Continuous Constellation for Total and Spectral Solar Irradiance in the next 35 Years

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TOMC
(TSSI Operational Monitoring Constellation)
Presentation Outline

• Quick history of TSSI and the transition from research to operations as currently attempted.
• Keys to the TOMC implementation approach:
  – Low-Cost Small Launch Vehicle
  – Low-Cost Small Spacecraft Bus
  – Fully Integrated Mission Design
• Risk and cost assets of constellation implementation.
• Proposed implementation details.
TSSl Measurements – Past – Present - Future

37 years of overlapping measurements

Scramble to keep continuity

Sustainable solution
LASP Sun/Earth Climate Monitoring Mission History

Solar Environmental Record

1981 - 1989

1991 - 2003

2003 - 2015...

2013 - 2017

2017 - 2022

"One activity ranks above all others for determining solar influence on global change: Monitor the total and spectral irradiance form an uninterrupted series of spacecraft radiometers employing in flight sensitivity tracking."

"Solar Influence on Global Change" (1994 National Academy of Science Report)
21 years to implement

- Total and Spectral Solar Irradiance Sensor (TSIS)
- LASP selected to provide in 1998 by TRW and LockMart
- Contracted in 2001 to TRW for NPOESS as a PI instrument.
- Started Implementation in 2001 and continued through 2006 in this configuration
- TSIS was de-manifested along with other climate sensors in 2006 following the Nunn-McCurdy Program Review.

- Re-manifested in 2008 to fly on NPOESS C1
  - High priority given in the Earth Science Decadal Survey
  - 2007 NRC Workshop: Options to Ensure the Climate Record Workshop
- February, 2010: New restructuring NPOESS, creation of Joint Polar Satellite System (JPSS) GSFC Managed
- 2011 TSIS directed to be implemented on the Polar Free Flyer (PFF) component of JPSS.
- 2013 PFF removed from JPSS and became independent program
- 2014 PFF converted to Solar Irradiance, Data And Rescue (SIDAR) program and TSIS identified to fly on ISS
- 2015 TSIS manifested on ISS for launch in 2017
- 2016 TSIS responsibility will transfer to NASA from the current NOAA responsibility
TSIS is an operational sensor on ISS. (provides a daily data record)

Will be located on ELC-3 site 5 in order to track the sun

TSIS is manifest on SpaceX-15 scheduled to launch Aug. 6, 2017
Current Implementation is the TSIS Monitoring Instruments: TIM and SIM

TSIS has two primary instruments to accomplish the CDR measurements:

- **Spectral Irradiance Monitor (SIM)**
  - 200 – 2000 nm
- **Total Irradiance Monitor (TIM)**
  - 96% of energy
Future Implementation is the TSIS Monitoring Instruments: TIM and SIM

TSIS has two primary instruments to accomplish the CDR measurements:

**Total Irradiance Monitor (TIM)**

- 200 – 2000 nm

**Spectral Irradiance Monitor (SIM)**

- 96% of energy
**Long Term Implementation for TSIS-2**

- Over 32 studies have been completed by NASA, LASP and Industry in the past 10 years on implementation strategies. (*LASP participated in every one as the TSIS instrument organization.*)
- Most are based on Weather monitoring model.
  - Nadir pointing, earth looking, high resolution large data sets
  - Long term orbit and global coverage launch opportunities
- Few take advantage of robust TSIS design.
  - Low data rate; focused data set
  - Highly tolerant LEO orbit options
  - Existing data systems and operations
  - Robust instrument design
Climate Takes Commitment

35 Years of Successful Research Total Solar Irradiance (TSI) Acquisition
$1.3B investment

Turbulent Conversion to Operational System

Operational Implementation Optimized over 25 Years

60 years of Sun/Earth Climate Monitoring

- Many of the acquisition models used for Climate data are derived from weather monitoring.
  - Weather is like a newspaper (Quick)
  - Climate is like an encyclopedia (Correct)

- The Best way to insure Climate Data Records are through overlapping long term and low cost measurements.
Continuity, Continuity, Continuity …

Solar Irradiance Climate Data Record Depends on Continuity

This is recognized by:

- Global Observing System for Climate (GCOS)
- The World Climate Research Programme (WCRP)
- The International Radiation Commission (IRC)
- The Global Energy and Water Cycle Experiment (GEWEX) Radiation Panel
- The US Climate Change Science Program (USCCSP)
- National Academy of Science
- **TSIS given high priority by National Academy of Sciences (NAS)** 2007 *Mitigation* Report

- Has been one of top two priorities within JPSS
NASA will start examining its options for Total Solar Irradiance Sensor holdings in 2014, Frelich said. The agency will wait until 2015 to give the instrument's builder, the Air Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder, the go-ahead to begin development of the new instrument, which would be the second of its kind in space. The first, Total Solar Irradiance Sensor, is now on NOAA's Polar Free Flyer, which is set to launch in 2017.

procure new [Total Solar Irradiance Sensor] instruments and to launch them, almost undoubtedly, as hosted payloads.”

Michael Frelich

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Michael Frelich
Tipping Point for Successful Design of Disaggregated Critical LEO Earth Observing Space Systems
**TSSI Operational Monitoring Constellation (TOMC)**

**T** Total and Spectral Solar Irradiance
- Continuation of the Climate Data Record (CDR) over a proposed 25 year implementation.

**O** Operational
- Data analysis, production and distribution using the existing proven systems.

**M** Monitoring
- Overlapping measurements provide unbroken observation measurements.

**C** Constellation
- Multiple space assets reduce risk to on orbit or launch vehicle failure.
TSSI Operational Monitoring Constellation (TOMC)

• A proposed implementation for the TSIS-2 acquisition of the Total and Spectral Solar Irradiance (TSSI) Climate Data Record (CDR).

• TOMC is designed to follow on to the current TSIS-1 on the ISS and proposes a 22 year TSSI CDR collection scheme following the Solar Radiation and Climate Experiment (SORCE) focused small mission implementation model.

• TOMC takes advantage of new technology in small spacecraft components and design and low cost, robust simple launch vehicle availability.
Keys to Successful Implementation

1) Low Cost Launch

Super Strypi Missile
The solid-fueled Super Strypi launcher is developed by Sandia National Laboratories and Aerojet, under an Air Force OSR-4 contract. The rocket is based on an enlarged version of Sandia’s Strypi sounding rocket.

2) Very Capable but Small, Low Cost, Spacecraft Bus

- The LASP Micro (Mighty) Bus (LMB)
- Mature spacecraft architecture tailored to SIM & TIM needs.
- Robust design with ample margins results in a high reliability, low cost solution.

3) All Interfaces Managed and Integrated Within One Organization

Fully Integrated Mission
- Interface control between hardware, software, test and verification.
- LASP spacecraft design and operations allow for optimization and automation of spacecraft hardware and software to provide a lowest cost approach to autonomous operations and data processing.
Keys to Successful Implementation

1) Low Cost Launch

Rocket Lab Electron
The liquid-fueled Electron launcher is developed by Rocket Lab, New Zealand/USA.
Electron is designed for a nominal payload of 150kg to a 500km sun-synchronous orbit for $4.9M.

2) Very Capable but Small, Low Cost, Spacecraft Bus

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**Current State of Small Satellite Technology**

**Small Satellite Class Definitions**

<table>
<thead>
<tr>
<th>Satellite Class</th>
<th>Mass Range</th>
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<tbody>
<tr>
<td>Small satellite</td>
<td>100 and 500 kg (220 and 1,100 lb),</td>
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<tr>
<td>Micro satellite</td>
<td>10 and 100 kg (22 and 220 lb)</td>
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<tr>
<td>Nano satellite</td>
<td>1 and 10 kg (2.2 and 22.0 lb).</td>
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<tr>
<td>Pico satellite</td>
<td>0.1 and 1 kg (0.22 and 2.20 lb),</td>
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<tr>
<td>Femto satellite</td>
<td>10 and 100 g (0.35 and 3.53 oz)</td>
</tr>
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</table>

- Many Nano-satellites are based on the “CubeSat” standard
  - Consists of any number of 10 cm x 10 cm x 10 cm units
  - Each unit, or “U”, usually has a volume of exactly one liter
  - Each “U” has a mass close to 1 kg and not to exceed 1.33 kg
    - (e.g. a 3U CubeSat has mass between 3 and 4 kg)
- Micro-satellites, such as the LASP Micro Bus (LMB), are larger and more capable but often share common avionic components with Nano-satellites

**“CubeSat”**

Much experience in building and flying satellite systems.

**We are in the “Age of ”U”**
### Projection Estimates for Small Satellites

- **2013 Projection estimated:**
  - 93 nano/microsatellites would launch globally in 2013;
  - 92 nano/microsatellites actually launched
  - An increase of 269% over 2012

- **2014 Projection:** A significant increase in the quantity of future nano/microsatellites needing a launch.
  - 260 nano/microsatellites
  - An increase of 300% over 2013

- **2015 – 2016 Projection:**
  - Currently 650 future nano/microsatellites (1 – 50 kg)
  - Currently 48 future (2014+) picosatellites (< 1 kg)
  - An increase of 134% over 2014 (reaching maximum capacity of launch availability)

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**Acknowledgment:**

Many statistics and data are provided by the SpaceWorks Enterprises, Inc. (SEI) Satellite Launch Demand Database (LDDB) • The LDDB is an extensive database of all known historical (2000 – 2013) and future (2014+) satellite projects with masses between 0 kg and 10,000+ kg
## Characteristics of SmallSat’s

<table>
<thead>
<tr>
<th>Small Satellites</th>
<th>Micro Satellites</th>
<th>Cube/Nano Satellites</th>
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<tbody>
<tr>
<td>$20M-$80M</td>
<td>$3M-$18M</td>
<td>$100K-$2M</td>
</tr>
<tr>
<td>Robust Propulsion</td>
<td>Limited Propulsion</td>
<td>Very limited Propulsion</td>
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<tr>
<td>Redundancy available</td>
<td>Selective Redundancy</td>
<td>Single String</td>
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<tr>
<td>Very Accurate Pointing</td>
<td>Accurate Pointing</td>
<td>Good Pointing</td>
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<tr>
<td>Substantial Launch Vehicle</td>
<td>Shared Ride or Small Launch Vehicle</td>
<td>Shared Ride in many readily available P-POD</td>
</tr>
<tr>
<td>High Data Capability</td>
<td>High Data Rate</td>
<td>Low Data Rate</td>
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<tr>
<td>Very Large Apertures</td>
<td>Large Apertures</td>
<td>Small Apertures</td>
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- Robust Propulsion
- Limited Propulsion
- Very limited Propulsion
- Selective Redundancy
- Single String
- Accurate Pointing
- Good Pointing
- Shared Ride or Small Launch Vehicle
- Shared Ride in many readily available P-POD
- High Data Rate
- Low Data Rate
- Large Apertures
- Small Apertures
TSIS-2… Implementation via Small Satellite Constellation

• TOMC is a robust, low-cost, long term solution to the TSI/SSI monitoring for Climate Data Record continuity
  
  1. Low cost launch on large sounding rocket.
  2. Implemented via a LASP-built, very capable but small, low-cost, spacecraft bus, fully integrated with TSIS instruments.
  
  3. Manage all interfaces within one organization for simplification and optimization, including a low cost constellation operations and integrated Data Processing System.
Why Take the risk? (because it is lower overall)

- Larger expenditure does not guarantee successful implementation.
  - Challenger loss (Spartan)
  - Glory loss (Glory/TIM instrument)
  - NPOESS (Nunn–McCurdy enactment)

- Math and History support redundant lower cost higher individual risk approach

- Political/financial risk dominates long term sustainable measurements
  - Low annual cost for observation/measurement system

- Overlapping measurements and integratable new technology

- Only one measurement at risk. (disaggregation)
This figure shows the instantaneous probabilities of TSI measurements acquired by future TOMC flights after the initial TSIS-ISS.

*It also shows the realistic expectation that Total Solar Irradiance Calibration Transfer Experiment (TCTE), an 18-month mission that, here, is optimistically plotted as lasting 3 years.*
# TOMC Implementation Plan

(.requires control over launch date)

## TOMC PHASING

<table>
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<td>TOMC-4</td>
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<td>TOMC-5</td>
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### Acronyms

- PDR - Preliminary Design Review
- CDR - Critical Design Review
- PER - Pre-Environmental Review
- PSR - Pre-Ship Review
- ORR - Operational Readiness Review
- LRR - Launch Readiness Review
- PMR - Pre-Manufacturing Review
- PR - Parts Review

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**TOMC-1**
- TSIS Inst.
- S/C (LMB)
- Super Strypi Missile Operations
- Climate Data Record
- NASA Oversight

<table>
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<th>Phase</th>
<th>1-LRD</th>
<th>2-LRD</th>
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**TOMC-2**
- TSIS Inst.
- S/C (LMB)
- Super Strypi Missile Operations
- Climate Data Record
- NASA Oversight

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**TOMC-3**
- TSIS Inst.
- S/C (LMB)
- Super Strypi Missile Operations
- Climate Data Record
- NASA Oversight

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**TOMC-4**
- TSIS Inst.
- S/C (LMB)
- Super Strypi Missile Operations
- Climate Data Record
- NASA Oversight

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**TOMC-5**
- TSIS Inst.
- S/C (LMB)
- Super Strypi Missile Operations
- Climate Data Record
- NASA Oversight

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• Earliest launch possible in 2018 if funding starts in FY 2015.
• Funding higher in first 3 years to establish hardware programs.
• Production of instruments, spacecraft and launch vehicle sustained over program.
• 25 years of CDR data production and archiving and operations.
The TOMC implementation is less than half the cost of large missions, with a system level reliability as implemented (through a constellation of small low-cost spacecraft) higher than large missions.
TOMC Implementation Concept

• Components to be implemented in a low volume production environment over 20 years, with first unit available in 2019.
• Existing TSIS instrument design with TCTE modification to eliminate the need for the Microprocessor Unit (MU).
• Instruments to be integrated with LASP Micro Bus (LMB) spacecraft at existing LASP facilities in Boulder Colorado.
• Launch Vehicle to be delivered on 4-year cadence with launch site payload integration similar to a sounding rocket.
• LASP existing operation and data system used from cradle to grave for entire constellation, with data products delivered to NASA data centers for archiving and distribution.
• 5-year 70% Probability of Success (POS) implementation with 4-year launch cadence to insure overlap and reduce risk.
• Light Touch NASA management oversight modeled after SORCE mission success.