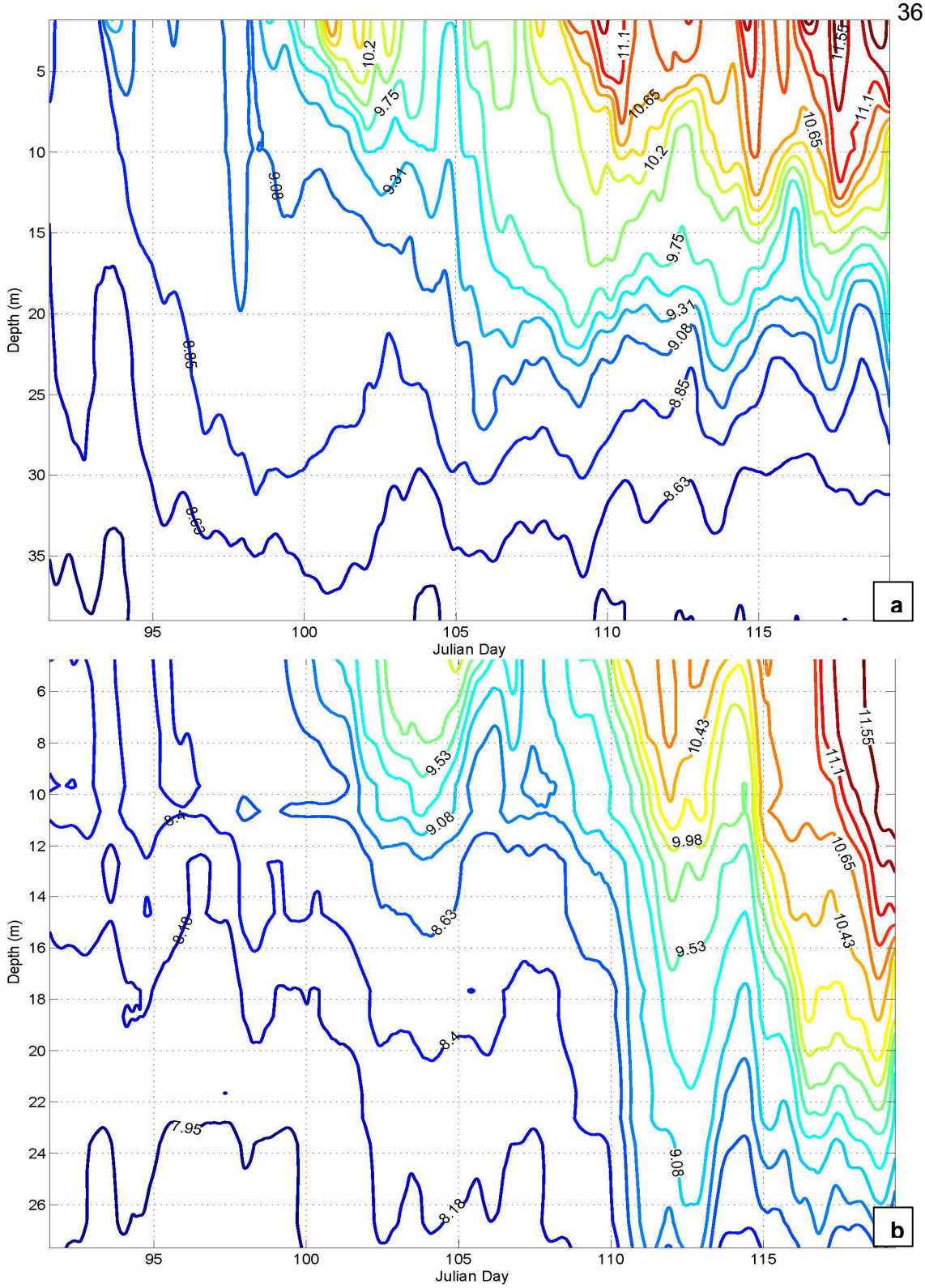

Figure 1. 21. April 2003 temperature contours at SR520 (a) and SWA (b). Isotherms occur at about 0.23 °C intervals.

For the north-south velocity at MWY (Figure 1. 18c), the first mode eigenvector is characteristic of the first vertical mode for a seiche and explains 56% of the total velocity variance (Table 1. 6). The zero crossing indicates the maximum temperature gradient is near 22 meters (Figure 1. 18c). Isotherm dynamics indicate a first horizontal mode seiche (Figure 1. 21). Between JD 105 and 110, isotherms upwell at SWA and down well at SR520 and from JD 110 to 115 isotherms upwell at SR520 and down well at SWA. After JD 115, a large down well occurred (11 meters) at SWA and a minor upwell occurred (4 meters) at SR520. These observations are characteristic of a first mode horizontal seiche (Figure 1. 11). For a first mode vertical and first mode horizontal seiche (V1H1), isotherm displacement will be zero near the center of the lake and greatest near the end of the lake. SR520 is close to the center of the lake and SWA is near the end of the lake (Figure 1. 3); therefore, isotherm displacement will be greater at SWA compared to SR520.

Table 1. 6 Percent of total variance explained by each PCA mode for temperature and north-south velocity component at each station for April 2003.

Station	Mode 1	Mode 2	Mode 3	Combined Variance for the Three Modes	Percent Water Column Covered by Instrument
SR520	38	27	13	78	61
SWA	67	11	10	88	77
MWYVN	56	21	8	85	69

At SR520 and SWA, the first mode temperature eigenvectors show variance decreases with depth, not the sub-face maximum expected for oscillations about the density interface shown in Figure 1. 15. The profiles could represent surface heating or surface upwelling of the density interface. At SR520, surface temperatures increased in the upper 20 meters starting near JD 100 and similar surface heating occurred at SWA (Figure 1. 21); however, upwelling also occurred at the two locations. At SR520, upwelling occurred near JD 105 and to a smaller extent near JD 112. Upwelling was more significant at SWA. A significant upwelling event occurred between JD 105 and 110 and another event occurred near JD 114. The first mode temperature eigenvector contains information about surface heating and the V1H1 seiche; V1H1 significance is strengthened when the expansion coefficients are analyzed.

At SR520, second vertical mode dynamics are almost as important as the first vertical mode; the second mode explains 27% of the total velocity variance (Table 1. 6). The eigenvector indicates maximum variance occurred between the 15 and 20-meter depth, which is present in the isotherms (Figure 1. 18). Second mode features are visible between the 8.85 and 9.08 ^{o}C isotherms for JD 98 to 105 (Figure 1. 19a and Figure 1. 21a). Second vertical mode features at SWA are very small (11%) compared to the first vertical mode (67%) and are not apparent in the isotherms.

The first mode expansion coefficients represent density perturbations extracted from the average density series (Figure 1. 22). As noted earlier, the density perturbations are 180° out of phase between SR520 and SWA. If this phase difference were from surface heat flux, then one end of the lake would cool while the other end warms. This differential heating and cooling would have to arise from atmospheric conditions or heat flux from the Cedar or Sammamish Rivers. Heat from the Cedar River is shown to be insignificant in section 1.3.7. Atmospheric conditions would have to vary over a scale of 10 km, which is an order of magnitude smaller than typical weather patterns (100 – 5000 km, Benoit and Cushman-Roisin, 1994). Also noted earlier at SR520 and SWA, upwelling occurred at one station while down welling occurred at the other. Upwelling at SWA will create cooler temperatures while the corresponding down welling at SR520 will create warmer temperatures. The first mode temperature expansion coefficients response described these opposing temperature (density) perturbations, which is corroborated by isotherm displacements. Therefore, the first mode temperature eigenvectors must describe a first mode vertical and first mode horizontal type seiche. Seasonal surface warming is superimposed on top of the V1H1 seiche but was removed when the temperature series were de-trended before performing the PCA.

The first mode temperature eigenvectors and expansion coefficients represent the observed density perturbations at SR520 and SWA for year 2003. At MWY, 56% of the north-south velocity variance can be characterized by a first vertical mode seiche, 67% of the temperature variance at SWA can be characterized by a first vertical mode seiche, and the isotherm's response can be characterized by a first horizontal mode seiche. Thus, isotherm response can be characterized by a V1H1 seiche with some second vertical mode and first horizontal mode V2H1

characteristics present near the central part of the lake. This second mode character could result from the floating bridge. Wind-setup of the free water surface could depress the isotherms below or internal waves could propagate off the bridge.

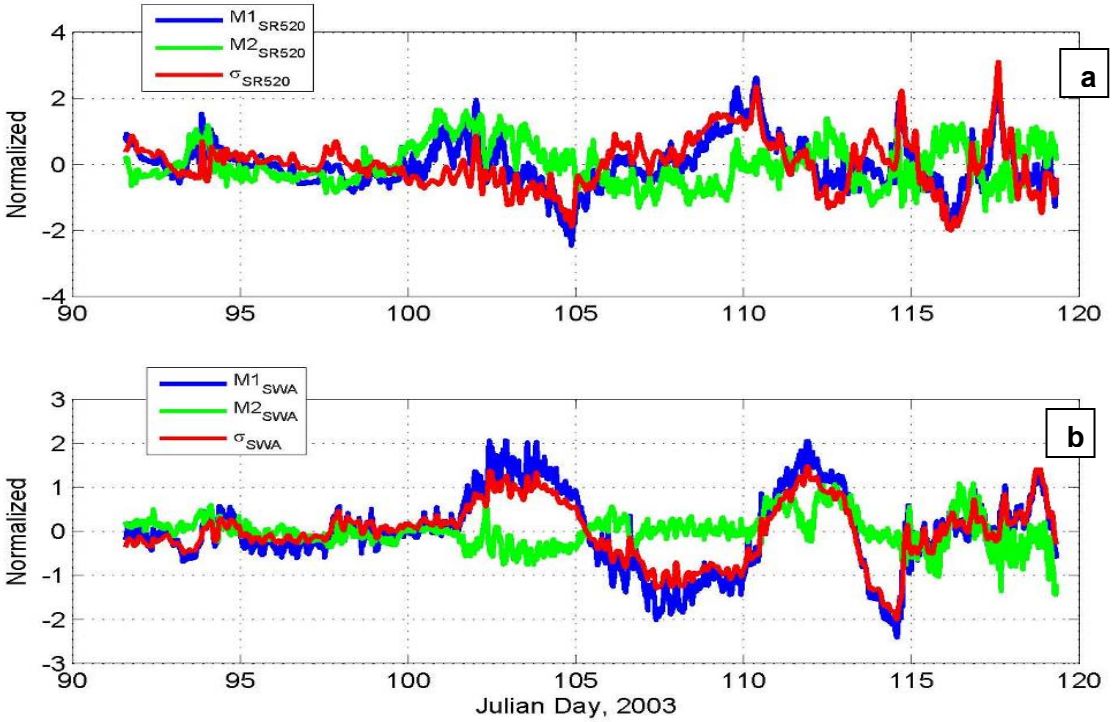

Figure 1. 22. First (blue) and second (green) mode expansion coefficients plotted against density perturbations (red) shown in Figure 1. 17b. The series have been scaled for better presentation. SR520 is (a) and SWA is (b).

1.3.1.2 March 2004 Observations

For the NOA, MWY, and SWA temperature arrays, data was interpolated to a common depth interval and the average density was determined (Figure 1. 23a). At NOA, the average density time series was less than the average density at MWY and SWA for Julian Days: 62 to 71, 74 to 92, and 102 to the end. Each time series was de-trended using a fitted curve and density perturbations were determined by subtracting the fitted curve from the average density (Figure 1. 23b). The SWA density perturbations are 180° out of phase with the NOA density perturbations; MWY tends to lie between NOA and SWA. This response is consistent for a horizontal internal seiche for an odd-numbered mode (first mode, third mode, fifth mode, etc.).

Eigenvectors for temperature are presented in Figure 1. 24 and percent of total variance is given in Table 1. 7. In 2004, the first mode temperature eigenvectors

contain much more information compared to the 2003 observations: 74% at NOA compared to 38% at SR520, 83% at SWA compared to 67%, and 55% at MWY (Table 1. 6 and Table 1. 7). Subsurface maximums are present in the NOA (18 (m)) and MWY (16 to 19 (m)) eigenvectors (Figure 1. 24a and b), which is consistent with oscillations about the density interface (Figure 1. 15). At SWA, variance decreases with depth and suggests surface heating or upwelling of the density interface may occur (Figure 1. 24c). The first mode expansion coefficients have greater amplitude than the second mode at NOA and SWA (Figure 1. 25a and c), and the first mode describes the density perturbations (Figure 1. 26). As in the 2003 observations, the NOA and SWA density perturbations are 180° out of phase, which is unlikely to result from spatial differences in atmospheric conditions.

Table 1. 7 Percent of total variance explained by each PCA mode for temperature and north velocity component at each station for March 2004.

Station	Mode 1	Mode 2	Mode 3	Combined Variance for the Three Modes	Percent Water Column Covered by Instrument
NOA	74	14	5	93	57
MWY	55	26	7	88	41
SWA	83	11	3	97	77

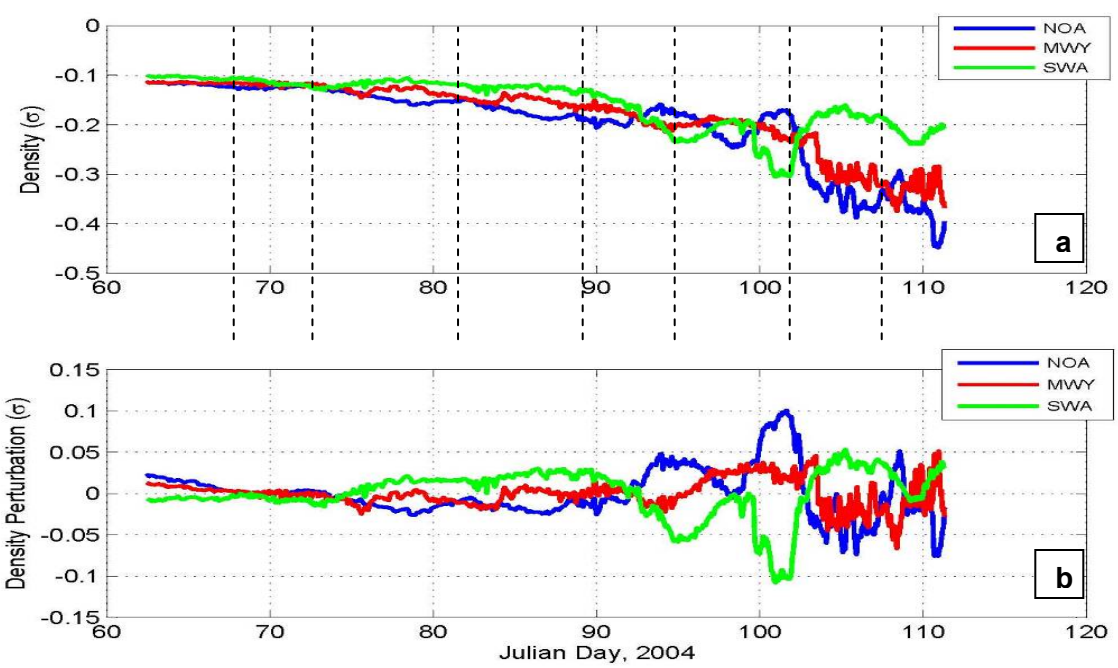

Figure 1. 23. March 2004 time series of the averaged density (a) (σ=ρ-1000 (kg/m^3)) at NOA, MWY, and SWA and the corresponding density perturbation (observed less trend) (b). Temperature readings were interpolated to a common depth interval between the three locations. Vertical dashed lines represent periods defined in section three.

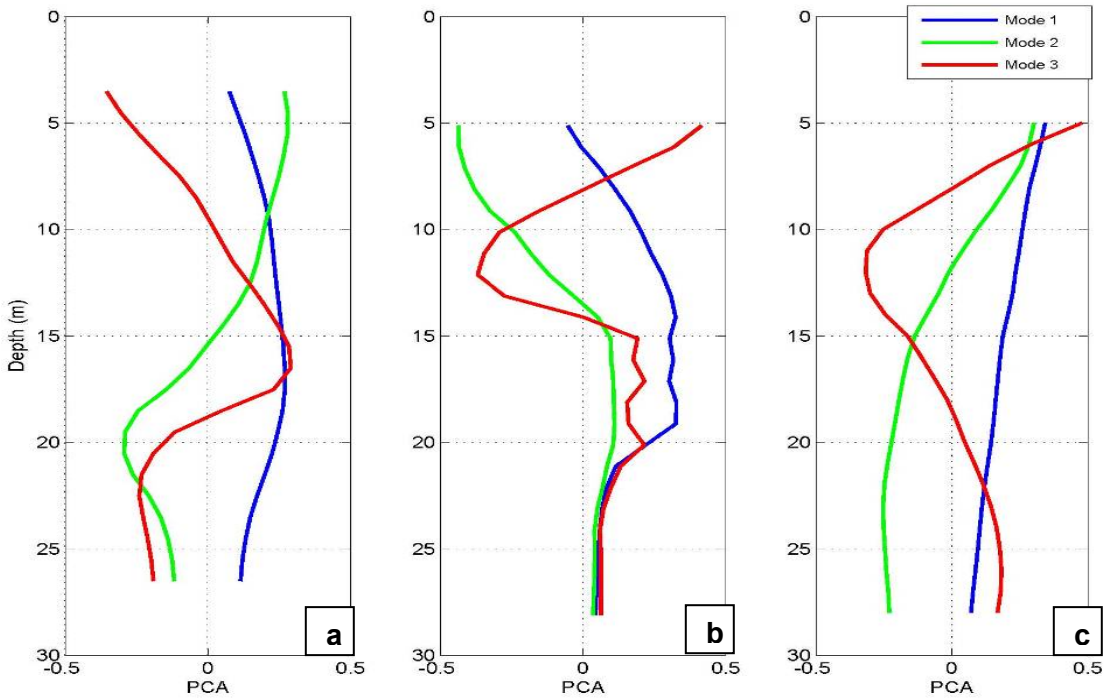

Figure 1. 24. March 2004 eigenvector modes for temperature at NOA (a), MWY (b), and SWA (c). Percent of variance for the dominant modes are given in Table 1. 7.

Isotherm displacement at NOA and SWA opposed each other and was observed near JD 95, 100, 105, and 109 (Figure 1. 27). The same pattern is observed in the density perturbations and the first mode expansion coefficients (Figure 1. 26). The opposing displacements at NOA and SWA and the mild displacement at MWY are indicative of a first mode horizontal internal seiche (Figure 1. 11b). At SWA, upwelling occurred near JD 77, 90, 98, 105, and 111 with concurrent down welling at NOA. At NOA, a mild upwelling occurred near JD 85 and a stronger upwelling occurred near JD 100. The more prevalent upwelling at SWA will produce greater near-surface variance compared to NOA; this condition was observed in the corresponding first mode eigenvectors. The eigenvector at SWA represents upwelling of a first vertical mode type internal seiche, and the eigenvector at NOA is characteristic of a first vertical mode type internal wave with infrequent upwelling. The first mode eigenvectors and expansion coefficients represent a V1H1 type internal seiche response.

The isotherm analysis revealed that the dynamics of the lake were determined by a V1H1 type internal seiche response; a weaker V1H1 response occurred in year 2003 compared to year 2004. The V1H1 type response suggests the Wedderburn

Number would be appropriate for determining the dynamic response between isotherm tilt and surface wind stress.

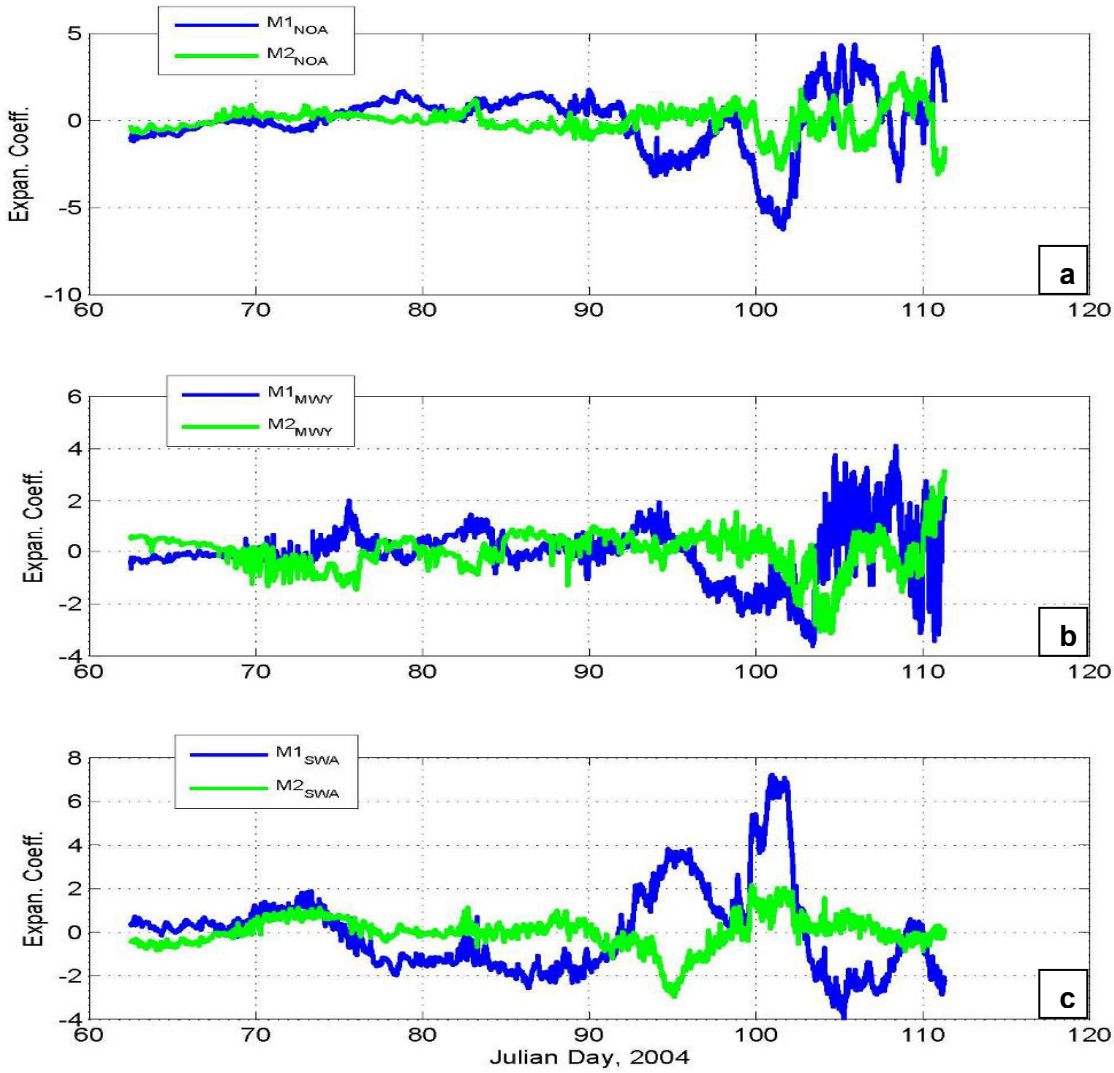

Figure 1. 25. March 2004 expansion coefficients for the first and second mode eigenvectors presented in Figure 1. 24. NOA is (a), MWY is (b), and SWA is (c).

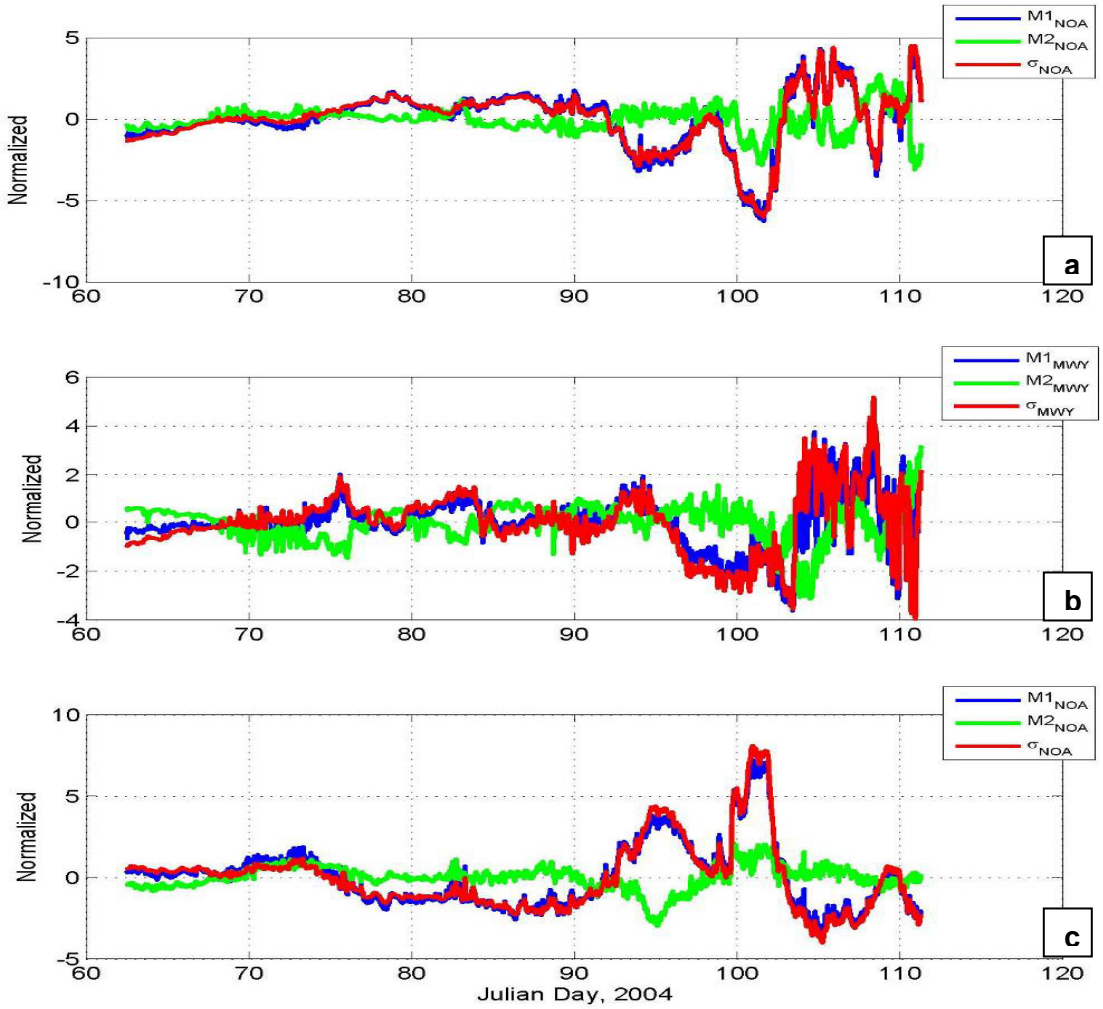

Figure 1. 26. First (blue) and second (green) mode expansion coefficients plotted against density perturbations (red) shown in Figure 1. 23b. The series have been scaled for better presentation. NOA is (a) and MWY is (b), and SWA is (c).