ACORDE: A new method to calculate onboard radiation doses during commercial flights

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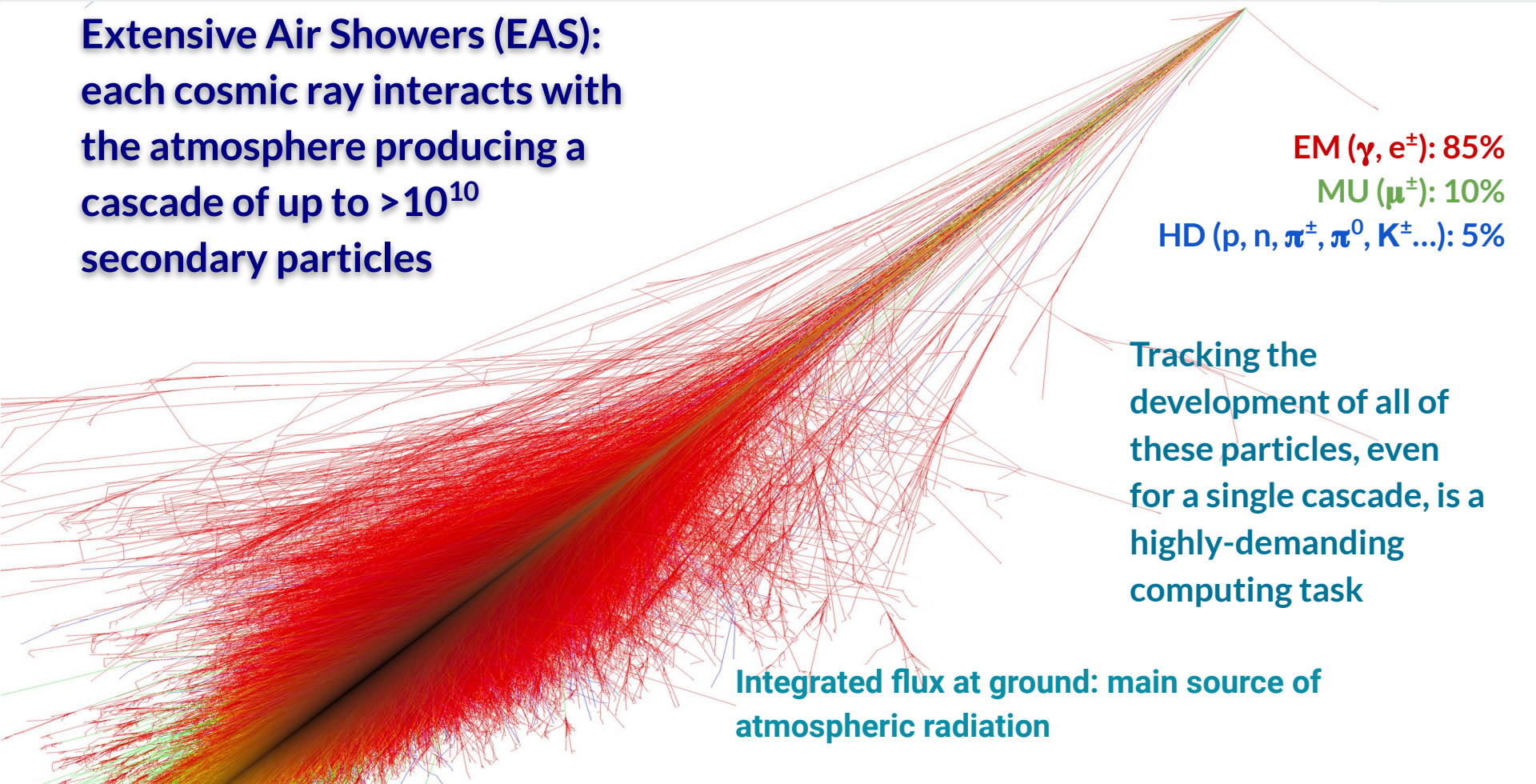
Extensive Air Showers (EAS): each cosmic ray interacts with the atmosphere producing a cascade of up to >10^{10} secondary particles



EM (γ, $e^{\pm}$): 85%

MU ($\mu^{\pm}$): 10%

HD (p, n, $\pi^{\pm}$, π^{0}, $K^{\pm}$...): 5%

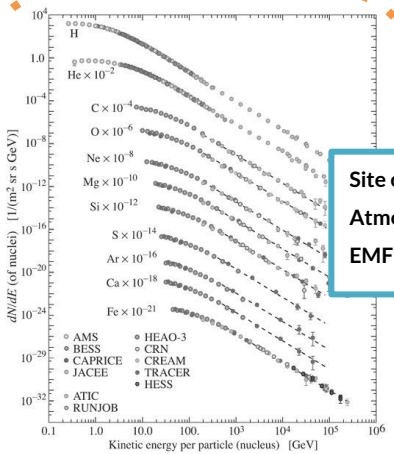
Tracking the development of all of these particles, even for a single cascade, is a highly-demanding computing task

Integrated flux at ground: main source of atmospheric radiation

ARTI, from GCR flux to signals or doses everywhere in the World

C. Sarmiento-Cano et al, EPJ C(1019) 2022

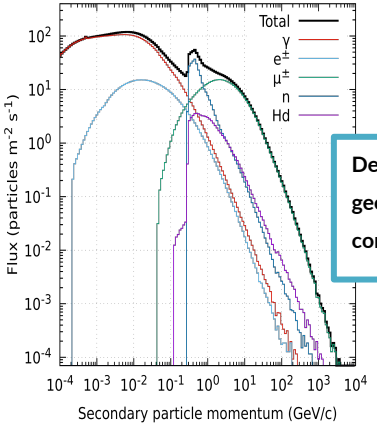
docker S0 - ARTI
Corsika, Magcos, GDAS



GCRs models

Site characteristics
Atmospheric and
EMF's conditions

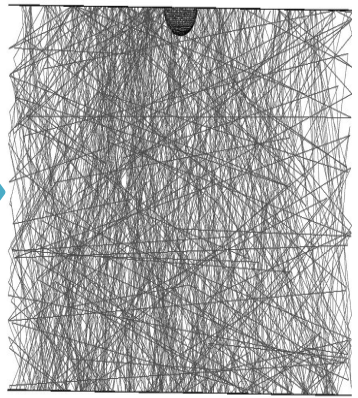
docker S1 - ARTI
analysis tools



Secondaries

Detector's type,
geometry and
conditions

docker S2 - ARTI
Geant4

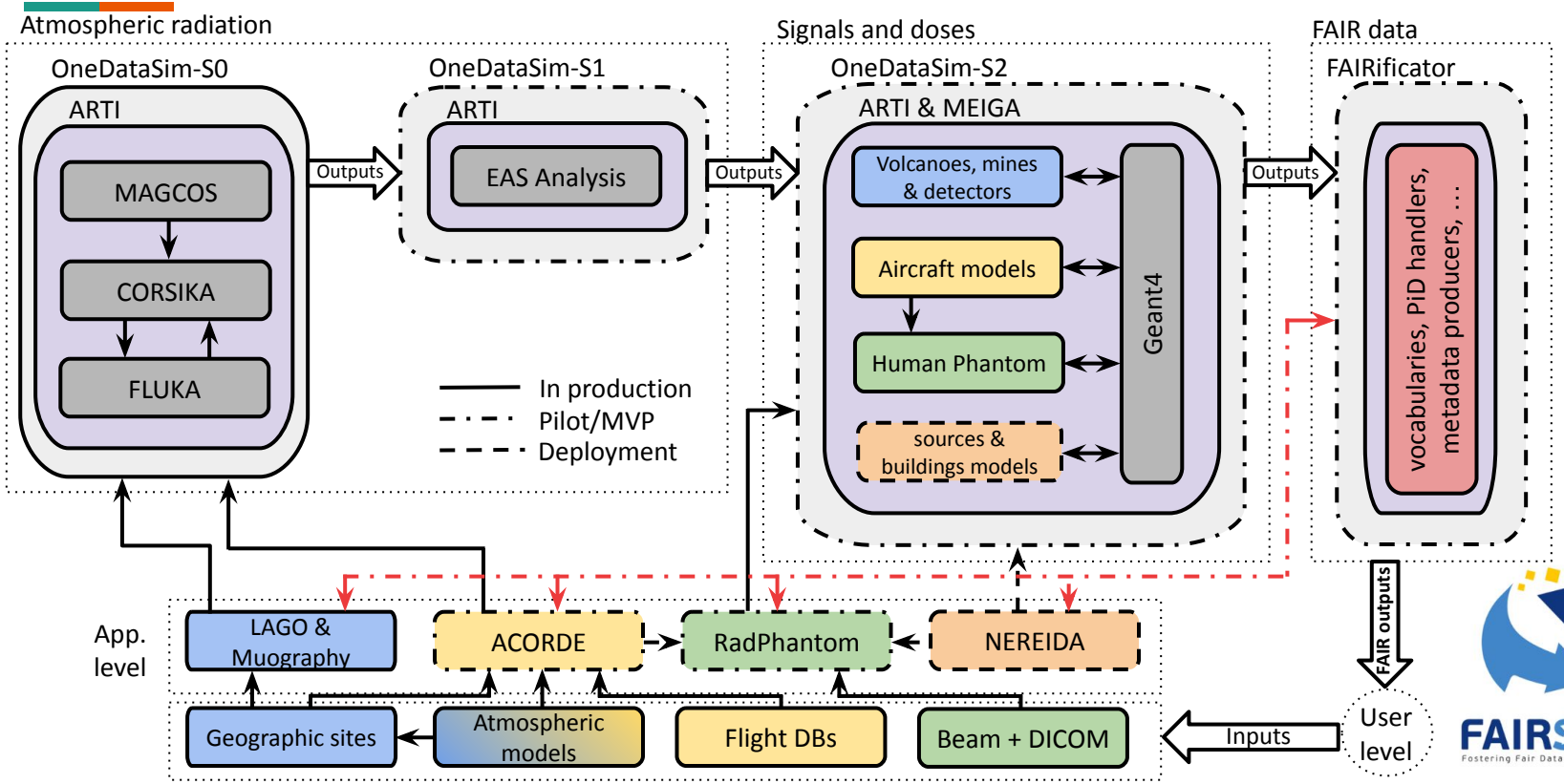


Signals

ARTI is publicly available

Enabling data-driven workflows for highly demanding simulations

O. Núñez-Chongo et al, CMMSE 2024, J. Supercomputing, submitted



Cloud implementation

A.J. Rubio-Montero el at, IEEE WSC52266(9715360) 2021

HPC provider assigns cloud resources to EOSC:
n Nodes, *r* GB/TB of RAM, *d* TB local storage

Infrastructure Manager

web-based service with templates for distributing to available resources in virtual clusters. Installs OS, in our case, ubuntu 20.04 + slurm manager

docker HUB

docker containers with our codes are deployed from docker HUB in the virtual cluster

virtual cluster

docker

ubuntu

slurm workload manager

FAIRSFAIR

FAIR: catalogs are findable, accessible, interoperable, and reusable

B2FIND

ONEDATA

Results are stored at cloud-based storage services. Access trough personal tokens

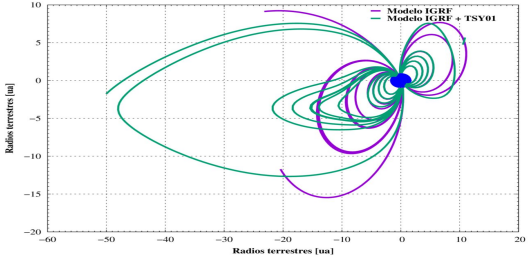
B2HANDLE

PID (Persistent IDentifiers) are assigned for each data catalog

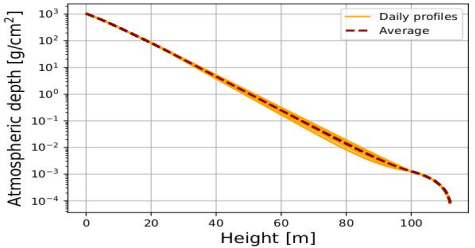
ACORDE: Application COde for the Radiation Dose Estimation

A tool designed to accurately calculate the radiation dose during commercial flights based on start-of-the-art codes

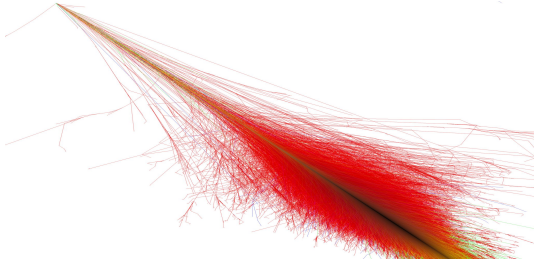
1. Segmentation of real flight paths from public databases



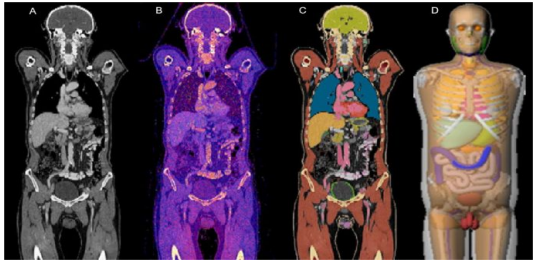
2. On route real-time EMF condition (IGRF-13+TSY model)



3. On route GDAS atmospheric profiles



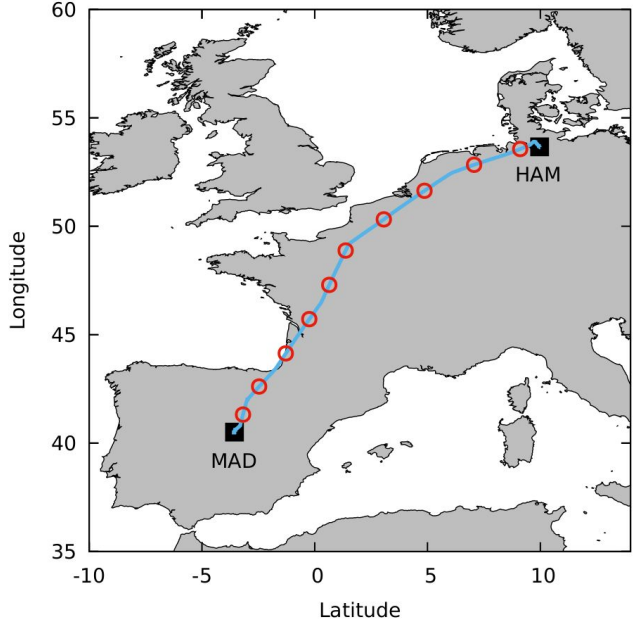
4. On route integrated secondary particles flux at flight altitude (ARTI)



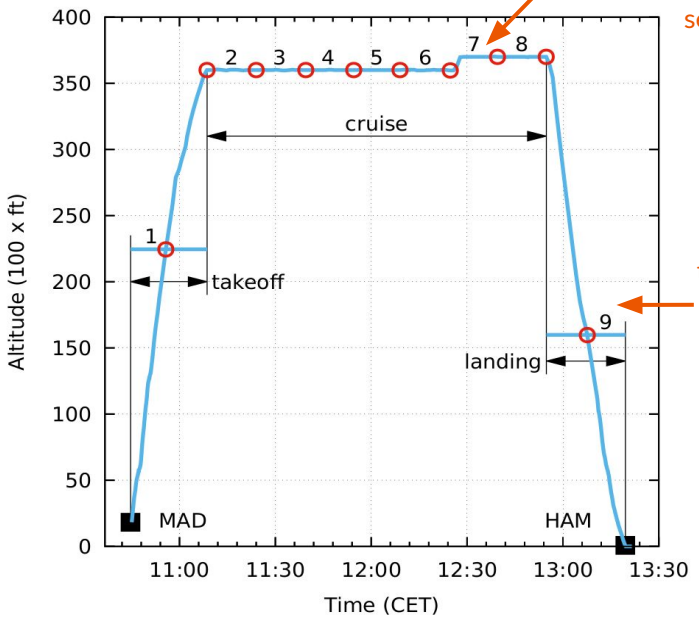
5. Dose calculation in Geant4 models of the aircraft and a human phantom

ACORDE calculation example: IB3270 MAD-HAM 16/Nov/2021

Asorey, Suárez-Durán and Mayo-García, ARI Mayo-García, Appl Radiat Isot 2023 Jun;196:110752.



From the real track gathered from public databases, ACORDE segments the route and find the main waypoints

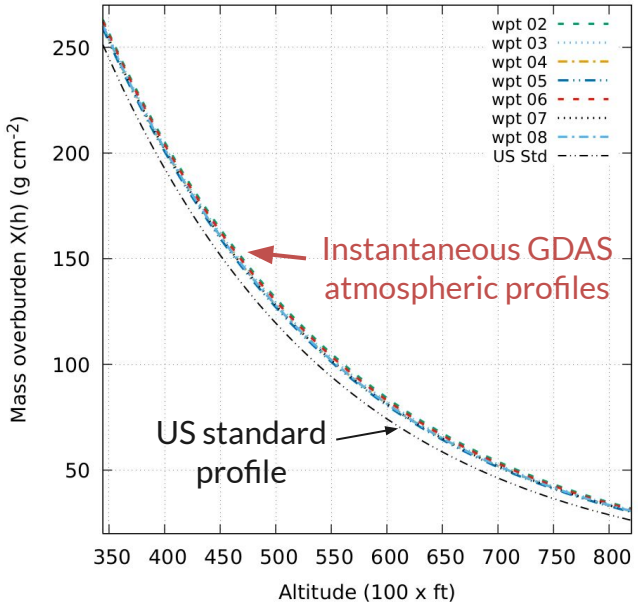


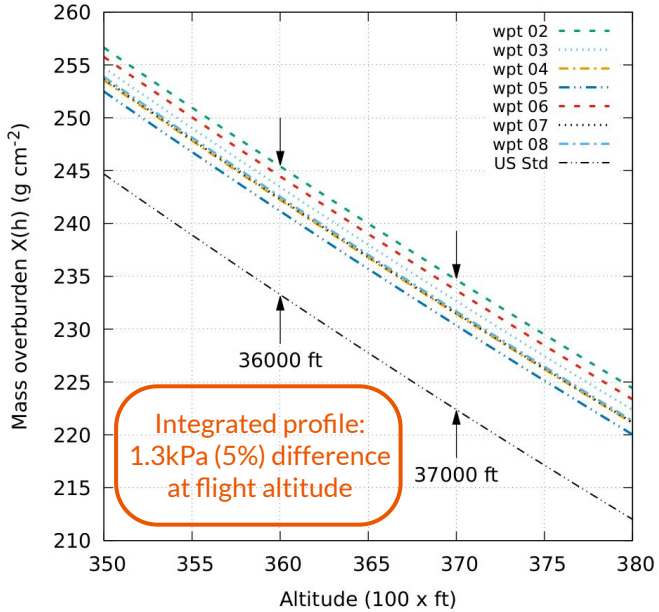
the worst case scenario is considered for mixed altitude segments

takeoff and landing waypoints are located at the midpoint of each interval

The cruise stage is automatically derived from the analysis of the track altitude as a function of time and its derivatives

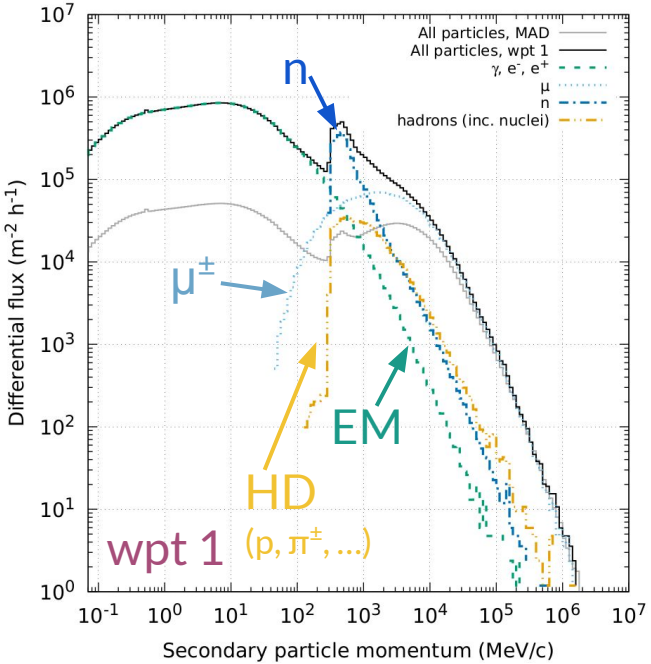
Local GDAS atmospheric profiles at each waypoint

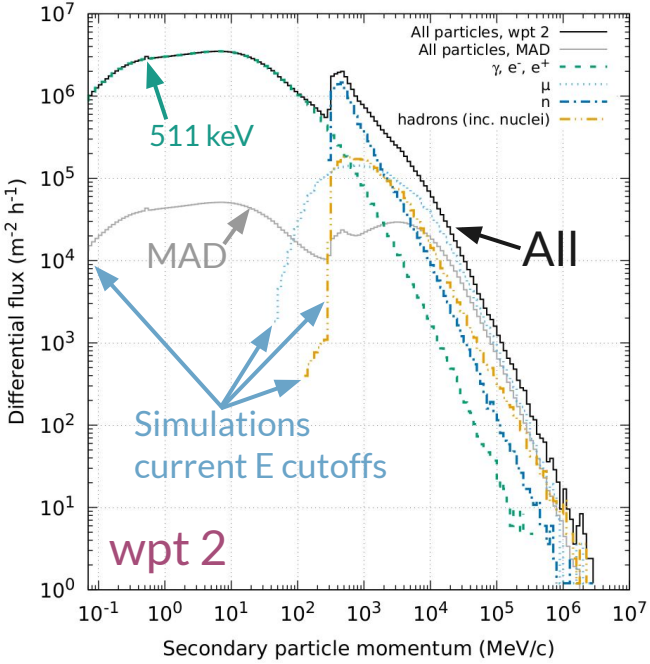




Atmospheric profiles are gathered from GDAS database for each waypoint within a ±1.5h time window and used for the corresponding segment

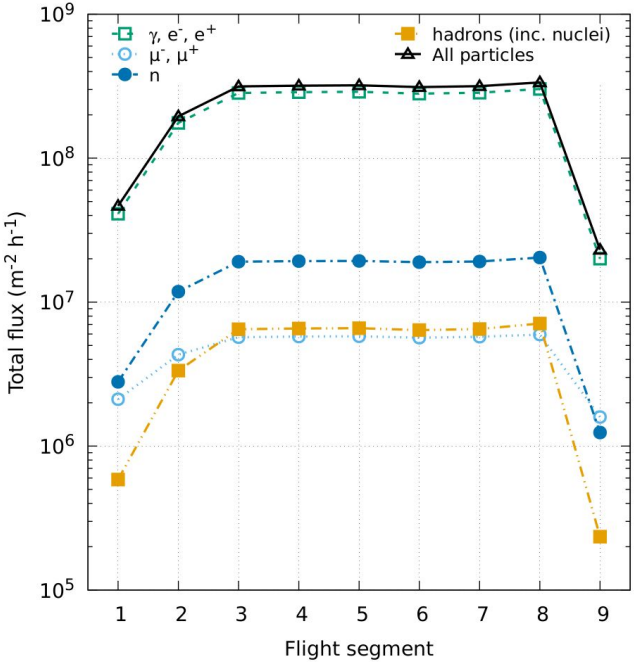
Secondary particles at each waypoint





Secondary particles momentum spectrum expected during the takeoff segment (~7 km) and at the 1st cruise waypoint (~ 11 km). MAD all-particle spectrum is included for comparison.

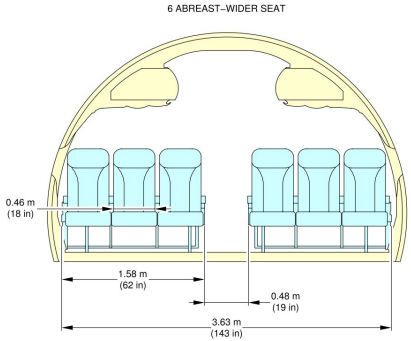
Effective dose for IB3270: E_A= 11.7 µSv and E_C = 9.2µSv (ΔE=+23%)

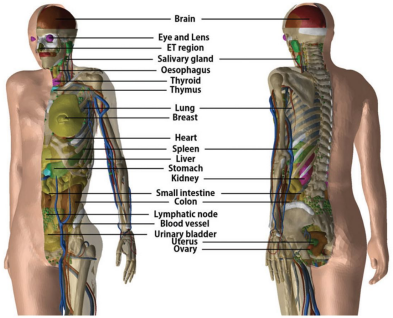


From the absorbed dose $D_{R,T,i}$ at waypoint *i*, total effective dose E_A is calculated following ICRP 147

$$E_A = \Sigma_i E_i$$

$$E_A = \Sigma_i [\Sigma_T w_T \overbrace{(\Sigma_R w_R D_{T,R,i})}^{H_{T,i}}]$$





Integrated secondary particle flux is propagated through a Geant4 model of the vessel and a simplified ICRP110-based voxelized anthropomorphic phantom. Same waypoints were used for calculating the dose in CARI-7A

Extended simulation campaign: 324 flights

- 287 regular random IB flights
- 37 West-East and East-West flights operated by JL and CX
- ACORDE dose (E_A) compared with CARI-7A standard calculation dose (E_C)
- Absolute

$$\Delta E = (E_A - E_C)$$

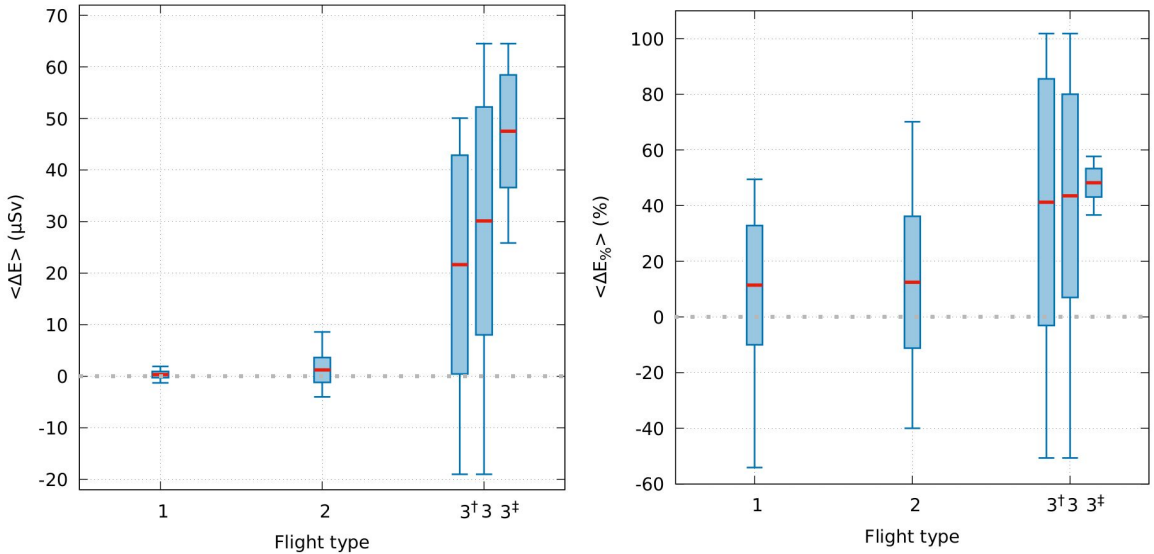
and relative differences

$$\Delta E_{\%} = 2\,\Delta E / (E_A + E_C)$$

were computed and averaged

- **long flights: significant differences**

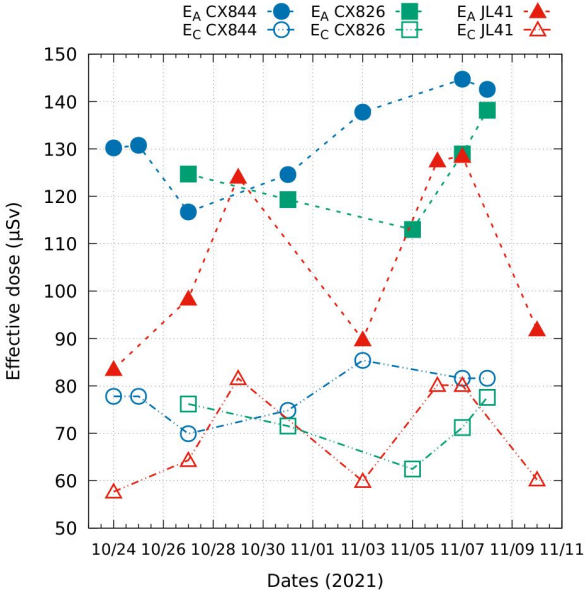
1: Short (153), 2: Intermediate (58), 3: Long (113), 3†: Regular flights (76), 3‡: W-E and E-W flights (37)

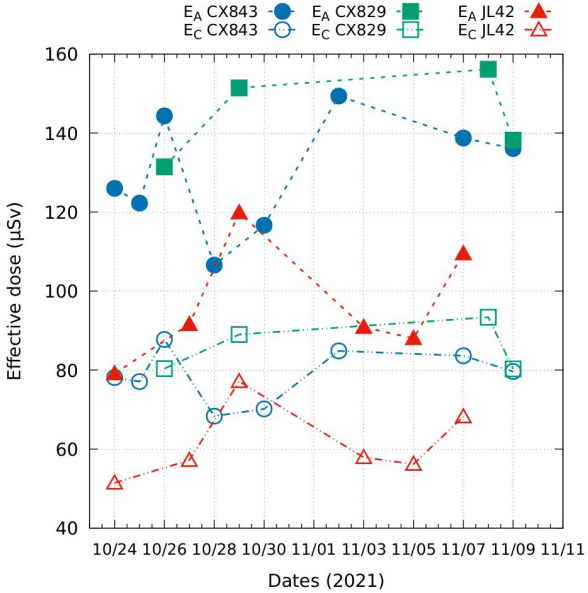


Type 3	$\langle \Delta E \rangle = (30 \pm 22)$ μSv	$\langle \Delta E_{\%} \rangle = (44 \pm 37)$ %
Type 3†	$\langle \Delta E \rangle = (22 \pm 21)$ μSv	$\langle \Delta E_{\%} \rangle = (41 \pm 44)$ %
Type 3‡	$\langle \Delta E \rangle = (48 \pm 11)$ μSv	$\langle \Delta E_{\%} \rangle = (48 \pm 5)$ %

Detailed analysis: W-E and E-W during heightened solar activity period

- Special subset (3‡) West-East and East-West flights (37)
  - CX843 (JFK-HKG) - CX844 (HKG-JFK)
  - CX829 (YYZ-HKG) - CX826 (HKG-YYZ)
  - JL42 (LHR-HND) - JL41 (HND-LHR)
- Flights selected from Oct, 24th to Nov, 10th (2021)
- Geomagnetic disturbances observed for early November 2021
- **E_A and E_C doses showed similar trends but a significant offset**



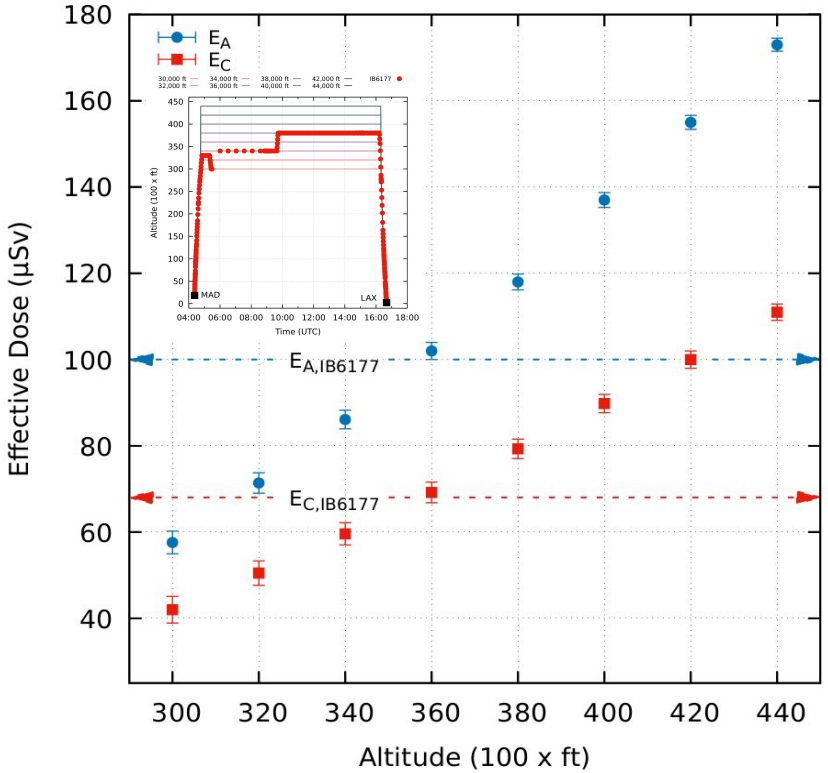


ACORDE capabilities: evaluating the altitude effect

- IB6177 (MAD-LAX)
- ACORDE automatic completion of waypoints over the Atlantic ocean
- Artificially changed cruise altitude from lvl 300 to lvl 440 in 2 kft steps
- E_A and E_C :
  - original flight (dots)
  - modified flights (lines)

E_A(track)/E_A(300) ~175%

E_A(440)/E_A(300) ~300%



ACORDE: conclusions and future perspectives

- **Effective dose calculation for aircrew and passengers using real flight data and conditions**
- Tested on >300 flights and using CARI-7A standard calculation as reference
  - Absolute differences are compatible with zero (1σ) for short and intermediate flights
  - For long (>4h) flights, ACORDE's doses are generally larger than CARI-7A ones.
  - Significant differences are observed for long flights in west-east-west routes.
- Compute-intensive application: ~ (370 CPU·h + 20 GiB) per hour at cruise altitude. Up to now:
  - +600 flights (~7,000 hours): ~2.6M CPU·hours, 150 TiB intermediate data, 3 GiB of final FAIR-capable data
- Work in progress
  - Improved fuselage models and voxelized anthropomorphic phantoms
  - Extended energy range for neutrons and other secondaries
  - Gamma-Scout onboard dose estimation allows simple experimental validation for ACORDE
  - Improve the dose calculation during solar activity events (GLE, SPE, …)

Thanks!

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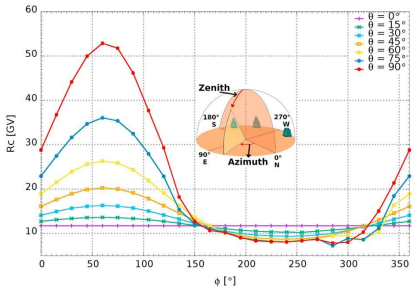
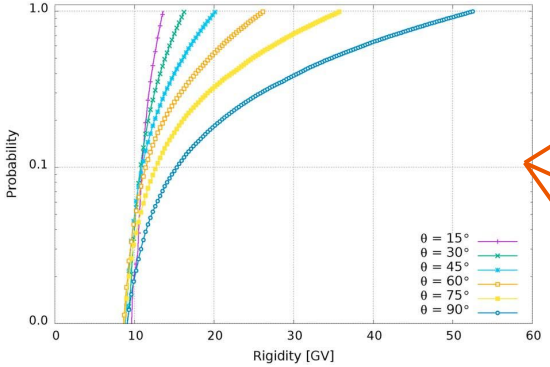
DASH

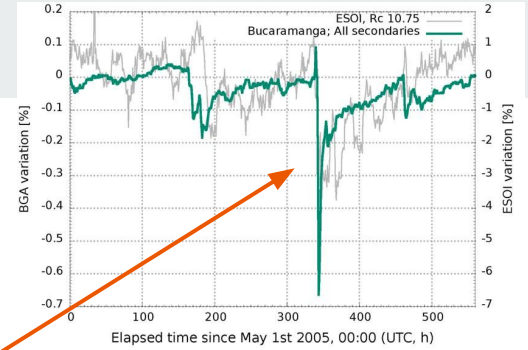
backup slides

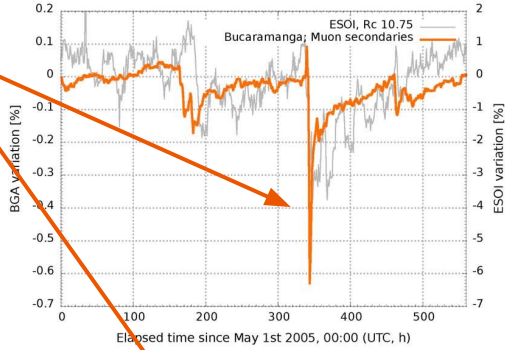
Time-dependent local geomagnetic effects

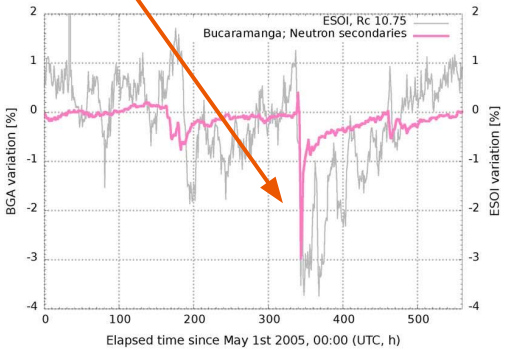
*M. Suárez-Durán et al., Space Weather **16**(5), 2018*

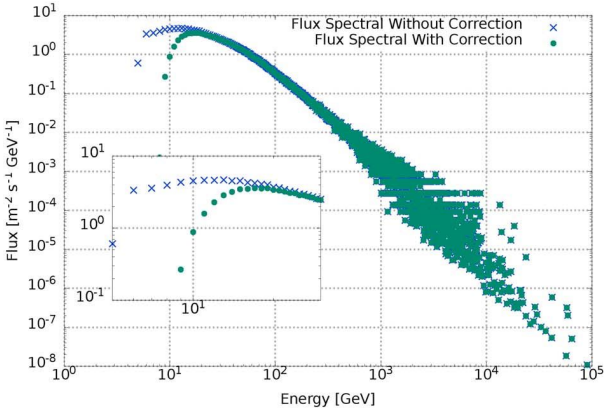


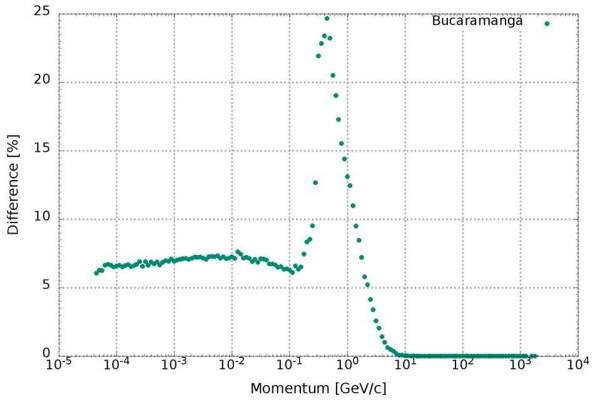






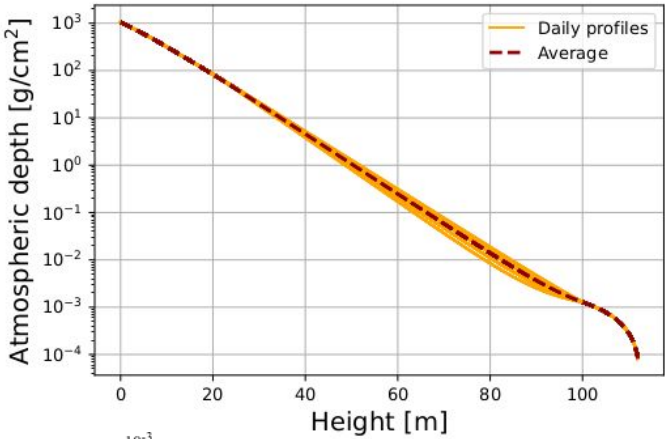


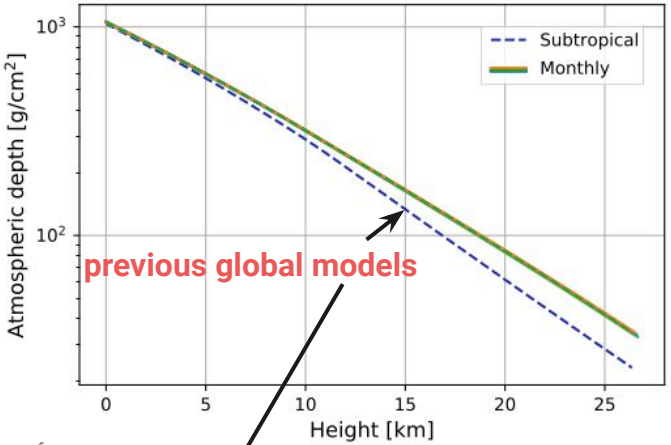




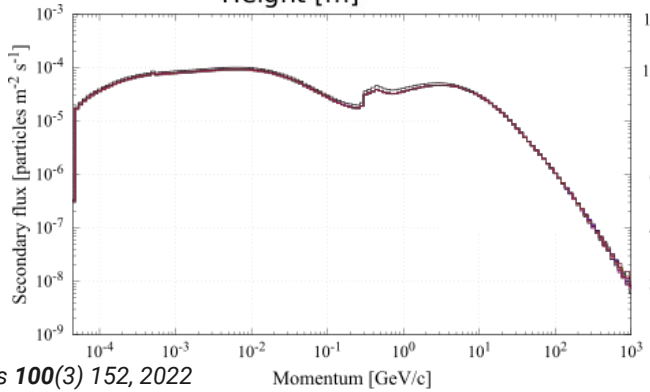
Local atmospheric effects

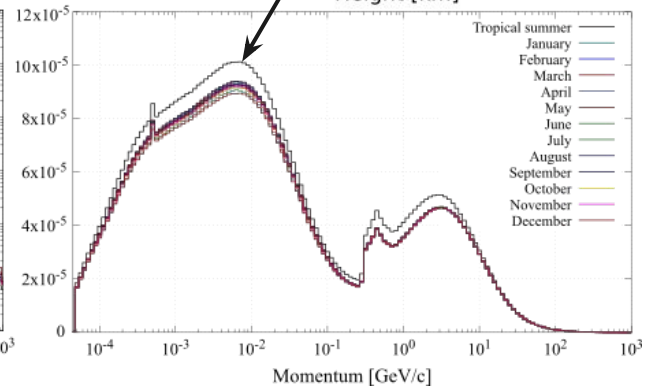
Monthly-averaged or instantaneous local atmospheric profiles from GDAS





previous global models





J. Grisales et al., Can. J. in Phys ***100****(3) 152, 2022*