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Final Report on the First Step in Distributed Remote Sensing

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FINAL REPORT ON THE FIRST STEP IN DISTRIBUTED REMOTE SENSING

by

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ABSRACT

Distributed remote sensing (DRS) has a number of promising applications; the World Laboratory's First Step in DRS documented and discussed them widely. Acceptance for DRS is growing in the U.S., the Former Soviet Republics (FSRs), and among global scientific, political, and military leaders. Ecological and defense applications were discussed in international meetings in Dubna and Erice. Its dual-use applications have solid support. The World Laboratory's Global Environmental Monitoring (GEM) project is appropriate, feasible, and an excellent vehicle for communication and cooperation, which could grow rapidly into a global effort.

I. INTRODUCTION

The 1991 Erice International Seminars on Planetary Emergencies discussed at considerable length distributed remote sensing (DRS) from constellations of small satellites for global awareness and ecological measurements.[1] Sufficient interest was generated to warrant follow-up action. A pilot project to define a "First Step" towards DRS was instituted, and a committee was appointed to study DRS and define a broader project, composed of Dr. E. Teller of the Hoover Institution, Prof. T.D. Lee of Columbia, Dr. K. Goebel of the Geneva World Laboratory, Dr. G. Barenboim of the Geneva World Laboratory, Dr. R. Leopold of Motorola's IRIDIUM, and Dr. G. Canavan of Los Alamos.

The committee worked during the past year to further define and document the concepts. This note reviews their findings and summarizes some of the reference materials produced. The "First Step" evolved rapidly. Over the course of the last year it was used to define the Global

Environmental Monitoring (GEM) project of the World Laboratory, which was discussed by an international group of scientists from the U.S. and the Former Soviet Republics (FSRs) in Dubna in July and Erice in August of 1992. Thus, the charter of the "First Step" committee has been successfully completed, and this is both its first and last report.

II. BACKGROUND

Work over the last decade on "brilliant pebbles" and "brilliant eyes" for missile defenses has significantly advanced the technology, improved the performance, and reduced the cost for small sensors and satellites. "Brilliant pebbles" and "brilliant eyes" have now reached a point where it is arguably practical to consider using them at acceptable costs for precision measurements of key ecological and defense phenomena from the large constellations of satellites needed for global coverage.[2]

These issues are covered in the report on "Distributed Remote Sensing for Defense and the Environment" discussed in the 1991 Erice Seminars on Planetary Emergencies.[3] It gives estimates of the types and sizes of constellations needed for DRS for defense and the environment, discusses in some detail the sensors required for meteorological and climate measurements, and sketches out the passive and active sensors needed for moving target indication and high-resolution imaging to support global awareness and warning of preparations for aggression.

A companion paper, "Low-Level Satellites Expand Distributed Remote Sensing," goes into greater detail on the status of the technologies, concepts, and requirements for DRS for defense and global awareness.[4] It establishes a performance map in terms of the space and time resolutions available from various sizes of constellations of visible, infrared (IR), real-aperture radar, synthetic aperture radar (SAR), and laser ranging and detection (lidar) systems. Much work of the last year has concentrated on confirming and extending those performance maps and assessing their adequacy for ecological and defense phenomena of interest.

The paper on "Distributed Remote Sensing from Constellations of Small Satellites"[5] performs a more extensive analysis of the concepts for environmental and climate applications and gives an assessment of the status of the technologies required. It also discusses the application of DRS to the U.S. Earth Observing System (EOS). That subject is covered further in the "Report of the EOS Engineering Review Committee,"[6] which discusses possible roles for DRS in resuming lapsed climate measurements and testing out new sensors such as lidars and SARs.

III. NEW RESULTS

The Seminars on Planetary Emergencies identified a number of new applications that could be supported by DRS technologies, which could have great global impact. Two are relatively well defined and of particular interest. The first is a constellation of visible-IR sensor satellites to provide frequent revisit times for prompt, local information on the status of agriculture. The second is a constellation of satellites with moderate resolution visible and IR sensors to provide constellations needed are discussed in a joint Los Alamos-Livermore analysis of the "Application of Distributed Remote Sensing to Landsat-Type Sensors," which discusses the revisit times and spatial and spectral resolutions required.[7]

An interesting aspect of that analysis is the quantification of the revisit times needed. A single, visible-IR satellite such as Landsat in a polar sun-synchronous orbit would give coverage about every 16 days, which is too infrequent to be of interest to either farmers or news organizations. But a constellation of 16 satellites would give coverage every day, which could be adequate for agribusiness. And about 64 satellites would give near-continuous viewing of every point on the globe. Using more efficient orbits inclined over the areas of interest would reduce constellation sizes by factors of 2-3. Thus, the constellations required appear practical.

"Application of Distributed Remote Sensing to Landsat-Type Sensors" also discusses the sensors required and the availability of advanced technologies such as wedge filters, "megapixel" focal plane arrays, and the compact communication circuitry needed for them. It provides detailed designs of the two limiting sensors: a low-spatial resolution IR scanner that could provide the hyperspectral IR information, which appears to have the greatest leverage for agricultural applications, and a few-meter resolution, electronically-zooming, visible-IR camera that could apparently meet the requirements for global news and awareness applications.

A very important aspect of these sensors is that they could be very small; each could weigh on the order of a few kilograms and consume only a few watts of power. That means that they would not necessarily require a dedicated satellite, but could instead be added on to any satellites in relevant orbits. The report also assesses the rough communication bandwidths required to report their observations locally and archive them globally. It is interesting that the bandwidths required are typically only on the order of a few hundred kilobits per second, which is on the order of the likely initial excess capacity on communication constellations such as Motorola's IRIDIUM. Its 77 satellites would appear to be attractive hosts, as would communication constellations proposed by TRW, Orbital Sciences, and others in the U.S. and by the Lavochkin, Elas, and other Enterprises in the FSRs, which are discussed below.

IV. REPORTING

These analyses and reports have been discussed with a number of U.S. agencies, as well as in international meetings. This section gives a brief review of the reporting and its reception. One important contact was the U.S. Office of Technology Assessment (OTA), which requested a summary of the status, issues, and prospects for DRS for significant applications in environment, defense, and intelligence as background for a recent OTA Workshop. That assessment was transmitted in the form of a letter report, which was used in the OTA deliberations.[8] While the final OTA report does not emphasize DRS technology, it does recognize the new applications made possible by DRS in addressing the issue of the financial viability of further remote sensing applications and the related issue of the U.S. government's role in underwriting the development of those capabilities.[9]

These results were also reported and presented in the U.S. Department of Energy's (DoE's) Study of DRS, along with a brief summary of the level of readiness of each component technology.[10] The study was performed by the JASONs, which is a group of distinguished, independent academics, who could provide the thoughtful, long-range, independent evaluation needed. Their draft report recognizes the potential importance of DRS in addressing both growing problems in proliferation and in filling key gaps in environmental monitoring.[11] When available, it should make an objective assessment of these opportunities available to decision makers at high levels in government.

Information on these analyses and developments was exchanged in a series of meetings between World Laboratory members at the Hoover Institute and in Colorado Springs. The meetings gave definition to the World Laboratory's Global Environmental Monitoring (GEM) project, which was discussed in detail at an international meeting in Dubna, Russia, in July of 1992.

V. OPPORTUNITIES

The opportunities that have been discussed and quantified range from NASA's scientific EOS measurements and Motorola's commercial IRIDIUM project to DoD Director of Defense Research and Engineering's (DDR&E's) Thrust on Global Surveillance and Communication. Opportunities in the civil, defense, and intelligence areas include EOS, improved Landsats, new options for agriculture, global private news satellites, dual-use of defense sensors, and others.

The EOS Engineering Review recognized that small satellites and sensors could effectively complement the capabilities of large planned EOS satellites in two primary ways.[12] They could quickly resume lapsed measurements of the Earth's radiation budget, and they could apply advanced lidar, radar, and other advanced technologies to the measurement of winds, water vapor, and deforestation, which are essential measurements that are not addressed by the primary sensors on large EOS satellites. NASA formally endorsed both applications; the Space Council made them part of current U.S. Space Policy.

Commerce has demonstrated the continued viability of Landsat for its original applications and arranged for its continuation for a mixture of civil, DoD, and intelligence applications. It also supported studies that showed that the Landsat concept could be significantly improved for those applications and extended to new markets using DRS technologies. Key to its conclusions were the two promising new concepts for larger constellations of smaller satellites or add-on sensors to give the faster revisit times needed for land, water, or agricultural management and the prompt imagery needed for news media.

These new concepts have potential commercial applications that have been explored in a preliminary fashion with Motorola's IRIDIUM, TRW, Orbital Science's Orbcom, and other communication satellite constellations, for which global spectral allocations were granted at the recent WARC Conference. With institutional impediments now largely out of the way, it appears feasible to explore possibilities of large-scale technology transfer of those applications in an efficient manner, given appropriate agency organization and support. That could be a fast and effective way to put these new technologies into the hands of the private sector industries that could apply them most rapidly and to greatest effect.

Defense applications include DoD DDR&E's Thrust to develop capabilities for global surveillance and communication and DoD Strategic Defense Initiative Office's (SDIO's) phenomenology and sensor efforts. DDR&E's surveillance thrust can be supported to a significant extent through remote sensing from space. DRS offers the possibilities for both the global infrared moving-target-indication sensors needed for detection of potential threats and the intermediate resolution visible-IR imagery needed for verifiable warning of aggression.[13] It could also contribute to the Thrust for precision weapon delivery. DRS could efficiently contribute the background and target phenomenology needed for the SDIO's proposed dual-use applications of SDI satellites and sensors, which are discussed further below.

Intelligence applications are likely to include new efforts in warning and preemption, which are related to--but partially intentionally duplicative of--DDR&E's Thrust, as well as new efforts in non-proliferation and expanded DRS efforts in technical intelligence. These activities could take advantage of the new possibilities for intermediate-resolution imagery and moving target indication discussed above.

VI. INTERNATIONAL COORDINATION

As mentioned above, discussions between World Laboratory representatives culminated in an international meeting in Dubna, Russia, in July 1992 to exchange information and explore joint projects in the application of DRS for measurements of global ecology, awareness, and warning of aggression. That meeting very successfully introduced U.S. government and non-government participants to a very large number of FSR administrators, scientists, projects, capabilities, and interests.[14] The U.S. delegation was led by the U.S. Space Council and had members from the DoE, DoD, SDIO, NASA, the Environmental Protection Agency, the Bureau of Land Management, ACDA, Los Alamos, and Livermore.

There were topical, technical sessions on DRS from space, air, and ground, which were useful in that the FSRs have addressed a balanced program across all elements, while the U.S. has concentrated on space rather than ground and air measurements. The meeting was chaired by Dr. G. Barenboim, Director of the Russian Ecological Station of Environmental Control (ESCOS) of the World Laboratory, who reviewed the goals and elements of the GEM project and the various environmental catastrophes in the FSRs, which it is intended to address. The U.S. discussed advanced DRS sensors, satellites, and communications, updating the Erice discussion of the previous year.[15] That was followed by a three day exchange of political and technical information, which cannot be summarized here. The proceedings should be a valuable source document for further interactions.

The presentations from Russian and other FSR leaders and scientists demonstrated an impressive array of capabilities in boosters, sensors, and satellites, but also exposed a number of problems. Perhaps the most awkward was the issue of using demilitarized FSR boosters as launchers for GEM satellites, which is viewed as an important issue, particularly by Russia and the Ukraine because of its potential for generating hard currency. It is a very divisive issue, because it cuts across U.S. domestic commercial space issues. The suggestion was that it would be appropriate for the FSRs to use their converted boosters to launch a large number of their GEM satellites, perhaps with U.S. assistance in integration.

This suggestion represents somewhat of a departure from last summer's discussions at Erice. There it appeared that real advances in DRS could only be made with miniaturized sensors and satellites. A closer examination of the FSRs' ability to build and convert boosters, sensors, and satellites and the favorable economics of doing so indicate that the FSRs could make a very effective contribution with current combinations of sensors and launchers.[16] If they can maintain projected launch schedules, they could provide useful data from visible and IR sensors as well as unique SARs for comparison with the data from other sources. In that process, the highest priority would appear to be in collaboration on the design of sensors, the exchange of information, and in its interpretation. In those areas, limited U.S. support could also have the greatest leverage.

There was great interest in the FSRs flying advanced U.S. sensors, but it was generally recognized that this would require still further relaxation of current tensions, so that it might be more practical to go through a transitional period of several years in which the U.S. and FSRs flew their own sensors with their own boosters, while working out means of exchanging data as a step towards greater cooperation. That would also provide time to investigate the extent to which assets and data bases from military satellites could be made available to the GEM project. That is unresolved as yet, although steps towards cooperation at Dubna and later are encouraging.

In the summary session, general satisfaction was expressed with the results of the meeting and with the use of the World Laboratory as a vehicle for coordinating FSR activities internally and internationally. The concluding sessions sought to better define dual-use satellites, aircraft, and ground stations and combining their data in integrated data banks.

VII. PROBLEMS

DRS is now accepted, but it is encountering some obstacles. One is the perception that it always requires a very large number of satellites. That is not the case; most applications discussed below and in the references can be addressed by constellations of a few to a few tens of satellites. What perhaps distinguishes DRS most clearly is, instead, sensors and satellites that are small and cheap enough to be replicated in numbers to achieve the prompt global coverage or prompt revisit times.

DRS is now accepted by many agencies, particularly DoD, NASA, and Commerce. DoD SDIO is actively pursuing applications of "brilliant eyes" sensors for launch warning and midcourse metrics, and is interested in pursuing dual-use applications for ecological monitoring and warning of aggression. DoD's DARPA is pursuing advanced technology development and demonstration that could lead to distributed global surveillance capabilities. NASA is evaluating DRS's capability to complement the measurements from large satellites. Commerce has explored extensions of Landsat, and DRS is also being actively addressed by industry.

That said, following up on these opportunities has exposed a number of technical and organizational issues. The Engineering Review endorsed DRS for EOS in part due to Livermore's innovative ideas for advanced versions of EOS's HIRIS, MODIS, and CERES sensors. But concerns were raised about the maturity of their designs, the availability of new components, and the long-term calibration of these new sensors, and follow-up was complicated by external confusion over program responsibility within DoE. The result is a fairly conventional and expensive DoE satellite to resume radiation measurements, whose required funding has met objections. There is not, as yet, a definite program to advance the development and deployment of the other advanced passive and active sensors.

In the improved Landsat area, Commerce and the Space Council were influenced by Livermore concepts for advanced imaging sensors for global news gathering derived from their design for a BE-HIRIS and Los Alamos' proposal for simple, useful sensors with more spectral flexibility for agricultural, water, or vegetation monitoring and management. Both appeared appropriate for deployment as add-on sensors to commercial communication constellations. However, only designs were available at the time of the Landsat interagency reviews, so they were not made part of the current program. Preliminary prototype data is now available that could be used to further evaluate advanced concepts.

The delay within DoE also slowed down the design and prototypes of commercial agricultural or imaging sensors. Some data is now available, but the evaluation has fallen behind the decision cycles of the IRIDIUM, TRW, and other satellite communication concepts. The resumption of these opportunities for technology transfer would require the prompt resumption and completion of these joint evaluations.

In seeking DoD applications, DRS advocates initially failed to penetrate studies of global surveillance and mobile targets. DRS concepts were eventually excluded--in part on the basis that initial concepts lacked an all-weather capability and the flexibility of the moving-target-indication capabilities of more-developed radars. DoD DDR&E's current thrust on global surveillance and communication has a somewhat broader charter within which initial DRS technologies could play a role, and to which advanced technologies could contribute fully. The current candidate for a global surveillance sensor is Landsat, which lacks both resolution and revisit time, so it is possible that the DoD's deliberations will return to DRS concepts for surveillance as well as precision weapon delivery.

Intelligence applications indicate an increased need for global awareness, which DRS intermediate-resolution imaging capabilities could support. DRS could also extend the multispectral imaging capability that Landsat has already shown to be useful. This is a separate field and it involves a number of different players, but increased intelligence activity in this area should make it possible to multiply the effectiveness of funds spent for civil and defense applications. Lack of access has been a problem in the past; there are indications that it could be less of a barrier in the future.

None of these problems is lethal. But the time to overcome them and get DRS back into the mainstream efforts in civil, defense, and intelligence efforts is short. Since there are major crosscuts between each of the areas, getting back in essentially requires getting back into all of them at once.

U.S. laboratories have been key players in advancing DRS this far. DRS offers a strong opening for DoE laboratories to bring their strengths in the physical sciences to bear on important and challenging programs in space. That opening is formalized in current space policy. Taking advantage of it would require the DoE to recognize the importance of space to the long-term role of the laboratories and not just a near-term issue of small satellite and sensor advance applications. This advantage could forge an alliance that could make the capabilities of the laboratories more readily accessible to other agencies. Such a development would be consistent with DOE Advisory Committee recommendations on directions for future emphasis.

The U.S. DoE is attempting to establish a national-level consortium involving government (e.g., DoE, NASA, DoD, DOC) and industry to develop and demonstrate advanced remote sensing technology with wide applications to commercial, civil, and national security remote sensing needs. Such a consortium could lever off three decades of sensor and satellite development for verification, arms control, and defense. It would have access to developments, skills, and facilities for advanced computing, information processing, radiation-hardened electronics, microprocessors, and materials. It would also pull together the key elements of DOE and permit the rapid assessment of the size and scope of this emerging international market. The consortium could evolve naturally within the framework of the National Technology Initiative from existing informal initiatives.

There are also problems in gaining support in the FSRs, particularly financial support. The ecological problems in the FSRs are staggering. It would appear that the GEM project could contribute to their solutions; it is less clear how DRS could contribute and how the U.S. could best interact with the GEM project. Many of the FSRs' problems have to do with ground contamination by chemical or radiological materials. DRS can remotely sense gross material migrations through vegetation, emissivity, and reflectivity changes, but current capabilities may not be sufficiently direct to replace ground measurements.[17] The FSRs, particularly Russia, could perhaps be well served by first improving ground measurements and then augmenting aircraft measurements, perhaps using satellites for data readout and transmission.

There appear to be many opportunities for collaboration, but the mechanisms for developing them are still in formation. Until they are in place, the World Laboratory, ESCOS, and GEM would appear to serve as useful default mechanisms for the exchange of the technical information needed to define useful collaborations. And the representatives at the Dubna meeting would appear to be appropriate contacts for such follow-up exchanges.

VIII. PROGNOSIS FOR DRS

The First Step in DRS went through a rapid process of development that produced a number of promising applications. The ecological applications were discussed thoroughly in the Dubna meeting. It will take some time to absorb all of the data presented there and refine joint efforts, but the GEM project still appears appropriate and feasible and appears to be an excellent vehicle for communication and cooperation.

The dual-use applications of DRS were discussed at length at the 1992 Erice Seminars on Planetary Emergencies.[18,19,20] Those projects have won wide support from their scientific communities. If political support for them can also be generated, it is likely that these joint U.S.-Russia efforts in dual-use of SDI assets can provide a framework for their extension to a wider range of sensors, a larger number of participants, integration of ground and air observations with those from space, and the archiving of results into a combined data base accessible to all friendly nations.

Dual-use of defense sensors is only a part of DRS. SDIO's satellites are but one set of possible vehicles, and they are not all that numerous. Even "brilliant eyes" would only offer a few tens of platforms, so they are not all that well matched for some applications. And there could be some problems in adding simple sensors to already expensive satellites, particularly when doing so might impact the survivability of the defensive sensors. But SDI satellites do provide a backbone for deployment, which could evolve in time. And the miniature science and technology integration (MSTI) buses that are to develop SDI's sensors do provide an early and inexpensive vehicle for jointly developing and cross-calibrating sensors. Moreover, the joint definition and design of sensors for MSTI could be a natural lead in to the more demanding joint design efforts that could emerge from the joint U.S.-Russia Early Warning Center approved by the Washington Summit, which will require similar integration efforts.

Acceptance for DRS is growing in Russia and the other FSRs among scientific, political, and military leaders. It is gaining appreciation at high levels in U.S. government. DRS can now count on the SDIO as a solid supporter of promising dual-use applications, and it can aspire to other supporters within the DoD, DoE, NASA, EPA, BLM, and others. It has legitimacy within the FSRs. Thus, it has the potential to start as a bilateral initiative and grow rapidly from there into a multilateral--potentially global--effort. Thus, it could, within a period of a few years, address the original goals for DRS in the service of global defense and ecology that led to the formulation of the First Step. It would be useful, and may be necessary, for the World Laboratory to remain involved in this processes of definition and information exchange for the next few years, until these roots take hold, but the process is under way. Thus, the First Step has accomplished its charter and can transfer responsibility back to the World Laboratory with full expectation of success.

IX. ACKNOWLEDGEMENT

This report gives one committee member's assessment of the opportunities and problems in realizing capabilities of DRS from space to contribute to the full range of understood and emerging civil and defense applications. I apologize for its narrow view. Given other responsibilities, there was not time to seek the broadening perspectives of the many colleagues who have in the past widened views of these areas. I look forward to comments on the final report in future Seminars on Planetary Emergencies, which should provide an excellent forum for airing those views.

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