Diurnal variation in cosmic ray flux observed with a WCD at Marambio Base

N.A. Santos[1], S. Dasso[1,2,3], A. M. Gulisano[2,3,4], L. Rubinstein[2,5], O. Areso[2], M. Pereira[2],

for the LAGO collaboration

[1] LAMP, DCAO, FCEyN, UBA, Buenos Aires, Argentina,

[2] LAMP, IAFE, UBA, CONICET, Buenos Aires, Argentina,

[3] LAMP, DF, FCEyN, UBA, Buenos Aires, Argentina,

[4] IAA, DNA, Buenos Aires, Argentina,

[5] LACEAC, FIUBA, UBA, FIUBA, Buenos Aires, Argentina.

LAMP Laboratorio Argentino de Meteorología del esPacio

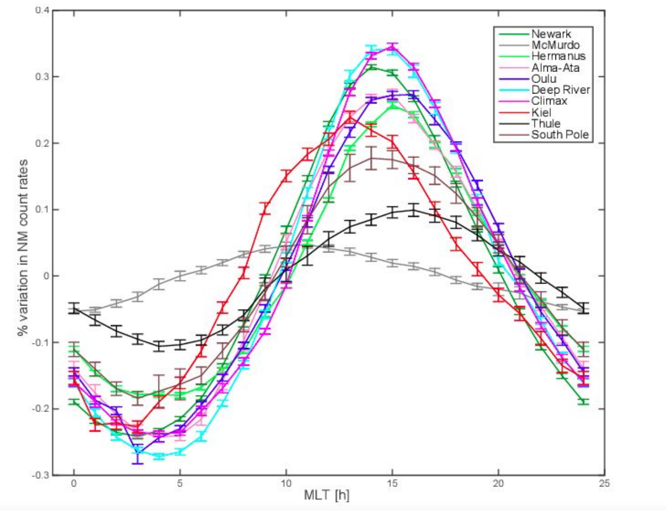
Diurnal variation in CR counting

Origins:

- Atmosphere (Pressure, temperature)
- Magnetosphere (Rigidity cut-off)
- Heliosphere (Anisotropies: Compton-Getting effect due to the Earth’s orbital motion, local solar anisotropy)

Solar diurnal anisotropy at Earth: Observations

Because of the Earth’s rotation,
a ground-based detector scans the local space
in the counter-clockwise directions and
thus detects the spatial anisotropy
expressed as a nearly- sinusoidal wave in the count rate.



Thomas, Simon et al. “Decadal trends in the diurnal variation of galactic cosmic rays observed using neutron monitor data.” *Annales Geophysicae* 35 (2017): 825-838.

- Introduction
- Motivation
- Objective
- Atmospheric effects
- Periodicities
- Anisotropy
- Conclusions

Solar diurnal anisotropy at Earth: Theoretical development

$$\frac{\partial f}{\partial t} + \underbrace{\mathbf{V}_{\mathrm{sw}} \cdot \nabla f}_{\text{Convection}} - \underbrace{\nabla \cdot (\mathbf{K} \cdot \nabla f)}_{\text{Diffusion}} - \underbrace{\frac{1}{3} (\mathbf{V}_{\mathrm{sw}} \cdot \nabla) \frac{\partial f}{\partial \ln p}}_{\text{Adiabatic cooling}} = q$$

Parker's CR transport equation

Solar diurnal anisotropy at Earth: Theoretical development

$$\frac{\partial f}{\partial t} + \mathbf{V}_{\mathbf{sw}} \cdot \nabla f - \nabla \cdot (\mathbf{K} \cdot \nabla f) - \frac{1}{3}(\mathbf{V}_{\mathbf{sw}} \cdot \nabla)\frac{\partial f}{\partial \ln p} = q$$

Parker's CR transport equation

Convection — Diffusion — Adiabatic cooling

Convection-diffusion theory

Solar diurnal anisotropy at Earth: Theoretical development

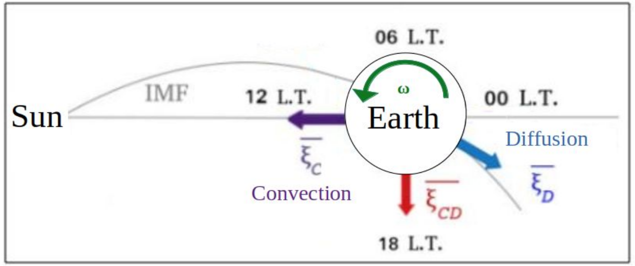
$$\frac{\partial f}{\partial t} + \mathbf{V}_{\rm sw} \cdot \nabla f - \nabla \cdot (\mathbf{K} \cdot \nabla f) - \frac{1}{3}(\mathbf{V}_{\rm sw} \cdot \nabla)\frac{\partial f}{\partial \ln p} = q$$

Parker’s CR transport equation

Convection Diffusion Adiabatic cooling

Convection-diffusion theory

Radial outward convection by the solar wind ξ_C
The inward diffusion along the IMF ξ_D
The net spatial anisotropy ξ_{CD} points at 18 hr LT



Forman, M. A. and Gleeson, L. J., “Cosmic-Ray Streaming and Anisotropies”, *Astrophysics and Space Science*, vol. 32, no. 1, Springer, pp. 77–94, 1975. doi:10.1007/BF00646218.

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Motivation

Anisotropy
can be modified due to the passage of interplanetary structures through the Earth's environment.

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Neutron monitors
median rigidity of detector response ~ **30 GV**

Lingri, D. et al. (2019). An Extended Study of the Precursory Signs of Forbush Decreases: New Findings over the Years 2008 – 2016. *Solar Physics*. 294. 70. 10.1007/s11207-019-1461-3.

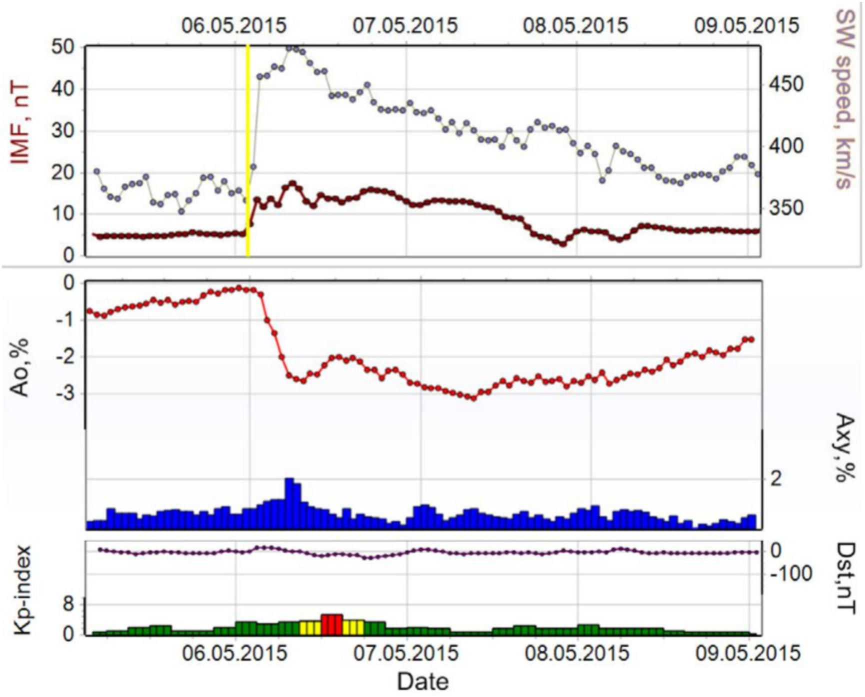
Muon detectors
median rigidity of detector response ~ **70 GV**

Kudela, K. and Storini, M., et al. Possible tools for space weather issues from cosmic ray continuous records. *Advances in Space Research*, vol. 37, no. 8, pp. 1443–1449, 2006. doi:10.1016/j.asr.2006.02.058.

Munakata, et al. Long-term Variation of the Solar Diurnal Anisotropy of Galactic Cosmic Rays Observed with the Nagoya Multi-directional Muon Detector. *The Astrophysical Journal*, vol. 791, no. 1, Art. no. 22, IOP, 2014. doi:10.1088/0004-637X/791/1/22.

Motivation

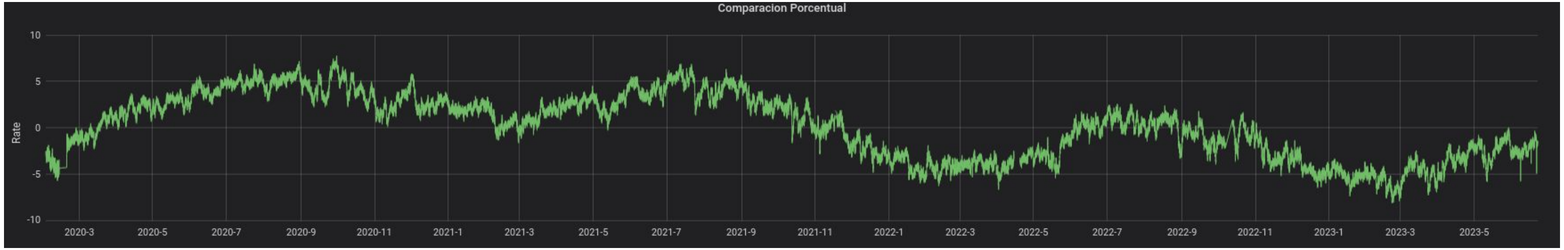
Anisotropy can be modified due to the passage of interplanetary structures through the Earth's environment.



Lingri, D. et al. (2019). An Extended Study of the Precursory Signs of Forbush Decreases: New Findings over the Years 2008 – 2016. *Solar Physics*. 294. 70. 10.1007/s11207-019-1461-3.

Objective

Characterization of the observed mean diurnal variation in the CR hourly flux data at Marambio base (Rc = 2.2 GV, 200 m a.s.l)



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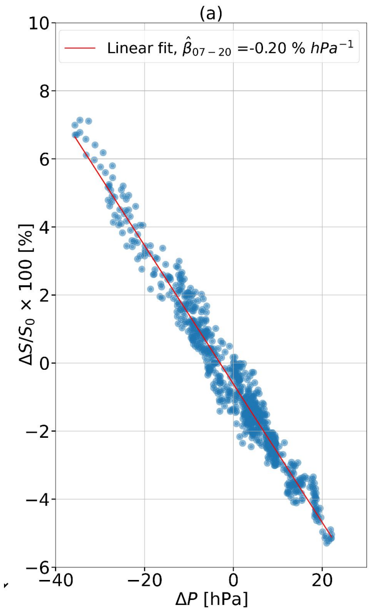
Data - Atmospheric effects

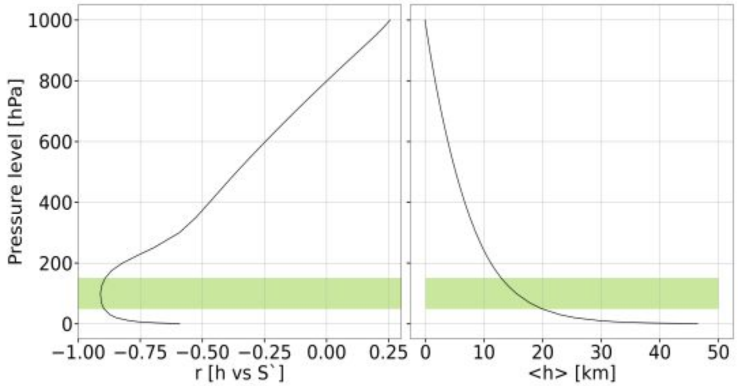
(1) Pressure



$$\frac{\Delta S'}{S_0} \times 100\% = \frac{\Delta S}{S_0} \times 100\% - <\hat{\beta}> \Delta P$$

Data - Atmospheric effects

(2) Temperature

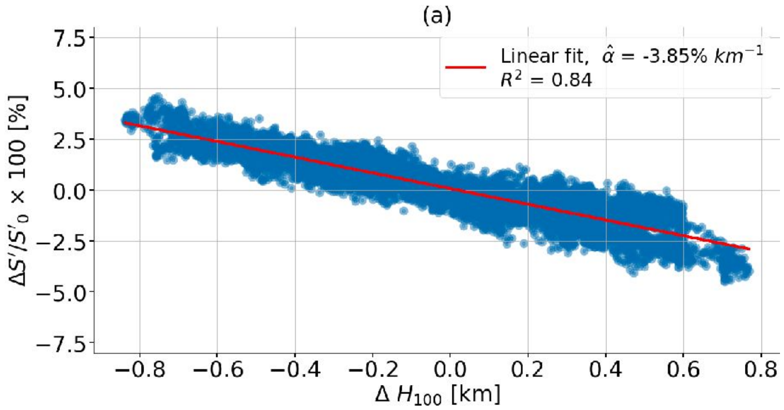


Local variations in air density caused by temperature changes. We used the geopotential height for this effect from ERA5 reanalysis

https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels

Data - Atmospheric effects

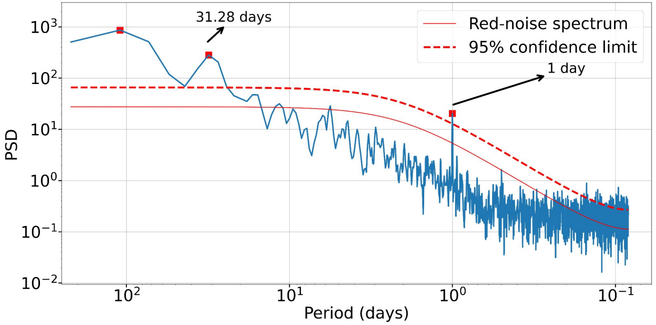
(2) Temperature



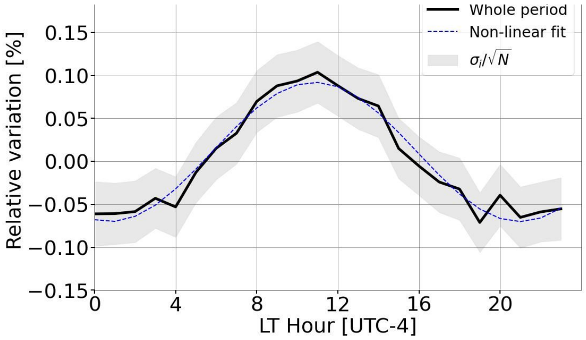
$$\frac{\Delta S''}{S_0} \times 100\% = \frac{\Delta S'}{S_0} \times 100\% - \hat{\alpha}\Delta H_{100}$$

Data - Periodicities

Spectral analysis

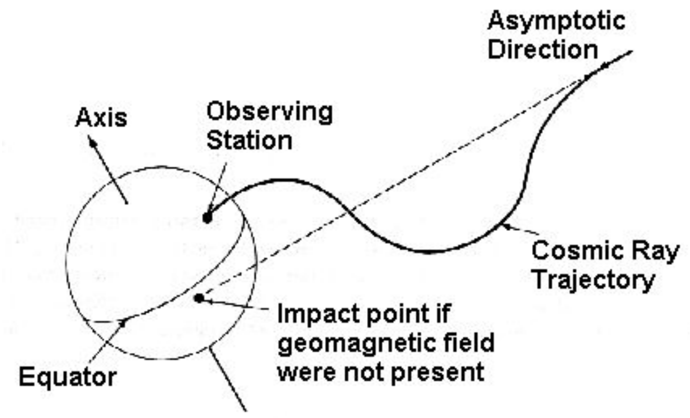


SEA analysis

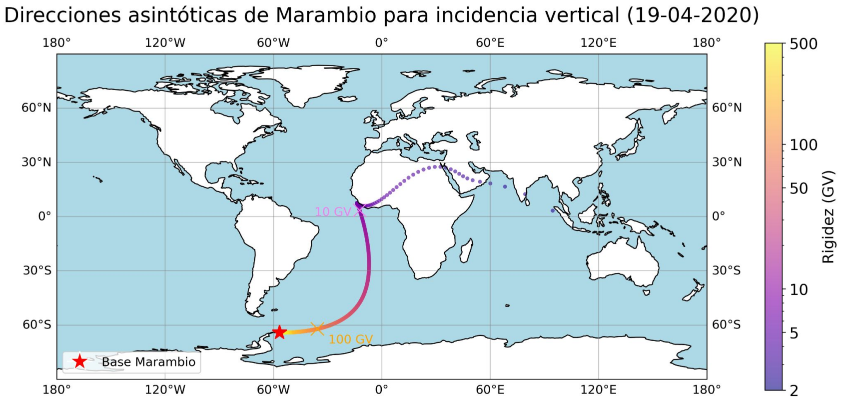


Mean amplitude ~0.1 %
Time of the maximum 11 LT

Data - Periodicities



https://github.com/NLarsen15/OTSO



Assuming a median rigidity of primary cosmic rays ~ 60 GV, then they entered ~55° to the east (~+3 - 4 hr)

Data - Anisotropy

	Expected	Neutron Monitor	WCD in Antarctica
Mean amplitude	-	~0.4 %	~0.1 %
Maximum	18 hr LT (ξ_{CD})	14-18 hr LT direction (e.g. A. Gil et al., 2022)	~14-15 hr LT direction (ξ_{obs})

Conclusions

- Periodicities found of 1 and 27 days.
- This diurnal periodicity is consistent with previous works on the diurnal solar modulation of GCRs.

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★ Next step: Statistical analysis of the diurnal variation based on a daily basis. Definition of thresholds.

Thanks for your attention!

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