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Bundesamt für Landestopographie
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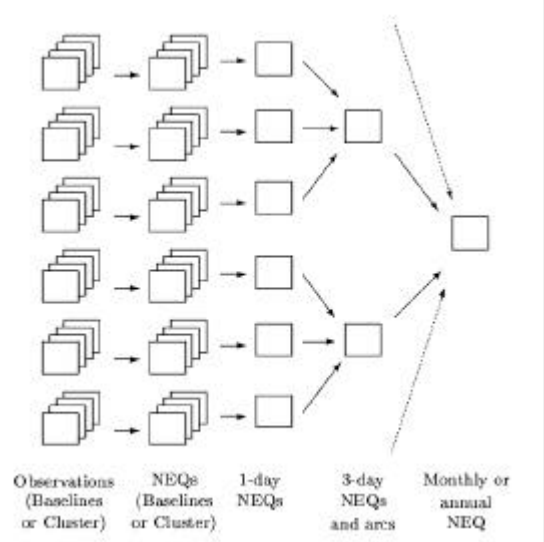
Using Combination techniques in the analyses of GPS observations of the Swiss permanent GPS Network 'AGNES'

E. Brockmann

Content

- Theory
  - Least Squares Adjustment
  - Combination schemes
  - Examples
- Praxis
  - AGNES network
  - Applications of ADDNEQ and the combination methods
    - Coordinates, velocities
    - Combinations with levelling
    - Troposphere
  - Alpine Network
  - Additional applications of AGNES

Sequential Adjustment: Idea



Processing of sequential solutions :

identical with processing all observations in a common adjustment

Least Squares Adjustment

The *Gauss-Markoff Model* (GMM) of full rank is given by e.g. KOCH [1988]:

$$\boldsymbol{E}(\boldsymbol{y}) = \boldsymbol{X}\boldsymbol{\beta} \quad ; \quad \boldsymbol{D}(\boldsymbol{y}) = \sigma^2 \boldsymbol{P}^{-1} \tag{2.1-1}$$

$\boldsymbol{X}$	$n \times u$ matrix of given coefficients with full rank $rg\boldsymbol{X} = u$; $\boldsymbol{X}$ is also called *design matrix*.
$\boldsymbol{\beta}$	$u \times 1$ vector of unknowns
$\boldsymbol{y}$	$n \times 1$ vector of observations
$\boldsymbol{P}$	$n \times n$ positive definite weight matrix
n, u	number of observations, number of unknowns
$\boldsymbol{E}(\cdot)$	operator of expectation
$\boldsymbol{D}(\cdot)$	operator of dispersion
σ^2	variance of unit weight (variance factor).

Parameter Elimination

$$\begin{bmatrix} \boldsymbol{N}_{11} & \boldsymbol{N}_{12} \\ \boldsymbol{N}_{21} & \boldsymbol{N}_{22} \end{bmatrix} \begin{bmatrix} \hat{\boldsymbol{\beta}}_1 \\ \hat{\boldsymbol{\beta}}_2 \end{bmatrix} = \begin{bmatrix} \boldsymbol{b}_1 \\ \boldsymbol{b}_2 \end{bmatrix}$$

Normal Equation

$$\left(\boldsymbol{N}_{11} \underbrace{-\boldsymbol{N}_{12}\boldsymbol{N}_{22}^{-1}\boldsymbol{N}_{12}}_{a}\right)\hat{\boldsymbol{\beta}}_1 = \boldsymbol{b}_1 \underbrace{-\boldsymbol{N}_{12}\boldsymbol{N}_{22}^{-1}\boldsymbol{b}_2}_{b}$$

Parameter estimate

Sequential Adjustment (1)

$$\begin{aligned} \boldsymbol{y}_1 + \boldsymbol{e}_1 &= \boldsymbol{X}_1\,\boldsymbol{\beta}_1 + \boldsymbol{O}_1\,\boldsymbol{\gamma}_1 \quad \text{with} \quad \boldsymbol{D}(\boldsymbol{y}_1) = \sigma_1^2\boldsymbol{P}_1^{-1} \\ \boldsymbol{y}_2 + \boldsymbol{e}_2 &= \boldsymbol{X}_2\,\boldsymbol{\beta}_2 + \boldsymbol{O}_2\,\boldsymbol{\gamma}_2 \quad \text{with} \quad \boldsymbol{D}(\boldsymbol{y}_2) = \sigma_2^2\boldsymbol{P}_2^{-1} \end{aligned}$$

or, in more general notation:

$$\boldsymbol{y}_i + \boldsymbol{e}_i = \boldsymbol{X}_i\,\boldsymbol{\beta}_i + \boldsymbol{O}_i\,\boldsymbol{\gamma}_i \quad \text{with} \quad \boldsymbol{D}(\boldsymbol{y}_i) = \sigma_i^2\boldsymbol{P}_i^{-1},\ i = 1,2$$

First step: Solving each individual NEQ

$$\begin{bmatrix} \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{X}_i & \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{O}_i \\ \boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{X}_i & \boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{O}_i \end{bmatrix} \begin{bmatrix} \hat{\boldsymbol{\beta}}_i \\ \hat{\boldsymbol{\gamma}}_i \end{bmatrix} = \begin{bmatrix} \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{y}_i \\ \boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{y}_i \end{bmatrix}$$

$$\begin{aligned} \hat{\boldsymbol{\beta}}_i &= \left(\boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{X}_i - \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{O}_i(\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{O}_i)^{-1}\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{X}_i\right)^{-1} \\ &\quad \cdot \left(\boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{y}_i - \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{O}_i(\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{O}_i)^{-1}\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{y}_i\right) \\ \boldsymbol{D}(\hat{\boldsymbol{\beta}}_i) &= \hat{\sigma}_i^2\left(\boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{X}_i - \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{O}_i(\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{O}_i)^{-1}\boldsymbol{O}_i'\boldsymbol{P}_i\boldsymbol{X}_i\right)^{-1} \end{aligned}$$

Sequential Adjustment (2)

Step 2: Aposteriori LSE

$$\begin{bmatrix} \hat{\beta}_1 \\ \hat{\beta}_2 \end{bmatrix} + \begin{bmatrix} e_{1II} \\ e_{2II} \end{bmatrix} = \begin{bmatrix} I \\ I \end{bmatrix} \hat{\beta}_c \text{ with } D\left(\begin{bmatrix} \hat{\beta}_1 \\ \hat{\beta}_2 \end{bmatrix}\right) = \sigma_c^2 \begin{bmatrix} \Sigma_1 & \emptyset \\ \emptyset & \Sigma_2 \end{bmatrix}$$

$$\begin{bmatrix} (X_1'P_1X_1 + X_2'P_2X_2) - X_1'P_1O_1(O_1'P_1O_1)^{-1}O_1'P_1X_1 \cdots \\ \cdots - X_2'P_2O_2(O_2'P_2O_2)^{-1}O_2'P_2X_2 \end{bmatrix} \hat{\beta}_c$$
$$= \begin{bmatrix} (X_1'P_1y_1 + X_2'P_2y_2) - X_1'P_1O_1(O_1'P_1O_1)^{-1}O_1'P_1y_1 \cdots \\ \cdots - X_2'P_2O_2(O_2'P_2O_2)^{-1}O_2'P_2y_2 \end{bmatrix}$$

Sequential Least Squares Estimation (3)

General:

$$\left(\sum_{i=1}^{m}\left(X_i'P_iX_i - X_i'P_iO_i(O_i'P_iO_i)^{-1}O_i'P_iX_i\right)\right)\hat{\beta}_c$$
$$= \sum_{i=1}^{m}\left(X_i'P_iy_i - X_i'P_iO_i(O_i'P_iO_i)^{-1}O_i'P_iy_i\right)$$

Special case: Accumulation

$$\left(\sum_{i=1}^{m} X_i'P_iX_i\right)\hat{\beta}_c = \sum_{i=1}^{m} X_i'P_iy_i$$

Applications: Superposition / Accumulation

$$\begin{bmatrix} \boldsymbol{X}_1'\boldsymbol{P}_1\boldsymbol{X}_1 & & \emptyset \\ & \boldsymbol{X}_2'\boldsymbol{P}_2\boldsymbol{X}_2 & \\ & & \ddots \\ \emptyset & & \boldsymbol{X}_m'\boldsymbol{P}_m\boldsymbol{X}_m \end{bmatrix} \begin{bmatrix} \hat{\boldsymbol{\beta}}_1 \\ \hat{\boldsymbol{\beta}}_2 \\ \vdots \\ \hat{\boldsymbol{\beta}}_m \end{bmatrix} = \begin{bmatrix} \boldsymbol{X}_1'\boldsymbol{P}_1\boldsymbol{y}_1 \\ \boldsymbol{X}_2'\boldsymbol{P}_2\boldsymbol{y}_2 \\ \vdots \\ \boldsymbol{X}_m'\boldsymbol{P}_m\boldsymbol{y}_m \end{bmatrix}$$

$$\left(\sum_{i=1}^{m} \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{X}_i\right) \hat{\boldsymbol{\beta}}_c = \sum_{i=1}^{m} \boldsymbol{X}_i'\boldsymbol{P}_i\boldsymbol{y}_i$$

e.g.: combination of coordinates

Parameter Transformation

GMM: $\Delta\boldsymbol{y} + \boldsymbol{e} = \boldsymbol{X}\Delta\boldsymbol{\beta} \quad ; \quad \boldsymbol{D}(\Delta\boldsymbol{y}) = \sigma^2\boldsymbol{P}^{-1}$

New Parameter: $\Delta\hat{\boldsymbol{\beta}} = \boldsymbol{B}\Delta\tilde{\boldsymbol{\beta}} + d\boldsymbol{\beta}$

NEQ system: $\boldsymbol{B}'\boldsymbol{X}'\boldsymbol{P}\boldsymbol{X}\boldsymbol{B}\Delta\tilde{\boldsymbol{\beta}} = \boldsymbol{B}'\boldsymbol{X}'\boldsymbol{P}\Delta\tilde{\boldsymbol{y}} \quad \text{with} \quad \Delta\tilde{\boldsymbol{y}} = (\Delta\boldsymbol{y} - \boldsymbol{X}d\boldsymbol{\beta})$

$$\begin{aligned} \widetilde{\boldsymbol{N}}\Delta\tilde{\boldsymbol{\beta}} &= \tilde{\boldsymbol{b}} \quad \text{where} \\ \widetilde{\boldsymbol{N}} &= \boldsymbol{B}'\boldsymbol{N}\boldsymbol{B} \quad \text{and} \\ \tilde{\boldsymbol{b}} &= \boldsymbol{B}'(\boldsymbol{b} - \boldsymbol{N}d\boldsymbol{\beta}). \end{aligned}$$

Applications: Reduction (1)

$$\boldsymbol{\beta}_{u\times 1} = \left[\ldots, \underbrace{\beta_i, \beta_{i+1}, \beta_{i+2}, \ldots, \beta_{i+m-1}}, \ldots\right]'$$

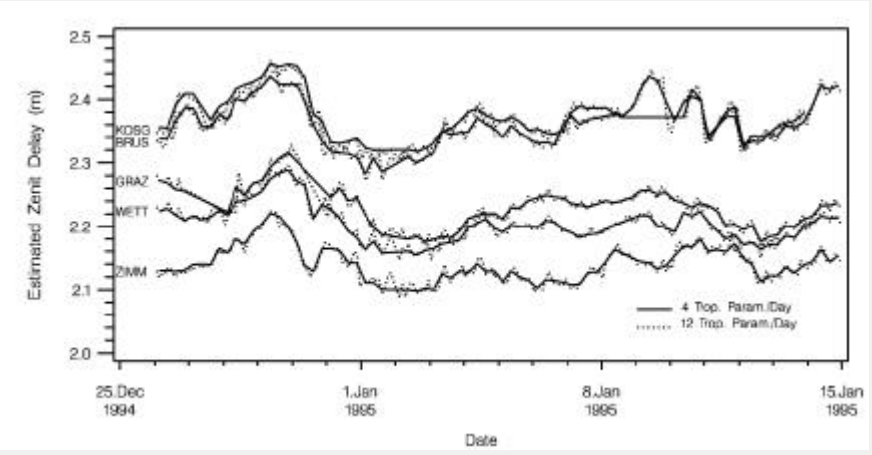
$$\tilde{\boldsymbol{\beta}}_{(u-m+1)\times 1} = \left[\ldots, \tilde{\beta}_i, \ldots\right]'.$$

$$\boldsymbol{\beta} = \boldsymbol{B}\tilde{\boldsymbol{\beta}} + d\boldsymbol{\beta} \quad \text{with}$$

$$\boldsymbol{B}' = \begin{array}{|cccccccc|l} 1 & & & & & & & & \\ & \ddots & & & & & \emptyset & & \\ & & 1 & & & & & & \\ & & & 1 & 1 & \ldots & 1 & & \leftarrow i \text{ and} \\ & & & & & & & 1 & \\ & & \emptyset & & & & & & \\ & & & & & & & & \\ & & & & & & & 1 & \leftarrow (u-m+1) \\ \hline & & & \uparrow & \uparrow & & \uparrow & \uparrow & \\ & & & i & i+1 & & i+m-1 & u & \end{array}$$

$$d\boldsymbol{\beta} = \emptyset.$$

Applications: Reduction (2)



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Application: Additional parameters (1)

$$\beta_i = F_i\delta_1 + G_i\delta_2 + c_i.$$

$$\begin{aligned}\widetilde{N}\widetilde{\beta} &= \widetilde{b} \text{ with}\\ \widetilde{\beta} &= [\delta_1, \delta_2]' ,\\ \widetilde{N} &= \begin{bmatrix} F_i'N_iF_i & F_i'N_iG_i \\ G_i'N_iF_i & G_i'N_iG_i \end{bmatrix}\\ \widetilde{b} &= \begin{bmatrix} F_i'(b_i - N_ic_i) \\ G_i'(b_i - N_ic_i) \end{bmatrix}.\end{aligned}$$

Velocities:

$$\beta_i = \beta_{t_0} + \Delta t_i\, v_{t_0}$$

$$\begin{bmatrix} X_1'P_1X_1 + X_2'P_2X_2 & \Delta t_1(X_1'P_1X_1) + \Delta t_2(X_2'P_2X_2) \\ \Delta t(X_1'P_1X_1) + \Delta t_2(X_2'P_2X_2) & \Delta t_1^2(X_1'P_1X_1) + \Delta t_2^2(X_2'P_2X_2) \end{bmatrix} \begin{bmatrix} \hat{\beta}_{t_0} \\ \hat{v}_{t_0} \end{bmatrix} = \begin{bmatrix} X_1'P_1y_1 + X_2'P_2y_2 \\ \Delta t_i(X_1'P_1y_1) + \Delta t_2(X_2'P_2y_2) \end{bmatrix}$$

Application: Additional parameters (2)

- Helmert parameters
- Fourier coefficients
- Blocking special frequencies (e.g. diurnal retrograde signales in NEQs containing ERPs)

Constraints

$$\boldsymbol{H\beta} = \boldsymbol{w} + \boldsymbol{e}_w \quad \text{with} \quad \boldsymbol{D}(\boldsymbol{w}) = \sigma^2 \boldsymbol{P}_w^{-1}$$

fictitious observations

$$\begin{bmatrix} \boldsymbol{y} \\ \boldsymbol{w} \end{bmatrix} + \begin{bmatrix} \boldsymbol{e}_y \\ \boldsymbol{e}_w \end{bmatrix} = \begin{bmatrix} \boldsymbol{X} \\ \boldsymbol{H} \end{bmatrix} \tilde{\boldsymbol{\beta}} \text{ with } \boldsymbol{D}\left(\begin{bmatrix} \boldsymbol{y} \\ \boldsymbol{w} \end{bmatrix}\right) = \sigma^2 \begin{bmatrix} \boldsymbol{P}^{-1} & \emptyset \\ \emptyset & \boldsymbol{P}_w^{-1} \end{bmatrix}$$

$$(\boldsymbol{X}'\boldsymbol{P}\boldsymbol{X} + \boldsymbol{H}'\boldsymbol{P}_w\boldsymbol{H})\tilde{\boldsymbol{\beta}} = \boldsymbol{X}'\boldsymbol{P}\boldsymbol{y} + \boldsymbol{H}'\boldsymbol{P}_w\boldsymbol{w}$$

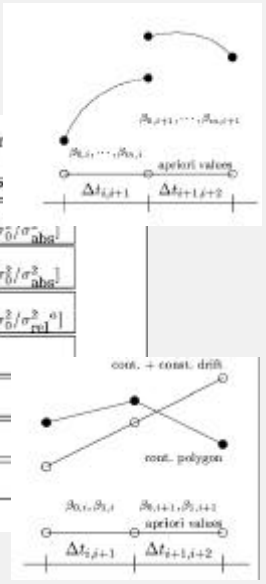
Applications of constraints

- coordinates (absolute constraints, free network conditions)
- velocities (absolute and relative constraints)
- troposphere (absolute and relative constraints)
- orbit (keplerian-, dynamical-, stochastic-) parameters
- center of mass
- earth rotation parameters (UT1 and nutation absolute value has to be constrained to a VLBI value and continuity constraints)
- satellite antenna offsets

Constraints in ADDNEQ

Table 2.1: Constraints and constraining options used in the pr

$H\beta = w + e$	H	w	P
Constraining and fixing on apriori values $\beta_i = 0 + e_i$	$[0, \cdots, 0, 1, 0, \cdots, 0]$	$[0]$	$[\sigma_0^2/\sigma^2_{abs}]$
Constraining and fixing on apriori values $\beta_{0_{new}}$ $\beta_i = \beta_{0_{new}} - \beta_0 + e_i$	$[0, \cdots, 0, 1, 0, \cdots, 0]$	$[\beta_{0_{new}} - \beta_0]$	$[\sigma_0^2/\sigma^2_{abs}]$
Relative constraints between parameters $\beta_i - \beta_{i+1} = 0 + e_i$	$[0, \cdots, 0, 1, -1, 0, \cdots, 0]$	$[0]$	$[\sigma_0^2/\sigma^2_{rel}{}^a]$
Continuity between subsequent polynomials: see eqns. (2.6-12), (2.6-13)			
Common polynomials in subsequent time intervals: eqn. (2.6-16)			
"Absolute" polynomials: eqns. (2.6-16), (2.6.3.3)			
Free networks: eqns. (2.6-18), (2.6-21)			



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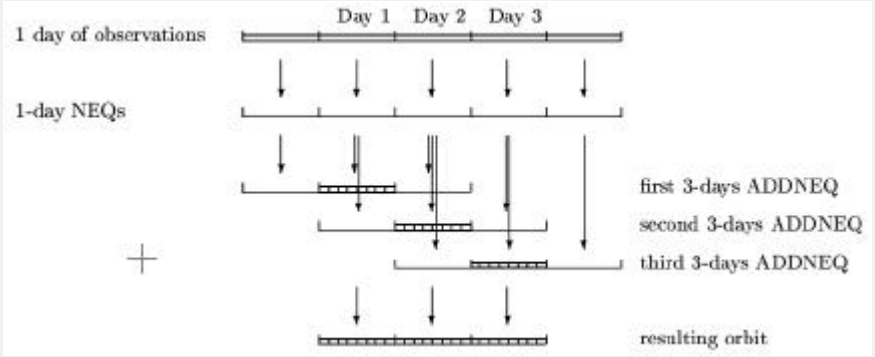
Combination of consecutive Daily arcs (1)



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Combination of consecutive Daily arcs (2)

$$\begin{aligned} \boldsymbol{y}(t,\boldsymbol{r},\dot{\boldsymbol{r}},q_1,q_2,\ldots,q_n)+\boldsymbol{e} &= \boldsymbol{y}(t,\boldsymbol{r}_0,\dot{\boldsymbol{r}}|_0,q_1|_0,q_2|_0,\ldots,q_n|_0) \\ &\quad + \begin{bmatrix} \boldsymbol{B}_{rv} & \boldsymbol{B}_q \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{rv} \\ \Delta\boldsymbol{q} \end{bmatrix} \end{aligned}$$

$$\begin{aligned} \boldsymbol{r}_c(t) &= \boldsymbol{r}(t;o_{c1},o_{c2},\ldots,o_{cn_c}) \\ &= \boldsymbol{r}(t;E_{c1},E_{c2},\ldots,E_{c6},q_{c1},q_{c2},\ldots,q_{cm_1}, \\ &\qquad s_{11},s_{12},\ldots,s_{1m_2},s_{21},s_{22},\ldots,s_{2m_2},\ldots,s_{n1},s_{n2},\ldots,s_{nm_2}) \end{aligned}$$

$$\boldsymbol{r}_i(t) = \boldsymbol{r}(t;o_{i1},o_{i2},\ldots,o_{im})$$

$$\begin{aligned} \boldsymbol{r}_i(t_{i+1}) &= \boldsymbol{r}_{i+1}(t_{i+1}) \\ \boldsymbol{r}_i^{(1)}(t_{i+1}) &= \boldsymbol{r}_{i+1}^{(1)}(t_{i+1}) \\ \boldsymbol{q}_i = \boldsymbol{q}_{i+1} &= \boldsymbol{q}_c \end{aligned}$$

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Combination of consecutive Daily arcs (2)

$$\begin{bmatrix} \boldsymbol{H}_{i+1} & \boldsymbol{Q}_{i+1} \\ \emptyset & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{E}_{i+1} \\ \Delta\boldsymbol{q}_{i+1} \end{bmatrix} = \begin{bmatrix} \boldsymbol{H}_i & \boldsymbol{Q}_i \\ \emptyset & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{E}_i \\ \Delta\boldsymbol{q}_i \end{bmatrix} + \begin{bmatrix} \boldsymbol{rv}_i|_0 - \boldsymbol{rv}_{i+1}|_0 \\ \boldsymbol{q}_i|_0 - \boldsymbol{q}_{i+1}|_0 \end{bmatrix}$$

$\boldsymbol{H}_i$ Jacobian matrix of the transition from a set of osculating elements to initial coordinates and velocities at time t_{i+1}; analytical formulae are given in [BEUTLER ET AL. 1996]:

$$\begin{bmatrix} \frac{d(\boldsymbol{r}_i)_j}{dE_{ik}}|_0 & \frac{d(\boldsymbol{r}_i^{(1)})_j}{dE_{ik}}|_0 \end{bmatrix}_{(6\times 6)} \quad ; \quad j=1,2,3;\ k=1,2,\ldots,6\ , \qquad (4.3\text{-}6)$$

$(\boldsymbol{r}_i)_j$ and $(\boldsymbol{r}_i^{(1)})_j$ being the j-th component of the vector $\boldsymbol{r}_i$ and $\boldsymbol{r}_i^{(1)}$

$\boldsymbol{Q}_i$ partials with respect to the dynamical parameters; numerical computation according to Section 3.2:

$$\begin{bmatrix} \frac{d(\boldsymbol{r}_i)_j}{dq_{ik}}|_0 & \frac{d(\boldsymbol{r}_i^{(1)})_j}{dq_{ik}}|_0 \end{bmatrix}_{(6\times m_1)} \quad ; \quad j=1,2,3;\ k=1,2,\ldots,m_1 \qquad (4.3\text{-}7)$$

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Combination of consecutive Daily arcs (3)

$$\Delta \boldsymbol{E}_{i+1} = \begin{bmatrix} \boldsymbol{K}_{i+1,i} & \widetilde{\boldsymbol{L}}_{i+1,i} & \widetilde{\boldsymbol{L}}_{i+1,i+1} \end{bmatrix} \begin{bmatrix} \Delta \boldsymbol{E}_i \\ \Delta \boldsymbol{q}_i \\ \Delta \boldsymbol{q}_{i+1} \end{bmatrix} + \widetilde{\boldsymbol{M}}_{i+1,i}$$

with

$$\begin{aligned} \boldsymbol{K}_{i+1,i} &= \boldsymbol{H}_{i+1}^{-1} \cdot \boldsymbol{H}_i \quad \text{(same as in the previous section)} \\ \widetilde{\boldsymbol{L}}_{i+1,i} &= \boldsymbol{H}_{i+1}^{-1} \cdot \boldsymbol{Q}_i \\ \widetilde{\boldsymbol{L}}_{i+1,i+1} &= -\boldsymbol{H}_{i+1}^{-1} \cdot \boldsymbol{Q}_{i+1} \\ \widetilde{\boldsymbol{M}}_{i+1,i} &= \boldsymbol{H}_{i+1}^{-1} \cdot (\boldsymbol{rv}_i|_0 - \boldsymbol{rv}_{i+1}|_0). \end{aligned}$$

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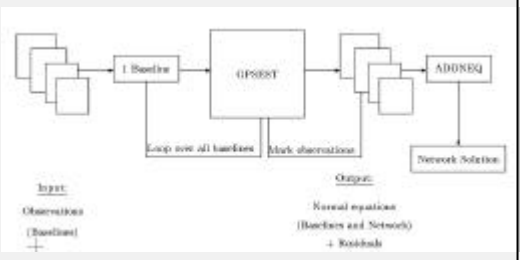
Combination Schemes (1)

- Baseline – Cluster to daily network solution (correlations…)
- Multi-Sessions (Weekly solutions to Yearly solutions)
- Hourly network -> daily network solutions (Troposphere estimation)
- Long arc computations



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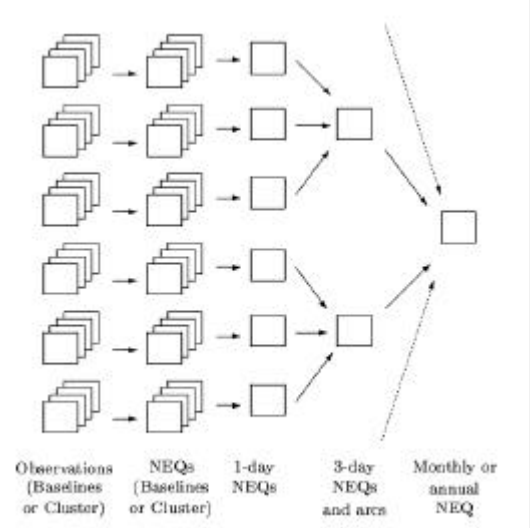
Combination schemes (2)



Combinations Used for:

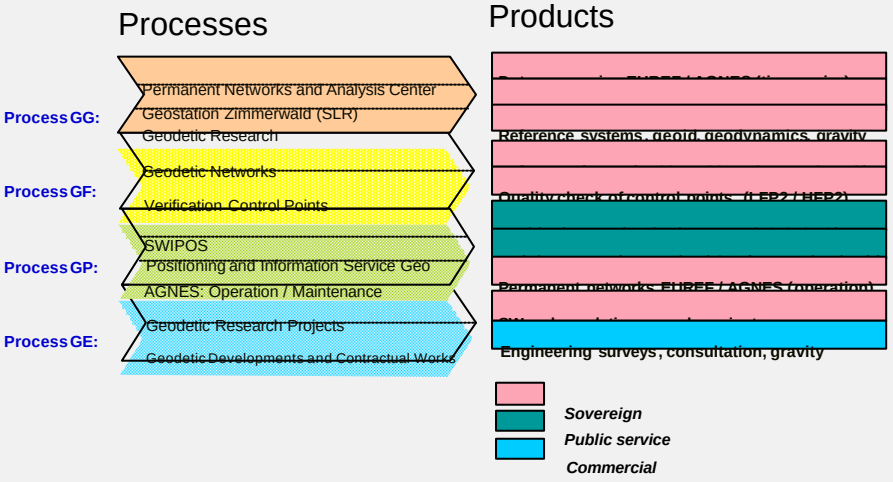
- Distributed processing in IGS, EUREF for all various kinds of parameters (within same technique):
  - Coordinates (SINEX format)
  - Troposphere (SINEX TRO format)
  - …
- Combination with big impact also within IAG: combination of different techniques (GPS, VLBI, SLR)
- In Federal Survey: combination of GPS, levelling, classical networks

Advantages / Disadvantages

- ☺ Computational burden minimal
- ☺ Statistically exact (same result as processing based on original observations)
- ☺ Formal accuracies can be verified/corrected by group rms estimates / repeatabilities / more reliable outlier detection

- ☹ New observation modeling (antennas, tides, orbits, troposphere, …) -> reprocessing necessary

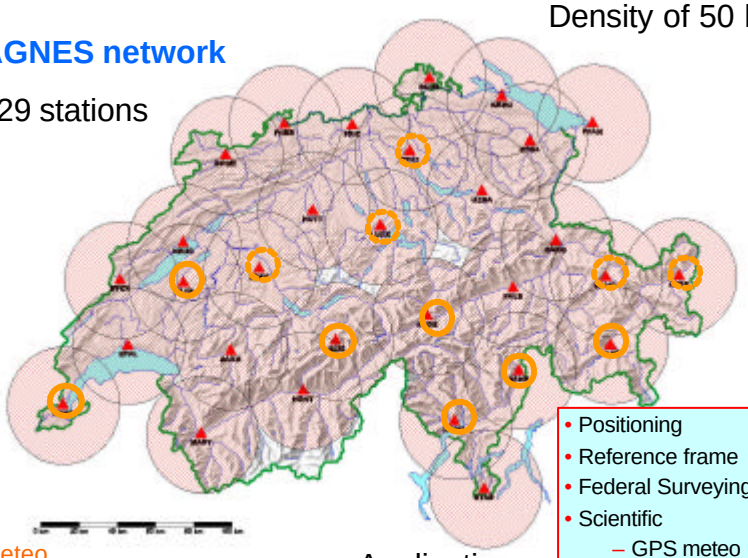
Products of the Geodesy Division



AGNES network

29 stations

Density of 50 km



Meteo
ANETZ
Stations

Applications:

- Positioning
- Reference frame
- Federal Surveying
- Scientific
  - GPS meteo
  - Geodynamics

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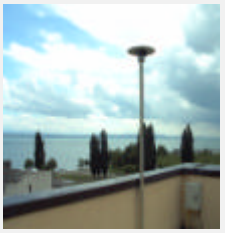
AGNES stations

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LV95 network

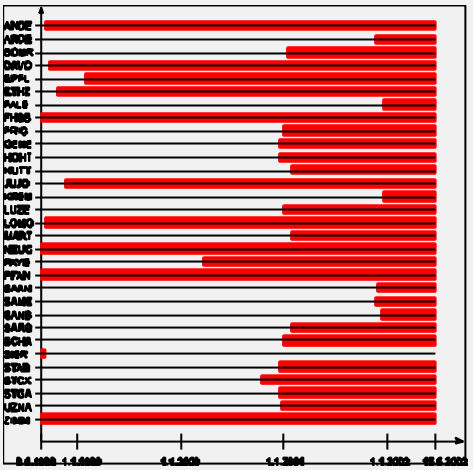
Swiss reference network (1989-1992)

History (2)

- 1998: re-measuring of LV95 (CHTRF98); differences below < 1 cm horizontally and < 3 cm vertically

- 1998: Start of the project with 8 permanent stations
- 2001: Completion with 29 permanent stations

History (3)



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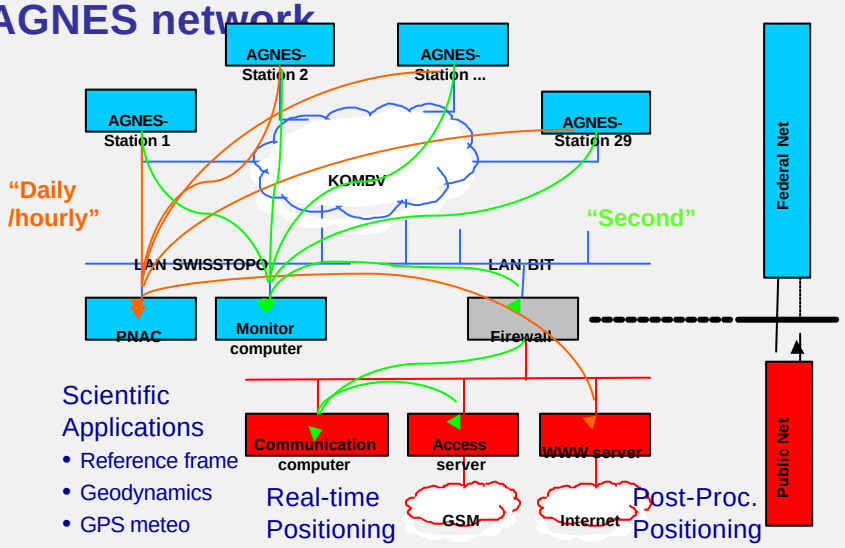
AGNES network



Scientific Applications

- Reference frame
- Geodynamics
- GPS meteo

Real-time Positioning

Post-Proc. Positioning

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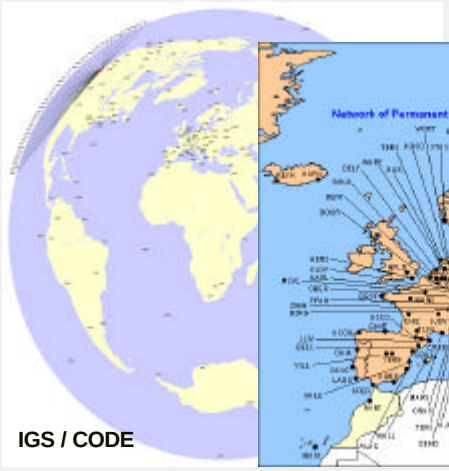
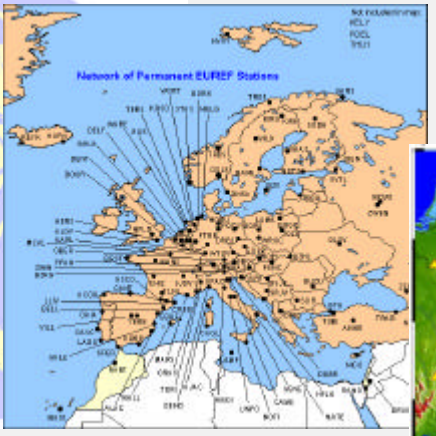
Permanent Networks / Analysis Center



EUREF (EPN)
Permanent Network



Network processed daily by swisstopo

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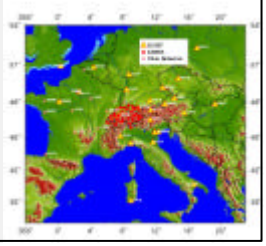
Permanent Networks and Analysis Center (PNAC):

Netzwerklösung	Stationen	Auswerteinterwal
EUREF subnetwork	20 (1 AGNES)	Daily observations with 21 days delay
AGNES + EUREF subnetwork	65 (29 AGNES)	Daily observations with 21 days delay
AGNES + EUREF subnetwork	63 (29 AGNES)	Hourly observations with 0.5 hours delay



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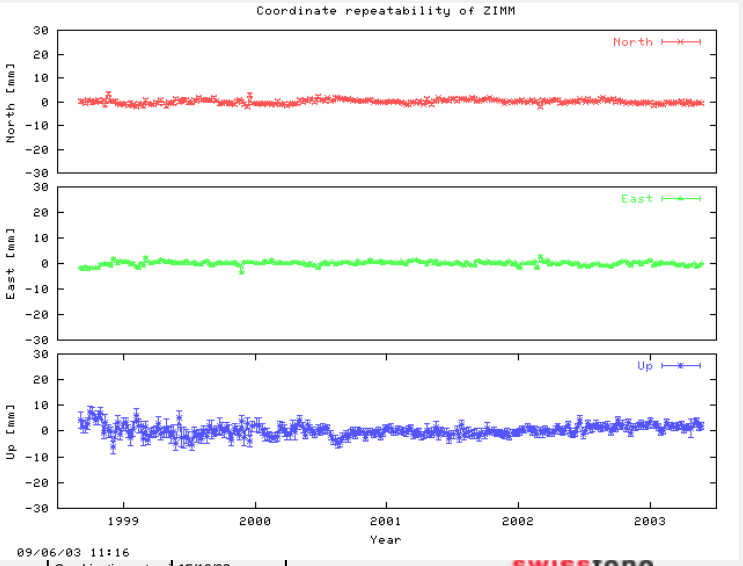
Time series: Zimmerwald (ZIMM)



2 cm

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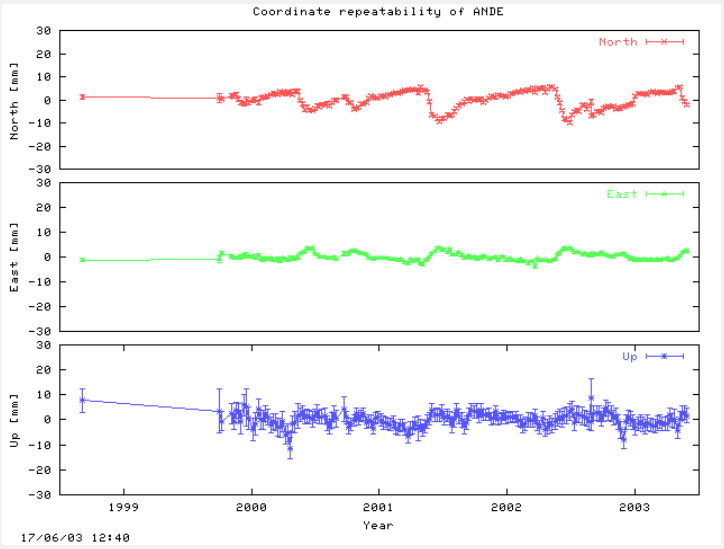
Andermatt



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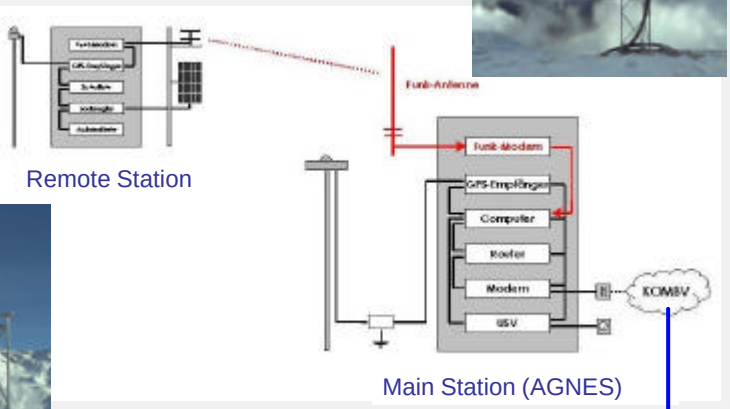
Remote GPS site DMAN

L1-only

2-4 hours wake-up



Automated Processing
(Bernese GPS Software)

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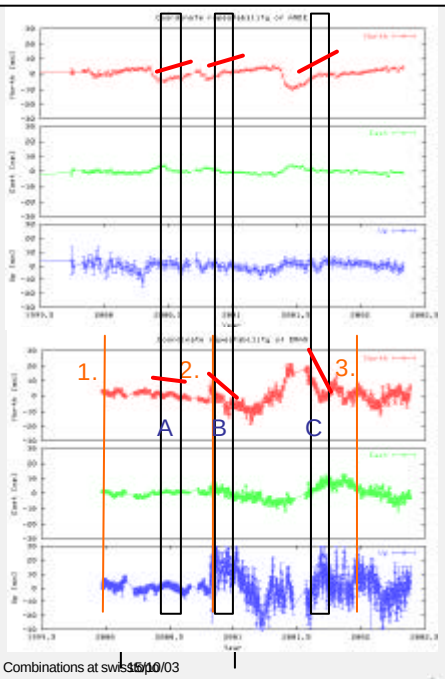
Repeatabilities



AGNES site

ZIMM-ANDE (L3 weekly solutions)

1.: 60 m baseline

2.: 3.7 km baseline

3.: 3.7 km baseline (Choke ring)

2 cm

A, B, C: Multipath tests (2 months)

remote site (only 2.5 % missing data)

ANDE-DMAN (L1 4-hour solutions)

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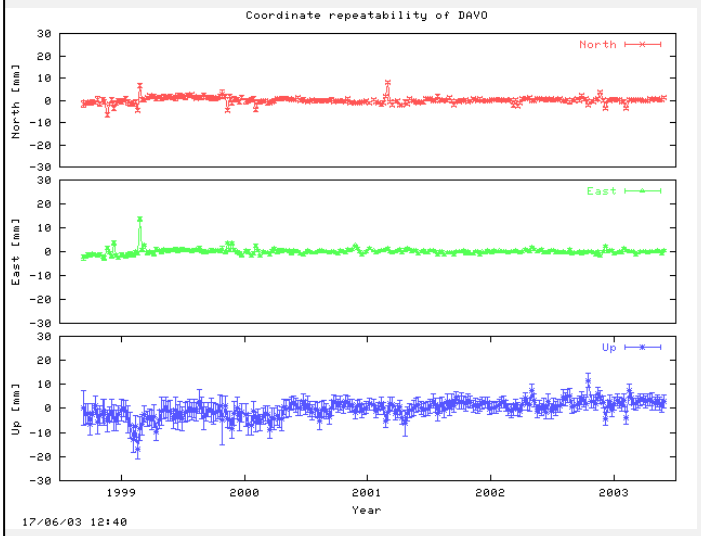
Davos



snow…

no radom…

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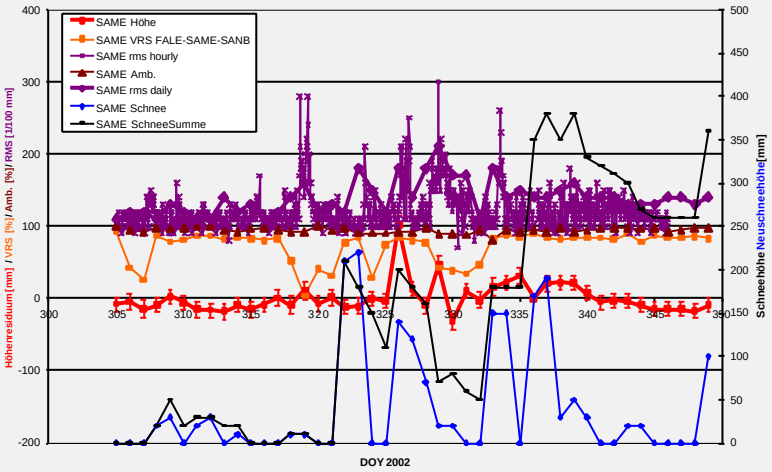
Correlation plot (Samedan)



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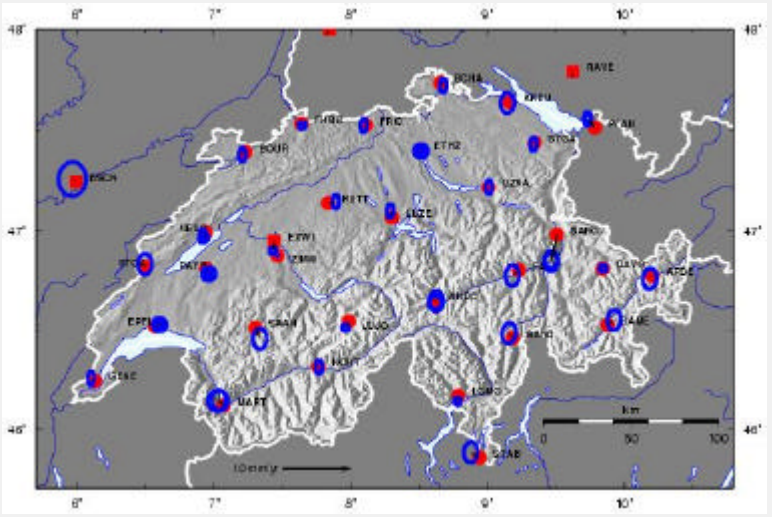
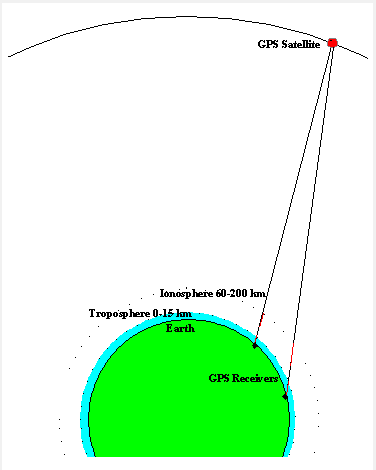
Velocities in ITRF00 (rel. ZIMM)

AGNES combination results available on: www.swisstopo.ch



GPS Meteorology



Path Delay — GPS

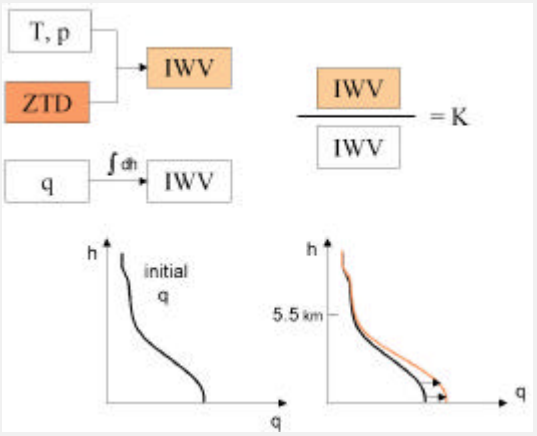
$$\Delta L = \int 10^{-6} N(s)\, ds$$

Refraction N — Meteo

Troposphere: < 15 km

Assimilation

Usage of GPS for numerical weather prediction

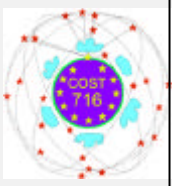


ZTD: Zenith Total Delay

IWV: Integr. Water Vapor

GPS meteorology

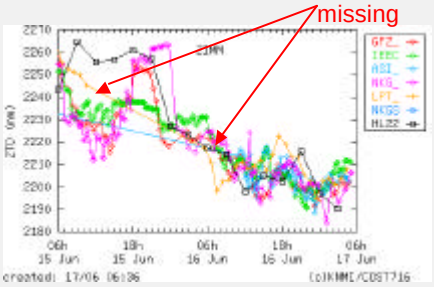
- Partners of swisstopo in Switzerland:
  - MeteoSwiss
  - University of Berne (IAP)
  - Swiss Federal Institute of Technology (ETH) Zurich
- COST 716:
  Exploitation of ground-based GPS for climate and numerical weather prediction applications (2000 – beginning 2004)
- since 2003: EU project TOUGH

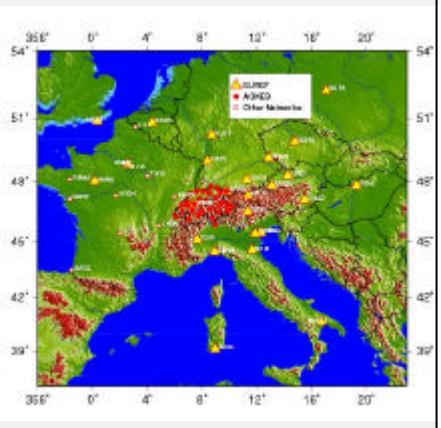


Hourly processing

- Since Dec. 2001
- 67 sites:
  - 21 EUREF
  - 29 AGNES
- Near real-time results of 6 centers at KNMI:

IGU orbits missing





http://www.knmi.nl/samenw/cost716/

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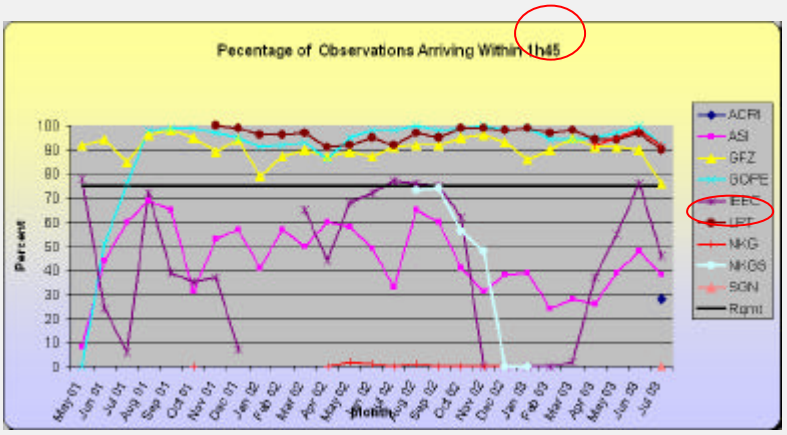
"Performance" of the hourly solutions

75%



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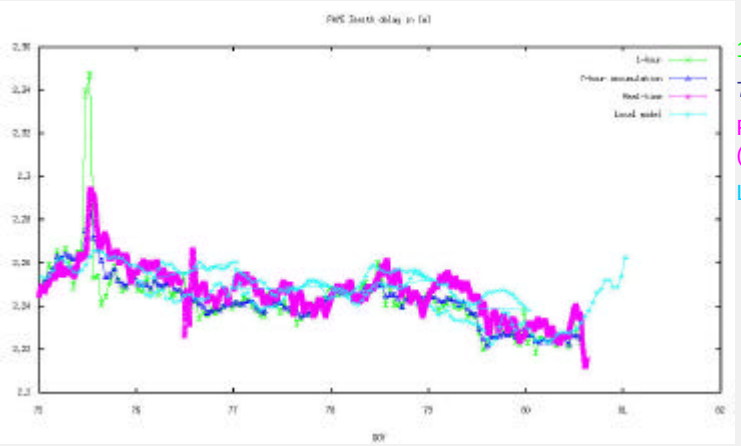
Real Real-time ZTDs

1 week (DOY 75 - 81, 2003)

Payern, March 22, 2003



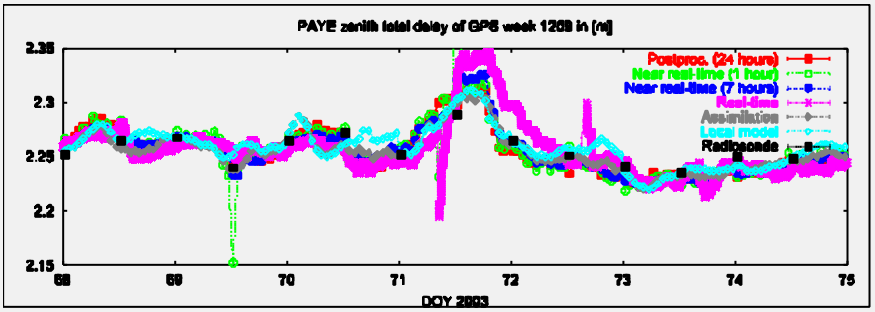
1-hour

7-hour accumulated

Real real-time (every minute)

Local Model

Comparisons (graphically)



Plots updated hourly on www.swisstopo.ch

Comparisons (numerically)

Statistics of the differences to the post processing (all sites)		
Near real-time (1 hour)	# differences [-]	50489
	offset [mm]	-0.3
	std [mm]	8.5
Near real-time (7 hours)	# differences [-]	51466
	offset [mm]	-0.1
	std [mm]	5.7
Real-time	# differences [-]	43153
	offset [mm]	2.5
	std [mm]	12.2
Local model	# differences [-]	36135
	offset [mm]	4.0
	std [mm]	8.1
Assimilation	# differences [-]	5244
	offset [mm]	8.9
	std [mm]	7.8
Radiosonde	# differences [-]	20
	offset [mm]	-5.0
	std [mm]	8.7

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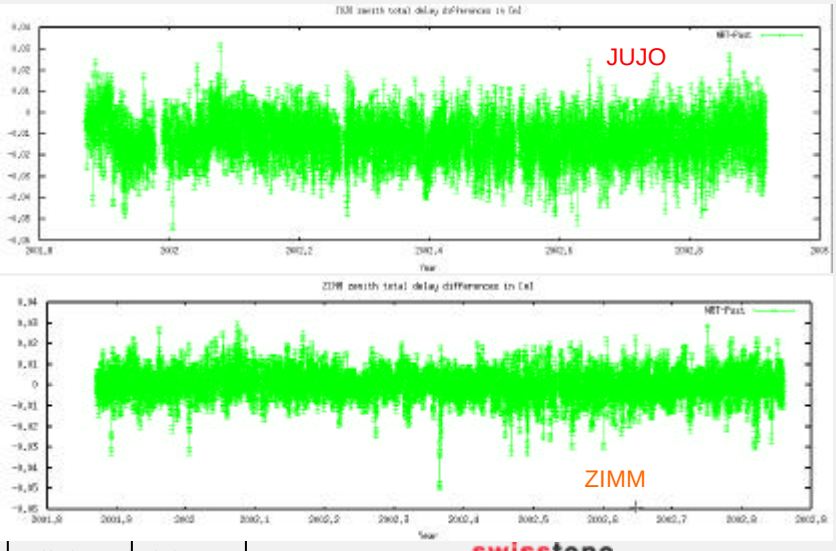
Vergleich: Postproc. versus NRT



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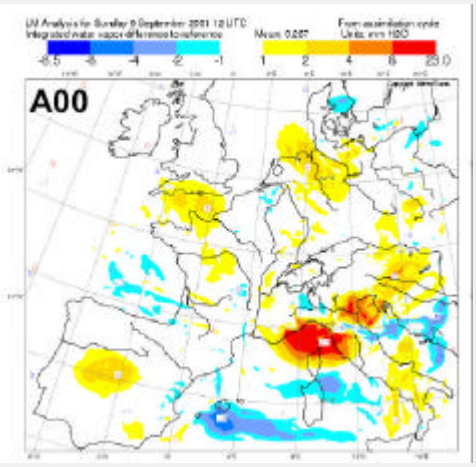
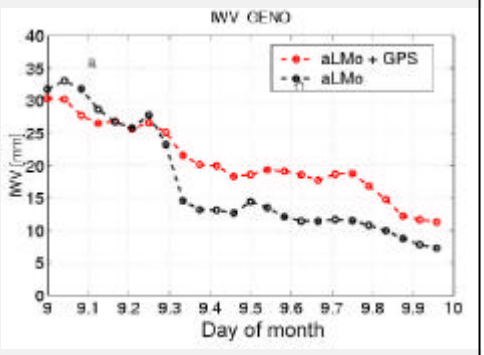
ZTD: 0.4 ± 6.4 mm

A00: 9.9.2001



Differenz IWV: Mit / Ohne GPS



IWV in Genua

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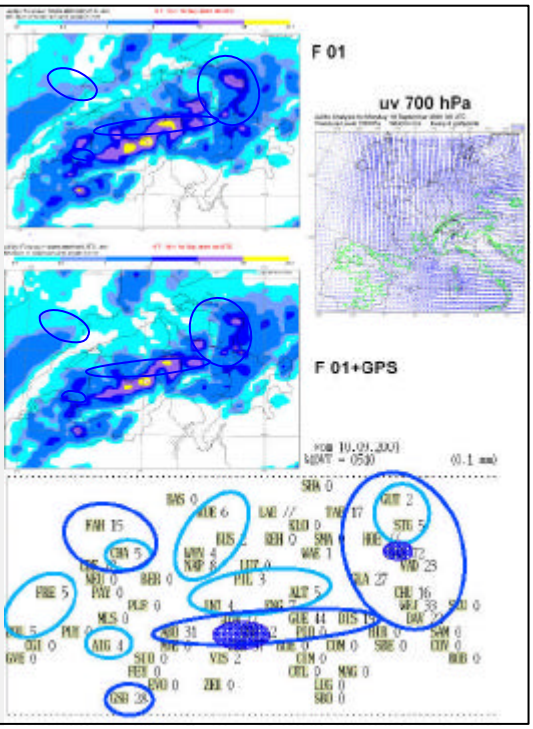
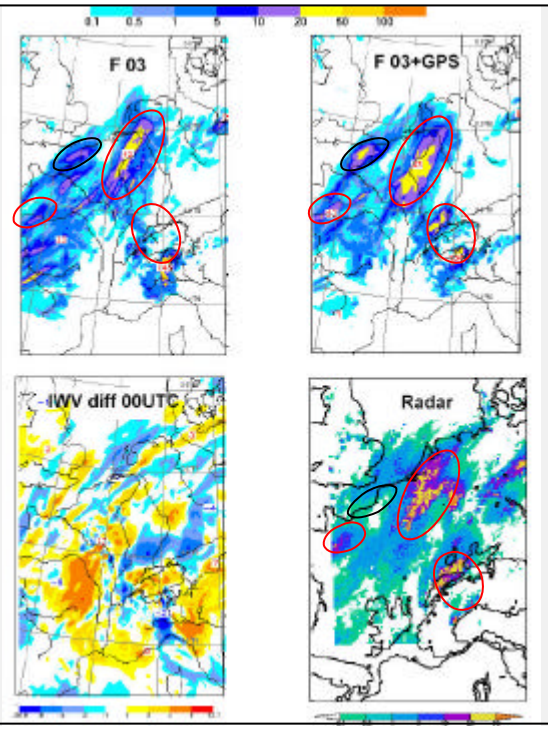
F01 Vergleiche



F03 Vergleiche



Trials at MeteoSwiss:

- Trials of Numerical Weather prediction at 3 different periods:
  - GPS has a significant influence on the prediction up to 6 hours
  - Positive / negative:
    - Summer +
    - Winter –
- More tests planned: operational run with / without GPS ZTD covering a longer time interval

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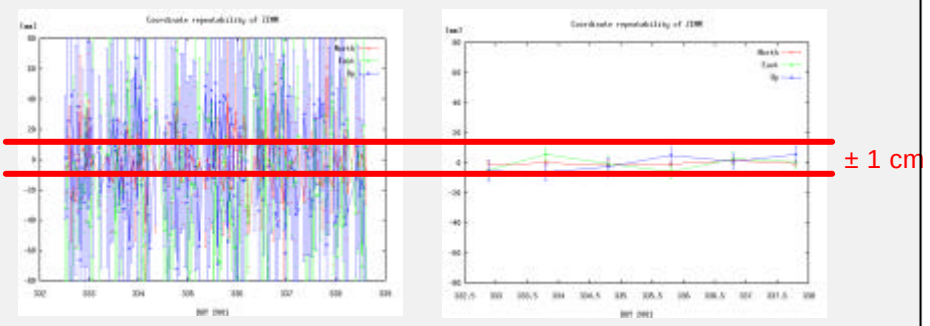
Coordinate validation in NRT

hourly ...

24-hour average...



		hourly...	7 24-hours ø	[150 weeks]
ZIMM repeatability in [mm]	North	16.0	1.0	0.9
	East	45.0	4.6	0.8
	Up	52.0	5.1	2.5

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AGNES in the federal Survey

- Maintenance of the LV95 reference frame
- Densifications (cantons)
- Connection to the height system

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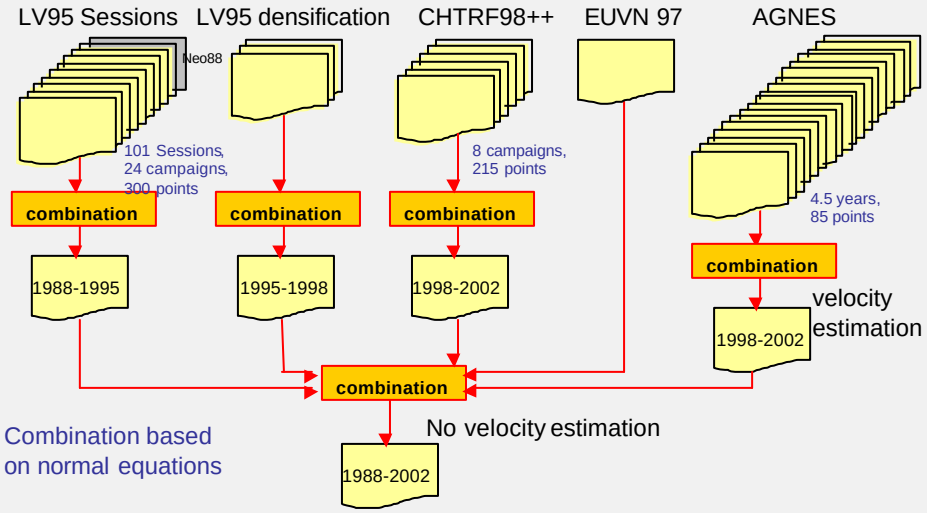
Combination scheme



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Final GPS combination

Campaign	# Stations	Helmert RMS north [mm]	east [mm]	up [mm]
LV95 (no Neo88)	278	1.7	3.3	9.7
LV95 densification	132	2.3	2.8	9.9
EUVN97	8	3.2	2.6	13.4
CHTRF98 ++	292	2.7	3.1	8.5
AGNES	85	0.9	1.2	1.8
Total:	551	2.2	3.0	8.8

- 180 sites = 2 times observed (" 4 years time difference)
- Totale # GPS phase L3 observations: 162‘827‘028

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GPS data analyses

- From campaigns and manual processing towards: less observers, longer measurements, automatically data analyses
  - auto_rinex.pl –c CAMPAIGN –n 5
  - report generation: „HTML Report„
  - Automatic new combined GPS solution

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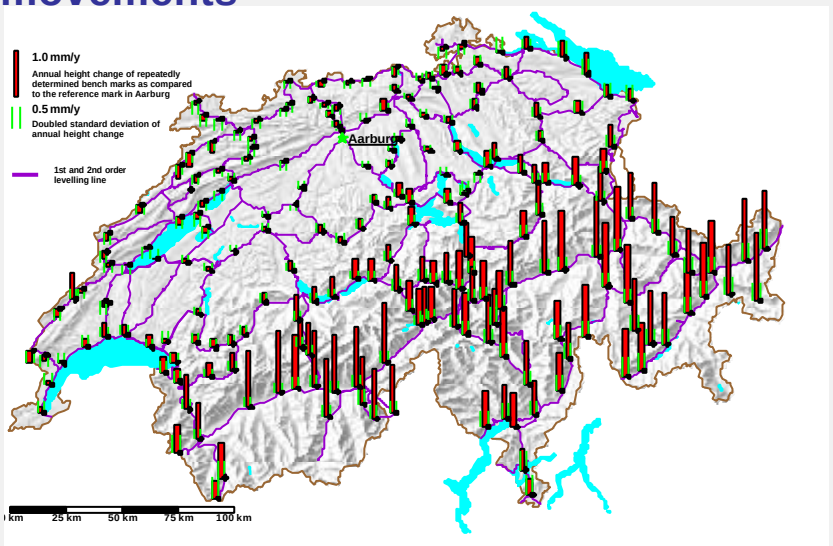
Leveling network LHN95: vertical movements



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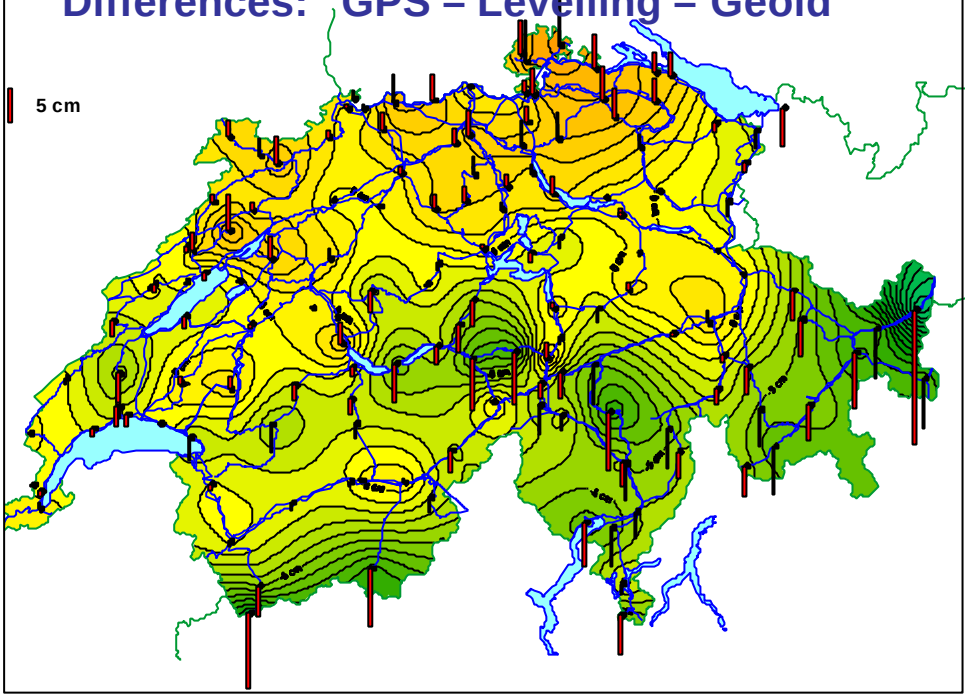
Differences: “GPS – Levelling – Geoid”

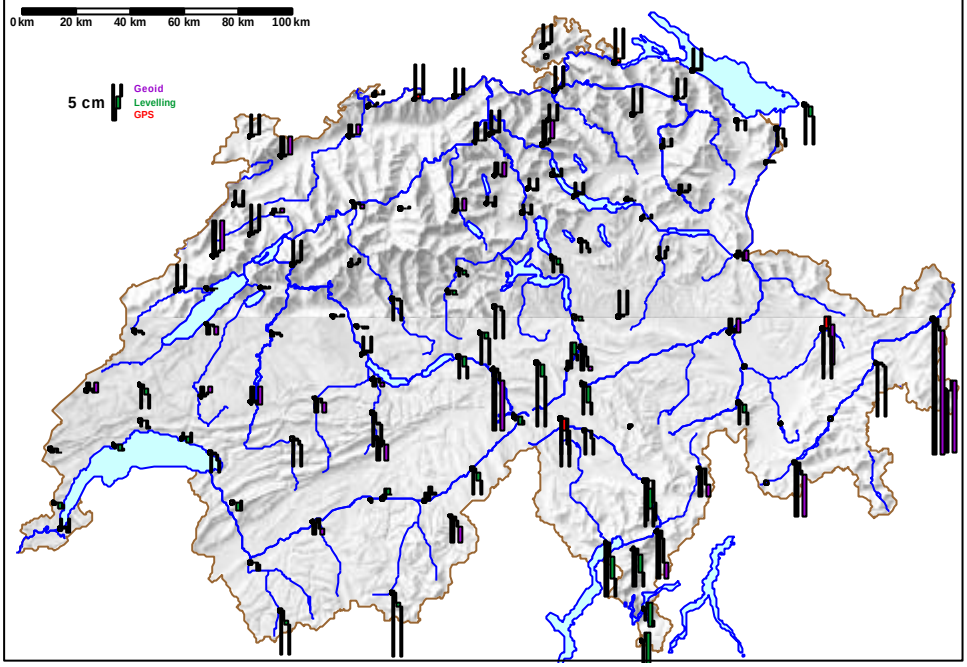


Common adjustment of GPS, levelling and Geoid

- Input
  - 152 points with h, H, N and with full variance-covariance matrix for each technique
- Assumption
  - Data sets linear independent and no systematical effects
- Residuals are distributed

$$v_h = Q_h \cdot (Q_h + Q_H + Q_N)^{-1} \cdot l$$
$$v_H = -Q_H \cdot (Q_h + Q_H + Q_N)^{-1} \cdot l$$
$$v_N = -Q_N \cdot (Q_h + Q_H + Q_N)^{-1} \cdot l$$

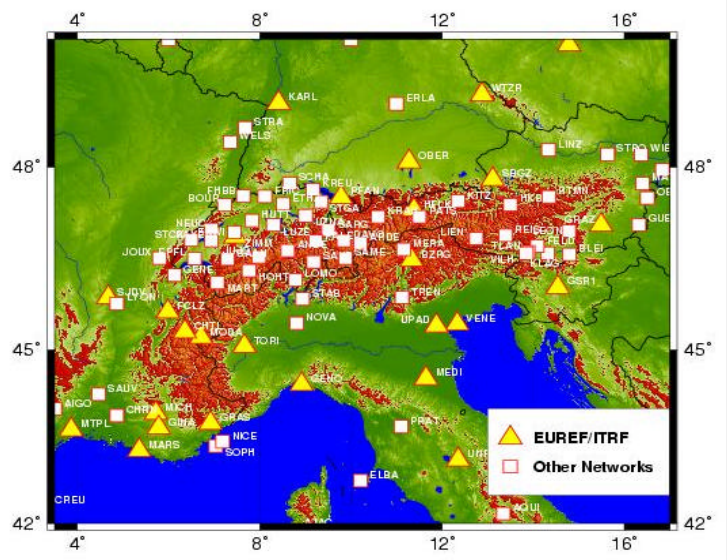
Residuals “GPS – Levelling – Geoid”



Reason for the differences / Corrective actions

- Reason
  - Mass models, reference frame ?
  - Astro inconsistencies (0,15“ must be explained) ?
  - ???
- Corrective actions
  - Computation of “separate Geoids”; Astro-only and GPS/Levelling-only
  - Usage of the gravity for the geoid determination
  - Additional measurements
- EUREF: ECGN Activity

Alpine network



„Contributors“

- IGN: Jean-Mathieu Nocquet
- PURDUE(CNRS): Eric Calais (?), …
- OLG: Guenter Stangl
- UPAD: Alessandro Caporali
- BKG: Georg Weber
- LPT: Elmar Brockmann

Questionaire

- Weekly solutions versus multi-year solutions
- Additional stations
- SINEX availability (free / only for group / not free)
- Combination activities

CENTER	SINEX	FILETYPE	# stations	x(y)	START	Distr.	Combin.
LPT	LPT.SNX	2	52(29)		1998.5	a	1
	WEEKLY.SNX	1	20(9)		1999.0	g***	1
		1	20(9)		1999.5	g***	1
		1	20(9)		2000.0	g***	1
		1	30(12)		2000.5	g***	1
		1	43(20)		2001.0	g***	1
		1	52(29)		2002.0	g***	1
IGN	RGP.SNX	2	23(5)		2001.5	a	1
	WEEKLY.SNX	1	14(1)		1998.5	a	1
		1	17(3)		1999.0	a	1
		1	19(4)		1999.5	a	1
		1	25(5)		2000.0	a	1
		1	27(5)		2000.5	a	1
		1	31(5)		2001.0	a	1
		1	39(9)		2001.5	a	1
PURDUE (CNRS)	REGAL.SNX	2	48(10)		1996.0	a	1
	WEEKLY.SNX	1	48(10)		1996.0	g	1
OLG	OLG.SNX	2	35(2),15(8)		1998.5	0	0
	WEEKLY.SNX**	1	30(1),10(2)		1998.5	a	1
		1	30(2),10(4)		1999.0	a	1
		1	35(2),15(5)		1999.5	a	1
		1	35(2),15(5)		2000.0	a	1
		1	35(2),15(8)		2001.0	a	1
UPAD	UPAD.SNX	2	?(4 I, 5 A)		2000.0	0	0
	WEEKLY.SNX	1	?(4 I)		2000.0	g *	1
		1	?(4 I, 5 A)		2001.5	g *	1
BKG	BKG.SNX	2	60(0)		1995.0	0	0
	WEEKLY.SNX	1	7(0)		1995.0	a	0
		1	13(0)		1996.0	a	0
		1	13(0)		1997.0	a	0
		1	35(0)		1998.0	a	0
		1	43(0)		1999.0	a	0
		1	45(0)		2000.0	a	0
		1	60(0)		2001.0	a	0
		1	60(0)		2002.0	a	0

swipos

The products.....

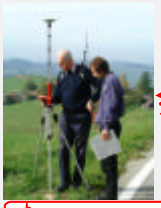
swipos – NAV (0.5 – 3 m)

- GPS reference station in Zürich (SRG)
- DGPS corrections using UKW/RDS till end of 2004
- in the future via internet (IP adresse, Port number)

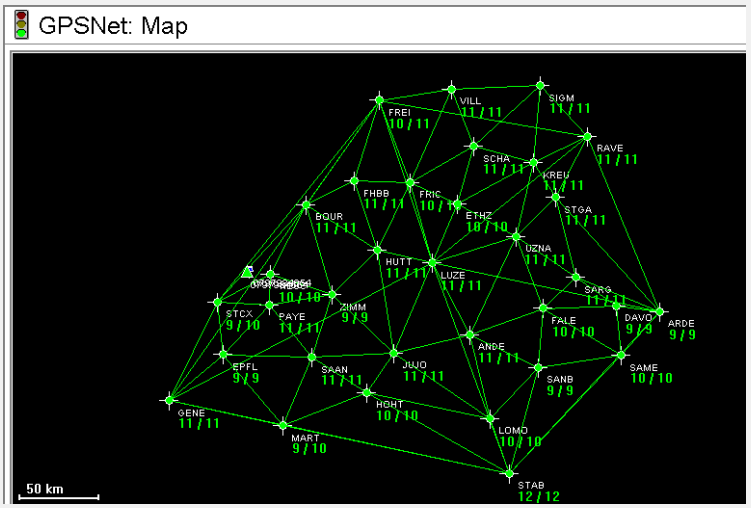
swipos - GIS/GEO (2-4 cm)

- Corrections and data of the AGNES sites
- data via www
- corrections via NATEL-D (GSM) (and internet ?)

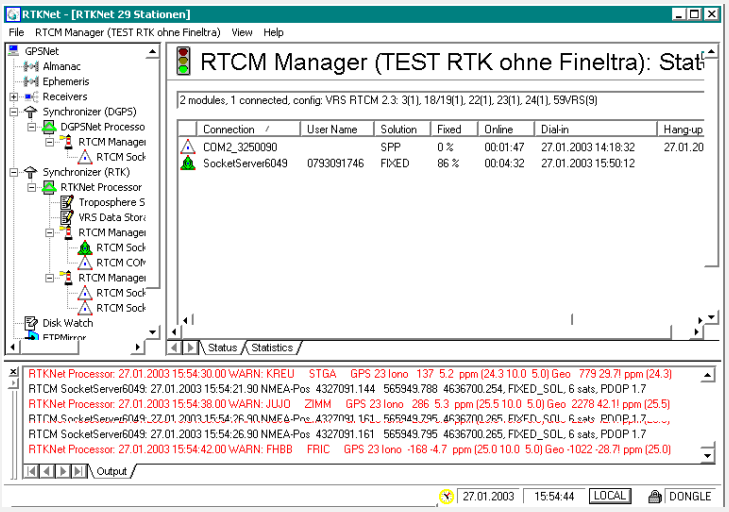
AGNES data flow



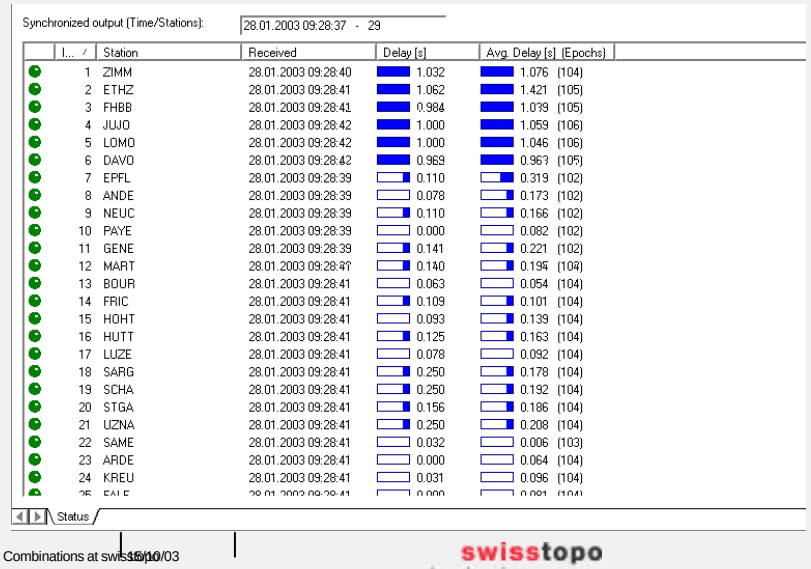
swipos - GIS/GEO: Real-time positioning



GPSNet: User Request

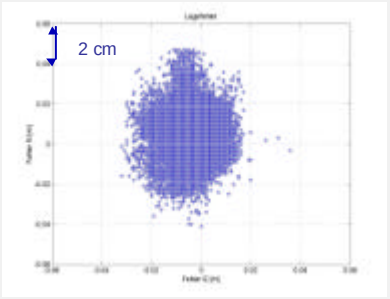


GPSNet Syncronizer

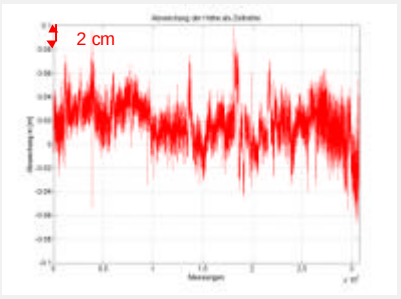


Positioning: Performance

- Test over 14 hours on the *swisstopo* roof using a Trimble 5700 receiver (with GSM)
- Registration of the RTK position every second; new initialization every 15 minutes



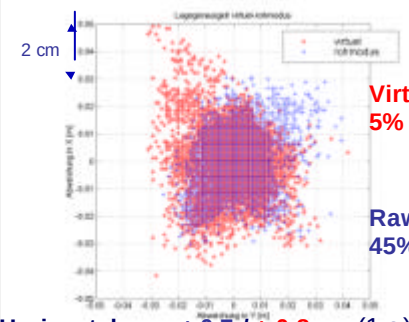
Horizontal rms: ±1.0 cm (1 s)



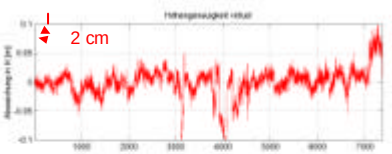
Vertical rms: ±1.8 cm (1 s)

Positioning: Performance (2)

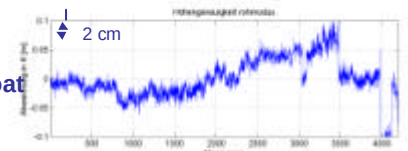
- Test over 4 hours on the *swisstopo* roof using 2 Trimble 5700 receiver (with 2 GSM) and 1 Zephyr antenna (+ antenna splitter)
- Registration of the RTK position every second; new initialization every 15 minutes



Virtuel: 5% float



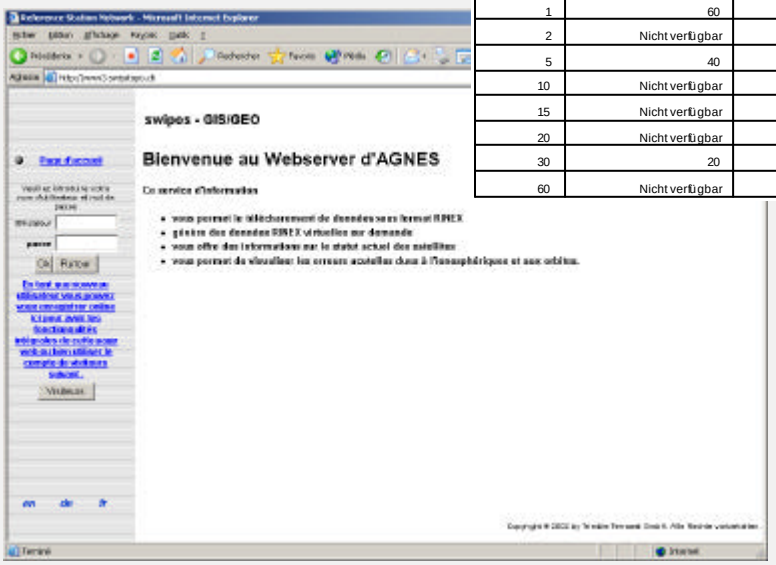
Raw: 45% float



Horizontal rms: ± 0.7 / ± 0.8 cm (1 s)

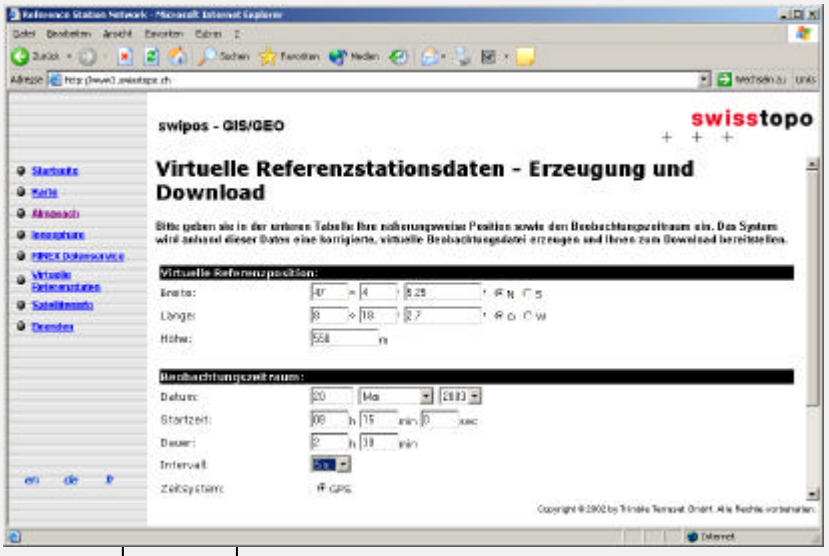
Vertical rms: ± 3.6 / ± 2.5 cm (1 s)

Web Interface



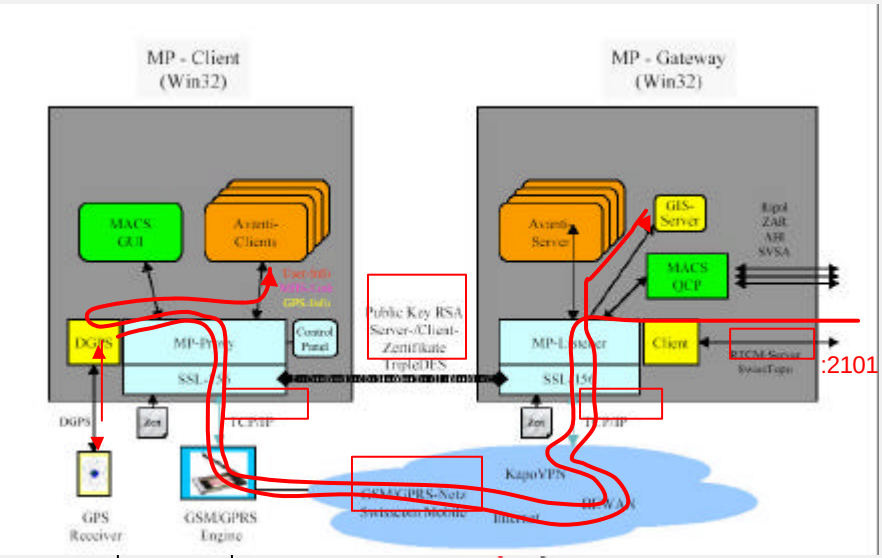
Intervall [s]	Preis Stundenfile alt (nur Station) [sfr]	Preis Epoche neu (Virtuell und Station) [sfr]**
1	60	0.0167
2	Nicht verfügbar	0.0278
5	40	0.0556
10	Nicht verfügbar	0.0972
15	Nicht verfügbar	0.1250
20	Nicht verfügbar	0.1389
30	20	0.1667
60	Nicht verfügbar	0.2500

Web Interface (2)



Kapo Bern

Kapo Bern (2)



Existierende Geräte

Thanks for your attention!