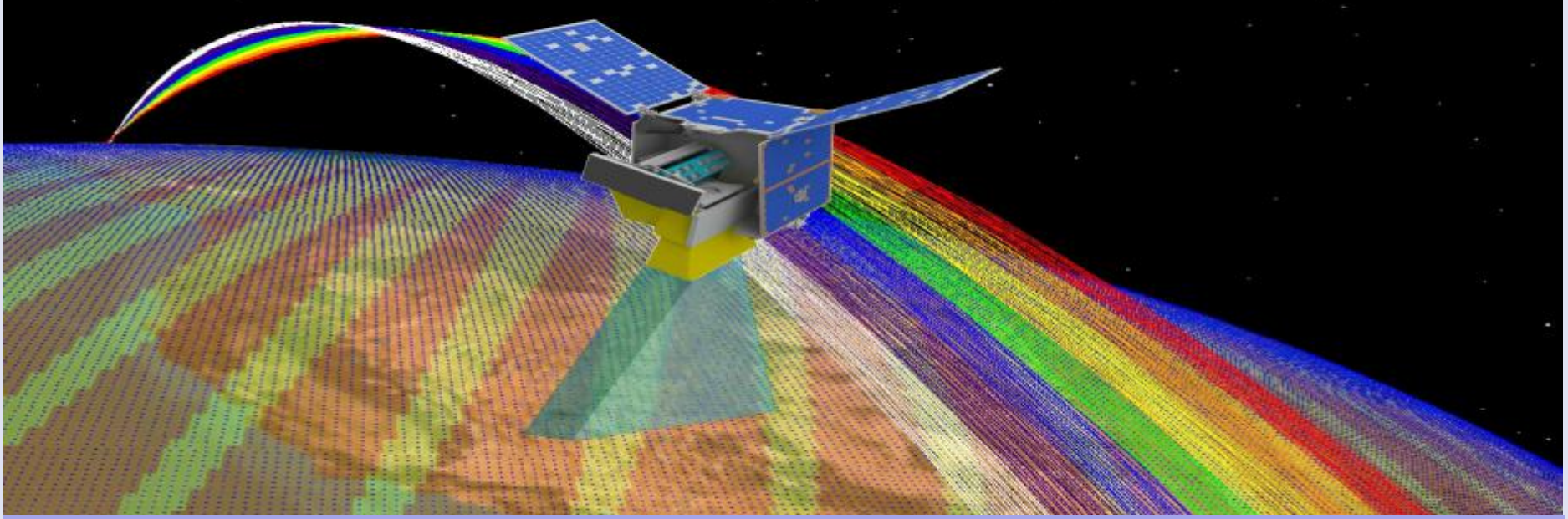
Global Science & Technology, Inc.

Partnering for Success

TerEDyn

The Terrestrial Ecosystem Dynamics Mission:
A Small Satellite Concept Offering an Unprecedented Combination of Spatial and Temporal Resolution to Augment Landsat Coverage



Dr. Darrel Williams, Global Science & Technology, Inc. (GST)

April 16, 2013

Presentation at "JACIE 2013"
Renaissance Grand Hotel
St. Louis, MO

Proprietary Information of Global Science & Technology, Inc.

Outline of Talk

- Why investigate capabilities of small satellite solutions?
- Sobering realization of the impact of cloud cover on acquiring sufficient Earth observations
  - especially when EO mission costs are approaching $1B per copy
- Chronology of events since mid-2010 when concept development was initiated
- Terrestrial Ecosystem Dynamics (TerEDyn) mission concept
- Summary

Why Investigate Smallsat Solutions?

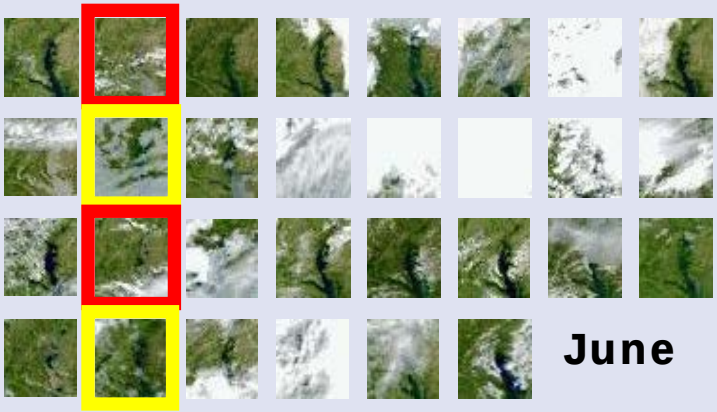
- **Spaceflight mission costs heavily driven by mass, volume & power**
- **Current economic environment is stressed nationally / globally**
- **Complexity & cost of Earth obs missions have risen dramatically**
  - LDCM cost ~$900 M; clone copy projected to cost ~$1.3B, take >5yrs to build
  - similar cost growth impacting other EO missions like IceSAT II, NOAA JPSS, etc.
  - **enhanced Landsat temporal repeat and ins. against data gap still needed**
- **April '10 SpaceNews, Sen. B. Mikulski, now Chair of the Senate Appropriations Committee "We need to see more Chevy-priced mission concepts, not just Cadillac-priced missions with uncapped cost growth"**
- **Technology evolution as demonstrated by smart phones, laptops, tablets needs to be embraced (smaller size, lower power demands, greater capability)**
  - smallsats offer pathway for quicker adoption of new technologies

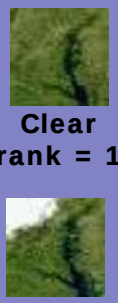
Rather Sobering Study in ’08 re: How often we really need to observe

Global Science & Technology, Inc.

Partnering for Success

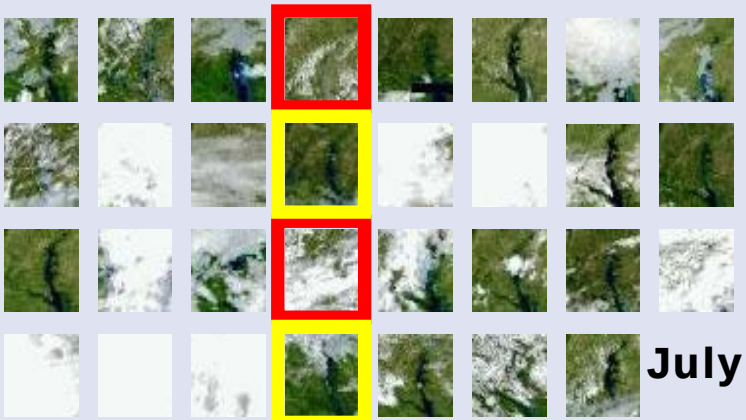
An example assessment of daily cloud cover using MODIS “Landsat-sized chips” for growing season months – June, July, August & Sept in DC area.



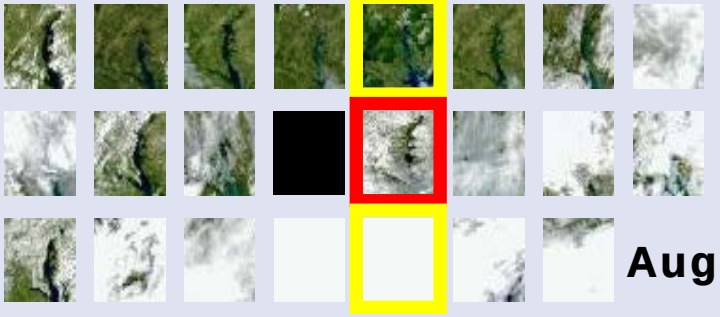


Clear
rank = 1

Mostly Clear
rank = 2

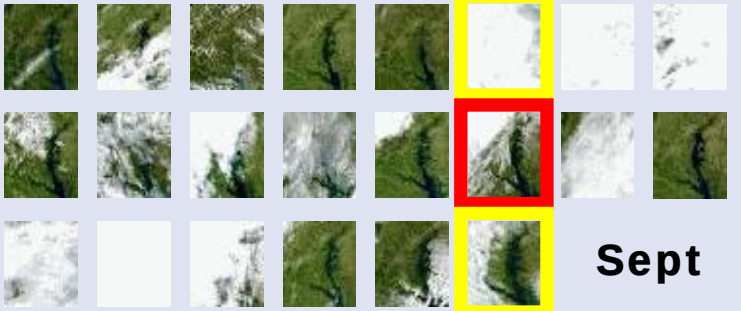


ANSWER: FOR MOST VEGETATED ZONES OF THE EARTH WE NEED DAILY REPEAT COVERAGE TO CREATE WEEKLY CLOUD-FREE DATA SETS!



Mostly Cloudy
rank = 3

Cloudy
rank = 4



Note: “8 day / week” calendar being shown due to 8-day repeat with Landsat’s 5 and 7 orbits; images highlighted by red and yellow border correspond to actual Landsat 5 and 7 obs dates.

- **Visual assessment of cloud cover in MODIS “Landsat sized” chips (see center column above)**
- **Each image assigned rank of 1 - 4 based on cloud cover in chip – then over an 8 yr period we assessed ability to create a cloud-free mosaic product if we had 1 day repeat coverage, 2 day repeat, and so on.**

Proprietary Information of Global Science & Technology, Inc.

Investigation of Smallsat Solutions

- **Transitioned from NASA to the private sector in Feb 2010**
  - Wanted to be able to knock on doors, ask questions, get candid answers
    - activities not permitted to engage in as a civil servant
- **Conducted exhaustive review of existing low-cost Earth imagers and small satellite missions**
  - Asked the question: **Does something reliable already exist that could, with adjustments, be morphed into a viable Landsat "LITE" mission?**
- **Realization that NASA's New Millennium Program EO-1, a smallsat, still operational ~ 10 yrs beyond its design life**
- **Evolution of improved imaging capabilities of Surrey's Disaster Monitoring Constellation (DMC) was noteworthy**
- **GST & Surrey US established teaming agreement June '10 and we began work to evolve a viable concept**
  - NASA's Earth Venture-2 Announcement of Opportunity, issued in March '11, sharpened our focus and sense of urgency
    - end-to-end mission cost had to be < $150M
  - Terrestrial Ecosystem Dynamics **(TerEDyn)** mission concept was the outcome

Global Science & Technology, Inc.

Partnering for Success

TerEDyn Overview

- **A low-cost, low risk concept based on lessons learned via NASA's historical oversight of Landsat missions, plus AVHRR, SeaWIFS & EOS Terra/Aqua MODIS --** takes advantage of evolution of Surrey's DMC capabilities
- **Would provide temporally robust datasets at 15m-30m 'field' scale to support scientific, strategic, humanitarian & commercial applications.**
  - goal is to make data available via free distribution from USGS EROS Center
- **Responsive to needs expressed in numerous government reports from such organizations as OSTP, USGEO, USGCRP, CEOS, etc.**
- **Fully mature proposal to build initial TerEDyn system was developed and submitted in Sept '11 to NASA's Earth Venture-2 competition**
  - Team member logo's shown below; a very serious effort costing $½M - $¾M

Proprietary Information of Global Science & Technology, Inc.

Surrey Satellite Technology US LLC — Changing the Economics of Space

USGS — science for a changing world

Ames Research Center

Global Science & Technology, Inc.

University of Maryland 1856

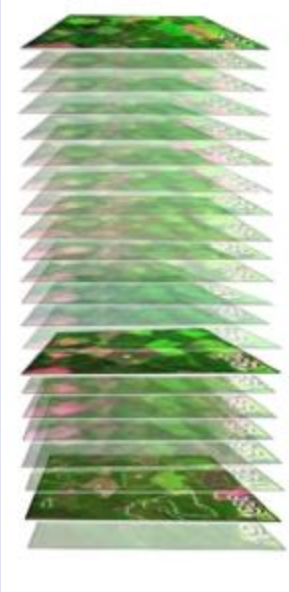
Department of Geography at the University of Maryland, College Park

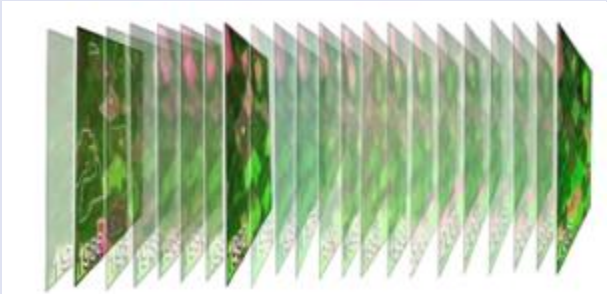
Australian Government — Geoscience Australia

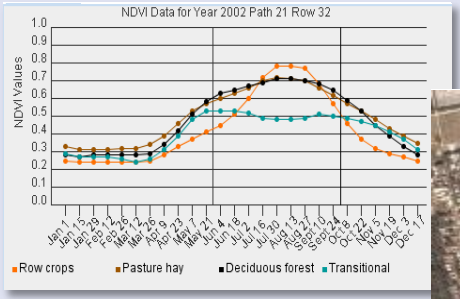
Why TerEDyn?

Background / Rationale for TerEDyn

39 yr archive of free data permits inter-annual change assessment.







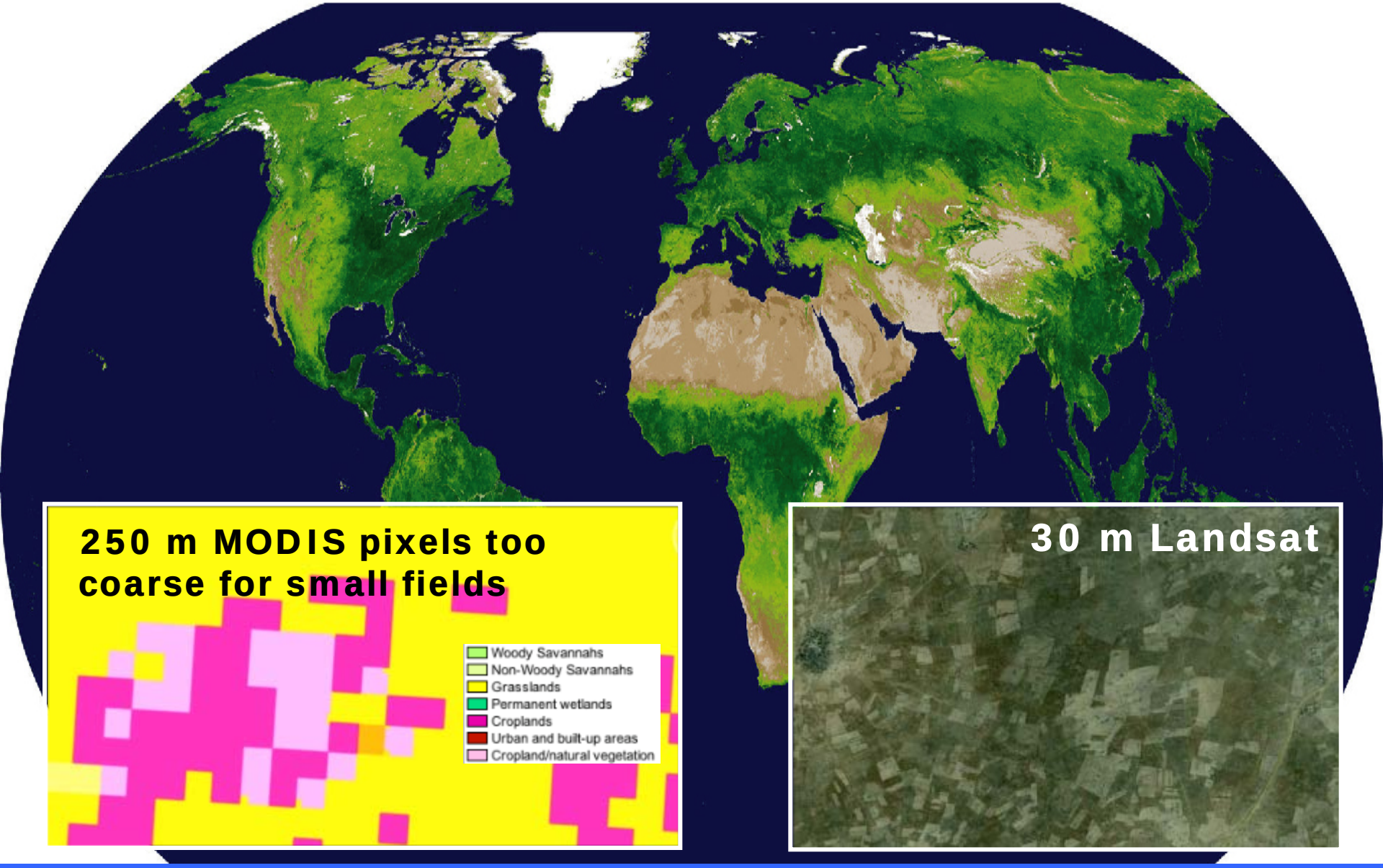
Community also needs an intra-annual archive of free data to monitor change within a growing season.

- **Understanding vegetation dynamics requires characterization of within-yr seasonality at "field scale" with 30m VNIR & SWIR imagery; ideally clear views once per week**

- **Landsat's 16-day revisit translates to annual mapping, at best, for much of the globe (with two Landsat's in orbit for past ~13 years, it still takes 3 - 5 years to create an ~ cloud-free global data set).**

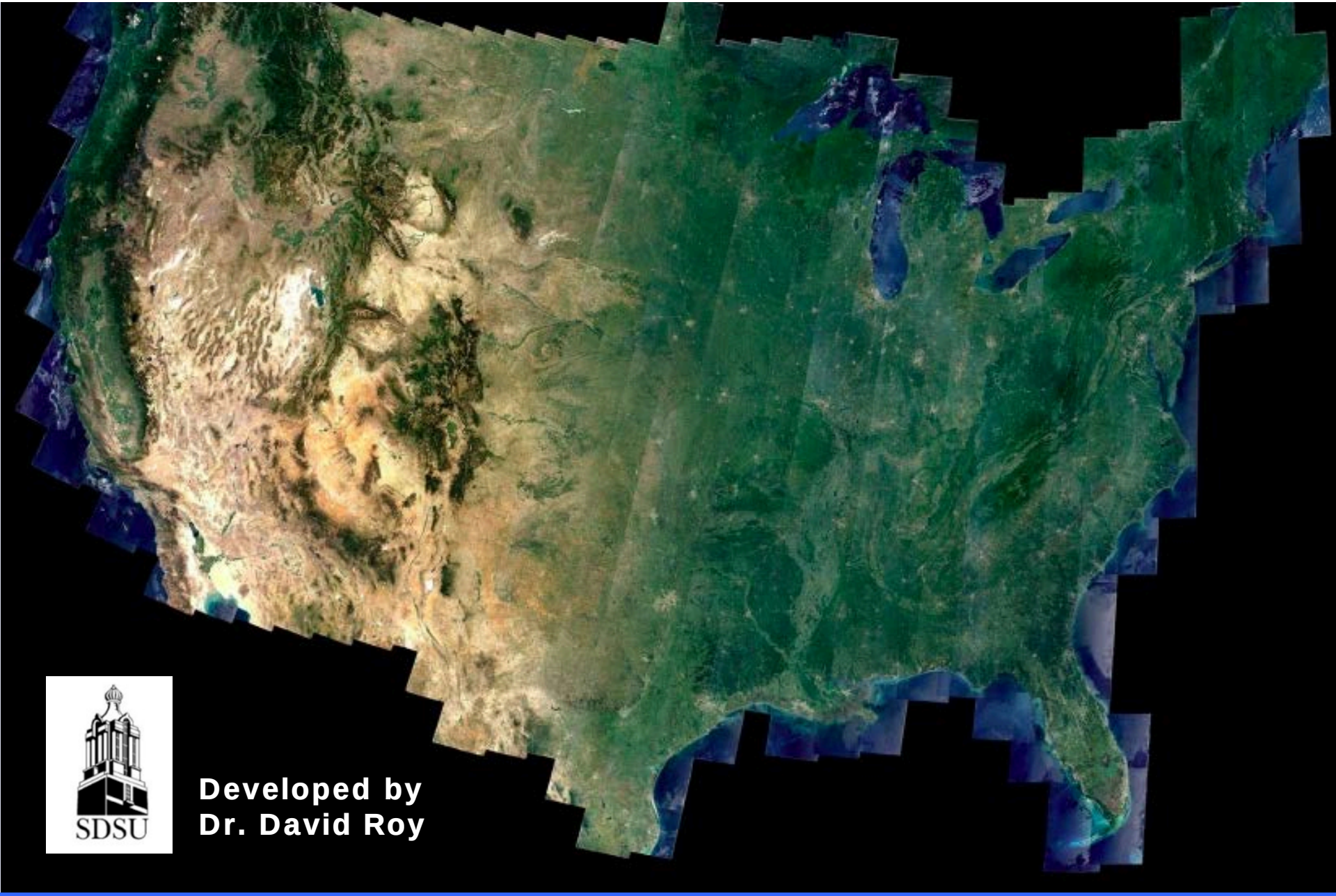
- **Such sporadic mapping cannot support applications that require more frequent observations at Landsat's "field scale."**
  - *Such as agricultural monitoring for global food security*

MODIS Enhanced Vegetation Index Map of the World



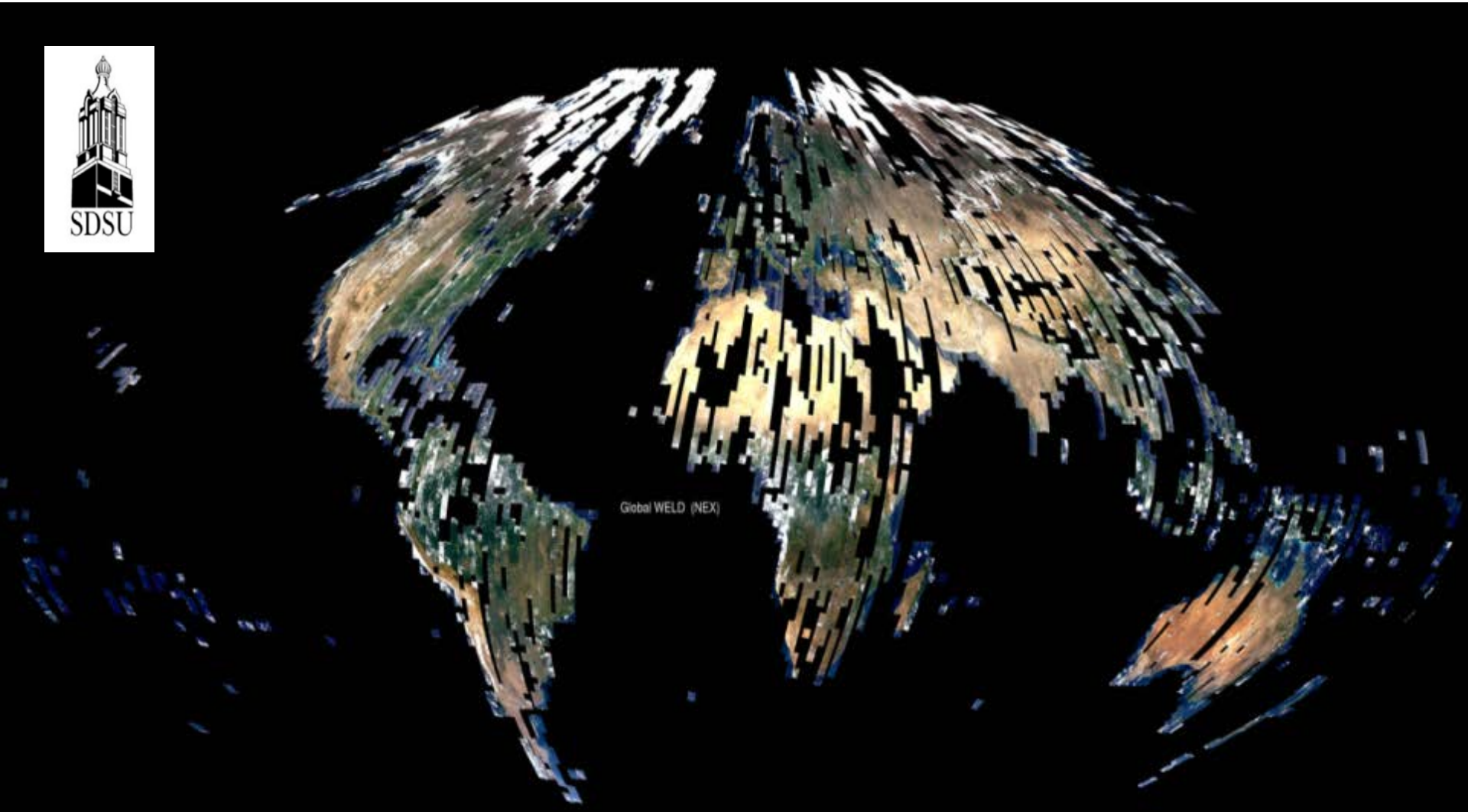
Want to be able to do this routinely at 15m - 30m via TerEDyn; currently takes ~5 years to create via Landsat.

Landsat WELD Continental Mosaic for July 2007



Could do this routinely, anywhere @ 15m via TerEDyn.

Landsat 7 WELD Global Mosaic for May 2010

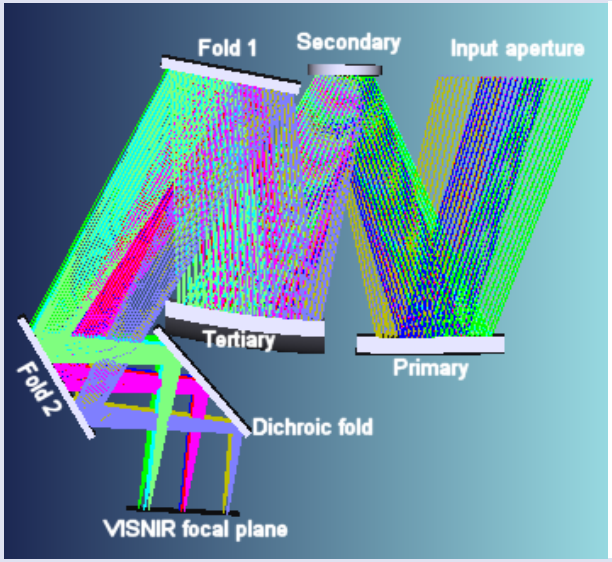


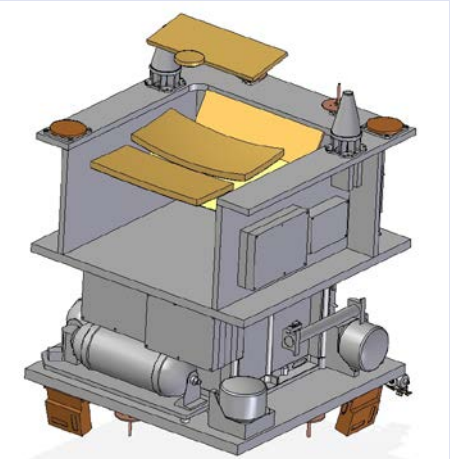
Developed by Dr. David Roy

Capability to generate this type of global product @ 30m already exists, but we could do it routinely @ 15m with TerEDyn.

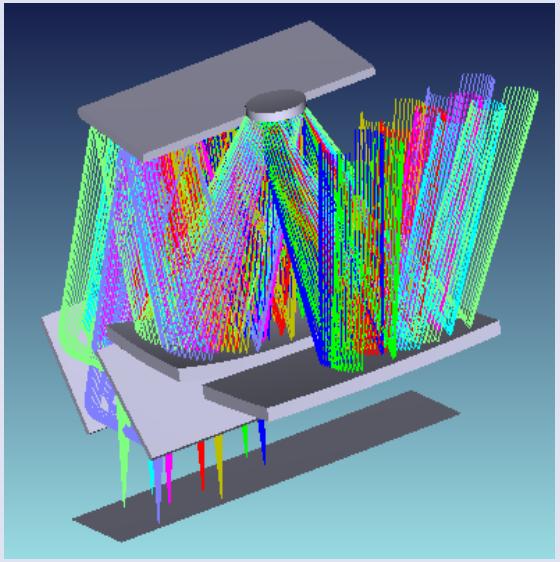
Proposed TerEDyn Imager

- **A Surrey built all reflective single aperture imager**
  - **Based on a wide-angle telescope design flown on RapidEye**
  - **TM Bands 1 – 4 @ 15m, band 5 @ 30m through a single lens**
  - **Imager swath is 390 km from an orbital altitude of 615 km**
    - **a standard TerEDyn "image" will be 390 km by 390 km**
    - **routine underflight of Landsat @ 705 km for cross cal during entire mission**
  - **Imager would be 'always on' when over sunlit land**
    - **combo of attributes yields 4x – 5x more imagery than any prior Landsat**





Optical surfaces imported to a modified SSTL-150 – opto-mechanics not shown.



Global Science & Technology, Inc.

Partnering for Success

Baseline Performance Specifications from Landsat Data Gap Study Team

Performance Parameter	Performance Goal: LDCM Specification	Baseline Specification[1]	TerEDyn Solution
Spectral Bands[2]	Blue1: 430-450 nm Blue: 450-520 Green: 525-600 nm Red: 630-680 nm NIR: 845-885 nm[3] SWIR(1): 1560-1660 nm SWIR(2): 2100-2300 nm	Green: 525-600 nm Red: 630-680 nm NIR: 845-885 nm[2] SWIR(1):1560-1660 nm	~~Blue1: 430-450 nm~~ Blue: 450-520 nm Green: 530-600 nm Red: 630-680 nm NIR: 850-890 nm[3] SWIR(1): 1560-1660 nm ~~SWIR(2): 2100-2300 nm~~
Radiometry	<5% error in at-sensor radiance, linearly scaled	<15% error in at-sensor radiance, linearly	<5% error in at-sensor radiance, linearly scaled
Spatial Resolution	30m GSD VNIR-SWIR; 15m panchromatic	10-100m GSD	30m VNIR*-SWIR; *all VNIR bands imaged @ 15m compressed to 30m
Geographic Reg.	<65m circular error	<65m circular error	<65m circular error
Band-to-Band Registration	uncertainty <4.5m or 0.15 pixel	uncertainty <0.15 pixel	uncertainty <0.15 pixel VNIR, <0.28 SWIR
Geographic Coverage	All land areas between ± 81.2° north and south latitudes, including island, atolls, and continental shelf regions <50m water depth	All land areas between ± 81.2° north and south latitudes at least twice per year	All land areas between ± 81.2° N and S latitudes via **"always on" imaging over sunlit land yielding much more coverage than LDCM**

[1] Acquired data must be characterized & verified against these specifications to ensure data quality & continuity.

[2] Landsat/LDCM bands given; must show and discuss any differences from these nominal bandwidths.

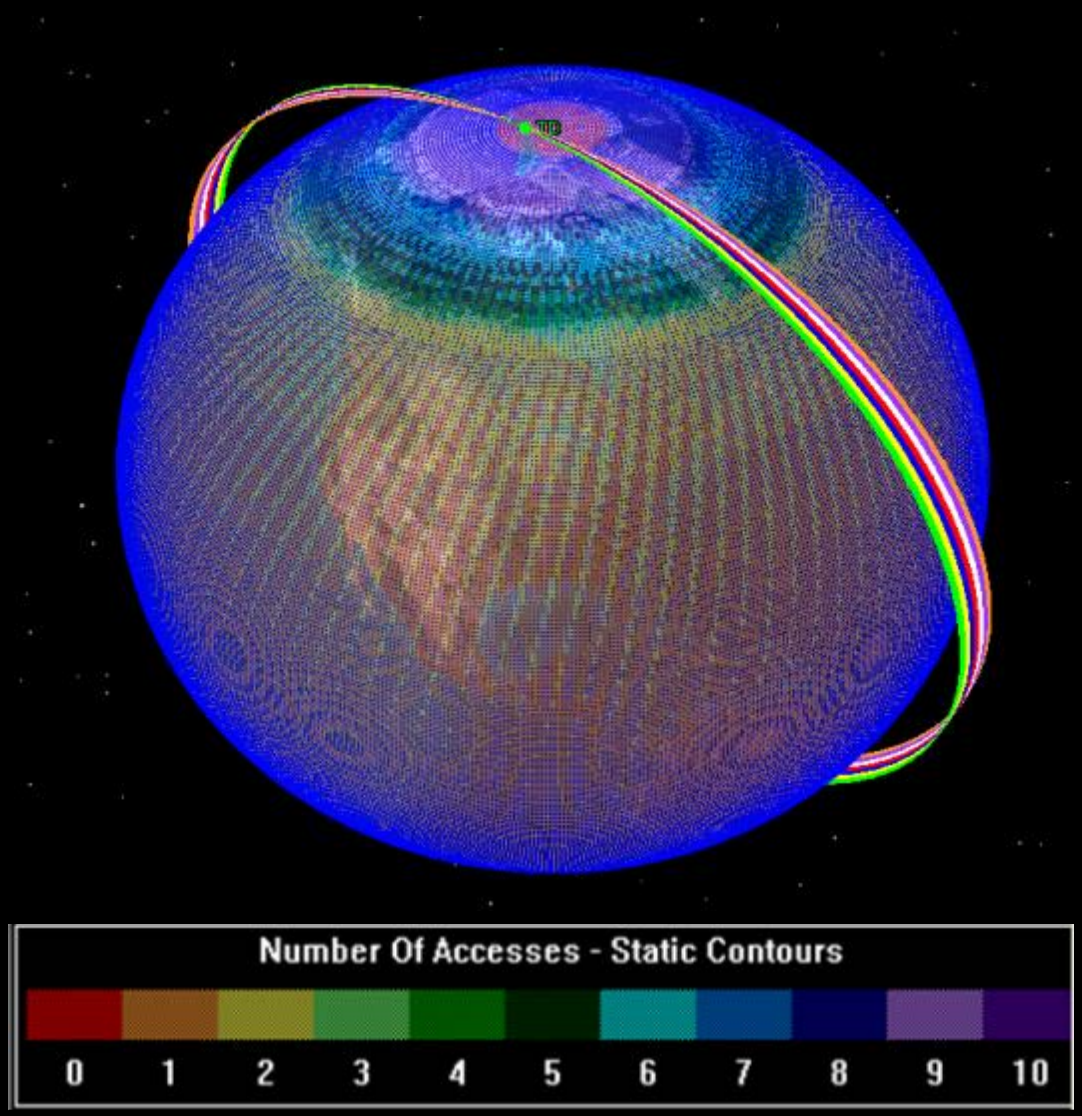
[3] NIR bandwidth given for LDCM; Landsat bandwidth of 780-900 nm is also acceptable.

Proprietary Information of Global Science & Technology, Inc.

TerEDyn Global Coverage in 7 days

TerEDyn would image a swath 390 km wide

- twice as wide as Landsat, completing global coverage in less than half the time
- imaging strategy is to be 'always on' over sunlit land, collecting ~4X the imagery ever acquired by a single Landsat mission
- flying at 615 km altitude, will routinely under fly Landsat at 705 km to permit cross calibration throughout the entire mission – not just at the beginning of mission.



Proprietary Information of Global Science & Technology, Inc.

TerEDyn Science Team

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 & Science Products
Tristan West	Joint Global Change Res Inst	Agricultural Productivity
Curtis Woodcock	Boston University	Primary Production Subgroup ldr / Land cover

TerEDyn Science Collaborators*

Name	Organization	Expertise or Area of Interest
Molly Brown	NASA Goddard Sp Flt Ctr	Food security / Disease vector analysis
Alex Held	CSIRO	Carbon accounting / general cal/val support
Steve Mackin	Surrey DMCii	Calibration
Gretchen Moisen	USDA US Forest Service	Forest assessment
Rick Mueller	USDA Nat'l Ag Statistics Ser	Agriculture

*** Means source of funding is external to EV-2 proposal response.**

What Others Think of TerEDyn

From D. James Baker, former NOAA Administrator (1993-2001); currently Director, Global Carbon Measurement Program, The Clinton Foundation.

"... the long temporal repeat provided by only one Landsat, when coupled with on-going uncertainties about the continuation of the program beyond the Landsat Data Continuity Mission ... is of great concern to the user community ... The TerEDyn concept is exciting because it addresses the critical issue of how to provide more frequent Earth observations at 30m spatial resolution"

From the Minister for Innovation, Industry, Science and Research within the Australian Government, Senator, Honorable Kim Carr

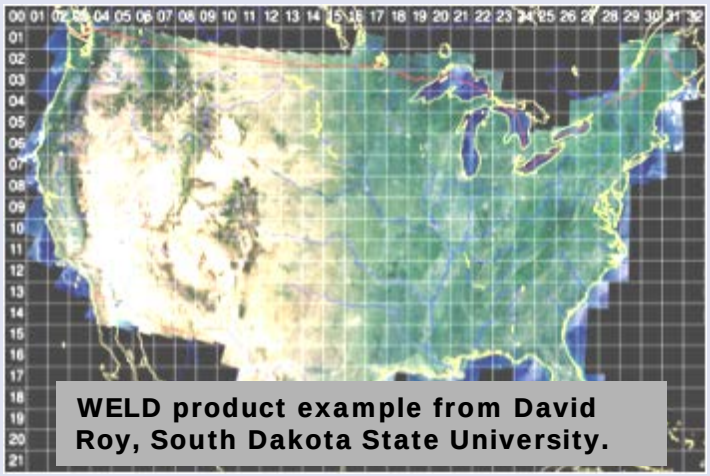
[NOTE: a Minister in Australia's parliamentary gov't is equivalent to Cabinet member in U.S. gov't; the Space Policy Unit and Geoscience Australia fall within his domain]

"On behalf of the Australian Government, I would like to formally provide our in-principle support for the TerEDyn concept."

"Considering that the Australian Government continues to rely heavily on Landsat-class data ... we hope that TerEDyn can assist in building and ensuring future capability. Due to this reliance, the Australian Gov't has an ongoing interest in the project's progress ..."

Recap of TerEDyn Concept

- **Short term goal:** **demonstrate ability to acquire scientifically valid imagery more frequently via lower-cost, smallsat solutions.**
- **Long term goal:** **validate smallsat solution leading to ability to obtain daily temporal repeat needed to create cloud-free data sets at 15m-30m**
- **Mission heritage**: **Concept draws heavily from lessons learned via NASA's oversight of Landsat missions**; **takes advantage of Surrey's DMC evolution**.
- **Heritage Science Leaders:** **Samuel Goward, U of Maryland** / GST, serving as PI, and **Darrel Williams, GST**, serving as Deputy PI
- **Heritage NASA Flight Project Advisors:** **Bryant Cramer & Dale Schulz** who oversaw development of the New Millennium Earth Observer-1 mission.
- **Outcome of NASAs EV-2 Competition:**
  - **TerEDyn was not selected from a list of 19 compliant, highly competitive proposals**
  - **CYGNSS, a nanosat constellation to measure ocean winds was chosen to improve extreme weather prediction**
  - **Seeking alternative funding sources for TerEDyn**



WELD product example from David Roy, South Dakota State University.

Smallsats Offer A "Chevy" Solution

A "Cartoon" Analogy Comparing a Landsat Flagship Mission to a Smallsat Solution

"Landsat"

Landsat Data Continuity Mission build started 2005

Both cars provide a VG to E driving experience and either will get you to your destination, but there are obvious differences in cost and expectations.

Both types of cameras will provide VG to E pictures, but each fills a niche with obvious differences in cost and expectations.

"TerEDyn"

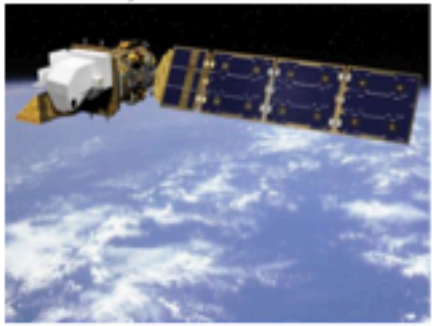
Terrestrial Ecosystem Dynamics

- **Sam Goward (UMD) observation – "Why are we only building and launching IBM 360 mainframe computer equivalents in an era of laptops, IPAD's and smart phones?"**
- **CJ Tucker statement: "I would far rather have decent quality data all the time, than slam dunk high precision data sets that might have gaps."**
  - *"If I don't have the data, there isn't much I can do to fill in the gaps."*
- **TerEDyn would demo low cost, reliable performance & dramatically enhance temporal repeat coverage needed to create data sets with minimal cloud contamination.**

SPACENEWS®

The Rime of the Ancient (Land) Mariner

By Samuel N. Goward, Darrel L. Williams | Apr. 1, 2013



Landsat 8. Credit: Orbital Sciences artist's concept

The March 4 *SpaceNews* had a good editorial on the Landsat program ["Enjoy Landsat 8 — While It Lasts," page 18]. However, for those uninitiated in Landsat affairs, it was rather incomplete.

Welcome to a sad tale of many twists and turns told by two ancient Landsat mariners. We are still not certain who shot the Landsat albatross (several names come to mind) but we have had bad luck ever since. Continuation of Landsat past version 8 is only the most recent turn.

Summary

- ***"Smallsat technology has progressed far enough (that) … there is no technical reason why smallsats can't equal the performance and reliability of traditional satellites"*** **… Dr. Bryant Cramer (EO-1)**
- ***"Why are we only building and launching IBM 360 mainframe computer equivalents in an era of laptops, IPAD's and smart phones?"*** **observation by Prof Samuel Goward (UMD)**
- ***"I would far rather have decent quality data all the time, than slam dunk high precision data sets that might have gaps. If I don't have the data, there isn't much I can do to fill in gaps."*** **observation by Dr. Compton (Jim) Tucker (NASA Goddard)**
- **The TerEDyn mission concept is targeted at validating smallsat solutions for *augmentation — not replacement* — of Landsat**
  - **more frequent coverage & low-cost ins against crippling data gap**
- **TerEDyn was not selected under NASA's EV-2 competition**
  - **we are seeking alternative funding sources**

SMALLSAT SOLUTIONS CAN OFFER BIG RESULTS