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SAR Options for Near Equatorial Environmental Monitoring

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ABSTRACT. This paper reviews the applications and requirements that might be placed on a SAR satellite dedicated to providing service over the Brazilian/Amazonian region of interest. Options and performances are described for various SAR sensors operating in wavebands ranging from P though L, S and C, to X-band and applicable launch options are identified. A possible overall system configuration is described, together with likely operations timelines.

1.0 Introduction

Synthetic aperture radar (SAR) observations made from space have the capability to provide, by day or by night, information determining the state of the environment in near equatorial regions which are frequently shrouded by cloud and rain from observation by visual and infra-red sensors

The paper discusses the type of information that needs to be gathered in order to provide a useful environmental monitoring service, reviews how that information requirement influences the requirements that have to be placed on such a mission, and presents an overview of various implementations of a space SAR satellite system, indicating the extent to which each supports the overall mission objectives.

2.0 Mission Requirements

Particular information products that need to be generated for an environmental monitoring service in near equatorial regions should include information that services the needs of agriculture, rain forest development/protection, pollution, maritime activities & interests, and government intervention / activity co-ordination during natural

MONITORING SERVICE	INFORMATION REQUIREMENT
forest support activities	rain forest development infrastructure: roads, housing, airfields mineral retrieval / mining drug related crops
support to agriculture	crop health / yield soil moisture bio-mass estimation
crisis monitoring	pollution flooding infrastructure damage
maritime activities	shipping bathymetry oil slicks

Table 1 Information Products & Mission Requirements

crises. These overall objectives have been assembled in the list presented in Table 1. It isacknowledged that each information product is associated with a number of different SAR system parameters that include revisit rate, operating wavelength and polarisation, image quality specifications, and mission coverage specifications. These parameter sets provide the basis for an outline analysis of the various possible system implementations so that an initial recommendation can be made for an equatorial environment monitoring mission.

Having identified the need for these types of service, the mission design exercise can begin to address issues that include;

* SAR satellite characteristics needed to facilitate extraction of the desired information products,
* specific regions over which the information is to be gathered,
* frequency with which such information products should be updated,
* ground support infrastructure required to control and disseminate the information flow from the satellite.

SAR CHARACTERISTICS FOR FEATURE EXTRACTION

The principal characteristic required of the SAR is sufficient performance that the shape and reflectivity of the desired ground features can be measured with adequate accuracy to support the information extraction process. Provision of the information/measurements base to effect a successful transformation of information requirements into specific performance parameters that need to be placed on the SAR instrument has been the subject of long and intensive research in many institutions around the world. Such information has been used to effect the translations presented in Table 2 where it can be seen that in addition to the applicable revisit times listed, primary SAR instrument requirements are also listed. These performance requirements include operating wavelength(s) and polarisation(s), desired viewing angle, sensitivity, and spatial resolution. The other primary parameters, measurement accuracy and swath width, need to be specified as follows; accuracy in terms of the variation in parameter value to be expected from the feature being observed; swath width in the context of revisit time, coverage, and orbit inclination.

INFORMATION PRODUCT	MISSION REQUIREMENT				
	RESOLUTION (m)	SENSITIVITY (dB)	INCIDENCE ANGLE	FREQUENCY BAND	REVISIT (days)
forest support activities					
rain forest felling..	20 - 50	-15 (L)	15° -40°	L (S C)	10 - 20
infrastructure development eg airfields/housing........	5 - 10	-20	larger	S X	5 - 20
mineral retrieval / mining activities.....(HH and HV)...	5 - 10	-20	"	S x	5 - 20
drug related crops..	20 - 50	-15/-20	"	L	10 - 20
support to agriculture					
crop monitoring..................................(HH and HV)...	10 - 30	-20/-25	20° - 40°	L (S C)	10 - 20
soil moisture.(hydrological modelling)............(HH)....	10 - 30	-25(HH)	10° - 20°	L	2 - 5
bio-mass estimation...........................(HH and HV)...	30 - 100	-20(HH) / -30(HV)	not critical	P (L)	100 - 300
environmental crisis monitoring					
pollution, coastal..........(very complex issue)...........	5 - 30	-25	10° - 35°	C (L)	ASAP
flooding..	20 - 100	-20	20° - 40°	L (S C)	1 - 3
support to maritime activities					
shipping................(detection).......(HH and HV).....	5 - 50	-20/-25	> 25°	not critical	<1
bathymetry..	20 - 50	-25	10° - 35°	(P) L (C)	100 - 300
oil slicks...	10 - 50	-25	"	(L) C (X)	<1

Table 2 Information Products and Corresponding Mission Requirements

COVERAGE ISSUES and REQUIREMENTS

It is interesting to examine how sensor design influences the way in which observations will be made at in near equatorial latitudes. Consider observation regions located close to the equator say within the latitude band ± 15° which amounts to a distance excursion of around ± 1500km either side of the equator. A satellite making such observations with optical and passive microwave sensors can comfortably fly in a zero inclination (equatorial orbit) because those sensors can be oriented to have useful fields of view that allow observation at ground incidence angle as large as 50 to 60° to one side of (and including) the nadir to similar angles on the other side of the nadir. However, the ground resolution associated with such sensors degrades rapidly with increasing incidence angle. SAR sensors operate differently from optical sensors and have a viewing capability that renders them blind near the nadir (incidence angles smaller than about 15°) and causes their operation to be impaired by ambiguous returns at larger incidence angles (typically greater than 40° to 50°).

As a result of the near nadir incidence angle limitation, it is clear that a SAR satellite designed to image at the equator and in the near equatorial regions, cannot operate from an absolute equatorial orbit. Rather, it must operate from an orbit whose inclination must allow viewing of the equator at least at the minimum incidence angle. The impact of this constraint can be seen in Figure 1: its principal consequence is that revisit to given near-equatorial locations are no longer on a regular orbit by orbit basis at 100 min intervals as can be achieved for optical sensors in fully equatorial orbits, but on a daily basis.

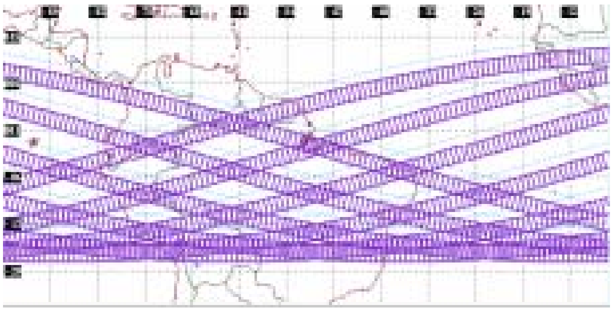

Figure 1 Coverage from an Orbit Inclined at 15°

A feature of the asymmetric viewing geometry that has characterised space SARs to date, is that if the asymmetry is arranged to provide a South side viewing preference, observation of the Amazon basin would be facilitated from an orbit inclined at around 15°. The coverage extent would then range from some 10°N to around 20°S. However, an orbit inclined at around 30° would be needed to provide coverage over the whole of Brazil

ORBIT ALTITUDE

Orbit altitude impacts on two key mission features, coverage and revisit time. However, the impact effected through SAR sensor performance is different from that effected through optical sensor performance. Both types of sensor may be expected (and in this paper are assumed) to make use of circular orbits. With the optical sensor, increasing altitude brings unequivocal improvements in coverage. Indeed, for a given viewing angle, the rate of coverage increase is slightly faster than the rate of altitude increase while there are corresponding degradations in spatial resolution. The situation with SAR is different. While there increases in coverage can be achieved by raising orbit altitude, the rate of increase is much smaller, and is critically related to antenna area and operating frequency by the impact of ambiguities.

In order to illustrate the case, it is interesting to compare the coverage capability provide by a fixed area of antenna operated at two different frequencies. The coverage provided by a SAR operating at C-band using $10m^2$ antenna area increases from around 650 / 700km at 400km altitude, to 900 /1000km at 1000km altitude. At a lower operating frequency, L-band, the same area of antenna provides coverage only to distances some 300km away from nadir. Here, the impact of altitude on coverage is much less pronounced, rising from around 280km at 400km altitude, to 340km at 1000km altitude. However, in both these cases, while spatial resolution is totally unaffected, the major impact of altitude variations is seen to be on sensitivity, where in both cases degradations approaching 10dB in magnitude are experienced.

The consequence on mission characteristics of this aspect of space SAR performance is that the selection of orbit altitude will be influenced more by spacecraft features than by SAR performance features. Generally, the major SAR performance input will be a drive to lower altitudes in order to provide best sensitivity, while the spacecraft input will be a drive to higher altitude to mitigate atmospheric drag.

Atmospheric drag is a feature whose impact decreases rapidly with altitude. For instance, at 300km altitude orbit lifetimes are on the order of weeks; at 400km, on the order of weeks to months, at 500km, several months, and above 600km, rapidly rising to years. The analyses presented in the rest of this paper assume that operation at an altitude of 660km where the lifetime may be expected to be several years, and may be sustained with a quite modest mass allocation for fuel.

REVISIT INTERVAL

The real issue for orbit revisit period is the need to regularly image locations from which information is required. This issue has two significant drivers, the rate at which the particular observed feature changes, and the proportion of time that the particular location is obscured by cloud, rain and the absence of daylight. The second set of drivers are very pertinent to optical sensors but only affect radar sensors under extreme conditions of torrential rain. The first set of drivers are application related and estimates have been provided in Table 2, indicating the extent to which very rapid updates are needed. It is clear that for most applications, updates on the timescale of days and even weeks is satisfactory provided that the access can be guaranteed. With SAR, noting the probable absence of propagation impediments, such guarantees can be made with good confidence. Therefore the major mission parameters that will need to be specified to ensure the appropriate revisit interval are orbit inclination and SAR sensor coverage capability.

IMPACT OF SWATH WIDTH AND COVERAGE ON REVISIT INTERVAL

It can be seen from the data assembled in Table 2 that most applications can be satisfied with a revisit interval in the region of 10 days, although crisis events call for as rapid a response as possible. Therefore it is appropriate to consider two levels response capability, one that is provided through repeated observations made regularly using the same swath width and viewing geometry. Such a capability can be provided by suitable choice of orbit altitude so that on successive days, new regions are imaged. Typically such regions may be adjacent to regions imaged earlier so that over a period of days, imaging of a total (larger) region is accomplished. The rate at which such a total region can be imaged depends on the inclination of the orbit, and the width of the swath selected for the imaging activity.

A separate consideration is the rate at which a given region can be revisited, in order to satisfy the demands of providing a crisis monitoring service (although simultaneous provision of a both a crisis and a regular service would introduce a conflict with the regular service being the likely victim). The rate at which such a crisis zone can be revisited will be set by the coverage capability; however, successive observations will be made at different viewing angles. For crisis observations, this is unlikely to be a problem.

The typical displacement between successive swaths around the equator that is required to ensure contiguous coverage is given by the product of the image swath width and the cosecant of the orbit inclination. Noting that for an orbit altitude of 660km, the orbit period is such that the Earth rotates through some 2725km between successive equator passes, the orbit altitude may be specifically chosen so that on a daily basis, the imaging pass is displaced by a multiple of one or more swath widths from its previous (day) location. This will effect a fine tuning on orbit altitude. The task of inclination selection and swath width selection can now be tuned to provide the desired coverage. and revisit rate. Assuming the 15° orbit inclination presented in Figure 1 and a constant viewing geometry, it can be seen from Table 3 that the revisit period resulting from a 50km swath will be 14 days. Similarly, the crisis revisit time provided by a system in which the antenna is sized to provide access between say 15° and 35° which corresponds to 240km, will be 3 days.

SWATH / COVERAGE (km)	REVISIT TIME (days)
30	24
40	18
50	14
60	12
70	10
250	3
350	2
700	1

Table 3 Impact of Swath Width and Coverage on Revisit Time

It is interesting now to examine the impact on these revisit times, of taking the same area of antenna ‘real estate’ and operating that antenna at a higher frequency. Suppose the step from operating the $3.3m^2$ required at C-band to operating an antenna of the same area at X-band. Individual swath widths are reduced to around 35 to 40km because the beam is narrower, but the coverage extent is nearly doubled to 470km. In this condition, the regular revisit period increases to between 18 and 20 days, while the crisis revisit time is improved to between 1 and 2 days.

3.0 System Options

The total system which will provide the required information comprises a space segment that includes SAR, platform, data handling / downlinking capability and launch options, and a ground system that includes data reception facilities, data handling and information extraction facilities, and a network through which information products generated by the system can be presented to users.

3.1 Space Segment

RATIONALE FOR SIZING OF SAR SENSOR

The rationale for selection of spacecraft size has been approached from the perspective that the size of a SAR instrument is driven to a significant extent by the size of the antenna. This in turn is driven by constraints of pure physics and the need to maintain the response of the instrument to ambiguous signals at an acceptably low level. A consequence of this constraint is that antenna area, A, needs to be maintained above a certain critical size given in equation 1 by the well known SAR criterion;

$$A > 4 \frac{v_s R \lambda \tan\iota}{c}$$

where v_s = satellite on-orbit velocity
R = slant range to image zone
λ = operating wavelength
ι = incidence angle
c = velocity of light

If the choice of mission characteristic is subsequently made that for reasons of desired coverage and favoured viewing angle of particular ground features, it can be seen that the ability to image to incidence angles of around 35° will be a sensible selection, regardless of operating frequency, This means that at low frequencies, a very large area of antenna will be needed, but relatively low transmitter power: at intermediate frequencies, smaller areas will provide similar

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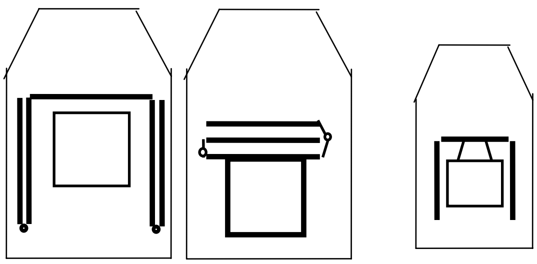
access capability but will need somewhat more power: while finally, at the highest frequencies, very small antenna area will provide coverage access but RF power requirement increases to very high levels.

ACCOMMODATION OPTIONS

This trend makes a direct impact on the size of vehicle that will be needed to launch satellites carrying such SARs. SARs operating at the highest frequencies (C and X) have the potential to be launched using a Taurus class of vehicle, while the intermediate frequency (L and S) instruments can potentially be launched in the Rockot/LLV2 class. However, the large antenna area (some $40m^2$) demanded of the lowest frequency (P-band) instrument in order to image out to 35° would demand the service of a large launch vehicle of the Ariane 4 class and a complex deployment scheme.

P&L-band S-band C&X-bands



Rockot / LLV2 class Taurus class
10 x 1.4 (L&S) 5 x 1.1 (S) 5 x 0.66 (C&X)
10 x 1.5 (P) 5 x 0.36 (X)

Figure 2 Outline Accommodation Options

SAR INSTRUMENT OPTIONS

Examining these options from the standpoint of the data assembled in Table 2, it can be seen that no one operating frequency fully satisfies the mission requirements of all of the applications. Instead, sub-sets of the applications call for instruments operating at particular frequencies. In particular, it can be seen that the bio-mass measurement is particularly favoured by observations made at P-band.

Operation at P-band introduces the specific issue of appropriate platform selection because of the impact of the very large antenna needed to provide satisfactory rejection of ambiguities at this low frequency for the large incidence angles considered during the earlier discussion of coverage. When further detail of the bio-mass application is examined, it becomes clear that the information product does not place particular constraints on the incidence angle at which the raw image data is to be gathered. Therefore it is possible to conceive a P-band SAR in which the operating incidence angle is much reduced compared with the 35° considered in the coverage discussion. Reviewing the P-band issue from the standpoint of coverage, it can be seen that there is no strong driver for regular revisits on the order of days; rather, revisits on the order of months are acceptable. Noting these relaxations for P-band application (bio-mass estimation), the design concept of an appropriate SAR can be directed towards a system using an antenna significantly smaller than that which would be needed to image incidence angles around 35° from nadir

With the relaxed design concept, the principal constraint on near nadir imaging will come from the geometric distortions that result from imaging close to the nadir (this effect is called 'layover') and from the onset of ambiguities at the far side of the image swath.

Analysis of the design issues associated with this type of SAR indicate that satisfactory performance will be achieved with an instrument using an antenna measuring some 10m x 1.5m. This size is very much smaller than the 10m x 4m which would be needed to image to 35 degrees in order to provide the few days access and coverage capability discussed in the earlier section.

Parameters of the SAR, together with the predicted performance are assembled in Table 3.

PARAMETER	VALUE
SAR SYSTEM	
Operating altitude	600 km
Operating frequency	435 MHz
Antenna dimensions	10m x 1.5m
RF Power mean	100 W
Chirp bandwidth	5 MHz
PERFORMANCE	
Access	15° - 29°
Swath width	150km
Spatial resolution	100m to 60m
Sensitivity NEσ0	-30 to -25dB

Table 3 P-band SAR Details

Continuing the examination of mission requirements and applications, it is evident that although not all, wide range of the applications could be met by a SAR operating at L-band, provided that the instrument were able to image out to around 35°. Such a SAR can be conceived and despite the higher operating frequency, would utilise an antenna measuring some 10m x 1.4m which is larger than the P-band antenna discussed earlier (because of the greater coverage capability demanded). The design parameters and performance of a typical implementation of this type of SAR are presented in Table 4.

It is interesting to note that a SAR operating at L-band although not able to provide the same quality of data for bio-mass estimation as one operating at P-band, can nevertheless provide useful data for that application.

PARAMETER	VALUE
SAR SYSTEM	
Operating altitude	600 km
Operating frequency	1257 MHz
Antenna dimensions	10m x 1.4m
RF Power mean	100 W
Chirp bandwidth	30 -- 10 MHz
PERFORMANCE	
Access	15° to 35°
Swath width	70km
Spatial resolution	10 -- 30m
Sensitivity NEσ0	-30 -- -25dB

Table 4 L-band SAR Details

In addition to L-band applications, it can also be seen that useful performance for a number of applications could be gained from a SAR operating at C-band. Operation of such a SAR would benefit from the growing information extraction experience which is currently being gained in the user community from the use of ERS and Radarsat data.

PARAMETER	VALUE
SAR SYSTEM	
Operating altitude	600 km
Operating frequency	5300 MHz
Antenna dimensions	5m x 0.66m
RF Power mean	300 W
Chirp bandwidth	30 -- 10 MHz
PERFORMANCE	
Access	15° - 35°
Swath width	35 km
Spatial resolution	10 -- 30m
Sensitivity NEσ0	-22 -- -27dB

Table 5 C-band SAR Details

The accommodation of such a SAR would benefit significantly from operation at the higher frequency because of the reduced size of antenna needed to provide the necessary coverage/access. At C-band, the antenna demand is reduced to 5m x 0.66m. Design parameters and performance for a typical implementation of such a SAR are presented in Table 5

Finally, the bandwidth demands imposed by the high resolution requirements for monitoring infrastructure developments and unauthorised activities provide a design drive to operating bands where a wider frequency allocation exists. Such bands are S (3.1 to 3.3GHz) and X (9.5 to 9.8 GHz).

Operation at X-band allows use to be made of the smallest antenna 5m x 0.36m. However, the small antenna leads to large demands in the RF power budget (600w) in order to maintain adequate sensitivity at the high bandwidths needed to secure fine resolution. Details of the performance of the X-band option are presented in Table 6.

PARAMETER	VALUE
SAR SYSTEM	
Operating altitude	600 km
Operating frequency	9650 MHz
Antenna dimensions	5m x 0.36m
RF Power mean	600 W
Chirp bandwidth	60 MHz
PERFORMANCE	
Access	15° - 35°
Swath width	35 km
Spatial resolution	5m
Sensitivity NEσ0	-20 dB

Table 6 X band SAR Details

SAR operation at S-band provides an interesting alternative to X-band. Fine resolution operation is still possible but the larger antenna required to provide the same coverage brings the benefit of a reduced mean RF power demand from the 600W dneeded to provide 5m resolution at X-band to a more managable 200W.

Additionally, operation at S-band and brings the possibility of meeting at a compromise level, most of the applications that are ideally serviced by SARs operating at L-band and C-band. The design parameters and performance of the S-band SAR option are presented in Table 7.

PARAMETER	VALUE
SAR SYSTEM	
Operating altitude	600 km
Operating frequency	3200 MHz
Antenna dimensions	5m x 1.1m
RF Power mean	200 W
Chirp bandwidth	60MHz
PERFORMANCE	
Access	15° - 35°
Swath width	35 km
Spatial resolution	100m to 60m
Sensitivity NEσ0	-20 dB

Table 7 S-band SAR Details

DOWNLINK ISSUES

Although Brazil has a ground station in the central region of the Amazon basin through which ERS data is received, a major issue is the transfer of data from that site to the Eastern seaboard where the main infrastructure exists. If data is transferred to the central station then the spacecraft can provide a direct downlink service without the need for any on-board storage, However, if receiving stations on the Eastern seaboard are the principal sites for data reception, and the central site is not used, then the spacecraft needs to carry sufficient on-board memory to store nearly 2000km of data which corresponds to a data acquisition period of some 300 seconds.

Assuming that the regular imaging service can be provided at a resolution level of 20m with a swath width of 50km, then a data transfer rate of around 50 to 60 Mbits/sec is required. In addition, to accommodate the 300 seconds of data acquired while the satellite is out of sight of the Eastern receive stations, the on-board data store must be sized to store some 15 to 20 Gbits.

3.2 Ground Segment

ELEMENTS OF A REGIONAL SAR OBSERVATION NETWORK

A network capable of providing the functions for regional SAR observation will comprise a mission control centre, a satellite control centre and at least one SAR satellite. The discussion presented in the previous section indicates the advantages in observational access that accrue from flying the satellite of such a network in an optimally inclined orbit. This section draws together the arguments that have been made so far and postulates a regional observation network that will provide for the owner, an optimised, SAR observation capability

The radar satellite needed to provide the observation service would be suitable for launch on a number of the smaller launch vehicles that are currently available or under development. The principal characteristics of a possible satellite are shown Figure 3. The satellite is capable of imaging on both sides of the nadir track. This will be achieved by rotations the about the roll axis (parallel to the flight vector). The SAR instrument is designed with an antenna of sufficient size that unambiguous imagery can be gathered from swaths displaced from the nadir by up to 600 km although for the P-band option, this access capability is restricted so that the far side of the image swath is located some 300km from nadir.

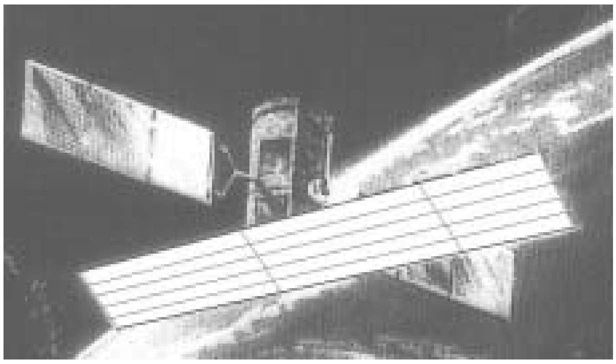


Figure 3 A Typical SAR Satellite

The SAR will typically operate for periods of around 5 to 7 minutes during imaging passes over the Brazilian area. During these passes it will have line of sight communication to the ERS data reception station and to any new data reception stations that might be implemented on the eastern side of Brazil In these case of access being made through a network that includes the ERS station, there will be no need in that situation for any on-board data storage. However, it is probable that with the current advances in solid state memory, the satellite would carry the means of storing a number of images from regions outside the reception area of the network ground stations. Such storage would be particularly relevant if access were made only through stations located on the eastern side of the country.

Such an on-board memory would provide the owner with the facility to make out-of-area observations either for national interest or to support international activities, perhaps in the disaster monitoring domain. A diagram showing the outline structure of the observation network is presented in Figure 4 where it can be seen that the mission control centre lies at the hub of the network.

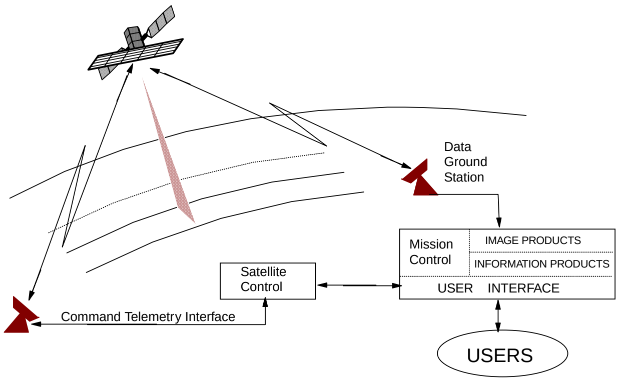


Figure 4 Diagram of Overall System

SYSTEM CONTROL AND MANAGEMENT

The mission control centre manages the interface between Users and the network, balancing and prioritising requests for information with the current location/status of the satellite and with the current status of the network archive from which the particular product requested by the User can potentially be drawn.

The acquisition of echo data on board the satellite will be scheduled from the satellite control element where local decisions will be made as to whether that echo data will be stored on board for later transmission to the ground station, or whether it will be directly linked to the ground in real time as it is acquired. The inclusion of an on-board memory means that the content of that memory has to be carefully controlled and appropriate allocations made in the network activity cycle for the data in the memory to be transferred over the down link. This calls for specific scheduling of activities on board the satellite and at the ground station and conflicts between the need to undertake fresh image acquisitions that may need immediate access to the downlink will have to be prioritised against the need to use the downlink for transfer of data from memory.

DATA HANDLING / INFORMATION EXTRACTION

When the data is received at the ground station, the most immediate task to be undertaken will be storage of the gathered data in a raw data archive. The sizing and organisation of this archive will be a key feature of the system. Given that the Brazilian region covers some 2000 x 3000 km^2 and that the raw data provides corresponds to 20m resolution imagery at 4 looks, if images of the whole region are to be retained, then the volume of data to be stored for each image amounts to some 60Gbytes per image.

Given that Exabyte tape cartidges are able to store around 5Gbytes of uncompressed data, each Amazon data set will occupy 12 Exabyte tapes, a volume of data that will be acquired every 20 days. Clearly, this does not respresent an enormous volume of storage medium, typically being on the order of a “few filing cabinets worth” per year.

Processing of the raw data into basic images will be simultaneous with this activity. The rate at which this processing can take place is now sufficiently fast that the generation of a 1000km length of data can be processed into a full precision image well within one hour. Such processing operations are no longer a critical area in the image formation activity. Of greater consequence is the time taken by human interpreters to examine and understand the images and to extract useful information from them, although there are now many automatic algorithms which can assist the interpreter in these tasks.

NETWORK OPERATION TIMESCALES

A diagram is presented in Figure 5 showing how the various elements of the network might be expected to respond to a nominal priority request for information that involves specific imaging activity from the satellite rather than extraction of previously acquired imagery from the archive. Here it can be seen that although the time between the initial request for information and the arrival of the satellite at a position from which it can make the observation can be large, up to 1 day, there can be appreciable delays elsewhere in the network.

The extent to which these delays can be minimised involves an intricate interaction between human and machine resources, and the funding lines that support their acquisition. The areas that are driven by human activity are those between submission by the user of his initial request and generation of the corresponding command sequence for the satellite, and the area of dissemination of the requested information back to the user. Much can be done to improve these response times through the use of present day electronic communication techniques, and the human response times can be optimised by operating procedures that give simple person to person and man-machine interfaces, and clear guidance on establishment of priorities.

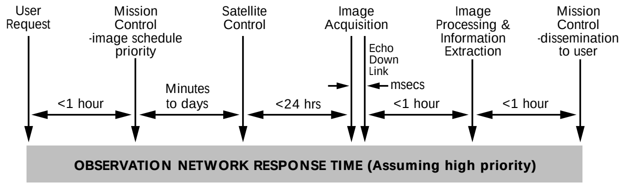


Figure 5 Network Operations Timeline

There will certainly be a delay between generation of the appropriate command sequence, its transmission to the satellite, and its execution on-board the satellite. Generally, it will be necessary for the satellite to configure itself to make the observation after such an instruction has been received. Such configuration involves beam pointing which can be performed either electronically or mechanically. If performed electronically, then the response time can be very fast; instantaneous in the context of the operations timeline, but will be significantly slower if performed mechanically, for instance, by rotation of the platform. However, the SAR element of the network will be significantly cheaper is the beam pointing is performed mechanically, and if the rotation can be comfortably completed within the period of one orbit, then the additional 100 minute delay can be accommodated in the operations timeline without undue impact.

With appropriate guidelines in place for the human operatives within the network it will possible to achieve overall response times from the network of 3 to 5 hours, providing the satellite is in an opportune position to acquire the desired imagery. However, given that the more probable situation will be that an appreciable delay - somewhere between 1 and 24 hours - will be encountered between request and availability of satellite to make the observation, A typical delay of around 12 hours should be expected. In this situation, the added improvement in the operational timeline that results from electronic beam steering brings only a marginal improvement for the added risk and expense.

SYSTEM HOUSEKEEPING

In addition to these all these strategic functions, the network must also maintain tactical control of the component elements of the network. Throughout all the main-stream activities, the satellite control centre will maintain a regular check on the general health of the satellite element by monitoring the wealth of telemetry data that will be returned to ground. From time to time it will execute control functions to make corrections to orbit altitude, to adjust the nominal satellite attitude, and when necessary, make appropriate adjustments to payload equipments to maintain quality standards in the image products being formed from data delivered from the satellite to the ground.

4 Summary

The paper has reviewed a number of options through which various SAR observation applications might be undertaken. The requirements of these applications have been related to the most applicable types of SAR and system and SAR options have been reviewed covering a wide spectrum of possible operating frequencies (from P-band through to X-band. Satellite options have been recommended suited to launch by vehicles in the class ranging from Taurus through to Rockot/LLV2.

It can be seen that a number of benefits are gained from the use of a radar satellite flying in an orbit optimally inclined to cover the Brazilian region. Improved access time is gained to areas within the region and the total image can be built up in shorter times. Because the total image build up time is shorter than that which would be obtained from polar orbits, this advantage can be traded for a smaller radar *(than would be needed to provide the same capability from polar orbit)* providing narrower swaths and because the access time to the region has been significantly improved, it can be argued that the need for rapid electronic beam steering is relaxed. Therefore it is possible to design the small radar to be of a simple form employing only a fixed beam and relying rotation of the platform for any beam steering.

Because the radar is smaller, it is better suited for integration onto a smaller platform so that the overall observation satellite can be smaller. It can therefore be launched by a smaller launch vehicle. The smaller size and greater simplicity of radar mean that the overall manufacturing programme can be shorter so that the observation network can be implemented more quickly.

Ultimately, the result of all of these features is that by this logical process of mission optimisation to a specific regional service, rather than to a global service, the owner nation can acquire a dedicated observation network, optimised to his particular needs, in a shorter time frame, at lower cost, and at lower risk. The owner nation will then be in possession of an asset that brings real benefits to the nation in terms of prestige, useful technical information products, improvements to the national skill base gained through exercising of the network, and the opportunity to be major participant in the world remote sensing community.

Anais VIII Simpósio Brasileiro de Sensoriamento Remoto, Salvador, Brasil, 14-19 abril 1996, INPE, p. 171-180.

ABSTRACT

This paper reviews the applications and requirements that might be placed on a SAR satellite dedicated to providing service over the Brazilian/Amazonian region of interest. Options and performances are described for various SAR sensors operating in wavebands ranging from P though L, S and C, to X-band and applicable launch options are identified. A possible overall system configuration is described, together with likely operations timelines.