Usage of IGS TEC Maps to explain RF Link Degradations by Spread-F, observed on Cluster and other ESA Spacecraft

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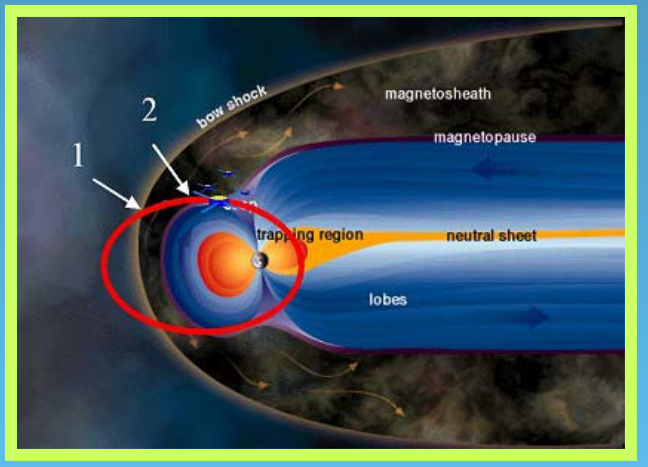
Introduction

- ***RF link anomalies were observed on the Cluster spacecraft in autumn and spring 2001, 2002 and 2003:***
  - Sudden variations of the received RF signal power.
  - The duration of these disturbances ranged from 10 minutes to 4.5 hours, occurrence mostly in the local evening hours.
  - Maspalomas and Villafranca are the nominal tracking sites.

- ***A cross-disciplinary working group of experts at ESOC and ESTEC started investigations in January 2003:***
  - Spread-F could be identified as the source.
  - IGS TEC maps played a key role to relate the observed phenomena to Spread-F.
  - Recommendations for the operations of Cluster and other ESA missions.

Problem Description

Characteristics of the Cluster Mission (1)



- The 4 Cluster spacecraft were launched in July/August 2000.
- Highly eccentric polar orbits with heights ranging between 18000 km and 120000 km, line of apsides initially in the ecliptic plane.
- Ideal tetrahedron constellation in one orbital position, the inter-spacecraft distance ranged from 100 km to 5000 km up to now.
- The argument of perigee increases by about 5 degrees per year due to Moon and Sun attraction, causing the apogee to move southward.
- The orbital period of about 57 hours results in an average visibility from one ground station in the order of 22 hours, subdivided into 2 – 3 passes of typically 10 hours length, for all 4 spacecraft per orbit.

Problem Description

Characteristics of the Cluster Mission (2)

- All science data acquired during non-visibility periods are stored on-board and dumped to ground during the visibility periods.
- Initially, Villafranca was the only nominal ground station. Maspalomas became the second nominal ground station in September 2002.
- Nominally SC1 and SC2 are tracked from Villafranca, SC3 and SC4 are tracked from Maspalomas.
- The Telemetry & Telecommand uplink frequency is 2064 – 2077 MHz, the downlink frequency is 2242 – 2256 MHz.

Problem Description

Observed phenomena (1)

The uplink/downlink RF signal power is monitored via the receiver <u>Automatic Gain Control (AGC)</u> on-board resp. at the ground station.

– The AGC level of the satellite receiver shows strong and fast fluctuations as increasing and decreasing signal strength.

– The AGC level of the ground station receiver shows the same behavior.

– If the variations are too strong-, data dump has to be stopped to avoid data losses.

– It is vital that enough time is available to downlink the data stored on-board before they get overwritten.

Problem Description

Observed phenomena (2)

– 23 events were registered until May 2002 at Villafranca, no event was observed at Redu from May – September 2002.

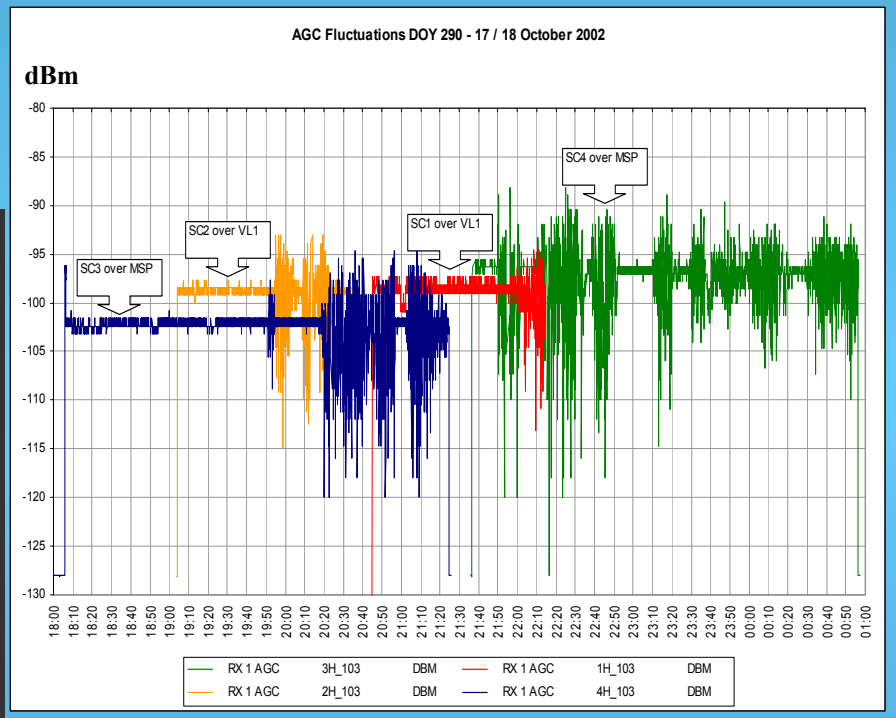
– Of a total of 96 passes for SC3 and SC4, 33 have been affected between mid September and end of October 2002 at Maspalomas.

– From 16 September – 31 December 2002 4 events were observed at Villafranca and 54 events at Maspalomas.

– All passes with fluctuations as seen from Maspalomas were in a window with an elevation <60 degrees and an azimuth range between 90 - 240 degrees, i.e. into the southern direction.

Problem Description

Observed phenomena (3)



– 91% of the documented events occurred in the September - December period, and they appeared during late evening hours between 19:50 to 02:00 UT.

– Due to the Cluster orbit and position of apogee relative to the Sun, most of the pass time in autumn is in the late afternoon up to early morning.

– The inspection of recent tracking data indicates enhanced presence of RF link disturbances at Maspalomas also for September – December 2003.

The Spread-F phenomenon

Creation of Spread-F

– Upwelling flux tubes of reduced plasma density "plasma bubbles" above the geomagnetic equator, their diameter is 20 – 200 km.

– After reaching the apex height in the geomagnetic equatorial plane around post-sunset, they move on either side of the geomagnetic equator and break into small patches.

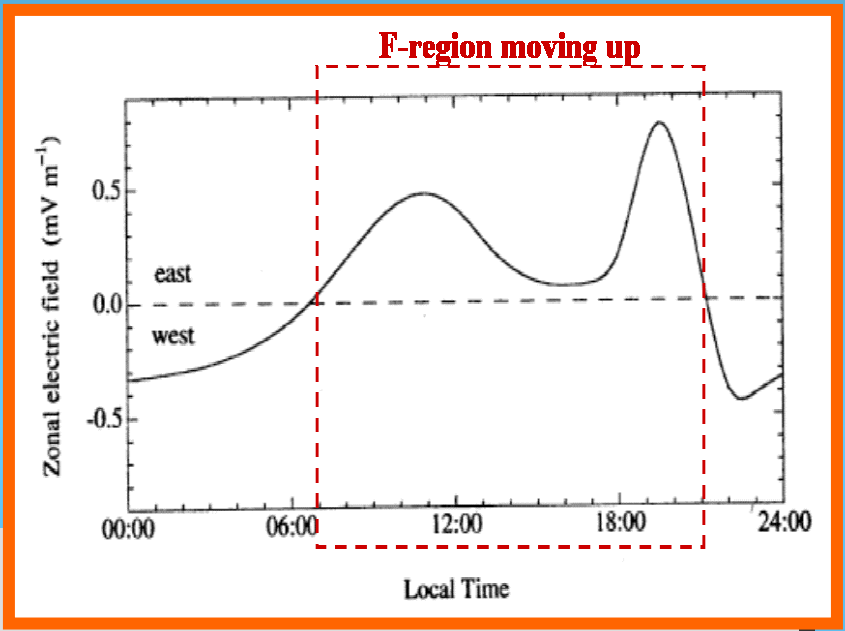
– Around 18:00 LT there can be a strong increase in the east-bound E-vector, causing the F-layer to move upwards due to Lorentz force.

– Around 21:00 LT the E-field reverses and directs to west. Lorenz force causes the F-region now to come down, and it can then become unstable.

* Effect on radio links: steep variations of the signal strength (scintillations).

The Spread-F phenomenon

Spread-F requires



– Well-developed eastward E-field at the geomagnetic equator.

– Sharp raise of the F-layer's height around sunset (above ~ 400 km).

– Geomagnetic storms (induced by Sun).

– The european longitude sector is stronger affected than others.

– Spread-F occurs within ~ ±15º lat. of geomagnetic equator between 400-1000 km altitude, primarily between 20:00-23:00 LT, but also in the post midnight sector during high geomagnetic sub-storms (induced by Earth).

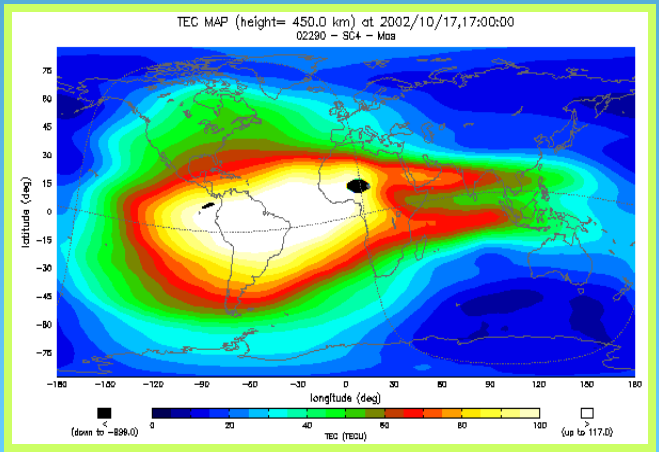
Applicability of Spread-F to observed link anomalies

Cluster (1)

– IGS TEC maps were used to find out whether the affected RF links passed through potential areas of Spread-F.

– For the majority of the reported anomalies this could be confirmed.

Applicability of Spread-F to observed link anomalies

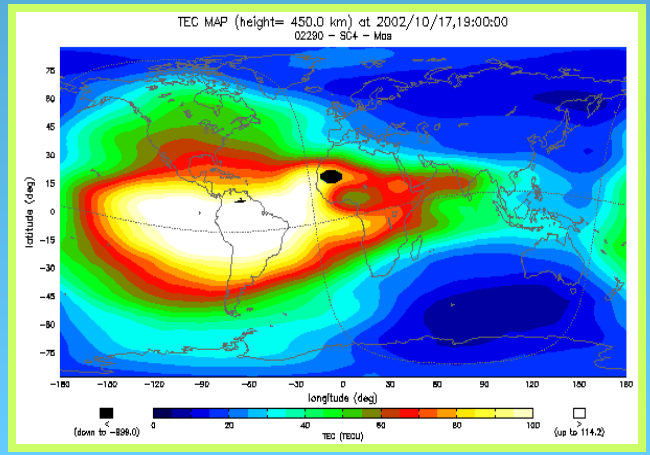


Cluster (2)

Maspalomas

← 17:00

19:00 →



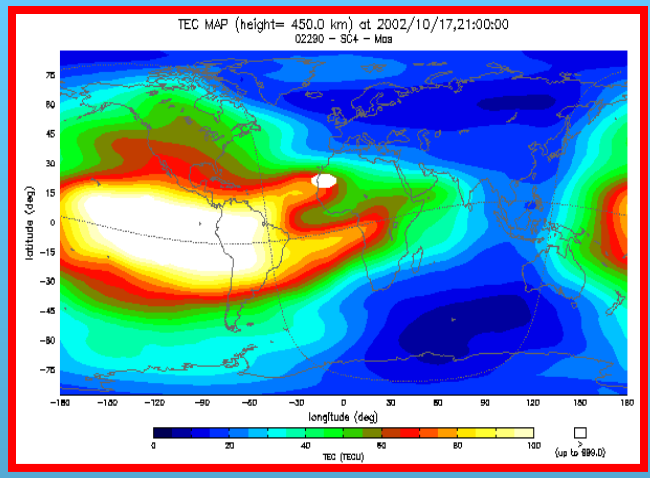
Maspalomas
17/10/2002,

SC4 pass from 17:59 – 21:24 UT,

fluctuations from 19:45 UT to pass end.

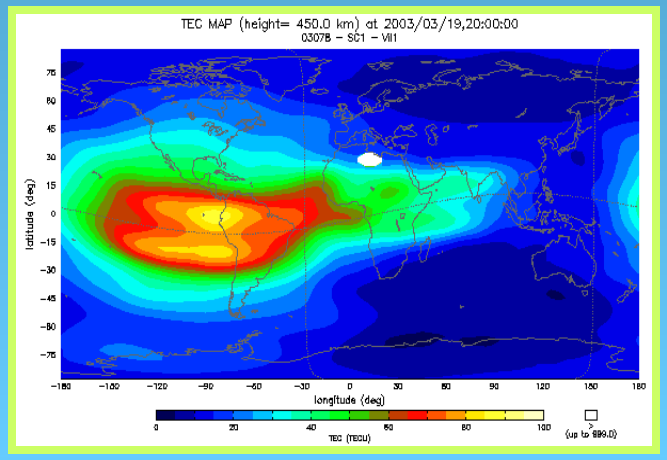
Maspalomas

21:00 →



esa TOS-GN

Applicability of Spread-F to observed link anomalies

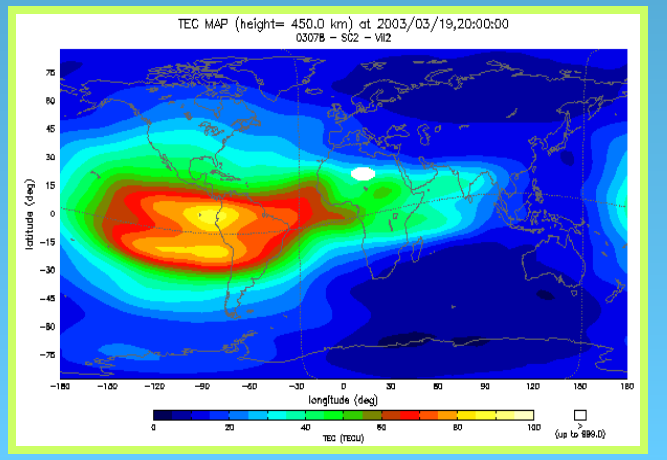


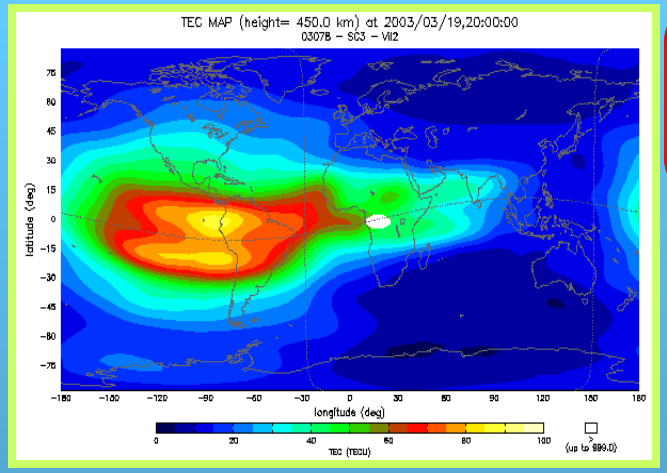
Cluster (3)

19/03/2003

Villafranca

← SC1 SC2 →





Fluctuations

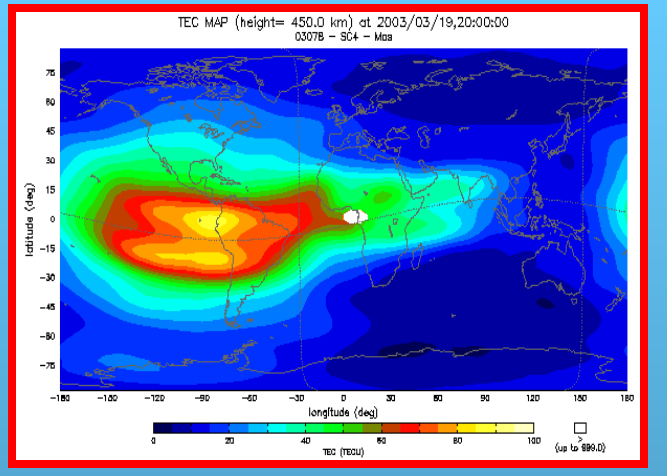
20:40 – 21:00 UT

on SC4.

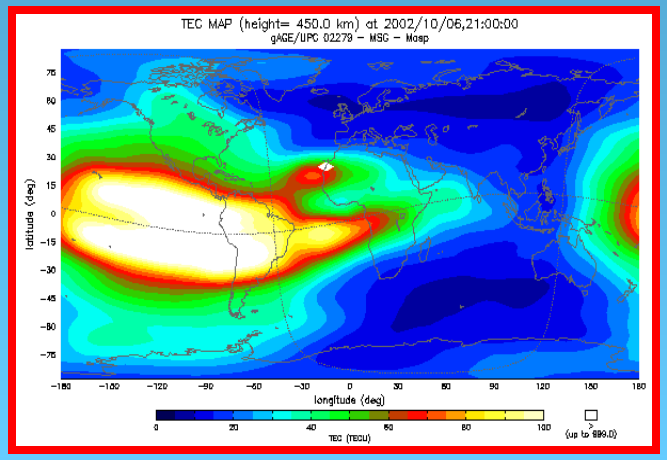
Villafranca

Maspalomas

← SC3 SC4 →



Applicability of Spread-F to observed link anomalies

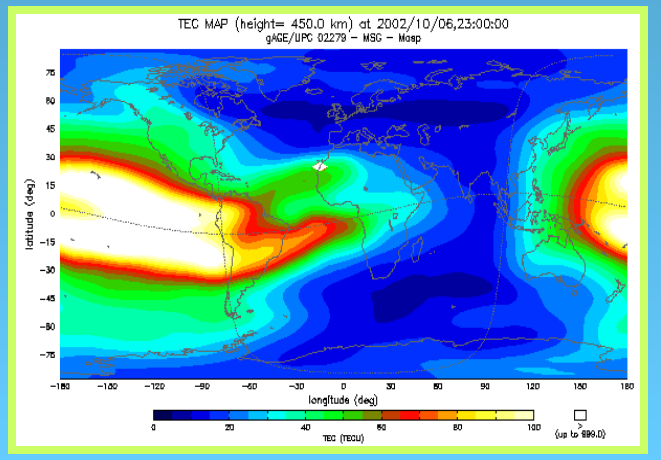


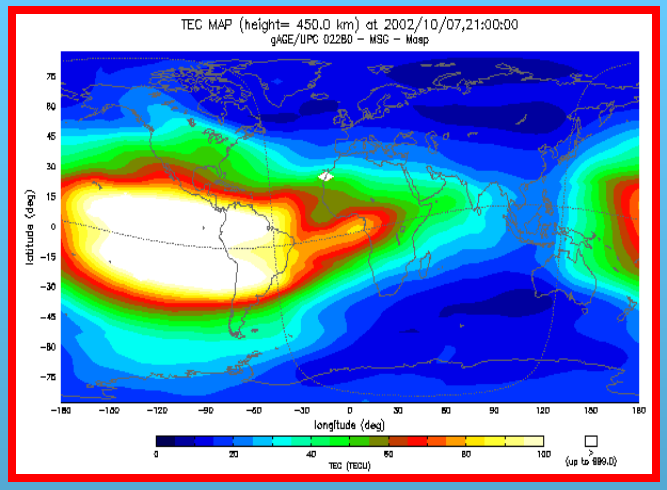
MSG-1

06/10/2002

Maspalomas

← 21:00 23:00 →





Fluctuations

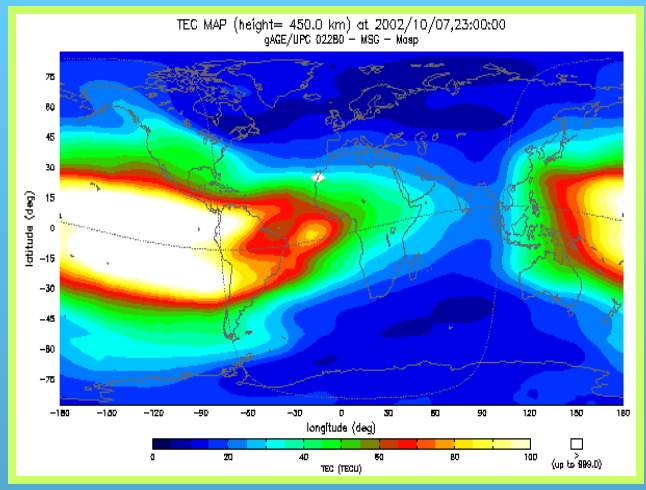
21:00 – 22:30 UT

on both days.

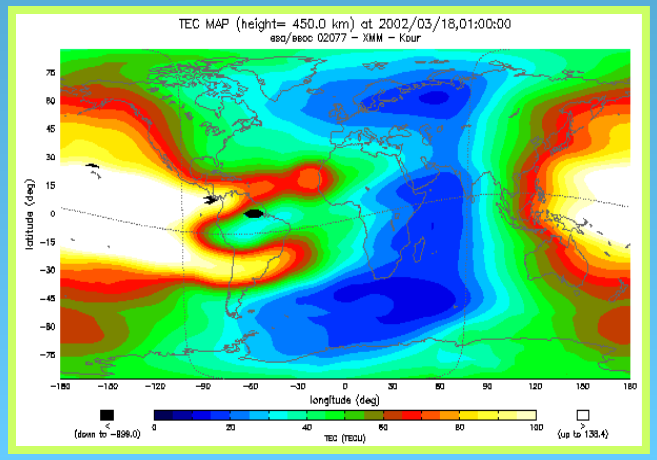
07/10/2002

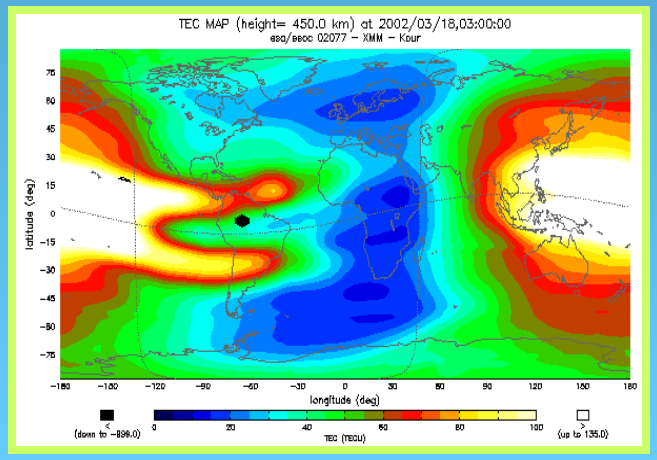
Maspalomas

← 21:00 23:00 →



Applicability of Spread-F to observed link anomalies



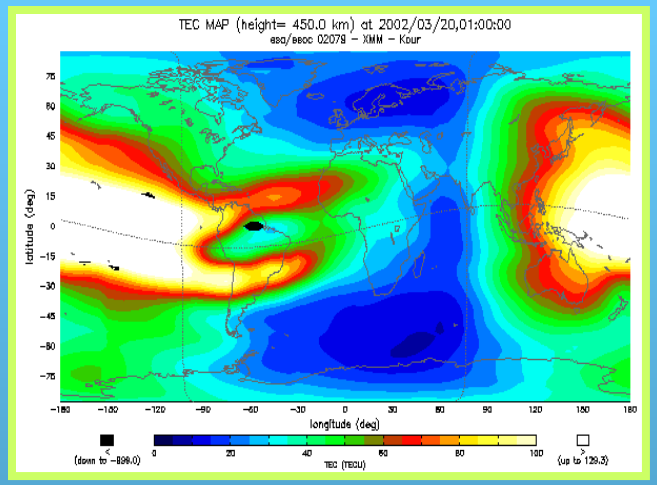


XMM

18/03/2002

Kourou

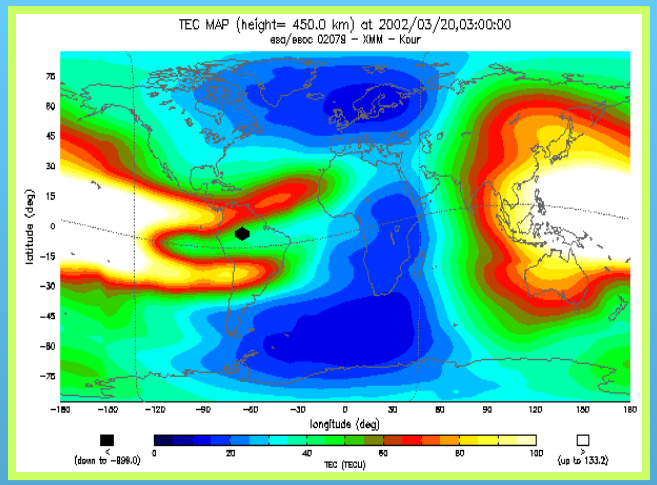
← 01:00 03:00 →



Fluctuations

01:30 – 02:30 UT

on both days.



20/03/2002

Kourou

← 01:00 03:00 →

Operational consequences for Cluster

The most practicable consequences:

- ***Usage of another nominal ground station than Maspalomas, e.g. Perth (conflicts with other missions) or 2nd antenna at Villafranca.***
- ***Reduction of the Cluster perigee by 7 – 9 degrees during the next constellation change manoeuvres.***

Possible consequences for future ESA spacecraft and missions

Some of the most important consequences:

- ***Usage of X-band rather than S-band in future missions.***
- ***Preferably usage of non-equatorial tracking sites.***
- ***Installation of an ionosonde at Maspalomas (at other sites?) ?***

Conclusions

- *The Cluster spacecraft suffer from seasonal link degradations up to complete signal loss.*
- *A working group of experts from ESOC and ESTEC could identify Spread-F as source of the problem.*

+ *Several proposals were made by the working group to handle the Spread-F problem in routine operations of the Cluster spacecraft.*
+ *Recommendations were made how to take care about Spread-F in future missions planning and design.*
+ *The installation of ionosondes at selected ESA tracking sites for Spread-F forecasts is considered.*
+ *The relevance of Spread-F for new navigation satellite systems, namely Galileo, should be investigated.*

- *IGS TEC maps played a key role to relate Spread-F appearance to observed satellite link disturbances at Cluster and other ESA spacecraft.*