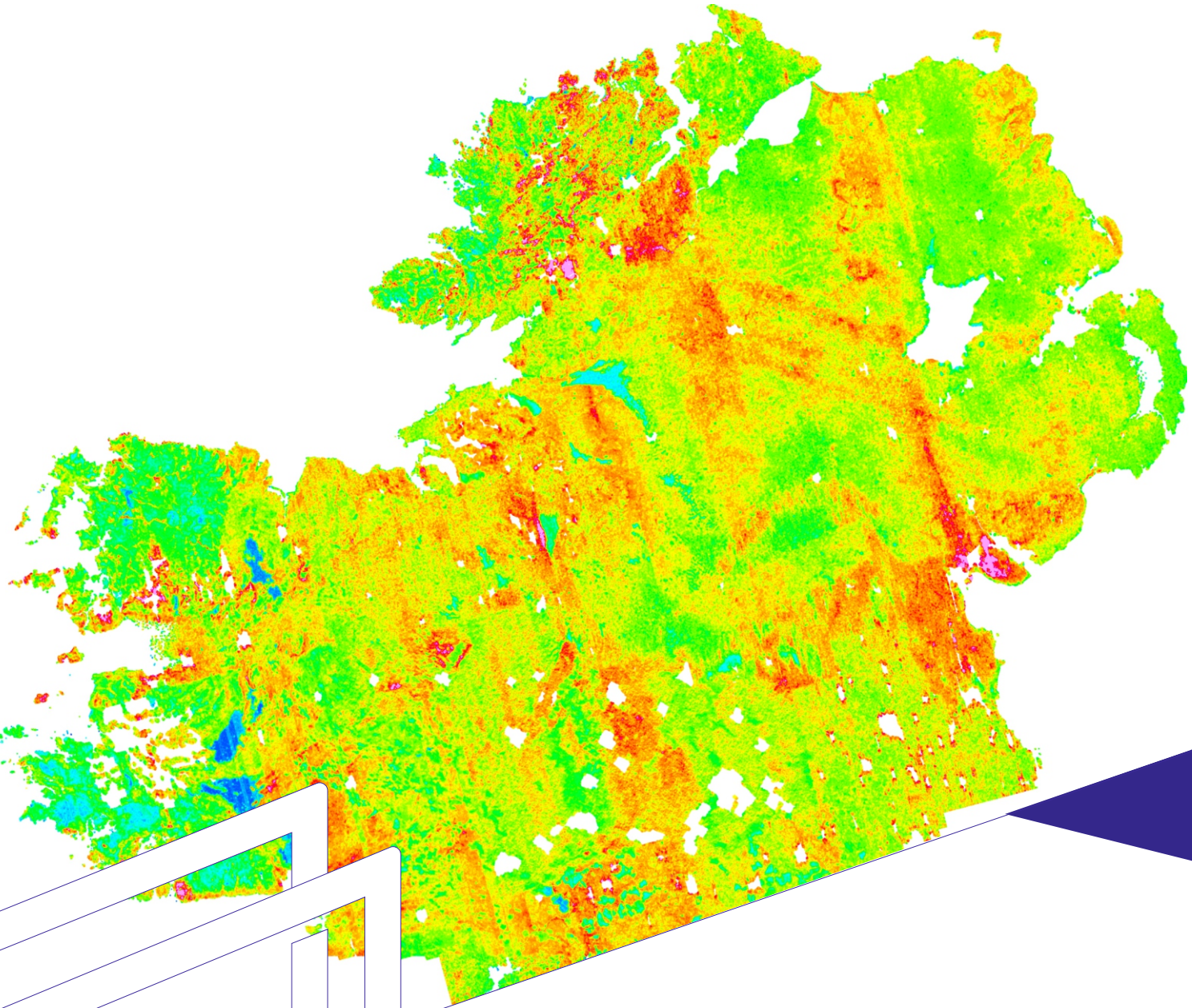
Rialtas na hÉireann
Government of Ireland

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Processing and Merging of Caesium 137 airborne data for the Tellus Programme



Geological Survey Ireland Report 2021

Geological Survey Ireland is a division of the Department of the Environment, Climate and Communications

Document Information

Project title: Cs137_Merge2021

Date 02/07/2021

Prepared By	Date	Comment
Mohammednur Ture	29/04/2021	V1
Mohammednur Ture (edited)	06/05/2021	V2
Mohammednur Ture(edited)	14/05/2021	V3
Mohammednur Ture(edited)	17/06/2021	V5
Mohammednur Ture(edited)	22/06/2021	V6

Reviewed By	Date	Comment
Jim H.	29/04/2021	V1
Mark M.	14/05/2021	V3
Jim H.	15/05/2021	V4
Jim H.	18/06/2021	V5
Jim H.	24/06/2021	V6

Approved By	Date	Comment
Jim H	02/07/2021	

Version History

Ver. No.	Ver. Date	Comment	Revised By

Contents

FIGURES

TABLES

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

Disclaimer

Copyright

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 survey blocks between 2005 and 2019. Data has 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 spectrum was preferred.

The merged ^{137}Cs data show typical values ranging between 0.01 and 11.09 kBq/m^2 with most values less than 4 kBq/m2 and show well-defined banding of higher values along NNW-SSE and WNW-ESE orientations (Figure2) in the north of the island of Ireland. 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 has been 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 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 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 decay of ^{137}Cs post-Chernobyl and earlier fallout.

1. Introduction

Caesium-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 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 between 2005 and 2006. Surveys were then carried out on an annual basis since the first survey in the Republic of Ireland in 2012. Data from the different survey blocks are then merged together to form a seamless dataset.

The Tellus Caesium-137 data have been extracted from airborne spectrometer 256 and 512 channels generated from the gamma-peak at 662 keV using PRAGA4 software. 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, 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 eigen-vectors are sorted by decreasing signal variance.

In spectrum analysis, Principal Component Analysis (PCA) methods are used to extract non-correlated spectrum signatures – eigen-vectors 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 limited number of NASVD/MNF eigen-vectors. These eigen-vectors 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 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, to facilitate a merge with the then new TB data set.

All the Tellus radiometric data collected to date were processed using PRAGA4 software in February, March and April 2021, with the exception of the North Midlands data (2014), as the raw data for this block were collected using two different aircraft. As details for each aircraft were not available at the time the previously released company delivered ^{137}Cs data were used.

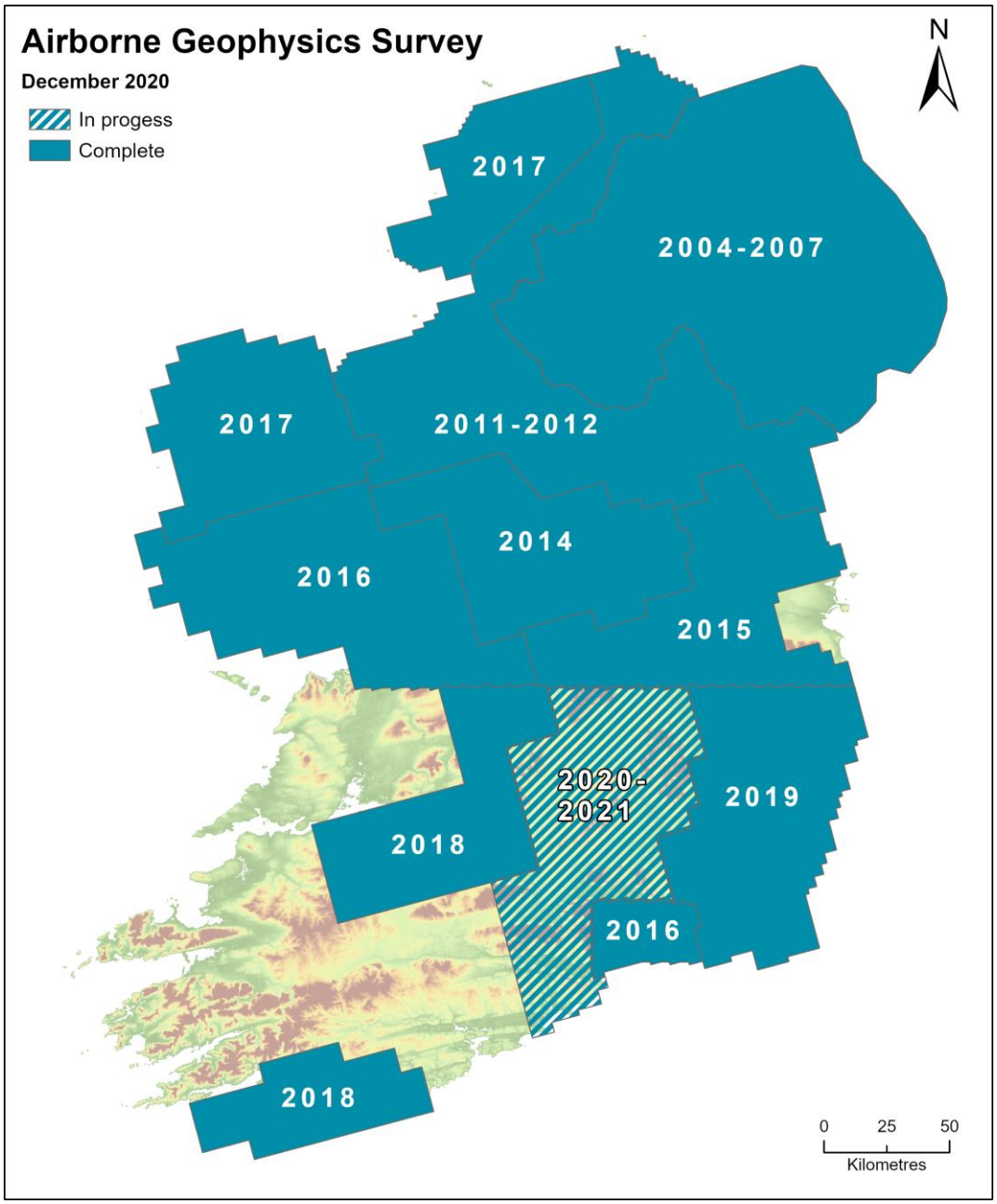


Figure 1: Tellus Survey blocks by year (2004 – 2021)

Before processing of new survey data, the previously processed data from Northern Ireland and Tellus Border were re-processed. This allowed an

assessment as to whether the new processing produced similar results as to those already described and published. It was concluded that the newly processed data produces a similar results providing confidence in the approach: The previous process showed min, max and mean values of 0.06, 9.78 and 2.98 KBq/m^2 which compared well with the reprocessed values of 0.04, 10.7 and 2.92 KBq/m^2 (before temporal correction).

^{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

Block	Year	Min	Max	Mean	Channels
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	6.5	9.8	2.9	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. 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 relates to the Chernobyl accident in 1986, 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-λt	Temporal correction
A9	2021	0	-0.0231	0	1.000	A9=A9*1
A8	2021	0	-0.0231	0	1.000	A9=A8*1
A7	2019	2	-0.0231	-0.0462	0.955	A9=A7*0.955
A6	2018	3	-0.0231	-0.0693	0.933	A9=A6*0.933
A5	2018	3	-0.0231	-0.0693	0.933	A9=A5*0.933
A4	2017	4	-0.0231	-0.0924	0.911	A9=A4*0.911
A3	2017	4	-0.0231	-0.0924	0.911	A9=A3*0.911
A2	2016	5	-0.0231	-0.1155	0.891	A9=A2*0.891
WFD	2016	5	-0.0231	-0.1155	0.891	A9=WFD*0.891
A1	2015	6	-0.0231	-0.1386	0.871	A9=A1*0.871
TNM	2015	7	-0.0231	-0.1617	0.850	A9=TNM*0.871
TBCAV_NI	2012	9	-0.0231	-0.2079	0.812	A9=TBCAV_NI*0.812

- Temporal variation was applied to all blocks to bring 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. Statistics of each block was 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 and clipping to 100 m altitude and are shown in Table 3.

Table 3: ^{137}Cs 2021 statistics (in kBq/m^2) by block for the merged dataset, after temporal correction, overlap adjustment and coastal and 100 m flight altitude clipping. *A6 block has no common boundary with other blocks and is not merged.

BLOCK	Min	Max	Mean	Channels	Year flown
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 temporal corrected to reflect ^{137}Cs responses in the year 2021, individual blocks could 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 by GSNI (Young and Donald, 2013) and provides a known reference. Table 4 shows the merging steps and adjustments applied for each step. The final merged image is presented in Figure 2.

As can be seen from Table 4, no adjustment was done between A1 and A7 blocks. Due to a large amount of high survey altitudes within the overlap zones between A1 & A7 little quality data was available to provide effective correction factors which could then be applied to the rest of the survey data. Therefore it was decided that the best approach was not to apply any correction factors to these two blocks.

The A6 block currently has no overlap with any other block. Hence, it was not merged with other datasets and has instead been released as single block. ^{137}Cs data were processed for Block A6 and treated in the same way as the other survey blocks with temporal adjustment applied. The A6 data were clipped for altitude ≤ 100 m, gridded and 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. * indicates no overlap correction was made between A1 and A7 blocks.

Merging Blocks	Mean ratio at overlap Bq/m^2	Merge name
A)Northern grids		
NITBCAV/AURUM	0.924	NITBCAVAURUM_MERGE
NITBCAVAURUM_MERGE/TNM	1.16	NITBCAVAURUMTNM_MERGE
NITBCAVAURUMTNM_MERGE/A4	1.18	NITBCAVAURUMTNMA4_MERGE
NITBCAVAURUMTNMA4_MERGE/A3	0.967	NITBCAVAURUMTNMA4A3_MERGE
NITBCAVAURUMTNMA4A3_MERGE/A2	1.17	NITBCAVAURUMTNMA4A3A2_MERGE
B) South-eastern grids		
A1/A7*	1.00	A1A7_MERGE
A1A7_MERGE/WFD	1.57	A1A7WFD_MERGE
C) A and B MERGE		
A/B (AB)	1.105	NITBCAVAURUMTNMA4A3A2A1A7WFD_MERGE
AB/A5	1.32	NITBCAVAURUMTNMA4A3A2A1A7WFDA5_MERGE

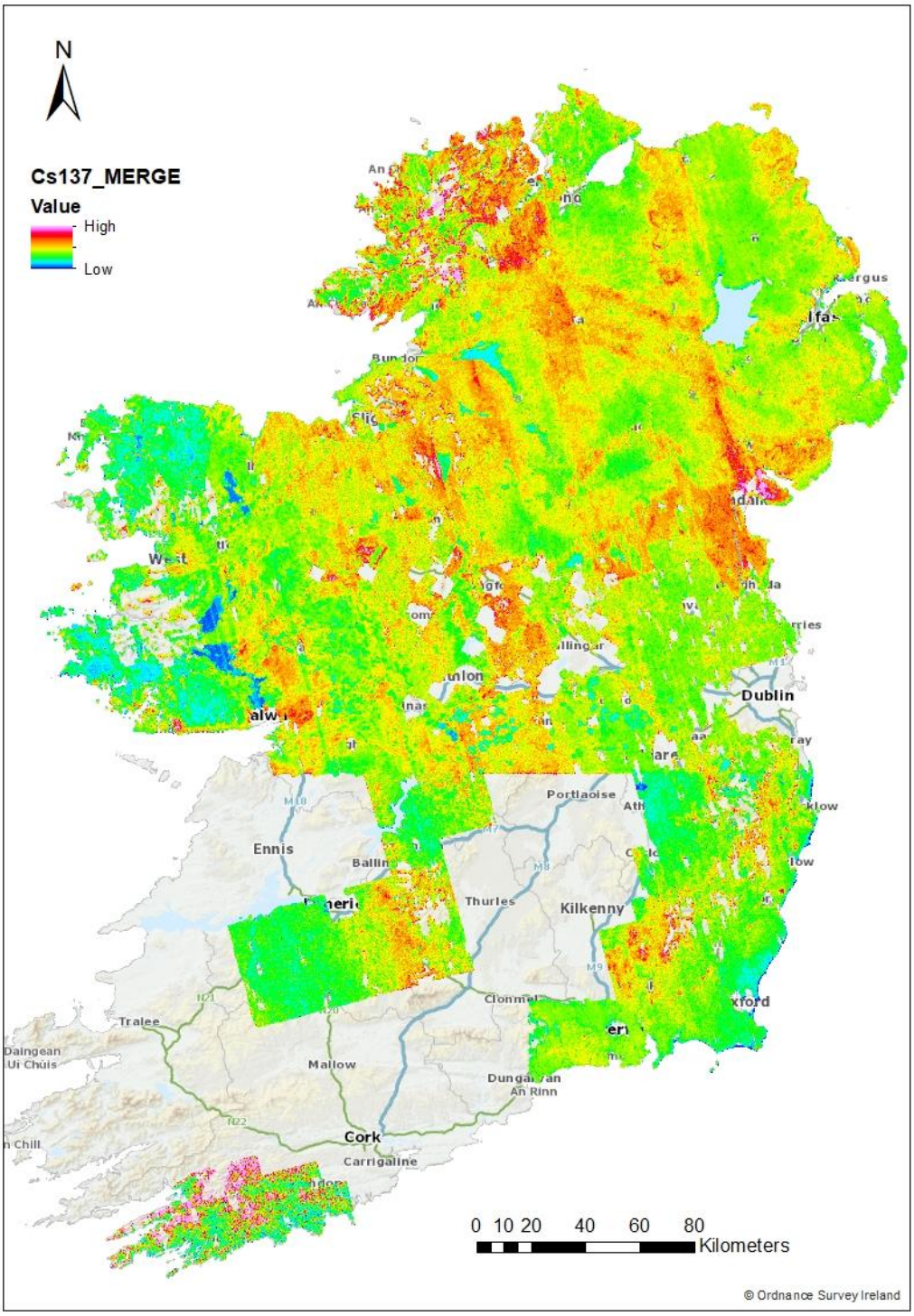


Figure 2: ^{137}Cs Merge 2021 and A6 block displayed with a linear colour scale 0 – 5 kBq/m^2.

3. Merged Results

The final merged ^{137}Cs data ranges between 0.01 and 11.09KBq/m^2. The mean of the merged data is 2.49KBq/m^2, with standard deviation is 0.76KBq/m^2. 97% of the merged data are lower than 4KBq/m^2

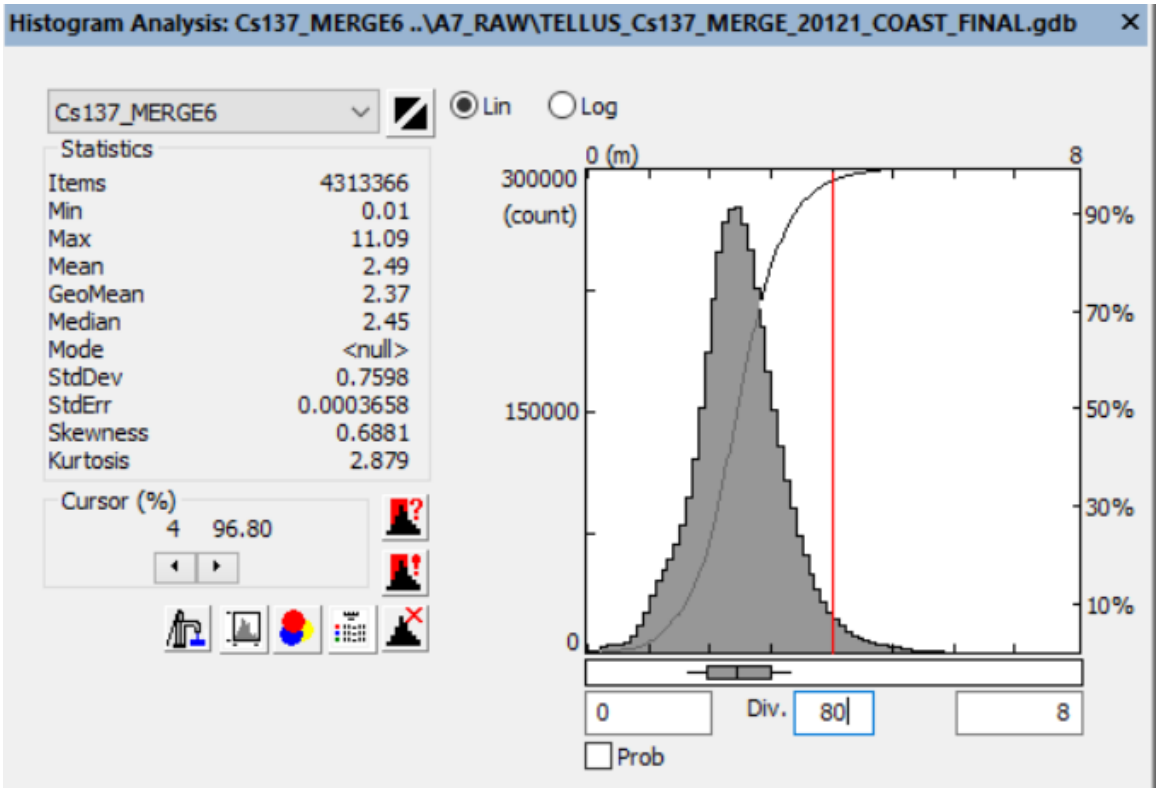


Figure 3: Statistics of merged ^{137}Cs

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

4. Error Analysis

1. As the current merging based on 2012 merge of NITBCAV data, the initial data assessment was comparing the mean values of 2012 and 2021 processed ^{137}Cs values. The mean value of 2012 and 2021 are 2.533 and 2.417 KBq/m^2 respectively. The data deviation (error) between the two is given by

   $\frac{2.533 - 2.417}{2.533} * 100 = 4.57$, which is about 5%.

2. Errors in the data are observed over water bodies due to attenuation of gamma ray signal by water. A good example is data from the Waterford block. The mean of raw ^{137}Cs data over this block before clipping to the coastline was 1.45KBq/m^2 (Table 1). After data recorded over the sea has been removed, the mean is 2.09 KBq/m^2 (Table 3). Therefore, surveys with significant parts of the measured data recorded over water bodies show reduced values in comparison with other areas may and therefore may show data variability while merging.

3. High fly altitudes can also lead to data errors, with higher survey altitudes resulting in a decrease in the ^{137}Cs data. Therefore ^{137}Cs data were clipped to altitude less ≤ 100 m. Care must be taken when high values are observed around clipped areas in the data, which are associated with high fly ares.

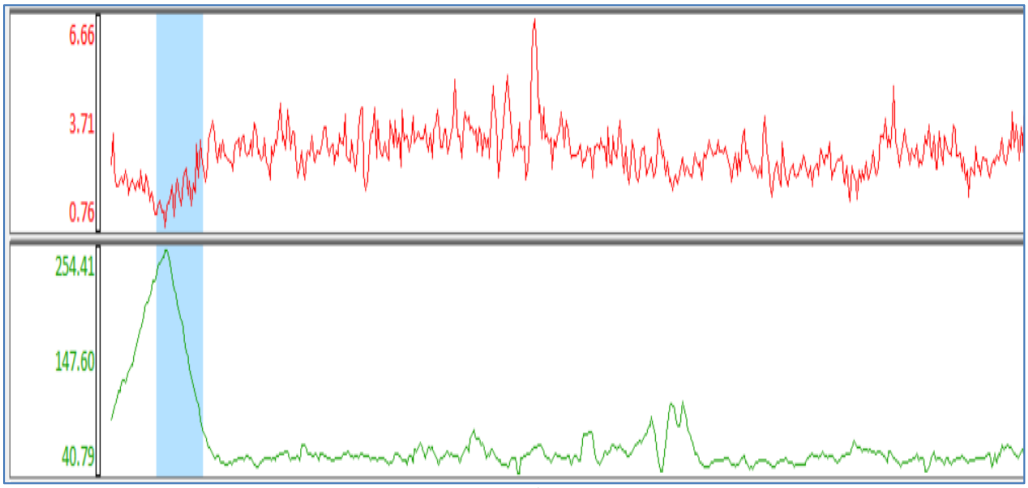


Figure 4: Effect of high fly on data. Top panel is ^{137}Cs, bottom panel is altitude (m)

4. Errors in the merged data can also be assessed by investigating the ratio between overlapping survey blocks (Table 4 & 5).

Table 5: Merged data deviations

Blocks	Ratio @ overlap	X-Mean [1]	sqr (X-Mean) [2]	sqrt[2]/(N-1)
NITBCAV/AURUM	0.924	-0.231	0.05336	0.08167
NITBCAVAURUM_MERGE/TNM	1.160	0.005	0.00002	0.00177
NITBCAVAURUMTNM_MERGE/A4	1.180	0.025	0.00062	0.00884
NITBCAVAURUMTNMA4_MERGE/A3	0.967	-0.188	0.03534	0.06647
NITBCAVAURUMTNMA4A3_MERGE/A2	1.170	0.015	0.00022	0.00530
A1/A7	1.000	-0.155	0.02403	0.05480
A1A7_MERGE/WFD	1.570	0.415	0.17223	0.14672
A/B (AB)	1.105	-0.05	0.00250	0.01768
AB/A5	1.320	0.165	0.02723	0.05834
Overall Mean	**1.155**			

Maximum deviation between survey blocks is observed with the merging of WFD with A1A7 block while the minimum deviation was between NITBCAVAURUMTNMA4_MERGE and the A3 block. The mean across all blocks is calculated at 1.155 (i.e. a 16% variation).

Based on the above discussion it is felt that the best representative of the expected error on the processed Cs^{137} data is plus or minus 16%.

Therefore a measured value of 4000 Bq/m^2 would result in an expected range of values of 3360 – 4640 Bq/m^2.

5. Merged data set Information

Merged database: **Cs137_Merge_2021.gdb**

Definition of 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)
GCLEAR: Ground clearance altitude (m)
SID: Survey ID: TB for Tellus Border, CAV for Cavan and NI for Northern Ireland, A1-A7 stands for A1-A7 blocks, WFD for Waterford block, TNM for Tellus north midlands

Cs137_MERGE_2021: merged Caesium channel with adjustment at overlap zones in $\frac{\text{KBq}}{\text{m}^2}$

Cs137_2021_BY_BLOCK: merged Caesium channel without adjustment at overlap zones in $\frac{\text{KBq}}{\text{m}^2}$

Definitions of the xyz file:

Cs137_MERGE_2021: merged Caesium channel with adjustment at overlap zones
Cs137_2021_BY BLOCK, merged Caesium channel without adjustment at overlap zones

GRIDS:

Cs137_MERGE_2021.GRD (binary Geosoft grid, gridded using inverse distance weighted with 50m cell size).
Cs137_MERGE_2021.GXF (Grid Exchange File, transformed from the GRD)
Cs137_MERGE_2021.TIFF (Georeferenced Raster image transformed from the GRD)

6. General References

IAEA-TECDOC-1363 (2003). Guidelines for Radioelement Mapping using Gamma Ray Spectrometry Data

IAEA Technical report 323 (1991). Airborne Gamma Ray Spectrometer Survey, Vienna

ICRU (1994). Gamma ray spectrometry in the environment: International Commission on Radiation Units and Measurements: ICRU REPORT 53, 7910 Woodmont Avenue, Bethesda, Maryland 20814, USA.

Jones, D.G. and Scheib, C. (2007). A preliminary interpretation of Tellus airborne radiometric data. British Geological Survey Commissioned report,CR/07/061. 70pp.

Montaj plus Praga4 (Geosoft): Advanced solution for the mapping and processing of gamma-ray spectrometry data acquired by modern spectrometers using NaI(Tl) detectors

US EPA (2002) Facts about Cesium-137, internal report

Young, M.E and Donald, A.W. (eds) (2013). A guide to the Tellus data Geological Survey of Northern Ireland, Belfast. ISBN 978-0-85272-763-8 (pdf) and ISBN 978-0-85272-761-1 (Hard back)