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LUSI MITIGATION IMPLICATIONS OF BPLS AND OTHER SUBSIDENCE MEASUREMENTS

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Abstract

Since the beginning of LUSI eruption, extrusion of mud has been accompanied by deformation of the land surface extending out as much as three km from the main vent. Deformation generally consists of subsidence, however also includes uplift in certain areas and minor surface faulting and cracking as surface blocks of sediment move. BPLS monthly leveling since 12/2007 by laser surveying gives the most reliable measure of vertical movement around the perimeter of the mud ponds. This has been augmented by differential GPS measurements that extends farther out. Subsidence beneath the mud within the levees is difficult to be measured accurately. Rapid subsidence, rising mud, and continuous addition of dirt to maintain the internal dikes make it impossible to maintain a system of benchmarks in the inner area. Shape of the surface beneath the mud can be estimated by indicators such as early GPS measurements, tilting of partially buried buildings, and the rate at which tiers of sandbags have disappeared beneath the mud. We have synthesized all available data to produce a contour map of estimated total deformation for the first 35 months of eruption despite limitations of the data such as variable quality, contradictions, poor point distribution, and observations over variable time intervals.

Pre-eruption land surface near LUSI was a nearly level plain about 4 m above MSL sloping about 0.45 m/km NE toward the sea and away from the artificially high channel and levees of the Porong River. Land around the vent has subsided in the form of an asymmetrical shallow funnel where the gentle tilt of about 10 m/km around the margins increases dramatically near the vent. Early ITB continuous differential GPS measurements of horizontal movement indicated a point of maximum subsidence about 250 m northwest of the main vent. Our contours indicate 65 million m^3 of mud is presently stored. About 60% occupies the subsidence depression, the rest is confined by the dikes. About 200 m south of the vent is a flexure zone trending generally east-west that separates fast subsidence from slower subsidence to the south. This flexure has caused difficulty in mitigation by blocking flow of mud southward towards disposal points along the Porong River.

On the west side of the subsidence cone, flexure toward the vent area has stretched the ground surface, breaking it with steep north-northeast trending fractures that localize methane gas venting. These resulting blocks settle unevenly, creating horsts and grabens with offset less than 15 cm. This fracturing probably extends east beneath the levees although it is not clearly expressed there. Transverse to this pattern near the former toll road bridge is a 100 m-wide zone characterized by the highest subsidence rates outside the levees. This subsidence of about 1.5 m in three years is much less than an estimated 40 m subsidence beneath the mud near the vent, but lies across natural drainage and causes local flooding. At present rates of subsidence, this area will be below sea level in four years and become a pond unless constantly pumped. Until the road realignment is completed, most of the commercial traffic of East Java must travel through this area, and the proposed realignment still lies perilously close to northwesterly expanding subsidence. Increased methane venting

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and ground cracking has made West Siring Village too hazardous for continued habitation.
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1 Introduction

LUSI refers to a large eruption of boiling mud 2 km north of the Porong River 25 km south of Surabaya in East Java. Eruption began May 2006, causing great destruction, and continues today at about 100,000 m^3/day. Extensive discussions of the geology and hydrology of this eruption are available in the literature and will not be repeated here (Davis et al., 2008; Mazzini et al., 2007; Plumlee et al., 2008; UNEP/OCHA, 2006). The essential point for this paper is that the great mass of solids, fluids, and gases erupted have resulted in a volume loss at depth causing the original land surface, now partially buried by erupted mud, to subside in irregular ways. Estimation of the amount, rate, and distribution of subsidence and uplift is necessary for effective mitigation planning. Prediction of where high rates of subsidence will occur in the future allows for evacuation and avoidance. Estimation of the shape of subsidence beneath the mud lake allows calculation of the volume of stored mud. That volume, combined with the recorded volume of mud pumped, both adjusted for water content, allowing calculation of the average long-term rate of eruption, which is the best guide for planning future mud pumping and storage needs. This paper presents a compilation and interpretation effort to estimate amount, rate, and distribution of subsidence.

2 Methods

There have been many repeat measurements of elevation in the LUSI area by various agencies over different periods using different points. We have attempted to compile this data into compatible format so that it all can be compared at the same time, plotted in a GIS system, and used to construct interpretative contour maps. When the data are compared many contradictions and improbable measurements are revealed. In such cases we evaluate sources of uncertainty in the record and reconcile the data to produce a subjective estimate of the true value that is used for plotting. Reasons for the choice of subjective value or for rejection of the point are written in the tables.

Four sources of data have been compiled into four data tables. The oldest dataset is differential GPS measurements for 25 points collected by a team from Bandung Institute of Technology (ITB) from July 2006 until March 2007. The second oldest and the most reliable data set is a loop of 30 stations measured by conventional surveying every month by Virama Karya company surveyors from December 2007 until April 2009. The third set is differential GPS measurements for 14 points collected by BPLS operational field crew from December 2008 until April 2009. The fourth and least reliable set includes 5 estimates partially based on a topographic survey of the inner dikes by Widya Bumi Amarta (WBA), the Lapindo surveying contractor, in December 2008 compared to another in May 2009.

To overcome the lack of continuous records, we tried to calculate a long term rate of deformation for each point. We generally subtracted the most recent reliable elevation from the earliest reliable elevation and divided by the number of months between the measurements. This introduces error to the extent that the rate changes through time, which it certainly did in some places during the early days. Curves of the most recent measurements outside the present dikes, however, show a consistent rate of subsidence over many months. The ITB data available to us lacked absolute elevation but was already expressed as month to month rate.

Rate of subsidence is an important parameter, but estimates of total subsidence are needed to calculate mud volume and evaluate flooding hazard. Our estimate of total subsidence effective April 2009 as plotted on the attached contour map is simply calculated by multiplying the various monthly rates by the elapsed 35 months of eruption prior to April 2009. The 4000 cm contour represents an average subsidence of 114 cm/month. The 100 cm contour represents 2.9 cm/month.

The contours on the map are subjectively drawn to honor the most reliable data and our mental model of geological processes controlling the subsidence. The contours are labeled in centimeters of subsidence. Spacing of contours was partially guided by tilting calculations based on partially submerged buildings within the mud pond. Note that areas with 0 to 1 m of subsidence are contoured with a 20 cm interval. Areas from 1 to 5 m subsidence are contoured with a 100 cm interval, and areas with more than 5 m subsidence are contoured with a 500 cm contour interval. We did not contour the whole area with a 1 m interval because the central pit would have been black with contours and the area outside the dikes would have lacked any detail. The greatest subsidence of 45 m is contoured to be about 250 m northwest of the vent based on early continuous differential GPS measurement by ITB of horizontal displacement vectors from relief well 1 and relief well 2 that project to intersect there.

3 Volume of Mud

The subsidence contours define the base of the mud deposit. In order to calculate volume of stored mud, the upper surface must also be defined. At close range the mud surface appears flat, but it is actually not. In April 2009, the average slope outward from the vent is 3 m/km. This may be unusually low reflecting recent rapid subsidence and collapse of the retaining dike on the north side. In October 2008, the slope was about 6 m/km on the west side. Subtracting the average elevation of the top surface from the average elevation of the bottom surface, we calculated an average depth for four separate mud ponds. Multiplying the area of the ponds by the depth yields an estimate of total volume of stored mud of about 65 million m^3. Pumping records indicate 42,935,697 m^3 of slurry pumped. Eighty percent of the slurry is water, so 8,587,139 m^3 of solids have been dumped into the Porong, although very little trace of this sediment remains at present. The sum of the pumped solids and stored solids calculated after 1018 days is thus about 73,649,647 m^3, or an average of 72,350 m^3 of solids erupted per day. This is significantly higher than estimates generally used, but that discrepancy may result from uncertainties over the ratio of water to solids at eruption and in storage. The one positive aspect of subsidence is the increased capacity for mud storage within the confining dikes. It appears that subsidence basin allow the dikes to contain more than twice as much mud as could be contained by the dikes alone.

4 Pattern of deformation

Since the very beginning of the eruption, extrusion of mud has been accompanied by deformation of the land beneath the mud extending out as much as two km from the main vent. The deformation generally consists of subsidence, but includes uplift in certain areas and minor surface faulting and cracking as blocks of alluvial sediment move up and down relative to each other. Repeated monthly leveling since December 2007 by conventional surveying instruments gives the most reliable measure of vertical movement around the perimeter of the mud ponds. This has recently been augmented by differential GPS measurements that extend further out Exact distribution of subsidence beneath the mud within the levees is difficult to determine. Rapid subsidence, rising mud, and continuous addition of dirt to maintain the internal dikes has made it impossible to maintain a system of benchmarks in the inner area. The shape of the surface beneath the mud can only be estimated by using indicators such as early differential GPS measurements, tilting of partially buried buildings, and the rate at which tiers of sandbags have disappeared beneath the mud near the central vent. We have attempted to synthesize all available data to produce a map of total deformation and rate of deformation for the first 35 months of eruption despite various limitations of the data such as variable quality, contradictory data, poor point distribution, and observations over variable time intervals.

Before the LUSI eruption the land surface in the area formed a nearly level plain about 4 m above MSL that sloped about 40 cm/km to the east toward the sea 10 km distant and slightly more steeply to the north away from the levees and artificially high channel of the Porong River. In our interpretation, land around the vent has subsided in the form of a shallow funnel where the gentle tilt of about 10 m/km around the margins increases dramatically to more than 150 m/km near the vent. This funnel shape is not symmetrical. Early continuous differential GPS measurements of horizontal as well as vertical movement indicate a point of maximum subsidence about 250 m northwest of the main vent. About 200 m south of the vent is a flexure zone trending generally east-west that separates fast subsidence to the north from much slower subsidence to the south. This flexure has caused great difficulty in mitigation efforts by blocking flow of mud southward towards disposal points along the Porong River.

On the west side of the cone, flexure down toward the vent area has stretched the ground surface, breaking it with steep, generally north-northeast trending fractures that bound soil blocks and partially localize methane gas venting. These blocks settle unevenly, creating an up and down "horst and graben" pattern with offset generally less than 15 cm. The slight relative uplift of the "horst" blocks by downward wedging of the "graben" blocks may account for incongruous local increases in elevation in the area of subsidence. The fracturing probably extends beneath the dikes confining the mud although it is not clearly expressed there. Transverse to fracture pattern in the area where the toll road alignments crosses the western levees is a 200 m-wide zone characterized by the highest subsidence rates outside the levees. This subsidence of about 1.5 m in three years is much less than an estimated 45 m maximum subsidence beneath the mud near the vent, but lies across the natural drainage and causes local flooding. At present rates of subsidence, this area will be below sea level in four years and become a pond unless constantly pumped. Until the new road alignment is completed, most of the commercial traffic of East Java must travel through this area.

5 Predictions and recommendations

Based on past observations, we can expect the area affected by subsidence outside the dikes to expand slowly firstly as water, then shale beneath are mobilized, flowing toward the vent. Subsidence rates over most of the area will be less than 2 cm/month except the northwest side of the ponds where it may reach 5 cm/month. The most damaging effect of this slow subsidence will be to disrupt drainage at the northwest corner of the ponds so that it will be chronically flooded. After three more years much of this area will be below sea level. If constant flooding is not acceptable the area will have to be filled with dirt or constantly pumped. Continued ground fracturing accompanied by ever shifting vents of water and methane can be expected. The area of West Siring will become increasingly dangerous, unhealthy, and unpleasant, and the residents there should be resettled with buildings destroyed to discourage returns or squatters.

The central zone of very high subsidence can also be expected to expand. This may not be much noticed until the inflection point approaches the western dike near the point where accelerated subsidence has already been observed. Then the western dike may begin to collapse rapidly like the inner collar dike did in spring 2008. This may occur only after several years, and the affected area will probably already be flooded by surface water by then. If the population can be evacuated before that time hardship can be reduced.

Acknowledgements

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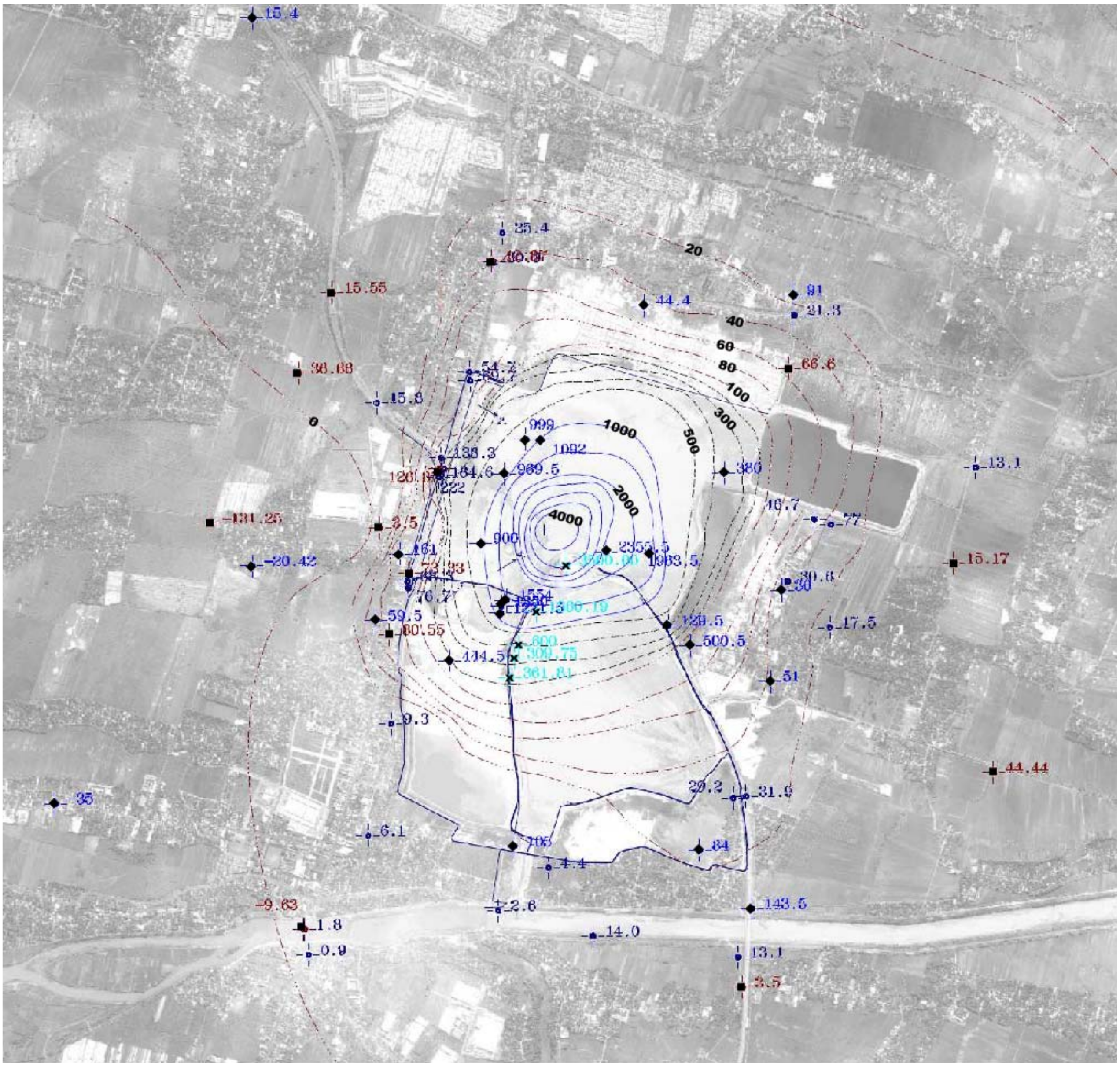

Figure 1: Estimated total subsidence for first 35 months of LUSI eruption in centimeters. Areas with 0 to 100 cm of subsidence are contoured with a 20 cm interval (red). Areas from 100 to 500 cm subsidence are contoured with a 100 cm interval (black), and areas with more than 500 cm subsidence are contoured with a 500 cm contour interval (blue). The oldest data set is differential GPS measurements for 25 points (black diamond) collected by a team from ITB from July 2006 until March 2007. The second oldest and the most reliable data set is a loop of 30 stations (blue circle) measured by conventional surveying every month by BPLS contract surveyors Virama Karya December 2007 until present. The third set is differential GPS measurements for 14 points (red square) collected by BPLS operational field crew from December 2008 until present. The fourth and least reliable set includes 5 estimated points (cyan X) partially based on topographic surveys of the inner dikes by Widya Bumi Amarta (WBA), the Lapindo surveying contractor, in December 2008 and May 2009 and also on the count of layers of sand bags that have sunk beneath the mud over 20 months

Table 1: Continuing laser theodolite leveling measurements. The best subsidence data is shown in this table of measurements by the BPLS surveying contractor, Virama Karya Company. Many stations have a 16-month record repeated every month. The measurements with a laser theodolite give an actual elevation. We subtracted the final elevation from the initial elevation and divided by the length of record to calculate an average monthly rate. That rate multiplied by 35 months gave our estimate for total subsidence as of April 2009

LABEL	EastUTM	NorthUTM	APR09 (m)	MAR09 (m)	FEB09 (m)	JAN09 (m)	DEC08 (m)	NOV08 (m)	OCTO8 (m)	SEP08 (m)	AUG08 (m)	JUL08 (m)	JUN08 (m)	MAY08 (m)	APR08 (m)	MAR08 (m)	FEB08 (m)	JAN08 (m)	DEC07 (m)	TOTAL	RECORD	RATE	EST TOTAL	MY EST	COMMENT
benchmark	(m)	(m)	9-Apr	9-Mar	9-Feb	9-Jan	8-Dec	8-Nov	8-Oct	8-Sep	8-Aug	8-Jul	8-Jun	8-May	8-Apr	8-Mar	8-Feb	8-Jan	7-Dec	CHANGE	MONTHS	mm/month	cm	(cm)	
BM 46A	687380	9165489	9.991	9.997	9.988	9.987	9.974	9.983	9.982	9.988	9.986	9.964	9.996	10	9.994	10.075	10.032	10.027		0.036	15	2.4	8.4	0.9	Keeping only last year because of up down early
BM VK-01	689691	9164483	2.999	3.018	3.019	3.005	3.033	3.014	3.013	3.019	3.036	3.033	3.02	3.026	3.027	3.077	2.999	3.043	2.985	-0.014	16	-0.9	-3.06	8.2	Keeping only last year because of up down early
BM VK-02	689785	9165477	3.886	3.894	3.9	3.895	3.926	3.904	3.912	3.926	3.925	3.935	3.935	3.931	3.931	3.971	3.912	3.951	3.915	0.029	16	1.8	6.34	13.1	Keeping only last year because of up down early
BM VK-05	688444	9165737	4.036	4.048	4.01	4.014	4.045	4.035	4.038	4.034	4.022	4.03	4.066	4.064	4.045	4.142	4.086	4.11	4.148	0.112	16	7	24.5	2.6	Keeping only last year because of up down early
BM VK-06	687763	9168580	3.237	3.27	3.28	3.236	3.253	3.232	3.264	3.275	3.246	3.269	3.284	3.284	3.291	3.407	3.355	3.387	3.358	0.121	16	7.6	26.47	15.8	Keeping only last year because of up down early
BM VK-07	688421	9169365	3.404	3.444	3.457	3.445	3.445	3.435	3.467	3.489	3.448	3.486	3.498	3.509	3.51	3.637	3.594	3.63	3.603	0.199	16	12.4	43.53	30.9	Keeping only last year because of up down early
BM VK-08	691114	9168218	1.646	1.681	1.699	1.647	1.687	1.678	1.688	1.72	1.659	1.687	1.69	1.699	1.691	1.831	1.756	1.832	1.802	0.156	16	9.8	34.13	13.1	Bumpy record but last 12 months looks reasonable. Keeping only last year
BM VK-09	690299	9167324	2.556	2.582	2.603	2.555	2.62	2.581	2.594	2.613	2.59	2.612	2.615	2.617	2.616	2.717	2.651	2.735	2.697	0.141	16	8.8	30.84	17.5	Keeping only last year because of up down early
BM VK-16	688127	9168173	-	-	-	-		2.13	2.236	2.308	2.346	2.43	2.492	2.586	2.641	2.808				0.678	8	84.8	296.63	222	Data ends Nov08 but combined with replacement VK-22
BM VK-17	690062	9167580	-	-	-	-	-		1.565	1.591	1.558	1.578	1.6							0.035	4	8.8	30.63	30.6	no comment
BM VK-18	689831	9166376	8.283	8.312	8.312	8.302	8.341	8.328	8.347	8.337	8.356									0.073	8	9.1	31.94	31.9	Acceptable long record with up and down
BM VK-21	687935	9167579	3.902	3.928	3.94	3.934	3.951	3.97	4.024	4.058										0.156	8	19.5	68.25	68.3	Looks good and consistant. Started Sep08
BM VK-22	688110	9168164	2.849	2.925	2.97	3.001	3.058	3.093	3.201	3.271										0.422	8	52.8	184.63	184.6	Rate since Sept08
BM VK-23	688280	9168752	3.69	3.732	3.753	3.729	3.751	3.747	3.787	3.815										0.125	8	15.6	54.69	54.7	no comment
BM VK-24	690306	9167899	1.971	2.006	2.015	1.955														-0.016	3	-5.3	-18.67	77	Omitted first value which caused only up. Short record undependable
BM-01	688137.28	9168210								-	-	-	-	-	-	-		2.578	2.645	0.067	1	67	234.5	155.5	Discard - one month data in uncertain period
BM-12	688724.24	9165978.79	4.78	4.789	4.753	4.761	4.777	4.77	4.78	4.769	4.775	4.76	4.795	4.797	4.795	4.872	4.82	4.855	4.898	0.118	16	7.4	25.8	4.4	Keeping only last year because of up down early
BM-W01	687714.48	9166159.09	5.967	5.98	5.984	5.956	5.943	5.976	5.975	5.983	5.955	5.955	5.982	6.004	5.988	6.079	6.035	6.044	6.021	0.054	16	3.4	11.8	6.1	Good data last year shows low rate. up and down. Keeping only last year b
BM-W03	688974.05	9165596.14					3.739	3.73	3.748	3.732	3.752	3.732	3.772	3.782	3.771	3.844	3.786	3.82	3.869	0.13	12	10.8	37.92	14	Keeping only last 8 months because of variability before 4/08
BM-W04	689757.38	9166367.03								-	-		7.644	7.647	7.648	7.705	7.639	7.694	7.694	0.05	6	8.3	29.17	29.2	Agrees with nearby-but early record uncertain values
BM-W07	690213.34	9167929.92								-	-		-		2.106	2.236	2.169	2.265	2.276	0.17	4	42.5	148.75	46.7	Ignored last measurement. Early record uncertain values
BM-W08	690100.45	9169071.68	2.148	2.186	2.203	2.17	2.203	2.182	2.206	2.229	2.173	2.221	2.217	2.222	2.221	2.396	2.322	2.366	2.321	0.173	16	10.8	37.84	21.3	Keeping only last year because of up down early
BM-W10	688465.73	9169531.65	2.726	2.77	2.778	2.75	2.773	2.761	2.786	2.808	2.766	2.799	2.809	2.816	2.813	2.947	2.902	2.927	2.9	0.174	16	10.9	38.06	25.4	Keeping only last year because of up down early
BM-W11	688283.92	9168703.26	2.769	2.811	2.834	2.812	2.835	2.834	2.879	2.909	2.895	2.924	2.955	2.989	3.008	3.138	3.111	3.151	3.164	0.395	16	24.7	86.41	69.7	Keeping only last year because of up down early
BM-W12	687939.93	9167541.88	3.41	3.438	3.451	3.442	3.461	3.489	3.526	3.558	3.547	3.584	3.616	3.653	3.673	3.775	3.75	3.791	3.827	0.417	16	26.1	91.22	76.7	Keeping only last year because of up down early
BM-W13	687842.45	9166785	4.384	4.392	4.395	4.373	4.363	4.391	4.393	4.406	4.383	4.379	4.412	4.432	4.416	4.511	4.467	4.49	4.462	0.078	16	4.9	17.06	9.3	Looks good data for last year although low result. Keeping only last year be
Pier-JMP	688122	9168272	2.047	2.099	2.132	2.138	2.176	2.192	2.265	2.31	2.319	2.373	2.419	2.485	2.521	2.673	2.658	2.717	2.763	0.716	16	44.8	156.63	138.3	Keeping only last year because of up down early
TTG-1304	686567.01	9162606.12	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	13.826	0	16	0	0	0	Assumed stable
TTG-1305	687355.13	9165632.49	9.416	9.43	9.421	9.405	9.393	9.421	9.413	9.42	9.395	9.391	9.422	9.432	9.422	9.513	9.468	9.466	9.45	0.034	16	2.1	7.44	1.8	Keeping only last year because of up down early
TTG-1322	689470	9163398	5.32	5.345	5.337	5.32	5.356	5.338	5.336	5.337	5.344	5.34	5.343	5.337	5.341	5.386	5.319	5.358	5.367	0.047	16	2.9	10.28	6.1	Erratic until Apr08. Early values discarded. Should be stable

Table 2: BPLS Operations Group Differential GPS measurements began relatively recently but extend farther away from the mud ponds

LABEL	EastUTM	NorthUTM	04/09 (m)	03/09 (m)	02/09 (m)	01/09 (m)	12/08 (m)	TOTAL	RECORD	RATE	CALC TOTAL	MY EST	Comment
benchmark	(m)	(m)	9-Apr	9-Mar	9-Feb	9-Jan	8-Dec	CHANGE	MONTHS	mm/month	(cm)	(cm)	
1304	686567.007	9162606.122	13.826	13.826	13.826	13.826	13.826	0	4	0	0	0	Considered stable - all measurements relative to this
DG 01	687359.75	9165635.443	9.631	9.586	9.625	9.604	9.62	-0.011	4	-2.75	-9.63	-9.63	Up and down-ignore-does not agree with levels
DG 02	687835.653	9167282.513	3.562	3.512	3.584	3.581	3.581	0.019	4	4.75	16.62	80.55	Eliminated final measurement for better agreement with levels. Variable (even-up 0.3-down 7.2-up 5)
DG 03	687945.755	9167626.755		3.224	3.231	3.272	3.247	0.023	3	7.67	26.83	73.33	Seems low so ignored first up for better agreement with levels (up 2.5-down 4.1-down 0.7)
DG 04	688116.654	9168212.031	2.829	2.856	2.878	2.923	2.974	0.145	4	36.25	126.87	126.87	Good consistant data
DG 05	688408.392	9169374.699	3.558	3.623	3.727	3.619	3.607	0.049	4	12.25	42.87	42.87	Variable but agrees with levels (up 1.2 up 10.8 down 10.4 down 6.5)
DG 06	687512.267	9169197.325	3.457	3.515	3.466	3.297		-0.16	3	-53.33	-186.67	15.55	Disregarding first measurement. Uncertain and variable (21.2 cm range up 16.9 up 4.9 down 5.8)
DG 07	687780.542	9167880.581		3.39	3.407	3.392		0.002	2	1	3.5	3.5	Short up and down
DG 08	687323.945	9168743.936	2.918	2.856	2.939	2.883		-0.035	3	-11.67	-40.83	36.66	Needs longer record. Undependably variable (up 5.6 down 8.3 up 6.2)
DG 09	689811.454	9165308.347	5.446	5.475	5.433	5.476		0.03	3	10	35	3.5	Threw out last measurement-down up down stable
DG 10	690993.121	9167683.034	2.128	2.142	2.125	2.141		0.013	3	4.33	15.17	15.17	Up and down
DG 11	690071.427	9168770.782	2.13	2.112	2.075	2.094		-0.036	3	-12	-42	66.6	Uncertain -modified to reflect only first two measurments thus agree with nearby
DG 12	691216.299	9166512.945	1.907	1.922	1.944			0.037	2	18.5	64.75	44.44	Short record prob not typical of 35 months. Far from vent- subsidence fairly recent
DG 13	689032.163	9172521.841	2.569	2.608	2.569			0	2	0	0	0	Variability cancels-expected stable
DG-14	686829.55	9167905.52	3.326	3.295	3.251			-0.075	2	-37.5	-131.25	-131.25	2 month record consistant (up 4.3 up 7.6)
DG 15	688102.155	9168282.087	8.532					0	0				Only one measurement - no rate

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References

Davies, R.J., Brumm, M., Manga, M., Rubiandini, R., Swarbick, R., Tingay, M. (2008) The East Java mud volcano (2006 to present): An earthquake or drilling trigger? Earth Planet. Sci. Lett., doi: 10.1016/j.epsl.2008.05.029, accessed May, 2008.

Mazzini, A., Svensen, H., Akhmanov, Aloisi, G., Planke, S., Malthe-Sørenssen, A., Istadi, B., (2007) Triggering and dynamic evolution of the LUSI mud volcano, Indonesia. Earth Planet. Sci. Lett. 261: 375-388.

Plumlee, G.S., Casadevall, T.J., Wibowo, H.T., Rosenbauer, R.J., Johnson, C.A., Breit, G.N., Lowers, H.A., Wolf, R.E., Hageman, P.L., Goldstein, H., Berry, C.J., Fey, D.L., Meeker, G.P., Morman, S.A. (2008) Preliminary analytical results for a mud sample collected from the LUSI mud volcano, Sidoarjo, East Java, Indonesia: U.S. Geol. Surv. Open-File Report 2008-1019.

UNEP/OCHA (2006) Environmental Assessment – Hot Mud Flow East Java, Indonesia: United Nations Disaster Assessment and Coordination Mission Final Technical Report, Joint United Nations Environment Program/Office for the Coordination of Humanitarian Affairs Environment Unit, http://www.un.or.id/upload/ lib/Indonesia hot mud flow East Java final report.pdf.

