The Development of Precise Positioning Capabilities in Mass Market Devices

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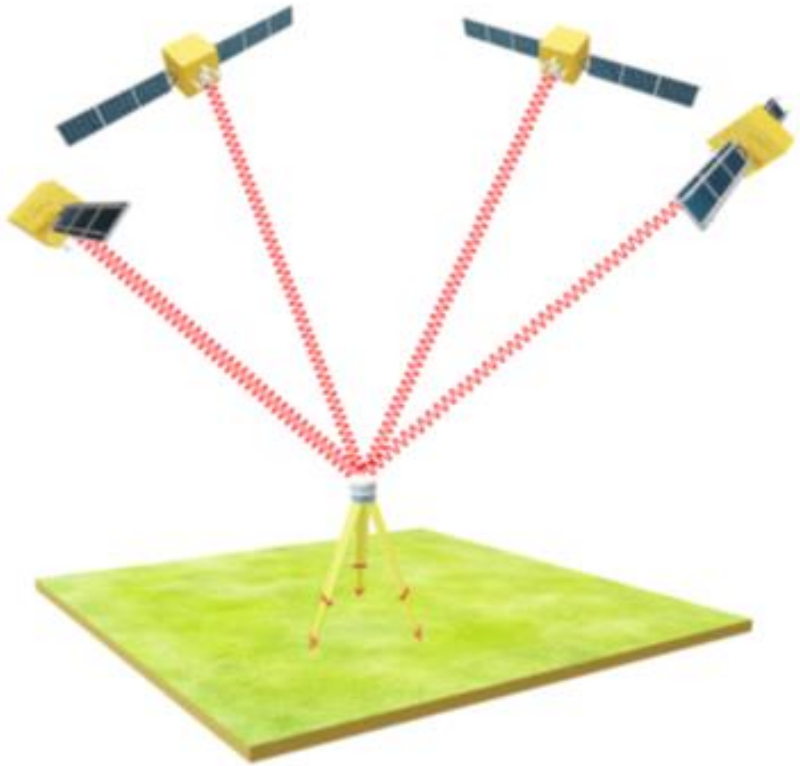
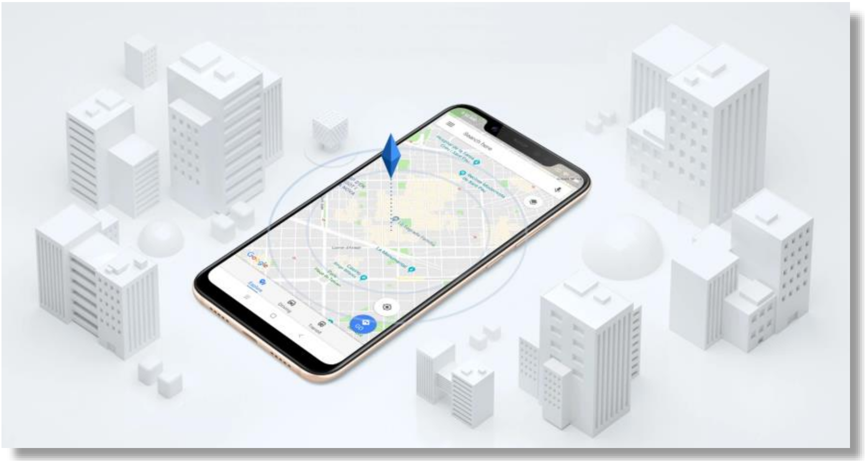
Presentation Outline



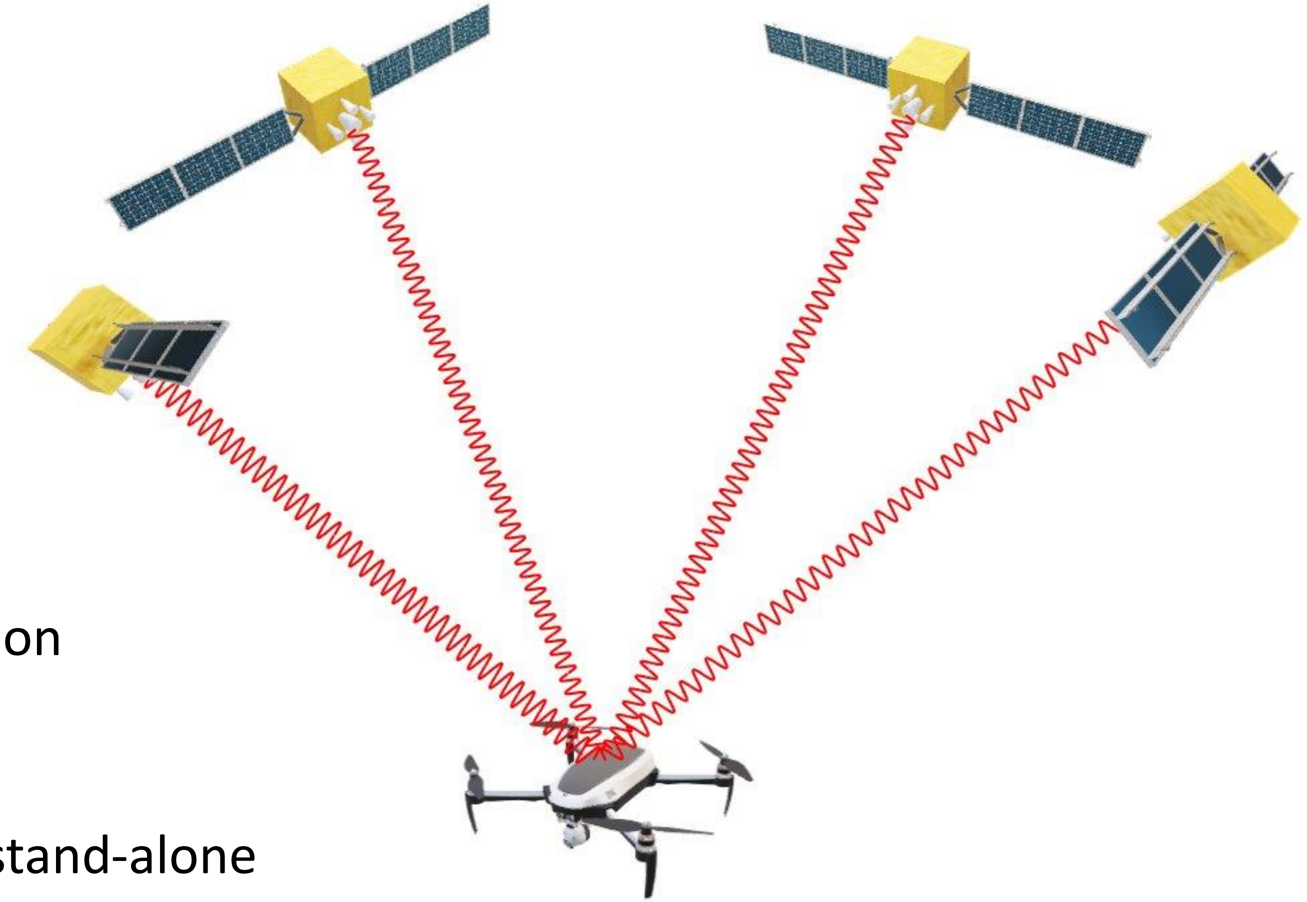
- Basics of GNSS Positioning
- GNSS System Developments
- System Provided Precise Point Positioning
- Reference Frame Evolution
- Mass Market Positioning
- Summary of Implications



The Basics of GNSS Positioning

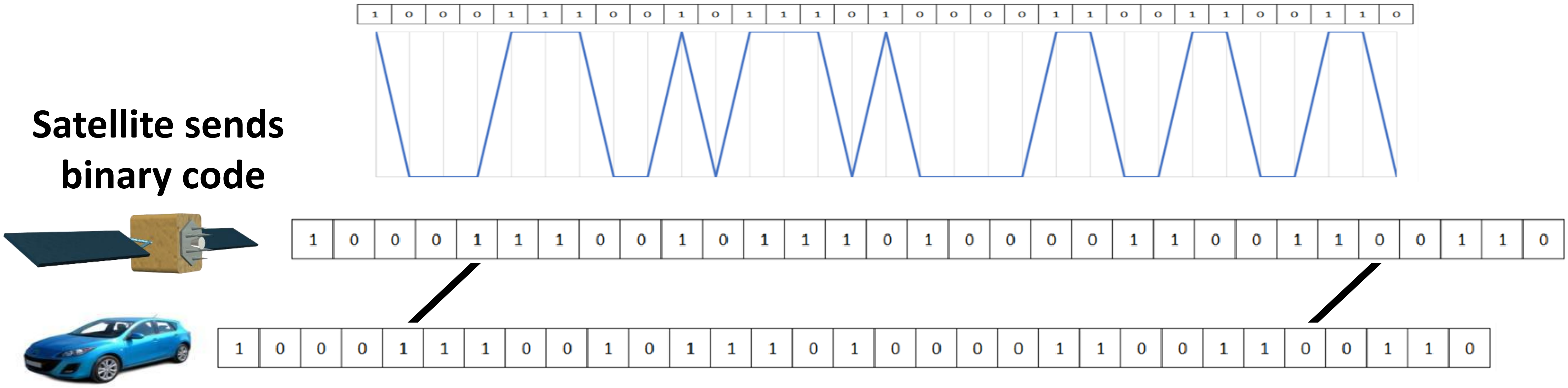
Single Point Positioning

- The technique for which GPS was originally invented;
- Originally for the military but now officially ***“dual-use”****;*
- Receivers now widely available as consumer electronics;
- Accuracy in the range of 1 to 10m is typical but can be worse depending on local conditions;
- Key issue is that because Single Point Positioning is based on a stand-alone receiver it is difficult to check for the many possible sources of errors.



User receivers make “Pseudo-range” measurements

Satellite sends binary code

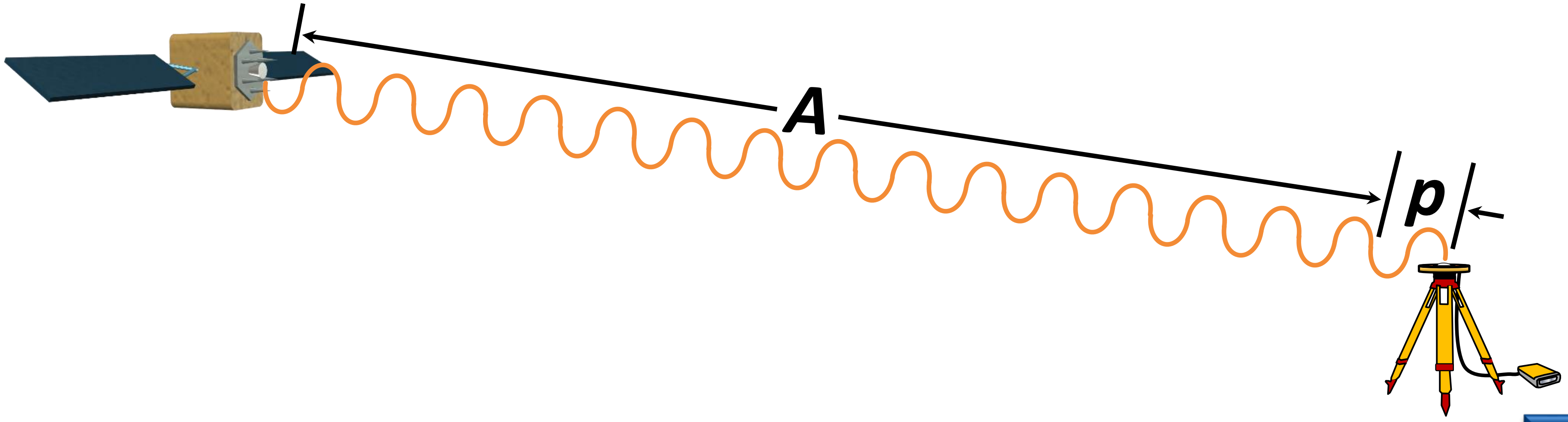


User’s receiver generates same binary code that it should be hearing from the satellite at a particular time

- *Difference between what it should hear and what it does hear is the time delay*
- *Range Distance = Time Delay * Speed of Light*
- *Not the true range; part of the time delay is due to Receiver Clock Offset ~ hence the term “pseudo-range” ~ leads to need for 4 Satellites for 4 unknowns.*

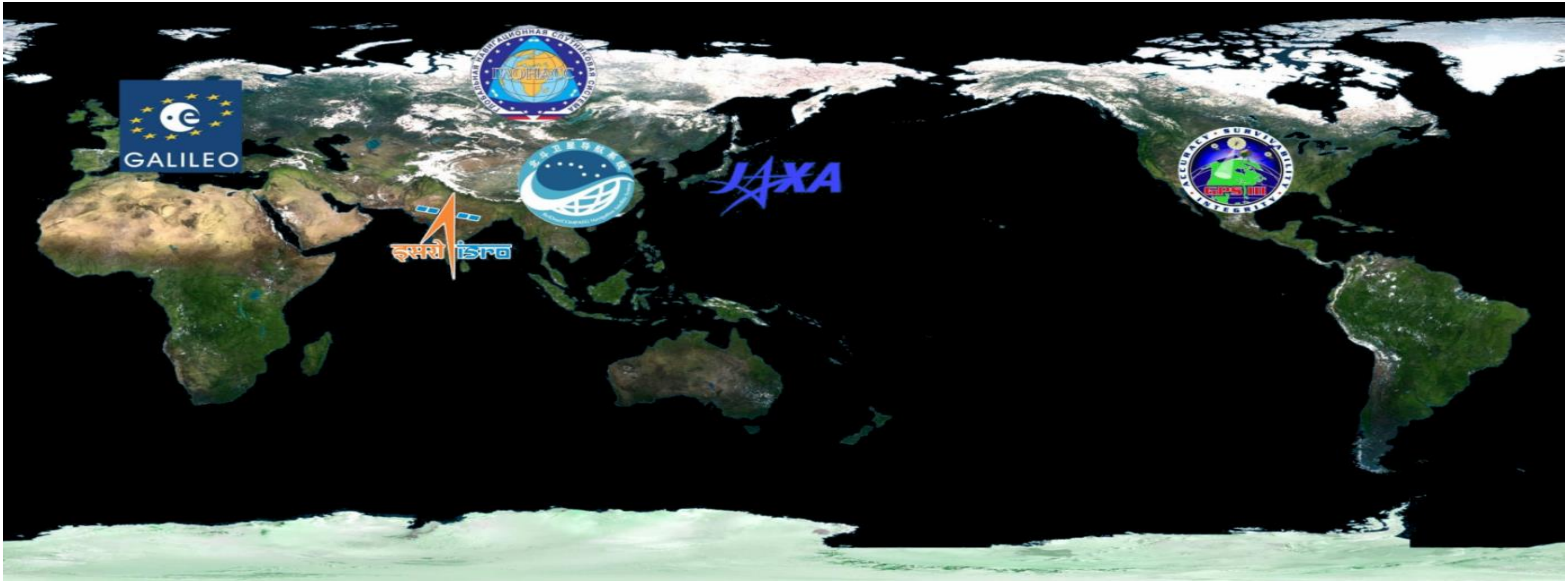
Precise Positioning Measures the Underlying Carrier Signals

- Instead of timing the signal for range measurements, Precise Positioning measures the phase of the underlying carrier signal;
- Such "*carrier phase measurement*" enables relative positioning with an accuracy of centimetres and even millimetres;
- Accessing the underlying carrier signal is easiest when the ranging codes are known ~ otherwise expensive "codeless" techniques are required.



GNSS System Developments

From 1 GPS to 4 Global Navigation Satellite Systems (GNSS) and 2 Regional Systems (RNSS)



More Satellites with better signals on more frequencies

Multiplier 3

	L5 / L5OC / E5a / B2a	L2 / L2C / L2OC	E6 / LEX	L1 / L1OC / E1 / B1
GPS	30	30		30
GLONASS	24	24		24
Galileo	30		30	30
BeiDou	35		35	35
QZSS	3	3	3	3
IRNSS	7			
	129	← ARNS* Bands	→	122

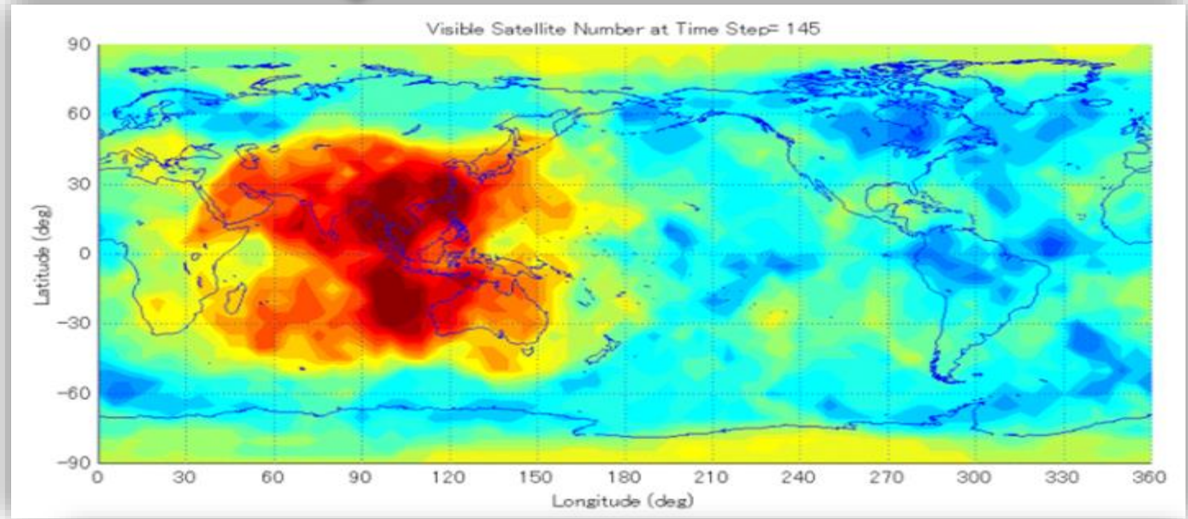
Frequency band used by the system, with N = number of satellites

Frequency band not used by the system

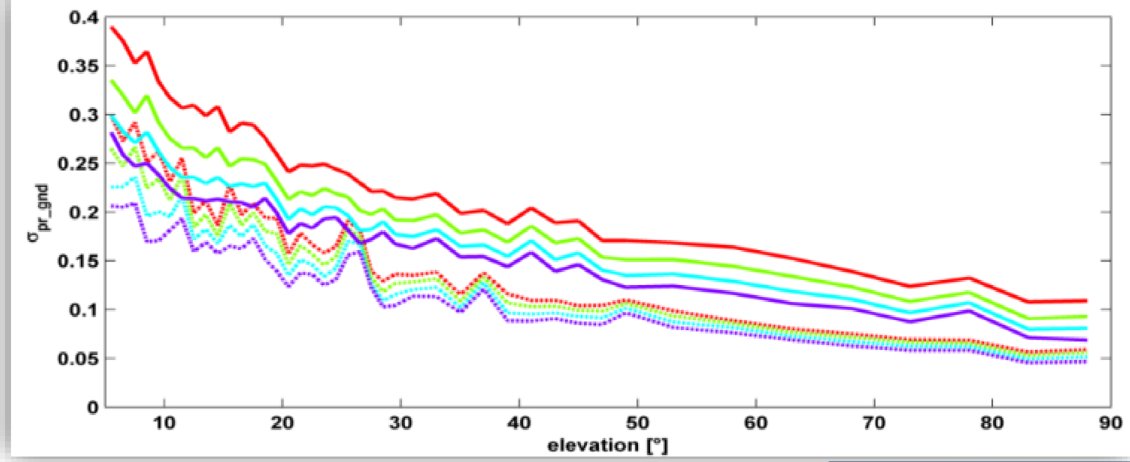
** ARNS = Aeronautical Radio Navigation Service: Frequency bands allocated worldwide to GNSS on a primary basis, granting a better protection against interference*

Source: GNSS User Technology Report, Issue 1, copyright © European GNSS Agency, 2016

Multiplier 1

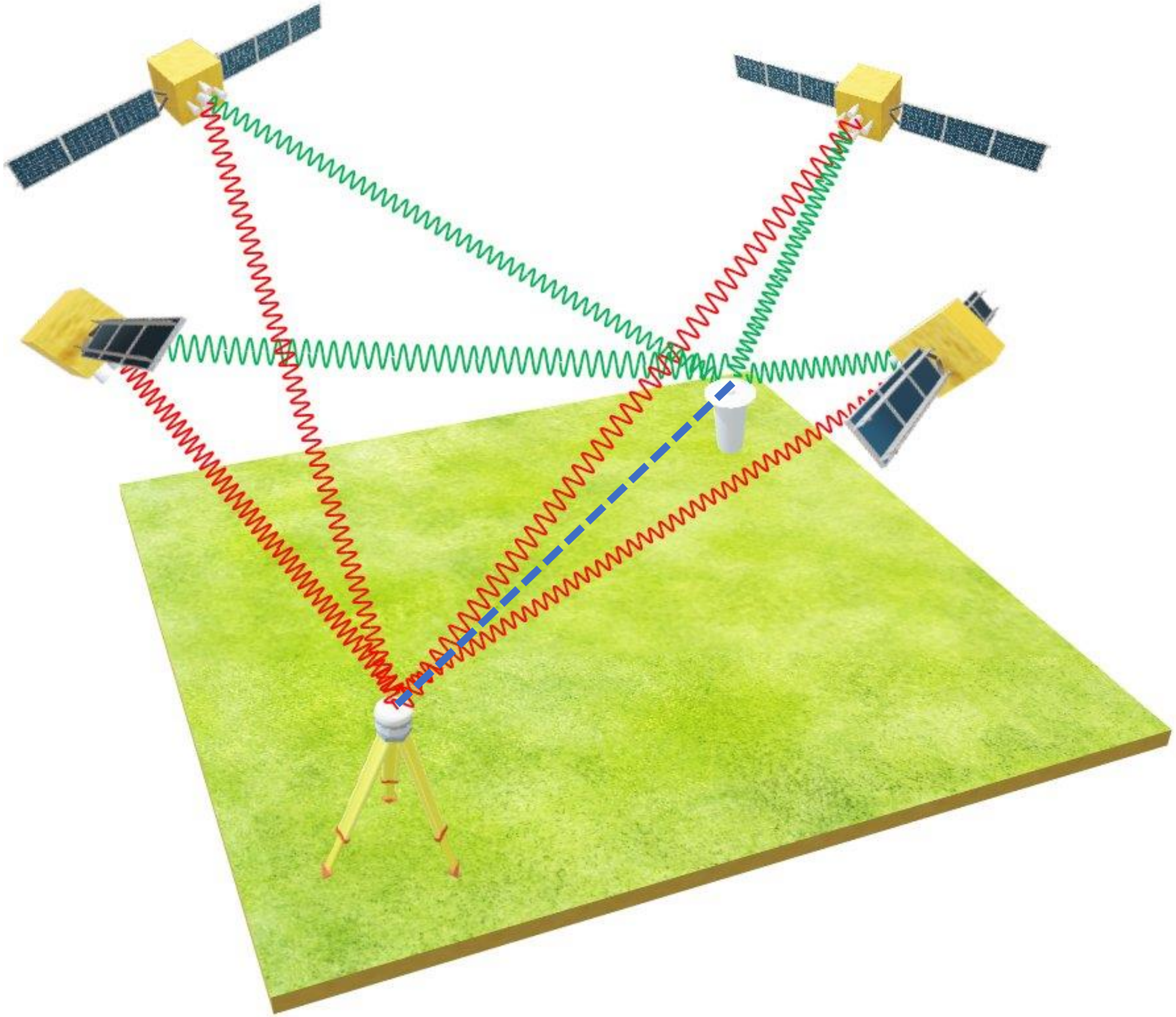


Multiplier 2

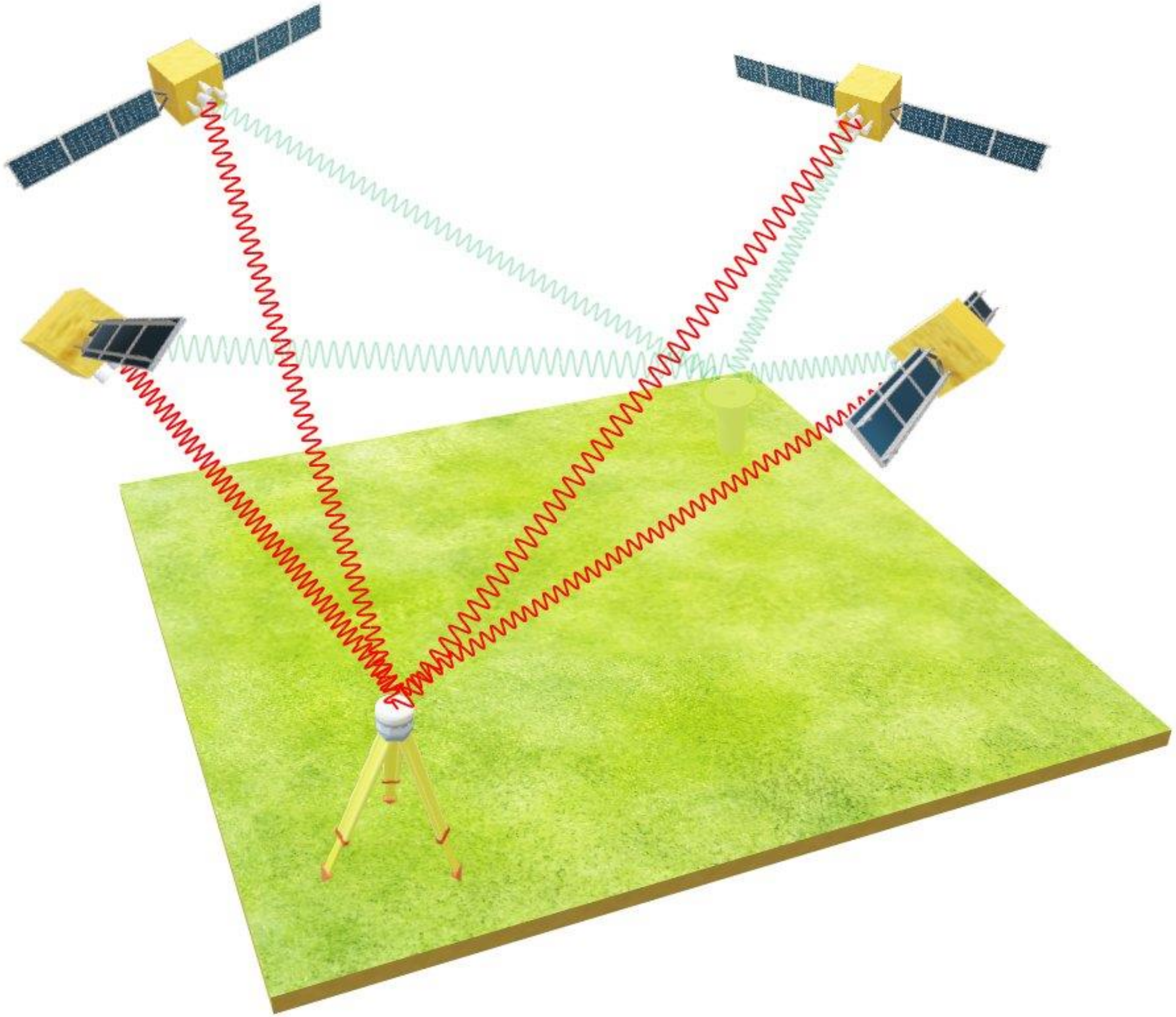


Precise Point Positioning (PPP)

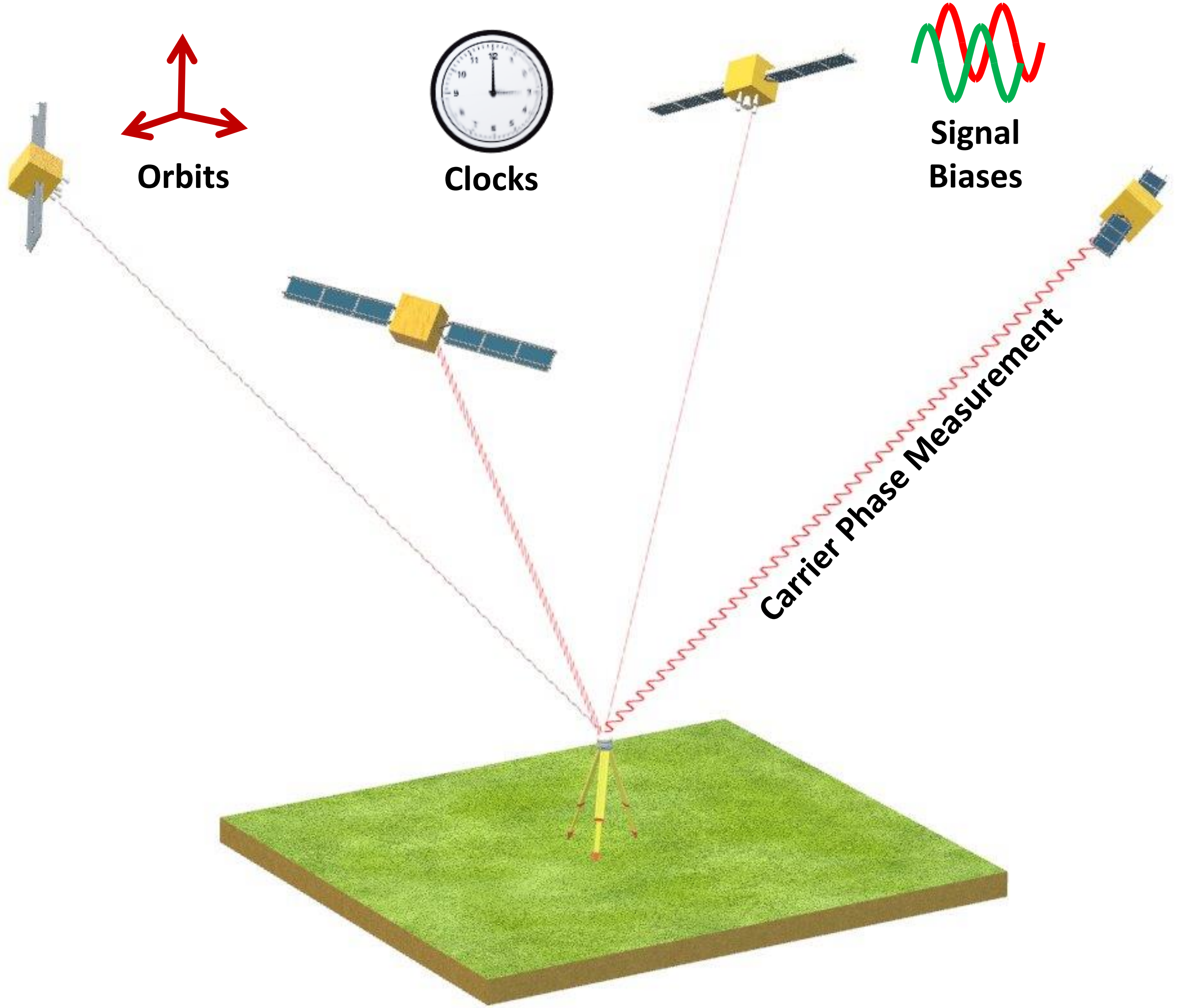
Precise Positioning - from Differential only to Point Positioning as well



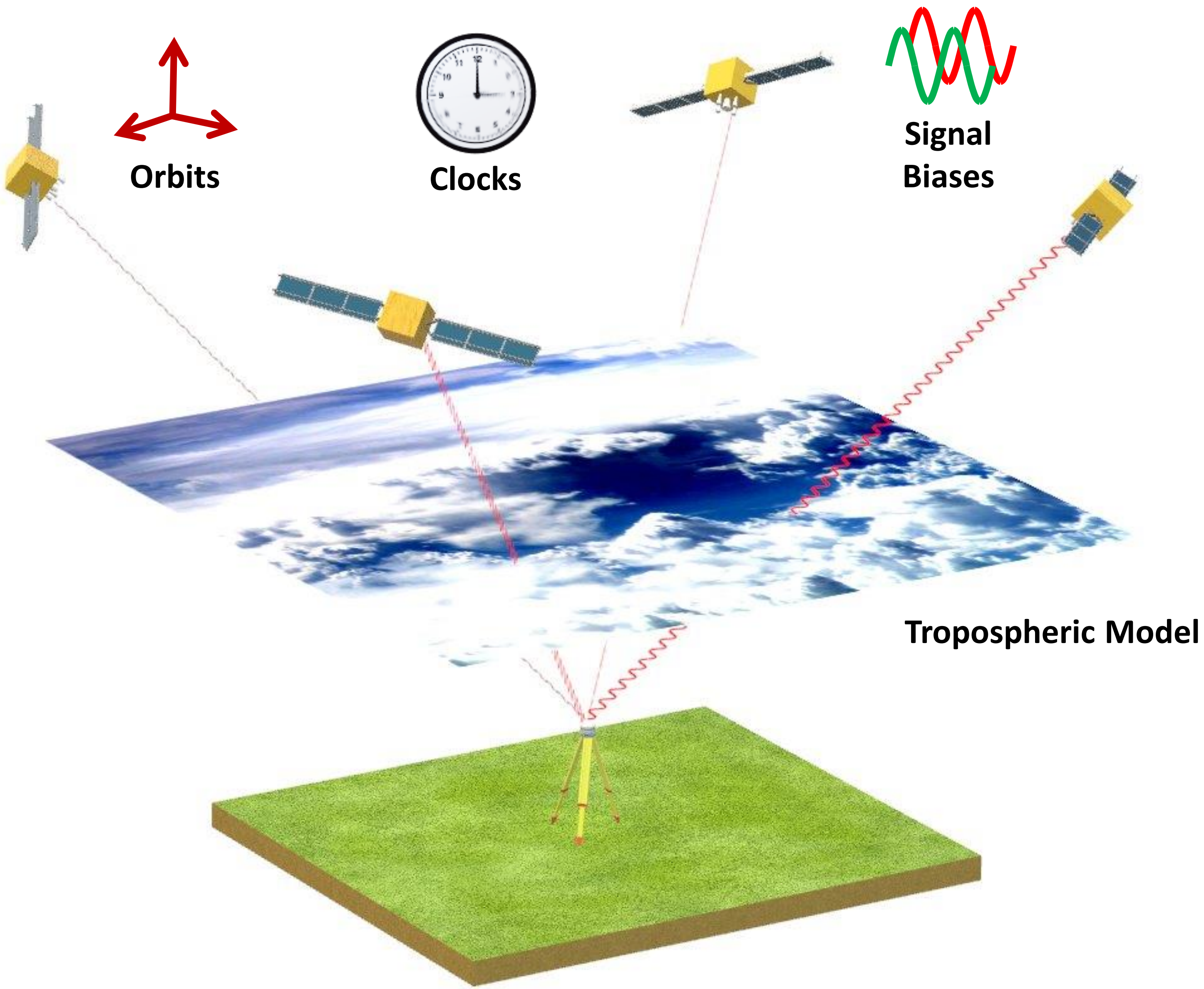
Precise Positioning - from Differential only to Point Positioning as well



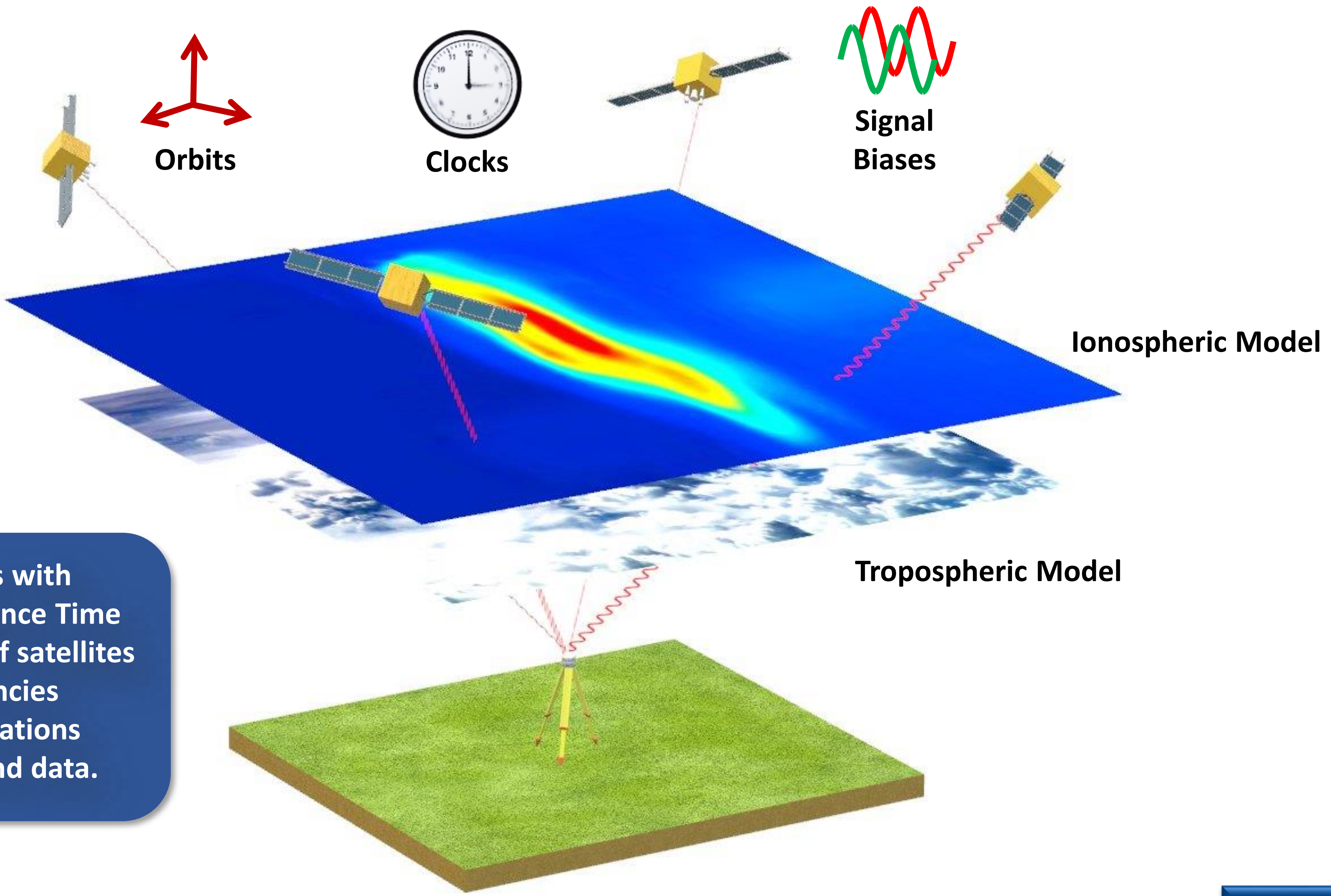
Precise Point Positioning



Precise Point Positioning



Precise Point Positioning

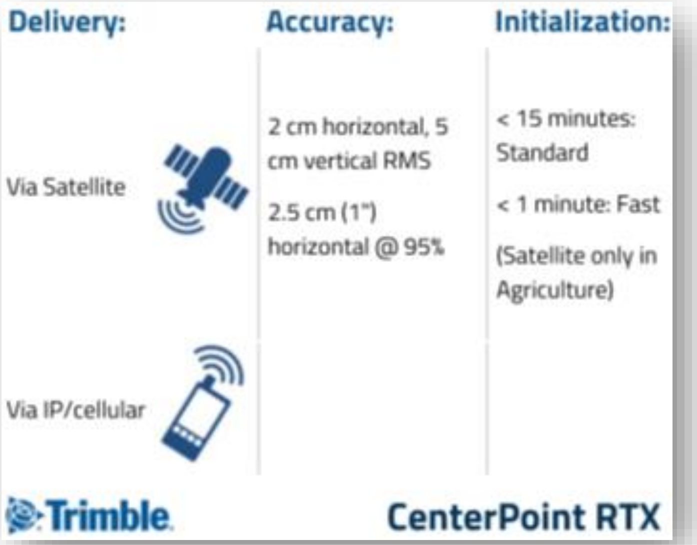


Phase Observations with
Accuracy and Convergence Time
depending on number of satellites
number of frequencies
density of ground stations
and bandwidth to send data.

Commercial Augmentation Services

Commercial GNSS augmentation services that deliver correction information through satellite communication channels

Company	Services	Accuracy (horizontal)	Convergence time	Notes
OmniSTAR	OmniSTAR HP	5–10 cm (95 %)	<45 min	
	OmniSTAR G2	8–10 cm	<20 min	
	OmniSTAR XP	8–10 cm	<45 min	
	OmniSTAR VBS	<1 m (95 %)	<1 min	Pseudo-range corrections
Trimble	CenterPoint RTX	<4 cm (95 %)	<5 min	
	RangePoint RTX	<50 cm (95 %)	<5 min	
	ViewPoint RTX	<1 m (95 %)	<5 min	
Fugro	Starfix.G2+	3 cm	Not provided	Uses ambiguity resolution
	Starfix.G4	10 cm	Not provided	
	Starfix.G2	10 cm	Not provided	
	Starfix.XP2	10 cm	Not provided	Third party corrections
	Starfix.HP	10 cm (95 %)	Not provided	
	Starfix.L1	<1.5 m (95 %)	Not provided	
NavCom	StarFire	<5 cm (68 %)	Not provided	
C-Nav	C-NavC2	8 cm (95 %)	Not provided	StarFire algorithms
	C-NavC1	15 cm (95 %)	Not provided	StarFire algorithms
Veripos	Apex 2	<5 cm (95 %)	Not provided	Own reference station network and calculations
	Apex	<5 cm (95 %)	Not provided	
	Ultra 2	<10 cm (95 %)	Not provided	JPL reference station network and calculations
	Ultra	<10 cm (95 %)	Not provided	
	Standard 2	<1 m (95 %)	Not provided	Pseudo-range corrections
	Standard	<1 m (95 %)	Not provided	
TerraStar	TerraStar-C	Not provided	Not provided	Uses ambiguity resolution
	TerraStar-D	<10 cm (95 %)	Not provided	
	TerraStar-M	<1 m (95 %)	Not provided	Pseudo-range corrections
Novatel	CORRECT (PPP)	4 cm	20–40 min	TerraStar-C corrections
Hemisphere	Atlas	4 cm	10–40 min	



Performance	TerraStar-L[1]	TerraStar-C	TerraStar-C PRO
Horizontal Accuracy[2]	40 cm (RMS) 50 cm (95%)	4 cm (RMS) 5 cm (95%)	2.5 cm (RMS) 3 cm (95%)
Vertical Accuracy[2]	60 cm (RMS)	6.5 cm (RMS)	5 cm (RMS)
Convergence Time[3]	< 5 min	30-45 min	< 18 min
Supported GNSS	GPS/GLO	GPS/GLO	GPS/GLO/GAL/BDS
Supported Platform	OEM7, OEM6	OEM6	OEM7

HEXAGON POSITIONING INTELLIGENCE TERRASTAR

Source: Choy, Kuckartz, Dempster, Rizos and Higgins, GPS Solutions, July 2017

System Provided PPP

PPP Augmentation Signals via GNSS

International Committee on Global Navigation Satellite Systems

System	SV Orbit	Augmentation Signal for PPP	Frequency (MHz)	Bandwidth (bps)
Galileo/	MEO	E6	1278.75	500
GLONASS/ SDCM	MEO GEO	L1 or L3 ? L1 or L5 ?	? ?	?
BeiDou-3	GEO	B2b	1207.14	1000
QZSS	IGSO and GEO	L6D, L6E	1278.75	2000
Australia	GEO	L1 L5	1575.42 1176.45	250 250

India and Nigeria as well!

Source: FIG Presentation by Choy, Lilje and Higgins, ICG13, Xi'an, China, November 2018

IGNSS

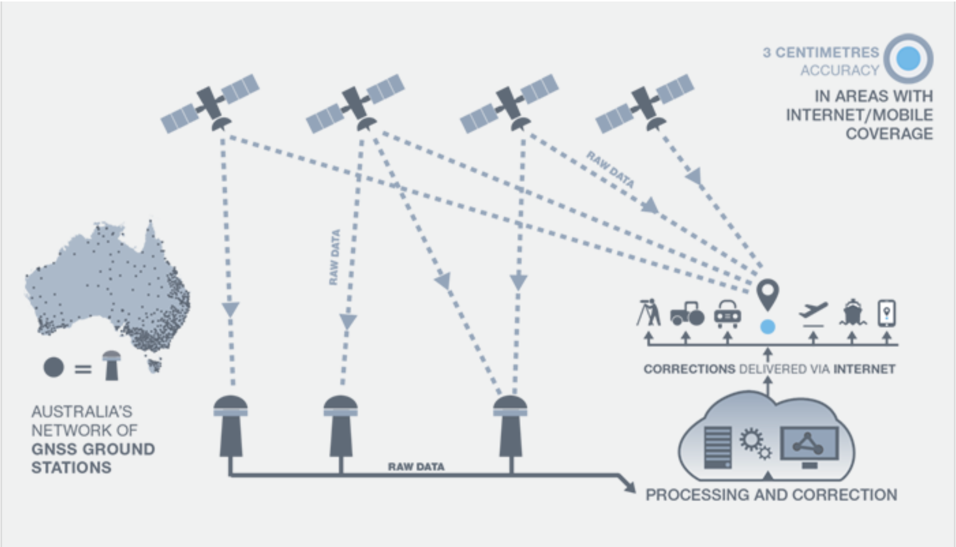
GNSS PPP Service Characteristics

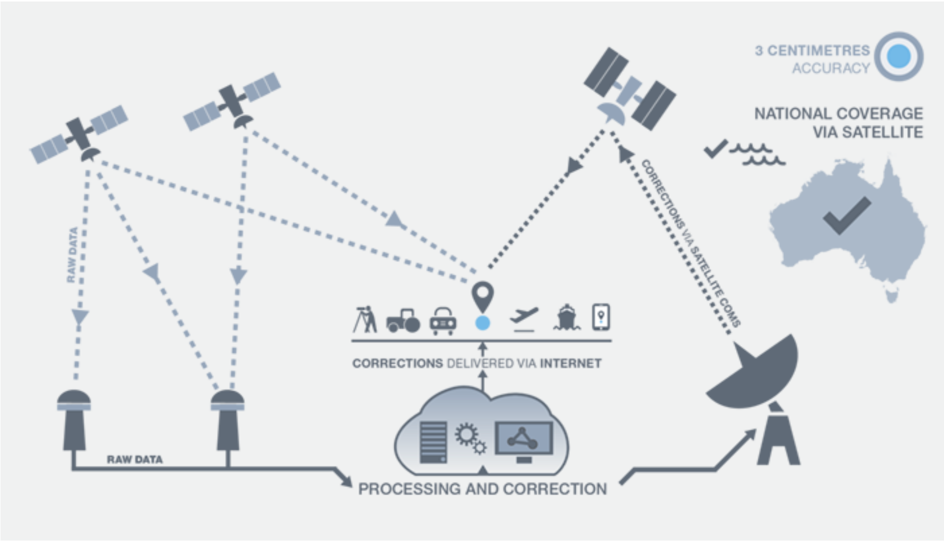
System	Coverage	Format	Supported GNSS/RNSS	Service
Galileo	Global	Open ?	?	?
GLONASS/ SDCM	Global	Commercial ?	?	?
BeiDou-3	Regional	Open ?	?	?
QZSS	Regional	Open	GPS, QZSS, GLO & GAL	PPP-AR SSR-RTK (JAP)
Australia	Regional	Open	GPS & GAL	PPP-float

* PPP-float: Standard float ambiguity PPP
PPP-AR: Ambiguity resolved PPP
SSR-RTK: RTK based on state space representation method

Source: FIG Presentation by Choy, Lilje and Higgins, ICG13, Xi'an, China, November 2018

Australia's National Positioning Infrastructure (NPI)





Two funding measures with a total value of AU$225 million over 4 years

- **National Coverage with Satellite Delivery of 3 levels of service:**
  – GPS Single frequency standard SBAS ~ better than 1 metre accuracy;
  – Dual Frequency/Dual Constellation SBAS (L1, L5 ~ GPS/Galileo ~ 30cm with high integrity);
  – Precise Point Positioning (PPP) ~ better than 10 centimetres;
- Status see Geoscience Australia presentation by Dawson at ICG13, Nov 2018;
- ***All 3 service levels already available via SBAS Test Bed.***

Source: Geoscience Australia

Real Time PPP Performance

- The RMS obtained considering the results from 26/08/2018 to 31/08/2018 is as follows:

	PPP through RTCM GPS+GAL	PPP through SBAS L1 GPS	PPP through SBAS L5 GPS+GAL
RMS North (cm)	2.96	4.64	3.79
RMS East (cm)	4.55	5.48	4.75
RMS Up (cm)	9.21	13.61	10.72

- Two constellations PPP through RTCM provides state-of-the art performances.
- SBAS signal can sustain a PPP service with 5 cm accuracy in horizontal and 10 cm accuracy in vertical (RMS).
- SBAS results present higher noise than the RTCM solution due the lower update rate and lower resolution of the corrections in the SBAS channel.

10th Multi GNSS Asia Conference, Melbourne AU - 23-25 October 2018

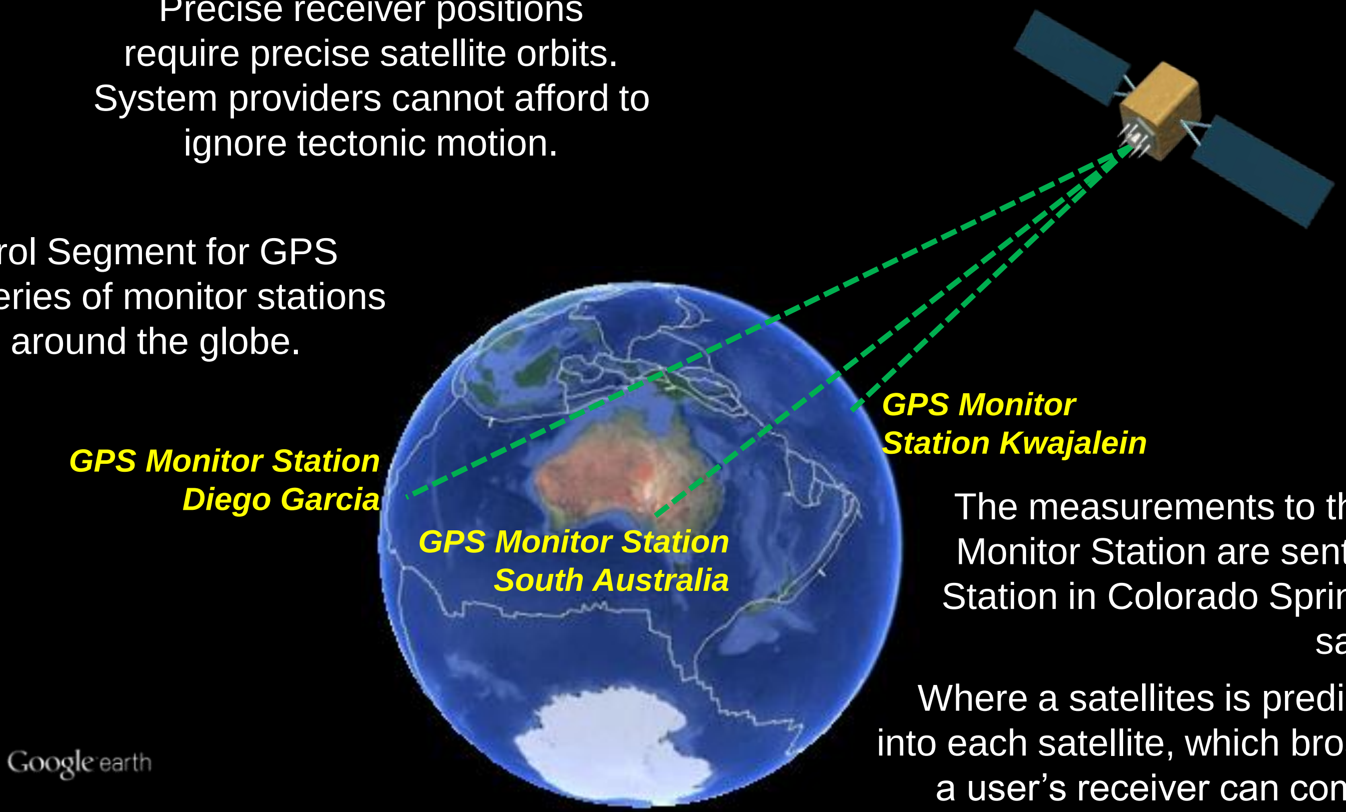
The Effect of Plate Tectonics

Effect of Plate Tectonics on GPS Orbits

Precise receiver positions require precise satellite orbits.
So system providers cannot afford to ignore tectonic motion.

Precise receiver positions require precise satellite orbits. System providers cannot afford to ignore tectonic motion.

The Control Segment for GPS includes a series of monitor stations spaced around the globe.



The measurements to the satellites from each Monitor Station are sent to the Master Control Station in Colorado Springs where orbits for all satellites are computed.

Where a satellites is predicted to be is uploaded into each satellite, which broadcasts its position so a user’s receiver can compute its own position.

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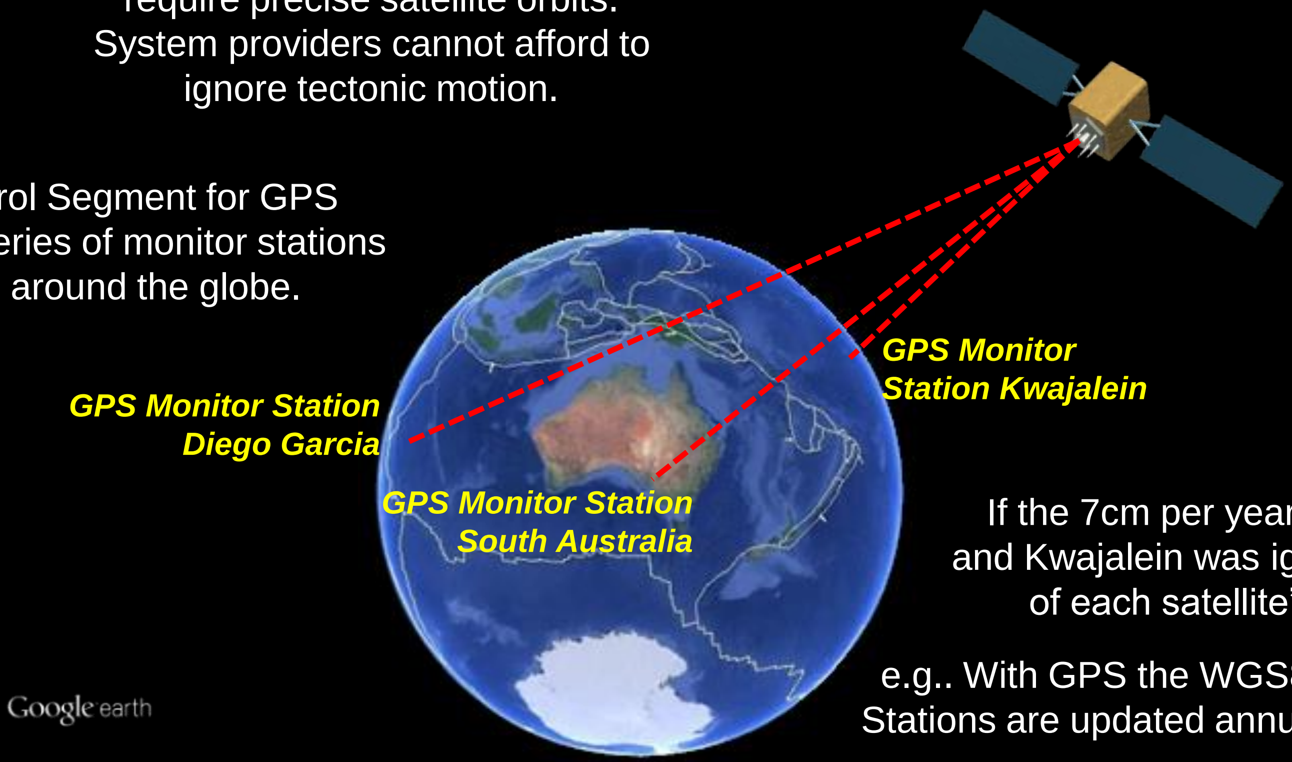
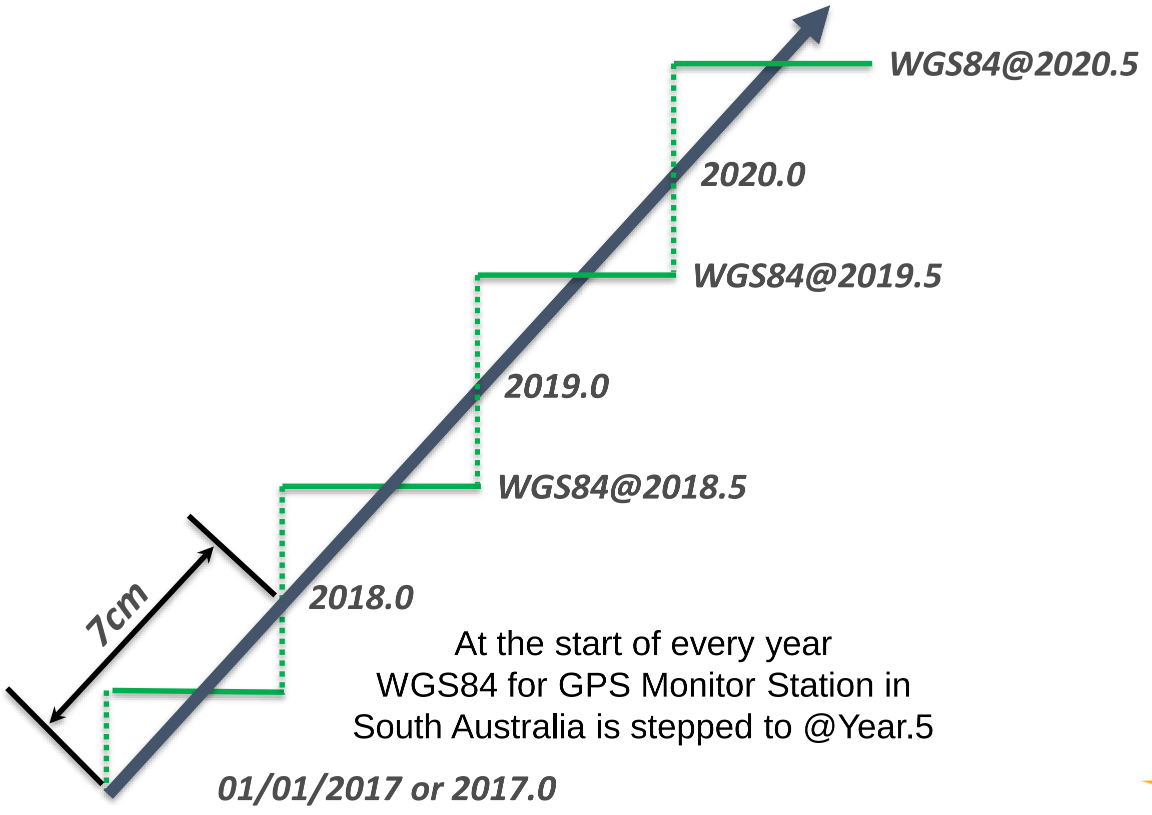


If the 7cm per year between South Australia and Kwajalein was ignored, then the accuracy of each satellite's orbit would be affected.

e.g.. With GPS the WGS84 coordinates of Monitor Stations are updated annually to remove this effect.

Ongoing Evolution of WGS84



Consequence for Australia is that by 2020 there will be over 1.8m difference between GDA94 and WGS84@2020.5
(7cm/year for 26.5 years)

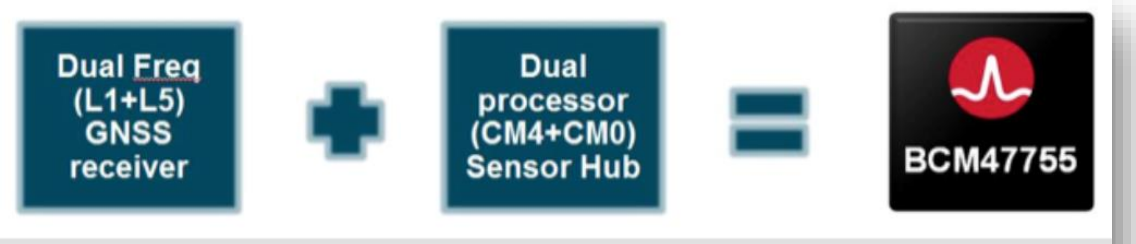
This is how GPS addresses Tectonics. All other GNSS will have to address this as well.

Mass Market Positioning

Mass Market Positioning – Smartphone Chips

Latest version of Android supports true multi-constellation multiple frequencies (L1 and L5) and a jamming detector

Source: GPS World May 2017



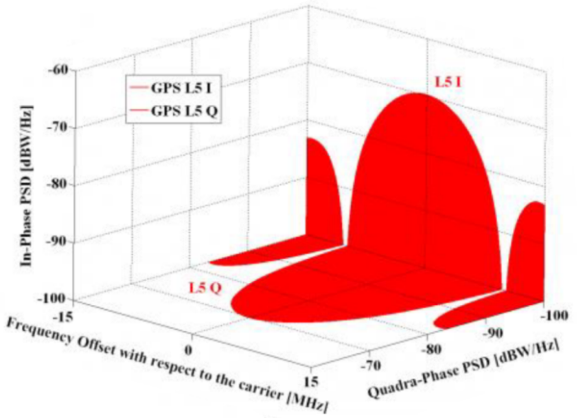
Dual-frequency receiver and dual processor in Broadcom's new L1/L5 chip.

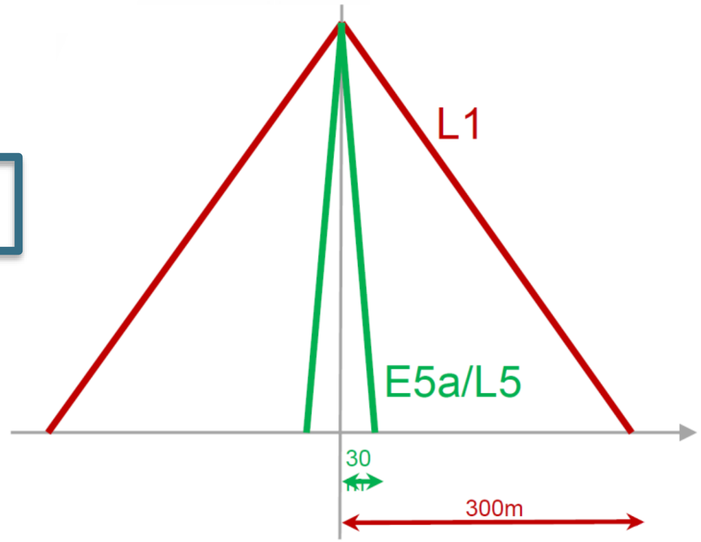
Source: GPS World September 2017

Why is L5 Signal Important?

GAL E5a/GPS L5 signal characteristics

- Center frequency 1176.45 MHz
- More powerful signals
- Pilot signal has no data bits
  - Use simple PLL versus Costas loop
  - 6dB theoretical tracking advantage
- Chipping rate 10.23 MHz versus 1.023MHz for L1

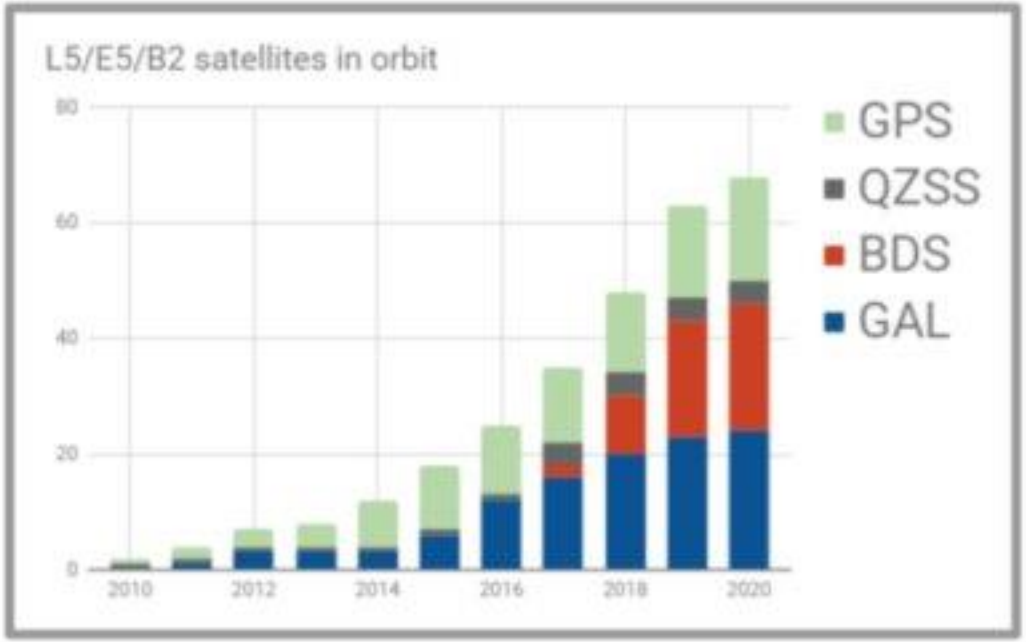




Why is L5 Signal Important?

L5/E5 satellites in orbit

GAL	0	1	3	3	3	6	12	16	20	23	24
BDS	0	0	0	0	0	0	0	2	10	20	22
QZSS	1	1	1	1	1	1	1	4	4	4	4
GPS	1	2	3	4	8	11	12	13	14	16	18
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020



Only based on the increasing available signals in space, L5 receivers improve their performance significantly year over year!

Why is L5 Signal Important?

Summary and next steps

- Until today mass market devices were single frequency only
- Industry is moving towards dual frequency
  - Increase of accuracy in open environment
  - More robust to multipath in urban scenarios
- Number of SVs broadcasting in the L5 band are growing every year
- Carrier phase measurements have been improved
  - E.g Better cycle slip detection
- Broadcom HW (BCM4775) is also capable of tracking the full E5 signal and L2
  - E5a+E5b might be enabled in future releases
- Broadcom Successfully tested RTK and PPP internally

Overarching comment: Important to remember these slides are from a Smartphone Chip supplier not a Survey Equipment supplier.

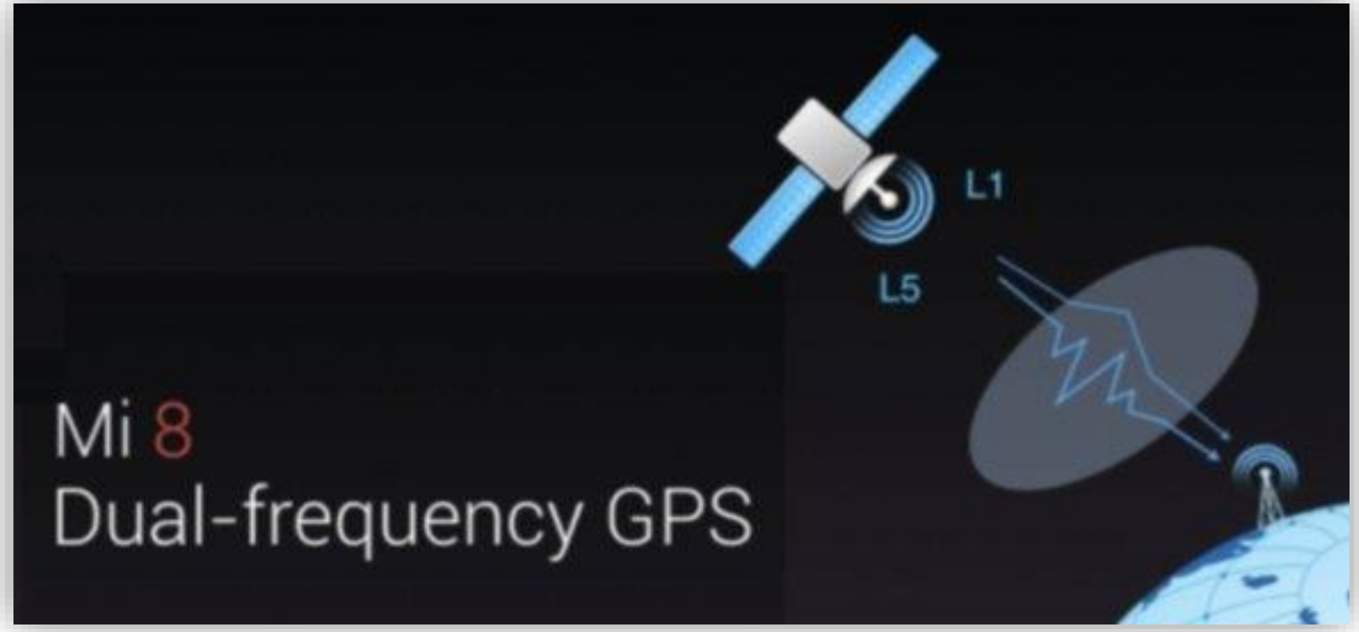
Mass Market Positioning is Evolving Quickly

Version of Android released that supports true multi-constellation multiple frequencies (L1 and L5) and jamming detection

Source: GPS World May 2017

Dual-frequency receiver and dual processor in Broadcom's new L1/L5 chip.

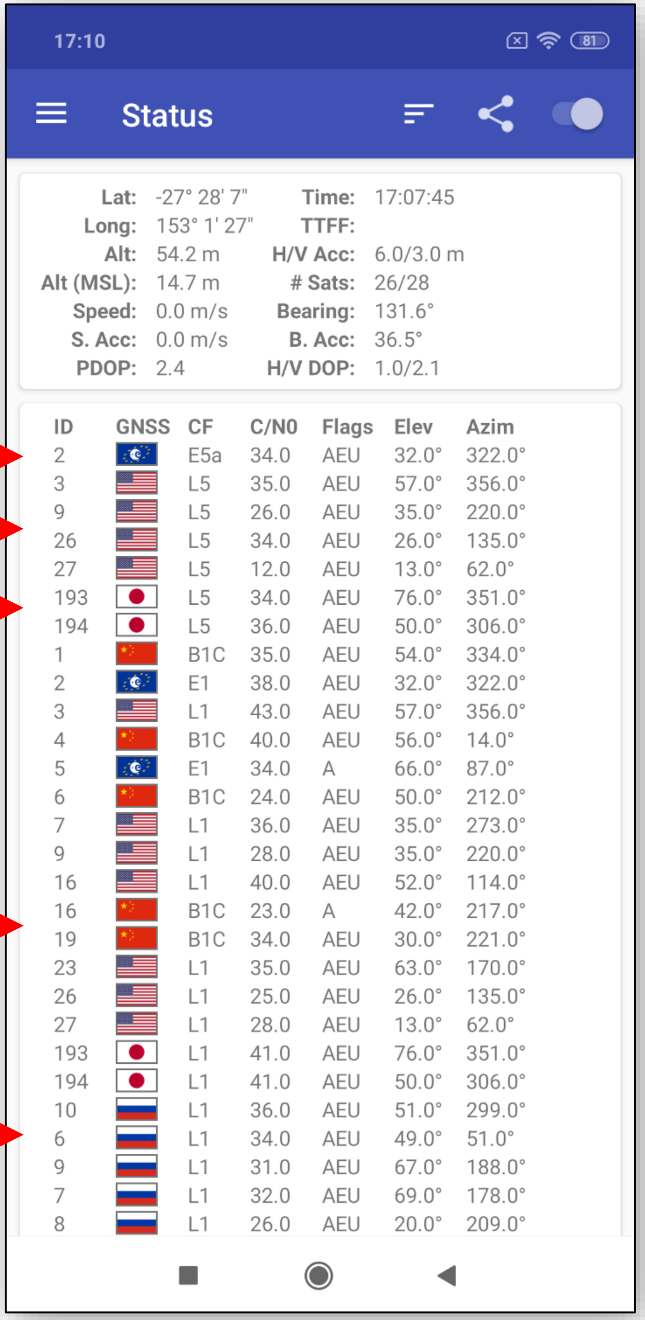
Source: GPS World September 2017



Source: Xiaomi Today, June 2018, www.xiaomitoday.com/gps-mi-8-test/

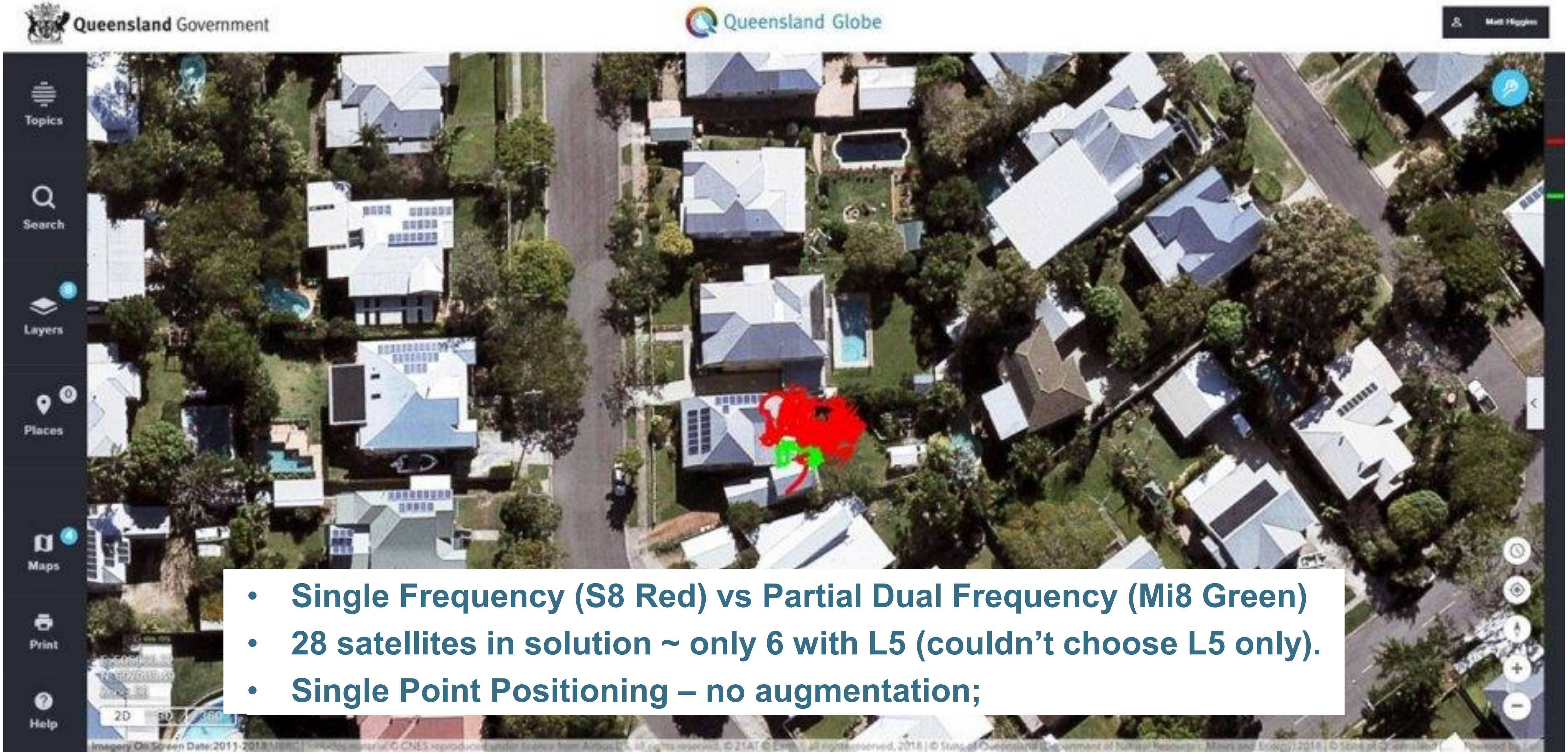
World's First Dual Frequency GNSS Chip in a SmartPhone

- Tracking 19 Unique Satellites
- Tracking on 26 Channels because 7 satellites broadcasting L1 and L5 so using 2 channels
- Galileo Dual Frequency SV 02
- GPS Dual Frequency SV 03, 09, 26 and 27
- QZSS Dual Frequency SV 193 and 194
- Also BeiDou Single Frequency
- And Glonass Single Frequency



Lat:	-27° 28' 7"	Time:	17:07:45
Long:	153° 1' 27"	TTFF:	
Alt:	54.2 m	H/V Acc:	6.0/3.0 m
Alt (MSL):	14.7 m	# Sats:	26/28
Speed:	0.0 m/s	Bearing:	131.6°
S. Acc:	0.0 m/s	B. Acc:	36.5°
PDOP:	2.4	H/V DOP:	1.0/2.1

ID	GNSS	CF	C/N0	Flags	Elev	Azim
2		E5a	34.0	AEU	32.0°	322.0°
3		L5	35.0	AEU	57.0°	356.0°
9		L5	26.0	AEU	35.0°	220.0°
26		L5	34.0	AEU	26.0°	135.0°
27		L5	12.0	AEU	13.0°	62.0°
193		L5	34.0	AEU	76.0°	351.0°
194		L5	36.0	AEU	50.0°	306.0°
1		B1C	35.0	AEU	54.0°	334.0°
2		E1	38.0	AEU	32.0°	322.0°
3		L1	43.0	AEU	57.0°	356.0°
4		B1C	40.0	AEU	56.0°	14.0°
5		E1	34.0	A	66.0°	87.0°
6		B1C	24.0	AEU	50.0°	212.0°
7		L1	36.0	AEU	35.0°	273.0°
9		L1	28.0	AEU	35.0°	220.0°
16		L1	40.0	AEU	52.0°	114.0°
16		B1C	23.0	A	42.0°	217.0°
19		B1C	34.0	AEU	30.0°	221.0°
23		L1	35.0	AEU	63.0°	170.0°
26		L1	25.0	AEU	26.0°	135.0°
27		L1	28.0	AEU	13.0°	62.0°
193		L1	41.0	AEU	76.0°	351.0°
194		L1	41.0	AEU	50.0°	306.0°
10		L1	36.0	AEU	51.0°	299.0°
6		L1	34.0	AEU	49.0°	51.0°
9		L1	31.0	AEU	67.0°	188.0°
7		L1	32.0	AEU	69.0°	178.0°
8		L1	26.0	AEU	20.0°	209.0°

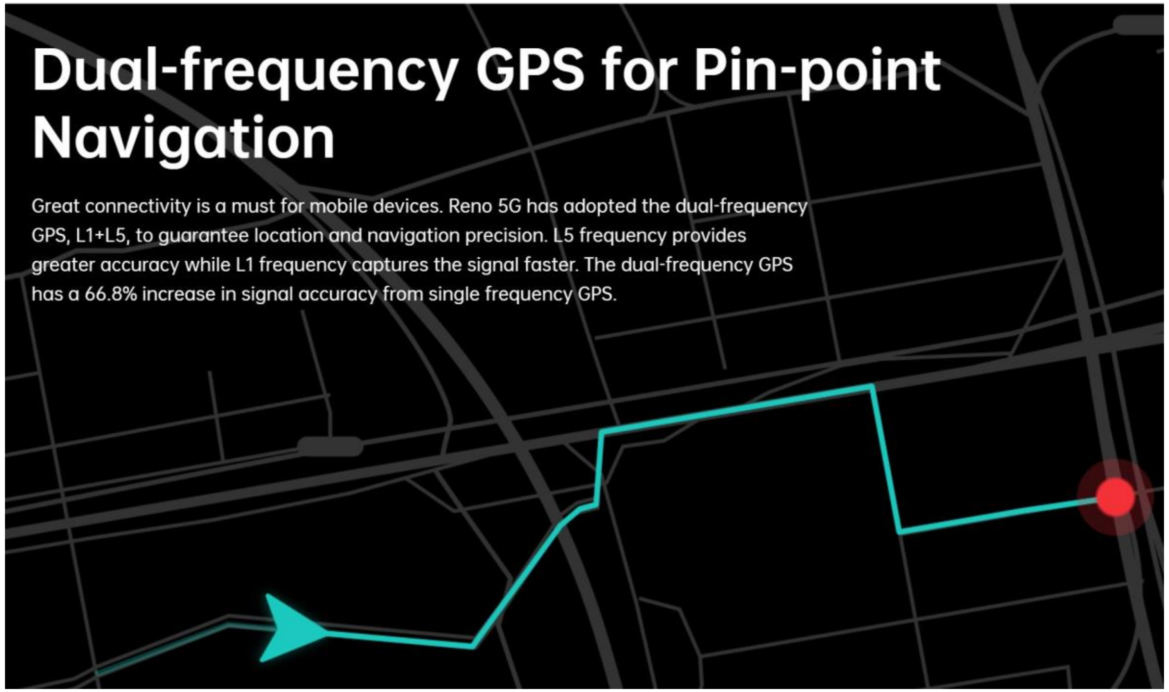


- Single Frequency (S8 Red) vs Partial Dual Frequency (Mi8 Green)
- 28 satellites in solution ~ only 6 with L5 (couldn't choose L5 only).
- Single Point Positioning – no augmentation;

Apps are available to write Rinex Files

Dual Frequency GNSS Phones are now proliferating…

Mi 9



HUAWEI Mate20
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Different Levels of Mass Market Positioning Capability

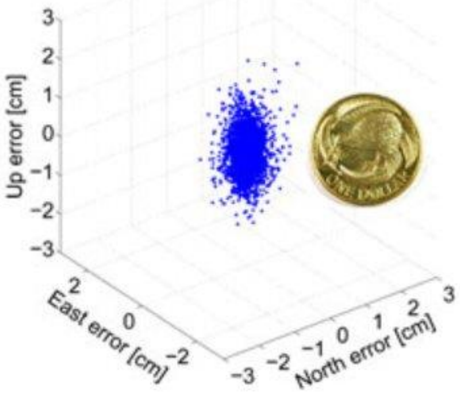
University research uses smartphones for precision GNSS (Source: GPS World Sept, 2018)

- Many smartphone GNSS chips smooth the observations making RTK difficult;
- This work used uBlox chip based receivers which do not do smoothing;
- **These results are using single frequency with an ionosphere-weighted model applied ~ L1-L5 chips will preform even better…**

Also used low cost external antenna

- Android 5.1 system on Quad-core 64bits CPU
- Up to 2cm accuracy L1 GNSS RTK
- Works as Rover or Base Station
- Supports WiFi / BT / 4G LTE multiple data networks
- Supports majority of GIS & Land Survey app
- IP65, 1.2m drop, rugged design for field work

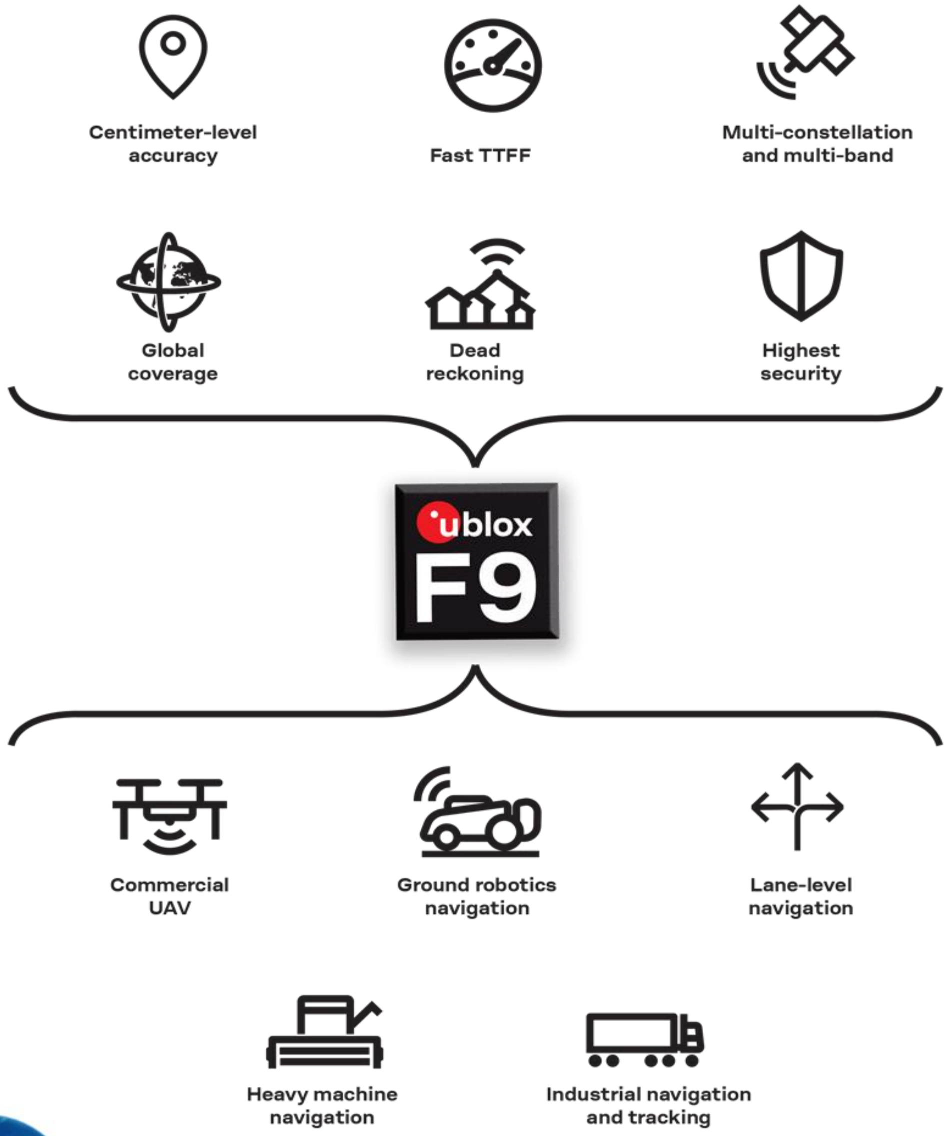
Source: www.datagnss.com/handheld-rtk



Precise centimeter-level positioning on a smartphone during 24 hours in Dunedin, New Zealand. Blue dots show repeatability of one epoch data in comparison to precise benchmark coordinates. The repeatability is more or less the size of a one-dollar New Zealand coin (diameter of 2.3 cm) in all three dimensions. (Image: University of Otago)

Source: Odolinski and Teunisen quoted in GPS World September 2018

Hardware and Services for Emerging Applications



BOSCH
Geo++®
MITSUBISHI ELECTRIC
ublox

Sapcorda

Joint Venture called Sapcorda Services will bring high precision GNSS positioning services to Mass Markets

Source: www.u-blox.com/en/high-precision-positioning, June 2018

Conclusion

Conclusion

- Continued GNSS system developments will lead to more and more capable applications;
- Free and open PPP will create whole new industries where uptake of precise positioning services has been affected by price and/or access ~ analogous to government open data policies;

- Low cost hardware means high precision, high reliability will no longer be “special”, it is becoming mainstream;
- Precise positioning (both range and phase based) through low cost hardware will create opportunities for a next generation of applications;
- Growing ubiquity will demand growing reliability, which will drive continually improving algorithms and models ~ orbits, clocks, biases, ionosphere, troposphere, multipath etc;
- Addressing GNSS vulnerabilities (jamming, spoofing, etc) will continue to grow in importance;
- Mass market users will start to expect comparable positioning capability in GNSS denied environments ~ e.g. indoors etc;
- Relevant Government Agencies and Professionals will need to continue to evolve Supporting Infrastructure ~ both Hard Infrastructure such as CORS and Soft Infrastructure such as Datums and Standards.

IGNSS 2020

Sydney, Australia

5 - 7 February 2020

Thanks for your attention - matt.higgins@qld.gov.au