Federal Agency for
Cartography and Geodesy

Reference frames and geodetic products

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Introductory and Refresher Course on Satellite and Lunar Laser Ranging

Stuttgart, Germany, October 20, 2019

Overview

- **The 3 pillars of geodesy and the reference frames:**
  - Geometry – Orientation – Gravity field
  - Contributions by SLR
  - Parameters for actual ITRF generation

- **SLR-based products generated within the ILRS:**
  - Organizational aspects
  - Characteristics of different products
  - Examples

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The 3 Pillars of Geodesy

Earth geometry and kinematics:

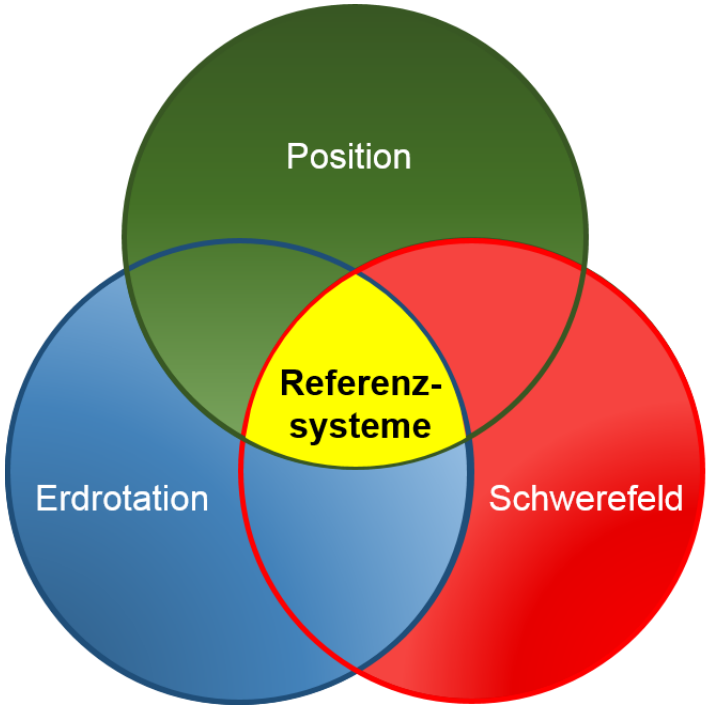
Shape of the Earth and its variation

Earth orientation and rotation:

Earth rotation and its variation

Earth gravitational field:

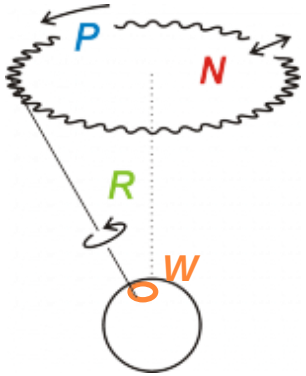
Static (mean) and variable gravity field



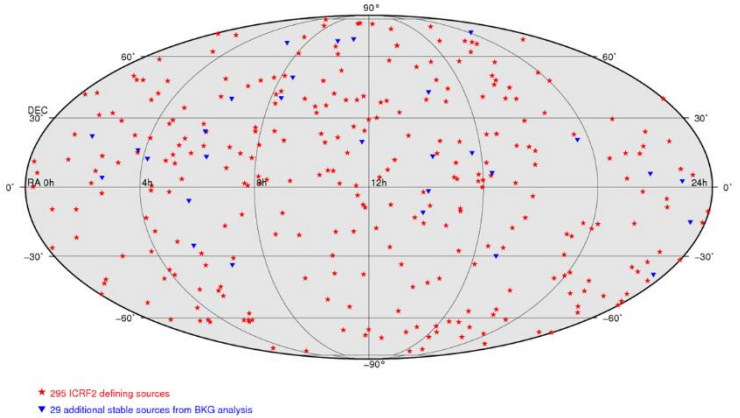
❑ Requirement for integrated estimation:
highly accurate, homogeneous, long-term stable reference frame

The 3 Pillars of Geodesy: Relationships

Earth Orientation

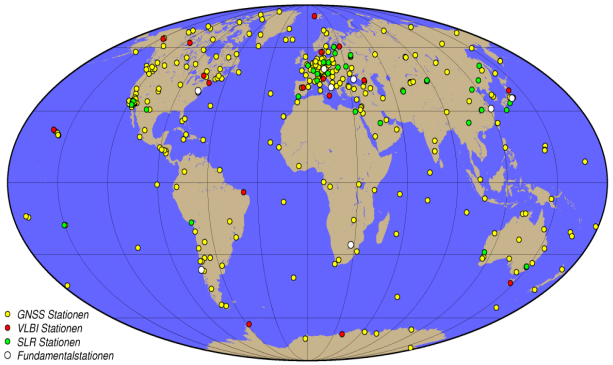


Celestial Reference Frame



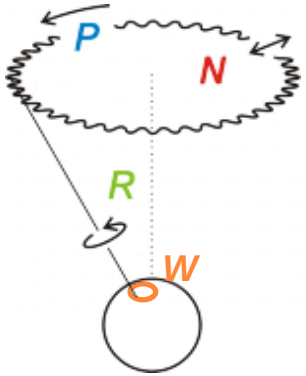
EOP

Terrestrial Reference Frame

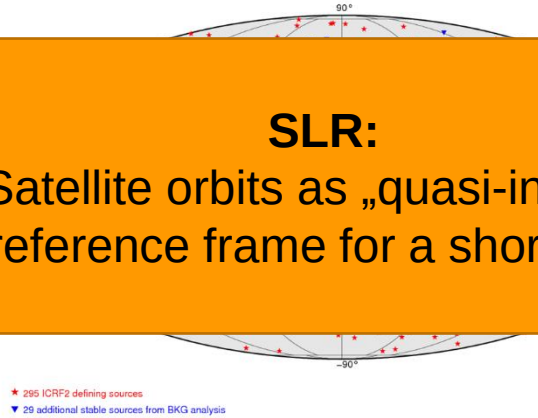


The 3 Pillars of Geodesy: Relationships

Earth Orientation



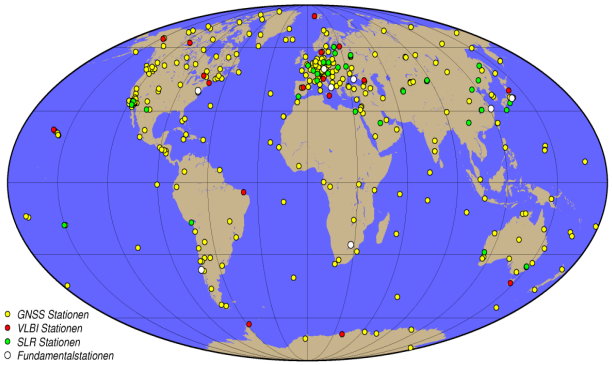
Celestial Reference Frame



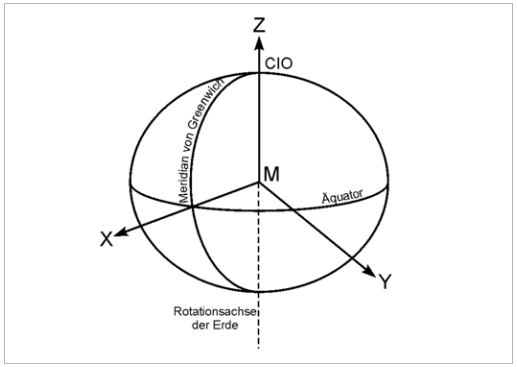
SLR:
Satellite orbits as „quasi-inertial“ reference frame for a short time

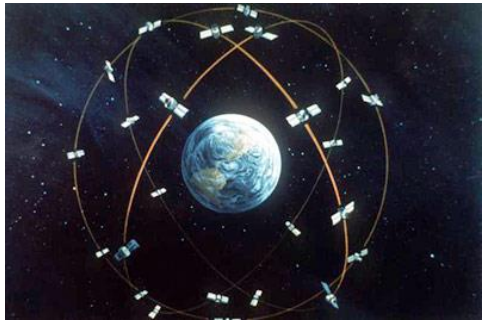
EOP

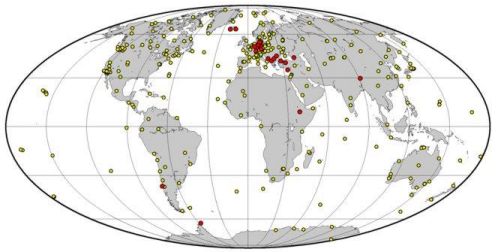
Terrestrial Reference Frame



Reference System and Reference Frame







ITRF2008 STATION POSITIONS AT EPOCH 2005.0 AND VELOCITIES
IGS STATIONS

DOMES NB.	SITE NAME	TECH. ID.	X/Vx	Y/Vy	Z/Vz	Sigmas	SOLN	DATA_START	DATA_END
					-m/m/y-				
10001S006	Paris	GNSS OPMT	4202777.371	171367.999	4778660.203	0.001 0.001 0.001			
10001S006			-.0125	0.0178	0.0107	.0001 .0000 .0001			
10002M006	Grasse (OCA)	GNSS GRAS	4581690.901	556114.831	4389360.793	0.001 0.001 0.001	1	00:000:00000	03:113:00000
10002M006			-.0133	0.0188	0.0120	.0001 .0000 .0001			
10002M006	Grasse (OCA)	GNSS GRAS	4581690.900	556114.837	4389360.793	0.001 0.001 0.001	2	03:113:00000	04:295:43200
10002M006			-.0133	0.0188	0.0120	.0001 .0000 .0001			
10002M006	Grasse (OCA)	GNSS GRAS	4581690.900	556114.836	4389360.797	0.001 0.001 0.001	3	04:295:43200	00:000:00000
10002M006			-.0133	0.0188	0.0120	.0001 .0000 .0001			
10003M004	Toulouse	GNSS TOUL	4627846.029	119629.333	4372999.818	0.001 0.001 0.001			
10003M004			-.0114	0.0193	0.0121	.0001 .0000 .0001			
10003M009	Toulouse	GNSS TLSE	4627851.831	119640.017	4372993.553	0.001 0.001 0.001	1	00:000:00000	03:335:00000
10003M009			-.0114	0.0193	0.0121	.0001 .0000 .0001			
10003M009	Toulouse	GNSS TLSE	4627851.828	119640.020	4372993.552	0.001 0.001 0.001	2	03:335:00000	00:000:00000
10003M009			-.0114	0.0193	0.0121	.0001 .0000 .0001			
10004M004	Brest	GNSS BRST	4231162.578	-332746.680	4745130.926	0.001 0.001 0.001	1	00:000:00000	06:207:00000
10004M004			-.0115	0.0172	0.0115	.0001 .0000 .0001			
10004M004	Brest	GNSS BRST	4231162.578	-332746.675	4745130.916	0.001 0.001 0.001	2	06:207:00000	08:163:36000
10004M004			-.0115	0.0172	0.0115	.0001 .0000 .0001			
10004M004	Brest	GNSS BRST	4231162.576	-332746.678	4745130.921	0.001 0.001 0.001	3	08:163:36000	00:000:00000
10004M004			-.0115	0.0172	0.0115	.0001 .0000 .0001			
10020M001	Chize	GNSS CHIZ	4427603.244	-31506.045	4575621.805	0.001 0.001 0.001			
10020M001			-.0112	0.0186	0.0118	.0001 .0001 .0001			
10023M001	La Rochelle	GNSS LROC	4424632.565	-94175.229	4577544.083	0.001 0.001 0.001			
10023M001			-.0116	0.0184	0.0111	.0001 .0000 .0001			

Reference System Geodetic Observations Reference Frame

REALIZATION

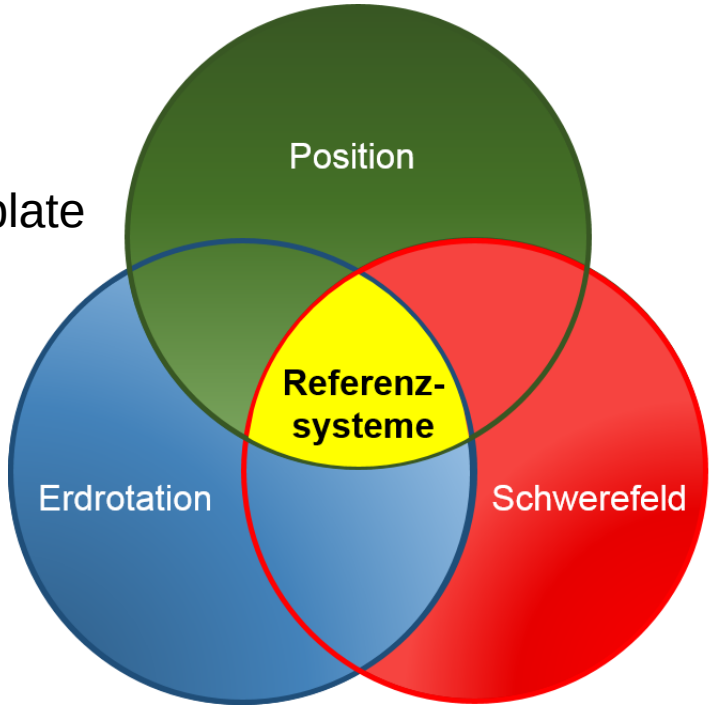
The 3 Pillars of Geodesy: Contributions by SLR

Contributions by SLR:

(1) Geometry:
- Coordinates of SLR stations
- Position variations due to, e.g., plate tectonics, loading deformation
- Scale

(2) Earth Rotation:
- Polar motion
- Length of Day (LOD)

(3) Gravity Field:
- Geocenter
- Low-degree harmonics of Earth‘s gravity field: depending on satellites



Parameter Space and Actual ITRF Computation

	GNSS	VLBI	SLR
Station coordinates + velocities	XG	XV	XS
Satellite orbits	X		X
Quasar coordinates		X	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	(x)	X	(x)
Geocenter	(X)		X
Earth‘s gravity field	(x)		X
Troposphere	X	X	
Ionosphere	X	(x)	
Technique-specific parameters	xG	xV	xS

Parameter Space and Actual ITRF Computation:
⇒ only few parameter types are included

	GNSS	VLBI	SLR
Station coordinates + velocities	XG	XV	XS
Satellite orbits	-		-
Quasar coordinates		-	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	-	X	-
Geocenter	*(X)*		*X*
Earth's gravity field	*(x)*		*X*
Troposphere	*X*	*X*	
Ionosphere	*X*	*(x)*	
Technique-specific parameters	*xG*	*xV*	*xS*

Parameter Space and Actual ITRF Computation

No Direct combination possible;
Co-location sites and Local Ties are needed

Station coordinates + velocities	XG	XV	XS
Satellite orbits	-		-
Quasar coordinates		-	
Polar motion + rates	X	X	X
Universal Time (dUT)		X	
Length of Day (LOD)	X	X	X
Nutation (+ nutation rates)	-	X	-
Geocenter			
Earth's gravity field	*(x)*		*X*
Troposphere	*X*	*X*	
Ionosphere	*X*	*(x)*	
Technique-specific parameters	*xG*	*xV*	*xS*

Direct combination is possible

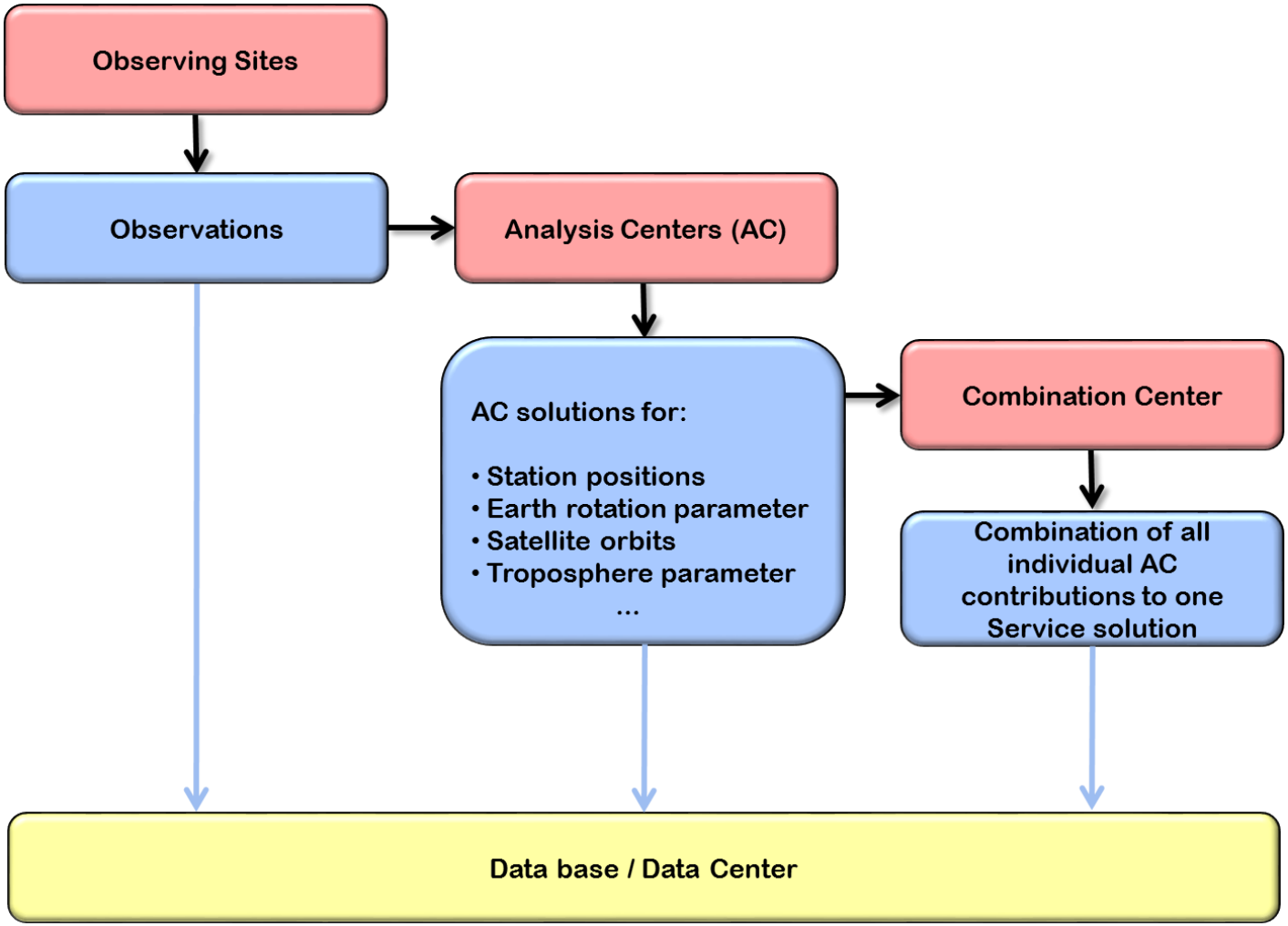
- The 3 pillars of geodesy and the reference frames:
  - Geometry – Orientation – Gravity field
  - Contributions by SLR
  - Parameters for actual ITRF generation

- **SLR-based products generated within the ILRS:**
  - Organizational aspects
  - Characteristics of different products
  - Examples

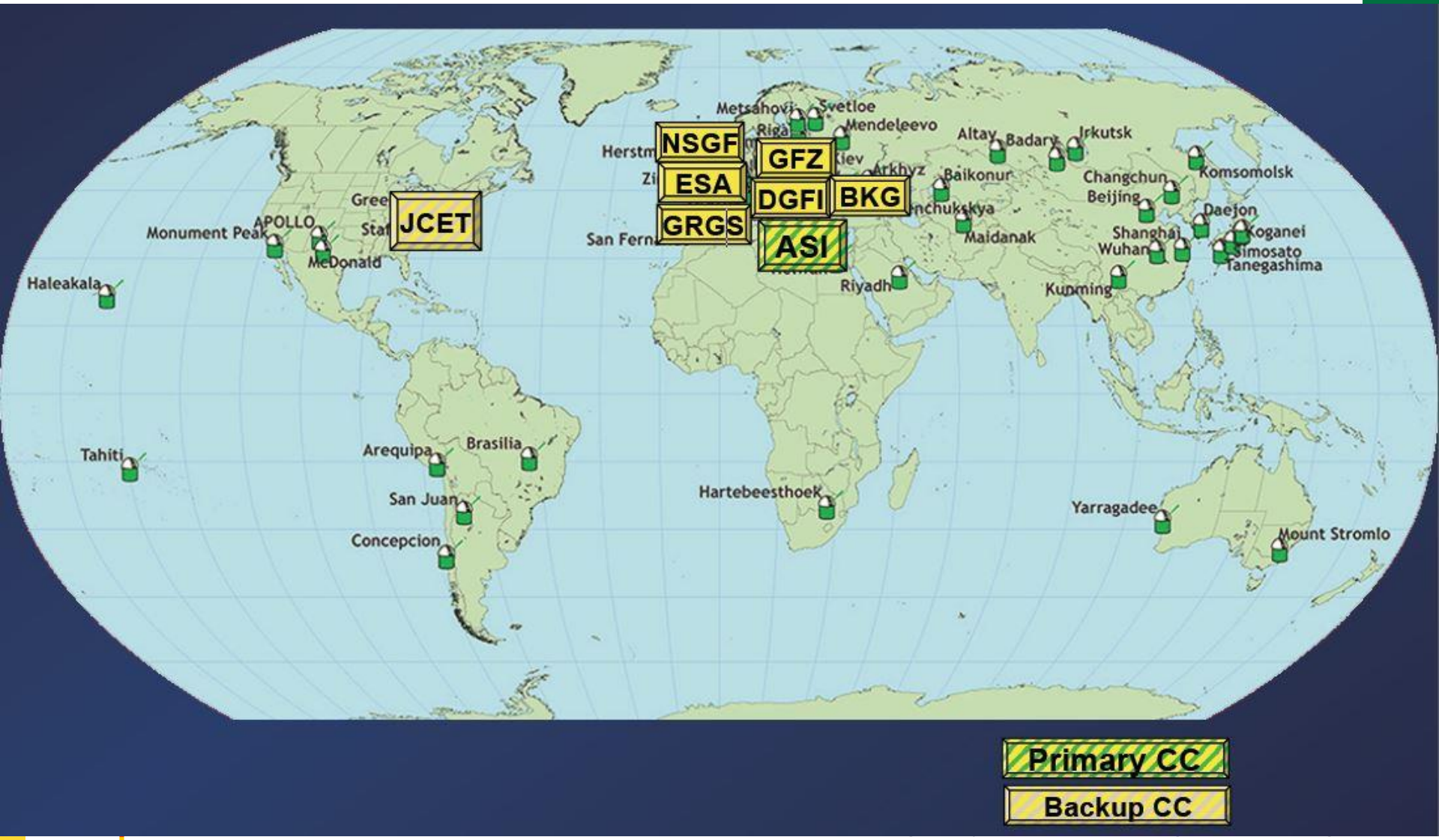
The ILRS – International Laser Ranging Service

- Under the umbrella of IAG (International Association of Geodesy)
- Integrated into the IERS as one of the Technique Centers
- Organizing product generation, data/product holding, exchange between individual groups, support new developments, exchange of knowledge

The ILRS – International Laser Ranging Service



ILRS Analysis and Combination Centers



ILRS Analysis Centers: Software Packages used

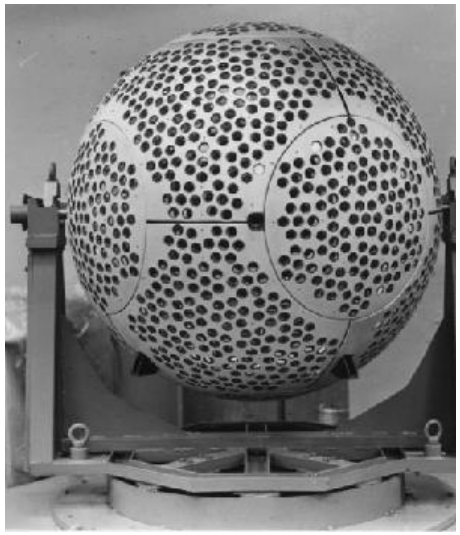
- A broad variety of analysis software packages used among the Analysis Centers helps to reduce the „Analysis Noise“

ILRS Analysis Centre	Software Package
ASI, Italy	Geodyn
BKG, Germany	Bernese GNSS Software, SLR development version
DGFI-TUM, Germany	DOGS-OC
ESA	NAPEOS
GFZ, Germany	EPOS
GRGS, France	GINS / Dynamo
JCET, USA	Geodyn
NSGF, UK	SATAN

SLR-based Products by the ILRS

- 7-day solutions = 7-day orbital arcs

- **Satellites** used for operational products:
  - LAGEOS, LAGEOS-2:
    - Orbital height ≈ 5.800 km
  - ETALON-1/-2:
    - Orbital height ≈ 19.000 km



- **Parameters** estimated:
  - Satellite orbits
  - Station coordinates
  - Earth rotation parameters: x-/y-pole, LOD
  - Range biases for selected stations

SLR-based Products by the ILRS

(1) Operational products

- **DAILY** products (= „Rapid“ product) are due 2 days after last observation day:
  - e.g. for the DAILY orbital arc Tuesday-Monday, the product needs to be delivered on Wednesday morning (UT)
- **WEEKLY** products (orbital arc Sunday - Saturday) are due on Wednesday

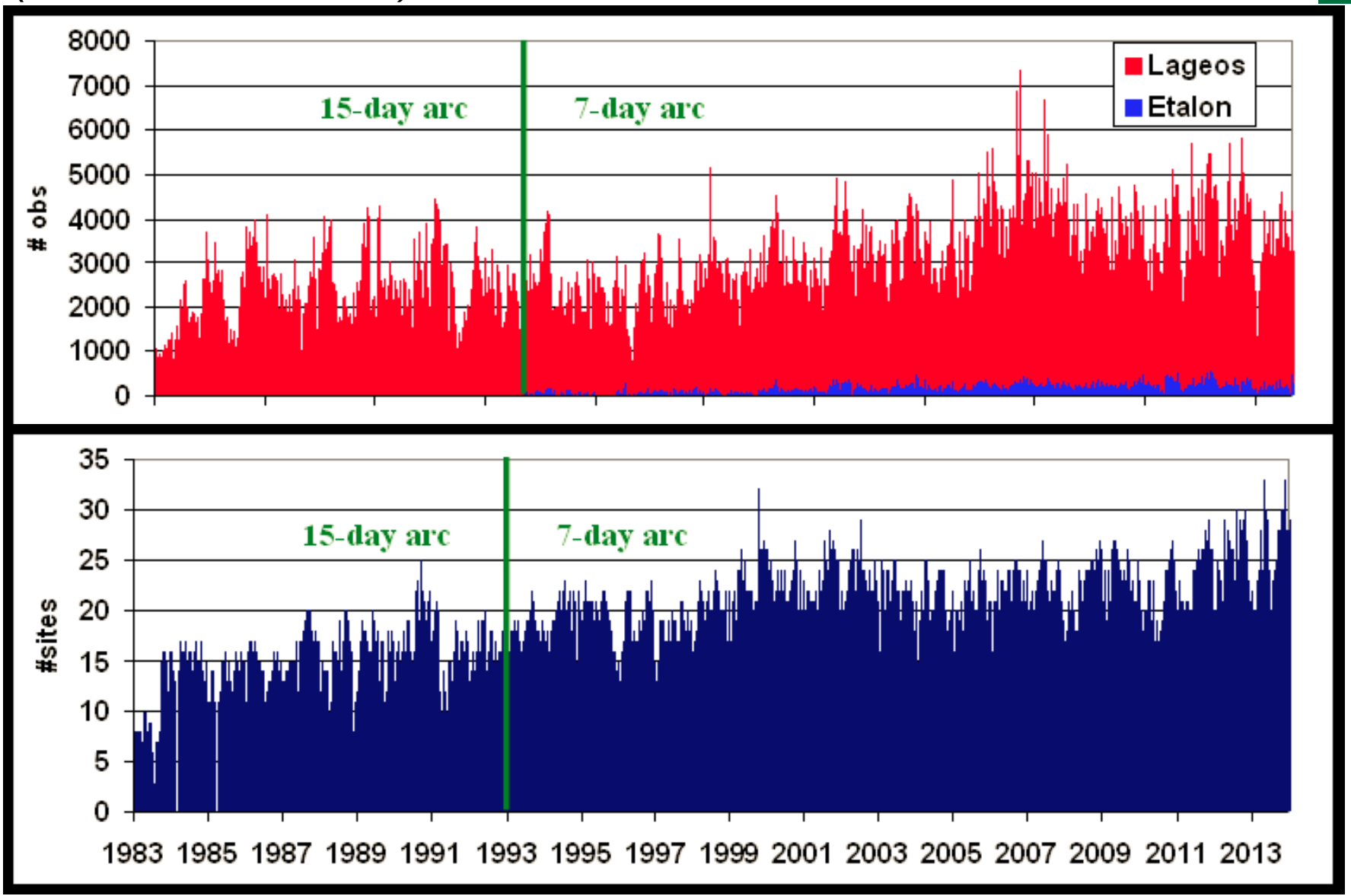
(2) Special study products:

- Estimating range biases to investigate potential sytematic errors
- Inclusion of the LARES satellite
- Estimation of low-degree gravity field coefficients
- Impact of non-tidal loading

(3) Re-analysis for ITRF generation (e.g. input for ITRF2020)

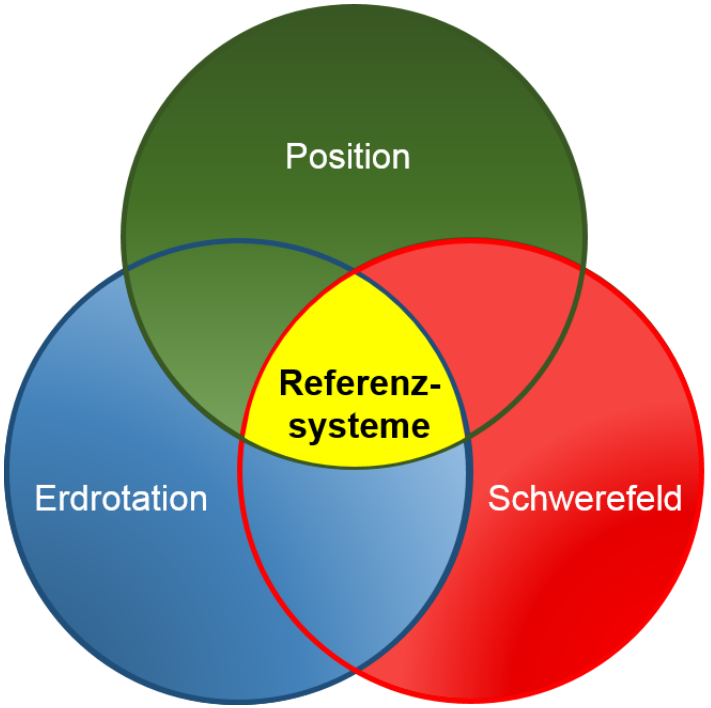
ILRS Analysis Statistics per Orbital Arc

(from Luceri et al., 2014)



Geodetic Products by the ILRS

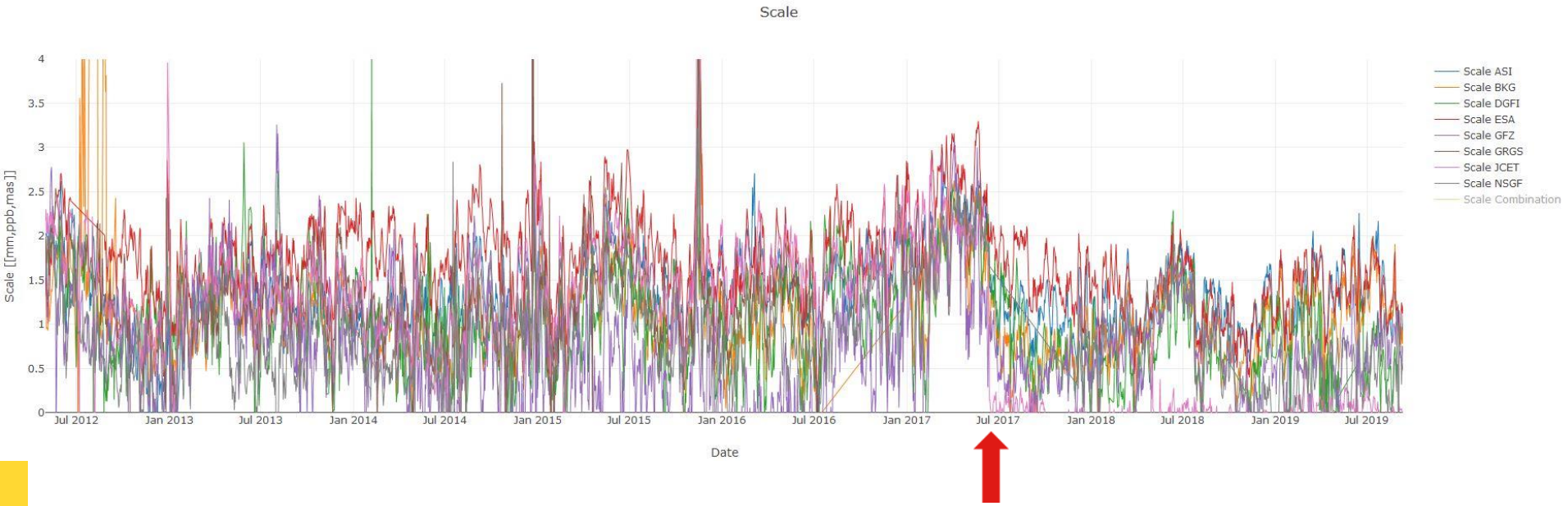
- Station coordinates:
  - DAILY
  - WEEKLY
  - via ITRF
- Station velocities:
  - via ITRF
- ERPs:
  - DAILY
  - WEEKLY
- Satellite orbits:
  - WEEKLY
- Geocenter / Gravity field: no official ILRS product yet



ILRS DAILY Solution Series: Scale

Scale w.r.t. actually used ITRF (using „Core Sites“):

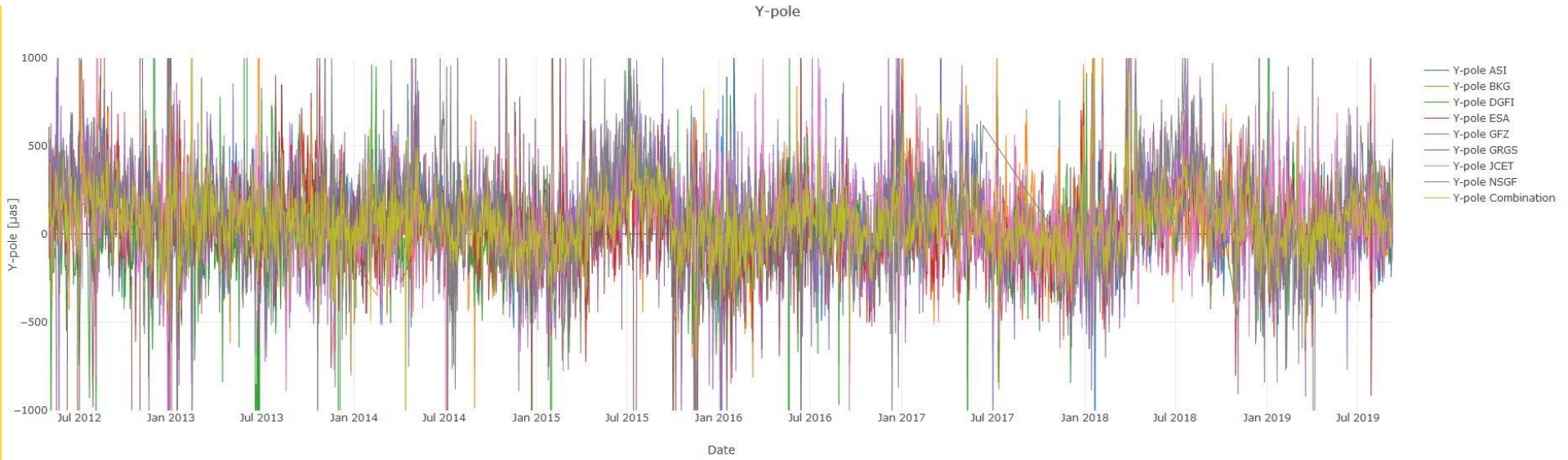
0.3 – 2.0 ppb



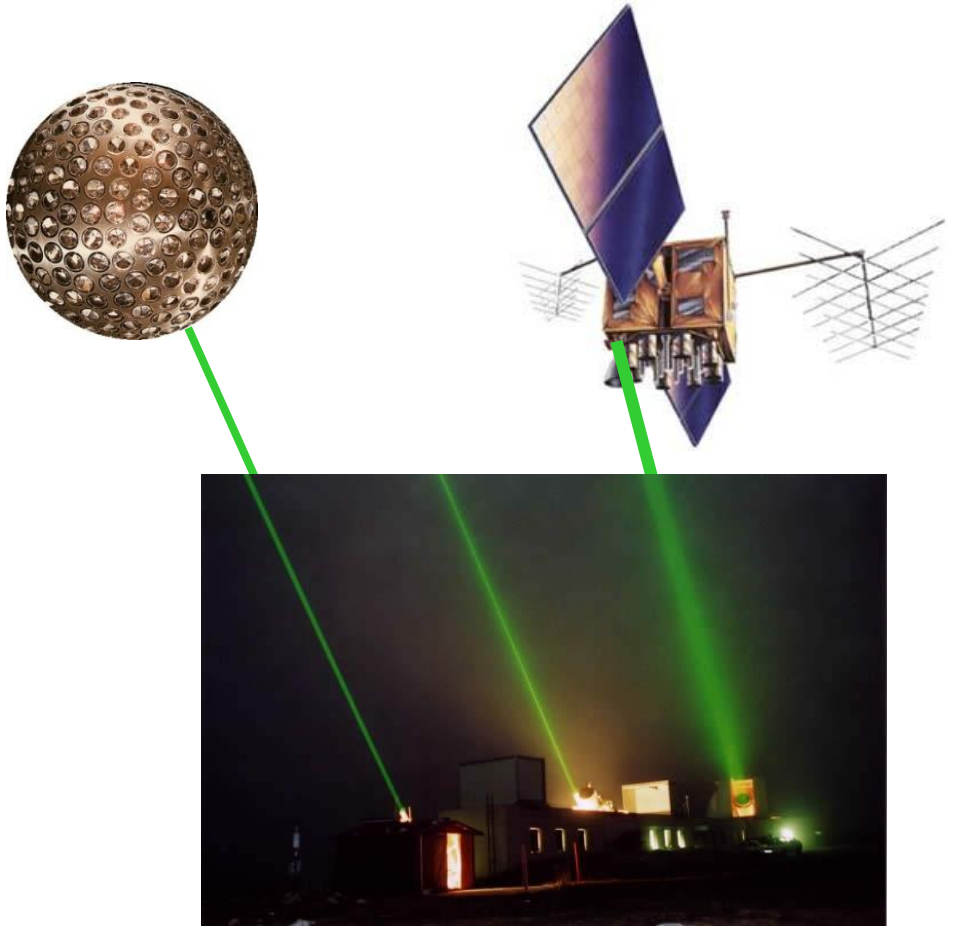
Starting point of using ITRF2014 in SLR analysis

ILRS DAILY Solution Series: Polar motion

Polar motion w.r.t. IERS Bulletin A



Thank you for your kind attention!



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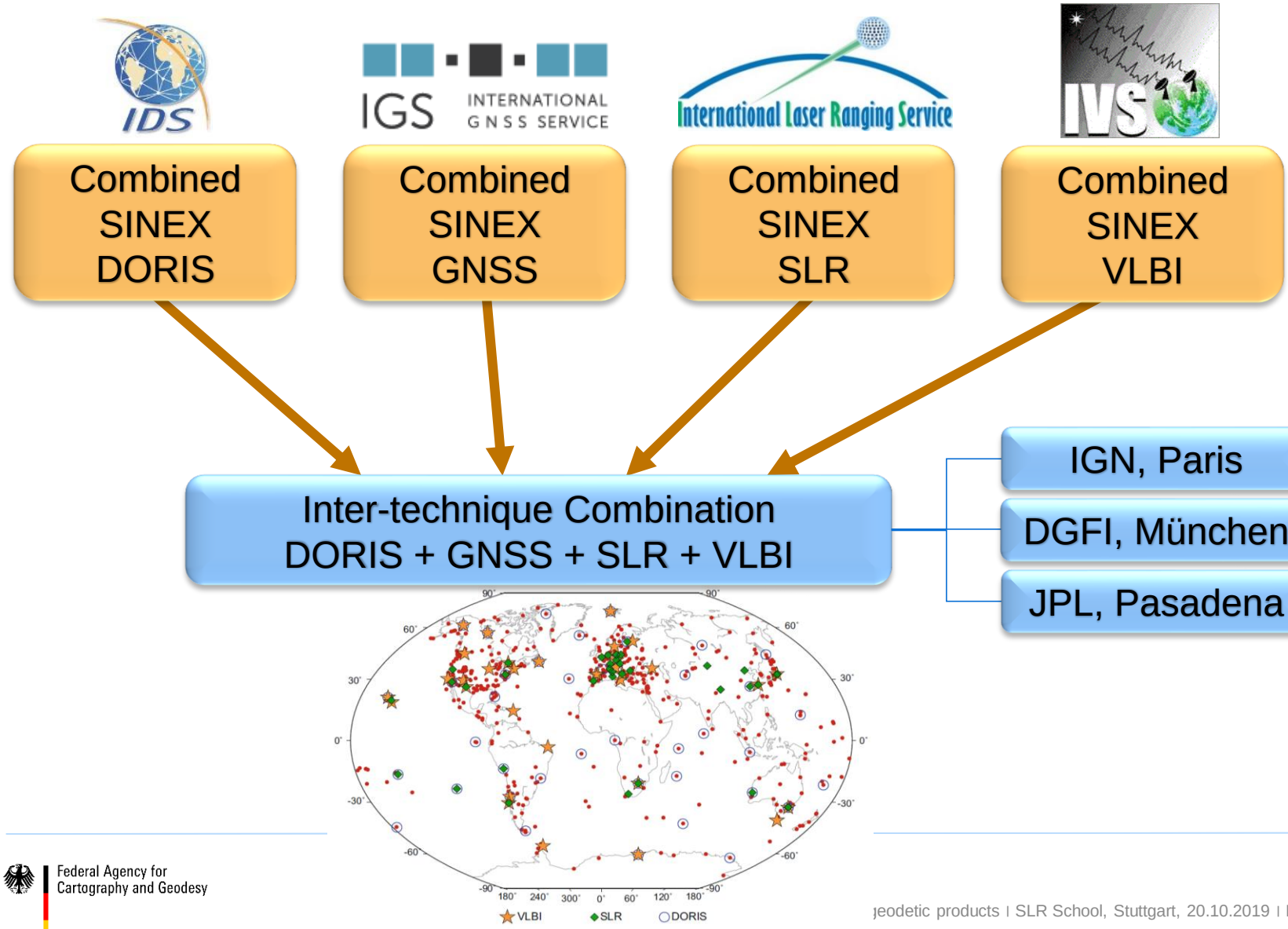
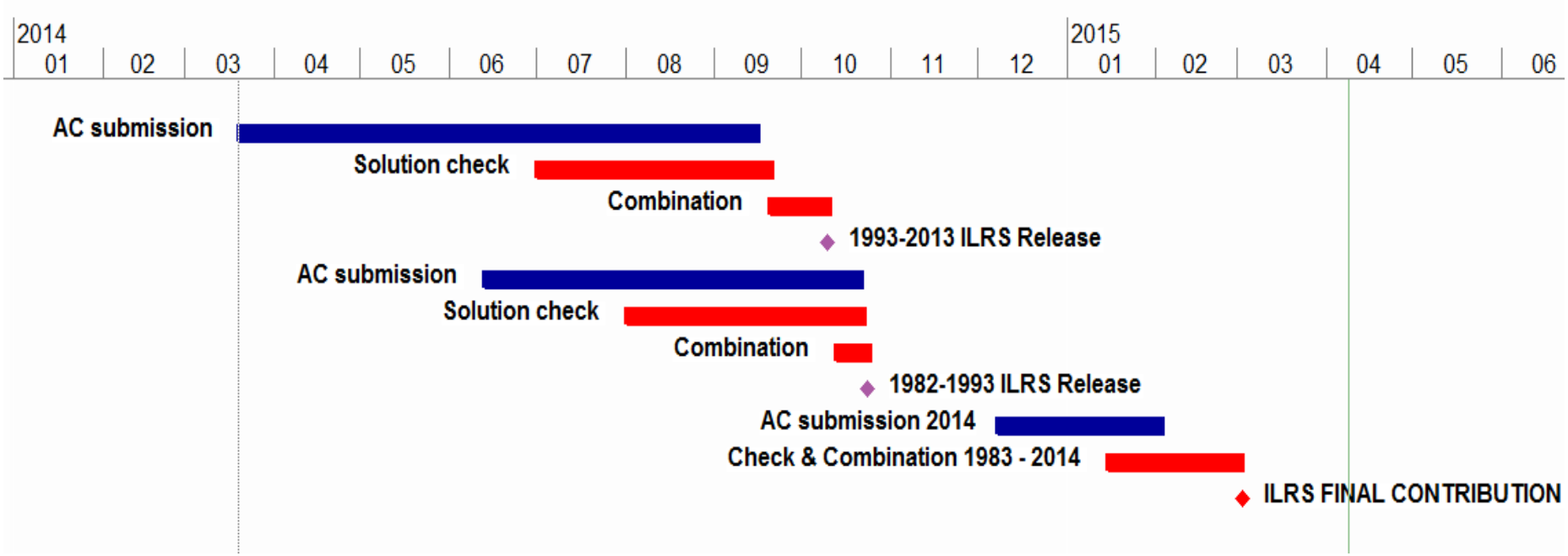
Current ITRF approach



ITRF2014 generation: ILRS Time Line



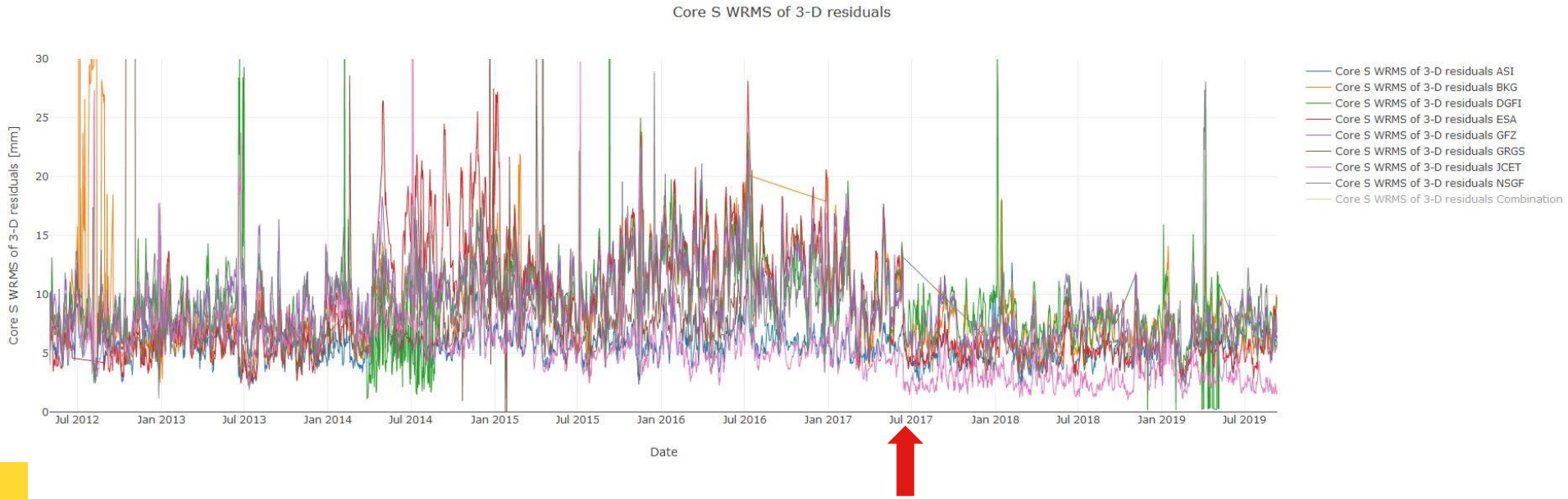
ILRS Analysis Centers: Organization

- The organization and exchange between the ILRS Analysis and Combination Centers is done within the **„ILRS Analysis Standing Committee“** (formerly „Analysis Working Group“)
  - Define the guidelines for product generation
  - Define next steps forward by organizing Pilot Projects
- Led by the 2 Analysis Coordinators:
  - Erricos Pavlis (JCET, US)
  - Cinzia Luceri (ASI, Italy)
- Meeting usually twice per year (EGU in April; ILRS Workshop in Oct/Nov)
- Participation is open for any interested people

SLR data analysis: DAILY solution series

Global 3-D WRMS w.r.t. actually used ITRF (using „Core Sites“):

5 - 10 mm



Starting point of using ITRF2014 in SLR analysis

Consistency between AC contributions