IERS Earth Rotation (UT1) Dissemination

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Outline

- What is the IERS?
- Earth rotation angle (UT1)
- Leap Seconds
- Measures and Predictions of Earth rotation
- How the IERS provides for its customers

What is the IERS?

- The International Earth Rotation and Reference Systems Service (IERS) provides:
  - International Celestial Reference System (ICRS) and its realization the **International Celestial Reference Frame** (ICRF)
  - International Terrestrial Reference System (ITRS) and its realization the **International Terrestrial Reference Frame** (ITRF)
  - **Earth orientation parameters**: angles <1'' adjusting the **rotation transformation between the ICRF and the ITRF**
  - **Conventions** (i.e. standards, models, and constants) used in generating and using reference frames and EOPs
  - **Geophysical data** to study and understand variations in the terrestrial reference frames and the Earth's rotation
- Many users: for operational tasks (navigation, geo-localisation, space techniques, time keeping) and fundamental studies (geophysics, astronomy)

Earth Rotation Time (UT1)

- UT1 determined from the Earth's rotation angle (with respect to the "non rotating origin):
  $\theta = \Omega$ UT1 where Ω is the reference Earth's angular velocity ($7.2921151467064\ 10^{-5}$ rad/s)

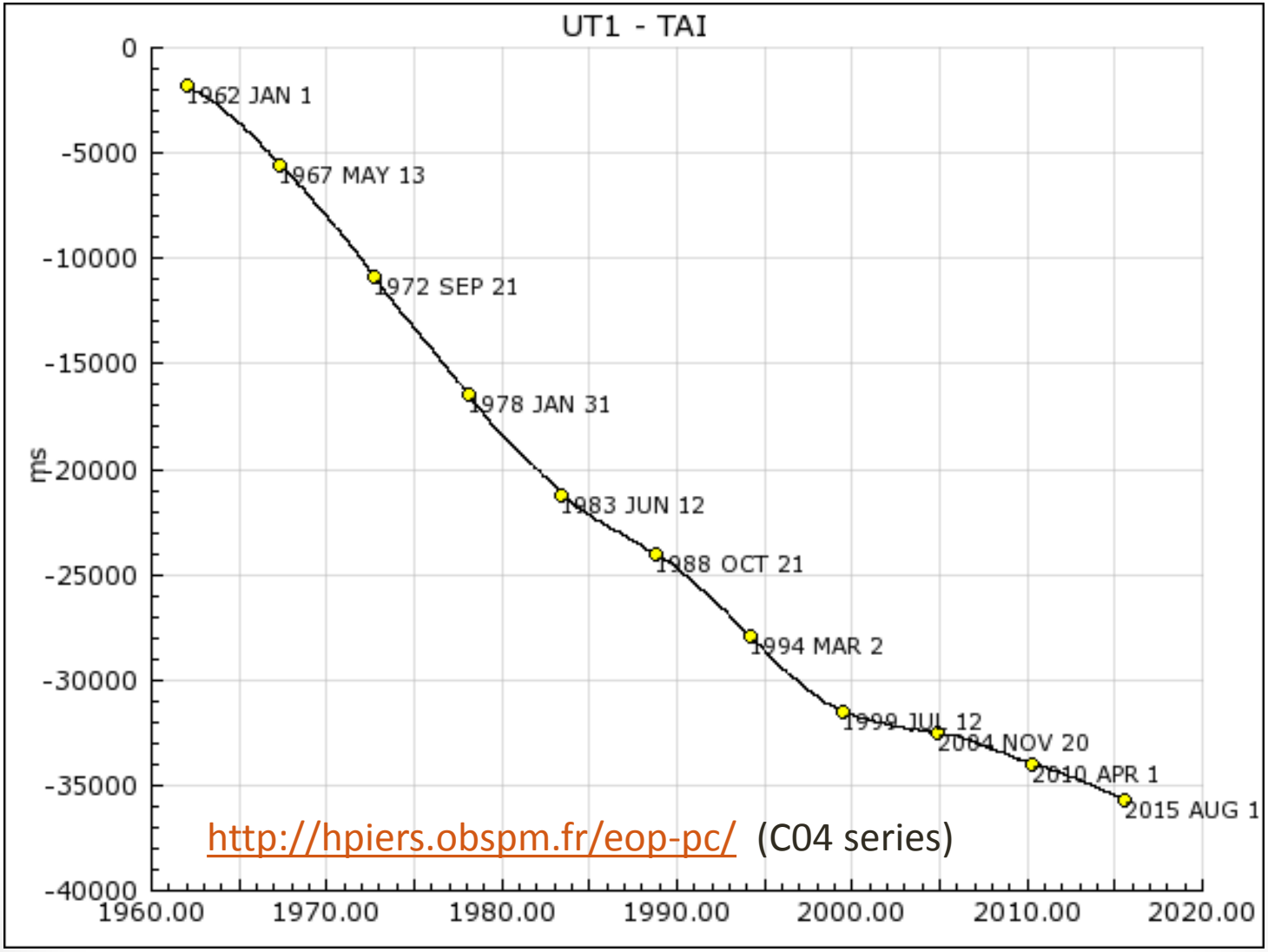
- $\theta = \Omega$ UT1 is "adjusted" by observing "fixed" objects far outside of Earth:

$$\theta = \underbrace{\Omega\ \text{TAI}}_{\text{Uniformly varying}} + \underbrace{\Omega\ (\text{UT1} - \text{TAI})}_{\text{Adjusted}}$$

- Provided parameter UT1-UTC instead of UT1-TAI

- Users of Earth orientation (including UT1) typically want to connect locations on the ground with directions in space
  - E.g. GNSS systems, astronomers pointing telescopes, etc.

UT1-TAI since the 1960s



UT1 or LOD irregularities

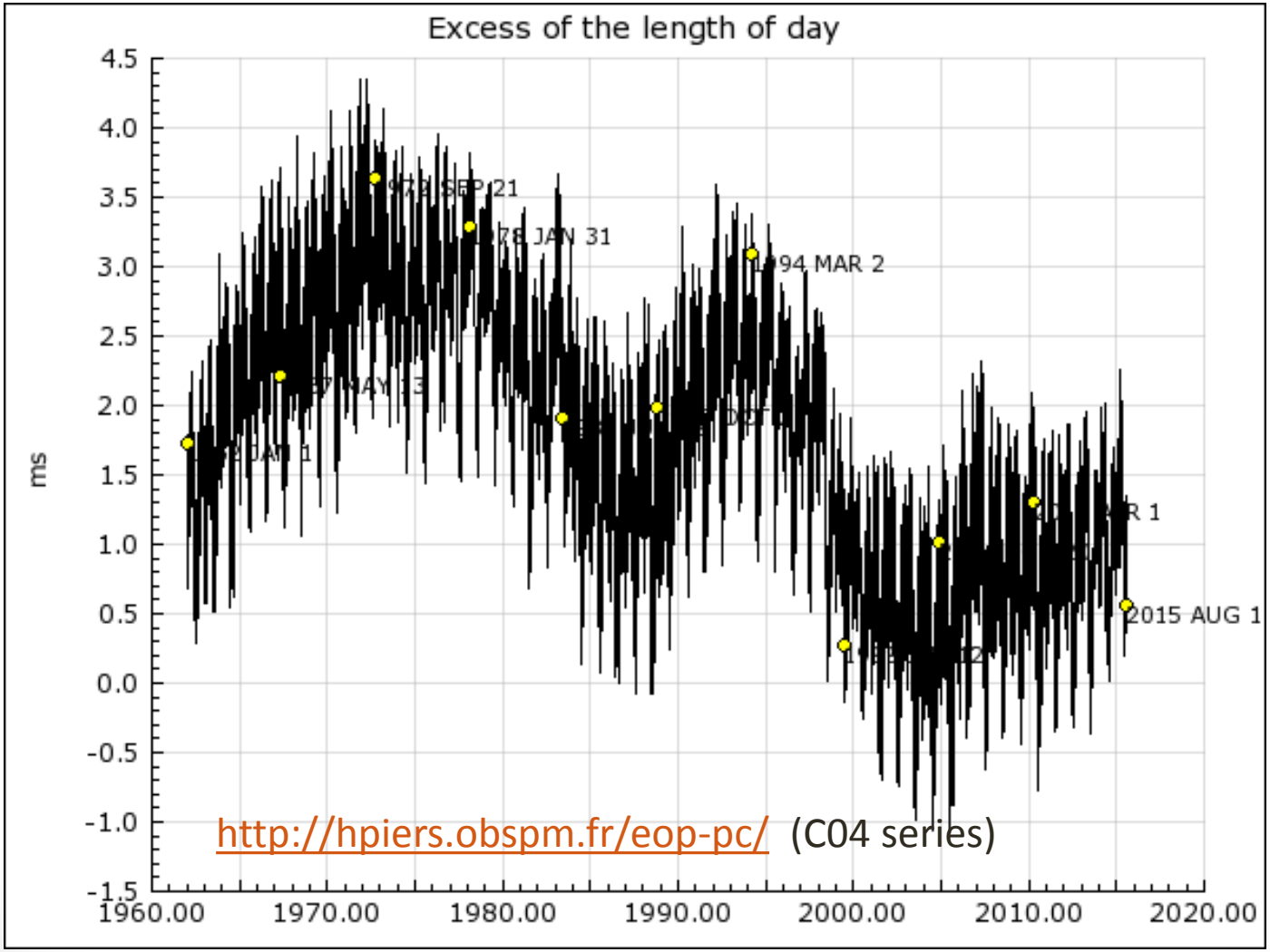
- UT1 – TAI variations reflect the non-uniform Earth's rotation rate

- Length-of day offset ΔD with respect to SI day D=86400 s:
  $\Delta D/D = -d(UT1 - t)/dt$ where t = TAI
  $-1.0 \text{ ms} < \Delta D < 4 \text{ ms}$ over the last 40 years

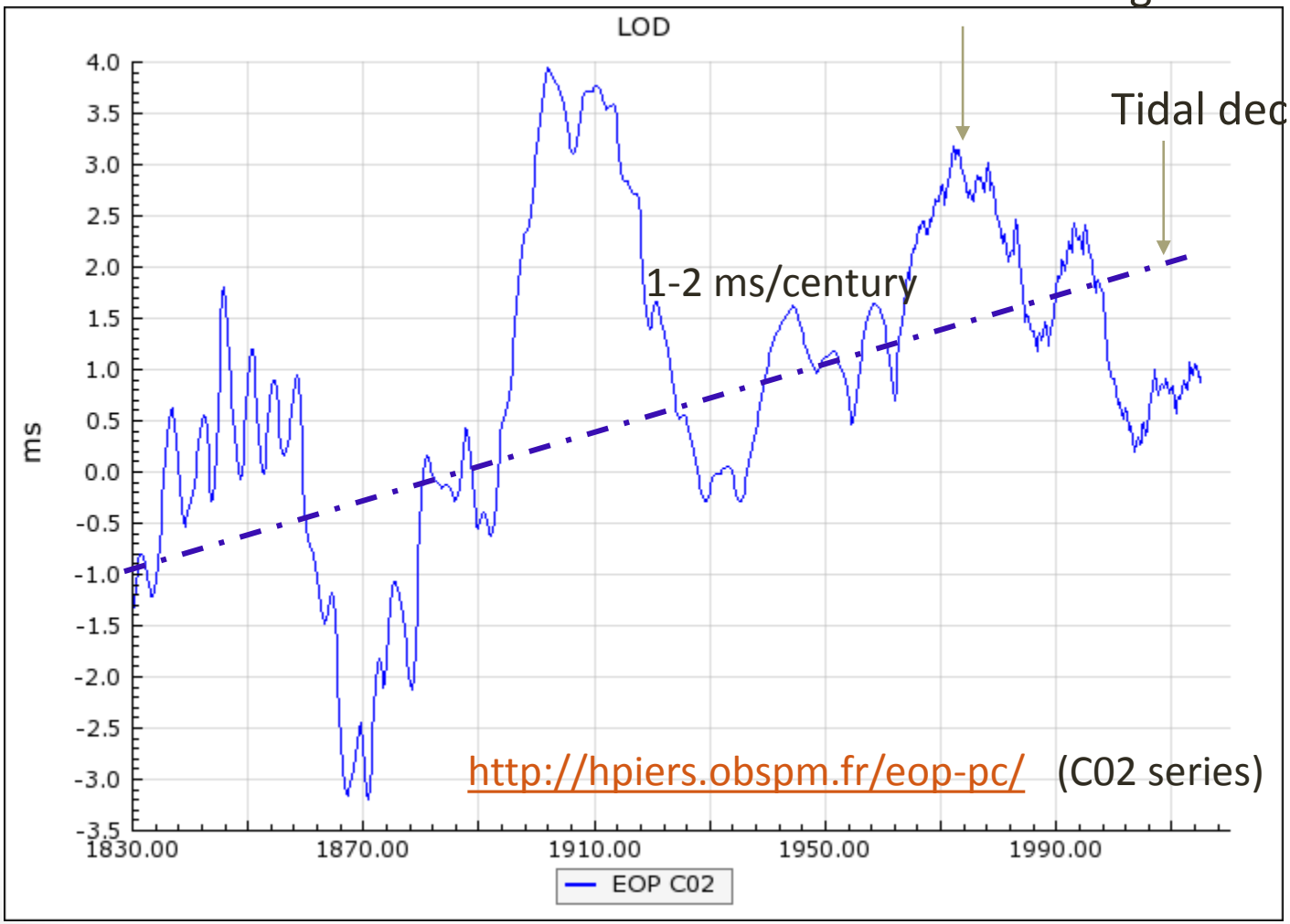
- Cumulative effect causes UT1 to gradually diverge from UTC

- Significant variability due to mass transport in hydro-atmospheric layers mixing with tidal deceleration → Difficult to predict ΔD or UT1-UTC accurately

Length of day offset since the 1960s



Length of day offset since the 1830s

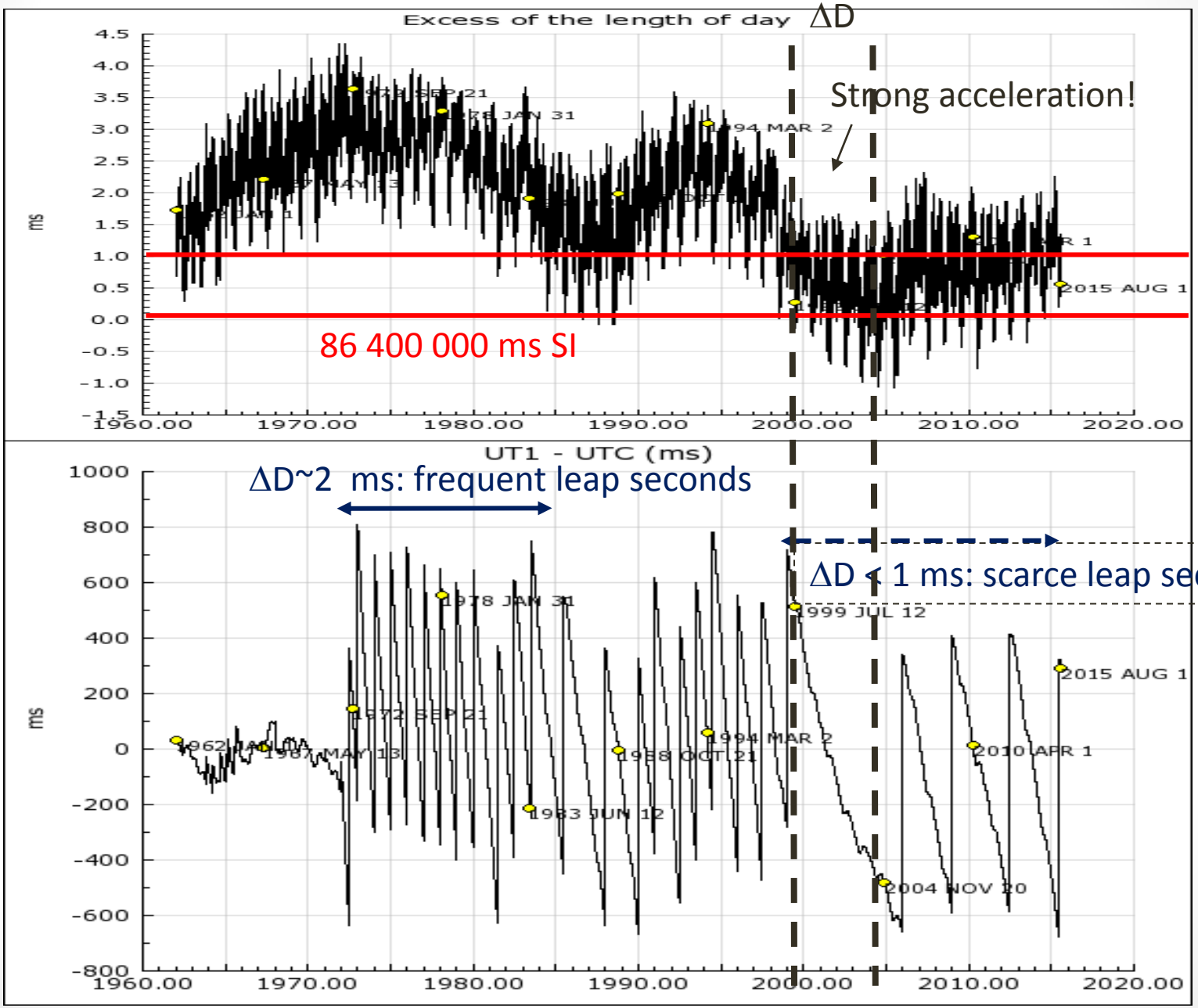


Leap seconds

- UT1 diverges from UTC in reason of
  - the way in which UTC was defined
  - tidal deceleration (over secular period)
  - Decadal variations in UT1: core-mantle coupling, hydrology(?)

- Generally UT1 “runs slow” compared to UTC (negative slope of UT1-UTC), except when Length-of-Day < 86400 s TAI
- Leap seconds were implemented in 1972 as a way to constrain the divergence
  - Allows the Earth to catch up with the clocks
  - Note that to do this, all clocks are stopped by 1 second
  - UTC is adjusted by leap seconds to ensure that |UT1-UTC| < 0.9s
- Whether to continue with this definition is being discussed in the International Telecommunications Union (ITU)
  - ITU provides framework for UTC

UT1-UTC


Excess of the length of day ΔD
Strong acceleration!
86 400 000 ms SI
ms
2015 AUG 1
UT1 - UTC (ms)
ΔD~2 ms: frequent leap seconds
ΔD < 1 ms: scarce leap seconds
1978 JAN 31
1999 JUL 12
1972 SEP 21
1994 MAR 2
1988 OCT 21
1983 JUN 12
2010 APR 1
2004 NOV 20
1960.00
1970.00
1980.00
1990.00
2000.00
2010.00
2020.00

Leap second logistics

- Leap seconds are added or subtracted from the last second of a UTC month.
  - First preference given to end of June or end of December
  - Second preference given to end of March or end of September
    - To date, leap seconds have only occurred in June and December
- Since 1972, there have been 26 leap seconds
  - All have been **positive**
- When will the next leap second be?
  - Difficult to determine due to Earth's rotation irregularities
  - IERS will provide notification of next leap second roughly 6 months in advance
    - Note ITU only requires 8 weeks notification

Measuring Earth rotation

- Measure using technique: Very Long Baseline Interferometry
- Need to observe “fixed” objects external to Earth: coordinated observations of extragalactic sources from radio telescopes located around the world
- Coordinated through the International VLBI Service for Geodesy and Astrometry (IVS)
- Time from observation to analyzed product can be less than a day
  - Typically data are only a few hours old when used in EOP product generation

Predicting Earth rotation

- Earth orientation parameters are predicted for use by real-time (operational) users
- Predictions are made on a variety of scales
  - Few hours to a few decades
  - Prediction accuracy (hours): < 100 μs (i.e. 0.0001 s)
  - Prediction accuracy (year): < 100 ms (i.e. 0.1 s)
    - Note that if using UTC ≈ UT1, the error is roughly 10 times larger than if using 1-year predictions
- Predictions are used to determine when leap seconds need to be introduced
- Predictions are generated by IERS at the same time that the Earth rotation measurements are collected, combined, and distributed

UT1-UTC dissemination

- Links the terrestrial and celestial reference frames
- Determined through VLBI, satellite laser ranging (SLR), and global navigation satellite systems (GNSS) observations; IERS collects, combines, and distributes Earth rotation information
- Provide 5 parameters: PMx, PMy, **UT1–UTC**, dX, dY
- EOP products:
  - IERS Rapid Service/Prediction Center (http://maia.usno.navy.mil)
    - Bulletin A - Rapid determination and prediction of EOPs
  - IERS Earth Orientation Center (http://hpiers.obspm.fr/eop-pc/)
    - Bulletin B – Final determination of EOPs
    - Bulletin C – Leap second announcement
      +leap second file for Network Time Protocol
      ftp://hpiers.obspm.fr/iers/bul/bulc/ntp/leap-seconds.list
    - Bulletin D – Determination of DUT1 (i.e. UT1–UTC to an accuracy of 0.1 s)

Data delivery

- WEB SITE:
  - http://www.usno.navy.mil/USNO/earth-orientation/eo-products
  - http://hpiers.obspm.fr/eop-pc (Earth Orientation Center)

- Current Methods for Flat Files
  - Web-based delivery (http)
  - Internet-based delivery (ftp)
  - E-mail
- Methods under Development
  - Improved transfer protocol
    - NTP-like
    - Provide current estimates of UT1 through EOP predictions
- Methods under Consideration
  - Improved file structure (xml format,…)

UT1 NTP (NIST)

- Effort supported by US National Institute of Standards and Technology (NIST)
- Utilizes IERS Bulletin UT1 predictions
  - Data updated at least every 30 days
- Provides UT1 through Network Time Protocol (NTP)
- Users must be on white list to utilize new service
- See http://www.nist.gov/pml/div688/grp40/ut1_ntp_description.cfm for additional information

Summary

- IERS has 25+ years of experience providing Earth orientation data to the scientific and operational user communities
- IERS provides everything that you need to determine and utilize the relationship between clock time and Earth rotation (UT1–UTC)
  - Observations, predictions, algorithms, and software
- Whatever decision the ITU makes, the IERS will continue to serve the community by providing the necessary data and expertise