SELF-SIMILAR CLUSTERING IN THE SEQUENCES OF VOLCANIC ERUPTIONS

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General approach

We consider clustering of events

OVER TIME ONLY

(ignoring any behavior in *space*)

We consider clustering of events

TAKNG INTO ACCOUNT THEIR *SIZE*

(this is not usual, and is a specific property of our approach)

We consider volcanic sequences only of

CALIBRATED EVENTS

(with size estimates; accuracy may be limited)

We consider only data sets that are

COMPLETE OR NEARLY COMPLETE

General approach(2)

We look for
self-similar, or ***fractal, clustering behavior***.

The main assumption in such an approach is that the system in question has **no intrinsic time scale**,
or characteristic time, or characteristic period,
(like typical repose time of a volcano).
(*In a case that such a periodic tendency exists,
it will be noticed in the course of analysis*).

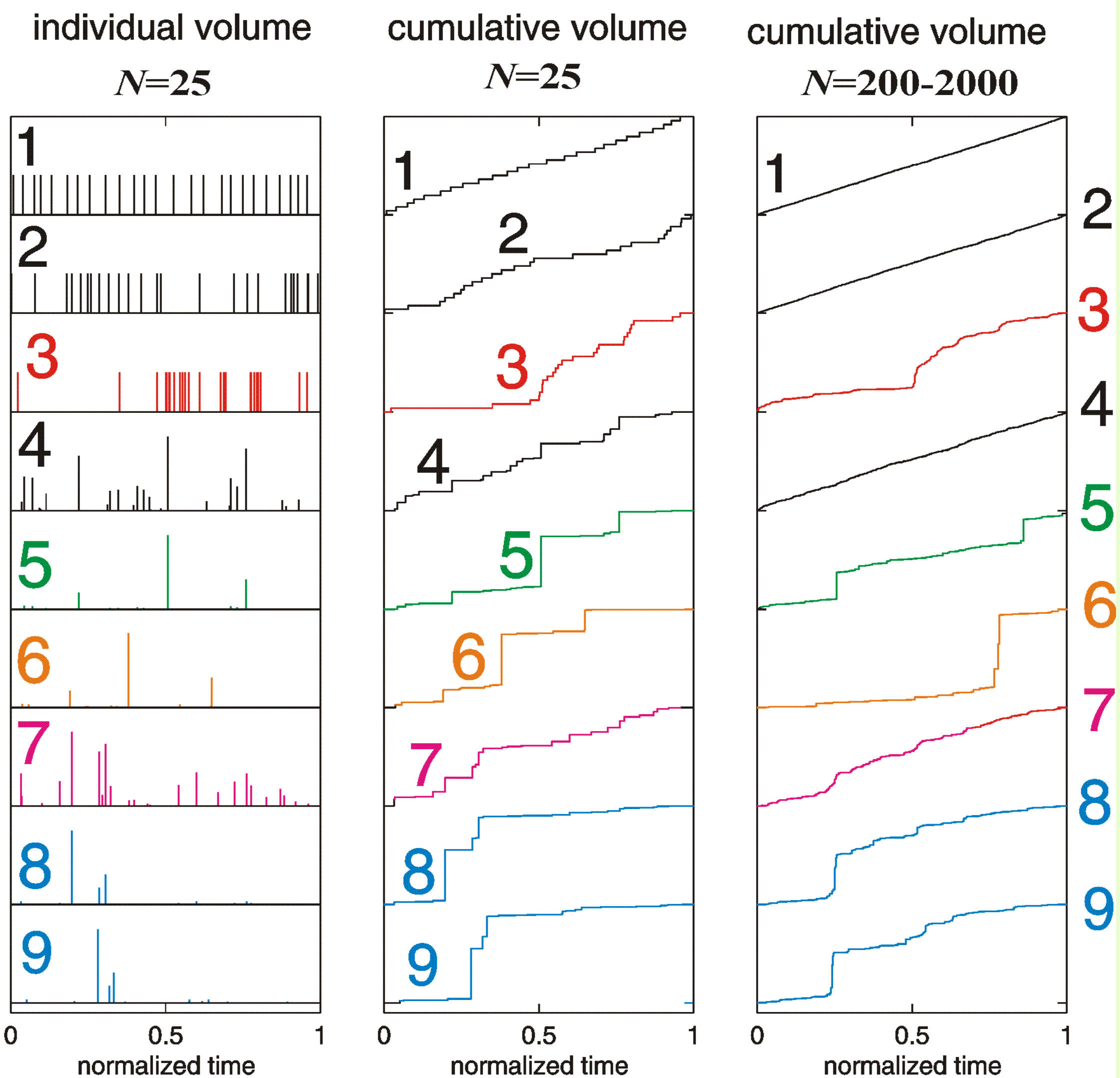
Self-similar behavior: any segment of the process can serve as a compressed copy of the process
common examples: river network; mountain relief

forms of irregularity

VARIOUS FORMS OF IRREGULARITY

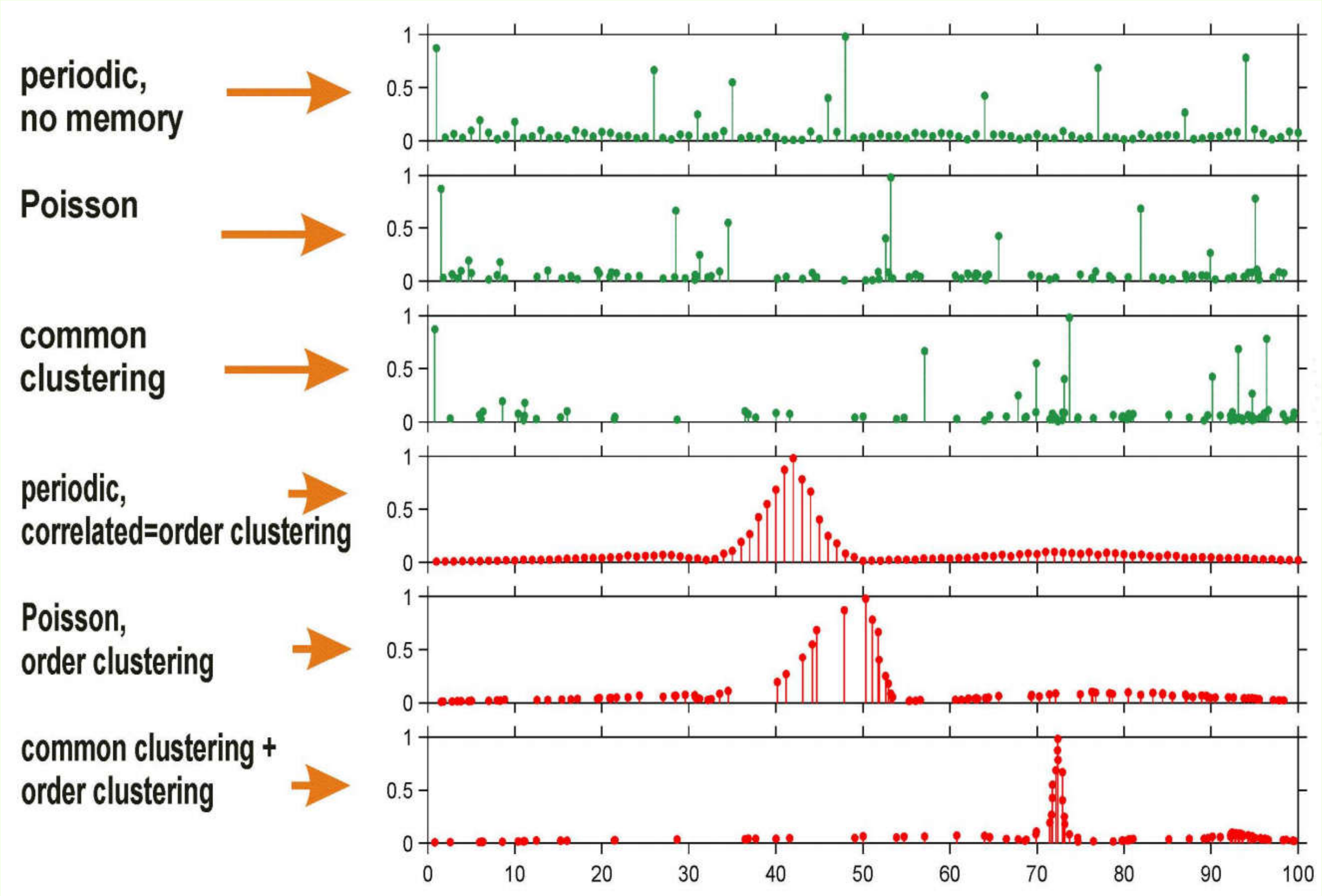
MODE of BEHAVIOR

	TEMPORAL	*SIZE distribution*
1	QUASI-PERIODIC	*CONSTANT size*
2	POISSONIAN ("purely random")	*CONSTANT size*
3	CLUSTERED	*CONSTANT size*
4	POISSONIAN ("purely random")	EXPONENTIAL law
5	POISSONIAN ("purely random")	POWER law
6	CLUSTERED	POWER law
7	POISSONIAN ("purely random") O.C.	EXPONENTIAL law
8	POISSONIAN ("purely random") O.C.	POWER law
9	CLUSTERED O.C.	POWER law



O.C. : "order clustering"

Common clustering and order clustering



If the data behave in a manner that does not contradict the self-similarity assumption,

we determine from them the parameter **D** called **“CORRELATION DIMENSION”**.

Or “**correlation index**”

In case of no clustering, **D =1**, (or **D ≈1)**,

otherwise,

(1) 0 <D <1 and

(2) D <1 significantly in statistical sense

techniques:

(1) in *time domain*, by CORRELATION INTEGRAL

(2) in *frequency domain*, by Fourier transform and determination of POWER SPECTRUM

Common clustering and order clustering: what to measure

We use three modifications of data processing that produce parameters of clustering (e.g., D) values that characterize:

(1) **common clustering only**

based on the event sequence in time,

ignoring event sizes (or assuming unit-size events).

(2) **order clustering only**

from the sequence of "masses" of events, ordered as in reality,

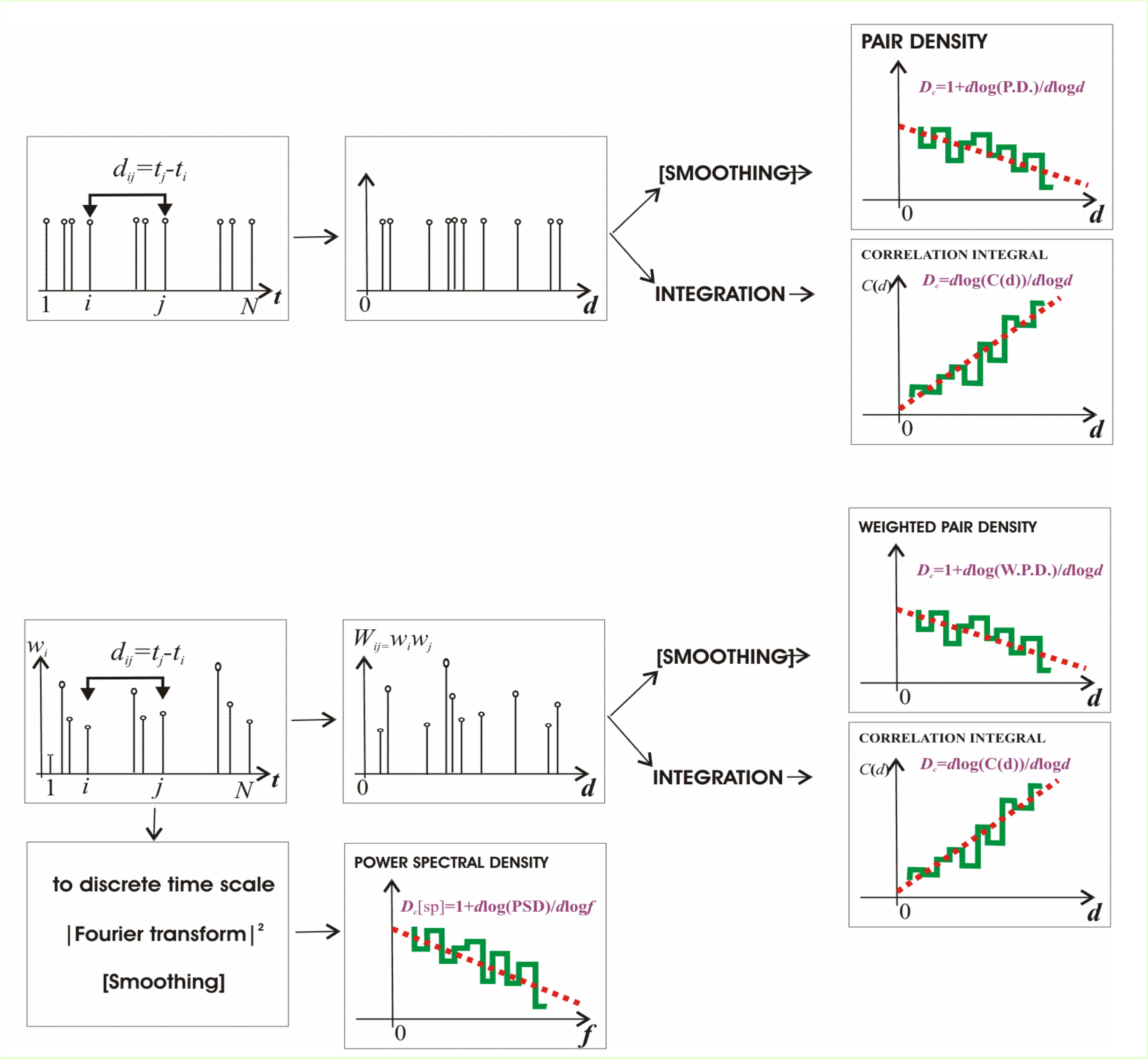
but **ignoring true times,**

assuming unit (or constant) time step between events

(2) **intermittency**, or clustering of the system output/productivity over time, as the joint effect of common and order clustering

from the "massive" event sequence as is

Measuring D_c



Common clustering and order clustering: the concept

Common clustering: $D_c<1$ or $D_s<1$;

event *sizes:* ignored;

event *times:* accurate times bear all information.

essence: **short inter-event intervals appear unusually often**

Order clustering: $D_{c1}<1$ or $D_{s1}<1$:

event *sizes:* *the sequence* of sizes bears all information

event *times*: order only used, true times ignored

essence: **big events occur too often as close neighbors in the time-ordered event list**

Common clustering and order clustering: independence

INDEPENDENCE:

(1) Order and common clustering can *appear* independently in natural event sequences

(2) *Empirical measures* of order and common clustering represent different, independent aspects of data.

FROM A PHYSICAL VIEWPOINT, order and common clustering seem to be two different manifestations of intermittency, or of a general tendency that can be formulated in the following statement:

nature dislike uniformity at all scales.

D_{cm} / D_{sm} is just a measure of such non-uniformity

Common clustering, order clustering and intermittence

Both common and order clustering may contribute to *intermittency*.

____

What is ***intermittency*** of volcanism?

intermittency is an episodic manner of the output of volcanic products;

in other words, production rate of volcanic material is non-uniform or burst-like.___________________

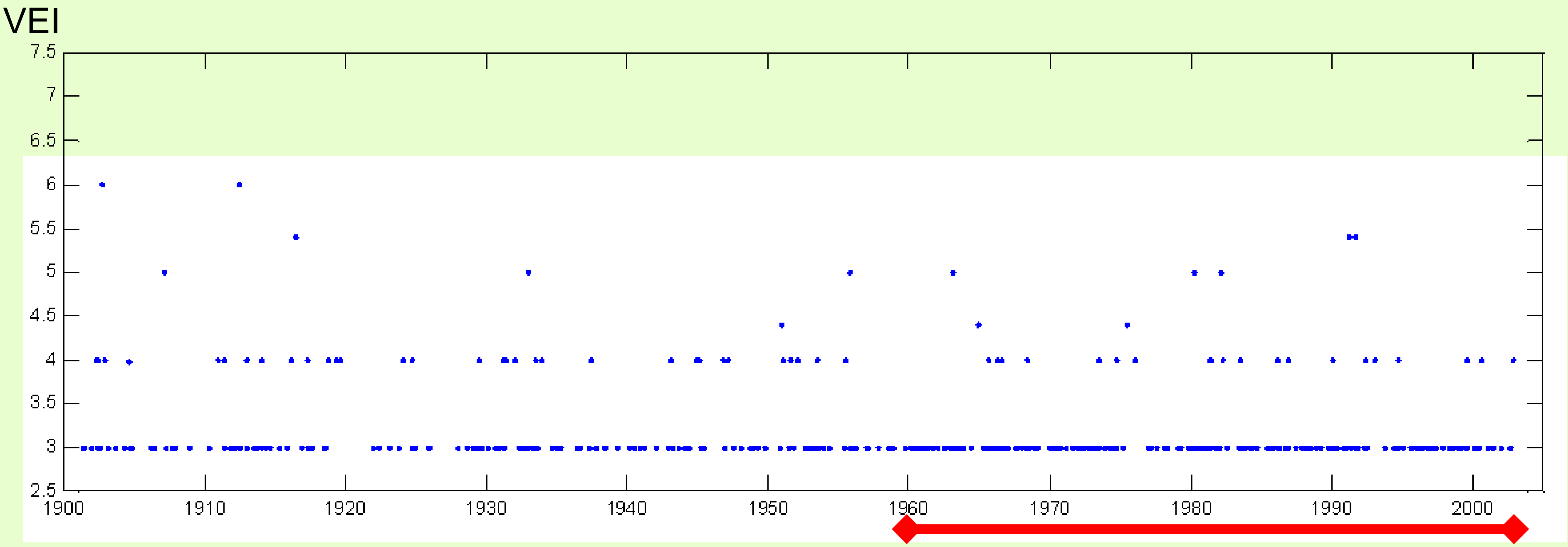
When non-uniformity is of the same manner *on each scale*

intermittency is called *self-similar* of *fractal*

Global eruption catalog of Smitsonian Inst.: selecting window for data analysis

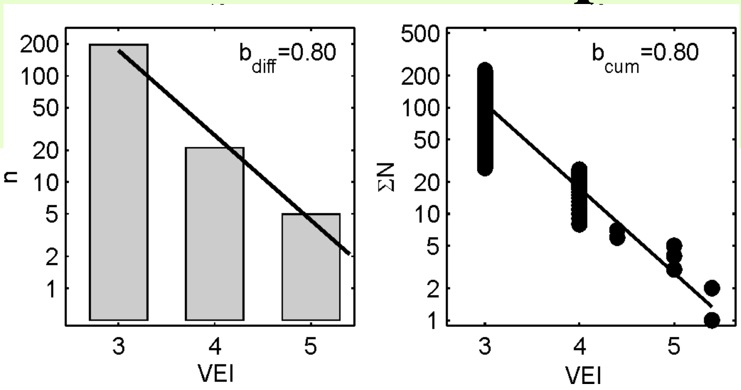
DATA SOURCE: Courtesy of Lee Siebert (Smitsonian Inst., Washington DC, USA)
Siebert, L., T. Simkin (2002-). Volcanoes of the World...(http://www.volcano.si.edu/gvp/world/).

VEI: "volcano explosivity index": a magnitude-like, logarithmic measure of the eruption size

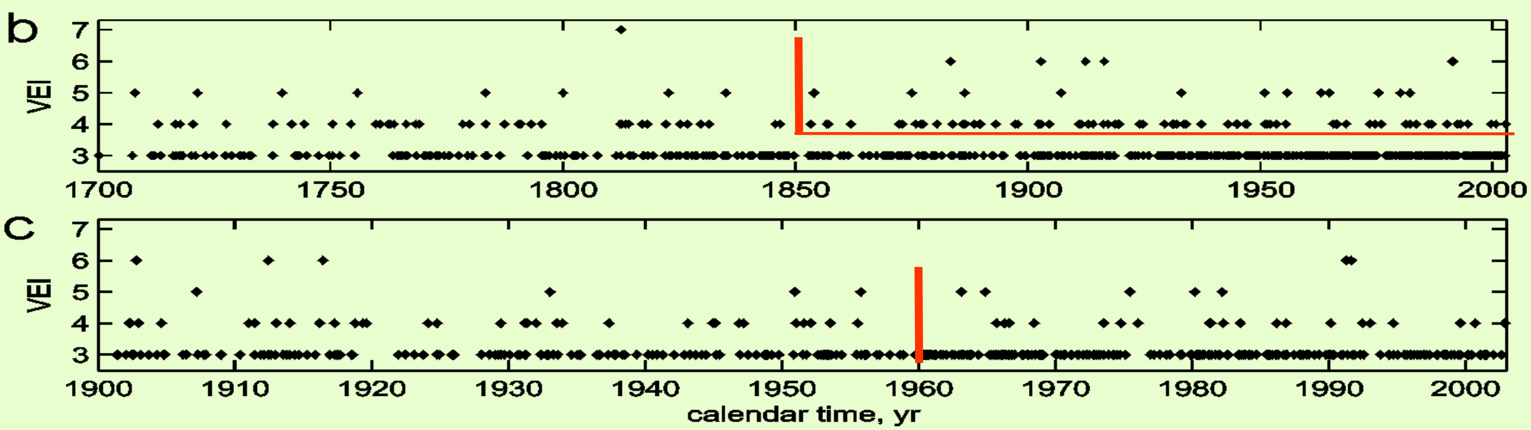


SELECTING DATA WINDOW: VISUAL ANALYSIS
Example: for **VEI ≥ 3,** selected **1960-2002**

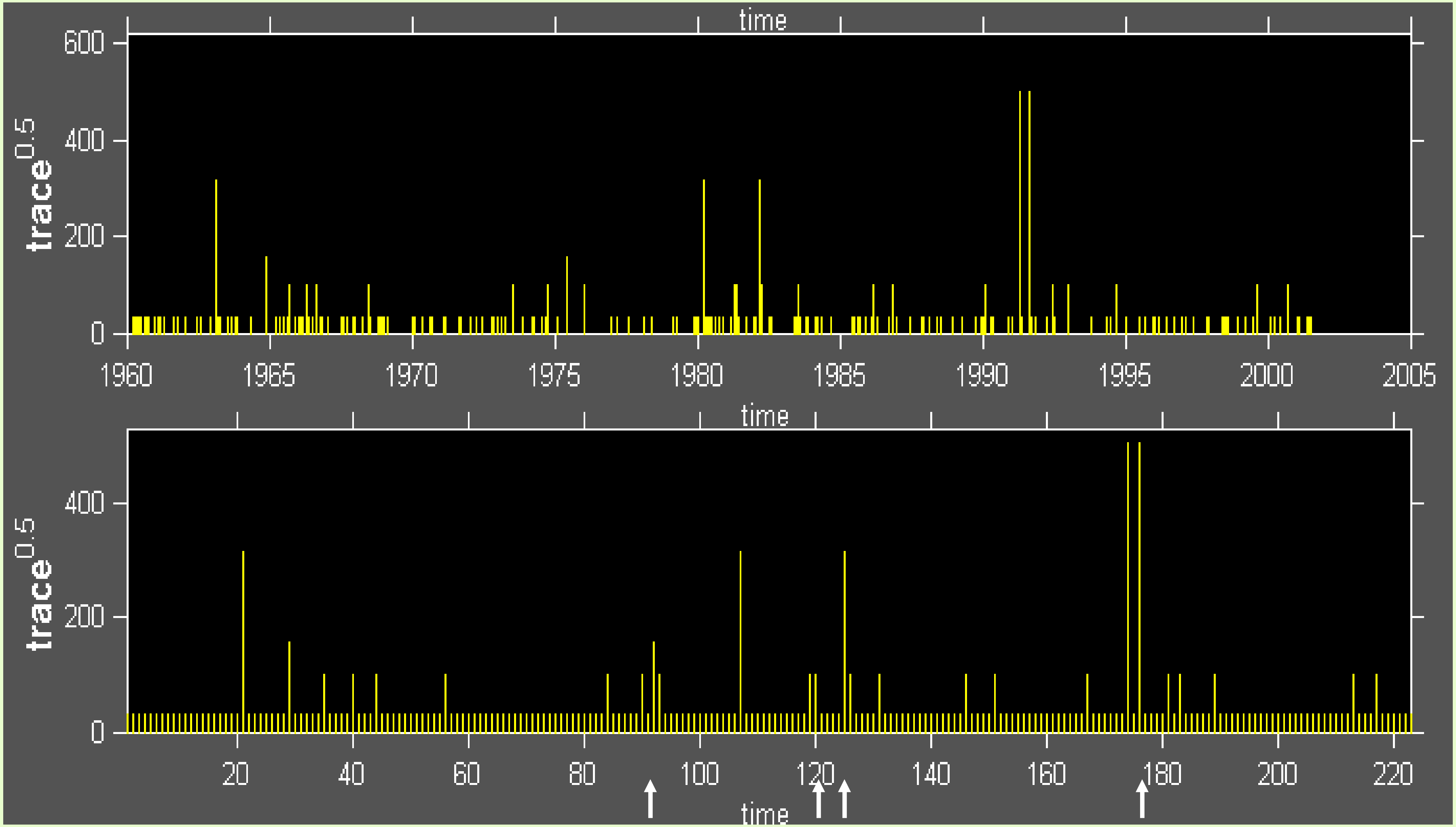
Time window/size threshold selection
Completeness check



SMI-3 data set-
Checking approximate completeness



Global eruption catalog of Smitsonian Inst.: time sequence 1960-2002

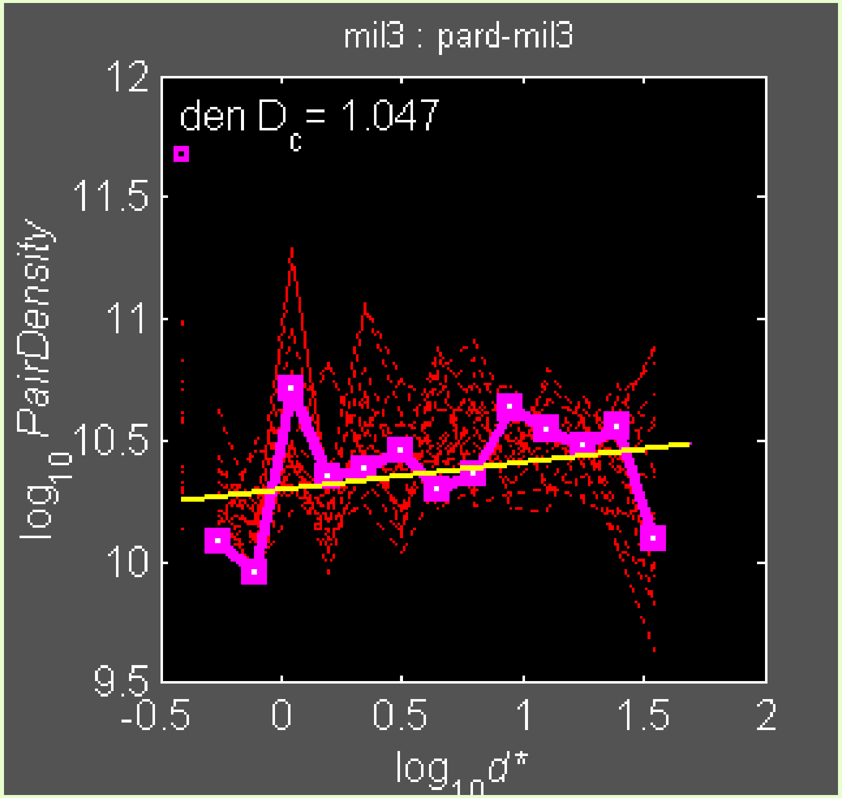


TOP: data sequence over true time scale

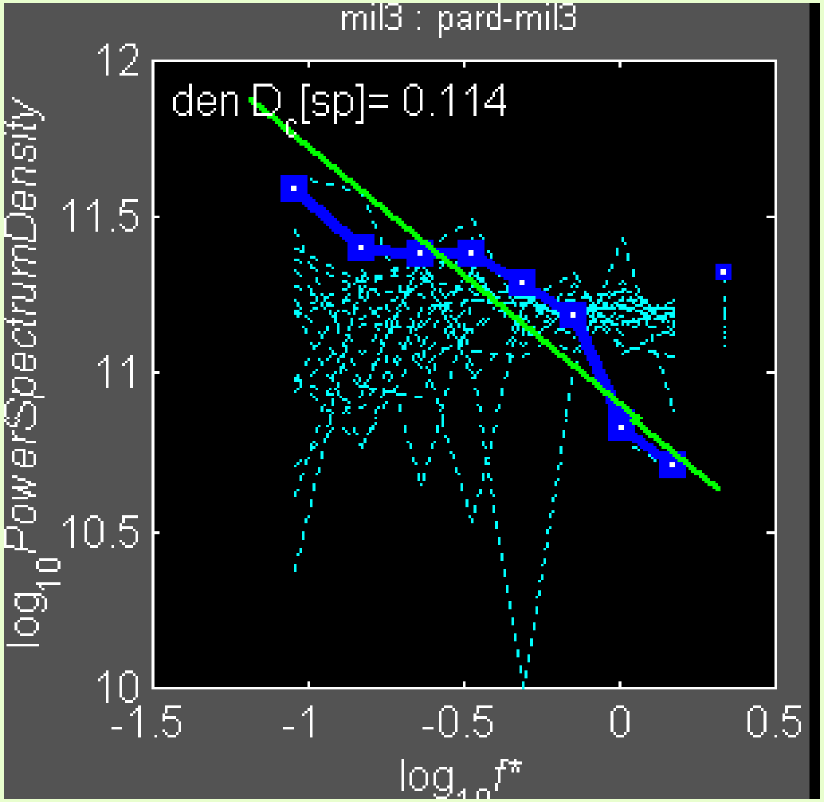
BOTTOM: ordered sequence only

spike size shows relative event size as $10^{VEI/2} \approx \text{volume}^{0.5}$

Global eruption catalog of Smitsonian Inst.: data processing

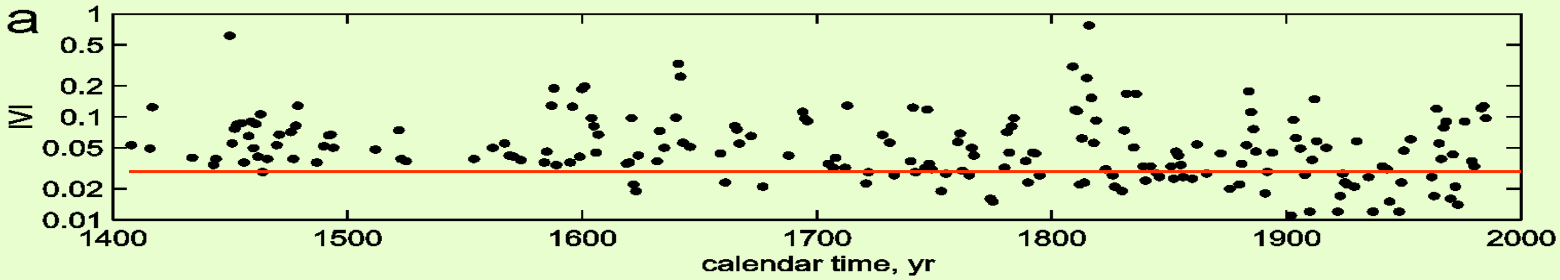


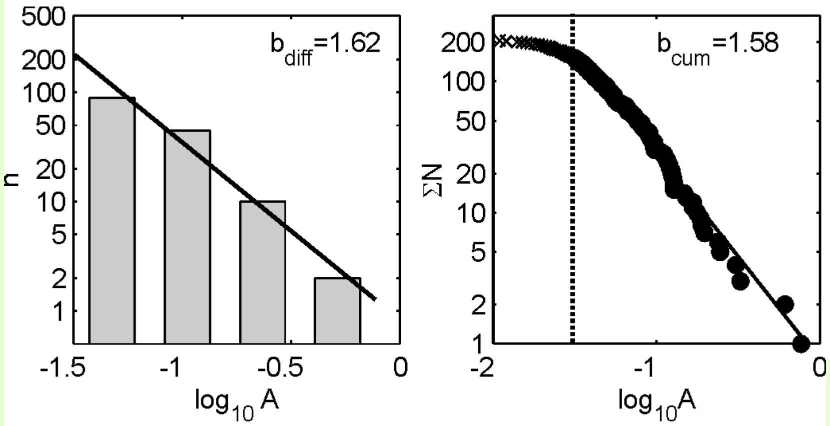
Estimating D_{c1}



Estimating D_{s1}

IVI data- size threshold selection
Completeness check





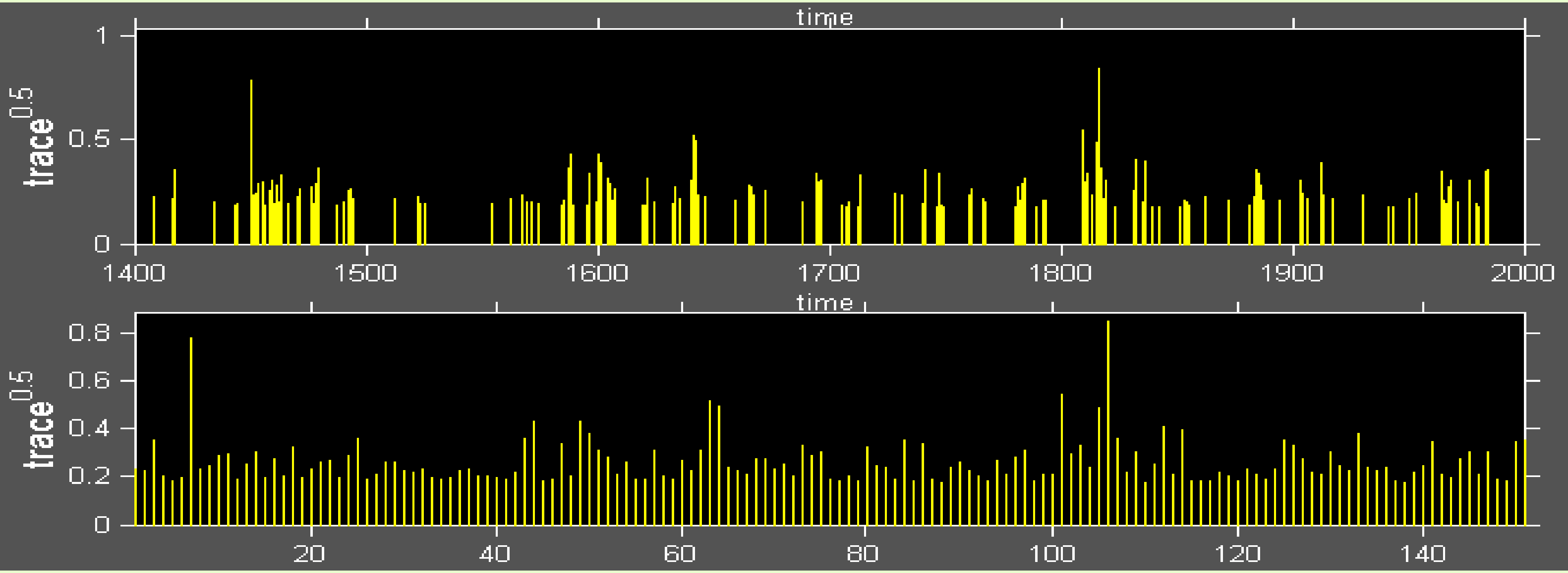
IVI data –

selecting lower threshold

Global IVI data set of A.Robock: data preparation

IVI: "ice core volcano index": a measure of volcanic dust intensity as buried in glaciers.

DATA WINDOW: 1400-1985 as given by A.Robock
DATA PREPROCESSING:
(1) Data for Northern and Southern Hemisphere merged
(2) For events synchronous over both hemispheres, max(IVI(NH),IVI(SH)) is taken

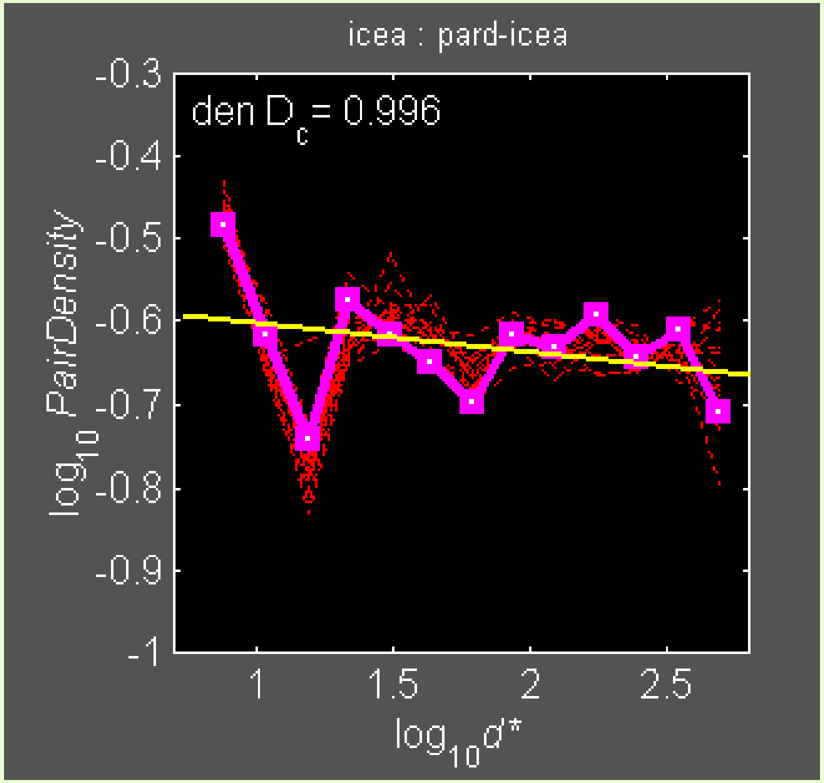


DATA SOURCE: Courtesy of Alan Robock,
(Rutgers University, New Brunswick, NJ, USA),

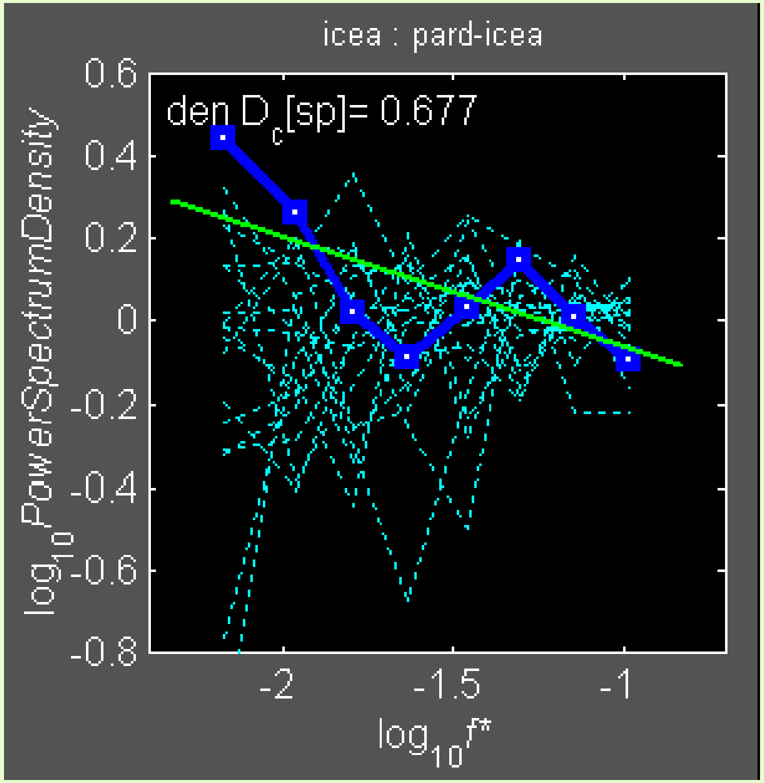
Robock, A., and M. P. Free, The volcanic record in ice cores for the past 2000 years, in *Climatic Variations and Forcing Mechanisms of the Last 2000 Years*, P. D. Jones (Ed) pp. 533–546, Springer-Verlag, New York, 1996.

Data sequence shown as $IVI^{1/2}$

IVI data set of A.Robock- data processing
Каталог IVI по А.Робоку : обработка данных



Determination of D_{c1}



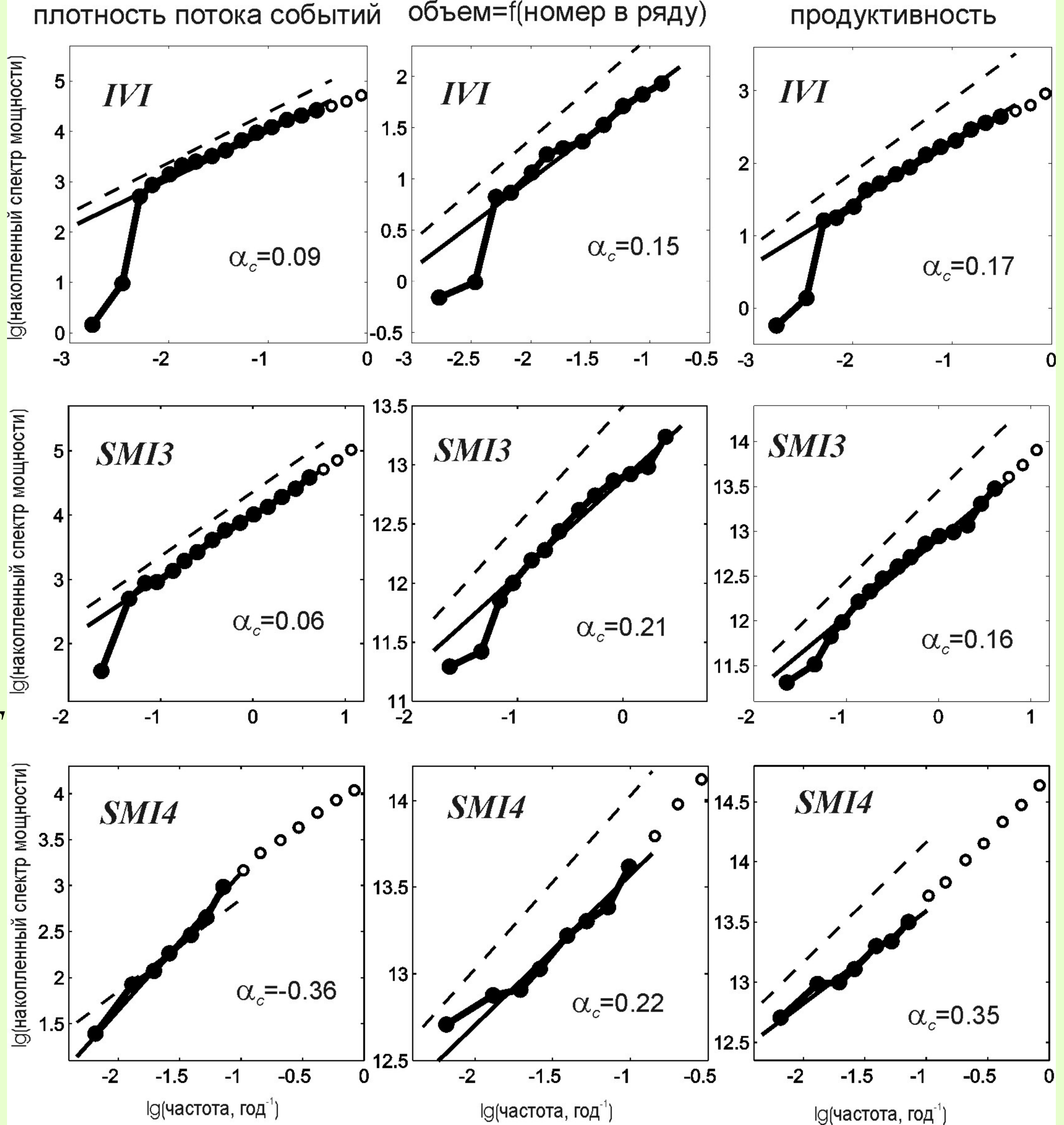
Determination of D_{s1}

Integrated power spectra $I(f)$

$$I(f) = \int_0^f PSD(f')df'$$

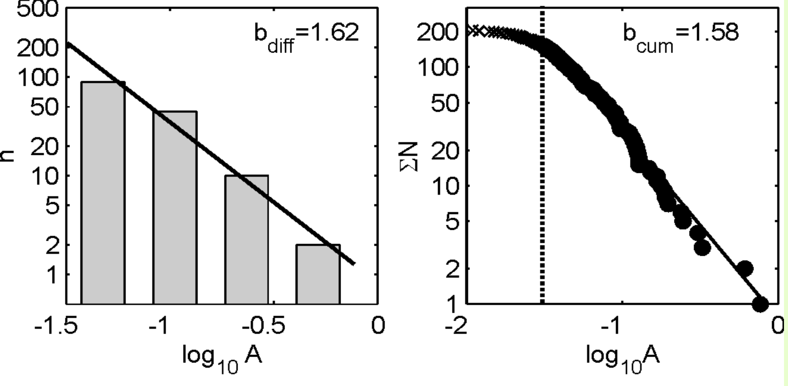
$$PSD(f) = \overline{2\left|\int_0^T F(t)\mathrm{e}^{-2\pi i f t}dt\right|^2 / T}$$

$$\alpha_c = 1 - D_s$$



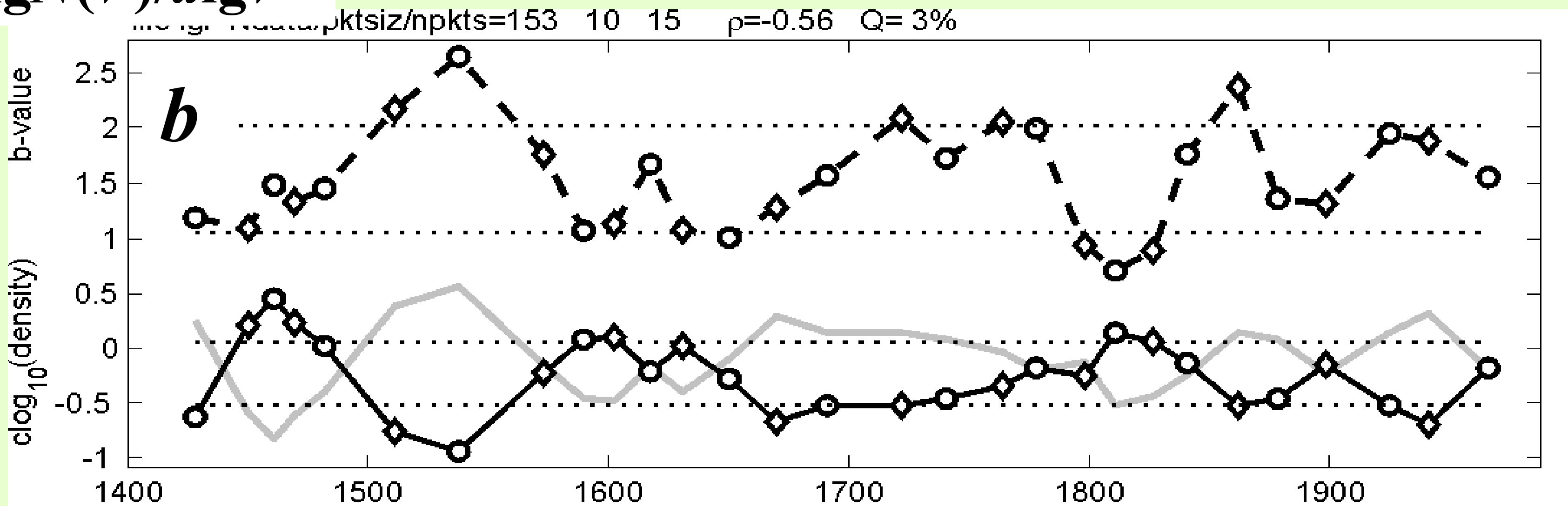
Numerical estimates of significance based on integrated spectra

data set/ processing mode	D_c	α_c	$\sigma(\alpha_c)$	100Q	100Q (density)
IVI/1(t)	0.91	0.090	0.09	17%	~1%
IVI/V(n)	0.85	0.150	0.12	10%	2%
IVI/V(t)	0.83	0.170	0.09	1.4%	~0.5%
SMI3/1(t)	0.94	0.060	0.09	24%	20%
SMI3/V(n)	0.79	0.210	0.09	2.4%	3.8%
SMI3/V(t)	0.84	0.160	0.07	3.2%	7%
SMI4/1(t)	[1.36]	-0.360	0.33	-	-
SMI4/V(n)	0.78	0.220	0.23	21%	-
SMI4/V(t)	0.65	0.350	0.35	13%	-



Correlation between:
(1) b-value [order anti-clusters]; and
(2) event density or frequency [common clusters]

$b = d\lg N(V)/d\lg V$



λ

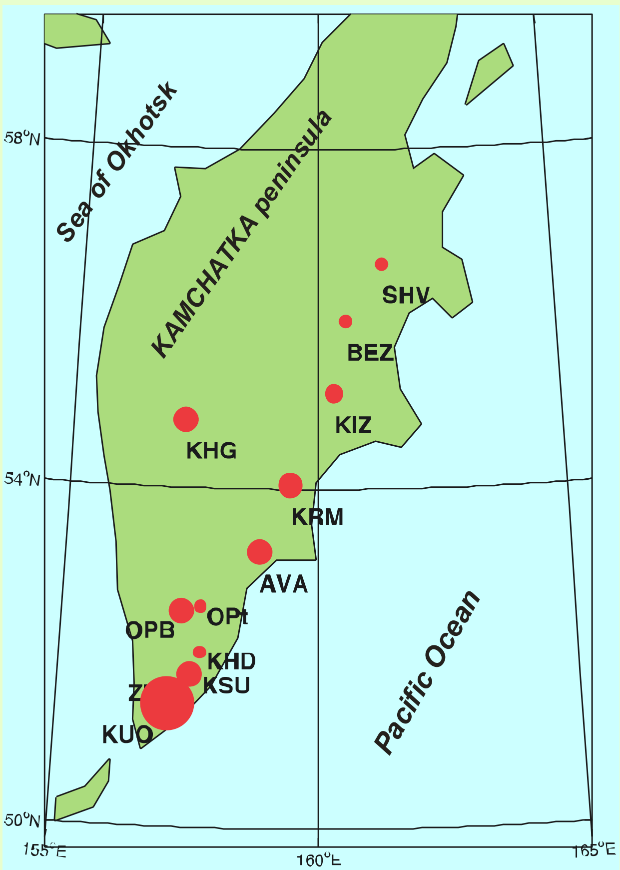
Данные: IVI, 1400-1985
Всего событий: 153
Размер пакета: 10
Число пакетов: 15
Коэффициент корреляции: -0.56 (Q=3%)

$\lambda = dN(t)/dt$

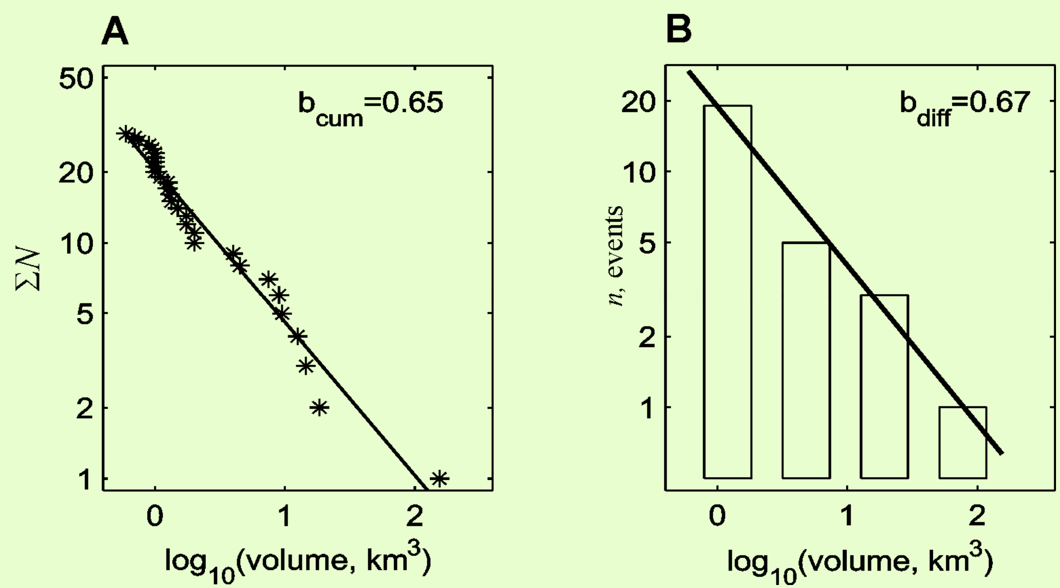
(локальная плотность точек)

Intermittency and clustering of explosive Holocene eruptions on Kamchatka

(A.A Gusev , V.V. Ponomareva , O.A.Braitseva , I.V.Melekestsev , L.D.Sulerzhitsky)



The catalog contains, since 8000 BC, 29 events with the volume of products of 0.7 km3 and above, assumed to be near to complete

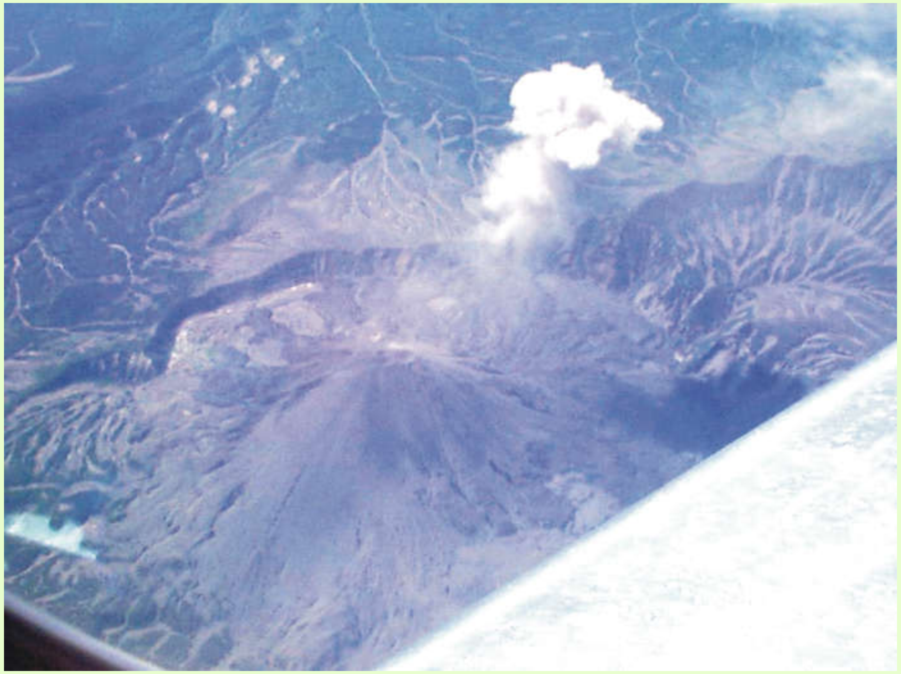


EXAMPLE craters/calderas

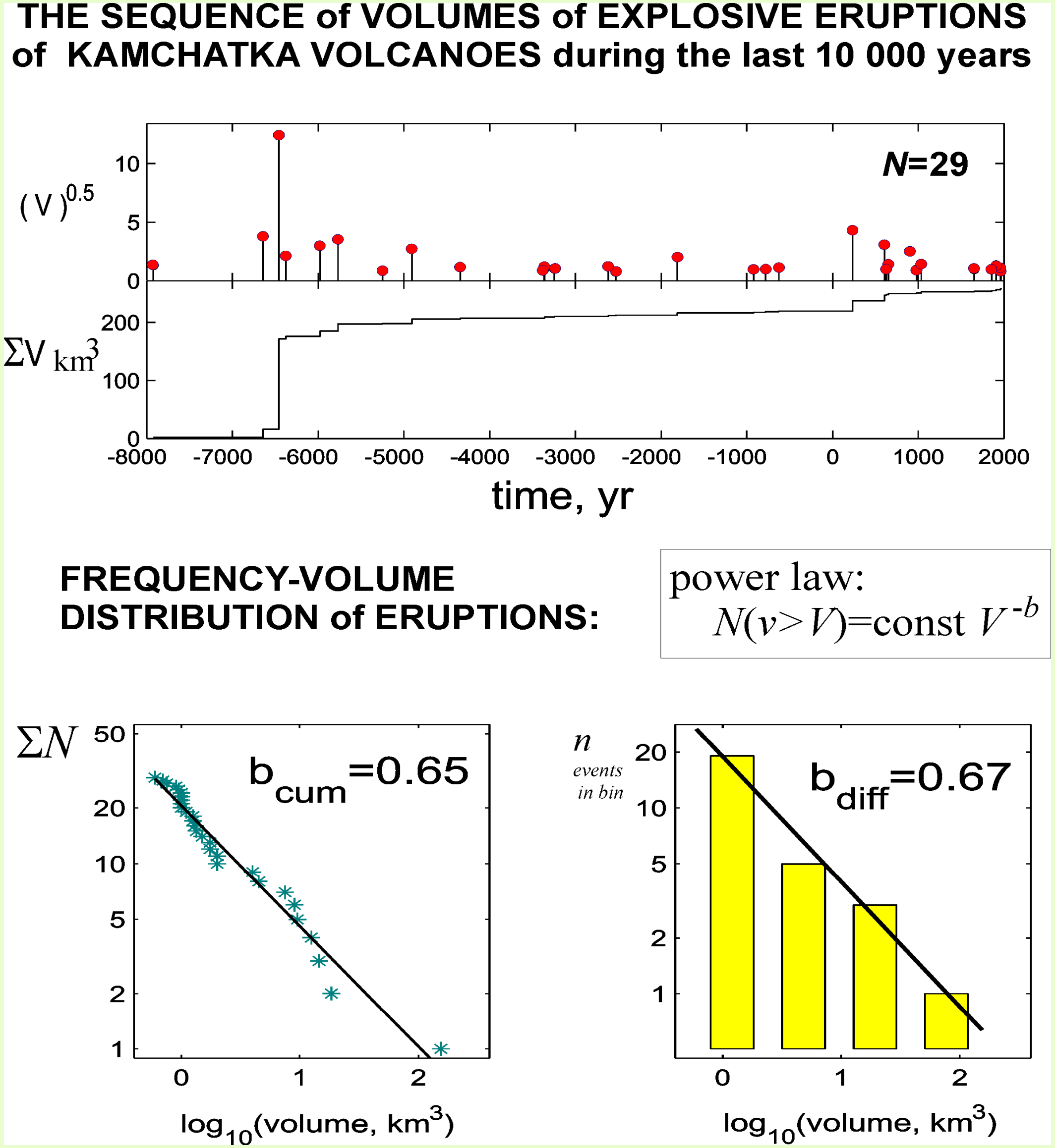
KSU Ksudach 2 km^3 1907

KHG Khangar 13 km^3 -5769

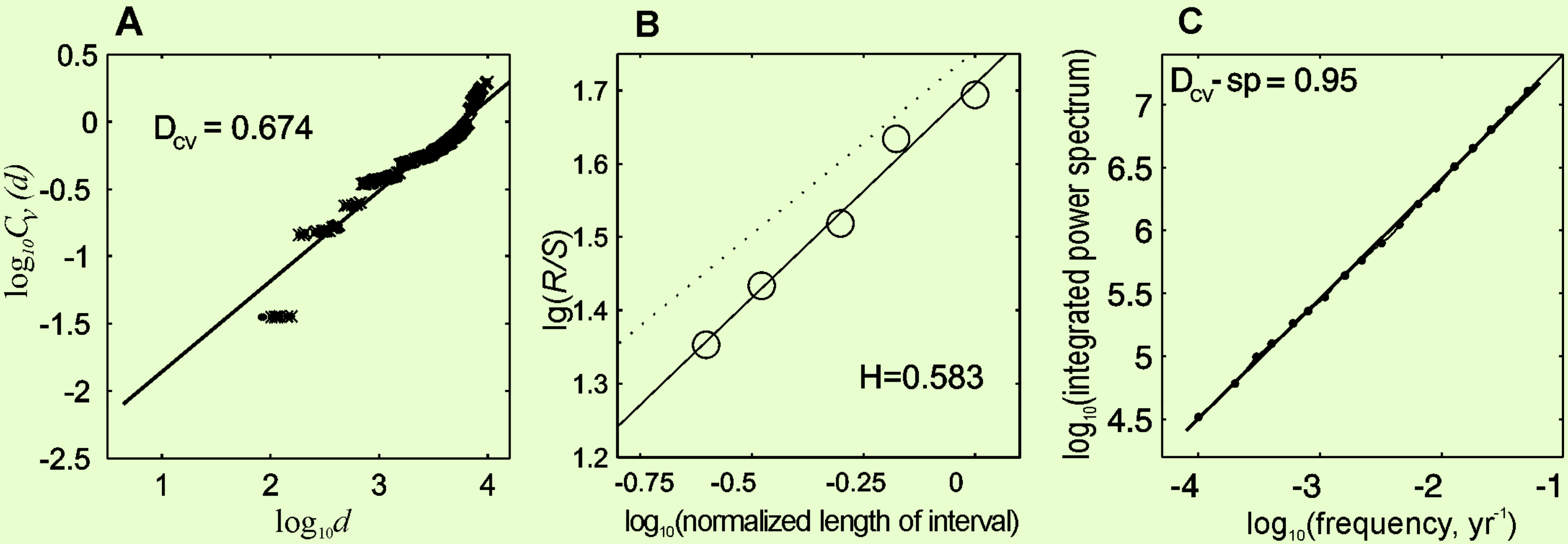
KRM Karymsky Caldera 16 km^3 -6642



Sequence of events; volume distribution



Kamchatka (2)



Characterization of intermittency by Dcm, Dsm and H

Estimates of significance for hypothesis: D<1
(time domain only)

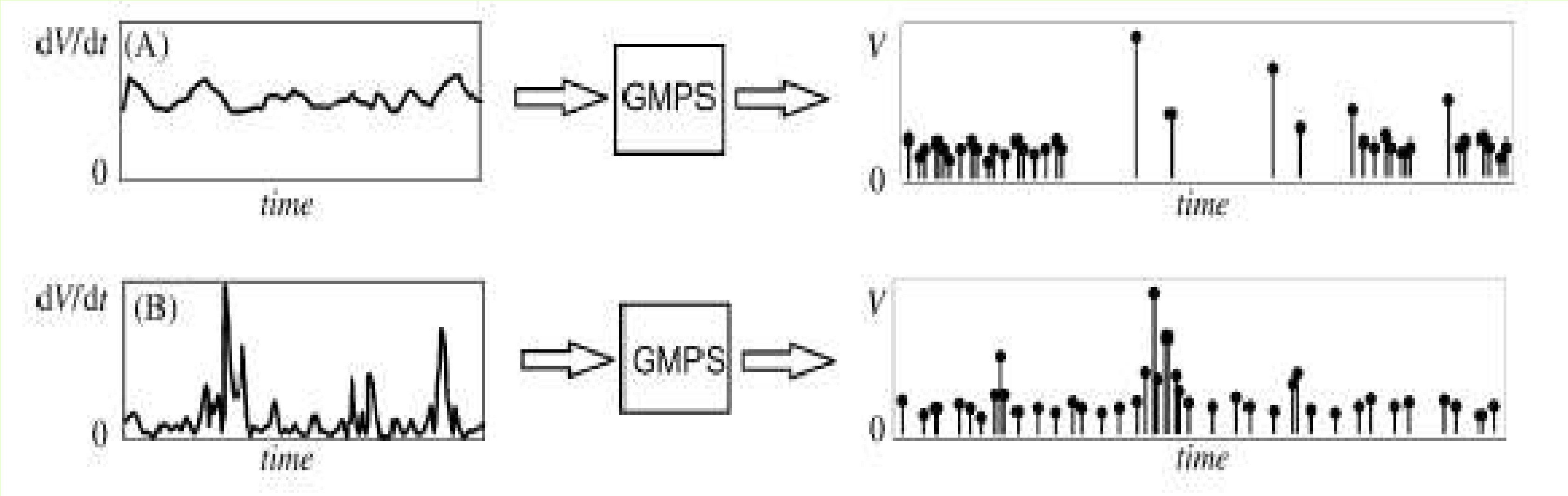
Time window: -8000 - 1990, size range: 0.7 km^3+, n=29

Estimated Dcm=**0.67** Δt range: 100-10000 yr

Kind of phenomenon in question	hypothesis	significance level: Prob(D=1)
common clustering	**Dc <1**	**4.8%**
order clustering	**Dc1 <1**	**3.7%**
intermittency of output	**Dcm <1**	**3.4%**

Global magma plumbing system

(? very hypothetic; but needed to explain coordinated action of many distant centeers)



Two hypothetic modes of behavior of the global magma plumbing system.

(Top) The case of modestly varying input material rate and the limited volume of the plumbing system proper; the output discharge pulses are frequent when they are small, and rarified when they become larger; ***negative order clustering results***. **No match to data**

(Bottom) Wildly varying input material rate and, again, the limited volume of the plumbing system proper. In agreement with observations, discharge pulses are larger when they are more frequent, and ***positive order clustering arises,*** **as seen in the data**

Conclusions

(1) Common clustering, ORDER CLUSTERING **and EPISODICITY OF THE OUTPUT OF VOLCANIC PRODUCTS (OVP) (listed in the order of increasing degree of expression) seem to be characteristic features of volcanic-eruption sequences, both on global and regional scale**

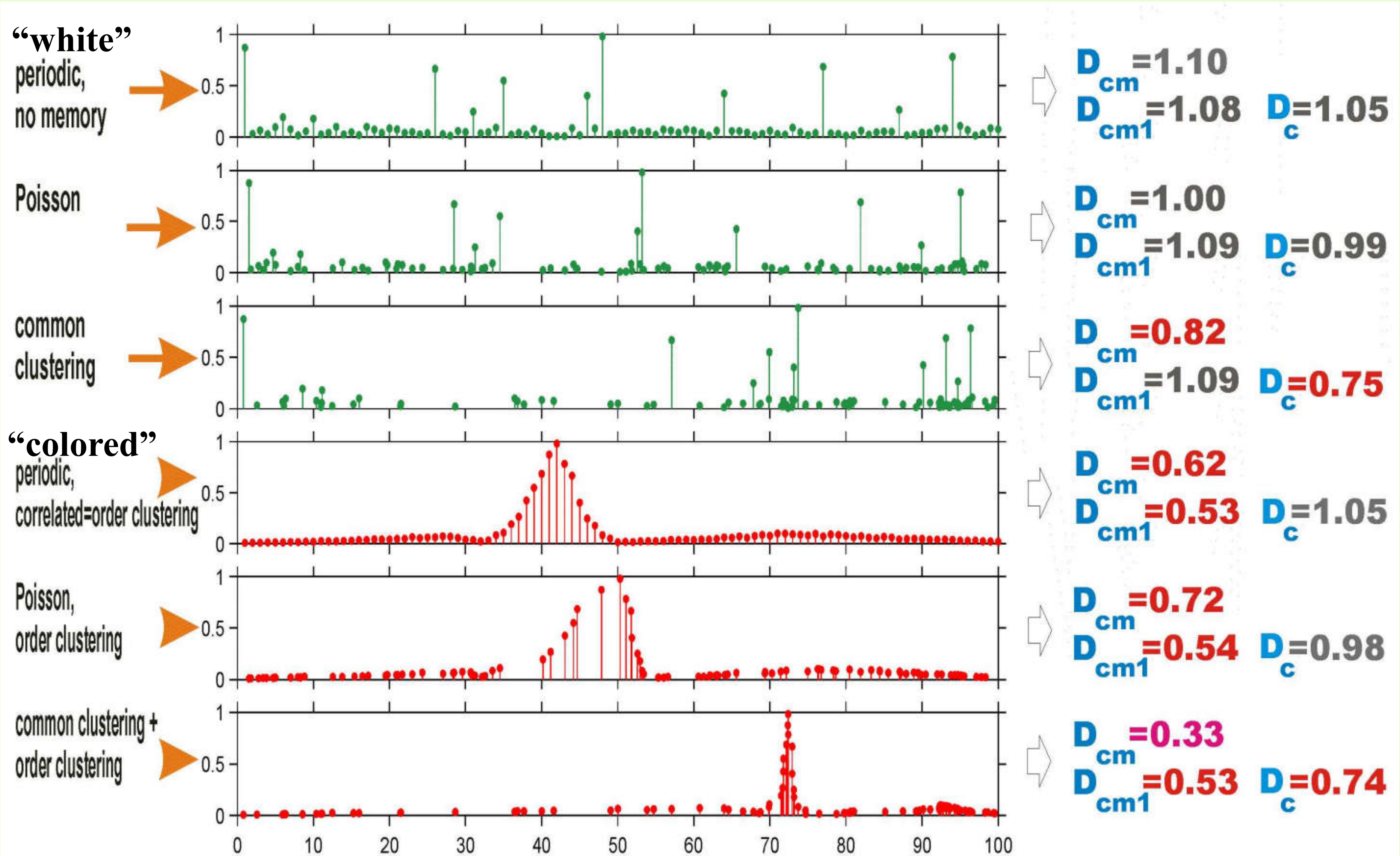
(2) These three features all show self-similar (fractal) behavior; no characteristic periods are manifested.

(3) Common and order clusters arise in positively correlated manner, their joint action enhances the episodicity of OVP

(4) Data of historical geology indicate episodicity of OVP on time scales of 10^5-10^8 yr; in the present study similar behavior is observed on time scales of 10-500 yr.

(5) Taking into account the clustering behavior of explosive eruptions may significantly modify the estimates of impact of volcanism on climate

Common clustering and order clustering: illustration 2



Global eruption catalog of Smitsonian Inst.: table of results

TIME WINDOW	VEI range	number of events	significance level: Prob(D=1)	estimated D
-2000-2002	6+	28	TD, FD: none	$D_{c1}=1.01$
1400-2002	5+	40	TD, FD: none	$D_{c1}=1.22$
1900-2002	4+	65	TD, FD: none	$D_{c1}=1.06$
1960-2002	3+	223	TD: none **FD: 0.5%** **TD+FD:0.7%**	$D_{c1}=1.05$ $D_{s1}=\mathbf{0.12}$ $D_{[c1+s1\text{-}combined]}=\mathbf{0.67}$

Conclusion: order clustering is rather likely for the [1960-2002, VEI=3+] data subset

IVI data set of A.Robock- table of results

TIME WINDOW; hemispheres	IVI range	number of events	significance level: Prob(D=1)	estimated D
1400-1985 **NH+SH**:	0.03+	151	TD: none **FD: 3%** **TD+FD: 3%**	D_{c1}=1.00 D_{s1}=**0.68** $D_{[c1+s1\text{-combined}]}$=0.98
1400-1985 **NH**:	0.03+	132	TD: 22% **FD: <0.1%** **TD+FD: <0.1%**	D_{c1}=0.98 D_{s1}=**0.12** $D_{[c1+s1\text{-combined}]}$=0.97
1400-1985 **SH**:	0.03+	37	TD, FD: none	D_{c1}=1.01

Conclusion: order clustering is very likely for global (NH+SH) and NH IVI data sets