UT1 Combination and Prediction

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11th IVS Technical Operations Workshop:
Pre-recorded Presentation

What are Earth Orientation Parameters? Why needed?

- **Position of satellites, celestial objects best described in a celestial reference frame.**
- **Position of earth-bound objects best described in terrestrial reference frame.**
- **If one wants to use one (e.g., satellites) to find the other, need to know relationship (angles) between the two frames.**
- **Using Earth orientation parameters with IERS/SOFA models => accurate angles.**
  - ➢ *One of those angles, the Earth Rotation Angle, is directly related to UT1.*
- **Highly variable: models *alone* can't quantify to accuracy required by modern geodetic measurements. Must measure, plus predict for real-time users.**
  - NOTE: The UT1 EOP is the <u>most</u> variable.

What are Earth Orientation Parameters? Characteristics and Specifics

EOPs needed to accurately model the terrestrial to celestial reference frame transformation.

- Systems with knowledge of location, attitude, and pointing directions in a celestial (inertial) frame can use EOPs to relate that information to a terrestrial (Earth-fixed) frame.

EOPs consist of 5 parameters updated daily.

- Observables and residuals to models from which the terrestrial reference frame orientation relative to the celestial frame can be determined.
- Direction cosine matrix calculations from terrestrial-to-celestial require EOP inputs. (Example is the USNO Earth Orientation matrix calculator.)

Terrestrial frame is the International Terrestrial Reference Frame (ITRF)

- Rotates with the Earth.
- The orientation of the WGS 84 is based on the ITRF.

The celestial frame is the International Celestial Reference Frame (ICRF).

- ICRF is inertial and is based on locations in space of distant extragalactic objects, such as quasars.

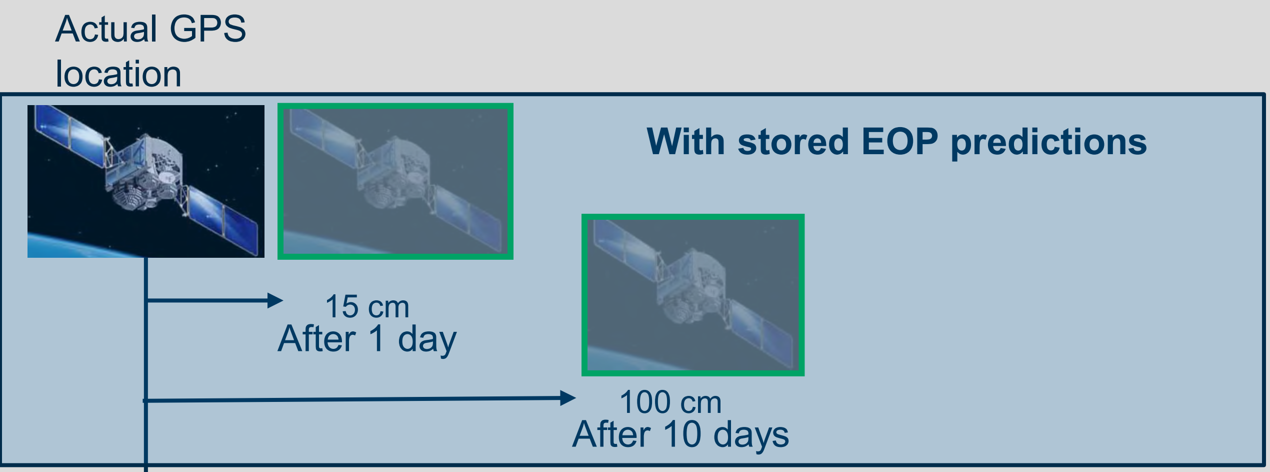
UT1 is essentially a measure of Earth rotation about its spin axis.

- A more precise definition can be found by reading Chapter 5 of the IERS Conventions (https://iers-conventions.obspm.fr and then downloaded the most recently updated version.)

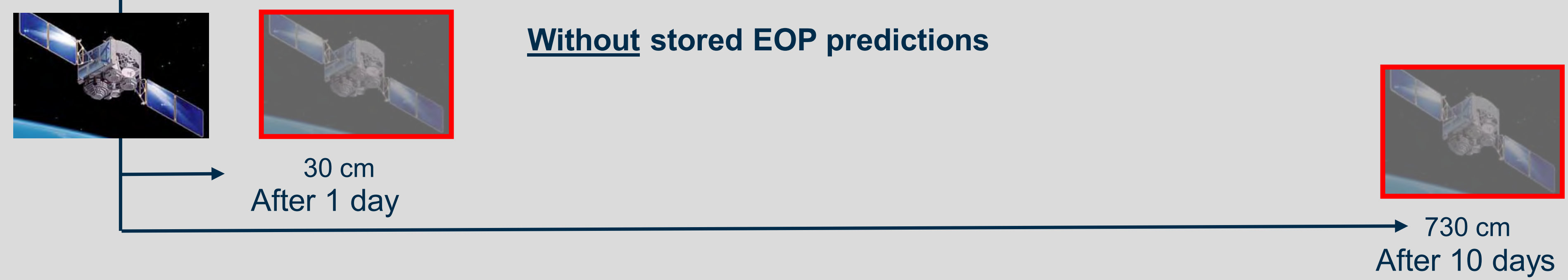
Example of the Importance of EOPs:

Drift in knowledge of GPS (or other navigation satellite) spacecraft locations

Most of the drift would be due to a lack of knowledge of UT1.



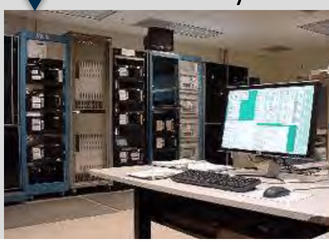
Without EOP estimates, inertial locations of GPS and GPS determined Earth-based locations drift significantly.



Note that Galileo, Beidou, and GLONASS may have different errors depending on their orbits, but the concept would be the same.

Production and Distribution of EOPs:
Observations, Processing, and Users

Observations
Very Long Baseline Interferometry



USNO and Int'l Correlators

US and Int'l VLBI partners

GPS and Int'l GNSS service and USNO "UTGPS"

Atmospheric data NOAA and Navy

Laser ranging and other sources

US Naval Observatory Earth Orientation Parameters analyses and processing

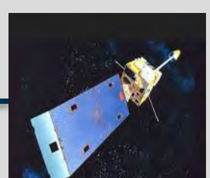
Tidal, seasonal, and leap second models

Near-real time users not constrained by GPS format

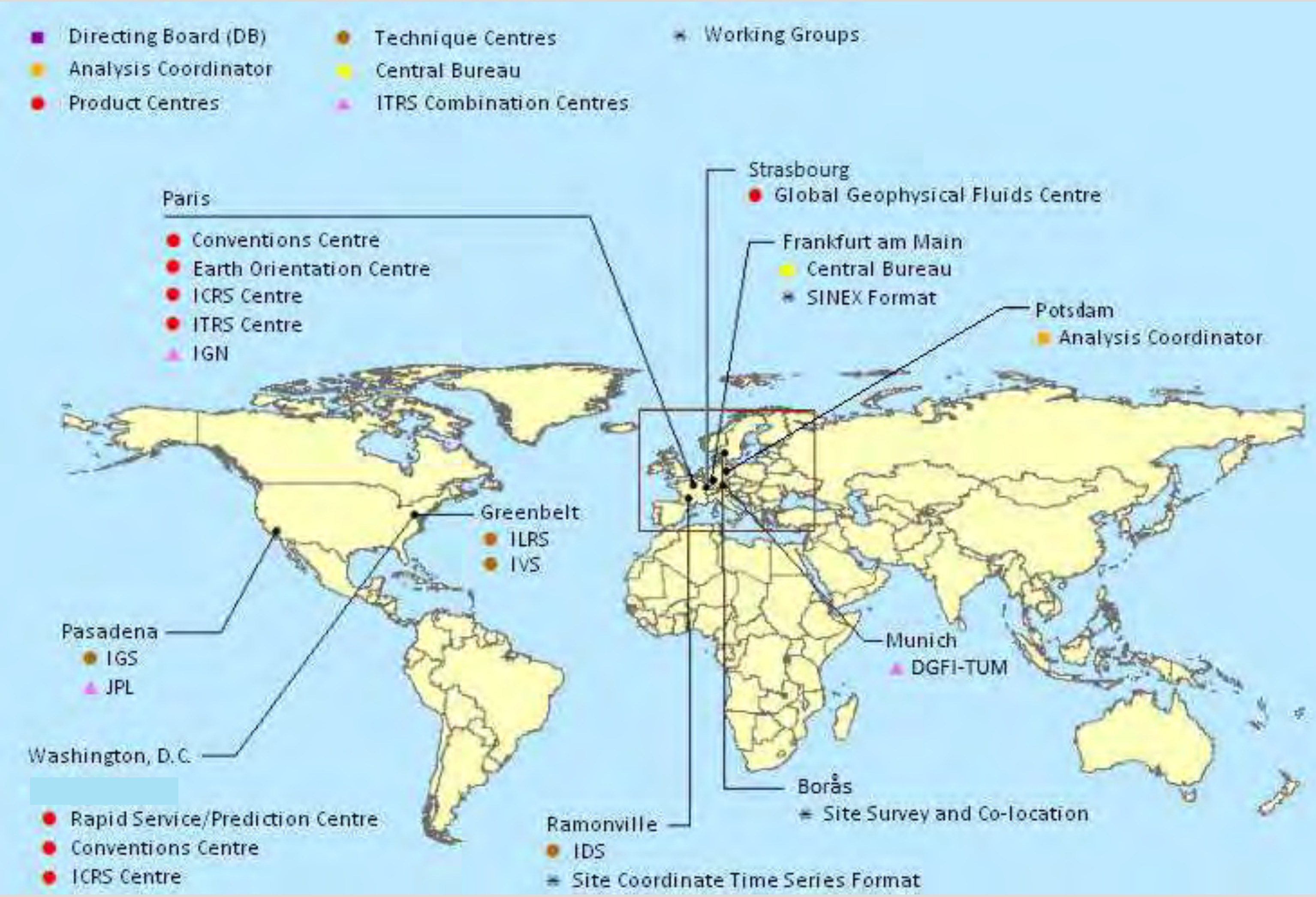
EOPs produced:
Polar Motion, UT1-UTC, and Celestial Pole Offsets.

Partners who provide data for GPS processing and formatting

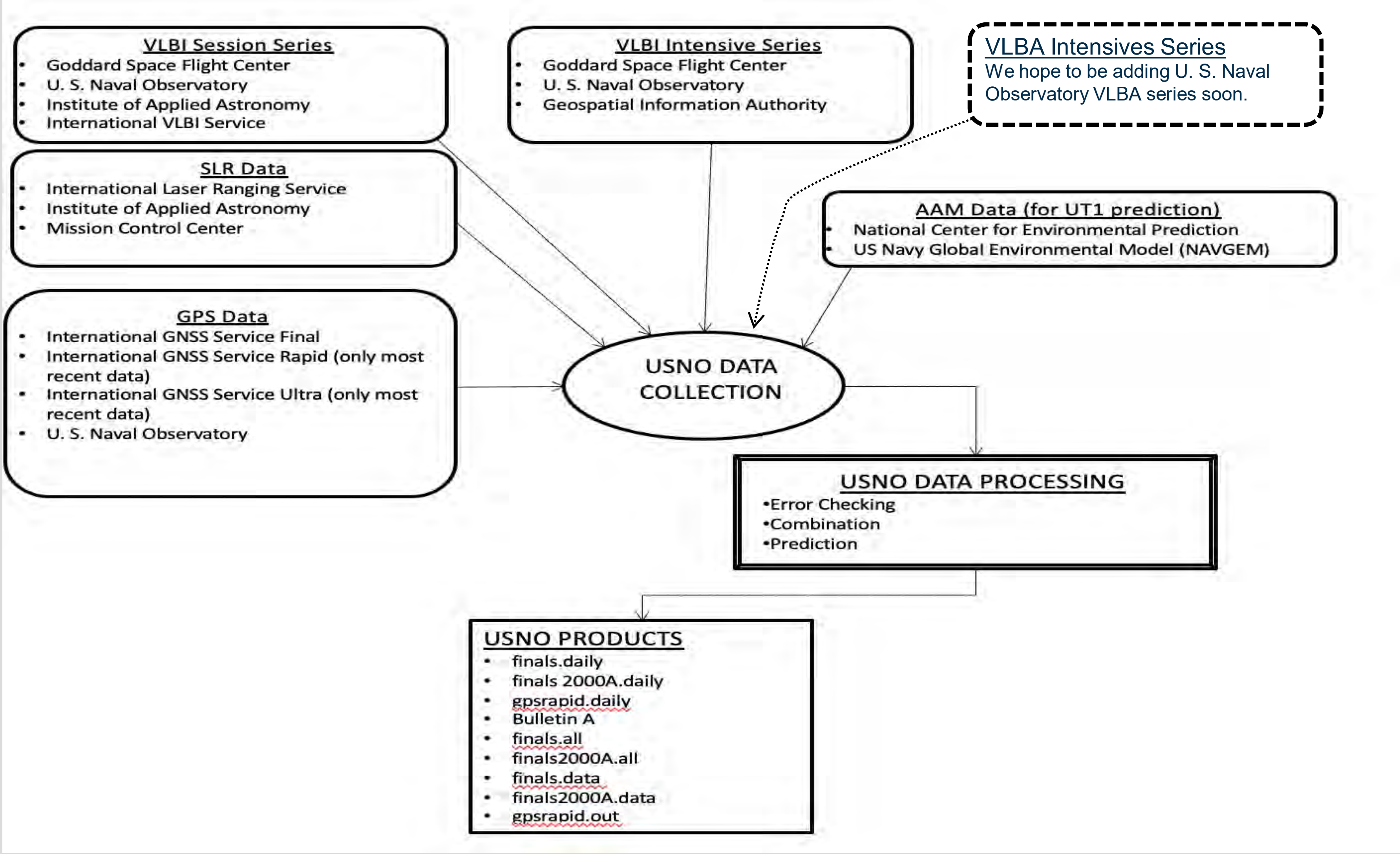
Special customers



Participation in International Earth Rotation and Reference System Service (IERS) Provides Observational Data



Production and Distribution of EOPs:
Providers and Products Details



EOP Combination and Prediction: Definitions

EOPs estimates are made each day for past, present, and future dates.

- ***The EOP Combination*** **refers to past EOP estimates. I.e., each day recent estimates of past EOPs are made. E.g., on 18-Apr-2021 EOP combination estimates provided in finals.daily were:**

Recent past estimates of EOPs, such as UT1-UTC, are re-estimated based on newly processed observations.

Calendar date / MJD				<------ Polar motion estimates ---->				UT1-UTC (sec)		LOD (sec/day)	
21	4 9	59313.00	I	0.087573	0.000020	0.418821	0.000030	I-0.1752797	0.0000101	0.4512	0.0070
21	410	59314.00	I	0.087453	0.000091	0.419871	0.000091	I-0.1757548	0.0000100	0.5027	0.0123
21	411	59315.00	I	0.087103	0.000091	0.420732	0.000092	I-0.1762861	0.0000224	0.5573	0.0135
21	412	59316.00	I	0.086830	0.000091	0.421362	0.000092	I-0.1768384	0.0000251	0.5189	0.0166
21	413	59317.00	I	0.086981	0.000091	0.421896	0.000092	I-0.1772971	0.0000246	0.4000	0.0200
21	414	59318.00	I	0.087708	0.000091	0.422496	0.000091	I-0.1776446	0.0000311	0.2995	0.0233
21	415	59319.00	I	0.088770	0.000092	0.423217	0.000091	I-0.1778864	0.0000396	0.1697	0.0216
21	416	59320.00	I	0.090196	0.000092	0.423813	0.000091	I-0.1779889	0.0000299	0.0546	0.0236
21	417	59321.00	I	0.092170	0.000091	0.424407	0.000091	I-0.1780128	0.0000256	-0.0087	0.0177
21	418	59322.00	I	0.094210	0.000094	0.425262	0.000092	I-0.1779536	0.0000188		
21	419	59323.00	P	0.095943	0.000600	0.426234	0.000400	P-0.1778425	0.0001080		
21	420	59324.00	P	0.097431	0.000891	0.427211	0.000659	P-0.1777098	0.0002041		
21	421	59325.00	P	0.098793	0.001122	0.428113	0.000882	P-0.1776573	0.0003028		
21	422	59326.00	P	0.100065	0.001322	0.428902	0.001085	P-0.1777699	0.0004021		
21	423	59327.00	P	0.101295	0.001502	0.429599	0.001275	P-0.1781092	0.0005017		

EOP Combination and Prediction: Definitions

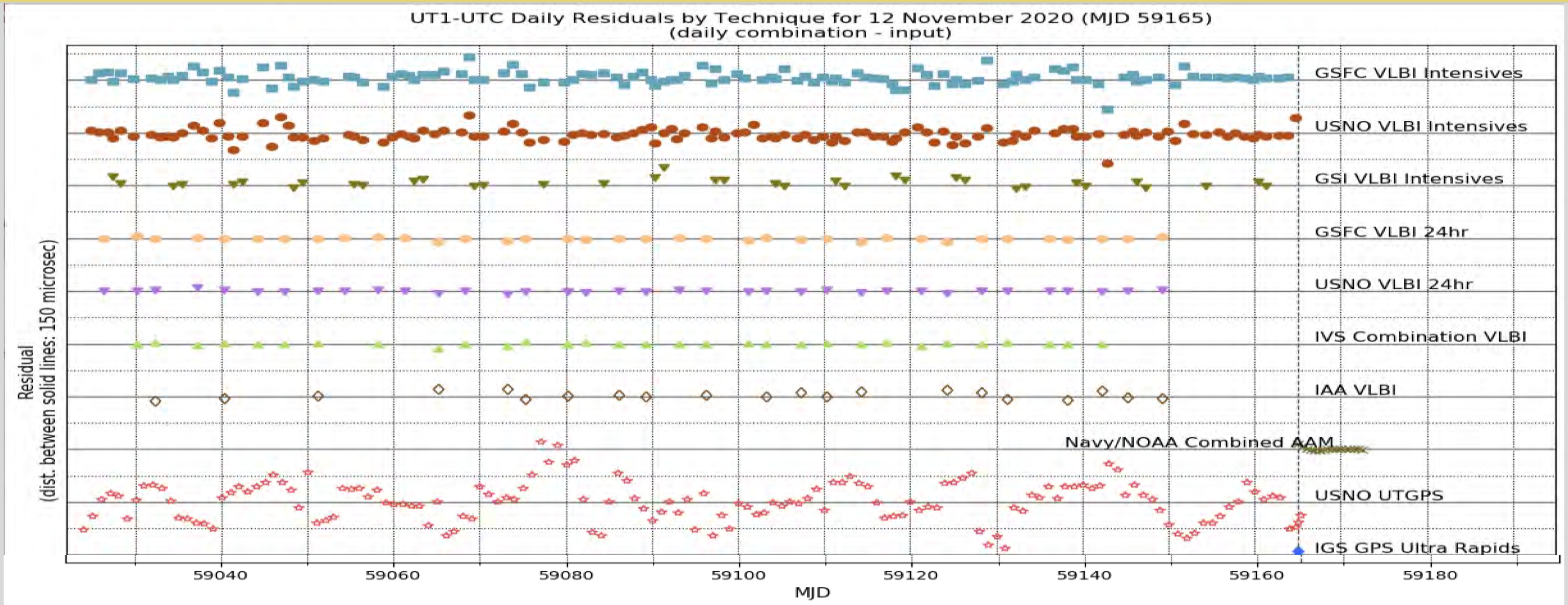
- ***The EOP Predictions*** **refer to current and future EOP estimates. I.e., each day we re-estimate our predictions of what EOPs *will be* in the future. E.g., on 18-Apr-2021 EOP prediction estimates provided in finals.daily were:**

Calendar date / MJD <------ Polar motion estimates ----> UT1-UTC (sec) LOD (sec/day)

21	4 9	59313.00	I	0.087573	0.000020	0.418821	0.000030	I-0.1752797	0.0000101	0.4512	0.0070
21	410	59314.00	I	0.087453	0.000091	0.419871	0.000091	I-0.1757548	0.0000100	0.5027	0.0123
21	411	59315.00	I	0.087103	0.000091	0.420732	0.000092	I-0.1762861	0.0000224	0.5573	0.0135
21	412	59316.00	I	0.086830	0.000091	0.421362	0.000092	I-0.1768384	0.0000251	0.5189	0.0166
21	413	59317.00	I	0.086981	0.000091	0.421896	0.000092	I-0.1772971	0.0000246	0.4000	0.0200
21	414	59318.00	I	0.087708	0.000091	0.422496	0.000091	I-0.1776446	0.0000311	0.2995	0.0233
21	415	59319.00	I	0.088770	0.000092	0.423217	0.000091	I-0.1778864	0.0000396	0.1697	0.0216
21	416	59320.00	I	0.090196	0.000092	0.423813	0.000091	I-0.1779889	0.0000299	0.0546	0.0236
21	417	59321.00	I	0.092170	0.000091	0.424407	0.000091	I-0.1780128	0.0000256	-0.0087	0.0177
21	418	59322.00	I	0.094210	0.000094	0.425262	0.000092	I-0.1779536	0.0000188		
21	419	59323.00	P	0.095943	0.000600	0.426234	0.000400	P-0.1778425	0.0001080		
21	420	59324.00	P	0.097431	0.000891	0.427211	0.000659	P-0.1777098	0.0002041		
21	421	59325.00	P	0.098793	0.001122	0.428113	0.000882	P-0.1776573	0.0003028		
21	422	59326.00	P	0.100065	0.001322	0.428902	0.001085	P-0.1777699	0.0004021		
21	423	59327.00	P	0.101295	0.001502	0.429599	0.001275	P-0.1781092	0.0005017		

Future prediction estimates of EOPs, such as UT1-UTC, are re-estimated based on newly processed observations *and updated Atmospheric forecast inputs*.

Input Data Used in the UT1-UTC Combination and Predictions



Input series	Est Relative influence Range of 1 to 10 (1 lowest; 10 highest)
GSFC VLBI Intensive	8.0
USNO VLBI Intensive	8.0
GSI VLBI Intensive	8.5
GSFC VLBI 24-hour	9.75
USNO VLBI 24-hour	9.75

Input series (continued)	Est Relative influence Range of 1 to 10 (1 lowest; 10 highest)
IVS Combined VLBI 24-hr	10.0
IAA VLBI 24-hr	6.0
AAM	9.75*
USNO UTGPS	5.0
IGS Ultra Rapids	8.0

* AAM data influences predictions and not combination values.

Estimated RMS residuals of EOP Input series (2019)

Table 1: *Estimated accuracies of the contributions to the IERS RS/PC combination results for 2019 with respect to the IERS RS/PC EOP series. Units are milliseconds of arc (mas) for x, y, dX, and dY and milliseconds of time (ms) for UT1–UTC. (All acronyms used in this table are defined in the Acronyms section of the Appendix of the IERS annual report for 2019.)*

		Estimated accuracy				
	Contributor	x	y	UT1–UTC	dX	dY
	ILRS SLR	0.16	0.15	–	–	–
	IAA SLR	0.24	0.20	–	–	–
	MCC SLR	0.15	0.20	–	–	–
VLBI Intensives	GSFC VLBI Intensive	–	–	0.018	–	–
	USNO VLBI Intensives	–	–	0.014	–	–
	GSI Intensives	–	–	0.016	–	–
VLBI 24-hour series	GSFC+ VLBI	0.13	0.09	0.005	0.06	0.06
	IAA+ VLBI	0.30	0.29	0.008	0.06	0.09
	IVS+ VLBI	0.11	0.12	0.004	0.05	0.06
	USNO+ VLBI	0.11	0.07	0.005	0.06	0.06
	IGS Final	0.01	0.01	–	–	–
	IGS Rapid	0.03	0.03	–	–	–
GPS LOD related ….	IGS Ultra*	0.04	0.04	0.028*	–	–
	USNO GPS UT*	–	–	0.047*	–	–

* The GPS LOD related quantities are measuring the derivatives of the UT1-UTC. The accuracies reported are estimates.

In addition, Atmospheric Angular Momentum will be used as another input to the combination in the near future.

Not All Intensive Sessions are Used: Primary Intensives Baselines

- **Only S/X intensive sessions which have a consistently reasonable solution and which have well established baselines are used.**
  - **Current standard baselines used operationally**

#	Baseline	Analysis Center	Comment
1	Kk-Wz	GSFC, USNO	Nominally available in INT1 series – observed Monday through Thursday (I-series)
2	Is-Wz	GSI*, GSFC, USNO	Nominally available in INT2 and INT3 series – observed Saturday, Sunday and some Mondays. (Q-series) Is has been off-line for Sx observations since 15-June-2020; nominal return to operations 15-May-2021.
3	Mk-Wz	GSI*, GSFC, USNO	Mk has temporarily replaced Is for duration of the Is outage.

* GSI is the Geospatial Information Authority of Japan
Kk – Kokee Park; Wz – Wettzell; Is = Ishioka; Mk= Mauna Kea

Files used: gsf2020a.eopi.gz (GSFC), usn2020b.eopi.gz (USNO), gsiint2c.eopi (GSI)

Not All Intensive Sessions are Used:
Additional Intensives Baselines Available

- **Other S/X baselines that have been characterized that can be used.**

#	Baseline	Analysis Center	Comment
1	KkNy	GSFC, USNO	Ny is used when Wz is off-line
2	KkSv	GSFC, USNO	Sv is used when Wz is off-line
3	IsNy	GSI*, GSFC, USNO	Ny is used when Wz is off-line
4	ShWz	GSFC, USNO	Could fill in if Kk is not available.
5	KkWn	GSFC, USNO	62 sessions observed as of 20 April 2021… may be easily characterized quickly….
6	IsWn	GSFC	> 60 sessions observed as of 20 April 2021… maybe easily characterized….

- **3-station baselines can be characterized in the future, but are not currently used in operations.**
- **Some VLBA stations may be used as a backup and/or additional inputs in the near future.**

Criteria for Inclusion of an Intensives Baseline into the Combination

Criteria provided should be considered necessary, but not necessarily sufficient.
(One does not know if a series will be acceptable until it is thoroughly examined and tested in EOP simulation run of historical results – a type of hind-cast simulation.)

- There should be at least 60 observed intensives with formal errors less than 30 μsec.
- There should be an analysis done of the residuals versus formal errors to ensure a reasonable correlation – especially if the residual RMS is greater than about 50 μsec.
  - Note, the IVS S/X intensives RMS is < 20 μsec. It is hoped that the VGOS intensives RMS will be even smaller.
- There should be fewer than three outliers whose residual is > 4*sigma per 60 sessions.

If the criteria are met, systematic corrections based on residuals of the series versus the C04 reference series are determined.

- Offset and slope are computed using robust line fit tools assuming the series has stationary drift and offset.

Note, additional information was provided at the eVGA 2019 conference, presentation by Maria Davis entitled, "The IERS Rapid Service / Prediction Center UT1-UTC combined solution: Present and future Contributions", Las Palmas de Gran Canaria, March 2019.

VLBI 24-hour Series

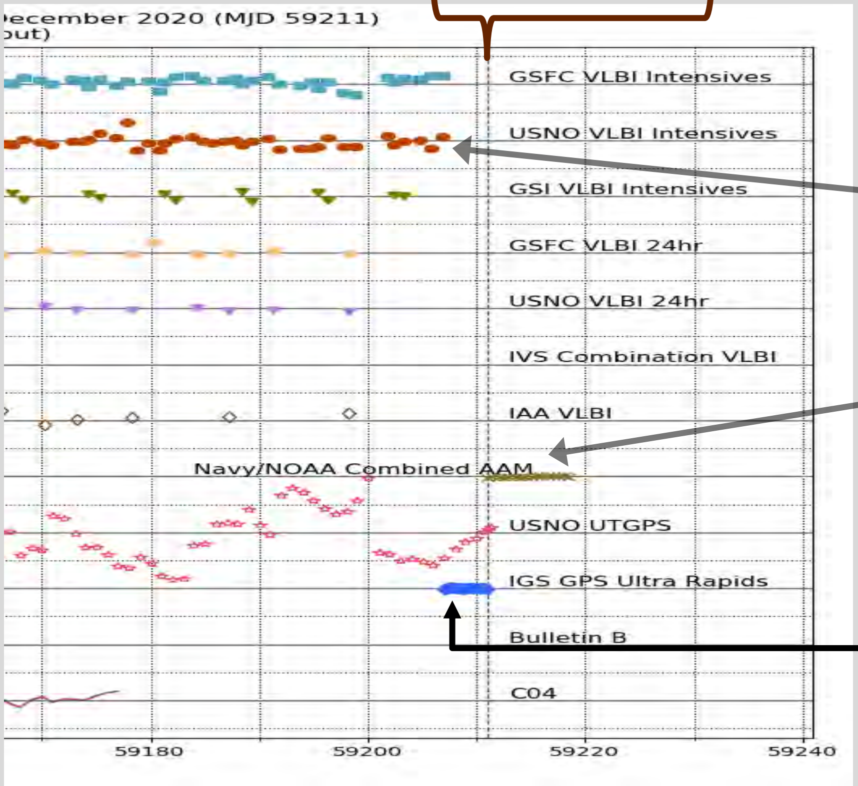
- **“R1” and “R4” sessions are used in the combination.**
- **Current Analysis Center files used:**

#	Analysis Center	Series	Comment
1	GSFC	gsf2020a.eoxy.gz	Created by NASA Goddard Space Flight Center.
2	USNO	usn2020d.eoxy.gz	Created by USNO.
3	IVS	ivs20r1X.eops.gz	IVS combined solution – Generally available a week or two after the GSFC and USNO data.
4	IAA	iaa2007a.eops.gz	Created by the Institute of Applied Astronomy of the Russian Academy of Sciences in St. Petersburg, Russia.

Latency Between VLBI Observation and Use in the EOP Combination

- **Occasionally several days between VLBI observation and the analysis of that observation – called *latency*.**
- **In addition, especially around major holidays, no VLBI observations are made for several days. Example below is what occurred on 28-Dec-2020.**

28 Dec 2020



- On 28 Dec 2020, the last VLBI observation was 4+ days previously.

23 Dec 2020 18:00 hr UTC

AAM forecast data is available after the current date.

IGS Ultra LOD observations are used to fill in the gap between current day and last IVS observation.

Intensives Latency for Year 2020

Timeline of VLBI intensives observation times and usage in the IERS RS/PC combination and prediction solution.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Intensives and Observation Times (UTC)	INT3 (08:00) INT1† (19:00)	INT1† (19:00)	INT1† (19:00)	INT1† (19:00)	INT1† (19:00)	INT2†† (07:00)	INT2†† (07:00)
Time of arrival to IERS RS/PC °	Monday INT3	Monday INT1	Tuesday INT1	Wednesday INT1	Thursday INT1	Frid. INT1 Saturday INT2	Sunday INT2
Estimated reliability	87%	79%	85%	66% *	88%	92%	79%

† INT1 intensives contain the Kk-Wz baseline and are correlated at USNO.
†† INT2 intensives contain the Is-Wz baseline and are correlated at GSI.
††† INT3 intensives contain the baseline and are correlated at Bonn.

* Some of the missing intensives were due to maintenance at Wz; Ny was substituted, but not used in the EOP combination. EOPCP looking at using KkNy for these days.

How well does the IGS LOD fill in the VLBI latency gaps?

- Depending on the number of days of latency of the VLBI intensives, the UT1-UTC solution will drift by the results shown in the table below – provided IGS Ultra LOD inputs are available to “fill in the gaps”.

Latency (Days)	Mean (μsec)	STD (μsec)	RMS (μsec)
1	0.4	22.3	22.3
2	0.8	37.5	37.5
3	1.3	49.1	49.1
4	1.8	59.1	59.1
5	2.2	67.6	67.7
6	2.7	74.3	74.3
7	3.1	79.0	79.0
8	3.4	82.1	82.2
9	3.8	83.7	83.7
10	4.1	84.2	84.3

We estimate that after about 10 days without any UT1 update from VLBI (or LLR), then GPS LOD cannot “fill in the gap…”. GPS depends on EOP in order to make accurate estimates…

Predictions using Atmospheric Angular Momentum

- Short term predictions of UT1-UTC (from 1 to 7 days from the current date) are heavily influenced by the contribution of Atmospheric Angular Momentum.
- Longer term predictions are made using a simple differencing technique and more details can be found in the IERS RS/PC contribution to the 2019 IERS Annual Report (or even in the 2018 report). See: https://www.iers.org/IERS/EN/Publications/AnnualReports/AnnualReports.html

Table 3a: *RMS of the differences between the EOP time series predictions produced by the 17:00 UTC daily EOP solutions and the 14 C04 combination solutions for 2019. Note that the prediction length starts counting from the day after the date of the solution epoch.*

Days in future	PMx (mas)	PMy (mas)	UT1−UTC (ms)
0	0.05	0.04	0.042
1	0.30	0.23	0.061
5	1.90	1.25	0.198
10	3.46	1.88	0.463
20	5.75	2.84	1.851
40	7.21	4.04	6.259
90	8.45	8.66	19.983

EOP Results: Available files

Various available files:

- finals.daily, finals2000A.daily – 90 past combination, the current, and 90 future day results. ”finals2000A.daily” has dX/dY CPOs; finals.daily has dpsi/deps. (Updated daily.)
- finals.data, finals2000A.data – EOP solution from 1992, predictions one year out in the future. (“2000A.” has dX/dY). (Updated weekly.)
- finals.all, finals2000A.all – EOP solution from 1973. (Updated weekly.)
- gpsrapid.daily, gpsrapid.out – EOP solutions for IGS and other users. (.daily updated daily; .out updated weekly)
- Bulletin A – weekly solution, human-readable format; not recommended for computer readable data. (Updated weekly.)
- finals.daily.extended, finals2000A.daily.extended – “proposed” solution which will be updated daily but has results from 1992 and predictions out to one year into the future. (Updated daily.)

Locations of Files:

- **https://cddis.nasa.gov/archive/products/iers/**
- **https://www.iers.org/IERS/EN/DataProducts/EarthOrientationData/eop.html**

Within several months, there will be EOPs available on a public US web site.

EOP Results: Standard Format

- **EOP results are in many different formats; the format discussed here is the finals2000A.daily, finals2000A.data, finals2000A.all format.**

```
20 919 59111.00 I  0.206702 0.000090  0.338644 0.000091  I-0.1764067 0.0000120  0.4216 0.0072  P    -0.025     0.121      0.010     0.154
20 920 59112.00 I  0.205716 0.000090  0.337259 0.000091  I-0.1767892 0.0000113  0.3196 0.0080  P    -0.065     0.123      0.015     0.155
20 921 59113.00 I  0.204594 0.000091  0.336032 0.000091  I-0.1770116 0.0000105  0.1149 0.0074  P    -0.093     0.125      0.022     0.157
20 922 59114.00 I  0.203411 0.000091  0.335001 0.000091  I-0.1770104 0.0000095 -0.1156 0.0070  P    -0.109     0.126      0.031     0.158
20 923 59115.00 I  0.202323 0.000091  0.334037 0.000091  I-0.1768105 0.0000092 -0.2557 0.0058  P    -0.116     0.126      0.040     0.158
20 924 59116.00 I  0.201317 0.000091  0.333024 0.000091  I-0.1764616 0.0000065                 P    -0.117     0.127      0.049     0.159
20 925 59117.00 P  0.200439 0.000602  0.331887 0.000400  P-0.1760479 0.0001080                 P    -0.114     0.127      0.058     0.159
20 926 59118.00 P  0.199587 0.000893  0.330691 0.000659  P-0.1756011 0.0002041                 P    -0.109     0.128      0.067     0.160
20 927 59119.00 P  0.198747 0.001126  0.329471 0.000882  P-0.1751510 0.0003028                 P    -0.103     0.128      0.076     0.160
```

Year/ Month/ Day

MJD

Combination (=I) or Prediction (=P) flag For Polar Motion (PM)

PMx, Pmxerr (arcsec)

PMy, Pmyerr (arcsec)

Combination (=I) or Prediction (=P) flag for UT1–UTC

UT1-UTC (sec), UT1-UTCerr (sec)

LOD (sec)

Celestial Pole Offsets (milliarcsec)

EOP Results: Standard Format

- **Readme.finals2000A format file**

```
The format of the finals2000A.data, finals2000A.daily, and finals2000A.all files is:

Col.#     Format  Quantity
-------   ------  -------------------------------------------------------------
1-2       I2      year (to get true calendar year, add 1900 for MJD<=51543 or add 2000 for MJD>=51544)
3-4       I2      month number
5-6       I2      day of month
7         X       [blank]
8-15      F8.2    fractional Modified Julian Date (MJD UTC)
16        X       [blank]
17        A1      IERS (I) or Prediction (P) flag for Bull. A polar motion values
18        X       [blank]
19-27     F9.6    Bull. A PM-x (sec. of arc)
28-36     F9.6    error in PM-x (sec. of arc)
37        X       [blank]
38-46     F9.6    Bull. A PM-y (sec. of arc)
47-55     F9.6    error in PM-y (sec. of arc)
56-57     2X      [blanks]
58        A1      IERS (I) or Prediction (P) flag for Bull. A UT1-UTC values
59-68     F10.7   Bull. A UT1-UTC (sec. of time)
69-78     F10.7   error in UT1-UTC (sec. of time)
79        X       [blank]
80-86     F7.4    Bull. A LOD (msec. of time) -- NOT ALWAYS FILLED
87-93     F7.4    error in LOD (msec. of time) -- NOT ALWAYS FILLED
94-95     2X      [blanks]
96        A1      IERS (I) or Prediction (P) flag for Bull. A nutation values
97        X       [blank]
98-106    F9.3    Bull. A dX wrt IAU2000A Nutation (msec. of arc), Free Core Nutation NOT Removed
107-115   F9.3    error in dX (msec. of arc)
116       X       [blank]
117-125   F9.3    Bull. A dY wrt IAU2000A Nutation (msec. of arc), Free Core Nutation NOT Removed
126-134   F9.3    error in dY (msec. of arc)
135-144   F10.6   Bull. B PM-x (sec. of arc)
145-154   F10.6   Bull. B PM-y (sec. of arc)
155-165   F11.7   Bull. B UT1-UTC (sec. of time)
166-175   F10.3   Bull. B dX wrt IAU2000A Nutation (msec. of arc)
176-185   F10.3   Bull. B dY wrt IAU2000A Nutation (msec. of arc)
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Bulletin A Special Messages to Users

- In every Bulletin, there are messages to users that provide useful information. These messages can be updated to users on any given Thursday.

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*                                                                      *
*             There will NOT be a leap second introduced               *
*                   in UTC at the end of June 2021                     *
*                                                                      *
* The US Naval Observatory's Rapid Service/Prediction Center website  *
* (maia.usno.navy.mil) must undergo modernization and has been         *
* offline since 24 October 2019. The expected completion of work and  *
* return of service will be no earlier than Summer of 2021.            *
*                                                                      *
* Although the Bulletin A makes several references to maia, the        *
* paragraph above supersedes any information contained in the          *
* Bulletin A text.                                                     *
*                                                                      *
* Updated EOPs are available at NASA's Archive of Space Geodesy Data: *
*   https://cddis.nasa.gov/archive/products/iers                       *
*   ftps://gdc.cddis.eosdis.nasa.gov/products/iers                     *
* Daily EOP data may be available here by 18:00 UTC, and Bulletin A   *
* EOP data may be available by 20:00 UTC.                              *
* For additional information on accessing CDDIS, please refer to:     *
*   https://cddis.nasa.gov/About/CDDIS_File_Download_FAQ.html          *
*                                                                      *
* Updated EOPs may also be available at IERS:                          *
*   https://datacenter.iers.org/eop.php                                *
* EOP data files are uploaded directly from USNO to this site each    *
* day. For further information, contact the IERS directly.             *
*                                                                      *
* Users should verify results obtained from these sites; we cannot    *
* guarantee the integrity or timeliness of files provided at           *
* third-party sites.                                                   *
*                                                                      *
* Questions and enquiries about EOPs can be emailed to the             *
* following address:                                                   *
*   usn.ncr.navobsydc.mbx.eopcp@mail.mil                               *
*                                                                      *
* Distribution statement A.                                            *
*   Approved for public release: distribution unlimited.              *
*                                                                      *
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Updates:

- Each year the IERS RS/PC makes a contribution to the IERS Annual Report.
- In addition, members of the RS/PC present new developments at conferences such as the AGU, EGU, and Journées Systèmes de référence spatio-temporels.
- A new smoothing cubic spline software has been developed at Virginia Tech University by principle investigator Dr. Mark Psiaki
  - Accepts derivative/rate inputs – older operational cubic spline required determining a constant of integration from which derivative (LOD) inputs would be integrated forward.
  - Developed in MATLAB – Makes testing new data series easier and faster to evaluate.
    - Need to port code to another, more operational language such as python.
    - Hope to make the code operational within 12 to 18 months.
- Whenever significant new models are developed and accepted by the IERS Community through the IERS Conventions, the IERS RS/PC will utilize those models.

Final Slide: Acknowledgements

Thank you for your Attention.

I would like to thank all of the IERS RS/PC staff for their hard work and dedication to producing EOPs for our customers. Without them we could not produce a good product. The RS/PC staff is listed in the IERS RS/PC Contribution to the IERS Annual Report and are listed below:
Maria Davis, Nathan Shumate, Merri Sue Carter, and Kate Oldak.

I would also like to thank the USNO Scientific Director, Dr Brian Luzum who had in the past taught me most of what I know about EOP operations.

Backup Slides

EOP Combination and Prediction:

Combination and Prediction updates

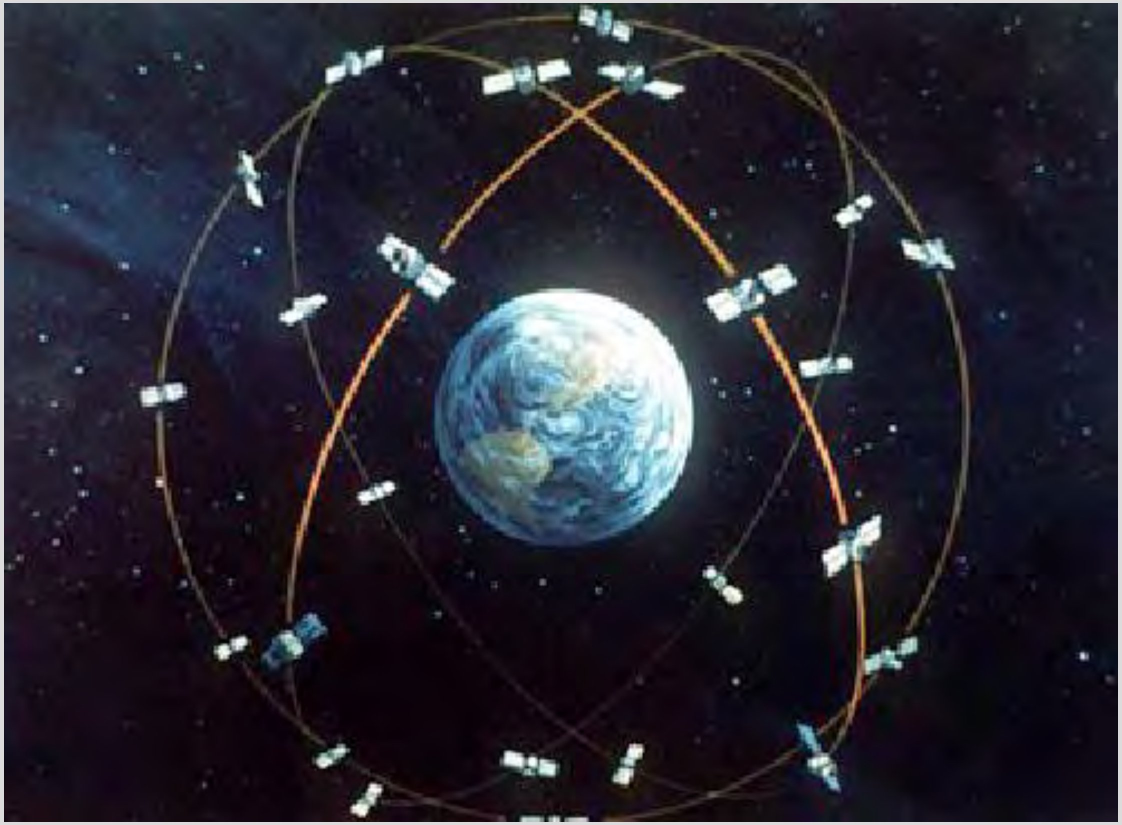
- **Each day, as new observations are obtained, the UT1-UTC combination is recomputed for as much as 1 year in the past. So values EOP values could change for up to 1 year into the past.**
  - Note, for practical purposes, only small very small changes in the past occur after intensives and 24-hour VLBI observations are finalized and made available to the combination. E.g.., if there is a 21 day latency from the 24-hour observation to finalization of the solution, then the combination results could change a bit during that past 21 day interval, but not much before that date.
    - An exception to this “rule-of-thumb” is if a past VLBI observation is re-analyzed and republished or if there is a system change.
- **Each day, new predictions are made out to 90 days in the future, and once per week on Thursday, new predictions are made out to 365 days.**
  - UT1-UTC predictions from 1 to 7 days into the future are heavily influenced by AAM forecast model results. USNO currently uses a combination of Navy and National Center for Environmental Prediction (NCEP) and Navy NAVGEM Atmospheric Angular Momentum (AAM) forecasts.
  - After 7 days, the predictions are made by a simple differencing technique as described in the IERS Rapid Service / Prediction Centre (RS/PC) contribution to the 2019 IERS Annual report.

At GPS Altitude

1” corresponds to 128.85 meters at GPS altitude

SO:

10 cm accuracy at GPS altitude requires 0.000 8” accuracy in polar motion or 0.052 ms in UT1-UTC



IERS Observing Network