From Earth Observation to Desertification Monitoring and Drought Early Warning

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1 Introduction

Advances in Earth Observation (EO) now permit the gathering of a wide array of atmospheric, terrestrial and marine data that are of relevance to international environmental agreements. Similarly, since the Rio Conference, multilateral environmental agreements have grown in number, scope and complexity. Many of these agreements contain provisions for monitoring, reporting and assessing both climatic and environmental changes and the impacts of such changes on the sustainable economic development of people.

Considering these new developments, in March 2001 the European Space Agency (ESA) launched the TESEO program which focuses on the use of advanced space EO technology for monitoring the implementation of four international treaties, namely the Ramsar Convention, the Kyoto Protocol, the U.N. Convention to Combat Desertification (UNCCD) and the Convention on Marine Pollution (MARPOL).

Within the framework of this program, Sarmap-Switzerland, in collaboration with the Remote Sensing Department of the University of Valencia (Spain), EOS-France and the Chinese Academy of Forestry, has been selected by ESA to:

- Make an exhaustive review of actions, provisions and objectives of the U.N. Convention to Combat Desertification, with a particular focus on provisions where spaceborne EO may enhance the Convention’s implementation efficiency;
- Identify, collect and analyze the Convention’s end user requirements in terms of information and products and derive a list of strategic requirements; and
- Analyze recent work using spaceborne EO applications and sensors for the assessment of land degradation and desertification; summarize the main advantages and drawbacks of existing spaceborne sensors and derive a list of open issues for further consideration.

This article summarizes the findings of the first phase of this TESEO study on desertification.

2 Earth observation, desertification and the UNCCD

Spaceborne EO has many attractive advantages for the assessment of both environmental changes and the impacts of such changes on people’s living standards and development aspirations. It is generally accurate and objective; it has globally consistent coverage and because it is sensed from space, it can present a wide range of data synoptically. Nonetheless, the use of spaceborne EO data also has some limitations: only people with sufficient technical expertise can interpret and analyze EO data; it is expensive to obtain although the use of spaceborne EO technology may lead to many economies of scale. It will also not eliminate core political and institutional obstacles to environmental protection.

After nearly two decades of political failure, the international community has, with the UNCCD, launched an innovative initiative to reverse and prevent the mismanagement of the world’s drylands. Where past Plans of Action to Combat Desertification ignored the complex interplay of socio-economic influences behind drylands over-exploitation, the Convention confronts them directly. The Convention suggests a new holistic and participatory approach that aims to make development of drylands sustainable. To date, none of the other UNCED regimes has adopted such elements of the bottom-up approach initiated under the Desertification Convention. In this respect, the Convention has some unique features compared to other environmental treaties: in stating that desertification is primarily a problem of sustainable development, it draws attention to the interface between sustainable natural resource management and economic development issues, notably in poor countries with scarce and/or overexploited natural resources.

Yet, the Convention is not a perfect legal instrument to combat desertification: desertification remains a poorly understood concept (notably the complexity of the phenomena and the interaction between poverty and land degradation issues), which has not grabbed the imagination of policy-makers and the public at large. Desertification involves a very complex set of interactions and, thus issues, with few easily identifiable causes, or tidy solutions. Moreover, estimates of areas involved range from one third of the world to close to 50 percent; and people affected from 1 in 6 to 1 in 3. Finally, despite attempts to establish a global connection between desertification and other conventions such as climate change or biological diversity, no such mechanism has been clearly identified.

A better use of EO data is, therefore, becoming more and more critical to understanding desertification processes and human impacts on natural ecosystems and can ultimately contribute to the design of improved policy instruments. The areas, which could directly benefit from use of spaceborne EO technology in the implementation framework of the Convention to Combat Desertification fall under three main headings:

- The collection and analysis of short-term and long-term data and information to identify causal factors, both natural and human, contributing to land degradation, desertification and/or drought; increase knowledge of the processes leading to land degradation, desertification and drought; and understand better the interaction between climate and desertification and assess the process and effects of drought on desertification;
- The systematic observation of the state of the environment to assess qualitative and quantitative trends in natural resources; evaluate the causes and consequences of desertification, notably ecological degradation; and monitor the effects of land degradation and desertification to improve the value of strategies to combat desertification; and
- The establishment and/or strengthening of early warning systems to evaluate the impacts of natural climate variability on regional drought and desertification and generate seasonal to inter-annual climate predictions to improve the efficiency of programs mitigating the effects of droughts on affected population.

A more systematic use of spaceborne EO technology will also provide additional implied benefits to the Convention. It will enhance the reporting system and the development and updating of national action plans as new scientific data becomes available. By fostering greater understanding of both the desertification and drought processes, EO data may feed into the broader political process by raising public awareness and concern, which, in turn, will foster efficiency and encourage greater public support of the Convention. It will also facilitate the design and implementation of rehabilitation or reclamation measures as well as the mitigation of drought impacts; it will strengthen the ability of the Convention to monitor treaty-relevant behavior as well as instances of non-compliance. When used in a co-operative spirit, EO data could enhance performances and help outside experts assist country Parties in developing remedies. But most importantly, it will help in harmonizing methodologies, procedures and formats for the gathering and analysis of information required for better decision-making. This information would be key at both the national and international levels. Another significant benefit is that more efficient harmonization has the potential to reduce the costs involved in providing and processing relevant information needed to devise and implement desertification rehabilitation and drought mitigation measures.

3 Benefits that can be expected from earth observation

A preliminary analysis of value of current and forthcoming operational sensors in use to tackle desertification issues concludes that the range of information that can be extracted from EO data is wide, even if some methods are still experimental. While the most advanced operational products are those currently based on meteorological geostationary systems, the most promising ones are the ones based on hyper-spectral and SAR instruments. ENVISAT, the new European satellite successfully launched on March 1, 2002 is a promising complete system for the monitoring of desertification processes, due to the presence on board of MERIS, ASAR, GOMOS and AATSR instruments. The integration of these data combined with a very high spatial resolution optical sensor will enable the extraction and retrieval of the most relevant parameters related to desertification and drought. Sarmap's analysis also highlights the fact that robust physical models should be further develop to retrieve bio- and geophysical parameters, instead of relying on empirical or semi-empirical approaches.

4 Defining end-users information needs

End users' and strategic requirements as defined under the TESEO program was a complicated task in view of the complexity of desertification problems observed in the different biophysical, social and economic settings and the great variety of end users. According to the preliminary findings of the study, end users' needs fall under two main categories: more adequate information and capacity building.

End users vary from policy-makers operating at international organizations through to managers and researchers at regional, national and local levels, through to land users who farm, herd and utilize the land in various ways. These different end-user groups require different information. Nevertheless, they all have something in common: they all require improved information on the direct and underlying causes of desertification; desertification status, severity, trends and impacts at national level for policy making and for the preparation of projects and programs to combat desertification, including rehabilitation and reclamation measures.

Among the information needs identified so far, the following can be emphasized: better aggregation of data sets at multiple scales, improved compilation of information, better integration of case studies through improved networking among all institutions dealing with desertification research. Moreover, the Convention seeks to promote an enabling framework, with overarching policies and measures that feed into sectoral programs: forestry, agriculture and livestock management. These programs are expressed through land action programs, which are implemented at the level of, and through, local communities. Each of these levels needs data and information to understand both (desertification and drought) processes and causes, and to respond effectively to change and the impacts of natural disasters, notably drought.

Therefore, from a technical standpoint, end user requirements are closely related to the variables and indicators of desertification and impacts of droughts. Monitoring and early warning systems to provide convenient descriptions of the current state or conditions of resources increasingly use indicators. These indicators are also in the process to be developed to gauge performances and predict responses, notably remedial or mitigation actions. The efficiency of end users will, therefore, depend upon the relevance of these indicators and the frequency interval at which they are recorded or monitored.

5 Defining indicators for desertification monitoring and drought early warning

The question of indicators of desertification and drought has long been debated prior to and at the Convention. Many development specialists, however, note that the current indicator system agreed upon by the Conference of the Parties (i.e. implementation indicators to monitor the impacts of National Action Plans and indicators for impact monitoring) is not yet adequate for the monitoring and assessment of desertification trends and for providing early warning in case of drought. Furthermore, the absence of a common set of indicators amenable to EO and the lack of common mapping standards is currently hampering the use of EO and meteorological satellites.

A small group of experts of the Convention's Asia Thematic Program Network (TPN1) met in Beijing on November 26—29, 2001 to determine a common set of desertification benchmarks and indicators for further consideration by the Asia TPN1 countries first, then by the Committee of Sciences and Technology of the Convention. The reference system proposed by this expert group includes four groups of benchmarks and indicators: *pressure, state, desertification impacts* and *implementation*. Pressure indicators characterize driving forces, both natural and human-related, which affect the status of natural resources and the environment and lead to desertification. State indicators characterize the status of natural resources with a particular focus on land resources. Desertification impact indicators are applicable to the evaluation of the effects of desertification and drought on both natural resources and the sustainable development of local population, while implementation indicators should be used to evaluate the actions taken by end users to combat desertification and the effects of drought. In spite of the fact that there is, for the time being no consensus on a comprehensive indicator framework for desertification monitoring and early warning, this reference system represents perhaps one of the most advanced framework for benchmarks and indicators for the monitoring and assessment of desertification.

6 Potentials of existing and future EO systems

EO currently provides end users with valuable qualitative (i.e. land cover classes and changes) and quantitative (i.e. bio- and geophysical parameters) information via products, many of which are already operational or semi-operational.

According to Table 1, the range of information that can be extracted and/or retrieved from EO data is wide, even if some methods are still experimental:

- Most operational products for desertification monitoring and early warning are currently based on meteorological geostationary systems.
- Low spatial resolution active microwave systems, which delivered in the past decade valuable information on soil moisture, are limited to one satellite only.
- The most promising products are those based on hyper-spectral and SAR instruments. Products based on polar orbiting low spatial resolution optical systems or those having a high to medium spatial resolution and a limited number of channels will become of limited use when hyper-spectral and SAR derived products will be fully operational. We could imagine, that the use of the first ones will be replaced in the next decades by the second generation of meteorological geostationary systems.
- High spatial resolution SAR systems could strongly-especially for the retrieval of bio, geophysical parameters (i.e. soil moisture, vegetation biomass)-improve their capabilities, if operational multi-frequency (X-/C- and L-band) polarimetric sensors were available.
- ENVISAT, the latest ESA satellite launched on March 1, 2002, is the most advanced complete system for the monitoring of desertification processes, due to the presence on board of MERIS, ASAR, GOMOS and AATSR instruments. The integration of these data combined with a very high spatial resolution optical sensor will enable the extraction and retrieval of the most relevant parameters with in the desertification issue.
- The retrieval of bio- and geophysical parameters should be further developed by robust physical models, instead of relying on empirical or semi-empirical approaches.

7 Limitations affecting the use of EO systems

In spite of these potentials, the type of information that can be extracted from EO satellites, is often unknown to end-users. Therefore, there is a need for promotion of and education in the benefits of using EO. It should be pointed out that the Remote Sensing Community should deliver standard products tailored to user needs and not raw data. This requires a huge effort, but this is the only way to make EO an attractive and widely used information source.

Desertification does not depend exclusively on meteorological, hydrological, physical and biological factors (which can be measured by EO sensors), but also on the socio-economic aspects as well as on land use. These ancillary data (such as economic pressures, poverty, etc.) cannot be measured either directly or indirectly by EO instruments. Therefore, monitoring desertification trends will require the development of models integrating biophysical and ancillary factors and hence the principal parameters driving desertification processes. The identification of these parameters (at local, regional and global scale) would also enable the development of predictive models, for the establishment of forecasting/early warning systems.

Despite the recognition of the utility of EO and spaceborne systems by the Desertification Community, there are three relevant issues hindering the use of EO that must be addressed in priority:

- *Costs* - A widely spread opinion among the desertification community that EO data and tools (in terms of hardware and software) are very expensive in spite of the many economies of scale that EO could provide;
- *High-Tech* - Most of the desertification community still believes that EO is a ‘high-tech tool’, which is restricted to specialist use only; and
- *Software* - The absence of reliable and automatic “EO tools” that can help the desertification community to streamline data analysis for desertification monitoring and early warning in case of drought.

Therefore, the final goal of TESEO’s next phases should be to develop such an EO tool, potentially based on factorial analysis, to determine the factors and hence the principal parameter driving desertification processes. The identification of these parameters (at local, regional and global scale) would enable predictive models, for the establishment of forecasting. Again, the role of EO at this level is relevant, since episodic events, which cannot be predicted, have to be detected by EO systems.

8 Conclusions of the TESEO first phase

In spite of the many advantages, which could be derived from a better integration of EO technology in the Convention’s implementation process, a number of institutional, technological and capacity issues should be overcome. They include the need to agree on an indicator reference base to develop a co-coordinated suite of environmental monitoring systems with long-term data continuity at appropriate spatial, spectral and temporal scales. Other issues concern the high cost of EO data, the lack of linkages between data providers and end users, the lack of consistency and standardization of data sets and mapping procedures and the lack of infrastructure for access to and use of data sets. Furthermore, EO also requires significant technical expertise to be properly interpreted. Such expertise, however, is generally scarce in developing countries and, therefore, some countries may feel at a disadvantage when it comes to utilizing EO for monitoring desertification trends and assessing the impacts of drought and, more globally verifying compliance to environmental treaties, the UNCCD in particular.

It is, therefore, not surprising that the Desertification Convention is only indirectly referring to EO for the study, monitoring and assessment of the various factors (direct or indirect) inducing desertification and drought.

All these “institutional” issues should be addressed in priority as to boost the use of EO for desertification assessment and monitoring and drought early warning. As a result, a number of capacity building actions should be addressed urgently, including the development of a comprehensive indicator reference base for use in different regions and agro-climatic zones, at different scales and for different categories of users; the development of integrated national and regional database and desertification information systems on desertification and drought; the creation of global databases on desertification from satellite data to stimulate the growth of EO technology; the strengthening and expansion of existing networks on desertification monitoring and information; the training of staff, notably in the field of new EO and communication technologies; and the development of awareness campaigns enhancing the role of EO in desertification (and environmental) monitoring and early warning.

These conclusions are in line with the United Nations meeting organized in 1999 on synergies among international environmental treaties, which recommended the harmonization of data gathering and analysis, and identified remote sensing technology as “an under-utilized resource” that should focus more explicitly on treaty monitoring and implementation”. Similarly, a recent report commissioned by the European Union called for “greater dialogue between EO data suppliers and environmental treaties in order to make country Parties to treaties more aware of the detailed and tailored capabilities of satellite data and inform suppliers’ of users requirements”.

Table 1 Review of factors/indicators that can be retrieved from EO

Factors/indicators	EO Status	Sensor/Techniques	Ground measurements	Frequency	Scale
1. Climate / Meteorological					
Aerosols	O	4	no	d	g
Land surface temperature & emissivity	O	6	no	d	g
Albedo	O	2,5,6	no	d	g,r,l
Smoke and Ash	O	4	no	d	g
Upper tropospheric humidity	O	2	no	d	g
Wind direction and velocity	O	2	no	d	g
Sea surface temperature	O	2, 5	no	d	g
Cloud cover & type	O	2	no	d	g
Atmospheric chemicals gases	O	4	no	w	g
Clear sky radiance	O	2	no	d	g
2. Hydrological					
Surface water	O	5,6,8 / b	no	w	l
Turbidity of water	SO	6	no	w	l
Ground water	SO	8	yes, Ground Control Points	w	l
Soil moisture	E	1,8	yes, sample	d	l
Snow cover	SO	5,6,8 / b	yes, sample	d	l
Snow wetness	E	8	yes, sample	d	l
3. Physical					
Salinity	E	5,6	yes, rainfall	m-y	l
Eroded land	SO	5,6 - 8	yes, DEM – no	m-y	l
Shift in sand sheet / Sand dune area	SO	8	no	d-m	l
Water logging	SO	5,6,7,8 / b	no	w-m	l
DEM	O	3,6,8	yes, Ground Control Points	u	l
Subsidence	O	8	yes, Ground Control Points	m	l
4. Biological					
Vegetation Cover, Use / Change	O	5,6,7,8 / a,b	yes, sample	m-y	l,r
Vegetation indices	O to SO	5,6 / a	no	m-y	l,r
Crop area	O	5,6,8 / b	yes, sample	w-m	l,r
Crop productivity	SO	5,6 / a , 8	yes, sample & meteo	w-m	l,r
Biological productions	SO	5,6 / a , 8	yes, sample & meteo	w-m	l,r
Vegetation biomass	E	5,6 / a, 8	yes, sample	m-y	l,r
Forest burnt area	O	5,6,8 / a,b	no	m-y	l,r
5. Episodic					
Crop damages	SO	5,6,7,8 / a,b	no	—	l
Flooding	SO	8 / b	no	—	l
Dust storm	SO	4	no	—	r,g
Bush and Forest Fire	O	2,4,5	no	—	l,,r
Landslides	SO	8	yes, Ground Control Points	—	l
Forest Clear Cut	SO	5,6,7,8 / b	no	—	l
6. Socio-Economics					
Census data	SO	7	yes, mean # of persons/house	y	l
Buildings (number & distribution)	SO	7	no	y	l

O = Operational, SO = Semi-Operational, E = Experimental;

1 = Low spatial resolution active microwave; 2 = Geostationary meteorological; 3 = Low spatial resolution radar altimeter;

4 = Low spatial resolution ultra-violet; 5 = Low spatial resolution optical; 6 = Medium to high spatial resolution; 7 = Very high resolution optical; 8 = Spaceborne SAR;

a = Vegetation Indices; b = Land cover/use changes; w = weekly, m = monthly, y = yearly, u = one time; g = global, *r* = regional, l = local