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Systematic Data Acquisitions—A Prerequisite for Meaningful Biophysical Parameter Retrieval?

Ake Rosenqvist, Anthony K. Milne, and Reiner Zimmermann

***Abstract*—Implementation of systematic earth observation data acquisition plans over extensive regions, in which the spatial and temporal components of relevant ground targets are adequately taken into account, is a prerequisite for successful retrieval of bio- and geophysical parameters and imperative to accommodate extrapolation of locally developed models to regional scales as required in the context of terrestrial carbon cycle science. Straightforward in concept, but surprisingly uncommon in mission operations thus far, the key characteristics of such a systematic data acquisition strategy are outlined in this paper.**

***Index Terms*—Biophysical parameter retrieval, data consistency, data continuity, earth observation strategies, image mosaics, long-term continuity, satellite acquisition planning, spatial consistency, synthetic aperture radar (SAR), temporal homogeneity.**

I. Introduction

A. Background

Retrieval of bio- and geophysical parameters from remote sensing data is an important field of research, and the prospect of extracting such information in an operational manner with a high degree of accuracy is a strong driver of current scientific work. *Meaningful* parameter retrieval, however, requires not only the availability of appropriate inversion algorithms, but also that locally developed models can be applied in an extensive regional context. In terrestrial carbon cycle research, with its direct impact on economic and political decision-making processes—notably the UNFCCC Kyoto Protocol—accurate assessment and detection of changes in vegetation biomass and carbon stocks over extensive areas are of paramount importance and a challenge that the implementation of the Protocol imposes on the remote sensing science community. Regional extrapolation becomes imperative if the applications are to be more than of academic interest, and spatiotemporally consistent data, and thus the implementation of systematic data acquisition plans, therefore, becomes a requirement.

B. Inadequacy of Current Data Archives

Providing long-term systematic and repetitive observations over large areas is *potentially* one of the major strengths of remote sensing technology, in particular for microwave sensors, which are not limited by low sun angles or persistent cloud cover. If we limit the discussion to sensors with a resolution better than about 100 m, however (hereafter, referred to as fine-resolution sensors), it can be argued that the actual usefulness of the satellite data collected during the past three decades—the so-called "global archive"—may turn out to be very limited, as the data generally lack both spatial and temporal consistency, which render them inadequate for most operational purposes. Gold nuggets may certainly be found, but for most applications relating to phenomena of regional-scale or broader, the fragmentation of the archives can be expected to seriously limit the usefulness of the data.

Inconsistent data archives is a problem characteristic for fine-resolution sensors that typically are not acquired homogeneously over large areas, but instead generally collected with local focus over sites that have been specifically requested by commercial or scientific users. This results in some passes being acquired systematically over long periods of time, while the data coverage over neighboring passes may be totally neglected. Most satellite missions also entail some kind of gap-filling background mission objective when operational resources permit, but the actual usefulness of such piecemeal global archives is questionable, as the data are generally acquired without considerations of the impacts of temporal effects. Optical satellites, notably Landsat [1], generally do better than their microwave counterparts, but cloud cover seriously reduces the availability of useful data over regional scales.

C. Coarse-Resolution Data Archives

The usefulness of systematic and consistent data observations can be demonstrated by a coarse-resolution sensor such as the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), which despite its 1-km spatial resolution, is utilized extensively worldwide. Its success with respect to broad use can probably be attributed at least as much to its tremendous data archive, as to the characteristics of the sensor itself. The AVHRR archive features attributes that are important in the context of regional-scale biophysical parameter retrieval: multitemporal wall-to-wall global coverage, consistent sensor characteristics, and availability since the early 1980s. AVHRR data are furthermore both affordable and easily accessible, which, although not directly related to the discussion here, are two further key points for wide use. Applying an AVHRR-type of acquisition strategy directly to fine-resolution sensors is, however, not feasible due to the significantly higher data rates and associated operational and technical constraints the improved spatial resolution brings about, and a fine-resolution observation plan consequently requires a higher degree of planning if regional fragmentation is to be avoided.

II. Characteristics of a Systematic Observation Strategy

In the design of a systematic data observation strategy for fine-resolution sensors, focused on the collection of data for geo- and biophysical parameter retrieval over regional scales—the requirement for *meaningful* parameter retrieval as argued for here—the following key aspects of the plan have to be carefully considered:

- regional consistency;
- adequate repetition frequency;
- accurate timing;
- sensor consistency;
- long-term continuity.

A. Regional Consistency

Maintaining regional consistency in space and time in the data observation plan is imperative in order to allow extrapolation of locally developed retrieval algorithms to regionally extensive units, e.g., the application of a stand-derived biomass retrieval model to an extensive

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A. Rosenqvist is with the Earth Observation Research Center, National Space Development Agency of Japan, Tokyo 104-6023, Japan (e-mail: ake@eorc.nasda.go.jp).

A. K. Milne is with the University of New South Wales, Sydney, 2052, Australia (e-mail: t.milne@unsw.edu.au).

R. Zimmermann is with the Max Planck Institute for Biogeochemistry, 07745 Jena, Germany (e-mail: rzimmer@bgc-jena.mpg.de).

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ecological region. *Spatial consistency* in this context refers to large regional coverage without acquisition gaps, while *temporal consistency* refers to limiting the time window in the regional data capture so that temporal variations between neighboring passes are minimized. The requirement for temporal consistency is primarily determined by the land cover and its seasonal influence and the time period of research interest.

Both spatial and temporal consistency are illustrated by the semicontinental Japanese Earth Resources Satellite 1 (JERS-1) synthetic aperture radar (SAR) coverage over northern South America shown in Fig. 1 [2], [3]. The nearly 60 passes making up the mosaic were acquired sequentially during a two-month period in 1996, targeted to coincide with the predominantly high-water season of the Amazon River Basin. The seasonal influence on the backscatter is apparent in the data, with inundated forest appearing bright. As water levels change rapidly, a missed acquisition, or a replacement of one pass with another acquired during a different season, would interrupt the temporal consistency of the dataset and induce errors or uncertainties in the analysis. Notable, however, is that although the coverage is 99% spatially complete, the few remaining gaps are not only very apparent visually in the mosaic, but will obviously also prevent any kind of information extraction in those specific areas, hence further highlighting the significance of the arguments put forward.

B. Adequate Repetition Frequency

Many terrestrial parameters are in a continuous state of change, and in many cases, it is these changes that are of interest in ecological research and in practical applications. Terrestrial carbon cycle research is largely focused around the change component in vegetation status and condition, and unless the temporal dynamics of the relevant ground parameters are adequately taken into account, the acquisitions will merely constitute snapshots in time. Specification of temporal repetition needs is, thus, an important component to an optimal data acquisition strategy, in addition to the requirements for spatial and temporal homogeneity.

What is "adequate" depends on the ground parameter of interest and the repeat capability of the satellite. Net primary production (NPP), for instance, is a rapidly varying parameter that would require daily to weekly acquisitions during the vegetation period for adequate sampling, while seasonal flooding dynamics may be sufficient to monitor on a weekly to monthly basis. Forests, on the other hand, with decadal growth cycles and interannual changes, may be sufficient to cover at an annual repetition, or less. Hence, the requirements on the temporal revisit frequency is highly land cover dependent, and a spatial stratification of the observation area into dominant land cover types may thus be required in the formulation of a regional-scale acquisition strategy.

C. Accurate Timing

Accurate timing of the observations is another important component to consider, not only as inconsistent seasonality interrupts temporal consistency in regional datasets as discussed above, but it may also introduce bias in time series of data. Annual acquisitions of, for example, forest cover by microwave sensors should preferably be taken under the same physical and structural circumstances that affect the backscatter signal, meaning that acquisitions should be performed during similar dielectric conditions of the forest and during the same season to ensure comparability of both components every year. As the occurrence of such stable conditions may vary considerably from year to year, it may actually be desirable to have more than just one overpass annually in order to enable selection of the best time for dielectric and structural preconditions. Spring acquisitions should generally be avoided in the boreal and temperate zones, as thaw and snowmelt may obscure actual changes. In the tropical zone, the dry season is preferred, due to more stable dielectric and larger radiometric dynamic range between bare soils and vegetation cover.

D. Sensor Consistency

Optical sensors can record data in several spectral channels and with several spatial resolutions simultaneously, thereby bypassing the need to specifically select a predefined sensor mode for each data take. Microwave sensors are much more limited in this respect. While the JERS-1 and European Remote Sensing 1 and 2 (ERS-1/2) satellites featured SAR instruments with fixed sensor parameters, Radarsat, Envisat, and the Advanced Land Observing Satellite (ALOS) allow—or will allow—variable polarizations, off-nadir angles, and spatial resolutions (ScanSAR). While this, on one hand, brings greater opportunity in being able to more adequately characterize the backscatter of objects and surfaces and, therefore, to potentially devise better retrieval models, it introduces a measure of conflict, as different applications have different sensor requirements. A conflict of interest may also arise between locally focused basic research—e.g., investigations of the effects of variable incidence angles and polarizations—and the more operational, regional-scale applications discussed in this short communication, which require repetitive large-area coverage with a constant fixed configuration. In order to avoid, or at least to minimize, fragmented acquisitions arising from a number of different sensor combinations, this issue should be addressed by the science community at an early stage in the mission, and a best "tradeoff" set of sensor parameters should be sought. The availability of spatially and temporally consistent datasets at regional scales is more likely to govern the extent ot which remote sensing data are used for environmental applications in the fugure than a specific sensor configuration.

E. Long-Term Continuity

Assuring long-term decadal continuity of acquisitions with intercomparable sensors is a well-known requirement that will not be dealt with further here. It is sufficient to note that long-term sensor continuity—both optical and microwave—is imperative to support any kind of climate-change-related research, during and beyond the lifetimes of individual satellite missions.

F. Case Examples

Illustrating well the importance of systematic data acquisitions and the new information that regional-scale datasets may provide, Richey *et al.* describe [4] how dual-season JERS-1 SAR mosaics covering the Amazon River Basin were utilized to estimate the areal coverage and inundation status in the river basin at the periods of high water and low water (high-water mosaic depicted in Fig. 1). Each mosaic was classified into flooded and nonflooded areas based on their backscatter intensities as delineated by image segmentation. The flooding information was subsequently used as input to a regional-scale CO_2 emission model developed, to obtain significantly improved estimates of CO_2 fluxes from the rivers and wetlands in the central Amazon River Basin. The example demonstrates the fundamental importance of maintaining both spatial and temporal consistency over large areas, as well as that accurate timing (in targeting the basin at its low and high water levels) is critical. It also demonstrates the utility of compiling the data into radiometrically and geometrically consistent image mosaics, without which the investigation above would not have been feasible.

Another illustrative example is provided by the SAR Imaging for Boreal Ecology and Radar Interferometry Applications (SIBERIA) project, in which C- and L-band SAR data were used to derive maps of forest cover and growing stock volume over a 1 million-km^2 region in central Siberia [5]. Using a mobile ground receiving station

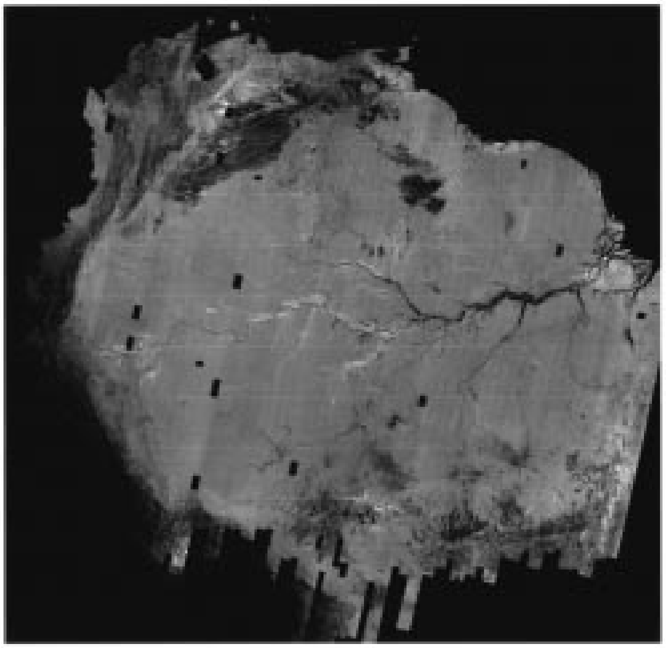

Fig. 1. JERS-1 SAR mosaic over northern South America, illustrating nearly complete coverage with spatiotemporal consistency over subcontinental scales. (Global Rain Forest Mapping Project © NASDA/METI/JPL/JRC).

transported to nearby Mongolia for this purpose, ERS-1/2 C-band data in interferometric tandem mode and JERS-1 L-band SAR data could be acquired simultaneously during two limited-time windows, forming a near-complete two-season coverage over the region. Synergetic analysis of the multitemporal, multifrequency, and interferometric information collected allowed for stratification of the forest into four biomass classes and ensuing generation of 98 1 : 200 0000-scale map sheets, which were provided to the Russian Forest Service. Execution of a project like SIBERIA unmistakably relies on the availability of spatially and temporally consistent data over extensive regions, and it is evident that the dedicated data observation plans implemented for ERS and JERS specifically for this campaign were fundamental prerequisites for its success. SIBERIA also demonstrates the benefits of multisensor approaches, but as consistent and nearly simultaneous coverage with several sensors over extensive regions rarely exist, it underscores the need for closer coordination between the space agencies in their planning and operations of present and near-future earth observation missions.

III. Conclusion

While it may be argued that "meaningful" bio- and geophysical parameters can be extracted even from a single scene without an extensive spatial and temporal context, we believe that it is time to move on from local-scale research to regional-scale operational applications. Parameter inversion is an important area of research *because* of its potential impact on regional and global-scale issues of public concern. Climate change and environmental degradation are disquieting realities not only for the science community, but also for policy makers and the general public, who through a number of international conventions addressing these issues indicate a will for a change. The general public, furthermore, have the right to demand that the not insignificant resources spent on earth observation worldwide are utilized in favor of the public good and for the preservation of the environment.

The inability of remote sensing technology to be used for ecologically meaningful data interpretation by a wide community and, consequently, its political acceptance and support is thus not primarily a problem of its technical complexity, but can be attributed to a large extent to the lack of spatially comprehensive observations over sufficient long time periods. We believe that the establishment of long-term spatiotemporally comprehensive data acquisition strategies in line with what has been discussed above would greatly stimulate the development of operational applications required to support the regional-scale information needs posed by climate change science and environmental treaties, for the benefit of the public, the science community, as well as for the space agencies.

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