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A RETROSPECTIVE STUDY OF PARTICLE RETENTION ON THE OUTER BANKS OF THE SCOTIAN SHELF 1956-1993

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by

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ABSTRACT

Cong, L., J. Sheng and K.R. Thompson. 1996. A retrospective study of particle retention on the outer banks of the Scotian Shelf, 1956-1993. Can. Tech. Rep. Hydrogr. Ocean. Sci. 170: viii + 132 pp.

Retention indices for the Scotian Shelf, based on the trajectories of water particles at 30 m depth, are calculated for each March and April over the period 1956 to 1993 using a three-dimensional circulation model. The model is driven by density gradients, wind stress and flows through its open boundaries. The circulation driven by horizontal density gradients is assumed steady and diagnosed from all avaliable density data for the region. Forcing by wind stress is assumed spatially uniform and equal to that observed at Sable Island. The open boundary conditions are that (i) sea-level is clamped to zero along the shelf break; (ii) outward propagating gravity waves leave the model domain through the southeast open boundary; (iii) sea-level is linear along the northeast open boundary and equal to zero at the shelf break. The time-varying coastal sea-level at northeast open boundary is inferred from sea-level observed at Halifax using a statistical scheme. The predicted trajectories show that most of the particles seeded on the Scotian Shelf are carried to the southwest by a relatively strong coastal current (the Nova Scotian Current). However particles are retained over some offshore areas, including the Gully, Banquerau Bank, Western Bank and Emerald Bank. To quantify the tendency of particles to remain in the same general area we introduce a "retention index" defined as the proportion of particles retained in a box of a given size. We also compare the annual variation in retention indices for known spawning sites of Scotian Shelf cod with their year-class success. Significant positive correlations are found between the retention indices for March-April and the catch rate of cod of length 18-23 cm from the July research vessel surveys around Western Bank. This suggests that good year-classes may be

associated with reduced dispersion of larvae from their spawning areas during this critical period in their early life history.

RÉSUMÉ

Cong, L., J. Sheng and K.R. Thompson. 1996. A retrospective study of particle retention on the outer banks of the Scotian Shelf, 1956-1993. Can. Tech. Rep. Hydrogr. Ocean. Sci. 170: viii + 132 pp.

On a calculé les indices de rétention pour la plate-forme Scotian à partir des trajectoires des particules d'eau à une profondeur de 30 m, entre mars et avril au cours de la période de 1956 à 1993, à l'aide d'un modèle de circulation en trois dimensions. Les paramètres du modèle sont les gradients de densité, la force d'entrainement du vent et les courants à travers des frontières ouvertes. La circulation provoquée par les gradients horizontaux de densité est considérée comme stable et elle est calculée à partir de toutes les données de densité disponibles dans la région. Le forçage par la force d'entrainement du vent est considéré comme uniforme dans l'espace et égal à celui observé pour l'ile de Sable. Les conditions pour les frontières ouvertes sont: i) le niveau de la mer est fixé à zéro le long de la faille du plateau; ii) les ondes de gravité qui se propagent vers l'extérieur quittent le domaine du modèle par la frontière ouverte du sud-est; iii) le niveau de la mer est linéaire le long de la frontière ouverte du nord-est égal à zéro au niveau de la faille du plateau. Le niveau de la mer au niveau de la côte à la frontière ouverte du nord-est, qui varie dans le temps, est calculé à partir du niveau de la mer observé à Halifax à l'aide d'une formule statistique. Les trajectoires prédites montrent que la plupart des particules qui se retrouvent sur la plate-forme Scotian sont transportées vers le sud-ouest par un courant côtier relativement fort (courant de la Nouvelle-Écosse). Toutefois, des particules sont retenues à certains endroits au large, notamment dans le Gully, sur le Banquereau, sur le banc Occidental et sur le banc Émeraude. Pour mesurer la tendance des particules à rester dans la même zone générale, nous introduisons un "indice de rétention", lequel est défini comme la proportion de particules retenues dans une boite de la même taille. Nous comparons également la variation annuelle des indices de rétention dans des frayères connues de la morue de la plate-forme Scotian en fonction du succès des classes annuelles. On observe des corrélations positives significatives entre les indices de rétention pour mars-avril et le taux de capture de la morue de 18 à 23 cm de longueur mesuré dans le cadre des études du navire de recherche, en juillet, dans la zone du banc Occidental. Ces résultats indiquent que de bonnes classes annuelles pourraient être associées à une réduction de la dispersion des larves hors de leurs frayères durant cette période cruciale des premiers stades de leur vie.

1. INTRODUCTION

Significant biological changes, such as shifts in the temporal distribution of cod larvae and collapses in the cod fishery, have occurred in eastern Canadian waters in recent years. It is generally believed that variations in the physical oceanographic environment of the North Atlantic may play an important role in the population dynamics of cod (de Young and Rose, 1993). In this report we examine the influence of shelf circulation, and in particular the effect of dispersion by wind and density driven currents, on the survival of cod larvae on the outer Scotian Shelf. The transformation of wind stress into particle dispersion is highly non-linear. It is therefore perhaps not surprising that simple correlations of wind and cod recruitment have had limited success in explaining year to year variations in the abundance of cod. In this report we use a three-dimensional (3D) model as a non-linear filter to convert wind stress, water density and coastal sea-level into more biologically-meaningful indices such as the proportion of particles that are retained on a particular offshore bank during a particular spawning season. Our specific objectives are twofold: (1) to calculate time series of retention indices for different parts of the Scotian Shelf and (2) correlate the time-varying indices with cod recruitment to test the hypothesis that higher retention in the spawning area during the larval stage leads to stronger year classes.

The retention index used in this report is defined as the percentage of water particles that remain in a box of a given size centered on a given location over a given period. The size of the box is arbitrary. We took it to approximate the size of the offshore spawning areas (eg. Frank et al., 1994). If we assume cod larvae are passively advected, and retention near their birth site is favorable to survival, we can then interpret the retention indices as proxies for the probability of survival of cod larvae. In a recent literature review Sclafani (1992) concluded that, on average, the center of mass for early yolk-sac larvae is at a depth of about 30-40 m. It has also been reported that spring is one of two major spawning periods for eastern Scotian Shelf cod (Frank et al., 1994). Consequently, we calculated the retention indices based on the movement of particles seeded at 30 m depth and subsequently tracked for each March and April over last 38 years.

The trajectories of the particles are calculated numerically using model-predicted flow fields at 30 m depth. The time-varying flow fields are calculated using the 3D shelf circulation model developed by Sheng and Thompson (1993). It is driven by a time-varying but spatially-uniform wind stress and inflows through the open boundaries. The wind stress is calculated from observations at Sable Island. The open boundary conditions are that (i) sea-level is clamped to zero along the shelf break; (ii) outward propagating gravity waves leave the model domain through the southeast open boundary; (iii) sea-level is linear along the northeast open boundary and equal to zero at the shelf break. The time-varying coastal sea-level at the northeast open boundary is inferred from sea-level observed at Halifax using a straightforward statistical scheme. The winter baroclinic shelf circulation is treated as the model background flow. It is diagnosed from measured density profiles using the robust diagnostic method proposed recently by Sheng and Thompson (1996a).

The outline of this report is as follows. The circulation model is described in Section 2, along with the winter baroclinic flow at 30 m depth diagnosed from observed density profiles. In Section 3 the calculation of the retention indices is discussed. Results are described in Section 4 and summarized in Section 5.

2. CIRCULATION ON THE SCOTIAN SHELF

Our underlying assumption is that the dynamics controlling the evolution of the circulation is sufficiently linear that we can approximate the flow by a linear combination of two flow components. The baroclinic component is assumed steady over the course of a season and is diagnosed from observed density profiles. The barotropic component is driven by surface wind and flows through the open boundaries of the model (Sheng and Thompson, 1993). The model domain and the bathymetry of the Scotian

Shelf are shown in Figure 1.

2.1 Baroclinic Flow

The winter baroclinic flow at 30 m depth on the Scotian Shelf was diagnosed from all available vertical density profiles collected over the last 70 years. (These data were kindly provided by Dr. Ken Drinkwater of the Bedford Institute of Oceanography). The detailed description of the method is given by Sheng and Thompson (1996a) and Sheng and Thompson (1996b). One feature of the method is that it does not require interpolation of the density data onto a model grid. It is also robust and straightforward to use (see Sheng and Thompson, 1996a). Note that the baroclinic flow at 30 m depth can be calculated from the surface baroclinic flow by including a correction term to allow for horizontal density variations in the top 30 m. For circulation on the Scotian Shelf in winter, it was found that this correction term was generally small.

The diagnosed surface baroclinic flow agrees reasonably well with current observations (Sheng and Thompson, 1996a) and reproduces most of the known features of the large-scale circulation. The flow at 30 m depth is reinforced between Canso and Banquerau Banks by an onshore flow around the western flank of Banquerau Bank. It accelerates as it passes Middle Bank and then splits into two branches: one turns southward and approaches the shelf break over the eastern flank of Sable Island Bank; the other flows northward before turning westward on approaching the coast and being reinforced by an onshore flow around Western Bank (Figure 2). The strong coastal jet (the Nova Scotian current) runs through Emerald Basin and then over LaHave Bank. Several small-scale features are also evident including clockwise gyres around Middle and Western Banks and a counter-clockwise gyre over Emerald Basin.

2.2 Barotropic Flow

A detailed description of the 3D barotropic shelf circulation model is given by Sheng and Thompson (1993) and Thompson and Sheng (1996). A brief discussion is provided below.

The linearized horizontal momentum and continuity equations governing 3D barotropic flow on the continental shelf are taken to be:

$$\frac{\partial \vec{u}}{\partial t} + \vec{f} \times \vec{u} = -g\nabla\eta + \frac{\partial}{\partial z}\left(\mu\frac{\partial \vec{u}}{\partial z}\right) \tag{1}$$

and

$$\frac{\partial \eta}{\partial t} + \nabla \cdot \int_{-h}^{0} \vec{u} dz = 0 \tag{2}$$

where $\vec{u} = (u, v)$, η is the surface elevation, and the rest of the notation is standard.

The top and bottom boundary conditions are

$$\mu\frac{\partial \vec{u}}{\partial z} = \begin{cases} \vec{\tau}/\rho & z = 0 \\ k\vec{u} & z = -h \end{cases} \tag{3}$$

where $\vec{\tau} = (\tau_x, \tau_y)$ is the wind-stress.

Sheng and Thompson (1993) suggested the following decomposition:

$$\vec{u} = \vec{u}_E + \vec{u}_R \tag{4}$$

where $\vec{u}_E$ is the steady Ekman flow, which can be calculated locally, and $\vec{u}_R$ is the remainder, which satisfies the following momentum and continuity equations:

$$\frac{\partial \vec{u}_R}{\partial t} + \vec{f} \times \vec{u}_R = -g\nabla\eta + \frac{\partial}{\partial z}\left(\mu\frac{\partial \vec{u}_R}{\partial z}\right) - \frac{\partial \vec{u}_E}{\partial t} \tag{5}$$

and

$$\frac{\partial \eta}{\partial t} + \nabla \cdot \int_{-h}^{0} \vec{u}_R dz = -\nabla \cdot \int_{-h}^{0} \vec{u}_E dz \tag{6}$$

The associated boundary conditions are given by (3) with $\vec{\tau} = 0$. $\vec{u}_R$ is numerically calculated using the Galerkin-spectral method. This involves expressing $\vec{u}_R$ in terms of vertical structure functions. Thompson and Sheng (1996) found that four vertical structure functions were adequate for modelling the subtidal circulation on the Scotian Shelf.

This model has been used by Thompson and Sheng (1996) to hindcast the wind-driven circulation on the Scotian Shelf during the Canadian Atlantic Storm Project (CASP) in the winter of 1985-6. The same model setup is used in this report: the model horizontal resolution is defined by $\Delta x = 5.33$ km and $\Delta y = 7.41$ km, and the model time step was $\Delta t = 50$ sec. The values of other model parameters were set the generally accepted values and are given by Thompson and Sheng (1996).

The spin-up time of the model is about 24 hours for the Scotian Shelf. It follows that the initial conditions are relatively unimportant for the integration periods of interest here which are on the order of one month. Therefore, we took the initial conditions to be a state of rest.

The model domain has two solid boundaries (Figure 1). One is around Sable Island and the other coincides approximately with the 10-m isobath adjacent to the coast. The three open boundaries include the offshore boundary that runs approximately along the 200-m isobath, and two cross-shelf boundaries. The cross-shelf boundary near Louisbourg is upstream in the sense of shelf wave propagation and is called the "backward boundary". It is important in driving the flow on the shelf. The other cross-shelf boundary is near Yarmouth and is called the "forward boundary".

The solid boundary condition is zero normal transport. Sea-level along the offshore boundary is clamped at zero based on the belief that the continental slope insulates the shelf from the effect of low-frequency barotropic flow in the adjacent deep ocean (eg. Schwing, 1992). The gravity-wave radiation condition is used along the forward boundary. A time-varying but linear sea-level distribution is imposed along the backward boundary:

$$\eta_B(\xi, t) = \eta_L(t) \left[1 - \frac{\xi}{L}\right] \tag{7}$$

where ξ is position along the cross-shelf boundary with $\xi = 0$ at the coast, $\eta_L(t)$ is the time-varying sea-level there and L is the shelf width.

2.3 Forcing the Barotropic Model

The wind field is assumed spatially-uniform and equal everywhere to that observed at Sable Island. (Six-hourly data over the period 1956-93 were kindly provided by the Canadian Climate Center.) Gaps in the wind record were filled by the long-term mean. The transformation of the six-hourly wind observations to stress was based on the drag coefficient formula of Large and Pond (1981). The stress time series was then low-pass filtered to suppress variations with periods shorter than 12 hours. Finally, linear interpolation was used to map the stress down to the required model time step.

To specify the backward boundary condition according to (7) a long time-series of $\eta_L(t)$ is needed. The only coastal sea-level record covering the period of interest is that observed at Halifax. (Halifax sea-level data was kindly provided by the Marine Environmental Data Service, MEDS, and prepared by Anderson, (1994).) Sheng and Thompson (1996c) proposed a simple statistical scheme for transforming Halifax adjusted sea-level into coastal sea level at the backward boundary, $\eta_L(t)$. They first determined η_L by assimilating observations of coastal sea-level and currents made during about 100 days of CASP into their 3D shelf circulation model. They then estimated the optimal transfer function between Halifax sea-level and η_L according to the following simple statistical scheme:

$$\eta_L(t) = b + \sum_{j=-M}^{M} a_j \eta_H(t + j\Delta T) + \epsilon \qquad (8)$$

where η_H is Halifax sea-level, ΔT is a suitably chosen time interval, the a_j and b are regression coefficients to be determined, and ϵ is random noise. We chose $M = 15$ and $\Delta T = 3$ hours. The regression coefficients in (8) are plotted in Figure 3a and time-series of η_L and its estimated value according to (8) are shown in Figure 3b. Clearly the fit of the statistical model is reasonable. We used these regression coefficients to transform Halifax sea-level over the last 38 years into a time series of η_L which was then used to drive the model according to (7).

To correct Halifax sea-level for the inverse barometer effect, we added air-pressure recorded at Shearwater and then low-pass filtered the adjusted sea-level to suppress motions with periods shorter than 27 hours and thus the diurnal and semi-diurnal tides. (The air-pressure data was also provided by MEDS and prepared by Anderson (1994)).

3. RETENTION INDICES

The displacement of a particle seeded in the model is related to the flow at 30 m according to

$$\frac{d\vec{x}}{dt} = \vec{u}_d(\vec{x}) + \vec{u}_b(\vec{x}, t) \tag{9}$$

where $\vec{x}(t)$ is the horizontal position of the particle at time t, $\vec{u}_d$ and $\vec{u}_b$ are model-predicted horizontal velocities from the baroclinic and barotropic submodels respectively. Note that for simplicity, and the absence of strong observational evidence for the systematic vertical migration of larval cod (see for example Sclafani (1992)), we set the vertical velocity of the particle to zero. Integrating this equation we have

$$\vec{x}(t) = \vec{x}(t_0) + \int_{t_0}^{t} \left[\vec{u_d}(\vec{x}, t') + \vec{u_b}(\vec{x}, t')\right] dt' \tag{10}$$

for a particle at position $\vec{x}(t_0)$ at initial time t_0. A fourth-order Runge-Kutta scheme was used to integrate the displacement equation. This method propagates the solution over a time interval h by combining information from several Euler-type steps. The accuracy of the method is sensitive to the choice of h and the derivatives of the function being integrated (i.e. $\vec{u}_d$ and $\vec{u}_d$). We obtained stable results with a time step h of 30 minutes and a two-dimensional parabolic interpolation method to calculate the horizontal velocity at any horizontal position and time.

To describe quantitatively particle retention on the Scotian Shelf, we introduce the following retention index:

$$R(\vec{x}_B, t) = \frac{N(\vec{x}_B, t)}{N(\vec{x}_B, t_0)} \tag{11}$$

where $N(\vec{x}_B, t_0)$ is the number of particles seeded in a box of a given size centered at $\vec{x}_B$ at initial time t_0, and $N(\vec{x}_B, t)$ is the number of original particles remaining at some later time t. Clearly, R always lies between 0 and 1. Higher values of R correspond to higher retention of particles in the given box. If R is 0 then all the particles are flushed from the box between time t_0 and t.

The dimensions of the box are arbitrary. We chose it to be 43 km and 60 km in the x and y directions respectively to correspond approximately to the size of the offshore cod spawning areas on the Scotian Shelf (e.g. Frank et al. 1994). The separation distance between the centers of adjacent boxes was 8.7 km and 14.8 km in the x and y directions respectively. In each box, 1089 (33×33) particles were uniformly seeded giving an initial horizontal spacing of about 1.3 km and 1.9 km in the x and y directions respectively. The number of retained particles at some later time t, $N(\vec{x}_B, t)$, was then calculated taking into account the trajectories of all the seeded particles. The size and shape of boxes close to model boundaries, and the initial number of particles $N(\vec{x}_B, t_0)$, were adjusted accordingly. If any particle touched a solid boundary, or passed through an open boundary, it was assumed permanently lost.

4. RESULTS

Retention indices were calculated for each March-April from 1956 to 1993. The results are presented in Figures 4 to 41 in the following sequence: (1) time series of the forcing terms; (2) particle positions and retention indices for the middle and end of March; (3) particle positions and retention indices for the middle and end of April. To explain in more detail the kind of information presented in these figures we now describe Figure 4 as an illustration.

Time-series of the forcing terms for March-April, 1956 are shown in Figure 4.1. The series include (a) air pressure variations at Sable Island about the longterm mean; (b) air pressure variations at Shearwater about the longterm mean; (c) eastward and (d) northward wind stress at Sable Island; and (e) Halifax sea-level. The black dots in Figures 4.1a-d correspond to raw data with missing values replaced by their means. The solid lines in these figures are the result of low-pass filtering the observations. The thin line in Figure 4.1e is smoothed sea-level and the thick line is smoothed adjusted sea-level. The three numbers in parentheses in the right bottom corner of each panel are as follows: the total number of observations for March-April of the given year; the number of missing data; the number of missing data in the largest gap. Furthermore, periods with missing data are marked by vertical shadow lines.

Figure 4.2 shows the spatial distribution of particles and retention indices at different times in March, 1956. The particle positions at the initial time, March 1 of 1956, are shown in Figure 4.2a. The particles are denoted by small circles shaded with different intensities in gray to indicate their initial positions. The gray gradually darkens from west to east and from north to south. The particle positions on March 30 of 1956 are shown in Figure 4.2b. It can be seen that a small portion of the particles initially close to the backward boundary are retained over Banquerau Bank and the Gully. The particles initially close to the coast quickly move southwestward with the strong nearshore current and some of them exit from the model domain through the forward and southern offshore boundary. It is also evident that some particles are retained over Western Bank and Emerald Bank. Figure 4.2b also shows that some particles on Western Bank on March 30 came from areas upstream, such as Banquerau Bank.

Retention indices for 15 and 30 days after the initial release on March 1, 1956 are shown in Figures 4.2c and d respectively. The size of the box used to calculate the retention indices is shown in the bottom right corner in these panels. Retention indices are relatively low close to the coast and over the western shelf region in contrast to the

Gully, Banquerau, Western and Emerald Banks. It is interesting to note that these offshore areas include the major spawning areas and nursery grounds for Scotian Shelf cod (Scott, 1983; Frank et al. 1994).

Figure 4.3 shows the particle positions and retention indices 15 and 30 days after the initial release of particles on April 1, 1956. The results are presented in the same fashion as Figure 4.2, except that the initial positions of the particles, which are the same as those in Figure 4.2.a, are not shown. Figures 5-41 are presented in the same fashion as Figure 4, but for 1957-93.

Interannual variations in the April retention index for Western Bank are shown in Figure 42a. As part of a preliminary study of the effect of the physical environment on the abundance of Scotian Shelf cod, Dr. Ken Frank of the Bedford Institute of Oceanography kindly provided estimates of year-class success for this region which were then correlated with this retention index. To calculate a proxy for year-class success Dr. Ken Frank first noted that cod spawning on the Scotian Shelf is bi-modal with spawning occurring in spring and fall. The VPA for this region produces a single recruitment estimate each year and does not separate the contributions made by the two spawning components. Therefore, the VPA-based recruitment estimates were not examined in relation to the spring retention index. Instead Dr. Ken Frank used the catch rate at length for age 1 cod from the July research vessel surveys. He argued that the use of these data could result in a finer time resolution of the magnitude of recruitment generated from each spawning component. Among 8 size classes of cod he grouped the three smallest classes (9-17cm), the two intermediate classes (18-23cm) and the three largest (24-32cm) to reflect the abundance of fall spawned cod from the previous year, the abundance resulting from spring spawning of the previous year and fish older than age 1 respectively.

Time series of the catch rates of the July research surveys around Western Bank in the period of 1969-93 for 4 size classes are plotted in Figures 42b-e. The correlation between the plotted catch rates and the Western Bank retention index are presented in Table 1. The only significant correlations between retention and catch for the two intermediate size groups, i.e. those indicative of spring spawning. The sign of the correlation coefficients was positive suggesting that stronger year classes are associated with higher retention during the early life stage.

5. SUMMARY

We have described an initial attempt to calculate retention indices for offshore banks on the Scotian Shelf and relate them to cod recruitment. The retention indices were derived from the trajectories of many particles advected in flow fields predicted by a 3D numerical circulation model. The circulation model had two components. One was a diagnostic submodel that provided an estimate of the seasonal mean near-surface associated with horizontal density gradients. The other component was a barotropic submodel driven by Sable Island wind stress and open boundary conditions inferred from sea-level at Halifax.

Calculated particle trajectories and retention indices for March and April over the last 38 years show that most particles at 30 m drifted southwestward. However a small number of particles were retained over the offshore areas including The Gully, Banquerau, Western and Emerald Banks. These retention zones include the main spawning sites for Scotian Shelf cod.

We compared time series of retention for Western Bank with cod abundance in the same area. The only significant correlations were for the two intermediate size groups, i.e., those indicative of spring spawning in the year corresponding to the retention index. The sign of the correlations was positive suggesting that stronger year classes are associated with higher retention during the early life stage. We note however that the correlations, although statistically significant, imply that only about 20% of the variance in cod abundance can be accounted for by interannual variations in retention. It would be interesting to adjust the start date of the particle releases used to calculate retention (i.e. t_0) to reflect interannual changes in the start of spawning as predicted, for example, by sea-surface temperature.

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Table 1. Correlation between the spring retention index for Western Bank and catch at length from the July research vessel survey of NAFO Division 4VsW.

Length (cm)	R (March)	R (April)	R (March×April)
9-11	0.08	0.02	0.05
12-14	0.11	0.10	0.19
15-17	0.16	0.21	0.27
18-20	0.19	0.38	0.43
21-23	0.21	0.35	0.43
24-26	0.02	0.11	0.08
27-29	0.00	0.05	0.04
30-32	0.03	0.06	0.02

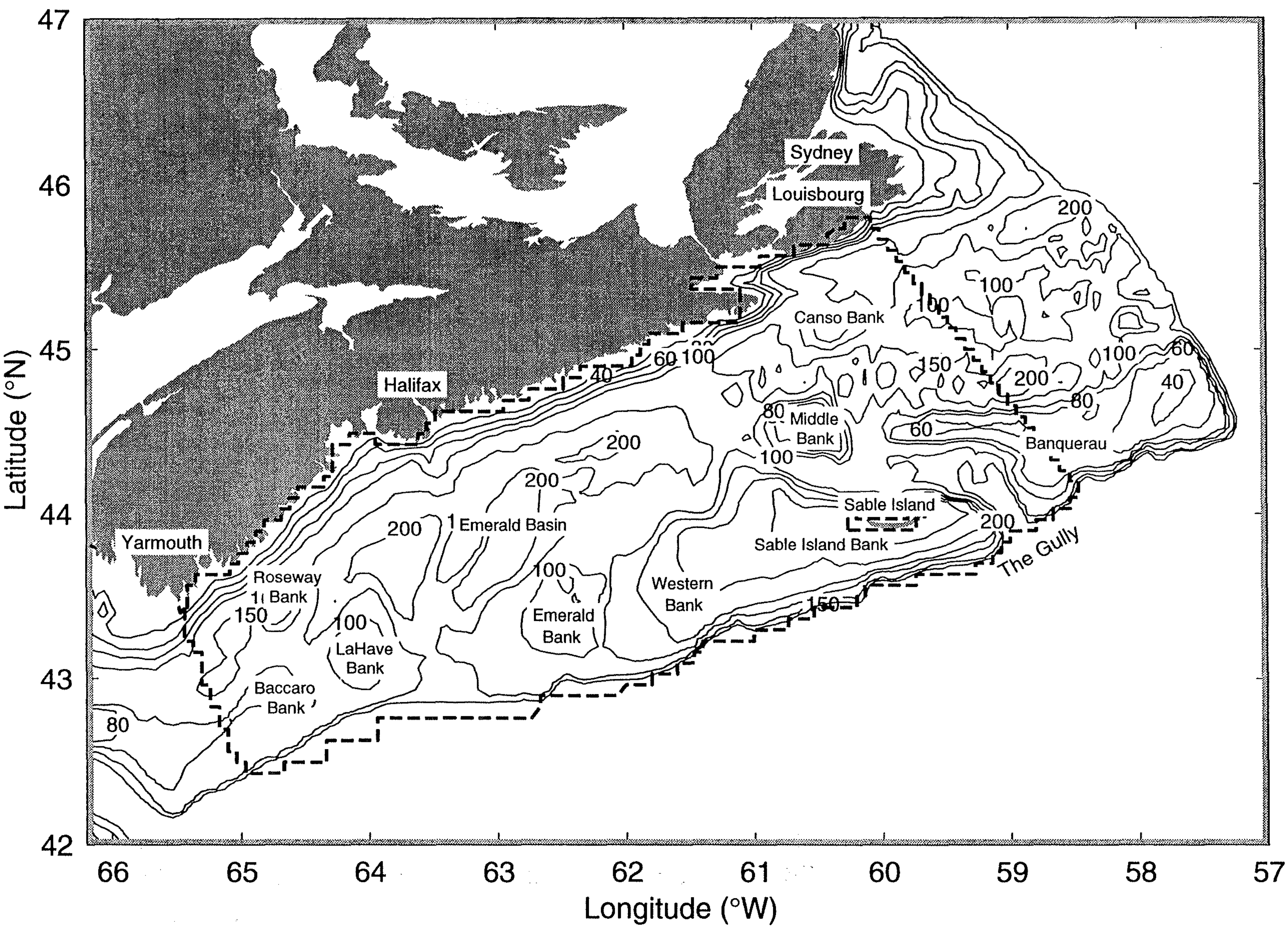

Figure 1: Main bathymetric features of the Scotian Shelf. The dashed lines show the boundaries of the model domain.

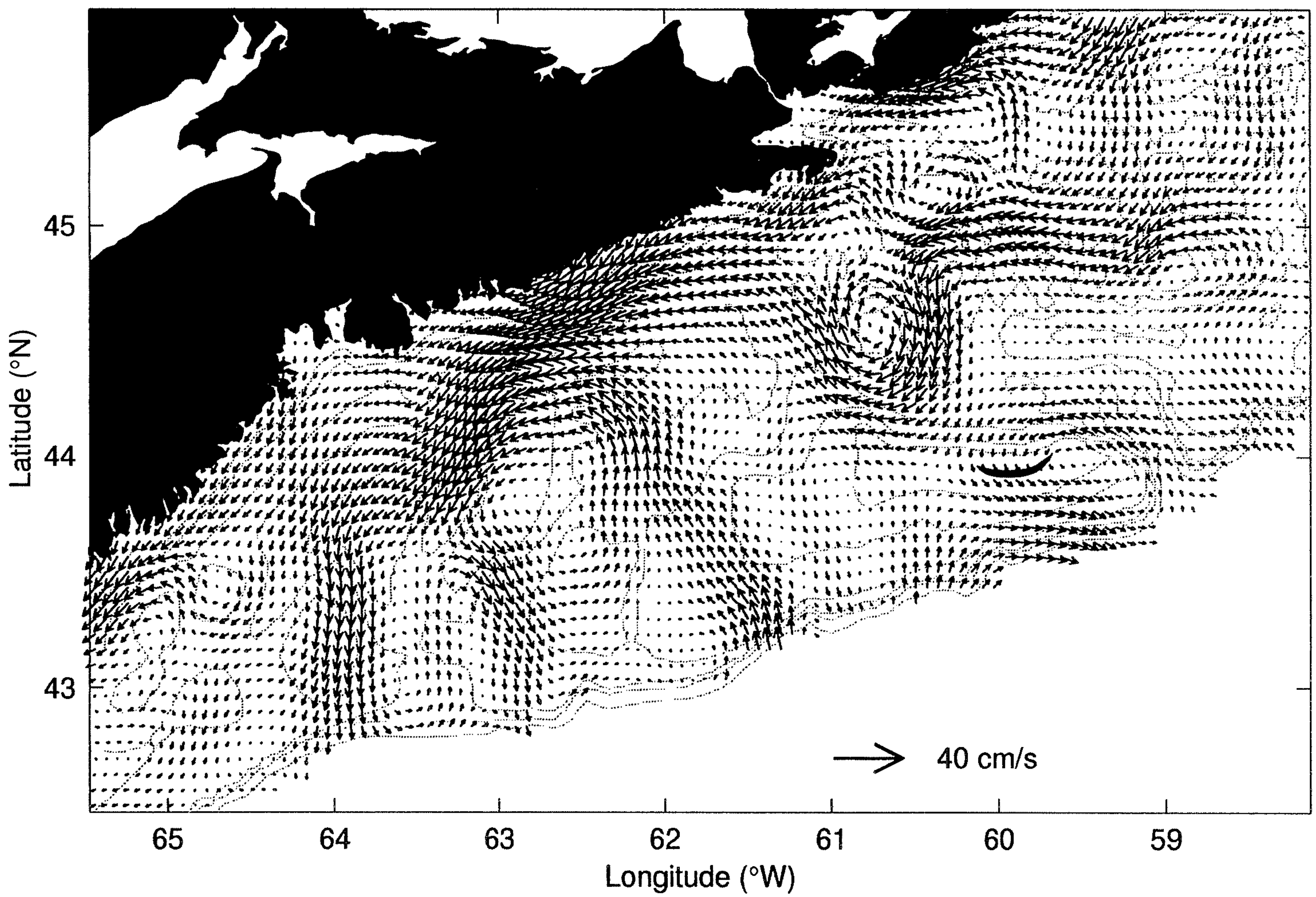

Figure 2: Winter circulation at 30m on the Scotian Shelf (December through April inclusive) diagnosed using the method of Sheng and Thompson (1996a) and observed profiles of water density.

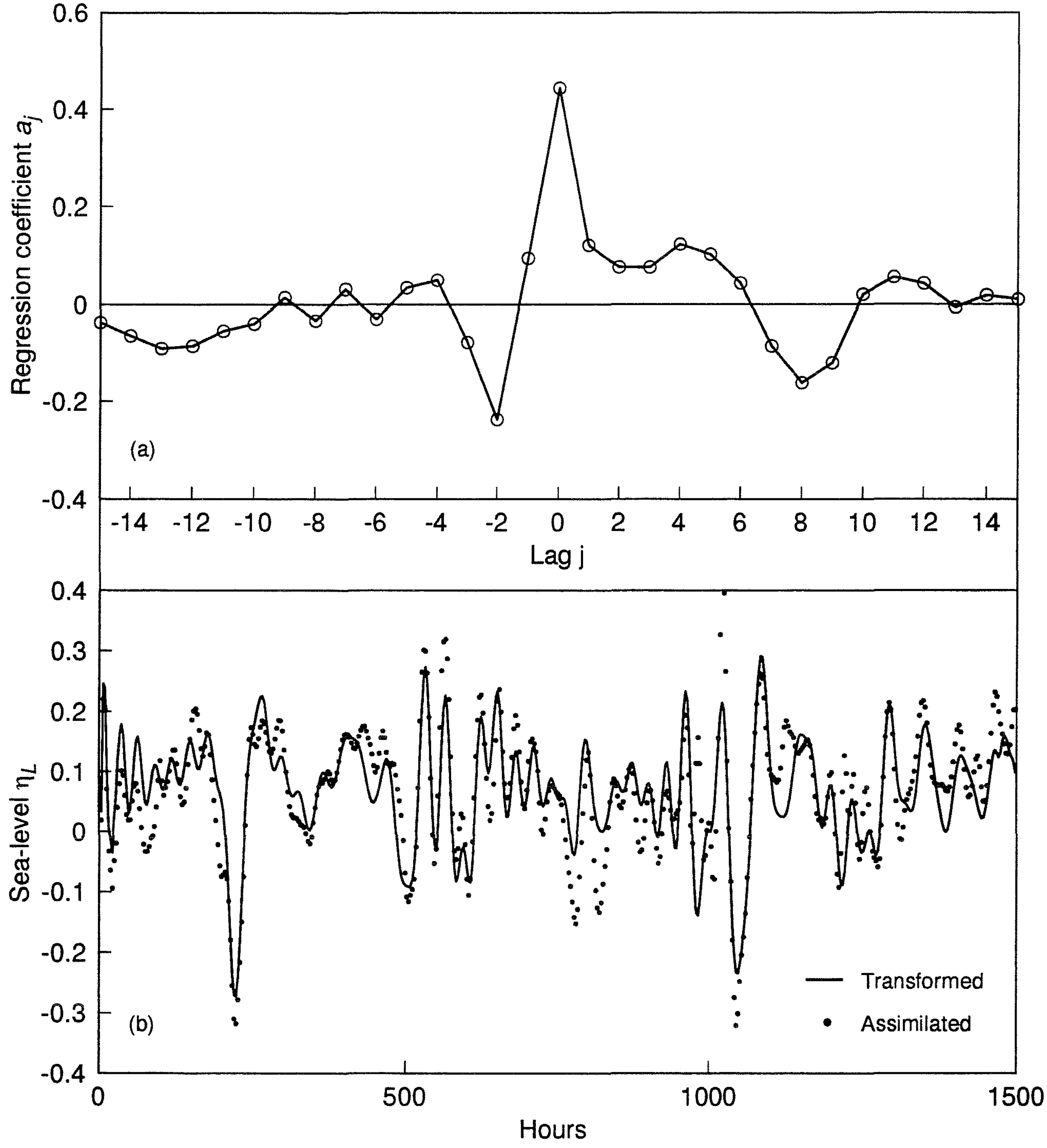

Figure 3: Optimum transfer function for converting Halifax sea-level into the backward boundary condition as parameterized by Louisbourg sea-level. (a) Regression coefficients; (b) Comparison of Louisbourg sea-level from the optimum transfer function (transformed) and the assimilation model (assimilated).

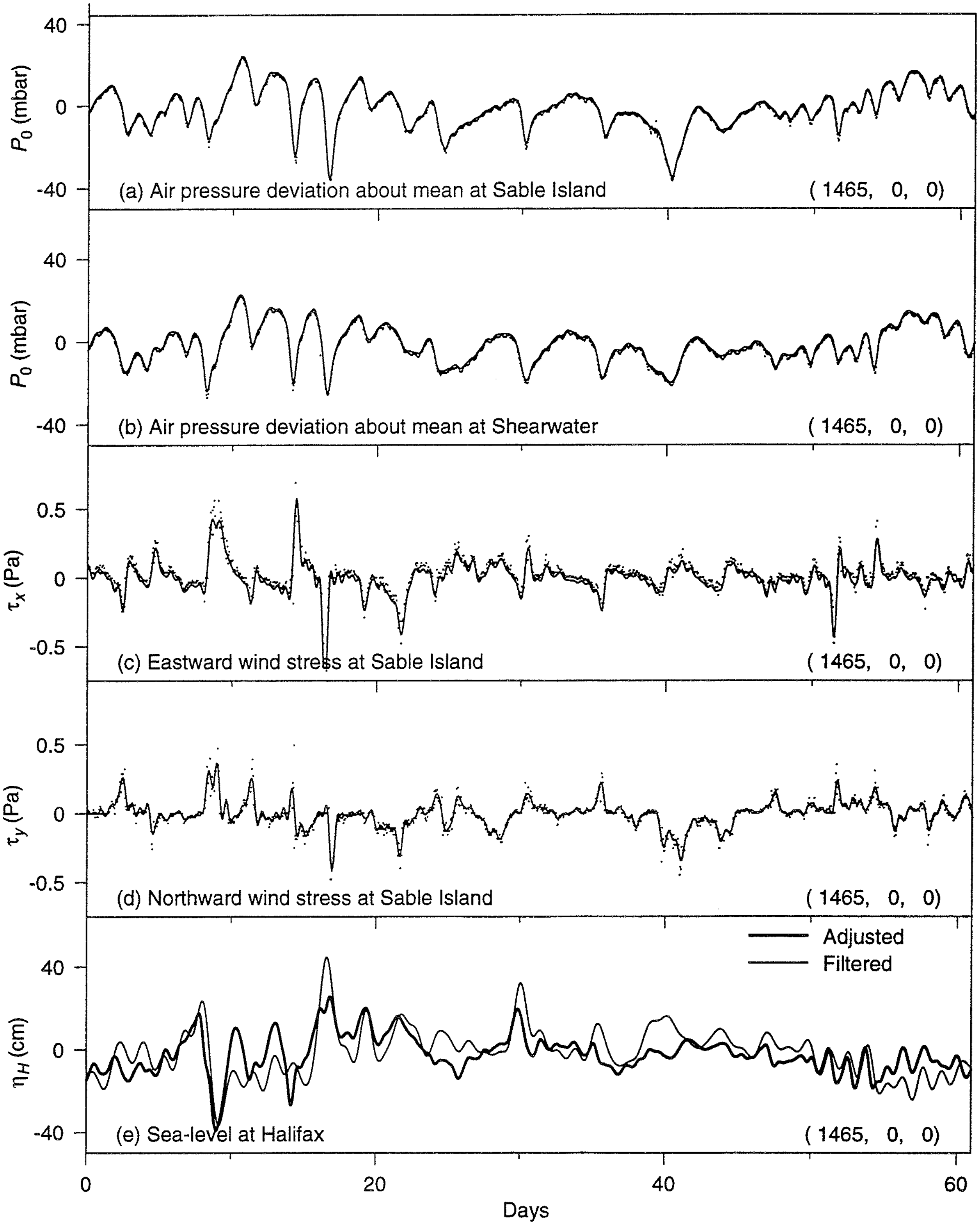

Figure 4.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1956). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

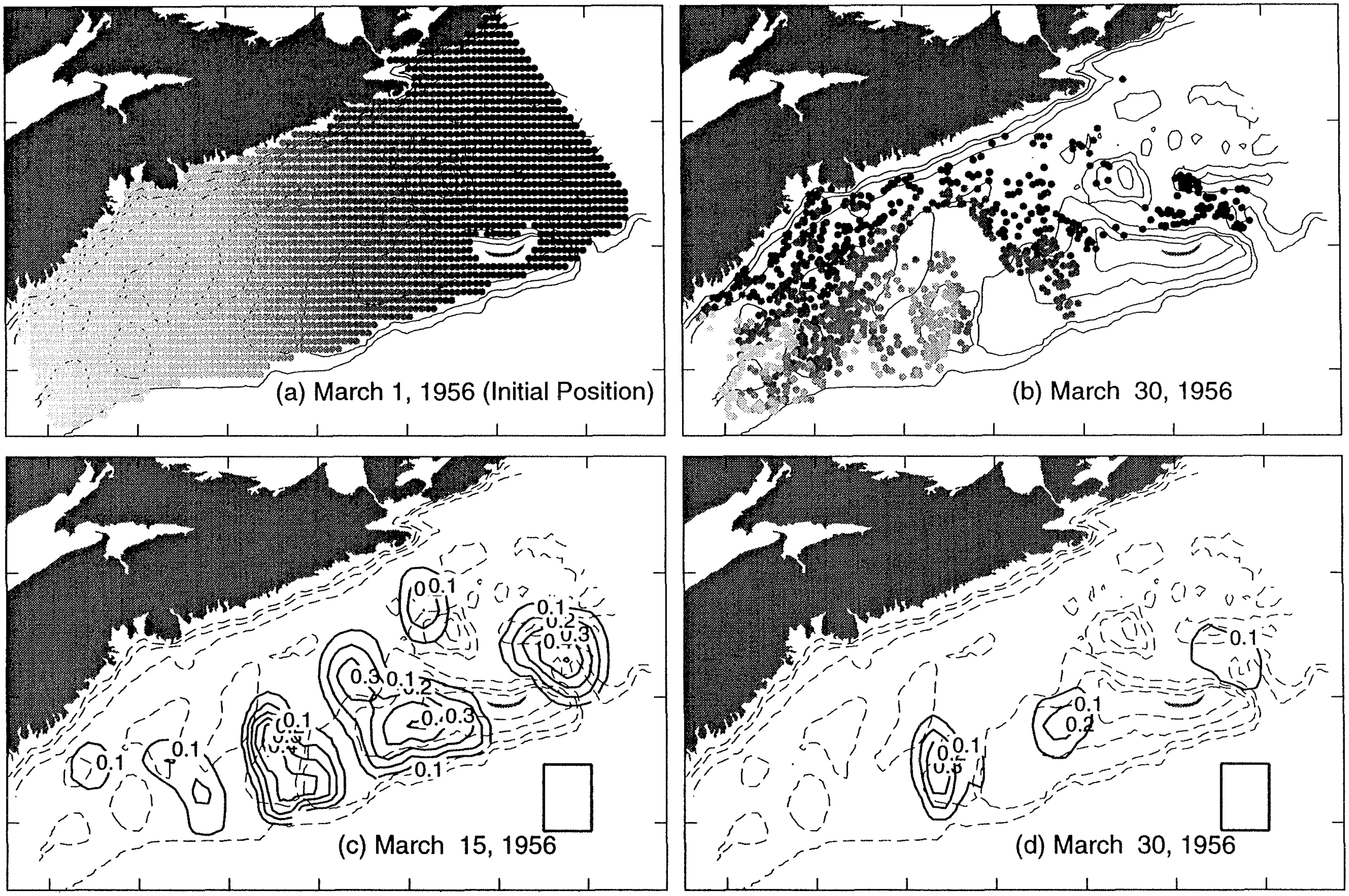

Figure 4.2: Dispersion in March 1956. (a) Initial positions of particles shaded with different intensities in gray to indicate starting positions; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

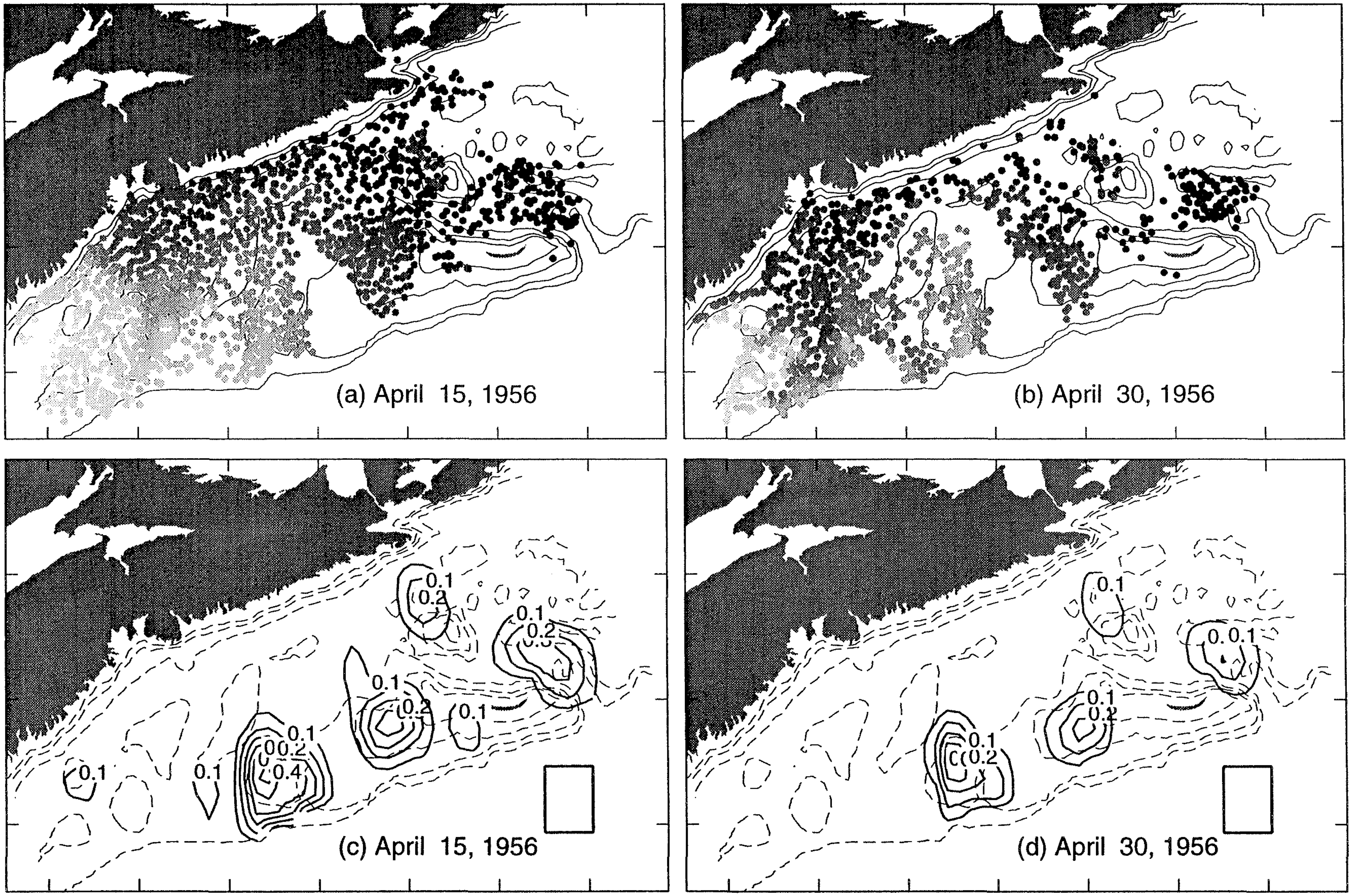

Figure 4.3: Dispersion in April 1956. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

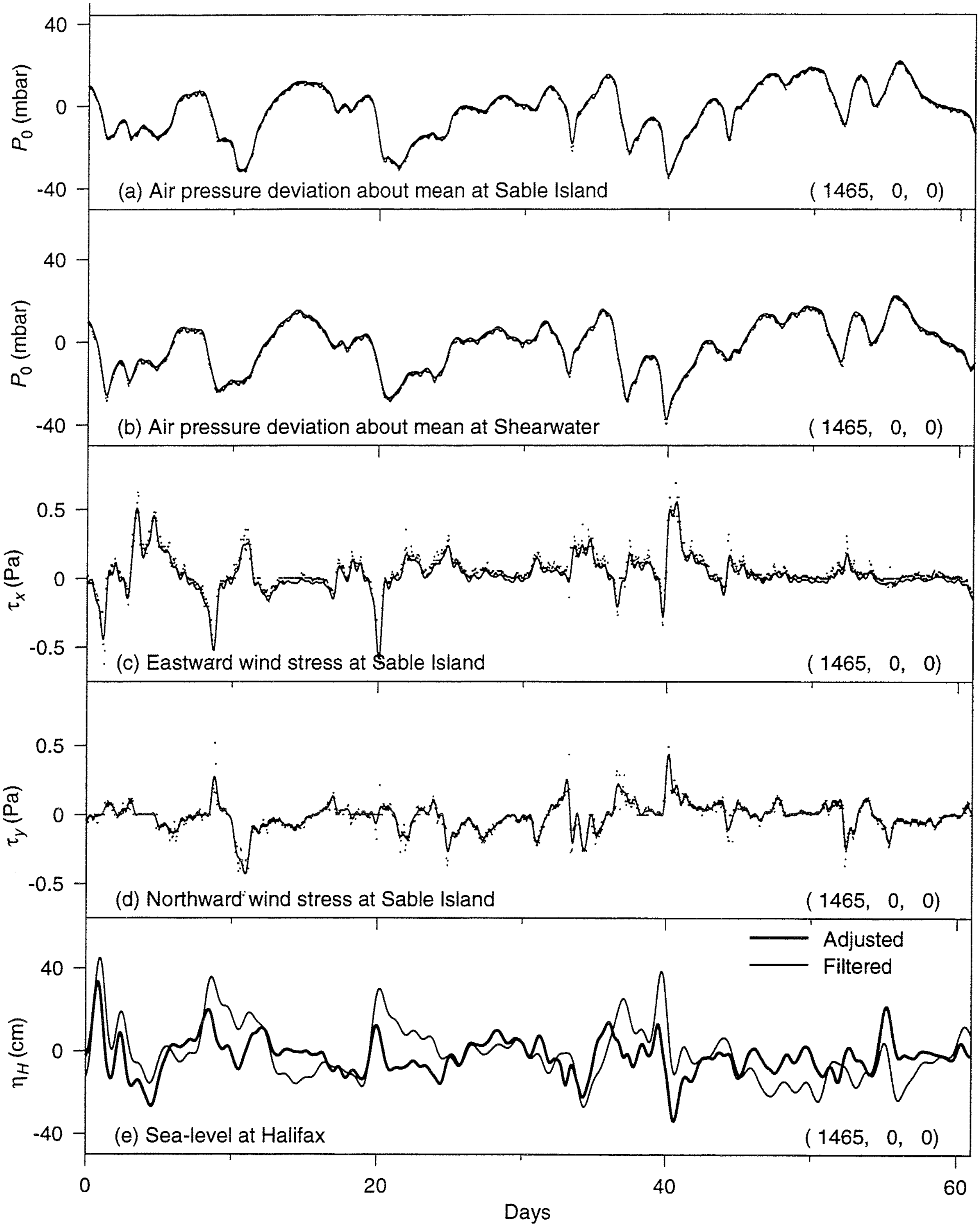

Figure 5.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1957). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

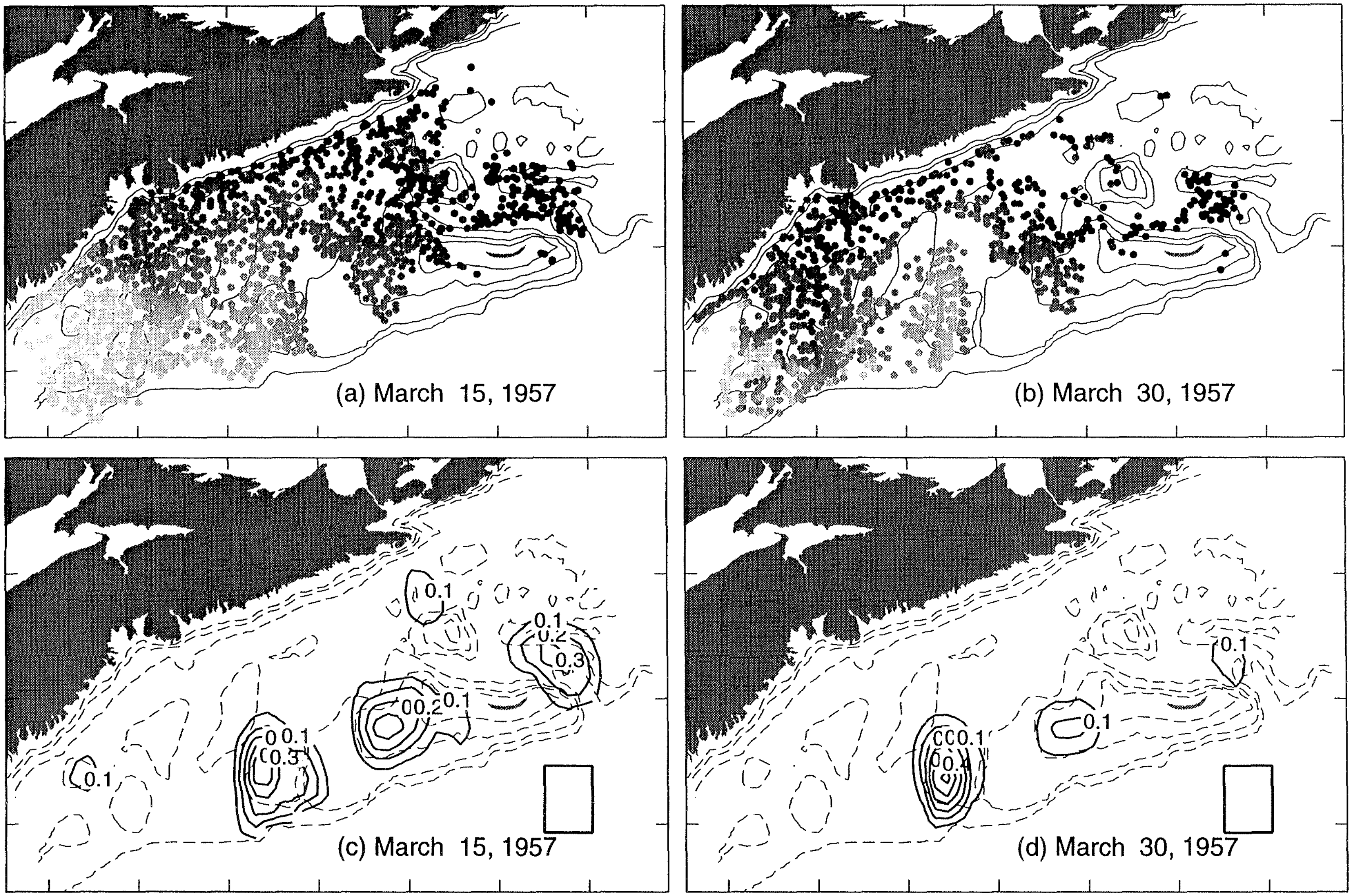

Figure 5.2: Dispersion in March 1957. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

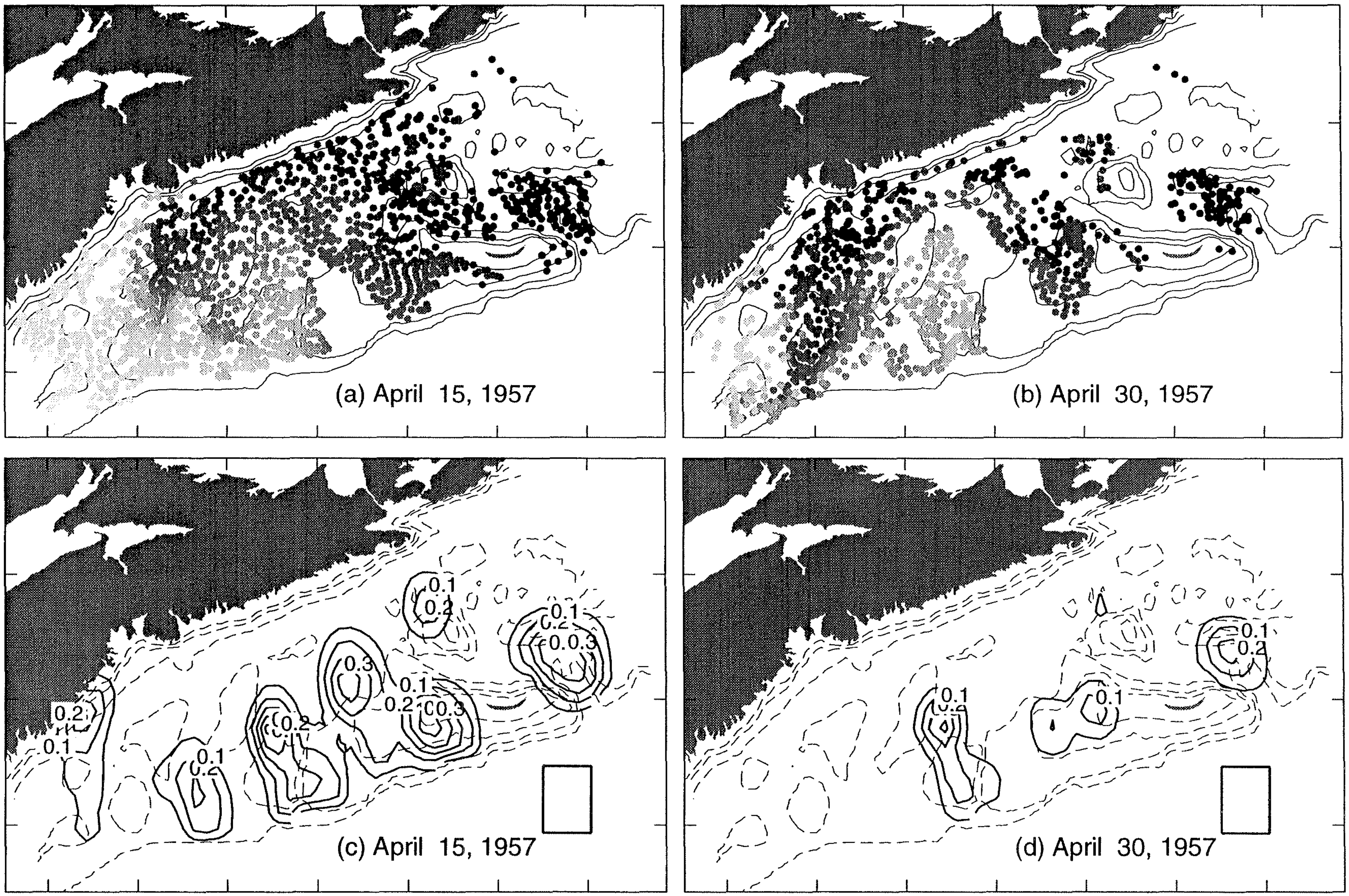

Figure 5.3: Dispersion in April 1957. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

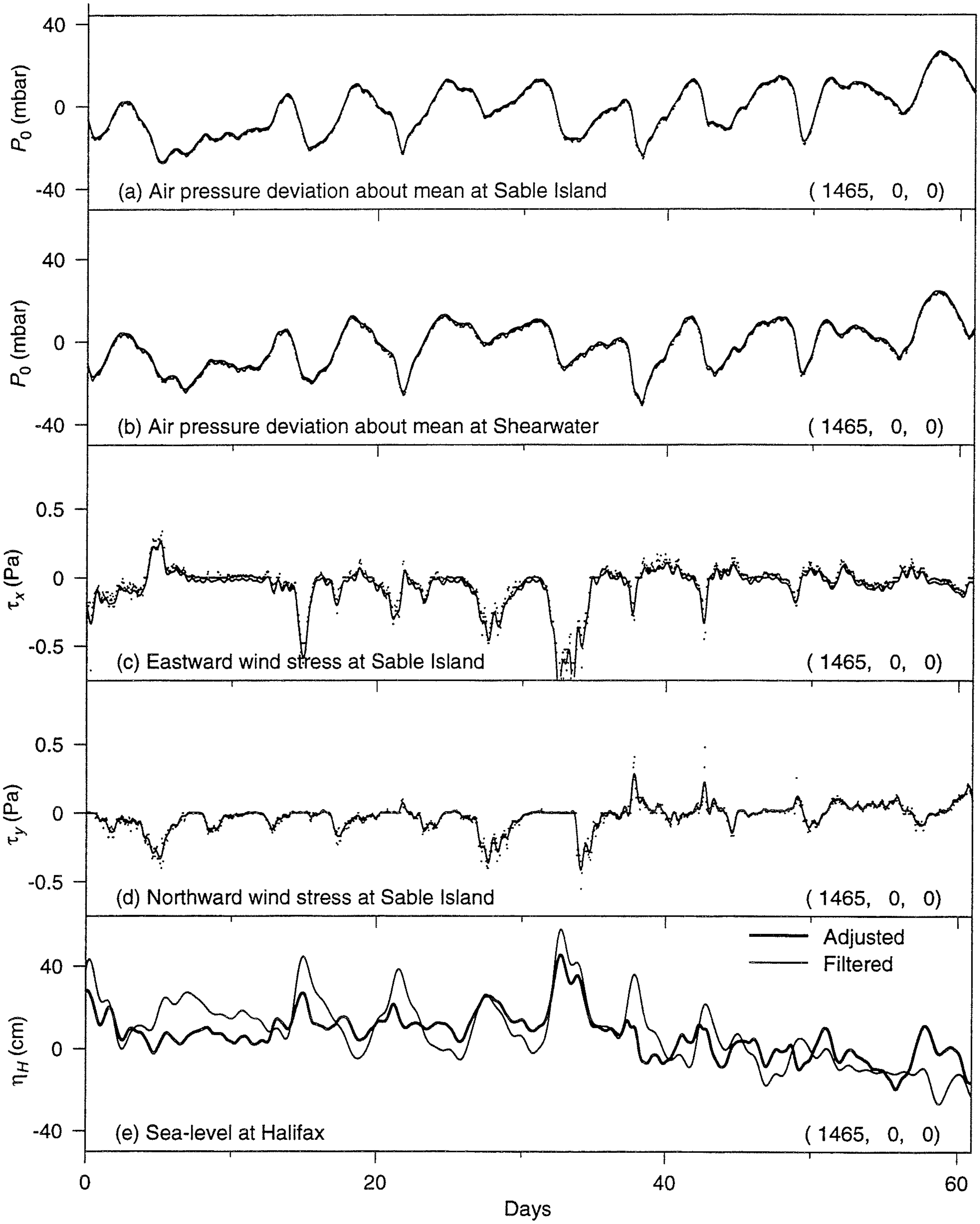

Figure 6.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1958). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

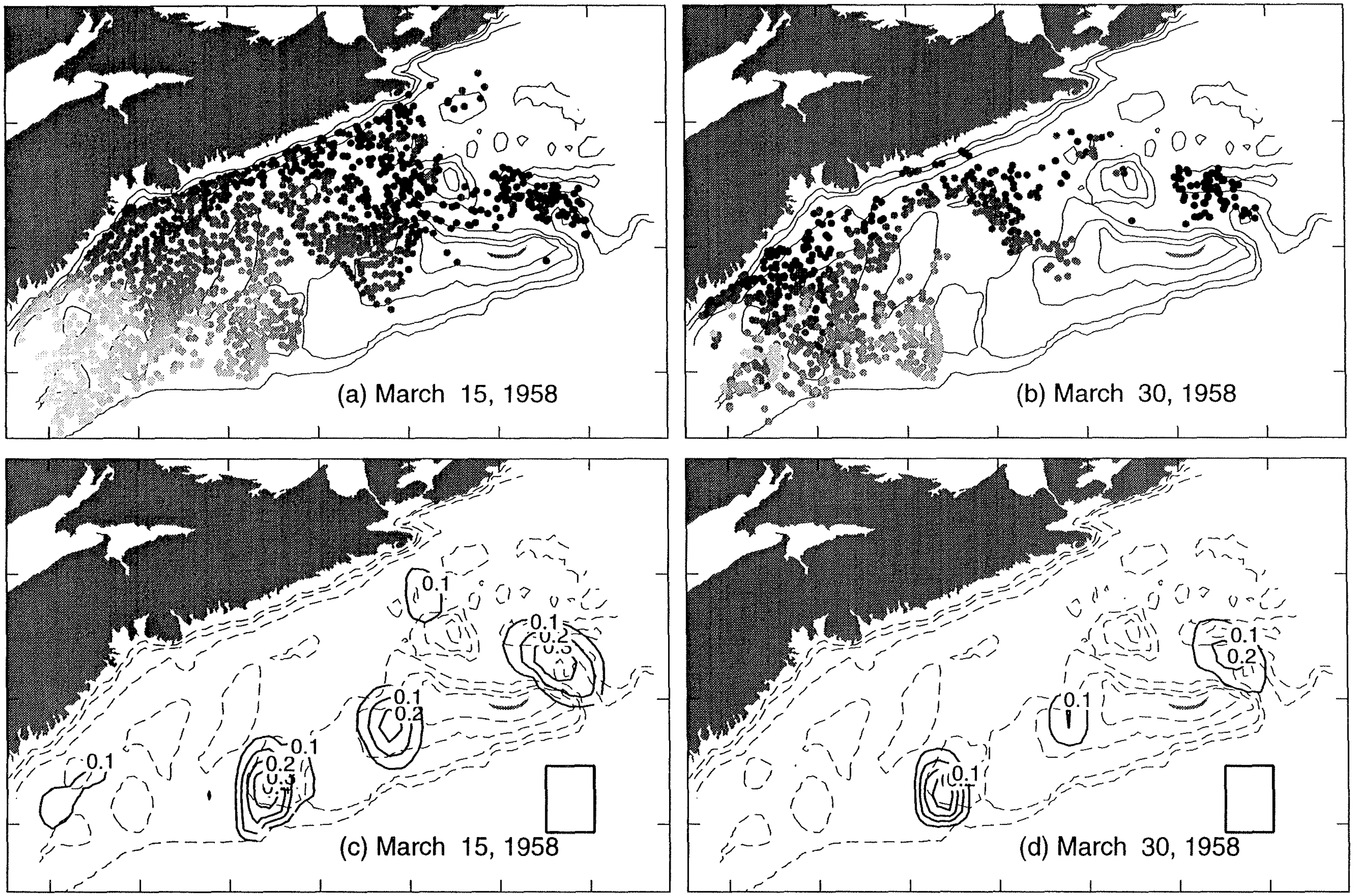

Figure 6.2: Dispersion in March 1958. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

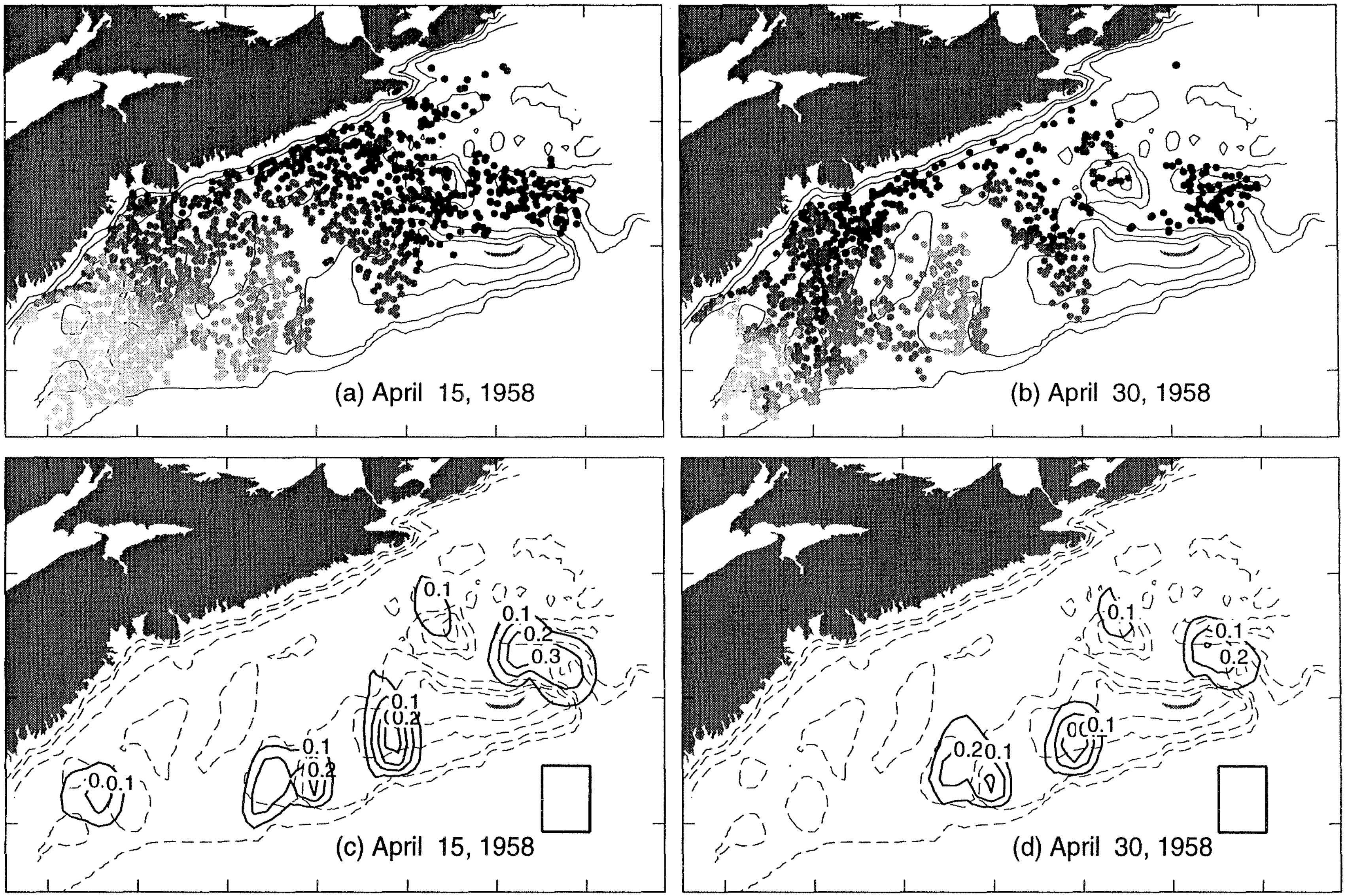

Figure 6.3: Dispersion in April 1958. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

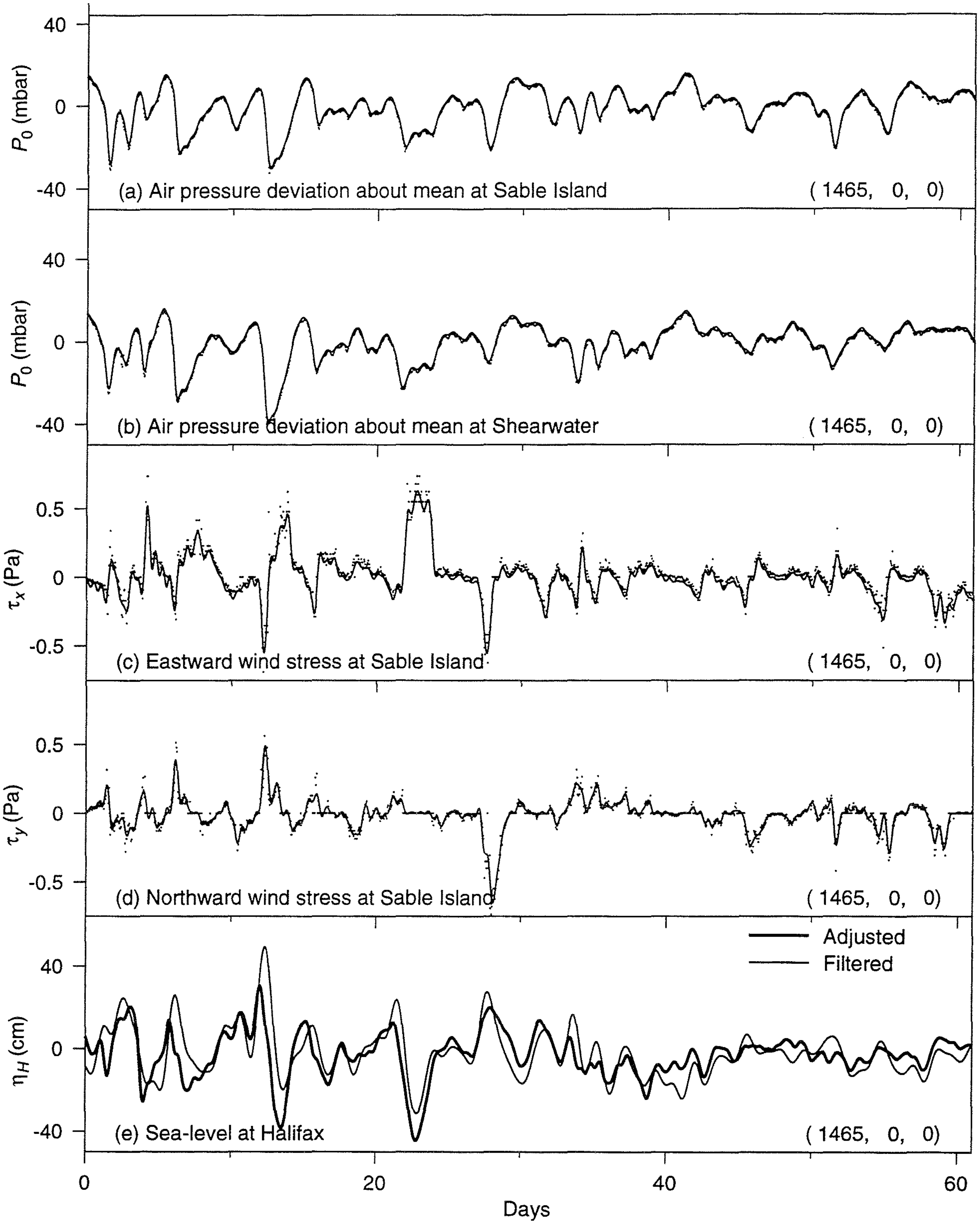

Figure 7.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1959). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

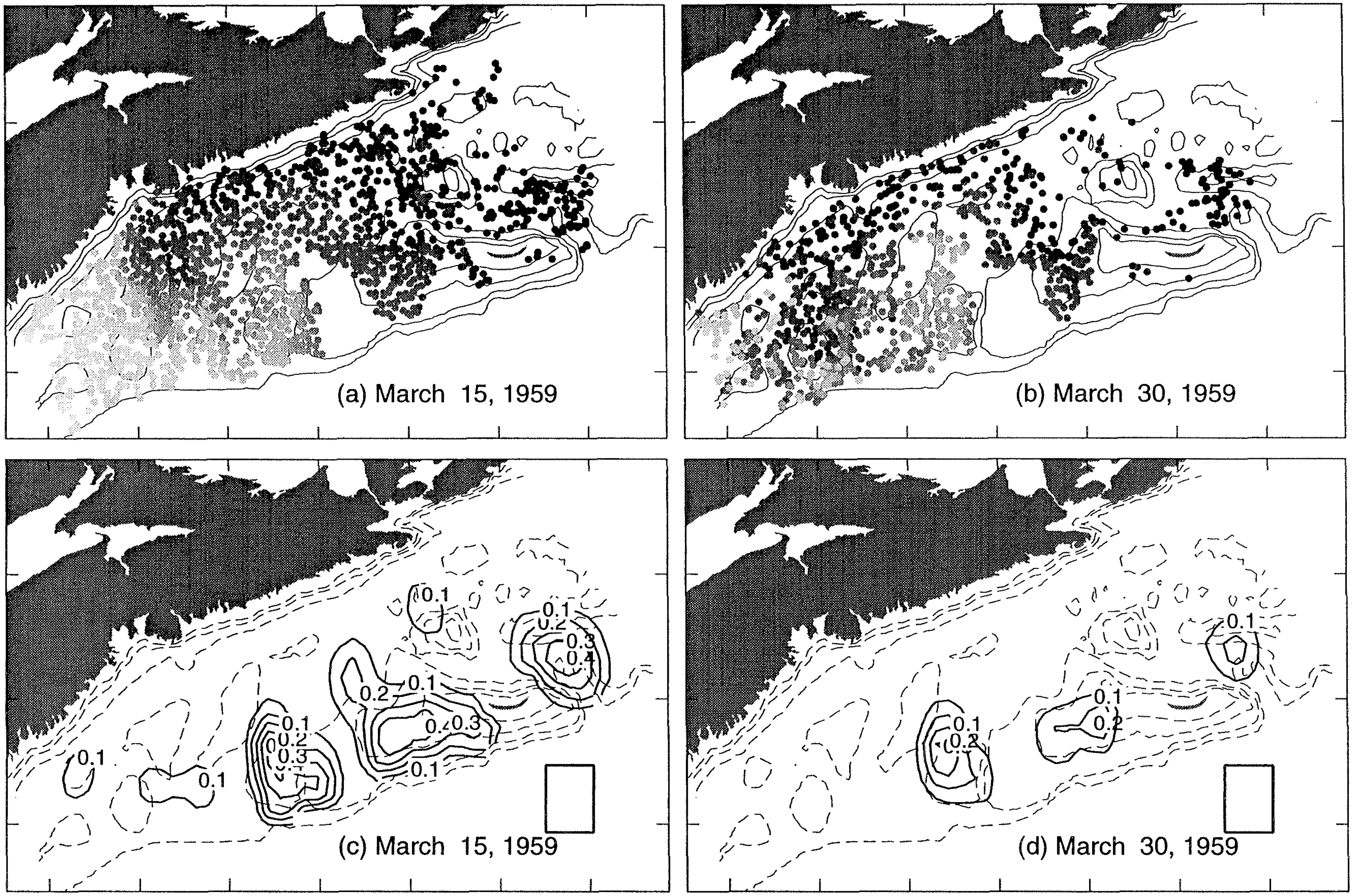

Figure 7.2: Dispersion in March 1959. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

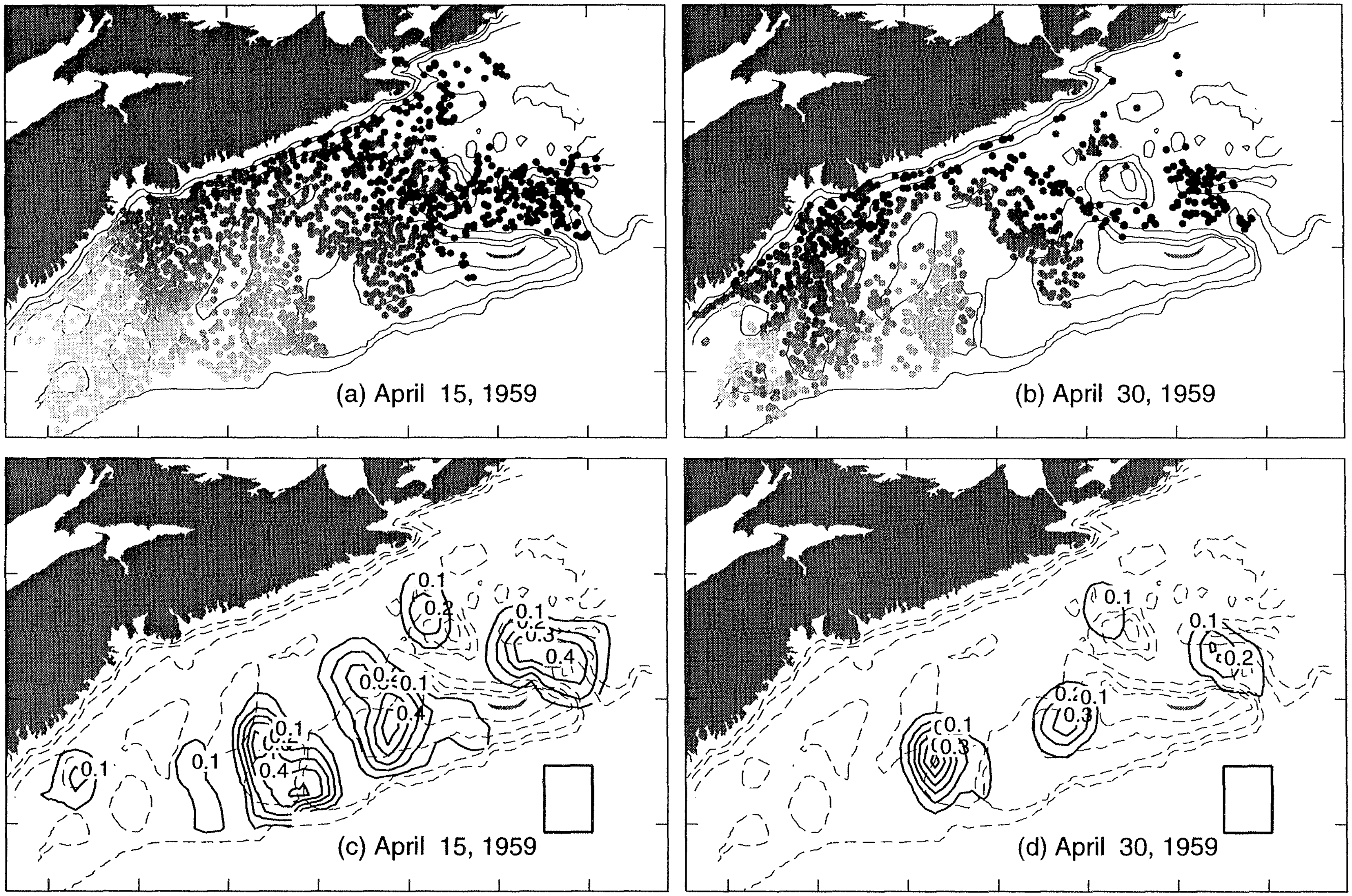

Figure 7.3: Dispersion in April 1959. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

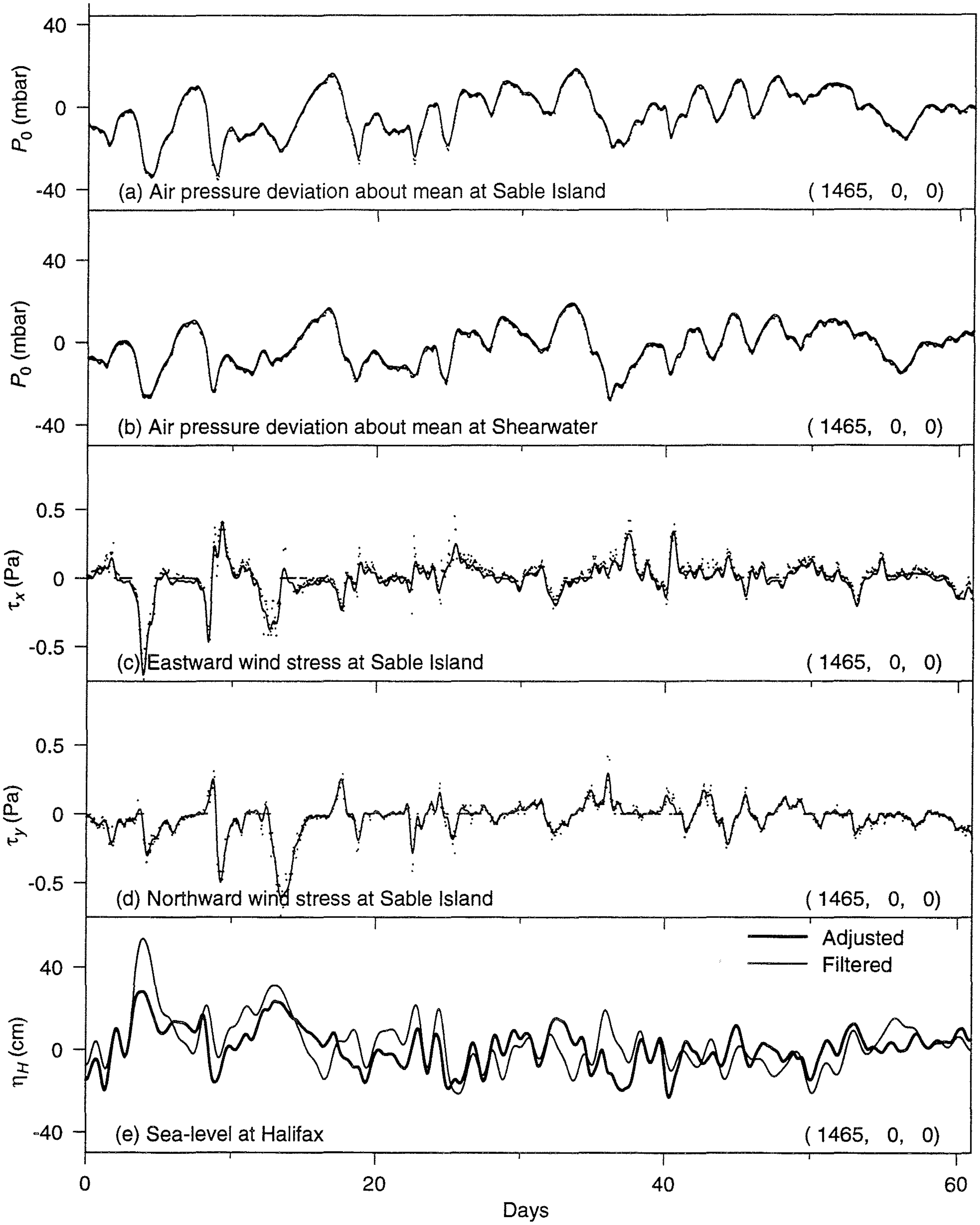

Figure 8.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1960). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

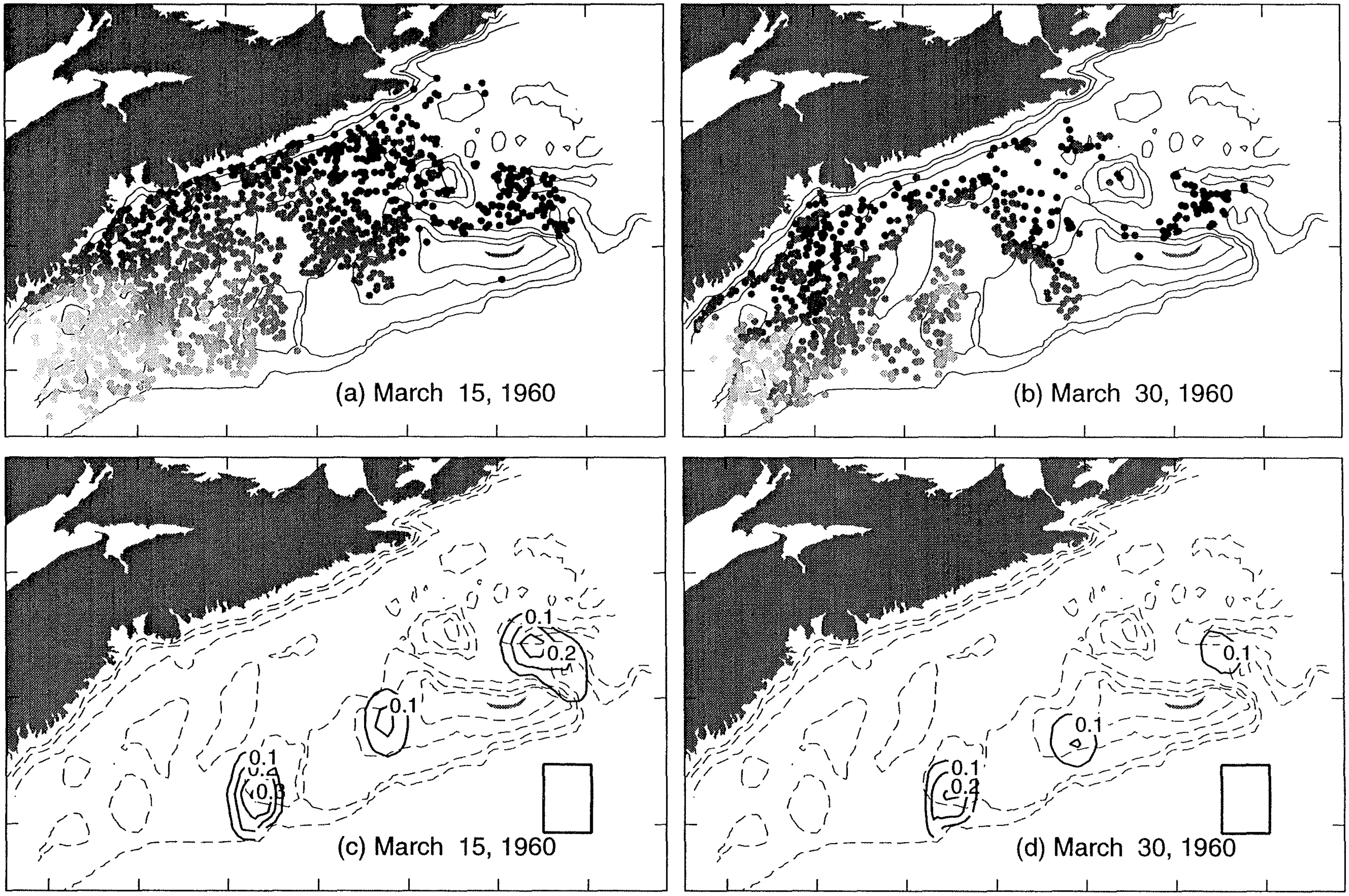

Figure 8.2: Dispersion in March 1960. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

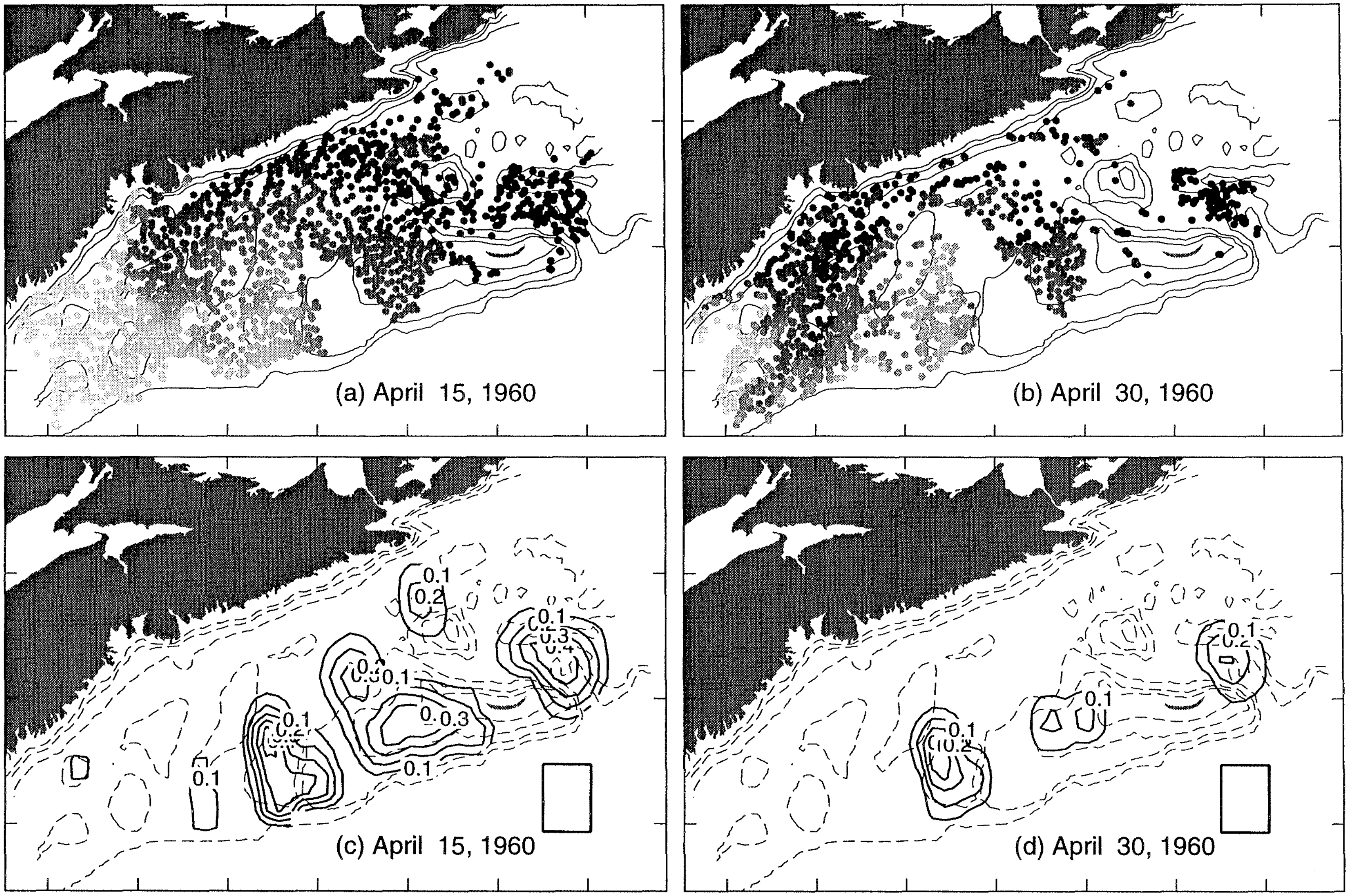

Figure 8.3: Dispersion in April 1960. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

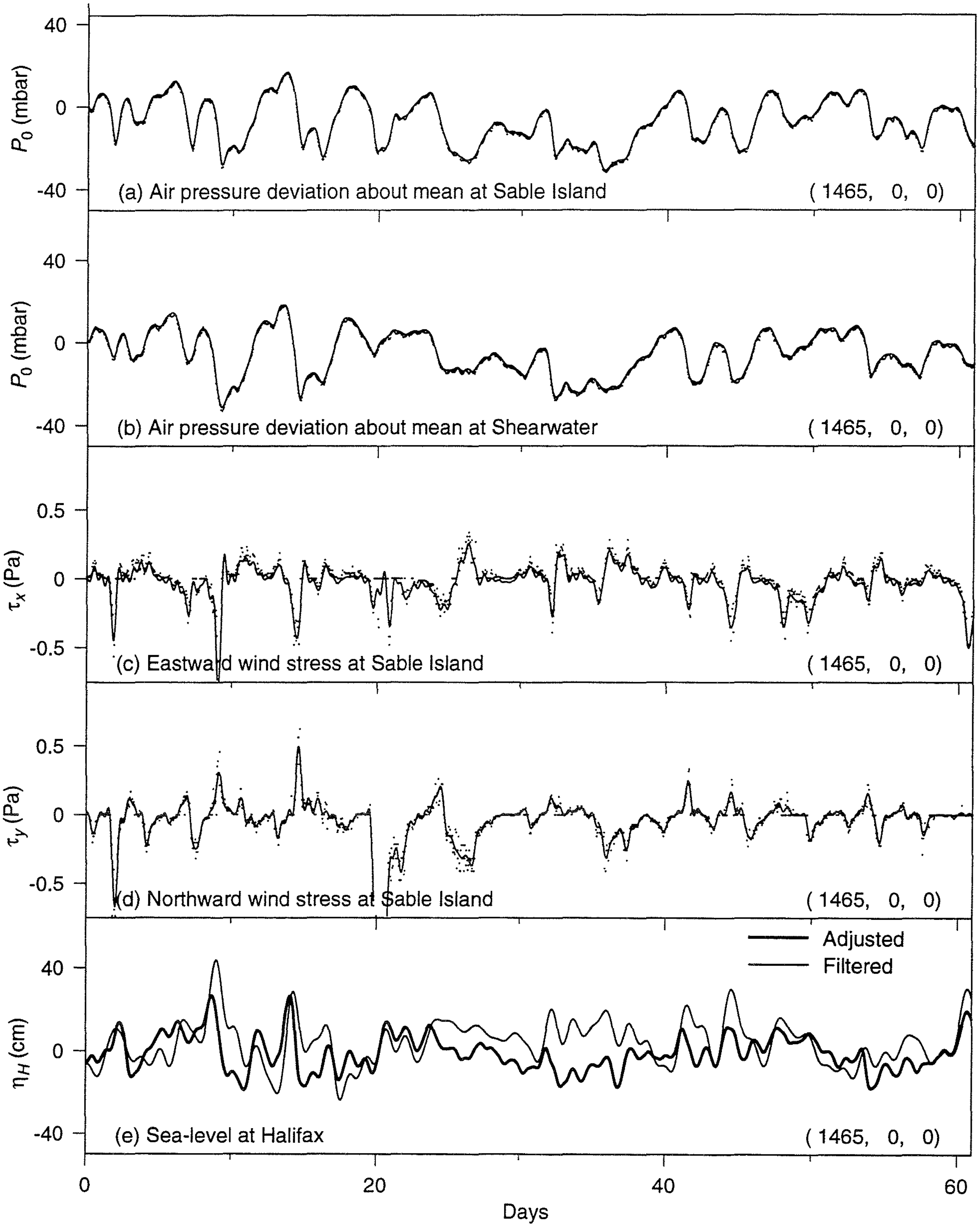

Figure 9.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1961). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

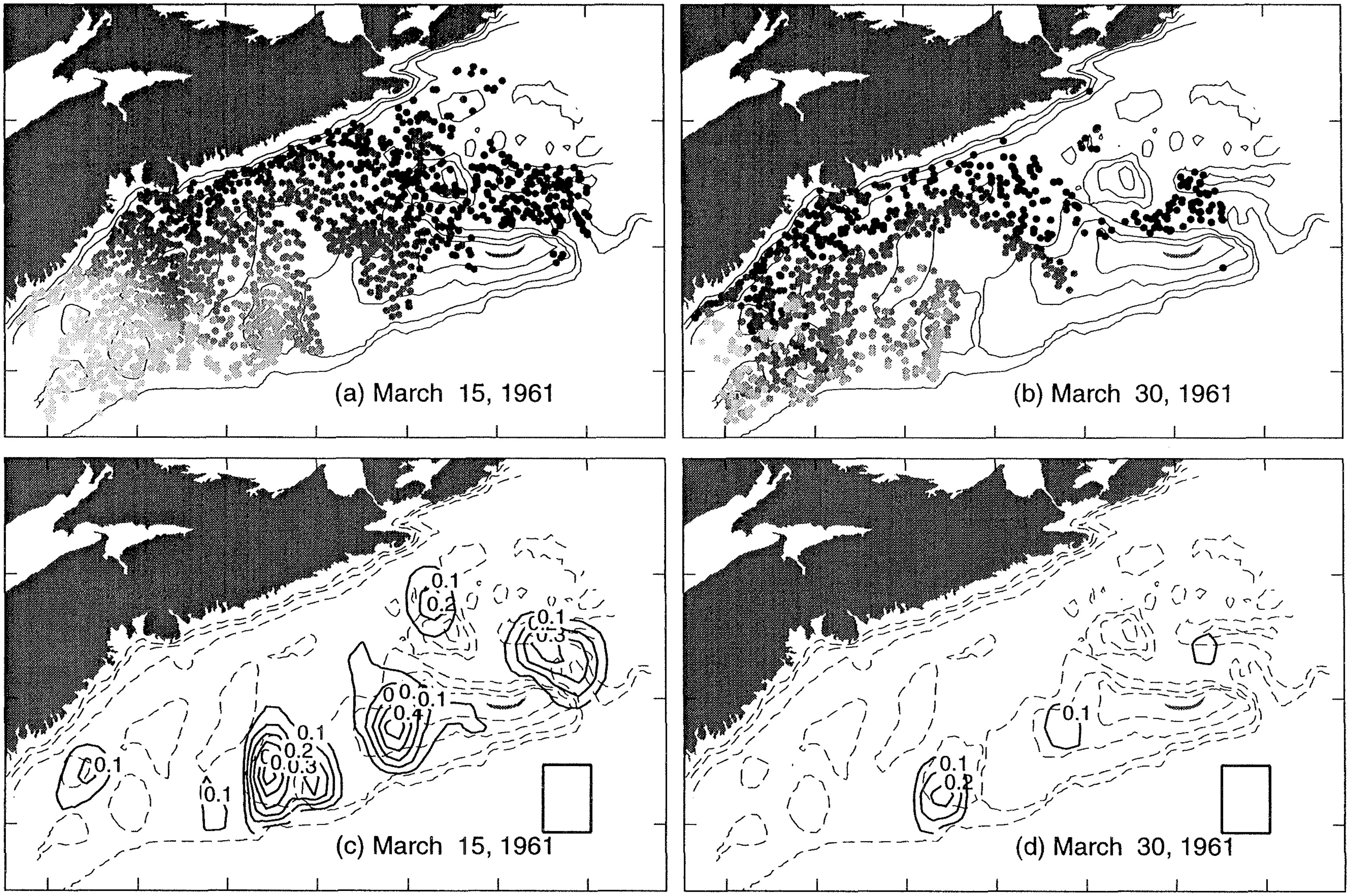

Figure 9.2: Dispersion in March 1961. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

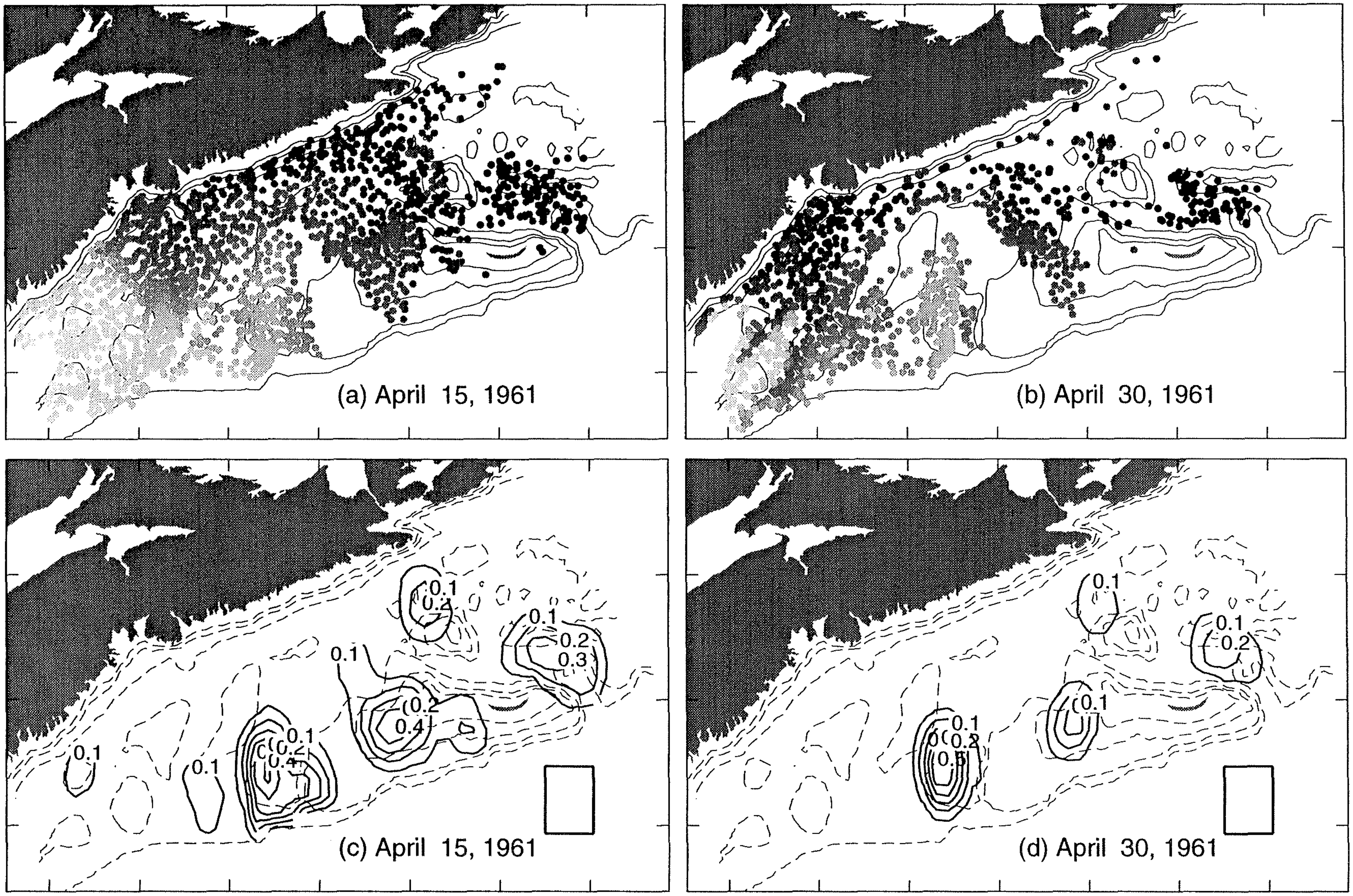

Figure 9.3: Dispersion in April 1961. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

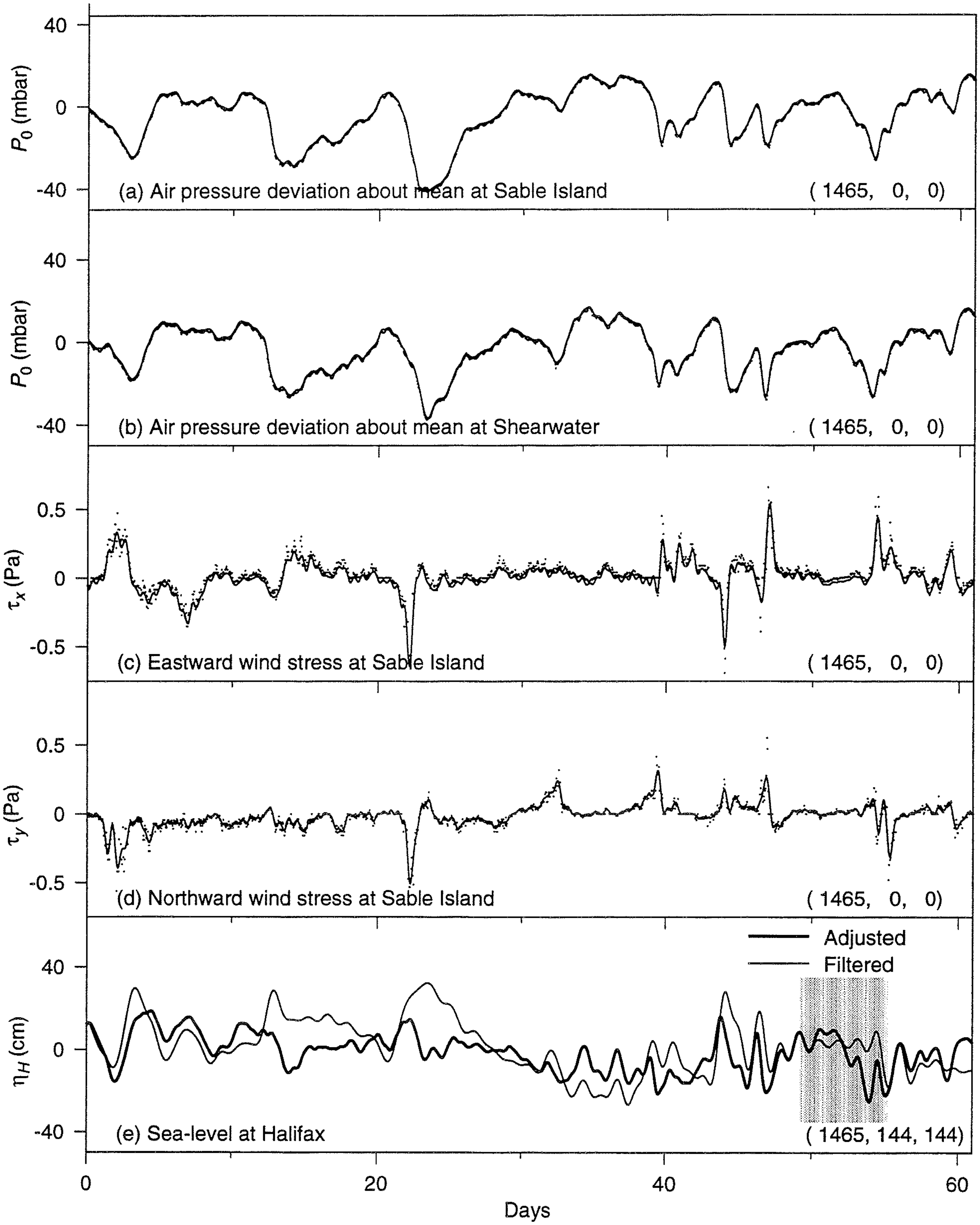

Figure 10.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1962). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

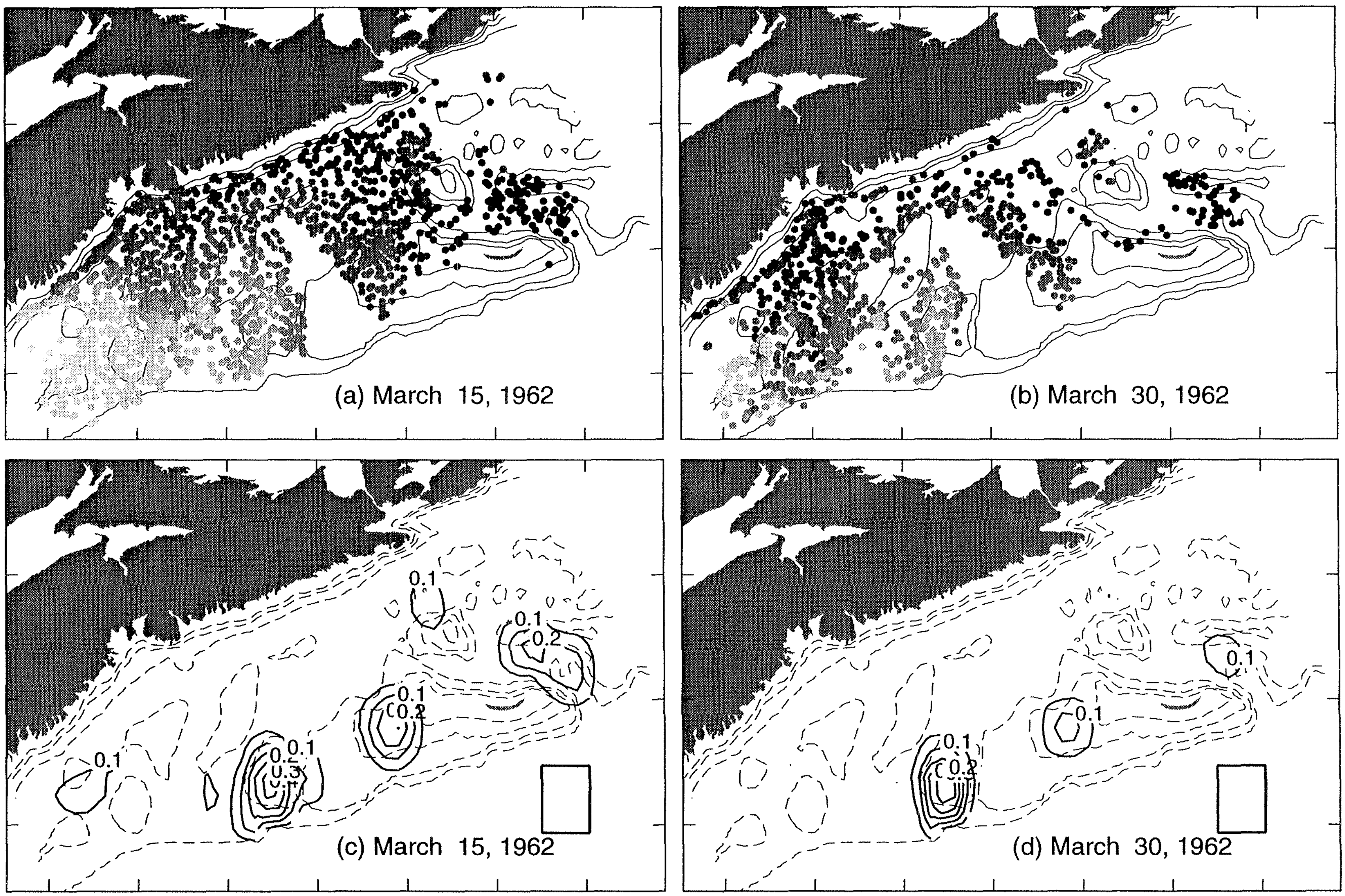

Figure 10.2: Dispersion in March 1962. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

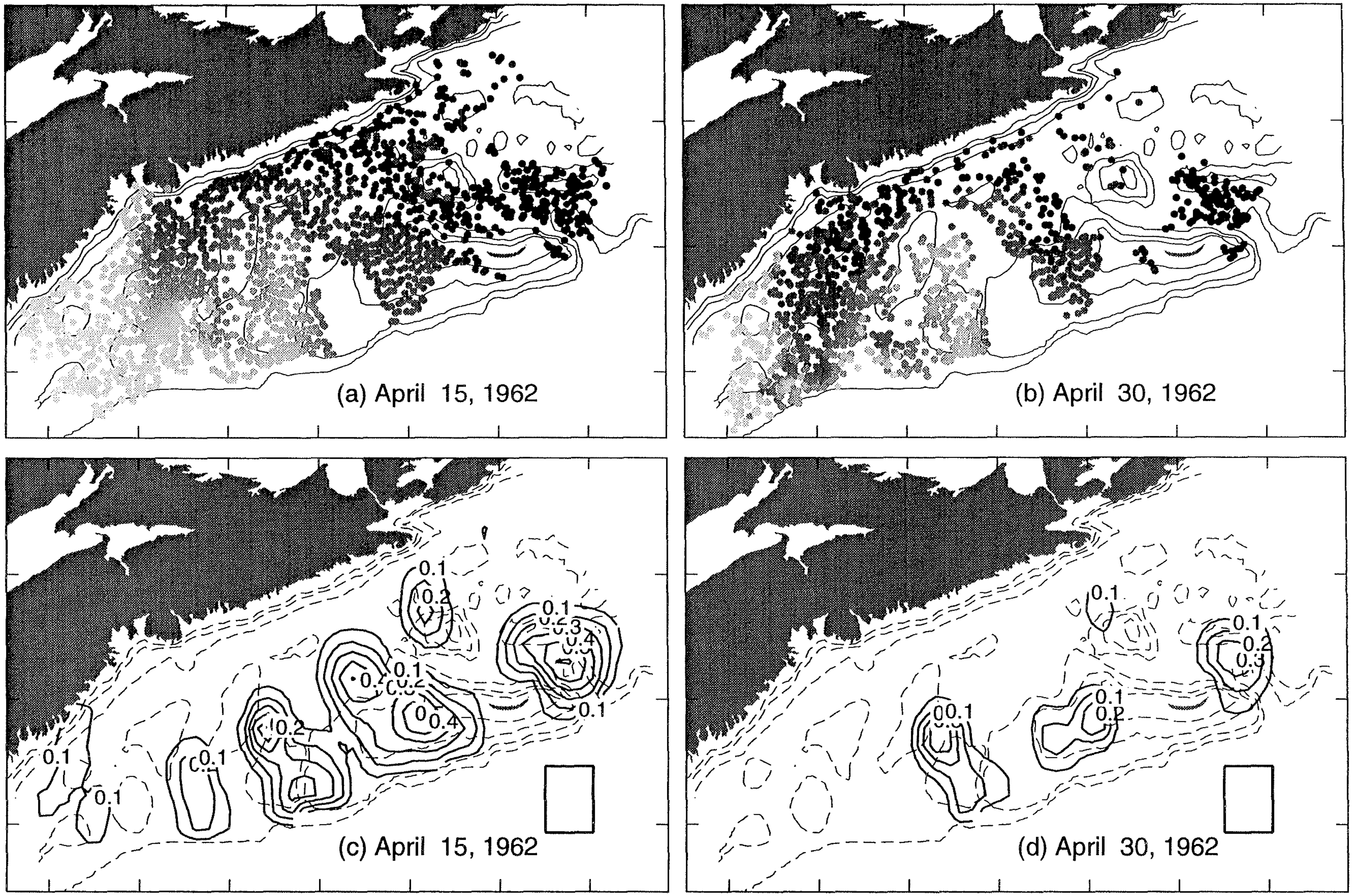

Figure 10.3: Dispersion in April 1962. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

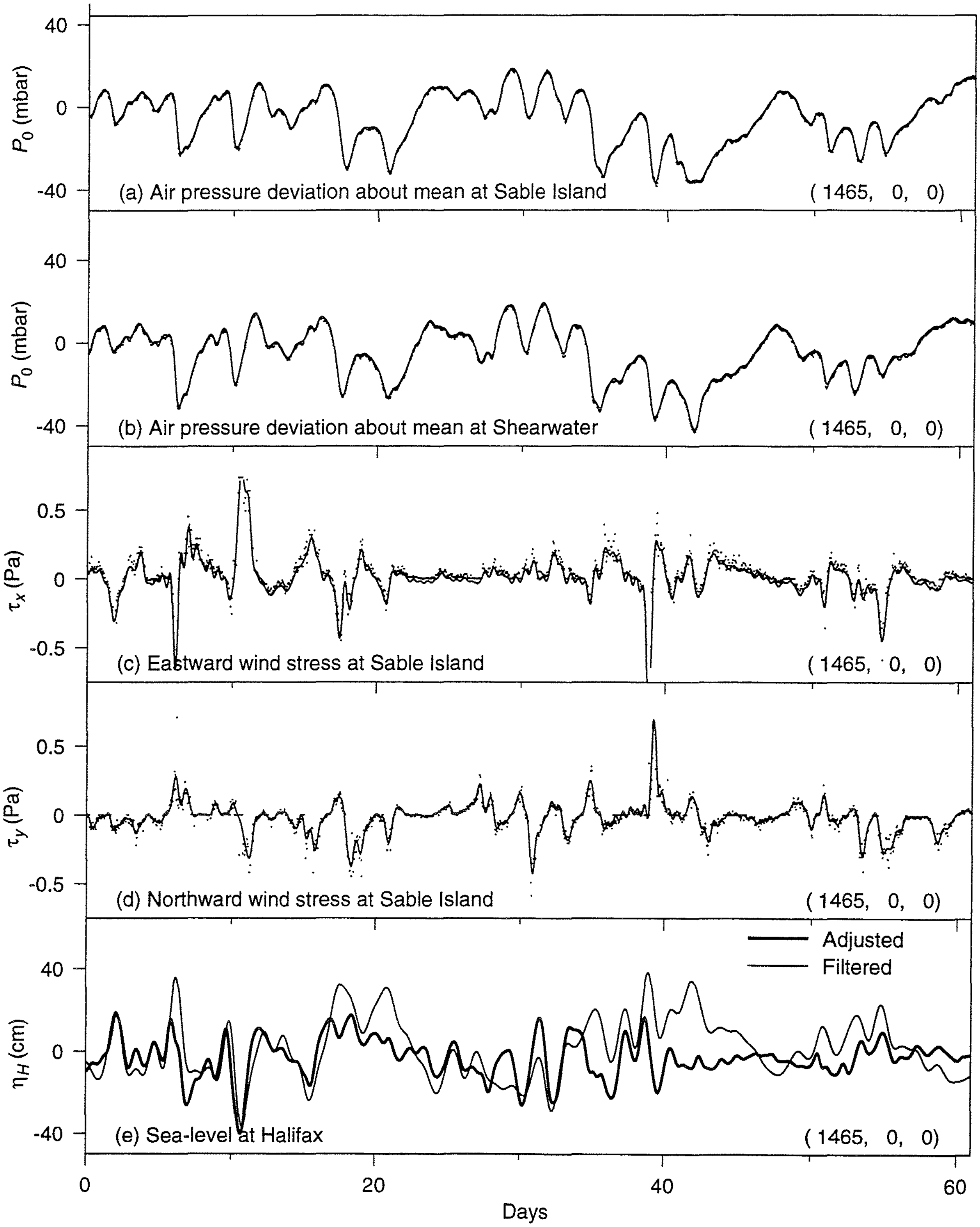

Figure 11.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1963). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

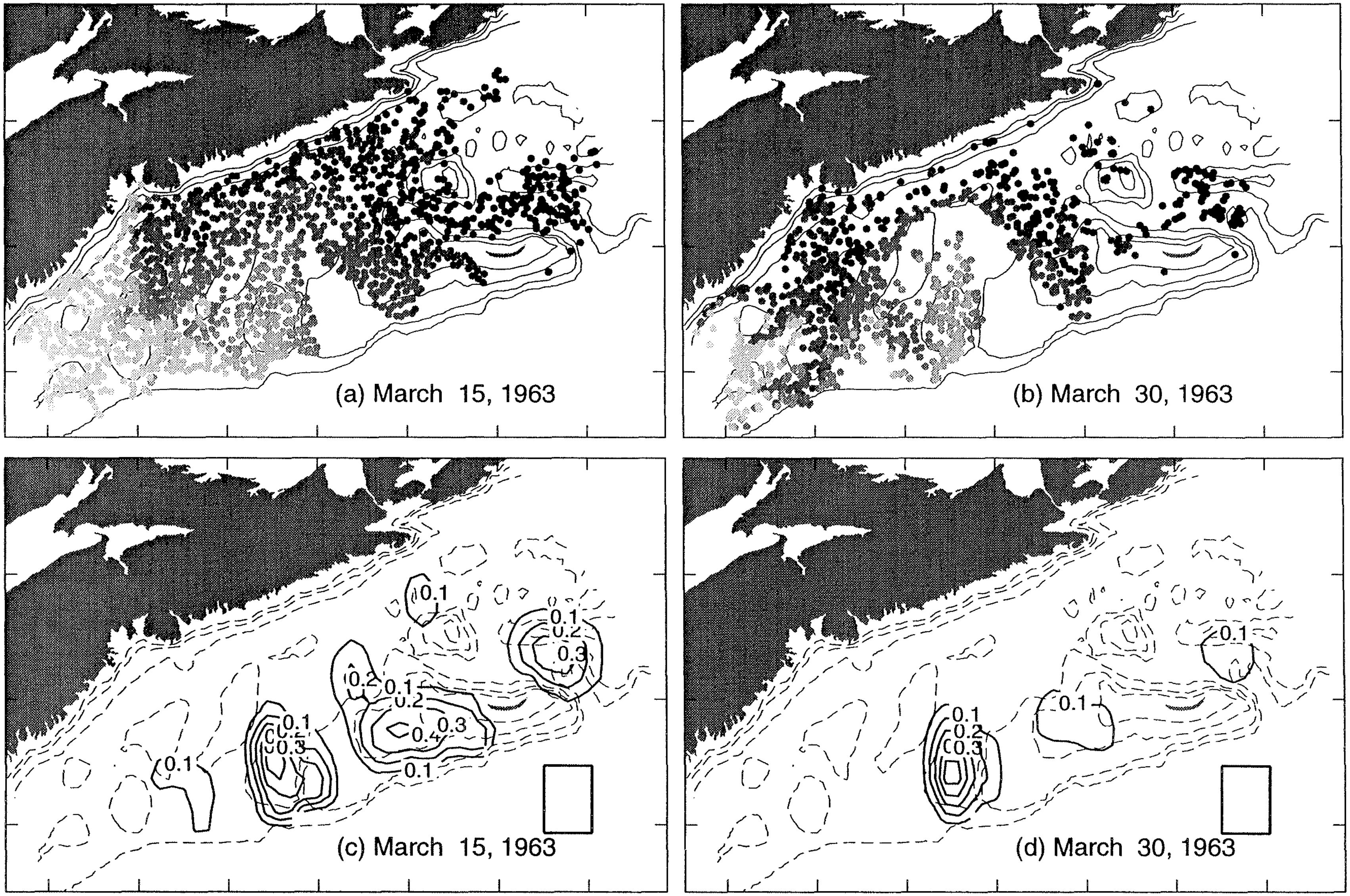

Figure 11.2: Dispersion in March 1963. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

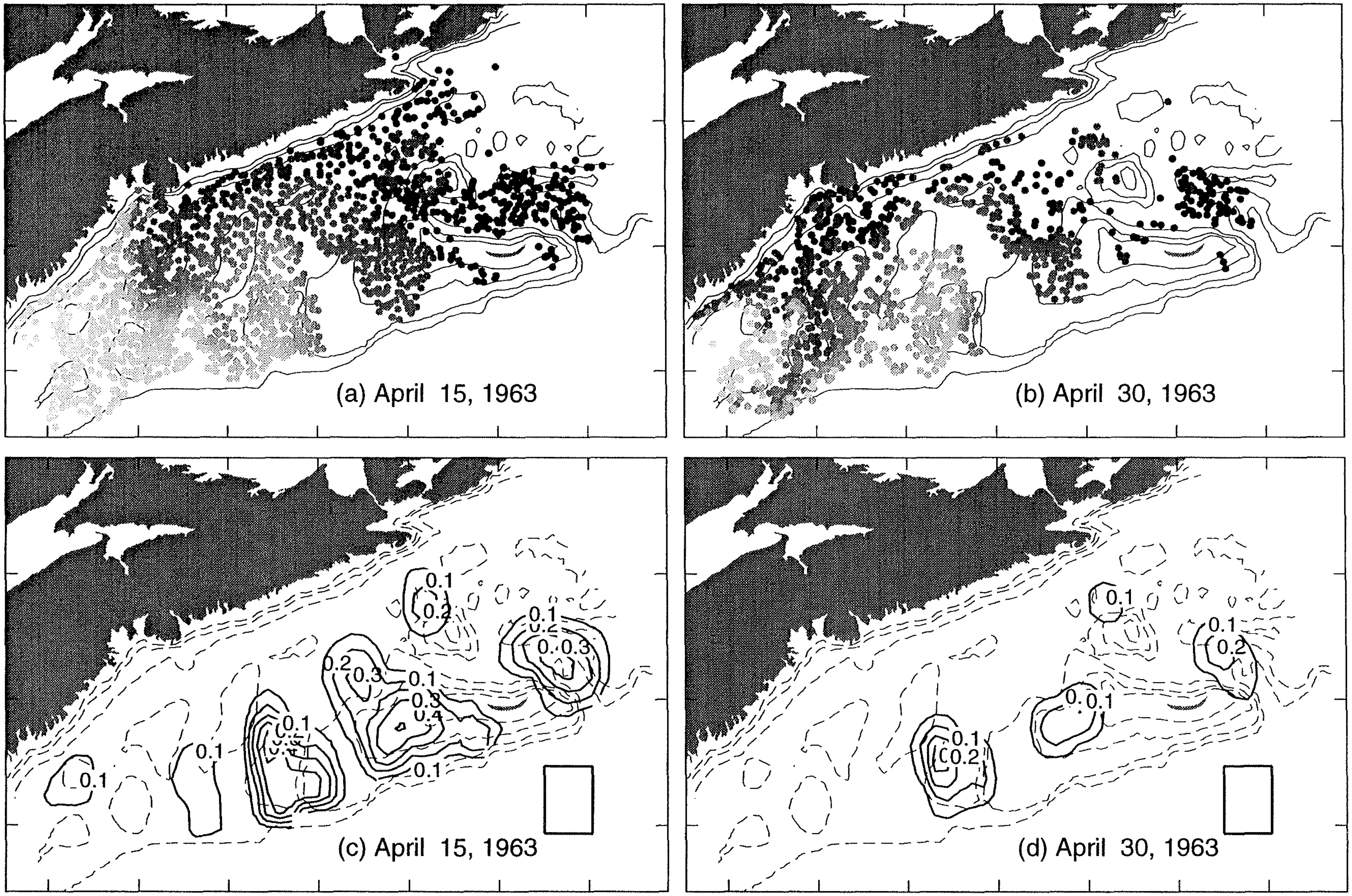

Figure 11.3: Dispersion in April 1963. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

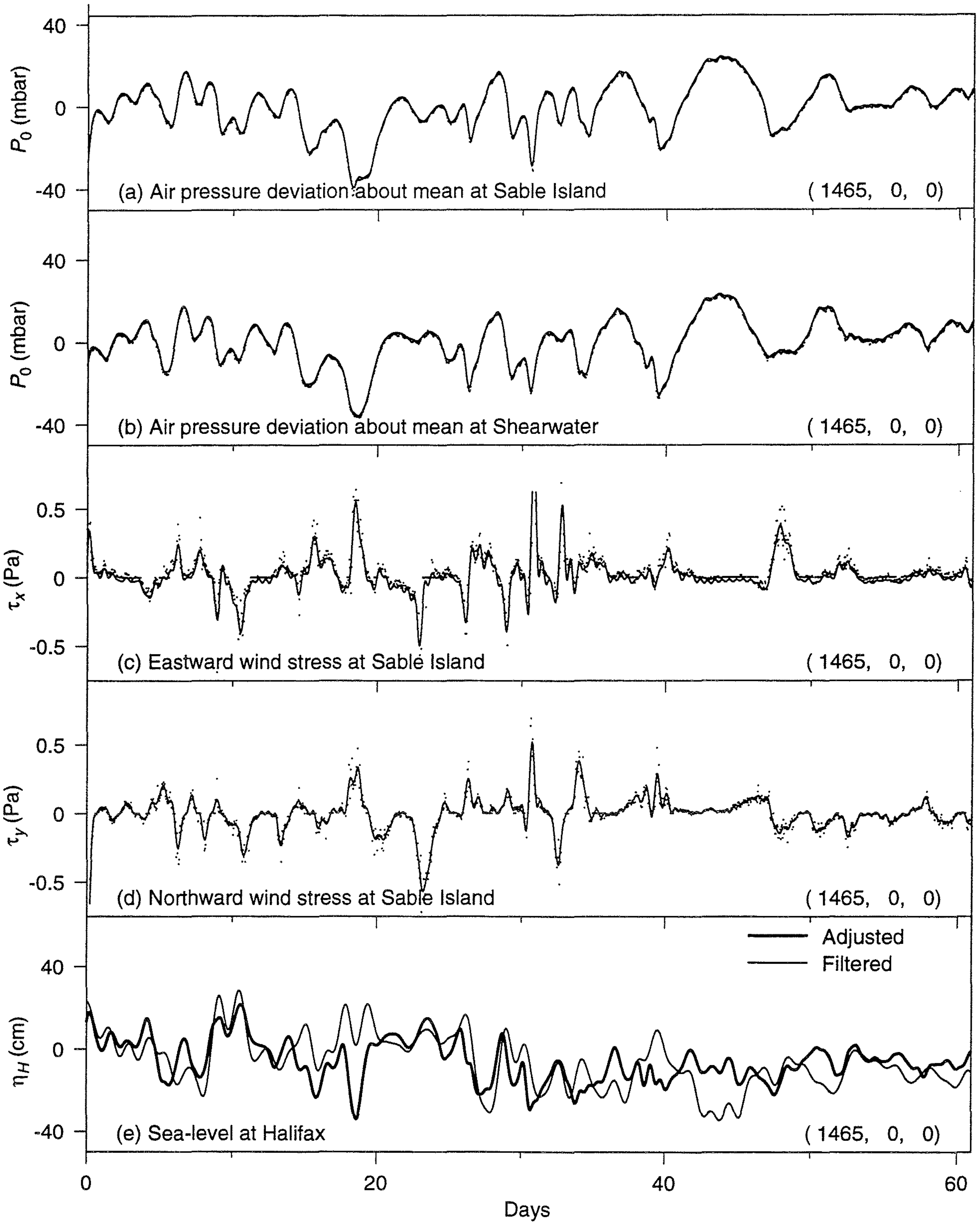

Figure 12.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1964). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

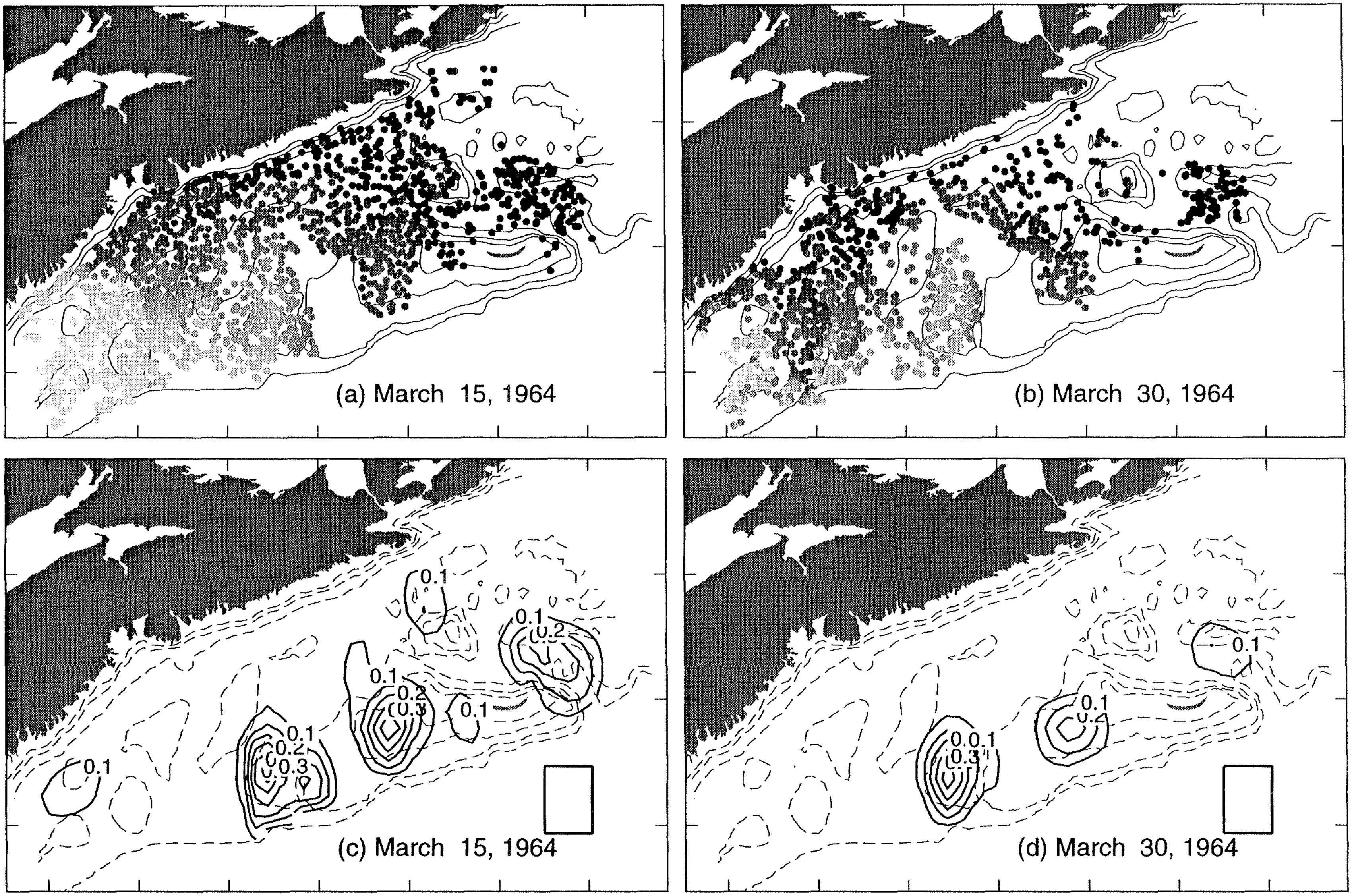

Figure 12.2: Dispersion in March 1964. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

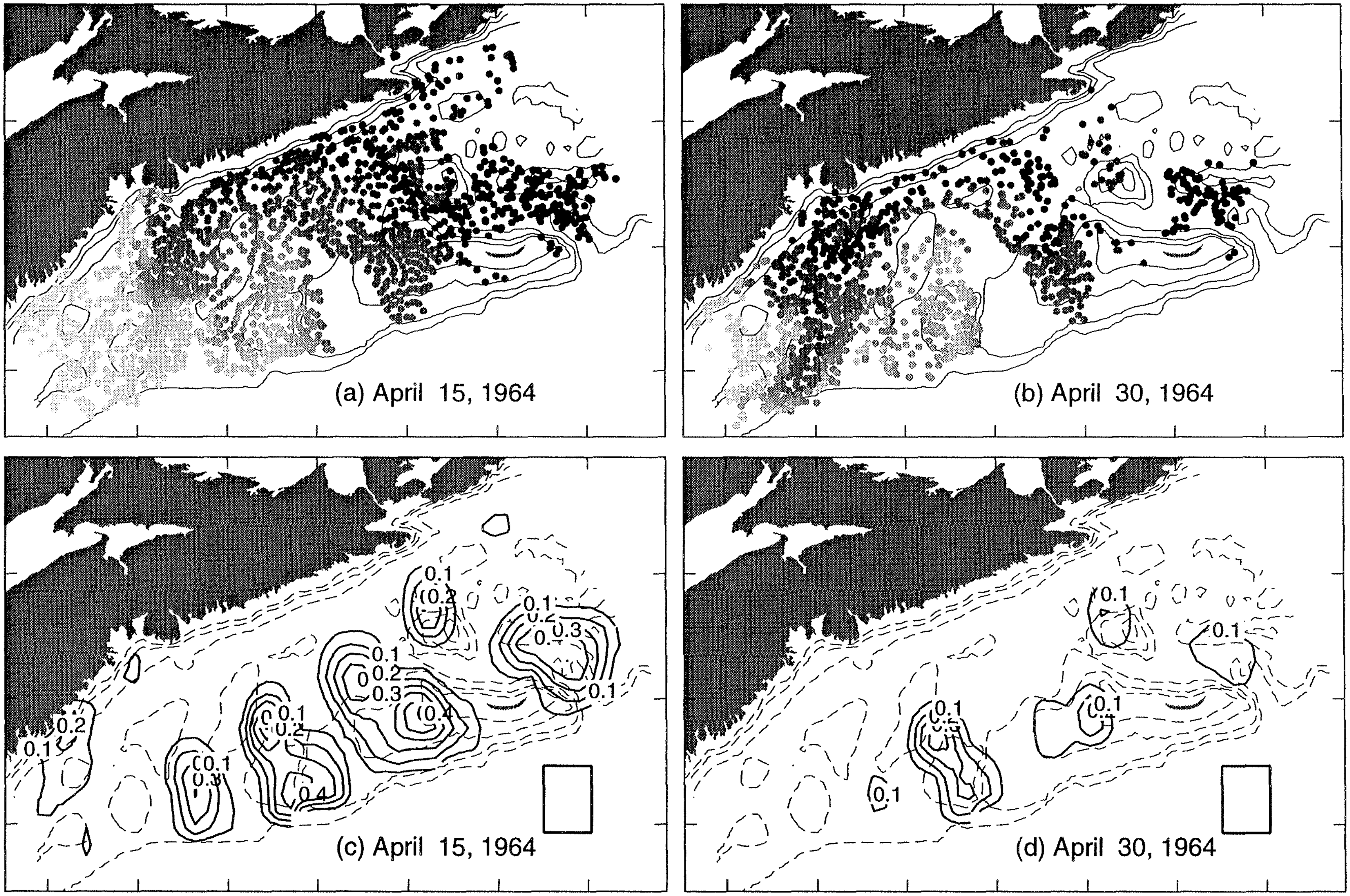

Figure 12.3: Dispersion in April 1964. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

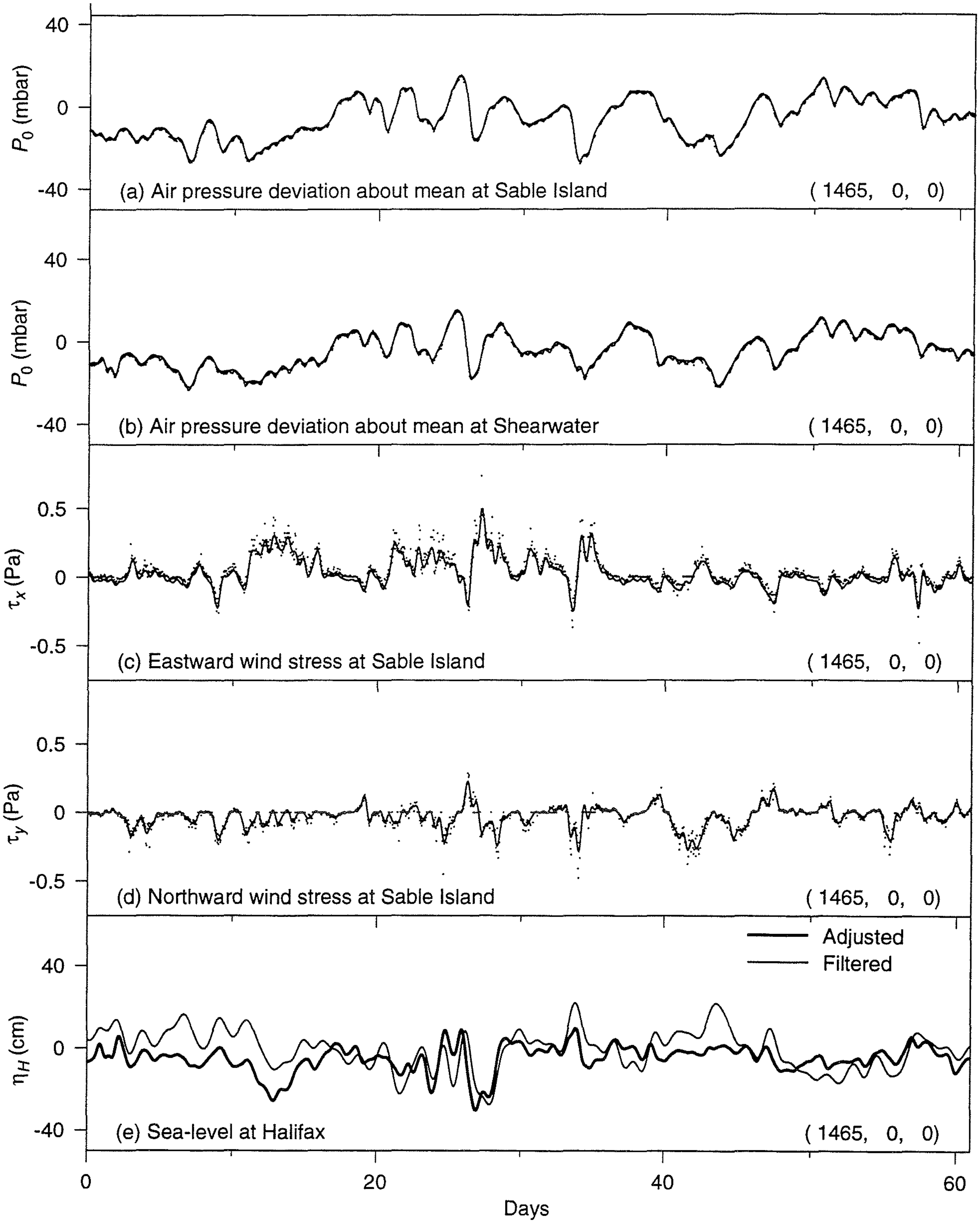

Figure 13.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1965). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

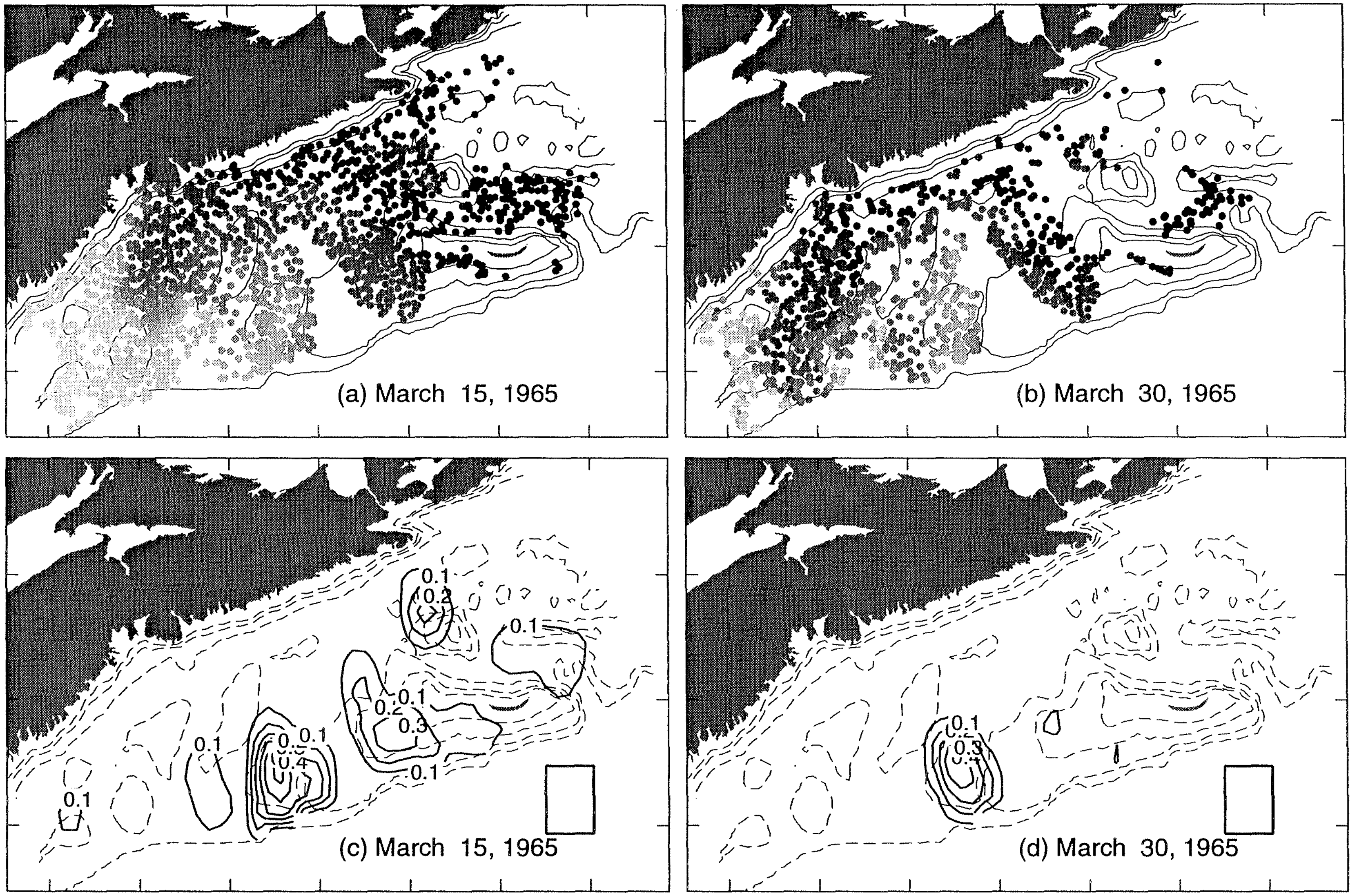

Figure 13.2: Dispersion in March 1965. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

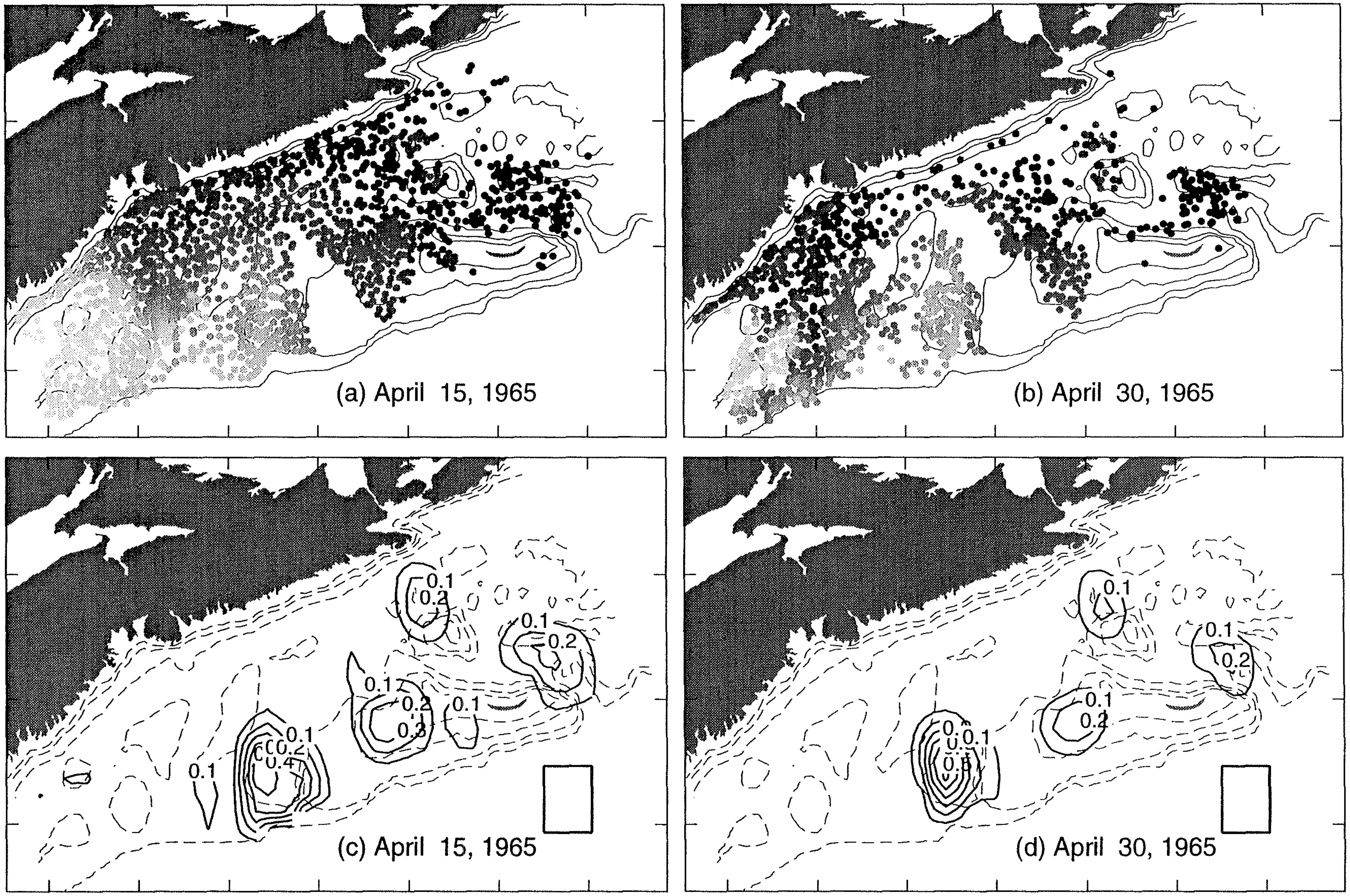

Figure 13.3: Dispersion in April 1965. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

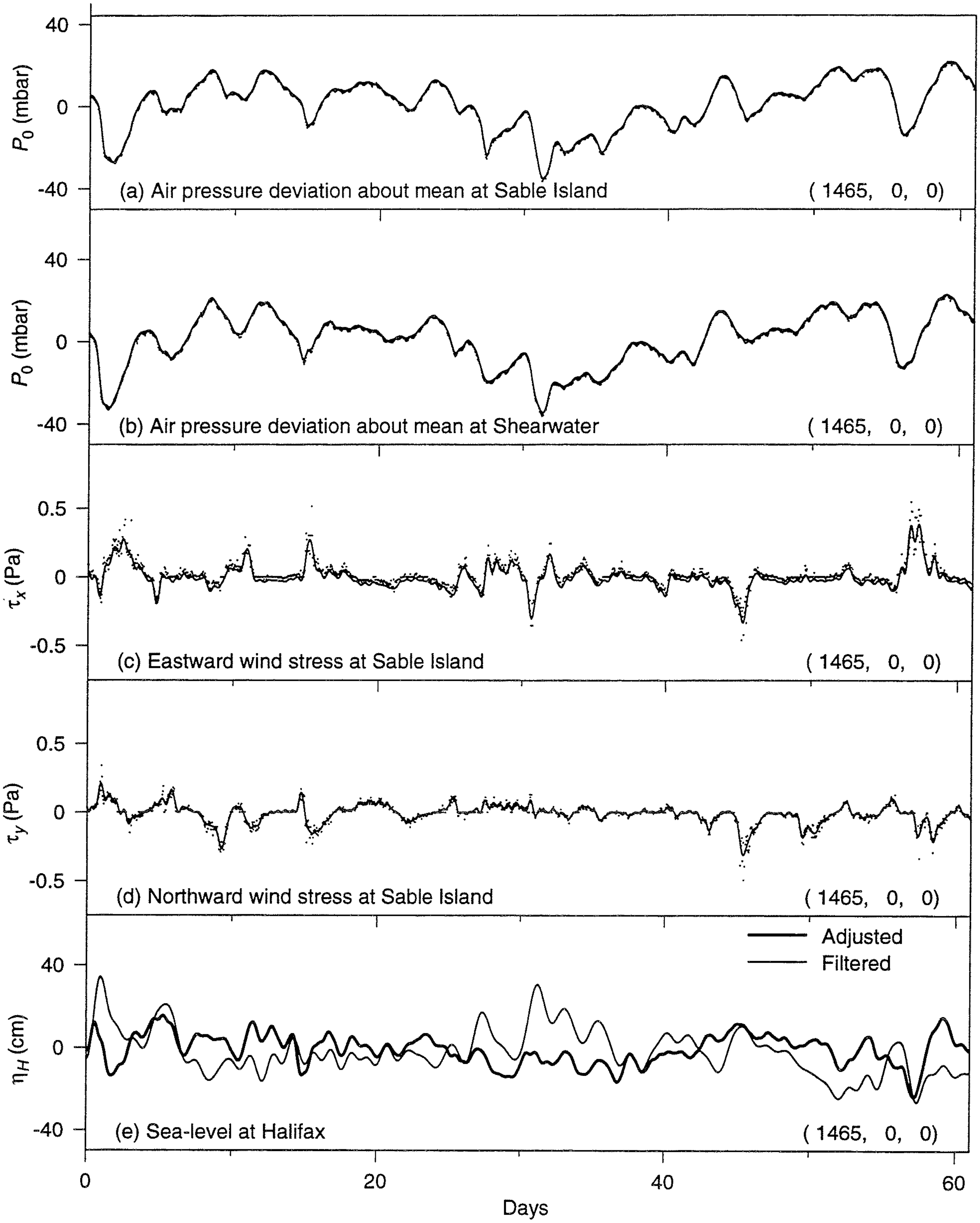

Figure 14.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1966). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

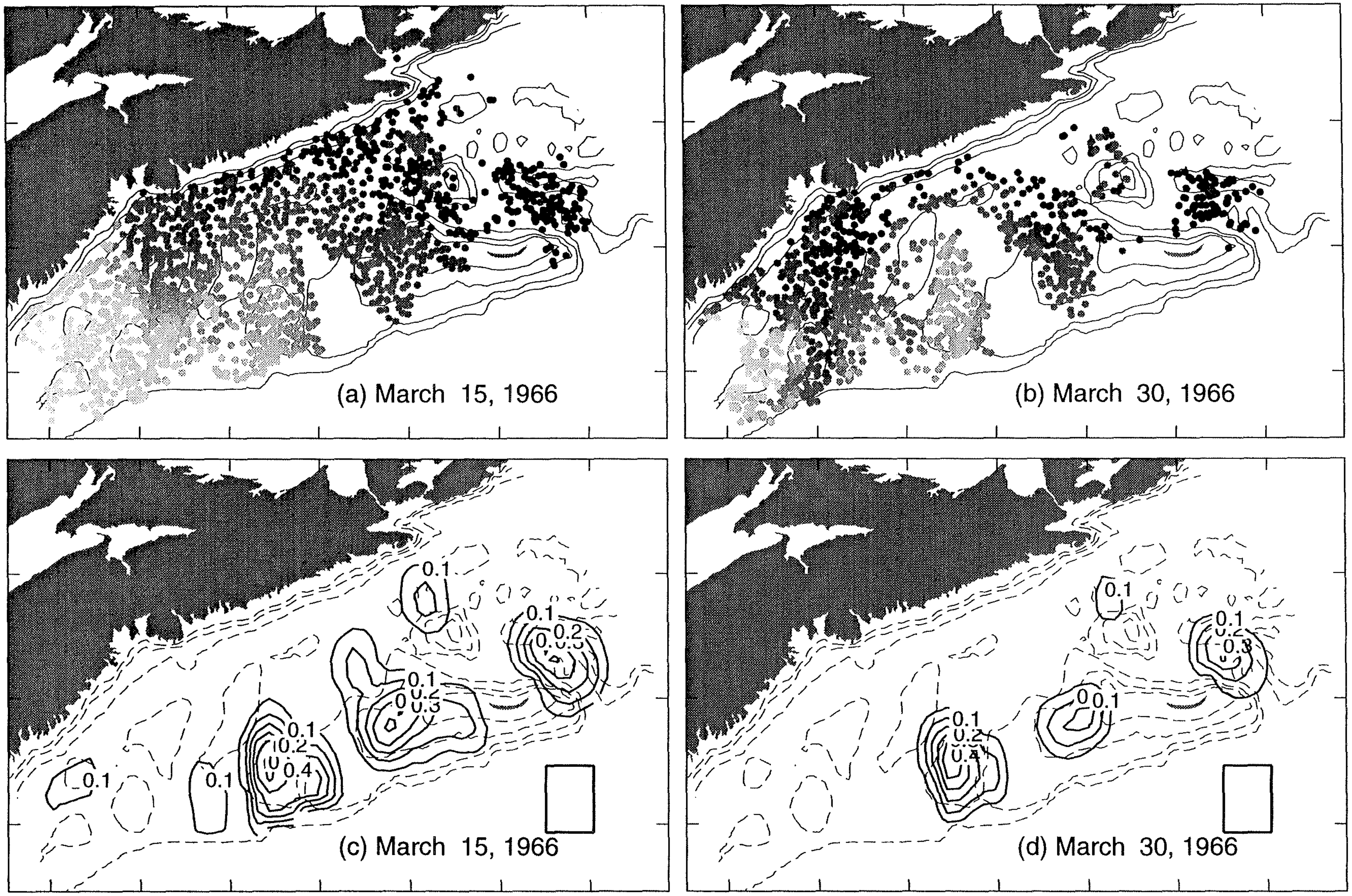

Figure 14.2: Dispersion in March 1966. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

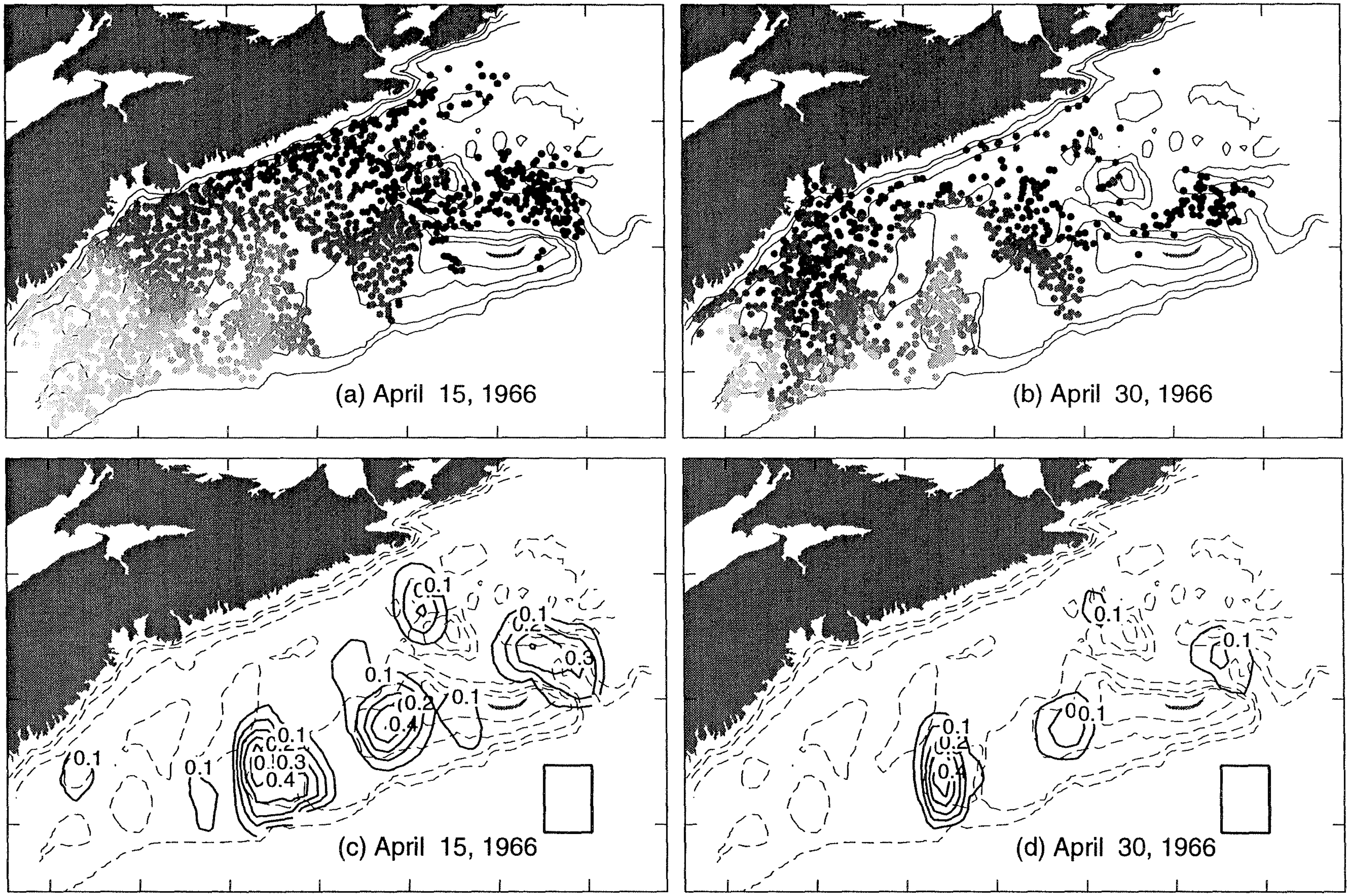

Figure 14.3: Dispersion in April 1966. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

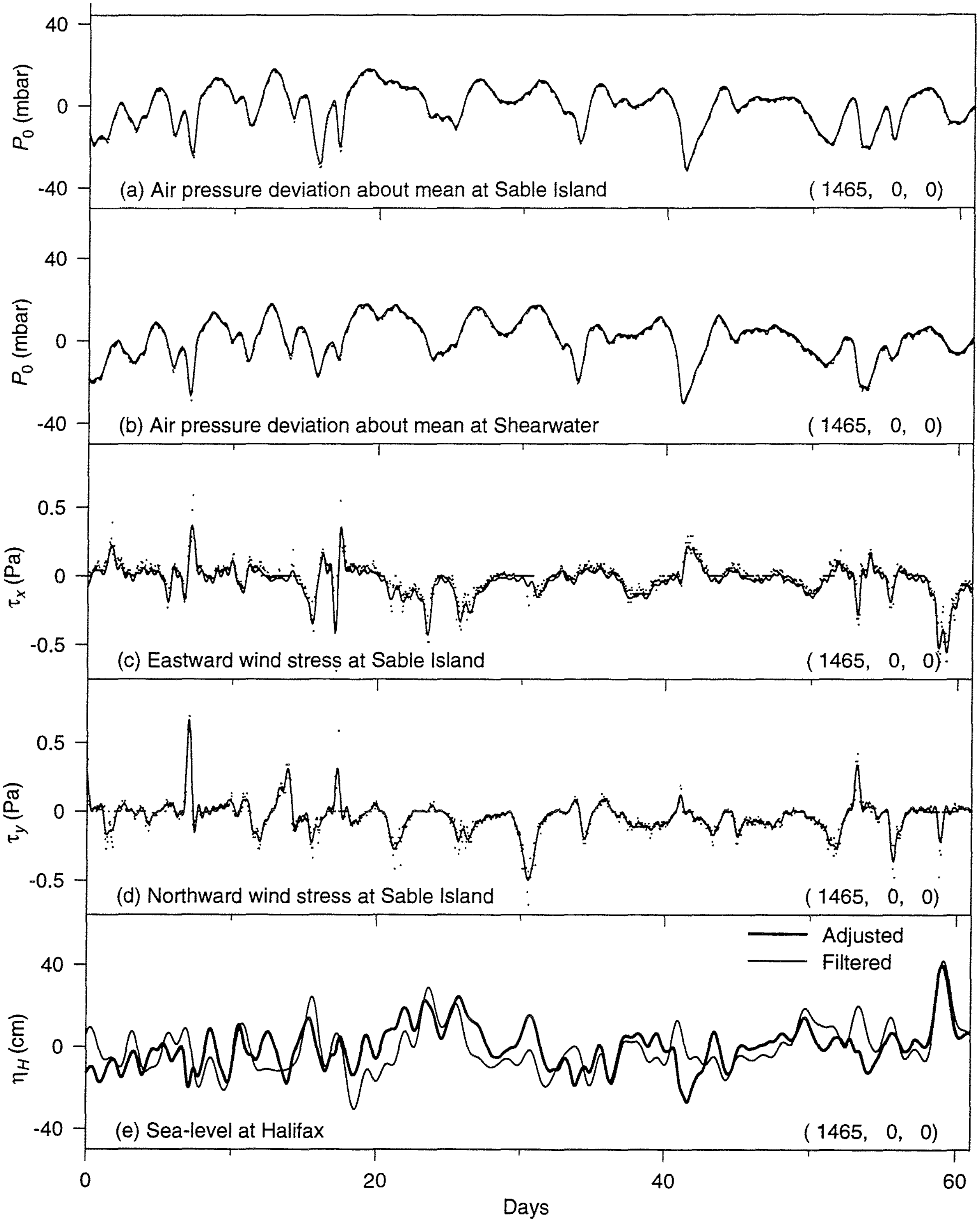

Figure 15.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1967). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

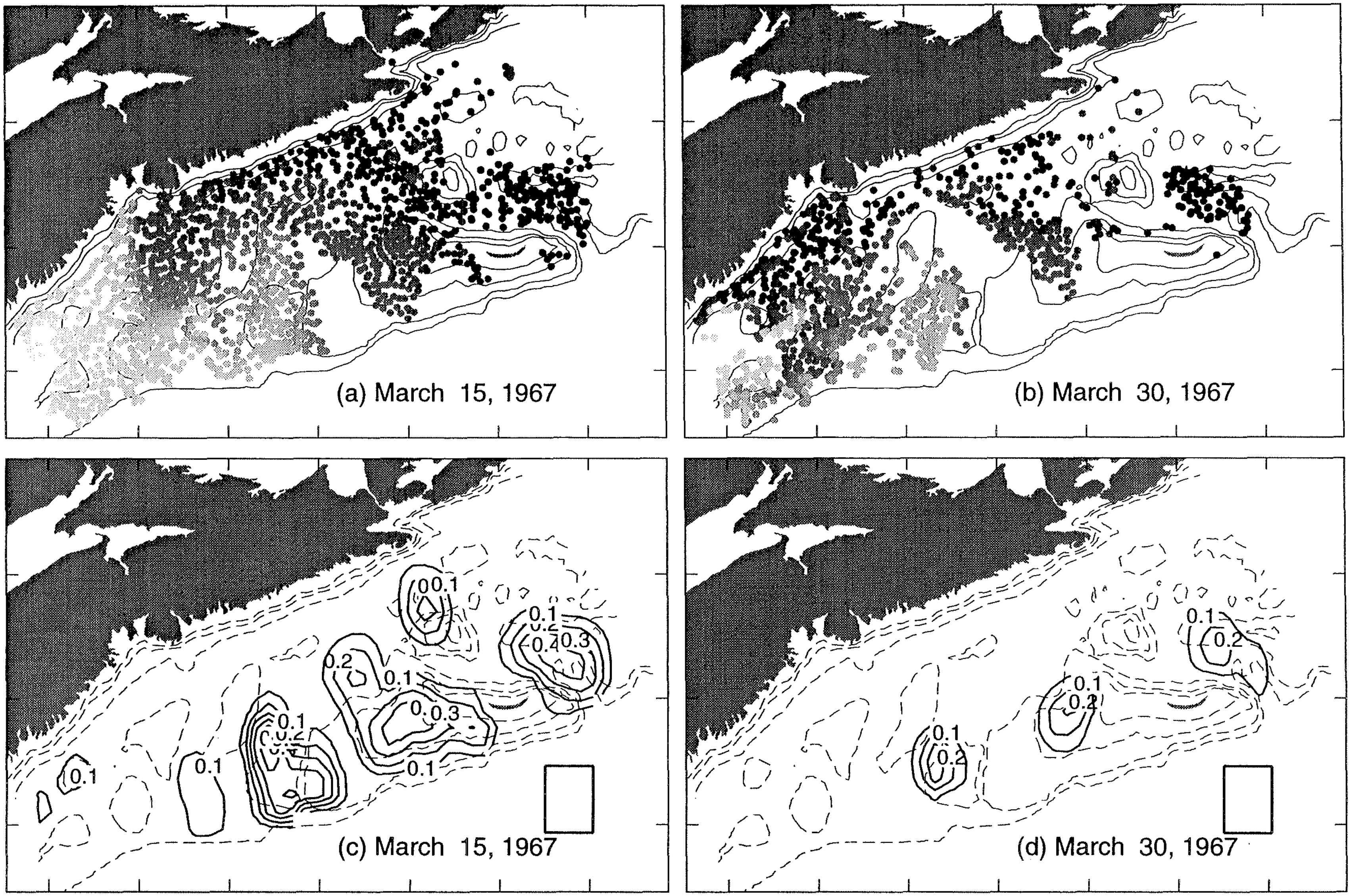

Figure 15.2: Dispersion in March 1967. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

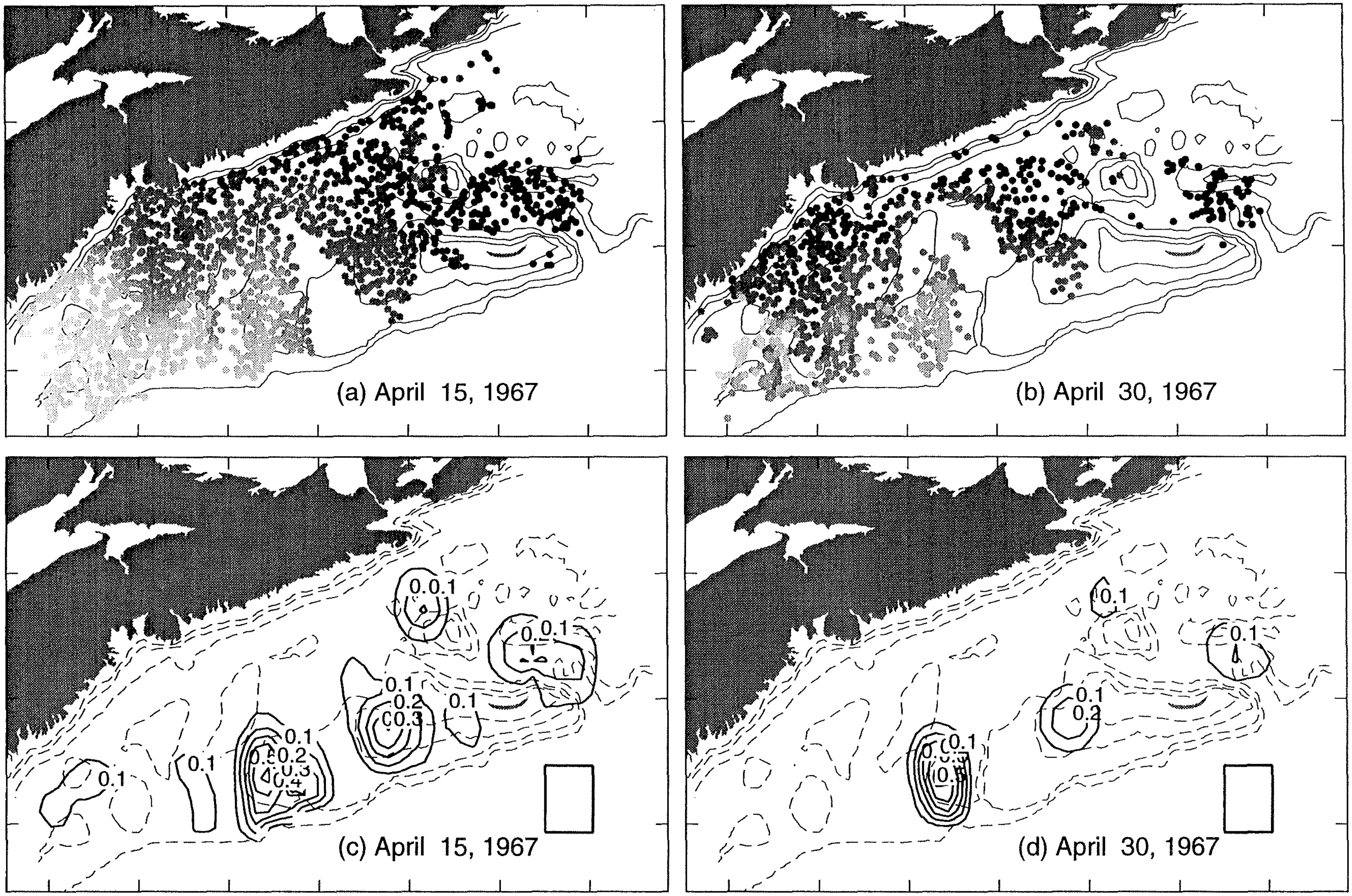

Figure 15.3: Dispersion in April 1967. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

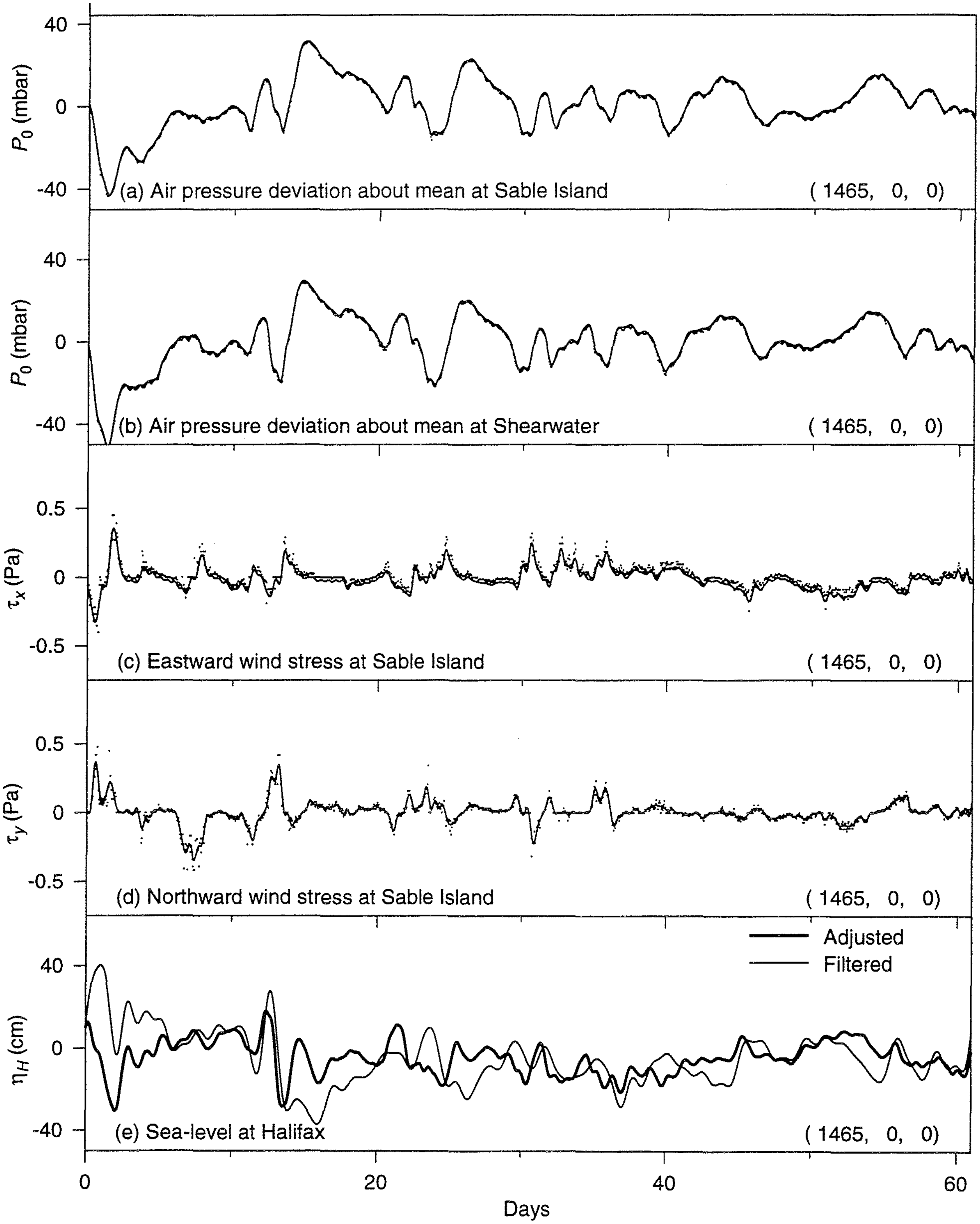

Figure 16.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1968). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

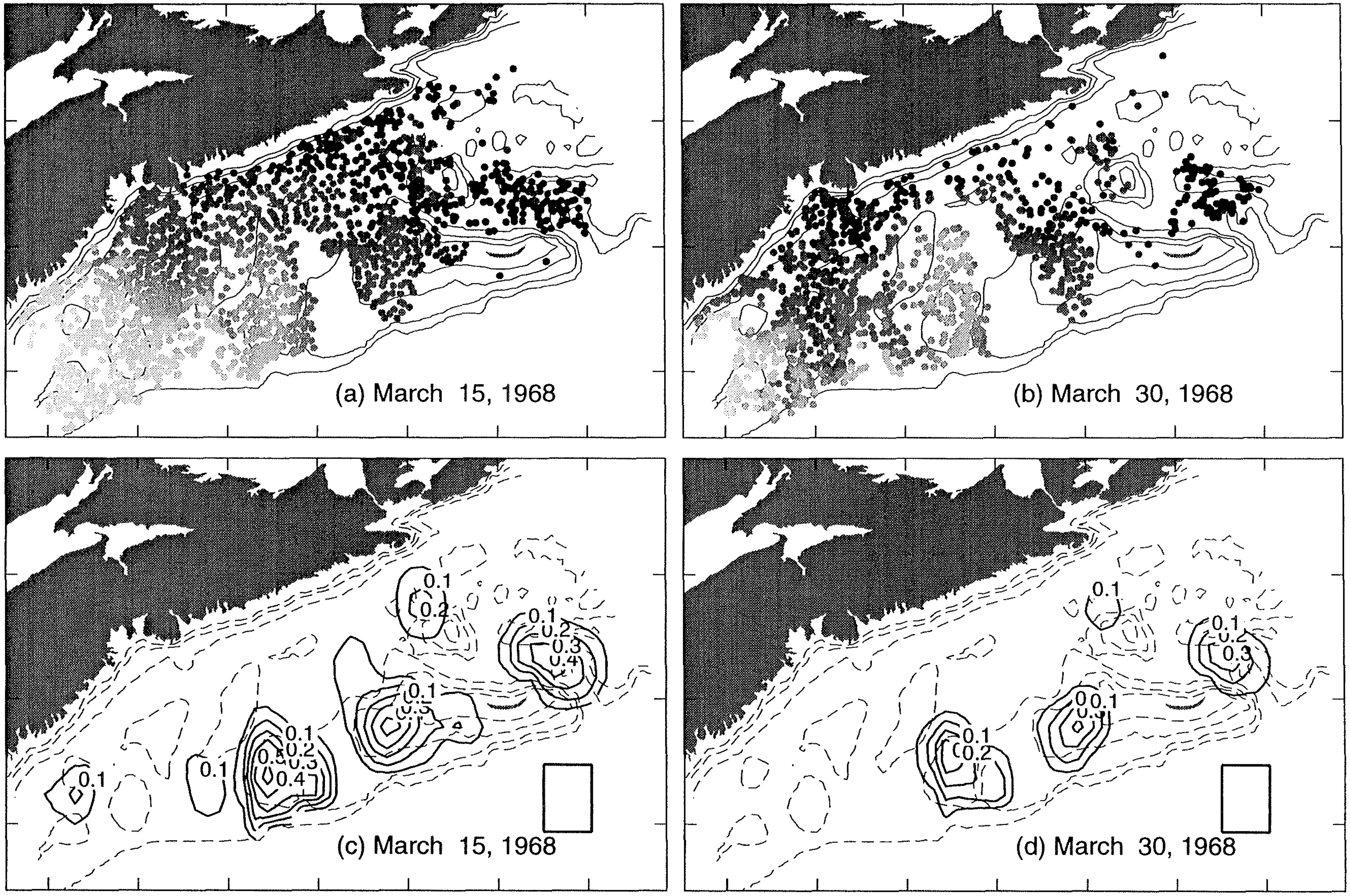

Figure 16.2: Dispersion in March 1968. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

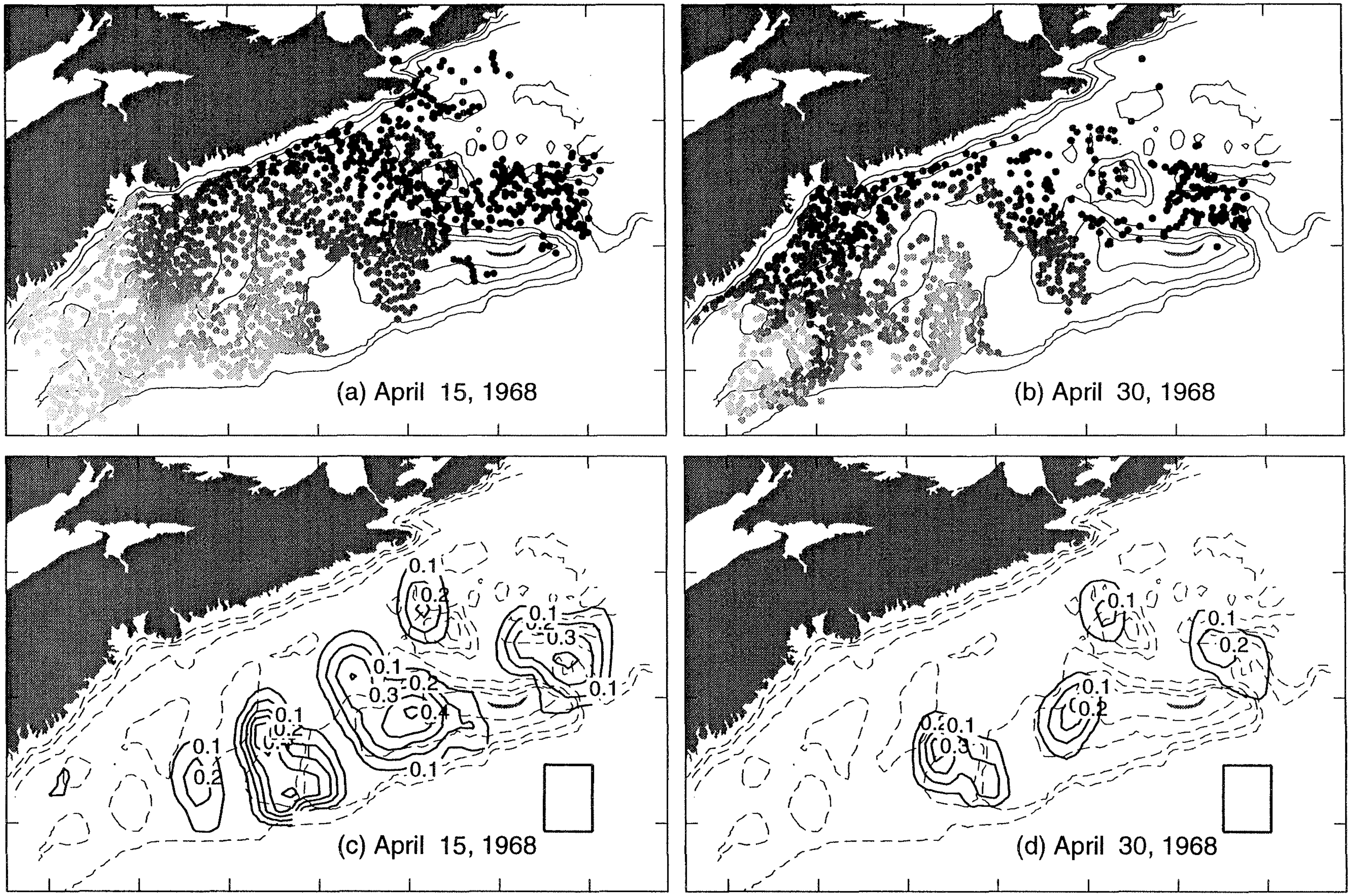

Figure 16.3: Dispersion in April 1968. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

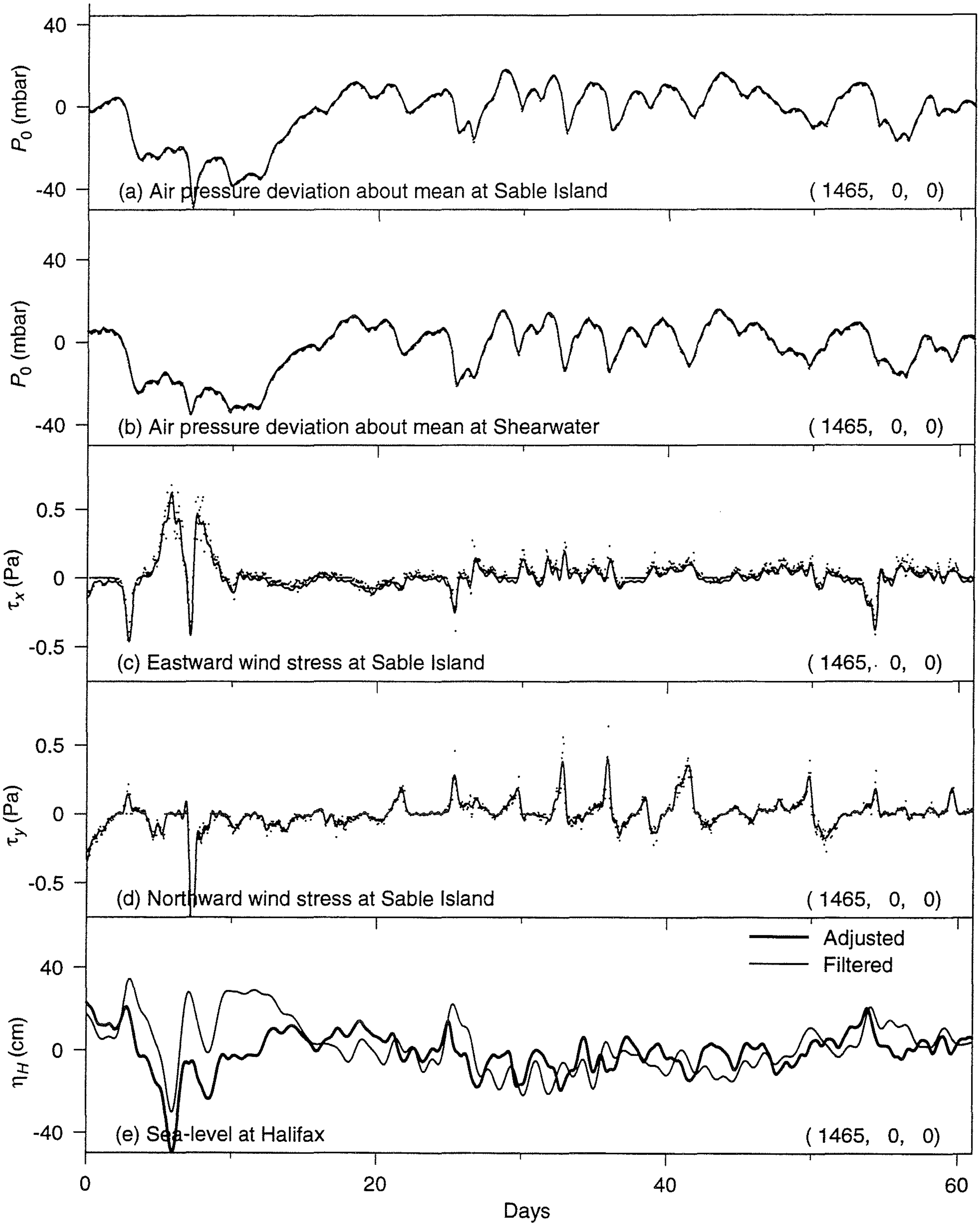

Figure 17.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1969). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

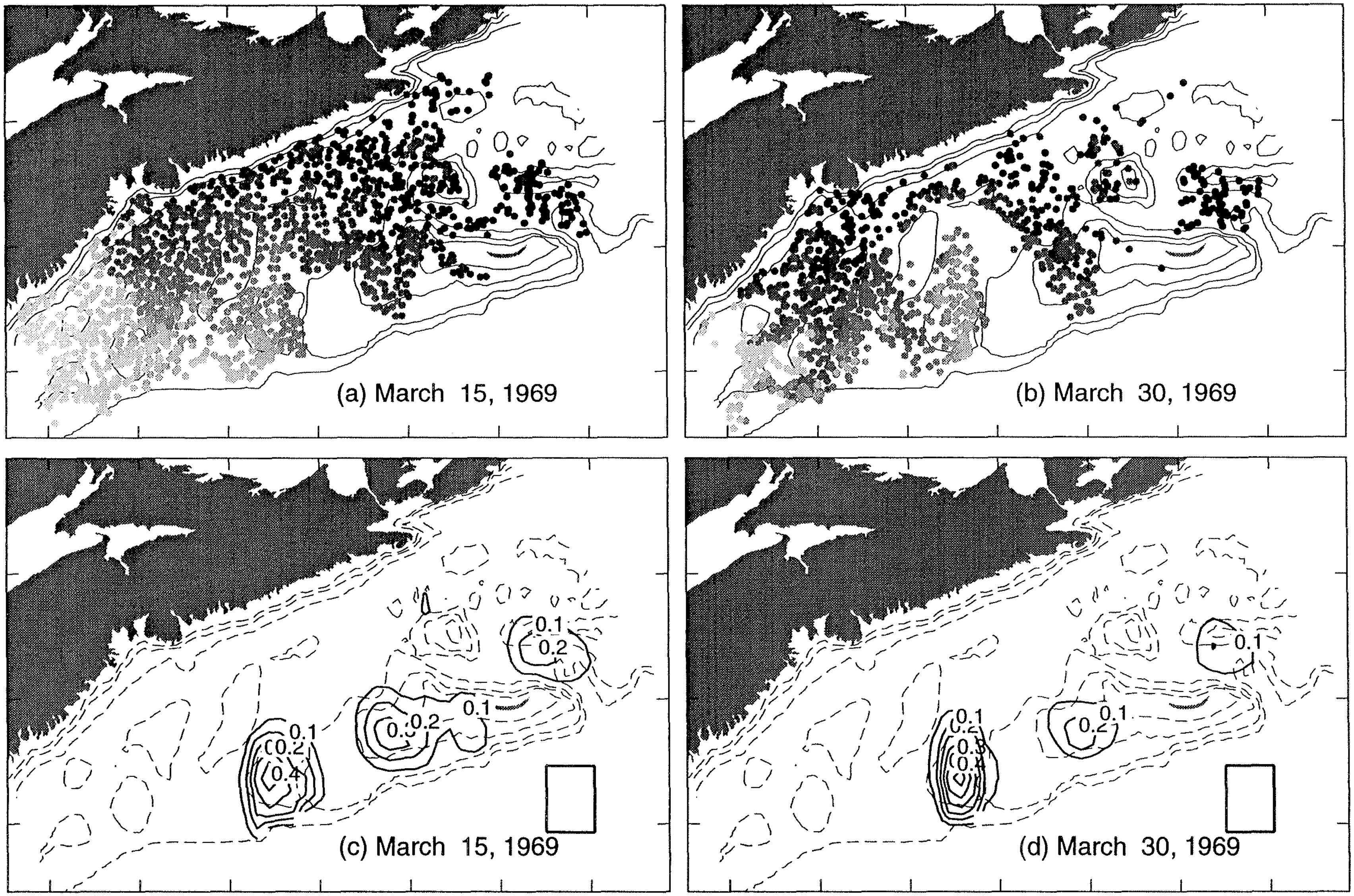

Figure 17.2: Dispersion in March 1969. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

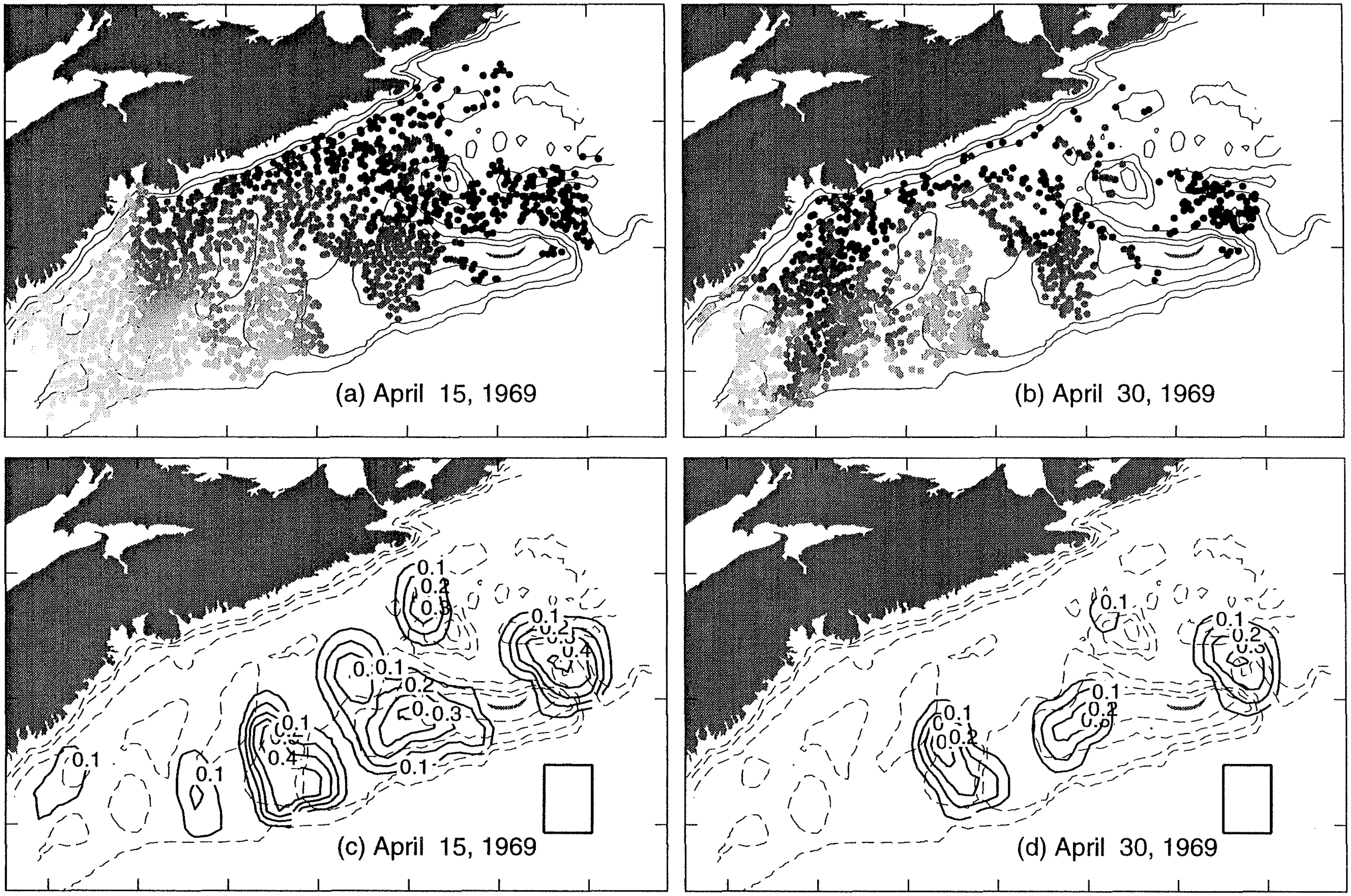

Figure 17.3: Dispersion in April 1969. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

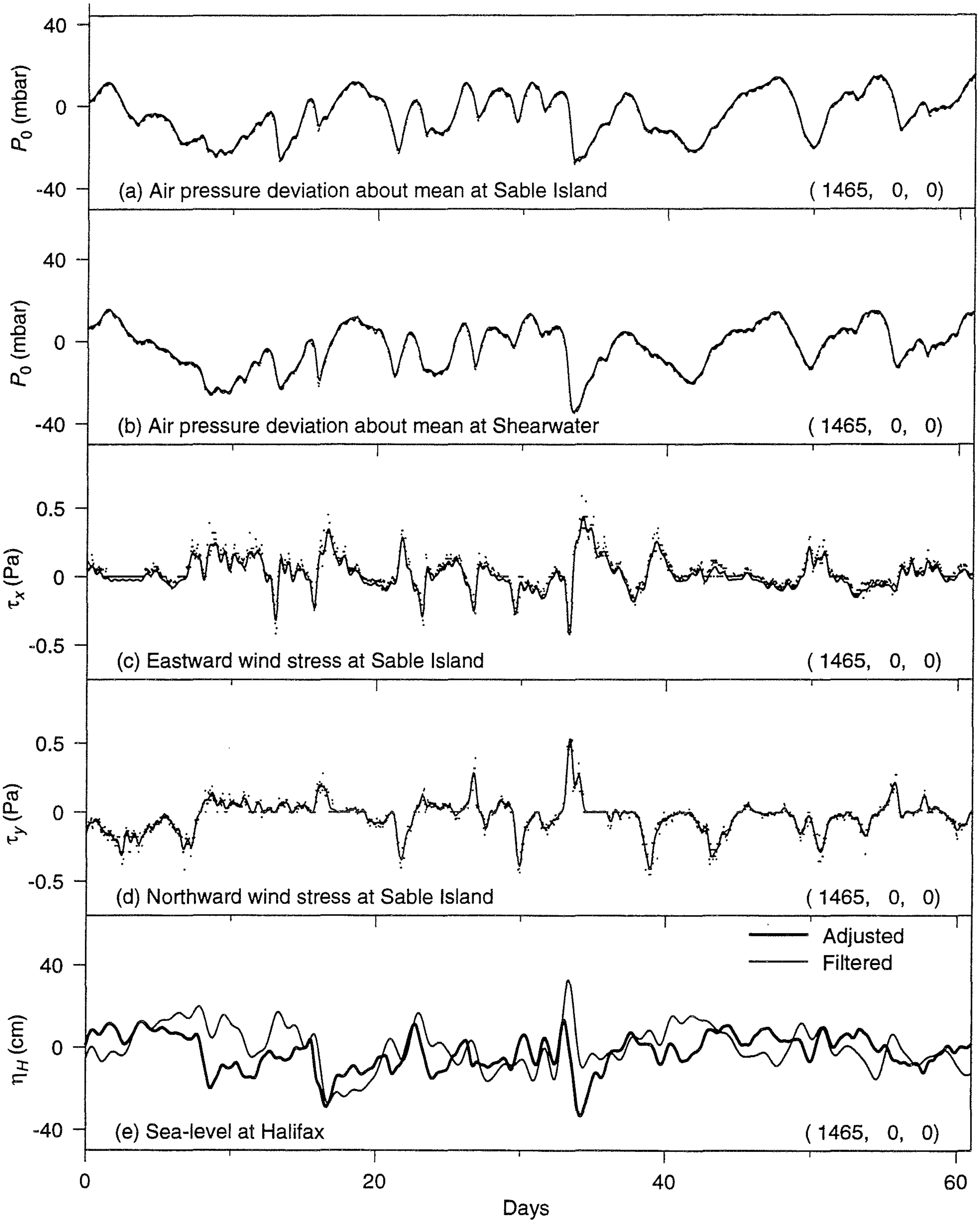

Figure 18.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1970). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

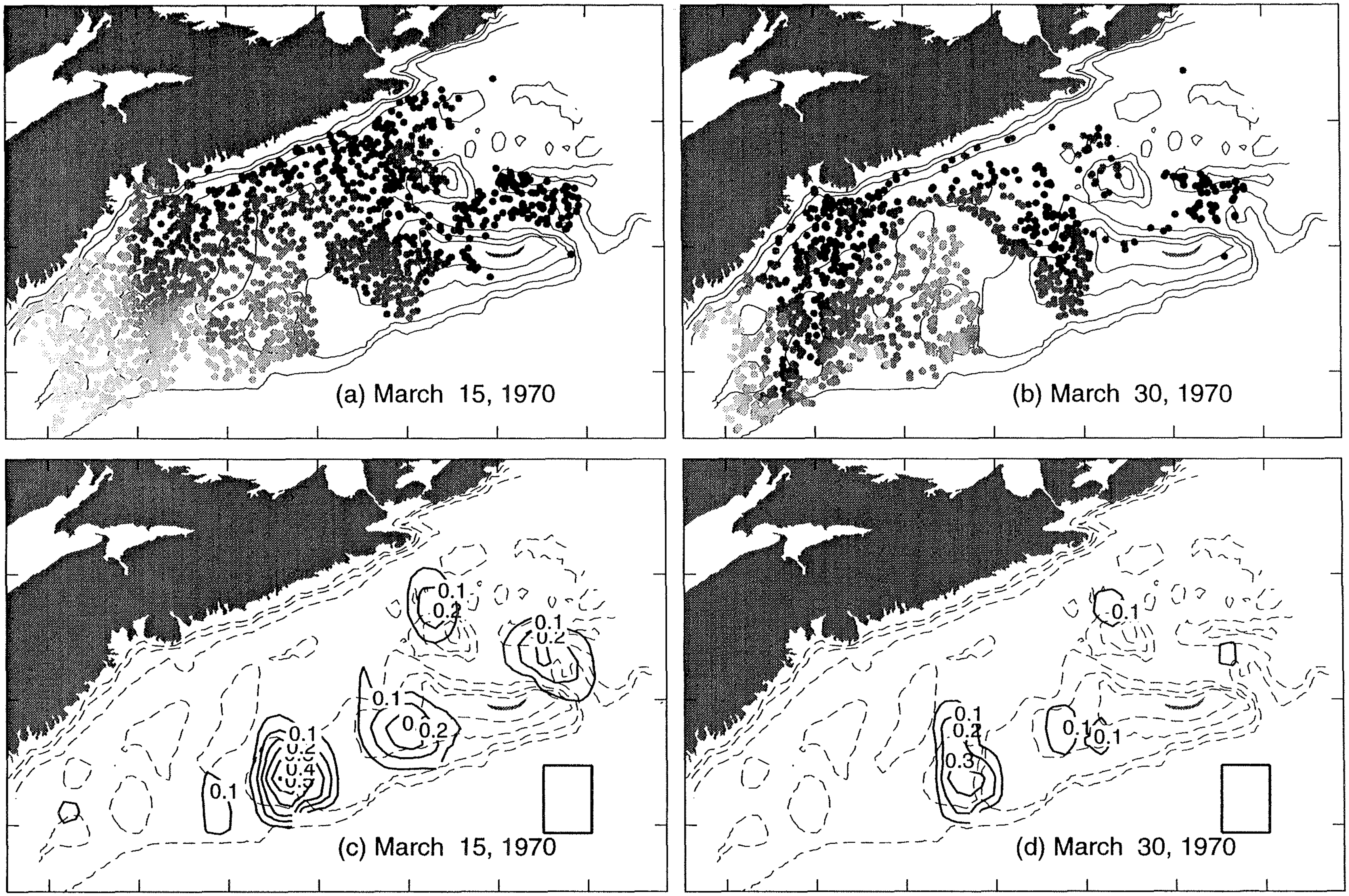

Figure 18.2: Dispersion in March 1970. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

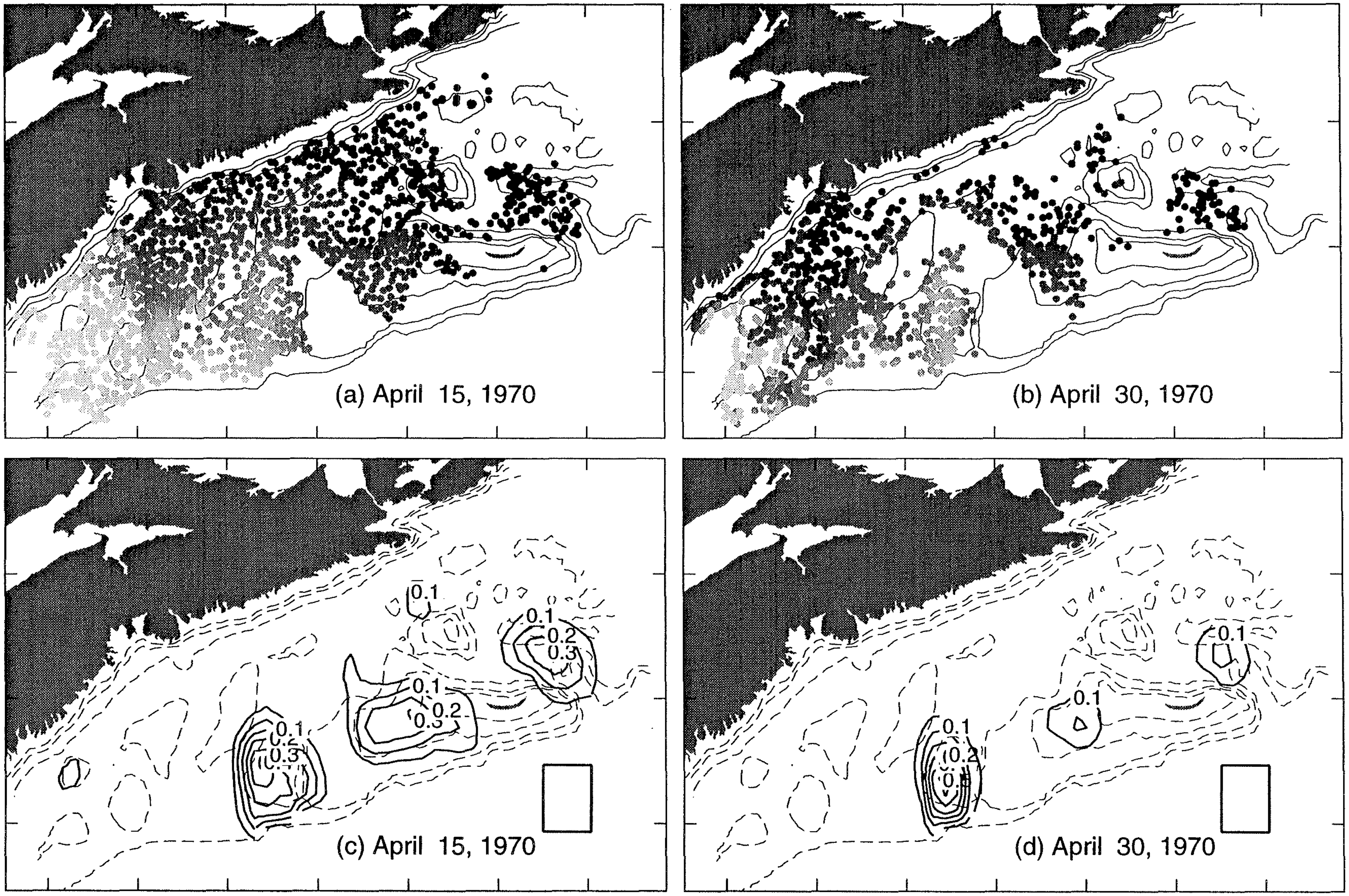

Figure 18.3: Dispersion in April 1970. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

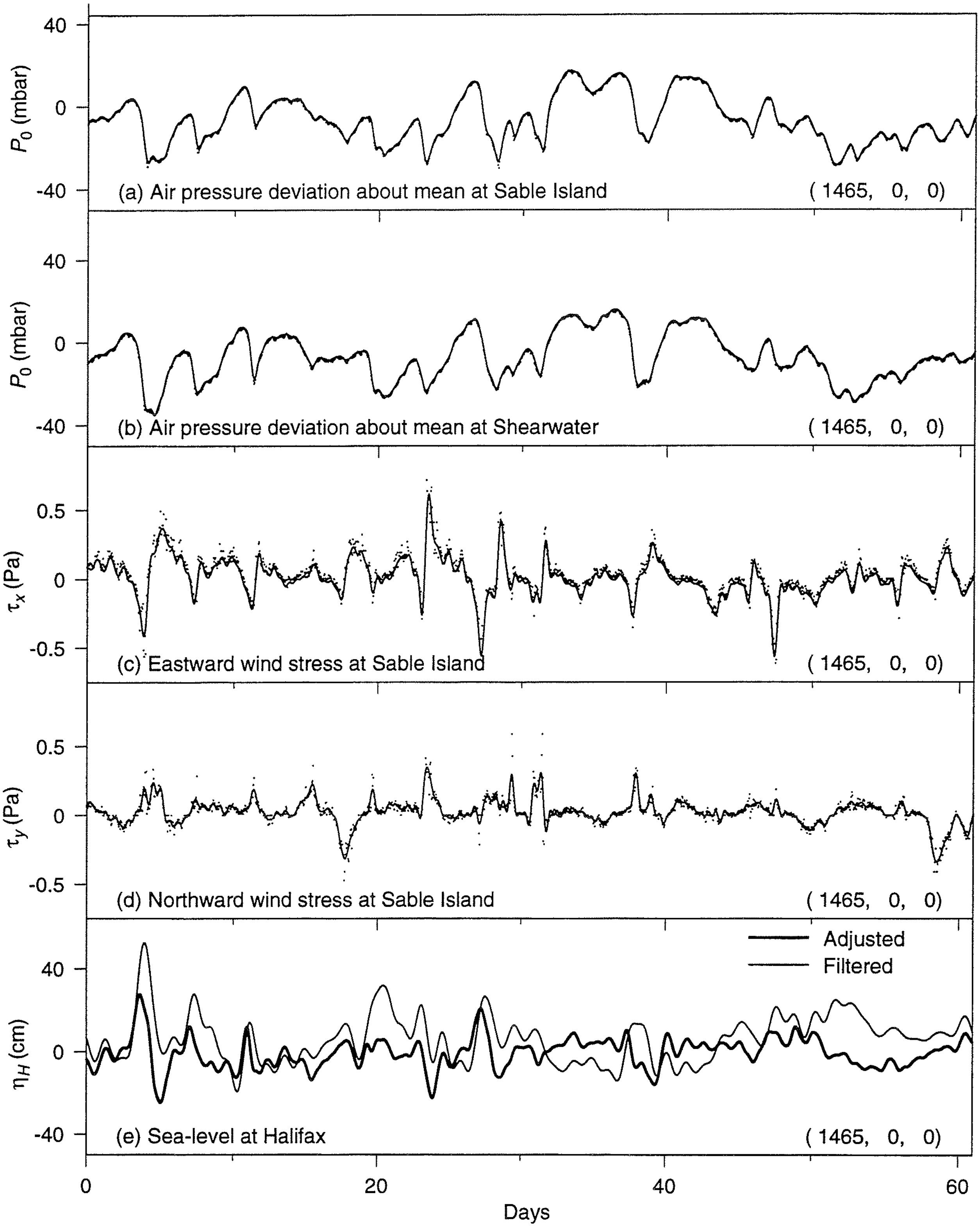

Figure 19.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1971). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

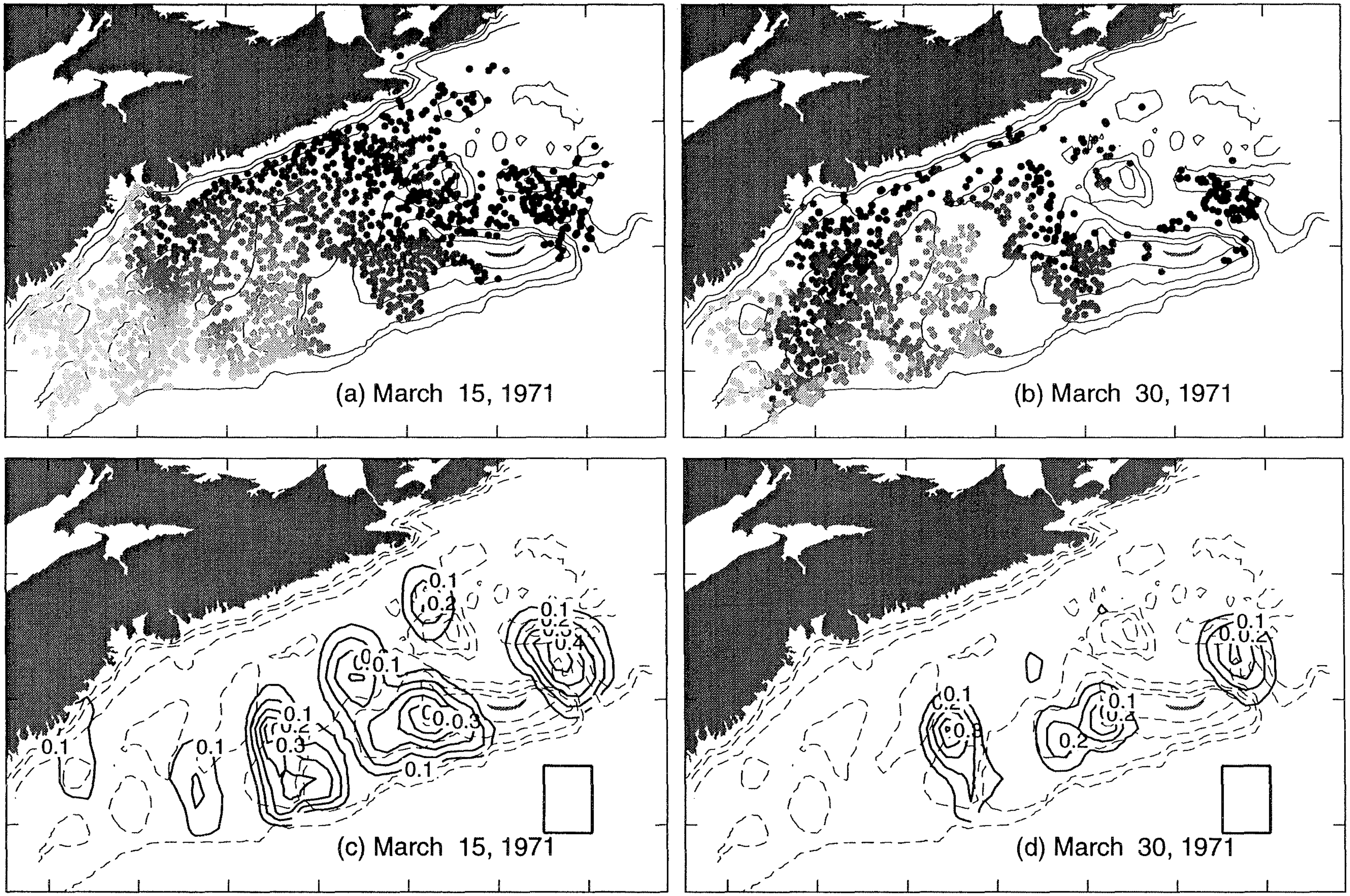

Figure 19.2: Dispersion in March 1971. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

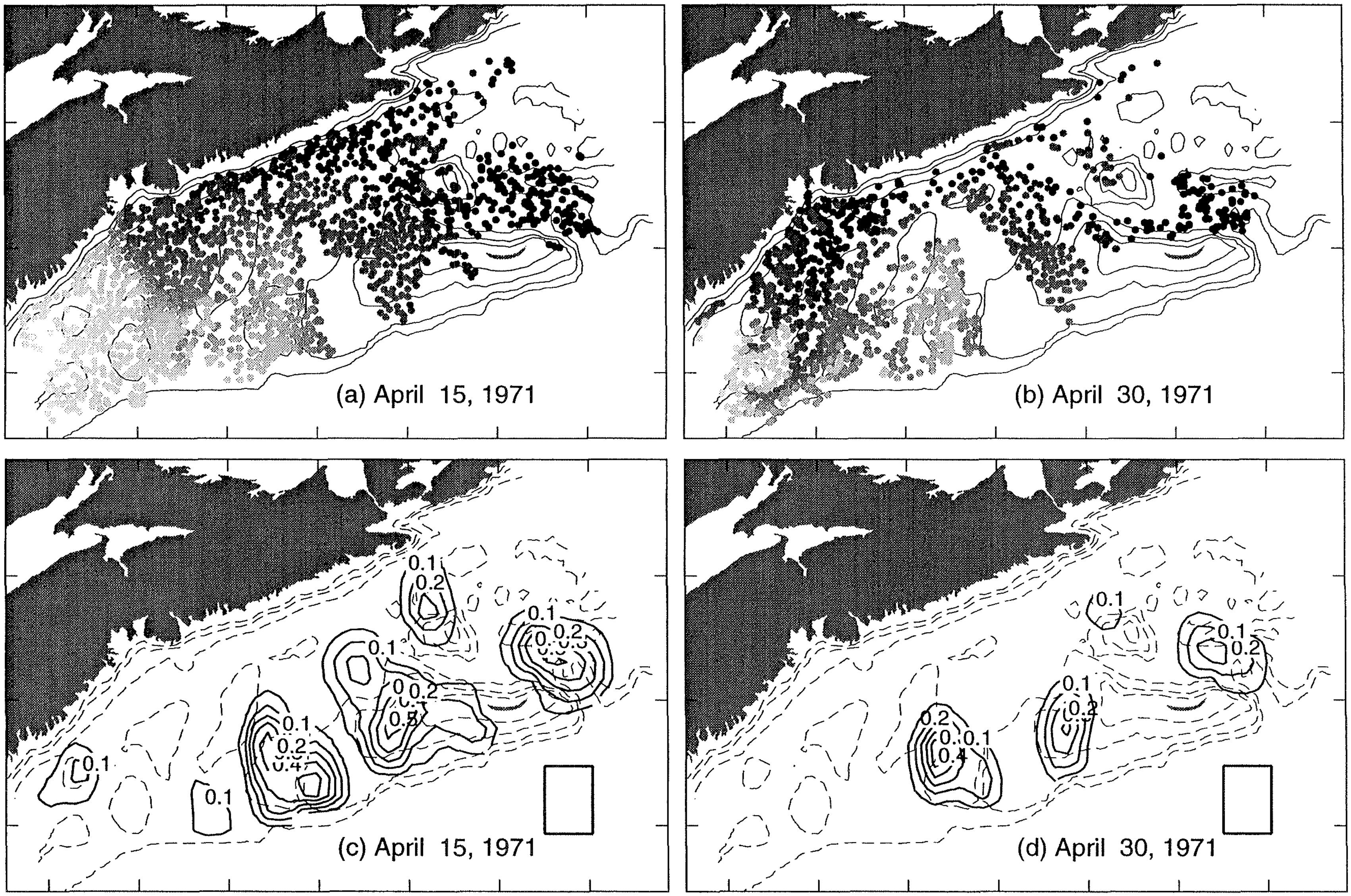

Figure 19.3: Dispersion in April 1971. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

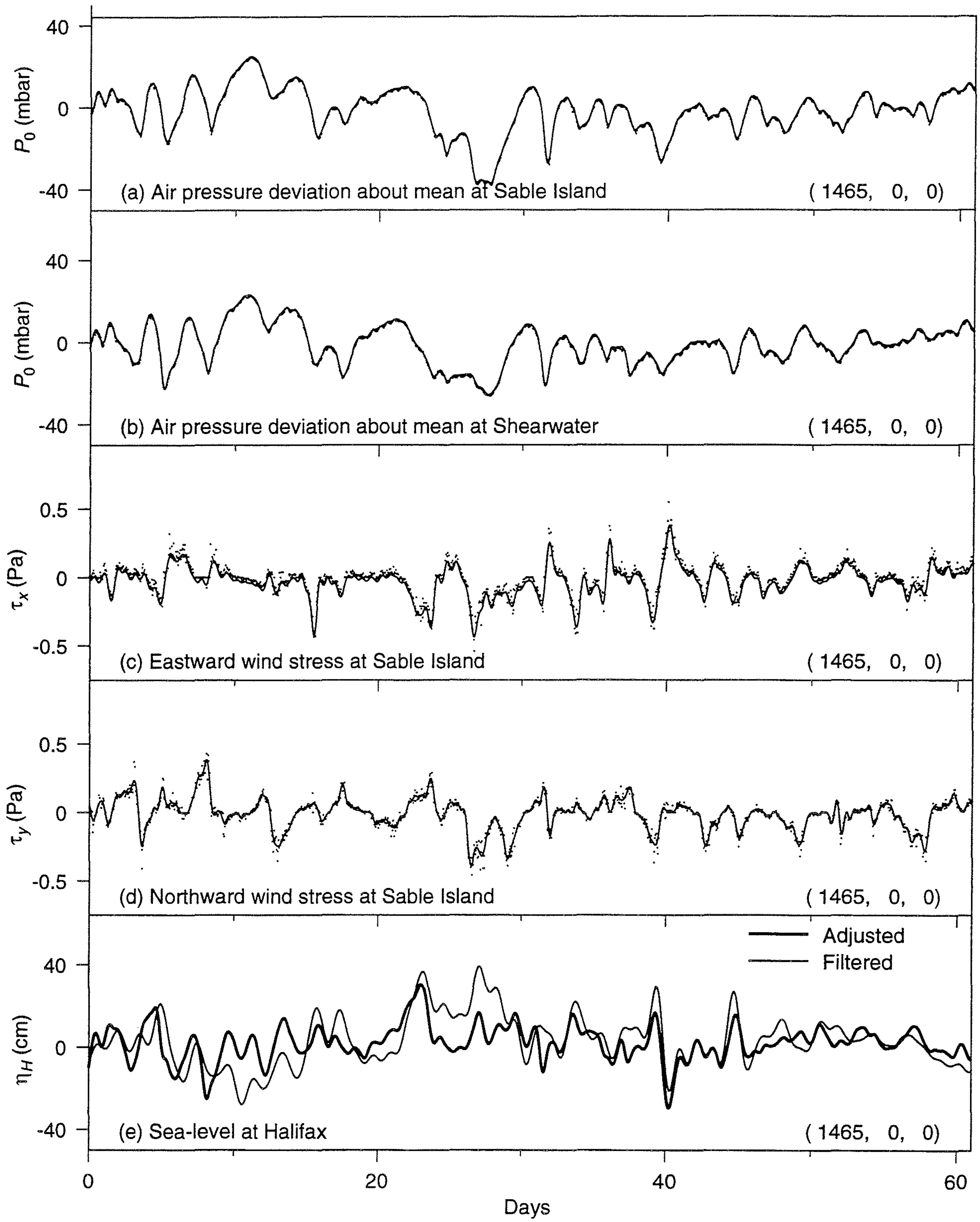

Figure 20.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1972). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

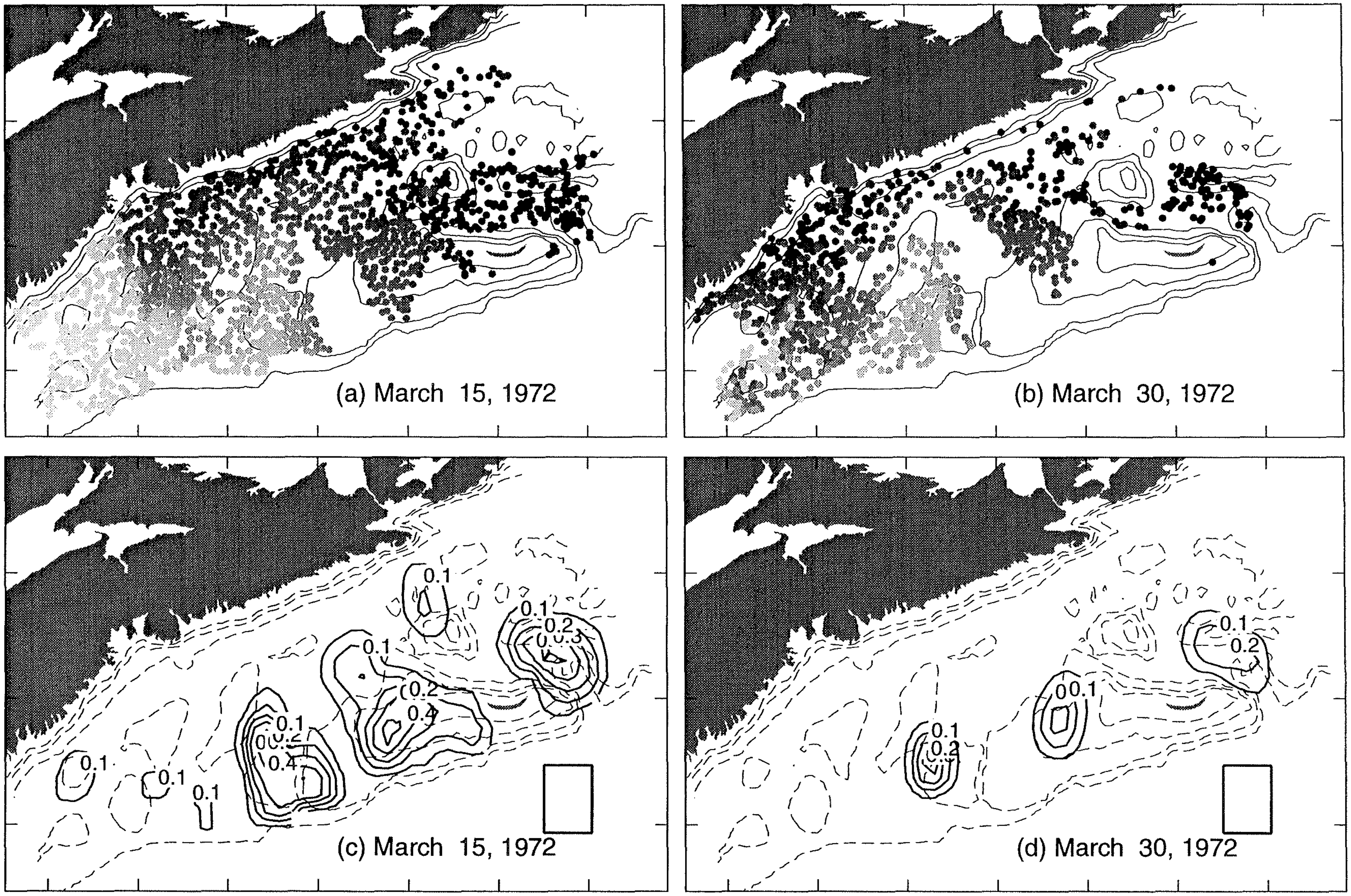

Figure 20.2: Dispersion in March 1972. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

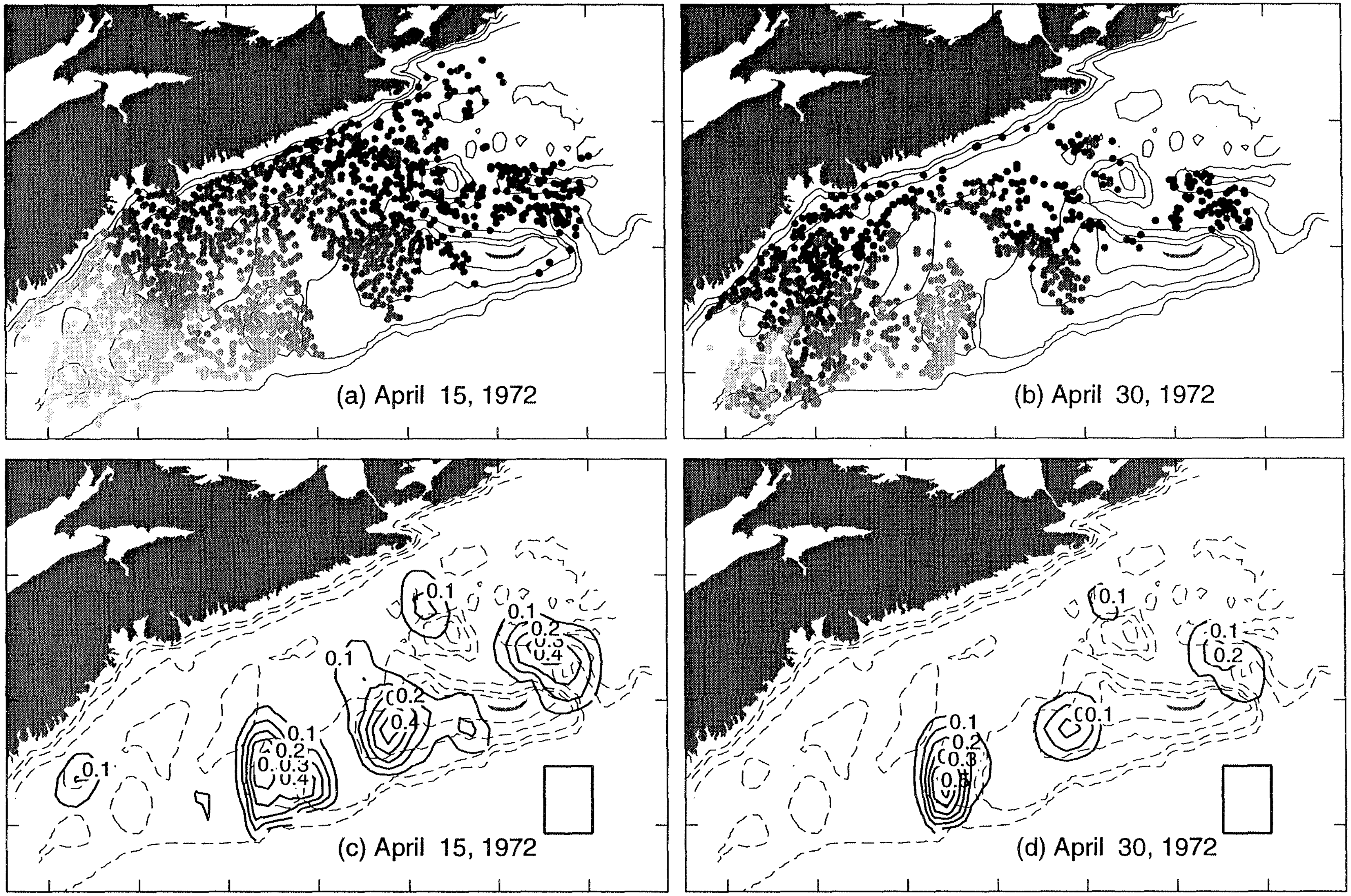

Figure 20.3: Dispersion in April 1972. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

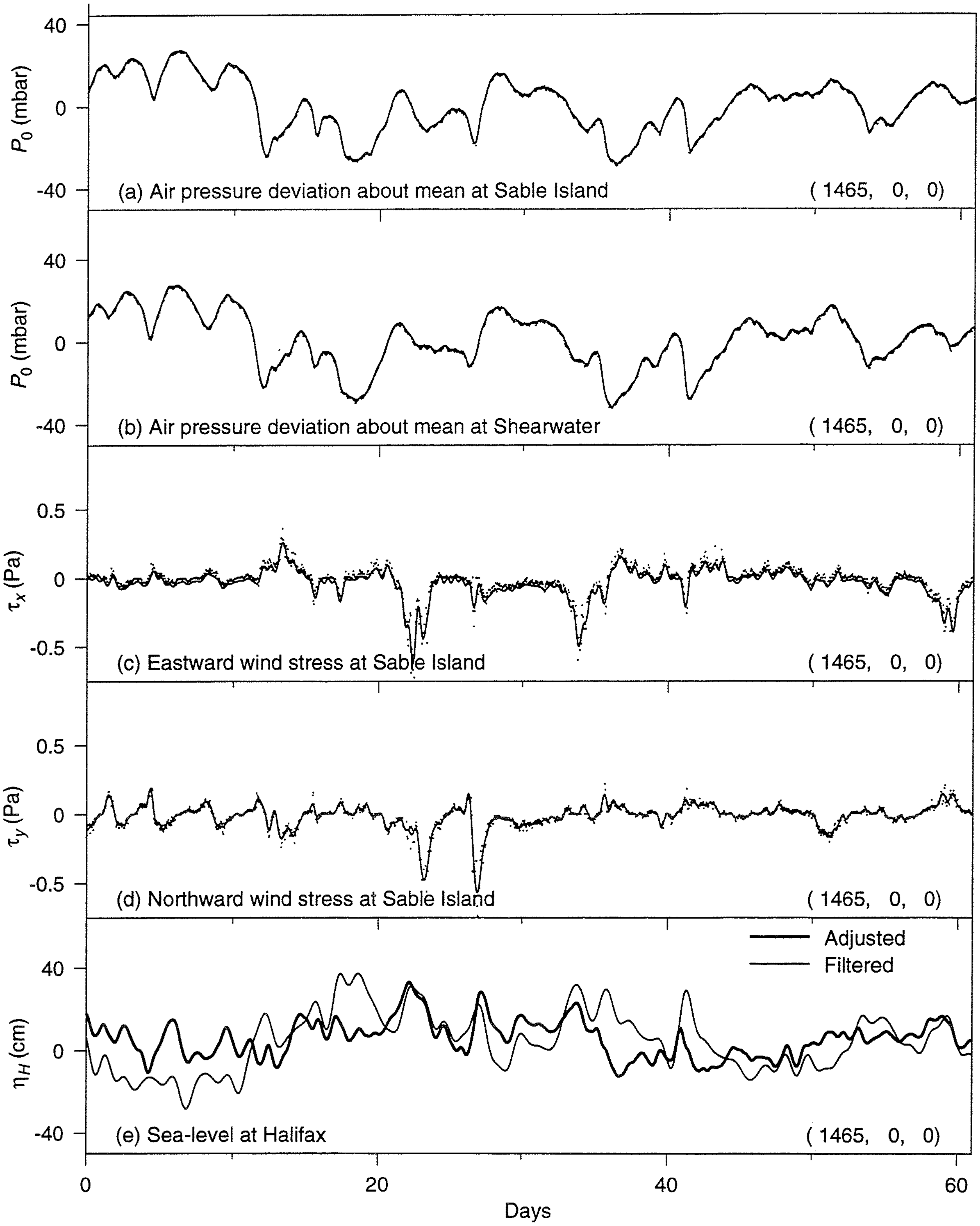

Figure 21.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1973). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

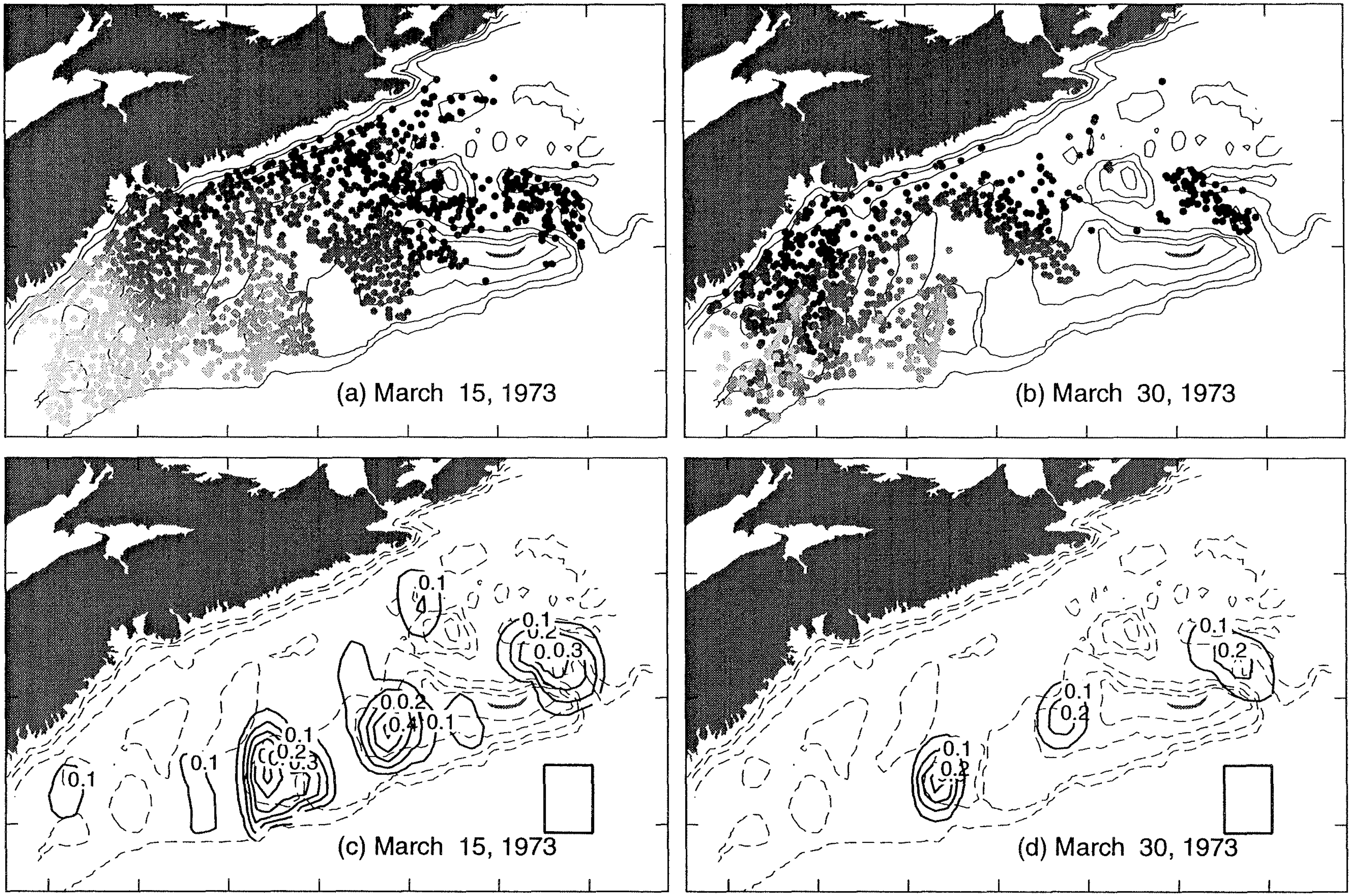

Figure 21.2: Dispersion in March 1973. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

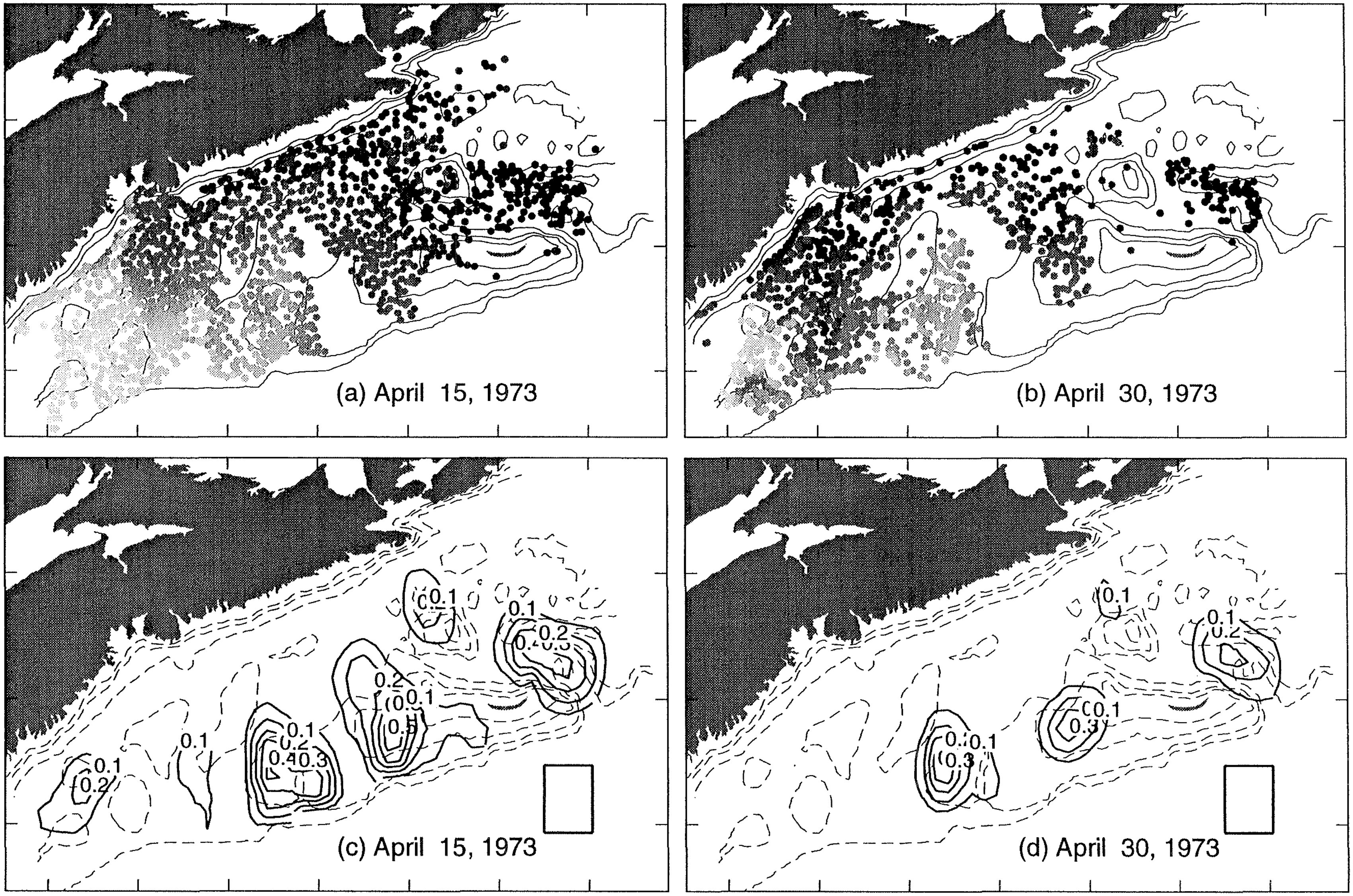

Figure 21.3: Dispersion in April 1973. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

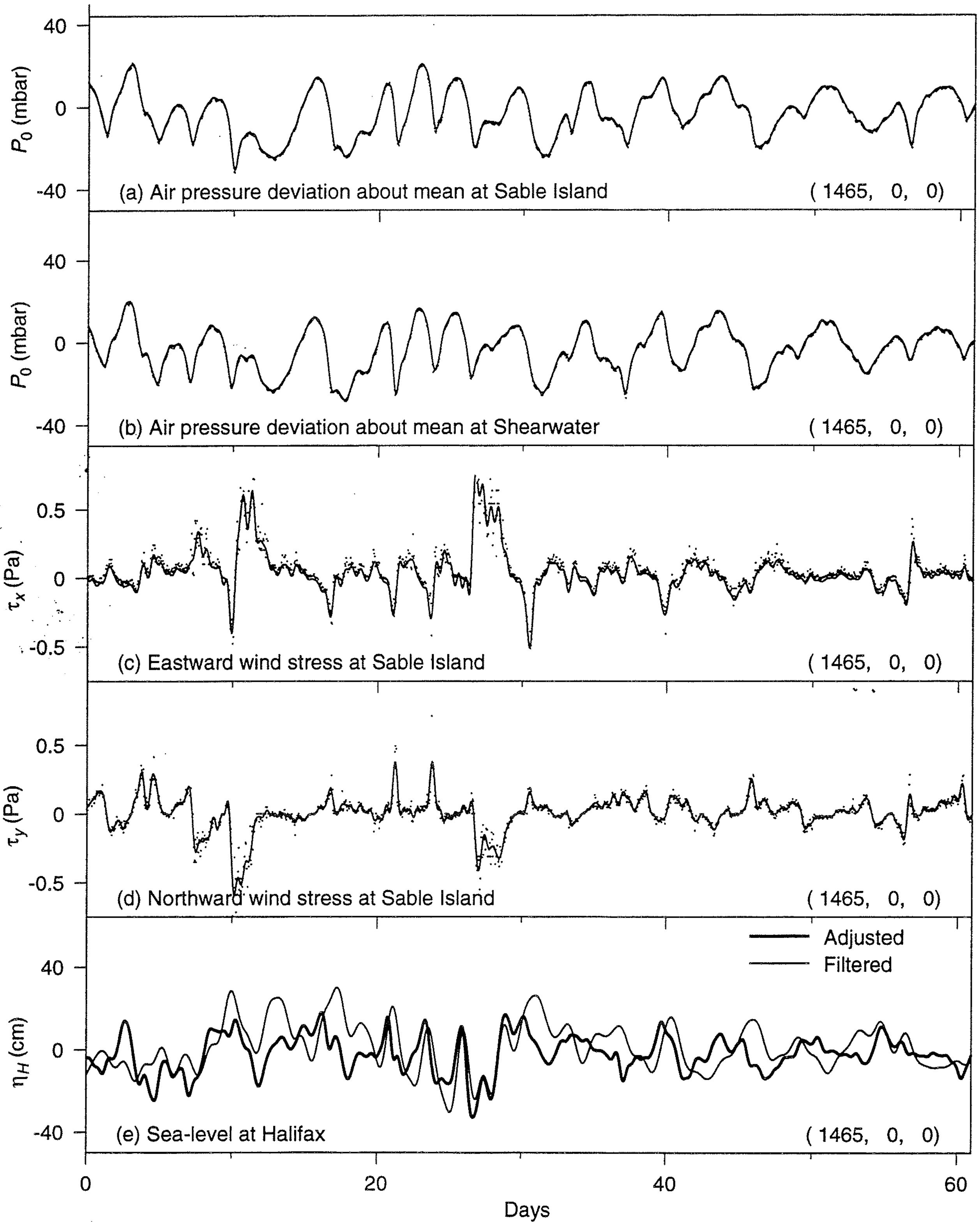

Figure 22.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1974). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

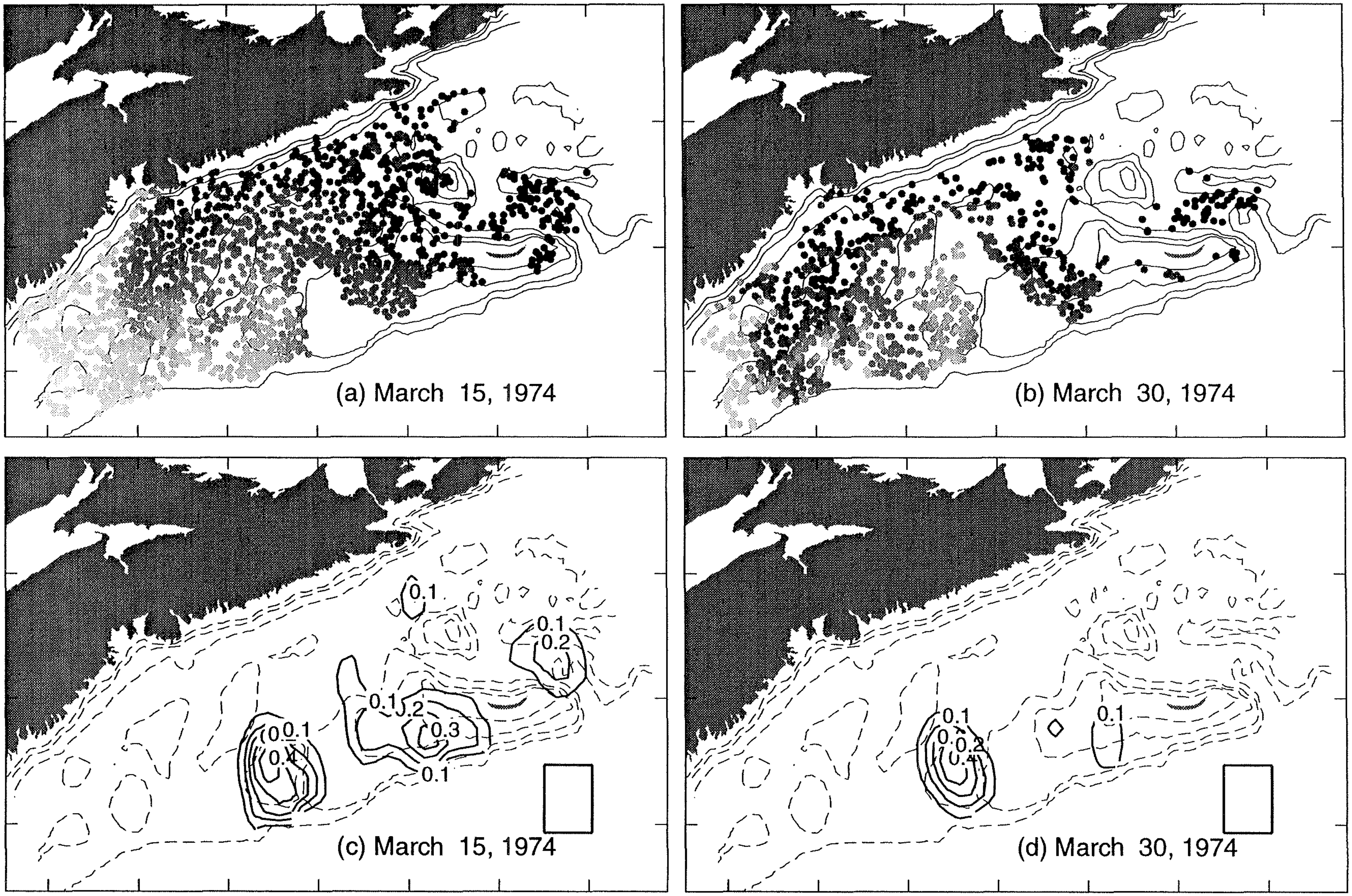

Figure 22.2: Dispersion in March 1974. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

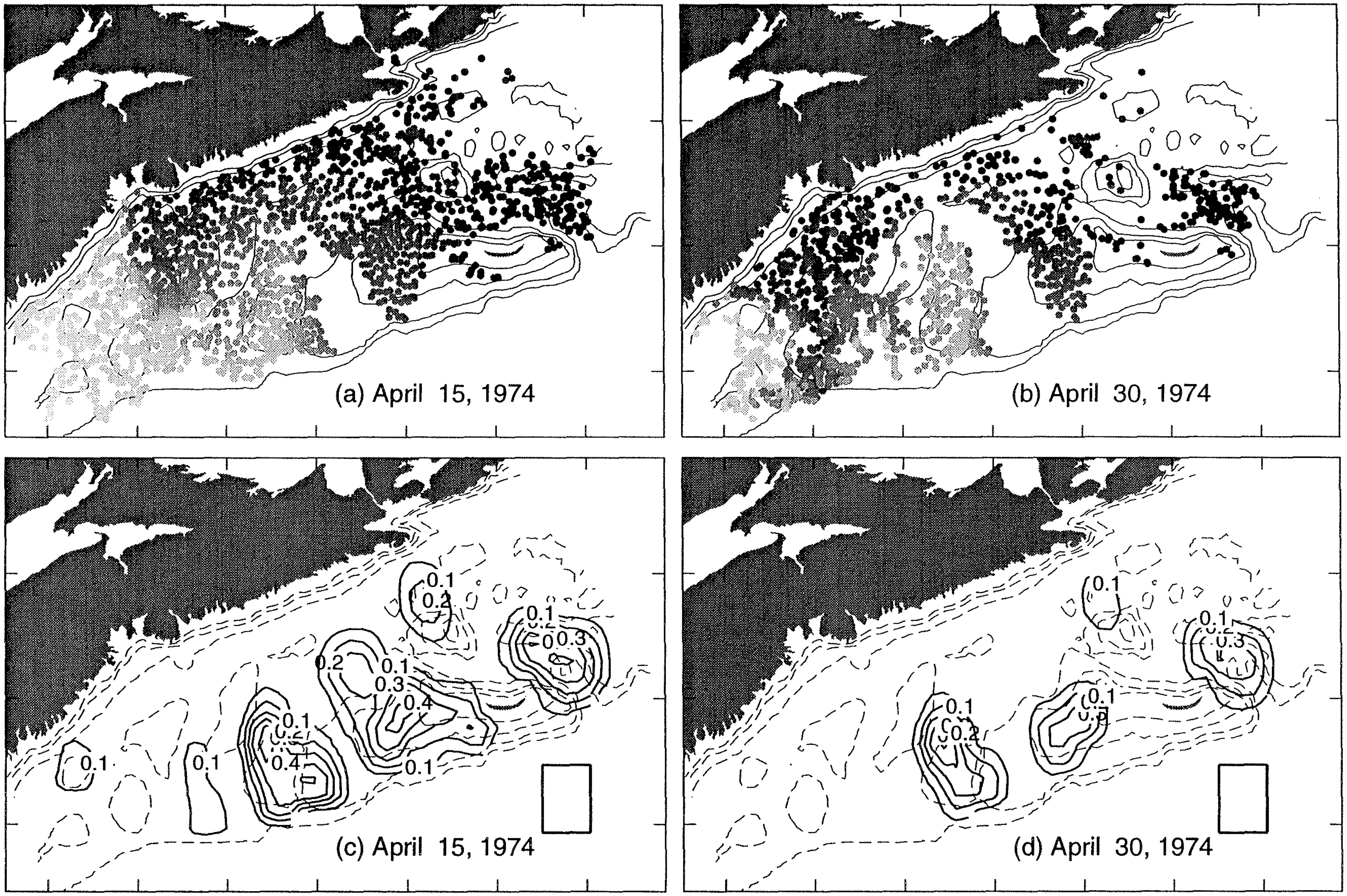

Figure 22.3: Dispersion in April 1974. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

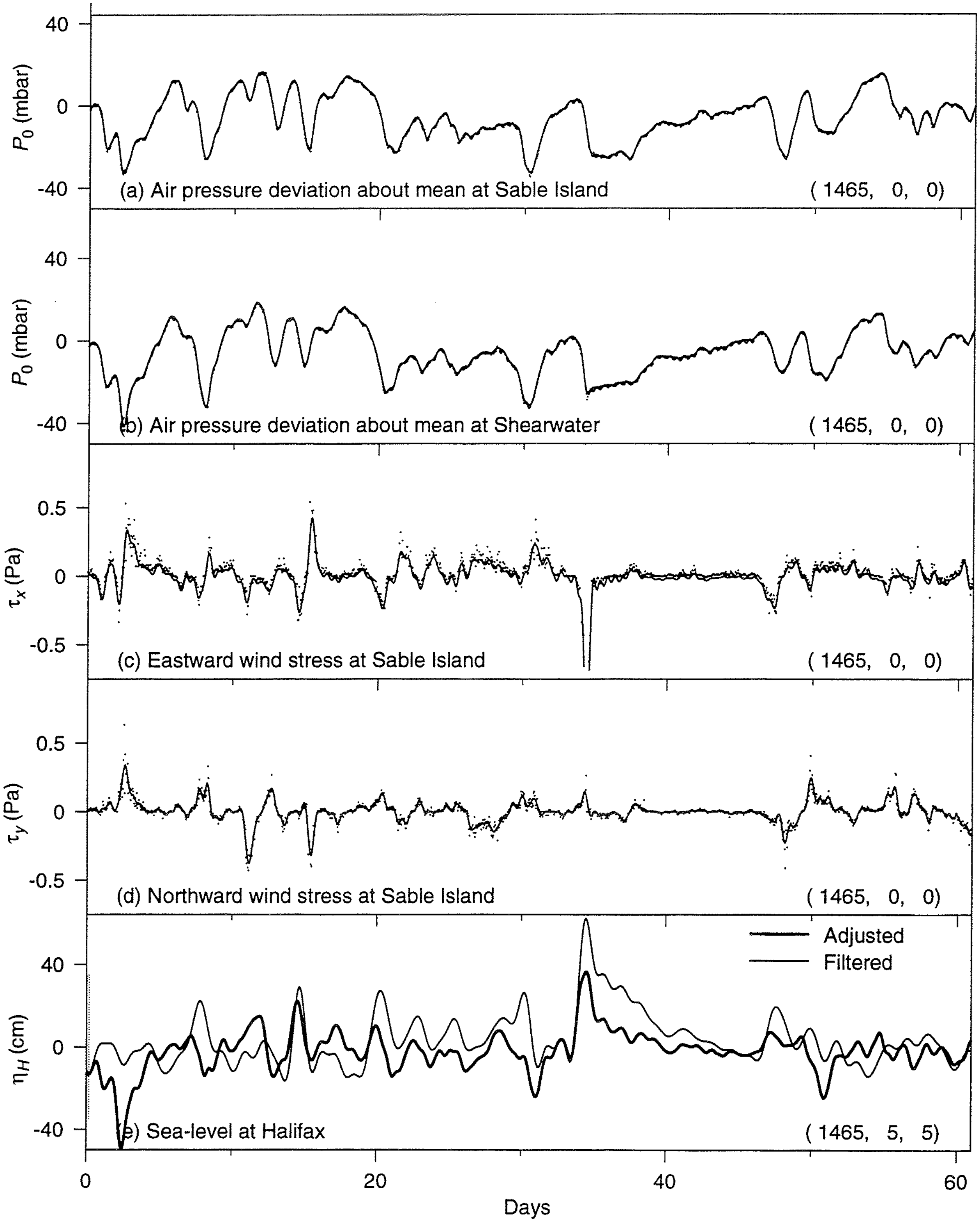

Figure 23.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1975). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

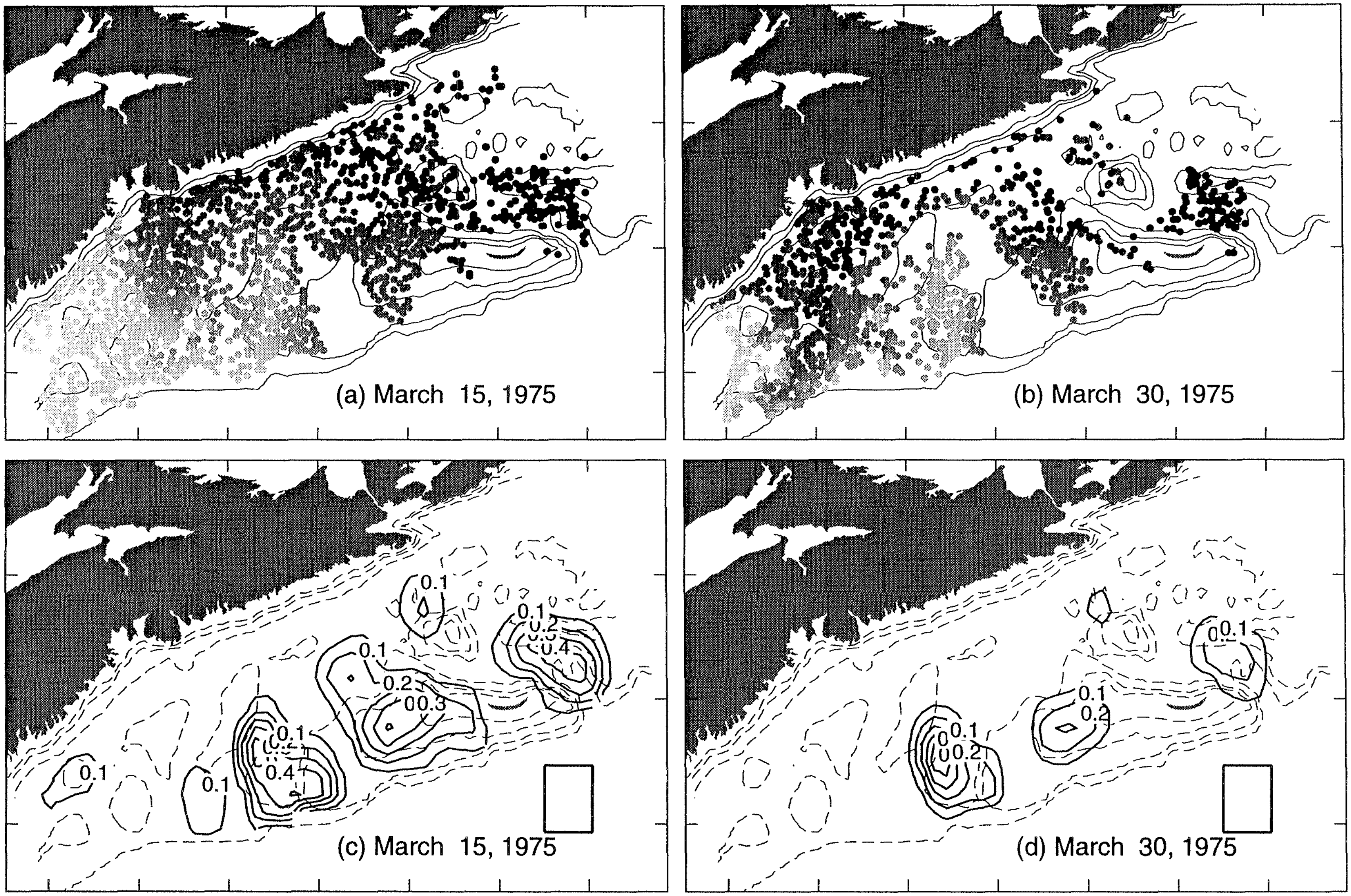

Figure 23.2: Dispersion in March 1975. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

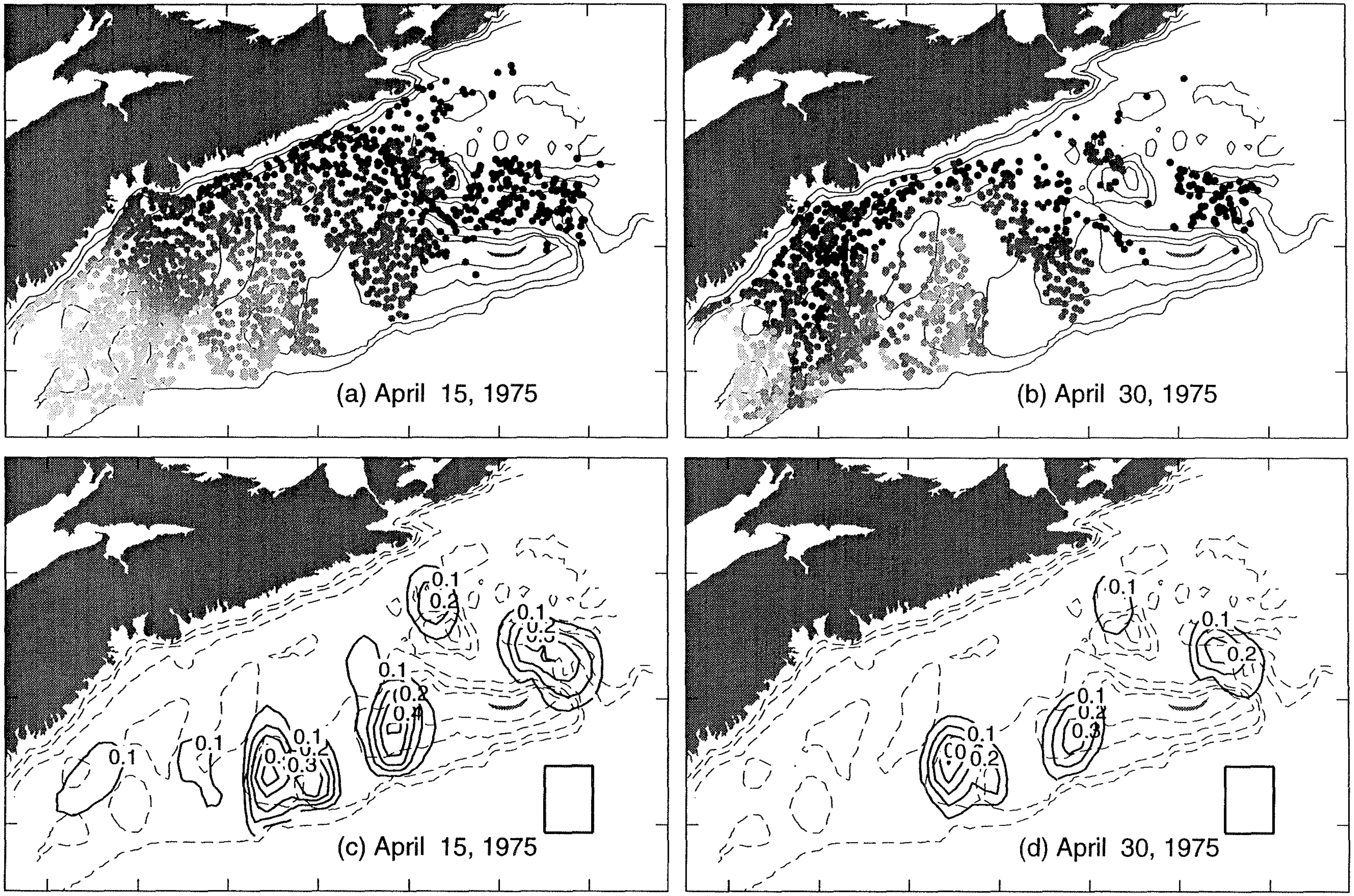

Figure 23.3: Dispersion in April 1975. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

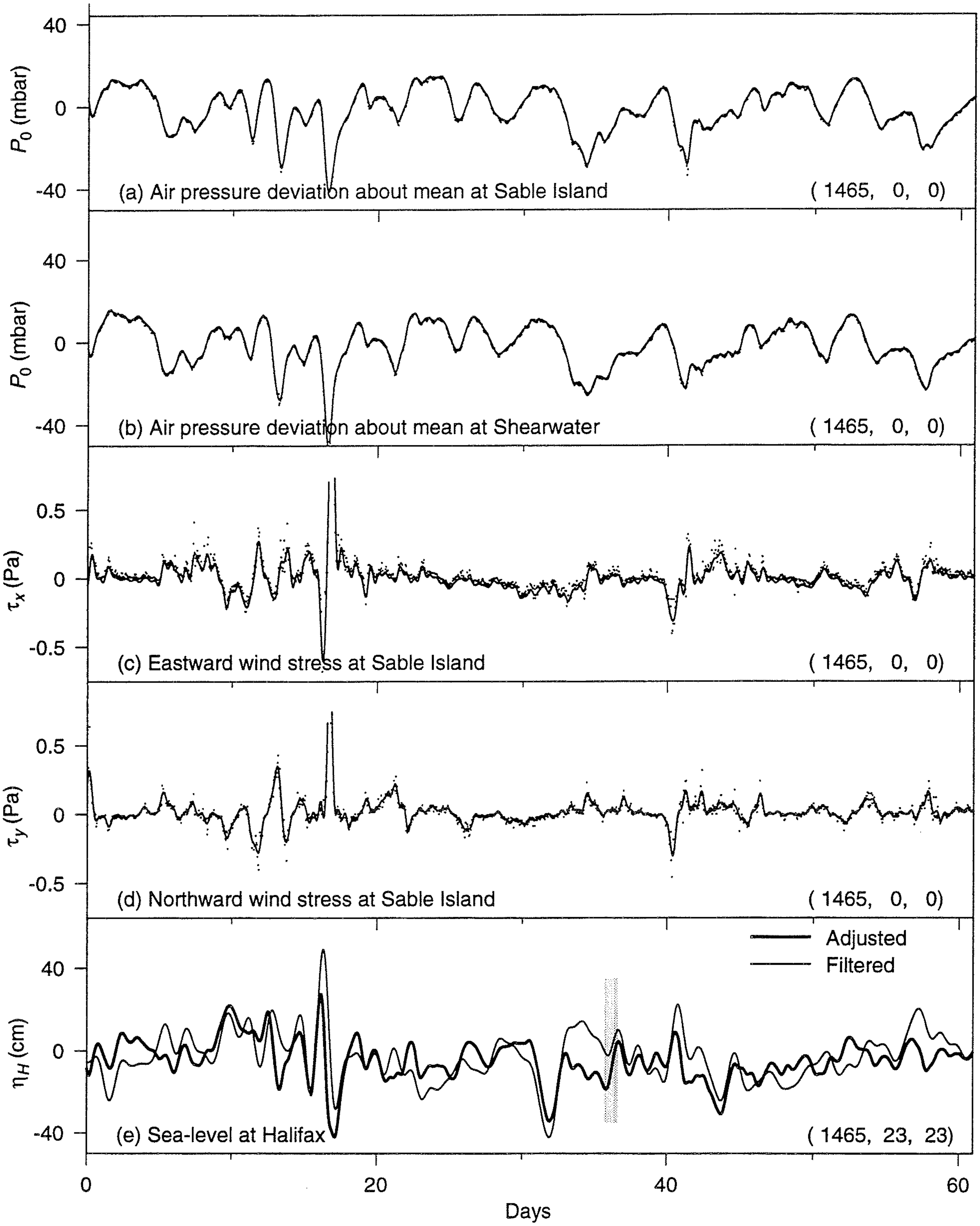

Figure 24.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1976). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

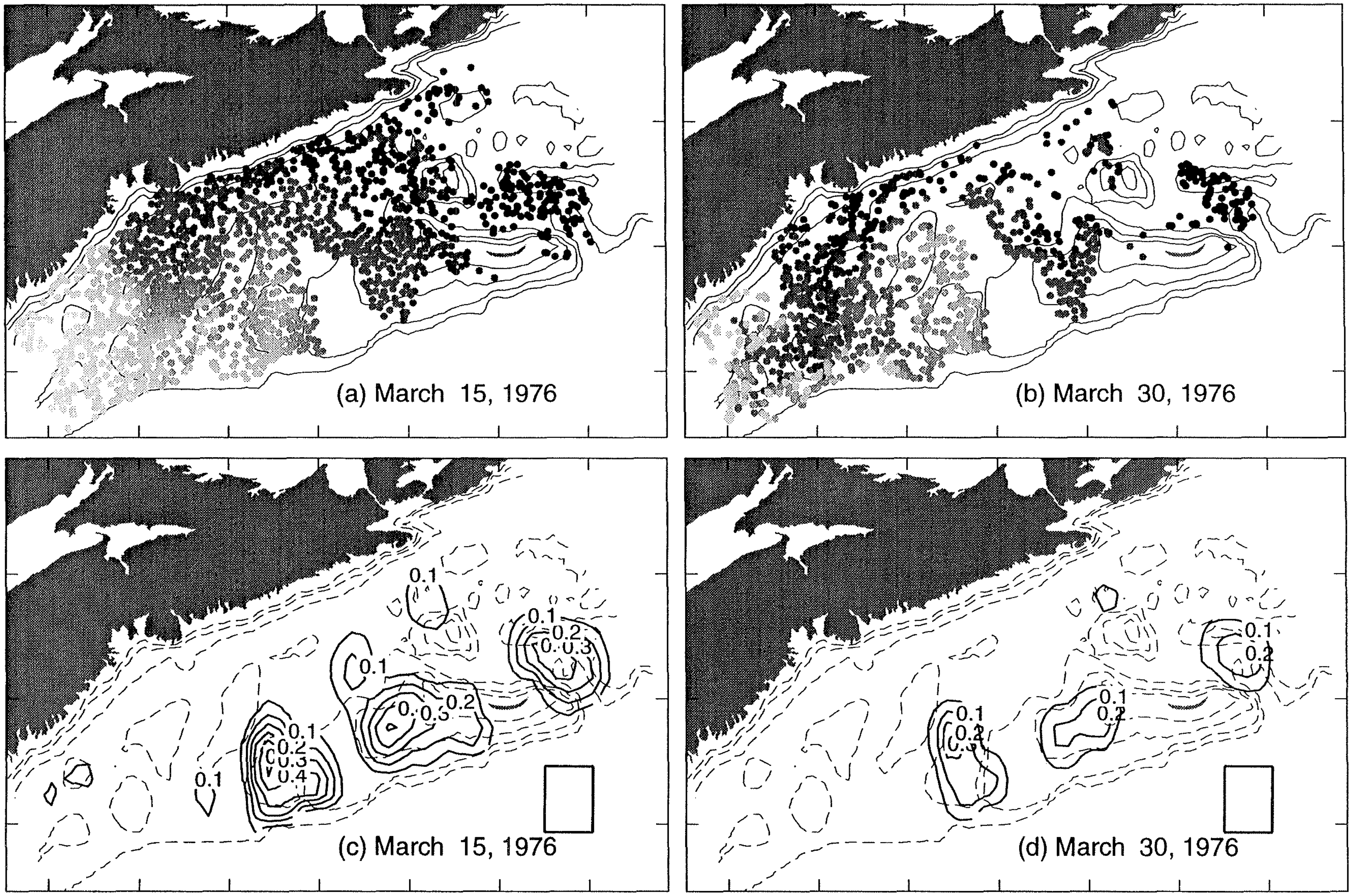

Figure 24.2: Dispersion in March 1976. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

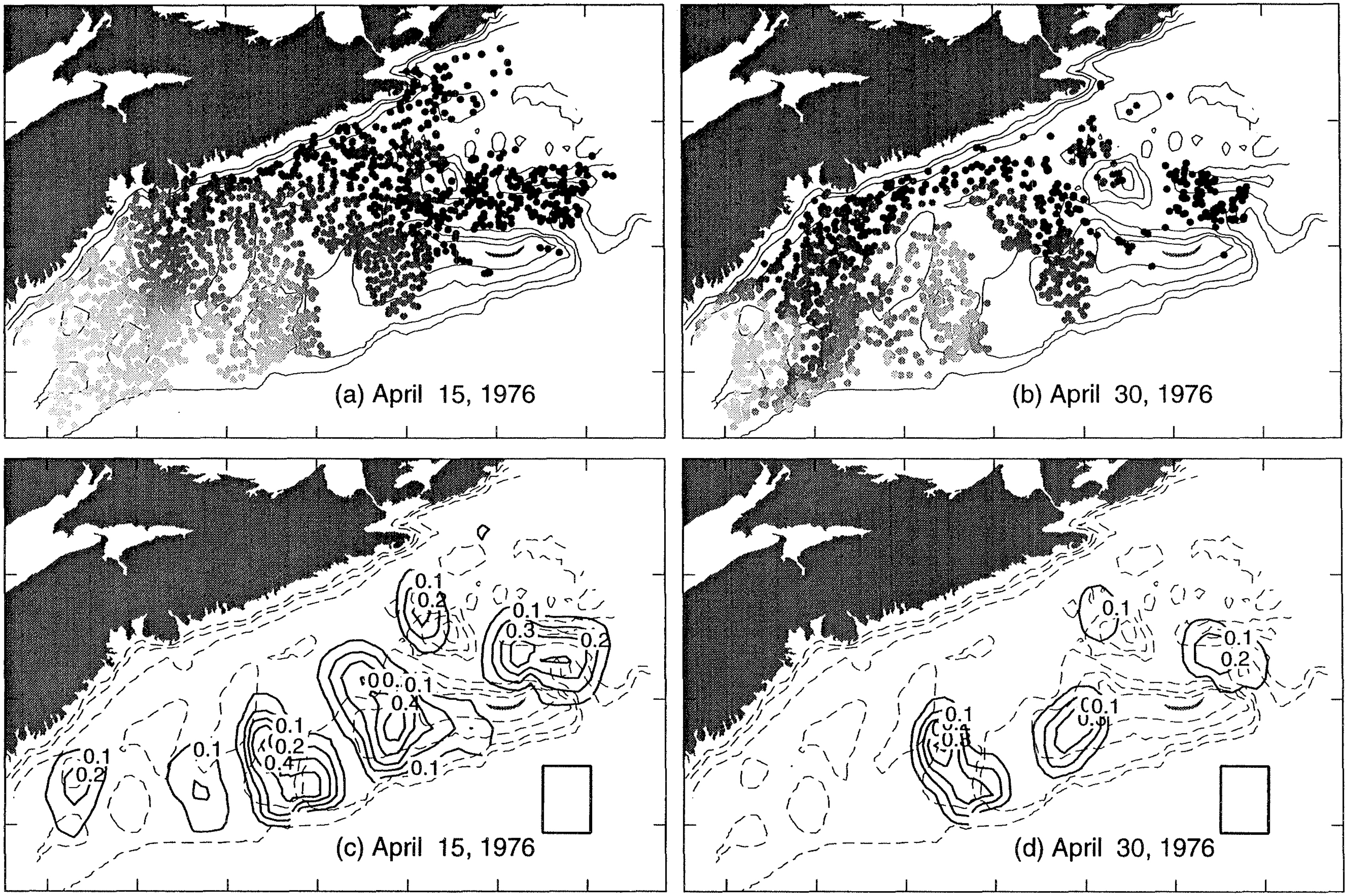

Figure 24.3: Dispersion in April 1976. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

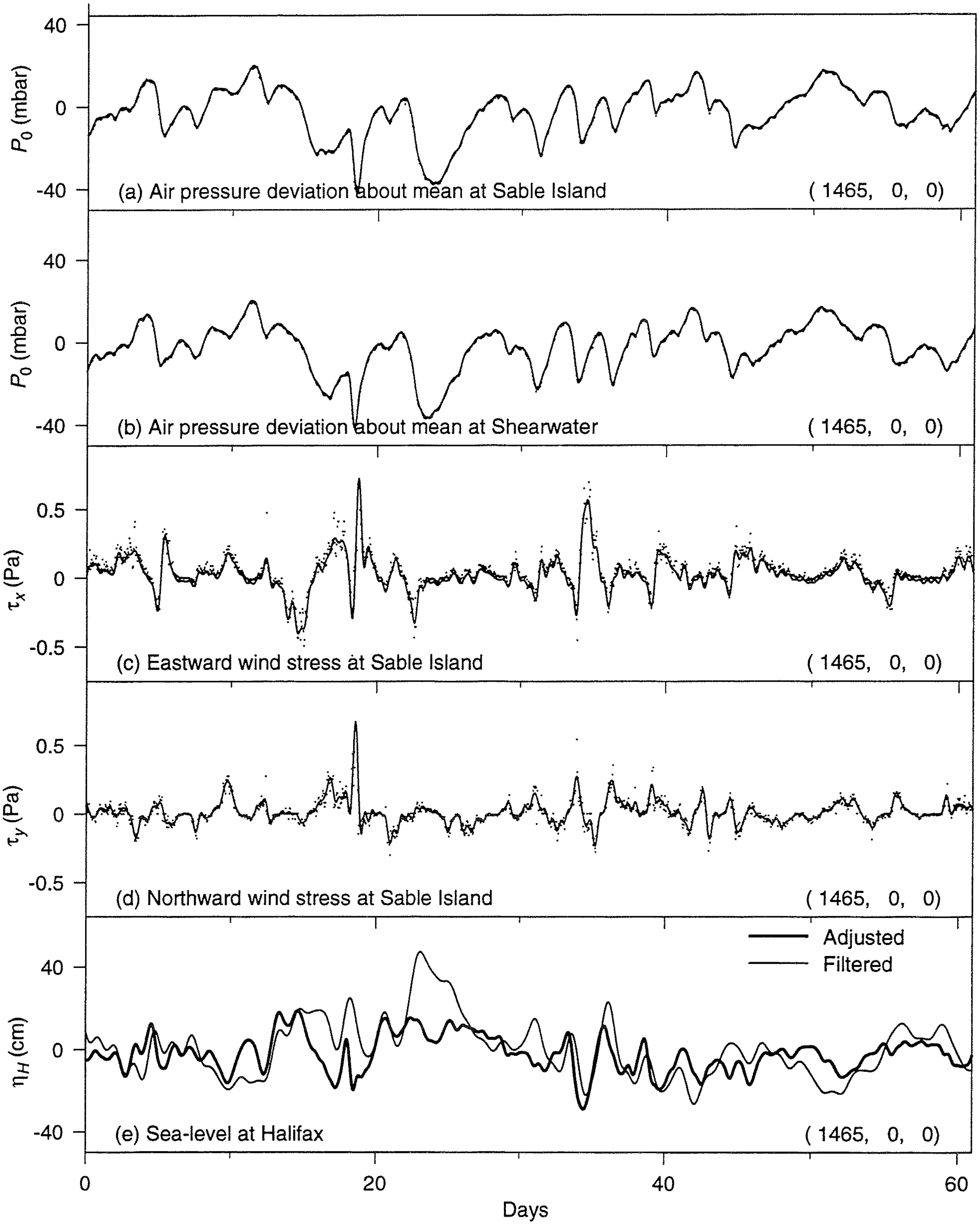

Figure 25.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1977). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

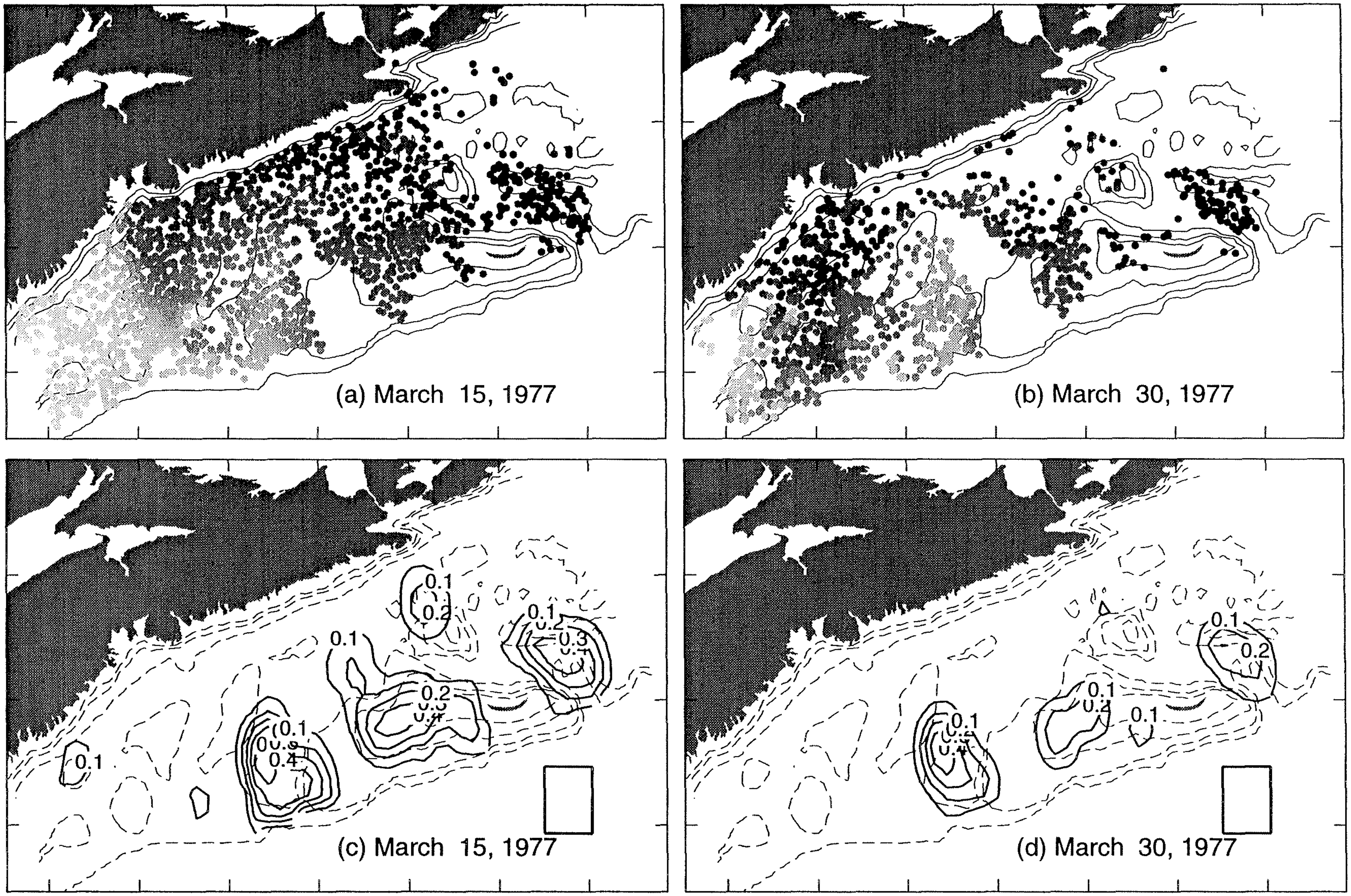

Figure 25.2: Dispersion in March 1977. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

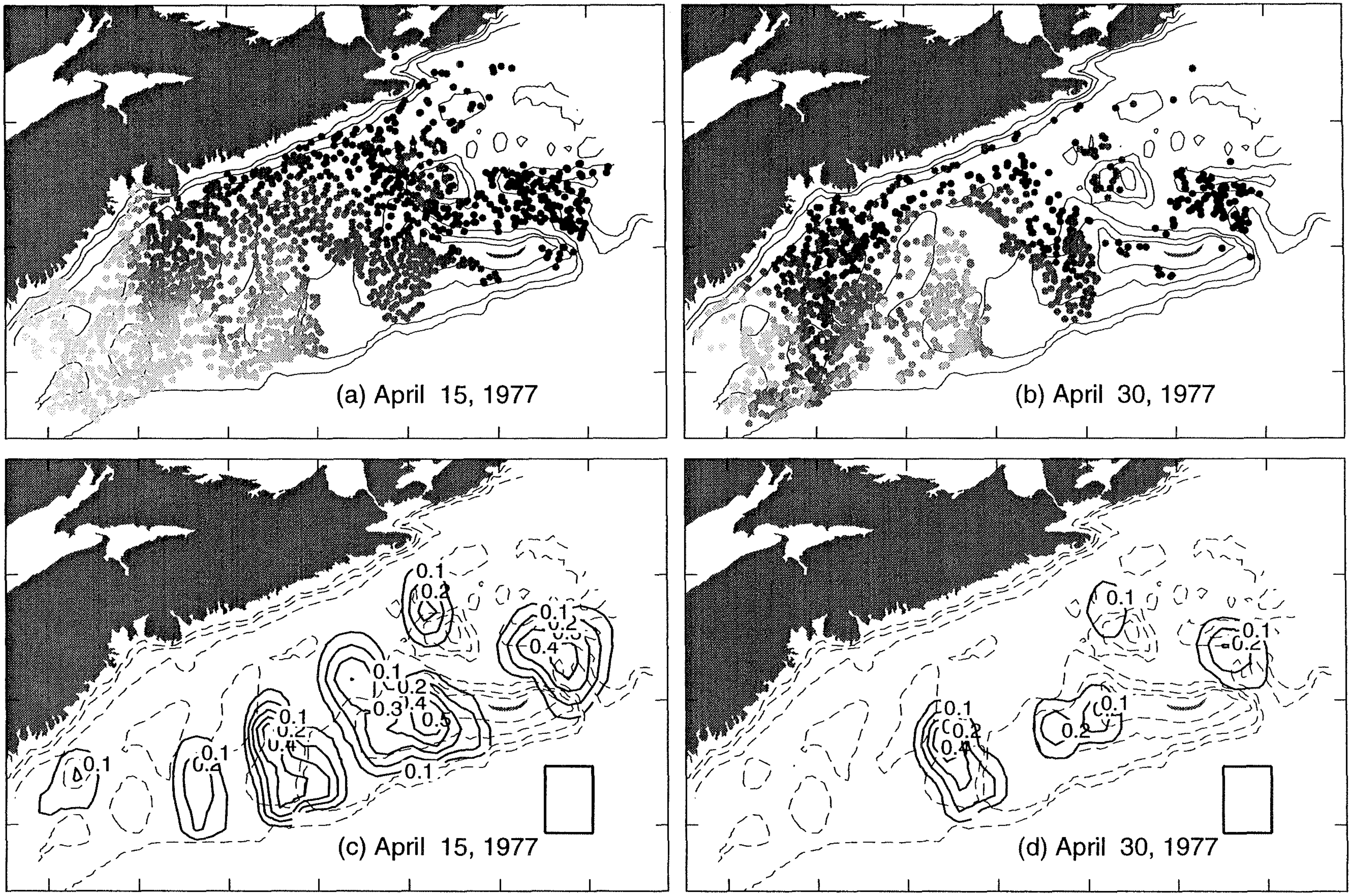

Figure 25.3: Dispersion in April 1977. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

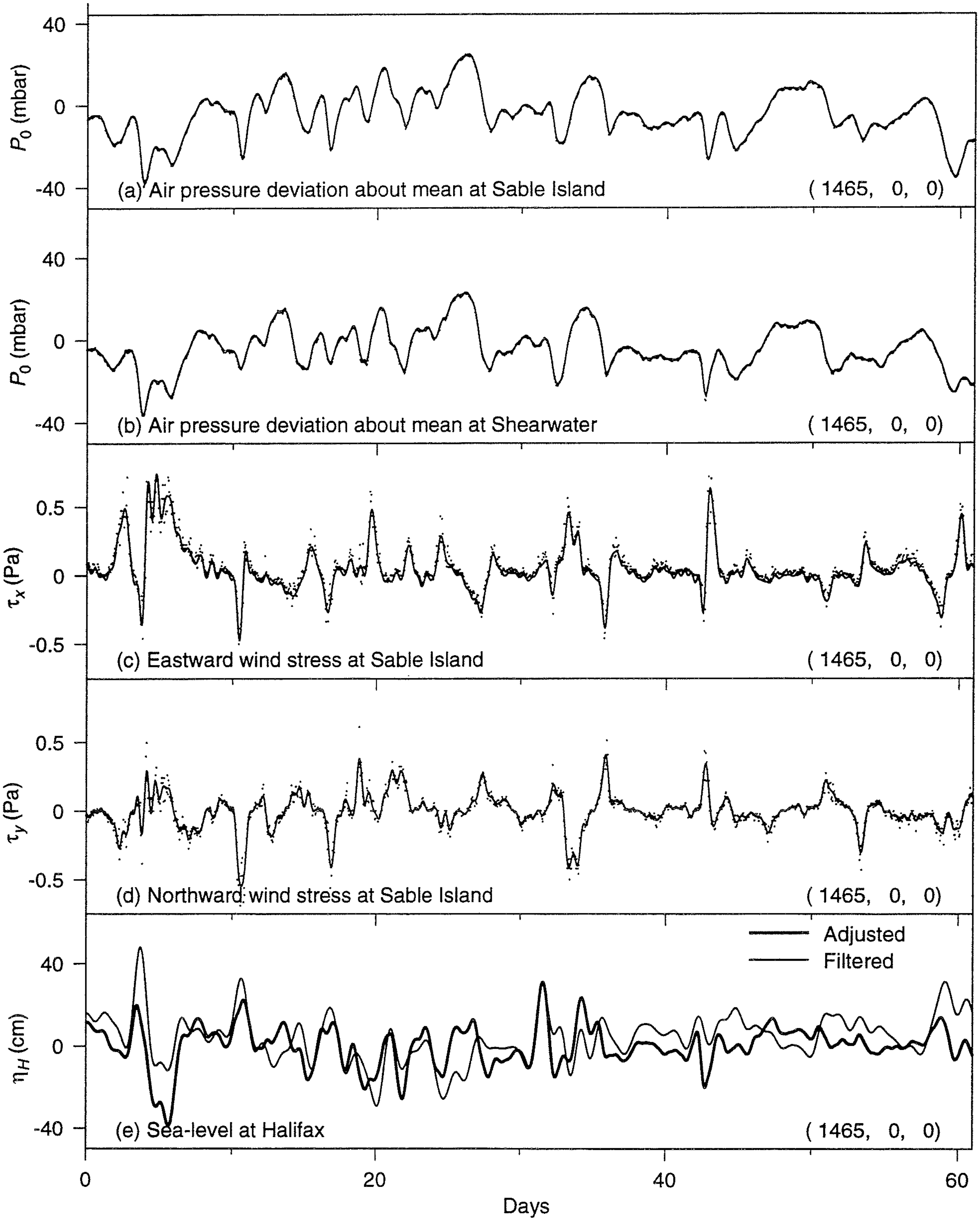

Figure 26.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1978). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

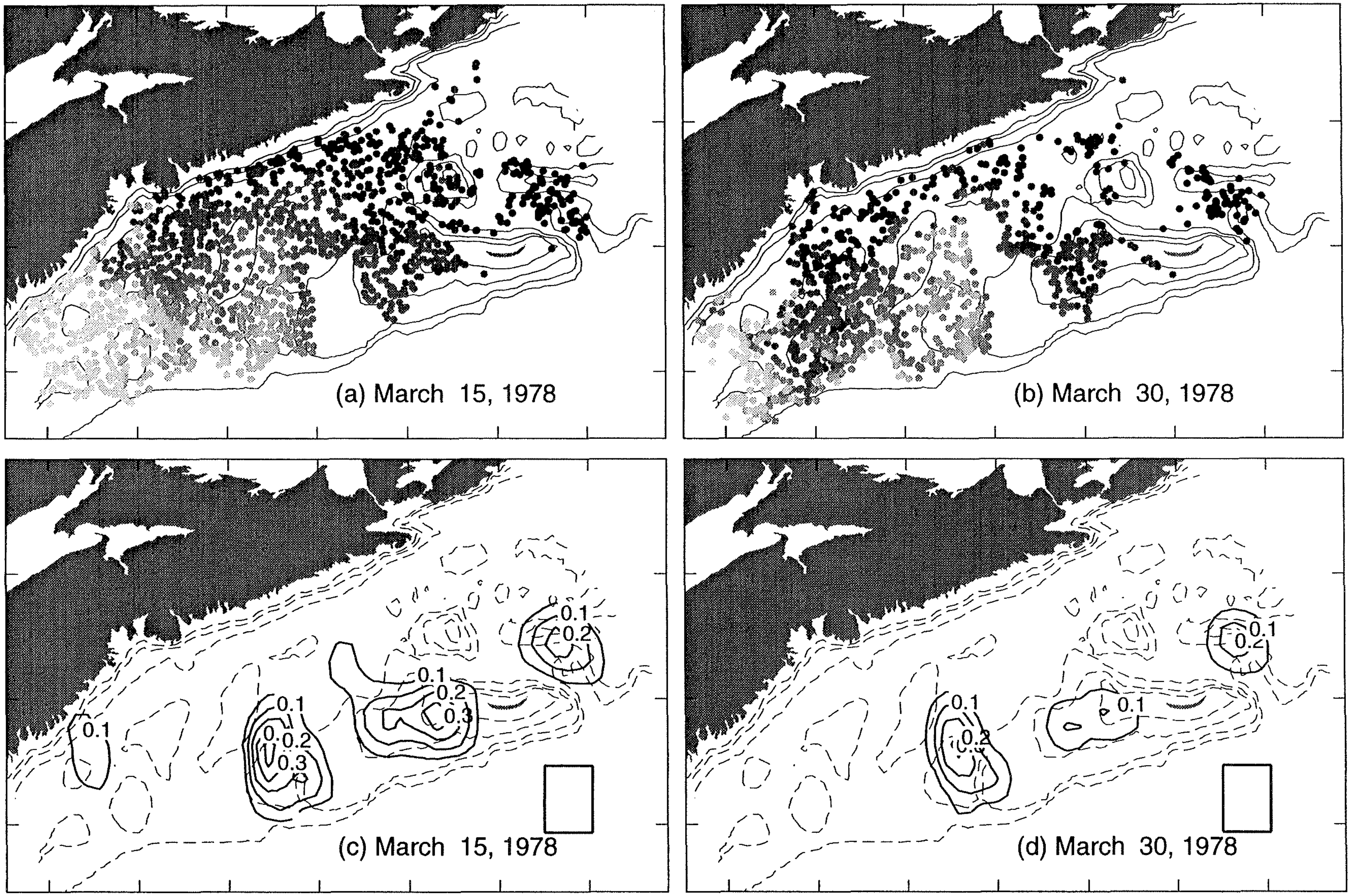

Figure 26.2: Dispersion in March 1978. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

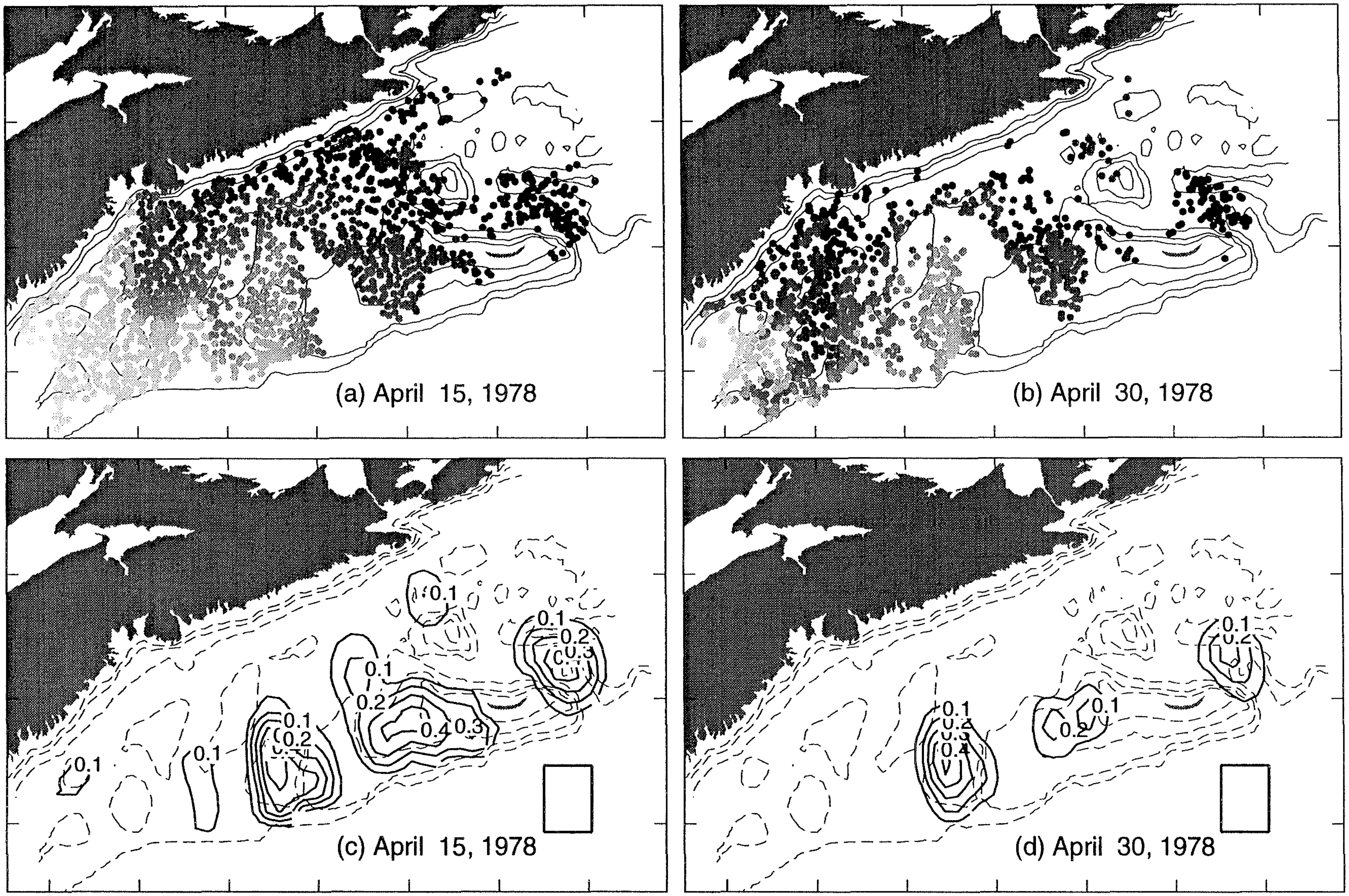

Figure 26.3: Dispersion in April 1978. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

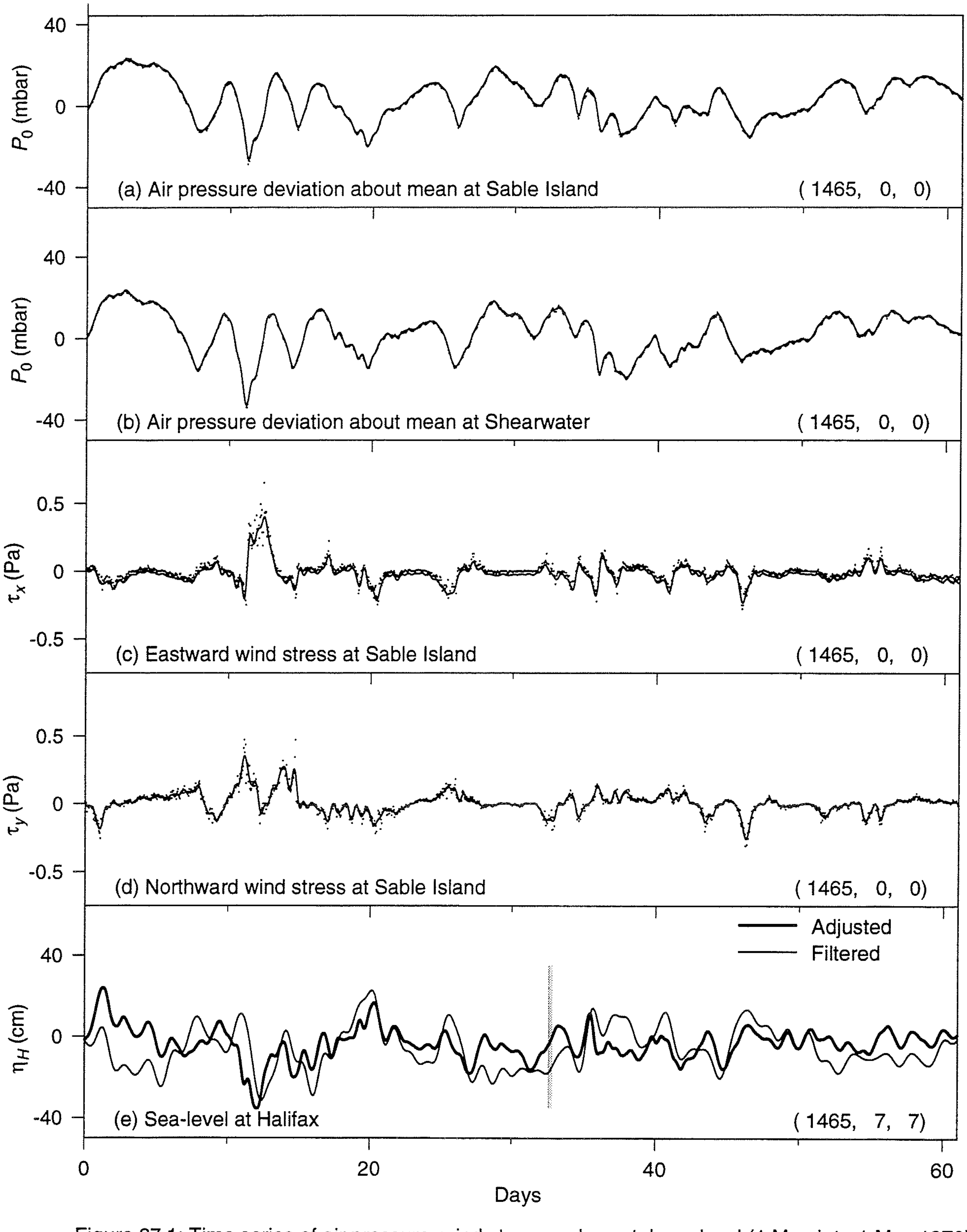

Figure 27.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1979). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

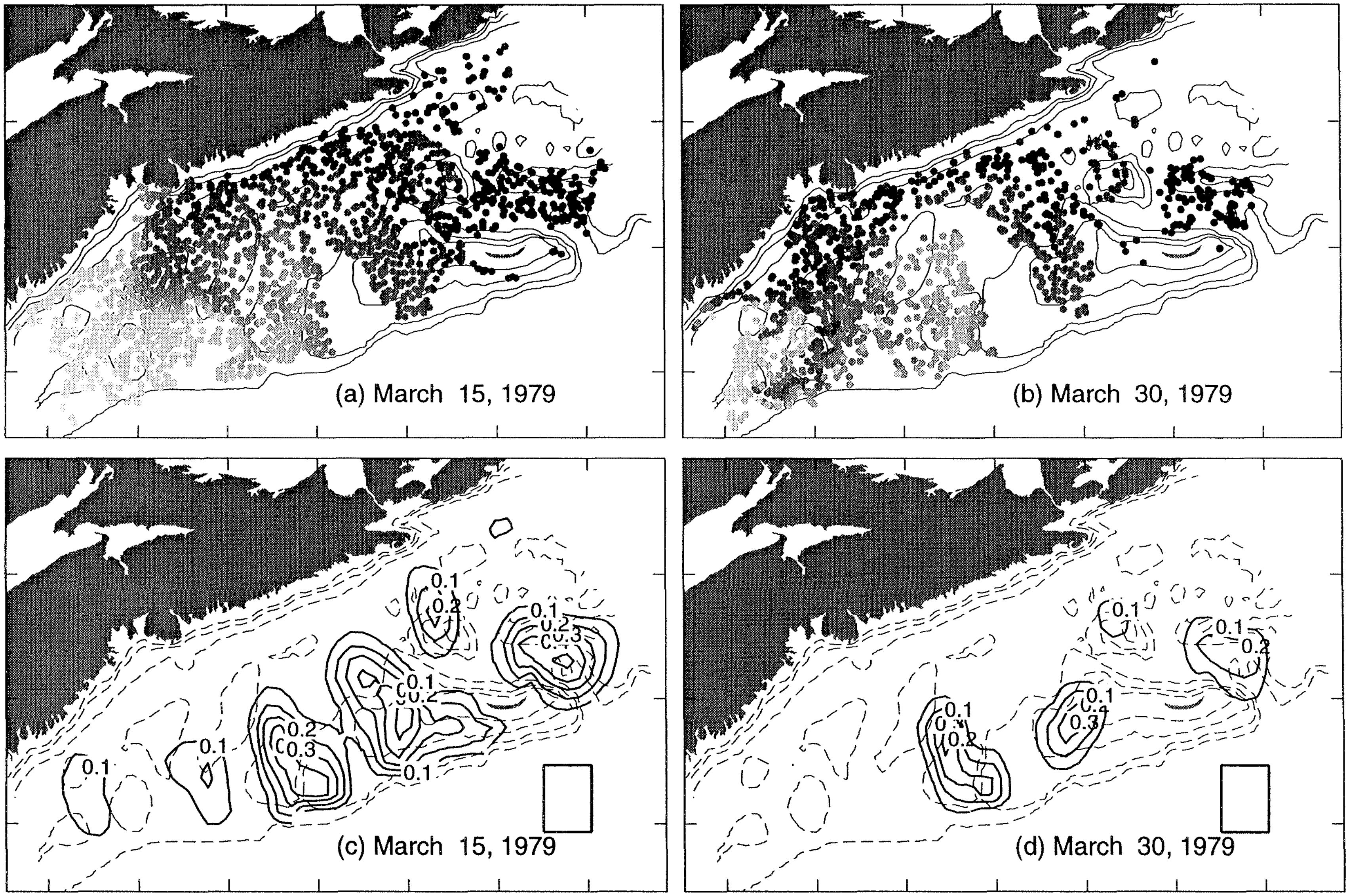

Figure 27.2: Dispersion in March 1979. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

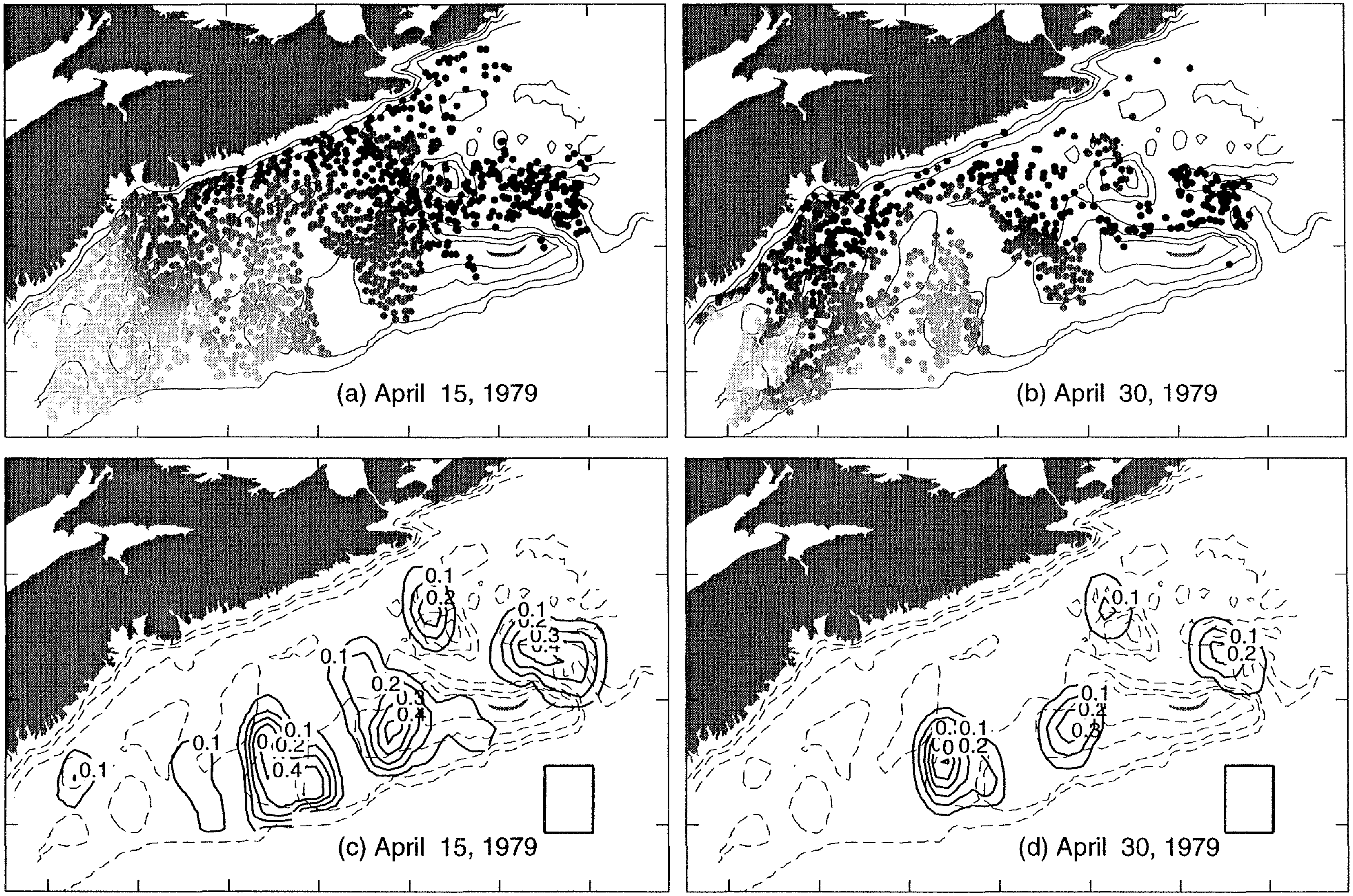

Figure 27.3: Dispersion in April 1979. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

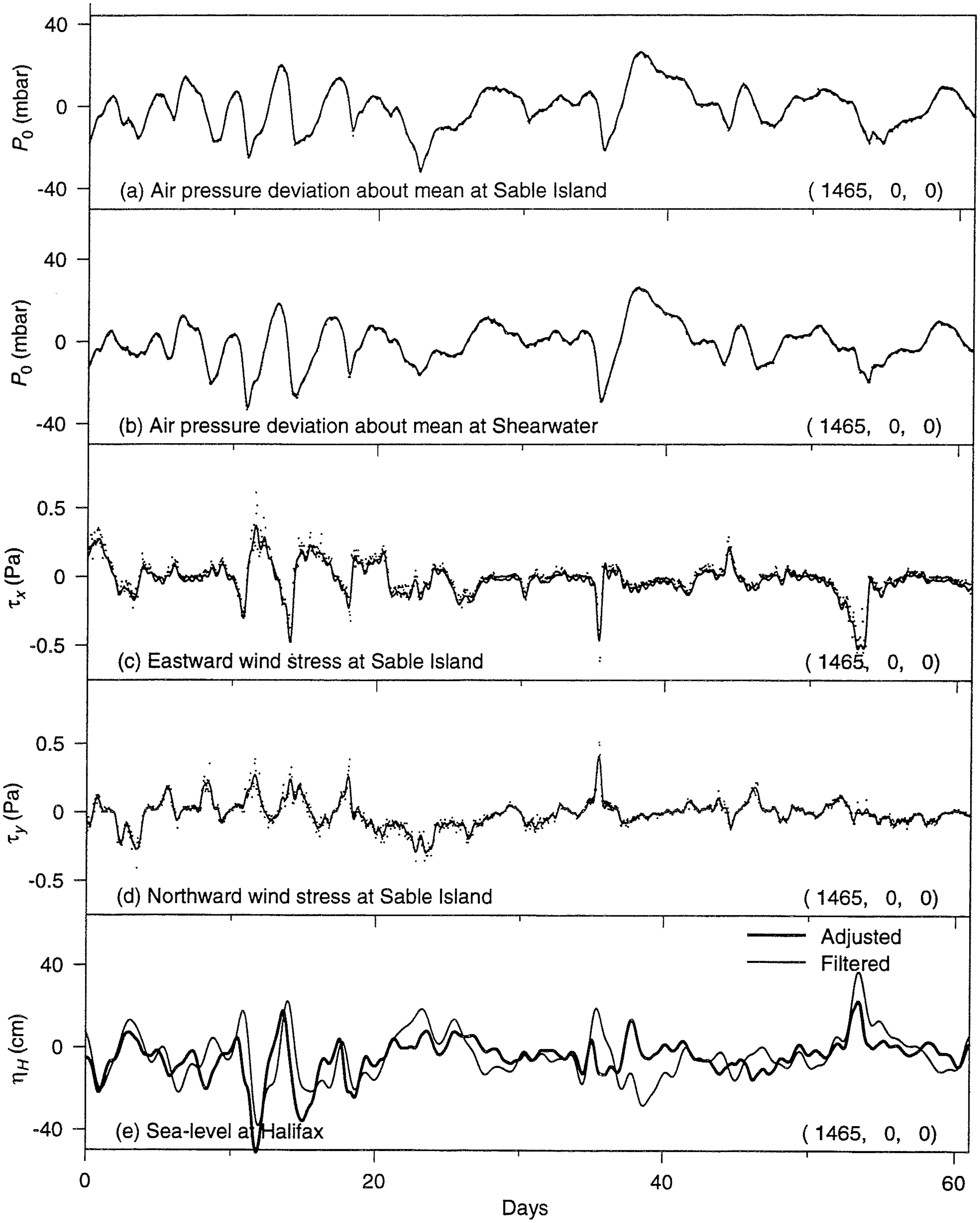

Figure 28.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1980). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

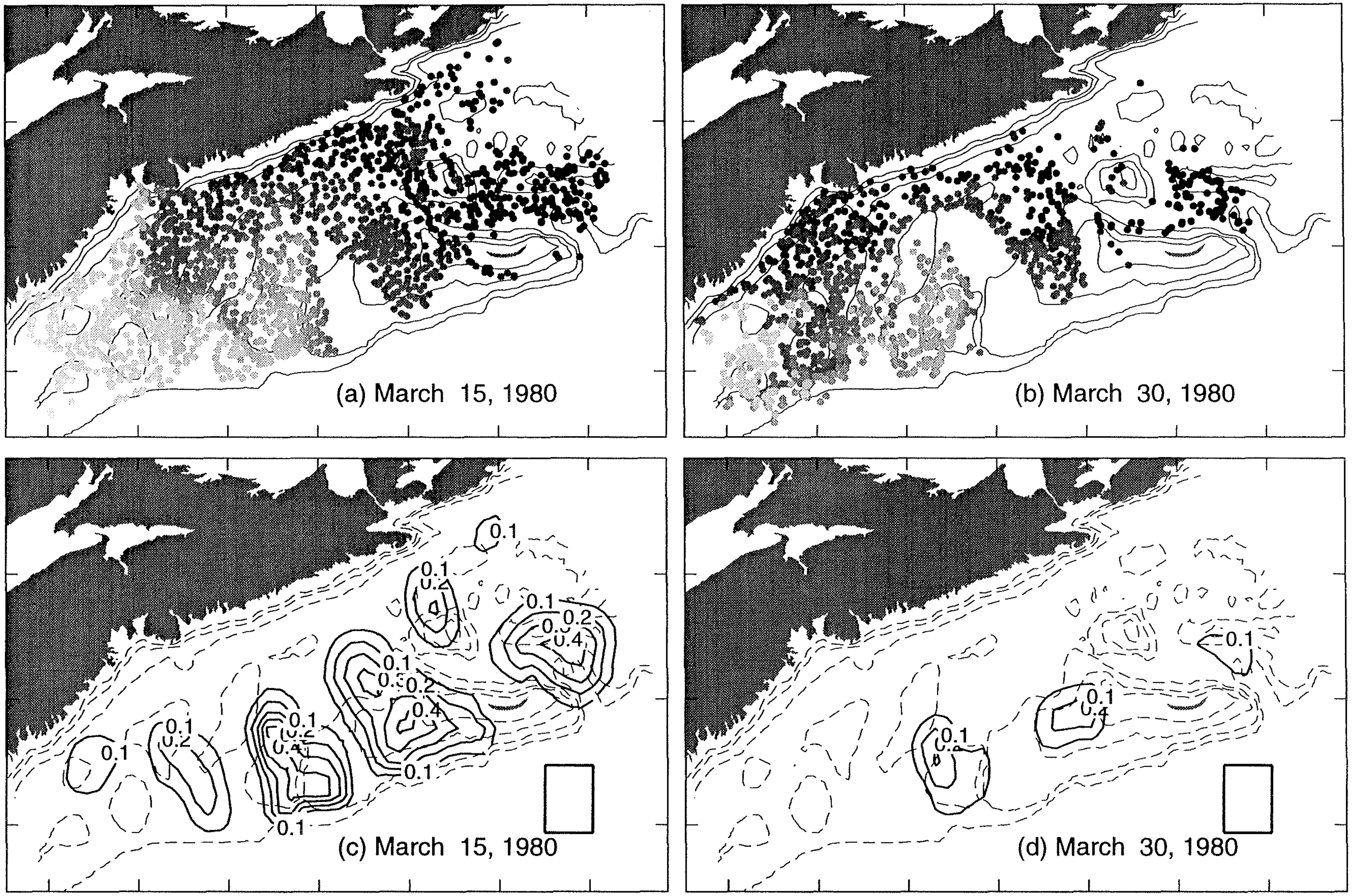

Figure 28.2: Dispersion in March 1980. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

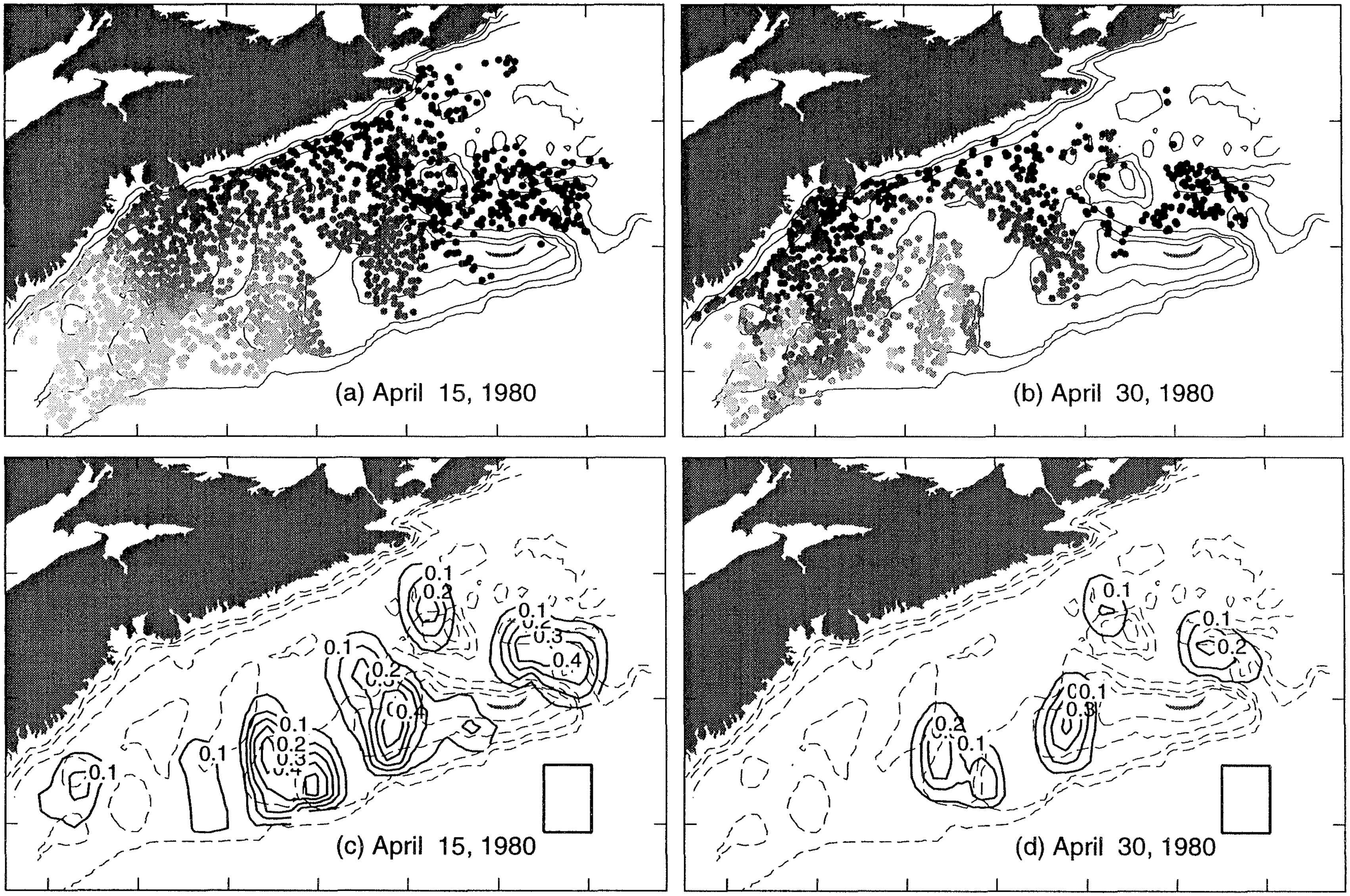

Figure 28.3: Dispersion in April 1980. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

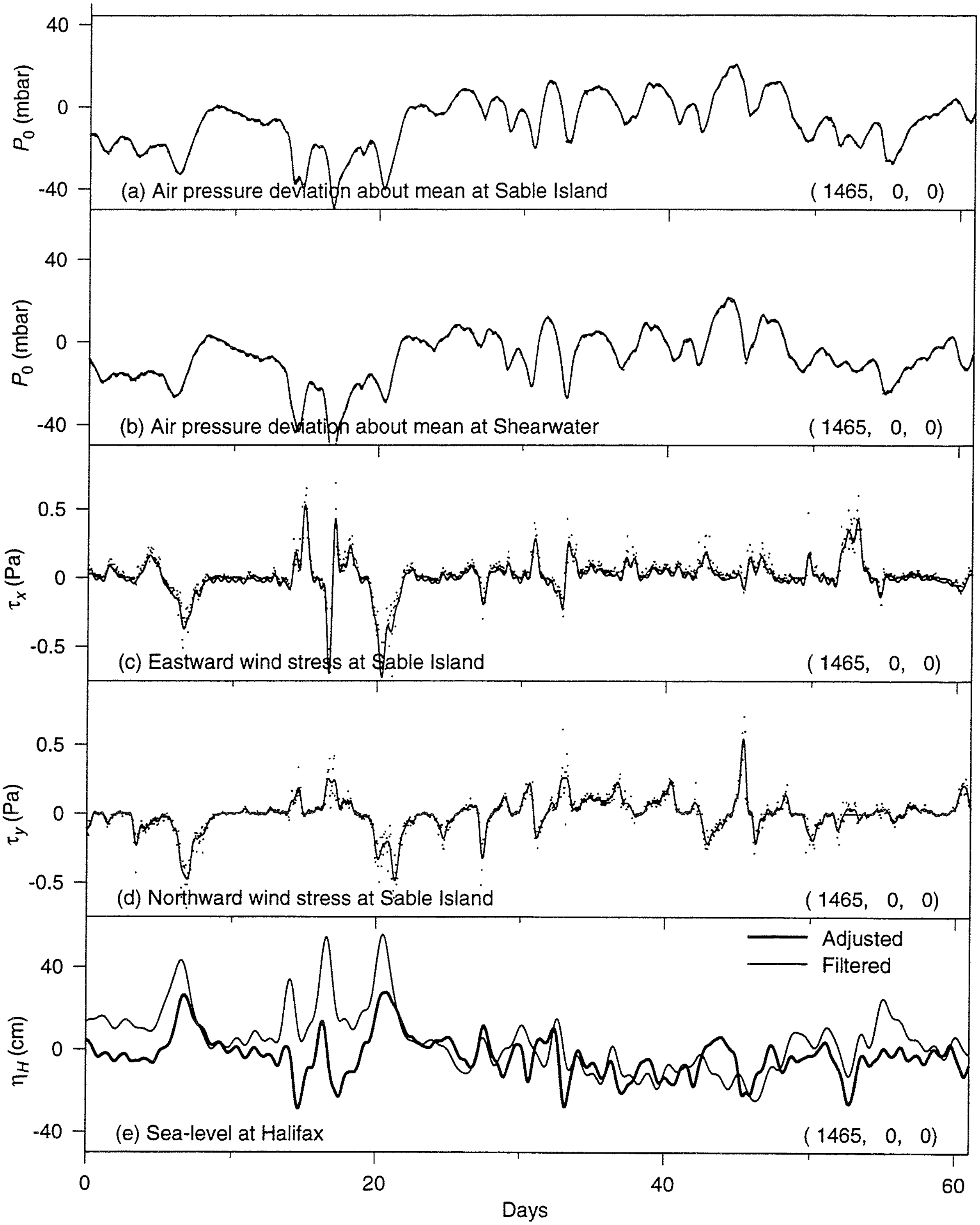

Figure 29.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1981). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

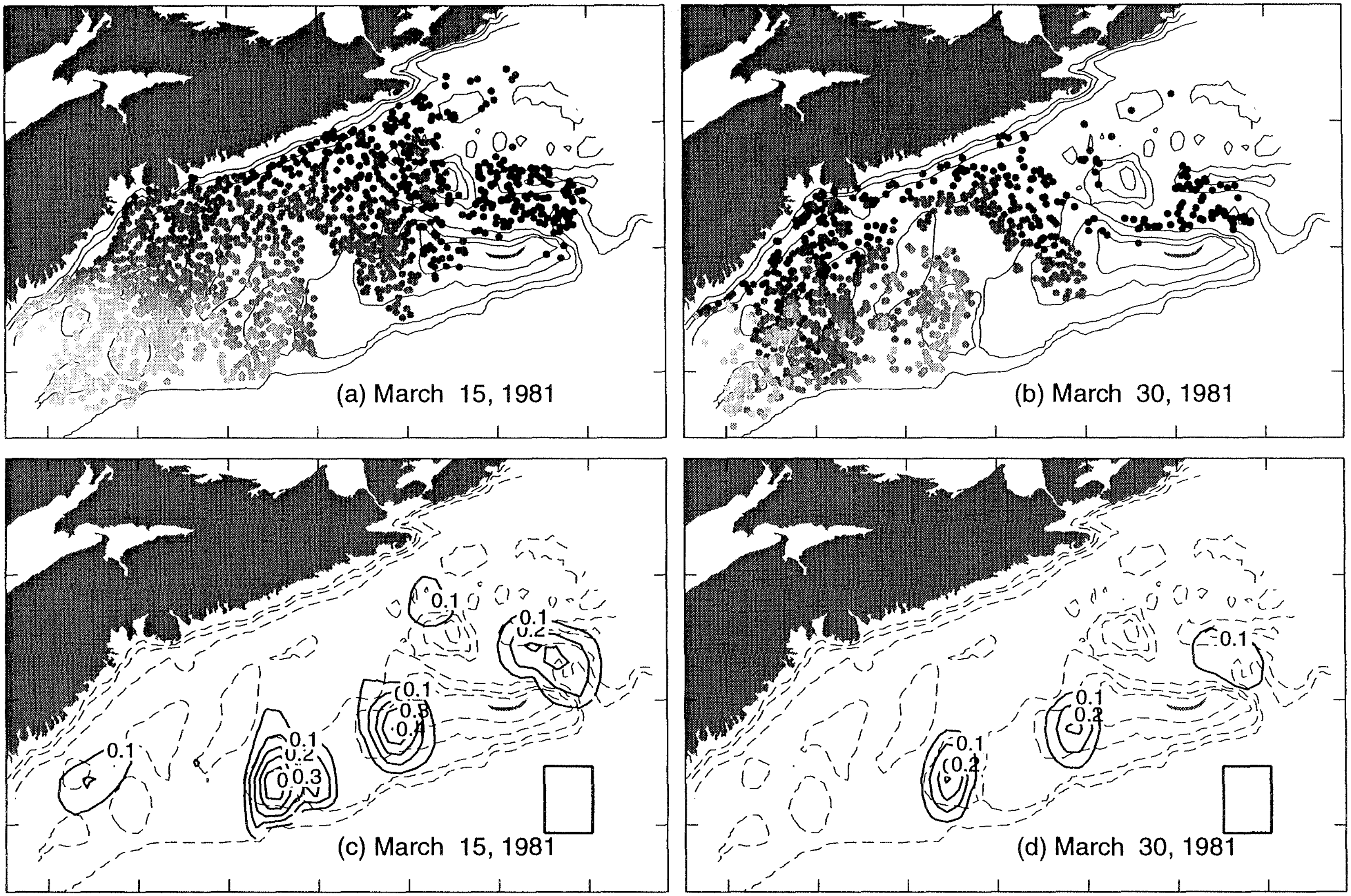

Figure 29.2: Dispersion in March 1981. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

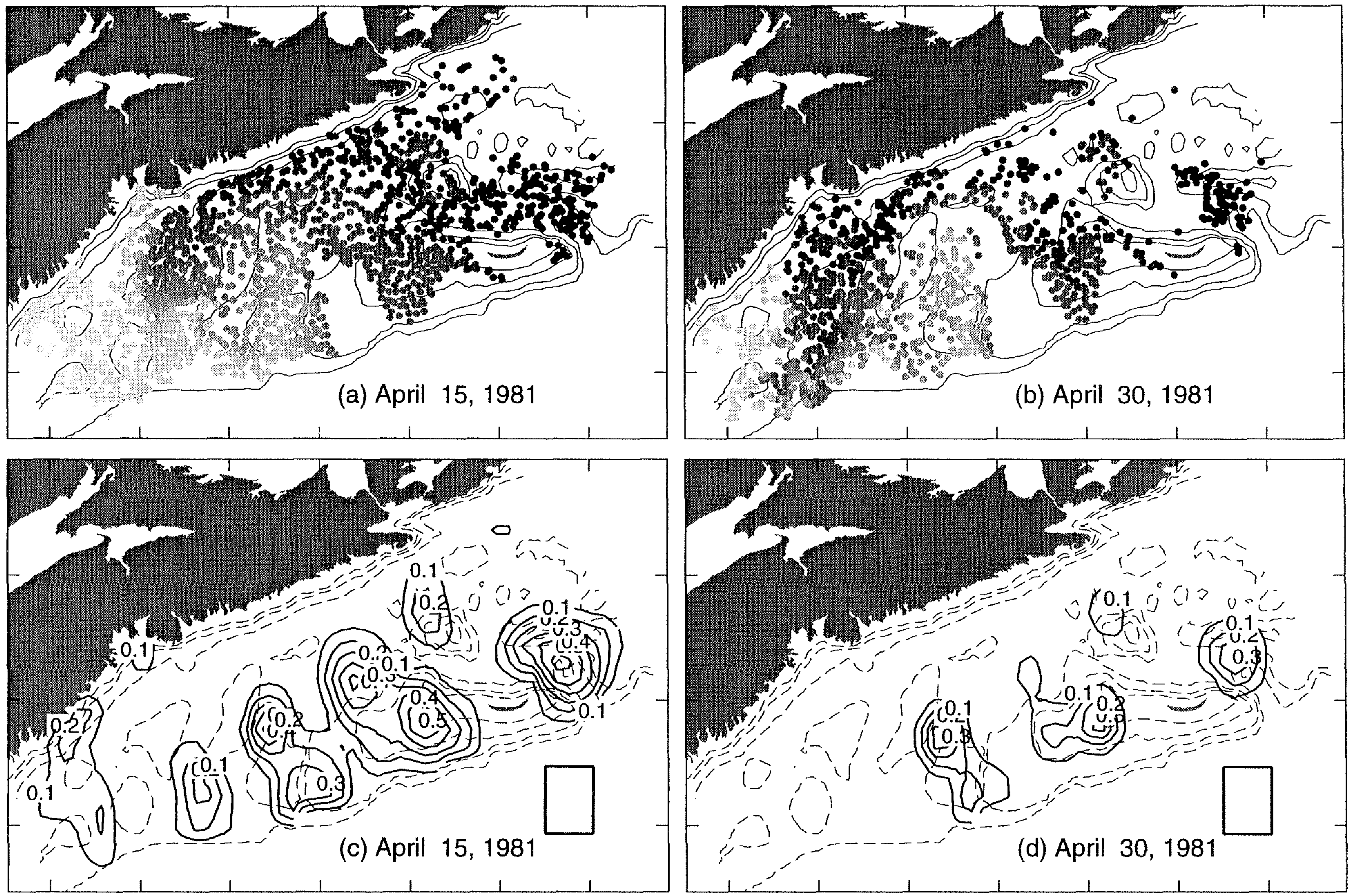

Figure 29.3: Dispersion in April 1981. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

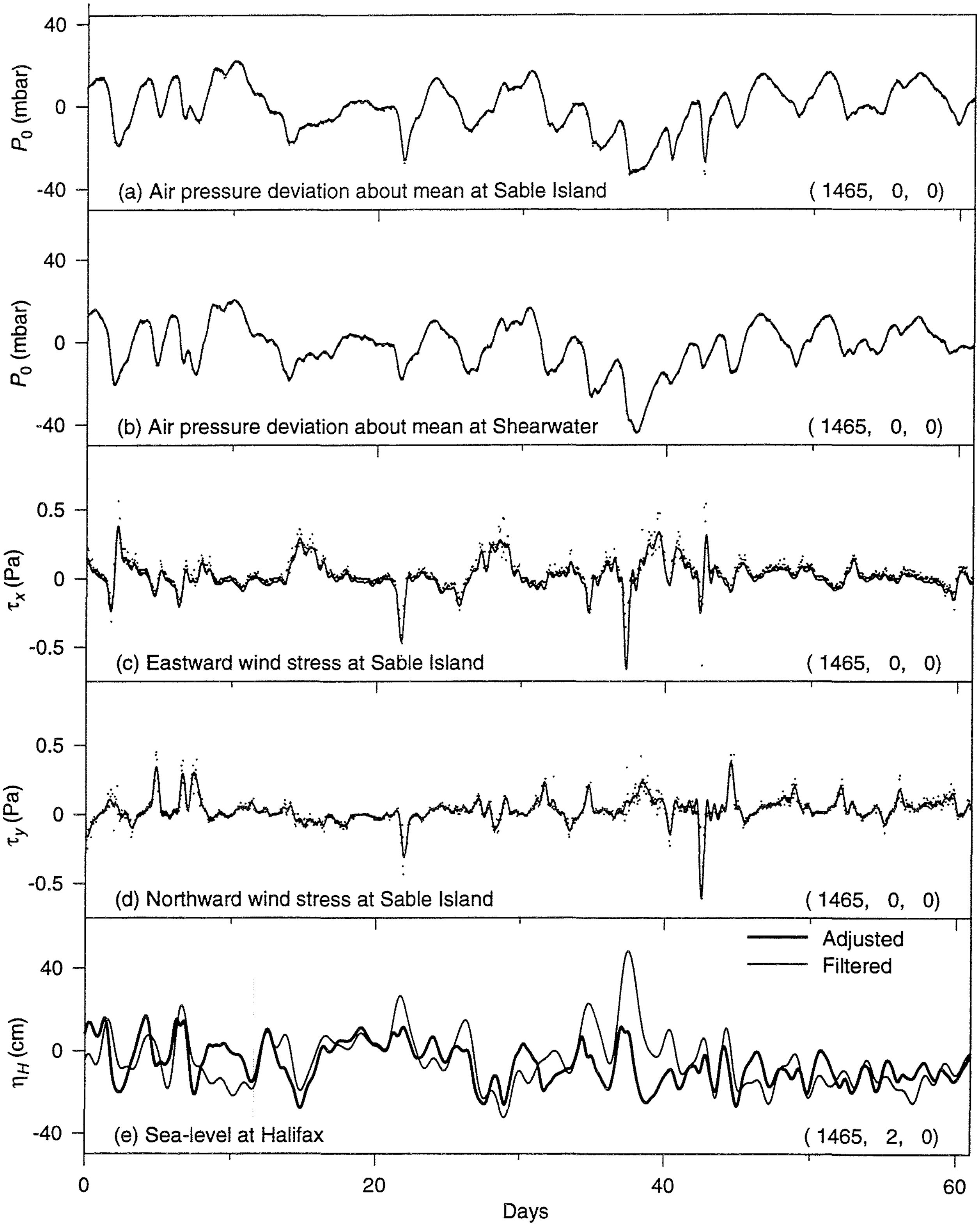

Figure 30.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1982). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

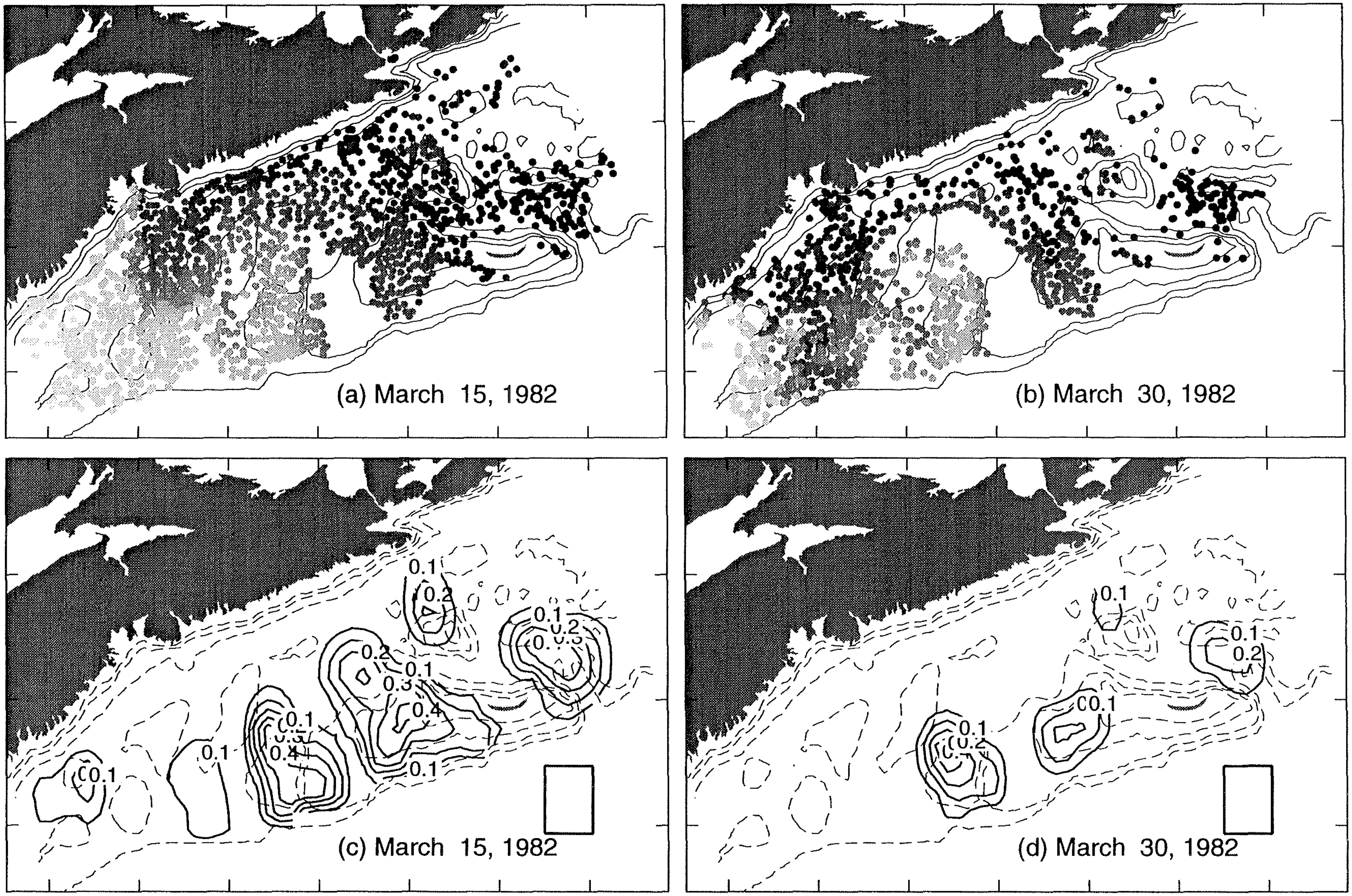

Figure 30.2: Dispersion in March 1982. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

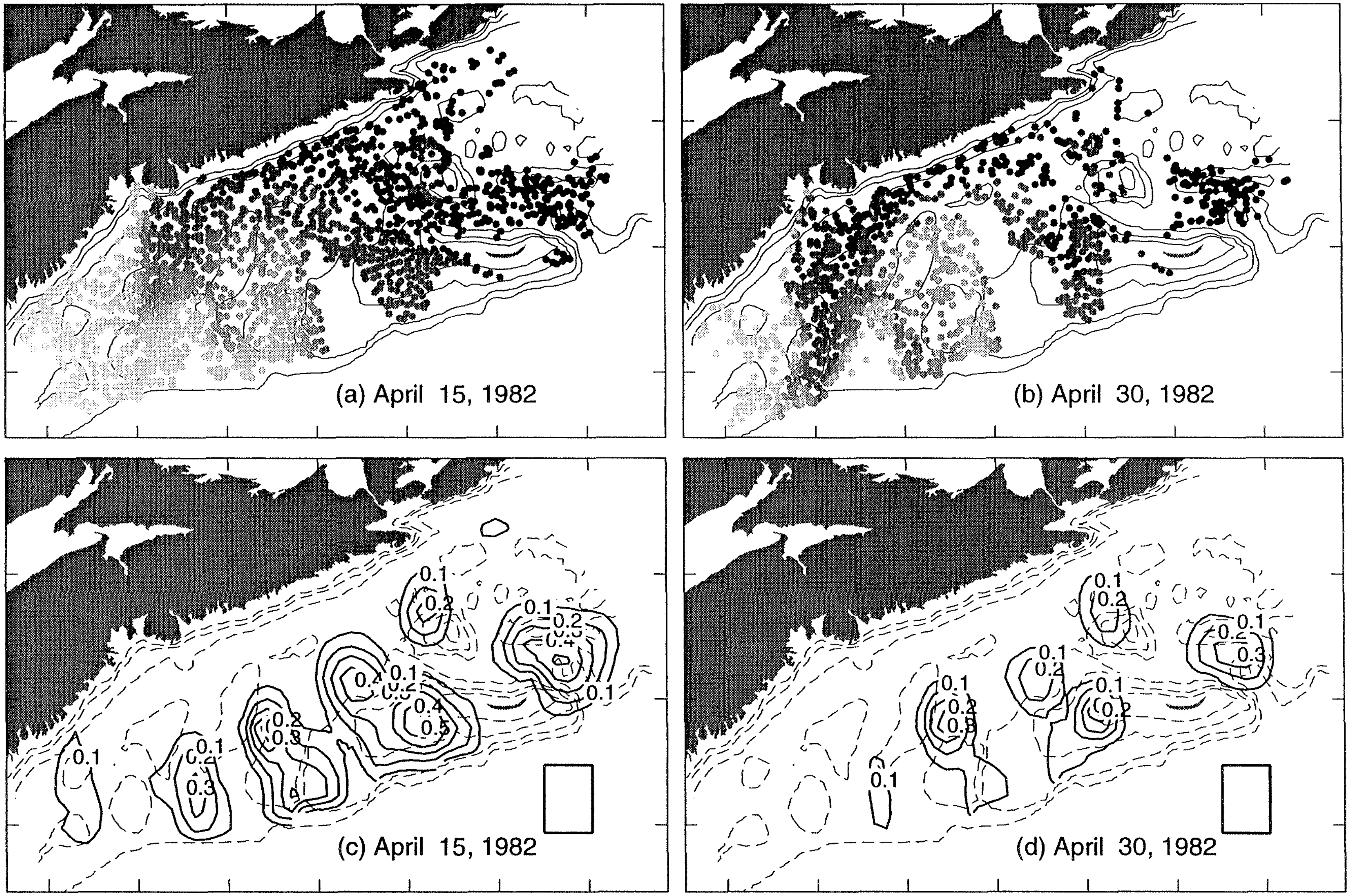

Figure 30.3: Dispersion in April 1982. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

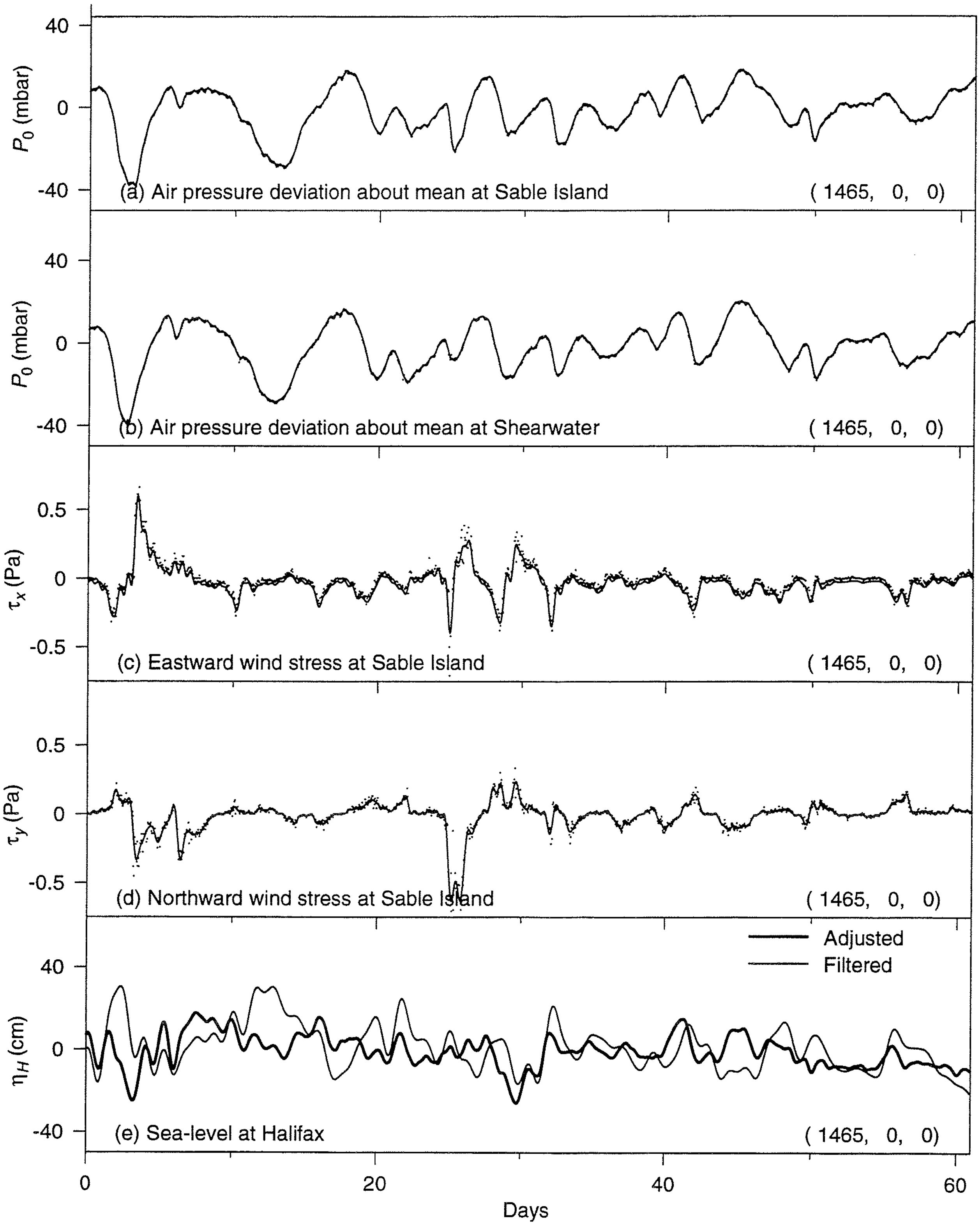

Figure 31.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1983). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

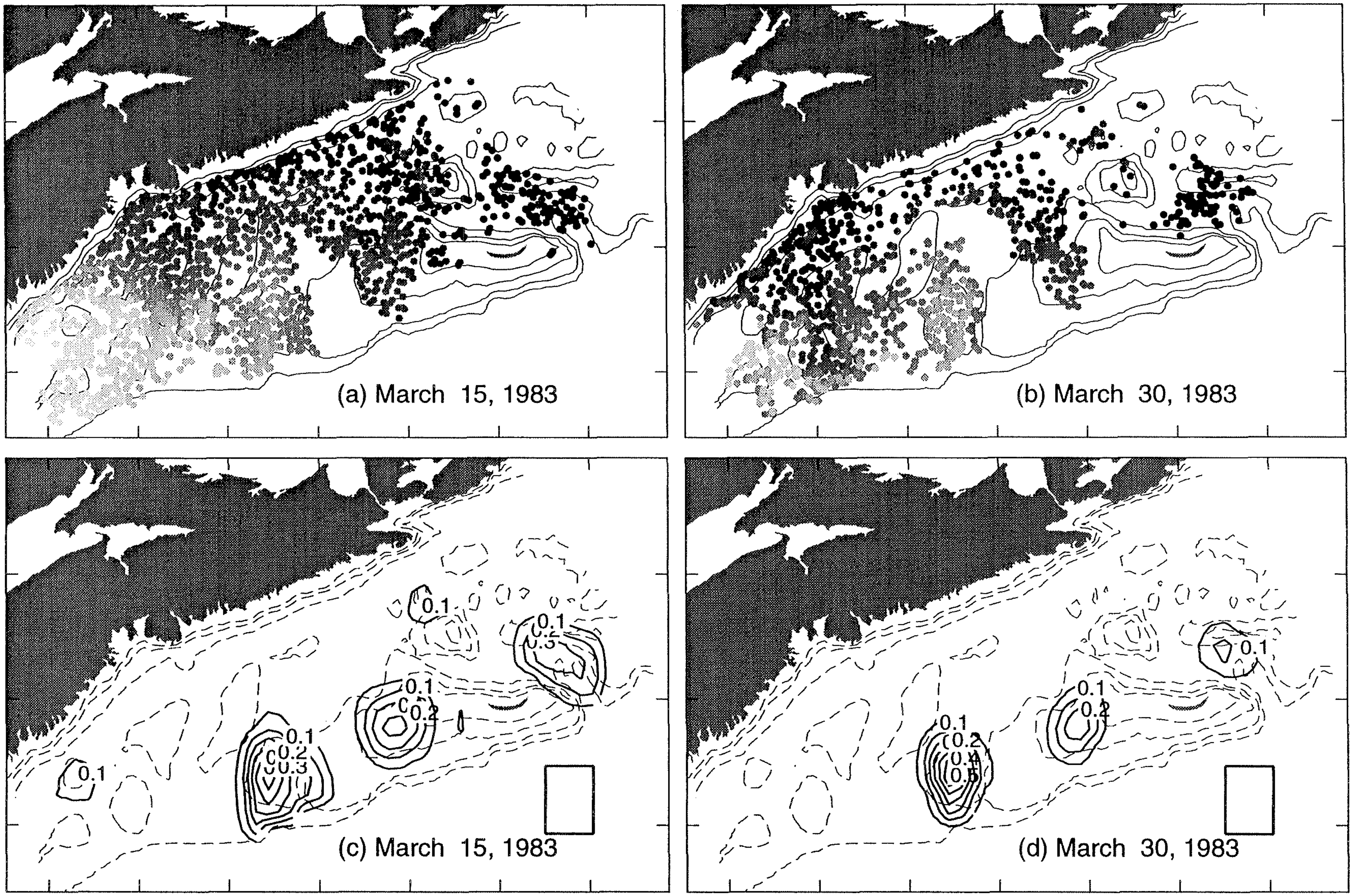

Figure 31.2: Dispersion in March 1983. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

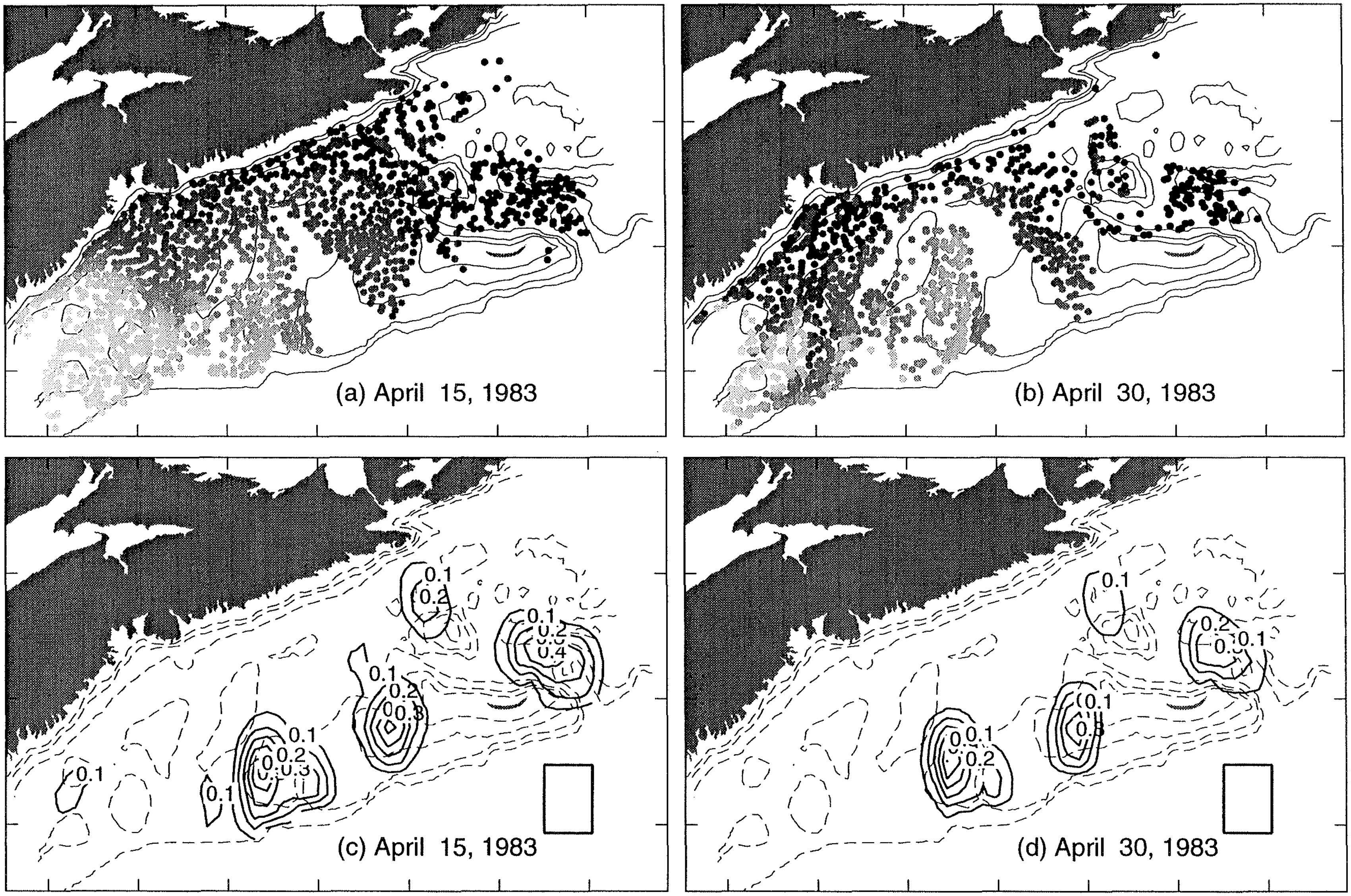

Figure 31.3: Dispersion in April 1983. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

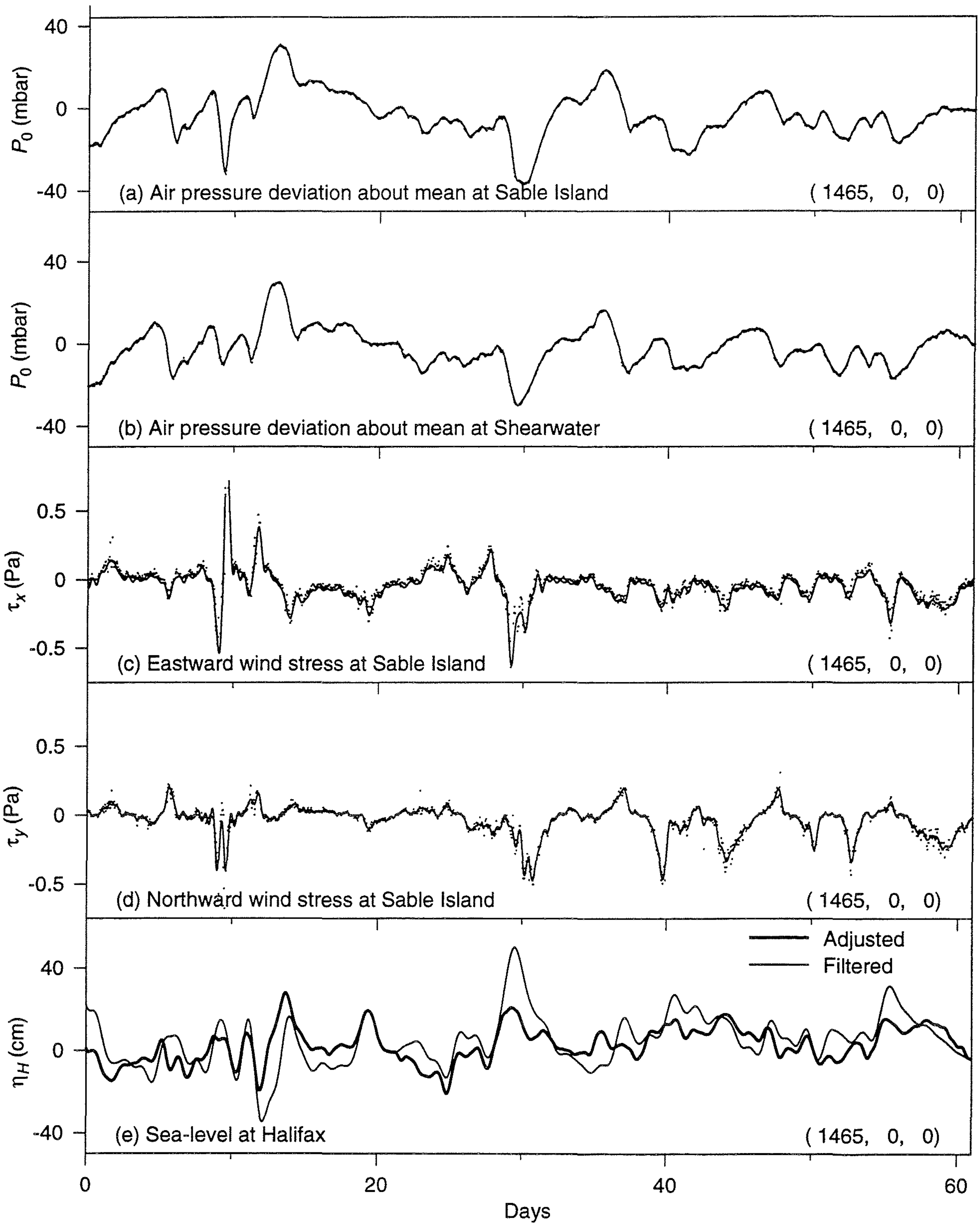

Figure 32.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1984). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

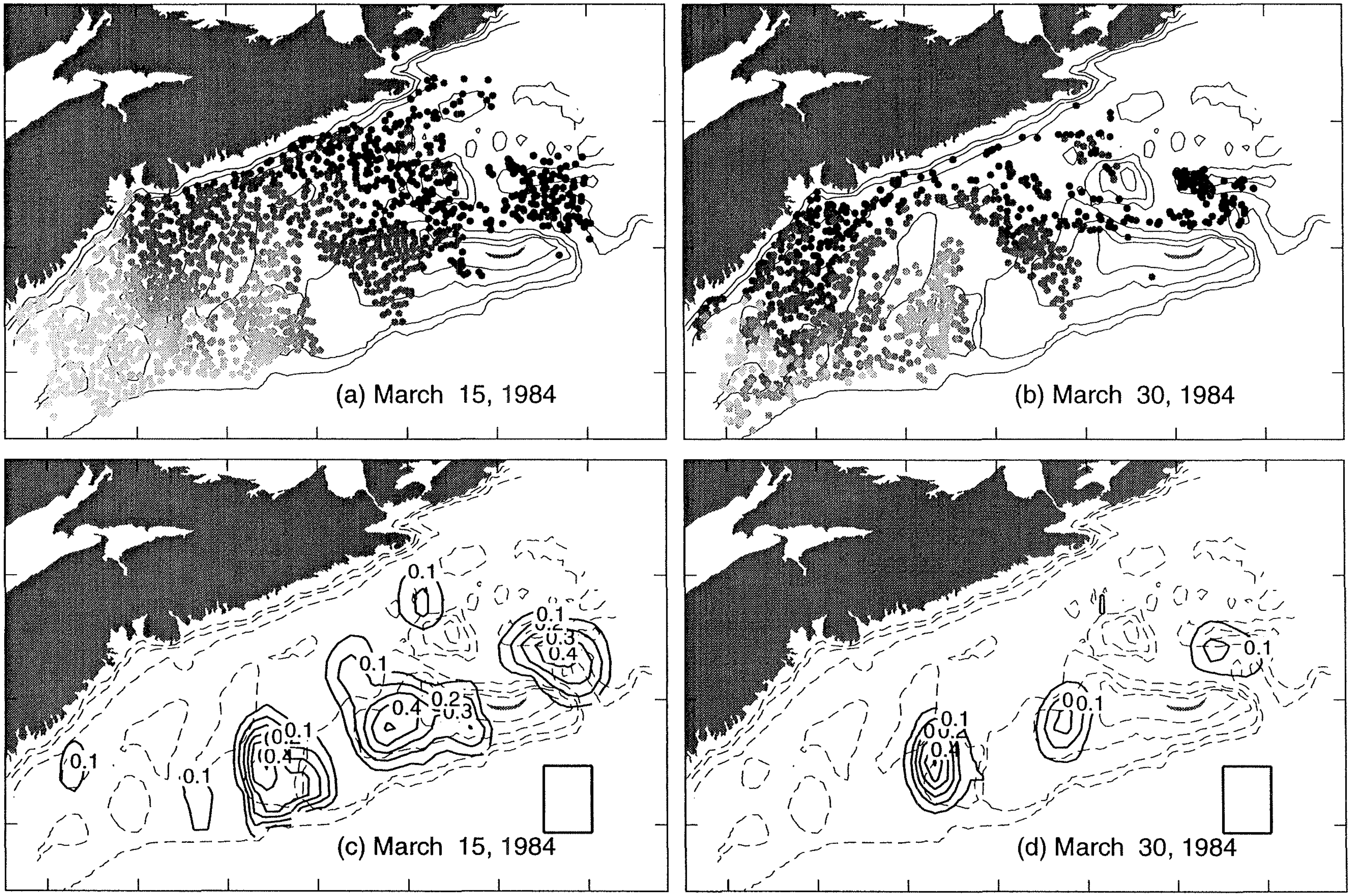

Figure 32.2: Dispersion in March 1984. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

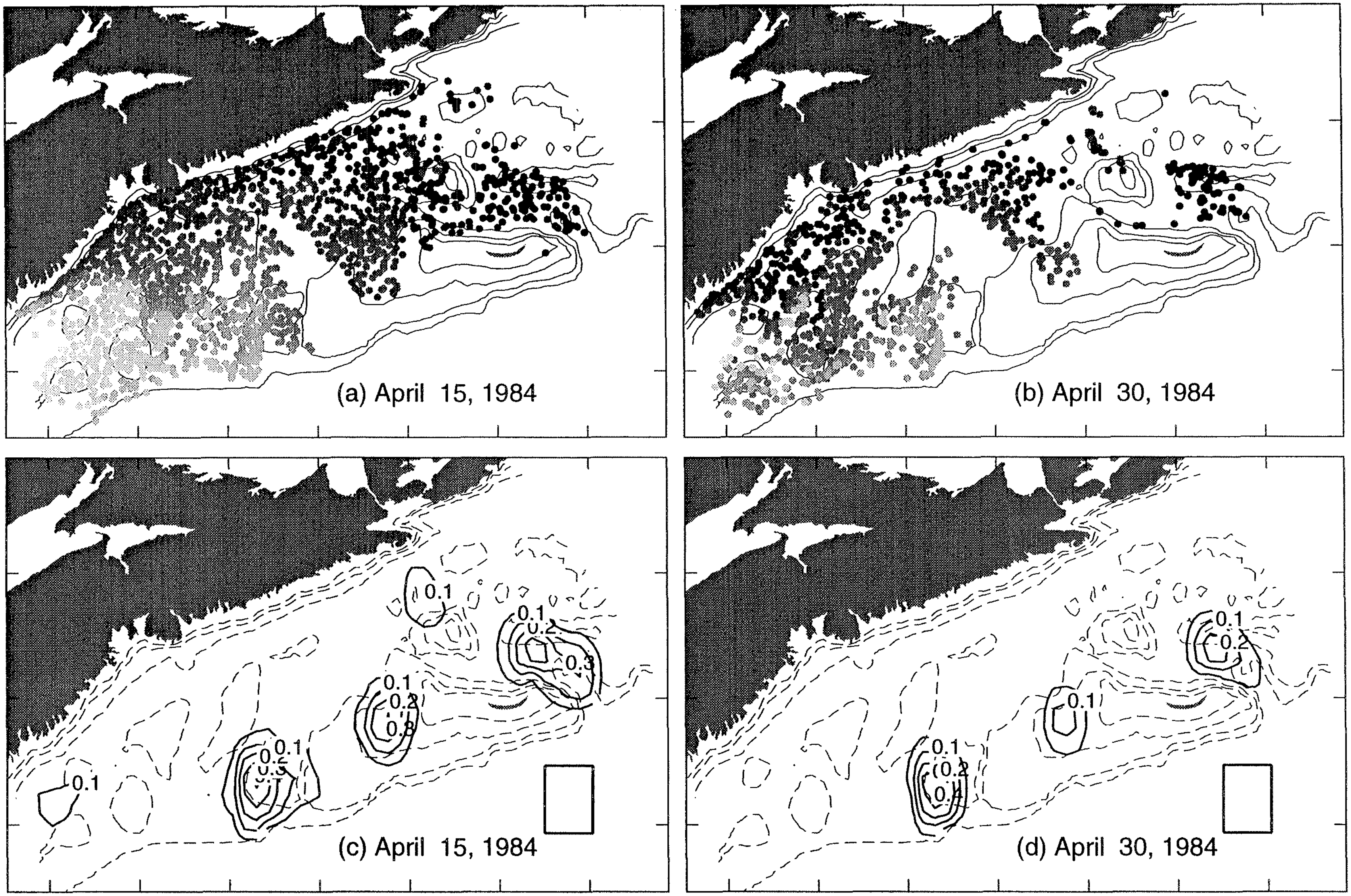

Figure 32.3: Dispersion in April 1984. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

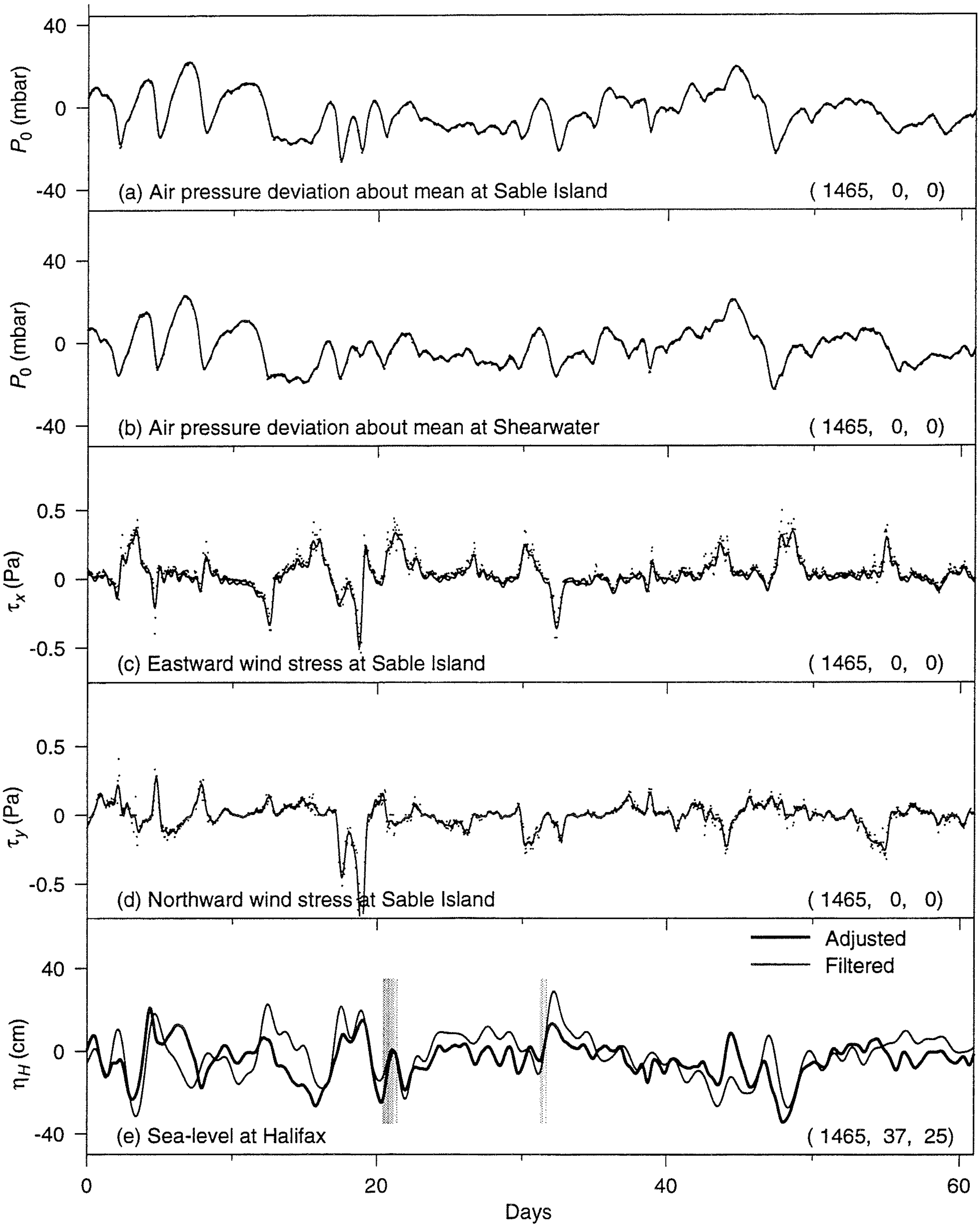

Figure 33.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1985). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

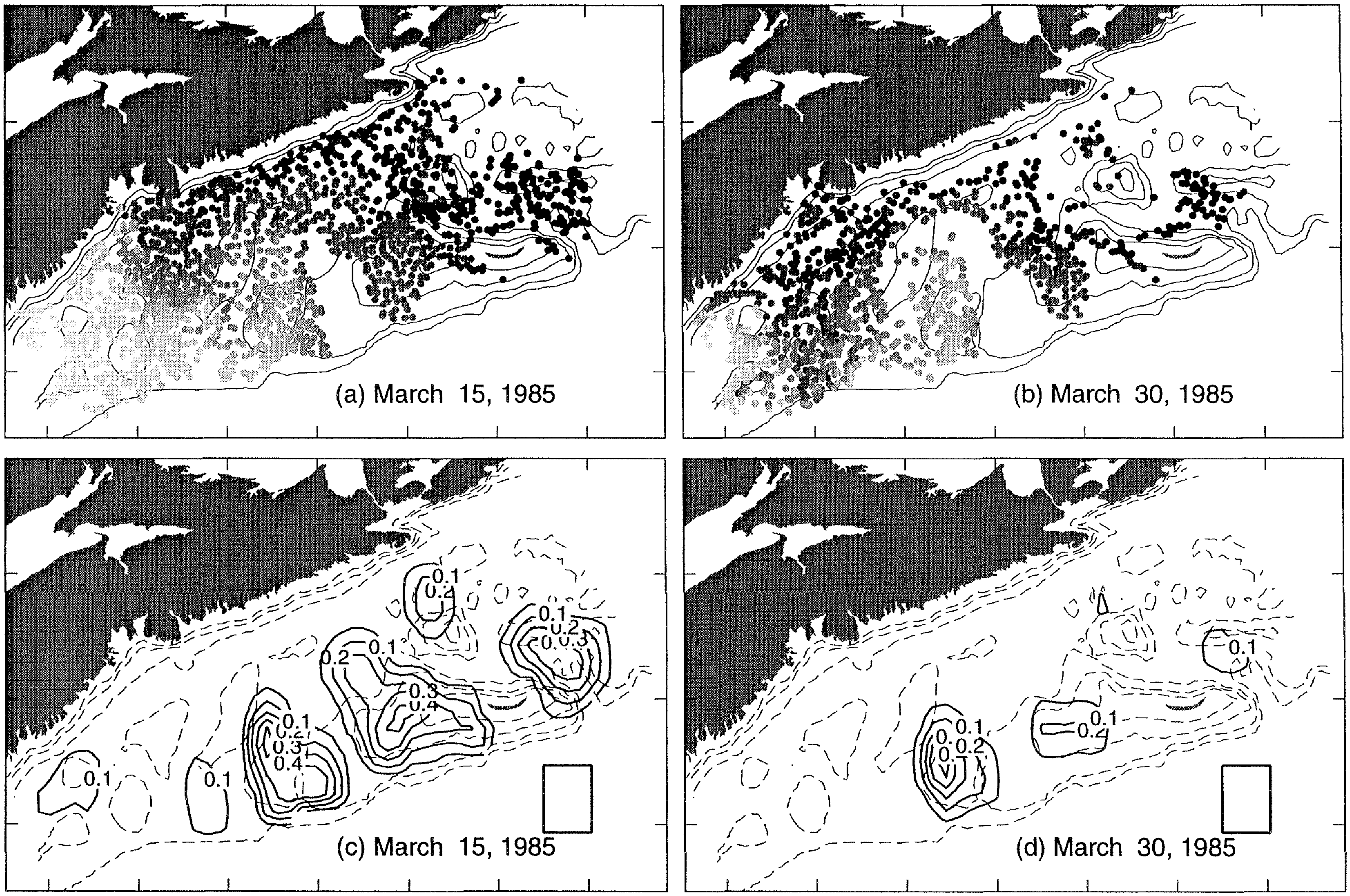

Figure 33.2: Dispersion in March 1985. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

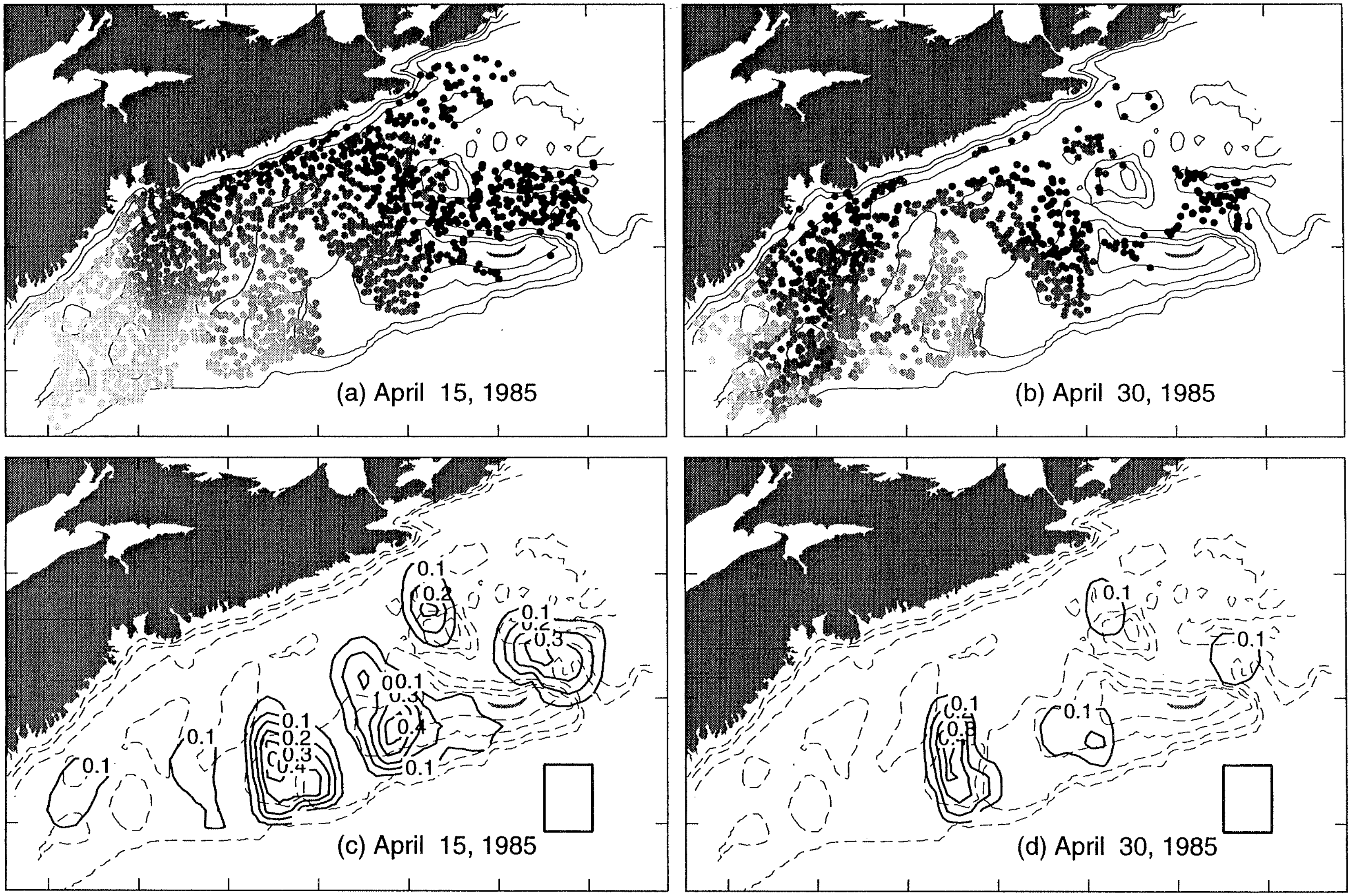

Figure 33.3: Dispersion in April 1985. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

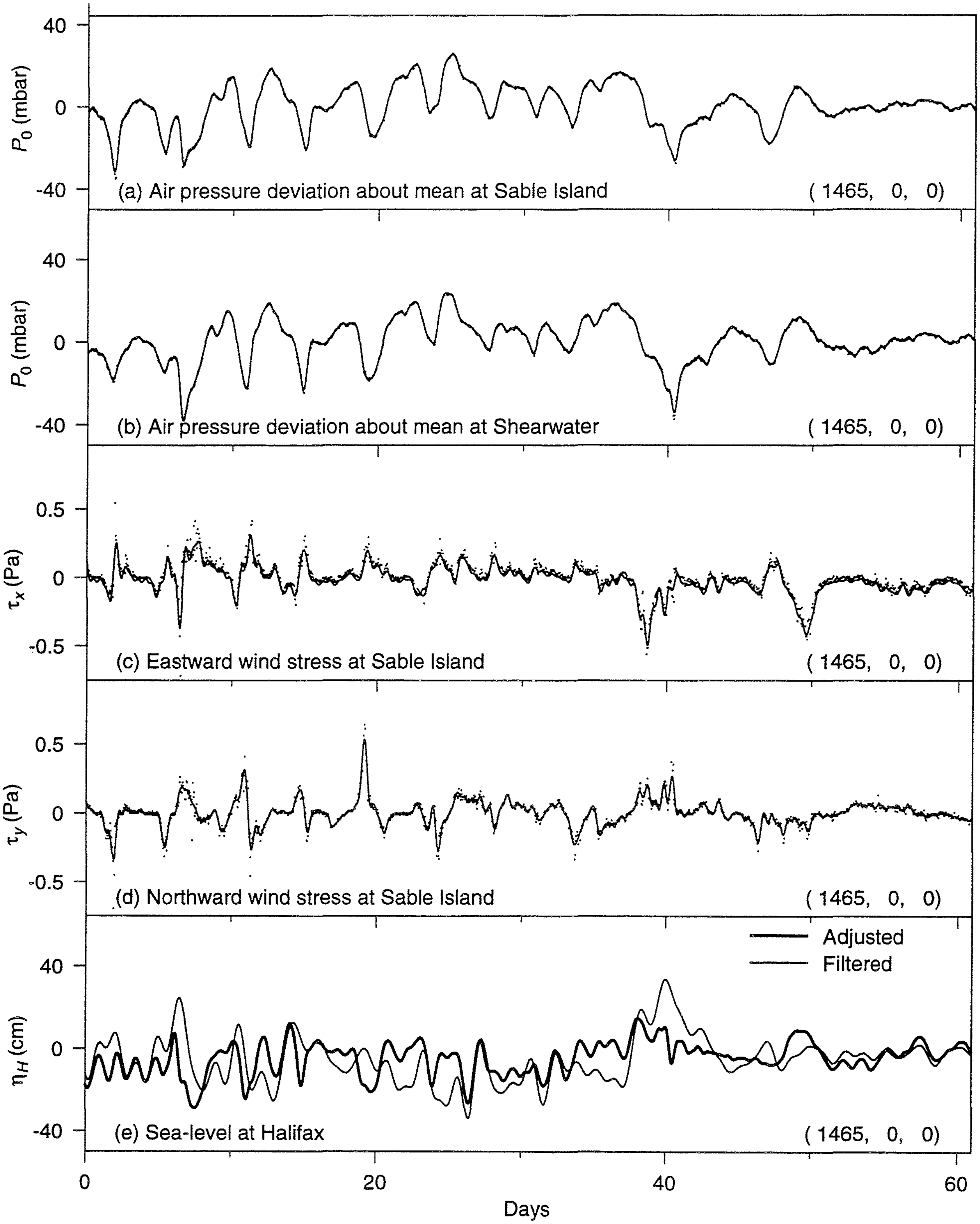

Figure 34.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1986). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

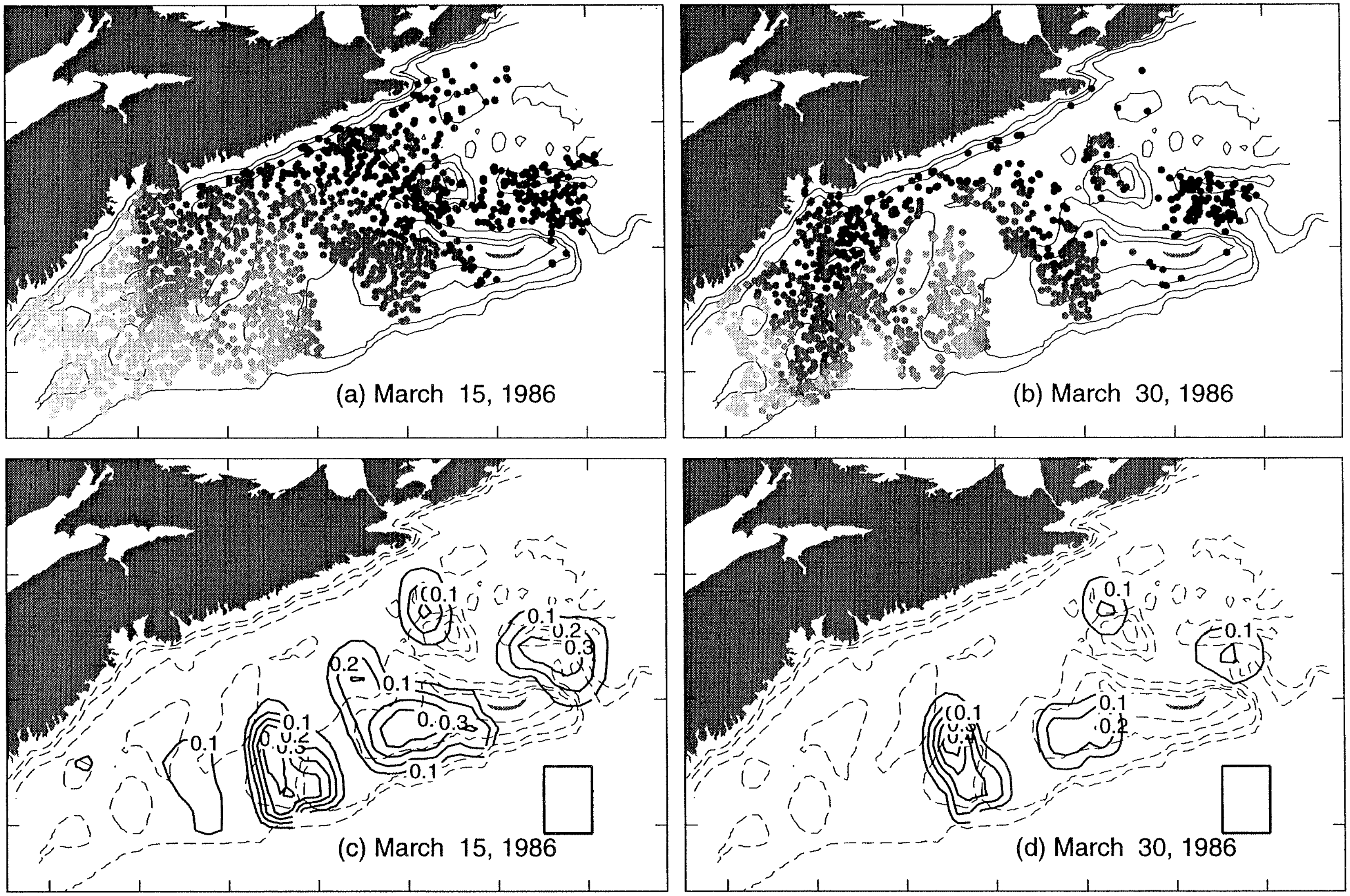

Figure 34.2: Dispersion in March 1986. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

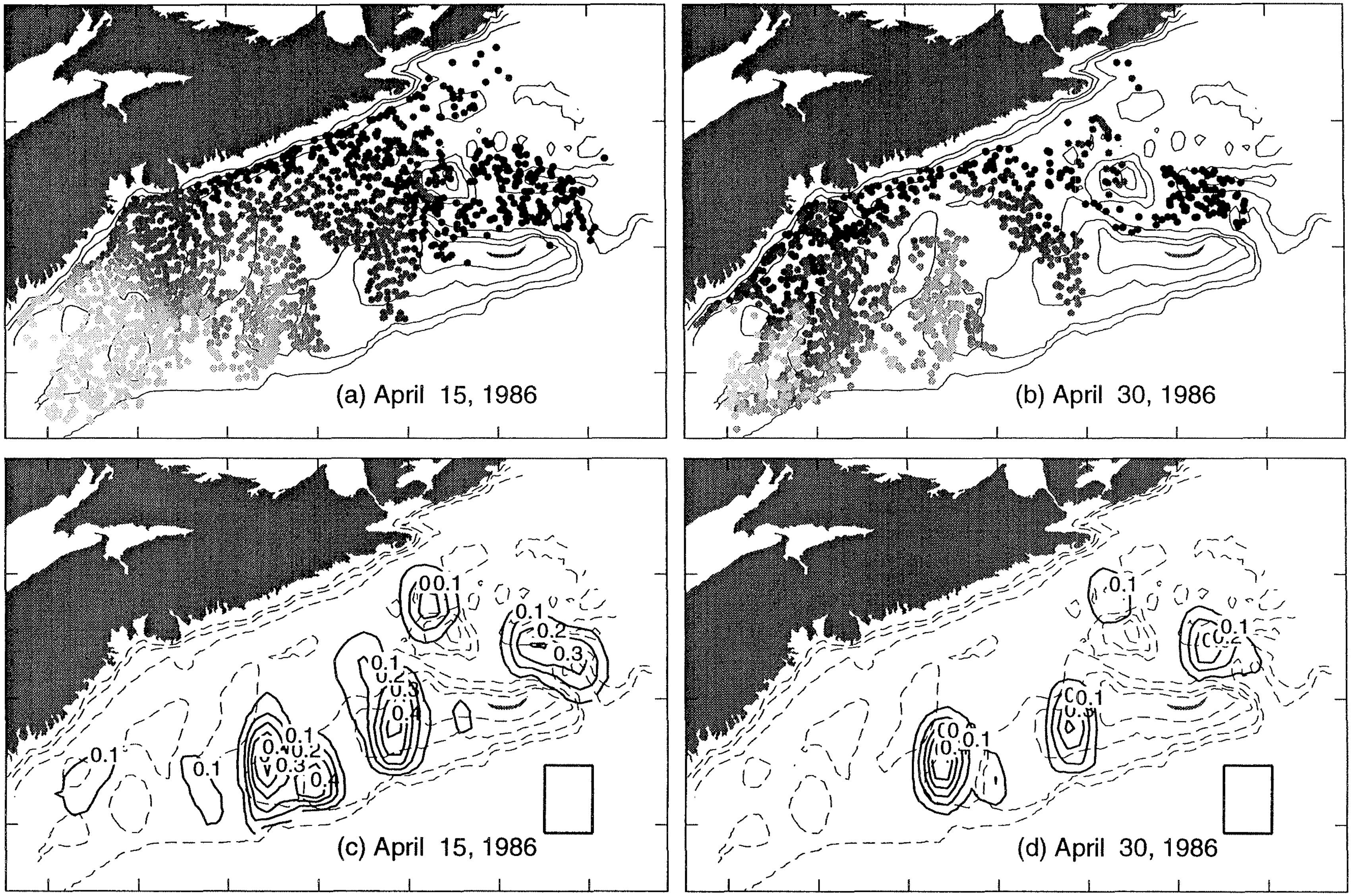

Figure 34.3: Dispersion in April 1986. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

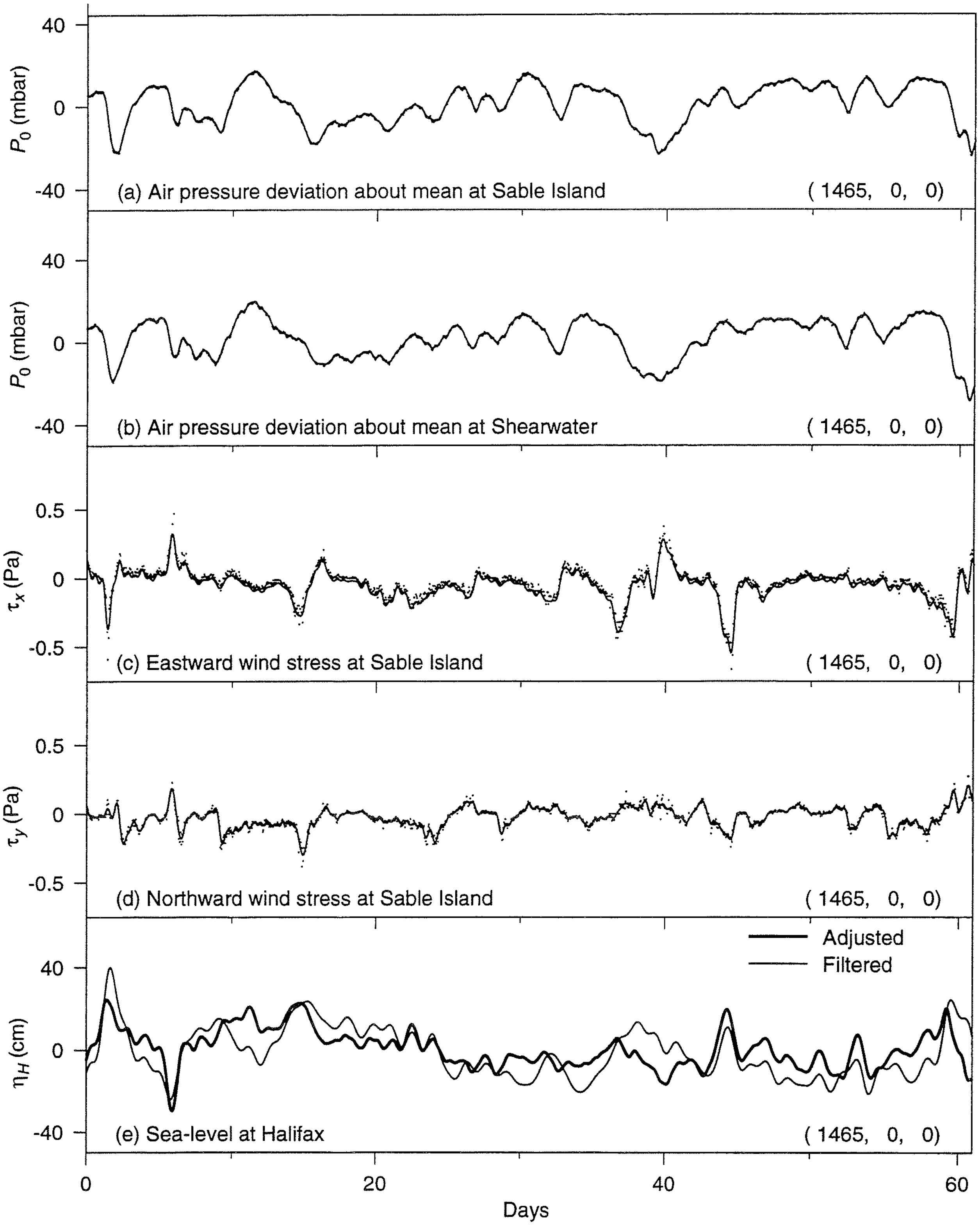

Figure 35.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1987). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

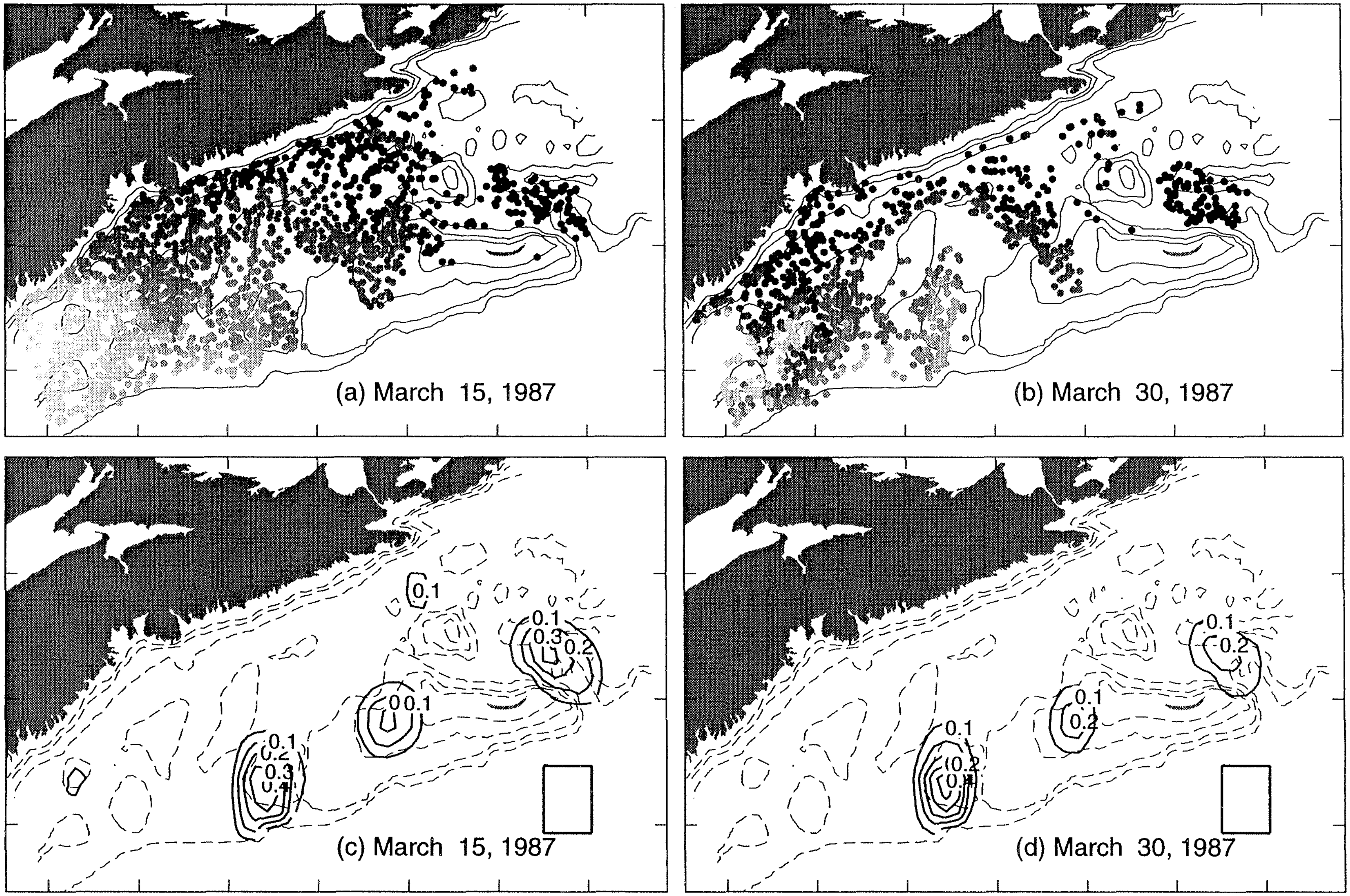

Figure 35.2: Dispersion in March 1987. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

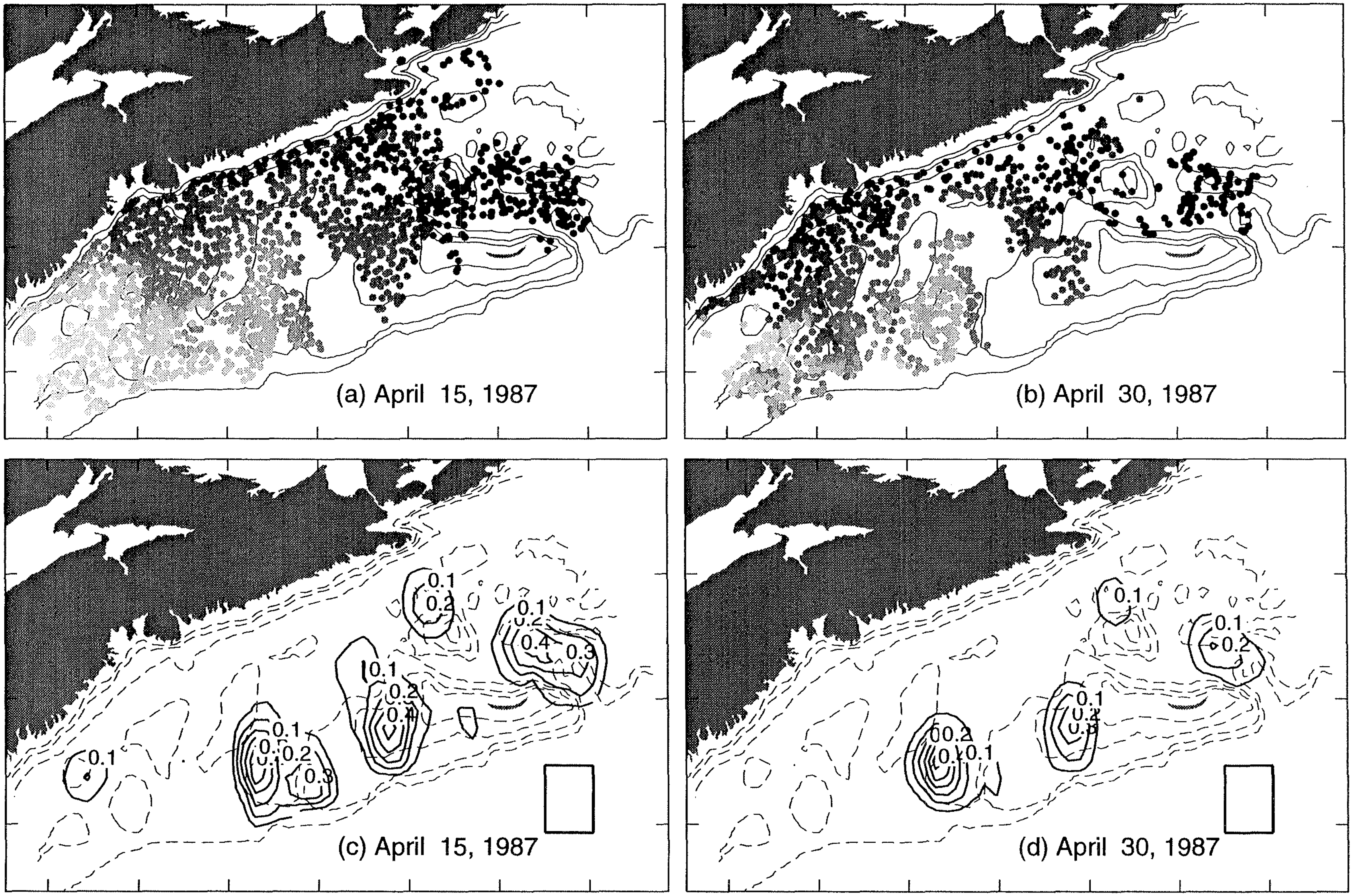

Figure 35.3: Dispersion in April 1987. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

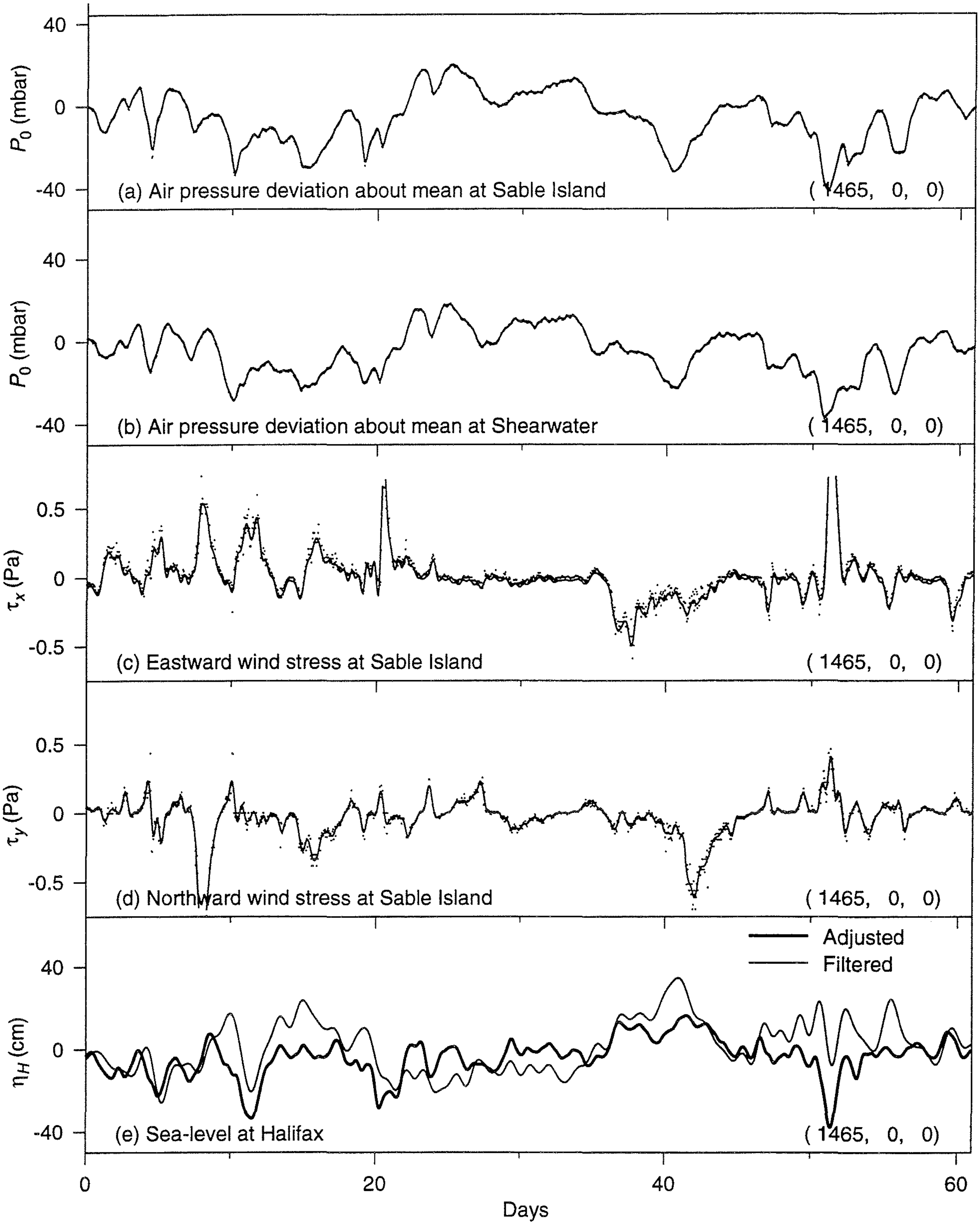

Figure 36.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1988). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

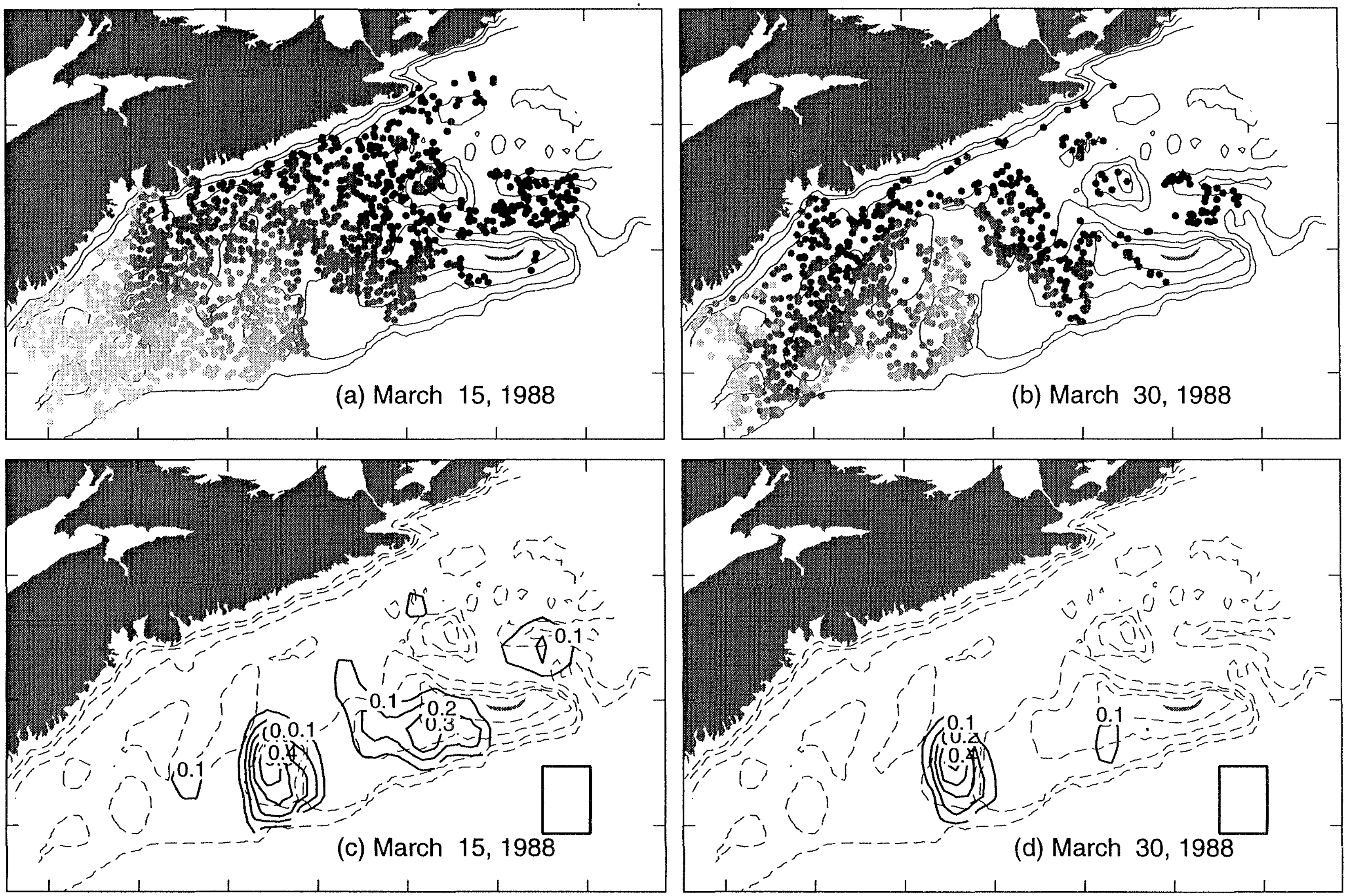

Figure 36.2: Dispersion in March 1988. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

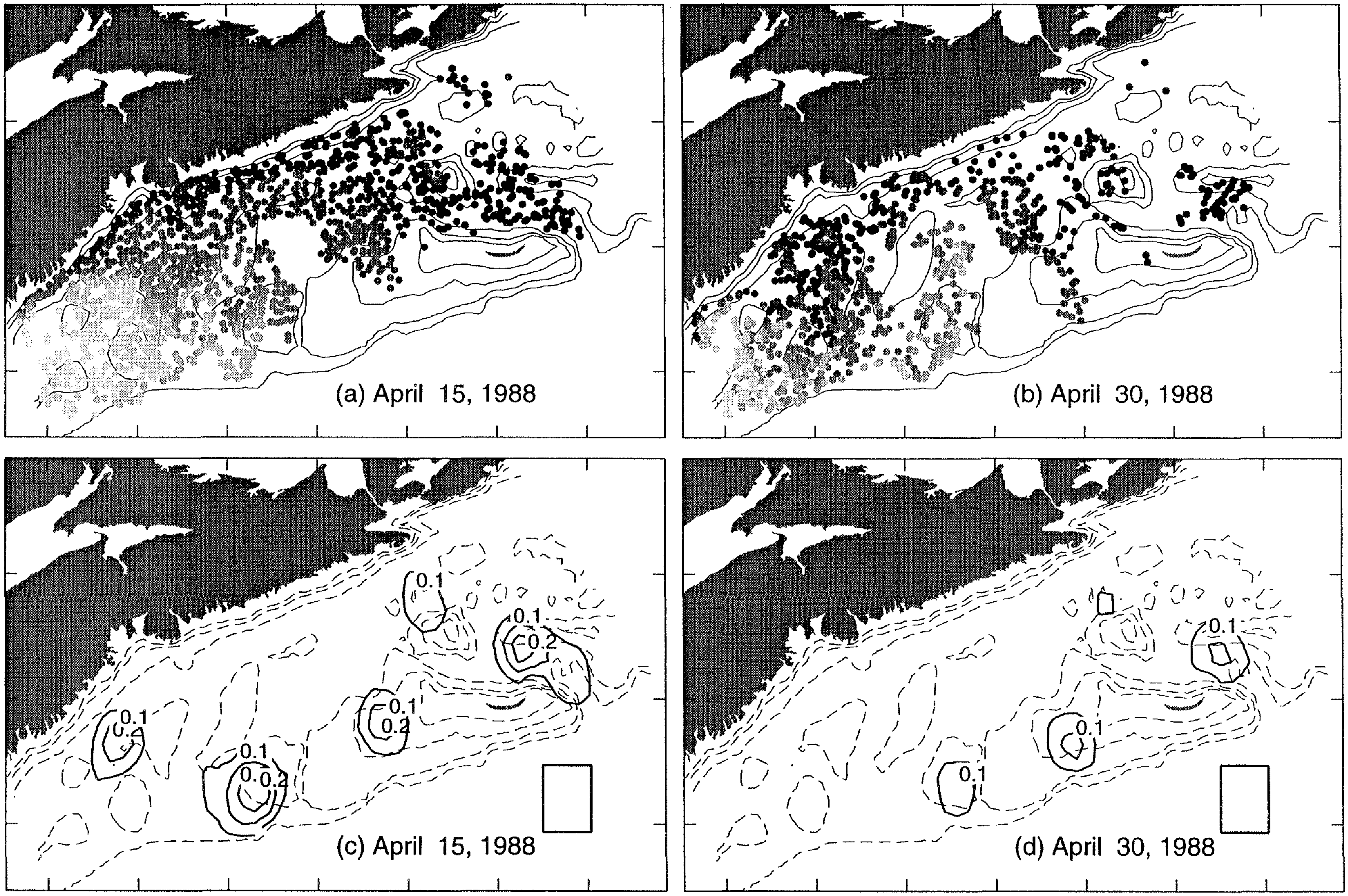

Figure 36.3: Dispersion in April 1988. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

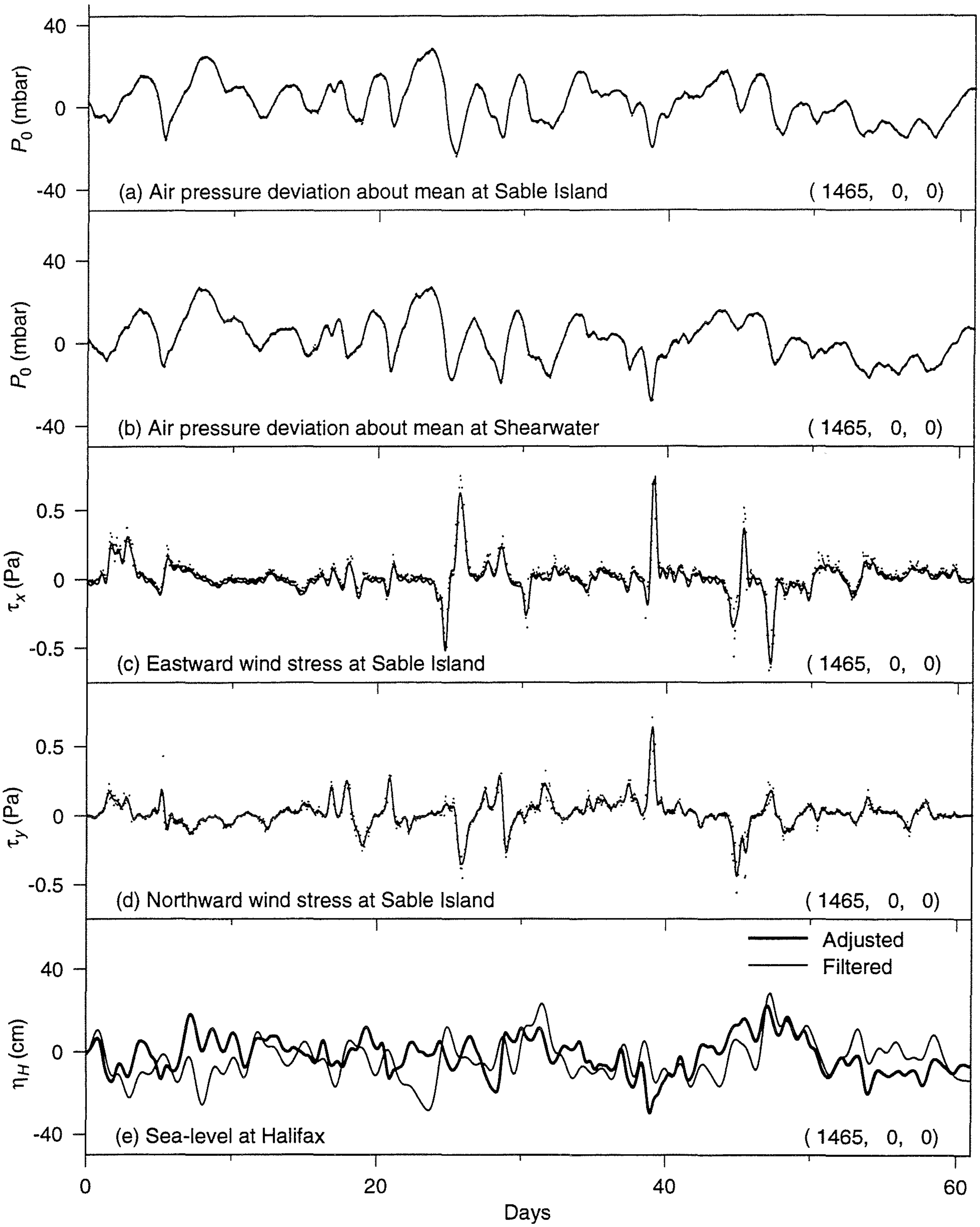

Figure 37.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1989). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

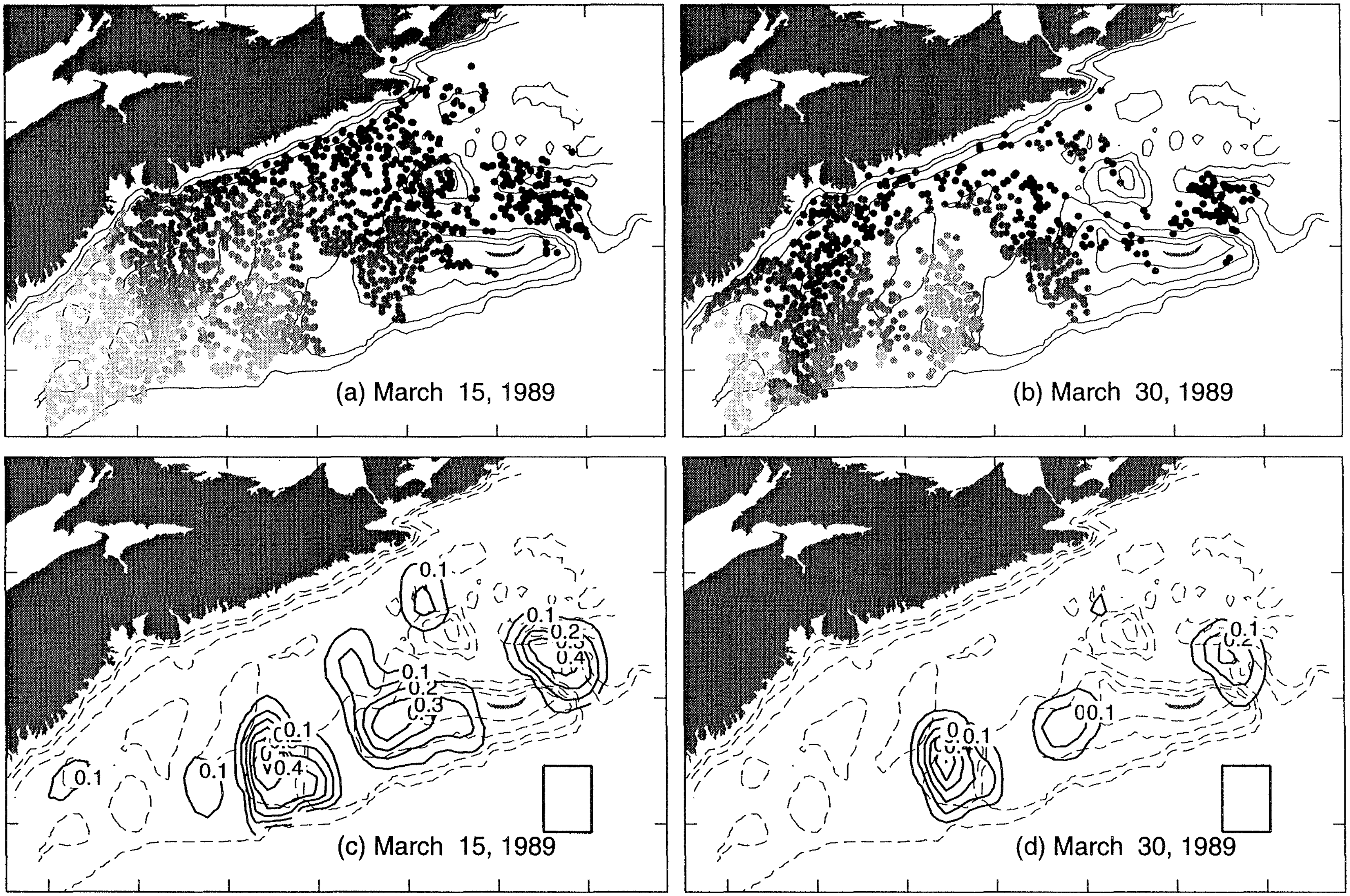

Figure 37.2: Dispersion in March 1989. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

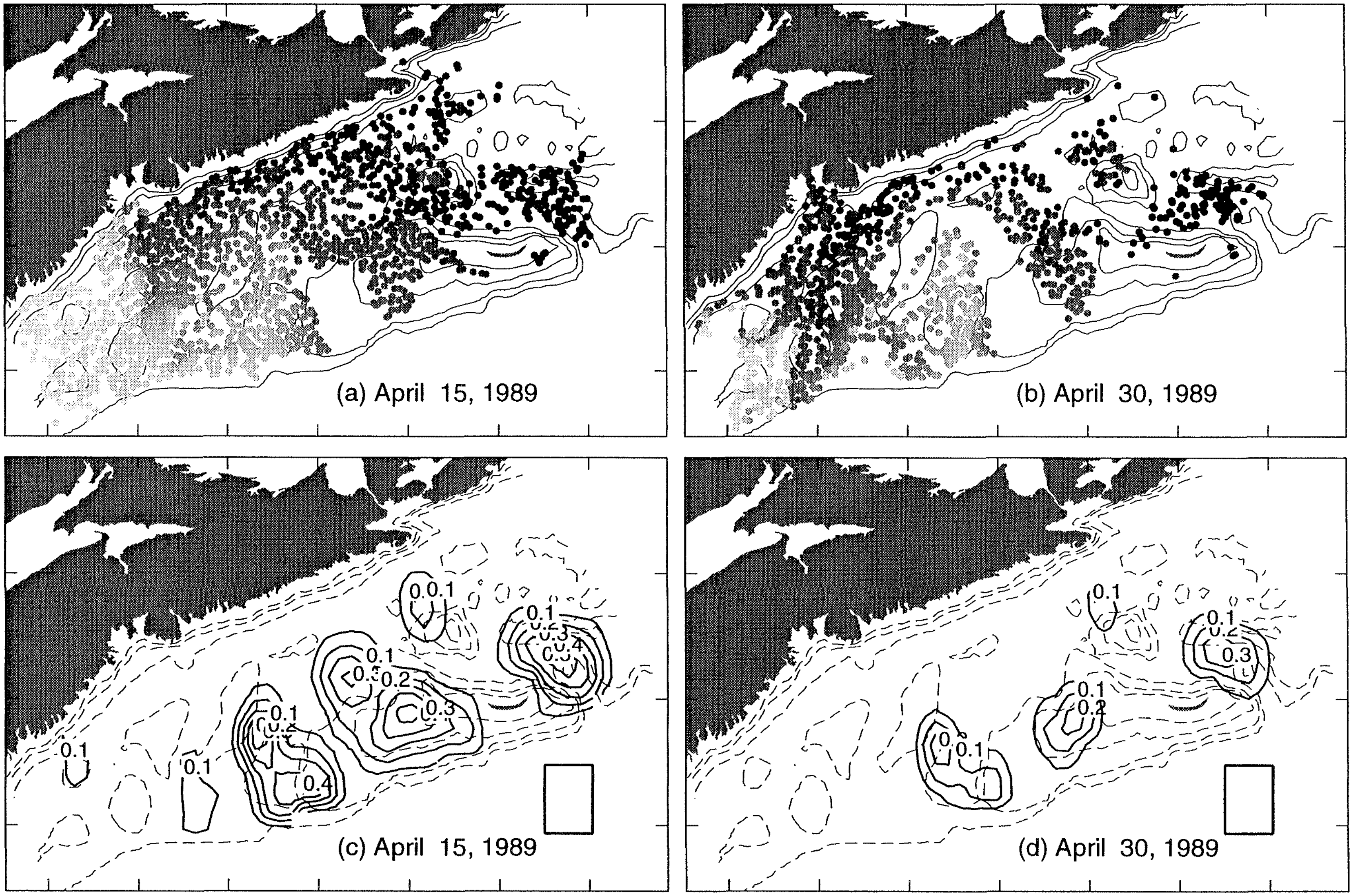

Figure 37.3: Dispersion in April 1989. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

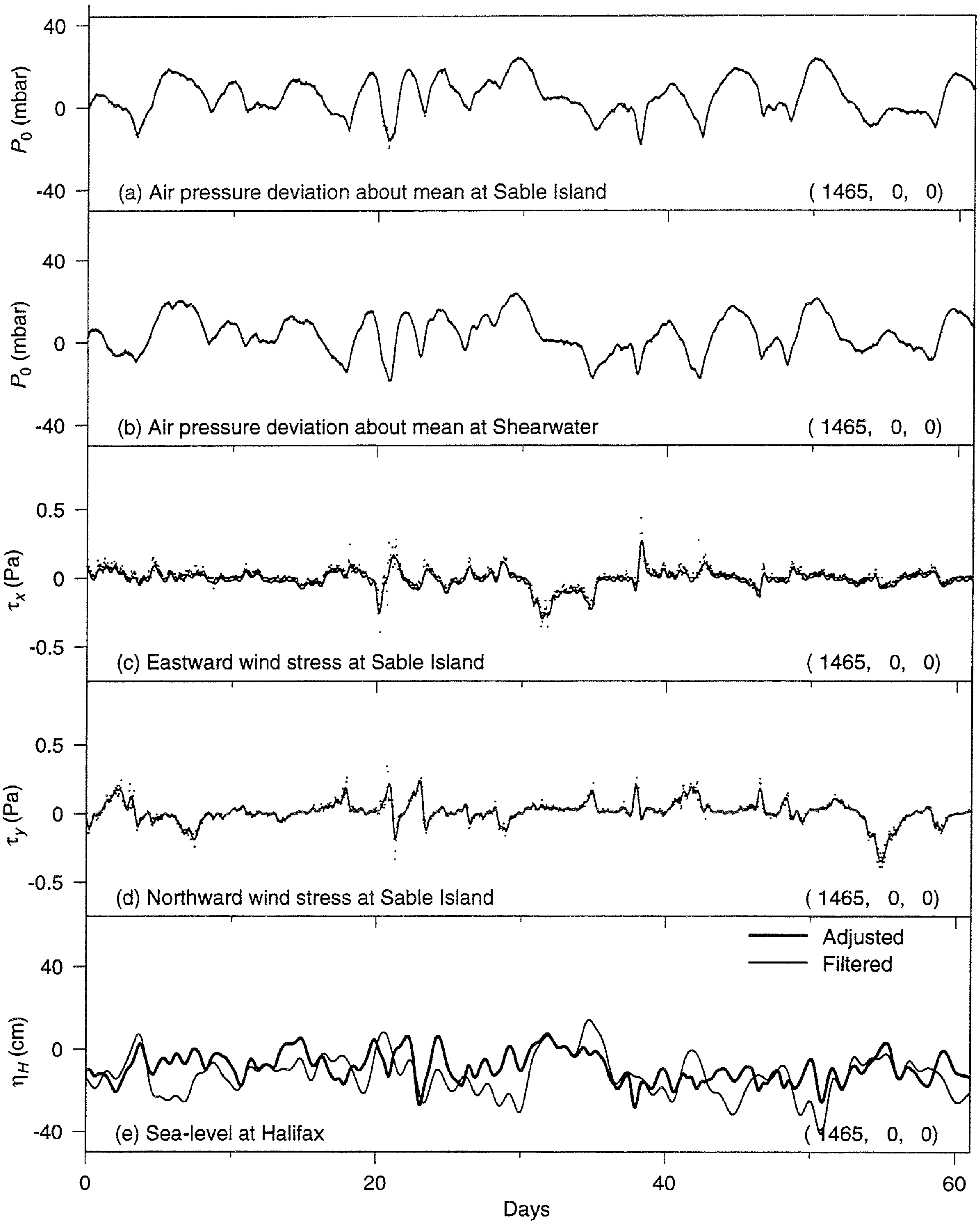

Figure 38.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1990). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

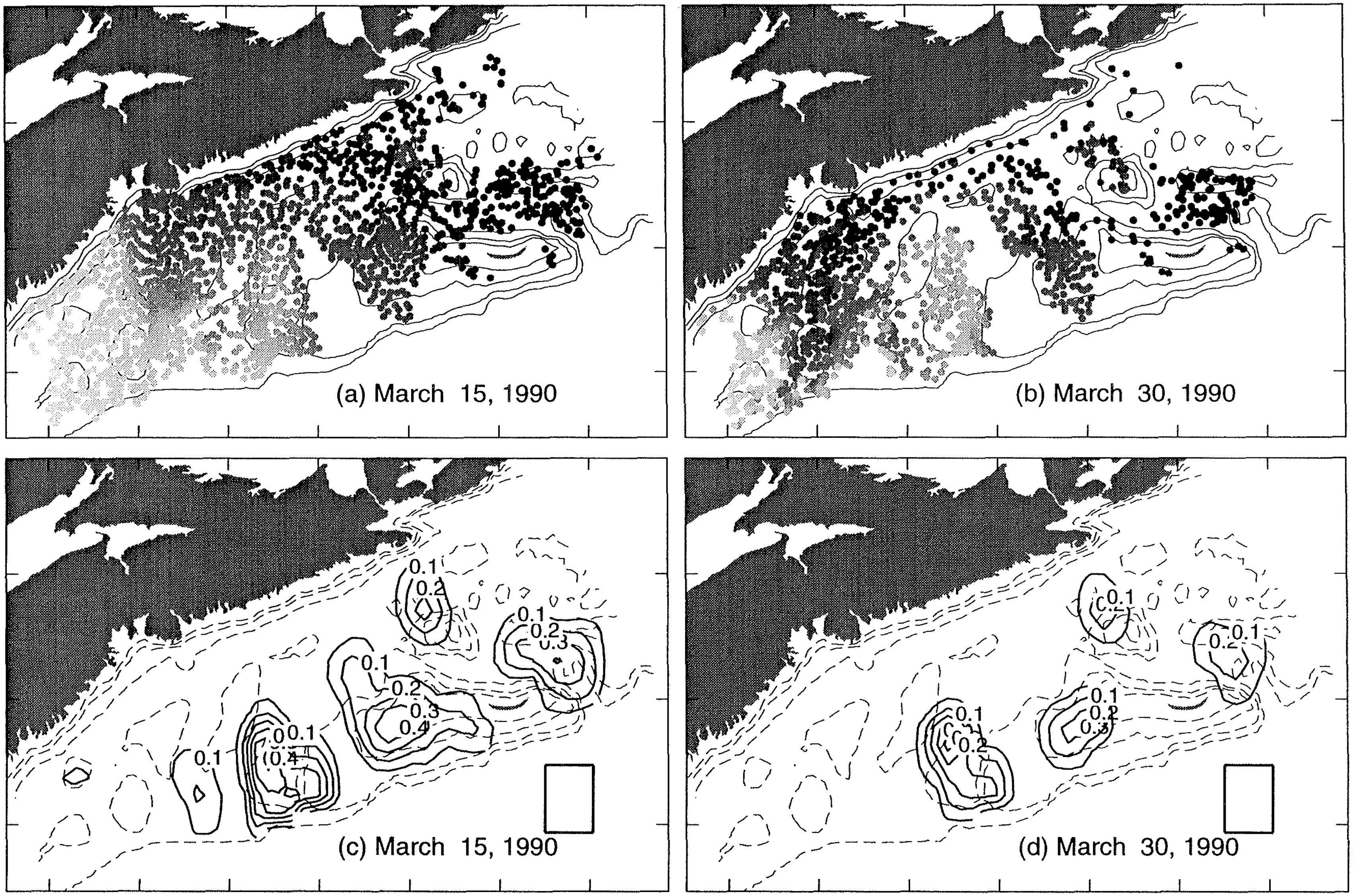

Figure 38.2: Dispersion in March 1990. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

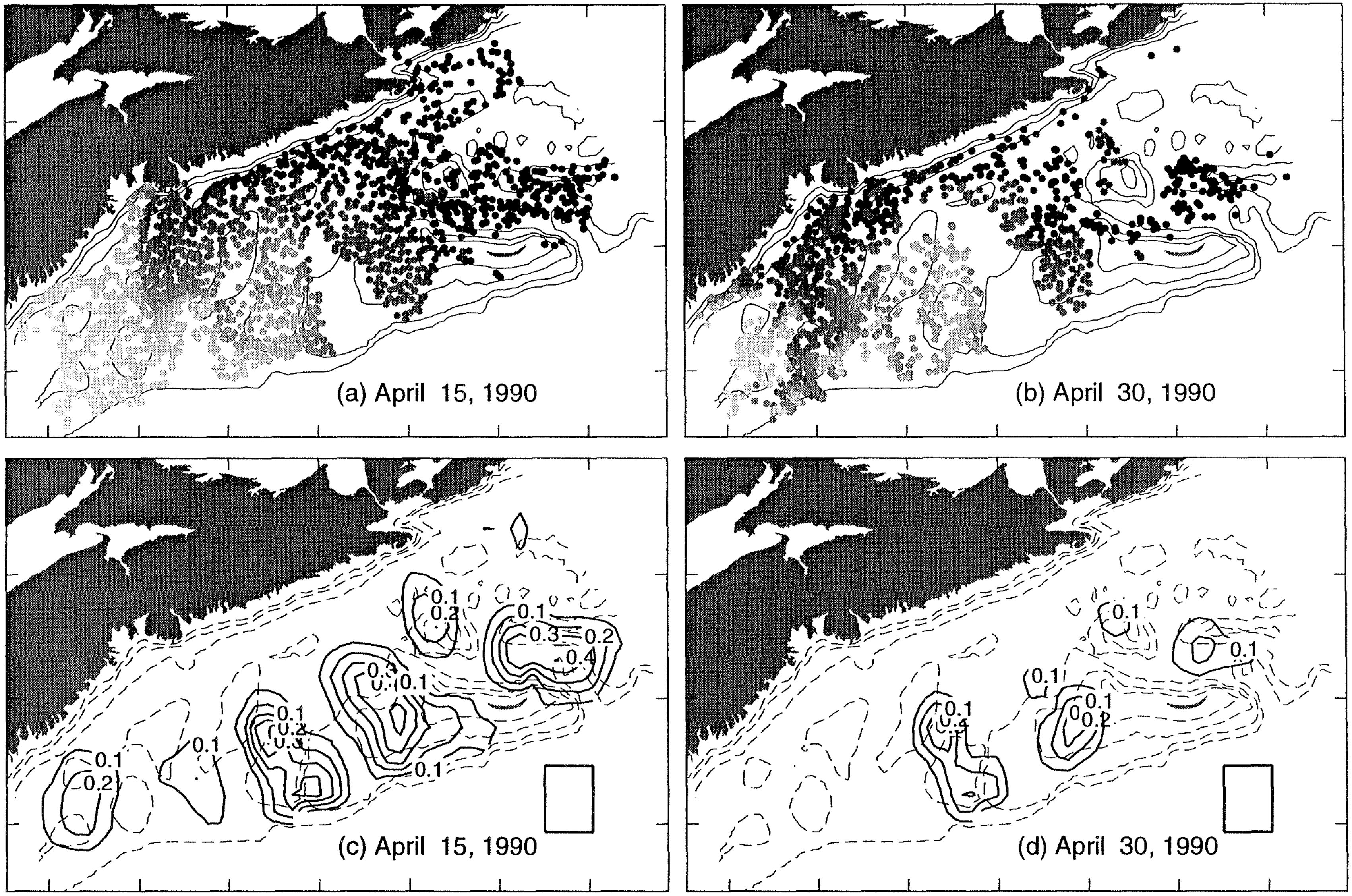

Figure 38.3: Dispersion in April 1990. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

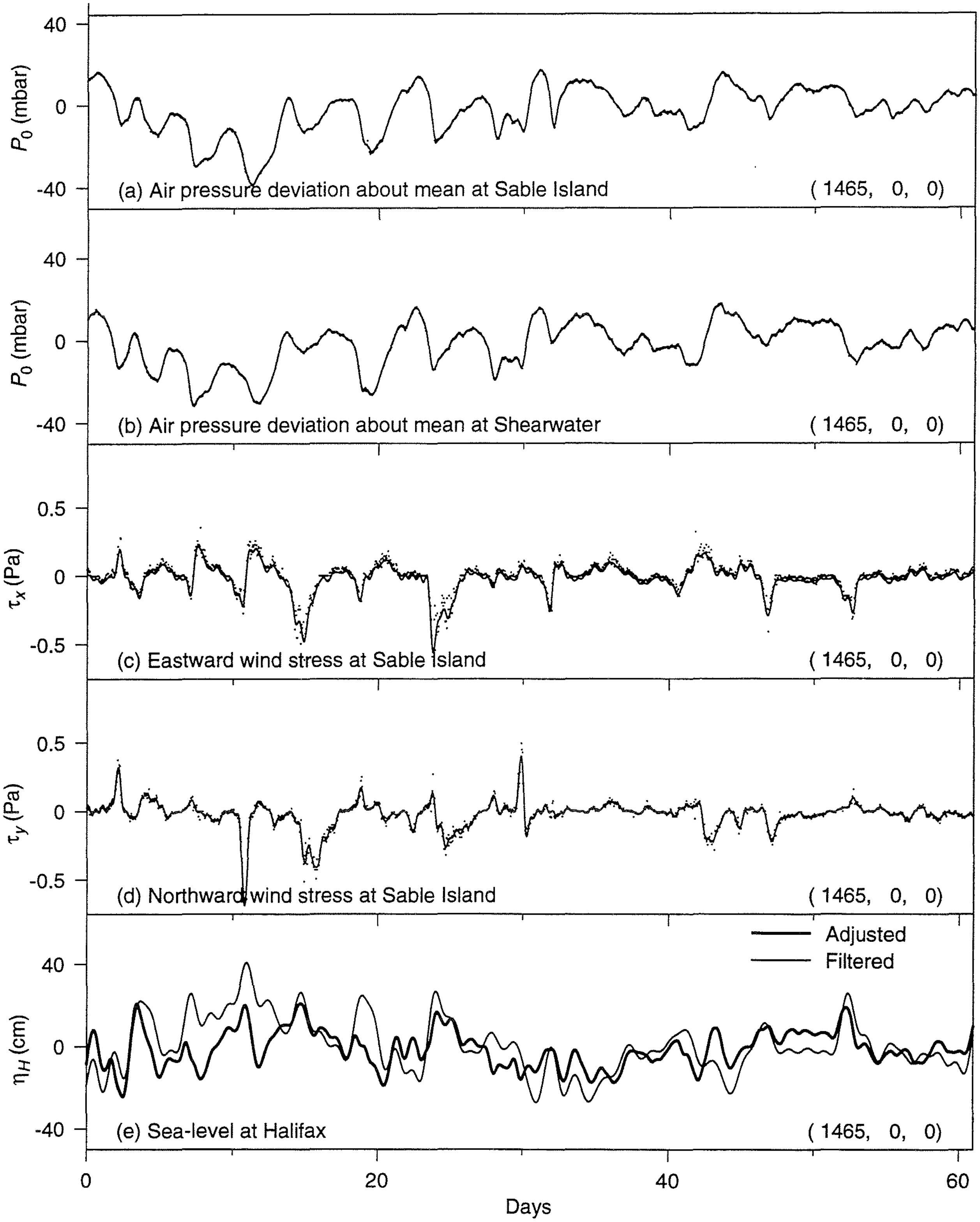

Figure 39.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1991). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

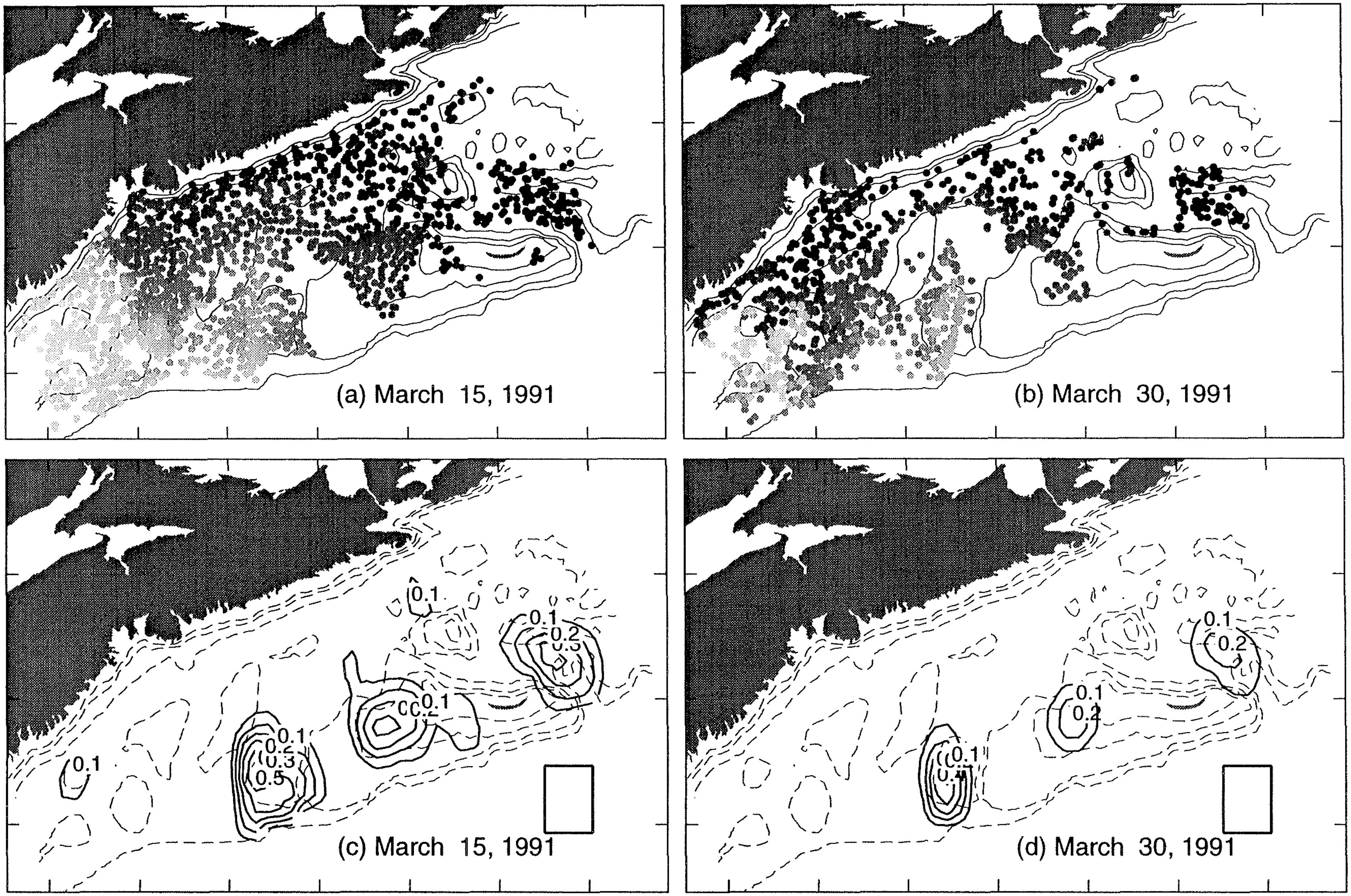

Figure 39.2: Dispersion in March 1991. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

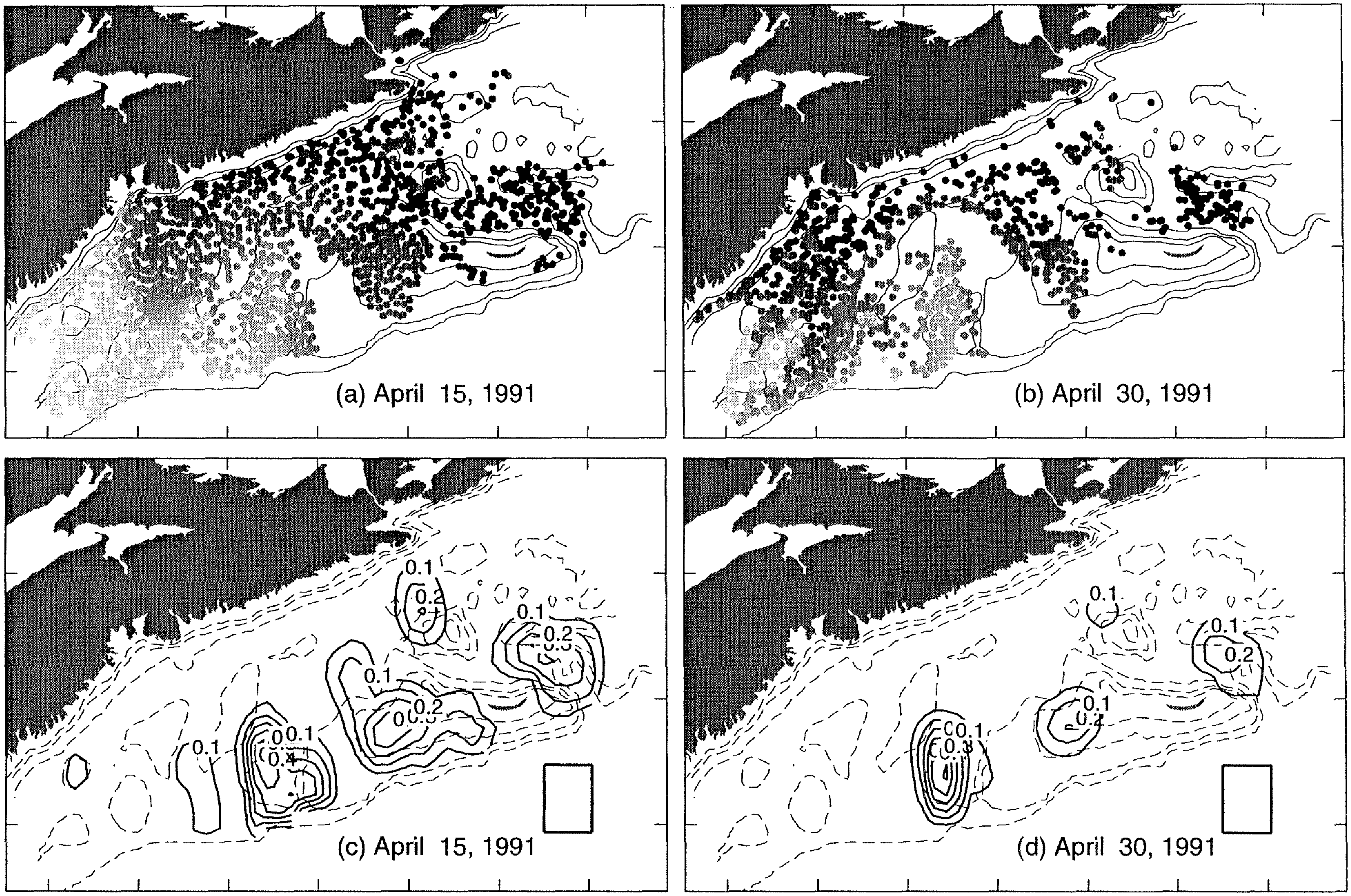

Figure 39.3: Dispersion in April 1991. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

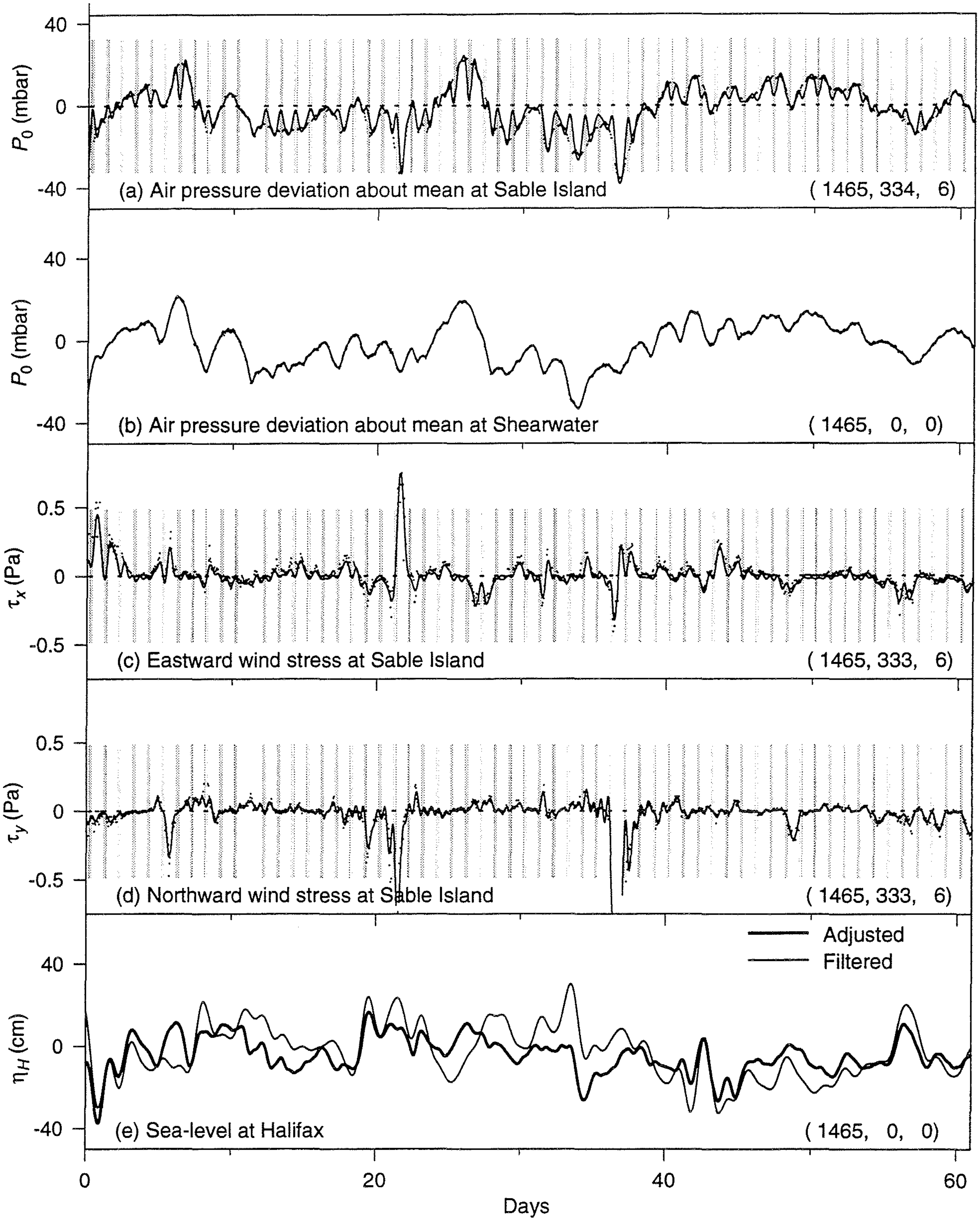

Figure 40.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1992). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

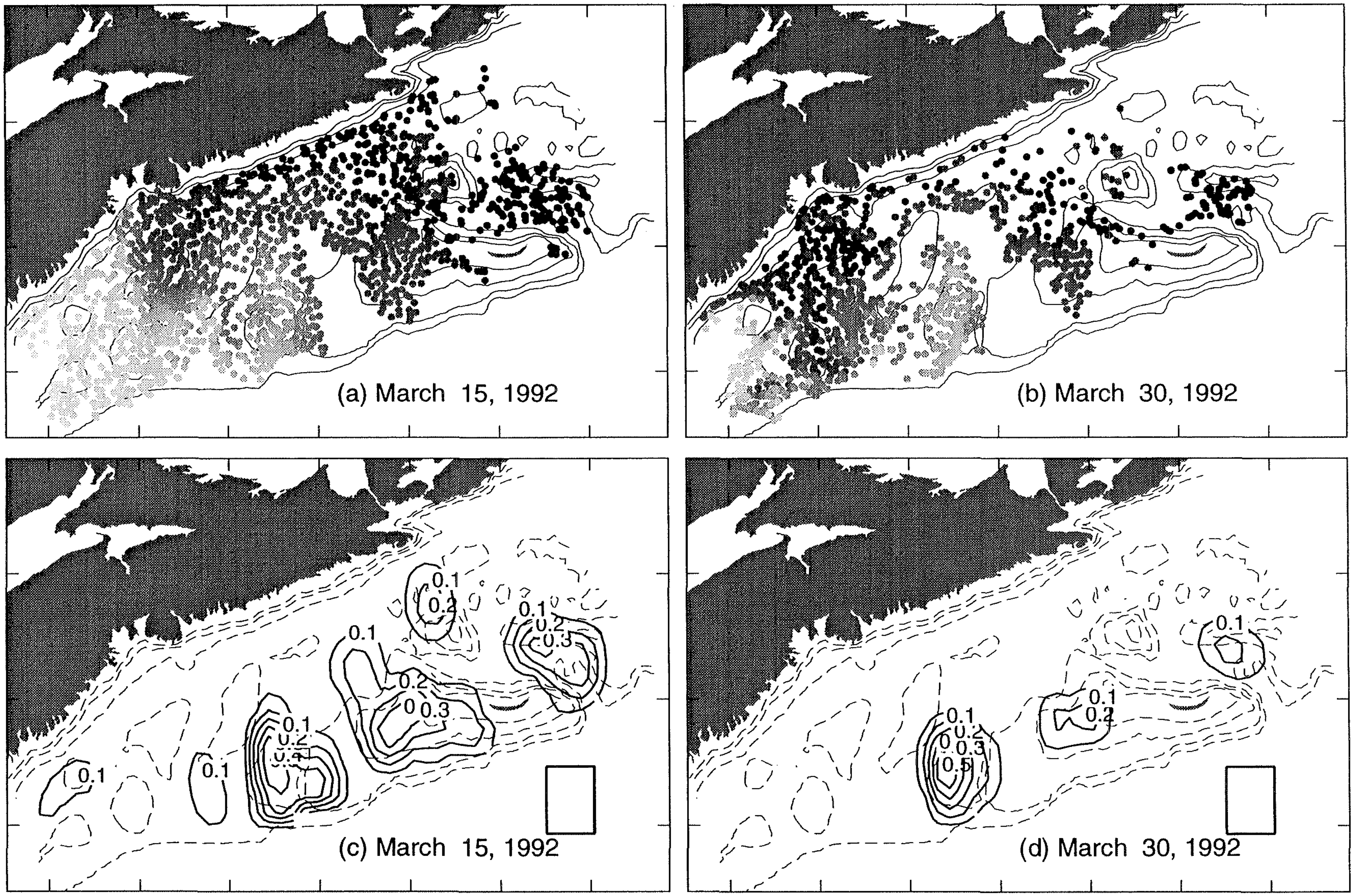

Figure 40.2: Dispersion in March 1992. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

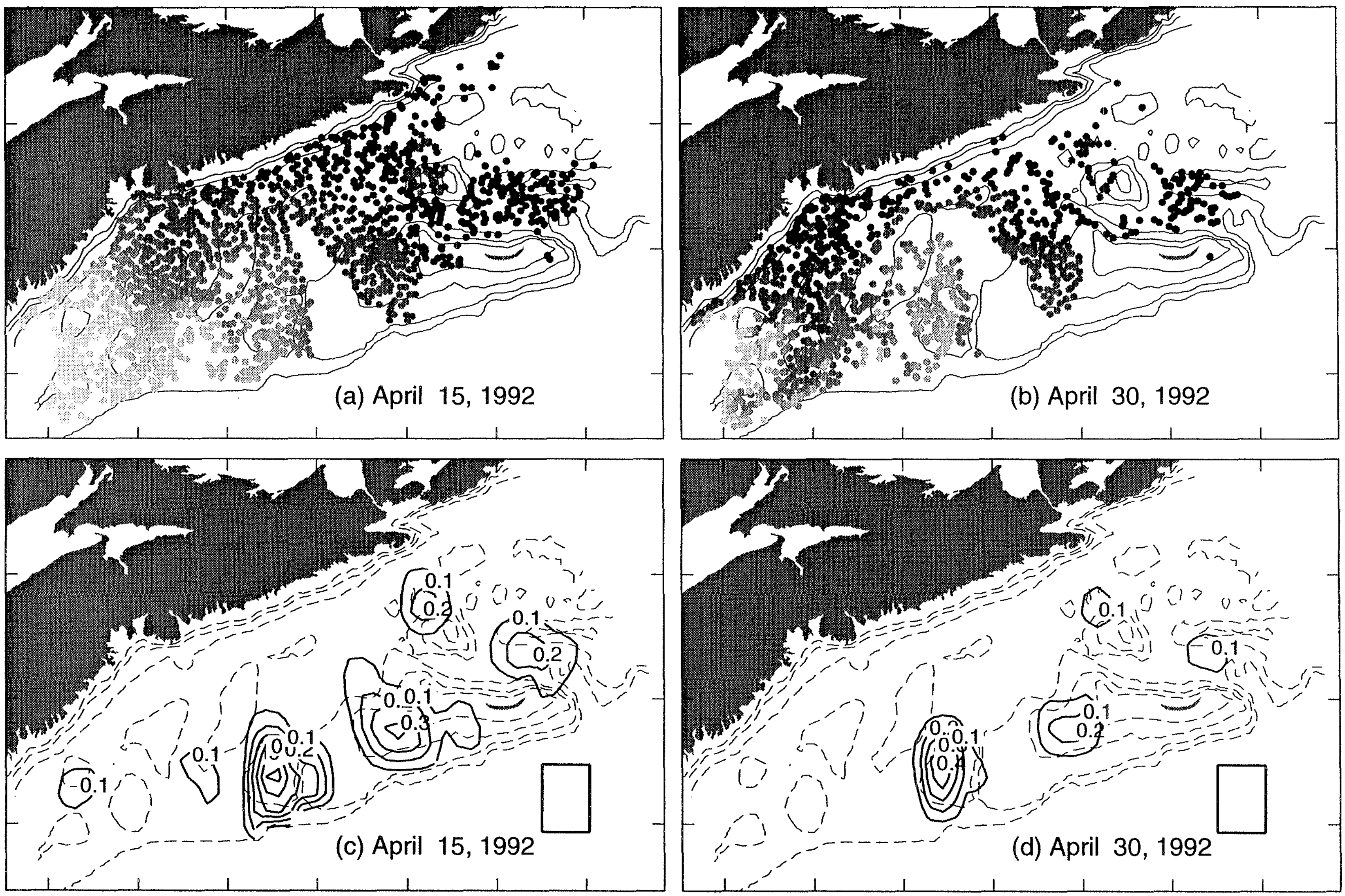

Figure 40.3: Dispersion in April 1992. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

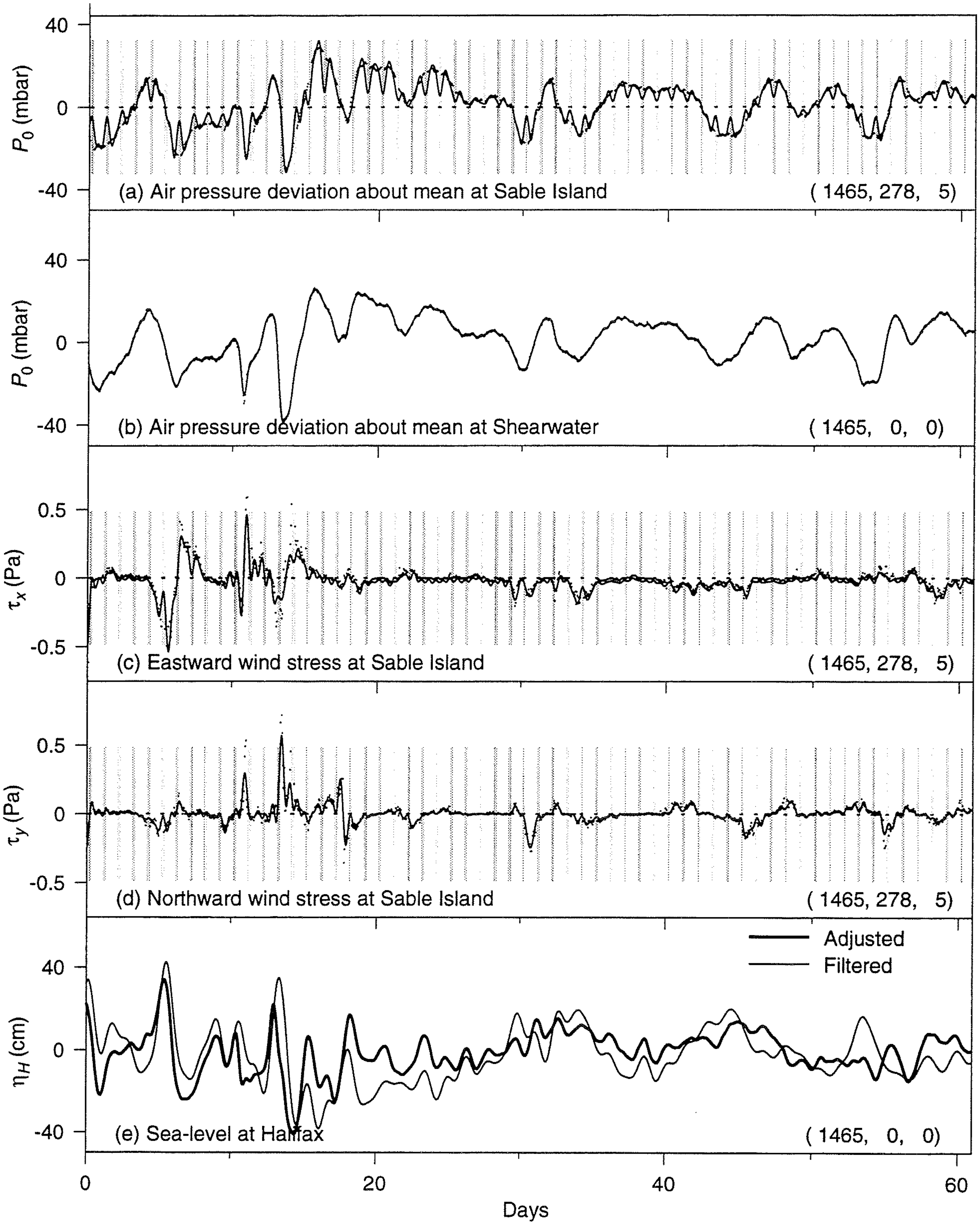

Figure 41.1: Time series of air pressure, wind stress and coastal sea-level (1 March to 1 May 1993). The 3 numbers in brackets give (i) total number of hourly data points; (ii) number of missing points; (iii) number of points in the longest gap.

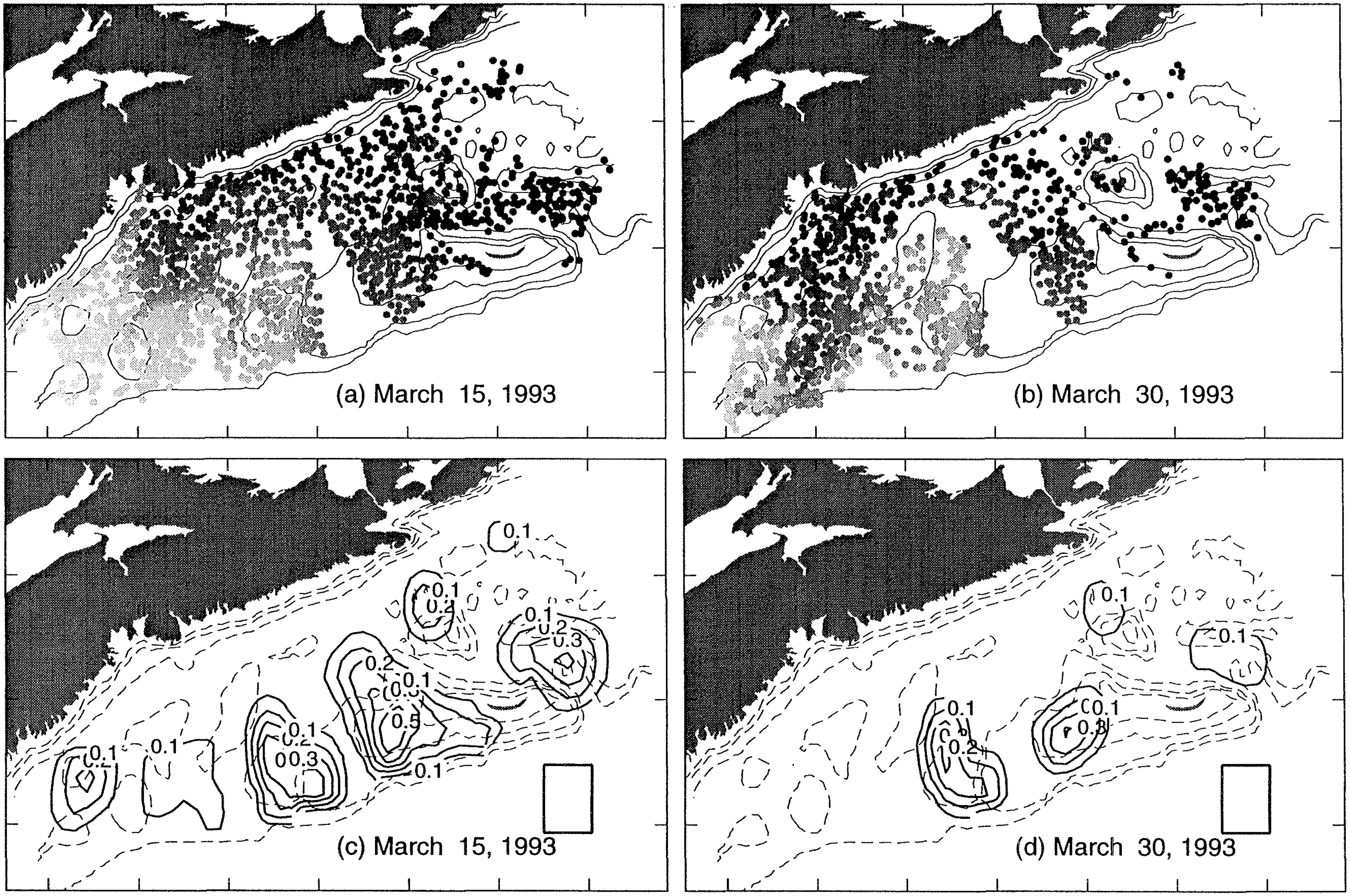

Figure 41.2: Dispersion in March 1993. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

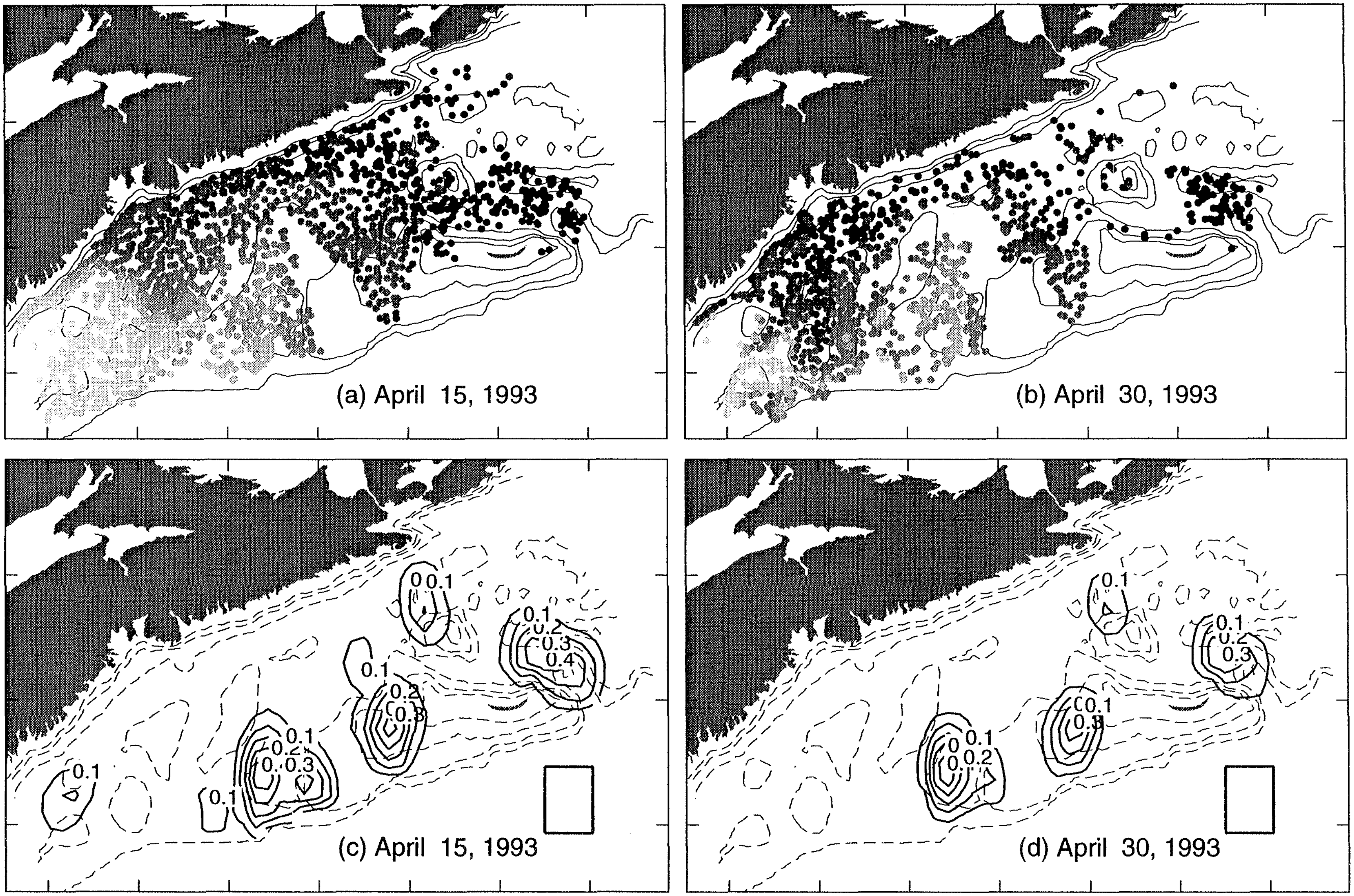

Figure 41.3: Dispersion in April 1993. (a) Positions of particles, shaded with different intensities in gray, indicating positions after 15 days; (b) Positions of particles after 30 days; (c) Retention index showing the proportion of particles remaining in a box of given size (see bottom right corner) after 15 days; (d) Same as (c) but after 30 days.

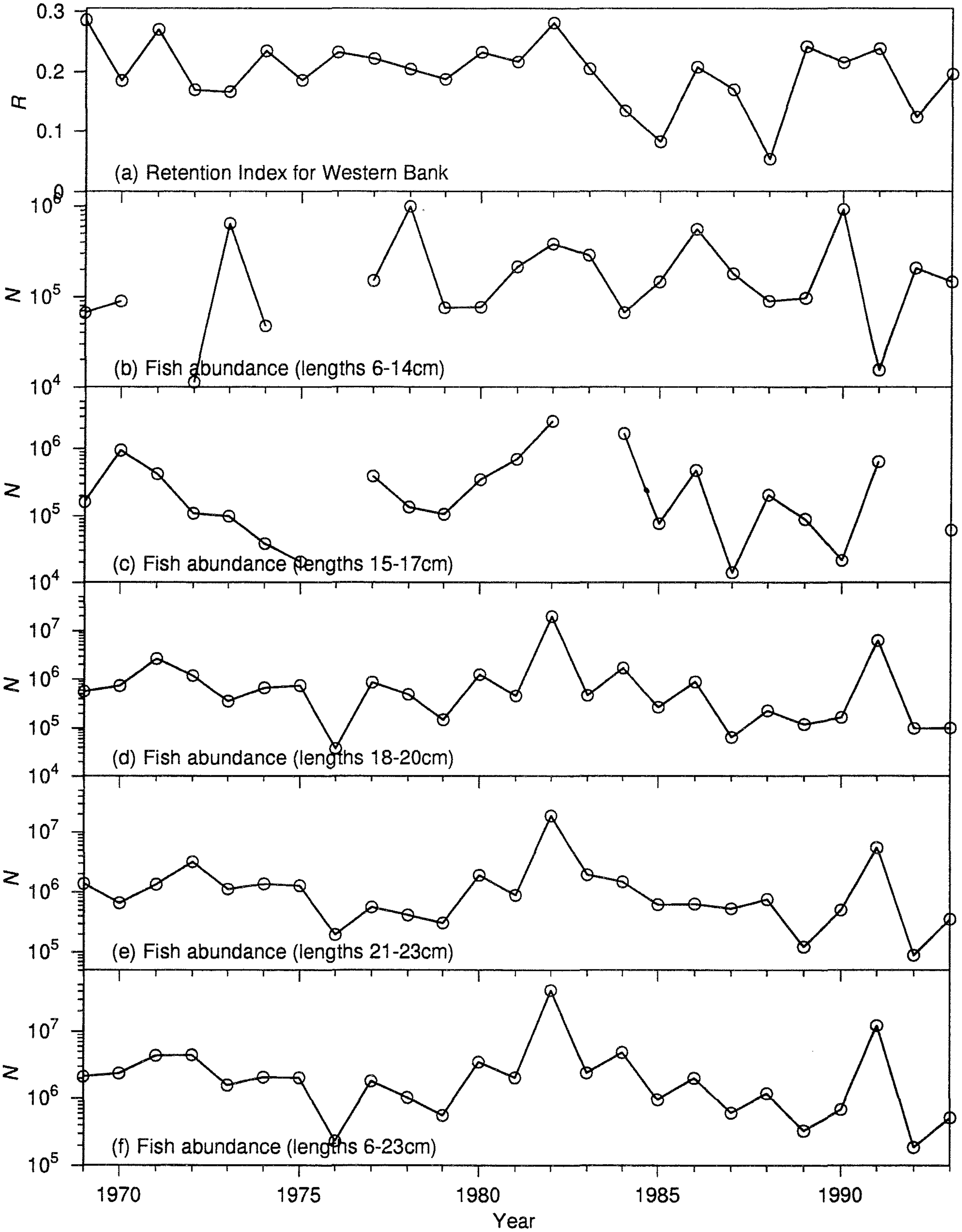

Figure 42: Retention of particles and cod abundance on Western Bank (1969 - 1993). (a) Retention index R from 1 April to 25 April; (b) Abundance of fish of lengths 6-14cm on Western Bank; (c) through (f) Same as (b) but for different length classes.