GPS surveying to monitor slow movements/deformations on slopes

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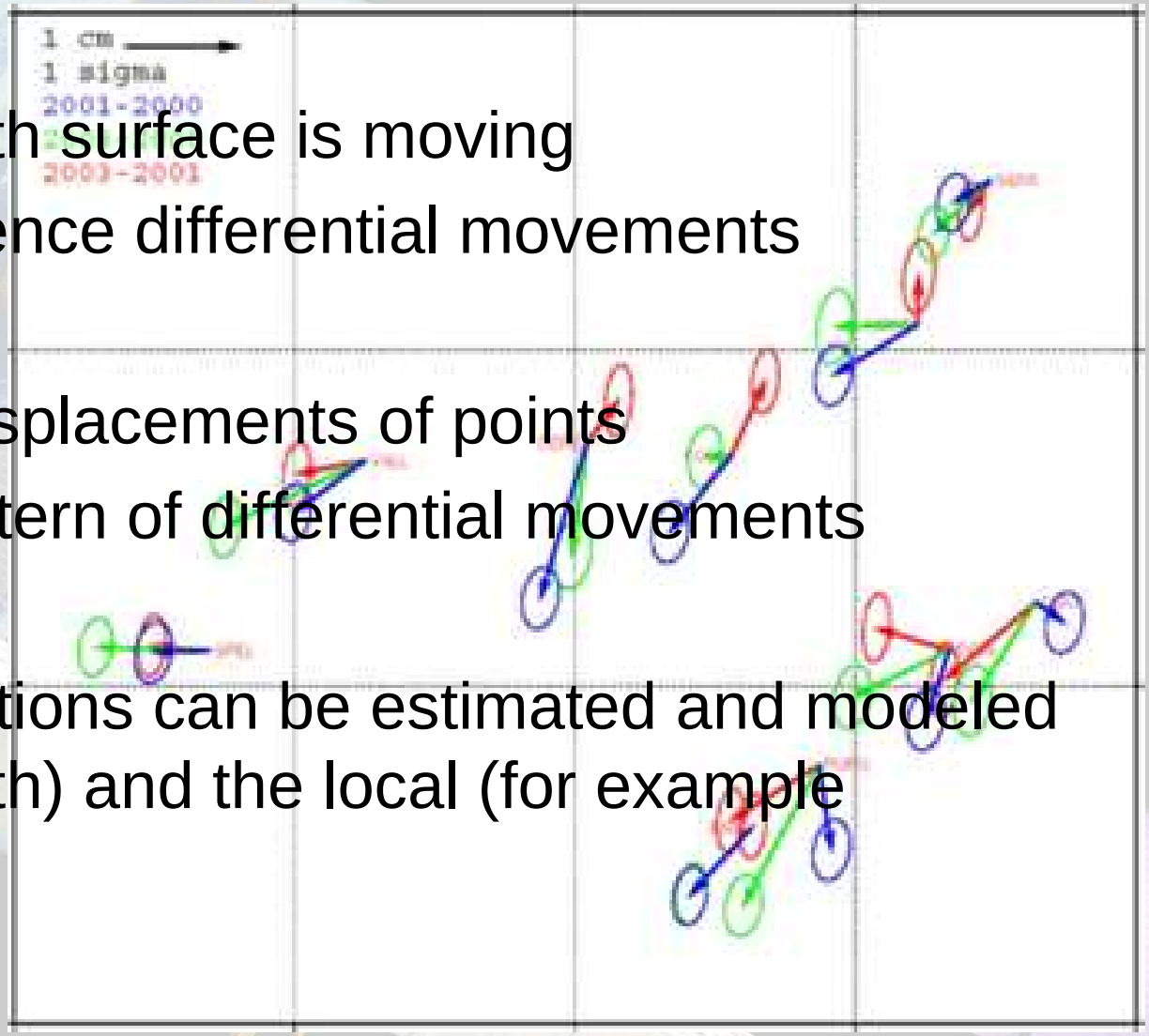
Movements and deformations

Earth is not a rigid body

1) every point on the Earth surface is moving

2) different points experience differential movements

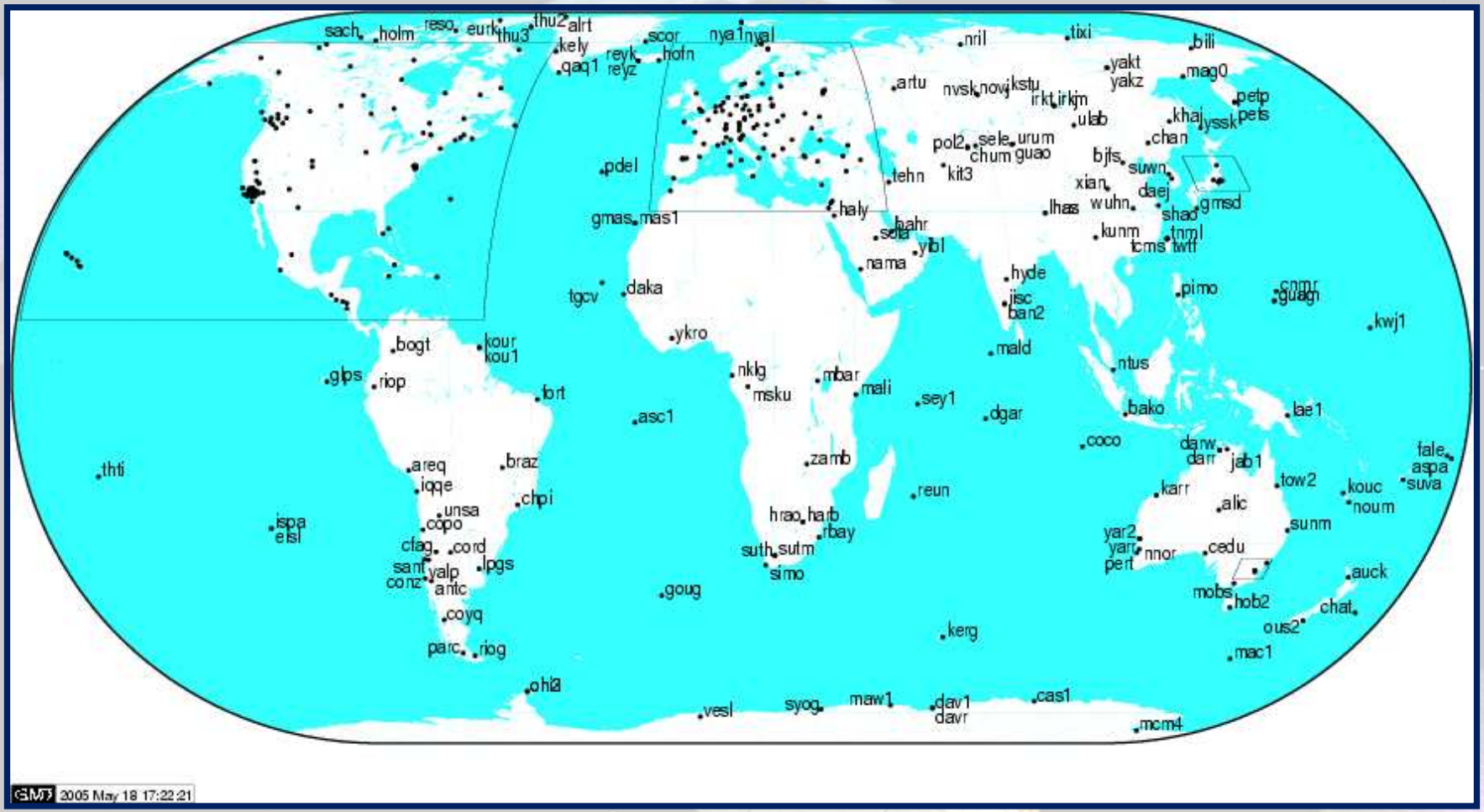


Movements: individual displacements of points

Deformations: spatial pattern of differential movements

Movements and deformations can be estimated and modeled at both the global (Earth) and the local (for example landslides) scale

Global permanent networks…

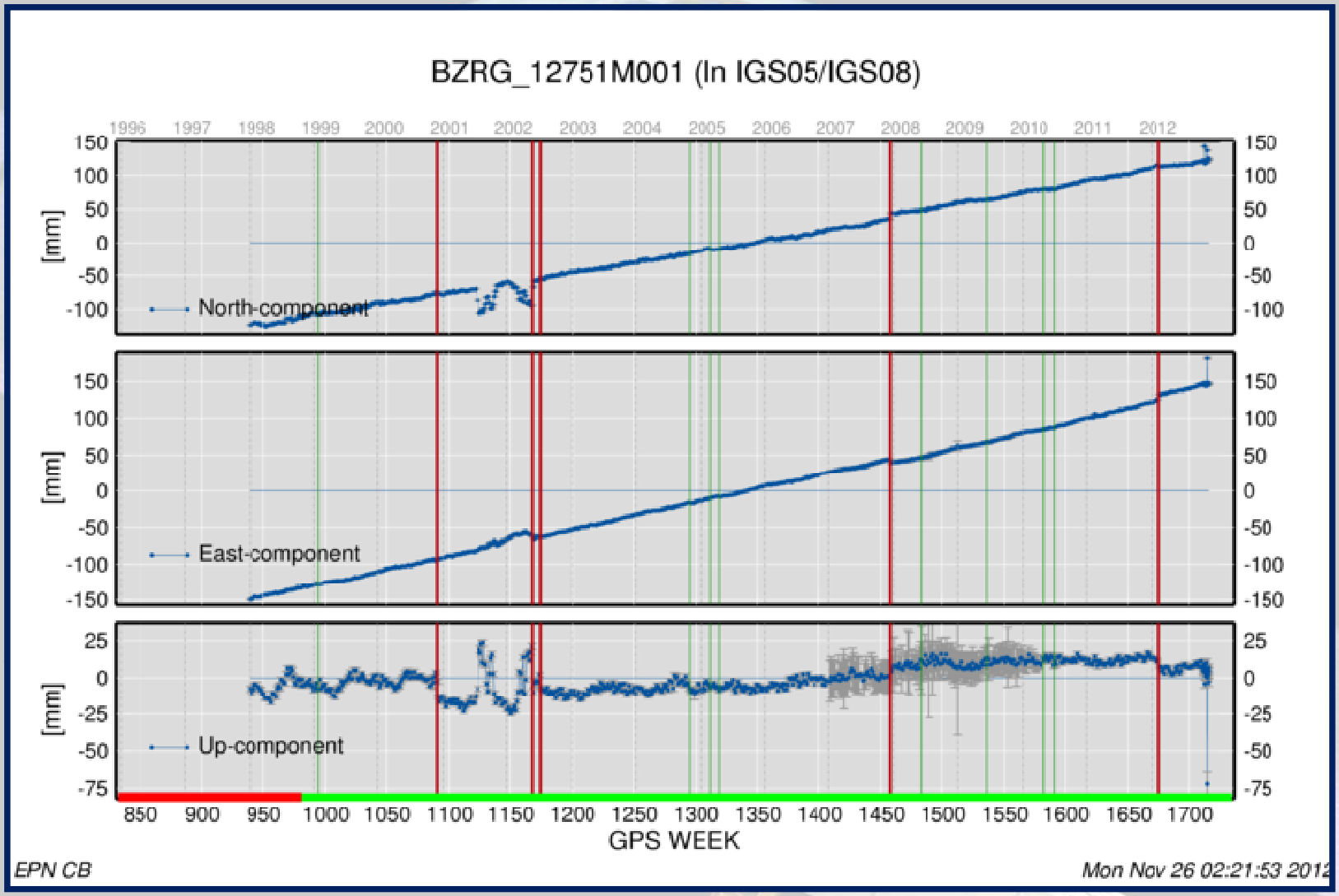


VLBI, SLR and GPS global networks monitor the movements of their permanent stations...

…individual movements…

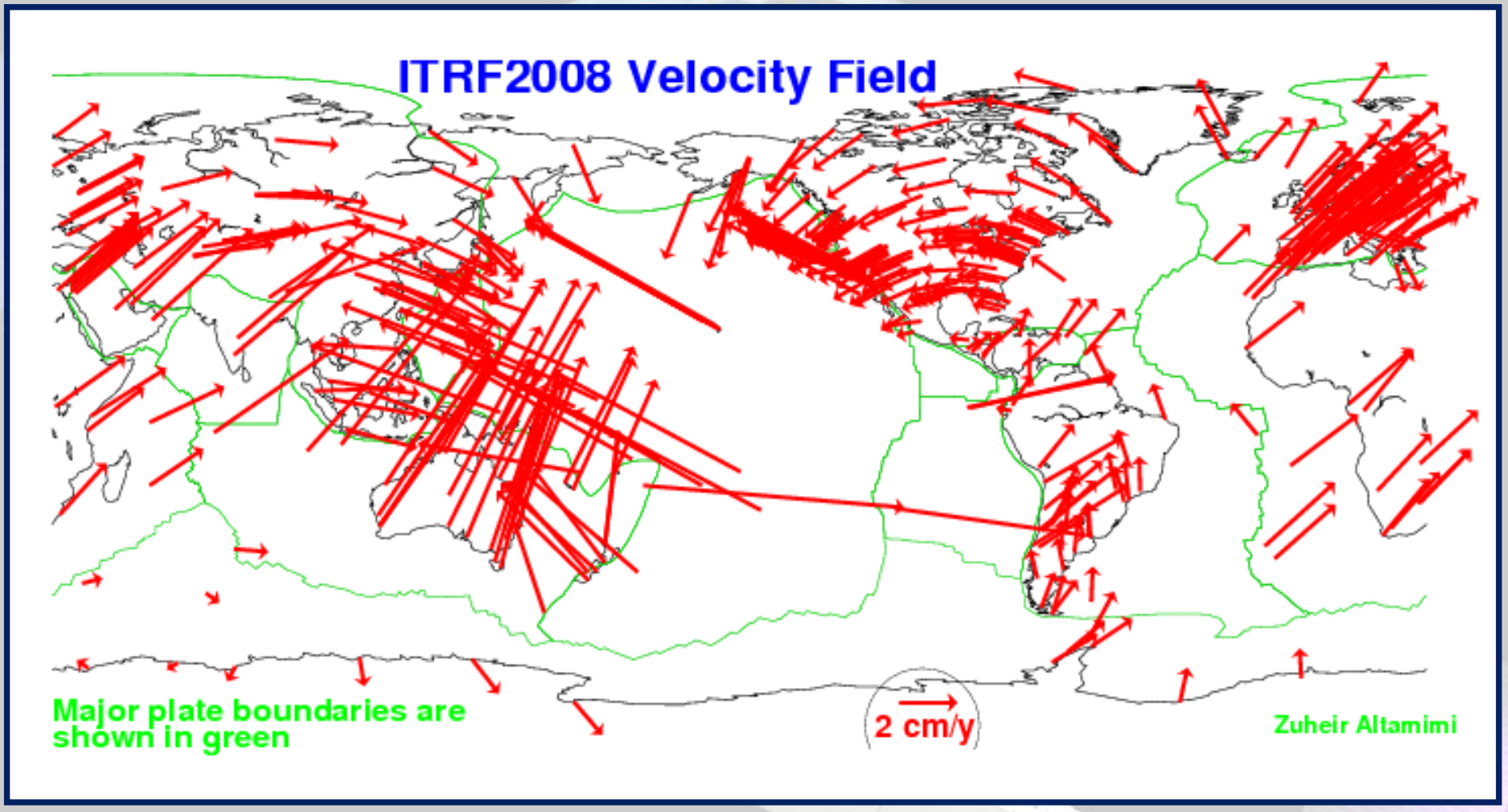
- ✓ coordinates must be estimated with accuracies better than the suspected displacements
- ✓ movements and deformations are modeled by analyzing time series of estimated coordinates of permanently operating stations

…time series analysis…



(BZRG estimates in the last about 15 years)

…global deformations!



the International Terrestrial Reference Frame

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Global Positioning System

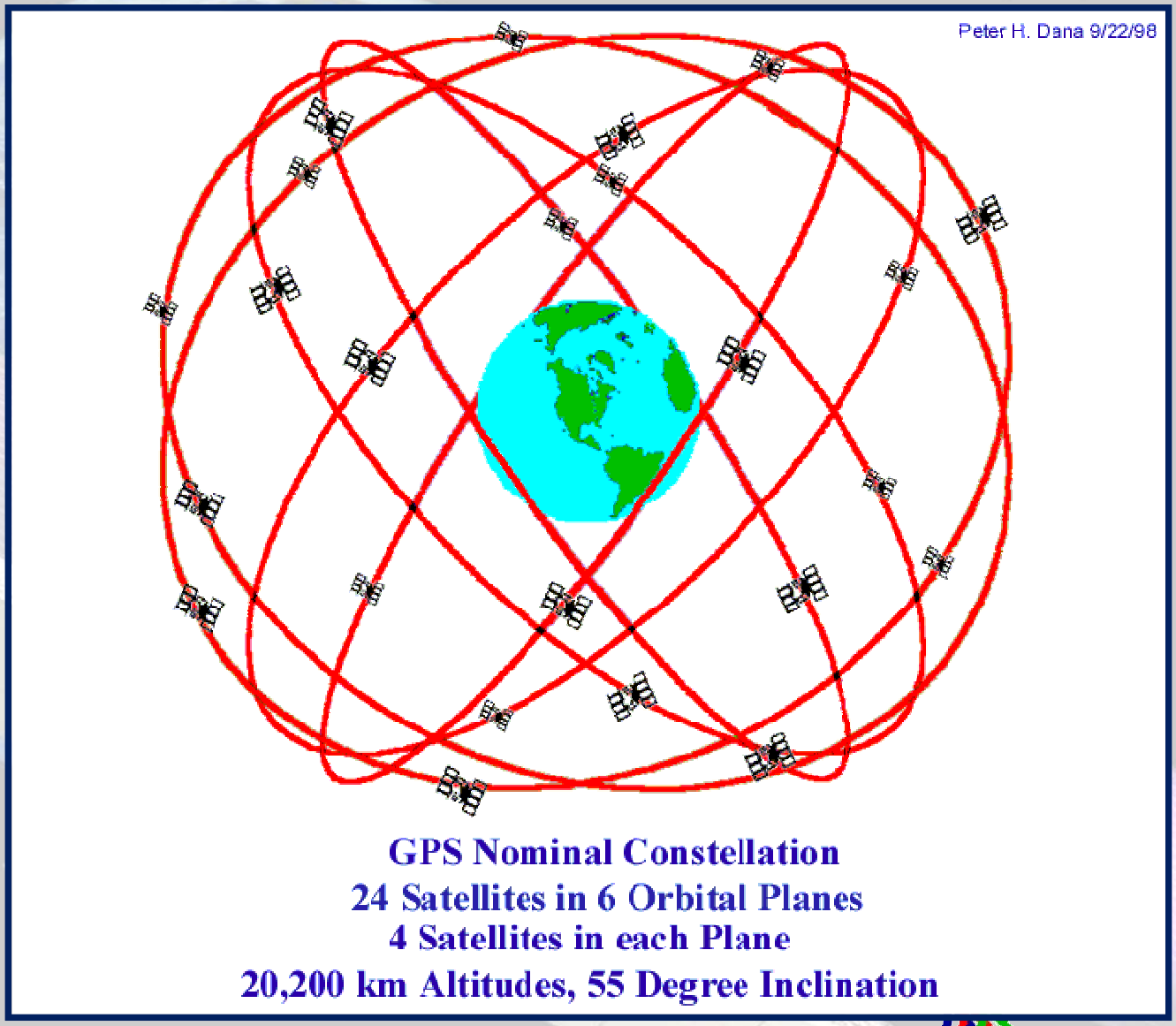
At present, 31 operational satellites, displaced on 6 different orbital planes

$i = 55°$ $e \approx 0$

$a \approx 26000 km$

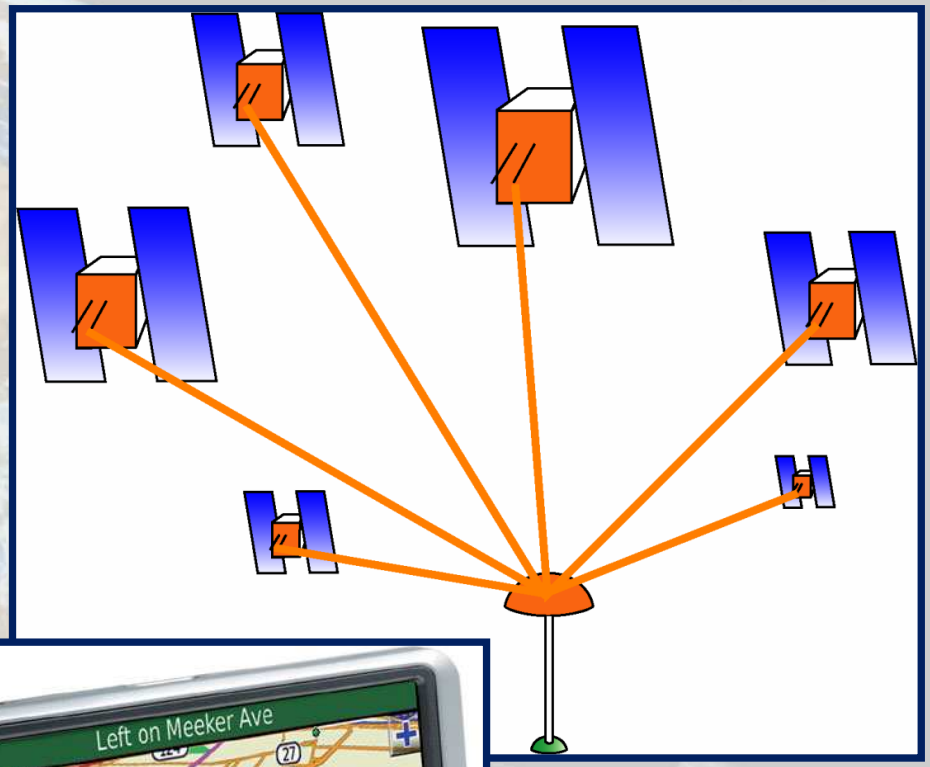
$T = 12h$

Each satellite moves at about 4 km/sec



Absolute positioning/navigation

A GPS receiver observes signal travel times (ranges) from all the in-view GPS satellites: 1-10 m accurate



Navigation, from individual vehicles to fleets

No geodetic monitoring!

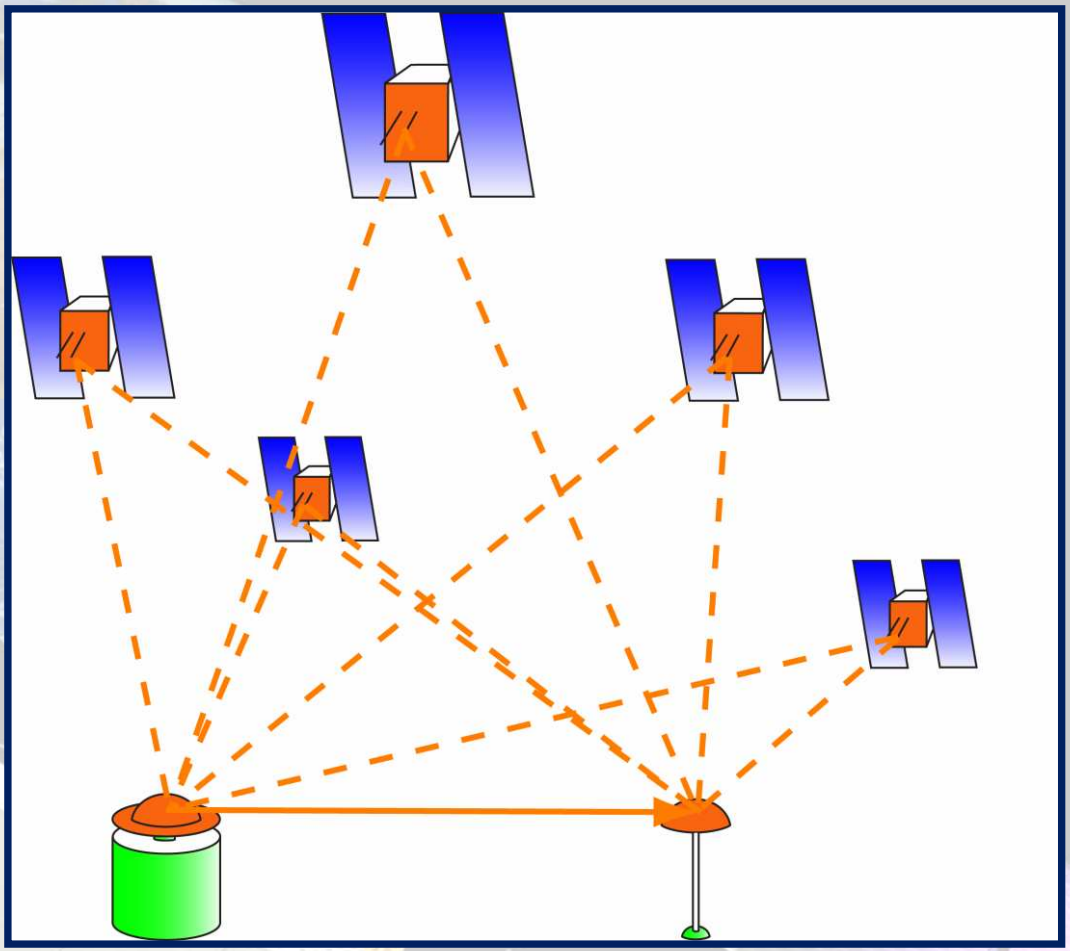
Relative positioning

A reference and a rover GPS stations observe range differences:

the baseline between the two receivers can be estimated

Given the position of the reference station,

the rover position can be derived



Kinematic / fast static relative positioning

The rover is moving or occupies points for few epochs

Accuracies in the range 2-5 cm – 1 m

Instrumental cost: 500 - 10000 €

(for the rover)

High precision navigation

Cadastral and cartographic surveying

No geodetic monitoring!

Local deformation monitoring

To monitor local deformations

Positions of geodetic benchmarks must be estimated

✓at different epochs (campaigns)

✓continuously in time (permanent networks)

✓with accuracies better than the suspected displacements

Time differences of coordinates (displacements / movements) of individual points must be modeled

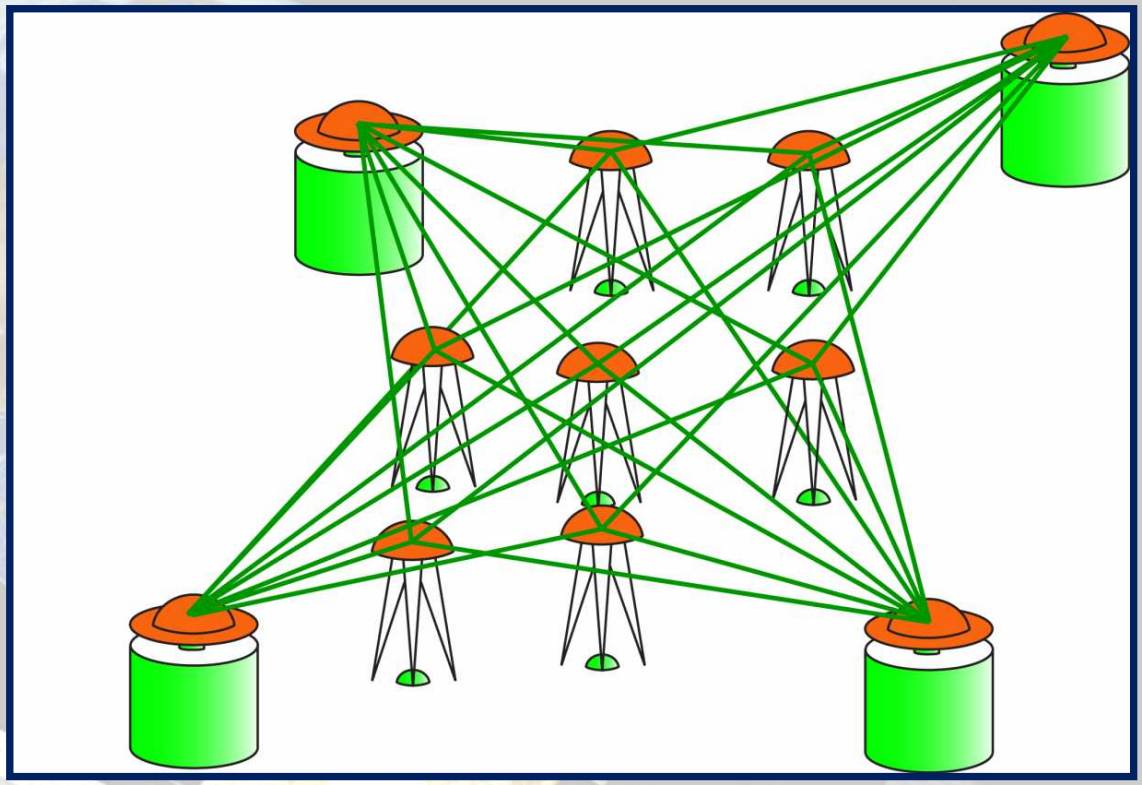
The spatial pattern of movements/deformations must be inferred

…Local networks

Network monumentation

Survey planning
(redundant schemes)

Static surveys and
data post processing



Adjustment of the local network in ITRF

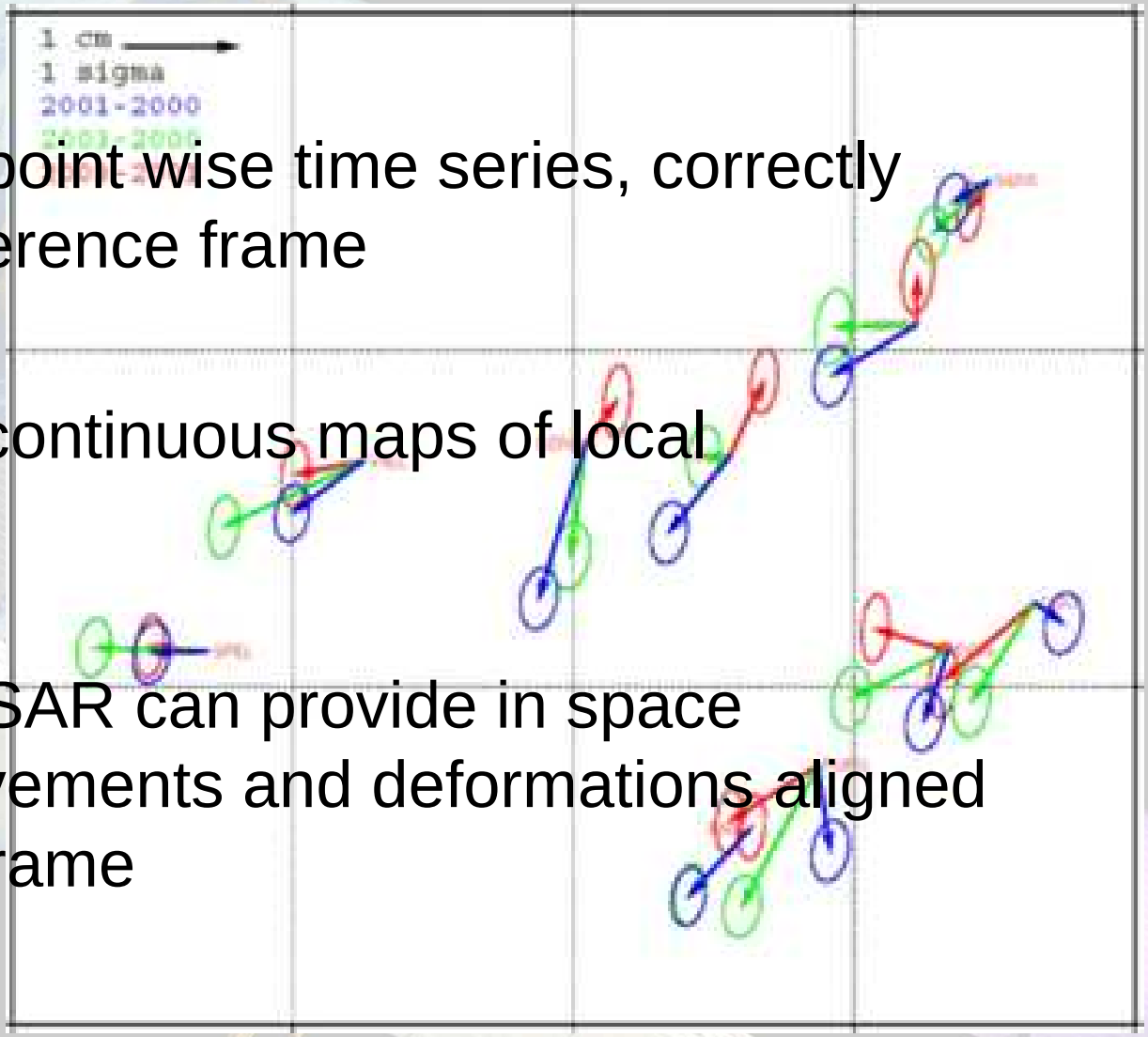
Repeated campaigns: movements and deformations analysis

GPS and SAR synergy

GPS provides in space point wise time series, correctly aligned to the global reference frame

SAR provides in space continuous maps of local deformations

Integration of GPS and SAR can provide in space continuous maps of movements and deformations aligned to the global reference frame



Needs of SloMOVE project

Aims: monitoring and interpretation of natural hazard in mountain area

- **Technologies integration**
  - **SAR (COSMO-SkyMed). Laser Scanner**

    High spatial resolution and high accuracy
  - **GPS**

    Reference frame introduction and high accuracy

- **Training**

Structure and topics of the SloMOVE course

Index

- Fundamentals of statistics
- Reference systems and frames
- GPS principles
- GPS relative positioning
- GPS network
- Exercises
- Laboratory

Structure and topics of the SloMOVE course

Fundamentals of statistics

- Stochastic modeling of observation errors
- Covariance propagation law
- Least Squares principle and estimator
- Outlier rejection: the global and the local tests
- Confidence intervals of the estimates and parameters testing

Structure and topics of the SloMOVE course

Reference systems and frames

- Reference systems and transformation
- Global reference frames for geodetic monitoring
- Time models for point motions
- ITRF
- Adjustment of a local network in ITRF
- Local frames for local monitoring
- Geoid undulation: the height problem

Structure and topics of the SloMOVE course

GPS

- The GPS basic ideas and positioning classes
- The GPS system
- GPS signals
- Code observation equations
- Phase observation equations
- Atmospheric delays
- Code real time point positioning

Structure and topics of the SloMOVE course

GPS relative positioning

- Combination of GPS observations
- The baseline estimation by double differences
- Single epoch error budget of DD
- Typical static phase DD processing for:
- fast static survey
- static local networks

Structure and topics of the SloMOVE course

GPS network

- Network simulation
- Planning the survey
- Adjustment of the network
- Analysis of the results
- Analysis of time series
- Global and individual displacements
- Displacements analysis

Structure and topics of the SloMOVE course

Exercises

- Leveling network setup
- Leveling network adjustment
- Reference frames transformations
- Coordinates transformations
- Geodetic network simulation and adjustment
- Time series analysis

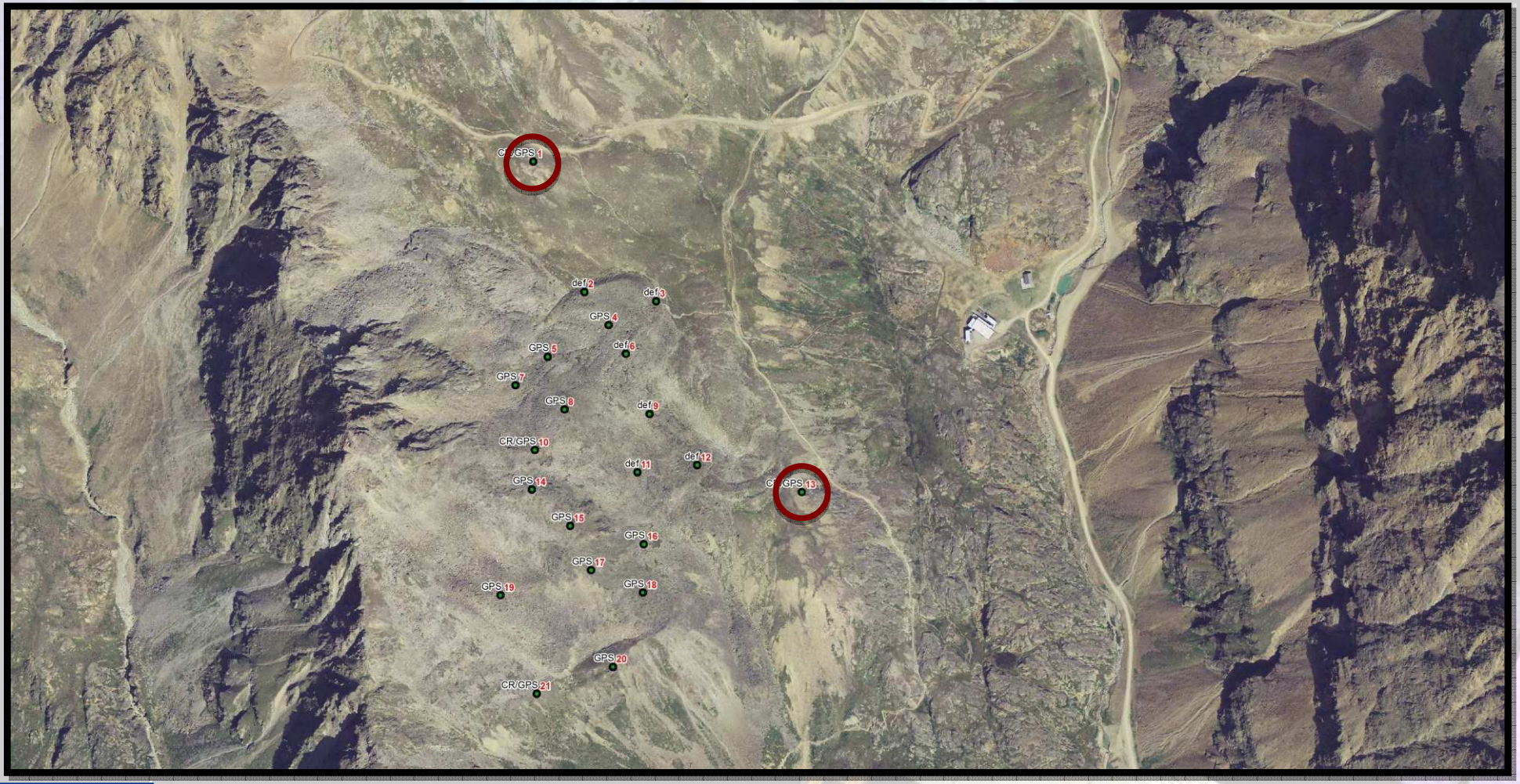
Structure and topics of the SloMOVE course

Laboratory

- Networks simulation
- Static Survey
- Data post processing
- Network adjustment

Val Senales network

Designed, established and surveyed by SloMove team (EURAC and Provincia di Bolzano)



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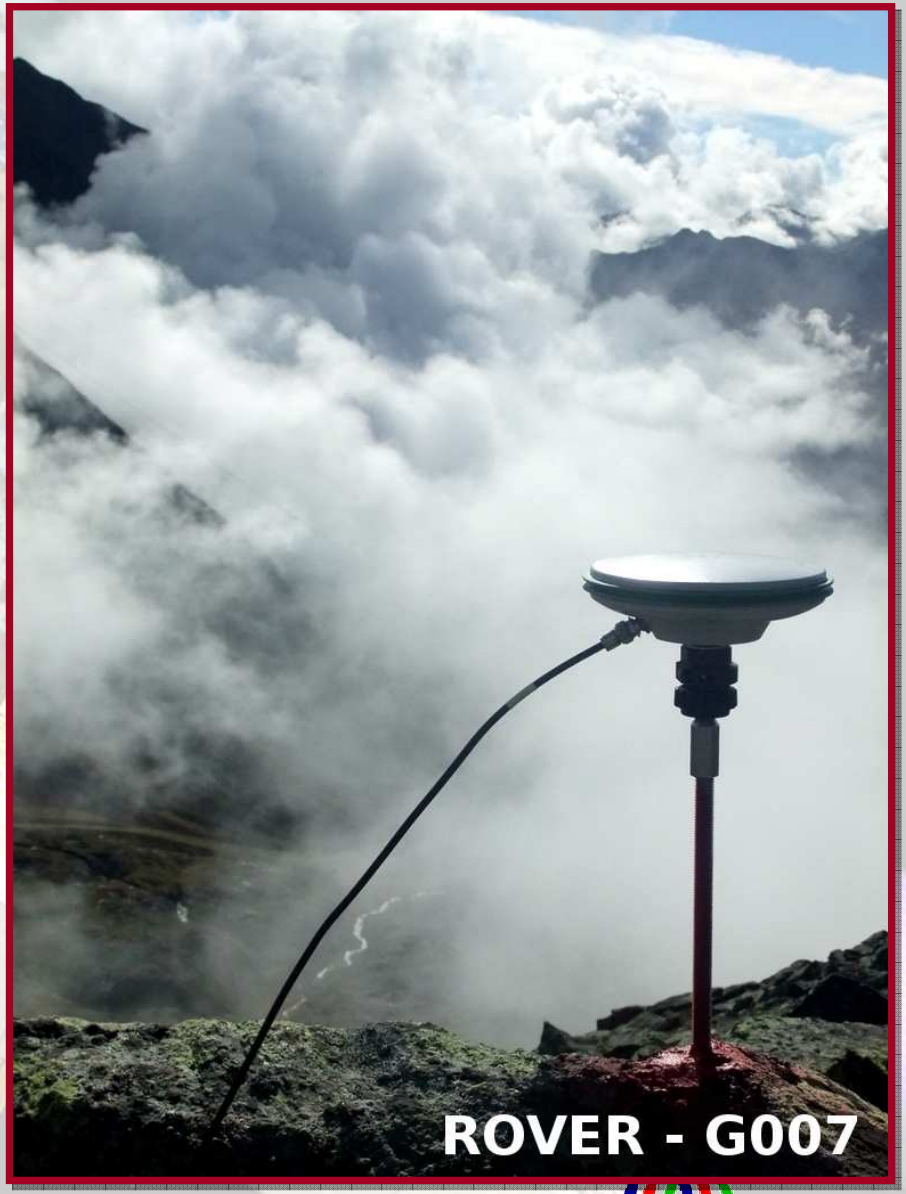
Val Senales monumentation

SloMove team (EURAC and Provincia di Bolzano)



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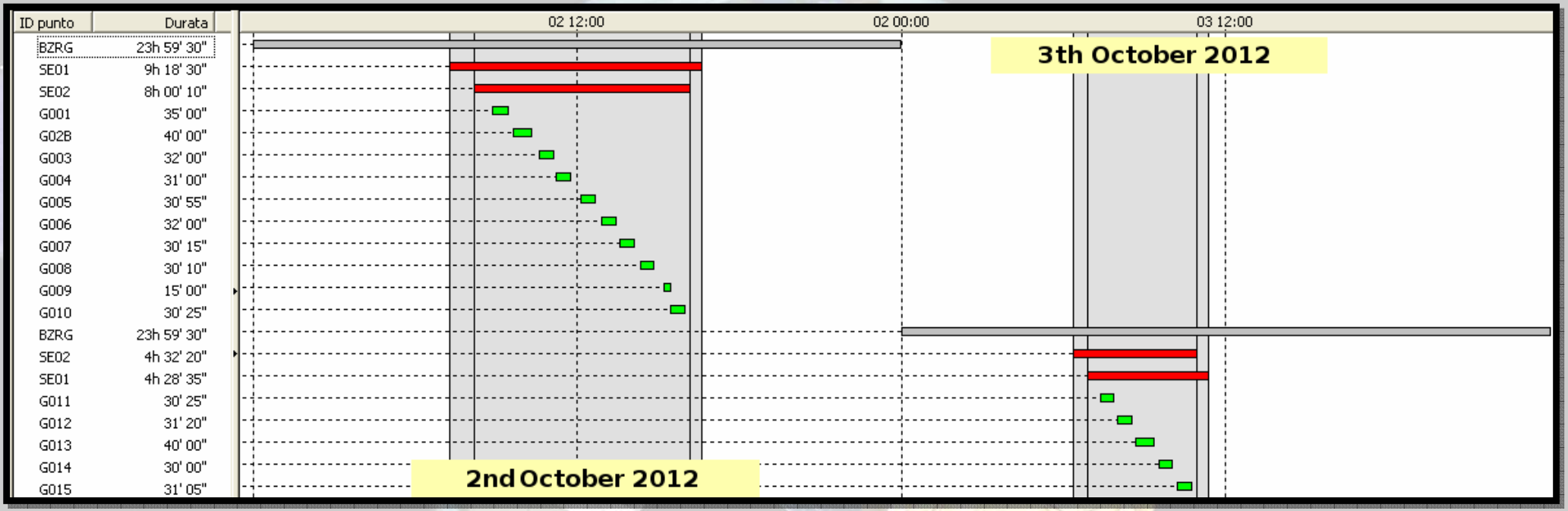
Val Senales surveying
SloMove team (EURAC and Provincia di Bolzano)

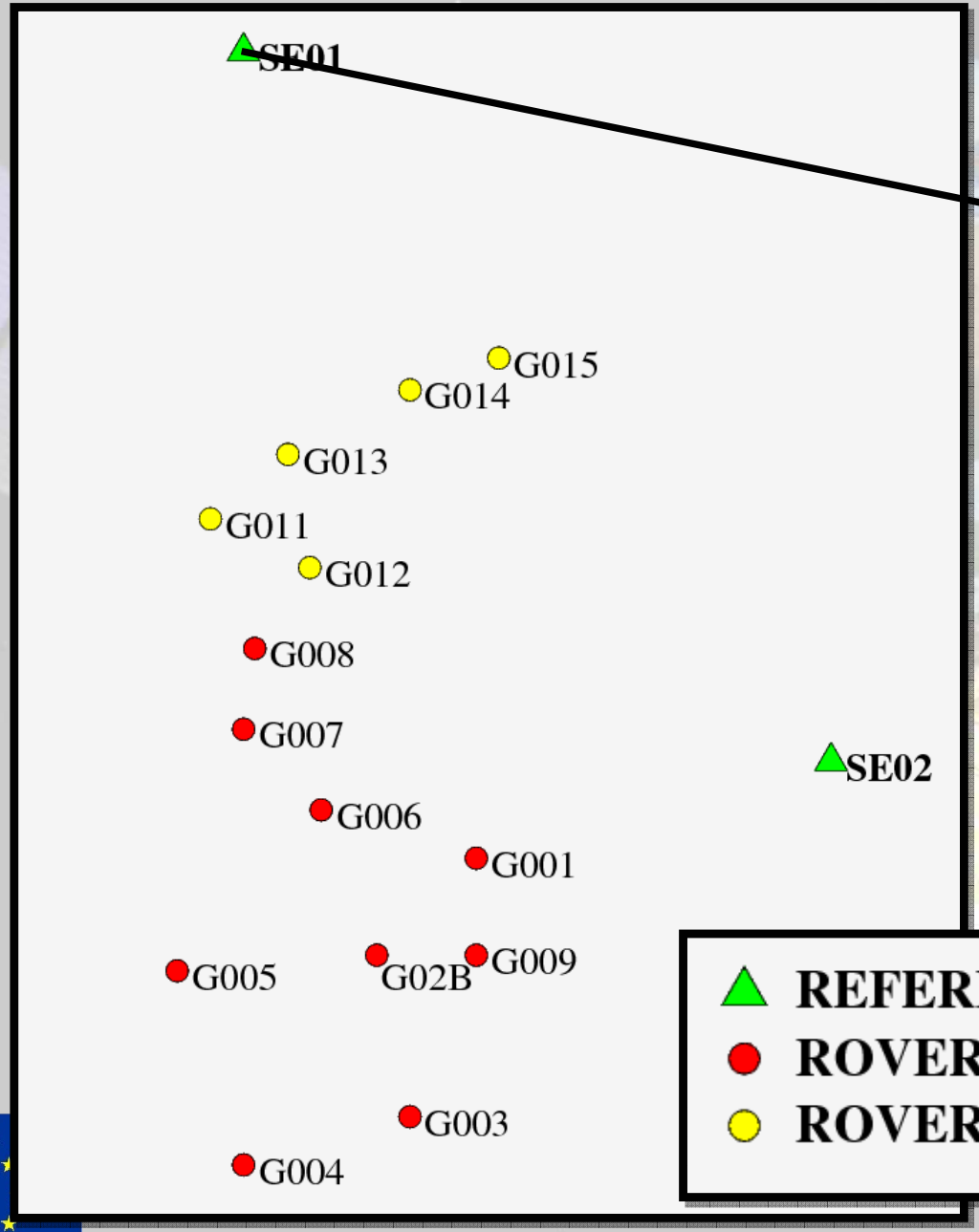


Data input: observation files. navigation files (brd)

Elaboration parameters:

- Cut-off angle: 10°
- Tropospheric model: Hopfield
- Frequencies: L1+L2 (local network). L3 (global network)

Val Senales network



Processing Strategy

BZRG fixed

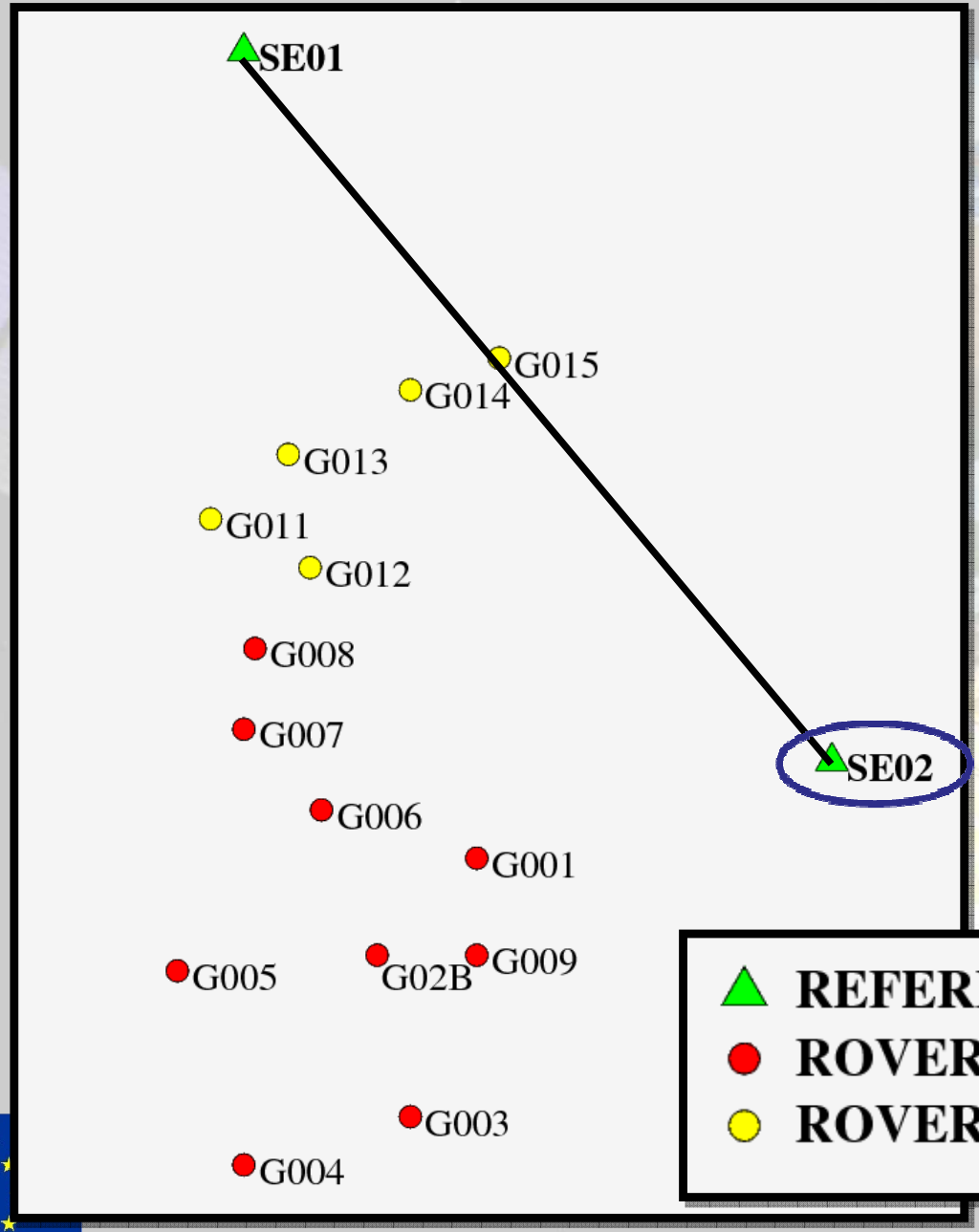
Bolzano RDN Permanent Station

ETRF 2000 epoch 2008.0

X (m)	Y (m)	Z (m)
4312657.772	864634.407	4603844.229

SE01 Estimated

Val Senales network



Processing Strategy

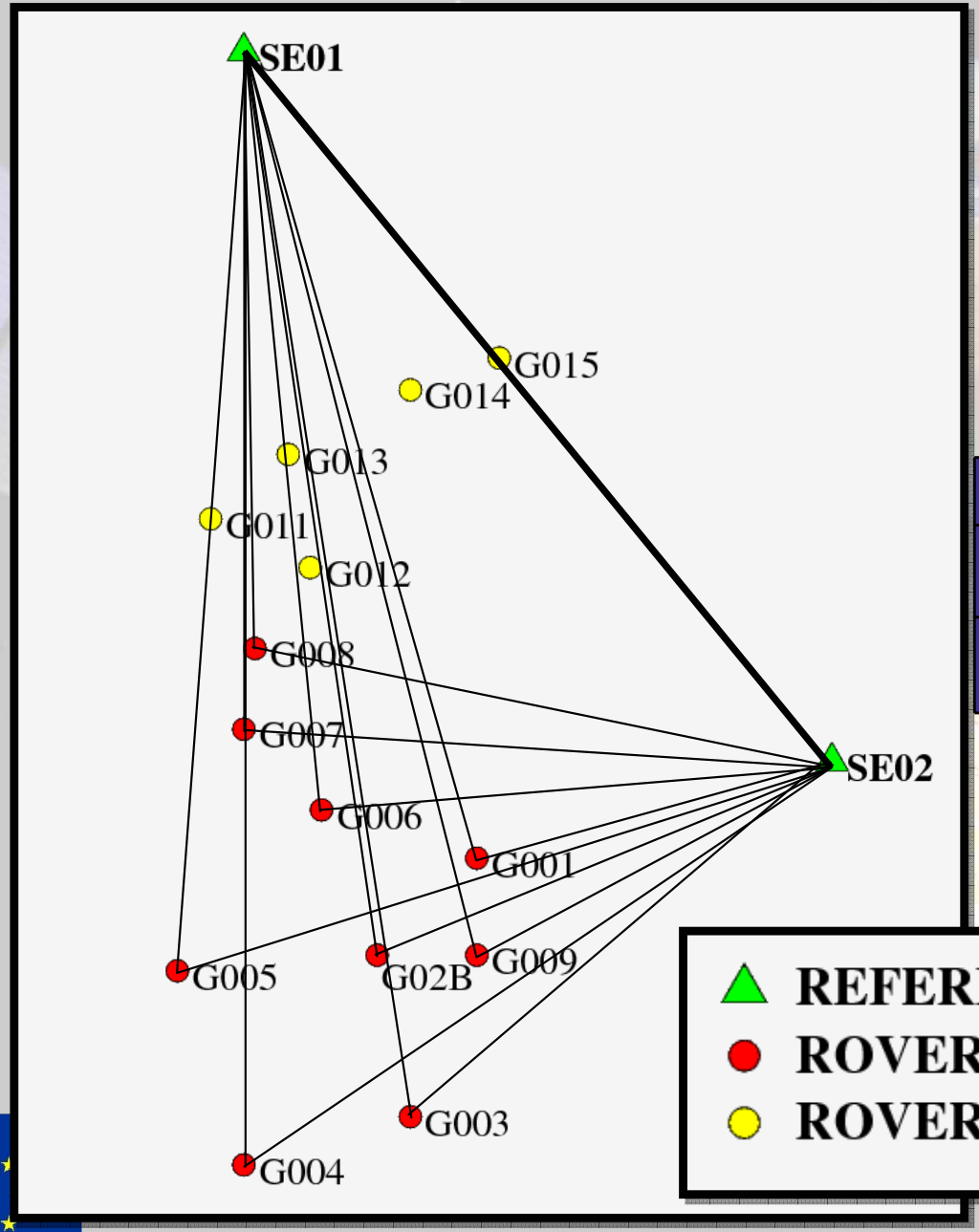
SE01

(Fixed from previous estimate)

	X (m)	Y (m)	Z (m)
SE01	4300553.766	818311.351	4626719.300

SE02 Estimated

Val Senales network



Processing Strategy

SE01 and SE02

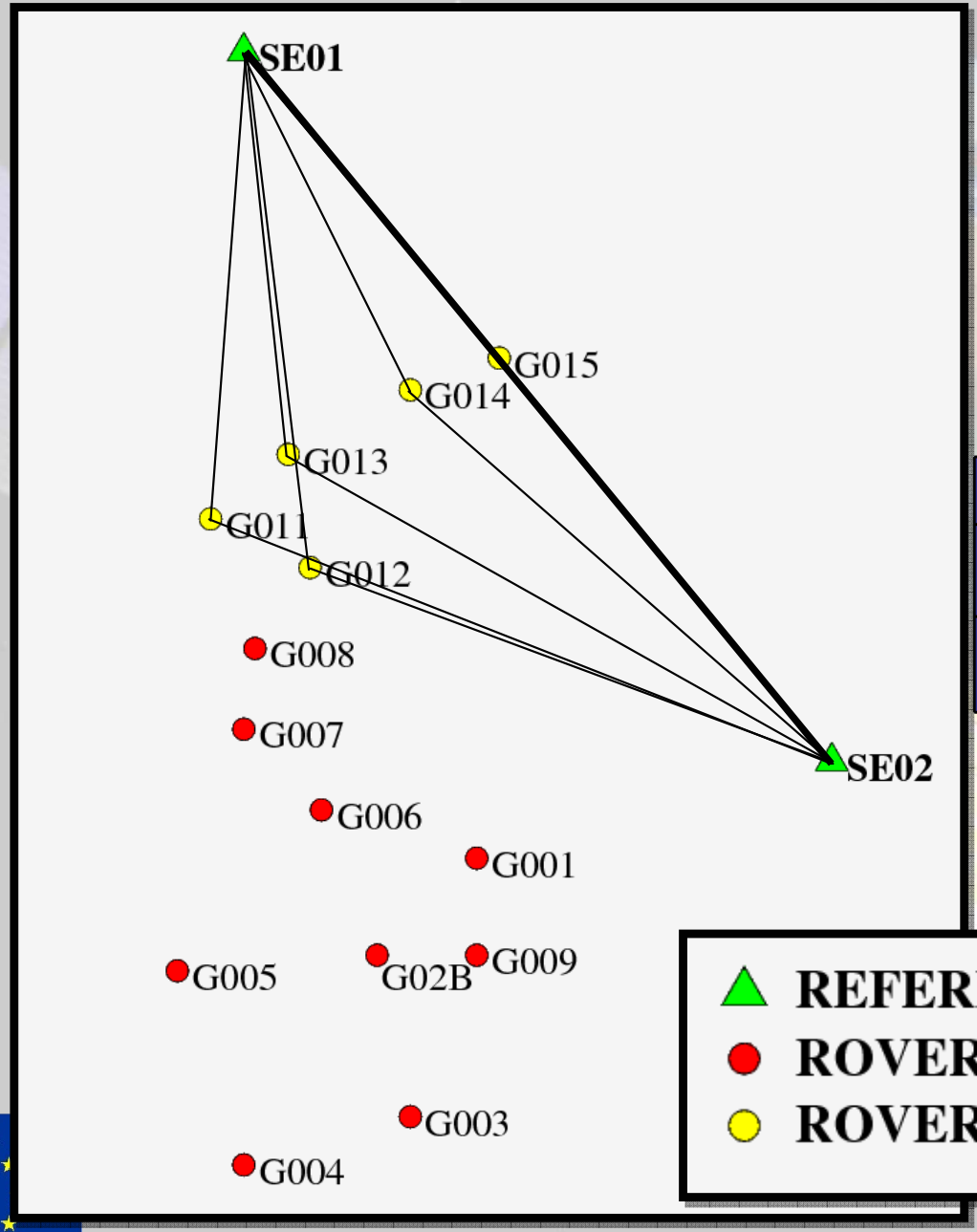
(Fixed from previous estimate)

	X (m)	Y (m)	Z (m)
SE01	4300553.766	818311.351	4626719.300
SE02	4300737.472	818757.263	4626281.049

2 nd October

ROVER Estimated

Val Senales network



Processing Strategy

SE01 and SE02

(Fixed from previous estimate)

	X (m)	Y (m)	Z (m)
SE01	4300553.766	818311.351	4626719.300
SE02	4300737.472	818757.263	4626281.049

3 th October

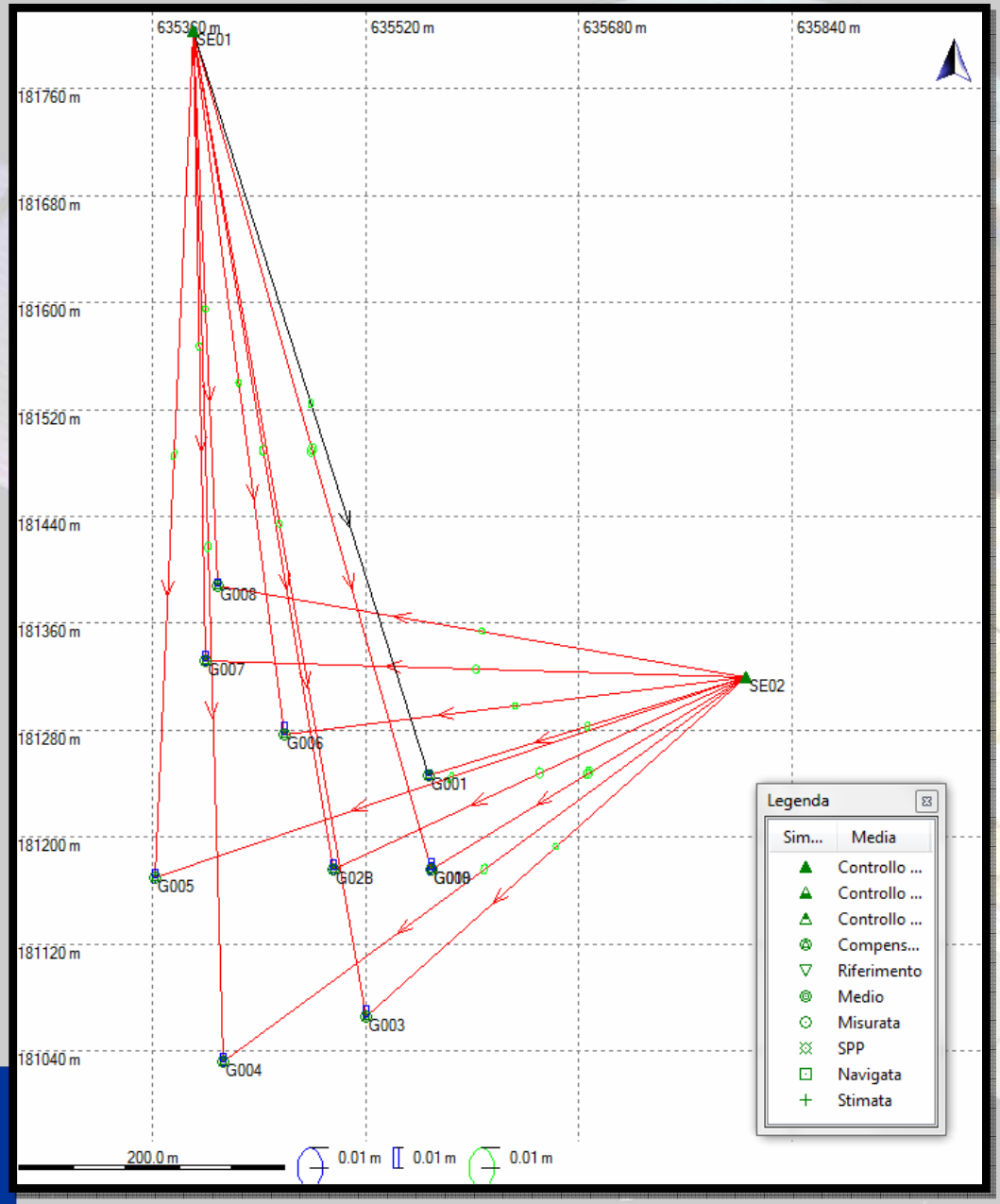
ROVER Navigated

Data processing and results

	E (m)	N (m)	N (m)
SE01	635390.574	5181803.01	2704.277
SE02	635805.051	5181320.14	2565.64

ID punto	E (m)	N (m)	UP (m)	Err E (mm)	Err N (mm)	Err UP (mm)
2 nd October						
G001	635567.555	5181246.236	2603.042	0.2	-2.5	4.9
G003	635520.293	5181065.930	2575.289	0.8	2.6	-1.7
G004	635413.073	5181031.942	2585.909	0.7	0.1	-0.2
G005	635362.282	5181169.258	2666.831	1.3	0.6	-8.1
G006	635459.430	5181276.518	2660.346	-3.3	0.1	-11.6
G007	635400.489	5181331.506	2698.730	0.2	0.4	-1.7
G008	635409.513	5181388.000	2697.583	-1.9	-0.2	7.2
G009	635569.310	5181176.270	2596.780	0.1	-1.1	-0.9
G02B	635495.894	5181176.045	2616.350	0.5	-0.3	-1.5
3 th October						
G011	635378.916	5181478.888	2684.520	-0.6	2.4	-1.0
G012	635447.916	5181449.174	2683.728	-0.5	0.4	3.4
G013	635429.373	5181523.452	2664.586	-2.1	-4.5	-3.5
G014	635515.821	5181568.571	2648.522	0.6	0.5	-7.9
G015	635572.974	5181592.665	2632.475	-0.4	0.1	-2.9

Data processing and results



Graphical results

Adjusted baselines

and

confidence ellipses

Future

A zero campaign has been surveyed in Val Senales area

New campaigns will allow the monitoring of movements