12.540 Principles of the Global Positioning System Lecture 23

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OVERVIEW

- Run through HW 03.
- Final lecture: Application area and GPS results
  - Analysis of contemporary motions in the Tien Shan region of central Asia.
  - Example of evolution of a network
  - Issues faced when generating multi-year (decade) velocity model.

Homework 03

Results from analyses:

Phase	-2225432.8807	-4676994.9505	3711598.8548
Rinex file	-2225431.6719	-4676995.2141	3711599.9580
L1 only	-2225401.05	-4677074.26	3711596.32
LC data	-2225395.55	-4677062.77	3711585.48
Diff BKAP	-2225432.72	-4676994.79	3711599.45
Erwan	-2225468.944	-4676973.873	3711593.862
Lili	-2225402.870	-4677022.626	3711614.283

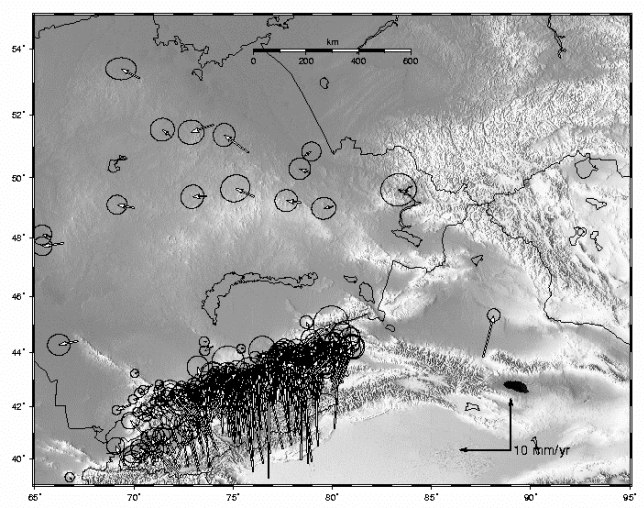
Central Asia Analysis

- Network
  - Development of network
  - Transition from “pins” with tripods to IVTRAN fixed-heights monuments
  - Continuous stations
- Analysis methods
  - Pre-continuous station analysis
  - Merger with global GPS analyses
- Motion relative to Eurasia
  - Methods of used to realize a Eurasia fixed frame
- Vertical motions
  - Vertical motions as a function of existing topographic heights

Network

- Development of Network
  - First measurements made in July 1992; just after start of International GPS Service (IGS). Since then measurements each year and often multiple campaigns per year.
  - The current network has over 1000 sites, many of them being recovery marks for the main stations (typically 3 per location)
  - Network extends from Kyrgyzstan to the Kazakh Platform
  - In 1995, the first continuously operating stations installed. Currently, 9 continuous sites with 2 IGS sites (POL2, SELE)
  - Results available on web at: http://www-gpsg.mit.edu/~tah/cont98g/cont98.html (Pages include time-series, phase residuals, atmospheric delay estimates)

Regional view of network



Zoom

Eurasia Fixed Frame realized using ITRF2000

50% confidence ellipses shown

Monument evolution

- Original monuments were mainly steel pins in bedrock which required tripod setups
- Starting in 1995: IVTRAN designed fixed-heights were installed. Simplified setup. Three recovery marks installed for each original monument.
- After 1995, measurements made on the recovery marks rather than original marks.
- With the original marks and fixed height marks, for many stations two independent velocity estimates (results shown later)

Analysis methods

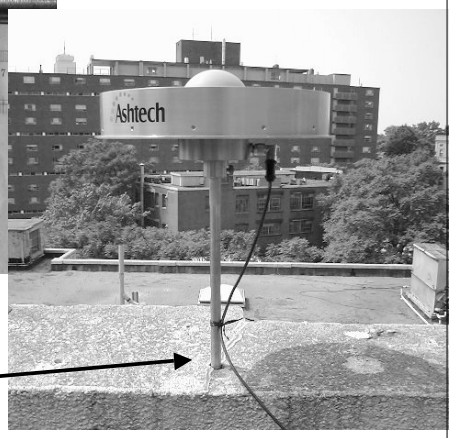
- Prior to 1995; selected IGS from Europe, Asia and Australia included in the analysis of regional data
- After 1995 when POL2 became an IGS site and was routinely included in the IGS analysis; only local sites included in the MIT analysis
- Using GAMIT/GLOBK; regional analyses are included in the Scripps Institution of Oceanography IGS (SOPAC) analysis including orbit improvement (more important in early data). ftp://garner.ucsd.edu/pub/hfiles
- Campaigns are combined with SOPAC h-files for velocity field and repeatability analyses.

Analysis Method

- Types of analyses performed with combined files:
  - Velocity field analysis. Multiple types
    - Global: Global selection of sites along with regional sites. Eurasian frame then defined using the ITRF2000 Eurasian rotation pole.
    - Eurasian: Only sites from Eurasia included. Eurasian frame defined to minimize velocities of stable Eurasian sites
    - In both analyses: Option to force velocities at nearby sites (<0.5 km separation) to be the same (some exceptions)
  - Repeatability analysis:
    - Each campaign is rotated/translated to best align as a function of time with positions and velocities from one of the velocity analyses.

IVTRAN Monuments

Rod length 355 mm



Monument components

Installed monument (SST antennas used in Central Asia

Statistical analysis

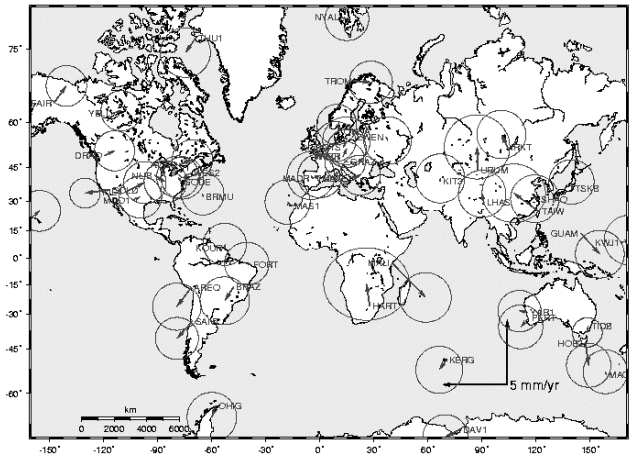
- Since the network contains both continuous sites and campaign sites, we include statistical process noise in the velocity analyses to account for temporal correlations in the time series.
- Each site has random walk process noise (2 mm)^2/yr
- Without process noise, velocities of continuous sites would have sigmas of < 0.1 mm/yr; with process noise sigmas are between 0.6 and 1.0 mm/yr e.g.

Site	Random Walk (mm/yr)			White noise (mm/yr)		
	E	N	U	E	N	U
POL2	0.5±0.6	3.0±0.6	-0.5±1.1	0.2±0.1	3.3±0.1	-1.1±0.2
SELE	0.9±0.8	3.7±0.8	-2.5±1.2	1.7±0.1	3.8±.0.1	-2.1±0.2

Frame Realization

- Realization of Eurasian frame; Two methods used
  - ITRF2000: Used global distribution of sites(52) on many plates to rotate/translate frame onto ITRF2000. ITRF2000 Eurasia pole used to rotate to Eurasia fixed frame
    - Fit to ITRF2000 (52-sites):
    - Horizontal RMS 0.8 mm/yr; $\sqrt{\chi^2/f}$ 1.2
    - Vertical RMS 1.8 mm/yr; $\sqrt{\chi^2/f}$ 2.4
  - Eurasia only: Used 14 sites on stable Eurasia to define frame
    - Fit to Eurasian sites only(14-sites)
    - Horizontal RMS 0.5 mm/yr; $\sqrt{\chi^2/f}$ 0.8
    - Vertical RMS 1.8 mm/yr; $\sqrt{\chi^2/f}$ 2.3
- Notice χ^2 is <1 for Eurasia but >1 for global; sigmas depend on size of region considered.

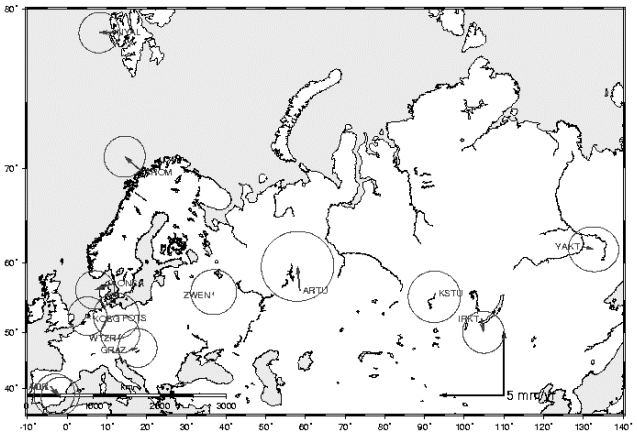
ITRF2000 Residuals



Horizontal RMS 0.8 mm/yr

52-sites

Eurasia only residuals

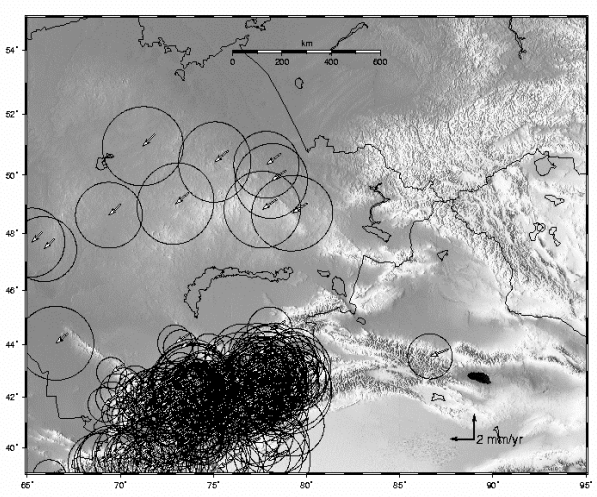


Horizontal RMS 0.5 mm/yr

14 sites

Postglacial rebound model at NYAL, ONSA

Difference between Realizations



Zoom

RMS Difference 1.3 mm/yr

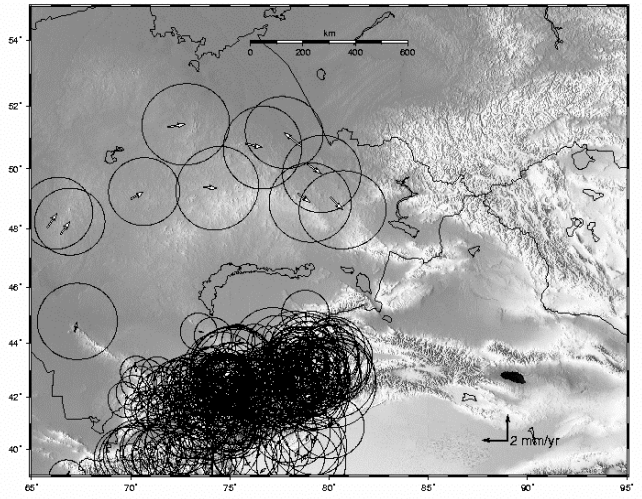
Set by systematic
-1.3 mm/yr E
-0.7 mm/yr N

If removed 0.1 mm/yr RMS

Local Frame realization

- Another method for frame realization is the use of local stations (1200x1800 km region) in forming velocity solution.
- The frame is then found by rotation/translation to best match the Eurasia only realization
- In this method, effects of global scale systematic errors should be reduced.
- RMS difference of velocities is 0.4 mm/yr ($\sqrt{\chi^2}$/f 0.2) and only slightly changed by estimating rotation/translation between fields.

Local Frame Realization Differences



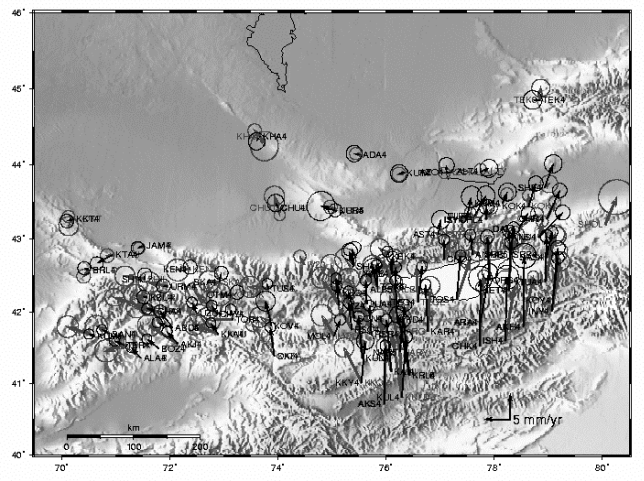
Zoom

Differences between co-located sites

- Of the approximately 400 sites with high-quality velocity estimates, 104 sites are collated between old and new monument styles.
- Comparison:

Analysis	Horizontal RMS	3D-RMS
Global	1.9 mm/yr ($\sqrt{\chi^2}$/f 1.0)	2.5 mm/yr ($\sqrt{\chi^2}$/f 1.1)
Regional	1.9 mm/yr ($\sqrt{\chi^2}$/f 0.9)	2.4 mm/yr ($\sqrt{\chi^2}$/f1.1)

Collocated velocity estimates

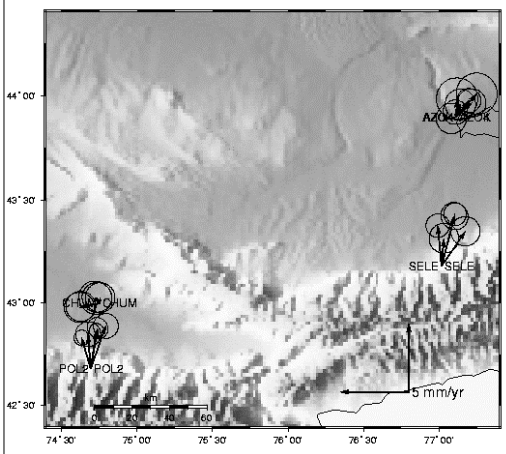


Zoom

50% confidence intervals

Differences are consistent with sigmas

Motion in Eurasia Frame

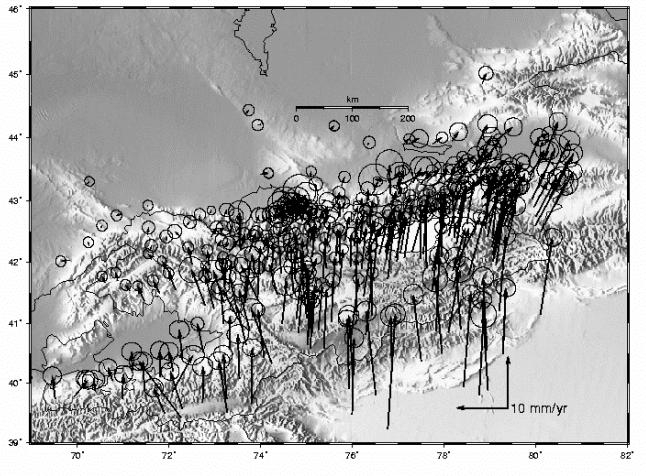


Motion from difference analyses

Best Estimates:

Site	East mm/yr	North mm/yr
POL2	0.5±0.6	3.0±0.6
SELE	0.9±0.8	3.7±0.8
AZOK	1.2±0.9	1.1±0.9
CHUM	-0.3±1.0	0.4±1.0

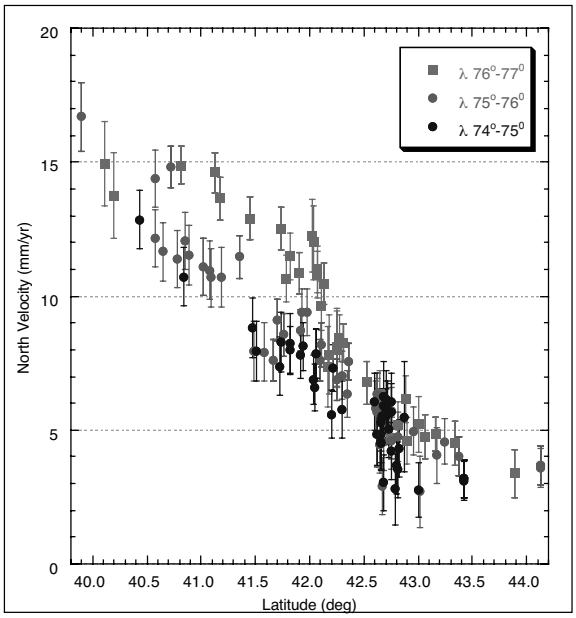
Complete Velocity Field



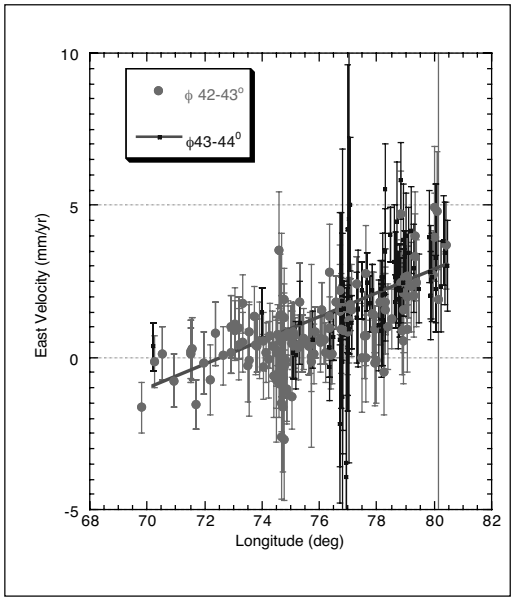
Zoom

Field dominated by North-South compression

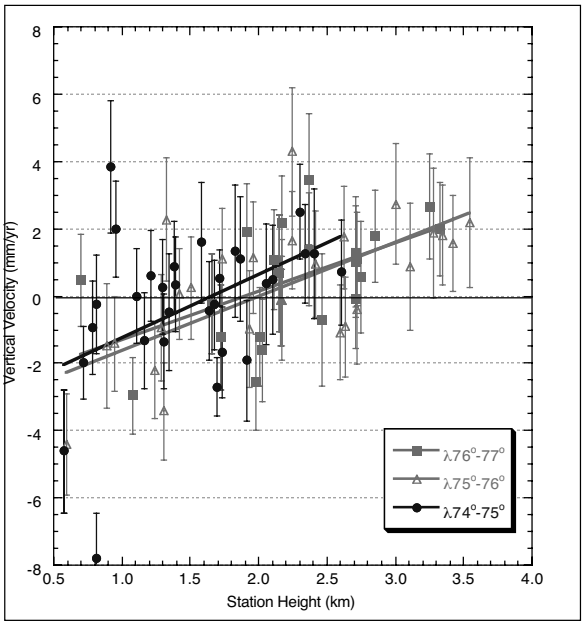
Also East-West extension to East



Profile of North Velocities



East Velocities as function of Longitude



Height Rates versus Height

Regression of height rate versus height yields values between 1.4-1.9 (mm/yr)/km

Conclusions

- North of the Tienshan the motion of sites relative to Eurasian appears to be less than 1 mm/yr
- Within the Kyrgz Tienshan ~13 mm/yr North converge
- East west extension across the range front of ~3 mm/yr
- Height rate range of ~4 mm/yr
- Median RMS scatter of position estimates 1.4-1.8 mm horizontal and 4.6 mm height.
- Consistent statistics are obtained with random walk process noise of $(2\ mm)^2/yr$.

Tools

- Most modern GPS analyses now contain hundreds of GPS sites
- For the remainder of the lecture we examine results with the GAMIT/GLOBK matlab tools available at: http://www-gpsg.mit.edu/~tah/GGMatlab
- Current programs are velview and tsview.