TRENDS IN DORIS DATA FORMATS

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The basic data

- **at each frequency**
  - **cycle count (= phase difference)** N, N'
  - **times of beginning and end of count in on-board time** t_1, t'_1, t_2, t'_2

- **at one frequency**
  - **the on-board time of reception of the synchronization signal**
    - equivalent to a pseudo-range measurement (as the transmission time is known in beacon time)
    - useable for master beacons (time synchronized)

The "difficulties" with DORIS

- **Measurements at the two frequencies are not simultaneous**
  - **but almost simultaneous (offset less than 50 µs)**
    - variable with "old" receivers (Spot 2-3-4, Topex, Envisat)
    - constant (better) with "new" receivers (Jason, Spot 5)
- **Observations during passes are not always continuous**
  - **situation has improved with "new" receivers**
- **Time synchronization of the system is limited**
  - **only two beacons are time synchronized**
    - only the "long term" behavior of the on-board clock is accessible
  - **measurement times are "loosely synchronized" to TAI**
    - clock offset can be large in initial processing stages
  - **pseudo-range measurements are not simultaneous with phase measurements**
    - "completely independent" measurement types

The 1.0 data formatting strategy

- **Strategy**
  - use pseudo-range and orbit to compute a global timing polynomial for the entire arc

$$T = t + a_0 + a_1(t - t_0) + a_2(t - t_0)^2 + a_3(t - t_0)^3$$

  - adjust a polynomial to over a month of frequency offsets adjusted over master beacons to obtain the on-board global frequency drift model $\Rightarrow f_{local}$
  - adjust beacon frequencies for every pass as part of an orbit determination process
  - convert 2 GHz data into radial velocity and TAI times

$$\begin{bmatrix} t_1 \\ t_2 \\ N \end{bmatrix} \Leftrightarrow \left| \begin{array}{c} T_1 = P(t_1) \\ \Delta T = T_2 - T_1 \\ V = \dfrac{c}{f_{beacon}\,\Delta T}\left[(f_{beacon} - f_{local})\Delta T - N\right] \end{array} \right.$$

  - combine 2 GHz and 400 MHz data to compute the ionosphere contribution at 2 GHz

The 2.0 data formatting strategy

- **Strategy**
  - **use pseudo-range and orbit to compute a global timing polynomial for the entire arc**

$$T = t + a_0 + a_1(t - t_0) + a_2(t - t_0)^2$$

  - **convert 2 GHz data into radial velocity and TAI times**

$$\begin{bmatrix} t_1 \\ t_2 \\ N \end{bmatrix} \Leftrightarrow \left| \begin{array}{c} T_1 = P(t_1) \\ \Delta T = [T_2 - T_1]_{0.1\mu s} \\ V = \dfrac{c}{\bar{f}_{beacon}\,\Delta T}\left[(\bar{f}_{beacon} - \bar{f}_{local})(t_2 - t_1) - N\right] \end{array} \right.$$

  - **combine 2 GHz and 400 MHz data to compute the ionosphere contribution at 2 GHz**

Version 2.0 data processing

- **Basic processing equation**
  - **typical pseudo-range rate processing**

$$V = c\left(\frac{\delta f_{local}}{f_{local}} - \frac{\delta f_{beacon}}{f_{beacon}}\right) + c\left(1 + \frac{\delta f_{beacon}}{f_{beacon}}\right)\frac{\tau_2 - \tau_1}{\Delta T}$$

  - **relative beacon frequency bias in front of Doppler term (discussed in Biarritz)**
  - **depends upon relative on-board frequency bias**
    - needs to be determined in a separate process
    - determination through adjustment to offsets over master beacons not necessariliy consistent with long term drift given by time-tagging polynomial
- **Solution: move the on-board frequency term into the measurement**

$$V_{2.1} \equiv V_{2.0} - c\frac{\delta f_{local}}{f_{local}}$$

The 2.1 data formatting strategy

- **Strategy**
  - **use pseudo-range and orbit to compute a global timing polynomial for the entire arc**

$$T = t + a_0 + a_1(t - t_0) + a_2(t - t_0)^2$$

  - **derive this polynomial to obtain the on-board global frequency drift model**

$$f_{local} \approx \bar{f}_{local}\left(1 + a_1 + 2a_2(t - t_0)\right)$$

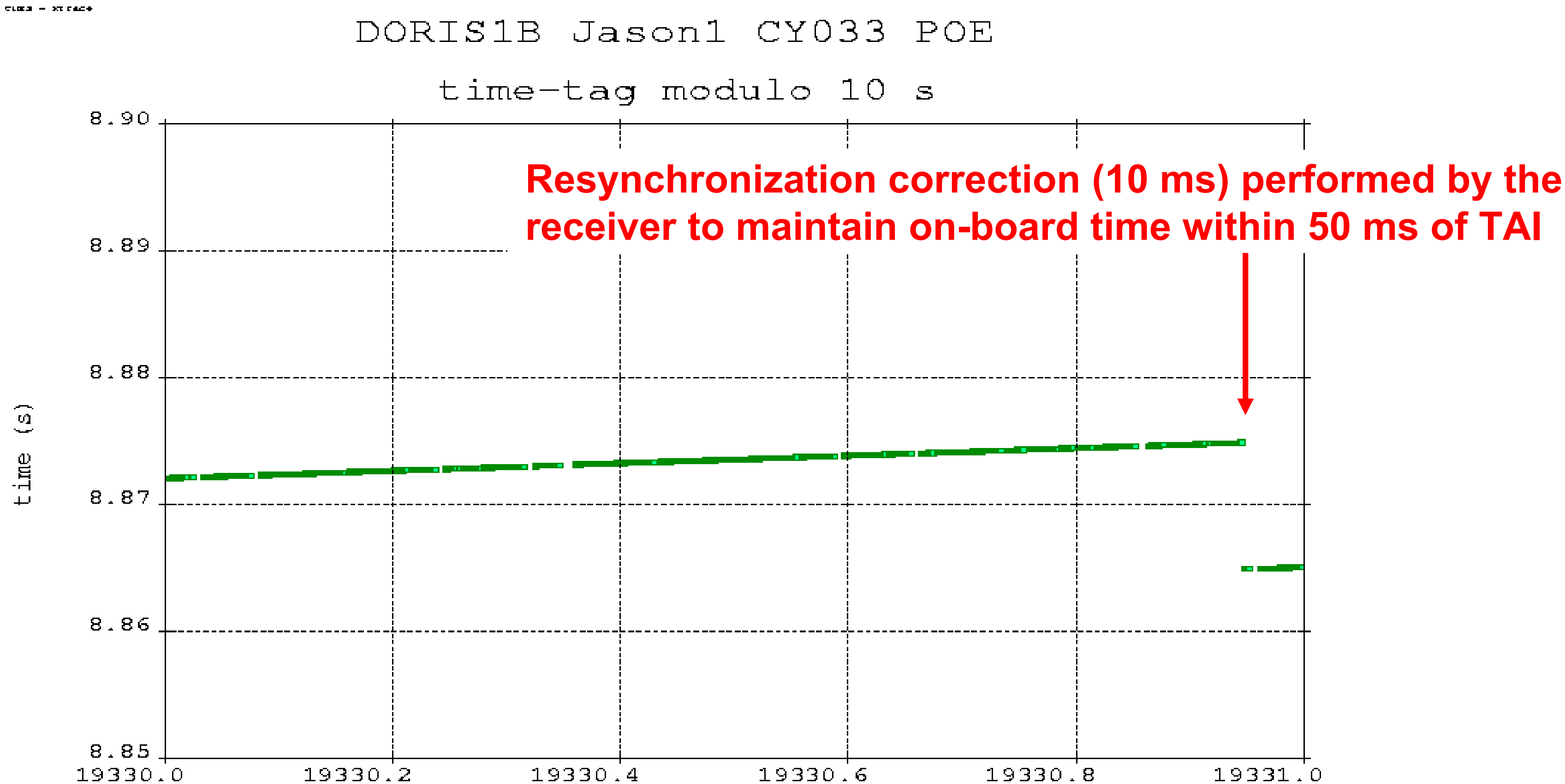
  - **convert 2 GHz data into radial velocity and times consistent with TAI**

Changes

$$\begin{bmatrix} t_1 \\ t_2 \\ N \end{bmatrix} \Leftrightarrow \left| \begin{array}{c} T_1 = P(t_1) \\ \Delta T = [T_2 - T_1]_{0.1\mu s} \\ V = \dfrac{c}{\bar{f}_{beacon}\,\Delta T}\left[\left(\bar{f}_{beacon} - f_{local}\right)(T_2 - T_1) - N\right] \end{array} \right.$$

  - **combine 2 GHz and 400 MHz data to compute the ionosphere contribution at 2 GHz**

Timing polynomial



The timing polynomial (parabola) is easy to retrieve from the time-tags of data => it is possible to reconstruct on-board time-tags and raw 2 GHz data

Ionosphere correction

- **Old iono correction was computed from 400 MHz residuals**

$$I = \frac{V'}{\alpha} - \frac{c}{\alpha^2}\frac{\eta_2' - \eta_1'}{\Delta T} \text{ with } \alpha = \frac{f}{f'} \text{ and } \eta = \text{propagation time}$$

  – strong dependence upon beacon frequency offset mean that iono corrections for passes unprocessed at CNES are wrong (=> data removed from files)

- **New iono correction slightly more complex than for most dual frequency systems**

$$I = \frac{V - \beta V'}{1 - \alpha^2 \beta} - c\frac{\delta f_{beacon}}{f_{beacon}}\frac{(\eta_2 - \eta_1) - \beta(\eta_2' - \eta_1')}{(1 - \alpha^2\beta)\Delta T} \text{ where } \beta = \frac{\Delta t}{\Delta t'}$$

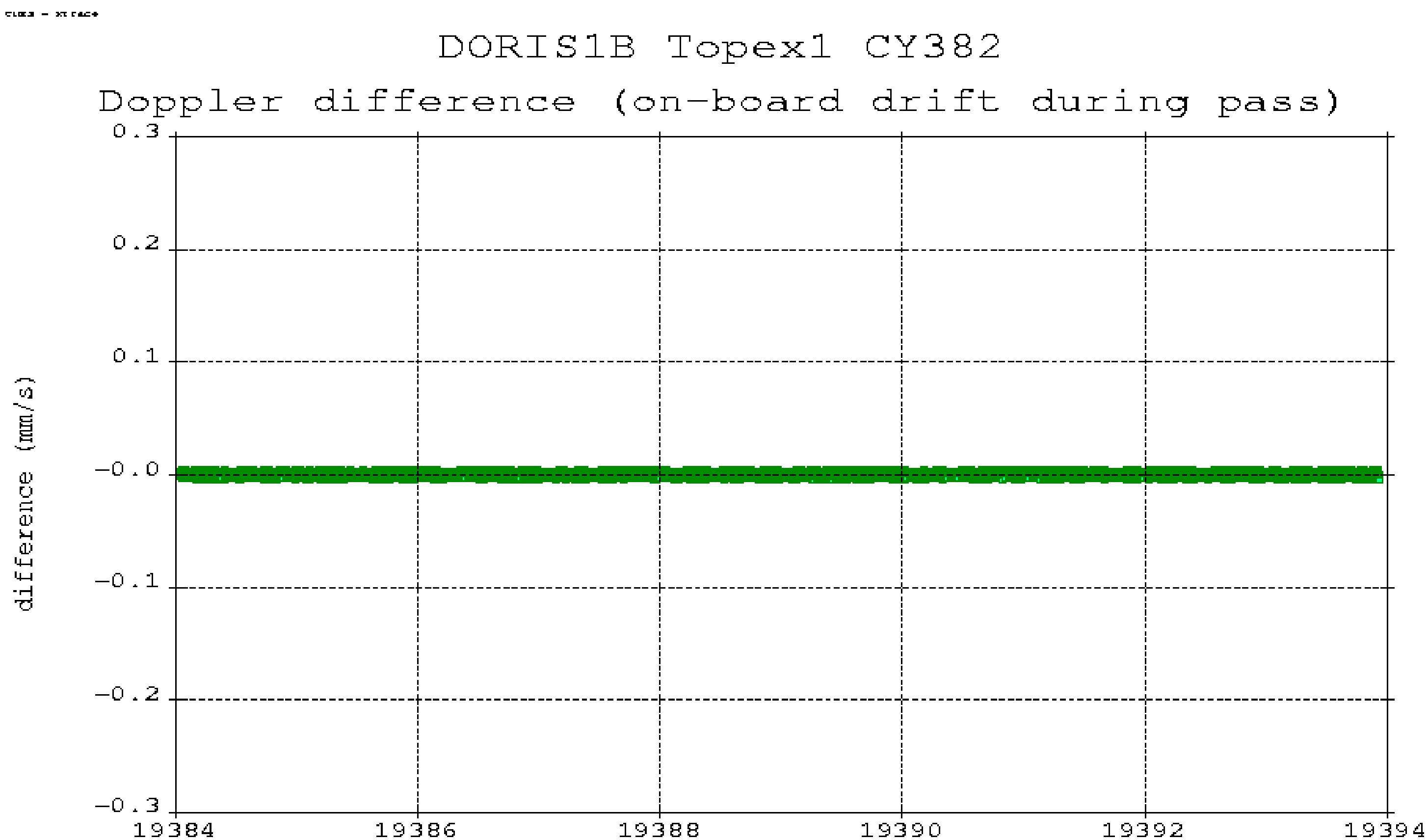
  – takes into account differences in center of phase location and in measurement times at the two frequencies

  – almost completely orbit and frequency independent => correction can be computed very early in the processing chain

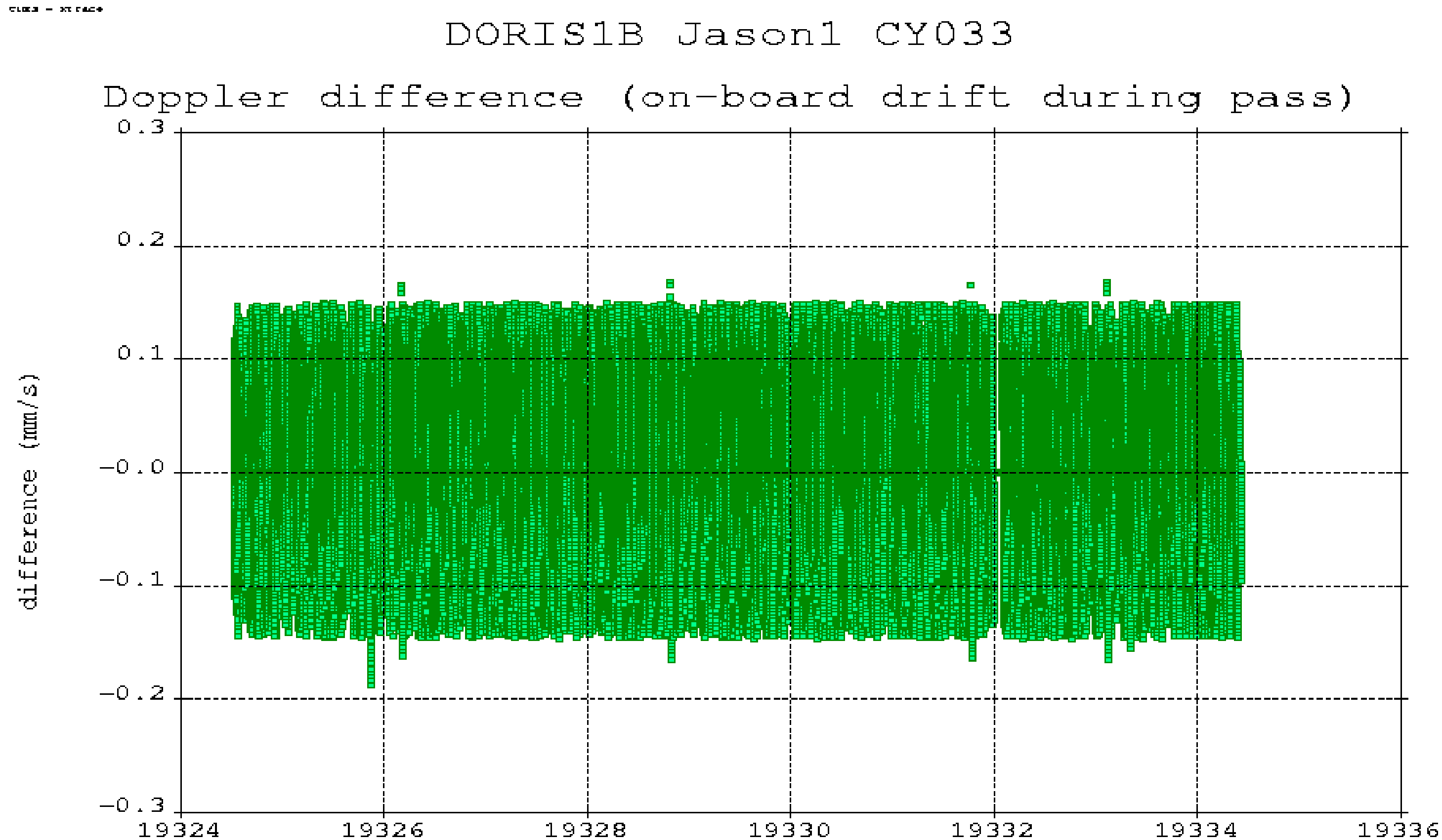
Transition to 2.1 data

- Transition from 1.0 to 2.x data also included the introduction of a channel indicator and of nearly all edited data
- Started with Jason and
  - cycle 358 for TOPEX (6 June 2002)
  - arc 418 for SPOT2 (14 Feb. 2002)
  - arc 174 for SPOT4 (22 Feb. 2002)
- Implementation is not yet fully complete
  - currently on-board frequency is constant per pass (estimated at middle of pass)
    - software modifications have been made to account for drift within pass
    - ready to be implemented (tests cycles checked by P. Willis)
  - still old ionosphere correction (=> fully eliminated passes are not provided)
    - software modifications have been made
    - tests cycles not yet verified by anyone outside CNES

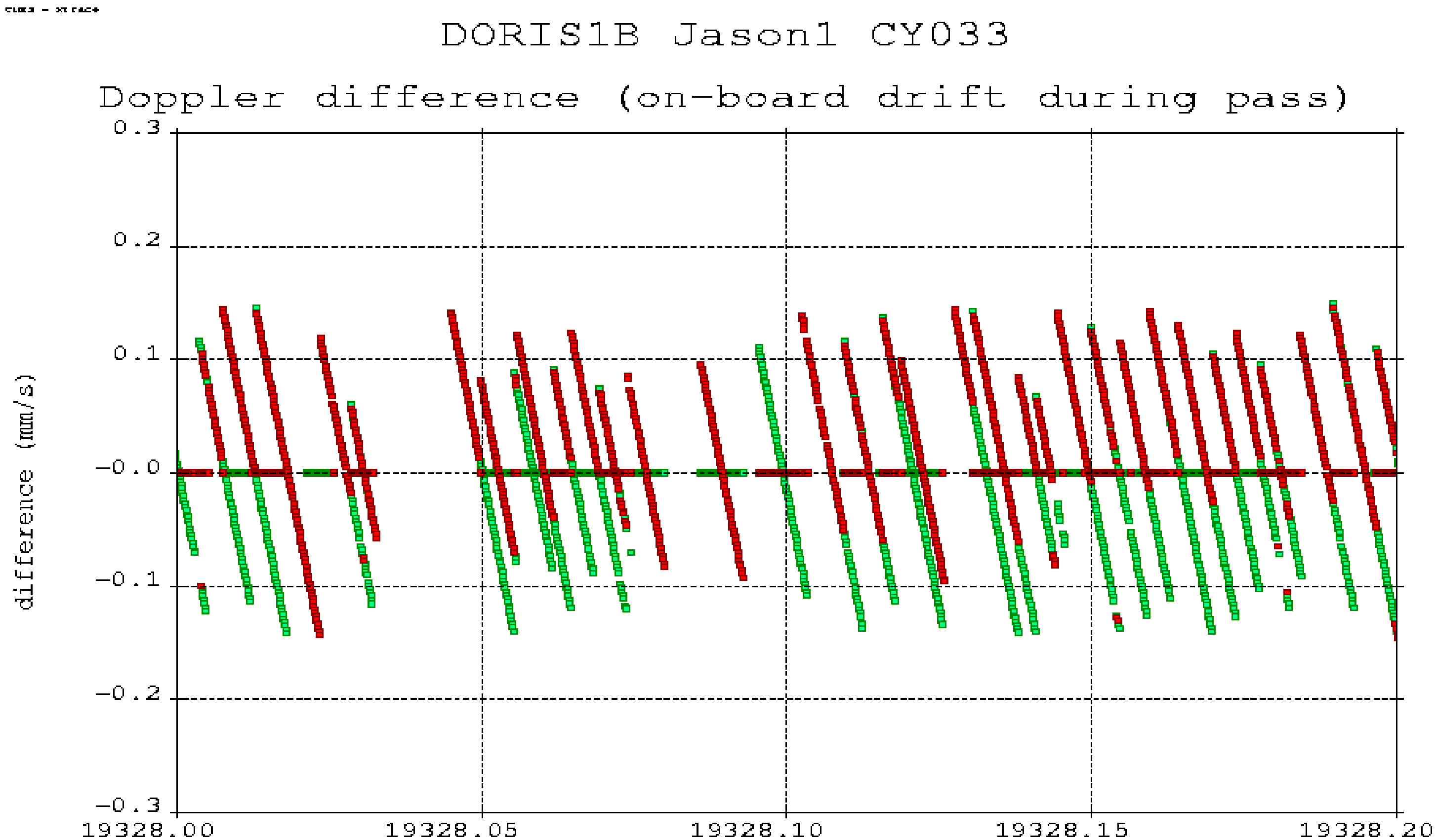
Difference in Doppler data (TOPEX)



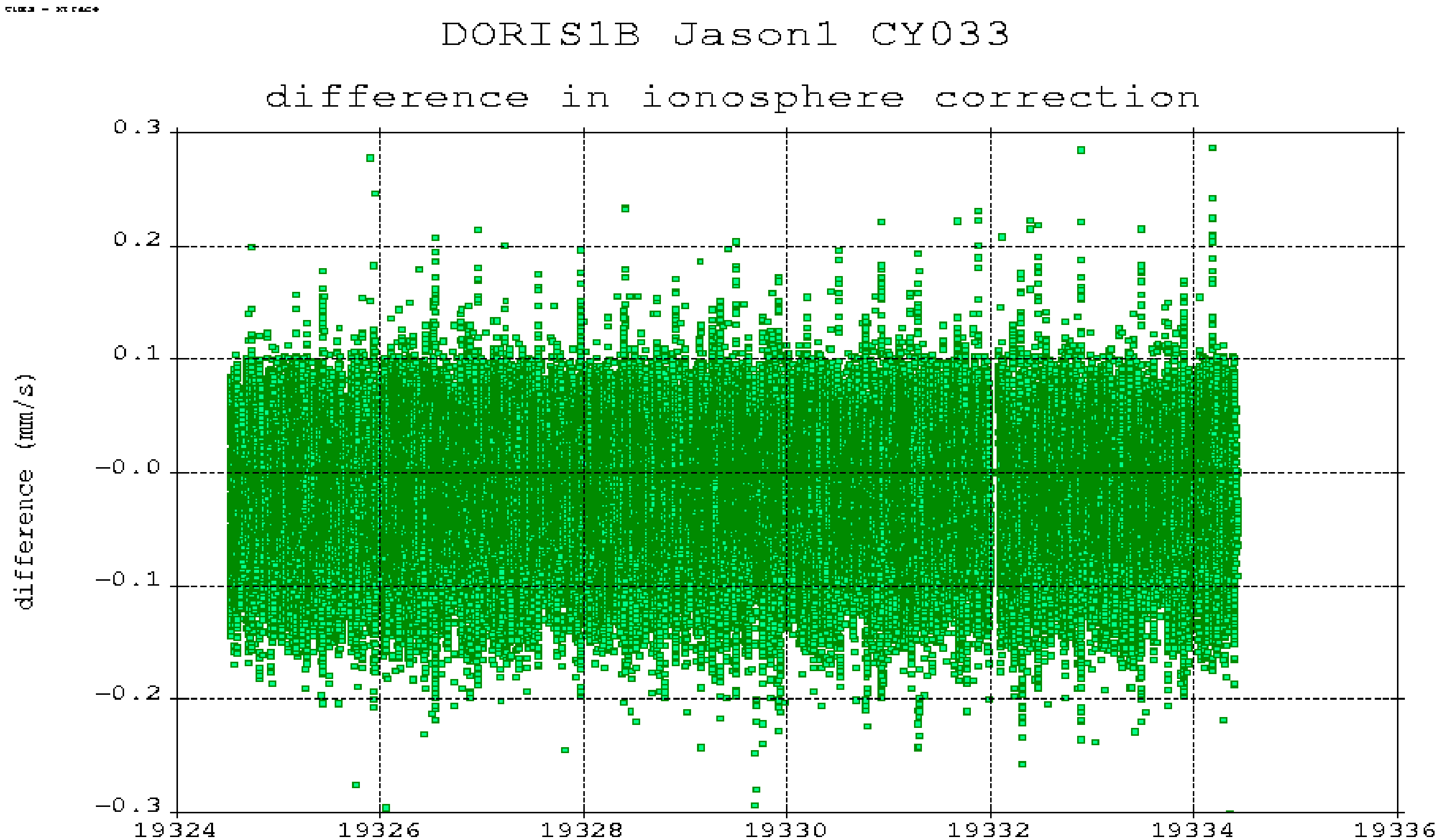
Difference in Doppler data (Jason)



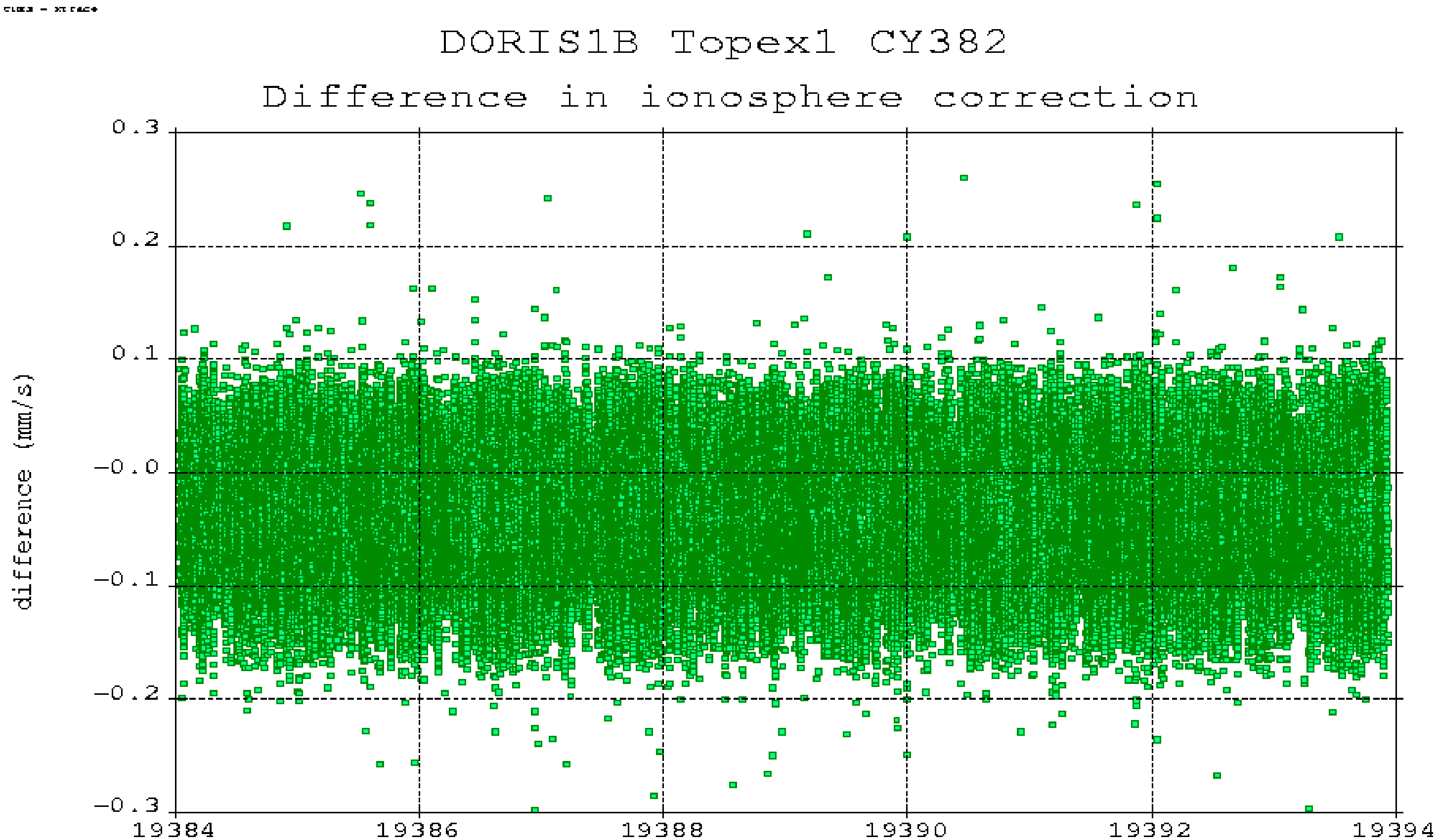
Difference in Doppler data (Jason)



Difference in ionosphere correction



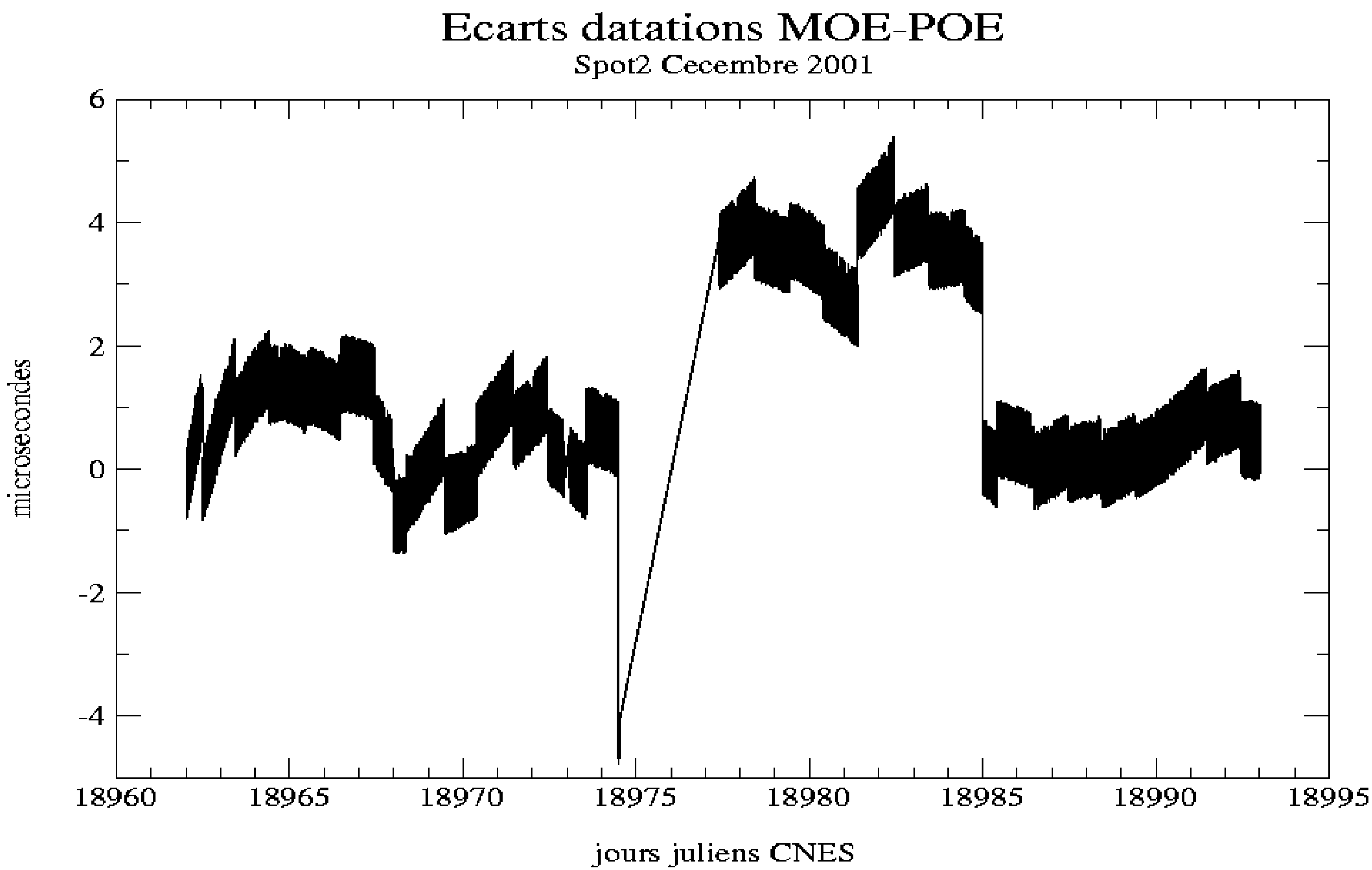
Difference in ionosphere correction



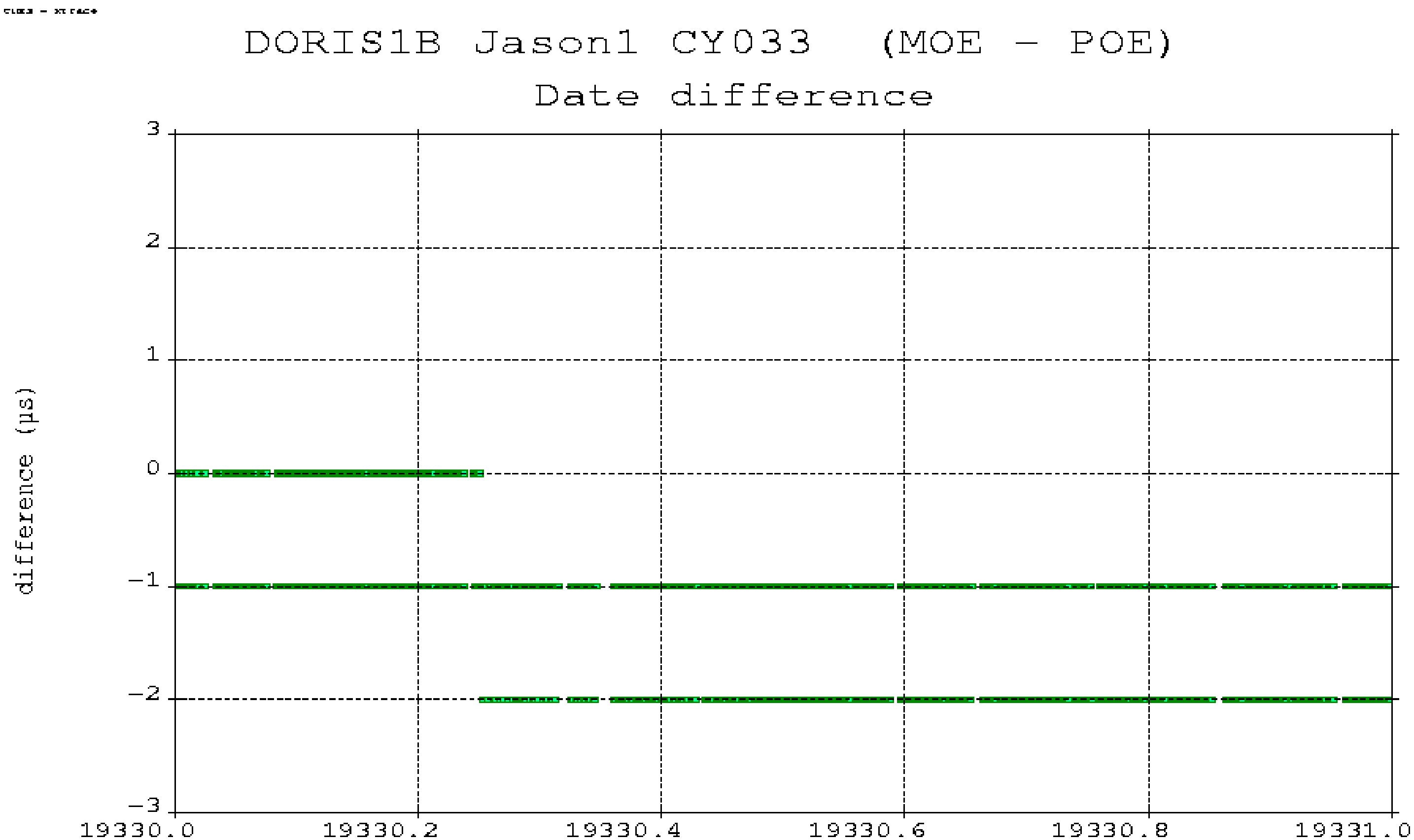
MOE versus POE data

- Export DORIS data can be generated during MOE and POE production
  - MOEs are rapid daily orbits computed for all the DORIS satellites within a couple days of data acquisition
  - POEs are high precision fully validated orbits computed for 7 to 10 day arcs within a few weeks of data acquisition
- Only POE data are currently made available
  - most significant difference is time-tagging: polynomial model over 4 days for the MOE (MOE = last day of the four) versus full arc polynomial model for the POE
- Tests conducted at CLS show that station positioning gives significantly different results for MOE and POE (about 4 mm RMS difference)
  - test was not actually conducted starting from version 2.1 data
  - an IDS AC campaign is needed to confirm/contradict this result
    - relation between time-tagging and positioning need to be clarified
- Transition to MOE data would be the best way to secure data delivery schedule

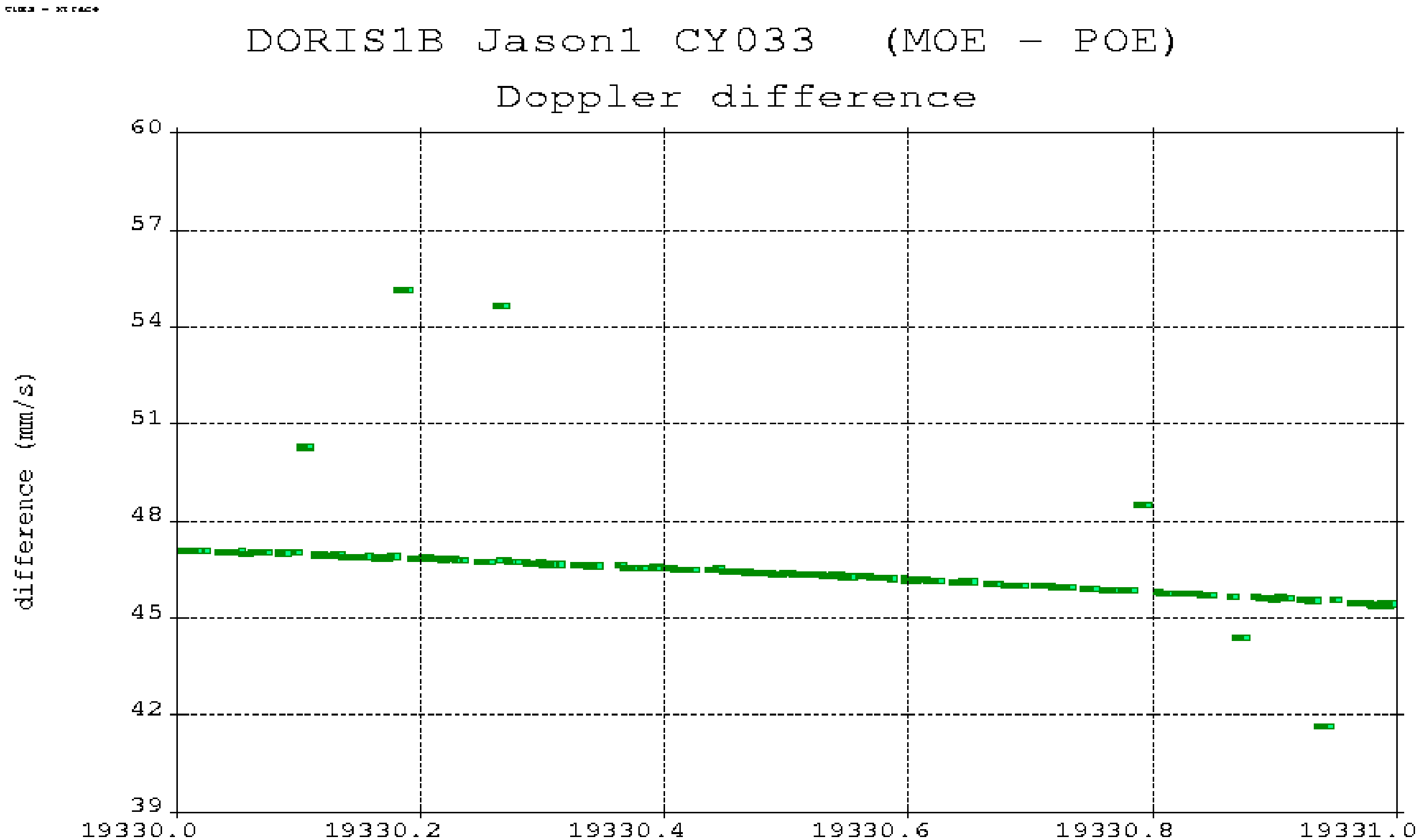
MOE versus POE time-tags



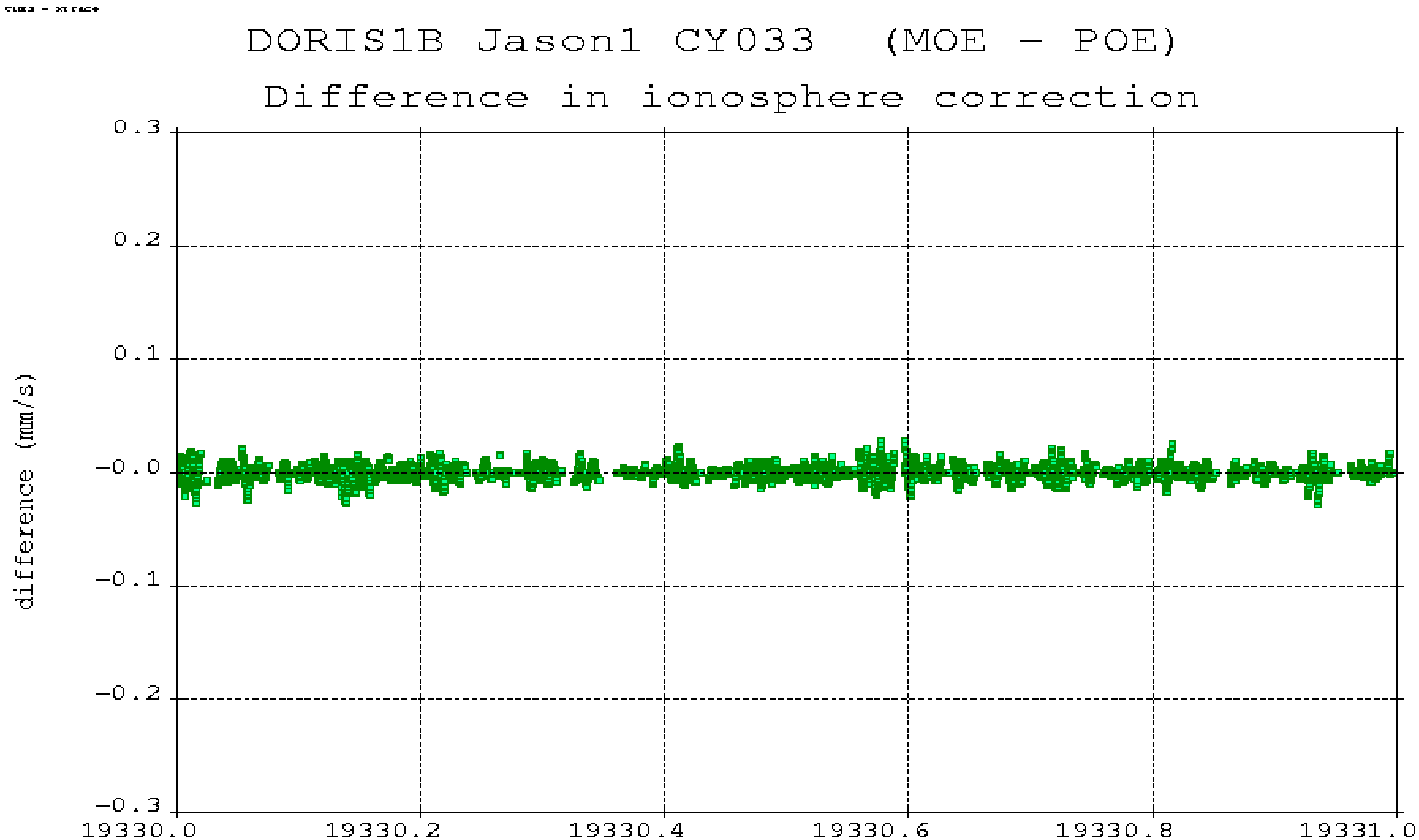
MOE - POE date difference



MOE - POE Doppler difference



MOE - POE ionosphere correction difference



Shifted frequency beacons

- Some beacons in the network will now have different nominal frequencies

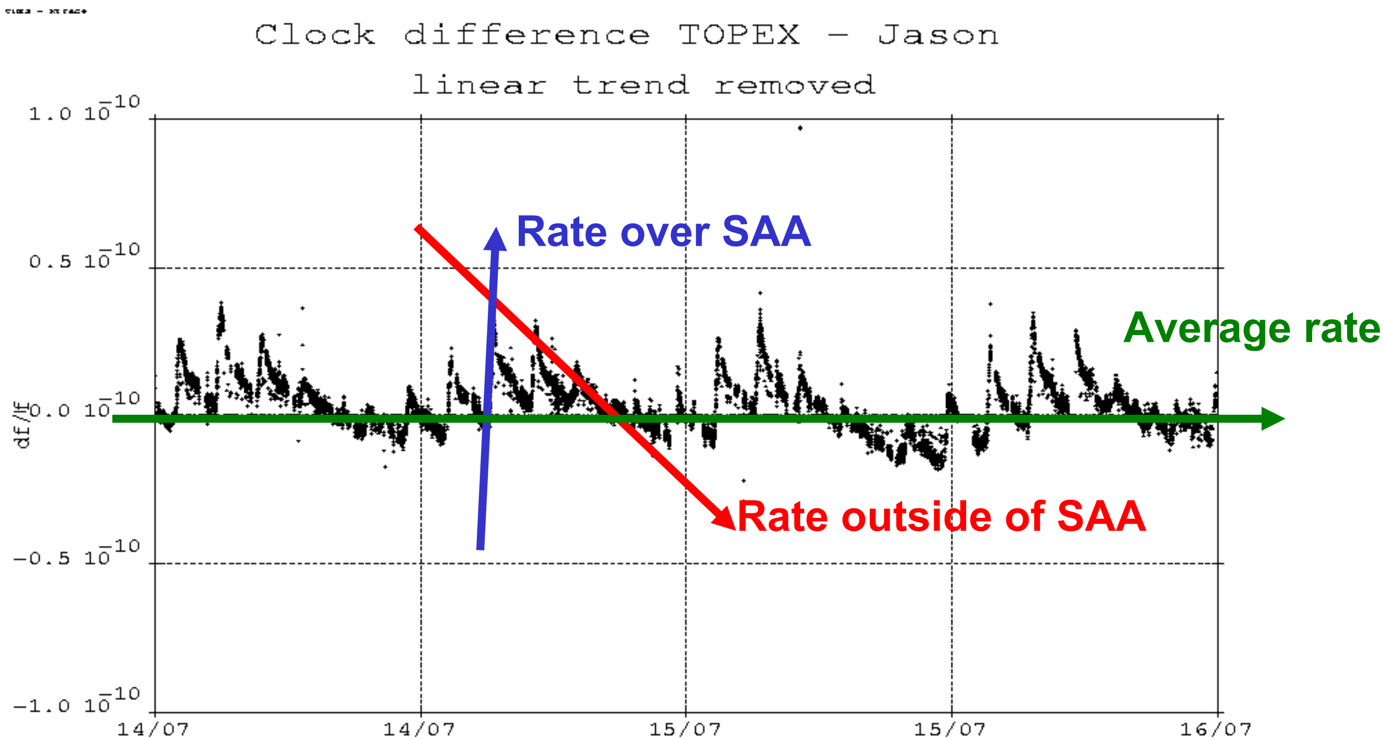
$$\bar{f}_{beacon}^{shifted} = \bar{f}_{beacon}\left(1 + \frac{29}{5 \times 2^{24}} k\right) \quad \text{with k integer}$$

- The shifted nominal frequency will be used to convert the data from cycle count to velocity
  - Users do not need the frequency to process data as the modeling equation only involves the relative frequency bias df / f

- The nominal frequency is only required if users want to reconstruct the real absolute bias from the relative bias
  - Does anyone intend to do this ?
  - Should we include the nominal frequency information with the data ?
    In the site logs ?

Jason, SAA and time determination

- **The on-board clock frequency varies very fast over the SAA**
  - **the frequency variation rate is different between the SAA and the rest of the world**



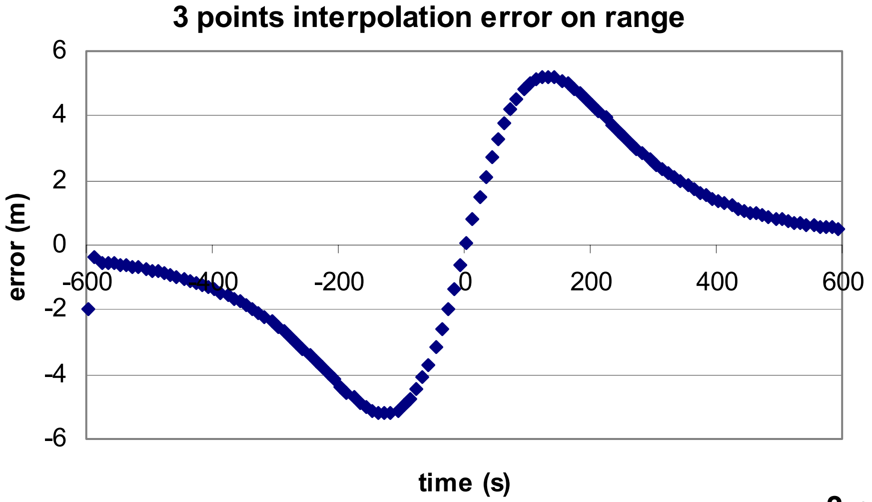
Jason, SAA and time determination

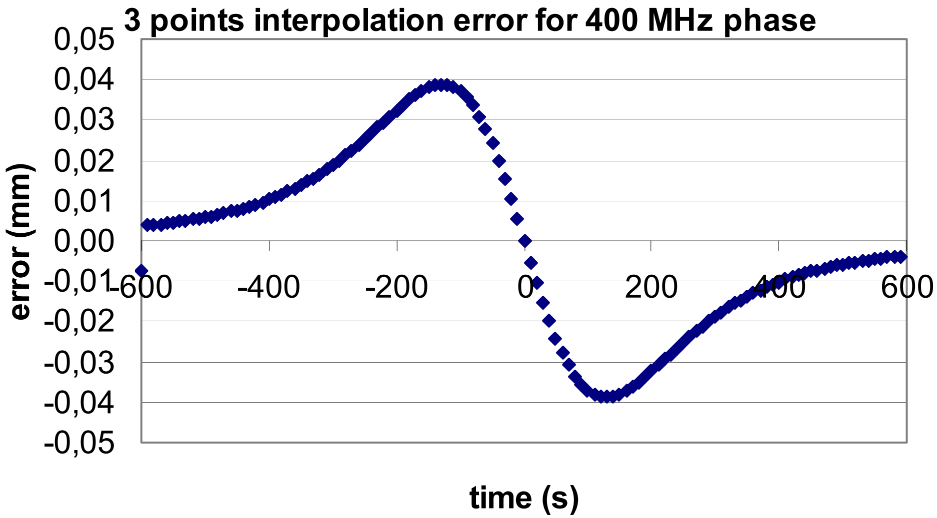
- **There are only two master beacons**
  - **each pass over a master beacon formally provides one normal point**
    - the timing polynomial is a parabola adjusted globally to all these points which represents the average behavior of the clock
  - **between points the clock rate varies fast over the SAA and slowly elsewhere**
    - however only the integrated behavior is available
  - **even if Kourou data are not used, Toulouse data only provide an integrated view of the clock behavior**
- **This average rate is used to correct the Doppler data of all stations**
  - **it introduces a frequency drift on all stations, not only those over the SAA**
- **Solutions ?**
  - **apply no frequency correction to data (equivalent to 2.0 format)**
    - OK except if clock modeling approach is used (Gipsy-Oasis for exemple)
  - **use more complex on-board clock model (two slopes) ?**
    - difficult to know when to change slope !

GPS-like phase data format

- **Well suited for data from "new" receivers**
  - **possible to only keep 10 s sampled data for clarity**
    - keep only "end of count" phase data
- **Handling of pseudo-range data**
  - **asynchronous pseudo-range and phase data**
    - split into 2 files ?
  - **Proposal = interpolate pseudo-range data to times of phase data using the phase**
    - looks acceptable given the low resolution of the pseudo-range
- **Handling of 400 MHz data**
  - **should it be interpolated to 2 GHz data sampling times or left as is ?**
    - Interpolation looks safe and would simplify processing by users
- **Handling of meteo data**
  - **cumbersome with RINEX MET format**
    - and difficult to produce (combination of all satellites for a given day)

Interpolation errors





Ancillary data

- **Satellite attitude**
  - **only nominal models for SPOT (no quaternion data)**
  - **model with external inputs (SPA_SATATT) for TOPEX and Jason**
    - quaternion data also available for Jason and TOPEX (more complex)
    - TOPEX SPA_SATATT updated by JPL on a regular basis
    - Jason SPA_SATATT updated by CNES on a regular basis, but requires analysis of quaternion data to refine transition dates

Ideal Data Format Guidelines

- True to the original measurements
  - keep all the information
- Independent from receiver type and version
  - minimize the number of formats
- Compatible with similar data formats
  - minimize user software developments
- Simple
  - easy to read, easy to use
- Storage efficient
  - minimize data storage requirements
- etc.

How well does the current format score ?

- **True to the original measurements**
  - **not good: loss of the single frequency timing measurement (pseudo-range)**
  - **improved with recent evolutions**
    - in particular with the release of all edited data and the capacity to reconstruct raw 2 GHz measurements
- **Independent from receiver model**
  - **quite good given the evolutions in the technology of the system !**
    - transition from integer cycle count to phase sampling, transition from single to multiple channels, introduction of beacons with shifted frequencies
- **Compatible with similar data formats**
  - **good in reference with similar pre-existing systems (e.g. TRANET)**
  - **but not very good with respect to GPS !**
- **Simple**
  - **easy to use, corrections included**
- **Small size**

Conclusion

- **The current format is holding fairly well given the complexity and the many recent changes to the system**
  - **it will be difficult to go much further with the current type of format**

- **The next step should be a transition to phase data**
  - **it would be in line with the evolution of the system and of orbit determination software**
  - **interpolation on the ground (or better, in the receivers) could make DORIS really GPS like**
  - **the price to pay is to abandon sequencing between beacons**
    - reduction of the network coverage by single frequency instruments