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Social Environmental Vulnerability to Global Environmental Change — Climate Change: A Perspective From Geomatics and Geospatial Analysis & Modeling

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Abstract: The global environmental change is defined as the combination of modifications in the Atmosphere-Ocean-Biosphere Earth system on planetary scale. These modifications lead, among others, to the terrestrial warming, the modification of the biodiversity, desertification, acid precipitations and the eutrophication of waters. Climatic change, a main component of the global environmental change, is caused direct or indirectly by human activity. The climatic change takes place in a time in which the stability and resilience of the ecosystems are in risk due to the anthropogenic impact induced by the development at the expense of the deterioration or sustainability of the natural resources. Vulnerability defined as the degree of susceptibility or incapacity of a system to respond to the adverse effects of the climatic change (it includes the climatic variability and extreme events) describes a central concept in the investigation of climatic change, as well as, in the communities of investigation related to hazard and natural risk, poverty and development, food security and sustainability science. Geomatic and spatio-temporal analysis and modeling have played a fundamental roll in the characterization analysis and assessment of vulnerability to climatic change. The contribution of the remote sensing includes the study and monitoring of drives forces (perturbations, stress) on human-environment system, the study, monitoring and location of exposure system and its sensitivity conditions and monitoring of the impacts on the system. In the future, due to the growth of users communities, to the greater sophistication of his needs and to the exponential increase in the volume and complexity of the data, it will be need to migrate towards a new paradigm in the interaction data - users of remote sensing in which the emergent technologies will be able to offer new alternatives allowing that, automatic or semiautomatic information and knowledge can be generated by support of intelligent learning system. On the other hand, in the vulnerability assessment, the analysis and spatial modeling face new challenges such as: How link the global, National, regional, and local scales. How to solve scale mismatches in social-Ecological system. To respond to some of these questions, there are proposals toward integration of spatial data processes and data models, which can facilitate the search of spatio-temporal knowledge within processes on agents or individuals' level. In the same way, agent-based modeling, together with other recent technologies such as location aware technologies, mobile objects data bases, and the spatio-temporal knowledge discovery can allow in the future advancing towards a people-based perspective, which is centered on individuals and in the space-time, which would facilitate modeling of complex processes as vulnerability to the environmental and climatic change.

Key words: global environmental change, climate change, vulnerability, geomatic, spatial analyses, modelling

1. Global Environmental Change — Climate Change

Through geological time, climatic changes associated with changes in the earth's orbit around the sun have determined major changes in vegetation cover. Over the past 300 years human influence on earth has

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become extensive and intensive global; in last decades scientific reports have indicated that we are living in an era in which human activities are getting a negative effect on the Earth system on an unprecedented extent. The provision of ecosystem services, such as food production, clean air and water, or a stable climate, are under severe and increasing pressure. The pace of global environmental change that we are currently examining has not been observed before in human history and has an increasing impact on human well-being [1, 2].

The term climate change has been placed at the top of the agenda for scientific discussions. However, alongside this topic, the concept of Global Environmental Change has evolved in scientific discussion, which has often been mixed or confused with climate change. Many changes in the Earth system directly involve changes in climate, however, some changes can have significant consequences without affecting the climate. Global Change is called the combination of modifications in the Earth-Atmosphere-Oceans-Biosphere system on a planetary scale; this is how this concept is broader than that of climate change. In this sense, Global Change is understood as the integration of environmental problems caused by events that have their origin in human activities and that depend on the quantity of the planetary population, their level of consumption — in particular energy — and the choice of technologies. These causes are those that lead, among others, to global warming, the thinning of the ozone layer, the modification of biodiversity, land degradation (includes desertification) and/or decrease in water, air, minerals, lands [3, 4].

According to McAlpine C. A. et al. (2010) [5] "at local and regional scales, the pressures of unsustainable land use are equal to or even more important than climate change triggered by CO_2 on a larger scale. According to these authors, it is critical to concurrently and proactively address climate change and environmental sustainability problems, adopting a complementary and preventive assessment of the vulnerability of critical natural resources and not waiting until the CO_2 problem has been resolved." These authors argue that a new paradigm is required in politics, in which land use, change in land use, forestry, biodiversity and sustainable economic and social development are recognized as integral components of mitigation strategies and adaptation to climate change.

Regarding climate change, the scientific evidence recorded in the first report of the Intergovernmental Panel on Climate Change (IPCC) of 1990, revealed its importance as an issue that deserved a political platform among countries, to address its consequences. The IPCC defines climate change as a change in the state of the climate that can be identified by changes in the average and/or variability in its properties, due to natural or because of human activity [6].

2. The Concept of Vulnerability

Vulnerability is a complex concept, generally it can be defined as the degree to which a system, subsystem, or a component of the system can experience damage due to exposure to a disturbance or stress [1]. This definition and the concept it encompass are not new; It has emerged from research on risks and threats, food security, global environmental change, climate change, and resilience.

According to Kienberger S. and Zeil P. (2006), the concept of vulnerability provides a useful framework to study and examine the consequences of global change and understand and raise awareness in society of abrupt and/or slow changes in the environment, as well as what may occur in the future. For its part, Cutter S. (2003) [7] states that vulnerability is a conceptual approach that allows the scientific community to change the focus of research, from one that focuses on questions that are only of interest to scientists, to research focused on the interest of decision makers.

[1] Disturbance refers to an extreme and sudden event, stress is slow and continuous process.

According to Turner et al. (2003) [8] the vulnerability analysis of the Socio-ecological system is one of the central elements of the dialogue between science and decision makers. According to this author, the topic of sustainability broadens and redirects vulnerability analysis and includes the following aspects: it directs attention to the complex socio-ecological system, considers its sensitivity to exposure, its response capacity (resilience) and adaptation of system, the interaction of multiple disturbances and tensors, the dynamics, transversally and scalar nesting of threats.

Over the past decades, efforts to assess vulnerability to climate change have initiated a process of developing the theory and practice of assessment, which is reflected in the IPCC reports. The first assessments of vulnerability to climate change were made based on the impacts generated; then it goes to a so-called first generation evaluation scheme, in which non-climatic factors are taken into account and recognized the potential of adaptation measures to reduce impacts; it is followed by a so-called second generation scheme, in which particular attention is given to the system's ability to adapt to climate change. Finally, today an "adaptation policy evaluation" scheme is proposed, the objective of which is to contribute to the design of policies, through specific recommendations for adaptation measures [9].

Fussel H. (2007) [9] proposes a conceptual scheme of vulnerability, made up of the following dimensions: a) Temporal reference (Present vs. Future vs. dynamic), b) sphere-scope (internal vs. External vs. transversally in the scale), c) knowledge domain (socioeconomic vs. biophysical vs. integrated), d) vulnerable system, e) system attributes and f) threat.

3. Geomatics, Spatial Analysis and Assessment of Vulnerability to Global Environmental Change — Climate Change

3.1 Geomatics and Spatial Analysis Concepts

Geoinformatics is an interdisciplinary science that allows complex, heterogeneous data series and information from diverse sources on a given territory to be integrated, managed, and analyzed in a simple and easy way.

According to Goodchild (1997) [10], Geoinformatics is one of the many terms used today to describe activities related to the computational management of digital geographic information. Other terms used are Geomatics, and Geographic Information Sciences. According to this author, the term is very broad and includes three different areas: a) The sciences related to research and development associated with geographic information technologies and geographic data; b) the provision of geographic data and c) geographic information technologies.

The content of what is currently considered as geomatic includes: geodetic reference systems, global positioning systems, Geographic Information Systems (GIS), photogrammetry, remote sensing, mapping, as well as traditional inventory techniques. Geomatics has its foundations in the theories of mathematics, physics, chemistry, astronomy, physical geology, and satellite technology. It uses tools such as database managers, computer graphics and artificial intelligence, and lately especially important electronic communication technologies, mainly the Internet, which play a fundamental role in the distribution of geographic databases. Its applications are in basic (topographic) and thematic cartography, in the management of spatial data for a large number of applications (agriculture, geography, environmental sciences, geography, oceanography, forestry, geology, geophysics, civil engineering and biology [11].

The spatial analysis that had its origin in the quantitative revolution of the 1960s is the bridge that connects geography with Geomatics. Spatial analysis provides a distinct perspective on the world, a exceptional lens through which to analyze events, patterns, and processes that operate on or near Earth's surface. Geospatial analysis answers the questions of what happens, where, and makes use of geographic information which connects the features and phenomena of the Earth's surface with its site. The concept that man uses to understand, navigate, and exploit the world is reflected in the concepts of spatial analysis [12].

It is increasingly recognized that computational methods and Geomatics in general can be valuable tools for analyzing a geographic area and its social system in terms of vulnerability to natural and technological threats. There are numerous potential natural and human-induced threats that must be considered in a vulnerability analysis; generally, an area will have more than one threat, and in relation to this the Geomatic has the advantage of allowing the analysis of the spatio-temporal relationships of said threats

The concept of place is the basis of geographic thinking. Geographic location offers a fundamental strategy for organizing and synthesizing observations about the real world. Geographic information science and geographic information systems (GIS) enhance this central geographic research approach by enabling the collection, storage, analysis, and communication of geographic data and information, facilitating holistic and comprehensive thinking about place [13].

Geospatial thinking and reasoning facilitate the transfer of spatial knowledge, as well as the development of skills that make it possible to differentiate facts that have some regularity from facts that are chaotic or random. Geospatial thinking and reasoning, because it is endemic at all scales, to most facets of daily life, can help to understand the cultural and regional differences that occur on the Earth's surface [14].

3.2 Remote Sensing to the Analyze and Evaluate Vulnerability to Global Environmental Change

An impressive ability to observe the earth from space has developed in recent decades. The daily, global, and synoptic observation of the earth's surface has revolutionized the study of the earth and has led us to a new era of multidisciplinary, in the space-time dimension. In the coming decades, the processing and analysis of satellite data will bring more discoveries and greater capacity to predict the processes of the Earth's surface, face environmental challenges, which is essential to protect and preserve human life and ecosystems [1].

Vision from space provides scientists with images and global parameters not achieved by any Earth observation system in terms of frequency, homogeneity, spatial, spectral, and temporal resolutions, and coverage. The global and continuous vision from space is unique in its ability to study the dynamics and variability of terrestrial processes. The remote sensing has contributed to great scientific achievements, new discoveries, transforming the earth sciences, and opening new currents of research [1].

In order to facilitate and visualize the analysis of the great contribution that remote sensing has made and makes in the analysis, evaluation and mapping of vulnerability and its different components, Fig. 1 shows a simplified scheme for the analysis and evaluation of vulnerability (in the sustainability context) proposed by Turner et al. (2003) [8] is a conceptual approach that integrates elements of risk/threat schemes, property law, and ecological theory into a multiscale vulnerability model. From the analysis of said conceptual framework it can be said that the contribution of remote sensing is transversal to the whole process; and includes from the study and monitoring of the various disturbances and stresses to which the socio-ecological system is exposed, the study, monitoring and location of the exposed system and its sensitivity conditions to the determination and monitoring of the impacts suffered by the system.

In relation to the disturbances and stresses to which the system is exposed, the importance of remote sensing is evidenced in the great advances that have occurred in the study of the atmosphere, the weather and natural disasters prediction, changes in the ozone and global pollution, knowledge of ocean dynamics and their relationship with climate, monitoring and changes in environmental conditions. In relation to this last factor of tension, it is worth mentioning, due to the importance that it has as a triggering agent for multiple environmental processes responsible for global environmental change, including climate change, the great contribution that remote sensing makes through the study and monitoring of changes in land cover and use, which includes aspects such as: monitoring of agricultural land, estimation of deforestation, mapping of land cover, determination of vigor of vegetation, determination of biomass, mapping of urban expansion, surface body water, glacier monitoring.

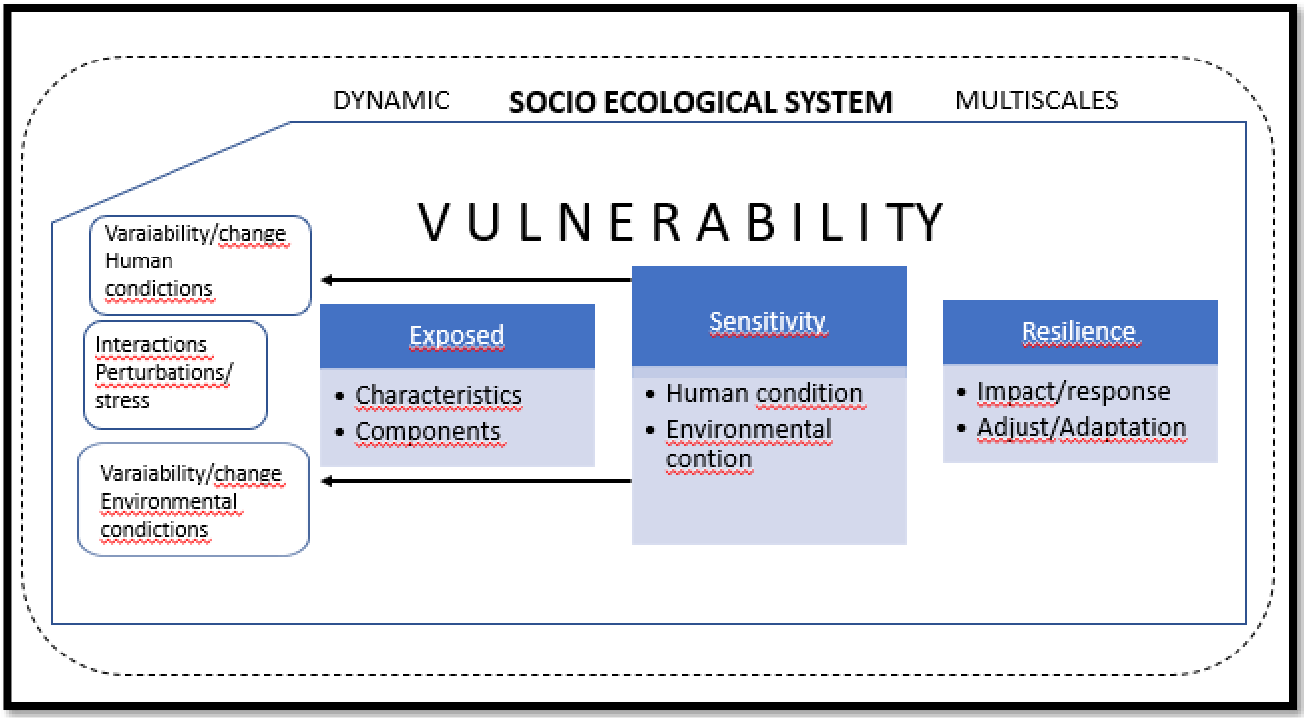

Fig. 1 Conceptual framework (simplified) of vulnerability components [8].

The importance of Remote sensing in the analysis of exposure characteristics and sensitivity is manifested on the one hand in the location of the system, or components of the exposed system, and on the other in determining its characteristics that define its sensitivity. In both cases, given the great increase that satellite missions have had in recent decades and their great potential (due to their varied spatial, spectral and temporal resolution) to record the elements and phenomena of the Earth's surface, the role of remote sensing will be increasingly important. Furthermore, if the transversally in space-time of processes related to global environmental change-climate change is taken into account, which implies that the study of such processes must be addressed at different spatial-temporal scales, it is easy to understand the great significance for the scientific community to have remote sensing data at different spatio-temporal resolutions and scales.

However, to fully capitalize investments in earth observation systems, and advance science and knowledge, in this case of vulnerability, a basic infrastructure is required, which includes the following aspects [1]:

- Optimal processing of satellite data can only be achieved if there is a trained workforce to process and interpret such data. Concern with this issue, it can be mention that there is a gap between industrialized and developing countries; in the last there are much to do.

- It is essential that there is complete and open access to satellite data for academia, the government, and private companies. At this respect in the last decade important satellite data are free (such as LANDSAT AND SENTINEL data) which, together with tools for processing, available in the web, such data, is having a really and positive impact on information generation to use and incorporate in the models.
- -The greatest benefit of satellite data will be obtained when the data and "information" are integrated into the state of the art of the models and analyzed with sophisticated methods. In the last decade, a great quantity of algorithms is available in the web for such work.

On the other hand, users in all domains require information or information related to services that is specific, concise, reliable, low cost, and timely. The needs of users are only partially being met and, in general, companies, in the process of extracting information from such data and images, add little added value by applying processes based on expert knowledge that are complex, expensive and time consuming. In the future, processes will be even more difficult to execute and manage, due to the growth of user communities (including vulnerability), the greater sophistication of their needs and the exponential increase in the volume and complexity of data, due to a rapid increase in the number of missions, number of sensors, type of recorded data, sensor resolution, number of spectral bands and difference in formats. This implies, among other things, migrating towards a new paradigm in the interaction of data — remote sensing users in which emerging technologies will be able to offer new alternatives allowing information and knowledge to be generated, automatically or semi-automatically, through the support of intelligent learning systems. In this way, intelligent systems will become increasingly important, as well as the fusion of remote sensing data with other data; data mining, knowledge and information discovery and other data exploration techniques will be basic to understand the complexity of the data and observed phenomena [15, 16].

4. Geospatial Analysis and Modeling to Assessment Vulnerability to Global Environmental Change — Climate Change

The discussion on the importance and challenges of geospatial analysis and modeling in relation to vulnerability analysis and assessment, will focus on two fundamental aspects: the complex nature of the socio-ecological system and the influence of the transversally of scales on processes of global environmental change — climate change.

According to Turner et al. (2003) [8] a complete vulnerability analysis should ideally consider the whole system. But as the author himself puts it, due to data constraints and other considerations, a simplified vulnerability assessment invariably is required. However, the analyst must be aware that vulnerability rests on a system — the socio-ecological system — which is complex, multifaceted and integrated, with connections that operate on different spatio-temporal scales; a system of resource use around which man has organized in a particular social structure (population distribution, resource management, consumption patterns, norms and associated rules).

The concept of complexity is a property of the observer-modeller approach process, rather than an inherent property of the system. Complexity implies the impossibility of fully explaining-representing-using a single model the behavior of the socio-ecological system [15]. According to this author, in the formalization of a scientific problem and the resulting model, complexity is at stake every time the interest of the observer — the goal of his conceptual map — is affecting what the observer sees, that is, in a pre-phase -analytical a) the choice of scale in the space-time dimension, to which reality must be observed and b) the previous definition of what should be considered as a system of interest, in relation to a selection of variables to include in the model.

One of the key statements of complex systems theory is the emergence of new properties on a higher scale that is difficult, if not impossible, to predict from components analysis. Recently, integrated studies of the socio-ecological system have revealed complex new patterns and processes that are not evident when studied separately by the social and natural sciences. Easterling and Kok (2002) [16] define the domain of the socio-ecological system as too complex for analytical solutions and too structured and organized for a purely statistical treatment, hence its analysis and modeling must be approached in a comprehensive way. In this sense, Cutter S. (2003) [7] argues that there is enormous potential for spatial analysis and modeling to take the lead in developing spatial models of comprehensive threat assessment, an opportunity that should not be ignored. This author says that the goal should be to develop an accurate and easily comprehensible visualization of risks, threats, and vulnerability, which will require refining relationships between the Geoinformatics research community — including modeling and visualization — and the community responsible for emergency preparedness and response. The author concludes that one of the areas in vulnerability science that requires significant development is the modeling community; dynamic non-static models are required, which integrate risk exposure with place-based biophysical and social indicators; although there are highly sophisticated and advanced risk models in the natural, social, health, and engineering sciences, most of these are for specific threats.

According to Eakin H. and Luers A. (2006), some of the changes that are considered in relation to vulnerability analysis are: a) addressing multiple tensions and their degree of interaction, b) considering socioeconomic and biophysical uncertainty, c) consider the influence of the transversely of the scales; there is a mismatch between the science of climate change, which works on a global scale, and the strategic analysis of the needs for adaptation to climate change (national-regional scale) and capacity and mandate of the agencies at the local level to decide and coordinate specific adaptation measures. In addition, many of the initiatives such as those of the IPCC focus a lot on climate issues with insufficient attention to other processes of environmental and social change. Tools to address the problem of scale such as rescaling, nested economic models, and GIS have often been limited by data constraints, modeling capacity, and the lack of appropriate integration schemes.

On the other hand, Easterling and Kok (2002) propose that the analysis of climate change-global environmental change should be approached in a multiscale way, in such a way that it reflects the cognitive and organizational aspects of man as well as the scales at which the natural processes. This author says that the virtue of models resides in the value of their predictions as useful knowledge for decision-making, through a range of levels of spatial scale. Models must provide information to decision makers at the scale levels that concern them. In this respect, the analysis and modeling face another problem [17], there is also a mismatch between the scales of ecological processes and the institutions responsible for their management, which contributes to a decrease in resilience socio ecological. The question of how to resolve these mismatches of scale remains a frontier for research in politics and the management of the socio-ecological system; resolving these mismatches is a fundamental aspect in reducing vulnerability (building resilience).

Thus, vulnerability modeling addresses the need to couple the dynamics of the socio-ecological system with results that are useful for its evaluation. Easterling and Kok (2002) [16], propose that one way to approach this requirement is to conceive it in the context of hierarchy theory and complex systems. In this regard, the hierarchy theory states that the easiest way to tackle global change problems in a complex and multi-scalar system is to understand how the elements of the system behave at a certain level of space-time scale. Comment the same author, that in turn, complexity can be better understood in those portions of the scale that are in the transition from deterministic to stochastic. This transition tends to occur more on the medium scale (mesoscale-regional) than on the macroscale. In this context, the mean scale can be the focal point to focus modeling efforts.

Finally, in relation to the sciences and technologies of geographic information, it is important to highlight that in the last decades basic and applied science have been revolutionizing, allowing holistic and integrated approaches for the analysis of geographic space and its qualities. For their contribution to the modeling of complex temporal spaces processes, the proposals for integrating data models and process models deserve mention, which can facilitate the search for spatio-temporal knowledge within processes at the agent or individual level, and in data about specific cases and places [18]. As this author points out, this integration builds on progress in object-oriented data modeling, which presents a good opportunity to couple process models and spatial data models allowing exploration and explanation of space-time phenomena.

The idea is to exploit the ability to model the change and movement of geographic entities, from object-oriented process models (includes models based on individuals — IBM — commonly used in ecology and models based on agents — MBA — used in social sciences) that have been developed independent of GIS. Three integration schemes are proposed, one focused on MBA, another focused on GIS and a third approach that uses a middleware environment to connect MBA-GIS systems. Additionally, MBAs in association with recent geospatial science and technologies such as location technologies, mobile object databases, and space-time discovery of knowledge may enable the future to advance towards a people-based perspective, that focuses on individuals, on space-time and on the allocation of activities in the physical and virtual worlds, which would facilitate the modeling of complex processes [19].

5. Conclusions

This article attempts to present to the reader with some aspects of the role of geomatics in the analysis and evaluation of vulnerability to global-climatic environmental change. An important aspect that must remain in the reader's mind is that climate change must be addressed within a broader context of global environmental changes occurring in the Earth system. Geomatics and spatial modeling and analysis have contributed and continue to contribute significantly in vulnerability analysis and assessment. Towards the future there are new challenges that these disciplines must face, and their contribution will be key to carrying out a vulnerability assessment, so that the results are available to decision-makers.

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