Elektromágneses geofizika, a Föld mélye és a légkör

Electromagnetic Geophysics, Depth of the Earth, Atmosphere

SZARKA, László Csaba

TIBOR HORVÁTH' S CELEBRATION
ENGINEERING GEOLOGY AND ROCK MECHANICS CONGRESS
Budapest, 7th of November (Thursday), 2024

Horváth Tiborral, akit ma köszöntünk, a Nehézipari Műszaki Egyetem Bányamérnöki Karán 1972-1977 között évfolyamtársak voltunk; a geofizikus- és geológus tankörök szétválásáig tankörtársak is. A Dudujka-völgyi kollégiumban pedig négy éven át szomszédos szobában laktunk. A focipályán, a „Henger FC”-ben ő „Beckenbauer” volt, én csak „Breitner”.

With Tibor Horváth, whom we are greeting today, we were classmates at the Faculty of Mining of the Technical University of Heavy Industry between 1972 and 1977, until the separation of geophysics geology. In the Dudujka Valley dormitory, we lived in an adjacent room for four years. On the soccer field, in the so-called Henger [Roller] FC he was "Beckenbauer", I was just "Breitner".

Tibor javaslata alapján 47 évvel később megtisztelő előadói felkérést kaptam az őt köszöntő ünnepi konferenciára.

47 years later I am honored to be invited by Tibor to give a talk at the celebratory conference welcoming him.

I will tell you in some examples what scientific questions I have dealt with since the year of our MSc degrees; Tibor became geologist, me: geophysicist.

Several results are from electromagnetic geophysical methods (both pure and applied geophysics), I got at the Sopron research institute.

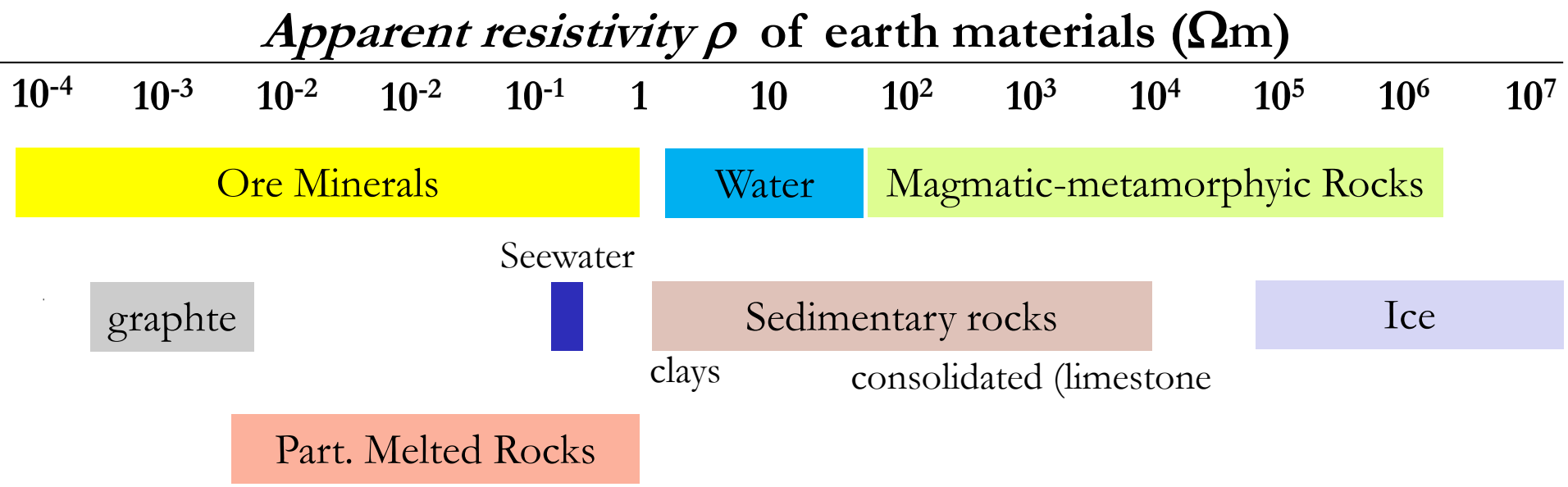
I also address some problems in climate change-focussed environmental science.

The examples presented here are selected mostly from my inauguration lectures for Corresponding Membership (2013) and Ordinary Membership (2019) at the Hungarian Academy of Sciences.

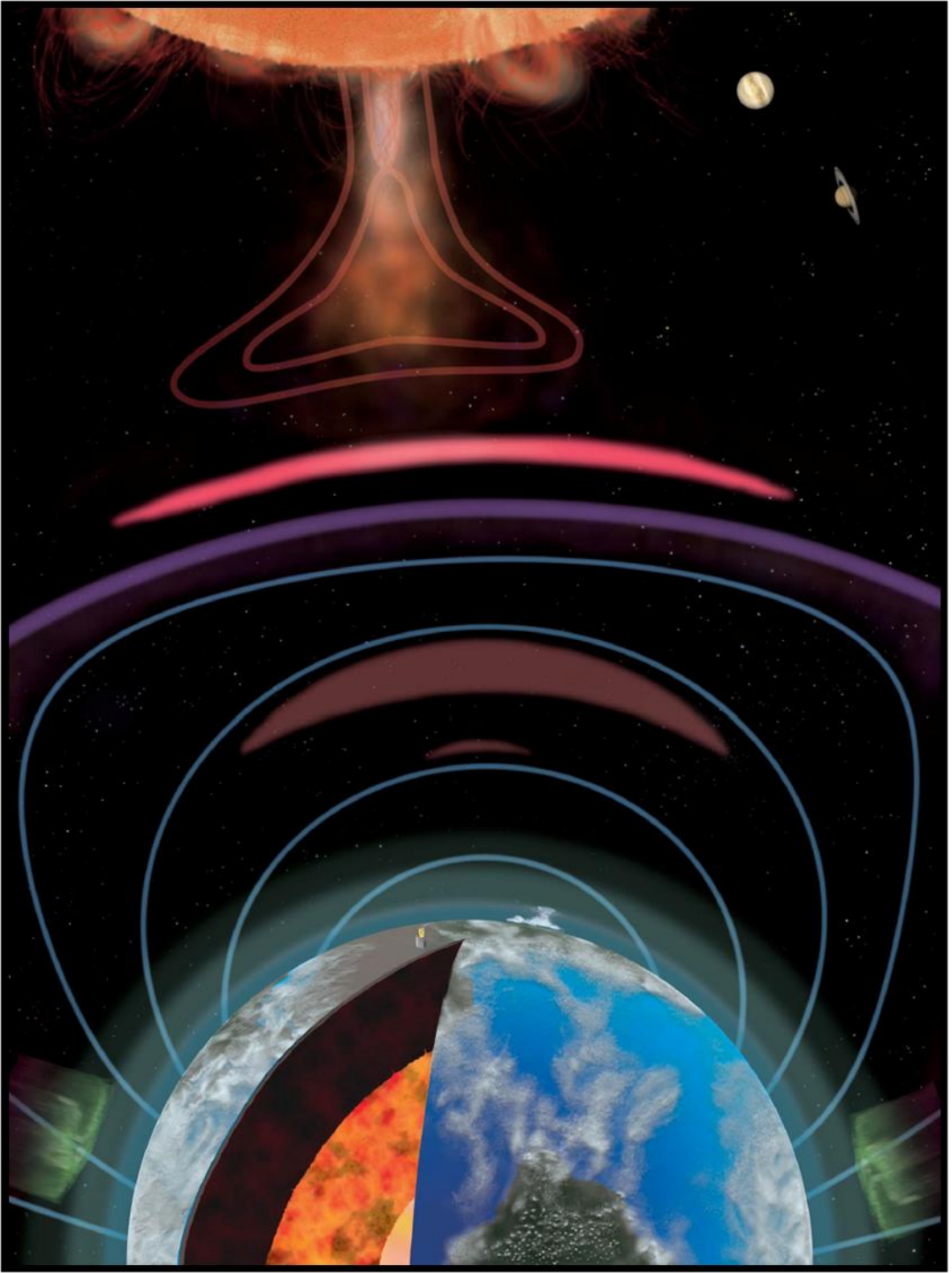
Electrodynamics from geophysical perspectives

EM waves	Gen. electrodynamics	Quasi-stationarity	Stacionarity	Static fields
$\frac{\partial \mathbf{D}}{\partial t} \gg \mathbf{j}$		$\left(\frac{\partial \mathbf{D}}{\partial t} \ll \mathbf{j} \text{ and } \frac{\partial}{\partial t} \neq 0\right)$	$\left(\mathbf{j} \neq 0, \quad \frac{\partial}{\partial t} = 0\right)$	$\left(\mathbf{j} = 0, \quad \frac{\partial}{\partial t} = 0\right)$
$\text{rot}\,\mathbf{H} \cong \frac{\partial \mathbf{D}}{\partial t}$ $\text{div}\,\mathbf{B} = 0$ $\mathbf{B} = \mu\mathbf{H}$	$\text{rot}\,\mathbf{H} = \mathbf{j} + \frac{\partial \mathbf{D}}{\partial t}$ $\text{div}\,\mathbf{B} = 0$ $\mathbf{B} = \mu\mathbf{H}$	$\text{rot}\,\mathbf{H} \cong \mathbf{j}$ $\text{div}\,\mathbf{B} = 0$ $\mathbf{B} = \mu\mathbf{H}$	$\text{rot}\,\mathbf{H} = \mathbf{j}$ $\text{div}\,\mathbf{B} = 0$ $\mathbf{B} = \mu\mathbf{H}$	$\text{rot}\,\mathbf{H} = \mathbf{0}$ $\text{div}\,\mathbf{B} = 0$ $\mathbf{B} = \mu\mathbf{H}$ (magnetostatics)
$\text{rot}\,\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\text{div}\,\mathbf{D} = 0 \quad (\delta = 0)$ $\mathbf{D} = \varepsilon\mathbf{E}$	$\text{rot}\,\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\text{div}\,\mathbf{D} = \delta$ $\mathbf{D} = \varepsilon\mathbf{E}$	$\text{rot}\,\mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ $\text{div}\,\mathbf{D} = \delta$ $\mathbf{D} = \varepsilon\mathbf{E}$	$\text{rot}\,\mathbf{E} = 0$ $\text{div}\,\mathbf{D} = \delta = \text{constant}$ $\mathbf{D} = \varepsilon\mathbf{E}$	$\text{rot}\,\mathbf{E} = 0$ $\text{div}\,\mathbf{D} = \delta = \text{constant}$ $\mathbf{D} = \varepsilon\mathbf{E}$ (electrostatics)
$\text{div}\,\mathbf{j} = 0, \frac{\partial \delta}{\partial t} = 0$ $\mathbf{j} = 0, \sigma = 0$	$\text{div}\,\mathbf{j} + \frac{\partial \delta}{\partial t} = 0$ $\mathbf{j} = \sigma\,\mathbf{E}$	$\text{div}\,\mathbf{j} + \frac{\partial \delta}{\partial t} = 0$ $\mathbf{j} = \sigma\,\mathbf{E}$	$\text{div}\,\mathbf{j} = 0, \frac{\partial \delta}{\partial t} = 0$ $\mathbf{j} = \sigma\,\mathbf{E}$	$\text{div}\,\mathbf{j} = 0, \frac{\partial \delta}{\partial t} = 0$ $\mathbf{j} = 0, \ \sigma = 0$
Atmosphere, space physics (plasm: j=vxB)	**Georadar**	**EM induction methods**	**Geoelectric methods**	**Geomagnetism (magnetostatics) Electostatics**

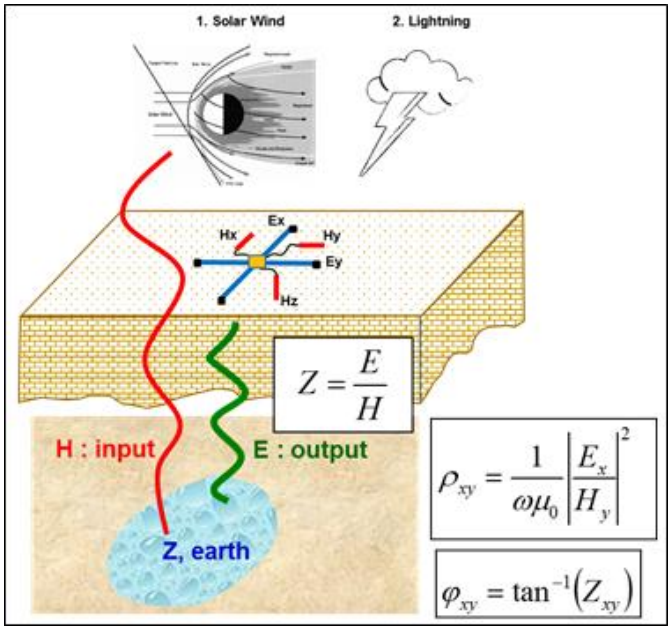
EM field + nuclear interactions, beyond classical electrodynamics:
NMR (Nucláris Mágneses Rezonancia), IP (Indukált Polarizáció),
H_2O evaporation, GHE (Greenahose Effect)



$\rho = 1/\sigma$ (σ: *electrical conductivity*)



My field was magnetotellurics



A quick question about the climate:

Can you imagine that the climatic (atmospheric) processes are independent of the Earth System?

Surface EM field

E, H

charges

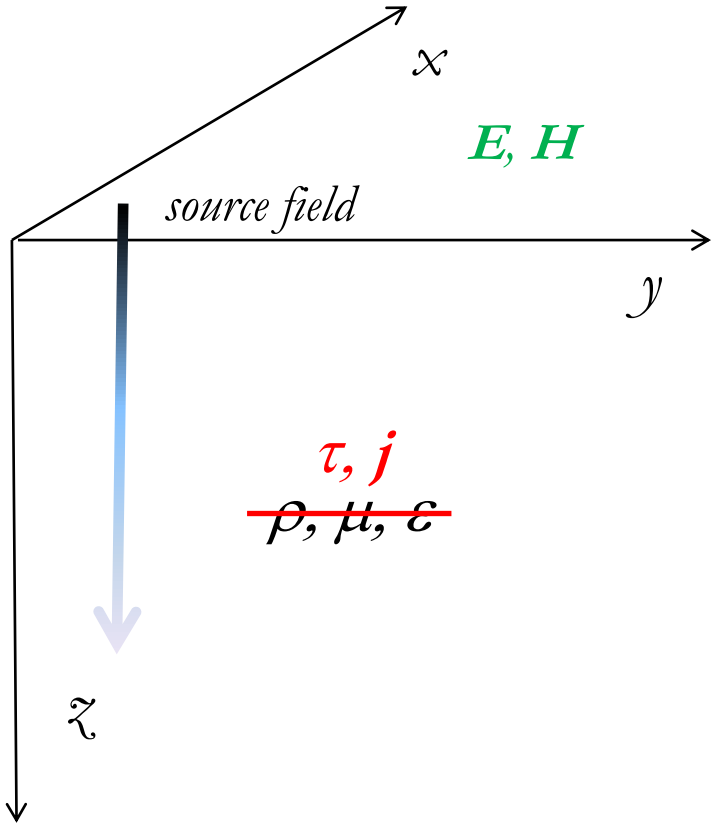
τ

currents

j

Distribution of *ρ, μ, ε* at depth

Characteristics of the source field (geometry- and/or time variation)



Source field: *f(z)* *f(y,z)* *f(x, y, z)*

τ, j:

f(z)	**1D**	**2D**	**3D**
f(y, z)	**2D**	**2D, 3D**	**3D**
f(x, y, z)	**3D**	**3D**	**3D**

Note the common structure in very different geophysical anomalies

r: távolság, V: térfogat, A felület

Gravitációs és geomágneses anomáliák

Gravitációs tér: $$\boldsymbol{g} = -\ \gamma\ \mathbf{grad}\left[\int_V (d/r)\, dV\right]$$

γ: gravitációs állandó, d: kőzetsűrűség

Mágn. tér (dipól): $$\boldsymbol{H_m} = -(\mu_0/4\pi)\ \mathbf{grad}\left[\int_V \boldsymbol{M}\,\mathbf{grad}\,(1/r)\, dV\right]$$

μ_0: a vákuum mágneses permeabilitása, $\boldsymbol{M}$: kőzetmágnesezettség

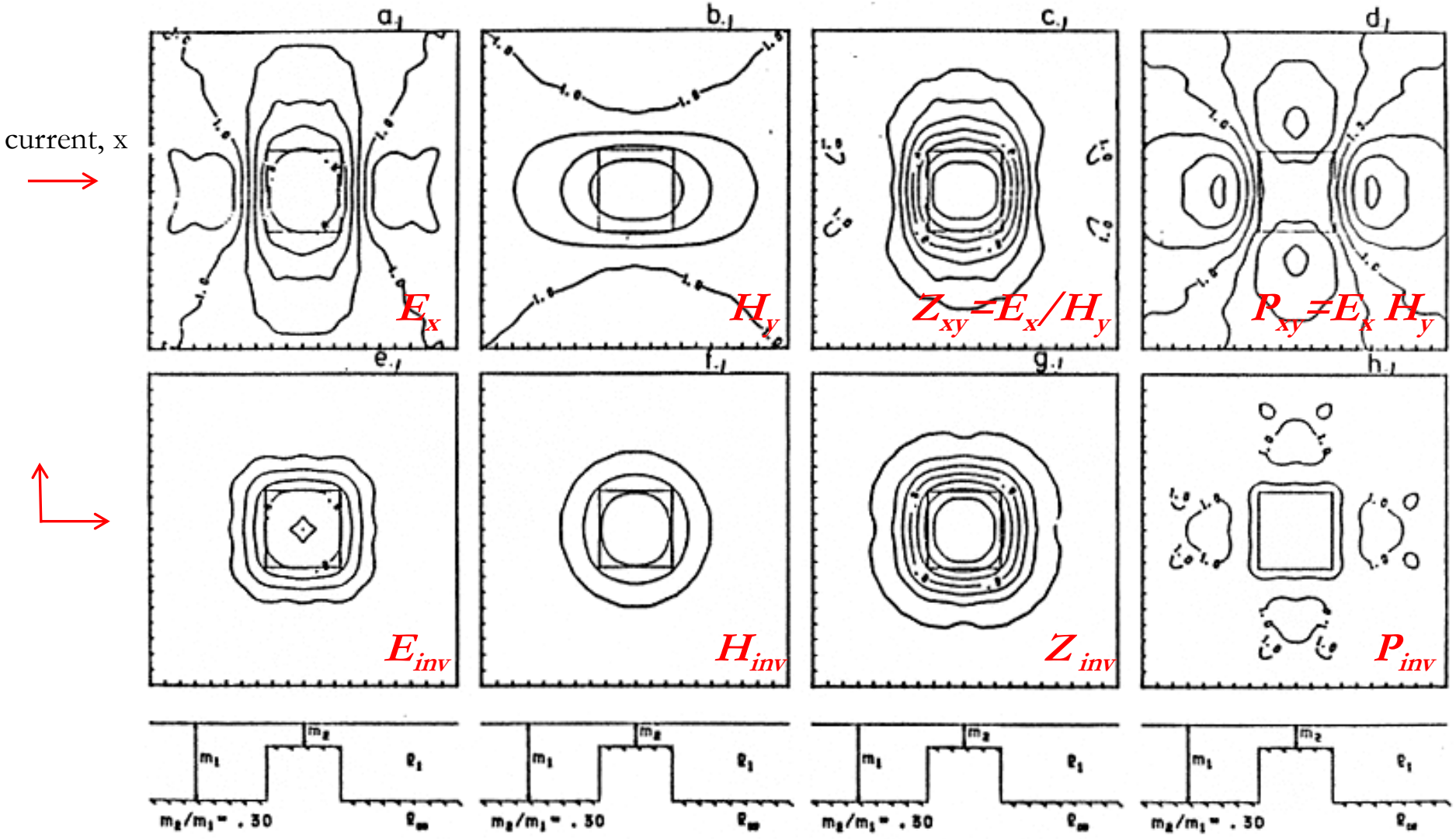
Elektromágneses anomáliák

Mágn. tér (áram): $$\boldsymbol{H_e} = -\ (1/4\pi)\ \mathbf{rot}\left[\int_V (\boldsymbol{j}/r)\, dV\right]$$

$\boldsymbol{j}$: térbeli áramsűrűség

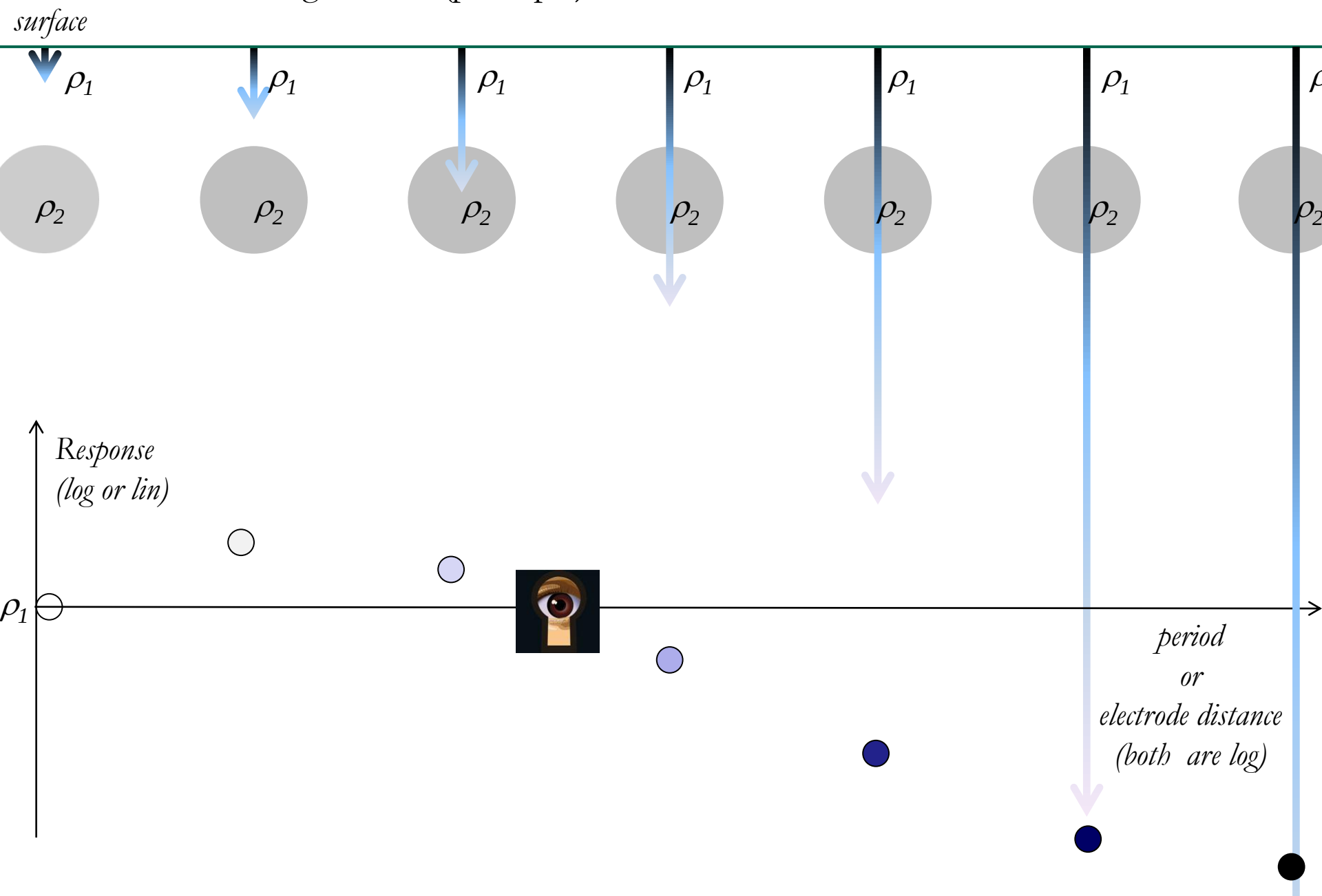
Elektromos tér: $$\boldsymbol{E} = -(1/4\pi\varepsilon_0)\ \mathbf{grad}\left[\int_V (\delta/r)\, dV + \int_A (\tau/r)\, dA\right]$$

ε_0: a vákuum dielektromos permittivitása, δ: tértöltés-sűrűség, τ: kőzethatár-felületi töltéssűrűség



Analogue (physical) modelling:
DC electric and magnetic surface anomalies over 3D
due to an x directed electrode pair (upper row: a, b, c, d);
and invariant anomalies from x and y directed currents (lower row: e, f, g, h):
Szarka L.: Geophysical Prospecting 1987 *„Let the data speak!"* (Berkhout 2021)

„Sounding Curve" (principle)

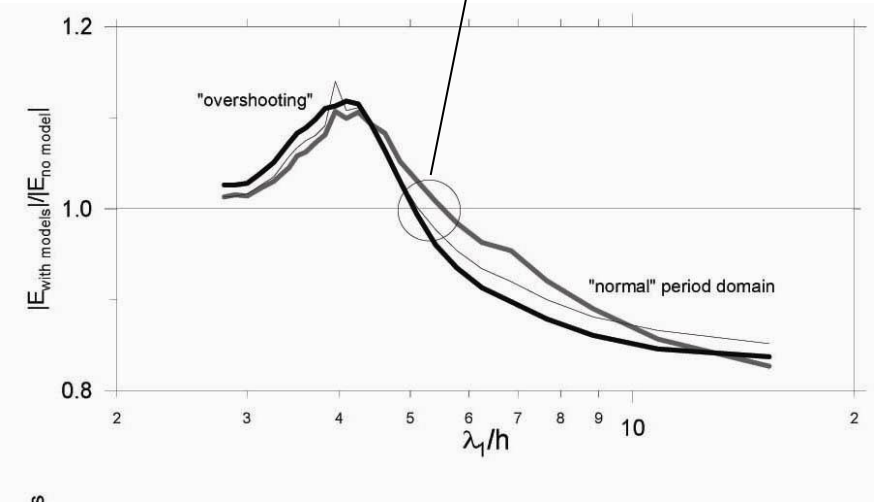


Acta GG 1992
Geophysical Prospecting 1999

or

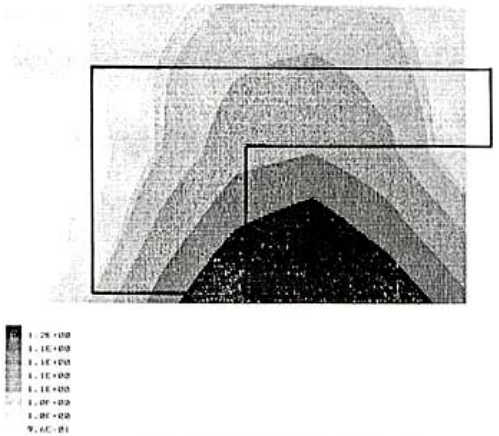
„Let the data speak” (Berkhout 2021)

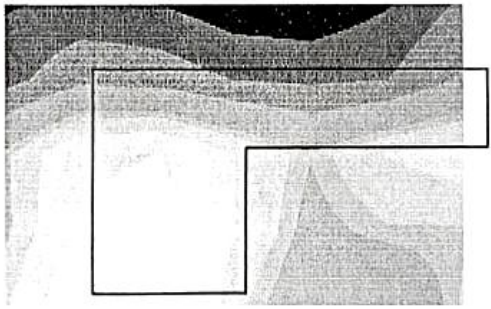
„Keyhole”

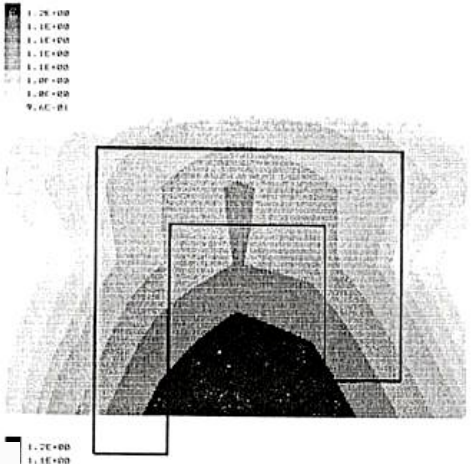


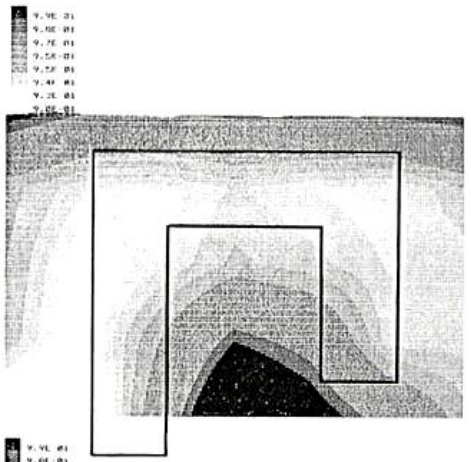
Robust anomalies in the „normal”and overshooting period ranges

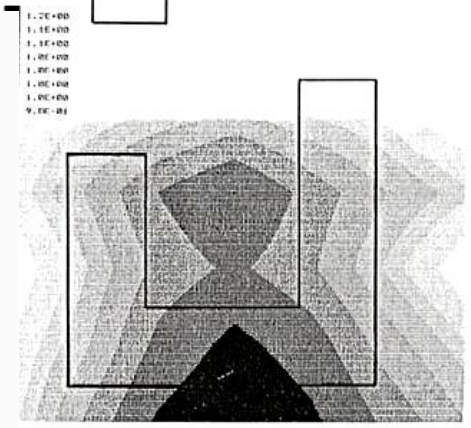
„Keyhole”

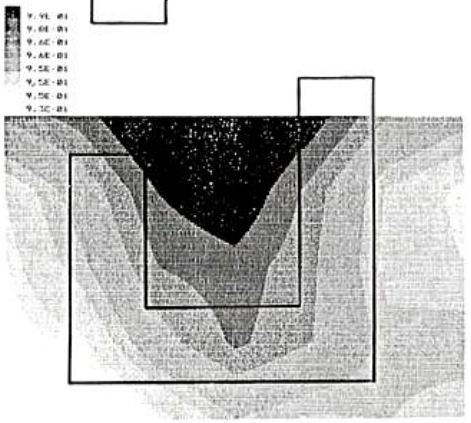












The magnetotelluric impedancie tensor $\begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix}$

$$E_x = \boldsymbol{Z_{xx}} H_x + \boldsymbol{Z_{xy}} H_y$$
$$E_y = \boldsymbol{Z_{yx}} H_x + \boldsymbol{Z_{yy}} H_y$$

Geological dimensionality	Number of tensorial elements	Number of independent invariants
1D	2^1	2-1=1
2D	2^2	4-1=3
3D	2^3	8-1=7

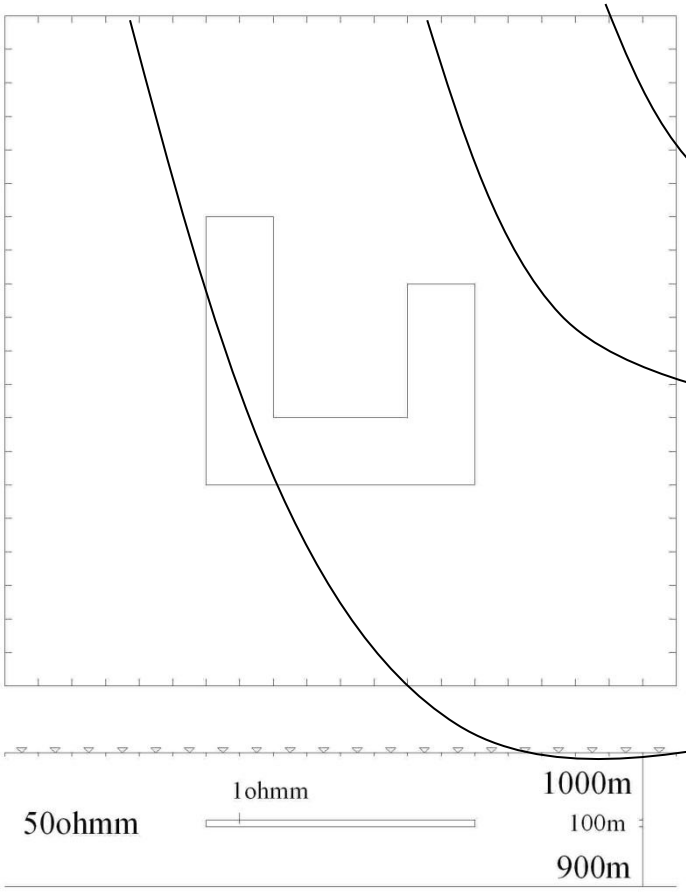
Szarka L., Menvielle, M:
Geophysical Journal International, 1997

or

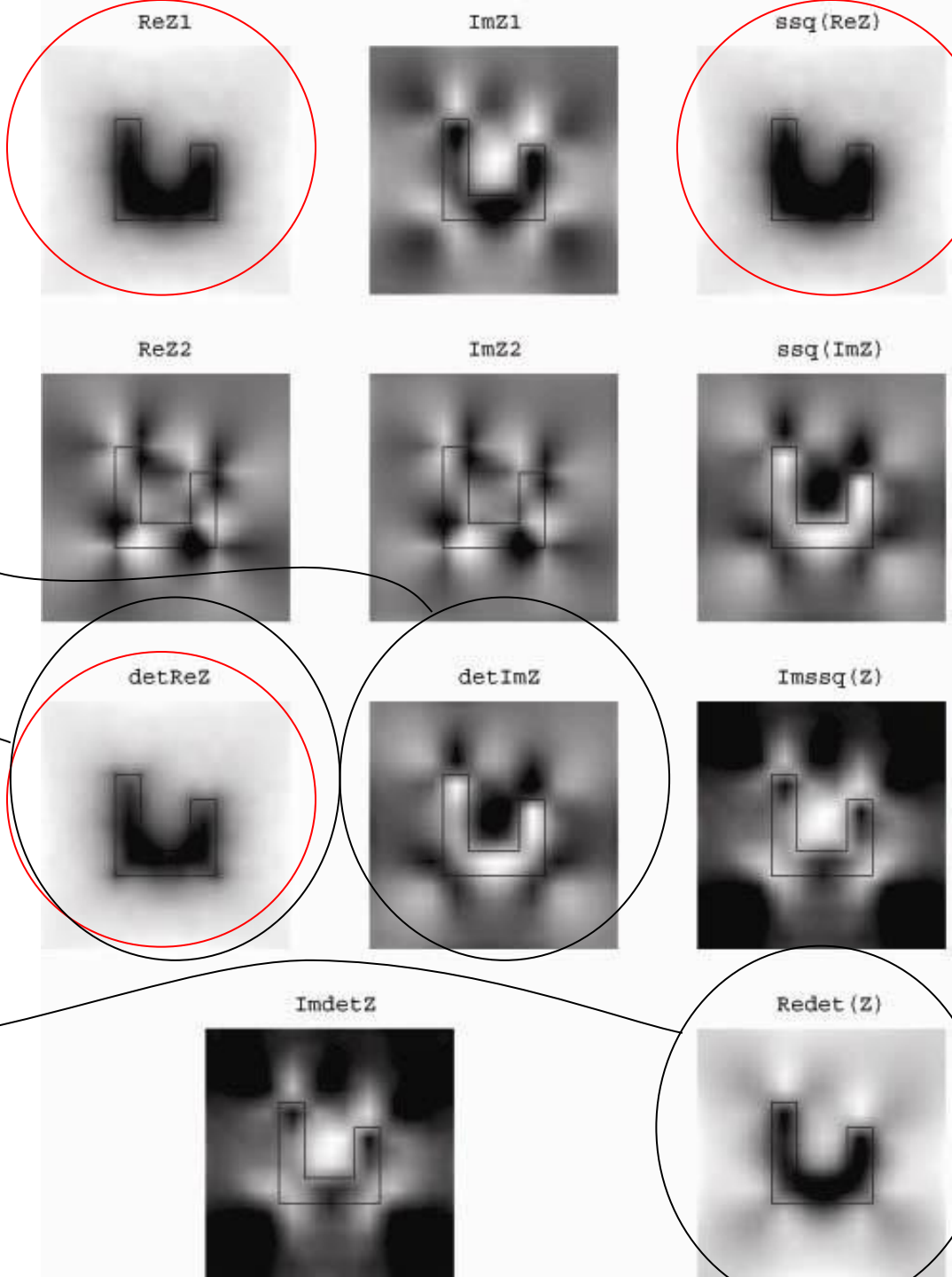
„Let the data speak!" (Berkhout 2021)

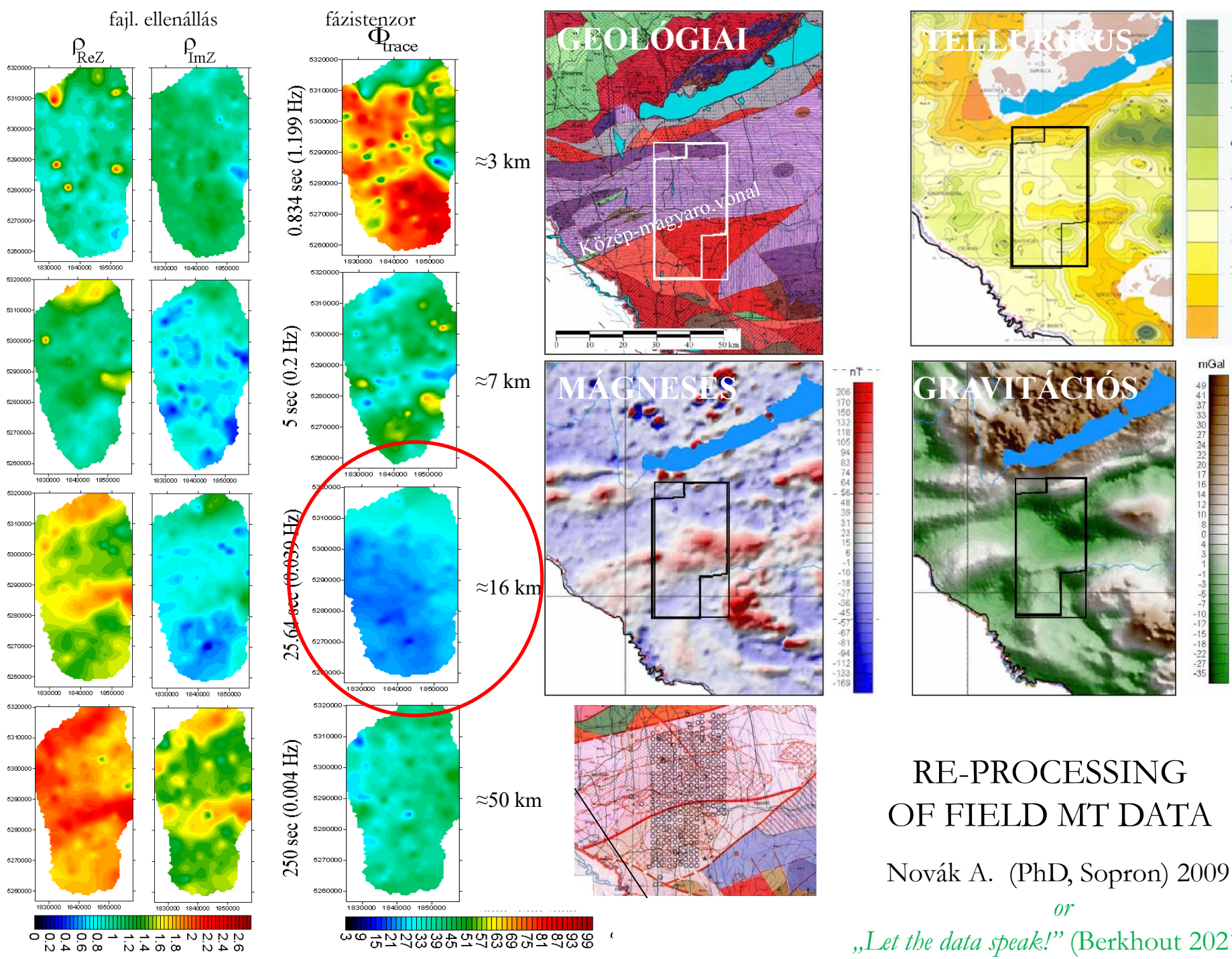
$$\det(\mathbf{Z}) = Re\ \det(\mathbf{Z}) + i\ Im\ \det(\mathbf{Z})$$

$$Re\ \det(\mathbf{Z}) = \det Re(\mathbf{Z}) - \det Im(\mathbf{Z})$$



50ohmm, 500ohmm





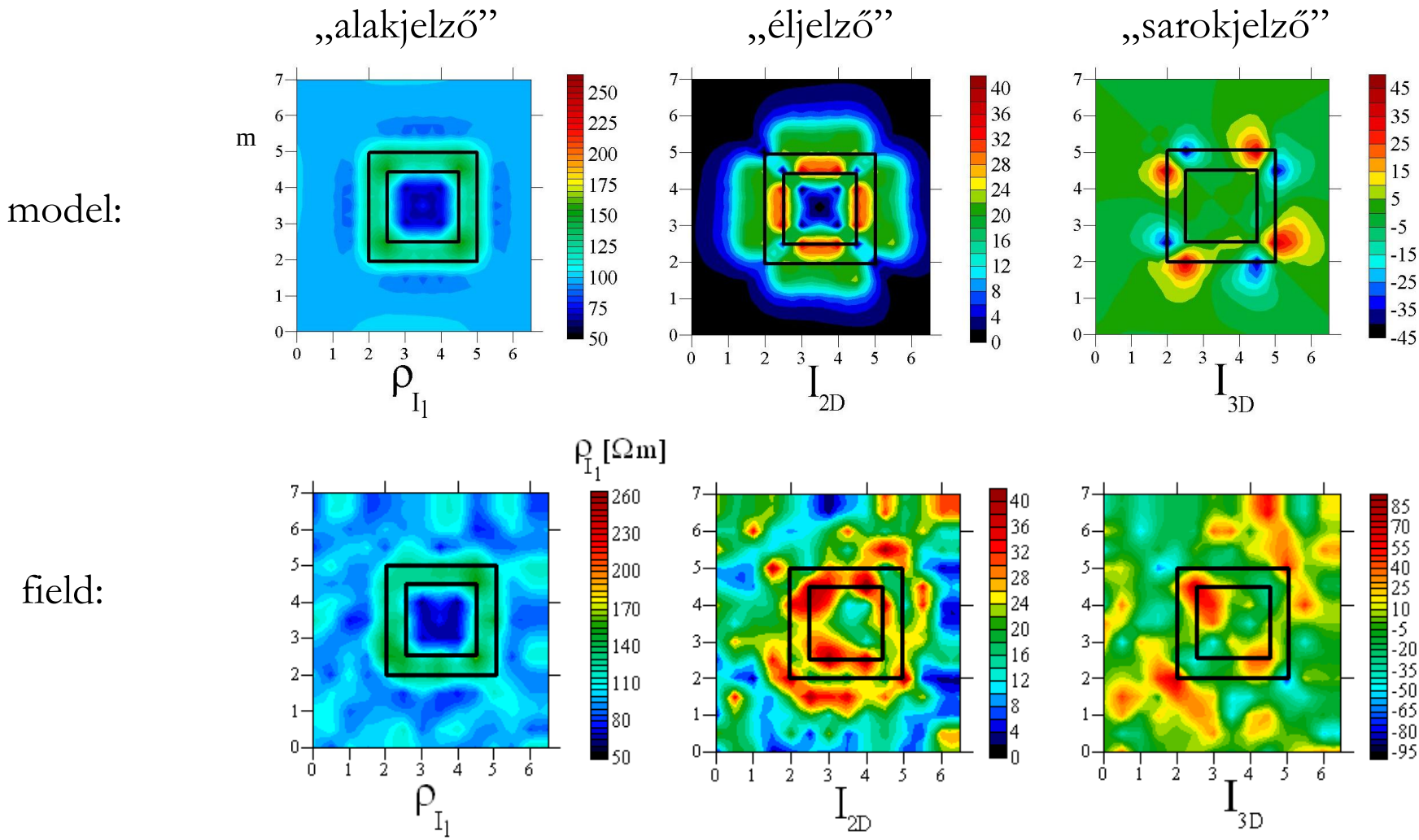
RE-PROCESSING OF FIELD MT DATA

Novák A. (PhD, Sopron) 2009

or

„Let the data speak!" (Berkhout 2021)

In field only the basic (areal) invariants can be used



agreement: good weak or weak

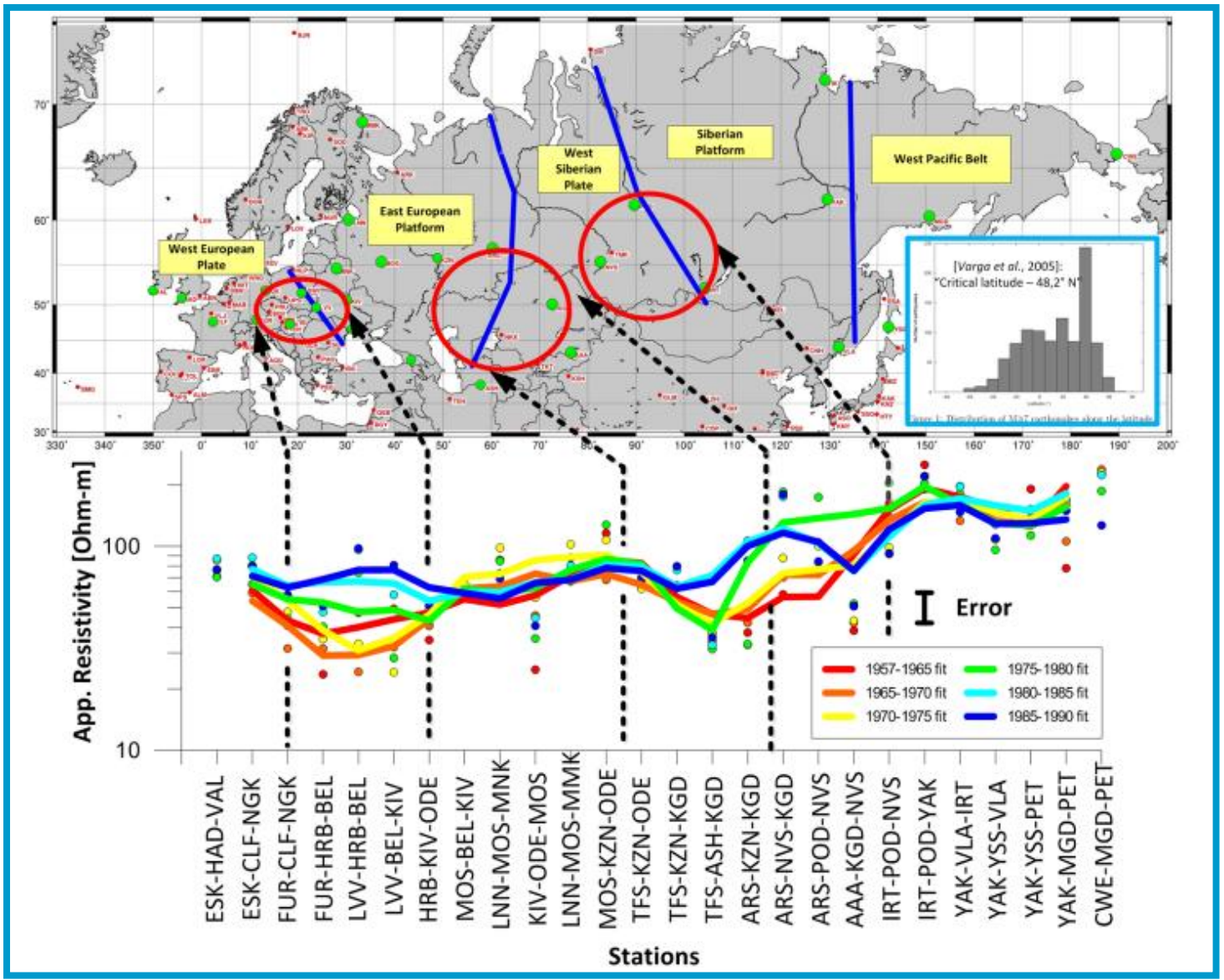
Novák A. (PhD, Sopron), 2009

or

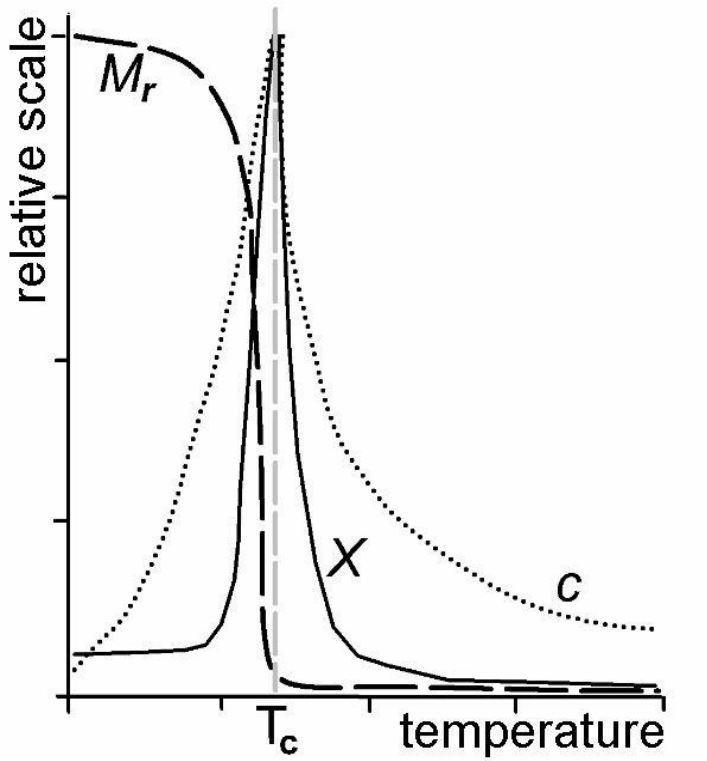
„Let the data speak! (Berkhout 2021)

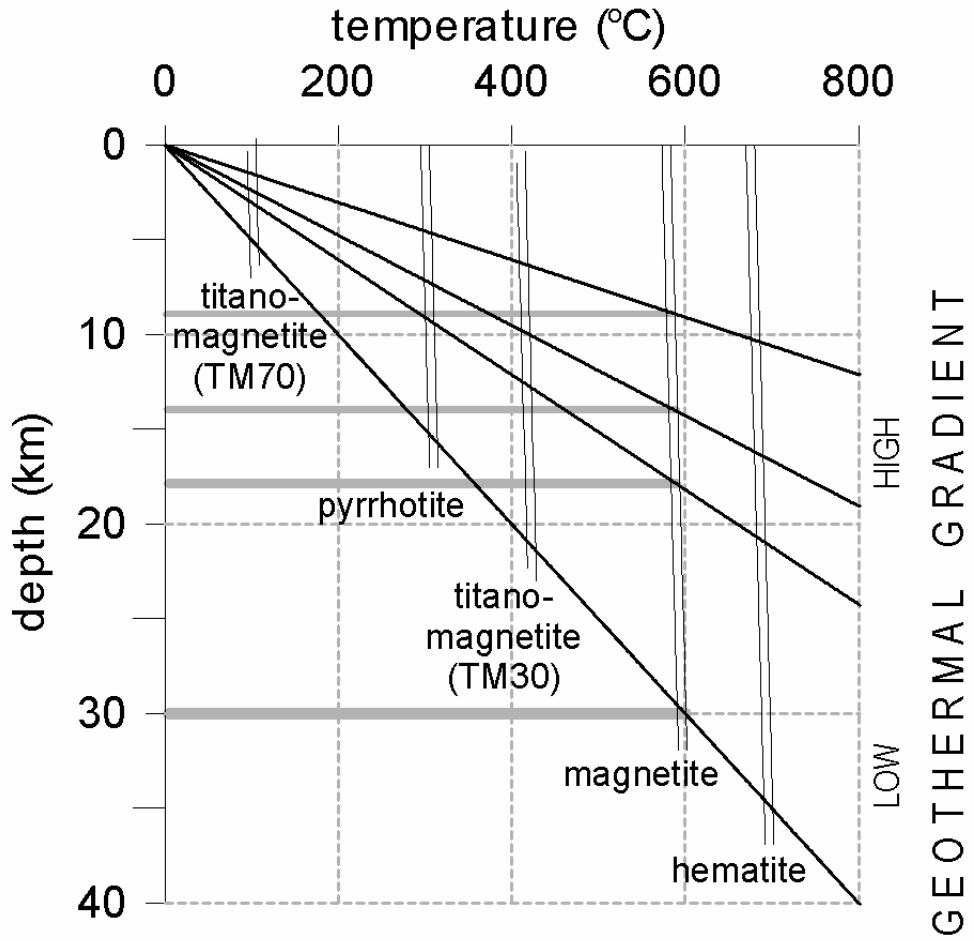
IAGA 12th Scientific Assembly, Mérida (Yucatán, Mexico, 26-31 August, 2013) Paper J5-4:
Features of the long-term variations of the Earth's impedance and its gradients
(Petrishchev M. S., Semenov V. Yu.)

„The greatest changes in the resistance of the Earth in time – in active regions"



Possibility of extraordinary magnetization ("second-order magnetic phase transition").in the narrow range of the earth's crust above the Curie depth?



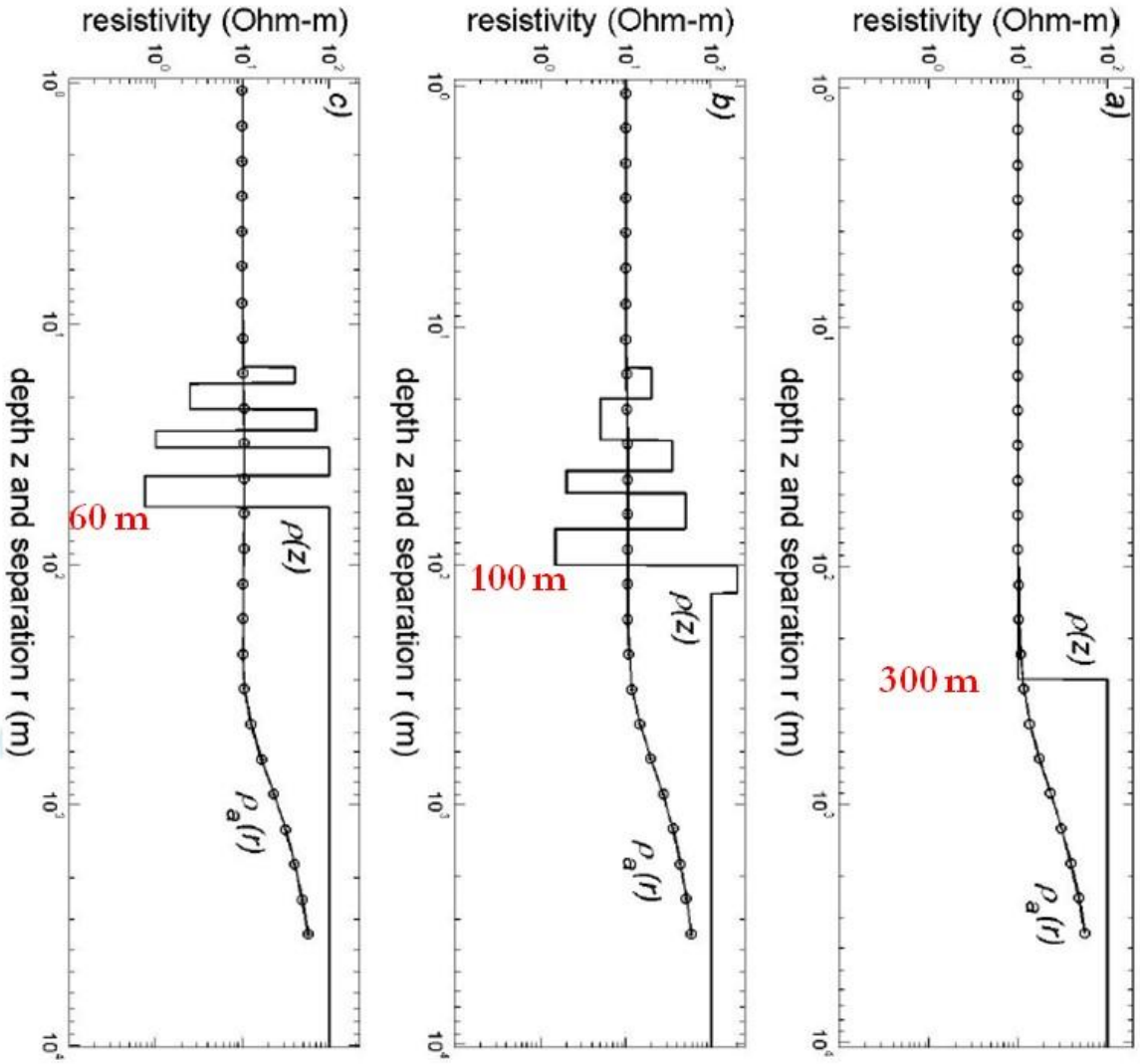


Kiss J., Prácser E., Szarka L.: Geophysical Research Letters, 2005

In geophysics

a good match between the model and the measured values is a necessary but not sufficient condition

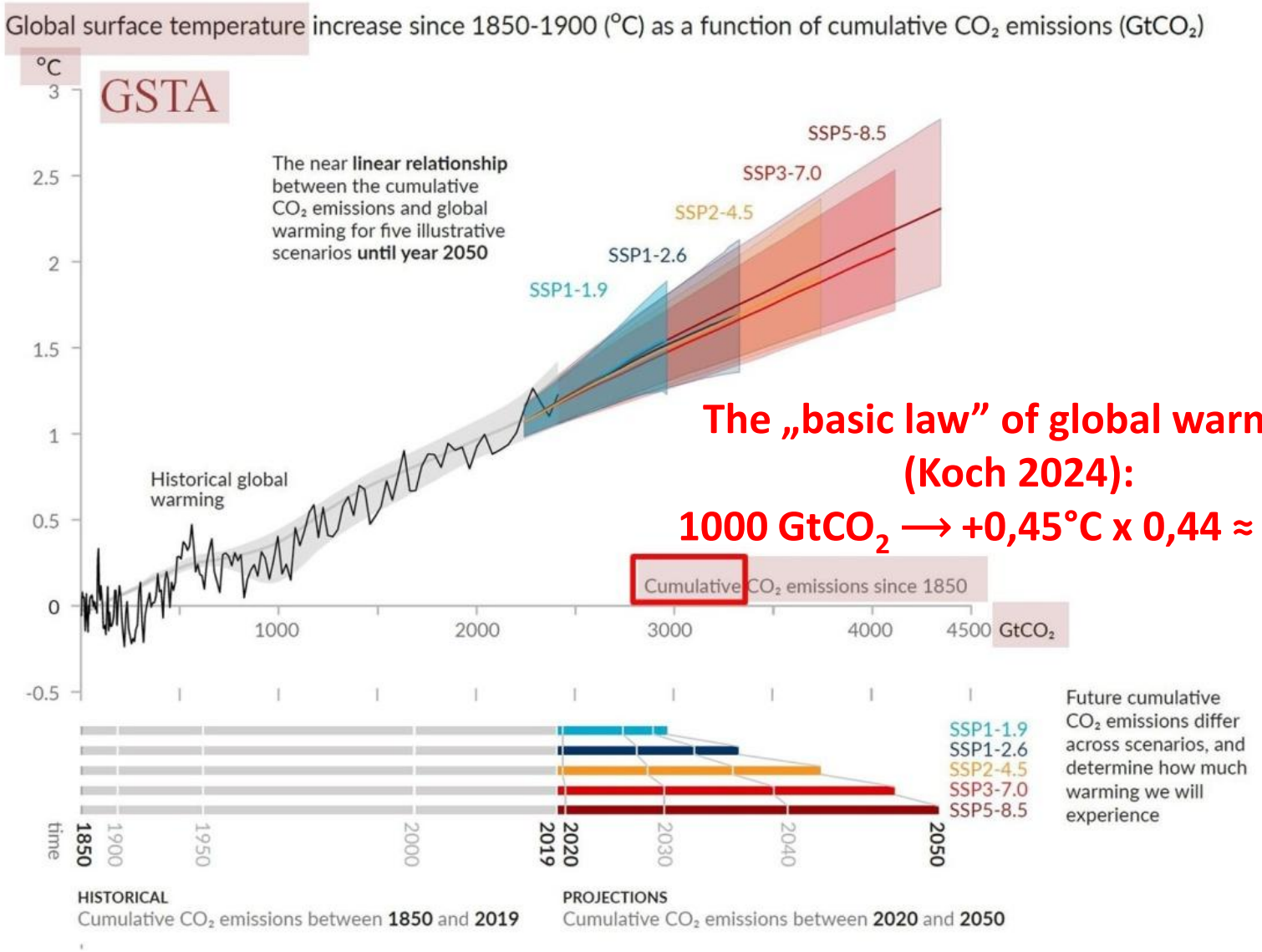
Three completely different interpretation options of the same VES sounding curves.



In climate science

the model curve and the measured temperature data do not even match!

Every tonne of CO_2 emissions adds to global warming

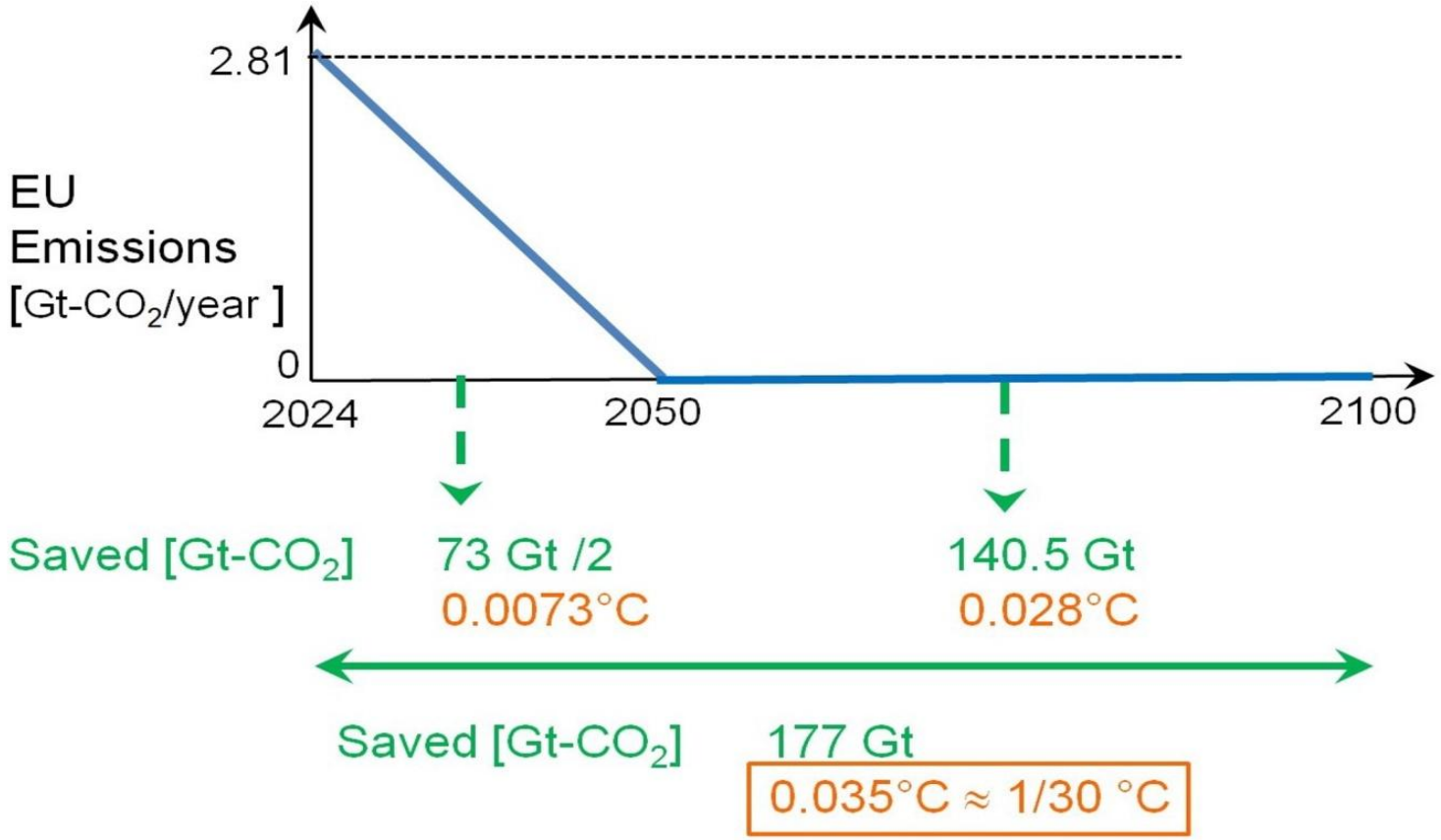


The „basic law" of global warming (Koch 2024):

1000 $GtCO_2$ ⟶ +0,45°C x 0,44 ≈ 0,2°C

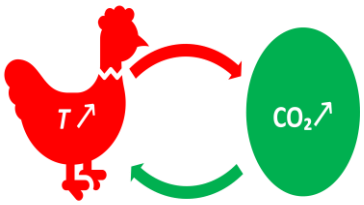
Figure SPM.10: Near-linear relationship between cumulative CO2 emissions and the increase in global surface temperature.

Figure by Koch (2024) shows the perfect realization of the Net Zero plan of EU.



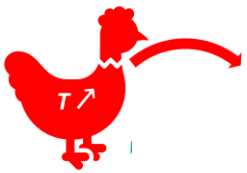
On basis of global emission data (~40 $GtCO_2$/year),
CO_2 „saved" between 2024 and 2100: ~2500 Gt.
On basis of global warming law it means 0,5 °C.

Price: giving up all fossils (80% of the energy source of the humanity), without any real solution. An impossible mission.

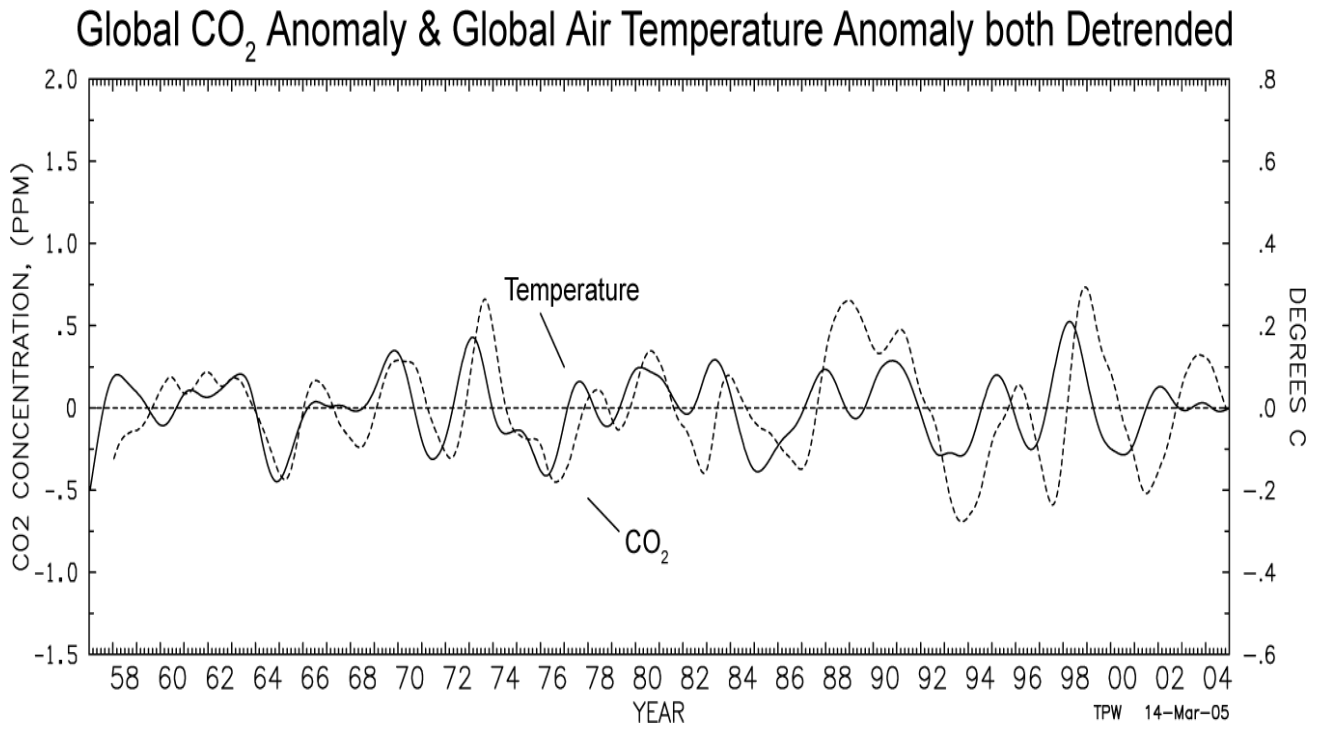


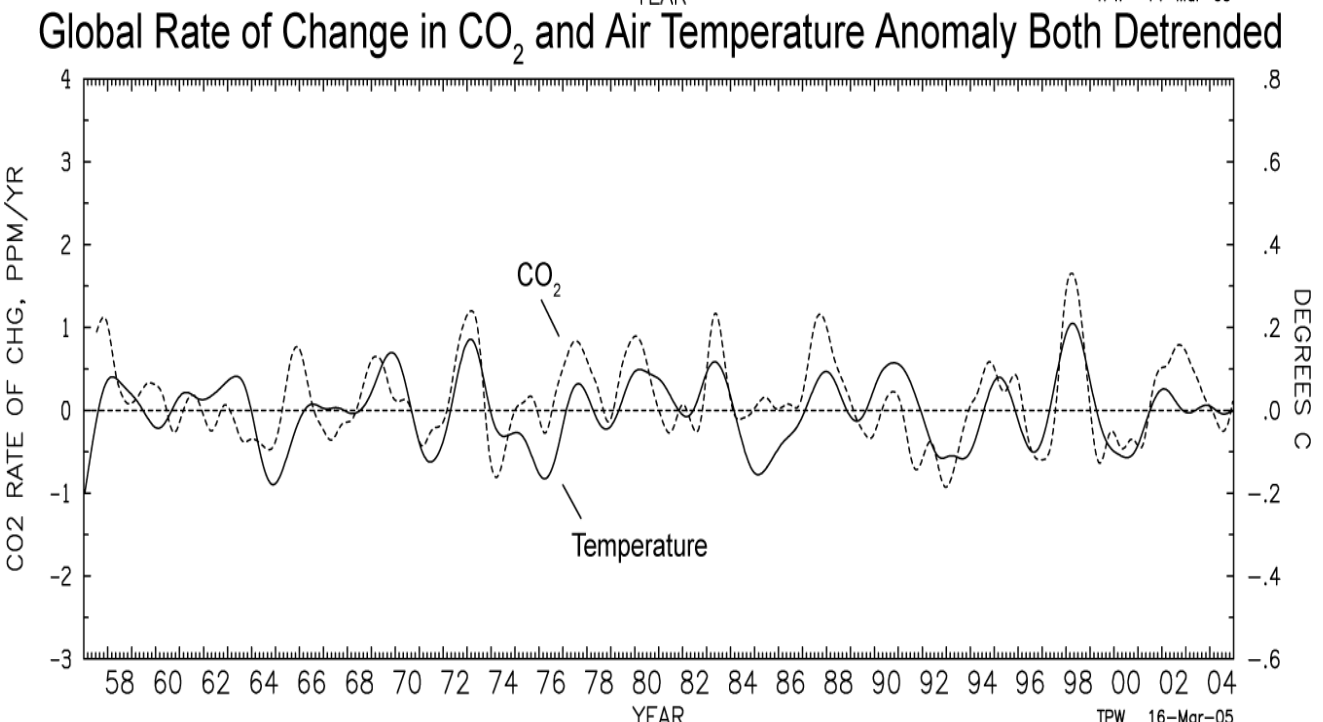
ΔT^a
és
$\Delta CO_2{}^a$

Charles David KEELING (2005, Tyler Prize Lecture)



ΔT^a
és
$\Delta CO_2{}^a/\Delta t$





A LIST OF SOLAR VARIATIONS

Short Term Orbital Forcings (STOF)
Schwabe: ~11 years
Hale: ~22 years
Gleissberg: 80-100 years
José: 155-185 years
Suess (de Vries): 200-250 (~210) years
„Grand”: 300-400 years
Eddy: 800-1200 years
Bray-Hallstatt: 2100-2500 years
(Charvatová cycle: 2402 years)
Milankovitch cycles
etc.

It is easily possible that all solar variations are due to angular momentum variations of the planets in the Solar System

IMPACTS:

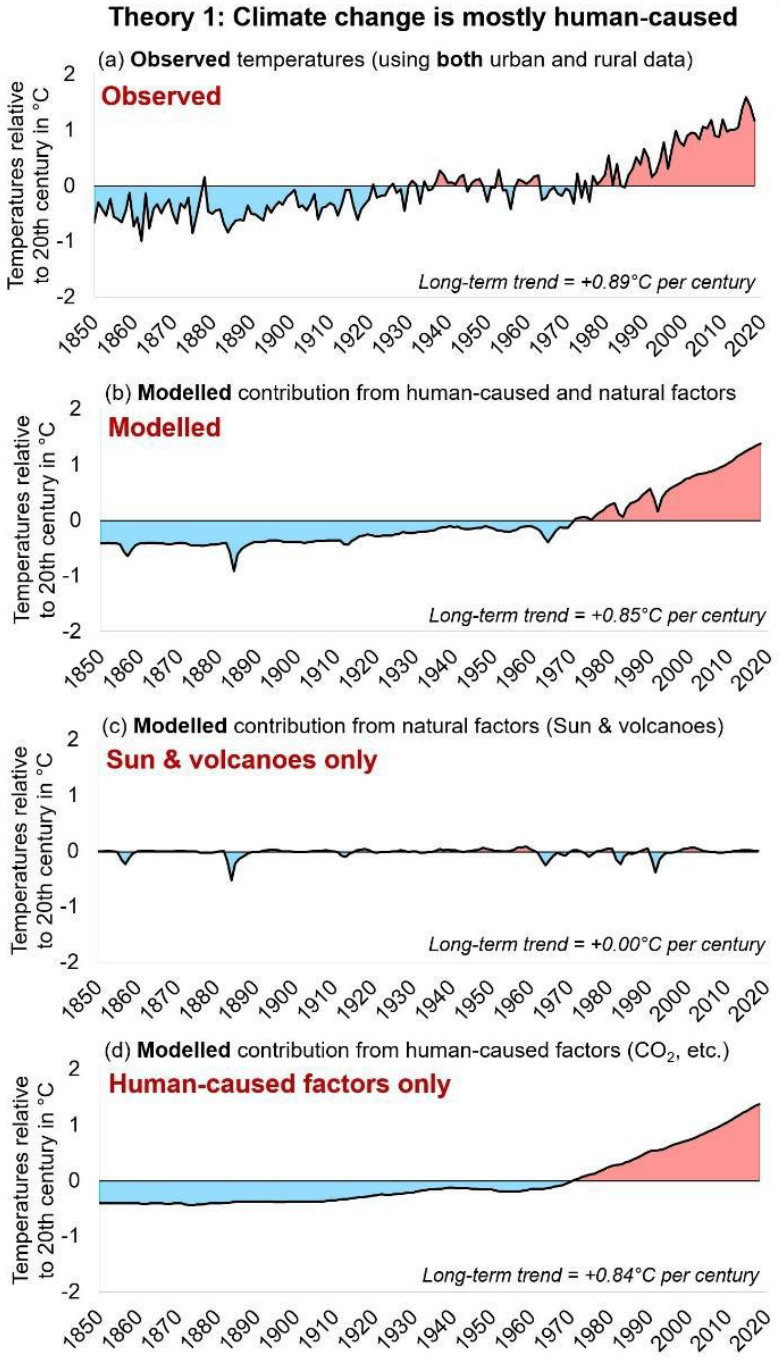
EVIDENCES FOR CLIMATE CHANGE

Paleoclimate proxies (bio, geo, cryo)
Quantitative data (astro-, hydro etc.)
Observations

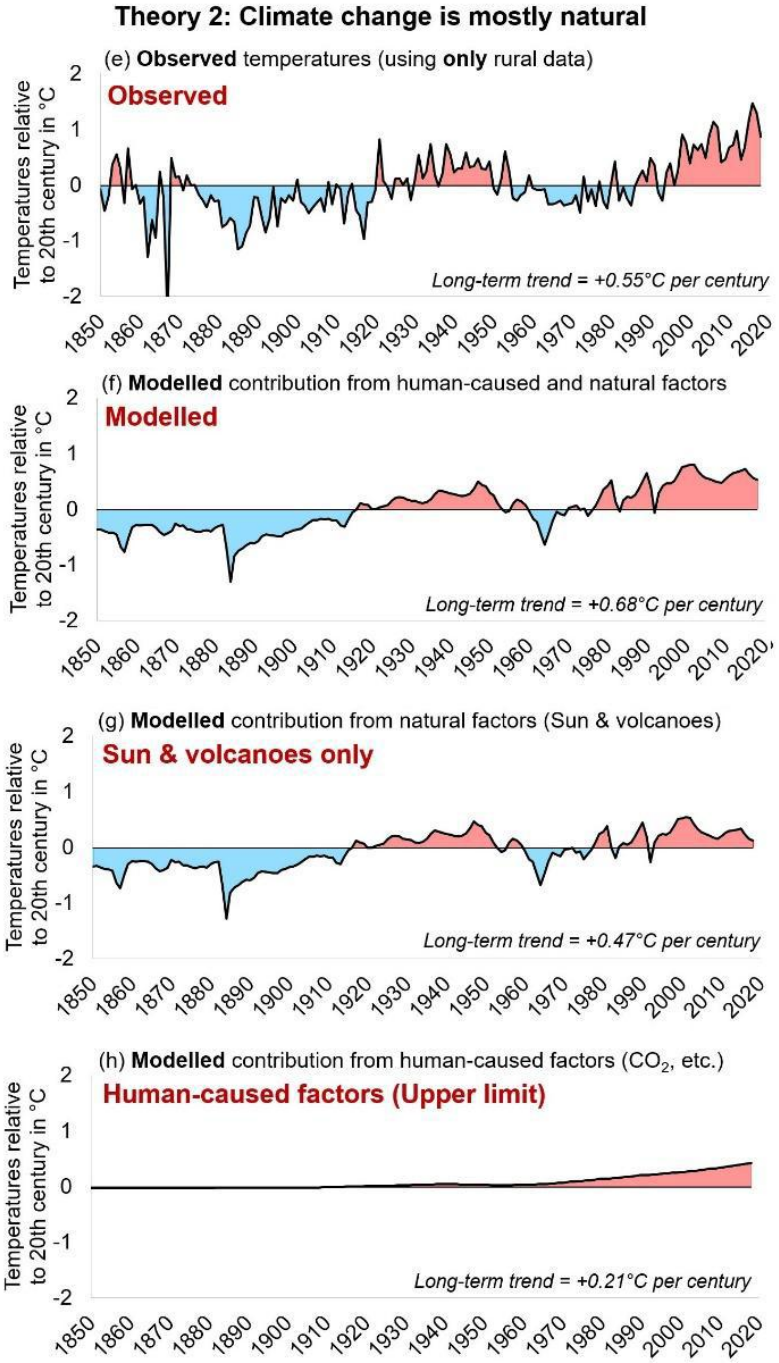
EVIDENCES FOR GLOBALLY CONCURRENT SUDDEN CLIMATE CHANGES ARE KNOWN FROM GEOLOGY:

Bond events:
~1000-1500 k years (1470 ky?)
Dansgaard–Oeschger (DO) events
~3 kyears (between -12 ky and -120 ky)
Heinrich events:
~6 k years

IPCC



Connolly et al. (2021)

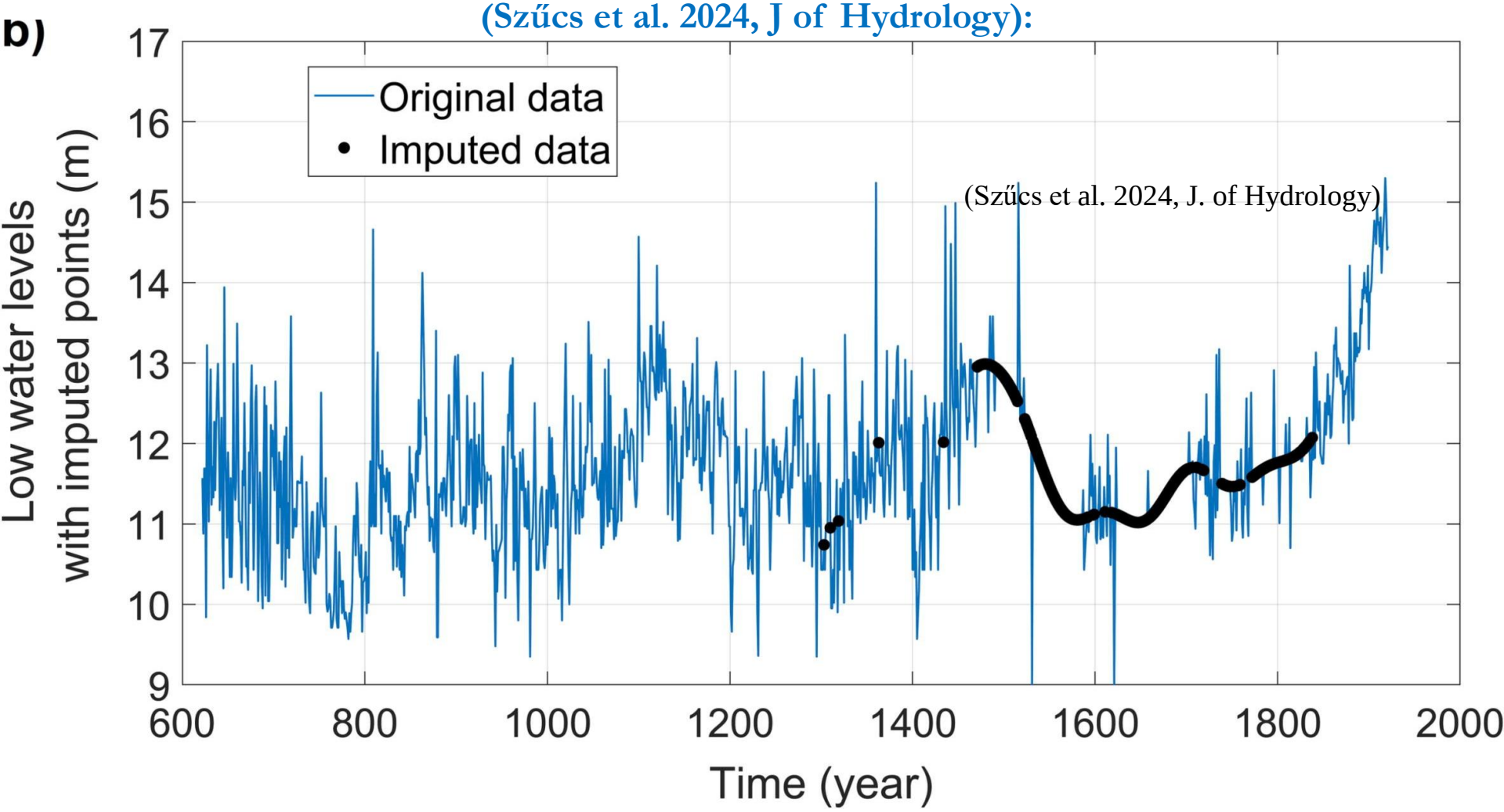


The conclusion depends on the data considered.

Taking into account all data, it is impossible to arrive to the same conclusion as IPCC does.

The water level of river Nile between 622 és 1921

(Szűcs et al. 2024, J of Hydrology):



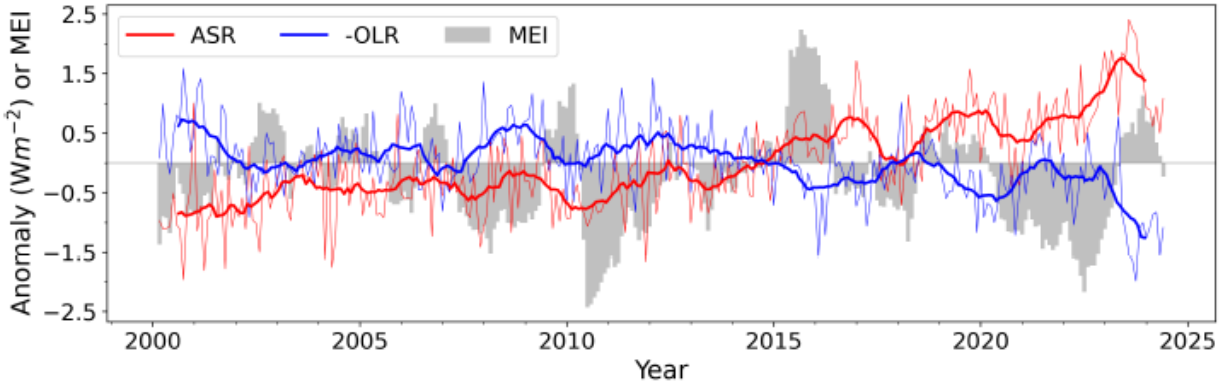
In February 2024, we put the world's longest climate time series consciously measured by humans into the hands of climate researchers.

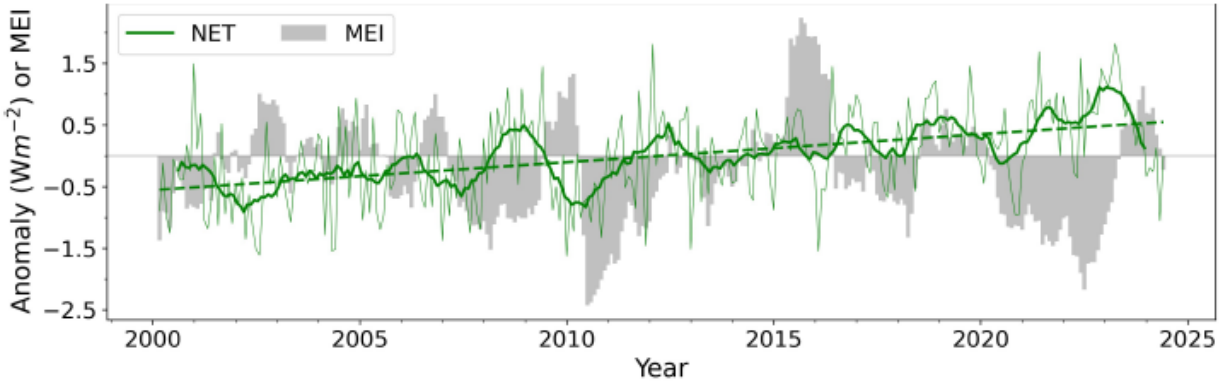
Instead of climate models, for quantitative observations and mappings you need:

„Let the data speak!" (Berkhout, 2021)

Global Mean All-Sky TOA Flux Anomalies (CERES EBAF Ed4.2; 03/2000–06/2024)

Loeb 2024





Trends (Wm^{-2} per decade; 2.5-97.5% CI)

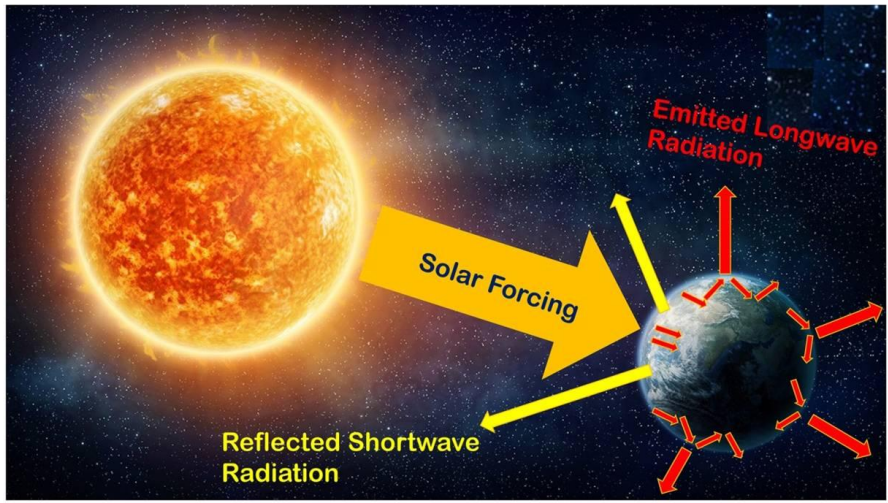
ASR: 0.81 ± 0.21

−OLR: −0.36 ± 0.20

NET: 0.45 ± 0.18

NET=ASR-OLR

ASR (Absorbed Solar Radiation) is increasing
OLR (Outgoing Longwave Radiation):is increasing
NET (EEI imbalance) is increasing



INTERPRETATION, AS AN INVERSE PROBLEM

– the factors of human origin: ***A*** ("anthropogenic"),
– extraterrestrial factors: ***E***,
– those originating from the interior of the Earth: ***I*** (“internal”),
– and the – arbitrarily complicated – functional relationship between them (i.e. the mapping of observation data varying in time and space): ***O*** ("observation"), then

$$f\,(A, E, I) = O$$

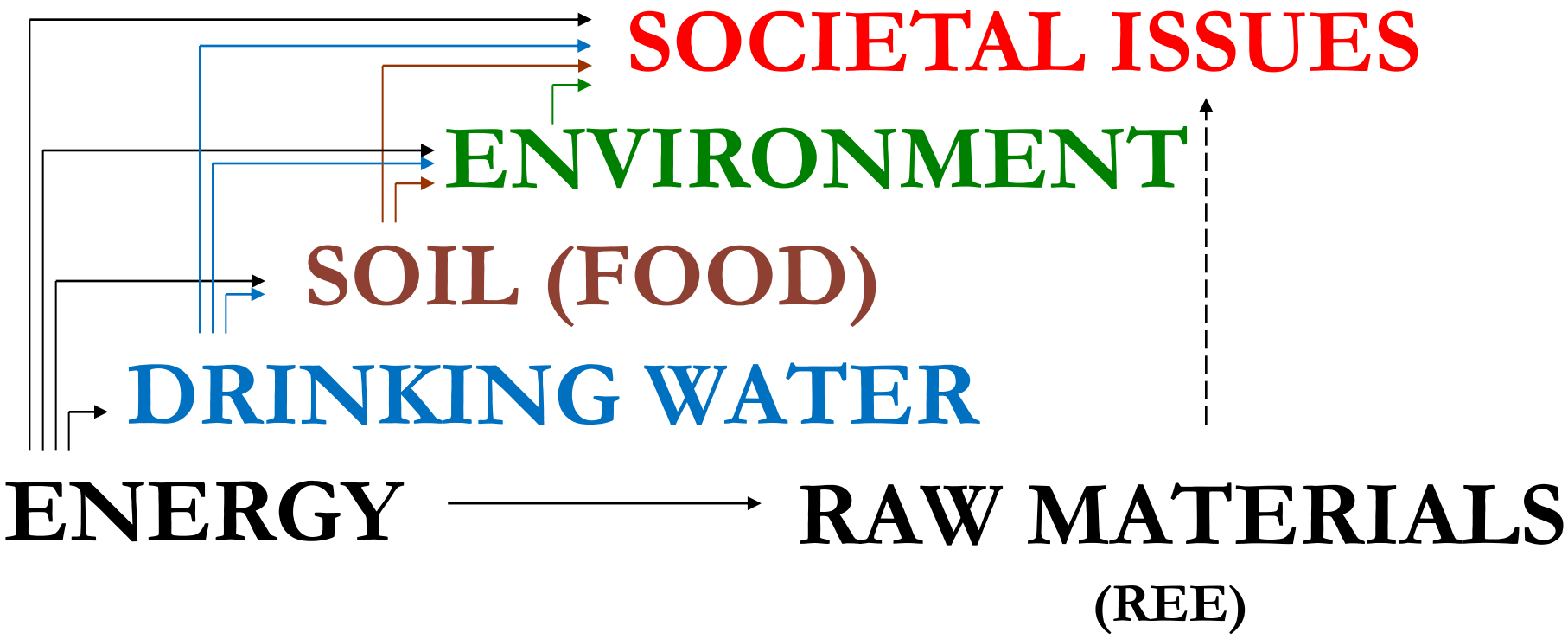
The solution to this relationship is

$$A = f^{-1}(O)$$

only if ***E*** and ***I*** do not change in time and/or space:

Both ***E*** and ***I*** they change all the time!

GLOBAL ISSUES
(THE HUMANE VIEW):



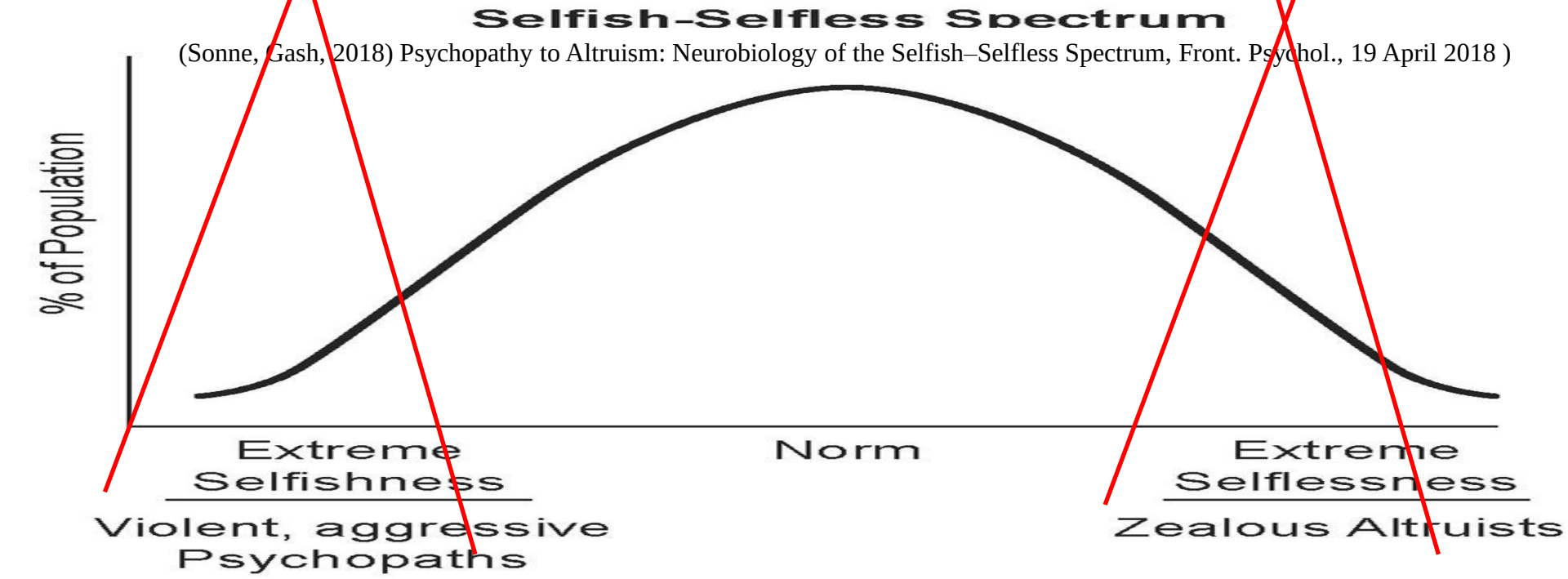
After Richard Smalley (2003)

How Man Thinks: three types for the Earth-Man relationship

„prey”

„gift”

„taboo”



(Sonne, Gash, 2018) Psychopathy to Altruism: Neurobiology of the Selfish–Selfless Spectrum, Front. Psychol., 19 April 2018)

„…anyagi hatalmának korlátlan növekedésével az emberiség egy olyan hajóskapitány helyzetébe került, akinek hajója szilárdságát már annyi acél és vas biztosítja, hogy a tájoló mágnestűje kizárólag a vasszerkezetekre reagál; az északi irányt végleg elveszítette. A hajót már nem lehet úgy irányítani, hogy elérjen valamilyen célt, hanem körbe-körbe fog sodródni, a szélnek és az áramlatoknak kiszolgáltatva.”
(Heisenberg, 1958)

E kérdés számos eltérő értelmezési lehetőséget nyújt, de azokba e keretek között nincs mód belemenni. Újabban úgy gondolom, hogy az Ember nagyobbnak képzeli magát, mint amilyen: a vasszerkezeteken kívüli Föld hatalmas és csodálatos.

“In what appears to be its unlimited development of material powers, humanity finds itself in the position of a captain whose ship has been built so strongly of steel and iron that the magnetic needle of its compass no longer responds to anything but the iron structures of the ship; it no longer points north. The ship can no longer be steered to reach any goal, but will go round in circles, a victim of wind and currents.”
(Heisenberg, 1958)

This question offers multiple interpretation possibilities, but there is no way to go into them within this framework. More recently, I believe that Man imagines himself to be bigger than he is: the Earth outside the iron structures is vast and wonderful.

Summary, conclusions

Electromagnetic Geophysics:

- strict consistency, exactness, points out difficulties and limitations.

"Climate-centric environmental science"

- overconfident conclusions from little data (sometimes from one single correlation); essential relationships are ignored. Empiri impartiality and reasonableness are damaged.

Quantitative Earth Science:

Primarily, the scope and responsibility of quantitative earth science is the reevaluation of natural resources (resources and the environment), the realistic exploration of possibilities, both globally and domestically.

It should be unbiased.

„Bármennyire is fejlődjenek tehát fizikai elméleteink, mégis mindig oly feltevésekre fognak támaszkodni, melyek tovább nem bizonyíthatók. − Szemben ezen, a tudomány fejlődése közben érlelt meggyőződéssel, valóban a jelenkor egyik legcsodálatosabb tévedésének kell mondanunk, hogy annyian hallgatnak azon álpróféták szavára, kik a vallás dogmái helyett természettudományi dogmákat kínálgatnak, középkori türelmetlenséggel, de történeti jogosultság nélkül.

Az igazi természettudós az ily önámítástól távol áll, tudja, hogy osztályrészéül a természet végokaival szemben a lemondás jutott; de azért nem csügged el, mint Faust, ki véges munkáért végtelen jutalmat követel, hanem ernyedetlenül halad előre az elérhetetlen cél felé, s örömet talál magában a kutatásban s azon eredményekben, melyeket az emberiség anyagi jólétének előmozdítására értékesít.”

Báró Eötvös Loránd, 1877

„No matter to what extent our physical theories are improving, they shall always rely on assumptions that cannot be proved any further. In contrast to this, with the conviction matured during scientific progress, we ought to regard it as one of the most surprising faults of our days that there are so many who take heed of the false prophets offering scientific dogmas instead of religious ones, with medieval intolerance, but without historical authorization.”

Such self-illusion is foreign to a true scientist's nature. The true scientist knows that it is renunciation that has fallen to his lot in terms of understanding nature's ultimate causes; he, however, does not get disheartened like Faust, who requests an unlimited reward for his limited work, but keeps going towards the unreachable target, and enjoys research itself and the results which he utilizes for the promotion of the material good of mankind.”

Baron Roland Eötvös, 1877