Large-scale phenomena on interannual to interdecadal time scales detected from tide gauges and atmospheric data

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Climate variability at decadal to interdecadal time scales may, to a significant part, be associated with variations in the global atmospheric circulation pattern. Interannual to multidecadal sea-level variations at these time scales are partly resulting from mechanical forcing of the atmosphere. Consequently, changes in the atmospheric circulation pattern are recorded in the sea level. Coastal relative sea level (RSL) acts as a low-pass filter of the forcing and therefore it is particularly sensitive to variations of the forcing on longer time scales.

The global data set of monthly mean RSL data available at the Permanent Service for Mean Sea-Level (PSMSL) provides a basis to study the decadal variability of coastal RSL in relation to atmospheric parameters over nearly the last one hundred years. In the present study, the patterns or ”finger-prints” found in the RSL data are compared to similar patterns in atmospheric parameters (in particular, air pressure). Global data sets of monthly means of relevant parameters such as air pressure, temperature, percipitation and sea level, covering the last up to 200 years are generally biased towards the Northern Hemisphere and towards recent decades. The best data coverage with long records is found on both sides of the North Atlantic (see Figure 1). Therefore, the analyses reported here are mainly restricted to these regions. The time scales considered are interdecadal time scales and the seasonal cycle.

Climate variability at decadal to interdecadal time scales can be expected to introduce long-period modulations of the seasonal cycle in climatological parameters with characteristic spatial patterns [Plag and Tsimplis, 1999]. Sequences of geographic maps of the seasonal cycle are constructed for subsequent time intervals for the different parameters [see Plag and Tsimplis, 1999, for a detailed description of the methodology]. These maps reveal distinctive spatial variations of the seasonal cycle. For example, in North Atlantic air pressure the transitions from land to ocean are characterised at the western boundary by smooth variations of the seasonal cycle and at the eastern boundary by phase changes of 180 degrees over a narrow ($\approx$ 100 km wide) zone following approximately the coast line. For each investigated parameter, significant temporal variations of the seasonal cycle are found in both amplitude and phase. These variations are spatially coherent with the largest temporal changes generally close to the boundaries of climate domains. For example, in air pressure the largest variations are found close to the narrow transition zone at the eastern boundary of the North Atlantic. However, detecting temporal variations in such small-scale spatial patterns of the seasonal cycle requires climatological data sets with high spatial resolution.

To derive spatial patterns of interdecadal variations, the time series are low-pass filtered. Due to the presence of gaps in all time series, integration over time is used to strongly reduce shorter period variations. Thus, for each time series $x(t)$, we consider the function

$$y(t) = \int_0^t r(t')dt', \qquad (1)$$

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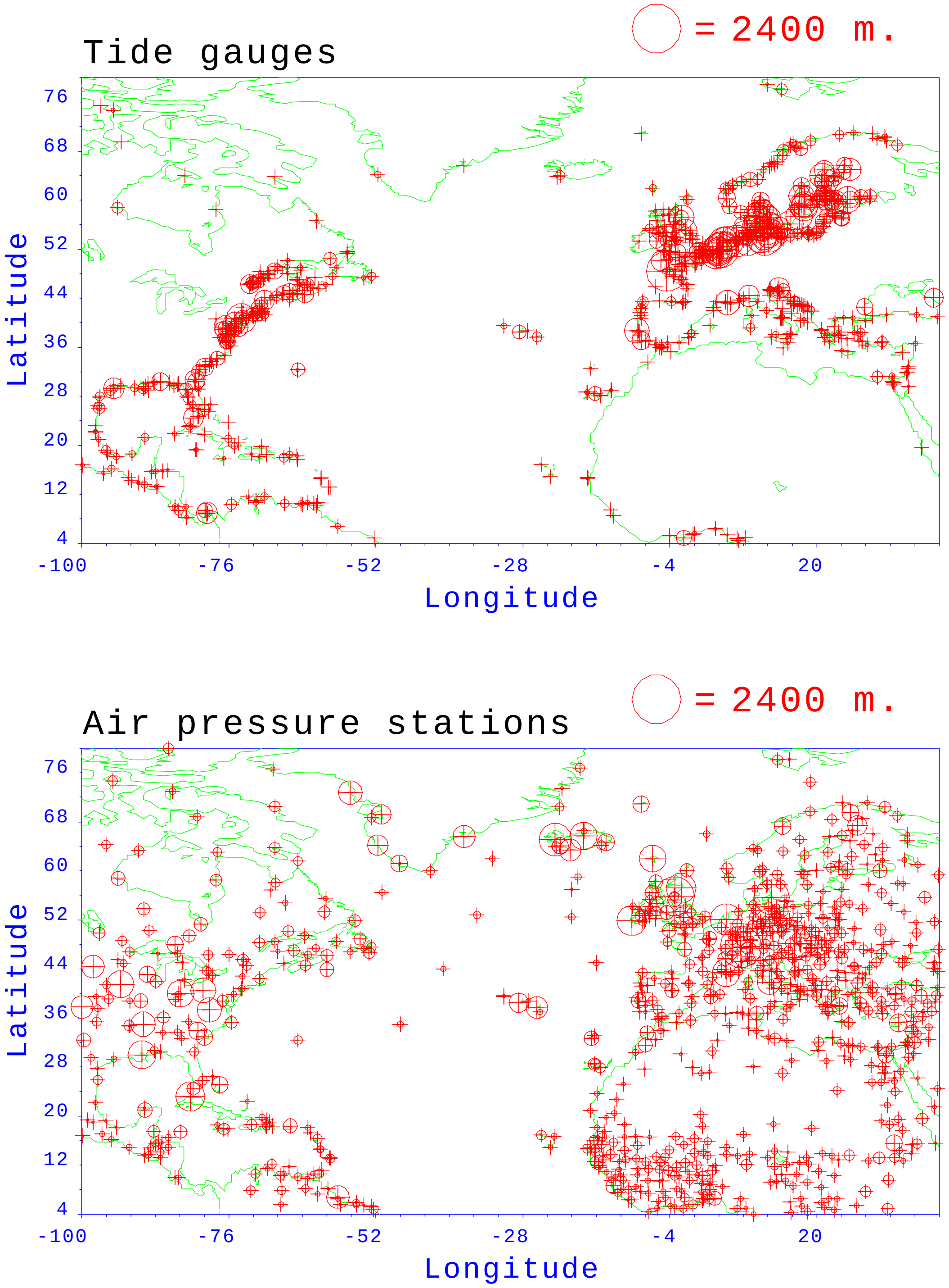

Figure 1: Location of time series.
Upper diagram: RSL; Permanent Service for Mean Sea Level data base [Spencer and Woodworth, 1993]. Lower diagram: Air pressure; The Global Historical Climatology Network, Carbon Dioxide Information Analysis Center. Note that the size of the circles at each station is proportional to the length of the time series in months.

where $r(t)$ is the residual after the seasonal cycle and a linear trend have been removed, i.e.

$$r(t) = x(t) - [A_{\mathrm{Sa}} \sin(\omega_{\mathrm{Sa}} * t - \varphi_{\mathrm{Sa}}) + A_{\mathrm{Ssa}} \sin(\omega_{\mathrm{Ssa}} * t - \varphi_{\mathrm{Ssa}}) + a + bt.] \tag{2}$$

Here, Sa and Ssa denote the annual and semiannual harmonic constituents, respectively. The parameters A_{Sa}, φ_{Sa}, A_{Ssa}, φ_{Ssa}, a and b are determined in a least squares fit to $x(t)$.

Auto- and cross-correlation functions of these y–functions are used to describe a spatial pattern. Auto-correlation functions of the long RSL records show a high spatial coherency for both the European and the East coast of North America, indicating a 80 year-scale variation. Cross-basin correlation reveals a clear anti-correlation of this long-period variation (see Figure 2). Without further evidence, this pattern might be interpreted as a slow east-west oscillation in RSL.

However, it has to be noted that all long RSL records available from the East coast of North America originate from stations further south than most of the European stations. In fact, all of them have latitudes lower than the Netherlands. The only European station at a comparable latitude is Cascais, and for Cascais we find a good correlation with (for example) New York with only a small time lag of approximately 8 years. Thus, the pattern may also be explained as a slow north-south oscillation.

In air pressure records, the same long-period oscillation is found and a similar spatial pattern is revealed (see Figure 3). Spatial coherency is found for all stations at latitudes higher than Vienna and also for those at lower latitudes. There is a clear anti-correlation in the air pressure of these north and south regions. For both regions, air pressure appears to be anti-correlated with sea level, which is in agreement with an inverted barometer response of sea level to air pressure variations.

Taking into account the definition of $y(t)$, a periodic variation in the original time series will have the form

$$\int_0^t a \sin \omega t dt = \frac{a}{\omega}(1 - \cos \omega t). \tag{3}$$

Therefore, we can interpret the results shown in Figure 2 as a variation with an amplitude of the order of 40 mm. For air pressure in Europe, we find a similar oscillation with an amplitude of 1 to 2 hPa. Assuming an inverted barometer response, then the variation in air pressure could explain about 50 % of the variation found in RSL.

The results presented here indicate the presence of a slow north-south variation in air pressure and sea-level at a time scale of approximately 80 years. It is speculated that this oscillation is related to a variation in temperature on a similar time scale as described in Schlesinger and Ramankutty [1994].

References

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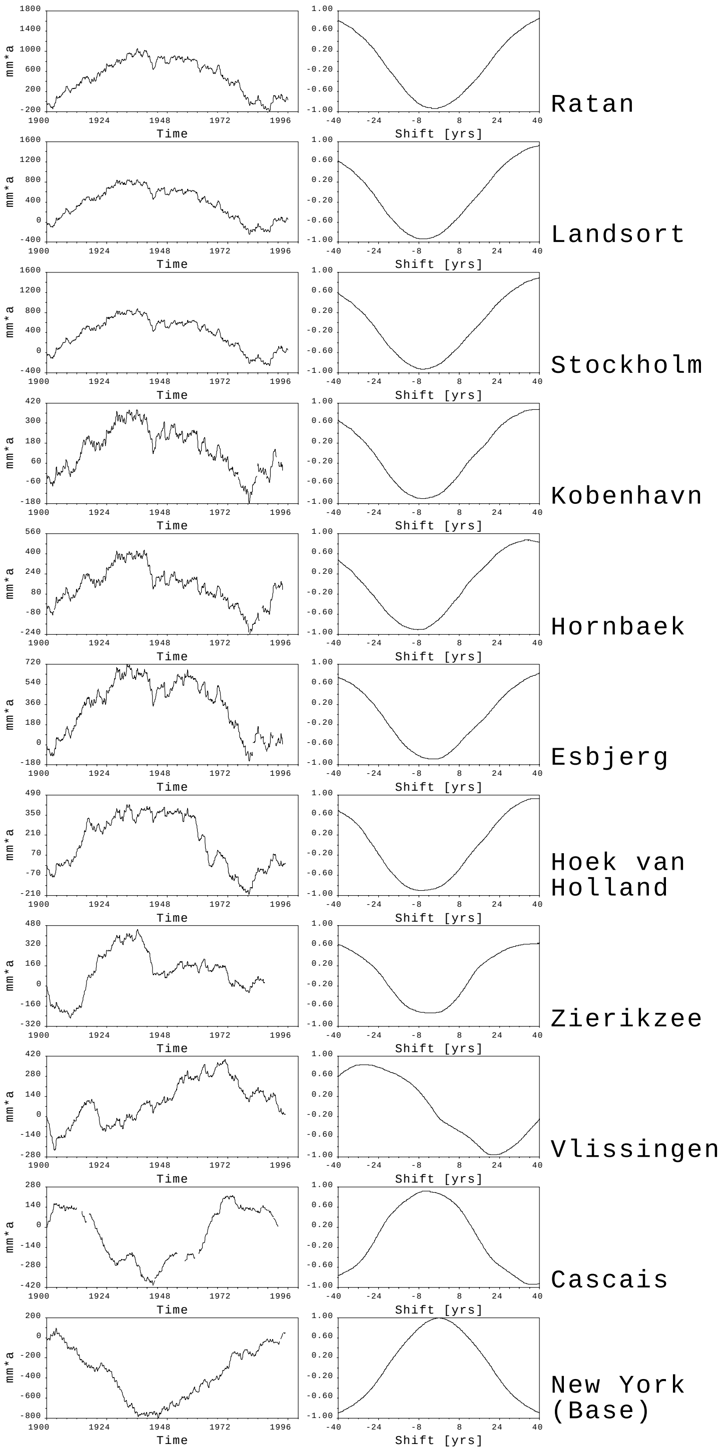

Figure 2: Cross-correlation of RSL time series.
Left column: RSL function as defined in eq. 2 for New York and several European stations. European stations are sorted according to latitude with high latitudes on top. Note the high degree of coherency for all series north of Zierikzee. A similar picture is found for stations on the East coast of North America. Right column: Crosscorrelation of the RSL function for the European stations with the RSL function for New York. Note that all European stations except for Cascais are anti-correlated with New York. The anti-correlation is found for all other long records from the East coast of North America.

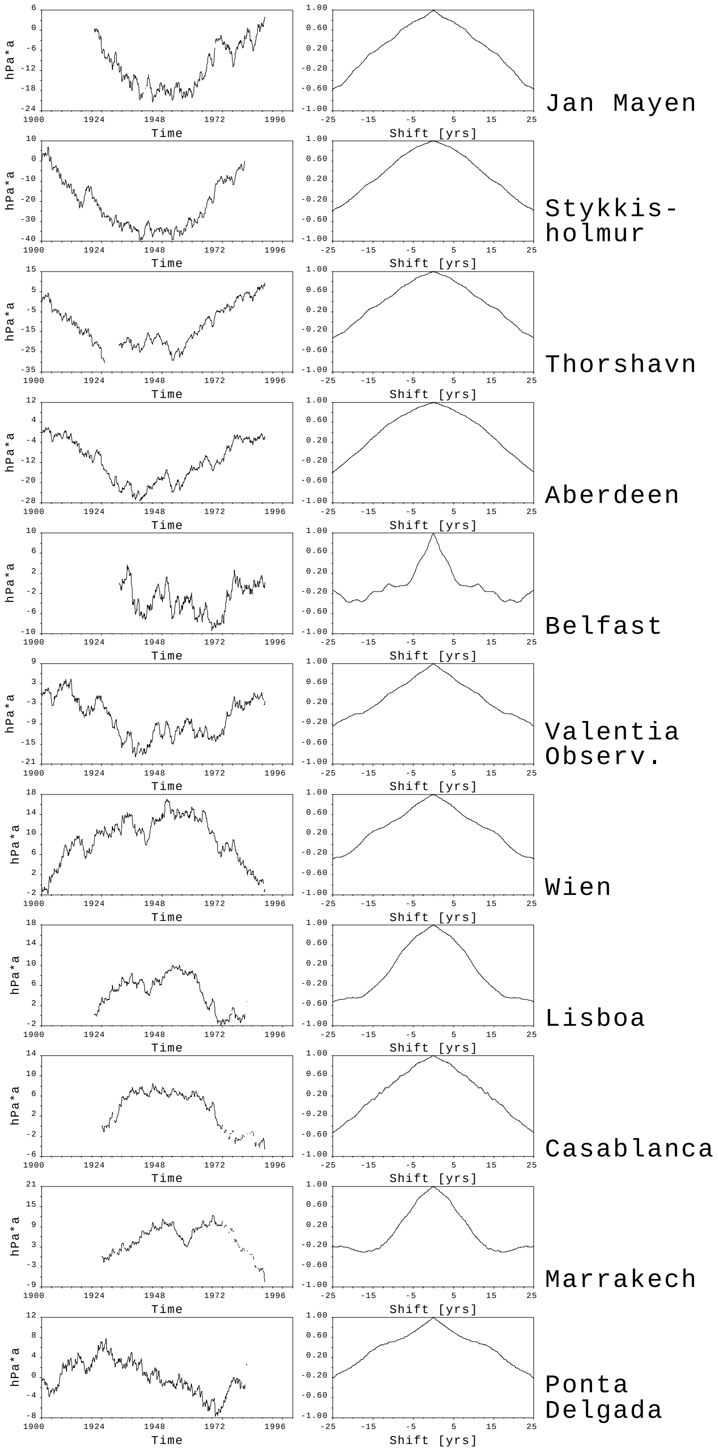

Figure 3: Auto-correlation of air pressure time series.
Left column: Air pressure function as defined in eq. 2 for several European stations. Stations are sorted according to latitude with high latitudes on top. Note the high degree of coherency for all series north of Viena (Wien). Right column: Auto-correlation of the air pressure function.