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por

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ABSTRACT

This paper is a description of a program named NSV for tidal data processing. Despite the considerable volume of the paper, it deals only with the most important elements of NSV, including its practical use. It is not possible to describe everything, even all algorithms, used in a program of several thousands statements, having a lot of different options and applications.

In the acronym NSV, SV is simply the name of an old program, while N means "New". The "New" itself means that we use an old algorithm, which has proven its validity, but through a new program, which has a lot of new elements. It is also related with the necessity a scientific program to be steadily improved, which we are namely doing with NSV.

The paper has two parts. In Part I more attention is given to the theory of NSV. People, more interested in the applications, may go directly to Part II, which deals with the practical use of NSV.

I. Basic algorithm of NSV.

I.1. General remarks about the method of analysis used by NSV.

The main function of NSV is tidal analysis by a method which will be referred as MV66. Its original version can be found in (Venedikov, 1966a,b, Melchior & Venedikov, 1968, Melchior, 1978, 1981). In NSV are also used ideas and algorithms for various kinds of processing of Venedikov (1979, 1981, 1984, 1986), Venedikov & Ducarme (1979), Simon et al. (1989), Toro et al. (1990, 1991, 1993a), Fernandez et al. (1993) as well as suggestions made by Baker (1978a,b), Meyer (1980) and others.

MV66 is applied since a lot of time, successfully surviving a tremendous development of the computers, a considerable increase of the observation precision, as well as the appearance of more and more sophisticated tasks. This makes necessary to refresh the information about this method. Therefore we shall give the main principles of MV66 in some of the next Sections. We shall try to do this in a way which can be better understood than before.

However, NSV is not an application of a standard MV66. For example, in MV66 are given numerically fixed filters, while NSV is building up the filters at every application, and this can be done in many different ways. Actually, NSV is a sophisticated computational device through which, we hope, the processing can become an interesting research work in two directions:

(i) the user can apply MV66 in many variants, actually creating and testing different methods of analysis and

(ii) he can use various options which allow to study the data,

looking for perturbations and particular phenomena.

Of course, despite the statement (i) above, the user cannot escape from the fundamental scheme of MV66, whose elements are:

(a) model of the tidal signal which involves the grouping of the tides and the use of new (at the time) unknowns (Venedikov, 1961, 1966a) directly related with the unknown tidal parameters,

(b) filtration of intervals of length n , e.g. $n = 48$, without overlapping,

(c) processing of the filtered numbers by MLS (the Method of the Least Squares).

The model mentioned in (a) seems to be completely justified. It has been employed in most of the Earth tide methods of analysis, e.g. in the methods of Chojnicki (1973), Schüller (1977) and ETERNA of Wenzel (1994a,b), as well as in Tamura et al. (1991), Ishiguro et al. (1983).

It can easily be shown that our model is equivalent to the model of the ocean tidal phenomena of Munk and Cartwright (1966), discussed also by Meyer (1982). Hence, any good program for Earth tide data analysis, using our model, including NSV, can be applied on ocean tidal data.

The computational scheme (b) and (c) is more controversial. The matter is that it can be conceived as a sampling of the data over a step of $n = 48$ hours. Such a sampling is of course illegal. It would be absolutely funny to expect to find waves of frequencies concentrated around 1 and 2 cpd (cycle per day) using data with a step 2 days.

The elementary proof that (b) and (c) are not a simple sampling is that MV66 has provided a huge amount of useful results and we do not know about any failure. Another one is that all other reasonable methods provide results very close to those of MV66. In this sense, although these methods have been created as negations of MV66, all of them are in favor of MV66.

In relation with this problem, the flexibility of NSV, about which is said in (i) and (ii) can be useful. Unlike the original version of MV66, NSV allows to use various filters. Thus the length of the filters $n = 48$ can be replaced by any even number of the same order, e.g. $n = 36, 40, 42, 50, \dots$. It is also possible to use a shift $s \neq n$. Although $s < n$ is theoretically unacceptable, it is experimentally interesting to use such values. Even $s = 1$ is available, which is totally transforming our way of filtration into a moving filtration, similar to Chojnicki and ETERNA.

Other examples of flexibility is that one can change and test the grouping of the tides, the model of the drift, to determine the LP tides in many variants, to look for relations with non-tidal data and so on.

It is also interesting that through NSV can be computed residuals, drift, amplitude and phase variations and search for new tidal and non-tidal frequencies in different variants.

1.2. General model of the tidal data and model of the tidal signal.

Let $y(t)$, $t = 1, 2, 3, \dots$ are hourly tidal data or observations, t being the time in hours. Almost all large records have gaps. Therefore the sequence $t = 1, 2, 3, \dots$ should be understood as having jumps at the time of the gaps.

We would like to recall that one of the merit of MV66 is that it takes the data such as they are, with gaps and arbitrary length, rejecting any production of artificial data through interpolation. In such a way we have followed the principle to adjust the algorithm to the

data and not the data to the algorithm.

In principle, an analysis of $y(t)$ through the Method of the Least Squares (here and further MLS) consists in the following.

We have first to create a model $M(t; x_1, x_2, \dots, x_m)$ of $y(t)$, which is a function of t and some unknown parameters x_1, x_2, \dots, x_m . Then writing

$$(1) \quad y(t) = M(t; x_1, x_2, \dots, x_m), \quad t = 1, 2, \dots$$

we get a system of equations of number equal to the number of the data, in unknowns x_1, \dots, x_m . Finally, the system (1) is solved by the MLS. The use of MLS allows to get results with known optimum qualities and, which is very important, though sometimes neglected, with a well defined estimation of the precision.

Generally, (1) has the expression

$$(2) \quad y(t) = \underbrace{w_t}_{\text{tidal signal}} + \underbrace{d_t}_{\text{drift}} + \underbrace{a_t}_{\text{perturbations due to some phenomena}} + \underbrace{\varepsilon_t}_{\text{noise}}$$

where w_t is the most interesting component and can be called the useful signal in the data $y(t)$.

The remaining terms, with respect to w_t , can be considered as noise, having both random and deterministic components. However, for some purposes, The second component d_t can also be considered as useful signal, which has to be well estimated and studied.

The third component a_t can be due to different meteorological phenomena, among which the air-pressure seems to be the most important. Within this Part I it will be ignored. However, in Part II we shall briefly consider the model of a_t used by NSV.

The last term ε_t is random component. We know that it is correlated, i.e. ε_t is not a WN (white noise). One of the reason for the correlation is that we are not able to create good enough models for d_t and a_t , thus charging ε_t by the errors of these models. In the same time we do not dispose by any good estimation of the autocorrelation function or the covariance matrix of ε_t . This in principle does not allow us to apply rigorously MLS directly on the hourly data $y(t)$.

It is very natural to begin here with the model of w_t .

In any case w_t is generated by a theoretical signal like

$$(3) \quad W_t = \sum_{\omega} H_{\omega} \cos(\phi_{\omega} + \omega t)$$

where ω takes a set of *known* discrete values

$$\omega = \omega_1, \omega_2, \omega_3 \dots$$

H_{ω} is *known* theoretical amplitude and

ϕ_{ω} is *known* theoretical phase at $t = 0$.

In Figure 1.a and 1.c is represented how looks the amplitude spectrum (H_{ω} as a function of ω) of W_t in the main D and SD domains of ω . Each line of this spectrum is corresponding to a term in (3), i.e. to a tidal wave or tide of frequency ω (here and further under frequency we understand angular frequency or velocity).

If W_t is represented by (3), the generated or observed signal w_t is

$$(4) \quad w_t = \sum_{\omega} \delta_{\omega} H_{\omega} \cos(\phi_{\omega} + \omega t + \kappa_{\omega}) = \sum_{\omega} h_{\omega} \cos(\varphi_{\omega} + \omega t)$$

where:

δ_{ω} is *unknown* observed amplitude factor,

κ_{ω} is *unknown* observed phase shift with respect to ϕ_{ω} ,

$h_{\omega} = \delta_{\omega} H_{\omega}$ is *unknown* observed amplitude and

$\varphi_{\omega} = \phi_{\omega} + \kappa_{\omega}$ is *unknown* observed phase.

For the Earth tide data this expression has theoretical and empirical basis, supported by an abundant experience. More generally, including the case of ocean data, W_t can be considered (Munk et al., 1966), as an input to a system (Earth and ocean) with output w_t . Provided the system is linear, the output can be represented through (4). In this sense (4) as well as the model of w_t here considered can be used for both Earth and ocean tidal data. We have already a lot of experience in the application of our programs on ocean data (Carvajal, 1993).

The tidal part in (2) becomes very simple if (4) is represented as

$$(5) \quad w_t = \sum_{\omega} (u_{\omega} \cos \omega t + v_{\omega} \sin \omega t)$$

$$u_{\omega} = h_{\omega} \cos \varphi_{\omega}, \quad v_{\omega} = -h_{\omega} \sin \varphi_{\omega}$$

which is linear with respect to the unknowns u_{ω} and v_{ω} . However, a serious complication is that we have too many ω , some of which differ very little, i.e. the components of (5) are linearly dependent. E.g., in the development of Tamura are 1200 waves, i.e. 2400 unknowns and still more in (Xi Quinwen) and other new developments.

A solution of the problem is suggested through our model (Venedikov, 1961, 1966a).

The idea is to realize that the actual physical unknowns are not the amplitudes and the phases, h_{ω} and φ_{ω} , but the parameters δ_{ω} and κ_{ω} .

These parameters define completely the output (4), i.e. they carry the total information about the phenomena.

There are theoretical and empirical evidences that δ_ω and κ_ω do not vary very fast with ω . Hence, the actual number of different unknown quantities is not the huge number of h_ω and φ_ω , but much lower.

This idea is applied in the following way.

As shown in Figures 1.a,c, there is a concentration of the energy in some bands or grouping of the tides around a small number of frequencies of some more important tides. These bands or groups can be defined through frequency intervals, say $\Omega_1, \Omega_2, \dots, \Omega_\mu$. In Figures 1.a,c a variant of such intervals are demonstrated. Each Ω_j there has a name which is the symbol of Darwin of the most important tide in the corresponding interval.

As far as Ω_j are narrow, we may suppose $\delta_\omega = \text{const.}$ and $\kappa_\omega = \text{const.}$ for $\omega \in \Omega_j$. Then, in order to get linear expressions, we define the unknowns

$$(6) \quad \left. \begin{array}{l} \xi_j = \delta_\omega \cos \kappa_\omega = \text{const.} \\ \text{and} \\ \eta_j = -\delta_\omega \sin \kappa_\omega = \text{const.} \end{array} \right\} \text{for } \omega \in \Omega_j, \quad j = 1, 2, \dots, \mu$$

Using this, (5) is transformed in the following simple expression

$$(7) \quad w_t = \sum_{j=1}^{\mu} (c_{tj} \xi_j + s_{tj} \eta_j)$$

with coefficients at the unknowns

$$(8) \quad c_{tj} = \sum_{\omega \in \Omega_j} H_\omega \cos (\Phi_\omega + \omega t), \quad s_{tj} = \sum_{\omega \in \Omega_j} H_\omega \sin (\Phi_\omega + \omega t).$$

NSV is using a generalization of this model. Namely, given Ω_j is not obligatory an interval, but, more generally, it is a set of frequencies ω . This means that we can extract some tides from a group corresponding to an interval and let them shape separate groups.

An example are the waves which we shall call P3 whose origin is the tidal potential of 3d degree. These are small waves whose spectrum is shown in Figures 1.b,d. The inconvenience of their existence is that if these waves remain in one and the same Ω_j with other waves, the condition (6) is theoretically false.

An option of NSV is to take apart the P3 and let them create groups like those in Figures 1.b,d. Somewhat surprisingly, it appeared possible to separate such groups, i.e. to determine the corresponding parameters δ and κ , although they are overlapping other D and SD groups.

The practical use of NSV will be discussed in Part II.

Nevertheless, it may be interesting how simply this option of NSV is used.

At the first stage of work of NSV it sets a series of questions. One of them is

2.6. (SEPP3) SEPARATE THE TIDES OF DEGREE 3 ? y

If the answer is "y" (yes) as above, the P3 are determined separately. If the answer is negative, the P3 are let in their natural groups. Then NSV is applying a theoretical modulation of the amplitudes of P3. When 2.6. (SEPP3) is accepted this modulation is excluded.

Following this definition of Ω_j , NSV allows to pick up some other tides, e.g. given meteorological tide like S1, S2,...

I.3. Model of the drift.

Due to the model discussed in Section I.2, we dare say that the most interesting component, the useful tidal signal w_t , is the least problem of the tidal data processing. Much more serious problems create the remaining components in (2), especially the drift d_t .

In the following $I_i = I(T_i)$ will denote an interval of the data with central epoch T_i and I -s will mean a set of I_i .

A natural solution of the drift problem, which seems (but only seems) to be good, is that of (Horn, 1959): d_t is represented, over a single I_i of length 732^h , as a polynomial of t . Wenzel (1976a) has suggested the drift to be approximated in I -s, named blocks, which may be defined by the gaps in the data, i.e. also in large I -s. However, there are not evidences that such approximations can be successful.

Our attempts to approximate d_t in large I -s, have shown that such approximations are not successful, even using polynomials of very high powers. The matter is that the approximation of d_t in an I_i by a polynomial of power k implies the supposition that d_t has not continuous derivatives of the same order. Since d_t is very often changing its behaviour, this supposition is not justified for large I -s.

In Figure 2 is shown an attempt to approximate the drift in a large interval by a polynomial, using the analysis method (Toro et al., 1993b). The power $k = 17$ is not arbitrarily selected. It is chosen using the AIC criterion of Akaike (Sakamoto et al., 1986). We get residuals which are obviously not satisfying.

In Figure 3 is given the approximation of the drift in the same data, but in separate I -s of length 48^h , through the option RESAN of NSV. The residuals now are incomparably better than in Figure 2.

In this relation NSV is applying an approximation of d_t in short I -s in the following way.

The whole record is partitioned in I -s of equal length n , say $n = 48$. In principle, the I -s are without overlapping, i.e. the shift between I_i and I_{i+1} is $s = n$ or, if there is a gap, $s > n$. Optionally,

for experimental purposes, one can use $s > n$ (without gaps) or $s < n$, i.e. intervals with overlapping.

The default value of n is $n = 48$, which has been most frequently used in the applications of MV66. As said above, NSV can use other values of n . Nevertheless, we shall sometime use the number 48, as if it a fixed one, but it should be understood that optionally we can use other values.

Within every I_i is used a time τ measured from T_i , i.e.

$$(9) \quad \tau = t - T_i = -\nu, -\nu + 1, \dots, \nu, \nu = (n - 1)/2,$$

e.g.

$$\tau = -23.5, -22.5, \dots, +23.5 \text{ for } n = 48.$$

The model of d_t in I_i is accepted to be

$$(10) \quad d_t = \zeta_{i0} + \zeta_{i1}(\tau/\nu) + \dots + \zeta_{ik}(\tau/\nu)^k, \tau = t - T_i, T_i - \nu \leq t \leq T_i + \nu$$

where, it is very essential, ζ_{il} , $l = 0, 1, \dots, k$ are unknowns specific for given I_i . This is indicated by the subscript i of ζ_{il} .

Between the models of d_t in the neighboring I_i and I_{i+1} are not imposed any conditions, although theoretically we should have equal values at time $T_i + n/2$ and $T_{i+1} - n/2 = T_i + n/2$ (if there is not a gap). Our explanations are (i) we do not use d_t at just $T_i + n/2$, because $\nu = n - 0.5$ and (ii) the lack of conditions allows arbitrary discontinuities between I_i and I_{i+1} . If there are important discontinuities within given I_i , they do not affect the global approximation of d_t in the other I -s. If the situation in given I_i is too bad, NSV allows to distinguish this and eliminate such an I_i .

In connection with this model and our partition into I -s it is convenient to use some vectors of size or dimension n .

Let $c(\tau)$ is a function of τ , e.g. $c(\tau) = \cos \omega\tau$. We shall denote by \mathbf{c} the vector column (calling it only vector) of the values of $c(\tau)$ in any I_i

$$(11) \quad \mathbf{c} = [c(\tau)] = [c(-\nu) \ c(-\nu + 1) \ \dots \ c(\nu)]^*$$

where $*$ denotes the transposition of a matrix.

In the case of $y(t) = y(T_i + \tau)$ and $d(t) = d(T_i + \tau)$ we shall use the vectors

$$(12) \quad \mathbf{y}_i = \mathbf{y}(T_i) = [y(T_i + \tau)]$$

$$\mathbf{d}_i = \mathbf{d}(T_i) = [d(T_i + \tau)]$$

whose elements are the values of $y(t)$ and $d(t)$ in given I_i . Here τ is taking the values (9) while T_i and the subscript i remain fixed, indicating the relation with given $I_i = I(T_i)$

Let, according to (11),

$$(13) \quad \mathbf{p}_i = [(\tau/\nu)^i]$$

Then the model (10) of the drift can be represented in the vector form

$$(14) \quad \mathbf{d}_i = \mathbf{d}(T_i) = \sum_{l=0}^k \zeta_{il} \mathbf{p}_l.$$

In NSV for intervals of $n \geq 48$ the default value of k is $k = 2$ and, if $n < 48$, $k = 1$. If LP (long period) waves are determined, using large I -s, e.g. $n = 360$, $k = 1$. If LP are determined in parallel with the D or SD waves, k is set to be $k = 0$.

Of course, k is optional and can be modified if the question:

3.1. (NFINT)NEW POWER k OF THE DRIFT POLYNOMIALS ?

gets an answer "y". Then the user is asked to enter the value of k .

At the end of this discussion of d_t we would like to point out that a very interesting model is suggested in (Tamura et al., 1991, Ishiguro et al., 1983).

I.4. The stage of filtration of NSV.

NSV is proceeding the determination of the main species D, SD,... together, at one and the same time, but in parallel, independently from each other. Thus in the first stage mentioned in (b), Section I.1, we apply different filters for every species. In this relation in the following we have in mind filtration and processing related with one of the species.

More concretely, the first stage consists in the application of one even and one odd filter. The filters can be considered as vectors, according to (11), namely

$$(15) \quad \mathbf{f} = [f_\tau], f_\tau = f_{-\tau} \text{ (even filter)}$$

$$\mathbf{g} = [g_\tau], g_\tau = -g_{-\tau} \text{ (odd filter), } \tau = -\nu, -\nu + 1, \dots, \nu.$$

where f_τ and g_τ are the coefficients of the filters.

The filtration consists in the computation of the filtered numbers

$$(16) \quad u(T_i) = \mathbf{f} * \mathbf{y}_i = \sum_{\tau=-\nu}^{\nu} f_\tau y(T_i + \tau),$$

$$v(T_i) = \mathbf{g} * \mathbf{y}_i = \sum_{\tau=-\nu}^{\nu} g_\tau y(T_i + \tau)$$

related with I_i . We have an application of \mathbf{f}, \mathbf{g} on the I -s. Thus the filters are applied with a shift $s \geq n$, unlike the usual moving filtration when a filter is applied with $s = 1$.

In the second stage of the analysis, the set of $u(T)$ and $v(T)$ are processed by MLS, instead of the hourly data $y(t)$. This is namely seeming to be a sampling with a step $n = T_{i+1} - T_i$. Therefore this procedure needs our explanations.

Let $y(t)$, $t = 1, 2, \dots, N$ are N data without gaps. If $y(t)$ can be submitted to a Fourier analysis, we have to compute, for given Fourier frequency $0^\circ < \omega < 180^\circ$,

$$(17) \quad x(\omega) = (2/N) \sum_{t=1}^N \text{Exp}(i\omega t) y(t) \quad (i^2 = -1).$$

Let $N = qn$ and the data are partitioned in our I -s I_i of length n . Just the same $x(\omega)$ can be computed in the following 2 stages.

(i) We compute the filtered numbers (16) using as filters

$$(18) \quad \mathbf{f} = [(2/n) \cos \omega \tau] \text{ and } \mathbf{g} = [(2/n) \sin \omega \tau]$$

which will be called FFIL (Fourier Filters).

(ii) then, using the filtered numbers (16), we compute

$$(19) \quad x(\omega) = (1/q) \sum_{i=1}^q \text{Exp}(i\omega T_i) [u(T_i) + iv(T_i)]$$

which is identical to $x(\omega)$ in (17).

Thus we have, rather similarly to NSV: stage (i) filtration of intervals I_i without overlapping, and stage (ii) processing of the filtered numbers which is a Fourier analysis of data with a step n hours.

If only (19) is considered, this would seem as an illegal analysis of a sampled data over a step n hours. On the contrary, if the nature of the filters is considered, we have a legal direct processing of hourly data.

By the way, the computations after (19) is much faster than (17), i.e. more computing time is not always necessary for getting better

results.

Let us denote

$$(20) \quad \mathbf{c}(\omega) = [\cos \omega\tau] \quad \text{and} \quad \mathbf{s}(\omega) = [\sin \omega\tau]$$

The response of the filters \mathbf{f}, \mathbf{g} to a frequency ω is

$$(21) \quad \rho_f(\omega) = \mathbf{f}^* \mathbf{c} \quad \text{and} \quad \rho_g(\omega) = \mathbf{g}^* \mathbf{s}.$$

If $\rho(\omega) = 0$, the corresponding ω (wave of frequency ω) is eliminated and, if $\rho(\omega) \cong 0$, ω is retained or reduced by a factor $\rho(\omega)$. Otherwise, ω is amplified by a factor $\rho(\omega)$.

If $\mathbf{f}^* \mathbf{p}_1 = \mathbf{g}^* \mathbf{p}_1 = 0$ for the vectors in (14), we have an elimination of the d_t in all I_i , as far as (14) is a good model of d_t .

Let $\mathbf{f} = \mathbf{f}_D$, and $\mathbf{g} = \mathbf{g}_D$ are created through (18) for $\omega = \omega_D = 15^\circ$ and $n = 48$, ω_D being one of the main D frequencies. Then we have

$$(22) \quad \rho_f(0) = \mathbf{f}_D^* \mathbf{p}_0 = \rho_g(0) = \mathbf{g}_D^* \mathbf{p}_0 = 0,$$

i.e. \mathbf{f}_D and \mathbf{g}_D eliminate a drift represented by a constant which can arbitrarily changing its values.

Further

$$(23) \quad \begin{aligned} \rho_f(15) &= \rho_g(15) = 1 \\ \rho_f(30) &= \rho_g(30) = 0 \\ \rho_f(45) &= \rho_g(45) = 0. \end{aligned}$$

Since all D tides have $\omega \cong 15^\circ$, SD tides - $\omega \cong 30^\circ$ and all TD tides - $\omega \cong 45^\circ$, we can say that the filters \mathbf{f}_D and \mathbf{g}_D amplify the D tides and eliminate or retain the SD and the TD species.

If we build up filters using once $\omega_{SD} = 30^\circ$, then $\omega_{TD} = 45^\circ$, which are also Fourier frequencies for $n = 48$, we shall get, together with \mathbf{f}_D and \mathbf{g}_D , 3 pairs of filters which, actually, separate the main tidal species, eliminating a model of the drift of very low power $k = 0$.

It appears that in the Fourier analysis we have a first stage consisting in application of filters which are tending to eliminate the drift (however, only as a constant in every I_i) and separate the main tidal species.

If there is a drift and the sophisticated tidal spectrum, we have to apply MLS instead of Fourier. In (Venedikov 1964b) is shown that the application of MLS directly on $y(t)$ has also the stage filtration of I_i .

We have also FFIL but they have to be orthogonalized with respect to the drift polynomials. I.e. we have filters which eliminate the drift with the least possible deviations from FFIL. From this stage we get $u(T)$, $v(T)$ which are further processed.

In (Venedikov, 1964a) and (Wenzel, 1976a,b, 1977, Chojnicki, 1978, Meyer, 1980) has been established that the hourly $y(t)$ are correlated

(non-WN or colored noise). On the contrary, for various reasons, one of them the distance n between our I_i , $u(T_i)$, $v(T_i)$ are not correlated or considerably less correlated than $y(t)$. Follows the natural idea the second stage to be made, as said in (c) in Section I.1, i.e. to process $u(T)$, $v(T)$ by MLS as observations instead of $y(t)$.

Again in (Venedikov, 1964b) is shown that in this way we shall get estimates of the unknowns very close to the direct processing of $y(t)$. In the same time we shall have a more correct application of MLS with a rigorous estimation of the precision. The latter will reflect the effect of the drift and meteorological perturbations, which are frequency dependent, i.e. different for the main tidal species.

I.5. Construction of the filters by NSV.

The main idea is to get the filters as operators, solving equations about the data $y(t)$ in one, whichever I_i , according to the MLS. This idea has been applied in (Venedikov, 1966b) and further developed in (Venedikov, 1984) and NSV.

It has been said that the expression (5) cannot be used because there are too many waves. However, if we remain within a given short I_i , with $n = 48$, (5) can approximate the tidal signal using a very small number of the most important waves. Taking into account this and the model (14), we may use the following equations in vector form

$$(24) \quad \sum_{\omega} [u_{\omega} c(\omega) + v_{\omega} s(\omega)] + \sum_{l=0}^k \zeta_{1l} p_l = y_i$$

for the data in anyone fixed I_i , where ω takes a limited number of values, e.g. $\omega = 15^\circ$, 30° and 45° .

The solution of (24), according to MLS, can be represented as

$$(25) \quad u_{\gamma}(T_i) = f_{\gamma} * y_i, \quad v_{\gamma}(T_i) = g_{\gamma} * y_i$$

where γ is one of the frequencies ω in (24) and f_{γ}, g_{γ} are vectors obtained through the orthogonalization of $c(\gamma)$ and $s(\gamma)$ respectively, with respect to all other vectors in (24). This means that f_{γ}, g_{γ} are filters which remain as close as possible to the FFIL, the deviations being imposed by the presence of the drift. Due to the orthogonal properties, f_{γ}, g_{γ} will amplify the corresponding $\omega = \gamma$ and eliminate all $\omega \neq \gamma$, as well as the model representing the drift.

Let first $\gamma = \omega_D$, then $\gamma = \omega_{SD}$ and, finally, $\gamma = \omega_{TD}$. If the subscript γ in (25) is replaced by 1, 2 and 3 corresponding to D, SD and TD, as well as to 1 cpd, 2cpd and 3 cpd, in the same way as above we shall get 3 pairs of filters f_j, g_j through which we shall get 3 sets of filtered numbers which can be used

$$(26) \quad \begin{aligned} u_1(T_i), v_1(T_i) &- \text{ for the determination of the D tides,} \\ u_2(T_i), v_2(T_i) &- \text{ for the determination of the SD tides,} \\ u_3(T_i), v_3(T_i) &- \text{ for the determination of the TD tides,} \end{aligned}$$

Obviously, all this can be expanded for the determinations of tides of higher frequencies like 4, 5 and 6 cpd.

Since the construction of the filters is related with the equations (24), we have to select the components, taking part there and, of course the number n which is the length of the I -s, as well as of the filters.

In NSV the default option is

$$(27) \quad \begin{aligned} n &= 48 \text{ as length of the filters and } I\text{-s,} \\ k &= 2 \text{ for the model of the drift} \\ S1, O1, S2, M2, S3, S4, S5, S6 &\text{ as tidal components.} \end{aligned}$$

The set of tides indicated here means that ω in (24) takes the values of the frequencies of these waves, i.e. $\omega = \omega(S1), \omega(O1), \dots, \omega(S6)$. Obviously to each tide or ω are corresponding two vectors $c(\omega), s(\omega)$. We shall denote the couple (c,s) corresponding to a tide by the symbol of the corresponding tide.

In order to get a good approximation and separation it may be necessary to deal with 2, even more than 2 tides of one and the same species, e.g. S1 and O1. Then (24) cannot be directly solved. Therefore NSV first makes an orthogonalization of such components, after which (24) is solved. E.g. if in (24) are included S1, O1, Q1 then O1 is made orthogonal to S1 and Q1 - orthogonal to both S1 and O1.

In NSV the filters are obtained in the following way, which is an ordinary application of MLS on the data of any I_i .

Let C is the matrix of all vectors taking part in (24). Then (24) can be represented as

$$(28) \quad Cx_i = y_i$$

where x_i is the vector of all unknowns in (24). It is essential, that C is one and the same for all I_i , while x_i is different, depending on y_i .

The MLS solution, under the assumption of WN, is given by the estimates

$$(29) \quad \tilde{x}_i = (C^*C)^{-1}C^*y_i.$$

If (27) is used, C is created by the following vectors or components

$$(30) \quad \begin{array}{cccccccccccc} C = [& p_0 & p_1 & p_2 & S1 & O1 & S2 & M2 & S3 & S4 & S5 & S6 &] \\ & & & & \downarrow & & \downarrow & & \downarrow & & \downarrow & & \downarrow \\ F = [& & & & f_1, g_1 & f_2, g_2 & f_3, g_3 & f_4, g_4 & f_5, g_5 & f_6, g_6 & & &] \end{array}$$

where each tide should be understood as the couple of the corresponding vectors $c(\omega)$ and $s(\omega)$. According to what was said above, here O1 and M2

are only components of O1 and M2, orthogonal to S1 and S2 respectively.

NSV, in relation with (29) creates the matrix $F = C(C^*C)^{-1}$. It is composed by vectors, corresponding to the vectors in C, some of them shown in (30).

Since $F^*C = I$ (identity matrix), every couple f, g in F are filters amplifying the corresponding tide and eliminating all other tides, together with the drift vectors p_1 . Thus f_1, g_1 will amplify S1, will eliminate all other tides (but only the orthogonal component of O1) and the drift model.

We obtain, through the MLS solution (29) and the matrix F the filters (f_1, g_1) , (f_2, g_2) and (f_3, g_3) which can be used to eliminate the drift and separate the tidal species. They can be used for the separate determination of the D, SD and TD tides respectively. In this relation we shall call these filters D, SD and TD filters.

Through (30) we also get filters f_j, g_j , $j > 3$, which can be used for the determination of the species of higher frequencies.

In the application of NSV all elements (24) of the filters can easily be changed. It is even possible to make them amplify and eliminate selected non-tidal frequencies.

In Figure 4 is shown that the default filters (27) of NSV do not considerably deviate from the FFIL.

Very important characteristic of a filter is the quantity which we shall call RSTN (signal-to-noise ratio), computed through

$$(31) \quad RSTN = (2/n)\text{Var}(y(t))/\text{Var}(h)$$

where h is a filtered signal of power 1, amplified by factor 1. The variances are computed theoretically, under the assumption of a WN.

If NSV is reasonably applied, we have

$$(32) \quad \begin{aligned} &\text{for the filters in NSV: } RSTN \cong 0.75, 0.80 \\ &\text{for the optimum Fourier filters: } RSTN = 1. \end{aligned}$$

We loose about 20-25% of precision and information which is the price of the elimination of the drift.

A high RSTN is of crucial importance. It is a guarantee that we remain close to the theoretically motivated scheme in (Venedikov 1964b) and the FFIL and that we can process the $u(T)$ and $v(T)$ instead of $y(t)$.

Therefore NSV cannot use high pass filters without a separation of the main species. Such filters have much lower RSTN than pass band filters like our filters. For example, the filter of Pertsev, applied as a high pass filter by Chojnicki and ETERNA, has a very low RSTN = 0.06. Due to this these methods are obliged to apply a moving filtration with a shift $s = n$.

It should be noted that this filter remains an excellent device for the estimation of the drift, as a low-pass filter. Then it is also a pass band filter with a very high RSTN = 0.81.

In Figure 5 is shown the response of some of the filters of NSV. Compared to FFIL, we have a better elimination of the low frequencies (the drift) and better separation of the main species. The FFIL eliminate the non-tidal frequencies 7.5, 22.5 and 37.5. Our filters do not eliminate them because there has never been evidences for particular power concentrated at these domains of the spectrum.

I.6. Processing of the filtered numbers.

The second stage of the analysis consists in applying the method of the least squares on the filtered numbers. This means that we have to create the observation equations for $u(T_i) = \mathbf{f}^* \mathbf{y}_i$ and $v(T_i) = \mathbf{g}^* \mathbf{y}_i$ where \mathbf{f}, \mathbf{g} is one of the pairs of filters in (30), i.e. in $\mathbf{F} = \mathbf{C}(\mathbf{C}^* \mathbf{C})^{-1}$.

These filters eliminate (more or less well) the drift. Therefore, in creating the equations we have to take into account only the tidal component. We have to use the model considered in Section I.2, namely (6), (7) and (8). Obviously, we have to take into account the effect of the filters which an amplification of the tides by the factor (21). Also \mathbf{g} is changing all phases by $\pi/2$, while \mathbf{f} keeps the phases the same.

Having in mind all this we get, the observation equations

$$(33) \sum_{j=1}^{\mu} [c_{jf}(T_i) \xi_j + s_{jf}(T_i) \eta_j] = u(T_i)$$

$$\sum_{j=1}^{\mu} [-s_{jg}(T_i) \xi_j + c_{jg}(T_i) \eta_j] = v(T_i), i = 1, 2, \dots, N$$

where N is the number of the I -s and the coefficients at the unknowns ξ and η are

$$(34) \quad c_{jl}(T) = \sum_{\omega \in \Omega_j} \rho_l(\omega) h_{\omega} \cos(\varphi_{\omega} + \omega T),$$

$$s_{jl}(T) = \sum_{\omega \in \Omega_j} \rho_l(\omega) h_{\omega} \sin(\varphi_{\omega} + \omega T),$$

where $l = f$ or g corresponding to the filters \mathbf{f} and \mathbf{g} ,

$\rho_f(\omega)$ is response of the even filter \mathbf{f} ,

$\rho_g(\omega)$ is response of the odd filter \mathbf{g} .

Since ω is multiplied by T and the shift between the intervals is $s = n$ (if there are not gaps), it seems that ω can be considered as $s\omega$, e.g. 48ω , with heavy aliasing problems. Actually, the coefficients remain functions of the initial ω through $\rho(\omega)$ and they can easily be solved. All suspected aliases are either eliminated through low $\rho(\omega)$ or they can be taken into account in the equations, if it is necessary.

After the equations (33) are created, it is a well known MLS procedure to solve them, to obtain the estimates of the unknowns ξ and η , then δ and κ , accompanied, of course, by estimates of their variances, i.e. of the precision. For the experimentation of different variant of the analysis, e.g. using different grouping of the tides, NSV provides the criterion of AIC of Akaike (Sakamoto, et al., 1986). The use of AIC is very simple: among several variants, the best one is the variant with the lowest AIC.

We recall that (33) are equations for one of the tidal species. We have such equations created for all species we want to determine, which

are solved in parallel, but independently. This allows to get estimates of the variances different for every species.

Generally, the estimation of the precision through the filtered numbers, which is thus frequency dependant, is one of the most important features of NSV.

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Generally, the estimation of the precision through the filtered numbers, which is thus frequency dependant, is one of the most important features of NSV.

II. Application of the program NSV.

NSV has been developed using the ALPHA computer of the Computing Center of the University Complutense of Madrid. Available are the source routines which have to be compiled and linked. If another computer is used, small modifications are necessary, at least the subroutines for the date and time determination should be replaced.

Also available is a PC version of the program which can be directly used on PC of type 486 and 586. Available is a package with the .EXE of NSV, accompanied by some permanent data files, necessary for the execution, as well as by a small data bank, prepared for processing, according to the formats used by NSV.

The execution is made using the command "NS". NSV needs a series of files accompanying the program and, of course, some tidal data files.

II.1 Data files.

A data file is composed by hourly ordinates or observations. It can be organized in the well known and widely used, in the Earth tidal domain, international format, like Example 1

Example 1. A data file.

<u>date DT</u>	<u>12 consecutive ordinates</u>											
YYMMDDH	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
[13]8710162	2006	4134	5738	6625	6738	6173	5157	3984	2938	2216	1913	1970
[13]8710170	2193	2294	2027	1243	-63	-728	-1213	-3780	-5435	-5146	-3899	-1846
[13]8710172	592	3034	5003	6156	6353	5660	4333	2757	1341	432	210	666
[13] 0	(a blank line or line with YY = 0 means a gap)											
[13]8710202	362	2642	5026	6854	7502	6834	4854	2028	-1033	-3640	-5206	-5346
											

Here [13] are 13 columns which are not used by NSV so that in [13] can be written any 13 symbols, e.g. 13 blanks.

In Example 1 is shown how a gap is indicated. Notice:

(i) One zero or blank line is enough to indicate a gap of any length. Several blank lines have the same effect.

(ii) If there is not a gap but a jump between two lines which is not corrected, it should be indicated as a gap between these lines, although there is not a gap.

In this format 5 columns or digits are reserved for one ordinate. NSV allows to use larger numbers of columns, namely 6, 7, 8 or 9 columns per ordinate. The number of the columns is defined by the input number NCOL, as shown in Section II.3.

The ordinates should be integer numbers. Whatever are the data, the unit of an ordinate should be 0.1 of the usual unit, e.g. 0.1 μ gal. Whatever unit is used, the amplitudes provided by the analysis are in unit 10 times greater, e.g. data in 0.1 mbars - amplitudes in mbars. However, one should take care the δ factors to be of the order of 1.

The effect of the units can be controlled using a multiplying constant SCALE (see Section II.3) as well as a multiplying constant (Sections II.2,4). If the unit is 0.1, as said above, SCALE = 0.1. If, unit 0.001 is used, SCALE = 0.001. For unit 1, SCALE = 1, etc.

II.2. Control file (CFILE).

Every data file should be accompanied by a control file (CFILE). It is convenient but not necessary both files to have one and the same name, but different extensions, e.g. BRU3M.DAT with a CFILE BRU3M.TIT.

A CFILE can have the form exactly the same as the CFILES used in ICET and the program of Ducarme (1975). It is, however recommendable, to use CFILE in the particular form of NSV which is more comprehensive and flexible, and is allowing to give more information. NSV is automatically able to distinguish which form is used.

Example 2. A control file (CFILE)

```
!NAME_STATION      3      (follow 3 lines with name of the station)
STATION 0201 BRUXELLES-UCCLE      COMPOSANTE VERTICALE      BELGIQUE
 50 47 55 N      04 21 29 E      H 101 M
GRAVIMETRE A SUPRACONDUCTIVITE GWR T3
!COMPONENT          Gravimeter
!LONGITUDE_WEST_DEGREES      -4.3581
!LATITUDE_NORTH_DEGREES      50.7986
!ALTITUDE_KILOM.            0.100
!GRAVITY_GALS              981.0
*!AZIMUTH_FROM_N_CLOCKWISE    0.0
!MULTIPLYING_CONSTANT        0.9907
!TIME_CORRECTION_SECONDS      -30 seconds, negative = retardation.
!NO_INERT._CORRECTION_PARIISKII
!END
```

A CFILE consists, as shown in Example 2, of some control words (CW) which have a "!" in the first column. In many cases, CW is followed by a corresponding information, distant from the CW by at least one blank. A CW can be abbreviated by the first letters, at least the first 3, e.g. !COMP instead of !COMPONENT.

The !NAME, !COMP, !LONG and !LAT are obligatory, while all other CW are optional. With the exception of !NAME, which is at the first place, the CW can be given in any order. Letters upper or lower case can be used. One can add any number of rows with comments, which should not begin by an ! in column 1. Thus *!AZIMUTH in Example 2 is like a comment. Comments can be written before or after the numerical data but separated by at least one blank, like (follow 3 lines with...). The last CW should be !END.

The CFILE in Example 3, with the exception of the shorter name, is equivalent to the CFILE in Example 2.

Example 3. CFILE equivalent to Example 1 (without !NAME).

```
!Name      1      (follows only 1 line)
STATION 0201 BRUXELLES-UCCLE  COMPOSANTE VERTICALE  BELGIQUE
           data, rearranged in comparison with Example 1:
!Lat       50.7986  degress, north
!Long      -4.3581  degress, positive to the West
!altitude  0.100   kilometers
!Grav      approximately  981.0  gals
!COMPONENT Grav  here only the first letter G is important
*!AZIMUTH  for gravity data is not necessary
!Mult      0.9907
!TIME      corr.    -30  seconds, negative = retardation.
!NO_IN     means NO_INERT._CORRECTION_PARIISKII
!END
```

The information used after !COMP is only the first letter of the first word. It is possible to use (only the letters upper case are important):

Gravimeter or Vertical component;
Horizontal component, Tiltmeter or Clinometer
Extenzometer horizontal
Strainmeter vertical
Ocean data, Air-pressure or temperature or Meteo data.

The cases O, A or M are processed using the theoretical tides of the static ocean tides.

There are a few more CW, some of which are:

!SEPARATED_POTENTIAL_3		see 2.6. (SEPP3)
!ADD_LUNISOL_WAVES_TAMURA		see 1.1.1. (LUNISOL)
!ADD_VENUS/JUPITER_WAVES_TAMURA		see 1.1.2. (VEN/JUP)
!THRESHOLD_AMPLITUDE	0.1	see 1.1.4. (MIN.AMPL)
!NO_CORRECTION_POTENTIAL_3		see 1.2.1. (NOCP3)
!LENGTH_INTERVALS	36	see 3.1. (NFINT)
!POWER_DRIFT_POLYNOMIALS	1	see 3.3. (KELIM)
!PRINT_ONLY_4_DECIMALS		see 6.1. (OUT4)
!DELTA_KAPPA_CORRECTIONS		see 6.3. (DKCORR)

A number is added after the CW which need a numerical information.

The effect of all these CW can be obtained using corresponding options in a dialogue (Section II.4), indicated here through "see ... ". In the dialogue can be used a help, explaining the meaning of the options. E.g., if the question

6.3. (DKCORR) DELTA AND KAPPA CORRECTIONS ? h

gets the answer h, as above, the user will obtain the information how to create the input which should follow !DELTA_KAPPA_CORRECTIONS or !DEL.

II.3. Data bank.

It is supposed that the user disposes by several data files. It is also expected that these data files can be subject to multiple processing, i.e. they have to be at disposition for a while, if not for ever. Therefore NSV is organizing a simple information system.

It is necessary to write the names of the data in one or more OPEN files. In Example 4 is given an OPEN file called OPENA.DAT, which is accompanying the PC version of NSV.

Example 4. File OPENA.DAT with names of the files at disposition

Data, prepared as example for the use of the program NSV:

```
BRU3MP.TIT
BRU3MP.DAT
5 0.1
AIR-PRESSURE, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92

BRU3M.TIT
BRU3M.DAT
5 0.1
SUPRA, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92

BRU3MT.TIT
BRU3MT.DAT
5 0.1
BRUSSELS, TEMPERATURE, 3.8 MONTHS, 01.01.92-30.04.92

DUMMY.TIT
DUMMY.DAT
5 0.1
Names of data which do not exist
```

In the first line should be written a common name of the data, like "Data prepared as ..." in Example 4. Then follow, separated by a blank line, the names of every file in 4 lines. Their content is:

```
Line 1: Name of the CFILE, e.g. BRU3M.TIT
Line 2: Name of the data file, e.g. BRU3M.DAT
Line 3: The numbers: NCOL and SCALE, e.g. 5 0.1 (Section II.1)
Line 4: A short name of the data, e.g. SUPRA, BRUSSELS, 3 MONTHS,...
```

Up to 20 data files can be described in OPENA.DAT. There can also be included dummy names.

It is possible to organize an arbitrary numbers of OPEN files, e.g. OPENA.DAT, OPENB.DAT, OPENC.DAT ..., containing different sets of data. However, if a cross-regression will be used between some files, all of them should be written in one and the same OPEN file.

The names of the OPEN files should be written in the existing file OPENOPEN.DAT, e.g.

Example 5. OPENOPEN.DAT with the names of the OPEN files.

*This is the content of OPENOPEN.DAT

*(lines beginning by * are comments)
OPENA.DAT
OPENB.DAT
OPENC.DAT
*This is the end of the content

II.4. Start of the program NSV and a simple variant of analysis.

The work of the PC version of NSV is initiated by the command NS. At the beginning we get a message like

```
START OF THE PROGRAM NSV/1996 ON 25.06.1996 10h 26m 11.4sec  
WITH WISHES FOR GOOD RESULTS FROM  
VENEDIKOV, VIEIRA, DE TORO & ARNOSO FROM MADRID
```

Afterwards NSV is displaying the information from the OPEN files. If OPENA.DAT in Example 4 is used, this information will be:

```
DATA AT DISPOSITION:  
FILE 11 BRU3MP.DAT AIR-PRESSURE, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92  
FILE 12 BRU3M.DAT SUPRA, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92  
FILE 13 BRU3MT.DAT BRUSSELS, TEMPERATURE, 3.8 MONTHS, 01.01.92-30.04.92  
FILE 14 DUMMY.DAT Names of data which do not exist
```

Follows a message to choose the number of the data file to be processed. In this case it can be an integer between 11 and 13.

```
ENTER NR OF THE DATA FILE TO BE PROCESSED : 12
```

where "12" is the answer of the user.

If there is no answer (return key), NSV will display the information from the next OPEN file, e.g. OPENB.DAT, then the next one, OPENC.DAT, as many OPEN files as many names are given in OPENOEN.DAT.

After the answer "12" follows a series of messages which do not need the intervention of the user.

The dialogue continues by getting the question:

```
0.0. SOME OPTIONS ?
```

If the answer is a blank (return), NSV proceeds the analysis using default values and options.

II.5. Options and questions.

NSV has a set of options. They are selected in a dialogue, during which NSV set up questions which have to be answered. The initial question has been given in Section II.4. If the answer is H or h (help), all questions are displayed. In Table 1 are given most of the questions. A few questions related with details of some options are not shown.

The answer of every question, written in the same line as the question, can be:

Y or **y** - accepted option,

H or **h** - NSV will provide explanations about the option,

Any other single letter is equivalent to Y or y

2 letters, e.g. CC, - brakes the dialogue, start of the processing.
blank or RETURN key - rejected option. In the following this answer
will be denoted RET.

The underlined questions in Table 1 are "main" questions. If the
answer is RET, the control goes to the next main question. Also, if the
answer is RET to 1.1. the next question is 1.2. If the answer is RET to
1.2. the next question is 2.0.

In all other cases RET makes appear the next question.

In any case after 4.0. follows 5.0. If the answer to 4.0. is "y",
then 4.1, 4.2,... are displayed, but later, during the execution.

Under some conditions, some question are not displayed. If 5.1. or
5.2. are used, 4.1. is not displayed. If 4.1. is used, the execution is
interrupted after terminating its function, thus 4.2., 4.3,... are not
displayed.

Example 6. A dialogue with NSV:

```
0.0. SOME OPTIONS ? x
1.0. (CORR) SOME CORRECTIONS AND CHANGES ?
2.0. (ANAL) CHANGES IN THE ANALYSIS ?
3.0. (FIL) CHANGES IN THE FILTERS ? x
3.1. (NFINT) NEW LENGTH n OF THE FILTERED INTERVALS ? x
ENTER n (EVEN NUMBER.LE.800): 44
3.2. (SHIFT) NEW SHIFT s OF THE FILTERED INTERVALS ? x
ENTER s (ANY INTEGER): 60
3.3. (KELIM) NEW POWER k OF THE DRIFT POLYNOMIALS ? x
ENTER THE VALUE k 0
3.4. (TIDEF) NEW TIDAL CONSTITUENTS OF THE FILTERS ? ss
END OF THE CONTROL INPUT AND
START CONSTRUCTION OF THE FILTERS AT 12h 34m 18.8sec CPU TIME: 27.85
END CONSTRUCTION OF THE FILTERS AT 12h 34m 20.2sec CPU TIME: 29.22
START OF THE DATA PROCESSING, CPU TIME SET TO 0
```

In Example 6 "x" (meaning y or yes), "ss" (meaning start of the
processing) and the numbers "44" (for n), "60" (for s) and "0" (for k)
are input given by the user. The questions 1.0. and 2.0. have the
negative answers RET. Therefore 1.1., 1.2.,..., 2.1., 2.2.,... are
skipped.

The effect of this dialogue is that NSV will use filters of length
 $n = 44$, shifted by $s = 60$, i.e. omitting 16 ordinates between the
intervals. The filter will eliminate power $k = 0$, i.e. only an arbitrary
constant, different in every interval.

The processing has started after the answer "ss" with the message

END OF THE

II.6. Short comments of some options.

We think that the best and easiest way to understand the options is
to use NSV, the explanations which can be displayed after an H or h and,
most efficient, by making experiments. Therefore in the following we
shall briefly concern only few options, which may be of greater
interest.

1.1.3. (ADDW) ADDITIONAL WAVES ?

ADDW makes possible to deal with some waves which are not included in the potential development. They can be added to one of the existing species, D, SD,... or they can form a new species called AW. The waves can be defined either by a frequency (angular) or by an argument number of Doodson.

The option may be interesting for detection of particular tidal or non-tidal phenomena, as well as for including some particular waves which may exist in the ocean tidal phenomena.

2.1. (LONG) DETERMINATION OF THE LONG PERIOD (LP) WAVES ?

It is possible to determine LP using large filters of default length $n = 360$ which, however, can be optionally modified.

A new option of SV is to determine LP in parallel with the D (option named LONG(D)) or SD (option named LONG(S)) species, using the useful filters of length of the order of $n = 48$. This option may be applied to obtain the drift free of LP. This will be shown later in an example.

2.2. (MAIN) MAIN TIDAL SPECIES TO BE DETERMINED, CHOOSE D, SD,... ?

The default option of NSV is to determine the D, SD and TD waves. However, it is possible to determine also the species QD (quarterdiurnal, 4 cpd), FD (fifthdiurnal, 5 cpd) and D6 (sixthdiurnal, 6 cpd), as well as species defined by 1.1.3. (ADDW)

2.3. (WGHT) WEIGHTS OF THE FILTERED NUMBERS ?

The $u(T), v(T)$ can be weighed by the estimated variances through the solution of (28). The option can be efficient in dealing with records having strong perturbations. If the use of this option improve considerably the results, it is possible that in the data are gross errors.

2.5. (ADDGR) ADDITIONAL TIDAL GROUPS FOR ELIMINATION OF A LEAKAGE ?

Since nothing is perfect, the separation of the main species by the filters is also not perfect. This may have an effect only for data of very high precision, e.g. theoretical model data. This option can strongly reduce the leakage.

4.0. (TVAR) TIME VARIATIONS, RESIDUALS ?

This set of options can be very useful for the detection of various anomalies in the data. Since such anomalies may be potential volcano and earthquake precursors, (TVAR) can be helpful for these fundamental problems.

Here we shall concern only some of these options.

4.1. (RESIN) RESIDUALS AND DRIFT IN THE FILTERED INTERVALS ?

RESIN deal with the data separately in every interval I_i , using the expressions (28) and (29)

$$(35) \quad \mathbf{C}\mathbf{x}_i = \mathbf{y}_i \quad \text{and} \quad \tilde{\mathbf{x}}_i = (\mathbf{C}^*\mathbf{C})^{-1}\mathbf{C}^*\mathbf{y}_i = \mathbf{F}^*\mathbf{y}_i$$

where \mathbf{F} is the matrix of the filters. In (30) are indicated only the filters which are used for the tidal analysis. Here, in (35), take part all filters or vectors of the matrix \mathbf{F} .

The hourly residuals provided by RESIN are computed through

$$(36) \quad \mathbf{r}_i = \mathbf{y}_i - \mathbf{C}\tilde{\mathbf{x}}_i.$$

These residuals are usually too small. However, big anomalies in single ordinates, e.g. gross errors, can be determined.

Some of the elements of the vector $\tilde{\mathbf{x}}_i$ are the estimates $\tilde{\zeta}_{i1}$ of the drift unknowns ζ_{i1} in (10) and (14). Using $\tilde{\zeta}_{i1}$ in (10), RESIN is computing the drift for all points in the intervals.

RESIN is not used, when TORO1 or TORO2 are applied.

If RESIN is used, the execution is terminated after its application.

4.2. (RESAN) HOURLY RESIDUALS AND DRIFT AFTER THE ANALYSIS ?

RESAN provides hourly residuals, as well as the drift d_t in two variants: filtered d_t and residual d_t called also drift + noise. The residual d_t is obtained as the difference between the observations $y(t)$ and the computed or adjusted tidal signal.

The filtered d_t is obtained through a moving filtration. The filter is not indicated in (30) but it is there. This is the first filter in the matrix \mathbf{F} , corresponding to the vector \mathbf{p}_0 . The filtered drift is actually the estimate $\tilde{\zeta}_0$ of the unknown ζ_0 in (10) and (14), obtained hour by hour.

The filtered drift is a smoothed drift, its values d_t being strongly correlated. In our opinion, more information is provided by the residual drift.

The hourly residuals are obtained as the difference between $y(t)$ and (estimated tidal signal + filtered d_t).

About other options related with the question 4.0. the user can find the information using the help option as well as through experimentation.

5.0. (CROSS) EFFECT OTHER SERIES (INPUT CHANNELS) OF DATA ?

Very essential option through which the component a_t in (2) is modeled and eliminated (approximately, of course)

The use of this option depends on the questions:

5.1. (TORO1) REGRESSION MODEL1 WITHOUT PHASE SHIFT?

5.2. (TORO2) REGRESSION MODEL2 WITH PHASE SHIFT ?

In principle the idea of De Meyer (1982) is used but through our model (Simon et al., 1989, Toro et al., 1991, 1993a). Now this is done in the following way.

Let FILE1 are some tidal data, while FILE2 are data of a phenomenon which is perturbing FILE1. E.g. FILE1 are the gravity data BRU3M.DAT and FILE2 are the air-pressure data BRU3MP.DAT.

Let $u(T)$ and $v(T)$ are filtered numbers obtained from FILE1, $p(T)$ and $q(T)$ are corresponding filtered numbers obtained from FILE2, \bar{p} and \bar{q} are the mean values of $p(T)$ and $q(T)$ and

$$(37) \quad \begin{aligned} \Delta p(T) &= p(T) - \bar{p}, \\ \Delta q(T) &= q(T) - \bar{q}. \end{aligned}$$

If MODEL 2 (TORO2) is accepted, the equations (33) are modified into

$$(38) \quad \begin{aligned} \sum_{j=1}^{\mu} [c_{jf}(T) \xi_j + s_{jf}(T) \eta_j] + b_1 \Delta p(T) - b_2 \Delta q(T) &= u(T) \\ \sum_{j=1}^{\mu} [-s_{jg}(T) \xi_j + c_{jg}(T) \eta_j] + b_1 \Delta q(T) + b_2 \Delta p(T) &= v(T). \end{aligned}$$

Here b_1 and b_2 are regression coefficients which can be represented as

$$(39) \quad b_1 = b \cos \beta, \quad b_2 = b \sin \beta, \quad \text{where}$$

b is a coefficient of proportionality and

β is a phase lag of the effect of FILE2 on FILE1.

We get b_1 and b_2 , b and β separately for the main species, i.e. NSV is looking for frequency dependent relations.

If MODEL 1 is applied, it is accepted that $\beta \equiv 0$ and we get only one regression coefficient $b_1 = b$.

It is possible to deal at once with 6 files like FILE2, i.e. in (38) to put 6 pairs of unknowns b_1 and b_2 . However, it is very unlikely to be successful if more than two files FILE2 are considered.

5.3. (CROSSC) CORRECTING CROSS REGRESSION COEFFICIENTS ?

If neither 5.1 nor 5.2 is used, CROSSC can correct the filtered number using given regression coefficient b , common for all frequencies. The corrections to $u(T)$ and $v(T)$ are $bp(T)$ and $bq(T)$ respectively. Notice that here are used $p(T)$ and $q(T)$, instead of $\Delta p(T)$ and $\Delta q(T)$.

II.7. A few examples.

7.1. Options SLOW and TOR01.

Table 2 is a copy of the output provided by NSV. B1 are values of the coefficients b_1 in (9). We have got B1 frequency and time depending.

We have an application of SLOW with intervals of length 30 days and shifted by 30 days. The last interval has 46 days because there are left 16 days of data which cannot shape an interval of the selected length.

The output using this option as well as the output of all options for time variations is in a form suitable to use a plotting program. Therefore the dates are written in a not very convenient form.

In addition to this output we get the values of δ and κ for selected tides for the same time intervals and similar format.

7.2. Options LONG, TOR01, TOR02 and VGR.

In Table 3 we have variants of the results of the analysis about the long period waves. In the title is given part of the output when only one of the variants is applied.

When VGR is not applied, the tidal group called MF unify all LP tides. However, the filters which amplifies MF, are retaining or eliminating the longer tides, e.g. SSA and SA.

When VGR is applied, we have the variants

VGR(MTM): the LP tides are separated in groups MF and MTM

VGR(MTM,MSOM): the LP tides are separated in groups MF, MTM and MSOM.

However, in Table 3 are given only the results for MF.

This example has needed a preparation of the file NGROUPS.DAT, where the groups used MF, MTM and MSOM are defined through intervals of the frequency ω .

Table 3 is also an example how the criterion AIC can be used. We have an important reduction of AIC at the first step LONG \Rightarrow (LONG,TOR01). Further we have not any improvement, even AIC is slightly raising. We have to remain at the lowest value, i.e. to accept the result (LONG,TOR01).

7.3. Option LONG(D), TOR01 and RESAN.

Let a filtered or residual d_t is determined using RESAN. In both cases, if CROSS is used, taking into account the air-pressure (AP), the estimated effect is subtracted from d_t .

If CROSS is not used, d_t remains charged by the effect of AP.

Also, if LONG is used, but only the variants LONG(D) or LONG(S), the estimated LP are subtracted from d_t .

In Figures 6, 7 and 8 are given examples of the determination of the drift.

More evident are the effects at the data of the superconducting gravimeter in Figure 6. RESAN provides a drift charged by the effect of the air-pressure where the most important signal is the LP tides. One can very distinguish the monthly and halfmonthly period.

The application of TORO1 eliminates quite well the effect of the air-pressure and the manifestation of the LP waves becomes completely clear.

At the end, through LONG(D) the LP are determined and thus eliminated. We get a drift in which we can look for some geophysical phenomena.

In Figures 7 and 8 the procedures are repeated for ocean data. We have similar effects as in Figure 6, but not so strong.

In Figure 6 we use a filtered d_t . We get data looking less noisy but, due to the smoothing, there are some small waves.

7.4. Options RESFN and TORO1.

In Figure 9 are given the D residuals of the filtered numbers, obtained using RESFN. The same residuals are computed after TORO1 is proceeding a regression on air pressure data. Obviously, there is a considerable reduction of the magnitude of the residuals.

However, the effect is not so strong for the SD residuals.

7.5. Option SLOW.

In Figure 10 is shown an example of the study of the slow time variation of the tidal parameters. SLOW can represent the δ factors of one wave as a function of the δ factor of another wave. If there is a correlation, this can be explained by a variation of the sensibility. This effect is well demonstrated in Figure 10.

7.6. Estimation of the precision by NSV using model data of the noise.

In principle, the reasonable estimation of the noise made by NSV is one of its most important properties.

Let \mathbf{V} is the covariance matrix of the data $y(t)$ and $\mathbf{V} = \mathbf{T}^*\mathbf{T}$, where \mathbf{T} is an upper triangular matrix, and let \mathbf{y} denotes the vector whose elements are all $y(t)$. According to the theory, we would have a correct application of MLS, if we work with the transformed data $\mathbf{u} = \mathbf{T}^*\mathbf{y}$, instead of \mathbf{y} . The reason of the transformation is that the noise of \mathbf{u} becomes WN.

Since \mathbf{V} is not available, NSV applies the transformation of \mathbf{y} in our filtered numbers u and v . This is done under the supposition that u and v are also charged by a WN.

In Figure 11 is represented a simulated white noise. Its spectrum is representing the effect of the noise in the frequency domain. About the spectrum is used such a scale, that the level of the noise should be of the same order as the standard (the square root of the variance) of the simulated noise.

The spectrum obtained is according to the theoretical level of the noise which is the constant $L_\omega = \sigma = 1$ over the whole frequency domain.

In Figure 12 are shown the D and SD filtered numbers u . They obviously behave as a WN. NSV is applying filters, normalized in such a way that in the case of WN, u and v should have the same variance as the data. Indeed, the level of the spectrum of u in Figure 12 is

corresponding to $\sigma = 1$.

In Figure 13 is shown a simulated stationary noise obtained as an MA (moving average) of the white noise. Unlike the WN, the spectrum is showing an accumulation of the energy at the D and SD domains, corresponding to the theoretically determined level of the noise. We have, more or less, similar picture of the real noise of the tidal data, mainly due to the meteorological effects in which are some variable D and SD waves.

As shown in Figure 14, the filtered numbers behave as a WN because the spectrum is maintaining a constant level. However, we have a higher level for the D filtered numbers and lower level for the SD filtered numbers, which is realistically corresponding to the spectrum of Figure 13.

In Table 4 are given the results of the estimation of the noise through ETERNA and NSV, using different filters.

7.6. Analysis results.

Table 5 is a copy, with very few modifications, of the analysis of the data file 12, BRU3M.DAT. There is applied a cross-regression with the air-pressure data, BRU3MP.DAT

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Table 1. List of the questions/options of NSV.

- 1.0. (CORR) SOME CORRECTIONS AND CHANGES ?
 - 1.1. (THEOW) THEORETICAL WAVES (TIDAL POT. DEVELOPMENT) ?
 - 1.1.1. (LUNISOL) ADDITIONAL LUNI-SOLAR TERMS OF TAMURA ?
 - 1.1.2. (VEN/JUP) TIDAL WAVES OF VENUS AND JUPITER ?
 - 1.1.3. (ADDW) ADDITIONAL WAVES ?
 - 1.1.4. (MIN.AMPL) IGNORE WAVES UNDER A THRESHOLD AMPLITUDE ?
 - 1.1.5. (PRDEV) PRINT THE TIDAL POTENTIAL DEVELOPMENT ?
 - 1.2. (DATA) DATA CORRECTIONS ?
 - 1.2.1. (NOCP3) NO CORRECTIONS FOR POTENTIAL OF ORDER 3 AND 4 ?
 - 1.2.2. (NOINC) NO CORRECTION PARIISKII (ONLY GRAVIMETERS) ?
 - 1.2.3. (SECCOR) TIME CORRECTION IN SECONDS ?
 - 1.2.4. (MULT) MULTIPLYING CORRECTION ?
 - 1.2.5. (CUT) RESTRICT (CUT OFF) THE INTERVAL OF THE DATA ?
 - 1.2.6. (ADJUST) ADJUST THE VOLUME OF THE DATA TO OTHER SERIES ?
- 2.0. (ANAL) CHANGES IN THE ANALYSIS ?
 - 2.1. (LONG) DETERMINATION OF THE LONG PERIOD (LP) WAVES ?
 - 2.2. (MAIN) MAIN TIDAL SPECIES TO BE DETERMINED, CHOOSE D, SD, ... ?
 - 2.3. (WGHT) WEIGHTS OF THE FILTERED NUMBERS ?
 - 2.4. (VGR) CHOOSE THE VARIANT OF GROUPING ?
 - 2.5. (ADDGR) ADDITIONAL TIDAL GROUPS FOR ELIMINATION OF A LEAKAGE ?
 - 2.6. (SEPP3) SEPARATE THE TIDES OF DEGREE 3 ?
- 3.0. (FIL) CHANGES IN THE FILTERS ?
 - 3.1. (NFINT) NEW LENGTH n OF THE FILTERED INTERVALS ?
 - 3.2. (SHIFT) NEW SHIFT s OF THE FILTERED INTERVALS ?
 - 3.3. (KELIM) NEW POWER k OF THE DRIFT POLYNOMIALS ?
 - 3.4. (TIDEF) NEW TIDAL CONSTITUENTS OF THE FILTERS ?
 - 3.5. (RESPF) RESPONSE OF THE FILTERS TO SOME TIDES ?
 - 3.6. (SPECF) SPECTRUM OF THE FILTERS ?
- 4.0. (TVAR) TIME VARIATIONS, RESIDUALS ?
 - 4.1. (RESIN) RESIDUALS AND DRIFT IN THE FILTERED INTERVALS ?
 - 4.2. (RESAN) HOURLY RESIDUALS AND DRIFT AFTER THE ANALYSIS ?
 - 4.3. (FAST) FAST AMPLITUDE AND PHASE VARIATIONS ?
 - 4.4. (RESFN) RESIDUALS OF THE FILTERED NUMBERS ?
 - 4.5. (FILN) PRINT THE FILTERED NUMBERS ?
 - 4.6. (SLOW) SLOW AMPLITUDE AND PHASE VARIATIONS ?
- 5.0. (CROSS) EFFECT OTHER SERIES (INPUT CHANNELS) OF DATA ?
 - 5.1. (TORO1) REGRESSION MODEL 1 WITHOUT PHASE SHIFT ?
 - 5.2. (TORO2) REGRESSION MODEL 2 WITH PHASE SHIFT ?
 - 5.3. (CROSSC) CORRECTING CROSS REGRESSION COEFFICIENTS ?
- 6.0. (OTHER) OTHER OPTIONS ?
 - 6.1. (OUT4) OUTPUT WITH ONLY 4 DECIMALS OF DELTA ?
 - 6.2. (ARTW) ADD AN ARTIFICIAL WAVE ?
 - 6.3. (DKCORR) DELTA AND KAPPA CORRECTIONS ?

Table 2. Output when the options **SLOW** and **TOR01** are applied.
Data used: Station Brussels, Superconducting gravimeter.

TIME VARIATIONS OF THE REGRESSION COEFFICIENTS

NR INT	INTERVAL FROM	TILL	CENTRAL EPOCH DAYS	DATA USED DAYS	B1(D)	B1(SD)	B1(TD)	B1(QD)
1	86111500	86121423	15.0	30.0	-0.325	-0.421	-0.359	-0.075
2	86121500	87011323	45.0	30.0	-0.354	-0.351	-0.441	-0.237
3	87011400	87021223	75.0	30.0	-0.458	-0.214	-0.223	-0.075
4	87021300	87031423	105.0	30.0	-0.378	-0.463	-0.508	0.017
5	87031500	87041323	135.0	30.0	-0.377	-0.241	-0.428	-0.733
6	87041400	87051323	165.0	30.0	-0.351	-0.298	-0.692	0.048
7	87051400	87061223	195.0	30.0	-0.444	-0.395	-0.228	-0.310
8	87061300	87071223	225.0	30.0	-0.309	0.012	-0.099	-0.441
9	87071300	87081123	255.0	30.0	-0.344	-0.435	-0.228	-0.223
10	87081200	87091023	285.0	30.0	-0.313	-0.188	-0.183	-0.040
11	87091100	87101023	315.0	30.0	-0.342	-0.289	-0.298	-0.320
12	87101100	87112523	353.0	46.0	-0.350	-0.418	-0.330	-0.304

Table 3. Application of the options **LONG**, **TOR01**, **TOR02** and **VGR**.
Data: Station Brussels, Superconducting gravimeter, 21.04.82-20.01.93.
and air-pressure for the same interval.

FILTERED INTERVALS OF LENGTH 360 HOURS
SHIFT (DISTANCE BETWEEN THE EPOCHS) OF THE INTERVALS 360 HOURS
APPROXIMATION IN THE INTERVALS BY DRIFT POLYNOMIALS OF POWER 1
AND TIDES: MF S1 O1 Q1 S2 M2 N2 S3
DATA USED: 3927 DAYS, 92520 READINGS, 3 BLOCKS, 257 INTERVALS
82.04.21.00/82.06.09.11 82.06.02.00/86.10.29.23 86.11.15.00/93.01.19.23

Options used	δ (MF)	σ (δ)	κ (MF)	σ (κ)	σ (y)	AIC
LONG	1.1463	0.0163	1.262	0.811	21.00	4594.
LONG, TOR01	1.1483	0.0046	0.007	0.231	5.98	3305.
LONG, TOR01, VGR(MTM)	1.1467	0.0047	0.016	0.234	5.96	3307.
LONG, TOR02	1.1482	0.0046	0.006	0.231	5.98	3308.
LONG, TOR02, VGR(MTM)	1.1466	0.0047	0.014	0.234	5.97	3309.
LONG, TOR01, VGR(MTM, MSOM)	1.1467	0.0047	0.009	0.234	5.97	3312.

Table 4. Estimation of the precision using models of the noise.

Estimation of the precision of the white noise in Figure 11

Tidal species :		D	SD	TD	QD
Theoretical level of the noise :		1.00	1.00	1.00	1.00
Programs	variants	Mean Square Deviations MSD			
ETERNA	ET49	1.20	1.07	0.99	1.20
	ET51	0.98	1.02	1.00	1.16
	ET239	1.03	1.07	0.96	1.18
NSV	V48	1.00	1.00	1.02	1.00
	V36	1.01	1.04	1.04	1.01
	V40	0.99	1.00	1.00	0.99
	V44	0.98	1.00	1.03	1.04
	V52	0.99	0.98	1.00	1.04

Estimation of the precision of the stationary noise in Figure 13

Tidal species :		D	SD	TD	QD
Theoretical level of the noise :		3.08-3.99	0.93-1.81	0.65-0.84	0.47-0.52
Programs	variants	Mean Square Deviations MSD			
ETERNA	ET49	4.50	1.58	0.70	0.57
	ET51	3.68	1.49	0.71	0.55
	ET239	3.86	1.55	0.69	0.56
NSV	V48	3.30	1.45	0.77	0.51
	V36	2.90	1.10	0.64	0.47
	V40	3.13	1.45	0.73	0.47
	V44	3.25	1.43	0.79	0.52
	V52	3.35	1.52	0.73	0.47

ET_n means filters of ETERNA of length *n*.

V_n means filters of NSV of length *n*

Table 5. Example of the output when the gravity data BRU3M.DAT are processed. A cross-regression (TORO1) is applied, using the air-pressure data BRU3MP.DAT.

```
START OF THE PROGRAM NSV/1996 ON 28.06.1996 14h 16m 39.0sec
WITH WISHES FOR GOOD RESULTS FROM
VENEDIKOV, VIEIRA, DE TORO & ARNOSO FROM MADRID
DATA AT DISPOSITION:
FILE 11 BRU3MP.DAT AIR-PRESSURE, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92
FILE 12 BRU3M.DAT SUPRA, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92
FILE 13 BRU3MT.DAT BRUSSELS, TEMPERATURE, 3.8 MONTHS, 01.01.92-30.04.92
FILE 14 DUMMY.DAT Names of data which do not exist
THE DATA FILE TO BE PROCESSED IS
FILE 12 BRU3M.DAT SUPRA, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92
END READING DATA IN NDTF.FOR FROM FILE 12
DATA INTERVAL: 92.01.01.00. - 92.04.01.12.
NUMBER DATA 2208 NUMBER BLOCKS, 1
START READING DATA FROM CONTROL INPUT FILE 72
INFORMATION FROM THE CONTROL DATA FILE:
!NAME 3
!Comp G
!Longitude_WEST_DEGREES -4.3581
!LATITUDE_NORTH_DEGREES 50.7986
!ALTITUDE_KILOM. 0.100
!GRAVITY_GALS_OR_ZERO 981.0
!MULTIPLYING_CONSTANT 0.9907
!TIME -30
!NO_INERT._CORRECTION_PARIISKII
0.0. SOME OPTIONS ? Y
5.0. (CROSS) EFFECT OTHER SERIES (INPUT CHANNELS) OF DATA ? Y
5.1. (TORO1) REGRESSION MODEL 1 WITHOUT PHASE SHIFT ? Y
ENTER NUMBER(s) OF FILE(s)=2nd, 3d...7th CHANNEL
IN ONE ROW : 11.
THE SECOND... DATA FILE TO BE PROCESSED IS
FILE 11 BRU3MP.DAT AIR-PRESSURE, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92

END READING DATA IN NDTF.FOR FROM FILE 11
DATA INTERVAL: 92.01.01.00. - 92.04.01.12.
NUMBER DATA 2208 NUMBER BLOCKS, 1
END OF THE CONTROL INPUT AND
START CONSTRUCTION OF THE FILTERS AT 14h 17m 10.1sec CPU TIME: 31.08
END CONSTRUCTION OF THE FILTERS AT 14h 17m 11.6sec CPU TIME: 32.62
START OF THE DATA PROCESSING, CPU TIME SET TO 0
DATA FILE 12:
BRU3M.DAT
SUPRA, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92
PROCESSING THE DATA, BE SO KIND TO WAIT...
END OF THE DIRECT PROCESSING, I.E. END FILTRATION,
CREATION OF MODEL EQUATIONS AND NORMAL EQUATIONS;
FOLLOWS: RESOLUTION OF THE NORMAL EQUATIONS AND OUTPUT
```

STATION 0201 BRUXELLES-UCCLE

COMPOSANTE VERTICALE

50 47 55 N 04 21 29 E H 101 M P 4M D 90KM 981 117 301
 GRAVIMETRE A SUPRACONDUCTIVITE GWR T3
 LEAST SQUARE ANALYSIS OF INDEPENDENT FILTERED NUMBERS (VENEDIKOV/MV66)
 PROGRAM NSV, VERSION 20.06.1996 FOR PC 486/UNIVERSITY COMPLUTENSE
 PROGRAMMING VENEDIKOV, VIEIRA, DE TORO, ARNOSO,
 INSTITUTO DE ASTRONOMIA Y GEODESIA, C.S.I.C-U.C.M, MADRID

FILTERED INTERVALS OF LENGTH 48 HOURS
 SHIFT (DISTANCE BETWEEN THE EPOCHS) OF THE INTERVALS 48 HOURS
 APPROXIMATION IN THE INTERVALS BY DRIFT POLYNOMIALS OF POWER 2
 AND TIDES: S1 01 S2 M2 S3 S4 S5 S6
 TIDAL POTENTIAL DEVELOPMENT OF TAMURA
 THEORETICAL ELEMENTS OF THE TIDES COMPUTED AFTER TAMURA
 TIME CORRECTION -30.0 SECONDS
 ANALYSIS ON 28.06.1996, START: 14h 17m 11.6sec, END: 14h 17m 13.2sec
 CPU TIME USED: 1.60 SEC. FOR DATA OF LENGTH .25 YEARS
 DATA USED: 91 DAYS, 2208 READINGS, 1 BLOCKS, 46 INTERVALS
 REGRESSION MODEL 1 OF DE TORO, VENEDIKOV, VIEIRA
 CROSS-REGRESSION, ADDITIONAL CHANNELS (INDEPENDENT VARIABLES):
 DATA FILE 11:
 BRU3MP.DAT
 AIR-PRESSURE, BRUSSELS, 3 MONTHS, 01.01.92-01.04.92
 THEORETICAL MODULATION OF THE D AND SD WAVES OF ORDER 3
 THE INERTIAL CORRECTION (PARIISKII) IS *NOT* INTRODUCED
 THE DATA ARE MULTIPLIED BY :9907
 92.01.01.00/92.04.01.23

WAVE GROUP	ESTIMATED	AMPLIT.	PHASE
ARGUM. N WAVE	AMPL. M.S.D.	FACTOR M.S.D.	DIFF. M.S.D.

REGRESSION ON CHANNEL=FILE 11

B1(D) REGRESSION COEFFICIENT = -.3336, MS ERROR= .0147

1B9-13X 143 Q1	7.038	.017	1.14022	.00280	-.0972	.1427
142-149 58 01	35.400	.019	1.14266	.00061	.0509	.0305
152-158 48 NO1	3.097	.017	1.13067	.00634	.6312	.3213
160-169 56 K1	51.497	.020	1.13213	.00044	.1838	.0222
171-177 40 J1	2.868	.016	1.14683	.00631	-.0848	.3099
181-1J3 105 001	1.918	.018	1.15473	.01076	-.2668	.5200

REGRESSION ON CHANNEL=FILE 11

B1(SD) REGRESSION COEFFICIENT = -.2920, MS ERROR= .0378

2A7-23X 99 2N2	1.395	.007	1.13470	.00534	4.1523	.2686
242-249 50 N2	6.764	.007	1.15039	.00125	3.0903	.0608
252-259 56 M2	35.267	.008	1.17388	.00027	2.7392	.0130
261-268 39 L2	1.175	.012	1.13667	.01201	5.4301	.6248
270-2J3 133 S2	17.302	.007	1.18950	.00048	1.3055	.0221

REGRESSION ON CHANNEL=FILE 11

B1(TD) REGRESSION COEFFICIENT = -.3846, MS ERROR= .0499

315-375 68 M3	.427	.005	1.08662	.01299	-.1729	.6844
382-3X5 14 S3	.010	.004	2.29255	.94942	-88.0543	25.3928

STANDARD DEVIATIONS: D .549 SD .225 TD .147

AIC (AKAIKE): D 179. SD 11. TD -79.

END OF THE PROCESSING 28.06.1996, 14h 17m 13.3sec CPU TIME 1.71 SEC.

$\log(10^4 H_\omega)$, H_ω in μgals

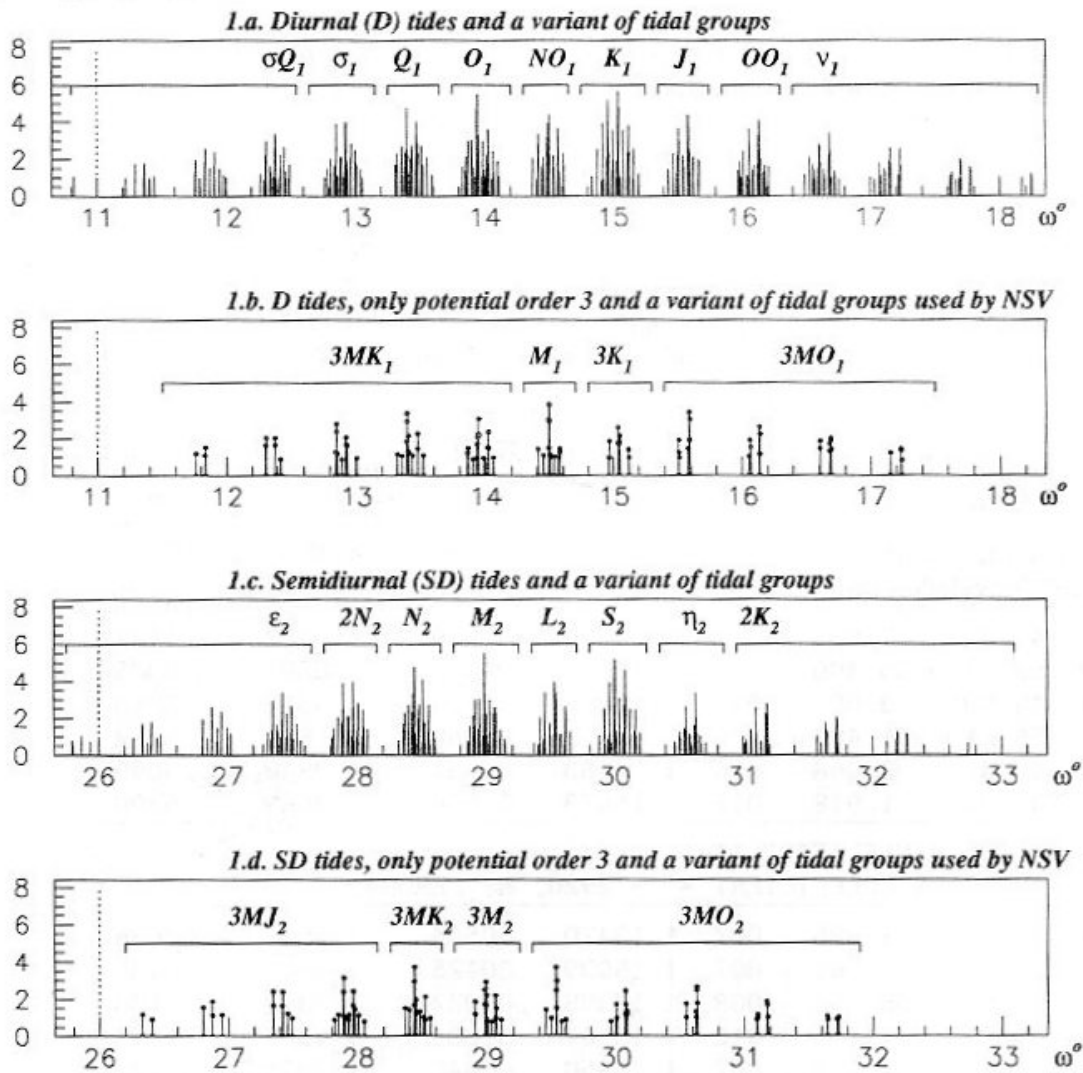
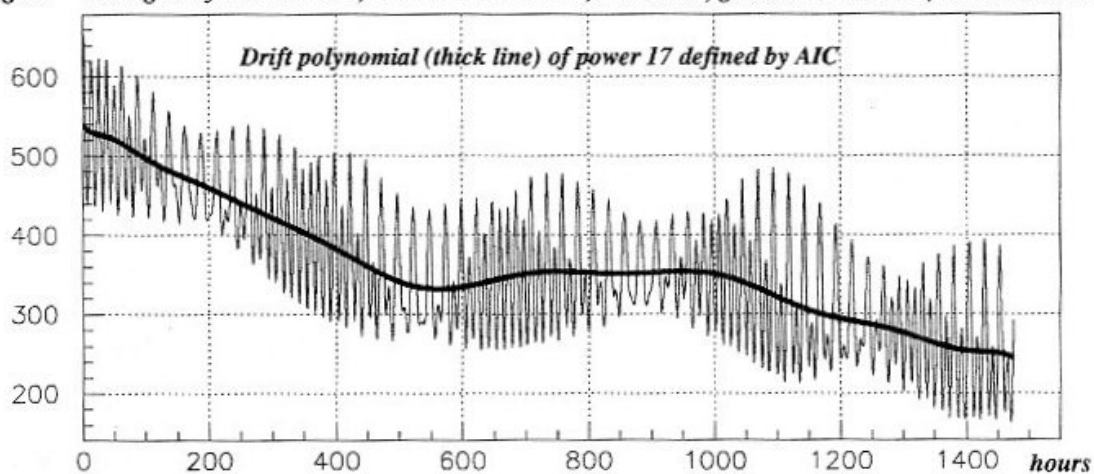


Figure 1. Theoretical tidal amplitude spectrum H_ω , tidal gravity station Brussels.
Development of the tidal potential of Tamura.

GRO105

27/06/96 14.53

μgals Tidal gravity observations, Cueva de los Verdes, Lanzarote, gravim. LCR 434/G, 1.03.91/11.05.91



μgals Hourly residuals (drift and tidal signal subtracted)

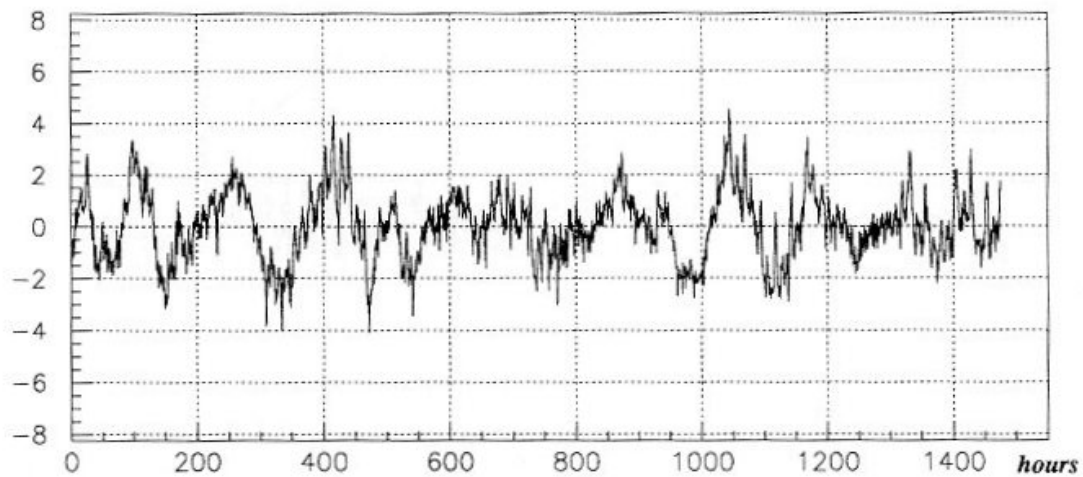
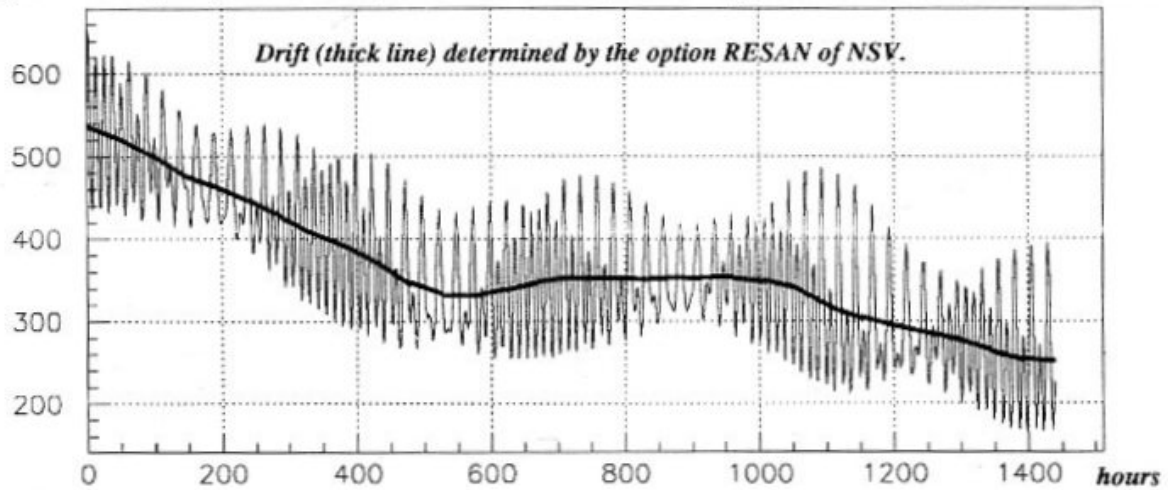


Figure 2. Approximation of the drift using a polynomial for an interval of 2 months.

GROT06

27/06/96 14.53

μgals Tidal gravity observations, Cueva de los Verdes, Lanzarote, gravim. LCR 434/G, 1.03.91/11.05.91



μgals Hourly residuals, option RESAN

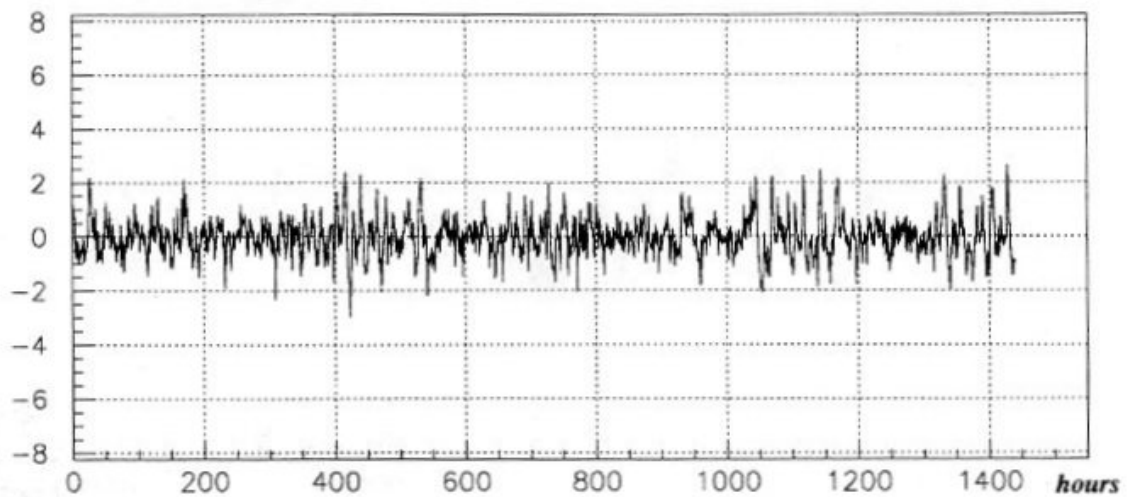
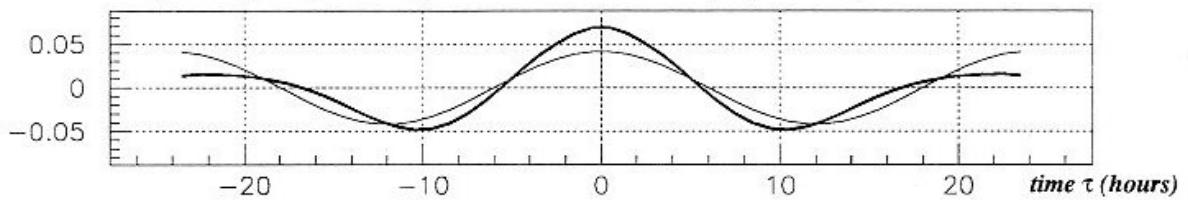
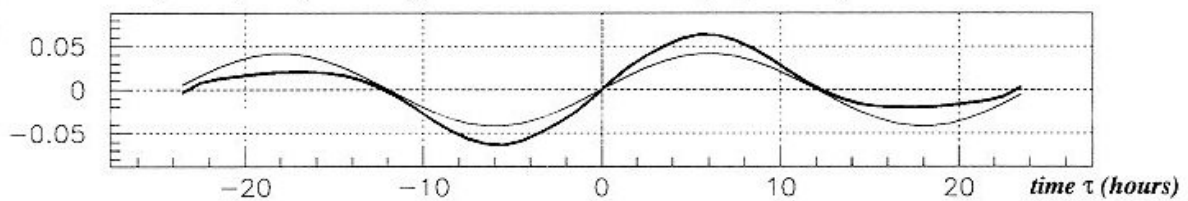


Figure 3. Drift approximated by polynomials in independent intervals of $n = 48$ hours

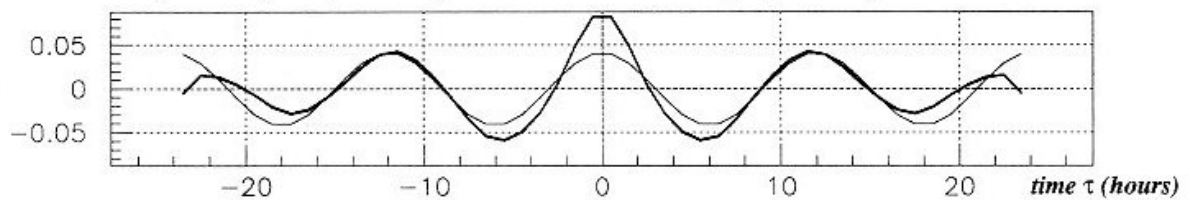
NSV, even D filter (thick line), RSTN = 0.802 and FFIL $(2/n) \cos 15^\circ \tau$, RSTN = 1.000



NSV, odd D filter (thick line), RSTN = 0.802 and FFIL $(2/n) \sin 15^\circ \tau$, RSTN = 1.000



NSV, even SD filter (thick line), RSTN = 0.745 and FFIL $(2/n) \cos 30^\circ \tau$, RSTN = 1.000



NSV, odd SD filter (thick line), RSTN = 0.813 and FFIL $(2/n) \sin 30^\circ \tau$, RSTN = 1.000

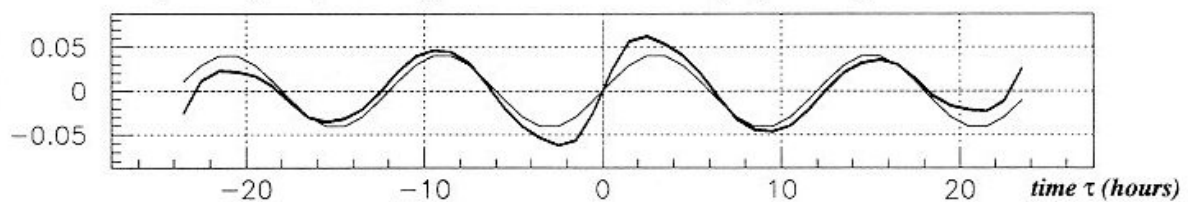
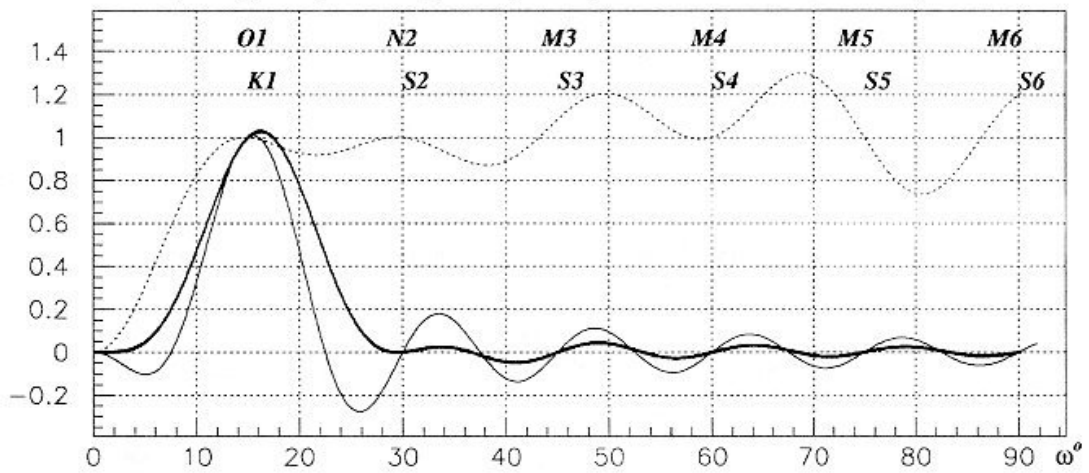


Figure 4. Default filters of NSV and Fourier filters FFIL in the time domain, $n = 48$.

Even D filter of NSV (thick line), corresponding FFIL and Pertsev (dotted line)



Even SD filter of NSV (thick line), corresponding FFIL and Pertsev (dotted line)

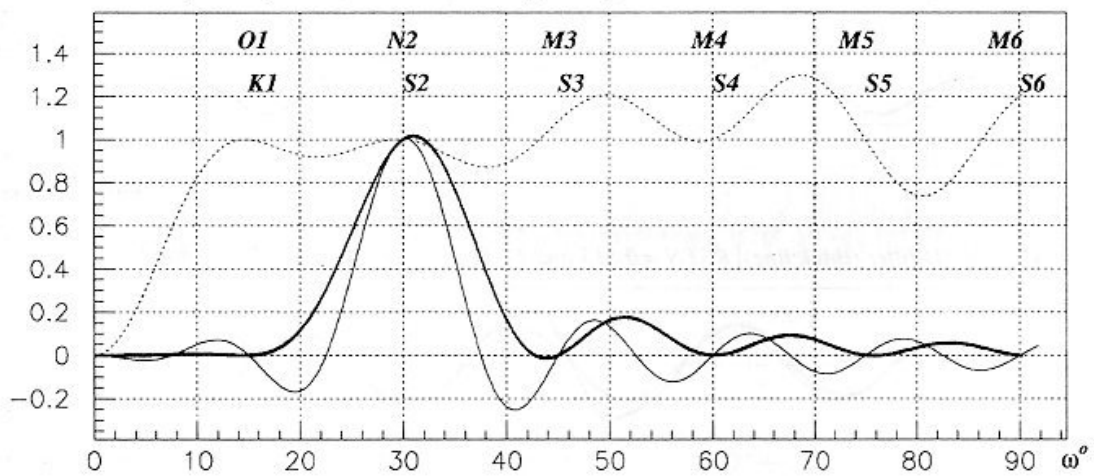
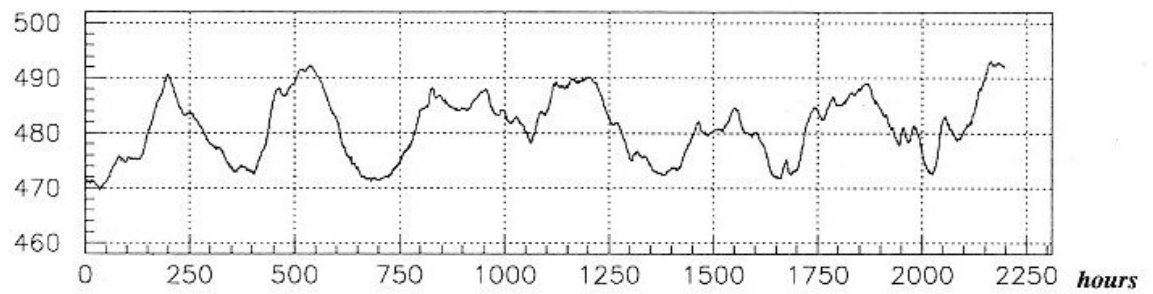


Figure 5. Filters of NSV, FFIL and Pertsev (high pass) in the frequency domain.

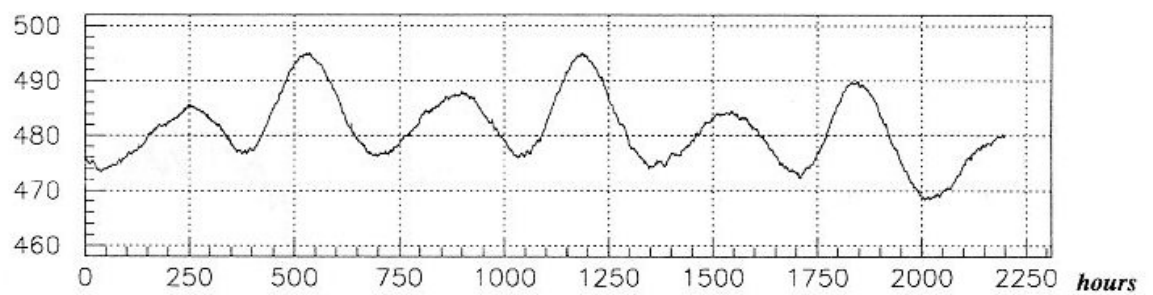
GROT01

27/06/96 14.54

μgal Residual drift (drift + noise), option RESAN



Residual drift, air-pressure taken into account, options RESAN and TORO1



Residual drift, air-pressure and LP taken into account, options RESAN, TORO1 and LONG(D)

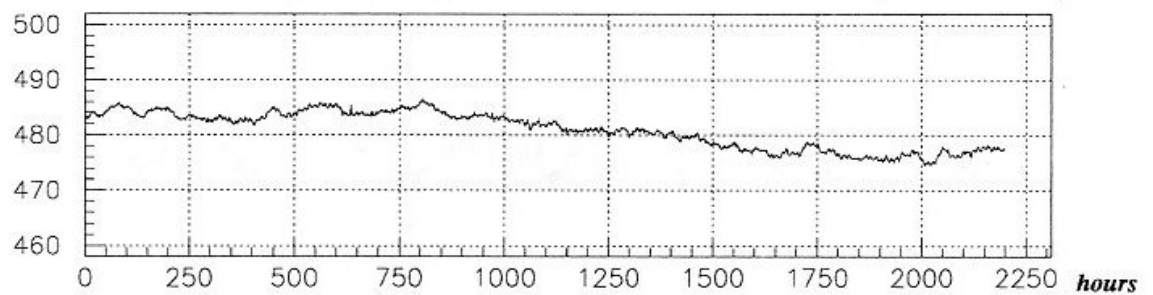
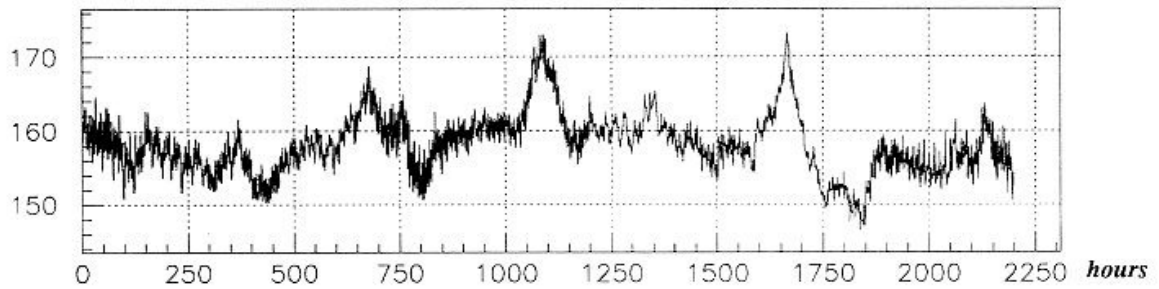


Figure 6. Determinations of the drift using the program NSV on data of Supra/Brussels

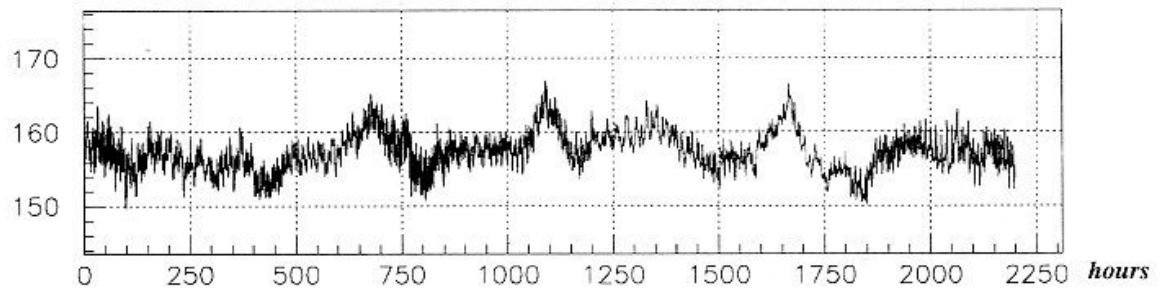
GROT03

27/06/96 14.54

cm Mean sea level as residual drift, option RESAN



Mean sea level, air-pressure taken into account, options RESAN and TORO1



Mean sea level, air-pressure and LP taken into account, options RESAN, TORO1 and LONG(D)

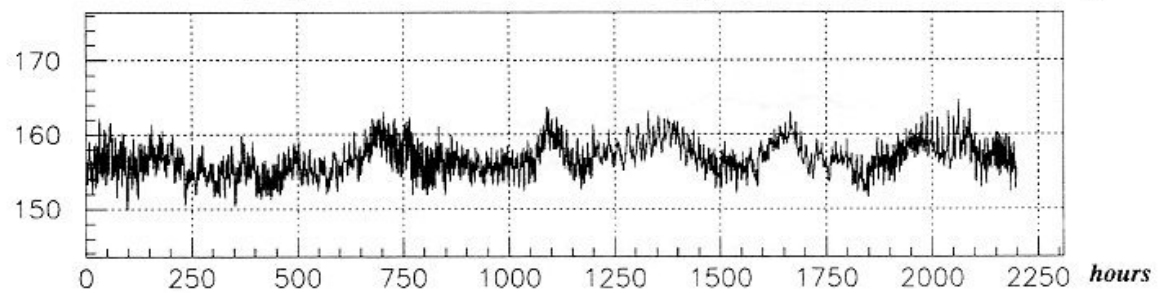
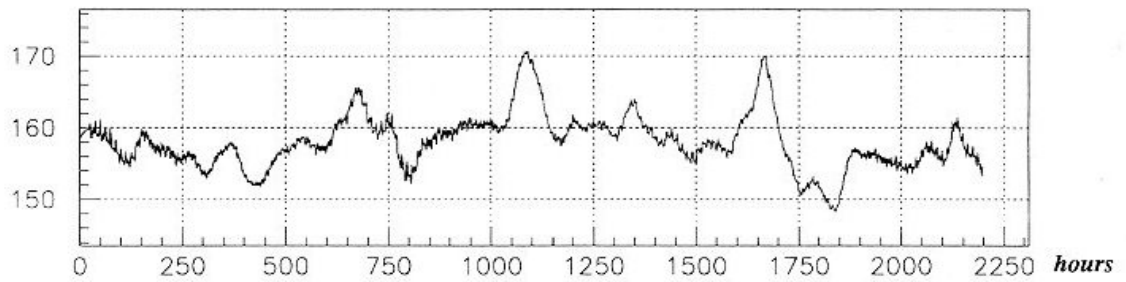


Figure 7. Determinations of the mean sea level using the program NSV on ocean data/Lanzarote

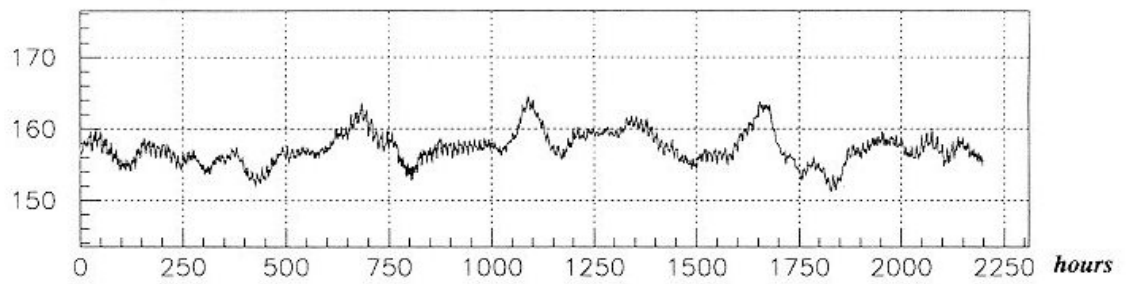
GROT04

27/06/96 15.03

cm Mean sea level as filtered drift (FDRIFT), option RESAN



Mean sea level, air-pressure taken into account, options RESAN and TORO1



Mean sea level, air-pressure and LP taken into account, options RESAN, TORO1 and LONG(D)

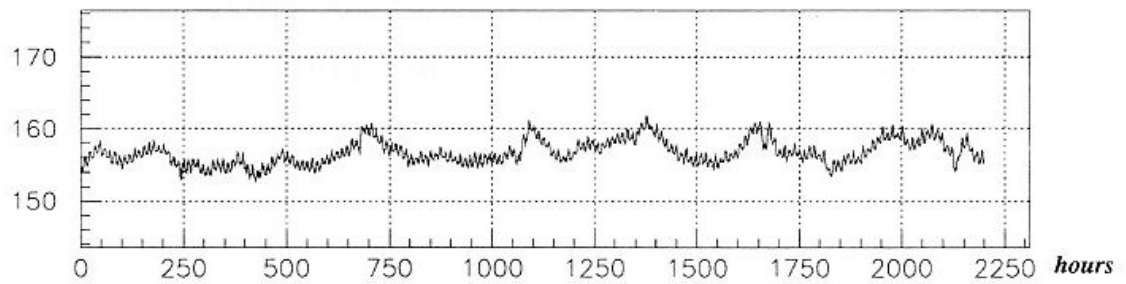


Figure 8. Determinations of the mean sea level using the program NSV on ocean data/Lanzarote

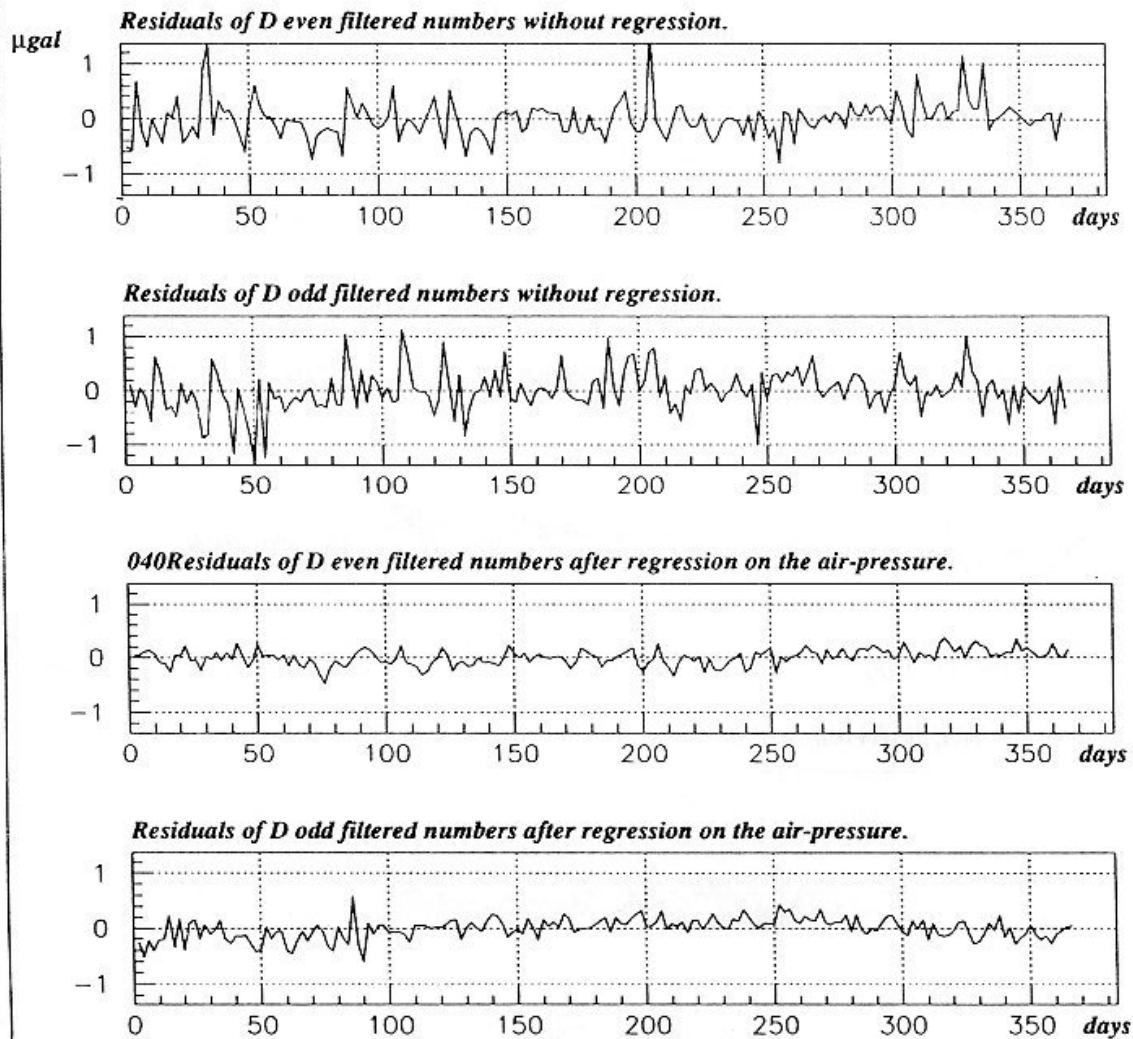


Figure 3. Study of the effect of the air pressure, options RESFN and TORO1 of NSV.
Data from superconducting gravimeter, Brussels, 15.11.1986-15.11.1987

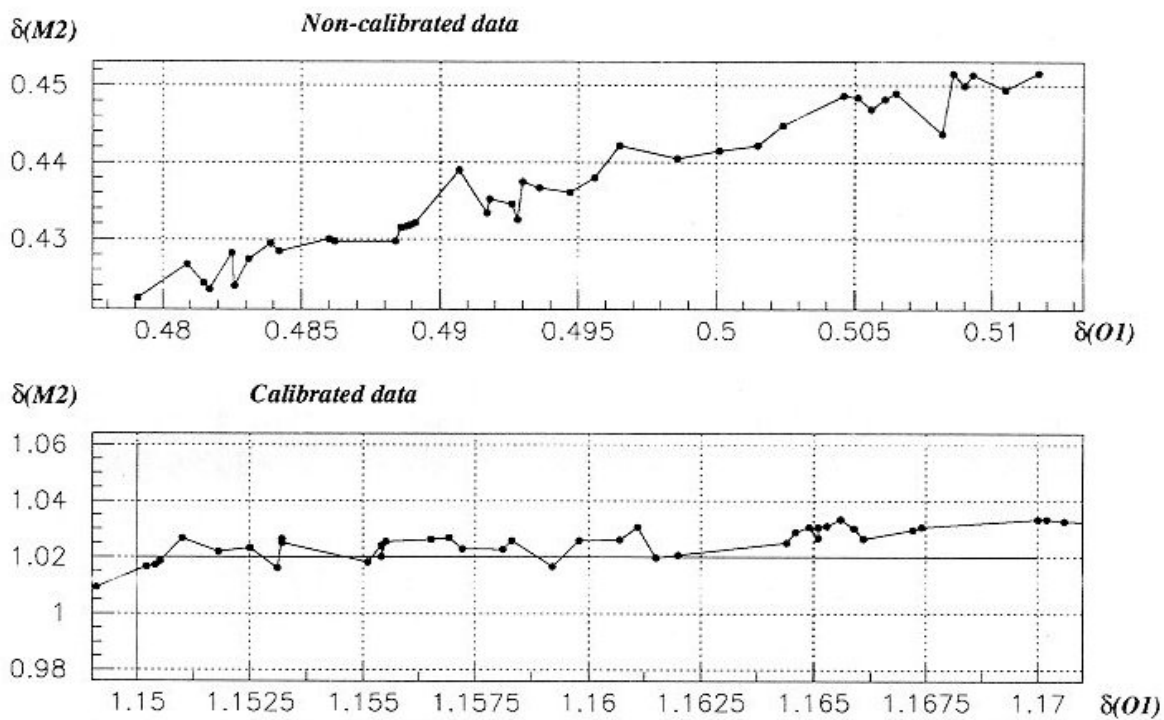
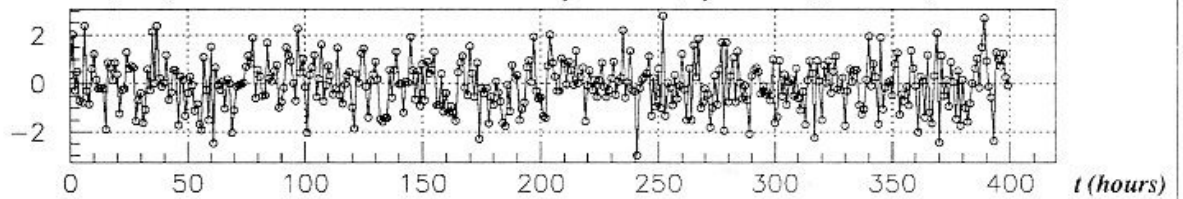
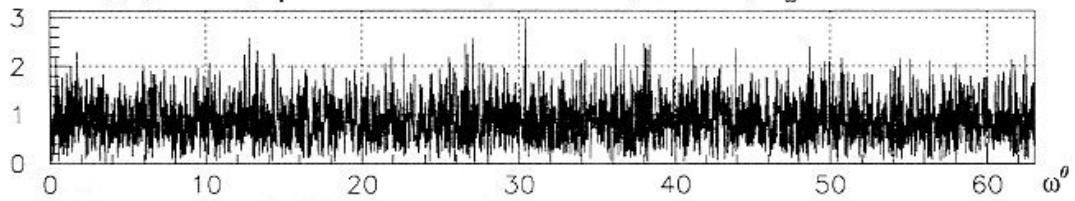


Figure 10. Program NSV, option SLOW, intervals of length 30 days without overlapping.
Station Lanzarote, gravimeter LCR G434/D, 14.05.87-13.06.1991

Sample of a simulated Gaussian white noise x_t , with $\text{Var}(x_t) = \sigma^2 = 1$, first 400 of $n = 18000$ points.



Energy spectrum of x_t or observed level of the noise represented by S_ω



Theoretical level of the noise $L_\omega = \sigma = 1$

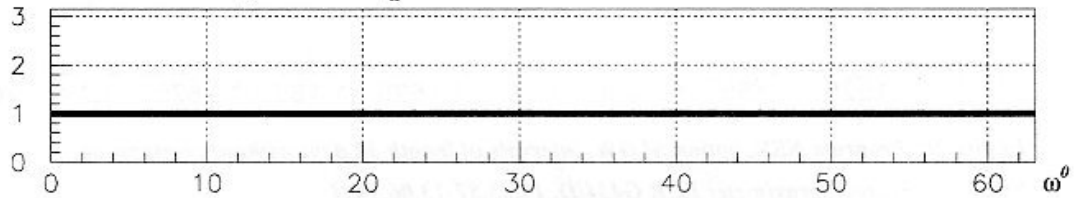


Figure 11. Gaussian white noise in time (x_t) and frequency domain (S_ω).

$S_\omega^2 = (n/2) p_\omega = (n/4) h_\omega^2$, where p_ω is power and h_ω is amplitude at frequency ω .

Mathematical expectation $E(S_\omega^2) = L_\omega^2 = \sigma^2 = 1$

GROT08

27/06/96 15.04

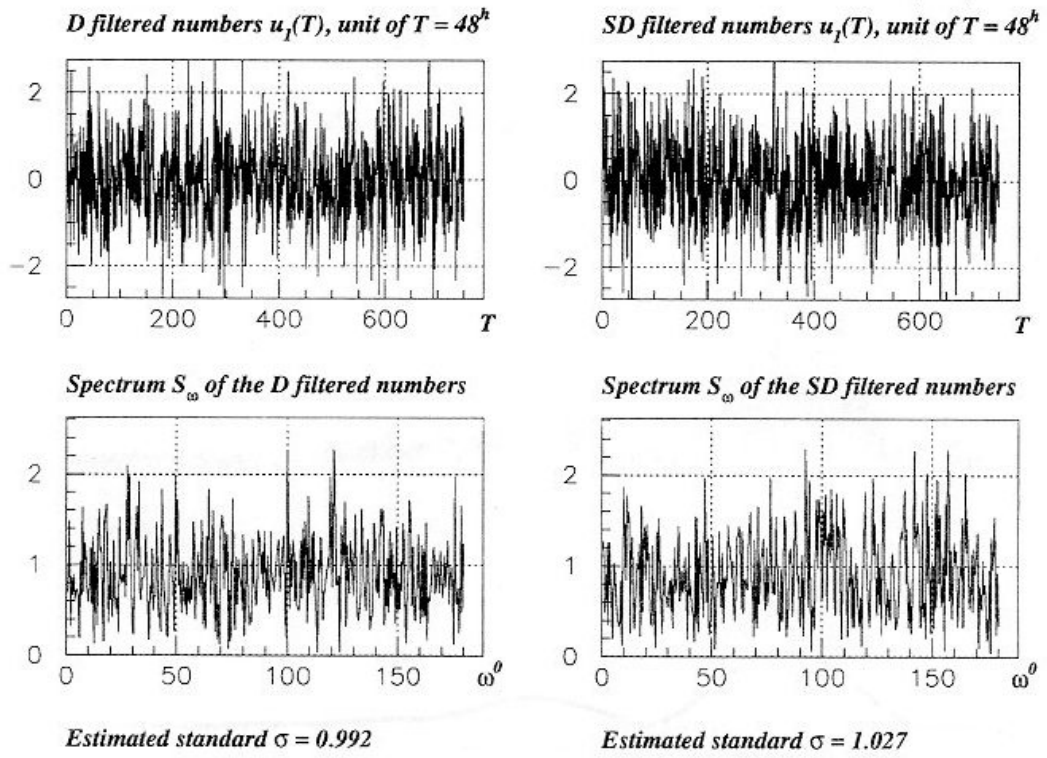
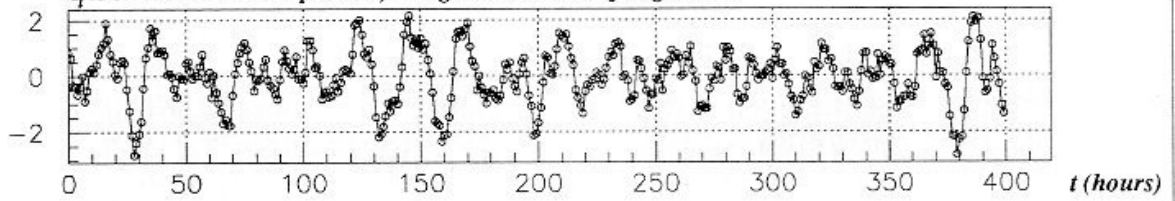
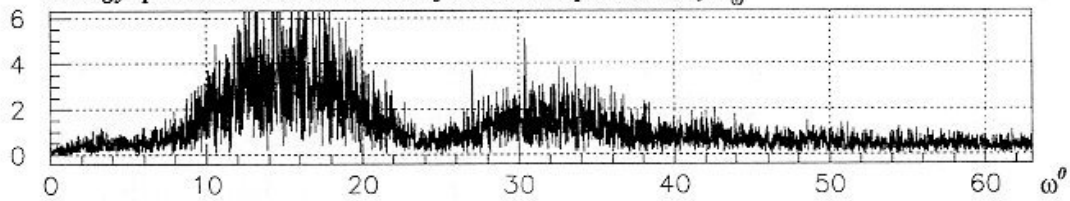


Figure 12. Analysis of simulated white noise x_t by the program NSV.

Sample of Gaussian correlated stationary noise z_t , $\text{Var}(z_t) = \sigma^2 = 1$, first 400 of $n = 17952$ points. z_t is simulated as MA process, using the WN data of Figure 11.



Energy spectrum or observed level of the noise represented by S_ω



Theoretical level of the noise = L_ω , varying with ω

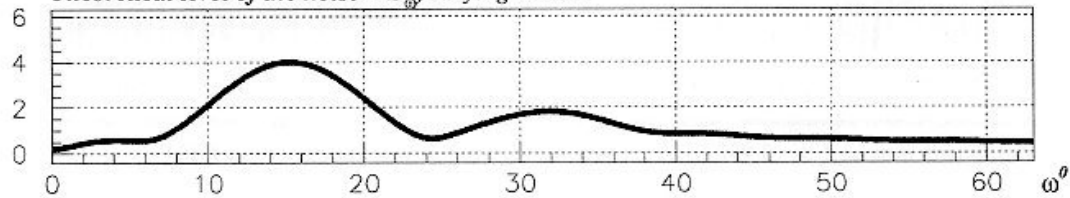


Figure 13 Simulated stationary noise in time (z_t) and frequency (S_ω) domain.

Mathematical expectation $E(S_\omega^2) = L_\omega^2$

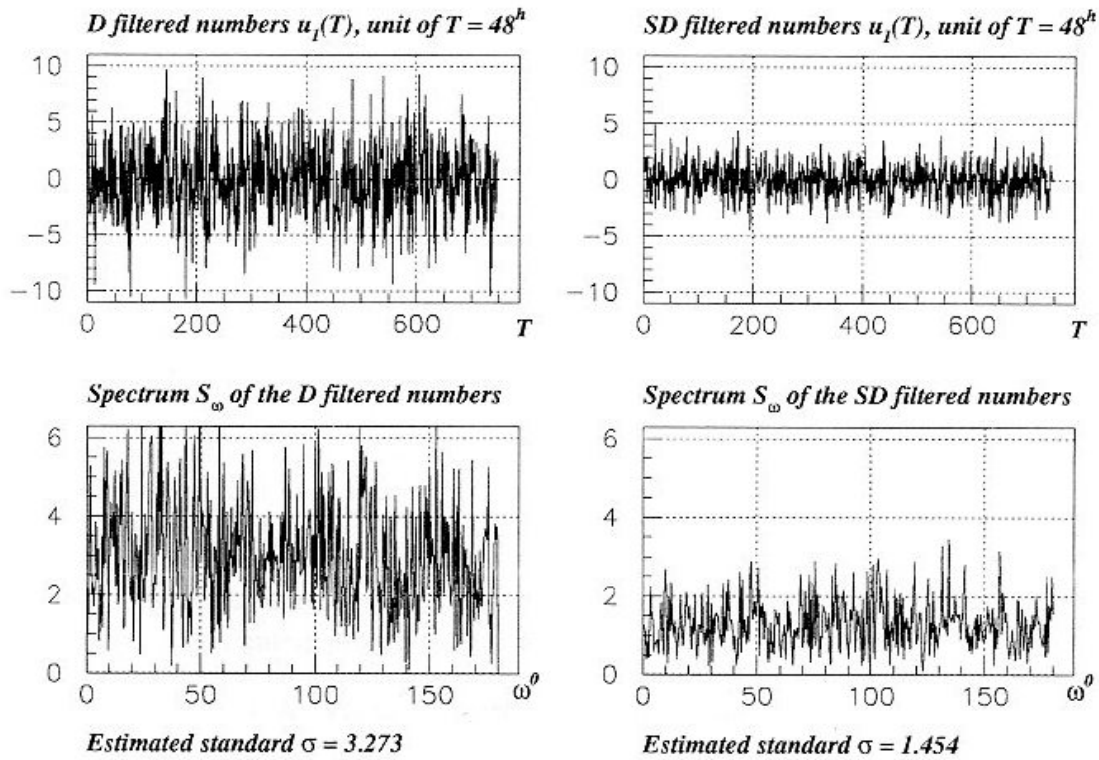


Figure 14. Analysis of simulated correlated noise z_t by the program NSV.

PUBLICACIONES DEL INSTITUTO DE ASTRONOMIA Y GEODESIA
DE LA UNIVERSIDAD COMPLUTENSE — MADRID

(Antes Seminario de Astronomía y Geodesia)

- 1.—Efemérides de 63 Asteroides para la oposición de 1950 (1949).
- 2.—E. PAJARES: Sobre el cálculo gráfico de valores medios (1949).
- 3.—J. PENSADO: Órbita del sistema visual σ^2 U Maj (1950).
- 4.—Efemérides de 79 Asteroides para la oposición de 1951 (1950).
- 5.—J. M. TORROJA: Corrección de la órbita del Asteroide 1395 "Aribeda" (1950).
- 6.—R. CARRASCO y J. M. TORROJA: Rectificación de la órbita del Asteroide 1371 "Resi" (1971).
- 7.—J. M. TORROJA y R. CARRASCO: Rectificación de la órbita del Asteroide 1560 (1942 XB) y efemérides para la oposición de 1951 (1951).
- 8.—M. L. SIEGRIST: Órbita provisional del sistema visual Σ 728-32 Orionis (1951).
- 9.—Efemérides de 79 Asteroides para la oposición de 1952 (1951).
- 10.—J. PENSADO: Órbita provisional de Σ 1883 (1951).
- 11.—M. L. SIEGRIST: Órbita provisional del sistema visual Σ 2052 (1952).
- 12.—Efemérides de 88 Asteroides para la oposición de 1953 (1952).
- 13.—J. PENSADO: Órbita de ADS 9380 = Σ 1879 (1952).
- 14.—F. ALCÁZAR: Aplicaciones del Radar a la Geodesia (1952).
- 15.—J. PENSADO: Órbita de ADS 11897 = Σ 2438 (1952).
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- 19.—J. BALTÁ: Recientes progresos en Radioastronomía. Radiación solar hiperfrecuente (1953).
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- 26.—J. M. TORROJA: Nueva órbita del Asteroide 1557 (1942 AD) (1954).
- 27.—R. CARRASCO y M. L. SIEGRIST: Rectificación de la órbita del Asteroide 1290 "Albertine" (1954).
- 28.—J. PENSADO: Distribución de los períodos y excentricidades y relación período-excentricidad en las binarias visuales (1955).
- 29.—J. M. GONZÁLEZ-ABOIN: Nueva órbita del Asteroide 1372 "Haremari" (1955).
- 30.—M. DE PASCUAL: Rectificación de la órbita del Asteroide 1547 (1929 CZ) (1955).
- 31.—J. M. TORROJA: Órbita del Asteroide 1554 "Yugoslavia" (1955).
- 32.—J. PENSADO: Nueva órbita del Asteroide 1401 "Lavonne" (1956).
- 33.—J. M. TORROJA: Nuevos métodos astronómicos en el estudio de la figura de la Tierra (1956).
- 34.—D. CALVO: Rectificación de la órbita del Asteroide 1466 "Mündleira" (1956).
- 35.—M. L. SIEGRIST: Rectificación de la órbita del Asteroide 1238 "Predappia" (1956).

- 36.—J. PENSADO: Distribución de las inclinaciones y de los polos de las órbitas de las estrellas dobles visuales (1956).
- 37.—J. M. TORROJA y V. BONGERA: Resultados de la observación del eclipse total de Sol de 30 de junio de 1954 en Sydkoster (Suecia) (1957).
- 38.—ST. WIERZBINSKI: Solution des équations normales par l'algorithme des cracoviens (1958).
- 39.—J. M. GONZÁLEZ-ABOIN: Rectificación de la órbita del Asteroide 1192 "Prisma" (1958).
- 40.—M. LÓPEZ ARROYO: Sobre la distribución en longitud heliográfica de las manchas solares (1958).
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- 42.—F. MARTÍN ASÍN: Un estudio estadístico sobre las coordenadas de los vértices de la triangulación de primer orden española (1958).
- 43.—ST. WIERZBINSKI: Orbite améliorée de h 4530 = γ Cen = Cpd -48° , 4965 (1958).
- 44.—D. CALVO BARRENA: Rectificación de la órbita del Asteroide 1164 "Kobolda" (1958).
- 45.—M. LÓPEZ ARROYO: El ciclo largo de la actividad solar (1959).
- 46.—F. MÚGICA: Un nuevo método para la determinación de la latitud (1959).
- 47.—J. M. TORROJA: La observación del eclipse de 2 de octubre de 1959 desde El Aaiun (Sahara) (1960).
- 48.—J. M. TORROJA, P. JIMÉNEZ-LANDI y M. SOLÍS: Estudio de la polarización de la luz de la corona solar durante el eclipse total de Sol del día 2 de octubre de 1959 (1960).
- 49.—E. PAJARES: Sobre el mecanismo diferencial de un celóstato (1960).
- 50.—J. M. GONZÁLEZ-ABOIN: Sobre la diferencia entre los radios vectores del elipsoide internacional y el esferoide de nivel (1960).
- 51.—J. M. TORROJA: Resultado de las observaciones del paso de Mercurio por delante del disco solar del 7 de noviembre de 1960 efectuadas en los observatorios españoles (1961).
- 52.—F. MÚGICA: Determinación de la latitud por el método de los verticales simétricos (1961).
- 53.—M. LÓPEZ ARROYO: La evolución del área de las manchas solares (1962).
- 54.—F. MÚGICA: Determinación simultánea e independiente de la latitud y longitud mediante verticales simétricos (1962).
- 55.—P. DÍEZ-PICAZO: Elementos de la órbita de la variable eclipsante V 499 Scorpionis (1964).
- 56.—J. M. TORROJA: Los Observatorios Astronómicos en la era espacial (1965).
- 57.—F. MARTÍN ASÍN: Nueva aportación al estudio de la red geodésica de primer orden española y su comparación con la red compensada del sistema europeo (1966).
- 58.—F. SÁNCHEZ MARTÍNEZ: La Luz Zodiacal. Luz del espacio interplanetario (1966).
- 59.—J. M. GONZÁLEZ-ABOIN: Variaciones de las coordenadas geodésicas de los vértices de una red, por cambio de elipsoide de referencia (1966).
- 60.—F. SÁNCHEZ MARTÍNEZ y R. DUMONT: Fotometría absoluta de la raya verde y del continuo atmosférico en el Observatorio Astronómico del Teide (Tenerife), de enero de 1964 a julio de 1965 (1967).
- 61.—M. REGO: Estudio del espectro de la estrella 31 Aql. en la región $\lambda\lambda$ 4000-6600 A (1969).
- 62.—C. MACHÍN: Mareas terrestres (1969).
- 63.—J. M. TORROJA: La estación para la observación de satélites geodésicos de la Facultad de Ciencias de la Universidad de Madrid (1969).
- 64.—M. J. SEVILLA: Reducción automática de posiciones de estrellas (1970).
- 65.—J. M. TORROJA: Memoria de las actividades del Seminario de Astronomía y Geodesia de la Facultad de Ciencias de la Universidad de Madrid en 1969 (1970).
- 66.—M. J. SEVILLA: Los cálculos de estación en triangulación espacial (1970).
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