Radiation Measurements of the Fukushima Nuclear Accident

COSC 445/545 Final Project

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Introduction

On March 11th, 2011, a 9.0 magnitude earthquake occurred approximately 72 km east of the coast of Japan. Dubbed the "Great East Japan Earthquake" among many other names, it triggered a powerful tsunami which travelled up to 10 km inland. The earthquake and tsunami caused widespread destruction along the eastern coast of Japan, resulting in tens of thousands of deaths and financial losses in the hundreds of billions of US dollars. The most memorable consequence of this event, however, is the damage sustained by the Fukushima-Daiichi nuclear power plant. Three nuclear reactor cores partially melted and spent fuel storage pools were damaged, resulting in considerable release of radioactive particles into the atmosphere.

The spread and magnitude of radioactivity released by the Fukushima accident is a subject of significant debate. TEPCO, the company operating the Fukushima reactors, was constantly changing their release estimates. Public trust in the ability of TEPCO and the Japanese government to accurately determine the risk from increased radioactivity to civilians living near the plant deteriorated.

This analysis examines the allegations that the Japanese Ministry of Education, Culture, Sport, Science, and Technology (MEXT) understated radioactivity measurements in areas around Fukushima in the months immediately following the accident. They are compared to the measurements of an independent non-profit Safecast who also took similar radiation measurements.

Radiation Exposure, Dose Rates, and Health Effects

Radiation is energy in the form of particles that are emitted by various different atomic and sub-atomic processes. The Sievert (Sv) is the unit that measures the potential health effects of resulting from radiation exposure. The radiation of concern in the Fukushima accident was gamma ray radiation emitted by radioactive cesium and iodine atoms that were released from the nuclear reactor fuel cores. Measurements taken on the timespan of less than a month are typically recorded in units of μSv/hr (1 Sv = 1e6 μSv). There are several pathways for an individual to be exposed to radiation, but external exposure is largely responsible for the majority of the gamma ray dose.

Everyone on planet earth is exposed to some level of background radiation, with typical annual background doses ranging from 1 to 10 mSv (1 Sv = 1000 mSv). The potential health effect of concern for people around the Fukushima accident is the increased chance of developing cancer in one's lifetime as a result of chronic exposure to elevated levels of radiation. The lowest recorded annual dose that resulted in an increased cancer risk is 100 mSv. This translates to exposure of 11.41 μSv/hr for an entire year. The scientifically accepted annual dose that causes a 5% increase in the probability of cancer over one's lifetime is 1000 mSv, or 1 Sv. This translates to exposure of 111.4 μSv/hr for an entire year.

Data Description and Manipulation

Both the MEXT and the Safecast data measured air samples for gamma radiation using different methodologies. The MEXT data was downloadable from the International Atomic Energy Agency (IAEA) website, while Safecast also hosted its raw data on the web in .csv format.[1] This required significant data manipulation to ensure that we were comparing similar radiation measurements.

The dose rate from radioactivity in the MEXT data was reported in μSv/hr. However, the Safecast data reported radioactivity in counts per second (cps), which needed to be converted to μSv/hr in order to compare the two data sets. This conversion depends on the type of instrument used. Fortunately, the Safecast data included the Device_ID of each measurement, and a conversion from cps to μSv/hr for every Device_ID was made available in the comments of some code from the Safecast Github repository.[2]

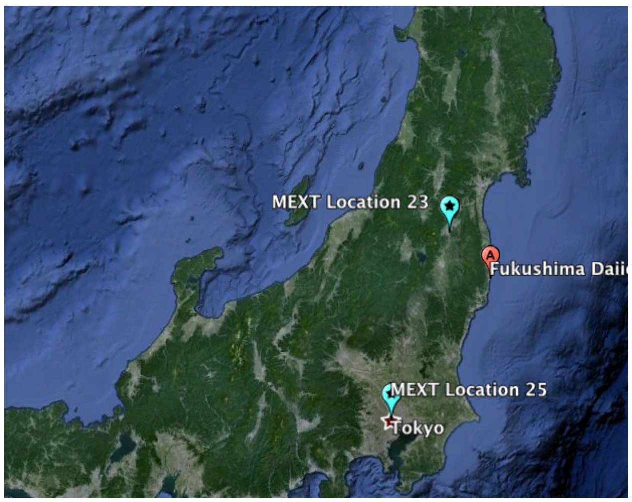
The MEXT measurements were taken at a fixed location at fixed times of the day from March 14th, 2011 to January 1st, 2012, amounting to approximately 330,000 entries. The Safecast measurements, on the other hand, were taken by placing a radiation detector on a car and driving through areas of interest, recording a measurement every few minutes. The raw Safecast data included over 32 million entries. However, the Safecast measurements ranged in time from April 23, 2011 to October 5, 2015. Thus, we only examined the Safecast entries that were within the date range of the MEXT data. This reduced the Safecast data set to around 2.1 million entries.

In order to compare one radioactivity measurement to another, however, the measurements must be similar in both time and space. Radioactivity concentration decreases exponentially in both of these dimensions. Thus we determined that a criteria of a Safecast measurement within 500 meters and one hour of a MEXT measurement. Because the Safecast data was measured using a car, nearly every Safecast measurement point had a slightly different latitude and/or longitude. By contrast, the MEXT data included only 47 different (latitude,longitude) locations. So, we calculated the distance from each of the 47 MEXT locations for every of the 2.1 million Safecast entries and added a column 'mloc_id' based on the MEXT location the entry was was nearest to. Based on that mloc_id, we generated a hashtable of all the times of the MEXT measurements taken at that MEXT mloc_id. Again iterating through the 2.1 million Safecast entries, we determined the closest MEXT measurement in time for the corresponding closest MEXT location. After filtering this data set for measurements that were at

[1] MEXT data: https://iec.iaea.org/fmd/data_set_information.aspx?id=6 , Safecast data: http://blog.Safecast.org/

[2] https://github.com/Safecast/Safecastapi/blob/master/script/ios_query.sql

most 500m apart in distance and 1 hour apart in time, we were left with 1,976 Safecast-MEXT measurement pairs. This is a huge reduction of data, which is the result of our filtering by proximity of location and time. Of the 1,976 rows of data, there were 7 unique locations where MEXT data was measured. We decided to focus our efforts on two unique locations, because they had the most associated Safecast measurements. MEXT locations with 'mloc_id' 23 and 25 made up 76% of all data points in the data set. MEXT location 23 was within the town of Fukushima, only a few kilometers away from the power plant. MEXT location 25 was in the heart of downtown Tokyo. Doing so, we filtered the data down to 1,511 entries. The map below shows MEXT locations 23 and 25 in relation to the Fukushima Daiichi nuclear power plant.

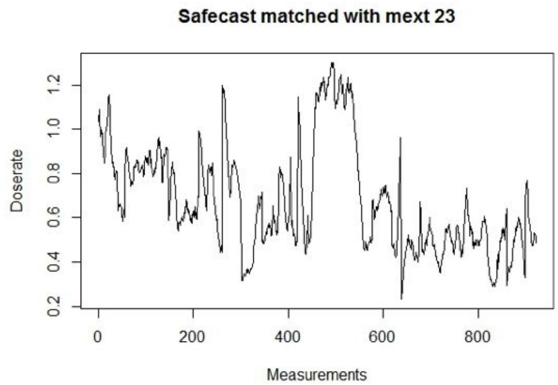


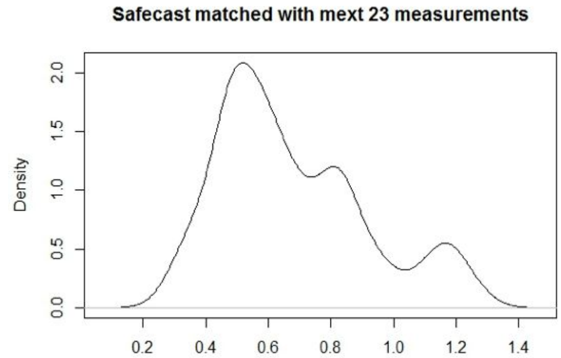
In this data set, each row represents a Safecast radiation measurement matched by the closest corresponding MEXT measurement. In total, however, there were only 17 unique measurements in time for MEXT location 23. MEXT location 25 only had 9 unique measurements in time. Because of the sparse data, it is hard to compare with confidence between the Safecast and MEXT data.

Analysis

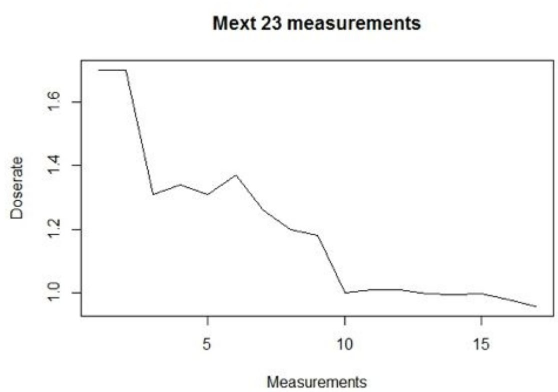
Time Series Analysis

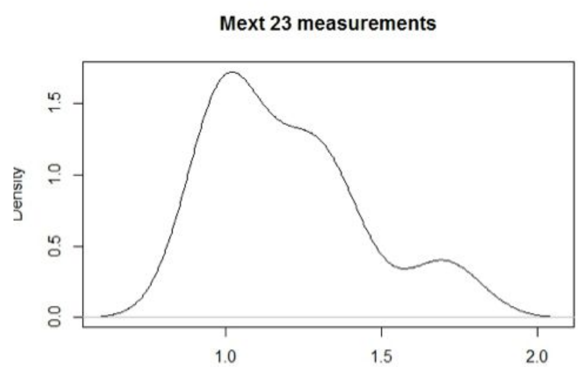
In order to understand how measurements for both Safecast and MEXT data sets changed over time we decided to plot the data. The first graph below depicts how measured dose rate changed over time for the Safecast data matched with MEXT location 23. We can see that the data fluctuates over time around the mean of 0.62 μSv/hr. There seems to be a few spikes in the data, but they usually come back down around the mean. The lowest measurement is 0.23 and the maximum measurement is 1.3 μSv/hr. The density plot provides a visual of how the measurements are distributed. You can see that there are more distributed on the high side than the lower side. However, many are distributed around the mean.





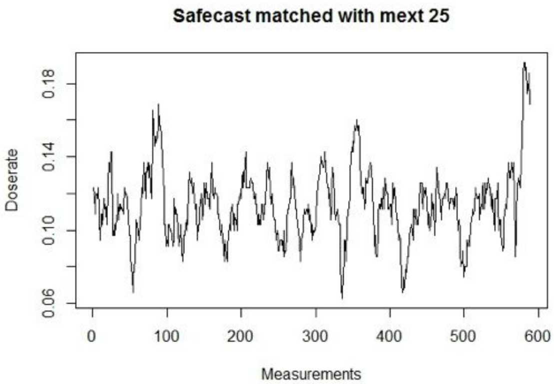
In order to compare the Safecast data to MEXT data we need to summarize the MEXT data at locations 23. The mean for MEXT location 23 is 1.2 with a minimum and maximum of 0.96 and 1.7, respectively. The time series plot and density can be seen below.

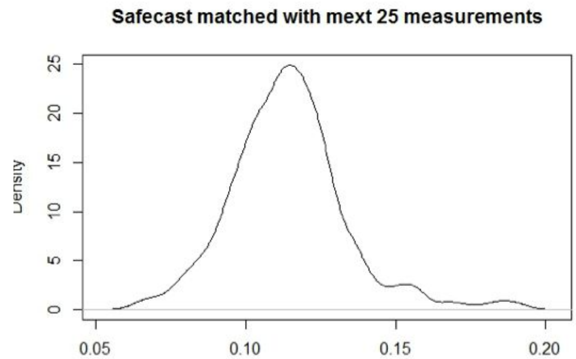




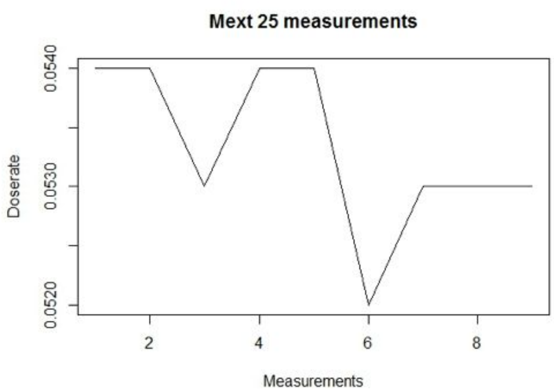
Comparing the Safecast and MEXT data at MEXT location 23, we can see that both are trending downward over time. Both are also distributed similarly in that they are skewed on the higher side of the mean. However, the MEXT data has a much larger minimum measured dose rate. Although both data sets have a downward trend and similar variability, the MEXT data has a higher measured dose rate. In fact, the mean MEXT measurement is 93.5% higher than that of Safecast.

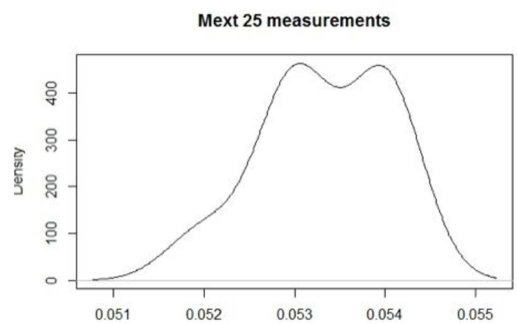
Now looking at the Safecast data that was matched with MEXT location 25, we see that the mean measured dose rate was 0.11 µSv/hr. The minimum and maximum measurements were 0.06 and 0.19 µSv/hr, respectively. This is a much tighter range of radiation measurements than the MEXT 23 location measurements. Below are the graphs for the time series plot and density plot.





Lastly, the MEXT data at location 25 has a mean measured dose rate of 0.53 μSv/hr. The minimum and maximum measurements are 0.052 and 0.54 μSv/hr, respectively. This is very little variability, but it steps from the fact that there are only 9 data points. The time series plot and density plot are plotted below. However, with such few points, very few conclusive results can be interpreted from the plots.



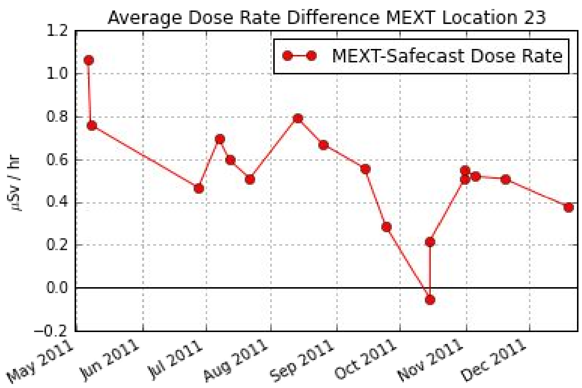


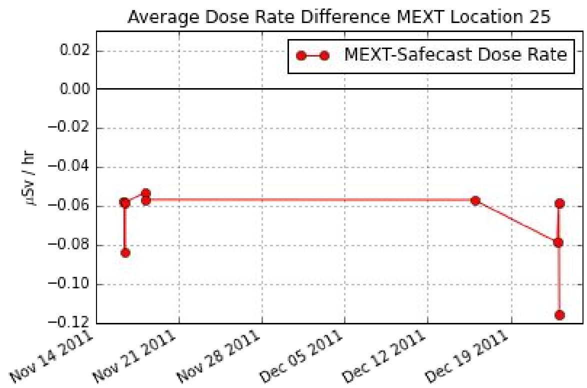
Comparing the Safecast and MEXT data at MEXT location 25, we can see that the Safecast data is pretty much random with an increase at the end. The MEXT data seems to be trending downward, but again there is very little data. There also seems to be a difference in how both data sets are distributed. The Safecast data is primarily distributed around the mean, but skewed slightly on the higher side. The MEXT data is bimodal and skewed toward the lower end. The mean of the Safecast data is also much higher than the MEXT data (107% higher).

The comparisons above suggest that both the Safecast and MEXT data sets are different at MEXT locations 23 and 25. If there were more data for the MEXT locations we could have used time series modelling to compare the data. However, with a limited amount of MEXT data, we decided to keep the analysis more simple and take the results with a grain of salt. Fitting ARIMA functions and then comparing would have been a much more robust method. That would provide better evidence to what data generating functions are comprising the data. If each data set had a different ARIMA structure, then you could conclude that the measurements are statistically different.

Dose Rate Difference

It is useful, however, to average the measured dose rate of all the Safecast measurements that are closest to a given MEXT (time,location) pair and compare that averaged Safecast dose rate to the single MEXT dose rate. The plots below show the difference in Safecast and MEXT dose rates as a function of time at MEXT locations 23 and 25.

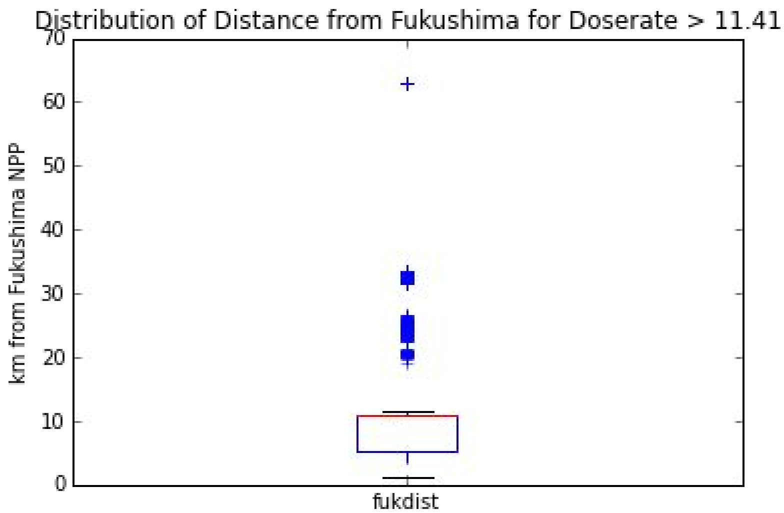




As can be seen in the plots above, the MEXT measurements were nearly always higher than the averaged Safecast measurements at MEXT location 23. At MEXT location 25, however, the averaged Safecast measurements were always greater than the corresponding MEXT measurement. It is also important to note the scale on both of these plots, however. At MEXT location 23, the MEXT measurement is only about 1 μSv/hr greater than the averaged Safecast measurement at the most. At MEXT location 23, the magnitude of the difference does not exceed 0.12 μSv/hr. Even a difference of 1 μSv/hr is a considerably small difference considering the all of the factors that can affect a radiation measurement, from counting statistics to detector efficiency to physical variation which

Risk Assessment

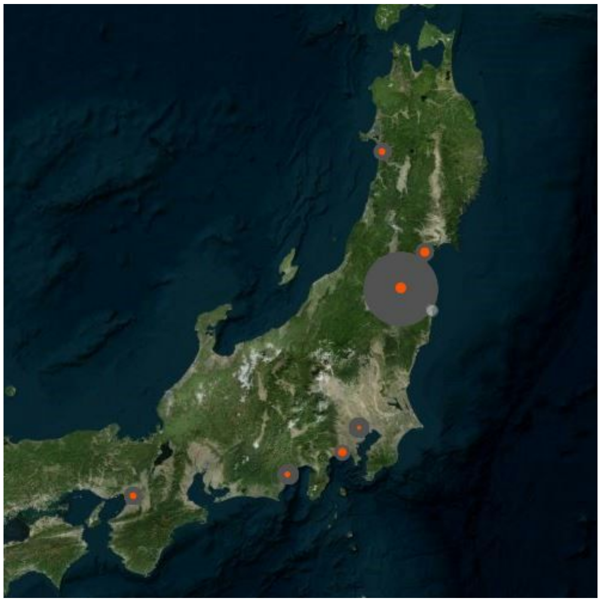
Both data sets were analyzed for dose rate measurements above 11.41 μSv/hr. If an individual was exposed to this dose rate for an entire year, they may have an increased probability of cancer in their lifetime. Within the timeframe of the MEXT data, 3613 of the 2117836 (0.17%) of the Safecast measurements recorded at least 11.41 μSv/hr. The majority of these were within 10km of the Fukushima power plant, well within the 20km evacuation zone. The box plot below shows the distribution of distances from the Fukushima power plant among Safecast measurements of 11.41 μSv/hr and above.

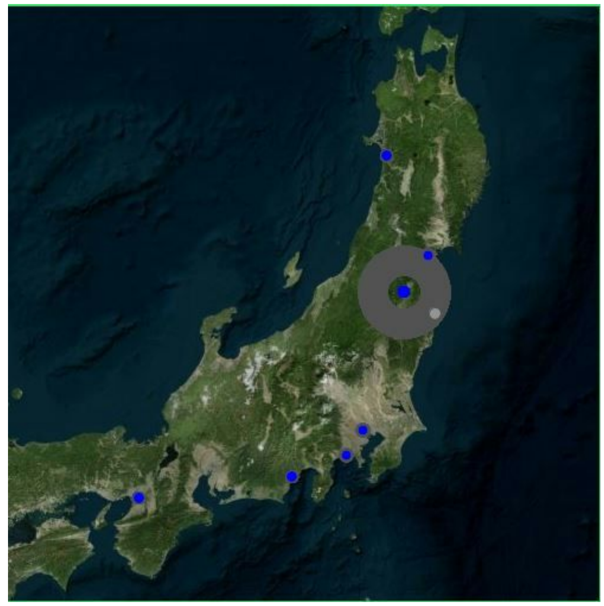


Unfortunately, none of the Safecast measurements above 11.41 μSv/hr were within 500m of a MEXT location. No MEXT measurements exceeded 11.41 μSv/hr either. Perhaps exploration of other MEXT datasets that are closer to the Fukushima nuclear power plant could provide more insight on how willing MEXT was to report potentially dangerous dose rate measurements.

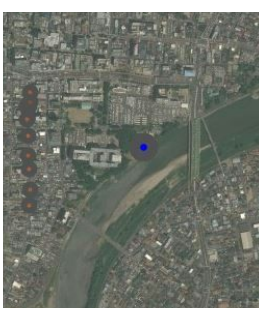
Visualization

To visualize the differences between the the data for Safecast and MEXT, Processing was used to map the dose rates for the data. The data was grouped primarily at seven locations, mapped using the latitude and longitude data for the recordings. The strokeweight of the markers are weighted by the dose rate of the samples. It is immediately noticeable from the map below, with Safecast data in orange and MEXT in blue, that the region closest to the Fukushima plant (recorded in Fukushima, Japan) site has by far the highest dose rate sampling. The Fukushima nuclear plant is denoted with the white dot on the below maps.





This map, however, can be misleading due to the data being collected over a long period of time. Due to the nature of radiation, sampling over several months makes it difficult to get details from the data by examining the entire set at once. To better visualize the data, plots were created for a small section of Fukushima separated by the dates they were collected on. Because data should not be examined across time over periods of more than an hour, some of the days have multiple maps created for the different times. For the vast majority of the points, the Safecast data dose rate was lower than the dose rate of the MEXT data. Values where the Safecast dose rate was higher are denoted by blue bands instead of gray, seen in the data taken from Oct 15th. From the images it is shown that the blue band markers happen to be the only Safecast data collected at that particular location near the South side of the river.



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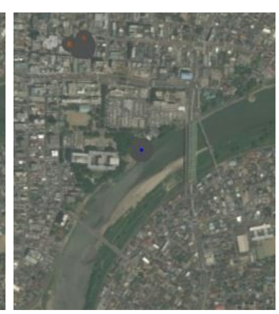

7/7/11

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8/25/11

9/14/11

9/24/11

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10/31/11 11 am

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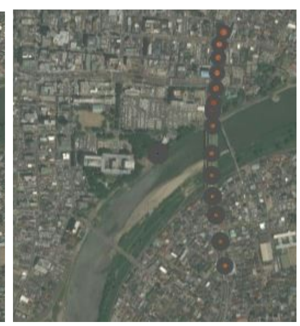
11/19/11



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Conclusions

Our attempts to compare the official government dose rate measurements in Japan following the Fukushima accident to those of an independent non-profit were made difficult by the lack of measurements comparable in both time and space. We decided to only compare measurements that were within 500m and 1 hour of each other. The results of this analysis indicated that there were not substantial differences in the measured dose rates between the two data sources, although the scope of this analysis was fairly limited by data availability. We determined that very few of dose rate measurements from either data source represented a significant threat to human well-being. Our analysis also provides evidence against allegations that the official Japanese government agency MEXT was purposely understating reported dose rates in the months following the Fukushima accident.