Bootstrapping Anisotropy Into Nowcasting Radiation Models - An Upgrade To MAIRE+

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Abstract

Radiation in the atmosphere due to cosmic rays and solar energetic particles becomes not insignificant at aircraft altitudes, and can increase by orders of magnitude during large solar events. The Met Office is currently in the process of implementing MAIRE+, a model we developed at Surrey to produce nowcasts of current radiation dose rates across the world based on real-time ground-level neutron monitor data. We present a new algorithm for MAIRE+ that converts neutron-monitor increases directly into globally anisotropic aviation-radiation fields. Currently MAIRE+ just uses neutron monitors based in Europe to determine radiation dose rates across the world based on the approximation of isotropy. However, real Ground-Level Enhancements (GLEs - space weather events that cause heightened radiation levels in the atmosphere at aircraft altitudes) are typically anisotropic in their early phases. Our new algorithm which is currently being developed will allow a MAIRE+-like model to utilise the full range of neutron monitors throughout the world, removing the necessity of assuming isotropy, while maintaining a data-driven nowcasting approach. Alongside this, we've also modified the codebase for the model, making it much more usable and maintainable, and with an easy-to-use API.

Background

MAIRE+ [1] is an isotropic atmospheric radiation model currently running on the Met Office systems. At Surrey we also developed an anisotropic model, AniMAIRE [2], which is capable of calculating anisotropic dose rates due to differing space weather conditions. However AniMAIRE has a couple of drawbacks that mean it can't currently be used for nowcasting. The two biggest issues are that it can't be run directly from experimental data alone, and that its currently too slow to run for nowcasting. Therefore we've been developing a 'best of both worlds' data assimilation model, that can approximate anisotropic dose rates directly from the world neutron monitor network, and with in principle higher speeds. We're currently dubbing this system 'MAIRE++'. We've also injected machine learning algorithms into MAIRE++, and improved the usability and maintence of all our MAIRE algorithms.

Method

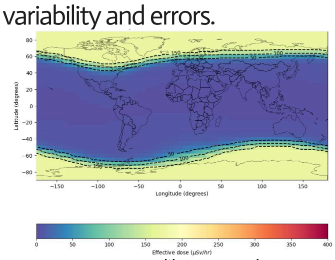
1. Check if a GLE has begun or not, using the regular MAIRE+ algorithm.
2. MAIRE+ uses predefined dual spectral calculation neutron monitors and a single 'normalisation' neutron monitor to determine isotropic dose rate maps for Earth. 'MAIRE++' generalises this algorithm to be used for many neutron monitor combinations at continuous locations on Earth.
3. 'MAIRE++' takes in current data from every neutron monitor on Earth, and then loops over every monitor, treating each one in turn as a separate normalisation monitor.
4. For each normalisation monitor, the nearest valid spectral calculation neutron monitor pair is selected, and then a normal generalised MAIRE+ run is done using these monitors and data as input.
5. After the loop over every monitor is finished, every generated map is collected and they are then interpolated together using the distance from a particular monitor to geographic location. The current interpolation weighting is the inverse square of distance, but other options are being explored.

Output Maps

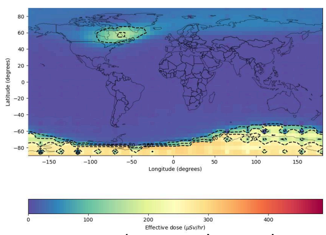
You can see from the maps below that MAIRE++ produces more complex results than MAIRE+. The maps shown are from the 06:55 20th Jan 2005 (GLE69). This could be interpreted as:

- MAIRE+ produces dose rates above Europe (specifically OULU in Finland) and geomagnetically interpolates them across the world
- 'MAIRE++' produces dose rates above every neutron monitor in the world and geomagnetically interpolates dose rates between them and other monitors

Note that MAIRE++ still depends on the quality of the input neutron monitor data ultimately and there are algorithm additions that likely need to be made to account for data variability and errors.



MAIRE+-like-example
(NAIN normalisation, NAIN-NEWK spec index)



Current 'MAIRE++' example
with 7 monitors

Next Steps

We found an important issue with the interpolation algorithm that needs to be patched. High statistical variations in certain neutron monitors cause erroneously extremely high dose rates. This will need to be fixed through either removal of neutron monitors that could cause anomalies, or through weighting via statistical errors. While the latter option would be the physically correct way to do this, it may also double runtimes.

Runtime in general is also an issue at the moment in 'MAIRE++' at the moment. Runtime scales linearly with the number of neutron monitors, so production level implementation will need either a good parallelised HPC or other optimisation.

References

[1] Hands, A. D. P., Lei, F., Davis, C. S., Clewer, B. J., Dyer, C. S., & Ryden, K. A. (2022). A new model for nowcasting the aviation radiation environment with comparisons to in situ measurements during gles. Space weather, 20(8), e2022SW003155.

[2] Davis, C. S. W., Baird, F., Lei, F., Ryden, K., & Dyer, C. (2024). Animaire-a new openly available tool for calculating atmospheric ionising radiation dose rates and single event effects during anisotropic conditions. Space Weather, 22(10), e2024SW003985.