Real-Time Estimation of GPS Satellite Clocks Based on Global NTRIP-Streams

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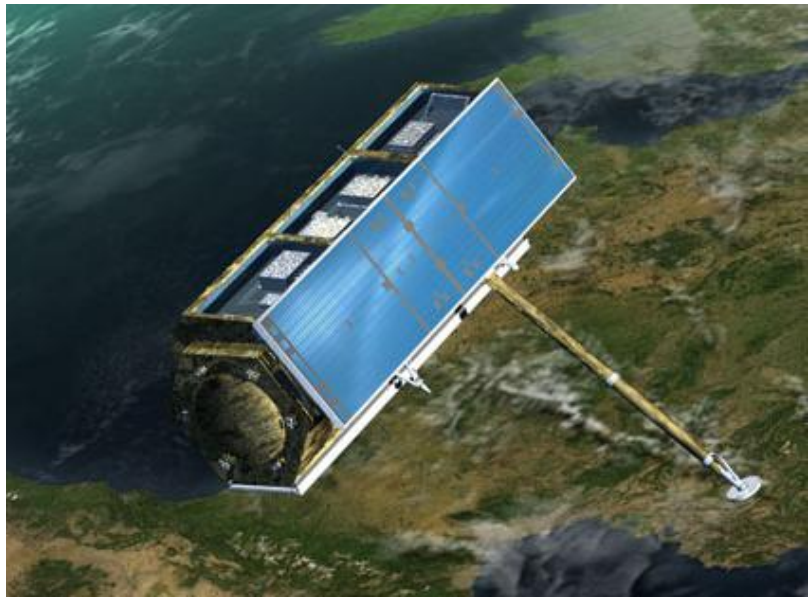
Agenda

- Motivation
- Data Dissemination via NTRIP
- Overview of the Real-Time Clock Estimation System
- Assessment of Clock Product Quality
  a) Orbit Determination Results
  b) Direct Clock Comparisons
- Conclusions and Future Work

Motivation

- GSOC routinely performs precise orbit determination
- Near real-time precise orbit determination (decimeter level) required for:
  - Occultation measurements (e.g. MetOp-A, TerraSar-X)
  - Altimeter missions (e.g. Sentinel-3)
- Requirements cannot be fulfilled with IGU predicted orbits/clocks



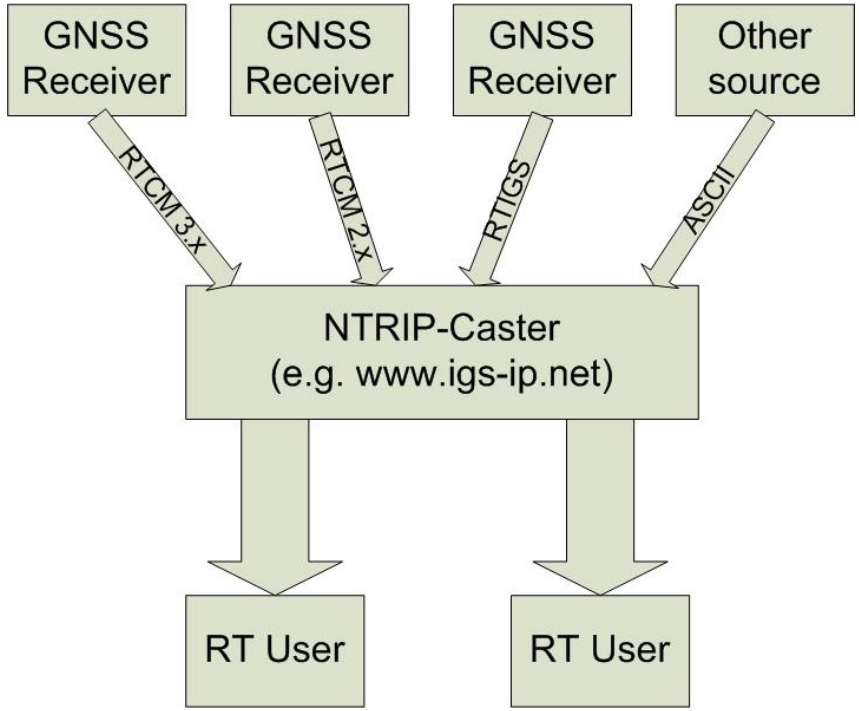
- Precise real-time GPS clock estimation established at GSOC to support current and upcoming space-missions

Motivation

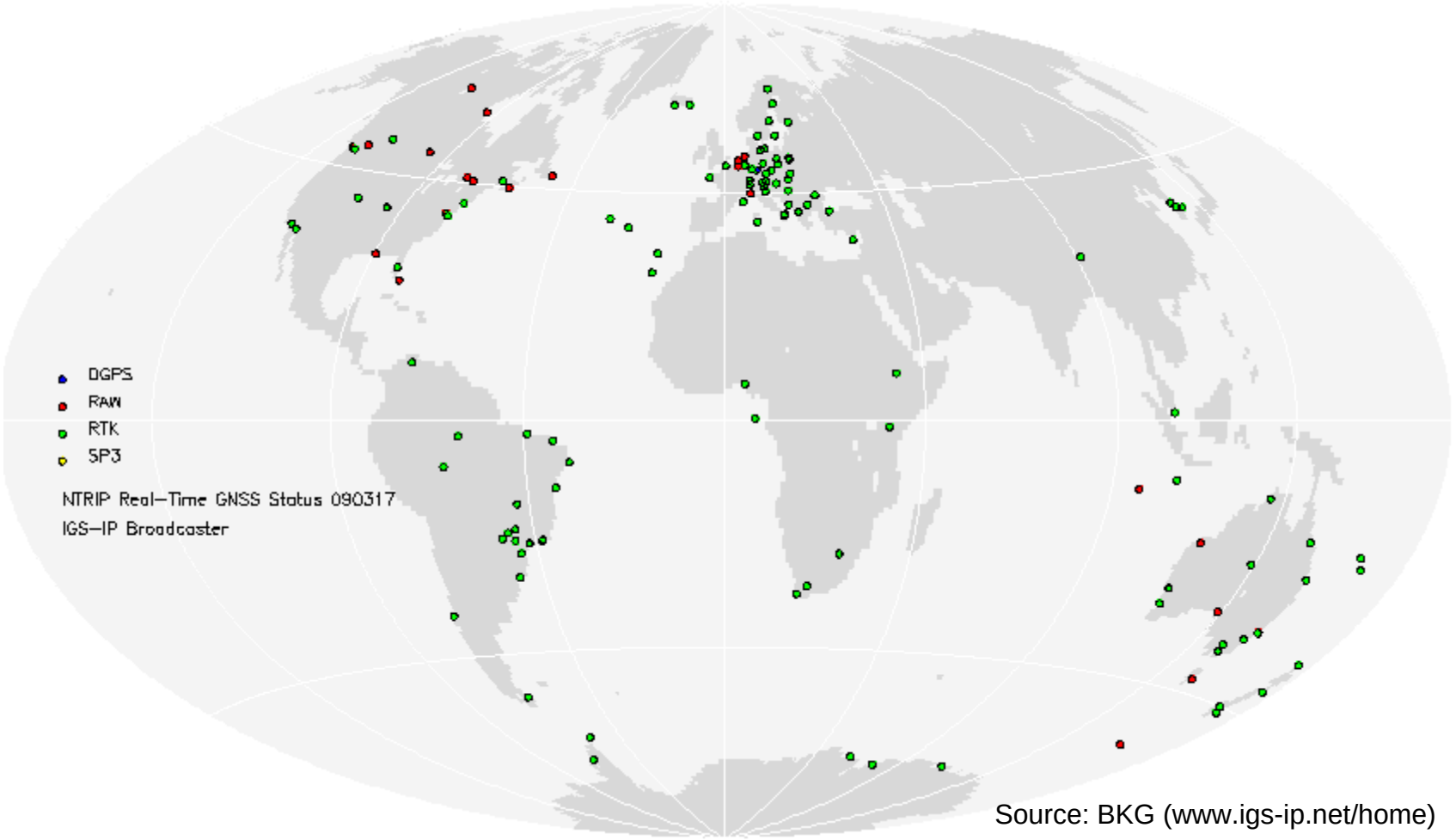
- Participation in IGS Real-Time Pilot Project (www.rtigs.net/pilot)
- Kick-off in October 2007
- Key objectives:
  - Maintain real-time tracking network
  - Production and monitoring of real-time products
  - Distribute real-time products to users
- Currently product submission by 3 real-time analysis centers
  - ESA/ESOC
  - NRCan
  - DLR/GSOC
- Orbit and clock comparisons w.r.t. IGS rapid products (Sept. 2008)
- Real-time product combination and dissemination (Jan. 2009)

Data Dissemination via NTRIP

- NTRIP (Networked Transport of RTCM via Internet Protocol) used for real-time data streaming
- Based on HTTP
- Developed by BKG (Federal Agency for Mapping and Geodesy)
- ~120 real-time tracking stations available
- Data formats:
  - RTCM 3.x
  - RTIGS
  - RTCM 2.x
- Typical transmission latency between 0.5s – 4s

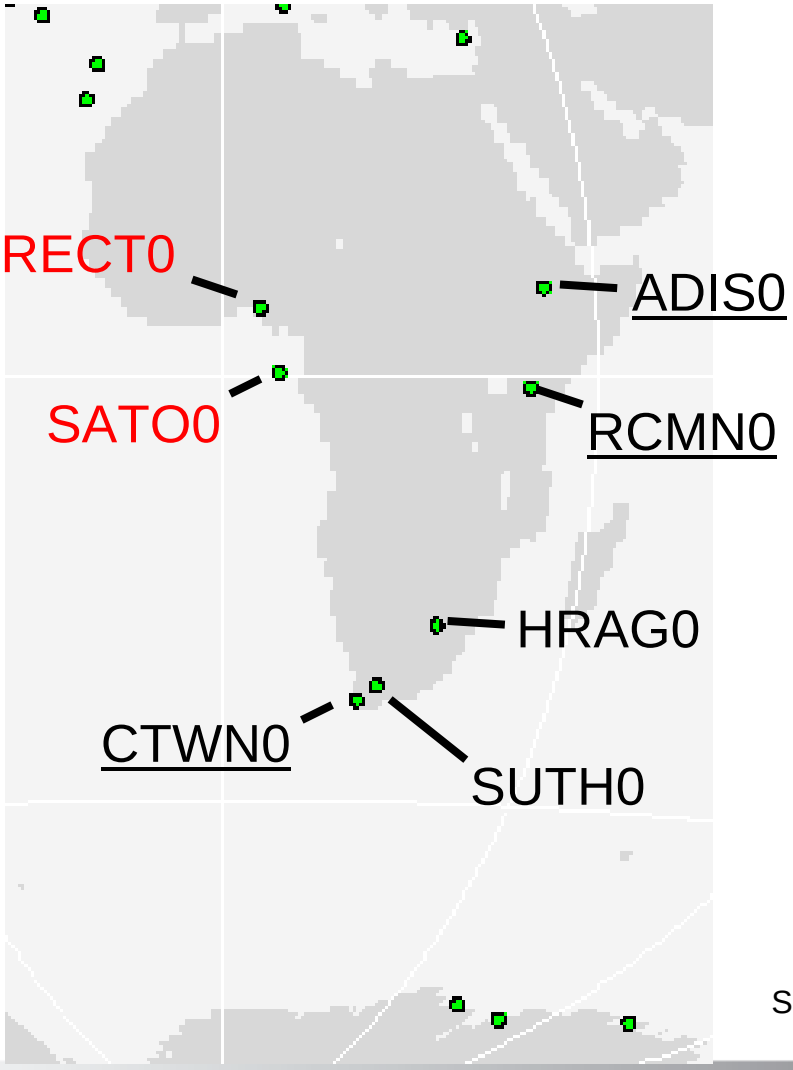


Data Dissemination via NTRIP (cont.)



Source: BKG (www.igs-ip.net/home)

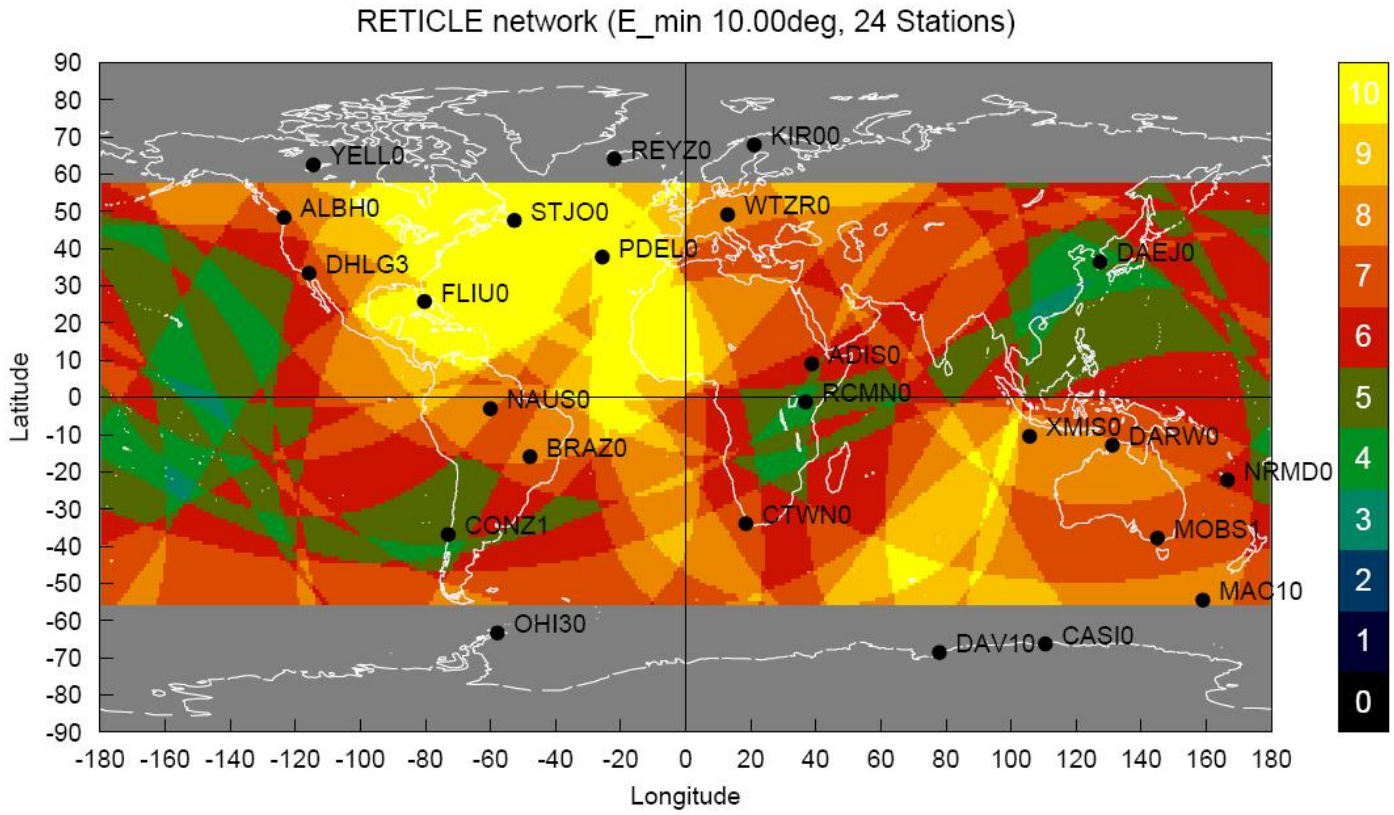
Data Dissemination via NTRIP (cont.)



Source: BKG (www.igs-ip.net/home)

Overview of RETICLE System

- Real-Time Clock Estimation (RETICLE) implemented at DLR/GSOC
- Real-time data streams from global network (~25 stations)



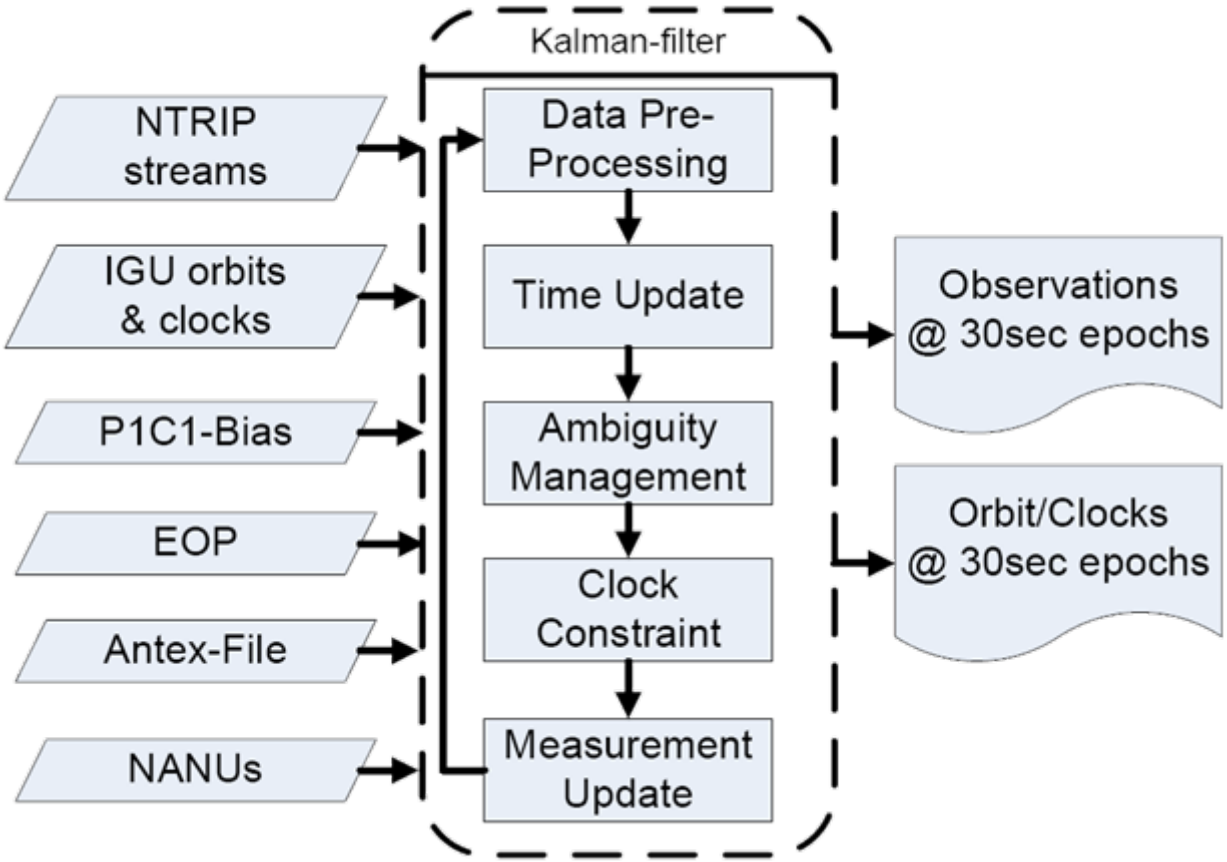
Overview of RETICLE System (cont.)

- RETICLE algorithm based on Kalman filter
- Processing of ionosphere-free pseudo-ranges and carrier-phases
- Estimation parameters:
  - GPS clock offset & drift
  - station clock offset
  - tropospheric zenith delay
  - carrier-phase biases (float values)
- Station coordinates from IGS Sinex-files or PPP-fit
- Clock parameters based on most recent IGU predicted orbits

Overview of RETICLE System (cont.)

- Modeled observations include corrections for:
  - Solid earth tides
  - Polar tides
  - Ocean loading
  - Tropospheric delay
  - Phase center offsets and variations
  - Differential code biases (P1-C1)
  - Phase wind-up
- Output:
  - SP3 file with 30 sec epochs
  - NTRIP data-stream every 5 seconds

Overview of RETICLE System (cont.)

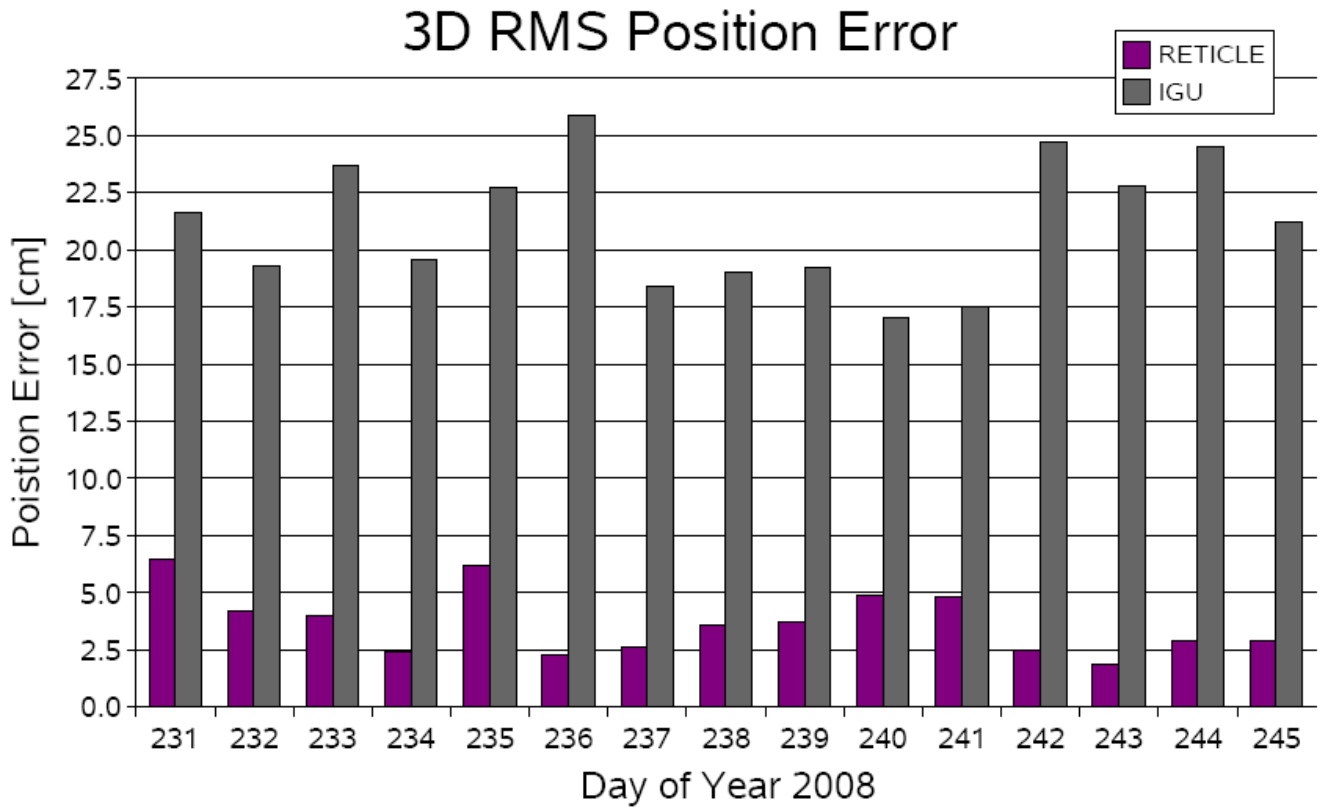


Assessment of Clock Product Quality

- Results of a precise orbit determination
- 15 days of flight-data from TerraSar-X
- 24h POD with DLR and IGU products
- POD with DLR's GHOST software:
  - iterative least-squares fit
  - un-differenced measurements
- CODE products (30s clocks) for reference orbit generation

Assessment of Clock Product Quality (cont.)

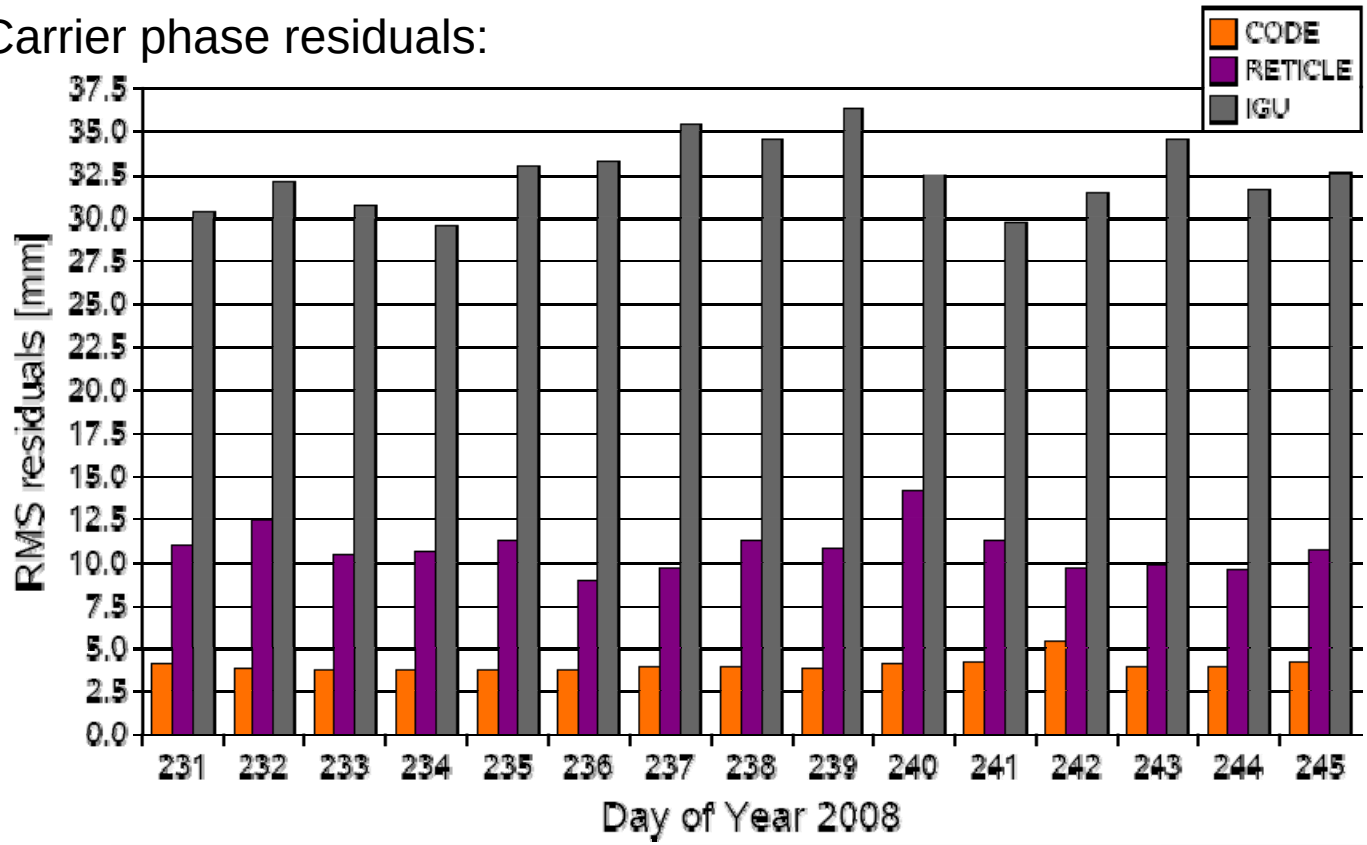
- 3D positioning error RETICLE: 2.5 cm – 6 cm
  IGU: 16 cm – 26 cm



Assessment of Clock Product Quality (cont.)

- Pseudorange residuals: ~75 cm for CODE and DLR
  ~110 cm for IGU

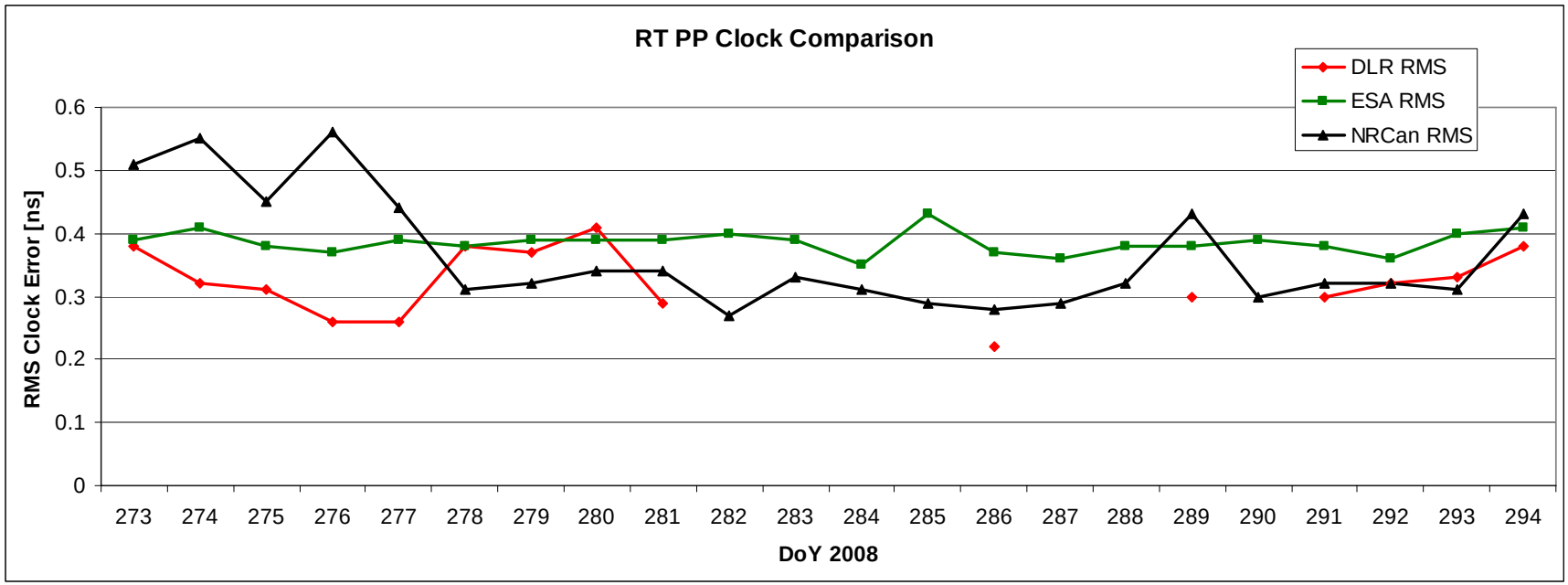
- Carrier phase residuals:



Assessment of Clock Product Quality (cont.)

- Clock comparisons w.r.t. IGS rapid products
- Provided by ESA/ESOC (ftp://nng.esoc.esa.de/gps/products/)

- RMS clock differences:



Assessment of Clock Product Quality (cont.)

- Clock comparisons w.r.t. IGS rapid products
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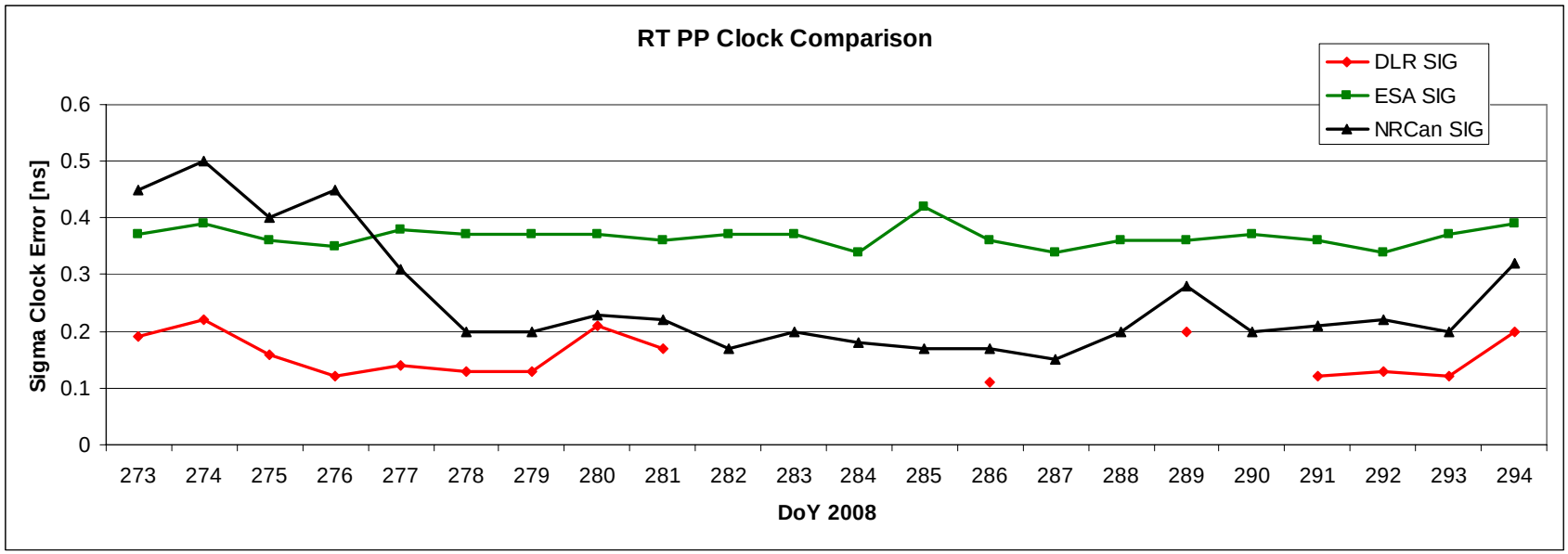
- Standard deviation of clock differences:



Conclusions and Future Work

- RETICLE orbit and clock products fulfill requirements for LEO-POD
- Current NTRIP-network is sufficient for global precise clock estimation
- Additional stations beneficial for improving global coverage

- Refine processing of observations (use C2 as well)
- Install DLR NTRIP-caster for distribution of RETICLE products
- Implementation of near real-time TerraSar-X POD