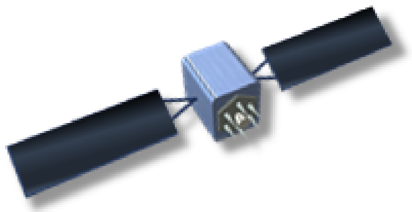

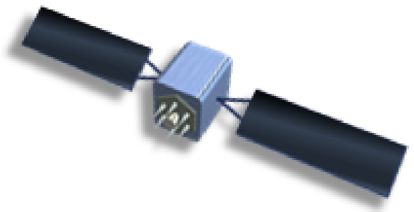

The Continuing Evolution of Precise Positioning from Specialist to Mass Market Applications: Recent Developments and Future Prospects

Matt Higgins

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Member US Space Based Position Navigation and Timing Advisory Board
Member Australian National Positioning Infrastructure Advisory Board
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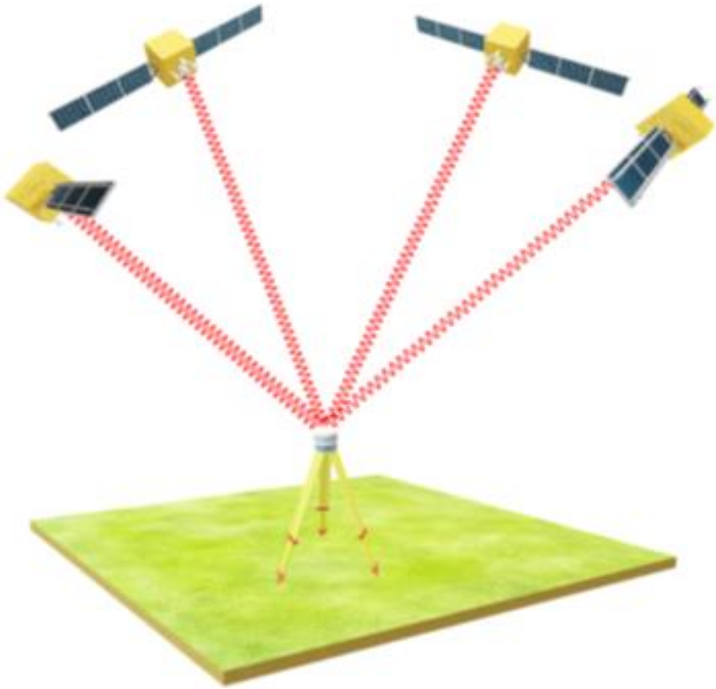
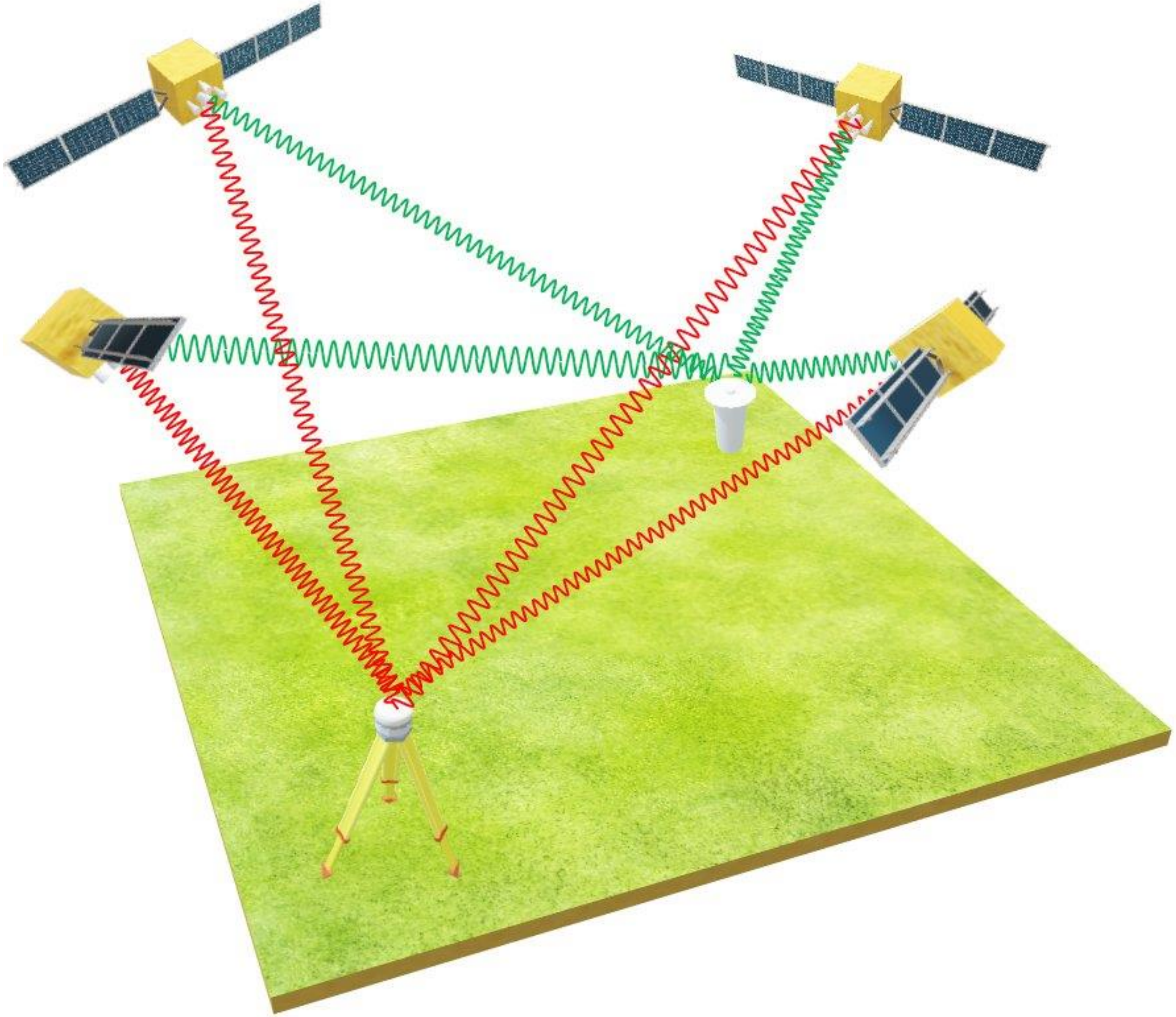
Presentation Outline

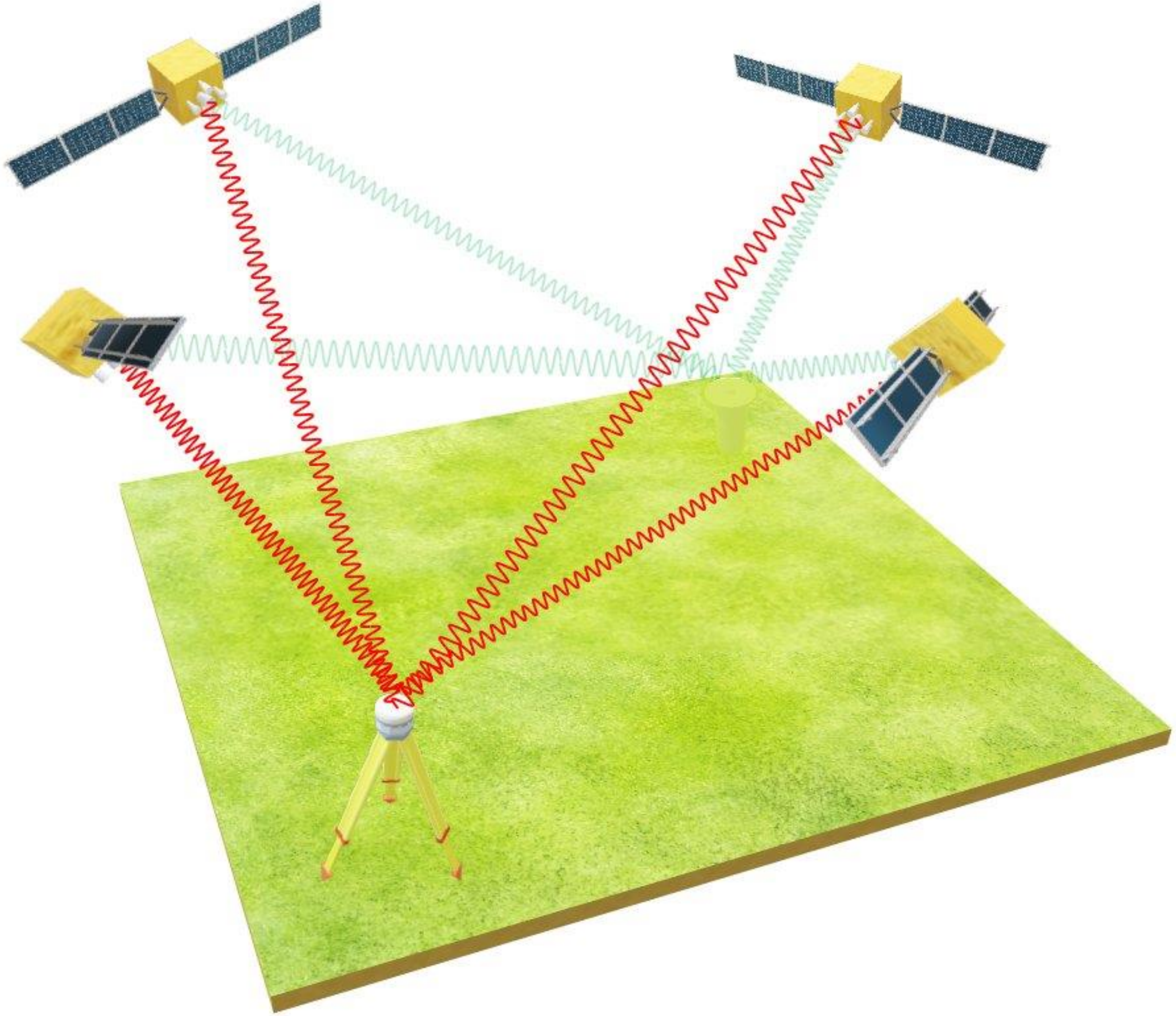
- What is Precise Point Positioning?
- System Provided PPP
- Application Developments
- Some thoughts on Implications



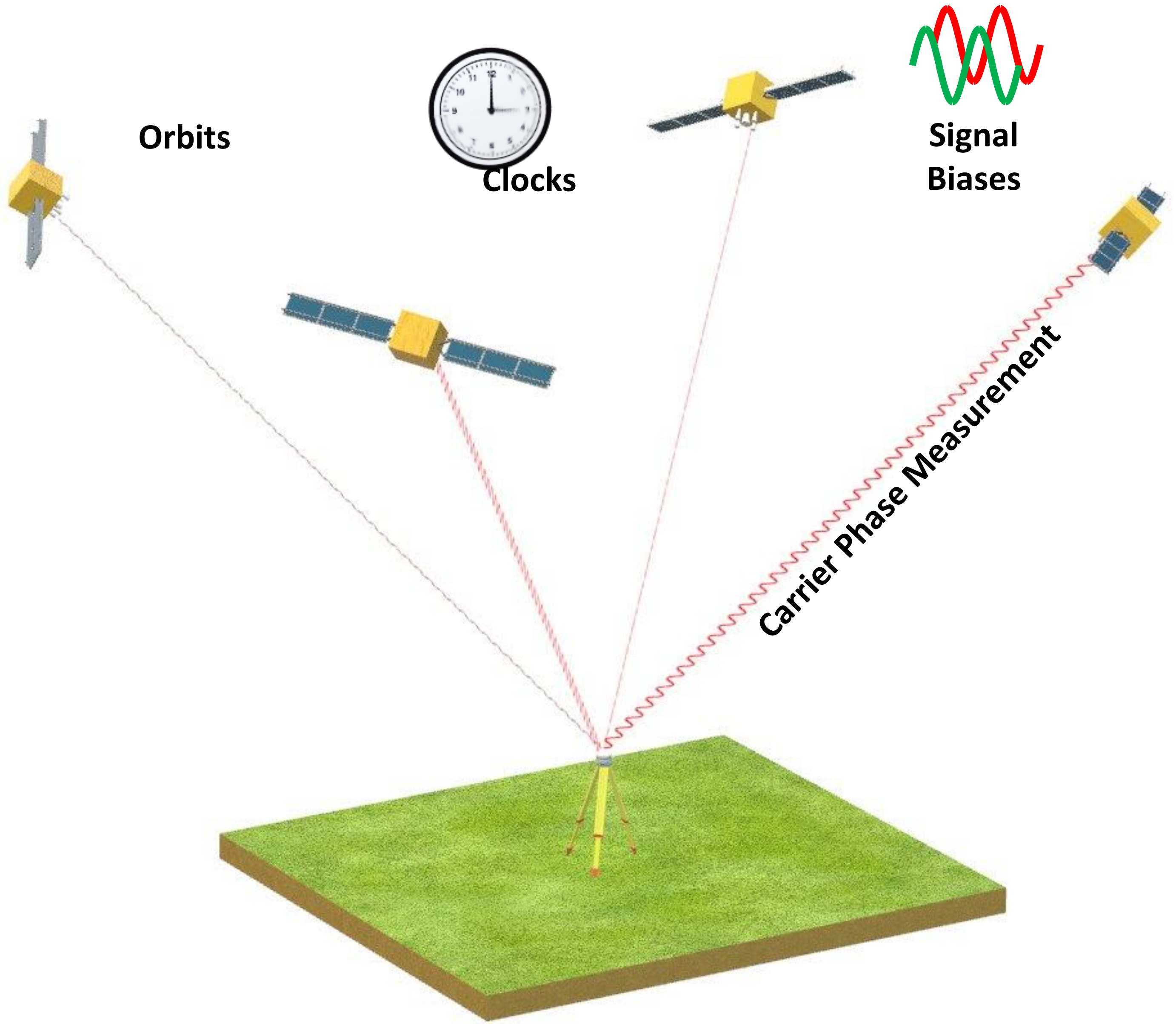
Precise Positioning - from Differential only to Point Positioning as well



Precise Positioning - from Differential only to Point Positioning as well



Precise Point Positioning



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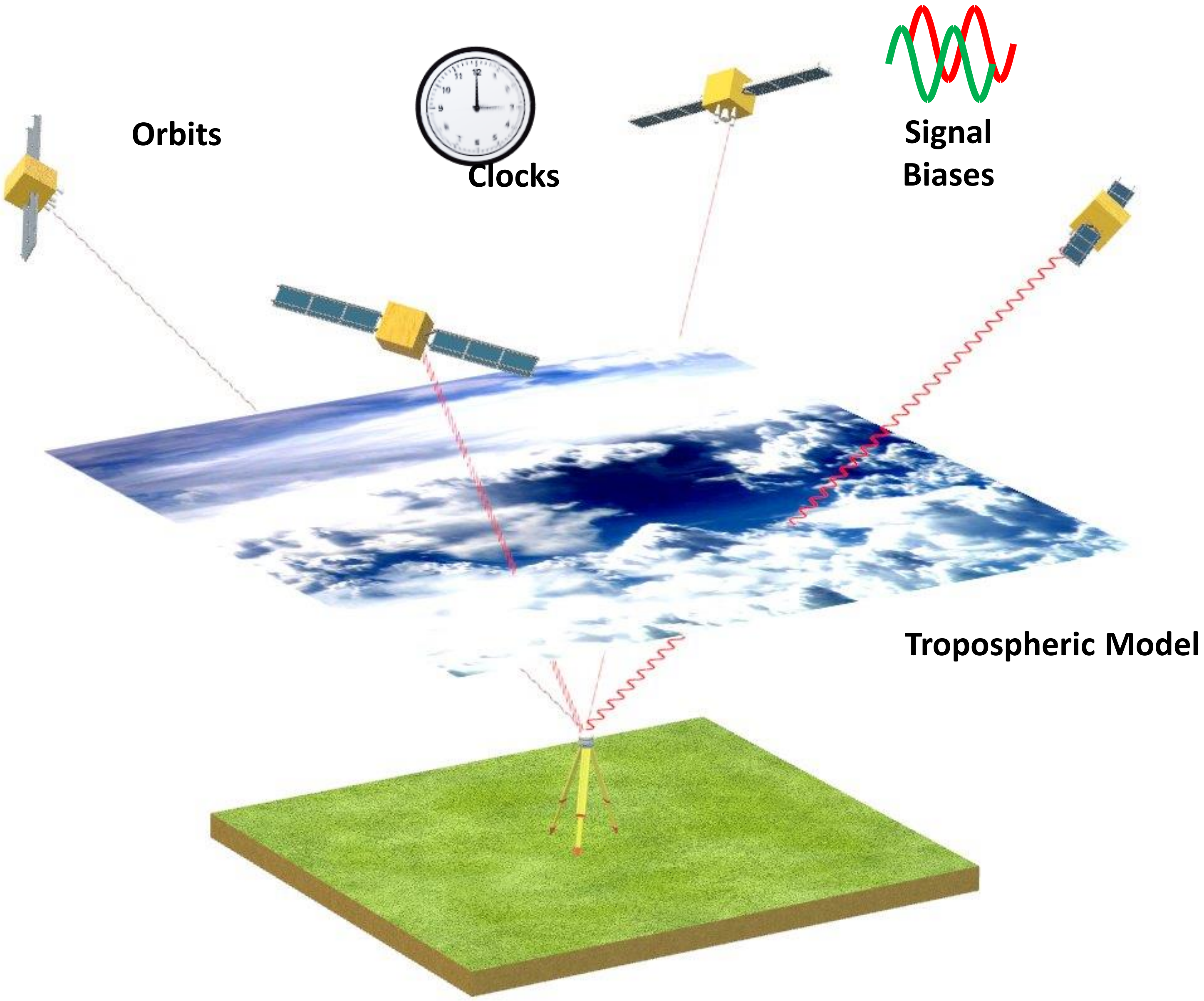
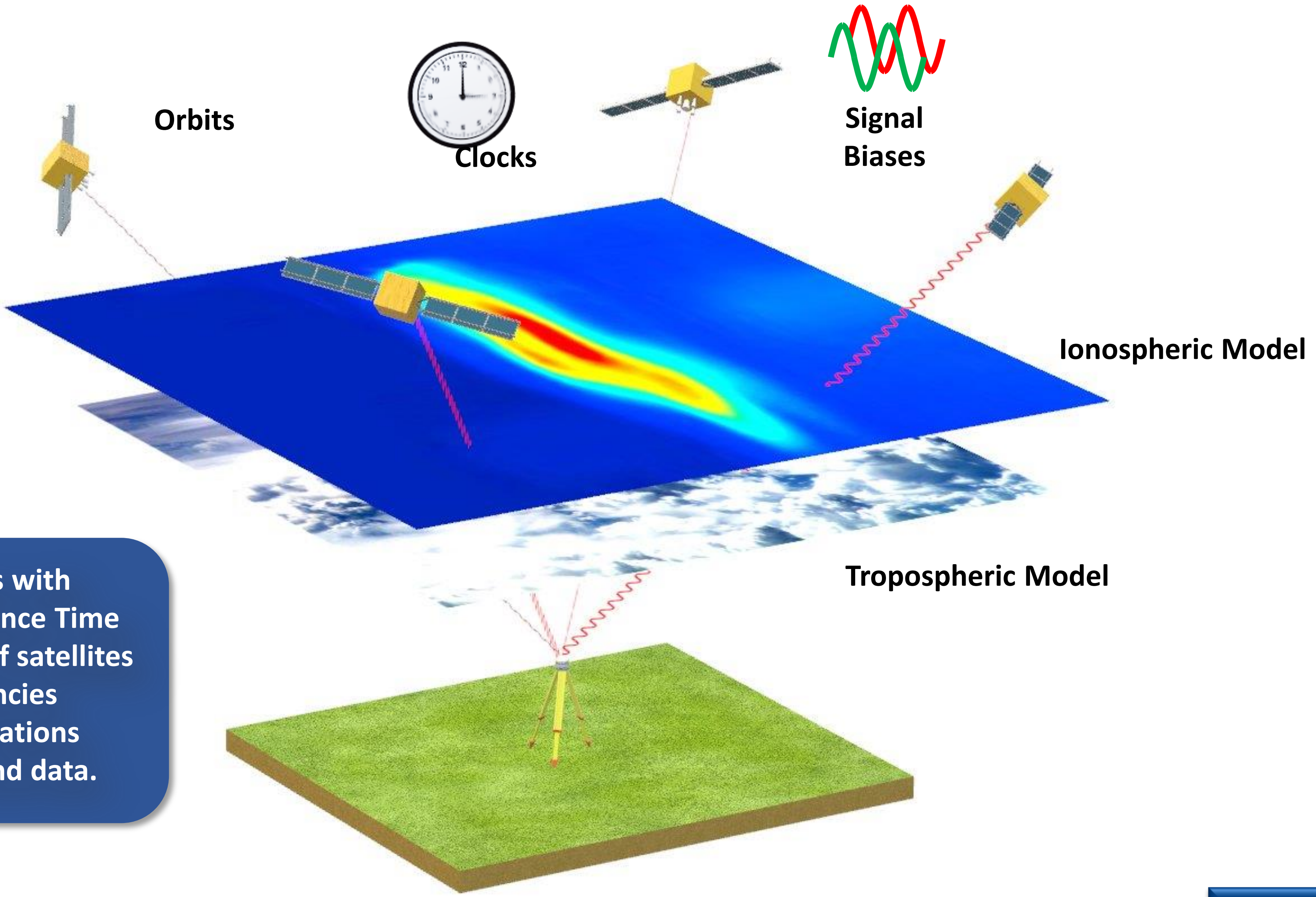
Precise Point Positioning



Precise Point Positioning

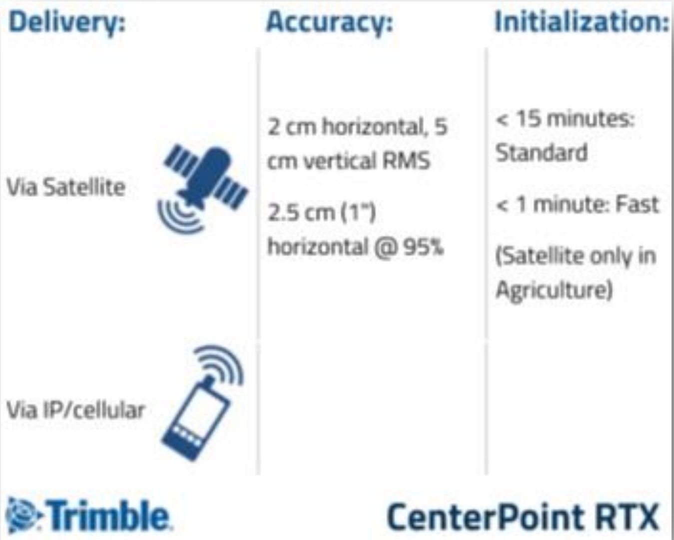


Phase Observations with Accuracy and Convergence Time depending on number of satellites number of frequencies density of ground stations and bandwidth to send data.

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

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

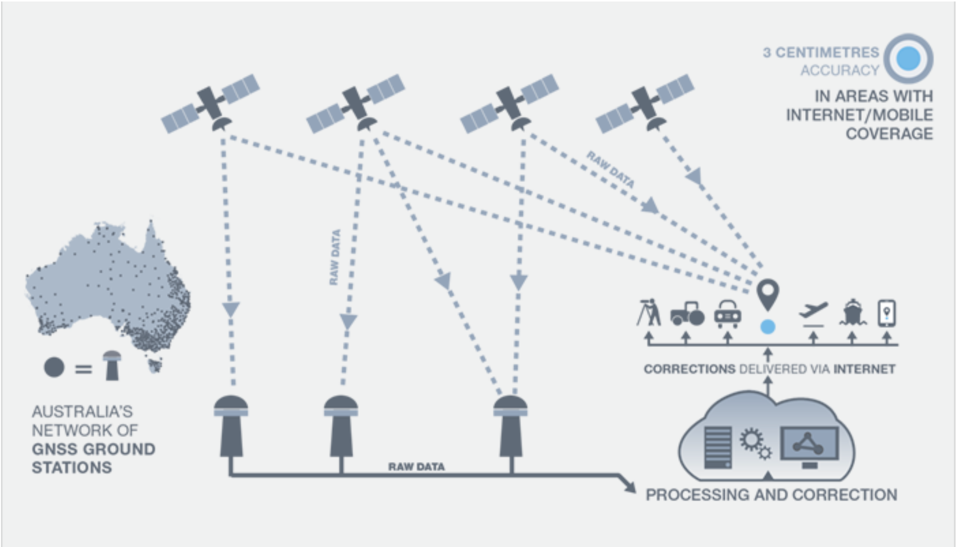
GNSS PPP Service Characteristics

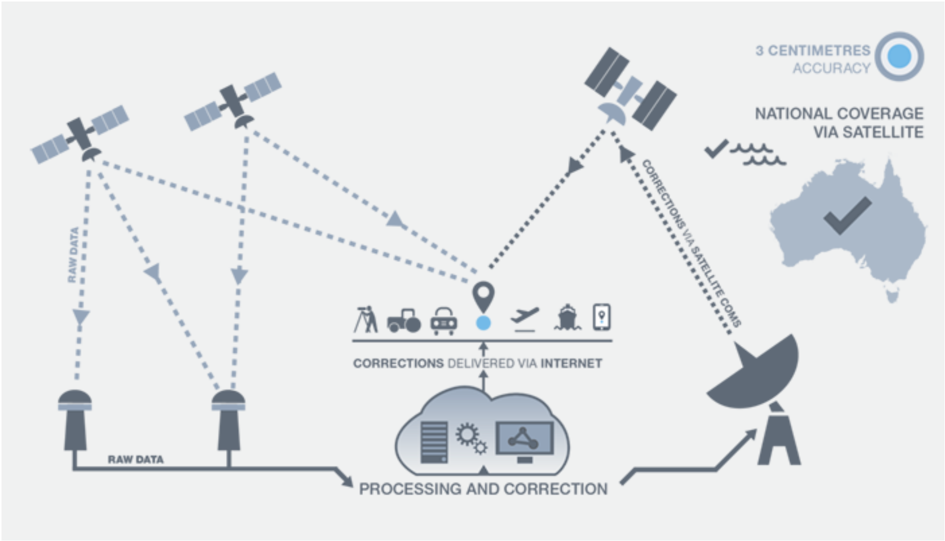
System	Coverage	Format	Supported GNSS/RNSS	Service
Galileo	Global	Open ?	?	?
GLONASS/ SDCM	Global	Commercial ?	?	?
BeiDou-3	Regional	Open ?	?	?
QZSS	Regional	Open	GPS, QZSS, GLO & GAL	PPP-AR SSR-RTK (JAP)
Australia	Regional	Open	GPS & GAL	PPP-float

* 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.***

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.

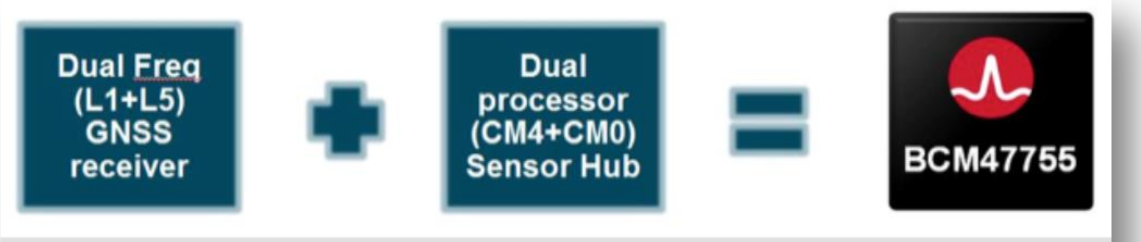
10th Multi GNSS Asia Conference, Melbourne AU - 23-25 October 2018

Application Developments

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



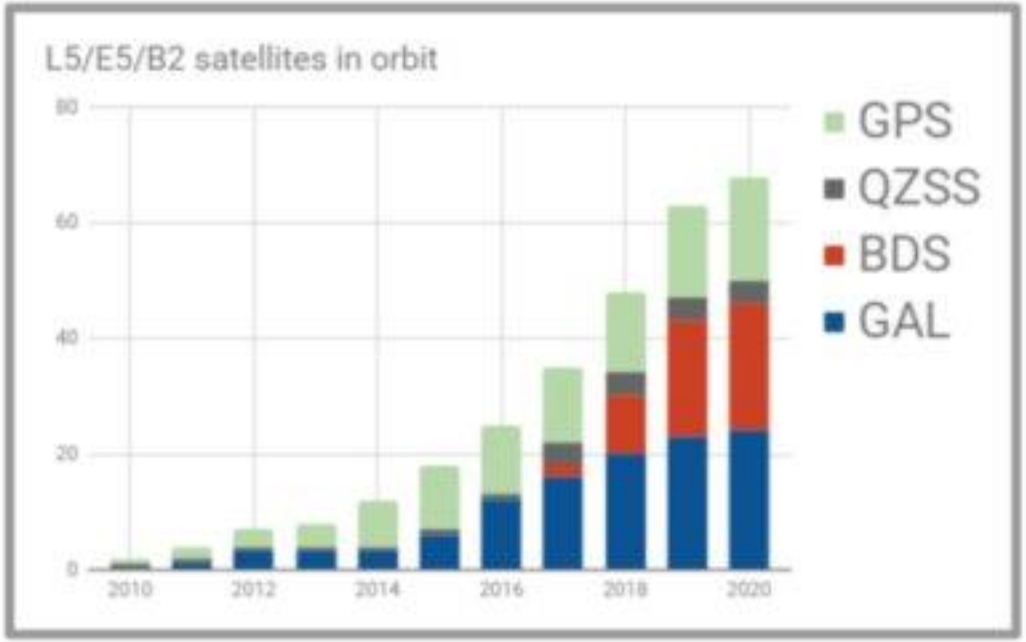
Dual-frequency receiver and dual processor in Broadcom's new L1/L5 chip.

Source: GPS World September 2017

Why is L5 Signal Important?

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?

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

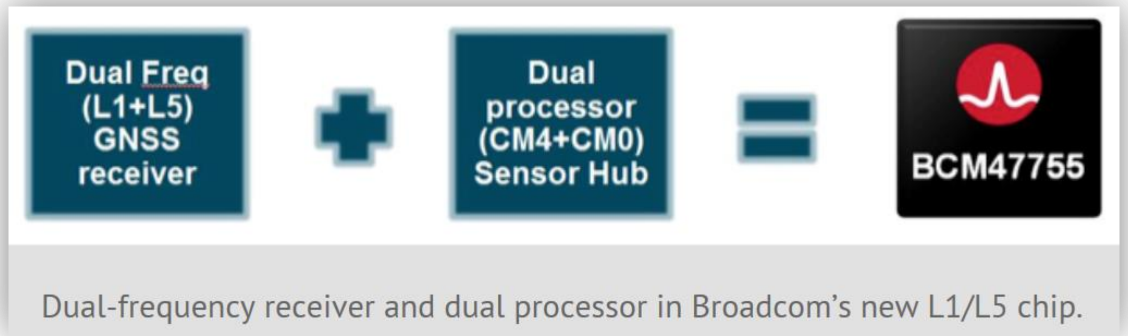
Summary and next steps

- 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

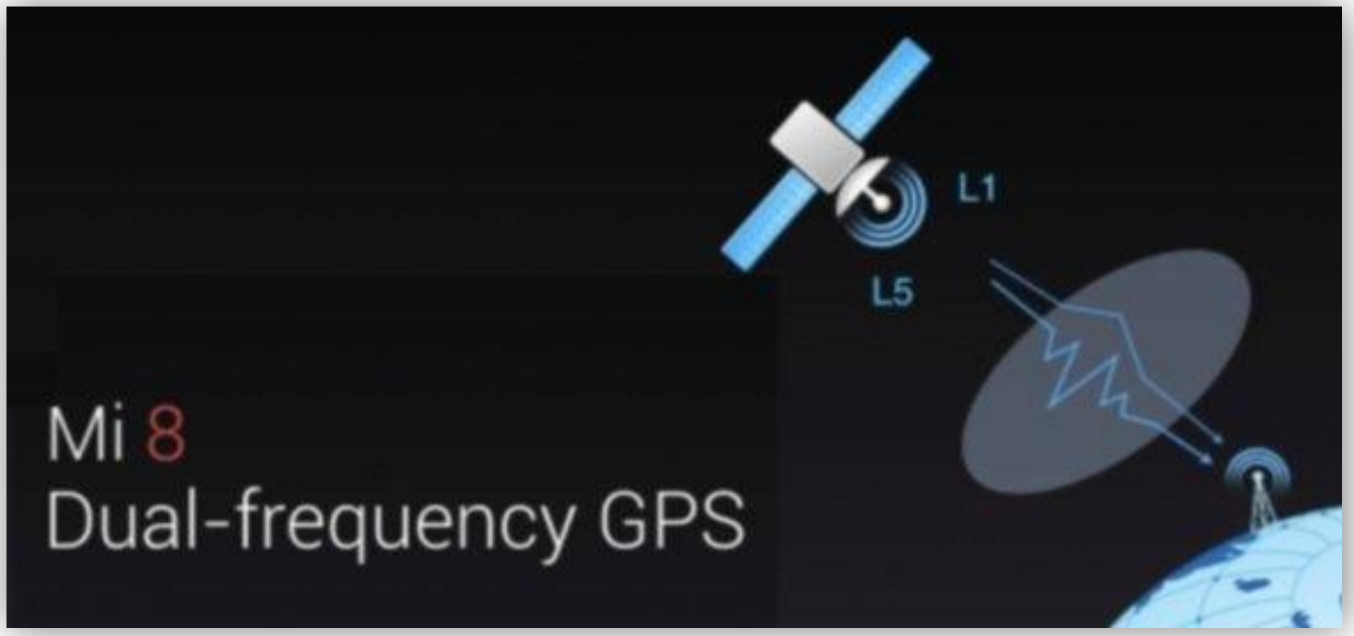
Mass Market Positioning is Evolving Quickly – Is there a phone yet?

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

Source: GPS World May 2017



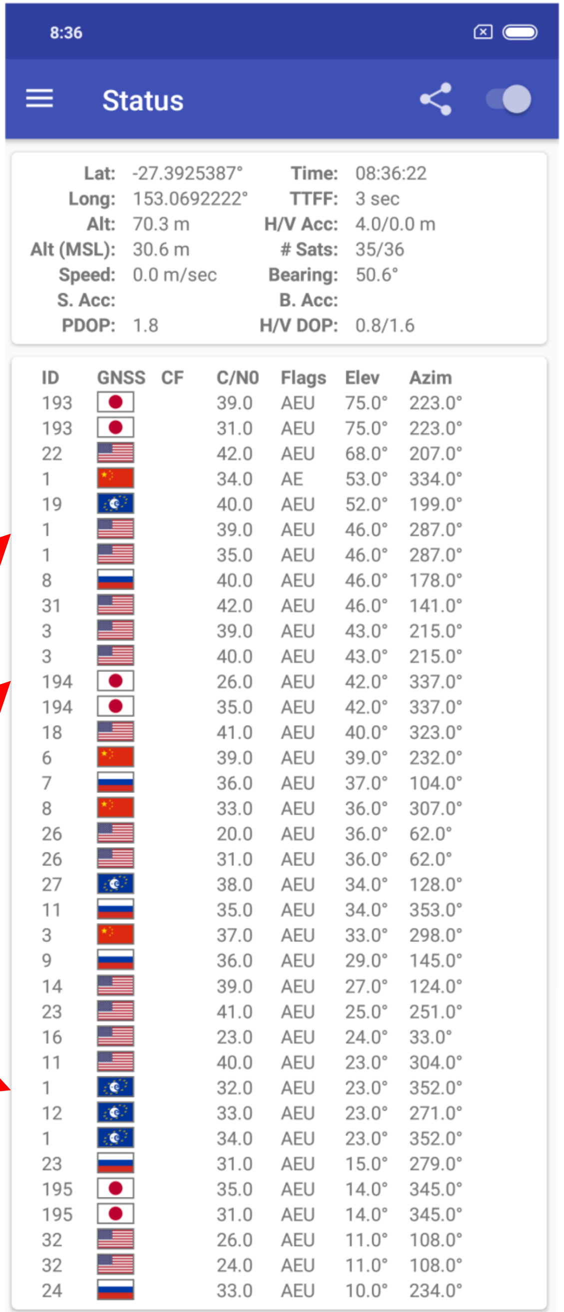
Source: GPS World September 2017



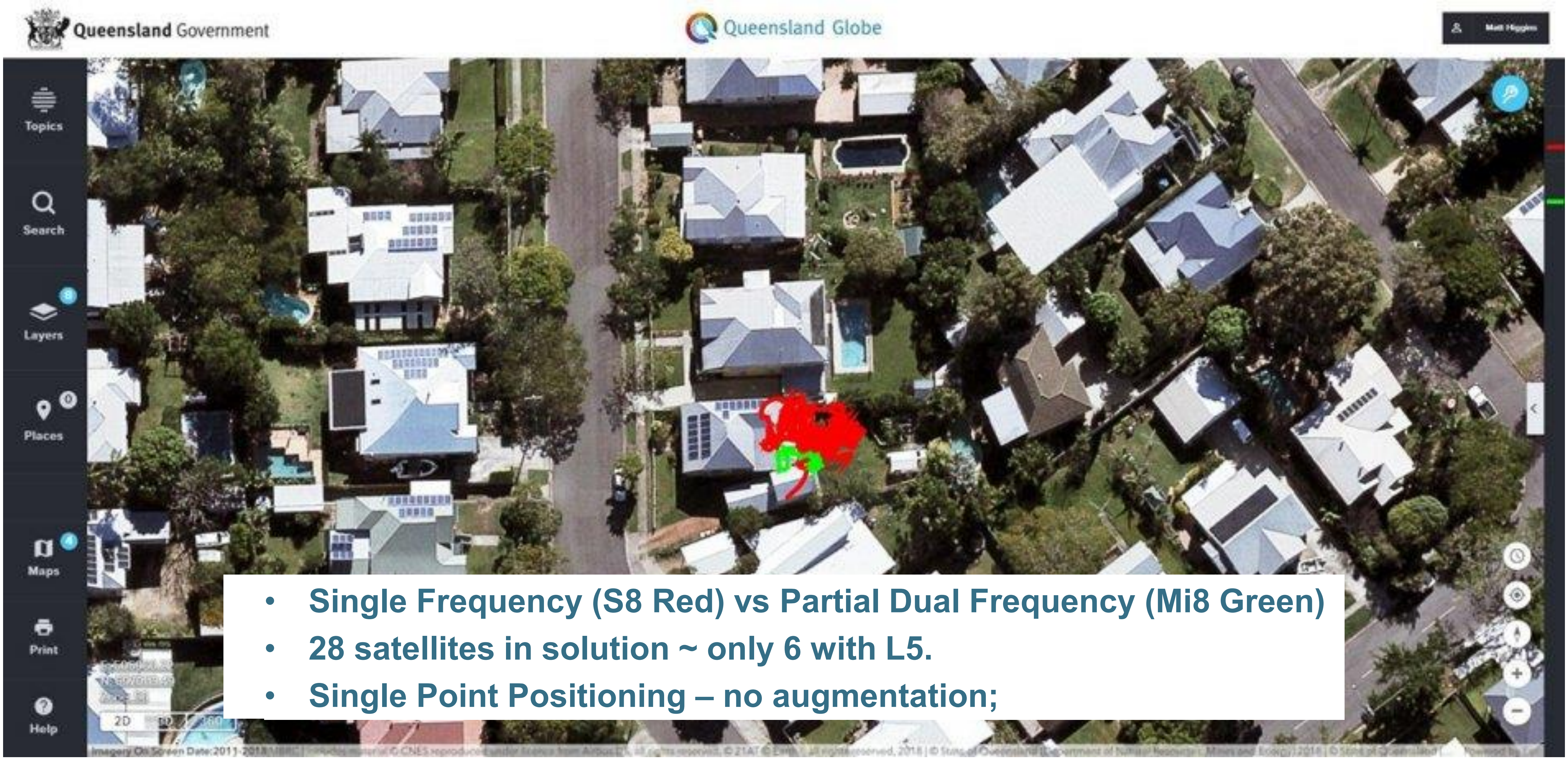
Source: Xiaomi Today, June 2018, www.xiaomitoday.com/gps-mi-8-test/

World's First Dual Frequency GNSS Chip in a SmartPhone

- Tracking 28 Unique Satellites
- Tracking on 36 Channels because 8 satellites broadcasting L1 and L5 so using 2 channels
- GPS Dual Frequency SV 01, 03, 26 and 32
- QZSS Dual Frequency SV 193, 194 and 195
- Galileo Dual Frequency SV 01



ID	GNSS	CF	C/N0	Flags	Elev	Azim
193			39.0	AEU	75.0°	223.0°
193			31.0	AEU	75.0°	223.0°
22			42.0	AEU	68.0°	207.0°
1			34.0	AE	53.0°	334.0°
19			40.0	AEU	52.0°	199.0°
1			39.0	AEU	46.0°	287.0°
1			35.0	AEU	46.0°	287.0°
8			40.0	AEU	46.0°	178.0°
31			42.0	AEU	46.0°	141.0°
3			39.0	AEU	43.0°	215.0°
3			40.0	AEU	43.0°	215.0°
194			26.0	AEU	42.0°	337.0°
194			35.0	AEU	42.0°	337.0°
18			41.0	AEU	40.0°	323.0°
6			39.0	AEU	39.0°	232.0°
7			36.0	AEU	37.0°	104.0°
8			33.0	AEU	36.0°	307.0°
26			20.0	AEU	36.0°	62.0°
26			31.0	AEU	36.0°	62.0°
27			38.0	AEU	34.0°	128.0°
11			35.0	AEU	34.0°	353.0°
3			37.0	AEU	33.0°	298.0°
9			36.0	AEU	29.0°	145.0°
14			39.0	AEU	27.0°	124.0°
23			41.0	AEU	25.0°	251.0°
16			23.0	AEU	24.0°	33.0°
11			40.0	AEU	23.0°	304.0°
1			32.0	AEU	23.0°	352.0°
12			33.0	AEU	23.0°	271.0°
1			34.0	AEU	23.0°	352.0°
23			31.0	AEU	15.0°	279.0°
195			35.0	AEU	14.0°	345.0°
195			31.0	AEU	14.0°	345.0°
32			26.0	AEU	11.0°	108.0°
32			24.0	AEU	11.0°	108.0°
24			33.0	AEU	10.0°	234.0°



- **Single Frequency (S8 Red) vs Partial Dual Frequency (Mi8 Green)**
- **28 satellites in solution ~ only 6 with L5.**
- **Single Point Positioning – no augmentation;**

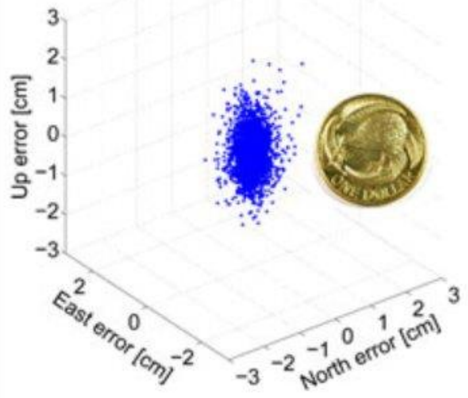
Different Levels of Mass Market Positioning Capability

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;
- Also used low cost external antenna;
- These results are using single frequency with an ionosphere-weighted model applied ~ L1-L5 chips will preform even better…

- 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

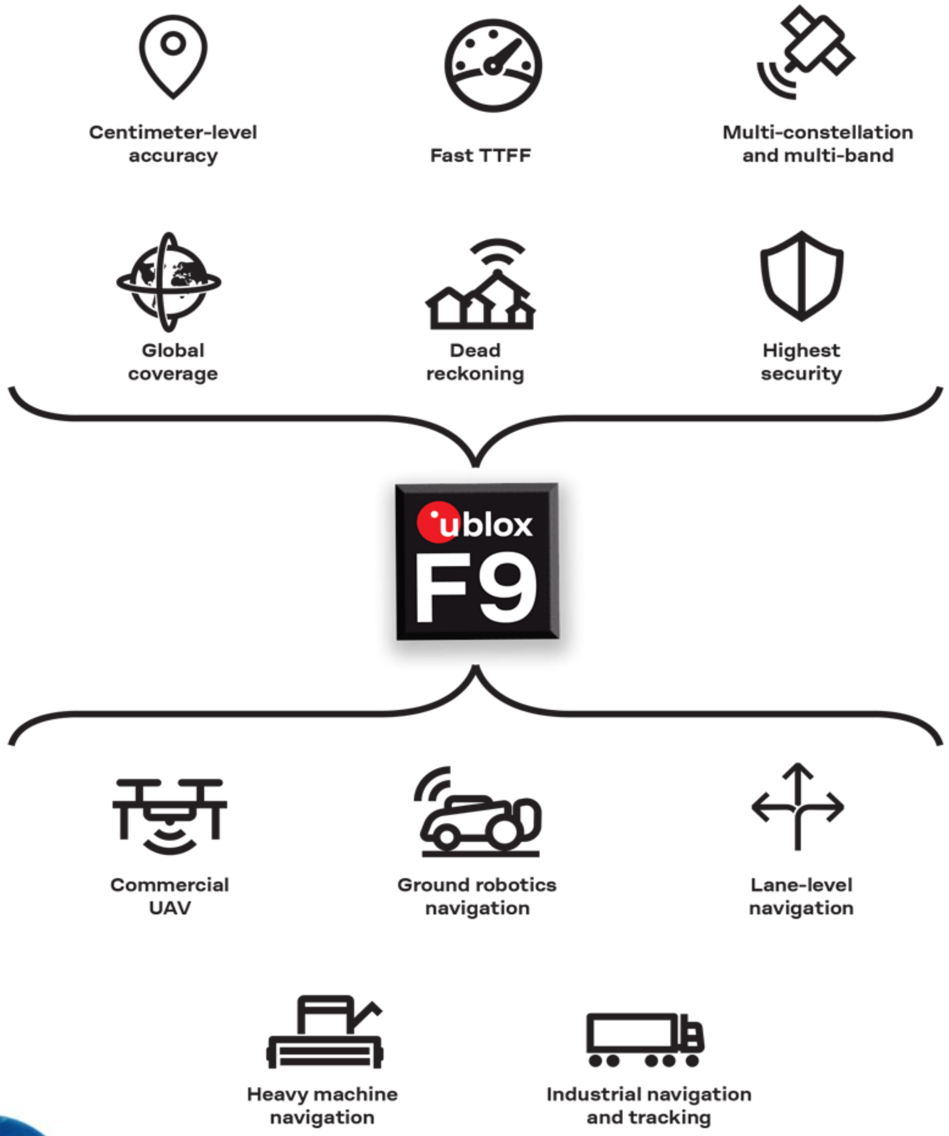
Source: www.datagnss.com/handheld-rtk



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



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

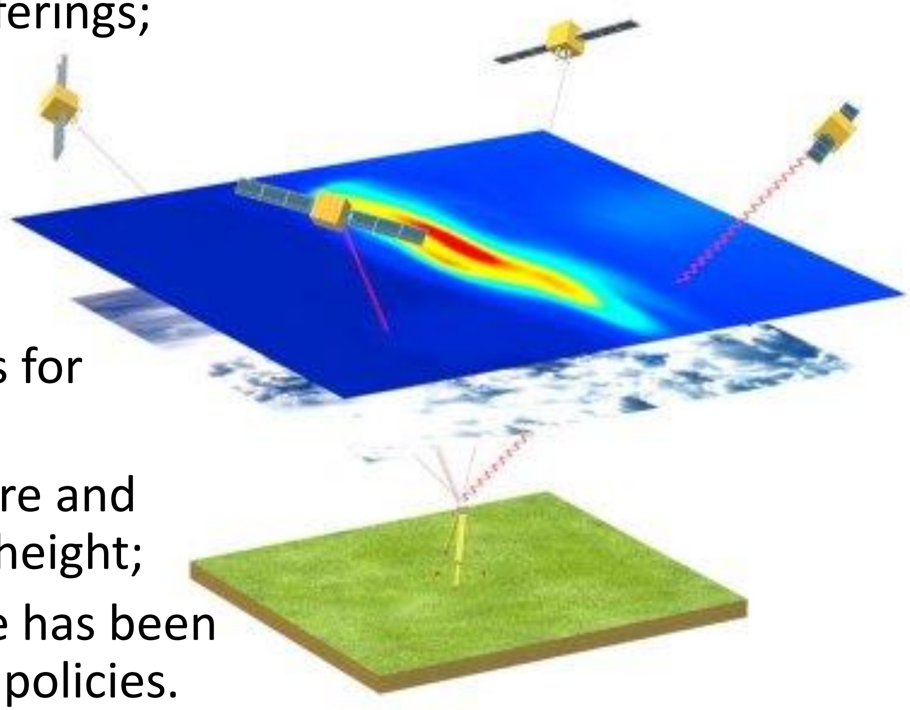
BOSCH
Geo++®
MITSUBISHI ELECTRIC
ublox
Sapcorda

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

Conclusion

Implications of System Provided PPP

- There was discussion at UN ICG on whether enhanced services are the role of System Providers or Industry. So I offer some thoughts from the context that several System Providers are already committed:
  - GPS itself affected many existing commercial players (compasses, sextants, street directories, etc) ~ technological development always does;
  - There are public good applications that require free and open services ~ analogous to the effect of SBAS on commercial DGPS players, who responded by evolving their offerings;
  - Good for developing countries with limited Comms and CORS;
- Also, the impact on Industry is unlikely to be total-destruction:
  - Impact will vary due to different business models ~ for some the service is about increasing market for receivers (or machinery);
  - PPP is only part of an end-to-end service so there will still be roles for industry ~ e.g. the user won't call the system provider for help;
  - PPP can't do everything, already differentiation between decimetre and centimetre services ~ even more pronounced for reliable precise height;
  - Free and open PPP will create whole new industries where uptake has been affected by price or access ~ analogous to government open data policies.



Note that the points on this slide are personal observations only and should not be taken as the position of IGNSS, any other person or organisation.

Implications of Mass Market Precise Positioning

- Low cost hardware means high precision, high reliability is no longer “special”, it is becoming mainstream;
- Precise positioning (both range and phase based) through low cost hardware will create opportunities for 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 will continue to grow in importance;
- Mass market users will start to expect comparable positioning capability in GNSS denied environments.

Note that the points on this slide are personal observations only and should not be taken as the position of IGNSS, any other person or organisation.

IGNSS 2020

Sydney, Australia

5 - 7 February 2020

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