TerEDyn: A Smallsat Mission Concept to Enhance Global Temporal Repeat Coverage at 30 m Resolution

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Deputy PI: Darrel L. Williams, Ph.D., Global Science & Technology, Inc.

The TerEDyn mission concept is targeted at *augmenting — not replacing —* Landsat coverage with more frequent temporal repeat coverage at 30 m in TM bands 1 - 5. TerEDyn's global imaging strategy is to be "always on" when passing over land during daylight hours, thereby yielding an unprecedented combination of spatial and temporal resolution for monitoring land surface dynamics. If selected for funding support under a current NASA competition, TerEDyn data would be made available free of charge via standard user interface protocols at the USGS EROS Center.

Introduction

The **Terrestrial Ecosystem Dynamics** mission concept, **TerEDyn** (pronounced "terra+dine"), is an innovative multispectral Earth observation smallsat mission designed to augment Landsat by providing more frequent global temporal repeat coverage. **TerEDyn** is both low-risk and low-cost because it takes advantage of proven, high-heritage components in the instrument, spacecraft, and ground segments. **TerEDyn** is U.S. Patent Pending.

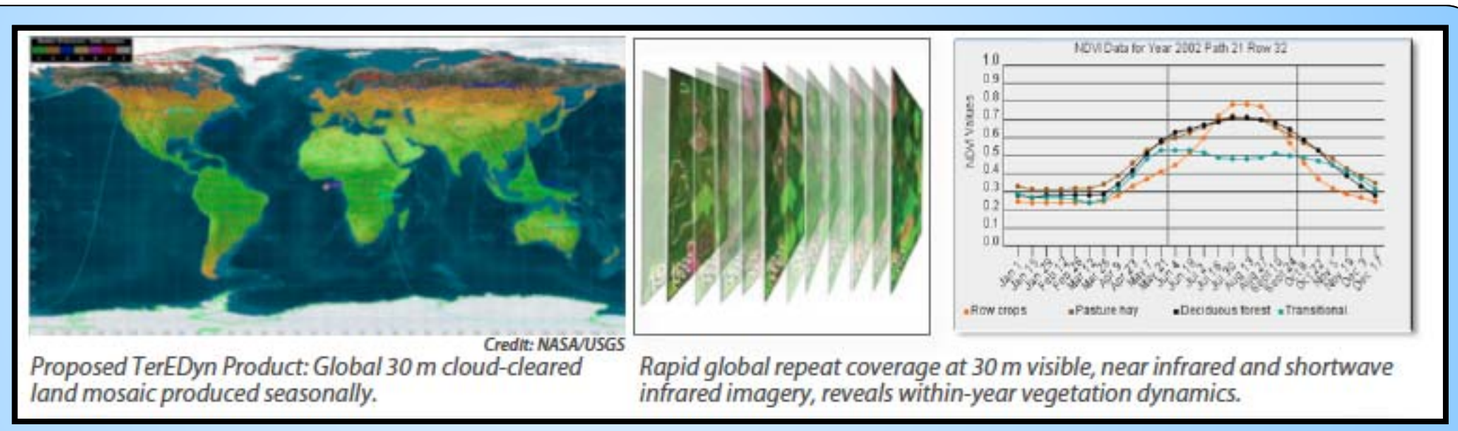
The TerEDyn Team

The people and organizations that comprise the **TerEDyn** team bring considerable past Earth observation experience to the project. The Principal Investigator (PI) is Dr. Samuel N. Goward, former Landsat 7 Science Team Leader. NASA Ames Research Center will provide project management oversight during the development phase and oversee mission operations once in orbit. NASA Ames is also responsible for accommodating the development of higher-level data products (see Figures 2 and 3) within their NASA Earth Exchange (NEX) computing facility. Global Science & Technology, Inc. (GST) Chief Scientist Dr. Darrel Williams, former NASA Landsat Project Scientist for ~20 years, spearheaded the development of the **TerEDyn** concept. GST has responsibility for managing the build of the integrated spacecraft and instrument by their team partner Surrey Satellite Technology US LLC (SST-US). USGS EROS Center will serve as the hub of the ground segment where TerEDyn data will be collected, processed, archived and distributed to the user community at no cost. The government of Australia has agreed to provide their Alice Springs ground receiving station capabilities, operated by Geoscience Australia, at no cost to the project in exchange for free access to data of Australia.

KEY TEREDYN ATTRIBUTES

TerEDyn combines the best attributes of the MODIS (frequent, global coverage) and Landsat (30 m resolution in TM bands 1 – 5, i.e., including SWIR) missions while serving as a demonstration/pathfinder mission that could lead to a constellation of low-cost observatories that would overcome the spatial limitations of MODIS and the temporal limitations of Landsat. **TerEDyn** is positioned in the land imaging trade space (i.e., spectral, spatial, radiometric, and temporal resolution) between the new Landsat Data Continuity Mission Operational Land Imager (OLI) and MODIS land measurements, and is aimed at achieving science goals that data from neither of these land observatories accomplishes even when combined in analyses. **TerEDyn** will fill a long recognized data gap by providing global sub-monthly cloud-cleared surface reflectance data sets at 30 m resolution (see Figures 2 and 3). TerEDyn's cloud-cleared data sets and higher-level products are expected to have tremendous utility for scientific, strategic, commercial and humanitarian applications such as providing the data needed to answer the question "How are terrestrial ecosystems changing as affected by human activities and natural events?"

Figure 1. More frequent coverage at 30 m will yield enhanced probability of generating cloud-cleared views, leading to better understanding of terrestrial ecosystem dynamics.



Proposed TerEDyn Product: Global 30 m cloud-cleared land mosaic produced seasonally.

Rapid global repeat coverage at 30 m visible, near infrared and shortwave infrared imagery, reveals within-year vegetation dynamics.

TEREDYN COST

There is another dimension of the satellite land imaging trade space that is rarely mentioned in scientific and user discussions, and that is the cost of the missions. **The total cost of the proposed TerEDyn mission is less than $150 million**, including launch and several years of on-orbit operations. **Subsequent clone copies of TerEDyn built under private industry best practices would cost less than half as much** and, therefore, would be within a cost range of affordability for both private industry and other nations. **A constellation consisting of a total five TerEDyn clones would yield global daily coverage at 30 m spatial resolution!**

"The TerEDyn concept is exciting because it addresses the critical issue of how to provide more frequent Earth observations at 30 m spatial resolution.... It has long been the opinion of many dedicated users of moderate resolution imagery that more frequent observations would be the most important way that the observations could be improved."

Excerpt from letter of support by D. James Baker, former NOAA Administrator, (1993-2001); current Director, Global Carbon Measurement Program, Clinton Foundation.

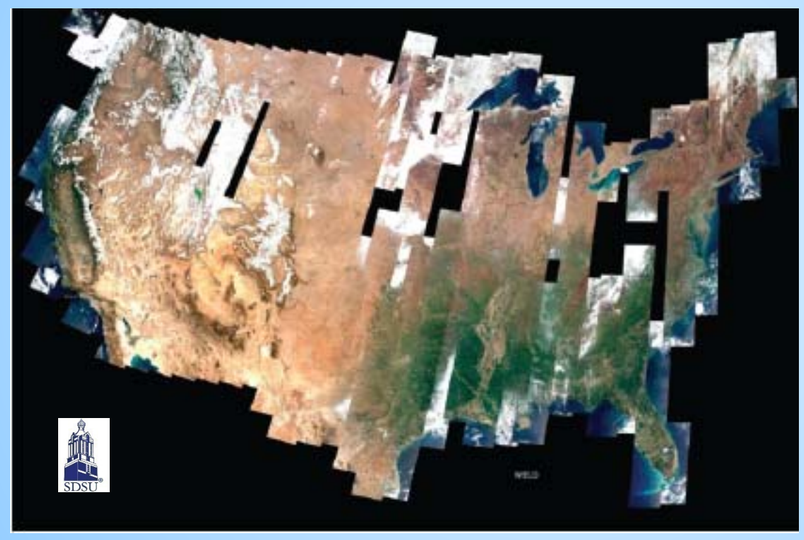
KEY TEREDYN DATA PRODUCTS

A key data product stemming from the **TerEDyn** mission will be the production of orthorectified, sub-monthly composited, cloud-cleared surface spectral reflectance measurements using the WELD (web-enabled Landsat data) approach developed recently by Dr. David Roy of South Dakota State University (SDSU). With its 390 km swath width imager, **TerEDyn** will acquire complete global land coverage on an 8-day repeat cycle at the equator. At mid-latitudes, this coverage improves to a 4 - 6 day repeat, while near-daily coverage is acquired in the high-latitude polar regions. Since the **TerEDyn** imager will be operated as "always on" over illuminated land, this robust imaging approach will result in the acquisition of 4x-5x the amount of daily imagery ever collected by any previous Landsat mission.

Figure 2 is an example of a WELD cloud-cleared monthly 30 m composite for July 2008 generated only using images acquired during Landsat 7's 16-day repeat cycle. **TerEDyn's more robust and more frequent repeat coverage is expected to yield mostly cloud-free monthly data sets as well as sub-monthly (bi-weekly) data sets that are predominantly cloud-free.** Sub-monthly composites of **TerEDyn** data will allow users to incorporate seasonal dynamics in land cover conditions at 30 m into their analyses using methods pioneered with seasonal data from coarser resolution sensors such as AVHRR and MODIS.

Figure 3 is an example of a global WELD cloud-cleared monthly 30 m composite for July 2010 based only on acquisitions stemming from Landsat 7's 16-day repeat cycle. The product was generated using ~6500 Landsat 7 scenes by implementing WELD processes within the NASA Ames NEX computing environment. The missing land areas are areas where cloud cover was greater than 40% and/or the data were missing from the USGS EROS archive. **TerEDyn's** robust "always on" image acquisition plan, coupled with its 390 km swath and 8-day repeat coverage, is expected to provide enough additional imagery to routinely fill in all of the blanks that exist in this example monthly global product.

Figure 2. Example of a cloud-cleared monthly 30 m composite product for the lower 48 states generated using only Landsat 7's 16-day repeat coverage.



WELD composite image product courtesy of Dr. David Roy of South Dakota State University.

TerEDyn will collect 4x – 5x as much data per month than Landsat; therefore, the expectation is that complete, nearly cloud-free monthly mosaics will be possible almost anywhere on Earth. Plans also call for generation of best available bi-weekly composites.

Figure 3. Example of a WELD cloud-cleared monthly 30 m global composite product generated using only Landsat 7 16-day repeat coverage.

Since TerEDyn will collect 4x–5x as much data per month as Landsat, the expectation is that more complete, nearly cloud-free monthly global mosaics will be possible. Plans also call for generation of best available bi-weekly composites on a continental/regional basis.

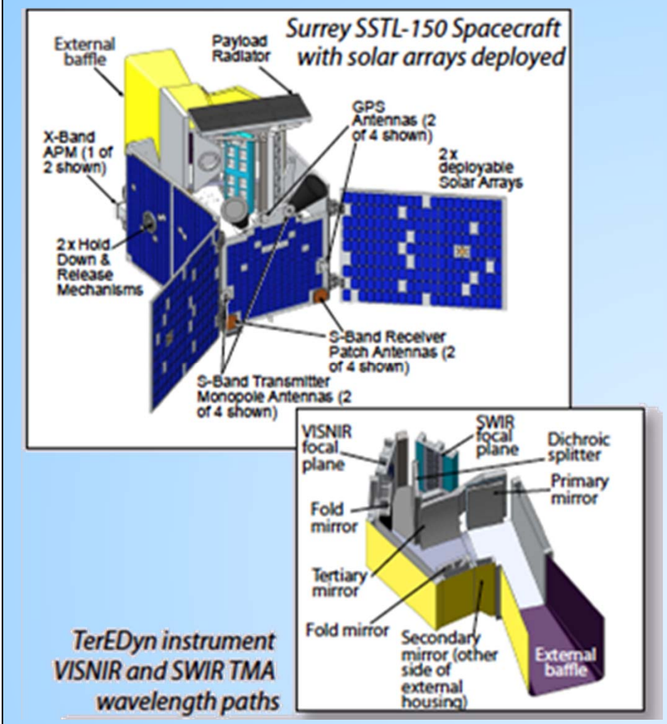
WELD composite image product courtesy of Dr. David Roy of South Dakota State University.

TerEDyn Science Underpinning

In addition to the PI, Dr. Samuel Goward, of the University of Maryland Department of Geographical Sciences, the **TerEDyn** Science Team consists of 14 individuals who are well experienced in the acquisition, calibration, processing, and analysis of moderate spatial resolution Earth observations. Many have served on the USGS-NASA Landsat Science Team and/or the prior NASA-funded Landsat 7 Science Team. **TerEDyn** also draws heavily from lessons learned via NASA's historical scientific oversight of Landsat missions, as well as experience with AVHRR, SeaWIFS and EOS Terra/Aqua MODIS instruments.

Name	Organization	Role & Subject Expertise
Samuel Goward	U. of Maryland	Principal Investigator / Science Products
Darrel Williams	Global Sci & Technology	Deputy PI / Calibration Oversight
Rama Nemani	NASA Ames Res Center	Project Scientist / NEX Oversight
Jennifer Dungan	NASA Ames Res Center	Assistant PI / Calibration and Validation
Jim Collatz	NASA Goddard Sp Flt Ctr	Science Products and NPP
John Dwyer	USGS EROS Center	Data (Pre) Processing / Sub-Group Leader / EROS Data Processing Oversight
Dennis Helder	South Dakota State U.	Calibration, Both Pre-Flight and On Orbit
Tom Loveland	USGS EROS Center	Annual Land Cover / Climate Data Record
Jeff Masek	NASA Goddard Sp Flt Ctr	Allocation Subgroup ldr / Forest Disturb/LEDAPS
Cynthia Rosenzweig	NASA GISS	Agricultural Productivity
David Roy	South Dakota State U.	Data Processing; WELD Products
John Schott	Rochester Inst of Tech	Calibration, Both Pre-Flight and On Orbit
Compton Tucker	NASA Goddard Sp Flt Ctr	Climate Data Record and Science Products
Tristan West	Joint Global Change Res Inst	Agricultural Productivity
Curtis Woodcock	Boston University	Primary Production Subgroup ldr / Land Cover

Figure 4. Drawings of the TerEDyn spacecraft and instrument concept are based on minor modifications to proven heritage solutions.



Major Mission Characteristics

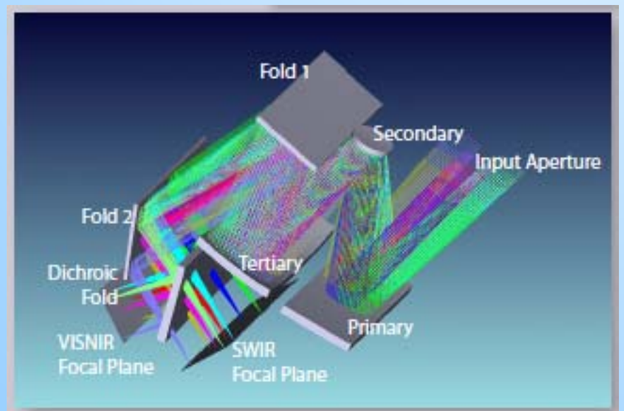
Launch Date	2015
Launch Vehicle	SpaceX Falcon-9
Mission Duration	2 yr
Orbit Type	Sun-Synch
Orbit Altitude	615 km
Spacecraft Bus	SSTL-150

Science Payload Key Facts

Mass (kg)	62.5 kg
Dimensions (mm)	425 x 425 x 342
IFOV	30 m @ 615 km in all bands
FOV	across track ~35 deg, along track 7.3 deg
Average SNR	>90:1 in all bands
Spectral Range	blue, green, red, NIR, SWIR
Band to Band Regist.	< .28 pixel
MTF	> 20% in every band
Data/day (Max uncompressed)	278 GB

Spacecraft Bus Characteristics

Bus and Instrument Launch Mass	250 kg
Solar Array Type	Triple-junction GaAs cells, total area 5 m^2
Array Power	199 W
Batteries	Li-ion cells providing 15 Ah capacity
Science Data Storage	144 GB, includes the HSDR and FMMU
Science Data Downlink	400 Mbps, X-Band
Telecommunications	S-Band uplink/downlink
Pointing Knowledge	10 arcsec
Pointing Accuracy	36 arcsec
Propulsion	Hot gas Xenon resistojet
Delta V	23.4 m/s



An enlarged ray tracing of wavelength paths is illustrated at left for the instrument shown above. Tabular summaries of key characteristics are shown above, right.

Information courtesy of Surrey Satellite Technology US LLC (SST-US).

TerEDyn Spacecraft And Instrument

TerEDyn is innovative in that it employs a streamlined, low-risk development approach featuring proven fixed price build processes for already proven instrument and spacecraft designs. Guided by GST Chief Scientist Darrel Williams (former Landsat Project Scientist), the commercial marketplace was reviewed in 2010 to identify already available high heritage platforms and sensors that might yield, with minimal modifications, significant Earth science breakthroughs. This resulted in the selection of our hardware provider Surrey Satellite Technology US LLC (SST-US), whose parent company, SSTL, has launched 36 spacecraft under firm-fixed-price contracts in the last 25 years, delivered on time and within budget, to address a mixture of Earth and space science objectives. Of these, 20 were Earth observing satellite missions and they have experienced a 100% mission success record over the past 11 years.

The performance of the Surrey-built imagers flying on the latest additions to the Disaster Monitoring Constellation (DMC) have been shown to be quite stable, trouble-free, and consistently calibrated to the Landsat 7 ETM+ imager to within 1% to 4%.

TerEDyn spacecraft and instrument characteristics are summarized in Figure 4 graphics and tables below.