The Role of Direct Readout (DR) in Near-Real-Time Remote Sensing Applications: Helping to Solve Societal Issues

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Abstract

Satellite Direct Broadcast (DB) has existed since the early 60's, and since then ground Direct Readout (DR) has been the cornerstone of real-time environmental monitoring. Beginning in the mid 80's NASA's primary interest in DR has been in the demonstration of practical applications of DR ground system technologies, including real-time data distribution, data mining, distributed processing and data archiving, and dynamic data management. These technologies combined with access to DR science processing algorithms (SPA)s have been playing an increasing role in temporal studies and tactical applications such as volcanic eruptions and plume tracking, sand storm dust distribution, snow and ice distributions, fire detection, weather nowcasting and polar winds, to mention a few. In the evolution of direct readout three things need to be in place in order to provide societal benefits: availability of freely transmitted instrument direct broadcast, access to direct readout science application algorithms and a decision-making infrastructure that makes use of DR results. These areas will be discussed in this paper along with the necessary supporting technologies. Additionally, this paper highlights DR's increasing role in temporal remote sensing research and tactical remote sensing.

Keywords: Direct Readout, Direct Broadcast, Polar Orbit, Tactical Applications, Real-time Processing, Environmental Monitoring, Disaster Management and Mitigation, Remote Sensing

1. Introduction

Direct Broadcast (DB) is the real-time transmission of satellite data to the ground. As the Earth is observed by satellite instruments, data is formatted and broadcast omni-directionally in a hemispheric pattern to Earth in real-time. Users who have compatible ground receiving equipment and are in direct line of sight to the satellite may receive these transmissions. This paper focuses primarily on NASA's direct broadcast satellites that freely broadcast data to the surface.

Direct Readout (DR), on the other hand, is the process of acquiring freely transmitted live satellite data. As DR technologies become more affordable and accessible - such as with the onset of the Internet - tools have been developed by the remote sensing community to make satellite data easier to acquire, process, and utilize. As a member of this community, NASA supplies many of these tools to foster global data exchange, scientific collaboration and a means for real-time environmental monitoring. Live local and regional environmental data, in turn, benefits environmental, commercial, and public interest decision making.

Direct broadcast satellites are no different than ones that don't have it, except for a secondary data path from the CCSDS data packaging module to the RF sub-system. Their differences are primarily in their ability to divert data packets directly to the RF downlink sub-system which gives no delay of observed data to the ground.

For the direct readout ground stations, on the other hand, they have to be uniquely tuned-in to receive directly broadcasted data and require specific software tools and science algorithm in order to utilize the instrument data. Fortunately, the commercial sector has been designing and building multi-mission direct readout systems which incorporate unique technologies and algorithms for NASA's class of DB satellites.

1.1 NASA's Direct Readout Model

In order to understand the needs of a geographic region, in terms of information necessary to deal with specific environmental issues, it is necessary to have a

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communication's path to those that can provide assistance. Additionally it is necessary to have an interpretation mechanism by which information requirements can be mapped to an organization's remote sensing mission, science algorithm development and programmatic priorities that dictate a schedule for when, if at all, specific developments are and can be made available to the general public. The Direct Readout Laboratory (DRL) at NASA GSFC plays this vital role, as the intermediary between remote sensing missions, such as Terra, Aqua, the NPP/NPOESS, and the DB community. The DRL encourages communication and maintains an open-door policy with the commercial and research and development sectors. This two-way information exchange is part of NASA's DR model, depicted in Figure 1. This model provides the DRL with critical information on the equipment currently in use, the technology being developed commercially, and the needs of the direct broadcast community. As a result, the DRL is able to report the "state of the community" to the NASA mission while providing the DB community with a two-way dialogue between the mission objectives and the user needs.

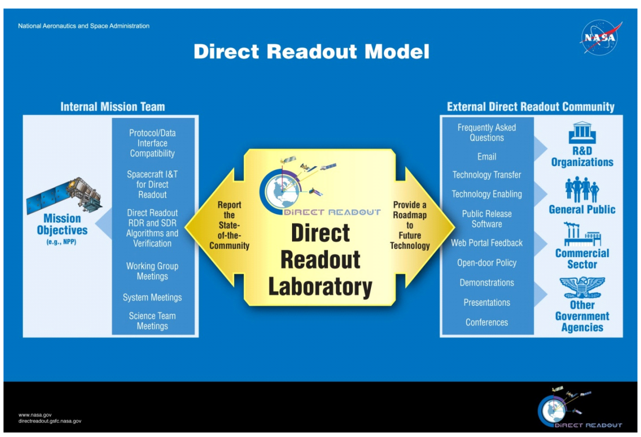

Figure 1 Roadmap to Direct Broadcast Data Usage

2. Derived Direct Readout Technologies

One of the primary results of the DR model, as described in Figure 1, is the identification of key technology categories that the DR end-user would have to contend with in order to be compliant with a multi-satellite and multi-instrument environment. These categories include: real-time system processing tools, CCSDS packet re-assembly and standard data reformatting tools, instrument-specific calibration and geo-registration algorithms, science processing algorithm wrapping schema and, real-time data distribution mechanisms. NASA GSFC through the DRL and the NPP/NPOESS missions have addressed these key technology categories in the form of specific technologies which are generic in nature and can be integrated into existing or developing DR systems. These technologies consititute what is called the International Polar-Orbit Processing Package now availble to the general public.

DR technology development follows a very focused roadmap which address the key areas defined above. These technologies have evolved over time to include characteristics in data and transmission schemas unique to every instrument and spacecraft as decribed in Figure 2.

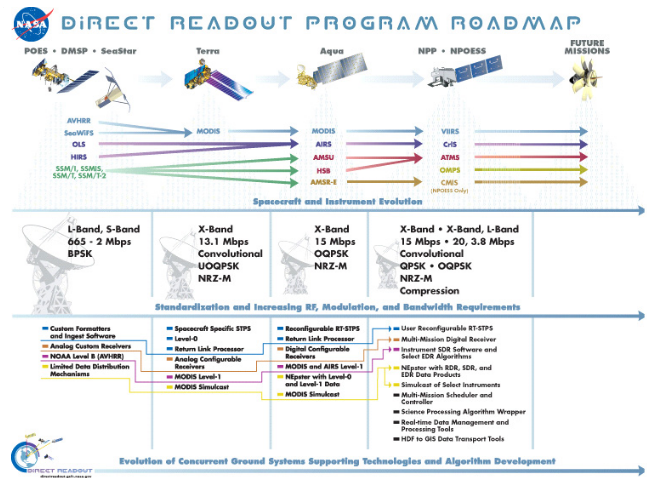

Figure 2 DR Technology Roadmap

3. Application Science Algorithms

Once DB is made possible on the spacecraft and agreements are in place to broadcast the instrument data freely; the second, equally as important component of the overall concept of DB needs to be addressed, application science algorithms. These provide, at a minimum, scientifically valid baseline products of geophysical parameters that can be of regional utility.

Within NASA's EOS missions, specifically Terra and Aqua, significant efforts have been made to develop science products that would stand to the scrutiny of global change studies. These science algorithms are supported by extensive calibration and validation campaigns post launch which have supported the now continuous update to these algorithms and enable accurate data and sensor continuity measurements.

The most important algorithms for the direct readout community have been for their use with the MODIS instrument on these two EOS spacecraft. This instrument with its support science algorithms provide geophysical parameters that are of high utility to the global community. But with any science quality algorithm there has to be a process by which to validate the ported, wrapped algorithm that is to be used in a direct readout environment. The porting process is necessary and is defined as the process of making necessary environmental algorithm changes/additions so as to allow such algorithm to function in a direct readout environment, where system infrastructure-based dependencies are removed and/or emulated, variable data blocks is the norm, and variable anc/aux data sources and conversions may exist. Once porting is complete the algorithm is supported by the Science Processing Algorithm (SPA) wrapper which provides a run-time interface standard and all the hooks and functions necessary for the direct readout user to incorporate such SPA into their existing processing chain or the IPOPP.

Prior to the release of an SPA, a rigorous validation process is undergone to ensure that the output product is scientifically valid and comparable to the equivalent institutional global algorithm product. This process, an example of which is described in Figure 3, ensures that science quality is maintained and forms a reference for any enhancements undertaken by the end user.

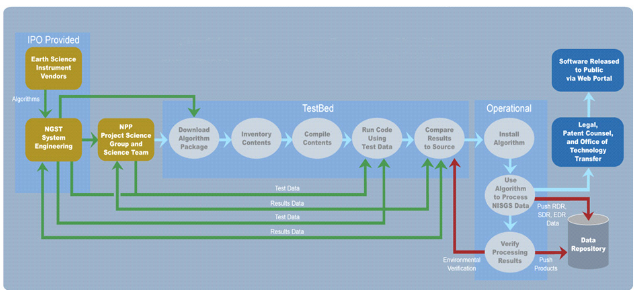

Figure 3 SPA Product Validation Process

Modifications to an SPA by direct readout users to suit local conditions and environmental variability is on the rise. Local users possess significant leverage on the utility of an SPA based on local access to in-situ data. Enhancements and/or changes to the SPA can come in the form adjustments to the input calibration tables at the Science Data Record (SDR or Level 1) level and/or the provision of finer resolution ancillary data sets. Additional types of modifications include data-type filters, such as local information on soil and vegetation type that requires reflectance adjustment or measurement exclusion. Regardless of the changes made, direct readout data users rely on the “reference” global product generated by the original SPA and/or by the corresponding NASA-DAAC provided product to ensure product quality continuity.

In the direct readout community regional products can be different when compared to the” reference” global product. In these cases a trade-off is made initially between the algorithm reduction in science quality and availability of the algorithm. An example of this is depicted in the Normalized Difference Vegetation Index (NDVI) product in Figure 4.

The reference global NDVI product is a 16-day composite product where the BRDF artifacts are reduced by the compositing process. In the SPA form, NDVI does not afford this process and generates a product every orbital pass. Nevertheless, these examples are few, and all direct readout users equipped with this information have made enhancements to the SPA to better suit their near-real-time needs.

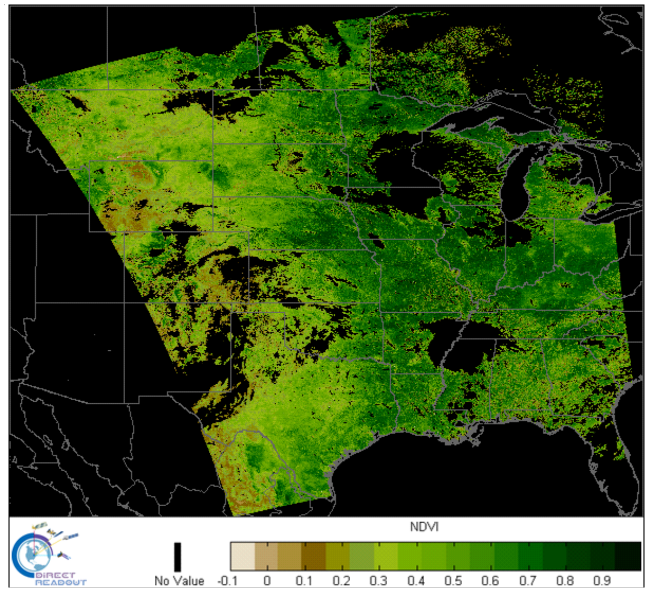

Figure 4 Direct Readout Normalized Difference Vegetation Index (NDVI)

4. Hazards Management and Mitigation

Environmental monitoring using DB from polar-orbiting satellites has become common place world-wide. There is an element of time criticality that is inherent in DB; It has shown to save lives and property by providing meteorological agencies with improved warnings of severe weather, especially tropical cyclones. The use of DB data in hazards monitoring and mitigation has legacy with the MODIS instrument which has been designed to extend the environmental observing capabilities of the Advanced Very High Resolution Radiometer (AVHRR) on NOAA operational satellites.

Over the last decade science algorithms have been playing an increasing role in real-time applications such as in hazards monitoring, man-made or other. From Figure 5,6 and 7 one can see the obvious uses of the DB MODIS instrument data which are enhancement to existing SPAs. Additional utility has been given to these products by augmenting the image product with information layers and encompassing them in an image transport mechanism as described in the next section. Direct readout users have also made use of individual spectral MODIS bands to generate their own products such as depicted in Figure 6 with the sand storm tracking.

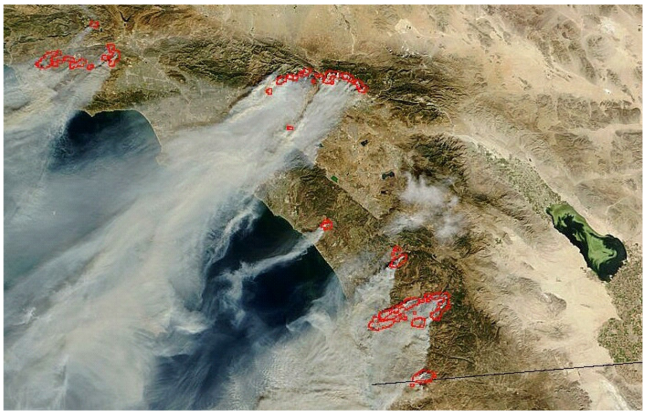

Figure 5 Fire Mapping with Hot Spots Overlay

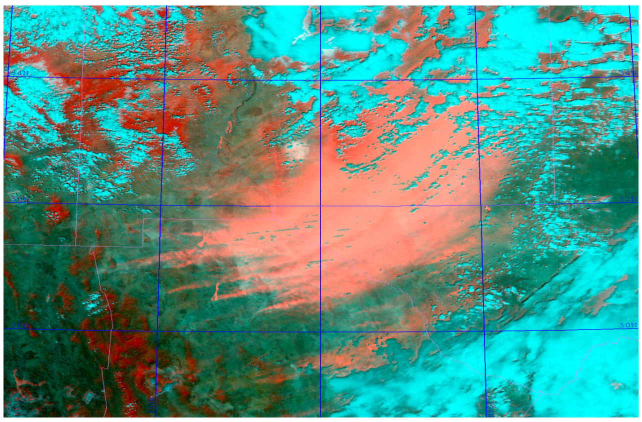

Figure 6 Sand Storm tracking

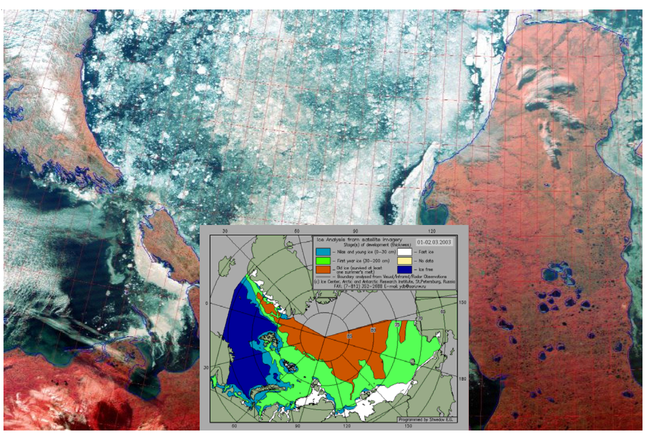

Figure 7   Sea Ice Monitoring on Shipping Lanes

5. Product Transport Mechanism

Most real-time applications make use of a geographic information system (GIS) that brings together various pieces of information and presents them in a way that allows for the user to accurately gauge environmental impact. These assessments are critical in the decision-making process. In this process, product transport mechanism must become ubiquitous if they are to be depended upon. The EOS missions have produced tremendous amount of data in HDF-EOS format, which unfortunately cannot be imported in a useful, semi-autonomous manner into most contemporary GIS systems. This has resulted in an alienation of the GIS community from the EOS community. However GIS remains one of the most important tools for analyzing NASA's EOS data and promoting real-time applications. GeoTIFF is one of the GIS-ingestible formats and therefore the ability to produce GeoTIFF from HDF-EOS, and eventually HDF-5, will greatly enhance the interoperability and public use of EOS/NPOESS data. The availability of GIS-ready products will significantly increase the accessibility, interoperability, and inter-use of such data; it will improve the data analysis and visualization, promote the use of EOS data not only in the global change research but also in the public who is concerned with issues such as environment and resource management, education, and community planning.

A primary step in making this happen is to enrich the GeoTIFF format with the necessary metadata. Geospatial metadata have been recognized for playing four roles: (i) Availability: metadata needed to determine the sets of data that exist for a geographic location. (ii) Fitness for use: metadata needed to understand how the data was acquired and processed (lineage) to determine if a set of data meets a specific need (iii) Access: metadata needed to acquire an identified set of data and (iv) Transfer: Metadata needed to process and use a set of data. Apart from these four obvious uses metadata can be an important component in triggering future research and development by means of a feedback mechanism. As users analyze the lineage metadata associated with a dataset, they may identify processes that may have degraded the data quality and discover alternate techniques that could potentially improve the data quality and make it suitable for a particular application.

As a prime example of metadata enhancement is the incorporation of standard color tables within the GeoTIFF format. Such tables would be helpful in promoting uniformity in visualizations of a particular Geophysical parameter. Over the years researchers have associated each EOS product with a colormap that best represents the parameter described in the product. The colormap used for the NDVI product, for example, is thus different from the colormap used for the ocean color product, which typically uses a log scale colormap. This implies that it would be beneficial for the user community if the standard colormap is encoded within the EOS GeoTIFF product. This would ensure that the user has access to the standard colorscale used for the product. The user however will have the flexibility to change the color scale within the GIS platform for further analysis. When producing EOS GeoTIFF products we must ensure that the encoded colormap is the standard colormap representative of the geophysical parameter. Geolocation and quality flag information would also form part of this ubiquitous product transport mechanism, and it validation would go through the same science validation process as described above and in figure 3.

6. Near-Real-Time Forecasting

Forecasting using direct broadcast data has been on the rise over the last 2 years. Many of the impediments to using DB data in forecast models include inadequate and reliable access to instrument data over forecast regions, initial condition data incompatibility, and availability of data format conversion tools. This situation has been compounded by the fact that most forecasting organizations have viewed NASA's EOS program as research satellites vs. operational ones. This has provided little political leverage to invest in the integration of this ubiquitous data into DoD and national meso-scale weather, ocean current and aviation models.

Despite these hurtles, many organizations are paving the road to using DB data in forecasting. The University of Wisconsin with their CIMSS Regional Assimilation System (CRAS) is generating 72 hr atmospheric product forecasts such as, rain rates as seen in Figure 8, surface winds, perceptible water, etc, at several atmospheric pressures.

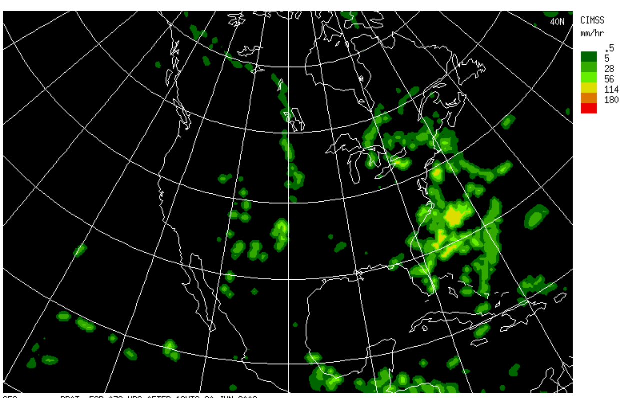

Figure 8 CRAS 72 hr Rain Rate Forecast

The US National Weather Service is using MODIS and AMSR-E Level-1 DB imagery through NASA's Short-Term Prediction Research and Transition Program (SPORT) in support of forecast validation and nowcasting. In other disciplines many nations are using polar-orbiting DB data for fish location and inventory forecasting, mosquito population and Malaria potential, flood prediction and typhoon track predictions.

The ultimate goal of the direct broadcast data user is to arrive at an understanding of its regional environment dynamics and derive information for decision support. Therefore the extent of DB's utility is directly proportional to the ability of the user to provide the derived information to a decision-making infrastructure; whether it be a large farmer assessing a fungal infestation or the federal government assessing damage extent of a tornado. Both require a mechanism or path for real-time DB products to reach appropriate decision-making bodies.

Summary

The ultimate goal of the direct broadcast data user is to arrive at an understanding of its regional environment dynamics and derive information for decision support. Therefore the extent of DB's utility is directly proportional to the ability of the user to provide the derived information to a decision-making infrastructure; whether it be a large farmer assessing a fungal infestation or the federal government assessing damage extent of a tornado. Both require a mechanism or path for real-time DB products to reach appropriate decision-making bodies.

It has been said that the use of DR will slowly fade away with the advent of high bandwidth network access. This statement taken in a vacuum may logically seem accurate, but the reality is that there are many other factors contributing to the decision by the end user to invest resources into having their own DR system. Increase in network bandwidth and reduced access costs will nevertheless affect the way direct readout users utilize direct broadcast data and derived products.

It is the authors belief that DB will never go away for the simple fact that DB has proven to be an indispensable backup to the primary store and forward method of obtaining high resolution global data. Because of the innate and built –in robustness of the DB system design on-board the spacecraft, DB data has been used as a gap filler when satellite data relays fail and access to near-real-time global data is delayed due to data processing backlogs. This last scenario can be argued by the fact that computational systems and network bandwidths will increase, but data volumes are commensurate with computational power. In other words, we're barely keeping up. And when considering expected data volumes and computational processing requirements for the next 20 years, the rate of increase will not be decreasing.

With the on-set of the National Polar Orbiting Earth Satellite System (NPOESS), a comprehensive, all-be-it not new, method of acquiring, processing and distributing near-real-time data products will be established. This concept will also be mirrored by many additional profit and non-profit organizations which will take advantage of real-time raw data access to generate and distribute near-real-time value added products. This "new" concept, fueled by increase in network bandwidth and global access, is fundamentally a regression to the centralized, large data processing system's model with a new distribution twist, which includes broadcasting of data products, of much lower volume, to the end user via ubiquitous communication and transport methods.

References

Coronado, P. and K.Brentzel. 2006. NASA Direct Readout for Its Polar Orbiting Satellites. In *Earth Science Satellite Remote Sensing Vol. 2: Data, Computational Processing, and Tools*, edited by J. Qu, W. Gao, M. Kafatos, R. Murphy, and V. Salomonson, 52-76. Beijing: Tsinghua University Press.