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Tsunami run-up heights of the 2003 Tokachi-oki earthquake

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Tsunami height survey was conducted immediately after the 2003 Tokachi-oki earthquake. Results of the survey show that the largest tsunami height was 4 m to the east of Cape Erimo, around Bansei-onsen, and locally at Mabiro. The results also show that the tsunami height distribution of the 2003 Tokachi-oki earthquake is clearly different from that of the 1952 Tokachi-oki earthquake, suggesting the different source areas of the 1952 and 2003 Tokachi-oki earthquakes. Numerical simulation of tsunami is carried out using the slip distribution estimated by Yamanaka and Kikuchi (2003). The overall pattern of the observed tsunami height distribution along the coast is explained by the computed ones although the observed tsunami heights are slightly smaller. Large later phase observed at the tide gauge in Urakawa is the edge wave propagating from Cape Erimo along the west coast of the Hidaka area.
Key words: The 2003 Tokachi-oki earthquake, tsunami height survey, tsunami numerical simulation, edge wave.

1. Introduction

On 26 September 2003, a large Tokachi-oki earthquake occurred at the southern coast of Hokkaido, Japan. The Japan Meteorological Agency (JMA) estimated the source parameters as follows: origin time, 4:50:07.5 (JST); epicenter, 41°46.7′N, 144°04.7′E; depth 42 km; the JMA magnitude, M_J 8.0. The seismic moment estimated from the teleseismic body waves was 1.0×10^{21} Nm, or Mw 8.0 (Yamanaka and Kikuchi, 2003). The aftershock area was almost the same as that of the 1952 Tokachi-oki earthquake (Ichiyanagi *et al*., 2004). The earthquake generated large tsunamis causing damage along the southern coast of Hokkaido. Immediately after the earthquake, the tsunami survey was conducted by tsunami researchers from all over Japan. Several survey teams covered all the coasts of the eastern Hokkaido and the northern Tohoku regions. The tsunami was also observed at the tide gauges in the Hokkaido and Tohoku regions (Hirata *et al*., 2003).

In this paper, observed tsunami run-up heights of the 2003 Tokachi-oki earthquake are compiled and compared with those of the 1952 great Tokachi-oki earthquake. The result of a numerical simulation of the 2003 tsunami is compared with the observed tsunami run-up heights. The generation mechanism of the large later phase observed at the tide gauge in Urakawa is also discussed.

2. Tsunami Height Survey

The tsunami assessment was conducted immediately after the earthquake. The survey along the southern coast of Hokkaido and the eastern coast of Tohoku was almost completed by 29th of September, three days after the earthquake. The survey was continued by 2nd of October and an additional assessment was conducted by JMA on 10th and 11th of October. The quick survey is particularly important for a moderate tsunami of which the run-up heights are less than 3 m. Most of tsunami deposits for such a moderate tsunami exist in a surf zone, so those deposits were quickly disturbed by high waves.

The results of the tsunami height survey are shown in Fig. 1 and Table 1. The tsunami heights are measured from various objects that the tsunami left behind (Fig. 2(a)), the line marked around the buildings by the tsunami (Fig. 2(b)), or eyewitness accounts. Most of tsunami heights are origi-

Table 1. Tsunami height survey results.

survey point	latitude (N)	longitude (E)	measured height (m)	tsunami arrival time[1)]	tidal correction (m)	reference tide gauge[2)]	corrected height (m)
Mukawa	42°32′39″	141°56′45″	0.48	6:40	0.70	Ura	1.2
Monnbetsu	42″28′24″	142°04′29″	0.60	6:40	1.00	Ura	1.6
Shizunaigawa	42″19′50″	142°22′04″	1.15	6:40	-0.05	Ura	1.1
Shizunaigawa	42″19′50″	142°22′04″	0.84	6:40	-0.05	Ura	0.8
Irifune	42″19′31″	142°22′14″	1.02	6:40	-0.15	Ura	0.9
Irifune	42″19′31″	142°22′14″	1.27	6:40	-0.15	Ura	1.1
Higashishizunai	42°18′00″	142°27′04″	1.79	6:40	-0.15	Ura	1.6
Mitsuishigawa	42°14′43″	142°34′03″	2.24	6:30	-0.25	Ura	2.0
Mitsuishi	42°13′21″	142°37′42″	2.06	6:30	-0.20	Ura	1.9
Ogifushi	42°11′32″	142°40′58″	2.48	6:20	-0.20	Ura	2.3
Ebuegawa	42°11′16″	142°42′54″	2.98	6:20	-0.15	Ura	2.8
Hidakahorobetsu	42°11′06″	142°43′15″	2.15	6:20	0.30	Ura	2.5
Urakawa-ko	42°09′53″	142°46′20″	1.40	6:20	0.00	Ura	1.4
Samani	42°07′58″	142°54′26″	2.57	6:00	0.35	Ura, Uta	2.9
Samani	42°07′45″	142°54′27″	2.80	6:00	-0.40	Ura, Uta	2.4
Samani	42°07′53″	142°54′40″	1.80	6:00	0.50	Ura, Uta	2.3
Horoman	42°05′02″	143°02′24″	1.28	6:00	0.40	Ura, Uta	1.7
Asahi-gyoko	42°03′49″	143°03′54″	2.05	6:00	0.20	Ura, Uta	2.3
Fuemai-gyoko	42°02′46″	143°06′06″	1.67	5:50	0.20	Uta	1.9
Fuemai-gyoko	42°02′37″	143°06′10″	1.60	5:50	0.30	Uta	1.9
Erimo-ko	42°01′07″	143°08′35″	2.55	5:40	0.25	Uta	2.8
Utabetsu	41°59′34″	143°09′41″	0.60	5:40	0.20	Uta	0.8
Utabetsuhigashi	41°59′37″	143°09′42″	0.95	5:40	0.10	Uta	1.1
Utabetsuhigashi	41°58′57″	143°09′57″	1.49	5:40	0.30	Uta	1.8
Erimotoyo	41°57′11″	143°12′38″	2.19	5:20	-0.45	Uta	1.7
Erimotoyo	41°57′01″	143°13′07″	0.70	5:20	0.50	Uta	1.2
Cape Erimo	41°55′23″	143°15′08″	2.70	5:20	0.50	Uta	3.2
Erimo-gyoko	41°56′00″	143°14′37″	3.30	5:20	-0.10	Uta	3.2
Erimo-gyoko	41°56′07″	143°14′39″	2.05	5:20	-0.05	Uta	2.0
Erimo-gyoko	41°56′09″	143°14′39″	1.40	5:20	0.50	Uta	1.9
Hyakuninhama	41°56′51″	143°14′24″	2.55	5:20	0.05	Uta	2.6
Hyakuninhama	41°56′47″	143°14′24″	2.40	5:20	0.50	Uta, Hir	2.9
Hyakuninhama	41°57′34″	143°14′33″	3.10	5:20	0.45	Uta, Hir	3.6
Hyakuninhama	41°57′34″	143°14′33″	3.90	5:20	-0.05	Uta, Hir	3.9
Hyakuninhama	41°57′36″	143°14′34″	4.01	5:20	-0.15	Uta, Hir	3.9
Hyakuninhama	41°59′47″	143°15′35″	3.04	5:20	0.40	Uta, Hir	3.4
Hyakuninhama	41°58′06″	143°14′38″	3.45	5:20	0.35	Uta, Hir	3.8
Hyakuninhama	41°59′45″	143°15′16″	3.20	5:20	0.00	Uta, Hir	3.2
Hyakuninhama	41°59′52″	143°15′17″	2.55	5:20	0.00	Uta, Hir	2.6
Hyakuninhama	42°01′04″	143°16′36″	2.95	5:20	0.15	Uta, Hir	3.1
Shoya-gyoko	42°02′35″	143°17′45″	1.90	5:20	0.30	Hir	2.2
Shoya-gyoko	42°02′39″	143°17′52″	1.50	5:20	0.40	Hir	1.9
Shoya	42°02′49″	143°18′45″	2.35	5:20	0.35	Hir	2.7
Meguro	42°07′20″	143°19′15″	1.95	5:20	0.45	Hir	2.4
Oshirabetsu	42°13′29″	143°19′07″	2.01	5:20	0.45	Hir	2.5
Oshirabetsu	42°13′28″	143°19′11″	2.59	5:20	0.30	Hir	2.9
Hiroo-gawa	42°16′48″	143°19′04″	2.70	5:20	0.45	Hir	3.2
Hiroo	42°17′26″	143°19′05″	1.90	5:20	0.40	Hir	2.3
Hiroo	42°17′22″	143°19′17″	2.27	5:20	0.40	Hir	2.7
Hiroo	42°17′22″	143°19′12″	3.43	5:20	-0.40	Hir	3.0
Hiroo	42°17′22″	143°19′12″	3.50	5:20	-0.40	Hir	3.1
Hiroo	42°17′22″	143°19′12″	2.84	5:20	-0.40	Hir	2.4
Hiroo	42°17′22″	143°19′12″	3.10	5:20	-0.40	Hir	2.7
Hiroo	42°17′22″	143°19′12″	2.99	5:20	-0.40	Hir	2.6
Hiroo	42°17′22″	143°19′12″	3.07	5:20	-0.40	Hir	2.7
Hiroo	42°17′22″	143°19′12″	3.12	5:20	-0.45	Hir	2.7
Hiroo	42°17′22″	143°19′12″	3.20	5:20	-0.45	Hir	2.8
Hiroo	42°17′22″	143°19′12″	3.07	5:20	-0.35	Hir	2.7
Hiroo	42°17′22″	143°19′12″	3.10	5:20	-0.35	Hir	2.8
Hiroo	42°17′22″	143°19′12″	3.48	5:20	-0.35	Hir	3.1
Hiroo	42°17′19″	143°19′06″	3.00	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	2.99	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	2.99	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	3.03	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	3.00	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	3.00	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	2.96	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	2.95	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	2.98	5:20	-0.40	Hir	2.6
Hiroo	42°17′19″	143°19′06″	3.08	5:20	-0.40	Hir	2.7
Hiroo	42°17′19″	143°19′06″	3.08	5:20	-0.40	Hir	2.7
Hiroo	42°17′19″	143°19′06″	2.89	5:20	-0.40	Hir	2.5
Hiroo	42°17′19″	143°19′06″	3.15	5:20	-0.45	Hir	2.7
Hiroo	42°17′50″	143°19′22″	3.14	5:20	-0.45	Hir	2.7
Hiroo	42°17′20″	143°19′17″	2.07	5:20	0.45	Hir	2.5
Hiroo	42°17′20″	143°19′17″	2.55	5:20	0.45	Hir	3.0
Hiroo	42°17′22″	143°19′17″	2.05	5:20	0.50	Hir	2.6

Table 1. (continued).

survey point	latitude (N)	longitude (E)	measured height (m)	tsunami arrival time[1)]	tidal correction (m)	reference tide gauge[2)]	corrected height (m)
Shinseikaigan	42°20′27″	143°20′29″	2.29	5:20	0.05	Hir	2.3
Toyoni-gawa	42°23′11″	143°22′08″	3.13	5:20	-0.40	Hir	2.7
Asahihama	42°25′09″	143°23′30″	1.39	5:20	0.30	Hir	1.7
Asahihama	42°26′12″	143°24′11″	2.94	5:20	0.30	Hir	3.2
Asahihama	42°26′13″	143°24′13″	3.26	5:20	-0.40	Hir	2.9
Hamataiki	42°28′12″	143°25′46″	3.28	5:20	0.10	Hir	3.4
Hamataiki	42°28′17″	143°25′48″	3.00	5:20	0.25	Hir	3.3
Hamataiki	42°28′37″	143°25′45″	2.38	5:20	-0.05	Hir	2.3
Hamataiki	42°28′35″	143°25′53″	2.62	5:20	0.45	Hir	3.1
Hamataiki	42°28′30″	143°25′56″	3.00	5:20	-0.40	Hir	2.6
Hamataiki	42°28′37″	143°26′00″	3.92	5:20	0.05	Hir	4.0
Horokayantou	42°31′29″	143°28′40″	4.42	5:20	-0.40	Hir	4.0
Horokayantou	42°31′30″	143°28′41″	3.69	5:20	-0.30	Hir	3.4
Banseionsen	42°31′58″	143°29′09″	4.49	5:20	-0.40	Hir	4.1
Banseionsen	42°32′01″	143°29′11″	3.20	5:20	0.10	Hir	3.3
Banseionsen	42°32′09″	143°29′20″	2.63	5:20	0.40	Hir	3.0
Oikamanai	42°33′28″	143°30′31″	4.28	5:20	-0.25	Hir	4.0
Oikamanai	42°33′34″	143°30′39″	2.40	5:20	0.45	Hir	2.9
Yudonuma	42°34′49″	143°31′50″	2.58	5:20	0.05	Hir	2.6
Yudonuma	42°35′07″	143°32′09″	3.07	5:20	-0.45	Hir	2.6
Yudonuma	42°35′57″	143°33′00″	3.35	5:20	-0.05	Hir	3.3
Yudonuma	42°36′00″	143°33′05″	3.30	5:20	-0.05	Hir	3.3
Yudonuma	42°36′39″	143°33′46″	2.40	5:20	0.60	Hir	3.0
Cyosetsunuma	42°39′17″	143°36′45″	3.16	5:20	0.30	Hir	3.5
Cyosetsunuma	42°39′37″	143°37′11″	3.52	5:20	-0.05	Hir	3.5
Ootsu-gyoko	42°40′14″	143°37′59″	2.62	5:20	0.15	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.24	5:20	0.45	Hir, Kus	2.7
Ootsu-gyoko	42°40′50″	143°38′05″	2.30	5:20	0.45	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.21	5:20	0.45	Hir, Kus	2.7
Ootsu-gyoko	42°40′50″	143°38′05″	2.20	5:20	0.45	Hir, Kus	2.7
Ootsu-gyoko	42°40′50″	143°38′05″	2.32	5:20	0.45	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.30	5:20	0.45	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.32	5:20	0.45	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.39	5:20	0.45	Hir, Kus	2.8
Ootsu-gyoko	42°40′29″	143°38′31″	1.97	5:20	0.35	Hir, Kus	2.3
Ootsu-gyoko	42°40′41″	143°38′44″	2.43	5:20	0.40	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.53	5:20	0.00	Hir, Kus	2.5
Ootsu-gyoko	42°40′50″	143°38′05″	2.50	5:20	0.00	Hir, Kus	2.5
Ootsu-gyoko	42°40′50″	143°38′05″	3.24	5:20	0.05	Hir, Kus	3.3
Ootsu-gyoko	42°40′50″	143°38′05″	2.09	5:20	0.15	Hir, Kus	2.2
Ootsu-gyoko	42°40′50″	143°38′05″	2.05	5:20	0.15	Hir, Kus	2.2
Ootsu-gyoko	42°40′50″	143°38′29″	2.78	5:20	-0.05	Hir, Kus	2.7
Ootsu-gyoko	42°40′50″	143°38′29″	2.58	5:20	0.05	Hir, Kus	2.6
Ootsu-gyoko	42°40′42″	143°38′02″	2.60	5:20	0.00	Hir, Kus	2.6
Ootsu-gyoko	42°40′42″	143°38′02″	2.32	5:20	0.00	Hir, Kus	2.3
Ootsu-gyoko	42°40′42″	143°38′02″	2.47	5:20	0.00	Hir, Kus	2.5
Ootsu-gyoko	42°40′42″	143°38′21″	1.65	5:20	0.00	Hir, Kus	1.7
Ootsu-gyoko	42°41′00″	143°38′47″	2.29	5:20	0.00	Hir, Kus	2.3
Ootsu-gyoko	42°41′00″	143°38′47″	2.54	5:20	0.00	Hir, Kus	2.5
Ootsu-gyoko	42°41′00″	143°38′47″	2.21	5:20	0.25	Hir, Kus	2.5
Ootsu-gyoko	42°41′00″	143°38′47″	2.51	5:20	0.25	Hir, Kus	2.8
Ootsu-gyoko	42°40′35″	143°38′13″	2.75	5:20	-0.50	Hir, Kus	2.3
Ootsu-gyoko	42°40′50″	143°38′29″	2.90	5:20	-0.40	Hir, Kus	2.5
Ootsu-gyoko	42°40′50″	143°38′05″	3.50	5:20	-0.50	Hir, Kus	3.0
Ootsu-gyoko	42°40′50″	143°38′05″	3.40	5:20	-0.50	Hir, Kus	2.9
Ootsu-gyoko	42°40′50″	143°38′05″	3.65	5:20	-0.50	Hir, Kus	3.2
Ootsu-gyoko	42°40′50″	143°38′05″	3.25	5:20	-0.50	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	2.95	5:20	-0.50	Hir, Kus	2.5
Ootsu-gyoko	42°40′50″	143°8′05″	3.10	5:20	-0.30	Hir, Kus	2.8
Ootsu-gyoko	42°40′50″	143°38′05″	3.00	5:20	-0.30	Hir, Kus	2.7
Ootsu-gyoko	42°40′50″	143°38′05″	2.80	5:20	-0.25	Hir, Kus	2.6
Ootsu-gyoko	42°40′50″	143°38′05″	2.70	5:20	-0.20	Hir, Kus	2.5
Ootsu-gyoko	42°40′40″	143°38′18″	2.95	5:20	-0.30	Hir, Kus	2.7
Ootsu-gyoko	42°40′39″	143°38′05″	2.31	5:20	-0.05	Hir, Kus	2.3
Ootsu-gyoko	42°40′39″	143°38′05″	1.77	5:20	-0.05	Hir, Kus	1.7
Ootsu-gyoko	42°40′38″	143°38′35″	2.27	5:20	-0.40	Hir, Kus	1.9
Ootsu-gyoko	42°40′41″	143°38′37″	2.55	5:20	-0.40	Hir, Kus	2.2
Tokachi-gawa	42°41′26″	143°39′34″	2.03	5:20	-0.25	Hir, Kus	1.8
Tokachibuto	42°42′30″	143°40′57″	2.83	5:20	-0.15	Hir, Kus	2.7
Hamaatsunai	42°47′29″	143°48′05″	2.93	5:20	-0.40	Hir, Kus	2.5
Atsunai-gyoko	42°48′25″	143°49′11″	1.02	5:20	0.20	Hir, Kus	1.2
Atsunai-gyoko	42°48′25″	143°49′11″	2.27	5:20	-0.40	Hir, Kus	1.9
Atsunai-gyoko	42°48′25″	143°49′11″	1.82	5:20	0.55	Hir, Kus	2.4
Atsunai-gyoko	42°48′27″	143°49′16″	0.91	5:20	0.20	Hir, Kus	1.1
Atsunai-gyoko	42°48′30″	143°49′21″	2.03	5:20	0.10	Hir, Kus	2.1
Kinashibetsu	42°51′12″	143°53′03″	2.25	5:20	-0.10	Hir, Kus	2.2
Otobetsuhigashi	42°55′16″	143°59′49″	1.11	5:20	0.40	Hir, Kus	1.5

Table 1. (continued).

survey point	latitude (N)	longitude (E)	measured height (m)	tsunami arrival time[1)]	tidal correction (m)	reference tide gauge[2)]	corrected height (m)
Pasyukurunuma	42°55′57″	144°00′04″	2.42	5:20	-0.10	Hir, Kus	2.3
Sarogawa	42°57′19″	144°03′43″	1.54	5:20	0.40	Hir, Kus	1.9
Sarogawa	42°57′19″	144°03′43″	2.27	5:20	0.35	Hir, Kus	2.6
Sarogawa	42°57′03″	144°03′43″	1.39	5:20	0.45	Hir, Kus	1.8
Shiranuka-gyoko	42°57′11″	144°05′12″	1.50	5:20	0.15	Kus	1.7
Shiranuka-gyoko	42°57′12″	144°05′12″	2.11	5:20	0.40	Kus	2.5
Koitoi	42°59′41″	144°11′45″	1.62	5:20	0.35	Kus	2.0
Kushiro-ko	43°00′01″	144°19′48″	1.20	5:20	0.40	Kus	1.6
Kushiro-ko	43°00′01″	144°19′48″	1.25	5:20	0.35	Kus	1.6
Kushiro-ko	42°59′00″	144°22′16″	1.46	5:20	-0.10	Kus	1.4
Kushiro-ko	42°58′54″	144°22′41″	1.38	5:20	-0.10	Kus	1.3
Kushiro-ko	42°58′54″	144°22′41″	0.85	5:20	0.40	Kus	1.3
Kushiro-ko	42°58′54″	144°22′41″	0.90	5:20	0.40	Kus	1.3
Kushiro-ko	42°58′54″	144°22′41″	1.00	5:20	0.40	Kus	1.4
Chiyonoura	42°58′00″	144°23′35″	1.16	5:20	0.00	Kus	1.2
Kushiro-gawa	43°00′24″	144°23′55″	1.35	5:20	0.10	Kus	1.5
Konbumori	42°57′03″	144°31′49″	1.22	6:00	0.10	Kus	1.3
Konbumori	42°57′53″	144°31′51″	0.42	6:00	0.65	Kus	1.1
Fushiko	42°56′58″	144°32′25″	1.50	6:00	0.15	Kus	1.7
Pondomari	42°57′04″	144°37′02″	1.55	6:00	0.05	Kus	1.6
Chippomanai	42°56′01″	144°44′42″	1.03	6:30	0.65	Kus, Akk	1.7
Senposhi	42°58′33″	144°43′21″	0.86	6:30	0.85	Akk	1.7
Monshizu	43°03′15″	144°46′54″	1.18	6:30	0.85	Akk	2.0
Akkeshi-ko	43°03′00″	144°51′01″	0.46	6:30	0.85	Akk	1.3
Tsukushikoi	43°00′54″	144°50′47″	2.28	6:30	-0.30	Akk	2.0
Tokotan	42°59′35″	144°52′27″	2.35	6:30	0.75	Akk	3.1
Tokotan	42°59′44″	144°52′07″	2.20	6:30	0.50	Akk	2.7
Tokotan	42°59′35″	144°52′18″	1.84	6:30	0.10	Akk	1.9
Horomanbetsu	42°59′14″	144°53′16″	1.70	6:30	0.55	Akk	2.3
Mabiro	42°59′20″	144°53′50″	3.74	6:30	0.25	Akk	4.0
Mabiro	42°59′20″	144°54′24″	2.88	6:30	0.45	Akk	3.3
Mabiro	42°59′20″	144°54′04″	3.92	6:30	0.50	Akk	4.4
Mabiro	42°59′22″	144°53′53″	3.76	6:30	0.50	Akk	4.3
Mabiro	42°59′19″	144°54′19″	2.28	6:30	0.00	Akk	2.3
Mabiro	42°59′17″	144°54′23″	1.94	6:30	0.00	Akk	1.9
Mabiro	42°59′20″	144°54′17″	2.33	6:30	0.00	Akk	2.3
Mochirippu	43°01′17″	145°01′16″	1.00	6:30	0.20	Akk, Och	1.2
Hichirippu	43°01′49″	145°01′39″	1.20	6:30	0.05	Akk, Och	1.3
Biwase	43°03′33″	145°05′16″	1.49	6:30	0.00	Akk, Och	1.5
Shinkawa	43°04′48″	145°06′36″	1.80	6:30	0.00	Akk, Och	1.8
Shinkawa	43°04′48″	145°06′19″	0.59	6:30	0.30	Akk, Och	0.9
Shinkawa	43°04′48″	145°06′19″	0.38	6:30	0.30	Akk, Och	0.7
Sakaki-cyou	43°07′21″	145°06′55″	1.14	6:30	0.05	Akk, Och	1.2
Sakaki-cyou	43°07′27″	145°06′59″	1.82	6:30	0.05	Akk, Och	1.9
Tofutsu	43°04′29″	145°09′02″	1.20	6:30	0.10	Och	1.3
Ochiishi	43°10′40″	145°30′29″	0.90	5:40	0.45	Och	1.4
Cyobushi	43°15′18″	145°33′27″	1.82	5:40	-0.40	Han	1.4
Hanasaki	43°17′08″	145°35′05″	1.41	5:40	-0.20	Han	1.2
Shichikari-gyoko	41°21′35″	141°26′38″	2.59	5:50	-0.15	Shi	2.4
Furuno-gyoko	41°20′57″	141°26′23″	1.45	5:50	0.00	Shi	1.5
Tomariminani	41°03′02″	141°23′20″	1.50	5:50	-0.25	Shi, Hac	1.3
Taroo-gyoko	39°43′45″	141°58′25″	0.49	5:45	0.05	Miy	0.5
Miyako-gyoko	39°38′23″	141°58′04″	1.11	5:45	-0.25	Miy	0.9
Miyako-gyoko	39°38′29″	141°58′04″	0.80	5:45	-0.10	Miy	0.7
Akamae	39°35′22″	141°57′40″	0.70	5:45	-0.30	Miy	0.4
Hirotawan	39°59′34″	141°37′23″	1.12	5:45	-0.15	Oof, Kes	1.0
Kesennuma	39°53′00″	1413°7′30″	0.70	5:45	-0.15	Kes	0.6

[1)]Tsunami arrival time (in Japan Standard Time of September 26, 2003).

[2)]Reference tide gauges are Hanasaki (Han), Ochiishi (Och), Akkeshi (Akk), Kushiro (Kus), Hiroo (Hir), Utaro (Uta), Urakawa (Ura), Shimokita (Shi), Hachinohe (Hac), Miyako (Miy), Oofunato (Oof), and Kesennuma (Kes).

nally reference to the sea level at the time of measurement. Because those tsunami heights are measured from the sea level at the shore, the error of the measurements is about 0.2 m. The tide levels are corrected using nearby tide gauge records (Hanasaki, Kushiro, Urakawa, Hachinohe, Miyako, and Kesennuma) or the calculated tide data from the tide table provided by the JMA (Ochiishi, Akkeshi, Hiroo, Utaro, Shimokita, and Ofunato). In Table 1, the reference station name is shown for each survey point. If two names are listed for one survey point in Table 1, the average of the two tide data is used. The observed tsunami heights due to the 2003 earthquake in Fig. 1 are calculated from the tide level at the time of the maximum tsunami. The arrival time of the maximum tsunami for each survey point is also listed in Table 1. Most of the arrival times are obtained from nearby tide gauge records except the survey points between Cape Erimo and Urakawa. The reason that we need to treat those survey points differently is discussed latter. The large tsunamis arrived at the Pacific side of the coast of Hokkaido and Tohoku about 2–3 hours after the time of the high tide. The large

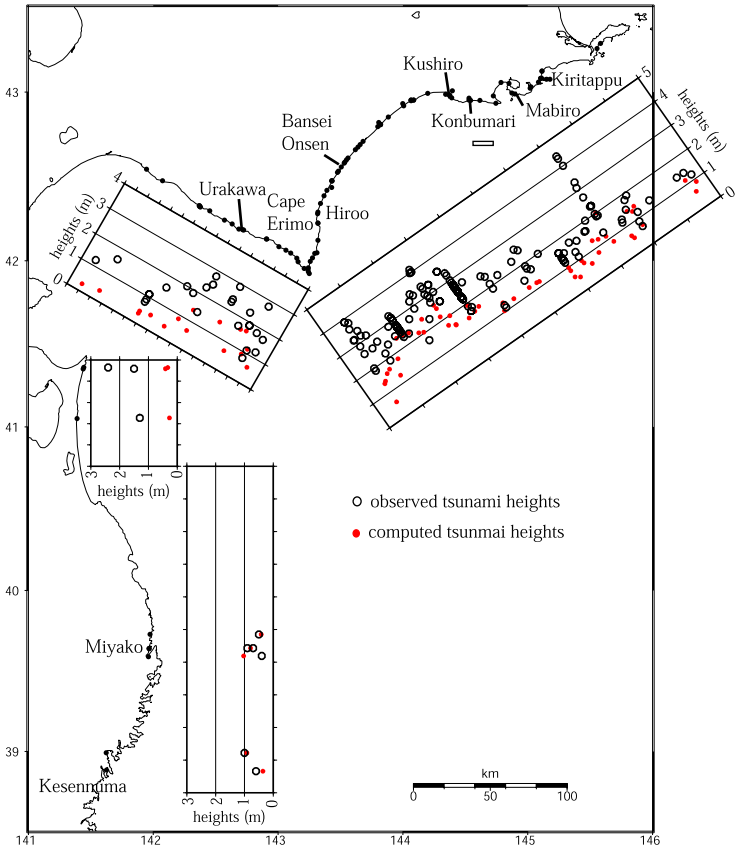

Fig. 1. Comparison of the measured (black circles) and computed (red circles) tsunami heights for the 2003 Tokachi-oki tsunami. The computed tsunami heights are obtained using the slip distribution estimated from the teleseismic body waves (Yamanaka and Kikuchi, 2003).

tsunami run-up heights about 4 m was observed at the east side of Cape Erimo and Bansei-onsen located about 70 km north-east of the Cape Erimo. Those places were close to the source region of the earthquake (Fig. 3). In general, the tsunami run-up heights were gradually decreased to the east and to the west away from those two places except Mabiro where the large tsunami height about 4 m is locally observed.

3. Numerical Simulation of the Tsunami

Slip distribution of the 2003 Tokachi-oki earthquake was estimated using the teleseismic body waves by Yamanaka and Kikuchi (2003). The vertical seafloor displacement is computed using Okada's (1985) equations (Fig. 3) and used as an initial condition of tsunami numerical computation. The finite-difference computations of the linear long-wave equations (see Satake, 1995) are carried out. The total reflection boundary condition is used at the coast. The grid size is 20 sec of arc (about 600 m). The time step of the computation is 1 sec to satisfy a stability condition. In Fig. 1, the results of the tsunami computation are shown with the observed tsunami heights. The computed tsunami heights slightly underestimate the observed tsunami heights because run-up computations with a finer grid system are not included in this simulation. The overall pattern of the computed tsunami height distribution is similar to the observed one. However, some details between the observed and computed tsunami heights are different. One is that the computed tsunamis largely underestimate the observed tsunami heights, about 4 m, to the east of Cape Erimo. Another is

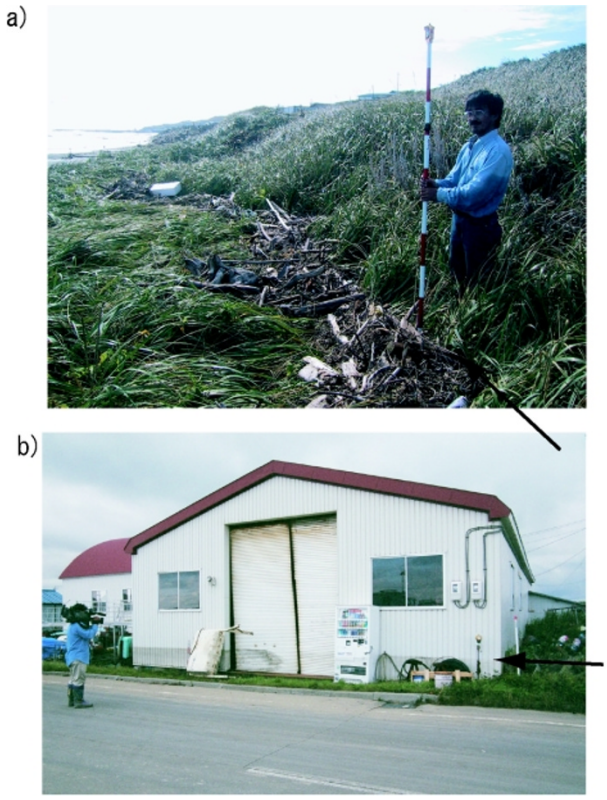

Fig. 2. a) A photo of the tsunami deposits carried by the 2003 tsunami where the tsunami height is measured. b) A photo of the water line around the building which was marked by the inundated tsunami.

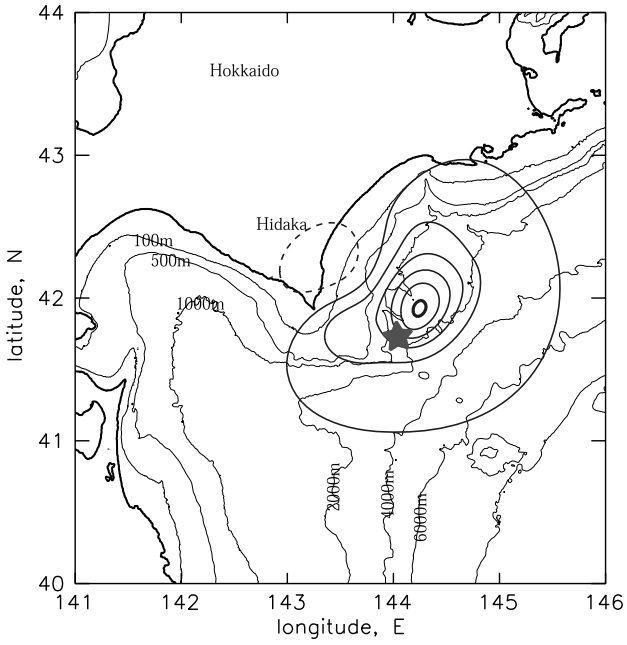

Fig. 3. Vertical deformation due to the 2003 Tokachi-oki earthquake calculated from the slip distribution estimated by Yamanaka and Kikuchi (2003). The star shows the epicenter of the mainshock. Closed contours show the vertical deformation (solid curves for uplift and dashed for subsidence with a 20 cm interval).

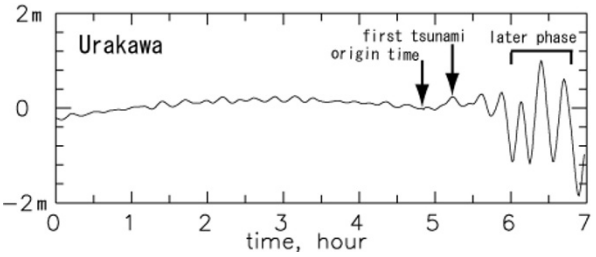

Fig. 4. The tsunami waveform recorded at the tide gauge in Urakawa. Time is the Japan standard time on September 26, 2003.

that the computed tsunamis are too small at Mabiro where a large tsunami was observed locally. Future studies using a nonlinear run-up computation with a finer grid system are necessary to understand the tsunami propagation in these regions.

4. A Large Later Phase of the Tsunami in the West Coast of Hidaka

The tsunamis generated by the 2003 Tokachi-oki earthquake were observed at tide gauges in the eastern Hokkaido and the northern Tohoku regions (Hirata *et al.*, 2003). Among them, the tsunami observed at Urakawa shows interesting waveforms (Fig. 4). The largest tsunami arrived about one hour after the first wave, and the amplitude was four times larger than the first wave. Snapshots of the computed tsunamis in Fig. 5 show that the largest tsunami arrived at Urakawa propagated from Cape Erimo along the west coast of the Hidaka area. The first wave at Urakawa was small because the large coseismic deformation area due to the earthquake was located on the other side of Cape Erimo (Fig. 3). The largest tsunami slowly propagates along the coast and

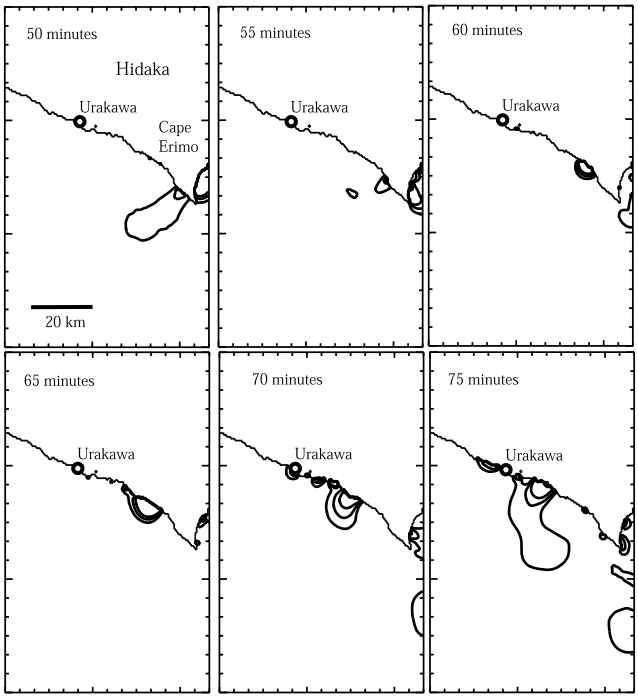

Fig. 5. Six snapshots of the computed tsunami propagation near the west coast of Hidaka area at 50, 55, 60, 65, 70, 75 minutes after the origin time of the earthquake. The contours show the tsunami heights of 15 cm, 30 cm, 45 cm.

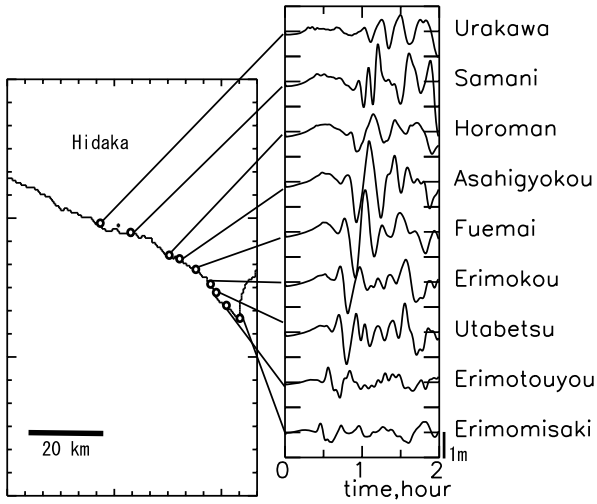

Fig. 6. The computed tsunami waveforms on the west coast of Hidaka Left map shows the location of the stations where the tsunami waveforms are computed. One tick mark in the vertical scale is 1 m. Time is measured from the earthquake origin time.

arrives at Urakawa (Fig. 5). This type of wave is called an edge wave (Gonzalez *et al.*, 1993). Figure 6 shows that the computed tsunami waveforms at the tsunami survey points between Cape Erimo and Urakawa. The later large phases of the tsunami, the edge waves, slowly propagate from Cape Erimo to Urakawa (Fig. 6). In order to find the arrival time of the maximum tsunami at the survey points between Cape Erimo and Urakawa, we used the computed tsunami waveforms in Fig. 6. The arrival times at those survey points are shown in Table 1 and used to correct the tide level.

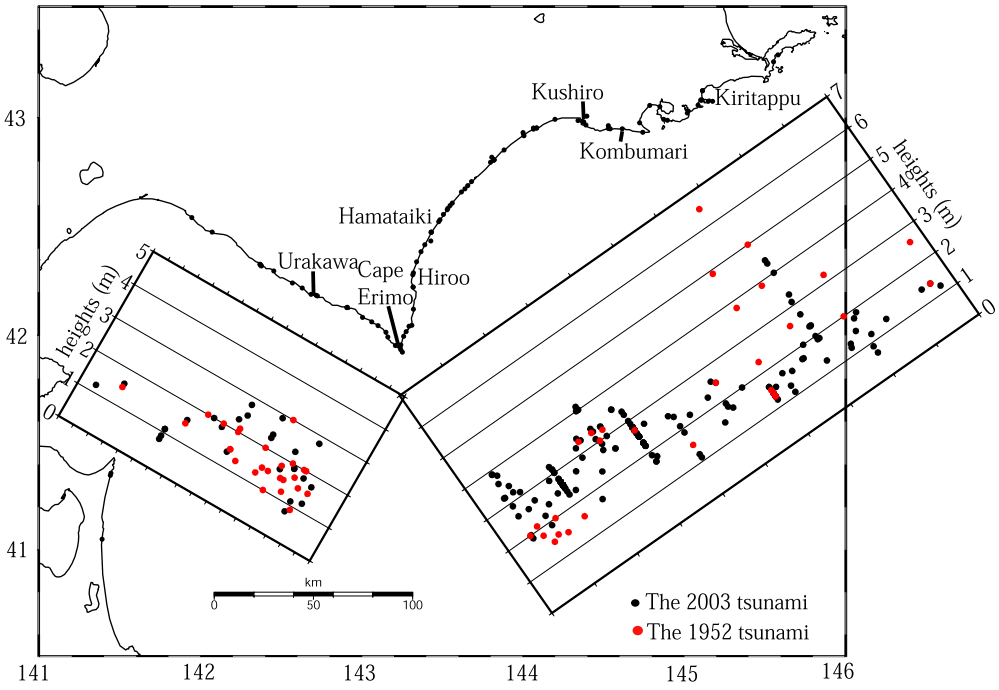

Fig. 7. Comparison of the observed tsunami heights of the 2003 Toklachi-oki earthquake (black circles) and those of the 1952 Tokachi-oki earthquake (red circles) reported by the Central Meteorological Observatory (1953).

5. Comparison of the Tsunami Heights of the 1952 and 2003 Tokachi-oki Tsunamis

The tsunami run-up heights of the 1952 Tokachi-oki earthquake were surveyed by the Central Meteorological Observatory (1953). The large tsunami heights of the 1952 Tokachi-oki event, 4–7 m, were observed between Kombumori and Kiritappu (Fig. 7). The tsunami heights of the 2003 event in this area were much smaller than the tsunami heights of the 1952 event (Fig. 7). In the regions between Kushiro and Hamataiki, and west side of Cape Erimo, the tsunami heights of the 1952 and 2003 events are similar to each other. In the region between Cape Erimo and Hiroo, the tsunami heights of the 2003 event were larger than those of the 1952 event. The large differences of tsunami heights in the region between Kombumori and Kiritappu indicate that the source processes or tsunami generation of the 2003 earthquake are different from those of the 1952 earthquake.

6. Conclusion

The tsunami survey immediately after the 2003 Tokachi-oki earthquake revealed that the tsunami height distribution of the 2003 Tokachi-oki earthquake is different from that of the 1952 Tokachi-oki earthquake. The result of the numerical simulation of the 2003 Tokachi-oki tsunami using the slip distribution estimated from the seismological data (Yamanaka and Kikuchi, 2003) shows that the overall pattern of the observed tsunami heights are explained by the computed ones. This indicates that the 2003 Tokachi-oki tsunami is not an unusual tsunami. The differences between the 1952 and 2003 tsunami height distributions suggest that the source processes or tsunami generation of the 1952 earthquake are different from those of the 2003 earthquake. The large later phase observed at the tide gauge in Urakawa is the edge wave propagating from Cape Erimo along the west coast of the Hidaka area.

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