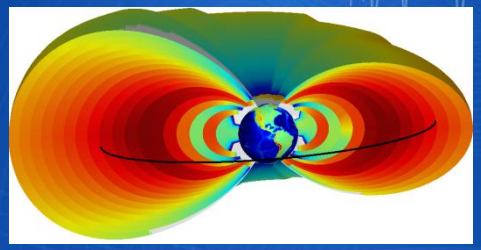

GREEN model

Global Radiation Earth ENvironment

(Version 1)

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cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

retour sur innovation

GREEN : Why a new model?

- **Existing global models:**
  - AE8/AP8 (reference models) composed of one model in solar MAX and another model in solar MIN
  - AE9/AP9 composed of a mean model or a perturbed or Monte-Carlo model with confidence levels
- **Existing local ONERA models:**
  - Electron: **SLOT** (2.3<L<5) , **OZONE** (L>4), **IGE-2006** (geostationary orbit), **MEO-V2**
  - Proton: **OPAL** (<800 km) **and IGP** (GEO)
- **Why a new global model?:**
  - To overcome the well-known deficiencies in the existing global models (AE8/AP8)
  - To deduce parameters linked to effects and to compare them with in-situ degradation measurements
  - To compare with AE9/AP9

GREEN : How to proceed?

➢ **Main principles:**

➔ GREEN (V0) is a new model composed of different existing global and local models

➔ A list of models has been defined to start with in the case of electrons and another one for protons. These two lists can be expanded and discussed at any time.

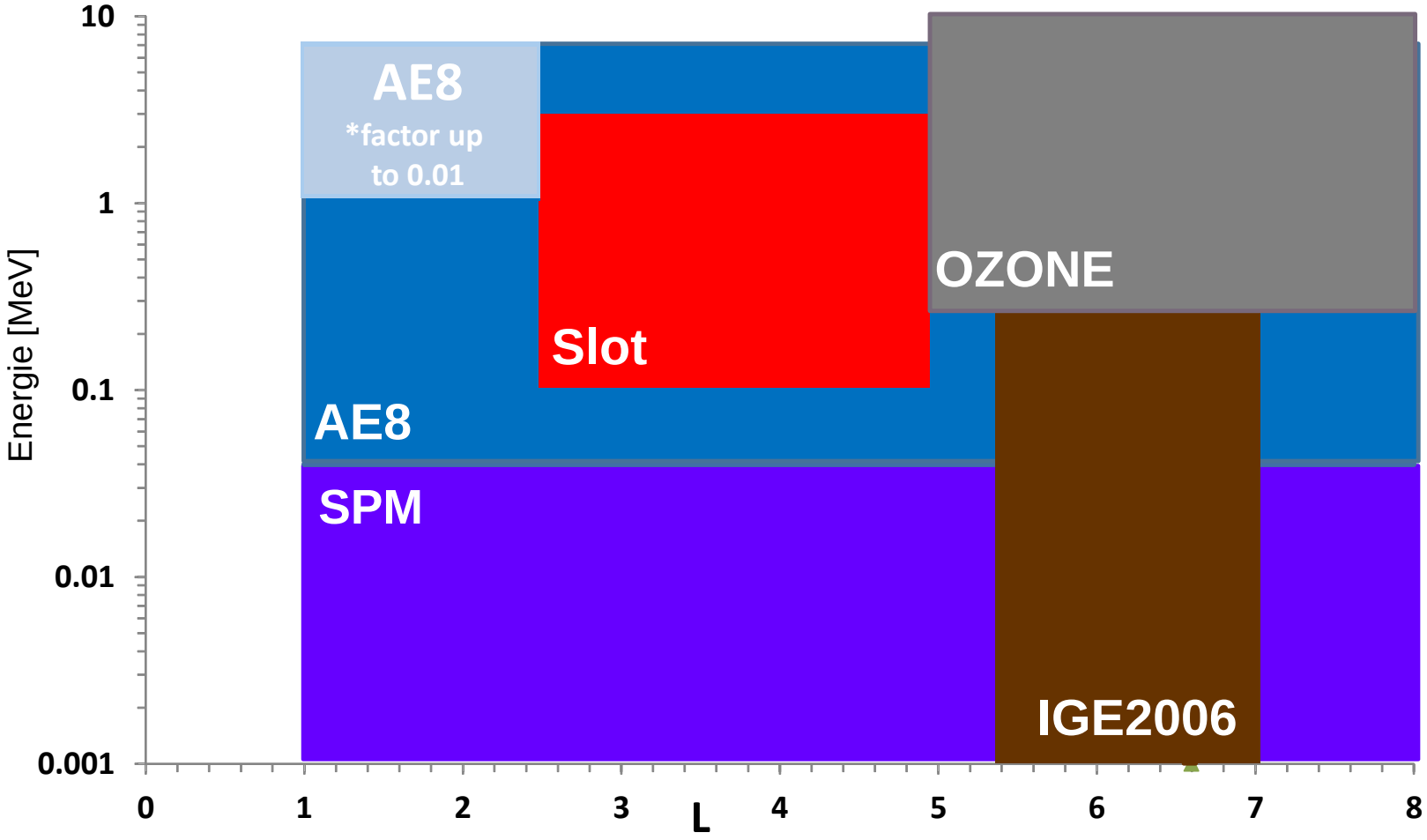
➔ A 3 dimension grid in Energy, B_{local}/B_{eq} and L has been defined and represents the global architecture of GREEN. This 3D grid (Ec, B/B_{Eq}, L) is the same as Salammbô's one with 133 steps in L, 133 steps in B/B_{Eq} and 49 steps in energy, in particular it allows a maximum cell size of 200 km.

➔ Flux from each model integrated in GREEN have been calculated on this grid.

➔ Then a priority order of the different models has been established according to space location or energy.

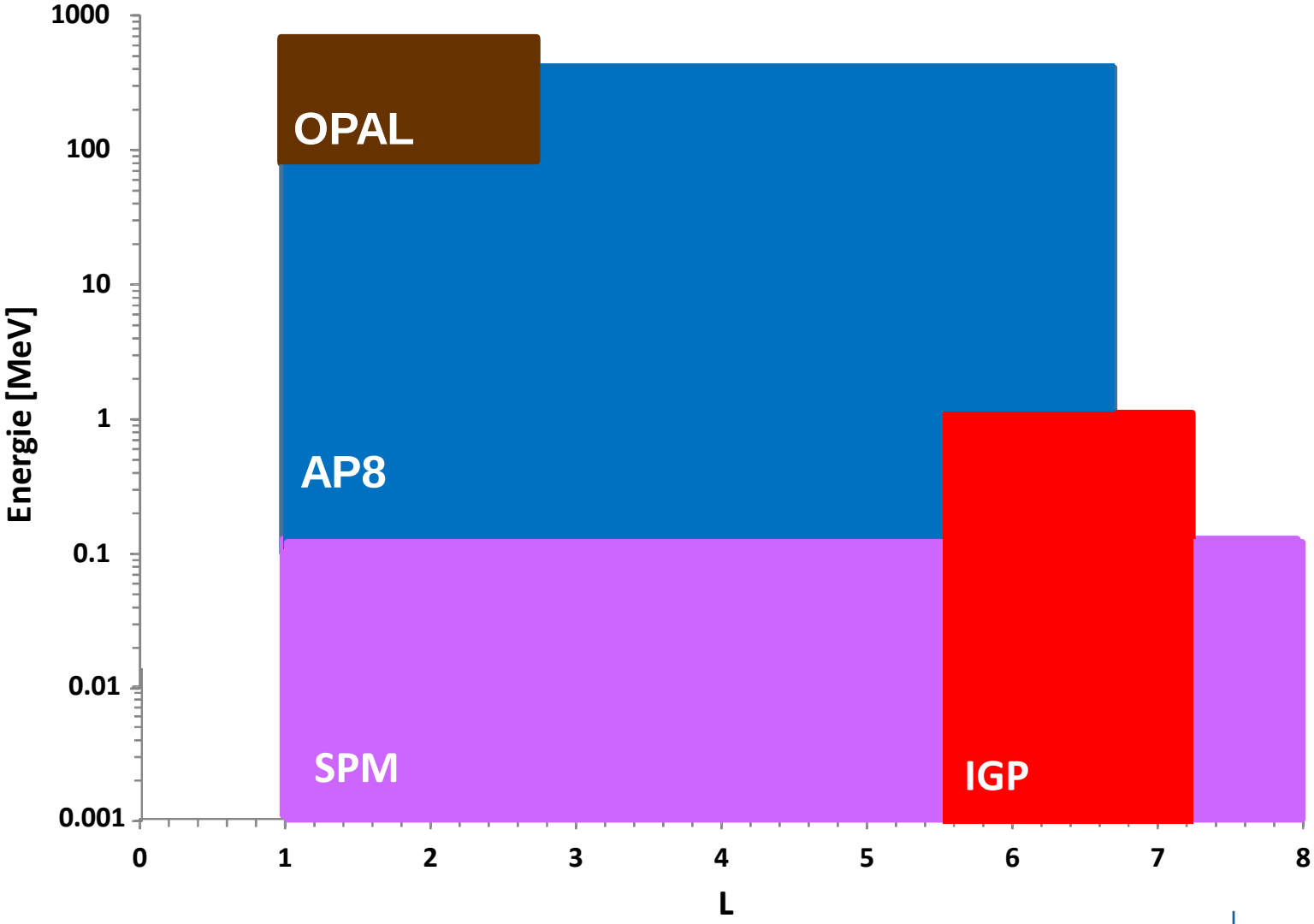
GREEN : Models contained in GREEN-e

➢ **Energy and L* (or L) coverage for models contained in GREEN-e:**



GREEN : Models contained in GREEN-p

- **Energy and L* (or L) coverage for models contained in GREEN-p:**

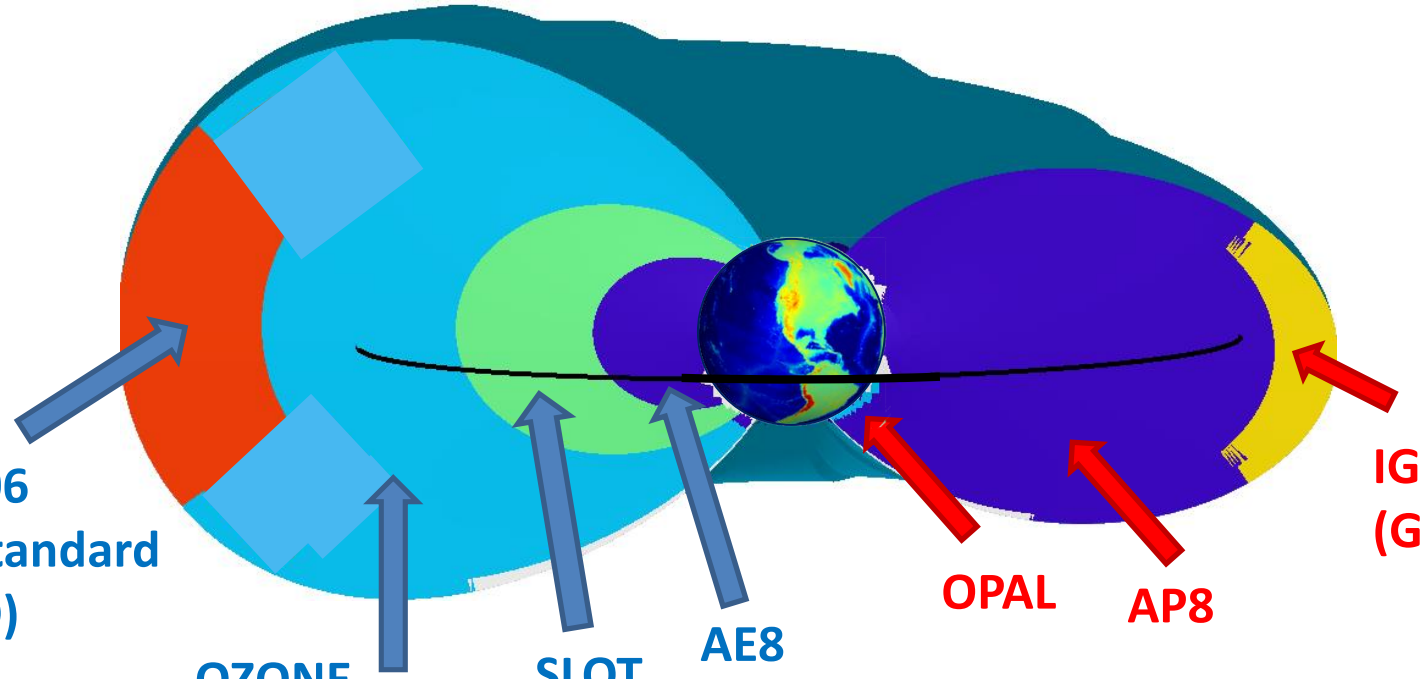


GREEN : Overview of models contained in GREEN

GREEN

GREEN-e
Electrons

GREEN-p
Protons



IGE-2006
(ECSS standard for GEO)

OZONE
Outer zone

SLOT

AE8

OPAL

AP8

IGP
(GEO)

GREEN : SLOT model (1/3)

➢ Data used:

37 years of data at LEO !!

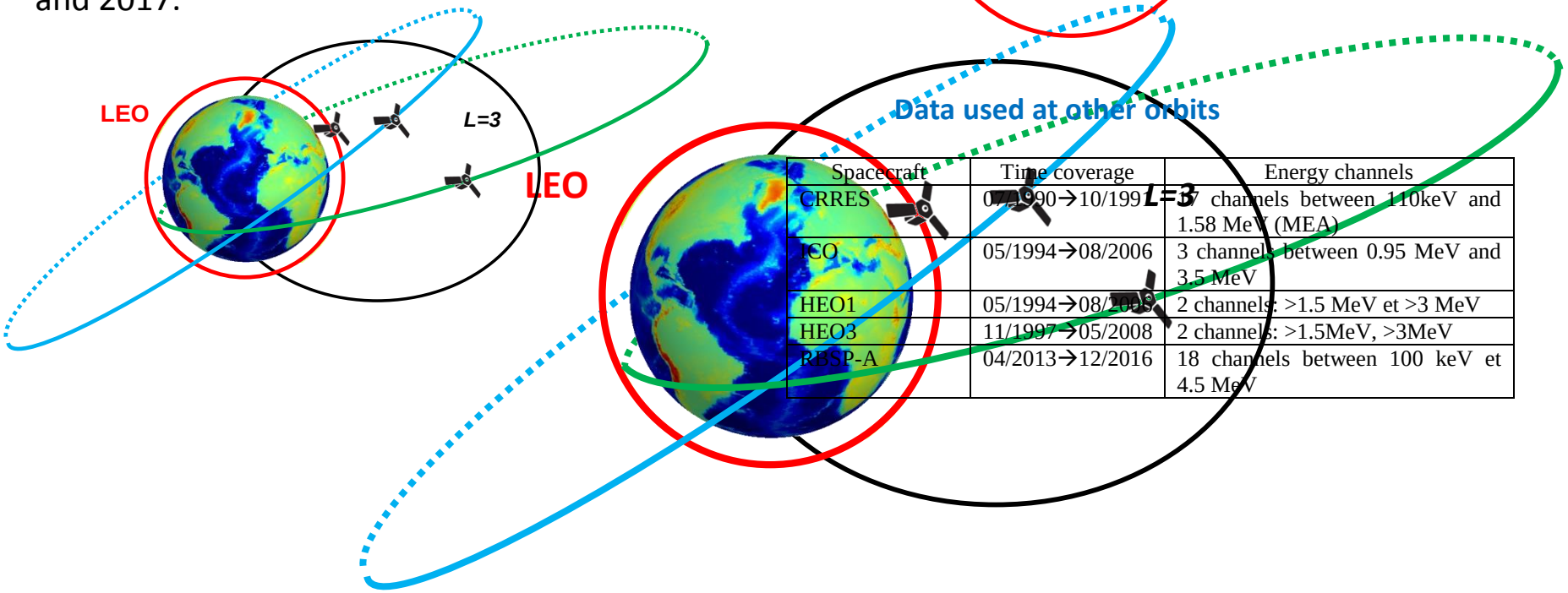
Only few models in this region exist. AE8 is well-known to under-estimate electron flux in this zone.

➔ New model was needed and has been developped in 2013 and improved in 2016 and 2017.

Data used at LEO orbit

Spacecraft	Time coverage	Energy channels
NOAA 6 SEM	07/1979→11/1986	>100 keV, >300 keV, >1.1 MeV
NOAA 10 SEM	10/1986→08/1991	>100 keV, >300 keV, >1.1 MeV
NOAA 12 SEM	06/1991→07/2002	>100 keV, >300 keV, >1.1 MeV
NOAA 15 SEM-2	07/1998→present	>100 keV, >300 keV, >3 MeV

This SLOT model is based on the correlation between flux at LEO orbit and flux along the magnetic field line



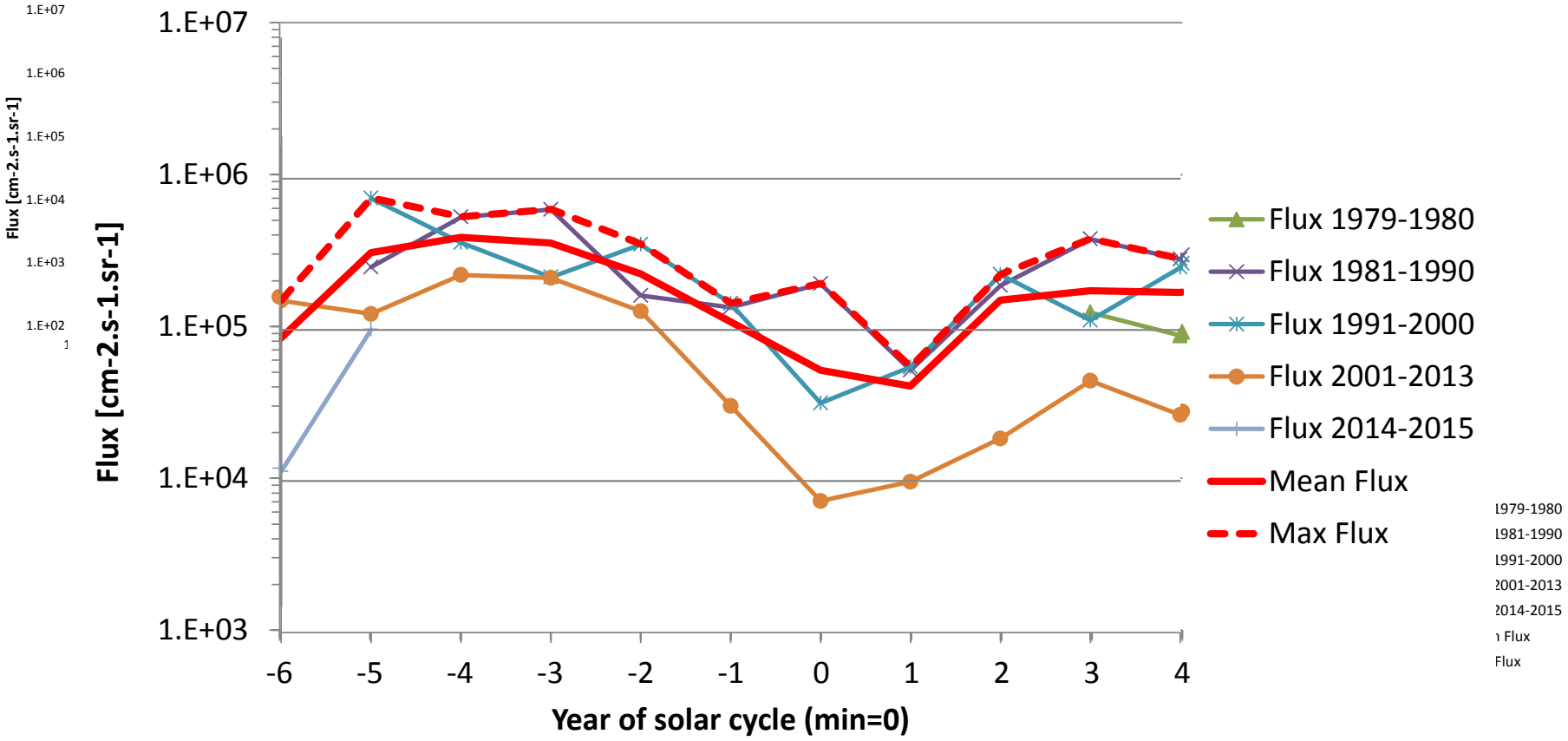
Data used at other orbits

Spacecraft	Time coverage	Energy channels
CRRES	07/1990→10/1991	7 channels between 110keV and 1.58 MeV (MEA)
ICO	05/1994→08/2006	3 channels between 0.95 MeV and 3.5 MeV
HEO1	05/1994→08/2008	2 channels: >1.5 MeV et >3 MeV
HEO3	11/1997→05/2008	2 channels: >1.5MeV, >3MeV
RBSP-A	04/2013→12/2016	18 channels between 100 keV et 4.5 MeV

GREEN : SLOT model (3/3)

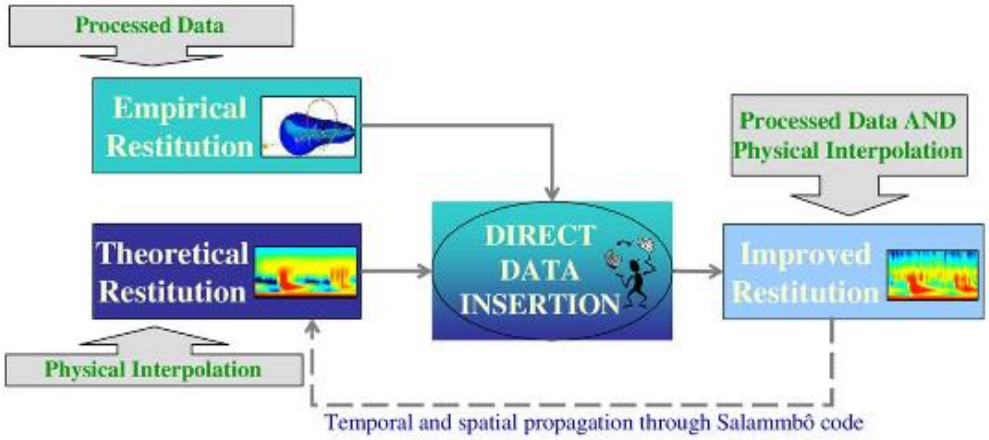
- **In 2016 and 2017 the SLOT model has been improved and reproduce the solar cycle modulation based on NOAA data:**

*Example at **100 keV**:*



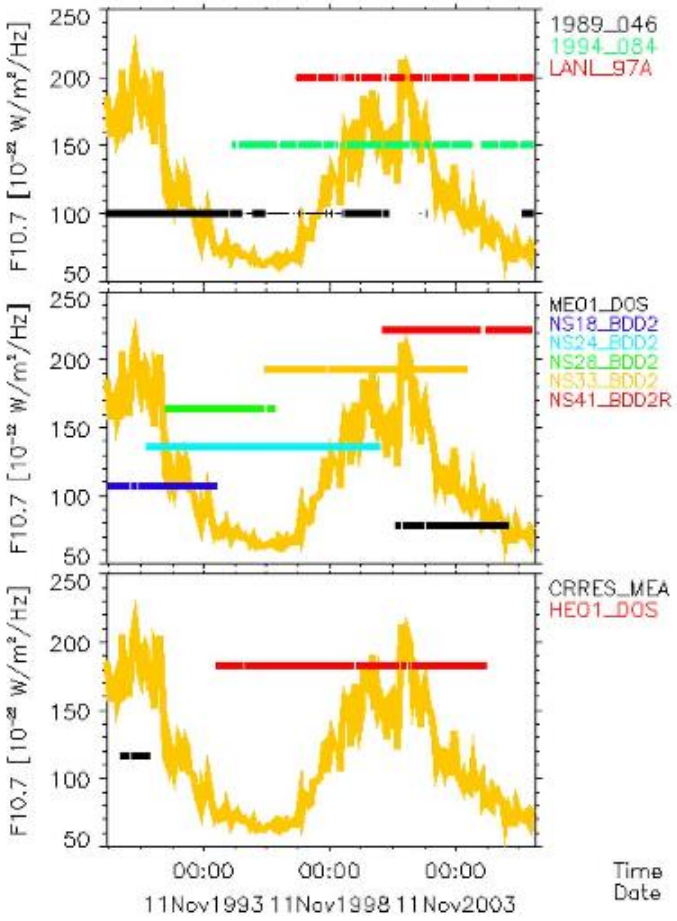
GREEN : OZONE model (1/2)

➢ **OZONE : an outer belt electron model based on data assimilation :**



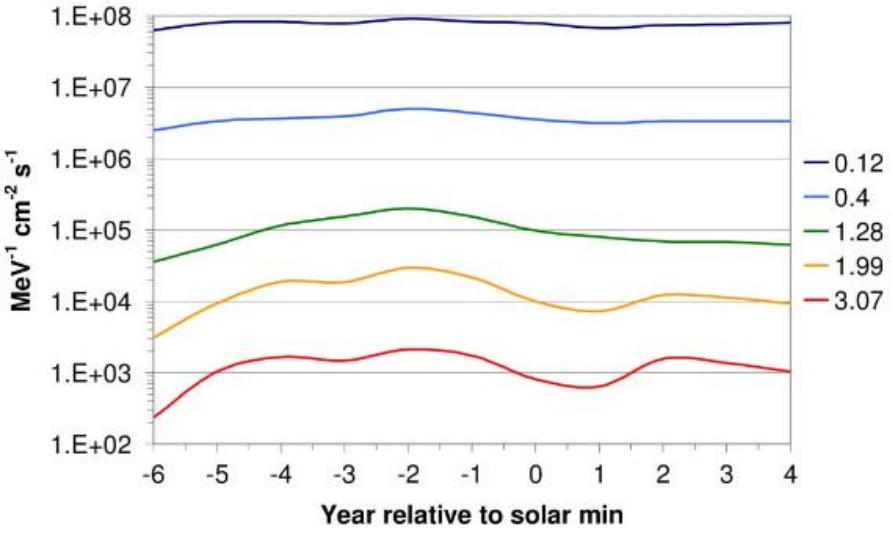
OZONE =
Salammbô physical model + data assimilation

Model valid for L*>4 and between 300 keV and 10 MeV, depending on the year of the solar cycle



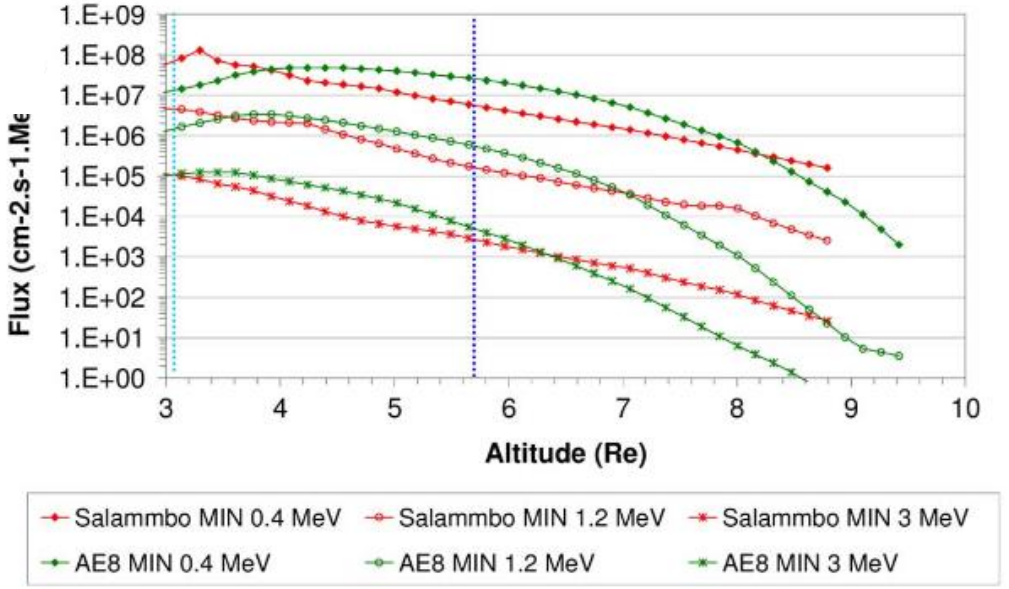
GREEN : OZONE model (2/2)

➢ **Examples of results:**



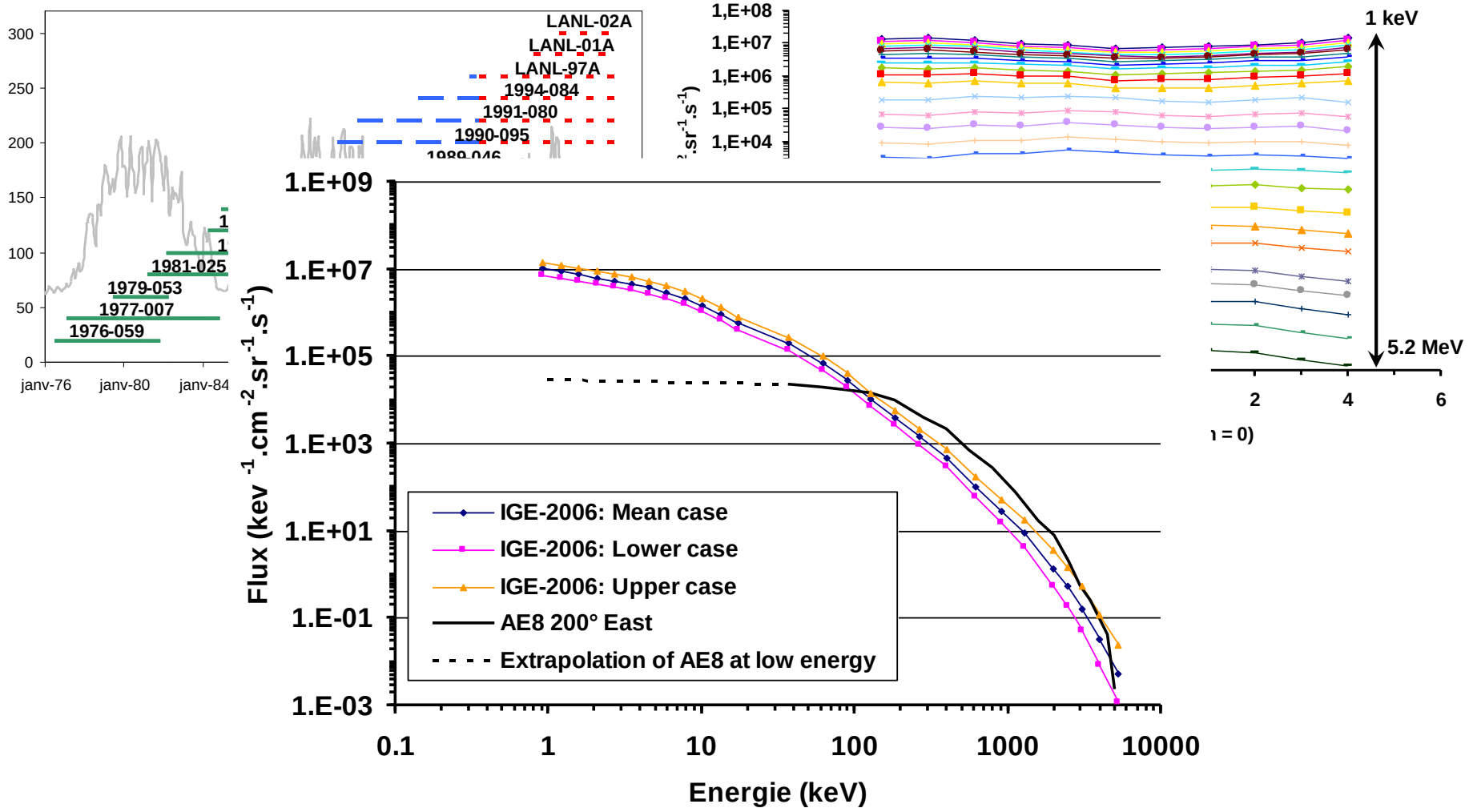
Omnidirectional differential fluxes at magnetic equator in the outer electron belt versus year relative to solar minimum at L=6*

Comparison of omnidirectional differential fluxes for 3 energies function of altitude between OZONE and AE8 min.



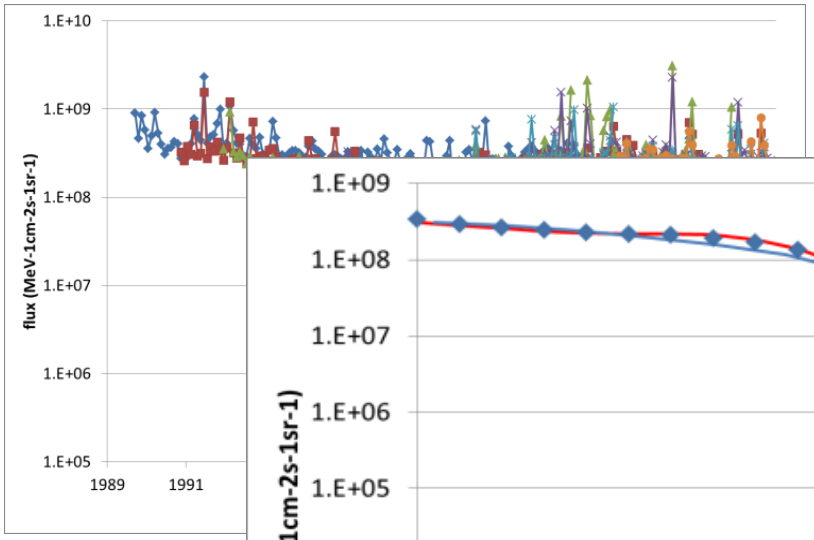
GREEN : IGE-2006 model

➢ **Model for electrons at geostationary orbit based on LANL data from 1976 to 2005:**



GREEN : IGP model

- **Model for protons at geostationary orbit based on LANL data from 1976 to 2005:**



*Monthly average **1 keV** proton flux measured at GEO by the **MPA** detector on board the different LANL spacecraft*

Monthly averag
flux measured
***CPA** detector*
different LAN

cycles of LANL data

GREEN : OPAL (1/2)

✓ **Description of the model**

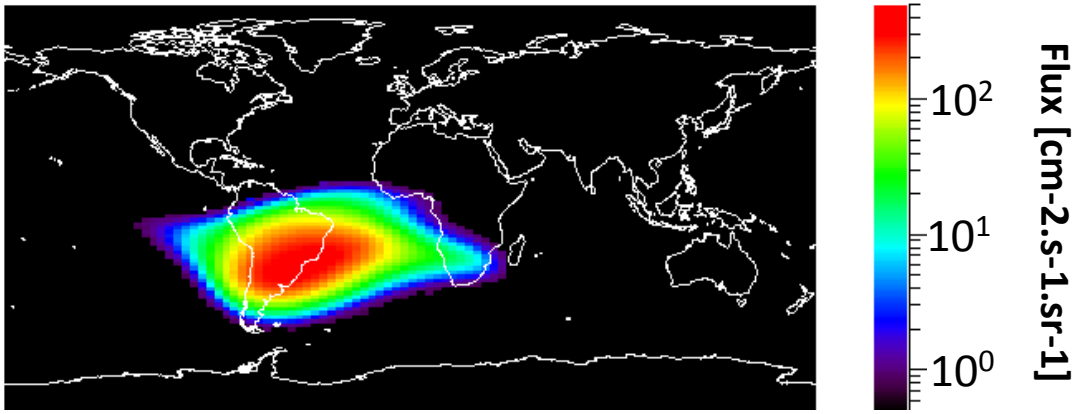
ONERA had an opportunity to develop a high energy proton model at low-altitude with NOAA data:

- Measurements near 850km since July 1978 on NOAA spacecraft
- Only two different detectors (SEM and SEM-2) with long time coverage and only few gaps

Main strengths of these data sets:

- 3 close energy channels on close orbits
- 38 years of measurements(more than 3 solar cycles)
- Detectors with well-known geometry
- Well-known position of the detectors on the spacecraft

NOAA-12 in 1997
P8 channel
Protons > 82 MeV

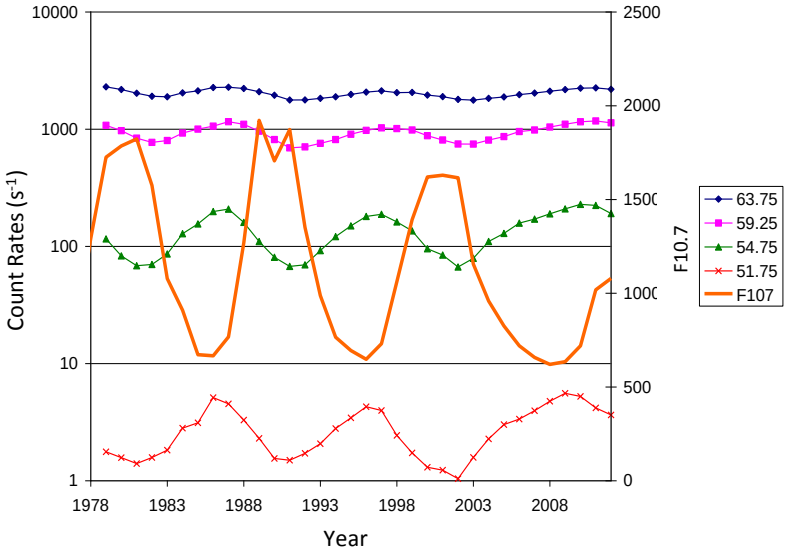


GREEN : OPAL (2/2)

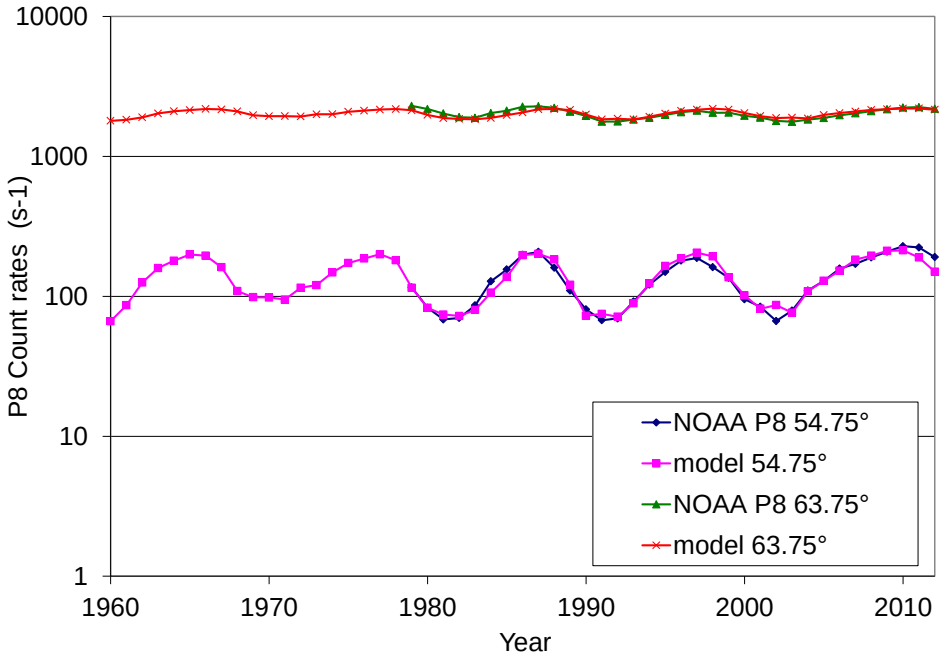
Two main steps in the model:

- correction of the maximum pitch angle being seen at a given altitude and L due to the drift of the magnetic field with time
- calculation of the time delay between F10.7 radio flux and protons fluxes dynamics.

➢ **Comparison between OPAL and data:**



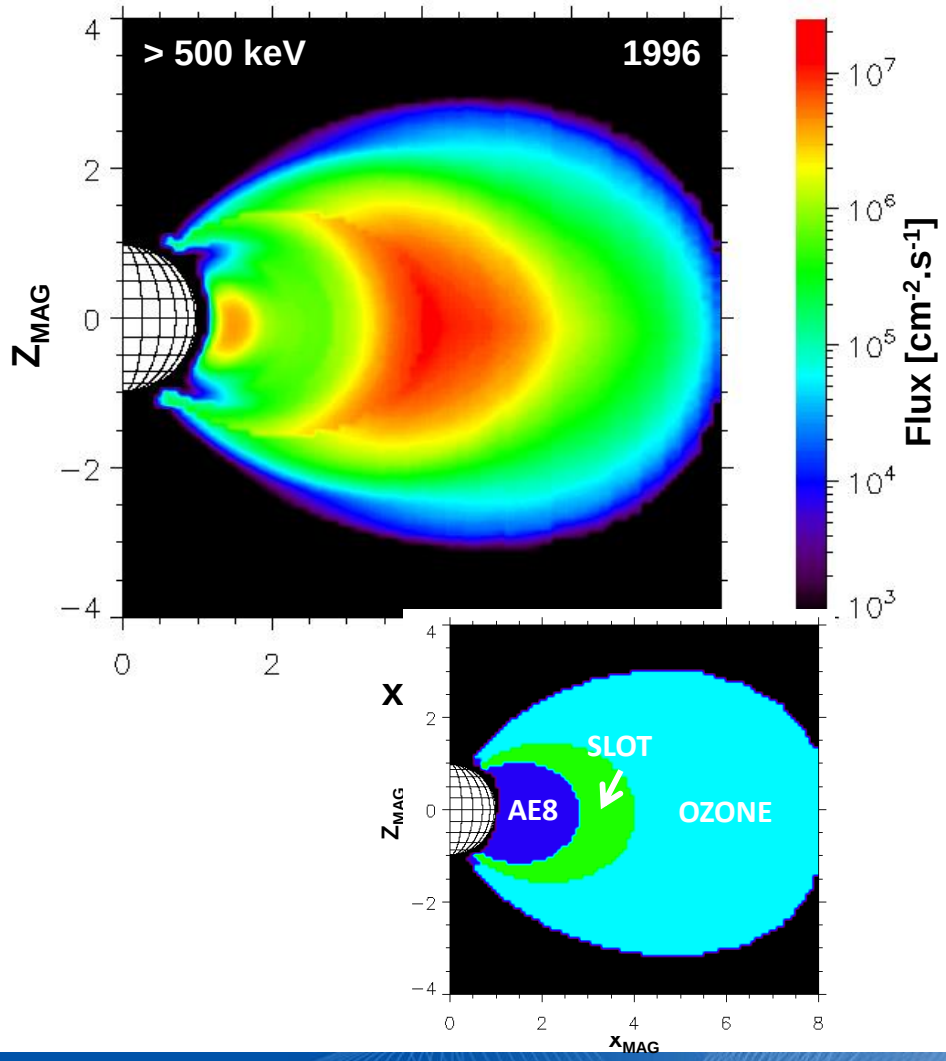
Evolution of count rates of P8 channel in the continuous NOAA data set for Lm=1.3 for different pitch angles and comparison with solar radio flux.

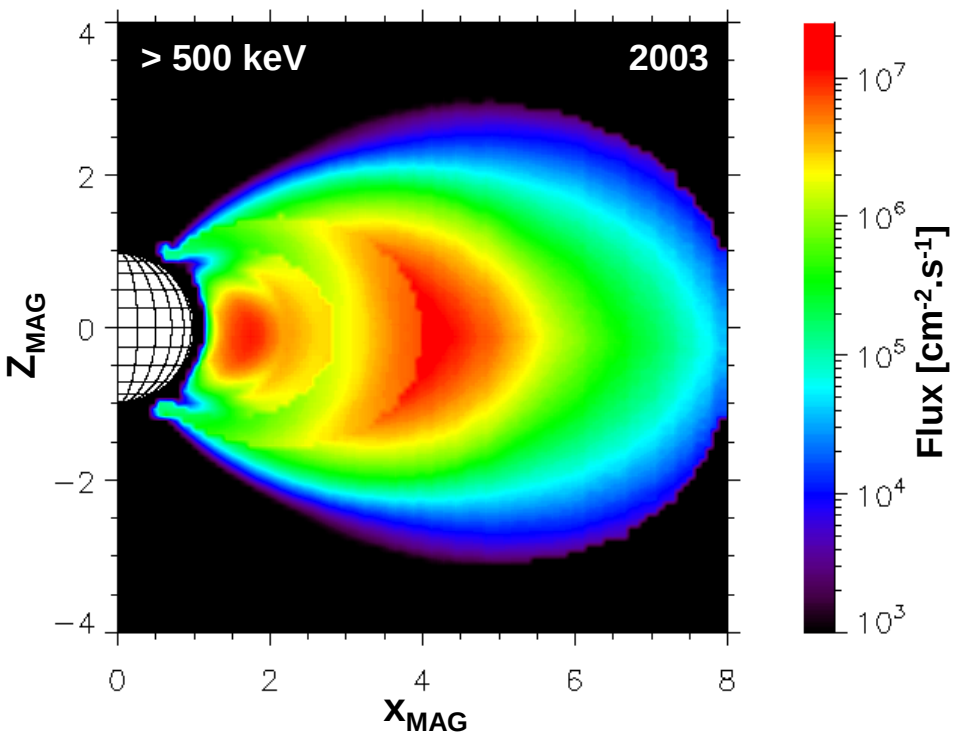


Comparison between count rates of P8 channel versus time at Lm=1.300 for 2 equatorial pitch angles and results of model at E> 82 MeV.

GREEN : Example of results for GREEN-e

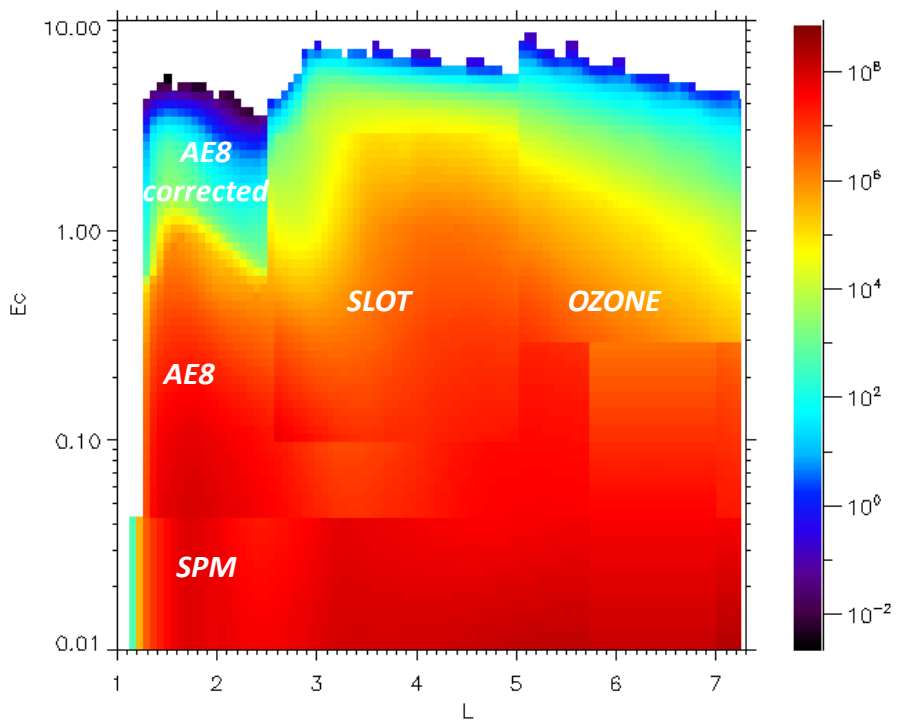
➢ **Meridian maps of >500 keV electron flux in 1996 (solar min) and 2003 (solar max):**

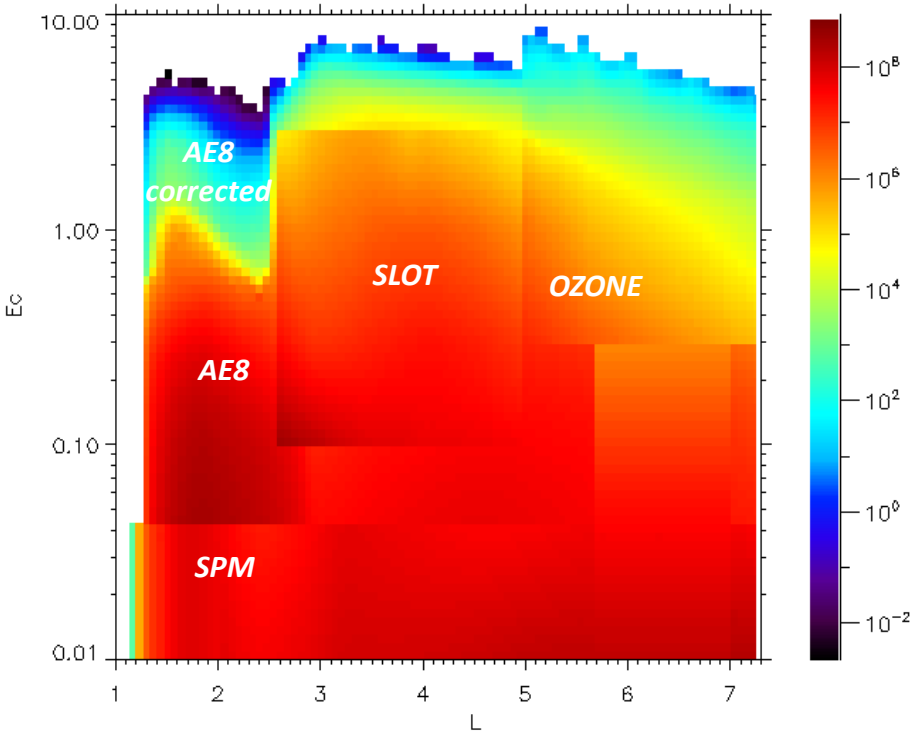




GREEN : Example of results for GREEN-e

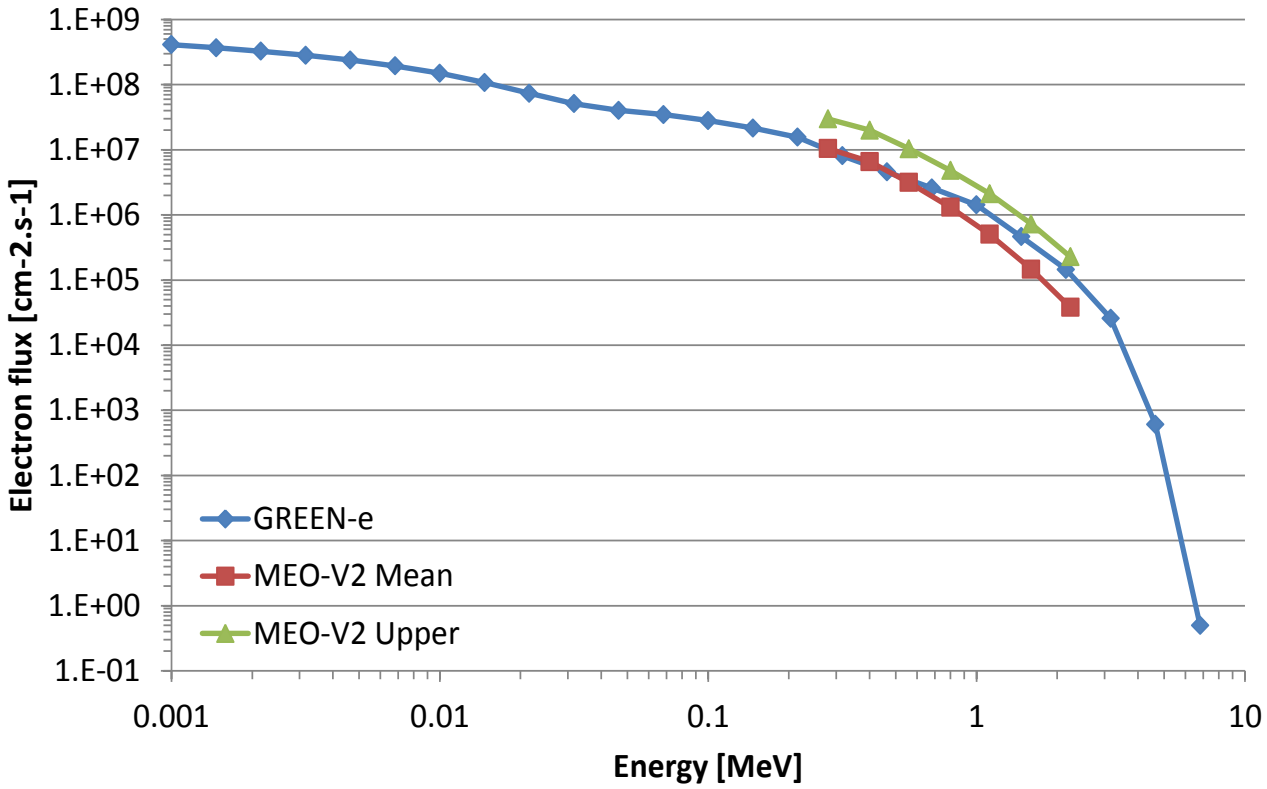
- **Mapping of electron flux in 1996 (solar min) and 2003 (solar max) versus L* and Energy at equator:**





GREEN : Validation (1/3)

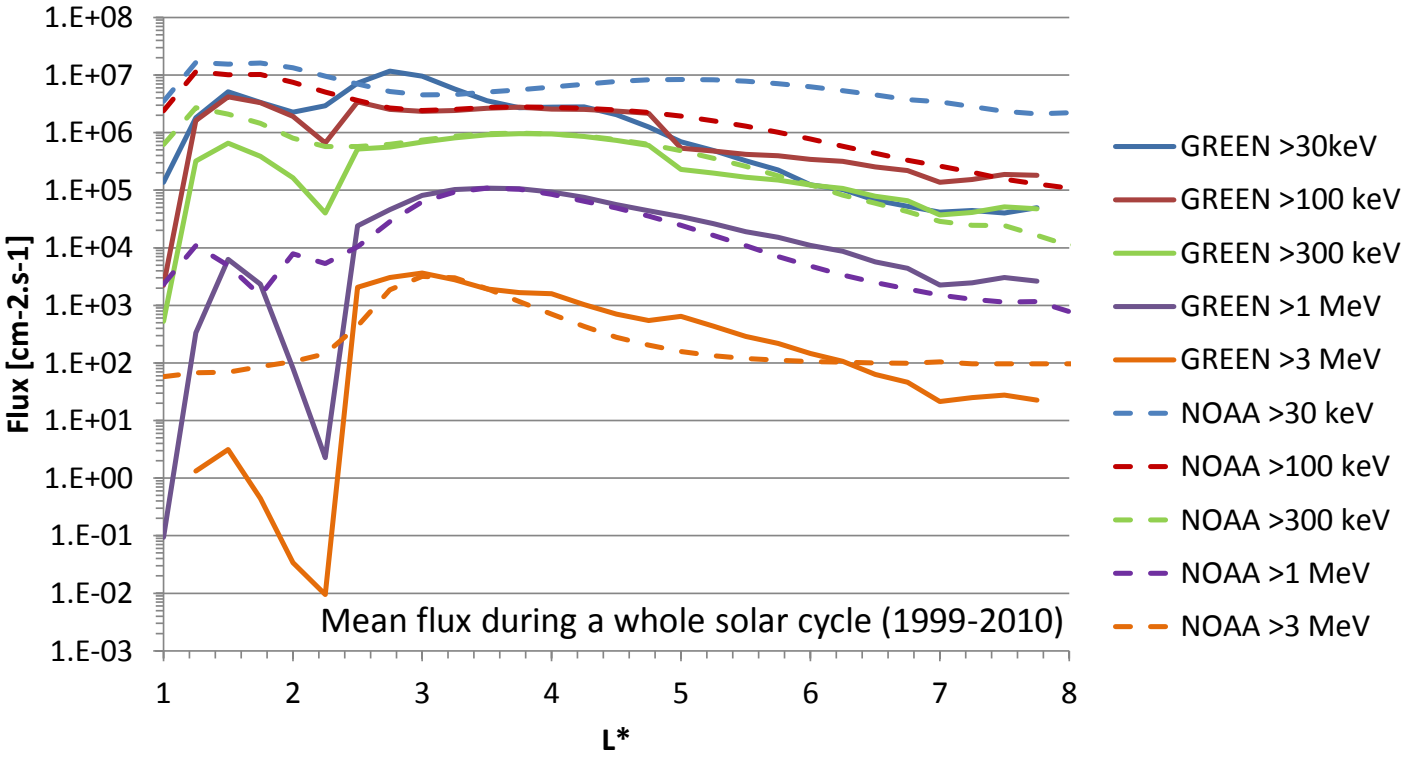
➢ **Comparison of electron flux provided by GREEN-e and MEO-V2:**



Mean flux on a whole solar cycle (11 years)

GREEN : Validation (2/3)

➢ **Comparison of electron flux provided by GREEN-e and NOAA (at NOAA-15 orbit, 825 km, 98°):**

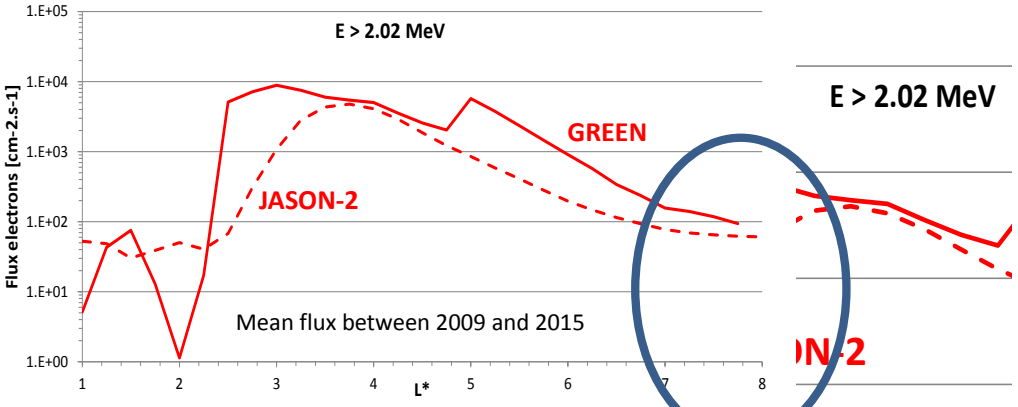


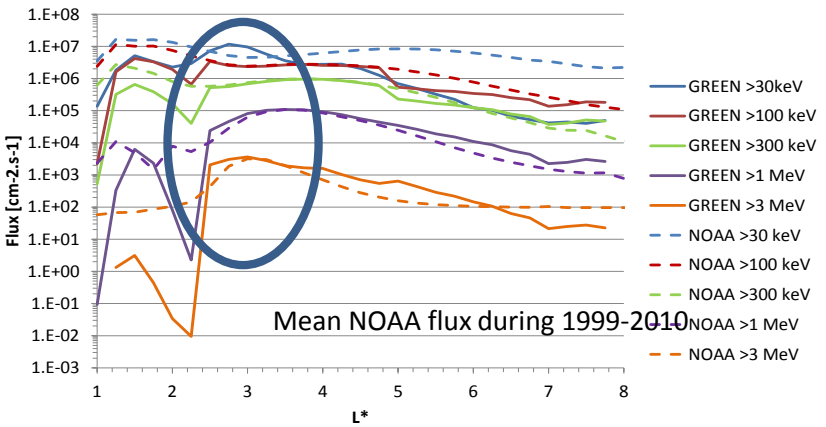
For L*<2.5 and E>1 MeV NOAA-15 measures the background al well as for L*>6 and E >3 MeV

The comparison between NOAA data and flux provided by GREEN is good except for E>30 keV (AE8 is the default model in GREEN for this energy)

GREEN : Validation (3/3)

➢ **Comparison of electron flux provided by GREEN-e and JASON-2 (1336 km, 63°):**





➔Time period of JASON-2 is not representative of a mean flux since begining of space age in the Slot region

GREEN : Conclusions and Perspectives

- ✓ GREEN-e model is composed of AE8, SPM, SLOT, OZONE and IGE-2006 and is valid from **1 keV to 10 MeV**
- ✓ GREEN-p model is composed of AP8, SPM and OPAL and is valid from **1 keV to 650 MeV**
- ✓ GREEN in a **solar cycle dependent** model
- ✓ A 'Worst case' version is in progress and would provide worst fluxes along an orbit as EOR for example
- ✓ New local models are needed where only AE8 and AP8 are available. Data with good quality and statistics are essential to hope for a reliable local model.