Data Repository Item 2006059

APPENDIX

Sources of Data for Vertical Velocity Computation

Vertical velocities of benchmarks relative to NAVD88 were calculated using the methods described in Shinkle and Dokka (2004). This involved the integration of several epochs of 1st order geodetic leveling data, as well as the relative sea level rise recorded at the long-standing tide gauge at Grand Isle, LA (East Point), and the global eustatic sea level rise. These latter two components were used to establish a linkage to the North America Vertical Datum of 1988 (NAVD88). Data and information regarding leveling data can be obtained at from the National Geodetic Survey at www.ngs.noaa.gov. A summary of leveling data sources and error constraints are provided below in Table DR1. Tide gauge data from Grand Isle, LA are available from the National Ocean Service www.nos.noaa.gov. Analysis of data from this tide gauge is provided in Shinkle and Dokka (2004). The vertical velocities cited in this paper (Table DR2) differ slightly from Shinkle and Dokka (2004) in that here a consensus value of 2.0 mm/yr for eustatic sea level rise is used (Miller and Douglas, 2004). Shinkle and Dokka (2004) used a value of 1.25 mm/yr that corresponded to the mean of the largest mode of rise estimates.

An additional leveling survey was conducted by Mr. Blake Amacker, Mr. Jordan Heltz, Mr. Clifford Mugneir, Mr. Imtiaz Hossain, and Dr. Roy K. Dokka of the Louisiana Spatial Reference Center to determine if differential motion along the Michoud fault was continuing as of January 05, 2005. Four benchmarks (BH1104, BH1096, BH1084, and BH1083) were surveyed using the same 1st order methods employed during the collection of the NGS data. BH1104 and BH1096 occur in the fault's footwall, whereas BH1084 and BH1083 are situated in the hanging wall. Additional NGS 1st order leveling surveys from 1985 (NGS Line L24903-2) and 1990 (NGS Line L25283-1) were included in this analysis. Each survey was indexed to BH1104 (set to 0 mm). The results are shown in Figure 3 and Table DR3 and suggest that motion along the Michoud fault likely ceased between 1995 and 2005.

Error Analysis

In order to relate changes in height differences revealed by leveling to a common datum, Shinkle and Dokka (2004) referenced each leveling epoch, i.e., survey, to the same benchmark (AT0688) located adjacent to the tide gauge. It was assumed that changes in elevation at that NAVD88 benchmark over time were equal to the relative sea level rise recorded by the tide gauge minus the eustatic component (Shinkle and Dokka, 2004). This seems reasonable considering that the tide gauge is longstanding (>20 years) and generally the product only by marine influences (Shinkle and Dokka, 2004). All changes revealed by leveling in the region were related to that single benchmark where its elevation could be established at any time in the context of NAVD88. Thus, assessment of the total maximum error (σ_{total}) at benchmarks in the study area relative to NAVD88 would involve the estimation of the uncertainties associated with each component measurement: the vertical displacement implied by pairs of leveling runs separated by a known time span (l), the vertical displacement at the point of beginning located at the water level gauge at Grand Isle-East Point (g), and the eustatic (e) sea level change. Uncertainties were estimated by calculating the error for each constituent measurement and then combining them according to the general law of error propagation (e.g., Borradaile, 2003). The combined uncertainty is expressed by,

$$\sigma_{total} = ((\sigma_e)^2 + (\sigma_g)^2 + (\sigma_l)^2))^{1/2} \qquad (1)$$

Uncertainties associated with leveling are due to random and systematic errors accumulated along the entire line of survey (e.g., Vanicek et al., 1980). Analyses of leveling errors are not benchmark specific, but instead reflect the integrity of the survey line as a whole. The geodetic leveling data used here are classified as 1st order, class II or better by the National Geodetic Survey/NOAA, and thus have passed stringent quality and accuracy requirements (Bossler, 1984). The high precision of 1st order leveling is due in large part to the exacting procedures that help minimize systematic and random error accumulation (e.g., Vanicek et al., 1980). For data to be classified as 1st order, class II, the maximum propagated standard deviation of elevation difference in millimeters (σ_l) between survey control points obtained from the least squares adjustment can be stated as,

$$\sigma_l = 0.7 * (b)^{1/2} \qquad (2)$$

where b is defined as the elevation difference accuracy. The elevation difference accuracy is the relative elevation error between a pair of control points that is scaled by the square root of their horizontal separation traced along existing level routes; the units of b are (mm)/ $\sqrt{d}$ (km), where d is the length of the leveled line. Starting with zero error at the point of beginning, progressive measurements result in the accumulation of error along the line, reaching a maximum at the end of the line. Because error accumulates and increases along the length of a leveling line, the error on an individual benchmark can be estimated based on its distance from the starting point along the level line. Table DR1 shows the error statistics for all level lines presented in this paper.

Uncertainties associated with the water level gauge also include the error related to the estimation of eustatic sea level rise. Recent consensus hydrographic and satellite altimetry estimates put the mean global increase in sea level at 1.5-2.5 mm/yr (Miller, and Douglas, 2004). If we equate this range to a 2 sigma estimate, then the standard deviation of the estimate of this component is ±0.50 mm/yr = σ_e. The standard error of the regression of the monthly mean sea levels for the Grand Isle-East Point tide gauge is ±0.97 mm/yr = σ_o (Shinkle and Dokka, 2004). Table DR2 provides 2σ errors for each benchmark velocity in the study.

Errors associated with the vertical displacements computed over the short level lines that straddle the trace of the Michoud fault (Fig. 3) are provided in Table DR3. The smaller uncertainties reflect the short distance between endpoints of the surveys (3.755 km). Because in this case only local relative movements adjacent to the Michoud fault were of interest, only errors associated with leveling were included.

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TABLE DR1. NATIONAL GEODETIC SURVEY/NOAA LEVELING DATA SOURCES USED TO COMPUTE VELOCITIES OF BENCHMARKS IN MICHOUD AREA*

Time interval (NGS lines used)	Number of Common Benchmarks	Length of Common Line (km)	Starting/Ending Benchmarks[†]	Maximum σ for two lines (mm)[§]	Maximum σ of Vertical Velocities (mm/yr)**
1955-1969 (L15414/A -L21664/2)	118	131.3	BH0398/AU0413	11.34	0.81
1969-1971 (L21664/2-L22314)	223	144.9	BH0848/AU0520	11.90	6.22
1971-1977 (L22314-L24133/21)	118	85.7	BH1193/AU0413	9.20	1.43
1971-1977 (L22314-L24133/22)	109	66.3	BH0397/BH1194	8.1	1.20
1971-1977 combined (L22314- L24133/21 & L24133/22)	227	158.2	BH0397/AU0413	12.45	1.92
1977-1995 (L24133/21- L25424/2)	61	57.0	BH1167AU0413	7.47	0.43

*Leveling data from National Geodetic Survey/NOAA.
[†]National Geodetic Survey permanent identifier code for benchmarks
[§] Describes the maximum standard deviation over the entire double run for two lines allowable under NGS 1st order class 2 specifications.
**Estimated value of two standard deviation uncertainty of relative vertical velocity that could have accumulated along the line.

TABLE DR2. VERTICAL VELOCITIES COMPUTED ON BENCHMARKS OF THE MICHOUD, LA AREA*

PID[†]	Location		Distance from BH1106 (km)[§]	Vertical velocity (mm/yr)								Benchmark attached to:**
	Latitude (ºN)	Longitude (ºW)		1955-1969	±2s	1969-1971	±2s	1971-1977	±2s	1977-1995	±2s	
BH1106	30.055	89.876	0			-10.60	6.19	-4.39	3.79	-6.31	2.89	headwall
BH1104	30.052	89.88	0.43			-10.41	6.19	-4.27	3.79	-5.95	2.89	headwall
BH1102	30.044	89.893	1.94	-8.81	3.03	-14.44	6.18	-5.05	3.79	-9.52	2.89	headwall
BH1096	30.034	89.909	2.9	-9.94	3.03	-16.25	6.18	-7.40	3.79	-10.57	2.89	0.1
BH1095	30.035	89.909	4.07					-15.92	3.78	-16.11	2.88	concrete post
BH1094	30.035	89.909	4.09					-11.13	3.78	-13.85	2.88	concrete post
BH1092	30.029	89.915	4.66					-18.83	3.78	-18.01	2.88	0.1
BH1088	30.026	89.911	4.81			-24.02	6.17	-13.53	3.78			well, -170m
BH1087	30.027	89.917	4.97	-13.98	3.03	-23.00	6.16	-14.18	3.78	-15.25	2.88	rod, -2m
BH1090	30.024	89.914	5.67			-19.62	6.16	-10.52	3.78			well, -176m
BH1089	30.023	89.913	5.82			-16.88	6.16	-7.14	3.78	-11.41	2.88	well, -2011m
BH1091	30.022	89.916	6.17			-20.73	6.16	-11.08	3.78			well, -178m
BH1084	30.017	89.932	7.77			-39.36	6.15	-26.04	3.77	-19.93	2.88	rod, -24m
BH1083	30.011	89.939	8.67			-39.08	6.14	-19.97	3.77	-16.61	2.88	concrete pier
BH1076	30.015	89.949	9.67			-35.44	6.14	-22.93	3.77	-17.43	2.88	building
BH1073	30.014	89.967	11.67	-16.15	3.02	-32.06	6.13	-18.93	3.76	-15.33	2.87	concrete post
BH1071	30.013	89.978	12.37			-41.73	6.12	-23.02	3.76	-15.02	2.87	concrete post
BH1067	30.013	89.991	13.17			-24.13	6.12	-12.27	3.76	-14.70	2.87	rod, -9.8m
BH1065	30.013	89.996	13.67			-28.03	6.12	-22.12	3.76	-15.06	2.87	concrete post

Note: Motions relative to North American Vertical Datum of 1988. Data form basis of Figure 2. The Michoud fault occurs between BH1091 AND BH1084.
*Methods based on Shinkle and Dokka (2004). See Table DR2 for sources of data and analysis of errors.
[†]Permanent identifier (PID) of benchmark (National Geodetic Survey/NOAA).
[§]Benchmarks are aligned approximately from ENE (BH1106) to WSW (BH1065).
**Information from NOAA data sheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl)

TABLE DR3. CUMULATIVE DISPLACEMENTS (MM) OF SELECTED BENCHMARKS ACROSS THE MICHOUD FAULT RELATIVE TO BENCHMARK BH1104 SINCE 1969

Year*	BH1083	±2σ	BH1084	±2σ	BH1096	±2σ	BH1104	±2σ	BH1084-BH1096	±2σ
1969	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1971	-54.940	3.837	-55.480	3.578	-11.190	2.669	0.000	0.000	-44.290	1.386
1977	-155.710	3.837	-195.210	3.578	-31.270	2.669	0.000	0.000	-163.940	1.386
1985	-260.770	3.837	-340.420	3.578	-75.900	2.669	0.000	0.000	-264.520	1.386
1990	-317.140	3.837	-406.970	3.578	-102.680	2.669	0.000	0.000	-304.290	1.386
1994	-342.220	3.837	-439.800	3.578	-112.160	2.669	0.000	0.000	-327.640	1.386
2005	-401.285	3.837	-444.380	3.578	-147.330	2.669	0.000	0.000	-297.050	1.386
Distance from BH1104 (km)	3.755		3.266		1.817		0.000		1.449	

*Leveling data from National Geodetic Survey/NOAA. 1969, line L21664/2; 1971, line L22314; 1977, line L24133/21; 1985, line L24903/2; 1990, line L25283/1; 1994, line L25517/1. Data for 2005 from Louisiana Spatial Reference Center.