CloudSat Mission Report
18 June 2012

A NASA EARTH SYSTEM SCIENCE PATHFINDER MISSION

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Topics:

1. CloudSat science accomplishments
   – G. Stephens
2. (a) A very busy year; (b) CPR performance
   – D. Vane
3. Spacecraft performance and Daylight-Only Operations (DO-Op)
   – I. Gravseth
4. Back in the A-Train: Overlap with CALIPSO – B. Braun
5. Data product development and release
   – P. Partain

CloudSat's Science Accomplishments

Graeme Stephens

A short list: *The Science Accomplishments of CloudSat (and CALIPSO)*

1. Vertical resolved and improved measurements of 3-D distribution of cloud phase and water or ice water content from CloudSat and CALIPSO.

2. New insights on Polar aerosol and cloud properties and related processes

3 .*CloudSat has provided the first global climatology of warm precipitation from boundary layer cloud systems. This is important because warm rain is now understood to be a key process controlling boundary layer and low cloud structure. In addition, because warm rain production is both sensitive to aerosol and also removes aerosol by coalescence scavenging, the CloudSat observations are providing unique insights into aerosol-cloud interactions on the regional to global scale*

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4. By combined use of CloudSat rain and precipitation radar aboard TRMM, Behrangi et al. (2012) showed that the quasi-global (60oS-60oN) oceanic mean rain rate is about 3.05 mm/day, considerably larger than that obtained from any individual sensor product and GPCP. Within the deep-tropics, especially within 20oS-20oN, the majority of precipitation measuring sensors (e.g., TMI, PR, AMSR-E, AMSU) show the highest agreement amongst themselves to quantify rain frequency and amount with a large fraction of total rain volume captured by the majority of sensors. However, towards higher latitudes and within the subtropical high pressure regions, a significant fraction of rainfall is missed by the majority of the sensors that can exceed 50% or more of total rain volume. CloudSat was able to complement the current capabilities of precipitation measuring sensors to give a more realistic precipitation measurement over ocean.

5. Together CloudSat and CALIPSO have provided us with a significantly more complete picture of the distribution of radiation in the Earth's atmosphere and advanced our knowledge of the role clouds and aerosols play in modifying it. New insights from our new merged flux/heating rate and precipitation products have already allowed us to refine estimates of amount of radiation that is absorbed into the world's oceans, given us a new appreciation for the importance of clouds in the Arctic climate system, and improved our understanding of both aerosol direct radiative effects and aerosol-cloud-precipitation interactions on global scales.

6. CloudSat, in conjunction with other A-Train members, has enabled innovative research in tropical convection and hurricanes. New framework has been developed to evaluate GCM cloud/convection parameterization.

7. ISCCP Weather States are associated with distinctive patterns of cloud vertical structure. Eventually, this should allow us to connect distinctive 3-D cloud structures, as well as radiative and latent heating distributions, with characteristic meteorological conditions and thence to the main aspects of the atmospheric general circulation.

8. Measurements of cloud vertical profiles from CloudSat serve as critical observational metrics for evaluation of climate models.

9. CloudSat observations offer unambiguous depiction of cloud vertical structure change to the surface temperature warming on interannual time scale.

10. characterizing the spatial structure of hydrometeor (cloud and precipitation) fields, especially in regard to vertical structure. The ability to characterize spatial structure in a detailed and self-consistent way over the entire globe has enabled us to study more effectively regional differences and to evaluate global models. This is especially important for those regions where little (if any) cloud radar data has ever been gathered before, such as over many of the world's remote oceans and the polar regions. The challenges before us now are to refine our understanding of what drives this structure, to transfer this understanding into models, and to continue the observations for sufficiently long that we can observe how these structures vary in time and change in response to forcings such as ENSO.

11) We developed a synergy cloud mask by using CloudSat and CALIPSO and obtain
global distribution of cloud occurrence.
The data is further compared with ISCCP in day time and showed good agreement in cloud cover (by Rossow's group).
CALIPSO detects more clouds in low levels over ocean while CloudSat detects more clouds in low levels over land
This is because the the strong attenuation of liar signals occurred and only CloudSat can penetrate them to low levels.

12) Global distribution of ice cloud microphysics is analyzed by using CloudSat and CALIPSO data.
Ice water content (IWC) is larger over land than over ocean due possibly to the larger vertical air motion over land.
The very large ice >100 micro-m can be found in the temperature ranges between -20 to -10 degrees C
in all latitude regions.
The unique feature is that the global distribution of oriented ice plate can be also examined by the algorithm. The global distribution of the mass ratio of ice plate to the total ice water content
showed that the ratio can exceed 10% in the temperature between -20 to -10 degrees C for all latitude regions.

CloudSat Project Status Report

Deborah Vane

A VERY Busy Year - 2011

18 April
CloudSat experienced a significant battery anomaly.
18 June
CloudSat executed a maneuver to exit the A-Train and to avoid a close conjunction with Aqua.
24 June
The S/C control computer was powered up successfully and re-established sequenced control of the S/C.
30 September
The Cloud Profiling Radar (CPR) was activated for 3 minutes, demonstrating DO-Op
12 October
CPR successfully activated for 5 minutes.
14-26 Oct
CPR operation increases from 20 to 54 minutes per orbit.
1 Nov
0.16 degree offset in pointing; SSR on continuously

By the end of CY 2011, ~400 operations memograms (directives) and >150 anomaly meetings.

CPR is now operating ~54 minutes in the daylight portion of the orbit, and the DO-Op mode has been successfully demonstrated.

ANOTHER Very Busy Year - 2012

3 Feb
Failed orbit-raise to re-enter the A-Train

The 3 Feb failure and the fact that GCOM-W1 launch was delayed until May, required a complete re-plan of CloudSat's ascent to re-enter the A-Train.

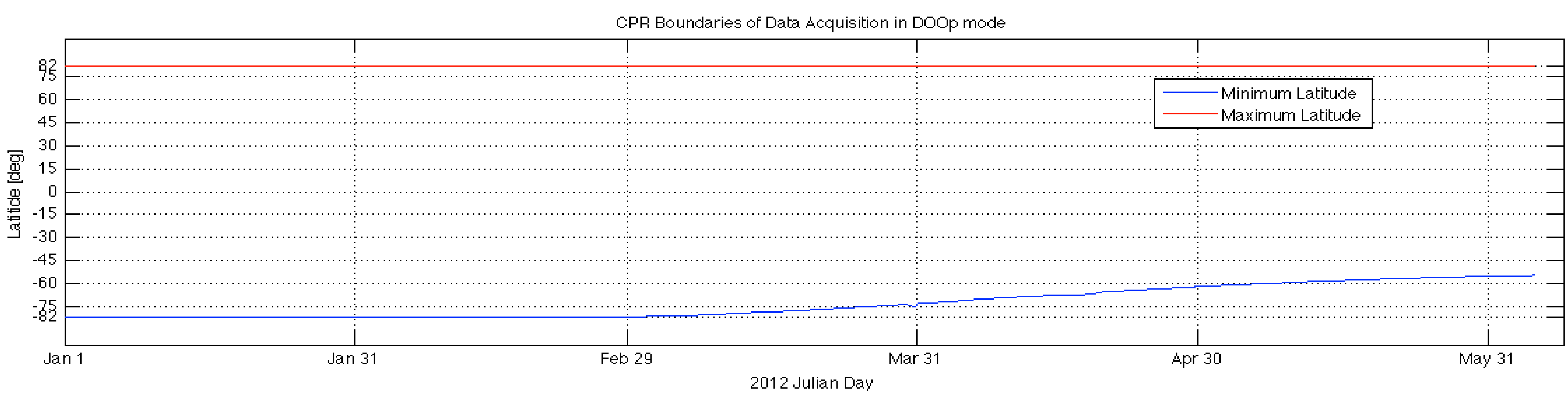
3 Feb – 5 May
- 6 'no-burn' demo-practice maneuvers on-orbit
- 4 successful thruster-burn maneuvers: orbit lower, orbit raise (trim), inclination decrease, orbit raise #1
- 1 failed orbit lower maneuver.

15 May
CloudSat successfully re-enters the A-Train!

PLEASE DROP BY THE BALL AEROSPACE POSTER AT TODAY'S POSTER SESSION.

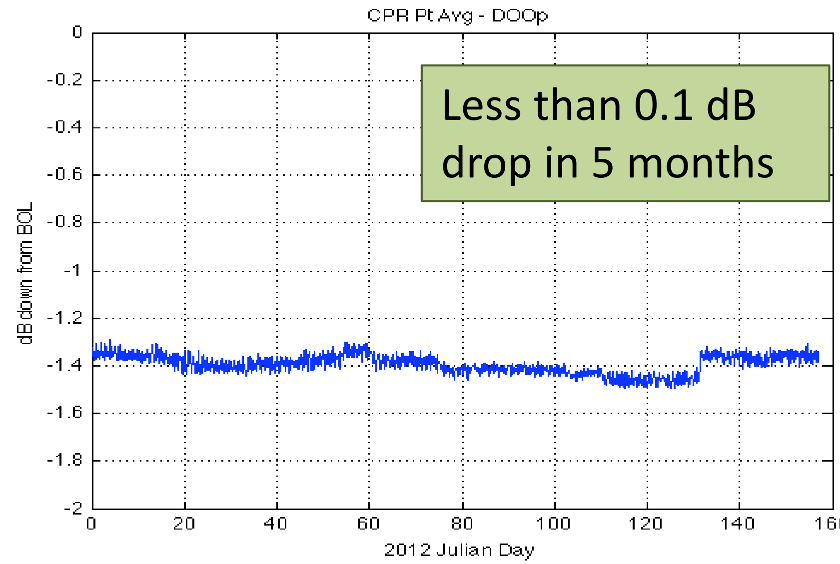
CPR Function

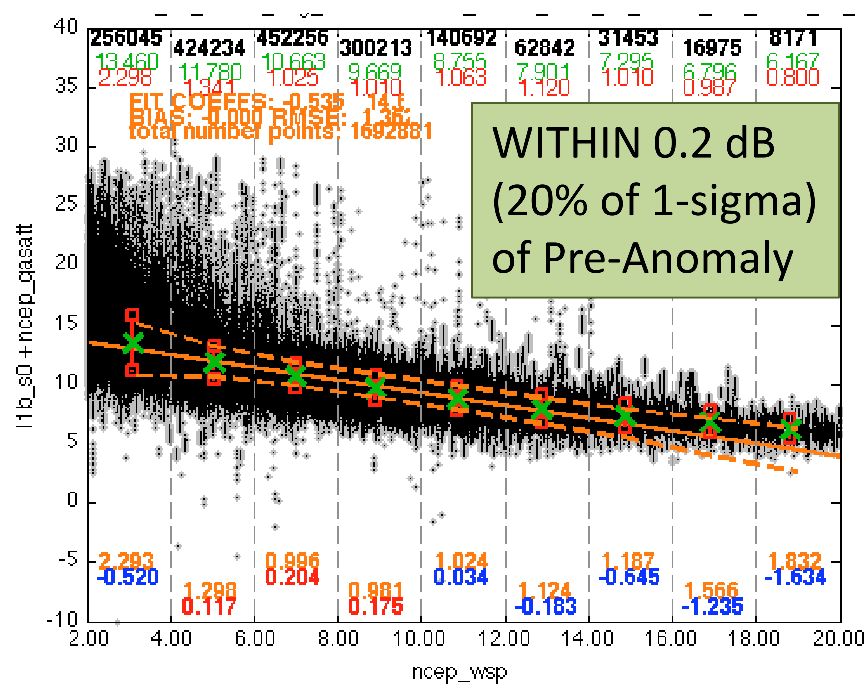
- CPR did not suffer any degradation because of the anomaly
  - Radar and spacecraft automated fault responses protected the instrument from harmful voltages.
  - Direct exposure to sun was never long enough to harm the radar
  - All radar functions unchanged with respect to the time immediately prior to the anomaly
  - CPR acquires data approximately 54.5 minutes every 99 (1 orbit).
    - It starts transmitting about 8 minutes after the spacecraft emerges from the dark side. So, in MJJ we miss almost entirely Antartica.
    - It stops transmitting less than a minute before entering the dark side. So we don't miss the Arctic.



CPR Performance

- CPR performance is actually improved with respect to 2010/2011
  - We regained a few tenths of dB in sensitivity because we now are back to **transmitting all the pulses** that we can.
  - Radar **calibration** and performance do not show any significant change between April 2011 and December 2012.
  - Rate of decay of RF Peak Power is smaller than pre anomaly because we run only 55% of the time. **EIK switchover possible next winter.**
- Pointing:
  - The correlation of DEM and CPR surface features indicates that DEM and CPR features are within 1 km most of the time (96%).
  - Largest areas of discrepancy are the usual suspects (Northern GreenLand, the Bolivar region and Alaska) where the DEM quality is degraded. But there is a new entry…
  - …for some reason New Zealand appears to be 2 km off. Keep this in mind until investigation is completed.



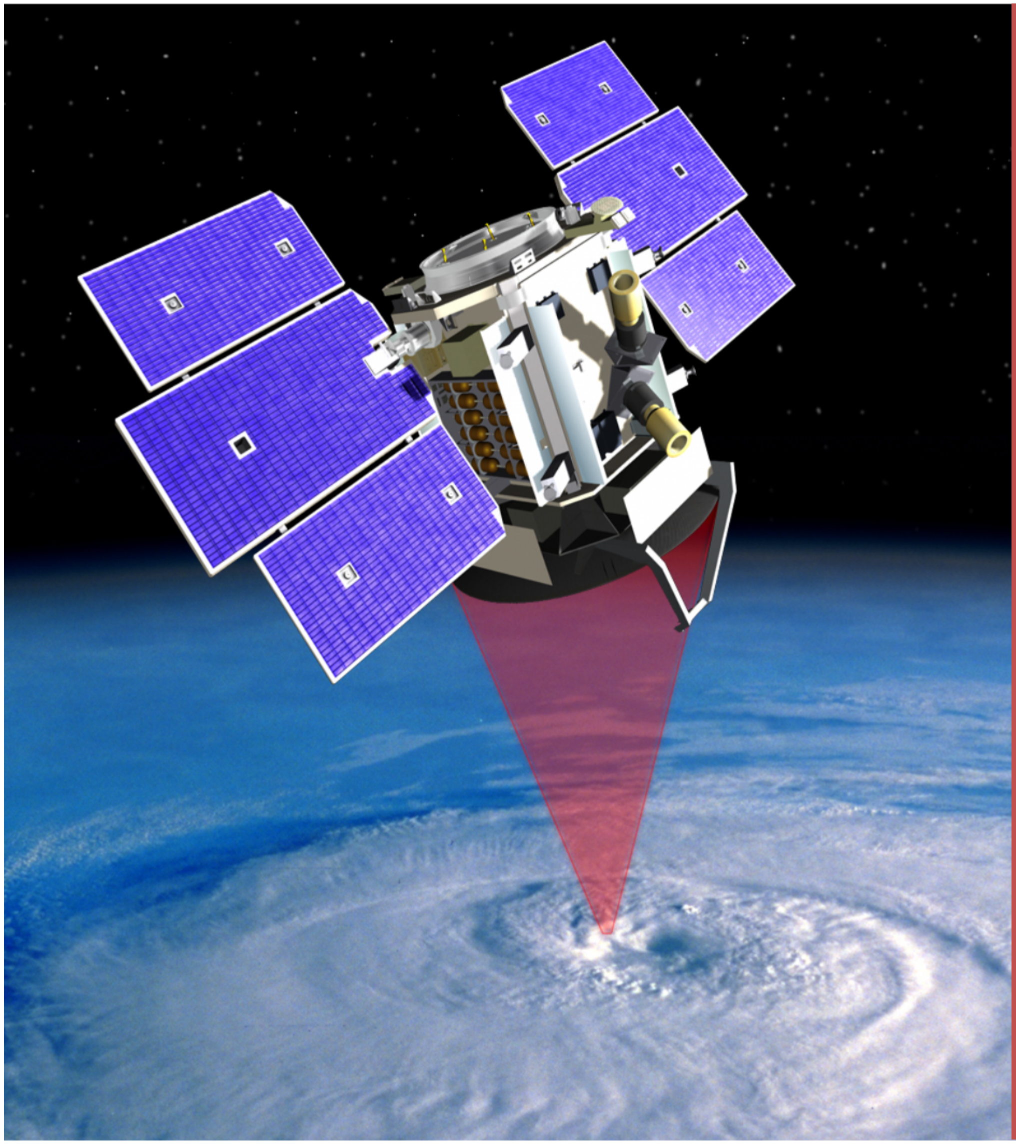


Spacecraft performance and Daylight-Only Operations (DO-Op)

These slides are being cleared by Ball Aerospace

Ian Gravseth
Ball Aerospace

On 17 April 2011 CloudSat suffered a battery anomaly that threatened to end the mission

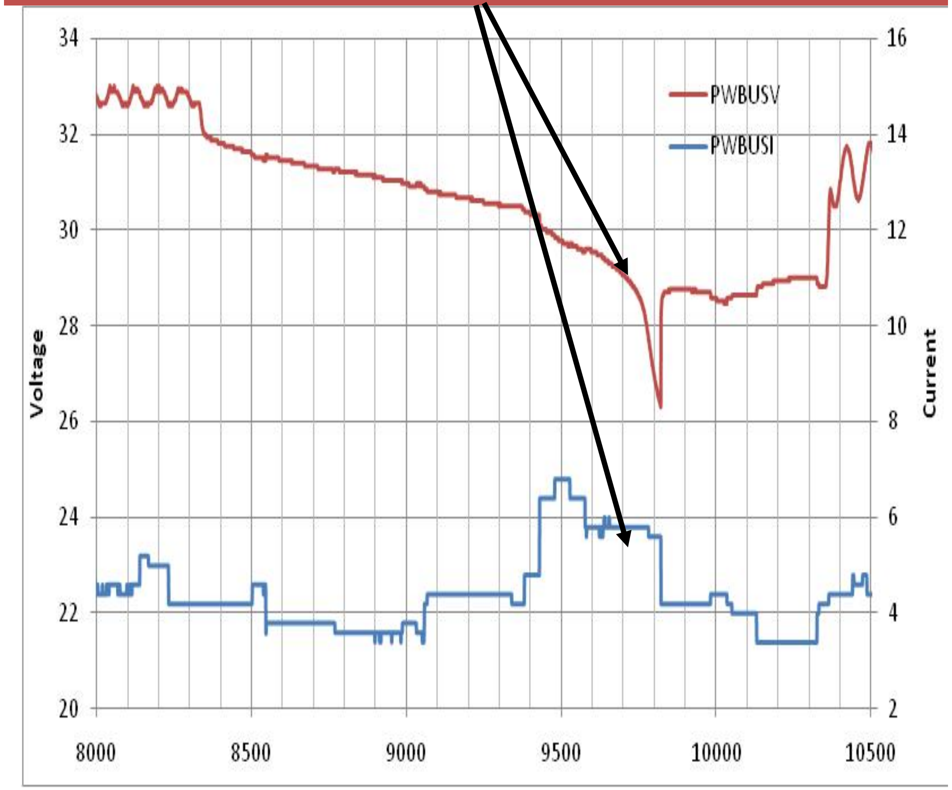


- The CS battery has a name-plate capacity of 40 amp-hr
- Just prior to the anomaly, the battery had been able to routinely support discharge rates of more than 15 amps
- After the anomaly, it could only support discharge rates of 5.25 amps or less
- To operate just the Bus through eclipse the battery needed to supply 7 amps
- To continue the mission it was necessary to develop a mode of operation that could live within this power constraint

CloudSat issues are caused by diffusion-limited current in the battery[1]

- Normal aging causes a loss of electrolyte in the battery
  - Capillary forces cause the separator to give up electrolyte to the nickel electrode
  - Charge/Discharge cycling causes electrochemical corrosion of the nickel electrode further reducing the available electrolyte
- Eventually a diffusion-limiting current is reached when there is insufficient electrolyte to support the current being withdrawn causing a sudden drop in voltage

- Voltage drops dramatically when discharge current exceeds 5.25 amps
- Voltage recovers when current is reduced to below 5.25 amps

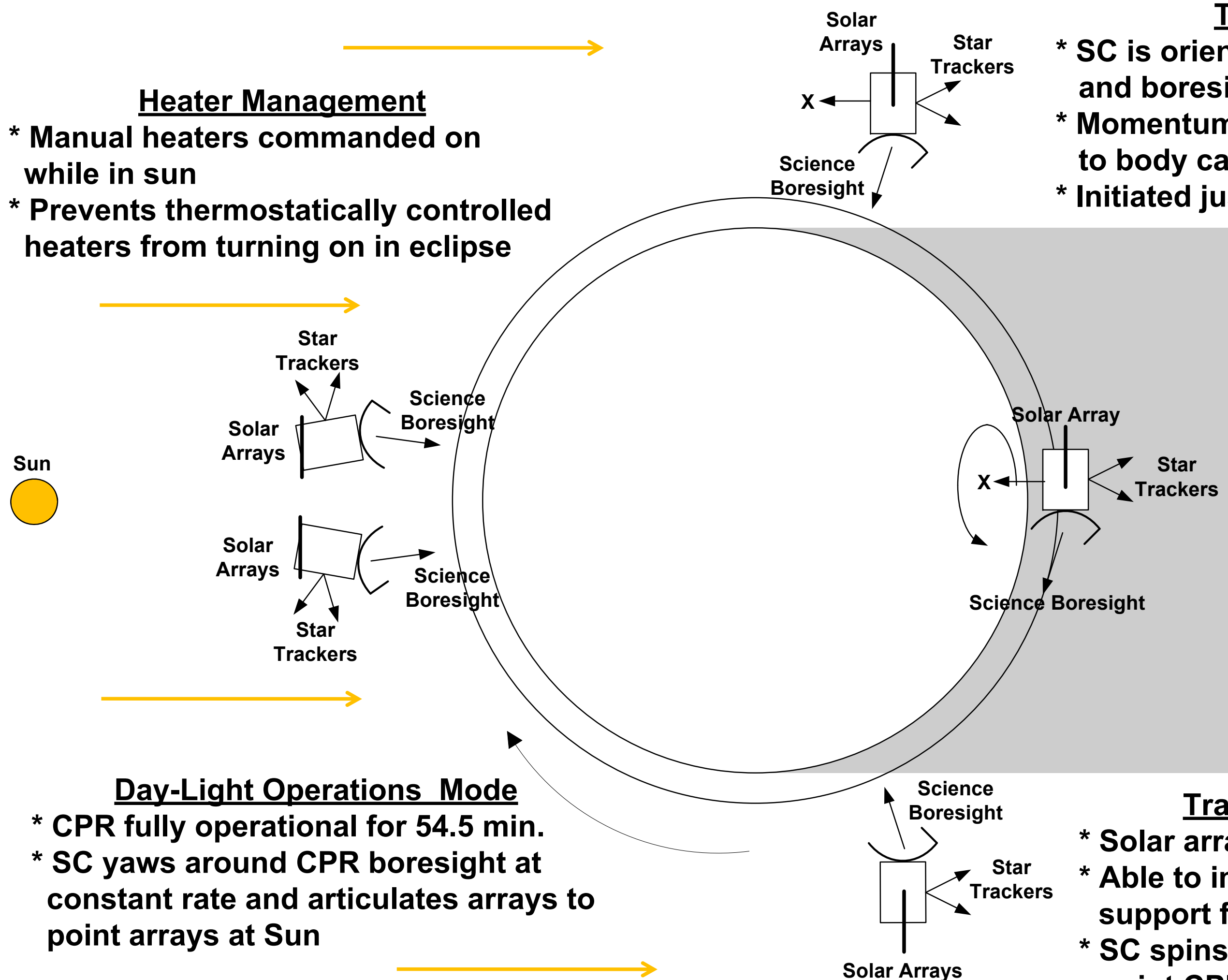


[1]Reference: Aerospace Report No. TR-98(8555)-16, Volume Tolerance Characteristics of a Nickel Hydrogen Cell, 2 July 1998, L. H. Thaller, M. V. Quinzin, and G. A. To

Daylight Only Operations (DO-Op) mode developed to deal with this battery issue

Heater Management
* Manual heaters commanded on while in sun
* Prevents thermostatically controlled heaters from turning on in eclipse

Transition to Hibernate
* SC is oriented with Y-axis normal to Sun and boresight pointed at Nadir
* Momentum stored in wheels is transferred to body causing SC to spin around X-axis
* Initiated just prior to eclipse entrance



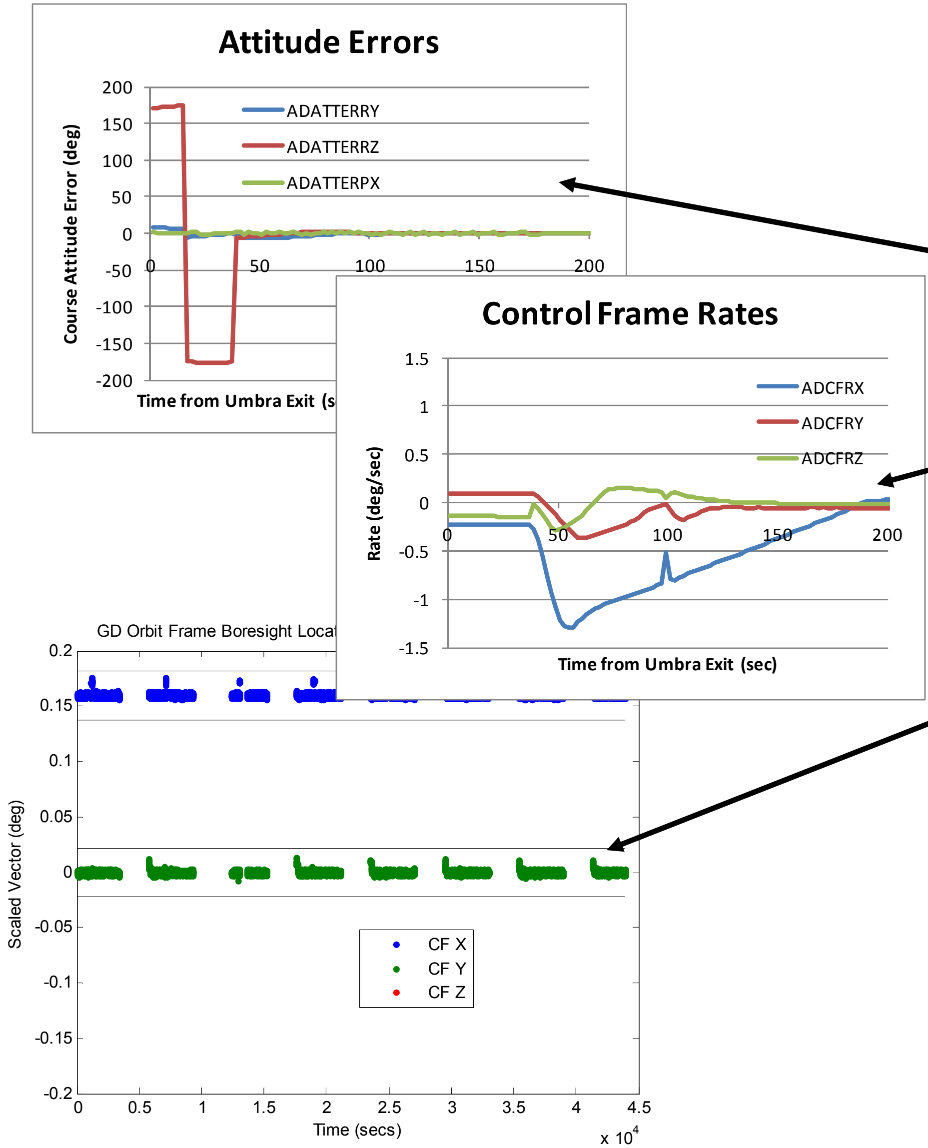
Hibernate
* Nearly all loads shed including Attitude Control System
* Very low power consumption
* Battery easily supports loads through eclipse
* Spin stabilization maintains SC attitude with respect to the Sun

Day-Light Operations Mode
* CPR fully operational for 54.5 min.
* SC yaws around CPR boresight at constant rate and articulates arrays to point arrays at Sun

Transition to Operations Mode
* Solar array is pointed at Sun at eclipse exit
* Able to immediately start recovery without support from battery
* SC spins down and maneuvers to point CPR boresight at nadir

STK Movie of CloudSat in DO-Op Mode of Operation

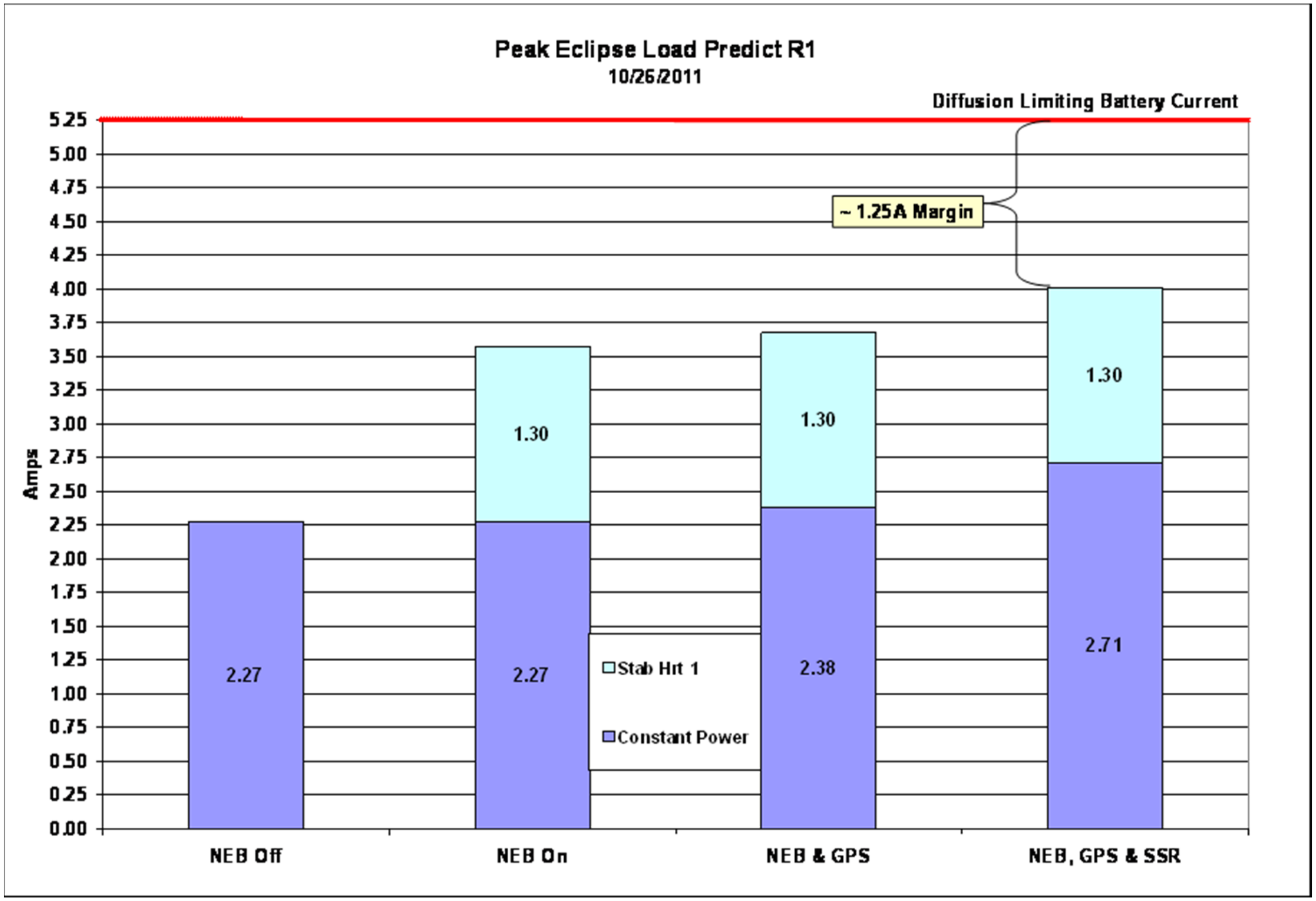
DO-Op has proven to be precise, repeatable, and very dependable



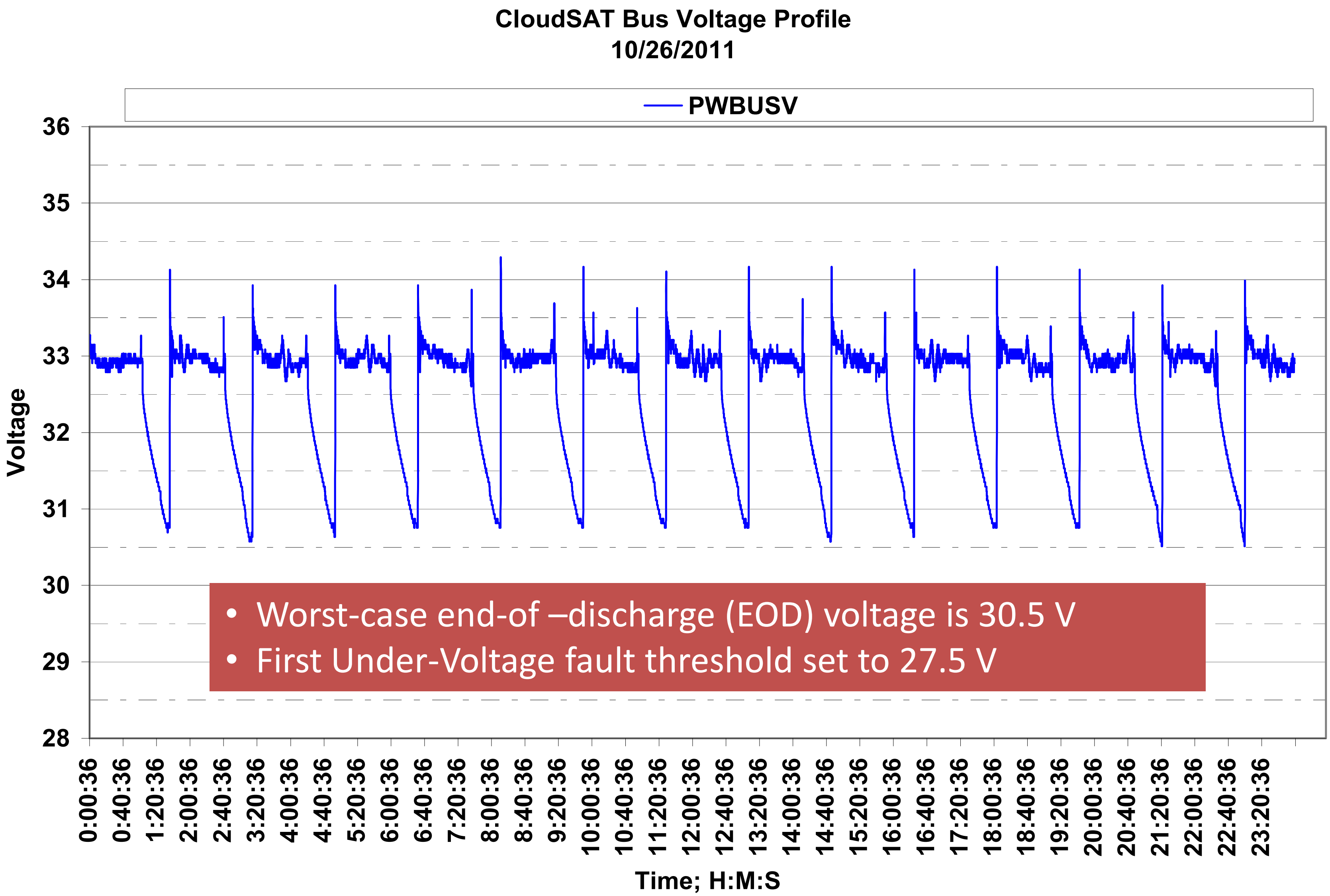
- Solar array is pointed within 10 degrees of the sun at eclipse exit. Able to start CPR power on ~ 30s after starting recovery
- Attitude errors smoothly converge with minimal overshoot during recovery
- Maneuver rates are well controlled and transition to the science attitude achieved within 5 min.
- No degradation in pointing accuracy using momentum bias and yaw steering in DO-Op
- Vehicle smoothly transitions into hibernate 40s prior to entering eclipse
- DO-Op operating flawlessly since September 2011

The battery easily supports Hibernate loads

- Peak discharge current in DO-Op is 4.0 amps providing 30% margin to battery diffusion current limit. Standby Mode (NEB off) has > 90% margin



Battery voltage is being maintained well above fault thresholds



- Worst-case end-of –discharge (EOD) voltage is 30.5 V
- First Under-Voltage fault threshold set to 27.5 V

Anticipated Future Performance

- Other than the battery all systems are operating well within normal parameters and there are no signs of degradation
- Redundancy is largely still in place
  - One command receiver is no longer functional
- Battery is being treated very gently minimizing the rate of degradation
- CPR elays should be able to support 8 more years of on/off cycling

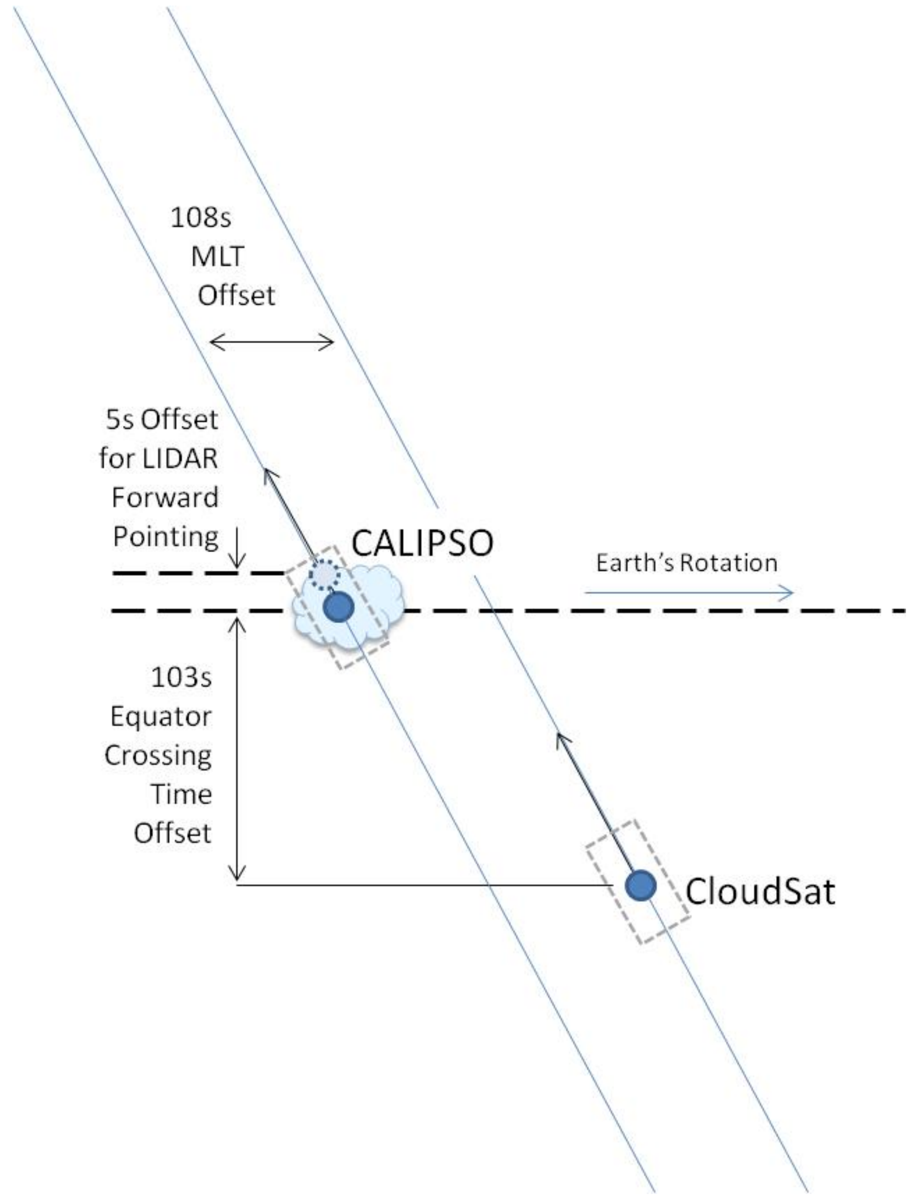
CloudSat should continue to meet mission objectives for many years to come

Back in the A-Train: Overlap with CALIPSO

Ron Boain, JPL, California Institute of Technology
Barbara Braun, Aerospace Corp.

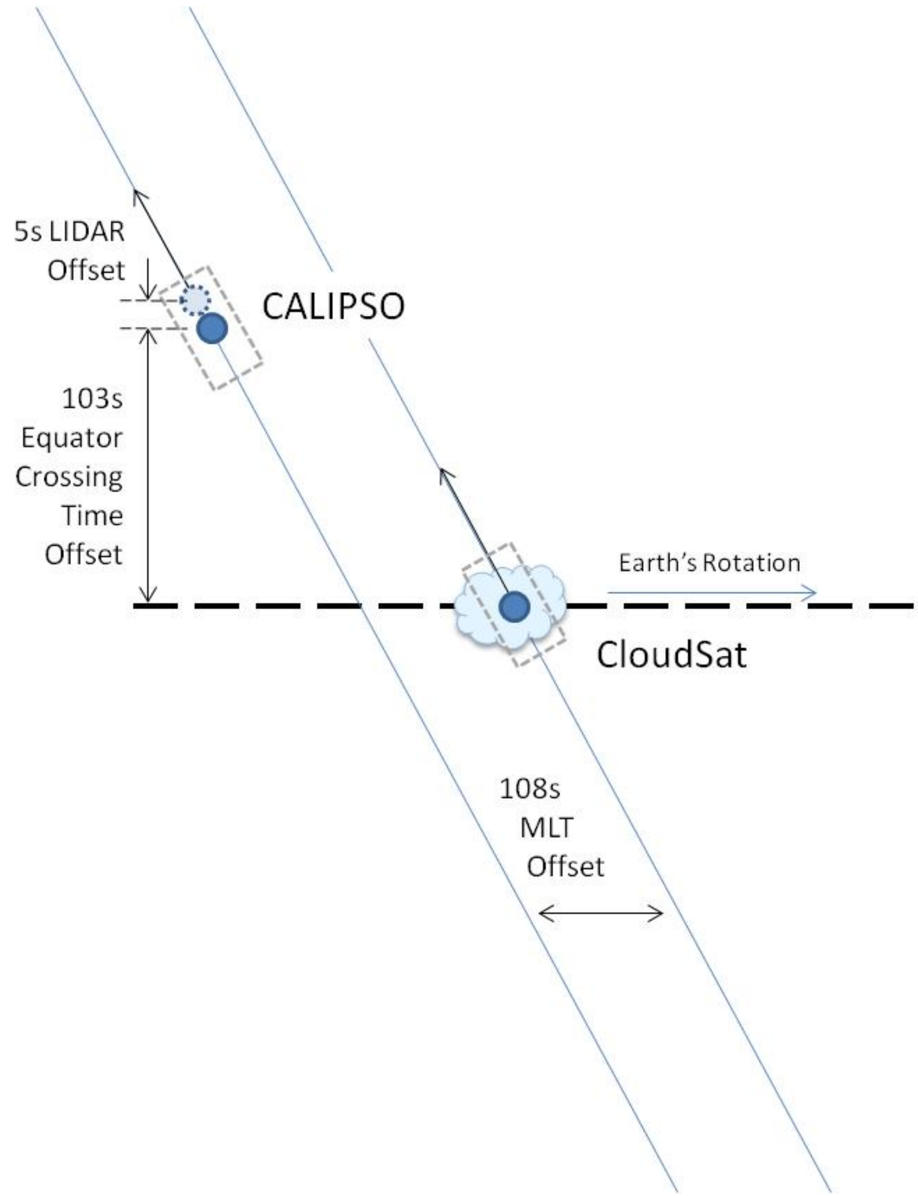
CloudSat's Control Box

- CloudSat is in its new A-Train Control Box
  - Control box is 43 seconds wide and centered 103 seconds behind the center of CALIPSO's control box
  - If both satellites are in the center of their boxes, CloudSat crosses the equator 103 seconds after CALIPSO crosses the equator
  - CALIPSO's LIDAR points a few degrees forward, so it sweeps the earth 5 seconds in front of CALIPSO's satellite sub-point



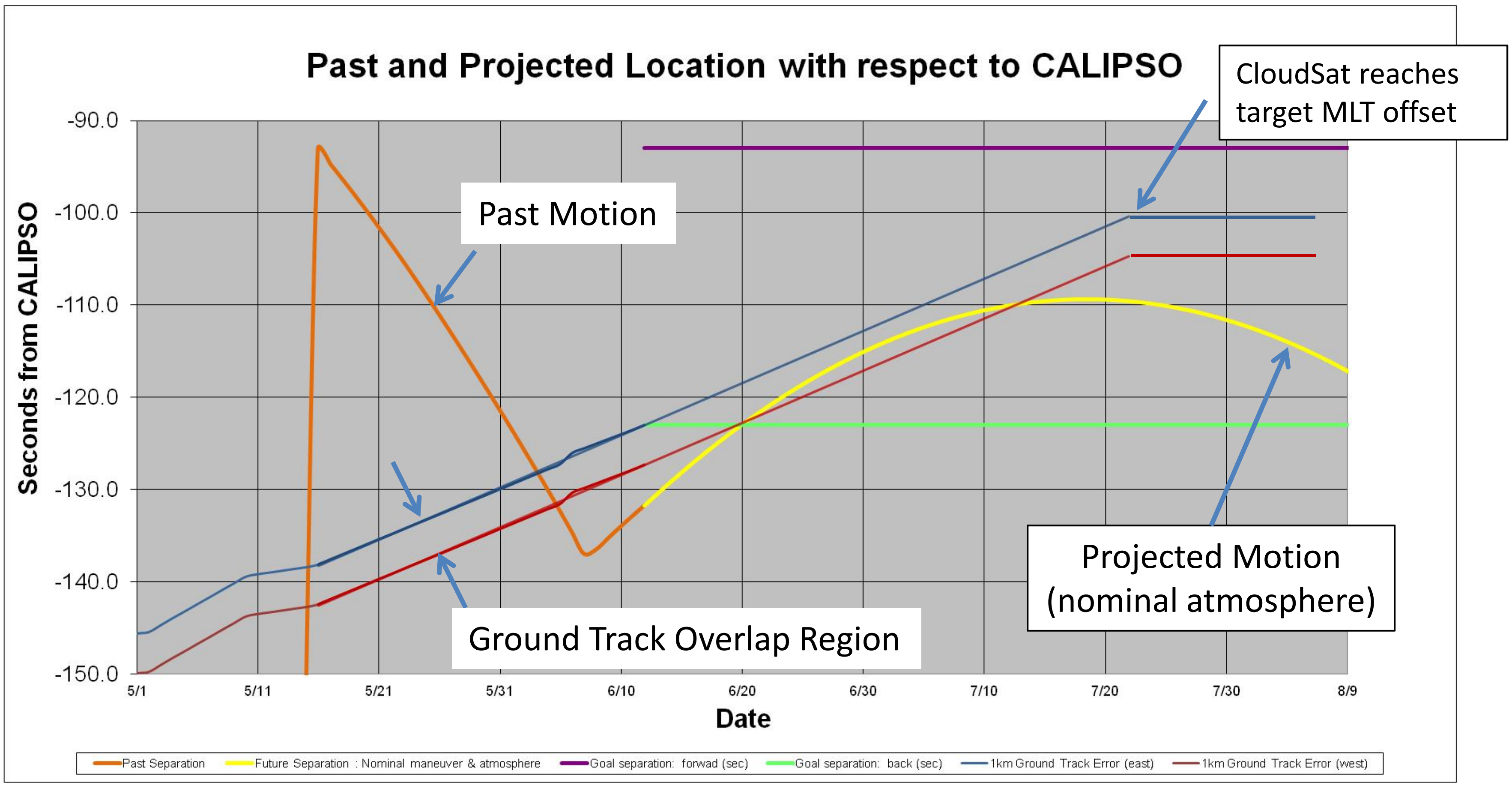
CloudSat's MLT Offset

- CloudSat is approaching its desired Mean Local Time (MLT) offset from CALIPSO
  – In late July, CloudSat will be at desired offset (and will maneuver to stop its drift)
  – This offset is 108 seconds, to compensate for the 103 second equator crossing offset, plus 5 seconds for CALIPSO's LIDAR forward pointing
  – When the time offset and the MLT offset match, the two satellites have good ground track overlap



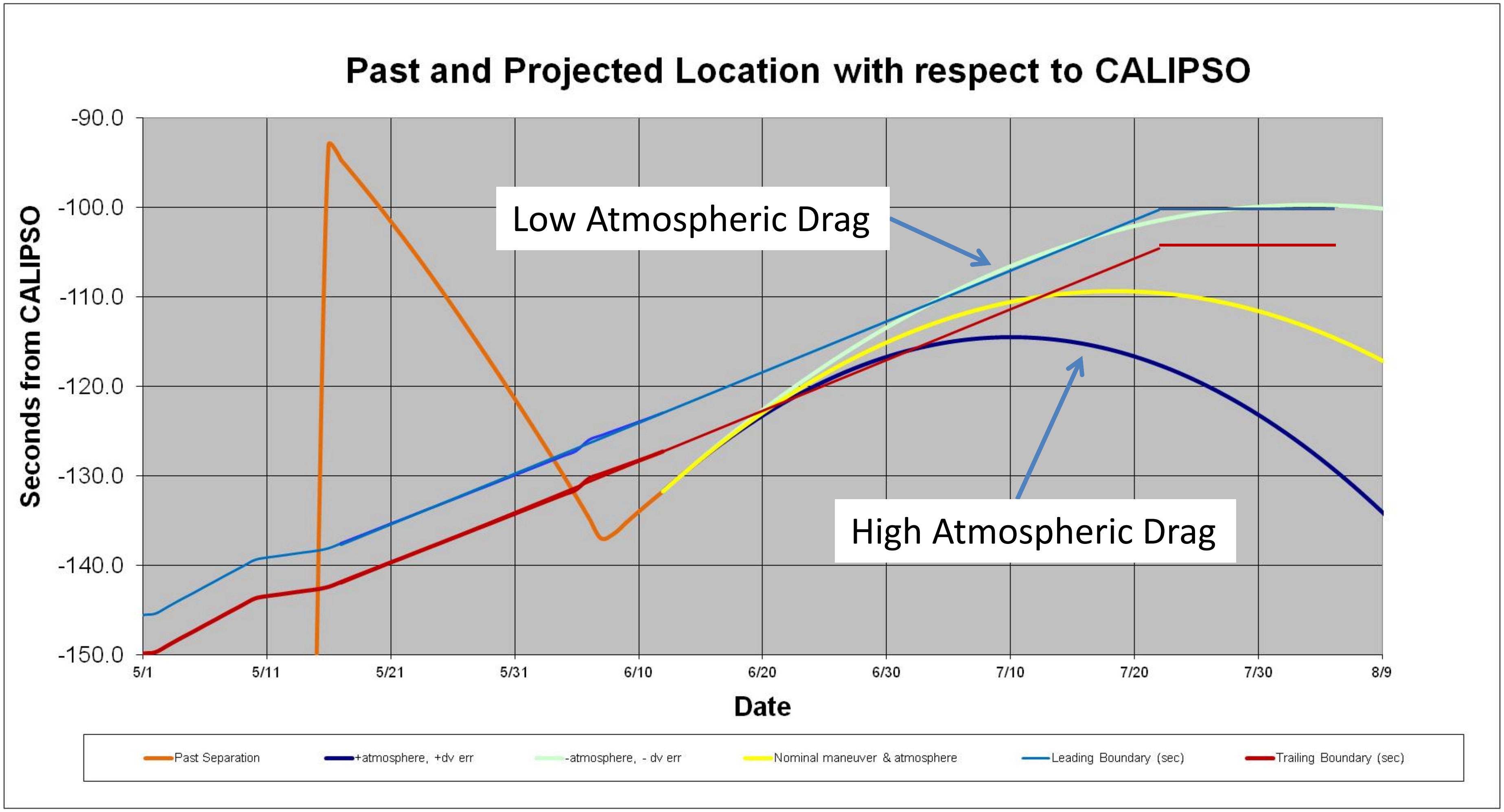
Coordinated Flying

- CloudSat and CALIPSO move independently in their control boxes
- CloudSat's goal is to keep the two satellites at the right distance from each other for good ground track overlap, while minimizing the number of CloudSat maneuvers



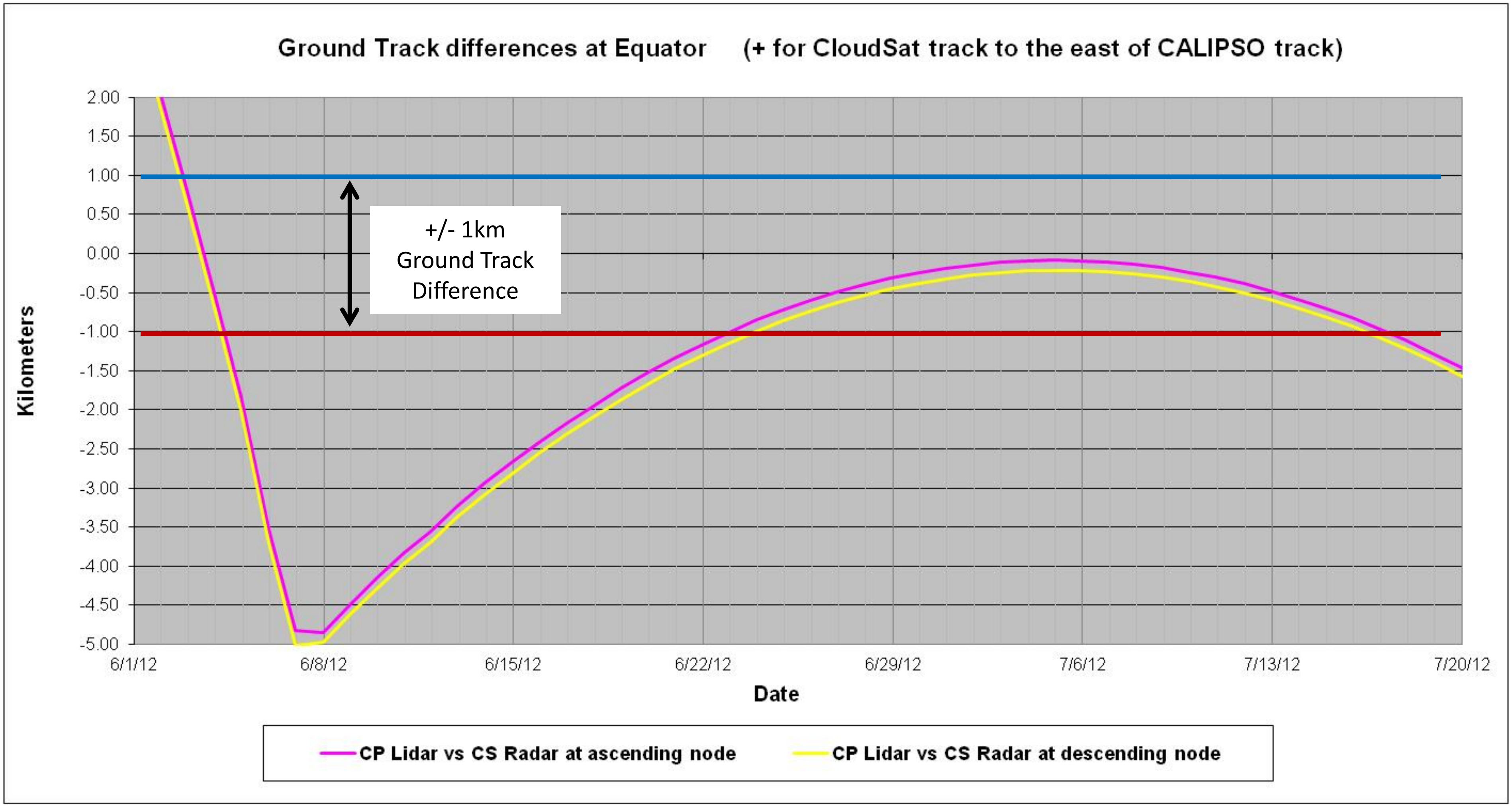
Coordinated Flying

- However, this is difficult, given the large effect that atmospheric drag plays in the relative motion of the two satellites



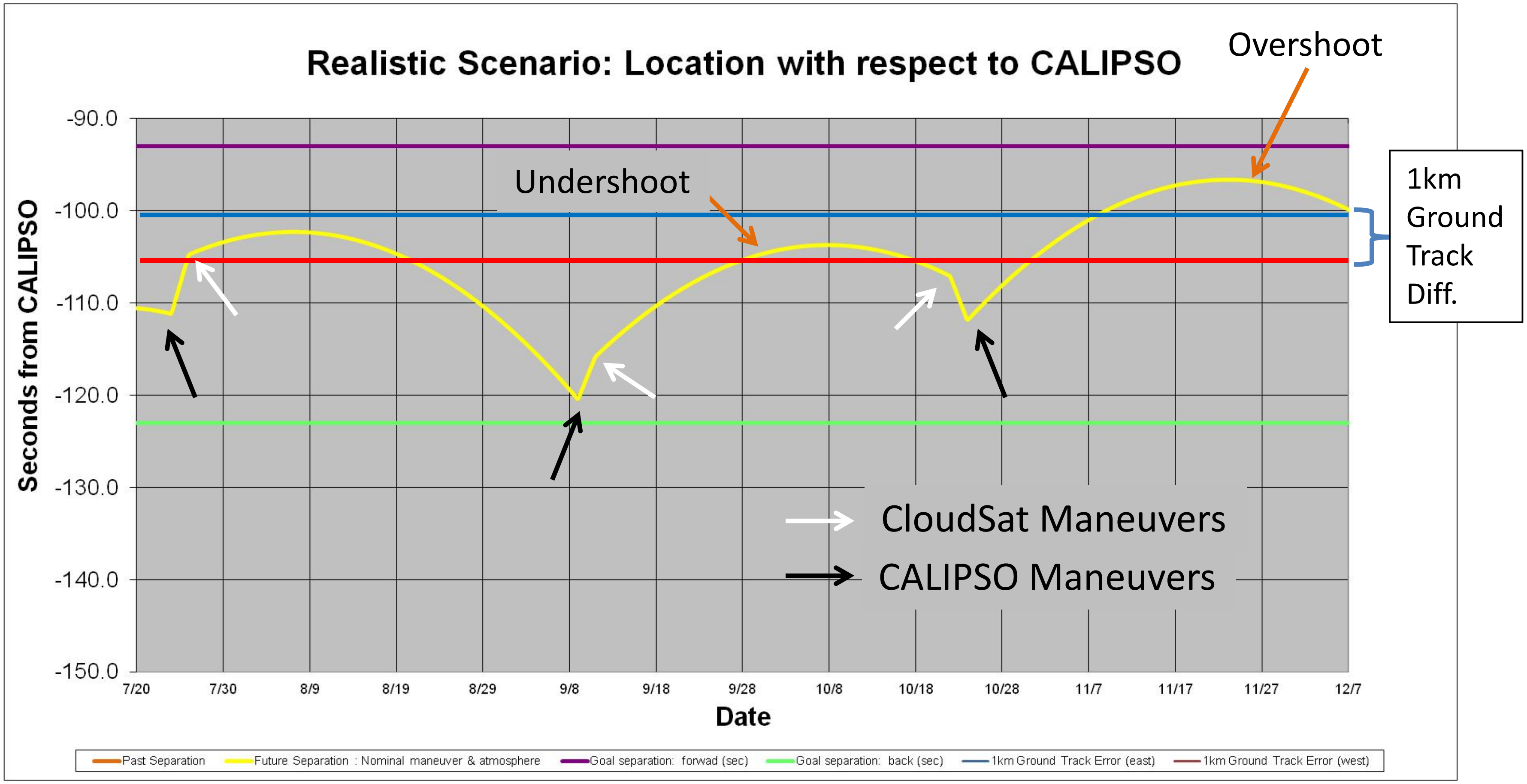
Coordinated Flying

- In the short term, we appear to be heading toward a period of good ground track overlap



Coordinated Flying

- Over the long term, we may have more difficulty maintaining this overlap
  - Initial plans are to try to limit maneuvers to one drag make-up maneuver for each CALIPSO drag make-up maneuver
  - The unpredictability of the atmosphere makes it difficult to get the “aim point” right



Coordinated Flying

- The goal is to keep CloudSat's ground track within +/- 1km of CALIPSO's ground track as much as possible
  - While conducting as few maneuvers as possible, nominally only drag make-up maneuvers
- While it is theoretically possible to achieve ground track overlap as much as 50% of the time, in practice this is difficult given the maneuver policy
  - The atmosphere is difficult to predict
  - Extra maneuvers to compensate for atmospheric change may not be operationally practical
  - Even when the ground tracks differ by more than 1km at the equator, they "come together" as they approach the poles
  - The orbits intersect at the poles, and further from the equator, the earth's rotation generates less ground "travel"
  - Good ground track overlap can still be achieved through much of the orbit

CloudSat Data Product Status

Philippe Partain
CloudSat Data Processing Center
Cooperative Institute for Research in the Atmosphere (CIRA)
Colorado State University

Epoch Summary

- **E00:** **2 Jun 2006 (day 153) - 7 Jul 2006 (day 188)**
  Spacecraft pointing error.
- **E01:** **7 Jul 2006 (day 188) - 15 Aug 2006 (day 227)**
  Pointing error corrected to point nadir.
- **E02:** **15 Aug 2006 (day 227) - 7 Dec 2009 (day 341)**
  Pointing changed again to minimize specular reflection.
- **E03:** **15 Jan 2010 (day 15) - 15 Feb 2011 (day 46)**
  Reduced CPR pulse rate due to battery anomaly.
- **E04:** **15 Feb 2011 (day 46) - 17 Apr 2011 (day 107)**
  Variable CPR pulse rate to manage battery health.
- **E05:** **27 Oct 2011 (day 300) - ~15 May 2012 (day 136)**
  CloudSat out of the A-Train due to another battery anomaly.
- **E06:** **~15 May 2012 (day 136) - present**
  CloudSat back in the A-Train formation.

R04 Data Products Released prior to the Battery Anomaly

E00 – E04: 2 Jun 2006 - 17 Apr 2011

Product	Description
1B-CPR-FL	Near-real time received echo powers
1B-CPR	Calibrated received echo powers
MODIS-AUX	MODIS subset around CloudSat footprint
ECMWF-AUX	ECMWF interpolated to CloudSat bins
2B-GEOPROF	Reflectivity & cloud mask
2B-CLDCLASS	Cloud Classification
2B-CWC-RO	Radar only liquid/ice water content
2B-TAU	Cloud optical depth
2B-CWC-RVOD	Radar + tau liquid/ice water content
2B-FLXHR	Radiative fluxes & heating rates
2B-GEOPROF-LIDAR	CloudSat/CALIPSO cloud mask
2B-CLDCLASS-LIDAR	CloudSat/CALIPSO cloud classification
2C-PRECIP-COLUMN	Column integrated precipitation
2C-RAIN-PROFILE	Vertical distribution of rain
2C-ICE	Radar/lidar microphysics

R04 Data Product Status (E05)

E05: **27 Oct 2011 - ~15 May 2012** (TBD)

1B-CPR-FL: Processed & released to subscribers.

1B-CPR: Processed & being evaluated.

MODIS-AUX: No MODIS data so files are filled with missing values.

ECMWF-AUX: Modified for ECMWF GRIB 2 format, processed & being evaluated.

2B-GEOPROF: Processed & being evaluated.

2B-CLDCLASS: Processed & being evaluated.

Evaluation of other Level 2 products to follow.

R04 Data Product Status (E06)

E06: **~15 May 2012 - present**

MODIS-AUX: Test files have been received from GSFC that continue to be evaluated at the DPC. **E06** will start with first available operational data set.

2B-GEOPROF-LIDAR & 2B-CLDCLASS-LIDAR: Coordinated flying with CALIPSO will begin **mid-July**, though some prior coincident data may be processed. Expect **~50%** footprint overlap.

R04 Enhanced Data Product Status

2B-FLXHR-LIDAR: P_R04 released to Science Team Dec 2011, issues prevent release to the general community (see DPC news page for details). **Version P1_R04 is being evaluated**.

2C-PRECIP-COLUMN: P1_R04 being modified to use NISE data set. **Reprocessing may wait until R05**.

2C-SNOW-PROFILE: **In beta**, ongoing test & evaluation.

The Next Release: R05 Data Product Status

0A-CPR & 1A-AUX (raw instrument & telemetry processing):
Being QC'd for the mission-to-date.

1B-CPR, **MODIS-AUX, ECMWF-AUX, 2B-GEOPROF, 2B-TB94**:
Processed for specified dates & **being evaluated** by developers.

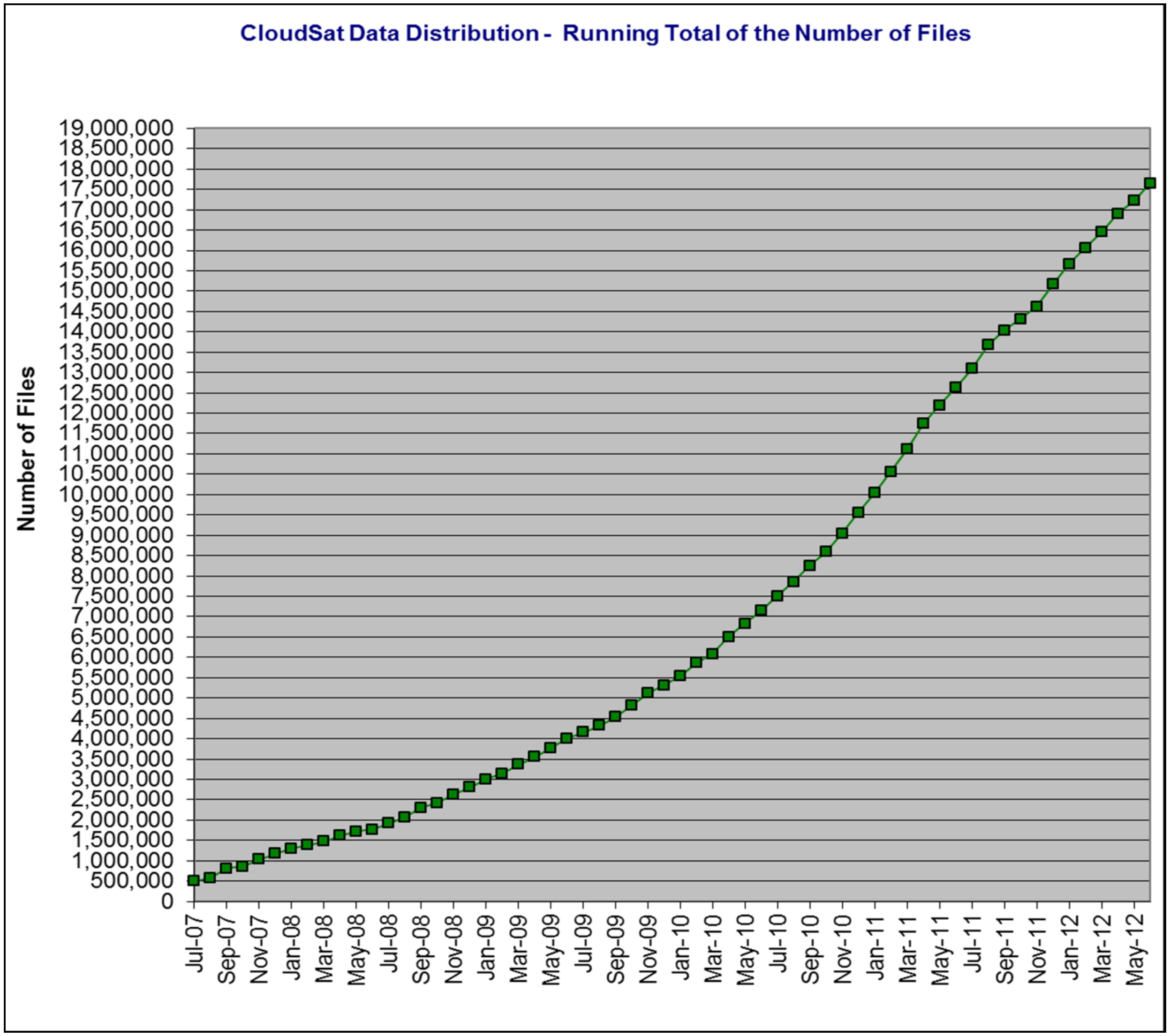
TAU and PRECIP products:
New development to ensure consistency when handling precipitation.

Level 3 Products:
Processing to begin with R05.

Data Distribution Summary

<u>Mission-to-date:</u>
Files: 17,649,993
Volume: 1.090 Petabytes

2839 Data Users
(currently average
~40 new users/month)



CloudSat-related Data Distribution Projects at the DPC

CloudSat

http://cloudsat.cira.colostate.edu

Mission standard & enhanced Level 1B, 2B, & 2C data products.

Year of Tropical Convection (YOTC)

http://yotc.cira.colostate.edu

Data from other platforms and models co-located with CloudSat.
AIRS, AMSR-E, CALIPSO, CERES, ECMWF MLS, and MODIS

Light Precipitation Validation Experiment (LPVEx)

http://lpvex.atmos.colostate.edu

International field project with airborne, land, and ship-based instrumentation in the vicinity of Helsinki, Finland (15 Sep – 15 Dec 2010)

See poster "*Products Available at the CloudSat Data Processing Center*" for more details