CURRENT STATUS AND EVOLUTION PROSPECTS OF THE DORIS NETWORK

LE RÉSEAU DORIS : BILAN ET PERSPECTIVES

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ABSTRACT - The deployment of the network of permanent orbit determination ground stations, one of the essential components of the DORIS system, has been going on over more than ten years, starting before the launch of the first satellite carrying a DORIS receiver. After a presentation of the evolution and the status (equipment and maintenance statistics) of this network, currently composed of 54 homogeneously distributed stations, we review the existing collocations with other space geodesy techniques (VLBI, SLR, or GPS), which contribute with DORIS to the realization of the International Terrestrial Reference System.
Through a general survey of the quality of the monumentation and mounting devices on which the antennas are installed, we try to assess their stability, for which an improvement action has been taken in order to guarantee its compatibility with the current accuracy of the DORIS positioning results. The purpose of the network's future evolutions will be threefold: to improve the geodetic quality of the existing stations, to fill the few remaining gaps in the global coverage, and to improve the reliability of the equipment through the development and deployment of a new generation of beacons.

***RÉSUMÉ** - L'implantation du réseau des stations permanentes d'orbitographie, l'une des composantes essentielles du système DORIS, qui a débuté avant le lancement du premier satellite porteur d'un récepteur DORIS, se poursuit depuis plus de dix ans. Après une présentation de l'évolution et de l'état actuel (matériel et statistiques de maintenance) de ce réseau, actuellement constitué de 54 stations réparties de manière homogène, nous faisons le point sur les co-localisations avec d'autres techniques de géodésie spatiale (VLBI, SLR, ou GPS) qui participent avec DORIS à la détermination du système de référence terrestre international.*
À travers une étude de la qualité de la monumentation et des supports utilisés pour l'installation des antennes, nous essayons d'évaluer leur stabilité, dont une action d'amélioration a été engagée afin de garantir sa compatibilité avec la précision actuelle des résultats du positionnement DORIS. L'objectif des futures évolutions du réseau sera triple : améliorer la qualité géodésique des stations existantes, combler les quelques trous qui demeurent dans la couverture globale, et améliorer la fiabilité du matériel par le développement et l'implantation d'une nouvelle génération de balises.

PAST EVOLUTION AND CURRENT STATUS OF THE NETWORK

History and general evolution

The DORIS ground stations network, one of the main components of the DORIS system, was designed bearing in mind an essential requirement for the precise computation of the orbits: to ensure an almost constant visibility of at least one ground station by the on-board receiver. This objective could be reached through the deployment of a sufficient number of well distributed stations.

The deployment of the network by the French national survey agency (IGN: Institut Géographique National), started in 1986. The network had 32 stations when the first DORIS receiver was launched on SPOT2 ten years ago (January 1990), and the initial objective of roughly 50 stations was reached by the end of 1993. From then on, installations of new stations have been going on at a slower pace, with the latest one taking place at St. John's (Newfoundland, Canada) in September 1999, bringing the number of stations up to 54.

Although the total number of stations has remained rather stable since the end of 1993, rising from 49 to 54, 23 of them have been moved or renovated during this six year period (Figure 1). A few sites have been fixed and upgraded following damages caused to the antenna by hurricanes. On the other hand, on several occasions the permanent closure of a building hosting one of our stations required us to find an alternative solution, which could take as long as one year, including the delay to obtain the frequencies clearance.

The renovation of a station can include some of the following operations:

- Beacon upgrade from version 1 to version 2,
- Antenna change and/or displacement. Alcatel antennas are nearly always replaced with Starec types, which resist high winds far better, and allow a more accurate geodetic survey,
- Monumentation improvement,
- New geodetic survey including the new and former antennas, and other interesting geodetic markers or instruments in the vicinity.

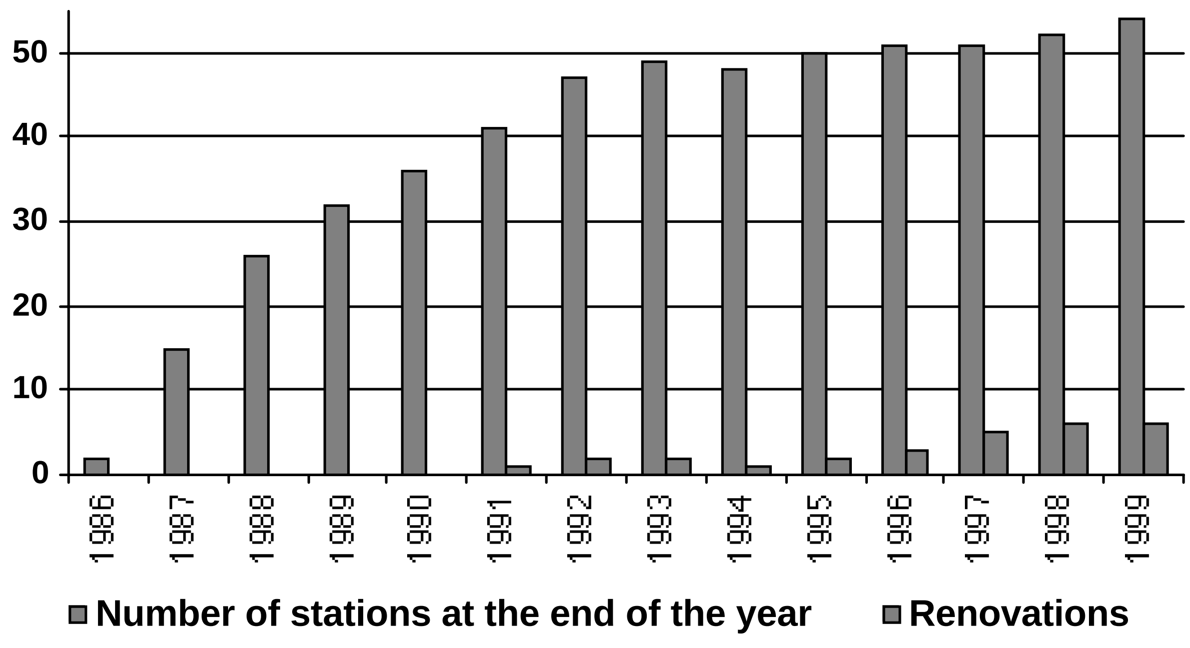

Figure 1 : evolution of the DORIS network

Information about the changes in the network status are made available through the DORIS mails. Moreover, detailed information in the form of a site log for each DORIS site is now available on the Internet, in the DORIS pages of IGN's web server.

The host agencies

At the time of writing (March 2000), the network consists of 54 stations, distributed over 30 different countries. The host agencies of these stations are :

- National survey organizations : 13 stations,
- Space agencies : 11 stations,
- Institutes of Astronomy, Geophysics, or Oceanography : 12 stations,
- Miscellaneous scientific institutes (universities, polar institutes, etc.) : 11 stations,
- Telecommunication stations : 3 stations,
- Meteorological stations : 3 stations,
- Other : 1 station.

Equipment

The distribution of the different types of beacons and antennas is currently:

- 1st generation beacon + Alcatel antenna: 24 stations,
- 1st generation beacon + Starec antenna: 19 stations,
- 2nd generation beacon + Starec antenna: 11 stations.

Maintenance statistics

IGN's maintenance service (SIMB : Service d'Installation et de Maintenance des Balises) handles around 130 intervention requests per year. An average of 12 beacons per year need to be exchanged.

The main failure causes for the first generation beacons are :

- Power supply unit : 70 %,
- Oscillator : 15 %,
- Amplifier : 15 %.

Unfortunately, the second generation beacon turned out to be less reliable, with 4 failures (all of them being amplifier failures) out of 14 beacons (including spares) installed at DORIS stations. They will nevertheless allow to replace some out of order first generation beacons, which are more than ten years old now, until the third generation ones are available.

The average proportion of transmitting beacons is about 85 %, but this rate nevertheless allows the global coverage rate (ratio of time during which the on-board instrument receives a signal) to remain at a good level, thanks to the density and homogeneity of the network. This coverage rate, the maximum theoretical value of which is 95% for TOPEX-Poseidon, is still above 80% when 15% of the stations are not transmitting.

DORIS in the IERS network

Since the official acceptation of DORIS in 1996 as one of the techniques contributing to the realization of the terrestrial reference system of the International Earth Rotation Service (IERS), the number of sites where the DORIS antenna is colocated with another technique has progressively increased, reaching now 33 out of the 54 current sites (Table 1). Moreover, these colocated sites are very well distributed over the world, half of them being located in the Southern hemisphere (Fig. 2).

DORIS stations	VLBI			SLR			GPS		
	Distance	(Status)	σ*	Distance	(Status)	σ*	Distance	(Status)	σ*
Arequipa				5 m	(P)	2	40 m	(P)	2
Ascension							9.6 km	(P)	3
Chatham Island							61 m	(P)	2
Cibinong							42 m	(P)	2
Dionysos				43 m	(M)	10			
Easter Island				12 m	(M)	10	54 m	(P)	10
Fairbanks	1.1 km	(P)	3				1.1 km	(P)	1
Goldstone	12.7 km	(P)	11	8 m	(M)	1	21.5 km	(P)	22
Guam							7.4 km	(P)	5
Hartebeesthoek	2.2 km	(P)	25	2.2 km	(M)	25	23 m	(P)	10
Kauai	0.4 km	(P)	10				0.3 km	(P)	10
Kerguelen							0.5 km	(P)	2
Kitab							0.1 km	(P)	2
Kourou							25 km	(P)	20
Krasnoyarsk							21 m	(P)	2
La Réunion							16 m	(P)	1
Libreville							15 m	(P)	1
Metsahövi	20 m	(M)	1	2.8 km	(P)	1	2.8 km	(P)	1
Mount Stromlo				39 m	(P)	1	65 m	(P)	1
Nouméa							47 m	(P)	3
Ny-Ålesund	1.6 km	(P)	2				1.6 km	(P)	2
Papeete				33 m	(P)	2	7 m	(P)	2
Ponta Delgada	0.9 km	(M)	2				10 m	(P)	1
Reykjavik							2.4 km	(P)	2
Richmond	1.2 km	(P)	3	1.2 km	(M)	2	1.2 km	(P)	2
Rio Grande							61 m	(P)	3
Saint John's	0.2 km	(M)	1				26 m	(P)	1
Santiago	0.2 km	(P)	1	2 m	(M)	1	73 m	(P)	1
Syowa							0.3 km	(P)	2
Terre Adélie							0.3 km	(P)	3
Toulouse	1.1 km	(M)	3				1.3 km	(P)	3
Yarragadee				16 m	(P)	10	37 m	(P)	10
Yellowknife	58 m	(P)	3				31 m	(P)	2

Table 1 : colocations between DORIS and other IERS techniques
(P) : permanent, (M) : mobile
* σ : survey RMS (1 σ) in mm

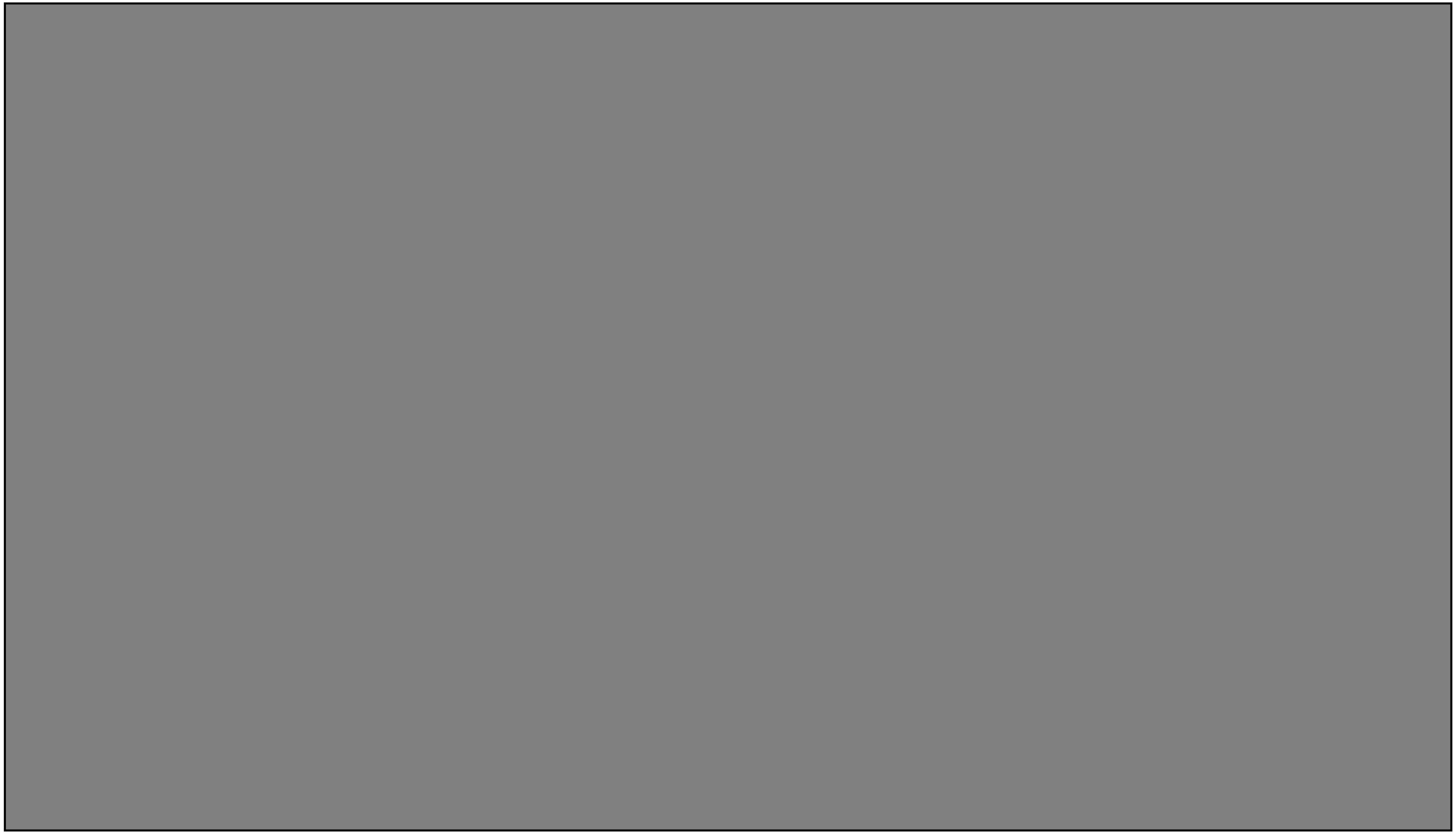

Figure 2 : DORIS stations colocated with other IERS techniques (VLBI, SLR or GPS)

DORIS and the tide gauges

With more than half of the stations located on coasts or on remote islands, DORIS is in a good position to meet the increasing demand for absolute positioning of tide gauges : 27 stations are located less than 50 km away from a GLOSS tide gauge, and at 16 of these sites (Table 2) the distance is less than 10 km, allowing a precise geodetic tie to be performed. The missing ties will be measured next time these sites are visited on the occasion of a station renovation.

DORIS station	Distance (km)	Geodetic tie
Easter Island	7	
Papeete	7	7/1995
Ascension	6.5	3/1997
Colombo	5	
St Helena	4	
Nouméa	3.6	4/1998
Kerguelen	3.3	11/1994
Reykjavik	2	5/1997
Tristan da Cunha	2	
Ponta Delgada	1.5	10/1998
Chatham Island	1.2	3/1999
Marion Island	1	
Syowa	1	
Terre Adélie	1	
Socorro	0.4	5/1998
St John’s	4	9/1999

Table 2 : DORIS stations located less than 10 km away from a GLOSS tide gauge

Antennas long term stability

Because of the improvements in the accuracy of the DORIS system’s results, especially in the field of point positioning, the specifications for the stability of the antenna reference point have become more demanding. When it is a matter of measuring geophysical displacements of the order of only one or two cm per year, it is necessary to guarantee that the stability of the antenna reference point is better than one centimeter over a ten-year period, not including the local geological movements. In this chapter we will try to assess the stability of the currently installed antennas.

The overall stability of a DORIS antenna, as well as other geodetic instruments, is influenced by the stability of the following elements [Combrinck 98]:

- The mounting structure: metal tower (guyed or not) of different heights, steel pole, metal plate with a forced centering device, etc.
- The monument on which this structure is installed: concrete pillar or block (founded or not on the underlying bedrock), concrete slab, building (whose stability will be dependent on its materials, size, foundations and age).
- The site on which the monument has been constructed.

While it is difficult to act on the geological stability of the site (although this aspect can be taken into account during the selection process of a new site), it is possible to improve decidedly the antenna stability by choosing the best possible combination of monument and mounting structure compatible with the requirements and constraints for the installation of a DORIS station. In particular, the length of the cables between the beacon – which should be in a building – and the antenna – which should have a clear horizon – is limited to 15 meters in order to keep the transmitted power at a sufficient level, which means that the antenna cannot be placed far away from the building. Therefore in many cases it is necessary to put the antenna on the building, or to use a high mounting structure if we wish to put it on the ground.

This is why most DORIS antennas are installed on a metal tower, set on a concrete support on the ground, or on top of a building. In the first years of the network deployment (until the beginning of 1992), Alcatel antennas were used, whose phase center position was known only to within ± 5 mm, and who are difficult to survey accurately because of the size of the radome. Most supporting towers were guyed in order to avoid them to be knocked down by strong winds, but at some sites the guy-wires were not placed so as to guarantee the antenna stability in the long term, and not all antennas were accurately centered above a ground mark, although in such cases the central tube of the base plate of the tower can be used as a reference mark. Nevertheless, the situation does not seem to be as bad as one might fear: the antenna horizontal offsets which were measured several years later, on the occasion of antenna changes, were generally of the order of 1 to 3 cm (including some sites where the antenna had been installed 12 years ago), which is quite acceptable considering the positioning accuracy of the DORIS system which was expected before the launch of SPOT-2: around 10 cm.

As of 1992, Starec antennas have been used for the installation of new stations and to upgrade existing ones. The position of their phase center is better known (to within 1 mm), and they can be accurately surveyed and centered above a ground mark. New installation methods were implemented when we started to install this kind of antennas, while the accuracy of the DORIS positioning results started to exceed the initial expectations:

- three guy-wires at 120°, whose tension is adjusted to center the antenna above the mark to within one mm,
- antenna installed on top of the tower using a triangular plate that can be precisely leveled, allowing the antenna verticality to be adjusted to within one mm.

Although the use of guying to center the antenna above the mark allows to do so very accurately while improving the rigidity of the tower (therefore giving it an excellent short term stability), it may not be the best solution in the long term in spite of the above precautions, in case one of the guys slackens or breaks for any reason. More recently, a few antennas were installed on a more rigid support, offering a better long term stability: one meter (or less) metal tower not requiring guy-wires, or forced centering device on a concrete pillar. Table 3 lists the **estimated** stability of the mounting structure and of the monument for each DORIS station, and gives an **estimated** overall stability which was deduced not only from these two criteria, but also takes into account the kind of antenna and its installation date. This estimate should neither be regarded as an indicator of the quality of the stations' computed coordinates and velocities, nor be used to classify them, since the actual stability of an antenna can only be properly assessed by surveying it with respect to a reference mark. The purpose of the current estimation is only to allow us to draw up a priority order for the next stations renovations.

Station	Current antenna		Mounting device		Monument		Overall stability
	Type	Installed	Description	Stability	Description	Stability	
Amsterdam	Starec	1997	Aluminum plate	***	Concrete pillar	***	***
Arequipa	Alcatel	1988	Guyed 2 meter tower	*	Building	**	*
Arlit	Alcatel	1992	Guyed 2 meter tower	**	Building	**	**
Ascension	Starec	1997	Aluminum plate	***	Concrete pillar	***	***
Badary	Alcatel	1991	Guyed 1 meter tower	**	Building	**	**
Cachoeira Paulista	Starec	1992	Guyed 2 meter tower	**	Building	**	**
Chatham Island	Starec	1999	Guyed 2 meter tower	**	Concrete block	***	***
Cibinong	Starec	1992	Guyed 3 meter tower	**	Concrete block	***	**
Colombo	Alcatel	1991	Guyed 3 meter tower	*	Building	**	*
Dakar	Alcatel	1987	Guyed 5 meter tube	*	Building	**	*
Dionysos	Alcatel	1989	Guyed 2 meter tower	*	Building	**	*
Djibouti	Alcatel	1987	Guyed 1 meter tower	*	Building	**	*
Easter Island	Alcatel	1988	Guyed 4 meter tower	*	Concrete block	**	*
Everest	Starec	1992	0.3 meter tower	***	Rock	***	***
Fairbanks	Starec	1999	6-meter pedestal	***	Concrete block	***	***
Galapagos	Alcatel	1991	Guyed 3 meter tower	*	Building	**	*
Goldstone	Starec	1996	Guyed 2 meter tower	**	Laser pad	***	**
Guam	Starec	1993	Guyed 2 meter tower	**	Concrete block	**	**
Hartebeesthoek	Alcatel	1997	3.5 m tower	*	Building	**	*
Kauai	Alcatel	1990	Guyed 3 meter tower	*	Building	*	*
Kerguelen	Starec	1994	Guyed 2 meter tower	**	Concrete block	**	**
Kitab	Starec	1996	Guyed 2 meter tower	**	Building	**	**
Kourou	Starec	1992	Guyed 2 meter tower	*	Building roof	*	*
Krasnoyarsk	Starec	1995	Guyed 1 meter tower	**	Building	**	**
La Reunion	Starec	1998	Guyed 3 meter tower	**	Concrete block	**	**
Libreville	Starec	1999	1 meter tower	**	Building	**	**
Manila	Alcatel	1991	Guyed 2 meter tower	*	Building	**	*
Marion Island	Starec	1999	Guyed 2 meter tower	**	Concrete block	***	**
Metsahovi	Alcatel	1988	Guyed 3 meter tower	**	Concrete block	***	**
Mount Stromlo	Starec	1998	Steel pole	***	Concrete slab	***	***
Noumea	Alcatel	1987	Guyed 5 meter tower	*	Concrete block	***	*
Ny-Alesund	Starec	1999	Guyed 2 meter tower	**	Building	*	**
Ottawa	Starec	1998	1 meter tower	***	High building	*	*
Papeete	Starec	1998	1 meter tower	***	Building	**	***
Ponta Delgada	Starec	1998	Guyed 2 meter tower	**	Building	**	**
Port Moresby	Alcatel	1988	6 m triangular tower	**	Building	**	*
Purple Mountain	Alcatel	1988	Guyed 3 meter tower	*	Building	**	*
Rapa	Starec	1996	Guyed 3 meter tower	**	Concrete block	***	**
Reykjavik	Starec	1998	Guyed 2 meter tower	**	Building	**	**
Richmond	Alcatel	1993	Guyed 1 meter tower	**	Building	**	**
Rio Grande	Starec	1995	Guyed 3 meter tower	**	Concrete block	***	**
Rothera	Alcatel	1992	1 meter tower	**	Timber bldg.	*	*
Santiago	Starec	1996	Guyed 2 meter tower	**	Laser pad	***	**
Socorro	Starec	1998	Guyed 3 meter tower	**	Building	**	**
St John's	Starec	1999	Aluminum plate	***	Concrete pillar	***	***
St-Helena	Starec	1997	Guyed 2 meter tower	**	Concrete block	***	**
Syowa	Starec	1999	Aluminum plate	***	Concrete pillar	***	***
Terre Adelie	Alcatel	1987	Metallic interface	***	Building	*	**
Toulouse	Alcatel	1997	Guyed 2 meter tower	**	Building	**	**
Tristan Da Cunha	Alcatel	1986	1 meter tower	**	Building	**	**
Wallis	Alcatel	1989	Guyed 2 meter tower	*	Building	**	*
Yarragadee	Starec	1999	Guyed 2 meter tower	**	Concrete block	***	**
Yellowknife	Alcatel	1989	1 meter tower	**	Building	*	**
Yuzhno-Sakhalinsk	Alcatel	1990	Guyed 2 meter tower	*	Building	*	*

Table 3 : estimated stability of the DORIS antennas,
from * (lowest) to *** (highest).

EVOLUTION PROSPECTS

The future evolutions of the network will aim at improving the following aspects :

- Long term stability of the antennas,
- Global coverage, by filling in a few remaining coverage "holes" (e.g. in the Pacific Ocean),
- Reliability of the stations, through the deployment of a new generation of beacons.

Improvement of the antennas stability

An improvement action has already started in this field. Concrete pillars have recently been built at Syowa and Amsterdam to replace the existing monumentation, and the antenna at Fairbanks was moved to a very stable antenna pedestal. The next station renovation will take place at Hartebeesthoek (South Africa) where a geological survey has been performed before the construction of a concrete pillar for the relocation of the antenna, which should take place in May. Moreover, we plan to renovate this year the following stations :

- Dakar (the station will be moved by 80 km),
- Djibouti,
- Easter Island,
- Kauai,
- Kerguelen,
- La Réunion,
- Metsahövi,
- Nouméa,
- Richmond (planned station closing),
- Wallis (moved to Futuna, where a permanent GPS station is operating).

Other stations are on our list and should be renovated next year : Arequipa, Colombo, Galapagos, Kourou, Manila, Port Moresby, Rothera, etc.

New stations

Several new stations are in project, and at the time of writing clearance has been granted for the following ones, whose installation should take place in the next months :

- Greenbelt (U.S.A.), which will replace the Ottawa station,
- Bermuda (U.K.),
- Midway (U.S.A.),
- Darwin (Australia).

The third generation beacons

The main new features of this new model of DORIS beacons, currently under development, will be:

- Possible frequency shift (within a ± 50 kHz range on the 2 GHz channel, ± 10 kHz on the 400 MHz channel), avoiding frequency jamming by nearby stations,
- Modulated 2 GHz channel,
- Unambiguous internal International Atomic Time (the whole time information is transmitted),
- Can be received even if the time has not been set,
- Possible remote control through a telephone line or Argos terminal.

Their planned delivery schedule is as follows:

- Prototype : July 2000,
- 5 pilot production units : January 2001,
- 5 units per month : from March to July 2001,
- 10 units per year in 2002, 2003 and 2004.

ACKNOWLEDGEMENTS

Ground stations spread all over the world have been playing and will keep on playing a fundamental role in the success of DORIS. We warmly thank all the host agencies who have been taking care of the maintenance of the stations for such a long time – more than ten years for many of them – for their continuous support and contribution to this success.

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