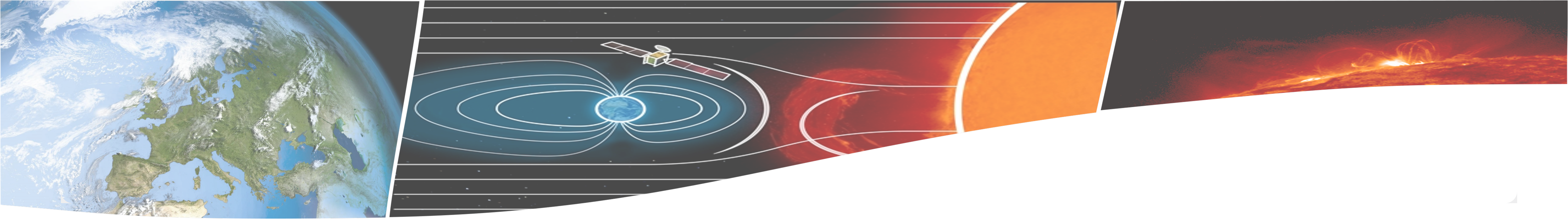

Probability and strength of extreme SPE spectra for G-stars

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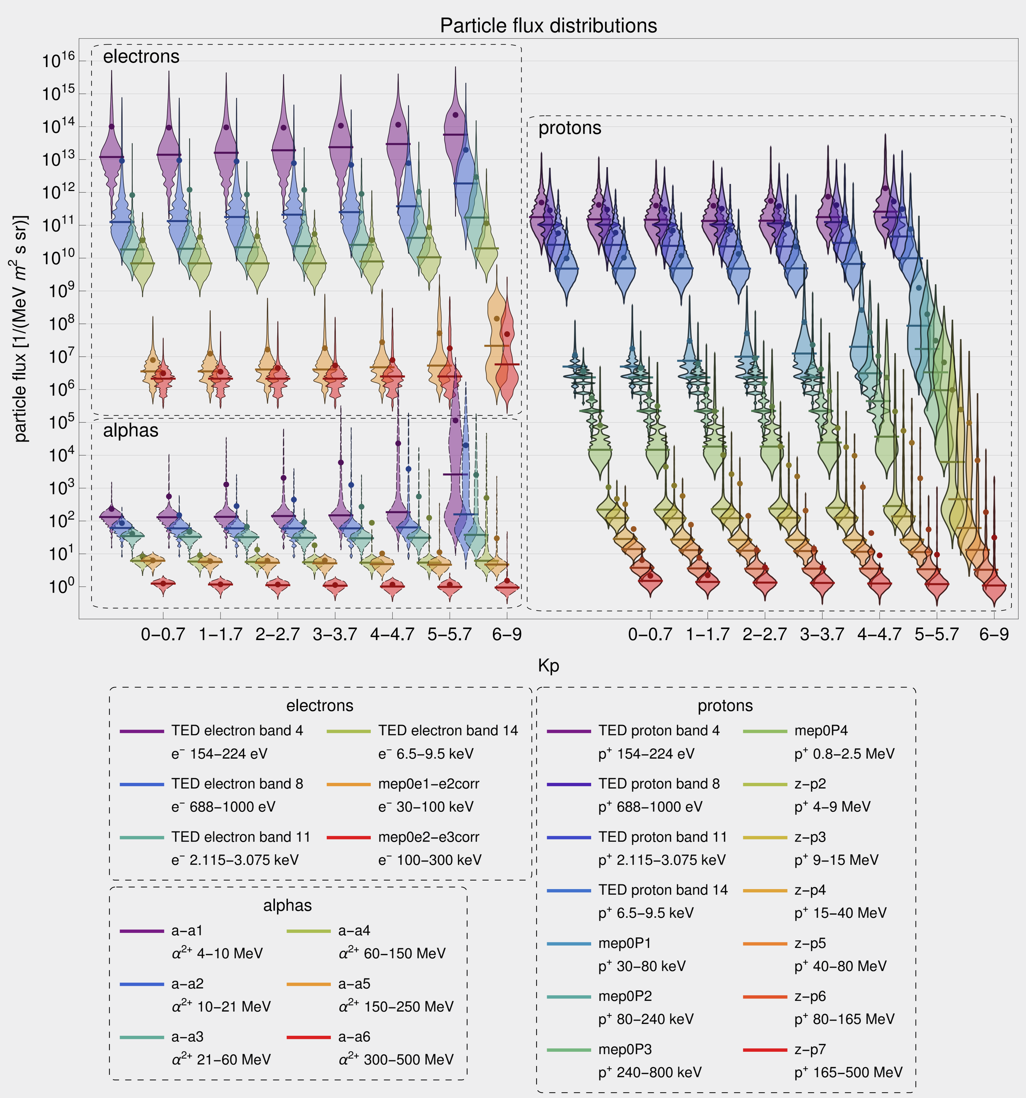
Abstract

Extreme solar particle events (SPEs) are rare by definition. In our solar system, satellites offer measurements of a couple of major SPEs. Some larger ones can be found in historical data such as ice cores - with limitations concerning the recorded spectral information. The shape of the spectrum, however, is crucial for a determination of the atmospheric impact. An offset of some kilometers in atmospheric altitude may distinguish between photolytic destruction or tropospheric wash out of chemical follow-ups.
In this work we will show a method to determine the probability and strength of severe SPEs of G-stars. This approach is based on a statistical analysis of in-situ particle measurements. We provide energy dependent particle fluxes e.g. a once in 10000 years SPE and the expected atmospheric energy deposition. These results can also be applied to exoplanets orbiting similar stars.

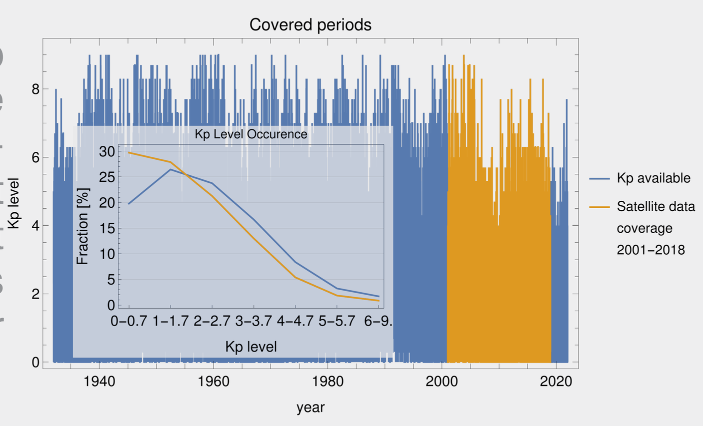
Particle Statistics

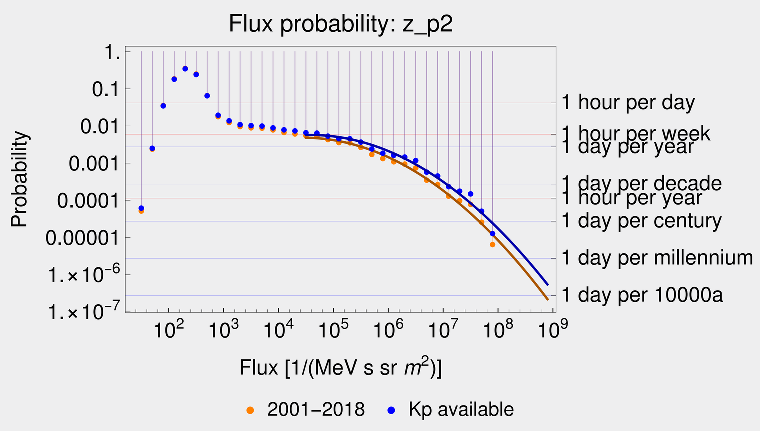


In-situ satellite measurements provide particle flux statistics. Low energy channels show a smooth transition to high Kp, high energy channels have a separate SPE population.

Scaling with Kp

Scaling with Kp enlarges the data base, taking into account 8 solar cycles. It also increases the chance for strong events.

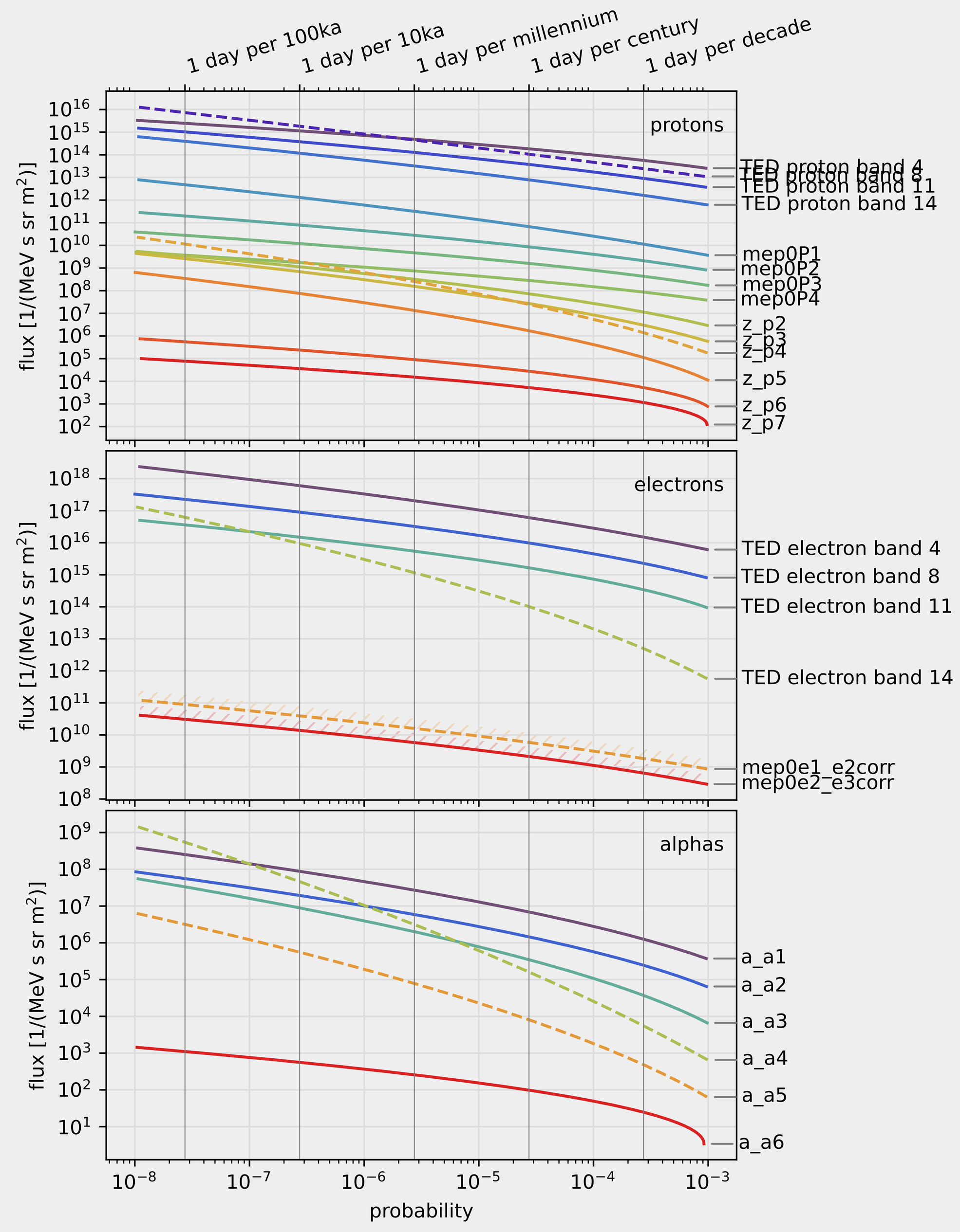




Scaling leads to increased probability for higher flux. Note that the flux is logarithmically binned.

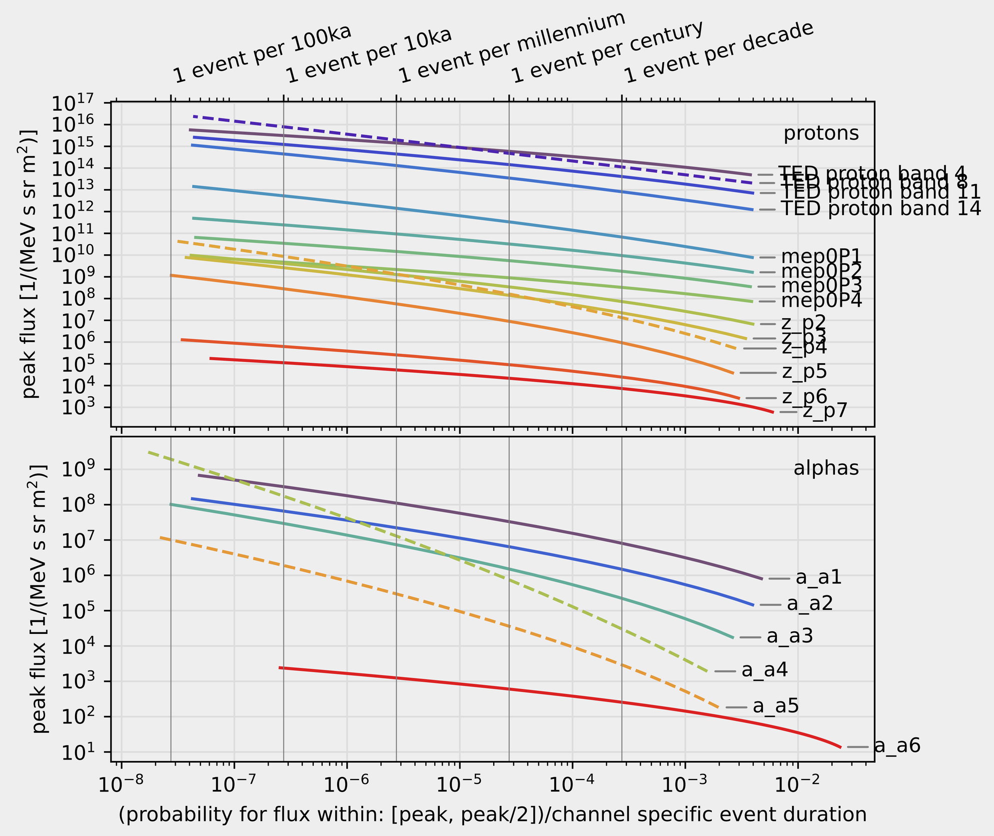
Most channels show probability distributions that permit parabular fitting.

Flux Probability



Flux probability for all channels. Dashed lines indicate problematic fits. Preliminary assumption: event duration is 24 h.

Probability and Duration

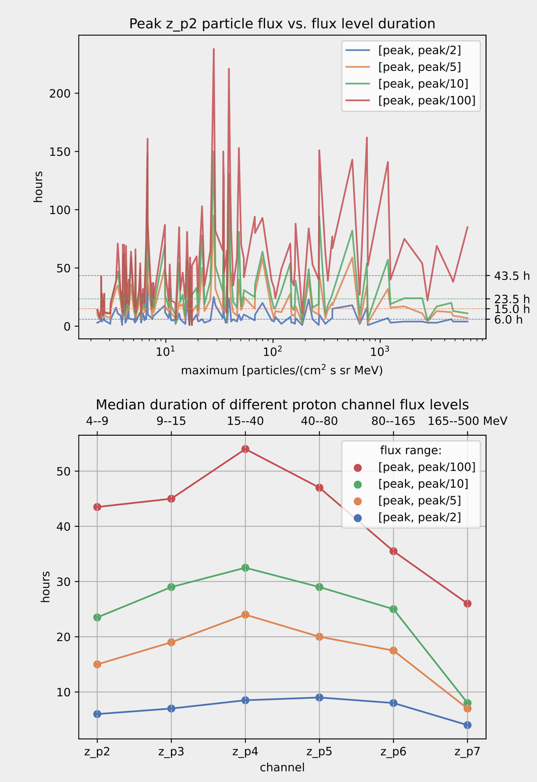


Combining the flux probability and the event duration we can refine the 24 h assumption by typical event lengths in the individual channels. Additionally the graph now shows the probability for flux within the range [peak, peak/2]. Thus the upper ticks convert to event probability.

Summary

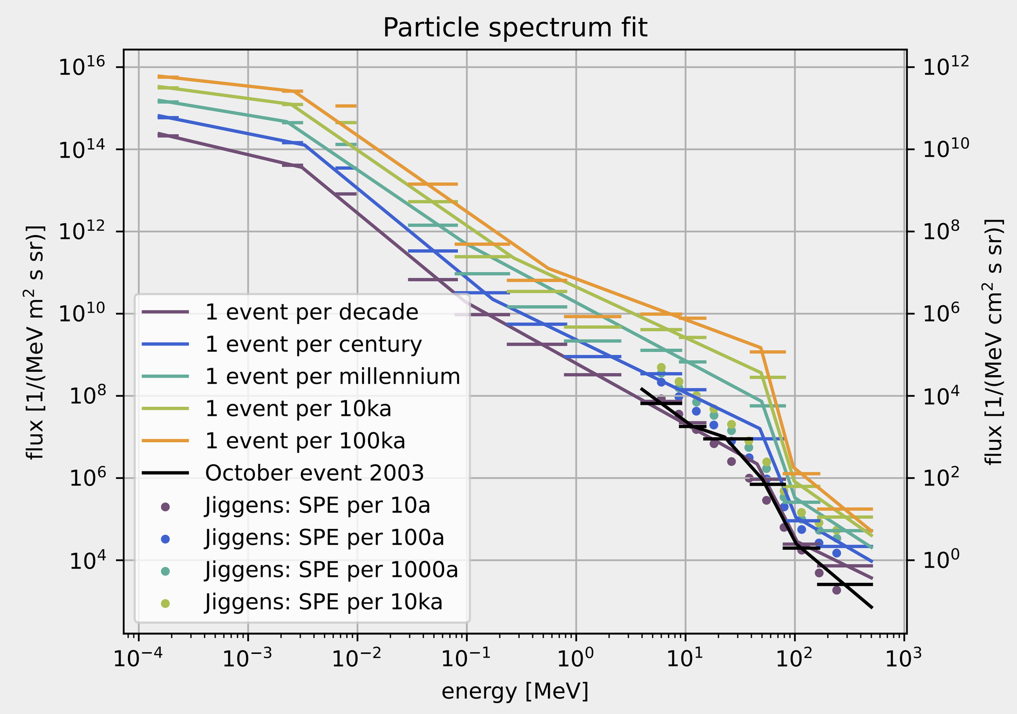
- Statistical flux probability distributions together with empirical peak level durations are used to derive particle flux during extreme events.
- The decadal event agrees with Jiggens et al. 2018. Rare events show higher flux.
- Covering 4 add. orders of magnitude in particle energy.
- Minimum peak durations may be used for refinements.
- May also be applied to other stars and their planets.

Event Duration

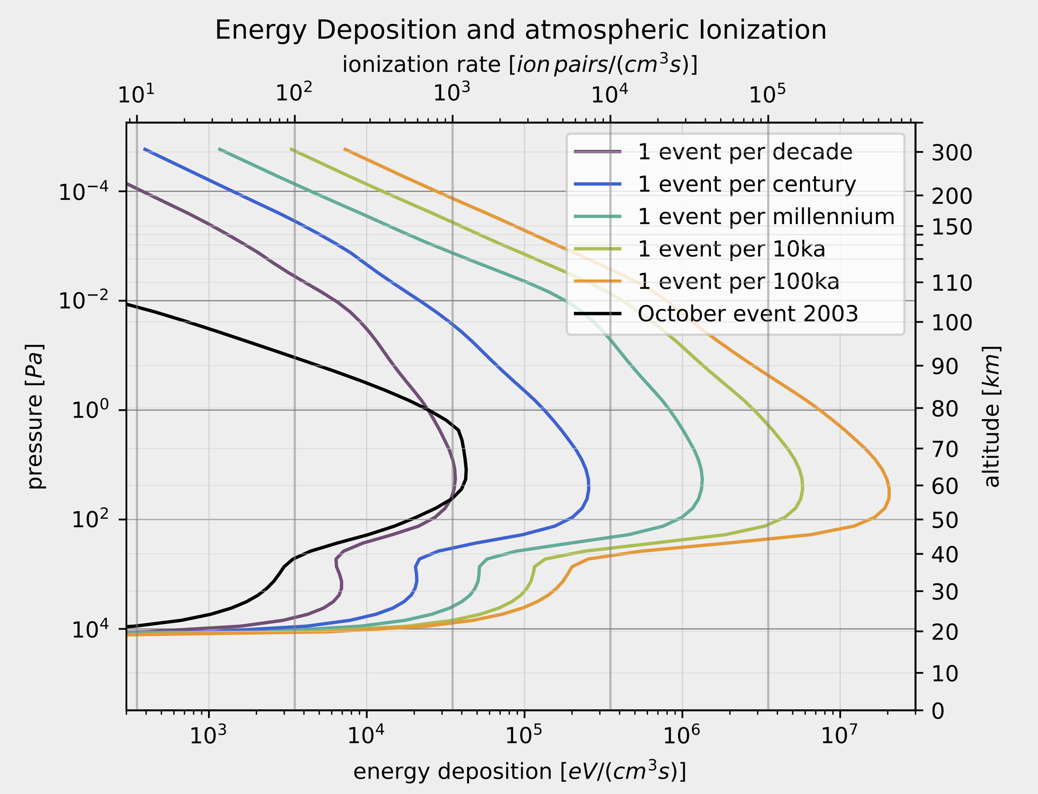


Particle events are identified by assuming a minimum flux peak of 100 times the median, events are separated if flux drops below 10 times the median. The event duration has been determined for every channel and different flux levels in relation to the individual event peak. Event duration is longest for 15-40 MeV particles while it decreases for higher energies. At low energies it seems to be constant (better seen for αs).

Resulting Extreme Events



The one-event-per-decade nicely agrees with Jiggens et al. 2018 as well as with the October event 2003. Note that this is the only event size that can be compared with data. For more extreme cases our spectra are significantly harder than Jiggens et al. 2018.
We should add that the spectrum will get slightly softer when considering a minimum period for the peak flux. Currently the only restriction is a flux between [peak, peak/2] for the typical period of the event.



The spectrum is applied to a terrestrial atmosphere using Geant4. Given adequate atmospheric parameters exoplanets can be modeled as well.

References:

Jiggens, P., Heynderickx, D., Sandberg, I., Truscott, P., Raukunen, O. and Vainio, R., "Updated Model of the Solar Energetic Proton Environment in Space", J. Space Weather Space Clim., 8, A31, 2018

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