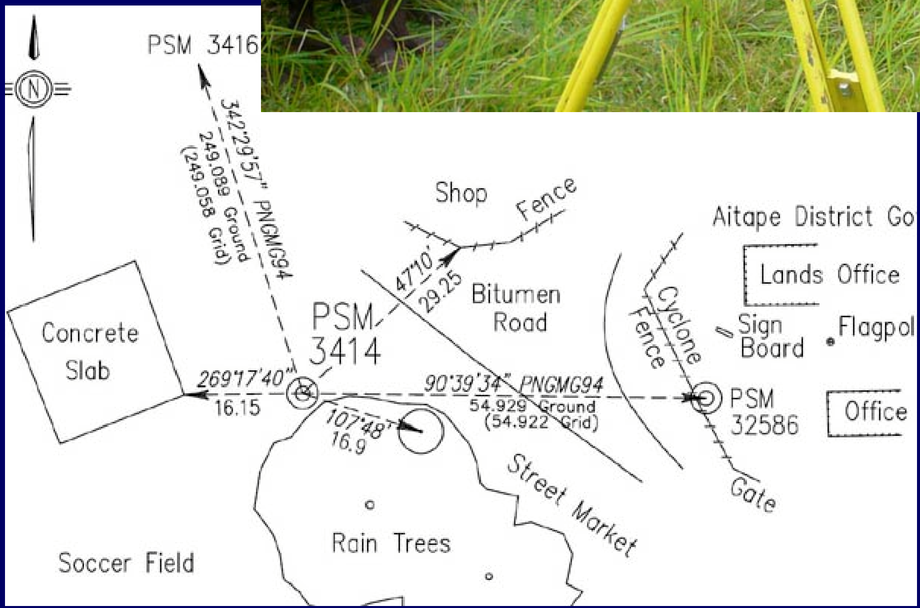
43rd Association of Surveyors PNG Congress, Lae, 12th-15th August 2009



Connecting a Cadastral Survey to PNG94 using GNSS

Richard Stanaway *QUICKCLOSE*

Workshop overview

Legal requirements to connect surveys to PNG94

Accuracy and Precision - Positional & Local Uncertainty

What GNSS equipment and technique to be used

Network design and observing procedure

Loop closures, fault finding and adjustment

Grid to Plane computations

Worked example

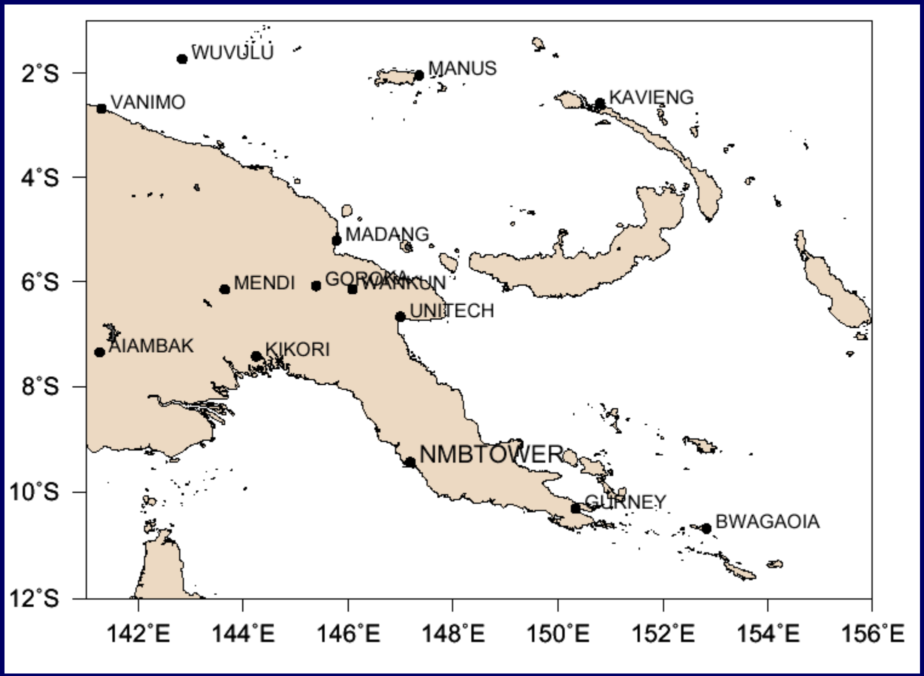
What is PNG94?

14 Stations around PNG surveyed by GPS between 1992 and 1994

5 cm accuracy

UTM Grid Projection is PNGMG94

Offset from WGS84 >1.5m



Gazetted national geodetic datum for PNG

Legal Requirements

Cadastral surveys to be connected to PNG94
(e.g. via connected PSMs)

A closed loop survey or double check is required
(for quality assurance)

Coordinates for survey should be legally traceable
(by proven connection to PNG94)

WGS84 and uncorrected ITRF not acceptable
for Cadastral Surveys in PNG (no datum point)

Handheld GNSS/GPS not acceptable
(no quality assurance or traceability)

Distances to be converted to local “ground” distance
(Grid distance is not a legal boundary dimension)

Pros. of using GNSS

mm / cm accuracy over hundreds of km

No line of sight required

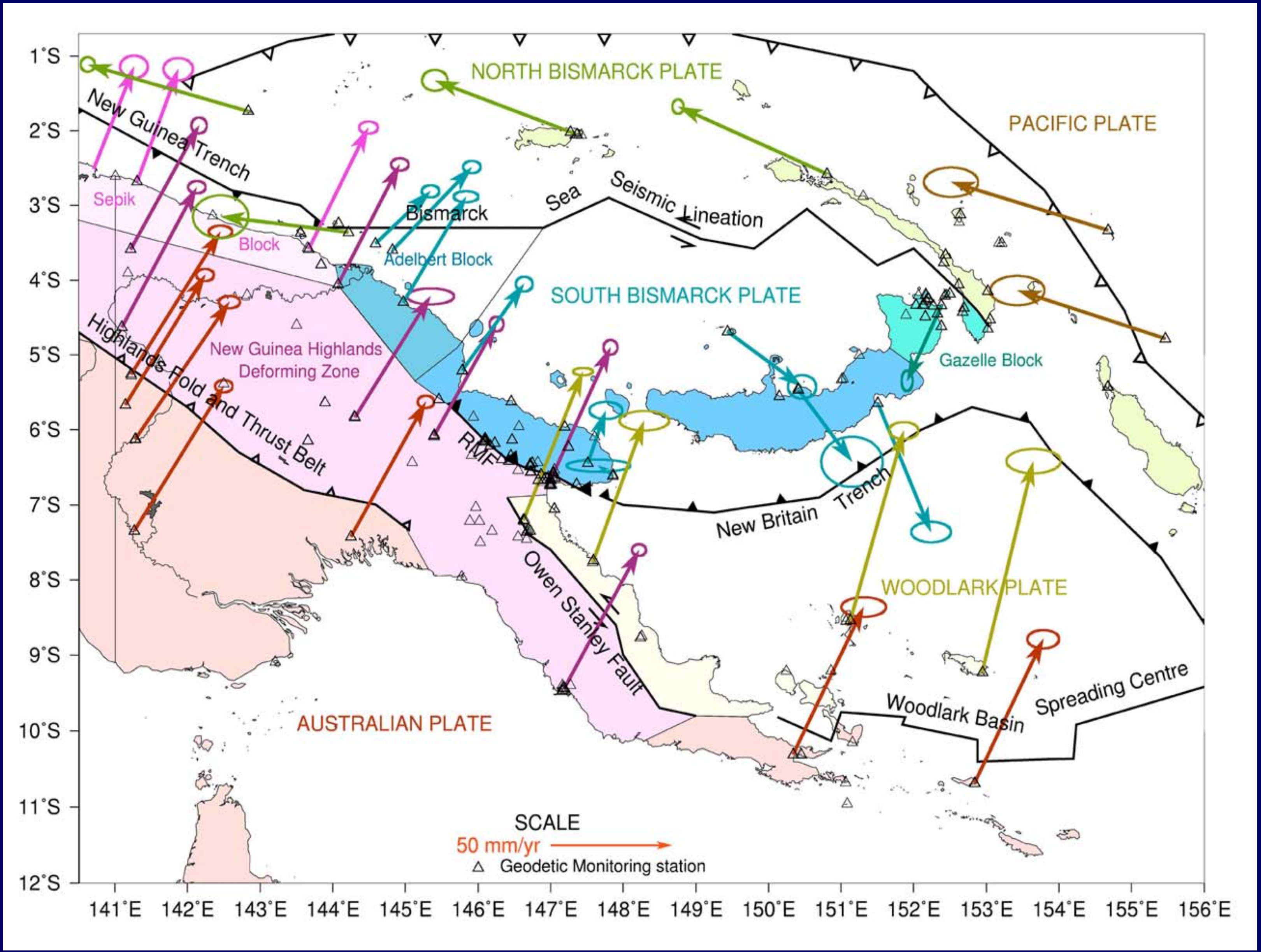
Fast

Cons. of using GNSS

Needs clear view of sky (requires tree clearing)

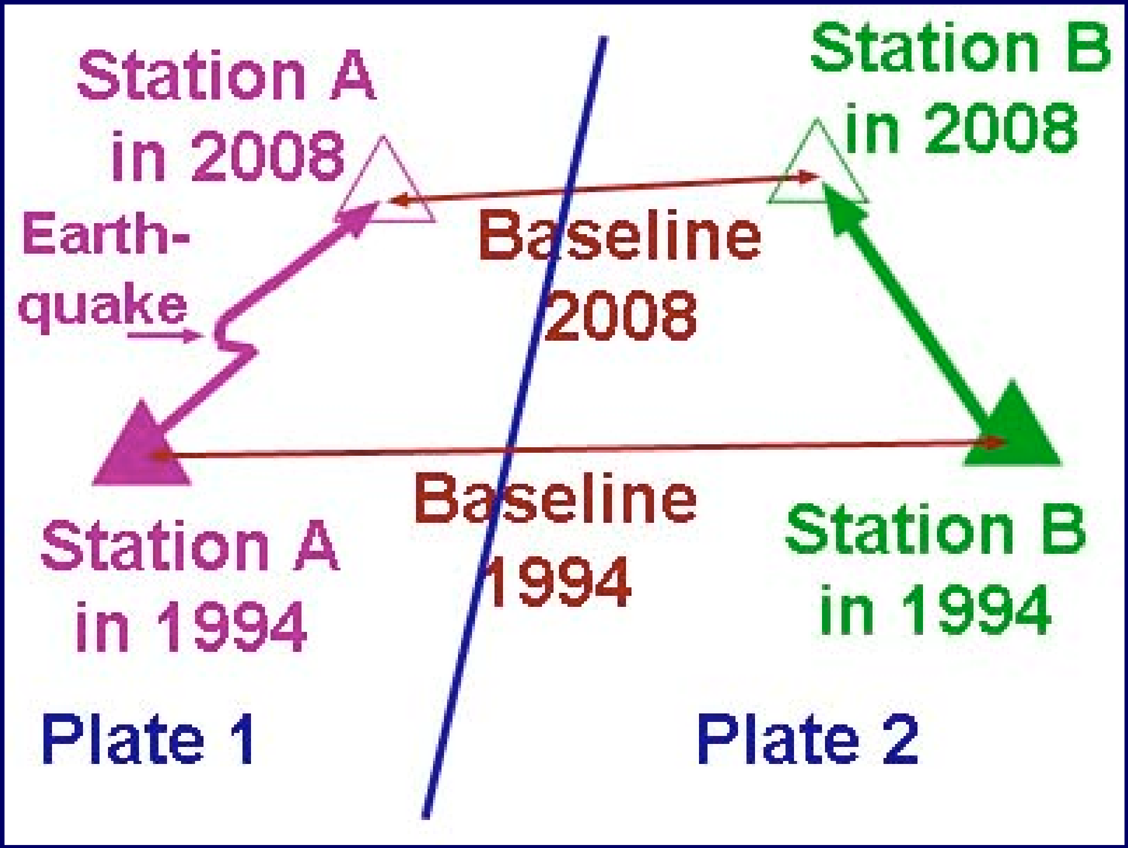
Large errors if incorrect technique used

Accuracy can cause problems!
(e.g. unmodelled tectonic deformation)



PNG site velocities and plates **Ellipses show error ell.**

Effect of tectonic deformation on survey baselines & PNG94



May need to use a model to get back to 1994 coordinates

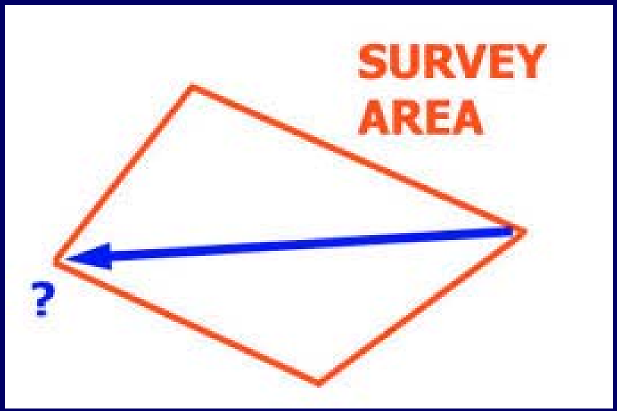
The guiding principle is that PNG94 coordinates for any point should not change from where they were on 1/1/94

Positional Uncertainty (PU)

How accurate a coordinate is with respect to PNG94

Local Uncertainty (LU)

How precise a coordinate is in relation to adjoining survey control or cadastral corners



Suggested PU and LU for PNG Cadastral Surveys

Classification	Application	Suggested Positional Uncertainty (PU)	Suggested Local Uncertainty (LU)
Urban Class 1	Urban, residential, commercial	100 mm	30 mm
Rural Class 1	Land used for resource extraction, utilities, pipelines	300 mm	100 mm
Rural Class 2 (A)	smaller settlement blocks	1 m	300 mm
Rural Class 2 (B)	larger settlement blocks	2 m	500 mm
Rural Class 3	Customary Registration of rural land for individuals or families	10 m	3 m
Rural Class 4	Other Customary Land surveys	30 m	10 m

PNG Cadastral surveying accuracy requirements (derived from *PNG Survey Directions, 1990*)

GNSS Equipment

Handheld (or vehicle based) stand-alone

3 - 50 metre "accuracy" on WGS84 or user datum

DGPS enabled geodetic receivers (e.g. OmniStar VBS)

1 metre precision in ITRF2005 (WGS84)

Precision DGPS enabled receivers (e.g. OmniStar HP)

0.1 metre precision in ITRF2005 (WGS84)

Single-Frequency geodetic receivers (carrier-phase)

(e.g. Sokkia Stratus, 1700CSX; Trimble L1 only; Leica GR20)

7-30mm precision up to 10 km from base station

Dual-Frequency geodetic receivers (carrier-phase)

(e.g. Trimble R8; Sokkia 2700ISX; Leica 1200)

7-30mm precision up to 50 km from base station

(2000 km with precise orbits)

GNSS Techniques & Cadastral Usage

Point Positioning

Uses broadcast orbit - <u>Not acceptable for Cadastral</u>

DGPS

1 receiver - Calibration with PNG94 reqd. and double-checks essential

Real-Time Kinematic

2 receivers - Double checks essential

Post-processed Static

2+ receivers - Loop closure or double checks reqd.

Precise Point Positioning (PPP)

1 d/f receiver - 6 hrs+ observations - Calibration with PNG94 reqd.

Static GNSS surveying

(preferred method)

Static GNSS - What's needed

1 single-frequency receiver

Requires CORS < 10 km range

2 or more single-frequency receivers

< 10 km from PNG94 control & between receivers

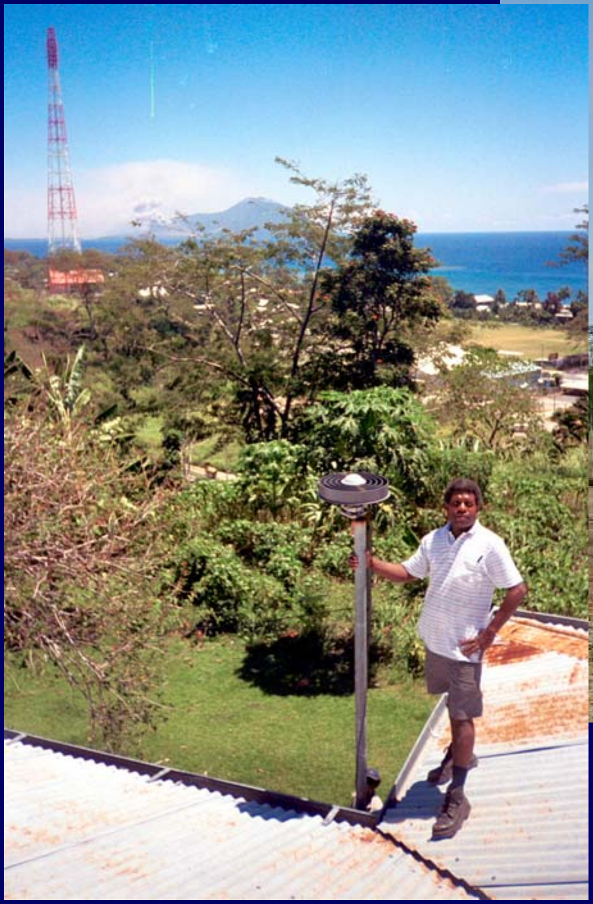
1 dual-frequency receiver

Requires CORS < 50 km range
or PPP observations (6 hrs+ observations)

2 or more dual-frequency receivers

< 50 km from PNG94 control (30 km is better)

Need post-processing and adjustment software
e.g. Trimble Geomatics Office, Sokkia Spectrum, GPPS



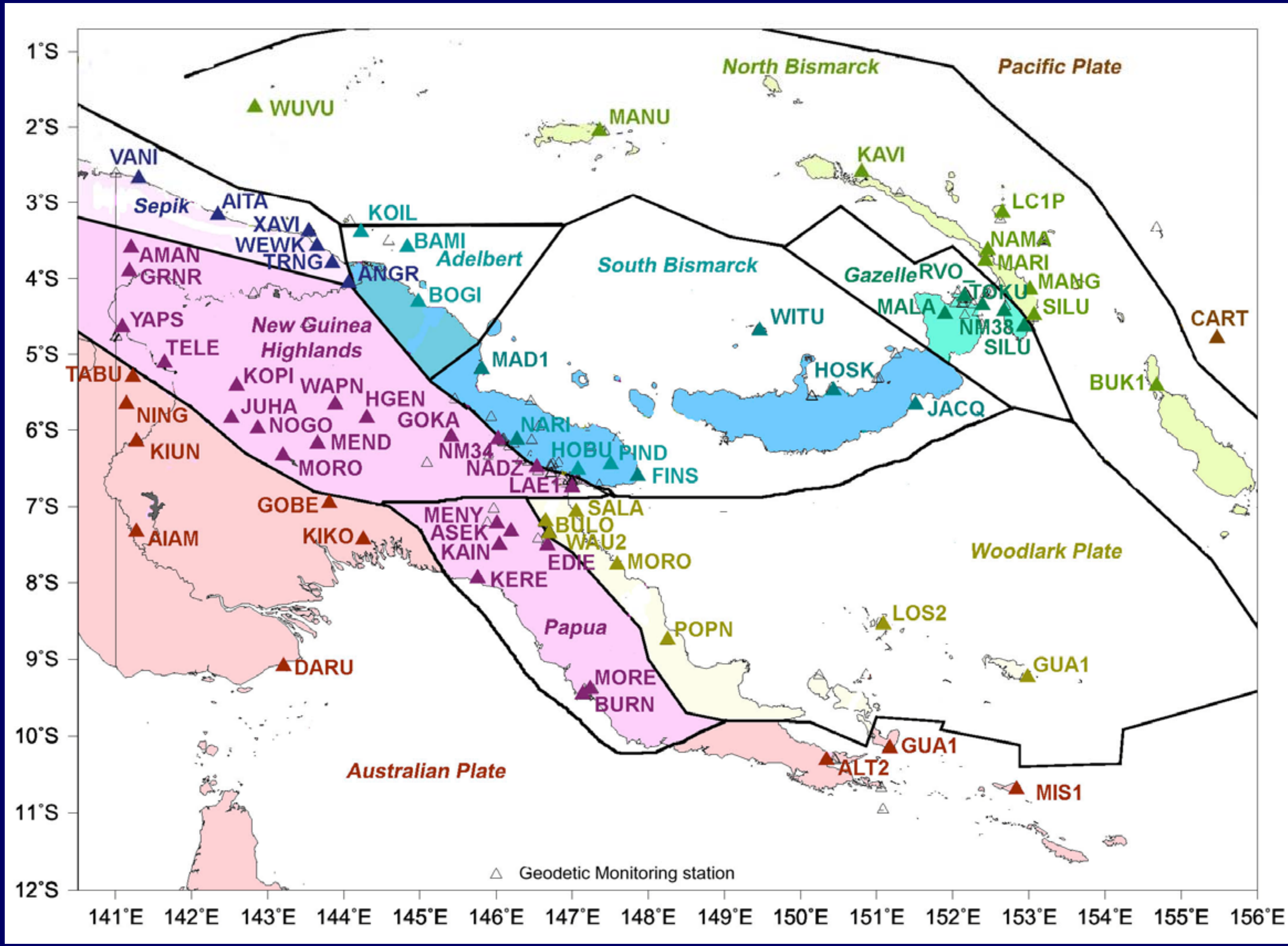
Lands Kenabot - KENB

NMB Base - MORE

UniTech Base - LAE1

Some continuous GPS (CORS) stations in PNG

1. Find nearest validated PNG94 station ON THE SAME PLATE (< 50 km)



PNG94 1st order control listing - Provisional update 7th June 2008 (verification required)

Station location			PNG94 Ellipsoidal Coordinates			PNGMG94 Grid Coordinates			MSL	Site Velocity	
Location	GPS ID	NMB Reg. No.	Latitude	Longitude	Ellipsoid Height	Zone	Easting	Northing	RL	E m/yr	N m/yr
Aiambak	AIAM	PSM 9550	-7°20'51.8206"	141°16'01.4470"	95.52	54	529475.73	9187801.94	21.7	0.037	0.058
Alotau - Gurney Airport	ALT2	PSM 9538	-10°18'37.5094"	150°20'18.0912"	94.87	56	208478.37	8859053.57	16.3	0.031	0.058
Buka Airport	BUK1	PSM 4871	-5°25'34.3712"	154°40'08.4373"	73.25	56	684918.22	9399967.57	4.3	-0.059	0.031
Daru	DARU	AA 440/A	-9°05'15.5229"	143°12'27.1952"	80.28	54	742639.83	8994719.42	4.9	0.035	0.055
Finschhafen	FINS	PSM 19471	-6°36'55.4209"	147°51'17.6868"	74.24	55	594504.66	9268686.35	9.5	-0.006	0.004
Goroka - Airport	GOKA	PSM 9833	-6°04'53.0717"	145°23'30.4470"	1664.47	55	322023.98	9327531.64	1585.4	0.023	0.046
Hoskins - Airport	HOSK	PSM 9795	-5°28'00.4073"	150°24'31.6614"	101.35	56	212869.72	9395119.32	18.0	0.022	-0.027
Kavieng - Airport	KAVI	PSM 9513	-2°34'53.0660"	150°48'22.5361"	78.81	56	256077.96	9714464.61	2.7	-0.067	0.027
Kenabot - Lands Base	KENB	PSM 23342	-4°20'45.1168"	152°16'07.9951"	136.69	56	418875.65	9519602.79	63.2	-0.002	-0.041
Kerema - Catholic Mission	KERE	PSM 31703	-7°57'28.0191"	145°46'19.0726"	97.57	55	364647.58	9120168.45	21.5	0.030	0.052
Kikori - Airport	KIKO	PSM 5583	-7°25'24.6531"	144°14'55.7677"	88.93	55	196298.45	9178490.00	12.01	0.035	0.054
Kiunga - Airport	KIUN	PSM 9465	-6°07'37.9805"	141°16'41.2696"	103.27	54	530773.45	9322724.61	27.7	0.038	0.056
Lae - Unitech DSLS Base	LAE1	PSM 31107	-6°40'25.3661"	146°59'35.4668"	140.37	55	499246.79	9262320.80	67.12	0.026	0.052
Lae - Unitech Sports	9799	PSM 9799	-6°40'16.9707"	146°59'52.3754"	130.31	55	499765.91	9262578.60	57.06	0.026	0.052
Lake Kopiago - Airport	KOPI	PSM 17001	-5°23'09.0852"	142°29'42.1907"	1412.79	54	665650.98	9404480.51	1327.7	0.031	0.055
Losuia	LOSU	AA 583	-8°32'07.2596"	151°07'30.8181"	85.16	56	293644.60	9056016.40	6.1	0.021	0.071
Madang - Airport	MAD1	GS 15495	-5°12'41.2891"	145°46'56.1940"	73.27	55	365044.17	9423829.87	5.0	0.023	0.039
Manus - Lombrum Secor	MANU	PSM 9522	-2°03'02.2944"	147°21'37.6363"	129.77	55	540084.32	9773337.48	50.8	-0.065	0.027
Mendi	MEND	PSM 3507	-6°08'36.7344"	143°39'22.1658"	1815.08	54	793981.21	9320198.80	1732.6	0.029	0.047
Misima - Airport	MIS1	PSM 9195	-10°41'19.9049"	152°49'58.9388"	87.46	56	481741.61	8818417.91	13.1	0.030	0.055
Moro - Airport	MORA	PSM 17442	-6°21'44.9072"	143°13'46.0940"	917.86	54	746627.49	9296194.53	837.4	0.033	0.054
Mount Hagen - Airport	HGEN	PSM 3419	-5°49'55.7591"	144°18'23.7948"	1710.15	55	201725.79	9354636.51	1626.5	0.030	0.048
Nadzab - Airport	NADZ	ST 31024	-6°33'47.9879"	146°43'39.6541"	148.83	55	469894.96	9274514.88	77.4	0.024	0.056
Namatanai - Airport	NAMA	GS 19461	-3°39'58.5422"	152°26'06.1582"	114.96	56	437261.32	9594742.59	43.9	-0.061	0.001
Nogoli Hides - Helipad	NOGO	PSM 30041	-5°56'02.4348"	142°47'16.7455"	1340.20	54	697930.59	9343770.78	1257.5	0.032	0.054
Pomio	JACQ	PSM 9515	-5°38'42.9782"	151°30'19.6067"	151.55	56	334476.29	9375795.22	77.3	0.020	-0.053
Popondetta	POPN	PSM 9371	-8°46'09.6499"	148°14'00.3966"	187.53	55	635667.54	9030425.34	106.8	0.024	0.054
Port Moresby - NMB Base	MORE	PSM 15832	-9°26'02.7696"	147°11'12.2016"	116.74	55	520498.42	8957148.59	41.3	0.028	0.053
Rabaul - RVO Base	RVO_	RVO	-4°11'27.1915"	152°09'49.5108"	266.24	56	407190.52	9536723.33	191.9	0.007	-0.052
Tokua - Airport	TOKU	GS 9822	-4°20'27.7832"	152°22'45.8215"	82.05	56	431137.64	9520146.01	9.5	-0.010	-0.036
Vanimo - Doppler	VANI	PM 63/1	-2°41'05.2819"	141°18'15.6562"	80.59	54	533829.65	9703242.49	3.4	0.013	0.045
Wankkun - Pillar	NM34	NM/J/34	-6°08'52.0739"	146°04'52.4422"	509.98	55	398344.12	9320370.15	436.7	0.026	0.047
Wau - MCG Base New	WAU1	WAU1	-7°20'57.0996"	146°42'55.7613"	1224.79	55	468599.31	9187638.65	1144.5	0.025	0.056
Wewak - Airport	WEWK	PSM 15497	-3°35'02.5848"	143°40'00.1481"	83.91	54	796268.18	9603418.22	5.8	0.017	0.053
Wuvulu	WUVU	PSM 15456	-1°44'07.5951"	142°50'10.0781"	79.03	54	704257.66	9808081.66	2.4	-0.068	0.019

Horizontal Coordinates - Positional Uncertainty < 0.05m, Ellipsoidal Heights - Uncertainty < 0.10m, MSL RLs - Uncertainty < 0.5m (except Lae & Kikori < 0.10m)

* **Coordinates require verification by resurvey**

A preliminary update for PNG94 showing selected stations

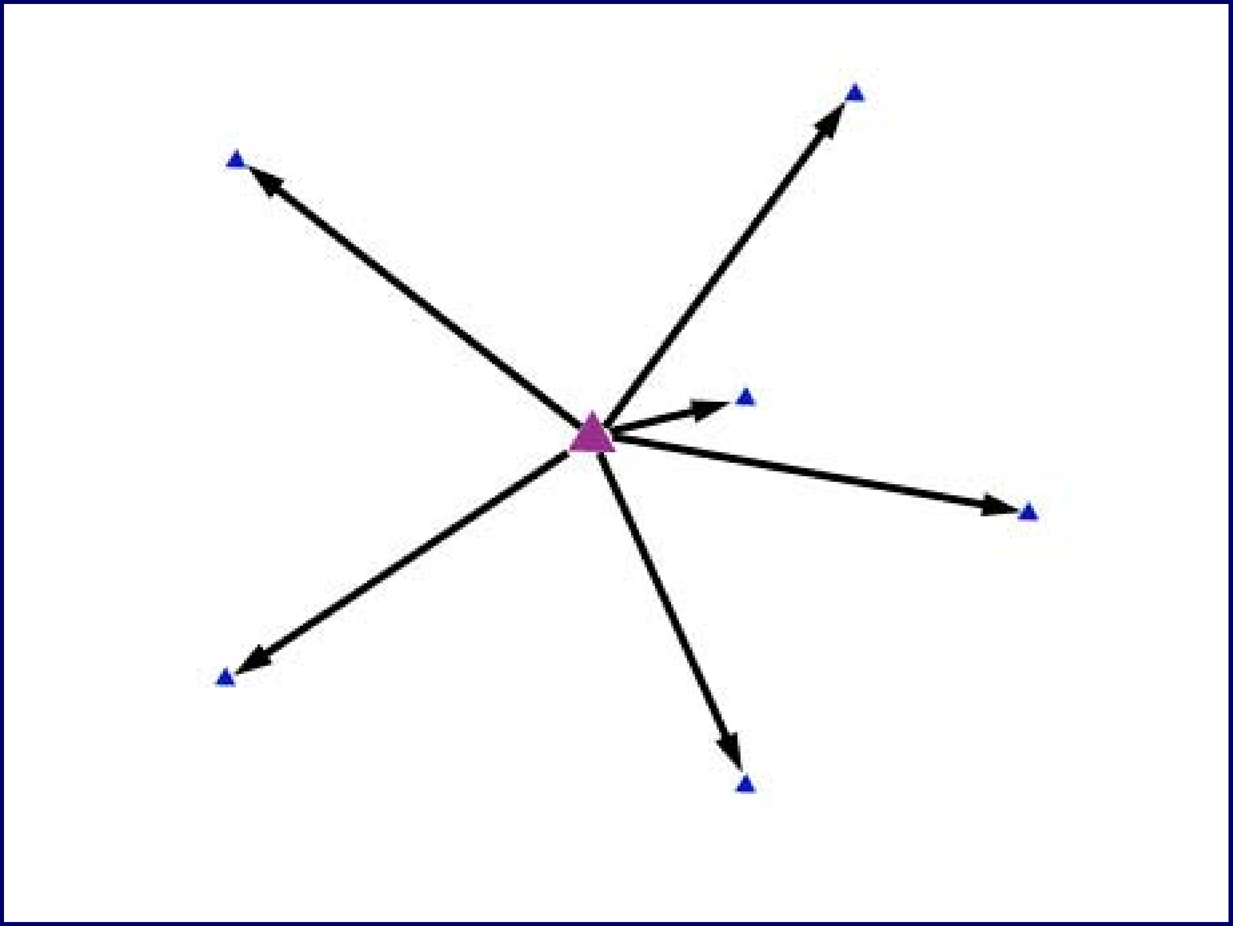
http://rses.anu.edu.au/geodynamics/gps/png/site_info/sitelogs.html

1. Obtain VALIDATED PNG94 coordinates
2. Obtain PSM sketches, plans & reports
3. Choose positioning equipment
4. Place new stations for GNSS
5. Clear vegetation

What if no station within 50 km on same tectonic plate?

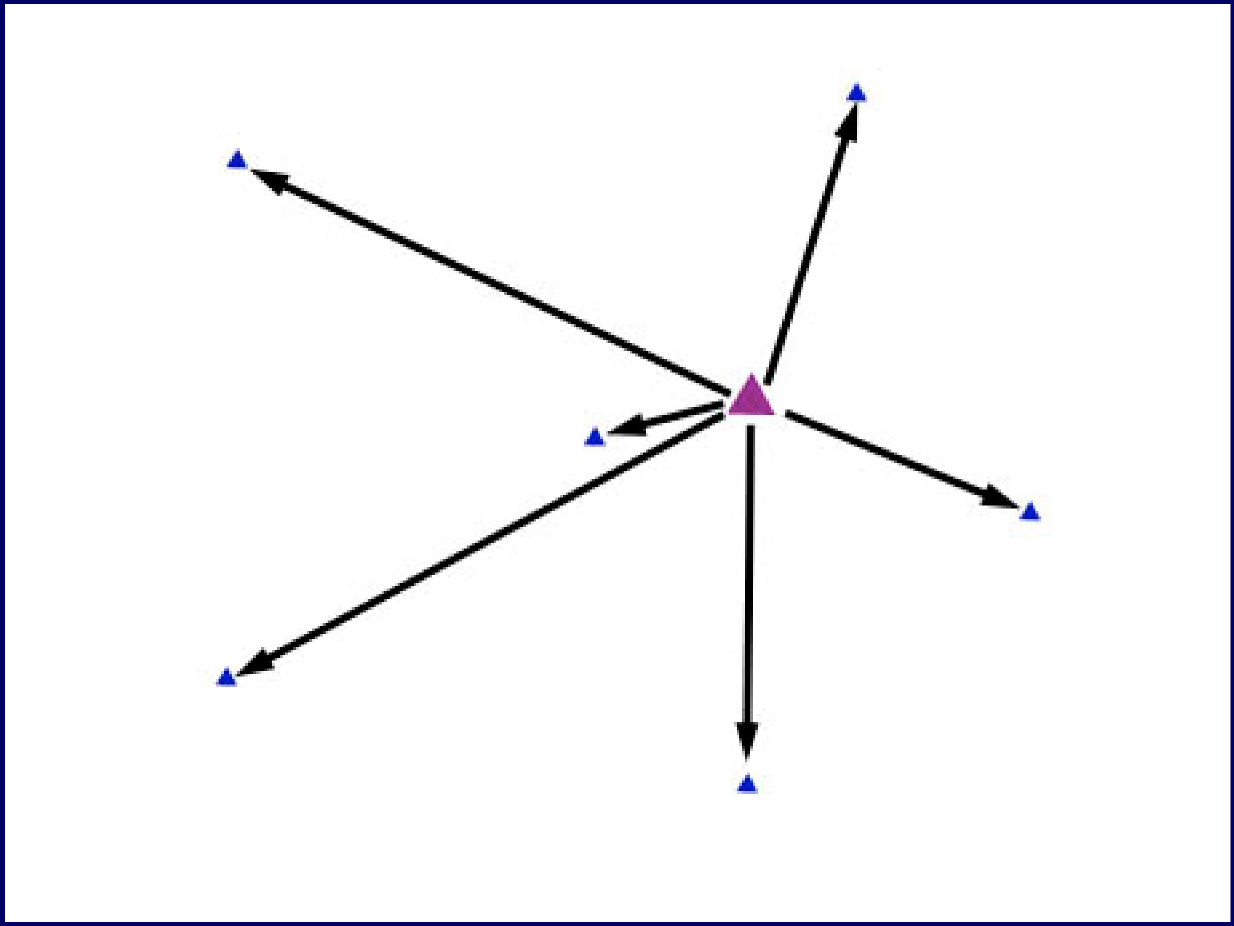
Use AUSPOS, NRCan, or IGS Precise Orbit

Network design - 2 receivers



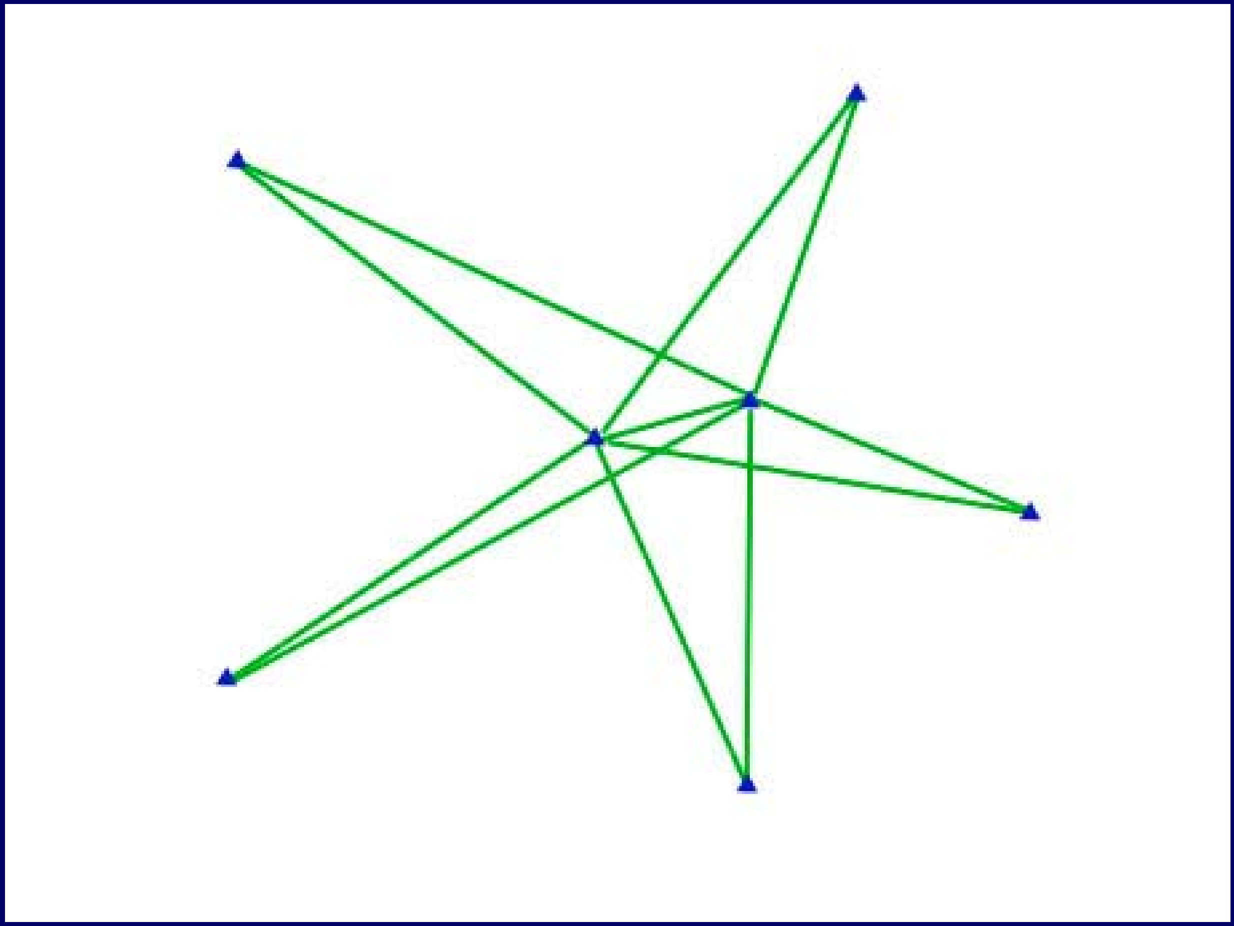
First set of radiations from central base station

Network design - 2 receivers



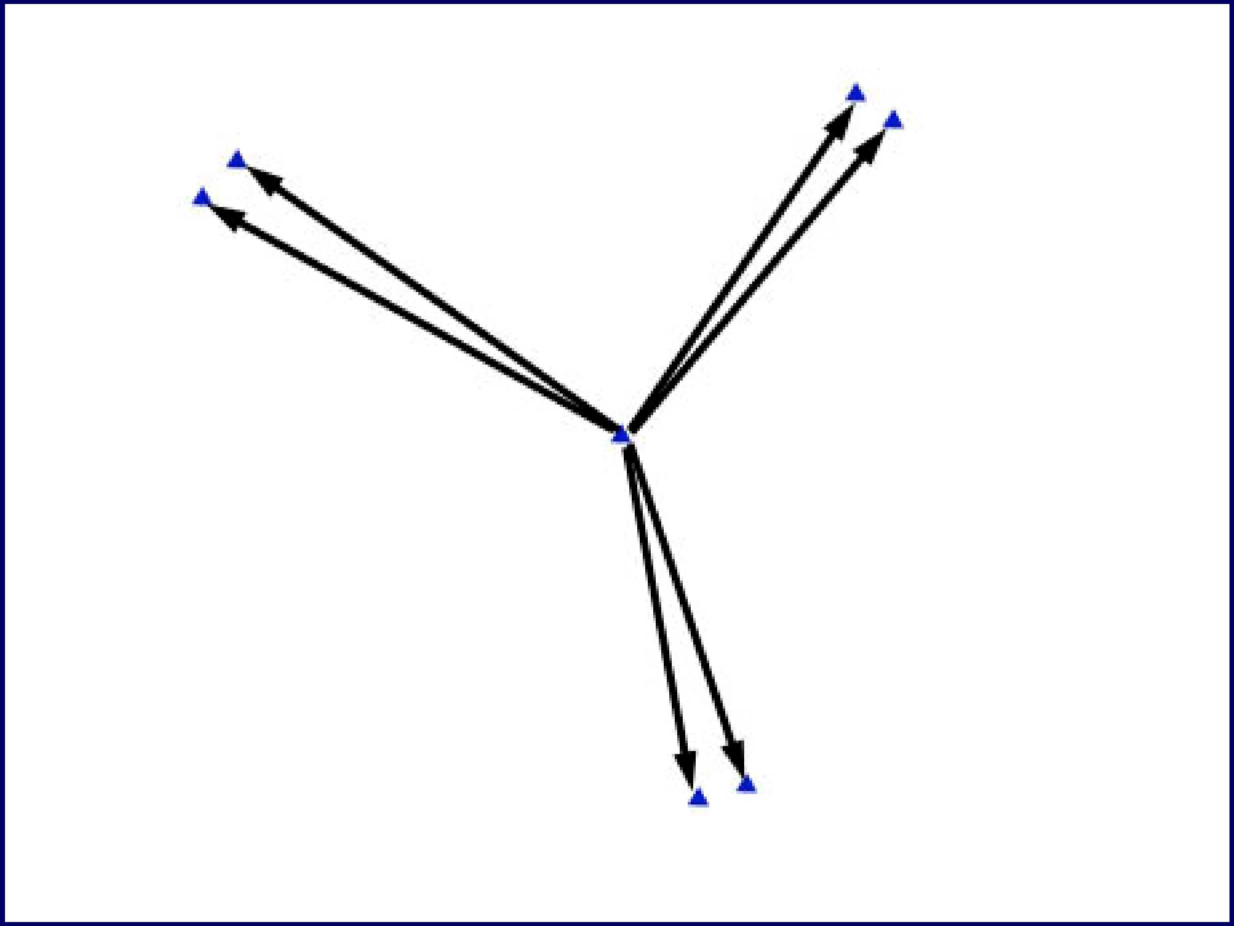
Second set of radiations from second station

Network design - 2 receivers



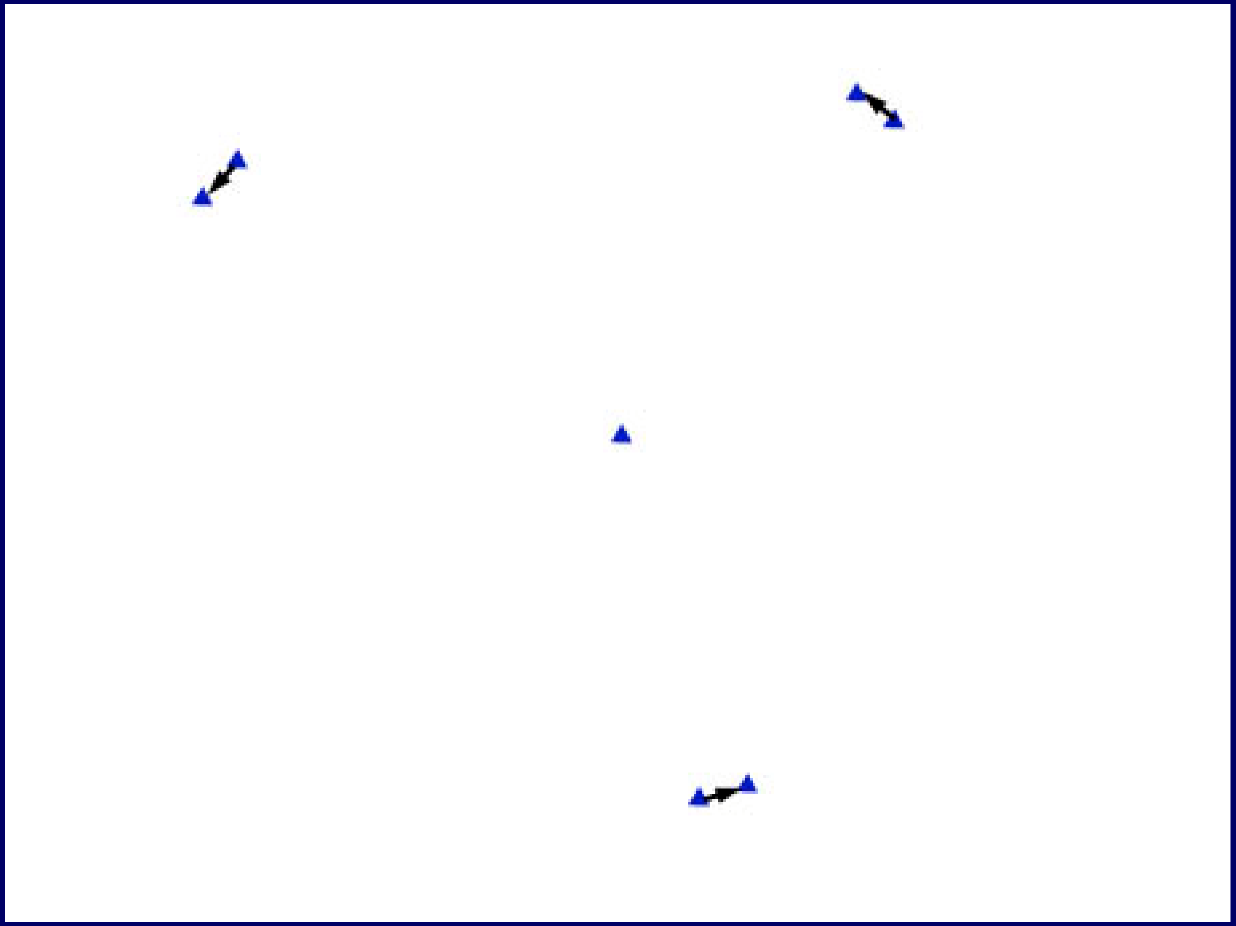
Minimum network of closed loops

Network design - to support total station surveys



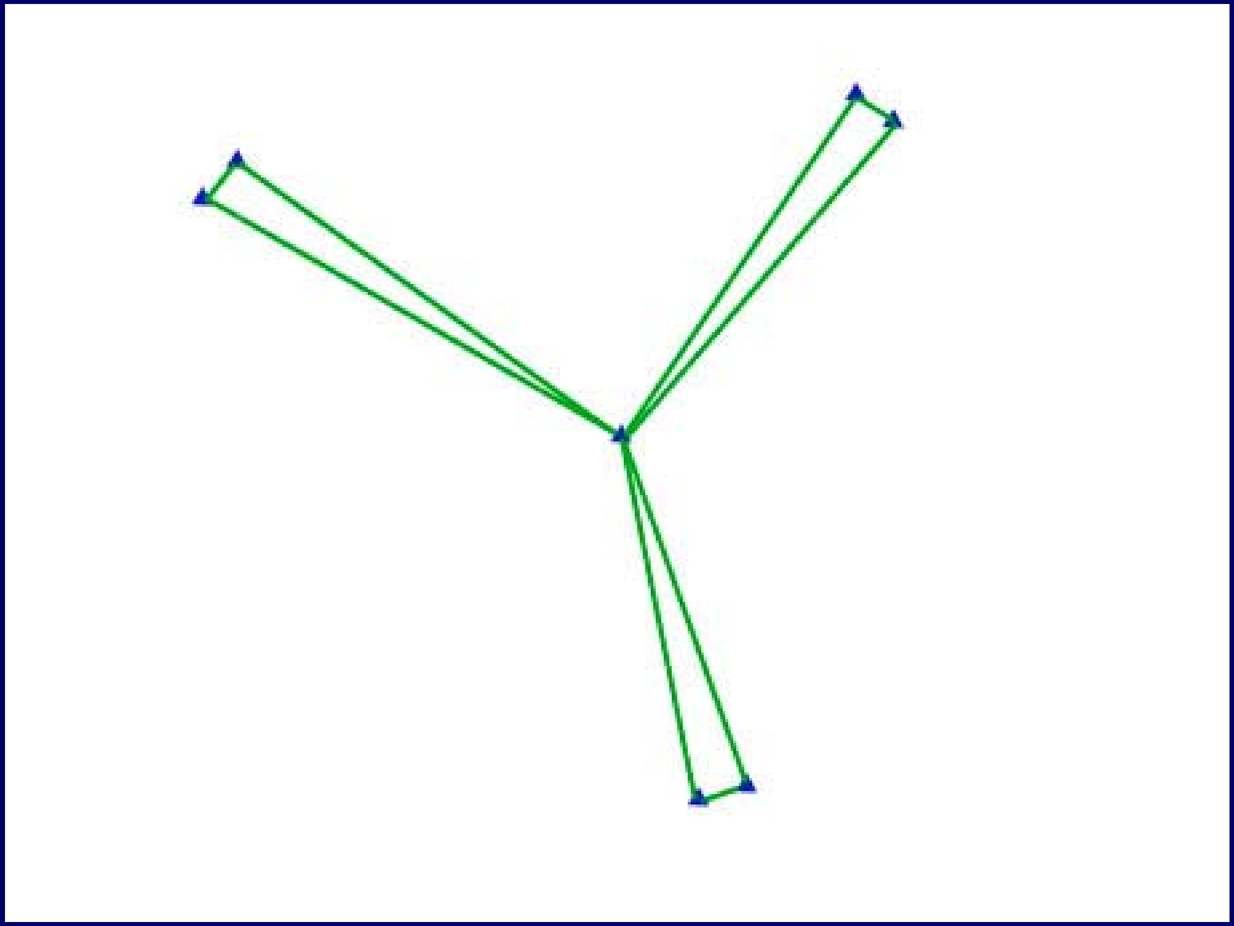
First set of radiations

Network design - to support total station surveys



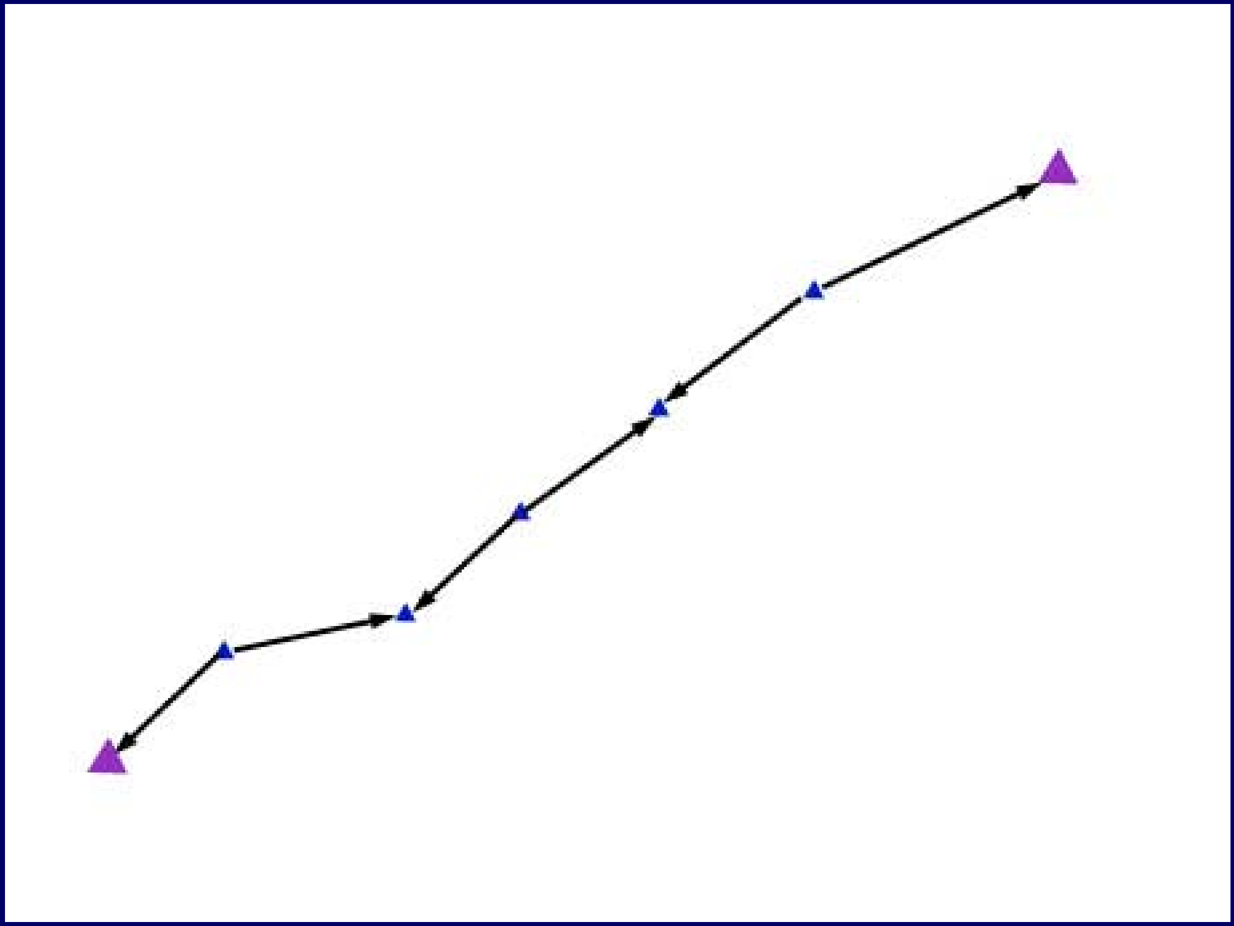
Baselines between stations

Network design - to support total station surveys



Closed loops

Network design - Corridor surveys



"Traverse" of baselines between PNG94 control

LEAP FROG TECHNIQUE

How long should I observe for?

Table 1. Occupation times for different baseline lengths (good observing conditions)

Baseline length	dual - frequency (minutes)	single - frequency (minutes)
0-5 km	15	30
5-10 km	20	40
10-20 km	30	60+ 50% chance
20-30 km	40	unlikely
30-40 km	50	
40-50 km	60	
> 50 km*	300	

** over 50 km requires PPP such as AUSPOS or precise orbit.*
If using AUSPOS start obs after 10:00 PNG Time if possible.

If <u>bad conditions</u> (nearby trees, high grass, buildings, towers, periods of bad DOP or SV availability, or if >400m elevation difference on baseline, then <u>double or triple the time</u>

AUSPOS best to get 24 hrs obs for best result

Receiver setup

Check free memory (download, backup and delete old files)

Set all observables recorded

10 second epoch (30 sec for AUSPOS / NRCan)

elevation mask 10° (5°-15°)

Clear any trees or branches nearby to improve sky visibility

Station and antenna setup

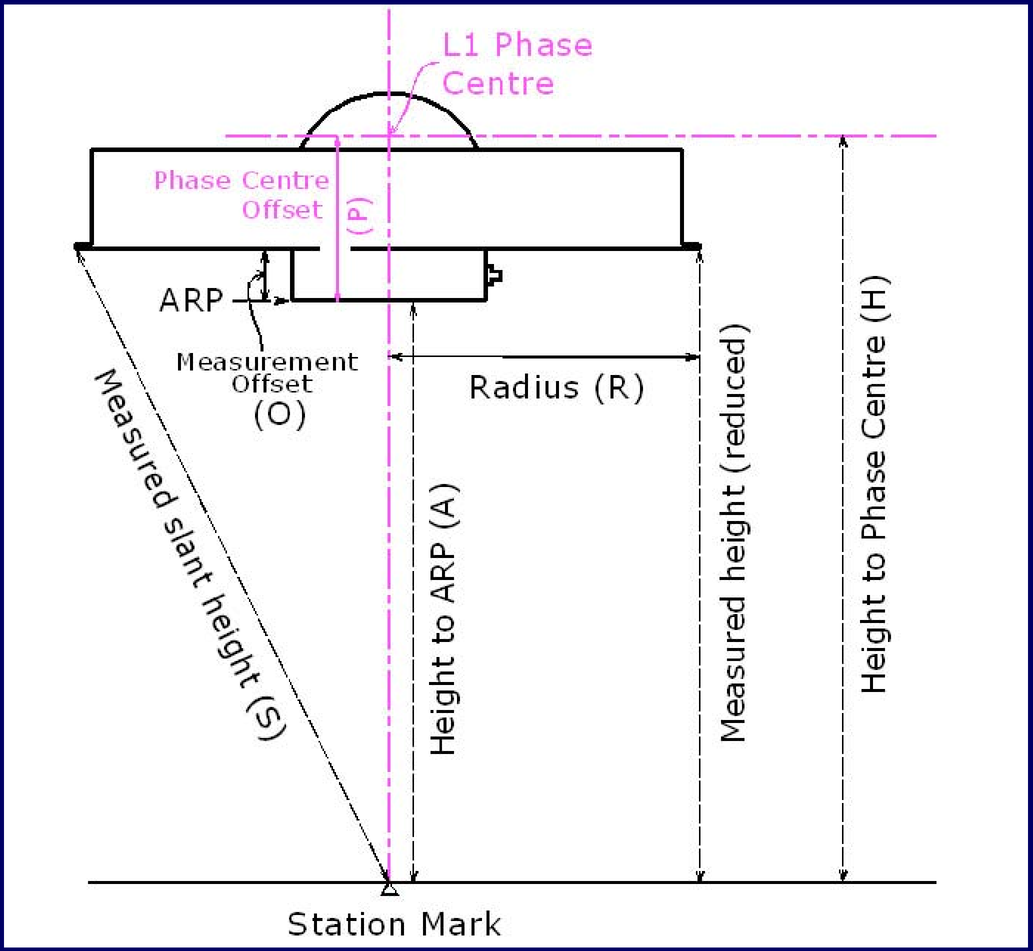
Check battery levels & eqpt.

Level and centre the antenna

Check centering with plumb-bob

measure antenna height (3 points)

kisim piksa



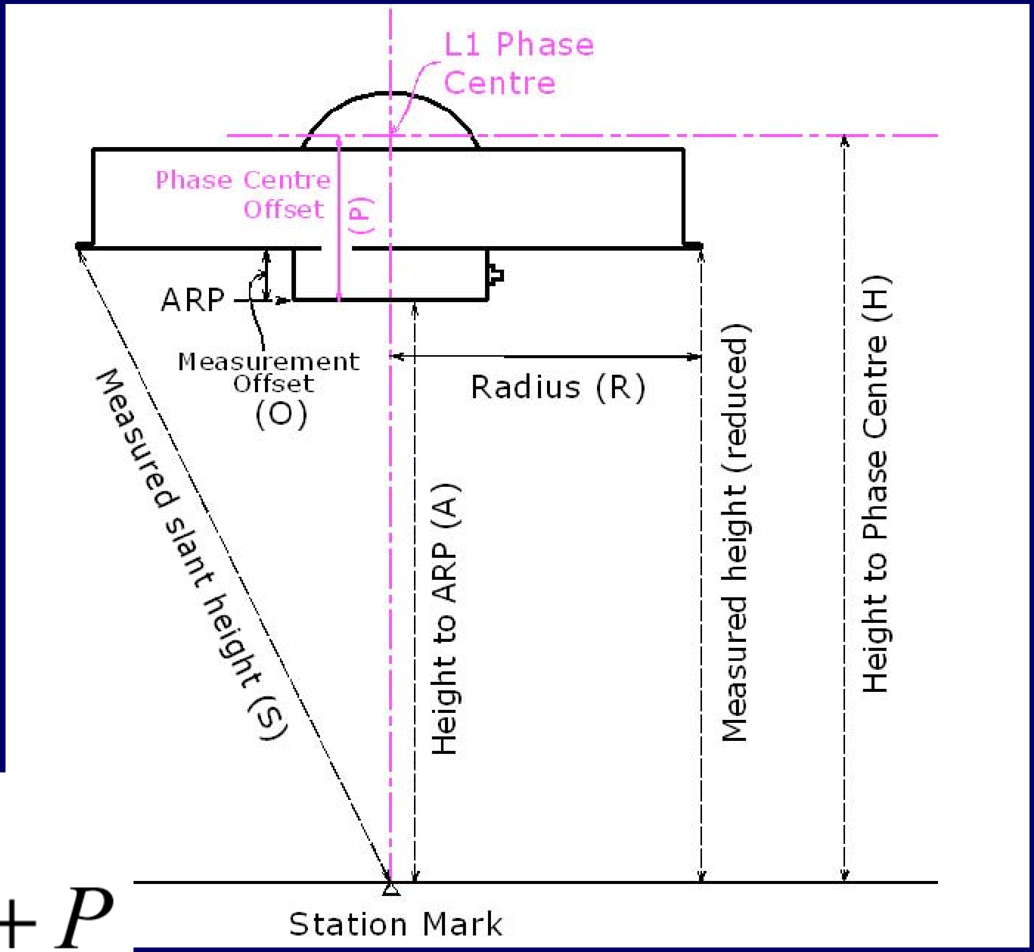
Site Log

GPS Occupation Log		Antenna sketch
Site ID or filename		show point where measurement
Station Name		to antenna is taken
Antenna type		
Antenna serial number		
Height measurement (start)		
Height measurement (end)		
Height to Phase Centre		
Date start		
Time start (PNG Time)		**Approximate position**
Time end (PNG Time)		Latitude
Date end		Longitude

Antenna heights (take care)

"Instrument height" is L1 antenna phase centre

"Antenna Reference Point (ARP)" is also commonly used



$$H = \sqrt{S^2 - R^2} - O + P$$

GPS data processing

Static baseline processing using carrier-phase observations

May need software to convert receiver raw data to RINEX (Receiver Independent Exchange Format) if different receivers used and for AUSPOS / NRCan

Can use AUSPOS if no PNG94 reference station used (or > 50 km from PNG94 Control), or for QA

AUSPOS **www.ga.gov.au/bin/gps.pl**

NRCan www.geod.nrcan.gc.ca/online_data_e.php

Baseline Processing

Setup project (can use WGS84 & UTM parameters)

Zone 54 South between the Indonesian border and 144° E
Zone 55 South between 144° E and 150° E
Zone 56 South between 150° E and 156° E

Use EGM96 Geoid if available

Load raw or RINEX data

Enter known PNG94 coordinates and ellipsoid height for validated PNG94 reference station (set as fixed)

Leave ? for orthometric (MSL) height

Run the baseline processing

Baseline assessment

Should use “fixed” solution as “float” solution
often unreliable for cm accuracy surveys

Shouldn’t use code solution for accurate surveys

L1 fixed or narrow lane fixed

L1/L2 fixed or ionospheric free fixed

If you get a float or code solution, reobserve
the baseline for longer or improved conditions

RMS should be between 0.004 and 0.030

Reference variance ideally 1, but up to 10 usually OK

Ratio 1:n   the higher n is the better (>10)

Reobserve if outside tolerances

Observe new station from different station (compare)

Loop Closure & Adjustment

Loop closures should be within PU and LU tolerances

If loop doesn’t close, 1 or more baselines
(usually float or high RMS will need to be reobserved)

Radiations (baselines not in loop) should have
two measurements from different stations,
and coordinates should agree within tolerances

Once loop closures have been checked - run
the Network Adjustment

Network Reference Factor ideally 1, but up to 5
usually OK
If > 1, then reduce weight of high RMS baselines
If < 1, then baseline precision underestimated
(not common)

AUSPOS or NRCan

Dual-frequency RINEX file required

Need 1 hr obs for + / - 20-30 cm

Need 6 hrs obs for + / - 2-3 cm

Need 24 hrs obs for + / - 1 cm

Should wait 2-3 days to get Rapid Orbit

Should wait 2-3 weeks to get Final Orbit

GDA94 and ITRF report sent by email

Ignore GDA94, and ITRF needs to be converted to PNG94 using site velocity or by comparison with PNG94 control

Using a site velocity model?

Need to convert AUSPOS / NrCan ITRF ellipsoid or cartesian coordinates to UTM (using geographical calculator)

The site velocity is the rate of change of coordinates due to overall tectonic movement (refer to Stanaway)

$$E_{PNGMG} = E_{UTM(ITRF)} + V_E(1994.0 - Y_M)$$

$$N_{PNGMG} = N_{UTM(ITRF)} + V_N(1994.0 - Y_M)$$

E_{PNGMG} and N_{PNGMG} are the PNG Map Grid Coords.

$E_{UTM(ITRF)}$ and $N_{UTM(ITRF)}$ are the ITRF/WGS84 UTM Coords at the time of measurement

V_E and V_N are site velocity components (Easting and Northing)

1994.0 and Y_M is the reference epoch and measurement epoch

Obtaining MSL values

Baseline processing or AUSPOS will give MSL values using the EGM96 geoid model if selected

If possible observe at a nearby 1st order MSL station (i.e. next to tide gauges) otherwise at any existing high order MSL station used as existing height datum

Compare EGM96 MSL with existing MSL. The difference is correction to be applied to all other EGM96 derived heights

Compare EGM96 MSL with existing MSL. The difference is correction to be applied to all other EGM96 derived heights

$$MSL_{local} = h - N_{EGM96} + c$$

$$c = MSL_{localdatum} - MSL_{EGM96}$$

EGM96 available on web if not built in to processing software, or use older PNG geoid model

Using RTK for control surveys

Should use post-processing for better reliability

RTK can be used for local < 5 km range control

Check that a geoid model is used in the system

Should not do RTK when DOP high or satellite availability is low

Before racing off, check the performance of the RTK by observing another fixed station first

Must do repeat measurement on different day at a different time of the day

Can use site calibration but geometry must be good (must span survey area)

Using OmniStar

For Rural Class 2A, 2B, 3 or 4 only

Uses ITRF2005 - So conversion to PNG94 required!

Three main service (accuracy levels):

OmniStar-HP (+/- 100 mm) - Rural 2A +
OmniStar-XP (+/- 300 mm) - Rural 2B, 3, 4
OmniStar-VBS (+/- 1000 mm) - Rural 3, 4

Requirements:

1. <u>Conversion</u> obtained by observing known PNG94
2. Displayed accuracy x 3 to get realistic tolerance
3. REPEAT OBSERVATIONS ESSENTIAL
4. Must “Close” survey by comparing with PNG94

Setting up a cadastral plane grid

Can’t use PNGMG distances for cadastral surveys where ground distances are required

Scale factor of 1 often used with PNGMG/AMG coords
MUST NOT DO THIS OR BIG ERRORS WILL HAPPEN

Scale factor can be very different from 1, especially at high elevations near the central meridian

Choose a local origin at centre of survey area (e.g. mean coordinates and height of rural land parcel)

Use same azimuth and drop “sleeping” figures off PNGMG coordinates so they are more manageable

Can extend Plane grid 10 km away from datum or less if there are large elevation changes

Plane Grid conversions

$$E_{PLANE} = E0_{PLANE} + \frac{1}{k_p}(E_{PNGMG} - E0_{PNGMG}) \qquad \text{(Eq. 4.11)}$$

$$N_{PLANE} = N0_{PLANE} + \frac{1}{k_p}(N_{PNGMG} - N0_{PNGMG}) \qquad \text{(Eq. 4.12)}$$

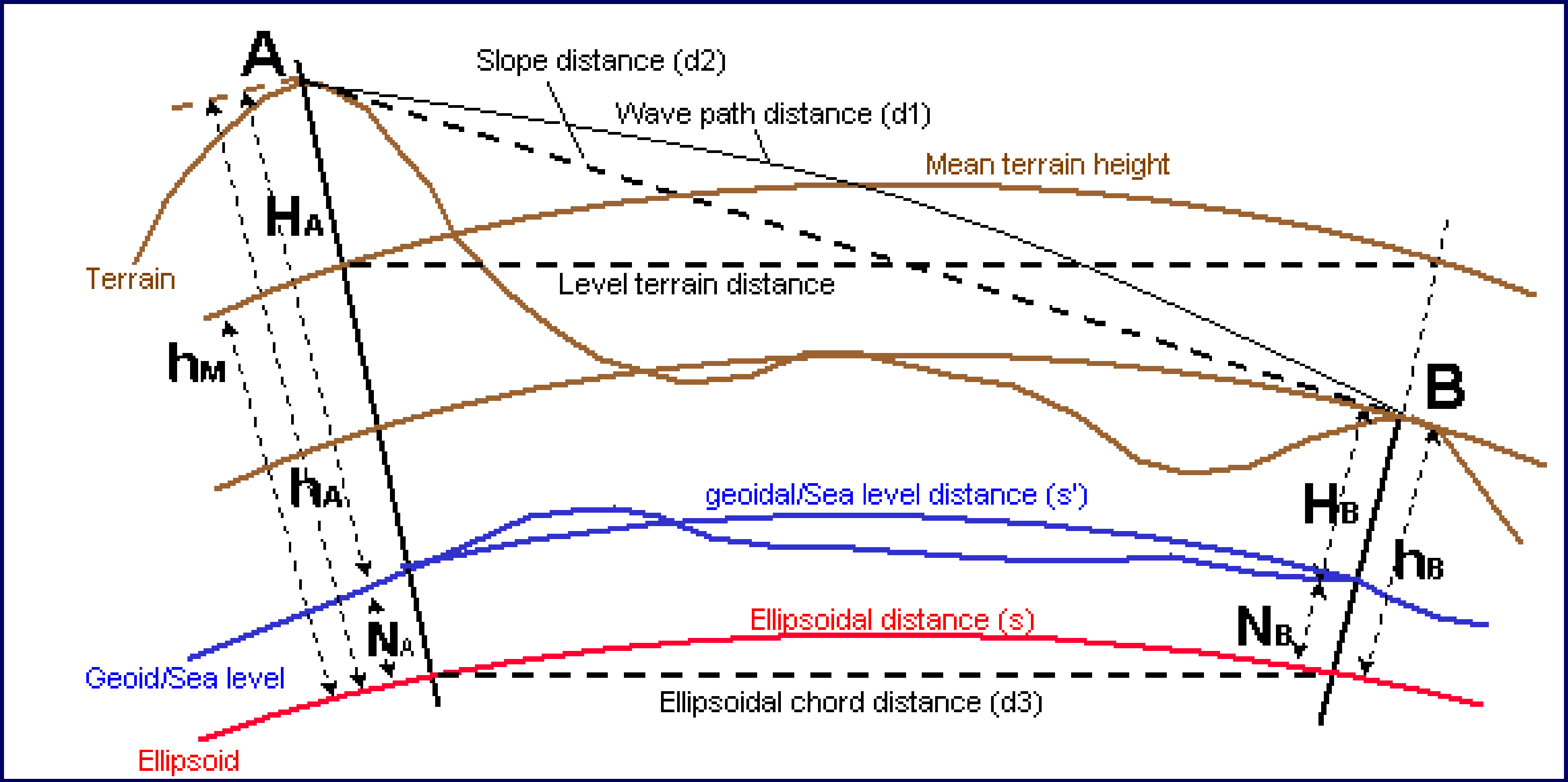
$$E_{PNGMG} = E0_{PNGMG} + k_p(E_{PLANE} - E0_{PLANE}) \qquad \text{(Eq. 4.13)}$$

$$N_{PNGMG} = N0_{PNGMG} + k_p(N_{PLANE} - N0_{PLANE}) \qquad \text{(Eq. 4.14)}$$

where,

E_{PLANE} & N_{PLANE} are the local plane coordinates
E_{PNGMG} & N_{PNGMG} are the PNGMG coordinates to be converted
$E0_{PLANE}$ & $N0_{PLANE}$ are the Plane coordinates of the Plane datum origin
$E0_{PNGMG}$ & $N0_{PNGMG}$ are the PNGMG coordinates of the Plane datum Origin
k_p is the is the combined PNGMG Grid and Height scale factor at the Plane Origin

Distances


A
Slope distance (d2)
Wave path distance (d1)
Mean terrain height
H_A
Terrain
Level terrain distance
h_M
B
h_A
geoidal/Sea level distance (s')
H_B
h_B
Ellipsoidal distance (s)
N_A
N_B
Geoid/Sea level
Ellipsoidal chord distance (d3)
Ellipsoid

1. Obtain VALIDATED PNG94 coordinates

2. Obtain PSM sketches, plans & reports

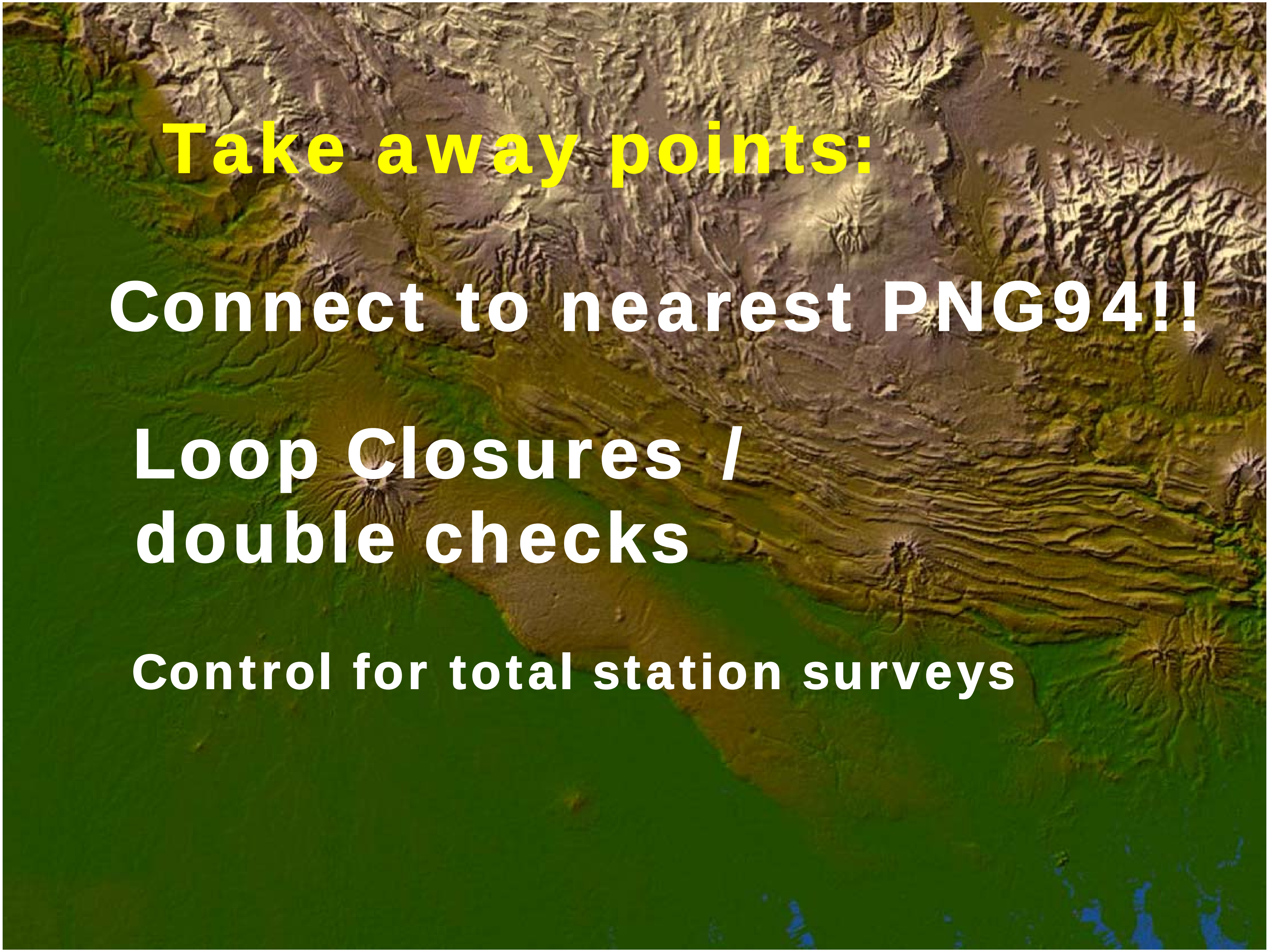
3. Choose positioning equipment

>10 km dual-frequency GPS (static)

<10 km single-frequency GPS (static)

<5 km single-frequency GPS (RTK)

<1 km line of sight: total stations


Take away points:
Connect to nearest PNG94!!
Loop Closures /
double checks
Control for total station surveys