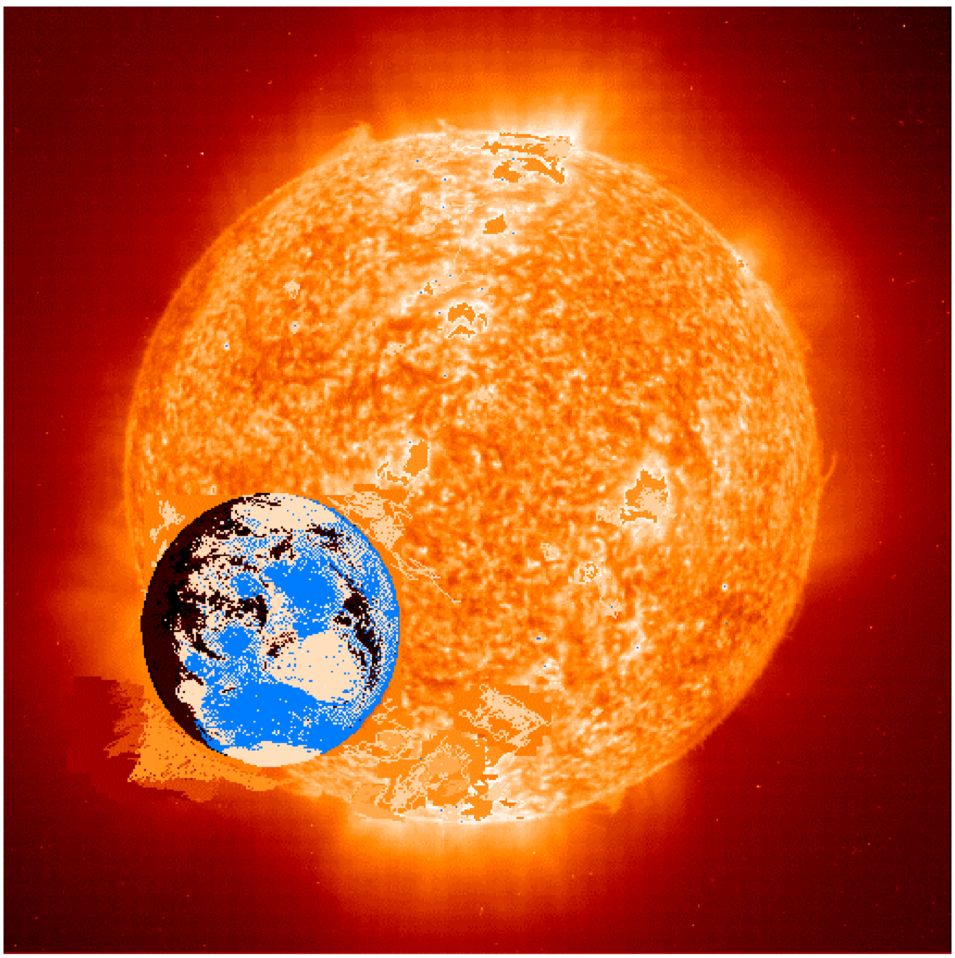
SPACE WEATHER

FINAL REPORT FROM THE FRENCH

EVALUATION GROUP ON NEEDS



July 1999

SPACE WEATHER

English Version*

Prepared by :

Daniel	BOSCHER	(ONERA)
Jean-Louis	BOUGERET	(Obs. de Paris-Meudon)
Jacques	BRETON	(CNES)
Pierre	LANTOS	(Obs. de Paris-Meudon)
Jean-Yves	PRADO	(CNES)
Manola	ROMERO	(ONERA)

assisted by Monique ORRU (CNES)

*English translation provided by: Space Environments and Effects Analysis Section, European Space Agency, ESTEC Noordwijk, The Netherlands.

English version approved by: J.-Y. Prado (CNES/DP)

Original Document:
METEOROLOGIE DE L'ENVIRONNEMENT SPATIAL
Document CNES/DP/CM n° 98-252, October 1998, Toulouse, France

Cover illustration:
Composition realised using EIT/SOHO images

C O N T E N T

PURPOSE OF THE DOCUMENT

Following the interest observed at the workshop "*Surveillance of solar activity"* held in Toulouse October 20 and 21, 1997 and at the symposium on the "*Météorologie de l'Espace* " of the PNST (*Programme National Soleil - Terre*) that was held also in Toulouse 1, 2 and 3 December 1997, CNES decided, during its programme definition seminar of 15 and 16 January 1998, to set up a working group to specify the issues at stake, in France and in Europe, of "space weather". This working group includes representatives of the scientific community, of ONERA and of CNES.

The present report is a synthesis of information collected by this group from numerous interlocutors, in France and abroad. It first concentrates on the assessment of the needs, which is to say on problems that are currently encountered.

The main conclusions were presented for comments on 17 September during a seminar gathering scientists and French users, in the presence of observers of ESA/ESTEC. The present report takes into account the opinions that have been expressed on this occasion.

The working group has the feeling, after this first phase, that, beyond the scientific interest, real economic and strategic issues exists in relation to "space weather" (that is to say the forecast and the restitution of solar activity and geomagnetic, ionospheric and thermospheric situations). It is therefore important to pursue this investigation.

This document will represent the French contribution to the European symposium organized by ESA on 11, 12 and 13 November in Noordwijk, as everything seems to indicate that the awareness and the initiatives required towards the setting up of a service able to cope with the needs defined herein, implies that the decisions be taken at a European level.

1 THE OBSERVED PHYSICAL PHENOMENA

1.1 The Sun

The Sun is an average star, situated on the main branch of the Hertzprung – Russell's diagram. It emits electromagnetic waves in the complete range of frequencies, from gamma rays to radio waves. It also produces a magnetic field as well as particles.

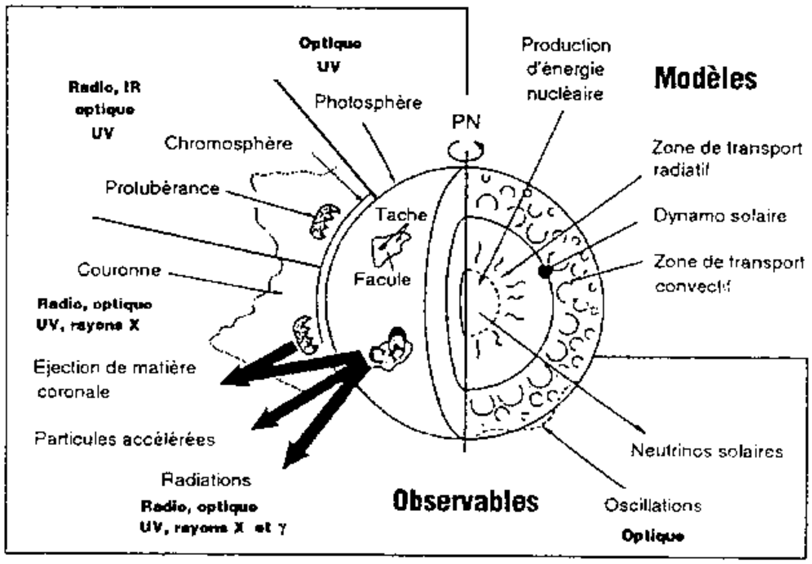


Fig. 1 :
Sketch of the region and solar processes

It is these three components (waves, fields and particles) that interact with the Earth, and can provoke disturbances of its environment (fig. 1).

The Sun emits electromagnetic waves, like a black body would do at a temperature of about 5700 K, with the maximum of its spectrum situated in the visible domain. The total flux of these waves varies very little in time. It varies essentially in the high frequency domain (UV rays and beyond) and in the low frequencies (radio). This variability is associated with solar spots, active magnetic centres due to the fluid motions close to its surface, and that can degenerate in an eruption. The sun spots follow a cycle of about 11 years (or of 22 years, if one takes account of the polarity of the magnetic field), being more numerous over a period of 5 years (solar maximum), and less numerous after (solar minimum). The last solar maximum (cycle 22) was in May 1989 (fig. 2).

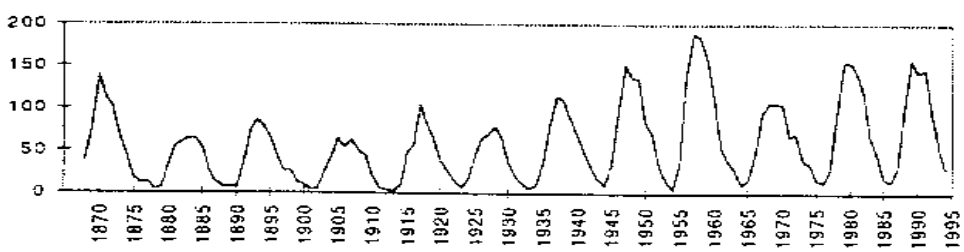


Fig. 2 : Yearly averaged solar spots number (1870-1995)

The magnetic field of the Sun is nearly dipolar close to its surface. It stretches gradually because of the rotation and the emission of particles and forms two hemispheres, separated by a neutral sheet: the "ballerina skirt" named so because of its shape (fig. 3). In one hemisphere the field is directed towards the Sun, whereas it is directed away from it in the other one. It is driven by the rotation of the Sun, forming in the vicinity of the Earth an angle of about 45° with the Sun-Earth direction.

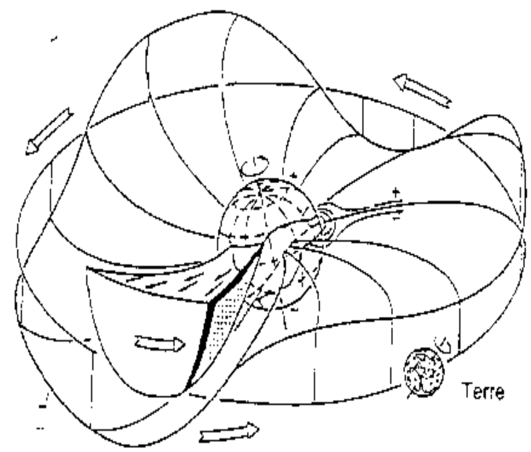


Fig. 3 :
Configuration of the solar magnetic field as a "ballerina skirt"

Finally, particles are continuously ejected from the Sun. Most of these particles have a low energy, constituting a plasma called the solar wind which moves away from the sun with an averaged speed of 400 km/sec in the equatorial regions and 800 km/sec elsewhere. In fact, the magnetic field and particles are intimately related, the field being "frozen" in the plasma. Disruptions of the particle flux are associated with modifications of the field. During eruptions a part of the energy of the Sun can escape from the neighbourhood of the Sun, the solar corona. They are associated with coronal mass ejections (CME) that, if they head toward the Earth, can produce some violent magnetic storms there. During these eruptions, more energetic particles, reaching several hundreds of MeV can be also ejected from the Sun, constituting solar proton events (SPE). Also coronal holes, that are at the origin of the fast solar wind, can reach the equatorial regions, in particular during the decrease of the cycle and interact with the Earth, also leading to magnetic storms. These two types of disruption (CME and coronal holes) give birth to shocks that can also freely propagate in the heliosphere.

1.2 THE EARTH AND ITS ENVIRONMENT

The Earth is a planet orbiting around the Sun, at a distance of about 150 million kilometres. The Earth is surrounded by an atmosphere, constituted mainly of oxygen and nitrogen, and a magnetic field, nearly dipolar. Its atmosphere is heated mainly by the solar radiance. The high frequency part of the spectrum (UV and beyond), includes very high energy photons that can dissociate atoms at high altitudes and ionize them, creating the ionosphere, whose electronic density maximum is situated around 250 km altitude. This ionosphere is constituted of different layers, according to its main composition (E,F and D layers). Because of the way it is heated it is very dependent upon solar illumination, being hotter and denser during the day than during the night, and differs if situated in equatorial or polar regions.

The magnetic field of the Earth interacts with the interplanetary field to produce the magnetosphere, a cavity bounded by the magnetopause where the particles of the solar wind cannot directly penetrate and that spreads to about 60000 km on the day side and more than 1 million km on the night side (magneto-tail). This magnetosphere constitutes an obstacle to the supersonic and superalfvénic solar wind, creating a shock upstream, located at about 100000 km, this region being called the magnetosheath (fig. 4).

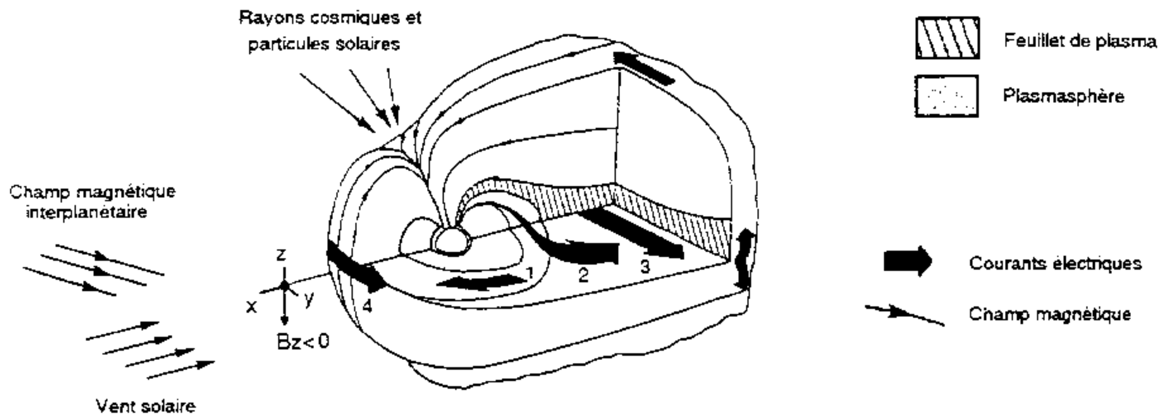


Fig. 4 : The magnetosphere
(1) Ring current (2) magnetic field aligned currents
(3) neutral sheet currents (4) magnetopause currents

A system of currents maintains this system: magnetopause currents and tail currents. In the tail the currents imply the presence of a neutral sheet, starting around 60000 km. In the internal part of the magnetosphere the dipolar field controls the motions of the particles that remain trapped there (radiation belts).

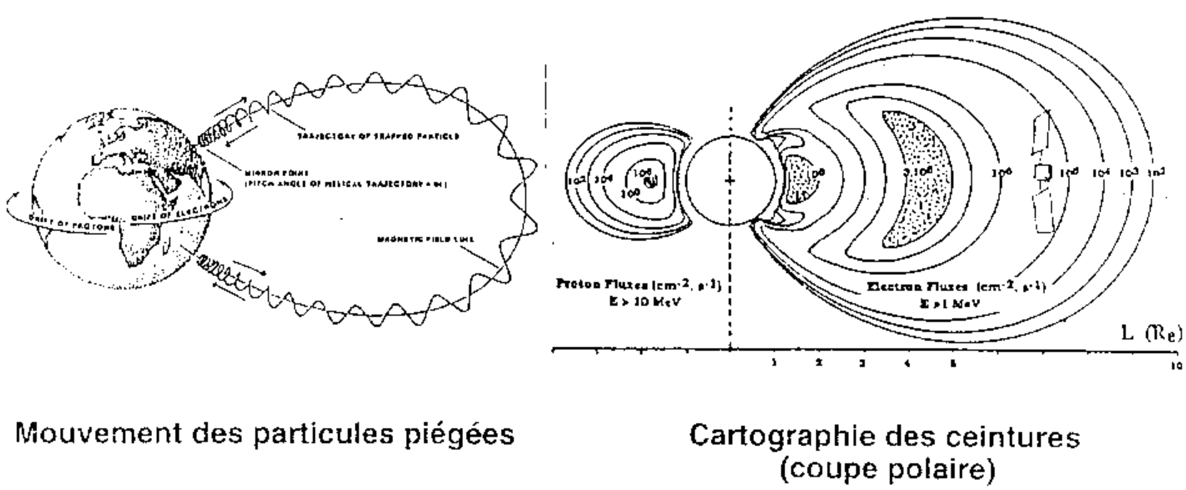


Fig. 5 Particle trapping

In fact, the magnetosphere is not completely impermeable to external particles. On the one hand, very high energy particles (above 1 MeV for protons) can enter directly the magnetosphere, while generally only traversing it. On the other hand, during reconnection phases, when the component of the interplanetary magnetic field along the axis of the terrestrial dipole is in the direction of the terrestrial magnetic moment, a part of the energy stored in the solar wind can penetrate in the magnetosphere. Particles of the solar wind can then enter the tail of the magnetosphere, enhancing tail currents that can, during impulsive phases, be partly directed towards the Earth, creating field aligned currents, that close themselves in the ionosphere near the auroral latitudes, and the ring-current near the plasmapause (fig. 5). These impulsive phases are named sub-storms, they can occur several times per day and can generate localised perturbations of the ionosphere, in particular close to the auroral oval.

As a summary, concerning the charged particles located inside the magnetosphere, one distinguishes three populations (see Figure 6 where the energy of protons is shown according to the Mc Ilwain parameter, parameter related to the Earth's magnetic field lines). The first one has an internal origin (ionospheric plasma). It is constituted of ions (including protons) and electrons of low energy, of the order of one eV. It spreads out to the plasmapause. The second one is of external origin (cold plasma, hot plasma), it is related to the entry of solar wind particles. These particles, coming from the tail of the magnetosphere, are heated by various processes and can arrive in the inner magnetosphere with much higher energies, above 100 keV, participating therefore in the refilling of the radiation belts. Beside these, albedo neutrons (resulting from the cosmic ray interaction with the atmosphere) can disintegrate in the magnetosphere, creating protons of high energy (above 10 MeV) contributing to the radiation belt. Finally, the third population corresponds to ions of very high energy (above 100 MeV), crossing the magnetosphere. These different populationscannot reach the Earth surface, as they are definitely lost when they hit the upper atmosphere

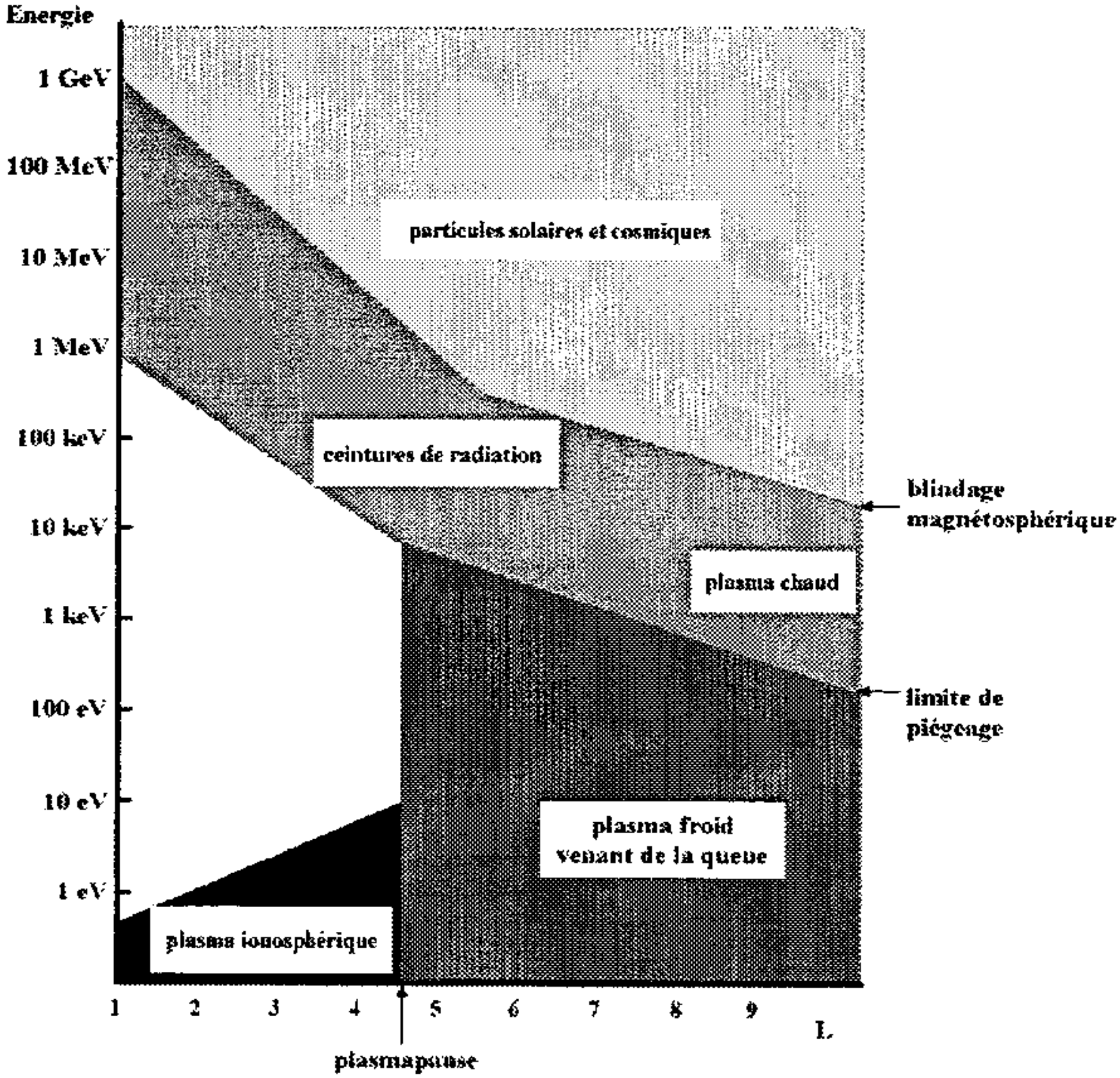


Fig. 6 Proton energy versus the Mc Llwain parameter

By contrast, the cosmic neutrons, not being deviated by the magnetic field, and interacting very little with the neutral atmosphere, reach the ground, leading to a dose effect well known by specialists (35 mrem/year at sea level). Their rate is slightly dependent on the solar cycle.

Most components of the terrestrial environment are well known on average. For long-term effects, some models are currently available (MSIS-90, DTM-94 for the atmosphere for example, taking account of the solar cycle, AP8-AE8 for radiation belts, IRI90 for the ionosphere). However, for short time scales, these models are uncertain and the influence of strong perturbations of the environment is badly reproduced, although some of these models take into account magnetic activity.

1.3 The perturbations of the environment

Two types of strong disturbances can modify in a considerable way the charged particle populations around the Earth: solar proton events (SPE) and magnetic storms. These two types of events are a priori independent. Storms can take place during solar minimum periods when no proton events are recorded. During a proton event energetic solar protons arrive in the vicinity of the Earth long before (several days) the associated storm (if any) occurs.

Solar proton events are clearly related to solar eruptions (fig. 7). They occur preferentially during the solar maximum period and shortly thereafter (-2 years, +4 years). Energetic protons (up to a few hundreds of MeV) arrive in less than one day in the neighbourhood of the Earth, modifying the highest energy population penetrating the magnetosphere by a significant amount over several days, up to 15 days due to solar rotation (actually an active centre, source of the proton sporadic emissions, can be visible again 15 days after, but it is a very rare event). Some high energy electrons are also detected during these events, but this higher energy population is not seen in the magnetosphere. Outside the magnetosphere these very high energy ions are of course present; they are the ones that can endanger a remote mission, on the way towards other planets or towards the Moon. Due to the configuration of the terrestrial field, these high energy ions can also penetrate in the polar zones and can disrupt space craft crossing high latitudes (MIR and the International Space Station, LEO and SSO satellites) and can even perturb regular air plane flights traversing the polar regions by indirect effects.

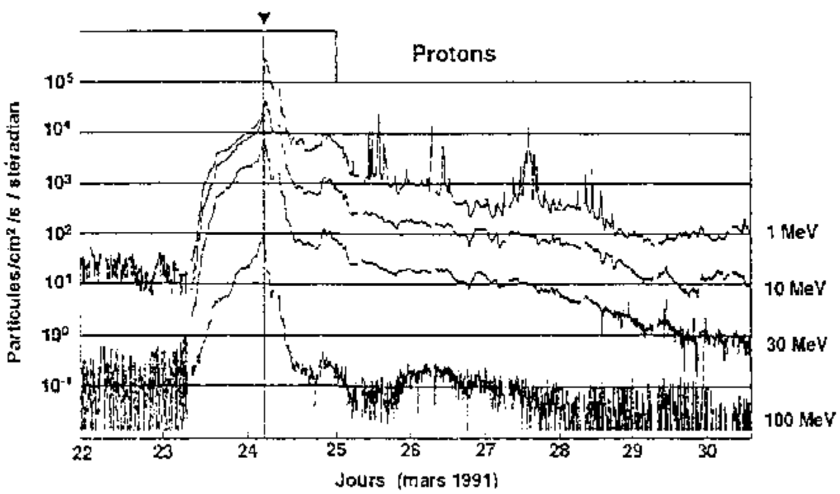


Fig. 7 :
Solar proton event observed with GOES spacecraft in March 1991

Magnetic storms have several origins. They are in any case associated with variations of the solar wind: coronal mass ejections , interplanetary shocks and coronal holes in conjunction with the Earth. The dynamic pressure of the solar wind determines the strength of the storm and the importance of its effects. The effect is actually stronger since during the storm periods (several days) the component of the interplanetary field necessarily has an orientation favouring the reconnection several times. The key parameter of these storms is therefore the solar wind pressure, which can be very important in the cases of coronal holes and coronal mass ejections. However, in this latter case the storm lasts less time, around one day (some coronal holes can last several months at low heliospheric latitude, triggering some recurrent magnetospheric storms with a 27 day period). The effects of magnetospheric storms are observed on cold ionospheric plasma and on hot particles (protons and electrons up to 1 MeV). These populations can be significantly perturbed during and following storms. Field aligned currents are enhanced in intensity and extension. Therefore the auroral oval is broadened strongly and extends to low (magnetic) latitude. The ionosphere is strongly perturbed. Some induced currents are generated on the ground. Ionospheric plasma is heated and ions of terrestrial origin can be accelerated and injected to high altitude, and can participate in the ring currents. The plasmasphere decreases in extension (the plasmapause decreases in altitude - L), but bubbles of plasma can persist at high altitude. The population of hot plasma grows, and fills the ring current (the Dst index decreases strongly). High energy electrons (several hundreds of keV), are generated close to the plasmapause. They are then scattered relatively slowly towards higher altitudes, filling all the external part of the electron belt. During magnetic storms the atmosphere spreads in altitude.

Finally, proton events are often associated with coronal mass ejections (eruptions well connected to the Earth). This occurs close to the solar maximum. For the last cycle one can recall the storms of March 1989, October 1989 and March 1991, the first being associated with the general electrical outage in Quebec. In this case, besides the individual effects of the two processes, electrons and protons associated with the eruptions (the solar and cosmic particles of fig. 6) can penetrate the magnetosphere and be accelerated there. In addition, because of the storm the magnetospheric shielding efficiency can be lowered. A secondary proton belt (around 30 MeV) and a belt of electrons of about 10 MeVs can also be created.

✽ ✽

✽

2 EFFECTS OF THESE PERTURBATIONS, DETRIMENTAL EFFECTS AND NEEDS OF SOCIETY

EFFECTS OF THESE PHENOMENA ON OUR SOCIETY

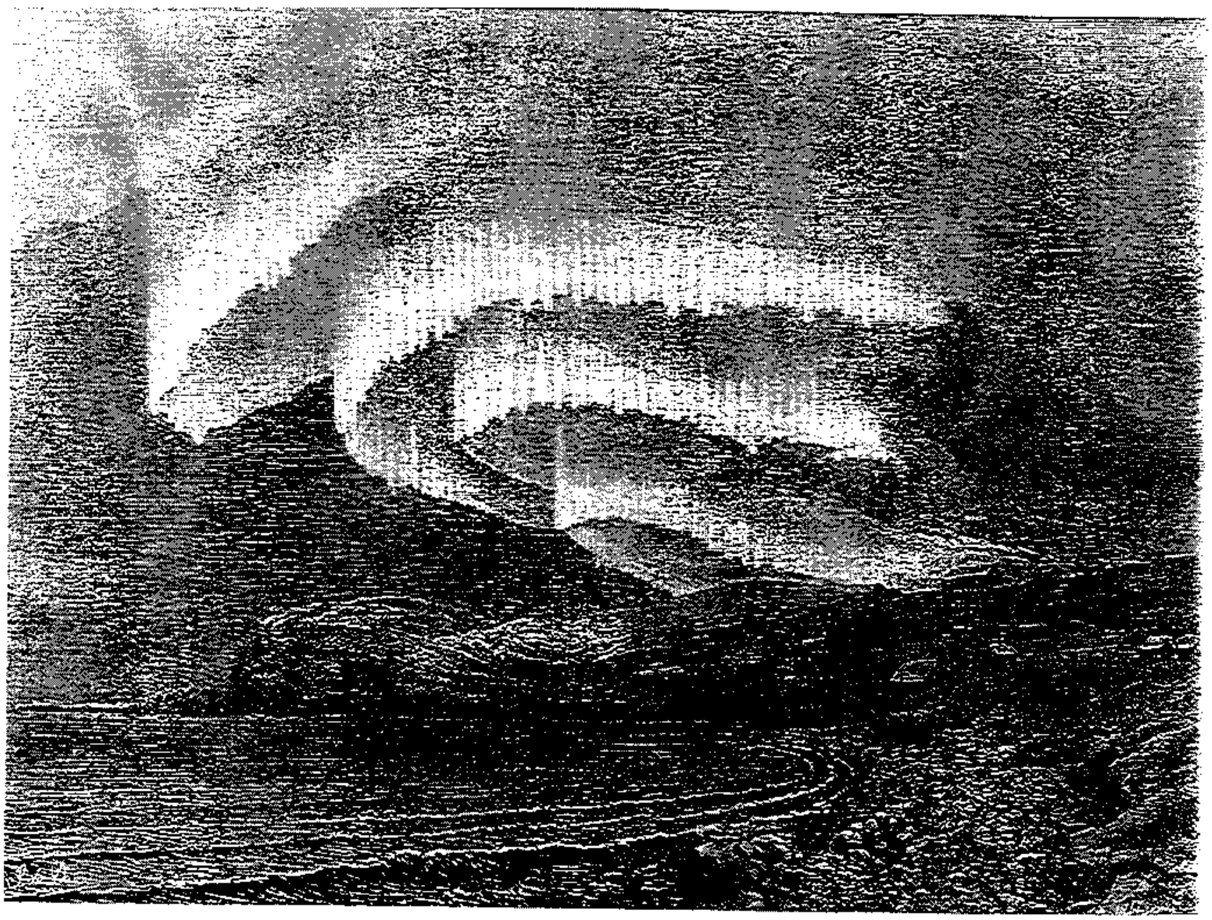


Fig. 8 : Aurora borealis observed in 1839 in Norway

The physical phenomena described in the previous chapter have always existed (fig. 8) and nothing indicates that there will be important modifications of their features in the next decades (unlike the situation of the climate of our planet). So, if our ancestors were able to live with them for millennia, can one not bet that we will know how to do so as well? The answer is no because even if our environment remains unchanged, it must be recognised that our technological civilisation is taking new directions. The novelty here is that our society, through its activities and through its systems, becomes more and more vulnerable to these disruptions which are sometimes of an aggressive character.

Why?

a) We use space more and more. Hundreds of satellites, are today in operation in more "vulnerable" orbits, frequently as key positions at the heart of large networks of information compilation or distribution. In addition, they are manufactured with more and more miniaturised components, which makes them more vulnerable than ever before.

b) We are more and more familiar with the ionosphere. In transmission (telecom, broadcasting, navigation,...), in reflection (RADAR's, ground-to-ground telecom,...); one even performs fine metrology through the ionosphere (navigation, altimetry,...). Any unanticipated ionospheric modification can either disrupt or even temporarily interrupt the working of these large systems. The case of the US presidential plane, AF1, which was deprived of all radio connection over a rather long period is often quoted.

c) Global co-operation and the internationalisation of information and interactions leads to increasing interconnection and to considerably extended areas attached to networks. A single disruption is likely to propagate very far (one saw it in the case of electrical power distribution networks).

d) This situation is even more serious in certain domains since the logic of deregulation and global competition leads operators to utilise networks very close to their saturation or tolerance limits. The smallest departure creates a breakdown, the propagation of which one no longer know how to stop.

DETRIMENTAL EFFECTS AND EXPECTATIONS OF OPERATORS

2.1 LAUNCHES

a) The assessment of the failure probability (expressed per thousandth) of ARIANE 5 related to the particle environment is estimated, according to the type of orbit, as the following values (source: Directorate of Launchers of CNES)

Type of orbit	Without SPE	SPE of type August 1972
GTO Reference 2360 s	0.3/0.4	0.3/0.4
SSO Reference 2100 s	0.02	0.6/0.8
extended Celestri 6500 s	0.1/0.3	0.8/1.5
extended XMM 6500 s	0.2/0.4	1.3/2
GTO + 19000 s	0.6/1.3	6/10

The GTO+ orbit last until it reaches 35,000 km altitude. Apart from this, aspects of the launcher "versatility" can lead to the launcher still being active after many hours. Therefore, for certain types of launch, expected accumulated doses can be high.

To simplify:

- in normal GTO a forecast does not provide any advantage. The probability of failure is the same during an eruption and outside an eruption (the effect of the shielding of the Earth's magnetic field).
- in SSO, it changes from 2.10^{-5} to 10^{-3}

- for the extended orbit (Celestri, XMM), it shifts from 2/ 3.10^{-4} to 1 / 2.10^{-3}
- finally for GTO+ (19.000 s) it shifts from 10^{-3} to 10^{-2}.

The solar eruption of August 1972 without necessarily being an unsurpassable maximum is nevertheless a high level in recent history. One can assume that on average such an event can occur once per cycle, i.e. once every 11 years. The length is of the order of some days (3 to 5 typically).

There is a certain abundance of eruptions with slightly lower level. For example, the eruption of early April 1998 probably had a peak value of 1/10 of the one of 1989 and of 1/20 of the one of 1972.

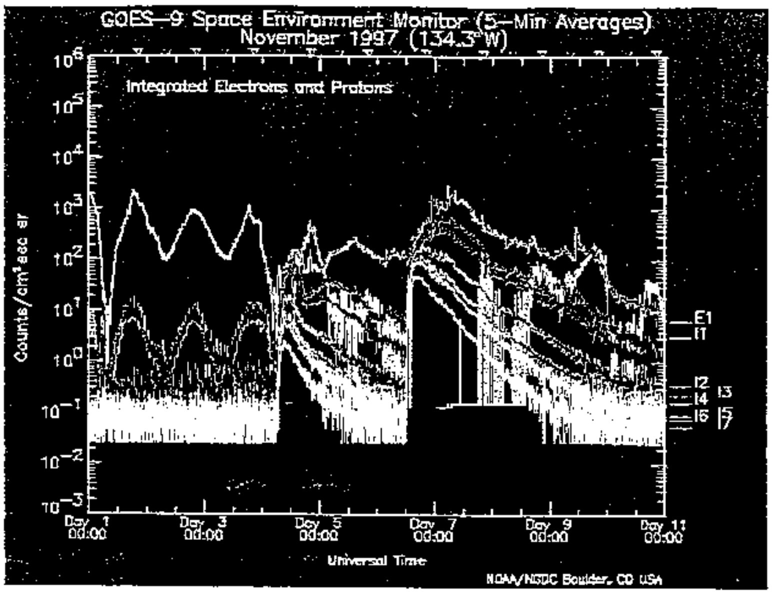


Fig. 9 : Proton events of November 1997

Let us recall that, on November 4th and 6th, 1997, i.e. some days after the ARIANE 502 launch (30 October 1997), proton events took place (fig. 9) whose intensity could have seriously disrupted the navigation control of the launcher through their impact on integrated circuits.

There is a real risk, somewhat analogous to the risk of lightning. Is it necessary to be protected against it?

b) For a launcher, where the target global reliability default must be kept below 20 to 30.10^{-3}, the above numbers, even though they are substantial, are not dramatic at first sight. However, it is usefuk to recall that if one estimates the "value" of a launch of AR 5 to be 3 billion Francs (launcher + payload), the cost in probability when one launches during an eruption is therefore of $3 \times 10^9 \times 10^{-3}$ = 3 MF for every SSO and "extended" orbit launch, and $3 \times 10^9 \times 10^{-2}$ = 30 MF for every launch in GTO+. One can appreciate therefore that a service in the field of "Space weather" has a real economic (and strategic) value.

c) There is not only the financial risk. One can also use "Space weather" to optimize space mission performances.

Hence, for certain US launchers the countdown includes, 6h before the launch, the taking into account of the forecast of exospheric temperatures (hence vertical profile of atmospheric density - fig. 10) to plan the earliest opening and dropping of the launcher fairing, therefore saving mass injected into orbit.

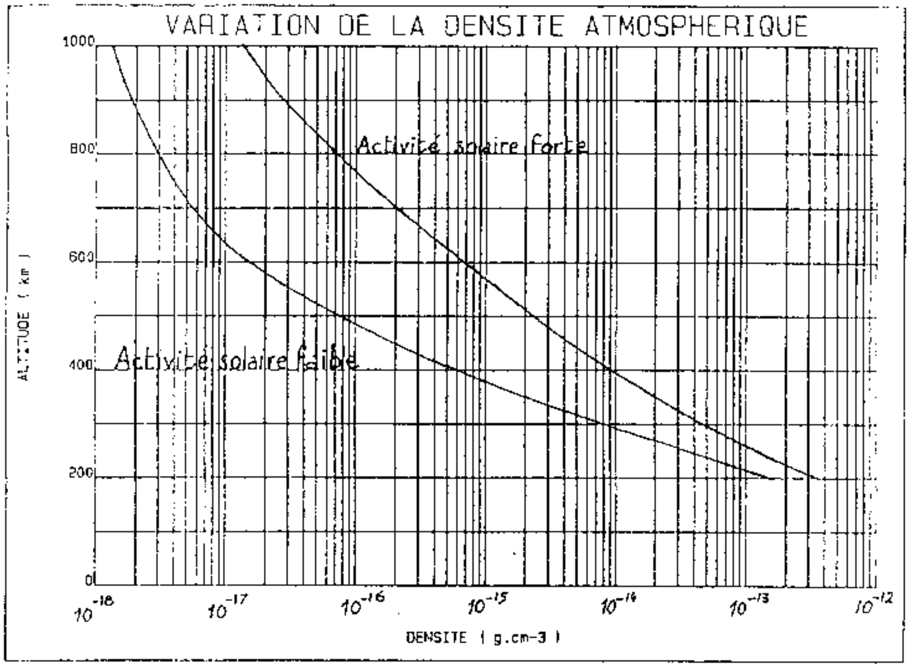


Fig. 10 :
Vertical atmospheric density profiles

d) Today, forecasts of solar activity or magnetospheric or thermospheric states are not taken into account in Ariane launch operations. A draft of an alert procedure has been studied by Aérospatiale (based on the principle of an energy threshold), but nothing is yet validated, or implemented. The Directorate of Launchers of CNES (DLA) gives priority to solutions based on hardening (by shielding, or by fault tolerant architecture) before considering solutions constraining the timing of launches taking into account alarms. However, the related studies and developments are not costed yet and as a consequence no changes are proposed in the future evolutions of Ariane 5.

e) If a service were to be proposed, it would be useful if it could provide information related to key times in the countdown. Representatives of DLA indicate as key times:

- 24/48 hours before launch, an answer to the question: "is there a dangerous risk level?" At this time, one accepts a few inaccuracies and imperfections.
- Six hours before: beginning of the filling. It is certainly then that the most rigorous forecast must be known.
- Ten minutes before: start of the synchronized sequence.

f) Finally, is there an interest to assess the received dose? It is probably interesting, but it does not seem necessary to place a particular sensor on the launcher for this purpose. It is admitted that sufficient information can be derived from global observations.

2.2 SATELLITES IN ORBIT

Effects of charged particles on satellites (see Ref.1) can be divided into two broad classes:

- cumulative effects for which an improvement of models is necessary, but they do not require a forecast of the "space weather" type;

- sporadic effects for which the necessity of forecasts could appear.

The sporadic effects are essentially electrostatic discharges or single events. In the first case, these discharges occur between elements of the satellite that reached a certain difference of potential because of their exposure to the plasmas of magnetospheric storms, or to an accumulation of particles of higher energy. The radiation and the fields produced, following a coupling with structures and circuits, are capable of generating parasitic signals interpreted as false commands. In the seventies this phenomenon became a preoccupation because of the growth of electronic circuit sensitivity. Initially, the main cause of discharge was the exposure of thermal coatings to the plasmas injected between 0 and 6h local time. This inconvenience has been mastered gradually by ad-hoc design and quality rules and nowadays the main causes of problems are heterogeneous structures (cables, multi-layered structures of dielectric/conductors...) exposed to the less dense but more penetrating radiation. The increase in the use of "micro-technology" types of equipment should lead to increased attention to these phenomena. Another worrying factor for the future concerns the consequences of the foreseeable growth of solar generator voltages and couplings of these voltages with plasmas.

"Single events" are logical state flips produced by charges deposited by heavy ions along their trajectory when they impact very integrated electronic components. Increase of the integration of VLSI leads to the situation that, although initially sensitive to the heavier and fastest ions - i.e. a minor component of the spectrum, VLSI components are now in practice susceptible to the whole range of cosmic radiation (and solar in the case of solar heavy ions events) and also to secondary radiation produced in the circuit material itself by fast protons. They therefore become sensitive to solar eruptions and to the highest energy protons of the magnetospheric radiation belts. The preoccupying tendencies for the future are on the one hand the strong growth of the number and diversity of on-board electronic components and on the other hand the interest in using commercial "components" not especially developed for space applications.

For these two types of effect, orbits of middle altitude (MEO) frequented by constellations, are dangerous, especially because for a constellation a breakdown due to the environment could possibly affect the whole fleet.

One can include in the sporadic effects noise created in detectors (CCD, channeltrons...) and optics (Cerenkov effect in refractive media) by radiation, noises that can, in certain cases, overwhelm the signal, or even lead to a life time reduction.

Three domains of activities concerning satellites could potentially benefit from the setting up of a forecast system the space environment:

- the design of satellites,
- their operation,
- analysis of anomalies.

1. Regarding the first point the reaction is unanimous: behaviour in response to accumulated dose is sometimes a limiting factor in component choice, some extreme "fluxes" can sometimes be taken into account in upper bound potential calculations ("NASCAP type"

calculations) or in single event rates. However, at present the environment does not appear as a sizing factor leading to constraints which could be relaxed by using better alerts during flight. A more careful analysis would be necessary if events in flight would appear with new technologies (high potential solar generators, micro-technologies) but the basic idea is more to design the device to be resistant to extreme cases, rather than to take protective measures according to an alert.

2. Regarding operations, opinions are more diverse. They range from the position where the environment is not a sizing factor of the operation team to one where, with notice of the order of about ten hours and a reliability of prediction of the order of 80%, a reduction of operation costs could be obtained. In any case these opinions are given as the immediate qualitative "reactions" which would need to be studied in more detail if a forecast service existed.

   One can include in this category of intervention the actions already implemented for scientific missions (D2B, XMM...), consisting of switching off detectors in intense flux zones to avoid their premature ageing. For this eventuality the existence of forecast delays between the hour and 2 or 3 days depending on the mission would allow improvement in the programming and the autonomy. For example, one could choose the various objectives according to the expected level of noise related to the space environment.

3. The existence of in-flight operational anomalies is today's reality. Their cost in the US is estimated to be about thirty million US dollars per year for those attributable to the space environment. An important problem is to identify as quickly as possible if an observed anomaly is actually due to the environment. Fast restitution (~ 1 day) is therefore a clear requirement. Data can be found on the WWW, but two features must be improved.

   - The reliability of these data (calibration, security of access...),
   - Their exhaustiveness (nature of particles, energy ranges, possibility to reconstruct the local environment from measurements performed at other points...).

   It is therefore in this aspect that the most immediate and best established need exists for satellites in orbit, considerations of other needs being felt at the present time as a matter for reflection for when a reliable forecast system exists.

Insurance companies wish to know *a posteriori* the space environment, not for taking into account for damage compensation, but to appreciate the part of the risk related to the environment compared to risks of different natures (design, quality of manufacture, operations' professionalism).

Remark concerning § 2.1 and 2.2:

In the general context of reduction of costs and harsh competition it is perhaps necessary to avoid too radical solutions; there is an obvious tendency for designers to adopt «very high» constraints on launchers and satellites, so that they cannot be affected by the worse disruption which one can expect. This sizing approach is costly. One can wonder whether it is the only way. The acceptance of an operational constraint that would apply maybe, over two or three days once every ten years might allow to lower costs. After all it is well accepted that some terrestrial services are damaged during cyclones or earthquakes...

2.3 ORBIT CONTROL

2.3.1 Perturbations

One can derive the density of the terrestrial atmosphere at a given altitude from the exospheric temperature (Temperature at infinity, T_∞). This temperature, T_∞ , depends, among others, on the solar and geomagnetic activity.

Solar activity (Ref. 2) in the UV range has the effect of exciting the different molecules of the atmosphere and therefore increasing its temperature (effect on T_∞) and globally expanding the atmosphere (effect on density).

The influence of the ultraviolet radiance of the Sun on the atmosphere is measured with the help of the radio fluxes in the 10 cm range, $F_{10.7}$, (more for historic reasons rather than physical ones). The variations of this flux are of the order of a factor 5, between minimum and maximum of a solar cycle. On the time scale of a day the flux can be considered constant, but on the scale of several days, it can be very variable. One observes a strong correlation over 28 days, the period of the Sun rotation.

Geomagnetic activity, which is the response of the magnetosphere to the solar wind's impact, is assessed by means of the K_p index collected from 11 magnetic field observatories distributed over the Earth's surface. One uses 3 hour averaged values of K_p. A magnetic storm can lead to K_p variations of a factor 5 in a few hours.

Recently, thanks to the international INTERMAGNET programme, it has been possible to access with a one hour lag time the raw magnetic data recorded in about forty observatories of which a large number is situated in high latitude regions. These data are accessible on the WWW through four "Geomagnetic Information Nodes": Edinburgh, Ottawa and Paris (Ref. 8).

2.3.2 Orbital manoeuvres

Atmospheric drag causes a decrease in the semi-major axis that requires orbit corrections in order to maintain the satellite’s phase and altitude. In addition, precise orbit prediction is necessary for the planning of certain payloads (over 24 to 48 hours).

During quiet periods, the decrease of the semi-major axis of a helio-synchronous orbit of the SPOT type is less than 1 metre/day, but it reaches 6 m/day during periods of medium activity, and can rise to 50 m/day during strong events (fig. 11), which corresponds to a departure of 8 km for the position of the satellite in the orbit after one day.

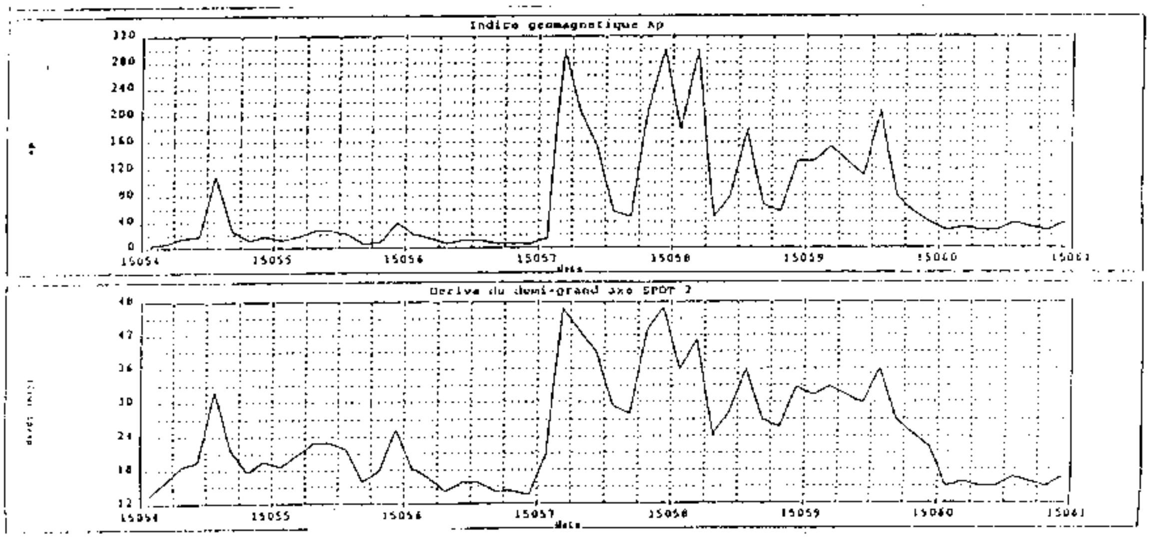


Fig. 11:Decrease of the semi-major axis of Spot 2 during high solar activity (20-21 October 1997)

The tendency to carry autonomous navigation systems (*Diode* type) will not remove the need for prediction for good planning (platform and instruments). The required target for atmospheric density prediction is 36-48 hours ahead.

It would be valuable to have 10.7 cm flux data and geomagnetic indices available more rapidly.

The weak link in the forecast chain is the modelling of the atmosphere, which has not sufficiently progressed since the 70's (Jacchia 77, DTM of F. Barlier): they are certainly able to give a statistically correct description of the atmosphere, but they certainly cannot pretend to represent the atmosphere at a given instant, nor to describe its dynamics on short or long term. Their empirical nature, founded on data acquired on two or three solar cycles, makes them only capable of describing situations over equivalent cycles, not considering all the possible secular variation.

Studies necessary for the implementation of missions using techniques such as atmospheric braking can provide the opportunity to re-boost the modelling work in this domain (for example at GRGS and LIS).

It is worth noting that efforts are being made to relate the density of the upper atmosphere in more detail to magnetic storms by assuming that triggered waves propagate around the Earth (Travelling Atmospheric Disturbances) and superimpose themselves in equatorial zones (Ref. 3).

2.3.3 Aero-braking

Space missions based on aero-braking will need precise and up-to-date information. The corridor around perigee for a satellite making aero-braking is located at about 120 kilometres and is very narrow: a few hundred meters. In cases of significant increases of atmospheric density, it is necessary to be capable, near the apogee (so several hours in advance), to raise the altitude of the following perigee in order to avoid over-severe braking.

2.3.4 Prediction of atmospheric re-entry

The forecast of atmospheric re-entry several months ahead, is based on the evaluation of solar activity. If one analyses the evolution of the predictions of re-entry of the MAGSAT satellite (Ref. 4), one notes (fig. 12) a departure of several months between a first forecast (in November 1979) based on the evaluation of the Wolf number of 200, and the reality (Wolf number of 160). The expected re-entry of MIR (corresponding to a solar activity maximum) could be a new opportunity to investigate these satellite re-entry forecast problems.

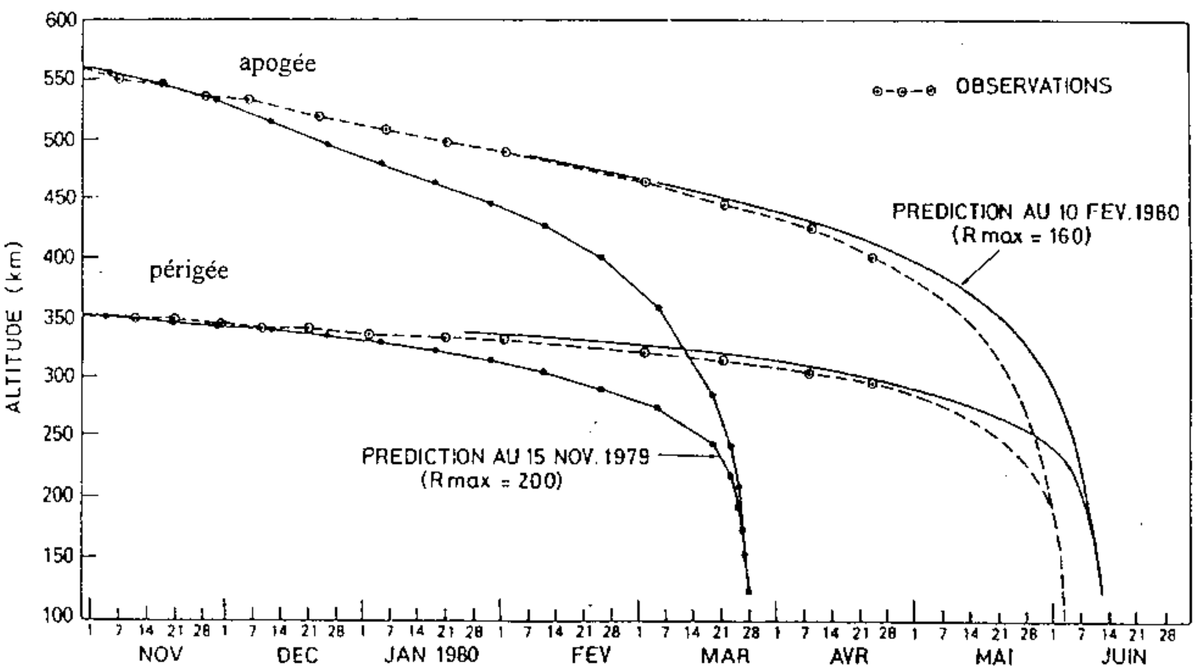


Fig. 12 : Prediction of the orbital descent of Magsat as a function of time.

2.3.5 Debris monitoring

In case of major flares, the heating of the atmosphere modifies the orbits of hundreds or even thousands of pieces of debris and therefore necessitates radar based re-acquisition, to re-calculate the related orbits and to re-evaluate the risks of collision. As an illustration, at the time of a violent event NORAD lost trace of 1300 pieces of debris.

2.4 MAN IN SPACE

2.4.1 Review of hazards.

The issue is to determine the usefulness of the forecast and the acquisition of certain "hazardous" situations, that is to say of situations where established standard limits concerning detrimental effects to a crew are about to be transgressed. The fact that present limits have to be revised (an order of magnitude as high as a factor 10 is sometimes mentioned) is a problem and a matter for research, but cannot be taken into account in the present phase of activities, centred on solely operational services.

For astronauts, NASA seems to consider today that the "acceptable" dose limits of exposure to hazardous environments is 250 mSv in 1 month, 500mSv in 1 year and 1500 mSv in a career. However, the following orders of magnitude are presented for information:

	Normal	SPE
Low altitude orbit type ISS	1 mSv/Day 360 mSv/Year	≅ 140mSv/eruption in EVA ≅ 100mSv/6 Hours in EVA

One should note that the construction of the station (on a orbit with 51 degrees inclination) will requires a lot of EVA and that it will take place during a full maximum of the solar cycle.

Earth-moon: one can experience 1 or several Sv per day in the case of solar eruption. Therefore a "sarcophagus" in the vehicle and an alert at least one hour before the highest fluxes is necessary to allow the crew to get into the most "protected" configuration.

Lunar base: The "screening" by lunar material can sometimes reduce the flux, but sizing based on the most unfavourable case is necessary, that is to say the preceding case. A space weather forecast will be necessary for a lunar base, capable of giving an alert signal a few tens of minutes before the most dangerous situations.

Concerning lunar expeditions we should note that between the Apollo 16 and Apollo 17 missions on 4 August 1972 to be precise, a very important eruption of solar protons took place. The dose received (at the Moon) reached 7 Sv/hour, at its maximum. In spite of the shielding afforded by the lunar module, astronauts who would have been unlucky enough to be on a mission at this time would have received a cumulated dose of 15 Sv, which is very probably a lethal dose.

Journey toward Mars: The "instantaneous" hazard is the same as for the Earth-Moon journey. However, the length of the journey is 100 times longer. The total hazard increases in proportion. There must be a zone on board shielded by a thickness of at least 50 g/cm^2 of Aluminium equivalent (fig. 13).

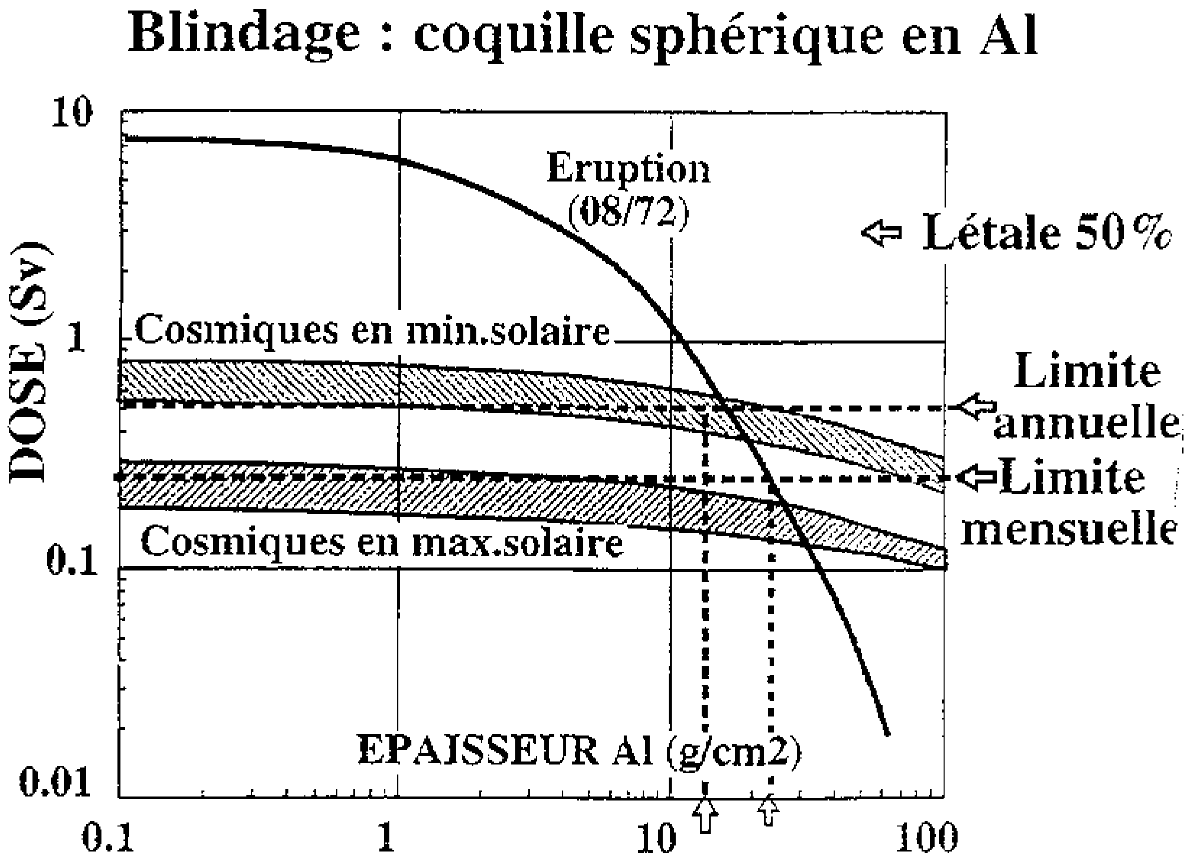


Fig. 13 : Manned mission to Mars: radiation induced biological hazards

Martian Base: One can estimate roughly that the atmospheric screening provides a reduction of the flux received by 20 to 30%. Qualitatively, the conclusions on the need of a shelter and an alert are the same as for the lunar base.

2.4.2 For manned flight operations, the USA and Russia rely on the same source of forecast and assessment: the SEC (Space Environment Centre of NOAA in Boulder).

So far, there have never been launch postponements or important operational changes related to a crew irradiation hazard. This is due mainly to the fact that all the orbits used were very well protected by the magnetospheric shield.

For the future, and in the general case, with orbits that can be more exposed, one can distinguish three aspects creating a demand:

a) Short-term lethal hazard (on ISS, responsible: USA)
b) Need for cumulated personal follow-up to manage the "individual career" on a medium-term time-scale (on ISS, responsibility: personal physician - national - of each crew member)
c) Necessity of reprogramming activities (e.g.: EVA,...) (on ISS: USA)

2.4.3 What to do? Nothing urgent for manned flights in the next 10 years. It is necessary to pursue research efforts for:

- knowledge

- taking part in the establishment of standards and limits

It is also necessary to contribute to the world-wide effort to supply raw data.

2.5 SPACE-GROUND PROPAGATION

2.5.1 Perturbations

Radio waves, in the frequency range 30 MHz to about 2 GHz , can be disrupted as they travel through the ionosphere, in different ways:

- attenuation of the signal,
- nearly total absorption,
- reflection,
- change of the propagation direction, and therefore modification of propagation path,
- variation of the phase of the signal.

The variability of the ionosphere results from:

- the variability of the input solar flux (essentially in the far UV part of the spectrum),
- the variability of the plasma of solar origin entering the magnetosphere,
- the atmospheric tides produced by the Sun and the Moon,
- its heating by the Sun that produces a daily cycle of expansion/contraction.

The first two reasons, the only ones that are not systematic, are a matter for space weather.

2.5.2 Trajectory and localisation

The CLS company, a subsidiary of CNES, uses data from Meudon for ARGOS (trajectory and localisation within a few hundred meters resolution) and for DORIS (precise orbit determination). For the precise trajectory (DORIS), the determination of clock bias requires that one does a precise ionospheric correction.

For ARGOS, which is mono-frequency (400 MHz), the need is to have the slant TEC (Total Electronic Content) for ionospheric corrections (see for example Fig. 14). The rise of the solar cycle is going to reinforce the importance of this information. Bent's model provides the TEC. Its parameters have been determined empirically with the help of data corresponding to periods of low and medium solar activity. It is therefore not very suitable for the coming years. Its only input (apart from the positions of the beacon and the satellite) is the R12 coefficient of the current month. R12 represents the number of sun spots averaged over the last 12 months. During high solar activity, ionospheric effects on localisation are of the order of 200 meters. It is therefore important to take them into account. Bent's model is accurate to 40%. It is a statistical result. The largest instability of the TEC occurs during sunset. Improvement depends on the geometry of the pass in the visibility window (high or low pass). This model is not the panacea (apart from the efficiency, it is necessary to take into account the computation time, the heaviness of the implementation in an operational context) but for the time being CLS does not know any other model. Contacts with CNET of Lannion are of interest for a future activity.

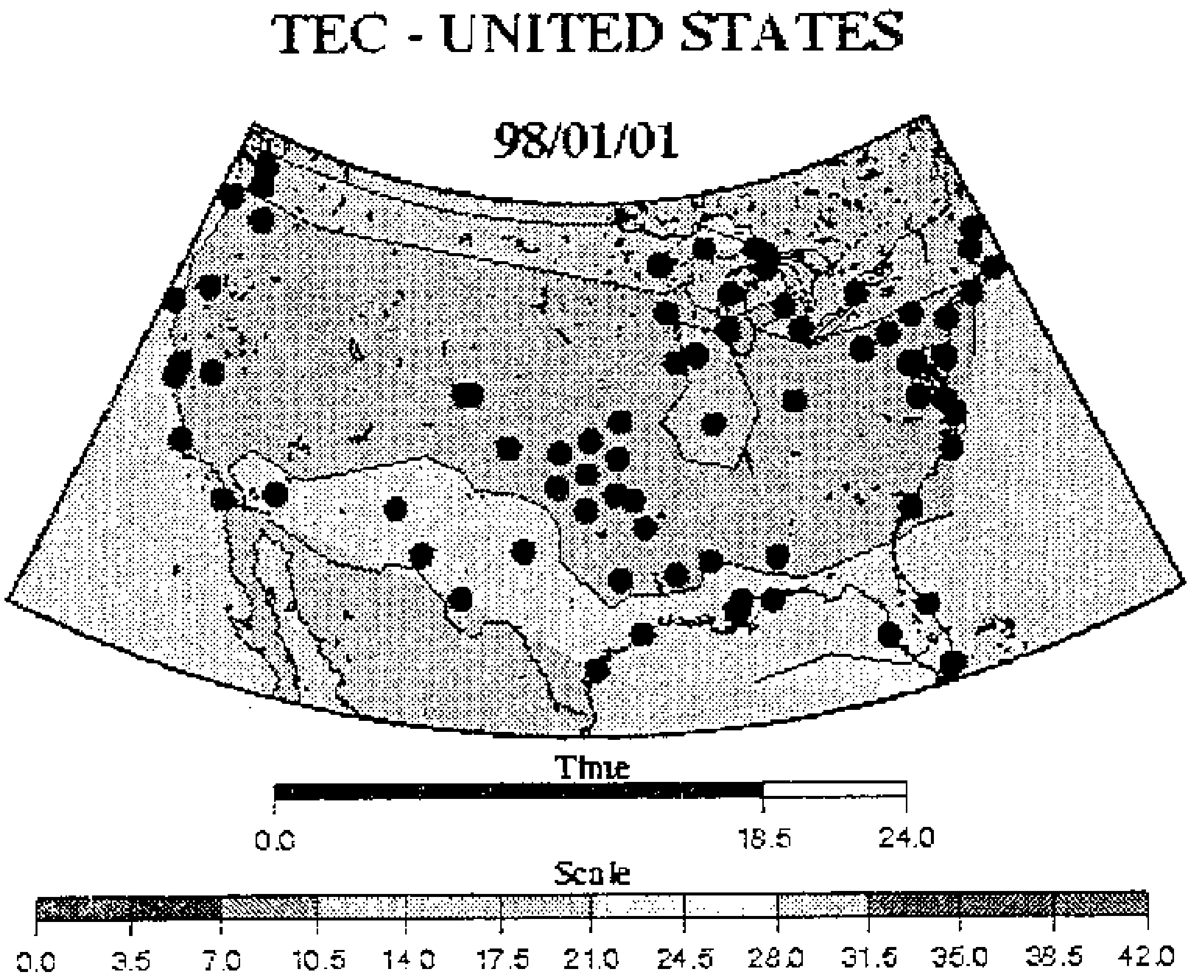


Fig. 14 : Total Electronic Content above the North-American continent (doc JPL server)

2.5.3 Navigation systems

Two ionospheric effects can seriously disrupt precise positioning of the GPS type:

- a complete loss of the data link, due to the scintillation of the ionosphere that can provoke an attenuation of the signal by up to 20 dB. The polar and equatorial zones are especially sensitive to these phenomena.

- in the case of mono frequency use (civil use), variations of propagation can lead to positioning error of the order of 30 meters.

Europe is making progress in its desire to be equipped with a navigation system which is complementary or even alternative to the American ”GPS” system (Ref. 5).

For the integrity of the system it is foreseen to deploy a network of about forty stations in Europe (RIMS: Ranging and Integrity Monitoring Stations). These stations will collect measurements, between themselves and a GPS/GLONASS or geo stationary satellite, and the data transmitted to the MCC's (Mission Control Centre) that will distribute continuously the corrections to be applied. Four MCC's are foreseen (Frankfort, London, Madrid, Rome), operated under the responsibility of national navigation agencies. A European GNSS agency is foreseeable in the coming 5 years.

The distributed data will be a very short term forecast (2 minutes), derived via a rough filtering. The goal for the precision of aircraft -satellite measurements is 50 centimetres. An important question is the homogeneity of the ionosphere and the existence of "bubbles" with sizes smaller than the mesh of the network of RIMS stations: bubbles "seen" by TOPEX-POSEIDON are of about 150 kilometres of diameter (in the equatorial zones or at high latitude).

A scientific group of ionospheric experts follows these studies (on the French side, Mr. Lassudrie, of CNET, Lannion).

THOMSON-CSF (Toulouse department) is in charge of the implementation of this RIMS network (about forty stations distributed on all over the continental Europe + Iceland).

This RIMS system could be used by a “space weather” service as a data supplier. In return it could be interested in getting predictions on longer times than the currently considered 2 minutes.

A test bed under ESA responsibility will be available at the end of 1999. The deployment of the operational system, European geo stationary Navigation Overlay System (EGNOS), is foreseen for 2003.

2.5.4 Altimetry

Oceanic altimetry missions use bi frequency altimeters to correct altimetric measurements by a term in $1/f^2$, proportional to the total electron content of the ionosphere in the nadir direction from the satellite. The use of two frequencies allows derivation of the TEC and makes this term negligible in the overall analysis.

This need for identification is the sole reason for the use of a bi-frequency system for altimetry over the oceans. For altimetry over ice or vegetation areas setting the bi-frequency is also justified by the need to characterise the surface state.

Other altimetry missions are mono-frequency ones (ERS2, GFO) and rely on models for the ionospheric correction.

The future operational need for repeated coverage will result in the deployment of multi-satellite systems. A reasonable scenario would be to have only one of them working in bi-frequency, that would allow characterisation of the state of the ionosphere, and the others in mono, which assumes that models of short term evolution of the ionsophere are sufficient.

On the longer term, assuming that the temporal variability of the ionosphere is possible to model, an operational system of several mono-frequency satellites is foreseeable.

The expression of the requirements in terms of the spatial wave-length remains to be specified.

Other needs than those identified here (altimetry, localization) could appear in the field of radar imagery.

JASON will only provide some TEC data with a 3 hour delay continuously over the oceans (millimetric accuracy). The broadcast of these data will be performed via CLS.

2.5.5 Business communication services

Future constellations of communication satellites (IRIDIUM, Global Star, Teledesic, Skybridge...) will be affected by ionospheric scintillation.

Satellite - aircraft links are performed at around 1.6 GHz (INMARSAT). Important attenuation (> 20 dB in equatorial regions, 10 dB in polar regions) is observed around local midnight due to the effect of ionospheric scintillation, related to solar activity.

2.6 GROUND-GROUND LINKS

Activities which have potential users of an operational space weather service are the following:

2.6.1 Broadcasting

This need emanates from TDF mainly for *Radio France Internationale*.

Communications in the HF band (also called decametric band - wavelengths of 10 to 100 m - or sometimes, improperly, short-waves, this label corresponding to wavelengths shorter than 80 m, therefore with frequencies above 3.75 MHz), depends strongly on the reflection of signals by the terrestrial ionosphere. Electromagnetic waves are attenuated while crossing the lower ionosphere (under 100 km altitude), where collisions between electrons and atmospheric molecules are frequent. This attenuation affects the various useful radio frequencies in different ways. It can become important following an increase of local electronic density to the point where it could cause blackout. Reasons for this increase can be as diverse as an increase of the solar UV flux following a solar eruption, an X-ray solar burst, a solar particle event with high-energy particles (electrons and protons), or an intense aurora borealis where high energy particle events produce a particular type of disruption called PCA (Polar Cap Absorption) that can last several days.

The Department for Frequencies of TDF includes a Decametric Wave Section whose main customer is RFI (*Radio France International*). The band managed ranges from 3950 kHz to 26100 kHz. The section uses IR5 indices (average number of spots over five months) communicated by CNET. The task of frequency management can be subdivided as follows:

- scheduling of frequencies
- choice of the most suitable band for one-hour data
- state of the occupation of the band.

Short-term solar indices are not used, therefore not allowing short-term effects of solar activity to be followed, and the forecast aspect is not clearly noted. On the other hand, effects of the solar cycle, averages on several months, are well described by the IR5 indices.

2.6.2 Military aspect of the post-nuclear disrupted environment

A need for ground-to-ground communications could not be identified. However, the space weather can have some indirect spin-off on the study of the post-nuclear disrupted environment. Of course this theme includes a strong aspect of confidentiality, but one can distinguish the following points:

Following a nuclear explosion, the electromagnetic pulse (EMP) disrupts the ionosphere up to 20 to 40 km altitude, mainly due to the effect of photo-electrons. One needs to characterise the evolution of the medium, which can depend on other disruptions and in particular on disruptions of solar origin. Roughly, the task is to correlate the effects of EMP with the natural environment, which it is necessary to have the best possible knowledge of.

It also has a spin-off effect on the vulnerability of satellites to nuclear explosion threats, and on satellite-to-ground communications.

The weight of space weather in this domain can be considered as being on the same level as other natural phenomena (lightning, etc...) and needs to be considered.

2.6.3 long distance HF communication system users

The aeronautic mobile service uses HF links between 2.8 and 22 MHz. Sudden Ionospheric Disturbances (SID) are observed during eruptions. They result in an abrupt absorption of waves by the D layer of the ionosphere, the relaxation to the normal situation taking place in a few tens of minutes. PCA's (Polar Cap Absorption) also disrupt links in the polar regions for several days.

The need for long distance communication in the HF domain (1.6-30 MHz) had been a bit hastily judged to be dying out because of the arrival of satellite communication systems. Nevertheless, it appears that governmental and military services continue to require it, either to palliate the unavailability of communications via satellites or for cost reasons. A communication system of 1 kW of power can be kept within an acceptable volume, a modest antenna area (frame of 1.5 meters is sufficient) and the deployment of the system becomes simpler, no longer requiring the intervention of an expert in communications, while providing an acceptable reliability. For example with such a system Rabat-Riad links are available 90% of the time. Frequency packs (100 Hz spacing) in the HF band are assigned to countries by the IRCC. It is up to the national authority to distribute the frequencies between its governmental administrations. The bandwidth are from 300 to 3100 Hz. Overlaps are resolved by assigning frequencies close to each other to geographically distant users.

For France more than ten organisations use HF networks in a regular way (armed forces, paramilitary services, networks of embassies).

In addition to the continuing interest of traditional users, civil aeronautics could give a new lease of life to HF systems for making the redundant system for satellite links (INMARSAT Aéro H) in the frame of the ATN system (Air Traffic Network) currently in the definition phase. The ATN system aims to extend the capacity of service communications between aircraft and ground services (control unit, technical and commercial services of companies). A completely redundant SATCOM system on an aircraft is estimated to cost 500 kUS$. It only offers an availability of about 95% (Sudden Ionospheric Disturbances, Polar Cap Absorption, satellite system itself). With redundancy via a completely independent HF system, relying on a network of a few stations distributed around the Earth (8 stations foreseen, 2 are already in place), the ATN would provide an availability of 99.9%, the links being made in one or two steps. The cost would be reduced since HF systems are today obligatory on all large transatlantic carriers. Rockwell-Collins have developed a modification kit with reduced cost allowing re-use of HF radio facilities currently on board aircraft for future ATN systems.

The needs of the users of HF systems

The establishment of a HF communication link between two terminals is done with the help of a normalised protocol, ALE (Automatic Link Establishment), on the following principle:

- the caller chooses a frequency according to what is thought to be best at the present instant (fixed tables, or updated on a more or less empirical basis according to previous link results, tables of LQA (Link Quality Analysis)) and issues a call,

- the receiver listens permanently to a set of frequencies (steps of 2, 5 or 10 frequencies per second),

- when the receiver detects the signal of the calling transmitter, the receiverr answers at the end of the call, on the same channel. Otherwise the caller tries again on another frequency. The time taken to establish a link is about 15 seconds for each attempt

Reducing the number of steps swept by use of better propagation models saves time and contributes to clearing the spectrum. In addition, making the first attempt on a frequency offering the best propagation increases the probability of a connection and reduces the number of attempts.

Rockwell Collins have developed software for propagation forecast, PROPMAN, based on IONSCAP, and offering an interface with data forecasts from SEC or other sensors.

A French or European service offering HF link users the input parameters for software of this type (forecast of bursts of X rays, magnetic storms ...with a time-lag of the order of one hour) would be strongly appreciated. The interface between such a service and a network of users could be made at a unique point, the update of the parameters being performed via a service of HF links (see fig 15 for example).

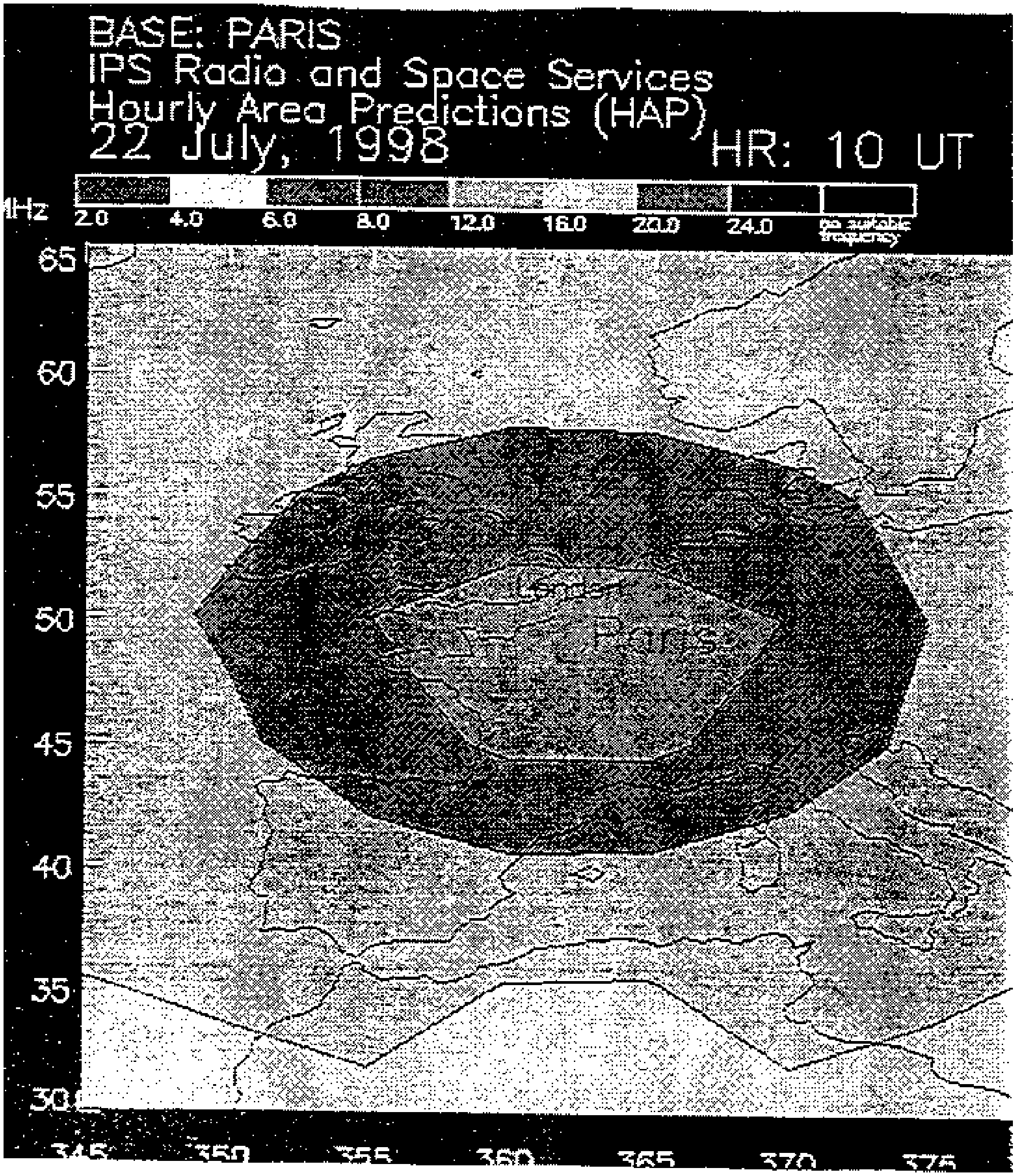


Fig. 15 : Map of forecasted optimal frequencies. Hourly update.

2.6.4 Over-the-horizon military RADAR.

The over-the-horizon RADAR is a device for remote detection (up to 4000 km). Implementations or studies exist in Australia, CIS, Japan, USA, or United Kingdom,..

a) Principle

Ionospheric layers are used like reflectors for radio waves with frequency between 3 and 30 MHz. The layers concerned range from E (150 km) to F (250 to 700 km).

The target of detection? Essentially ballistic missiles at launch (after this, they are above the ionosphere), but also planes and,.... why not, ships. Missiles are discriminated by their high radial speed, and because they follow a trajectory which quickly becomes almost horizontal. The area of detection can reach a radius of 4000 km. There is a central blind zone of about 600 to 800 km radius.

In favourable "cases" there are 15 to 20 minutes between the detection of the missile at launch and its arrival at the target.

The reflective medium is very variable and many adjustments are necessary (with the help of reference values) to establish a primary and return link suited to the observation; adjustments of frequencies and adjustments of the direction of emission.

b) Detrimental effects related to the environment

Due to strong solar and magnetic activity, induced ionospheric disruptions can lead to a complete black-out or a deviation of the beam. Even though the design of the radar allows a certain flexibility in the choice of frequencies and the orientation of the beam, there may be periods of total unavailability of the system.

The problem is to determine statistics of unavailability while taking into account the observed ionospheric situations and the design of the radar. The choice of design depends on considerations of physics, operations, and cost - efficiency.

The desirable service to be provided to such facilities should include:

Forecast, of the critical frequencies, electronic density, height of layers. Formulated 3 days ahead and re-calibrated 24 hours in advance.

As it is unacceptable to have zero capability of detection and alarm (the enemy being able to take advantage of it since it is aware), the headquarters must, from an operational view point, establish alternative solutions (AWACS,...). However, one can estimate that 1 to 2 days are necessary to prepare deployment.

c) Conclusion

- Either: one manufactures a system sufficiently sophisticated to not have any blind periods, but which probably has a very high cost;
- or: one makes it simpler by maintaining an alternative solution and uses a 36 hour ahead "alarm".

Finally, careful survey of good quality information on the environment will allow, in real-time and in restitution, determination of whether the temporary disabilities of the system are due to hardware problems, to the natural environment, or to an intentional disruption.

2.6.5 Over-the-horizon meteorological RADAR

Some recent studies showed that an over-the-horizon radar could constitute support to monitoring of the state of the sea. If such a project would be implemented, complementary information on the state of the ionosphere (altitude and vertical speed of layers), would be necessary.

2.6.6 Navigation systems

LORAN and OMEGA systems: for navigation the OMEGA system is strongly affected by SID's or PCA's (several tens of kilometres) but it is intended to withdraw this system. Nevertheless, the use of the LORAN system to transmit GPS type signals is under assessment by the US Coast Guard (EUROFIX system of the University of Delft).

2.7 AIR CREW STAFF

The European directive 96/29/EURATOM of 13 May 1996 (Ref. 6) must be applied by every country of the Union from 13 May 2000. Article 9 stipulates that air crew staff, classified among people exposed for professional reason, must not exceed a dose of 100 mSv over five consecutive years, provided that the effective dose does not exceed 50 mSv over one of these years. Member states can set a yearly "dose". According to Article 42, companies using planes must "take into account the exposure to cosmic radiation of air crew staff likely to experience an exposure above 1 mSv per year and these companies must apply measures, among others, to assess the individual exposure, not to exceed the above mentioned doses whose average is 20 mSv per year. The case of pregnant women is special because the legislation foresees that the foetus must not receive more than 1 mSv during its gestation.

The airline companies will be lead to flight re-assignment or to ground staff approaching the critical dose. During the Dublin Workshop (July 1998) a representative of the European Community specified that the legislation must apply to military staff as well as civilians.

Flights at an altitude above 8000 meters are affected by a risk of exceeding the 1 mSv per year threshold dose for monitoring (fig. 16). The average doses on certain long-range routes are of the order of 2 to 5 mSv per year (Ref. 7). Three solutions are *a priori* foreseeable:

1. dosimeters onboard aircraft giving an alert if the instantaneous dose exceeds some thresholds, as is done for Concorde (green from 1 to 100 µSv per hour, orange from 100 to 500 µSv per hour, red from 0.5 to 10 mSv per hour),
2. individual dosimetry film badges carried by staff,
3. an estimate of doses received on every flight, taking account of the flight plan (journey and altitudes).

The first two solutions are expensive considering the number of aircraft and staff concerned. Measurements made with films are complex to manage and less precise than those made during certain flights by the IPSN with sophisticated detectors, similar to those used by the French experiments on board MIR. The use of badges is subject to supplementary uncertainties: badges being forgotten for a flight or, on the contrary, badges being left in luggage and checked in airports by X-rays.

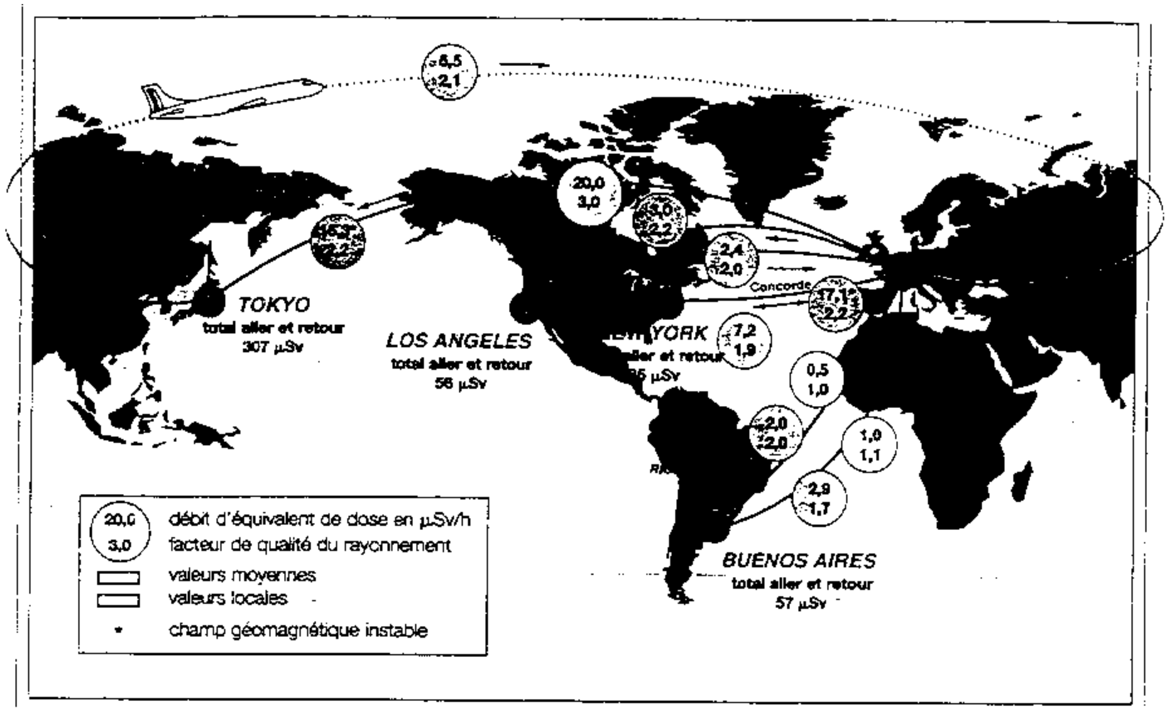


Fig. 16 : Hourly dose and quality factor of radiations received on-board a transatlantic flight

Without any definitive decision being taken, the preference, at French and German levels and very probably at European levels, moves toward the setting up of a data base that would allow estimation of the received dose from information about every flight. The merging of this data with the schedule of every member of the air crew staff would allow supervision of the received dose and provision of an annual approval document. Results could be compared to those provided by badges carried in a non-systematic manner by certain air crew staff and those provided by campaigns of on-board measurements with the help of sophisticated detectors. These experiments (on-board precise dosimetry of certain flights) would allow estimation of the dose received onboard from the cosmic ray data observed by ground based neutron monitors that permanently provide cosmic ray measurements and observe high energy protons generated by solar flares.

The main variation of the cosmic ray flux is related to solar activity: this flux is 20% larger during the minimum of the eleven year cycle compared to the maximum of the cycle, during which the complex structure of the interplanetary environment has a screening effect. On the other hand, solar flares can lead to non-negligible doses. The proton event of 23 February 1956 is the worst ever observed since 1942 with a level of 4500% the normal cosmic background. The dose would have been 10 mSv for the subsonic flights at 12000 meters and high latitude. Extrapolating this evaluation for Concorde, at 17000 meters, one finds a dose of 30 mSv, which is a more critical value.

Neutron monitors are permanently working scientific instruments. Their geographical latitude must be similar to that of exposed flights (Scandinavia, North Atlantic, Canada, Siberia), their response being identical whether they be in the northern hemisphere or the southern hemisphere. Figure 17 shows the monitors that could be well-located for this application. One of the European monitors is Finnish and the two others are French. The working French monitors, the one of Port-aux Francais (Kerguelen Islands) and the one of Dumont d'Urville

(Terre Adélie) are managed by the IFRTP (Institute Francais de Recherche et Technologie Polaire) in Brest. The transmission of their data to the Forecast centre of Meudon, via Brest, is done on a daily basis, but could be accelerated if needed.

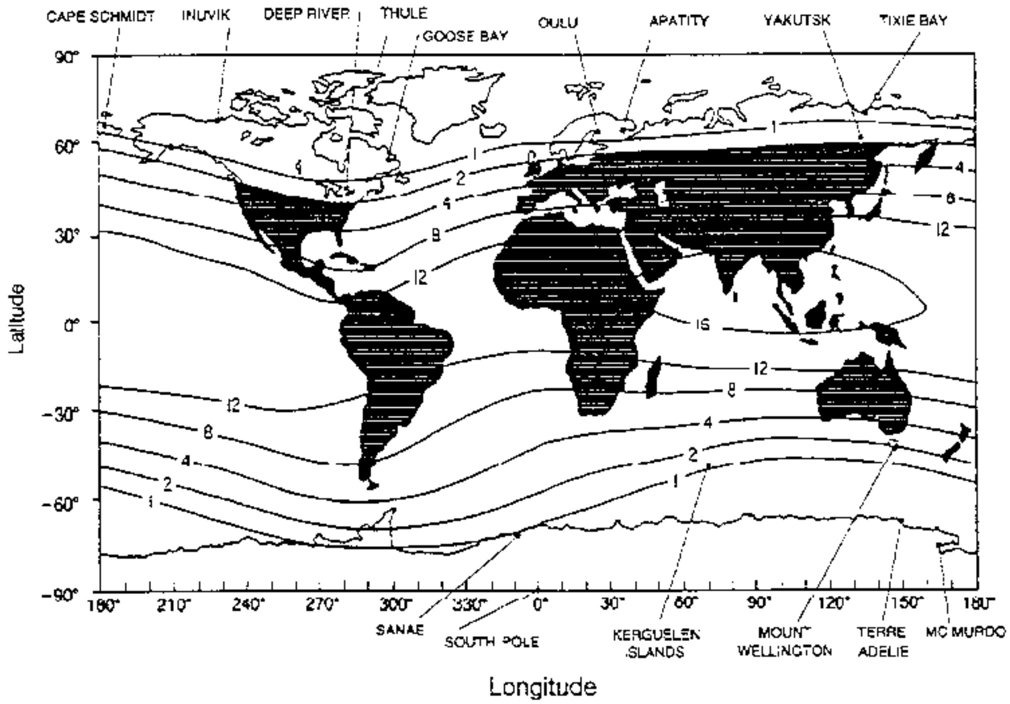


Fig. 17 : Distribution of the neutron monitors
The contour lines are iso-magnetic rigidity (GeV/c)

Passengers are not taken into account in the present legislation, except if they travel for professional reasons (in which case they can ask their employer to take advantage of a radio-protection follow-up). If legislation had to protect passengers or if in the future supersonic flights became the rule, it could be necessary to have a forecast of the risk for every flight. It would be foreseeable, for the preparation of each flight plan, to give forecasts in terms of probability of occurrence of eruption and/or a real-time state of the level of the cosmic rays (nowcasting).

2.8 EFFECTS ON ELECTRICAL NETWORKS

Modern electricity distribution networks are extremely complex and extended. Long distance cables carry electric currents induced by ionospheric perturbations during geomagnetic storms. The increase of the current in cables can provoke incidents in transformers, network breakdowns, and eventually complete chaos in the social and economic network of a region.

The US authorities, very concerned by this hazard, evoke a "worst" case which is not possible to completely rule out, namely a general electrical breakdown for up to 72 hours and concerning Boston, New York, Washington. It is true that the North-East American area with low conductivity soil, favours the conduction of charges on the surface. Nevertheless it remains true that other more general reasons exist which explain the increasing vulnerability of networks: interconnections on a large scale, transfers of high power between regions, the economic war between private operators that provokes each one to operate very close to the admissible maximum, and the absence of sanctions (a breakdown of this type is considered like a natural hazard and the customer is not indemnified)...

The importance of the considerable economic, social and strategic issues that are associated with these incidents goes without saying.

The European situation is not of the same nature as the American one. However, it deserves attentive examination, especially with regard to Scandinavia, so that its vulnerabilities can be revealed. The differences concern:

- the type of soil
- the extent of the interconnected area
- the very dense mesh of the network in France (and generally in Europe)
- the number of nuclear power stations

Knowledge of extreme situations of solar and geomagnetic activity is important for the sizing of the network and its conditions of use; a good quality forecast would be of considerable interest, allowing diversions and reconfigurations made necessary during the disturbed phase. The time frame for advance notification ranges from 2 days to 10 minutes. Care must be taken, however, since the incorrect alerts have a very high cost.

2.9 EFFECTS ON PIPELINES

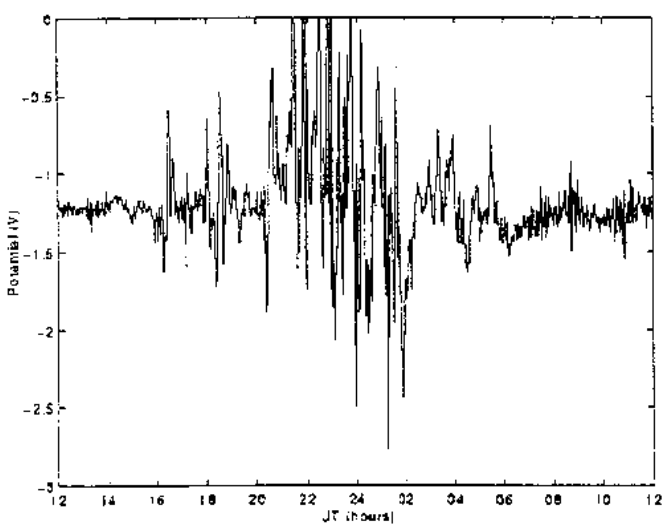


Fig. 18 : Induced potentials in pipe-lines (Lund, Sweden, 8-9 Nov. 1991)

Geomagnetic activity induces significant currents in pipelines that lead to erosion (fig. 18). Planned for a life time of fifty years, duct walls can lose 10% of their thickness in 15 years, if no palliative measure is taken. The problem not only concerns material in auroral regions but over the whole Earth. The solution used involves application of currents with polarity opposite to the induced currents.

A small potential difference is thereby maintained between the pipeline and the surrounding ground. The forecast of geomagnetic events allows planning of the application of the current and therefore limitation of the corrosion and then lengthening of the life-times of pipelines

2.10 MINING AND OIL PROSPECTING

The forecast of geomagnetic activity on a short term (some days) and on a medium term (some weeks) interests companies prospecting by airborne means. Geomagnetic activity disrupts campaigns of measurement. The reliability of forecasts is in this respect an important point. Let us recall that the present forecast quality is very different according to whether it is performed during the rise of the solar cycle (geomagnetic storm are in majority triggered by coronal flares and ejections) or during decreasing phase of the cycle (the recurrent storms are triggered regularly by stable coronal holes at every solar rotation of about 27 days).

For these applications it is also important to notice that it is the local geomagnetic field that is significant. To this end a reference station is installed in the prospecting zone. The situation differs therefore according to whether the prospecting is performed in the French metropolitan area (in this case the local field remained close to the global geomagnetic indices -Ap or aa), in the auroral regions (AE -auroral electrojet index) or equatorial (Dst equatorial index). The forecast centre of ISES situated in Ottawa is specialised in auroral zones forecasts. It does not appear that there is currently an operational forecast of the Dst index. It is a potentially important application, particularly for oil prospecting, which would certainly have to be analysed and to be developed.

2.11 EFFECTS ON THE TERRESTRIAL CLIMATE

2.11.1 The terrestrial climate is influenced by the space environment

In the overall energy balance describing the equilibrium of the terrestrial atmosphere, solar energy is by far the main energy source. It appears therefore logical to study whether possible fluctuations of the energy contribution from the sun can have impacts on the long-term terrestrial climate, and on the short term as well.

In fact, the theory of Milankovitch - now generally accepted – relates the large glaciations to orbital and attitude features of the Earth in relation to the Sun (semi-major axis, eccentricity, inclination of the axis of rotation of the Earth with respect to the plan of the ecliptic) that induce variations of the solar energy flux experienced by the Earth. The solar flux must therefore be measured with very large relative and absolute accuracy, and this in a large range of wavelengths. For example the fluctuations of the UV spectrum are important to know. These measurements are delicate and must moreover be continuous over periods significantly larger than the solar cycle.

Recently a correlation has been observed between cloud coverage and cosmic ray level. One knows that numerous cosmic rays arrive on the Earth during solar minimum period. This observation, although only established for a short period, has the advantage of being comprehensible in term of relation between cause and effect.

For completeness, we mention possible climatic variations related to the flux of meteoroids, and over a longer-term, related to galactic arms crossed by the solar system.

2.11.2 Objective evidence is very difficult to obtain

The terrestrial climate is sensitive to other parameters, often negligible (in absolute magnitude) with respect to solar radiation, but with much more important fluctuations or regulating effect that dominates. Oceans, aerosols of volcanic origin, biological and human activities are far from being negligible.

The models are therefore extremely complex, and the relation between cause and effect is often difficult to establish (e.g. the large eruption of El Chichon; announced as a test case for atmospheric models, but which could not lead to really conclusive results following the exceptional action of the El Niño current during the same period).

2.11.3 Methods

a) Regarding the analysis

In the case of phenomena determined by a large number of parameters, fortuitous correlation is common and can lead to interpretations and theories without any scientific foundation, where the relation between cause and effect cannot be established.

b) Regarding the measurement:

One must go back up in time as far as possible to reconstitute both the terrestrial climate and the solar activity (fig. 19). The methods that today seem the most efficient consist of drilling ice or other deposits, and the study of isotopes of deuterium and beryllium. The comparison of the relative concentrations of deuterium (sensitive to temperature) and of the abundance of beryllium (considered as an indicator of solar activity) have been undertaken for a period covering about 3000 years. Results do not give evidence of any obvious correlation, except for short periods, eliminating the possibility of a systematic effect, but still leaving the problem open; one can also question the validity of deuterium and beryllium isotopes as indicators.

Several other methods required for in depth examination exist, each being blemished with specific problems (growth circles of tree, varves, historic documents, etc.).

Some global and systematic measurements, mainly spacecraft-borne measurements are now beginning to become available (measurements of the solar constant, the solar spectrum and the cosmic particle flux, global measurements of the cloud coverage, etc.)

There is a move towards models of interactions allowing some global modelling (see for example the *TIMED* experiment, *Multiscale*, etc.).

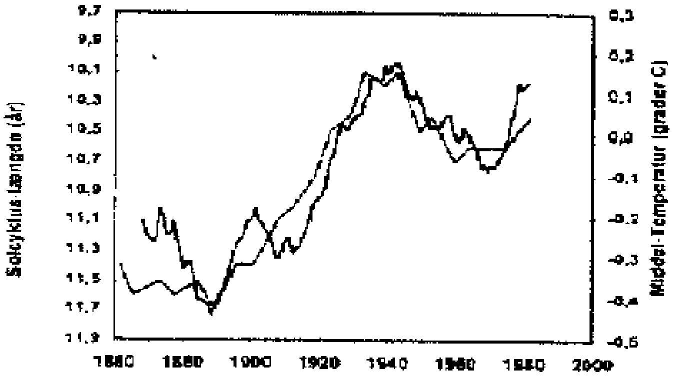


Fig. 19 : Plot of solar activity and terrestrial average temperature between 1860 et 1990.

In conclusion, the study of the effect of the space environment on the terrestrial climate, and in particular the fluctuations of solar activity at all scales is certainly a domain worthy of interest that can be approached rigorously while trying to understand causal relationships. The need for long-term measurements recorded and archived in a consistent manner is essential. Several measurements and recent methods allows to hope for progress in a close future.

2.12 DATA NEEDS FOR SCIENTIFIC RESEARCH

Data and indices collected in the framework of monitoring and forecasting of solar-terrestrial relations must be preserved and remain accessible. Fundamental scientific research needs them as complementary data allowing location of new observations in a general context. The development of empirical models for forecasting make systematic use of them. They are indispensable for testing the quality of new methods over a sufficiently long time. Theoretical models, that should replace more empirical methods for forecast, also require a large amount of data for their validation.

These data and indices cover solar activity, the state of the interplanetary environment (parameters measured in situ), the state of the magnetosphere and geomagnetic activity as well as measurements of cosmic rays. Since the majority of these phenomena is modulated by the eleven year solar cycle, and these cycles often differ from one another, it is on periods of several tens of years that this gathering must be performed.

Finally, quality of calibration and homogeneity of measurements are crucial. It is on this last point that indices play an important role since they provide a restricted but consistent view of phenomena over several tens of years, or even several hundreds of years.

<u>Example of Demeter</u>: It is also necessary to mention the interest in forecast and restitution of the ionospheric environment for missions interested in natural terrestrial signal analysis, as possibly produced during earthquakes (Demeter mission).

3 CURRENTLY EXISTING SERVICES

3.1 CURRENTLY EXISTING FORECAST CENTRES

Scientific work in solar astrophysics and geophysics is at the origin of the creation of many geomagnetic and solar observatories since the end of the last century, to which have been added numerous ionospheric stations as well as cosmic ray observation stations. Although alert messages were already distributed in the twenties for the purpose of radio communications using ionospheric propagation, the systematic exchange of data between laboratories really began in 1957 with the International Geophysical year, specifically aimed at allowing the data synthesis while multiplying observation sites. The present network of forecast centres (ISES: International Space Environment Service) functioning in the frame of the scientific unions (ICSU) largely results from this action that was aimed, in the first place, at scientific research.

This organisation, capable of collecting data from the different observatories, distributing them and making solar activity, geomagnetic and ionospheric forecasts, was useful for the development of applications, in particular applications related to the space environment and telecommunications. The distribution of ground and space data has been strongly developed in recent years since today one counts nearly 200 Web sites around the world (of which about fifty are in Europe) referenced for example on the http://www.geo.fmi.fi/spee/links.html site.

In comparison with this large number of sites distributing data related to solar-terrestrial relations, only a few centres provide forecasts regularly. Besides those of the ISES (centres of Ottawa, Boulder, Tokyo, Sydney, Peking, New Delhi, Moscow, Warsaw, Prague and Paris) some centres provide their forecasts to the public, often ionospheric (Rutherford-Appleton Laboratory, Northwest Research Associates), but also auroral (University of Alaska), generally on a weekly basis. For strategic reasons, many countries have their own ionospheric forecast centre, as in the case of France, with the one of France Telecom-CNET in Lannion. The Transmission and Ionospheric Systems (TSI) department measures and models the propagation, mainly in the ionosphere, for ground-to-ground communications and communications by satellites in a domain of wave lengths ranging from centimetric waves to VLF waves and predicts characteristics of the propagation channels according to the solar and geomagnetic environment.

To this end, propagation forecast software developed by the CNET is operated by users (armed forces, governmental services, industry, radio broadcasters). This type of software requires as input indices of solar activity provided by solar observatories, in particular by the Paris-Meudon Centre. Complementary data about the state of the ionosphere is obtained thanks to specific instruments, such as the modern technology numeric sounder SCIPION, which equips French survey stations, as well as a retro diffusive sounder (sounder of the Losquet island), which allows measurement of characteristics of the ionosphere in a zone of about 3000 km of diameter centred on France. CNET is chairing the COST 251 (Improved Quality of Telecommunication System Planning and Operations) activity.

The ISES network is organised to provide data and daily forecasts. Its centres are various regional centres, although they are financed at national level. Their forecasts are related to the needs of their region: the Ottawa centre is concerned mainly with north American geomagnetism, those of Sydney and New Delhi with ionospheric activity in their regions, and the one of Paris by the needs of space agencies.

3.2 PARIS-MEUDON CENTRE

The Meudon centre is the regional centre of the ISES for Western Europe. It is part of the department of solar physics and the scientific department COMPAS of the Meudon observatory. In comparison to the centre of Boulder (section 3.3) it is a small centre consisting of five people (two of them from CNRS, of which one is a researcher, two scientists of the contingent and a programming engineer funded by CNES). It provides daily data and standard forecasts to about fifty users, free of charge, by electronic mail and specific forecasts to space agencies, under contracts.

The first ones are mainly research laboratories (including the European sounder EISCAT) and telecommunications users (CNET - France Telecom, Deutsche Welle, Marconi, radio amateurs). An effort is also made to answer general questions from the public, and more specific questions from engineers, concerning solar-terrestrial relations. The Web site (http://www.dasop.obspm.fr/previ/) allowing other users to access the forecasts, had 2700 accesses from outside between 1 December 1997 to 31 July 1998.

Activities of the centre for space agencies are indicated in the list on the following page (asterisks indicate projects).

1. SPACE TRAJECTORY

Daily forecast especially for :

	SPOT2 Doris (1989-)	CNES
	SPOT3 Doris (1993-)	CNES
	TOPEX-POSEIDON Doris (1992-)	CNES-NASA
	ERS-1 (1990-)	ESA
	ERS-2 (1995-)	ESA
	HELIOS-1 (1995-)	CNES - DGA
	SPOT4 (1998-)	CNES
*	***HELIOS***-2	CNES - DGA

Regular provision of data to the Service of Trajectory of CNES
to Canadian Space Agency
to ISRO (Indian Space Agency)

2. ALTIMETRY

Particuliar forecast for :

*	***ENVISAT*** (1999-)	ESA
*	***JASON-1*** (2000-)	CNES-NASA

3. TECHNICAL STUDIES

- Participation to ESA study (Dassault,Onera…) : "Protection Against Radiations in Space" (1987).
- CNES study for *Hermès*: "Solar eruption prediction" (1988).
- CNES study for *SPOT4-HELIOS* "geomagnetic activity and centimetric flux prediction" (1992-93).

4. SATELLITES REENTRY CAMPAIGNS

For CNES :	- ***Skylab*** (1979)
	- ***Cosmos 1402*** (1983)
	- ***Cosmos 1900*** (1988)
	* ***MIR*** (1999)
For Indian Space Agency :	- ***SROSSC*** (1992)

5. ANOMALY INVESTIGATIONS

For CNES (Toulouse and Kourou), ESA (ESOC) and industry (Matra, Aérospatiale...)

6. MONITORING OF SPACE ENVIRONMENT DURING LAUNCH

SPOT2 (1989)	CNES-Toulouse
TDF2 (1990)	CNES-Toulouse

7. VALIDATION OF SCIENTIFIQUES EXPERIMENTS

PHOBOS	(1988-89)	CESR-Toulouse
HIPPARCOS	(1989-93)	ESA

In addition, the researcher managing the centre, P. Lantos, has scientific responsibility for the programme of cosmic ray observations of the IFRTP (Polar Institute): the centre distributes results from the cosmic rays monitors of Terre Adélie and the Kerguelens islands.

3.3 NOAA FORECAST CENTRE IN BOULDER

Situated in Boulder (Colorado, USA), the Space Environment Center depends on the one hand on the Oceanic and Atmospheric Research, and on the other hand on the National Weather Service of NOAA (National Oceanic and Atmospheric Administration). In total it includes 73 people of which 20 are doing post-doctoral training. Its mission is threefold:

- it makes the synthesis and dissemination of information concerning the space environment, present, past or forecasted, for users and added services industries.
- it performs research and develops techniques to improve the knowledge of the environment and its forecast.
- it plays an expert role for operators affected by disruptions of the space environment and also a role of general education for the public.

A part of the Space Environment Center is an operational service, working night and day 7 days out of 7, to collect data of interest for the knowledge of the space environment:

- ground based measurements of the magnetic activity indices type, images of the Sun at several wave lengths, through the ISES
- measurements made by the meteorological satellites (*TIROS*, *GOES*), the *ACE* satellite and scientific satellites (flux of particles, images of the Sun, measurements of the solar wind).
- results of models (Magnetospheric Specification Model).

It delivers space environment bulletins thanks to almost permanent presence of two people (a solar technician and a forecaster). These people are either staff of NOAA, either belonging to NOAA corps or US Air Force. During the solar minimum (until 1997), the technician was present 24 hours out of 24 (3 per day) and the forecaster 10 hours out of 24 (1 forecaster). From 1998 (rise of the solar cycle), the service has been increased to be completely assured (24 hours out of 24) by 3 technicians and 3 forecasters at the end of 1998.

3.4 INTEREST OF NETWORK BASED WORK

The ISES network (fig. 20) is first an organism benefiting from the support of the international scientific community via the Scientific Union. Endowed with a steering committee bringing together persons responsible for the various forecast centres, it enables co-ordination of projects and support (with respect to their own national authority) of observatories that need it, and organisation of Solar-Terrestrial Prediction workshops, extensively open, which are the main venues where methods and results related to Space Weather are presented. An exchange programme for forecasters between centres is also a noteworthy point.

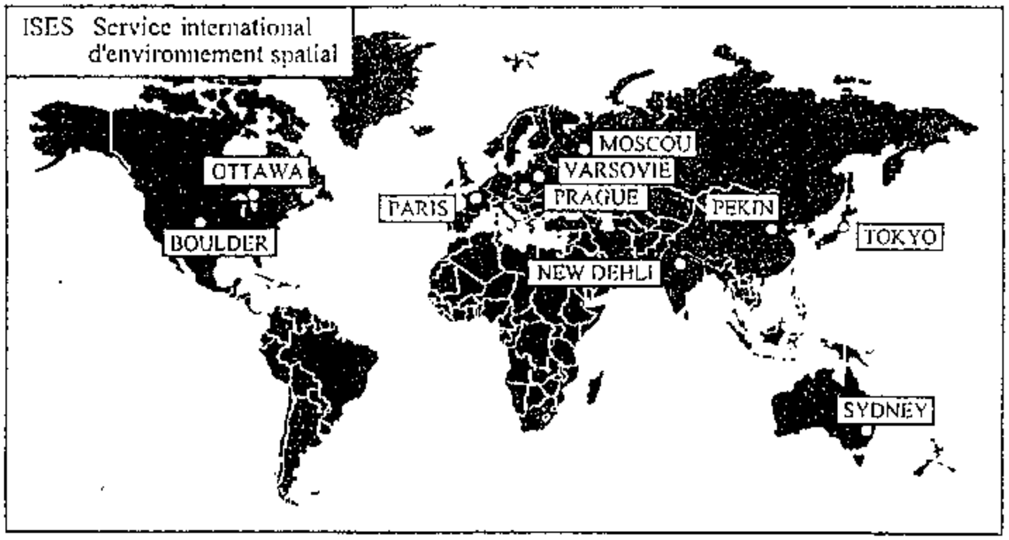


Fig. 20 : Location of the centres of ISES network

Web sites have already be mentioned above. They have been put into services these last years only. Before that, one of the essential roles of the ISES network was the collection and the distribution of data. The ISES network benefited strongly from two US actions: on the one hand the installation at USAF bases distributed around the Earth's surface of an optical observatory network to monitor the Sun (*SOON* network) and of a similar network of radio monitoring of the Sun, and on the other hand US meteorological satellites on geostationary orbit, the *GOES* satellites of NOAA, on which have been placed very early X-ray and interplanetary proton detectors. In the same way, X-ray data from the Japanese satellite Yohkoh were available for the sole purpose of forecast several years before they became public on the Web. The network allows better organisation of this type of collaboration while protecting the scientific interests implied in the satellite operations.

As we have seen, every forecast centre of the ISES network has its centres of interest related to the needs of its own customers. Therefore, every centre develops its methods and chooses its "products". The network provides the possibility to compare methods in detail (computer program comparison for example) and to validate the forecasts in common.

Finally one can note that a network of the ISES type has the advantage of making forecast centres with considerably differing size, financial means and types of users collaborate with one another. This is possible because, with regard to forecasts, if the number of "products" is related directly to the size of centres, their quality is an independent parameter. Finally, each centre keeps its autonomy (which is important considering cultural differences) while benefiting from a cordial collaboration.

3.5 LIMITATIONS OF THE PRESENT NETWORK

With the exception of the Boulder centre which, as we have seen, is very developed, the other centres are of a relatively small size: about twenty people for Sydney and Tokyo, a few people for the others. This is sufficient to send out daily messages, but they cannot assure 24 hours out of 24 hours operation. They send out alerts (called PRESTO messages) only during their active times and, where some of them are closed during weekends, only during working days.

A second limitation results from the fact that with the exception of Boulder, Tokyo and Sydney, ISES centres do not have their own instruments. They depend therefore on the existence of observatories in their zones (for every centre these ground data are the most recently available), although the Web and the provision of space data have fundamentally modified this aspect.

Finally, a third limitation of the network: with the exception of Boulder, the centres do not have budgets allowing development of forecast methods under contract by scientific laboratories or private companies. Each centre is doing it autonomously. For the time being, this does not represent a handicap (as seen with the quality of common forecasts - solar flare forecast, centimetric flux forecast and geomagnetic activity forecast-), but there is no doubt that when a forecast based on complex models and powerful calculation methods develops (this is the ambition of the Space Weather Program - Ref. 10), there will be a serious problem for all the other centres. It is also clear that in the present state, only the Boulder centre, because it belongs to NOAA, can anticipate having its own space data.

✲ ✲

✲

4. EVOLUTION OF THE SUPPLY AND DEMAND

A demand exists. It justifies about a hundred people currently working at the Space Environment Centre and even more at its military equivalent, the 55th Space Weather Squadron. How is this demand going to evolve? And what about the demand in Europe? What is going to be the evolution of the US public service provision, and what provision is it necessary to guarantee in a European zone?

THE DEMAND

Decrease of the demand?

1. Palliative measures: one can imagine that the present brainstorming on these problems of solar activity simply relaxes because some palliative measures for the detrimental effects will be developed:

- launchers and satellites in orbit: technologies immune to radiation (optronic?)
- orbital manoeuvres: development of on-board autonomy for navigation, payload programming...
- man in space: abandoning solely to the US responsibility management of the exposure of European astronauts to radiation;
- propagation of waves: systematic use of bi-frequency systems allowing the necessary corrections for space-ground systems to be made, disappearance of long distance HF communications.
- air crew staff: this is of regulatory nature and so can only lead toward an increase in the precautions taken. These precautions could however result in individual follow-up measures (badge) which would not justify the existence of a centralised service.
- effects on ground: the only domain of activity concerned is electrical energy distribution. Automatic protection systems could appear, making a forecast service superfluous.

It is likely that some of the users identified today can remove detrimental effects of solar activity on the terrestrial environment. It remains highly unlikely however, that no user will remain.

In addition, with widespread deregulated competition, the tendency for the operators will be to reduce working costs of systems in nominal mode, giving up costly palliative solutions and accepting the risk of some incidents from time to time. An alert service will then be valuable.

2. Progression of the knowledge: one can also envisage that decisive steps forward will be made in the understanding of the mechanisms relating the Sun to the terrestrial environment.

Nothing today allows one to hope that the complexity of the phenomena involved will be quickly clarified. As the science progresses, new phenomena are discovered and new questions open up. It is very unlikely that in the near future the understanding of Solar-terrestrial relations will reach a level so that monitoring of them become superfluous. On the contrary, it is the accumulation of observations that will be the basis of the progression of theories of these solar-terrestrial relations.

Increase of the demand?

1. Growth in volume: multiplication of satellite constellation operators, extension to other countries of instructions based on the European Directive related to the protection of air crew, renewal of interest in long distance HF communications.
2. Emergence of new types of users. Entry into a new solar cycle should rapidly allow perspectives for growth of this sector to be better identified.

One of the first future users which one can think of is meteorology. There is today no connection between space weather and classic meteorology. Nevertheless, newly identified phenomena such as 'sprites' and 'jets' testify to the existence of major interaction phenomena between the ionosphere and the atmosphere (Ref: doc. Sun-Earth Connection Roadmap, NASA).

When these processes become better understood, as is currently programmed by NASA through its Sun-Earth Connection Roadmap (TIMED, Magnetospheric Multiscale, Global Electrodynamics, ITM Dynamics missions...), it will be logical to envisage that prediction of geomagnetic activity will then be an input for the meteorological forecasts.

Evolution of the service provision?

The progression of the scientific understanding of Solar-terrestrial relations will potentially allow enrichment of the service: more precise and diversified forecasts, longer advance notice. Simultaneously, the evolution of US society (the role of the United States is predominant in the supply of the current service) suggests that two types of behaviour are going to restrict the civilian public service which comes to us from them

a) The military argued for their activity on national security grounds. They insist on the title "<u>National</u> Space Weather Program"! It is in their logic to establish positions less and less co-operative with respect to foreign countries.

b) People or private companies plan to develop and to commercialise added value products and targeted services based on the collected observation data. The SEC will certainly be invited to not overshadow these entrepreneurs and, therefore, to remain upstream, far enough from applied services.

With the demand tending to increase and the public service provision having a calling to cut down, an initiative therefore needs to be considered in Europe

❈ ❈

❈

5 DIFFERENT LEVELS OF SERVICE FORESEEABLE - THE NECESSARY MEANS

The present investigations enable us to synthesise a certain number of expressed needs.

SYNTHESIS OF THE NEEDS

The identified user needs (the number in the first column refers to the subsections of section 2) are summed up in Table 1. The last column "observable sources" indicates the observed data from which, with the present state of knowledge and available models, one develops the product sought by the user.

A classification of these same needs is presented in Table 2, according to two axes: the domain concerned and the characteristic time of the need considered. The reference times (month, day, hour, second) are orders of magnitude. It is necessary to note that the identified needs require (in restitution or forecast) shorter time deliveries than one day. One can consider that the demands expressed in days or months are already satisfied by existing means if one is concerned with the restitution but not forecasts.

Table 3 is a tentative of classification of needs expressed with respect to the scientific community. The classification by domain is the one adopted in the US Strategic Plan of the Space Weather Program.

Many scientific products are not requested as such by end users but they are necessary inputs to other scientific domains. End users are underlined.

TABLE 1 : PRELIMINARY SYNTHESIS OF USER NEEDS

N°	User	Needs	Type	Information provided by the service	Observables- source
1	Ariane V Launcher	Latch-up	p/h	Protons >10 MeV	X-ray flux
1	Launchers	Optimisation of flight planning (altitude for faring jettisoning),	p/h	Atmospheric density profile	UV flux (F10.7) Geomagnetic indices
2	Satellites in orbit	Support to anomaly analysis	r/h	Particles environment	Particles fluxes
3	Orbit control for LEO satellites	planning of manoeuvres and instruments	p/d	Atmospheric density	UV flux (F10.7) Geomagnetic indices
3	Aero-braking	Altitude and perigee corrections	p/h	Atmospheric density	UV flux (F10.7) Geomagnetic indices
3	Debris monitoring	continuity of the monitoring	p/h	Atmospheric density	UV flux (F10.7) Geomagnetic indices
3	Atmospheric re-entry	date of re-entry	p/m	Atmospheric density	Wolf number
4	Man in space	planning EVA	p/h	Doses / hour	Proton fluxes Cosmic ray flux
5	Localisation system ARGOS	ionospheric correction	r/h	correction term	Local total electronic content
5	Satellites based navigation system	ionospheric correction	p/s	Map of propagation corrections	Regional total electronic content
5	Altimetry	ionospheric correction	r/h	correction term	Local total electronic content
5	Geophysical signals detection	ionospheric correction	r/d	correction term	Local total electronic content
5	COMSATs	PIDB and PCA forecast	p/h	warning of perturbations	Solar activity Geomagnetic activity

Convention used for the 'Type' column: p= prevision r= restitution
m= month, d= day, h= hour, s= second

N°	User	Needs	Type	Information elaborated by the service	Observables - source
6	HF radio scattering	frequency planning	p/m	optimal frequency	ionospheric characteristics
6	Post-nuclear environment	discrimination of natural phenomena	r/h		
6	Communications HF (ALE)	optimisation of the HF frequency use	p/h	optimal frequency	ionospheric characteristics
6	Military Over-the-horizon radar	detailed knowledge of the path of particular echos	r/s	characteristics of the propagation medium	ionospheric characteristics
6	Meteorological Over-the-horizon radar	knowledge of the statistics of the paths of the due echos	r/h	characteristics of the propagation medium	ionospheric characteristics
7	Air crew staff	knowledge of the received doses	r/d	doses	neutron monitors
8	Electrical networks	management of collapse hazard	p/h	alarms	geomagnetic activity
9	Pipelines	prevention of corrosion	p/h	warning	geomagnetic activity
10	Geophysical survey	campaign planning	p/h	warning	geomagnetic activity
11	Meteorology	TBD			to establish
12	Scientific research	TBD			all parameters

Convention used for the ‘Type’ column: p= prevision r= restitution
m= month, d= day, h= hour, s= second

TABLE 2 : CLASSIFICATION BY DOMAIN OF INTEREST AND TYPICAL TIME

	PREVISION				RESTITUTION			
	MONTH	**DAY**	**HOUR**	**SECOND**	**SECOND**	**HOUR**	**DAY**	**MONTH**
ATMOSPHERE	• Atmospheric re-entry of satellites	• LEO satellite orbit control • Satellite atmospheric re-entry	• Aero-braking operation • Orbital debris monitoring • Launchers				• Trajectory • *Meteorology*	• Scientific researcl
PARTICLES		• Man in space • Air crew	• Launchers • Satellites	• Satellites		• Support to the analysis of spacecraft operational anomalies • Post-nuclear environment	• Air crew	• Scientific researcl
IONOSPHERE	• HF radio scattering		• COMMSATS • Long distance HF comms • Electrical networks • pipelines • Geological survey	• Navigation satellites (GPS)	• Military Over-the-horizon RADAR	• Localisation (ARGOS) • mono-frequency satellite based altimetry • Over-the-horizon meteorological RADAR	• Satellite based geophysics • Oil and mining prospection	• Scientific researcl • Altimetry bi-fréquence by satellite
Ser-vice	Publications	Normal service with administrative time	Permanent service 24/24	Automatic service	Automatic service	Permanent service 24/24	Normal administrative service	Publications

TABLE 3 : RELATIONS : PHYSICAL PHENOMENA –RESEARCH THEMA- USERS

(reference: National Space Weather Programme - Implementation Plan - January 1997)

Domain	Research theme	Expected products	Themes or users involved
CME	Physics of CMEs triggering factors	Occurrence Magnitude Duration	Geomagnetic perturbations
Solar activity, flares	Solar dynamo Precursors	Occurrence Magnitude Duration	Ionosphere Atmoshere
Solar and galactic particles	Origin and propagation Cosmic rays	Flux at orbital altitudes	<u>Man in space</u> <u>Air crew</u>
Solar rays UV/EUV/Xsoft	Variability of the sun in these wave length Interaction with the ionosphere and the thermosphere	Intensity Variations	<u>Meteorology</u>
Solar radio sound	Radio emission from the high altitude corona Triggering processes	Intensity Variations	<u>Communications</u> <u>RADAR's</u>
Solar wind	heating and acceleration processes Propagation	Density and velocity Magnetic field	Conditions for interaction with the magnetosphere
Particles et magnétosphere's magnetic field	Coupling solar wind/magnetosphere Initiation, expansion and relaxation of sub storms Transport and energisation of the magnetospheric plasma	Magnetic and electric fields Ions and electrons Aligned Currents and electrojet	Perturbations geomagnetic <u>Satellites</u>
Geomagnetic perturbations	Physical mechanisms of the perturbations Induction of surface currents	geo- magnetic indices Initiation, intensity and duration of geomagnetic sub storms	<u>Induced Currents in terrestrial networks</u> <u>(electric distribution pipelines</u>
Radiation belts	Radiation belts dynamics	trapped ions and electrons	<u>Satellites and launchers operators</u>
Auroras	Particle acceleration in auroral zones	geographical boundaries energy	Ionosphere Radiation belts

Domain	Research theme	Expected products	Themes or users involved
Ionospheric properties	Electronic density distribution response to storms et sub storms Production, transport and collapse of density structures	Electronic density Plasma temperature Drift velocity	Communication and navigation system Atmosphere
Ionospheric electric fields	Structure and response to variations in the magnetosphere Variability produced by the interactions in the equatorial zones	Global electric field global Electrojet current	Atmosphere
Ionospheric perturbations	Global variability Local irregularities	Initiation of perturbations Characteristics of propagation	Communication systems Wave propagation
Ionospheric scintillations	Mechanism of production of the scintillations	Occurrence between 200 et 600 km	Communication and navigation system Atmosphere
Neutral atmosphere	Chemical, radiative and dynamic processes in the high altitude atmosphere	Density, composition, temperature and velocity	Trajectory

Priorities

Table 4 below outlines a classification of the challenges related to the supply of some of the main parameters of the terrestrial geomagnetic environment, according to 3 categories: the maturity of the specification of the service required (R1), the maturity of the means necessary to offer the considered service (R2), and the importance of the issue at stake (R3). The feasibility and the opportunity for an initiative increases with the rank from 1 to 5**.**

Product required	User	R1	R2	R3
X-ray flux	Launchers Satellites	2 5	3 3	5 5
UV flux	Trajectory	3	3	4
Energetic particle flux	Air crew Man in space Satellites	5 5 3	5 5 3	5 4 4
Geomagnetic indices	Mining and oil prospection Electrical networks	1 2	3 4	2 2
Local total electronic content	Altimetry	5	3	3
Regional total electronic content	Navigation system	5	4	5
Ionospheric characteristics	Communications RADAR	5 2	4 2	5 3
Local atmospheric density	Launchers	5	4	3
Global atmospheric density	Trajectory Atmospheric re-entry Debris	5 4 4	4 4 4	4 4 4

The priorities that thereby appear for the service to offer are the follow-up of air staff crew; navigation by satellites; trajectory, and the environment of satellites.

The key physical elements and "time" factors concerning them seem to be:

- atmospheric density and exospheric temperature (forecast some hours, some days and some weeks ahead)

- total electronic content (forecast some minutes ahead, restitution some hours ahead)

- proton flux (forecast some hours to some days ahead).

An initiative is therefore to be considered in Europe, covering at least these priority needs.

Today, a service covering these parameters uses on board sensors, ground based sensors, models, etc... New ideas suggest that an improvement of the services could be obtained, either with dedicated micro-satellites, or with the help of instruments installed on board some more important satellites.

The funding or the progressive establishment of the corresponding capacity in Europe (modelling /forecast, but also corresponding physical measurements) can be according to various scenarios.

✵ ✵

✵

6 DEVELOPMENT FRAMEWORK AND SCENARIOS FOR INITIATIVES IN EUROPE

If it seems to us premature to propose a development strategy for an operational service, it is however useful to present the main criteria that the selected strategy will have to satisfy and to give some indications of the way to follow.

- **European, necessarily European**.

The physical phenomena involved on a planetary scale, and the means of observation and communities of users are essentially at the European scale (civilian aviation, navigation by satellite...) or world-wide. While strictly national interests are real (trajectory, communications, over-the-horizon RADAR), they do not justify treatment out of a European context.

- **A minimum of independence in the strategic sectors**

The service provided is currently extensively dominated by the SEC. This prominence of the US national centre of the ISES is certainly an asset for the quality of the service offered, but the ambiguity of its statute (responsibility at both national and international level) leaves open the possibility of a certain national privilege, desired by US political power for example in cases of commercial or industrial conflicts of interest. It is therefore necessary to identify 'strategic' sectors that one wishes to protect, at the European level against a possible stop to data provision.

- **A public European service**

This notion of public service is not redundant with the notion of independence. A European public service could rely exclusively on the American means, possibly in a commercial mode, and reciprocally a service independent of US data could be commercially provided or reserved to a particular category of users. It seems to us that the service considered must be essentially public, without forbidding oneself the supply of individualised services or products, on a commercial or contractual basis like *Météorologie Nationale*. The service currently offered by SEC can be considered as the reference for what this European public service could be.

- **Public value of scientific work**

It is useful to note that:

- a national programme (PNST) is especially interested is the development of this domain;
- two very large international instruments [TGE for *trés grands équipements* in French] (THEMIS and EISCAT) and space based TGE's (SOHO,...) co-operate to supply the scientific community with data of primary importance in this domain;
- archive centres (CDPP, BASS 2000, MEDOC), co funded by CNES-CNRS, address the concern with long-term storage;
- national scientific expertise in the physics of the ionosphere and the thermosphere has existed for more than thirty years in laboratories known within the discipline: CESR, CETP and LIS, and developed more recently with a modelling activity and numerical simulation of solar winds/magnetosphere/ionosphere/thermosphere couplings;
- operational models (for example SALAMMBO of ONERA).

- **Help the emergence of a new sector of commercial activity**

Downstream of the activities of data collection, treatment and dissemination, of general interest, dedicated activities with potential for commercial profit can appear. A dozen US entrepreneurs ('vendors') are already present in this embryonic market.

From the above, the following proposals for actions result:

- **To co-operate** with USA (NOAA, NASA), Japan, Russia...., ground stations, future space projects, models. Co-operation is on the one hand a means to recover the delay already existing, and on the other hand to position oneself as a credible partner for the future. On the short term, the use of instruments (of the ERME or COMRAD type) onboard geo-stationary satellites is to be encouraged. On the longer term, a co-operation in the GEOSTORM project of NOAA is foreseeable.

- **To ensure the support of the European scientific community** to contribute to the advancement of this program as a response to the expressed needs.

This can be done by relying on the existing structures (European Science Foundation, ISES, ESA...) while organising dedicated symposia. One of the difficulties faced by SEC is to transfer into usable operational tools (robust, stable, easy to use...) the available scientific knowledge. It will be necessary to encourage scientists to undertake this kind of work which complements their usual objectives.

- **Search for a European frame**

Initiatives are in progress in Europe. It is necessary to co-ordinate them. This responsibility cannot be assured in a strictly national frame.

The natural frame to assure the guardianship of a space weather service would be a meteorological organisation. It is a fact that a European organisation comparable to NOAA does not exist. Institutions that could sponsor this initiative are:

- The European Assembly of Science and Technologies, created in 1994, whose role is to give opinions and recommendations to the European Commission.
- The European Science Foundation, an association of the main European research organisations, that also provides opinions and recommendations in the scientific domain to the Commission,
- ESA, which is not presented here,
- EUMETSAT which operates European meteorology satellites.

- **Approach the identified users** (civil aviation administrations, airline companies, satellites operators...) to sensitise them to these questions and also to refine the specification of the specific service, in the context of encouraging the emergence of commercial provision of added-value products.

SCENARIOS FOR INITIATIVES IN EUROPE

Even assuming that an initiative in Europe to create a space weather service of a level comparable to the one in the USA would meet with sufficient support, the questions of its organisation and of its relations with the various organisations and existing national or European administrations arises.

The task attempting to set up an operational European Space weather service is original in several ways:

- it precedes the demand, since in the present state a part of the existing demand is satisfied by the use of the services of the Space Environment Centre of NOAA, a situation whose continuity is not guaranteed;
- space resources will certainly be present but not exclusive (terrestrial observatories, scientific models, data bases) but it cannot be strictly a space programme;
- partial but relevant initiatives have been taken or are in progress in Europe (HELIOS Centre of the university of Lund, in Sweden, system of RIMS stations for EGNOS...);
- important resources already exist and can play an important role for a Space Weather service: without priority order one can mention as national or European resources: THEMIS, EISCAT, BASS 2000 and MEDOC data bases, the CDPP, ...and with an international structure INTERMAGNET (magnetic station Network);
- the beneficiaries constitute a rather heterogeneous set, ranging from airline companies to operators of satellite constellations while encompassing terrestrial system operators (electric distribution, HF communications);
- as has already been said, it is not a scientific programme for which the working methods are well specified.

The model which it is necessary to be inspired by is not therefore one where a decision making authority gathers partners around a clear and unique objective, but rather one where a union of companies and administrations allows and supports activities for the setting up of an operational service after having identified a domain of common interest.

Of course all of these issues and questions apply to a greater or lesser extent on the other side of the Atlantic. It is therefore useful to analyse the US Space Weather programme, even though it is not necessarily immediately transposable in Europe.

The US Space Weather programme [Ref 10] is the outcome of an initiative of scientists that relied on the National Science Foundation to make administrations like NASA, NOAA, the DoD and others adhere to a common charter. The philosophy of the Space Weather Programme can be summarised by an analogy: it is about a "hunting license" delivered by the programme to all projects whose objectives are identified in the programme. Every agency sustains projects that it wants and inter-agency structures are built bit by bit.

Is such a model applicable for a European initiative? Between which partners?

The institutional parties involved in the domain could be:

- the European Commission, initiator of the directive on the air crew staff and of the EGNOS system (in association with EUROCONTROL and ESA)
- European and national space agencies and industries, both as potential customers (satellites and launchers) and as space and terrestrial resources suppliers,
- national research organisations (CNRS, Max Planck,...), indispensable for the sensitising of the scientific community
- in a second circle, the specialised governmental agencies (for France, CNET, ONERA, IPSN, OPRI for example).

The orchestra leader remains to be found. Eventually, if a European service was established, it would be necessary to think about federating these efforts under the umbrella of an International organisation that could rather naturally be the WMO (World Meteorological Organisation).

✼ ✼

✼

7 PROPOSALS OF INITIATIVES

On the short term, at the French level:

- Continue sensitising designers and operators (telecoms, launches, satellites,...), notably to the approach of the next solar maximum. Collect information concerning incidents and the physical data concerning disruptions associated with the terrestrial environment.

- To affirm oneself like a partner of the SEC while providing the support network to ACE. The NASA ACE satellite (Advanced Composition Explorer) carries a useful payload (RTSW Real Time Solar Wind) permanently transmitting parameters of the solar wind at the Lagrange point L1 about 30 minutes before its arrival in the terrestrial neighbourhood. The telemetry of RTSW is received mainly by a station in England and another in Japan. A request from SEC to complete this coverage by the use of stations of the CNES network is under consideration.

- Quickly propose a service based on the one offered by Meudon centre, while installing it in an already-validated operational context.

- To encourage the scientific communities, in France and in Europe, in the present dynamic progress in the understanding of the Solar-terrestrial relations, to think about the contribution that could be made to an operational service, to structure an implementation plan of the application of these advances and to approach the agencies with, as evidence, the tools which can now be foreseen for an improved service.

- To establish, with our European partners a "European Space Weather" initiative, for example by a quick establishment of a "European Initiative Group", which would be responsible for collecting the requirements (started already extensively by our group, in particular), existing national means and the scientific problem. A preliminary sensitising report could be prepared for mid 1999. It would also be useful to inform and to sensitise scientists, operators and designers by means of specialised symposia every two years (the first in 2000).

REFERENCES

1) Bourrieau, J.-P. David, L. Lévy - Cours d'environnement spatial, Edition Supaéro, Toulouse 1996.

2) Cours du CNES de Mécanique Spatiale 1995 - Tome 1 Les Perturbations d'orbite, C. Valorge

3) M. Ocko - Propagation of upper atmospheric storm effects towards lower latitudes COSPAR 98 (à paraître)

4) Environnement Terrestre et Planétaire – La Recherche n° 125, 1981 - Roger Gendrin

5) GNSS & WAAS architectures sept 96, ION-GPS-96, S. Loddo et al. Thomson-CSF

6) Journal officiel des Communautés européennes L159 du 29 juin 1996

7) Radiation Exposure of Civil Aircrew - Proceedings of Luxembourg CEC Workshop,
Radiation Protection Dosimetry, 48, n°1, 1993

8) http://www.intermagnet.org

9) "Le Soleil en face" Pierre Lantos, 1997, Masson

10) The National Space Weather Program, FCM-P31 – 1997, Office of the Federal Coordinator for Meteorological Services and Supporting Research

LIST OF ACRONYMS

ACE	Advanced Composition Explorer
ALE	Automatic Link Establisment
ATN	Air Traffic Network
CCD	Charged Coupled Device
IRCC	International Radio Consultative Committee
CIS	Community of Independent States
CLS	Collecte Localisation Sauvetage
CME	Coronal Mass Ejection
CNET	Centre National d'Etude des Telecommunications
DLA	Direction des Lanceurs (CNES)
D2B	Scientific Satellite (CNES-1975)
EGNOS	European Geostationary Navigation Overlay System
EMP	Electromagnetic pulse
ERS-2	Earth resource system
ESA	European space agency
ESF	European Science Foundation
EVA	Extra Vehicular Activity
GNSS	Global Navigation Satellites Systems
GPS	Global Positioning System
GRGS	Groupe de Recherche en Géodésie Spatiale
GTO	Geostationary Transfer Orbit
IEM	Impulsion Electro magnetic
IONCAP	Ionospheric Communication Analysis and Prediction Program
IFRTP	Institut Français pour la Recherche et la Technologie Polaires
IPSN	Institut pour la Protection et la Sûreté Nucléaires
ISES	International Space Environment Service
ISS	International Space Station
LEO	Low Earth Orbit
LIS	Laboratoire Image Signal
MCC	Mission Control Centre
MEO	Medium Earth Orbit
NOAA	National Oceanic and Atmospheric Administration
PCA	Polar Cap Absortion
RFI	Radio France International
RIMS	Ranging and Intergrity Monitoring Stations
SEC	Space Environment Centre
SID	Sudden ionospheric disturbance
SPE	Solar Proton Event
SSO	Sun Synchronous Orbit
TDF	Télédiffusion de France
TGE	Trés Grand Equipement
TEC	Total Electron Contact (CET)
VLSI	Very Large Scale Integration
XMM	X-ray Multi Mirror mission