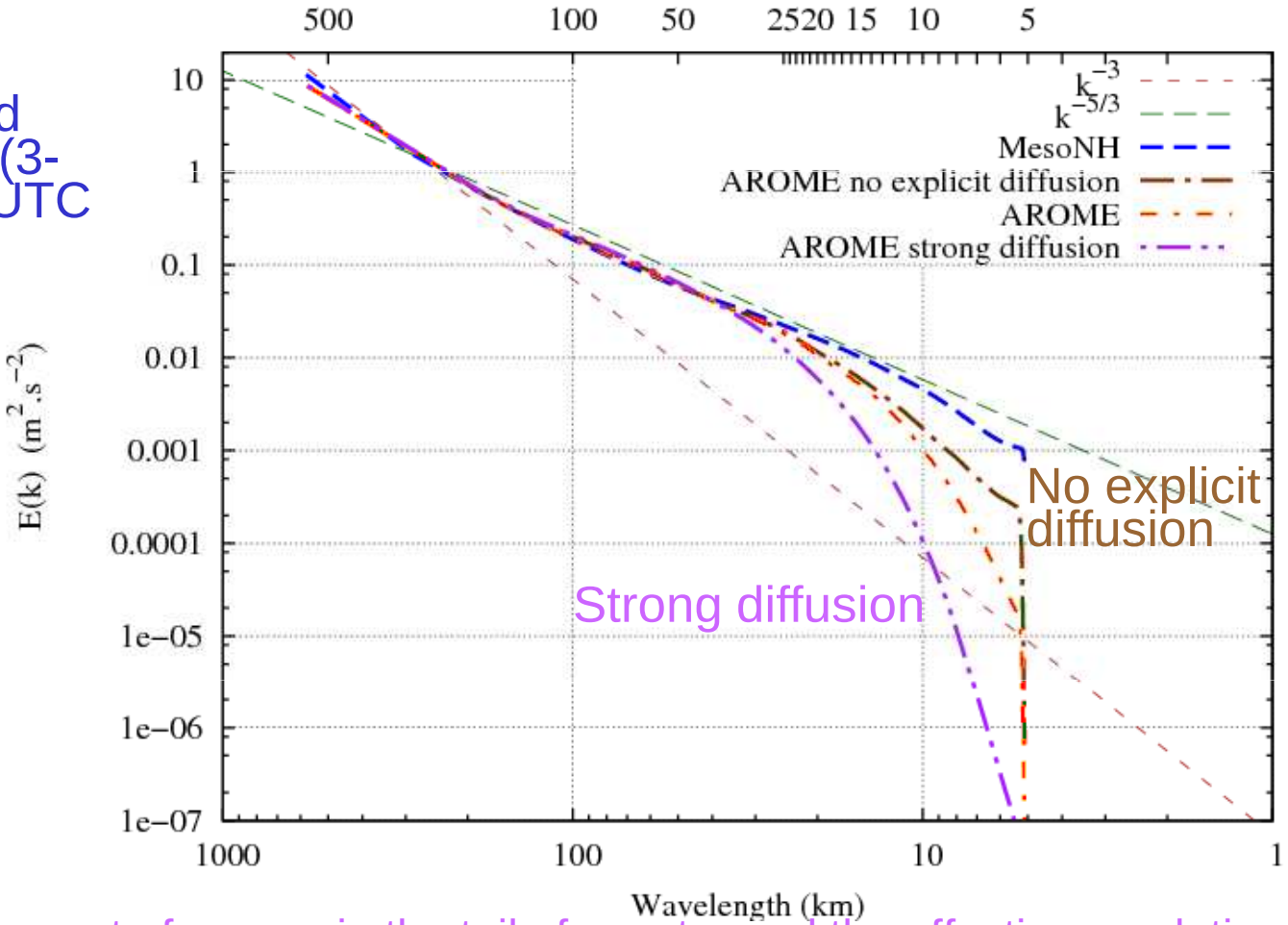
→ –3 and –5/3 slopes

→ Effective resolution:

- MesoNH: ~14 km 5-6 Δx
- AROME: ~ 24 km ~9-10 Δx, variance loss more important

AROME: Sensitivity to diffusion

KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC



AROME:

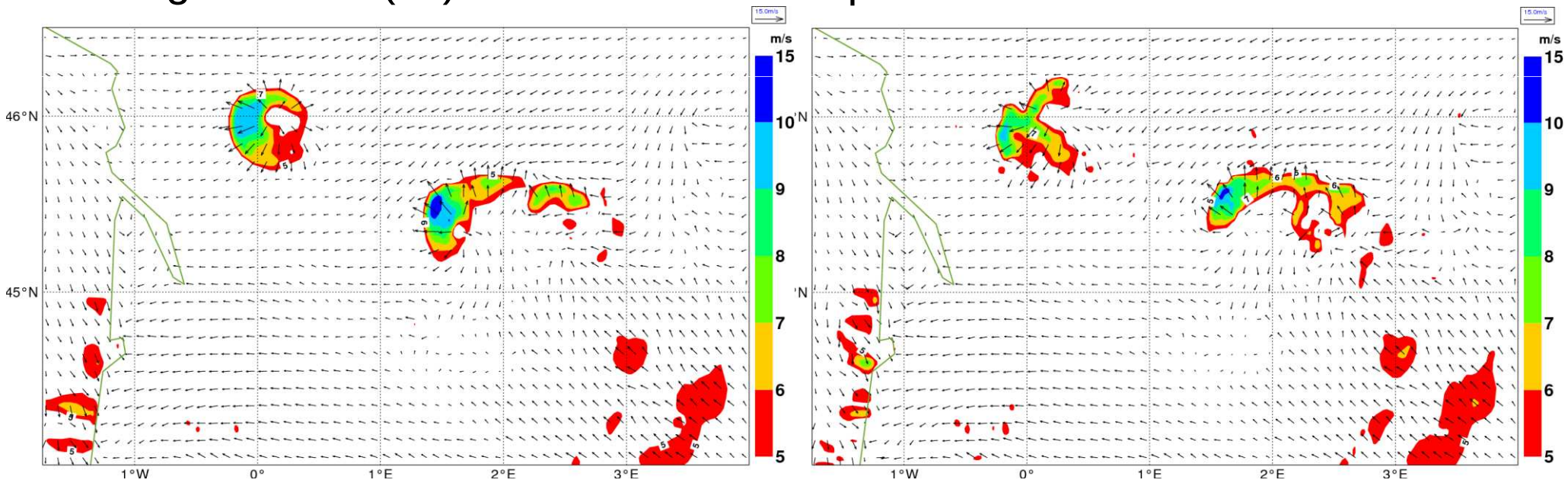
Stronger diffusion reduces the amount of energy in the tail of spectra and the effective resolution

When removing all explicit diffusion, a significant damping remains due to the implicit diffusion of the SL scheme

AROME: Sensitivity to diffusion

Strong diffusion (x4):

Operational diffusion:



Wind at 17 m (intensity and vectors, m/s), 15 UTC

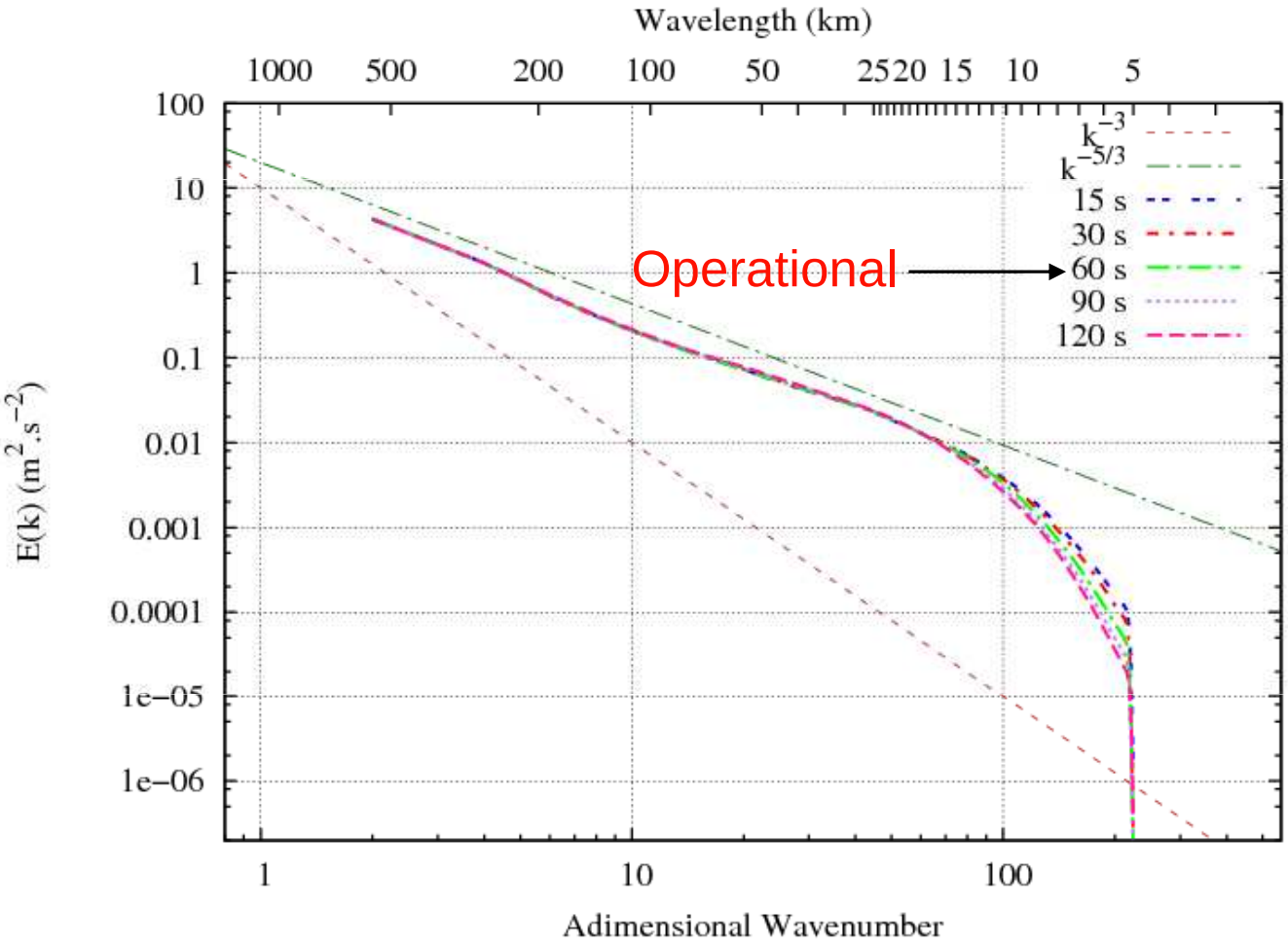
Strong outflow under the convective cells: « fireworks »

Old tunings of diffusion from ARPEGE and ALADIN

Not the case with operational tunings

4 – KE spectra

AROME: Sensitivity to time step duration

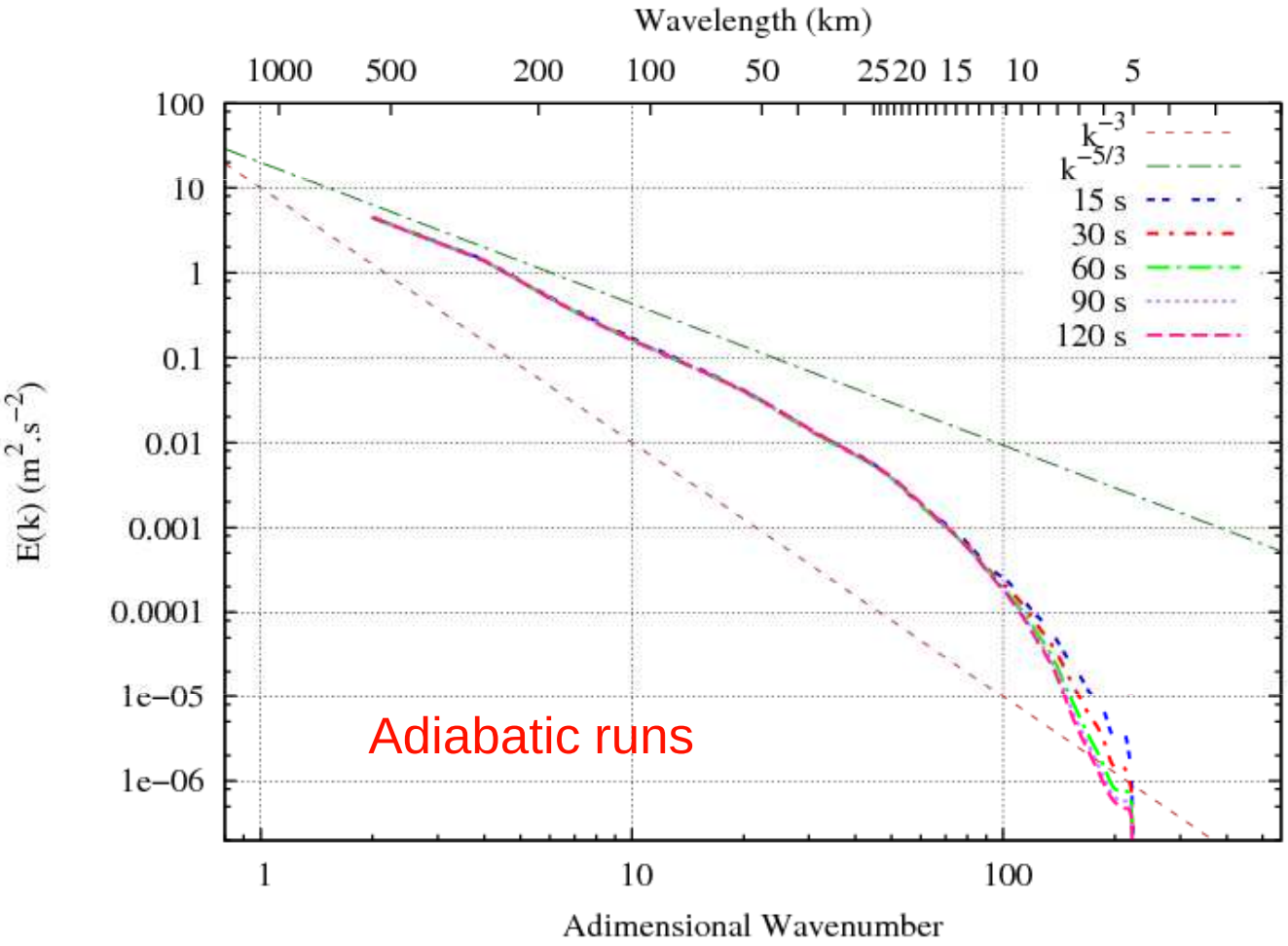


→ Implicit diffusion increases with larger time steps

KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC

4 – KE spectra

AROME: Sensitivity to time step duration



KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC

- → Implicit diffusion increases with larger time steps
- → Adiabatic runs confirm the impact of SL scheme
- → Large effect of physics on the amount of KE energy

MesoNH: Sensitivity to horizontal resolution

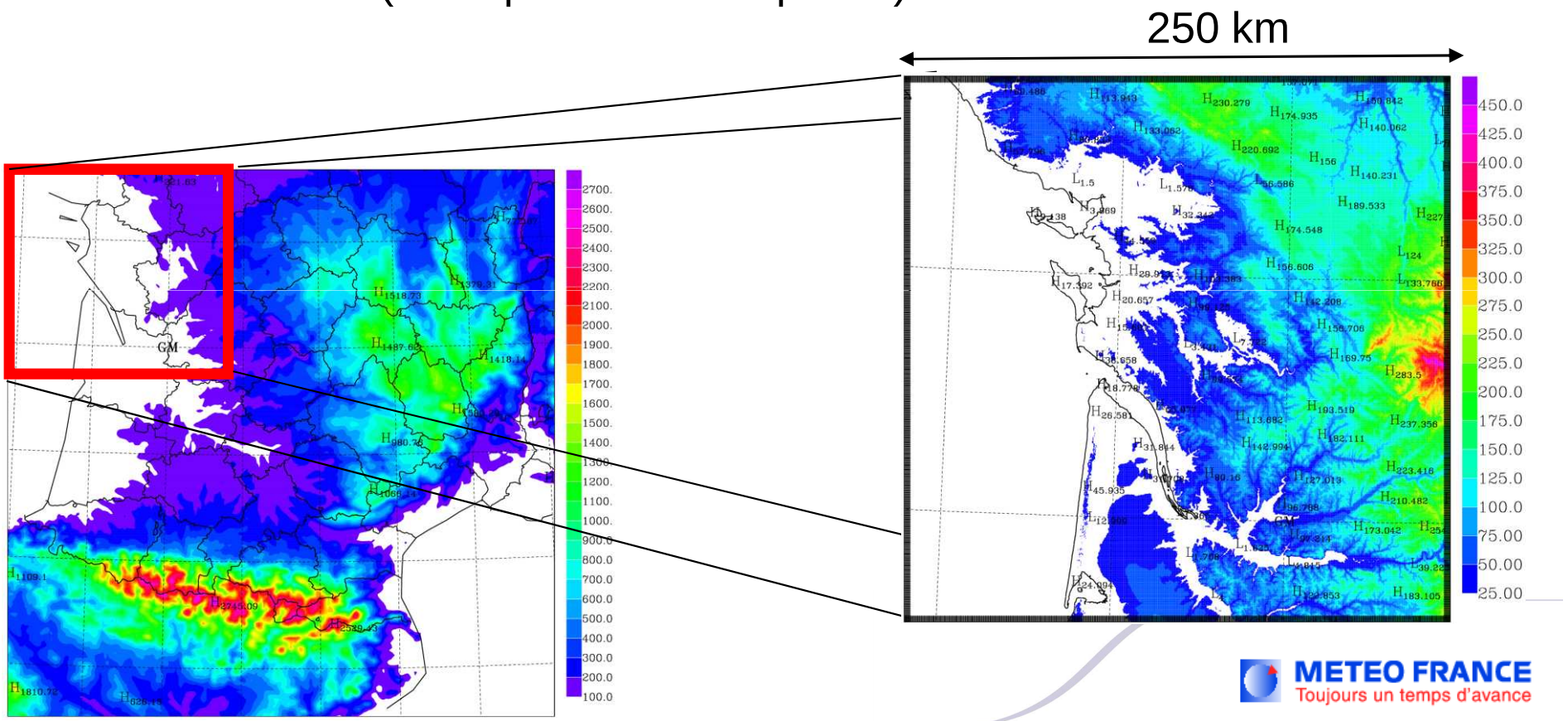
Resolution downscaling over a same smaller domain: 250x250 km²

Δx 2.5 km 1D Turbulence EDMF (100 points x 100 points)

Δx 1 km 1D turbulence EDMF (250 points x 250 points)

Δx 500 m 3D turbulence (500 points x 500 points)

Δx 250 m 3D turbulence (1000 points x 1000 points)



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MesoNH: Sensitivity to horizontal resolution

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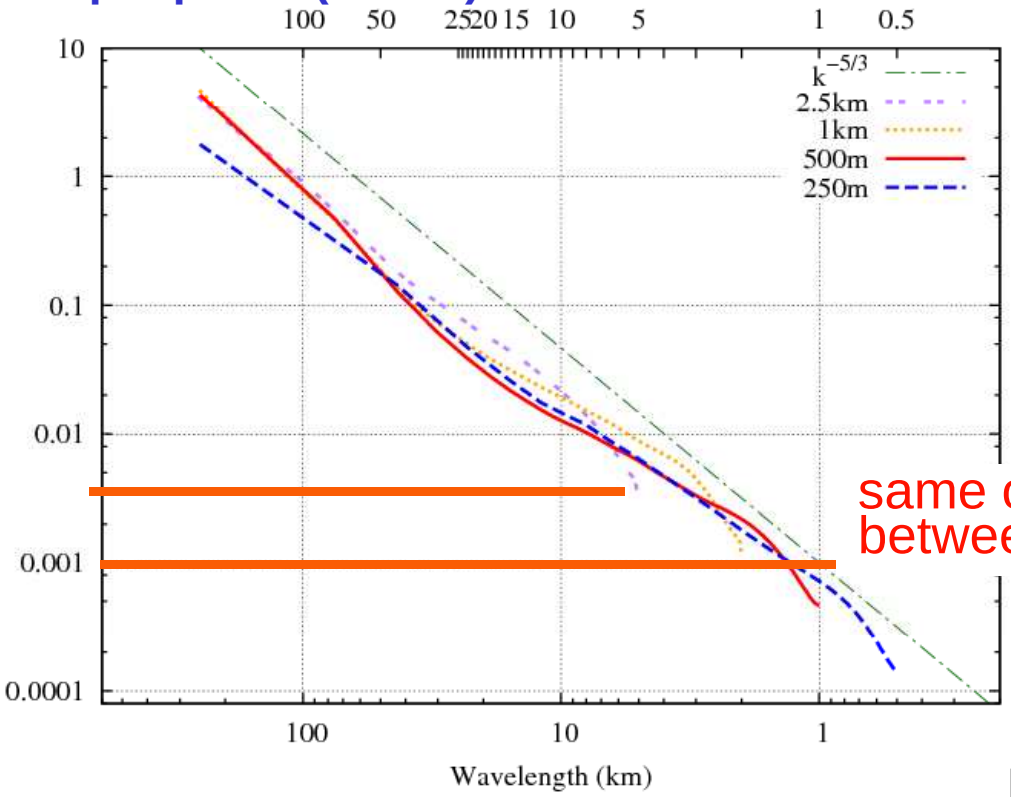
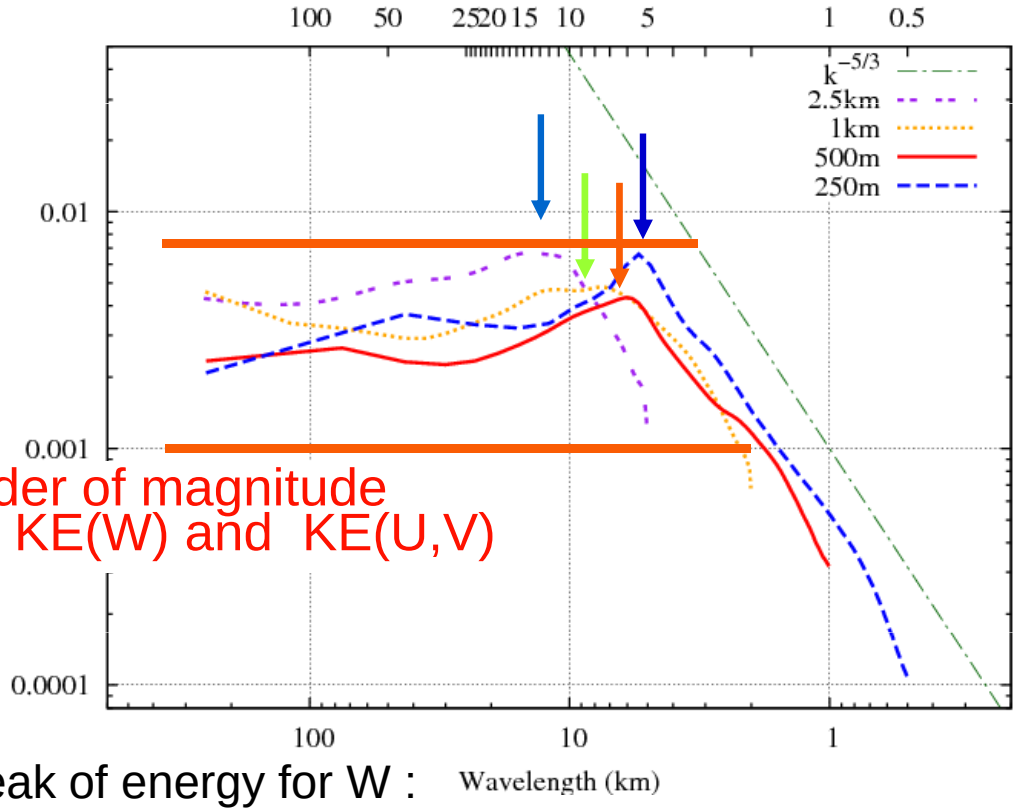


KE spectra (W)



same order of magnitude between KE(W) and KE(U,V)

More small structures when resolution increases, same effective resolution 5-6 Δx

Slope a bit less than –5/3, injection of energy due to convective motions?

Peak of energy for W :

- 12km for a 2.5 km resolution
- 8-9 km for a 1km resolution
- 6 km for a 500 m resolution
- 5 km for a 250 m resolution
- convergence?

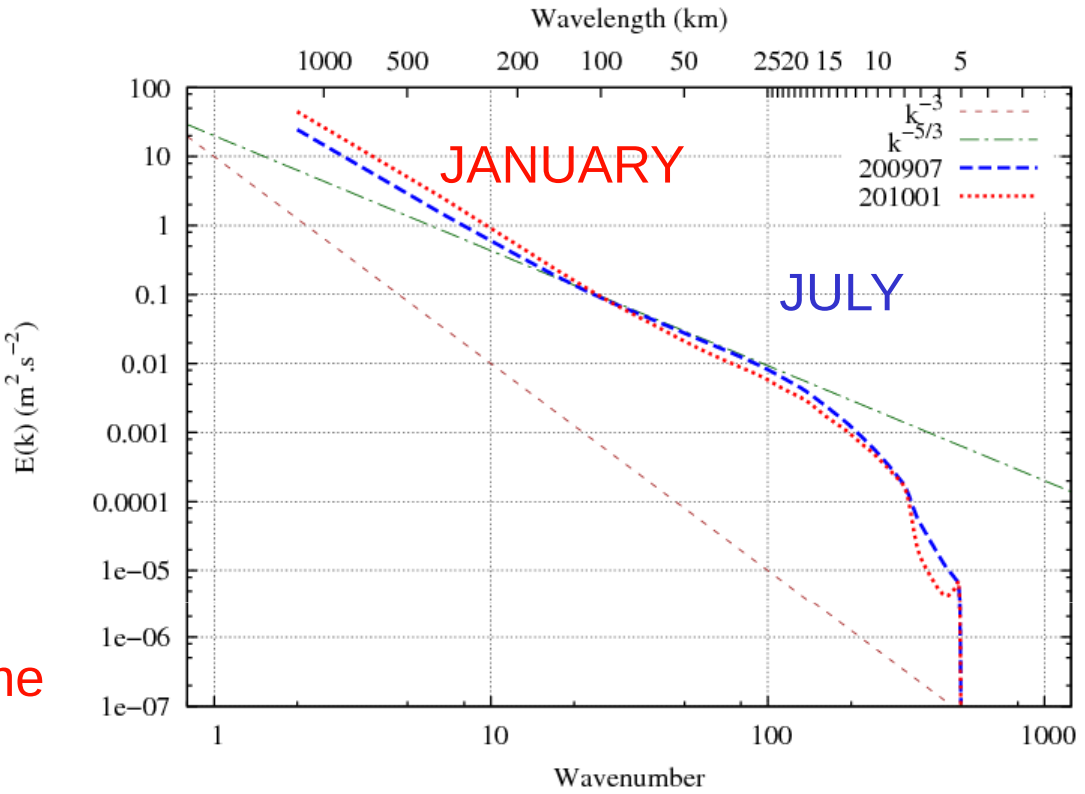
AROME: seasonal trend

2 periods :

- Summertime: JJA 2009
- Wintertime: DJF 2009-2010

Operational AROME forecasts:

- 00-30 H
- Starting from AROME analysis
- Over France 1255kmx1255km



KE spectra (U,V) averaged over the free troposphere (3-9km) between 06 and 06 UTC

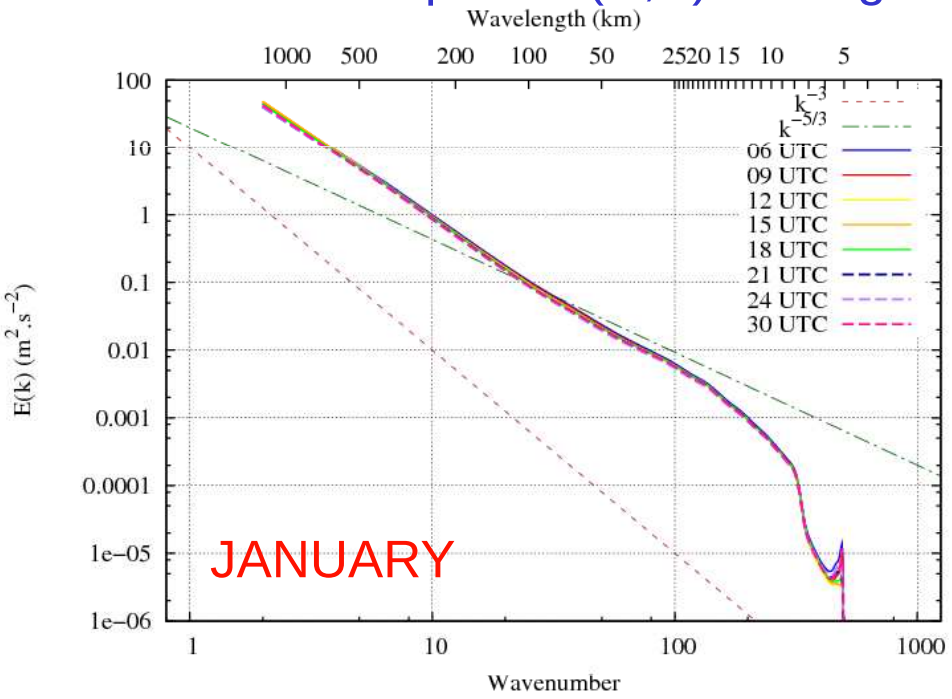
More energy in large scales in wintertime (synoptic lows)

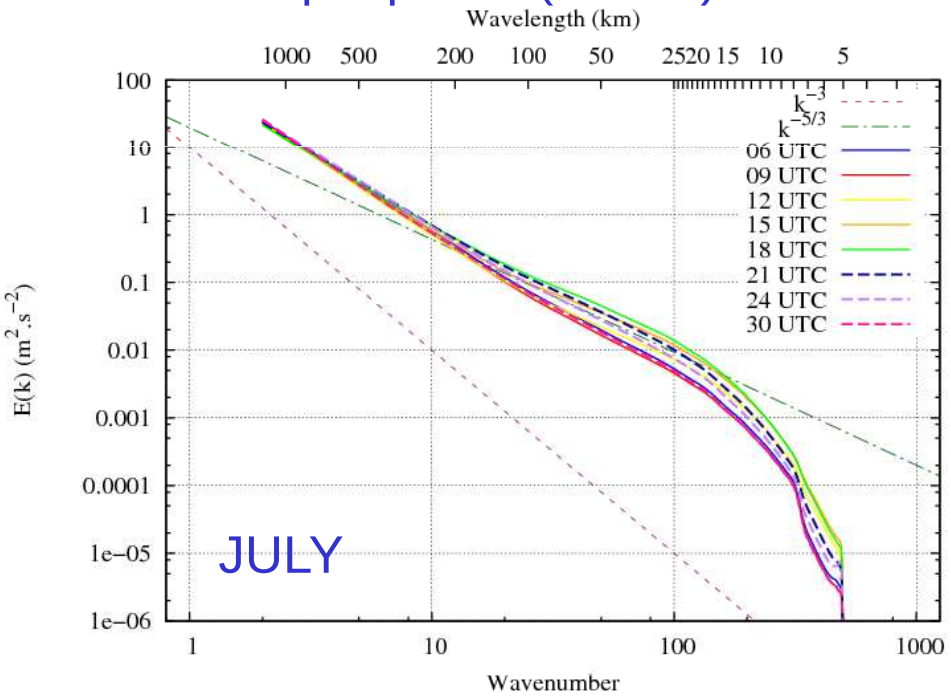
More energy in the mesoscale part in summertime (convection)

5 – Climatology of KE spectra

Diurnal evolution

KE spectra (U,V) averaged over the free troposphere (3-9km)





Small diurnal variation during wintertime

Strong diurnal variation during summertime

5 – Climatology of KE spectra

Diurnal evolution

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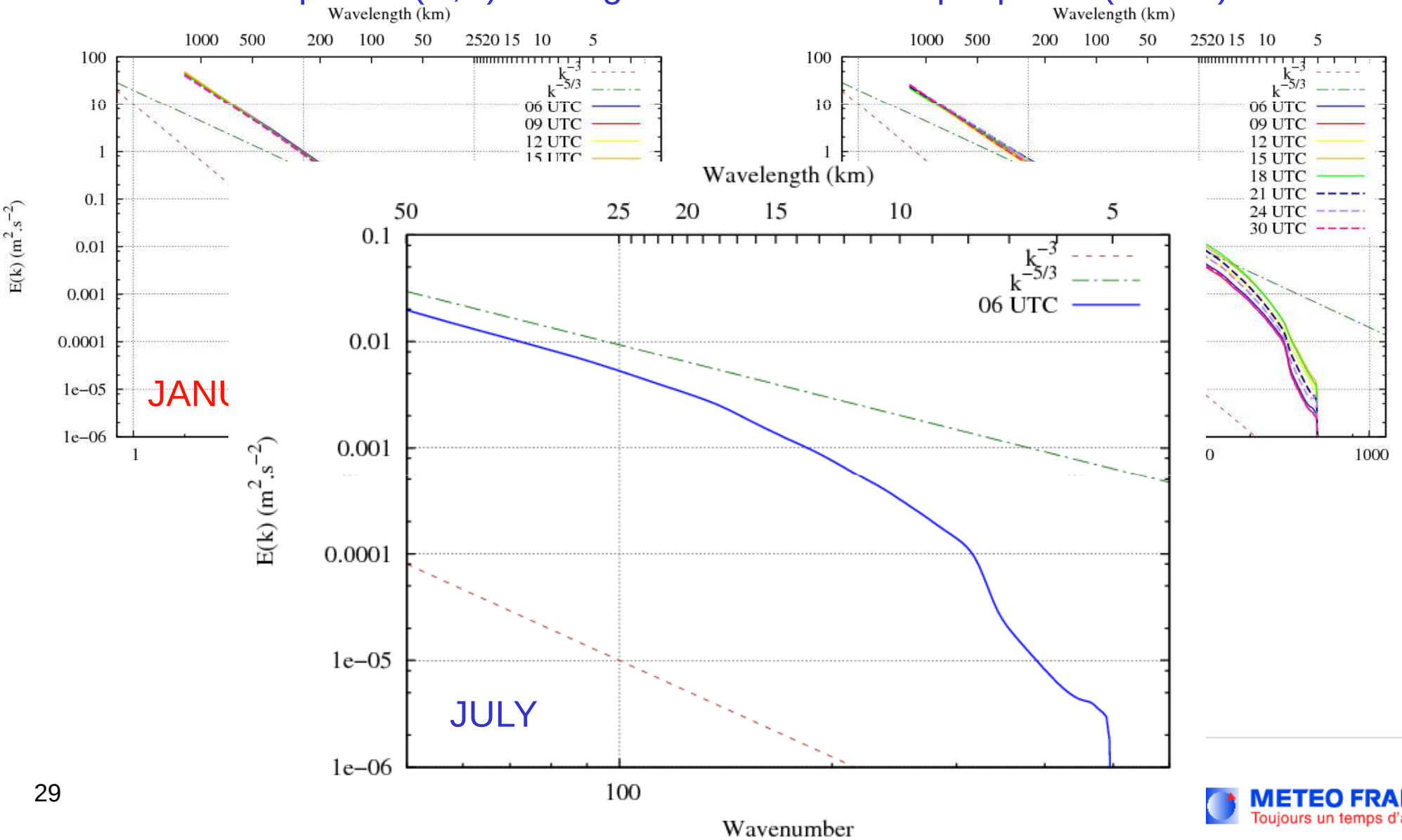

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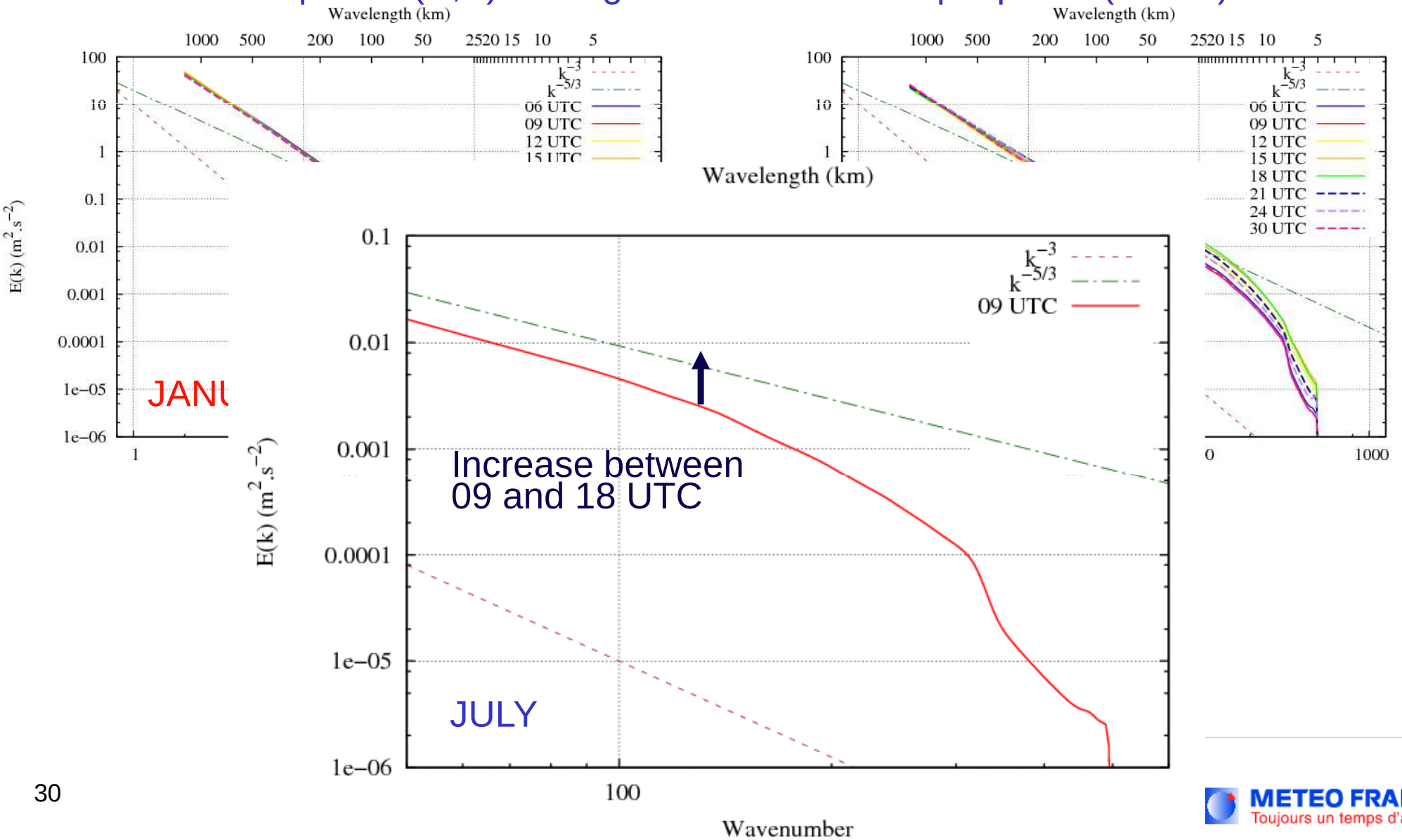

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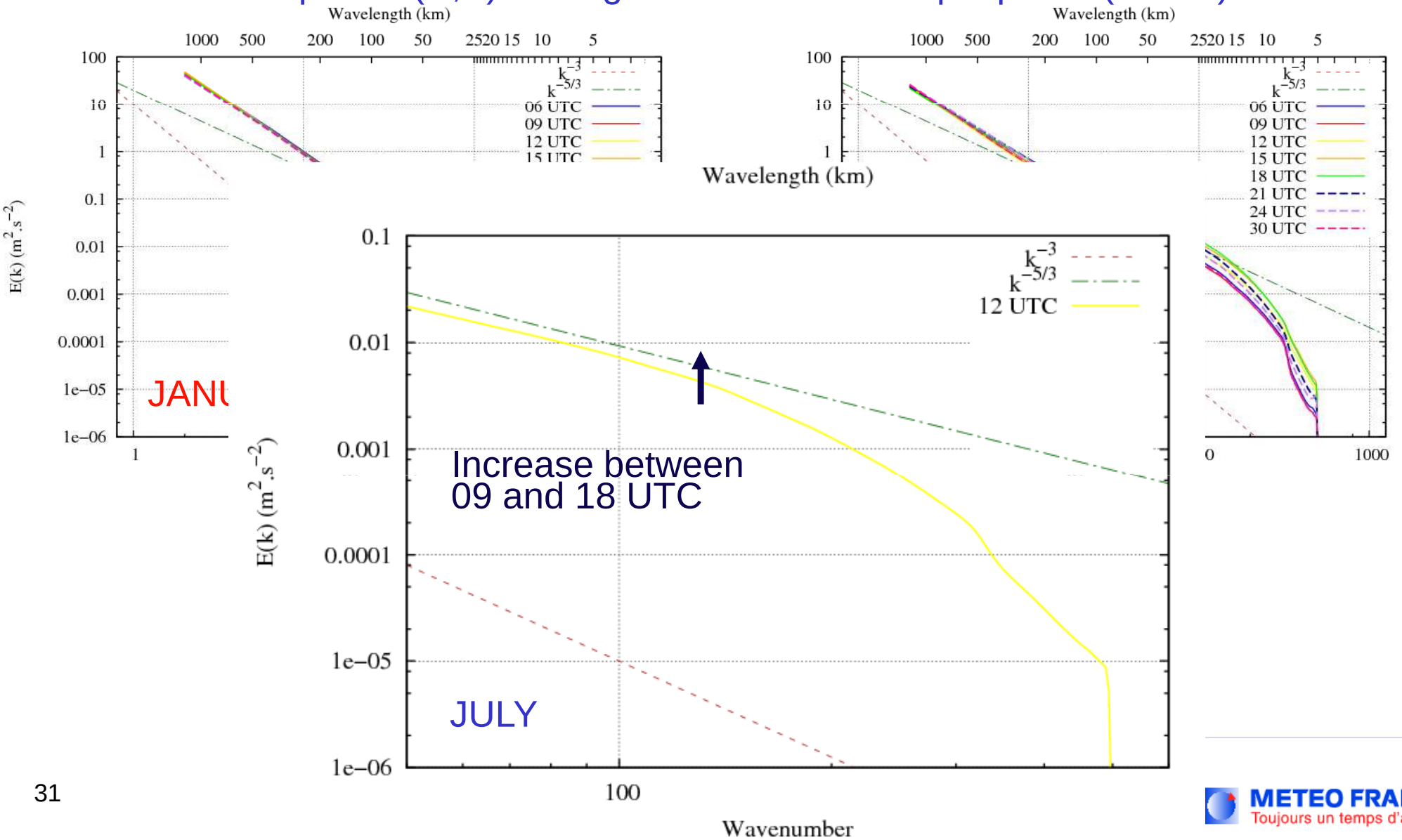

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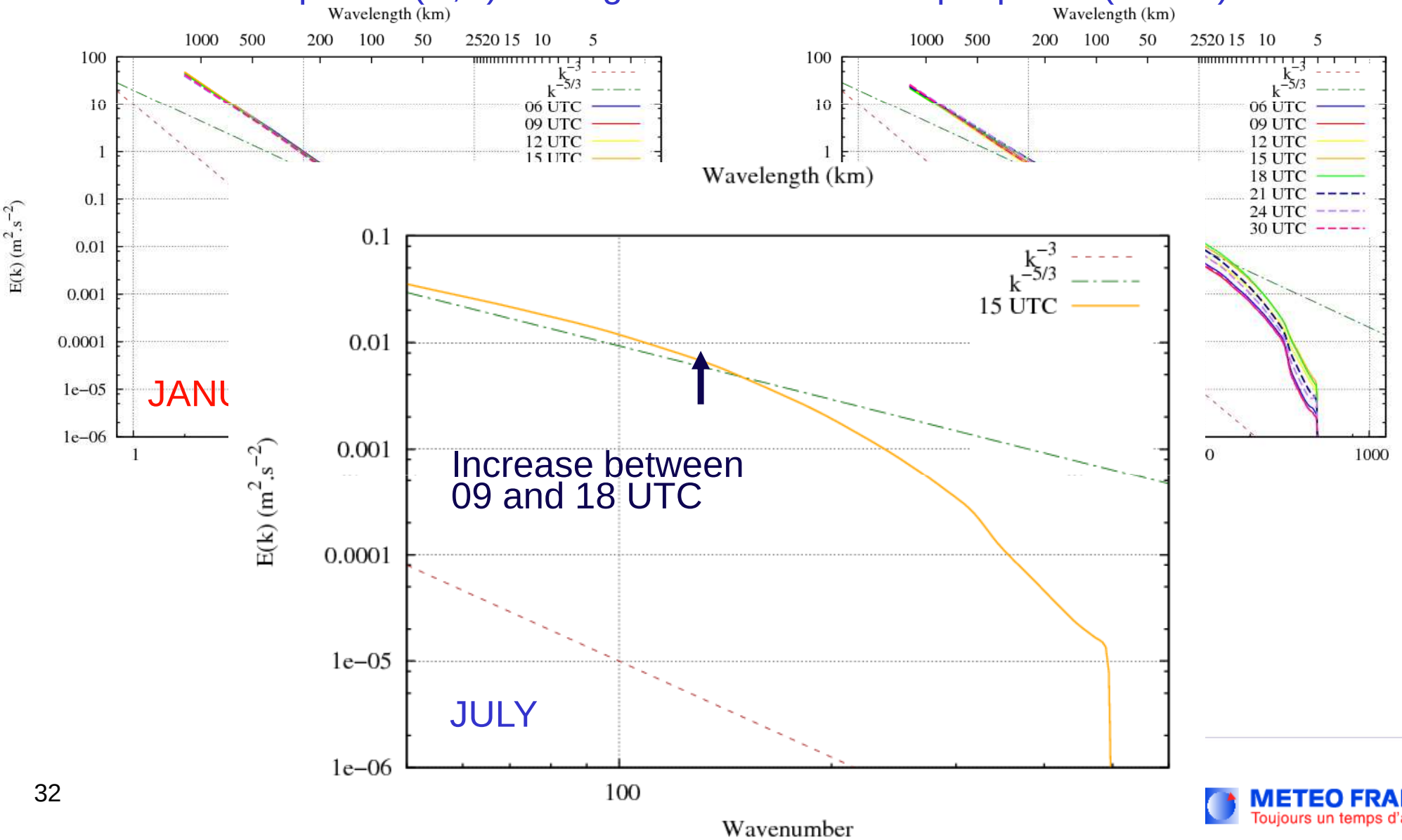

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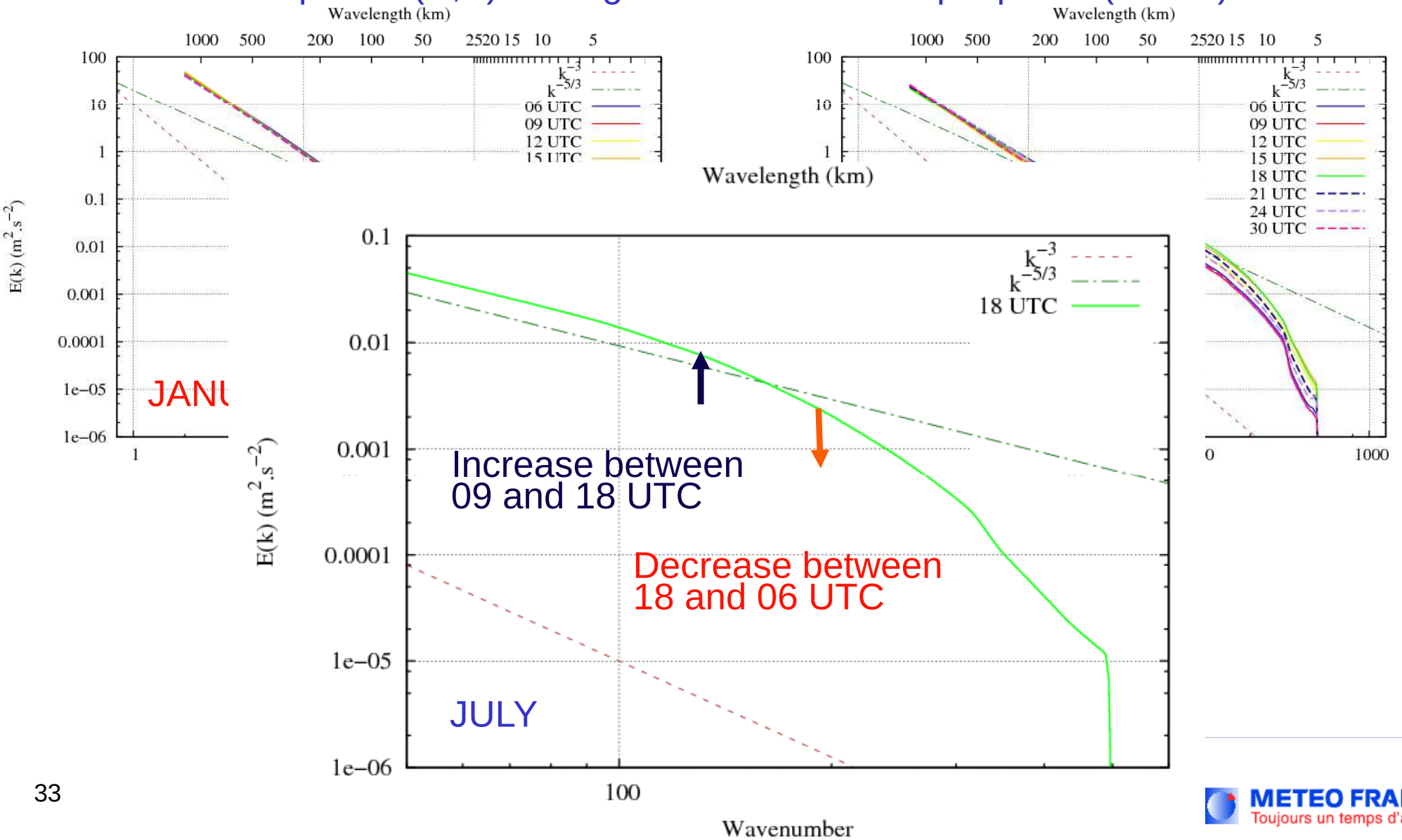

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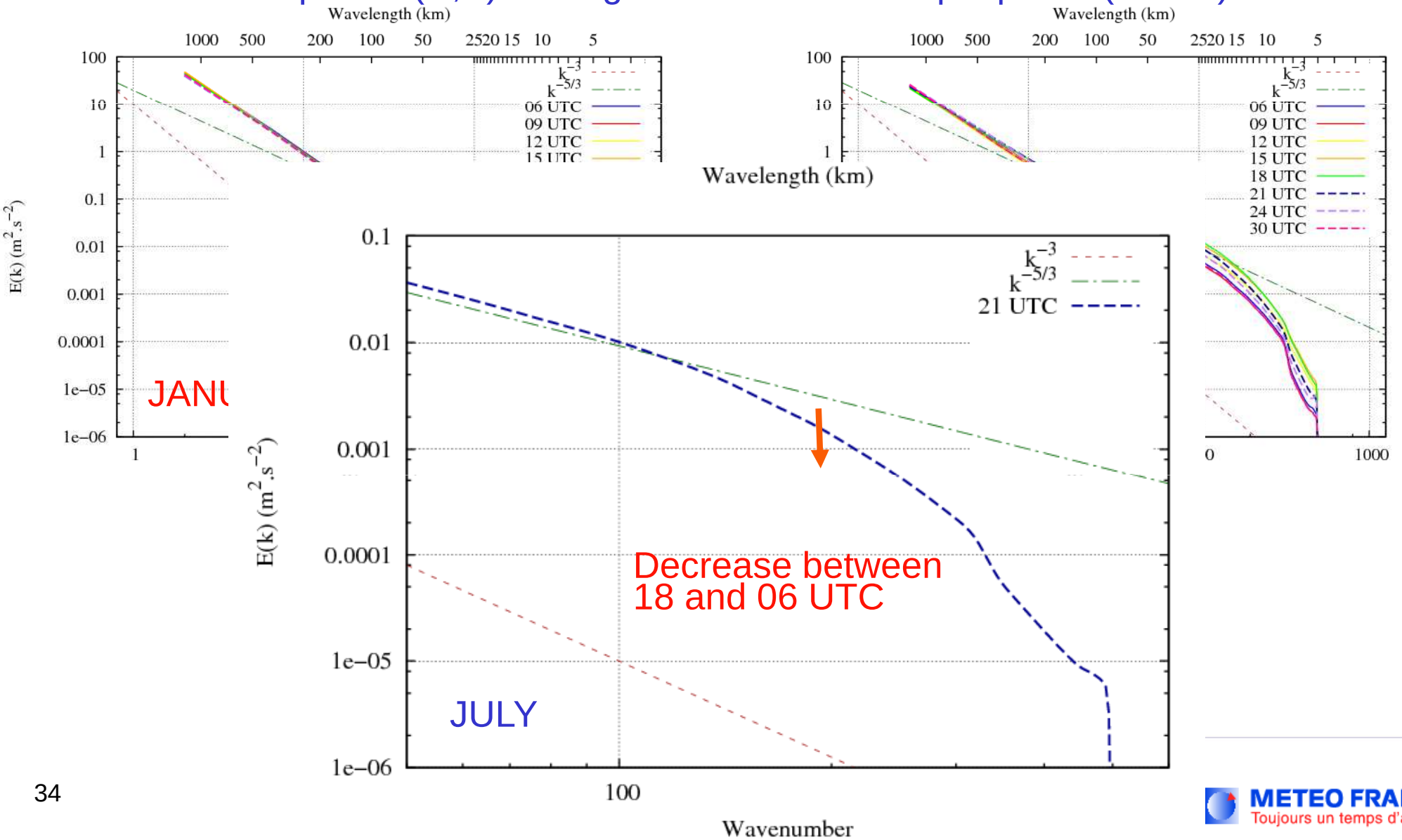
Diurnal evolution

KE spectra (U,V) averaged over the free troposphere (3-9km)



METEO FRANCE
Toujours un temps d'avance

5 – Climatology of KE spectra

Diurnal evolution

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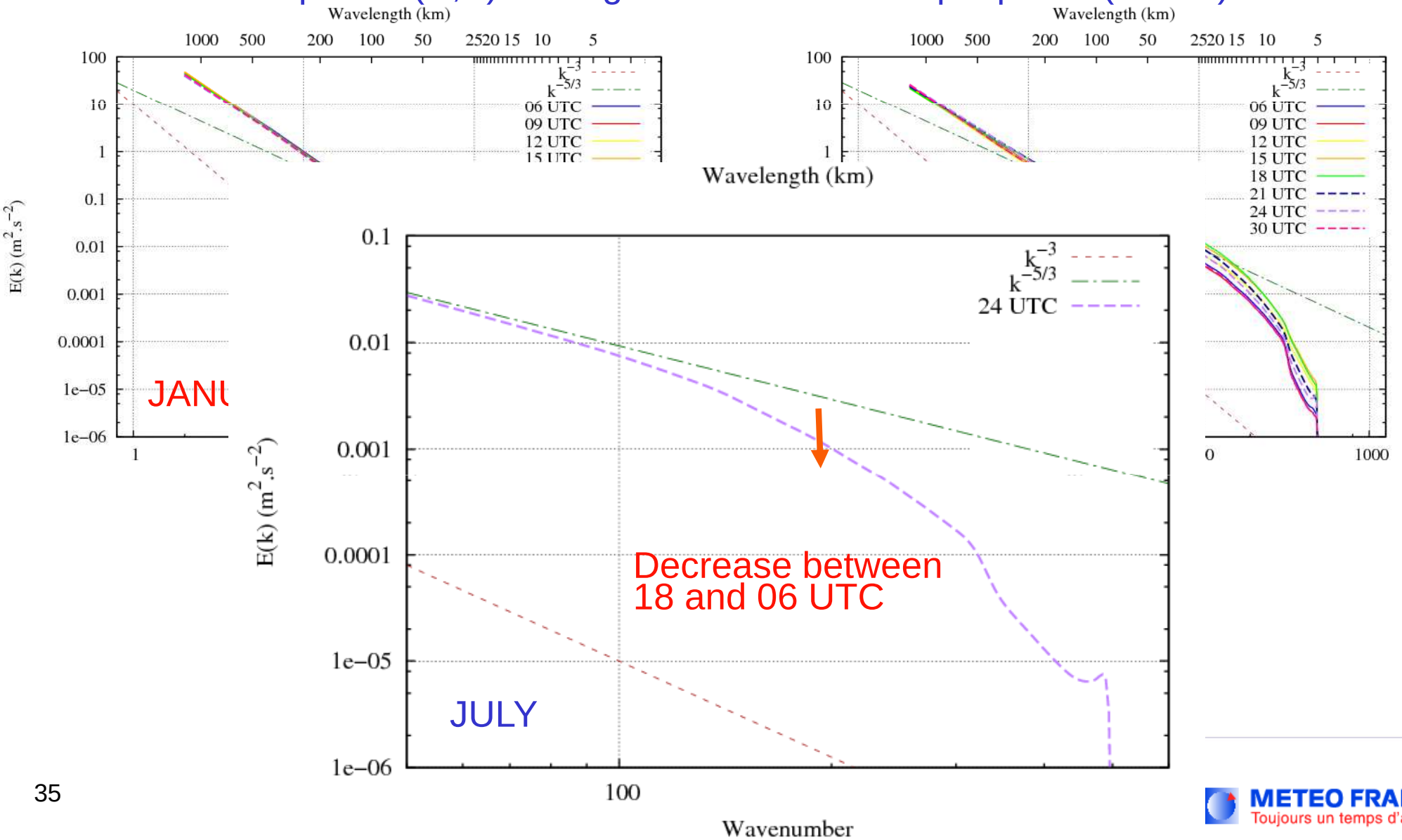

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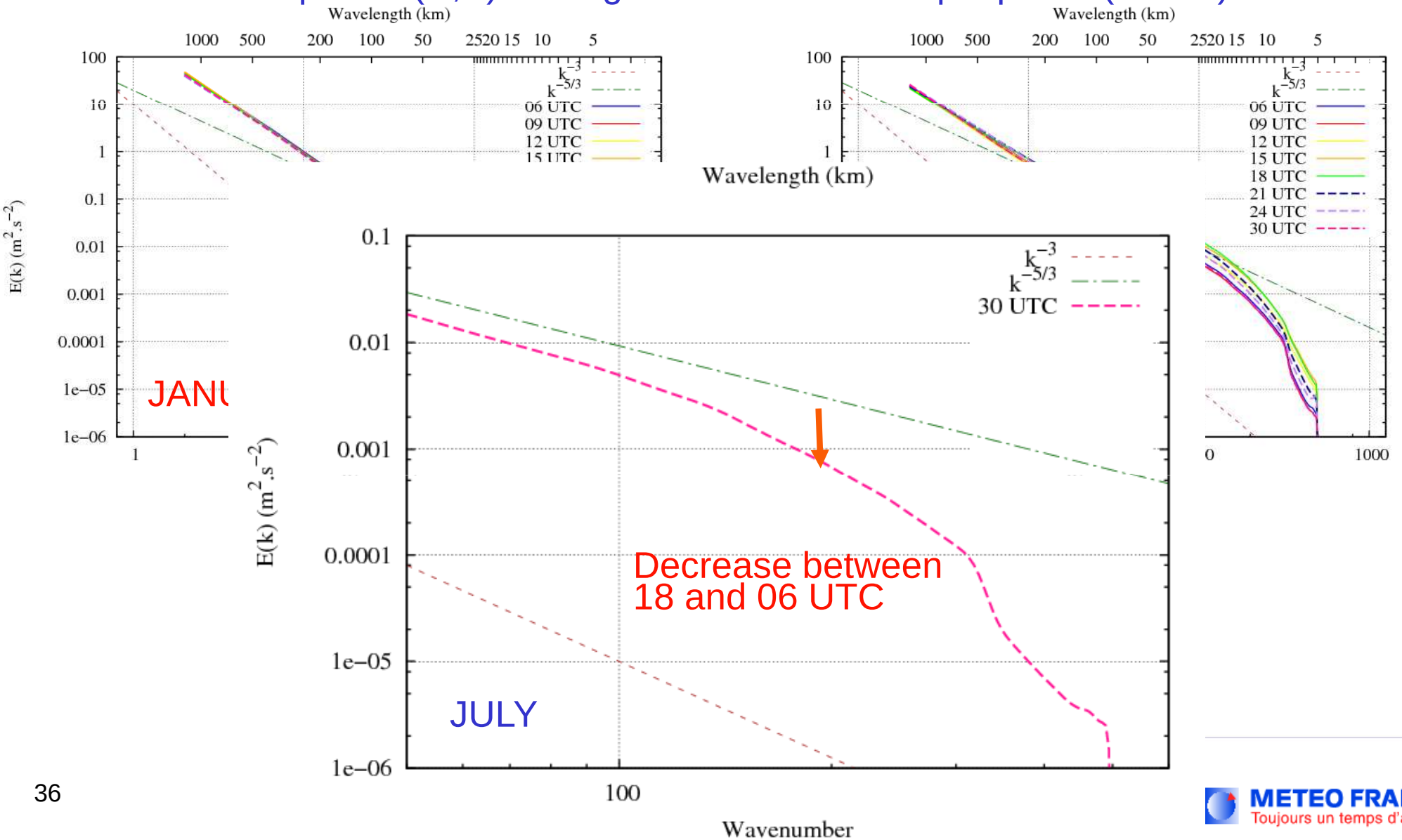

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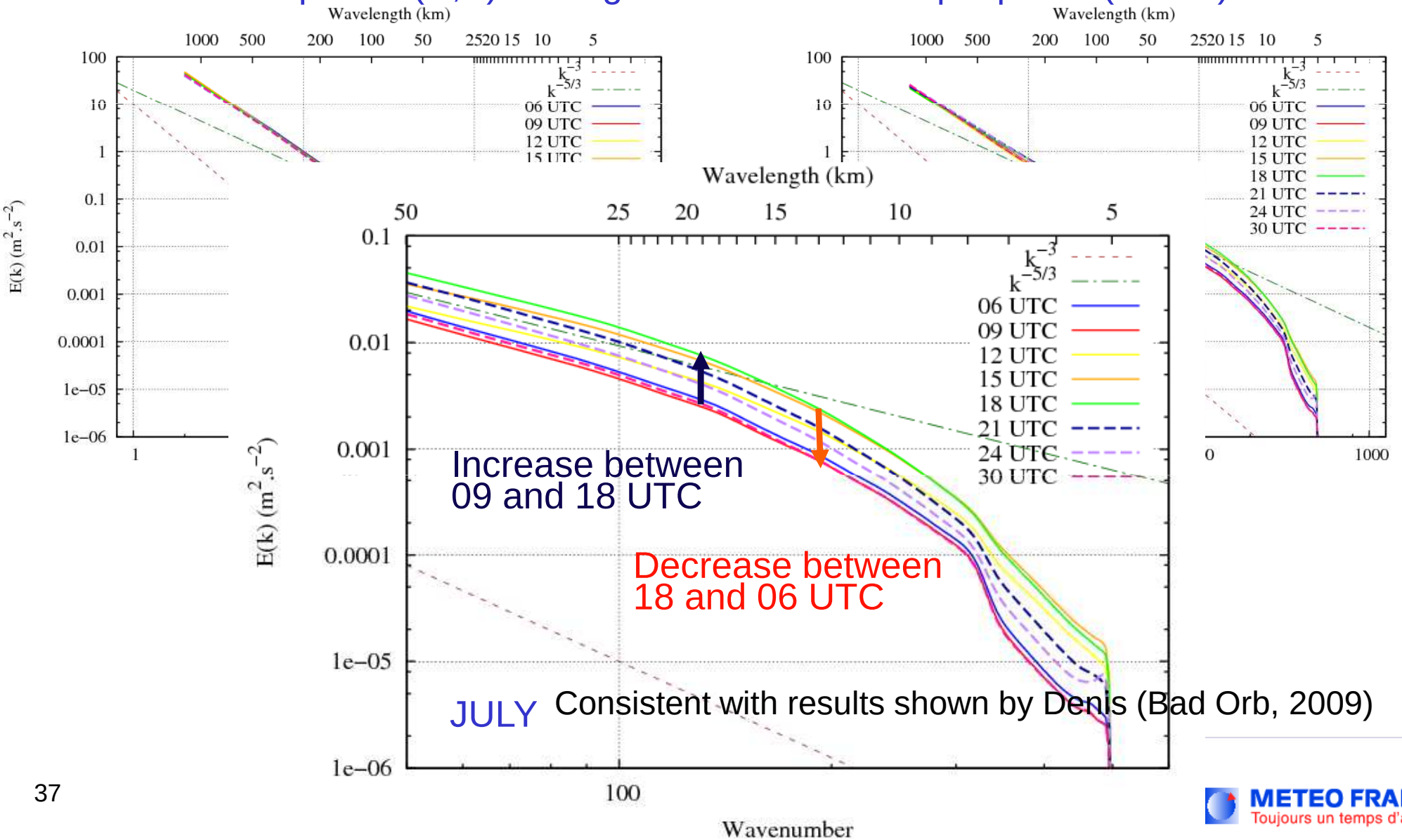

Consistent with results shown by Denis (Bad Orb, 2009)

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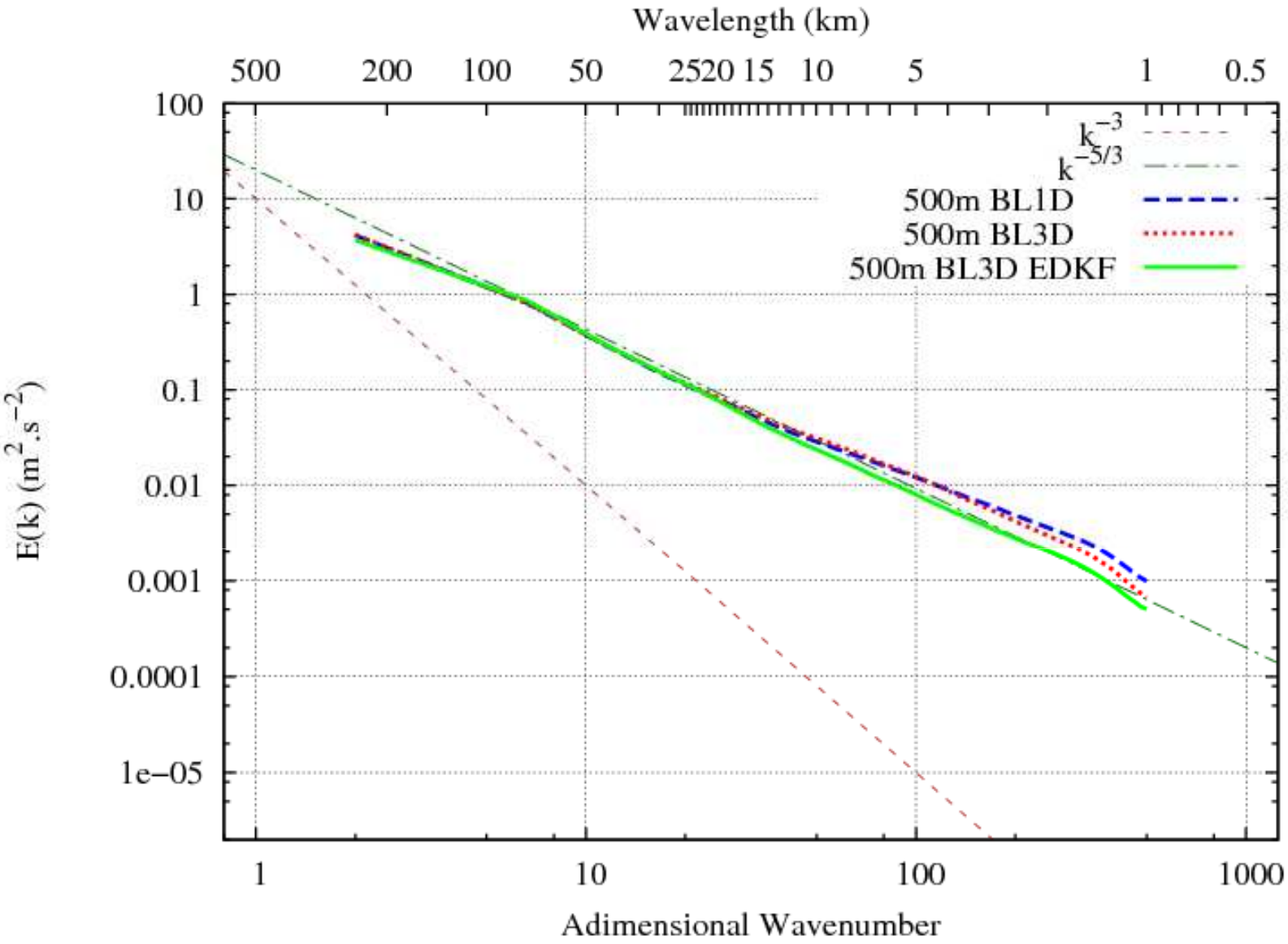
Conclusion

KE Spectra:

- allow to discrimate different dynamics
  - slopes (k^{-3} and $k^{-5/3}$) and effective resolution: 5-6 Δx for MesoNH, 9-10 Δx for AROME (partly due to implicit diffusion)
  - Impact of time step for SL scheme
- allow to characterize the effect of convection to the mesoscale part
- resolution downscaling simulations with MesoNH:
  - Fully explicit resolution of convective motions needs a resolution smaller than 250 m (analogy with Bryan et al. 2003)

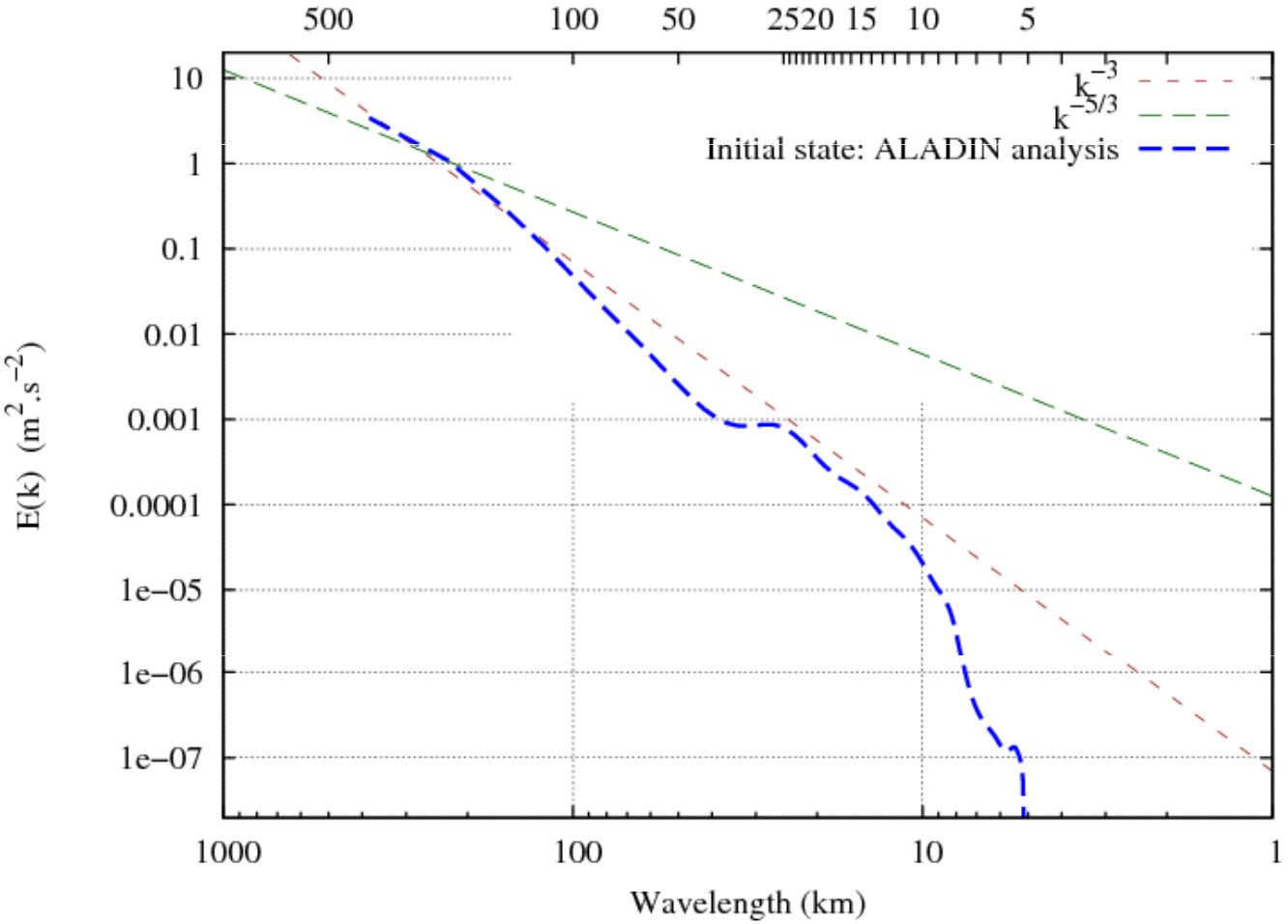
MesoNH: impact of turbulence scheme

KE spectra (U,V) averaged over the boudary layer (<3km) between 13 and 17 UTC



4 – KE spectra

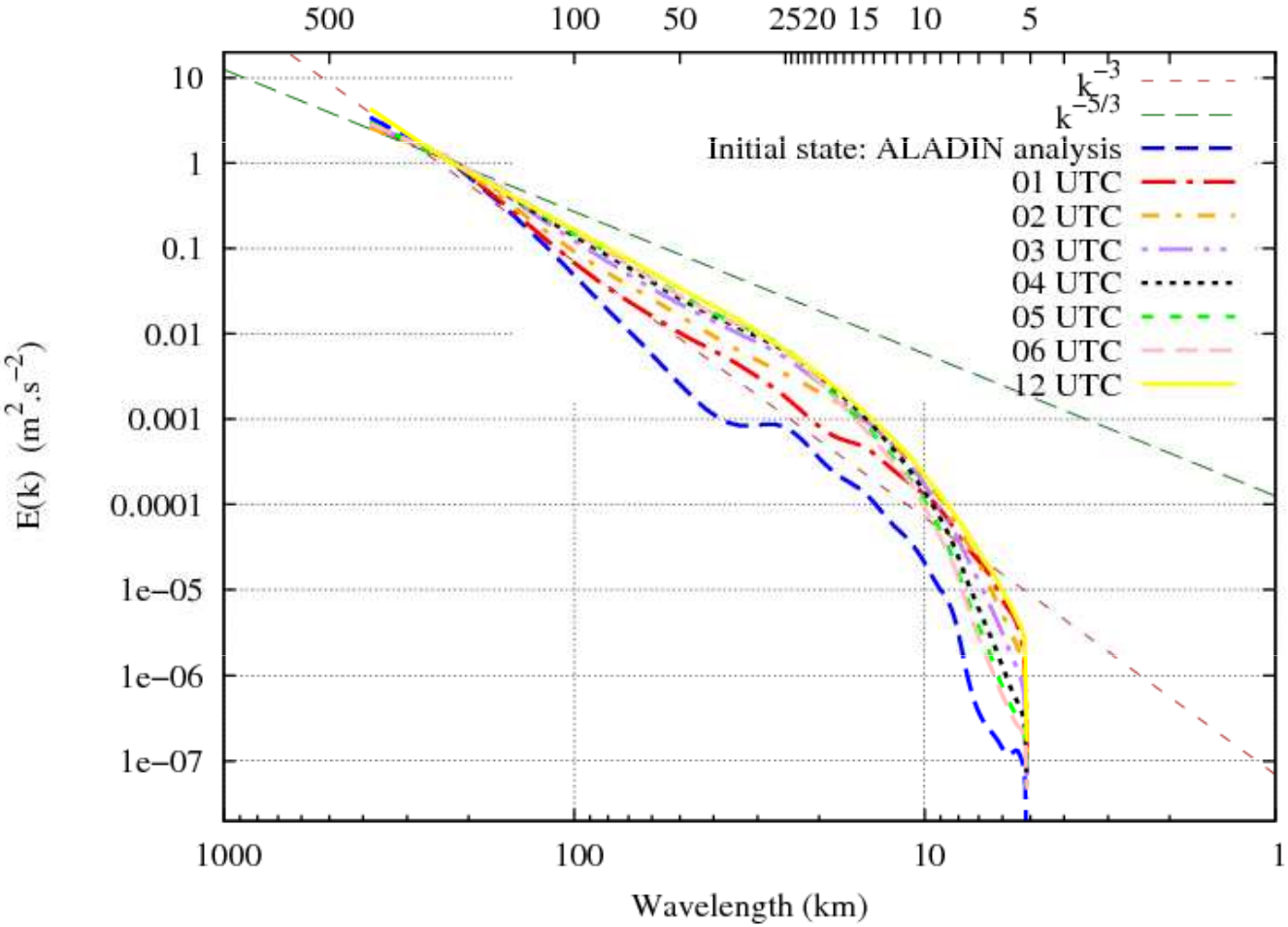
Temporal evolution



Hourly KE spectra (U,V) averaged over the free troposphere (3-9km) for AROME

4 – KE spectra

Temporal evolution



Hourly KE spectra (U,V) averaged over the free troposphere (3-9km) for AROME

Dynamical adaptation from ALADIN analysis
Spin up duration: 3-4 hours
Diurnal evolution

Introduction

1. Models
2. Case study
3. Simulations
4. Kinetic Energy spectra
5. Climatology of KE spectra