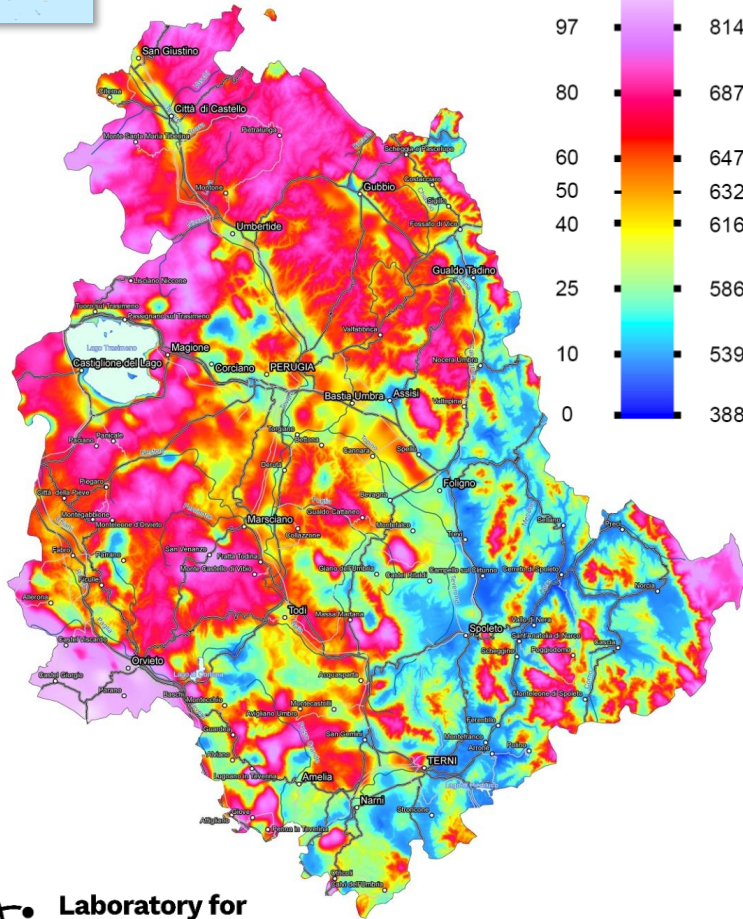




Umbria (Italy)

Area: 8456 km²

Population: 889000

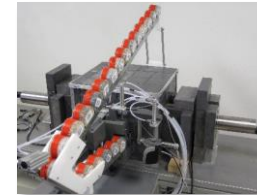


Terrestrial dose

Terrestrial contribution of ²³⁸U, ²³²Th and ⁴⁰K was evaluated via **γ-spectroscopy**. The **geological map** of Umbria was used as a guide for sampling campaigns and as an ancillary variable for multivariate interpolation via **Collocated CoKriging**.

Rocky geological formations

Investigated via **297 rock and soil samples** measured via **HPGe** laboratory analysis.



Quaternary deposits

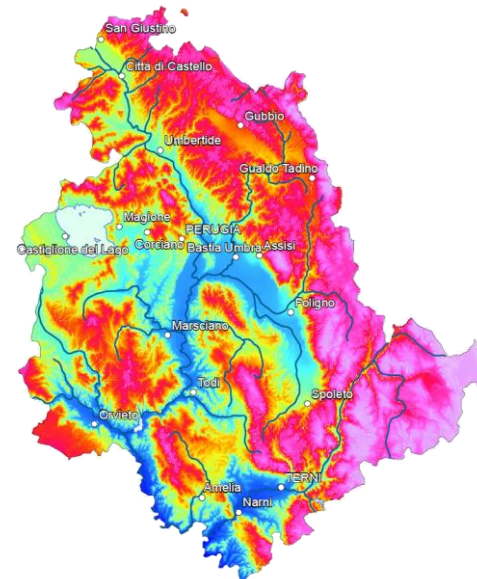
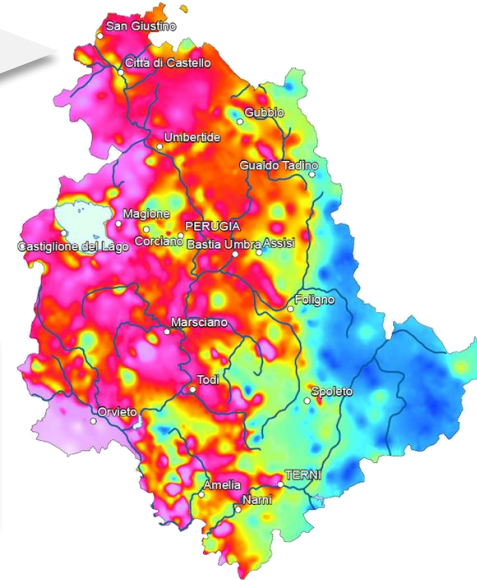
Studied via **7142 airborne γ ray measurements** through custom equipped aircraft.



Cosmic dose

Cosmic ray contribution is calculated through FAA's **CARI-6** software employing a **10m-resolution DEM** on the basis of:

- datetime;
- altitude and geographic coordinates.



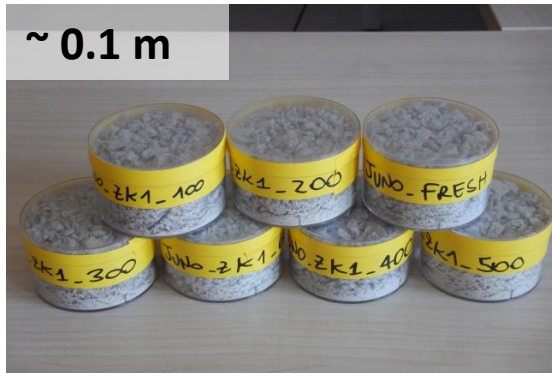
Display material

Different measurements techniques

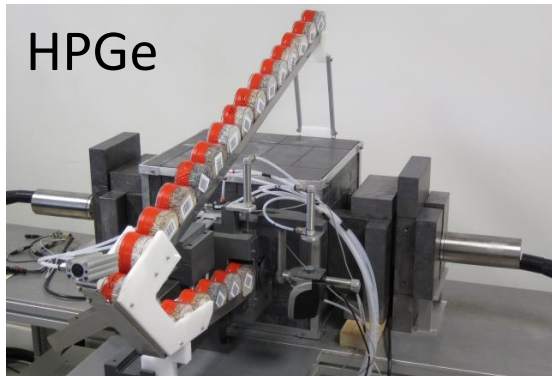
... in laboratory



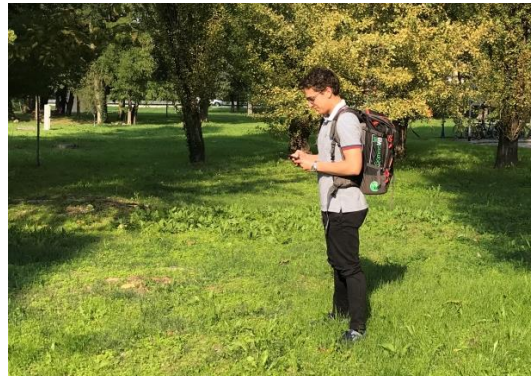
~ 0.1 m



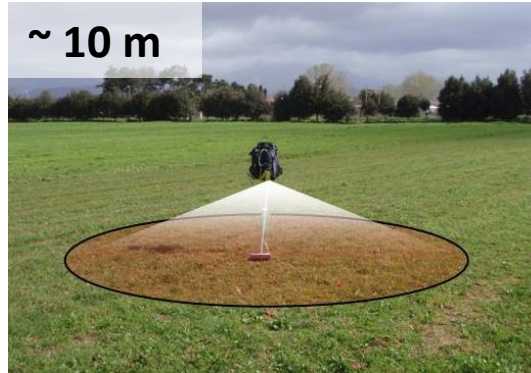
HPGe



... in situ



~ 10 m



NaI



... airborne



~ 100 m



NaI

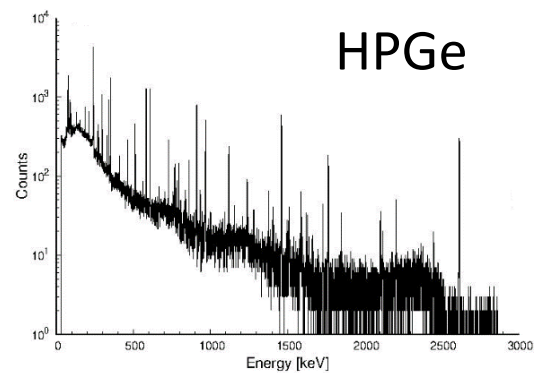
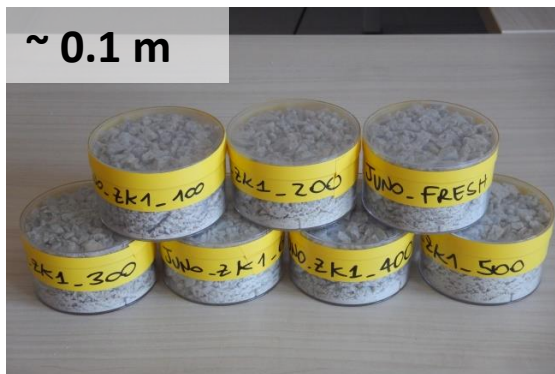


Different measurements techniques

... in laboratory



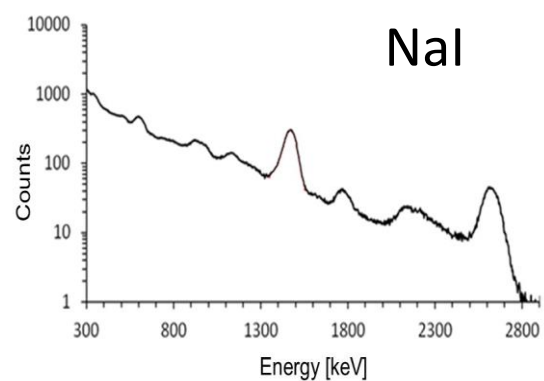
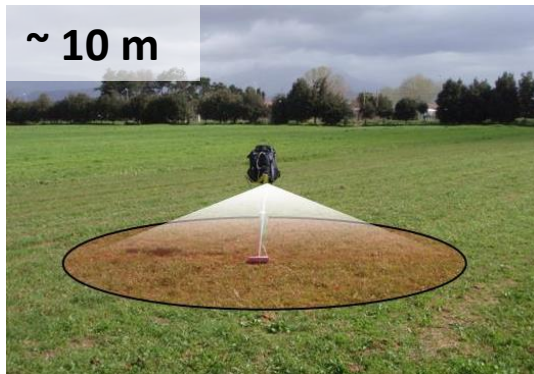
~ 0.1 m



... in situ



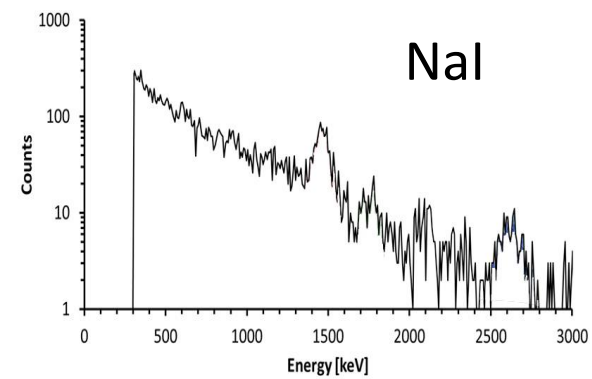
~ 10 m



... airborne



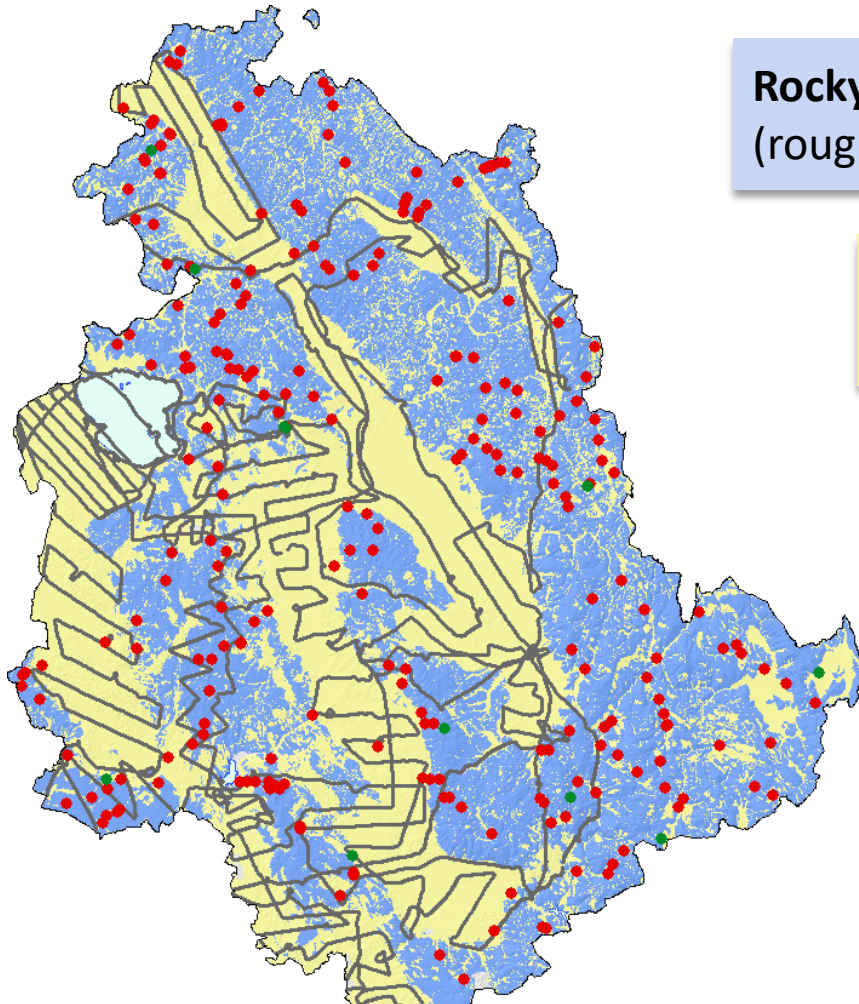
~ 100 m



Geological Map 1 : 10 000 scale

Rocky geological formations
(rough morphology, mountains)

Quaternary deposits and loose geological
formations (smooth morphology)



✓ 283 rock samples

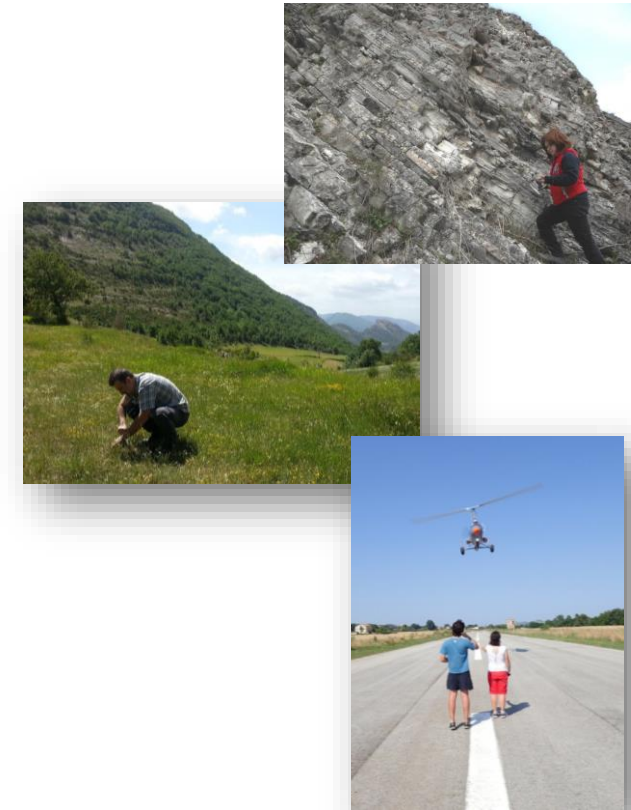
✓ 14 soil samples

✓ 7142 spectra acquired on flight

7439 point of measurements

~ 1 measurement / 1 km²

Group	A(km ²)	A (%)
Rocks	4220	50%
Deposits	4231	50%



**Our aircraft:
Radgyro**

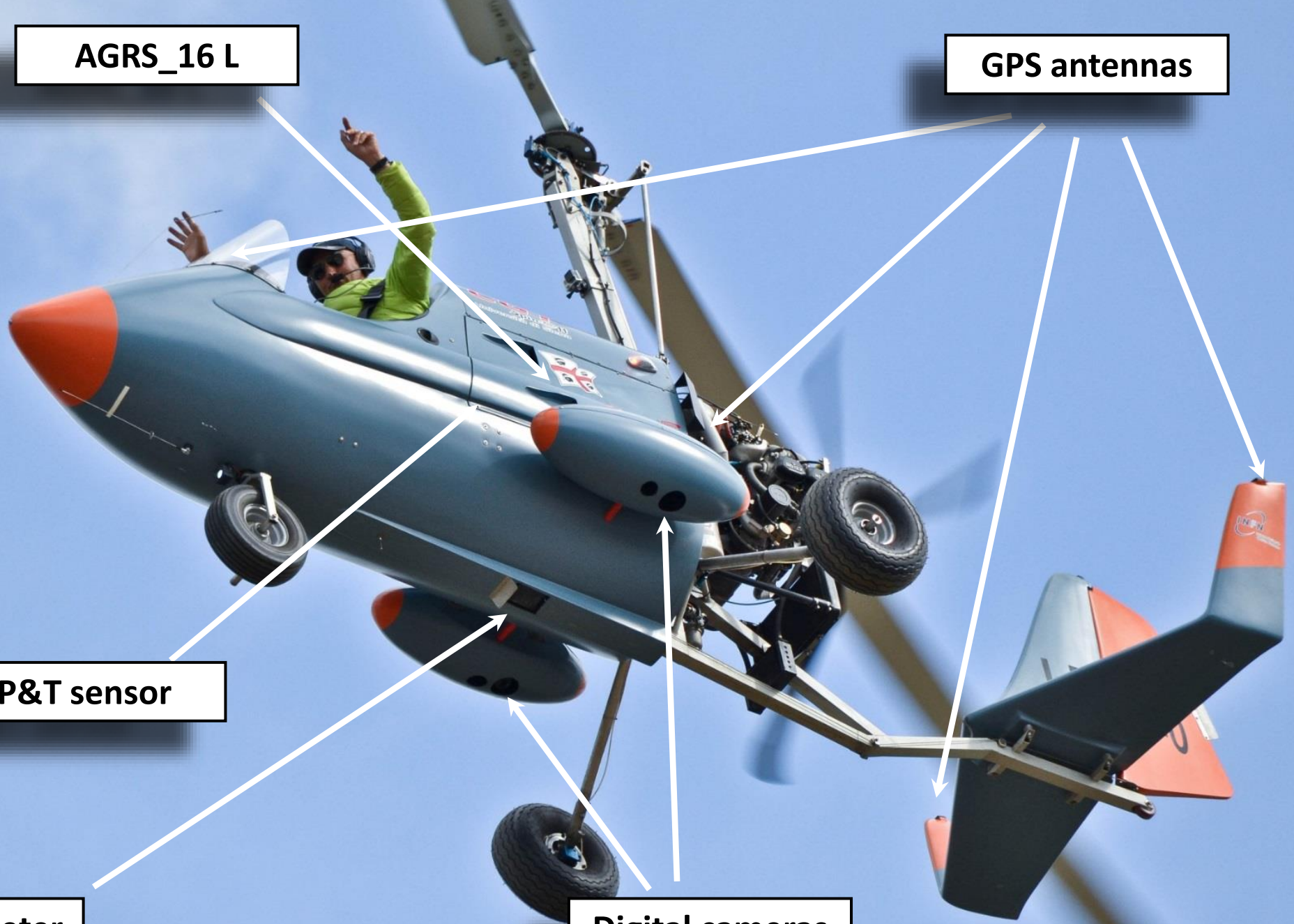
AGRS_16 L

GPS antennas

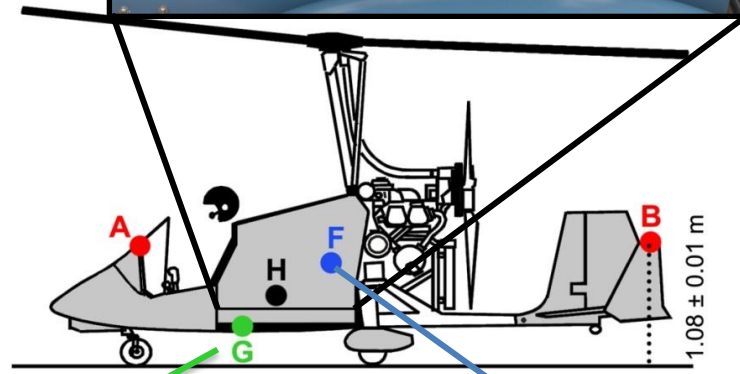
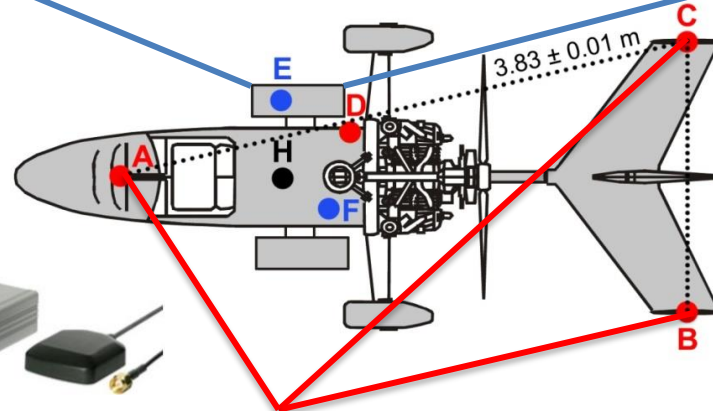
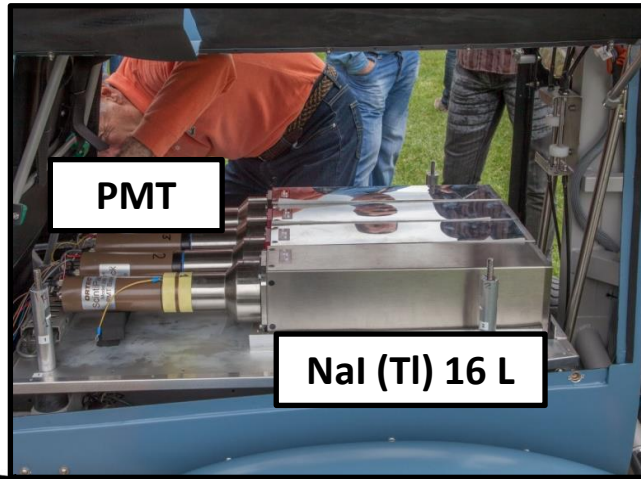
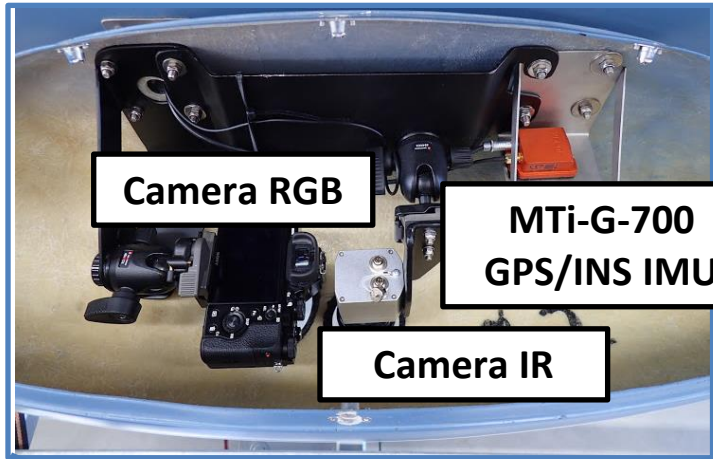
P&T sensor

Radar altimeter

Digital cameras



Our mobile laboratory: Radgyro

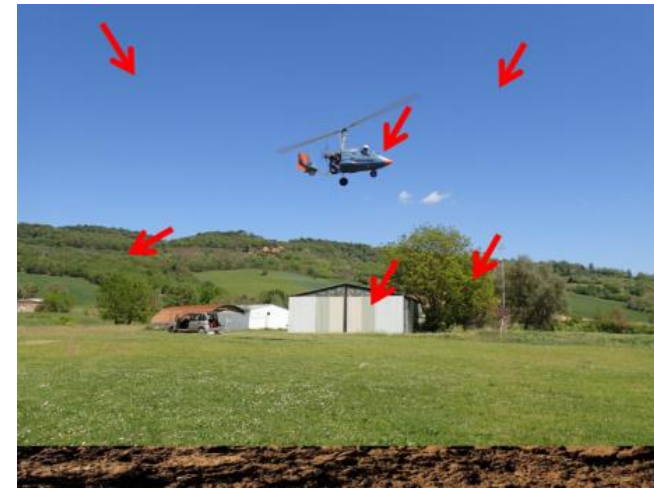


3 GNSS single freq. EVK-6 u-blox +
GPS ANN-MS act. antenna

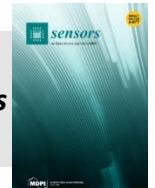
Toradex Oak USB Sensor
Atmospheric Pressure



Smartmicro® Micro
Radar Altimeter



M.Albèri et al. *Accuracy of Flight Altitude Measured with Low-Cost GNSS, Radar and Barometer Sensors: Implications for Airborne Radiometric Surveys* **Sensros (2017)**.



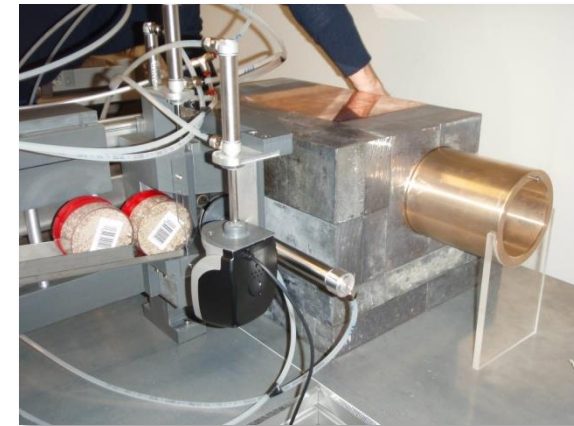
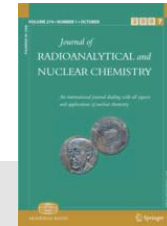
HPGe



Laboratory measurements: HPGe

- Detectors: 2 coaxial **HPGe** (Rel. Eff. 80%)
- **Energy resolution:** 2.02 keV at 1.33 MeV
- Working temperature: ~ **-190 °C**
- Cooling system: electromechanical
- **Shielding:** 10 cm Pb and 5 cm of Cu
- Sample volume: 180 cm³
- Standard measurement time: ~ **1 h**
- Systematic error on absolute activity: < 5%
- **Degree of automation:** 24 samples with barcode reading
- Compliant with IAEA¹ guidelines and the ANSI N42² standard

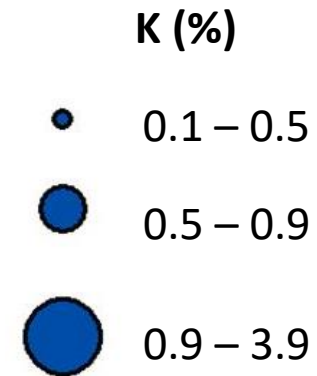
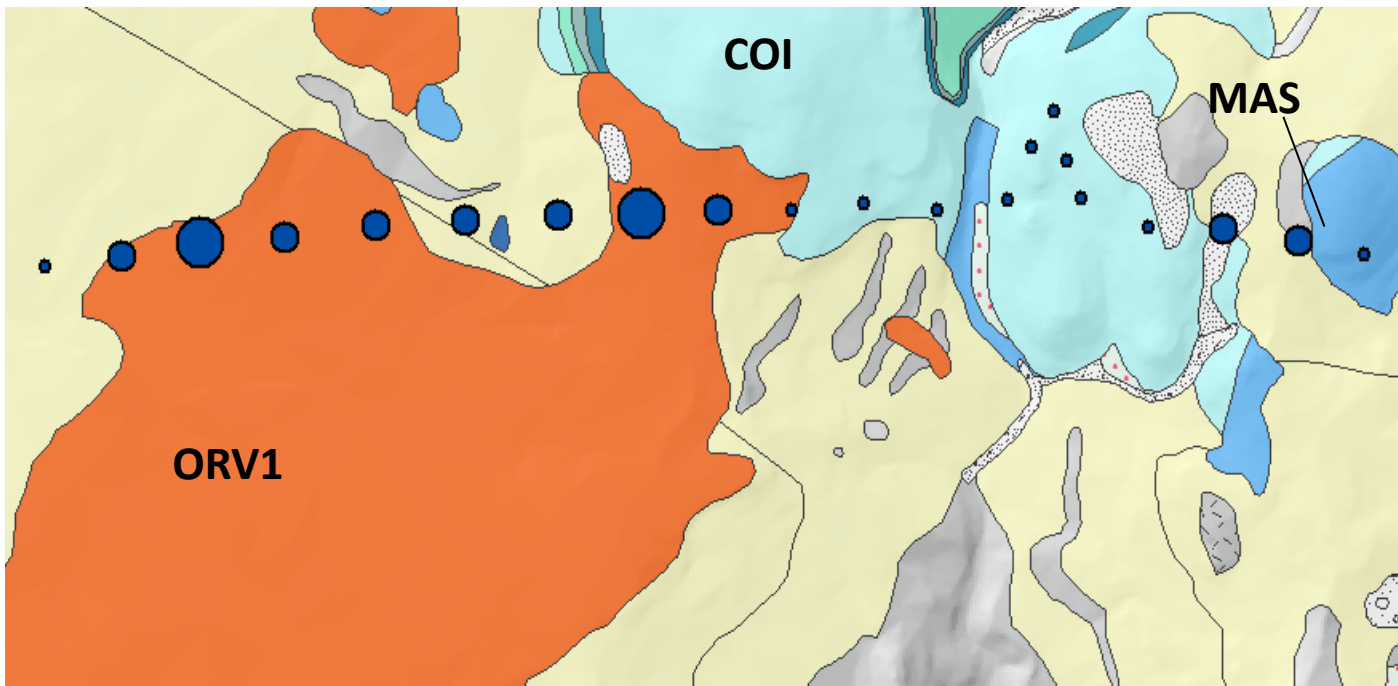
G. Xixha et al. *Calibration of HPGe detectors using certified reference materials of natural origin.* **J. Radioanal Nucl Chem (2015)**



¹ Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363, 2003.

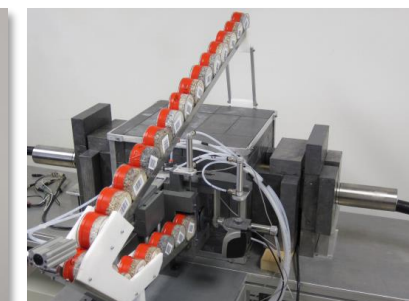
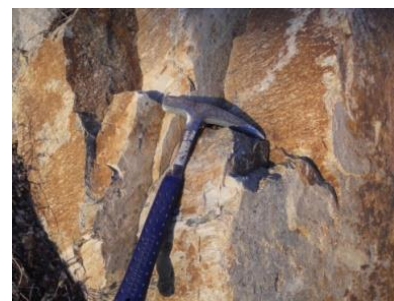
² American National Standard for calibration and use of Germanium Spectrometers for the measurement of Gamma-Ray emission rates of radionuclides. ANSI N42.14-1999.

Airborne data vs samples measurements



K (%)

	Corniola Formation Micritic limestone	$0.04^{+0.10}_{-0.03}$
	Calcare Massiccio Formation Compact and massive limestone	$0.03^{+0.07}_{-0.02}$
	Corsica unit (Orvieto syntheme) Tuff and lapilli tuff	1.54 ± 0.42

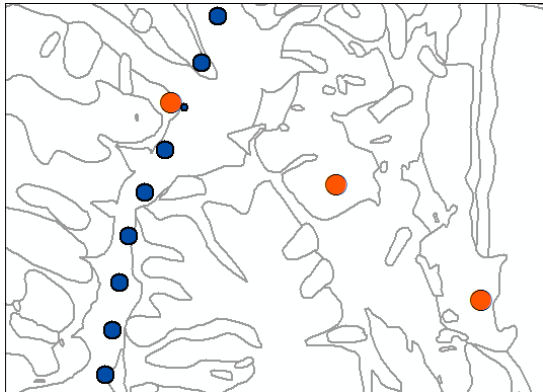


A multivariate interpolator: the Collocated CoKriging

The natural radioactivity map is obtained applying a multivariate geostatistical method:

Collocated CoKriging*

Primary variable
RADIOMETRIC DATA

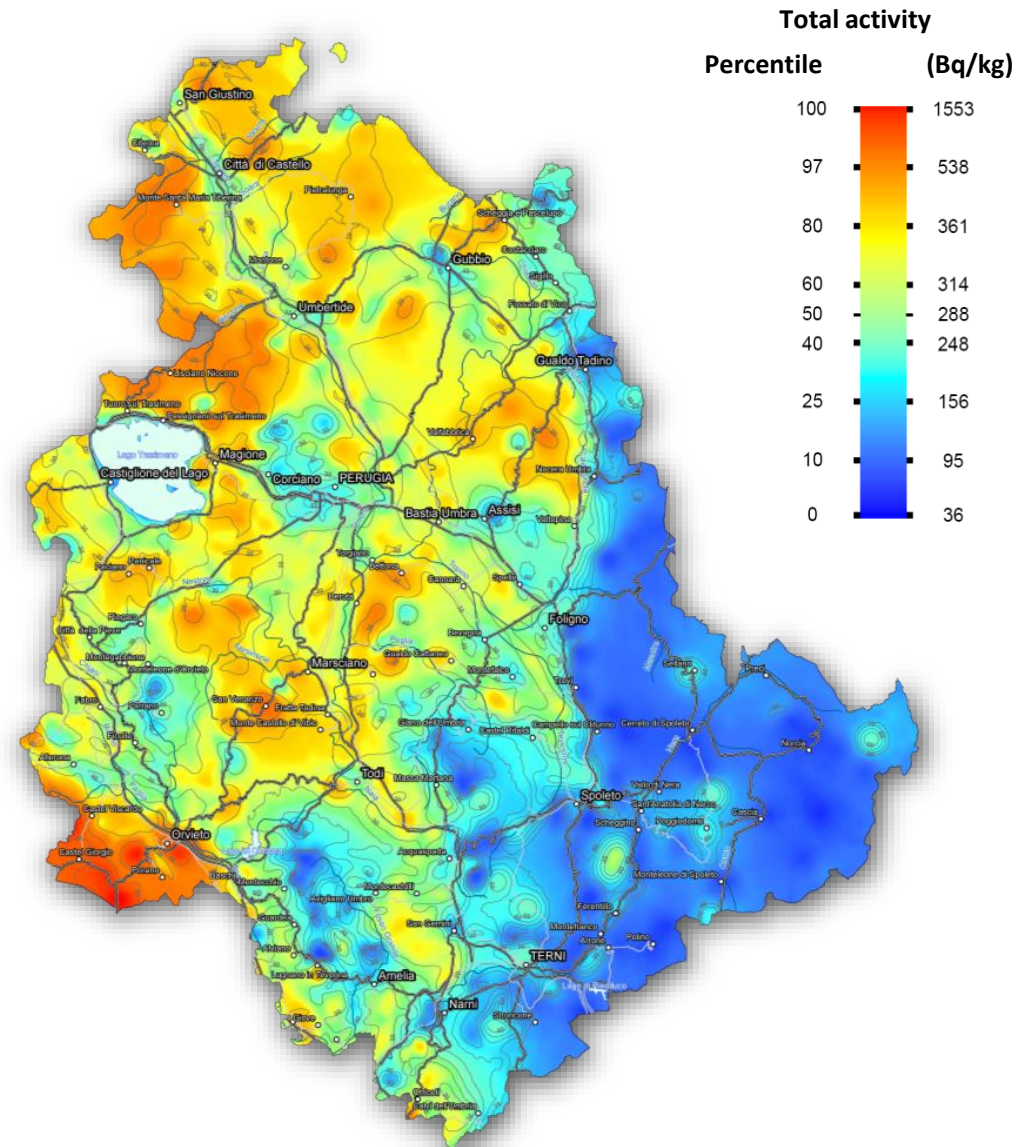


Secondary variable
GEOLOGICAL MAP



+

=

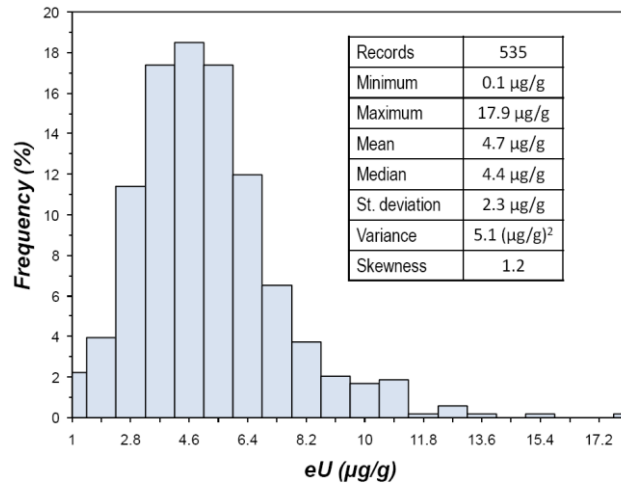


* Guastaldi E., et al., A multivariate spatial interpolation of airborne γ -ray data using the geological constraints. Remote Sens. (2013).

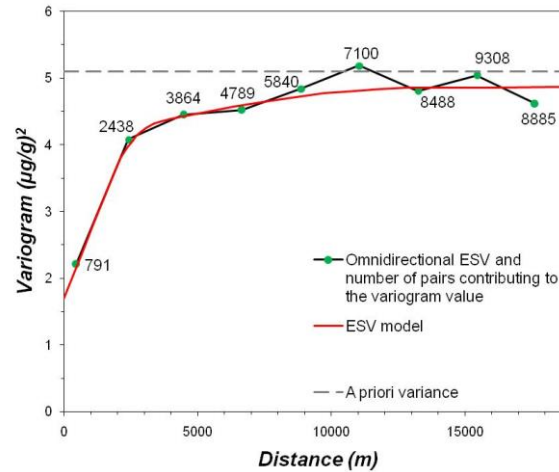
A multivariate interpolator: the Collocated CoKriging

During the estimation process difference **weights** are assigned on the basis of the **degree of confidence (overall uncertainties)** associated to the measurements

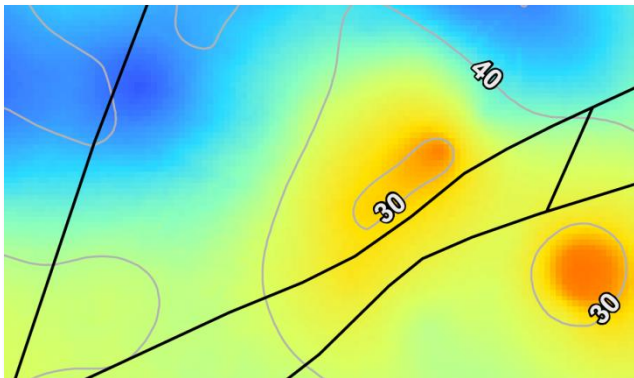
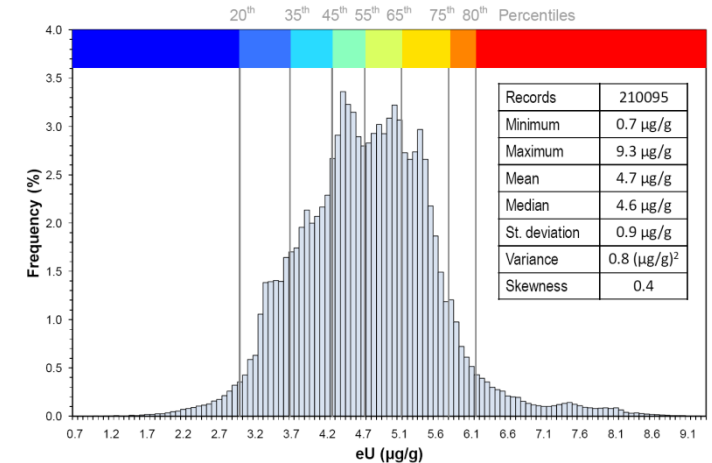
INPUT DATA



ESV MODEL



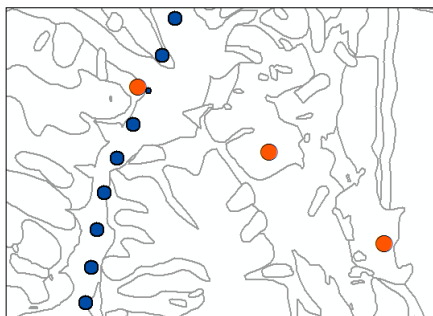
OUTPUT MODEL



The accuracy of the spatial model in terms of the variance normalized with respect to the estimated values is reported with contour lines in percentage.

A multivariate interpolator: the Collocated CoKriging

Primary variable:
RADIOMETRIC DATA

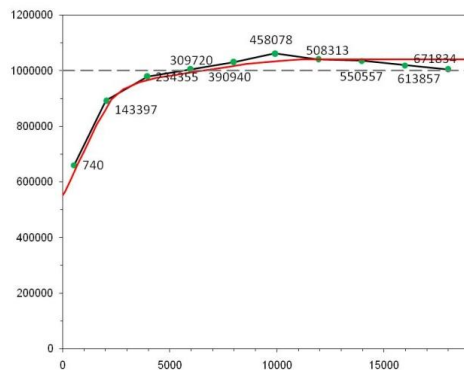
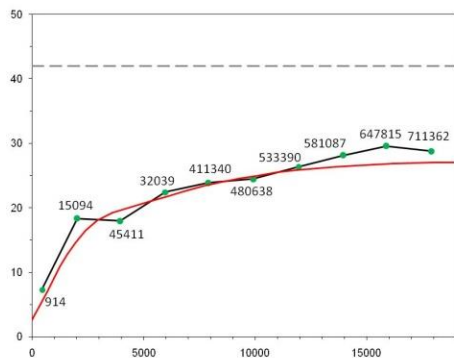


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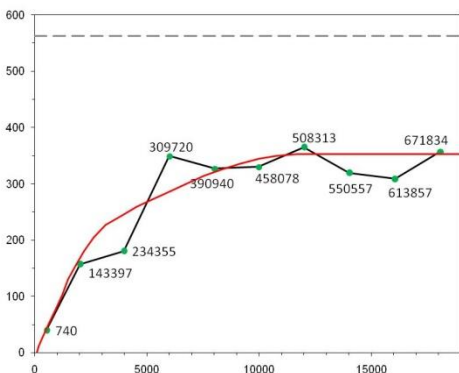
Secondary variable
GEOLOGICAL MAP



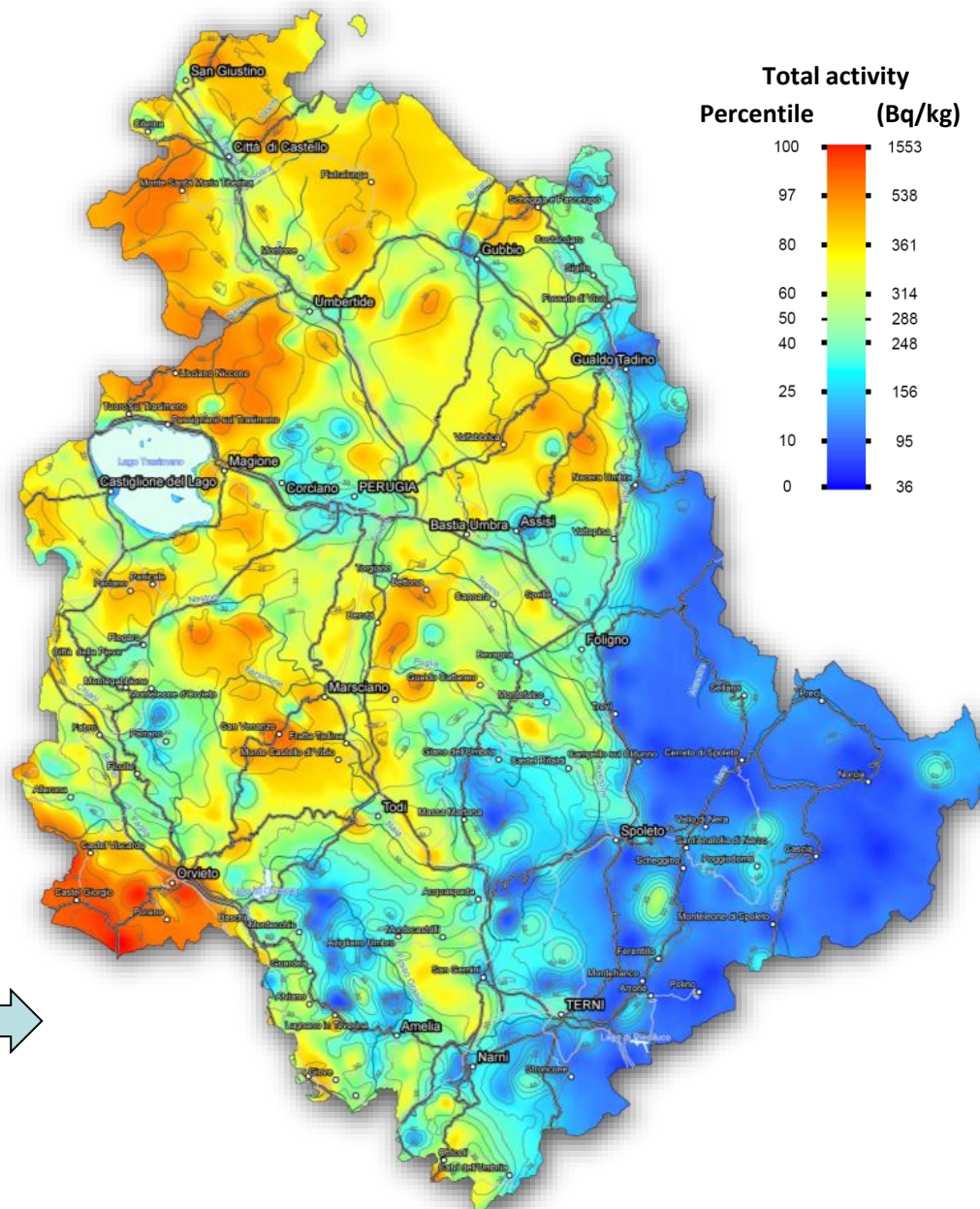
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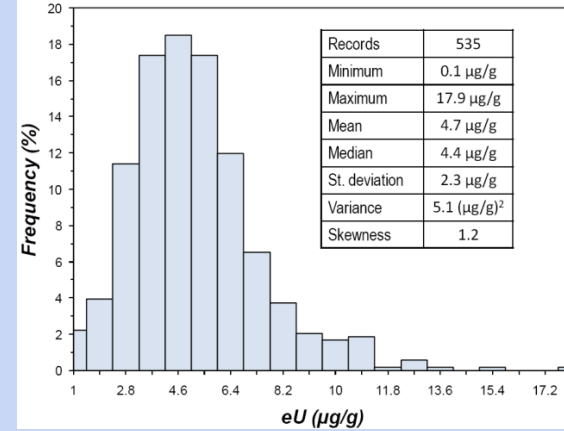
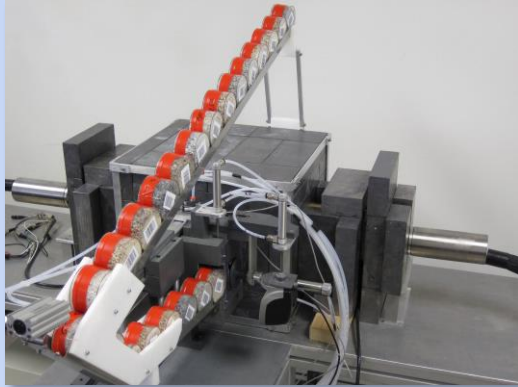
=



Cross
variogram



From abundances to terrestrial dose rate



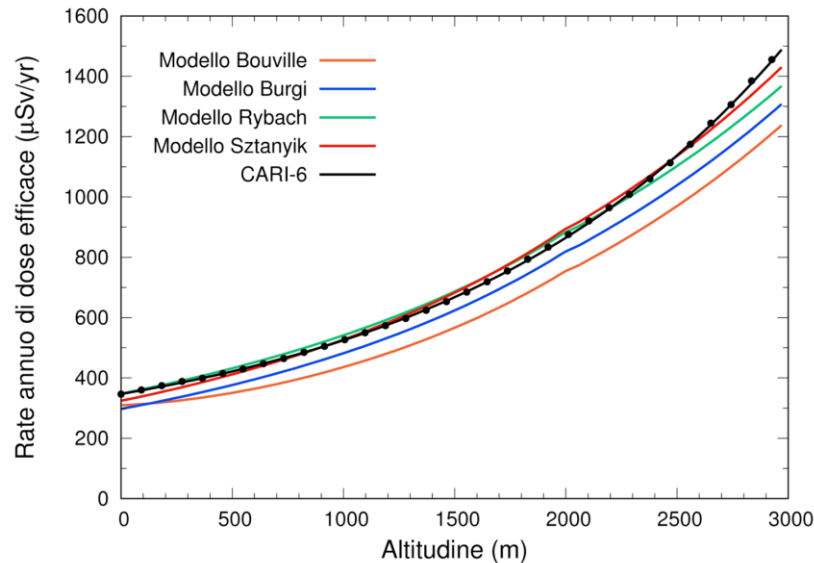
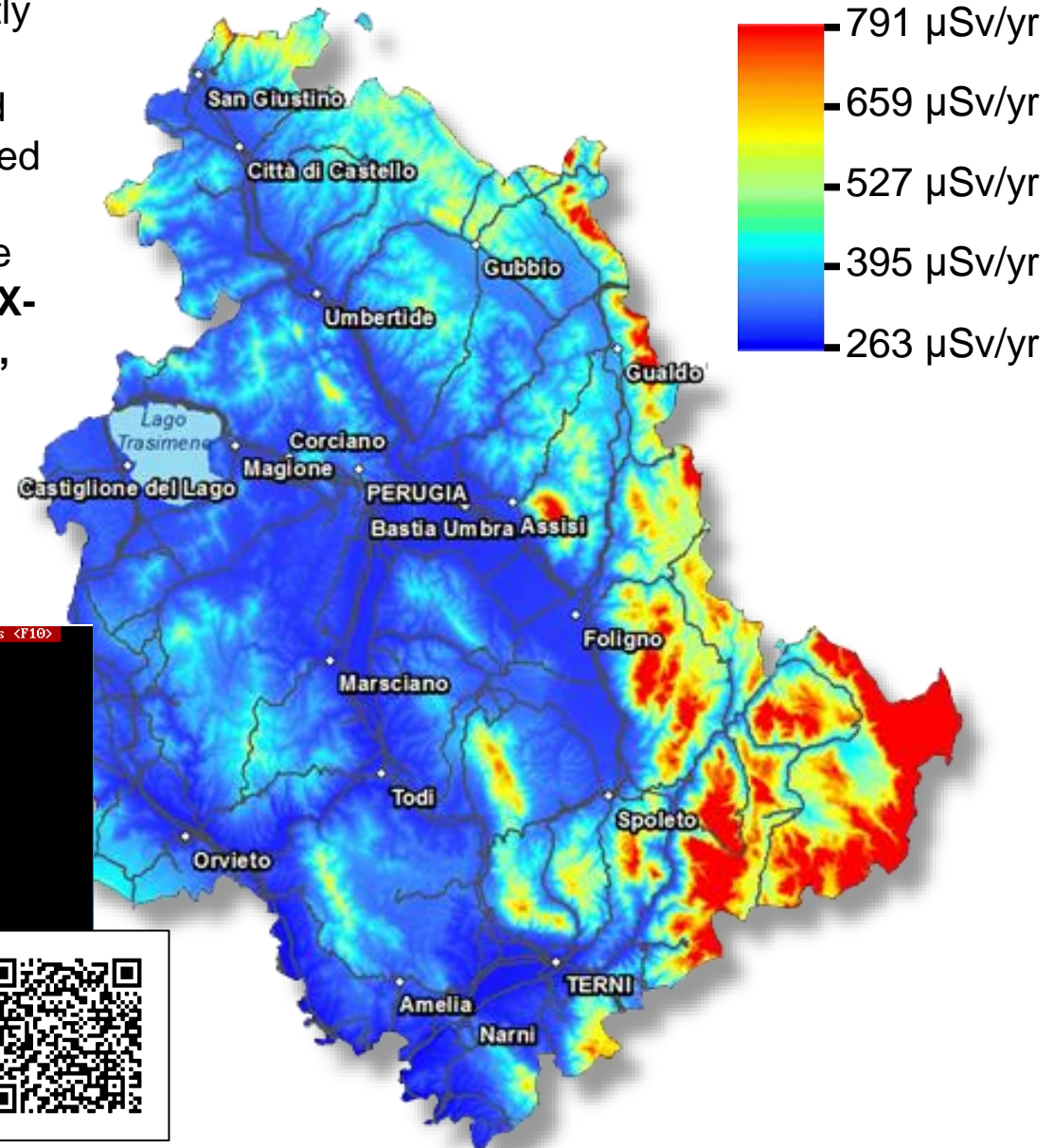
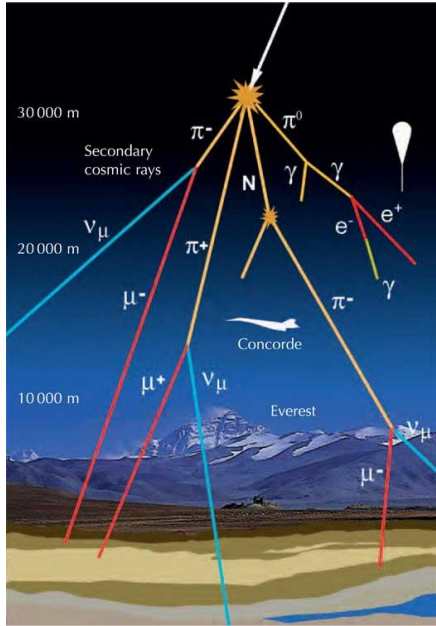
$$D_{ass} (nSv h^{-1}) = 0.7 \frac{Sv}{Gy} \cdot \left(0.0417 \frac{Gy}{\%} \cdot C_K(\%) + 0.462 \frac{Gy}{ppm} \cdot C_U(ppm) + 0.604 \frac{Gy}{ppm} \cdot C_{Th}(ppm) \right)$$

UNSCEAR. Sources and effects of ionizing radiation. Volume I: Sources Report to the General Assembly, with Scientific Annexes; United Nations Publications: 2000

Cosmic dose rate

The Earth and all living things on it are constantly bombarded by radiation from outer space. This radiation primarily consists of positively charged ions from protons to iron and larger nuclei derived from outside the Solar System. This radiation interacts with atoms in the atmosphere to create an air shower of secondary radiation, including X-rays, muons, protons, alpha particles, pions, electrons, and neutrons.

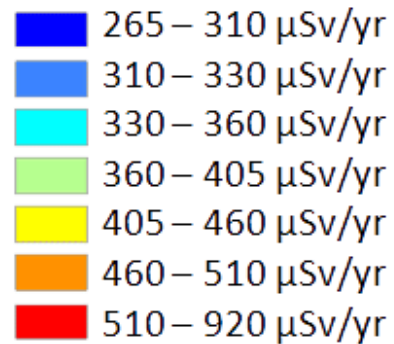
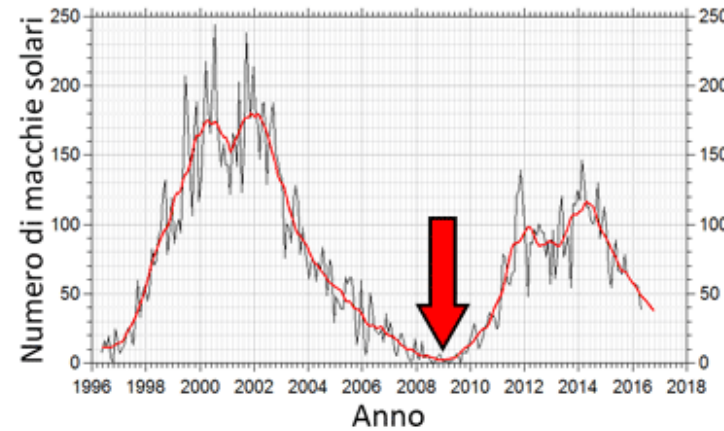
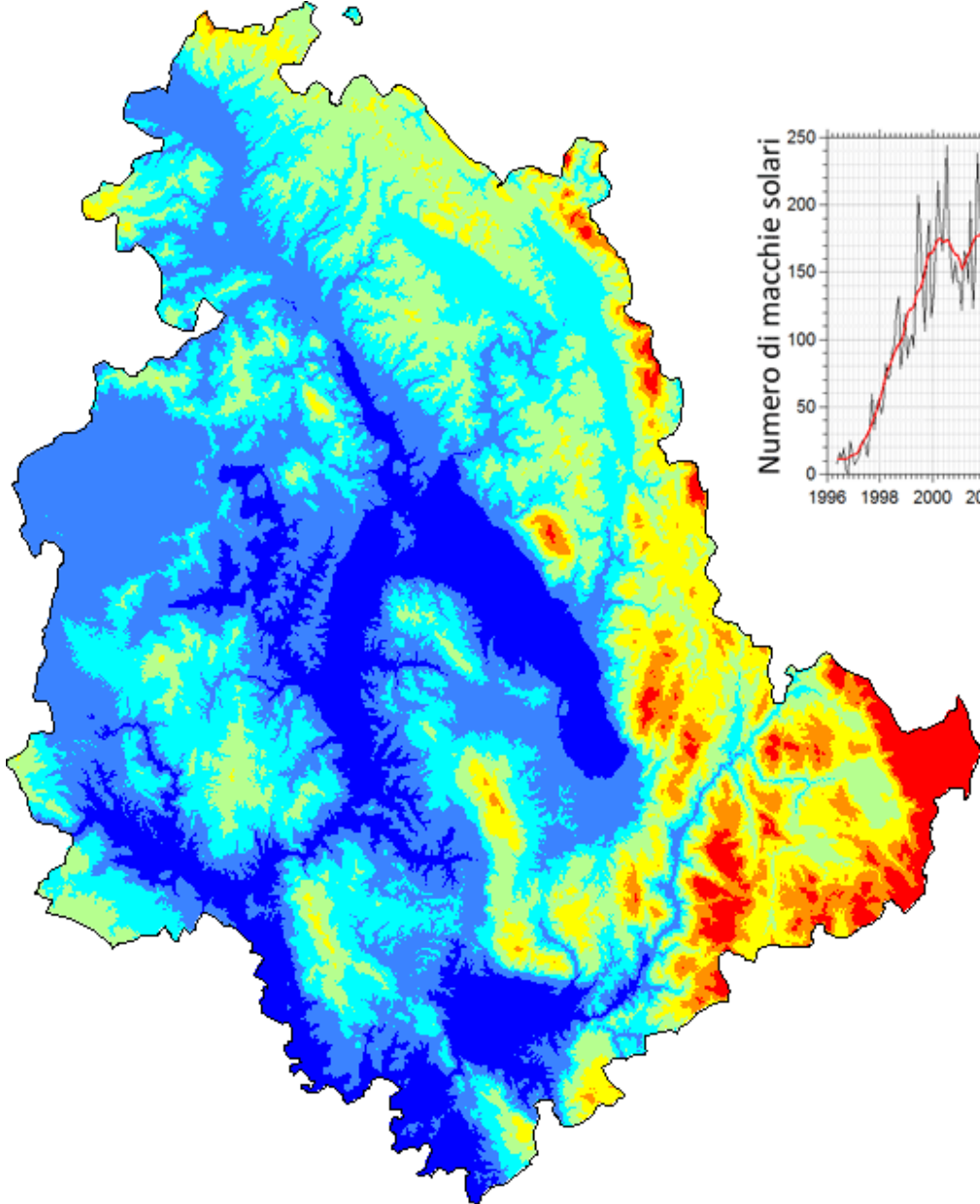
Cosmic dose rate is calculated via FAA's CARI-6 software.



```
To return to DATAIN MENU, press <F1>      To change entries, press <F10>
Geographic latitude, North or South <N/S> ? N
Degrees <0-90> ? 43
Minutes <0-59> ? 6
Geographic longitude, East or West <E/W> ? E
Degrees <0-180> ? 12
Minutes <0-59> ? 23
Will altitude be in gm/sq cm or feet <G/F> ? F
Altitude in feet <0-60000> ? 0
(Enter whole number)
```



Cosmic dose rate varying with solar cycles

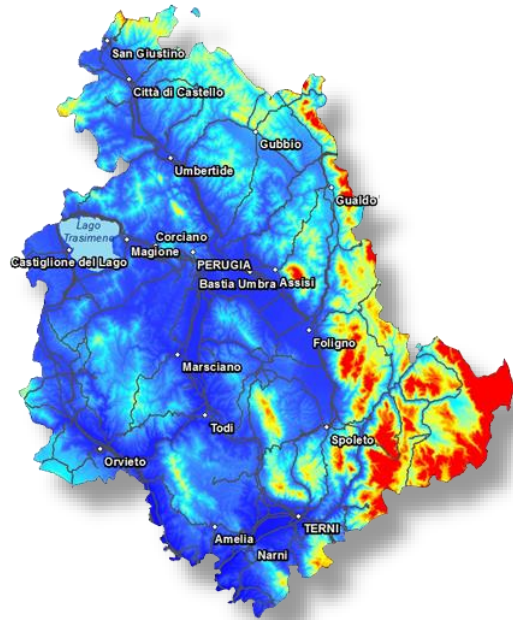


Cosmic dose rate is strongly affected by **solar activity**, which varies with time scales of **10-12 years**.

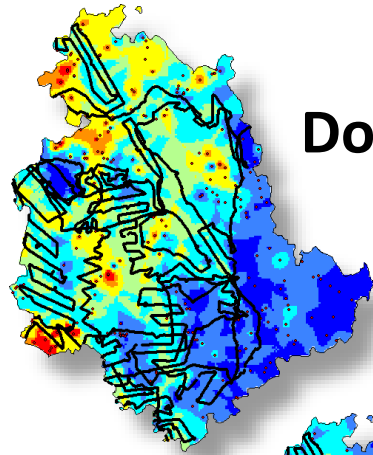
The cosmic effective dose rate was calculated **averaging** the values of last **11 years**.

Dose contributions: cosmic rays and terrestrial radionuclides

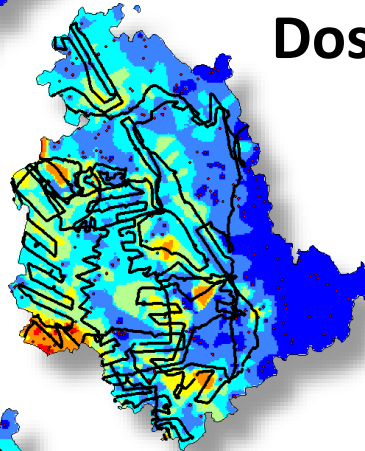
Cosmic dose
from CARI-6



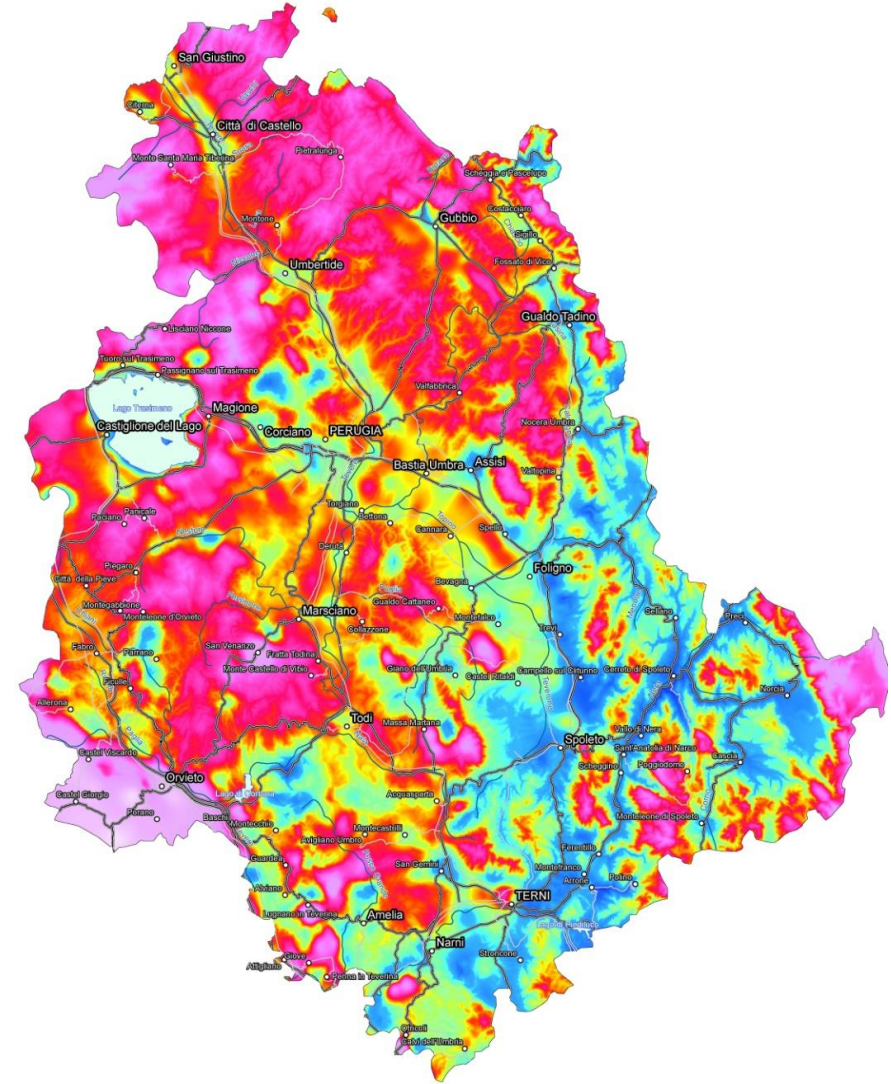
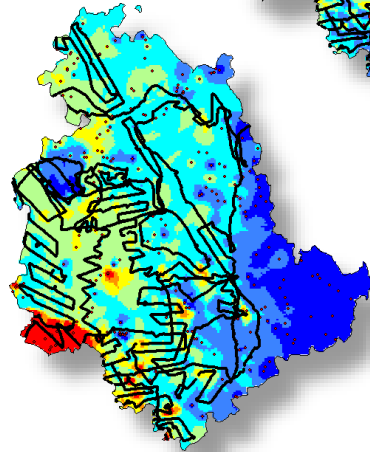
Dose from K



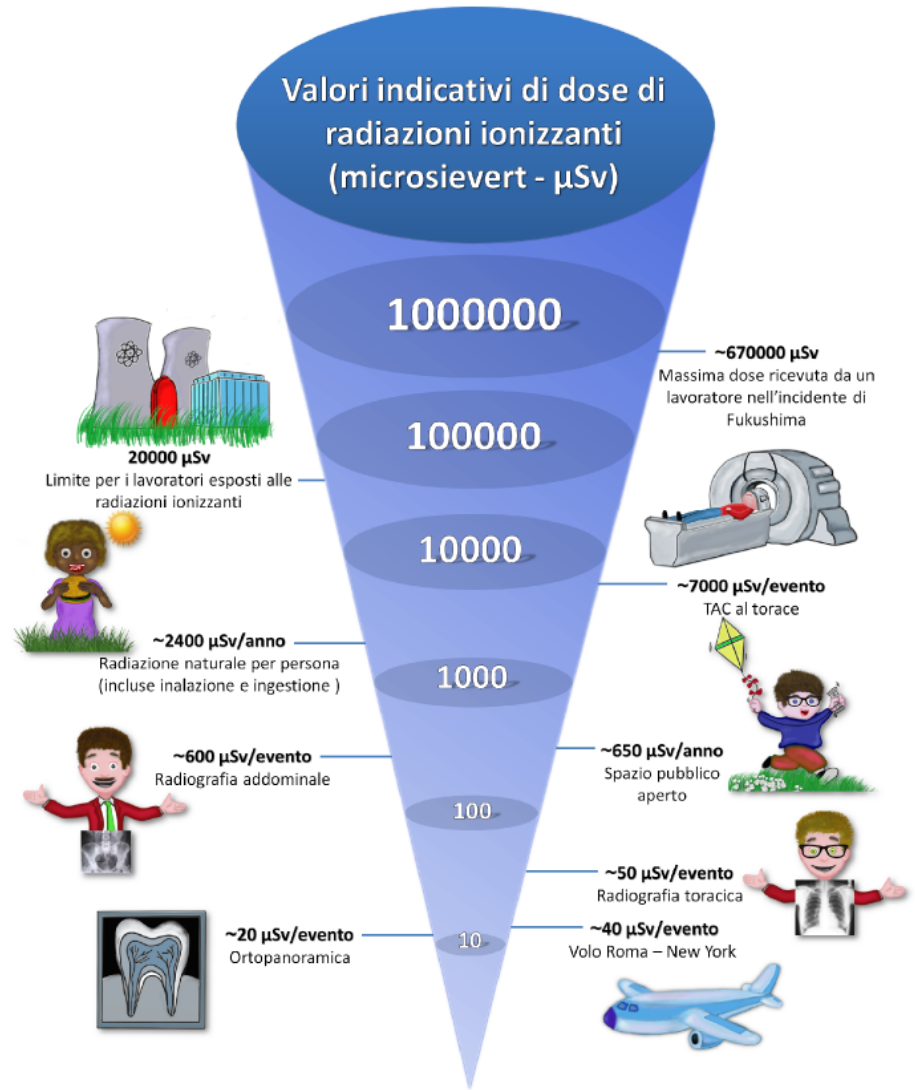
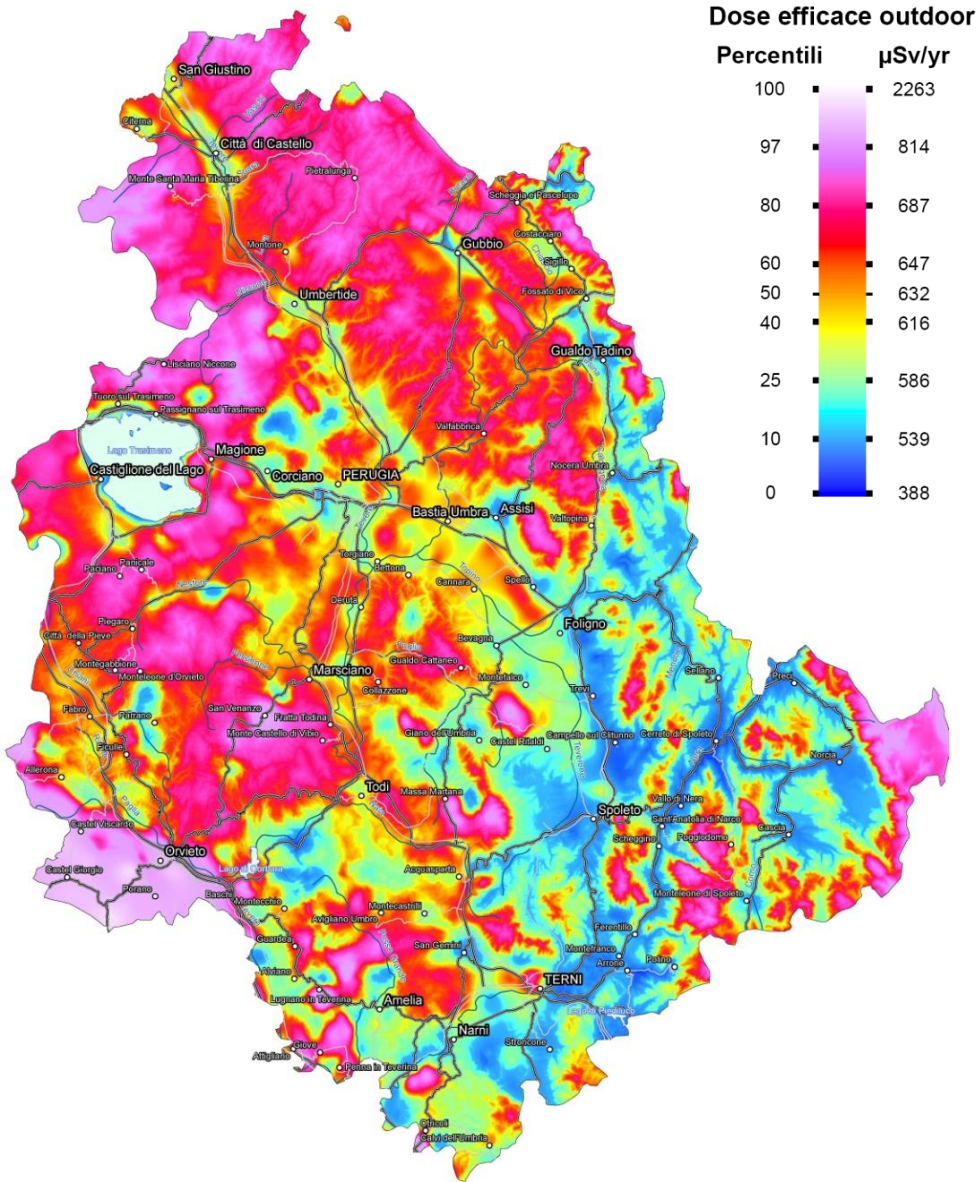
Dose from U



Dose from Th



Dose rate in everyday life



Publications



Total natural radioactivity, Tuscany, Italy

Callegari I., G.P. Bezzon, C. Brogгинi, G.P. Buso, A. Caciolli, L. Carmignani, T. Colonna, G. Fiorentini, E. Guastaldi, M.K. Xhixha, F. Mantovani, G. Massa, R. Menegazzo, L. Mou, A. Pirro, C.R. Alvarez, V. Strati, G. Xhixha, A. Zanon, Journal of Maps, 9 (3), 438 - 443 (2013)



Total natural radioactivity, Veneto (Italy)

V. Stratia, M. Baldoncinia, G.P. Bezzon, C. Broggini, G.P. Buso, A. Caciolli, I. Callegari, L. Carmignani, T. Colonna, G. Fiorentini, E. Guastaldi, M. K. Xhixha, F. Mantovani, R. Menegazzo, L. Mou, C. R. Alvarez, G. Xhixha, A. Zanon Journal of Maps, 11(4) 543 - 551 (2015)



A multivariate spatial interpolation of airborne γ -ray data using the geological constraints

Guastaldi E., M. Baldoncini, G. Bezzon, C. Broggini, G. Buso, A. Caciolli, L. Carmignani, I. Callegari, T. Colonna, K. Dule, G., M. K. Xhixha, F. Mantovani, G. Mass, R. Menegazzo, L. Mou, C.R. Alvarez, V. Strati, G. Xhixha, A. Zanon, Remote Sensing of Environment, 137, 1-11 (2013)



Uranium distribution in the Variscan Basement of Northeastern Sardinia

M. K. Xhixha, M. Albèri, M. Baldoncini, G.P. Bezzon, G.P. Buso, I. Callegari, L. Casini, S. Cuccuru, G. Fiorentini, E. Guastaldi, F. Mantovani, L. Mou, G. Oggiano, A. Puccini, C. R. Alvarez, V. Strati, G. Xhixha, A. Zanon, Journal of Maps, 12(5), 1029-1036 (2016)



Exploring atmospheric radon with airborne gamma-ray spectroscopy

Baldoncini M., M. Albèri, C. Bottardi, E. Chiarelli, K.G.C. Raptis, V. Strati, and F. Mantovani
Atmospheric Environment, 170, 259-268 (2017)

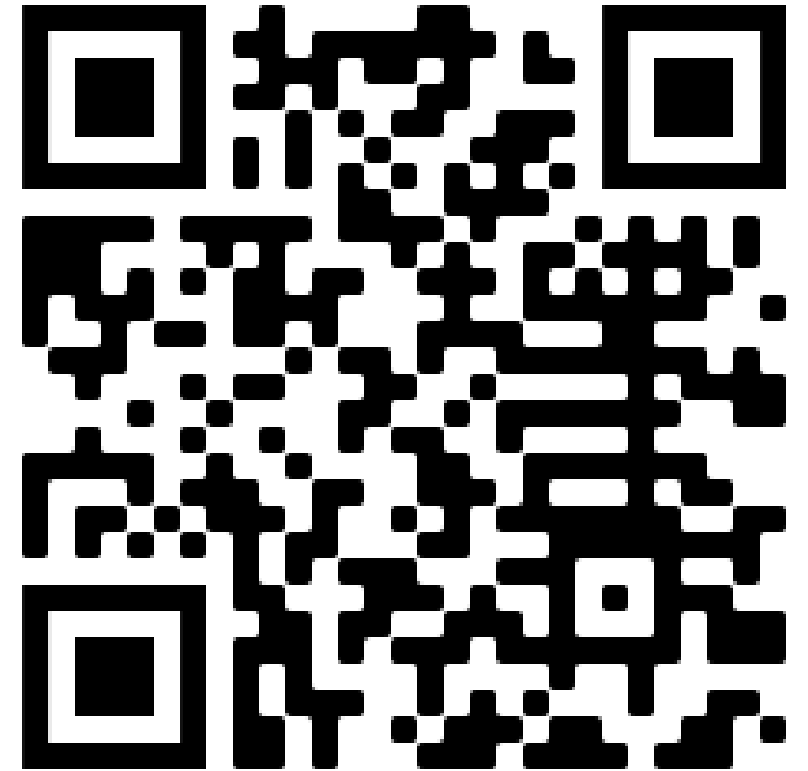
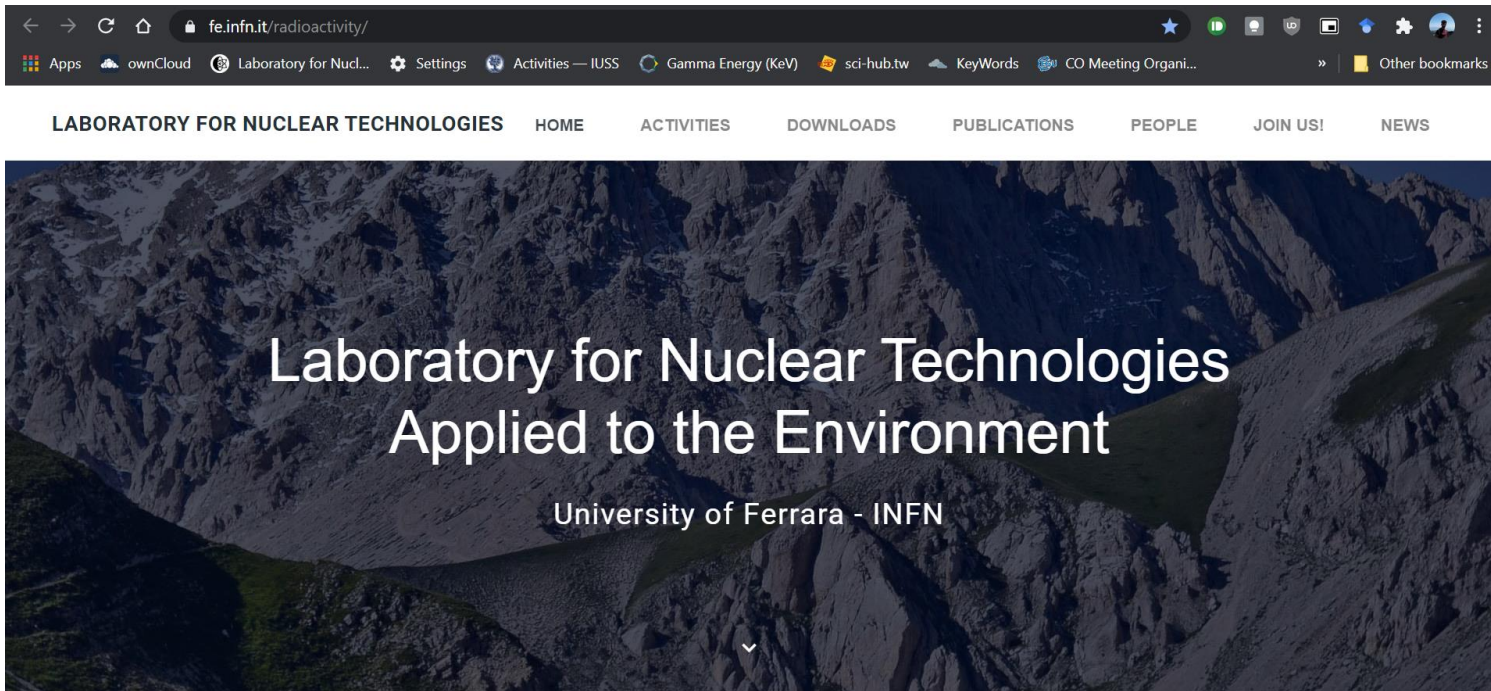


Airborne gamma-ray spectroscopy for modeling cosmic radiation and effective dose in the lower atmosphere

Baldoncini M., Albèri M., Bottardi C., Raptis K.G.C., Minty B., Strati V. and F. Mantovani
IEEE Transactions on Geoscience and Remote Sensing, 56(2) 823 - 834 (2018)



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