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Mini review Paper

CO_2: Vital constituent for the plant world and dynamic equilibrium or harmful pollutant?

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1. Context

Climate change is one of the main contemporary global challenges, characterized by complex and multidimensional dynamics that require a rigorous and integrated scientific approach. CO_2, an essential element for the photosynthetic process and the control of the carbon cycle, is at the center of oriented debates: on the one hand, it is identified as the greenhouse gas responsible for global warming, while on the other, it is considered indispensable for the survival of terrestrial ecosystems, as it is necessary for life on Earth and for the proliferation of autotrophs, the cornerstones of the entire food chain.

In light of the studies conducted, it is worth continuing to reflect on the role of CO_2 in the balance of life on Earth, asking how indispensable it is for the maintenance of ecosystems or, on the contrary, whether it represents a dangerous pollutant and a possible threat to the survival of life on Earth.

This contribution aims to propose an integrated scientific reflection, highlighting the importance of the contribution of Geomatics, as a scientific and technological discipline that, through dedicated protocols for sampling and management of geospatial data, allows to sample and represent environmental parameters continuously on the entire Earth's surface.

This discipline, which is based on the combination of skills and tools deriving from different areas of knowledge, such as geodesy, remote sensing, geographic information systems (GIS), photogrammetry, cartography, topography and geoinformatics, is to be considered essential for the analysis and monitoring of complex phenomena related to the climate, the biosphere and the lithosphere.

Through a multidisciplinary and rigorous approach, supported by satellite data, field observations and advanced climate models, it was possible to analyze the multiple interactions between CO_2, climate change, atmospheric and terrestrial dynamics, as presented in the case study related to the “Falcone e Borsellino” airport in Palermo, presenting how a new shared scientific approach, which goes beyond the reductionist vision of the “killer” role of CO_2, can define the complexity of the Earth system and climate dynamics in a more balanced and truthful framework.

2. Methodologies and Tools

The interdisciplinary approach suggested in this paper has integrated, through the use of GIS (Geographic

Information Systems), multispectral data from the Sentinel-2 mission of the Copernicus programme and ground data deriving from the analysis of paleoclimatic datasets in order to define and develop an innovative "index" capable of appreciating the capacity of plants to assimilate CO_2.

This index, called NVCD (Normalized Vitality Carbon Dioxide), combines spectral bands relating to visible, infrared and short-wave reflectance, allowing to evaluate the health status of the observed plants and their ability to "seize" carbon through the biochemical process of chlorophyll photosynthesis.

The satellite images were “anchored” to the real context through the use of historical paleoclimatic series reconstructed through the consultation of isotopic analyses performed on ice cores and ocean sediments, in addition to evaluations of the Earth's magnetic field through analyses conducted on ocean basalts.

Through these actions it was possible to introduce into the predictive model the different contributions generated by natural forcings, such as Milanković astronomical cycles, variations in solar activity and the dynamics of ocean and atmospheric currents, which were organized in a dedicated geodatabase, which allowed to reconstruct past climate scenarios considered essential for the verification of the index and the proposed models.

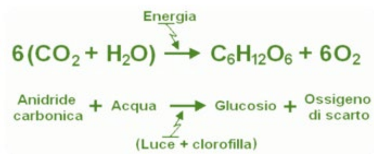
3. The value of natural forcings for geospatial data validation

The importance of geomatic techniques and methodologies in climate and environmental studies is fundamental for understanding the global climate and environmental dynamics of the planet. In particular, the climate and environmental data collected through these techniques are distinguished by their homogeneity and precision, allowing to cover the entire Earth's surface without performing mathematical manipulations to extend the information of a few data to the entire planet.

However, in order to define climatic and environmental “indexes” and “models” starting from the data obtained with the new methodologies, it was considered essential to operate “anchors” and “validations” that would allow to determine, with good approximation, the relationships existing between these data and those deriving from ground measurements and/or derived from paleoclimatic series. This improvement was considered essential to define the NVCD index and make it the most reliable and representative of reality.

The treatment of such complex issues requires an integrated approach that can avoid distortions in the interpretations of the relationships between CO_2 concentrations, vegetation and climate variations. Only in this way is it possible to define a solid knowledge base - "certain scientific bedrock" - that reflects the set of contributions of the forcings in play, paying particular attention to distinguishing between contributions of natural and anthropogenic origin.

These aspects are particularly significant in determining whether global temperature variations are attributable exclusively to CO_2, or whether other greenhouse gases and natural factors play a predominant role. Furthermore, it is essential to assess whether CO_2 represents a threat to the plant world or, on the contrary, a fundamental resource for its development.



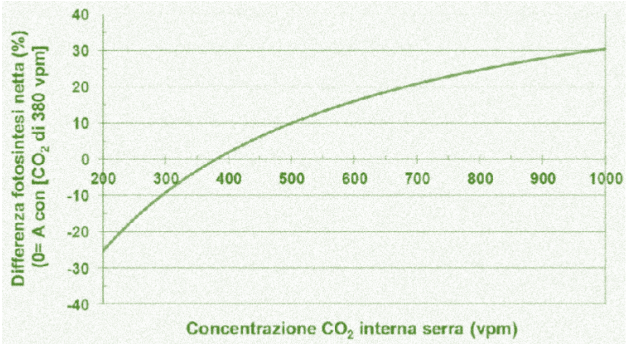
Glucose produced by photosynthesis is a primary source of energy for plant growth and is the basis of terrestrial and marine food chains. This sugar fuels the entire ecosystem, promoting the production of plant biomass and contributing to the sequestration of atmospheric carbon, which is stored in plants and soils.

However, the role of CO_2 is at the center of a heated debate: on the one hand, it is essential for plant growth, on the other, its excessive accumulation is linked to ongoing climate change. It is important to remember that without the natural greenhouse effect, the average temperature of the Earth would drop below -20°C, making the planet hostile to life.

However, the reduction in global forest cover, which from the pre-industrial period to today (from 1750 to today), has reduced the surface of forests from 55% to about 31% of the Earth's surface, according to FAO estimates, has also drastically affected the capacity for carbon sequestration, allowing, at the same time, its accumulation in the atmosphere as CO_2, also releasing enormous quantities of CO_2 that was stored in biomass and soil.

Considering the estimated average rate of CO_2 absorption of about 190 t/km2 of forest per year (Global Forest Watch), it is possible to estimate an “average annual loss of CO_2 absorption capacity” of 4.28×109 t/year, equal to a missed CO_2 sequestration of 1.20×10^{12} tons for the entire period.

In the agricultural context, CO_2 has demonstrated significant benefits, especially in protected growing environments such as greenhouses. Increases in concentration from 420 ppm to values between 750 and 1100 ppm have significantly improved the productivity of crops with a C3 photosynthetic cycle, such as wheat,



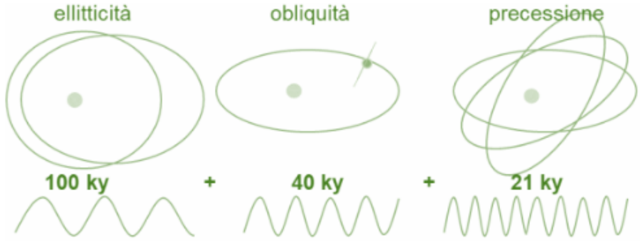
rice and soybeans. This effect is attributable to the increased photosynthetic efficiency at elevated CO_2 levels, a phenomenon similar to that observed during the Triassic, when concentrations of 2700 ppm favored the growth of lush forests.

In contrast, C4 plants, such as corn, sugarcane and sorghum, did not show a significant increase in productivity, since their internal CO_2 concentration mechanisms already make them highly efficient. However, these plants prove to be more resilient in conditions of high temperature and water scarcity, which are intensifying due to climate change.

Natural forcings, such as astronomical cycles and solar dynamics, play a crucial role in modulating global climate variations on Earth.

Milanković cycles, which include eccentricity, obliquity and precession, influence the distribution and intensity of solar insolation, determining the alternation between glacial and interglacial periods.

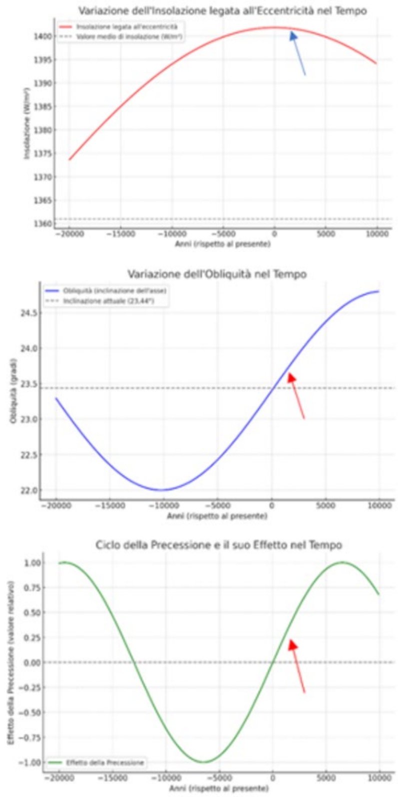
Currently, the Earth is in a phase of “low orbital eccentricity”, characterized by an insolation value of about 1,400 W/m², on the outer surface of the atmosphere. Furthermore, the inclination of the Earth's



axis placed in a median position (22.1° < 23.4° < 24.5°) should guarantee a balanced thermal distribution of energy between the poles and the equator.

However, this does not occur due to the asymmetric distribution of land on Earth, which, being concentrated in the Northern Hemisphere, produces greater heating and cooling of that hemisphere compared to the Southern Hemisphere, where the presence of the oceans produces a mitigating action.

Finally, the precession of the Earth's axis adds a further element of complexity, as the current Northern Hemisphere winter coincides with perihelion, resulting in milder winters and warmer summers, while in the Southern Hemisphere, where summer coincides with aphelion, less intense summers and colder winters are observed.



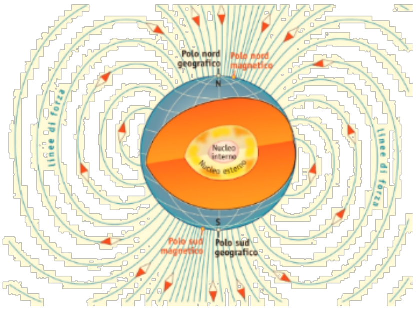
Rappresentazioni dei cicli tratte dallo studio matematico dei Cicli di Milankovic (A.Gallo, G. La Bella, 2022)

Solar activity, monitored through the number of sunspots, shows a direct relationship with climate variations.

Periods of low activity, such as those during the Spöder (1450-1560), Mauder (1645-1715) and Dalton (1790-1820) glacial minima, are associated with global cooling, while phases of high activity result in an increase in solar radiation incident on the planet's surface.

The Earth's magnetic field is directly connected to solar radiation and cosmic rays. Although it is defined as an "invisible shield" against solar radiation and cosmic rays, it is not considered a determining factor in global temperature variations.

The presence of the magnetic field generates around the Earth a system of magnetic field lines of force that envelop the Earth and extend into the surrounding space as a sort of protective bubble (magnetosphere). However, the field, at irregular intervals, shows movements of migration of the poles that also degenerate into a magnetic reversal.



During such "transition or reversal periods," the magnetic field weakens significantly, leaving the Earth temporarily more vulnerable to cosmic and solar radiation, allowing a greater percentage of radiation to come into contact with the Earth's atmosphere and lithosphere, hydrosphere, and biosphere, effectively contributing (indirectly) to the temperature transformations observed today.

Paleoclimatic studies show that periods of low intensity of the Earth's magnetic field (present-day conditions) are associated with an increase in cloud cover and precipitation, phenomena due to the greater formation of cloud condensation nuclei and to the increase in albedo.

Furthermore, the increased infrared radiation emitted by the lithosphere and biosphere, characterized by wavelengths commensurate with those of the molecular bonds of greenhouse gases such as H_2O, CH_4 and CO_2, contributes to an increase in the entropy of the atmospheric system, determining an increase in global temperatures.

Finally, ocean currents, such as the AMOC (Atlantic Meridional Overturning Circulation), significantly influence the distribution of heat on Earth.

A weakening of the AMOC has been linked through scientific data to the reduction in temperatures in northwestern Europe that led to the Last Glacial Maximum.

Paleoclimatic reconstructions also allowed us to estimate that the AMOC fluctuations during the Pleistocene (2.58 million - 11,700 years ago) contributed to the relationship between glacial and interglacial cycles. In particular, during glacial periods, it was found that the AMOC weakened, while during interglacial periods it tended to strengthen.

Regardless of the much-discussed "cause" or "accusation" as to who is determining the slowdown of the AMOC, if the current slowdown were to continue with this trend or even worsen, in Europe there would be a decrease in average temperatures of between 1-3° C, with peaks of up to 5-10° C for those territories located beyond the 50th parallel (51.5° N Parallel of Greenwich), a scenario that seems to describe and carefully replicate what already happened between 1650 and 1850 with the "Little Ice Age", in which the much-vaunted catastrophic actions of anthropogenic CO2 were not present.

The synthetic description provided highlights the primary importance of considering natural forcings in climate models, in order to avoid misleading interpretations that attribute global warming exclusively to CO_2.

4. CO_2 in the Environmental Impact Assessment of Transport Systems: The Case of Palermo

The case study of the urban area of Palermo offers a practical example of the application of geomatic technologies in the evaluation of the environmental impact of transport systems, which has been of interest to the authors for years (G. Salvo, G. La Bella, 2007).

The increase in CO_2 concentrations resulting from human activities, such as vehicular traffic, represents a major source of air pollution and satellite remote sensing technology represents a fundamental tool for monitoring and analyzing the health of terrestrial vegetation present in the vicinity of these particular areas.

The approach adopted in this contribution is based on a complex analysis that combines different spectral bands to estimate, indirectly, the capacity of plants to absorb CO_2 and to "lock it up" in the form of organic carbon.

This analysis methodology was achieved through techniques such as pixel scaling to homogeneous resolutions (RPER, Resize Pixel Equal Resolution) and the linear combination of relevant multispectral bands, techniques that aim to extract information not directly accessible through standard indices such as NDVI (Normalized Difference Vegetation Index) or NDWI (Normalized Difference Water Index), going beyond conventional analyses, adopting a methodology that leads research towards a greater integration between advanced technologies and understanding of fundamental ecological processes.

Given the impossibility of directly quantifying the carbon concentration in a plant from multispectral images, a mathematical indicator called Normalized Vitality Carbon Dioxide (NVCD) has been developed:

$$NVCD = \frac{[(B8A - B4) - (B2 + B3 + B11)]}{[(B8A + B4) + (B2 + B3 + B11)]}$$

Multispectral image analysis and the use of the Normalized Vitality Carbon Dioxide (NVCD) index confirmed the relevance of monitoring the physiological and structural health of plants to understand their contribution to atmospheric carbon sequestration.

The data obtained show that terrestrial vegetation, together with soils, is able to absorb approximately 30% of anthropogenic CO_2 emissions every year, a contribution that represents a fundamental condition in the mitigation of climate change, since, if correctly managed, it could lead to the restoration of disasters linked to deforestation and slow down the accumulation of this gas in the atmosphere.

The calculation of the NVCD index has highlighted how variations in vegetative vitality are closely related to the ability of plants to fix carbon. In particular, the combination of multispectral bands has provided an indirect, but effective, estimate of plant biomass and photosynthetic activity, offering an innovative tool for the evaluation of the ecological efficiency of plant ecosystems.

The primary role of plants for life on Earth is that they form the basis of the food chain. Therefore, the fact that they carry out the process of photosynthesis through which they convert carbon dioxide and water into sugars and oxygen is an established concept, which determines, first of all, how CO2 is essential for the plant world and subsequently, as in this biochemical process, plants are able to sequester atmospheric CO2, even if this process varies depending on the conditions and stage of development of the plants and their typology.

Studies indicate that the optimal CO_2 concentrations for the plant world are close to 600-700 ppm during the vegetative phase, that is, when plants are most engaged in the formation of leaves and biomass, while values of 1000-1200 ppm are essential during the flowering phase, when the plant invests energy in the reproduction and ripening of the fruits.

These levels of CO_2, much lower than those present in the atmosphere today (420 ppm), but commensurate with the levels present during the Triassic when the forests were lush, favor greater photosynthetic activity, improving the growth and general health of plants, which develop thicker stems and branches, improving their resistance to environmental stresses, such as drought and pest attacks. Furthermore, the increase in CO_2 reduces the time needed to complete the life cycle, allowing a faster transition between the vegetative and reproductive phases.

5. Conclusions

The analyses conducted demonstrate that the Earth's climate system is governed by a complex balance between natural and anthropogenic forcings. CO_2, although a crucial element for the carbon cycle and plant productivity, cannot be considered the sole responsible for climate variations. Natural forcings, such as astronomical cycles, solar activity and ocean currents, play a decisive role and must be integrated into climate models to ensure reliable guarantees.

Geomatics is confirmed as an indispensable discipline for the collection, processing and interpretation of geospatial data. Its application in the case study of Palermo has highlighted the importance of a multidisciplinary and technological approach to address environmental challenges. The adoption of advanced technologies and the promotion of sustainable strategies represent fundamental steps to mitigate the effects of climate change and ensure a more balanced and resilient future for the planet.

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