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Deformation monitoring and analysis using regional GPS permanent tracking station networks

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Outline

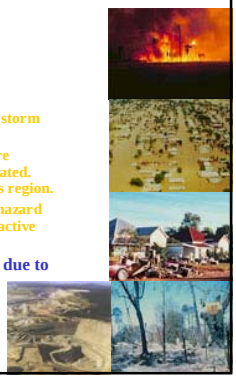
- Rationale
- Geo-hazard and its monitoring
- Continuously operating reference stations (CORS) network in Victoria – GPSnet
- Deformation analysis procedures
  - ✓ Selection of test areas, solution convergence
  - ✓ Statistical testing
- Data analysis
- Conclusions

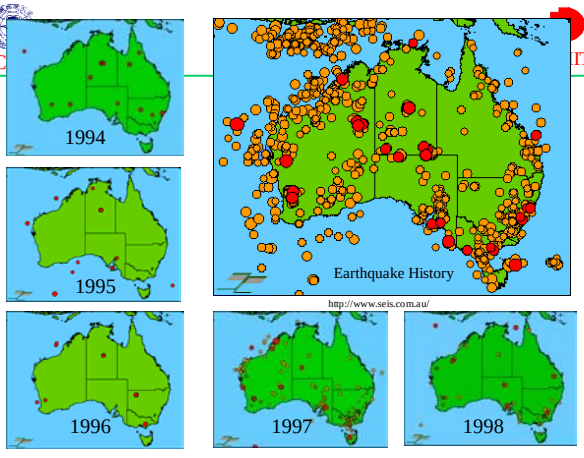
Rationale

- CORS - continuously operating reference stations
  - ✓ Permanent GPS tracking stations
- CORS networks play increasingly important roles as a vital geospatial infrastructure, eg
  - ✓ Internationally well established as a "ground" augmentation of GPS to improve positioning capability
  - ✓ High-precision reference frames, network RTK
  - ✓ ubiquitous positioning and LBS
- The questions are "how reliable of our CORS stations?"
  - ✓ Relative and absolute terms (micro- to macro- scales)
  - ✓ changes with time
  - ✓ Temperature, wind, setting-up, geo-hazard events, etc.

Geo-hazard and its monitoring

- Natural disasters are of a problem of global concern and may cause significant social, environmental and human losses
- Natural hazards are estimated at an average annual cost of Aus$1.25 billion in Australia
  - ✓ This includes earthquakes, landslides, floods, storm surges, severe winds, bushfire etc.
  - ✓ Victoria (Australia) is one of the regions where earthquake epicentres are relatively concentrated. There are potential risks of earthquake in this region.
  - ✓ Landslide is another considerable geological hazard in Australia and south-eastern Victoria is an active landslide area.
- In addition, the Earth's surface deformation due to human activities may also cause hazards
  - ✓ eg mining





Geo-hazard and its monitoring

- The ability to analyse and predict natural and non-natural hazards is of great importance
  - ✓ Such ability depends heavily on precise & reliable deformation info
- Deformation information can be acquired through
  - ✓ monitoring and analysis of the Earth's surface displacement, the movement of faults, landslide and some other deformations.
- GPSnet CORS stations provide a critical geospatial infrastructure,
  - ✓ high precision deformation information can be potentially obtained
  - ✓ lots of expenditure required for establishing dedicated deformation monitoring networks in this area can also be saved.
- It is of vital importance to investigate the feasibility to use GPSnet to monitor and analyse regional deformation

GPSnet

- GPSnet is a cooperative GPS base station network coordinated by Land Victoria
  - ✓ Victorian government initiative
    - ➢ Land Victoria, a division of the Department of Natural Resources and Environment,
  - ✓ an integral part of the new geodetic strategy for Victoria
- Established in partnership with industry and academia
  - ✓ GPSnet currently consists of 22 operating base stations
  - ✓ The average spacing of base stations is approximately 50km in the greater Melbourne region and 160km in rural Victoria.
- Records, distributes and archives GPS data for post processed, accurate position determination only

Major milestones

- Perceived in early 1990s
  - ✓ state wide geodetic infrastructure
  - ✓ economic benefit to reduce establishment cost
- July 1994
  - ✓ first single frequency pilot site at Ballarat started data recording (~80km from Melbourne)
- December 1995 and early 1996
  - ✓ dual frequency, public access
  - ✓ additional two sites established, Melbourne and Bendigo
- 1997
  - ✓ network design project conducted by RMIT
  - ✓ accuracy, sources of error, baseline length/density, site selection, potential radio interference, multipath effects etc.

Major milestones

- 1999-2004 many stations established
  - ✓ currently consists of 22 operating base stations and will contain 24 stations upon completion by 2005.
  - ✓ Seven stations broadcasting RTK signal
    - ➢ For mining activities, Ski site surveying
    - ➢ For FORMULA I, Grand Prix
  - ✓ RMIT proposed NRTK concept in 2000
- RMIT led a research team & won an ARC project in 2004
  - ✓ Australia Research council – ARC
  - ✓ Through regional/local atmospheric studies
  - ✓ $1.36 million project
  - ✓ RMIT, UNSW and UoM, Land Victoria and Dept of Lands/NSW
- CRC-SI established 2004
  - ✓ DGPS + LBS
  - ✓ CRC – cooperative research centre of spatial information

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GPSnet goals

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- GPSnet primary goals:
  - ✓ enhance the Victorian geodetic framework
  - ✓ provide easy access to accurate positioning information for a wide user community across the State
  - ✓ provide a mechanism for centimetre-positioning relative to the National Spatial Reference Systems.
- GPSnet secondary goals
  - ✓ From BBS to Web-based direct access
  - ✓ support both post and real-time surveying
  - ✓ real time transmission of GPSnet data
  - ✓ Multiple modal positioning support
  - ✓ NRTK, DGPS and Location-based services (LBS)
    - ➢ will enable near instantaneous centimetre-level accuracy positioning by a single GPS receiver in the field.

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Locations of current GPSnet Base Stations Providing Coverage in Rural and Regional Victoria With Indicative 100 Km Radius Circles of Coverage

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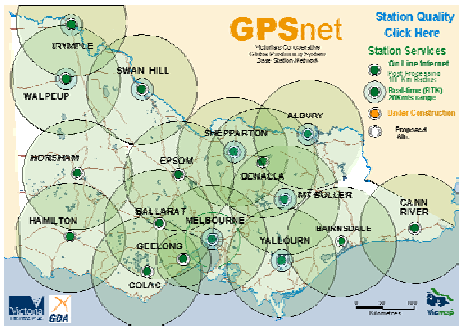

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Locations for Permanent GPS Base Stations in the Melbourne Region With Indicative 50 Km Radius Circles of Coverage

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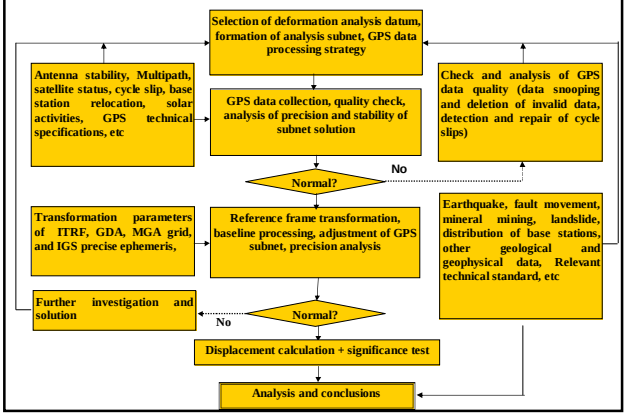
Victorian GPSnet

- The GPSnet uses a variety of receivers including Trimble, Leica dual-frequency receivers
- Record C/A code, L1/L2 carrier phase and Doppler data in the RINEX format at all sites
- The GPSnet has been widely used, including
  - ✓ Surveying, mapping, GIS, navigation,
  - ✓ open pit coal mining, Location based services
  - ✓ Agriculture, etc.
- Measurements interval as high as 1 second,
  - ✓ 24/7
  - ✓ Web-based "near real-time" access

Deformation Analysis process flow chart



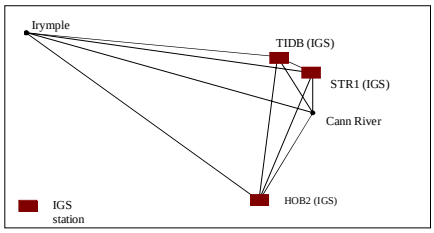
Solution convergence tests

- ✓ How much data should be used
- ✓ Precision of solution vs the length of data
- ✓ An experimental subnet is chosen

- Chronological development
  - ✓ History of stations
  - ✓ Formation of sub-net for different purposes of investigations
- Velocity and displacement computation
- Statistical test
  - ✓ The correlation of the amount data used and precision
  - ✓ Deformation detected significant or not
  - ✓ Relation between geo-hazard points of interests and stns

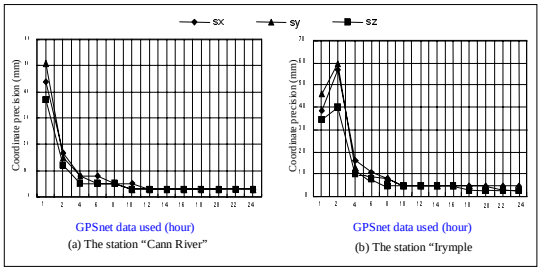
Solution convergence

- An experimental network is used to
  - ✓ investigate the relation between the precision of the solution and the amount of GPSnet data used
- It consists of two stations in the GPSnet and three IGS stations
  - ✓ The longest baseline in the GPSnet (735 kilometers)



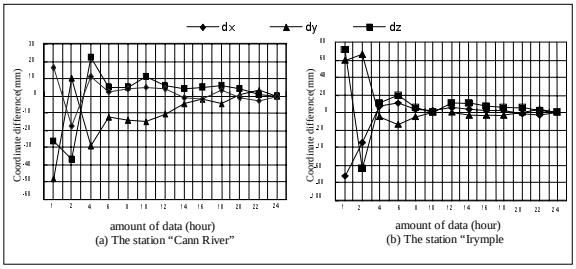
Solution convergence

The relation between the RMS error of coordinates in ITRF2000 and the amount of data used to generate the experimental network solution



Solution convergence

Differences between the coordinates derived from different amount of GPSnet data and the solution from 24 hours GPSnet data (ITRF2000)



Precision of GPSnet Solution

- **Overall, the precision of the solution depends on the length of the data used.**
  - ✓ **The higher of the solution precision, the longer of the data used**
  - ✓ **The solution tends stable when 20+ hours of data is used**
  - ✓ **When the data less than six hours, the RMS error of coordinates and the coordinate differences can be more than 20mm and 15mm respectively, which cannot meet the requirement for a high precision deformation monitoring.**
- **When the session length is close to 24 hours (e.g, 20+), the precision of coordinates is 3~5mm, and the coordinate differences can be less than 5mm, which means that the solution becomes quite stable.**
- **Therefore, daily solution (24 hours of data) can be used for high precise regional deformation monitoring and analysis**

Precision of GPSnet Solution

According to the feature and shape of the precision curves, it can be seen that the RMS error of the solution consists of two parts.

- One is the fixed error component not relating to the amount of data used;
- the other is the error which decreases with the increase of the amount of data used.

Using the law of error propagation, the coordinate precision of the solution can be expressed as follows:

$$m = \sqrt{a^2 + b^2 \cdot f(t)}$$

where, "m" is the precision of the coordinates, "f(t)" is a function of the amount of data used and "a" and "b" are the fixed error and the proportional error coefficient respectively. Based on the result of a number of trial computations, it is found that $f(t)$ can be approximately expressed by t^{-3} , ie.

$$m = \sqrt{a^2 + b^2 / t^3}$$

Precision of GPSnet Solution

Let $Y = m^2 \quad B = b^2 \quad X = 1/t^3 \quad A = a^2$

We get the following linear equation :

$$Y = A + BX$$

Take the station "Cann River" as an example,

we get the following equations:

$$m_x = \sqrt{19.853 + 1920.159 / t^3}$$

$$m_z = \sqrt{7.646 + 1357.213 / t^3}$$

$$m_y = \sqrt{2.978 + 2585.786 / t^3}$$

Precision of GPSnet Solution

The corresponding correlation coefficients are:

$$\rho_x = 0.8146 \quad \rho_y = 0.9054 \quad \rho_z = 0.6468$$

Taking a level of significance $\alpha = 0.05$

We get the critical value of correlation coefficient: $\rho_0 = 0.553$

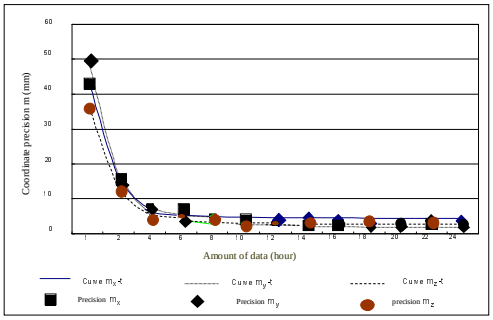
Since ρ_x ρ_y ρ_z are all bigger than ρ_0

the precision of solution is strongly related to amount of data.

A comparison of the "modelled" precision curve and actual precision curve is shown in the next Figure. These two curves agree well.

Precision of GPSnet Solution

Comparison of the theoretical precision curve and the precision of direct solution



Precision of GPSnet Solution

It can be seen from early formula that "m" tends towards "a" when "t" tends towards "∞".

This suggests that, theoretically, the precision becomes stable if the amount of data is unlimited.

The following results can be obtained:

when $t = 24$ hrs, $\{(m^2 - a^2)/m^2\}_{\max} < 6\%$

This indicates that, in practice, the precision of 24 hrs solution is enough stable.

Based on what is discussed above, it is concluded that 24-hour solution (or single-day solution) can be used for high precision deformation analysis.

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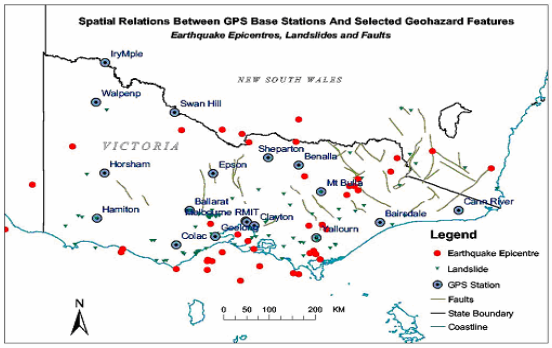
Spatial relationship between GPSnet stations and geo-hazard points of interest



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- The relations between GPSnet stations and geological features
- There are more than 10 relatively large faults within Victoria and some stations are close to faults and/landslide sites

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Deformation Analysis

- **A subnet of Victorian GPSnet is chosen**
- Only seven base stations
- Two-year data from 14 April 2002 to 14 April 2004 are used for local deformation analysis, due to various reasons
  - ✓ e.g. some data files are not available,
  - ✓ bad data format and
  - ✓ chronological data availability due to relocation of some stations.
  - ✓ Lots of data pre-processing effort

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Chronological developments of the Victorian GPSnet stations

GPSnet stations (date of operation)	Year of operation	No of Stations (Total)
Ballarat (01/12)	1995	1 (1)
Epsom (01/07) (relocated in 2002) Melbourne RMIT (01/08)	1996	2 (3)
Geelong (03/09)	1998	1 (4)
Benalla (13/07) Irymple (relocated in 2003) (26/01)	1999	2 (6)
Colac (30/10) Mt Buller (19/12)	2000	2 (8)
Swan hill (05/03) Hamilton (19/03) Shepparton (06/04) Walpeup (14/05) Horsham (02/06) Yallourn (21/06) (relocated in 2003)	2001	6 (14)
Cann River (01/09) Melb obs (IGS station) (18/11)	2002	2 (16)
Clayton (12/02) Bairnsdale (31/10)	2003	2 (18)
Albury (11/02)	2004	1 (19)

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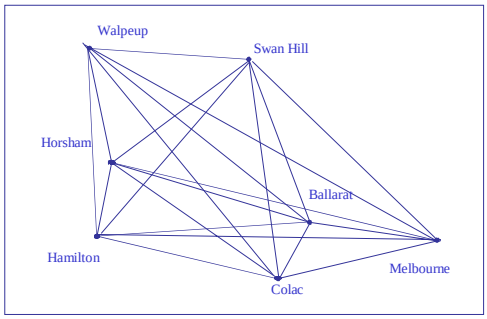
Deformation Analysis



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Deformation Analysis

- Absolute and relative displacements of the GPSnet subnet stations
- Significance test of absolute and relative displacements

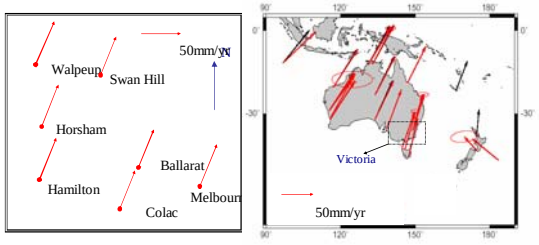
station	Absolute displacement (mm) and velocity (mm/yr)						relative horizontal displacement (mm)		
	dE	dN	dU	V	V/2	significance test	dE_r	dN_r	significance test
Melbourne	21	124	32	130	65	√	-6	-5	×
Ballarat	24	121	25	125	62	√	-3	-8	×
Colac	32	125	18	128	64	√	5	-4	×
Hamilton	35	128	16	134	67	√	8	-1	×
Horsham	20	135	34	139	70	√	-7	6	×
Walpeup	33	138	47	148	74	√	7	9	×
Swan Hill	27	131	45	142	71	√	0	2	×

Deformation Analysis

- The results of significance test show that
  - ✓ the relative horizontal displacements of all the subnet points are not significant
  - ✓ The relative horizontal positions of the subnet points are not notably affected from local geological features
- It can be inferred that currently, the faults and/or landslide body near these base stations are relatively stable
- However, the stability of the faults and landslide body still needs to be continuously analysed in the future

Deformation Analysis

Both the magnitude and direction of the absolute displacement of all the base stations in the subnet agree well with the velocity of approximately 7cm/year and direction of current Australia tectonic motion derived from other IGS measurements (Geoscience Australia, 2004)



Results from the method put forward in this paper

Results from other IGS measurements

Conclusive Remarks

- This paper investigates the feasibility to use local CORS network for geo-hazard monitoring purposes
- A number of critical issues associated with the suitability, geological stability, data quality of the GPS networks system, the precision and stability of the GPSnet solutions are investigated using geological information.
- For high precise positioning, it is recommended that
  - ✓ the minimum length of the data used to generate solutions is 12 hours
- The precision of 3-D coordinates derived from daily solution (24 hours data) is 3~5mm
  - ✓ the solution is quite stable and can meet the requirements of high precision deformation analysis

Conclusive Remarks

- Currently, the faults and/or landslide body near GPSnet base stations in the deformation analysis subnet are relatively stable
- The methodology of data processing and deformation analysis used in the paper seems feasible and effective.
- It is recommended that geological information needs to be taken into account when any new CORS stations are established.
- It is concluded that high-precision continuous tracking data from GPSnet is a very valuable asset and can provide a technically-advanced and cost-effective geoscientific infrastructure for deformation monitoring analysis
- Several relevant issues are under investigation

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