Investigation of Upload Anomalies Affecting IIR Satellites in October 2007

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Outline

- Overview
- Anomaly Sequence
  - *Space/Control Perspective*
  - *Signal-in-Space Perspective*
  - *Receiver "Coasting" Perspective*
- Event Timelines and Potential Impact Windows
- Anomaly Aftermath
- Ancillary "Anomalies"

Overview

- **14 Sep 07: Master Control Station (MCS) swap**
  - ***From Legacy MCS (20+ years of history)***
  - ***To Architecture Evolution Plan (AEP) MCS***
- **8-10 Oct 07, anomalies occurred on IIRs/IIR-Ms**
  - ***8 Oct 07, anomaly occurred on PRN19/SVN59***
  - ***8 Oct 07, anomaly occurred on PRN12/SVN58***
  - ***8 Oct 07, anomaly occurred on PRN14/SVN41***
  - ***9 Oct 07, anomaly occurred on PRN23/SVN60***
  - ***9 Oct 07, anomaly occurred on PRN16/SVN56***
  - ***10 Oct 07, anomaly occurred on PRN20/SVN51***

Interesting Anomalies

- Should have been simple anomalies
  - Anomalously packaged data sent in upload
  - Satellite goes to non-standard code (NSC)
  - Recover by reinitializing/restarting satellite
  - Users only see temporary interruption of service
- Conflicting reports on user observations
  - Most users saw just a temporary interruption
  - Some users saw huge pseudorange errors
- Conflicting user reports required investigation

General Sequence

Start at ⇨ *Satellite operating normally*

1. Anomalously packaged upload sent

   Satellite goes anomalous

2. Satellite restarted

   Satellite goes to NSC + default data

3. Standard code commanded

   Satellite goes to standard code + default data

4. Uploaded with data indicating unhealthy

   Satellite in standard code + normal “unhealthy” data

5. Uploaded with data indicating healthy

   Satellite in standard code + normal “healthy” data

Normal satellite start-up sequence

Back to ⇨ *Satellite operating normally*

Interesting Aspects of Anomaly Sequence

Start at ⇨ *Satellite operating normally*

1. Anomalously packaged upload sent

   Satellite goes anomalous (standard C/A + random data)

   Not too interesting

2. Satellite restarted

   Satellite goes to NSC + default data + clock reset

   Very interesting

3. Standard code commanded

   Satellite goes to standard code + default data

4. Uploaded with data indicating unhealthy

   Satellite in standard code + normal “unhealthy” data

5. Uploaded with data indicating healthy

   Satellite in standard code + normal “healthy” data

Back to ⇨ *Satellite operating normally*

Two-Hour Transmit, Four-Hour Curve Fit

IS-GPS-200D, Paragraph 20.3.4.4 (“Data Sets”)

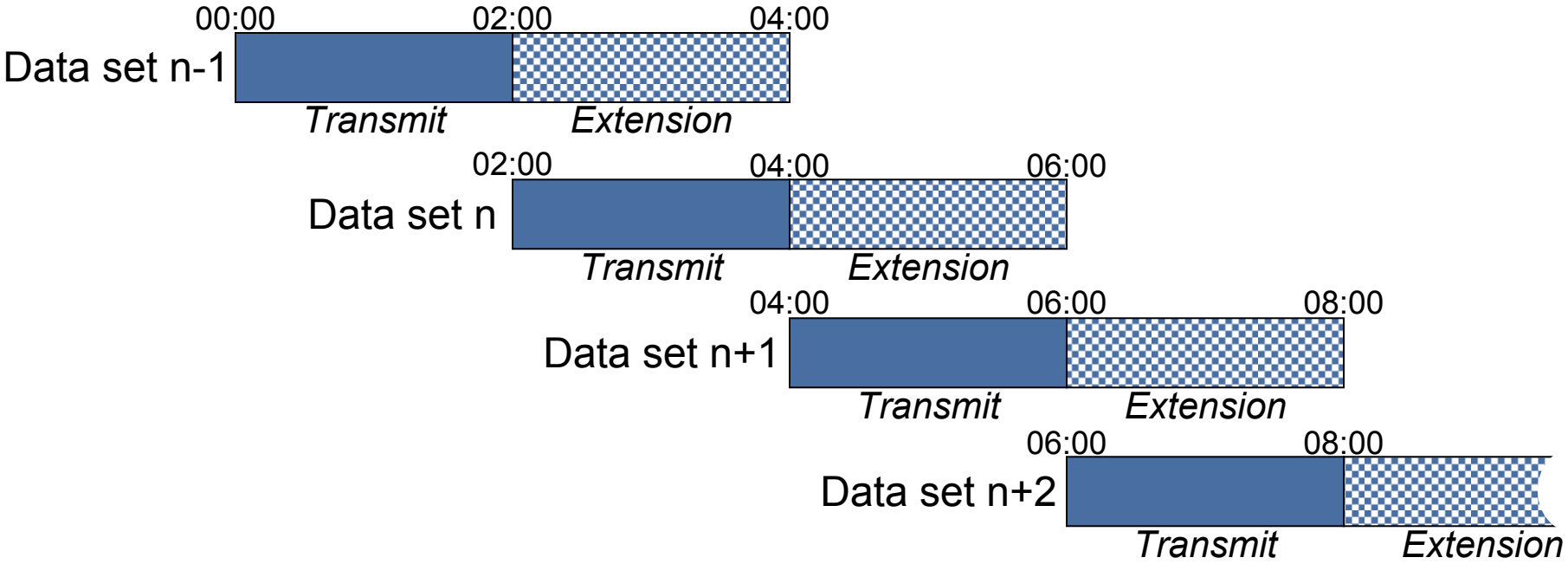
…

“The start of the transmission interval for each data set corresponds to the beginning of the curve fit interval for the data set. Each data set remains valid for the duration of its curve fit interval.

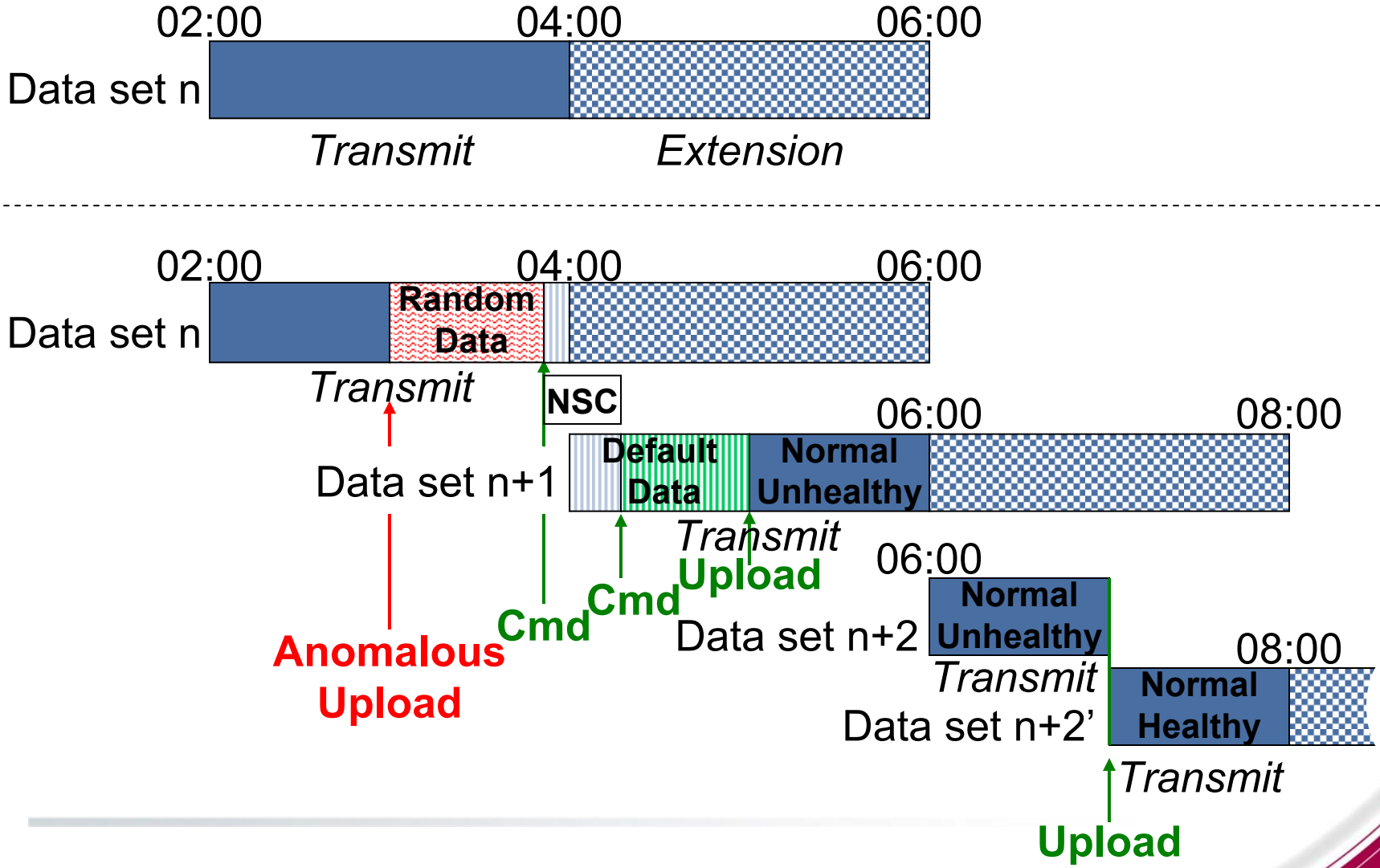
Normal Operations. The subframe 1, 2, and 3 data sets are transmitted by the SV for periods of two hours. The corresponding curve fit interval is four hours.”

…

Two-Hour Transmit, Four-Hour Curve Fit



Transmit/Curve Fit During an Anomaly



Coasting on Old Data

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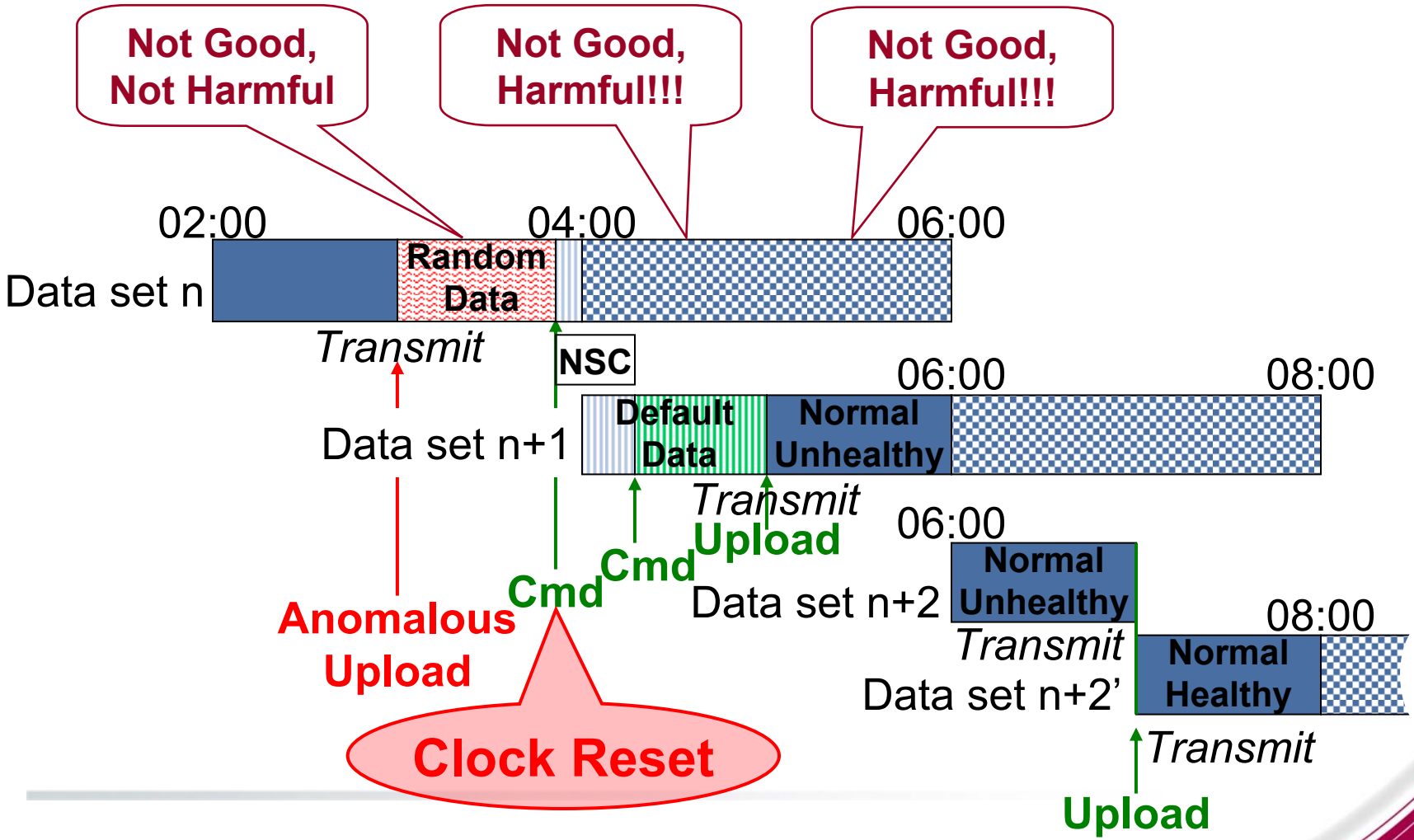
…

- **Allows receivers to “coast” on old data set**
  - **In case of a problem acquiring next data set**
    - **Reduced C/N_0 due to interference, obscuration, etc.**

Not Good Times to Coast



Coasting vs. Health Bits

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…

- **Health bits override assumed data set validity**
  - **No matter when health bits change during curve fit interval**
- **Receiver assumes risk if not reading health bits**

RTCA/DO-229D on the Subject

Paragraph 2.1.1.5.5 (“GPS UNHEALTHY Designation”)

The equipment shall designate any GPS satellite as GPS UNHEALTHY if the GPS satellite navigation message meets any of the following conditions:

a) ...;

b) Failure of parity on 5 successive words (3 seconds);

c) ...;

d) ...;

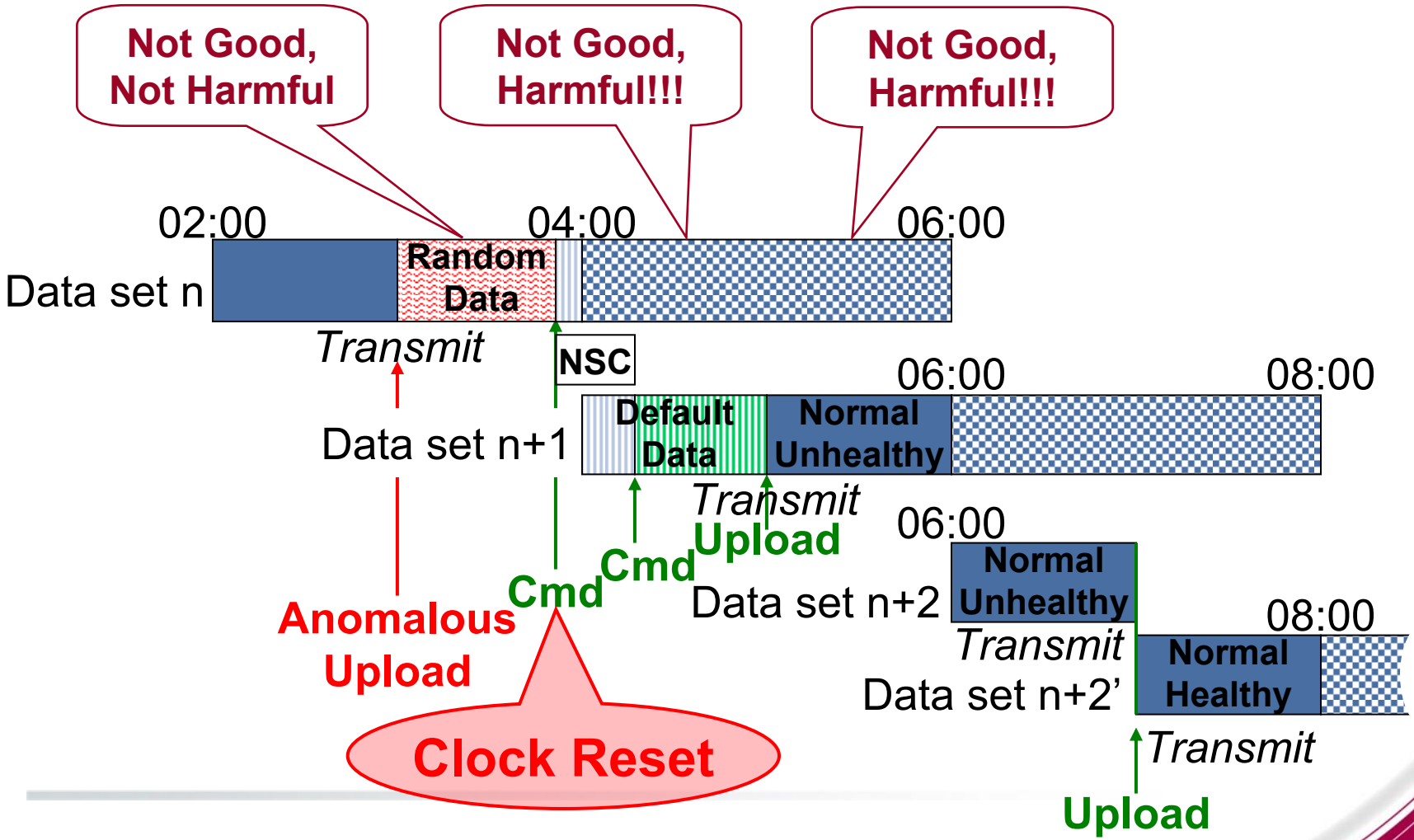
e) ...;

f) Default navigation data is being transmitted in subframes 1, 2, or 3 (ref. 20.3.3.2 of IS-GPS-200D, “Navstar GPS Space Segment / Navigation User Interfaces”, December 2004); or

g) The preamble does not equal 8B (hexadecimal) or 139 (decimal).

The GPS UNHEALTHY status for a satellite shall be changed only after the condition has cleared.

Not Good Times to Coast



Event Timelines

Event	PRN 19 / SVN 59	PRN 12 / SVN 58	PRN 14 / SVN 41
Anomaly start(1)	08 Oct 2007 04:15:06	08 Oct 2007 06:32:37	08 Oct 2007 21:01:42
Watchdog monitor off(2)	08 Oct 2007 06:22:17	Not done	Not done
PROM operation(3)	08 Oct 2007 09:01:53	08 Oct 2007 09:05:53	08 Oct 2007 21:40:45
Nonstandard code off(4)	08 Oct 2007 12:24:53	08 Oct 2007 11:40:04	09 Oct 2007 00:11:28
Set unhealthy(5)	08 Oct 2007 12:26:56	08 Oct 2007 11:56:55	09 Oct 2007 00:21:25
Set healthy(6)	08 Oct 2007 16:36:00	08 Oct 2007 16:49:00	09 Oct 2007 01:43:00
Duration	12:20:54	10:16:23	04:41:18

Event	PRN 23 / SV 60	PRN 16 / SVN 56	PRN 20 / SVN 51
Anomaly start(1)	09 Oct 2007 08:54:03	09 Oct 2007 11:59:28	10 Oct 2007 08:24:32
Watchdog monitor off(2)	Not done	Not done	Not done
PROM operation(3)	09 Oct 2007 08:58:41	09 Oct 2007 12:02:43	10 Oct 2007 08:32:31
Nonstandard code off(4)	09 Oct 2007 09:51:50	09 Oct 2007 12:54:17	10 Oct 2007 09:05:50
Set unhealthy(5)	09 Oct 2007 10:38:27	09 Oct 2007 13:29:25	10 Oct 2007 09:53:26
Set healthy(6)	09 Oct 2007 11:16:00	09 Oct 2007 13:59:00	10 Oct 2007 11:04:00
Duration	02:21:57	01:59:32	02:39:28

Event Timelines – Bad Times to Coast

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Event Timelines – One More Bad Time

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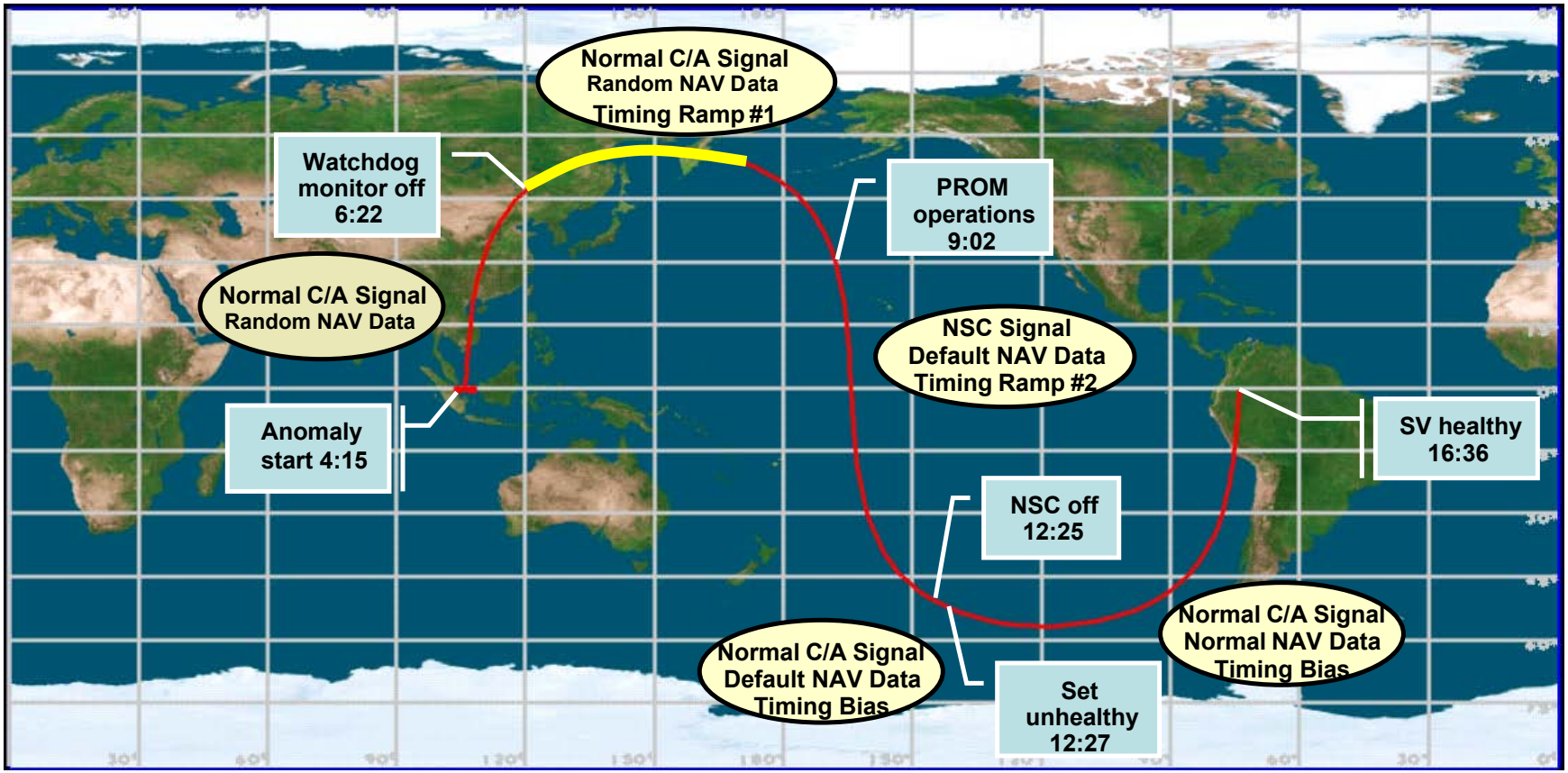
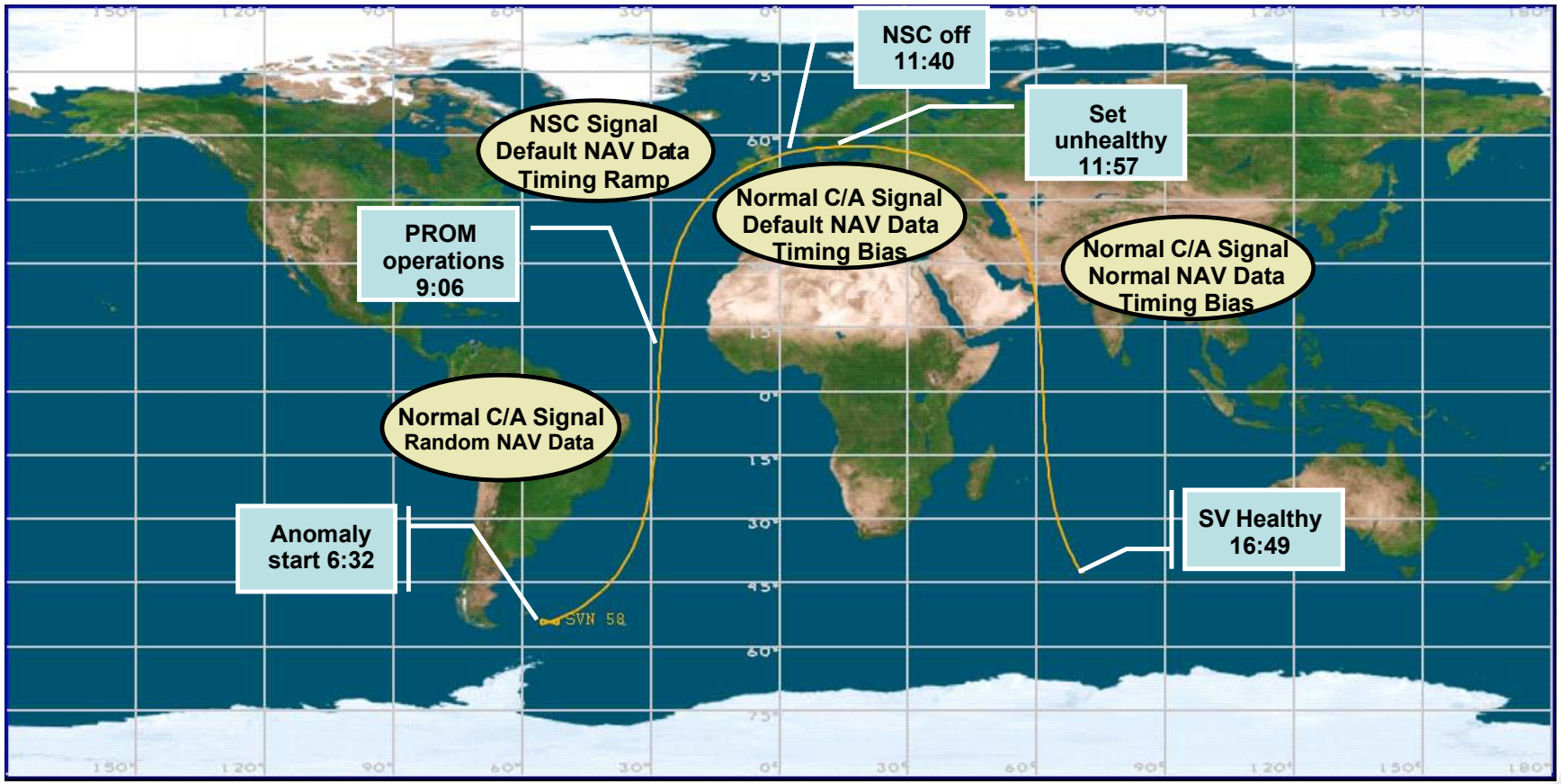
Set healthy[6]	09 Oct 2007 11:16:00	09 Oct 2007 13:59:00	10 Oct 2007 11:04:00
Duration	02:21:57	01:59:32	02:39:28

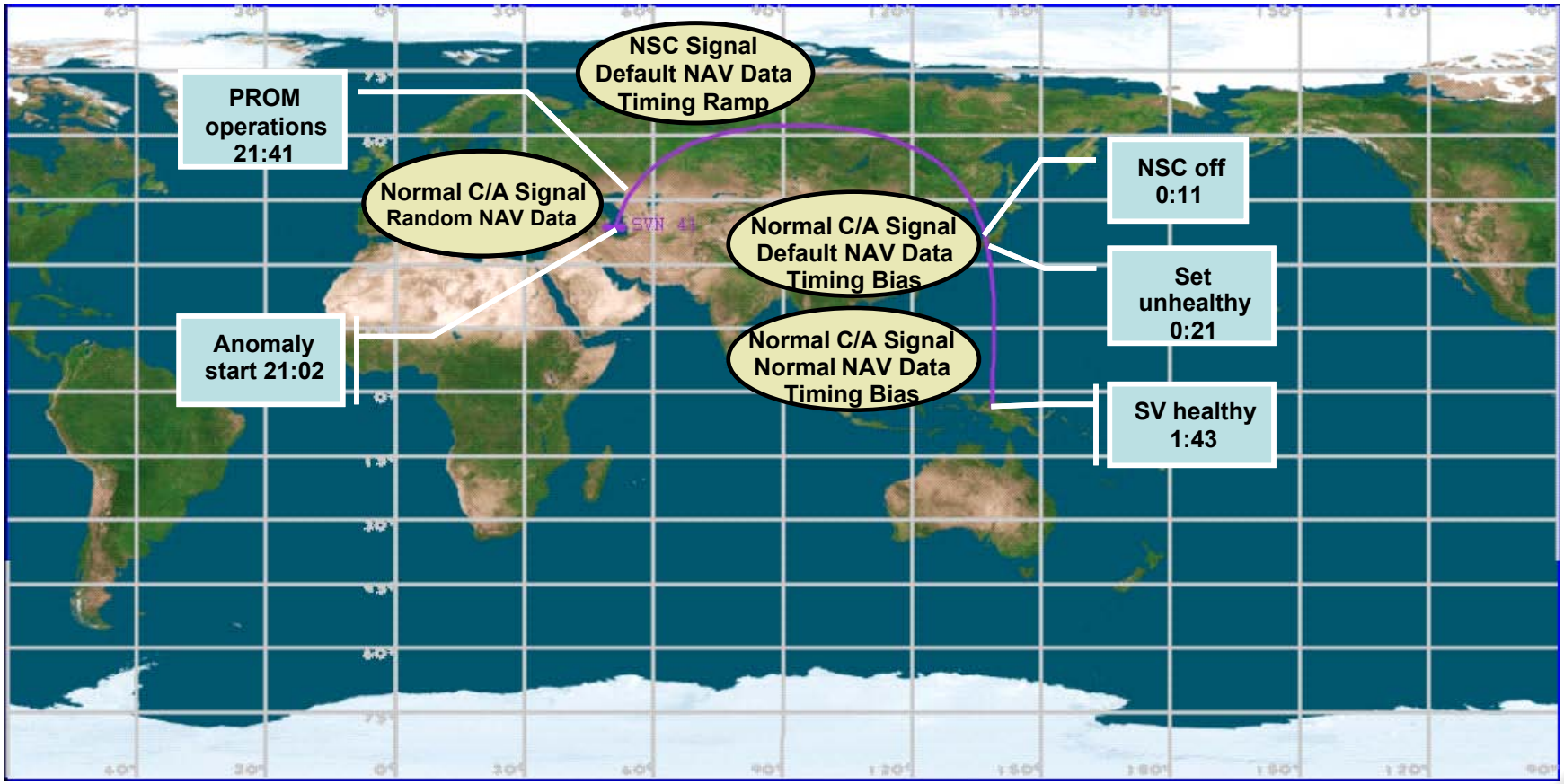
PRN 19 / SVN 59, 8 Oct 07



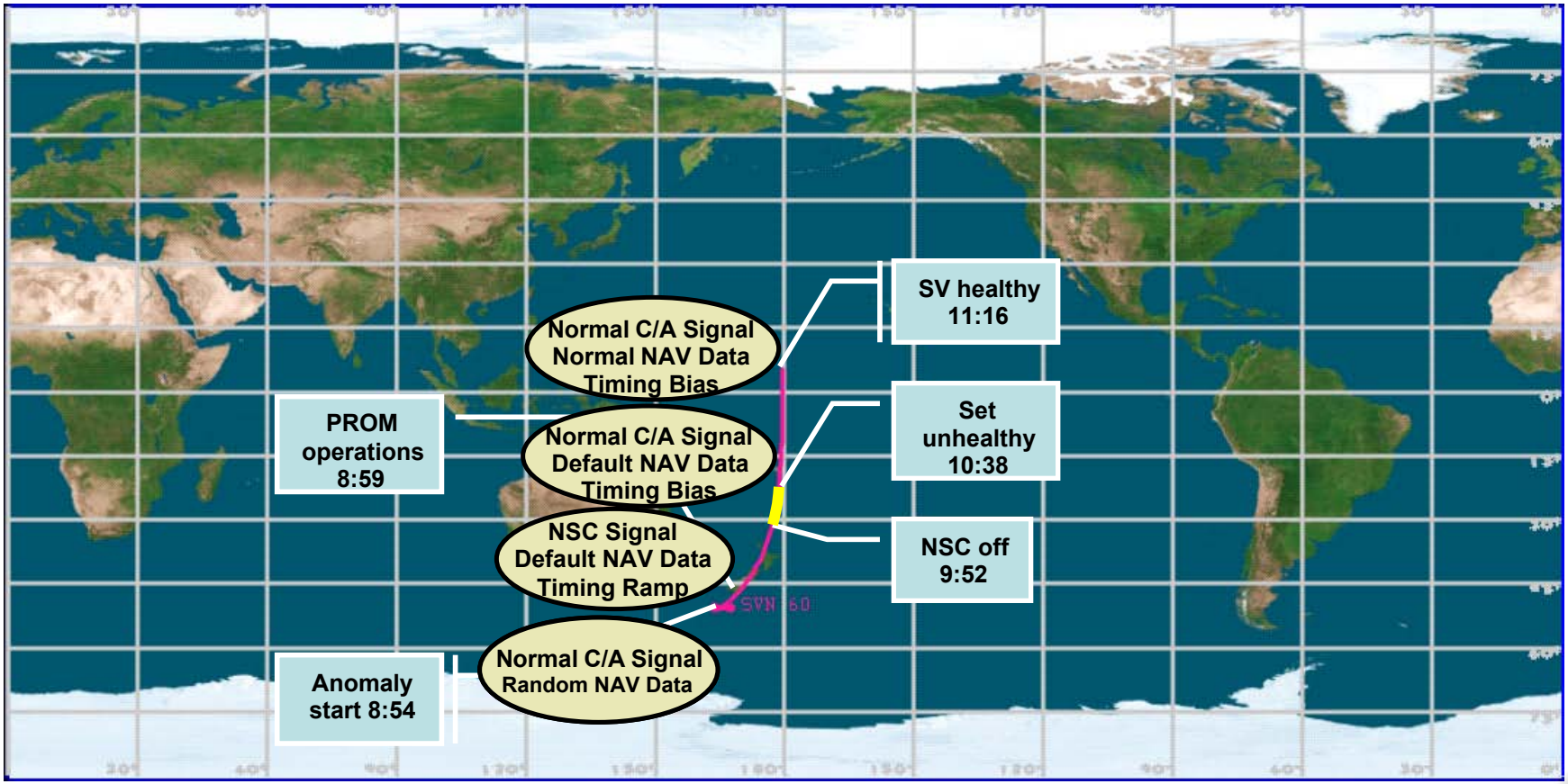
PRN 12 / SVN 58, 8 Oct 07



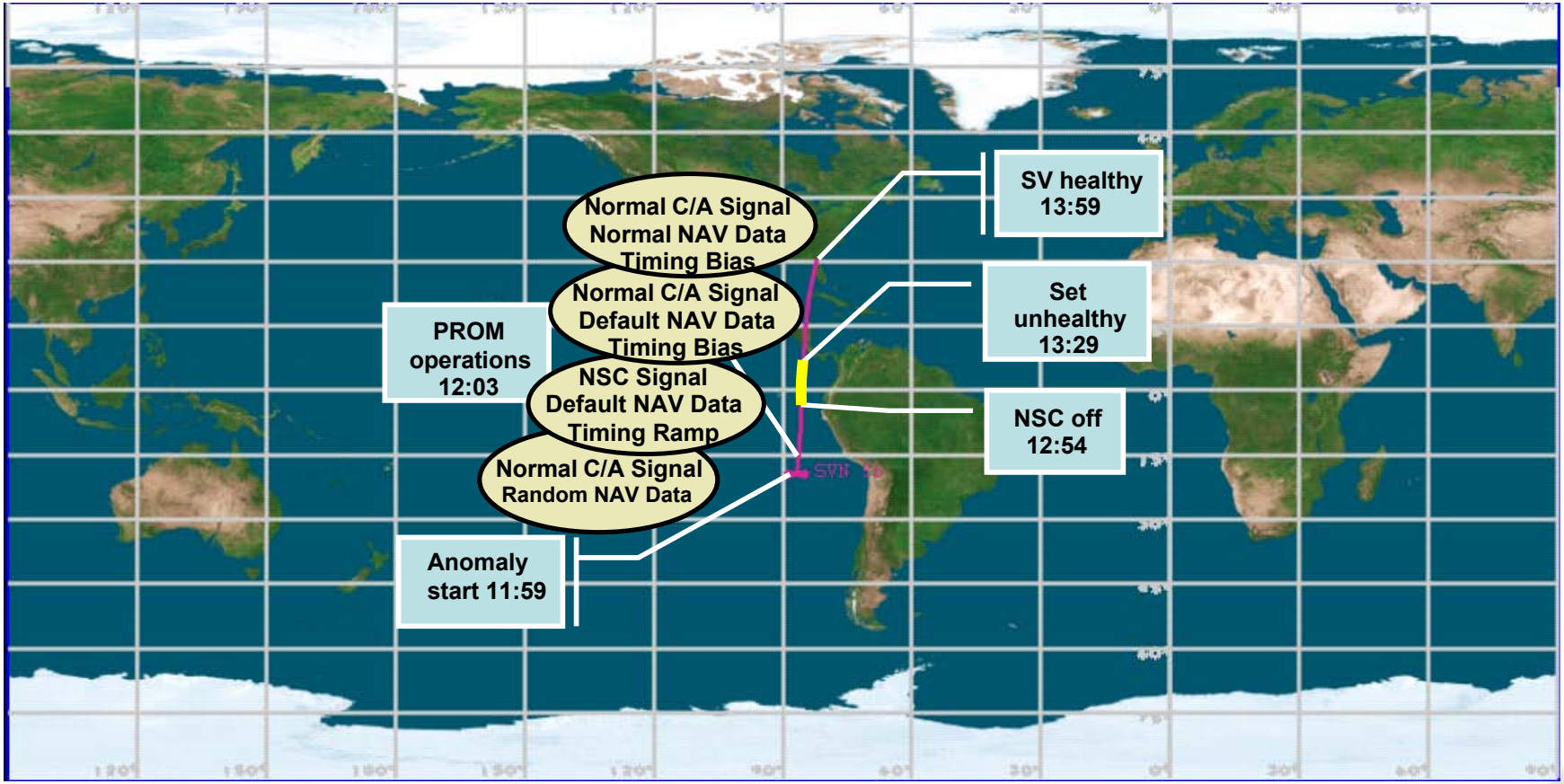
PRN 14 / SVN 41, 8-9 Oct 07



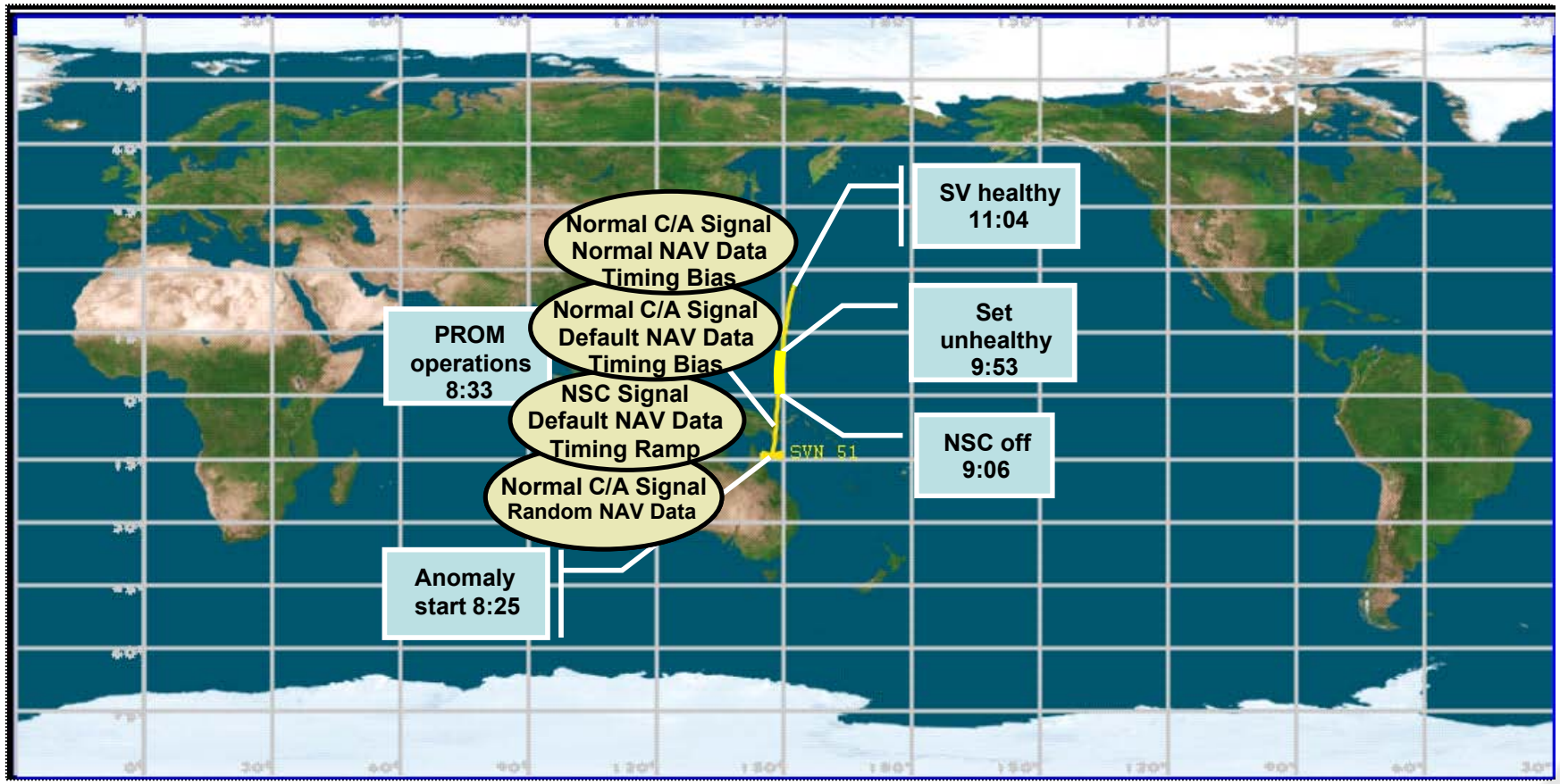
PRN 23 / SVN 60, 9 Oct 07



PRN 16 / SVN 56, 9 Oct 07



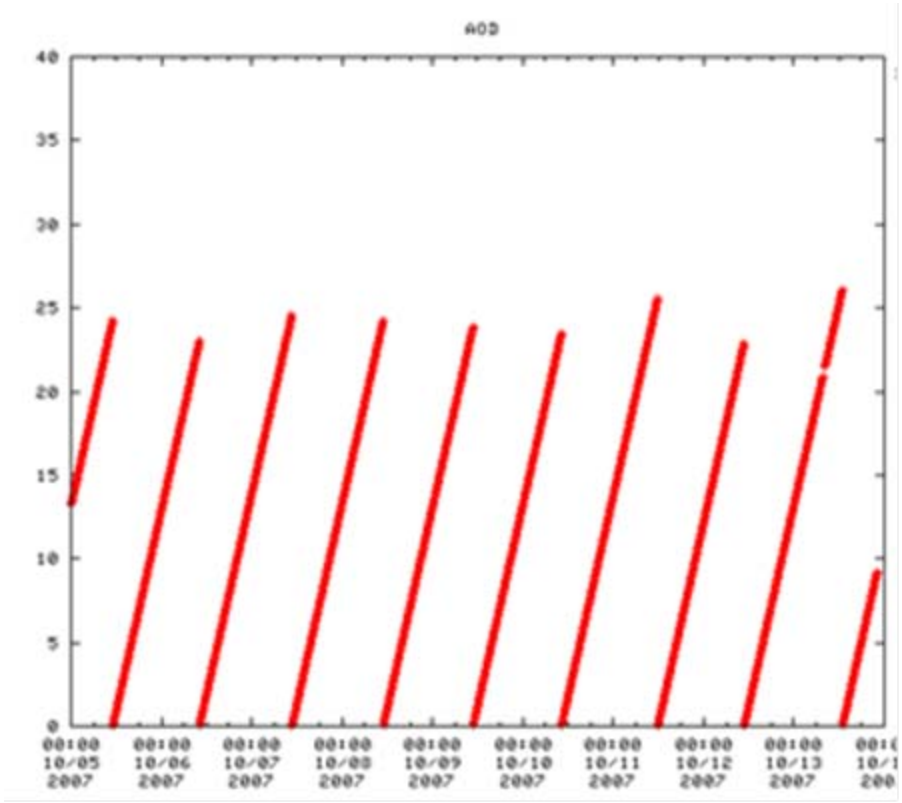
PRN 20 / SVN 51, 10 Oct 07



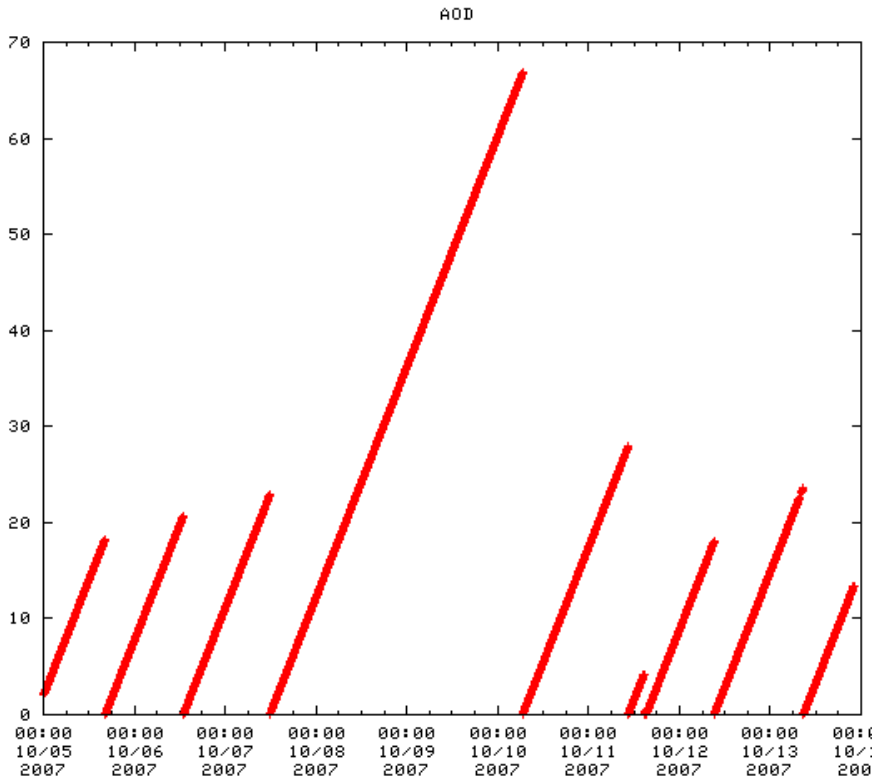
Anomaly Aftermath

- Anomalous packaging disconnect rapidly found
  - Kudos to the Navstar operations support teams!
- Upload-related software appropriately modified
  - Both on the ground and in the IIR/IIR-M satellites
- Guidance for civil receiver manufacturers coming
  - Will be in update of the *SPS Performance Standard*
    - Already in *PPS Performance Standard*
      - Very similar to RTCA/DO-229D
- Led to another set of interesting "anomalies"
  - Extended navigation with large ages of data (AODs)
    - No user reported problems due to these anomalies

Large AODs for IIR/IIR-M Satellites



PRN-05/SVN-35 AODs



PRN-31/SVN-52 AODs

Questions?