Ionospheric and cosmic ray monitoring:

Recent developments at the RMI

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Outline/Contents

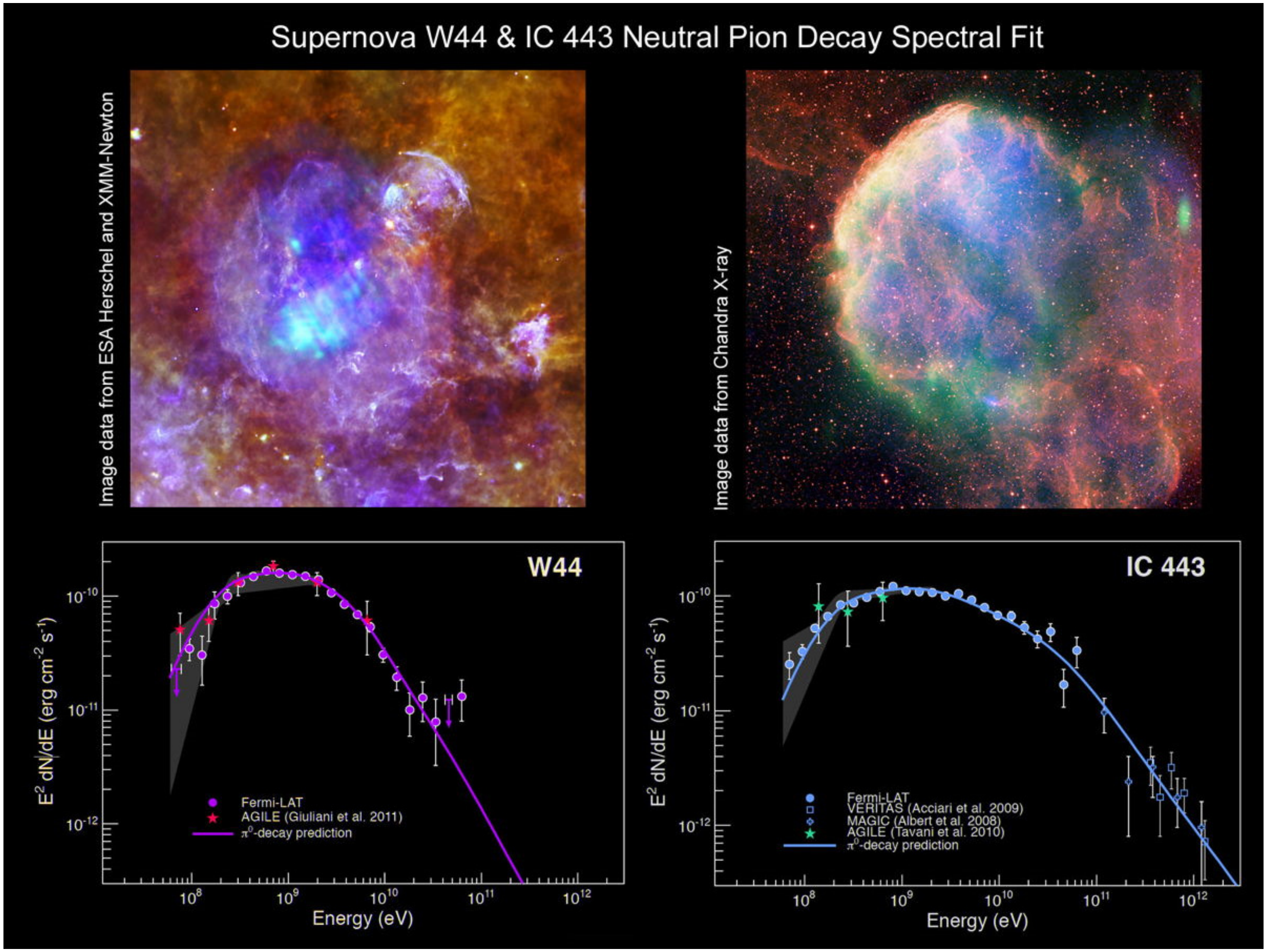
- Cosmic ray monitoring at Dourbes
  - Present status
  - Following research and developments

- Ionospheric monitoring and research:
  - Electron content profiles and reconstruction - topside ionosphere
  - Modeling of ionospheric parameters

Cosmic rays:

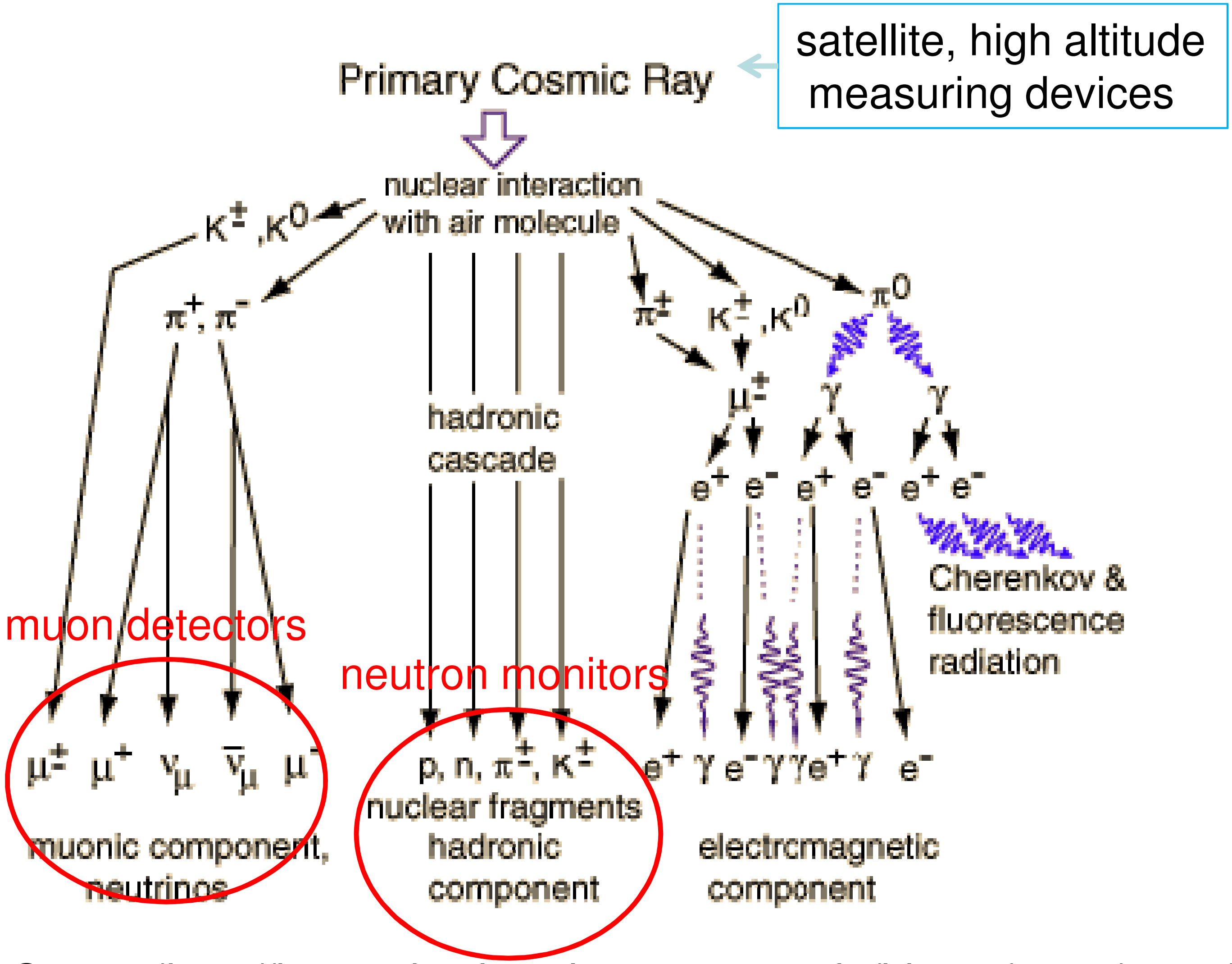
- Composition – protons(90%), α (9%), electrons, other
  - primary – accelerated at astrophysical sources: electrons, p, He, C, O, Fe, others.
  - secondary – interaction of primary particles with interstellar dust – Li, Be, B, others;
- Origin:
  - SNR
  - Extra galactic origin (particles with very high energies)
  - Others? unknown …

CR origins: Super Nova Remnants:



CREDIT: NASA/DOE/Fermi LAT Collaboration, Chandra X-ray Observatory, ESA

Secondary Cosmic Rays (SCR)



Source(http://hyperphysics.phy-astr.gsu.edu/hbase/astro/cosmic.html)

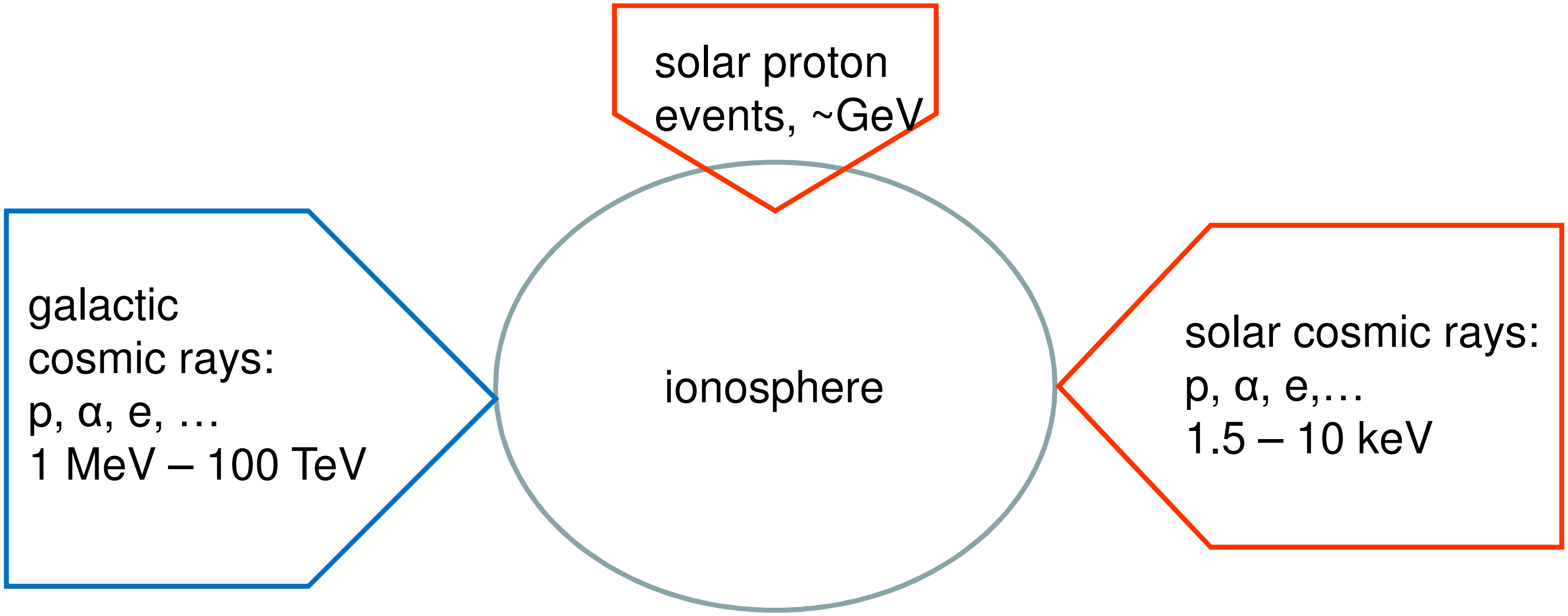
Ground based *monitoring*:

- Neutron Monitors
  - very high counting rate in comparison with space (satellite) detectors: possible to observe small & short term changes (0.5 %)
  - long-term reliability and automation
  - no saturation by intense bursts of solar energetic particles – this makes them very useful for space weather applications
  - 0.5 – 20 GeV
- Effects of the geomagnetic field:
  - rigidity cutoff (low energy cutoff)
  - narrow cone of viewing directions – the solid angle within which a NM ***sees*** the PCR piercing the magnetosphere

Solar Cosmic Rays

- **Solar Wind** – current of charged particles escaping from the surface of the sun: *p, e, α, ions (C, N, O, Ne, …)*. Heavy solar winds can lead to *interruptions in electricity network and communications.*
- Solar proton events:
  - **Coronal Mass Ejection(CME)** explosion of solar wind material – travels to the Earth in 3 to 4 days to (extreme cases < 24 h)
  - **Solar flare** – surface explosion of electro magnetic energy held by the solar magnetic field

Ionosphere and Cosmic Rays:



CR – lower ionosphere
(~ 50 km)

- day time ionization

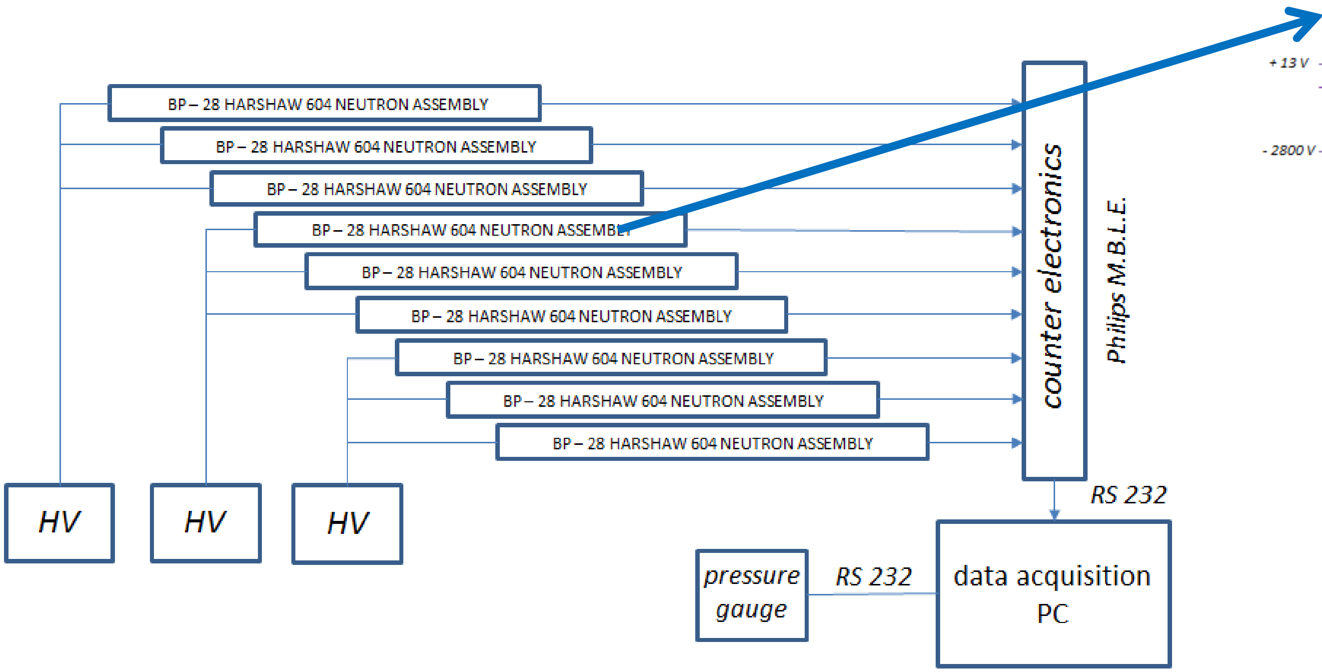
+ similar composition
- different energy range and fluxes

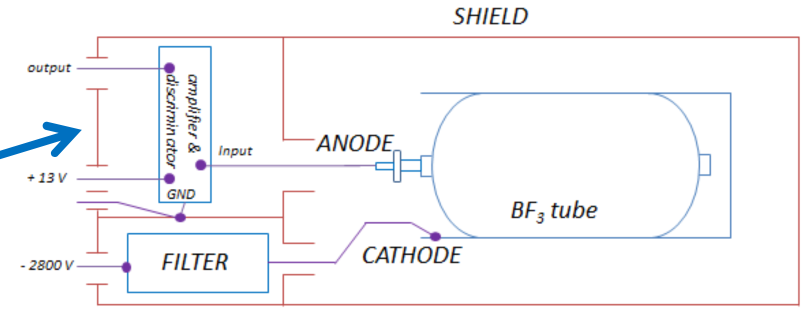
CR: Climatological and Space Weather impact:

- CR and cloud formation – climatological aspects – low clouds layer(as a result form aerosol formation by CR)
- Forecast of earth quakes ?!? – in the vicinity of a NM station
- May serve as precursors for Solar events!
  - the complex interaction of the GCR with Solar Flare transients, magnetic clouds, IMF and GMF may lead to pre-increase or suppression;
  - can be measured: a worldwide net of Neutron Monitors
  - offers: long lead times – up to 4 h.

CR monitoring at Dourbes

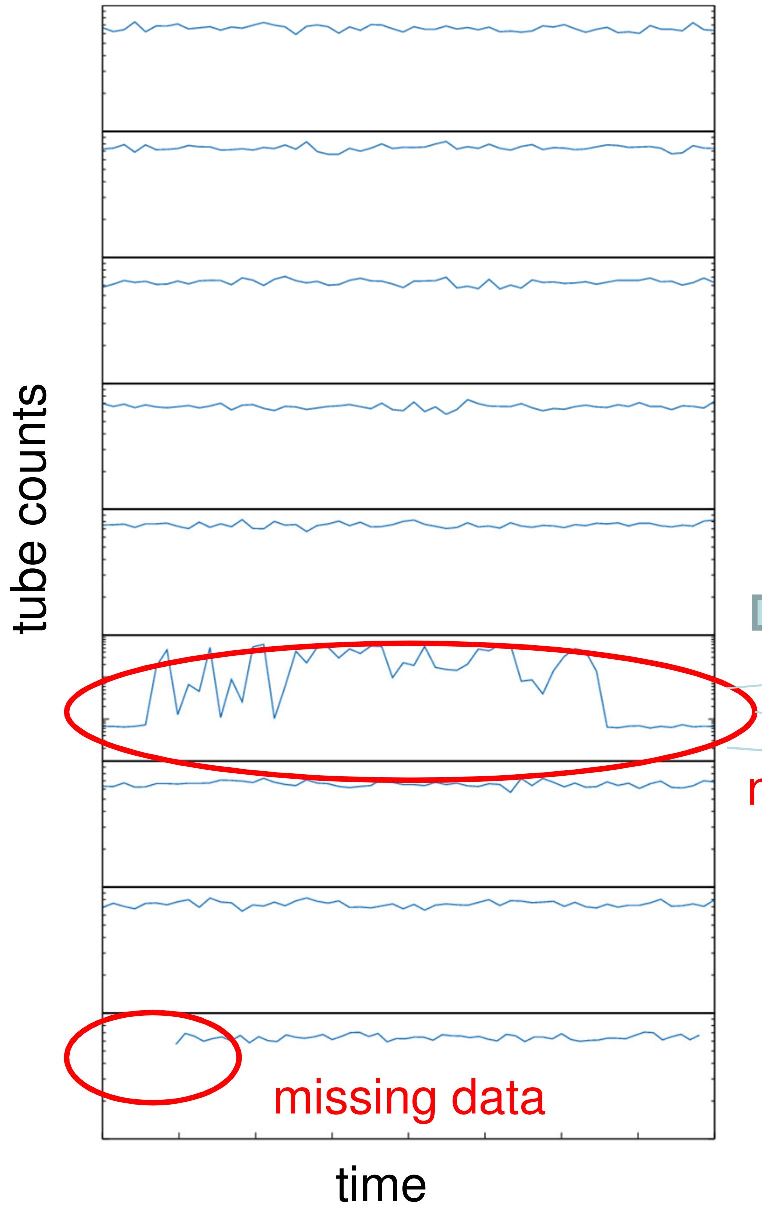
- 1965 – present
- 9-NM-64 proportional tubes filled with BF_3 gas:



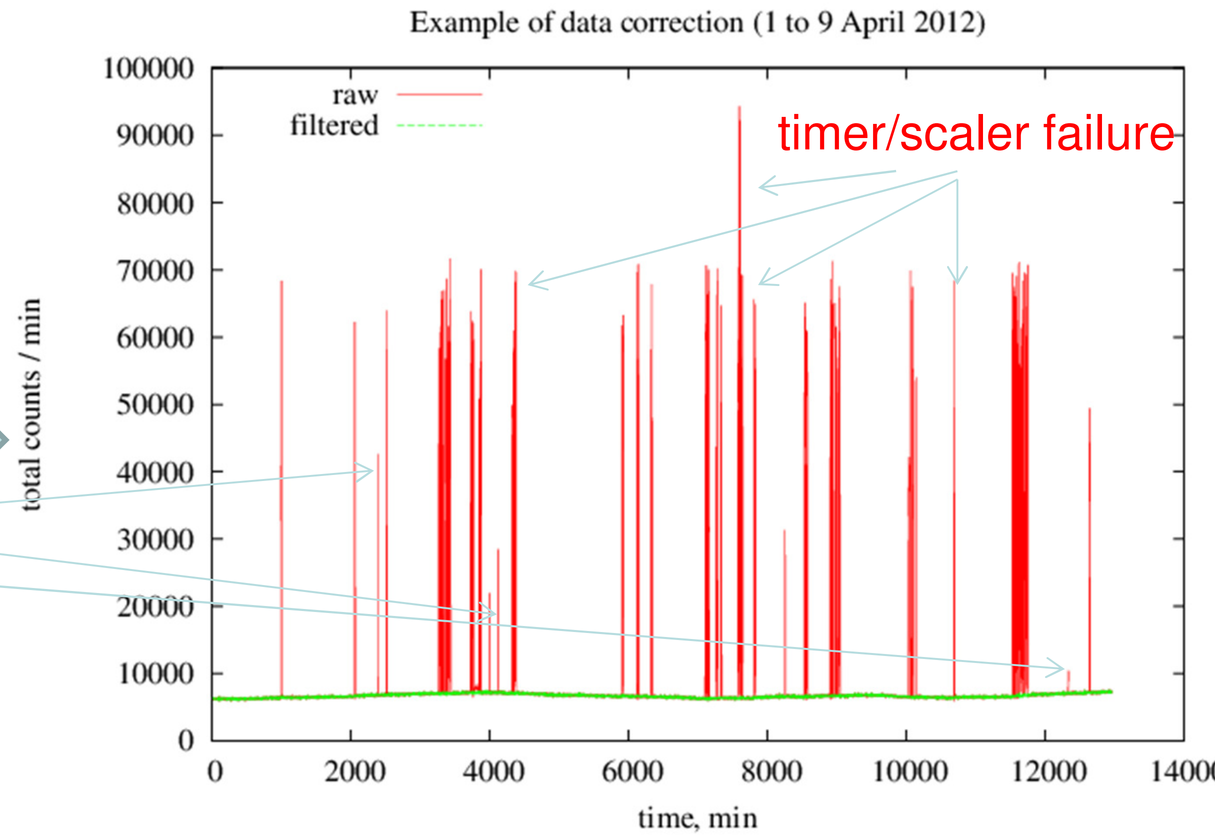


n – reflector
producer
moderator

Intensity recording and raw measurement:

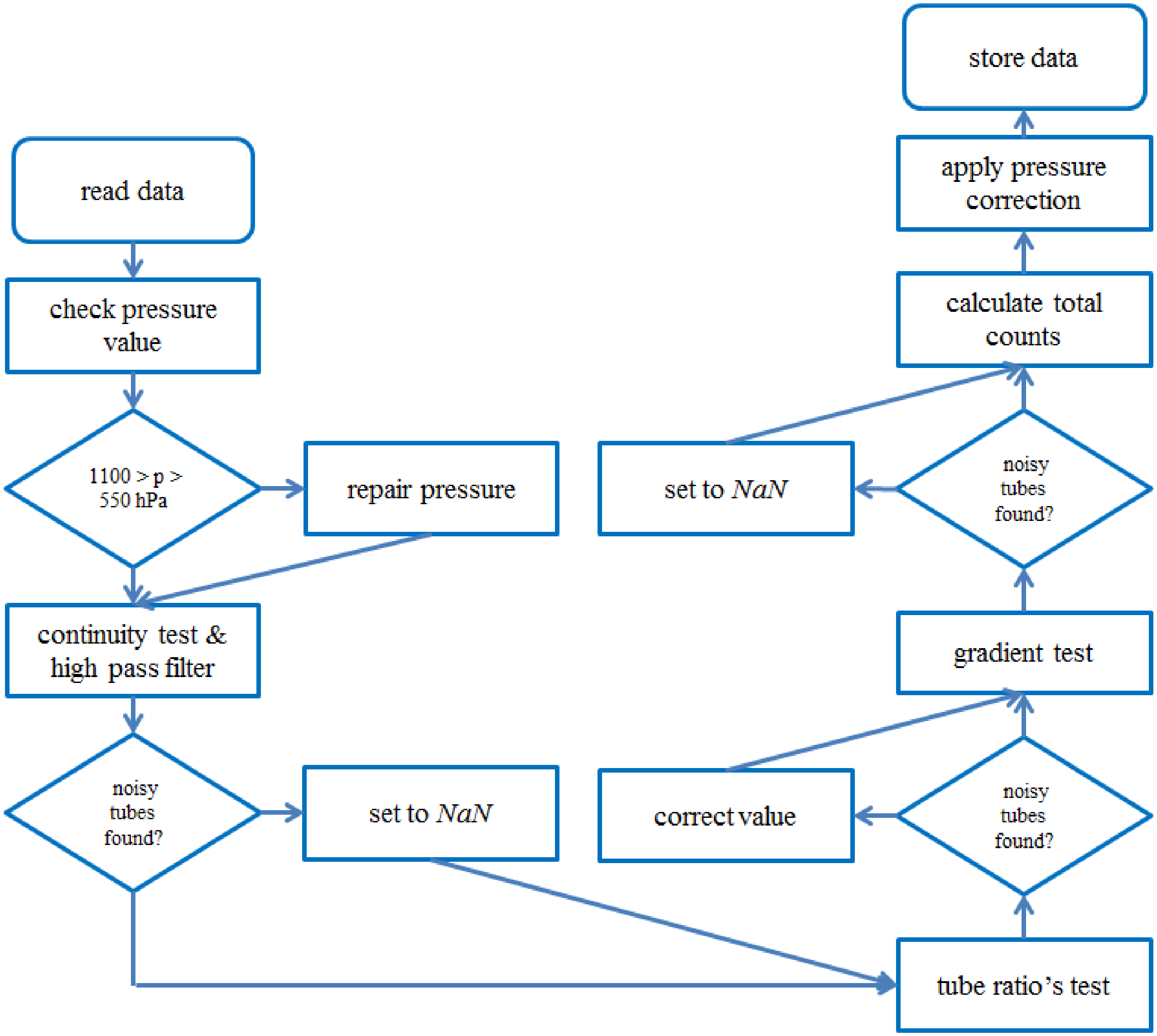


raw intensity record from the entire station

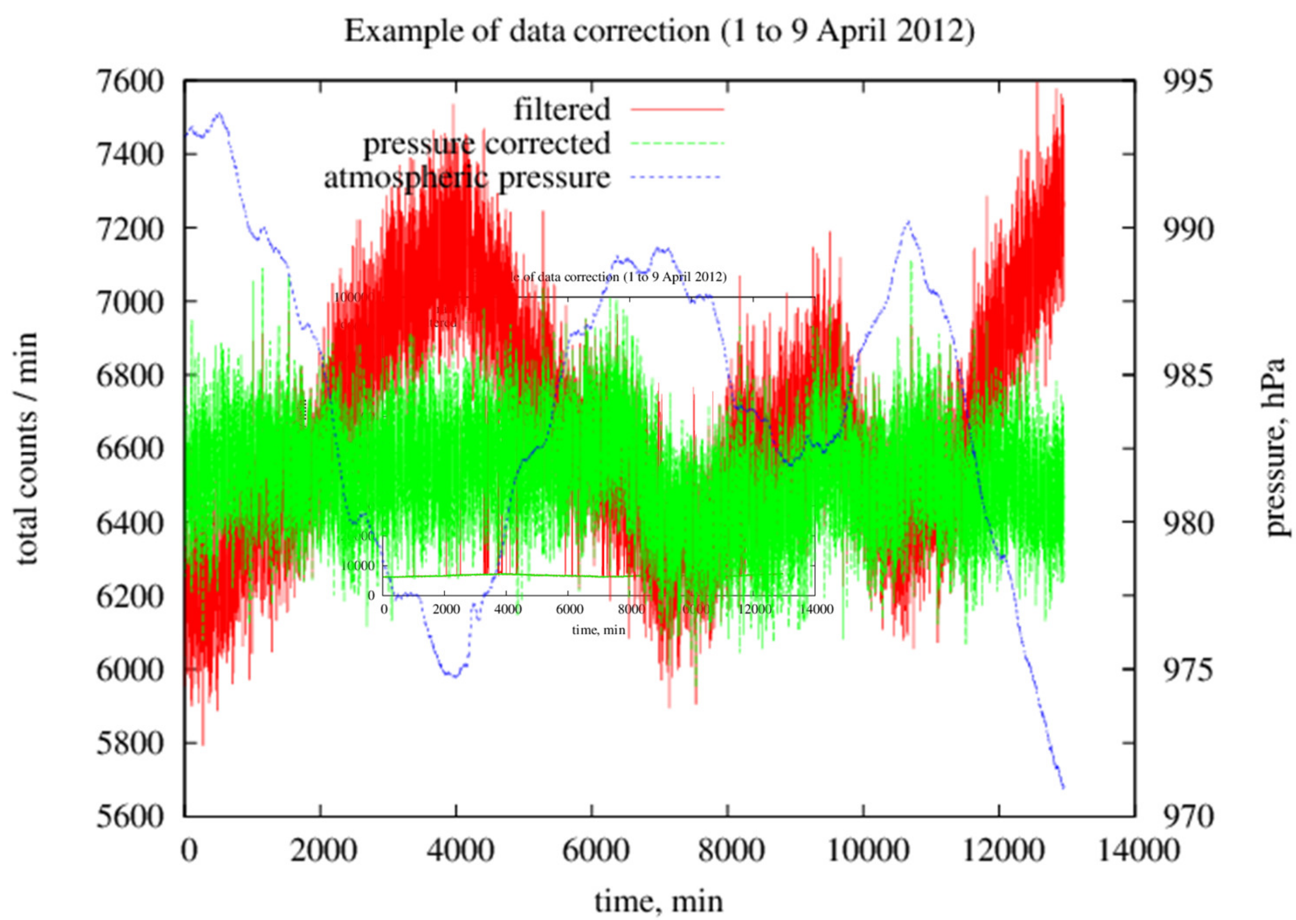


+ pressure measurements

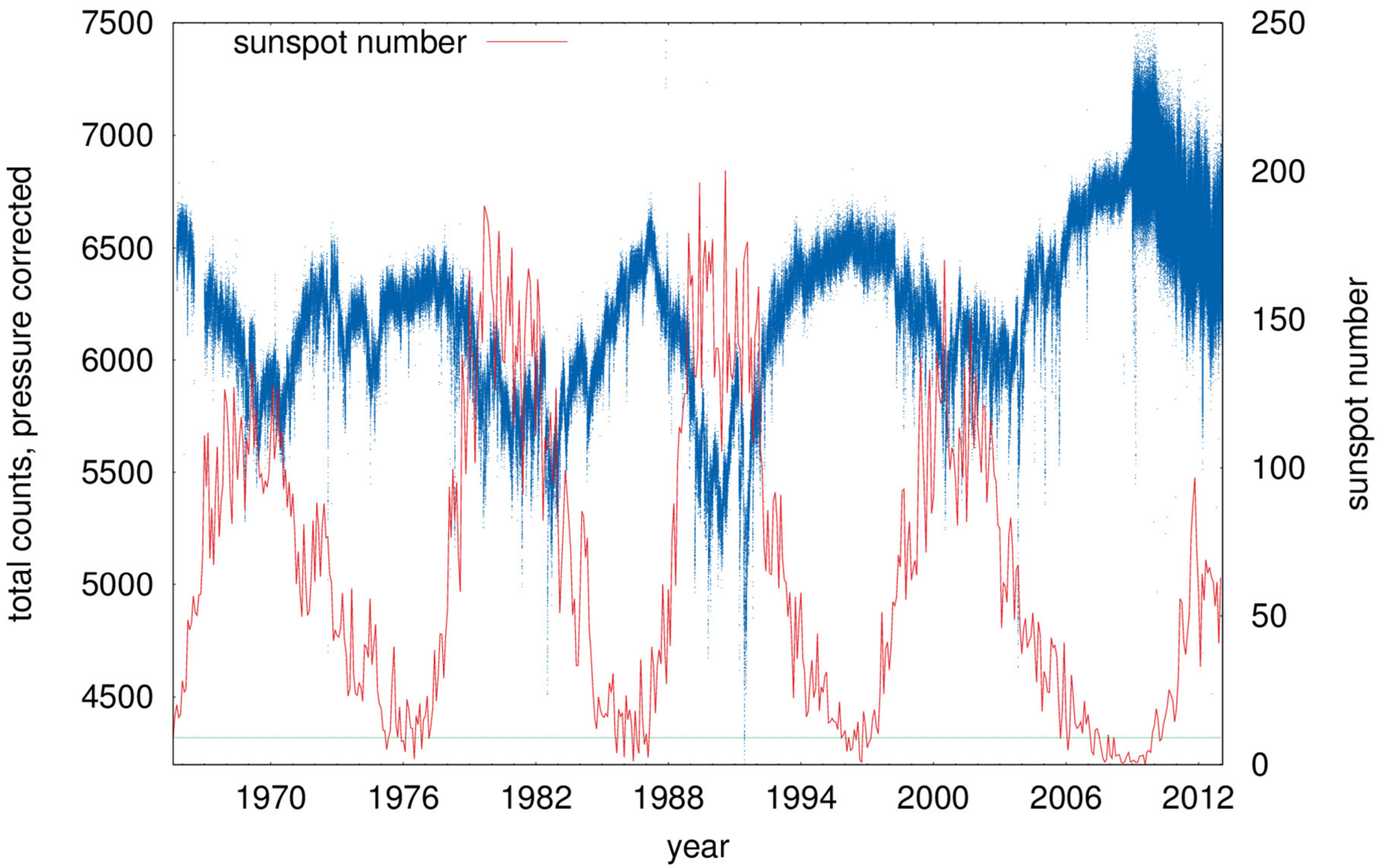
Real Time Automatic Data Correction (RTADC), Dourbes



RTADC: results



- CR modulation by the solar cycle:



Station parameters calculation

- Required for real time intensity plots as function of the asymptotic longitude
- Dourbes Neutron Monitor Station Parameters:

  position: 50.097 N, 4.590 E

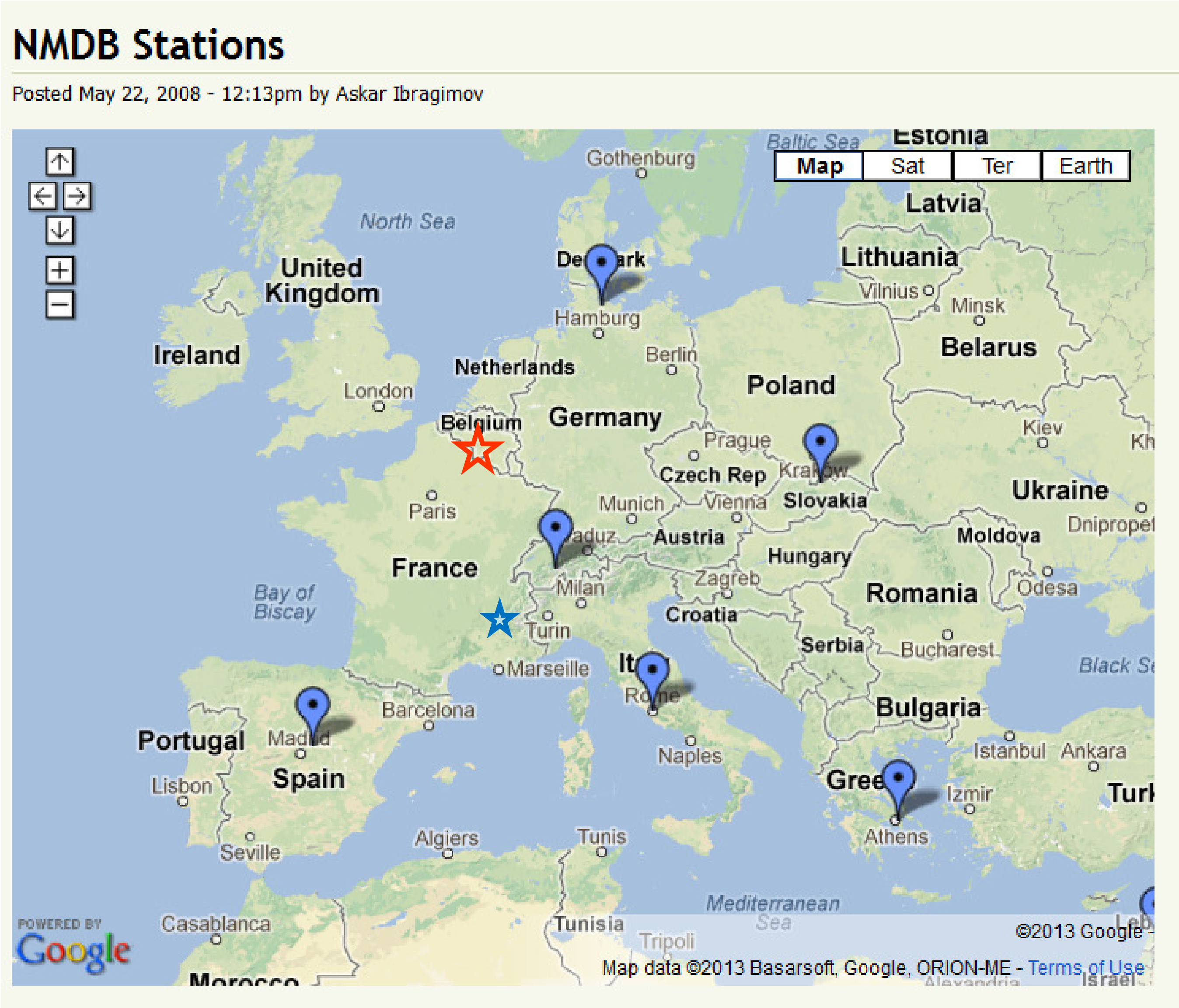
  elevation: 225 m

  geomagnetic cut-off: 3.18, GV

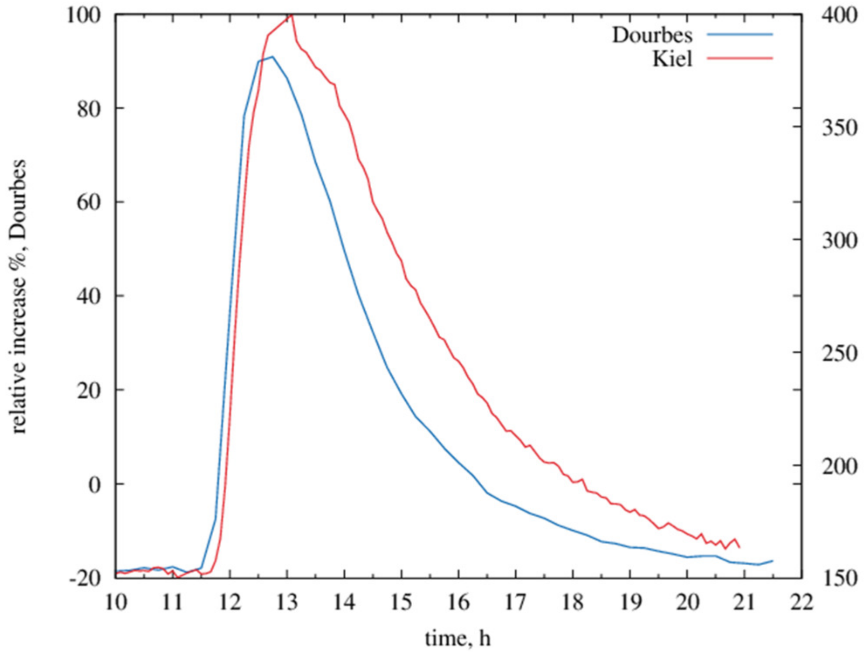
  average count rate, Solar max. 5840, counts/s

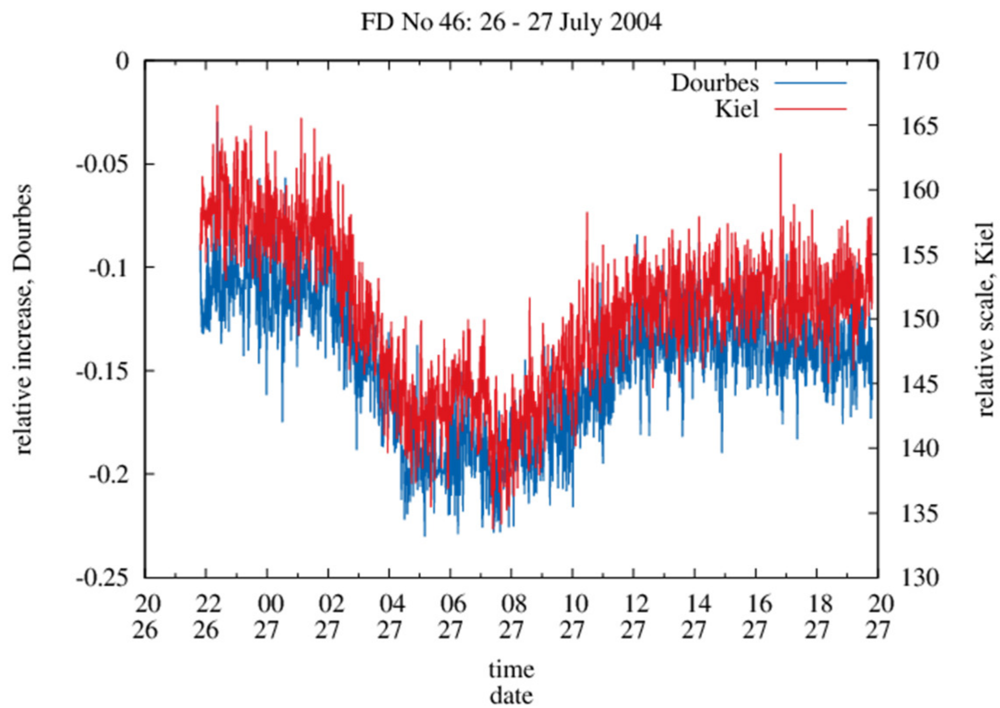
  average count rate, Solar min. 6480, counts/s
- DBSNM takes the important place in rigidities between Jungfrau and Kiel stations

European NMDB Stations:



Solar events as seen by a neutron monitor:



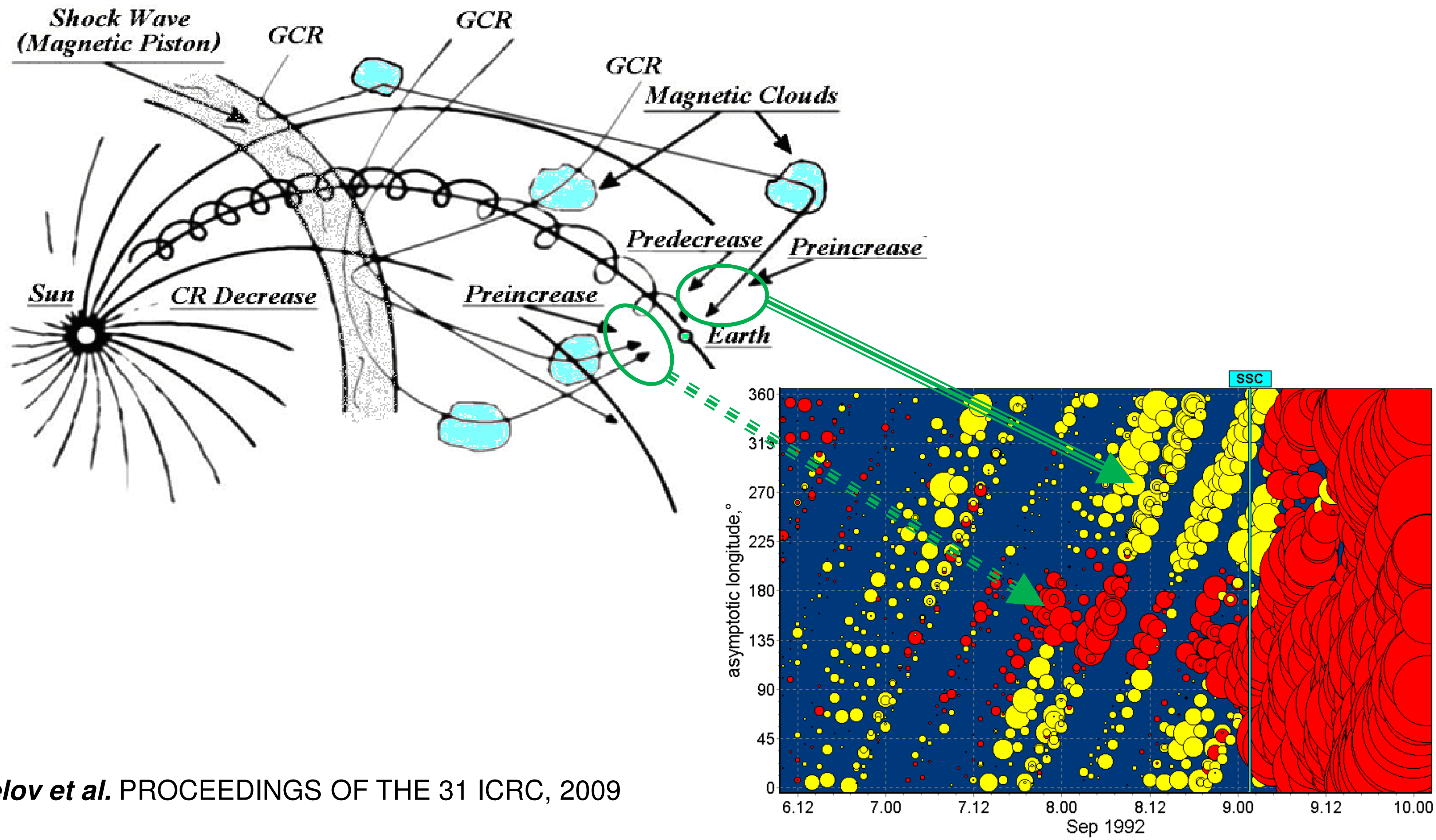


Ground Level Enhancement:
solar particles with sufficient energy to raise radiation levels at the surface

Forbush decrease:
result from magnetic fields following a CME suppressing the intensity of of the GCR

International cooperation

Forecasting Solar Events by NM: principles



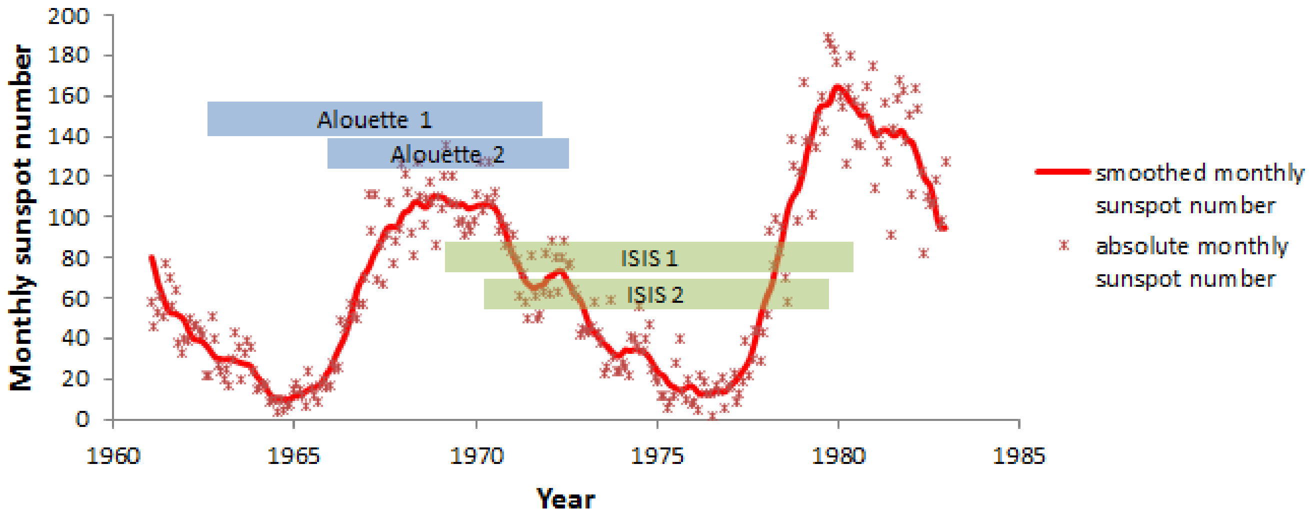
Belov et al. PROCEEDINGS OF THE 31 ICRC, 2009

Ionospheric research highlights

- Objectives:
  - The reconstruction of the ionosphere’s electron density profiles for the **complete ionosphere**
- There is scarce data for the topside ionosphere: the distribution of electrons in the topside of the ionosphere – the range from ~300 to 1000 km:
- Models have the goal to determine the influence of different external drivers on the best topside profiler

Topside ionospheric data

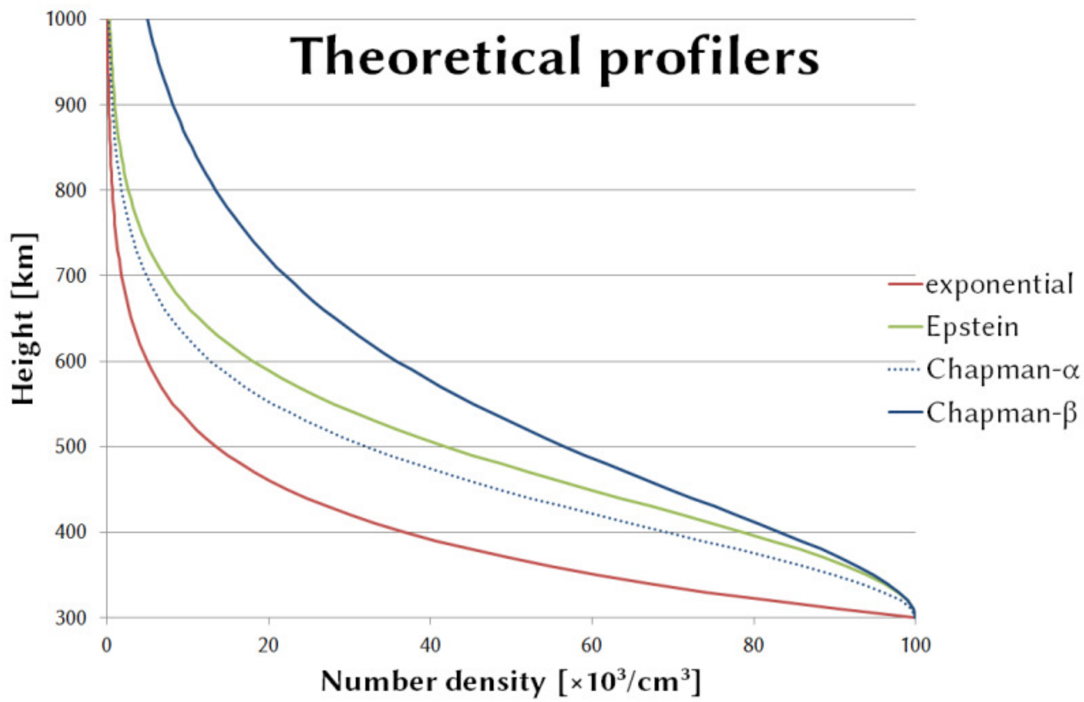
- A successful model depends largely on the quality of the measured/available data:
  - ➢topside ionograms data obtained from the Alouette-1 & 2 and ISIS-1 & 2 during the 1960 – 80.



- data from National Space Science Data Center (ftp://nssdcftp.gsfc.nasa.gov/)

Theoretical topside profilers

- There are different existing topside profiles:
  - exponential
  - Epstein
  - Chapman – α and – β



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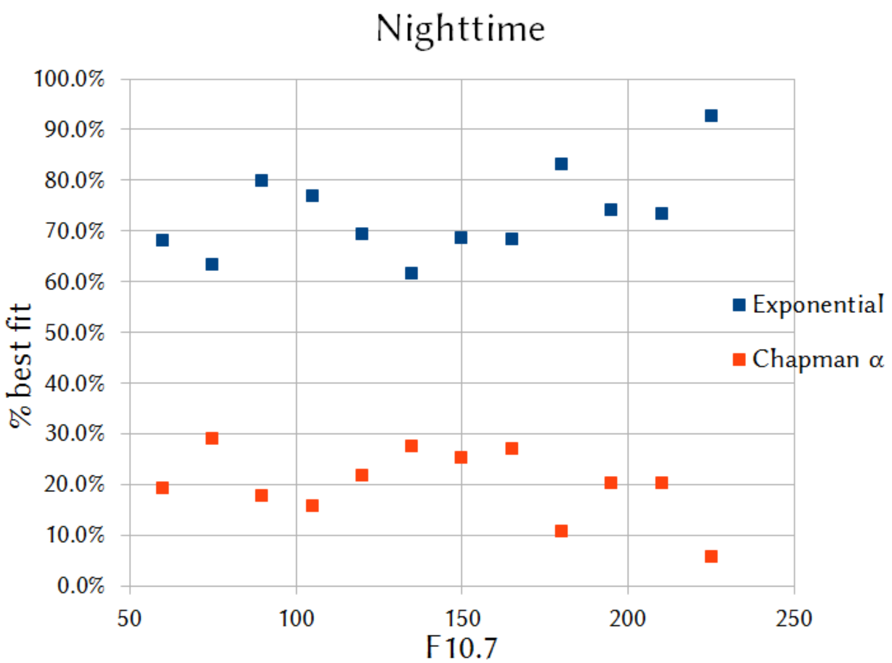
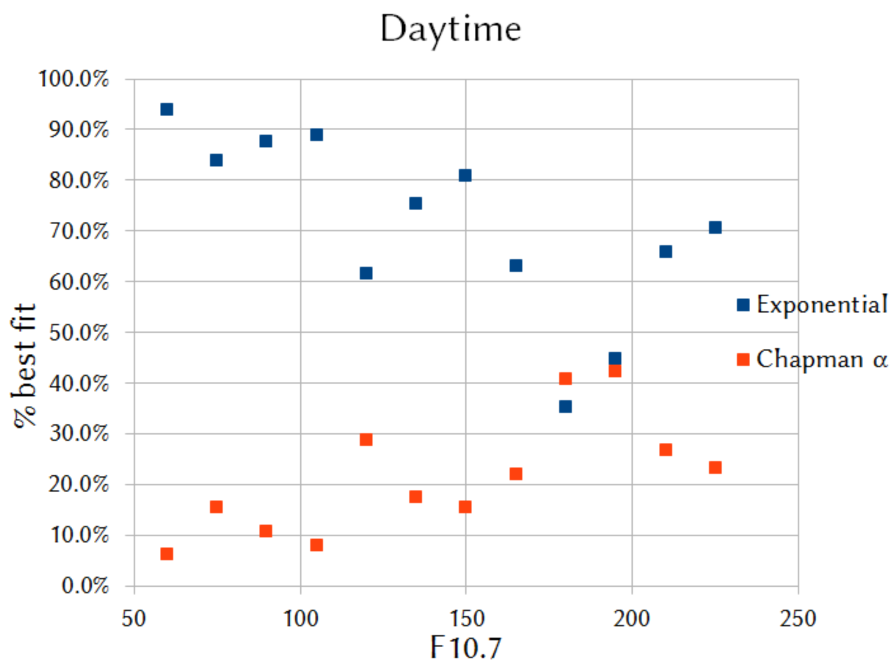
Coverage & systematic biases

- The distribution of profiles in the database is very **irregular**, both **temporal** and **spatial**.
- The requirement for the complete topside profiling introduces a bias towards *lower transition heights*.
- Due to the irregular coverage, artificial correlations between drivers can produce additional biases.
- Despite problems with data coverage, the influences of $F_{10.7}$, Kp, Dst , local time, season and magnetic coordinates on the best fitting profiler can be seen.

Influence of external drivers on profile shape:

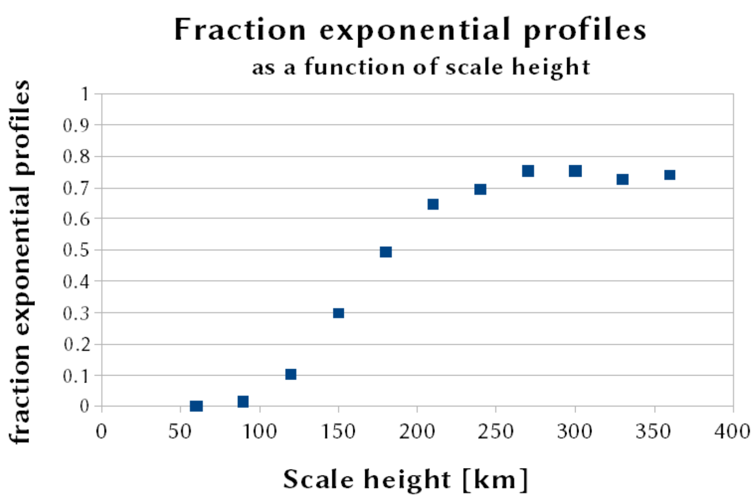
- Percentage of profiles best fitted by the **exponential** and **Chapman-α** profilers: relation to the $F_{10.7}$ solar activity index:

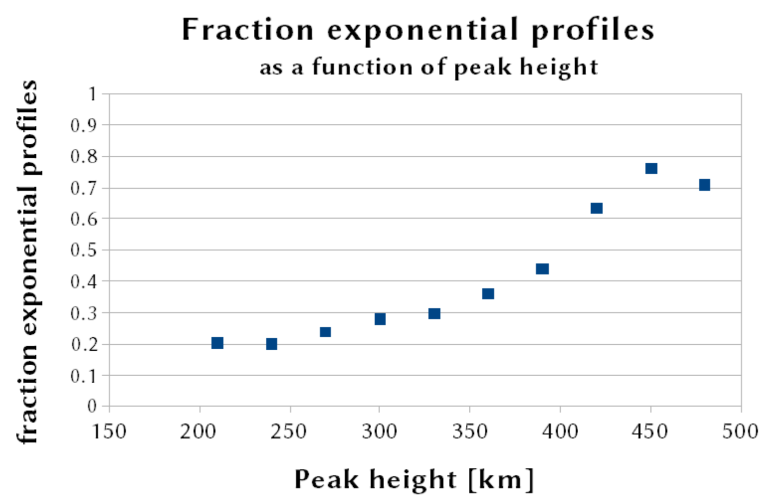




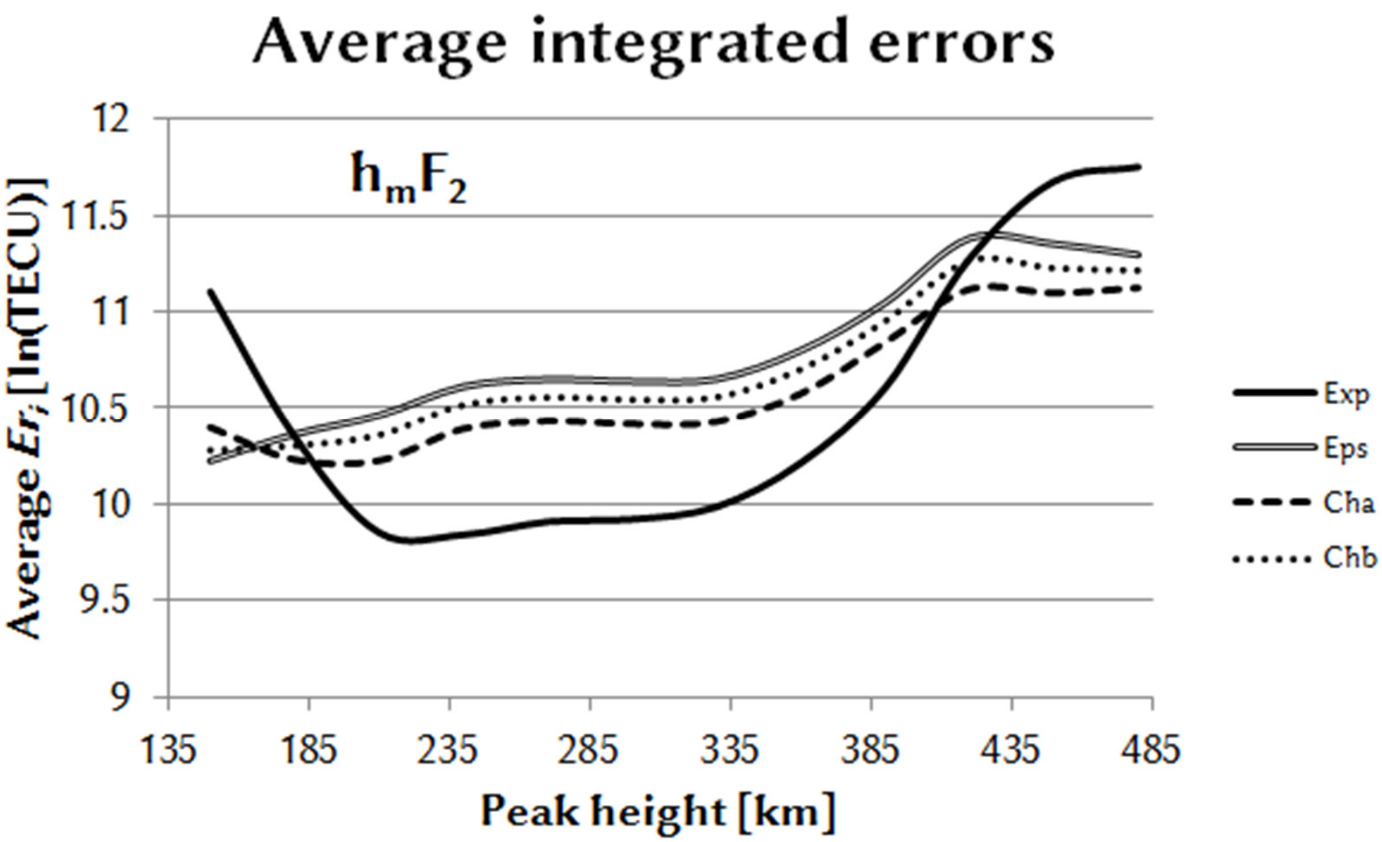
Profilers correlation with local characteristics:

- Correlations between best fitted topside electron densities and local ionospheric characteristics:
  - h_{mF2} and N_{mF2}





Correlation with local characteristics:



Reconstruction of topside ionosphere:

- The NSSDC topside sounder database is very useful, but care must be taken to alleviate possible biases and remove erroneous/incomplete profiles.
- The influence of external drivers ($F_{10.7}$, magnetic activity, local time, etc.) on profile shape was seen, but did not permit selection of the best profiler.
- It is recommended to choose profiler based on instantaneous and local characteristic of the ionosphere, such as h_{mF2} and f_{mF2}. Such profilers produces better results.
- The data can be used for development of own models of the ionosphere
- Modeling of ionospheric parameters (stochastic or deterministic methods)

CR monitoring overview

- Real Time Automatic Data Correction was developed and implemented; the data is available at http://ionosphere.meteo.be/sun/cosmicRay
- The correction algorithm was verified with data from the NMDB
- The corrected data is ready for submission to the NMDB

- The data is now used for development and test of algorithms for forecast of space weather events:
  - based on a single NM station data from Dourbes (e.g. NN)
  - using data for a range of rigidities from NMDB (DRS)