Variabilité et changement climatique, nonlinéarité et extrêmes des processus hydrologiques

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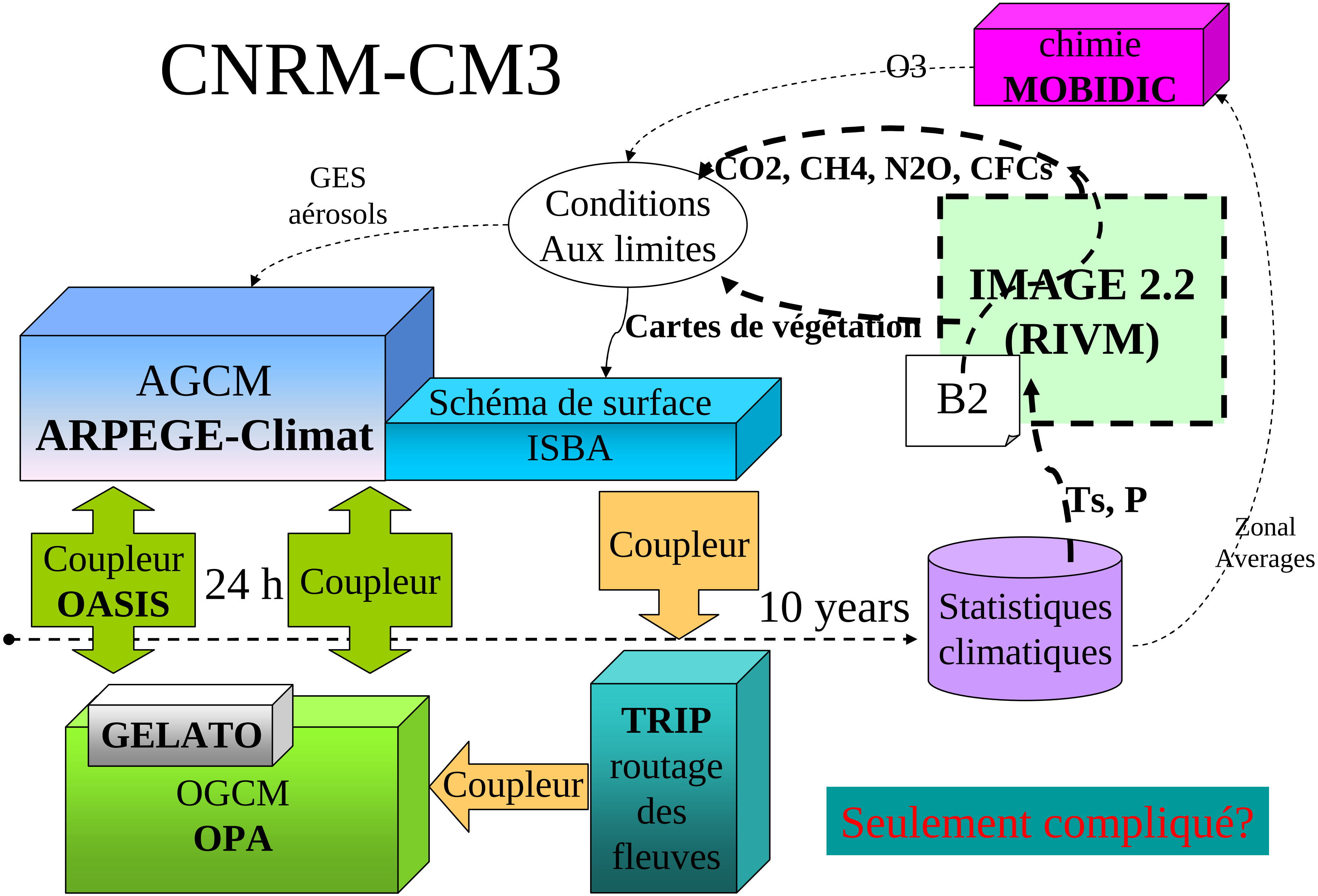
Premier questionnement

- Système atmosphère-hydrosphère
  - fortement nonlinéaire (ex. Re$\approx 10^{12}$)
  - complexe, pas seulement compliqué ($N >> 10^{29}$)!
- Première conséquence:
  - extrême variabilité sur grandes gammes d'échelles spatio-temporelles,
  - en particulier, échelle des fluctuations climatiques non empiriquement atteinte !
  - stationnarité… dans quel sens?

Second questionnement

- Peut-on alors:
  - espérer dégager des tendances linéaires?
  - observer/quantifier le changement à un échelle donnée?
- Ou doit-on:
  - observer à travers les échelles?
  - comment quantifier?

CNRM-CM3



Seulement compliqué?

Spectre de vent (Van der Hoven, 1957)

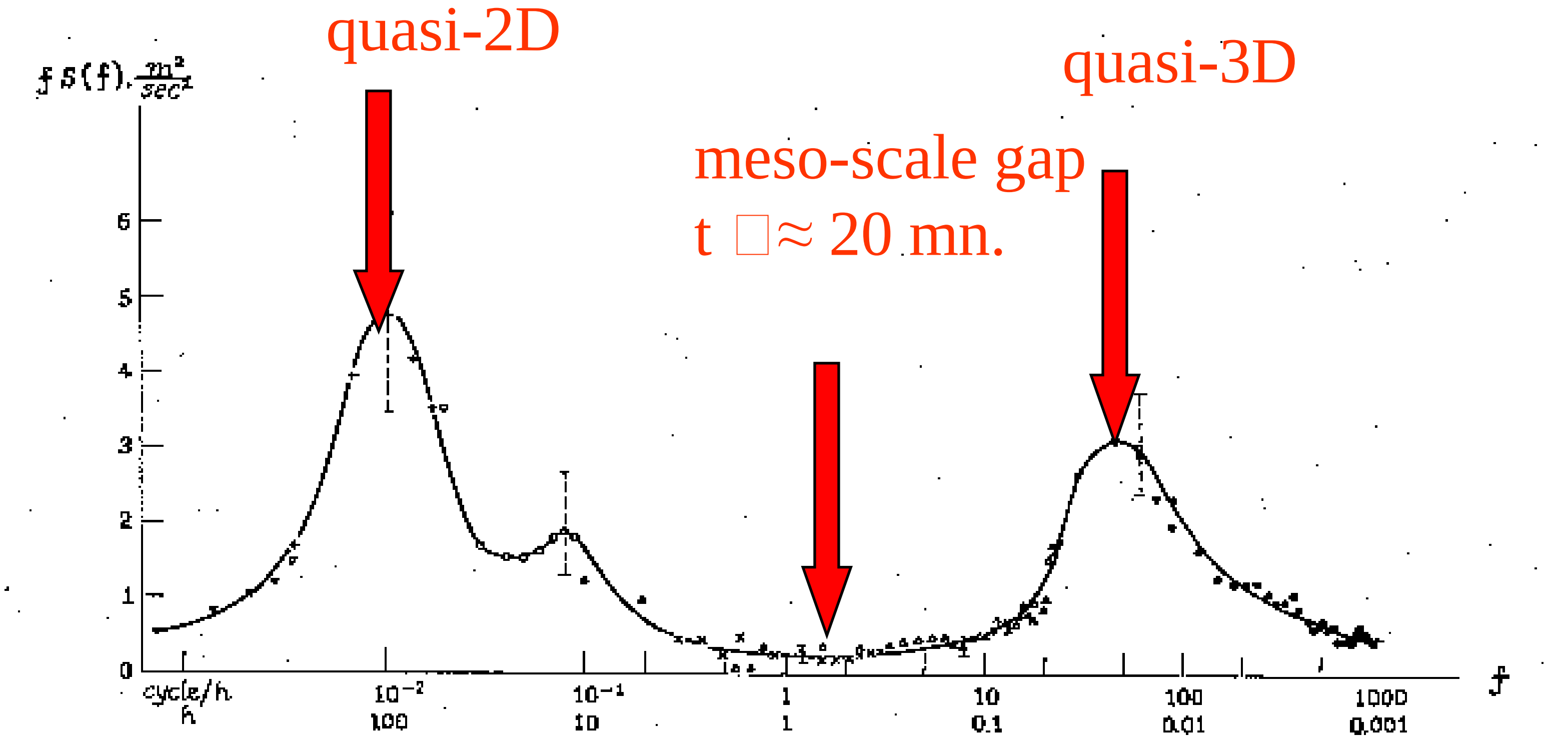


Fig. 3 Spectrum of the horizontal wind velocity. After Van der Hoven.[26] Some experimental points are shown on the graph; see reference 26.

La cascade de Richardson est décomposée en gamme macro, meso, micro…

Loi de diffusion de Richardson

Richardson (1926): mise en évidence une viscosité turbulente valide jusqu'aux échelles planetaires:

- $\nu(L) \approx \varepsilon^{1/3}\ L^{4/3}$

Associée avec une loi de diffusion anormale :

- $< r(t)^2 > \approx \varepsilon\ t^3$

qui correspond à la première loi quantitative en turbulence..

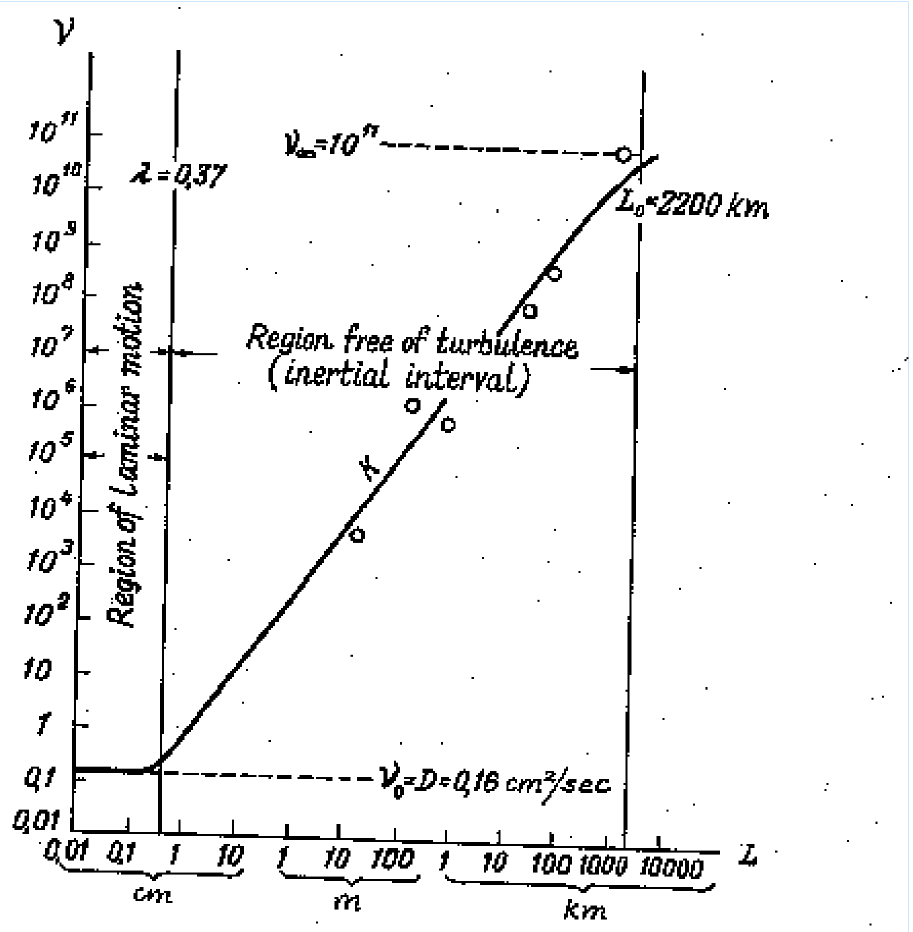
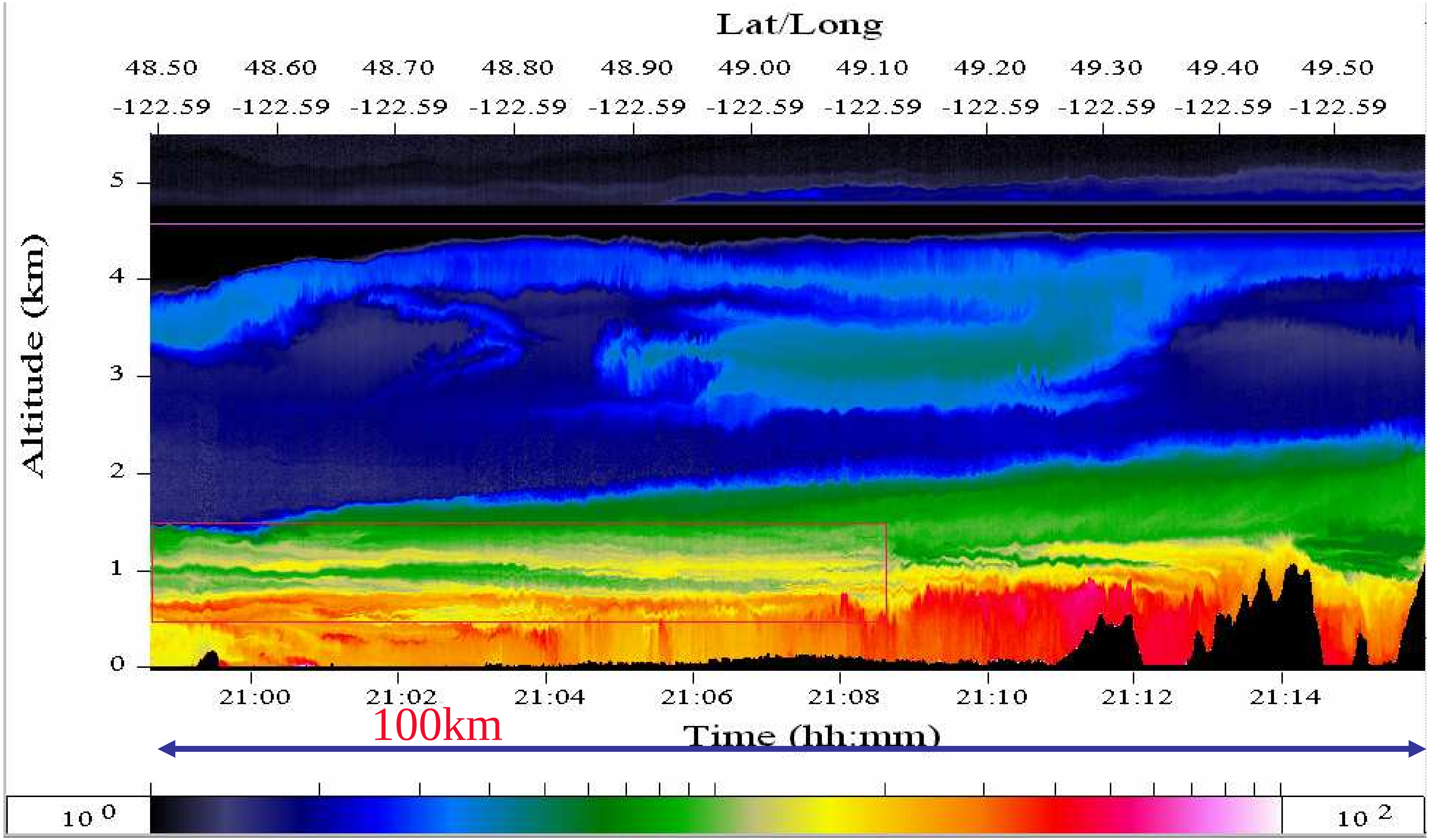


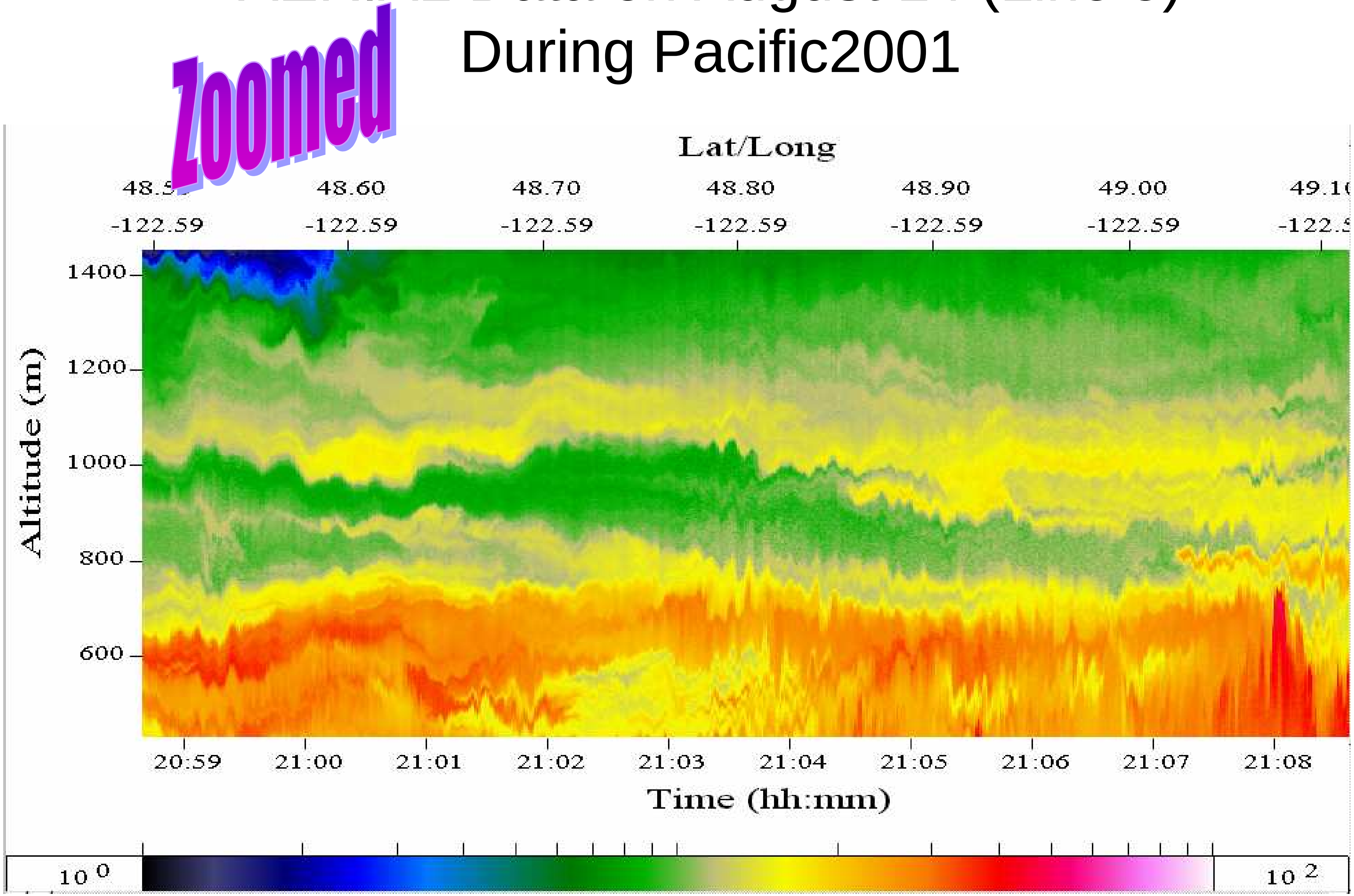
Fig. 1 The vertical diffusion coefficient $\nu(L)$ as a function of the turbulence scale L. Empirical points after Richardson.[19]

AERIAL Data on August 14 (Line 5 N-S) During Pacific2001

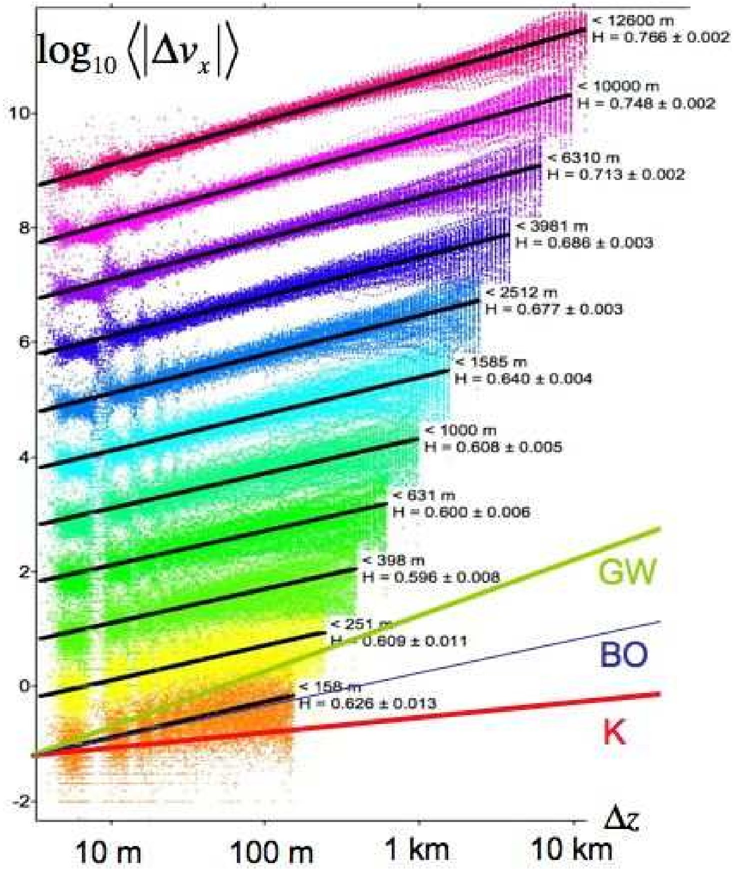


Lilley et al. Phys. Rev. E, 2004

AERIAL Data on August 14 (Line 5) During Pacific2001

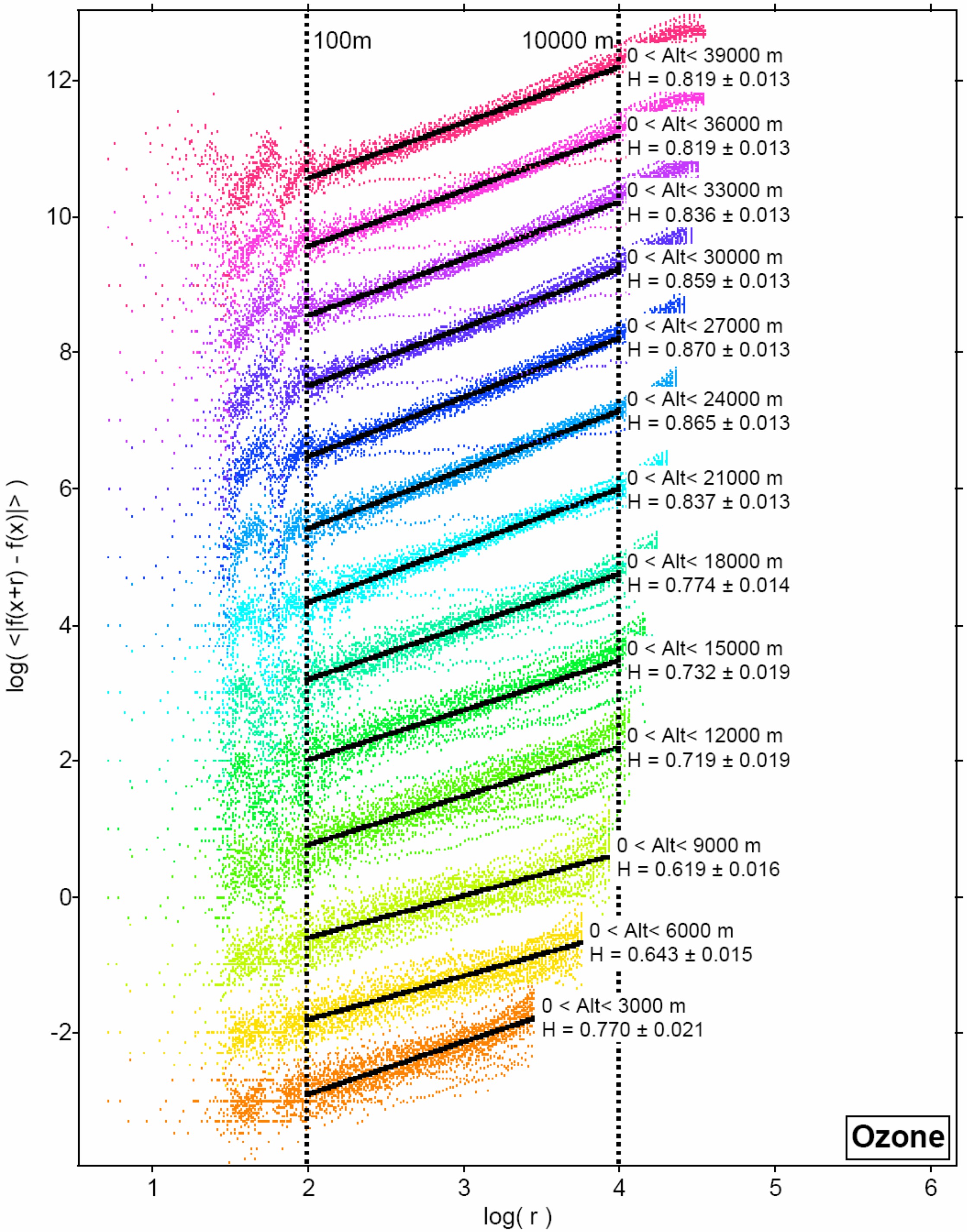


NOAA Winter Storms 04 experiment
(Pacific Ocean, 261 sondes, 13 km altitude)



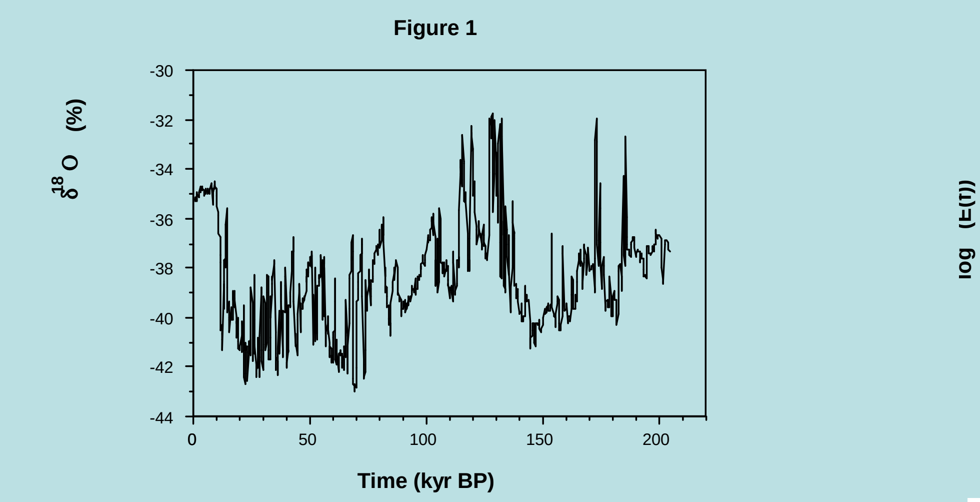
rms fits to the sonde mean absolute vertical shears of horizontal wind for layers of thickness increasing logarithmically. The reference lines have slopes:
H=1/3 (Kolmogorov), H=3/5 (Bolgiano-Obukhov), H=1 (gravity waves)

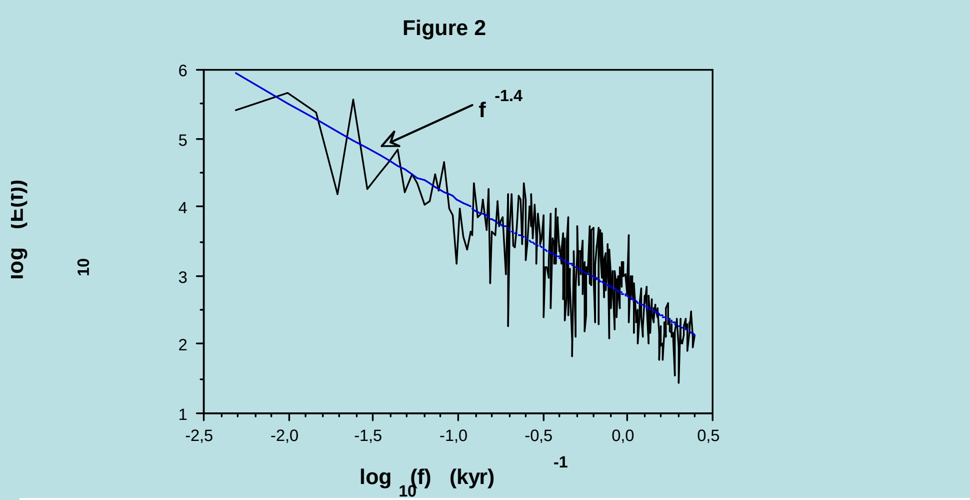
(Lovejoy et al., GRL, 2007).



100m
10000 m
0 < Alt< 39000 m
H = 0.819 ± 0.013
0 < Alt< 36000 m
H = 0.819 ± 0.013
0 < Alt< 33000 m
H = 0.836 ± 0.013
0 < Alt< 30000 m
H = 0.859 ± 0.013
0 < Alt< 27000 m
H = 0.870 ± 0.013
0 < Alt< 24000 m
H = 0.865 ± 0.013
0 < Alt< 21000 m
H = 0.837 ± 0.013
0 < Alt< 18000 m
H = 0.774 ± 0.014
0 < Alt< 15000 m
H = 0.732 ± 0.019
0 < Alt< 12000 m
H = 0.719 ± 0.019
0 < Alt< 9000 m
H = 0.619 ± 0.016
0 < Alt< 6000 m
H = 0.643 ± 0.015
0 < Alt< 3000 m
H = 0.770 ± 0.021
Ozone
log(<|f(x+r) - f(x)|>)
log(r)

GRIP Greenland Ice Core





High resolution (200 yr average) record the GRIP Greenland ice core (Johnsen et al., 1992; GRIP members, 1993; Dansgaard et al., 1993):

•3,000 m long, 1,200 data points

• sharp fluctuations at small time scales.

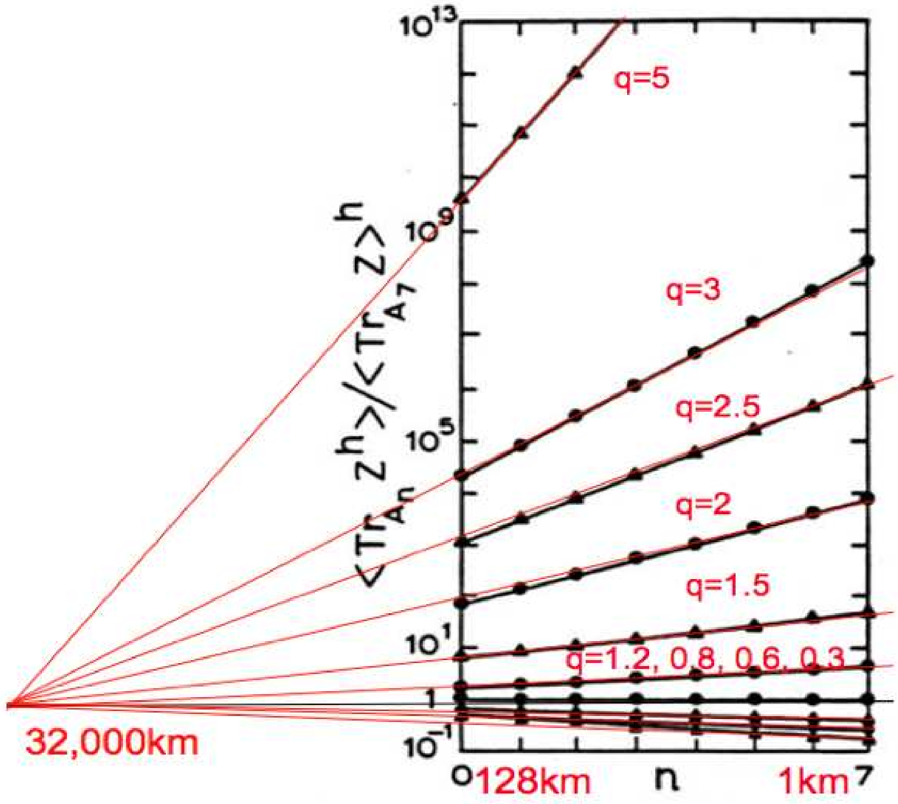
The power spectrum of the data (log-log plot);

•global straight line is an indication of scaling.

•no obvious frequency at (20 kyr)$^{-1}$ or (40 kyr)$^{-1}$

Schmitt et al., GRL, 1995

Outer scale of rainfall (ground radar)?



Normalized radar reflectivity from CAZLOR maps at 3km altitude over a three week period (McGill weather radar, 10 cm wavelength, 0.96^o angular resolution, 1 km pulselength. The maximum range determined by keeping the resolution to 1km and the curvature of the earth (S+L, JGR 1987) .

Outer scale of Clouds (NOAA +GMS)

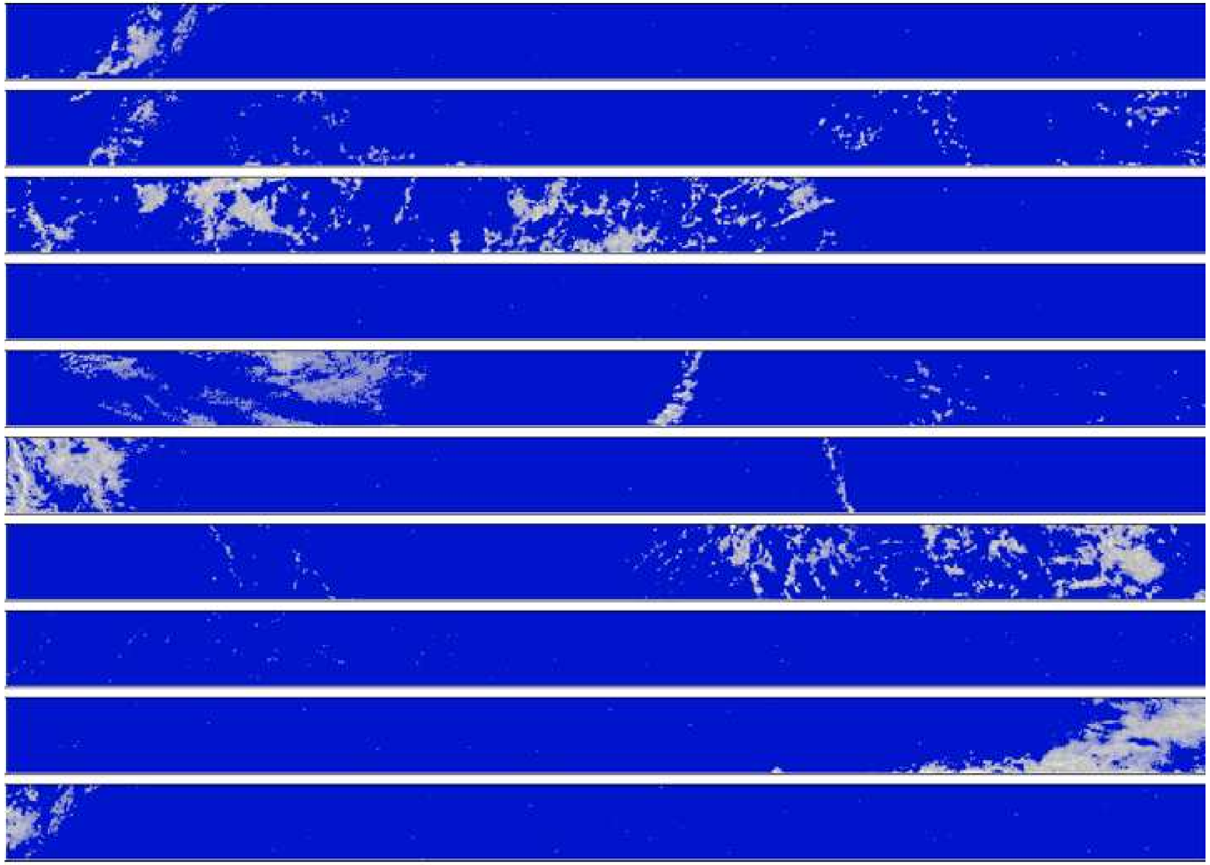
The multiscaling of the moments ($<\varphi_{\lambda}^{q}>$ vs scale ratio $\lambda = L_{eff}/l$ for fields degraded to resolution *l*; and the effective
outer scale L_{eff}=20,000km.

a) NOAA 12 infra red, b) NOAA 12 visible, c) NOAA 14 infra red, d) NOAA 14 visible, e) GMS-5 infra red, f) GMS-5 visible

909 Satellite images (≈ 10^{9}data points)

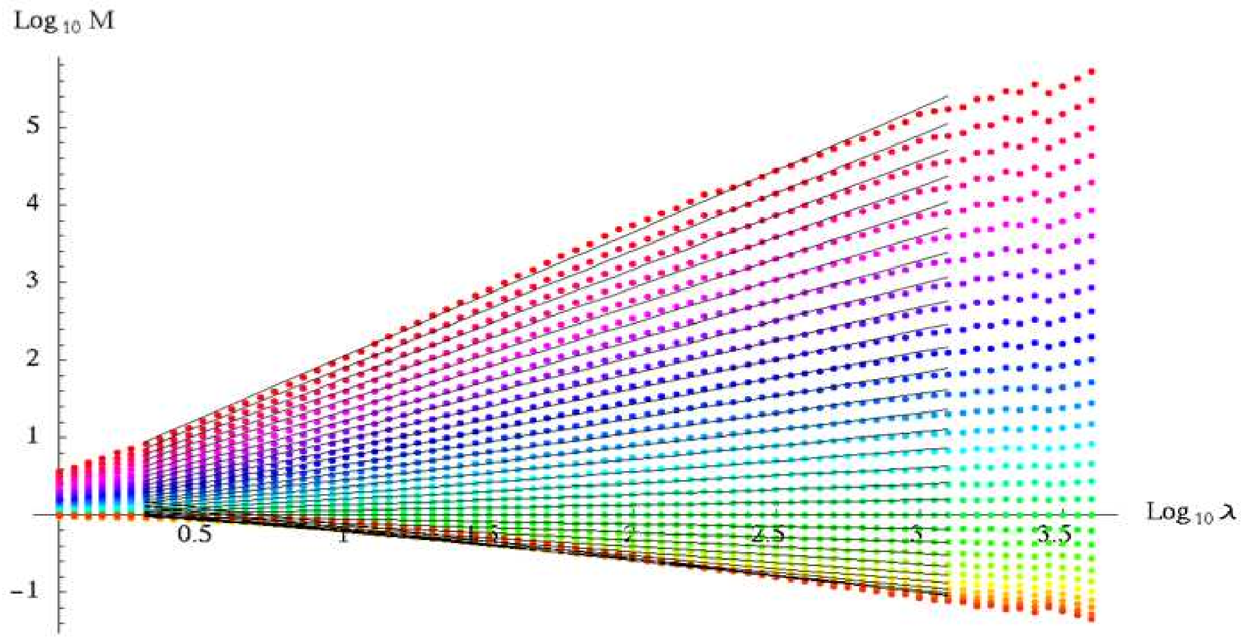
Lovejoy, Schertzer, Stanway , PR□L, 2001

Outer scale of rainfall (TRMM)



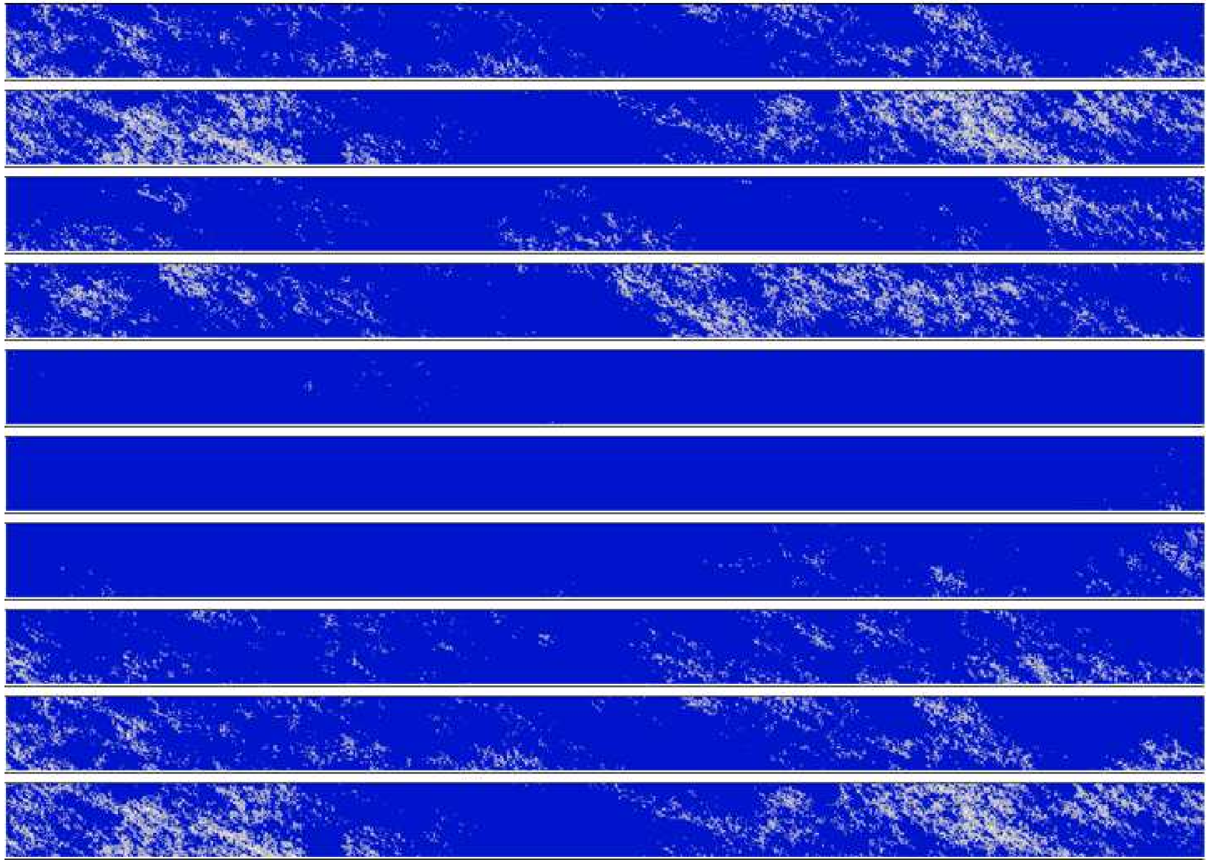
Log(Z) of a single TRMM orbit (49 x 9980 pixels), blue= under signal detection threshold

Outer scale of rainfall (TRMM)



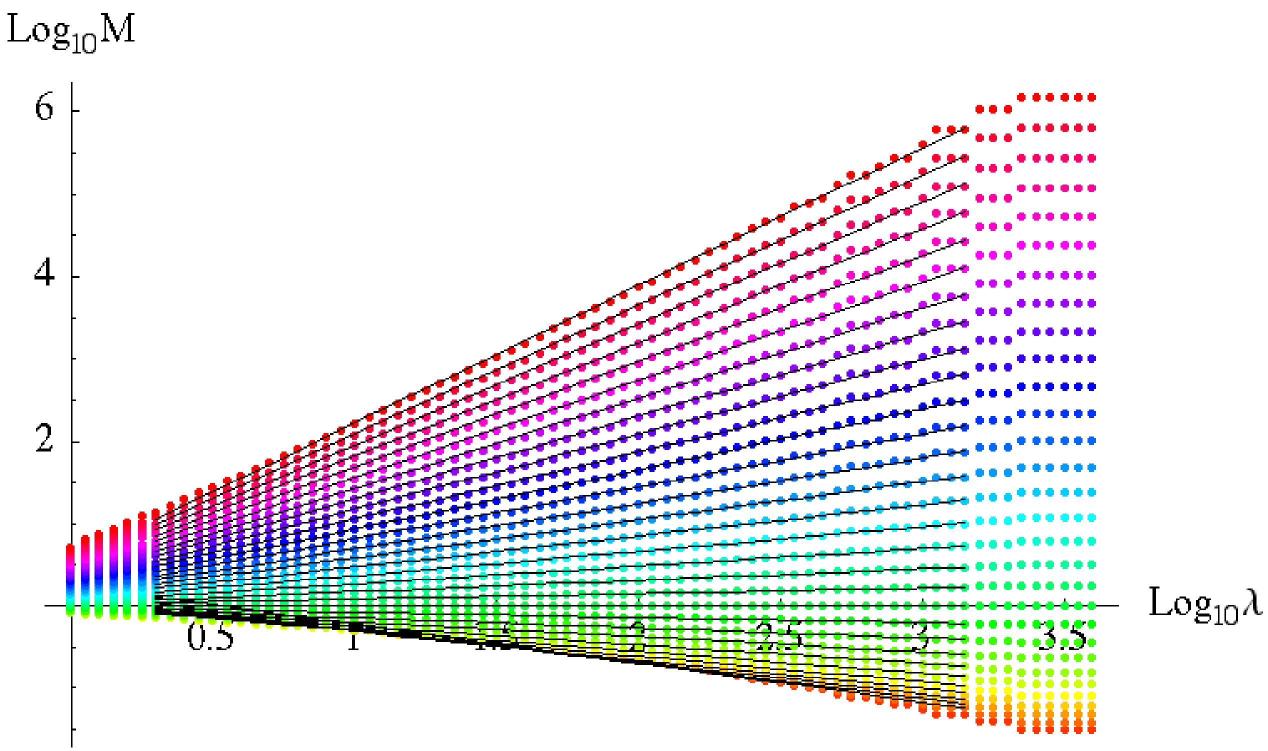
Log of the moments of reflectivity, normalized by the mean over all the orbits $<Z_1>$, of order q=0-3, $\delta q=0.1$, $\lambda = L_{earth}/L$ L_{eaerth} =20,000 km, black lines are linear regressions.

Outer scale of rainfall (TRMMsimulation)



Log(Z) of a simulated TRMM orbit data (C_1=0.63, α=1.5), blue= under signal detection threshold = men/2

Outer scale of rainfall (TRMM simulation)



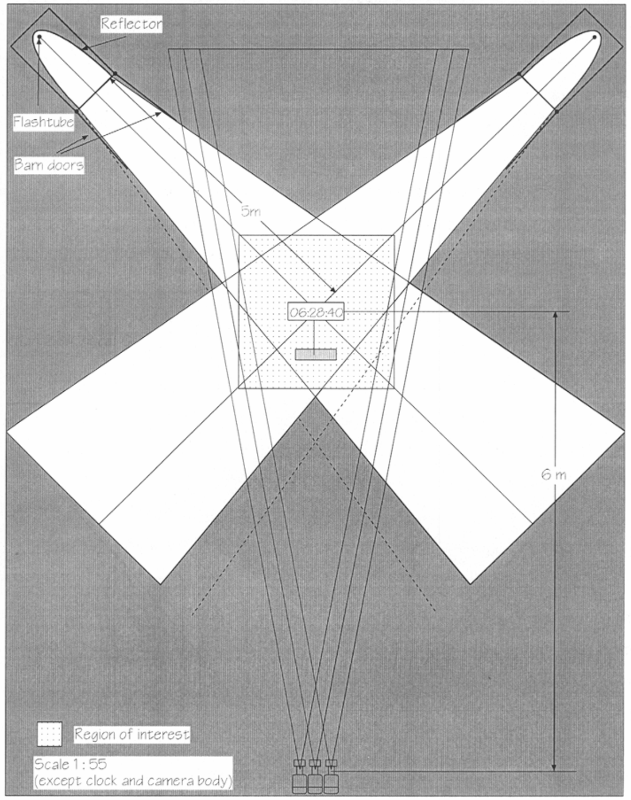
Log of the moments of the simulated reflectivity, normalized by the mean over all the orbits $<Z_1>$, of order q=0-3, δq=0.1, $\lambda = L_{earth}/L$ L_{eaerth} =20,000 km, black lines are linear regressions.

(Lovejoy et al., J. Atm. Res, .2007)

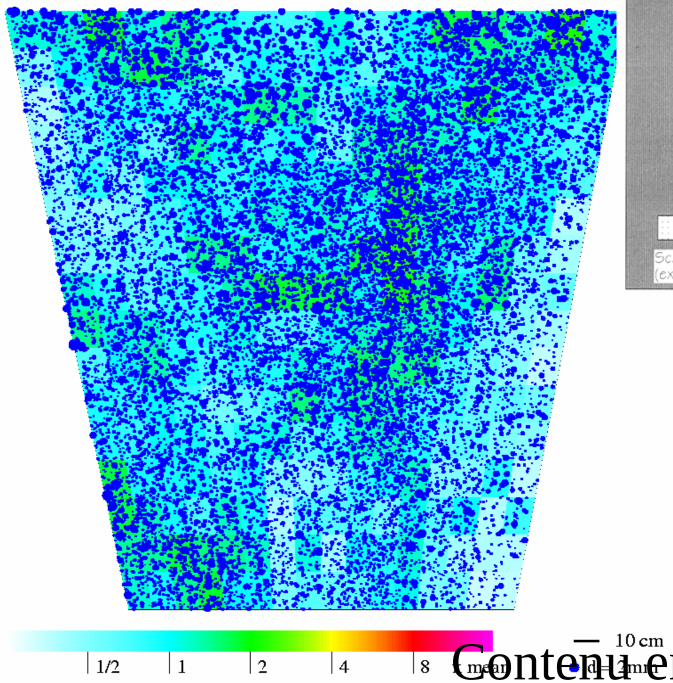
L’expérience Hydrop

Schéma montrant la place des flashs et des appareils photographiques

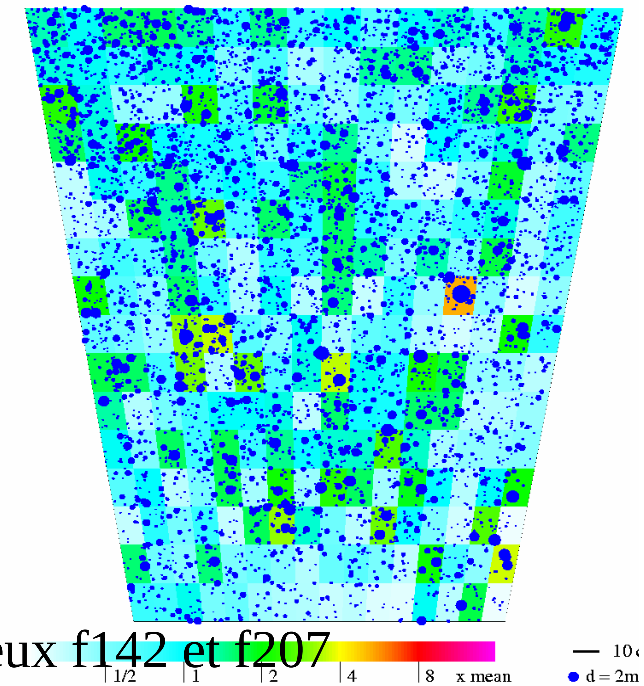
(Desaulniers-Soucy et al., Atmosph. Res. 2001)



Analyse multifractale: transition directe gouttes individuelles -> champ multfractal
(Lovejoy et al, PRL 2003, J. Hydrology, Lilley, 2006)



Projection along x of lwc density field from f207_12h38m50s_new, lambda= 16



Projection along x of lwc density field from f142_07h05m49s_new, lambda= 16

Contenu en eau des évenements pluvieux f142 et f207

f295,
11293
drops

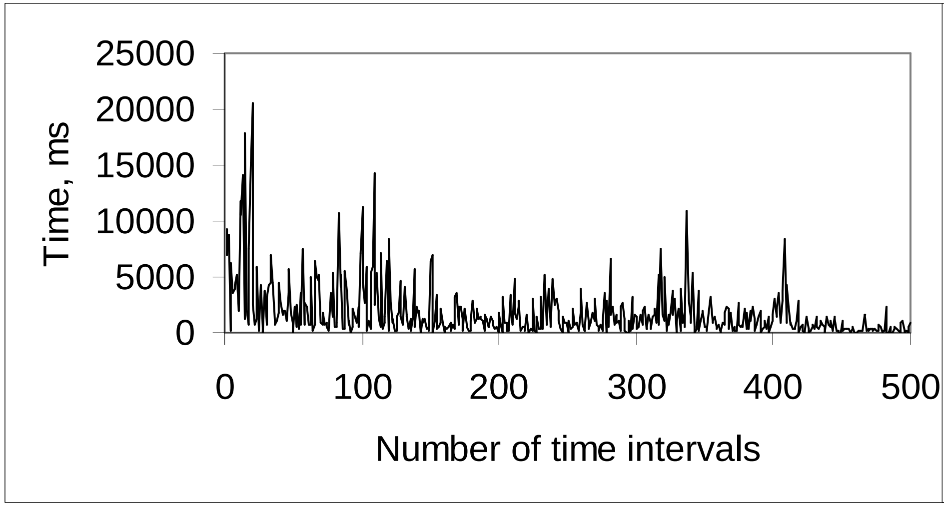
1m

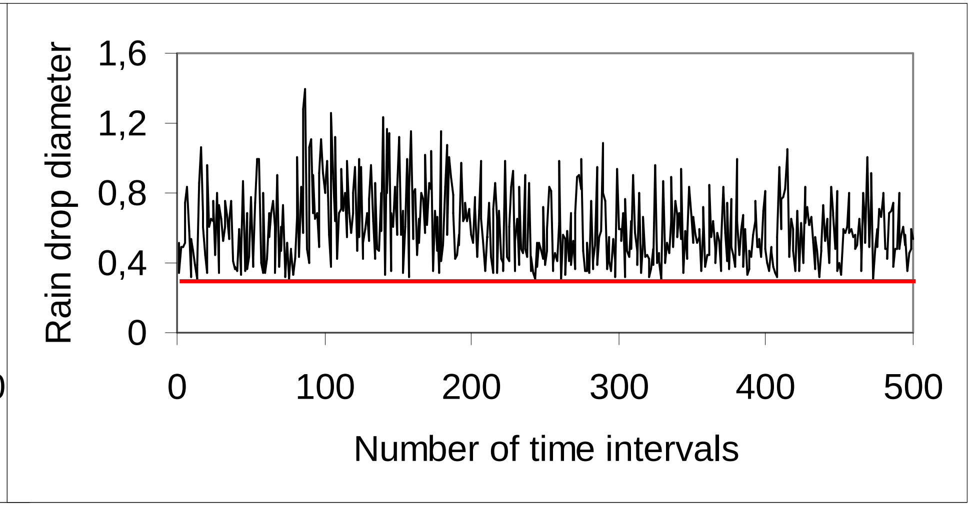
QuickTime™ and a
Animation decompressor
are needed to see this picture.

Les plus petites échelles de la pluie

Expérience de Grenoble en 1992 (Salles et al.)
lors d'un évenement pluvieux de 26 mm (selon un auget basculant)
Optical Spectro Pluviometer (OSP)

<u>Rapport</u> Λ_T: ≈ 10^8





Exemple d'un enregistrement des intervalles de temps entre gouttes

Exemple d'un enregistrement des diamètres de gouttes

Rain at Laboulaye (Argentina, 1982-2000)

rainrate

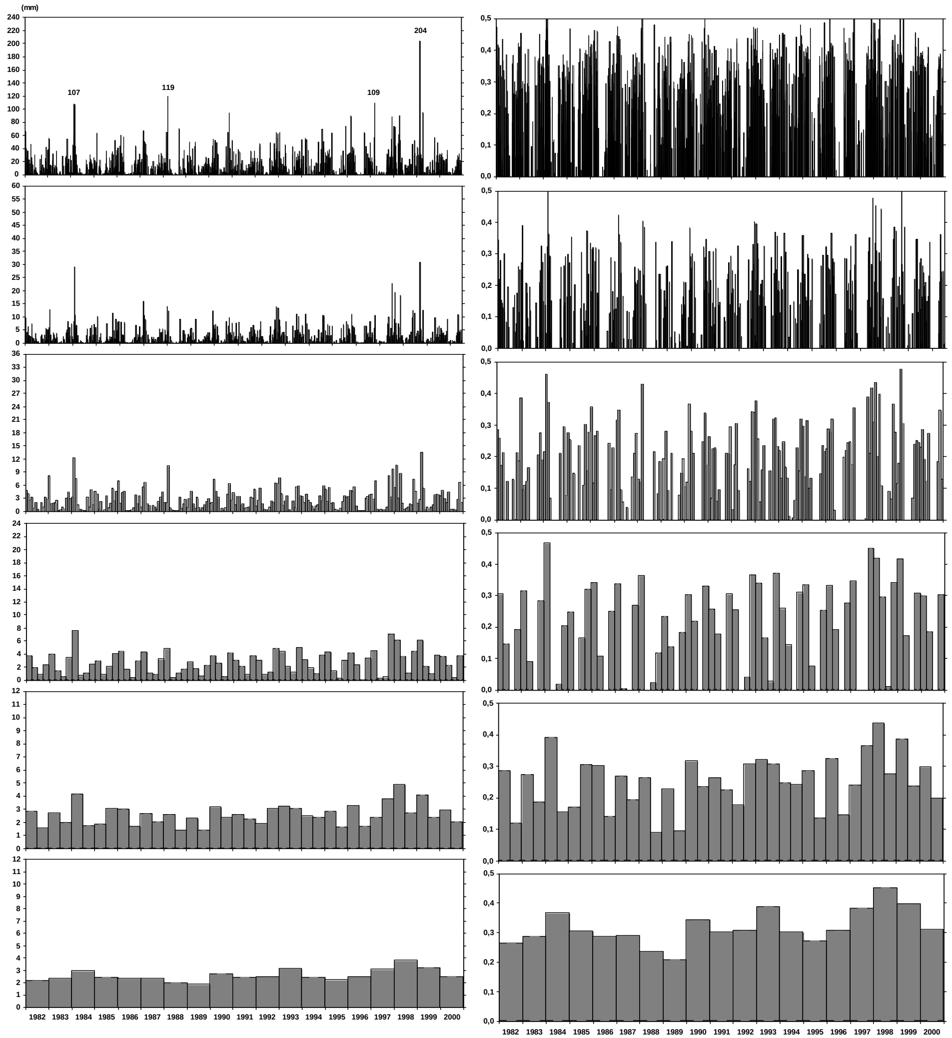
R_λ

at resolution

$\lambda = 1/N$

N =1, 10, 30, 90, 180, 365 days

Scale dependence



singularities

γ

$\gamma = Log_\lambda(R_\lambda)$

NO scale dependence !

singularities = key variables for multifractal analysis !

Precipitation scaling exponents and extremes

- Rainrate rather conservative: $H \approx 0$
- Rain intermittency
  - Mean intermittency:

It does not rain every day and/or everywhere:

C_1 measures how scarce is the rain: $C_1 \neq 0$

↑

- Intermittency variability:

α measures the diversity of rainfall regimes:

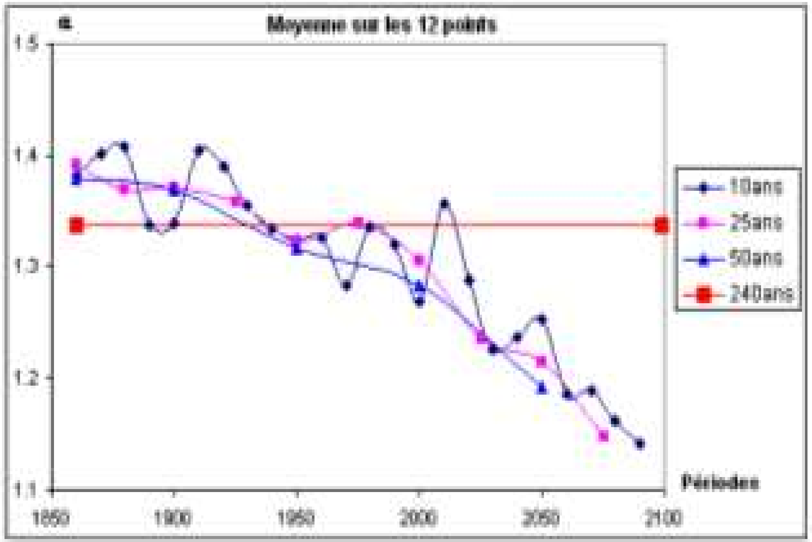
$\alpha = 0$: it rains or it does not

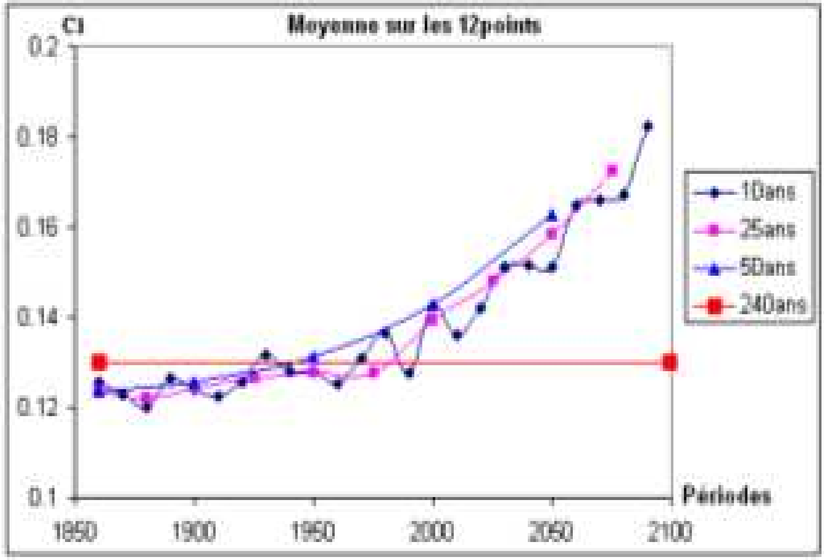
Trivial consequences for extreme

Increasing C_1 et α => increasing extremes

Decreasing ‘’ => Decreasing ‘’

Contradictory evolution!





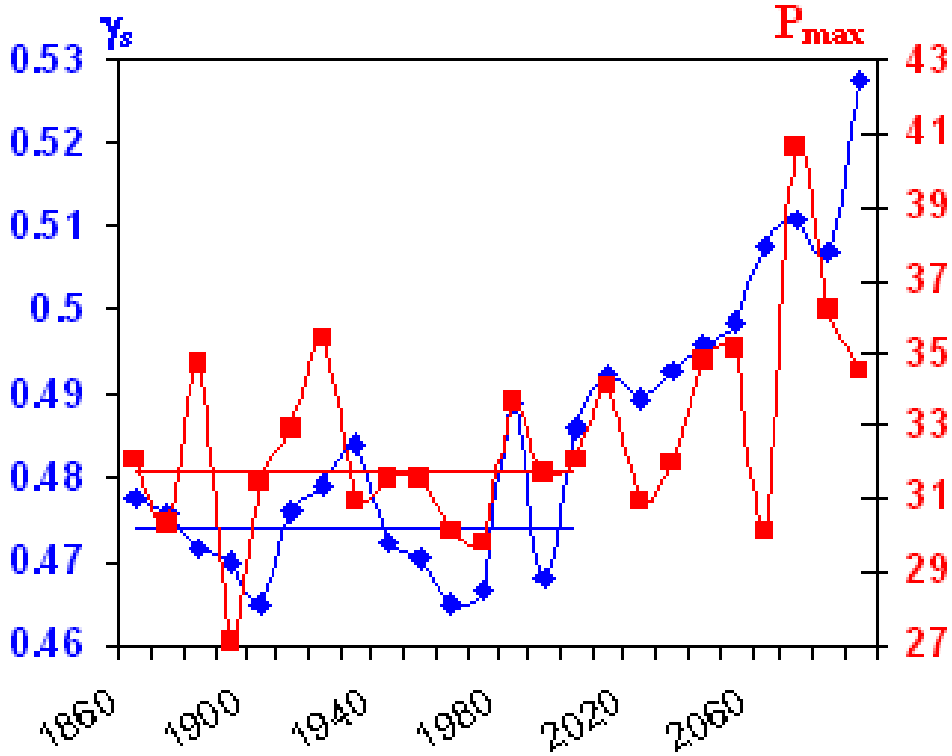
C_1 increases, α decreases
évolution of extremes?

Does it explain the complexity of the present debate ?

Refined analysis

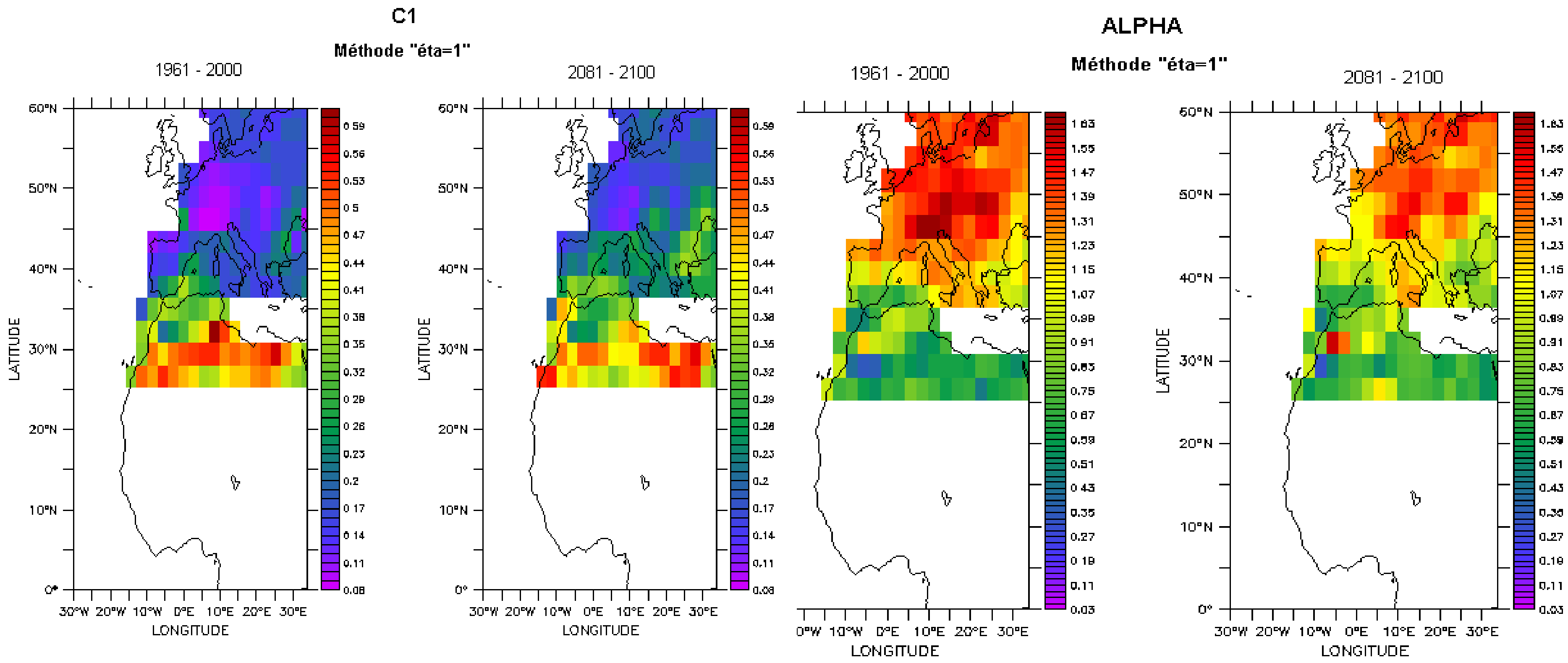
Look for the “Maximal Probable Singularity” γ_s (*) for a unique sample:

1. probability space well defined,
2. analytically defined by C_1 et α
3. scale independent,
4. much more stable than P_{max}



(*) Hubert et al., JGR, 1993; Douglas &Barros J. Hydro, 2003

Spatialisation de cette étude (AMMA)



R. Dupeuble et S. Siang-Chye, 2007

conclusions

- Problème central des échelles:
  - dans l'analyse des données
    - *dures* ou *molles* et leur inter-comparaison,
    - pour comprencre l'instationarité,
    - pour déterminer les extrêmes,
    - évidence d'une évolution contradictoire de α et C1.
  - modélisation:
    - 'descente en échelle' pas suffisante en soi !
    - interactions sur grandes gammes d'échelle indispensable:
      - Version *optimiste*: convergence *rapide*,
      - Version *optimiste:* convergence *lente !*
    - Intercomparaison avec les données dures plus indispensable que jamais!
    - Exercice concret : R2DS/GARP-3C

Scaling vs. GCM’s (1993)

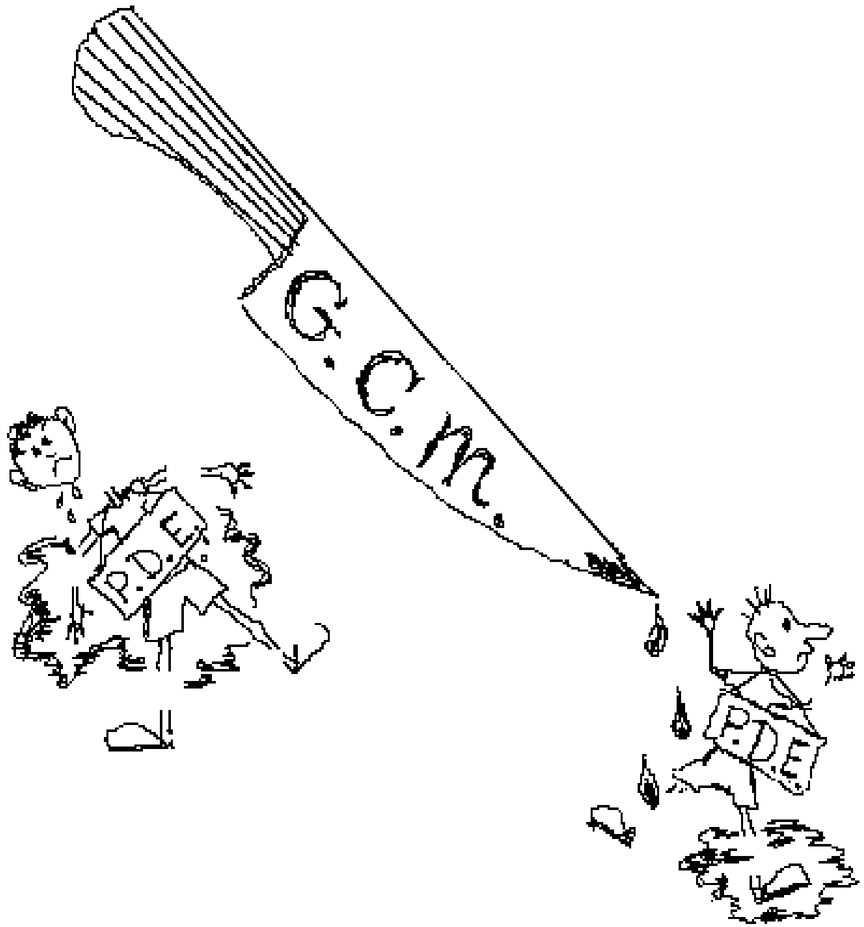
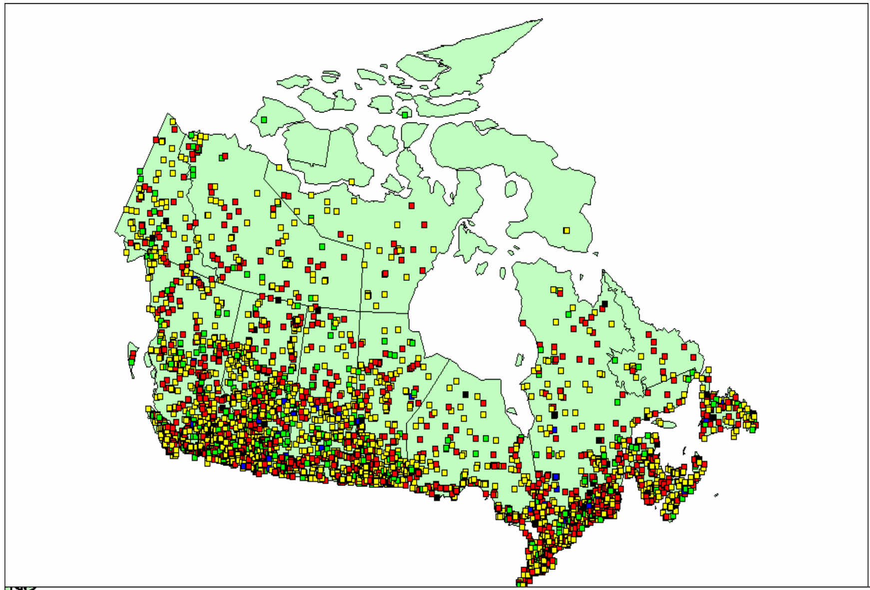
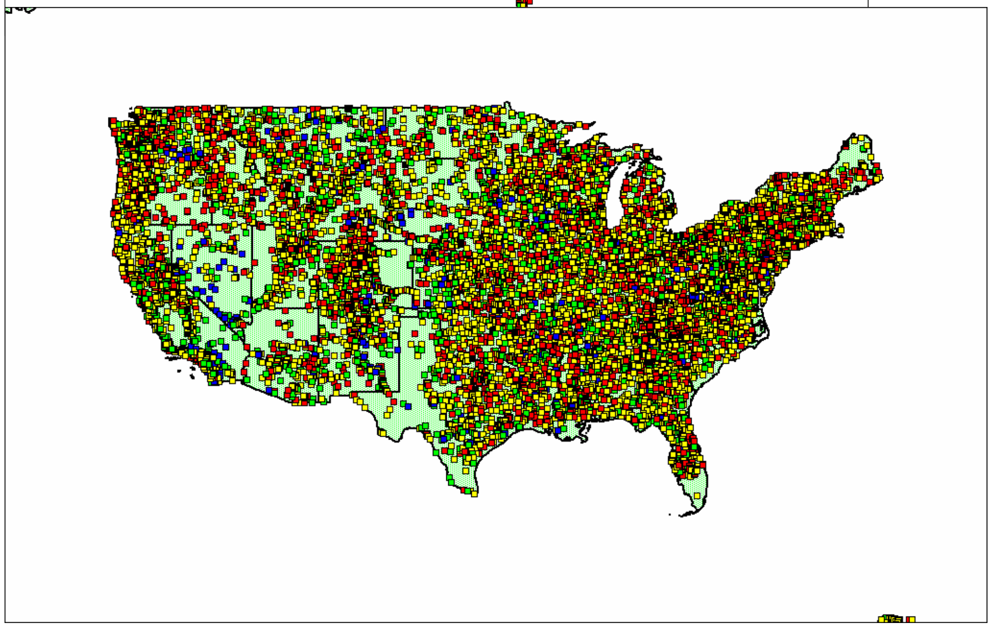


Figure 2— the drastic reduction of Partial Differential Equations to Ordinary Differential Equations in General Circulation Models (and in similar unwieldy numerical codes for geophysical simulations) is often ignored [S+L, NVAG, lecture Notes, 1993]

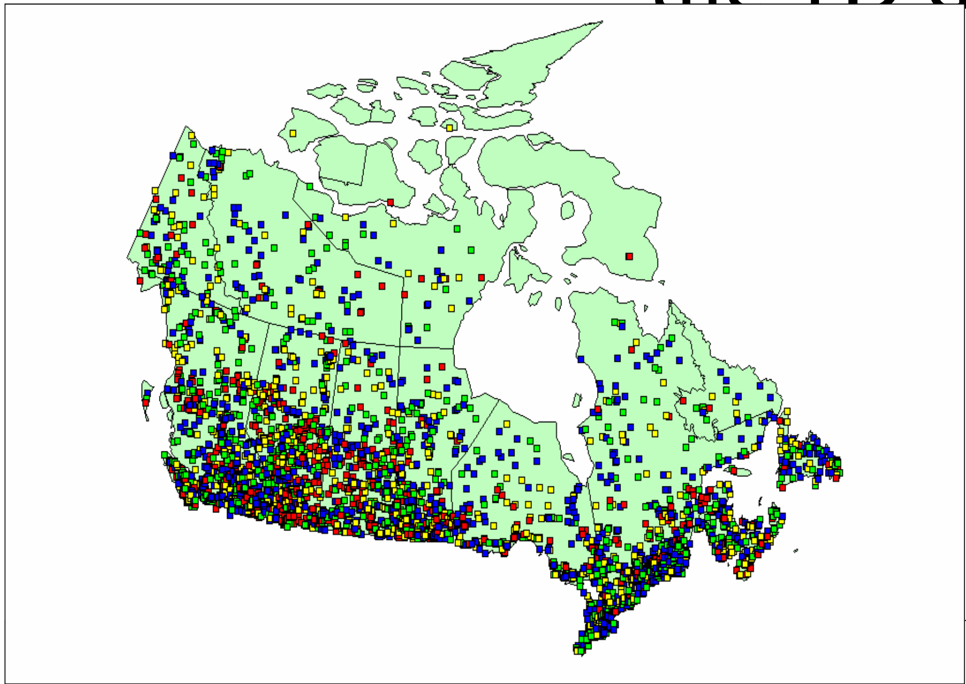
Results and maps obtained over the 1B data base

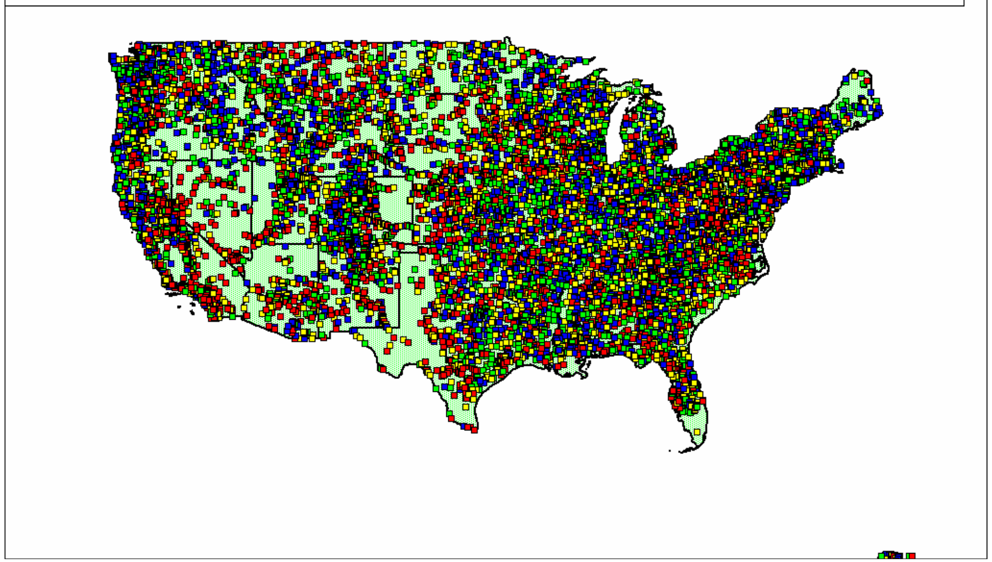




Multifractal parameter α:
>2 (1%; black);
2.0-1.5 (about 30%, red),
1.5-1.0 (about 52%, yellow),
1.0-0.6(about 15%, green),
<0.6 (about 2%, blue)

Results and maps obtained over the 1B data base



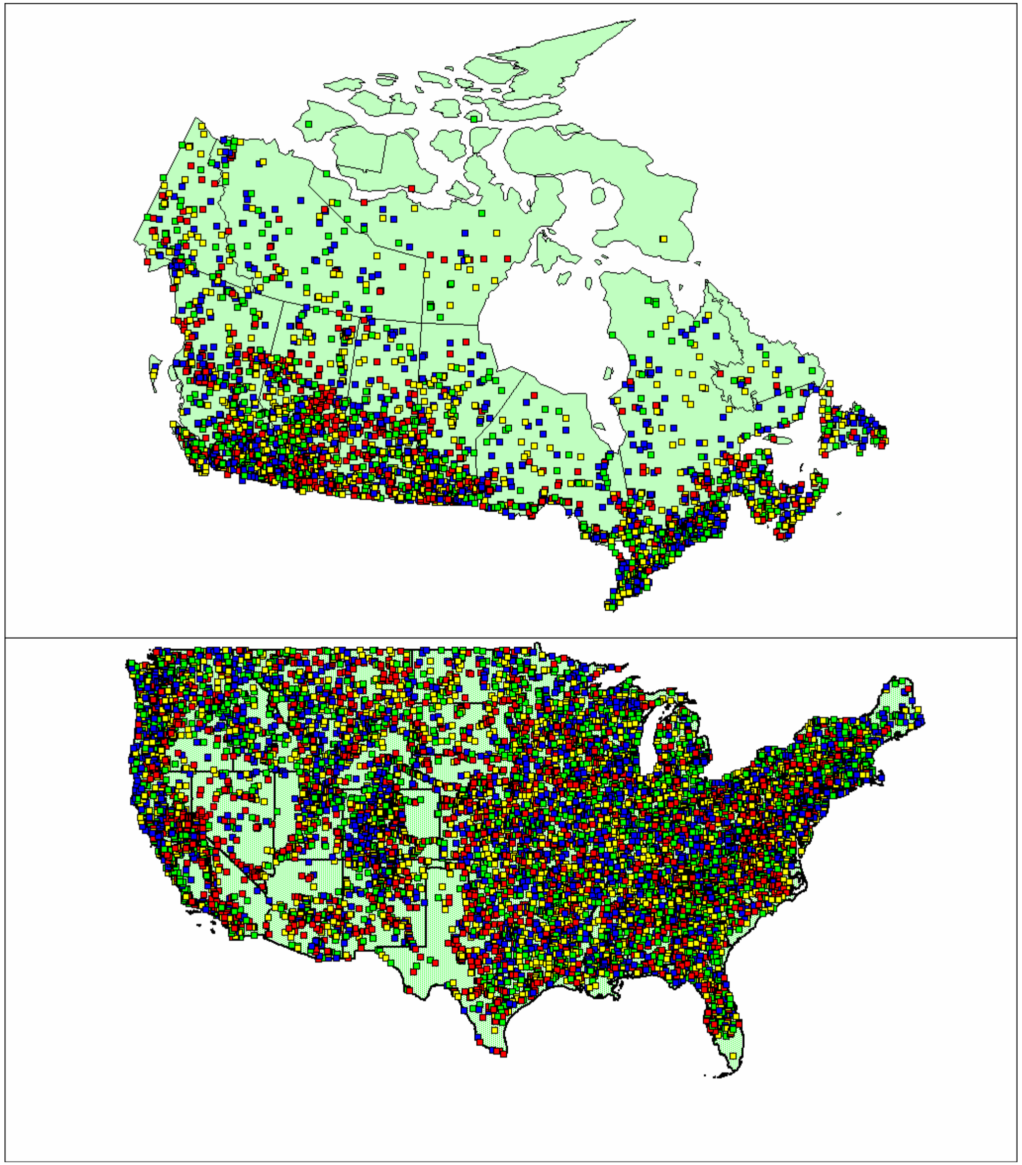


Multifractal parameter C1: about equally 25% between 0.9-0.2 (red), 0.15-0.2 (yellow), 0.1-0.15 (green) and 0.01-0.1 (blue).

Results and maps obtained over the 1B data base

Theoretical

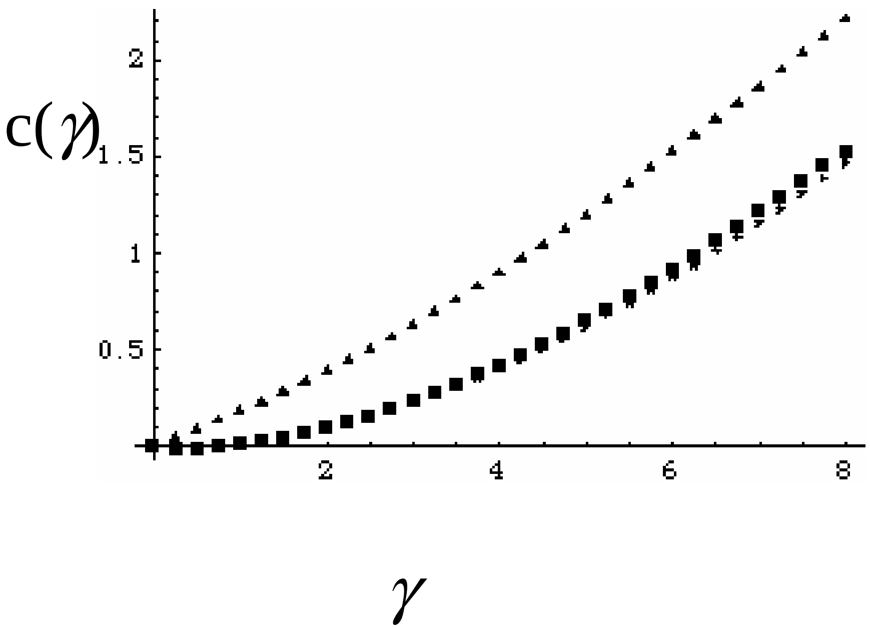
singularity γ_s :
about equally 25%
between
0.6-1.0 (red),
0.5-0.6 (yellow),
0.4-0.5 (green) and
0.1-0.4 (blue).



Probabilities and codimensions

$$\gamma = Log_{\lambda}(R_{\lambda})$$

$$c(\gamma) = -Log_{\lambda}(\Pr(\gamma' > \gamma))$$



Similarly to rain vs. singularities:

– probabilities are **scale dependent**,

– their logarithm (base λ),

'multifractal codimensions',

are **NOT scale dependent**

•return periods,

•IdF and QdF curves,

defined by multifractal parameters

Multifractal quantification

1. the scaling exponent H (often called Hurst exponent) of the statistical average :
2. the codimension C_1 (≥ 0) measures the clustering of the (average) activity at smaller and smaller scales;
3. the multifractality index α measures the clustering variability w.r.t. activity level
4. the exponent q_D ($0 < q_D \leq \infty$) of the power-law distribution of the extremes (Pareto law for $q_D < \infty$).

$$< R_\lambda > \approx \lambda^H$$

$$\Pr(R_\lambda > s) \approx s^{-q_D}$$

$$s >> 1$$

Scaling of rainrate (R) w.r.t. to time (OSP measurement)

TM: **statisical moments** :

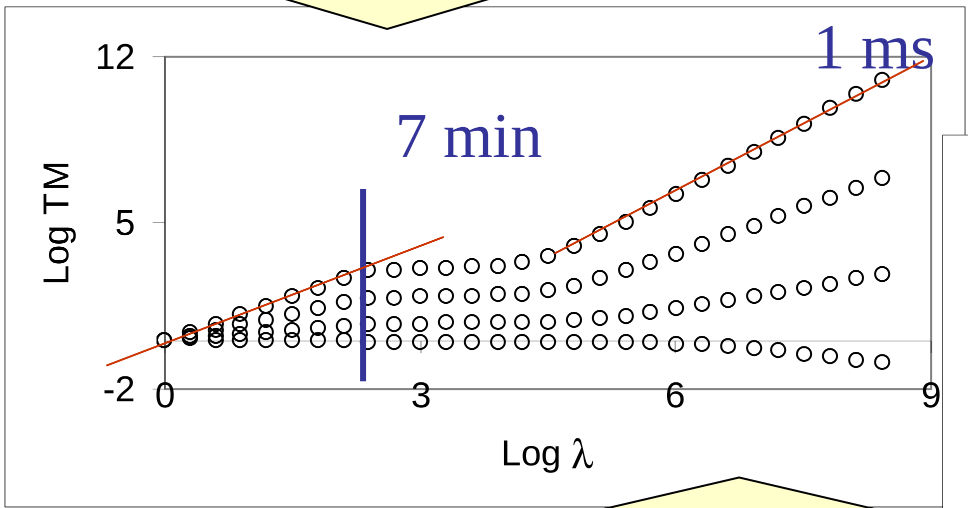
$$< R_\lambda^q > \propto \lambda^{K(q)}$$

λ is the (time) resolution,

< . > is the mathematical expectation,

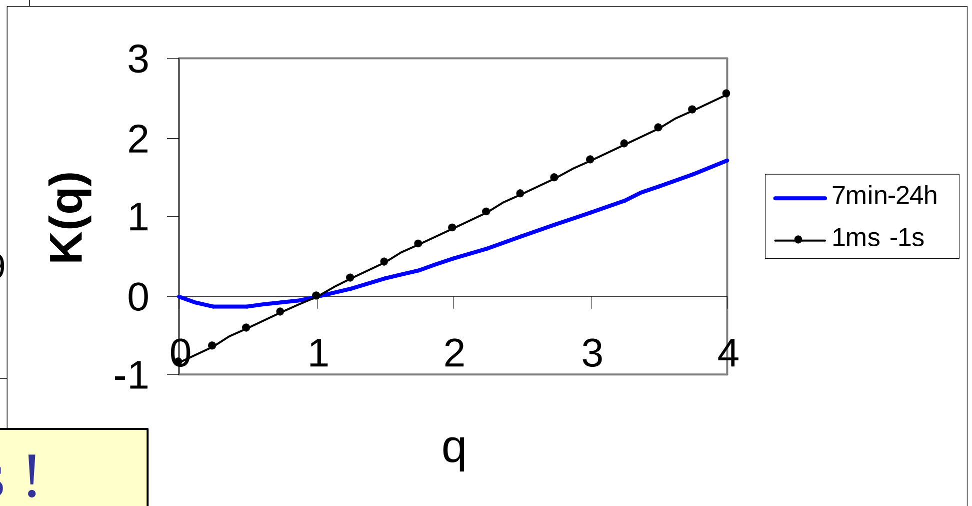
K(q) is the scaling exponent

Drops start to have a collective behavior



Too many zeroes !

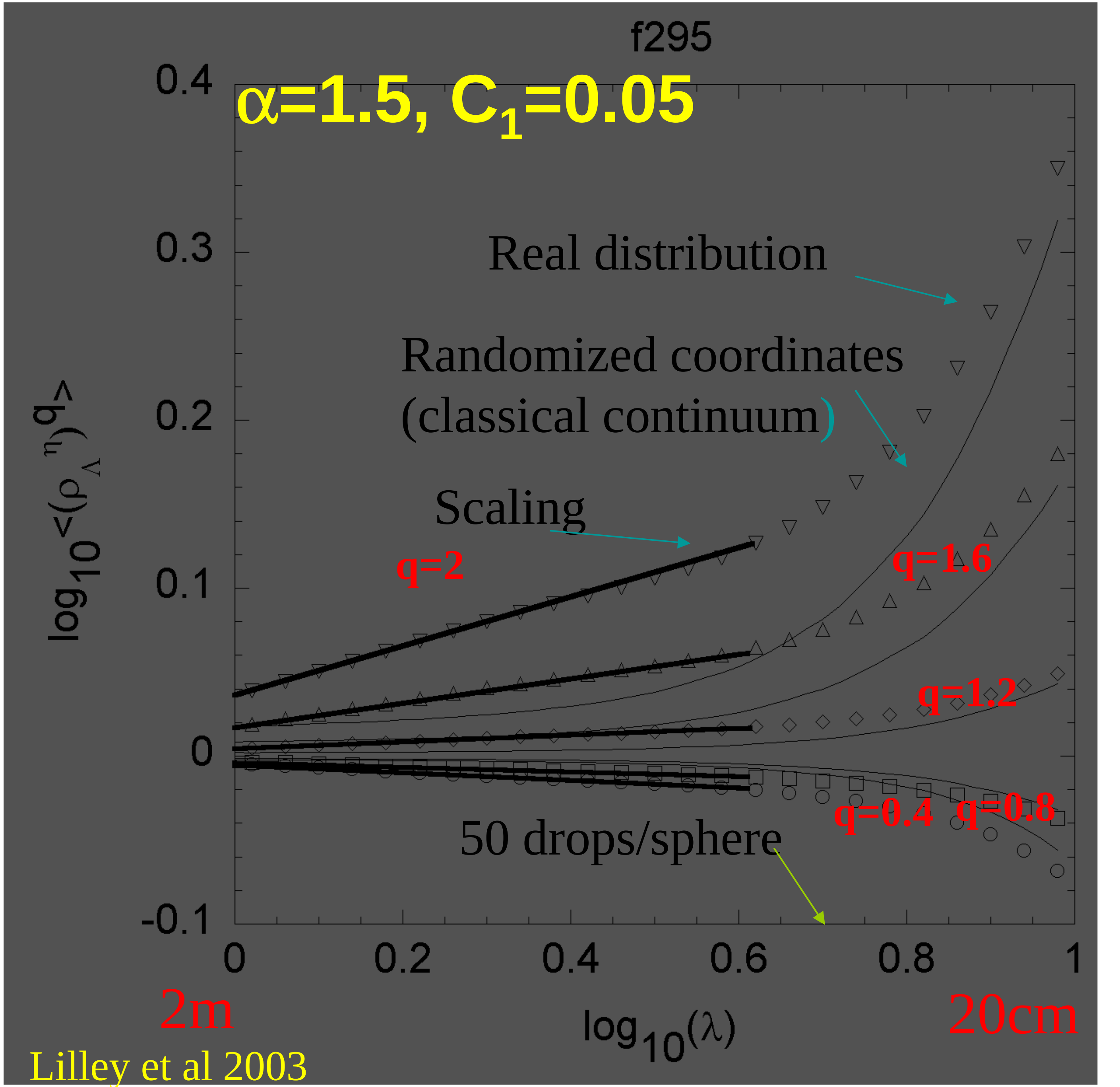
(diameter > 0,3 mm)



Water volume distribu-tion η=1 f295

$$\left\langle \left(\rho_{\Lambda}^{\eta}\right)_{\lambda}^{q} \right\rangle = \lambda^{K(q,\eta)}$$

15,000 drops



Lilley et al 2003