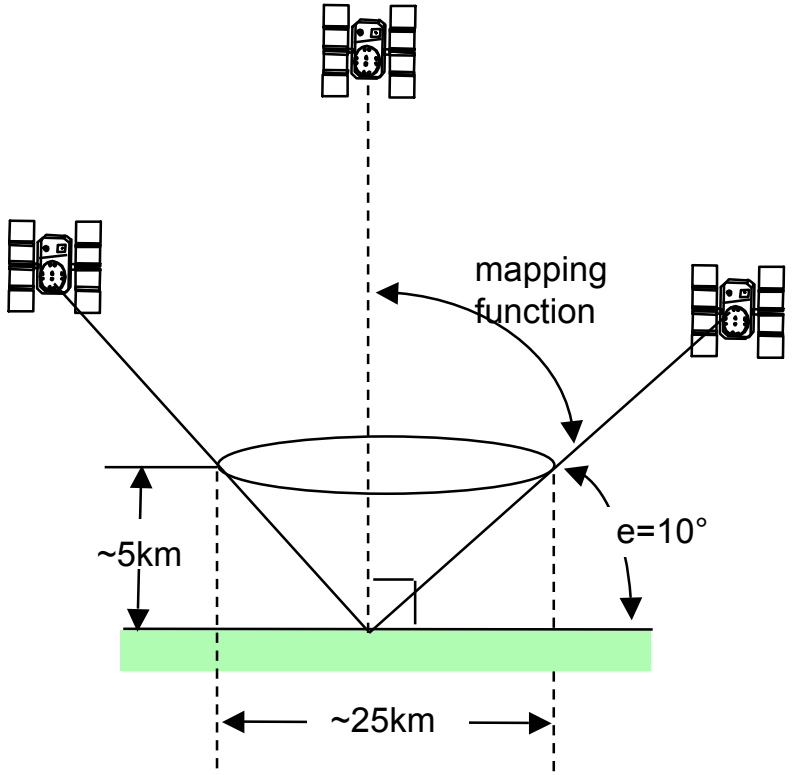
Ground Based GPS Meteorology



Fundamental Measurement

$$L_S = 10^{-6} \int N(s)ds$$

$$N = k_1 \cdot \left(\frac{P_d}{T}\right) + k_2 \cdot \left(\frac{e}{T}\right) + k_3 \cdot \left(\frac{e}{T^2}\right)$$

A mapping function, that is a mathematical model, is applied to determine how the signal delay changes with elevation angle. The results are averaged over all the satellites to give the ZTD.

Terrestrial Reference Frame

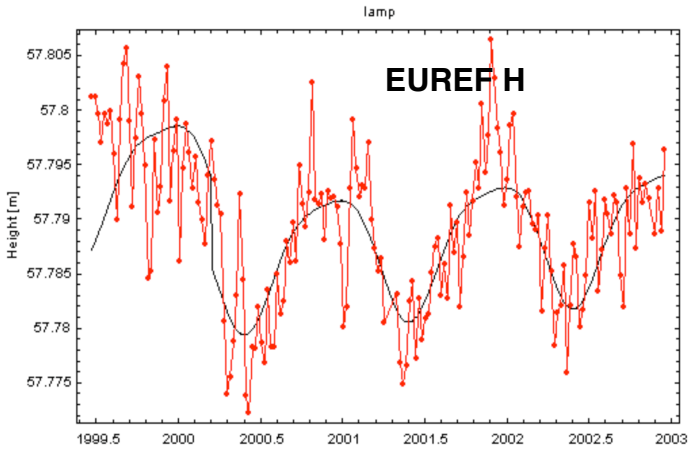
A terrestrial reference frame is defined by a set of positions and velocities at a given epoch

$$\vec{X}(t) = \vec{X}_0 + \vec{V}_0(t - t_0) + \sum_i \Delta\vec{X}_i(t)$$

Corrections due to various time changing effects, such as Earth tide displacement, ocean and atmospheric loading, and post glacial rebound.

GPS position time series shows:

- Linear trend
- Periodic signal: annual, *"seasonal biases in the precise orbit estimates or tropospheric delays, or tidal effects"*

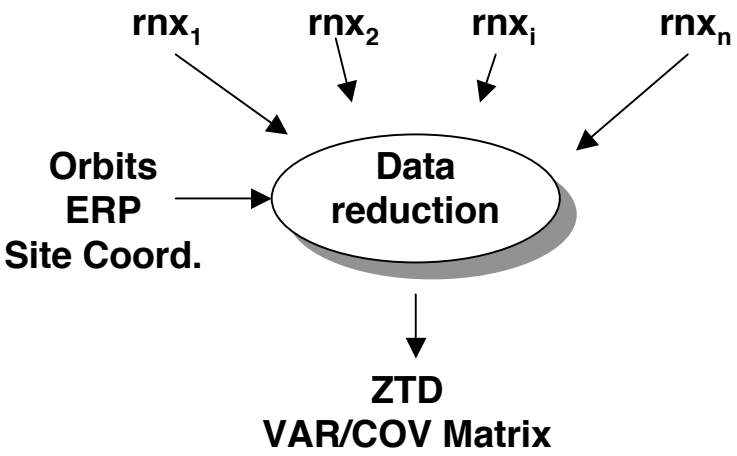


For Meteorological applications there is no need to estimate the station coordinates in the Near Real Time process, even if there is a need of monitoring them.

GPS Processing Strategy

Network Approach

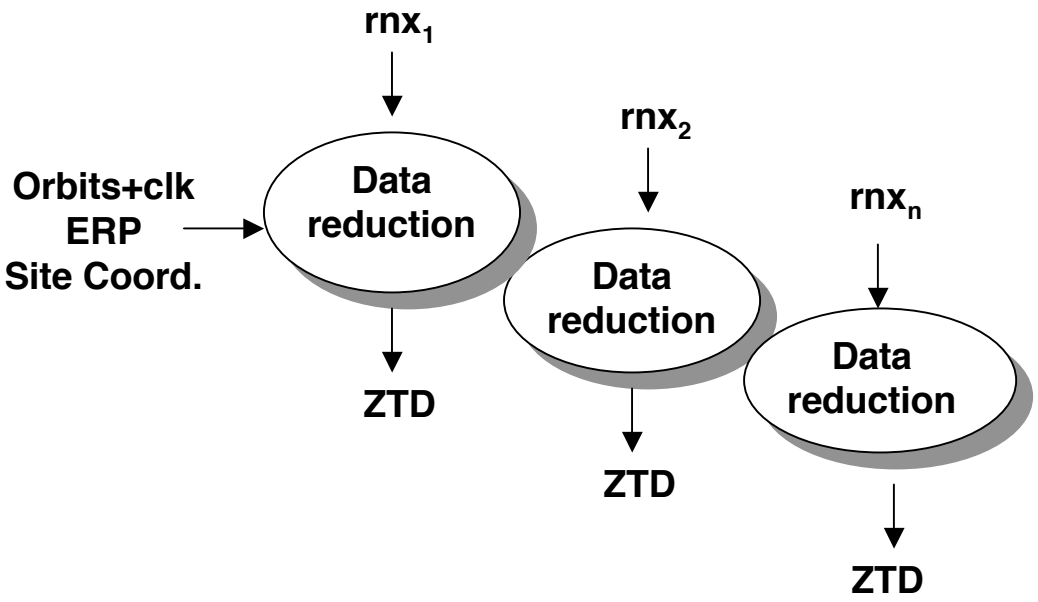
simultaneous analysis of all the data



- **Computing time increases more than proportionally with the number of stations**
- **Network has to be split in sub network**
- **VAR/COV Matrix**

Precise Point Positioning

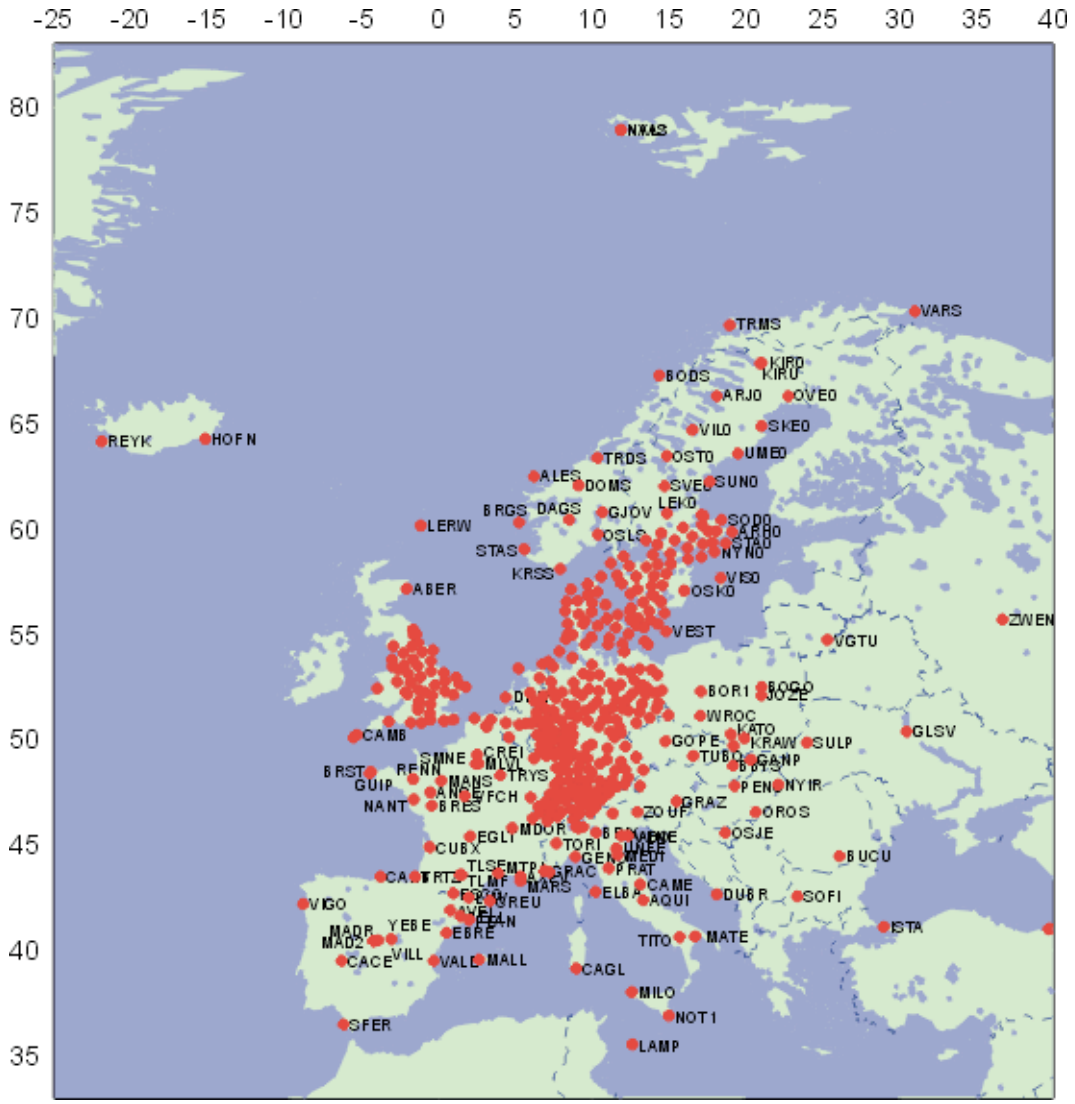
each station is analyzed independently



- **Computing time increases linearly with the number of stations**
- **Parallel processing**
- **No correlation between sites**

IMPORTANT: orbits and site coordinates must be in the same RF

GPS NRT Network



GPS Data Providers

Code	Name	Used by
	IGS Global Data Centres (GDC)	
IGNI	IGS GDC, Institut Géographique National, France	ACRI, ASI, BKG, SGN
CDDIS	IGS GDC, Godhard Space Flight Center, USA	ASI, BKG, GFZ, SGN
SIO	Scripps Institution of Oceanography, USA	SGN
BKGI	IGS RDC, Federal Office of Carthography and Geodesy, Germany	ACRI, ASI, BKG, GFZ, IEEC
	IGS Regional Data Centres (RDC)	
BKGE	EPN RDC, Federal Office of Carthography and Geodesy, Germany	ACRI, ASI, BKG, GFZ, IEEC, LPT, SGN
BKGL	IGLOS RDC, Federal Office of Carthography and Geodesy, Germany	BKG
	EPN Local Data Centres (LDC)	
ASI	EPN LDC, Agenzia Spatiale Italiana, Italy	ACRI, ASI, BKG, SGN
DUT	EPN LDC, DEOS, TU Delft, Netherlands	GFZ, GOP
IGNE	EPN LDC, Institut Géographique National, France	ACRI, ASI, BKG, GFZ
GOP	EPN LDC, GOPE, Czech Republic	BKG, GOP
OLG	EPN LDC, Austria	ASI, BKG
ROB	EPN LDC, Royal Observatory, Belgium	BKG, SGN
	National Data Centres	
AGNES	Automatisches GPS Netz Schweiz, swisstopo	LPT
AGRS	Active GPS Reference System for the Netherlands	*DUT*
ESGT	Ecole Supérieure des Géomètres et Topographes	SGN
IAC	Instituto de Astrofísica de Canarias, Spain	IEEC
IESG	The British Isles GPS Archive Facilities	GOP
ICC	Institut Cartogràphic de Catalunya, Spain	IEEC
IGN	Instituto Geogràfico National, Spain	IEEC
REGAL	Réseau GPS permanent dans les Alpes	ACRI, LPT, SGN
RGP	Réseau GPS Permanent, France	SGN
SAPOS	SAtellite POSitioning Service, Germany	GFZ
SATREF	Norwegian Mapping Agency, Norway	NKG
SWEPOS	National Land Survey, Gävle, Sweden	NKGS
DKNET	GPSnet.dk, Trimble centre Danmark	NKGS
	Others	
UNAVCO	University NAVSTAR Consortium, Boulder, USA	SGN

Near Real Time Processing Set-up

	GFZ	NKGS	NKG	ASI	IEEC	ACRI	BKG	GOP	LPT	SGN
software	EPOS	GIPSY	GIPSY	GIPSY	GIPSY	GAMIT	BSW	BSW	BSW	BSW
strategy	PPP	PPP	NET	NET	NET	NET	NET	NEQ	NEQ	NEQ
Initial data:										
orbit	GFZ	IGU	JPL15	IGU	JPL15	IGU	IGU	IGU	IGU	IGU
ERP	GFZ	IGU	JPL15	IGU	JPL15	IERS	IGU	IGU	IGU	IERS
clocks	GFZ	-	-	-	-	-	-	-	-	-
Orbit/clock estimation:										
orbit/clock	both	both				3 orb [a]				
window	12h	24h				9h				
sites	25	20								
cpu	8m	10m								
Coordinate estimation:										
method	pp(PPP)	pp(PPP)	pred	pp(PPP) [b]		pp	pp	nrt	pp [c]	pp
window	7 days	1 month	-	1 month	-	8 days	7 days	7 days	1 month	years
updates	daily[d]	monthly	-	monthly	-	quarterly	quarterly	daily	monthly	
ref.frame	ITRF00	ITRF00	ITRF00	ITRF00	ITRF00	ITRF00	ITRF00	IGS00	ITRF00	ITRF00
fiducials	all IGS	all IGS	none	17		5	13	all IGS	all IGS	sel.
$\sigma_{fiducial}$	1mm	1 mm		0.1 mm		3/6mm				
σ_{crd}	100 m	100 m				20/50mm				
Parameter estimation:										
window	12h	8h	12h	24h	12h	9h	4h	12h	7h	3h
interval	150s	300s	900s	300s	300s	60s	120s	30s	30s	30s
cutoff	7.5°	15°	10°	10°	10°	10°	10°	10°	10°	10°
σ_{obs}	cos z	10 mm	10 mm	10 mm			cos z	cos z	cos z	cos z
coordinates	fixed	fixed	fixed	fixed	est.	fixed	fixed	fixed	fixed	fixed
gradients	yes	yes	yes	no	yes	no	no	no	no	no
oc.loading	Pgtks	Schrnck	Schrnck	Schrnck	Schrnck	Schrnck	Schrnck	Schrnck	Schrnck	Schrnck
PCV	IGS_01	IGS_01		IGS_01	IGS_01	IGS_01	IGS_01	IGS_01	IGS_01	IGS_01
exclusions	-	-	sat&sta	sat&sta	sat&sta	sat&sta	-	sta&sat	sta&sat	sat
sites	220	120	23	41	28	35	81	52	63	55
start time	hh:30	hh:20	hh:15	hh:18	hh:25	hh:30	hh:25	hh:30	hh:37	
cpu	6m	15m	5m	50m		20m	15m	20-30m	20m	25m
ZTD modelling:										
ZTD_0	Saast	exp(h)	exp(h)	exp(h)	exp(h)	Saast	-	-	-	-
mf_0	hNmf	hNmf	hNmf	hNmf	hNmf	hNmf	-	-	-	-
mf	wNmf	wNmf	wNmf	wNmf	wNmf	wNmf	hNmf	hNmf	hNmf	hNmf
method	pc/rw	rw	rw	rw	rw	pl	pc	pc	pc	pc
constraints	2cm/$\sqrt{h}$	1.02cm/$\sqrt{h}$	1.02cm/$\sqrt{h}$	2cm/$\sqrt{h}$	1.02cm/$\sqrt{h}$	2cm/$\sqrt{h}$	20mm	1.2mm	1.2mm	no
interval	30m	15m	15m	5m	10m	15m	60m	60m	60m	60m
epochs	14,44	0:15:45	0:15:45	0:15:45[e]	0:10:60	0:15:45	30	30	30	30
σ_{ZTD}	LSQw	LSQ		LSQ			LSQw	LSQw	LSQw	LSQw
max σ_{ZTD}	none	20 cm	20 cm	none			1cm		1cm	

Tropospheric Delay Model

$$ZTD = m_h(\varepsilon)ZHD + m_w(\varepsilon)ZWD + m_\Delta(\varepsilon)\cot\varepsilon\left[G_N\cos\phi + G_E\sin\phi\right]$$

GAMIT

Stochastic variations (Gauss-Markov process) from the Saastamoinen model (for the dry and the wet component) are estimated with piecewise linear interpolation. The mapping functions are the Niell's (1996) dry and wet.

GIPSY

$ZHD = 2.276x1.1013e^{-h/H}$ h geodetic station height, H scale factor.

ZWD Stochastic variations (random walk).

The mapping functions are the Niell's (1996) dry and wet.

BERNESE

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Web Sites

ACRI: http://www.acri-st/tough
Data and quality monitoring

ASI: http://geodaf.mt.asi.it/html/GPSAtmo/ground.html
ASI ground-based GPS Met activities
Latest results, Plots & Statistics

GOP: http://pecny.asu.cas.cz/gop
Plot of ZTD estimates
GOP ultra-rapid orbits

LPT: http://www.swisstopo.ch/en/geo/pnac_results.htm
Plot of ZTD estimates

TUD: http://mgp4.geo.tudelft.nl/tough/
Development of Models for Use of Slant Delays

IEEC: http://www.ieec.fcr.es/english/recerca/gnss/rtmain.html
Real time solutions of the last 24 hours