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Climate and Communications

Geological Survey
Suirbhéireacht Gheolaíochta
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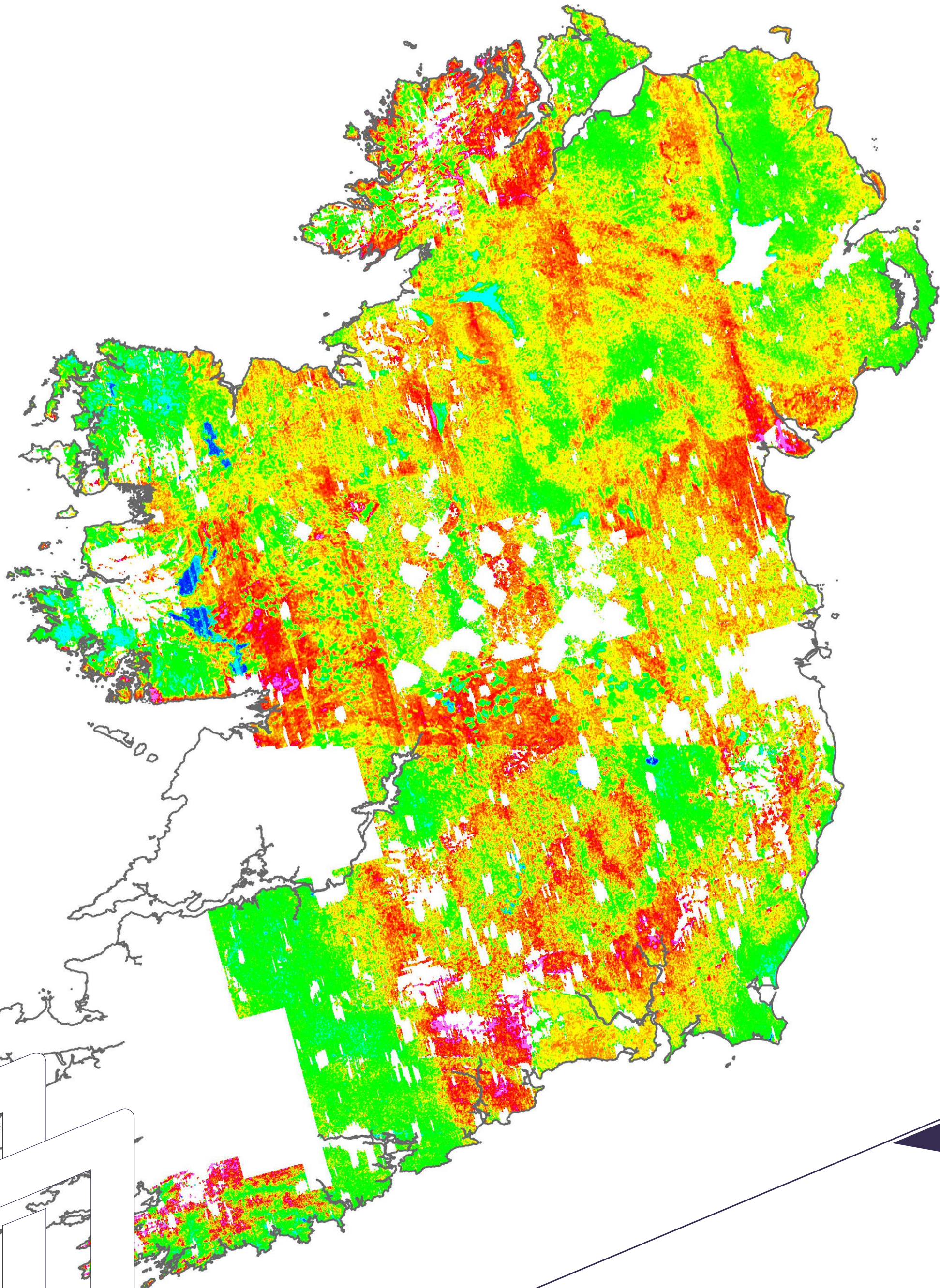
Caesium-137 airborne data: Processing and Merging for the Tellus Programme 2022



Geological Survey Ireland

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The Tellus Project

Tellus is a national programme to gather geochemical and geophysical data across the island of Ireland. The survey examines the chemical and physical properties of our soils, rocks and waters to inform the management of Ireland's environment and natural resources. The project is managed by Geological Survey, Ireland (GSI) and is funded by the Department of Environment, Climate and Communications (DECC)).

For more information on the Tellus Project please visit www.tellus.ie

Executive Summary

This report presents Caesium-137 (^{137}Cs) concentrations derived by the processing and merging of the Tellus airborne spectrometer data collected from a series of airborne survey blocks flown between 2005 and 2021. Data have been temporally corrected to 2021 and all data seamlessly merged into one dataset.

The Tellus ^{137}Cs concentration data were derived from airborne spectrometer 256 and 512 channel data at the spectral gamma-peak at 662 keV using PRAGA4 software. The process yields ^{137}Cs through three smoothed output spectrums: Least squares fitting (LSQ), Maximum Noise Fraction (MNF) and Noise Added Singular Value Decomposition (NASVD) spectrums. The results from each method were compared and the NASVD was preferred.

The merged ^{137}Cs data show typical values between 0.01 and 9.8 kBq/m^2, with most values less than 4 kBq/m^2 and show well-defined banding of higher values along NNW-SSE and WNW-ESE orientations (Figure 2). The main influence on ^{137}Cs distribution in Ireland relates to the 1986 Chernobyl incident and fallout from weapons testing. On the east coast, impact from the Sellafield Nuclear Plant in the UK is observed. ^{137}Cs distributions, as shown from the airborne data, are consistent with deposition by rainfall intercepting the contaminant plume following the Chernobyl nuclear accident. It is further controlled, in part, by topography. The bands are clearly not related to single flight lines, groups of lines flown together or blocks of data (Jones and Scheib, 2007). Similar linear features (banding) are seen in data from other parts of the UK and France but are probably more pronounced in the Tellus data owing to the close flight-line spacing (200 m). Concentrations of ^{137}Cs are in line with previously published values (Jones and Scheib, 2007), allowing for the decay of ^{137}Cs post-Chernobyl and earlier fallout. Laboratory analysis of ^{137}Cs in soil samples from the Tellus geochemical survey correlate well with the airborne ^{137}Cs measurements, giving confidence in the airborne results.

1. Introduction

Cs^{137} is a radioactive element with a half-life of 30.15 years. This particular isotope of caesium is both a beta and gamma emitter. It is produced in some abundance by fission reactions, which is the main source of long term contaminations after atmospheric tests of atomic bombs and nuclear accidents. Along with strontium-90 and plutonium isotopes, it is a principal source of radiation from radioactive waste and after nuclear reactor accidents.

The Tellus programme undertakes an airborne geophysical survey collecting magnetic, gamma-ray spectrometry and electromagnetic data across the island of Ireland. The first Tellus survey was carried out over Northern Ireland and Cavan-Monaghan between 2005 and 2006. Surveys were then carried out on an annual basis since the first survey in the Republic of Ireland in 2011. Data from the different survey blocks are then merged together to form a seamless dataset.

The Tellus ^{137}Cs data have been extracted from airborne spectrometer 256-channel data from the Northern Ireland (NI), Cavan (CAV), Tellus Border (TB), Charlestown (Aurum Block), Tellus north midlands (TNM) and A1 blocks. From block A2 onwards, the number of channels was changed to 1024, with new crystal sizes (67.2 L). The 1024-channel data were decimated to 512 channels, to run in PRAGA4 software. ^{137}Cs data were generated from the gamma-peak at 662 keV. The process yields ^{137}Cs through three smoothed output spectrums: Least squares fitting, Maximum Noise Fraction (MNF) and Noise Added Singular Value Decomposition (NASVD) spectrums. The NASVD output is preferred and used for the merging of all Tellus blocks.

In NASVD processing, radiometric data in each detector channel result in a Poisson distribution with the variance equal to the mean value of the count rate in this channel. The mean spectrum can be seen as an estimation of the variance of the statistical noise across the whole spectrum. Therefore, in NASVD, input spectra are normalized by the square root of the mean spectrum (and also by the spectrum total count) before a conventional principal component technique is applied. As a result, noise variance is equal (to one) across the whole spectrum and computed eigenvectors are sorted by decreasing signal variance.

In spectrum analysis, Principal Component Analysis (PCA) methods are used to extract non-correlated spectrum signatures - eigenvectors from the data in the presence of the noise. Subject to good statistics in the dataset (good signal variation and sufficient amount of data), PCA will separate responses of all radiometric sources from the noise and store them into a limited number of NASVD/MNF eigenvectors. These eigenvectors are subsequently ‘fitted’ back to input spectra, in a similar way as done by the LSQ fitting technique with the use of model detector responses.

The data from Northern Ireland (NI), collected in 2005/2006, from Cavan-Monaghan collected in 2006 (CAV) and from Tellus Border in 2011/2012 (TB) were previously processed (Hodgson and Ture, 2013) in the same way as the current processing described in this report. Temporal variation corrections (to account for radioactive decay with time) were applied to the NI and CAV datasets to reduce their ^{137}Cs concentrations equivalent to values for the year 2012, so as to facilitate a merge with the then new TB data set.

All the Tellus radiometric data collected before 2020 were processed using PRAGA4 software in February, March and April 2021, with the exception of the North Midlands data (2014), where the previously released company delivered ^{137}Cs data were used. All ^{137}Cs data collected and processed prior to 2020 were merged and released in October 2021, referred to as "*Tellus_Caesium137_Merge2021.*"

The latest phases of Tellus data included with this new merge are the A8, A9 and A6 blocks surveyed in 2020-2021, 2021 and 2016 respectively. The current merge is named "*Tellus_Caesium137_Merge2022*.".

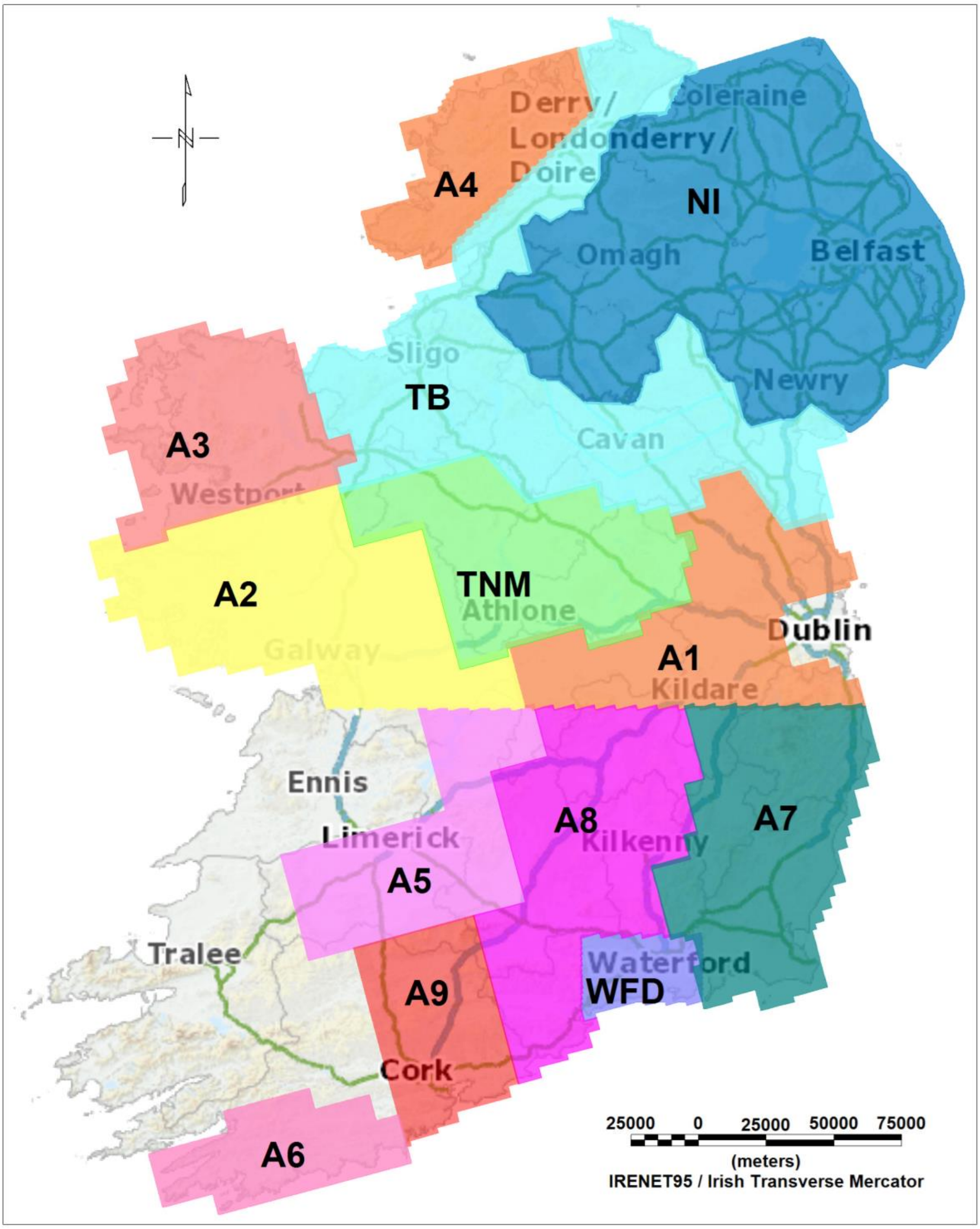

Figure 1: Tellus Survey blocks incorporated into the current ^{137}Cs merge (Merge2022). Note that the Cavan-Monaghan (CAV) block is not shown separately in this image, but is included with the Tellus Border (TB) block.

Before processing of the new survey data, the previously processed data from Northern Ireland, Tellus Border and Cavan were re-processed. This allowed an assessment as to whether the new processing produced similar results to those already described and published. It was concluded that the newly processed data produces very similar results and provides confidence in the approach. The previous processing showed minimum, maximum and mean values of 0.01, 9.80

and 3.00 kBq/m^2, which compares well with the reprocessed values of 0.04, 9.46 and 2.92 kBq/m^2 (for data with no temporal corrections applied, but clipped to remove high-fly data and data recorded over offshore and large inland waterbodies).

^{137}Cs data were then derived for each survey block. Statistics for individual blocks are given in Table 1 (^{137}Cs data shown in Table 1 have not yet been corrected for temporal variations or corrected for high fly effects).

Table 1: ^{137}Cs (kBq/m^2) statistics by block BEFORE application of coastal clipping, temporal correction and overlap zone adjustment. NITBCAV block refers to the merged block consisting of Northern Ireland (NI), Tellus Border (TB) and Cavan-Monaghan (CAV) blocks. The "_Corrected" suffix to the NITBCAV block name indicates that these data have been corrected for temporal decay to 2012.

Block	**Year**	Min	Max	Mean	Channels
A9	2021	0.00	7.17	1.70	512
A8	2020-2021	0.01	6.94	1.49	512
A7	2019	0.02	9.7	2.1	512
A6	2018	0.03	9.8	1.98	512
A5	2018	0.06	8.4	1.59	512
A4	2017	0.0	9.7	2.3	512
A3	2017	0.06	7.2	1.7	512
A2	2016	0.0	8.78	2.03	512
WFD	2016	0.34	3.99	1.45	512
A1	2015	0.013	9.33	2.7	256
TNM	2015	0.19	5.45	2.06	256
NITBCAV_Corrected	2012	0.42	9.46	2.50	256

The disintegration of a given quantity of any radioactive element can be expressed by the formula $N = N_0 e^{-\lambda t}$ where λ is the decay constant, N_0 is the number of parent nuclei at time t_0 and t is the time since t_0. N is number of parent nuclei remaining after time t. Correction factors were computed for each block to account for ^{137}Cs radioactive decay since the time (year) of the survey, t_0, and the present day in 2021 (when the most recent data were collected). The temporal variation corrections are indicated in Table 2 and were applied to all blocks to bring the ^{137}Cs levels to the year 2021.

Assuming that the main source of ^{137}Cs in Ireland is the Chernobyl accident, survey data measured several years ago will reflect higher ^{137}Cs concentration values than would be the case if the survey were flown today. Therefore, to allow merging of data collected at different times, all the survey data have been corrected to the current year 2021. As shown in the Table 2, the parent material in 2012, for example, is reduced by a factor of 0.812 to correct to the present day. Year 2012 in our case is the time when the NI, CAV and TB data were corrected for temporal variation to 2012 and merged into one data block.

Table 2: Temporal variation corrections applied to data blocks to account for ^{137}Cs radioactive decay since survey date and the present day (2021).

Block	Year	No. Years from 2021	decay constant	tλ	$e^{-\lambda t}$	Temporal correction
A9	2021	0	-0.0231	0	1.000	A9*1
A8	2021	0	-0.0231	0	1.000	A8*1
A7	2019	2	-0.0231	-0.0462	0.955	A7*0.955
A6	2018	3	-0.0231	-0.0693	0.933	A6*0.933
A5	2018	3	-0.0231	-0.0693	0.933	A5*0.933
A4	2017	4	-0.0231	-0.0924	0.911	A4*0.911
A3	2017	4	-0.0231	-0.0924	0.911	A3*0.911
A2	2016	5	-0.0231	-0.1155	0.891	A2*0.891
WFD	2016	5	-0.0231	-0.1155	0.891	WFD*0.891
A1	2015	6	-0.0231	-0.1386	0.871	A1*0.871
TNM	2015	7	-0.0231	-0.1617	0.850	TNM*0.871
TBCAV_NI	2012	9	-0.0231	-0.2079	0.812	TBCAV_NI*0.812

- Temporal variation was applied to all blocks to bring the data to 2021 ^{137}Cs levels.
- The output ^{137}Cs data correspond with activity per unit area (A_a), in units of Becquerels per square metre (Bq/m^2).
- The negative values and non-responses were clipped from the data. Data were converted from Bq/m^2 to kBq/m^2. The statistics of each block were checked, with data clipped to minimum of zero and the maximum value retained.
- It was observed that ^{137}Cs data are affected by high fly altitudes and all data were therefore trimmed (rejected) where flight altitude is greater than 100 m to reduce this altitude effect.
- A master database was created for the merged ^{137}Cs data and a corresponding XYZ ascii file was extracted.

The ^{137}Cs statistics for each block, after correction for temporal variation, clipping to the coastline and 100 m flight altitude, and overlap adjustment (Section 3) are shown in Table 3.

Table 3: ^{137}Cs 2022 statistics (in kBq/m^2) by block for the merged dataset AFTER temporal correction to 2021, overlap adjustment and coastal and 100 m flight altitude clipping.

BLOCK	Min	Max	Mean	Channels	Year flown
A9	0.10	6.21	2.52	512	2021
A8	0.12	9.55	2.86	512	2020-2021
A7	0.00	8.11	2.17	512	2019
A6	0.0	9.14	2.51	512	2018
A5	0.03	7.36	2.03	512	2018
A4	0.00	8.17	2.42	512	2017
A3	0.10	7.69	2.14	512	2017
A2	0.07	7.06	2.20	512	2016
WFD	0.30	4.85	2.09	512	2016
A1	0.48	6.43	2.49	256	2015
TNM	0.30	6.30	2.45	256	2014-2015
NITBCAV	0.01	7.95	2.42	256	2005-2012

2. Overlap zone adjustment

Once individual blocks have been temporally corrected to reflect ^{137}Cs responses in the year 2021, individual blocks can then be merged together into one seamless dataset. The merging procedure was carried out by referencing all survey blocks to the previously merged Northern Ireland, Tellus Border and Cavan dataset (NITBCAV). The NI ^{137}Cs data were published in 2013 by GSNI (A guide to the Tellus data, edited by Young and Donald, ISBN 978-0-85272-763-8[pdf]) and provide a known reference. Table 4 shows the merging steps and adjustments applied for each step. The final merged ^{137}Cs image is presented in Figure 2.

The A6 block lacked overlap with any other block prior to A9 block. The block currently has a small overlap zone with A9 and is merged with current merge (Merge2022). ^{137}Cs data were processed for Block A6 and treated in the same way as the other survey blocks, with temporal adjustment and data clipping to coastline and for flight altitude ≤ 100 m applied. The A6 data are presented with the merged data set in Figure 2.

Table 4: Overlap zone adjustment factors applied to produce smooth data transition across block boundaries.

Ratio of overlaps	Mean ratio at overlap	Merge name
NITBCAVAURUM_MERGE/TNM	1.097	NITBCAVAURUMTNM_MERGE
NITBCAVAURUMTNM_MERGE/A3	0.948	NITBCAVAURUMTNMA3_MERGE
NITBCAVAURUMTNMA3_MERGE/A2	1.062	NITBCAVAURUMTNMA3A2_Merge
NITBCAVAURUMTNMA3A2_MERGE/A5	1.112	NITBCAVAURUMTNMA3A2A5_MERGE
NITBCAVAURUMTNMA3A2A5_MERGE/A1	1.080	NITBCAVAURUMTNMA3A2A5A1_MERGE
NITBCAVAURUMTNMA3A2A5A1_MERGE/A7	1.090	NITBCAVAURUMTNMA3A2A5A1A7_MERGE
NITBCAVAURUMTNMA3A2A5A1A7_MERGE/A4	1.186	NITBCAVAURUMTNMA3A2A5A1A7A4_MERGE
NITBCAVAURUMTNMA3A2A5A1A7A4/WFD	1.300	NITBCAVAURUMTNMA3A2A5A1A7A4WFD-Merge
NITBCAVAURUMTNMA3A2A5A1A7A4WFD/A8	1.400	NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8_Merge
NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8/A9	1.030	NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8A9_Merge
NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8A9/A6	0.780	Merge2022

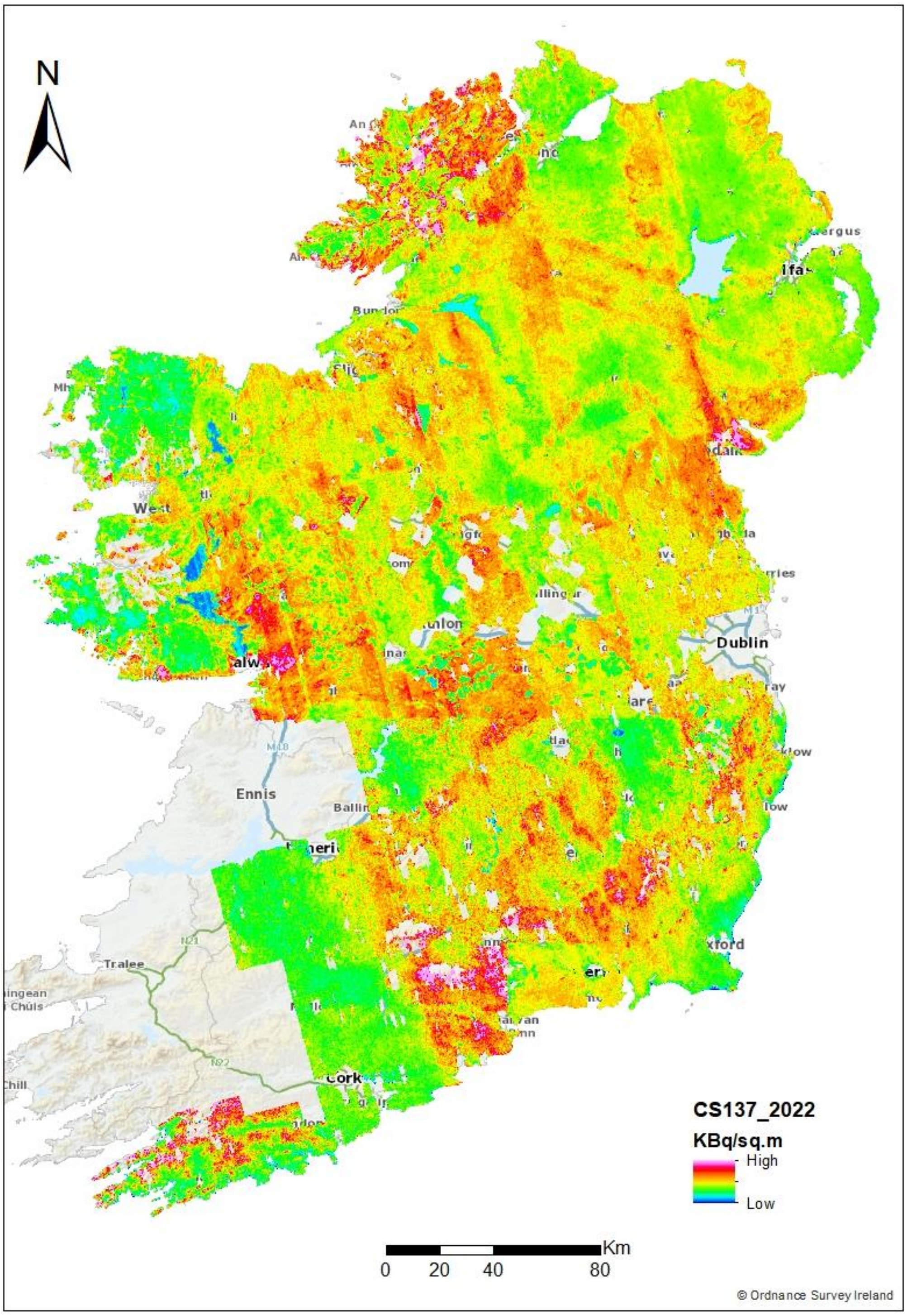

Figure 2: ^{137}Cs Merge 2022 displayed with a linear colour scale 0 – 5 kBq/m^2.

3. Merged Results

The final merged ^{137}Cs data range between 0.01 and 9.8 kBq/m^2. The mean of the merged data is 2.51 kBq/m^2, with standard deviation of 0.76 kBq/m^2. 96% of the merged data are lower than 4 kBq/m^2.

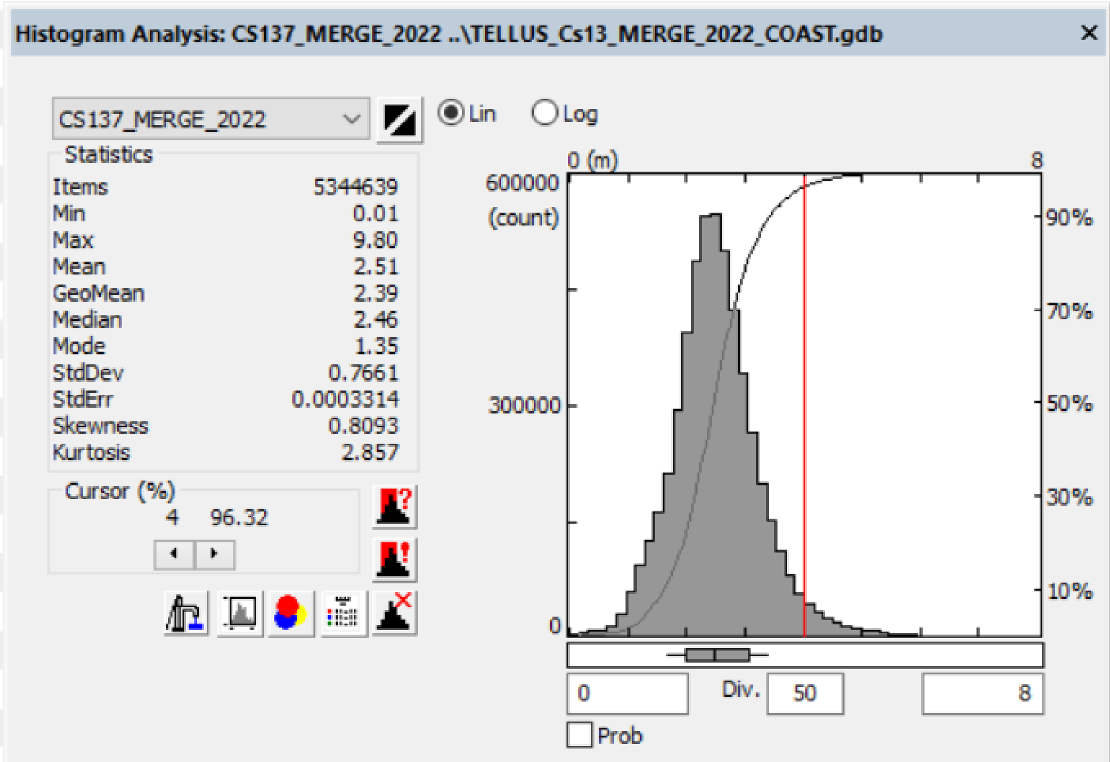

Figure 3: Histogram and statistics of the merged ^{137}Cs dataset.

Most of the data are shown to be less than 4 kBq/m^2, with the highest values recorded in the north and east of the island of Ireland. Mapped results (Figure 2) are consistent with those published previously by Jones and Scheib (2007).

4. Data Errors

1. As the current merge is based on the original 2012 merge of the NITBCAV data, an initial data error assessment can be made by comparing the mean values of the 2012 and 2021 processed ^{137}Cs values (both temporally corrected to 2021). The mean values of the 2012 processing and 2021 (test) re-processing are 2.533 and 2.417 kBq/m^2 respectively. The data deviation between the two is given by

$$\frac{2.533-2.417}{2.533}*100=4.580$$, which is about 5%.

The implication is that differences in the specific parameters chosen during data processing may result in a 5% uncertainty in the derived ^{137}Cs values.

2. Errors in the data were observed in high fly zones due to low signal amplitude and over water bodies due to attenuation of the gamma ray signal by water. A good example is the Waterford block data. The mean of the raw ^{137}Cs data over this block before clipping to the coast was 1.45 kBq/m^2 (Table1). After the offshore data have been clipped, the mean is 2.09 kBq/m^2 (Table3). Note that clipping to” coastline” includes both offshore and major inland water bodies (lakes).

3. The effect of high-fly is very clear in most areas (e.g., Figure 4), where generally reduced ^{137}Cs values are observed. Because of this effect, the ^{137}Cs data were clipped to altitudes less ≤ 100 m. As the 100 m threshold may not remove all spurious data associated with high fly altitudes, care should be taken when interpreting low values observed around high-fly-clipped areas.

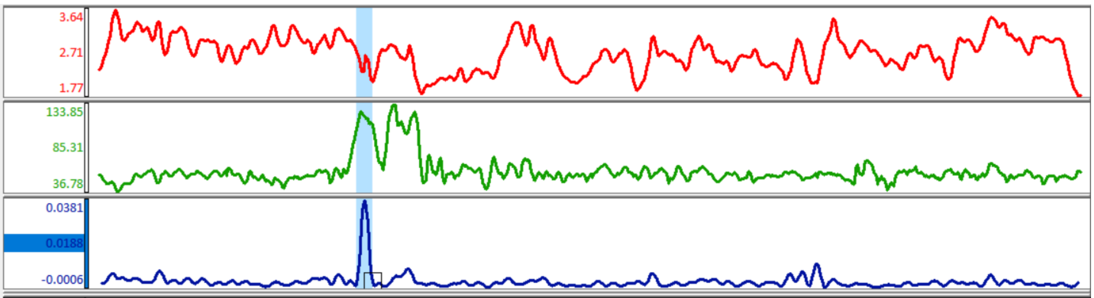

Figure 4: Data example from line B1098 in the Tellus Border Block illustrating the effect of high fly. Top panel is ^{137}Cs, the middle panel is flight altitude and the bottom panel is a low pass filter of the 4th difference of the ^{137}Cs data. The example illustrates that higher flight altitudes may correspond with reduced ^{137}Cs values and higher 4th difference noise in the ^{137}Cs data.

4. An indication of uncertainties in the merged dataset can be provided by an examination of the mean ^{137}Cs ratios in the overlap zones between survey blocks, as well as the differences between the data values in the overlap zones (mean, variance and standard deviation) (Table 5).

Table 5: Merged data deviations, assessed by examination of the data ratios and differences in the overlap zones between survey blocks.

Ratio of Blocks	Mean ratio in overlap zone (kBq/m^2)	Mean difference in overlap zone (kBq/m^2)	Variance of differences in overlap zone (kBq/m^2)	Standard deviation of differences in overlap zone (kBq/m^2)
NITBCAVAURUM_MERGE/TNM	1.097	0.021	0.000044	0.0066
NITBCAVAURUMTNM_MERGE/A3	0.948	-0.139	0.001932	0.0440
NITBCAVAURUMTNMA3_MERGE/A2	1.062	-0.025	0.000062	0.0079
NITBCAVAURUMTNMA3A2_MERGE/A5	1.112	0.025	0.000063	0.0079
NITBCAVAURUMTNMA3A2A5_MERGE/A1	1.080	-0.007	0.000005	0.0022
NITBCAVAURUMTNMA3A2A5A1_MERGE/A7	1.090	0.003	0.000001	0.0009
NITBCAVAURUMTNMA3A2A5A1A7_MERGE/A4	1.186	0.099	0.000980	0.0313
NITBCAVAURUMTNMA3A2A5A1A7A4/WFD	1.300	0.213	0.004537	0.0674
NITBCAVAURUMTNMA3A2A5A1A7A4WFD/A8	1.400	0.313	0.009797	0.0990
NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8/A9	1.030	-0.057	0.000325	0.0180
NITBCAVAURUMTNMA3A2A5A1A7A4WFDA8A9/A6	0.780	-0.307	0.009425	0.0971
Mean	1.099	0.013	0.002470	0.0497

The largest data deviation in Table 5 is observed at the merge of the A8 block (mean ratio of 1.400 kBq/m^2 and mean difference of 0.313 kBq/m^2).

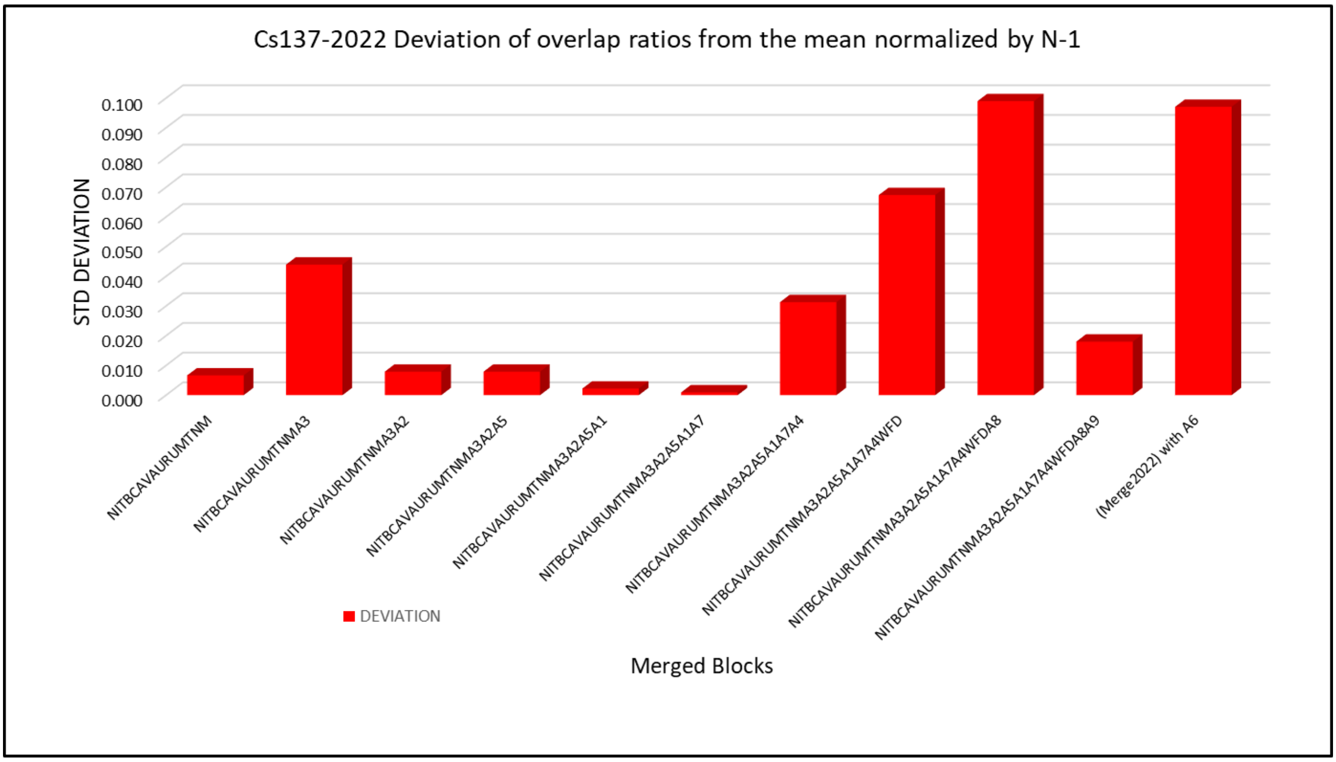

Figure 5: Data deviations in the merged dataset, as indicated by the standard deviation of the ^{137}Cs data differences in overlap zones. Vertical axis is column 5 of Table 5.

5. Merged data set Information

Merged database: **Cs137_Merge_2022.XYZ**

XYZ FILE, DEFINITION OF DATA CHANNELS:

X_ITM: Grid Easting (Irish transverse Mercator) at the mid position of the aircraft
Y_ITM: Grid northing (Irish transverse Mercator) at the mid position of the aircraft
DATE: Date (YYYYMMDD)
CLEARANCE: Ground clearance altitude (m)
SID: Survey ID: TB for Tellus Border, CAV for Cavan, NI for Northern Ireland, A1 – A9 for A1 – A9 blocks, WFD for Waterford block, and TNM for Tellus north midlands block

Cs137_MERGE_2022: merged Caesium channel with adjustment at overlap zones in $\frac{kBq}{m^2}$

Cs137_MERGE2022_BY BLOCK: merged Caesium channel without adjustment at overlap zones in $\frac{kBq}{m^2}$

GRIDS:

TELLUS_Cs137_MERGE_2022.GRD
(Binary Geosoft grid, gridded using inverse distance weighted algorithm, with 50 m cell size).
TELLUS_Cs137_MERGE_2022.GXF
(Grid Exchange File, transformed from the GRD file).
TELLUS_Cs137_MERGE_2022.TIFF
(Georeferenced Raster image, transformed from the GRD file).

6. General References

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