La sfida della scienza del clima

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However, all the mouths of the Nile, with their yield of grain, and the canals at Canopus, are obviously artificial and not natural. And Egypt was nothing more than what is called Thebes, as Homer, too, shows, modern though he is in relation to such changes.

(...)
This happened to the land of Argos and Mycenae. In the time of the Trojan wars the Argive land was marshy and could only support a small population. But now the opposite is the case, for the region is completely dry and barren, while the Argive land that was once dry and barren owing to the water has now become fruitful. Now the same process that has gone on over whole countries and on a large scale must be supposed to be going on over whole countries and on a large scale.

(...)
So it is clear, since there will be no end to this process, that neither the Tanais nor the Nile has always been flowing, but that the region from which they flow was once dry: for their effect may be fulfilled, but time cannot. And this will be equally true of all other rivers. But if rivers come into existence and perish and the same parts of the earth were not always moist, the sea must needs change correspondingly. And if the sea is always advancing in one place and receding in another it is clear that the same parts of the whole earth are not always either sea or land, but that all this changes in course of time.
L’Optimum Climatico Medioevale

I Vichinghi, sfruttando l’optimum climatico medioevale riescono ad esplorare tutto l’Atlantico Settentrionale.

Erik il Rosso, viaggia e fonda colonie in Groenlandia e Nord America (Vineland).
La piccola era glaciale

Dopo il 1450, le cose cambiano. Sul settore EuroAtlantico le temperature volgono al freddo: è arrivata la Piccola Era Glaciale.

[Diagram showing temperature changes from 1000 AD to 1900 AD, with labeled periods of Medieval warm period and Little ice age.]
Il Sistema Clima

Atmosfera

Evaporazione

Ghiaccio Marino

Precipitazioni

BIOSFERA

Fiumi

Umidità del Suolo

Oceani
La Macchina del Clima

Radiazione Solare

Radiazione Terrestre
Il Bilancio di Radiazione

Radiazione Solare

Bilancio Netto

Radiazione Terrestre

Polo Nord

Polo Sud
Le differenti teorie della Circolazione Generale da quella piu’ antica di Hadley (1735) alla visione moderna di Bergeron (1928)
Hadley Circulation
Climatologia SST
Climatologia
U Zonale
200mb
Climatologia
Precipitazioni
Globalizzazione del Clima

Una serie di carestie senza precedenti, i cui effetti furono moltiplicati dal regime coloniale, colpi l’India nella seconda metà del XIX secolo.(1861,1866,1876-1878, 1897-1901). L’inserimento dell’agricoltura tropical nel sistema europeo mise in rilievo che la carestia, prodotti dai fallimenti della stagione delle piogge, non erano solo limitati all’India, ma si erano verificate anche in Cina e in Brasile.

Lo sforzo di comprendere si allargo’. Jevons, econoista e statistico, elaborò una teoria secondo la quale i cicli delle macchie solari influenzavano i cicli economici e in special modo un ciclo di undici anni tra crisi finanziarie che aveva appena scoperto.

Sir Gilbert Walker, direttore del servizio meteorologico indiano nel … cerco’ di prevedere le variazioni interannuali dei monsoni collegate ai disastri. Si imbarco’ in una colossale football per cercare di trovare relazioni che collagassero i monsoni indiani ad altri fenomeni climatici, coordinando uno sforzo di raccolta dati senza precedenti. Analizzando i dati che gli arrivavano da tutto l’impero fu in grado di individuare una serie di relazioni a lunga distanza tra la pressione al suolo, di cui la più famosa e la più importante è l’Oscillazione Meridionale.
The interactions between atmosphere and oceans in the tropics dominate the variability at interannual scales. The main player is the variability in the equatorial Pacific. Wavetrains of anomaly stem from the region into the mid-latitudes, as the Pacific North American Pattern (PNA). The tropics are connected through the Pacific SST influence on the Indian Ocean SST and the monsoon, Sahel and Nordeste precipitation. It has been proposed that in certain years the circle is closed and a full chain of teleconnections goes all around the tropics. Also shown is the North Atlantic Oscillation a major mode of variability in the Euro_atlantic sector whose coupled nature is still under investigation.
Michelson-Morley Experiment
A scientific consideration of climate (I)

Crucial experiments like the famous experiment of Michelson e Morley are not possible in climate science.

How is it possible a scientific investigation of climate?
A scientific consideration of climate (II)

We can make experiments if we represent the climate system via a set of mathematical relations: the equation of climate.

The equation of climate are very difficult, but they can be solved by numerical methods.

We can then treat very complex mathematical equations, paying the price of a enormous number of elementary operations.
Fortunatamente, Avevamo le Equazioni ...
Le Equazioni di Navier-Stokes

\[
\begin{align*}
\frac{\partial u}{\partial t} + \vec{v} \cdot \nabla u - 2\Omega \sin \theta v - \frac{uv \tan \theta}{a} + \frac{uw}{a} &= -\frac{1}{\rho a \cos \theta} \frac{\partial p}{\partial \lambda} + F_\lambda \\
\frac{\partial v}{\partial t} + \vec{v} \cdot \nabla v + 2\Omega \sin \theta u - \frac{u^2 \tan \theta}{a} + \frac{vw}{a} &= -\frac{1}{\rho a} \frac{\partial p}{\partial \theta} + F_\theta \\
\frac{\partial w}{\partial t} + \vec{v} \cdot \nabla w - \frac{u^2 + v^2}{a} &= -\frac{1}{\rho} \frac{\partial p}{\partial z} - g + F_z \\
\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T &= \frac{1}{C_p \rho} \frac{dp}{dt} - Q \\
\frac{\partial \rho}{\partial t} + \vec{v} \cdot \nabla \rho + \frac{\rho}{a \cos \theta} \left[ \frac{\partial u}{\partial \lambda} + \frac{\partial}{\partial \theta} (v \cos \theta) \right] &= -\rho \frac{\partial w}{\partial z} \\
p &= \rho R t
\end{align*}
\]
Finite Differencing

\[ \frac{\partial U}{\partial t} + A \frac{\partial U}{\partial x} \]

Model

\[ U_{i}^{n+1} = U_{i}^{n-1} - \frac{A\Delta t}{\Delta x} (U_{i+1}^{n} - U_{i-1}^{n}) \]  \hspace{1cm} \text{Leapfrog}

\[ U_{i}^{n+1} = U_{i}^{n} - \frac{A\Delta t}{4\Delta x} \left[ (U_{i+1}^{n+1} - U_{i-1}^{n+1}) - (U_{i+1}^{n} - U_{i-1}^{n}) \right] \]  \hspace{1cm} \text{Implicit}

\[ U_{i}^{n+1} = U_{i}^{n} - \frac{A\Delta t}{2\Delta x} \left( U_{i+1}^{n} - U_{i-1}^{n} \right) + 2\left( \frac{A\Delta t}{2\Delta x} \right)^2 \left( U_{i+1}^{n} - 2U_{i}^{n} + U_{i-1}^{n} \right) \]  \hspace{1cm} \text{Lax-Wendroff}

Polar problem: filtering to prevent instabilities by CFL
Numerical Methods

Discretize the atmosphere

Fig. 2. Horizontal grid and geographical coverage.
Meteorologists in front of the Electronic Computer Project at the Institute for Advanced Study (Princeton)
Sort of crowded at the pole

CGAM's climate models use vertical and horizontal grids to divide up the atmosphere and oceans.
Modelli Matematici

- Vento
- Radiazione
- Temperatura
- Vapor Acqueo

- OCEANI -- SUOLO -- CRIOSFERA -- BIOSFERA
Numerical Models: Oceans

Atmosphere
- Sensible Heat
- Solar Radiation

Salinity
- EVAPORATION

Temperature
- Latent Heat Flux

Density
- RAIN

Currents
- TRANSPORT

Wind Stress
ACCOPPIATORE:
(1) Interpola dalla griglia Atmosferica a quella oceanica e viceversa
(2) Calcola i flussi
History of High Performance Computers

![Diagram showing the history of high performance computers with increasing parallelism and CPU frequencies over time.](image)

Courtesy Dr. Watanabe
Hadley Circulation and Zonal Wind
L’anidride carbonica

Valori massimi di anidride carbonica

Fig. 17. Monthly mean carbon dioxide concentrations (red curve, ppm) measured at Mauna Loa, HI. Blue line is the 12-month running mean. The data through 1973 are from C. D. Keeling at Scripps Institute of Oceanography. [Analysis provided by CMDL]
Storia dell’anidride carbonica
Fig. 2.1. Global annual surface temperature departures (°C) from the 1961 to 1990 average. The 95% confidence limits for the annual global estimates are shown (black error bars). [Sources: NOAA/NCDC; The Hadley Centre for Climate Prediction and Research and the Climate Research Unit of the University of East Anglia; and NASA GISS]
The climate in 2005

Fig. 1.1. Geographical distribution of notable climate anomalies and events occurring around the planet in 2005. [Source: NOAA/NCDSC online at www.ncdc.noaa.gov oa/climate/research/2005/ann/ann05.html]
The climate in 2005: the Arctic

Fig. 5.6. Sea ice extent in (left) March and (right) September 2005, when the ice cover was at or near its maximum and minimum extent, respectively. The magenta line indicates the median maximum and minimum extent of the ice cover, for the period 1979–2000. [Source: NOAA/National Snow and Ice Data Center (NSIDC)]

Fig. 5.7. Time series of the variability of ice extent in March (maximum) and September (minimum) for the period 1979–2005, normalized by the respective monthly mean ice extent for the period 1979–2005. Based on a least-squares linear regression, the rate of decrease in March and September was 2% decade$^{-1}$ and 7% decade$^{-1}$, respectively.
The climate in 2005: hurricanes

Fig. 4.23. Satellite montage of U.S. landfalling hurricanes. [Courtesy: C. Velden, University of Wisconsin—Madison, Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)]
The climate in 2005: Africa

Fig. 6.1. African 2005 annual (top) temperature anomalies (°C; 1971–2000 base), and (bottom) precipitation anomalies (mm; 1979–2000 base) from the CAMS–OPI dataset (Janowiak and Xie 1999). [Source: NOAA/NCDC]
The climate in 2005: Amazon River

**Fig. 6.18.** Rainfall anomalies (mm day$^{-1}$) in central Amazonia during the peak season (December–May) 1951–2005. Black arrows represent drought years 1983, 1998, and 2005.
The Permafrost in 2005

Fig. 5.11. (top) Location of the long-term University of Alaska permafrost observatories in northern Alaska 1978–2005. (right) Changes in permafrost temperatures (°C) at 20-m depth during the last 20–25 years (updated from Osterkamp 2003).
Scenarios

CO2

N2O

CH4
Surface Temperature Differences JAS

(2061-2090 minus 1961-1990)
Precipitation Differences JFM

(2061-2090 minus 1961-1990)
Precipitation Differences JFM

Total Precipitation (2061-2090 minus 1961-1990)
Il Protocollo di Kyoto risolverà il problema.

(a) CO₂ emissions (Gt C)

(b) CO₂ concentration (ppm)

(c) Global mean temperature change (°C)

WRE profiles
- WRE 1000
- WRE 750
- WRE 650
- WRE 550
- WRE 450

S profiles
-———-

SRES scenarios
-———-
A volte, sfidare la natura porta a risultati tremendi, vecchio mio!

D'accordo con te, Satanasso! Roba da farti accapponare la pelle!

FINE