CLARREO Mission Overview

Climate Absolute Radiance & Refractivity Observatory MCR

January 21, 2011

NASA Langley Research Center
This package contains a top-level overview of the CLARREO mission as of January 21, 2011.

For the latest news on the CLARREO mission or for contact information, please visit the mission web site at:

http://clarreo.larc.nasa.gov/
Contents

1. CLARREO Background
2. Science Measurements
3. Mission Concept
4. Observatory Concepts
5. Spacecraft Bus Concept
6. Mission Status
1. CLARREO Background
Mission Origins

CLARREO = Climate Absolute Radiance and Refractivity Observatory

• CLARREO was recommended as a top priority for NASA by the National Academy of Science
  – The 2007 Decadal Survey of “Earth Science and Applications from Space” identified CLARREO as one of the four high-priority “Tier 1” earth science missions

• CLARREO will be the cornerstone of the long-term climate observing system
  – Trend detection (decadal scale)
  – Improvement and testing of climate predictions
  – Calibration of operational and research sensors

CLARREO is the Next Step in Climate Observation
Societal Benefits

- Enable knowledgeable policy decisions based on internationally acknowledged climate measurements and models through:
  - Observation of high accuracy long-term climate change trends
  - Use the long term climate change observations to test and improve climate forecasts

Science Objectives

- Make highly accurate and SI-traceable decadal change observations sensitive to the most critical but least understood climate radiative forcings, responses, and feedbacks
  - Infrared spectra to infer temperature and water vapor feedbacks, cloud feedbacks, and decadal change of temperature profiles, water vapor profiles, clouds, and greenhouse gas radiative effects
  - GNSS-RO to infer decadal change of temperature profiles
  - Solar reflected spectra to infer cloud feedbacks, snow/ice albedo feedbacks, and decadal change of clouds, radiative fluxes, aerosols, snow cover, sea ice, land use
  - Serve as an in-orbit standard to provide Reference Intercalibration for broadband CERES, and operational sounders (CrIS, IASI), imagers such as VIIRS, AVHRR, geostationary

A Mission with Decadal Change Accuracy Traceable to SI Standards
2. Science Measurements
• As outlined in the Decadal Survey, CLARREO will make the following science measurements:
  – Solar reflected spectra: SI traceable relative uncertainty of 0.3% (k=2)*
  – Infrared emitted spectra: SI traceable uncertainty of 0.1K (k=3)*
  – Global Navigational Satellite System Radio Occultation: SI traceable uncertainty of 0.1K (k=3)*

• For each measurement CLARREO will acquire:
  – At least five (5) years of data to establish an initial climate benchmark
  – At least one (1) year of overlapping data between two like instruments for measurement verification

• To accomplish these measurements CLARREO will fly:
  – Two infrared spectrometers
  – Two solar reflected spectrometers
  – Two GNSS radio occultation instruments

* The term “k” refers to Coverage Factor as defined in NIST TN 1297.
Science Instruments

**Infrared (IR) Instrument Suite**
- Fourier Transform Spectrometer
  - Systematic error less than 0.1K ($k=3$)
  - 200 – 2000 cm$^{-1}$ contiguous spectral coverage
  - 0.5 cm$^{-1}$ unapodized spectral resolution
  - Nadir pointing, systematic within 0.2°
  - GIFOV: 25 km
  - Consecutive earth view orbit samples ≤ 200 km
  - NeDT < 10 K (1 σ)

**Reflected Solar (RS) Instrument Suite**
- Two Grating Spectrometers with Gimbal-mounted (1-axis)
  - Systematic error less than 0.3% ($k=2$) of earth mean reflectance
  - 320 – 2300 nm contiguous spectral coverage
  - 4 nm sampling, 8 nm resolution
  - GIFOV < 0.5 km by 0.5 km
  - Swath width ≥ 100km @600 km
  - Nadir viewing > 90% of the time
  - S/N ratio > 33 for $λ < 900$ nm, S/N ratio > 25 for $λ > 900$ nm
  - Polarization sensitivity < 0.5% ($k=2$) for $λ < 1000$ nm, < 0.75% ($k=2$) for $λ > 1000$ nm

**GNSS Radio Occultation Receiver**
- GNSS Receiver, POD Antenna, RO Antennae
  - Refractivity uncertainty 0.03% ($k=1$) for 5 to 20 km altitude range
  - Sampling for annual mean 10 degree latitude zones (1000 occultations/day)
Infrared Instrument Concept

- Metrology Laser Radiator
- QCL Radiator
- IR Instrument Mount
- IR FTS Scan Mechanism
- IR Scene Select Assembly
- IR Bench Radiator
- Cryo-Cooler Radiator
- Blackbody Radiator
- Mid IR Detector Optical Assembly
- Far IR Detector Optical Assembly
- IR Instrument Mount
- Verification Assembly
Infrared Instrument Operations

Earth views alternate with verification system views

Scene-Select Mirror Nominal Operation
1) Mirror points LOS in observatory velocity direction to “A”.
2) Mirror maintains LOS to “A” by rotating at a constant rate during integration period.
3) Mirror maintains LOS to “A” in anti-velocity direction until end of integration period.
4) Mirror moves to calibration (ambient) blackbody.
5) Mirror moves to zenith deep-space view.
6) Mirror moves to verification blackbody.
7) Mirror moves to zenith deep space view.
8) Mirror moves to calibration (ambient) blackbody.
9) Mirror points LOS to “C” to begin next nadir collect.

*Prior to Yaw Flip
2x Optical Packages
- Blue Channel 320-640nm, silicon detectors
- Red/NIR Channel 600-2300nm, HgCdTe detectors

- Commonality of design of two optical packages aids in calibration
- All-aluminum materials including telescope optics with Offner design
- Cooled focal planes tailored for each spectral region
  - 250 K for Silicon
  - 200 K for HgCdTe
Reflected Solar Instrument Operations

• Reflectance retrieval, calibration and inter-calibration requirements lead to three basic operating modes
  – Nadir Data Collection (>90% data collection time)
  – Solar Calibration
  – Inter-calibration of other on-orbit assets

• Verification of calibration drives the need for lunar views

Three basic operating modes for RSS instrument
Radio Occultation Instrument Concept

POD Choke Ring Antenna
Located on zenith deck of spacecraft for views to GNSS satellites

Receiver – RF receiver with additional capability for radio occultation processing (located inside spacecraft bus)

Ultra-stable Oscillator
Provides high-precision time reference for zero-differencing (inside Bus)

Laser Retro Reflector
Located on nadir side of spacecraft for precise orbit determination (POD) validation using Satellite Laser Ranging

Phased Array RO Antennas
Located on ram and wake faces with fields-of-view (FOV) oriented towards the Earth’s limb to view GNSS constellation Earth-occulting satellites (rising and setting)
Calibration to SI Standards

• Calibration Characterization at climate accuracy and time scales
  – Pre-launch characterization, testing, and calibration
    • Instrument builder site
    • Independent site calibration
    • SI traceable transfer radiometers, sources (e.g. NIST SIRCUS system)
  – Spacecraft Integration testing and calibration (vacuum chamber)
  – In orbit characterization, testing, and calibration
    • On orbit sources, verification of source accuracy
    • Earth viewing, solar, lunar & calibration operations schedules
    • Aircraft instrument under-flights
    • Future absolute calibration of the moon using high altitude balloon (30km) would provide an additional verification (5, 10, or even 20 yrs from now)
    • Engineering unit or instrument spares for ground testing anomalies.

Traceability to SI Standards is Key to Decadal Change Accuracy
3. Mission Concept
Mission Implementation

• **Lead Center: Langley Research Center**
  – Project Management; Science; Systems Engineering; Spacecraft; Payload; Infrared Instrument Suite; GNSS-RO; System Integration; Mission Operations; Science Data Processing

• **Supporting Center: Goddard Space Flight Center**
  – Reflected Solar Instrument Suite; Science support; Science Data Processing support

• **Category 1 mission, as defined in NPR 7120.5D (NID NM 7120-81)**

• **Class C payload risk classification, as defined in NPR 8705.4**
Mission Concept

- Three instruments (two of each)
  - Infrared (IR) Spectrometer
  - Reflected Solar (RS) Spectrometer
  - Global Navigation Satellite System-Radio Occultation (GNSS-RO)

- Four observatories, two dual-manifested launches on Minotaur IV+ vehicles
  - July 2018: Two Infrared (IR) Observatories, each with GNSS-RO
  - May 2020: Two Reflected Solar (RS) Observatories

- 609 km polar orbits (90° inclination)
CLARREO Orbit Selection

**Orbit Parameters:**
- Mean Altitude = 609 km (61-day ground track repeat cycle)
- Period = 5812.4 ± 0.25 secs (orbit maintenance requirement)
- Inclination = 90°
- RAAN = 0° or 180° (for reference inter-calibration)
4. Observatory Concepts
Observatory Summaries

IR/RO Observatory
CBE Mass: 389 kg
CBE Power: 437 W

- FTS
- CBE Mass: 76 kg
- CBE OA Power: 124 W
- Data Rate: ~228 kbps
- Data Volume: 26 Gb/day

- GNSS Receiver / Antennas
- CBE Mass: 18 kg
- CBE OA Power: 35 W
- Data Rate: ~119 kb/s
- Data Volume: 13 Gb/day

Reflected Solar Observatory
CBE Mass: 381 kg
CBE Power: 400 W

- Two Grating Spectrometers
- CBE Mass: 69 kg
- CBE OA Power: 96 W
- Data Rate: 1.3 to 325 Mbps
- Data Volume: 89 Gb/day

- Single-axis of rotation
- CBE Mass: 14 kg
- CBE OA Power: 17 W
- Data Rate: ~10 kb/s
- Data Volume: 370 Mb/day
The CLARREO observatories are relatively small among other Earth science spacecraft.

**Terra**
~4,900 kg
Atlas II Launch

**Icesat**
~1,000 kg
Delta 2 Launch

**Glory**
~500 kg
Taurus XL Launch

**CLARREO**
~460 kg x 2
Minotaur IV+ Launch

**SORCE**
~290 kg
Pegasus XL Launch

*Note: Images are not perfectly to scale*
Observatory Concept Mass Summaries

IR OBSERVATORY MASS BUDGET

<table>
<thead>
<tr>
<th>Component</th>
<th>CBE (kg)</th>
<th>Cont. (%)</th>
<th>Allocation (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>94</td>
<td>30%</td>
<td>122</td>
</tr>
<tr>
<td>Spacecraft¹</td>
<td>279</td>
<td>15%</td>
<td>319</td>
</tr>
<tr>
<td>Observatory Dry Mass Total</td>
<td>373</td>
<td>18%</td>
<td>441</td>
</tr>
<tr>
<td>Propellant</td>
<td>16</td>
<td>0%</td>
<td>16</td>
</tr>
<tr>
<td>Observatory Wet Mass Total</td>
<td>389</td>
<td>-----</td>
<td>457</td>
</tr>
</tbody>
</table>

RS OBSERVATORY MASS BUDGET

<table>
<thead>
<tr>
<th>Component</th>
<th>CBE (kg)</th>
<th>Cont. (%)</th>
<th>Allocation (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>84</td>
<td>29%</td>
<td>108</td>
</tr>
<tr>
<td>Spacecraft¹</td>
<td>282</td>
<td>15%</td>
<td>322</td>
</tr>
<tr>
<td>Observatory Dry Mass Total</td>
<td>366</td>
<td>18%</td>
<td>430</td>
</tr>
<tr>
<td>Propellant</td>
<td>16</td>
<td>0%</td>
<td>16</td>
</tr>
<tr>
<td>Observatory Wet Mass Total</td>
<td>381</td>
<td>-----</td>
<td>445</td>
</tr>
</tbody>
</table>

Notes:
1. Spacecraft mass include 6 kg for separation system components that stay with the bus.
Observatory Concept Power Summaries

Infrared w/RO Observatory

<table>
<thead>
<tr>
<th>IR OBSERVATORY POWER BUDGET</th>
<th>CBE (W)</th>
<th>Cont. (%)</th>
<th>Allocation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>159</td>
<td>30%</td>
<td>207</td>
</tr>
<tr>
<td>Spacecraft</td>
<td>278</td>
<td>10%</td>
<td>307</td>
</tr>
<tr>
<td>Observatory Power Total</td>
<td>437</td>
<td>17%</td>
<td>513</td>
</tr>
<tr>
<td>Available System Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4.9 m² array) = 668 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Power Growth</td>
<td>53%</td>
<td>-----</td>
<td>30%</td>
</tr>
</tbody>
</table>

Reflected Solar Observatory

<table>
<thead>
<tr>
<th>RS OBSERVATORY POWER BUDGET</th>
<th>CBE (W)</th>
<th>Cont. (%)</th>
<th>Allocation (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>113</td>
<td>30%</td>
<td>147</td>
</tr>
<tr>
<td>Spacecraft</td>
<td>287</td>
<td>10%</td>
<td>317</td>
</tr>
<tr>
<td>Observatory Power Total</td>
<td>400</td>
<td>16%</td>
<td>463</td>
</tr>
<tr>
<td>Available System Power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4.9 m² array) = 668 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Available Power Growth</td>
<td>67%</td>
<td>-----</td>
<td>44%</td>
</tr>
</tbody>
</table>
Observatory Concept Delta-V Budget

### Observatory Delta-V Budget

<table>
<thead>
<tr>
<th>IR/GNSS-RO and RS Observatories</th>
<th>ΔV  (m/s)</th>
<th>Hydrazine (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correction for Minotaur IV+ orbit insertion errors</td>
<td>40.1</td>
<td>10.6</td>
</tr>
<tr>
<td>In-plane transfer (pending Phase A trade studies)</td>
<td>2.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Collision avoidance</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Orbit inclination station keeping for 5 years</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Orbit altitude (period) station keeping for 5 years</td>
<td>16.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Controlled de-orbit</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td><strong>59.3</strong></td>
<td><strong>15.6</strong></td>
</tr>
</tbody>
</table>

Hydrazine capacity (ATK 80389-1 spherical tank) = 22.5 kg

**Notes:**

1) Minotaur IV+ insertion errors are 3-sigma values for altitude and inclination errors combined
2) Specific impulse = 210 s
3) Propellant calculated using 550 kg observatory NTE mass
4) In-plane transfer based on a 30-day, 180° change in true anomaly
Observatory Launch Configurations

Dual-manifest Configurations in Minotaur IV+ Fairing

2018 Dual Infrared/RO Observatory Launch

2020 Dual Reflected Solar Observatory Launch
Launch Vehicle Flexibility

CLARREO Observatories can be Dual-manifested on Minotaur IV+ (DPAF Required)

CLARREO Observatories can be Launched Individually on Falcon 1e, Taurus XL, Athena II (Shown in Falcon 1e Fairing)

Mass to 609 km Polar Orbit (kg)

- Pegasus XL: 530 kg
- Falcon 1e: 770 kg
- Taurus 3210: 1,220 kg
- Athena II: 1,274 kg
- Minotaur IV+ (Standard): 1,274 kg
- Taurus II (Low): 770 kg
- Atlas V (401/DSS): 530 kg
- Delta IV (Low): 770 kg
- Falcon 9: 530 kg

Orbit (km)
5. Spacecraft Bus Concept
Spacecraft Bus Requirements

The Infrared Observatory and Reflected Solar Observatory will use a common spacecraft bus meeting the following top-level performance requirements:

Orbit Definition:
- Orbit Period: 5812.4 +/- 0.25 s (609 km +/- 200m)
- Inclination: 90 +/- 0.1 degree

Spacecraft Reliability:
- The CLARREO spacecraft bus shall have a reliability of no less than 0.70 at 5 years

Consumables Lifetime:
- The CLARREO spacecraft bus shall have sufficient consumable resources to last 5 years

Decommissioning Policy:
- The CLARREO spacecraft bus shall comply with NPR-8715.6 for decommissioning

Launch Vehicle:
- The spacecraft bus shall be compatible for a dual manifested launch on a Minotaur IV+ launch vehicle

Payload:
- The spacecraft shall accommodate the payload mass, power, data rate/volume and Fields of Regard
Reflected Solar Observatory Drivers

Key Drivers for Reflected Solar Observatory

RS Reference Inter-calibration operations
- Require S/C yaw maneuver before and after gimbal slew and data collection

RS Instrument / gimbal motion relative to spacecraft

Iso view of RS Observatory showing FOV
Key Drivers for IR/RO Observatory

NOTES:
(1) “Ram” and “Wake” are relative terms due to the biannual year flips.
(2) “IR Zenith” and “IR Nadir” FOR accounts for 55° pointing needed for motion compensation in zenith and nadir views.

- Solar array range of motion (gray area)
  - Clears payload FOV’s
  - AD&CS components sized to handle torque from array

ISO view of IR/RO Observatory showing FOV’s
Common Spacecraft Bus Subsystems

**Electronic Power System**
- 83 A-Hr Li-Ion battery capacity
- 28V Direct Energy Transfer Power System
- Deployable, 4.9 m² (1262W EOL) single, two-axis articulating four panel array

**Command and Data Handling**
- Central Electronics Processor (C&DH / AD&CS)
  - Provide C&DH, Comm., Thermal, Propulsion, AD&CS and payload command and telemetry interfaces
- SSR: 128 Gbits/day (Includes contingency, margin & encoding)

**Communication**
- X-band downlink for science and engineering data
- S-Band for command uplink and H/K telemetry downlink

**Attitude Determination & Control**
- 3- axis stabilized attitude control system
- Star trackers, IMU, Coarse Sun Sensors, Magnetometer
- Reaction wheels, Magnetic Torque Bars
- GPS for orbit determination

**Propulsion**
- Monopropellant – Hydrazine blow down system
- 59.9 m/s estimated delta V budget (15.6 kg propellant)
- 4 + 4 2 N thrusters for injection dispersion, collision avoidance, and orbit maintenance

---

**CLARREO IR/GNSS-RO Observatory**
(Side view with S/A removed)

**Thermal**
- Bus thermal control using radiators, heaters and MLI
  - RS and GNSS-RO electronics rely on S/C bus for thermal control
  - Passive bus thermal control using radiators and MLI

**Mechanical / Structural**
- Al sheet over Al honeycomb panels
Spacecraft Bus Block Diagram

- **RF Communications**
  - S-Band Omni Antenna
  - S-Band Zenith Patch Antenna
  - X-Band Antenna
  - X-Band Transmitter

- **CLARREO Spacecraft Bus Block Diagram**
  - C&DH
    - C&DH / AD&CS Processors (2)
    - Solid State Recorder
    - Pyro Control
  - Electrical Power System
    - Power Distribution & Control Unit
    - Battery
    - Array Motor Drive

- **AD&CS**
  - Reaction Control Wheels (4)
  - IMU
  - Magnetometer
  - Magnetic Torque Burs (6)
  - GPS Receiver
  - Star Tracker (2)
  - Coarse Sun Sensors (6)

- **Propulsion**
  - Propellant Tank

- **Payload**
  - Solar Instrument Suite
  - Infrared Instrument Suite
  - GNSS-RO Instrument

- **Thermal Control / Survival Heaters**

- **Launch Vehicle Interface**

---

**Component** | **Redundancy**
--- | ---
Reaction Control Wheels | 4 for 3
Magnetic Torque Rods | Redundant Windings
Star Tracker Assembly | 2 for 1
Batteries | Additional cells
Power Distribution & Control Unit | Internally Redundant
C&DH / AD&CS Processor | 2 for 1
Solar Array | Additional strings
Solar Array Drive Assembly | Electrically Redundant
Solid State Recorder (SSR) | Internally Redundant
Thrusters | 8 for 4
6. Mission Status
Mission Status

- CLARREO successfully completed its Mission Concept Review (MCR) on November 17, 2010

- The next mission milestone is to complete Key Decision Point -A (KDP-A) planned for February/March 2011

- Following KDP-A the mission team will commence Phase A activities leading to a mission System Requirements Review (SRR) planned for early to mid-2012