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LSD PQSL Series 2014

Geodetic Survey

10 October 2014

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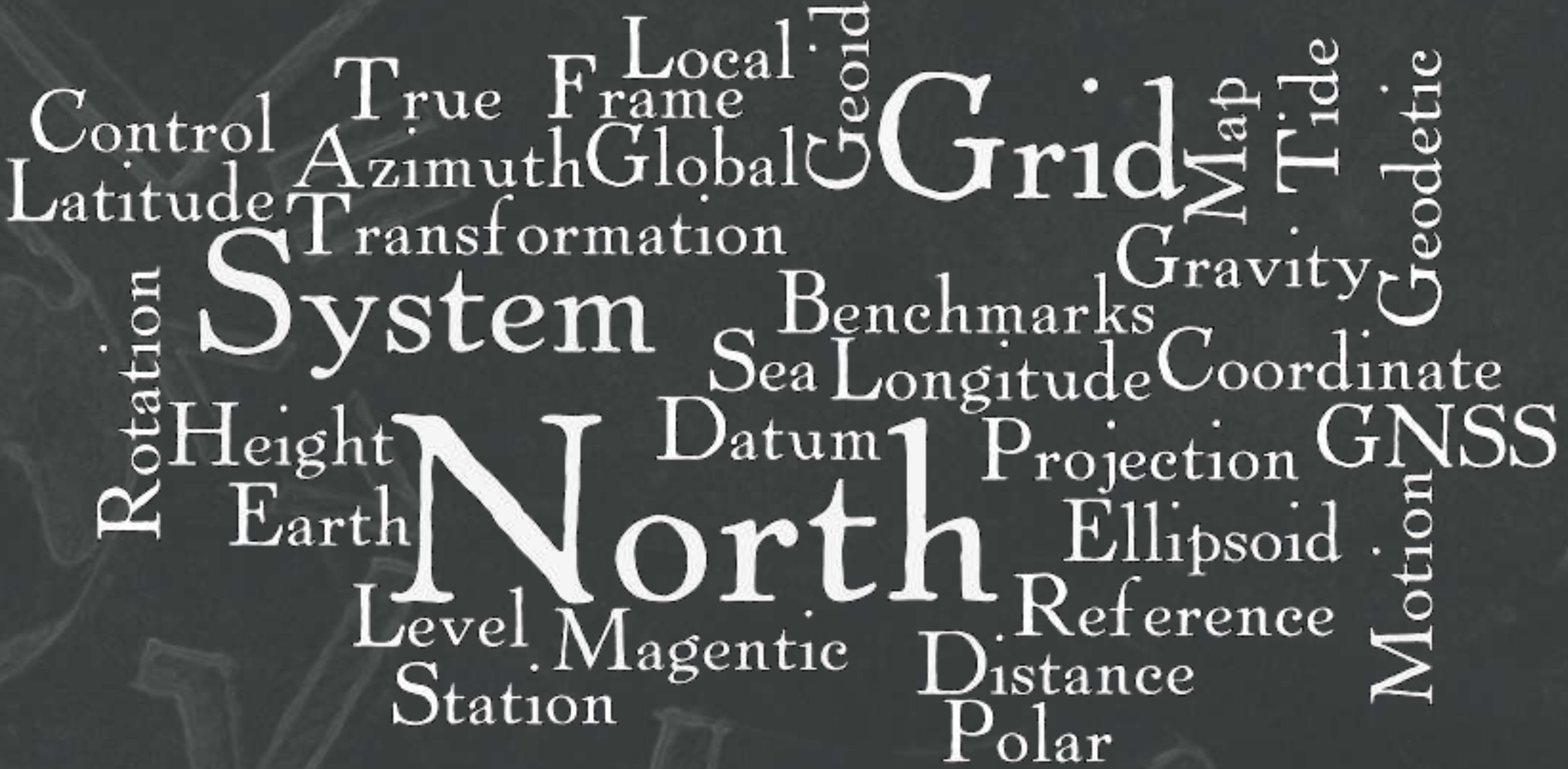
APC Rules & Guide – Appendix I Competence Areas: Geodetic Survey

- 1. Principles of geodesy
- 2. Geodetic datums and coordinate systems
- 3. Global geodetic reference systems
- 4. Geodetic control design and establishment
- 5. Global Navigation Satellite Systems
- 6. Network adjustment and transformation
- 7. High order measurements and corrections

… …


Local
True
Frame
Geoid
Grid
Map
Tide
Geodetic
Control
Azimuth
Global
Latitude
Transformation
Gravity
System
Benchmarks
Rotation
Sea
Longitude
Coordinate
Height
Datum
Projection
GNSS
Earth
North
Ellipsoid
Motion
Reference
Level
Magentic
Distance
Station
Polar

1. Principles of Geodesy

Geodesy

γεωδαισία

(**Greek:** geōdaisiā)

- **Geo-**: "Geō-" – Earth
- **-desy**: "- daiesthai" – to divide

Principles of Geodesy

- What is "Geodesy"?
- Wikipedia:
  - *"Geodesy (/dʒiːˈɒdɨsi/) — also known as geodetics or geodetics engineering — a branch of applied mathematics and earth sciences, is the scientific discipline that deals with the measurement and representation of the Earth, including its gravitational field, in a three-dimensional time-varying space. Geodesists also study geodynamical phenomena such as crustal motion, tides, and polar motion. For this they design global and national control networks, using space and terrestrial techniques while relying on datums and coordinate systems."*
  - http://en.wikipedia.org/wiki/Geodesy (Accessed on 12 September 2014)

Principles of Geodesy

- Freidrich Robert Helmert (1880)
  - *"Geodesy is the science of the measurement and mapping of the Earth's surface"*
    - http://www.ancient-wisdom.co.uk/geodesy.htm

- United Kingdom – Ordnance Survey
  - *"The science of geodesy, on which all mapping and navigation is based, aims firstly to determine the shape and size of the simplified 'figure of the Earth' and goes on to determine the location of the features of the Earth's land surface"*
    - http://www.ordnancesurvey.co.uk/docs/support/guide-coordinate-systems-great-britain.pdf (Page 6)

Principles of Geodesy

- United States – National Oceanic and Atmospheric Administration (NOAA)
  - National Ocean Service: *"Geodesy is the science of accurately measuring and understanding the Earth's geometric shape, orientation in space, and gravity field."*
    - http://oceanservice.noaa.gov/facts/geodesy.html
  - National Geodetic Survey: *"Geodesy is the science concerned with determining the size and shape of the Earth and the location of points upon its surface."*
    - http://www.ngs.noaa.gov/INFO/WhatWeDo.shtml

Principles of Geodesy

- Prof Chris RIZOS, President, International Association of Geodesy (IAG)
  - *“Geodesy now defined in terms of the following capabilities:*
    - *Determination of precise global, regional & local 3-D (static or kinematic) positions on or above the Earth’s (solid or aqueous) surface*
    - *Mapping of land, sea & ice surface geometry*
    - *Determination of the Earth’s (time & spatially) variable gravity field*
    - *Measurement of dynamical (4-D) phenomena:*
      - *Solid Earth (incl. cryosphere): surface deformation, crustal motion, GIA, polar motion, earth rotation, tides, water cycle, mass transport, etc.*
      - *Atmosphere: refractive index, T/P/H profiles, TEC, circulation, etc.*
      - *Ocean: sea level, sea state, circulation, etc. “*

Looking Down a Well: A Brief History of Geodesy

Principles of Geodesy

- United States – National Aeronautics and Space Administration (NASA)
  - NASA/Goddard Space Flight Center
    - https://www.youtube.com/watch?v=_Cj1vgmXr5M
    - http://svs.gsfc.nasa.gov/vis/a010000/a010900/a010910/
  - *"Geodesy deals with the measurement and representation of the Earth"*
  - *"It's the science of:-*
    - *Where things are*
    - *Where they have been, and*
    - *Where they are going"*

Geodesy: The Science about the Earth

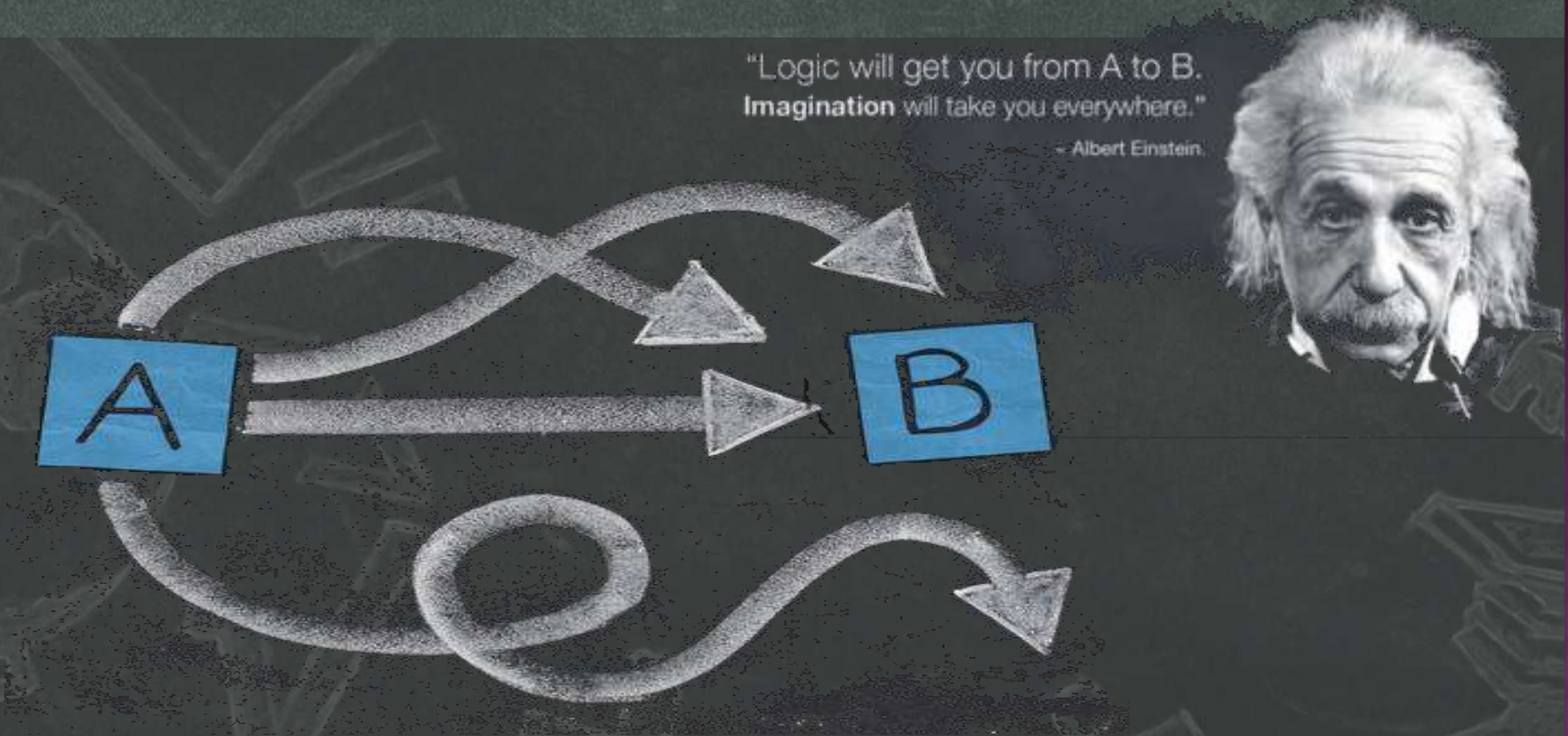
Science

- Measure
- Map
- Represent
- Determine
- Understand

Earth

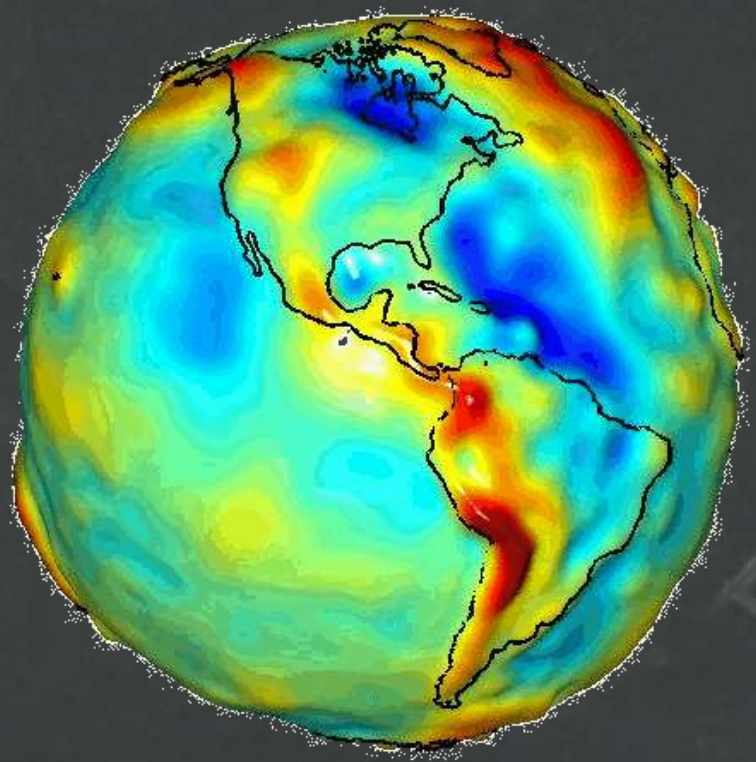
- Surface
- Geometry / Size & Shape
- Orientation / Direction
- Location / Position
- Gravity
- Dynamical phenomena
- …etc.

Geodesy: Get you from A to B



Geodesy: The Irregular & Dynamic Earth

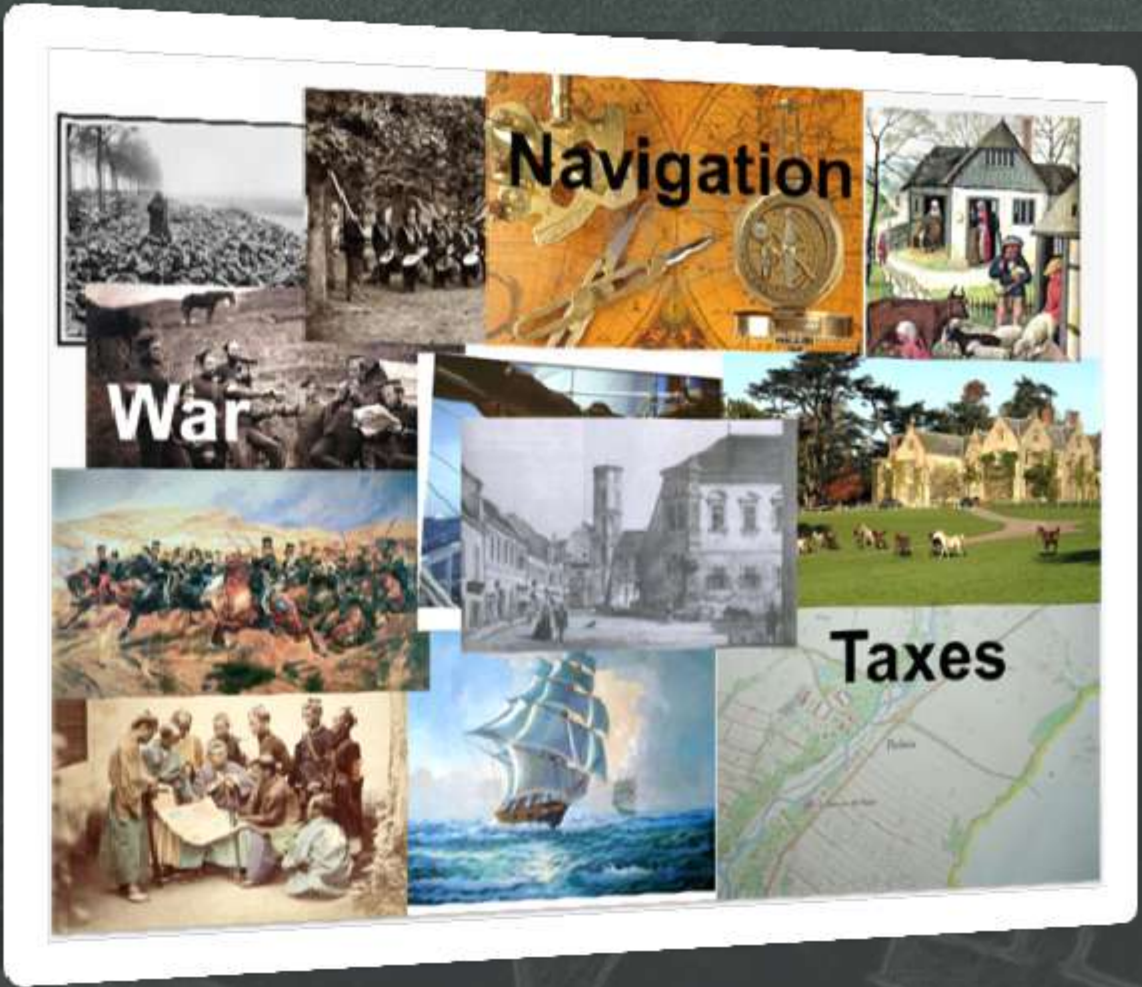
- Irregular Earth
  - Not a flat surface
  - Not a perfect sphere
- Dynamic Earth
  - Moving around the Sun in Space
  - Tectonic movements
  - Center & Rotation Axis



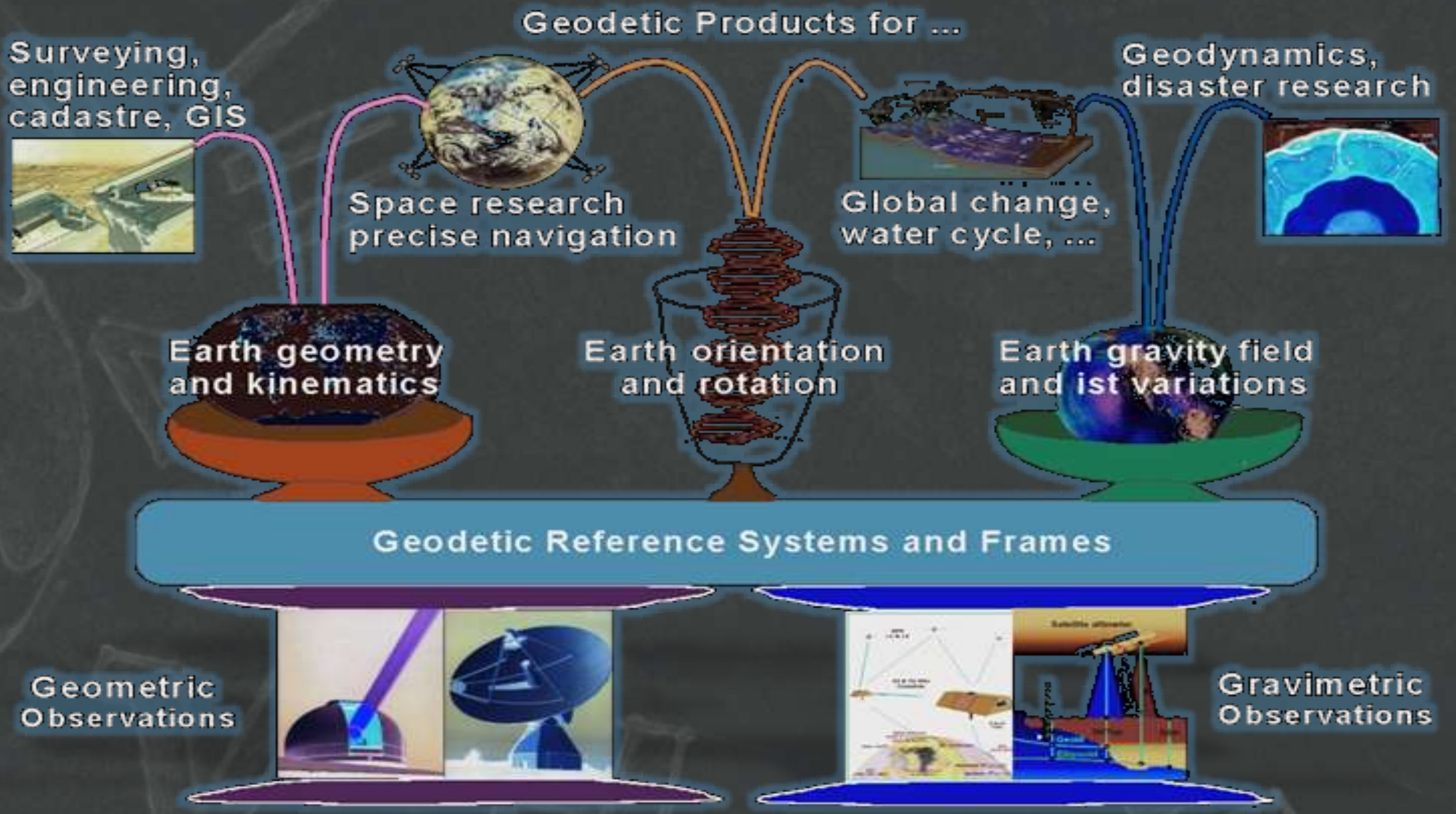
Global gravity model generated from GRACE measurements

(Source: http://ccar.colorado.edu/asen5050/projects/projects_2013/Chong_Joshua/content.html)

Geodesy: Applications



Geodesy: Reference Systems & Frames



2. Geodetic Datums and Coordinate Systems

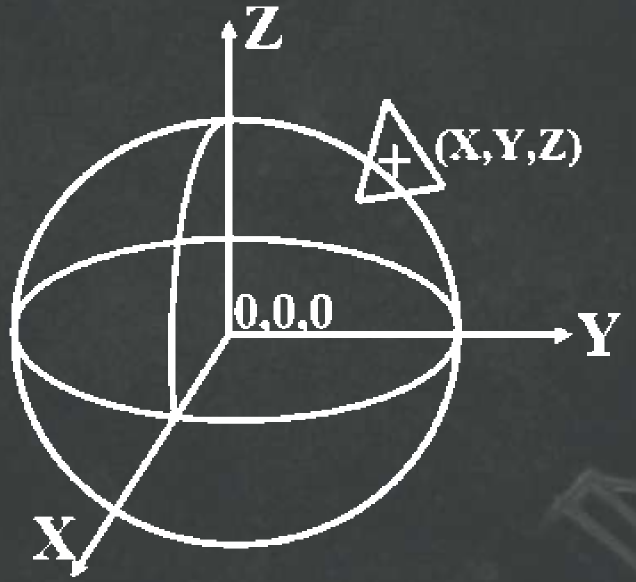
- How to present a "Position"?
- Coordinate Systems:
  - 1D (Line)
    - Chainage
  - 2D (Plane)
    - Chainage + Offset
    - Bearing + Distance
    - Grid (Northing, Easting)
    - Latitude and Longitude
  - 3D (Space)
    - 2D Coordinates + Height
    - Cartesian Coordinates (X, Y, Z)
    - Spherical Coordinates (Latitude, Longitude, Height above Ellipsoid)
- Require a suitable origin with respect to which the coordinates are stated

Geodetic Datum

- Geodetic Datum: "*A set of conventions necessary to define the spatial relationship of the coordinate system to the Earth*" (Ordnance Survey)
- Modern term: "Terrestrial Reference System" (TRS)
- The Earth as defined by
  - Origin Point & Orientation of the Axis
  - Reference geometric representation of the Earth
  - At a particular epoch

Geodetic Datum

- Origin: Geocentric (at the "Center" of the Earth)
- Orientation of Axis
  - Right-handed Cartesian coordinate system
  - Z-Axis to "North Pole" at a particular epoch
  - X-Axis to pass through the "Prime Meridian"
- Reference geometric representation of the Earth
  - Rotate about Z-Axis
  - Best-fitting Ellipsoid to the physical surface
  - Size / Shape: Semi-major & Semi-minor axis
- Scale
  - Unit: metre (SI Unit)
  - Uniform along 3 Axis



Earth Fixed/Centred Reference Frame

Geodetic Datum Realization

- Datum parameters could not be directly observed
- Datum Realized by observations made at reference point(s) on Earth
- Modern term: “Terrestrial Reference Frame” (TRF)
- Datum (TRS) vs Datum Realization (TRF)
  - Datum (TRS): The ideal definition
  - Datum Realization (TRF): Subject to error in measurements
- “Datum” is often commonly used for both TRS & TRF
- Simple case:
  - Datum: Local height datum
  - Datum Realization: a bench mark with the measured height value

Geodetic Datum Realization

- Before Space Age
  - Localized Realization of Geodetic Datum
    - e.g. Hong Kong 1980 Geodetic Datum
  - Realized by initial point(s) on Earth’s surface
  - Best-fitting localized geometric representation
- Development of Space Geodesy
  - Global Reference System
    - e.g. World Geodetic System 84 (WGS 84)
    - International Terrestrial Reference Frame (ITRF)
  - A global network of Reference Stations
  - Globally applicable and Geocentric

Hong Kong Geodetic Datum

- Developments of Hong Kong Geodetic Datum
  - Hong Kong Geodetic Datum (Before 1963)
  - Hong Kong 1963 Geodetic Datum
  - Hong Kong 1980 Geodetic Datum

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Hong Kong Geodetic Datum

- Origin
  - Trig. "zero" at Hong Kong Observatory
  - + other associated trigonometric stations

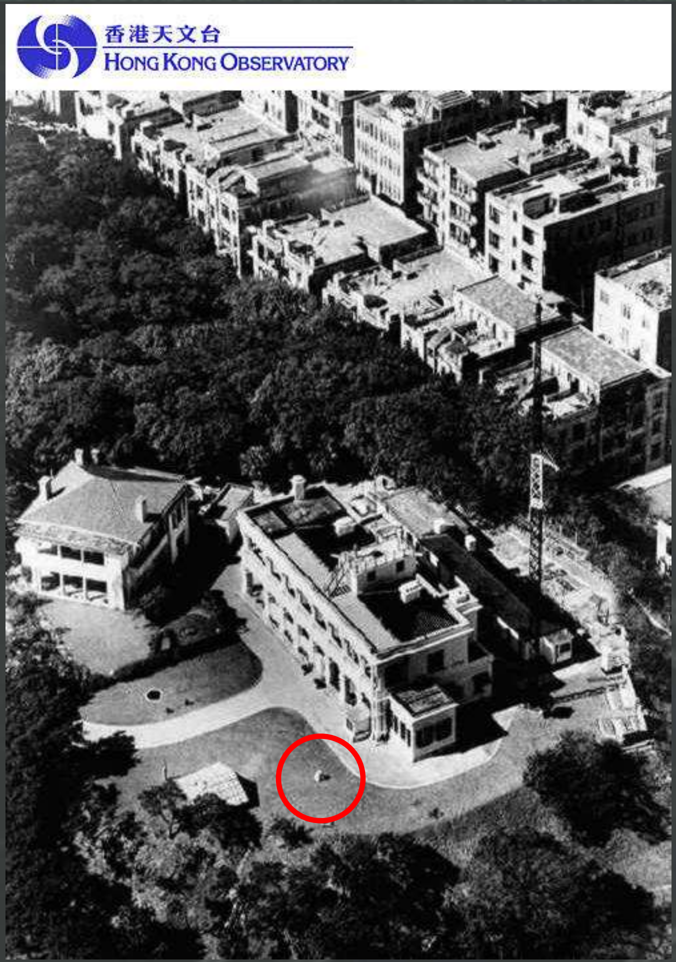
Synopsis of Bearings and Distances at each Station (in numerical order).

SYNOPSIS.

At Main Station No. 0.
ROYAL OBSERVATORY TRIG.
Cassini Plane Rectangular Co-ordinates in feet.
Convergency 00′—09″—from Bearing gives Azimuth.
Ground height at Station 108.3 feet above P.D.H.K.

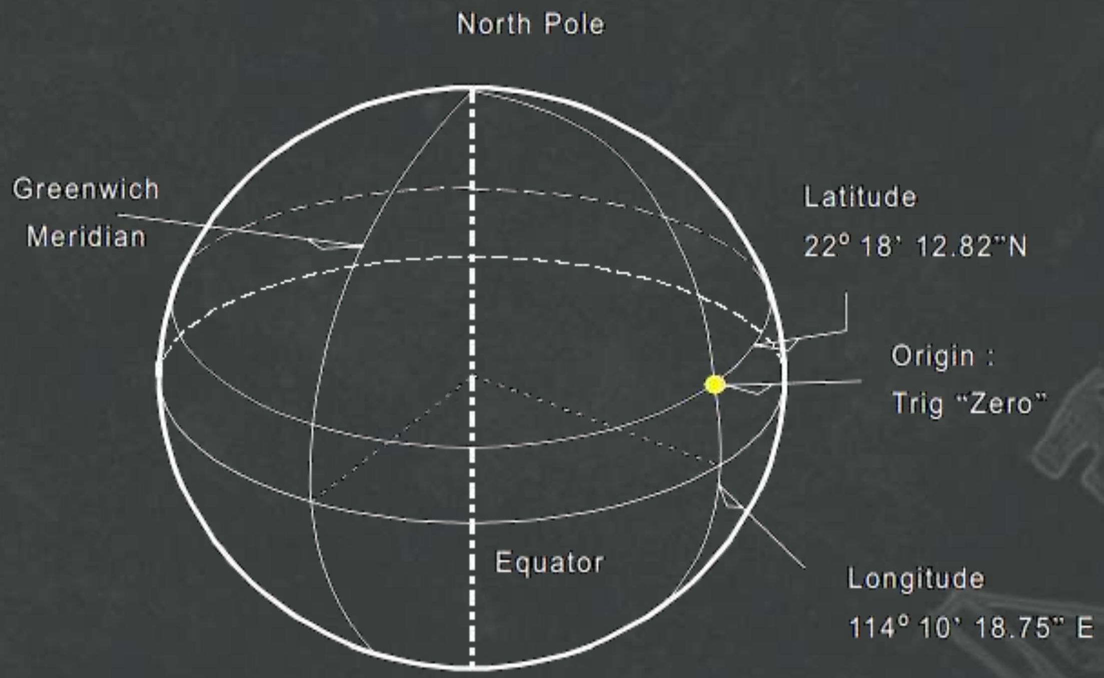
Lat. 22°—18′—12.82″ N.
Long. 114°—10′—18.75″ E.
9452.24 N: 9773.21 E.

No.	Station observed	Bearing °	′	″	Log. Diste. Feet
2	Partridge Hill	35	56	29	3.5851010
4	Tate's Cairn	35	58	29	4.3980414
3	Channel Rock	83	50	09½	4.1374778
JL	Jardine's Lookout	147	57	21	4.1851407
32	Mount Nicholson	165	50	48½	4.2027540
1	Victoria Peak	225	58	16	4.1332985



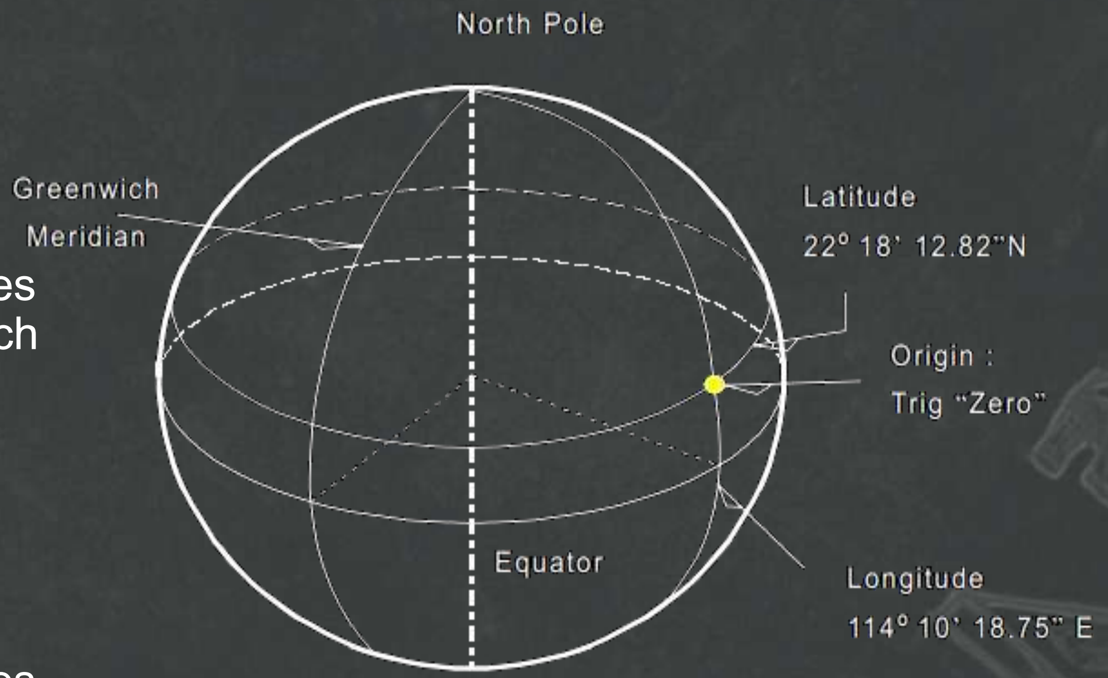
Hong Kong Geodetic Datum

- Origin
  - Latitude of Trig. “zero”
  - 1882 Astronomical observations
    - Major H.S. PALMER
    - Observed value: 22°18’11.89”N (+/- 0.19”)
  - Adopted value: 22°18’12.82”N



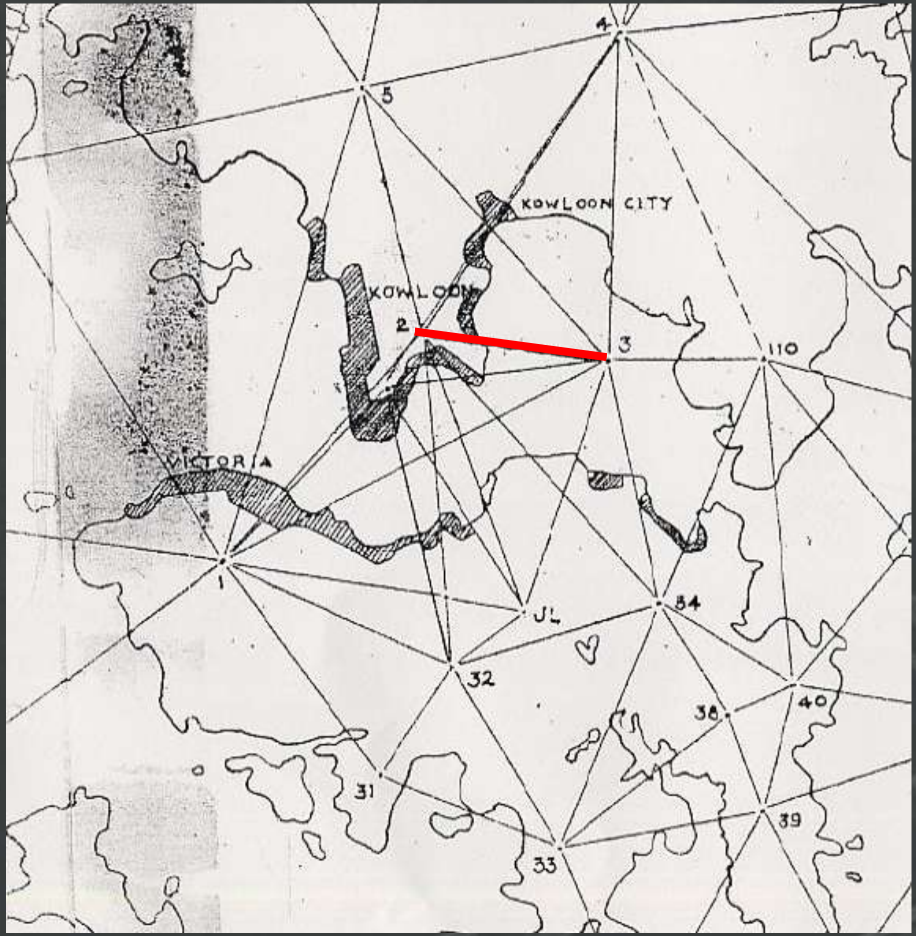
Hong Kong Geodetic Datum

- Origin
  - Longitude of Trig. “zero”
  - 1885: Lunar observations
    - Observed value: 7 hours 36 minutes 41.86 seconds East from Greenwich
  - 114°10’27.9”E
  - Sep to Nov 1924: 13 simultaneous observations of Bordeaux time signals made at Greenwich and Hong Kong
    - Observed value: 7 hours 36 minutes 41.25 seconds East from Greenwich
  - Adopted value: 114°10’18.75”E



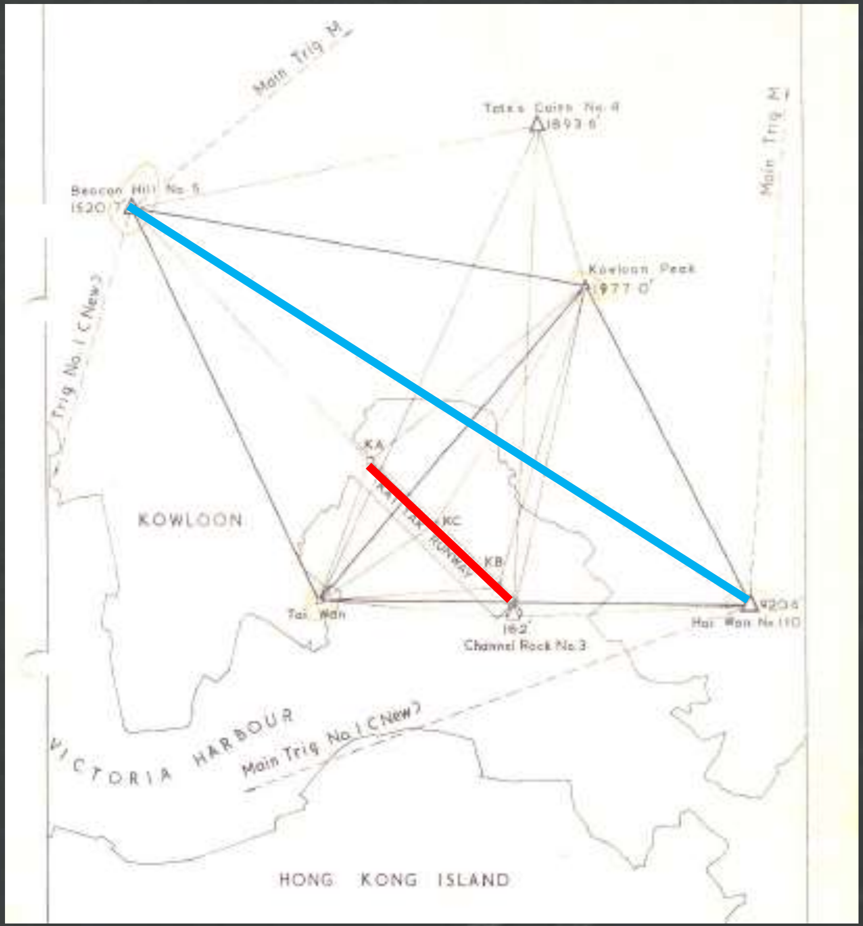
Hong Kong Geodetic Datum (before 1963)

- Scale (Base)
  - From Trig No. 2 (Partridge Hill – near Chung Yi Street, Ho Man Tin)
  - To Trig No. 3 (Channel Rock – a former big rock in the midst of Kowloon Bay, buried in the extension of runway of Kai Tak Airport)
  - Adopted value: <u>“anti-log 4.0608589”</u> (about 11,505 ft /3,507 m)
- Orientation (Azimuth)
  - From Trig No. 2 to Trig No. 3
  - Adopted value: <u>98° 12’ 00”</u>
- Source of observations unknown



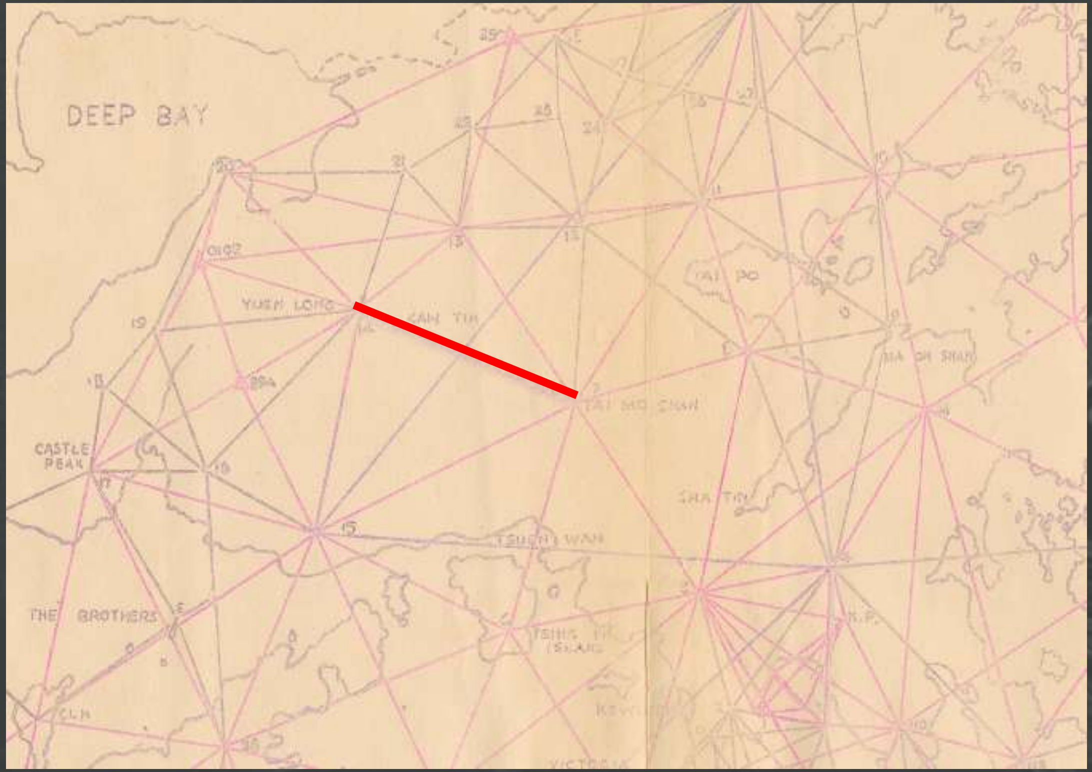
Hong Kong 1963 Geodetic Datum

- Scale (Base)
  - Invar measurement
  - Baseline along Kai Tak Runway as 7,050 ft
  - Extended by triangulation
  - From Trig. No. 5 (Beacon Hill, near today's Trig. No. 73.3)
  - To Trig. No. 110 (Hai Wan , near today's Trig. No. 72)
  - Tellurometer used



Hong Kong 1963 Geodetic Datum

- Orientation (Azimuth)
  - Astronomical observations by a team of visiting Geodesists in Feb 1960
  - From Trig No. 7 (Tai Mo Shan)
  - To Trig No. 14 (Au Tau)
  - Adopted value: 292° 52’ 58.4”
  - Accuracy +/- 0.2”

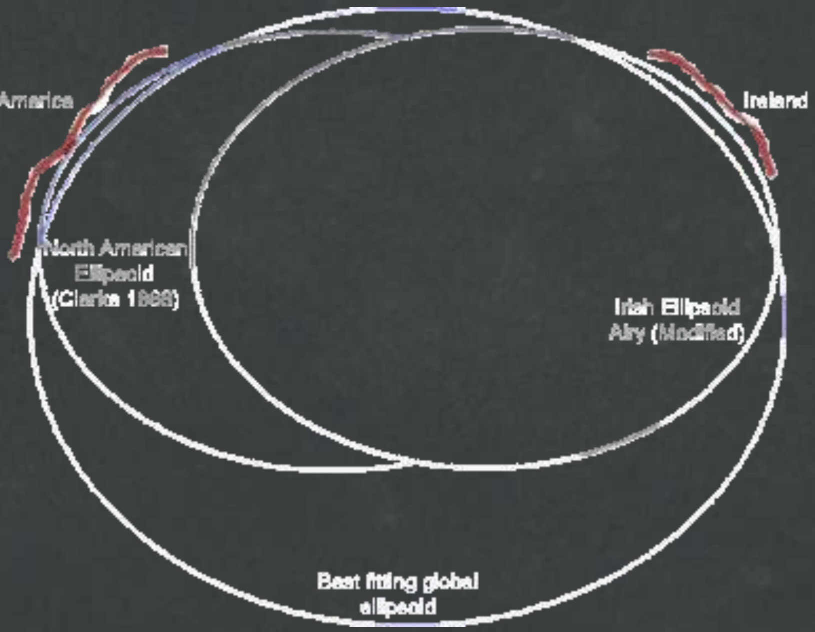


Hong Kong 1980 Geodetic Datum

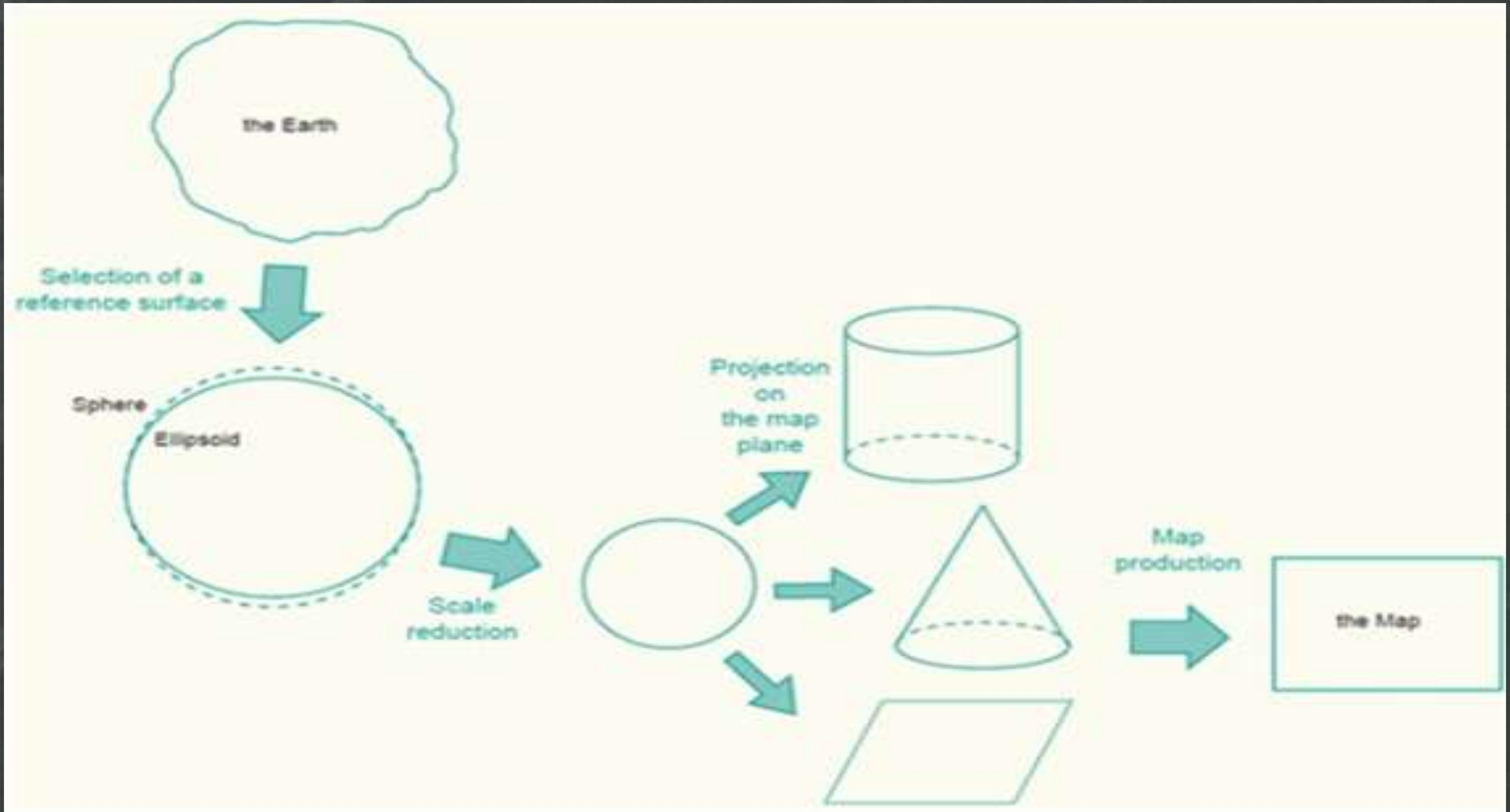
- Scale (Base)
  - Re-observation of distances between Trig. Stations by EDM
  - Metrification: using meter as unit of measurement
- Orientation (Azimuth)
  - Derived from 1963 Azimuth
  - From Trig No. 67.2 (Tai Mo Shan)
  - To Trig No. 94 (Au Tau)
  - Adopted value: 292° 59’ 46.5”

Hong Kong Geodetic Datum

- Reference Ellipsoid
  - Before 1963
    - Clarke 1880
      - Semi-major axis: 20,926,202 ft
      - Flattening: 1/294.978
  - Hong Kong 1963 Geodetic Datum
    - Clarke 1858
      - Semi-major axis: 20,926,348 ft
      - Flattening: 1/294.26
  - Hong Kong 1980 Geodetic Datum
    - International Hayford (1910)
      - Semi-major axis: 6,378,388m
      - Flattening: 1/297.0



Map Projection & Grid System



Map Projection

Hong Kong Grid Coordinate System

- Developments of Hong Kong Grid Coordinate System
  - Old Imperial Grid Coordinate System – Before 1963
  - New Imperial Grid Coordinate System – 1963
  - Old Metric Grid Coordinate System – about 1976
  - Hong Kong 1980 Grid Coordinate System

Hong Kong Grid Coordinate System

- Old Imperial Grid – Pre-1963
  - Geodetic Datum
    - Hong Kong Geodetic Datum (Before 1963)
  - Projection Method
    - Cassini Projection
  - Projection Origin
    - Trig No. 2
    - Geodetic Coordinate
      - 22° 18’ 43.684”N
      - 114° 10’ 42.794”E
    - Grid Coordinates
      - 12,566.69 ft N
      - 12,031.13 ft E
  - Grid Origin
    - Trig No. 1 (Victoria Peak)
    - Grid Coordinate
      - 5.18 ft N
      - 0.38 ft E

Hong Kong Grid Coordinate System

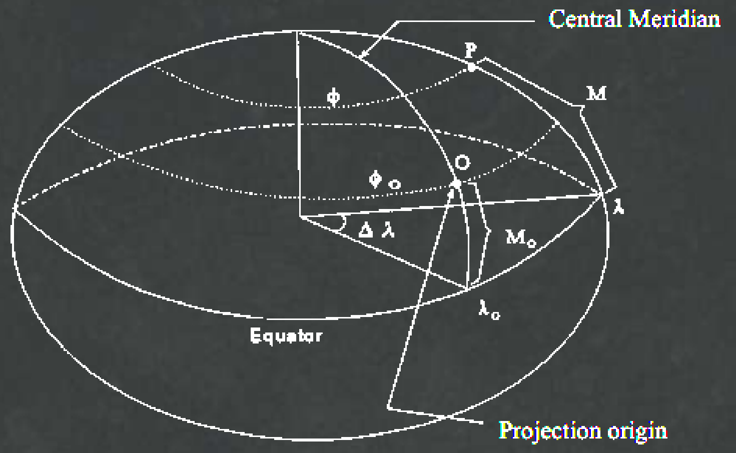
- New Imperial Grid – 1963
  - Geodetic Datum:
    - Hong Kong 1963 Geodetic Datum
  - Projection Method: No change
  - Projection Origin: No change
  - Grid Origin:
    - Trig No. 1 (Victoria Peak)
    - Grid Coordinate
      - 50,005.18 ft N (+50,000 ft)
      - 120,000.38 ft E (+120,000 ft)

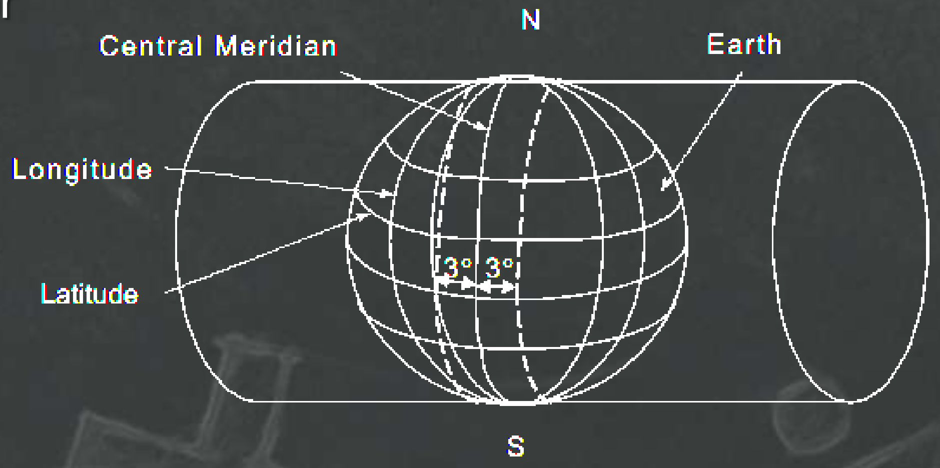
Hong Kong Grid Coordinate System

- Old Metric Grid – 1976
  - Geodetic Datum: No change
  - Projection Method: No change
  - Projection Origin: No change
  - Grid Origin
    - Trig No. 1 (Victoria Peak)
    - Grid Coordinate
      - 15,240m N (x 0.3048)
      - 33,026m E (x 0.3048 – 3,550m)

Hong Kong Grid Coordinate System

- Hong Kong 1980 Grid Coordinate System
  - Geodetic Datum
    - Hong Kong 1980 Geodetic Datum
  - Projection Method
    - Traverse Mercator





Hong Kong Grid Coordinate System

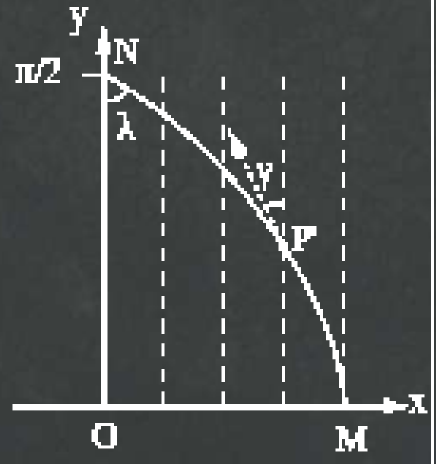
- Hong Kong 1980 Grid Coordinate System
  - Projection Origin
    - Trig No. 2 (Resurveyed)
    - Geodetic Coordinate: No change
    - Grid Coordinate
      - 819,069.80 N
      - 836,694.05 E
  - Grid Origin
    - No change
    - Grid Coordinate
      - 815,240m N (+ 800,000m)
      - 833,026m E (+ 800,000m)

Hong Kong Grid Coordinate System

- Character of Hong Kong 1980 Grid Coordinate System
  - Convergence
    - Grid North align to True North along Projection Meridian only

$$\gamma(\lambda, \phi) = \arctan(\tan\lambda \sin\phi),$$

$$\gamma(x, y) = \arctan\left(\tanh\frac{x}{k_0 a}\tan\frac{y}{k_0 a}\right).$$



    - \- ve at West, + ve at East of Projection Meridian
    - About -8' to +6' within Hong Kong
  - True North vs Grid North vs Magnetic North

Hong Kong Grid Coordinate System

- Character of Hong Kong 1980 Grid Coordinate System
  - Scale Factor
    - Uniform along Projection Meridian

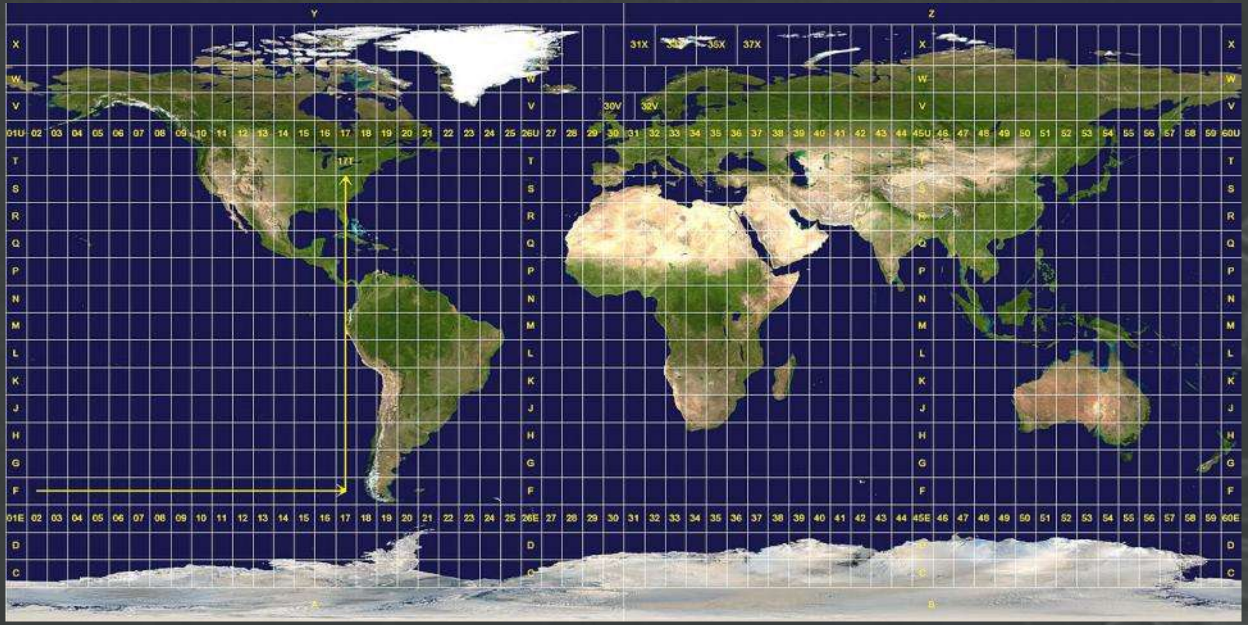
$$k(\lambda, \phi) = \frac{k_0}{(1 - \sin^2 \lambda \cos^2 \phi)^{1/2}},$$

$$k(x, y) = k_0 \cosh\left(\frac{x}{k_0 a}\right).$$

    - Increase when further away from Projection Meridian
    - < 15 ppm within Hong Kong

Map Projection

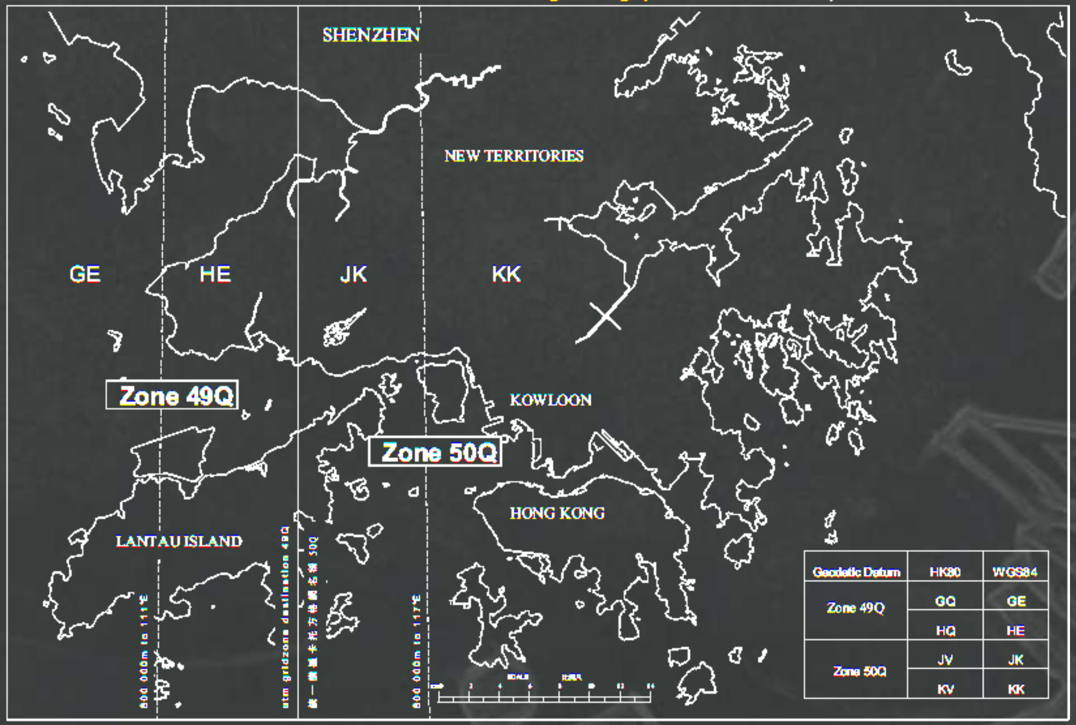
- Universal Traverse Mercator (UTM)
  - Longitude: Every 6 degrees
    - Zone 1 = 180˚W - 174˚W
    - Zone 2 = 174˚W - 168˚W …
    - Zone 30 = 6˚W - 0˚
    - Zone 31 = 0˚- 6˚E
    - Zone 32 = 6˚E - 12˚E …
  - Scale:
    - 0.996 along Central Meridian
    - about 1.004 for 255km away
  - Latitude: Every 8 degrees
    - C = 80˚S - 72˚S
    - D = 72˚S - 64˚S…
    - M = 8˚S - 0˚
    - N = 0˚ - 8˚N…
    - X = 72˚N - 84˚N
    - “A”, “B”, “X”, “Y” = Special bands



Map Projection

- Universal Traverse Mercator (UTM)
  - Hong Kong
    - Zone 49 = 108°E - 114°E
    - Zone 50 = 114°E - 120°E
    - Latitude Band: Q
  - Coordinates:
    - Northing
      - Equator as 0m
    - Easting
      - Central Meridian as 500,000m
      - i.e. Zone 49: 111°E
      - i.e. Zone 50: 117°E

UTM Grid Zone in Hong Kong (WGS84 Datum)



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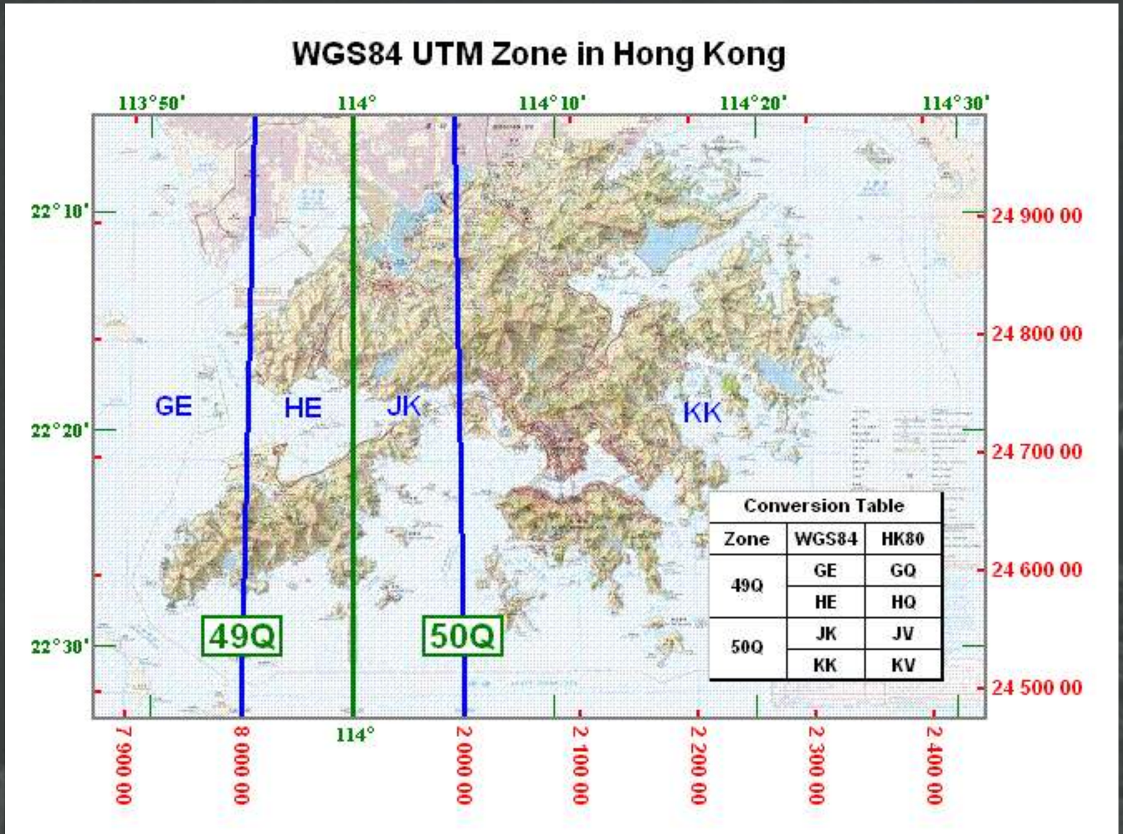
Map Projection

- Universal Traverse Mercator (UTM)
  - UTM Grid Reference
  - Also known as Military Grid Reference System (MGRS)
  - 100,000m x 100,000m Grid
  - Zone 49Q GE
    - 700,000E - 800,000E
  - Zone 49Q HE
    - 800,000E -114˚E
  - Zone 50Q JK
    - 114˚E – 200,000E
  - Zone 50Q KK
    - 200,000E – 300,000E
  - Different alphabetic grid for different Geodetic Datum
  - SMO Maps: Use WGS 84



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Map Projection

- Universal Traverse Mercator (UTM)
  - UTM Grid Coordinates
  - 100m x 100m Grid
    - 3 digit Easting / Northing
    - Truncate, don't round
  - 50Q 2,483,568 mN, 209,191 mE
    - Fall within 50Q KK
    - 209,1~~91~~ mE = 091
    - 2,483,5~~68~~ mN = 835
    - 50Q KK 091 835
  - 10m x 10m Grid: 4 digit
    - 50Q KK 0919 8356

3. Global geodetic reference systems

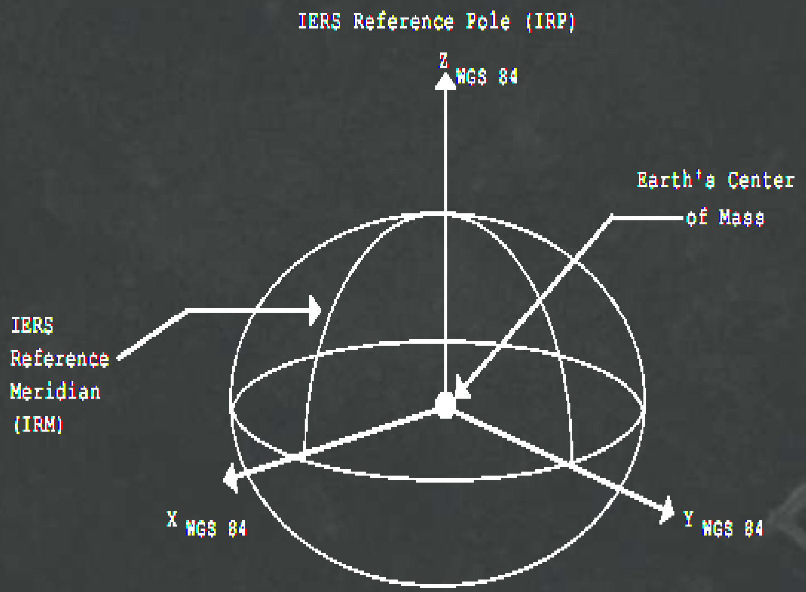
- World Geodetic System 1984 (WGS 84)
- International Terrestrial Reference System (ITRS) & International Terrestrial Reference Frame (ITRF)

World Geodetic System 1984 (WGS 84)

- Defined by the National Imagery and Mapping Agency (NIMA) of the United States Department of Defense (DoD)
- United States NAVSTAR Global Positioning System (GPS)
- Realizations: Coordinates of DoD Monitoring Stations
- Current Realization: WGS84(G1674) (epoch 2005.0)

World Geodetic System 84 (WGS 84)

- Origin
  - Geocentric, the center of mass being defined for the whole Earth including oceans and atmosphere
- Orientation of Axis
  - Initially given by Bureau International de l'Heure (BIH) of 1984.0
  - Z-Axis: The direction of the IERS Reference Pole (IRP).
    - = The BIH Conventional Terrestrial Pole (CTP) (epoch 1984.0) with an uncertainty of 0.005"
  - X-Axis: Intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin and normal to the Z-axis.
    - =The BIH Zero Meridian (epoch 1984.0) with an uncertainty of 0.005".
    - about 100 metres east away from the Prime Meridian at Greenwich, UK
  - Y-Axis: Right-handed, Earth-Centered Earth-Fixed (ECEF) orthogonal system



World Geodetic System 84 (WGS 84)

- Reference geometric representation of the Earth
  - WGS 84 Ellipsoid
  - 4 Defining Parameters
    - Semi-major Axis (a) = 6,378,137.0m
    - Flattening (f) = 298.257223563
    - Angular Velocity of the Earth
      - ω = 7,292,115.0 x 10^{-11} rad/s
    - Earth's Gravitational Constant
      - Mass of Earth's Atmosphere Included
      - GM = 3,986,004.418 x 10^{8} m^3/s^2
  - Rotational Axis: Z-Axis passing thru the Origin
- Scale: The local Earth frame, in the meaning of a relativistic theory of gravitation
- Time evolution in orientation will create no residual global rotation with regards to the crust
- Earth Gravitational Model: Earth Gravitational Model 1996 (EGM 96)

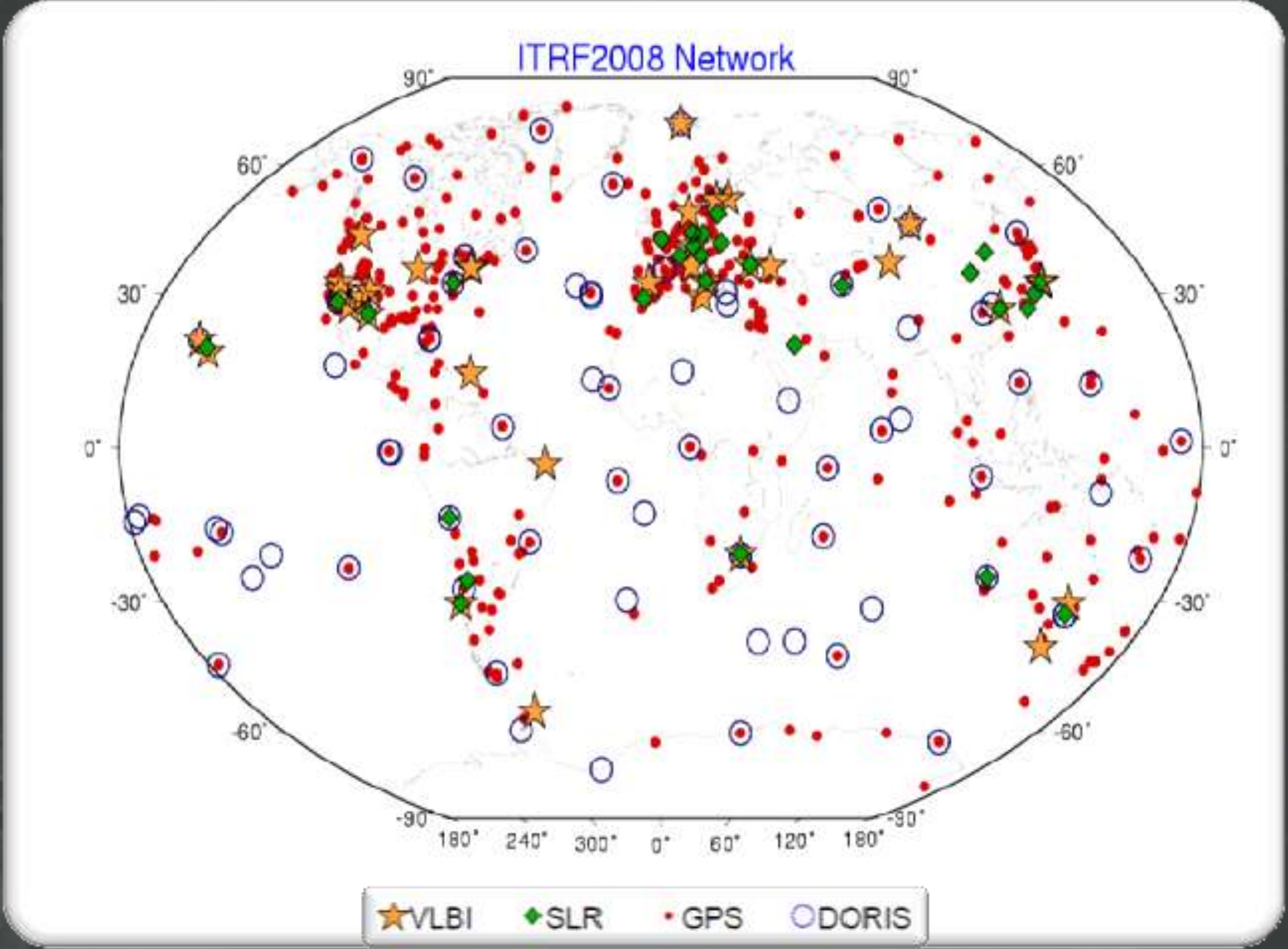
ITRS & ITRF

- International Terrestrial Reference System (ITRS) & International Terrestrial Reference Frame (ITRF)
  - ITRS is an ideal reference system as defined by the IUGG resolution No. 2 adopted in Vienna, 1991
  - ITRF is the realization of the ITRS
  - Realized and maintained by Product Centre of the International Earth Rotation & Reference Systems Service (IERS) of IAG
  - Combination of Individual TRF solutions (SINEX) from VLBI, SLR, GNSS and DORIS services
  - Current Realization: ITRF2008

International Terrestrial Reference System (ITRS)

- Origin
  - geocentric, the center of mass being defined for the whole Earth, including oceans and atmosphere
- Scale
  - Unit of length is the meter (SI).
  - Consistent with the TCG time coordinate for a geocentric local frame, in agreement with IAU and IUGG (1991) resolutions
  - Obtained by appropriate relativistic modeling
- Orientation
  - Initially given by the Bureau International de l'Heure (BIH) orientation at 1984.0
  - Time evolution of the orientation is ensured by using a no-net-rotation condition with regards to horizontal tectonic motions over the whole Earth
- equivalent to WGS 84

International Terrestrial Reference Frame (ITRF)



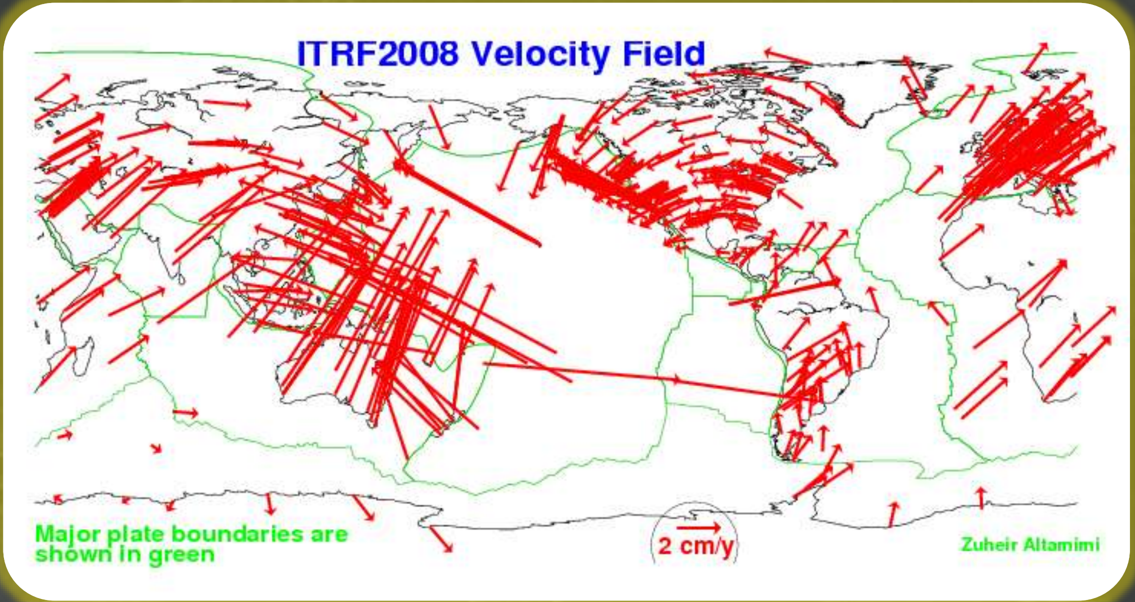
- ITRF 2008
- Solution based on reprocessed solutions of 4 space geodesy techniques
  - VLBI: 29 years
  - SLR: 26 years
  - GPS: 12.5 years
  - DORIS: 16 years
- Composed of 934 stations located at 580 sites
  - 463 sites in northern hemisphere
  - 117 sites in southern hemisphere
  - 105 co-location sites

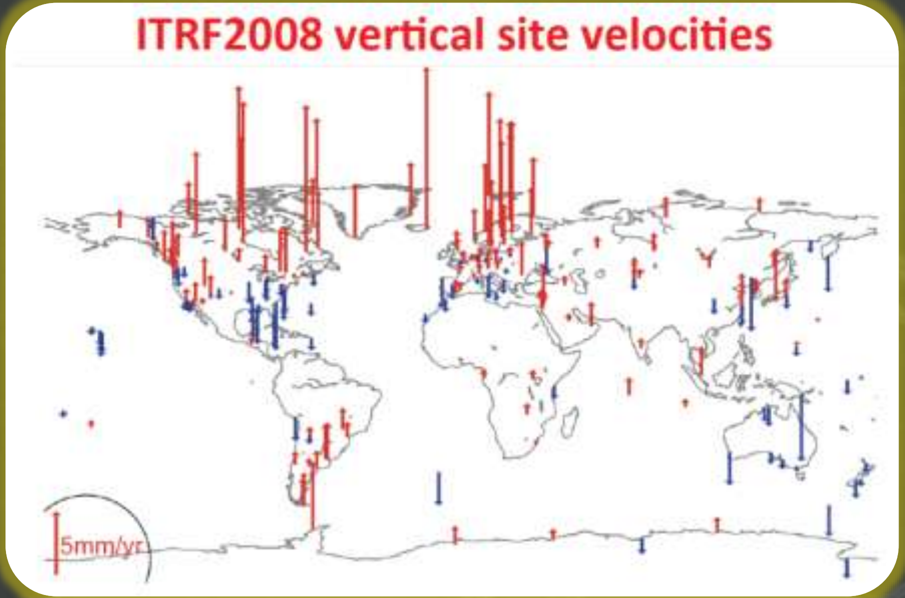
International Terrestrial Reference Frame (ITRF)

- ITRF 2008 Frame Parameters
- Origin
  - Zero translation parameters at epoch 2005.0
  - Zero translation rates with respect to the ILRS SLR time series
- Scale
  - Zero scale factor at epoch 2005.0
  - Zero scale rate with respect to the mean scale and scale rate of VLBI and SLR time series
- Orientation
  - Zero rotation parameters at epoch 2005.0
  - Zero rotation rates between ITRF 2008 and ITRF 2005
  - Applied over a set of 179 reference stations
    - 131 sites: 107 GPS, 27 VLBI, 15 SLR & 12 DORIS sites

International Terrestrial Reference Frame (ITRF)

- ITRF Solutions
  - X/Y/Z of Stations, Velocity of Stations, Earth Orientation Parameters
  - NO Reference Ellipsoid, NO Geoid Model





ITRF vs WGS 84

- The ITRS (and its realizations ITRFyy) vs. WGS84
  - Identical at 1m level in general
- WGS 84 (G1674) vs ITRF 2008
  - (G1674) Adopted ITRF2008 coordinates for more than half of the reference stations and velocities of nearby sites for the others
  - ITRF2008 and WGS84(G1674) are likely to agree at the cm-level

ITRF vs WGS 84

<table>
<tr><th>From</th><th>To</th><th>Epoch</th><th>Shift (m)</th><th>Transformation</th><th>Accuracy</th></tr>
<tr><td rowspan="2">ITRF90</td><td rowspan="2">WGS84 (original)</td><td rowspan="2">1984</td><td rowspan="3">0.7</td><td rowspan="2">7-parameters</td><td rowspan="2">0.01 m</td></tr>
<tr></tr>
<tr><td rowspan="2">ITRF91</td><td rowspan="2">WGS84 (G730)</td><td rowspan="2">1994</td><td rowspan="2">zero</td><td rowspan="2">0.1 m</td></tr>
<tr><td rowspan="2">0.2</td></tr>
<tr><td rowspan="2">ITRF94</td><td rowspan="2">WGS84 (G873)</td><td rowspan="2">1997</td><td rowspan="2">zero</td><td rowspan="2">0.1 m</td></tr>
<tr><td rowspan="2">0.06</td></tr>
<tr><td rowspan="2">ITRF2000</td><td rowspan="2">WGS84 (G1150)</td><td rowspan="2">2001</td><td rowspan="2">zero</td><td rowspan="2">0.1 m</td></tr>
<tr><td rowspan="3">0.01</td></tr>
<tr><td rowspan="2">ITRF2008</td><td rowspan="2">WGS84 (G1674)</td><td rowspan="2">2005</td><td rowspan="2">zero</td><td rowspan="2">cm-level</td></tr>
<tr></tr>
</table>

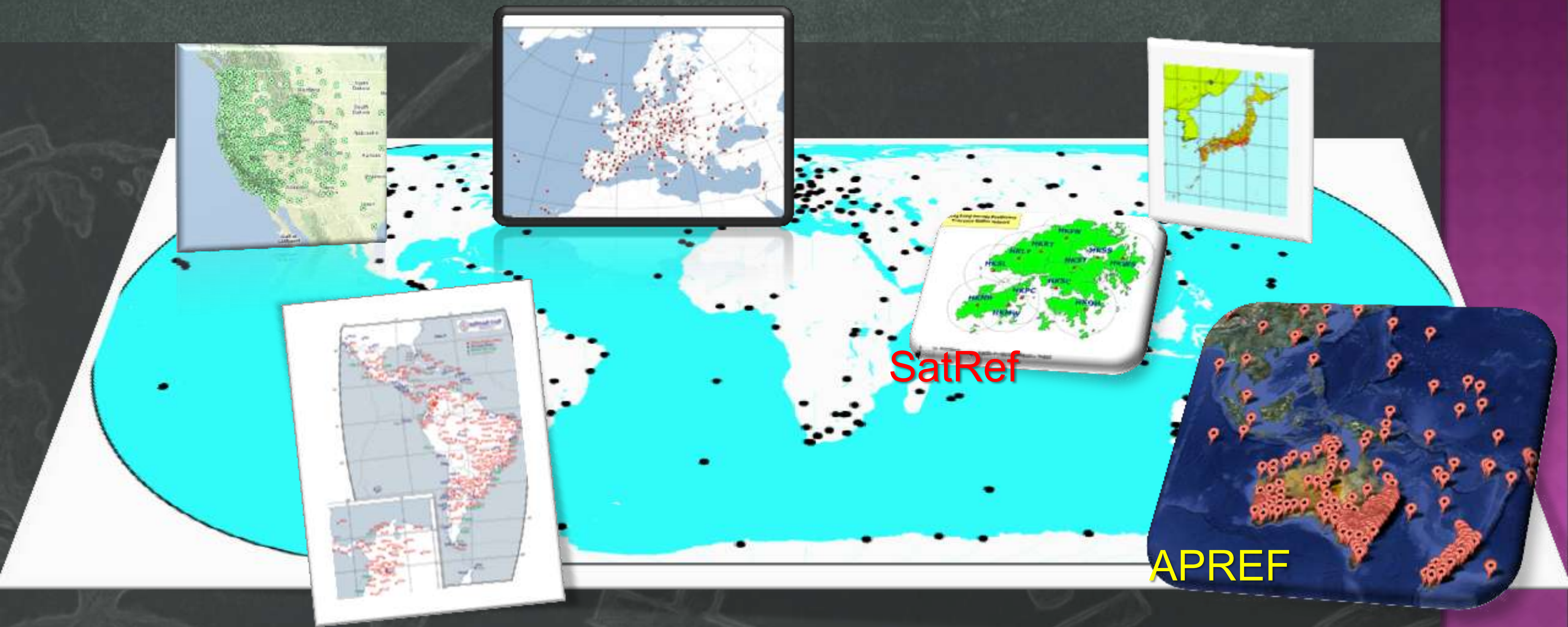
How to compute ITRF Coordinates

- Short-baseline DGNSS techniques, connect to Reference Stations with ITRF Coordinates
- Precise Point Positioning (PPP), using IGS orbit/clock products and special software
- Scientific software (Bernese, GMAT, GIPSY), long observation sessions, long baselines, connect to IGS or National Reference Stations
  - Web-based processing to connect to ITRF (via Tier 1/2 sites)
    - e.g. AUSPOS (Australia), OPUS (US NOAA), CSRS-PPP (Canada), APPS (US NASA JPL), SCOUT (US Uni of California, San Diego)…etc.

Connect to the ITRF

- Direct use of IGS Products (Station coordinates, Velocities, Orbits, Clocks, etc.) expressed in ITRF
- Use high precision GNSS techniques
- Process GNSS data together with IGS/ITRF global stations in free mode
- Align to ITRF by:
  - Constraining station coordinates to ITRF values at the central epoch of the observations
  - Using minimum constraints approach

Global / Regional / National CORS Networks



However …

- Geodetic Datums
  - 3D Coordinate Systems
- Irregular Earth's physical surface / Gravitational field
- Ellipsoids does not provide a practical meaningful reference of the 3rd dimension (height) with respective to the physical Earth
- Some reference systems to the Earth surface / gravity is required

Height Reference Systems

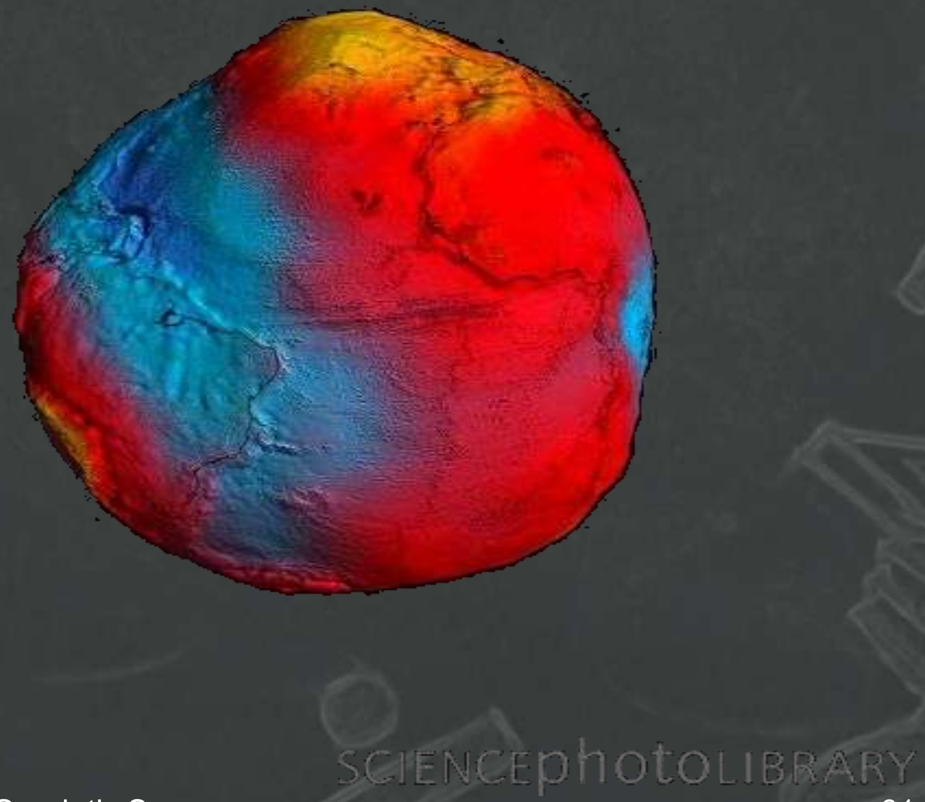
- A linear distance from a reference level
- Physically and geometrically meaningful
- No water runoff between points with equal heights
- No assumptions needed
- Easily measurable
- Practical

Height Reference Systems

- Mean Sea Level
  - Easily understandable reference surface
  - Physically measureable
  - Consistent
  - Unstable
    - Tidal changes
    - Seasonal changes
    - Terrain effects
    - Climate changes

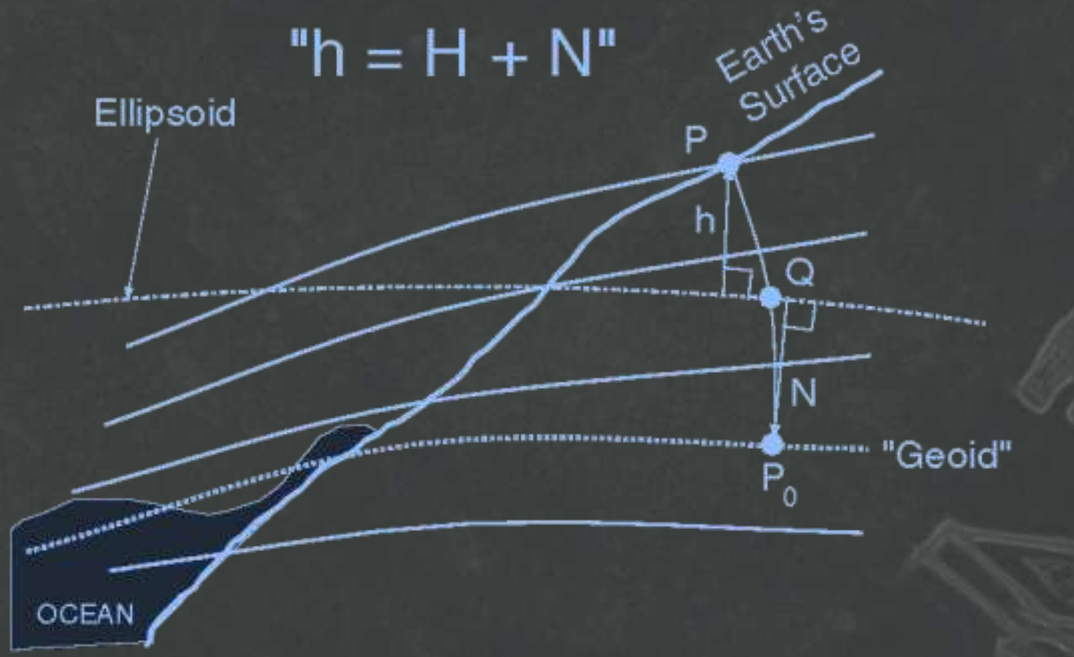
Height Reference Systems

- The Geoid: *The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level" (US NOAA)*



Height Reference Systems

- Orthometric Height
  - Height above “sea level”
  - Physically useful
  - Linear distance from Geoid to the Point along plumb line
  - Some assumption needed
    - i.e. gradient of g



h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)
N (Geoid Height) = Distance along ellipsoid normal (Q to P_0)
H (Orthometric Height) = Distance along Plumb line (P_0 to P)

Height Reference Systems

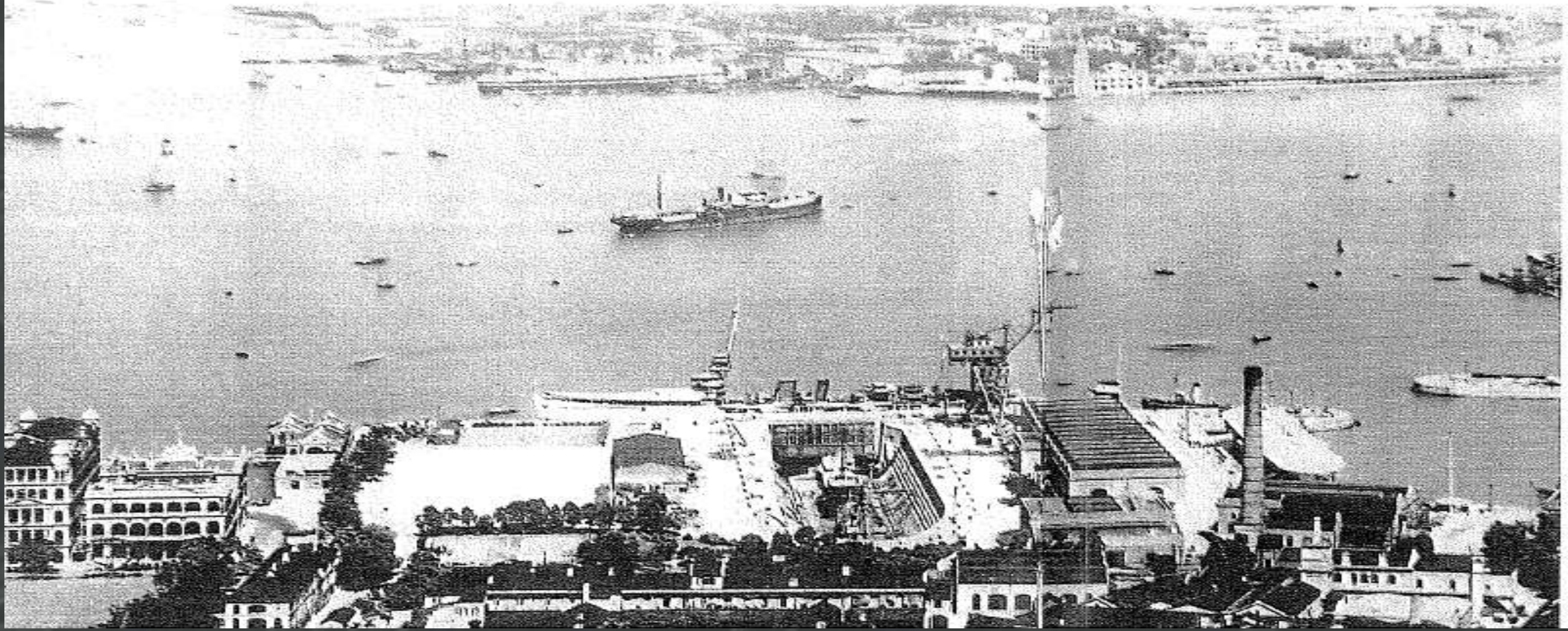
- Local Height
  - Height above a defined surface / point
  - Simple definition
  - May or may not be related to Sea Level / Geoid / gravity surface

Hong Kong Vertical Datum

- Hong Kong Principal Datum (HKPD)
  - Formerly known as “Ordnance Datum”
  - “Rifleman’s Bolt”: a copper bolt fixed in Hong Kong Naval Dockyard
  - The level of the “Bolt” was determined by H.M. Surveying Vessel “Rifleman” in 1866 as 17’10” (5.435m) above HKPD
- Hong Kong Chart Datum (HKCD)
  - Formerly known as “Admiralty Datum”
  - approximately the level of Lowest Astronomical Tide and is adopted as the zero point for Tide Tables since 1917
  - For all depths, heights above mean high water mark and submarine contours on Admiralty Charts and sounding plans
  - HKCD = HKPD – 0.146m

Hong Kong Vertical Datum

Naval Dockyard under construction



Hong Kong Vertical Datum

- Today's position: outside the entrance to the Lippo Centre on Queensway

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Hong Kong Vertical Datum

Hong Kong Vertical Datum

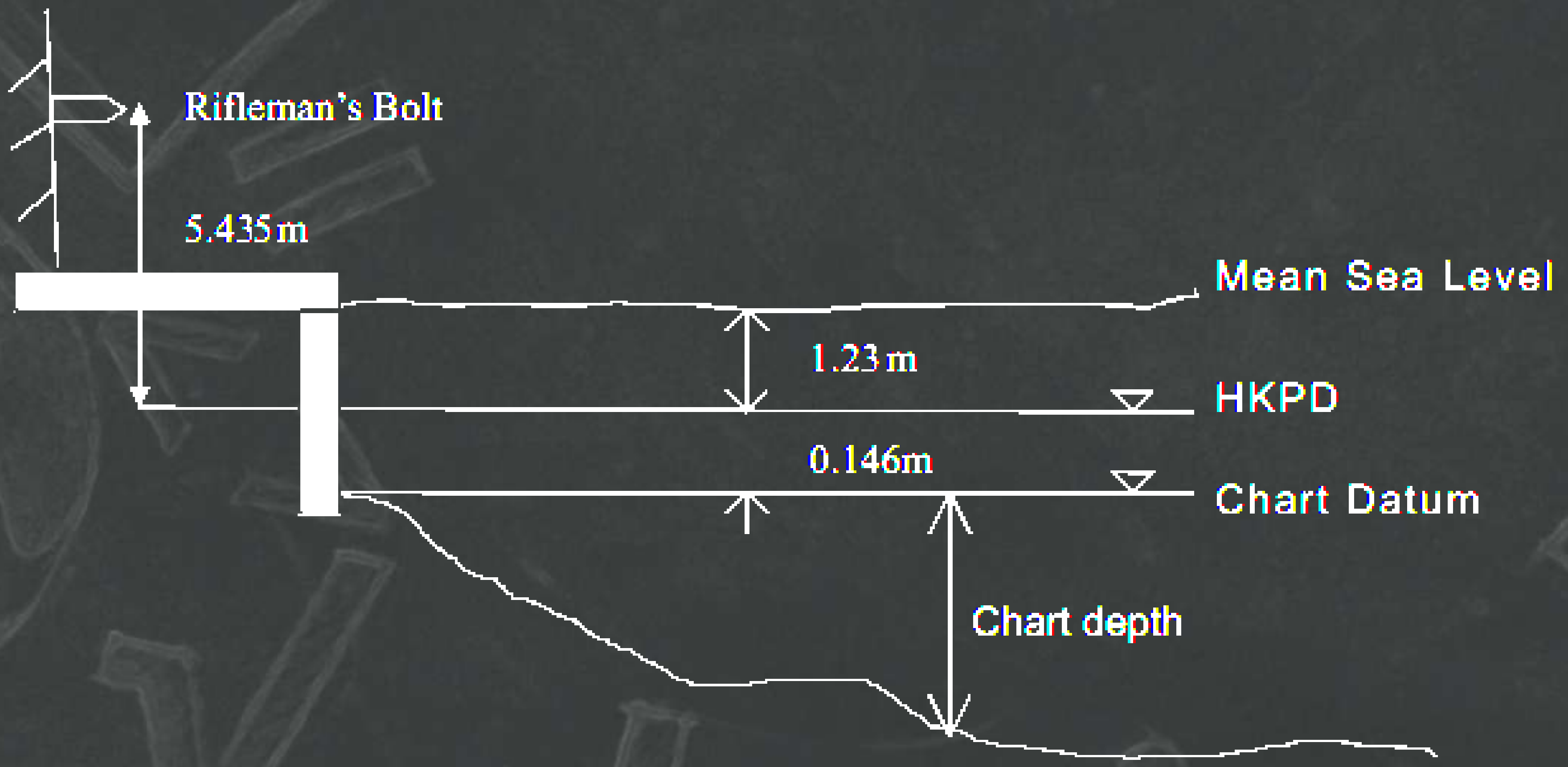
- Interpretation and General Clauses Ordinance (Cap. 1)
  - Schedule 1 – "Boundaries of the City of Victoria"

"… On the south-A line running due east from the southern extremity of the western boundary until it meets a contour in the vicinity of the Hill above Belchers 700 feet above principal datum, that is to say, a level 17.833 feet below the bench-mark known as "Rifleman's Bolt", the highest point of a copper bolt set horizontally in the east wall of the Royal Navy Office and Mess Block Naval Dockyard, and thence following the said contour until it meets the eastern boundary;"

Hong Kong Vertical Datum

- 1887/88
  - First Director of Observatory Dr. W. DOBERCK set up an automatic tide-gauge mount in a hut in the boat basin belonging to the Police Station at Kowloon Point (now Tsim Sha Tsui)
  - 6 bench-marks have been placed on buildings in Kowloon
    - Mean Sea Level in 1887-8 was 3.69 feet (1.12m) above the HKPD as is evident from a diagram supplied to the Royal Engineers by the Royal Naval Dockyard
- 1965-83
  - 19 years (1965-1983) observation records of the Automatic Tide Gauge situated at North Point, Victoria Harbour of Hong Kong Observatory
  - Mean Sea Level = 1.23m above HKPD

Hong Kong Vertical Datum



Hong Kong Vertical Datum

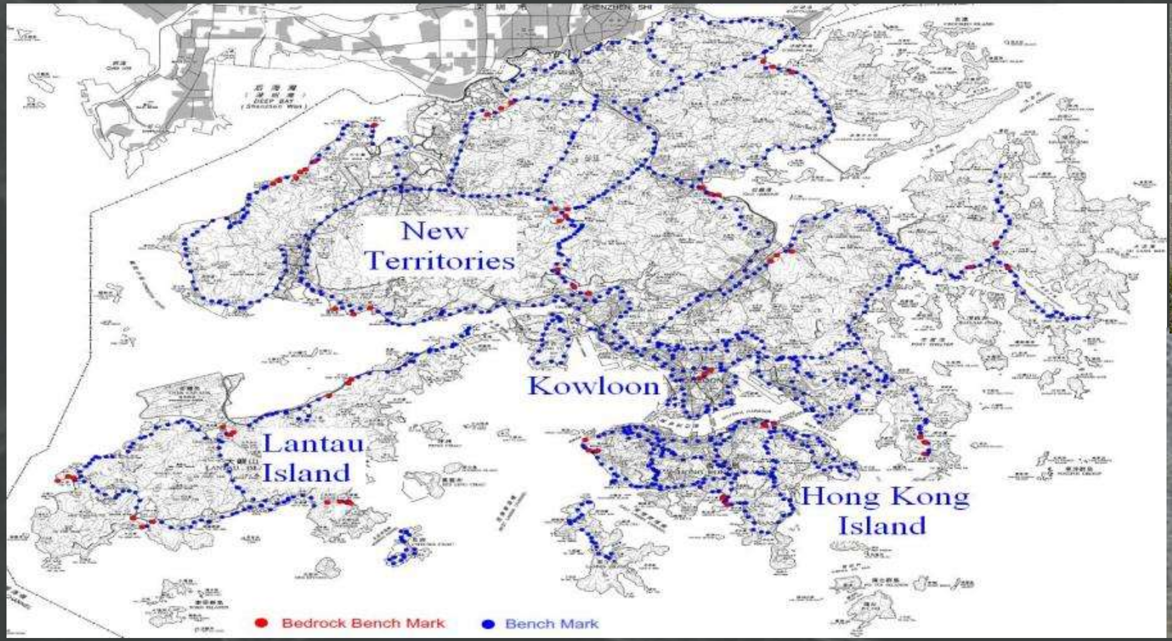
- Height above HKPD
  - The height of a point above HKPD means the distance measured along the vertical above the reference surface of HKPD
- HKPD is now implicitly defined by the network of bench marks established by the Geodetic Survey Section of Lands Department as the elevation of them are all surveyed with reference to HKPD

4. Geodetic Control Design & Establishment

- Hong Kong Geodetic Control Network
  - Vertical
    - Hong Kong Principal Datum
    - Hong Kong Chart Datum
  - Horizontal
    - Hong Kong 1980 Geodetic Datum
    - Hong Kong 1980 Grid Coordinate System
  - Maintained by Survey and Mapping Office, Lands Department

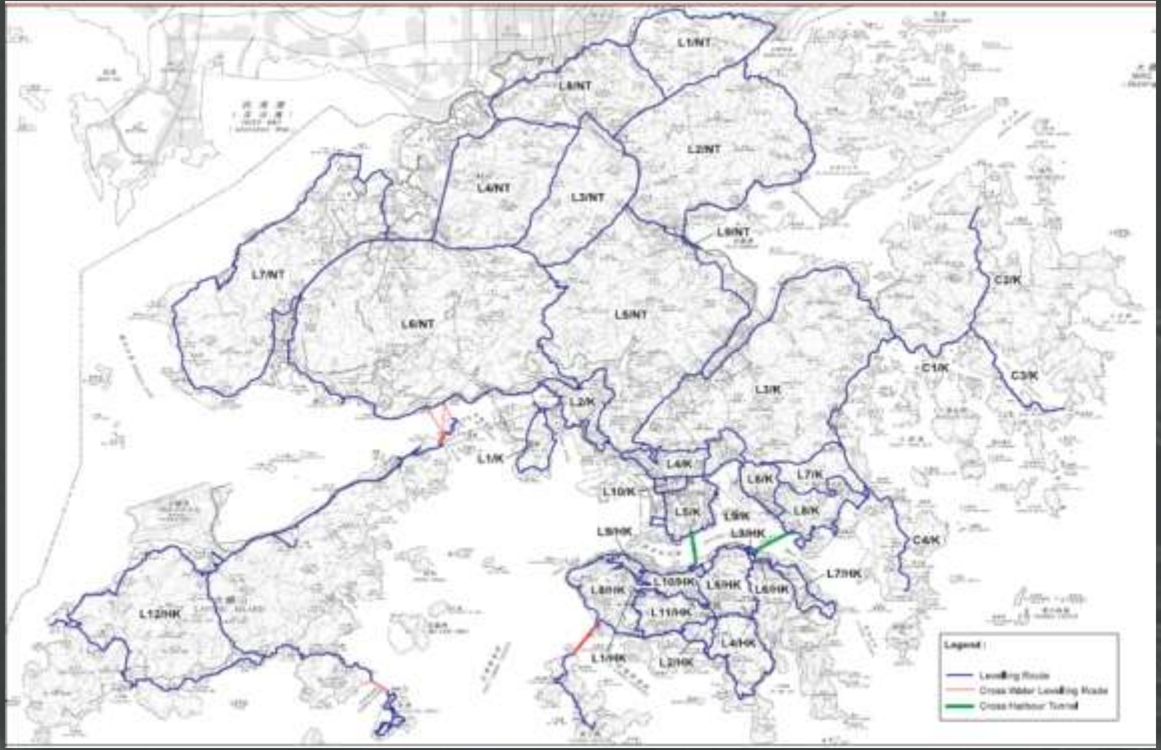
Hong Kong Vertical Control Network

- 2014
  - About 1,700 bench marks totally, include 63 bed rock bench marks
  - Along main roads, one in every 500m (about)

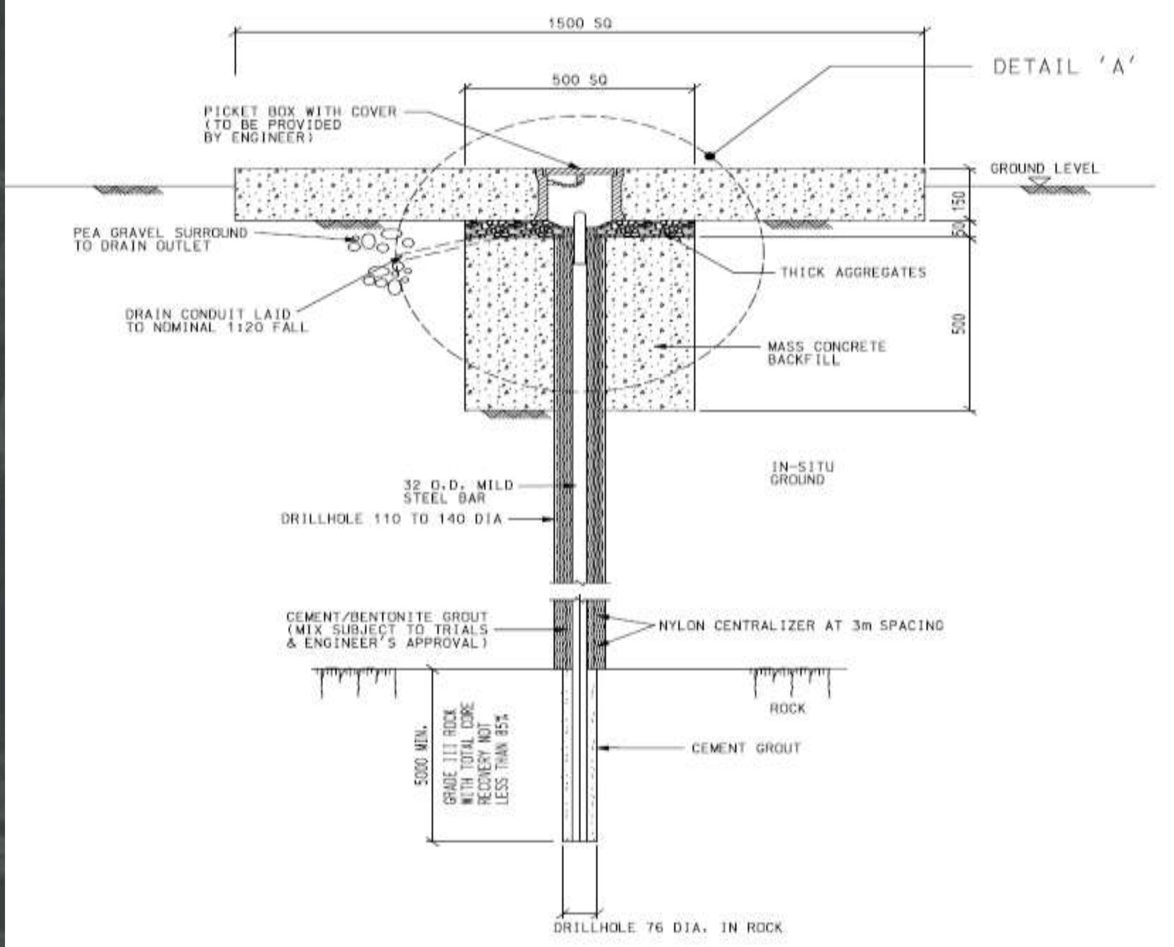


Hong Kong Vertical Control Network

- 2013 Levelling Networks
  - Inherited discrepancies within the Network over past decades
  - Systematic resurvey for 1092 Bench Marks since 2007
  - Tie to 63 Bedrock Bench Marks
  - After Readjustment
    - 88% of published height with residuals <1cm
    - 98% of height difference between adjacent marks with residuals <1cm
  - Improved consistency for HKPD
  - New 6-digit numbering: 2xxxxx



Hong Kong Vertical Control Network



Hong Kong Vertical Control Network

- Bench Mark Summary

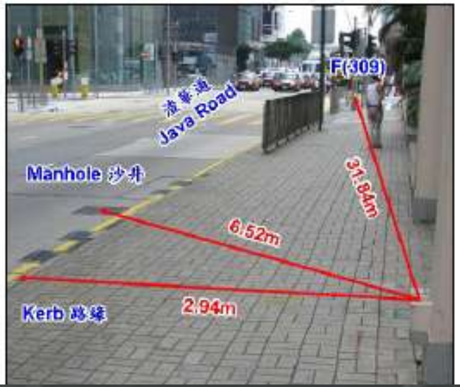
BENCH MARK SUMMARY

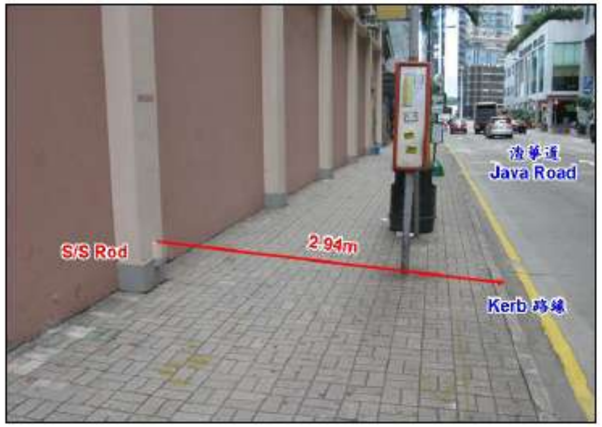
BENCH MARK NO. : 10611 *(FORMER NO.* :) *CLASS* : V1

Height above HKPD **:** 4.7620 m (To Top of Mark)	*HK 1980 GRID COORDINATES (APPROX.)*: N = 817 034 m E = 839 446 m *LOCALITY* : JAVA ROAD *SURVEY SHEET NO.* : 11-SE-2C

LOCATION MAP (Scale 1:2000)

STATION PHOTO





REMARKS :

Type of Mark :
Steel Rod (S/S Rod)

0.35m above ground level

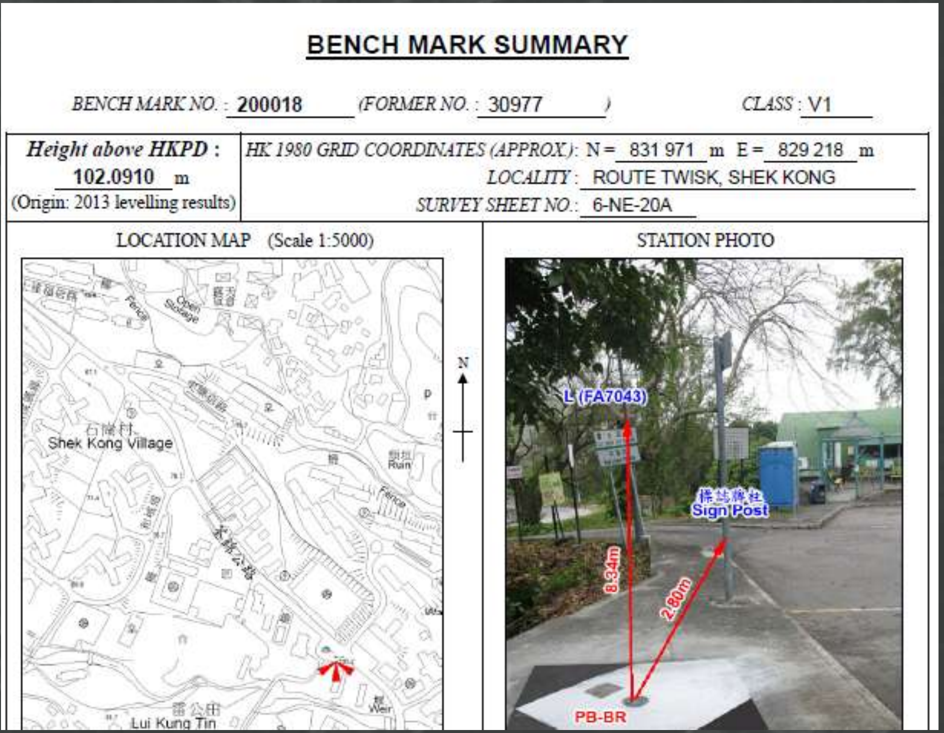
All measurements shown are in horizontal distance unless otherwise specified.

Prepared by : KWONG C W Checked by : LAW M W Approved by : CHOI C T, LS/G(HK&Is) Date : 29/02/2012

Geodetic Survey Section
SMO, Lands Department

Hong Kong Vertical Control Network

- Bench Mark Summary



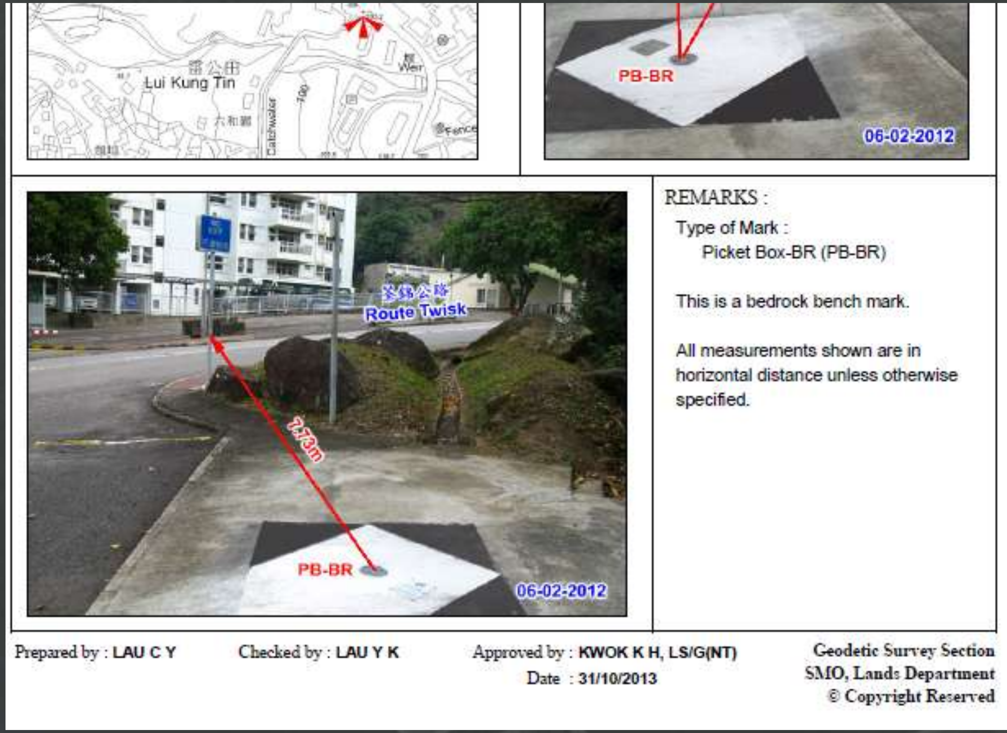
BENCH MARK SUMMARY

BENCH MARK NO. : 200018 *(FORMER NO.* : 30977 *)* *CLASS* : V1

Height above HKPD : 102.0910 m (Origin: 2013 levelling results)	*HK 1980 GRID COORDINATES (APPROX.)*: N = 831 971 m E = 829 218 m *LOCALITY* : ROUTE TWISK, SHEK KONG *SURVEY SHEET NO.* : 6-NE-20A

LOCATION MAP (Scale 1:5000)

STATION PHOTO



REMARKS :

Type of Mark :

Picket Box-BR (PB-BR)

This is a bedrock bench mark.

All measurements shown are in horizontal distance unless otherwise specified.

Prepared by : LAU C Y Checked by : LAU Y K Approved by : KWOK K H, LS/G(NT) Date : 31/10/2013

Geodetic Survey Section
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Hong Kong Horizontal Control Network

- 1845
  - Triangulation stations first appeared on the map of Hong Kong
- 1899-1900
  - Triangulation stations are shown on a Map prepared by Mr. TATE
- 1903-1904
  - Triangulation stations are shown on a Map prepared by Mr. W.J. NEWLAND
- No survey record found for the triangulation

Hong Kong Horizontal Control Network

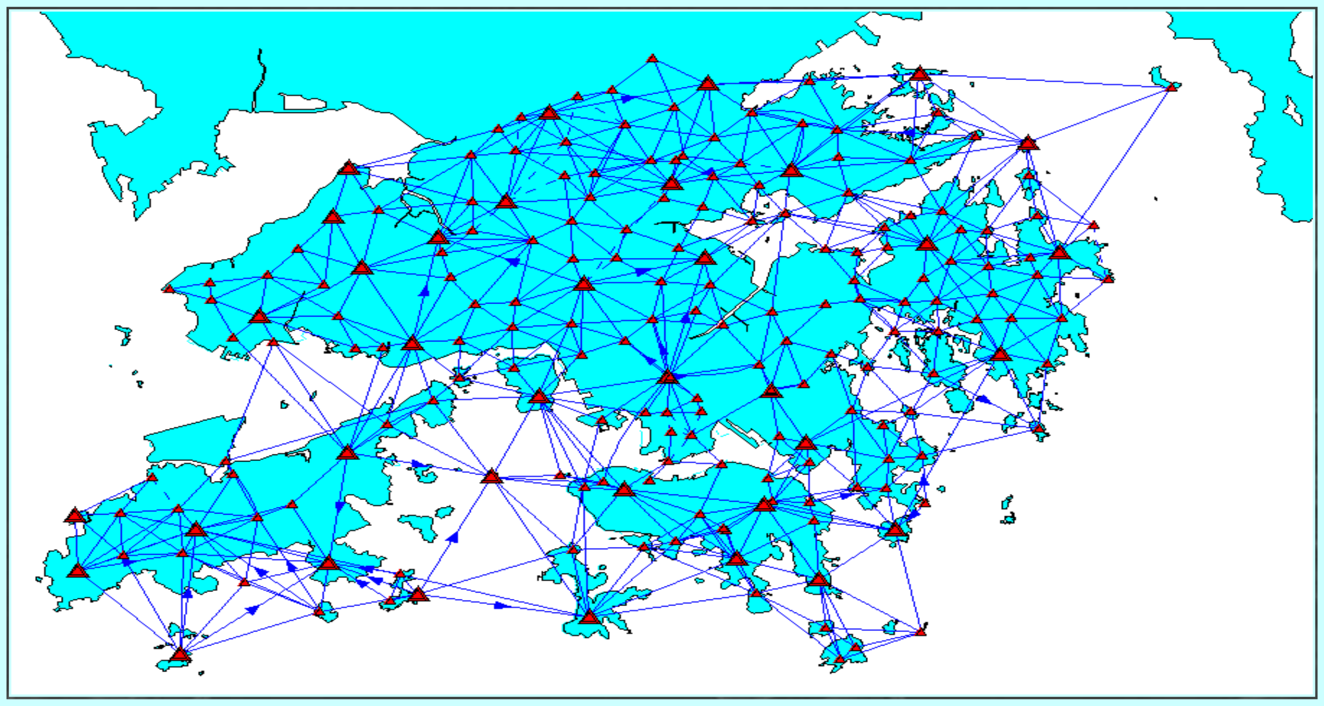
- 1928-29
  - Using air photographs taken in 1924/25 by the Royal Air Force
  - Ground controls provided by the 2nd Colonical Survey Section Royal Engineers
  - Production of military map of scale 1:20,000
- 1928-30
  - Ground control points adjusted by Geographical Section
- 1946-48
  - Ground control points adjusted by Crown Lands and Survey Office (former Lands Department)
  - Adopted as the Main Triangulation of Hong Kong on which all surveys were based up to 1963.

Hong Kong Horizontal Control Network

- 1957
  - 100-ft long Invar Tape
  - Established the 100-ft standard baseline
- 1963
  - Large Scale Mapping and Boundary Survey
  - Systematic Aerial Survey Project
  - Re-triangulation for the Hong Kong 1963 Geodetic Datum and Grid System
- 1976
  - Metrication policy
- 1978-79
  - Using EDM for Distance Measurements between Trig Stations
  - Improved accuracy and consistence for the Network
  - Established the Hong Kong 1980 Geodetic Datum and Grid System

Hong Kong Horizontal Control Network

- Main and Minor Triangulation / Trilateration Network
- About 240 Stations



Hong Kong Horizontal Control Network

- Main and Minor Control Traverse Stations
- About 3,700 Stations
- Pillars, Picket Boxes,
  Urban Suvey Marks (USM)

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Hong Kong Geodetic Control Network

- Geodetic Survey Specifications
  - Accuracy requirements
  - Equipment requirements
  - Network design
  - Field Observation procedures
  - Computation & Error corrections
  - Adjustment criteria
- Accuracy Standards of Control Survey
  - http://www.geodetic.gov.hk/smo/gsi/programs/en/GSS/GSI/svy_specifications.htm

Geodetic Survey Specifications

Content

Hong Kong Geodetic Control Network

Accuracy Standards of Horizontal Control Station Surveyed by Terrestrial Survey Method

		Assessment criteria for Least Squares Adjustment		Assessment criteria for traverse computation using Bowditch Rule	
Class	Class description	Allowable residual of distance measurement	Allowable residual of angular measurement	Allowable linear misclosure	Allowable angular misclosure
H1	Main Triangulation / Trilateration	1: 120,000	2"	—	—
H2	Minor Triangulation / Trilateration	1: 60,000	4"	—	—
H3	Main Control Traverse	1: 30,000	5"	1 : 30,000	$5''\sqrt{n}$
H4.1	Minor Control Traverse (Class 4.1)	1: 15,000 or 5mm (minimum)	10"	1 : 15,000	$10''\sqrt{n}$
H4.2	Minor Control Traverse (Class 4.2) Note : The origin of Class 4.2 station is Class 4.1 station.	1: 15,000 or 5mm (minimum)	10"	1 : 15,000	$10''\sqrt{n}$
H5	Traverse (Class 5)	1: 10,000 or 10mm (minimum)	20"	1 : 10,000	$20''\sqrt{n}$
H6	Traverse (Class 6)	1: 7,500 or 10mm (minimum)	30"	1 : 7,500	$30''\sqrt{n}$

Remark
n = Number of control stations of the traverse

Accuracy Standards of Vertical Control Station Surveyed by Terrestrial Survey Method

Class	Class description	Allowable difference between forward and backward run	Misclosure of level loop / level line or Residual of the height difference between stations (assessment criteria for Least Squares Adjustment)
V1	Precise Levelling (Class 1)	$4\sqrt{K}$ mm when $K \ge 1$ $0.9\sqrt{N}$ mm when $K < 1$	$4\sqrt{K}$ mm when $K \ge 1$ $0.9\sqrt{N}$ mm when $K < 1$
V2	Precise Levelling (Class 2) Note : The origin of Class 2 benchmark network is determined by GNSS / cross harbour levelling. (e.g. benchmark network in Lantau Island)	$4\sqrt{K}$ mm when $K \ge 1$ $0.9\sqrt{N}$ mm when $K < 1$	$4\sqrt{K}$ mm when $K \ge 1$ $0.9\sqrt{N}$ mm when $K < 1$
V3	Ordinary Levelling	$12\sqrt{K}$ mm	$12\sqrt{K}$ mm
V4	Precise Levelling and Trigonometrical Heighting	—	$12\sqrt{K}$ mm
V5	Trigonometrical Heighting (Class 5)	—	$30\sqrt{K}$ mm
V6	Trigonometrical Heighting (Class 6)	—	$50\sqrt{K}$ mm

Remark
K = Total distance run between stations in km.
N = Total number of set-up

Hong Kong Geodetic Control Network

Accuracy Standards of Horizontal Control Station Surveyed by GNSS

Class	Class description	Residuals of horizontal components of baseline (V_{Lat}, V_{Long}) shall be less than 2σ. where $\sigma = \sqrt{[a^2 + (b \cdot L)^2]}$, L = length of baseline
GH1	Regional Geodetic Control Stations for connection to International Terrestrial Reference Frame	a = 3 mm b = 0.01 ppm
GH2	Satellite Positioning Reference Station Network	a = 3 mm b = 0.2 ppm
GH3	GNSS Control Network / Triangulation Station / Trilateration Station	a = 3 mm b = 1 ppm
GH4	Main Control Traverse / Minor Control Traverse	a = 5 mm b = 1 ppm
GH5	GNSS Control Station (Class 5)	a = 10 mm b = 3 ppm

Remark

V_{Lat} = Residual of latitude component of GNSS baseline

V_{Long} = Residual of longitude component of GNSS baseline

Accuracy Standards of Vertical Control Station Surveyed by GNSS

Class	Class description	Residual of vertical component (ellipsoidal height) of baseline (V_{EH}) shall be less than 2σ. where $\sigma = \sqrt{[a^2 + (b \cdot L)^2]}$, L = length of baseline
GV1	Regional Geodetic Control Stations for connection to International Terrestrial Reference Frame	a = 9 mm b = 0.03 ppm
GV2	Satellite Positioning Reference Station Network	a = 9 mm b = 0.6 ppm
GV3	GNSS Control Network / Triangulation Station / Trilateration Station	a = 9 mm b = 3 ppm
GV4	Main Control Traverse / Minor Control Traverse	a = 15 mm b = 3 ppm
GV5	GNSS Control Station (Class 5)	a = 30 mm b = 9 ppm

Remark

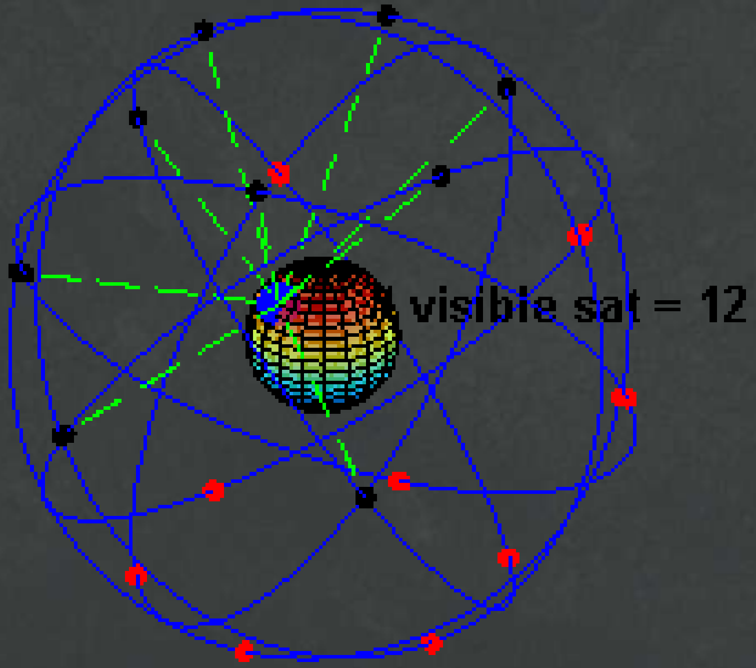
V_{EH} = Residual of vertical component (ellipsoidal height) of GNSS baseline

5. Global Navigation Satellite Systems

- **G**lobal **P**ositioning **S**ystem (GPS)
  - **NAV**igation **S**atellite **T**iming **A**nd **R**anging (NAVSTAR)
- **GLO**bal **NA**vigation **S**atellite **S**ystem (GLONASS)
  - Globalnaya navigatsionnaya sputnikovaya sistema
- **Galileo** Positioning System (Galileo)
- **BeiDou** **S**atellite Navigation System (北斗衛星導航系統, BDS)
- Other Regional Satellite Navigation Systems
  - India: Indian Regional Navigational Satellite System (IRNSS)
  - Japan: Quasi-Zenith Satellite System (QZSS)
- Satellite-Based Augmentation Systems: WAAS, EGNOS…etc.

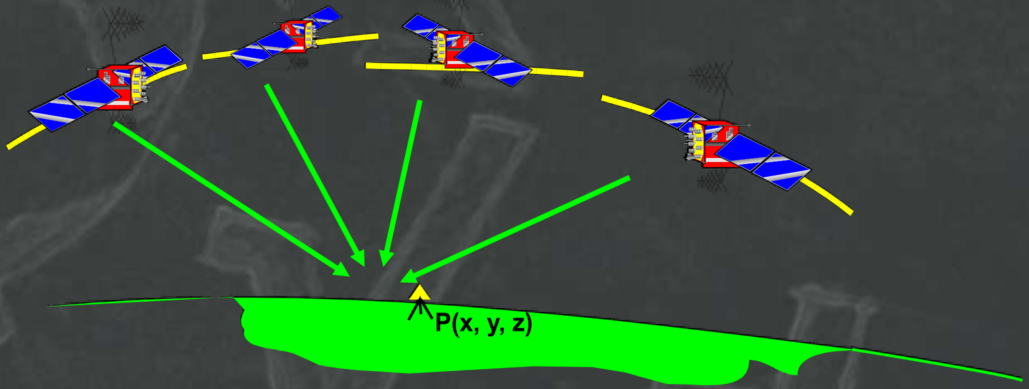
Basic Concept

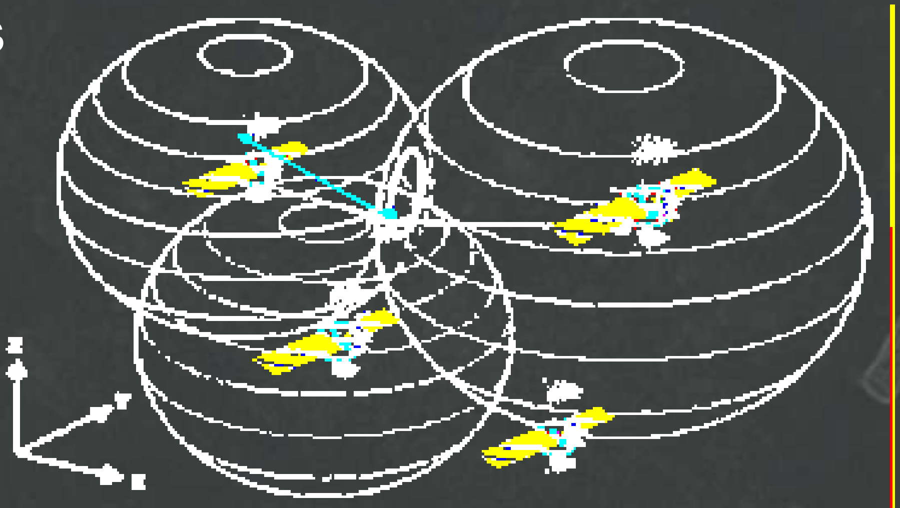
- 24+ NAVSTAR Satellites
- 6 Orbital planes
- 55° Inclination
- About 20,200 km above the Earth
- 11 hour 58 minutes orbit period
- Sending EM wave to the Earth



Basic Concept

- User measures distance to four satellites
- Satellites transmit their positions in orbit
- User solves for position and clock
- 3D Distance Intersection



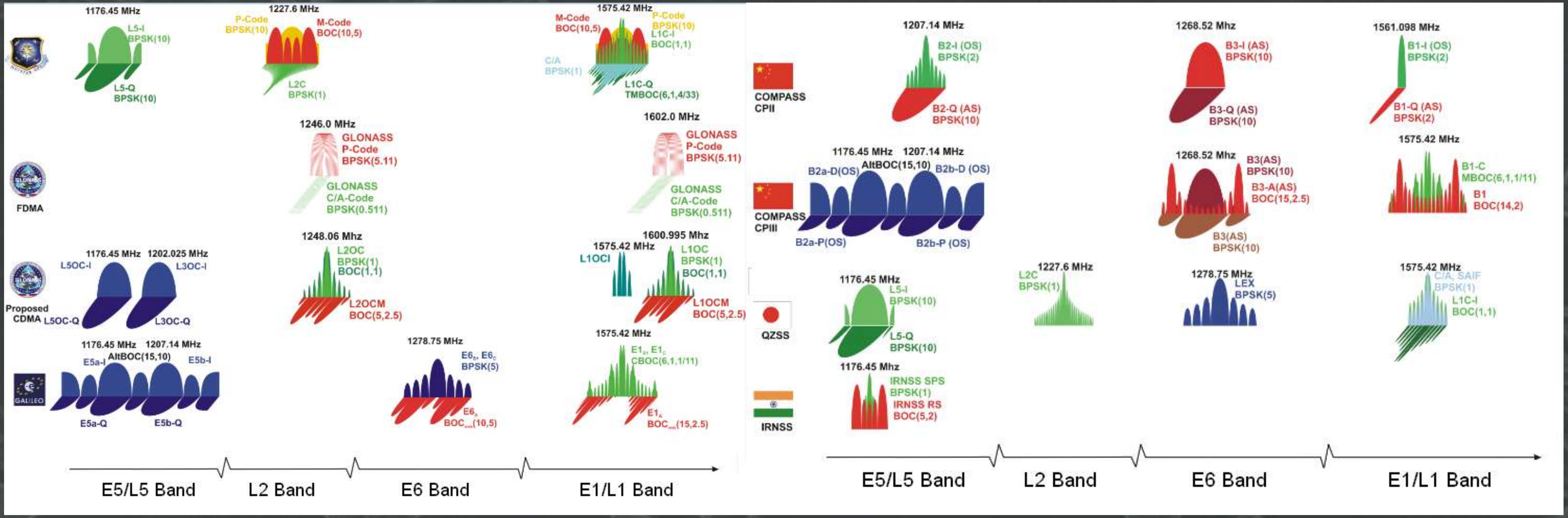


Basic Concept

- Signal – What / How are the information stored?
  - Code, Carrier, Navigation Messages
- Observables – What / How can we “measure”?
  - Pseudorange, Carrier phase
- Computation – How to use the above information?
  - Understand the Error Sources
  - Eliminate / Minimize the errors

Global Navigation Satellite Systems

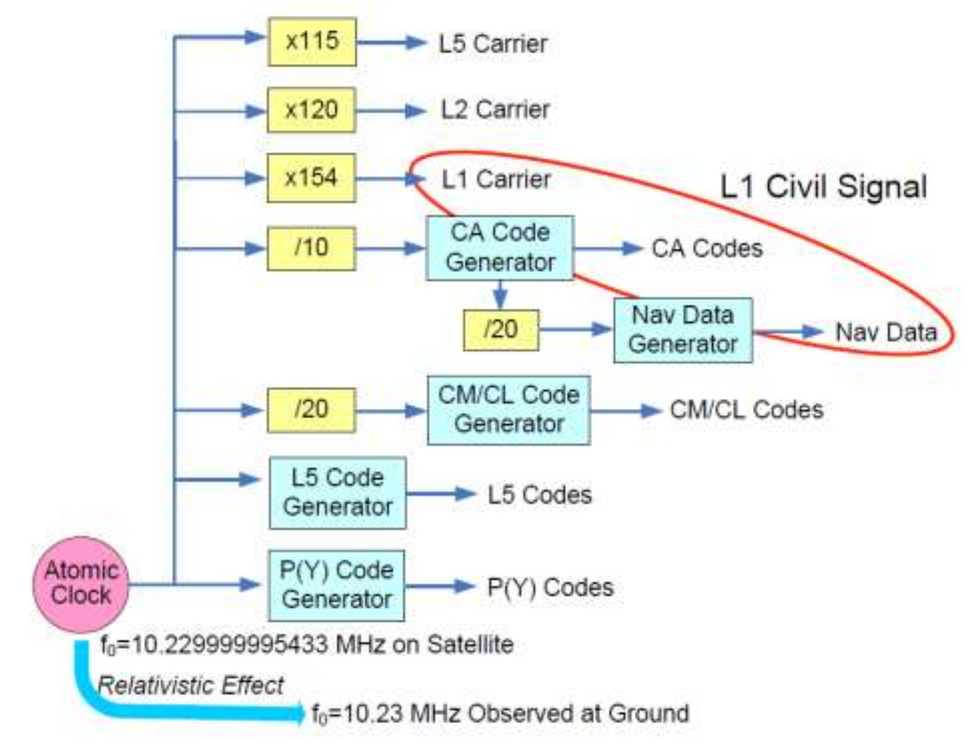
- Signals of GNSS Satellites



Global Navigation Satellite Systems

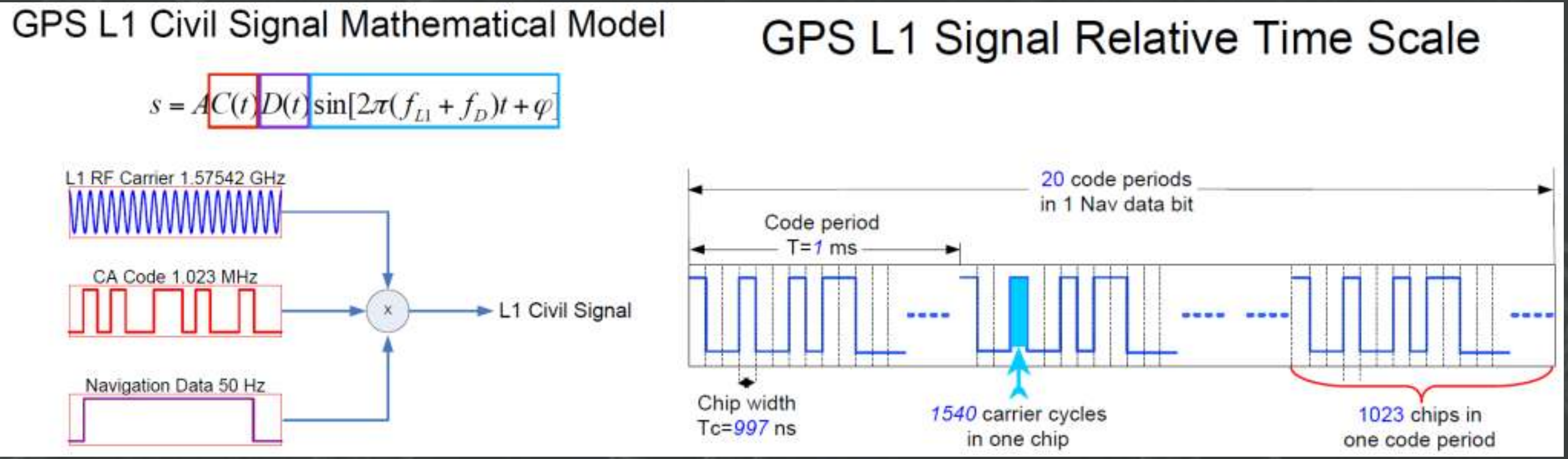
- Signals of GPS Satellites
  - Carrier Phase + Code

Band	L1		L2			L5	
Carrier freq (GHz)	1.57542		1.2276			1.17645	
Code	CA	P(Y)	P(Y)	CM	CL	CA	
Code length (chips)	1023	23,017,555.5		10,230	767,250	10,230	
Code period	1 ms	1 wk		20 ms	1.5 s	1 ms	
Chip rate (MHz)	1.023	10.23		1.023		10.23	
Data rate (bps)	50			25*	Data less	50*	Data less
Max power at receiver (dBW)	-157.7	-160.7	-163.7	-160		-154	



Global Navigation Satellite Systems

- Signals of GPS Satellites
  - Carrier Phase + Code

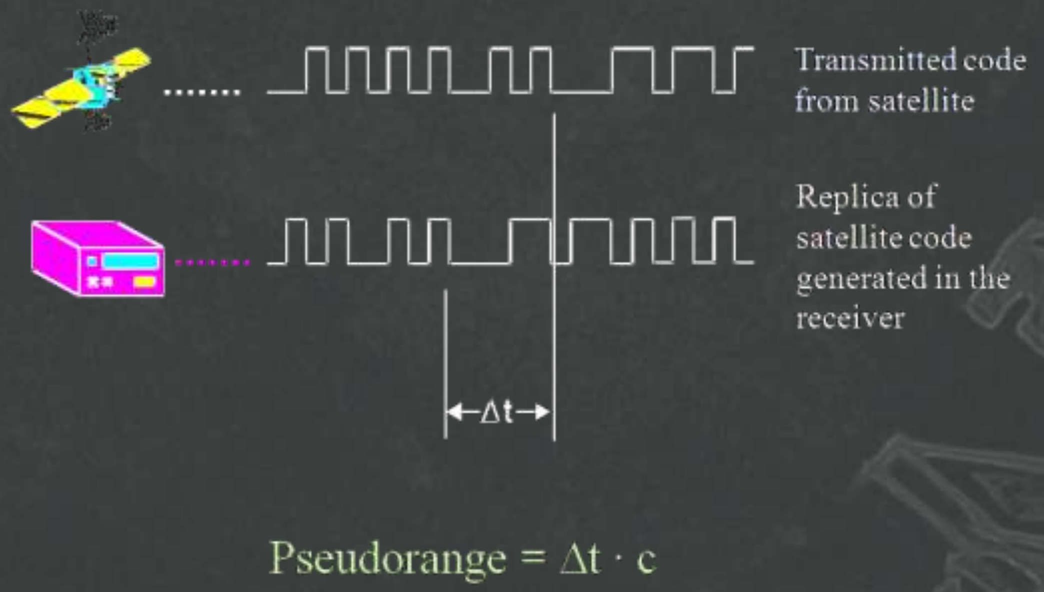


The Receiver

- Antenna receive the signal wave
- Decode / Demodulation (EM Wave to Digital)
- Observations
  - The Codes (C/A, P)
  - The Carrier (L1, L2)
  - Navigation Messages (Satellite Orbit Information)

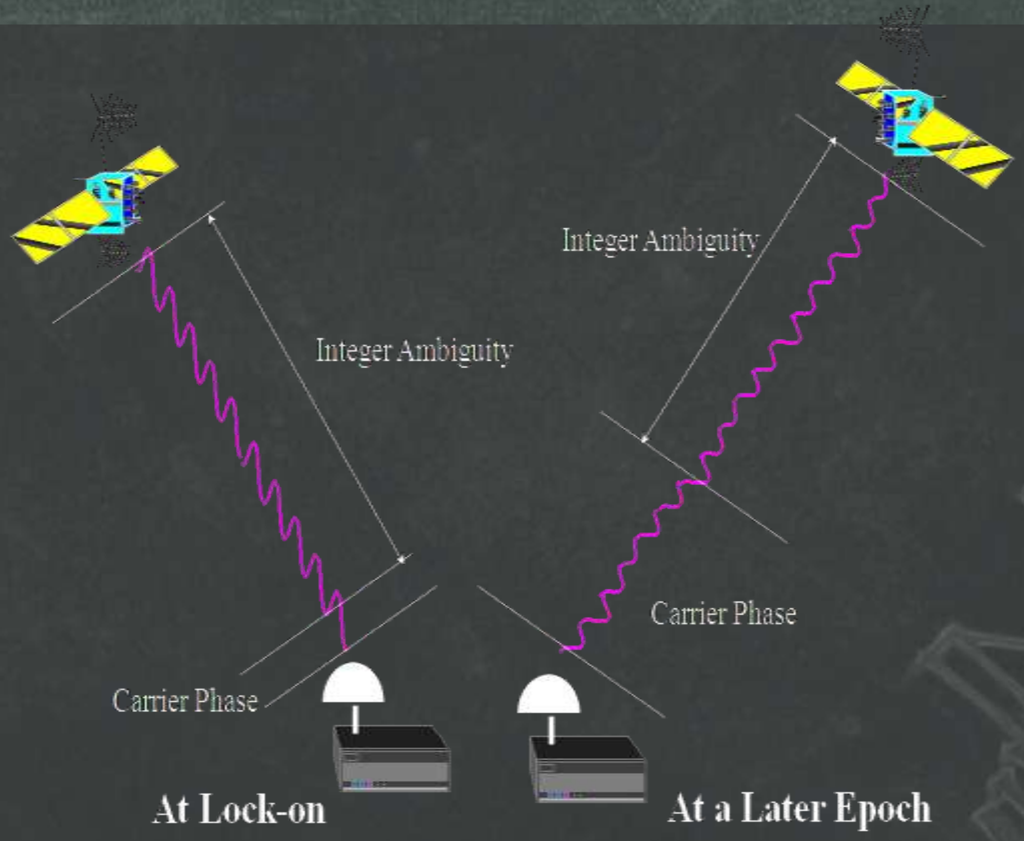
Pseudorange Measurement

- Measure the time delay (dt) to calculate the one-way range
  - Each satellite has a unique Gold Codes
  - Synchronised clocks in receiver and satellites
  - Receiver attempts to match received code with its own code
- “Pseudo”range = speed of light x dt
  - Range corrupted by Clock offsets, Atmospheric errors, Other error sources



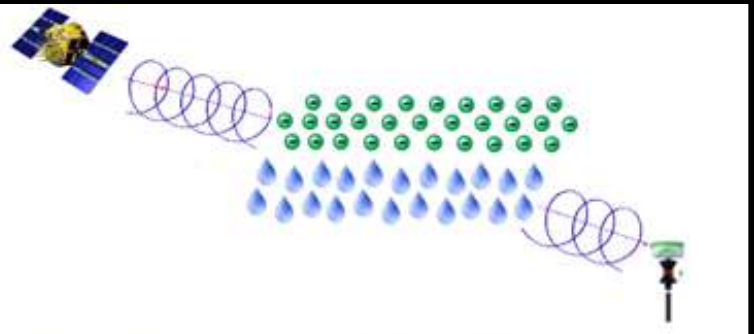
Carrier Phase Measurement

- Measure the Phase difference of L1/L2 carrier
  - Wavelength: about 19cm/24cm
  - Able to resolve up to 1/100 of wavelength (i.e. a few mm)
- Need to solve Integer ambiguity
- More difficult to access, measure and process



Factors affecting measurements

- Satellite
- Receiver
- Propagation
- Hardware
- Others



Error/effect type	Error/effect term
Satellite-related	Satellite orbit and clock errors
	Relativistic effect
	Satellite antenna phase center offset
	Phase wind-up
Propagation-related	Troposphere
	Ionosphere
Receiver-related	Receiver antenna phase center offset
	Sagnac effect
	Receiver clock error
	Solid earth tides
	Polar tides
	Ocean loading
	Earth rotation parameters
Hardware bias	Code bias (satellite/receiver)
	Phase bias (satellite/receiver)

Factors affecting measurements

Error source	Absolute influence	Relative influence
Satellite Orbit	2 … 50m	0.1 … 2 ppm
Satellite Clock	2 … 100m	0.0 ppm
Ionosphere	0.5 … >100 m	1 … 50 ppm
Troposphere	0.01 … 0.5 m	0 … 3 ppm
Multipath Code	m	m
Multipath Phase	mm … cm	mm … cm
Antenna	mm … cm	mm … cm

High Spatial Correlation (green)

Local (Calibration) (red)

Processing Observations

- Relative Positioning
  - Determine the vector between 2 receivers (Baseline)
  - Assumption: SIMILAR degree of errors during simultaneous observations
  - Solve integer ambiguity
  - Higher accuracy
- Differencing:
  - across receivers / satellites / time
- Cancel out the satellite and receiver clock errors

Processing Observations

- Propagation
  - Ionospheric effects
  - Tropospheric effects
- Baseline from known reference point
- Observations strategy
  - Dual-/Multi-frequency
  - Longer time observations
  - Shorter baseline
- Propagation errors can be effectively modelled and eliminated

Processing Observations

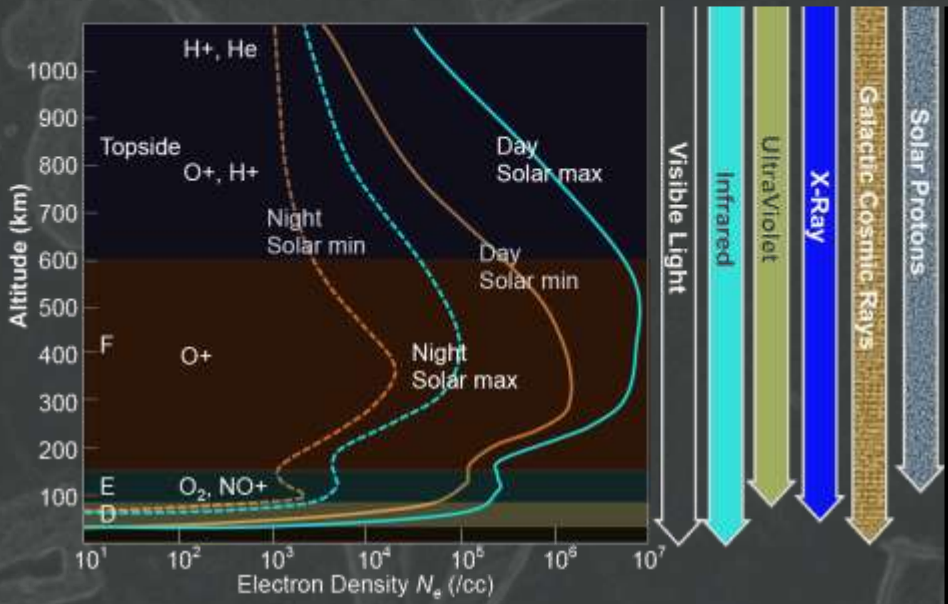
- The ionospheric code delay to GPS signal

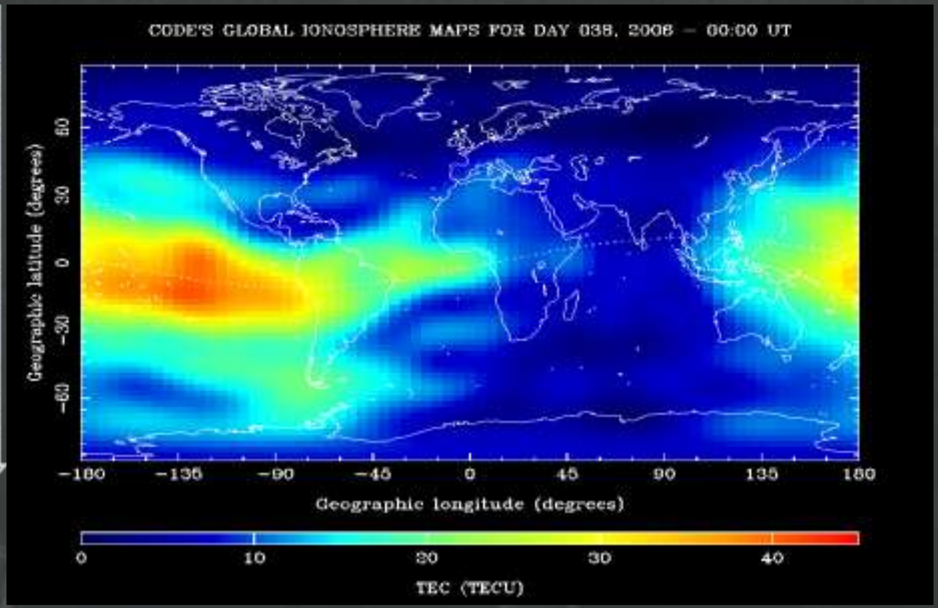
$$\Delta^{Iono} = \frac{1}{\cos z'} \cdot \frac{40.3}{f^2} TVEC$$

  - proportional to the integrated number of free electron along the transmission path (TVEC)
  - proportional to 1 / square of the transmission frequency (f)
  - proportional to 1/ cos (zenith angle from the ionospheric point, z')
- Magnitude: up to 30m
- Avoid low elevation observation and high ionospheric activity
- Solved by modelling and dual-frequency combination (about 22-27%)

Processing Observations

- Electron Density at different time of a day





Processing Observations

- Ionospheric scintillation

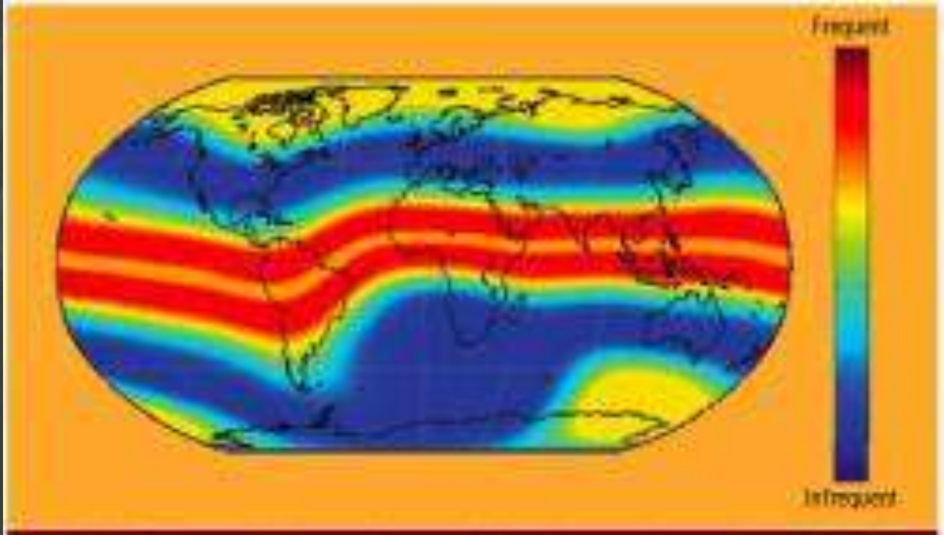
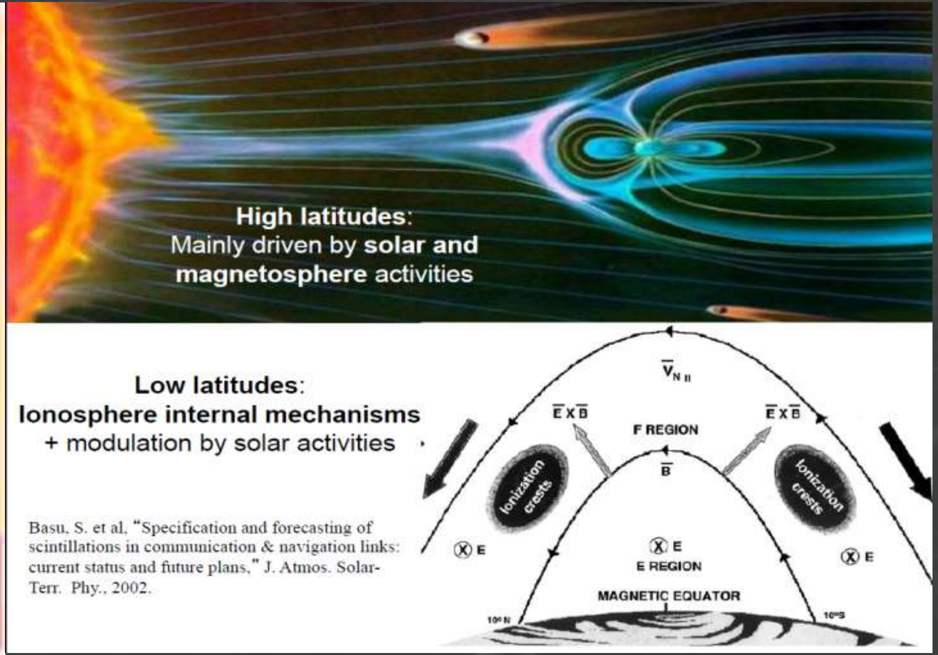


FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.



Processing Observations

- Troposhperic effects
  - Dry gases (primarily N2 and O2)
    - Causes zenith excess delay to approximately 2.3 m
    - varies with local temperature and atmospheric pressure
    - The dry atmosphere effect varies by less than 1% in a few hours
  - Water vapour
    - Cause delay in a smaller magnitude of 1-80 cm at zenith
    - Varies markedly 10-20% in a few hours
    - Less predictable even with surface humidity measurements

Processing Observations

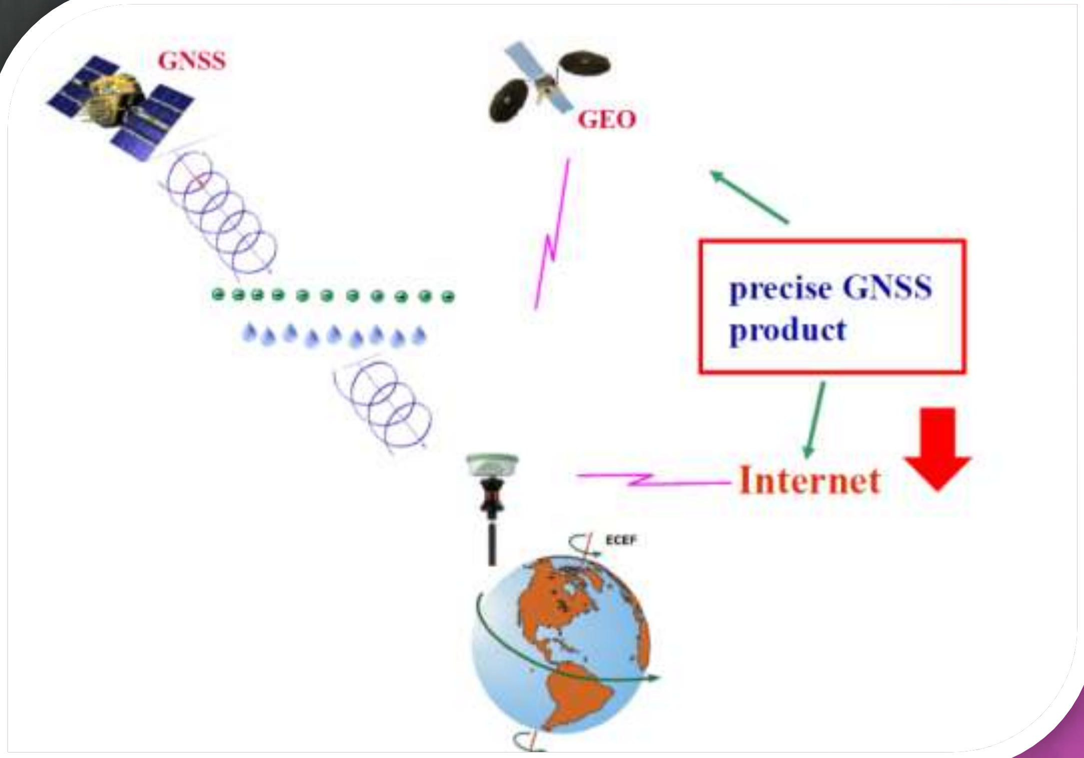
- Troposhperic effects
  - Prominent to signals at low elevation angles
  - Magnitude depends on the temperature, humidity and pressure, varies with the height of the user and the type of terrain below the signal path (Leick, 1995,: p.307)
- Solve by modelling and minimized by shorter baseline (<10km)
- May require metrological information for both reference and rover for longer baselines

Processing Observations

- Hardware error
  - Solved by calibrated models (e.g. Antenna model)
- Other error
  - Multipath
    - Avoid poor site condition
  - Satellite Orbit errors
    - Use precise orbits
- Always apply independent quality checks

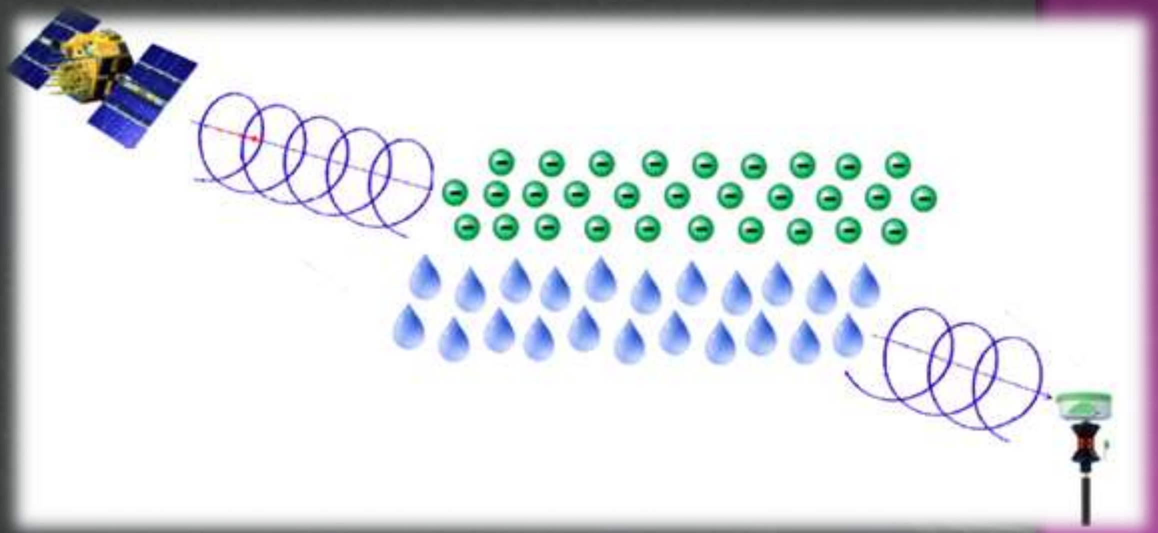
Precise Point Positioning (PPP)

- PPP: Positioning method based on the processing of GNSS observations from a single receiver and globally valid augmentation data (precise orbit and clock corrections and other corrections)
- Features
  - Single-receiver data processing (no baseline)
  - Absolute positioning (global consistent)
  - Requires precise orbit and clock corrections
  - Requires fractional phase bias corrections for ambiguity resolution
  - cm - dm positioning accuracy



Key Elements of Precise Point Positioning

- Error/effect mitigations
  - Subject to the effect of all error sources
  - Must mitigate every error source
- Require Precise GNSS augmentation data
  - Satellite orbit and clock correction data
  - bias correction data to recover the integer property of PPP phase ambiguity
- Positioning methods
  - Observation combinations
  - Positioning models
- Integer ambiguity resolution
  - To further improve positioning accuracy
  - To support real-time applications

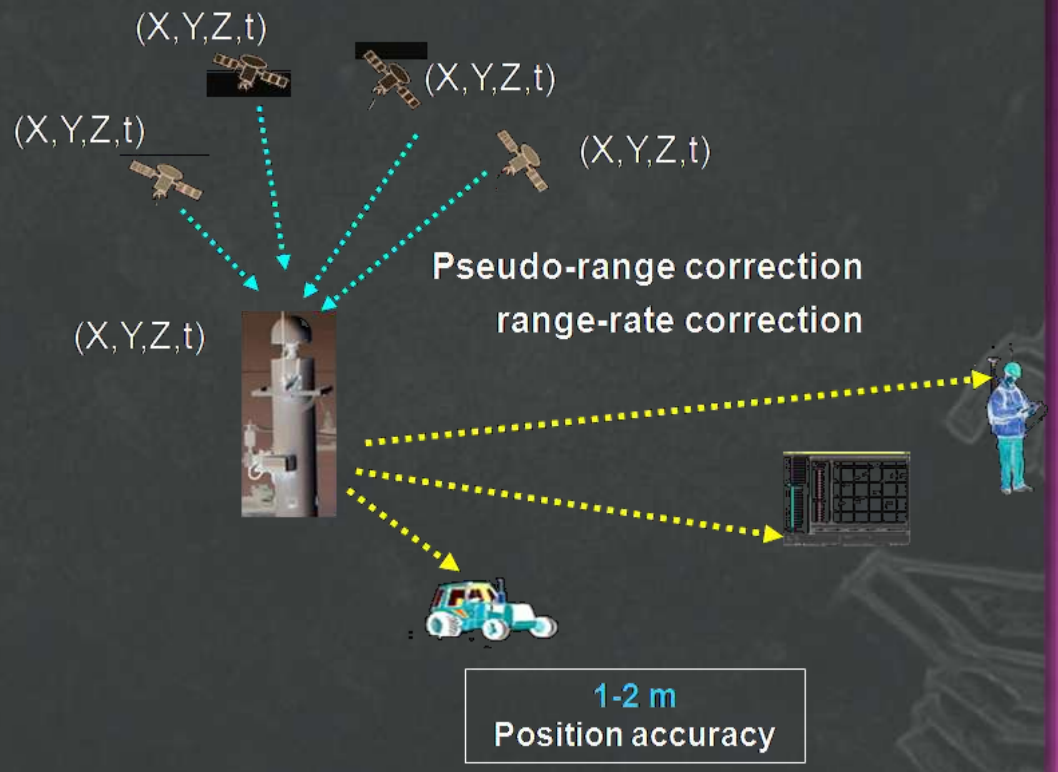


Real-time Satellite Positioning

- Stand-alone positioning: ~10m accuracy
- Static GNSS with baseline processing: cm-mm level
- Precise Point Positioning: cm-mm level
- Differential GNSS: meter level
  - Differential Range & Range Rate corrections
- Real-time Kinematic (RTK): cm level
  - Real-time Carrier Phase Observations
- Network RTK: cm-mm level

Real-time Satellite Positioning

- Differential GNSS
- Reference Station
  - Compare observed pseudoranges with reference
  - Check integrity of signal in space
  - Generate and broadcast range and range rate correction for each satellite
- Receiver
  - predict and apply the corrections to its own observations
- Calculate position with the corrected pseudoranges



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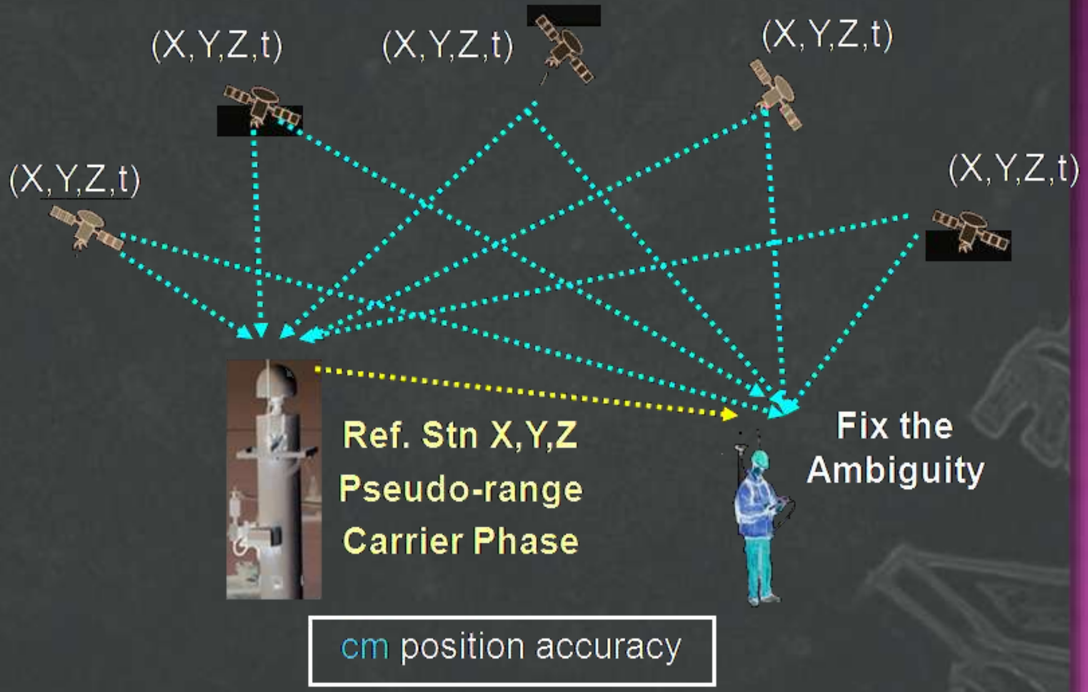
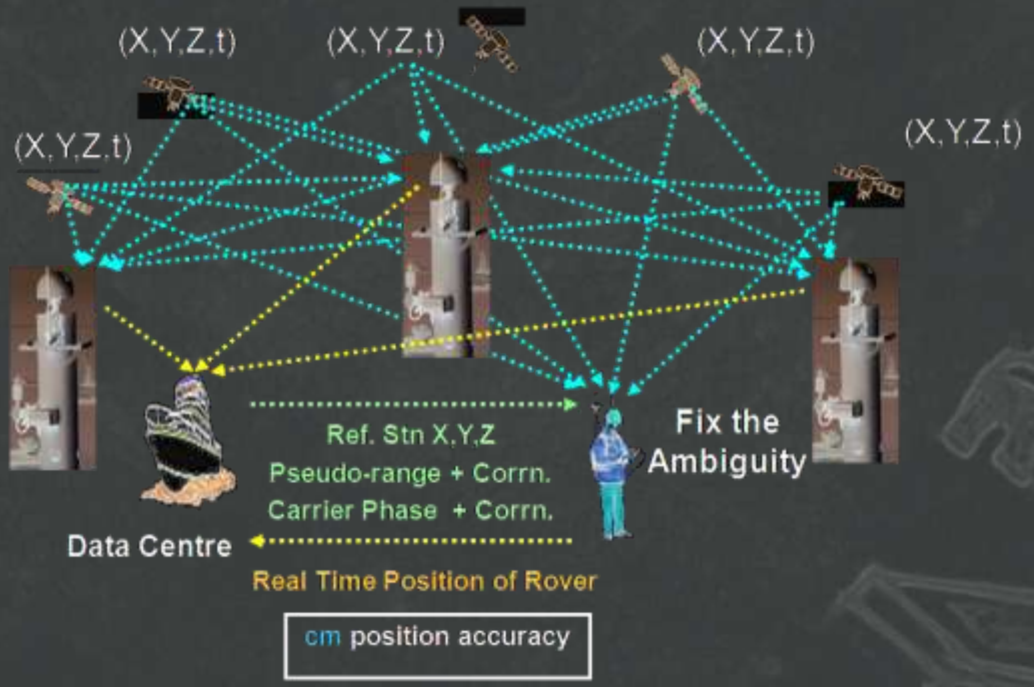
Real-time Satellite Positioning

- Real-Time Kinametic (Single RTK)
- Reference Station
  - Provide Reference coordinates
  - Send uncorrected Pseudorange & Carrier Phase observations
  - “Broadcast” mode: no computation required
- Rover Receiver
  - Fix the ambiguity and error modeling within short observation period
  - Process the reference + rover observed baselines in real-time



Real-time Satellite Positioning

- Network RTK
  - A network of reference stations to model the errors
- Rover
  - Send its approximate location to Data Center
- Receivers & Data Center
  - Determine the corrections for the individual users base on its position
  - Send modelled-corrections and observations back to user
- Rover
  - Process the received observations and corrections similar to RTK

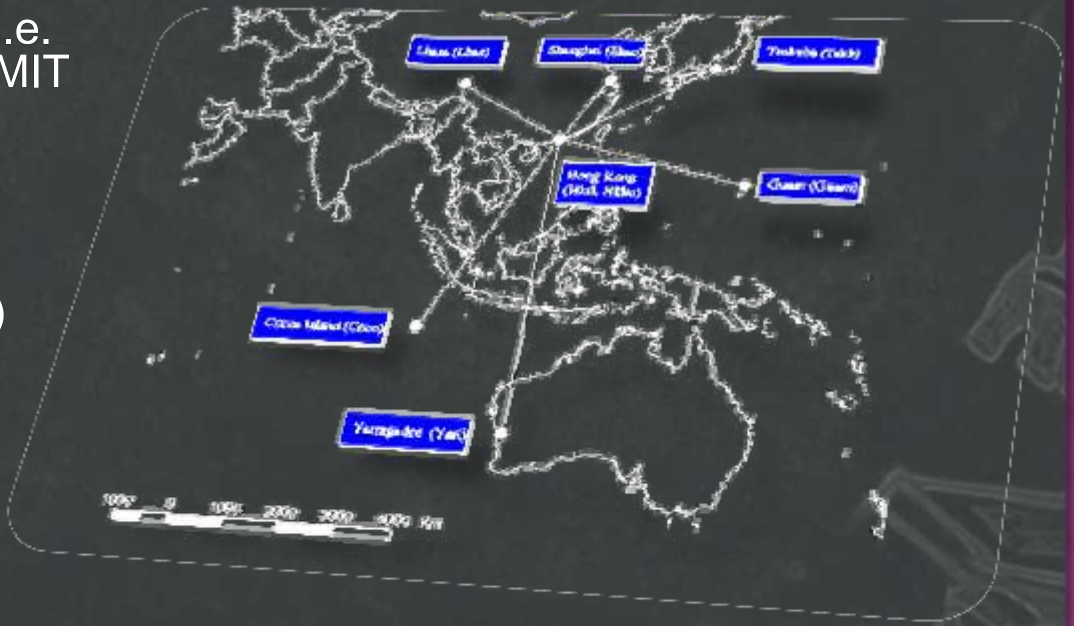


Hong Kong GPS Control Station Network

- 1990s
  - SMO started to apply the GPS technique
  - No. 512 Specialist Team, Engineers of the U.K. Military Survey started a Territory wide observation on a network of 15 stations in Hong Kong + 3 stations in Macau using GPS and Doppler satellite techniques
  - Provided a rigid link between the local HK1980 Datum and WGS84

Hong Kong GPS Control Station Network

- 1999
  - PolyU to compute the ITRF96(1998:121) (i.e. as at 1st May 1998) coordinates using GAMIT software for:
    - Trig. No. 75 (Kau Yi Chau)
    - Trig. No. 430 (Fanling)
  - SMO to provide Observation Data
  - Link to 6 International GNSS Service (IGS) Reference Stations
    - Lhasa (China)
    - Shanghai (China)
    - Tsukuba (Japan)
    - Guam (United States)
    - Yarragadee (Australia)
    - Cocos Island (Australia)
  - Connect to the International Terrestrial Reference Frame (ITRF)



Hong Kong GPS Control Station Network

- Hong Kong GPS 2000 Network
  - Adopted ITRF96 Coordinate of Trig. No. 75 as origin
  - Computed ITRF96 Coordinates of 46 existing Trig Stations
  - Determined the Transformation Parameters between Hong Kong 1980 Geodetic Datum and ITRF96
- Support static baseline processing & RTK survey

Hong Kong Satellite Positioning Reference Station Network

- Hong Kong Satellite Positioning Reference Station Network (SatRef)
  - Developed by SMO, Lands Department since 2001
  - 12 Continuous Operating Reference Stations (CORS)
    - 7 x 24 observations
  - 3 Integrity Monitoring Stations
  - Data Centre and Control Centre
    - Data Process and Management
    - Data Services delivered via Internet
    - Support high accuracy positioning

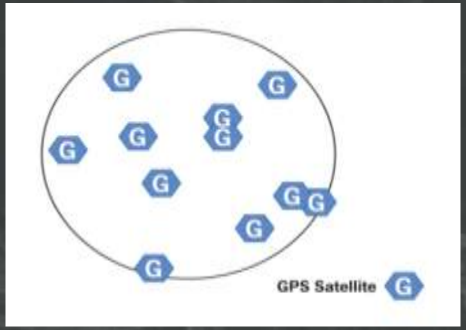
Hong Kong Satellite Positioning Reference Station Network

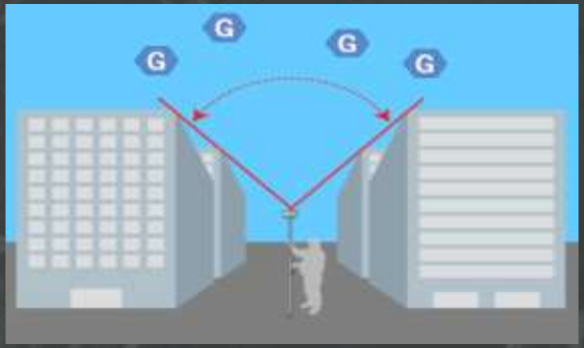
Hong Kong Satellite Positioning Reference Station Network

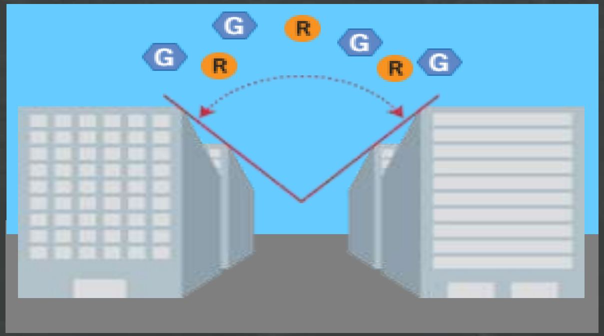
- SatRef Data Services
  - June 2006
    - Open to Government Departments & Contractors
  - February 2010
    - Open to Public for Free
  - Data Services:
    - RINEX Data Services
      - High precision & reliability positioning (Static Post-processing)
    - Network RTK Data Services
      - cm-level real time positioning
    - DGPS Data Services
      - m-level real time positioning

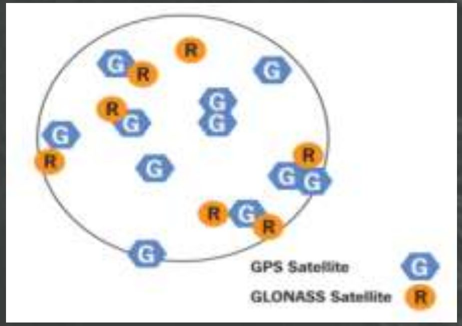
Hong Kong Satellite Positioning Reference Station Network

- 2013
  - Receive GLONASS Signal
  - Provide GPS+GLONASS Data Services



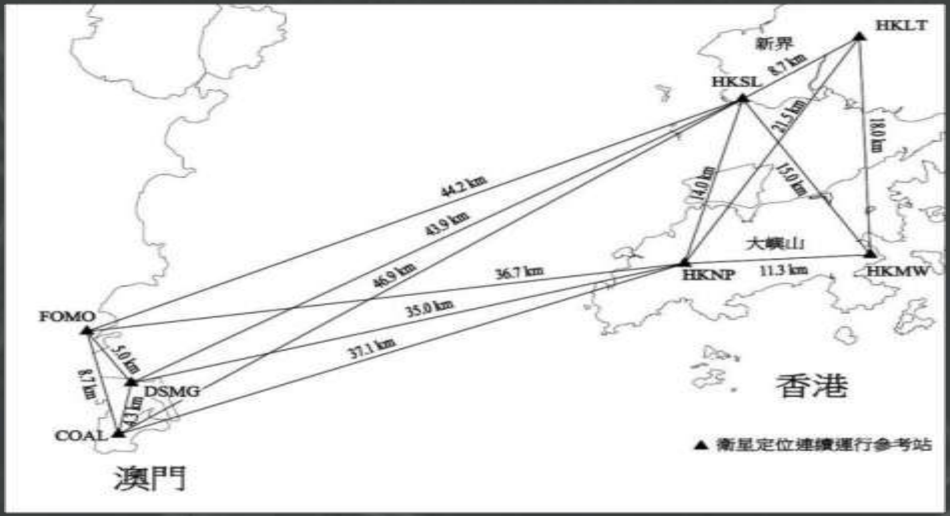






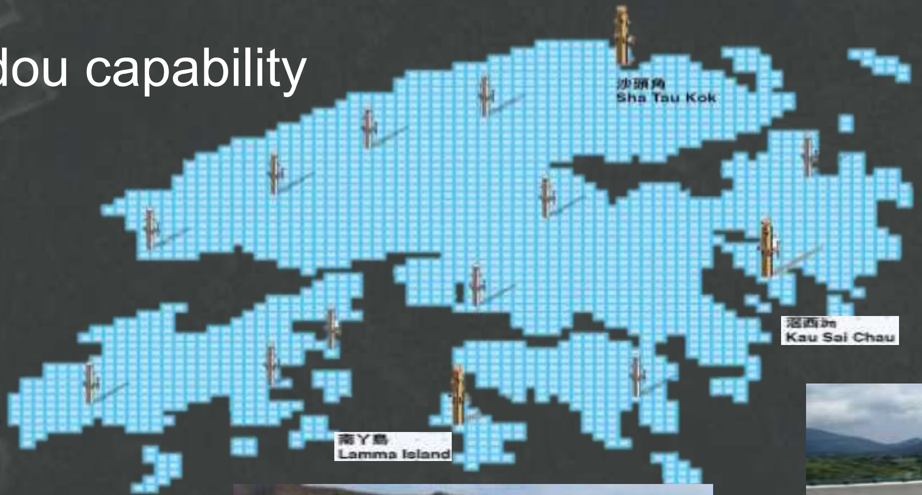
Hong Kong Satellite Positioning Reference Station Network

- 2013
  - Connect with Macao Network
  - Data Sharing



Hong Kong Satellite Positioning Reference Station Network

- 2013
  - 3 CORS with Beidou capability
    - Sha Tau Kok
    - Kau Sai Chau
    - Lamma Island



Hong Kong Satellite Positioning Reference Station Network

- 提升定位能力 Enhance positioning capability
- 提升生產力 Improve productivity
- 能於狹窄的天窗下獲得衛星定位成果 Availability in areas with limited sky window
- 改善定位精準度 Improve positioning accuracy
- 減低運作成本 Reduce operation cost

6. Network adjustment and transformation

- Network adjustment
  - Lease square adjustment
    - Observation equations: Model the relationship between observations, unknowns and the residuals
    - Can combine different types of observations
    - Overall best-fitted solution: Minimizes the sum of the squares of the residuals made in the results of every single equation
    - Approximation and weights can be added

Network adjustment and transformation

- Network adjustment
  - Surveying applications:
    - Solve coordinates of unknown points using angular / distance / levelling / GNSS / photogrammetric measurements
    - Error estimation / pre-analysis
    - Transformation of coordinates
    - Calibration of equipment

Network adjustment and transformation

- Network adjustment
  - Example:
    - Bowditch adjustment of traverses
    - Levelling loop/network adjustment
    - GNSS Baseline with terrestrial observations
    - EDM calibration
    - Transformation of coordinates between ITRF and HK 1980

Network adjustment and transformation

- Coordinate Transformation
  - Convert GNSS Survey Result to Hong Kong 1980 Grid + HKPD
    - Reference Stations: HK GPS 2000 Network / SatRef
    - Latitude / Longitude in WGS84 Datum (Reference Frame: ITRF96)
    - Height above ellipsoid
  - Perform Horizontal & Vertical Transformation separately
    - “2-step transformation”
    - Adopt global/local Geoid and relationship between Geoid surface & HKPD

Network adjustment and transformation

$$\tan\lambda = \frac{Y}{X}$$

$$\tan\phi = \frac{Z + e^2 \upsilon \sin\phi}{\sqrt{X^2 + Y^2}}$$

$$H = (X \sec\lambda \ \sec\phi) - \upsilon$$

WGS84 Datum
Geographic Coordinates

Latitude	ϕ
Longitude	λ
Ellipsoid Height	H

WGS84 Datum
Cartesian Coordinates

X,Y,Z

$$X = (\upsilon + H)\cos\phi \cos\lambda$$
$$Y = (\upsilon + H)\cos\phi \sin\lambda$$
$$Z = ((1 - e^2)\upsilon + H)\sin\phi$$

where a = semi-major axis of the reference ellipsoid

f = flattening of the reference ellipsoid

e^2 = first eccentricity of reference ellipsoid

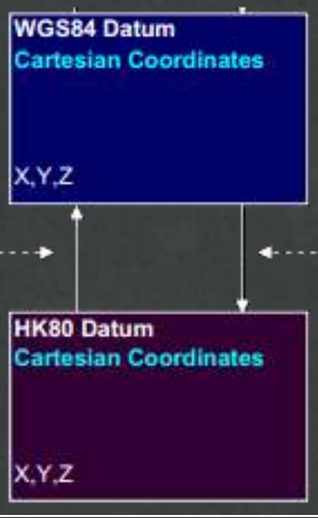
$= 2f - f^2$

υ = radius of curvature in prime vertical

$$= \frac{a}{\sqrt{(1 - e^2 \sin^2\phi)}}$$

Network adjustment and transformation

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} (1+S) & \theta_z & -\theta_y \\ -\theta_z & (1+S) & \theta_x \\ \theta_y & -\theta_x & (1+S) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{HK80}$$



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{HK80} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} (1+S) & \theta_z & -\theta_y \\ -\theta_z & (1+S) & \theta_x \\ \theta_y & -\theta_x & (1+S) \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84}$$

	From : ITRF96 (at epoch 1998:121) To : HK80 Geodetic Datum	From : HK80 Geodetic Datum To : ITRF96 (at epoch 1998:121)
X : Shift along x-axis	162.619 m	-162.619 m
Y : Shift along y-axis	276.961 m	-276.959 m
Z : Shift along z-axis	161.763 m	-161.764 m
θ_x : Rotation about x-axis	0.067741 "	-0.067753 "
θ_y : Rotation about y-axis	-2.243649 "	2.243648 "
θ_z : Rotation about z-axis	-1.158827 "	1.158828 "
S : Scale factor	1.094239 ppm	-1.094246 ppm

Network adjustment and transformation

HK80 Datum
Cartesian Coordinates

X,Y,Z

$$X = (\upsilon + H)\cos\phi\cos\lambda \quad (*4)$$
$$Y = (\upsilon + H)\cos\phi\sin\lambda$$
$$Z = ((1 - e^2)\upsilon + H)\sin\phi$$

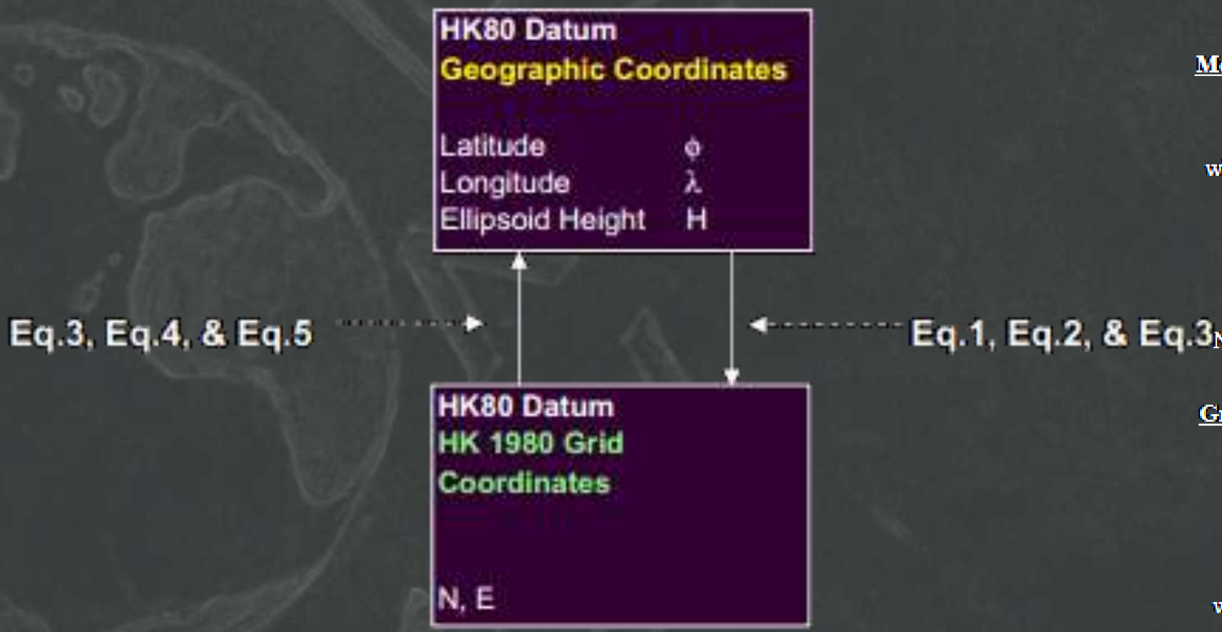
$$\tan\lambda = \frac{Y}{X}$$
$$\tan\phi = \frac{Z + e^2\upsilon\sin\phi}{\sqrt{X^2 + Y^2}}$$
$$H = (X\sec\lambda\sec\phi) - \upsilon$$

HK80 Datum
Geographic Coordinates

Latitude	ϕ
Longitude	λ
Ellipsoid Height	H

where
- a = semi-major axis of the reference ellipsoid
- f = flattening of the reference ellipsoid
- e^2 = first eccentricity of reference ellipsoid $= 2f - f^2$
- υ = radius of curvature in prime vertical $= \dfrac{a}{\sqrt{(1 - e^2\sin^2\phi)}}$

Network adjustment and transformation



Projection Formulae

Φ, λ to Grid co-ordinates

$$N = N_0 + m_0\{(M - M_0) + \upsilon_s (\sin \Phi)(\frac{\Delta\lambda^2}{2})(\cos \Phi)\} \quad \text{–(Eq. 1)}$$

$$E = E_0 + m_0\{\upsilon_s \Delta\lambda \cos \Phi + \upsilon_s \frac{\Delta\lambda^3}{6} (\cos^3 \Phi)(\psi_s - t^2) \} \quad \text{–(Eq. 2)}$$

Meridian distance, M

$$M = a [A_0'\Phi - A_2' \sin (2\Phi) + A_4' \sin (4\Phi)] \quad \text{–(Eq. 3)}$$

where $A_0' = 1 - \frac{e^2}{4} - \frac{3e^4}{64}$

$A_2' = \frac{3}{8}(e^2 + \frac{e^4}{4})$

$A_4' = \frac{15}{256} e^4$

Notes:
1. M_0 is computed using Eq. 3 by putting $\Phi=\Phi_0$ (Latitude of the projection origin.)
2. λ, Φ are in radian.

Grid Co-ordinates to Φ, λ

$$\lambda = \lambda_0 + \sec\Phi_p (\frac{\Delta E}{m_0 \nu_\rho}) - \sec\Phi_p (\frac{\Delta E^3}{6 m_0^3 \nu_\rho^3})(\psi_p + 2t_p^2) \quad \text{–(Eq. 4)}$$

$$\Phi = \Phi_p - (\frac{t_\rho}{m_0 \rho_\rho})(\frac{\Delta E^2}{2 m_0 \nu_\rho}) \quad \text{–(Eq. 5)}$$

where $\Delta N = N - N_0$

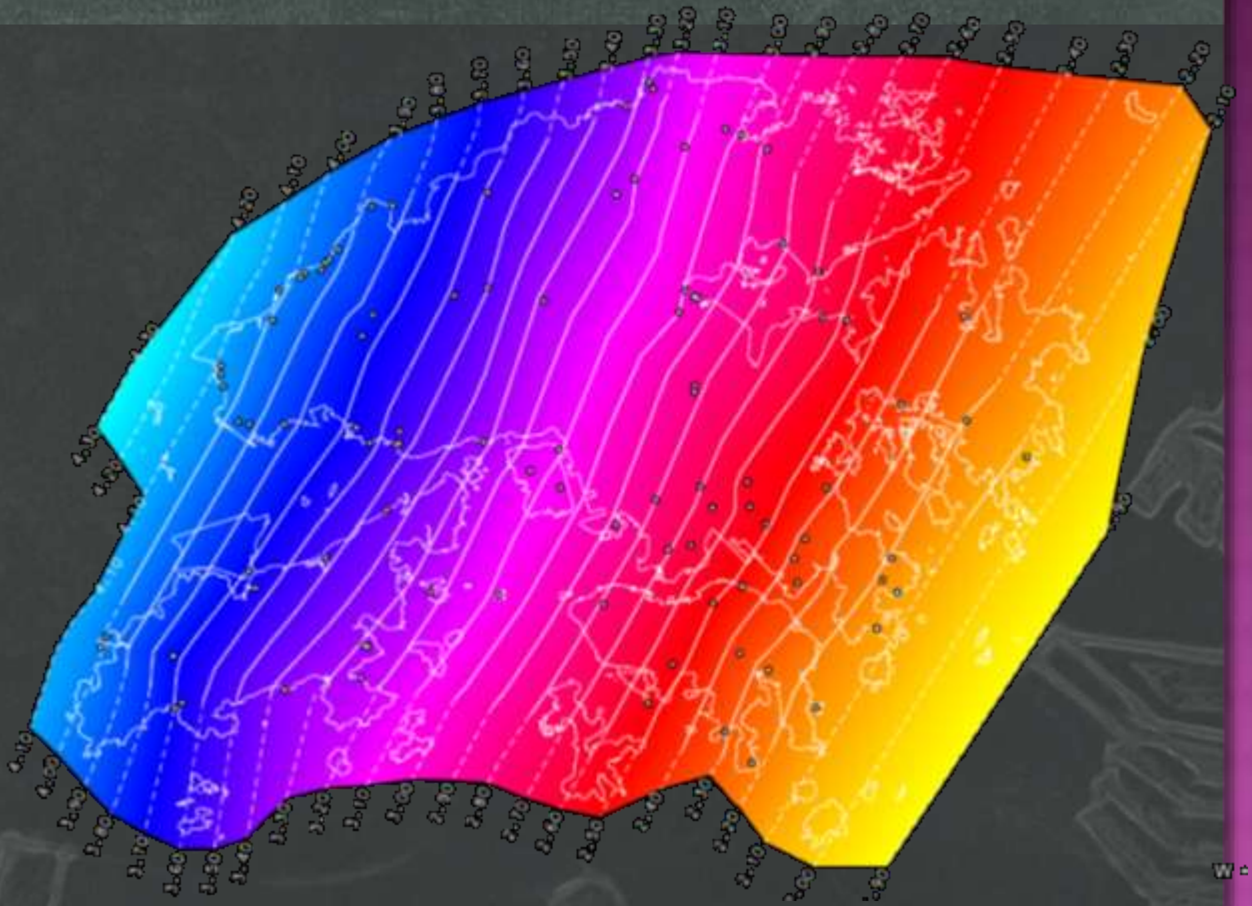
$\Delta E = E - E_0$

and Φ_p is the latitude for which $M = (\Delta N + M_0) / m_0$

Notes:
1. Φ_p must be computed by iteration using Eq. 3.
2. All other quantities, such as t_p, ρ_p, υ_p, ψ_p have their usual meanings but are computed using Φ_p.

Network adjustment and transformation

- Vertical Transformation
  - WGS84 – HKPD:
    - From -2.1m to -4.3m
    - Similar gradient across HK
  - Can be simplified as difference between 2 flat plane surfaces in space



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Network adjustment and transformation

- “2-step transformation”
  - Horizontal Transformation
  - Determine the local dH
    - Interpolation with reference to “Control Points for Height Model”
    - Adopt dH of nearby Points
  - Apply the dH to the measured ellipsoid heights

7. High order measurements and corrections

- Survey measurements
  - Distances and Angles (Horizontal / Vertical)
    - Tape measurements
    - EDM measurements
    - Levelling
    - Theodolite / Total Station
    - Laser scanning / LiDAR
  - Photogrammetric measurements
  - GNSS observations

High order measurements and corrections

- Errors in survey measurements
  - Gross Errors
    - Mistakes, Typo / Booking errors, Wrong assumptions / procedures, etc.
    - Significant & Unpredictable
  - Systematic Errors
    - Instrumentations, Environmental conditions, etc.
    - Repeatable under the same measurement conditions
    - Same magnitude and sign (+/-)
  - Random Errors
    - Unpredictable and are often caused by factors beyond the control
    - Under laws of probability and statistics

High order measurements and corrections

- Tape Measurement
  - Zero Error / Graduation Error
  - Temperature correction
  - Tension correction
  - Sag correction
- Calibration with Reference Tape / Standard length baseline
- Laboratory test
- Apply various corrections

High order measurements and corrections

- EDM Measurement
  - Prism / Constant Error / Scale Error / Cyclic Error
  - Curvature and Reflection correction
  - Reduction to Spheroidal distance
- Calibration with Standard length baseline
- Laboratory test
- Reciprocal observations / Simultaneous reciprocal observations
- Independent set of observations in different environment

High order measurements and corrections

- Levelling
  - Levelling staff zero / graduation error
  - Collimation error
  - Curvature & Refraction
  - Ground heating
- Regular checking of levelling staff
- Procedures
  - Two-peg tests before field work
  - Even number of setups
  - Avoid long / uneven levelling legs
  - Avoid readings close to ground
- Reciprocal observations / Simultaneous reciprocal observations
- Gravitational corrections

High order measurements and corrections

- Theodolite / Total Station
  - Errors of the axis / planes
  - Centering / Levelling
  - Curvature and Reflection
- Laboratory test
- Regular checks
- Face Left / Right
- Reciprocal vertical angles observations / Simultaneous reciprocal observations

High order measurements and corrections

- Steel Band Baseline
  - Hong Kong: Former LegCo Building (Closed)
  - Kowloon: Science Museum
  - NT: North District Government Office
- EDM Calibration
  - Plover Cove EDM Calibration Baseline
  - Maintained by SMO, Lands Department
- GNSS Calibration
  - Ap Lei Chau Calibration Network

Standard Length of Plover Cove EDM Calibration Baseline

Location of Baseline : Plover Cove Reservoir, Tai Po, New Territories

Approximate location described in HK1980 Grid Coordinates : (835 800 mN , 842 900 mE)

Date of Calibration : 26 September 2013

Baseline Section	Baseline Length (in metre)
0 - 1	29.980
0 - 2	99.966
0 - 3	179.964
0 - 4	300.002
0 - 5	470.016
0 - 6	520.011
0 - 7	1000.056
R - E	2065.910

Marks Description : -

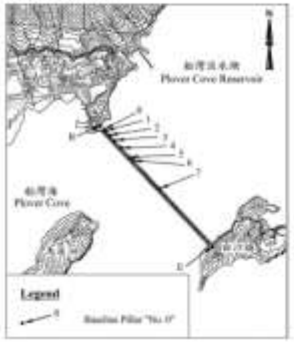
This EDM calibration baseline consists of ten concrete pillars with forced centring plates.

The Pillar numbers are 0, 1, 2, 3, 4, 5, 6, 7, R and E.

Standard error of the baseline length :

±(1 mm + 1 ppm)

Location Diagram :



Not to scale

Photograph of the baseline pillars

Remarks :

Booking of the EDM baseline can be made through the SSO/GI, Geodetic Survey Section of Lands Department at Tel. : 2231 3497 or by Fax : 2116 0778.

Geodetic Survey Section
Survey and Mapping Office
Lands Department

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High order measurements and corrections

- Understand the accuracy of each equipment / method
  - Sources of errors
  - Corrections required
  - Assumptions / precautions
  - Proper field procedures
- Pre-analysis for survey design
- Redundancy of observations
- Independent checking / verification
- Network Adjustment

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Thank you