SiGLE: Estimation of Aircrew Potential Radiation Exposure During Ground Level Events

SiGLE

Nicolas Fuller
Paris Observatory / LESIA
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l'Observatoire de Paris LESIA

Background

- Mandatory for French companies to account for normal and *exceptional* solar activity
- Developped in the frame of the SIEVERT system in 1999+ by Dr. P. Lantos
- SiGLE first results were published in 2001 (*proc. SOLSPA, Vico Equense, Italy*)
- Model fully described in *Rad. Prot. Dos. 104, N°3, 2003* and following papers in 2004 and 2005

Objectives

- To estimate doses rate at flight altitude in case a significant GLE occurs
- To be operational in the frame of SIEVERT System -> simple approach
- To estimate doses during the past GLE’s (which have not been studied with particle transport code
- New application for neutron monitors
- To use existing measurements onboard Concorde and calculations during GLE

Concorde measurements during GLE 42 and 59

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Date	*Route and company*	*Time of take-off*	*Time of landing*	*Measured dose*	*Conversion into ICRP 60*
29/09/1989	Paris-New York (AF)	10:19 UT	13:43 UT	120 µSv	144 µSv
29/09/1989	New York-London (BA)	13:56 UT	17:19 UT	140 µSv	168 µSv
29/09/1989	New York-Paris (AF)	17:07 UT	20:37 UT	70 µSv	84 µSv
14/07/2000	Paris-New York (AF)	09:11 UT	12:40 UT	120 µSv	144 µSv
14/07/2000	New York-Paris (AF)	12:19 UT	15:50 UT	50 µSv	60 µSv

GLE 42 and GLE 59 rigidity spectrum power law ($\propto R^{-\gamma}$) exponents are known from Lovell *et al.* and Duldig :

$\gamma_{GLE42} = -4.7$ and $\gamma_{GLE59} = -7$

- J.L. Lovell, M.L. Duldig and J.E. Humble, "An extended analysis of the September 1989 cosmic ray ground level enhancement", *J. Geoph. Res.,* vol. 103, pp. 23733-23742, 1998.
- M.L. Duldig, "Fine time resolution analysis of the 14 July 2000 GLE", in Proc. 27th Int. Cosmic Ray Conf , July 2001, SH, pp. 3363-3366.

Global schema

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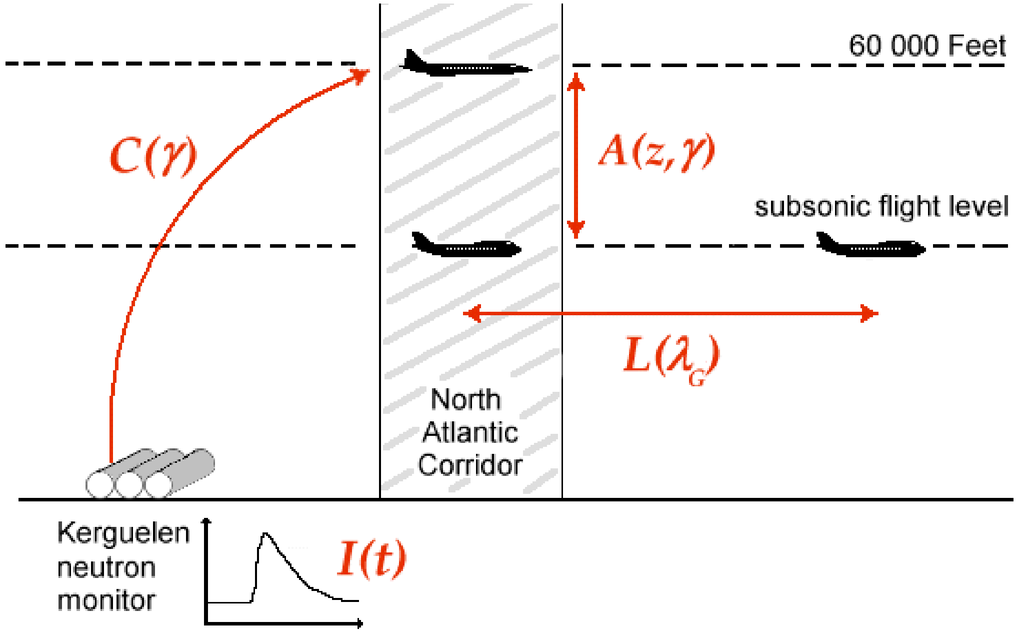
Kerguelen NM (R=1.14 GV)



$D(t) = A(z,\gamma) \times L(\lambda_G) \times C(\gamma) \times I(t)$

IPEV

anisotropy neglected

$C(\gamma)$ and $I(t)$ functions: convert monitor output into dose rate

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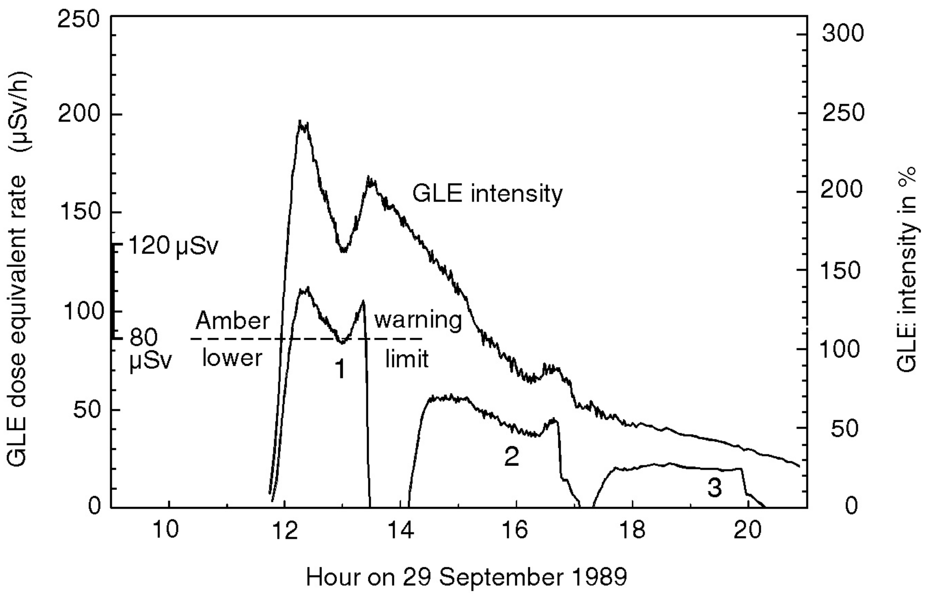
- Dose rate at 60000 ft proportional to neutron monitor output
- Compute the coefficient to fit measurements on Concorde (see figure)
- $C_K(-4.7) = 0.59\ \mu$Sv/h/%

  and $C_K(-7) = 4.06\ \mu$Sv/h/%

  other values are obtained by interpolation

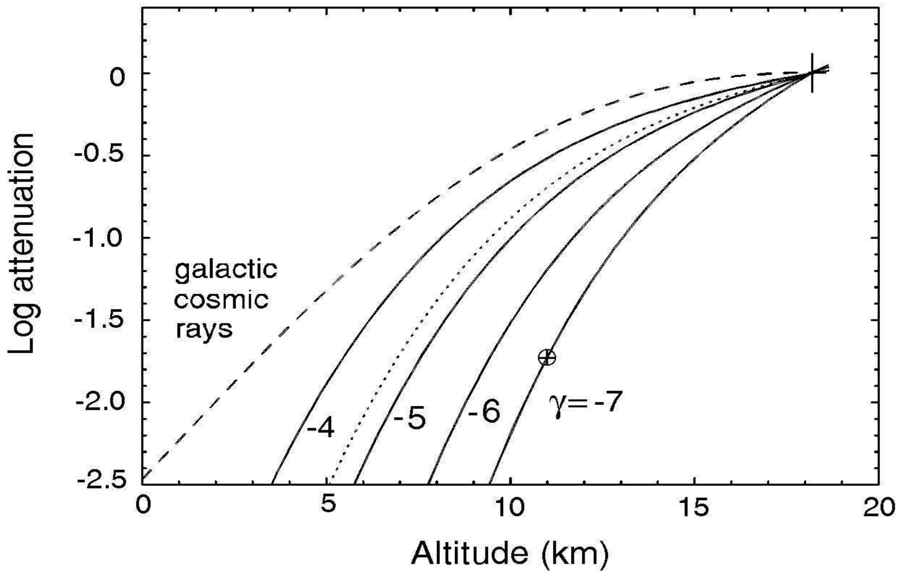


$$D(t) = A(z,\gamma) \times L(\lambda_G) \times C(\gamma) \times I(t)$$

with $L = 1$

A function: dose attenuation with altitude

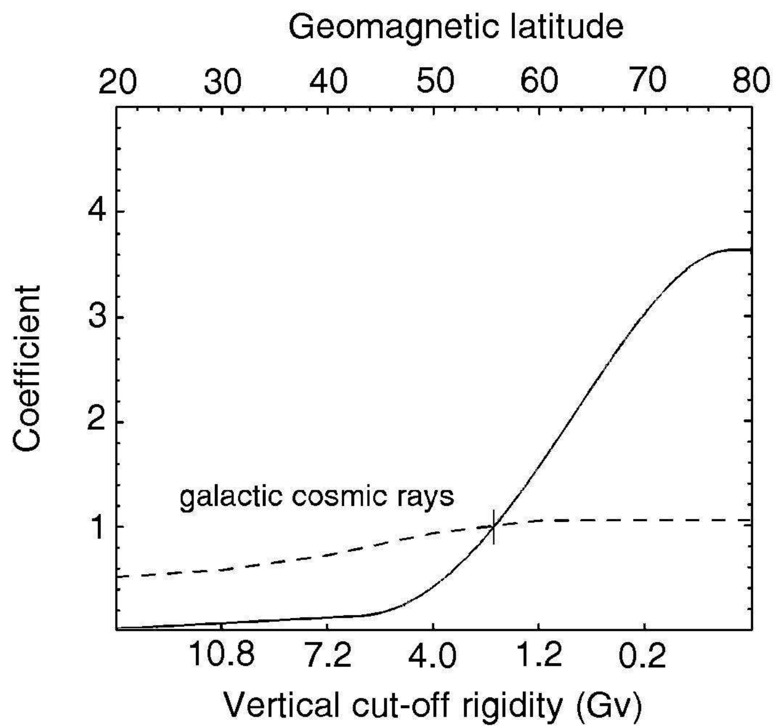
- Relative attenuation deduced from O'Brien *et al.* calculations for GLE 42
- Radiation dose for GCR (γ=-2.5) also decreases below Pfotzer max.
- Homothetical curves based on quadratic interpolation in Log
- Prague–NY flight measurements during GLE 60 / April 15 2001 (Spurný & Dachev)



- K. O'Brien, W. Friedberg, H.H. Sauer and D.F. Smart, "The atmospheric cosmic- and solar energetic particle radiation environment at aircraft altitudes", *Adv. Space Res.* ,vol.21,n°12, pp. 1739-1748, 1998.
- F. Spurný and Ts. Dachev, "Measurement on Board an Aircraft during an Intense Solar Flare, Ground Level Event 60, on April 15, 2001", *Radiat. Prot. Dosim.*, vol. 95 n°3, pp. 273-275, 2001.

L function: north-south variation of the dose

- *L* is the relative variation of the dose with the geomagnetic latitude
- It is deduced from world maps of effective dose for GLE42 by Beck *et al.* and O'Brien & Sauer
- 35 000 ft / Greenwich meridian



- P. Beck *et al.*, "In-flight Validation and Routine Measurement", *Radiat. Prot. Dosim.*,vol. 86, pp. 303-308, 1999.
- K. O'Brien and H.H. Sauer, " An Adjoint Method of Calculation of Solar-Particle-Event Dose Rates", *Technology,* vol. 7, pp. 449-456, 2000.

Spectrum power law exponent calculation

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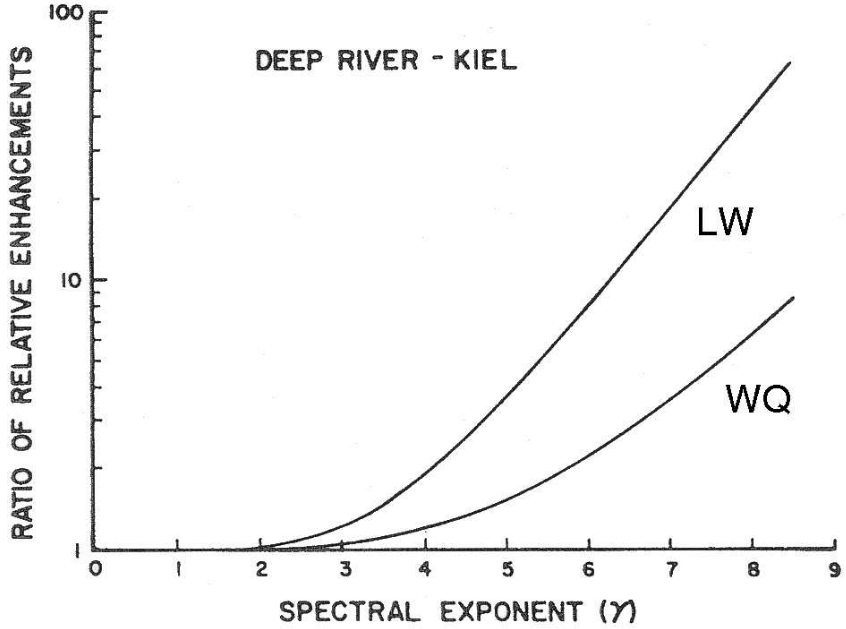
- This parameter is essential to get the estimated dose. An average 4.7 can be used otherwise, but with less precision
- Lockwood and Webber and Webber and Quenby give a method to get γ from the ratio between 2 monitors (figure by Palmiera *et al*.)
- $R_{DeepRiver} \cong R_{Kerguelen} \cong 1.2$ and $R_{Kiel} \cong R_{Moscow} \cong R_{Newark} \cong 2.3$
- Comparison for 16 GLE -> WQ gives good results: mean diff=0.09 and σ=1.01
- Possibility to get $\gamma(t)$



- Webber W.R., Quenby J.J., 1959, *On the derivation of cosmic ray specific yield functions*, Phil Mag., 4, 654.
- Lockwood J.A., Webber W.R., 1967, *Differential response and specific yield functions of cosmic ray neutron monitors*, J. Geophys. Res., 72, 3395.
- Palmiera R.A., Bukata R. P.and Gronstal P.T., 1970, *Determination of the solar flare cosmic ray rigidity spectrum using worldwide neutron monitor network*, Can. J. Phys., 48, 419.

Results of SiGLE for past GLE

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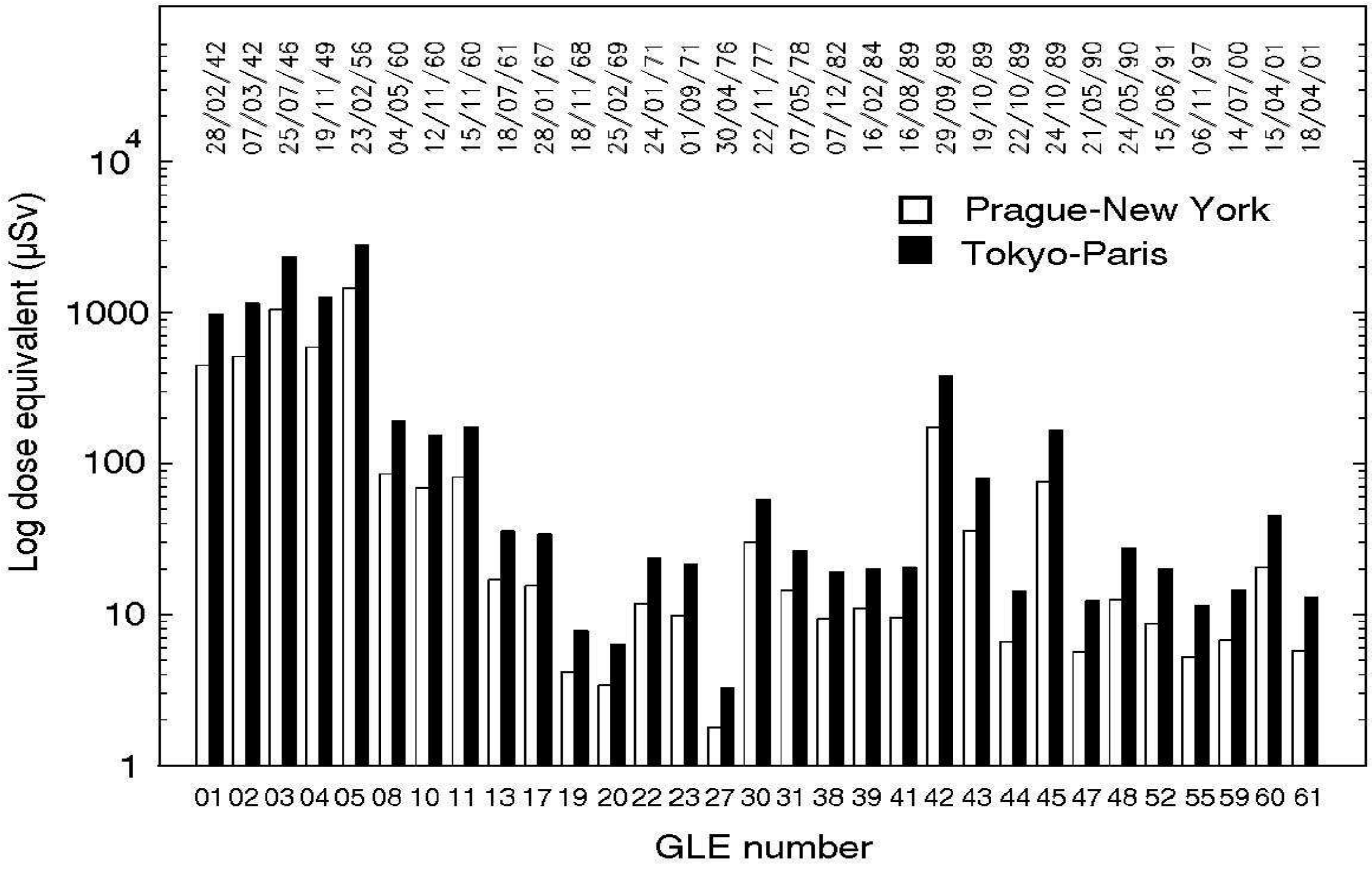

- GLE > 10%
- Prague-NY -> typical of North Atlantic route subsonic flight
- Tokyo-Paris (polar route) -> high geomagnetic latitude
- Only the 5 first ones > 1mSv

Model evaluation

- Rare measurements -> check compatibility with other estimates / other model
- Another indication that the model is correct: Amber warning recorded aboard AF Concorde (> 80 μSv/h) and no warning on BA

-> "BVFF on 29-9 starting at 30W amber light on, on radiation indicator, with index between 80 and 120 μSV/h up to JFK"

GLE number	Authors	dose rate estimate µSv/h	comments
05 (23 Febr. 1956)	Armstrong et al. (1969)	10000 - 60000	lower and upper limits
	Dyer and Lei (2001)	16720	
	present work	9680	with GLE amplitude of 4400 % (as observed with Leeds NM)
	present work	19800	with GLE amplitude of 9000 % (Dugall, 1979)
21 (30 Mar. 1969)	Wilson (1998)	13	based on measurement
	present work	7	
30 (22 Nov. 1977)	Strady (1979)	96 µSv	No flight plan / No time of departure / Total GLE dose Based on measurement
	present work	97 µSv	Total GLE dose
42 (29 Sept. 1989)	O'Brien et al. (1992)	147	derived from article figure
	O'Brien et al. (1998)	32	derived from article figure
	Beck et al. (1999)	222	derived from article figure
	O'Brien and Sauer (2000)	277	derived from article figure
	Dyer and Lei (2001)	929	based on CREAM measurement
	present work	575	
66 (29 Oct. 2003)	Getley (2004)	0.5 µSv	based on measurement / Total GLE dose LA-NY
	Present work	0.34 µSv	Total GLE dose

Results for GLE 69 (20/01/2005)

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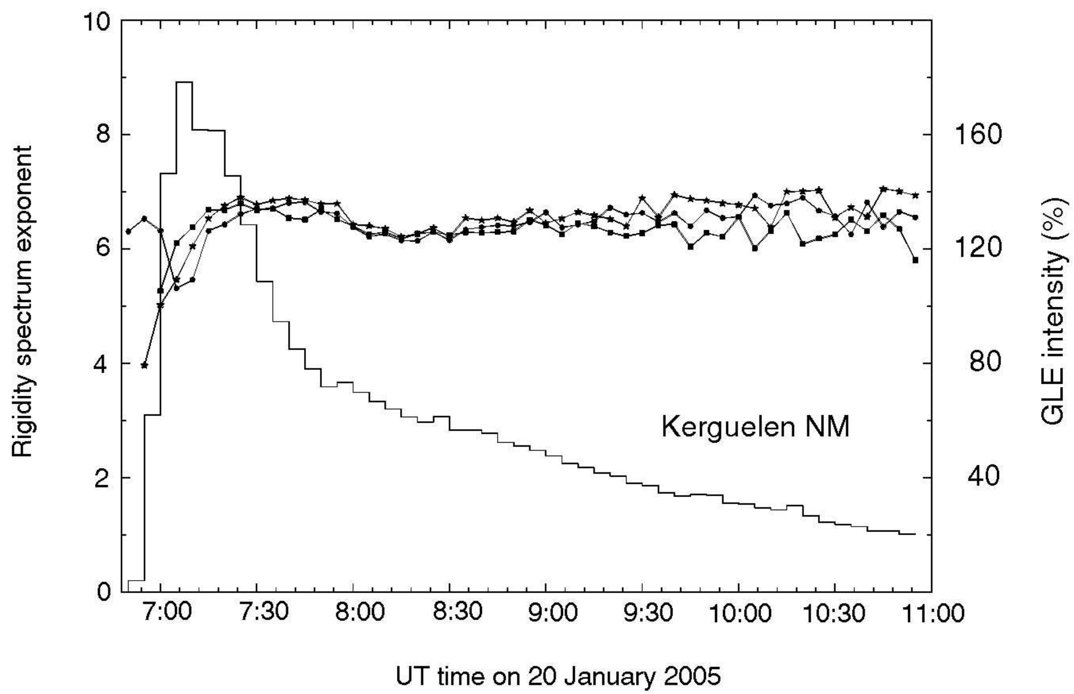
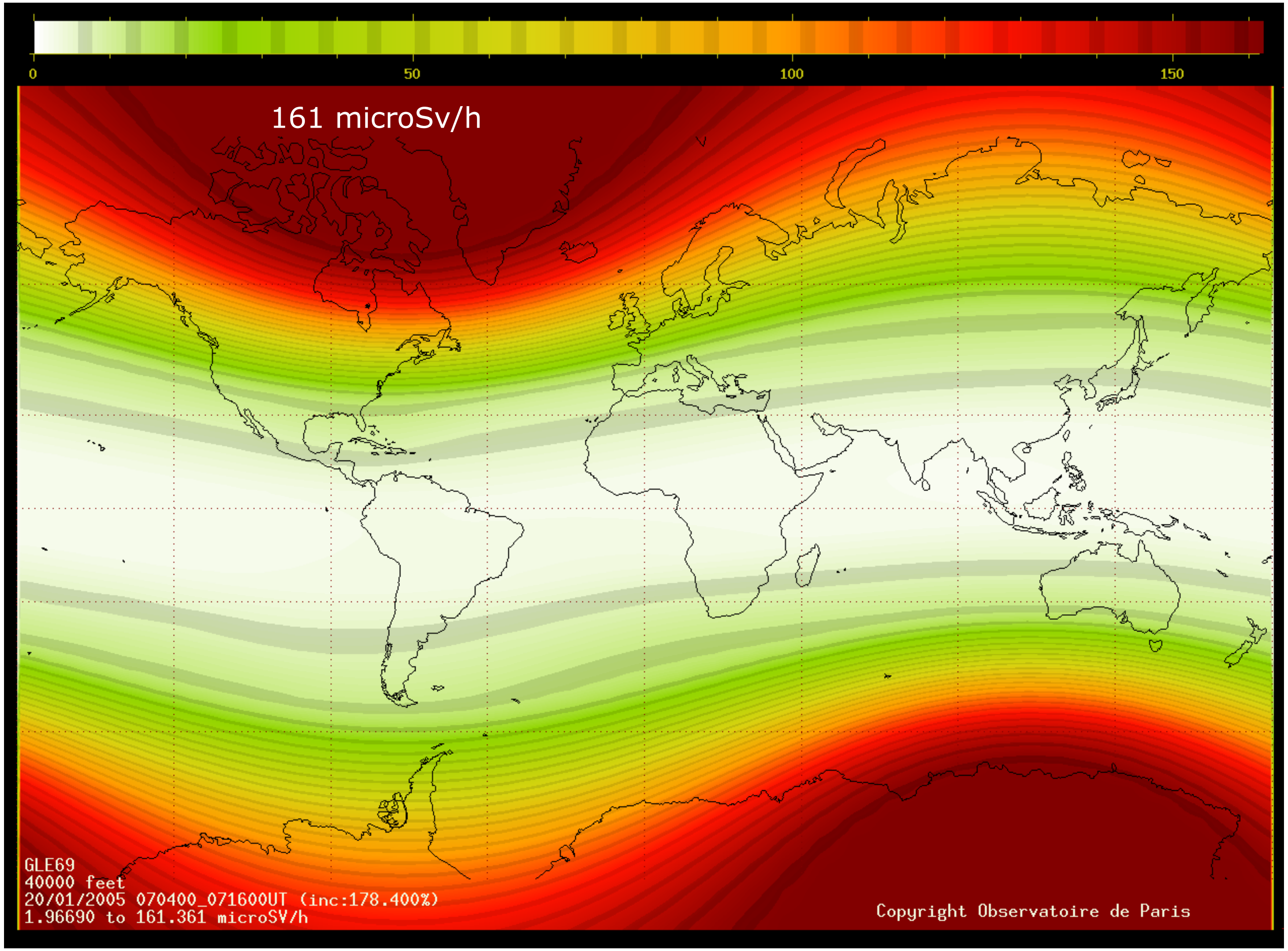
- I_{max} = 178% (Kerguelen NM) -> one of the strongest of the last 50 years
- γ_{max} = -6.0 (between -5 and -7 in recent papers)
- Importance of flight plan (Siberian route example)



Route	Dose received from GLE 69 (µSv)	Dose received from GCR (µSv)	Total dose (µSv)
Paris-Washington	53.1	39.4	92.5
Paris–San Francisco	96.9	65.8	162.7
Tokyo–Paris (polar route)	88.3	61.8	150.1
Paris-Tokyo (south Sib. route)	14.1	44.3	68.4
Osaka-Paris (north Sib. route)	60.8	70.6	131.4
Los Angeles-New York	15.2	61.8	77.0
Buenos Aires-Paris	11.7	35.3	47.0

Results for GLE 69 (20/01/2005)

SiGLE



GLE anisotropy

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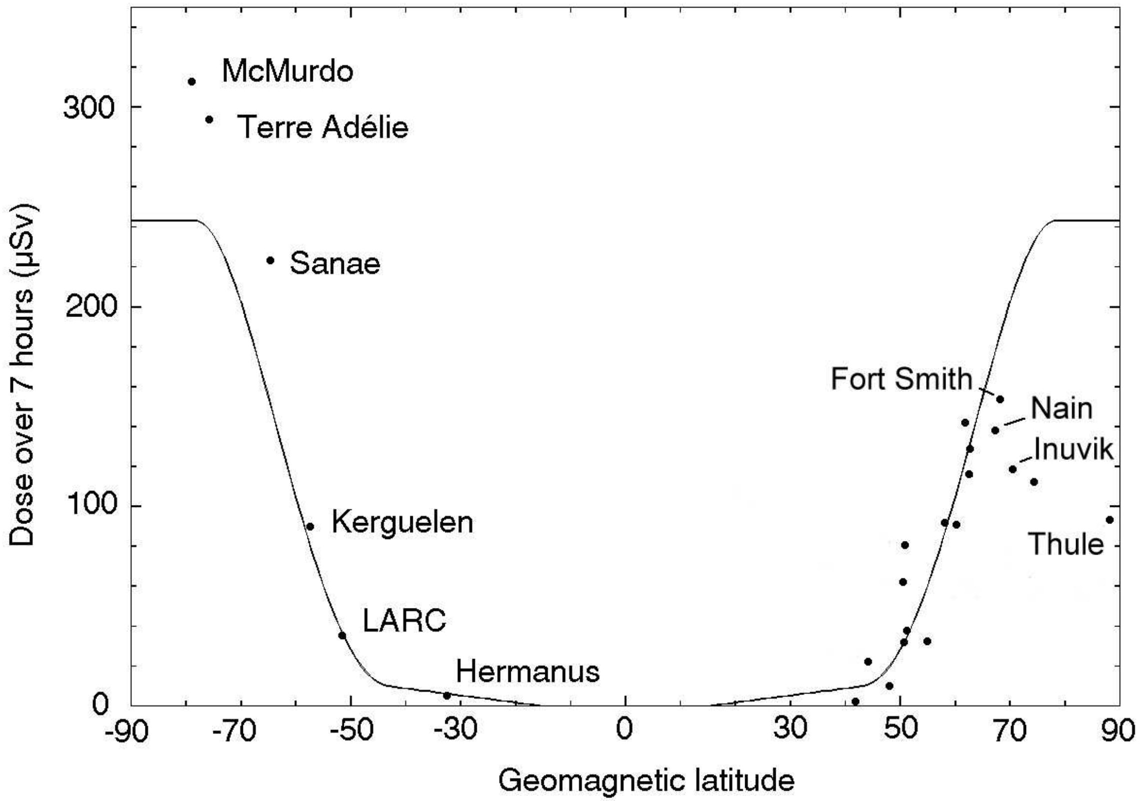
- High north-south anisotropy for GLE69
- Cumulated doses using other NM time profiles
- Overestimation for latitude > 65°
- Correction of SiGLE results in function of N/S anisotropy of NM measurements

-> Diff 23% & 43% for GLE and 14% & 25% for total dose



Route	Dose received from GLE 69 (µSv)	Dose received from GCR (µSv)	Total dose (µSv)
Paris–San Francisco	**73.9 (96.9)**	65.8	139.7
Tokyo–Paris (polar route)	**49.8 (88.3)**	61.8	111.7

Improvements with NMDB

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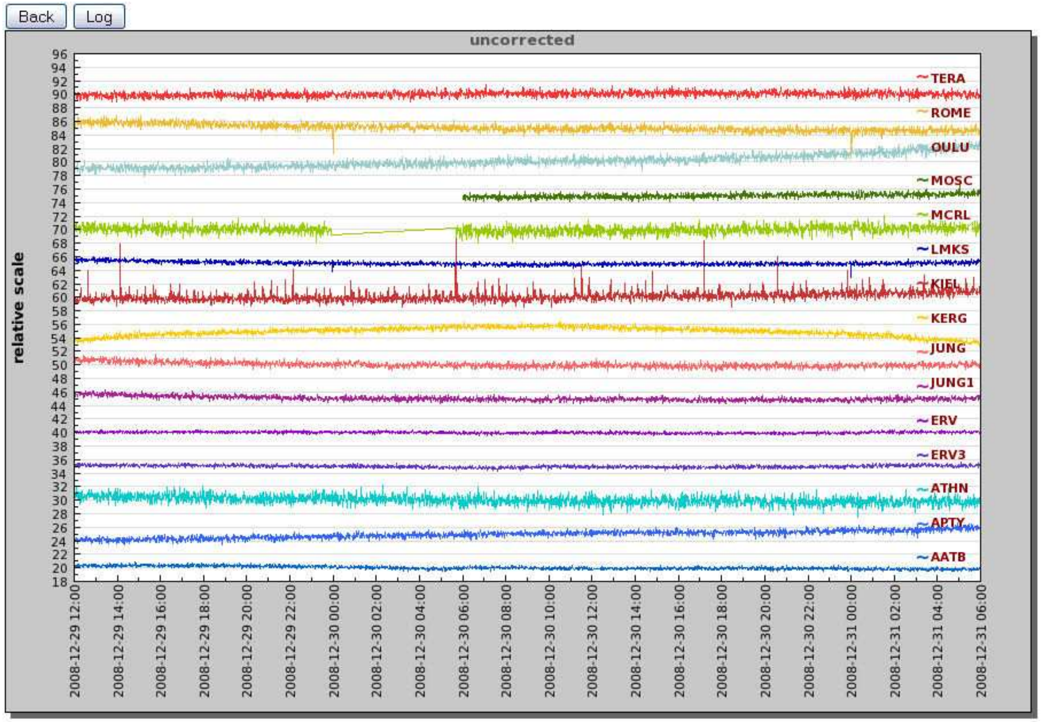

www.nmdb.eu

- European FP7 project from jan 2008 - jan 2010
- More than 20 NMs at various locations
- Real time GLE alert
- Calculation of GLE parameters in real time
  -> Spectrum
  -> Anisotropy

Summary

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- In the frame of SIEVERT system, SiGLE has been developed to fulfil the French legal requirements.
- It has been used for 4 GLEs in an operational context.
- Validation is difficult due to lack of measurements, but good agreement with other estimates.
- This model will evolve as new measurements/calculations will be available
- More precise results can be achieved by taking into account:

  - the anisotropy of the event (even as a time function)

  - the power law exponent as a time function from NM network

  - the effect of geomagnetic storms

  - …
- For very strong GLE, retrieving dosimeters should be considered