Coincidence Level Among Terrestrial Reference Frames Available through GNSS Broadcast Messages

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Broadcast GNSS Ephemerides

▶ <u>Predictions</u> that must be used for direct (non-augmented) real-time Positioning, Navigation and Timing

▶ Represent a <u>real-time realization</u> of the operational terrestrial reference frame

▶ Accessible by following procedures documented in respective space to user segment Interface Control Documents

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7-Parameter Transformations using Ephemerides
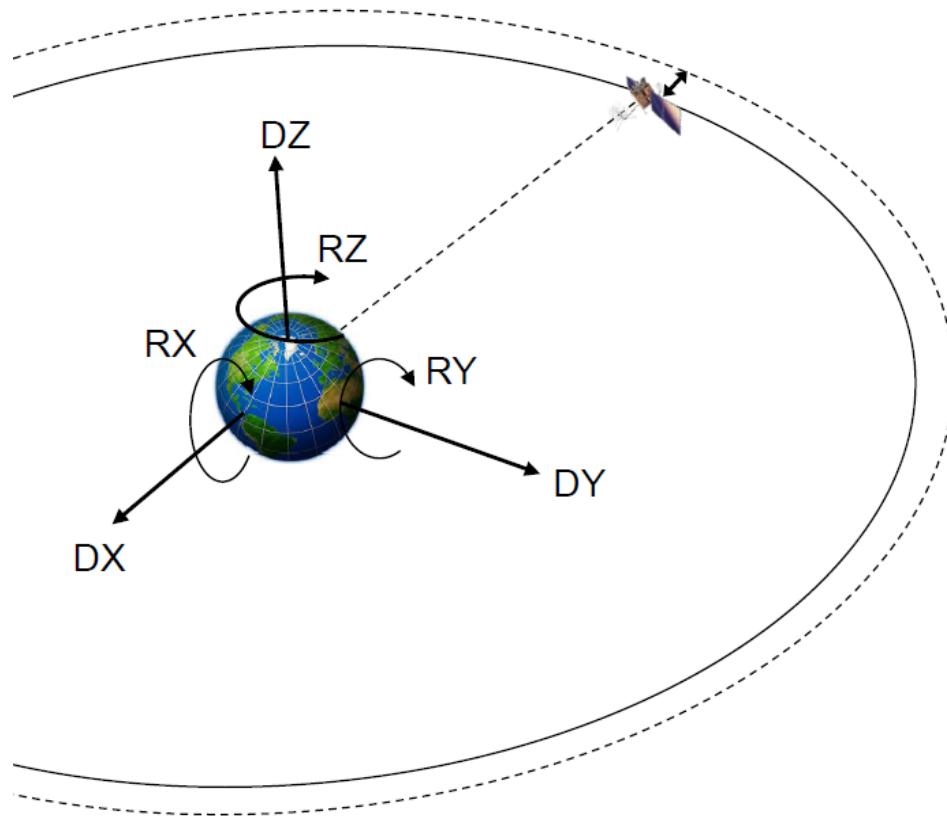
For each GNSS, 7-parameter Helmert transformations were computed between the IGS reference frame (ITRF 2008) and the Earth-fixed coordinate frames used by the navigation messages.

A Helmert transformation consists of

- 3 translation parameters (DX, DY, DZ)
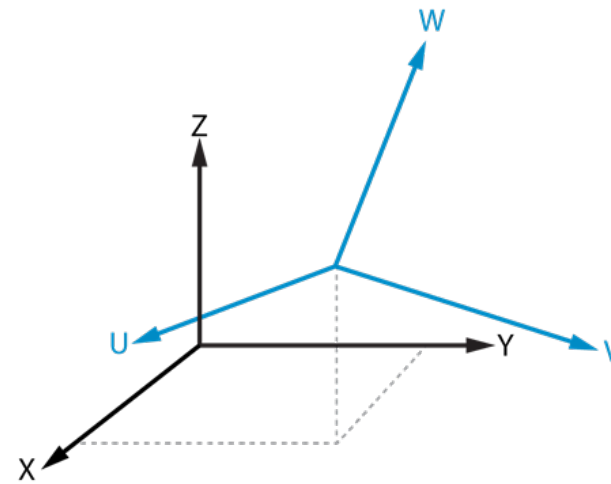- 3 rotation parameters (RX, RY, RZ)
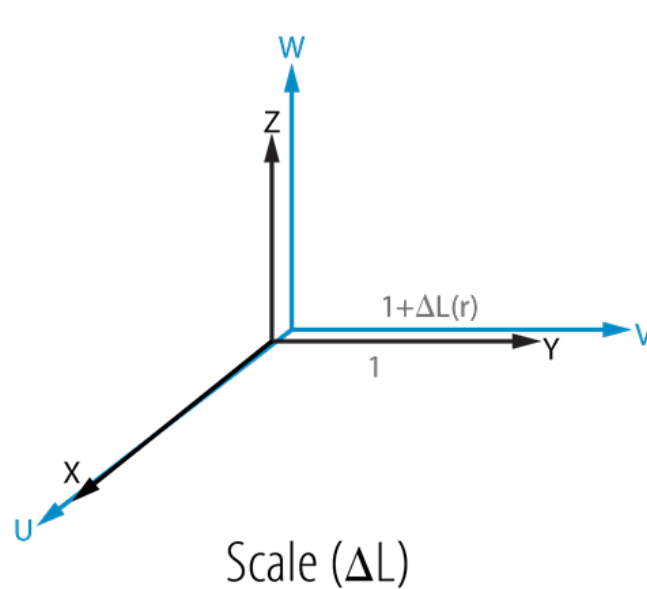- 1 scale parameter

Note that at Earth's surface,
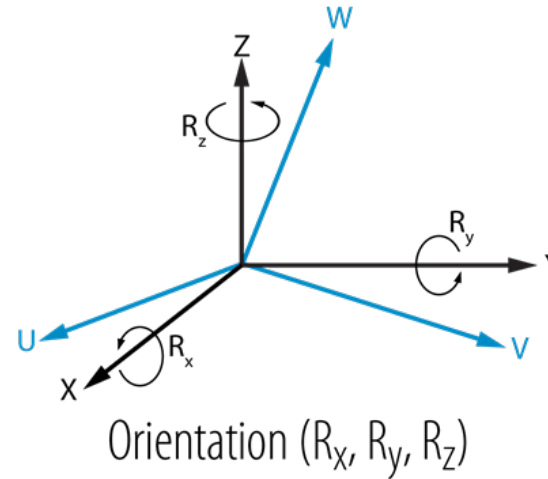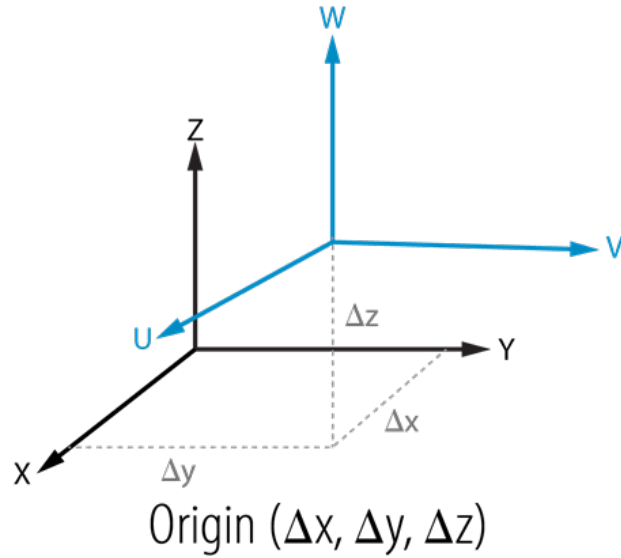
$$1 \text{ mas} \approx 3.09 \text{ cm}$$

$$1 \text{ ppb} \approx 0.64 \text{ cm}$$

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7 Parameter Transformation

Origin (Δx, Δy, Δz)

Orientation (R_x, R_y, R_z)

Scale (ΔL)

Total

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Terrestrial Reference Frames in GNSS

Data Span: First 8-10 weeks of 2016

► Terrestrial Reference Frame used in Broadcast Ephemerides

  ▪ GPS
    • WGS 84 (G1762')
  ▪ GLONASS
    • PZ-90.11
  ▪ Galileo
    • GTRF16v01
  ▪ BeiDou
    • CTRF2000

► <u>Terrestrial Reference Frame used in Post-Fit MGEX Ephemerides</u>

  ▪ ITRF2008 as generated by CODE and Wuhan University (BeiDou)

► All Broadcast and Precise Ephemerides were obtained from:
  ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex

  ▪ CODE= Center for Orbit Determination in Europe
  ▪ MGEX = Multi GNSS Experiment, Coordinated by the International GNSS Service for Geodynamics (IGS)

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Constellations and Tracking Networks Used

Constellation	# of Satellites	# of IGS Stations in MGEX	Satellites Tracked (PRN) (SC s/n for GLONASS)
GPS	29	73	01, 02, 03, 05, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31
GLONASS	22	70	730, 747, 744, 742, 734, 733, 745, 743, 802, 717, 737, 721, 715, 716, 736, 854, 720, 719, 855, 731, 732, 735
Galileo	7	67	11, 12, 19, 22, 24, 26, 30
BeiDou	5 GEO	5	01, 02, 03, 04, 05
	5 IGSO	7	06, 07, 08, 09, 10
	3 MEO	11	11, 12, 14

Data Span: First 8 weeks of 2016, except for BeiDou, where first 10 weeks were used

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Numerical Results: <u>Mean values</u>
Data Span: First 8-10 Weeks of 2016

GNSS	DX (cm)	DY (cm)	DZ (cm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	RSS of 7 Parameters (cm at Re)
GPS	-1	0	-3	-0.53	-0.30	-0.72	-0.31	4.3
GLONASS	2	2	10	-0.39	-0.04	-2.84	-7.58	14.5
Galileo	0	-2	-4	-0.03	0.35	-0.69	-1.90	5.2
BeiDou (MEO)	-5	0	-20	-2.04	1.14	4.37	2.12	25.7
BeiDou (MEO, IGSO)	7	36	-23	-0.87	1.34	7.28	-4.09	49.1
BeiDou (MEO, IGSO, GEO)	50	-92	-10	-1.50	1.16	3.55	18.5	106.6

Largest value for each row shown in red

At mean Earth Radius
1 mas = 3.09 cm
1 ppb = 0.64 cm

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Numerical Results: <u>Standard Deviations</u>
Data Span: First 8-10 Weeks of 2016

| GNSS	DX (cm)	DY (cm)	DZ (cm)	RX (mas)	RY (mas)	RZ (mas)	Scale (ppb)	RSS of 7 Parameters (cm at Re)
GPS	1	1	2	0.64	0.38	0.81	0.20	4.2
GLONASS	3	2	5	0.44	0.34	3.11	1.02	11.5
Galileo	5	2	1	0.31	0.16	0.40	0.61	5.7
BeiDou (MEO)	10	11	14	1.46	2.24	4.50	0.73	26.0
BeiDou (MEO, IGSO)	16	19	19	1.05	2.02	3.96	2.29	34.3
BeiDou (MEO, IGSO, GEO)	24	50	13	1.08	1.87	4.45	7.74	59.0

Largest value for each row shown in red

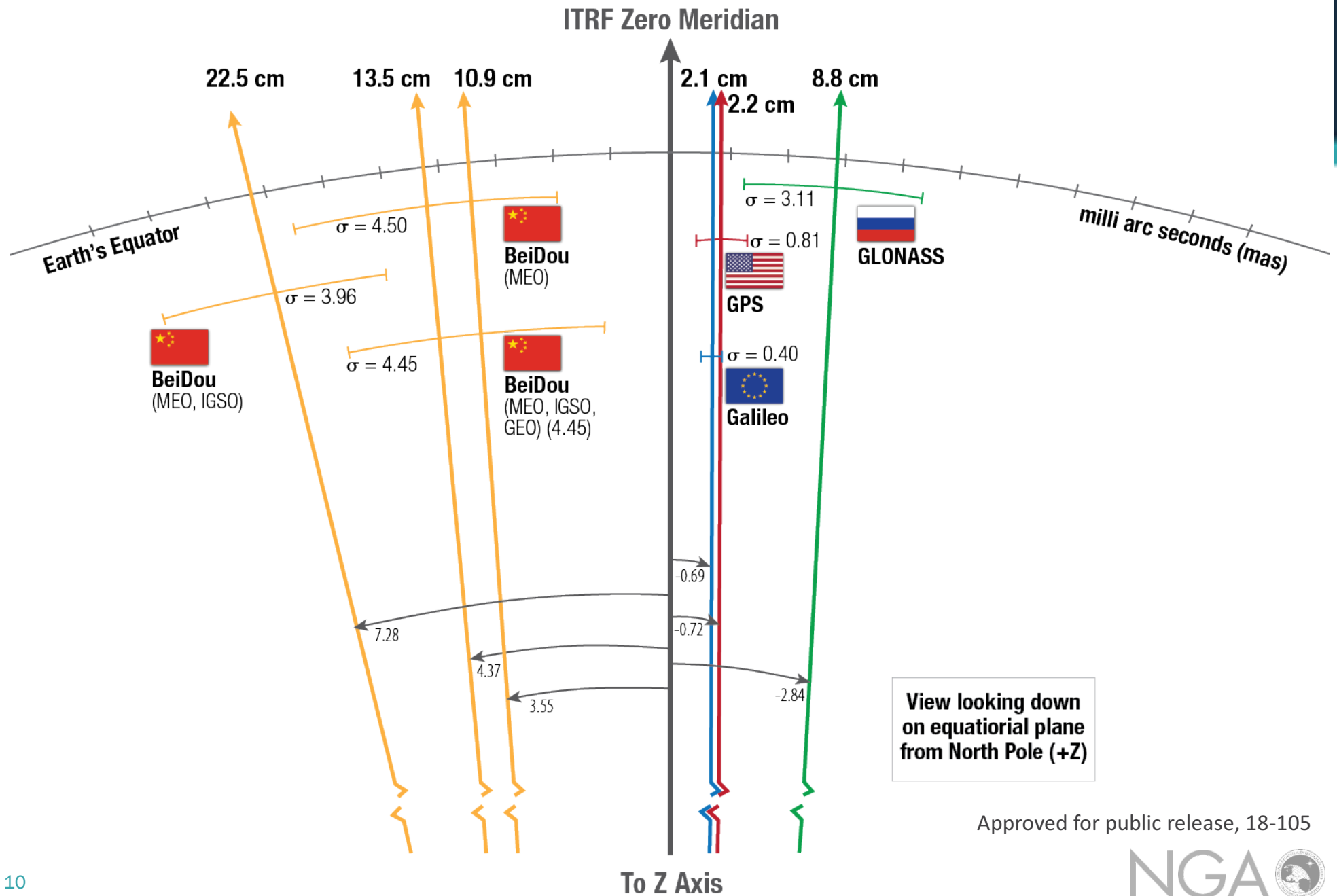At mean Earth Radius
1 mas = 3.09 cm
1 ppb = 0.64 cm

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Rotation around Z (Rz) => Location of Prime Meridian

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Rotation around Z (Rz) => Location of Prime Meridian

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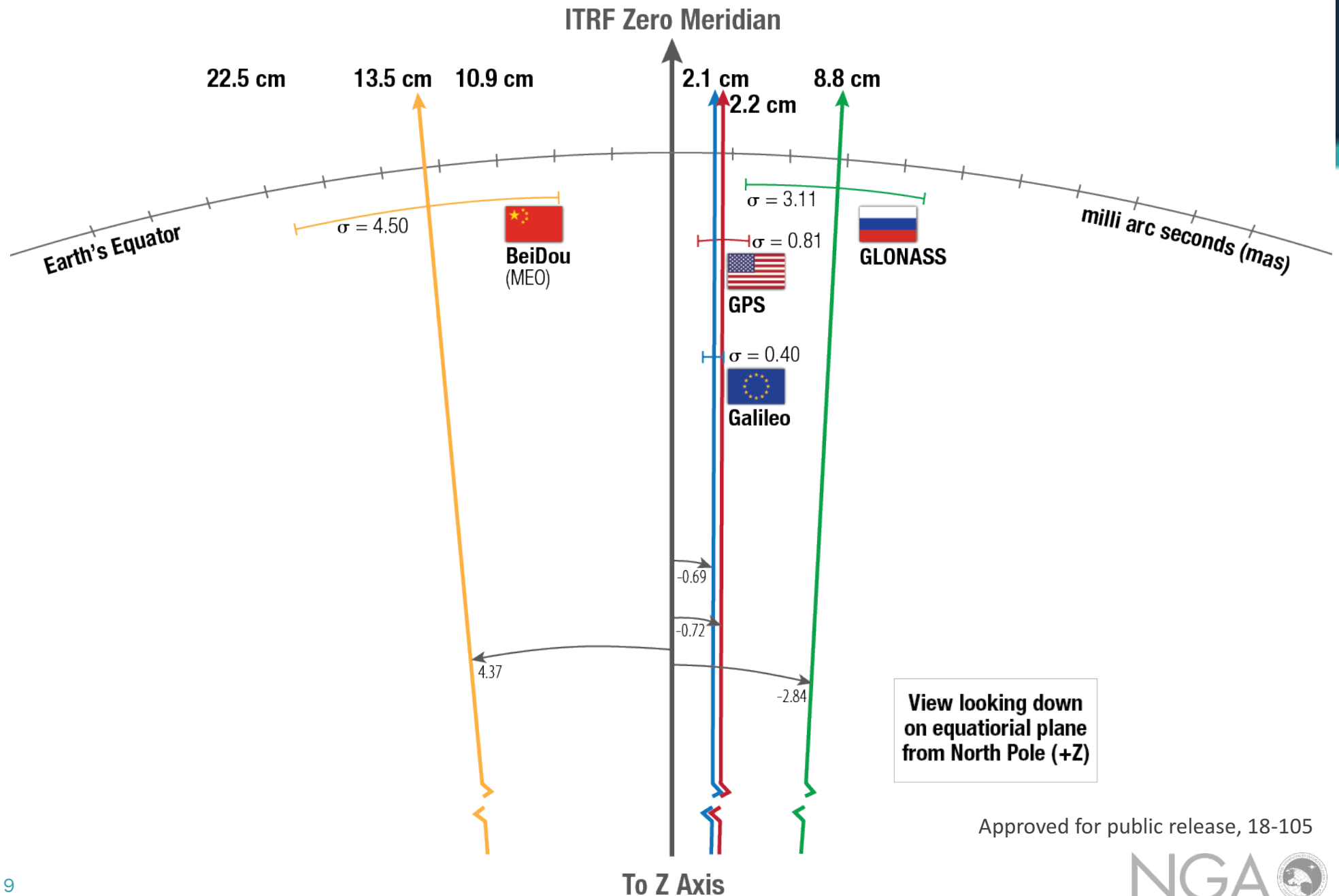
Conclusions

► Terrestrial Reference Frame Realizations Accessible via Broadcast GNSS Messages During the first 8-10 weeks of 2016 are:

- ▪ Coincident with the ITRF08 at a level of
  - • < 5 cm for GPS and Galileo
  - • < 10 cm for GLONASS
  - • < 20 cm for BeiDou MEO with larger differences for IGSO and GEO

- ▪ Repeatable on a daily and weekly basis at a level of
  - • ~ 5 cm for GPS Galileo and GLONASS
  - • ~ 15 cm for BeiDou MEO with larger values for IGSO and GEO

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