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SAR Formation Flying

Annex 1. Mission Concept and Requirements

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2. Evolution of Supported Applications

The original focus of the mission was defined to be flood monitoring, and the June 30 deliverable TK1.1 described the flood monitoring system that followed from the flood monitoring requirements obtained from users. A large number of spacecraft is required to meet the requirement for a 1 hour revisit time. Based on feedback from advisors since that report and considering the funding environment of the states and federal government it is considered unlikely that such as system is fundable within Australia. The proposal in that report that sales of Australian designed spacecraft to other countries could build the constellation size potentially for profit is one solution but the number of required sales makes this an ambitious plan.

Following this report an ACSER advisor suggested that a biomass/REDD (Reduction of Emissions due to Deforestation and Degradation) related application would be more likely to be implemented by the Australian government. This is due to the favorable funding environment for climate change related applications such as biomass/REDD. Feedback from the Department of Climate Change and Energy Efficiency was that biomass/REDD related data from an Australian designed L-Band SAR spacecraft (implemented by the Australian government or a foreign government) would be eagerly used within the department. While not an endorsement this does suggest that a biomass/REDD application may find favor with the government.

At the Garada SAR workshop held at UNSW on Dec 7 2011, feedback from the Head of the Board of Advisors of ACSER was that an Australian space mission must address the problems of the Murray Darling region to improve the likelihood that the Federal government will fund the implementation of the mission. Accepting this advice allows a compelling mission profile to now be described.

The problems of the Murray Darling region relate to drought. While a space mission cannot end a drought, it can help mitigate the effects. The importance of soil moisture monitoring is described by the Department of Agriculture and Food (http://www.agric.wa.gov.au/PC_92499.html):

“Irrigation aims to provide sufficient moisture to maintain plant growth. Monitoring soils moisture is the way to determine how much water is present. This will help with the efficient management of the water program…

Without the use of some form of monitoring, soils are usually either over- or under-watered.

Over-watering can produce waterlogging, resulting in poor aeration in the root zone, and can result in higher incidences of root diseases. On light soils, over-watering leaches plant nutrients, resulting in unnecessary expense, pollution of groundwater and eutrophication of wetlands.

Under-watering places the plants under stress. This results in poorer yields.

Clearly it is important to know how much water is in the soil, so that the right amount of irrigation can be applied, at the right time."

Farmnote 26/1990 (Reviewed August 2006) by Greg Luke, Irrigation Research Officer, Division of Resource Management, South Perth

When water is limited, it is especially important to ensure that what water is available is used to maximum benefit. Monitoring soil moisture from space may therefore be the "killer app" for an Australian SAR space mission. In fact, one of the strategic goals of the Argentine SAOCOM-1 and 2 L-Band SAR spacecraft (scheduled for launch 2012-2013) is monitoring soil moisture in "a 700 000 km^2 land dedicated to agriculture and cattle raising" in Argentina[1], a southern hemisphere competitor of Australia for worldwide wheat exports also subject to the effects of global warming on agriculture.

It should be noted that there are currently no operational methods for soil moisture mapping using SAR[2]; the development of such operational methods is in fact one of the goals of the upcoming Argentine L-Band SAR SAOCOM mission[3]. The Garada mission may be able to leverage the research that will be done with SAOCOM towards an operational method of soil moisture mapping using SAR from space. It is envisaged that further Australian research using ground and airborne SAR is required to develop an operational method of soil moisture mapping of the MDB using SAR.

This research should be completed before a GARADA mission is implemented. However there is already sufficient knowledge to define requirements with enough detail for a Phase 0 design study of a spaceborne SAR. Improvement in knowledge of end user (farmers and environmental authorities) requirements and development of an operational method for soil moisture mapping using SAR should not change some of the design features (for example the need for quad polarisation, a maximum incidence angle of at least 40° and a 6 AM revisit time) that existing research can already define.

Other applications supported by the Garada mission include forest change detection in support of REDD (Reducing Emissions from Deforestation and Forest Degradation) objectives[4] and flood monitoring both for disaster support and hydrological applications in the MDB[5] (Table 1).

Table 1: Applications supported by the Garada SAR Formation Flying mission

Application	**Currently an operational solution?**
High spatial resolution soil moisture measurement from space using SAR	N
Forest change detection	Y
Flood monitoring (disaster support and hydrological monitoring in the MDB)	Y

Forest change detection is assigned operational status since detection of clear cut forest, the requirement stated by the Department of Climate Change and Energy Efficiency[6], has been performed from spaceborne SAR imagery in the past[7]. Similarly flood monitoring would use the interferometric change detection method demonstrated by TerraSAR-X and TanDEM-X during floods in Pakistan[8].

3. Mission Concept

The requirements for soil moisture mapping from space (section 4) are the most descriptive in terms of allowing a flow down to mission design decisions including the SAR System specification described in TK3.3[9]. Accordingly the Garada mission concept has been defined in response to the soil moisture mapping requirements described in (1) so that the spacecraft design is traceable to requirements in accordance with best space engineering practice. It is important to note that the flood mapping and forest change detection applications are not deprecated as a result. In fact the SAR that results from meeting the soil moisture requirements is quad-polarisation and has the largest antenna of any L-Band SAR planned as described in section 5.1 below. This would make the spacecraft extremely capable for other applications including flood mapping and forest change detection. Table 1 describes two specific ways in which the design which results from meeting the soil moisture requirements improves the ability to support the flood monitoring and forest change detection applications.

3.1. Summary

The mission is to carry out high spatial resolution soil mapping measurement of the Murray Darling Basin (MDB) from space using two identical L-Band Quad-Pol SAR spacecraft. These spacecraft orbit in the same orbital plane at an altitude of 630 km in a Sun Synchronous Orbit (SSO) with a Local Time of Ascending Node (LTAN) of 6 am. The spacecraft fly in formation separated by half an orbit. The spacecraft has a SAR antenna with the dimensions 15.52m x 3.9m. Custom circuits using Commercially available Off The Shelf (COTS) components including microchip amplifiers developed for the mobile phone industry are used to amplify the radar signal for transmission to the ground. The Astrium “Snapdragon” spacecraft configuration (Figure 1) is used to package the required antenna size in a Falcon 9 launcher (with Delta IV-M selected as the backup launcher). The SAR with this antenna size can meet ambiguity requirements for quad polarisation out to 40° incidence angle with a 14% margin for failure of the distributed amplification circuits during the mission.

The Argentine SAOCOM L-Band SAR spacecraft[10] (SAOCOM 1A is planned for launch in 2014 and SAOCOM 1B is planned for launch in 2015) has 41% of the antenna area of the planned Garada L-Band SAR spacecraft. The Japanese ALOS-2 L-Band SAR spacecraft[11] (planned for launch in 2013) has 36% of the antenna area of the planned Garada L-Band SAR spacecraft. SAR antenna area is an important parameter in SAR performance. A performance assessment by Astrium concludes that the Garada 15.52m x 3.9m antenna will provide “excellent” performance over the Murrary Darling Basin[12].

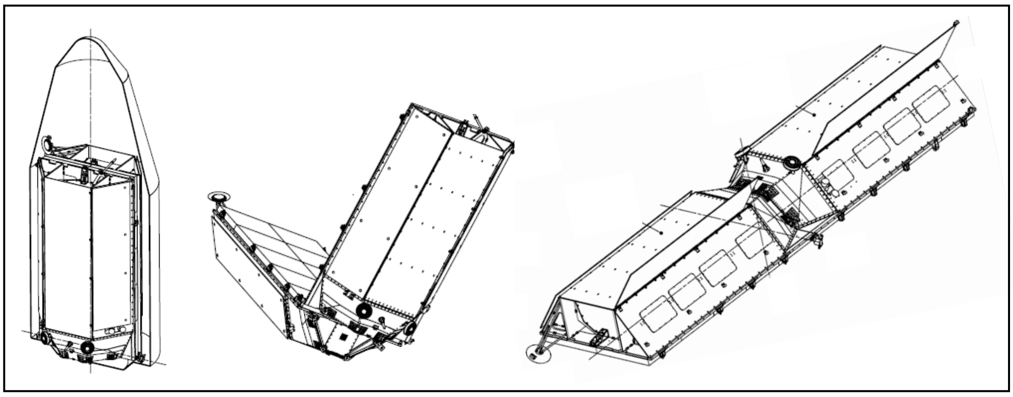

Figure 1: Astrium Snapdragon spacecraft configuration[9].

Specific aspects of the mission, with traceability to requirements, are described in more detail in the following subsections.

3.2. L-Band

The soil moisture mapping requirements described in (1) lead to the selection of L-Band (23 cm) to minimise the effects of surface roughness and vegetation in determining soil moisture[9]. While the flood mapping and forest change detection applications may operate in any approved SAR band, and hence do not allow a band to be selected, the selection of L-Band can also benefit those applications. L-Band allows flooding under vegetation to be detected, for example the inundation of vegetated land following a tsunami. L-Band is also the most appropriate band (in the range X-Band to L-Band) for research into forest biomass measurement retrieval from space. There are a number of additional advantages resulting from the selection of L-Band as summarised in Table 1.

Table 1: Additional advantages resulting from selection of L-Band

Advantage	Explanation
Market differentiation	There are existing X-Band and C-Band SAR spacecraft but currently no L-Band SAR spacecraft in orbit (SAOCOM[10] and ALOS-2[11] are planned).
COTS microamplifiers	L-Band is the same frequency band used by mobile phones, consequently Commercially Available Off the Shelf (COTS) microamplifiers are available which can be used in an appropriate circuit design to amplify the RF signal for radiation to the ground. This approach is compatible with highly deployable membrane antennas which would radically reduce the size (and potentially cost) of an L-Band SAR spacecraft.
Low loss line feeds	Transmitting the preamplifed signal from the bus to the

	circuit amplifiers is possible at L-Band using relatively low loss line feeds. At higher frequencies such as X-Band the losses become prohibitive, requiring waveguides or a space feed which add complexity and packaging requirements.
Cheaper highly deployable antenna	Garada is a stepping stone towards smaller and potentially cheaper L-Band SAR spacecraft which utilise highly deployable membrane antennas. By utilising the Astrium "Snapdragon" antenna design, which has already been the subject of a Phase-B design study[13], the antenna design is de-risked compared to a highly deployable design which the Garada project lacks the resources to investigate. COTS microamplifiers are being investigated in the Garada Phase 0 design study however. These are an enabling technology for future highly deployable antenna designs. A highly deployable L-Band antenna is expected to be cheaper than an X-Band highly deployable antenna. While smaller the X-Band antenna requires that the two membrane layers (an active and a ground plane) be held much more closely apart than at L-Band. Maintaining this closer membrane separation at X-Band is expected to lead to a more expensive deployable structure than at L-Band.
More extensive flood mapping capability	Flooding can be detected under vegetation (for example the inundation of coastal areas after a tsunami)
More suitable band for biomass research	Biomass retrieval methods that rely on backscatter information are limited by saturation of the backscatter cross-section above a certain biomass areal density. L-Band saturates at higher biomass densities than shorter wavelengths. L-Band is also more suitable than shorter wavelengths for POLInSAR[14] based biomass measurement methods which rely on an appreciable echo from the ground. The longer wavelength of L-Band enhances penetration of the tree canopy compared to shorter wavelengths.

3.3. Quad-polarisation

If the SAR is to be used operationally for soil moisture measurements then quad-polarisation is required (Section 4). Accordingly quad-polarisation is specified for the SAR which requires a larger antenna area to suppress ambiguities[9]. This results in a significantly bigger spacecraft due to the direct relationship between antenna size and spacecraft size for a SAR spacecraft unless a highly deployable antenna is used. However quad-polarisation has the additional advantages of allowing Faraday Rotation[9] to be compensated for and can be used for research into biomass measurements from space[14].

One remote sensing biomass measurement technique is POLInSAR which combines quad-polarisation and interferometry to determine the height of a forest[14]. The biomass areal density can then be estimated from the tree height. Tree height is determined by subtracting the height of the canopy from the height of the ground, with each height determined using across-track interferometry. Polarisation combinations are used which separate the echoes from the canopy and from the ground. This method relies on across-track interferometry where a baseline perpendicular to the line of sight is required to allow heights to be determined. However this baseline must be less than the critical baseline B_C, which is given in equation (6-156) of Elachi and van Zyl[15]. The critical baseline may be written as

$$B_C = \left| \frac{\lambda R B \tan\theta}{c} \right|$$

λ is the wavelength, R is the distance between the antenna and the point on the ground being illuminated, B is the signal bandwidth, θ is the incidence angle and c is the speed of light. Using θ=25° (the centre of the access region), λ=0.23 m, R=695 km (assuming an altitude of 630 km) and B=85 MHz the value of the critical baseline is B_C =21 km.

This creates a requirement for WP7 to determine whether the orbit propagation model predicts baselines less than this critical baseline for 3 day (two spacecraft) and 6 day repeat (same spacecraft) observations. If not then orbit control will be required to fly the spacecraft within a "tube" of approximately 10 km diameter if repeat pass interferometric observations are required for POLInSAR or other across track interferometry applications such as Digital Elevation Model (DEM) generation and earth movement detection due to subsidence and earthquakes.

3.4. Spatial resolution of 7-10 m stripmap, 60-100 m ScanSAR

There is a soil moisture research requirement[1] to provide "high resolution"stripmap multilooked parcels that are less than or equal to 250 m x 250 m and are the product of 25 x 25 multilooks to meet radiometric resolution requirements. Lower resolution ScanSAR multilooked parcels are to be approximately 1 km in resolution to replace a capability lost with the demise of Envisat earlier this year resulting in the loss of ASAR. To meet these requirements 7-10 m spatial resolution in stripmap mode is specified for the SAR. This can be achieved with the SAR system design described in TK3.3[9].

3.5. Incidence angle range of 8°-40° for soil moisture, 8°-50° supported

Soil moisture requirements originally specified a 20°-40° range for the incidence angles (Section 4). This was modified to 8°-40° to increase the access width to improve revisit rate to meet the 3 day revisit requirements. The upper limit was not increased in response to researcher feedback that SAR soil moisture methods are limited to this upper limit in incidence angle. The lower limit was decreased in consultation with the researcher after assurances from Astrium that the SAR design could cope with the issues associated with a steeper incidence angle (decreased range resolution is one problem).

3.6. SAR antenna size 15.5m x 3.9m, "Snapdragon" spacecraft design and Falcon 9 launch (Delta IV-M backup)

SAR soil moisture requirements specify a 3 day revisit time for the entire MDB in dual polarisation, with the requirement to also image selected targets within the MDB in stripmap mode in quad-polarisation. In order to image out to 40° incidence angle (the requirement for soil moisture observations, although the 40°-50° incidence angle range may also be of interest to soil moisture researchers) with quad-polarisation suppression of range ambiguities forces the antenna width (the dimension perpendicular to the direction of spacecraft travel) to be bigger than for dual polarisation.

CAD modeling by UNSW indicates that the maximal antenna size that can be accommodated in the minimum of a Falcon 9 and Delta IV-M shroud (the Delta IV-M shroud is the smaller of the two) using the Astrium "Snapdragon" design (Figure 1) is 15.5m x 3.9m. The report "Minimum SAR Antenna Size Assessment L-Band SAR - 390km swath (Quad Polar)" by Martin Cohen at Astrium[16] presents results of the analysis of the performance of a SAR antenna with the area 15.52m x 3.9m as the number of radiating rows is reduced to simulate end of life performance. The number of rows was decreased until the desired performance – particularly ambiguity suppression – was just achieved. It was found that reducing the number of radiating rows from 22 to 19 reached this limit. This is a reduction to 86% of the initial antenna radiating area. To allow for the loss of radiating elements (or more precisely the loss of the amplifier circuits providing power to the radiating elements) during the mission Astrium recommend the 15.52m x 3.9m antenna be specified for the Garada antenna design which provides a 14% margin against radiating element loss during the mission lifetime. Accordingly the 15.52m x 3.9m antenna design is selected to meet performance requirements at End of Life (EOL).

Both a primary and backup launcher are specified, with the cheaper Falcon 9 designated as the primary launcher. Although Falcon 9 has a bigger shroud the spacecraft must nonetheless be designed for the smaller shroud of the Delta IV-M for it to function as the backup launcher. The Falcon 9 launch cost is $54 M USD[17] while the Delta IV-M launch cost is $133 M USD in 2004 dollars[18].

A foldable or collapsible antenna design is required because there is no launcher with a shroud big enough to accommodate a 15.52m x 3.9m antenna. Even Ariane 5 with the 17m high fairing would not suffice (the fairing tapers at the nose). The Snapdragon configuration has the advantages over other foldable designs of only requiring one hinge for improved reliability and does not cantilever the antenna. The antenna is instead integrated into the body (Figure 1) which reduces the difficulty of ensuring antenna planarity. Therefore a snapdragon configuration spacecraft sized to the minimum of the Falcon 9 (primary) and Delta IV-M (backup) shrouds with an antenna area of 15.52m x 3.9m is chosen to meet performance requirements at EOL.

A performance assessment by Astrium concludes that this antenna will provide "excellent" performance over the Murray Darling Basin[16].

3.7. Two spacecraft half an orbit out of phase at 630 km altitude, 6 day repeat SSO with 6 am LTAN, left and right looking SAR

Revisit requirements (1) are for a 3 day revisit over the entire MDB where a revisit only counts if the azimuth direction of the spacecraft relative to the target is the same and the elevation angle is within 5° of the first pass. The azimuth requirement effectively means that only an ascending pass can revisit a previous ascending pass, and only a descending pass can revisit a descending pass. Consideration of the effects of these restrictions with a 6 day repeat orbit that was being considered led to the use two spacecraft with the second spacecraft half an orbit out of phase to achieve a 3 day revisit time. Subsequent calculations by Astrium detailed in TK3.3[9] confirm that this approach allows the 3 day revisit requirement for anywhere in the MBD in ScanSAR mode to be met.

As described by Astrium in TK3.3[9] a 6 day repeat orbit corresponds to an altitude of approximately 630 km. A 527 km altitude orbit will also give 6 day repeat but the higher altitude provides increased swath and access. Soil moisture requirements (Section 4) are for a constant 6 am revisit time, which leads to the selection of a Sun Synchronous Orbit (SSO) with a LTAN of 6 am. This time has the additional benefits of reduced Faraday Rotation[9], and an improved spacecraft power model due to constant solar illumination for most of the year while a SSO provides global coverage.

To meet revisit requirements the ability for the antenna to be both left and right looking is specified.

3.8. Circuit based microchip amplifiers for radar signal amplification

An innovative method of distributed amplification of the radar signals for transmission to the ground is being researched by UNSW as part of this project. This is based on a custom circuit design using COTS parts including microchip amplifiers from the mobile phone industry (which also operates in L-Band). This research will include fabrication of prototype circuits at UNSW. This approach leverages UNSW expertise in L-Band circuit design to increase the Australian contribution to the Garada design. Furthermore this distributed amplification approach is compatible with highly deployable membrane antennas which would radically reduce the size (and potentially cost) of an L-Band SAR spacecraft. This approach also offers a pathway to a fully active radar design (the “holy grail” of SAR antennas), where each phase centre can be individually controlled and the radar beam electronically steered precisely and efficiently.

As part of a follow on project to Garada the COTS circuits could be tested to determine their reliability in a space environment. If necessary a custom ASIC version of the circuit could be designed. This ASIC could then be fabricated by Silanna in Australia using radiation resistant silicon on sapphire technology.

4. Requirements

The user requirements for the applications of soil moisture monitoring, forest change detection and flood monitoring are described in Table 2 below.

Table 2: Summary of application user requirements

Application [source]	Frequency band	Resolution	Radiometric resolution	Incidence angle	Time between revisits	Revisit geometry	Revisit time	Coverage area
Soil Moisture [Rocco Panciera RP and Jeff Walker JW as indicated]	L-Band [to minimize the contributions of surface roughness and overlying vegetation to the radar echo -RP]	Stripmap - 250 m parcel after multilooking ScanSAR - 1000 m parcel after multilooking [sub km resolution in stripmap a major advance from SMAP - RP; 1 km resolution over a wide area was provided	Distinguish a 4% difference in reflectivity between two parcels of multilooked pixels [RP]	20° to 40° [this is the range of incidence angles that soil moisture retrieval has been studied, but a10° lower limit OK if SAR performance near nadir acceptable - RP]	Reimage the entire MDB at 1 km (multilooked) resolution every 2 weeks in Quad Pol and every 3 days in Dual Pol; Reimage selected targets at high resolution (250m multilooked) every 2 weeks in Quad Pol	Same azimuth angle (a pass made in ascending node must be revisited by an ascending node pass, a descending node pass must be revisited by a descending node pass); elevation angle within ±5° for revisit [RP]	6 AM [due to the thermal equilibirum between soil/air/vegetation and also the reduced capillary moisture raise in the top soil which happens during the night - RP]	Entire Murray Darling Basin [RP]

		by Envisat (JW) which failed 8 April]			[RP]			
Forest change detection [Stephen Ward SW and Shanti Reddy SR as indicated]	All bands suitable	30 m [SW]	Not specified	Not specified	Not specified	Not specified	Not specified	Regional forests (outside Australia) [SR]
Flood monitoring [TK1.1]	All bands suitable	3 m [TK1.1]	Not specified	Not specified	1 hour [TK1.1]	Unrestricted	Not applicable	East coast Australia [TK1.1]

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