UT1-UTC monitoring and prediction

Results of the survey made in Summer 2011 by the Earth Orientation Center of the IERS

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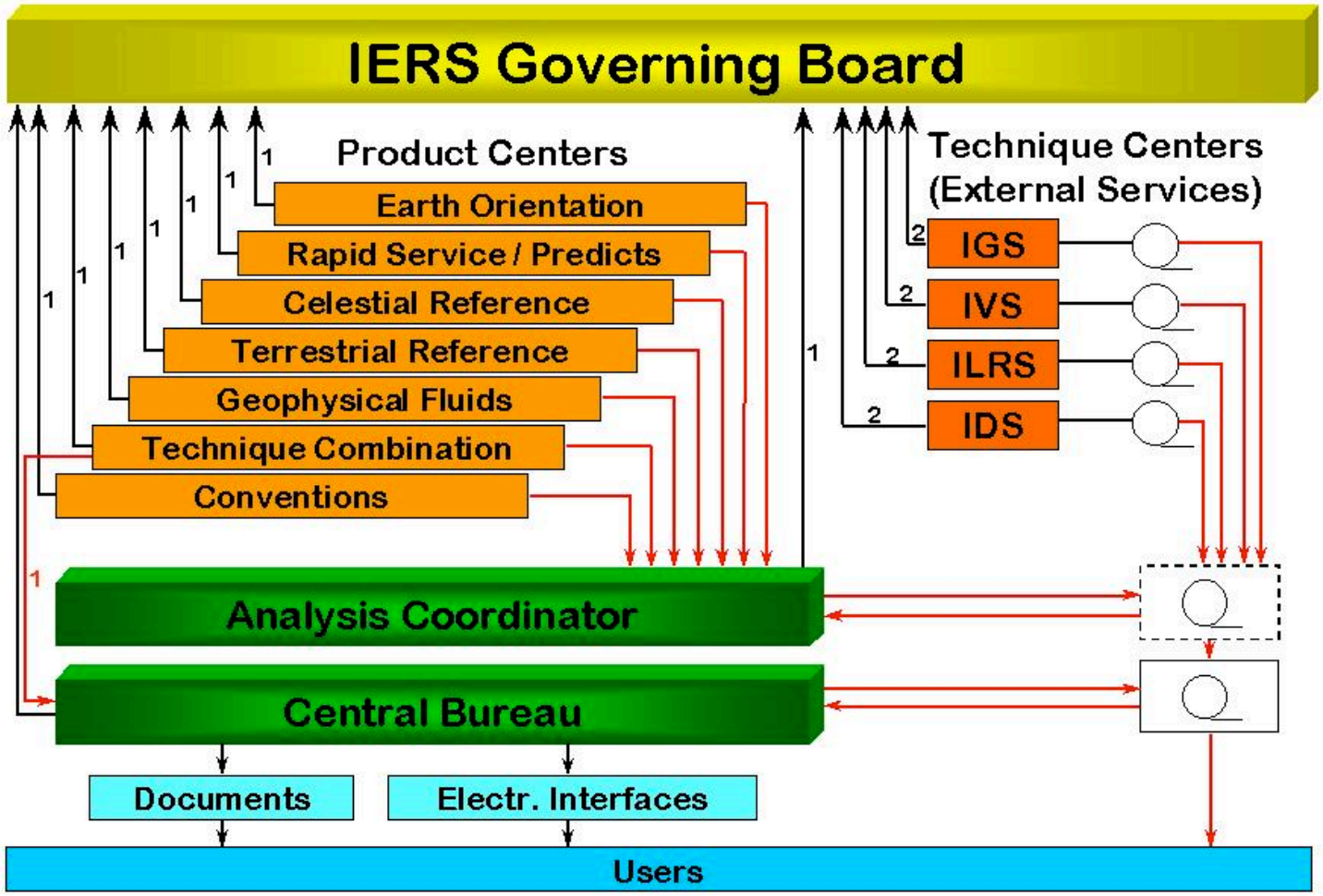
Outline

I - UT1 monitoring

II – UT1 Long-term prediction for leap seconds announcement

III - Survey concerning the proposal of UTC redefinition

International Earth Rotation and Reference Systems Service (IERS)



Missions of the IERS Earth Orientation Center

- Collect Earth Orientation Parameters (EOP) derived from the various techniques (LLR, SLR, GPS, VLBI and DORIS).
  - Polar motion (x,y)
  - Universal time (UT1-UTC, UT1-TAI)
  - Celestial pole offsets (Dpsi, Deps, DX,DY)

- Compute combined EOP solutions (Bulletin B and C04)

- Analysis of the EOP, in particular the determination of their consistencies with respect to the international terrestrial (ITRF) and celestial reference frames (ICRF).

- Bulletin C : Leap second announcement
- Bulletin D : DUT1 time dissemination

Why monitoring the Earth orientation?

Reference frame metrology, orientation of the platform Earth

- Satellite precise orbit determination
- Gravity fields
- Space navigation

Geophysical investigations

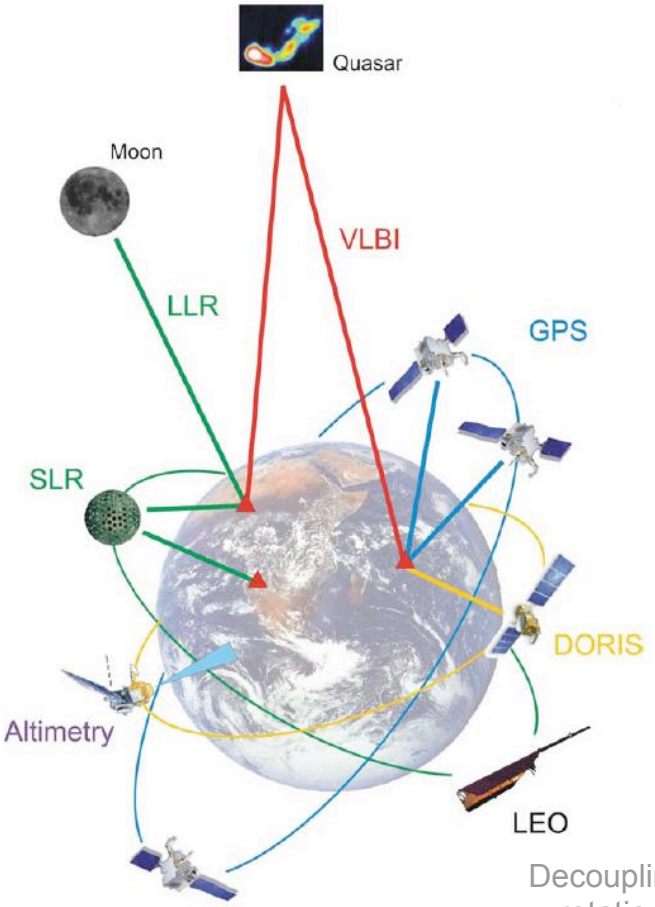
- Analysis of geophysical processes linked to earth rotation

Time

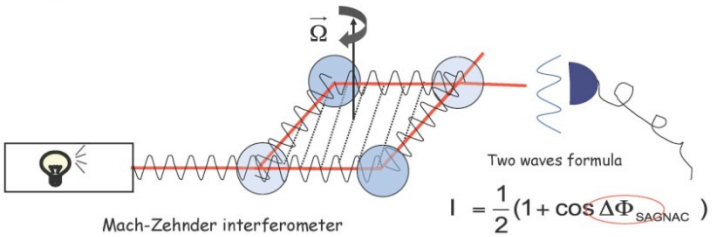
- Prediction and announcement of leap seconds insertions in UTC

Monitoring earth rotation variations

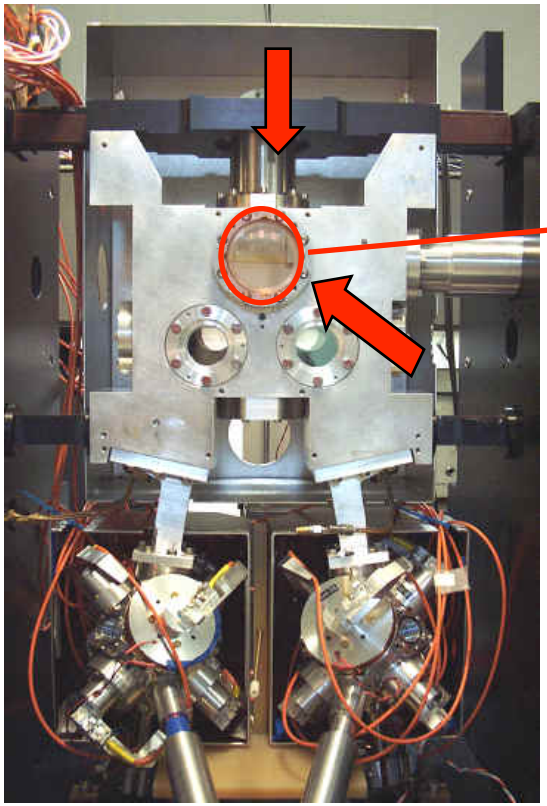
Geodetic space techniques

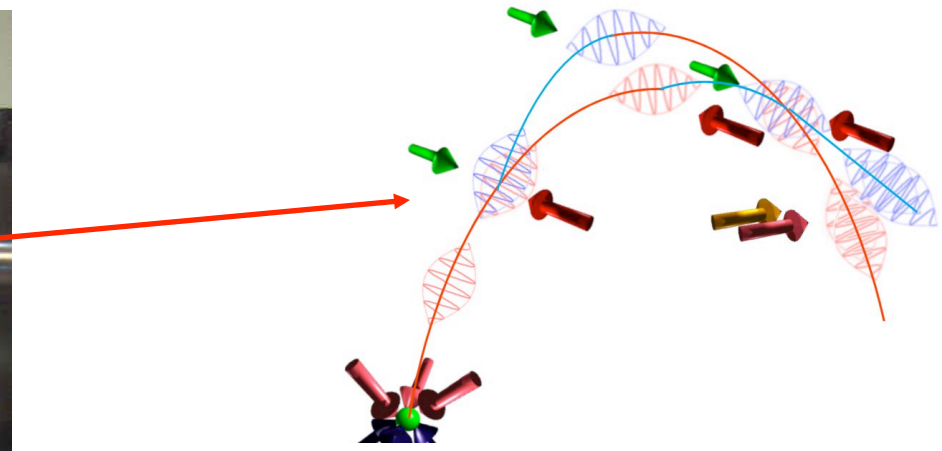


Gyroscope



Cold atom gyroscope (A. Landragin, SYRTE)





Beam experiment: 6.10^{-10} rad.s^{-1} at 1s

First ground cold atom gyro: ~ 2.10^{-7} rad.s^{-1} at 1s

small area 4 mm^2 and low flux

New experiment under realization: <10^{-9} rad.s^{-1} (1 ms) at 1s

large area ~ 1 to 10 cm^2 , larger flux (2D MOT)

Contribution of the various techniques to IERS

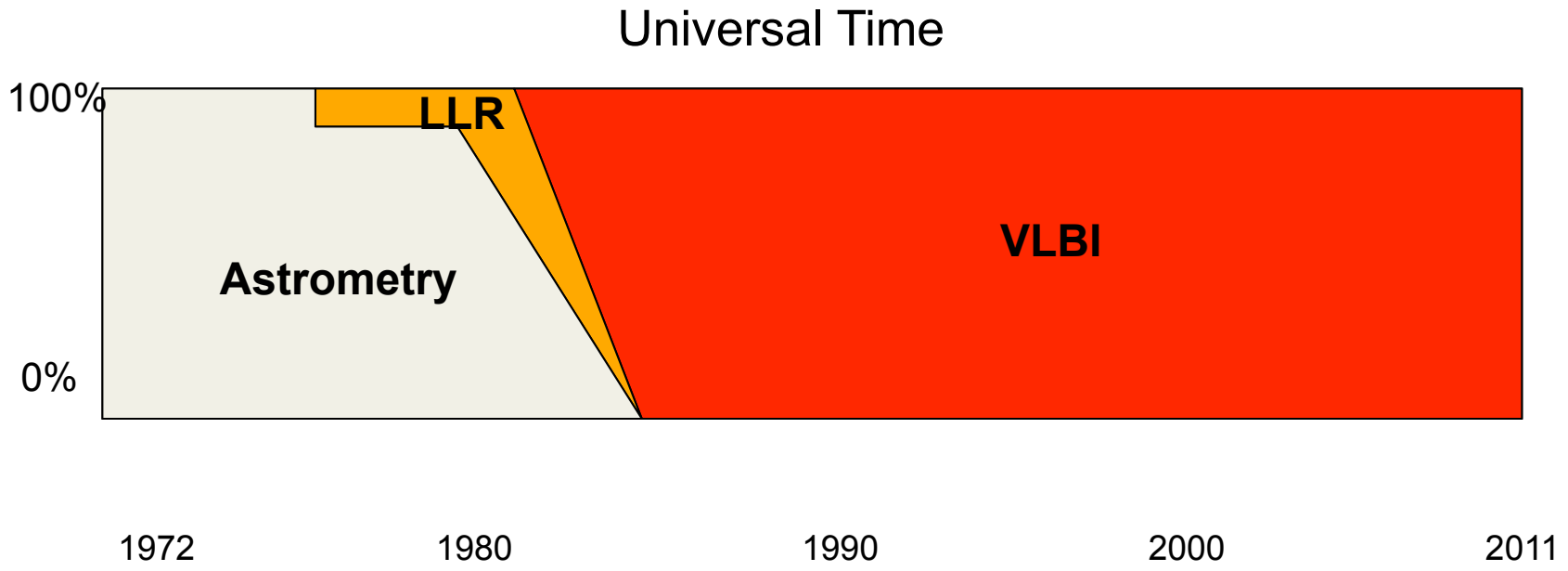
The number of stars matches the relative contribution of techniques

PRODUCTS	LLR	VLBI	SLR	GPS	DORIS
Extragalactic ref. Frame		***			
Tie to solar system	***	*			
Tie to Earth					
Precession-nutation	**	***	*	*	
Universal Time	*	***			
Earth Rotation					
High-frequency UT		***	*	**	
Polar Motion		**	**	***	*
Terrestrial Reference Frame					
Network coverage		*	*	**	***
Long-term geocenter	*	***	**	*	
Tectonic plate motion		***	**	***	***
Densification		*	*	***	**

Techniques for UT1/LOD determination

Technique	*since*	*EOP*	*Time Res.*	*Accuracy*
ASTROMETRY	1899	UT1	5 days	UT1: 1 ms
LLR	1969	UT0	1 day	UT0: 100 μs
SLR	1976	LOD	3 days	LOD: 60 μs
VLBI	1981	UT1 24h	3-4 days	UT1: 5 μs
		UT1 Intensive	1 day	UT1: 20 μs
GPS	1993	LOD	1 day	LOD: 7 μs

Contributions of techniques to IERS UT1 solutions



Long-term UT1-UTC prediction

Communities of users of Bulletins C and D

- Astronomy, astrophysics
- Time Service laboratories
- Computer centers
- Radio signal laboratories
- Radio-astronomy activities
- Geodesy
- Navigation, civil and military
- Geophysics
- Radio stations Post and telecommunication
- Hydrographic and oceanographic labs
- Surveying and mapping institutes
- Civil engineering Space research
- Etc ……

Description of the variations of the Earth Rotation

Length of day Variations

Secular drift

Energy dissipation (~ 2.4 ms/century)

Post-glacial rebound (~ -.5 ms/cy)

Decadal fluctuations

Core/mantle torque (amplitude ~ 5 ms)

Global ocean-atmosphere processes

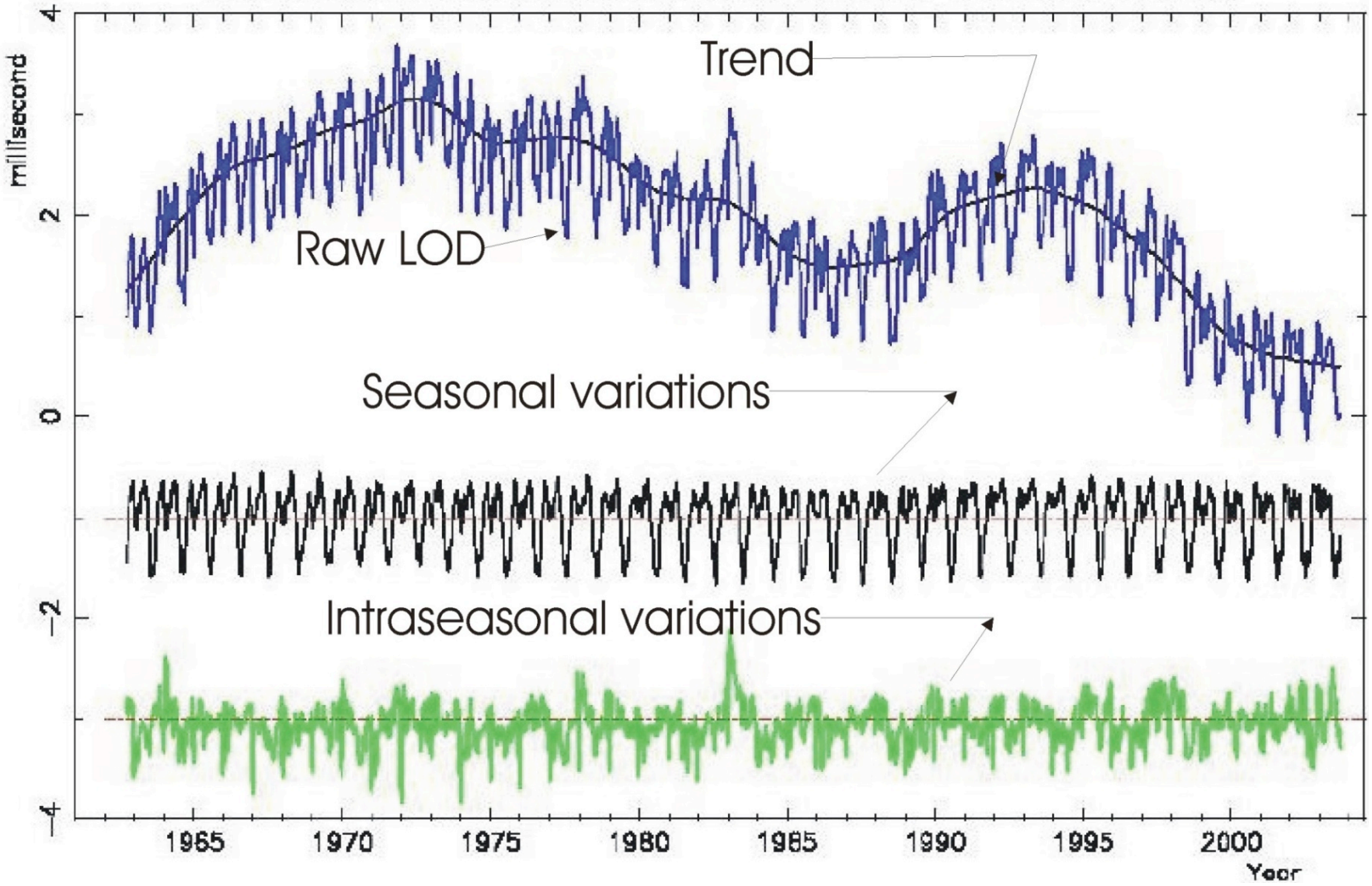
Variations from a few hours to about 2 years

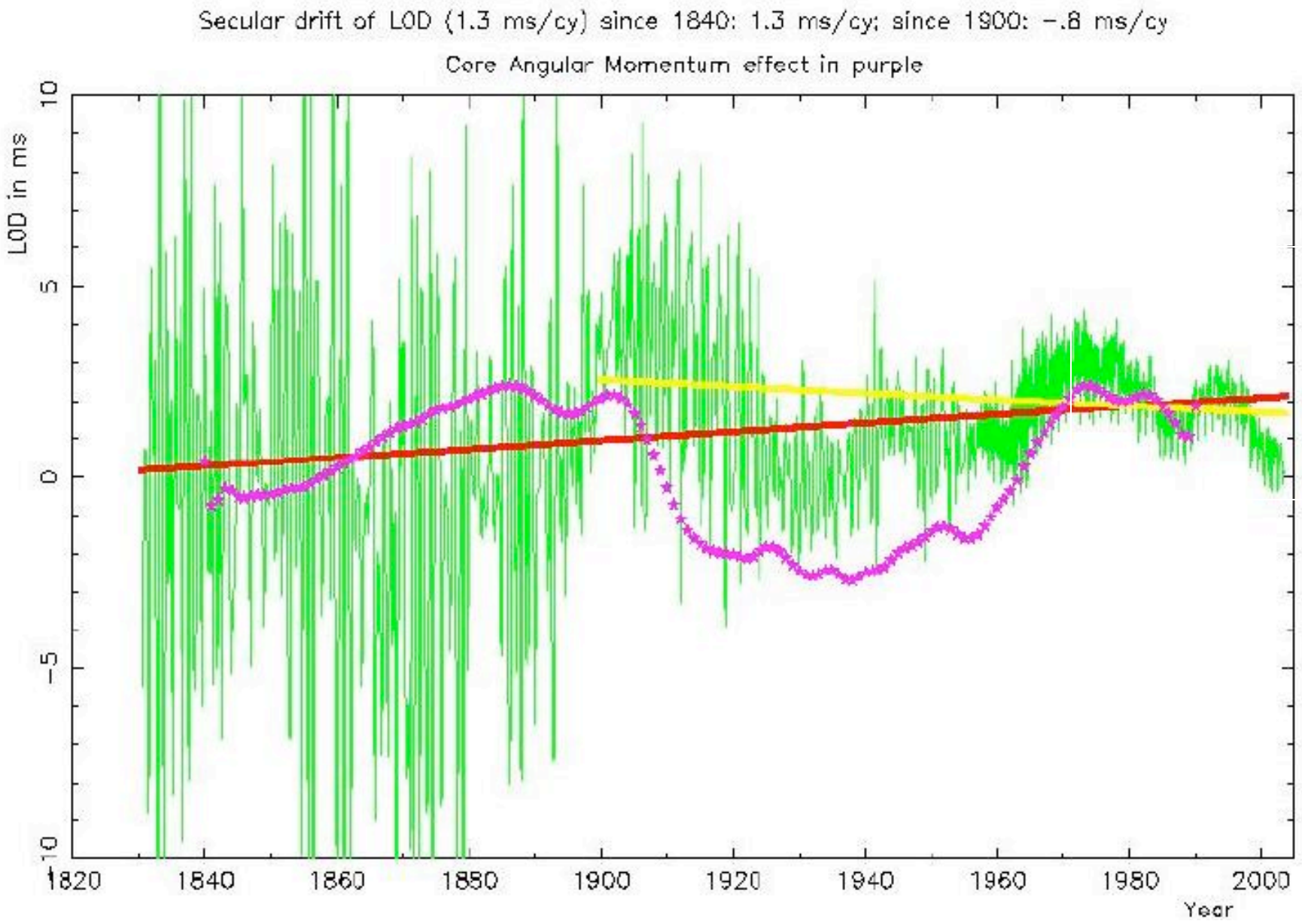
Atmospheric causes (zonal winds) (amplitude ~ 1 ms)

Diurnal and sub-diurnal variations

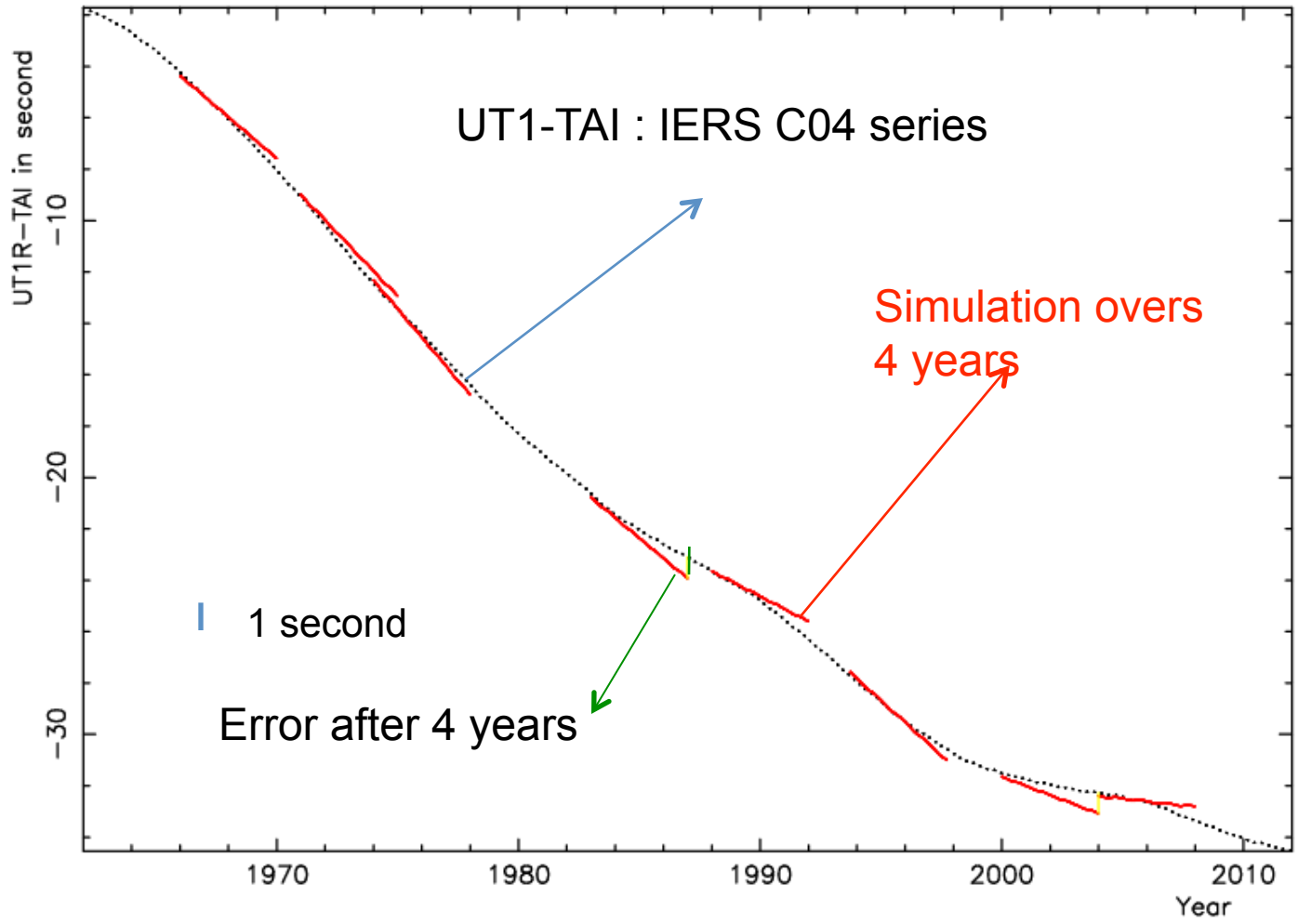
Ocean, atmosphere (amplitude ~200 μs)

Filtering the LOD



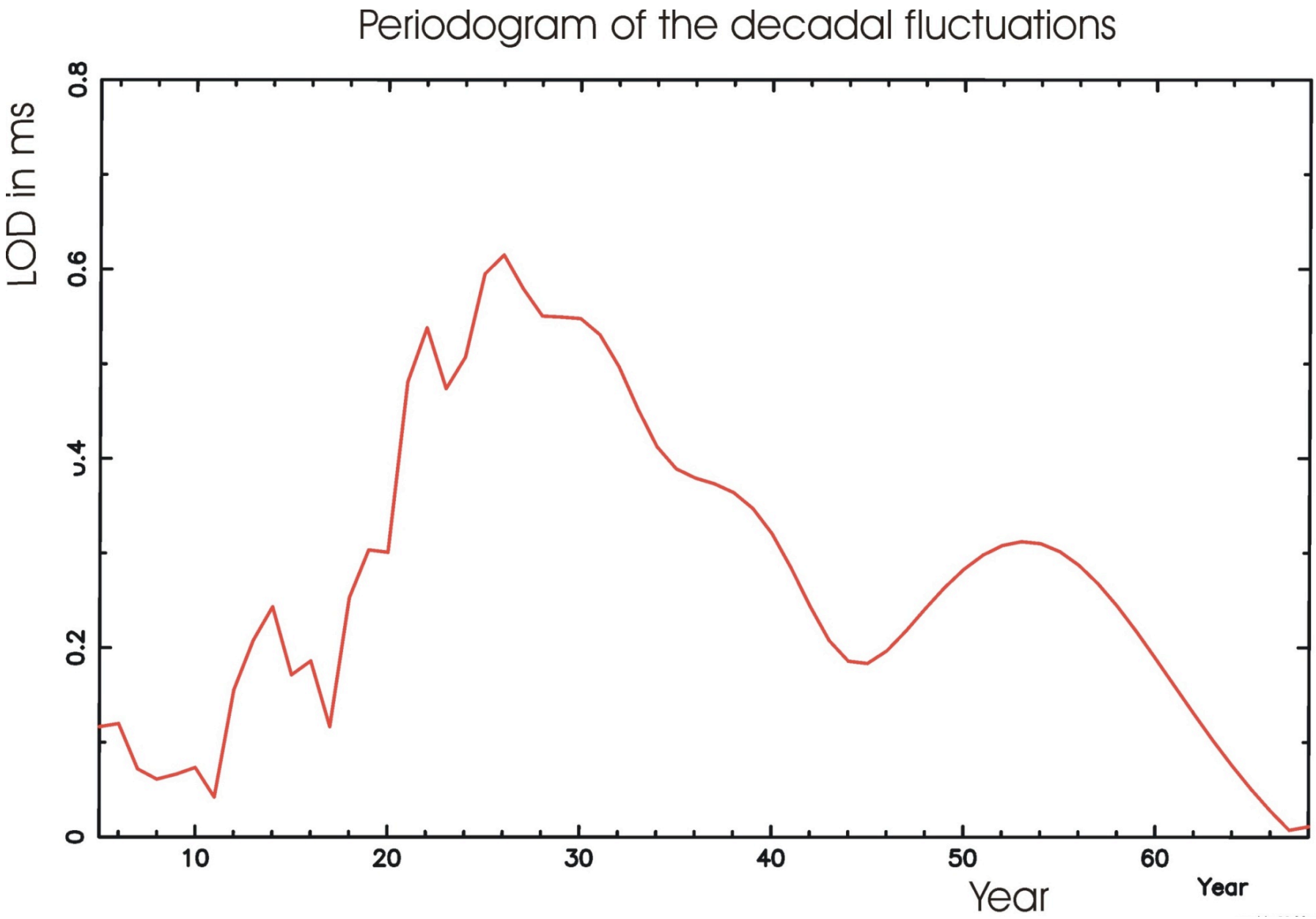

Secular drift of LOD (1.3 ms/cy) since 1840: 1.3 ms/cy; since 1900: -.8 ms/cy
Core Angular Momentum effect in purple
LOD in ms
10
5
0
-5
-10
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Year

Simulation: forecasting leap seconds 1 to 4 years Precision



Skill of the UT1 prediction statistics over 1963-2011

Horizon in year	Mean in s	Maximal error in s
1	**.07**	**.12**
2	**.15**	**.30**
3	.30	.55
4	.40	.80


Periodogram of the decadal fluctuations
LOD in ms
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
Year
Year

Survey

The Earth Orientation Center of the IERS at Paris Observatory is in charge of the leap second announcement

The relevant bulletins are:

Bulletin C: Announcement of the leap seconds in UTC

Bulletin D: Announcement of the value of DUT1 truncated at 0.1s for transmission with time signals.

A survey was made in Summer 2011 to find out the strength of opinion in the community of IERS users for maintaining or changing the present system using regular introductions of leap seconds

Last IERS survey 2002

Questionnaire IERS July-August 2011
The options

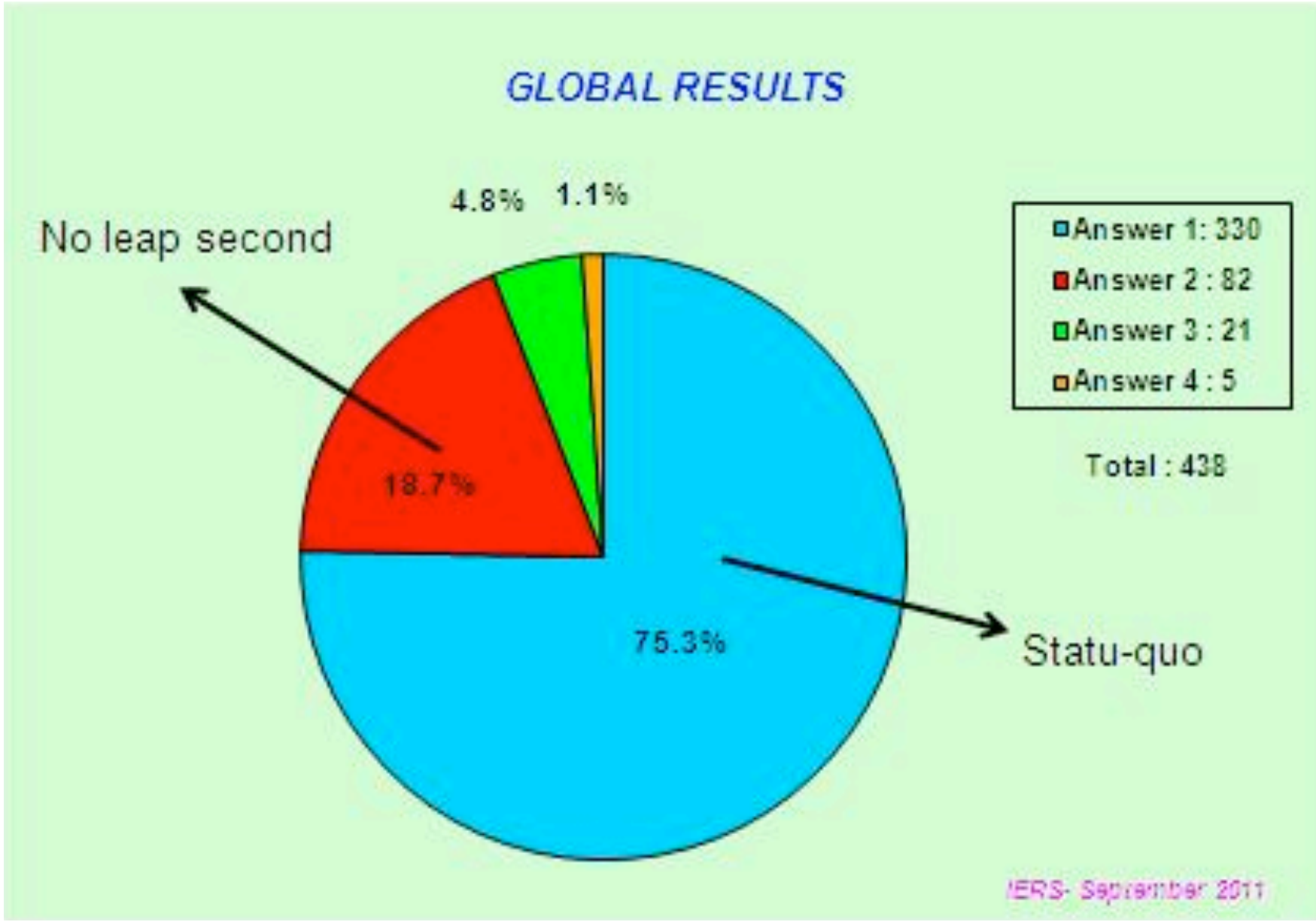
1.I am satisfied with the current definition of UTC which includes leap second adjustments

2.I prefer that UTC be redefined as a uniformly increasing atomic timescale without leap seconds and constantly offset from TAI. Consequently, UTC would increasingly diverge from the Earth's rotation.

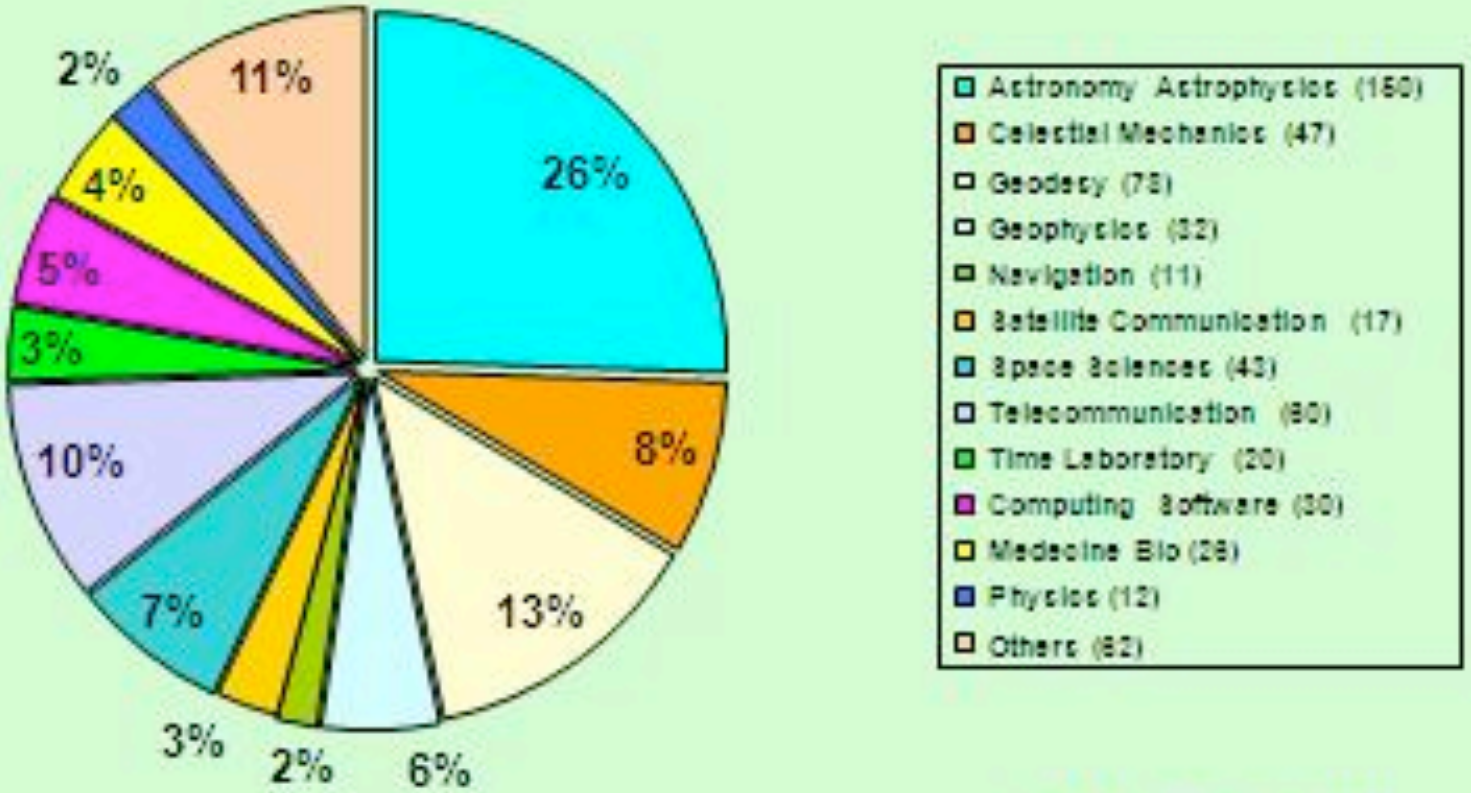
3.I have another preference

4.I have no opinion or preference

5.Comments


GLOBAL RESULTS
No leap second
4.8%
1.1%
18.7%
75.3%
Statu-quo
Answer 1: 330
Answer 2 : 82
Answer 3 : 21
Answer 4 : 5
Total : 438
IERS- September 2011

Field of activity



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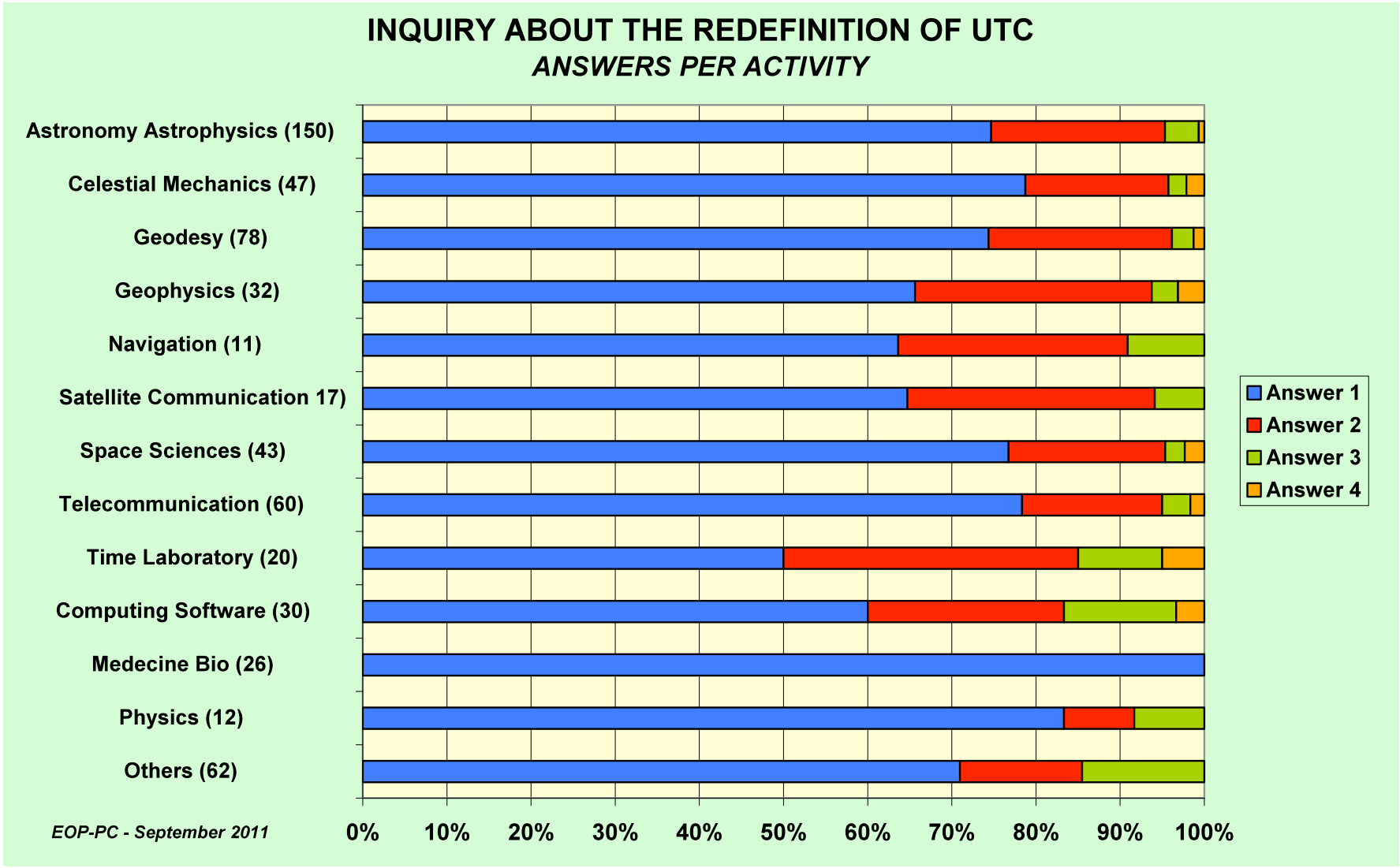
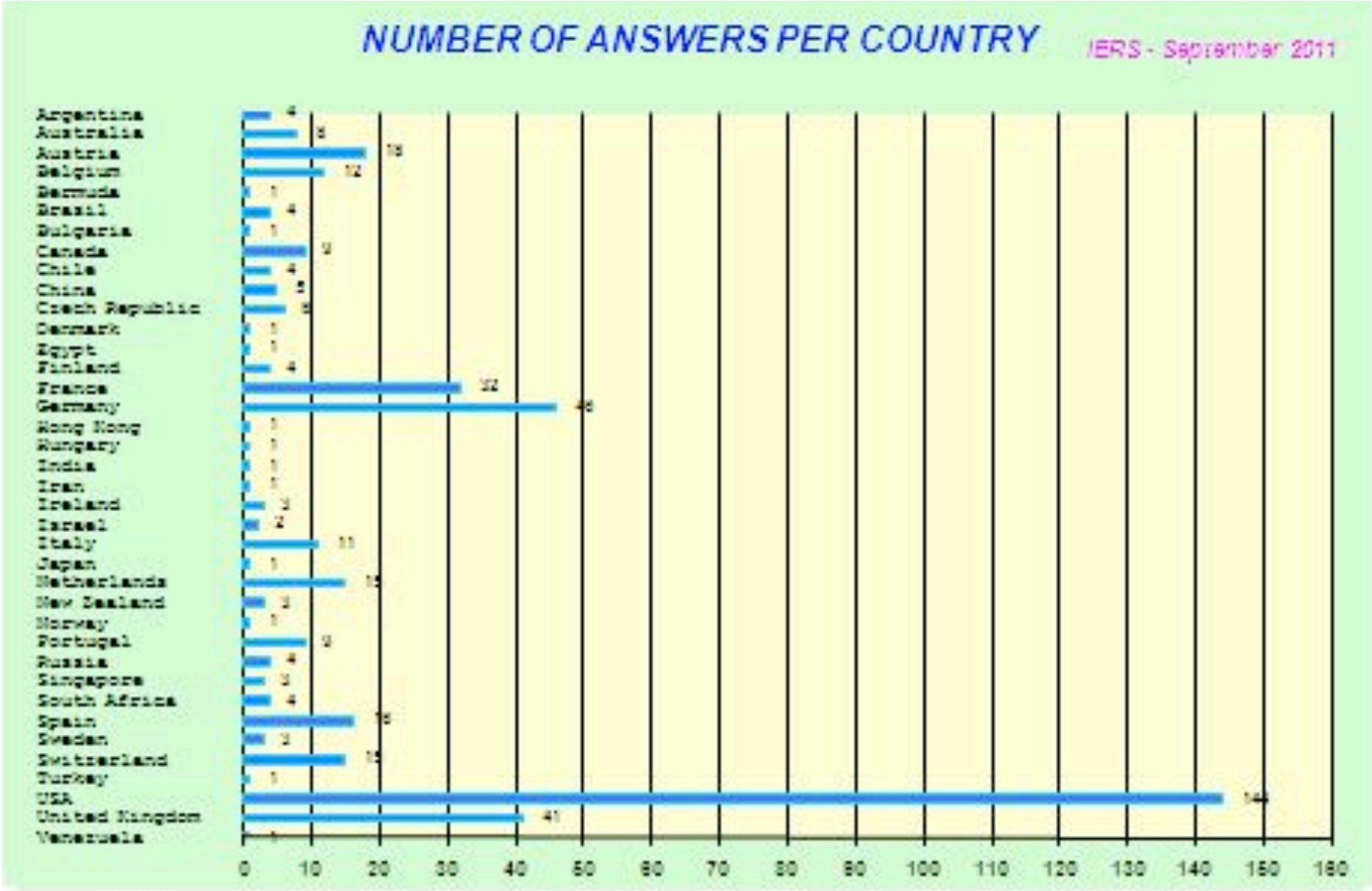

INQUIRY ABOUT THE REDEFINITION OF UTC
ANSWERS PER ACTIVITY
Astronomy Astrophysics (150)
Celestial Mechanics (47)
Geodesy (78)
Geophysics (32)
Navigation (11)
Satellite Communication 17)
Space Sciences (43)
Telecommunication (60)
Time Laboratory (20)
Computing Software (30)
Medecine Bio (26)
Physics (12)
Others (62)
EOP-PC - September 2011
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Answer 1
Answer 2
Answer 3
Answer 4


NUMBER OF ANSWERS PER COUNTRY
IERS - September 2011
Argentina
Australia
Austria
Belgium
Bermuda
Brasil
Bulgaria
Canada
Chile
China
Czech Republic
Denmark
Egypt
Finland
France
Germany
Hong Kong
Hungary
India
Iran
Ireland
Israel
Italy
Japan
Netherlands
New Zealand
Norway
Portugal
Russia
Singapore
South Africa
Spain
Sweden
Switzerland
Turkey
USA
United Kingdom
Venezuela
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160

Conclusion of the IERS questionnaire

- 447 responses, many responses grouped

- 75.3 % are for the statu-quo: no change in the current definition
- 18.7 % for switching to the new definition, No leap second
- 5 % for another solution
- 1 % have no opinion

- Answers and comments to the questionnaire available at the following web site:

http://hpiers.obspm.fr/eop-pc/questionnaire/result.php

General arguments for statu-quo (75%)

The present system, working well, is a good compromise between Earth rotation and atomic time scale.

Arguments to change are not sufficient compared to the advantages of a coordinated UTC time scale linked to the earth rotation.

Any changes in these areas will likely cause substantial confusion and disasters (principle of security)

In particular, risk of confusion and problems in the case of the increase of the tolerance UT1-UTC

A majority of UTC users are not aware of the difference between UT1 and UTC. If the new definition is adopted, they should.. When the difference DUT1 increases, 30s, 10 min, 1 hour, a lot of problems will arise..

There are too many softwares with the assumption of UTC being coordinated with the earth rotation. The costs of change would be important. Unforeseen problems could happen

No reason to maintain 3 different time scales UT (GPS) TAI and UTC differing by a constant offset

General arguments for statu-quo (75%)

In many country legal time is based on solar time

No strong argument to change. The current system works

” If it ain't bust, don’t fix it ! ”

Few problems were reported after the 2009 leap second introduction.

In a few decades who will remember the origin of the procedure?

There is no strong justification to adopt a time scale no longer related to the rotation of the Earth.

More time should be needed to evaluate the consequences of such a change (UNESCO statement)

General arguments for a change (19%)

- Ambiguity of date at the occurrence of a positive leap second which is potentially dangerous.
- Separating the two concepts (angle for UT1,time for UTC) would be an improvement for high-accuracy applications.
- Leap-seconds were a good idea in 1972 when people just had a few inaccurate analogue clocks, but now so much equipment has a clock, it is a nightmare to correct it all.
- Ignoring leap seconds will not be a significant problem for civil purposes
- Analyzing the performance of the time servers during the 2008/2009 leap second showed a worrying percentage of (otherwise well configured and well maintained) systems being a second out of sync with everyone else for hours and in some cases even days!
- Having a time scale that is discontinuous causes a lot of problems with writing and maintaining software for processing non-ground-based astronomical missions

General arguments for a change (19%) Cont'ed

- The last leap second event caused a global outage for me - across 50,000+ machines, and affecting 100M+ customers - due to a bug in the way leap second was handled. We now have to test every kernel version we operate (300+ kernels across 300,
- There is no technical reason for keeping the existing system other than TRADITION.
- Designing, operating and testing time service equipment for leap seconds require tremendous efforts
- Most databases can't deal with leap seconds and interval calculations can't. For this reason we need to unwind leap seconds
- The handling of leap seconds add a considerable complexity for equipment manufacturers and for operators in order to prepare and pre-program for the insertion/removal of a leap second.
- The possibility of leap seconds makes it impossible to compile calendar valid for decades/centuries.
- The leap seconds represent a nuisance for the modern applications requiring time synchronization

Other Proposals

- It would be useful for leap seconds to be scheduled further in advance
- With the ubiquitous use of NTP, I believe there is now an opportunity to separate civil time from the high-precision time/frequency dissemination services
- Time correction was applied on a deterministic date, and more rarely on January 01 00:00 every 10 years. Or even better, to apply them on each Feb 29.
- A better representation can preserve the existing and traditional meaning of UTC as civil time while also alleviating the problems faced by software systems.

Long-term effect of decoupling UTC from Earth Rotation ..