THE RESOURCE21 SCIENCE ADVISORY BOARD: RECOMMENDATIONS FOR A GLOBAL OBSERVATORY TO CONTINUE THE LANDSAT MISSION HERITAGE

Samuel N. Goward, Professor
Department of Geography
University of Maryland
College Park, MD 20742
sg21@umail.umd.edu

Alexander F. H. Goetz, Professor
Department of Geological Sciences
University of Colorado
2200 Colorado Ave.
Boulder, CO 80309-0399
goetz@cses.colorado.edu

John R. Schott, Professor
Rochester Institute of Technology
Chester F. Carlson Center for Imaging Science
54 Lomb Memorial Drive
Rochester, NY 14623-5604
schott@cis.rit.edu

Kurtis J. Thome, Associate Professor
University of Arizona
Optical Sciences Center
Meinel Building
1630 East University Boulevard
Tucson, Arizona 85721
Kurt.thome@opt-sci.arizona.edu

John J. R. Townshend, Professor and Chair
Department of Geography
University of Maryland
College Park, MD 20742
jt59@umail.umd.edu

Susan L. Ustin, Professor
Department of Air, Water and Land Resources
University of California
Davis, CA 95616
slustin@ucdavis.edu

Curtis E. Woodcock, Professor
Department of Geography
675 Commonwealth Avenue
Boston University
Boston, Ma 02215
curtis@bu.edu

Tom Koger, Director of Government Markets
RESOURCE21, LLC
Building 1103
Stennis Space Center, MS 39529
tkoger@resource21.com

Jay Pearlman, Chief Scientist
Robert W. Turner, Chief Engineer of Sensors
RESOURCE21 Project
The Boeing Company
Seattle, Washington 96124
jay.s.pearlman@boeing.com
robert.w.turner@boeing.com

ABSTRACT

RESOURCE21, LLC (R21) is exploring the use of the Landsat mission heritage to develop commercial applications for satellite-derived remote sensing information. They also believe that the technology they will deploy to meet their commercial goals will meet or exceed the requirements put forward by NASA and the US Geological Survey to accomplish the next-generation Landsat Data Continuity Mission (LDCM). Recently, R21 was awarded a contract to pursue formulation phase activities for the LDCM.

To assess the scientific quality of the proposed R21 approach, company representatives contracted several US land remote sensing research scientists to consider how the needs of scientific research will be best met with a next-generation Landsat-type observatory. This panel evaluated these science and application needs relative to Landsat continuity goals, and provided recommendations concerning refinements that enhance both science and applications goals of the LDCM observatory. This paper reviews the recommendations made by the RESOURCE21 Science Advisory Board within the context of both Landsat mission heritage and potential science and applications goals.

INTRODUCTION

Recently the Landsat mission observed a 30th anniversary, a remarkable success story, most recently advanced with the stunning success of the Landsat- 7 mission (Freden & Gorden, 1983; Goward & Masek, 2001). Following congressional guidance, continuation of the Landsat mission beyond Landsat-7, will be accomplished by purchasing the needed observations from the US commercial sector. Pursuit of follow-on Landsat observations is now underway under the Landsat Data Continuity Mission (LDCM, a.k.a. Landsat-8) program. The approach taken to pursue the LDCM mission is that a team of government engineers and scientists defined a detailed set of data specifications that any bidder will need to meet in order to be a successful supplier of the LDCM data (http://ldcm.usgs.gov/).

A series of workshops were held in 2001, as a pre-cursor to development and release for a request for proposals to pursue an LDCM data purchase from the commercial sector. The first workshop in particular, held at USGS Headquarters (January 9th & 10th), brought together representatives of the US government, US private industry and the US science community. Several representatives of the then-active NASA-sponsored Landsat Science Team, including several authors of this paper, participated in these discussions. At one point, at least a few of us suggested that a better dialogue between the US science community and US private industry was warranted, particularly with those vendors who thought that they might be able to commercially exploit the Landsat mission heritage concept. Thus began the dialogue between RESOURCE21 and representatives of the US science community, under the guidance of Dr. Goward. At the end of this 1st LDCM Workshop, we concluded that we would seek to define an acceptable forum in which to discuss possible approaches to LDCM.

THE RESOURCE21 SCIENCE ADVISORY BOARD

Initial discussions between Goward, Koger, Turner and Pearlman (TRW at that time), led to the conclusion that a small group of US scientists, who are not government employees, would be convened to discuss the LDCM mission and its implementation with R21 representatives. A consultancy context was developed for these discussions, with the proviso that all of the reports and memos produced by the SAB during their deliberations would be available, without restriction to NASA/USGS representatives and members of the science community for review and discussion. The SAB members believe that such an open dialogue is the only way that the advice they provide has any credibility within the open review context of the international scientific community.

Prior to the release of the LDCM RFP, the R21 SAB met twice in the spring 2001 (April and June) to discuss the draft LDCM Data Specifications (LDCM Draft Specs, 04/05/01). The Board membership during this pre-RFP Phase was as noted in Table 1. Dr. Jensen, prior to attending the April meeting, decided he was seriously over-committed and withdrew from the board. He did, however, supply substantial writing that contributed to the completion of the April meeting report (Goward et al., 2001a). Thus, for the June 2001 meeting, the SAB was reduced to 6 members (Goward et al., 2001b).

Following R21's selection to pursue the Formulation Phase of the LDCM program, R21 staff requested that Dr. Goward reconvene the SAB to assist them during this phase of the LDCM procurement. The re-convened board membership is noted in Table 2. This board met in June and July 2002.

Table 1
Pre-proposal Phase R21 SAB Members
March – December 2001

NAME	INSTITUTION	BACKGROUND
Alex Goetz	U. Colorado	HIRIS, Landsat
Samuel Goward	U. Maryland	Landsat, AVHRR
John Jensen	U. South Carolina	Applications
John Schott	Rochester Inst. Technology	Landsat, Industry, Thermal
Kurt Thome	U. Arizona	Optical Sensor Cal.
John Townshend	U. Maryland	MODIS, Landsat Pathfinder
Susan Ustin	U.C. Davis	HIRIS, AVIRIS, EOS Science

Table 2
Formulation Phase SAB Members
May – December 2002

NAME	INSTITUTION	BACKGROUND
Alex Goetz	U. Colorado	HIRIS, Landsat
Samuel Goward	U. Maryland	Landsat, AVHRR
John Schott	Rochester Inst. Technology	Landsat, Industry, Thermal
Kurt Thome	U. Arizona	Optical Sensor Cal.
John Townshend	U. Maryland	MODIS, AVHRR
Susan Ustin	U.C. Davis	HIRIS, AVIRIS
Curtis Woodcock	Boston U.	Landsat, MODIS

LDCM SCIENCE DELIBERATIONS

During both phases of the R21 SAB deliberations, specific topics of mutual interest to RESOURCE21 and the SAB members were identified for assessment and review (Table 3). The SAB membership attempted as much as possible to represent the best interests of the science communities of which they are members.

It is important to note that most of the SAB members have served and/or continue to serve on NASA EOS instrument and science teams, including Landsat 7, MODIS, ASTER and others. One of the primary goals for the Earth Observing System is to achieve global scale assessments of the Earth's environmental systems to assist in understanding how the Earth may change over the next few decades to century. Experiences in working with the observation systems have clearly demonstrated the importance of achieving global measurements in which the external or mitigating factors are minimized and therefore the measurements sought are maximized and easily processed with large-volume, automated procedures. Essentially all of the conclusions reached by the R21 SAB membership reflect the view that only with large area to global scale analyses of these Landsat-class measurements will we truly begin to understand the dynamics of the Earth's terrestrial environment.

Table 3
LDCM Topics Reviewed By R21 SAB

TOPIC	MEETINGS
LDCM Spectral Band Configuration	April 01, June01, June-July 02
Calibration	April 01, June 01, June 02, July 02
Atmospheric Attenuation	April 01, June 01, June 02, July 02
Registration & Geo-location	June-July 02
Long-Term Acquisition Approach	June 01
Post-Acquisition Cloud Detection	June-July 02
30m Data Production	June 01, June 02 - July 02
Data Archive and Distribution	June 01

LDCM Spectral Band Configuration

Pre-Proposal Deliberations. This topic consumed much of the time committed to the meetings in 2001 and a good part of the 2002 meetings. The LDCM spectral configuration proposed in the draft LDCM specifications, released first in November 2000 and revised in April 2001, differed from that used in the previous Thematic Mapper-type instruments orbited, since 1982 on Landsats 4, 5, and 7. [1] (Table 4). In particular a new blue band was added (443 nm), the near infrared was first split into two bands, to avoid water vapor absorption, a new SWIR band was added (1250 nm), the high spatial resolution pan band was narrowed and the thermal infrared deleted. In the revision 1 draft specs, the NIR was reduced to a single band. Thermal infrared measurements, cirrus cloud measurements and water vapor measurements were added as optional bands.

[1] Landsat 6 was lost during launch in 1993

Table 4
Comparison of Spectral Configuration
For Landsat 7 with LDCM Original (11/00) and Rev. 1 (4/01) Draft Data Specifications

Landsat-7	LDCM Draft Original (11/2000)	LDCM Draft Rev. 1 (4/5/2001)	Purpose
-	433 – 453	433 – 453	Coastal/Aerosols
450 – 520 nm	450 – 515	450 – 515	L7 heritage
530 – 610 nm	525 – 600	515 – 600	L7 heritage
630 – 690 nm	630 – 700	630 – 700	L7 heritage
750 – 900 nm	775 – 805	-	Band split to avoid water vapor originally
	845 – 890	845 (TBR) – 890	
-	1200 – 1300	1200 – 1300	Vegetation Feature
1550 – 1750 nm	1550 – 1750	1550 – 1750	L7 heritage
2090 – 2350 nm	2080 – 2350	2080 – 2350	L7 heritage
590 – 900 nm	500 – 700	500 – 700	15 m Pan Band
10400 – 12500 nm	-	*10400 – 12500*	L7 Thermal
		1360 – 1390	MODIS Cirrus Optional
		910 – 970	MODIS Water Vapor Optional

The SAB evaluated both sets of draft spectral band configurations in their deliberations conducted in April and June 2001. Their conclusions from these meetings are noted in Table 5.

Table 5
RESOURCE21 Science Advisory Board April 2001
LDCM Spectral Configuration Recommendations

#	Band	R21 SAB April 01 Recommendations	Science Priority	Use
1	**Dark Blue**	**433 – 453**	**3**	**Scattering/Coastal**
2	**Blue**	**450 – 515**	**1**	**Pigments/Scatter/Coastal**
3	**Green**	***525*[a] – 600**	**1**	**Pigments/Coastal**
4	**Red**	**630 – *680***	**1**	**Pigments/Coastal**
5	**NIR**	**845 – *880***	**1**	**Foliage/Coastal**
6	**SWIR 1**	**1200[b] – 1300[b]**	**4**	**Experimental**
7	**SWIR 2**	***1560 – 1660***	**1**	**Foliage**
8	**SWIR 3**	***2100 – 2300***	**1**	**Minerals/Litter/No Scatter**
		or 2020[c] – 2150[c]		
9	**Sharpening**	***630 - 680***	**3.5**	**Edges/Low Science Value**
10	**Thermal**	**10400[d] – 12500[d]**	**2.5**	**Clouds/land cover/fluxes Technical Problem**
		10400 – 11500 & 11500 – 12500		
11	**Cirrus**	**1360 – 1390**	**1**	**Cirrus Clouds**
12	**Water Vapor**	**910 – 970**	**4**	**Not Needed**

Essential, Secondary, Not Needed, *Italic s – Differs from LDCM Specs*

a. Typographical error in V1 LDCM spec. 525 nm is original Landsat ETM+ spec
b. SWIR1 spectral band pass not revised because it is not recommended for inclusion. If included it should be further reviewed.
c. The SAB is reconsidering this region based on technical constraints posed by R21 staff. The shift to the 2020 nm to 2150 nm is to use alternate detector material. Our analysis suggests that this is not desirable.
d. TIR spectral band pass not reviewed by R21 SAB. Should be considered further.

Overall the SAB believed that the direction pursued by the LDCM project staff is correct but conservative. Changing from a "whiskbroom" to a "pushbroom" sensor design substantially increased the signal to noise performance of the sensor. It is thus possible to narrow the spectral band passes to better define the spectral ground features sought, as well as to avoid unwanted variations introduced by the atmosphere, specifically absorption by water vapor and other gases. The SAB therefore recommended decreasing the upper band limit of the red band, to avoid red-edge contamination and recommended changing the band pass limits for the NIR, SWIR2 and SWIR3 to avoid, as much as possible, water vapor contamination. In addition, an error was noted in the lower limit of the green band pass in the draft data specification.

The R21 SAB membership also discussed and voted on the scientific value of each of the spectral bands presented in the draft data specifications. In the voting each member was asked to evaluate each band with a ranking of 1 for essential and 5 for minimal importance. Concurrence was high with all members agreeing that the basic original Landsat 7 band centers are of critical importance to continue mission success. They further noted that the addition of a spectral band to detect cirrus cloud presence is also vitally important.

The SAB membership considers the new dark blue band and continuation of the thermal infrared of secondary importance but potentially high importance. The primary reason these bands are not given as high a priority is because of weak evidence in the contemporary research literature of their value. There was considerable discussion of the Landsat thermal observations and their importance for terrestrial research. There is a strongly held view that only with Landsat-7 do we have the quality of TIR measurements to demonstrate their contributions to science and applications. Loss of the TIR measurements at this time would be unfortunate. The discussion of the "new" proposed blue band was equally difficult. Based on our understanding, such a two blue band system might well aid in aerosols assessments over land as well as permit coastal waters assessments. These are critically important issues for the utility and use of Landsat-class measurements. From the science community view it would therefore be valuable to include this band in the mission. It was also noted that the NASA EO-1 ALI (Advanced Land Imager) has collected substantial examples of the two blue band observations, which may provide a good empirical means to evaluate this possibility.

Finally, the SAB members concurred that the new SWIR (1250 nm) band is of uncertain scientific value today and therefore not appropriate for inclusion on LDCM. Also, because the SAB had made strong recommendations to avoid water vapor contamination on all of the mission-critical bands, they viewed the proposed water vapor band (940 nm) planned for correcting LDCM data for water vapor absorption in other bands redundant and not needed. Further, the SAB membership does not view the "panchromatic" 15m band of substantial scientific value. They believe that this use of focal plane space and data telemetry bandwidth would be better applied to other purposes (e.g. cirrus and aerosols). They recognize that members of the more applied communities would probably differ in this view.

Overall the SAB members came to the conclusion that the LDCM spectral configuration should, as much as possible, address issues of atmospheric contamination, such as cirrus clouds, aerosols and variable water vapor absorption that seriously hinder larger area, multi-scene analyses of Landsat measurements today. The final R21 SAB recommendations strongly reflect this perspective. The spectral band pass characteristics of the RFP 11/01 LDCM data specifications (Table 6), in concur with the consensus perspective that evolved in the R21 SAB discussions.

Table 6

LDCM Request for Proposals (RFP) Spectral Data Configuration*

#	Band	RFP Data Specs	Use
1	*"New" Blue*	*433 – 453*	*Aerosol/Coastal*
2	**Blue**	**450 – 515**	**Pigments/Scatter/Coastal**
3	**Green**	**525 – 600**	**Pigments/Coastal**
4	**Red**	**630 – 680**	**Pigments/Coastal**
5	**NIR**	**845 – 885**	**Foliage/Coastal**
6	**SWIR 2****	**1560 – 1660**	**Foliage**
7	**SWIR 3**	**2100 – 2300**	**Minerals/Litter/No Scatter**
8	**Sharpening*****	**500 – 680**	**Edges/Low Science Value**
9	*Cirrus*	*1360 – 1390*	*Cirrus Clouds*
10	*Thermal 1*	*10300 – 11300*	*Clouds/land cover/fluxes*
11	*Thermal 2*	*11500 – 12500*	*Not Needed*

** Italics note optional bands that will be studied by selected vendors during the LDCM Formulation Phase. ** Minimum bandwidth is 180 nm for band 7. *** The band may be panchromatic with a center wavelength as specified and a bandwidth of at least 160 nm or a red band with band 4 specification*

Formulation Phase Deliberations. We further reviewed the optional LDCM bands – "new' blue, cirrus and thermal infrared – during our LDCM Formulation Phase meetings in June and July 2002. We once again reaffirmed the conclusions that we had reached in 2001 with the one exception that we now place the "new" blue band priority slightly higher than that of the thermal infrared observations. Our order of priority on the optional bands stemming from these meetings is: 1) cirrus, 2) "new" blue and 3) thermal infrared. A further spectral question also was raised concerning cirrus detection, specifically whether a band centered at 1880 nm would be better than the MODIS 1380 nm specification.

Our specific conclusions on the optional bands are as follows:

a. **Cirrus:** Our recent experiences with satellite observations, particularly with MODIS and some of the newer sensors, is that cirrus cloud contamination is a significant global problem. Estimates from MODIS suggest at least 50% contamination is the mid-latitudes and humid tropics, with >30% elsewhere. This suggests cirrus identification and adjustment for is likely to be critically important for successful use of LDCM observations, particularly at high temporal frequencies. Preliminary analysis by SAB member A. Goetz indicates that the use of 1.38um or 1.88um spectral band passes in nearly an even tradeoff in capability.

b. **"New" Blue (443 nm):** Although this spectral band has been used in instruments such as Seawifs and MODIS, for ocean color work, little definitive scientific evidence exists now to demonstrate the value of this band in Landsat-class instruments for characterizing coastal waters or aerosols over land. However, everything we understand about remote sensing physics suggests that a substantial potential may exist.
   Aerosols contamination is one of the major un-answered terrestrial remote sensing problems. Our inability to characterize aerosols in observed scenes severely hinders derivation of at-surface spectral reflectance, which is essential if fully automated change detection methods are to be successfully implemented. We also believe that the potential of such a sensor system (with 2 blue bands) to support coastal and inland waters water pollution analysis could be substantial.
   Thus from the SAB perspective it would be worth taking the risk in adding this band because of the potential substantial advances that might be accomplished with such a sensor. We however also appreciate that with the ALI sensor design, adding additional bands increases the band-to-band displacement with topography problem.

c. **Thermal Infrared:** The SAB believes that the TIR portion of the spectrum is one of the four primary portions (visible, near infrared, shortwave infrared, thermal infrared) of the optical electromagnetic spectrum for land observations. TIR measurements substantially aid in analysis of land surface features and conditions.
   We believe that loss of TIR on LDCM is significant and may lead to a permanent loss of TIR on Landsat-class observatories, once it is deleted. Our perception is that the TIR sensor solid-state technology is currently not as mature as for Vis/NIR/SWIR and therefore is not ready for LDCM at the moment. However, it appears that micro-bolometer technology is improving to a level that it can fill this gap. The LDCM mission may be an important opportunity to test this technology. Loss of this technology couls also substantially impact post-acquisition cloud identification as well.

Calibration/Validation

The SAB recommends continuation of radiometric standards established with the Landsat 7 mission. Some of our most significant concerns relate to cross-detector calibration for the linear arrays. Precision relative and absolute calibration of such sensor systems has not been fully achieved or perhaps even addressed to date. How this might be done in the LDCM mission could be a significant challenge.

The SAB members believe that achievement of calibrations goals rather than requirements should be pursued by R21. We are particularly concerned with the 0.25% detector-to-detector requirement, which we believe to be too conservative. This will most certainly produce residual striping in the imagery. We appreciate that pre-flight accomplishment of a better detector-to-detector result may be difficult if not impossible. However, this should easily be accomplished during post-flight checkout with a sideways “slither” maneuver, assuming that the spacecraft is sufficiently agile. Other approaches are possible but this is potentially the easiest and most successful approach to improve the detector-to-detector knowledge.

Atmospheric Attenuation

As noted earlier, the SAB views the problem atmospheric variability in Landsat-class measurements of the primary constraints to effective regional and global scale applications of the land observations. We have strongly recommended changes in the spectral band passes to avoid water vapor absorption, as well as to identify and adjust for the presence of thin cirrus clouds. We also believe that aerosols attenuation as one of the most important remaining science uncertainties in Landsat-type observations. A focused effort to address this problem should be undertaken as soon as possible. This further explains our mixed support for the “new’ blue band, which at least has the potential for aiding in resolution of aerosols uncertainty.

Registration & Geo-Location

We strongly support approaches that minimize science community geo-processing of acquired imagery. We currently consume substantial resources achieving this intermediate goal. We therefore recommend achieving the LDCM data specifications goals as much as possible.

Because the use of a pushbroom technology for LDCM substantially complicates the optical aspects of the sensor design, an excellent knowledge of the sensor’s camera will be critical to allowing accurate geolocation. The reason that this is the case is that the pushbroom approach under consideration will mean that each spectral band will view a different location on the ground at a given time, with the spacecraft motion allowing the spectral nature of a ground point to be measured. This spectral approach is similar to that used for ASTER and MISR. Characterization of such a system will be a significant undertaking in the preflight characterization of the sensor and will prove a difficult problem to verify in flight. However, this effort will be critical if LDCM is to achieve its geo-location requirements <u>Perhaps our greatest concern with an ALI-type instrument design is the significant displacement between spectral bands that occurs as terrain varies. Our ballpark estimate is that there will be nearly a 0.5 pixel displacement band-to-band for every 500m variation in elevation. This is a new problem vis-à-vis previous Landsat MSS and TM sensor.</u> If these terrain-induced spectral band mis-registration are not removed from LDCM data products they will create substantial dissatisfaction with the LDCM observations in the science and applications communities. Our current understanding is that either the sensor light gathering design needs to be changed or the observations will need to be processed with an “adequate” digital elevation model to remove this problem. From the SAB view the latter DEM approach is most desirable. This is because it implies that a level 1Gt data product would be first scientifically acceptable level of data product. Such a geographically registered data product should have always been the primary Landsat observation data set distributed for scientific and applications uses.

This is not our “father’s” Landsat mission. This ALI approach poses new and not well-understood challenges that have not been previously confronted by most of the earth science community.

Long-Term Acquisition Plan

One of the many substantial successes of the Landsat-7 mission was the use of an automated system to update the daily acquisition schedule for the mission (Arvidson et al., 2001). This scheme is directed toward acquiring a seasonally refreshed, sunlit and essentially cloud-free global coverage for the US-held archive operated by the US Geological Survey. The basis for this approach has been including LDCM data specifications, with an indication that the NASA/USGS LDCM team will supply periodic updates to the basic files, including seasonality and cloud climatology such that the LTAP will operate to “optimally” acquire the global coverage needed to meet science goals.

The R21 Science Advisory Board strongly supports the use of an LTAP system for LDCM. However, the SAB also recommends that the Landsat 7 LTAP approach be updated and advanced for LDCM. The basic concept of employing an automated mission operations strategy to merge mission operational constraints with the expectations and constraints of observing the Earth’s land areas is fundamental to mission success. However, the component elements of the Landsat 7 LTAP approach are fine-tuned to the characteristics of the Landsat 7 platform and the ETM+ instrument. Further, the base seasonality and cloud climatology files are based on early versions of data sets from the AVHRR sensor and the International Satellite Cloud Climatology Project (ISCCP), which have been considerably advanced since this information was compiled for Landsat 7 six years ago. There is also an LTAP validation activity currently underway that is revealing important changes and enhancements that should be included in the LDCM implementation. There will be a clear need during the LDCM implementation phase to fully revisit the LTAP approach and adapt it to the specific, anticipated characteristics of the LDCM.

Post-Acquisition Cloud Detection

The Landsat 7 mission innovated a cloud detection approach referred to as the Automated Cloud Cover Assessment (ACCA) for use in the long-term acquisition plan as well as in the metadata files at the EROS Data Center. In the LTAP it is used to evaluate whether a specific scene has been acquired well enough (substantially cloud-free) so that the observatory can be used in other locations. In the metadata this information informs interested users whether a particular scene is usable (along with a look at the meta-imagery). The Landsat-7 ACCA approach uses only within-scene spectral properties (e.g., no inputs beyond the image in question or NIBIQ) to identify clouds (but not shadows). The heritage for this approach can be found in AVHRR and MODIS. Following a similar NIBIQ approach but not having TIR observations to resolve the clouds for LDCM is a "to-be-proven" technology. There simply is too little experience, with the possible exception of the EOS MISR team, to know whether such an approach would work. Validation of a non-TIR NIBIQ approach requires convincing evidence in comparison with the existing ACCA approach. Current Landsat Project Science Office LTAP validation activities are pursuing a geographically stratified validation of the current ACCA. The 200 scene Landsat data set might well provide a suitable basis to assess a non-TIR NIBIQ approach that might be used for LDCM.

The alternative of using accumulated clear-sky observations from previous acquisitions offers considerable potential in this regard but does require the compilation of a data set suitable for this purpose. Given the current LDCM configuration, Landsat-7 observations could be used for this purpose. Current validation of the Landsat-7 ACCA approach, using a geographical/temporal observation set, to insure adequate analysis in all locations and times across the globe. A similar validation analysis will be required to provide confidence in an LDCM "non-TIR" approach.

Production of 30 m Data

Starting from acquired 10m observations, some process must be employed to compile the required 30m LDCM measurements. There are many alternate approaches that might be taken, such as sub-sampling and moving averages. However most of these approaches degrade or substantially alter the sensor-measured radiometer, versus starting with a 30m IFOV instrument.

The SAB recommends first that detector-based calibration is applied prior to any aggregation. This insures that any detector bias is removed, as much as possible, prior to 30m aggregations. The SAB then secondly recommends that a simple 30m-on-center aggregation approach be employed. That is, no filtering or running averages are employed. This optimizes the translation of the 10m radiometry to 30m. Any alternate approach will degrade the radiometry and reduce the scientific qualities of the observations.

This aggregation approach, by the way, implies that the Landsat-7 level 1R data product is actually no longer relevant. The first level of relevant data product is level 1G (also note the previous comment concerning band-to-band registration and the level 1Gt product).

Data Archive and Distribution

The R21 SAB strongly supports the original observation record being deposited and maintained by the USGS facility. In the opinion of the SAB, the broad science community would be most accepting of the EROS Data Center as the archival repository. To date the USGS EDC has been reasonably successful in maintaining the Landsat historical observation record. Their success in operating the Landsat 7 data record has been exceptional and we anticipate similar and more advanced capabilities with LDCM

One of the more controversial aspects of the previous Landsat commercialization effort was the copyright restriction placed on the observations. How this subject is addressed for the LDCM may be more important to its success than all of the technical specifications being considered. R21 is proposing that the 30m observations produced from their observations are made available without restrictions to any interested user. On the other hand they will maintain commercial restrictions on the 10m observations to protect the economic potential of these measurements. They do propose a range of differing license arrangements for the 10m observations that would be negotiated with specific customers. The R21 SAB concurs that such a distinction between the "public good" data set and the commercial product meets the goals of the LDCM and the business goals of R21. One of the uncertainties is the disposition of the 10m observations archive over time. Does the long-term, 10m archive eventually revert to the public domain? If so, over what time period?

Other Topics

During our deliberations we have at various times taken initial steps on other topics but without fully considering them. They include:

- LDCM Data Users Handbook: One of the important sources of Landsat information has been the Data Users Handbook. Although such a document is not required under the LDCM data specifications, it is likely to be vitally important in supporting the scientific utility of the measurements. Details concerning sensor and platform characteristics are examples of important information needed to support scientific analysis of the observations.
- Industry/Science Community Interactions: Prior experiences in the remote sensing community do not provide useful examples of how US private industry and US scientists can successfully interact. The alternative perspectives and expectations of these two communities typically make initial interactions quite difficult. However, we are beginning to gain sufficient experience, through the previous NASA Scientific Data Purchase and this current Science Advisory Board to understand that it can and should be possible. As the LDCM procurement process moves ahead, this question will need considerable further attention.

SUMMARY AND CONCLUSIONS

This experiment in US industry/Science community interactions has, to date, been quite successful, at least at the small scale (~15 people total) that it has operated thus far. Focused attention on the Landsat follow-on LDCM activities have given both parties a common ground within which they have explored possible ways of not simply meeting US government data specifications but going beyond the specifications to determine how to best take advantage of the sensor and platform technologies available in the 21st century.

One of the major R21 SAB contributions to LDCM has been careful and detailed consideration of the sensor configuration for this system. A substantial evolution in thinking about sensor goals and therefore sensor configuration has taken place during these discussions. We believe that the sensor spectral configuration now proposed for the LDCM is the type of Landsat-class observatory enhancement that would be expected for a mission following Landsat 7. Seeking a contemporary sensor that more successfully either avoids or characterizes variable atmospheric contamination should be, and is now, a major goal for this Landsat follow-on mission. We believe that this evolution reflects the maturity of the remote sensing science community some 25-30 years after the spectral configuration of the original Landsat Thematic Mapper instrument was developed.

We also believe that every effort should be made to design this sensor to support large-scale, mass-volume processing of these observations. We have for too long analyzed these measurements one scene at a time. In part, this is because it has been so difficult to merge multiple scenes. The future of Landsat-class measurements is in large area, continental to global-scale assessments of terrestrial dynamics, specifically under the influence of human activities. This can only be accomplished when the undesired variabilities in the measurements are minimized as much as possible. Radiometry, geometry, atmospheric variations, cloud contamination all have to be well understood and easily addressed with automated procedures. Designing such characteristic into an observatory from the start is a whole lot easier that trying to remove unknown effects after the observations have been collected.

Finally, we worry that there are many aspects of this new observation approach (both technically and administratively) that we have failed to clearly understand and therefore ask appropriate questions about. We sincerely hope that all the players involved will remain engaged and seek to find a common, mutually agreed upon resolution of these questions. It is ultimately only from this constructive and supportive perspective that we can hope to celebrate a successful 60th anniversary of the Landsat mission.

ACKNOWLEDGEMENTS

We would like to thank all members of the US and international Landsat user community for helping us out in our deliberations. The continued sharing of knowledge is what makes working on and with these observations such a pleasure. We hope that we have in some way represented your interests in this dialogue as well.

REFERENCES

Arvidson, T., Gasch, J., & Goward, S.N. (2001) Landsat 7's Long Term Acquisition Plan - An Innovative Approach to Building a Global Archive, Special Issue on Landsat 7. *Remote Sensing of Environment*, 78, 13-26.

Freden, S.C. & Gorden, F., Jr. (1983). Landsat Satellites. In *Manual of Remote Sensing* (ed R.N. Colwell), Vol. 1, pp. 517-570. American Society of Photogrammetry, Falls Church, Virginia.

Goward, S.N., Goetz, A., Jensen, J., Schott, J.R., Thome, K., Townshend, J., & Ustin, S.L. (2001a). *Review of the 4/5/01 Landsat Data Continuity Mission Specifications*. RESOURCE21 Science Advisory Board, 9/13/01.

Goward, S.N., Goetz, A., Schott, J.R., Thome, K., Townshend, J., & Ustin, S.L. (2001b). *June 5-6 Review of LDCM Implementation Issues*. RESOURCE21 Science Advisory Board, College Park, MD, 12/18/01.

Goward, S.N. & Masek, J. (2001) Landsat 7 Special Issue. *Remote Sensing of Environment*, 78, 1-325.