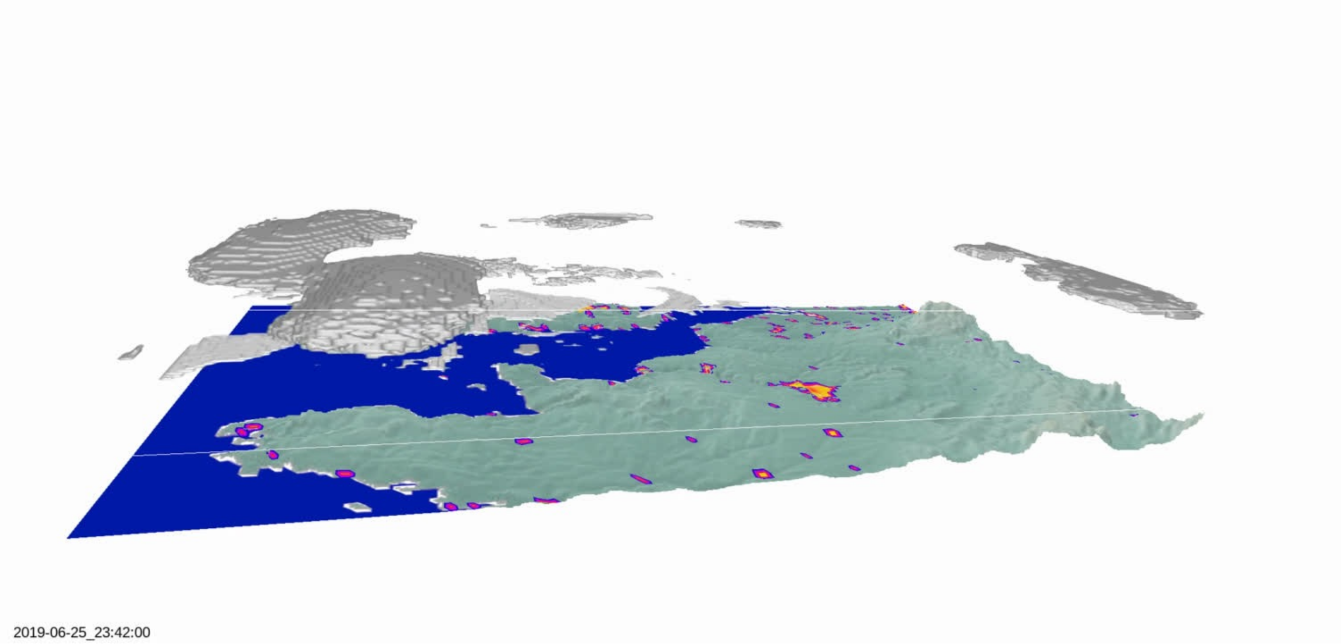

Temperature and wind statistics in the context of heat waves

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Financial support: ANR ‘LasWatex’
ANR ‘Transition’, University of Rouen’
ADEME ‘Hélios’
Normandy Region
Previous work with R.A. Antonia

Agence Nationale de la Recherche
ANR

Concepts and definitions introduced by previous lecturers:

S. Malinowski: ABL, orders of magnitudes, climate models,
-transport equations for velocity, temperature…
-atmosphere is hydrostatic
-huge range of scales
-separation horizontal-vertical directions
-CO2 in the models
-Rayleigh number: Corrsin and Ozmidov scales
-C_epsilon

D. Feranda: Thermal Turbulence, CAT,
EDR – extreme events, models for climate, role of the CO2
intensity of extreme events depending on the large scale of the atmosphere (analogs)

C. Brun: -Transport equations for velocity-potential temperature
-Radiation budget (1-st principle TD); stability ABL
-1-point energy budget equations
-Spectra

1. The question

Effect of the dynamics of

→temperature gradients induced by large-scales: e.g.

jet stream, monsoon (temperature gradients at high altitude/sea level),

internal variability (daily/annual variations) on

→temperature fluctuations variability

Context of blocking

Problem: unravel the mechanisms of genesis, persistence, and dissipation of energy→ focus on extreme events

2. Methodology

First principles + Triple decomposition framework

First principles? Navier Stokes, advection-diffusion of temperature…

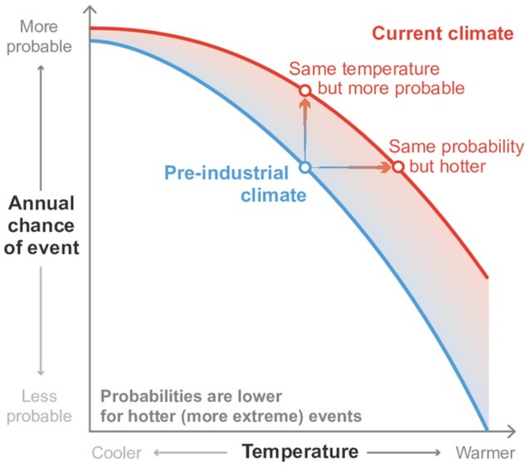
Which form? -constant physical properties of the fluid (constant density, viscosity, D)

-variable density, viscosity

-T/NT interfaces -with phase changes…

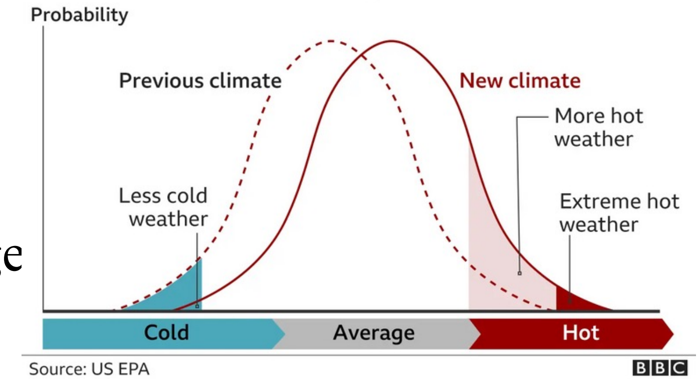
3. Results: 2003 summer, June 2019

Extreme events and climate change, a multiscale process

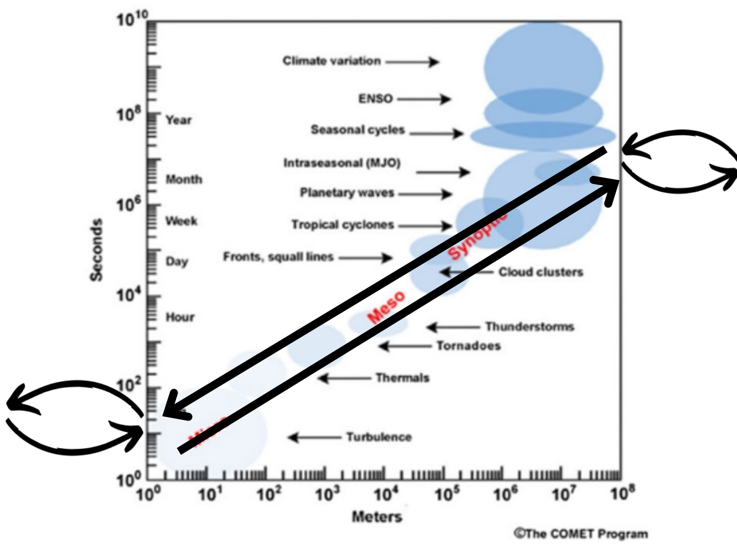


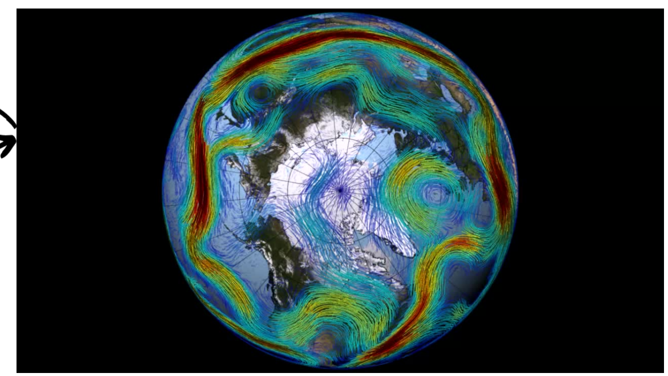
Sixth IPCC assessment report

- Climate change brings more frequent and more intense extreme events.
- Small scales are influenced by large scales but the opposite is also true.

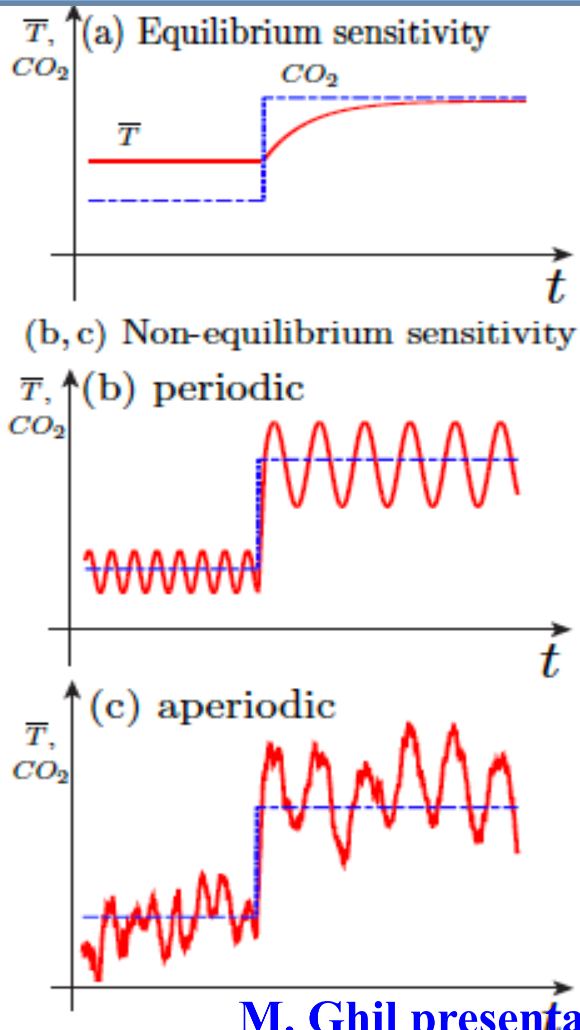


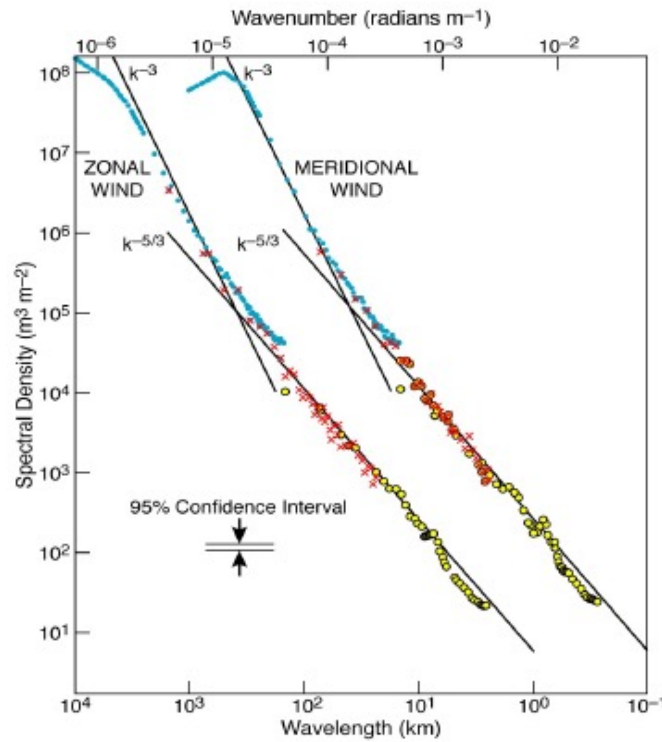
ISTOCK/MARC BRUXELLE





Climate scenarios:

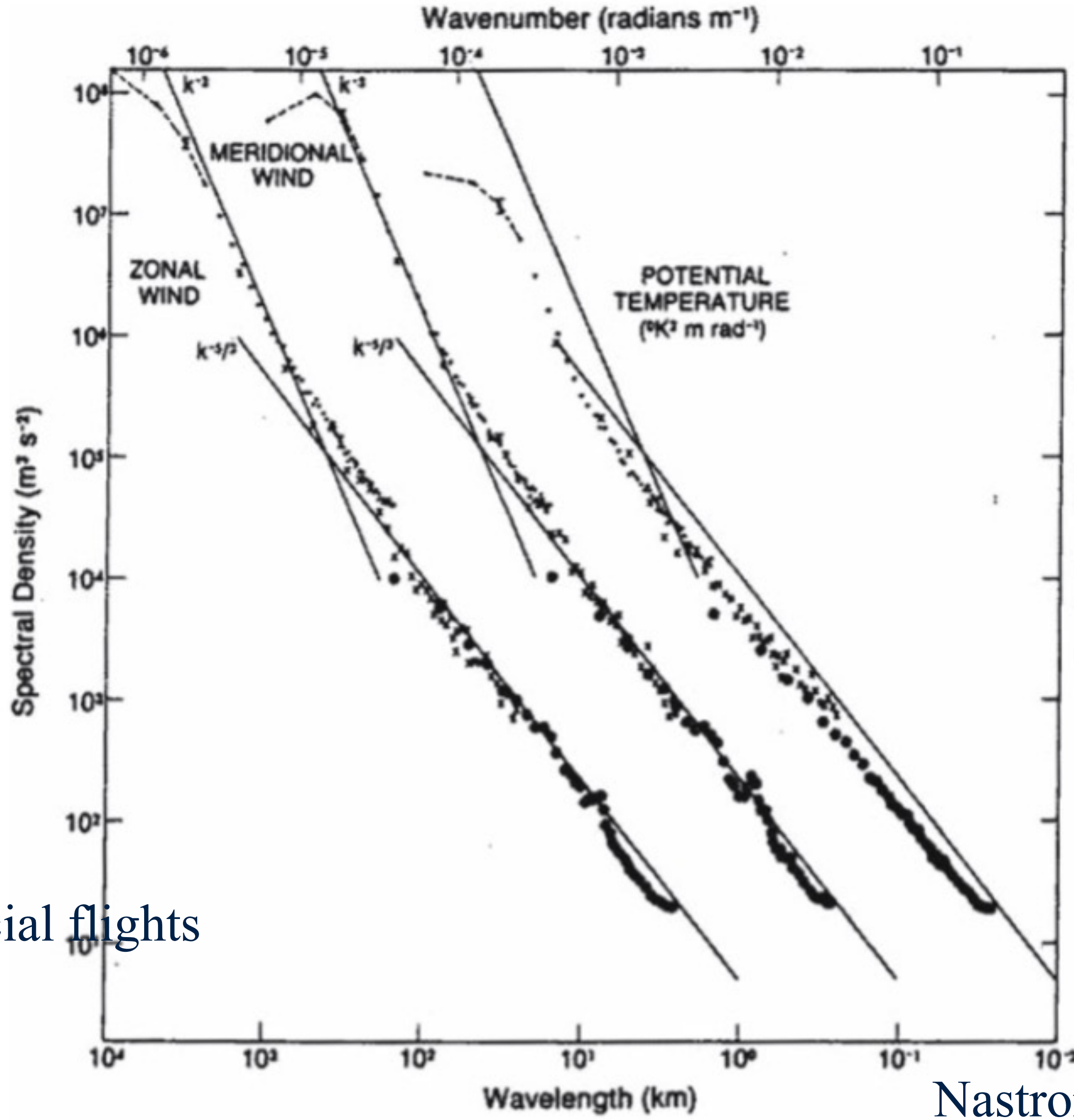




Nastrom and Gage, 1985

M. Ghil presentation, Minisymposium on « Climate change and turbulence »

1. Context. Scales: The MacroTurbulence

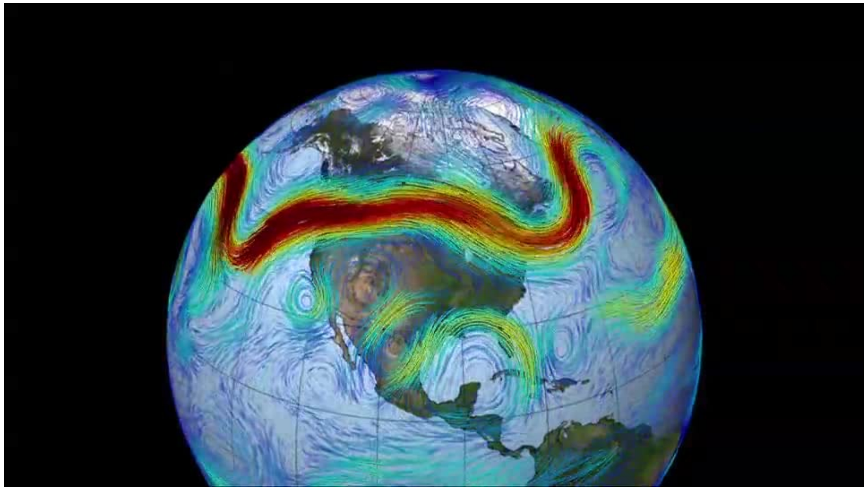


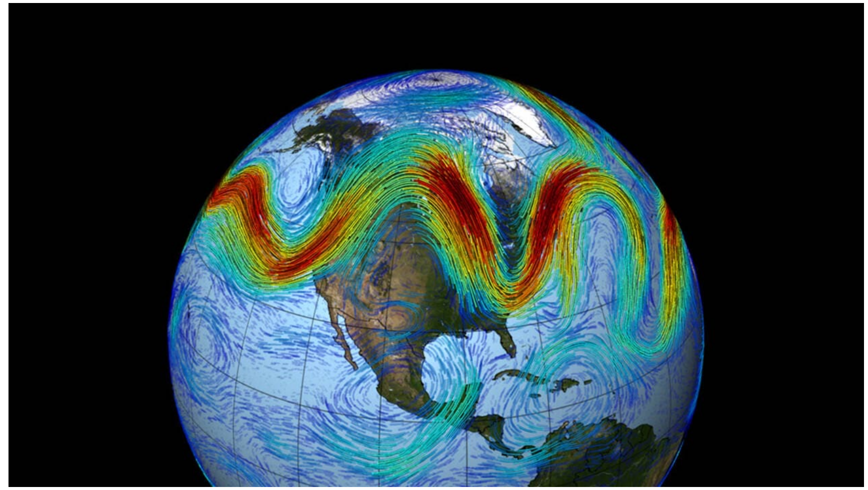
- Obs from commercial flights
- 9-12km altitude

Nastrom and Gage, 1985

All scales are present: different scalings, reflecting different physical mechanisms

1. Context. Blocking



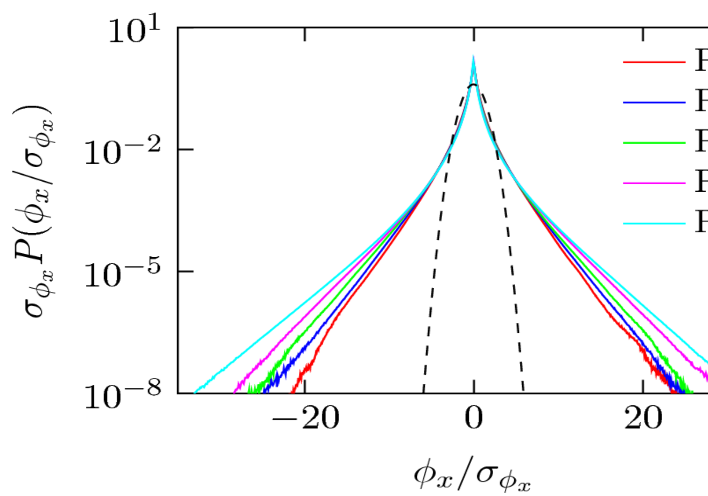


Blocking →Jet stream (periodic motion)→

Local variability of the temperature gradient

Energy source/Production / dissipation/diffusion/transport terms

= transport equations for temperature fluctuation



Tools and strategies

We aim to link statistics between large and small scales using first principles (equations)

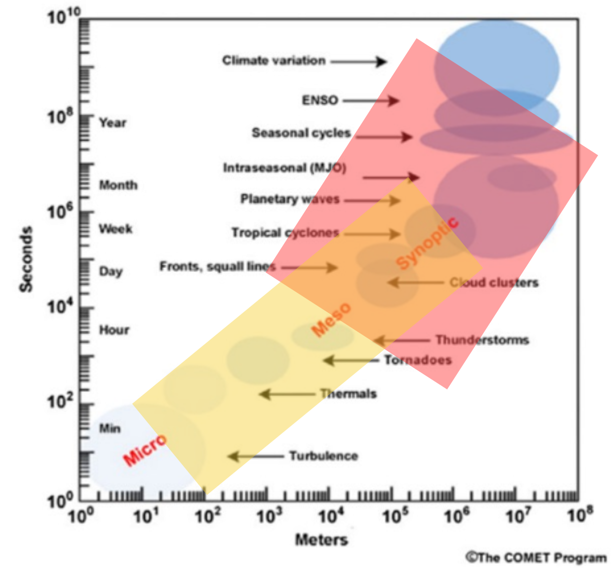
Use data for validation on all scales

Large scales: ERA 5 reanalysis

Small scales: WRF simulation

Colaborators cover with ERA5 (Fossa M. et al.)

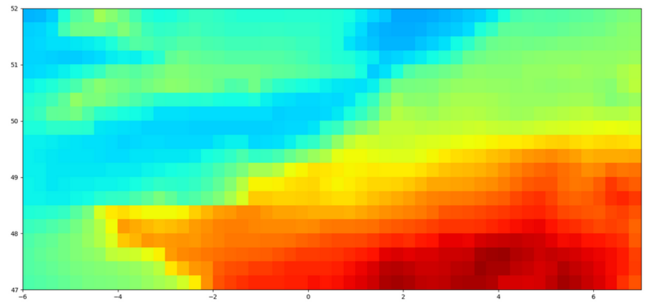
What we cover with WRF



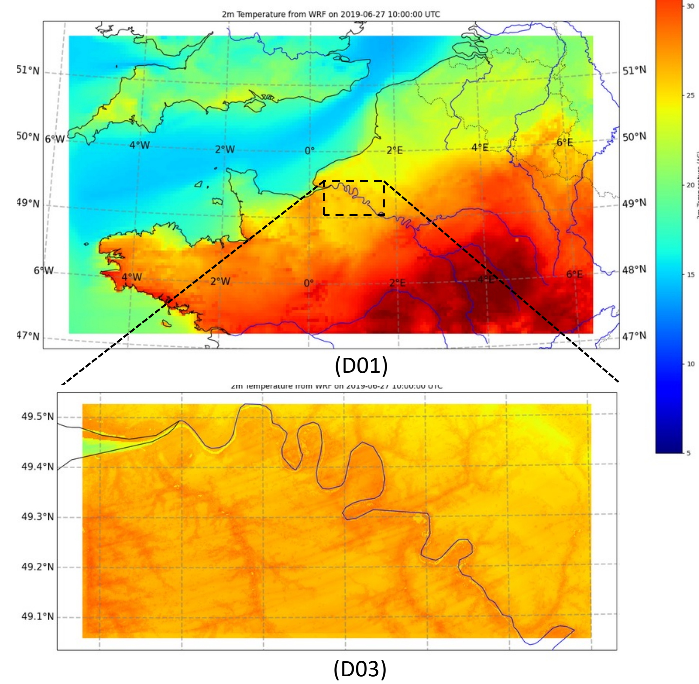
Why are we using WRF ?
Example with temperature extreme events

- To have a better resolution

ERA5

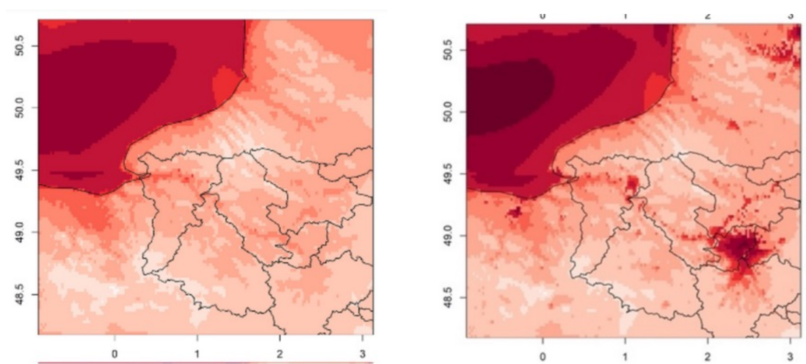


WRF

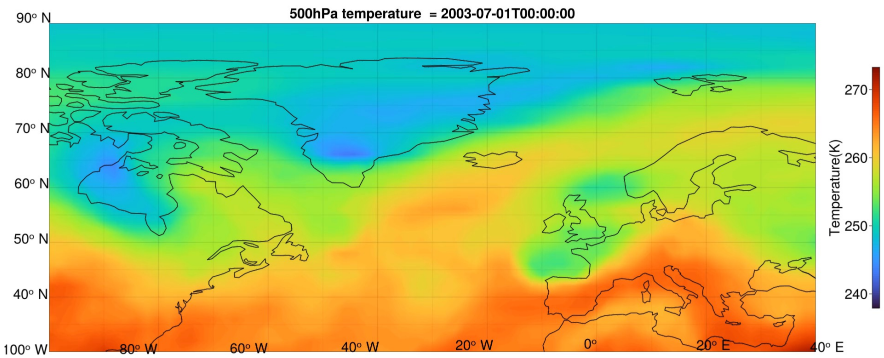


2m temperature resolution comparison
ft. Heatwave on June 27 2019 10:00

- To simulate new scenarios



1. Context. Blocking during the 2003 summer heat wave



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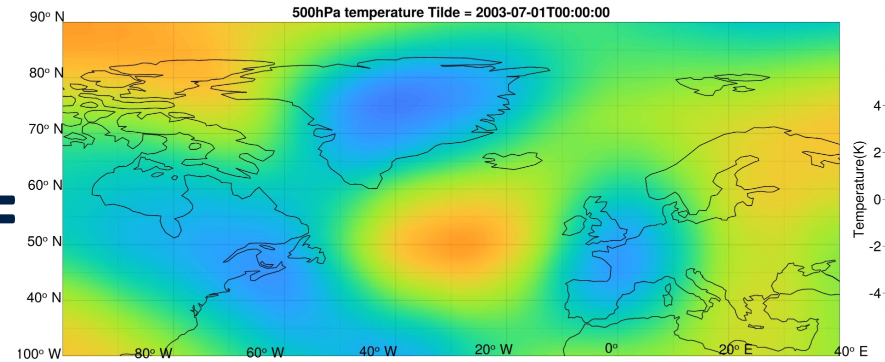

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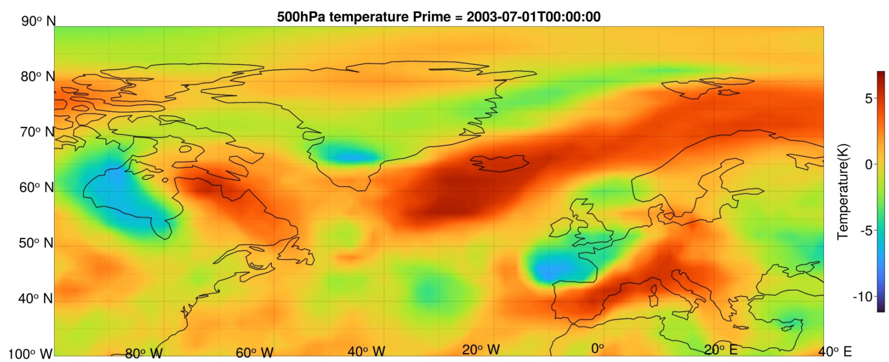
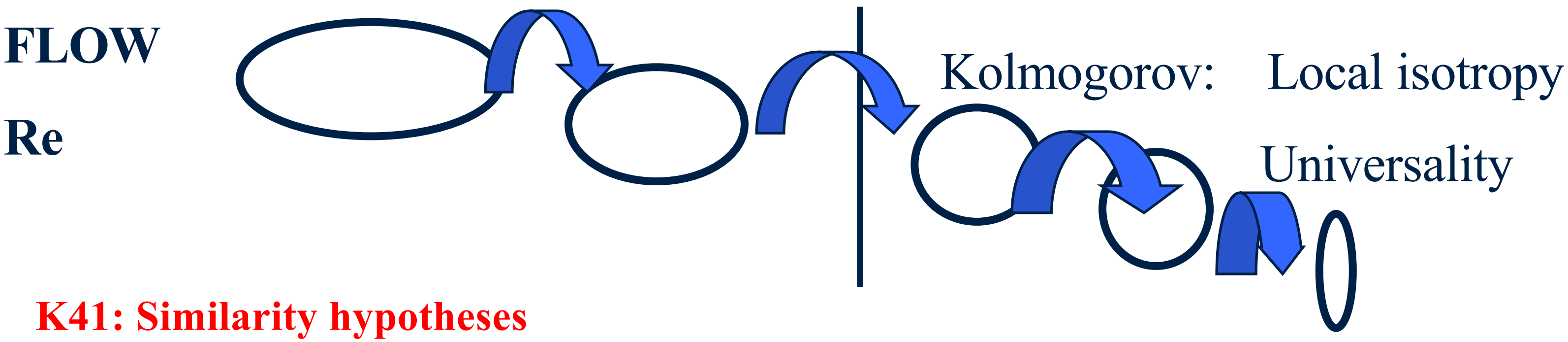


Mean + CM/Waves + Eddies = Turbulence at all spatiotemporal scales

2. Methodology to obtain Scale-by-Scale transport equations

Historical context and motivation



K41: Similarity hypotheses

HIGH Reynolds numbers

1st: $\overline{(\Delta u^*)^n} = f_{un}(r^*)$ $\quad r^* = r/\eta \quad \eta \equiv \left(\frac{\nu^3}{\bar{\epsilon}}\right)^{\frac{1}{4}}$

2nd : for $\eta \ll r \ll L$ (L is the integral length scale),

$$\overline{(\Delta u^*)^n} = C_{un} r^{*n/3}$$

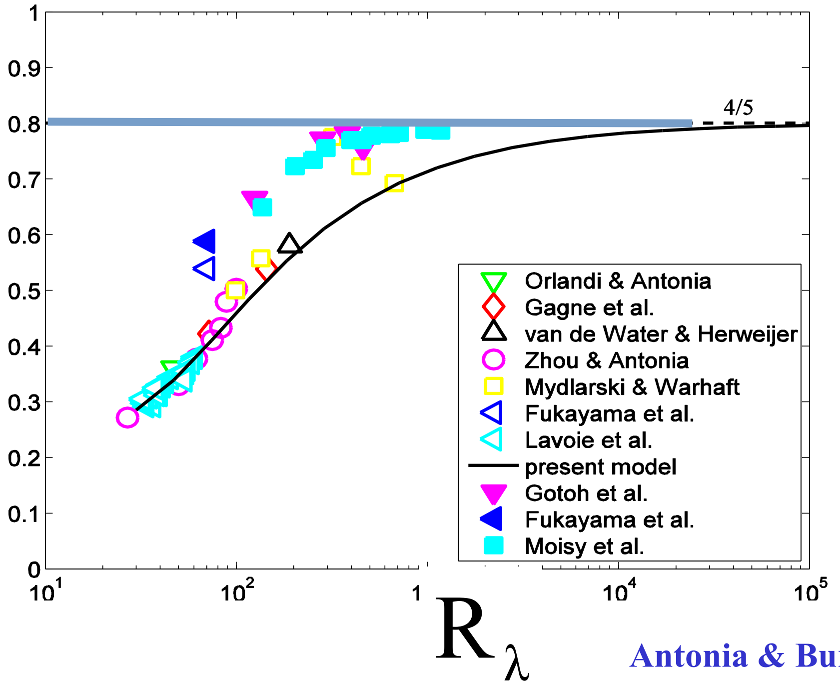
C_{un} = "universal" constants.

2. Methodology to obtain Scale-by-Scale transport equations

Historical context and motivation

Kolmogorov (1941) equation

$$-\frac{\overline{(\Delta u)^3}}{\bar{\epsilon}\, r} + 6\nu \frac{\frac{d}{dr}\overline{(\Delta u)^2}}{\bar{\epsilon}\, r} = \frac{4}{5}$$



Antonia & Burattini, 2006

HIGH Reynolds numbers

$$-\frac{\overline{(\Delta u)^3}}{\bar{\epsilon}\, r} = \frac{4}{5}$$

Error: Mix-up of infinite Reynolds number phenomenology, with mathematics.

Non-universality for moderate Reynolds numbers

1. Methodology to obtain Scale-by-Scale transport equations

II. Finite Reynolds number effect

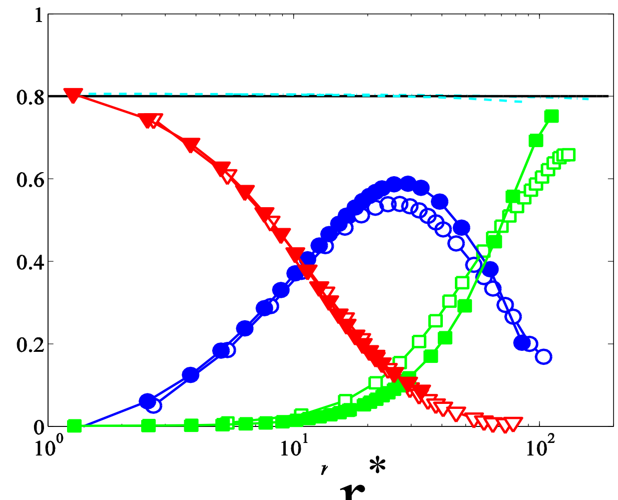
$$\frac{4}{5} = 6\nu \frac{\frac{d}{dr}\overline{(\Delta u)^2}}{\bar{\epsilon}\, r} - \frac{\overline{(\Delta u)^3}}{\bar{\epsilon}\, r} + I_f$$

Kolmogorov, 1941→ Saffman 1968, Danaila et al. 1999, Lindborg 1999

Finite Reynolds numbers- flows:

Grid turbulence, round jet,

channel flow (axis, near wall) …



Conclusion:

Energy transferred at a scale r= turbulent diffusion + molecular effects+

large-scale effects: shear, decay, mean temperature gradient …

Danaila et al., 1999

2. Methodology to obtain Scale-by-Scale transport equations

Finite Reynolds number effect

Similar questions hold for scalars and turbulent kinetic energy

$$\frac{4}{5} = 6\nu \frac{\frac{d}{dr}\overline{(\Delta u)^2)}}{\bar{\epsilon}\, r} - \frac{\overline{(\Delta u)^3)}}{\bar{\epsilon}\, r} + I_f$$

Kolmogorov, 1941

$$\frac{4}{3} = 2k \frac{\frac{d}{dr}\overline{(\Delta\theta)^2)}}{\bar{\chi}\, r} - \frac{\overline{\Delta u(\Delta\theta)^2)}}{\bar{\chi}\, r} + I_f$$

Yaglom, 1949
Danaila et al. 1999

$$\frac{4}{3} = 2\nu \frac{\frac{d}{dr}\overline{(\Delta q)^2)}}{\bar{\varepsilon}\, r} - \frac{\overline{\Delta u(\Delta q)^2)}}{\bar{\varepsilon}\, r} + I_f$$

R.A. Antonia et al. 1997
Danaila et al., 2004
Burattini et al., 2005

Real- Finite Reynolds numbers- flows: Slightly heated grid turbulence, grid turbulence with a Mean scalar gradient ..

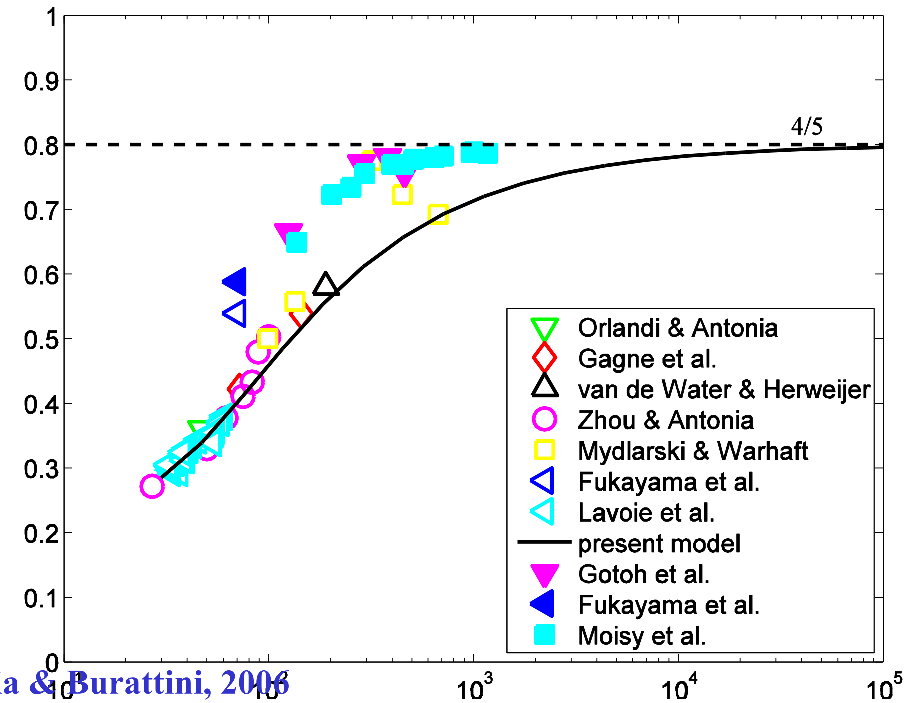
Same conclusion : Energy transferred at a scale r→ … large-scale effects

2. Methodology to obtain Scale-by-Scale transport equations

Finite Reynolds number effect

$$\frac{4}{5} = 6\nu \frac{\frac{d}{dr}\overline{(\Delta u)^2)}}{\bar{\epsilon}\, r} - \frac{\overline{(\Delta u)^3)}}{\bar{\epsilon}\, r} + I_f$$

Kolmogorov, 1941→ Saffman 1968, Danaila et al. 1999, Lindborg 1999



Antonia & Burattini, 2006

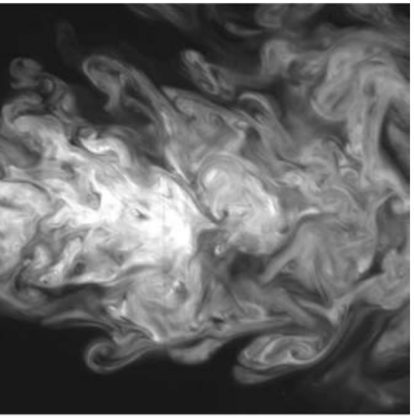
First conclusion:

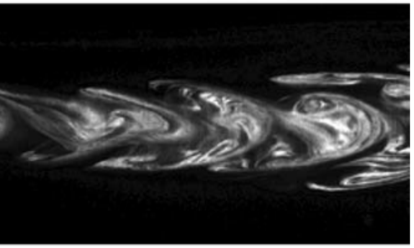
Part of the K41 theory was rederived so it can be correctly applied to real, finite Reynolds numbers flows.

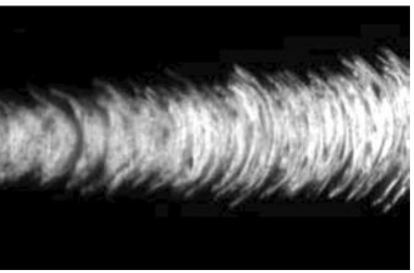
UNCLOSED Equation!!!

Other, complex flows →

2. Methodology to obtain Scale-by-Scale transport equations: VVF







Classical Terms

$$\frac{D}{Dt}\overline{(\Delta u_i)^2} + \frac{\partial}{\partial X_j}\overline{\frac{u_j^+ + u_j^-}{2}(\Delta u_i)^2} + \frac{\partial}{\partial r_j}\overline{\Delta u_j(\Delta u_i)^2} + 2\overline{\Delta u_i \Delta u_j}\frac{\partial \overline{U_i}}{\partial x_j}$$

$$=$$

$$-2\partial_{X_j}\overline{\Delta P\,\Delta u_i} + 2\overline{\Delta u_i \Delta \nu}\frac{\partial^2 \overline{U_i}}{\partial x_j^2} + \frac{\partial^2}{\partial r_j^2}\overline{(\nu^+ + \nu^-)(\Delta u_i)^2} + \frac{1}{2}\overline{\frac{\nu^+ + \nu^-}{2}\frac{\partial^2 (\Delta u_i)^2}{\partial X_j^2}} - \overline{\frac{\partial^2(\nu^+ + \nu^-)}{\partial r_j^2}(\Delta u_i)^2}$$

$$- \overline{\frac{\partial(\nu^+ + \nu^-)}{\partial r_j}\frac{\partial (\Delta u_i)^2}{\partial r_j}} + \overline{\Delta\nu \frac{\partial}{\partial r_j}\frac{\partial}{\partial X_j}(\Delta u_i)^2} - 2\overline{\epsilon_{VV}^+} - 2\overline{\epsilon_{VV}^-}$$

New terms

$$+\overline{\frac{\partial}{\partial X_j}\frac{(\nu^+ + \nu^-)}{2}[\frac{\partial}{\partial X_j}\frac{(\Delta u_i)^2}{2} + \frac{\partial}{\partial X_i}(\Delta u_i \Delta u_j)]} + \overline{\frac{\partial}{\partial X_j}(\Delta\nu)\,[\frac{\partial}{\partial r_j}\frac{(\Delta u_i)^2}{2} + \frac{\partial}{\partial r_i}(\Delta u_i \Delta u_j)]}$$

$$+\overline{\frac{\partial}{\partial r_j}(\Delta\nu)\,[\frac{\partial}{\partial X_j}\frac{(\Delta u_i)^2}{2} + \frac{\partial}{\partial X_i}(\Delta u_i \Delta u_j)]} + 2\overline{\frac{\partial}{\partial r_j}(\nu^+ + \nu^-)[\frac{\partial}{\partial r_j}\frac{(\Delta u_i)^2}{2} + \frac{\partial}{\partial r_i}(\Delta u_i \Delta u_j)]}$$

$$+2\overline{\frac{\partial \Delta\nu}{\partial X_j}}\Delta u_i[\frac{\partial \overline{U_i}}{\partial X_j} + \frac{\partial \overline{U_j}}{\partial X_i}]$$

- Specific variable viscosity flows terms reflecting viscosity gradients, as well as turbulence production and spatial decay.
- The closure of the triple term and the viscosity-velocity terms modeling would allow us (after an analytical resolution and/or a numerical integration) estimating the characteristic time of the **mixing** and thus, to **predict** its quality at each downstream position.

Voivenel et al., Physica Scripta 2015
Krawczynski et al., J. of Turbulence, 2015
Danaila et al., Physica D 2011
Thiesset et al., Phys. Rev. E, 2013

2. Methodology to obtain Scale-by-Scale transport equations

Local homogeneity.
Flow stationarity.
Lateral diffusion and shear effects along the radial direction y.

$$\frac{D}{Dt}\overline{(\Delta u_i)^2} + \frac{\partial}{\partial X_j}\overline{\frac{u_j^+ + u_j^-}{2}(\Delta u_i)^2} + \frac{\partial}{\partial r_j}\overline{\Delta u_j(\Delta u_i)^2} + 2\overline{\Delta u_i \Delta u_j}\frac{\partial \overline{U_i}}{\partial x_j}$$
$$=$$
$$+\frac{\partial^2}{\partial r_j^2}\overline{(\nu^+ + \nu^-)(\Delta u_i)^2} + + \overline{\frac{\partial}{\partial X_j}\frac{(\nu^+ + \nu^-)}{2}\left[\frac{\partial}{\partial X_j}\frac{(\Delta u_i)^2}{2} + \frac{\partial}{\partial X_i}(\Delta u_i \Delta u_j)\right]} - 2\overline{\epsilon_{VV}^+} - 2\overline{\epsilon_{VV}^-}$$

Or, when U and $\overline{\nu}$ depend on x only:

$$\underbrace{\bar{U}\frac{\partial}{\partial x}\overline{(\Delta u_i)^2}}_{\text{Transport}} + \underbrace{\frac{\partial}{\partial y}\overline{\frac{\nu^+ + \nu^-}{2}(\Delta u_i)^2} + \frac{\partial}{\partial r_j}\overline{\Delta u_j(\Delta u_i)^2}}_{\text{Turbulent Diffusion}} + \underbrace{2\frac{\partial \bar{U}}{\partial x}[\overline{(\Delta u)^2} - (\Delta v)^2] + 2\overline{\Delta u \Delta v}\frac{\partial \bar{U}}{\partial y}}_{\text{Production}}$$
$$=$$
$$\underbrace{\overline{\frac{\partial}{\partial x}(\nu^+ + \nu^-)\frac{\partial}{\partial x}(\Delta u_i)^2} + \frac{\partial^2}{\partial r_j^2}\overline{(\nu^+ + \nu^-)(\Delta u_i)^2}}_{\text{Destruction by viscosity gradients}} \underbrace{- 2\overline{\epsilon_{VV}^+} - 2\overline{\epsilon_{VV}^-}}_{\text{Dissipation}}$$

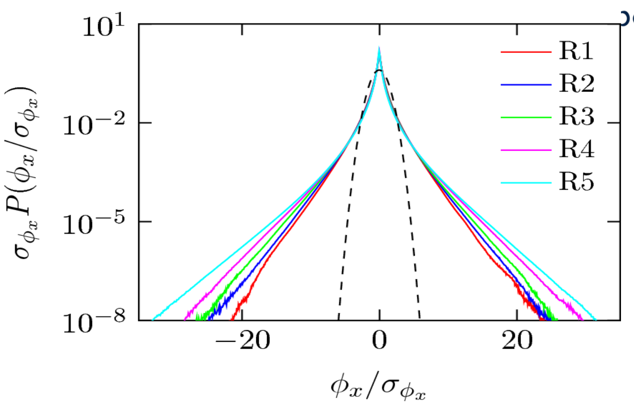
High-order moments →

2. Methodology. Theoretical framework

$$\frac{\partial}{\partial t}\langle(\Delta\phi)^{2n}\rangle(\mathbf{r}) + \underbrace{\frac{\partial}{\partial r_i}\langle(\Delta u_i)(\Delta\phi)^{2n}\rangle(\mathbf{r})}_{\text{transport term}} + \underbrace{2n\Gamma\langle(\Delta u_2)(\Delta\phi)^{2n-1}\rangle}_{\text{production term}}(\mathbf{r}) = J_{2n}(\mathbf{r})$$

$$J_{2n}(r) = nD\langle(\Delta\phi)^{n-1}\left[\frac{\partial^2(\Delta\phi)}{\partial x_i'^2} + \frac{\partial^2(\Delta\phi)}{\partial x_i^2}\right]\rangle$$

$$J_{2n}(r) = \underbrace{2D\frac{\partial^2}{\partial r_i^2}\langle(\Delta\phi)^{2n}\rangle}_{\text{...port}} - \underbrace{n(2n-1)\langle(\Delta\phi)^{2n-2}\left[\chi(\mathbf{x}+\mathbf{r}) + \chi(\mathbf{x})\right]\rangle}_{\text{dissipative source term}},$$



2nd order

$2\langle\chi\rangle$

$\neq f(r)$

4th order

$12\langle(\Delta\phi)^2\chi\rangle$

$= f(r)$

Role of Large-scale, quasi-periodic component?

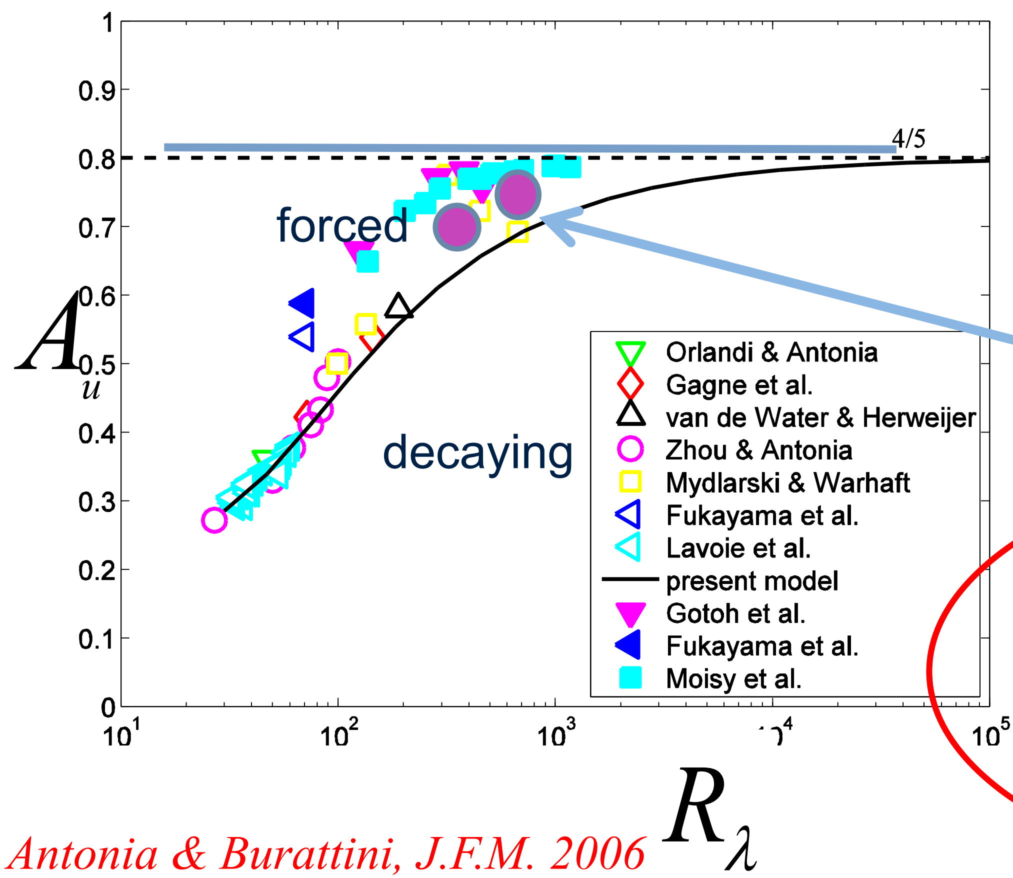
Gauding, and al., and Danaila, Int. J. Heat and Fluid Flow. 2017

Gauding, and al., and Danaila, J. Fluid Mech. 2021

2. Methodology to obtain Scale-by-Scale transport equations: flows with Coherent Motions

$$\frac{4}{5} = 6\nu \frac{\frac{d}{dr}\overline{(\Delta u)^2)}}{\bar{\epsilon}\, r} - \frac{\overline{(\Delta u)^3)}}{\bar{\epsilon}\, r} + I_f$$

➔**Non-universality for moderate Reynolds numbers**



Antonia & Burattini, J.F.M. 2006

→Forced, anisotropic

→Decaying flows: grid turbulence, jets ..

→Decaying, but populated by CM

Which is the role played by the mean shear and waves/CM in energy itself and energy transfer?

2. Methodology to obtain Scale-by-Scale transport equations: flows with Coherent Motions/waves

I. Background and major question

-interaction between coherent motion (CM)
turbulent/random motion (RM)
during energy transfer

Historically:

-identifications of CM [Hussain 1983, Reynolds & Hussain 1972, …].

-dynamics of CM, their representativity for turbulence ..

-From an analytical viewpoint, Reynolds et Hussain [*J. Fluid Mech.* 1972] derived the 1-point kinetic energy budget, including the coherent motion.

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2. Methodology. Transport equations

The approach. Phase-averages

Triple decomposition [3]: $\beta = \overline{\beta} + \widetilde{\beta} + \beta'$

Phase-average: $\langle \beta \rangle = \overline{\beta} + \widetilde{\beta}$

Phase-averaged Strain: $\langle S \rangle = \overline{S} + \widetilde{S} = \frac{1}{2}\left(\frac{\partial \langle U \rangle}{\partial y} + \frac{\partial \langle V \rangle}{\partial x}\right)$

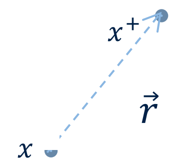
[3] Reynolds and Hussain 1972

Thiesset, Antonia and Danaila, J. Fluid Mech. 2013,2014, 2020
Bouha, PhD thesis, 2016
Portela et al, 2020 Gattere et al. 2023
Barbano et al., B. Layer Met., 2022
Finnigan and Einaudi…

2. Methodology. Theoretical framework

$$\partial_t\theta + u_j\partial_j\theta = \alpha\partial_j^2\theta.$$

$$\partial_t\theta^+ + u_j^+\partial_j^+\theta^+ = \alpha\partial_j^{2+}\theta^+.$$



- Reynolds Decomposition $\theta = \overline{\theta} + \theta.$
- Taking into account stationarity, inhomogeneity and local isotropy.
- After multiplication by $\delta\theta$, followed by a time average.

$$\overline{(\delta v)^2} = \overline{(\delta w)^2} = \overline{(\delta u)^2} + \frac{r}{2}\frac{\partial\overline{(\delta u)^2}}{\partial r}.$$

Isotropy Test

Advection · Production · Turbulent Diffusion

$$2\overline{U}_j\partial_j\overline{(\delta u_i)^2} + 2\overline{\delta u_j\delta u_i}\partial_j\overline{\theta} + \frac{1}{2}\left(\partial_j + \partial_j^+\right)\overline{\left[\left(u_j + u_j^+\right)(\delta\theta)^2\right]}$$

$$\frac{\partial}{\partial r_j}\overline{\delta u_j(\delta\theta)^2} = 2\alpha\frac{\partial^2}{\partial r_j^2}\overline{(\delta\theta)^2} + \frac{1}{2}\alpha\frac{\partial^2}{\partial X_j^2}\overline{(\delta\theta)^2} - 4\overline{\chi}.$$

Transfer · Diffusive Term · Inhomogeneity Term · Mean dissipation rate

- Isotropic Context .
- Self similarity over all scales.
- . $R_\lambda \sim 10^6.$

Yaglom 1949

$$-\overline{\delta u(\delta\theta)^2} + 2\alpha\frac{\partial}{\partial r}\overline{(\delta\theta)^2} = \frac{4}{3}\overline{\chi}r.$$

Kolmogorov 1941

$$-\overline{\delta u(\delta u_i)^2} + 6\upsilon\frac{\partial}{\partial r}\overline{(\delta u_i)^2} = \frac{4}{5}\overline{\varepsilon}r.$$

Thiesset, Danaila and Antonia, J. Fluid Mech. 2013, 2014
Thiesset and Danaila, J. Fluid Mech. 2020
Bouha, PhD thesis, 2016

2. Methodology. Theoretical framework

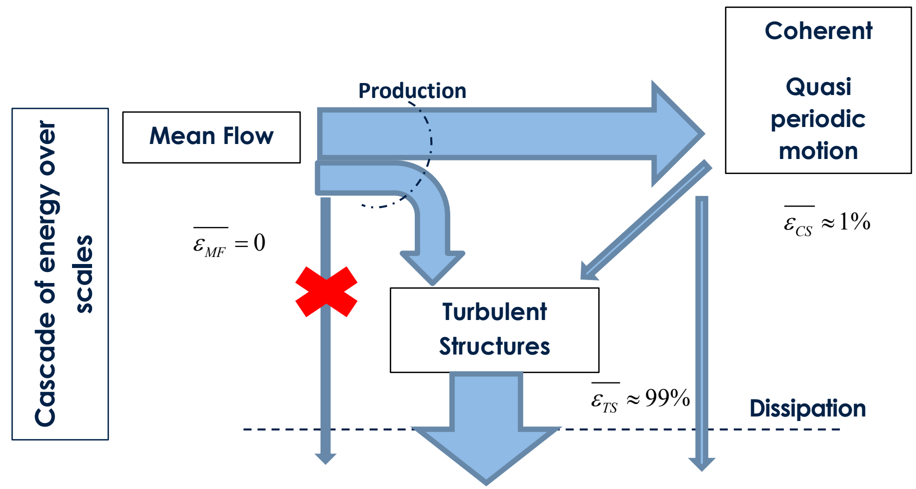
Analytical considerations

Triple decomposition

$$u_i = \overline{U_i} + \tilde{u}_i + u_i'.$$
$$\theta = \overline{\theta} + \tilde{\theta} + \theta'.$$

A. K. M. F. Hussain, J. F. M. 26, 1983

$[\ldots']$	Turbulent fluctuations
$[\tilde{\ldots}]$	Coherent fluctuations
$\overline{\ldots}$	Time average
$\langle\ldots\rangle$	Phase average



Emergent terms of Scale-by-Scale-budget of turbulent fluctuations

Dynamical field

[F. Thiesset, L. Danaila and R. A. Antonia, J. F. M. 749, 2014]

Scalar field

Dynamical field		Scalar field
$-\overline{\langle \delta u \delta q^2 \rangle}$	Total Transfer	$-\overline{\langle \delta u \delta \theta^2 \rangle}$
$\overline{\delta \tilde{u} \delta \tilde{q}^2}$	Coherent Transfer	$\overline{\delta \tilde{u} \delta \tilde{\theta}^2}$
$\frac{2}{r^2}\int_0^r \overline{\left(\delta \tilde{u}_i \frac{\partial}{\partial r} \langle \delta u' \delta u_i' \rangle \right)} ds$	Forcing	$\frac{2}{r^2}\int_0^r \overline{\left(\delta \tilde{\theta} \frac{\partial}{\partial r} \langle \delta u' \delta \theta' \rangle \right)} ds$

Thiesset, Danaila and Antonia, J. Fluid Mech. 2013, 2014
Thiesset and Danaila, J. Fluid Mech. 2020
Bouha, PhD thesis, 2016

2. Methodology to obtain Scale-by-Scale transport equations: flows with Coherent Motions

Transverse Velocity

$$v$$

Band pass filter

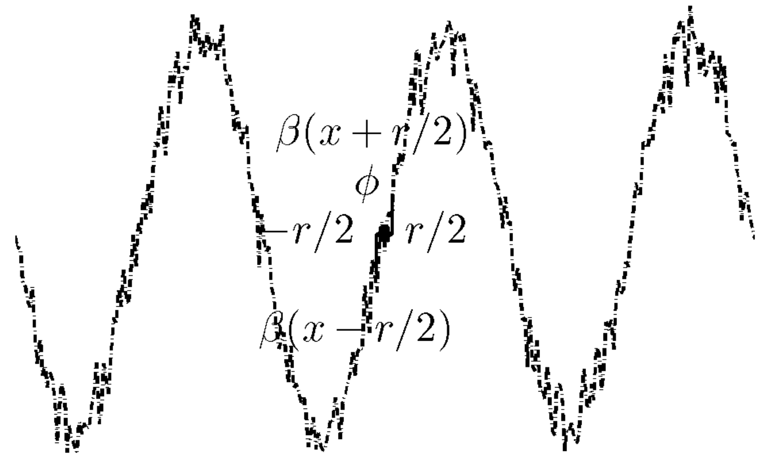
$$v_f$$

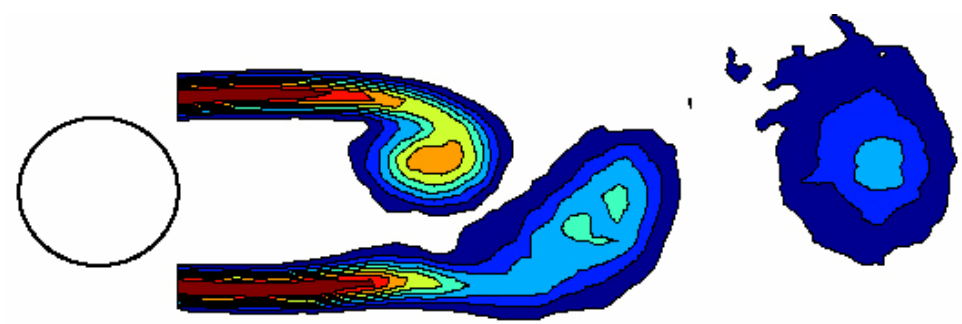
Hilbert Transform

$$h$$

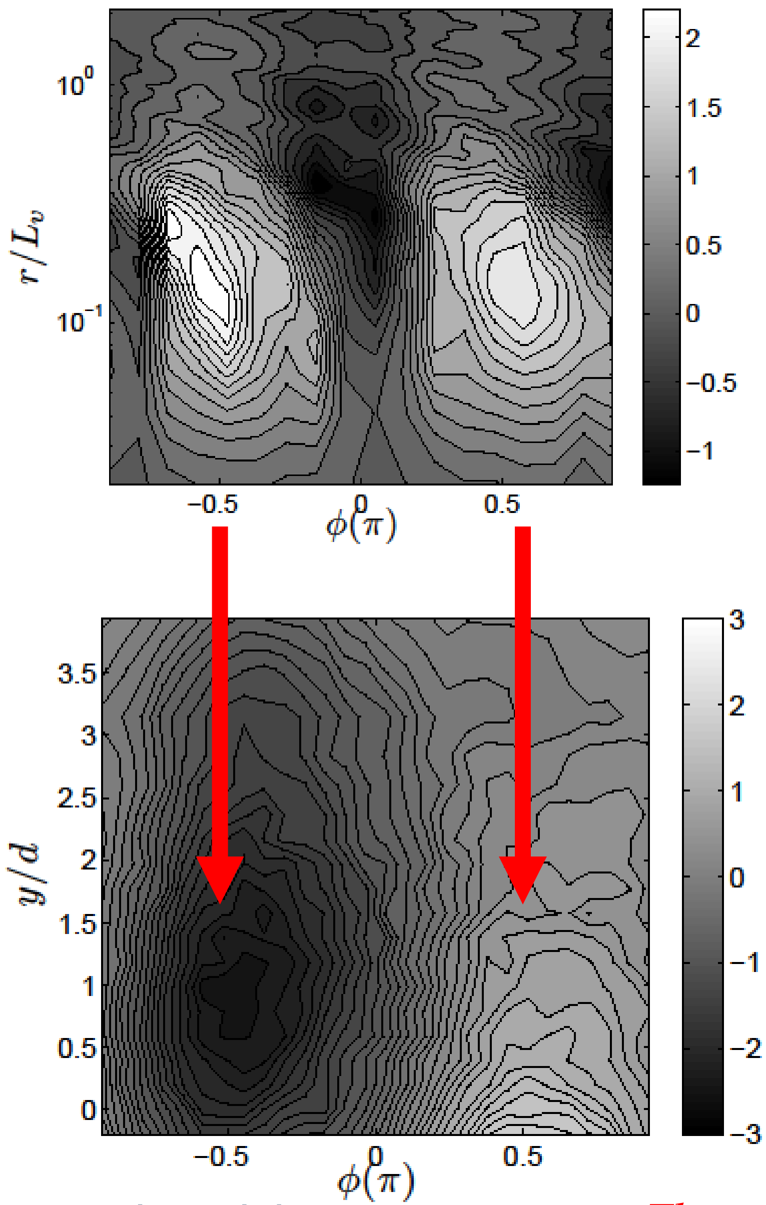
Phase

$$\varphi = \tan^{-1}\left(\frac{h}{v_f}\right)$$





3. Results. Phase-scale distribution of the kinetic energy



$$-\frac{\left\langle \Delta u_{//} \Delta q^2 \right\rangle}{\overline{\varepsilon'} r}(r,\phi)$$

Total energy transfer is

-both positive and negative;

maximum:

-When: CM is present

-At scales where turbulent kinetic energy is maximum

Phase-averaged vorticity component

Thiesset, Danaila and Antonia, J. Fluid Mech. 2013, 2014

Effect of energy injection on jet-waves-random interactions across scales, case study: 2003 western Europe summer heat wave

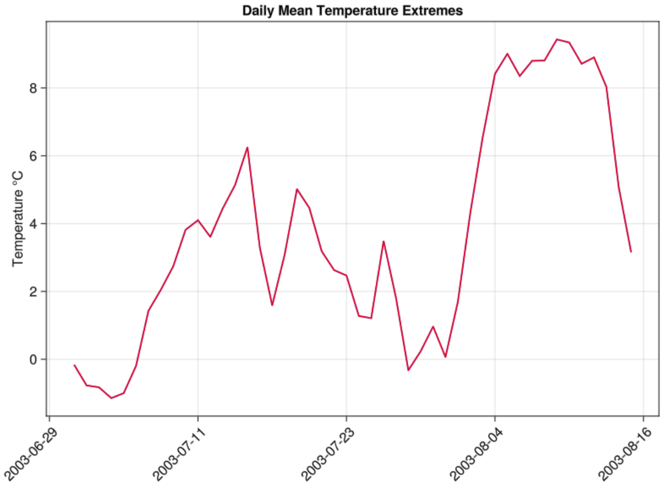
Manuel Fossa[1] , Luminita Danaila[1] and M. Ghil[2]

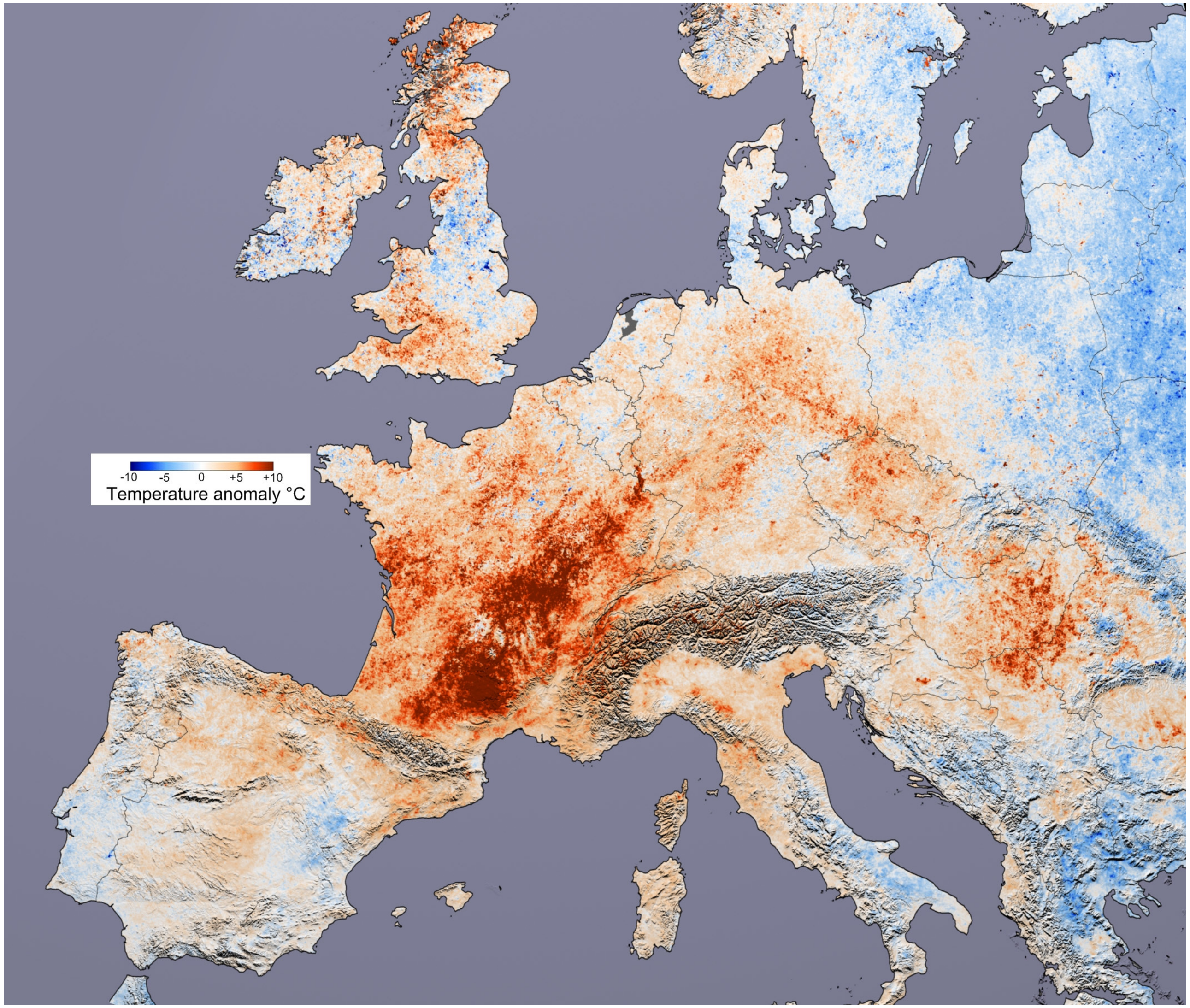
[1] M2C, CNRS, University of Rouen Normandy, France

[2] ENS Paris France, and UCLA, USA

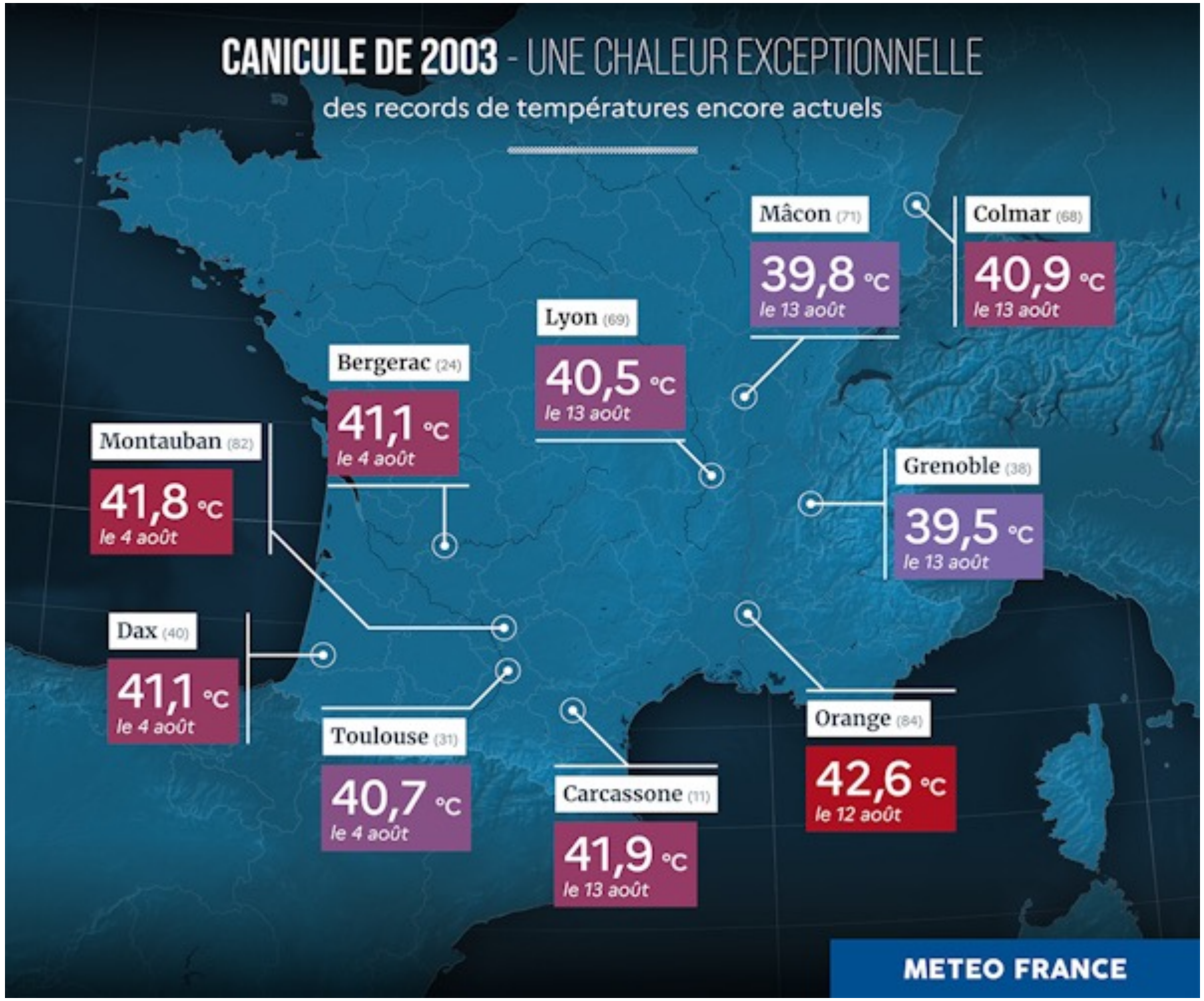
Outline

- Highest death toll (40 000 in France)
- Up to 12°C higher than average



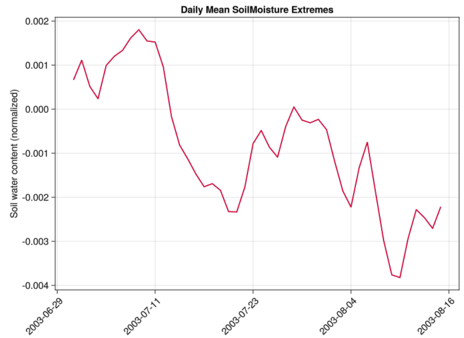


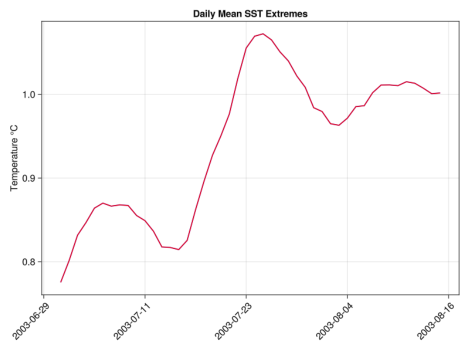
Outline

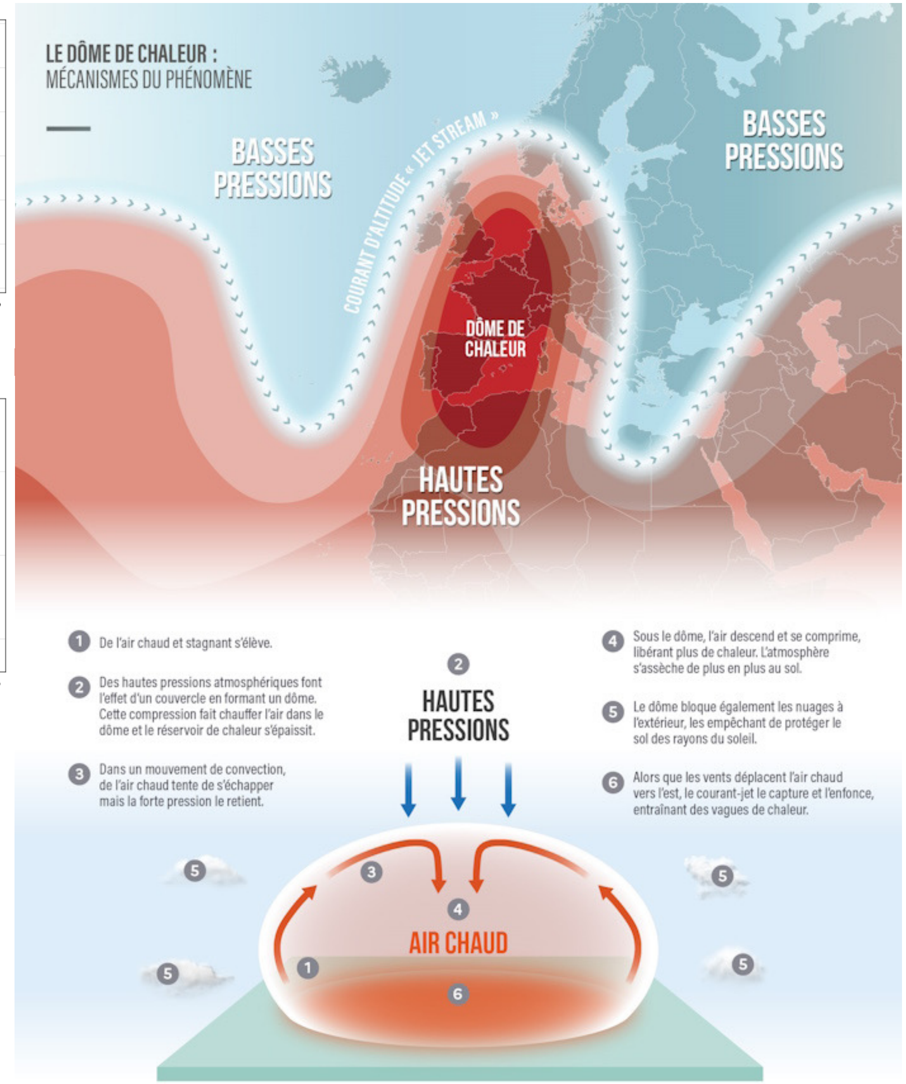

CANICULE DE 2003 - UNE CHALEUR EXCEPTIONNELLE
des records de températures encore actuels
Mâcon (71)
39,8 °C
le 13 août
Colmar (68)
40,9 °C
le 13 août
Lyon (69)
40,5 °C
le 13 août
Bergerac (24)
41,1 °C
le 4 août
Montauban (82)
41,8 °C
le 4 août
Grenoble (38)
39,5 °C
le 13 août
Dax (40)
41,1 °C
le 4 août
Toulouse (31)
40,7 °C
le 4 août
Orange (84)
42,6 °C
le 12 août
Carcassonne (11)
41,9 °C
le 13 août
METEO FRANCE

How it is explained so far:

- Pre-existing conditions:
  - Blocking
  - Soil moisture deficit
  - Sea surface temperatures







METEO FRANCE

Objectives:

1. Compare statistics of Nastrom & Gage, Lindborg and Cho with real space observations

2. Model statistics from the Transport equations from first principles.

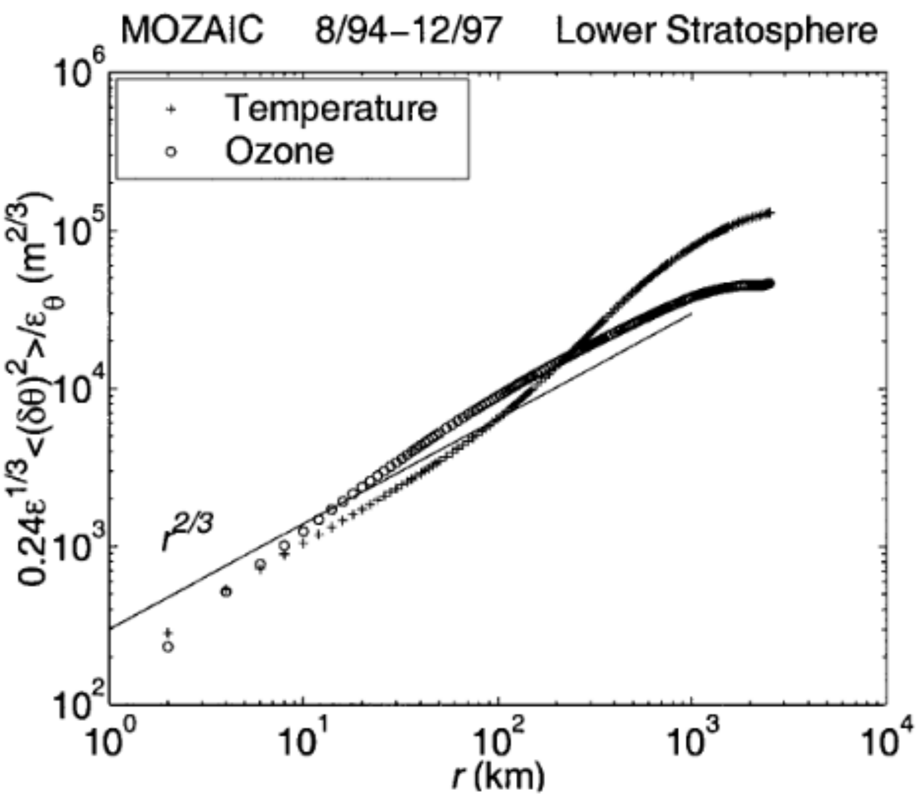
2-points: How do we compute statistics from obs?

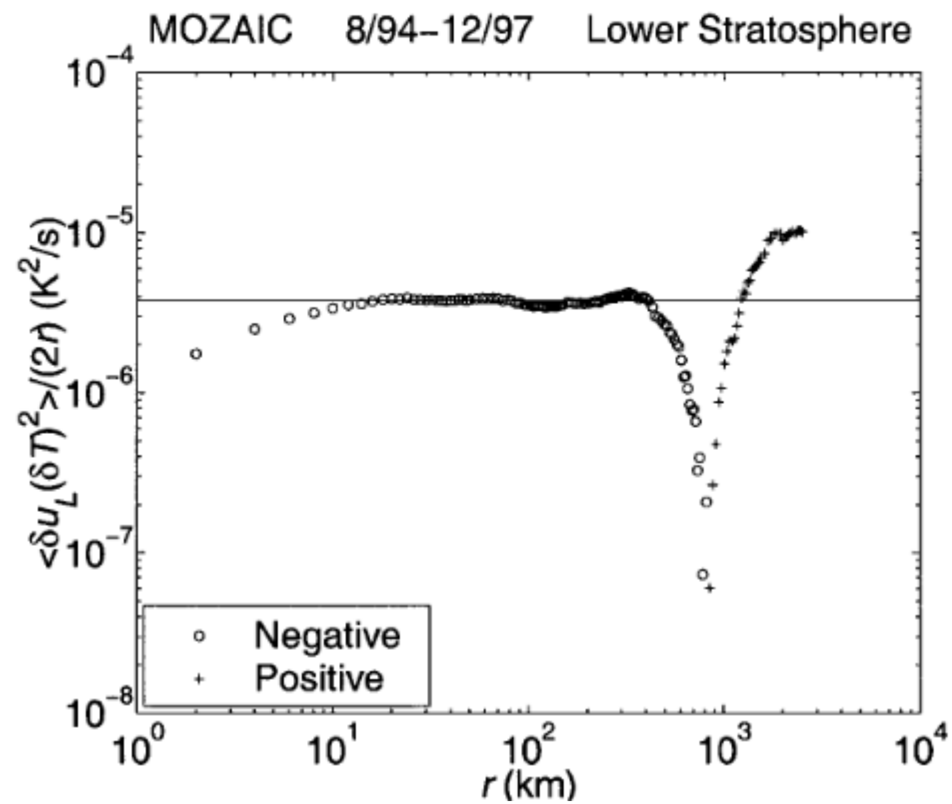
Structure Function (either in real or spectral space):
High-order statistics of a transported quantity along a direction and distance $\vec{r}$

- 2nd order: Energy of the transported quantity along $\vec{r}$
- 3rd order: Indicates the direction of the cascade along $\vec{r}$
- 4th order: Indicates the probability of occurrence of rare & extreme events along $\vec{r}$

Added Value:

1. No Taylor hypothesis needed
2. Mid-troposphere, gridded observations: Real spatial vector $\vec{r}$
3. Transport equation based on Advection-diffusion



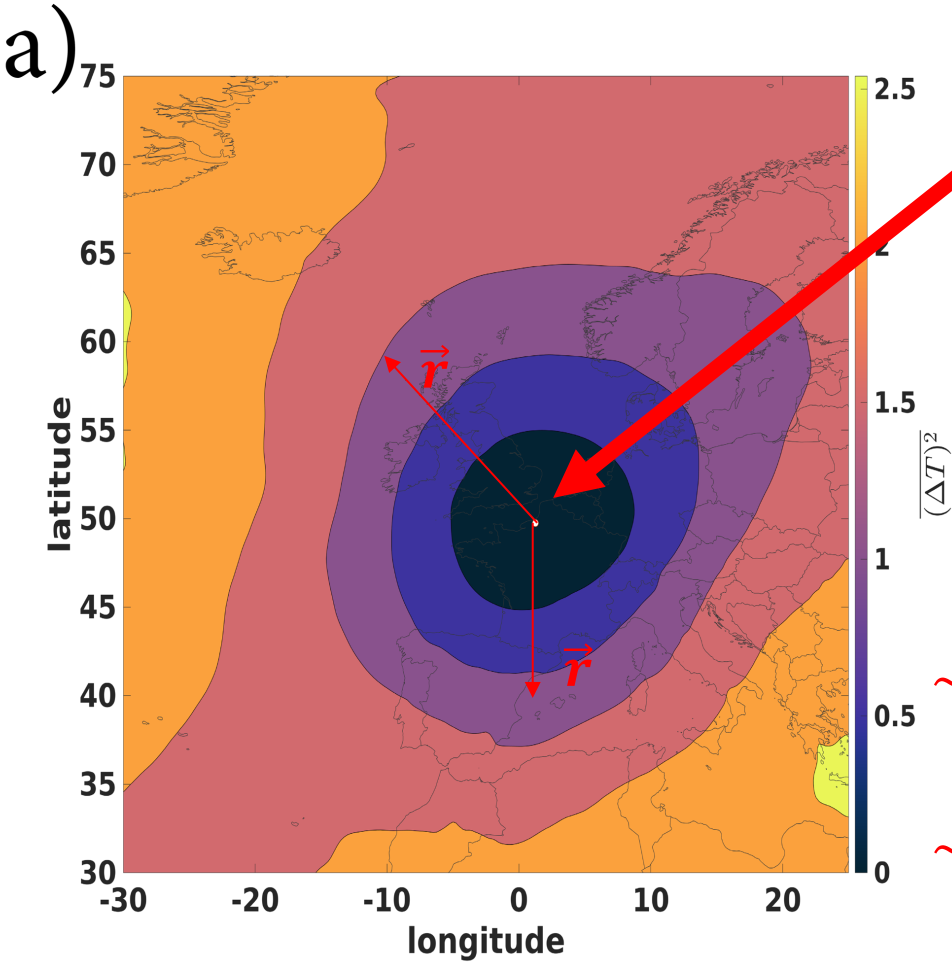


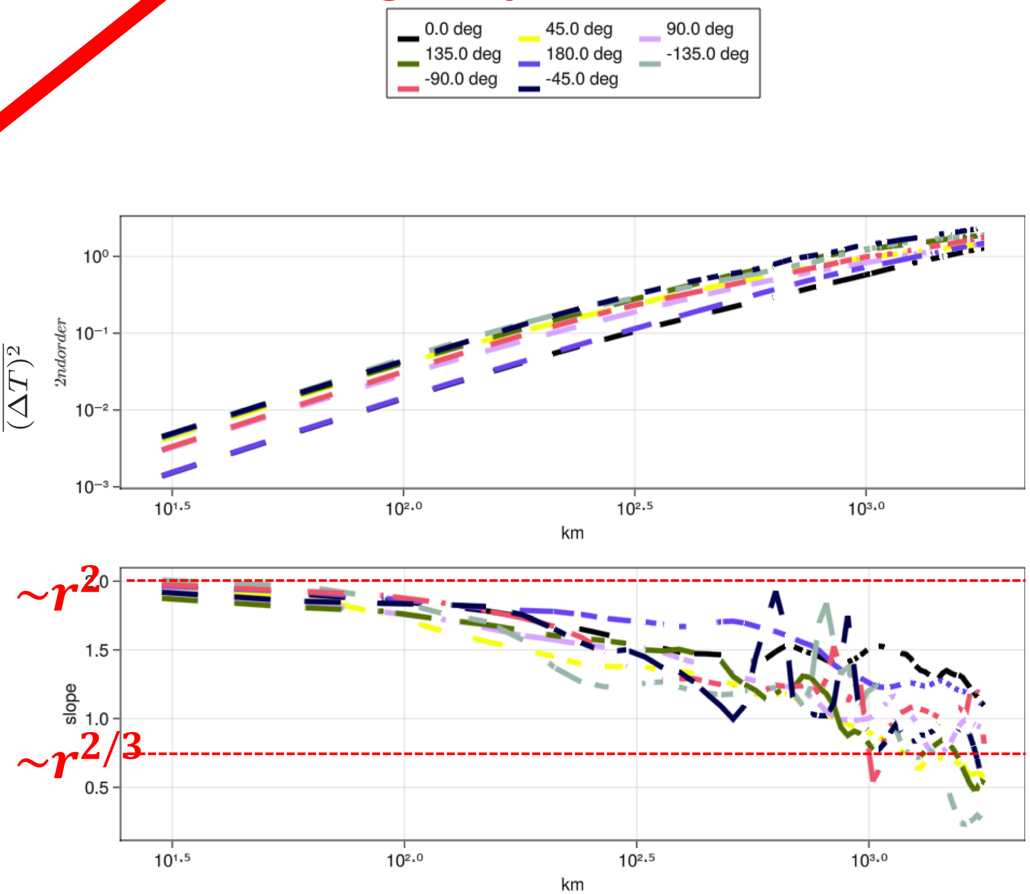
- Obs from commercial flights
- 9-12km altitude
- Temperature derived from velocity via Taylor hypothesis

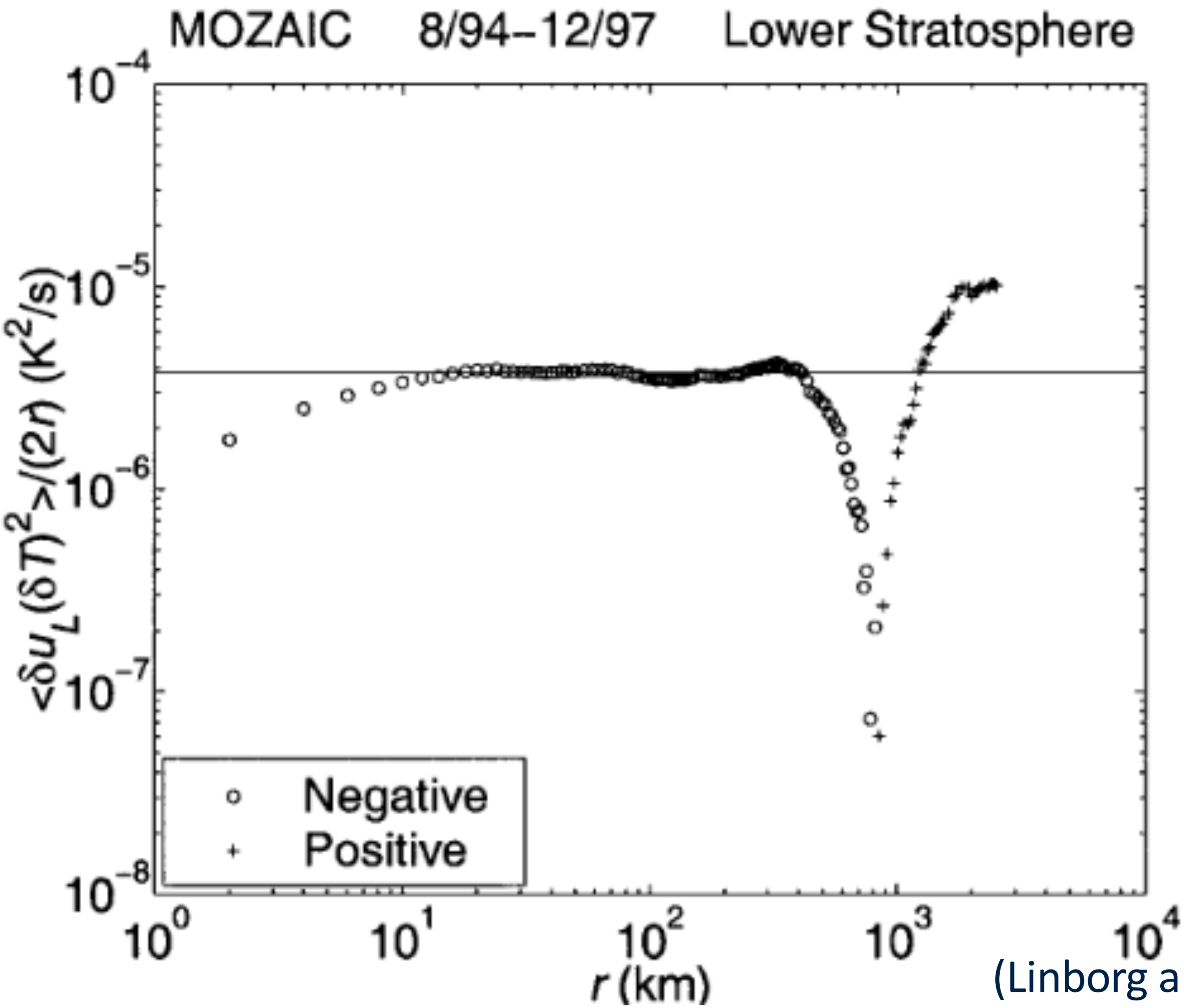
(Linborg and Cho, 2000)

3.
Large-scale temperature link with local, Rouen city temperature variability

2nd-order structure function





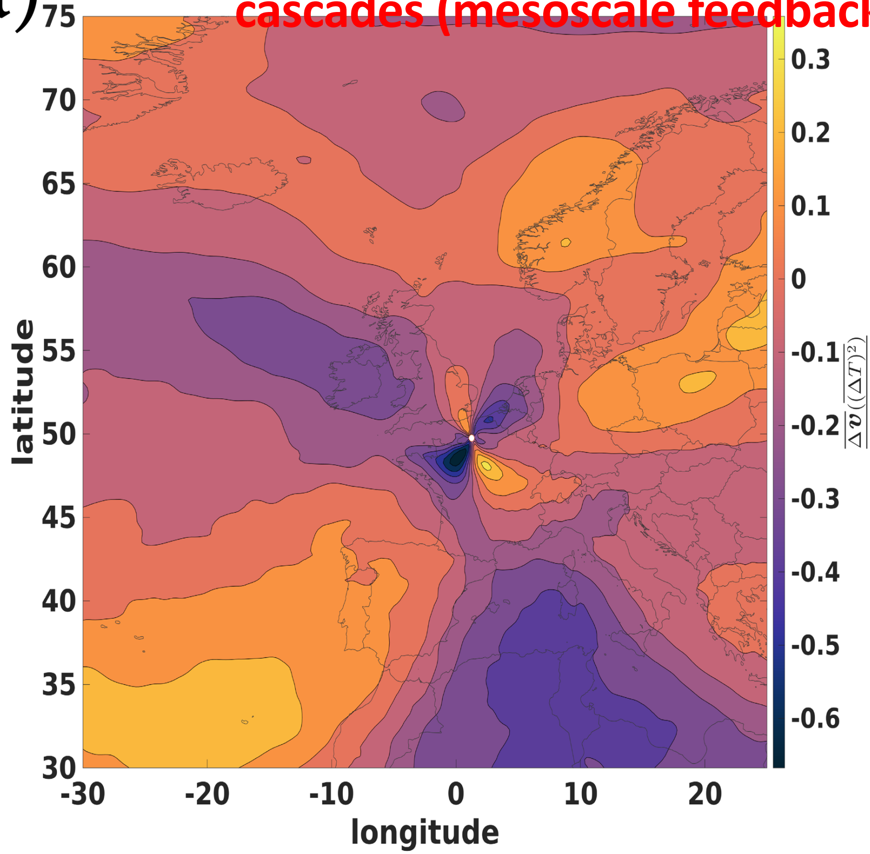


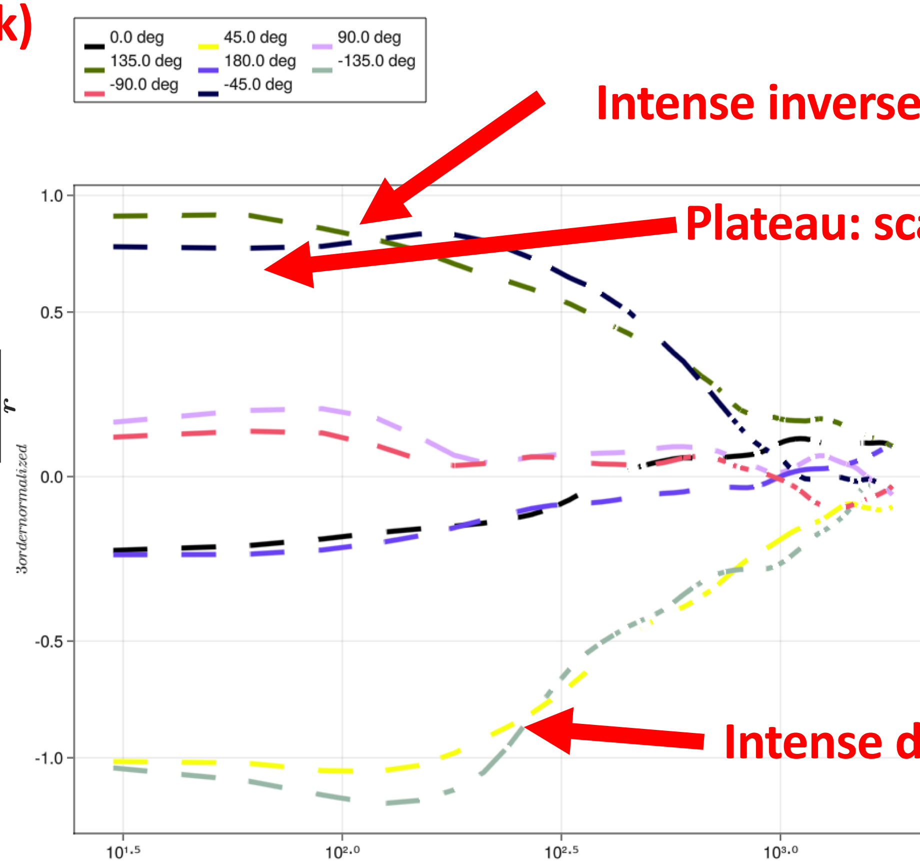
(Linborg and Cho, 2000)

3rd-order structure function

Hypothesis: vortex stretching (3D, due to wave breaking) or additional 2D cascades (mesoscale feedback)

a)





Intense inverse cascade

Plateau: scaling range

Intense direct cascad

Methodology I: Data

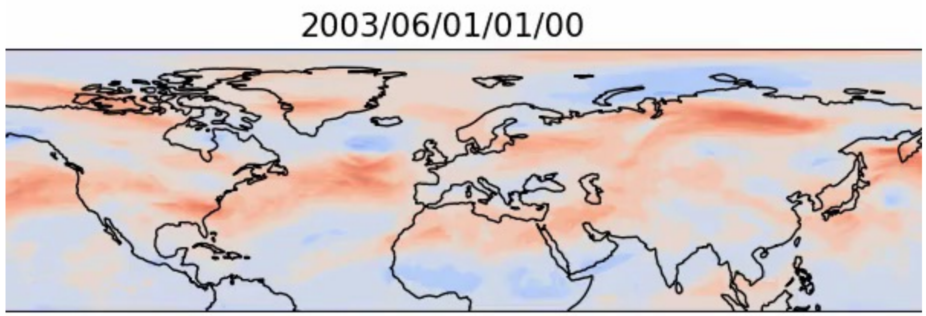
ERA5 Reanalysis: 06/01/2003-08/31/2003

- Hourly time step
- Northern hemisphere @ 0.25° by 0.25° resolution (~30km)
- Three pressure levels: 200hPa (~9km height), 500hPa (~5km height), 850 hPa (~2km height)
- Variables used in computations (Total, Mean, Coherent, Random) : Temperature, Zonal Wind, Meridional Wind, TOA Net Thermal radiation, atmosphere gases/clouds feedback climate kernels

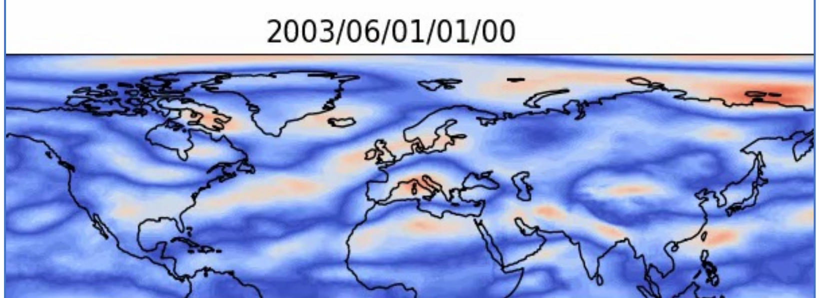
We will show computations mostly at the 500hPa pressure level because it represents a good approximation of both upper tropopause and near-surface flows.

Methodology I: Triple Decomposition

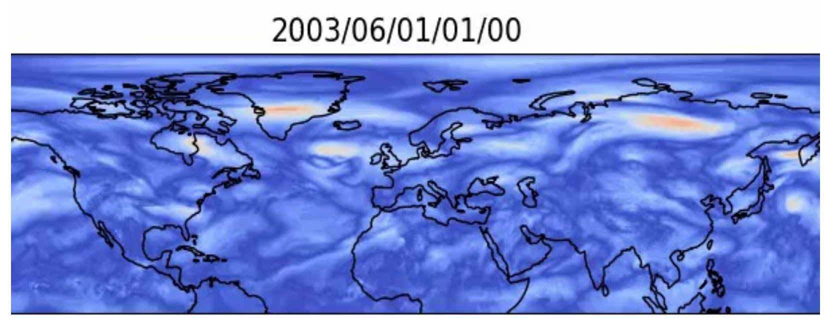
Temperature



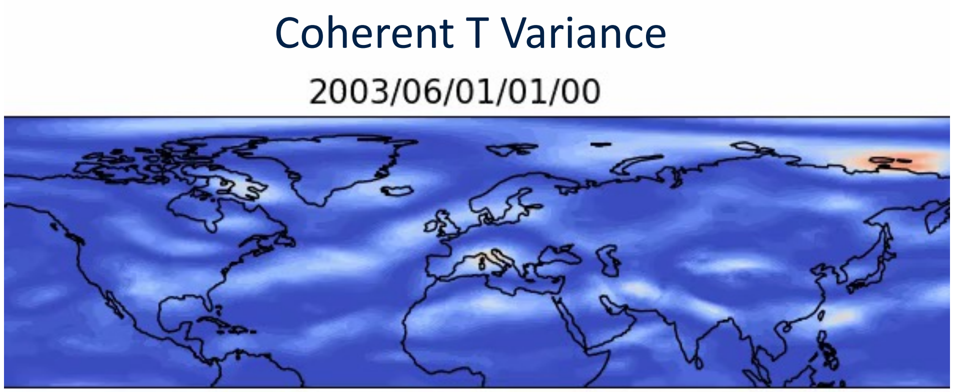
Coherent T

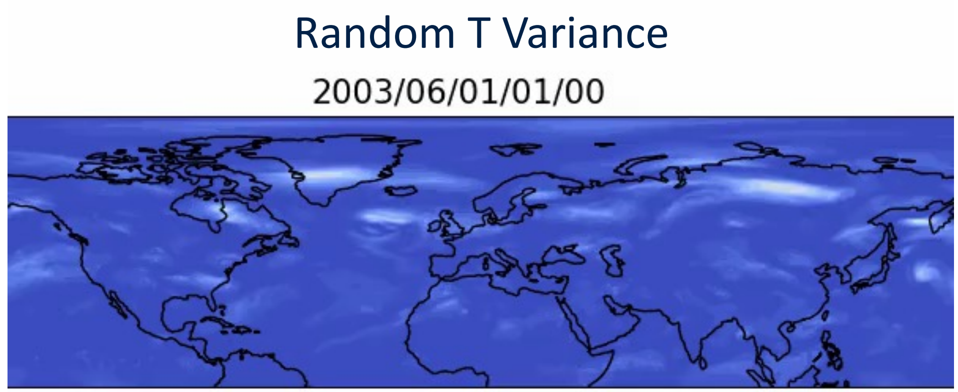


Random T



Methodology I: Decomposed Variance



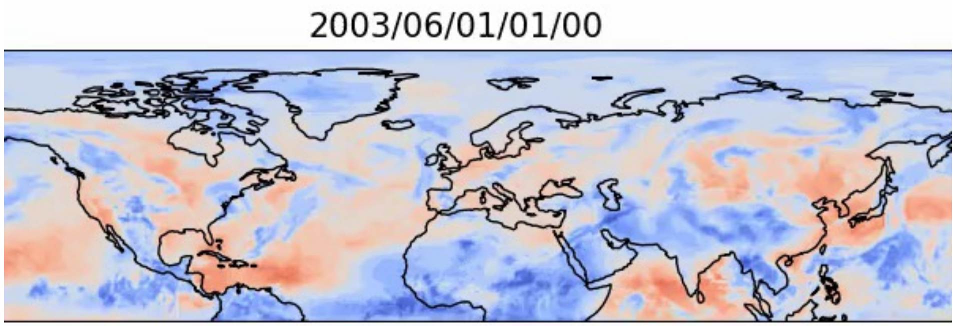


(white/red colors => high T Variance)

- Coherent T Variance decreases over western Europe is correlated with sudden increase in variance North Eurasia and East Asian Seas
- Random T Variance progressively bypasses West Europe around beginning of July
- Large mixing occurs in Eurasia at the same Time

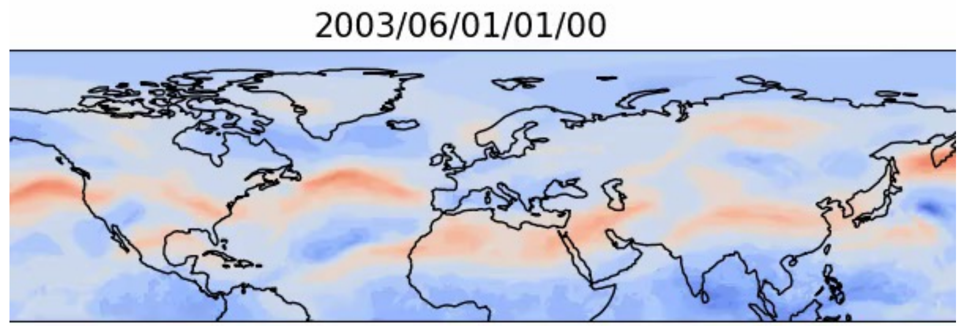
Methodology I: Energy injection and Forcing

Net Thermal radiation @ 500hPa



(red colors => net thermal radiation deficit)

Temperature @ 200 Hpa



- Deficit progressively stagnates and increases over the Middle East and North of the Himalayan Range
- => Excess energy heats the atmosphere around those locations

- The Jet steam progressively breaks East of those areas
- => Large stagnating eddies appear West of Europe

Methodology I: Temptative explanation

Net radiation Deficit Middle-East/North of Himalyan Range

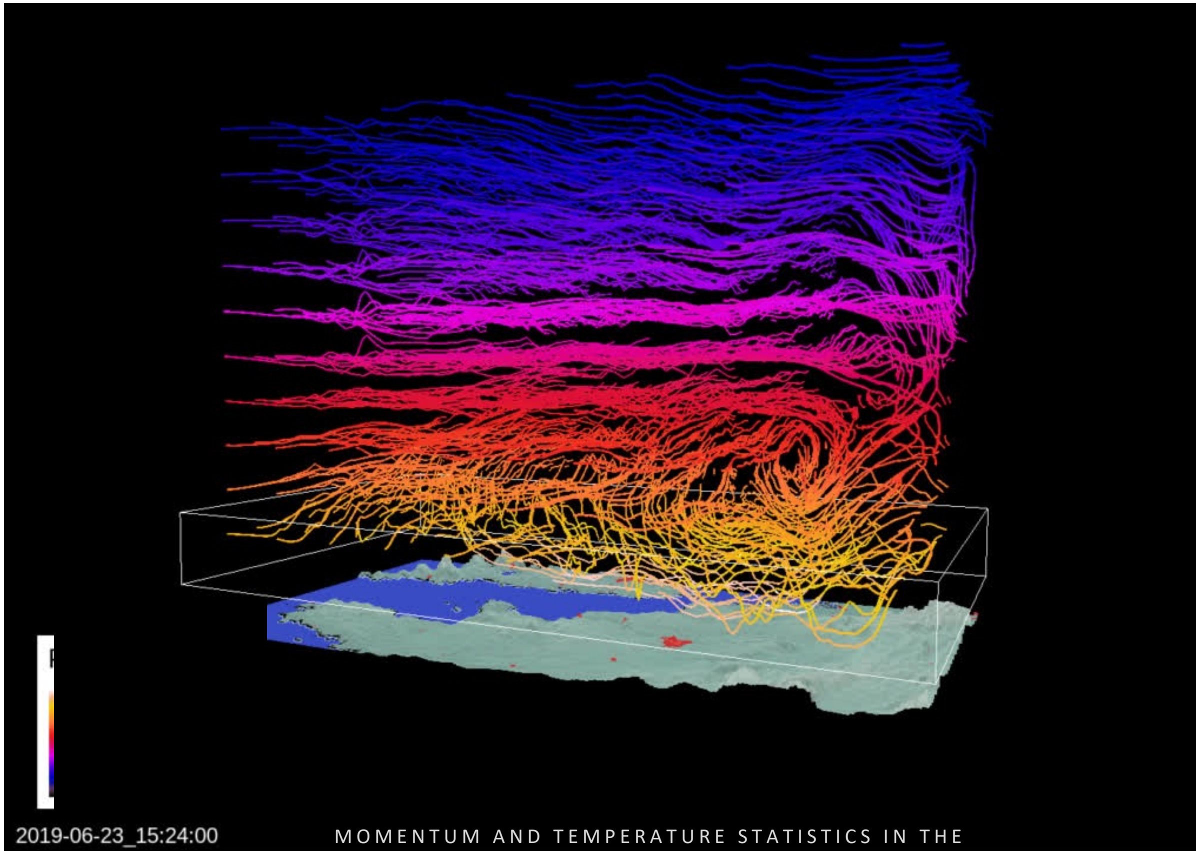
Increase in the poleward temperature advection around those longitudes

Rossby Wave Break West of this poleward advection

Large eddies appear both on the North West Side, and the North East-Side

France is sandwiched between those two sides with hot air coming from south and no westerlies due to wave breaking

Blocking Event



MOMENTUM AND TEMPERATURE STATISTICS IN THE ATMOSPHERE USING THE APPROACH OF TURBULENCE

The WRF model

Advantage:

- Highly customisable
- Wide community
- Reliable
- Can go to high resolution

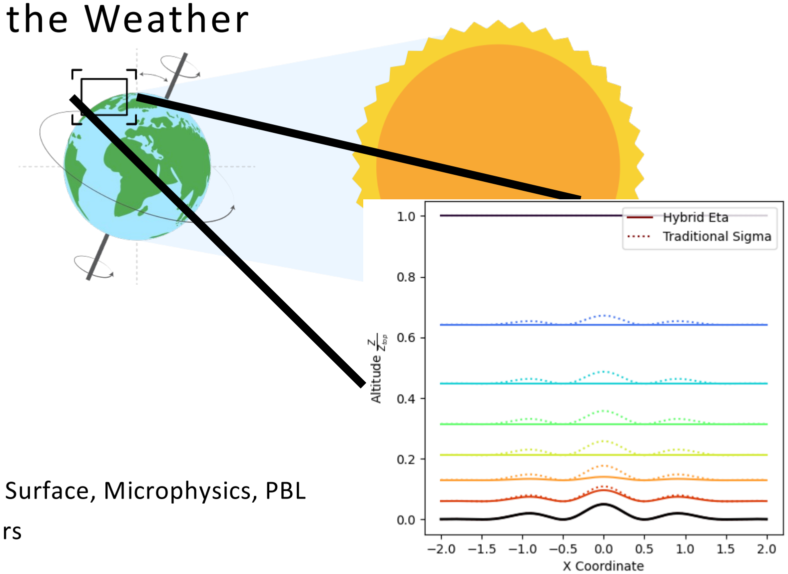
Drawback:

- harder to run at high resolution

THE WRF MODEL

Taking into account all (significant) forces we can predict the Weather

$$\mathbf{F} = m\frac{d\mathbf{v}}{dt} = m\mathbf{a}\,.$$ → Fluid continuum → $$\frac{Du}{Dt} = -\frac{\nabla p}{\rho}$$ (+F) →

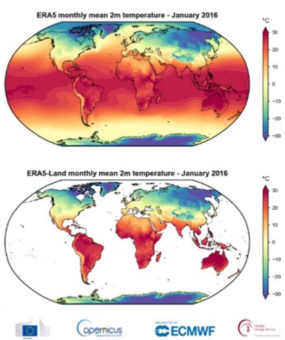


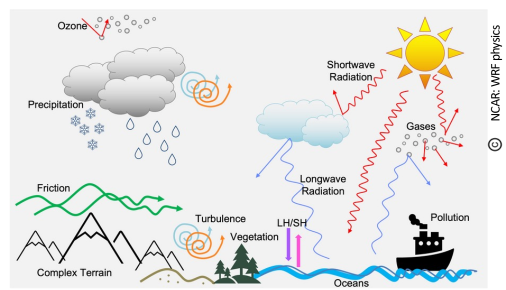
Taking into account Gravity, Centrifugal, Normal forces(Pressure gradient) and influence of topography

$$\partial_t U + (\nabla \cdot \mathbf{V}u) + \mu_d \alpha \partial_x p + (\alpha/\alpha_d)\partial_\eta p \partial_x \phi = F_U$$
$$\partial_t V + (\nabla \cdot \mathbf{V}v) + \mu_d \alpha \partial_y p + (\alpha/\alpha_d)\partial_\eta p \partial_y \phi = F_V$$
$$\partial_t W + (\nabla \cdot \mathbf{V}w) - g[(\alpha/\alpha_d)\partial_\eta p - \mu_d] = F_W$$
$$\partial_t \Theta_m + (\nabla \cdot \mathbf{V}\theta_m) = F_{\Theta_m}$$
$$\partial_t \mu_d + (\nabla \cdot \mathbf{V}) = 0$$
$$\partial_t \phi + \mu_d^{-1}[(\mathbf{V} \cdot \nabla \phi) - gW] = 0$$
$$\partial_t Q_m + (\nabla \cdot \mathbf{V}q_m) = F_{Q_m}$$

What goes here?

Physics(Coriolis, Radiation, Surface, Microphysics, PBL mixing) and Numerical filters





- We use ERA5 reanalysis for the initial state and Boundary conditions

'm'= moist potential temperature
(if all the moisture were condensed and the released latent heat was added to the parcel)

Simulation characteristic

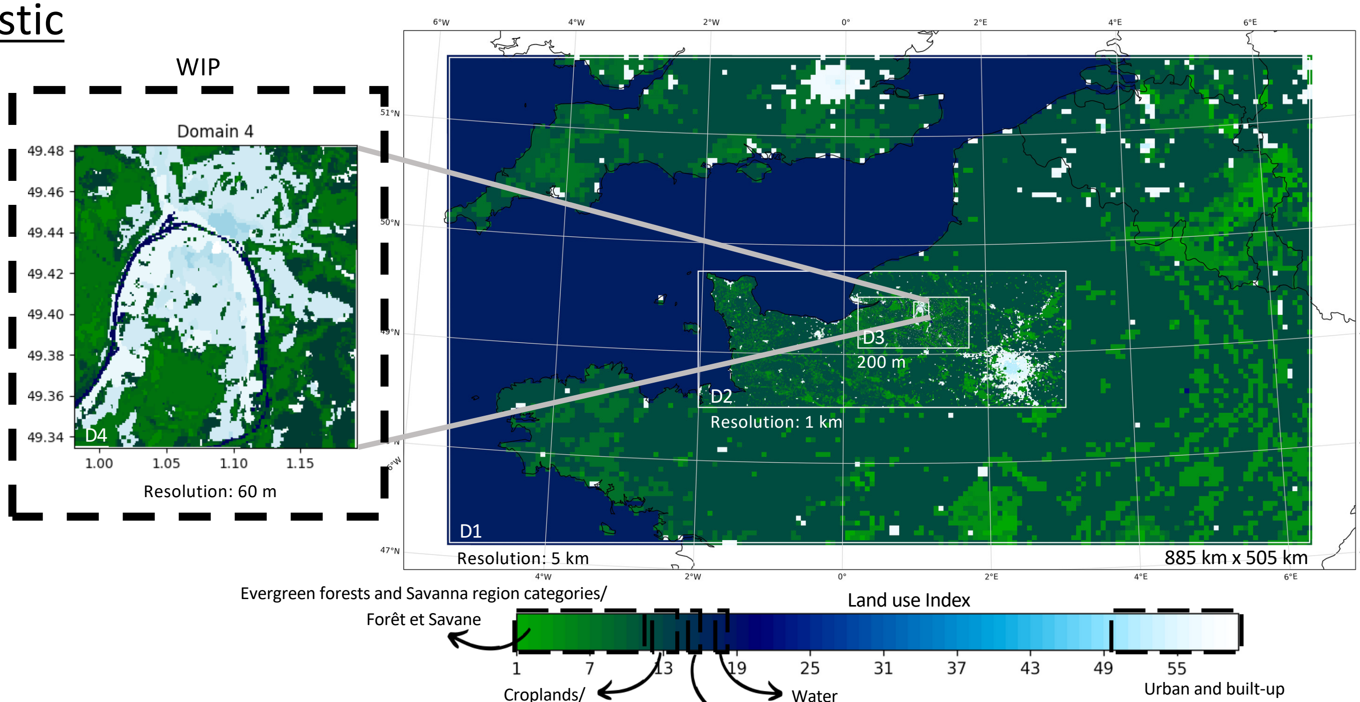
Domains :

D1 = 5km D3 = 200m

D2 = 1km D4 = 60m

Possible change to domains :

- D1 might be expended to include more of the Atlantic
- D4 will be implemented.
- D2 and D3 may be adapted if need be.



Studied time: 24-28 June 2019

Bulletin de santé publique canicule. Bilan été 2019.

Publié le 9 octobre 2019
Mis à jour le 9 octobre 2019

IMPRIMER PARTAGER

Points clés

L'été 2019 a été marqué par deux canicules très étendues et intenses, avec des dépassements des seuils d'alerte entre le 24 juin et le 7 juillet et le 21 et le 27 juillet. Lors de ces deux canicules, pour la première fois, respectivement 4 et 20 départements, représentant 7 % et 35% de la population Française métropolitaine, ont été placés en vigilance rouge, compte-tenu des températures diurnes exceptionnelles.

Santé publique France

Été 2019 : deux canicules exceptionnelles

05/03/2020

L'été 2019 a été marqué par deux vagues de chaleur assez courtes (6 jours) mais d'une intensité record pour un mois de juin pour la première et record tous mois confondus ex æquo avec celle d'août 2003 pour la seconde.

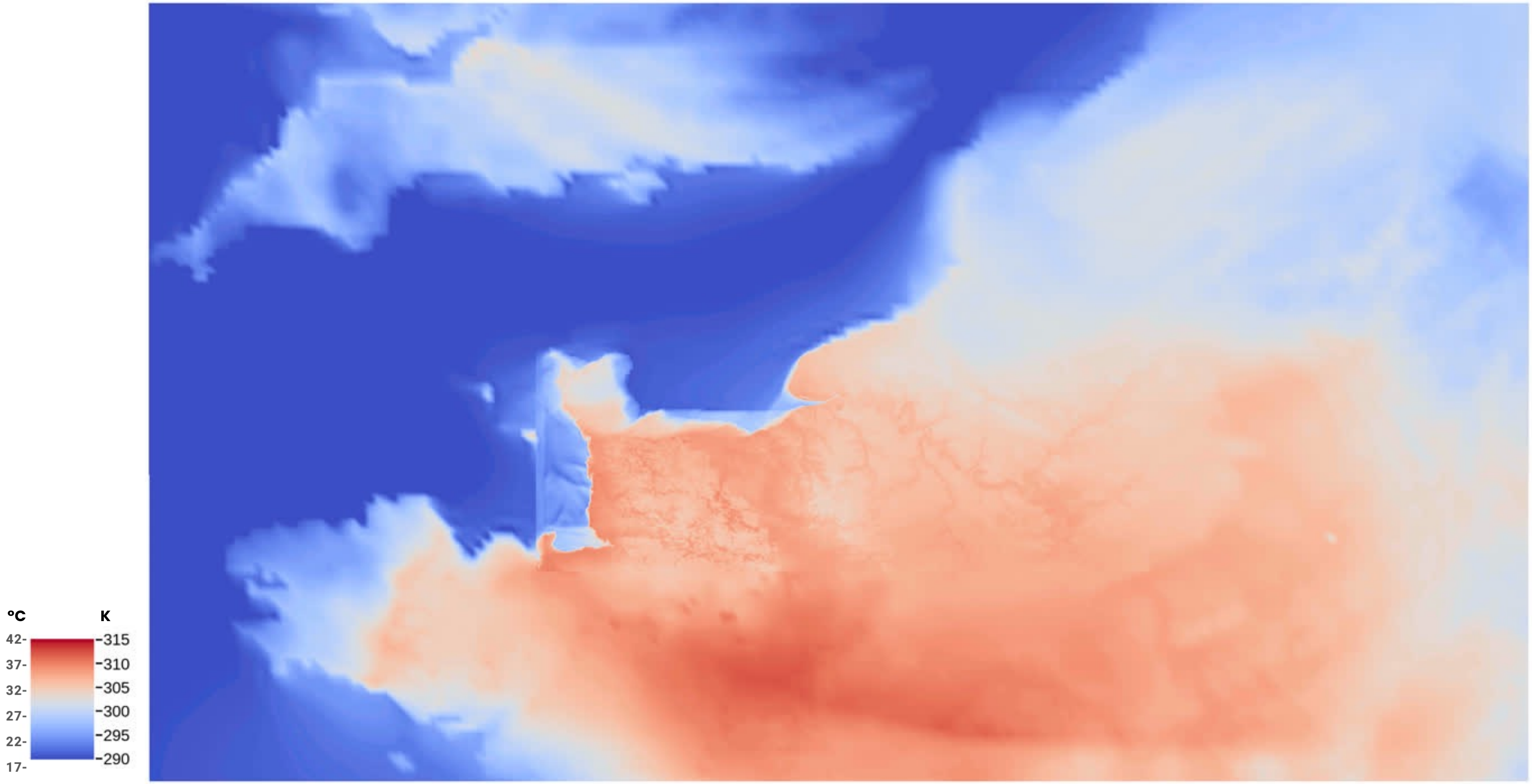
46 °C en France !

Le nouveau record absolu de chaleur national a été battu lors de la canicule de juin. Le mercure a en effet atteint 46 °C à Vérargues (Hérault) le 28 juin 2019 : c'est la température la plus élevée jamais mesurée en France. De nombreux records absolus tous mois confondus sont tombés avec souvent plus de 40 °C sur le Sud-Est en juin et sur le nord du pays en juillet.

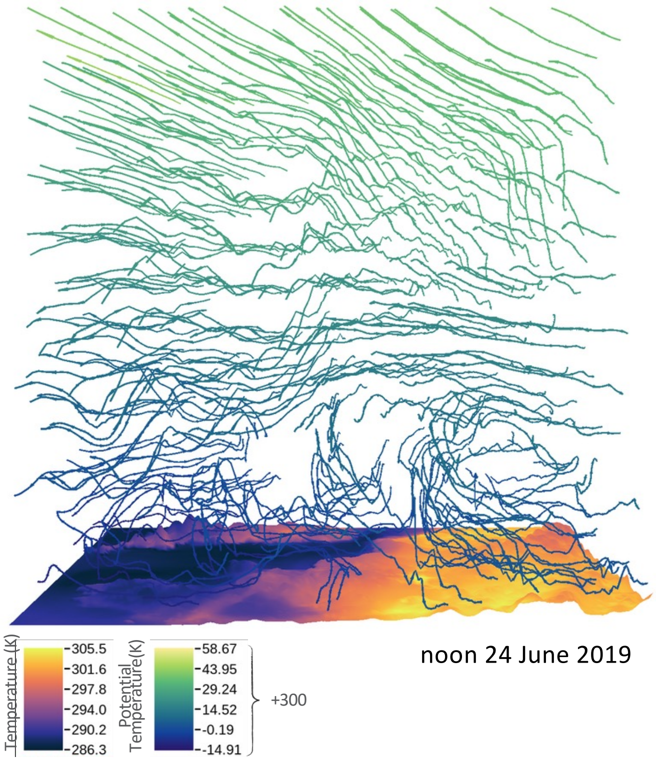
Fin juin, la vigilance rouge canicule a été utilisée pour la première fois depuis sa création en 2004.

Météo-France

Evolution of the temperature at a level 2m above ground level

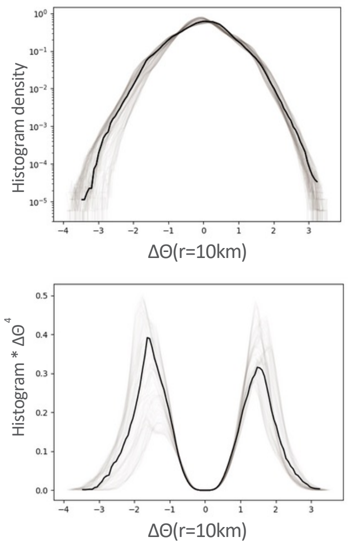


Results: Potential temperature spread.

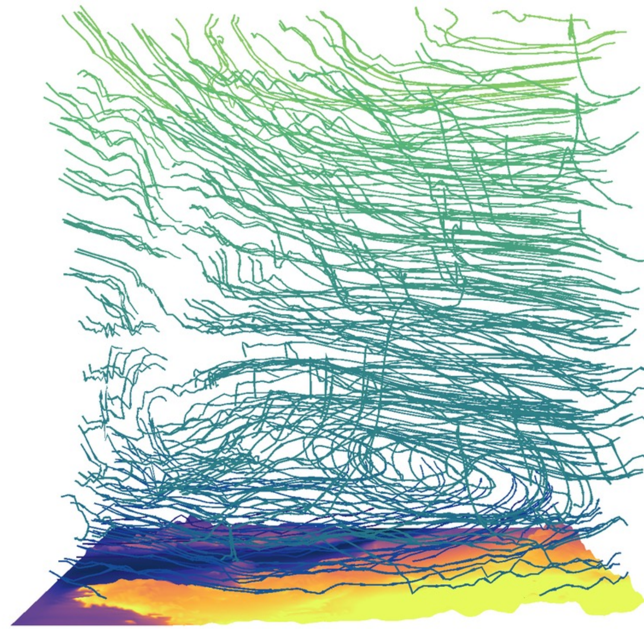


noon 24 June 2019

PDFs of potential temperature increment in the PBL

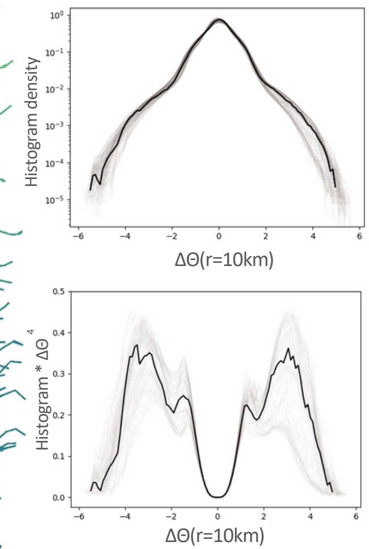


Kurtosis 3.31 ± 0.19



noon 27 June 2019

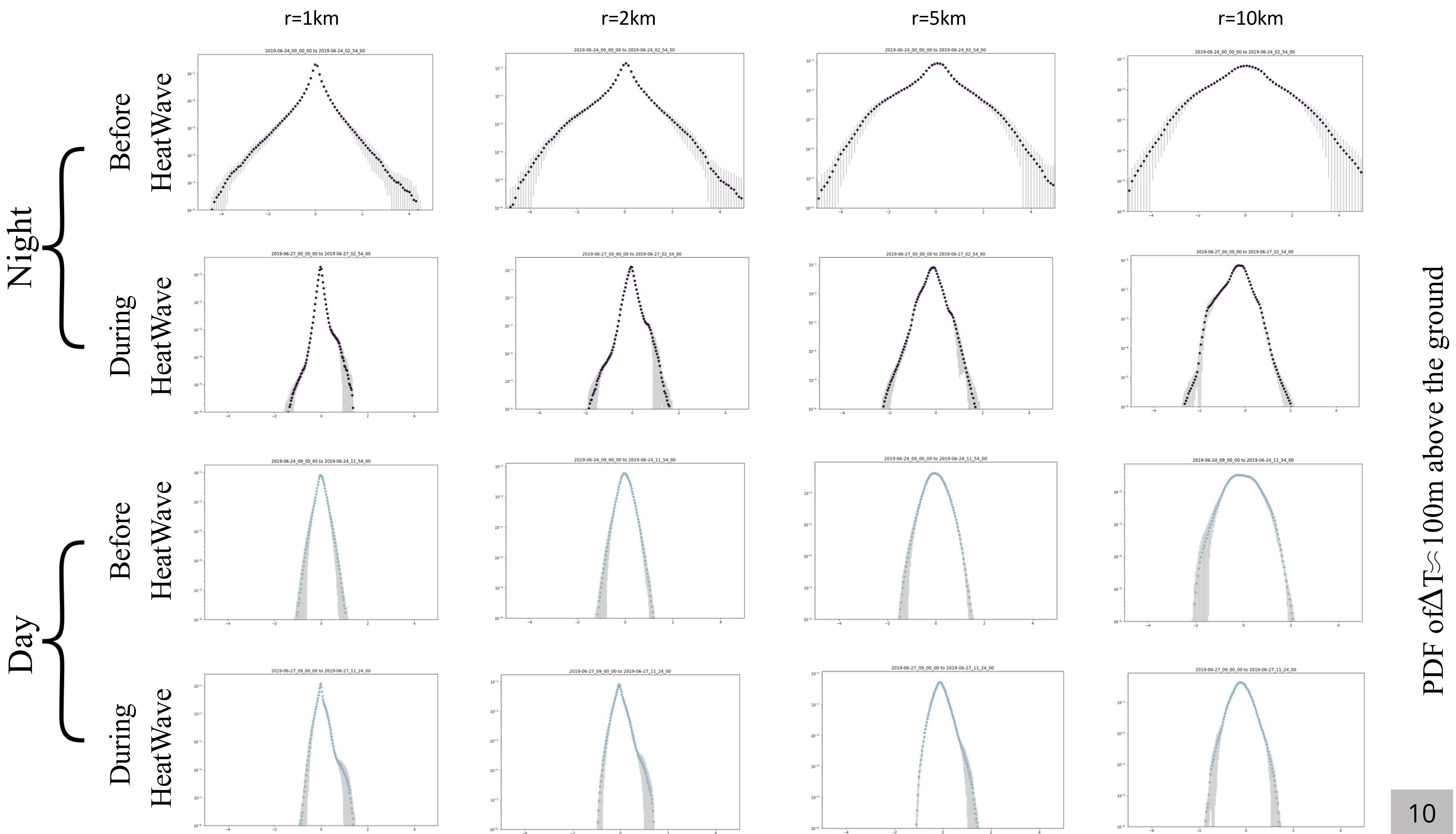
PDFs of potential temperature increment in the PBL



Kurtosis 6.10 ± 0.34

Visualization & Analysis Systems Technologies. (2023) Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers (VAPOR version 3.8.0) [Software]. Boulder, CO: UCAR/NCAR - Computational and Information System Lab. doi:10.5281/zenodo.7779648

Turbulent behaviour across layers leads to mixing of scalars like potential temperature extending the tails of increment PDFs, corresponding to more extreme events.


r=1km
r=2km
r=5km
r=10km
Night
Before HeatWave
During HeatWave
Day
Before HeatWave
During HeatWave
PDF of ΔT≈100m above the ground