OPAL : ONERA Protons Altitude Low

(High energy protons at low altitude)

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R&T SYSTEMES SPATIAUX

retour sur innovation

OPAL : NOAA data base

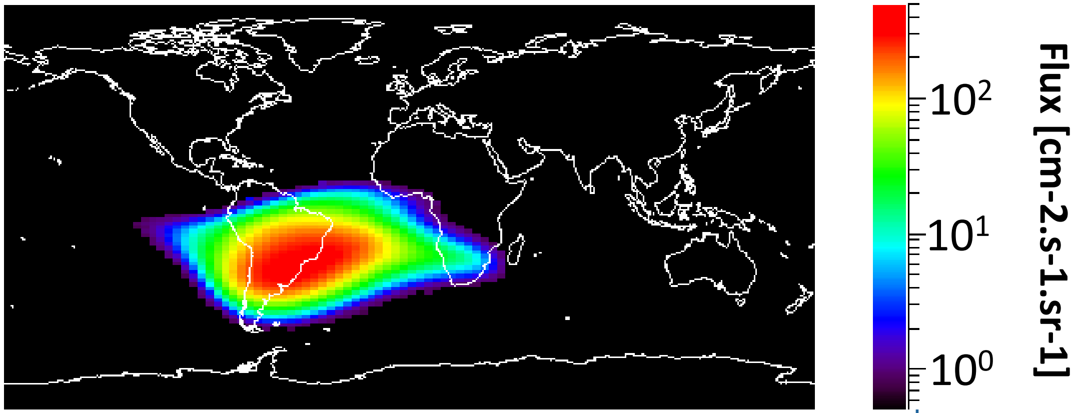
ONERA had an opportunity to develop a high energy proton model at low-altitude with NOAA data:

- Measurements near 850km since July 1978 on NOAA spacecraft
- Only two detectors (SEM and SEM-2) with long time coverage and only few gaps
- 3 channels (P6: E>20, P7: E>40 and P8: E>82MeV) for SEM 1978-2004 (26 years) until NOAA14
- 4 channels (P6: E>16, P7:36, P8:72 and P9:142MeV) for SEM2 1998-now (19 years) since NOAA15

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



OPAL : Analysis of the whole NOAA data set (1/2)

- ✓ **Verification of geometric factors and energy channels**: on SEM, thermal coating added → slight change of energy 16 MeV channel becomes 20 MeV for ex. Calculation of the influence of the environment (front, back) and detection threshold (not exactly identical on all detectors).
- ✓ **Verification of the influence of the orbit and the position of the detector** :counts in ascending and descending orbits, altitudes slightly different.
- ✓ **Comparison of data from the different spacecraft** : comparison on overlaps period (two by two) and analysis of the differences (influence of the altitude of spacecraft at 825 km or 860 km).
- ✓ **Analysis of contaminations in the data**: measurements of channels P6 and P7 on SEM and on SEM2.
- ✓ **Comparison of SEM and SEM2 measurements**: cross calibration in counts

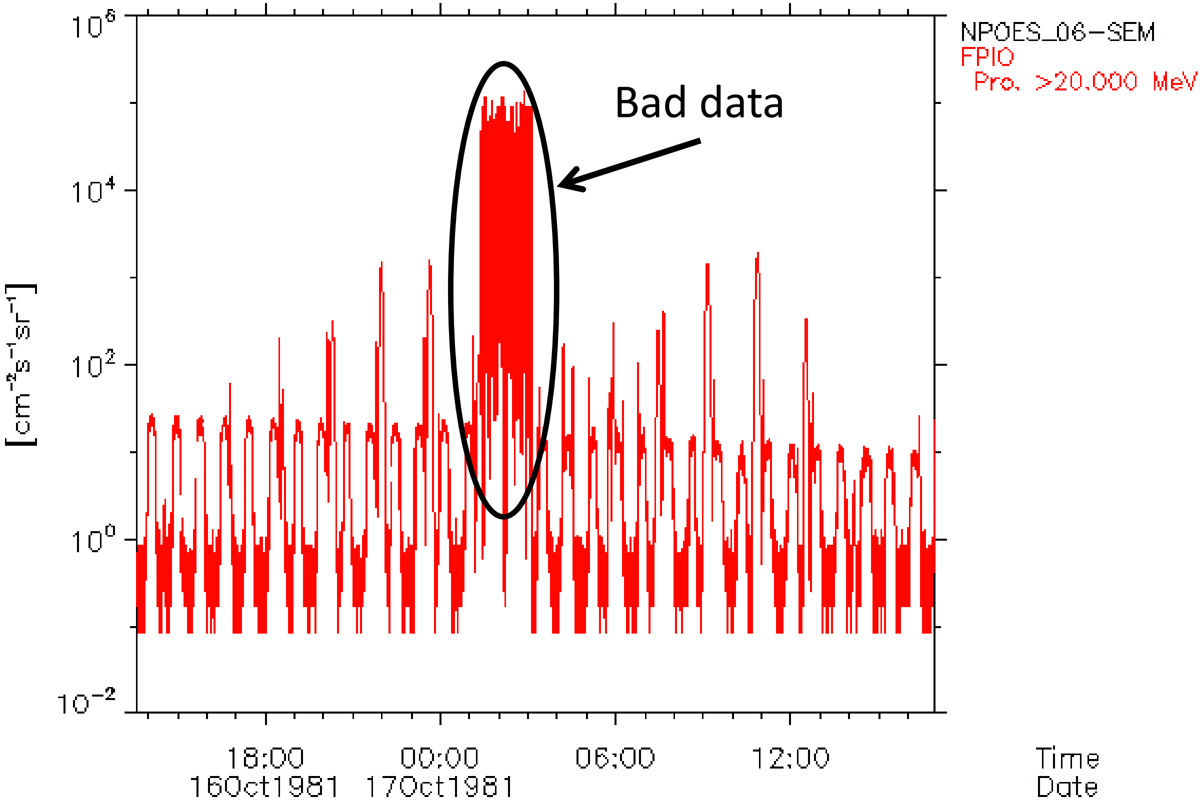
According to this accurate analysis, a reference data set has been defined:
→ NOAA 06-10-12 and 15 (same altitude, long time coverage, very few gaps in data)

OPAL : Analysis of the whole NOAA data set (2/2)

✓ **Comparison of P6, P7 and P8 channels** and analysis of solar cycle influence on measuremen

✓ **Filtering of b**

✓ **Analysis of d** * for north and south he ast border of the SAA, c ferences between P6-l



➔**Finally, only F**

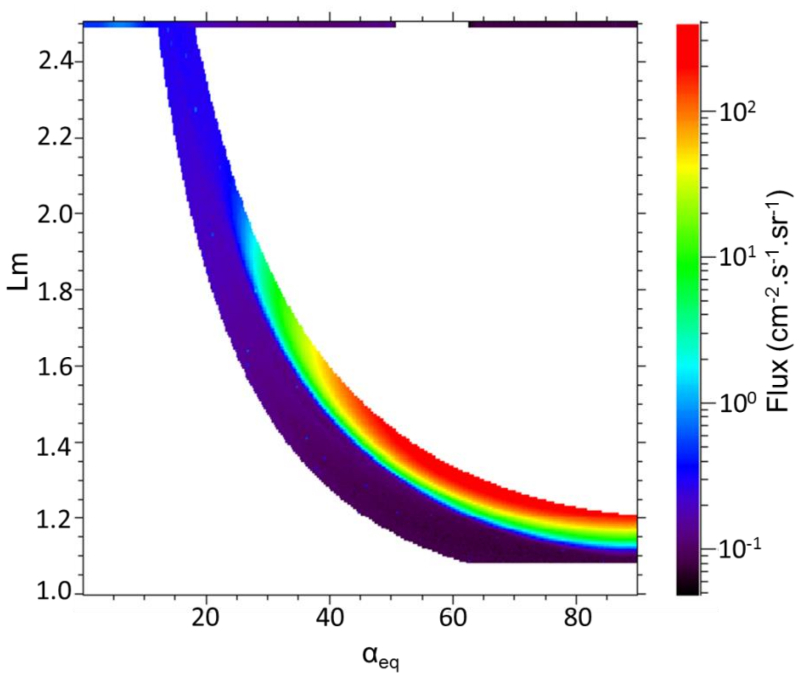
- according to t compared to P7 channel ar

- P7 channel is also contaminated by electrons on SEM

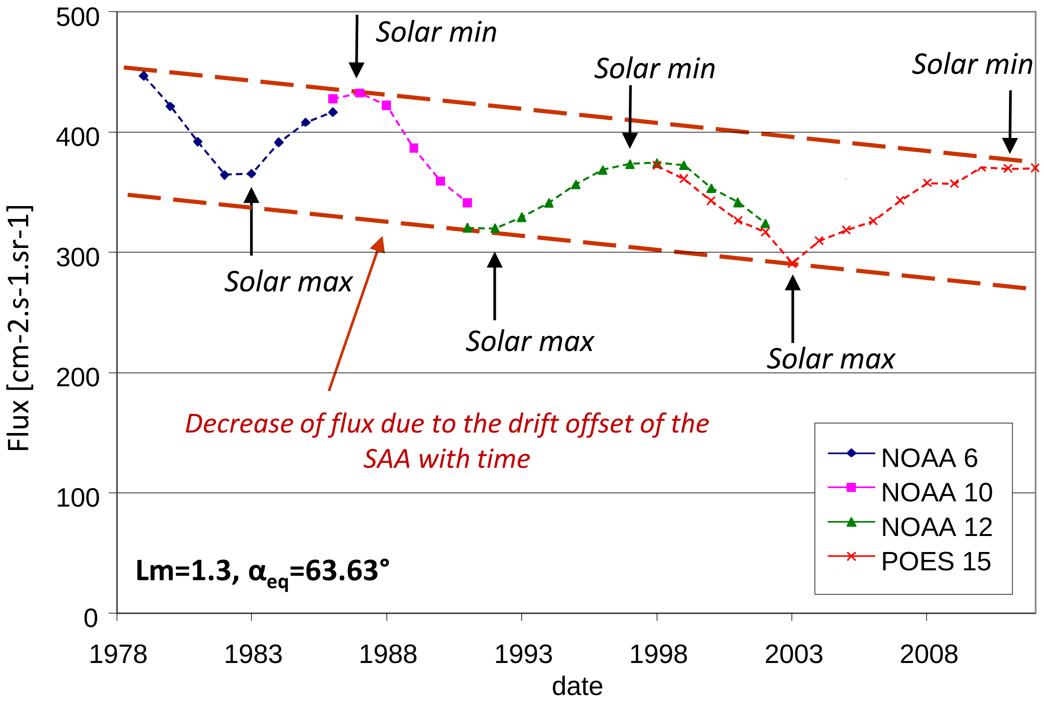
OPAL : Development of the model (1/5)

- **Solar cycle influence on fluxes:**

Mapping of equatorial pitch angle-Lm for NOAA-12 data in 1997.



Evolution of protons flux with time at given Lm and α_{eq}.

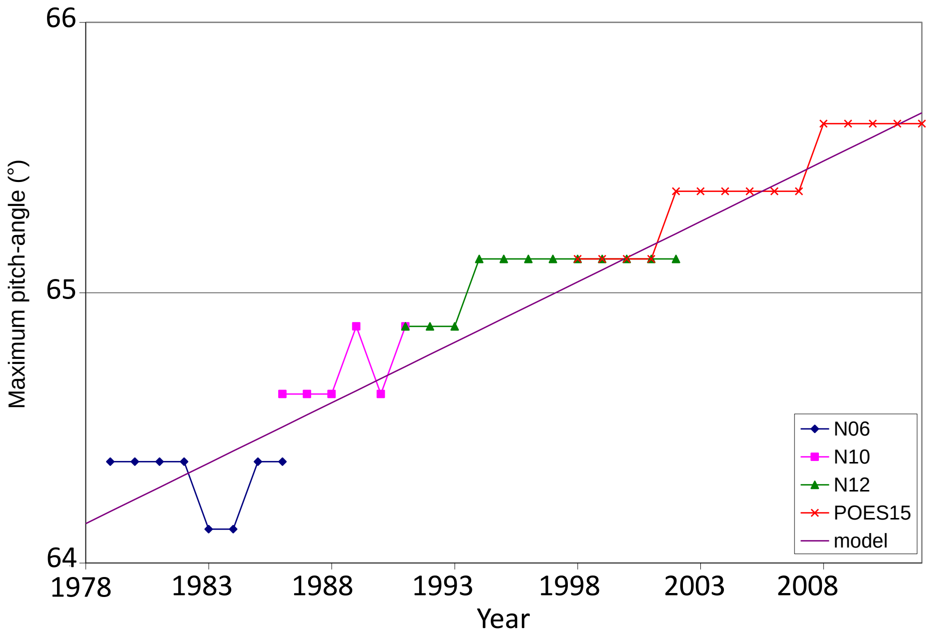


=> A correction of pitch angle is needed to take into account the drift offset of the SAA with time

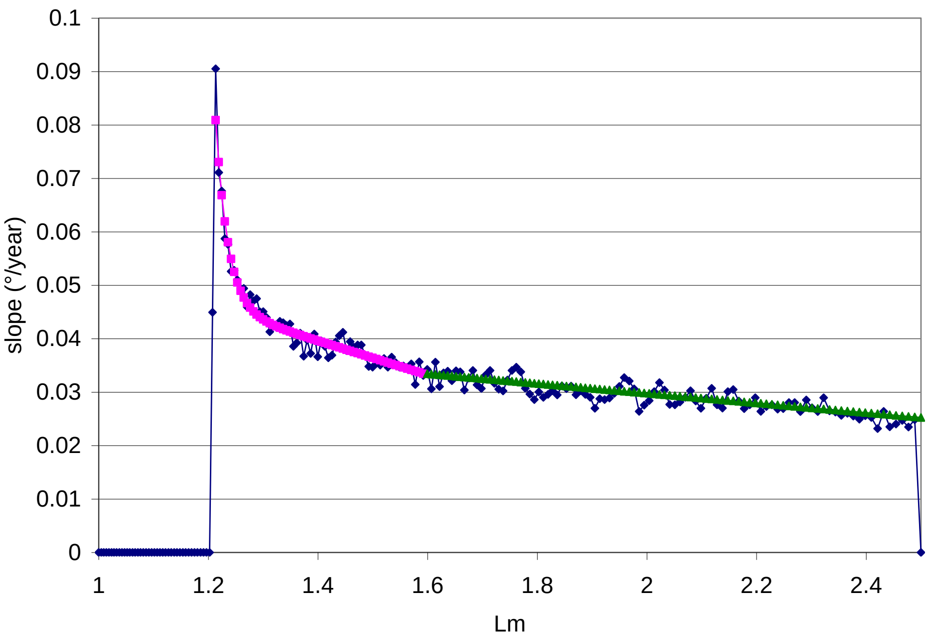
OPAL : Development of the model (2/5)

- **Pitch angle correction:**

Evolution of the maximum pitch angle (°) with time at Lm=1.3



Pitch-angle correction (°/year) versus Lm

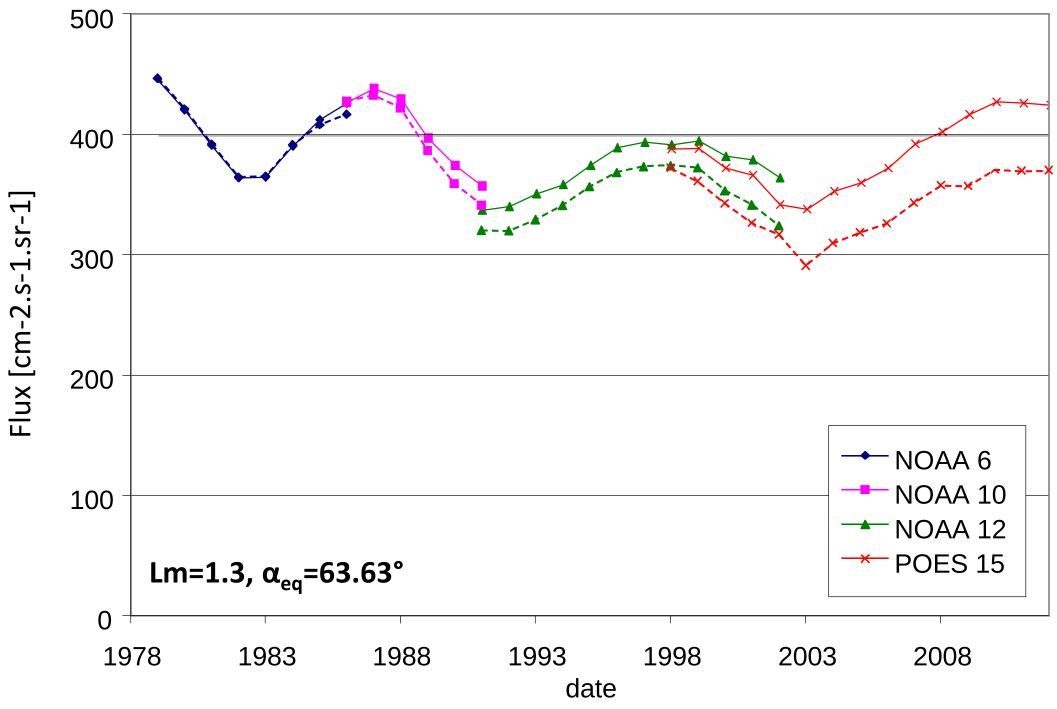


Lm<1.595, slope = exp(-43.701Lm+49.682)-0.032Lm+0.0844

Lm>1.595, slope = -0.0091Lm+0.048

OPAL : Development of the model (3/5)

Evolution of protons flux with time at given Lm and α_{eq}.

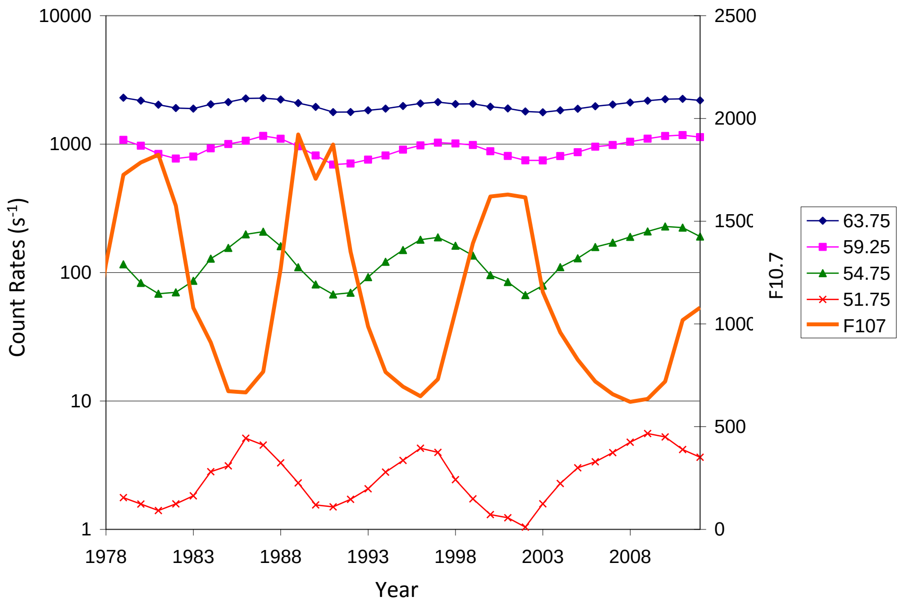


With correction of the pitch angle

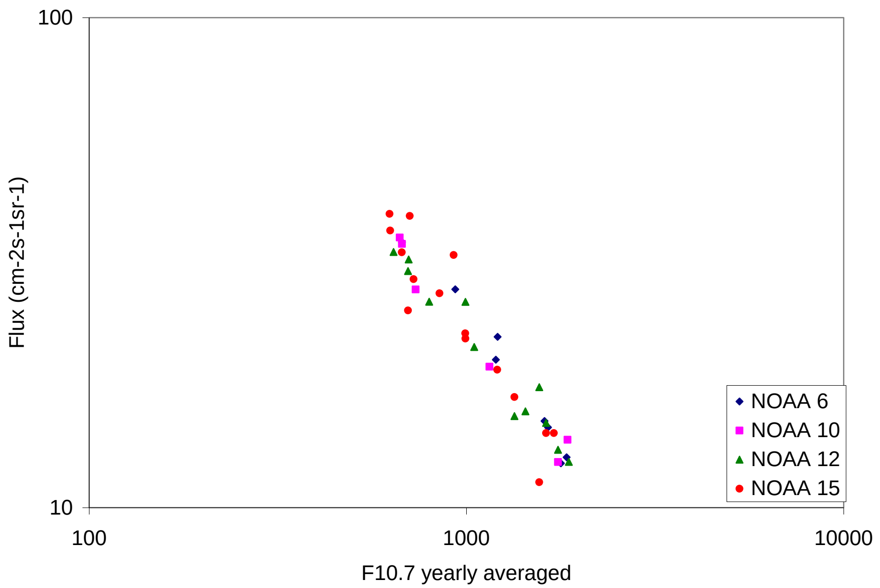
OPAL : Development of the model (3/4)

➢ **Analysis of counts versus F10.7:**

➔ A time delay has to be taken into account (inertia of the system)



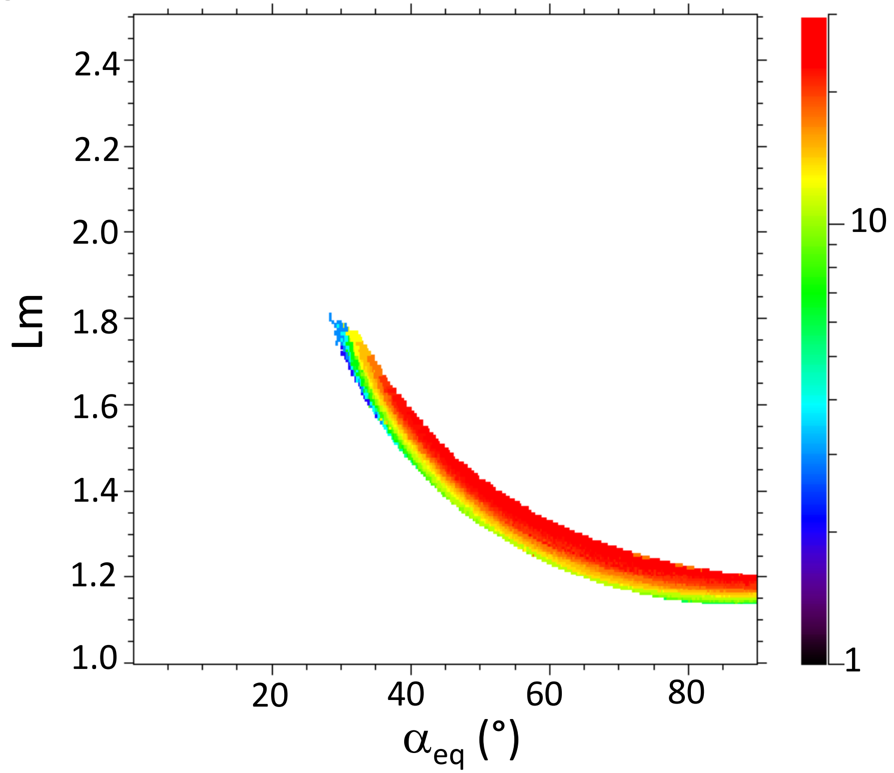
Evolution of count rates of P8 channel in the continuous NOAA data set for Lm=1.3 for different pitch angles and comparison with solar radio flux.



Example of correlation between yearly flux and F10.7 (for Lm=1.300 and α_{eq} = 54.63° with a delay of 14 months).

OPAL : Development of the model (4/4)

Once the year is taken into account by the pitch angle offset, the time delay between the evolution of yearly flux and F10.7 has to be calculated for each Lm and each equatorial pitch angle:

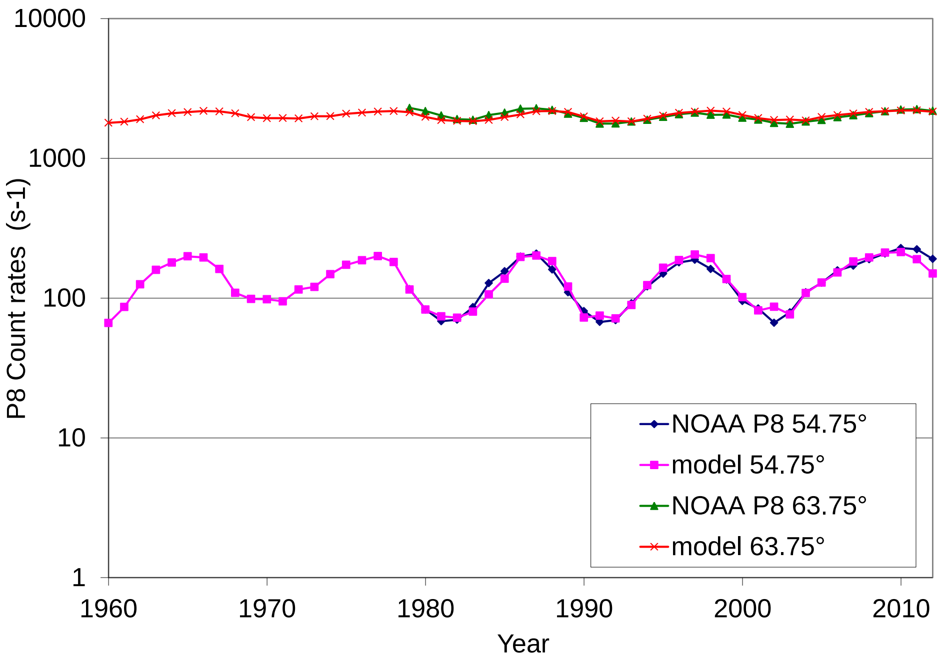


Time delay (in months) in a Lm-equatorial pitch angle mapping.

➔ **The OPAL model depends on year and solar radio flux F10.7 for E>82 MeV**

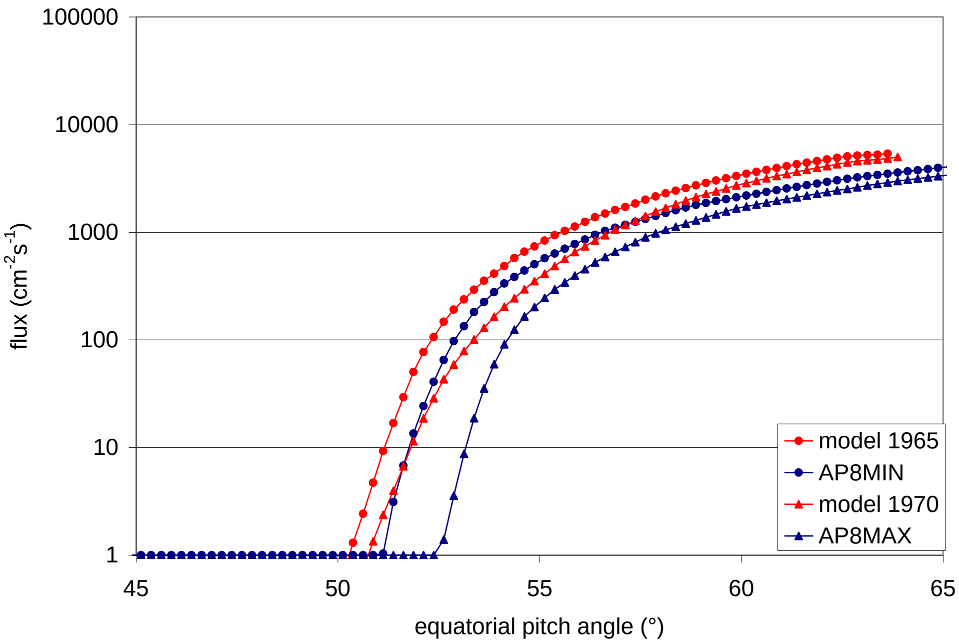
OPAL : First results at 82 MeV

➢ **Comparison between OPAL and data:**



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.

➢ **Comparison with AP8:**



Comparison of protons flux E>82 MeV with AP8 at Lm = 1.300.

➔ OPAL is globally higher at this Lm value. The belt is a little bit larger, especially in maximum conditions.

OPAL : Extension at high energy (1/2)

➢ **Use of JASON-2/ICARE and NOAA/HEPAD:**

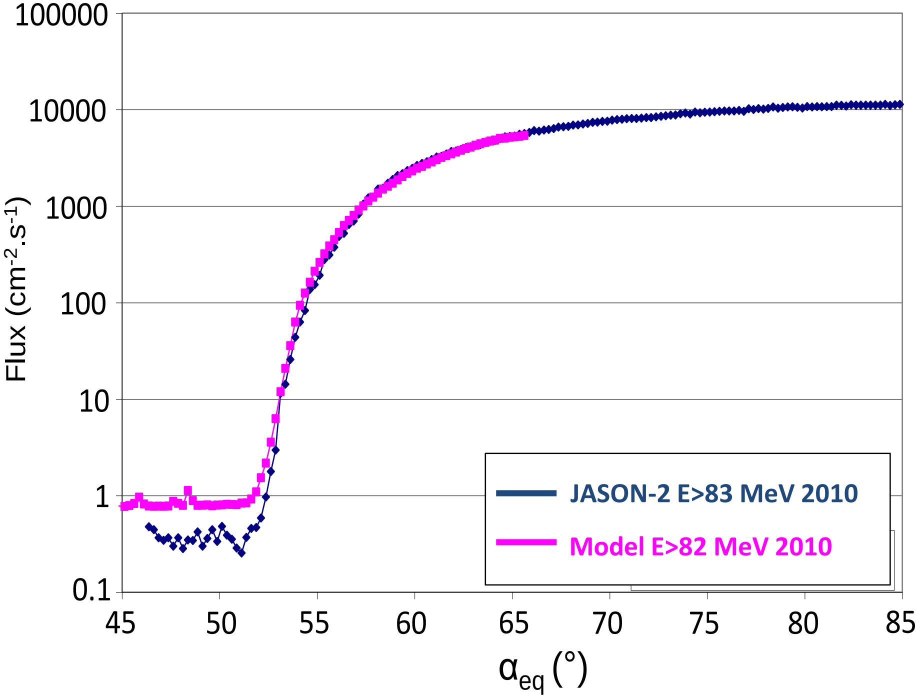
- JASON-2/ICARE between 80 and 300MeV and NOAA/HEPAD between 400 and 650MeV on 6-7 years.

- The same analysis describes before has been done with these data:
  - filtering, anisotropy analysis, magnetic coordinate analysis, correlation with F10.7.
  - verification of the consistency with the solar cycle, and in energy..

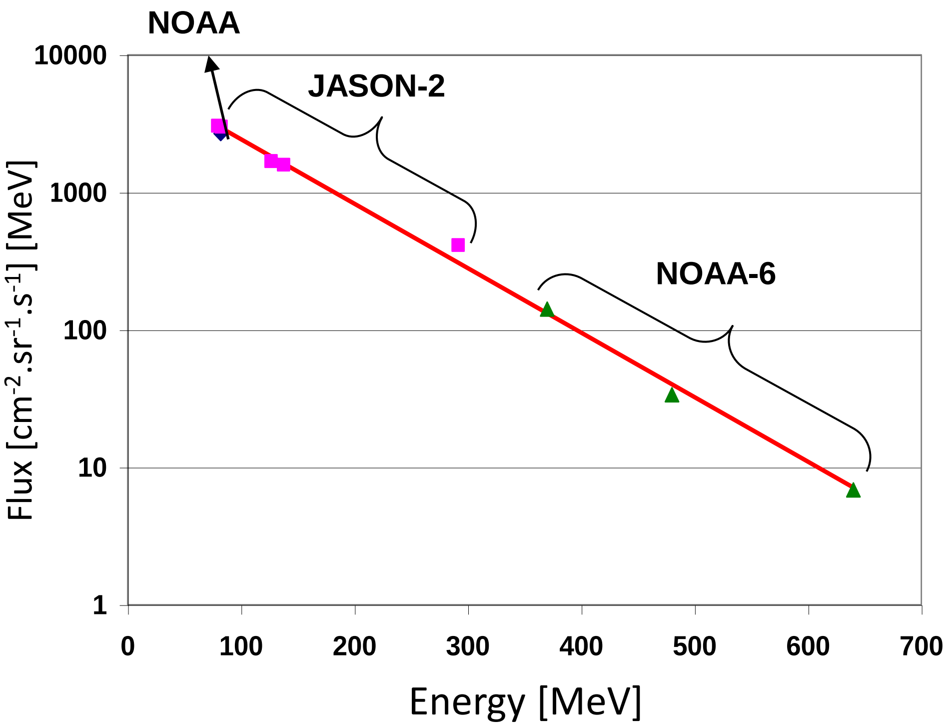
➔ the equatorial pitch angle offset seems to work at all energies and the correlation with F10.7 (time delay) too.

OPAL : Extension at high energy (2/2)

The model has been extended for energy beyond 82 MeV up to 650 MeV with an exponential law in energy



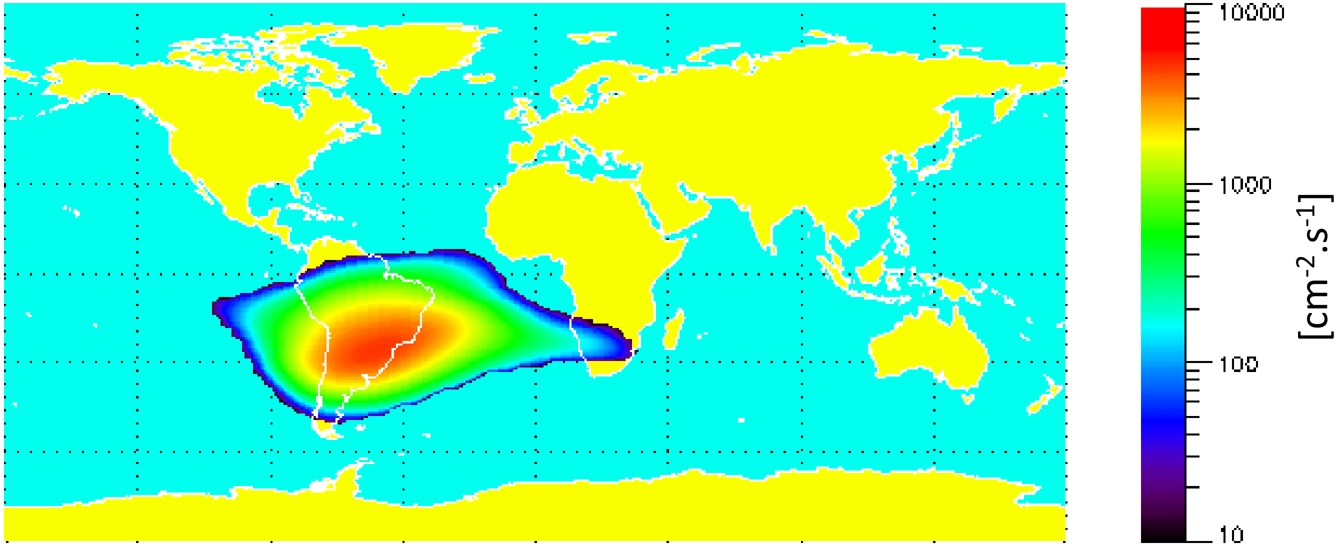
Comparison of proton flux at E>82 MeV from the model with JASON-2/ICARE measurements in 2010.



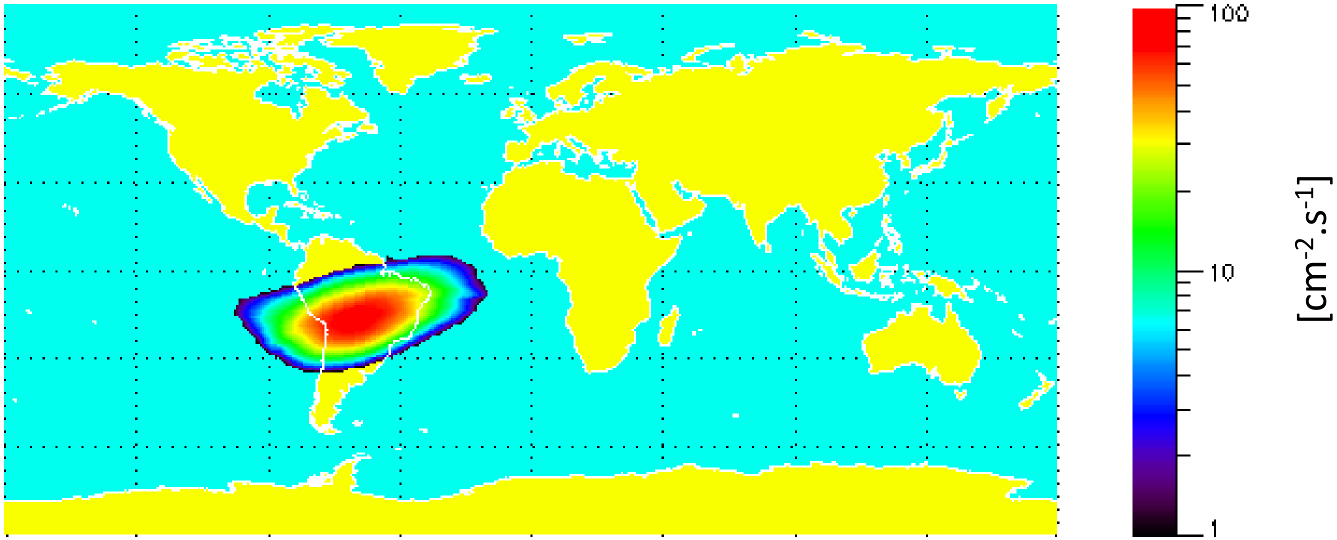
Consistency of measurements for Lm=1.300, α_{eq}=58.63°

OPAL : Example of results

Proton flux
E>82 MeV
800km
2010



Proton flux
E>650 MeV
800km
2010



OPAL : Conclusions and perspectives

➤ **Conclusions:**

- OPAL provide proton flux at altitude < 800 km
- OPAL is valid for energies between E>82 MeV and E>650 MeV
- It relies on the knowledge of the magnetic field and the F10.7 solar flux (difficult to extrapolate)

➤ **Perspectives:**

- Measurements from JASON-2 and JASON-3 between 80 and 300 MeV and between 800 and 1330 km on 8 years and 1 year respectively
- Re-analysis of SAC-C data at 715 km providing proton flux between 10 and 50 MeV on 11 years
- LPT measurements on GOSAT
- EPT measurements on PROBA-V

It has been proved that OPAL could be extended up to 40 MeV for L>1.5. Beware, however, of the creation-disappearance of radiation belts.

Boscher et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 61, NO. 6, DECEMBER 2014