



Geant4 modeling of radiation exposure in ultra-long-haul flights: a **proposal**

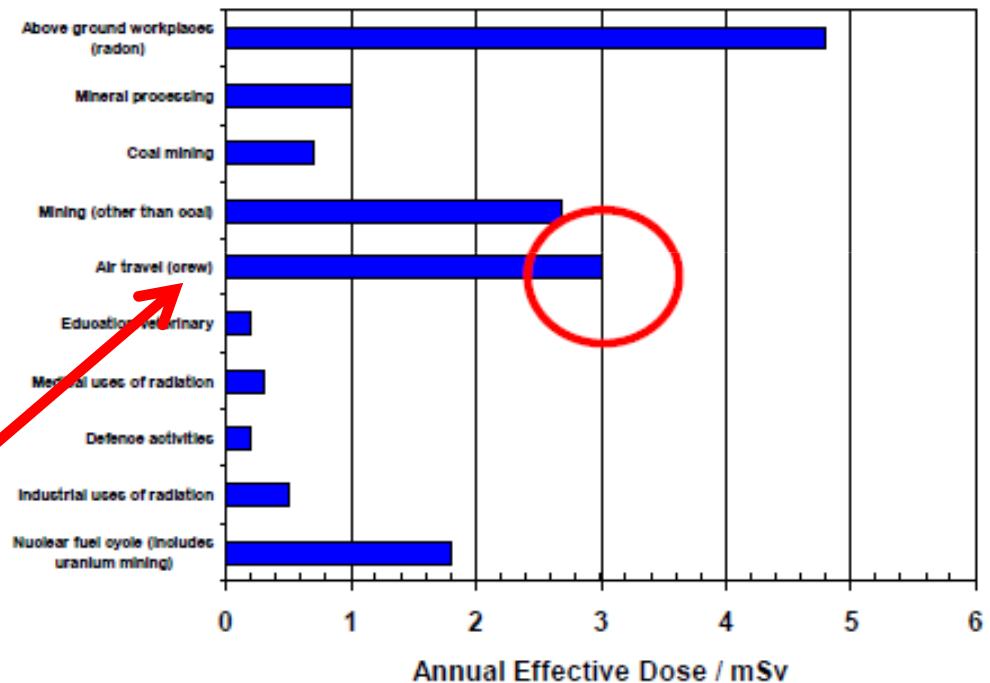
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Context:

in-flight radiation exposure

- Aircraft **crew** radiation exposure is close to **a few mSv / year** and a **few $\mu\text{Sv/h}$**
- The dose received during a flight ($\sim 8\text{h}$ for Atlantic crossing) is approximately equivalent to **a chest X-ray radiography**
- 2nd highest exposure level for **crews**, after radon environmental exposure
- **Much activity** so far
 - Eg. EURADOS (2008)
 - "Be confident, the dose assessment onboard aircraft is under control" – JF Bottollier (IRSN, EURADOS, 2008)



From UNSCEAR 2000
P. Beck et al., EURADOS



Is it worth ?

- A lot has been studied on the question
 - Many codes : AVIDOS, CARI6, EPCARD, FDOScalc, FREE, PCAIRE, QARM, SIEVERT...(see EURADOS)
 - Agree within 20% for most of the codes
 - In our community: FLUKA : a mathematical model of Airbus A340
 - A. Ferrari et al., Radiation Protection Dosimetry (2004), Vol. 108, No. 2, pp. 91-105
 - The shielding influence of aircraft structures and contents has proven to be significant on radiation levels onboard
- Airlines have abandoned the usage of active & passive dosimeters (usually located on the back door of the cockpit)
- Instead, they now use predictive computing tools for radiation monitoring
 - Eg. Sievert in France, takes into account solar daily activity
 - In public access to any passenger but limited (see slide)
- Airline crew members may access his/her dose « history » from these estimations
- In case of radiation storms, recommendations are given to crews
 - Re-routing : horizontal / vertical profile changes
 - Limitation of number of long-haul flights
- However, the Geant4 Monte Carlo approach could offer more:
 - A realistic geometrical modelling of aircraft structures to investigate shielding effects depending on location within aircraft
 - Biological effects of radiation exposure
 - Effects on electronics



Objective of this proposal

- Simulate with Geant4 **radiation exposure in very-long-haul flights** with **precise geometrical modelling** of aircraft structure
- Perform in-flight radiation **dosimetry measurements** along with precise aircraft positioning in 3D
- **Compare** Geant4 simulations with measurements and other predictive tools (eg. Sievert)
- Simulate **potential effects** : radiobiology, SEE...



Who might be concerned/interested ?

- This proposal might be of potential interest to
 - Epidemiologists
 - Investigation of biological effects of radiation on « flying » workers
 - Potential Geant4-DNA applications
 - Frequent flyers
 - No upper limit on number of flights
 - Flight officers (in particular face, torso)
 - Limited to ~3 long-haul flights per month
 - Pregnant flight attendants
 - Rule depends on company
 - In France, she stops flying if dose > 1 mSv (Euratom 96-29)
 - Single Event Effects on flight computing systems
- Especially with the availability of ultra long-haul flights



Airline regulations

2005

Cancer fears limit Hong Kong air crews' New York trips

HONG KONG (AFP) — Airline Cathay Pacific has limited air crews' flights on the non-stop Hong Kong-New York route after it was found the journey could increase the likelihood of cancer, a report said Sunday.

Staff of the British-owned, Hong Kong-based airline say they have been limited to just two of the ultra long-haul flights per month since it was found the route exposed passengers and crew to high levels of cosmic radiation when they flew over the North Pole.

Union chiefs told the *South China Morning Post* radiation levels increase markedly at 26,250 feet above the pole and prolonged exposure could be harmful to cell DNA possibly causing cancers.

"If you do two and a half polar flights a month you are in the danger zone," Flight Attendants Union general secretary Becky Kwan was quoted as saying.

"At first when we heard about this everybody was worried. But we have had regular meetings with (air officials) and Cathay and guidance from an aviation doctor."

However, unions are concerned no such limits have been put on passenger flights. The report said officials felt it unnecessary as customers do not fly enough to be at risk.

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Published in USA Today, 2005-03-28

http://www.usatoday.com/travel/flights/2005-03-28-flights-cancer_x.htm



Radiobiological evidences

2009

Increased frequency of chromosome translocations in airline pilots with long-term flying experience

L C Yong, A J Sigurdson, E M Ward, M A Waters, E A Whelan, M R Petersen, P Bhatti, M J Ramsey, E Ron, J D Tucker

Occup Environ Med 2009;66:56-62 doi:10.1136/oem.2008.038901

- They determined the **frequency of translocations** in the peripheral blood lymphocytes of **83 airline pilots** and 50 comparison subjects.
- Their data suggests that **pilots with long-term flying experience may be exposed to biologically significant doses** of ionising radiation.
- **Epidemiological studies** with longer follow-up of larger cohorts of pilots with a wide range of radiation exposure levels **are needed** to clarify the relationship between cosmic radiation exposure and cancer risk.

Single Event Effects



- on October 7, 2008, a Qantas Airbus A330 ADIRU system got upset
- ADIRU/ADIRS provides information on speed, altitude, IRS of aircraft
- possible explanation : SEE could generate soft errors (non destructive)
- 12 people on-board seriously injured...

SAFETY DAVID KAMINSKI-MORROW LONDON

Qantas probe turns to cosmic rays

2009

Investigators studying 2008 A330 flight upset consider radiation as they seek to discover cause of data spikes

Australian investigators are to examine whether cosmic radiation played a role in the unexplained in-flight upset to a Qantas Airbus A330 in October 2008.

The inquiry has already determined that an air data inertial reference unit (ADIRU) provided erroneous data spikes just before the upset. Some of these spikes, in the angle-of-attack data, were not filtered by flight-control computers, which then commanded abrupt pitch-down movements.

The Australian Transport Safety Bureau has conducted extensive examination and testing of the suspect ADIRU, to check for elec-

tronic malfunctions, physical defects and possible software problems. Tests flights, using the A330 involved, have been made to check whether the ADIRU might have been subject to electromagnetic interference.

None of these has revealed any anomalies that might have explained the jet's behaviour.

Given the lack of evidence of a problem with the system, the safety bureau is considering – among other avenues of inquiry – the possibility of a “single event effect”, generated by particle impact from cosmic radiation. Upper-atmosphere collisions involving high-

energy solar or intergalactic radiation can create secondary stray particles – notably neutron showers that have the potential to interact with, and damage, high-density integrated circuits.

Single event effects “have been suspected of generating some of the soft errors that occur in a wide range of different aircraft systems”, says the safety bureau. These “soft” errors include non-destructive changes in logic states within digital electronics.

“The investigation team is evaluating the relevance, if any, of [single event effects] to the ADIRU fault that resulted in

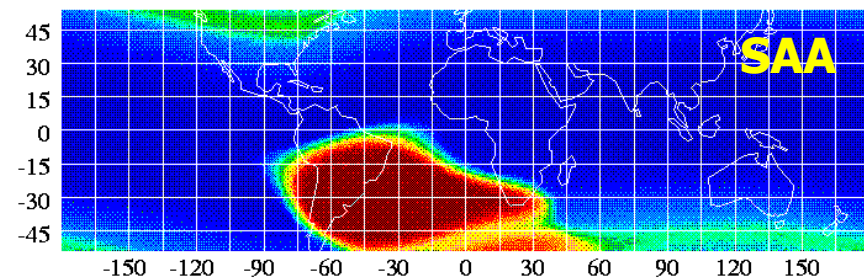
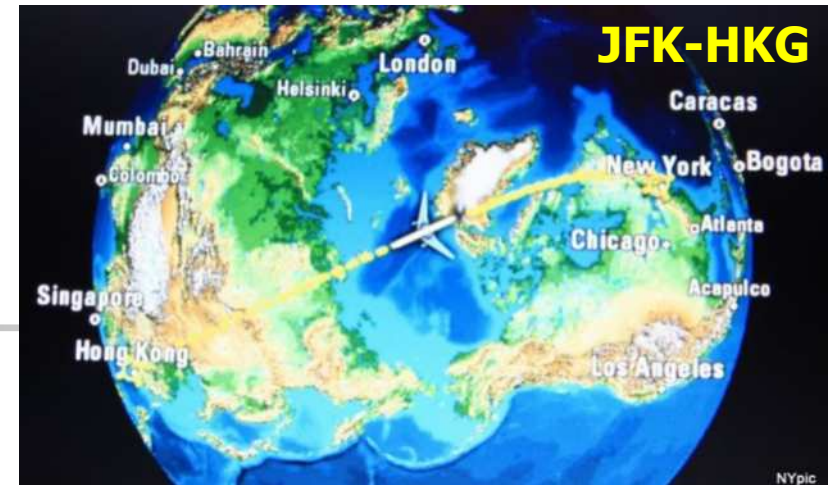
spikes being produced in ADIRU parameters,” the bureau adds.

Investigators are also assessing whether a known fault – “dozing” – might have contributed to the A330 upset. The dozing fault is a temporary issue which results in the ADIRU ceasing to output data for the remainder of the flight, although it resumes normal operation after power has been cycled on the ground.

Eleven passengers and a flight attendant were seriously injured during the upset, which occurred as flight QF72 was operating the Singapore-Perth route on 7 October 2008. ■

Which flights ?

- Mainly **two** types, entering **highest radiation level zones**
- **Ultra-long-haul** flights with routes close/over **North Pole**
 - EWR-SIN, DXB-SFO, ...
 - Up to 19 hours of flight
 - Shortest great circle
 - Achievable only by certain aircrafts
 - **B777-300 ER**
 - **A340-500**
- Flights through the **South Atlantic Anomaly**
 - A few airlines only (from S. America & Africa)

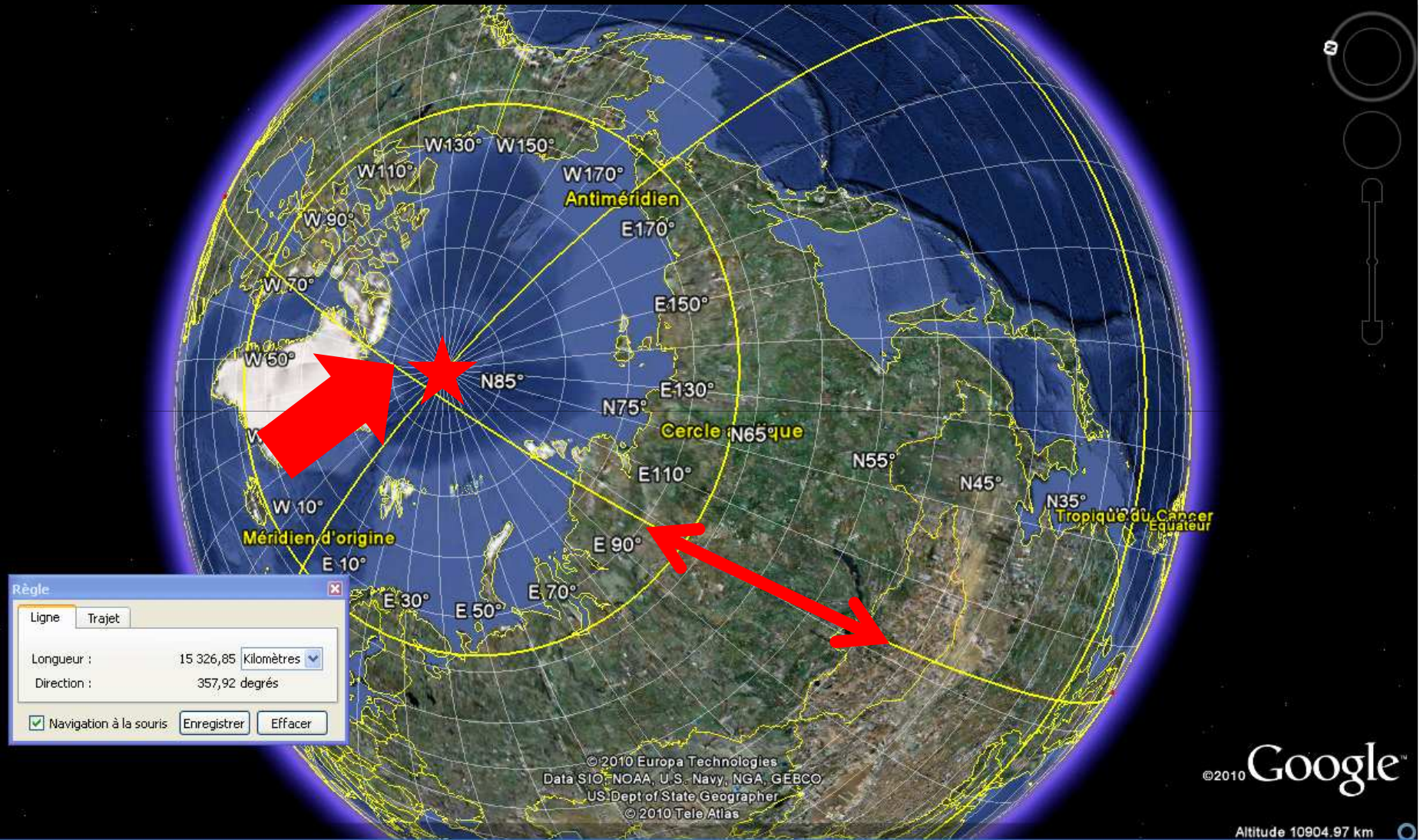




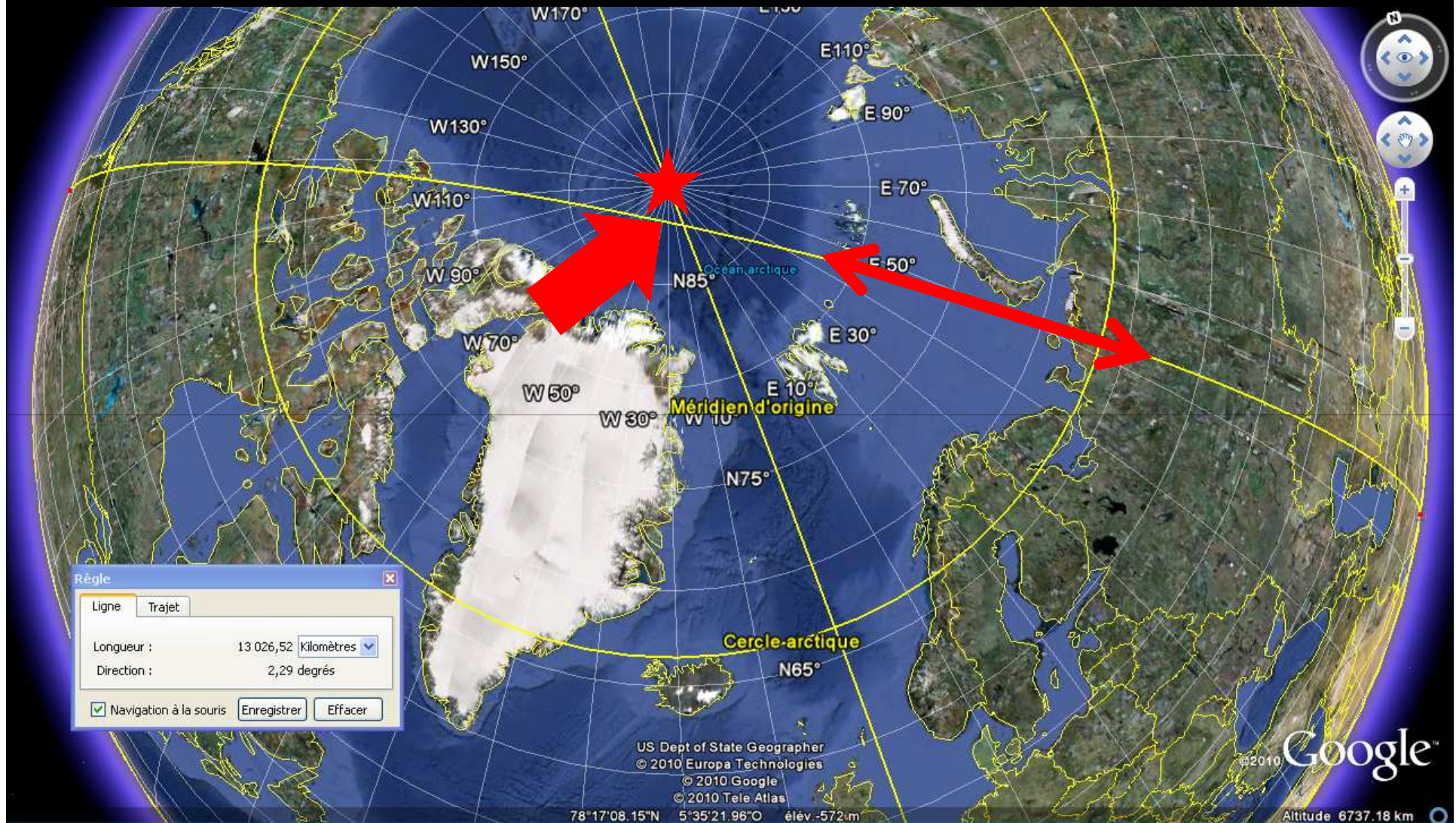
North-pole ULH flights

Aircraft type	Route	Distance (km)	Distance (mi)	Scheduled duration	Airline	Flight number
Airbus A340-500	Newark to Singapore	15,345	9535	18hr 50min	Singapore Airlines	SQ21
Boeing 777-200LR	Johannesburg to Atlanta	13,582	8439	16hr 40min	Delta Air Lines	DL201
Boeing 777-300ER	Dubai to San Francisco	13,041	8103	16hr 00min	Emirates	EK225
Boeing 777-200ER	Newark to Hong Kong	12,951	8047	15hr 50min	Continental Airlines	CO99
Airbus A380	Los Angeles to Melbourne	12,748	7921	15hr 25min	Qantas	QF94
Boeing 747-400ER	Los Angeles to Melbourne	12,748	7921	15hr 25min	Qantas	QF94
Boeing 747-400	Chicago to Hong Kong	12,542	7793	15hr 25 min	United Airlines	UA895
Airbus A340-300	New York to Johannesburg	12,845	7982	15hr 10min	South African Airways	SA204
Airbus A340-600	Sydney to Abu Dhabi	12,057	7492	14hr 50min	Etihad Airways	EY451

Newark to Singapore



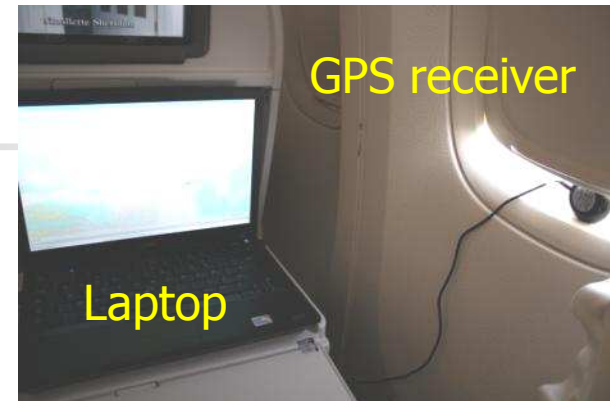
Dubai to San Francisco



What is needed ?

■ Hardware

- GPS tracking of 3D position
 - On portable computer unit
 - Power supply
- Online tracking of in-flight dose
 - One or several units: active dosimeter with computer recording, TEPC, NASA/ESA equipment like SREM...?
 - Need to **review what we can have access to**
 - Eg. RadEye B20 : dosimetry H'(0,07) 6,5 keV - 1250 keV, H*(10) 17 keV -1,3 MeV, simple counter
 - Power supply



■ Software : Geant4 simulations

- Incident particles: SPE & GCR spectra for the day of flight
- Materials & geometries for Earth
 - Atmosphere - varying density needed
 - Magnetic field (geomagnetic rigidity cut-off*)
- Materials & geometries from aircraft manufacturer
 - Windshield geometry : materials, layers, dimensions
 - Passenger window geometry : materials, layers, dimensions
 - Aircraft metal main body geometry, materials, panels...

**Geomagnetic rigidity is the minimum energy a primary proton must have to create a cascade which can reach sea level at that location.*

Requires precise technical information (like CAD) from aircraft manufacturer

From P. Beck et al.
CONRAD/EURADOS

ACREM, TEPC

- ACREM

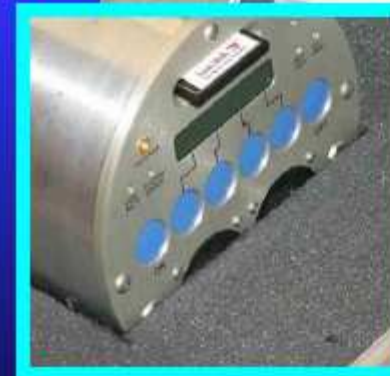
- fix installation
- GM counter



ACREM

- TEPC

- part time fix installed
- Micro dosimeter



ARC HAWK-TEPC

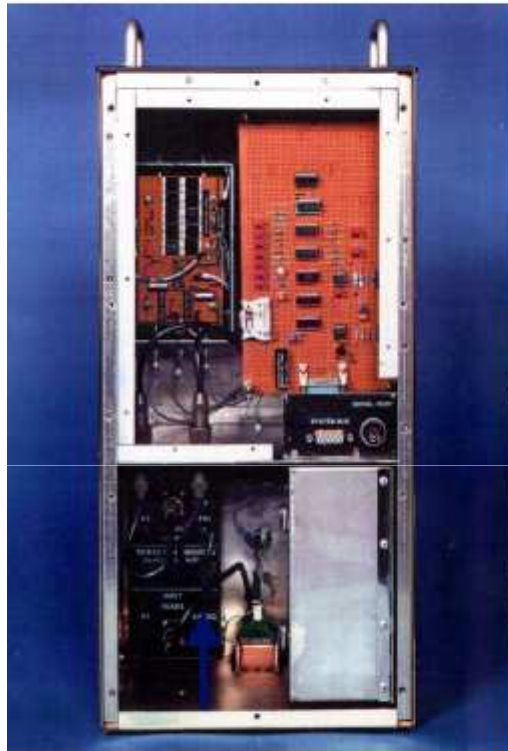
- A310, Lufthansa

Cosmic Radiation Effects & Activation Monitor (CREAM)

Calibrated against TEPCs at CERF and in-flight

“Space Shuttle”
version flown on
Virgin Atlantic
Boeing 747,
executive jets,
Shuttle and Mir

From P. Beck et al.
CONRAD/EURADOS



“Concorde”
version flown on
BA Concorde,
SAS Boeing 767
and NASA WB-
57F



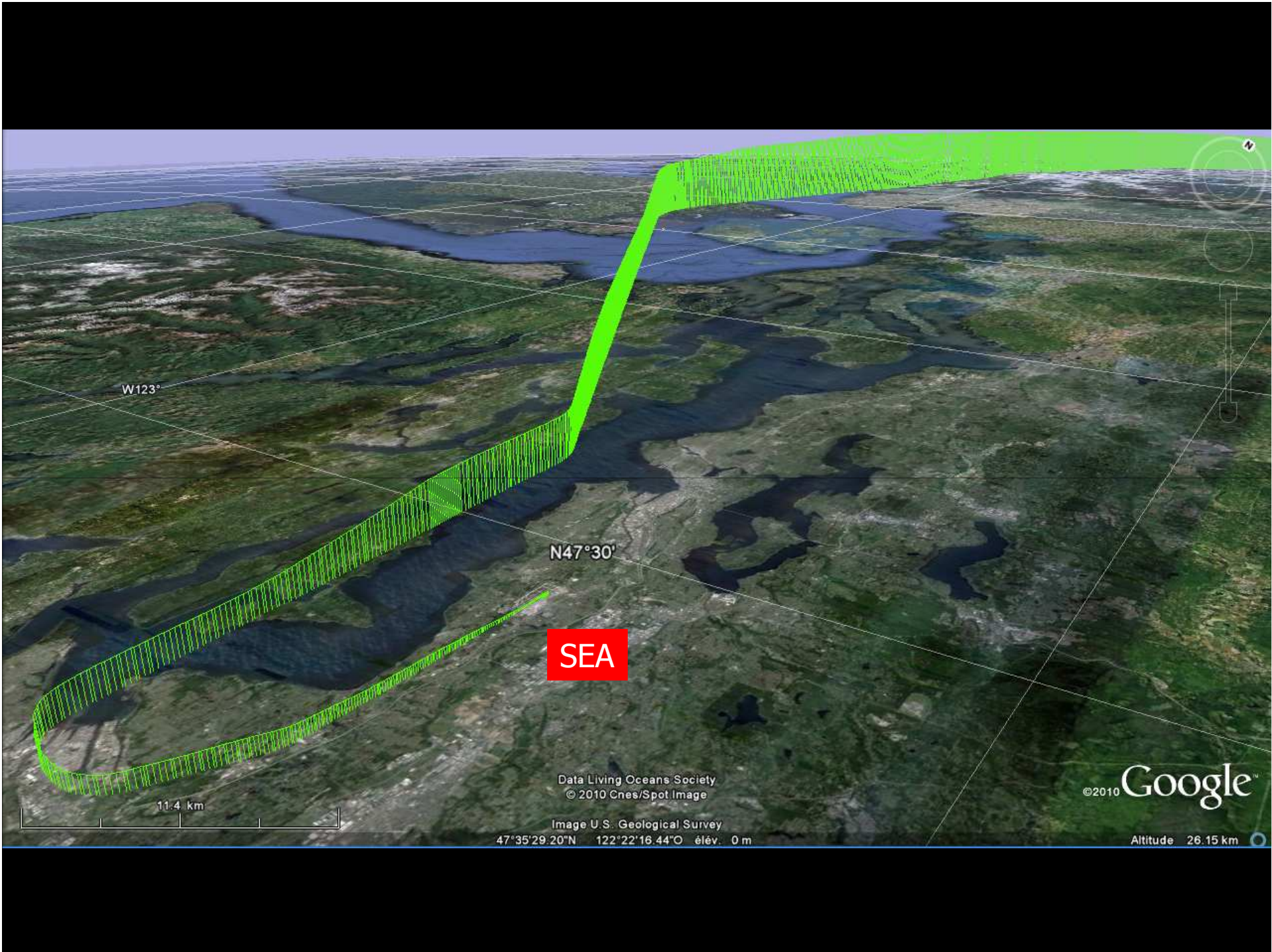
Shuttle Cdr Jim
Wetherbee
deploys CREAM
in SpaceHab
module on
mission STS-63



Example of actual flight lateral navigation profile

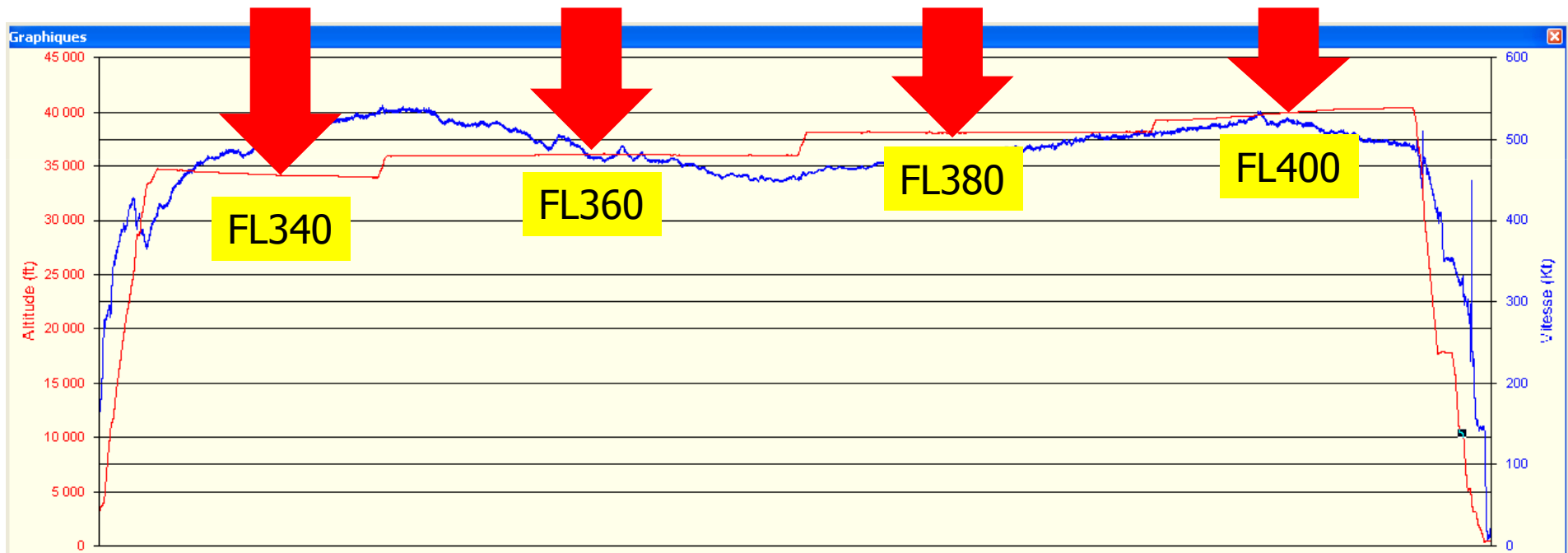
- Paris, France, to Seattle, WA, USA - day flight
- 17/08/2010
- A330-200
- 10 h 20 min





Flight **vertical** navigation profile

4 long duration exposures



Dose ?

(great circle routes)

The Sievert predictive tool

<http://www.sievert-system.org>

Calculate the dose received during this flight
radiation in the plane
The health effects of radiations
Measuring radiation and assessing its effects
The experts tell you more
Glossary
Search
Site map
Frequently asked questions

Type of aircraft : Subsonic

Calculate the cosmic radiation dose received during this flight vol

Calculate

SIEVERT System implemented and integrated by



"Subject to local regulation modifications, the flight dates and times include time difference and, if necessary daylight saving time. Check the flight time."

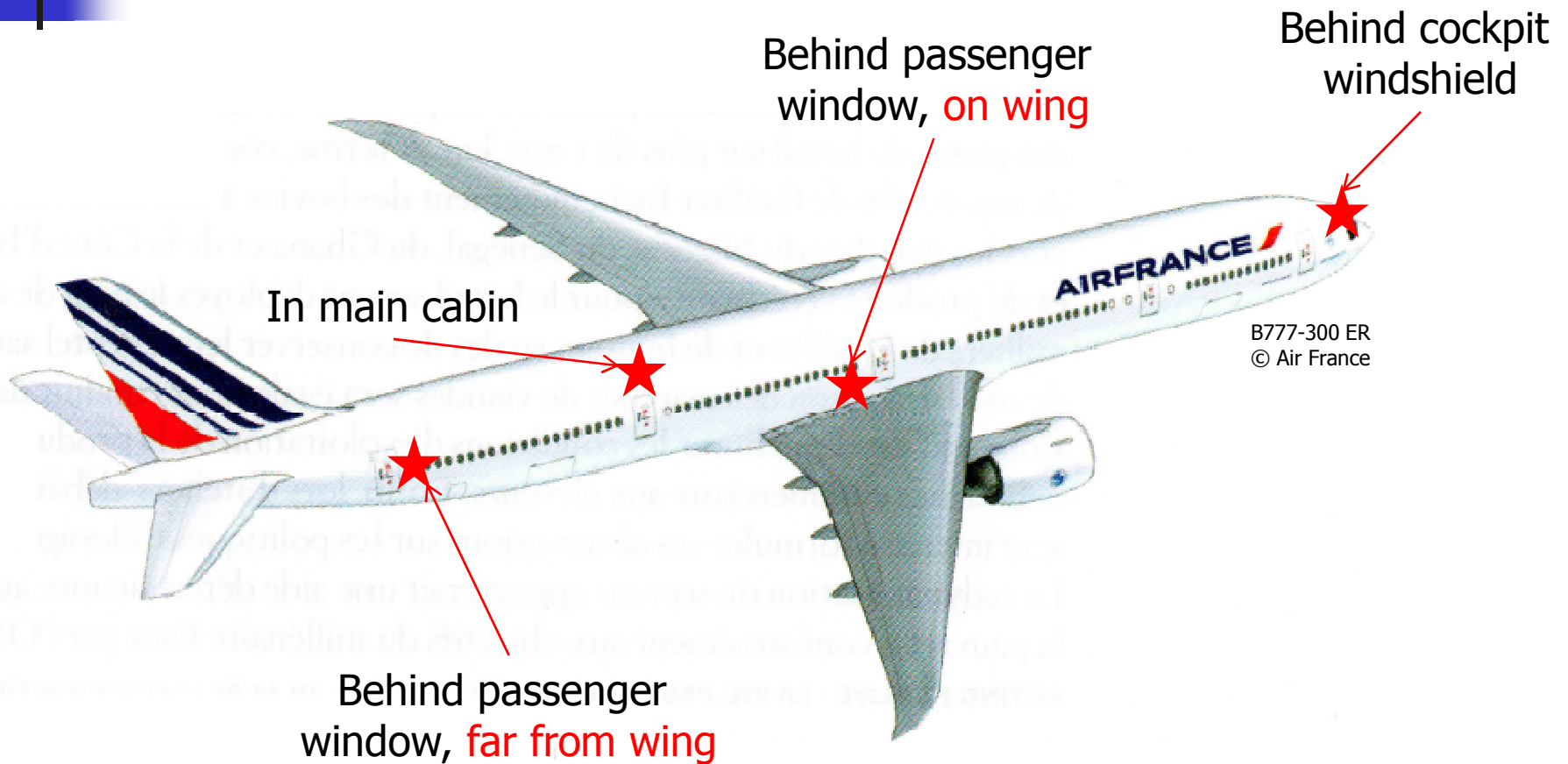
Dose received during the flight = 0.0851 mSv
Flying time = 10:20 (HH:MM)

~85 uSv

(a single chest X-ray is ~100 uSv)

Departure city	Arrival city	Departure date	Arrival date	mSv	Estimated
PARIS	SEATTLE	17/08/2010 10:30	17/08/2010 11:50	0,08510	Oui
				Total	0,08510

Possible dosimeter location

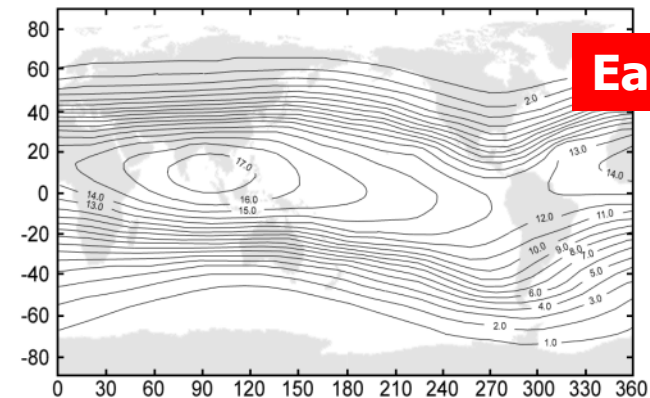
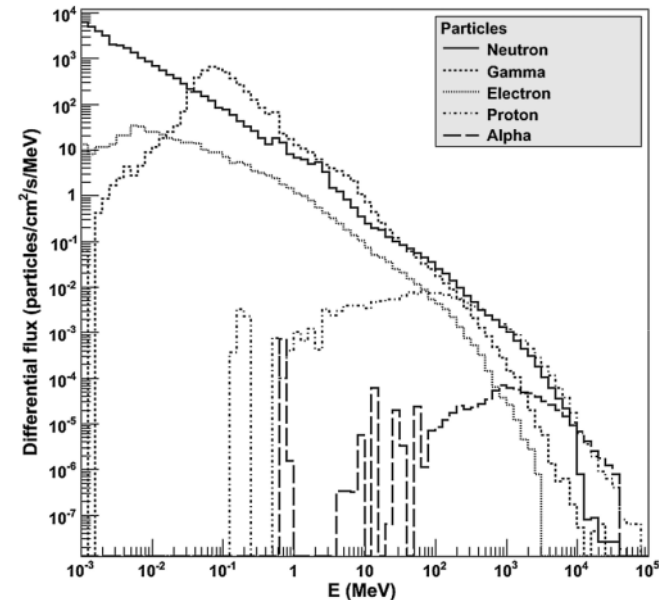


Geant4 simulations

- PLANETOCOSMICS (Geant4 based) well suited
 - Includes fine modelling of Earth atmosphere, magnetic field (rigidity cut-off), soil...
 - Follow similar approach as we did for a biochip mission on Mars planet
 - See A. Le Postollec et al., *Astrobiology* 9 (3) (2009) 311-323
 - Mesh mapping of Earth surface
- Need the most recent version

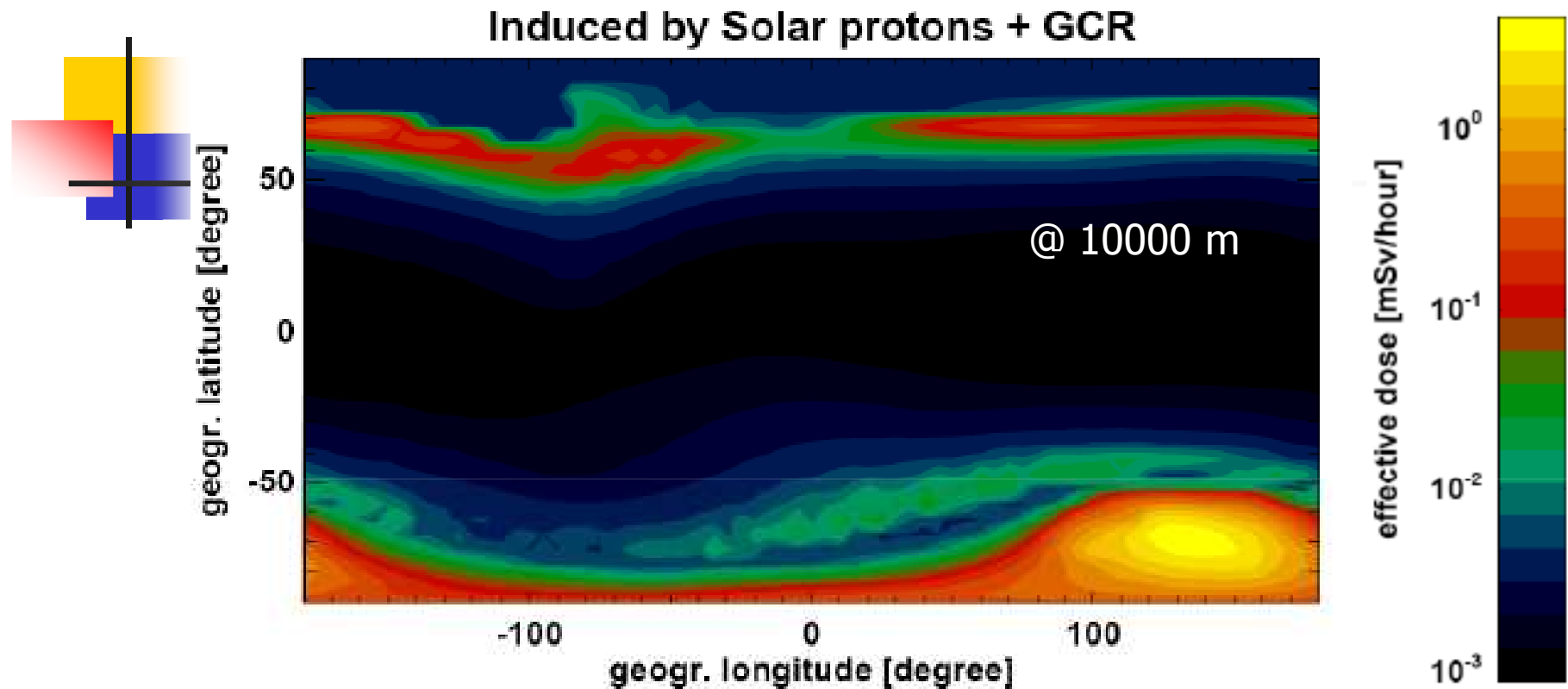
Particles on Mars ground

Mars



Earth

Example of MAGNETO/PLANETO-COSMICS simulations



Planetocosmics predictions

2005 January 20 ground-level enhancement (GLE) event.

This event, known as GLE 69, produced the highest intensity of relativistic solar particles since the famous event on 1956 February, 23.

What do we need from the aircraft manufacturer ?

For pilots

For window-seated passengers

Glass for windshield & passenger window : chemical composition, layers, dimensions from CAD...

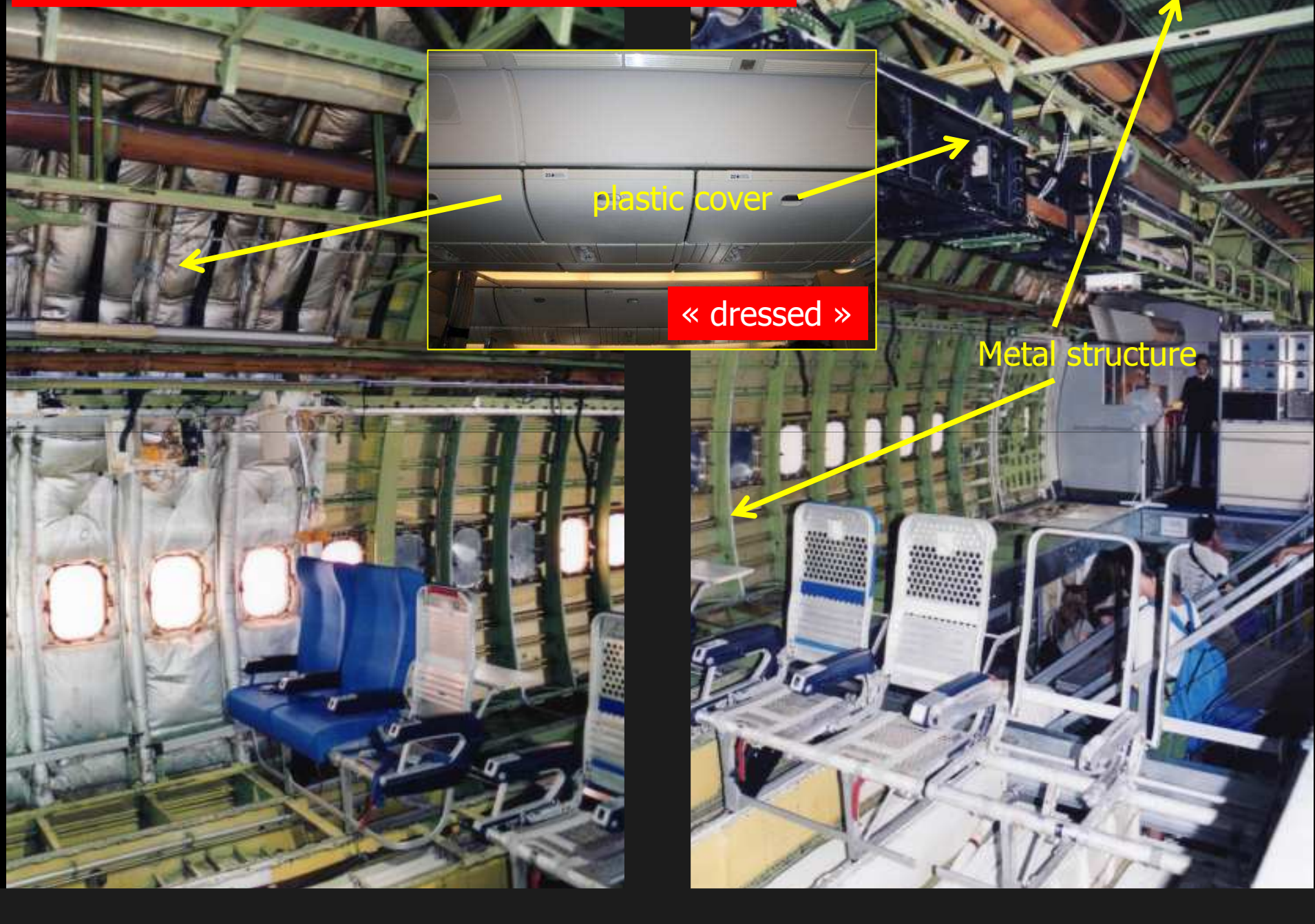


B777-200 ER

Transparent protective plastic cover, PMMA



« Naked » AF B747-200 @ Paris – Le Bourget



plastic cover

« dressed »

Metal structure



Geant4 & The Boeing Co.

- This meeting could be a great opportunity to **start a collaboration with The Boeing Company for the Geant4 modelling of dosimetry in air travel**
- This proposal **would require**
 - PLANETOCOSMICS/ Geant4
 - Selected ultra-long-haul flights flying close to NP
 - US-Asia : EWR-SIN
 - US-Middle East : SFO-DXB
 - Not many from Europe (eg. NRT-CDG AF277 – 1 h more)
 - eventually measure reproducibility
 - Several dosimeter units
 - Active dosimeter, TEPC,... ?
 - 2012 will be a **solar peak activity** period
 - Require approval of airline(s) : personnel contact may help
 - IN2P3 fundings will be asked, **others** ?
- We are looking for **collaborators**
 - Please, do not hesitate to join if you are interested



Thank you for your attention
