# A template for the development of a modern national reference frame

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& Quickclose

# Workshop presentation overview

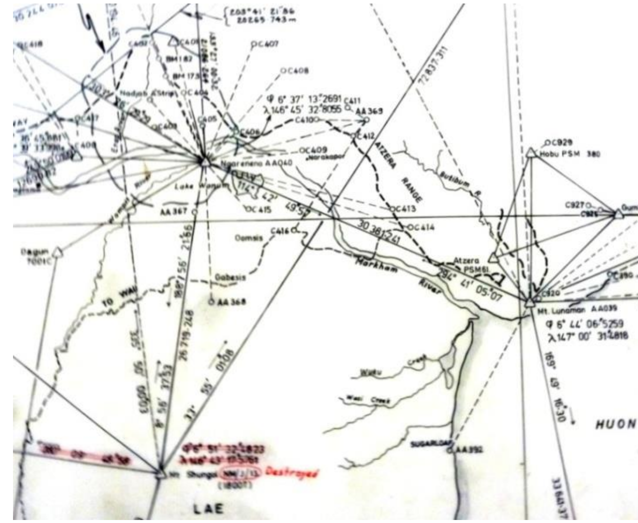
- What is the purpose of national geodetic reference frame?
- geodetic Infrastructure
- geodetic observations
- data processing and adjustment
- deformation and transformation modelling
- products for users and GIS

# What is the purpose of national geodetic reference frame?

- Positioning and the basis for spatial data and GIS
- Cadastral (including customary land and resource lease) surveys
- Engineering surveys (roads, ports, construction, mining, oil & gas)
- Topographic Mapping & DEM (LiDar ground control and imagery control)
- Asset Mapping (e.g. GIS surveys, general features, villages, street map, TLS)
- Hazard & environmental monitoring (volcanoes, landslides, subsidence)
- Plate tectonics, seismic deformation
- Sea level change (e.g. monitoring elevation and stability of Tide Gauges)
- Contribution to global and regional geodesy (e.g. GGOS, IGS, APREF)

# Monumentation – Evaluate existing infrastructure

- Identify existing primary control stations and levelled benchmarks from earlier survey networks (e.g. trig stations)
- (assess for accessibility, stability, GNSS (sky visibility), utility and proximity to development, cadastral connections)




AGD66 trilateration network,
Morobe Province, Papua New Guinea


- The purpose? To estimate transformation parameters and distortion grids from earlier geodetic datums
- traceability of geodetic frames and datums over time

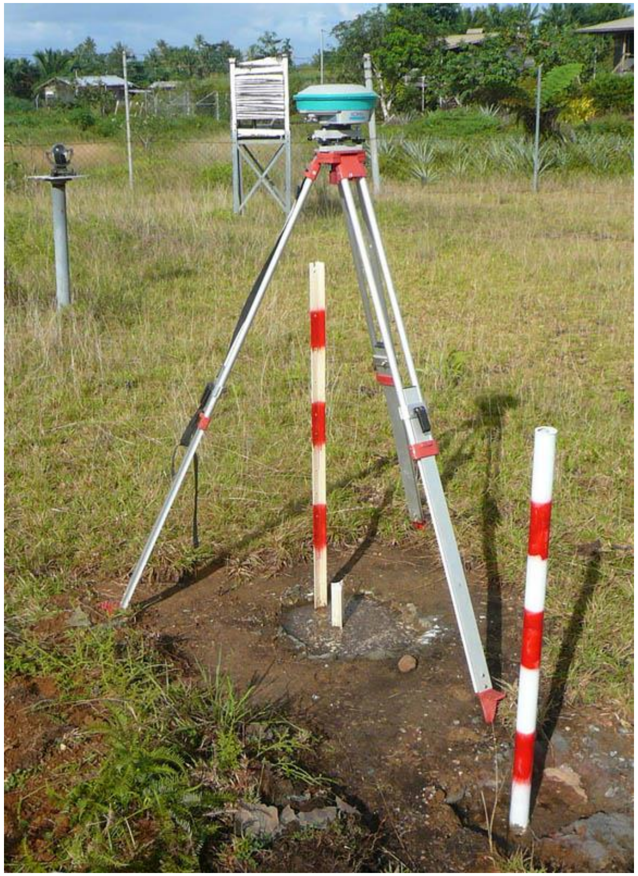
# Monumentation – Establish CORS

- continuously operating GNSS stations) in main towns and development areas to support RTK/NRTK and local static GNSS surveys.
- (Consider RTK and static range limitations, mobile network coverage for NTRIP, power supply and UPS backup)
- Tectonic monitoring and/or fit for purpose

COCO
Cocos Islands
IGS/ ARGN/ APREF pillar
Indian Ocean
Australia

# Monumentation – Augment existing infrastructure

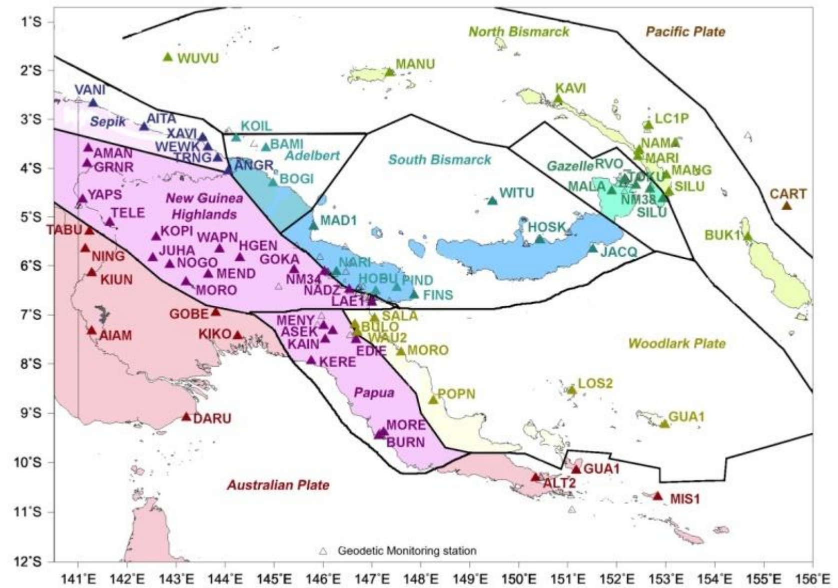
- Construct new passive geodetic stations at useful places like airports, port facilities (tide gauges), government offices, schools, playing fields, meteorological stations, resource sector camps (secure locations with no land ownership issues and good sky visibility)



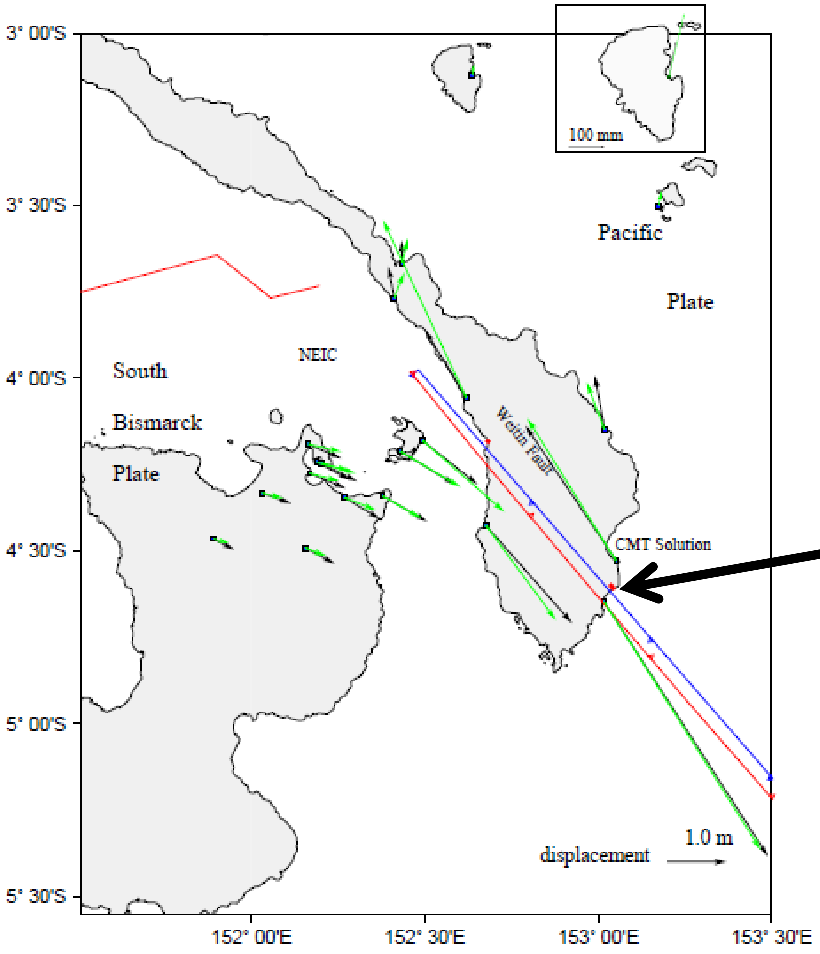
Kiunga, 2nd order station, Western Province, Papua New Guinea

# Monumentation – Tectonic & Sea Level monitoring

- Dense network of geotechnically stable geodetic monuments on either side of plate boundary or active fault zone.
- Consider optimum geometry for modelling and inversion of fault locking parameters.
- Regular network of stations within rigid portion of plate to enable inversion of plate model Euler pole.
- Siting of monitoring stations around each tectonic plate and boundary zone
- Tide Gauges well spaced around coastline away from river mouths.



# Direct measurement of seismic deformation




Mw8.0 Weitin Fault earthquake,
New Ireland, Papua New Guinea
16th November 2000 (Tregoning, ANU)

# Other geodetic networks – hazard monitoring

- Volcano monitoring networks
- Subsidence zones

  (e.g. Above underground mining operations, coal-seam gas extraction, groundwater and aquifer abstraction)
- Landslide monitoring
- Localised deformation monitoring

# Co-location with other geodetic sensors

**DORIS Beacon**
**(IDS Network)**

**Satellite Laser Ranging?**

**VLBI ?**

Co-location has very significant benefits for global geodesy and ITRF

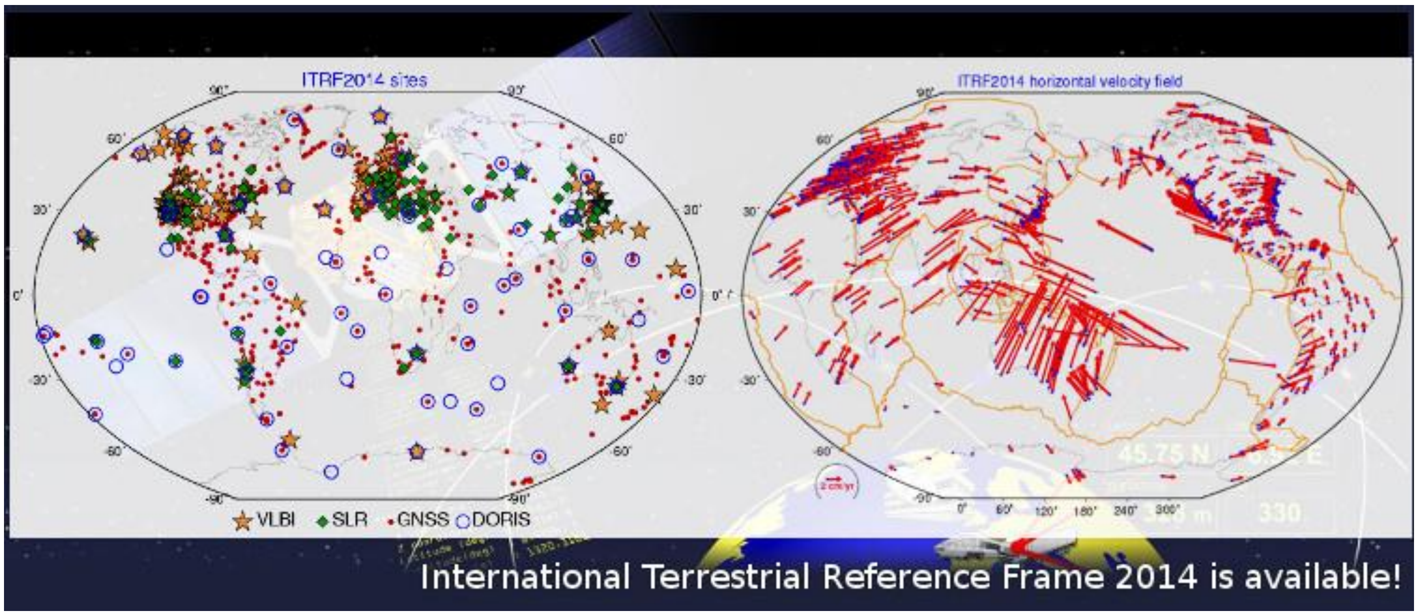
Port Moresby DORIS and APREF CORS
Papua New Guinea

**GNSS Antenna**
**APREF GNSS Network**

**Tie and stability check RM**
**(preferably should be instrument pillar)**

Co-location with gravity stations

# Contribution to global and regional networks




**ITRF (including IGS )**

**APREF**

(regional densification of ITRF)

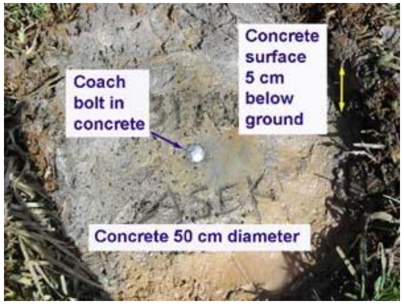
# Choice of passive geodetic monument construction

**considerations:**

- Cost & availability of materials
- longevity and stability of monument
- Risk of damage or vandalism (e.g. theft of brass plaques!)
- Deep footings and reinforcement if possible

Brass Plaque


Stainless steel bolt




Star Picket

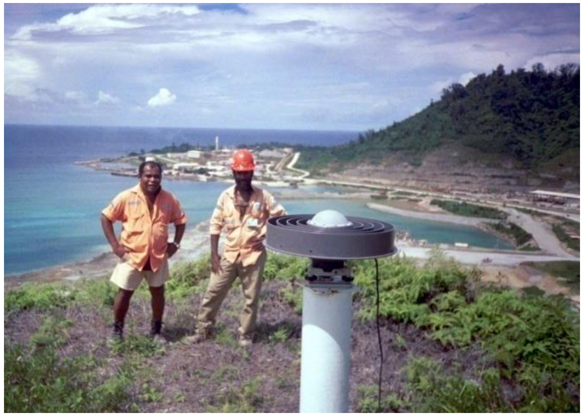

Galvanised Iron Pipe

# Geodetic pillars

**considerations:**

- Ideal for mining and CORS tie monitoring (already centred for total stations and GNSS antennas)
- Easily located
- Requires especially deep and robust footings and reinforcement

Lihir Mine Pillar
New Ireland
PNG

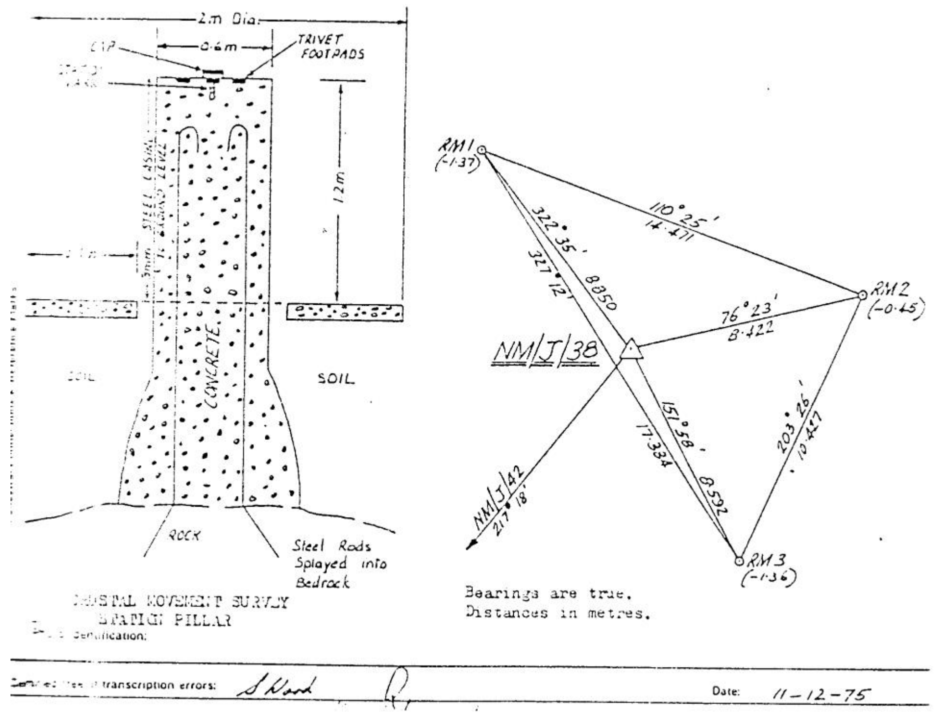


Kiunga
GPS base
Western Province
PNG

# Choice of monument siting

- Sky view for GNSS observations (Proximity of trees, vegetation growth (including future growth), structures, proposed structures)
- Utility – e.g. Is it within range of working area for reliable L1 fixed solution? Intervisibility with other stations for total station use
- Risk of destruction – located away from possible earthworks or construction, vehicles.
- Stability of site – On contiguous bedrock – not floaters!
- Avoid clay or deep soils, slopes, edges – requires very deep footings.

# Stability of stations – some pitfalls!




Tinbal – Crustal Motion Pillar
– New Ireland, PNG

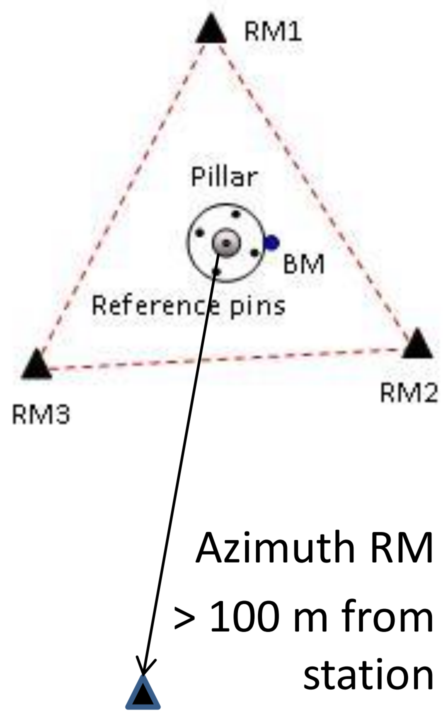
# CORS monuments – good enough for Tier 1?

**Roof or tower antenna mount limitations:**

- Unstable structure?
- Strong winds (e.g. cyclones) can induce wind shear deformation
- Thermal expansion of structure (e.g. steel tower)
- **Best construction is a low concrete pillar** with very deep footings and reinforcement - tied to bedrock. Requires long curing time.
- Consider sky visibility and multipath (remove young trees nearby)
- Tier 3 "Fit For Purpose" CORS for lower precision usage / infill

# Stability monitoring of primary control / CORS

- local RM network, low pillars, duplication (redundancy) at common sites, stability of tide gauges.
- Redundancy RMs at > 50 m to monitor site stability
- Azimuth RMs to support terrestrial surveys (e.g. cadastral and construction)
- Stable gravity station in local network



# Reference Marks and Witness Posts

- RMs especially important to verify stability of primary mark (and recovery of main mark if disturbed or vandalised). Constructed to similar standard to main mark (e.g. iron pin in concrete)
- Best located within 5 m of main mark and concealed slightly below ground level. 3 marks in a triangle around mark.
- Witness post ideally within 50 cm of station. e.g. star picket or galvanised pipe set in concrete. Also consider windsocks at airports (> 5 m away) , rugby goal posts (beyond dead ball line to avoid broken ankles), basketball posts.

# Tide Gauge – siting and monitoring network


Tide Gauges sited away from river mouths – areas of strong wave action or currents
Considerations: Subsidence and disturbance to wharf
Slipping of tide gauge zero mark over time – damage
Important to have nearby BM on bed-rock away from wharf

# Observations – Choice of equipment

- **GNSS sensors:**
- L1 only – limited to 10-15 km for fixed solution or so (cheaper)
- L1/L2, L1/L5 – anywhere on the Earth (more expensive)
- GPS only, GPS + Glonass, GPS + Galileo .........
- Beidou(Compass), QZSS, IRNSS capability .....
- Carrier-phase processing not yet fully interoperable with some GNSS services (e.g. GPS and FDMA Glonass)

  (so multi-GNSS of limited value for static GNSS)

  e.g. GPS only fixed solution + Glonass only float solution

# Choice of equipment considerations

- Does the equipment have a good warranty and reputation?
- Use a local supplier for warranty and ex- warranty support & repairs – even if it costs more.

  (customs hassles and 2-way air freight is also expensive!)
- Is the equipment robust (water proof) for extreme conditions?
- Do other organisations nearby have similar equipment?
- Antenna calibration (GEO++, NGS ANTCAL or individual antenna?)
- Remote area extras: external batteries and cables, spares
- Ongoing equipment maintenance budget.

# GNSS Observations for fiducial (zero order) network

- Ideally Tier 1 CORS monument for continuous measurement.
  Or campaign style observations, if there are budget constraints.
- For fiducial network recommend multi-day 24 hr observations
  (e.g. 7 day observations to mitigate unmodelled ocean-tide loading effects which primarily affect vertical precision)
- Repeat observations every six months for two to four (or more) years in order to model station time series in ITRF and average out seasonal signals e.g. draconitics, unmodelled hydrological and atmospheric pressure loading
- *5 hours of dual-frequency carrier-phase GPS observations can provide 15 mm precision in ITRF (30 mm for ellipsoidal height)*

# GNSS static observations for lower order networks

- GNSS base station running over CORS or fiducial station
- GNSS rover stations running at stations within radius of 30 km in order to optimise observation time and minimise tropospheric modelling errors and other common mode errors.
- Observation time 15 minutes to 2 hours depending upon baseline length, Satellite geometry (GDOP), availability and observing conditions (e.g. longer obs required if station near trees or buildings)
- 3+ receivers running concurrently provides redundancy. Unchecked baseline radiations are inadvisable.

# GNSS observations on older datum stations

- Important for estimating transformation between old and new datums to enable legacy spatial data (e.g. Topographic, engineering and cadastral plans) to be transformed accurately to a new datum **– maintaining traceability for spatial data**.
- Observe dense network in urban areas for high precision estimation (and evaluation) of parameters – typically a block shift, affine transformation, multi-parameter transformation or distortion grid.
- Locate bench marks (with local height datum) in order to estimate offset model between geoid model and local height datum surface (single offset, transformation plane or grid).

# Other geodetic measurements

- Total station measurements for site ties, RM surveys, observations to geodetic control (especially legacy control) under trees.
- EDM calibration baselines with stable instrument pillars
- **Important considerations:** using realistic atmospheric corrections in EDM equipment (e.g. atmospheric pressure and temperature – especially important for long EDM measurements and at higher elevations). 90 ppm correction typical at 3000 metre elevation.
- Verify prism constants
- Levelling ties at tide gauges to monitor TG stability.
- Sea level measurements at tide gauges

# GNSS Data processing and adjustment - Choice of software

- Can the software do dual-frequency carrier-phase processing?
- Can the software do network adjustment with weighting options?
- Does software support projected coordinates, geoid models?
- Can software utilise IGS precise orbits (e.g. Sp3)?
- Are different troposheric and ocean-tide loading models selectable?
- Multiple licences for field use – support agreement indefinite?
- **Bernese software (GNSS)** – widely used and supported – expensive $$$$ - Linux and Windows OS
- **GAMIT/GLOBK (GPS)** – less well used, ideal for batch processing– AND free for non-commercial applications – Unix/Linux OS.
- **Trimble Business Centre, Leica Geo O, Topcon Tools** – user friendly - $$
- **RTKLIB** – open source

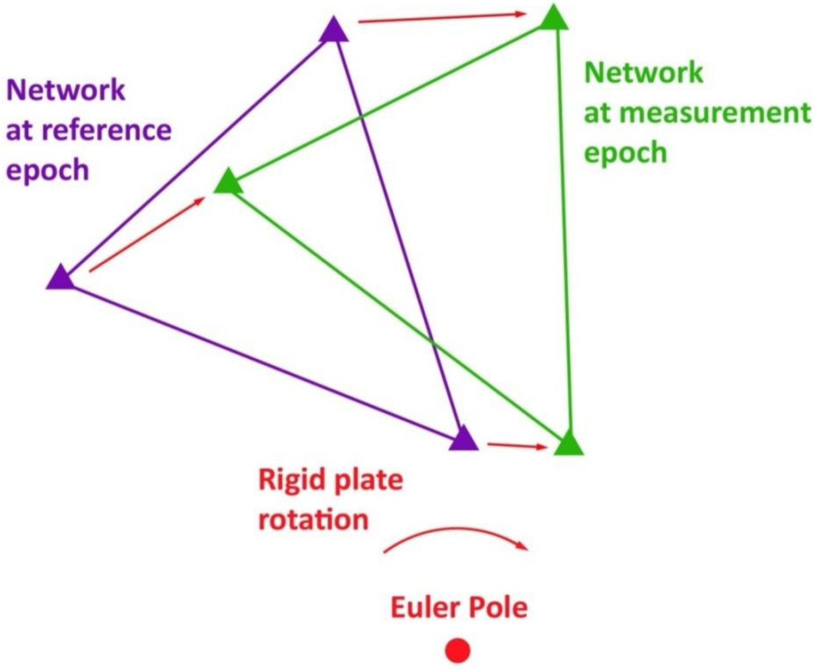
# Data processing and adjustment – Online services

## AUSPOS, OPUS, TRIMBLE-RTX, NRCAN-PPP, POSITIONZ-PP ..... etc.

- Relatively painless method of data processing (for RINEX)
- AusPOS and PositioNZ-PP ( Bernese), Opus(PAGES),
- No cost involved
- ITRF2008 (or soon ITRF2014) and local datum coordinates
- EGM2008 and local geoid model & uncertainty
- 5 hours data -> 15 mm Hor. & 30 mm Vert.
- Wait 2+ days for IGS Rapid orbit
- ITRF Agreement between different services typically 3-5 mm for 24 hr observations

# Choice of reference frame for GNSS data analysis

- ITRF at mean epoch of measurement is optimal
- Overcomes adverse effects of unmodelled localised deformation and plate rotation between reference epoch and epoch of measurement
- Transform solution to local frame/datum/fixed epoch of ITRF after adjustment.



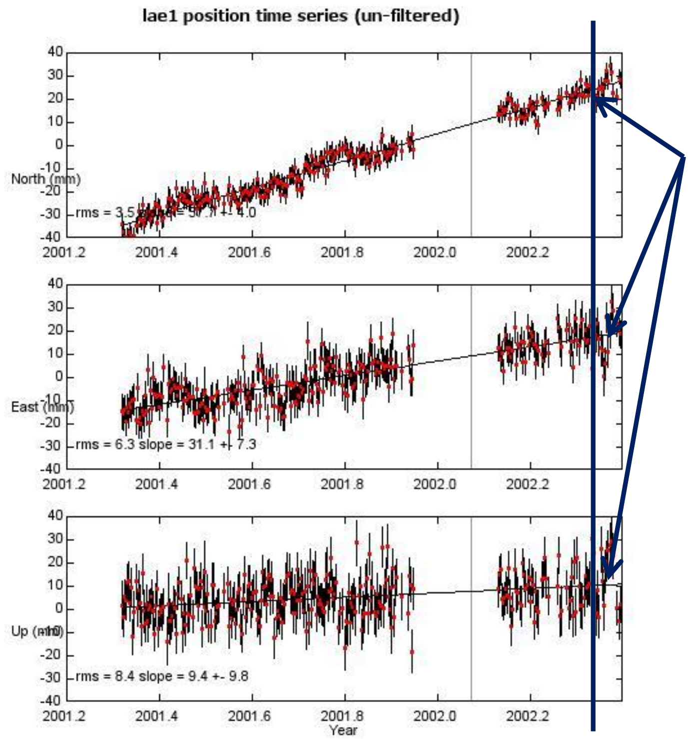
# Model station time-series in ITRF to estimate site velocity & reference epoch

Recommended approach for local datum reference epoch:

Choose epoch near end of timeseries.

Consider reference epochs of adjoining jurisdictions

Spectral analysis of time series to model noise




Select reference epoch for local frame (datum) determination

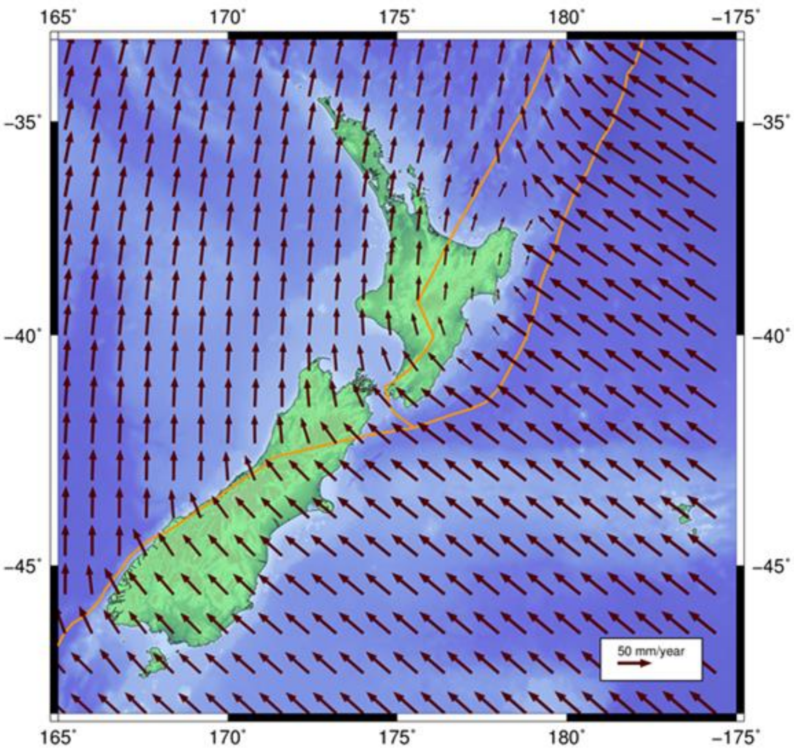
e.g. 2003.0

# Develop velocity (secular deformation) model

Enables ITRF coordinates at epoch to be propagated to another epoch (e.g. local datum reference epoch)

to model out underlying secular plate motion.

Alternatively a stable plate model by inversion of Euler Pole from site velocities, 14 parameter, 6 parameter or block shift rate can be derived (e.g. for smaller island states located away from plate boundaries)

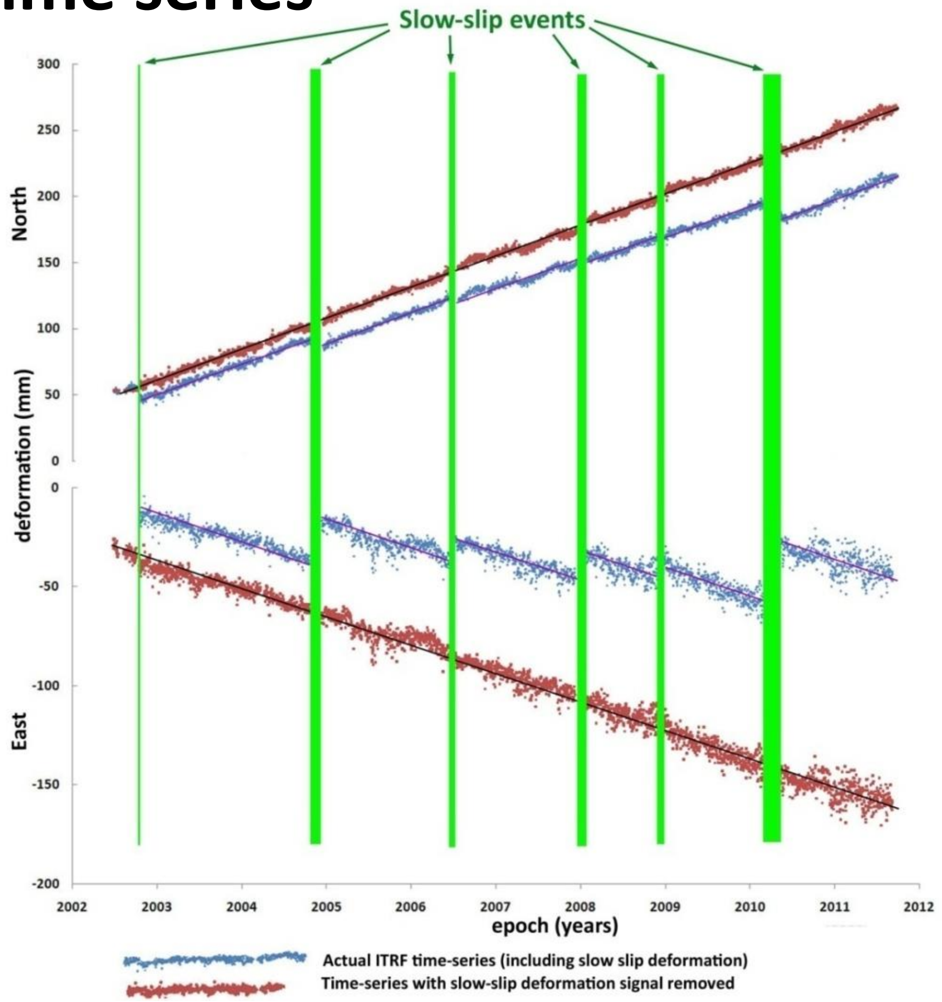


# Estimate seismic offsets in time series

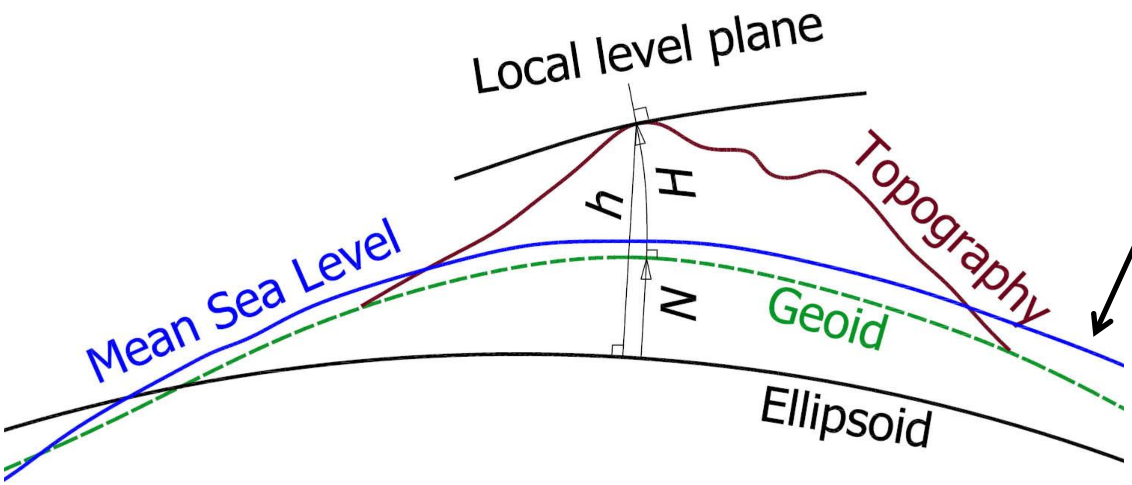
Gridded patch models of seismic deformation (including postseismic deformation)

Used in conjunction with secular (interseismic) deformation model.

If postseismic decay is significant, a gridded model of decay coefficients may be required



# Develop local geoid model to fit observed MSL




In Pacific region MSL sits between 0.7 m and ~1.5 m above the EGM2008 geoid

due largely to thermal expansion

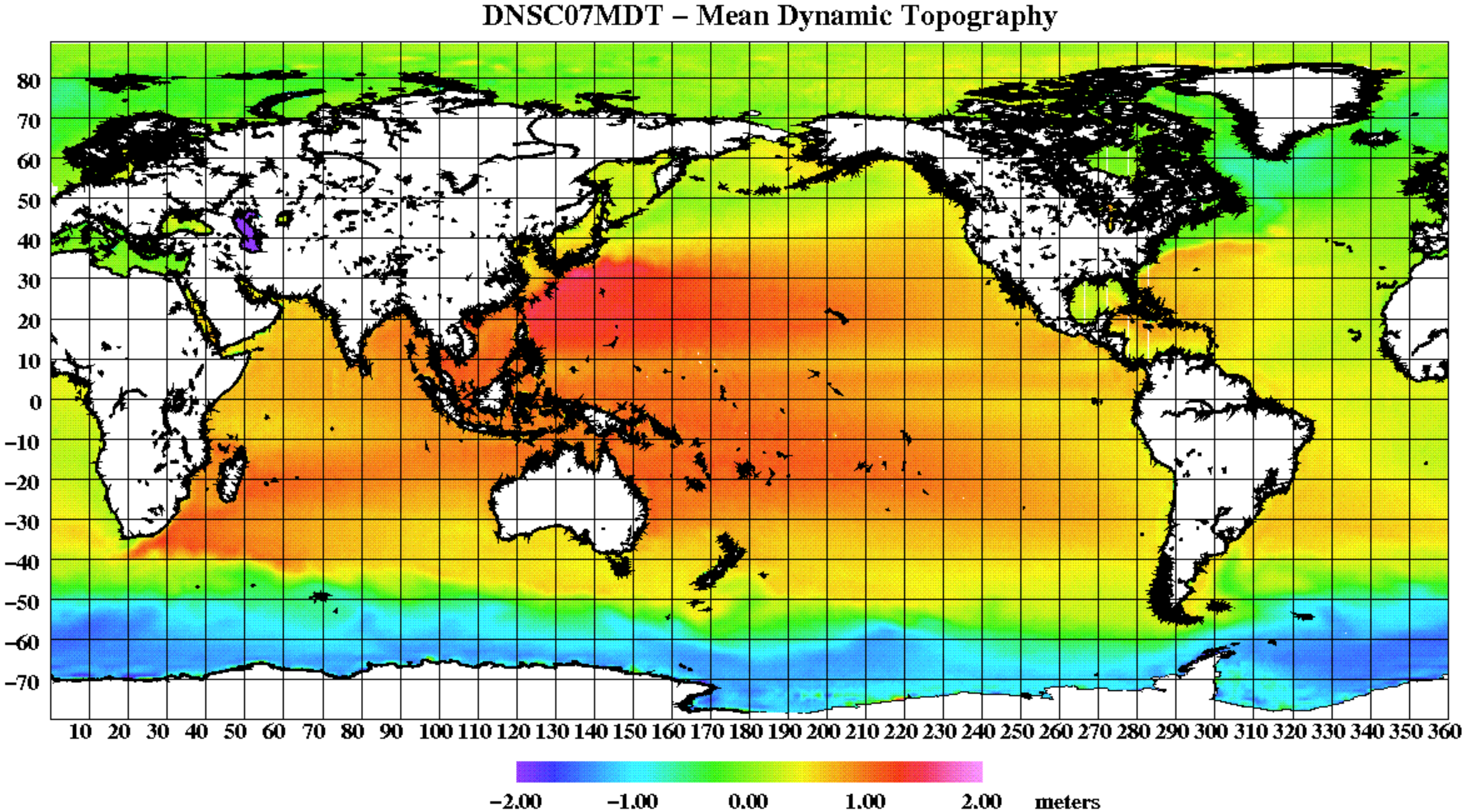
Observed MSL from TG

EGM2008 geoid

Offsets between observed MSL and EGM2008 can be interpolated (e.g. by kriging) and an “MSLoid” or hybrid geoid computed by adding offsets to EGM2008 N values

Other technique – using model of Mean Dynamic Topography (MDT) (ocean topography) from satellite altimetry

# Difference between MSL and EGM2008




Technical University of Denmark – National Space Institute

# Geodetic Adjustment

ITRF2014 at mean epoch of measurement for fiducial network and GNSS baseline processing

↓

Eliminate float or high RMS GNSS baselines
Evaluate weighting of fiducial station coordinates
Older baselines and legacy measurements not recommended

↓

Loop closure - robustly isolate incorrectly weighted baselines

↓

Run adjustment – tweak apriori and weighting to achieve RV of close to 1

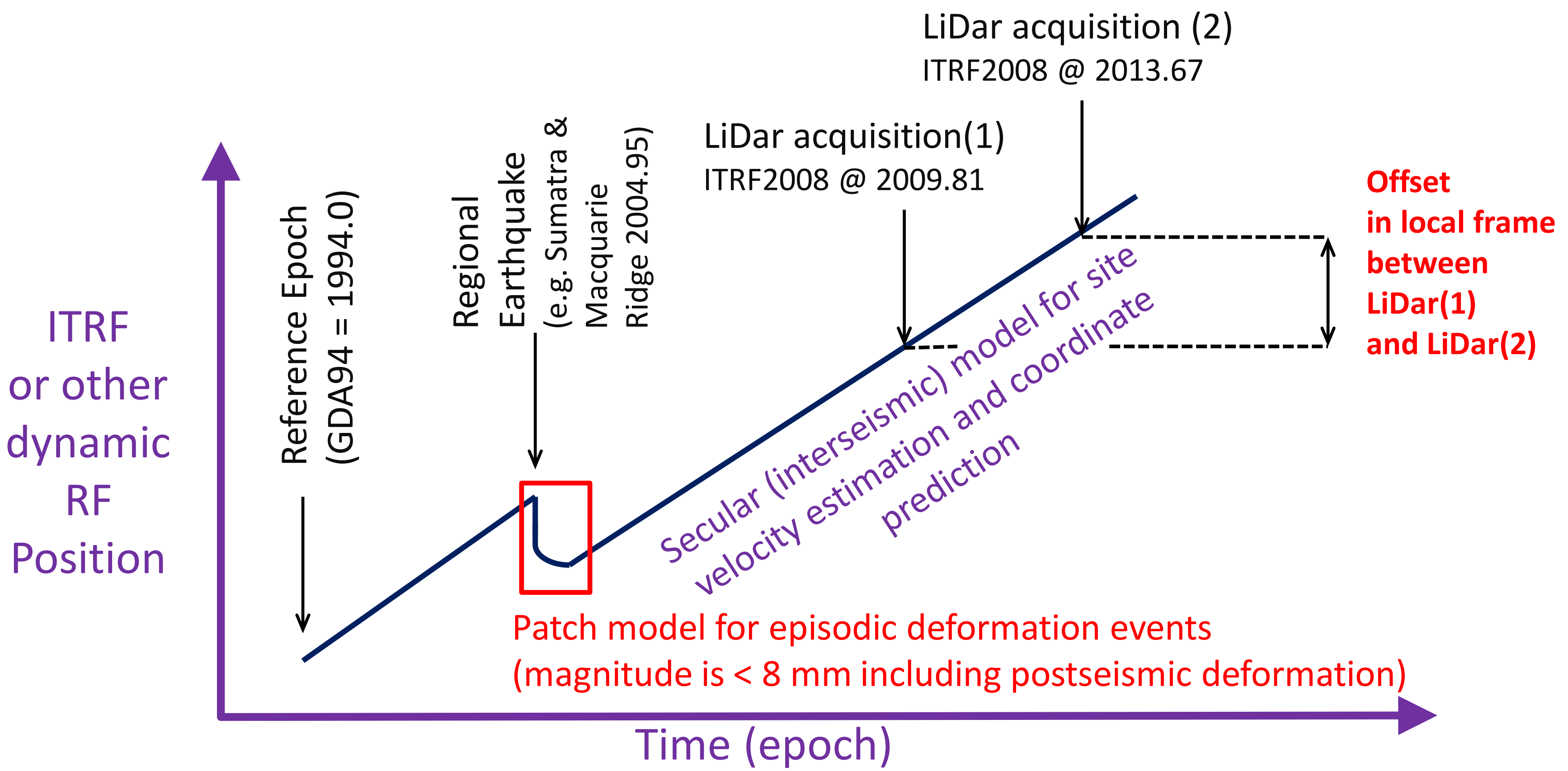
# Develop Map Grid(s) related to datum and ellipsoid

- UTM typically has large scale factors due to 6 deg wide zone
- UTM often not suitable for cadastral mapping and engineering surveys
- Options for best fitting map grid projection to keep scale factors close to 1.00000
- Selecting projection surface to coincide with mean elevation of region
- Local Transverse Mercator (LTM) (good for most jurisdictions) – Projection can be designed so that LTM bearings are aligned with underlying UTM grid bearings
- Stereographic Projection – Good for large square / circular regions
- Lamberts Conformal Conic – Good for higher latitude E-W shaped regions

# Compute transformation parameters from old datums

- Least squares estimation of transformation parameters by analysis of new datum and old datum coordinates.
- Requires robust filtering strategy (e.g. L1 Norm & eyeball) to isolate "rogue" coordinates and undocumented adjustment and realisation differences.
- 7-parameter model is the standard approach (mindful of larger rotations for reversibility), but also 3-parameter (small data sets) and distortion grids (e.g. NTv2)
- Need to provide parameters to GIS developers (e.g. ESRI, QGIS and MapInfo) EPSG, ISO-TC/211 and other geodetic registries

# Kinematic ITRF and spatial data management – care is required!



# Publication of datum definition, coordinates, station summaries etc.

- Publish datum technical specifications on the web
- Station maps, coordinate lists, uncertainties /VCV - SINEX and station diagrams on web (preferably free access)
- Online portal for Rinex data from CORS
- Post-processing / RTK services
- Coordinate, elevation and datum conversion services
- Subscription access to RT data streaming (e.g. RTK, NTRIP)
- New Zealand has a particularly good model for dissemination of geodetic data to users

# Example of datum access (New Zealand)

## Web-page for data

PositioNZ-RT – real-time data streams

Find out how to access real-time data from PositioNZ stations. more...

Text only version

Clickable map


PositioNZ stations | Velocity Model | Download data

Details | Timeseries | Availability | Photo

Data Access

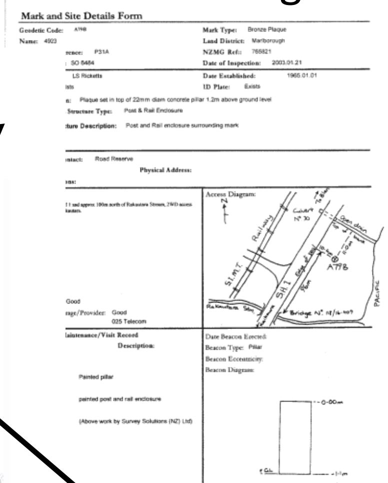
Details for KAIK

[Info] [Antenna] [Photo] [Notes]

| | |
|---|---|
| **Code:** | KAIK |
| **Name:** | Kaikoura GPS |
| **DOMES number:** | 50231M001 |
| **Datum:** | New Zealand Geodetic Datum 2000 |
| **Latitude:** | 42° 25' 31.68098" S |
| **Longitude:** | 173° 32' 1.17168" E |
| **Ellipsoidal height:** | 314.809 m |
| **Mark description:** | 5/8 thread in centre of 120 mm diameter stainless steel plate set in concrete pillar. |
| **Receiver:** | TRIMBLE NETR9 L1/L2+L2C/L5 GLONASS L1/L2 with 2 Maxwell-6 ASIC, |
| **Antenna:** | TRM55971.00 Zephyr GNSS Geodetic II - lead-based solder L1/L2/L5/G1/G2/G3/E1/E2/E5ab/E6/Compass |
| **Antenna height:** | 0.0550 |

Coordinates and elevation (including historical)
Uncertainty / class / order

## Location Diagram




## Antenna info

Details for KAIK

[Info] [Antenna] [Photo] [Notes]

| | |
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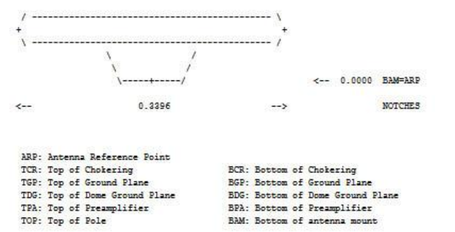


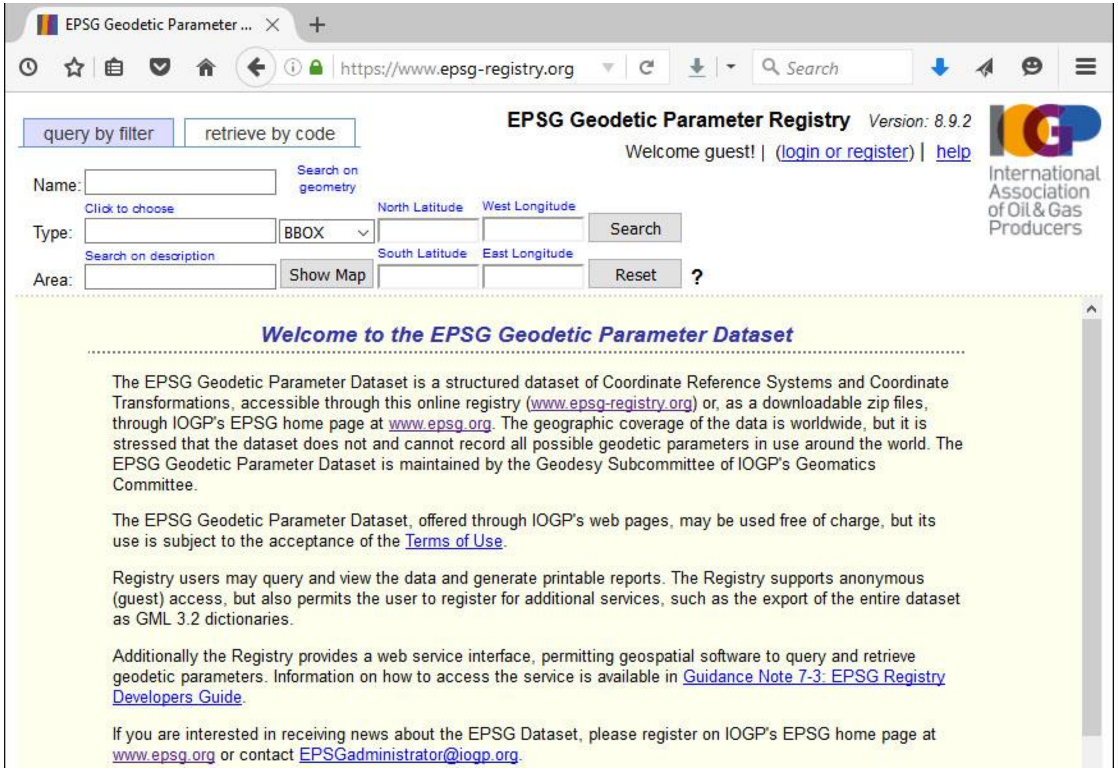

Details for KAIK

[Info] [Antenna] [Photo]

Station and mark photos

# Submission to IOGP/EPSG and ISO TC/211

- EPSG and ISO TC/211 geodetic registries used as authoritative data for GIS updates.



# GIS readable formats

## OGC WKT (Human Readable)

```
PROJCS["NZGD2000 / New Zealand Transverse Mercator 2000",
    GEOGCS["NZGD2000",
        DATUM["New_Zealand_Geodetic_Datum_2000",
            SPHEROID["GRS 1980",6378137,298.257222101,
                AUTHORITY["EPSG","7019"]],
            TOWGS84[0,0,0,0,0,0,0],
            AUTHORITY["EPSG","6167"]],
        PRIMEM["Greenwich",0,
            AUTHORITY["EPSG","8901"]],
        UNIT["degree",0.01745329251994328,
            AUTHORITY["EPSG","9122"]],
        AUTHORITY["EPSG","4167"]],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    PROJECTION["Transverse_Mercator"],
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    PARAMETER["central_meridian",173],
    PARAMETER["scale_factor",0.9996],
    PARAMETER["false_easting",1600000],
    PARAMETER["false_northing",10000000],
    AUTHORITY["EPSG","2193"],
    AXIS["Easting",EAST],
    AXIS["Northing",NORTH]]
```

- No standard yet for time-dependant transformations in GIS

## ESRI WKT

```
PROJCS["NZGD2000 / New Zealand Transverse Mercator
2000",GEOGCS["NZGD2000",DATUM["D_NZGD_2000",SPHEROID["GRS_19
80",6378137,298.257222101]],PRIMEM["Greenwich",0],UNIT["Degr
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,PARAMETER["latitude_of_origin",0],PARAMETER["central_meridi
an",173],PARAMETER["scale_factor",0.9996],PARAMETER["false_e
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Meter",1]]
```

## PROJ4

```
+proj=tmerc +lat_0=0 +lon_0=173 +k=0.9996 +x_0=1600000
+y_0=10000000 +ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m
+no_defs
```

# Thank You!

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or
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This presentation will soon be available:
http://www.quickclose.com.au/rfip2016.pdf