



Consiglio Nazionale delle Ricerche



ISTITUTO DI SCIENZA E TECNOLOGIE
DELL'INFORMAZIONE "A. FAEDO"

BEPPOSAX REENTRY PREDICTIONS ISSUED FOR THE TEMPORARY MISSION STRUCTURE ESTABLISHED AT THE CIVIL PROTECTION DEPARTMENT

by

Carmen Pardini and Luciano Anselmo

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BEPPOSAX REENTRY PREDICTIONS

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BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship

$$B = \frac{C_D A}{2M}$$

(where A , M and C_D are, respectively, the satellite average cross-section, mass and drag coefficient), was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed from 12 December 2002 to 12 January 2003 (Figure 1). All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data, as USSPACECOM two-line elements, were provided by the NASA/GSFC Orbital Information Group. The result obtained was $B_N = 0.01157 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 13 January 2003, 16:28 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model (JR-71).

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the 27-day (corresponding to one solar rotation) forecasts issued by the NOAA Space Environment Center were adopted. For the subsequent months, such 27-day values were repeated, being considered more realistic and reliable, in the present application, against the standard long-term monthly smoothed predictions.

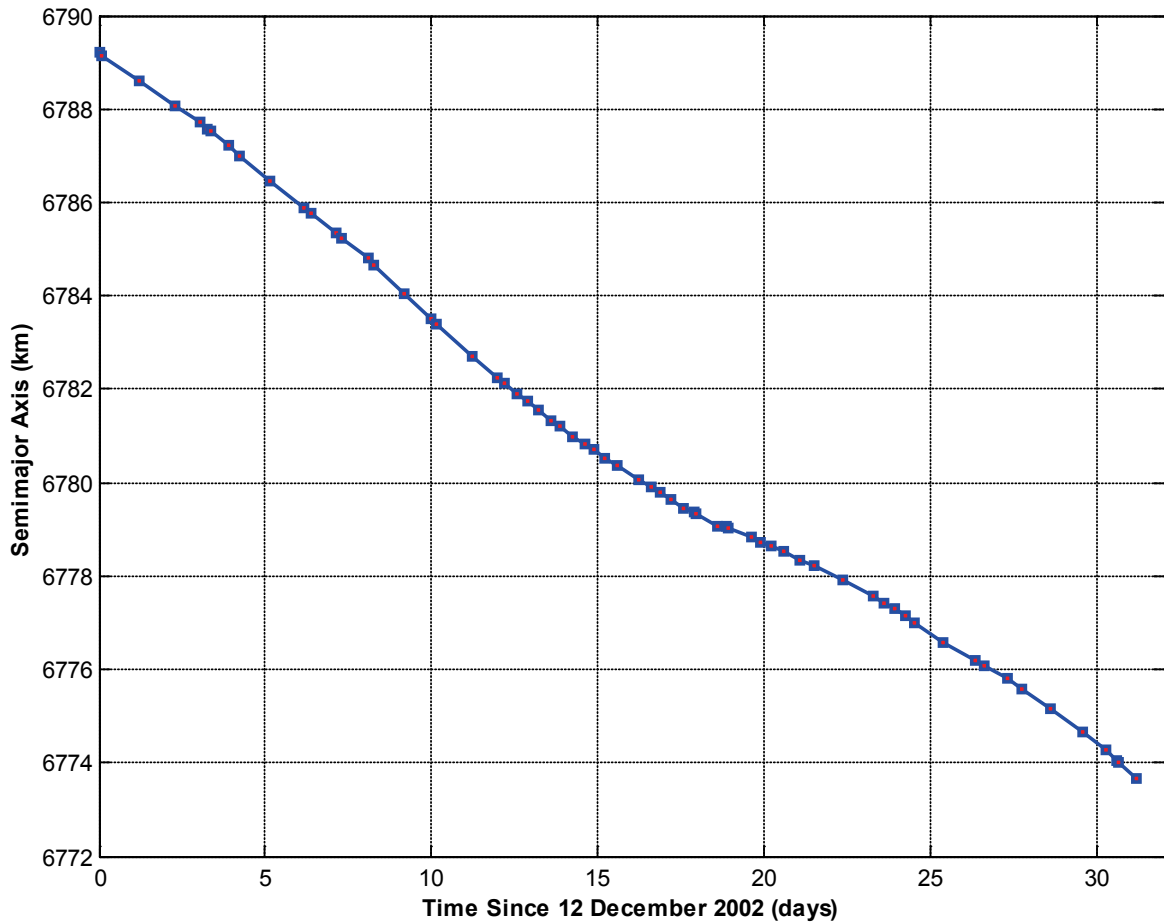


Fig. 1 – Observed semimajor axis decay of BeppoSAX from 12 December 2002 to 12 January 2003

Adopting for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last month, the nominal reentry date of 20 April 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window was computed by assuming a variation in the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window Definition

Reentry Window	Criteria	B (m ² /kg)	Reentry Date
Opening	$B_N + 25\%$	0.01446	2 April 2003
Nominal Reentry	B_N	0.01157	20 April 2003
Closure	$B_N - 25\%$	0.00868	22 May 2003

The reentry window includes the unavoidable uncertainties on the atmospheric model, the drag coefficient evolution and the space environment predictions (solar flux at 10.7 cm and A_p). Based on the experience of the past, the confidence level associated with the reentry window presented in Table 1 is approximately 90%.

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SATELLITE ORBITAL STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 92 minutes at an altitude in between 381 km (perigee) and 386 km (apogee). The orbit is inclined by 3.95 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

Because the orbit is near circular, the average altitude loss per revolution (Δh_{rev}) may be approximated using the following equation:

$$\Delta h_{\text{rev}} = -2\pi(C_D A/m)\rho a^2$$

In it ρ is the average atmospheric density along the orbit, a is the semi-major axis (i.e. the average distance from the center of the earth), while C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship

$$B = C_D A/m$$

was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed from 15 December 2002 to 15 January 2003 (Figure 1). All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data, as USSPACECOM two-line elements, were provided by the NASA/GSFC Orbital Information Group. The nominal ballistic parameter obtained was $B_N = 0.02272 \text{ m}^2/\text{kg}$.

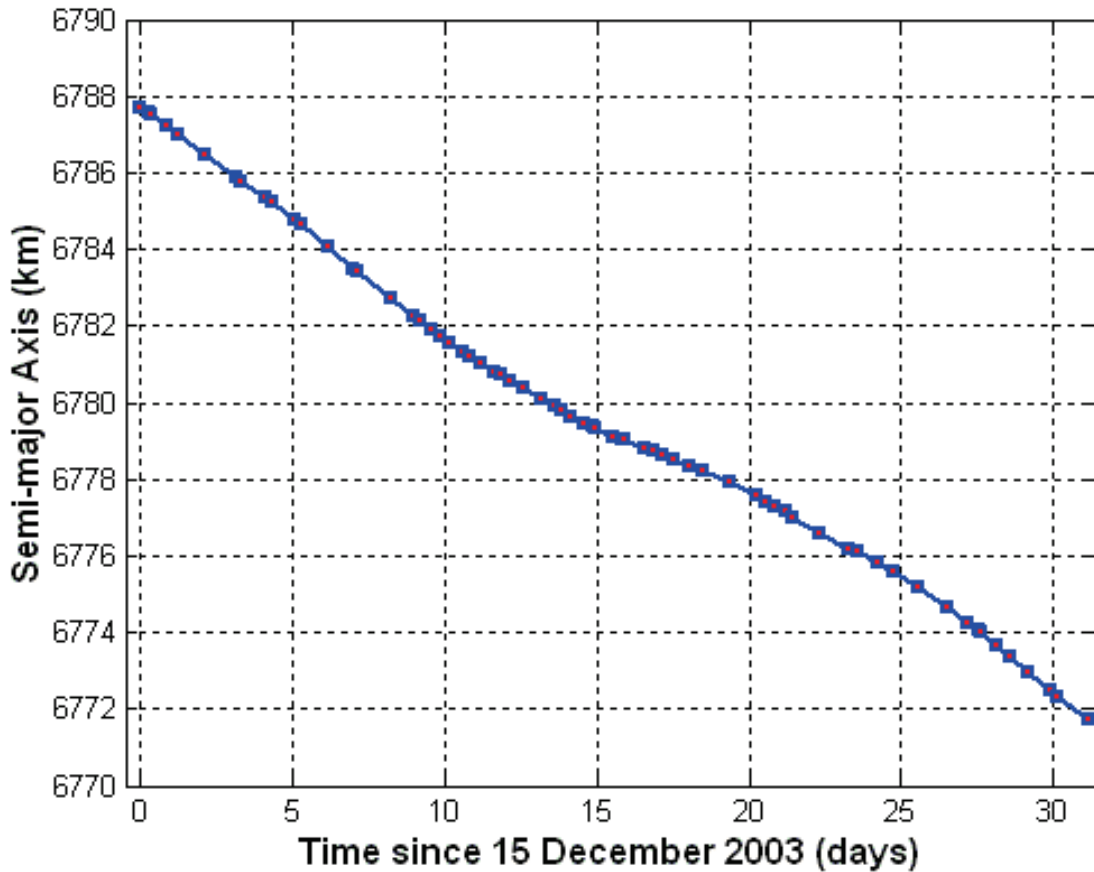


Fig. 1 – Observed semi-major axis decay of BeppoSAX from 15 December 2002 to 15 January 2003

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 15 January 2003, 16:02 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the 27-day (corresponding to one solar rotation) forecasts issued by the NOAA Space Environment Center were adopted. For the subsequent months, such 27-day values were repeated, being considered more realistic and reliable, in the present application, compared to the standard long-term monthly smoothed predictions.

Adopting for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last month, the nominal reentry date of 22 April 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window was computed by assuming a variation in the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.02840	4 April 2003
Nominal Reentry	B_N	0.02272	22 April 2003
Closure	$B_N - 25\%$	0.01704	24 May 2003

The reentry window includes the unavoidable uncertainties on the atmospheric model, the drag coefficient evolution and the space environment predictions (solar flux at 10.7 cm and A_p). Based on the experience of the past, the confidence level associated with the reentry window presented in Table 1 is approximately 90%.

NEXT UPDATE

The next reentry prediction will be issued on 30 January 2003.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBITAL STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 92 minutes at an altitude in between 374 km (perigee) and 379 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

Because the orbit is near circular, the average altitude loss per revolution (Δh_{rev}) may be approximated using the following equation:

$$\Delta h_{\text{rev}} = -2\pi B \rho a^2,$$

where ρ is the average atmospheric density along the orbit, a is the semi-major axis (i.e. the average distance from the center of the earth) and B is the satellite ballistic parameter [Ref. 1]. B is a complex function of spacecraft mass, size, shape, attitude and surface properties; in addition, it depends on the local atmosphere density, temperature and composition.

BALLISTIC PARAMETER EVOLUTION

In order to predict the future behavior of the ballistic parameter, critical for reentry predictions, a detailed study of its past evolution was carried out [Ref. 2]. Monthly average values of B were estimated by fitting, in a least squares sense, the BeppoSAX semi-major axis decay observed during the last three years. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data, as two-line elements based on US Space Surveillance Network measurements, were provided by the NASA/GSFC Orbital Information Group. Figure 1 shows the values of B obtained for the period following the satellite deactivation, on 30 April 2002.

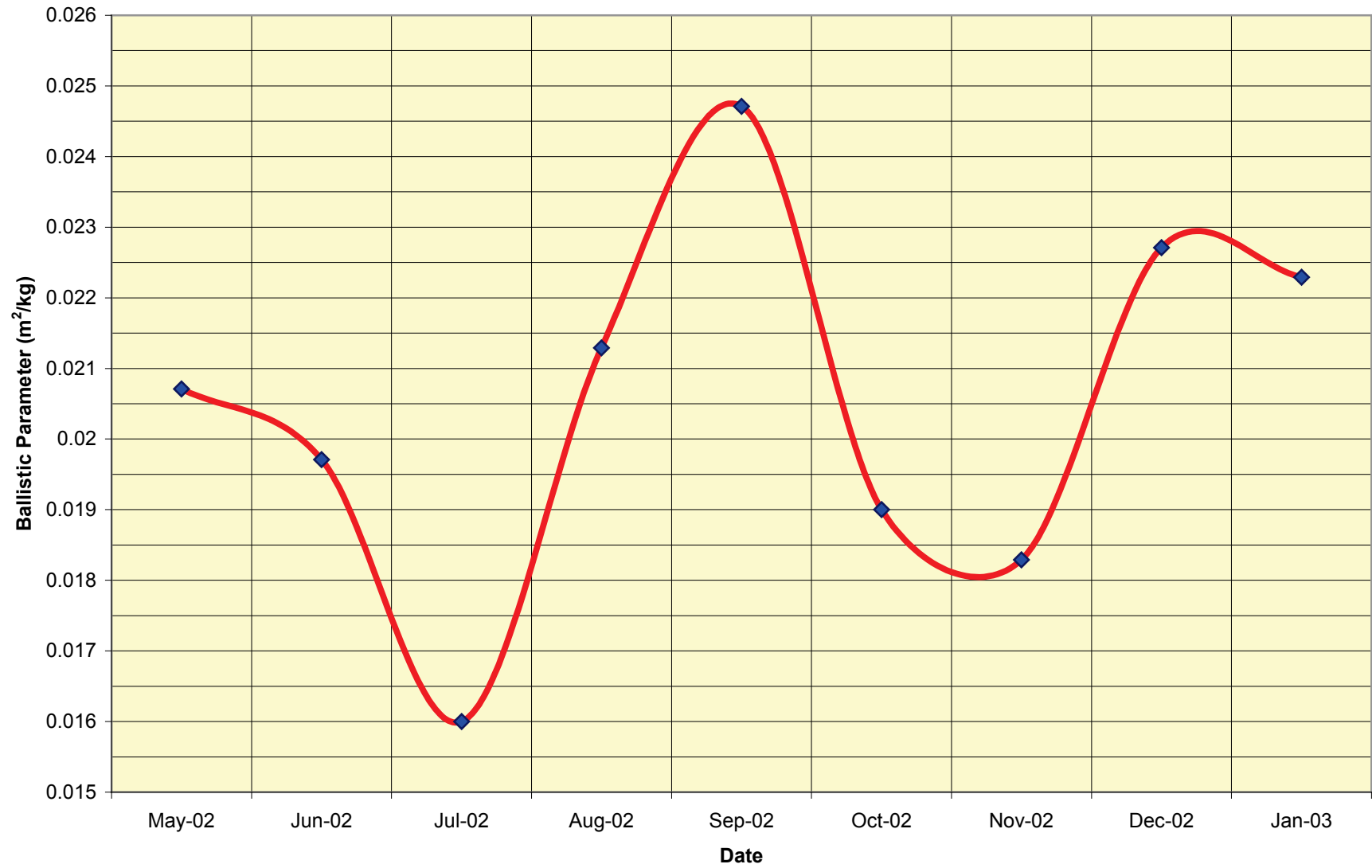


Fig. 1 – Ballistic parameter evolution (monthly averages) after the BeppoSAX deactivation (May 2002 – January 2003)

After the spacecraft switch off, and the consequent deactivation of the attitude control system, the average ballistic parameter obtained was (May 2002 – January 2003):

$$\langle B \rangle = 0.02051 \text{ m}^2/\text{kg} \pm 12\% \text{ (one standard deviation).}$$

As shown in Figure 1, during the last nine months the ballistic parameter oscillated around this average value, with no significant increasing or decreasing trend. Therefore, such a value was used for the nominal residual lifetime estimation.

BEPPoSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 30 January 2003, 02:24 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of 4.8 standard units per month [Ref. 2], while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

A reentry window with a confidence level of 90%, taking into account the observed variability of B and the intrinsic uncertainties of the solar activity predictions, was defined as follow. First of all, three-month running averages of B (after the satellite deactivation) and solar flux (after the last maximum) were computed to the present day. The three-month averaging period was chosen because comparable to the BeppoSAX residual lifetime. The statistical dispersions of such averages were therefore analyzed in order to find the ranges of variability assuring a confidence level of 90% (corresponding, in a normal distribution, to ± 1.645 standard deviations).

For B , a variability range of $\pm 8\%$ was found, which implicitly includes also the inaccuracies of the atmospheric model. For the solar flux, the variability range with respect to the decreasing trend recorded during the last 14 months [Ref. 2] was ± 17 standard units, corresponding to an air density variation of $\pm 22\%$ at the present satellite altitude and solar activity level. A reentry window with a confidence level of 90% could then be obtained by varying the nominal ballistic parameter by $\pm [(8\%)^2 + (22\%)^2]^{1/2} = \pm 23.4\%$.

Using for BeppoSAX the average ballistic parameter $\langle B \rangle$, the nominal reentry date of 10 May 2003 was obtained. Assuming a conservative attitude for the definition of the reentry window, a variation of $\pm 25\%$ was adopted, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m ² /kg)	Reentry Date
Opening	⟨B⟩ + 25%	0.02563	19 April 2003
Nominal Reentry	⟨B⟩	0.02051	10 May 2003
Closure	⟨B⟩ – 25%	0.01538	21 June 2003

LATITUDE BELT POTENTIALLY AFFECTED BY THE SURVIVING DEBRIS IMPACT

A reentry destructive analysis carried out for ASI by HTG [Refs. 3 and 4] has shown that 42 fragments of BeppoSAX, with a total mass of about 656 kg, will reach the ground. The fragments will rain down vertically, with respect to the local horizon, with terminal velocities in between 60 and 465 km/h. The debris footprint on the earth surface, aligned with the sub-satellite track, will be approximately 330 km long. Following the HTG results, the cross-track dispersion might reach ± 0.375 degrees, corresponding to about ± 42 km.

The definition of the latitude belt potentially affected by the impact of the surviving fragments results from the following relationship:

$$L_{\max} = I_{\max} + \delta + \Lambda,$$

where L_{\max} is the limiting latitude (North or South) of the above mentioned belt, I_{\max} is the maximum satellite orbit inclination, δ is a corrective term, for the conversion from geocentric to geodetic coordinates, and Λ is the maximum cross-track dispersion of the fragments. Taking into account the higher orbital inclination foreseen during the reentry window, $L_{\max} = 4.356$ degrees. Therefore, the BeppoSAX surviving fragments might reach any location in between 4.356 degrees North and South.

The countries or territories crossed by the above mentioned latitude belt are the following:

- **Africa:** Burundi, Cameroon, Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Gabon, Kenya, Rwanda, São Tomé and Príncipe, Seychelles, Somalia, Sudan, Tanzania, Uganda. Cap Palmas, at the border between Liberia and Côte d'Ivoire, and the Niger river delta, in Nigeria, are also skimmed by the limiting northern latitude;
- **Asia:** Brunei, Indonesia, Malaysia, Maldives, Singapore;

- **Oceania:** Baker Island (USA), Federated States of Micronesia, Howland Island (USA), Jarvis Island (USA), Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea;
- **South America:** Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Venezuela.

This list of countries or territories updates those presented in Refs. 5 and 6.

By following the approach presented in Ref. 7 and considering, in the latitude belt between 4 degrees South and 4 degrees North, an average population density, in 2003, of 6.778 people per square kilometer [Ref. 8], the debris casualty area (30 m²) obtained by the HTG study [Refs. 3 and 4] implies an a priori expected number of human casualties of about 2×10^{-4} . Table 2 summarizes the reentry probability as a function of latitude.

Table 2

BeppoSAX Reentry Probability as a Function of Latitude

Latitude Belt	Reentry Probability
0° – 1° N or S	0.081
1° – 2° N or S	0.086
2° – 3° N or S	0.103
3° – 4° N or S	0.230

NEXT UPDATE

The next reentry prediction will be issued on 13 February 2003.

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8. Johnson, N.L., *Personal Communication*, 24 January 2003.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 92 minutes at an altitude in between 365 km (perigee) and 370 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three months. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02186 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 12 February 2003, 10:10 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of 4.8 standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last three months, the nominal reentry date of 6 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.02732	19 April 2003
Nominal Reentry	B_N	0.02186	6 May 2003
Closure	$B_N - 25\%$	0.01639	7 June 2003

At present, solar flux predictions are still the leading source of uncertainty. This situation will change only a few weeks before reentry, when the ballistic coefficient will play a comparable role. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime. If updated BeppoSAX state vectors will be available during the last 6 hours, the final uncertainty on the predicted reentry time might be reduced to ± 45 minutes, corresponding to one full orbital track.

NEXT UPDATE

The next reentry prediction will be issued on 27 February 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 91.8 minutes at an altitude in between 356 km (perigee) and 362 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three months. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02276 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 26 February 2003, 10:04 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of about five standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last three months, the nominal reentry date of 11 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.02845	25 April 2003
Nominal Reentry	B_N	0.02276	11 May 2003
Closure	$B_N - 25\%$	0.01707	13 June 2003

At present, the solar flux predictions are still the leading source of uncertainty. This situation will change only a few weeks before reentry, when the ballistic coefficient will play a comparable role. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued on 17 March 2003.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 91.4 minutes at an altitude in between 338.8 km (perigee) and 340.5 km (apogee). The orbit is inclined by 3.96 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.98 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last two months. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02253 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 17 March 2003, 01:41 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of about five standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last two months, the nominal reentry date of 2 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.02816	22 April 2003
Nominal Reentry	B_N	0.02253	2 May 2003
Closure	$B_N - 25\%$	0.01690	19 May 2003

At present, the solar flux predictions are still the leading source of uncertainty. This situation will change only a few weeks before reentry, when the ballistic coefficient will play a comparable role. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued no later than 27 March 2003.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 91.2 minutes at an altitude in between 328.6 km (perigee) and 331.0 km (apogee). The orbit is inclined by 3.959 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.981 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss (Figure 1), which will culminate in the satellite reentry on the earth.

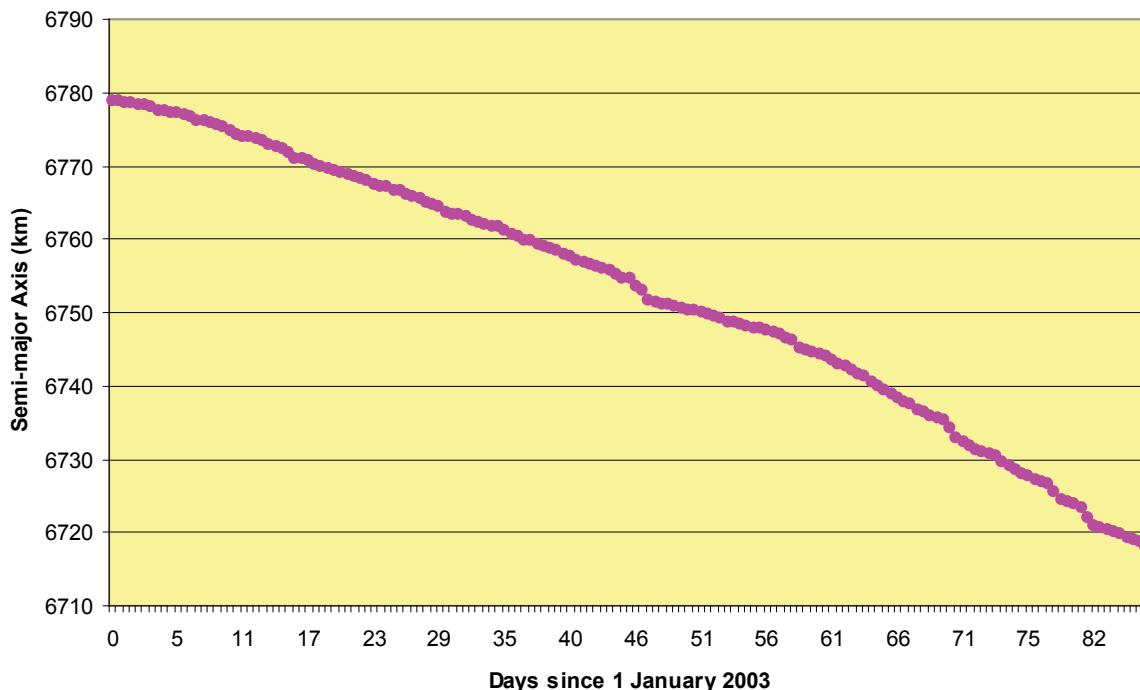


Fig. 1 – Mean semi-major axis decay observed since 1 January 2003

BALLISTIC PARAMETER ESTIMATION

Figure 2 shows the evolution of the BeppoSAX ballistic parameter observed since the deactivation of the satellite, on 30 April 2002. The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last month. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02400 \text{ m}^2/\text{kg}$.

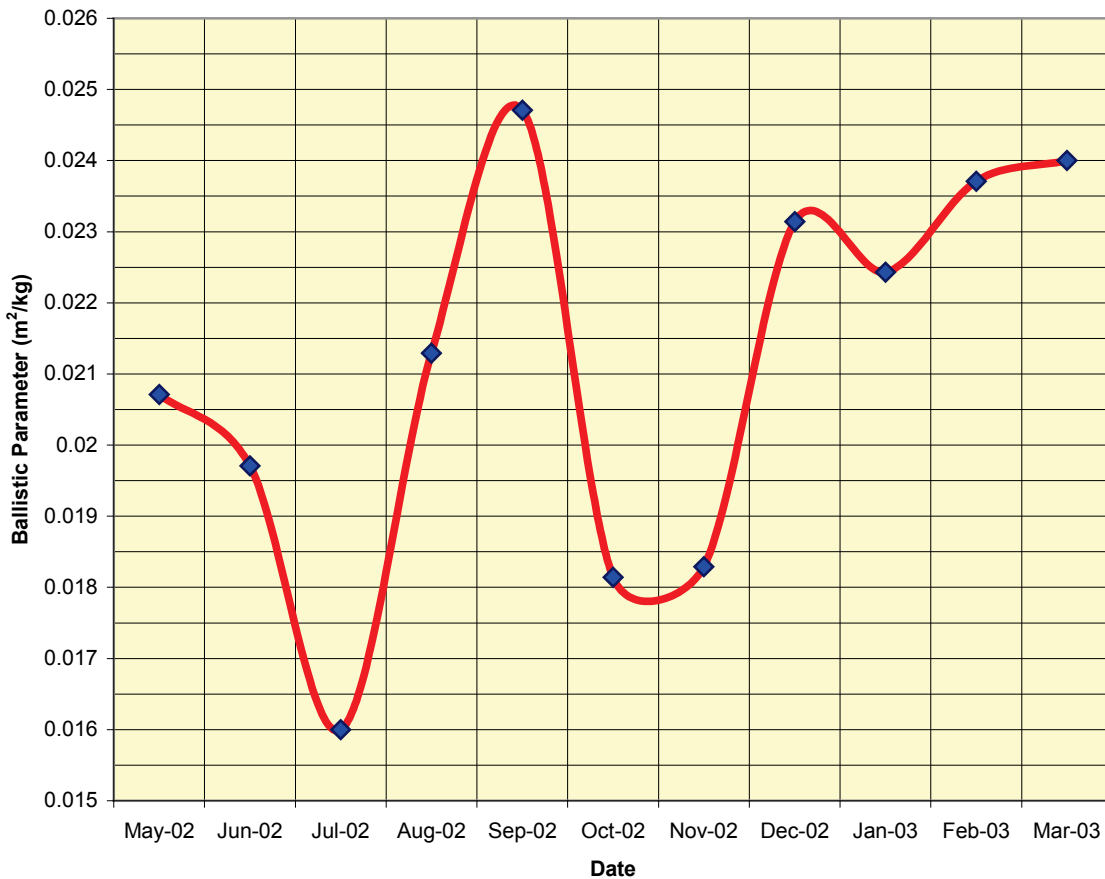


Fig. 2 – Ballistic parameter evolution (monthly averages) after the BeppoSAX deactivation (May 2002 – March 2003)

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 27 March 2003, 02:54 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and

degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of about five standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index. Figure 3 shows the observed and predicted values of the solar flux at 10.7 cm.

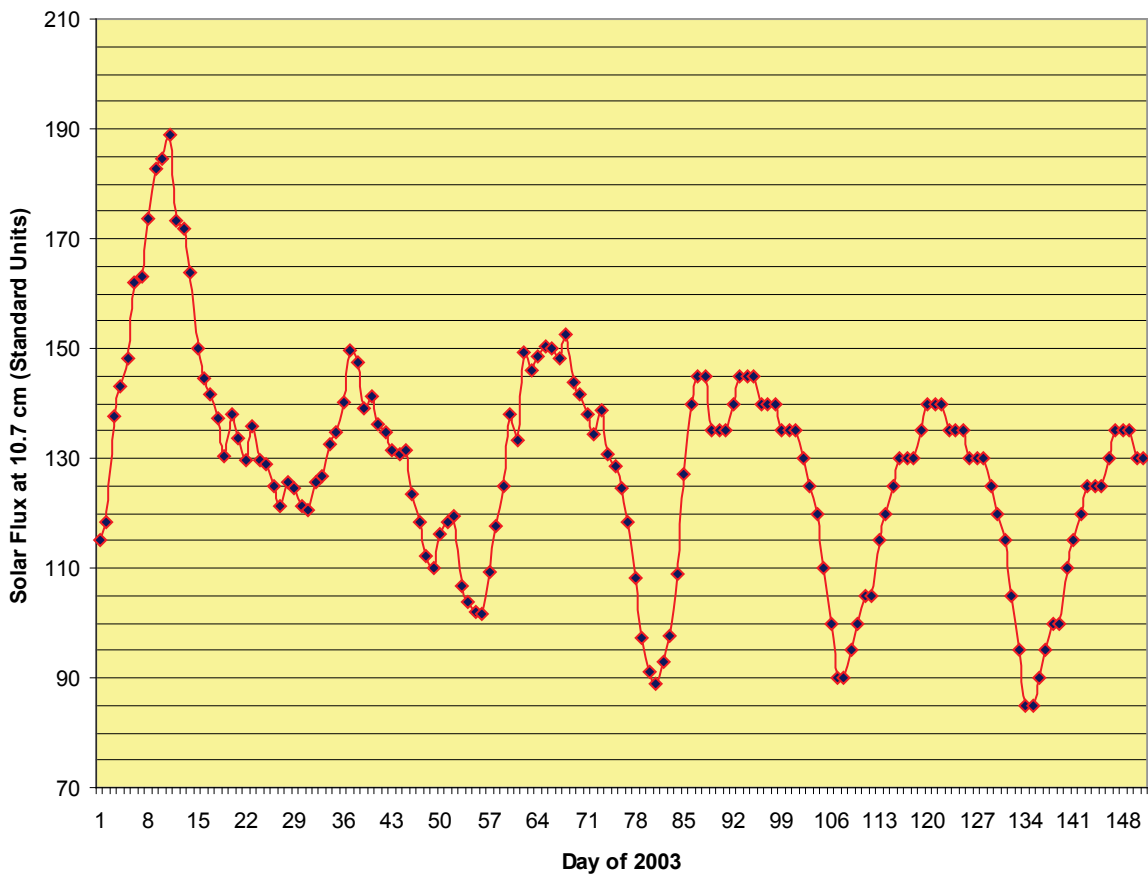


Fig. 3 – Observed (up to day 85) and predicted values of the solar flux at 10.7 cm

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last month, the nominal reentry date of 30 April 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1**BeppoSAX Reentry Window**

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.03000	23 April 2003
Nominal Reentry	B_N	0.02400	30 April 2003
Closure	$B_N - 25\%$	0.01800	13 May 2003

At present, the solar flux predictions are still the leading source of uncertainty. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued no later than 3 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently, the BeppoSAX satellite completes a revolution around the earth every 91.0 minutes at an altitude in between 317.2 km (perigee) and 320.5 km (apogee). The orbit is inclined by 3.95 degrees with respect to the equator, which means the satellite may fly over any location included in the latitude band between 3.97 degrees North and South. However, the motion is significantly perturbed by the residual atmosphere present at that altitude. The main effect of the resulting drag force is a progressively increasing altitude loss, which will culminate in the satellite reentry on the earth.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last month. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02329 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 2 April 2003, 01:13 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 27-day forecast (corresponding to one solar rotation), issued by the NOAA Space Environment Center, was adopted. For the subsequent months, such solar flux predictions were reiterated, applying an average reduction of about five standard units per month, while a constant average value ($A_p = 12$) was used for the geomagnetic planetary index.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last month, the nominal reentry date of 29 April 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m²/kg)	Reentry Date
Opening	$B_N + 25\%$	0.02911	24 April 2003
Nominal Reentry	B_N	0.02329	29 April 2003
Closure	$B_N - 25\%$	0.01746	8 May 2003

At present, the solar flux predictions are still the leading source of uncertainty. On the other hand, the ballistic parameter was relatively stable during the last two months. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

A PRIORI RISK ON THE GROUND

If the BeppoSAX fragments impact in an area of constant population density, the expected average number of casualties E_c can be calculated with the following equation:

$$E_c = P_I N (A_c/A_R), \tag{1}$$

where P_I is the probability of impact in the region, N is the total population in the region, A_c is the total effective casualty area for the impacting fragments, and A_R is the total area of the region. It should be emphasized that E_c is not the probability of a casualty: in theory the casualty expectancy may be greater than one, while the probability of casualty can never be.

The formula adopted in the NASA Safety Standard to compute the effective casualty area due to a satellite reentry is:

$$A_c = \sum_{i=1}^n \left(\sqrt{A_h} + \sqrt{A_i} \right)^2, \tag{2}$$

where $A_h = 0.36 \text{ m}^2$ is the projected human cross-section and A_i is the cross-section of each individual fragment reaching the ground. However, for people in the open, the effective casualty area of impacting inert debris is generally larger, due to winds, trajectory path angle, sliding, skidding or bouncing at ground impact, and splattering or cratering. Moreover, explosive debris can significantly increase the casualty area.

In the case of a reentering satellite like BeppoSAX, the fragments will rain down vertically, with respect to the local horizon, with only a minor horizontal velocity component due to local winds, with negligible consequences. Moreover, any material able to explode or burn should ignite at high altitude, during the breakup phase. Regarding sliding, bouncing or splattering at ground impact, the three effects are generally exclusive and because soft soil tends to be more common than hard surfaces (this is particularly true in the latitude belt potentially interested by the BeppoSAX reentry), the effective casualty area computed using Eq. (2) might be, at most, enhanced by a factor two.

Due to the orbital inclination with respect to the earth equator ($\cong 4$ degrees), the a priori reentry probability varies as a function of latitude, but for each parallel is independent on the longitude. Of course, the BeppoSAX reentry in the atmosphere cannot occur outside the ± 4 degrees latitude belt, even though the surviving fragments of the satellite might reach any location in between 4.356 degrees N or S. Table 2 summarizes the reentry probability as a function of latitude in the area of the planet potentially affected by the debris fall.

Table 2

BeppoSAX Reentry Probability and Average Casualty Expectancy as a Function of Latitude

Latitude Belt	Reentry Probability	Casualty Expectancy
3° – 4° S	0.230	1.14×10^{-4}
2° – 3° S	0.103	4.95×10^{-5}
1° – 2° S	0.086	3.96×10^{-5}
0° – 1° S	0.081	3.79×10^{-5}
0° – 1° N	0.081	4.09×10^{-5}
1° – 2° N	0.086	3.01×10^{-5}
2° – 3° N	0.103	3.06×10^{-5}
3° – 4° N	0.230	9.51×10^{-5}
4° S – 4° N	1.000	4.34×10^{-4}
4.356° S – 4.356° N	1.000	4.51×10^{-4}

Following Eqs. (1) and (2), and assuming a casualty area enhanced by a factor two, to take into account debris sliding, bouncing or splattering after the ground impact on

a typically soft soil, the expected average number of casualties in the latitude belt at risk (± 4.356 degrees) is about 4.51×10^{-4} (Table 2). This, of course, is a measure of a collective risk. The individual risk associated with the BeppoSAX reentry is measured by $E_d/N \cong 10^{-12}$. To put such extremely low individual risk in perspective, the annual individual fatality rate due to a non-occupational accident in a developed country is of the order of 10^{-4} .

Due to the small value of the expected average number of casualties, the probability to have one victim in the open is numerically the same, i.e. 4.51×10^{-4} . However, it must be emphasized that about 150-200 tons of orbital objects, mostly concentrated in payloads (satellites), platforms and rocket bodies, reenter the earth atmosphere every year without control. This implies at least 2 or 3 reentry events per month comparable or larger than BeppoSAX, in terms of the expected average number of casualties.

Moreover, an average of 3 meteoroids with diameters in between 1 and 10 meters, corresponding to masses in between 1 and 1000 metric tons, hit the earth every month. One week ago, for instance, a large stony meteorite, with a diameter of 1-2 meters and a mass of about 10 metric tons, exploded over the United States. Seen by people from Wisconsin to Ohio, it disseminated more than 500 fragments on a 130 km long and 30 km wide area of Illinois. In Park Forest, about 50 km south of downtown Chicago, several rocky chunks – some as large as 40 cm and weighing about 4 kg – hit houses, streets and the countryside at 200 km/h.

NEXT UPDATE

The next reentry prediction will be issued no later than 10 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently (12:00 UTC), the BeppoSAX satellite completes a revolution around the earth every 90.4 minutes, at an altitude in between 301.4 and 304.1 km, but the orbit is rapidly decaying due to air drag. The fragments of the satellite able to survive the atmospheric reentry might in principle reach any location inside the equatorial belt in between 4.36 degrees North and South. However, during the last two days of satellite lifetime, it will be possible to progressively exclude from the risk substantial areas of the above mentioned equatorial belt.

The final bulletins will provide maps and potential impact time windows for the regions of the equatorial belt still at risk. Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A / m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three weeks. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02186 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 9 April 2003, 15:51 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last three weeks, the nominal reentry date of 2 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m ² /kg)	Reentry Date
Opening	$B_N + 25\%$	0.02732	27 April 2003
Nominal Reentry	B_N	0.02186	2 May 2003
Closure	$B_N - 25\%$	0.01639	9 May 2003

At present, the solar flux predictions and the ballistic parameter evolution are the leading sources of uncertainty. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued no later than 17 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently (15:00 UTC), the BeppoSAX satellite completes a revolution around the earth every 90 minutes, at an altitude in between 287.6 and 291.5 km, but the orbit is rapidly decaying due to air drag. The fragments of the satellite able to survive the atmospheric reentry might in principle reach any location inside the equatorial belt in between 4.36 degrees North and South. However, during the last two days of satellite lifetime, it will be possible to progressively exclude from the risk substantial areas of the above mentioned equatorial belt.

The final bulletins will provide maps and potential impact time windows for the regions of the equatorial belt still at risk. Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the sole orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last two weeks. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02314 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 16 April 2003, 10:18 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last two weeks, the nominal reentry date of 1 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m ² /kg)	Reentry Date
Opening	$B_N + 25\%$	0.02893	28 April 2003
Nominal Reentry	B_N	0.02314	1 May 2003
Closure	$B_N - 25\%$	0.01736	5 May 2003

At present, the solar flux predictions and the ballistic parameter evolution are the leading sources of uncertainty. Geomagnetic storms might have a significant impact on the reentry date during the last ten days of satellite lifetime.

NEXT UPDATE

The next reentry prediction will be issued no later than 22 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently (12:00 UTC), the BeppoSAX satellite completes a revolution around the earth every 89.8 minutes, at an altitude in between 268.4 and 271.6 km, but the orbit is rapidly decaying due to air drag. The fragments of the satellite able to survive the atmospheric reentry might reach in principle any location inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . However, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. This implies at least two or three reentry events per month comparable or larger than that of BeppoSAX.

In the last two days of satellite lifetime, it will be possible to progressively exclude from the risk substantial areas of the above mentioned equatorial belt. The final bulletins will provide maps and potential impact time windows for the regions of the equatorial belt still at risk. Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the unique orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The nominal ballistic parameter B_N , defined according to the relationship $B_N = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last ten days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B_N = 0.02186 \text{ m}^2/\text{kg}$.

BEPPOSAX REENTRY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 21 April 2003, 16:13 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the orbital decay observed during the last ten days, the nominal reentry date of 1 May 2003 was obtained. In order to take into account the intrinsic uncertainties of this kind of predictions, a reentry window with an assumed confidence level of approximately 90% was computed by varying the nominal ballistic parameter B_N of $\pm 25\%$, as shown in Table 1.

Table 1

BeppoSAX Reentry Window

Reentry Window	Criteria	B (m ² /kg)	Reentry Date
Opening	$B_N + 25\%$	0.02732	29 April 2003
Nominal Reentry	B_N	0.02186	1 May 2003
Closure	$B_N - 25\%$	0.01639	4 May 2003

The solar flux predictions, the ballistic parameter evolution and the eventual geomagnetic storms are the leading sources of uncertainty.

NEXT UPDATE

The next reentry prediction will be issued no later than 25 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently (12:00 UTC), the BeppoSAX satellite completes a revolution around the earth every 89.5 minutes, at an altitude in between 256 and 259 km, but the orbit is rapidly decaying due to air drag. The fragments of the satellite able to survive the atmospheric reentry might reach in principle any location inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . However, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. This implies at least two or three reentry events per month comparable or larger than that of BeppoSAX.

In the last two days of satellite lifetime, it will be possible to progressively exclude from the risk substantial areas of the above mentioned equatorial belt. The final bulletins will provide maps and potential impact time windows for the regions of the equatorial belt still at risk. Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the unique orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last seven days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02229 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 24 April 2003, 03:59 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last seven days, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	12:56 UTC
Nominal Impact	30 April 2003	21:48 UTC
Closure	3 May 2003	04:34 UTC

NEXT UPDATE

The next reentry prediction will be issued on 26 April 2003.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently (12:00 UTC), the BeppoSAX satellite completes a revolution around the earth every 89.1 minutes, at an altitude in between 240 and 244 km, but the orbit is rapidly decaying due to air drag. The fragments of the satellite able to survive the atmospheric reentry might reach in principle any location inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . However, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. This implies at least two or three reentry events per month comparable or larger than that of BeppoSAX.

In the last two days of satellite lifetime, it will be possible to progressively exclude from the risk substantial areas of the above mentioned equatorial belt. The final bulletins will provide maps and potential impact time windows for the regions of the equatorial belt still at risk. Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the unique orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last five days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02514 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 26 April 2003, 08:06 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last five days, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	06:54 UTC
Nominal Impact	30 April 2003	00:57 UTC
Closure	1 May 2003	07:56 UTC

NEXT UPDATE

The next reentry prediction will be issued no later than 28 April 2003, in the morning.

• Prepared by Luciano Anselmo and Carmen Pardini •

BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The fragments of the satellite able to survive the atmospheric reentry might still reach in principle any location inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . On the other hand, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. This implies at least two or three reentry events per month comparable or larger than that of BeppoSAX.

In the last 24 hours, it will be possible to exclude from the risk substantial areas of the above-mentioned equatorial belt, while maps and impact time windows will be provided for the regions potentially interested by the debris fall. However, a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A / m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last three days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02540 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 27 April 2003, 13:47 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last three days, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	13:20 UTC
Nominal Impact	30 April 2003	01:17 UTC
Closure	30 April 2003	21:41 UTC

NEXT UPDATE

The next reentry prediction will be issued on 28 April 2003, in the morning.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The fragments of the satellite able to survive the atmospheric reentry might still reach in principle any location inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . On the other hand, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. For instance, two upper stages (one Russian and one American) decayed during the last two days, and another one (European) will reenter in the coming 48 hours.

In the last 24 hours, it will be possible to exclude from the risk substantial areas of the above-mentioned equatorial belt, while maps and impact time windows will be provided for the regions potentially interested by the debris fall. However, a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last two days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02471 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 27 April 2003, 22:40 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last two days, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	16:47 UTC
Nominal Impact	30 April 2003	03:08 UTC
Closure	30 April 2003	20:16 UTC

NEXT UPDATE

The next reentry prediction will be issued on 28 April 2003, as soon as new two-line orbital elements will be available.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The fragments of the satellite able to survive the atmospheric reentry might still reach in principle most locations inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . On the other hand, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. For instance, three upper stages (two Russian and one American) decayed during the last three days, and another one (European) will reenter in the coming two days.

In the last 24 hours of the BeppoSAX lifetime, it will be possible to exclude from the risk substantial areas of the above-mentioned equatorial belt, while maps and impact time windows will be provided for the regions potentially interested by the debris fall. However, a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported, as in the case of the recent Proton rocket body reentry, seen over Brazil in the morning of April 26.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last two days. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02539 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 28 April 2003, 09:01 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last two days, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	17:10 UTC
Nominal Impact	30 April 2003	01:00 UTC
Closure	30 April 2003	14:03 UTC

NEXT UPDATE

The next reentry prediction will be issued on 28 April 2003, in the evening.

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BEPPOSAX REENTRY PREDICTIONS

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SATELLITE ORBIT STATUS

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The fragments of the satellite able to survive the atmospheric reentry might still reach in principle most locations inside the equatorial belt in between 4.36 degrees North and South. The probability to hit a person in the open is 4.5×10^{-4} , while the chance to strike a commercial aircraft in flight is of the order of 10^{-7} . On the other hand, about 150-200 tons of orbital objects reenter the earth atmosphere every year without control. For instance, three upper stages (two Russian and one American) decayed during the last three days, and another one (European) will reenter in the coming two days.

In the following bulletins, it will be possible to exclude from the risk substantial areas of the above-mentioned equatorial belt, while maps and impact time windows will be provided for the regions potentially interested by the debris fall. However, a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported, as in the case of the recent Proton rocket body reentry, seen over Brazil in the morning of April 26.

BALLISTIC PARAMETER ESTIMATION

The ballistic parameter B , defined according to the relationship $B = C_D A/m$, where C_D , m and A are, respectively, the satellite drag coefficient, mass and average cross-sectional area, was estimated by fitting, in a least squares sense, the satellite semi-major axis decay observed during the last day. All the relevant orbit perturbations were included and the Jacchia-Roberts 1971 model was adopted to describe the varying atmospheric density. The orbital data were provided by the NASA/GSFC Orbital Information Group and by Nicholas L. Johnson of NASA/JSC. The value obtained was $B = 0.02729 \text{ m}^2/\text{kg}$.

BEPPOSAX DECAY WINDOW

The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 28 April 2003, 17:52 UTC) with a numerical trajectory predictor including the geopotential harmonics up to the 16th order and degree, the luni-solar attraction, the solar radiation pressure with eclipses and the aerodynamic drag. The air density was computed with the Jacchia-Roberts 1971 model.

Concerning the predicted solar flux at 10.7 cm (used by the atmospheric model as a proxy of the solar irradiance at extreme ultraviolet frequencies) and the geomagnetic planetary index A_p , the last 45-day forecast, prepared by the U.S. Air Force and issued by the NOAA Space Environment Center, was adopted.

Using for BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during the last day, the ground impact uncertainty window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	17:15 UTC
Nominal Impact	29 April 2003	22:57 UTC
Closure	30 April 2003	08:25 UTC

NEXT UPDATE

The next reentry prediction will be issued as soon as new significant results will be available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 28 April 2003, 23:46 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed over 25 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	18:47 UTC
Nominal Impact	29 April 2003	23:26 UTC
Closure	30 April 2003	07:20 UTC

Due to the physical nature of the event (uncontrolled satellite decay from circular orbit) and the unique orbit data source (a few American military sensors), a rough estimate of the reentry location, with an uncertainty of several thousand kilometers along the final trajectory, will be available only some hours after the fact, unless reliable and consistent visual observations are reported.

RISKY SUB-SATELLITE TRACKS

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1.

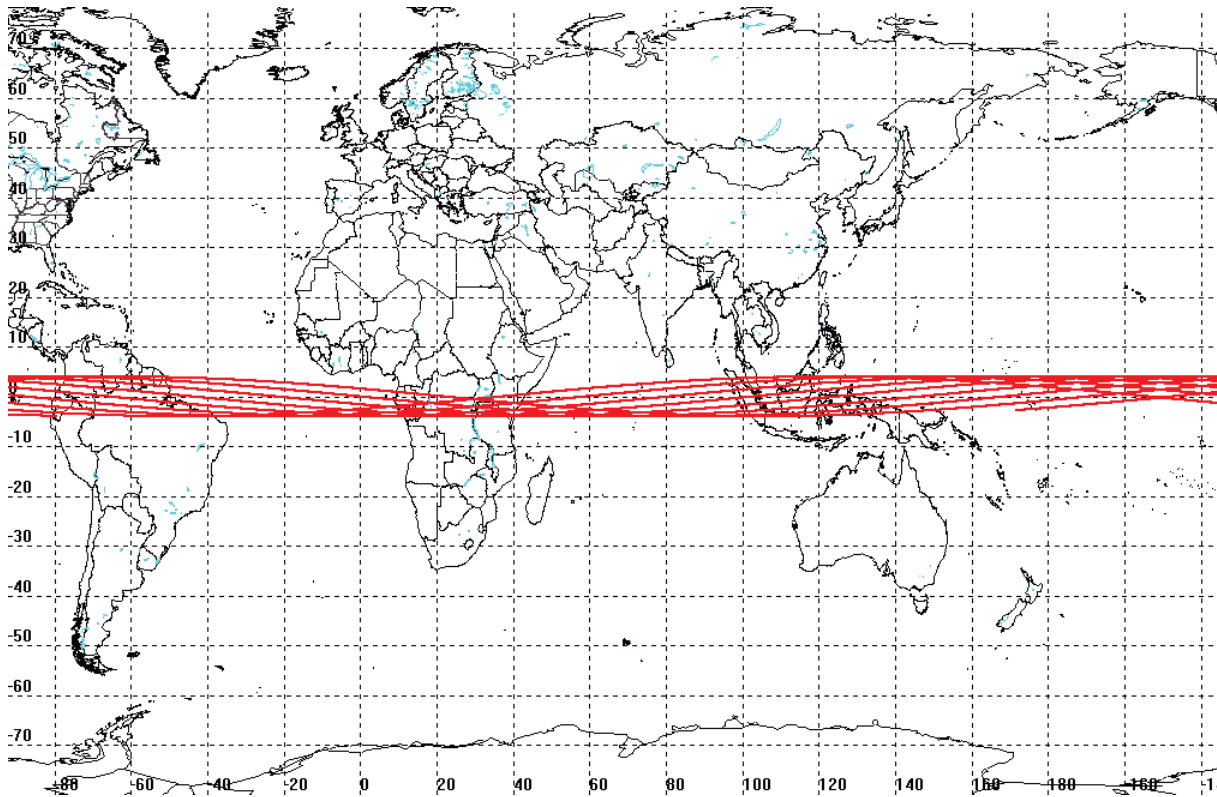


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

NEXT UPDATE

The next bulletin will be issued as soon as new significant results will be available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 29 April 2003, 04:11 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed over 35 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	20:04 UTC
Nominal Impact	29 April 2003	23:55 UTC
Closure	30 April 2003	06:23 UTC

During the last three days three upper stage reentries have occurred: one over Brazil (a Russian Proton stage), in the morning of April 26, one over Central America (an American Atlas-Centaur stage), in the afternoon of April 27, and a third one over China (a Russian Soyuz stage), in the morning of April 28. A European Ariane third stage will reenter as well in the next 36 hours, in between 7.6 degrees North and South. It should be emphasized that none of the above-mentioned reentry events is related to BeppoSAX.

RISKY SUB-SATELLITE TRACKS

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1.

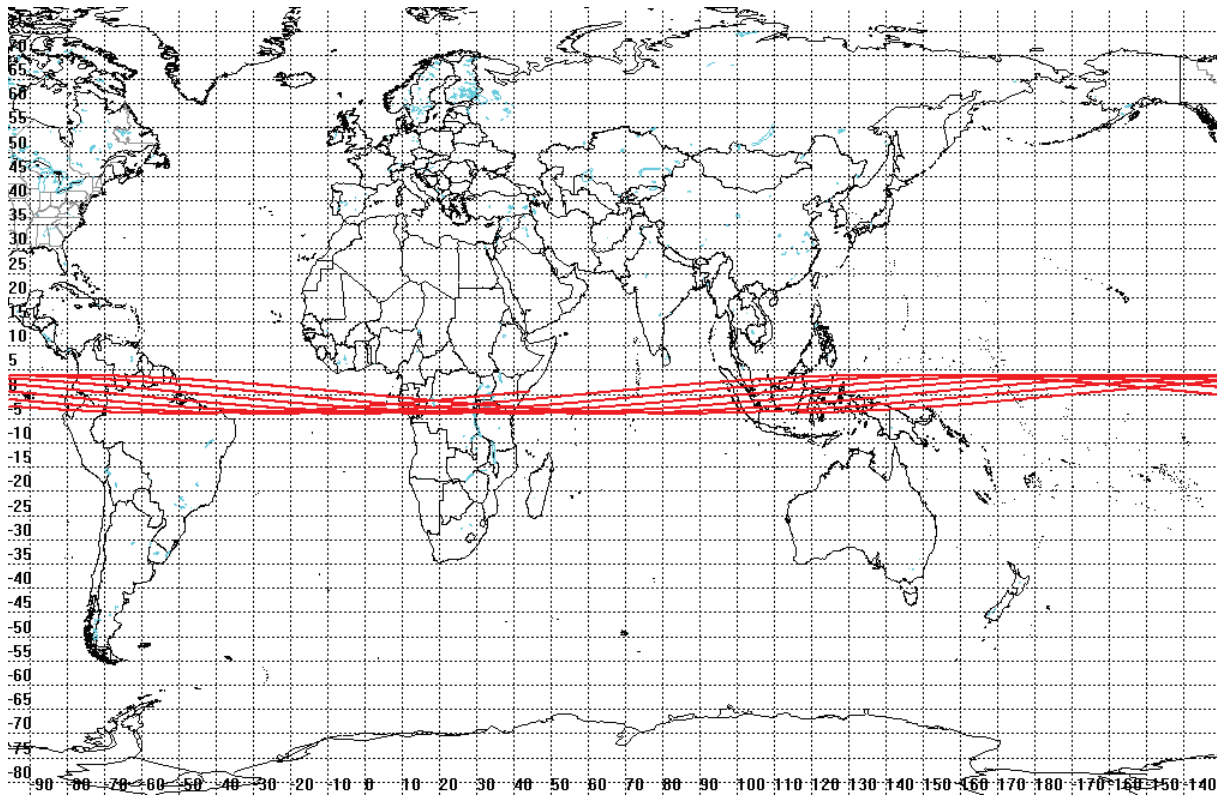


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

NEXT UPDATE

The next bulletin will be issued as soon as new significant results will be available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 29 April 2003, 07:08 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed over 34 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	20:35 UTC
Nominal Impact	29 April 2003	23:51 UTC
Closure	30 April 2003	05:17 UTC

During the last three days, three upper stage reentries have occurred: one over Brazil (a Russian Proton stage), in the morning of April 26, one over Central America (an American Atlas-Centaur stage), in the afternoon of April 27, and a third one over China (a Russian Soyuz stage), in the morning of April 28. A European Ariane third stage will reenter as well in the next 36 hours, in between 7.6 degrees North and South. It should be emphasized that none of the above-mentioned reentry events is related to BeppoSAX.

RISKY SUB-SATELLITE TRACKS

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1.

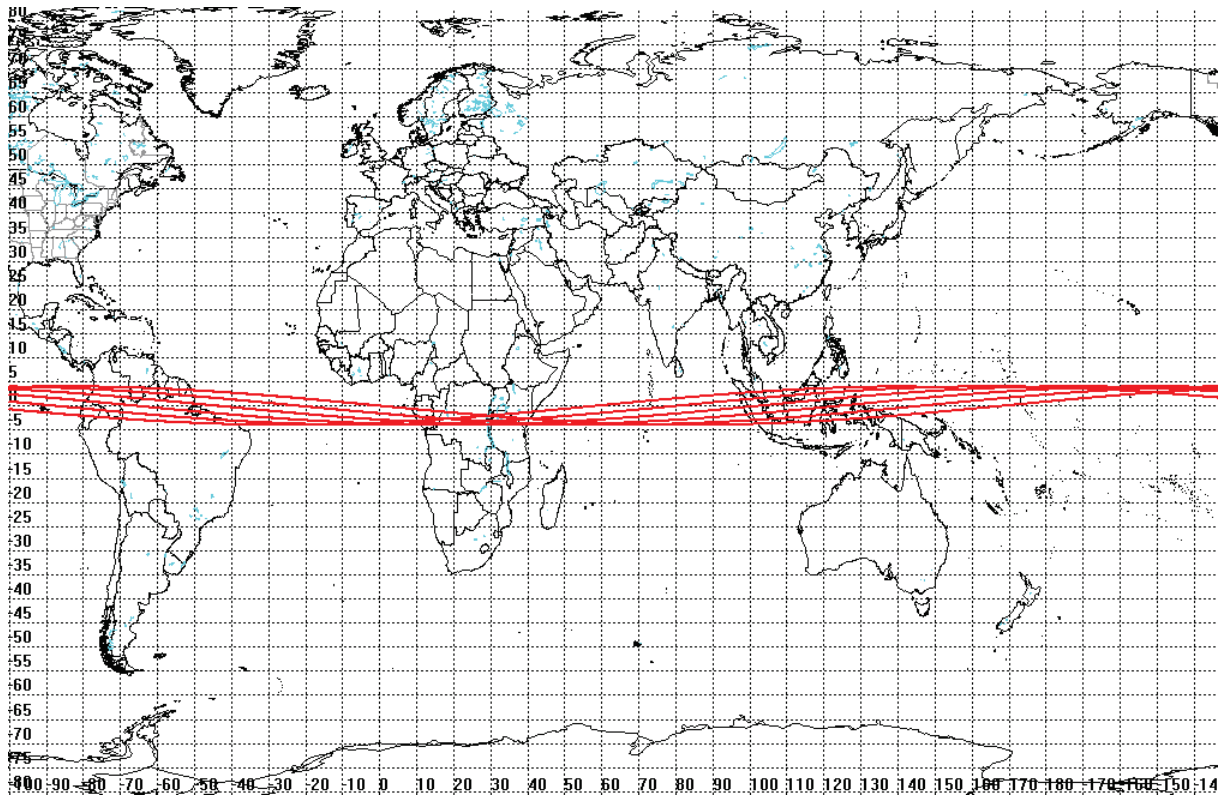


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

NEXT UPDATE

The next bulletin will be issued as soon as new significant results are available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 29 April 2003, 07:08 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during 34 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	20:35 UTC
Nominal Impact	29 April 2003	23:51 UTC
Closure	30 April 2003	05:17 UTC

During the last four days, three upper stage reentries have occurred: one over Brazil (a Russian Proton stage), in the morning of April 26, one over Central America (an American Atlas-Centaur stage), in the afternoon of April 27, and a third one over China (a Russian Soyuz stage), in the morning of April 28. A European Ariane third stage will reenter as well in the coming 36 hours, in between 7.6 degrees North and South. It should be emphasized that none of the above mentioned reentry events is related to BeppoSAX.

AREAS OF THE PLANET POTENTIALLY INVOLVED

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1 and their coordinates are provided in Table 2.

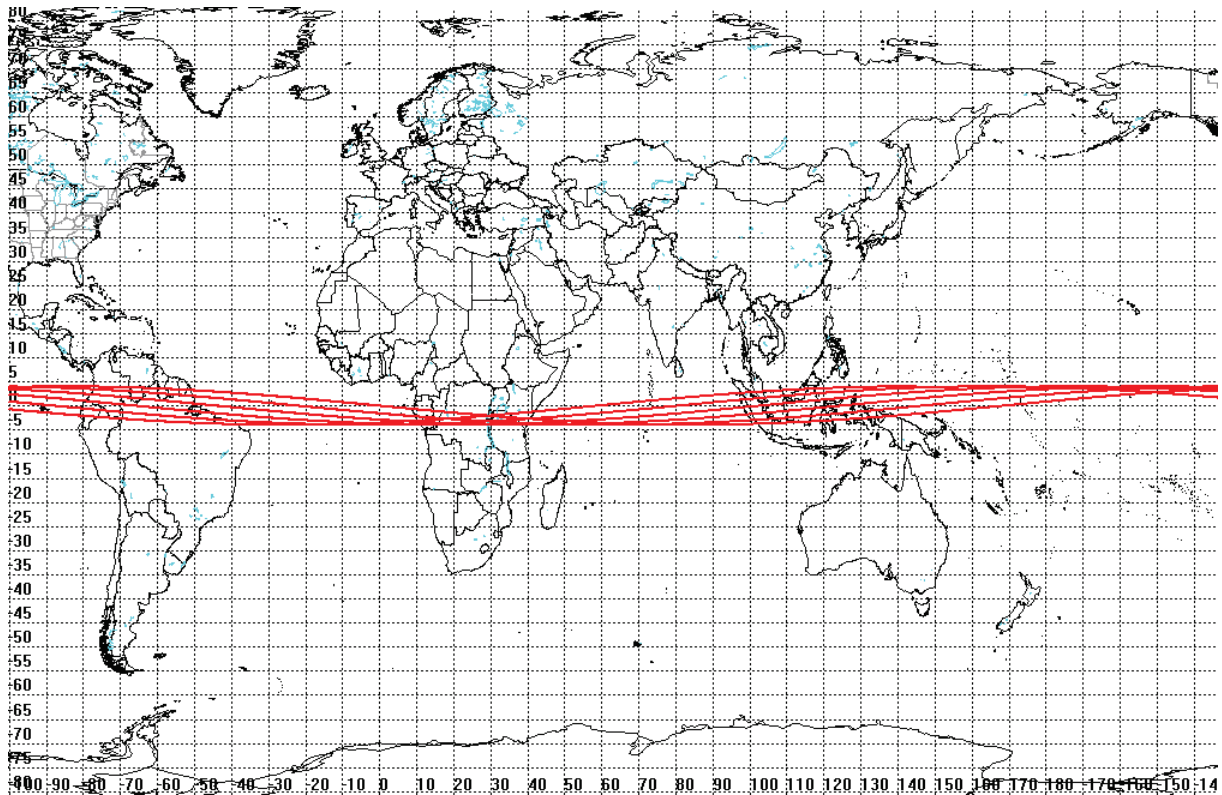


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

Table 2

Geographical Coordinates of the Ground Tracks Potentially at Risk

LAT (deg)	LON (deg E)
1.6029	213.6535
2.3416	225.1714
2.9729	236.7
3.4678	248.2397
3.8034	259.7891
3.9642	271.3448
3.9427	282.902

3.74	294.4558
3.3655	306.0018
2.8364	317.537
2.1773	329.0606
1.4184	340.574
0.5945	352.0805
-0.2566	3.5849
-1.0961	15.0926
-1.8855	26.6085
-2.5887	38.1366
-3.1731	49.6786
-3.6117	61.2342
-3.8842	72.8008
-3.9777	84.3737
-3.888	95.9477
-3.619	107.5174
-3.1833	119.0781
-2.601	130.627
-1.8992	142.1636
-1.1103	153.6894
-0.2705	165.2079
0.5815	176.7239
1.4069	188.2426
2.1677	199.7684
2.8289	211.3046
3.3602	222.8523
3.7368	234.4103
3.9415	245.9758
3.9645	257.5441
3.8051	269.1104
3.4704	280.67
2.9762	292.2194
2.3451	303.7573
1.6063	315.2844
0.7938	326.8037
-0.0552	338.3197
-0.9018	349.8378
-1.7071	1.363
-2.4341	12.8996
-3.0494	24.45
-3.5243	36.0142
-3.8368	47.5901
-3.9723	59.1737
-3.9243	70.7595
-3.6952	82.342
-3.2956	93.9163
-2.7439	105.4794
-2.0659	117.03
-1.2929	128.5694
-0.4605	140.1006

0.3931	151.6283
1.2284	163.1576
2.0073	174.6935
2.6939	186.2393
3.2564	197.7967
3.6689	209.3652
3.9122	220.9422
3.9749	232.5233
3.8542	244.1036
3.5556	255.6783
3.0931	267.2436
2.4881	278.7977
1.7685	290.3408
0.9676	301.8754
0.1221	313.4056
-0.7292	324.9369
-1.5471	336.4744
-2.2939	348.0226
-2.9351	359.5842
-3.441	11.16
-3.788	22.748
-3.9598	34.3446
-3.9484	45.9445
-3.7542	57.5422
-3.3863	69.1327
-2.8619	80.7121
-2.2055	92.2791
-1.4474	103.8344
-0.6226	115.381
0.2308	126.9231
1.0736	138.4662
1.8669	150.015
2.5741	161.5735
3.1626	173.1438
3.605	184.7258
3.8807	196.3171
3.9769	207.9138
3.8891	219.5109
3.6214	231.1035
3.1861	242.6876
2.6036	254.2608
1.9009	265.823
1.1105	277.3764
0.2689	288.9249
-0.5853	300.4735
-1.4128	312.0276
-2.1752	323.5919
-2.8372	335.1695
-3.3681	346.7612
-3.743	358.3658

-3.9443	9.9798
-3.9625	21.598
-3.7967	33.215
-3.4548	44.8255
-2.9526	56.4255
-2.3137	68.0131
-1.5678	79.5889
-0.7495	91.1554
0.1033	102.7169
0.9514	114.2788
1.7555	125.8461
2.4784	137.423
3.0867	149.0119
3.552	160.6131
3.8526	172.2245
3.9743	183.8425
3.9115	195.462
3.667	207.0782
3.2523	218.6867
2.6866	230.285
1.9965	241.8726
1.2137	253.4513
0.3747	265.0249
-0.4818	276.5984
-1.3161	288.1771
-2.0897	299.7658
-2.7665	311.3678
-3.315	322.9844
-3.7093	334.6144
-3.9309	346.2546
-3.9692	357.9
-3.8224	9.5451
-3.4974	21.1845
-3.0094	32.8142
-2.3813	44.432
-1.6425	56.0384
-0.8275	67.6356
0.0259	79.2281
0.8782	90.8211
1.6897	102.4199
2.4227	114.029
3.0431	125.651
3.5218	137.2864
3.8362	148.9336
3.9716	160.5887
3.9214	172.247
3.6878	183.9034
3.282	195.5536
2.7227	207.1949
2.0364	218.8267

1.2548	230.4507
0.4146	242.0707
-0.4453	253.6917
-1.2846	265.3192
-2.0642	276.9582
-2.3044	280.8411
-2.5325	284.7258
-2.7475	288.6123
-2.9481	292.5007
-3.1334	296.3909
-3.3023	300.2829
-3.454	304.1767
-3.5875	308.0721
-3.7023	311.9691
-3.7977	315.8676
-3.8732	319.7673
-3.9284	323.6682
-3.963	327.57
-3.9767	331.4726
-3.9696	335.3757
-3.9416	339.2792
-3.8929	343.1828
-3.8238	347.0863
-3.7345	350.9896
-3.6256	354.8925
-3.4976	358.7948
-3.3512	2.6964
-3.1872	6.5972
-3.0064	10.4971
-2.8099	14.396
-2.5985	18.2938
-2.3735	22.1904
-2.1361	26.0858
-1.8875	29.9798
-1.629	33.8721
-1.3621	37.7624
-1.0881	41.6501
-0.8087	45.5339
-0.5255	49.4119
-0.2403	53.2797
0.0447	57.1277
0.3262	60.9318
0.5968	64.6104
0.8324	67.8458
0.9658	69.6982
0.992	70.064

Taking into account the predicted dispersion of the fragments and the trajectory inaccuracies, the half width of the risky ground swath Σ associated with the above

mentioned ground tracks is a function of the sub-satellite latitude λ , North or South, as given by the following equation:

$$\Sigma(km) = 42 + 258.95 \sin(3.978^\circ - |\lambda|). \tag{1}$$

Figure 2 shows how the risky ground swath half width Σ varies as a function of the sub-satellite latitude λ , North or South, both in kilometers and nautical miles. As an example, the half width of the risky ground swath associated with a sub-satellite point on the equator ($\lambda = 0^\circ$) is 60 km, that is all the locations at less than 60 km from the sub-satellite track are potentially at risk. The swath half width decreases as higher latitudes, North or South, reaching the minimum value of 42 km at $\lambda = \pm 3.978^\circ$.

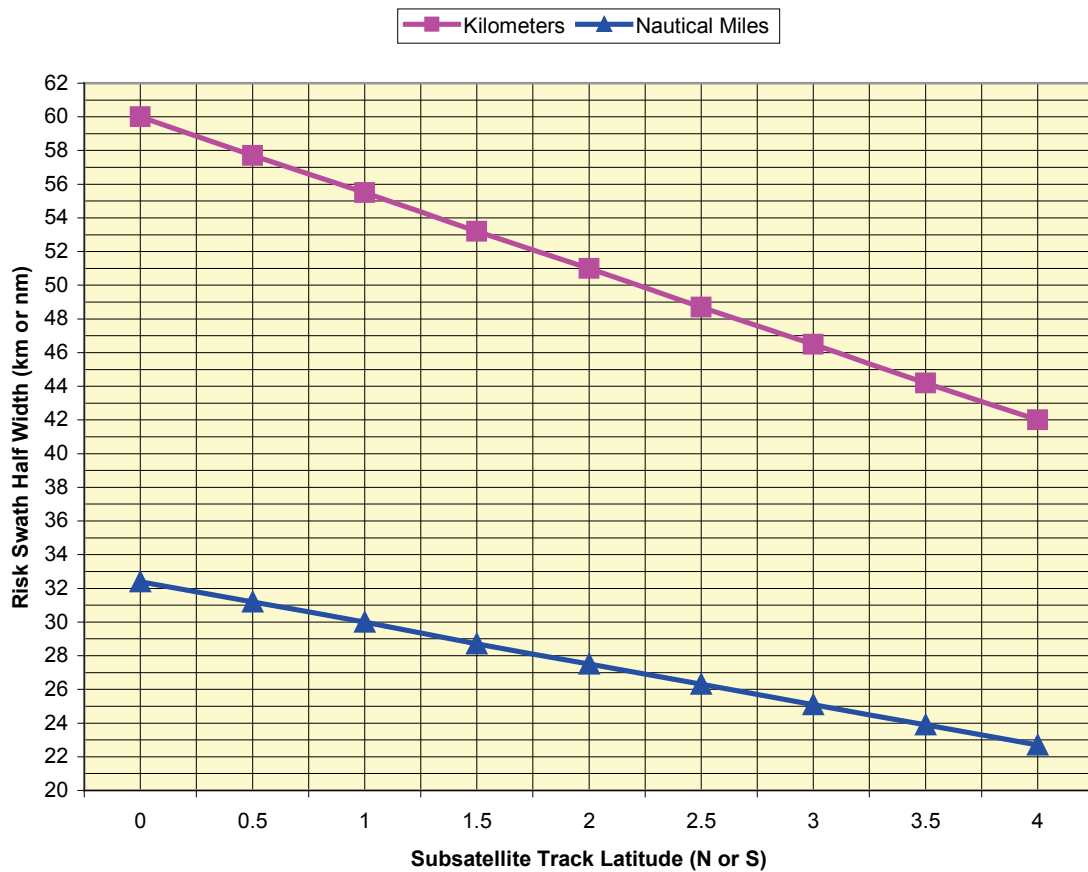


Fig. 2 – Half width of the risky ground swath as a function of the sub-satellite track latitude

The countries or territories that might still be potentially hit by the BeppoSAX falling fragments are:

- **Africa:** Burundi, Congo, Democratic Republic of Congo, the Pagalu Island of Equatorial Guinea, Gabon, Kenya, Rwanda, São Tomé and Príncipe, Seychelles, Somalia, Tanzania;

- **Asia:** Indonesia, Malaysia, Maldives, Singapore;
- **Oceania:** Baker Island (USA), Federated States of Micronesia, Howland Island (USA), Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea;
- **South America:** Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Venezuela.

The following countries or territories of the equatorial belt in between 4.36 degrees North and South are instead not included anymore – with a confidence level of 90% or higher – in the areas at risk for the BeppoSAX falling fragments: Cameroon, Central African Republic, the continental Equatorial Guinea, Ethiopia, Sudan, Uganda, Cap Palmas, at the border between Liberia and Côte d'Ivoire, the Niger river delta, in Nigeria, Brunei, Jarvis Island (USA).

LONGITUDINAL RISK TIME WINDOWS

A nominal impact time for the BeppoSAX main debris may be associated with any sub-satellite point of the risky ground tracks shown in Figure 1. By taking into account an impact uncertainty of ± 10 minutes and the time needed for the small centimeter sized particulate produced by the event to rain down through the affected air space (+ 20 minutes), a risk time window of 40 minutes can be associated with any specific location along the final sub-satellite tracks, as follow:

$$\text{Risk Time Window} = \text{Predicted Main Debris Impact Time (UTC)} \left\{ \begin{array}{l} +30 \text{ min} \\ -10 \text{ min} \end{array} \right. . \quad (2)$$

Table 3 lists the impact risk time windows, as a function of longitude, for the sub-satellite ground tracks potentially at risk, shown in Figures 1 and 3-6.

Table 3**Impact Risk Time Windows (UTC) Along the Risky Ground Tracks**

Longitude Band	Track No. 1	Track No. 2	Track No. 3	Track No. 4	Track No. 5	Track No. 6
180° – 120° W	29 APR 2017-2112	29 APR 2150-2245	29 APR 2323 30 APR 0018	30 APR 0056-0152	30 APR 0228-0323	30 APR 0403-0458
120° – 60° W	29 APR 2032-2127	29 APR 2205-2301	29 APR 2338 30 APR 0033	30 APR 0112-0218	30 APR 0243-0340	30 APR 0418-0514
60° W – 0°	29 APR 2047-2143	29 APR 2221-2316	29 APR 2353 30 APR 0048	30 APR 0128-0222	30 APR 0300-0356	30 APR 0434-0529
0° – 60° E	29 APR 2103-2158	29 APR 2236-2331	30 APR 0008-0104	30 APR 0142-0238	30 APR 0316-0412	30 APR 0449-0545
60° – 120° E	29 APR 2118-2215	29 APR 2251-2347	30 APR 0024-0120	30 APR 0158-0253	30 APR 0332-0427	30 APR 0505-0600
120° – 180° E	29 APR 2135-2230	29 APR 2307 30 APR 0003	30 APR 0040-0136	30 APR 0213-0308	30 APR 0347-0443	30 APR 0520-0615

CONTINENTAL RISK MAPS

The sub-satellite ground tracks at risk are presented in further detail, for specific continental areas, in the following maps (Figures 3-6).

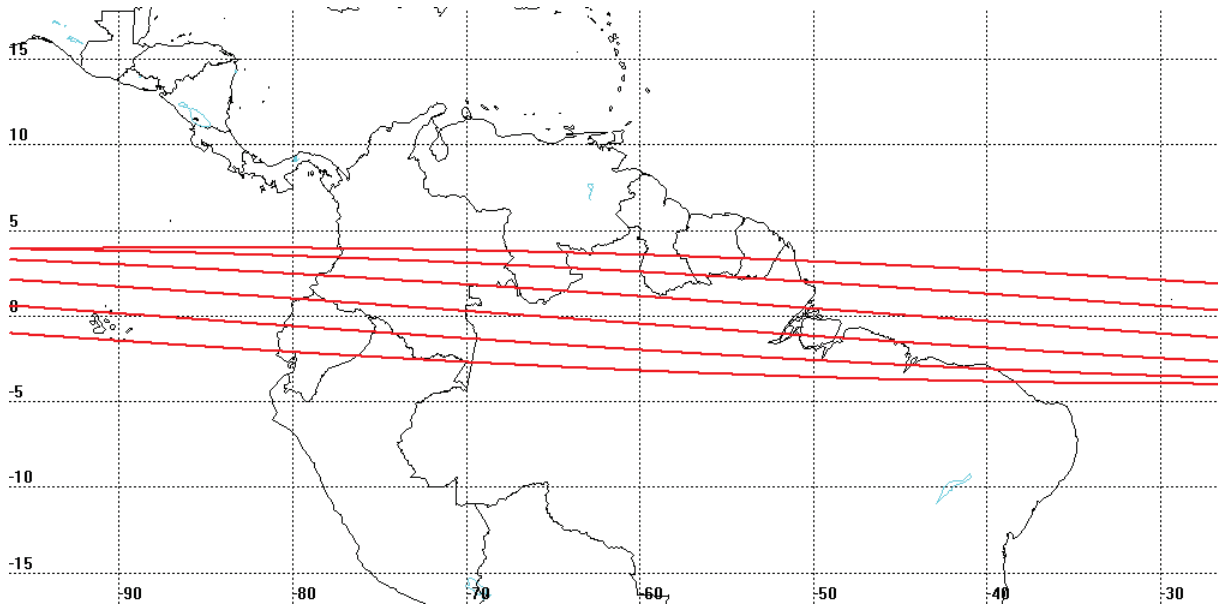


Fig. 3 – Sub-satellite tracks potentially at risk over South America

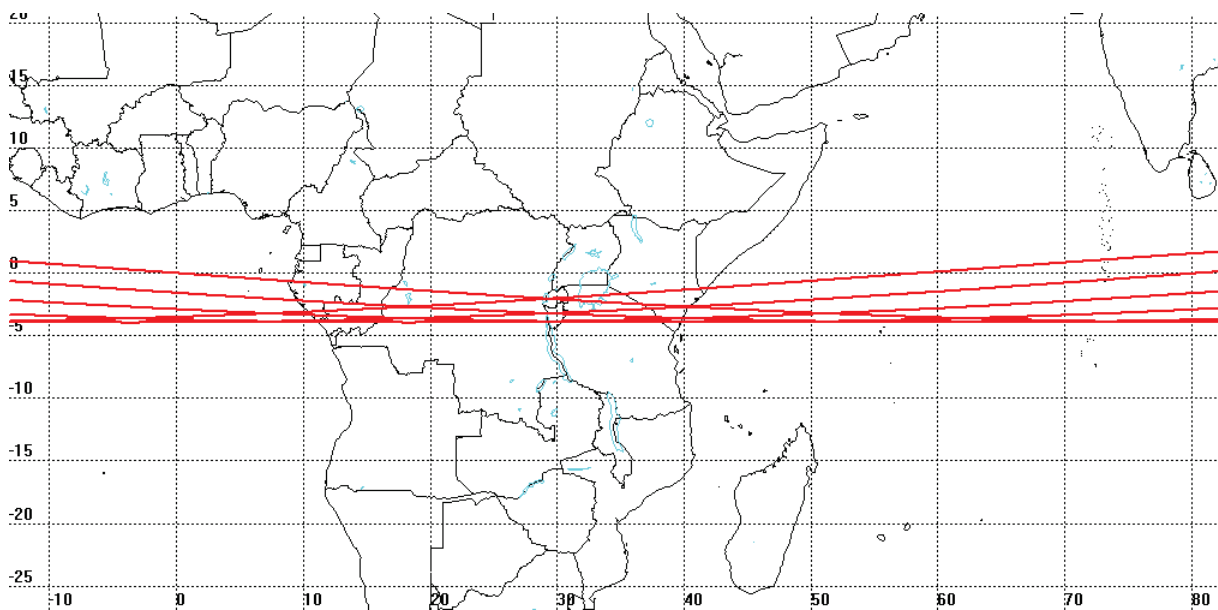


Fig. 4 – Sub-satellite tracks potentially at risk over Africa and Maldives

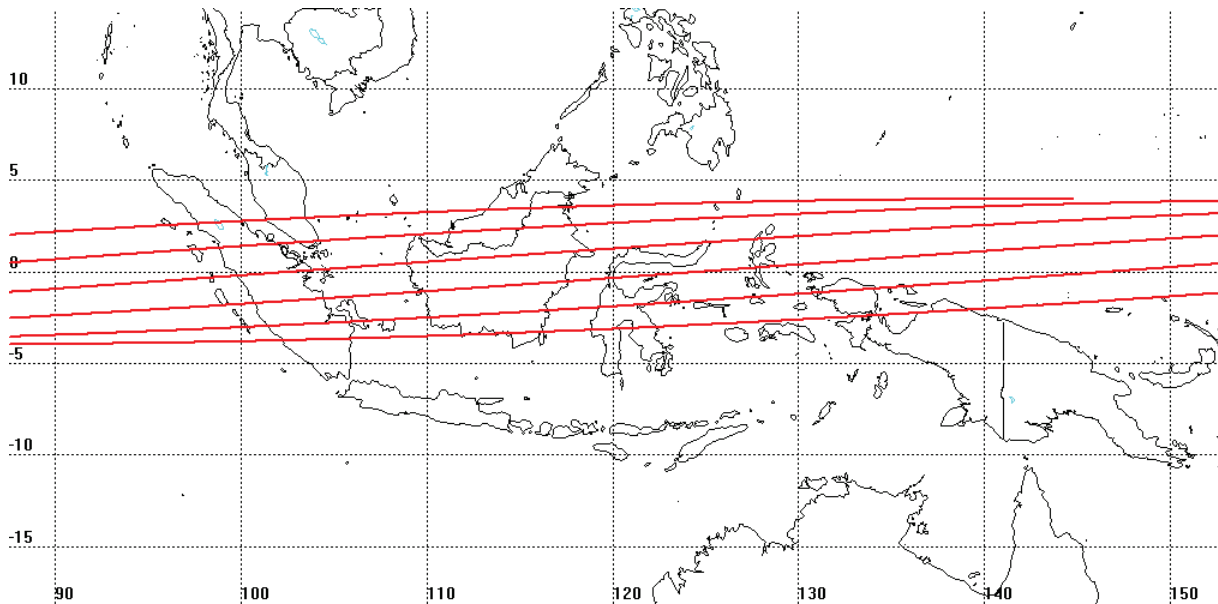


Fig. 5 – Sub-satellite tracks potentially at risk over Southeast Asia

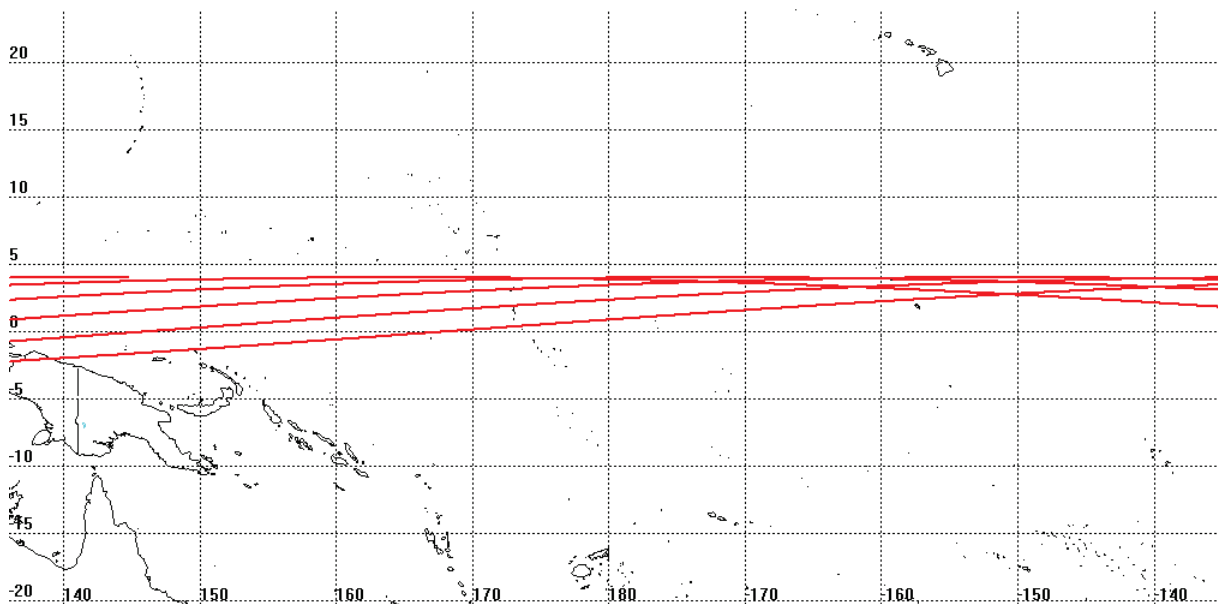


Fig. 6 – Sub-satellite tracks potentially at risk over Oceania

NEXT UPDATE

The next bulletin will be issued as soon as new significant results are available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 29 April 2003, 11:32 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during 12 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	22:57 UTC
Nominal Impact	30 April 2003	01:40 UTC
Closure	30 April 2003	06:13 UTC

During the last four days, three upper stage reentries have occurred: one over Brazil (a Russian Proton stage), in the morning of April 26, one over Central America (an American Atlas-Centaur stage), in the afternoon of April 27, and a third one over China (a Russian Soyuz stage), in the morning of April 28. A European Ariane third stage will reenter as well in the coming 36 hours, in between 7.6 degrees North and South. It should be emphasized that none of the above mentioned reentry events is related to BeppoSAX.

AREAS OF THE PLANET POTENTIALLY INVOLVED

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1 and their coordinates are provided in Table 2.

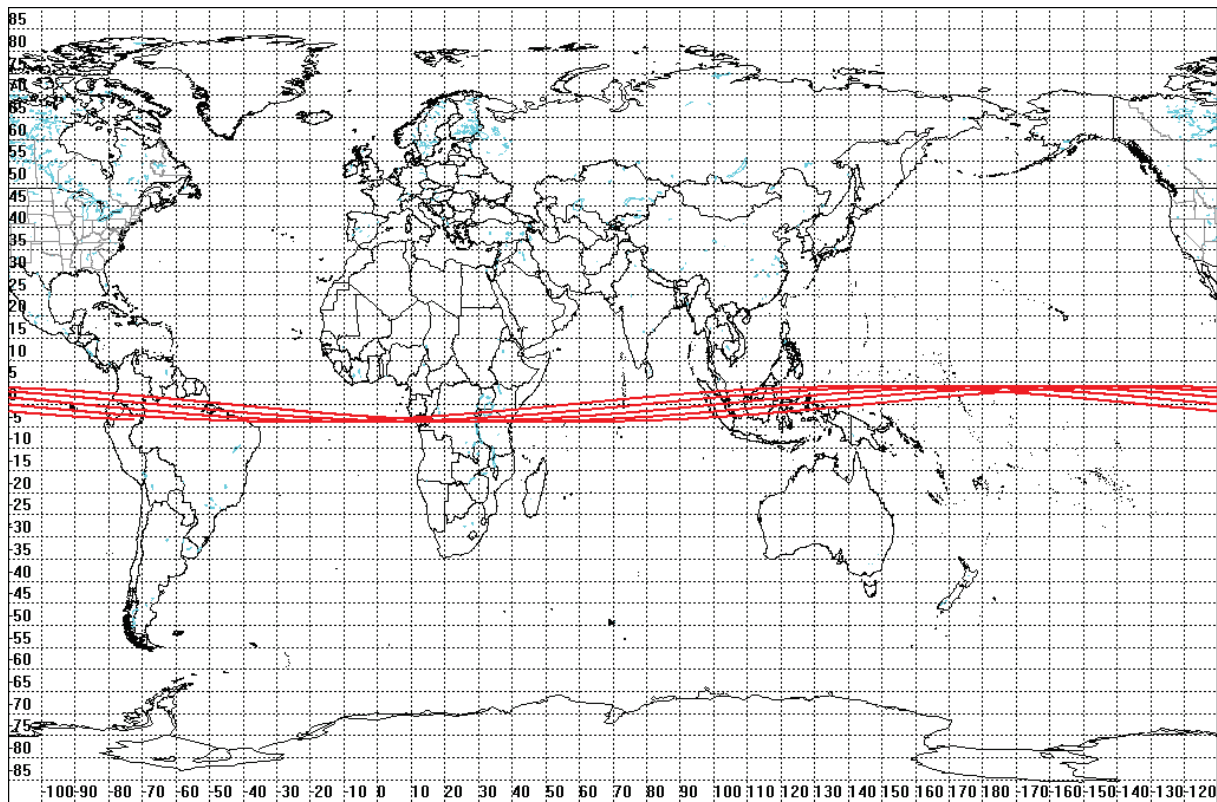


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

Table 2

Geographical Coordinates of the Ground Tracks Potentially at Risk

LAT (deg)	LON (deg E)
-3.5867	38.0848
-3.8688	49.6614
-3.9724	61.2442
-3.8927	72.8279
-3.6333	84.4069
-3.2063	95.9767
-2.6316	107.5343

-1.9358	119.079
-1.1511	130.6126
-0.3135	142.1384
0.5383	153.6614
1.3654	165.1868
2.1297	176.7192
2.7961	188.262
3.3339	199.8166
3.7181	211.3822
3.931	222.9557
3.9626	234.533
3.8114	246.1088
3.4845	257.6787
2.9969	269.2392
2.3714	280.7886
1.6368	292.3277
0.8269	303.8591
-0.0212	315.3871
-0.8685	326.9171
-1.6759	338.4541
-2.4064	350.0023
-3.0261	1.5641
-3.5062	13.1394
-3.8245	24.7261
-3.966	36.3202
-3.924	47.9163
-3.7005	59.5088
-3.306	71.0928
-2.7589	82.665
-2.0846	94.2243
-1.3143	105.7719
-0.4836	117.3111
0.3692	128.8464
1.2051	140.3832
1.9855	151.9265
2.6744	163.4798
3.2401	175.045
3.6563	186.6216
3.9036	198.2073
3.9706	209.7977
3.8539	221.388
3.5592	232.9733
3.1	244.5499
2.4977	256.1157
1.7802	267.6709
0.9806	279.218
0.1357	290.7611
-0.7155	302.3051
-1.534	313.8553
-2.2819	325.4161

-2.9246	336.9902
-3.4321	348.5782
-3.7808	0.1782
-3.9543	11.7864
-3.9444	23.3977
-3.7516	35.0063
-3.385	46.6073
-2.8616	58.1969
-2.206	69.7737
-1.4485	81.3384
-0.6244	92.894
0.2285	104.4451
1.0709	115.997
1.8638	127.5547
2.5707	139.1223
3.1589	150.7018
3.6009	162.2934
3.8762	173.8947
3.9719	185.5019
3.8835	197.11
3.6151	208.7142
3.1791	220.3103
2.5959	231.8961
1.8926	243.4714
1.1017	255.0382
0.2598	266.6005
-0.5942	278.1633
-1.4209	289.7318
-2.1821	301.3105
-2.8424	312.9024
-3.3711	324.5084
-3.7432	336.127
-3.9414	347.7546
-3.9562	359.3862
-3.7869	11.0161
-3.4415	22.639
-2.9361	34.2512
-2.2946	45.8508
-1.5467	57.4383
-0.7272	69.0165
0.1258	80.5898
0.973	92.1635
1.7751	103.7429
2.495	115.3322
3.0993	126.9338
3.5597	138.548
3.8547	150.1729
3.9704	161.8046
3.9012	173.4383
3.6505	185.069

3.2298	196.6925
2.6589	208.3063
1.9644	219.91
1.1786	231.5054
0.3379	243.0963
-0.5186	254.6876
-1.3513	266.2847
-2.1214	277.8923
-2.7929	289.5135
-3.3344	301.1494
-3.7205	312.7987
-3.9328	324.458
-3.9612	336.1224
-3.8043	347.7863
-3.4694	359.4444
-2.9724	11.0928
-2.3365	22.7296
-1.5917	34.3555
-0.7727	45.973
0.0824	57.5867
0.9338	69.202
1.7416	80.8244
2.4684	92.4582
3.08	104.1061
3.5475	115.7688
3.849	127.4443
3.97	139.1289
3.9689	143.025
3.9471	146.9214
3.9045	150.8179
3.8416	154.7144
3.7584	158.6105
3.6556	162.5063
3.5337	166.4015
3.3932	170.2961
3.2349	174.1899
3.0597	178.083
2.8684	181.9752
2.6621	185.8666
2.4418	189.7572
2.2087	193.647
1.964	197.5361
1.7091	201.4246
1.4451	205.3127
1.1736	209.2004
0.8958	213.0879
0.6134	216.9755
0.3277	220.8632
0.0402	224.7513
-0.2475	228.6399

-0.534	232.5291
-0.8176	236.4192
-1.0971	240.3102
-1.3707	244.2021
-1.6372	248.0948
-1.8951	251.9882
-2.143	255.8818
-2.3795	259.7749
-2.6033	263.6664
-2.8133	267.5538
-3.008	271.4327
-3.1862	275.2931
-3.3462	279.1106
-3.4848	282.8025
-3.5931	286.0549
-3.6493	287.9327
-3.6597	288.3046

Taking into account the predicted dispersion of the fragments and the trajectory inaccuracies, the half width of the risky ground swath is in between 60 km (on the equator) and 42 km (at extreme sub-satellite track latitudes, North or South).

The countries or territories that might still be potentially hit by the BeppoSAX falling fragments are:

- **Africa:** Burundi, Congo, Democratic Republic of Congo, Gabon, Kenya, Rwanda, Seychelles, Somalia, Tanzania;
- **Asia:** Indonesia, Malaysia, Maldives, Singapore;
- **Oceania:** Baker Island (USA), Federated States of Micronesia, Howland Island (USA), Kiribati, Marshall Islands, Palau, Papua New Guinea;
- **South America:** Brazil, Colombia, Ecuador, Guyana, Peru, Venezuela.

The following countries or territories of the equatorial belt in between 4.36 degrees North and South are instead not included anymore – with a confidence level of 90% or higher – in the areas at risk for the BeppoSAX falling fragments: Cameroon, Central African Republic, Equatorial Guinea, Ethiopia, Sudan, Uganda, Cap Palmas, at the border between Liberia and Côte d'Ivoire, the Niger river delta, in Nigeria, Brunei, São Tomé and Príncipe, Nauru, French Guiana, Suriname, Jarvis Island (USA).

LONGITUDINAL RISK TIME WINDOWS

Table 3 lists the impact risk time windows, as a function of longitude, for the sub-satellite ground tracks potentially at risk, shown in Figures 1 and 2-5.

Table 3

Impact Risk Time Windows (UTC) Along the Risky Ground Tracks

Longitude Band	Track No. 1	Track No. 2	Track No. 3	Track No. 4	Track No. 5
180° – 120° W		29 APR 2323 30 APR 0018	30 APR 0056-0152	30 APR 0228-0323	30 APR 0403-0458
120° – 60° W		29 APR 2338 30 APR 0033	30 APR 0112-0218	30 APR 0243-0340	30 APR 0418-0514
60° W – 0°		29 APR 2353 30 APR 0048	30 APR 0128-0222	30 APR 0300-0356	30 APR 0434-0529
0° – 60° E	29 APR 2236-2331	30 APR 0008-0104	30 APR 0142-0238	30 APR 0316-0412	30 APR 0449-0545
60° – 120° E	29 APR 2251-2347	30 APR 0024-0120	30 APR 0158-0253	30 APR 0332-0427	30 APR 0505-0600
120° – 180° E	29 APR 2307 30 APR 0003	30 APR 0040-0136	30 APR 0213-0308	30 APR 0347-0443	30 APR 0520-0615

CONTINENTAL RISK MAPS

The sub-satellite ground tracks at risk are presented in further detail, for specific continental areas, in the following maps (Figures 2-5), where a ground swath half width of 60 km was assumed as an example.

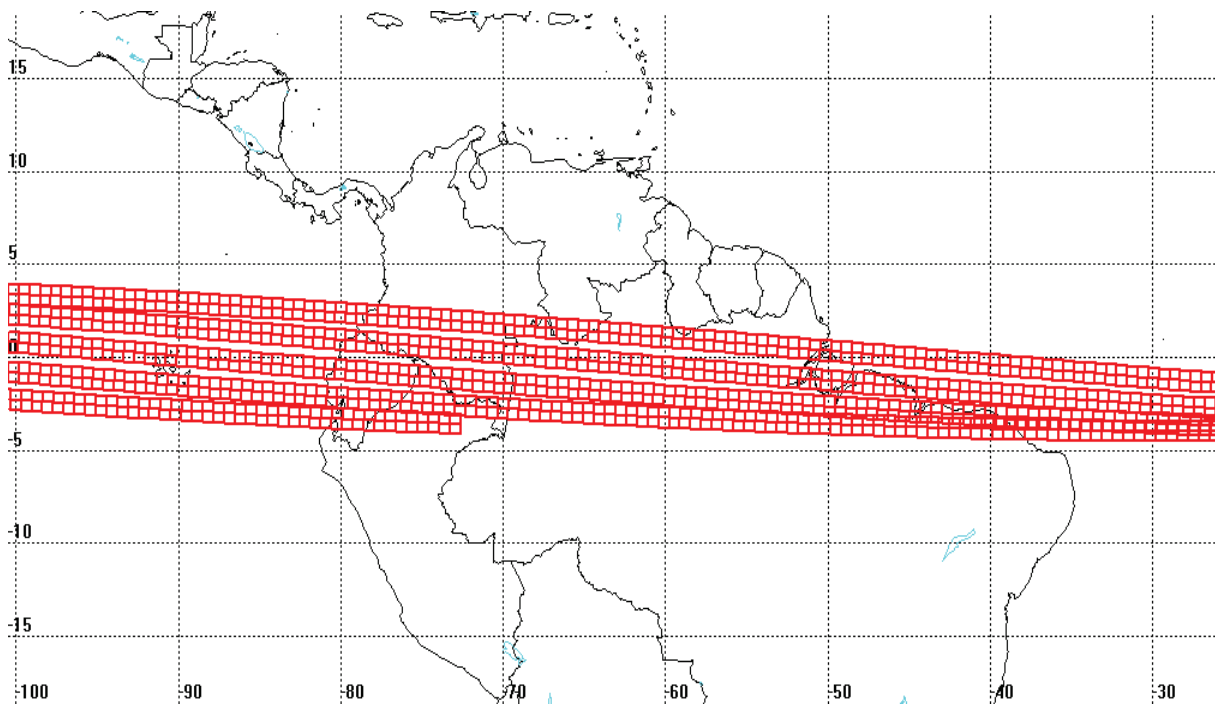


Fig. 2 – Sub-satellite tracks potentially at risk over South America

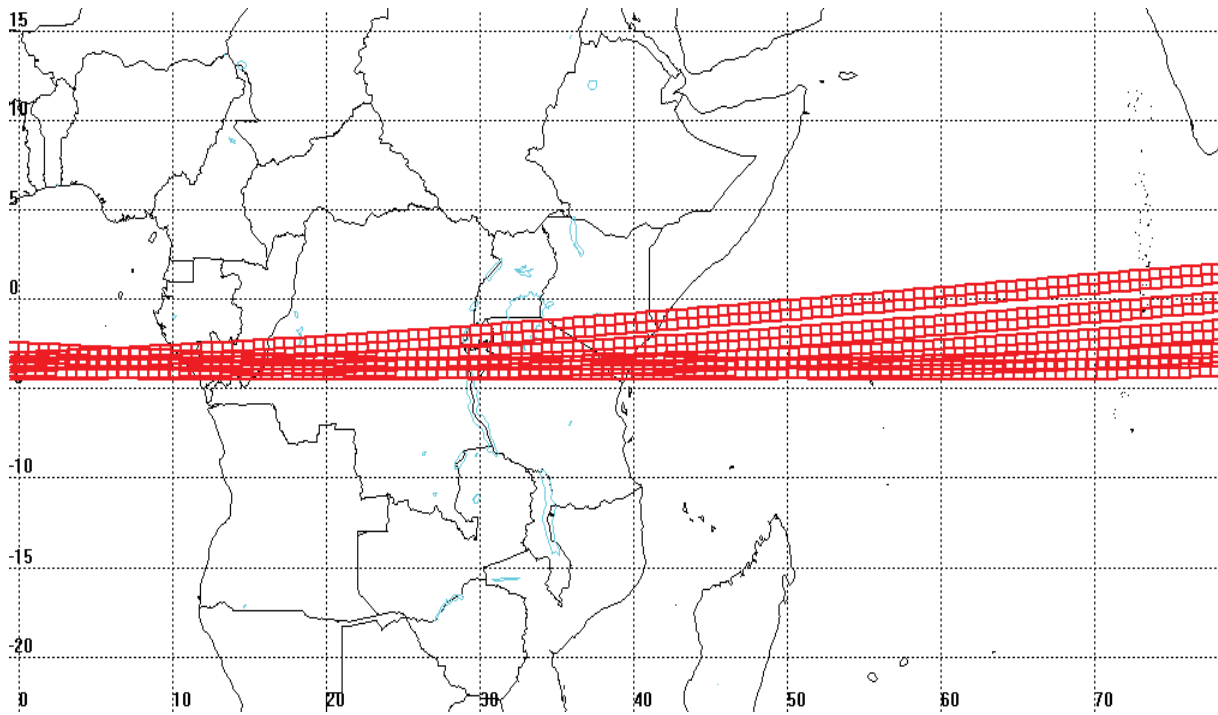


Fig. 3 – Sub-satellite tracks potentially at risk over Africa and Maldives

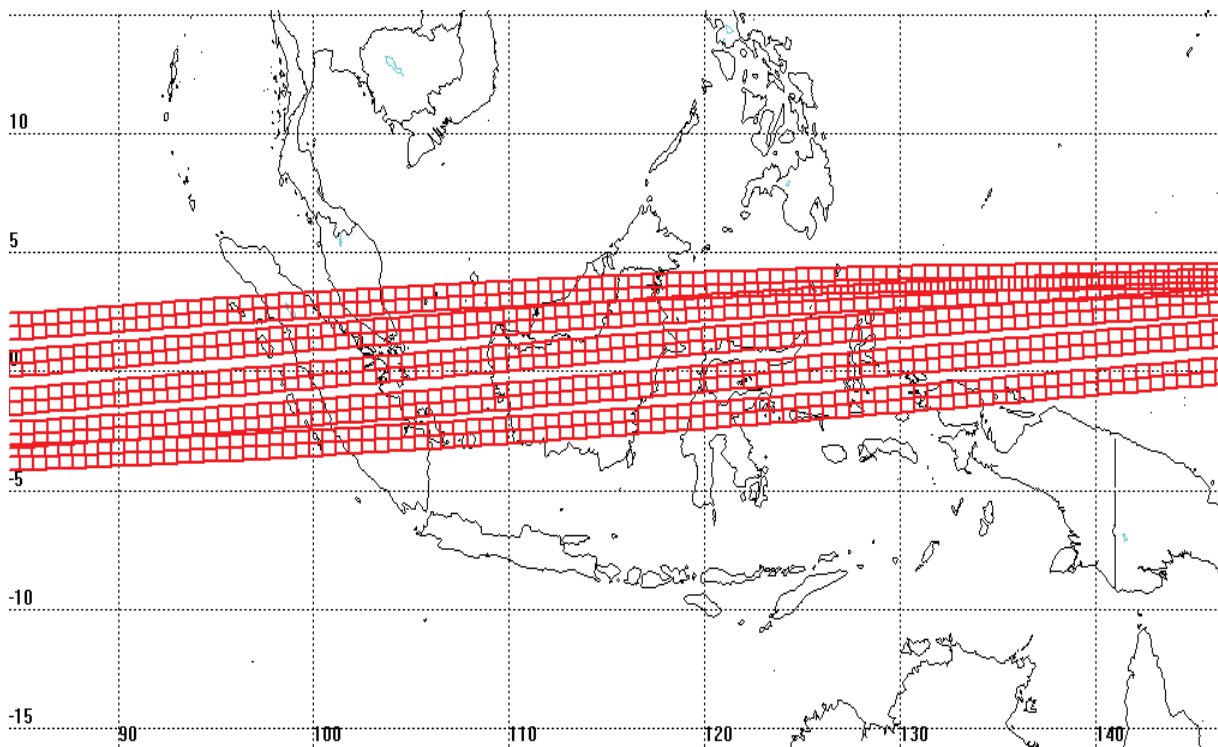


Fig. 4 – Sub-satellite tracks potentially at risk over Southeast Asia

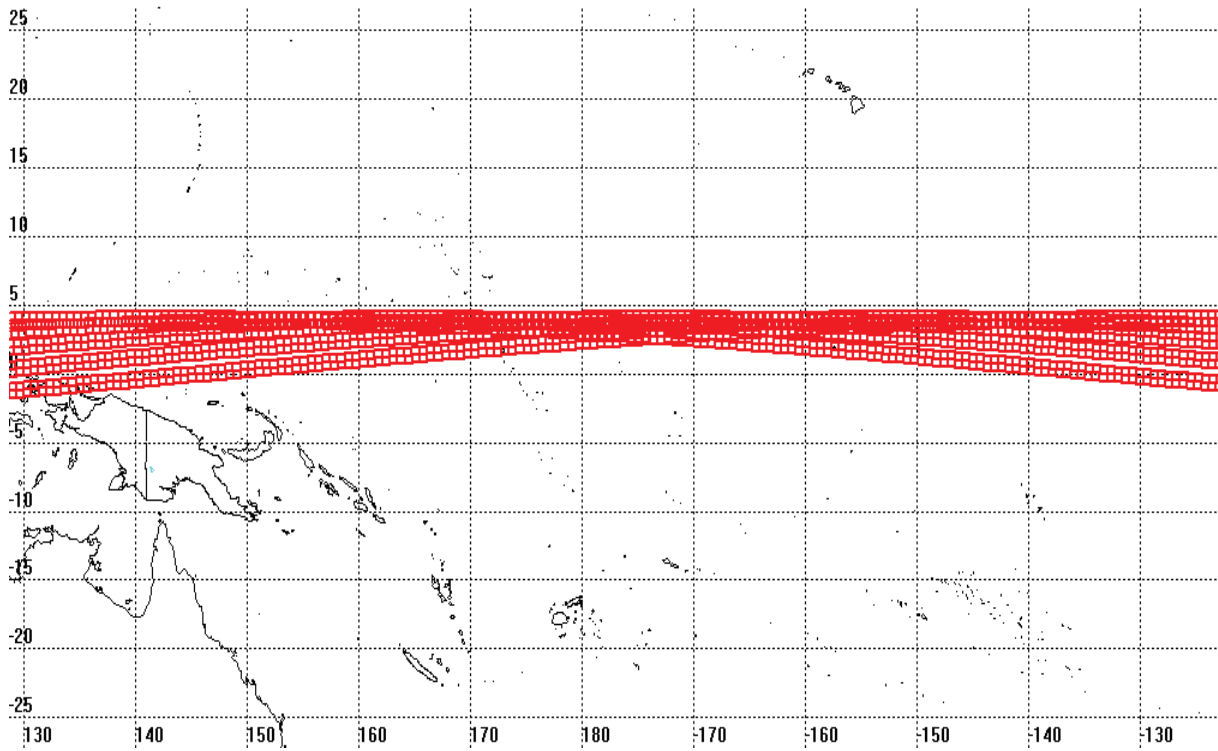


Fig. 5 – Sub-satellite tracks potentially at risk over Oceania

NEXT UPDATE

The next bulletin will be issued as soon as new significant results are available.

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BEPPOSAX REENTRY PREDICTIONS

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GROUND IMPACT UNCERTAINTY WINDOW

Currently BeppoSAX is approaching the reentry into the densest layers of the earth atmosphere. The expected residual lifetime of the satellite was computed by propagating its last available state vector (epoch: 29 April 2003, 18:52 UTC) with a numerical trajectory predictor including all the relevant perturbations. Concerning the predicted solar flux at 10.7 cm and the geomagnetic planetary index A_p , the last 3-day forecast, issued by the NOAA Space Environment Center, was adopted.

Using for the final orbits of BeppoSAX the ballistic parameter estimated by fitting the altitude decay observed during 19 hours, the ground impact time window shown in Table 1 was obtained for the main debris. The confidence level associated with such a window is approximately 90%.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	22:48 UTC
Nominal Impact	29 April 2003	23:36 UTC
Closure	30 April 2003	00:57 UTC

AREAS OF THE PLANET POTENTIALLY INVOLVED

Due to the current uncertainty on the reentry time, significant areas of the equatorial belt in between 4.36 degrees North and South might still be affected by the impact of the surviving fragments of BeppoSAX. The sub-satellite ground tracks potentially at risk are shown in Figure 1.

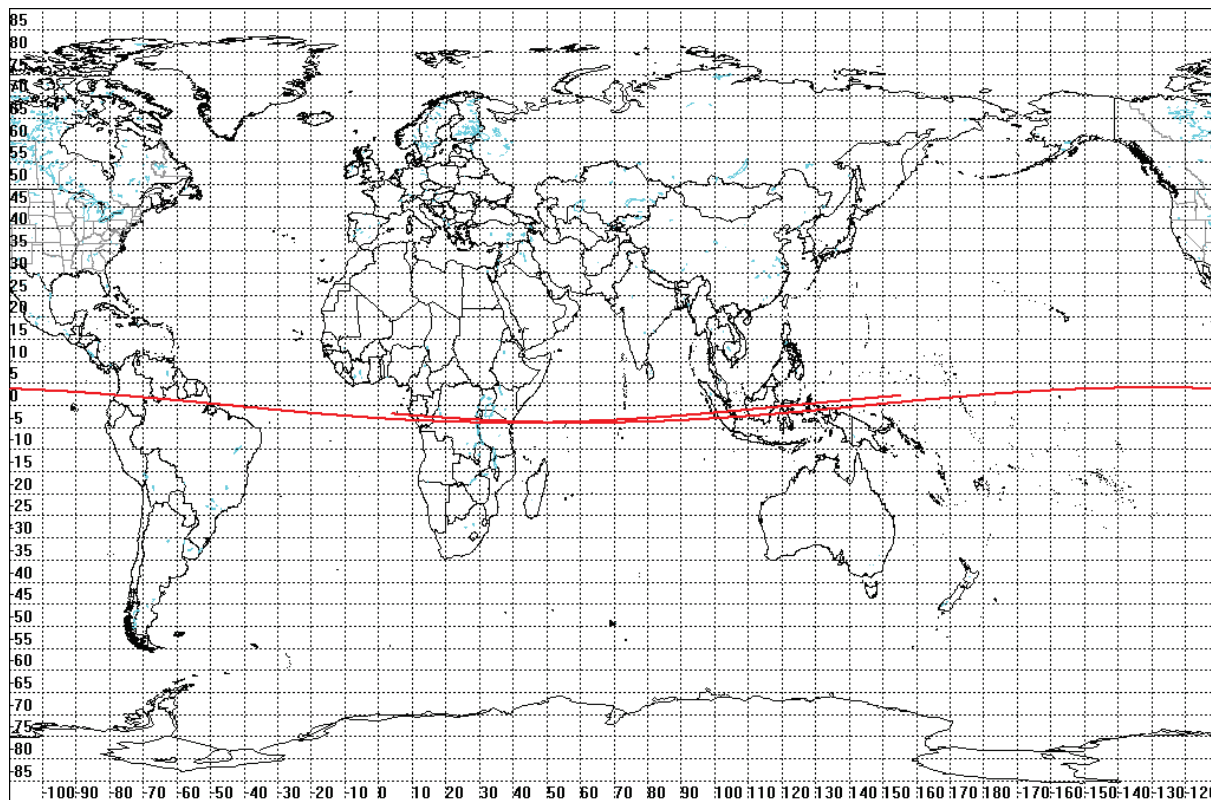


Fig. 1 – Sub-satellite tracks potentially at risk during the impact time window given in Table 1

The countries or territories that might still be potentially hit by the BeppoSAX falling fragments are:

- **Africa:** Burundi, Congo, Democratic Republic of Congo, Gabon, Kenya, Rwanda, Seychelles, Tanzania;
- **Asia:** Indonesia, Maldives;
- **Oceania:** Federated States of Micronesia, Kiribati, Palau;
- **South America:** Brazil, Colombia, Guyana, Venezuela.

The following countries or territories of the equatorial belt in between 4.36 degrees North and South are instead not included anymore – with a confidence level of 90% or higher – in the areas at risk for the BeppoSAX falling fragments: Cameroon, Central African Republic, Equatorial Guinea, Ethiopia, Sudan, Uganda, Cap Palmas, at the border between Liberia and Côte d'Ivoire, the Niger river delta, in Nigeria, Brunei, São Tomé and Príncipe, Nauru, French Guiana, Suriname, Somalia, Malaysia, Singapore, Marshall Islands, Papua New Guinea, Ecuador, Peru, Baker Island (USA), Howland Island (USA), Jarvis Island (USA).

LONGITUDINAL RISK TIME WINDOWS

Table 2 lists the impact risk time windows, as a function of longitude, for the sub-satellite ground tracks potentially at risk, shown in Figures 1 and 2-5.

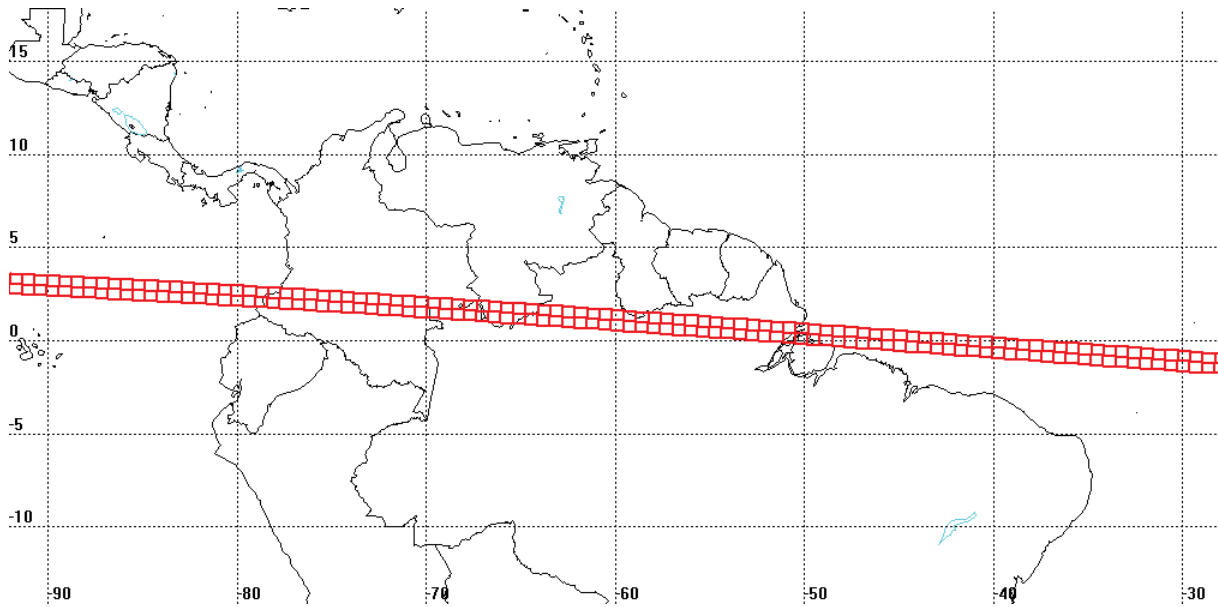
Table 2

Impact Risk Time Windows (UTC) Along the Risky Ground Tracks

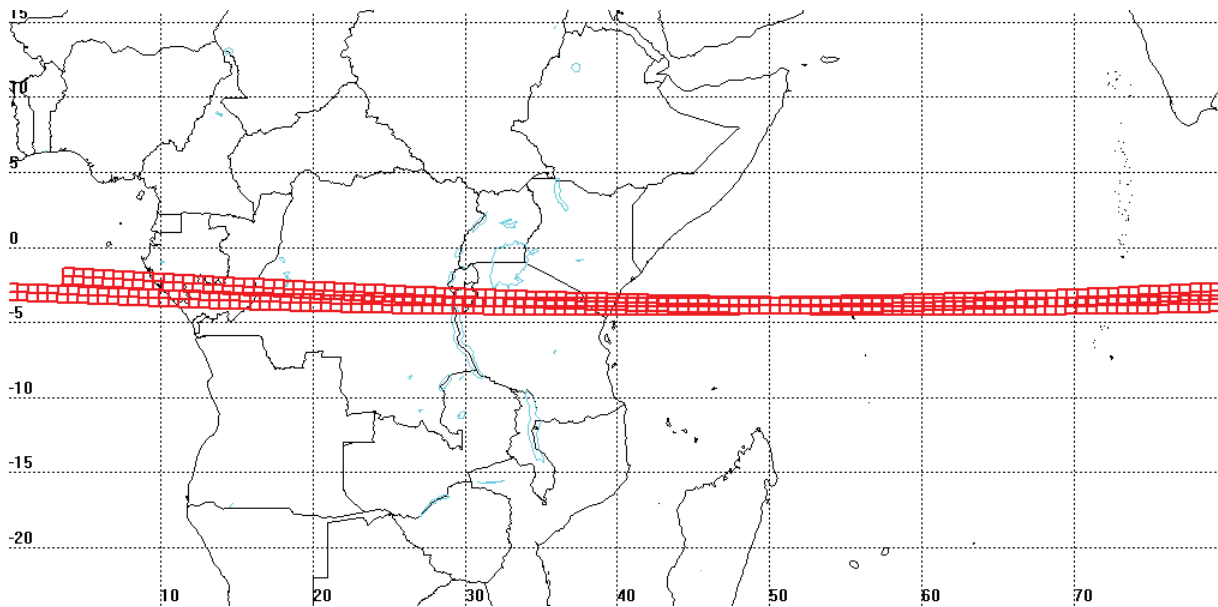
Longitude Band	Track No. 1	Track No. 2
180° – 120° W		29 APR 2323 30 APR 0018
120° – 60° W		29 APR 2338 30 APR 0033
60° W – 0°		29 APR 2353 30 APR 0048
0° – 60° E	29 APR 2236-2331	30 APR 0008-0104
60° – 120° E	29 APR 2251-2347	30 APR 0024-0120
120° – 180° E	29 APR 2307 30 APR 0003	30 APR 0040-0136

CONTINENTAL RISK MAPS

The sub-satellite ground tracks at risk are presented in further detail, for specific continental areas, in the following maps (Figures 2-5), where a ground swath half width of 60 km was assumed as an example.



**Fig. 2 – Sub-satellite track potentially at risk over South America
No. 2 of Table 2**



**Fig. 3 – Sub-satellite tracks potentially at risk over Africa and Maldives
Northern track: No. 1 of Table 2
Southern track: No. 2 of Table 2**

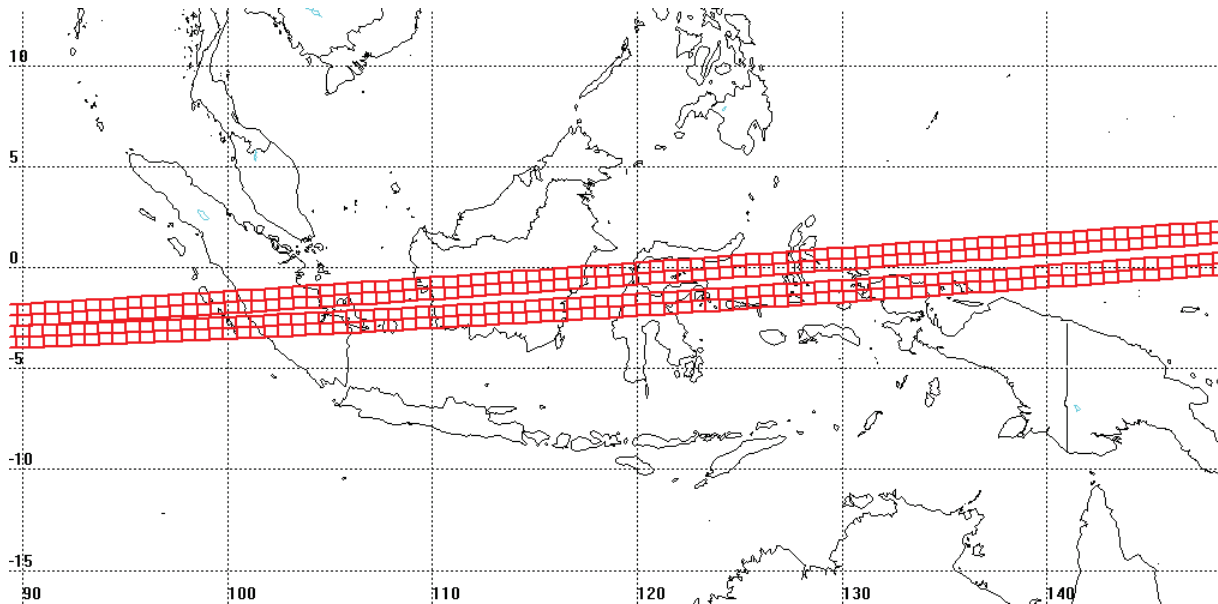


Fig. 4 – Sub-satellite tracks potentially at risk over Southeast Asia
Northern track: No. 2 of Table 2
Southern track: No. 1 of Table 2

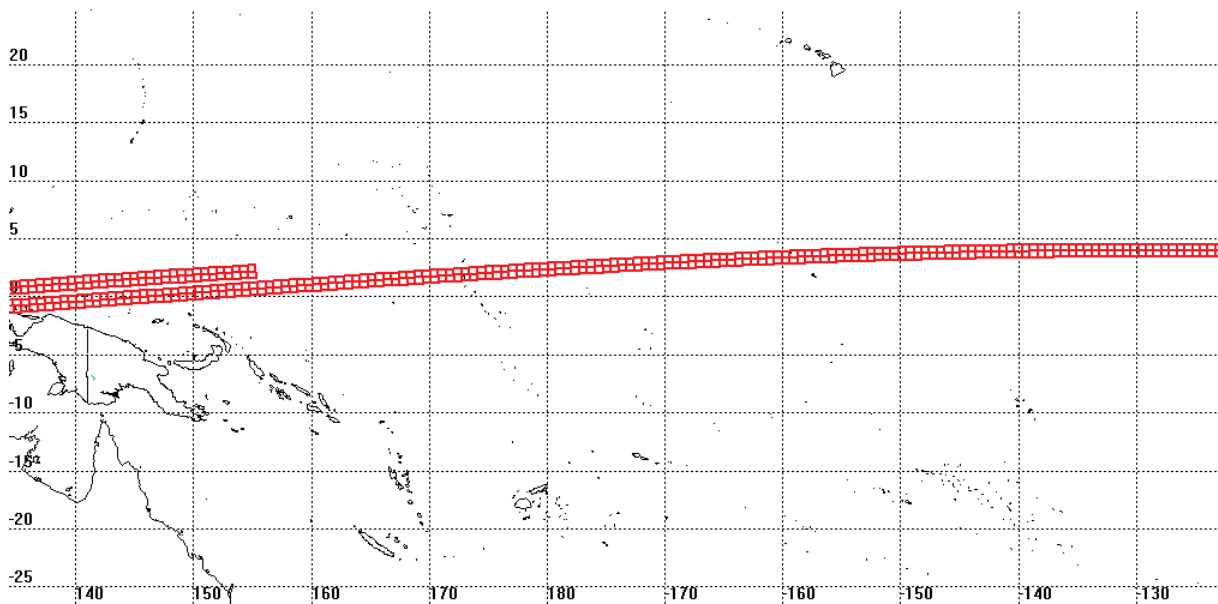


Fig. 5 – Sub-satellite tracks potentially at risk over Oceania
Northern track: No. 2 of Table 2
Southern track: No. 1 of Table 2

NEXT UPDATE

The next bulletin will be issued as soon as new significant results are available.

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BEPPOSAX REENTRY REPORT

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BEPPOSAX REENTRY

Based on the American Space Surveillance Network assessment, the estimated ground impact time for the BeppoSAX main debris was 29 April 2003, 22:06 UTC, with an uncertainty window of plus or minus 7 minutes. Figure 1 shows the sub-satellite ground track corresponding to the above mentioned decay window. A ground swath half width of 60 km was assumed.

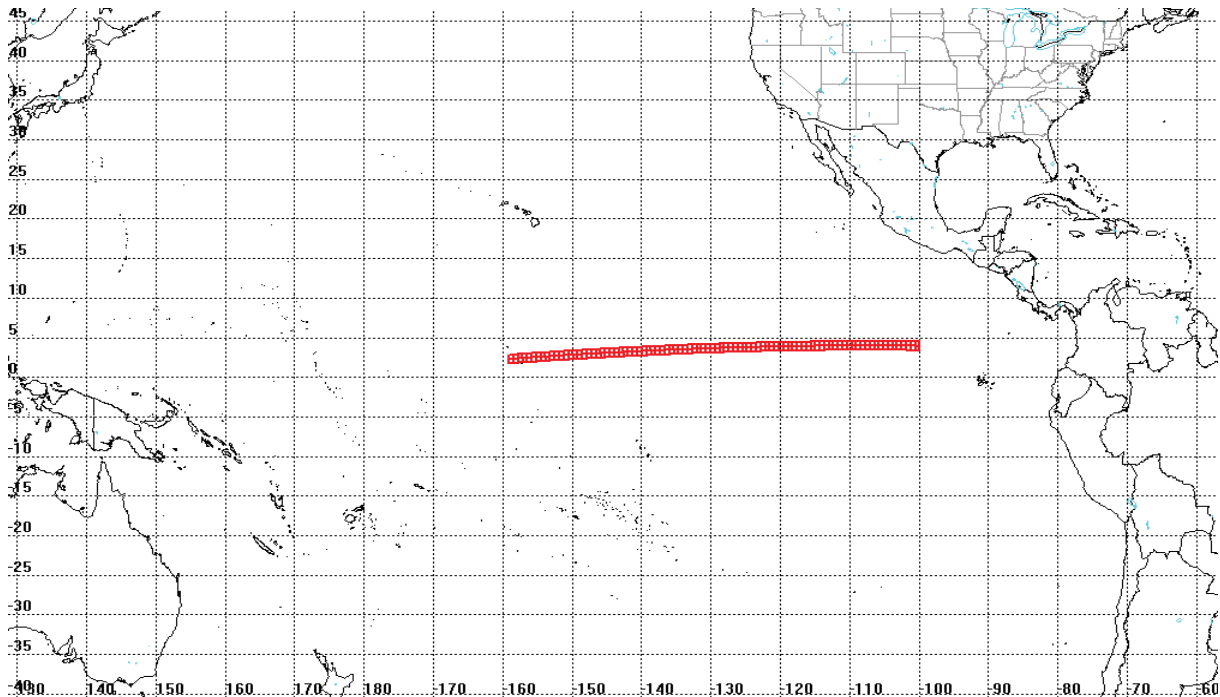


Fig. 1 – Sub-satellite track corresponding to the BeppoSAX decay window

No visual report concerning the satellite reentry time and area is at present available.

BEPPOSAX REENTRY REPORT

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BEPPOSAX REENTRY

Using for the final orbits of BeppoSAX the ballistic parameter estimated by considering the altitude decay observed during 7.3 hours (last couple of two line orbital elements available), the ground impact time window shown in Table 1 was estimated for the main debris. Figures 1 and 2 show the sub-satellite ground track corresponding to the above mentioned decay window. A ground swath half width of 60 km was assumed.

Table 1

Ground Impact Time Window for the BeppoSAX Main Debris

Impact Window	Impact Date	Impact Time
Opening	29 April 2003	21:45 UTC
Nominal Impact	29 April 2003	22:43 UTC
Closure	29 April 2003	23:43 UTC

The nominal reentry location, based on the American Space Surveillance Network assessment, is shown in the figures. It is affected by an uncertainty of plus or minus 3000 km along the trajectory. No visual report concerning the satellite reentry time and area is at present available.

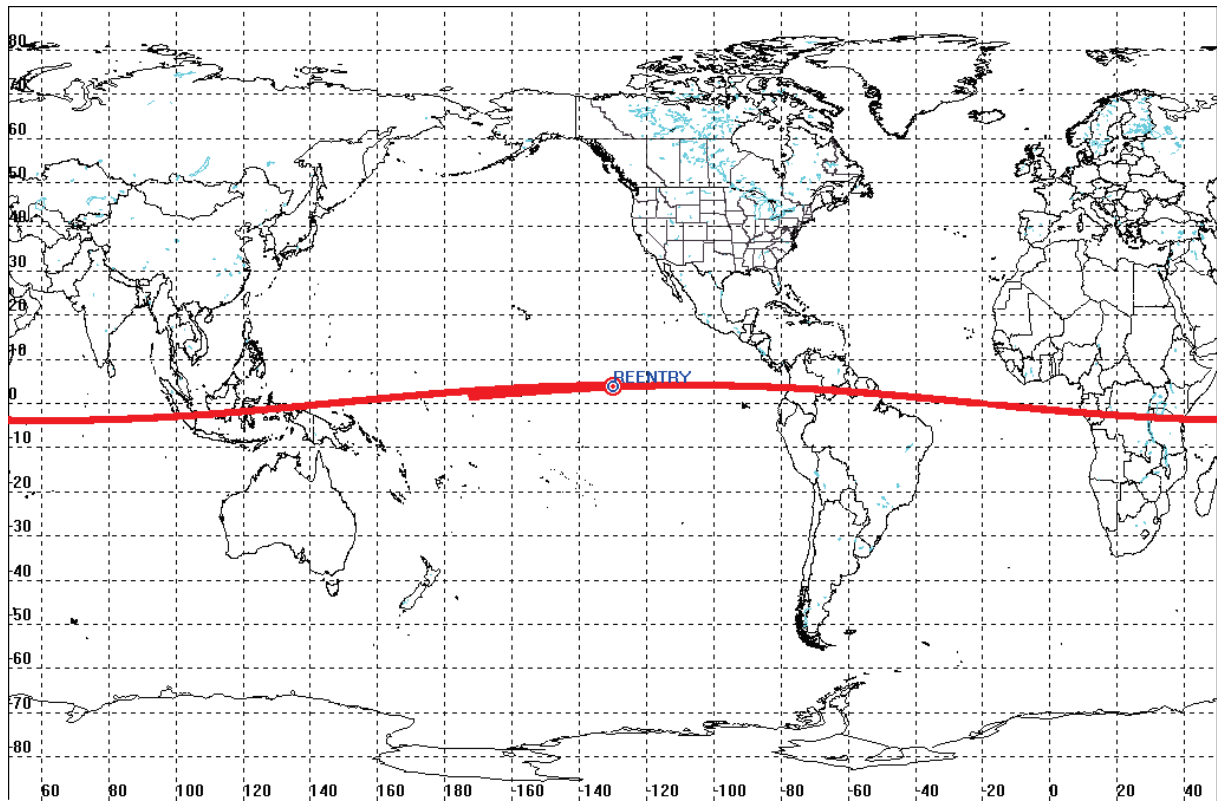


Fig. 1 – Sub-satellite track corresponding to the BeppoSAX decay window

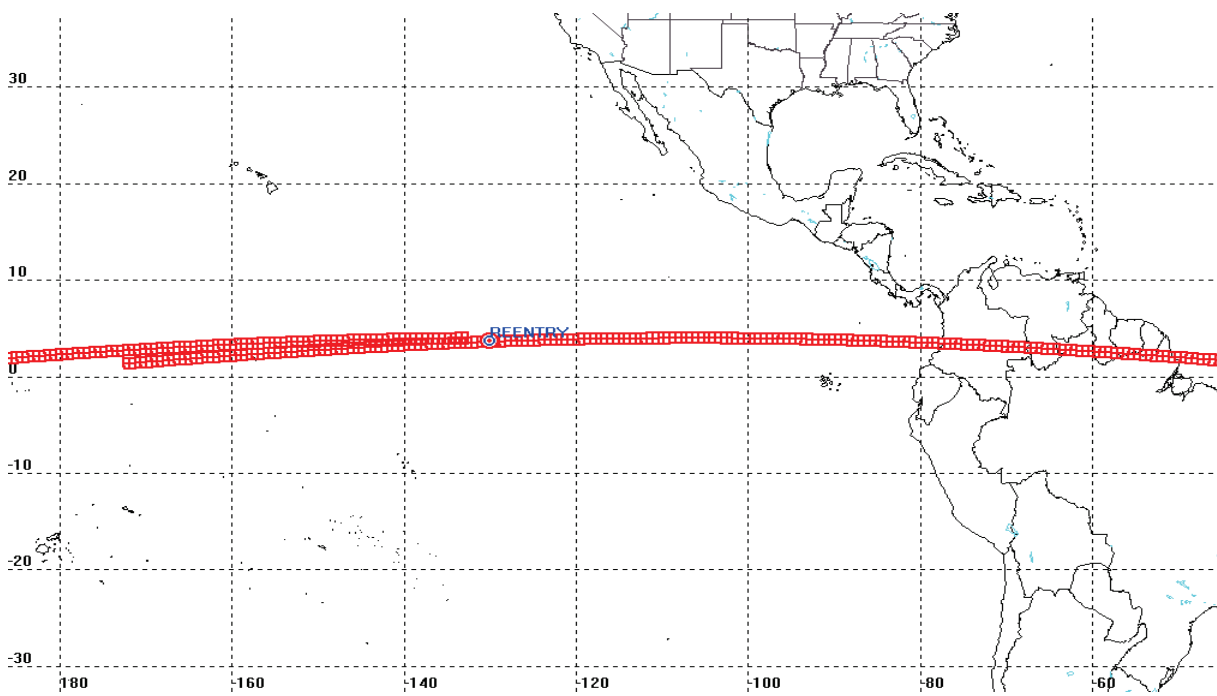


Fig. 2 – BeppoSAX reentry area



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MEMORANDUM DEL LABORATORIO DI DINAMICA DEL VOLO SPAZIALE

A: L. SALOTTI (ASI)
DA: L. ANSELMO & C. PARDINI (ISTI)
OGGETTO: RIENTRO DEL SATELLITE BEPPoSAX
DATA: 2 MAGGIO 2003
CC:

In relazione alle notizie giornalistiche relative alla presunta caduta di frammenti del satellite BeppoSAX sull'Ecuador e sulla Malesia, si riportano nelle Figure 1, 2 e 3 i tracciati corrispondenti all'unione delle due penultime finestre di rientro dell'ISTI e della US Space Surveillance Network (SSN):

- Apertura: Ore 21:00 UTC del 29 Aprile 2003;
- Chiusura: Ore 01:00 UTC del 30 Aprile 2003.

Per la dispersione dei frammenti perpendicolarmente alla traiettoria è stato considerato un valore massimo conservativo di 60 km.

Come è facile verificare, sia l'Ecuador che la Malesia risultano esclusi dalle aree potenzialmente a rischio corrispondenti alla finestra di rientro di cui sopra.





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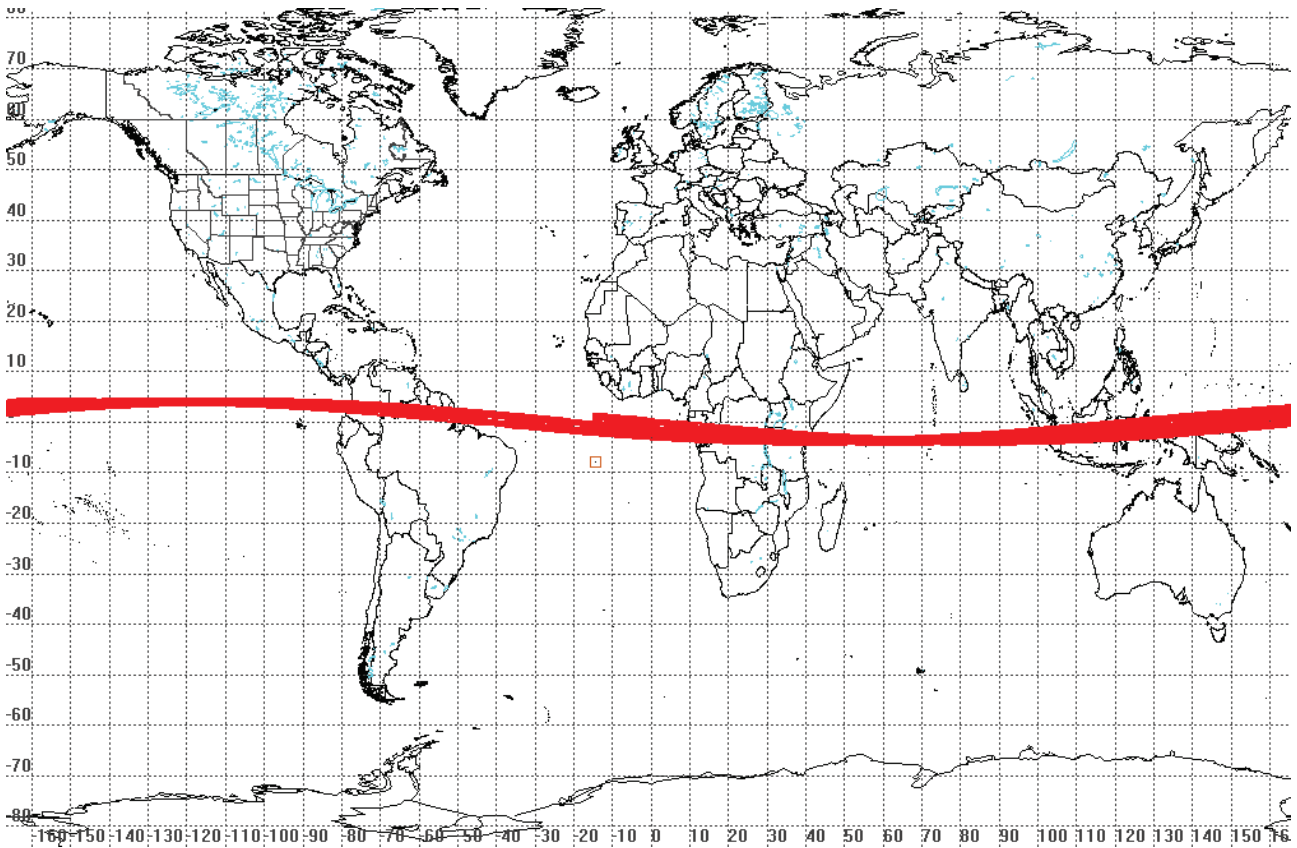


Fig. 1 – Aree a rischio potenziale di caduta ottenute sommando le due penultime finestre di rientro ISTI e US SSN

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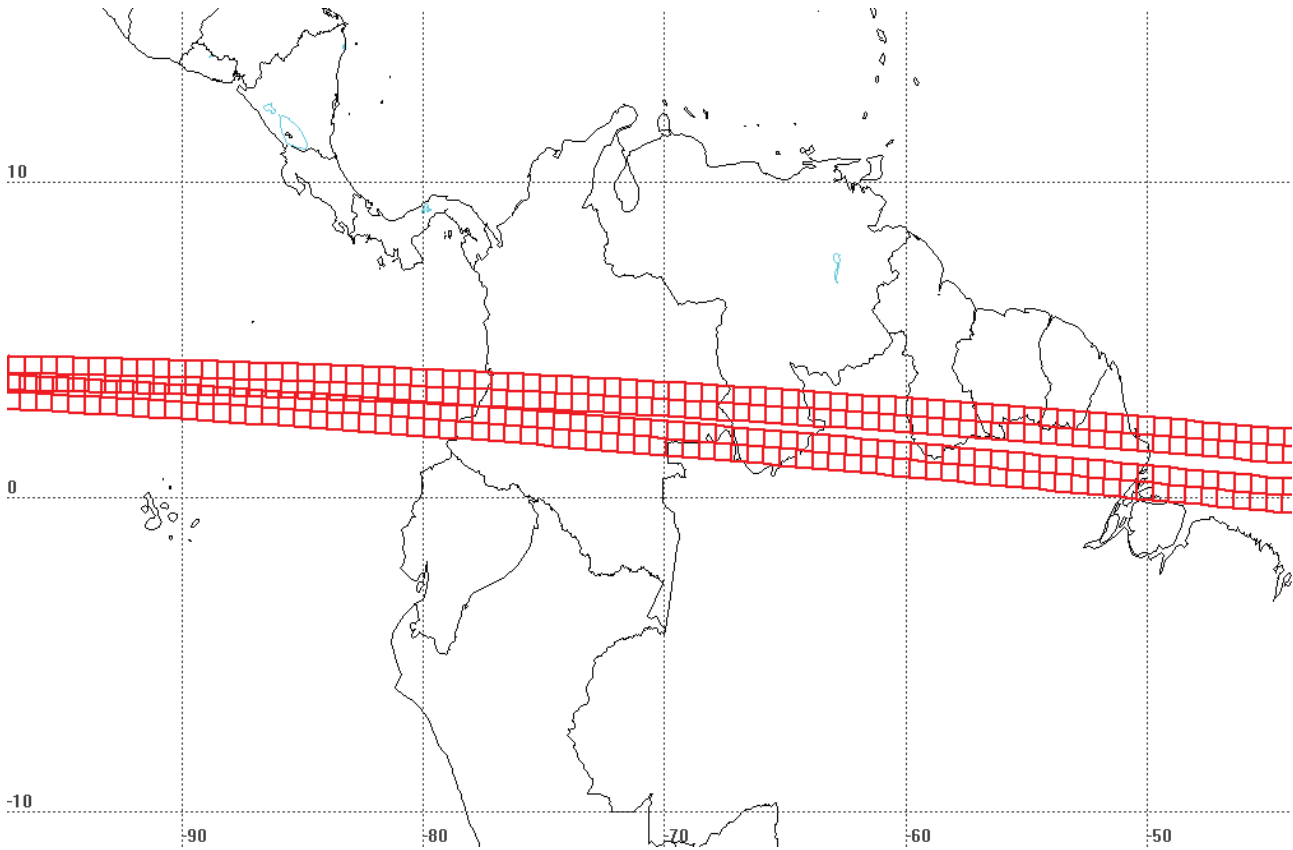


Fig. 2 – Dettaglio sul Sud America delle aree a rischio potenziale di caduta ottenute sommando le due penultime finestre di rientro ISTI e US SSN

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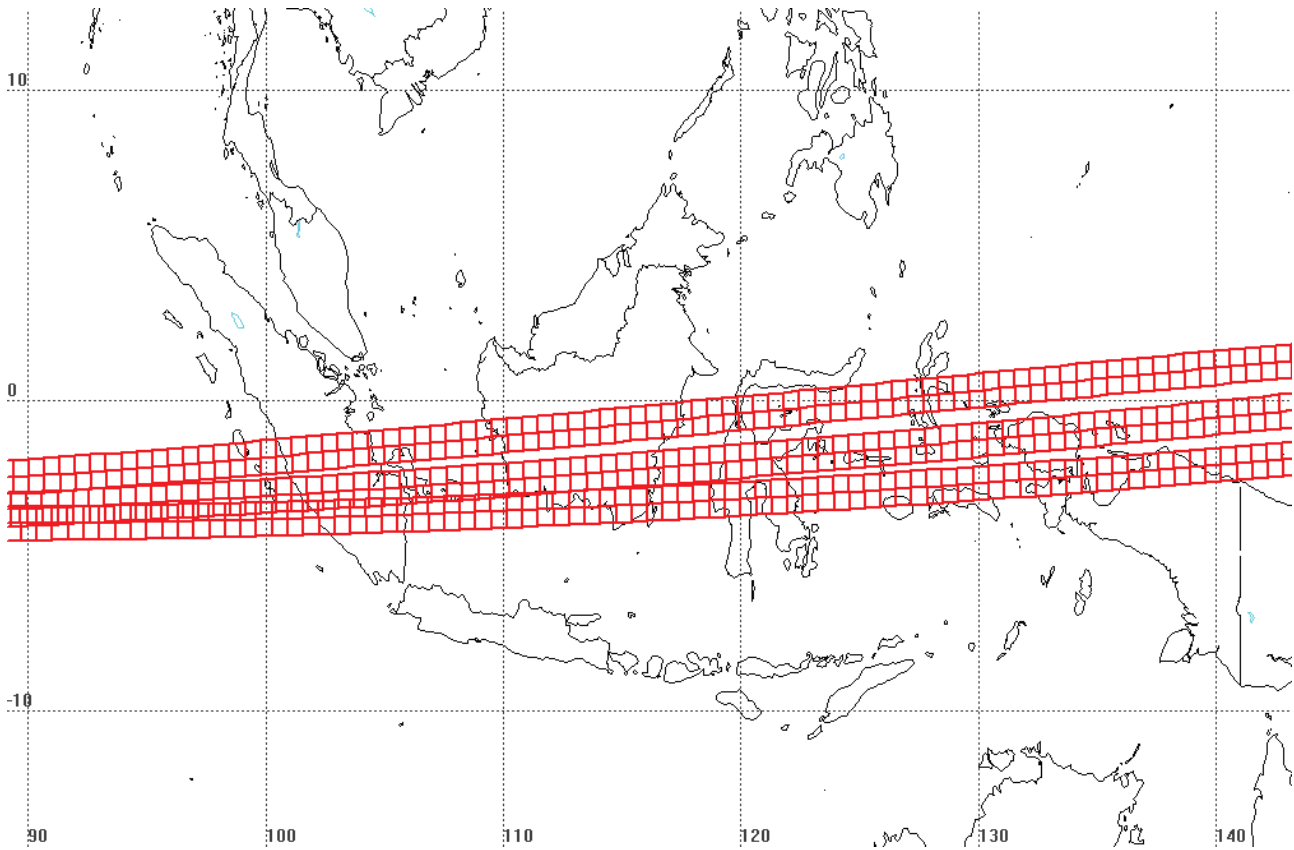


Fig. 2 – Dettaglio sul Sud-Est Asiatico delle aree a rischio potenziale di caduta ottenute sommando le due penultime finestre di rientro ISTI e US SSN

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