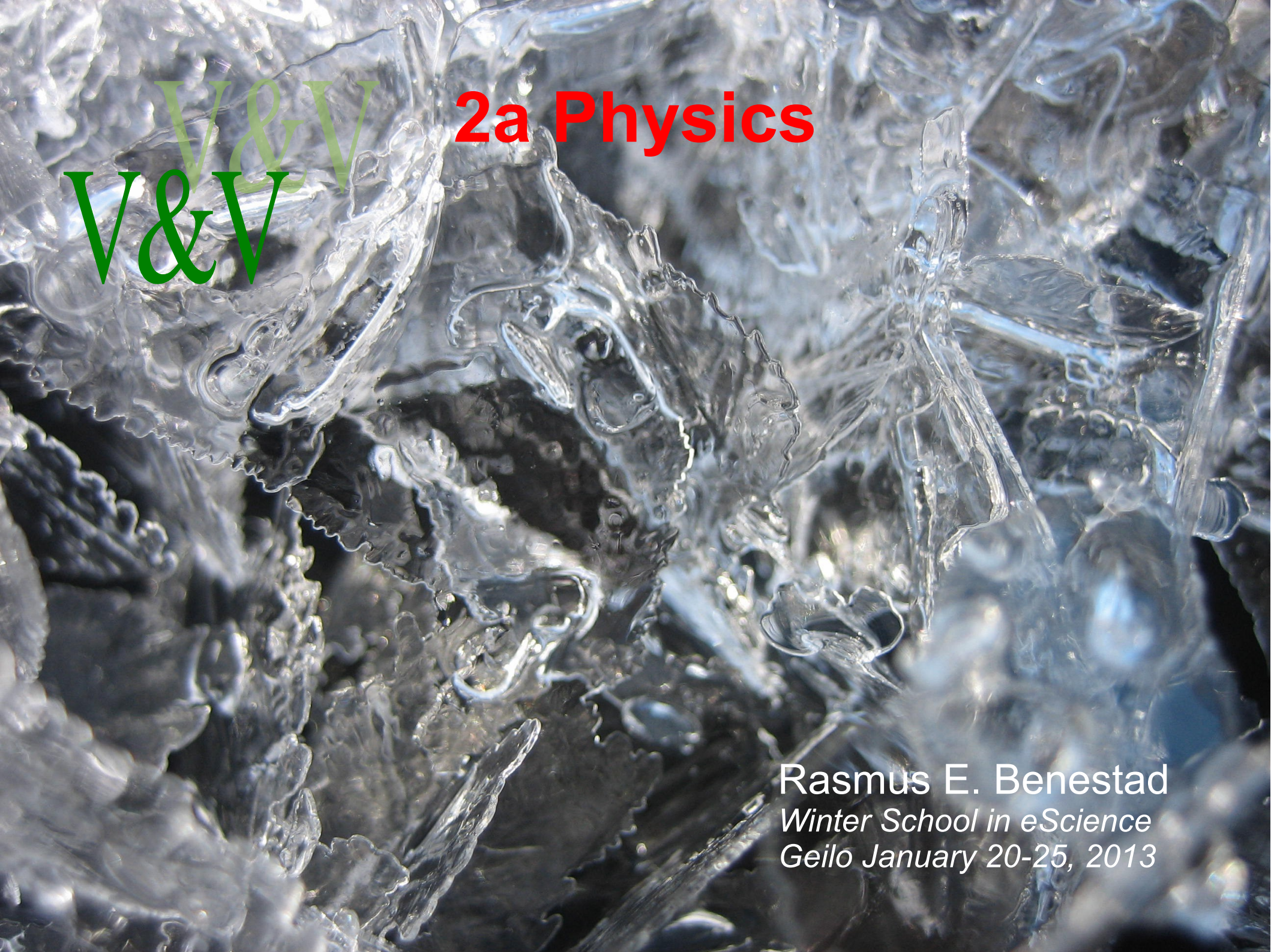


2a Physics

Rasmus E. Benestad

Winter School in eScience
Geilo January 20-25, 2013

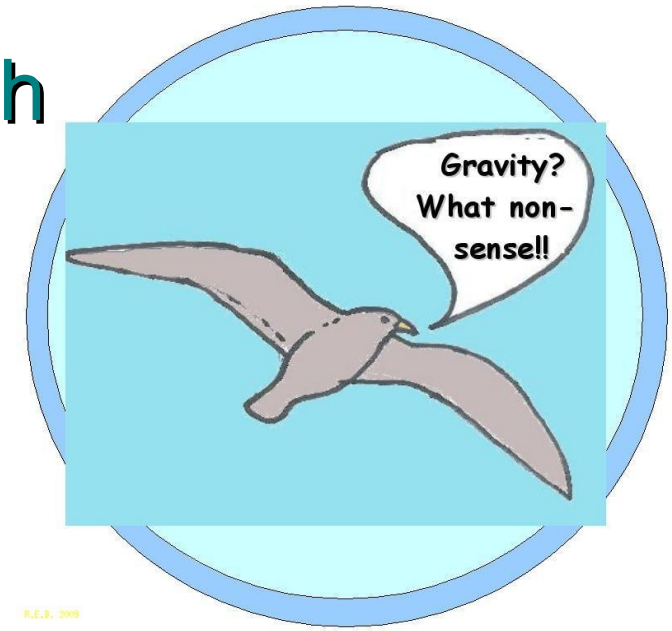
Independent source information

Knowledge-based verification.
Utilise **independent information**: physics, chemistry, etc.

How can physic be used for V&V?

E.g. things we know:

- Matter does not just appear or vanish
- Energy is conserved.
- Physics implies certain constraints
- Limited number of possibilities.



How to use additional info in V&V?

What do we want to V&V?
- data, models, results.

Essence: exploit **inter-dependencies**.

Beware of experimenter bias!
-Danger of being mislead by expectations
-Crowd tendencies – follow others' mistakes

Brian Clegg (2013), 'The blind physicist',Physics World, January

Dimensional analysis

The equation: *x=y*

Physical consistency - same physical units on both side of the equation (dimensional analysis & the Buckingham Pi Theorem).

[temperature]= [energy]/[M] = [L]2/[T]2

$$C = \frac{\Delta Q}{\Delta T}$$

Example (from Wikipedia)

- The **simple pendulum**: period T, mass M, length L, and gravity g:
- $f(T,M,L,g)=0 \rightarrow f(\pi)=0$
- $\pi=T^{a1}\ M^{a2}\ L^{a3}\ g^{a4}$
- Matrix: rows=dimensions, columns=variables: look for [a1,a2,a3,a4] that yields matrix product= [0,0,0]
- Physical units: T=t, M=m, L=l, $g=l/t^2$.

$$M = \begin{bmatrix} 1 & 0 & 0 & -2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$

$$a = \begin{bmatrix} 2 \\ 0 \\ -1 \\ 1 \end{bmatrix}.$$

$$\pi = T^2\ M^0\ L^{-1}\ g^1 \quad f(gT^2/L)=0 \rightarrow T \sim (L/g)^{1/2}$$

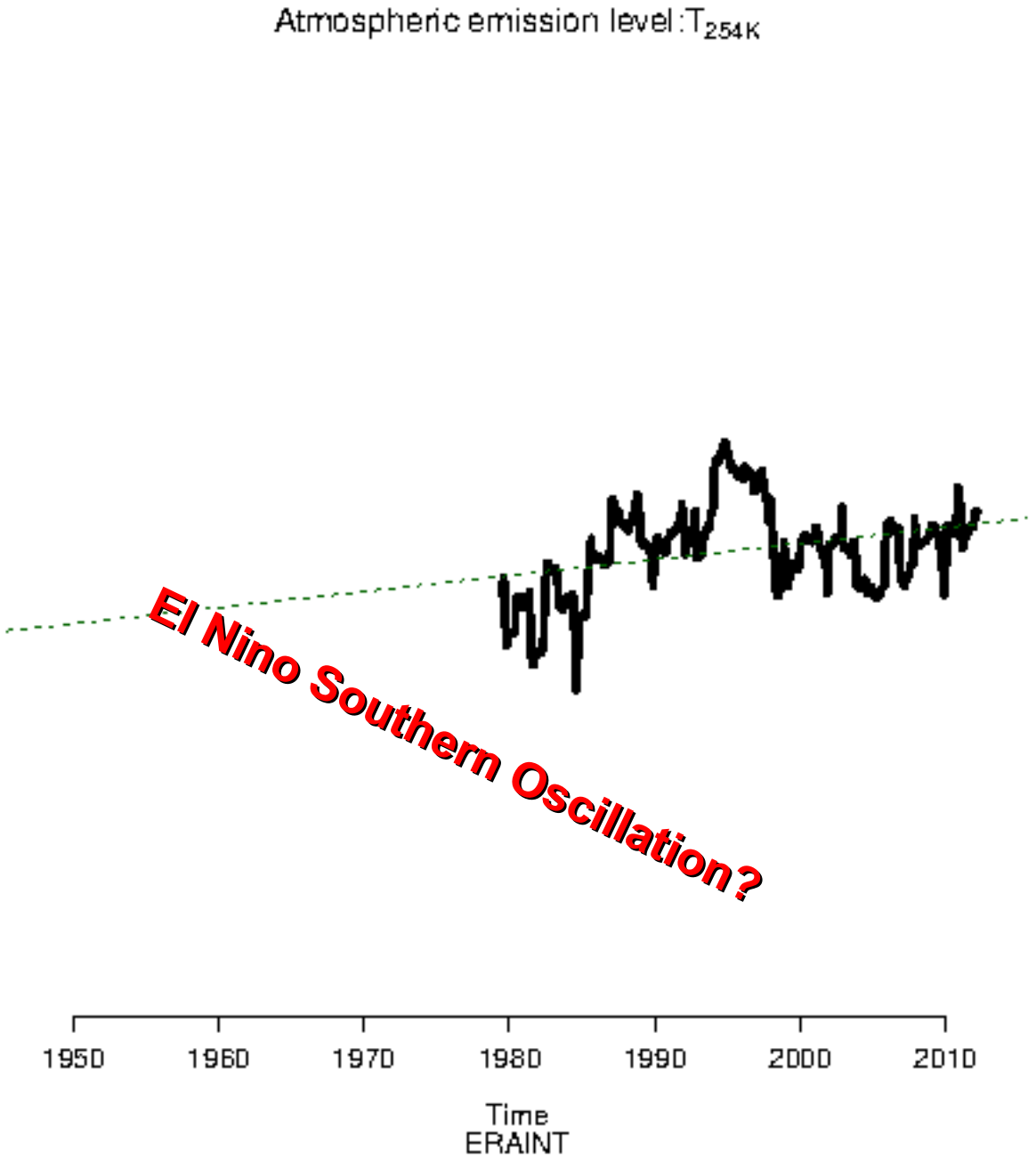
Some examples

Case 1. Expectations about the data
Case 2. Cycles and restoring forces
Case 3. Constraints implied by the hydrological cycle.
Case 4. How to make use of the energy budget.
Case 5. The CO_2 cycle and budget.
Case 6. The greenhouse effect.
Case 7. Climate change.

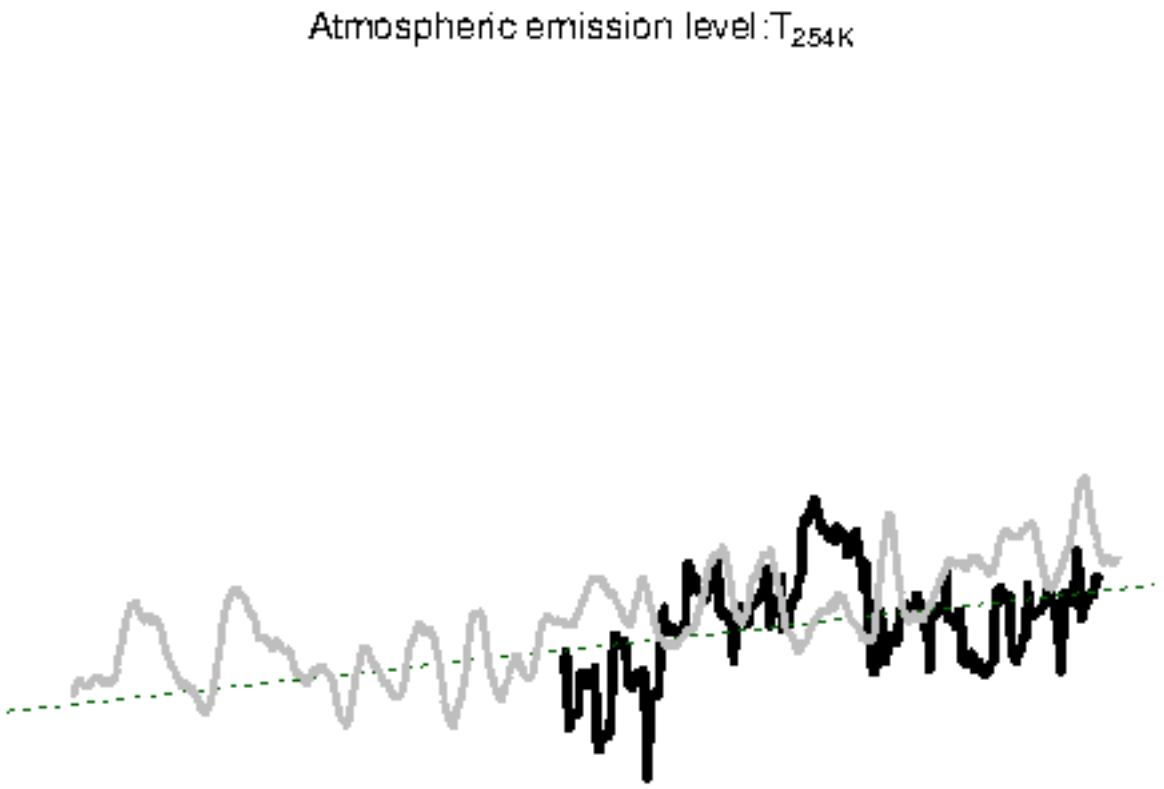
Case 1.

Verifying data

ERAINT from ECMWF database



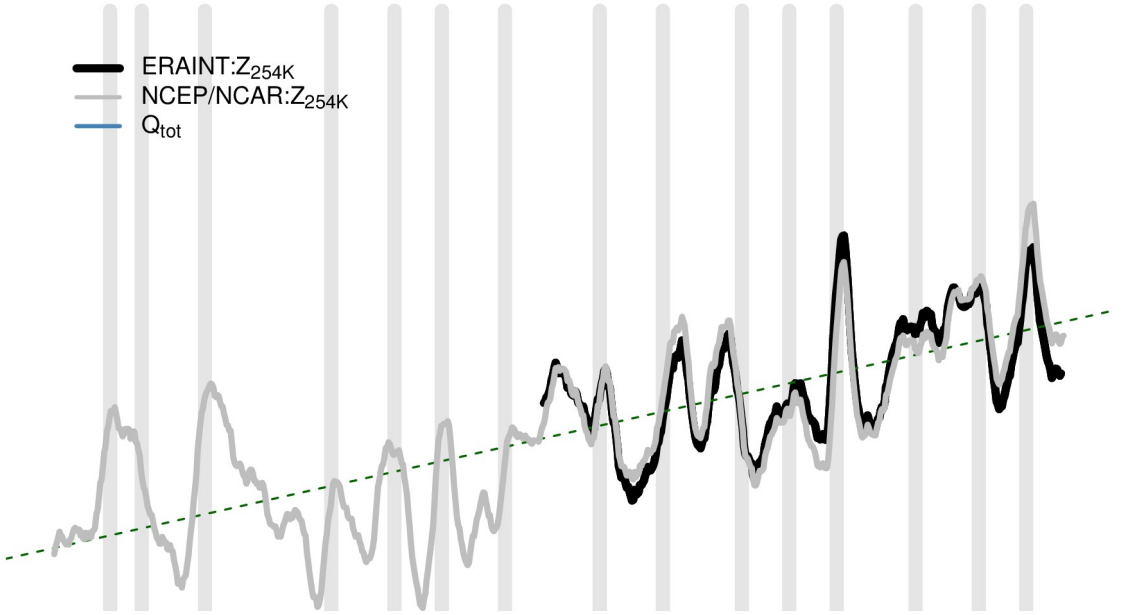
Verifying data
+NCEP/NCAR



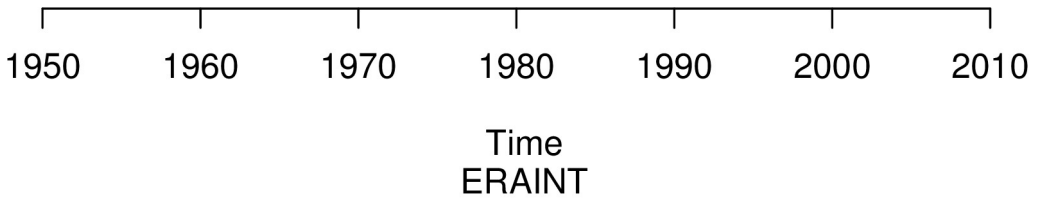
Equivalent & independent data

Verifying data
+NCEP/NCAR

Atmospheric emission level T_{254K} and relative humidity Q_{tot}

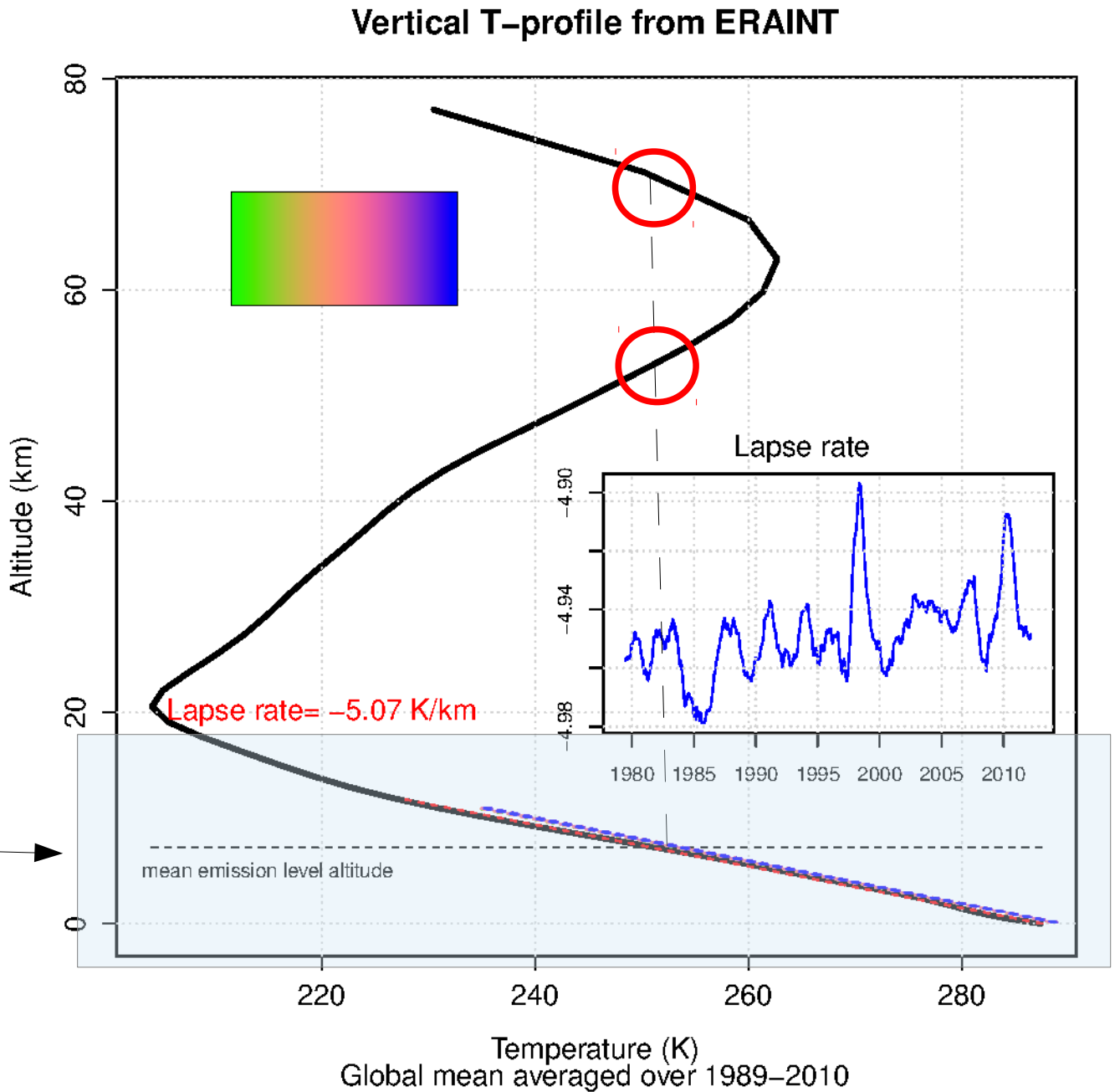


After checking the processing...



Reveal reasons for discrepancies

- Ask: **Why?!?**
- Case above: temperatures high above the troposphere cross T=254Kagain.

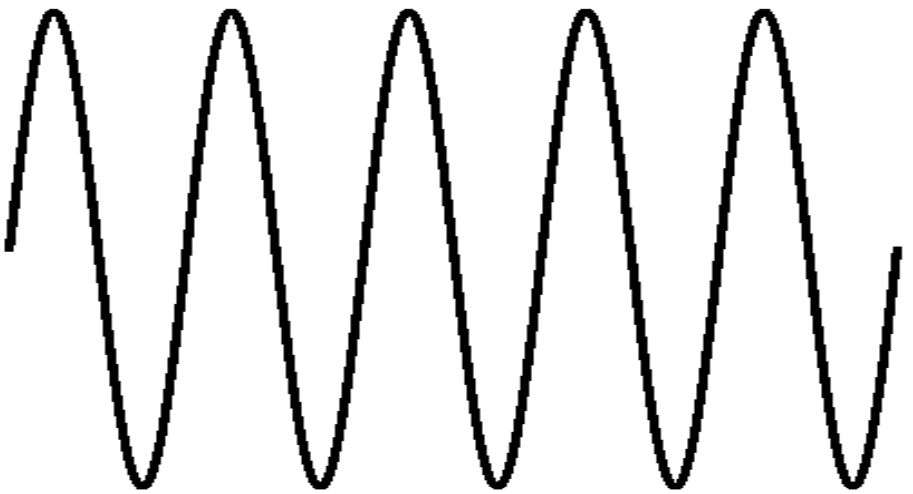


Region of interest

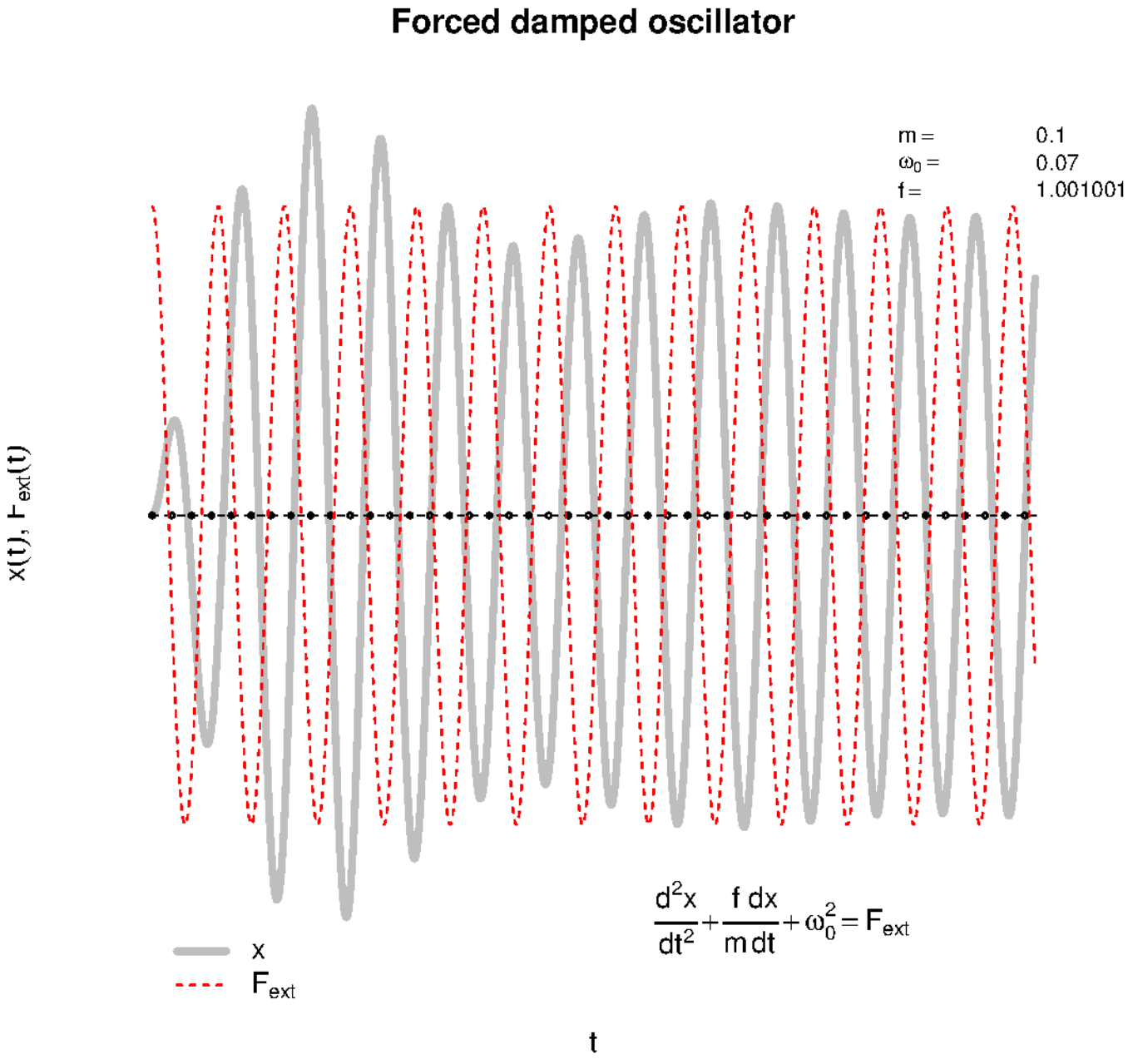
Case 2. Time structure

- Do we capture the processes? Physics?
- Is there any persistence?
- Does the system undergo cycles?
- Dependency and degrees of freedom.
- Spectral analysis.

$$d^2x / dx^2 = -\alpha\, x$$



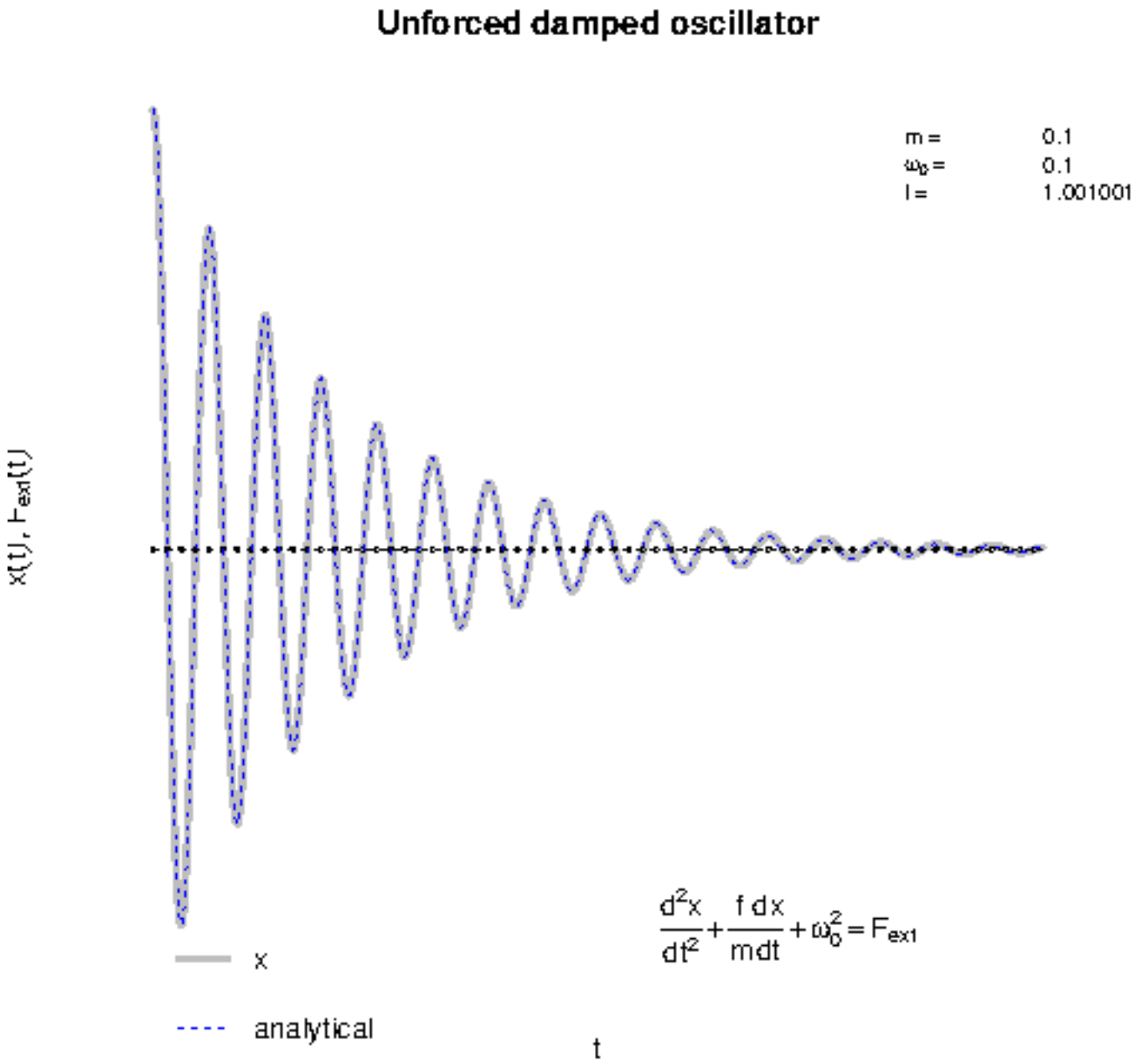
Special cases: forced oscillator



Simple systems.

Simulations can be compared with physical experiments & demonstrations.

Special cases: forced oscillator



Simulations can be compared with analytical solutions.

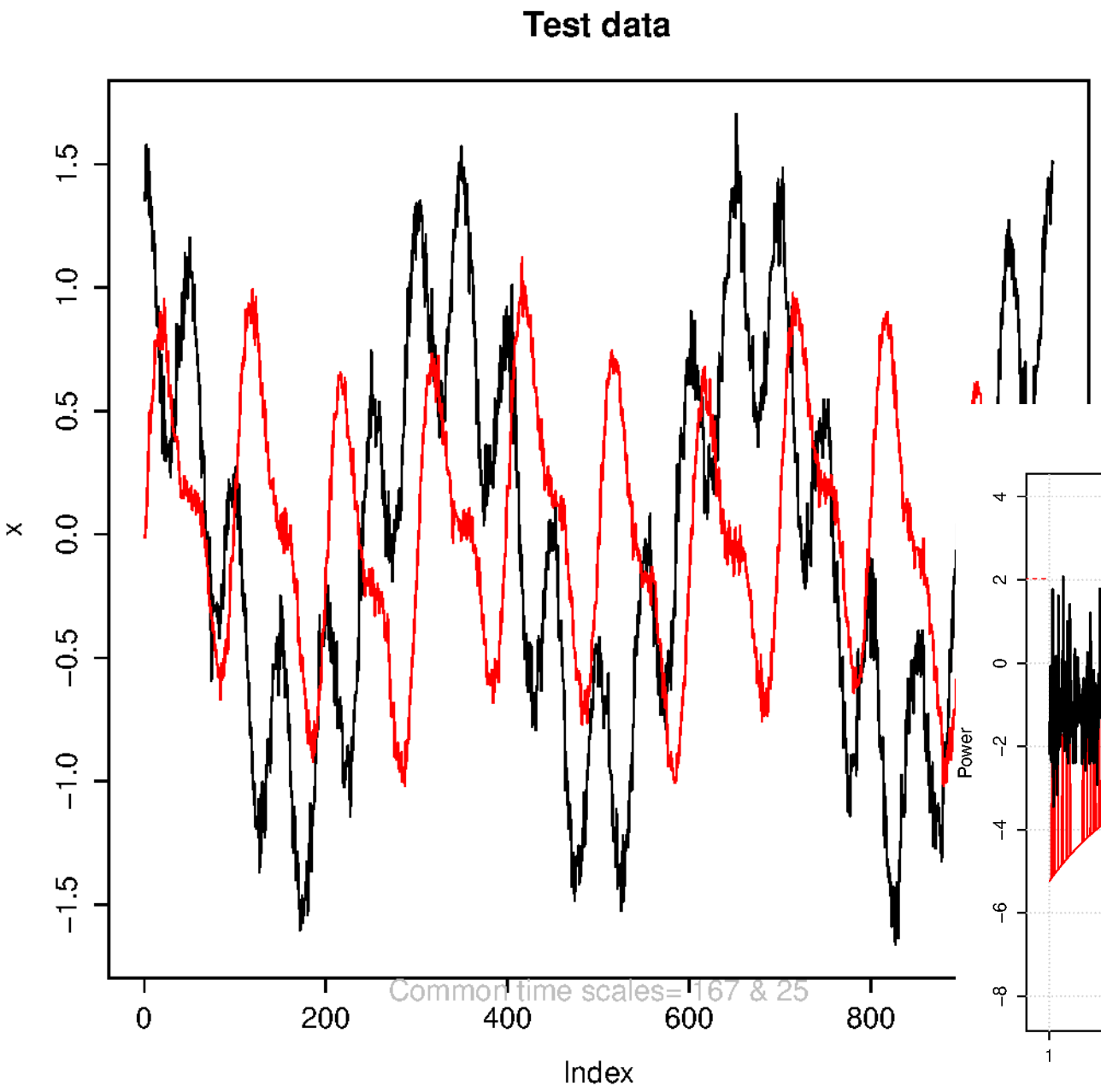
In some cases, approximate solutions.

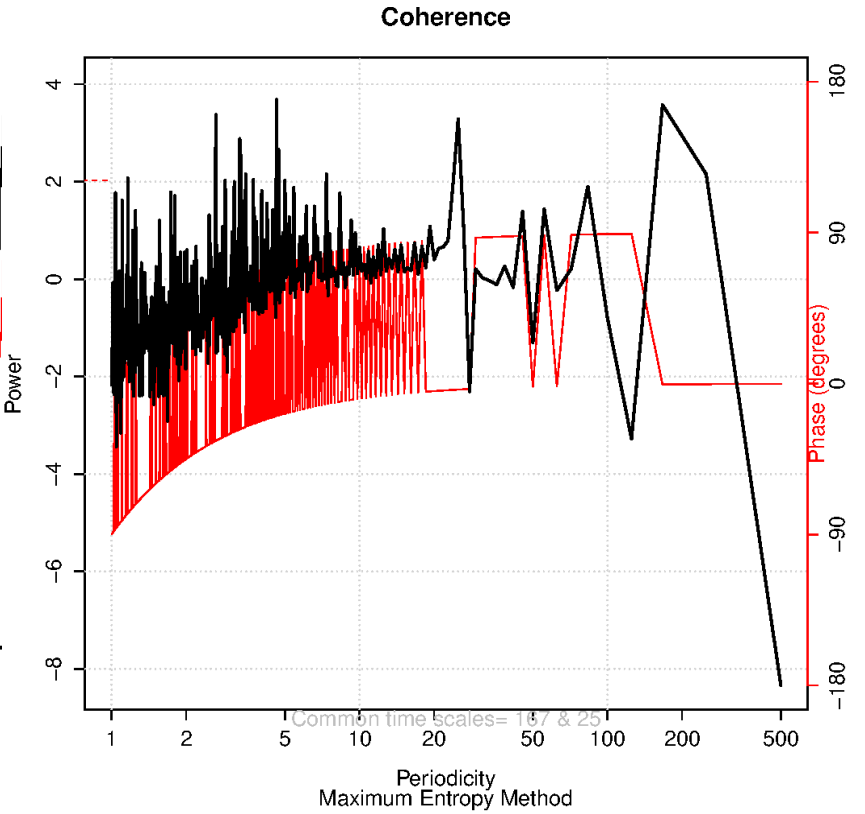
V&V & cycles

- Annual/daily cycle
  - Climate data often have the tell-tale signal of seasonal variations
- Known oscillations
  - e.g. El Nino, the tides, the monsoons
- Example: Harmonic oscillator
  - A restoring force; properties such as frequency determined by mass, length & stiffness.
- 'testcoherence()' in [`clim.pact`].
  - Input known signals

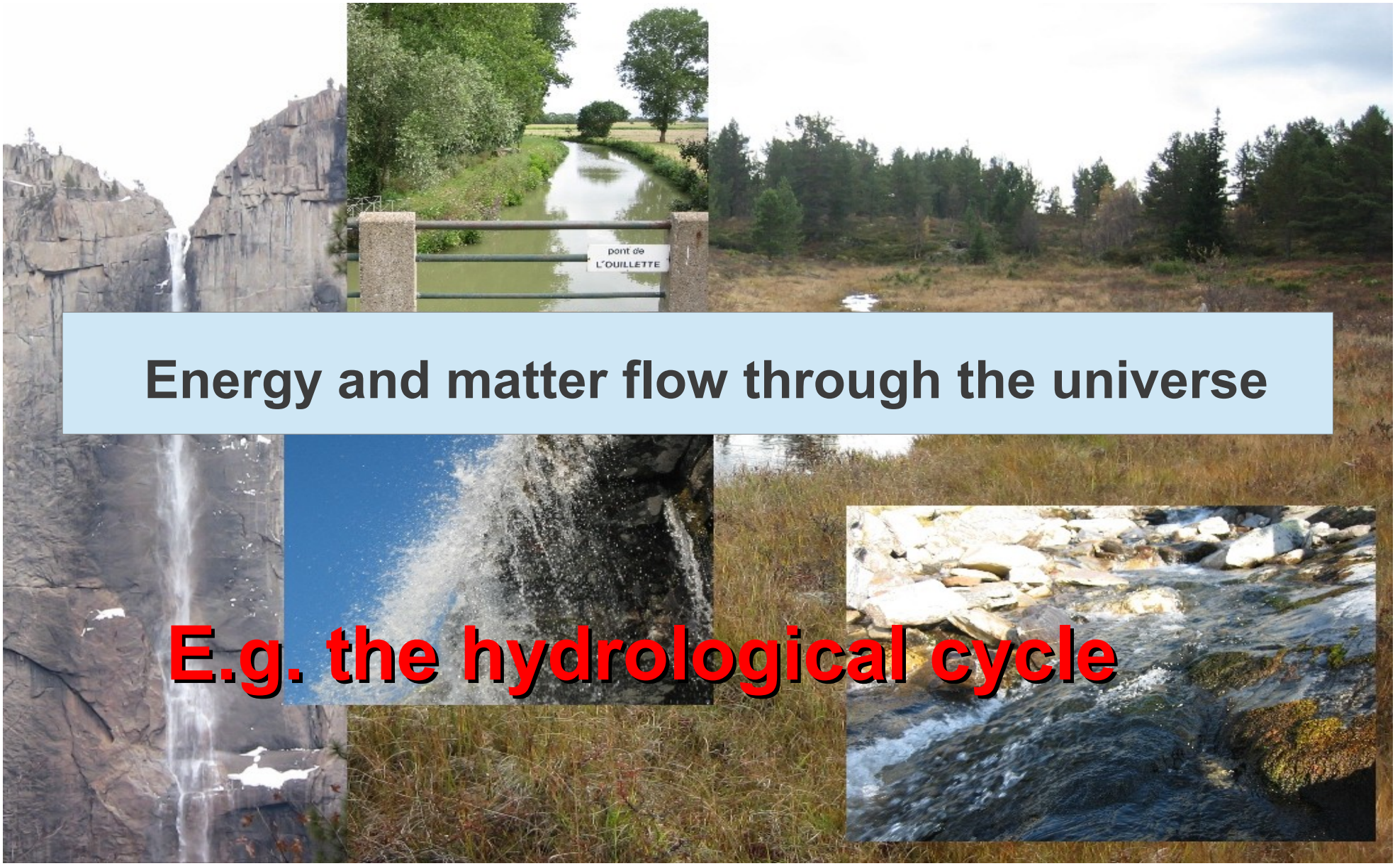
Coherence – common frequencies

V&V with signals of known frequencies and noise





Case 3. the hydrological cycle

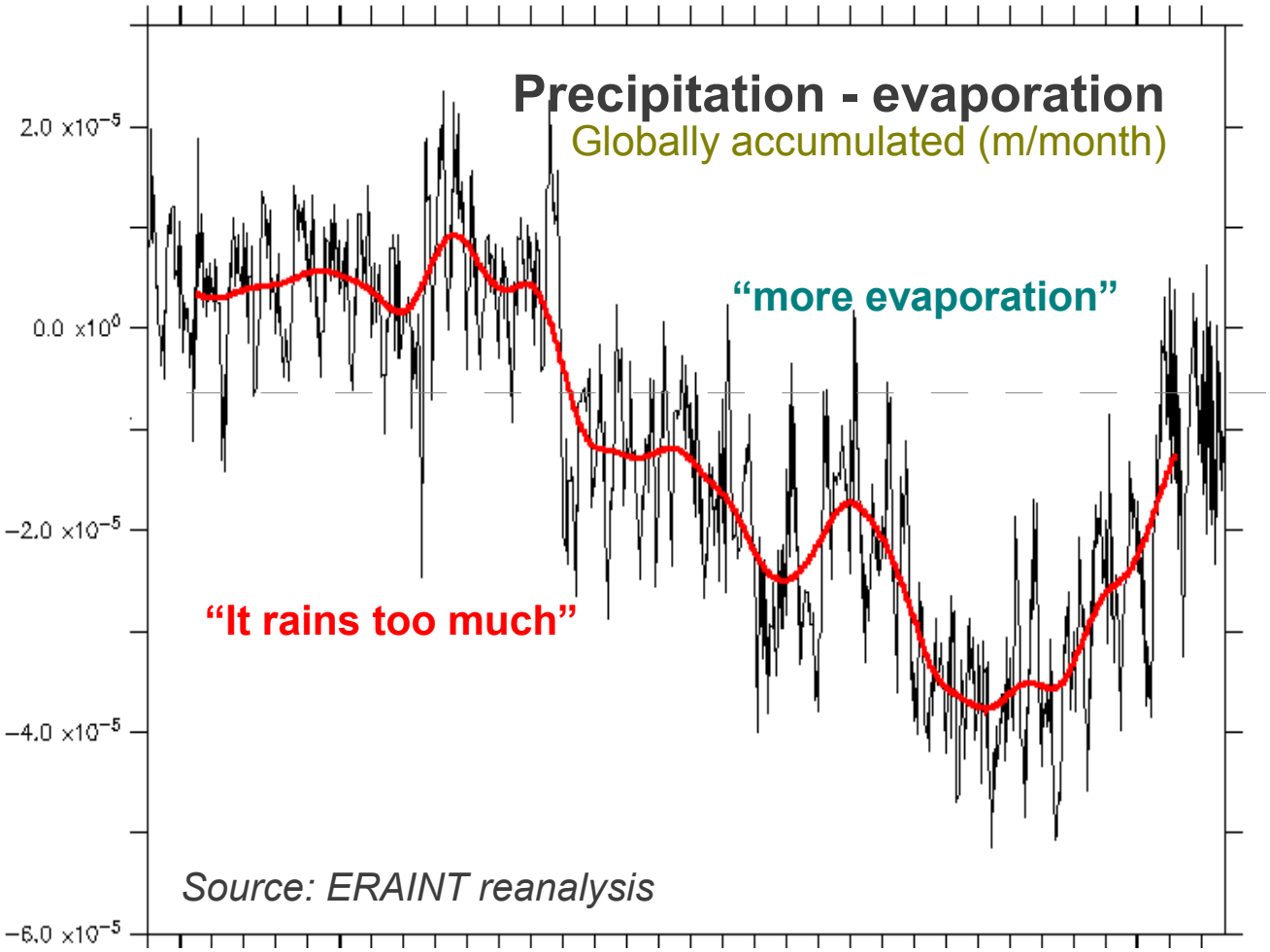


Energy and matter flow through the universe

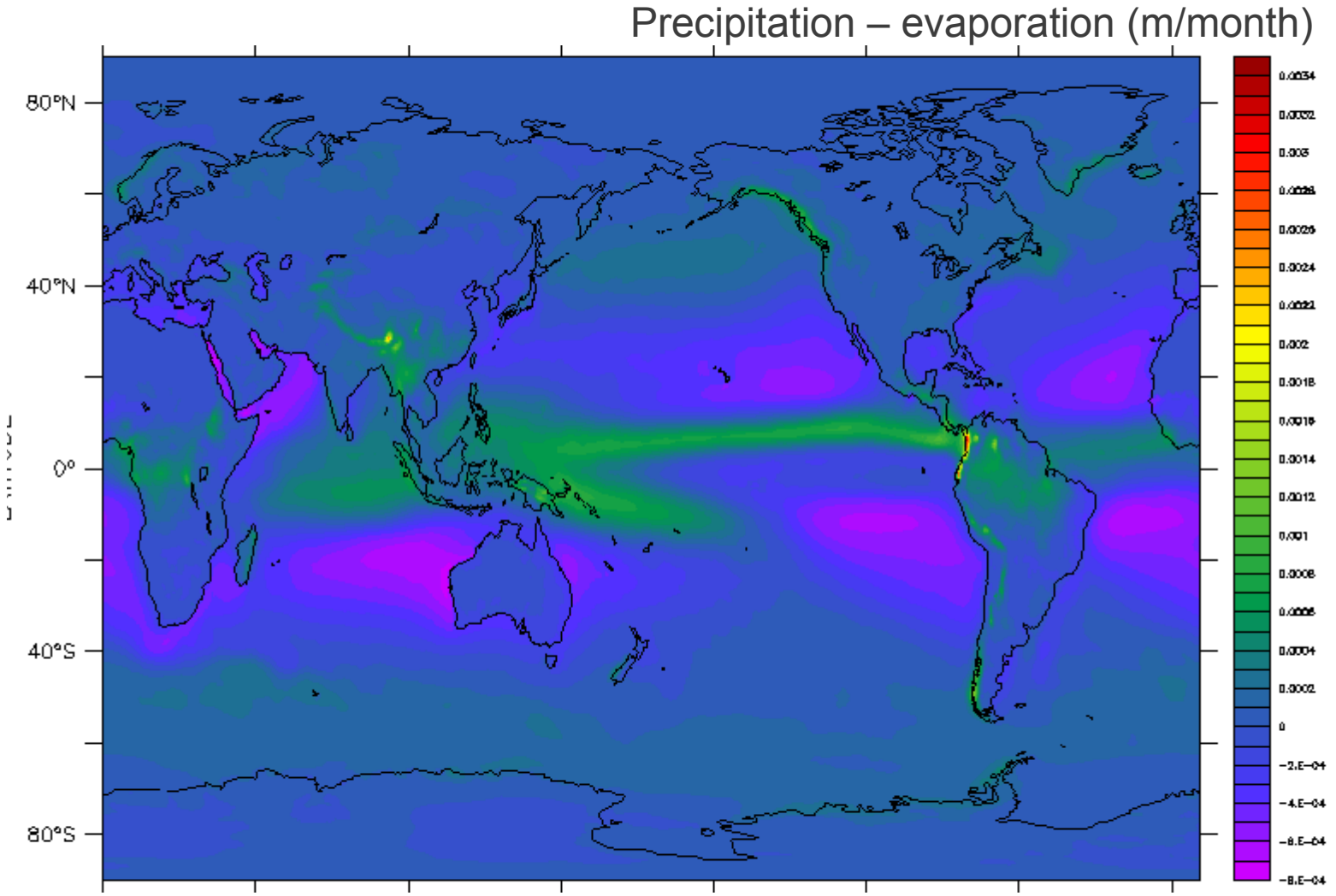
E.g. the hydrological cycle

The global H_2O turn-over

- Earth's water budget.
- Balance?
- Time lag...
- Instrumentation



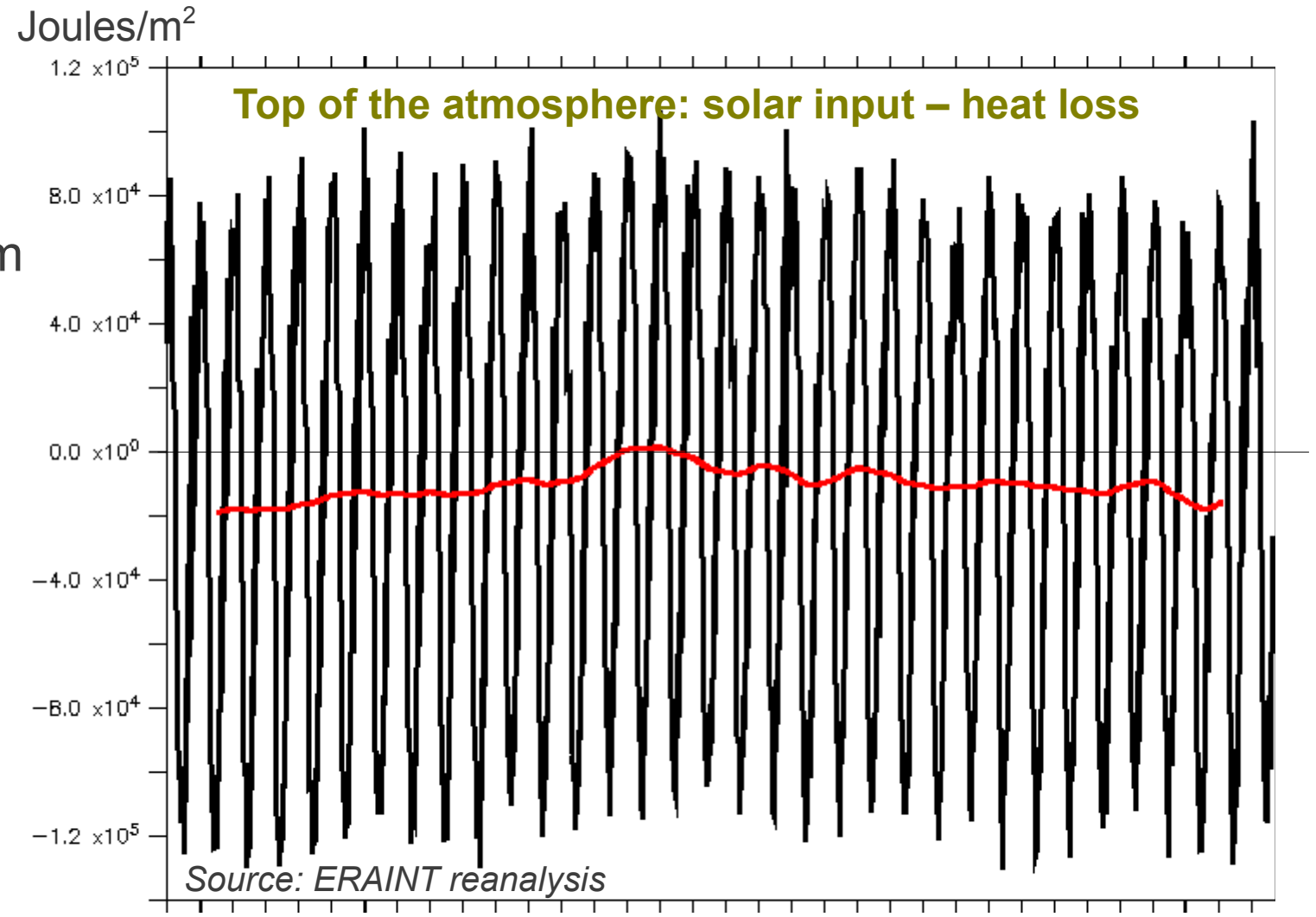
The geographical picture



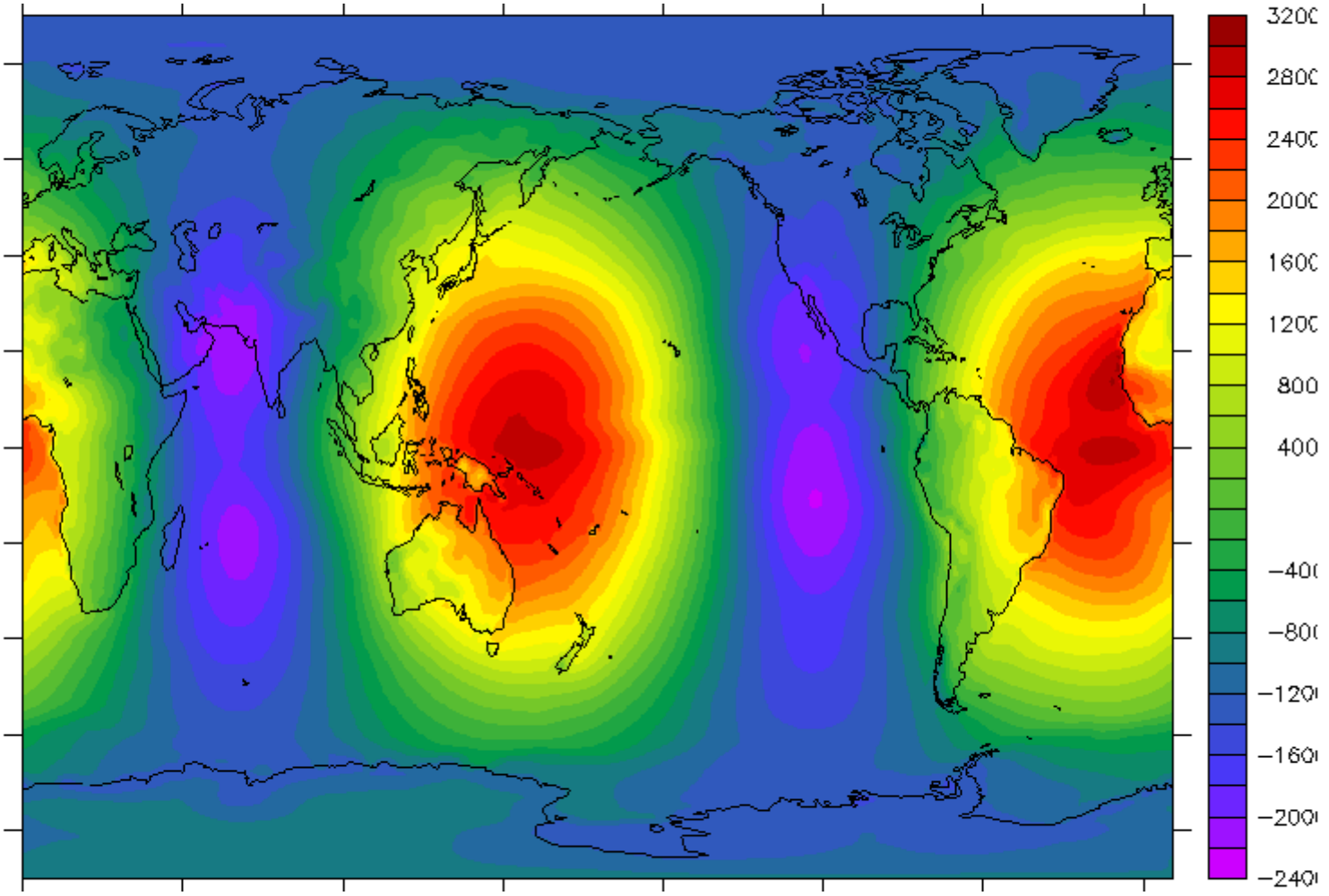
Case 4. The energy budget

Is the Earth really losing more energy than it receives from the Sun?

Is the reanalysis flawed?



The answer to the apparent energy discrepancy:



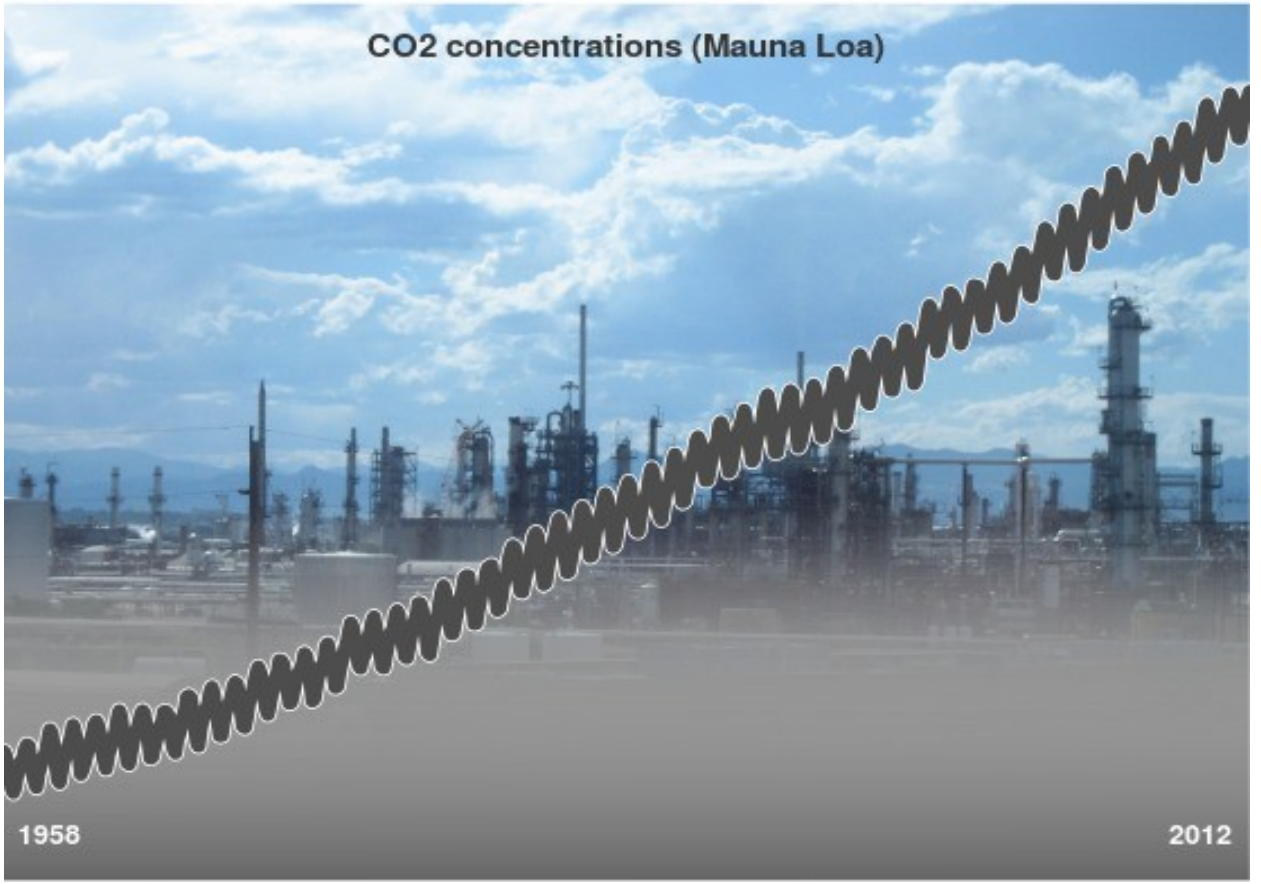
Solar energy – short wave radiation (visible light). Sampled every 12 hour...

Case 5. The Carbon budget.

- Conserved quantity
- Sources and sinks?
- Account for all C

Oceans, vegetation, volcanic eruptions, fossil energy, deposition, soil.

- O_2/N_2 dropping
- Ocean acidification
- Isotopes: less ^{14}C
- Different sites
- Satellites
- Fossil material combustion



Case 6. The greenhouse effect.

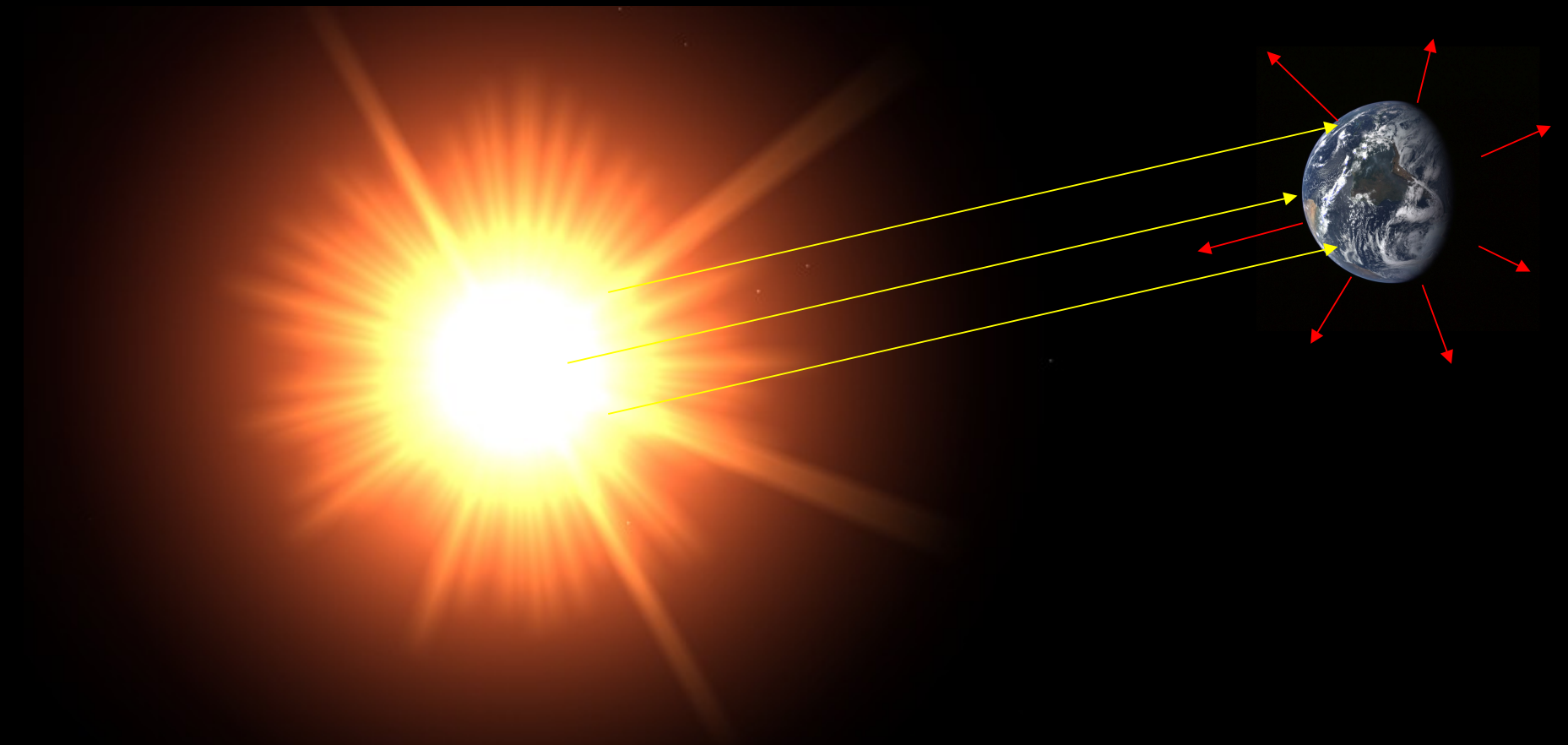
Expert *know-how* about the system/theory may be needed for V&V.

Is it possible to distil the essentials?

- What characteristics do we expect?
- What is the general picture?

(Greenhouse effect = GHE)

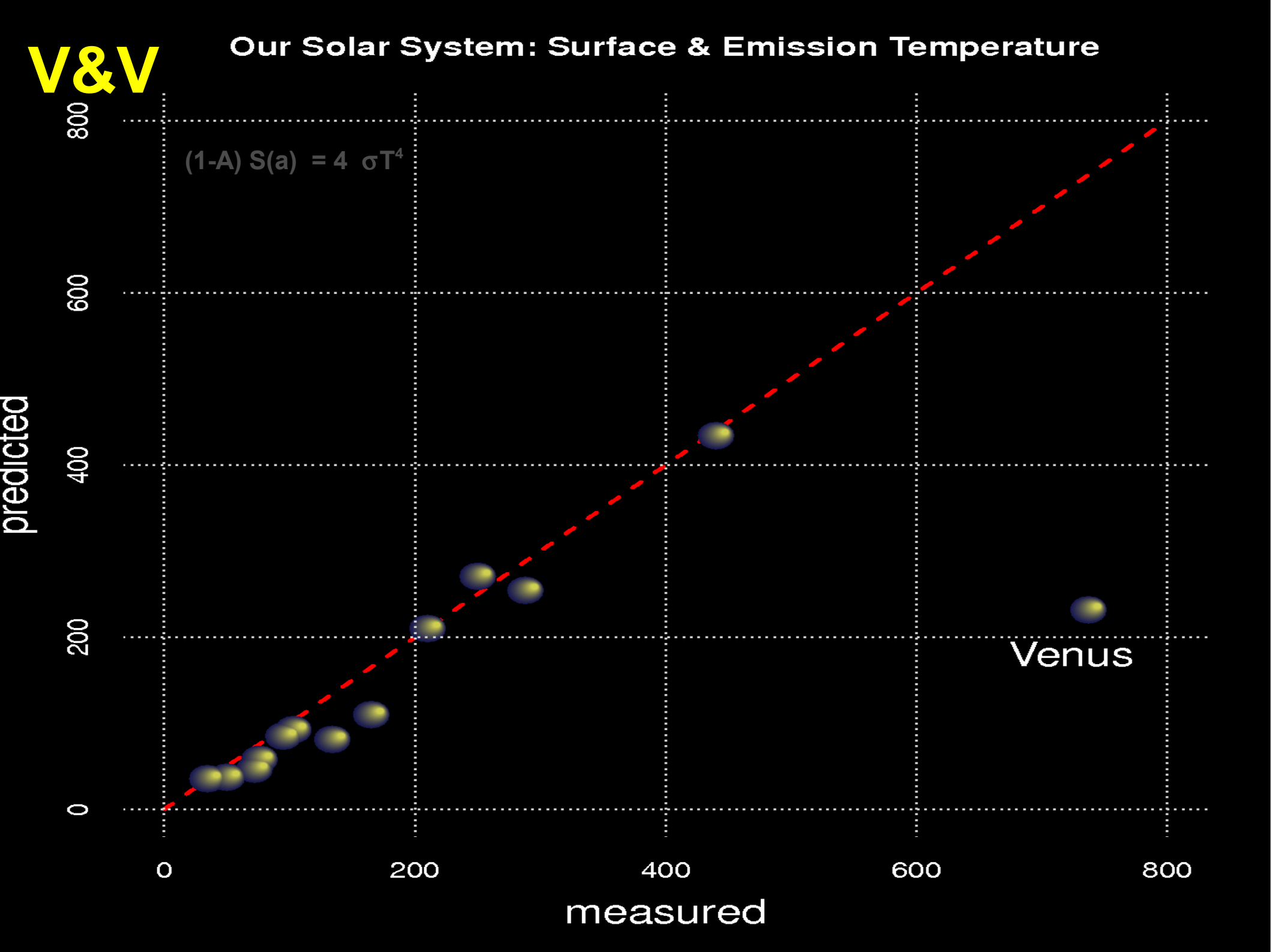
$$S\,(1-A)\,\pi\,r^2 = 4\,\pi\,r^2\,\sigma T^4$$



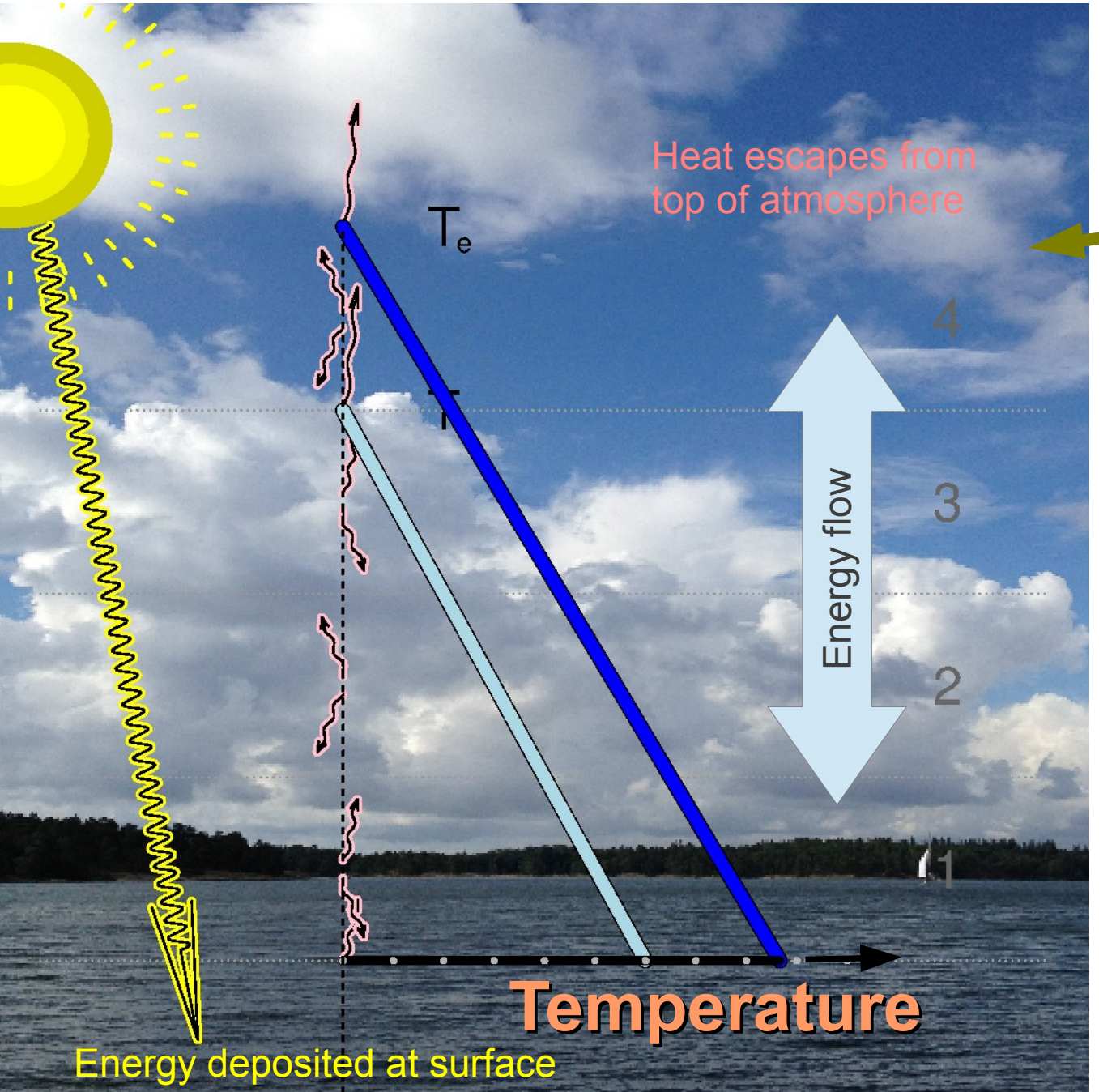
Light is energy.

The earth receives energy.

The earth loses energy


V&V
Our Solar System: Surface & Emission Temperature
(1-A) S(a) = 4 σT⁴
predicted
measured
0
200
400
600
800
Venus

GHE: a simple schematic

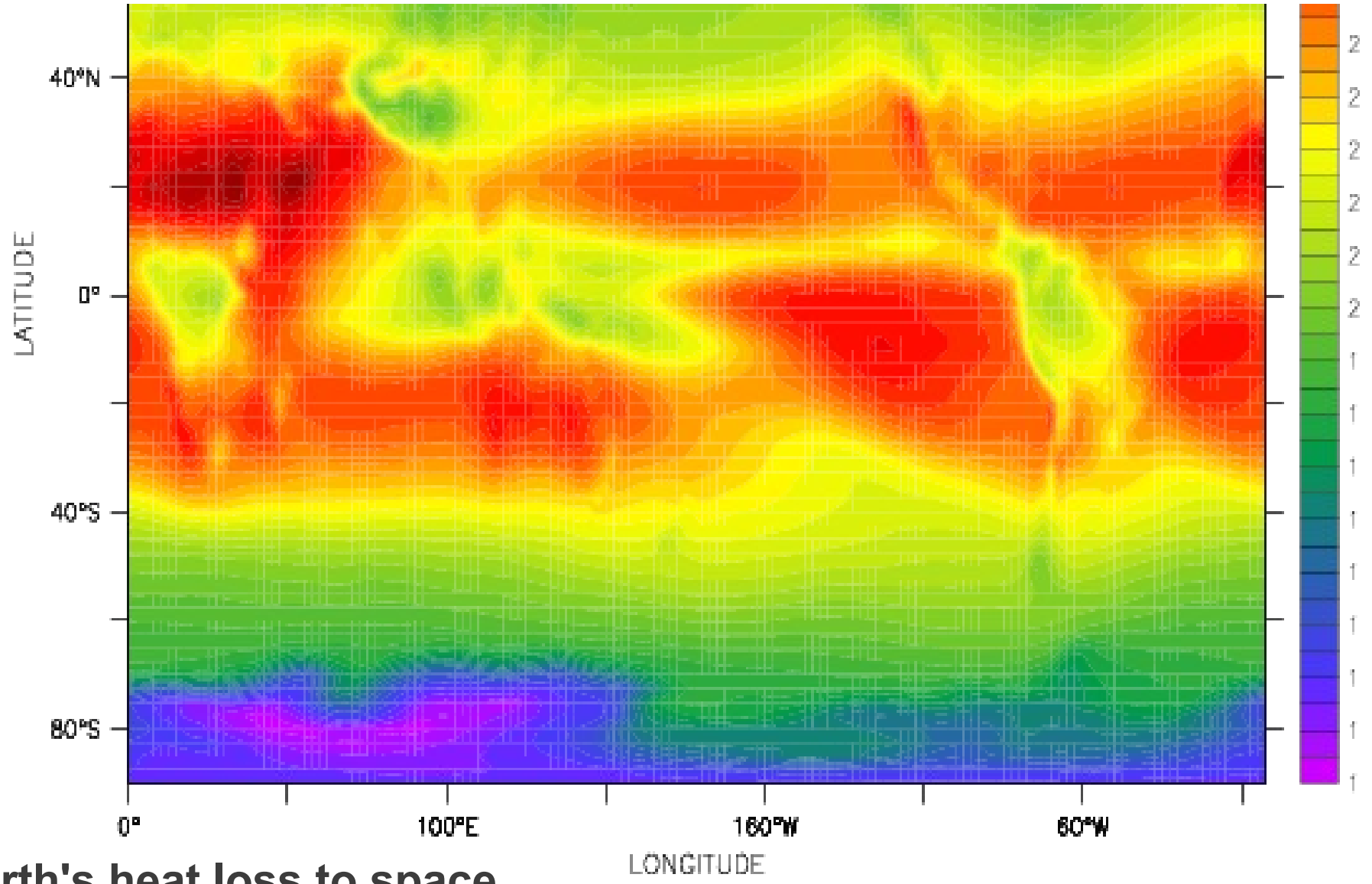


A vertical cross-section of the atmosphere

Energy flows through the universe like water

The Outgoing Longwave Radiation

Infrared light ('henceforth IR')



Earth's heat loss to space

OLR monthly means (W/m~2)

Case 7. V&V for climate change

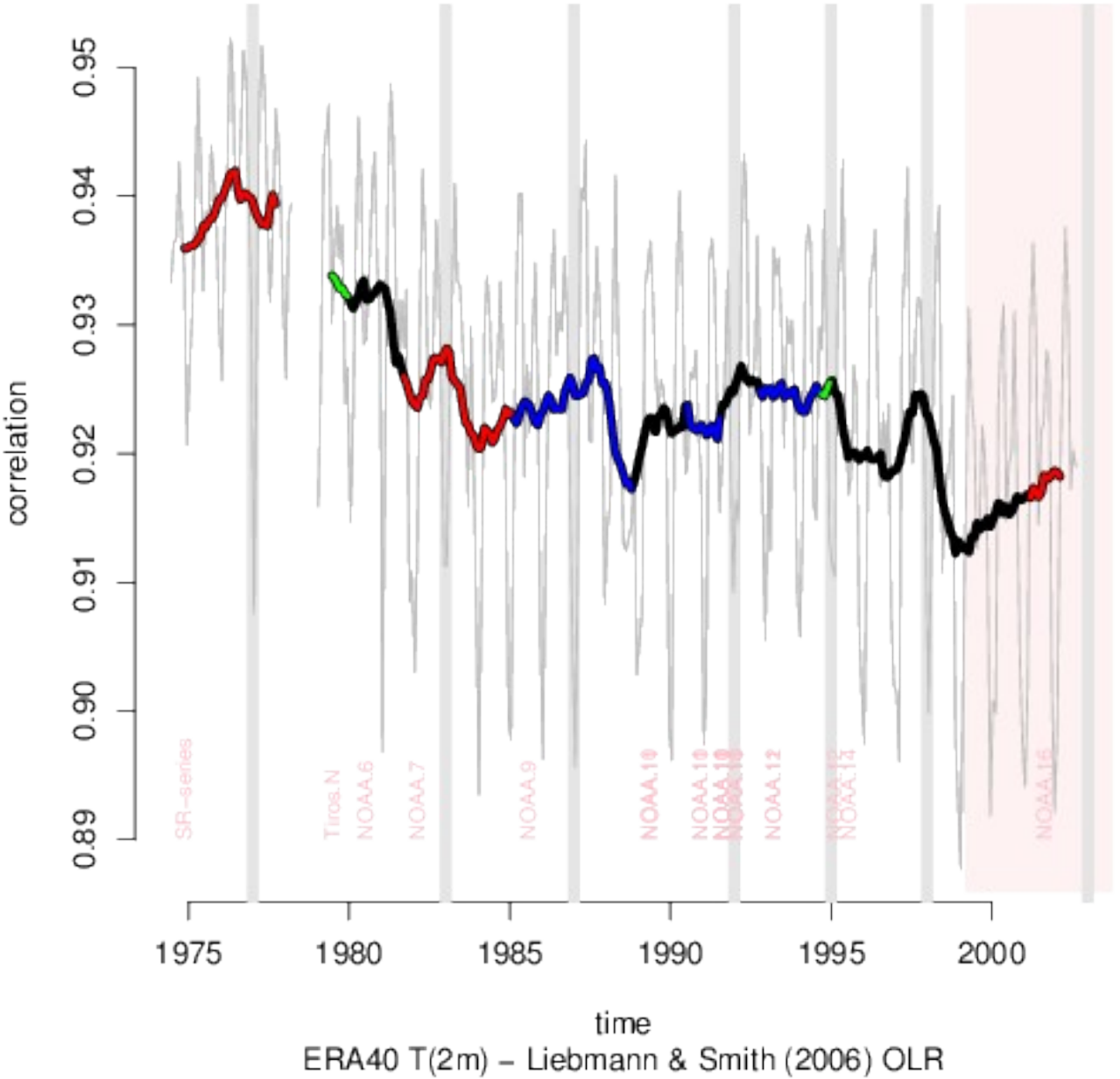
Global warming really taking place?

How good are the climate models?

Consistencies & inter-dependencies

The physics...

Correlation: geographical similarity



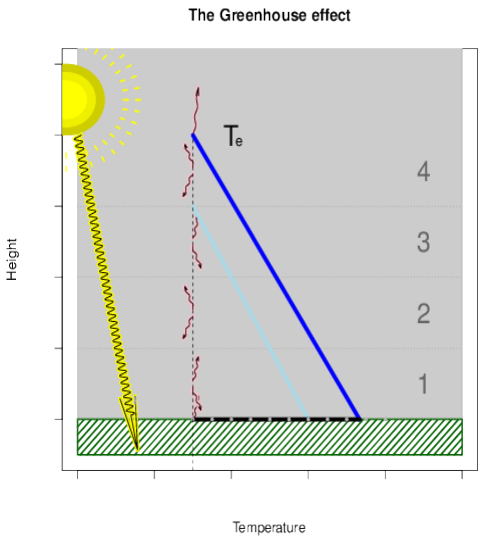
Correlation between surface temperature and OLR.

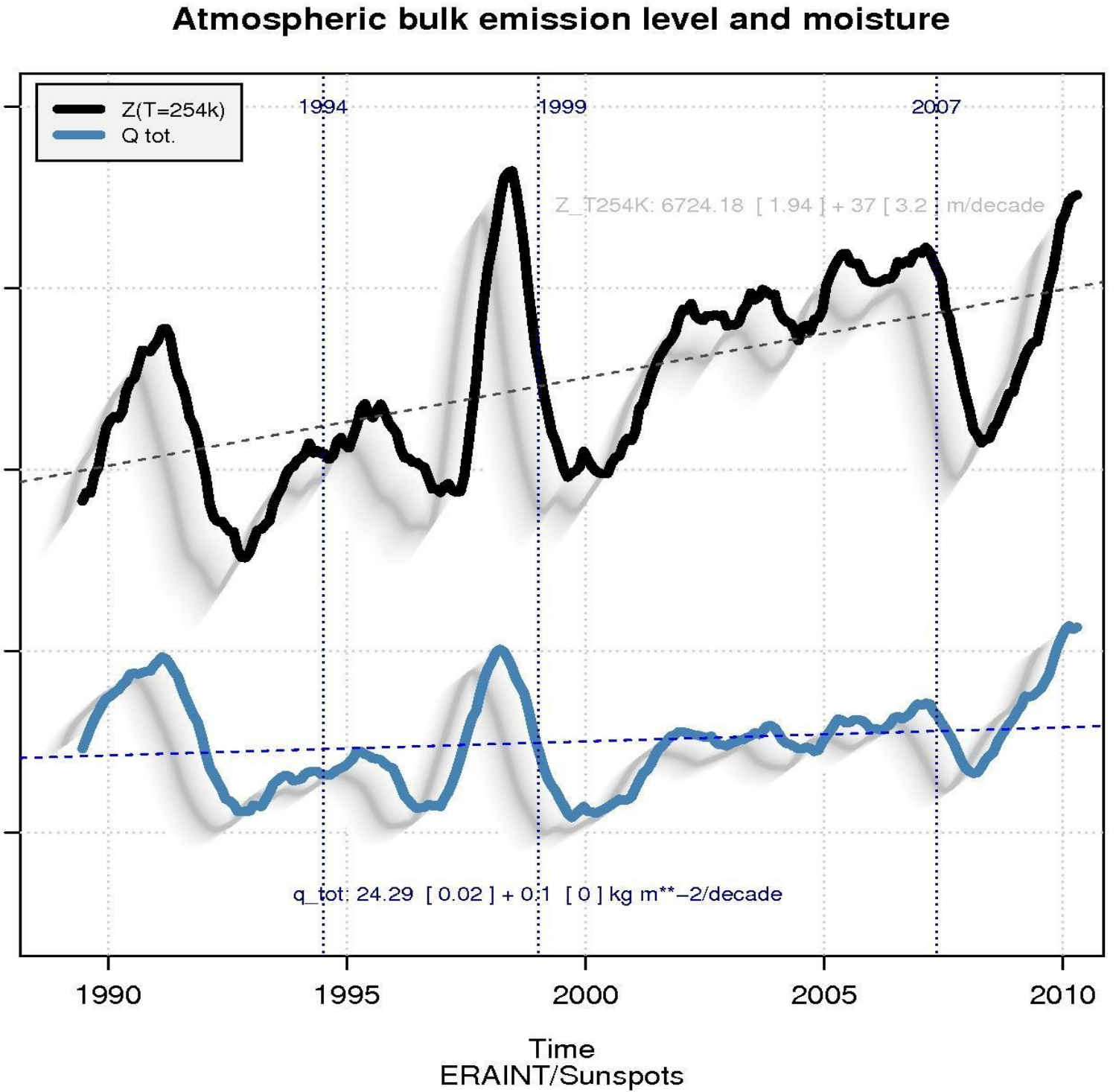
Expect lower for more opaque atmosphere.

Clouds or greenhouse gases.

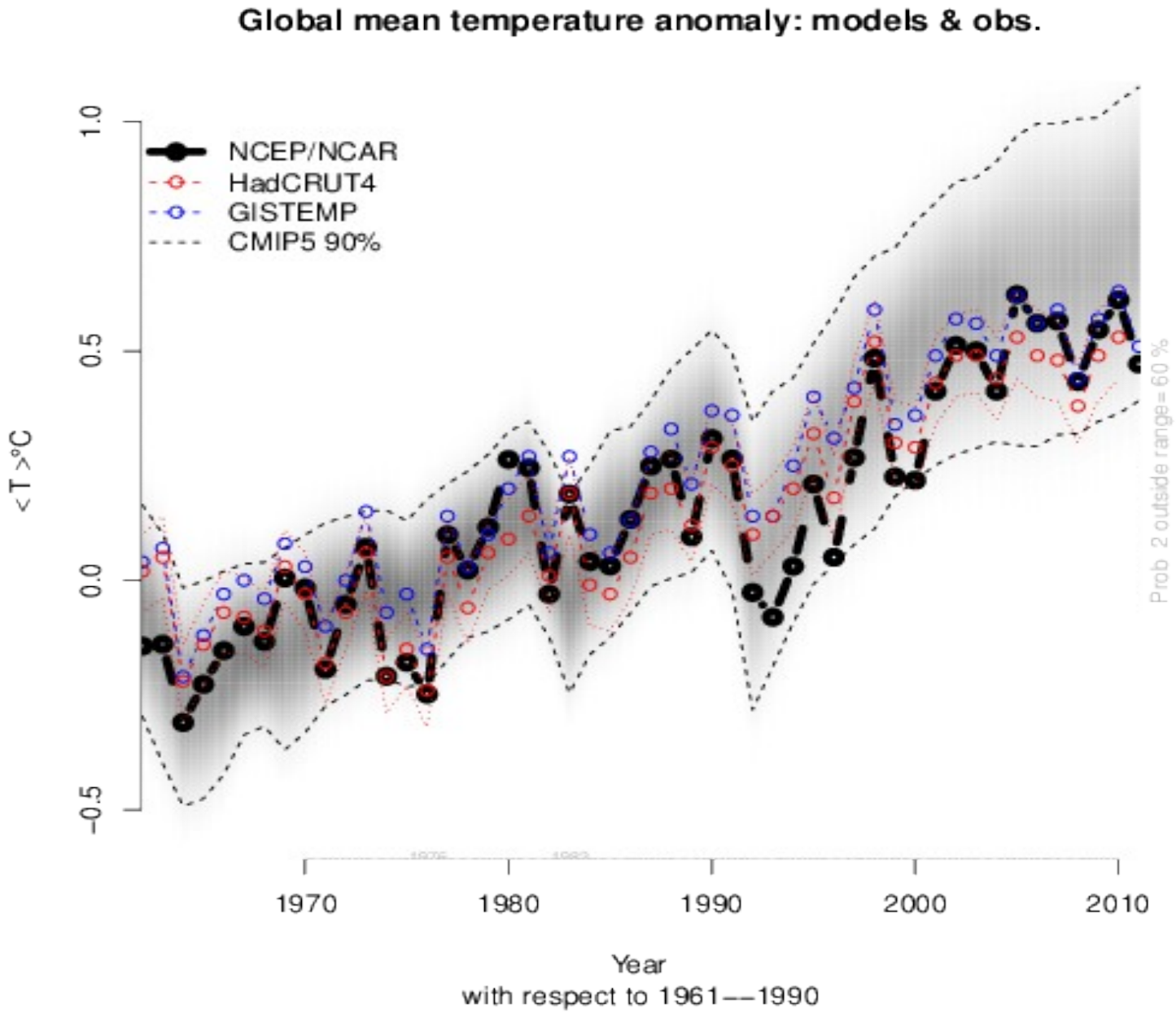
V&V: consistent with more IR absorbed

V&V: Rise in altitude for T=254K – corresponding to earth's heat loss, is roughly consistent with surface warming.





Climate models & global warming



Global climate models (GCMs) reproduce past global warming.

"Impossible to validate" - complex, many lines of computer code.

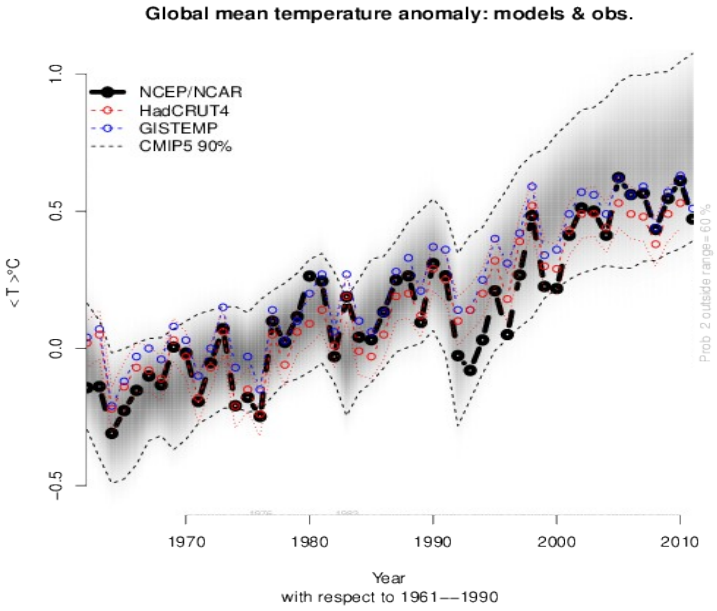
Other forms for V&V.

The comprehensive picture

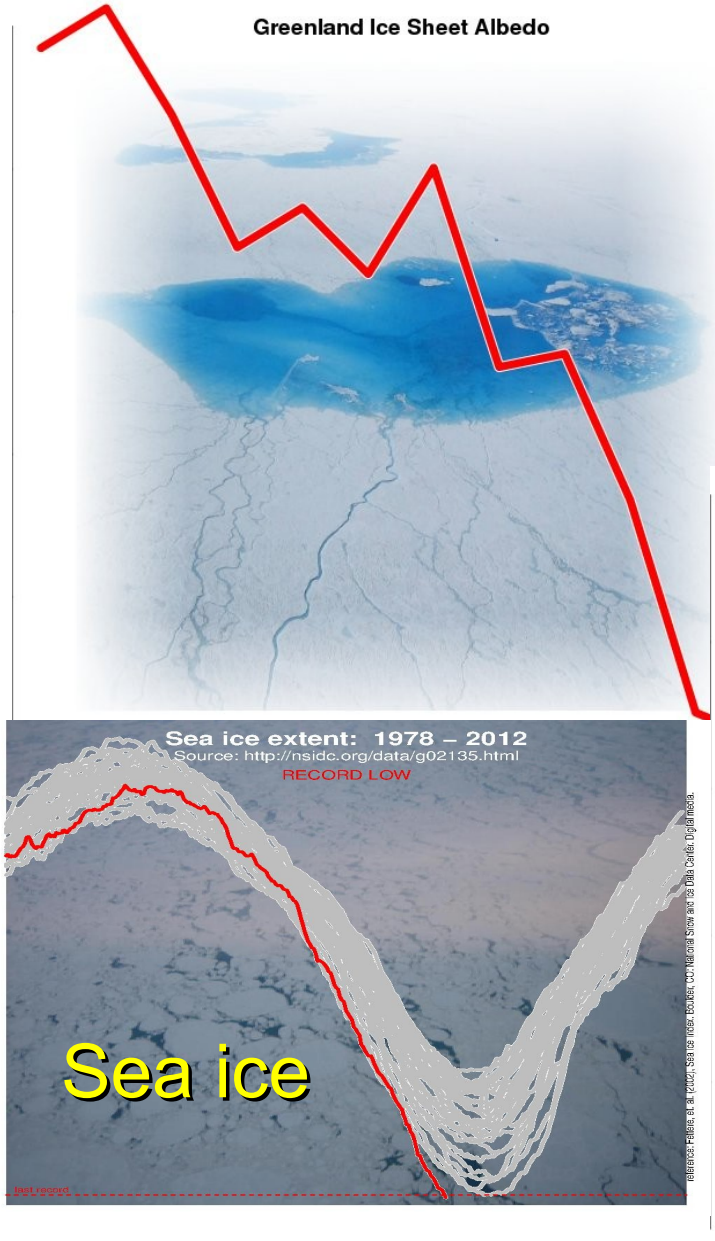
Global warming does not take place in isolation

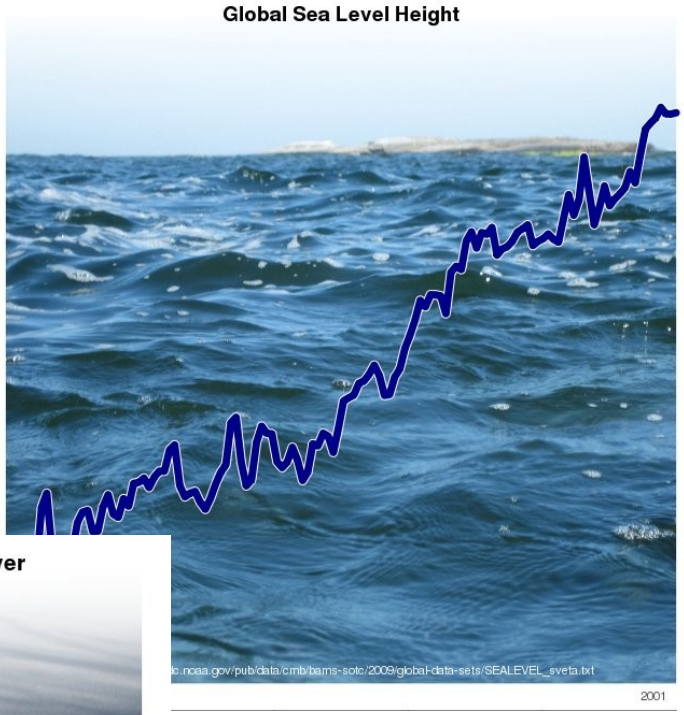
Question of energy and heat

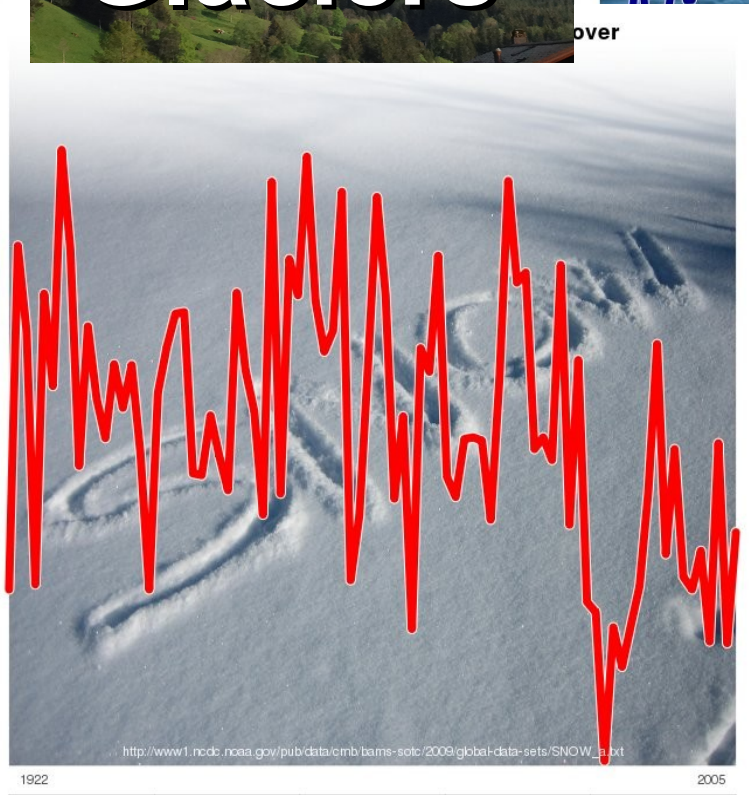
Many other aspects: response to higher temperatures according to physical considerations.



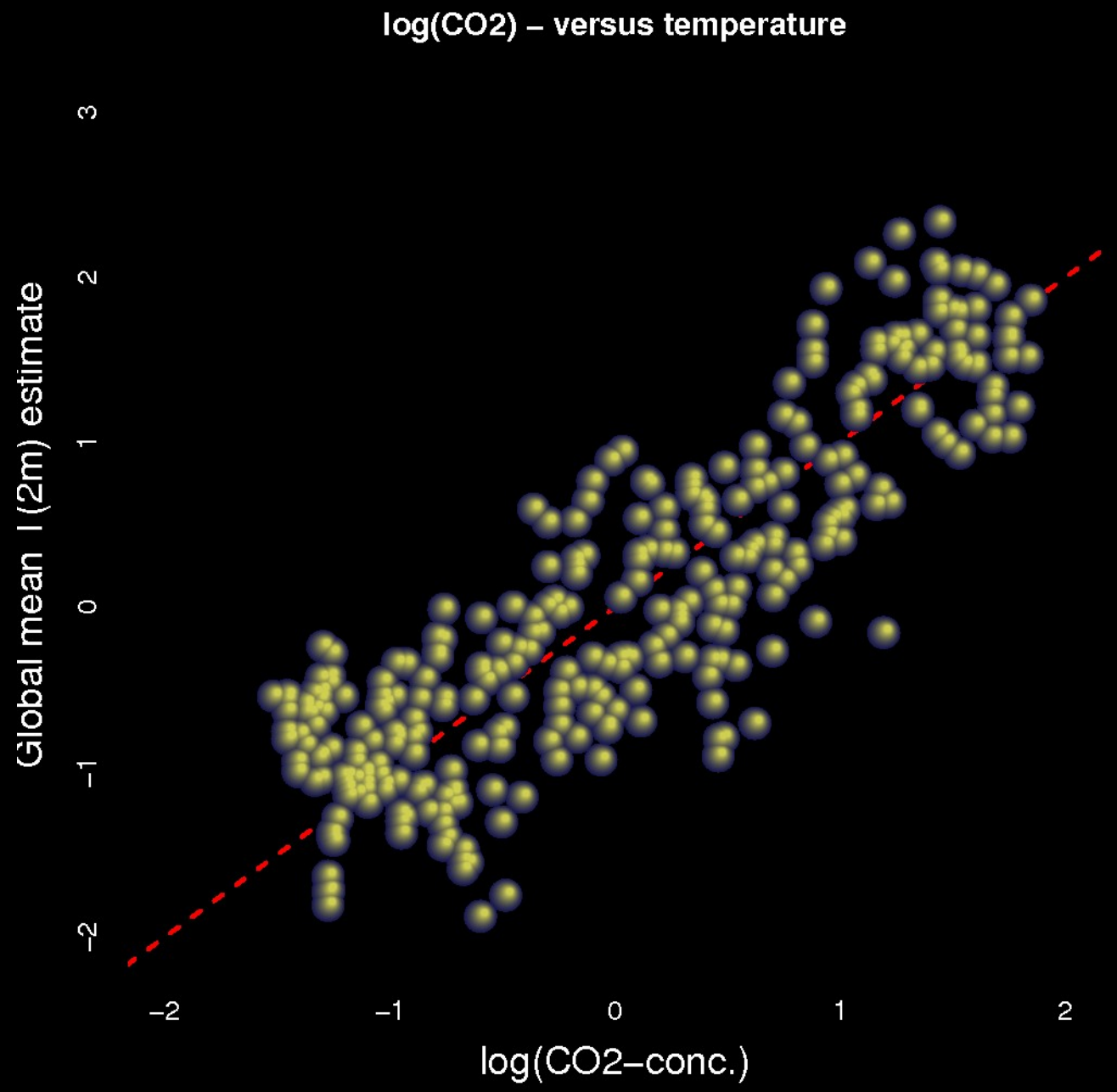
Independent aspects







All measurements: instrumental, ice cores

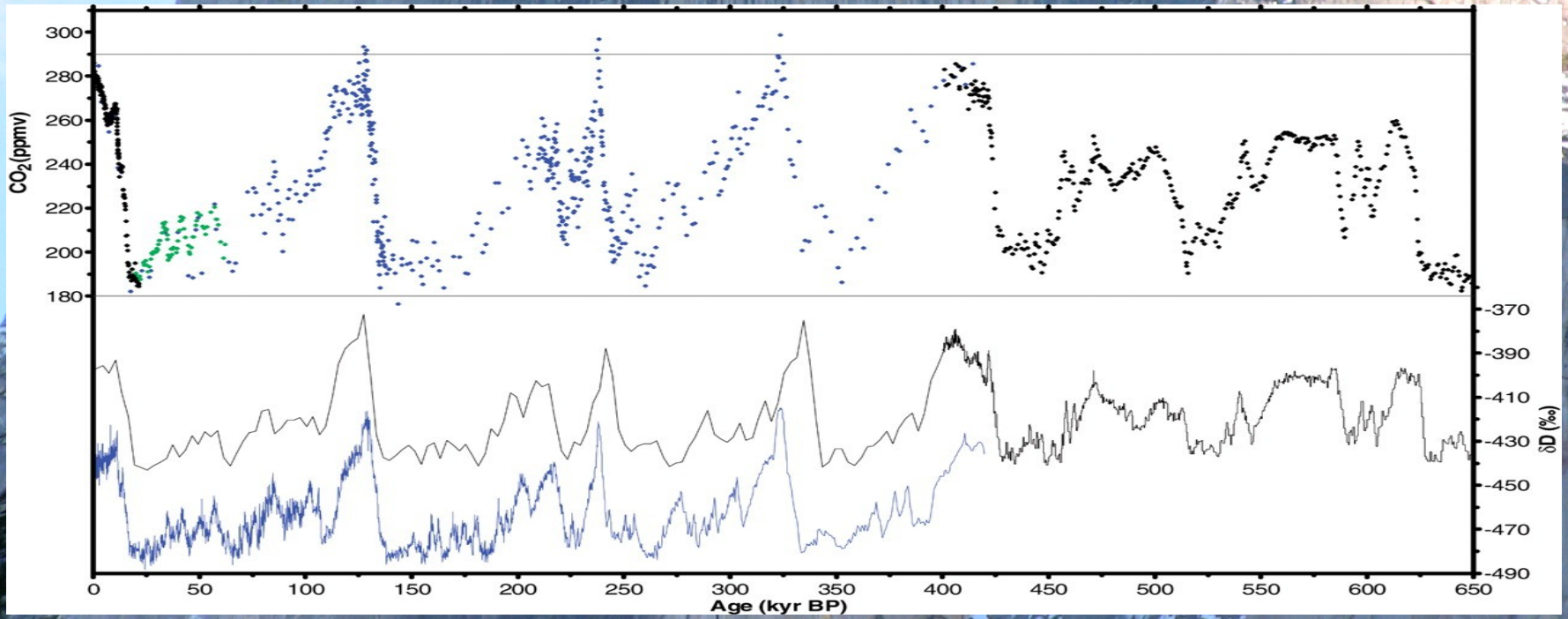


Climate change in general

Several independent lines of evidence

What is the story?

Is our climate sensitive to past changes?



Past events & Anecdotal evidence

Historical records
Old instrumental records
Signature in nature: tree rings, sediments, isotopes, air bubles trapped in ice
Fossils
Model simulations

Sources of information

What do they reveal?

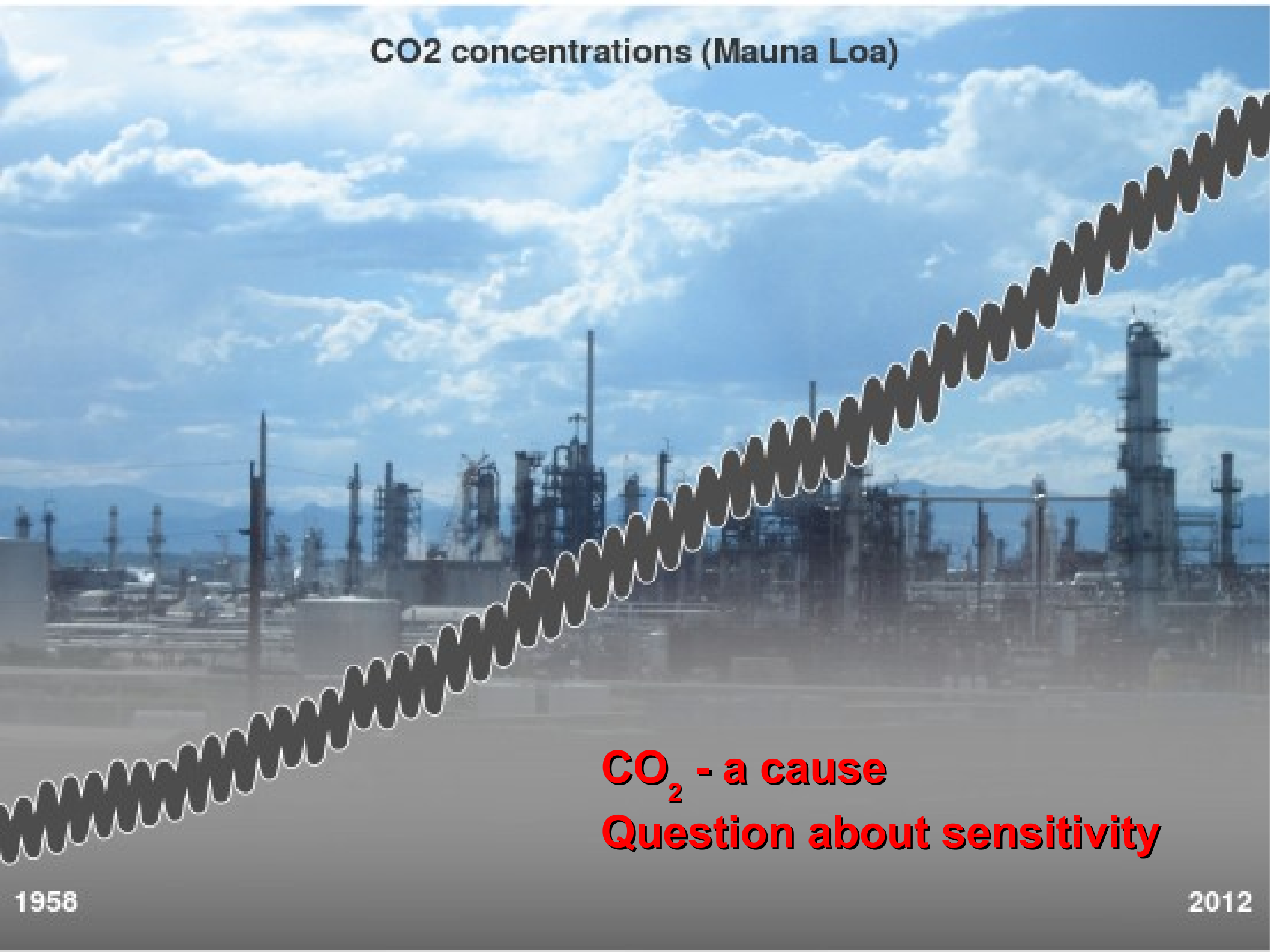
Quality of the measurements

Interpretation of the observations

What's the story?

The fossils in the first place

- the proof in eating the cake
- from a warm world of high CO_2



CO_2 - a cause

Question about sensitivity

Some enigmas remain...

Next lecture