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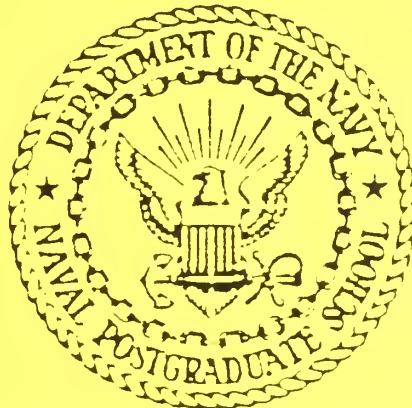
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A NOTE ON PROCESSING SEA LEVEL DATA

BY

LAURENCE C. BREAKER

JULY 1986

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# A Note On Processing Sea Level Data

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Abstract. Procedures for processing hourly observations of tidal elevation from NOAA/NOS tide gauges for the study of subtidal variability are outlined. Processing procedures include an adjustment for datum reference, low-pass filtering to remove the diurnal and semidiurnal tides, and a static correction for atmospheric pressure. These procedures are illustrated using a sequence of tidal elevation data from Santa Monica, California for the period 15 September to 15 December 1984.



## Introduction

The purpose of this note is to outline a set of procedures for processing hourly observations of tidal elevation to obtain information on subtidal variability.

### Recommended Processing Procedures

Sea level data obtained from the National Ocean Survey of the National Oceanic and Atmospheric Administration (NOAA/NOS) tide gages is normally provided on an hourly basis with tidal elevations given in feet. The first correction to be applied adjusts the tidal elevations which are referenced to an arbitrary datum initially, to datums which are referenced to either Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL), Mean Low Water (MLW), or Mean Lower Low Water (MLLW). NOAA/NOS provides the necessary data for each tide gauge location to make these corrections. The correction takes the following form:

$$\text{Adjusted Sea Level (feet)} = \text{Raw Observation (feet)} - \text{Correction (feet)}$$

To obtain MSL for example,

$$\text{MSL (feet)} = \text{Raw Observations (feet)} - \text{MSL Correction (feet)}$$

It is noted that because relative variations in sea level are generally of primary interest with regard to subtidal variability, no formal requirement to apply a datum correction in this case, exists.

The second adjustment that must be applied removes the diurnal and semidiurnal tidal components. The Godin low-pass digital filter is used to remove these components (Godin, 1972). The response of this filter can be expressed as



$$\tilde{A}_{25} \cdot \tilde{A}_{24}^2 / 25 \cdot 24^2$$

where

$$\tilde{A}_n(\sigma) = \frac{\sin(n\pi\Delta t\sigma)}{\sin(\pi\Delta t\sigma)}$$

$\sigma$  = frequency in cycles per day

$\Delta t$  = time interval between observations in days

$A_n$  represents the arithmetic summation of  $n$  observations with the filter operating on the data three times, first using 25-point means ( $\tilde{A}_{25}$ ) and then using 24-point means ( $\tilde{A}_{24}$ ), twice. According to Godin, the frequency band of this filter extends from 0 to 0.8 cycles per day (or 30 hours), beyond which the response is effectively zero. The response of this filter is shown in Figure 1. The half-amplitude cutoff is approximately 2.8 days (or ~66 hours). The amplitude of the diurnal and semidiurnal tidal components is reduced to less than 2% of the maximum value within the passband. A FORTRAN program implementing this tide-suppressing filter is contained in Appendix 1.

A third adjustment must be made to sea level data to remove the effects of atmospheric pressure. According to Lisitzin (1974), in the stationary case, the sea surface is depressed by 1 cm for every increase in atmospheric pressure of 1.005 mbar (and vice versa). It is noted, however, that such a simple static adjustment for atmospheric pressure does not take into account the effects of surface wind.

A relationship of the following form is recommended for making the sea level pressure (SLP) correction:

$$SL(t)_{adj} = (SL(t) - \overline{SL}) - (SLP(t) - \overline{SLP})^* \quad (1)$$

\* 1.000 vice 1.000cm/1.005 mbar is used here

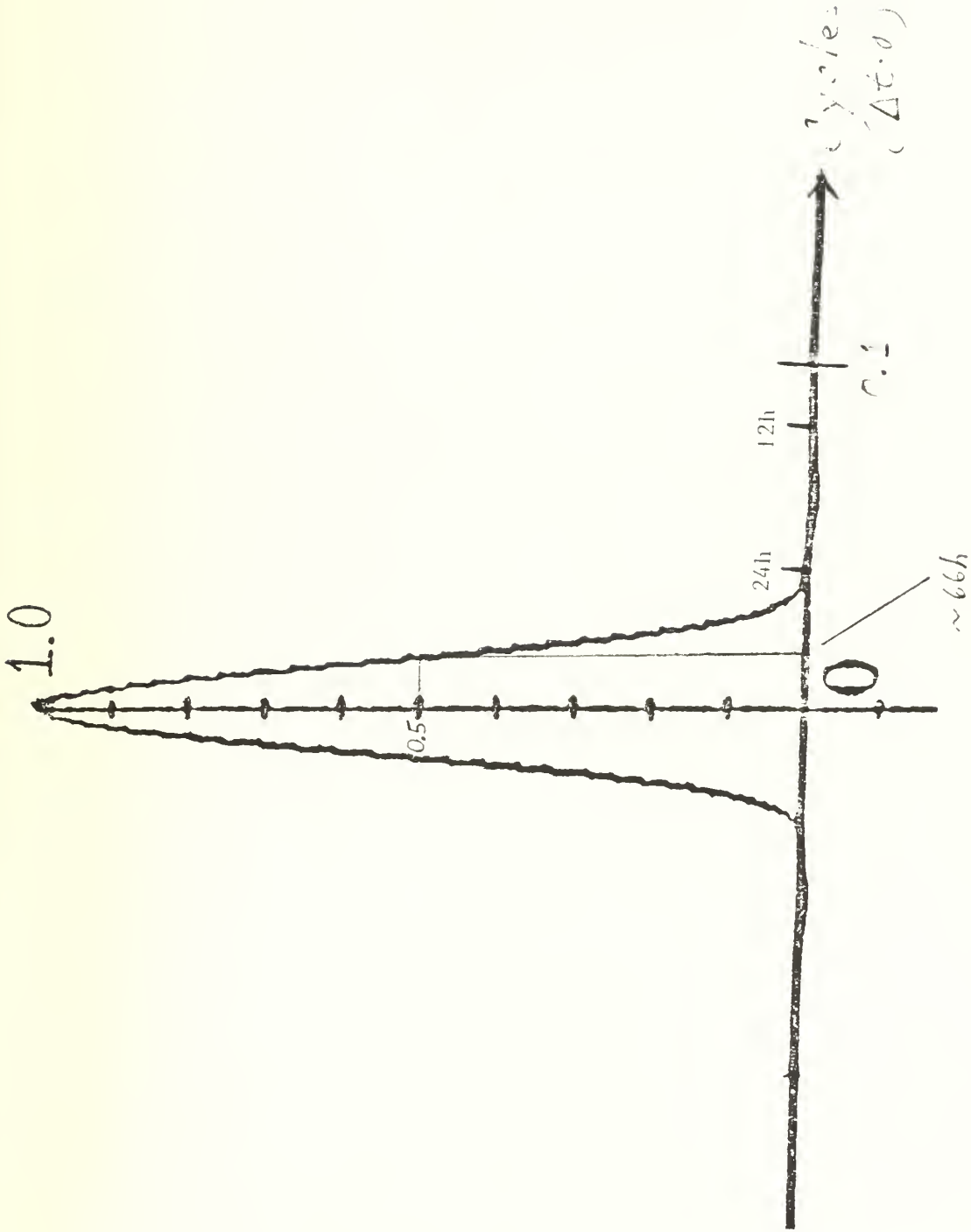


Figure 1. Response function for the Godin low-pass filter for removing the diurnal and semidiurnal tides from hourly observations. The passband extends from 0 to  $\sim 66$  hours.

where

$SL(t)_{adj}$  = Pressure corrected sea level (cm)

$SL(t)$  = filtered sea level (cm)

$\overline{SL}$  = mean value of filtered sea level (cm)

$SLP(t)$  = filtered sea level pressure (mbar)

$\overline{SLP}$  = mean value of filtered sea level pressure (mbar)

The filtered sea level should first be converted to centimeters. Next, the SLP data should be low-pass filtered in a manner similar to that used for the sea level data. In this regard, it is recommended that the Godin filter be applied to the SLP data as well. Equivalent filtering of SLP has the advantage of producing a smooth time series with the same "time constant" or degree of smoothness as the sea level data. As indicated, both  $SL(t)$  and  $SLP(t)$  should be mean corrected in order to complete the correction for atmospheric pressure. Finally, whether or not the two terms on the R.H.S. of (1) are actually added or subtracted will depend on the sign convention used to define sea level and sea level pressure. The correct choice, of course, will produce an adjusted series with decreases (increases) in sea level that correspond to increases (decreases) in sea level pressure.

#### An Example

A 92-day sequence of hourly sea level data from the NOAA/NOS tide gauge at Santa Monica, California was acquired to illustrate the foregoing procedures. A datum correction furnished with the data from NOAA/NOS was applied initially to produce a sequence referenced to MSL. Next, the Godin low-pass filter was applied to the sea level data to remove the diurnal and

semidiurnal tidal components (Figure 2). The upper panel in Figure 2 shows the mixed character of this tidal record which clearly contains both diurnal and semidiurnal components. The lower panel shows the sea level record with the tides removed. To apply the correction for atmospheric pressure, hourly SLP data from a nearby NDBC environmental data buoy (NDBC Buoy 46011 off Pt. Conception) were acquired. These data were likewise smoothed using the Godin low-pass filter (Figure 3). The predominant diurnal component in SLP is effectively removed using this filter (lower trace). In the final figure (Figure 4), the mean-corrected SLP (upper panel) is subtracted from the mean-corrected sea level (middle panel) to yield sea level which has been corrected for atmospheric pressure (lower panel).

## Discussion

Many different factors influence sea level. The time scales over which these factors are important vary from seconds to millenia. Only relatively short-term effects on sea level (< a few days) have been considered in the foregoing discussion. Although use of the Godin filter was recommended for removing the semidiurnal and diurnal tides, other tide-removing filters exist (Walters and Heston, 1982). In fact, Walters and Heston found that a so-called transform filter they describe generally had more desirable properties than the Godin filter. The only significant drawback they found in using the Godin filter is that in addition to removing tidal variations, it also attenuates variations in the 2 to 4 day range. For applications where information in this particular band is not of primary interest, however, the Godin filter is quite satisfactory.

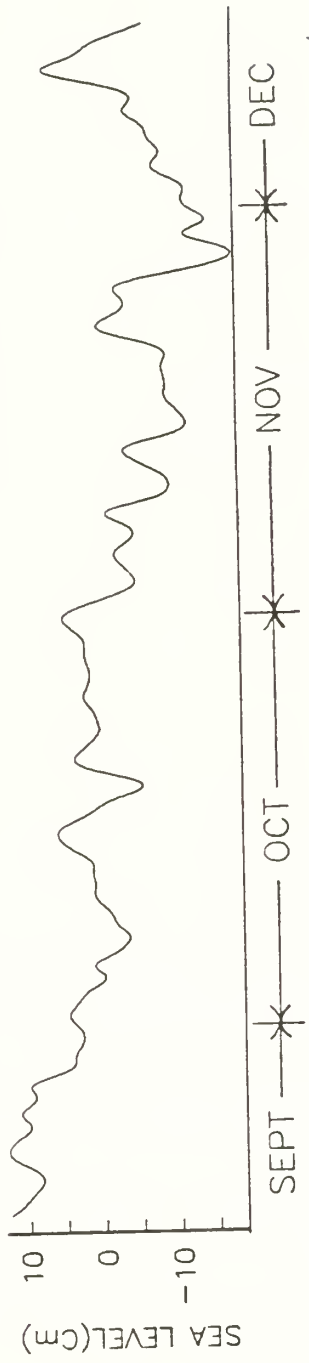
The simple adjustment for atmospheric pressure described here assumes that the direct response of the ocean to a change in SLP is hydrostatic.

Hamon (1966), however, has shown that such a simple one-to-minus one correspondence between SLP and sea level may not always be observed. Factors such as coastal trapped waves may contribute to the deviations from the hydrostatic approximation (Hamon, 1976). It is also possible to examine the phase relationship between SLP and sea level using the techniques of cross-spectral analysis (Hamon, 1966). When such an analysis is conducted, corrections for atmospheric pressure can be defined for a range of frequencies. Using this approach, Hamon (1966) found that changes in sea level often follow changes in SLP with lags ranging from 0 to 2 days.

SEA LEVEL—UNFILTERED



FILTERED SEA LEVEL



1 9 8 4

Figure 2. Hourly observations of sea level at Santa Monica, California from 15 September 1984 to 15 December 1984. Upper panel shows the original, unfiltered data and the lower panel the low-passed data using the Godin filter.

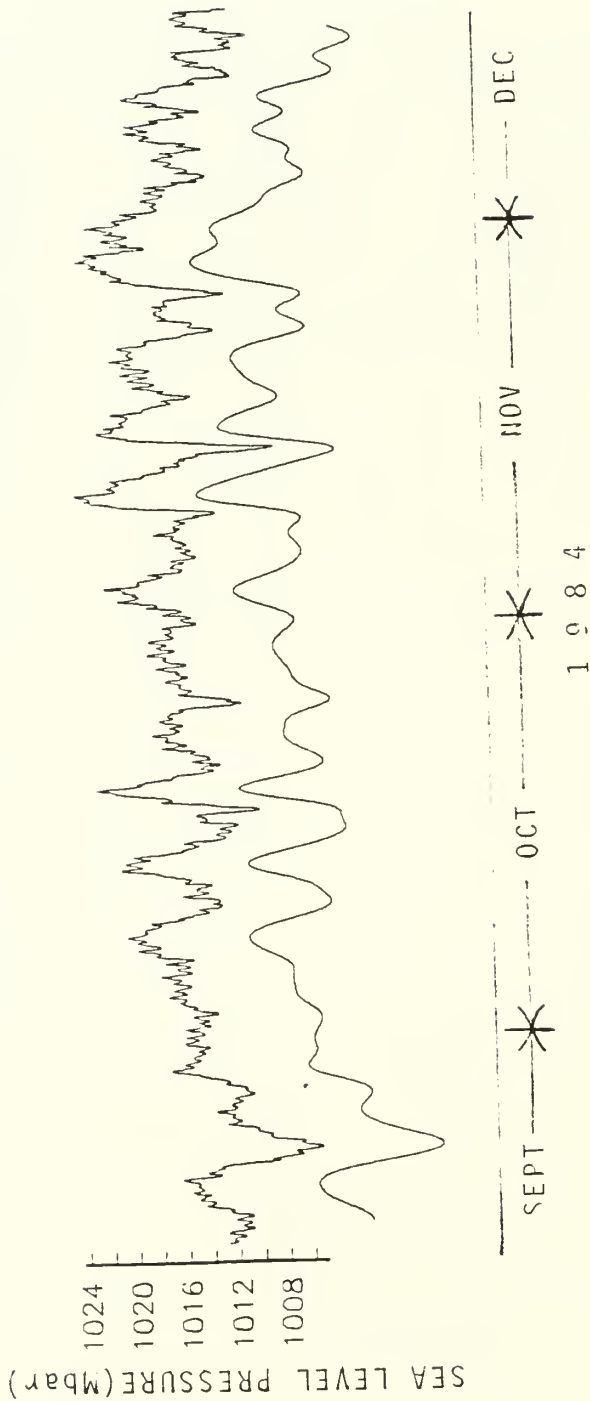


Figure 3. Hourly observations of sea level pressure at NDBC Environmental Data Buoy 46011 (34.9N, 120.9W). The upper trace represents the original unfiltered data and the lower trace the low-passed data using the Godin filter.

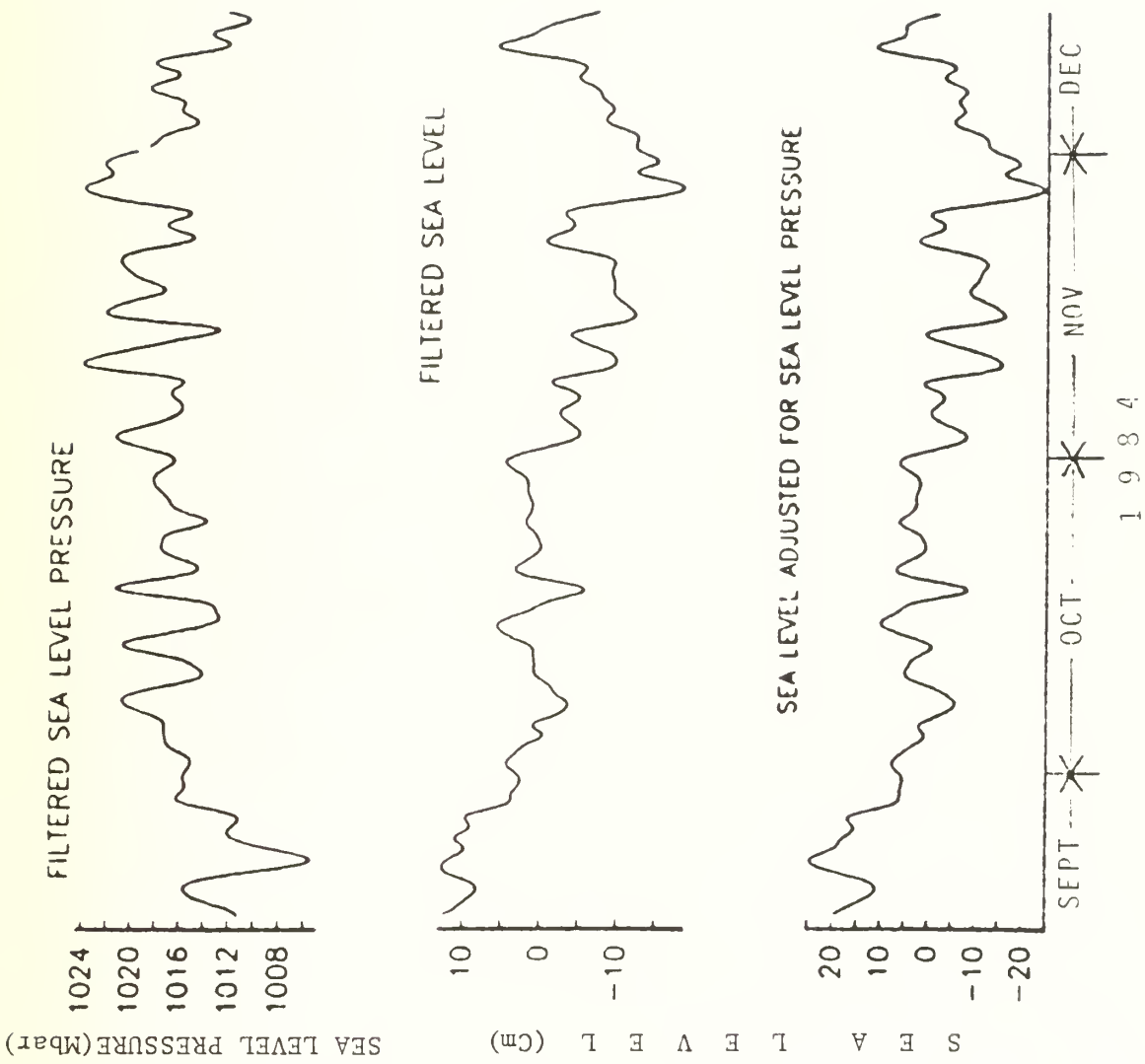


Figure 4. Filtered sea level pressure (upper panel), filtered sea level (middle panel), and filtered sea level corrected for filtered sea level pressure (lower panel).



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APPENDIX 1

FILE: GCDIN FORIRAN A1

```

C      GODIN FILTER APPLIES A 24 HR BOXCAR FILTER AND A 25 HR BOXCAR
C      CNCE TO HOURLY DATA. THE FIRST OUTPUT POINT IS 36 HOURS LATER
C      THAN THE FIRST INPUT POINT.
C
C      DIMENSION SL(3000)
C      INPUT ACTUAL NUMBER OF DATA POINTS TO BE READ IN THE FOLLOWING
C      STATEMENT
C      NREAD = NUMBER OF INPUT DATA POINTS
C      DO 66 J=1,NREAD
C         READ(5,11) SL(J)
66    CONTINUE
C      INSEPT ACTUAL DATA FORMAT IN THE FOLLOWING STATEMENT
C      11 FORMAT (DATA FORMAT)
C      FILTER THE DATA
C      CALL BCKCAR(SL,NREAD,24,1,NCUT1)
C      CALL BCKCAR(SL,NCUT1,24,1,NCUT2)
C      CALL BCKCAR(SL,NCUT2,25,1,NCUT3)
C      WRITE OUT THE FILTERED DATA
C      WRITE(6,14)
C      14 FORMAT(1X,'NUMBER OF FILTERED VALUES'//)
C      WRITE(6,15) NCUT3
C      15 FORMAT(11X,15,/)
C      DO 67 K=1,NCUT3
C         WRITE(6,12) SL(K)
67    CONTINUE
C      12 FORMAT(1X,F7.1)
C      STOP
C      END
C      SUBROUTINE BCKCAR(SL,NIN,LTH,IDEC,NCUT)
C      DIMENSION SL(2500)
C      NCUT = 0
C      ISTART = 1
C      20 IEND = ISTART + LTH - 1
C      IF(IEND.GI.NIN) GO TO 44
C      SUM = 0.
C      DO 30 I = ISTART,IEND
C      SUM = SUM + SL(I)
C      30 CONTINUE
C      NCUT = NCUT + 1
C      SL(NCUT) = SUM/FLCAT(LTH)
C      ISTART = ISTART + IDEC
C      GO IC 20
C      44 RETURN
C      END

```



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