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THE GPS ADJUSTMENT SOFTWARE PACKAGE -GEONAP- CONCEPTS AND MODELS

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Abstract

Different software packages for the static positioning with GPS have been developed at the "Institut für Erdmessung" since 1983. Based on the experiences with the old GEONAP program (1984) and the TI 4100 specific software TIPOSIT (1986) the new GEOdetic NAVSTAR Positioning package (GEONAP) is under development since 1988.

The basic concepts and models for the simultaneous adjustment on nondifferenced GPS observables in the multi-station, multi-session, multi-receiver and multi-frequency modes are described. Special consideration is given to different linear combinations of carrier and code phases which may be computed from dual frequency measurements.

The ambiguity problem can be solved with GEONAP through combinations of the standard geometric approach, code- and carrier phase combination methods, "wide-" and "extra wide laning" techniques and ionospheric modeling. A description of these methods is given.

The parameter estimation algorithm consists of a combination of the least squares adjustment in the Gauß-Marcov model and the Kalman filter. Parameters that may be estimated are receiver coordinates, short arc satellite orbits, receiver and satellite clocks, receiver and satellite hardware delays, tropospheric scaling parameters, ionospheric model parameters and ambiguities.

1 Introduction

During the last few years several programs for the geodetic adjustment of GPS observations have been developed. The favorit observable chosen for most of the programs is the "Double Difference".

At the Institut für Erdmessung (IFE) the nondifferenced GPS observable has been used since the beginning of our GPS research in 1983. Two different programs called GEONAP (*Wübbena 1985*) and TIPOSIT (*Wübbena, et.al. 1986*) were developed and used between 1984 and 1987. The first one was based on a general model for the carrier phase adjustment, the second one was TI4100 specific. GEONAP was quite unhandy and user unfriendly, it also lacked a good capability of cycle slip and ambiguity recovery. These disadvantages lead to an exclusive usage of TIPOSIT since 1986. TIPOSIT worked quite well for most of the processed data sets. Since ambiguity resolution was mainly done through the code-carrier combination method a modified version of the program could also be used for high precision relative kinematic positionings.

Based on the experiences with GEONAP and TIPOSIT a new program system has been under development since 1988. Although it is a completely new software the name was chosen to be GEONAP (GEOdetic NAVSTAR Positioning) because the underlying model is similiar to that one of the old GEONAP. The main aim of the development is to meet the current and probably future requirements of GPS users regarding adjustment software. Some of the requirements are and may be

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- the simultaneous adjustment of observations from different receiver types,
- the simultaneous adjustment of single and dual frequency measurements,
- a complete variance-covariance estimation,
- to keep the necessary observation time as small as possible,
- the full automatic operation.

2 The Basic Observation Equation

In this chapter the observation equation of a GPS observable as used by GEONAP will be derived and explained.

A GPS satellite antenna transmits an electromagnetic wave which consists of different signal components. These are

$L1$ - the in-phase carrier component of the L1 signal,

$L1_q$ - the quadrature carrier component of the L1 signal,

$L2$ - the L2 carrier signal,

P_1 - the P-code modulation of the L1 signal,

C_1 - the C/A-code modulation of the L1 signal,

P_2 - the P-code modulation of the L2 signal and

D - the binary data of the navigation message.

All components are directly derived from the satellite clock, thus, the transmitted phase of the signal $S \in \{L1, L1_q, L2, P_1, C_1, P_2\}$ from satellite i can be described by

$$\Phi_S^i(t^t) = t^i(t^t) f_S + d\Phi_S^i(t^t) \;, \tag{1}$$

with

t^t - the epoch of signal transmission,

$t^i(t^t)$ - the satellite clock reading at t^t,

f_S - the nominal signal frequency,

$d\Phi_S^i(t^t)$ - a phase delay due to satellite hardware.

Once transmitted by the satellite antenna the electromagnetic wave propagates approximately with the speed of light through the space. As long as the laws of geometric optics are valid for the signal propagation in the earth's atmosphere the signal components may be considered independently. In this case the phase of the component S reaches the antenna of the receiver j at the epoch

$$t_r = t^t + T_{S_j}^{\,i} \;, \tag{2}$$

where

$T_{S_j}^{\,i}$ - is the signal propagation time.

Due to the dispersive effect of the ionosphere the propagation times are different for all signal components.

The code tracking loop of the GPS receiver shifts an internal replica of the PRN code B in time until maximum correlation with the received code is reached. At this time the two code phases are identical within the measurement noise level. The reading of the internal code phase can be expressed as

$$\Phi_{B}{}_j^i(t_r) = \Phi_B^i(t^t) - d\Phi_{Bj}(t_r) - \epsilon\Phi_{B}{}_j^i(t_r) , \tag{3}$$

where

$d\Phi_{Bj}(t_r)$ - is a phase delay depending on receiver hardware and

$\epsilon\Phi_{B}{}_j^i(t_r)$ - is a random measurement error.

The carrier tracking loop measures the so called carrier beat phase. For the carrier signal C this can be defined as

$$\Phi_{m}{}_j^i(t_r) = \Phi_C^i(t^t) - \Phi_{C0j}(t_r) - d\Phi_{Cj}(t_r) - N_{C}{}_j^i(t_r) - \epsilon\Phi_{C}{}_j^i(t_r) , \tag{4}$$

with

$\Phi_{C0j}(t_r)$ - the phase of a receiver generated reference signal,

$d\Phi_{Cj}(t_r)$ - a phase delay due to receiver hardware,

$N_{C}{}_j^i(t_r)$ - the phase measurement ambiguity and

$\epsilon\Phi_{C}{}_j^i(t_r)$ - a random measurement error.

Since the reference signal is derived from the receiver clock its phase can be computed by

$$\Phi_{C0j}(t_r) = f_{C0} t_j(t_r) , \tag{5}$$

where

f_{C0} - is the nominal frequency of the reference signal and

$t_j(t_r)$ - is the receiver clock reading at t_r.

Using this relation a derived carrier phase observation can be computed to

$$\Phi_{C}{}_j^i(t_r) = \Phi_{m}{}_j^i(t_r) + \Phi_{C0j}(t_r) , \tag{6}$$

or with eqn. (4) to

$$\Phi_{C}{}_j^i(t_r) = \Phi_C^i(t^t) - d\Phi_{Cj}(t_r) - N_{C}{}_j^i(t_r) - \epsilon\Phi_{C}{}_j^i(t_r) . \tag{7}$$

The ambiguity is generally a function of time, however this function is constant as long as cycle slips do not occur. At this point it should be mentioned that phase measurements obtained from squaring type channels change twice as fast in time as the corresponding phases from code correlation channels. Phases from squaring type channels can be transformed to the original signal frequency by dividing them by 2. The ambiguity in such a phase can be an integer multiple of 0.5, i.e. half cycle ambiguities may be present instead of full cycle ambiguities.

A comparision of equation (7) with (3) shows that the only principle difference between code and carrier phase measurements is the carrier phase ambiguity.

From the phase measurement the transmission epoch of the signal S in the satellite time frame can approximately be computed by

$$\tilde{t}_S^i(t^t) = \frac{\Phi_{S}{}_j^i(t_r)}{f_S} . \tag{8}$$

Introducing the satellite and receiver clock errors as

$$\Delta t^i(t) = t^i - t \tag{9}$$
$$\Delta t_j(t) = t_j - t\,, \tag{10}$$

a pseudorange defined by

$$PRs_j^i(t_r) = c\left(t_j(t_r) - \bar{t}_S^i(t^t)\right)\;; \tag{11}$$

evaluates under consideration of (7) and (1) to

$$PRs_j^i(t_r) = c(t_r - t^t) + c\left(\Delta t_j(t_r) - \Delta t^i(t^t)\right) + c\left(dts_j(t_r) - dts^i(t^t)\right) + \frac{c}{f_S} Ns_j^i(t_r) + c\epsilon ts_j^i(t_r)\,, \tag{12}$$

where c is the speed of light. In the last equation the phase delay terms and phase measurement errors are transformed to time delays by dividing them by the signal frequency.

The receiver delay terms are assumed to be satellite independent, which means that possible interchannel biases are removed through calibration measurements.

Pseudoranges derived from different signal components are affected by satellite and receiver clock errors in the same way. However, the hardware delays are generally different. If only one signal component is considered there is no way to distinguish between clock errors and hardware delays. Only if different components are used simultaneously, a separation is possible. Both error terms are functions of time. The clock error function is quite complex, but the delay error may be described by simple models like constants or low degree polynomials. The use of non-differenced observables can take advantage of the stability in the delay terms, which could not be done if differenced measurements were used.

The first term in (12) contains the true propagation time of the signal component as defined by (2). The propagation time is related to the geometric distance through

$$c\left(t_r - t^t\right) = \left|\vec{X}^i(t^t) - \vec{X}_j(t_r)\right| + c\delta ts_{I\,j}^{\,i}(t_r) + c\delta t_{T\,j}^{\,i}(t_r) + c\delta ts_{M\,j}^{\,i}(t_r) + c\delta t_{R\,j}^{\,i}(t_r)\,, \tag{13}$$

with

$\vec{X}^i(t^t)$ - the coordinate vector of satellite i at the transmission epoch,

$\vec{X}_j(t_r)$ - the coordinate vector of receiver j at the reception epoch,

δts_I - the ionospheric delay of the signal S,

δt_T - the tropospheric delay,

δts_M - an additional delay describing multipath effects and phase center variations and

δt_R - the relativistic time effects.

One gets the complete observation equation if the first term in (12) is substituted by the right side of (13). Single terms may further be written as functions of other parameters. For instance the satellite coordinate vector can be introduced as a function of orbit parameters.

3 Linear Combinations

In this chapter some important linear combinations of carrier and code phase measurements shall be discussed. Besides the linear combination that yields ionospheric corrected measurements others can be used to improve the ambigutiy resolution, which is essential for high precision positioning. Among the infinite number of possible linear combinations only those seem to be valuable which

- have an integer ambiguity,
- have a reasonable wavelength,

- contain small ionospheric delays and
- keep the measurement noise small.

The dual frequency carrier phases ($L1, L2$) transmitted by an ideal satellite are a function of the satellite clock

$$t^i(t) = \frac{\Phi_1^i(t)}{f_1} = \frac{\Phi_2^i(t)}{f_2} \; . \tag{14}$$

The phase of the linear combination

$$\Phi_{n,m}^i(t) = n\Phi_1^i(t) + m\Phi_2^i(t) \tag{15}$$

fulfils the equation

$$t^i(t) = \frac{\Phi_{n,m}^i(t)}{f_{n,m}} \tag{16}$$

if the frequency is

$$f_{n,m} = nf_1 + mf_2 \; , \tag{17}$$

and the wavelength of the linear combination is

$$\lambda_{n,m} = \frac{c}{f_{n,m}} \; . \tag{18}$$

The ambiguity in this derived signal is

$$N_{n,m} = nN_1 + mN_2 \; , \tag{19}$$

i.e. the ambiguity is an integer if n and m are integers.

The ionospheric delays of the $L1$ and $L2$ signals are different, the effect in the linear combination will be

$$\delta\Phi_{n,m_I} = n\delta\Phi_{1_I} + m\delta\Phi_{2_I} \; . \tag{20}$$

The first order ionospheric effect on phase measurements can be written as

$$\delta\Phi_{1_I} = -\frac{C_I}{f_1} \tag{21}$$

$$\delta\Phi_{2_I} = -\frac{C_I}{f_2} \tag{22}$$

where

C_I - is a function of the total electron content which varies with time and location.

Introducing

$$\Pi f = f_1 \cdot f_2 \tag{23}$$

and inserting (21) and (22) into (20) yields the first order ionospheric effect in the phase of the linear combination

$$\delta\Phi_{n,m_I} = -\frac{C_I}{\Pi f}(nf_2 + mf_1) \; , \tag{24}$$

which can be transformed to an equivalent time delay by dividing by the signal frequency

$$\delta t_{n,m_I} = \frac{\delta\Phi_{n,m_I}}{f_{n,m}} = -\frac{C_I}{\Pi f}\frac{nf_2 + mf_1}{nf_1 + mf_2} = -\frac{C_I}{\Pi f}V_{I_{n,m}} \; . \tag{25}$$

The measurement noise in a pseudorange computed from the linear combination will be

$$\sigma_{n,m} = \lambda_{n,m}\sqrt{n^2 + m^2}\sigma_\varphi \; , \tag{26}$$

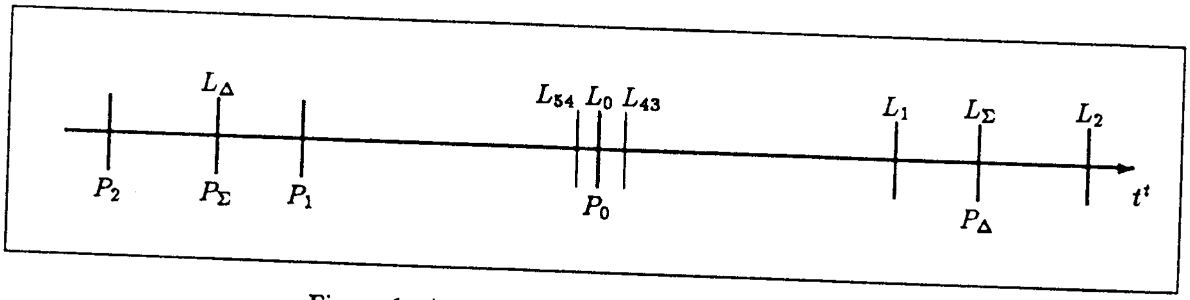

Figure 1: Apparent Signal Transmission Epochs

where σ_φ is the phase measurement noise in cycles of the original phases, which are assumed to be uncorrelated.

Linear combinations of code phases can be handled with the same formulas if the $L1, L2$ phases are first transformed to the frequencies of the corresponding carriers through

$$\bar{\Phi}_1 = f_1 \frac{\Phi_{B_1}}{f_{B_1}} \tag{27}$$

$$\bar{\Phi}_2 = f_2 \frac{\Phi_{B_2}}{f_{B_2}} . \tag{28}$$

Since code phases are delayed through the ionosphere by the same amount as carrier phases are advanced (first order effect) only the sign on the right side of equation (25) has to be changed.

All signals received at the same epoch at the receiver were transmitted at different epochs at the satellite due to the dispersive ionospheric effect. The apparent transmission epochs of some linear combinations are shown in figure 1. The carrier phase epochs are denoted with L and the code epochs with P.

Table 1 summarizes the characteristic values for the linear combinations. The column denoted λ contains the wavelength for receivers which are capable of tracking carrier phases with full cycle ambiguities. The column $\lambda_{1/2}$ is the respective wavelength for receivers with half cycle ambiguities on L2. V_I is the ionospheric amplification factor as defined in equation (25) and the measurement noise of pseudoranges is given for a phase noise of $0.1rad$ in the original observations.

The most important signals are the "wide lane" L_Δ and the "narrow lane" L_Σ. The amount of the ionospheric delay is the same for both signals but the signs are opposite. The wide lane has the largest wavelength and the narrow lane the smallest noise level. Of special interest are also the signals L_{43} and L_{54} since the ionospheric effect is quite small, so they may be used instead of the ionospheric corrected signal L_0. An advantage of L_{54} is the fact that the wavelenght remains the same if there are half cycle ambiguities on L2.

The ionospheric corrected signal L_0 can be obtained from the wide and narrow lane through

$$O_{L_0} = \frac{O_{L_\Sigma} + O_{L_\Delta}}{2} \tag{29}$$

and the ionospheric signal L_I is defined as

$$O_{L_I} = O_{L_\Sigma} - O_{L_\Delta} , \tag{30}$$

where O can be a signal transmission epoch, a propagation time or pseudorange.

The ambiguity biases in pseudoranges or pseudorange differences computed from these signals are

$$\bar{N}_0 = \frac{N_\Sigma \lambda_\Sigma + N_\Delta \lambda_\Delta}{2} \tag{31}$$

$$\bar{N}_I = N_\Sigma \lambda_\Sigma - N_\Delta \lambda_\Delta , \tag{32}$$

Signal	n	m	λ	$\lambda_{1/2}$	V_I	$\sigma_{0.1rad}$
Carrier	[–]	[–]	[cm]	[cm]	[–]	[mm]
L_1	1	0	19.0	19.0	0.779	3.0
L_2	0	1	24.4	12.2	1.283	3.9
L_Δ	1	-1	86.2	43.1	-1.000	19.4
L_Σ	1	1	10.7	5.4	1.000	2.4
L_{43}	4	-3	11.4	5.7	0.070	9.1
L_{54}	5	-4	10.1	10.1	-0.055	10.3
L_0	-	-	≈ 5.4	≈ 2.7	0.000	10.0
L_I	-	-	≈ 10.7	≈ 5.4	2.000	20.0
P-Code	[–]	[–]	-	-	[–]	[m]
P_1	1	0			-0.779	0.47
P_2	0	1			-1.283	0.47
P_Δ	1	-1			1.000	2.68
P_Σ	1	1			-1.000	0.33

Table 1: Linear Combinations of GPS Signals

or if the wide lane wavelength is expressed as

$$\lambda_\Delta = 8\lambda_\Sigma + 0.059\lambda_\Sigma \, , \tag{33}$$

and the wide lane ambiguity is assumed to be small ($N_\Delta \leq 3$)

$$\bar{N}_0 \approx N_0 \frac{\lambda_\Sigma}{2} = (N_\Sigma + 8N_\Delta)\frac{\lambda_\Sigma}{2} \tag{34}$$

$$\bar{N}_I \approx N_I \lambda_\Sigma = (N_\Sigma - 8N_\Delta)\lambda_\Sigma \, . \tag{35}$$

Under normal circumstances the wide lane ambiguity can easily be computed with an accuracy of ± 2 cycles. In this case the maximum approximation errors in (34) and (35) are ± 0.118 cycles of the respective wavelengths, which justifies the treatment of both signals as a function of the given wavelengths and with integer ambiguities.

The hardware delays of satellites and receivers have been neglected in this chapter in order to keep the relations clear. They can easily be introduced by computing the linear combinations of the original delays in $L1$ and $L2$.

4 Ambiguity Estimation

Several methods to solve the ambiguity problem are implemented in GEONAP. Ambiguities for different linear combination may be resolved using

- code phase measurements,
- geometric conditions or

- ionospheric conditions.

The wide lane ambiguity can easily be derived from the difference of the signals L_Δ and P_Σ. Only the hardware delays of satellites and receivers have to be modelled, since all other effects, except multipath errors, drop out in this difference. With the TI 4100 P-code measurements more than 90 % of the ambiguities can be solved within observation times of less than 5 minutes. A similar method may also be applicable for some C/A code receivers of the new generation, which are able to measure code phases with a very low meaurement noise.

The usage of geometric conditions is the standard approach to resolve ambiguities. With this method the ambiguities can only be estimated together with all other unknowns which appear in the pseudorange observation equation (12), this means also that all error sources will have some influence. In order to get values near integers the mean effect of unmodelled errors has to be small and the geometry has to be strong enough, which normally means that the observation times have to be long enough.

Any difference between the linear combinations of carrier phases is only a function of the ionosphere and the satellite and receiver hardware delays. If the ambiguity of one signal is known, all the others can be computed if the effect of the ionosphere is known or can be modelled with sufficient accuracy. In case of the ionospheric signal L_I only an approximate knowledge of the wide lane ambiguity is required.

With GEONAP the ambiguity resolution is done using the described methods. Each time an ambiguity is resolved for a specific linear combination the effective wavelength of the other linear combinations may change. Table 2 shows the factors to be applied to the original wavelength of a signal under the condition that the ambiguity of another linear combination is solved.

ambiguous Signal ⇒ / ⇓ unambiguous Signal	L_1	L_2	L_Δ	L_Σ	L_{54}	L_{43}	L_I	L_0
L_1	-	1	1	1	4	3	9	7
L_2	1	-	1	1	5	4	7	9
L_Δ	1	1	-	2	1	1	2	2
L_Σ	1	1	2	-	9	7	16	16
L_{54}	4	5	1	9	-	1	17	1
L_{43}	3	4	1	7	1	-	15	1
L_I	9	7	2	16	17	15	-	32
L_0	7	9	2	16	1	1	32	-

Table 2: Effective Wavelenghtfactor

The table has to be read in the following way. If, for instance, the L_1 ambiguity is known and the observations are corrected with this value, the effective wavelength of L_2, L_Δ and L_Σ remain the same but the ambiguity of L_{54} can only take values which are a multiple of 4 since

$$N_{54} = 5N_1 - 4N_2 \; ; \; N_1 = 0 \implies N_{54} = -4N_2 \,, \tag{36}$$

this means that the effective wavelength of L_{54} increases by the factor 4.

One very interesting case is found if the wide lane ambiguity is solved with an accuracy of ±1. In this case the maximum error in equation (35) is 0.059 cycles of the narrow lane or ionospheric signal wavelength. If in a next step the ambiguity of the ionospheric signal can be fixed the effective wavelength of the wide lane increases by the factor of 2 to 1.724m. The wavelength of the remaining signals increases to almost the same value. This method was introduced as the "extra wide laning" technique by the author in 1988 (*Wübbena 1988*). It can be used very effective in small sized networks, where the simple model of vanishing ionospheric delays in single difference observables can easily be used to fix the ambiguities in the ionospheric signals. The ambiguity of the extra wide lane may then be solved with relatively short observation times compared to standard approaches.

The occurence of signals with different wavelengths is another reason for the selection of non-differenced observables, since a differenced observable contains integer ambiguities only if the wavelengths of the original signals are identical or reduced to the smallest common multiplier. In the last case a loss of information has to be accepted. Different wavelengths are already present in the observations if full and half cycle ambiguity receivers are combined.

5 Parameter Estimation

The parameter estimation method of GEONAP is a combination of the least squares method with the Gauß-Marcov model and the Kalman filter. Theoretically the least squares Gauß-Marcov estimator is just a special case of the Kalman filter, however the algorithms of both are normally different. The least squares estimation is generally done through the computation and inversion of normal equations instead of working with the parameter or state vector and the corresponding covariance matrix as in the case of the Kalman filter. The computation of normal equations is often faster than the updating of the state vector and covariance matrix, especially if the majority of the parameters are static, which is normally the case in the GPS adjustment. For this reason GEONAP works with normal equations, however the algorithm is expanded in order to be able to introduce stochastic parameters which follow dynamical models.

The following is a brief description of the parameters which may be estimated with GEONAP. It should be noted that in normal data processing only a subset of the mentioned parameters are estimated.

Receiver coordinates are estimated for all stations, i.e. no coordinates are fixed. This is done since there is no observation equation where the coordinates of one station drop out. The introduction of a fixed station, as often done in double differencing softwares, is only correct if these coordinates are really known. This is seldom the case. Although the effect of errors in the fixed coordinates may be small, the covariance information of absolute and relative coordinates should be present in the results. For longer interstation distances even a double difference observable is able to estimate absolute coordinates with reasonable accuracies.

Satellite and receiver clock errors can be modelled with a second degree polynomial plus a complete stochastic model consisting of up to 4 parameters describing all the characteristic error sources of atomic and high quality crystal clocks. In the normal operation mode clocks are modelled with one parameter which is treated as white noise, this has the effect of implicitly eliminating clock errors as in a double difference model. The use of the full clock model introduces additional information into the adjustment. This is especially useful in combination with orbit improvements and if some receivers are operated with high quality cesium standards or hydrogene masers. In this case the clock information helps to separate orbital parameters of different satellites. If the observations of different receiver types with different observation epochs shall be adjusted simultaneously a complete modeling of the satellite clocks seems to be the only general and practicable way. Alternative approaches which try to synchronize measurement epochs through normal points or polynomial interpolation algorithms may work if high measurement rates are used, however the stochastics of the interpolated measurements should be analyzed carefully.

Hardware delays of satellites and receivers can be modelled with second degree polynomials plus one stochastic parameter. The last one can be a white noise, integrated white noise or Marcov process parameter. As with the clock errors the white noise model acts as an implicit elimination of the delay if the variance is chosen high enough.

An orbit improvement can be done with GEONAP with a short arc model. Up to 6 Keplerian parameters can be estimated for arcs of a few hours length.

Residual tropospheric refraction errors can be estimated with one scale parameter for each observed station. The parameter can be estimated as a constant or Marcov process parameter.

The electron content of the ionosphere can be estimated in different ways. One implementation solves for improved parameters of the Klobuchar model, another estimates arbitrary polynomials in a coordinate space defined by latitude and local time. The parameters of both models may be introduced as a function of time. This can either be done through polynomials in time or through stochastic models. Both models assume a single layer ionosphere. The mapping function of the vertical electron content into a slant electron content is one critical factor in such a model, so it may be improved by estimating a mapping function parameter. Further a stochastic model is implemented with one Marcov process parameter for each station-satellite pair. Correlations of these parameters can be introduced as a function of ionospheric subpoint distances.

The implementation of ionospheric models is mainly done for ambiguity estimation purposes and not for the estimation of refraction corrections for single frequency receivers, since in the latter case the accuracy requirements are much higher than in the former one. It should be noted that an ionospheric modeling is quite difficult. A careless use can lead to incorrect results. However, the method could successfully be used to resolve ionospheric signal ambiguities for interstation distance of several hundreds of kilometers.

One parameter is introduced for each non-resolved ambiguity and for each unrecovered cycle slip. GEONAP maintains a complete bookkeeping of ambiguities and cycle slips. Single ambiguities or linear combinations of ambiguities are fixed to integers if they pass a statistical test. The fixing is done by introducing an "observation" of the integer with an infinite weight.

The adjustment of observations is normally done session by session. A network adjustment combines the session solutions to a complete network solution. In case of remaining ambiguities the network solution may be resubstituted into the session solution in order to solve for more ambiguities.

External observations like terrestrial range measurements or fiducial point coordinates may be introduced into the adjustment. This may strengthen the ambiguity resolution or may define a reference datum.

6 Examples

Because of the limited space no examples can be given at this point. Some results of GEONAP processing can be found in papers presented at this symposium. Static positioning results are found in *Campos et.al., 1989* and kinematic positioning experiments are presented in *Seeber and Wübbena, 1989.*

7 References

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