RADARSAT Antarctica Mapping System 2
(RAMS-2)

Functional Requirements Document

Version 1.3 June 22, 2000

Vexcel Corporation
4909 Nautilus Court
Boulder, Colorado 80301
(303) 444-0094

RAMS-2 FUNCTIONAL REQUIREMENTS DOCUMENT

Signature Page

Prepared by:

Richard E. Carande   Date
Vexcel Corporation

Approved by:

Ken Jezek   Date
Ohio State University/BPRC

Verne Kaupp   Date
Alaska SAR Facility

Concurred by:

Kim Partington   Date
NASA Headquarters

CHANGE RECORD:

VERSION	DATE	Comments
Draft 1.0	March 3, 2000	Initial release of FRD, first draft
Draft 2.0	March 13, 2000	
Draft 3.0	April 3, 2000	
Draft 4.0	April 20, 2000	Last draft for comment
VERSION 1.0	April 25, 2000	• RELEASE FOR Design Review 4/27/00 and signatures • Requirement 3.3.17: Allowance made for 150 km frame size, instead of 300 km, in case of high Doppler drift along-track. • Many suggested changes at Design Review. Signature version will be 1.1 scheduled for May 12, 2000
Version 1.1		• Various “typo” fixes. • Replaced references to AMM2/3 with MAMM2/3 • Define “framing convention” to arbitrary frame start and stop • Add requirement for 2-D Doppler coefficients to be recorded in CEOS level 0 data for use by IFSAR processing • Requirement for scan files from ASF replaced with requirement for STF parameter files. • Added reference document regarding STF format
Version 1.2	May 23, 2000	• Processing Request generation • Test Data specification • Throughput rate for ASF processing • “magnitude” replaced with standard term “amplitude” • general editing, renumbering • issues needing verification and/or closure are flagged with <*open issue*>
Version 1.3	June 22, 2000	• June 21 meeting-driven modifications • <open issues> closed
Version 1.4	Aug 9, 2000	• Post-June 21 changes

ACRONYMS

ADD	Antarctic Digital Database
AIC	Antarctic Image Collection (?)
AMM	Antarctic Mapping Mission
ASF	Alaska SAR Facility
BAS	British Antarctic Survey
BPRC	Byrd Polar Research Center
CDR	Critical Design Review
CD-ROM	Compact Disc - Read Only Memory
CSA	Canadian Space Agency
CU	University of Colorado, Boulder
DAAC	Distributed Active Archive Center
DEM	digital elevation map
EOSDIS	Earth Observing System Data Information System
FTE	full-time equivalent
GCP	ground control point
GIS	geographical information system
GUI	graphical user interface
HDF	Hierarchical Data Format
IFSAR	interferometric SAR
IMW	International Map of the World
JPL	Jet Propulsion Laboratory
LZP	Level Zero Processor
MAMM	Modified Antarctic Mapping Mission
OSU	Ohio State University
PDD	Products Description Document
PDR	Preliminary Design Review
PRD	Project Requirements Document
RAMS	RADARSAT Antarctica Mapping System
SAR	synthetic aperture radar
SLC	Single-Look Complex
SNR	Signal-to-Noise Ratio
STF	SKY Telemetry Format
TBD	to-be-determined
TBW	to-be-written
VCP	Velocity Control Point

1 Introduction

This document presents the high level functional requirements for the RADARSAT Antarctica Mapping System 2 (RAMS-2) which is an augmentation to the existing RAMS installed and operated at the Byrd Polar Research Center (BPRC) at Ohio State University (OSU). The RAMS-2 will support the existing map-formation capability of RAMS, and in addition will have the capability to process interferometric SAR (IFSAR) acquisition pairs to a variety of IFSAR products including coherence maps and ice velocity maps. The input data will be acquired by the Canadian Space Agency's (CSA) RADARSAT spacecraft during the second and third Antarctic Mapping Missions planned for September 2000 and tentatively September 2001. Each of these campaigns is scheduled to last three 24-day RADARSAT orbit cycles. Major differences from the AMM-1 mission are: data will be acquired in the north-looking mode (no satellite maneuvers necessary), data will be acquired from a more diverse set of RADARSAT imaging geometry and modes, including the fine beam and extended-low modes, and attention will be paid to orbit requirements necessary for performing interferometric acquisitions. The Alaska SAR Facility (ASF) shall process the raw SAR data into appropriate data products, as described within this document, prior to ingest by RAMS-2.

Operations and delivery of RAMS-2 software is divided into two phases. Phase 1 upgrades the existing RAMS system to ingest the new data formats and produce image mosaic products identical (with a few exceptions) to the RAMS-1 products. In addition, interferometric processing will be carried out by RAMS-2 phase 1 software for the creation of a coherence image and raw interferometric products (interferograms and registration fields). Phase 1 software will produce a coherence mosaic map similar to the image mosaic map. The raw interferometric results will be archived for use in phase 2. Phase 2 will ingest the interferometric results and produce a global ice velocity map of the continent.

Phase 1 operations will last approximately 12 months starting approximately 6 months after the MAMM-2 mission start. Phase 2 operations will begin approximately 18 months after the MAMM-2 mission start and last for about 16 months. MAMM-3 operations, if required, will follow a similar schedule relative to the MAMM-3 mission start.

Purpose and Scope

This document specifies the functional requirements of RAMS-2 for RADARSAT. It applies to data processing starting from the point when telemetry has been received by ASF. Functional requirements are discussed in terms of interfaces, data, data quality, operation, throughput, and delivery, with the ultimate goal of completing the mission science objectives.

Change Control

The document version and date will be modified whenever changes are made. Updates will be provided to ASF, BPRC and NASA HQ.

Applicable Documents

[1] "RADARSAT: The Antarctic Mapping Project", Pathfinder Proposal submitted to NASA HQ, September, 1999.

[2] AMM-2 Project Requirements Document, Draft of February 17, 2000

[3] RADARSAT Antarctica Mapping System Functional Requirements Document, v1.04, February 5, 1996. (*FRD for original RAMS)*

[4] AMM-2 Mission Acquisition Plan, TBW (John Crawford, JPL)

[5] ASF RADARSAT Calibration/Validation Plan for AMM-2, TBW by 1 June 2000 (Nicholl, ASF)

[6] ASF AMM-2 Products Description Document, TBW

[7] RADARSAT Network Station Certification, RSI, RSI-GS-001, Rev. 2/1, 14 Jul 95.

[8] RADARSAT Canadian Data Processing Facility System Specification, RZ-SY-50-4381, Issue 7, Rev 1, 29 Sep 95.

[9] RADARSAT Data Products Specification, RSI-GS-026, November 7, 1997.

[10] CSA RADARSAT System Specification, RSCSA-SP002, March 28, 1996.

[11] Vexcel Level Zero Processor (SKY) Telemetry Format Document, Version 1, July 26, 1999 [to be updated shortly]

2 Overview

The RAMS-2 is an augmentation to the RAMS-1, (a.k.a. RAMS) installed at Ohio State University. The Functional Requirements for RAMS-1 are outlined in the RAMS FRD, referenced in the Applicable Documents section above. In this section we present an overview of the science requirements of the MAMM-2 followed by a description of the RAMS-2 system by presenting the existing RAMS-1 system, the existing interferometric software (Vexcel product PHASE), and finally an overview of the modifications and upgrades required for RAMS-2. This is followed by detailed requirements levied on the input data to RAMS-2 (mostly requirements on ASF), the processing functions of RAMS-2 (Vexcel), and the output products (Vexcel).

2.1 Mission Goals and Science Requirements

The goals of the MAMM-2 mission are:

> **Produce high-resolution image mosaics** of Antarctica north of –80 degrees for change detection measurements and studies to understand the response of the ice sheet to climate change.
>
> **Measure the surface velocity field** over coherent and/or trackable areas of the ice sheet north of –80 degrees for ice dynamics studies and for exploring the time varying nature of dynamical processes.

The two phases of RAMS-2 development and operations (defined herein) align with these two goals.

The science requirements [AMM-2 Project Requirements Document, Draft of February 17, 2000] are to construct image mosaics and ice velocity maps. These are summarized below:

2.1.1 Image Mosaic

Science Product	Accuracy	Spatial Resolution	Contribution to Measurement Objectives
2nd image mosaic of area north of –80 degrees	100 m absolute geolocation 1 dB relative and 2 dB absolute radiometric accuracy	25 m	Flow variations Mass balance Non-steady flow Calving Flux
Coherence mosaic of area north of – 80 degrees	100 m absolute geolocation	200 m	Flow styles surface physical properties

2.1.2 Velocity

Science Product	Velocity Accuracy Requirement	Grid Spacing	Contribution to Measurement Objective
Velocity field over coherent and/or trackable areas north of –80 degrees	1 m/yr (slow flow) 10% (fast flow) speed accuracy, 5 degrees in direction	5 km grid	Flow Styles Flow Variation Balance Velocity
Selected Study Areas (e.g., East and West Antarctic Ice Streams, Lambert Glacier)	5 % in speed, 5 degrees in direction	1 km grid	Mass Balance Ice Dynamics Nonsteady flow Calving Flux
Grounding Line Velocities north of –80 degrees	20% in speed, 10 degrees in direction	500 m grid within 20 km of the estimated grounding line	Grounding Lines

2.2 Existing Systems and Software

The proposed RAMS-2 system will be based on two currently existing and independent systems, both developed and supported by Vexcel: RAMS-1 and Phase™. RAMS-1 is the current system in place at Ohio State University and is being used to process the AIC-1 data to an image mosaic. Phase is Vexcel's commercial off-the-shelf (COTS) software for the interferometric processing of SAR data. Both of these systems represent mature and tested technology. The operations of the RAMS-2 system will be based on the RAMS-1 system, augmented by the Phase software, suitably upgraded to produce the ice measurements required. In its simplest form, RAMS-2 may operate identically to RAMS-1 ingesting the same (or similar) data and producing the same products. The interferometric software will operate within the RAMS-2 system, utilizing the RAMS database and many of the results obtained from the RAMS mosaicking process (e.g. block adjustment). However, operations of the interferometric software will be independent.

2.2.1 RAMS-1 System

The Byrd Polar Research Center (BPRC) at Ohio State University is currently completing a high-resolution (25 m pixel) radar mosaic of the entire continent of Antarctica. The data for this effort were gathered by the Canadian RADARSAT sensor, which had been rotated into a left-looking configuration in order to image the South Pole. Over 30 hours of data were collected during the six-week Antarctic Mapping Mission. These data were processed by the Alaska SAR Facility (ASF) into frames (roughly 100 km square) in a special format (slant-range presentation, 16-bit backscatter values) for the RADARSAT Antarctic Mapping Project (RAMP). Currently, BPRC has ingested 5773 frames in 321 orbital swaths while constructing the mosaic [*numbers to be verified*]

Vexcel Corporation designed and implemented a custom software system, the RADARSAT Antarctic Mapping System (RAMS), to perform this mapping effort. The system had to be capable of handling large data volumes far in excess of the actual storage available on hard disk. RAMS is designed around a flexible database (based on Unix directories and files) which provides for the organization of image pyramids, SAR processing parameters, spacecraft ephemeris, ground control points, tie points, digital elevation models (DEMs at multiple resolutions), processing status, etc. The database contains a record of the processing flow of each pixel, which enables the original input backscatter value to be estimated for each pixel in the final mosaic. The graphical user interfaces (GUIs) utilize this database, so as not to require the operator to know where (or how) data are stored.

Figure 1 shows a functional diagram of the RAMS-1 system now in place at BPRC. Four modules are in place to process the RADARSAT data from ASF-produced SAR imagery to a calibrated and mosaicked image map. The details of this system are presented in Norikane et al.[1]

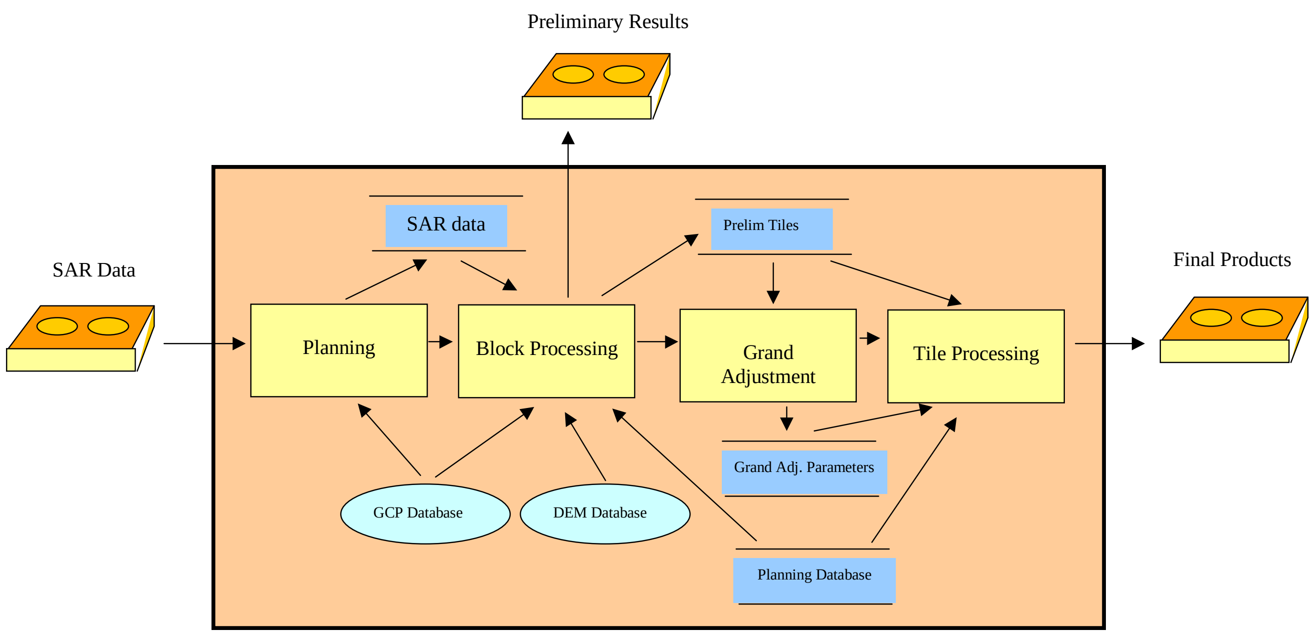

Figure 1 Overview of RAMS-1 system

The mapping effort begins by creating a new mission, which corresponds to a directory in a Unix file system. Details concerning the frames to be received from ASF (in the form of "scan results" files and CEOS leader files) are ingested into the database using an interactive program called Planning Tool. The primary function of this program is to allow the user to divide the

[1] Norikane, L., B. Wilson , and K. Jezek, "RADARSAT Antarctica Mapping System: System Overview – an update," IGARSS '98, 1998, pp 265-267.

mission into blocks. A block consists of a region of contiguous overlapping frames to be initially mosaicked together. This enables processing to proceed with enough disk space to store only a few blocks of data, rather than the whole mission at once. Thus the mosaicking proceeds in two stages: (1) block processing, in which frames are mosaicked within a block, and (2) tile processing, in which blocks are mosaicked together with a “grand adjustment” to construct final map tiles

2.2.2 Phase™ Software

The software system proposed for interferometric processing is a modification of Vexcel’s commercial interferometric processor, Phase™. This software will be integrated into the RAMS-2 system.

The Phase software is a general-purpose software package for processing interferometric SAR data pairs. It supports data from ERS, JERS and RADARSAT platforms. The code is written in C++ and is controlled by a JAVA GUI. Phase is one part of the Vexcel suite of packages that comprise the Vexcel 3DSAR Processing system. Other packages include a telemetry ingest module (SKY™), SAR processing module (Focus™), stereo terrain extraction (RaST™), and orthorectification processor (OrthoSAR™)

Phase software allows three modes of interferometric processing:

DEM creation of IFSAR pair through standard interferometry with GCPs,
Differential interferometry using two passes and an ingested DEM and
Three pass differential interferometry, requiring no DEM.

For RAMS-2, the two-pass differential interferometry mode will be modified to produce measurements of ice motion. The software will exploit two previously demonstrated techniques simultaneously: speckle correlation and IFSAR phase interpretation.

2.3 Overview of RAMS-2 Functional Description and Capabilities

A prime goal of the RAMS-2 design is to minimize changes to the system operations. To meet the throughput goals established for the AIC-2 program, it is essential that the operators be familiar with RAMS operations. For this reason, very little change in the original RAMS operations required to produce the image mosaic will take place. The major thrust of the design is to:

- Upgrade the RAMS database to handle new data products
- Add data conversion tools (e.g. SLC to RAMS format data)
- Add interferometric processing capabilities and associated tools
- Develop and implement velocity estimator that will conflate possible multiple and complementary data measurements, while dealing with little or no ground control.

The diagram shown in Figure 2 describes the high-level functions of the proposed system. Notice that the RAMS-1 system is essentially left intact, and that the operations have been augmented with the VPhase processor and the Velocity Estimator. Note that RAMS format image data can still be ingested directly into RAMS for mosaic production. But at this time, we are planning to ingest SLC data to minimize the ASF processing load.

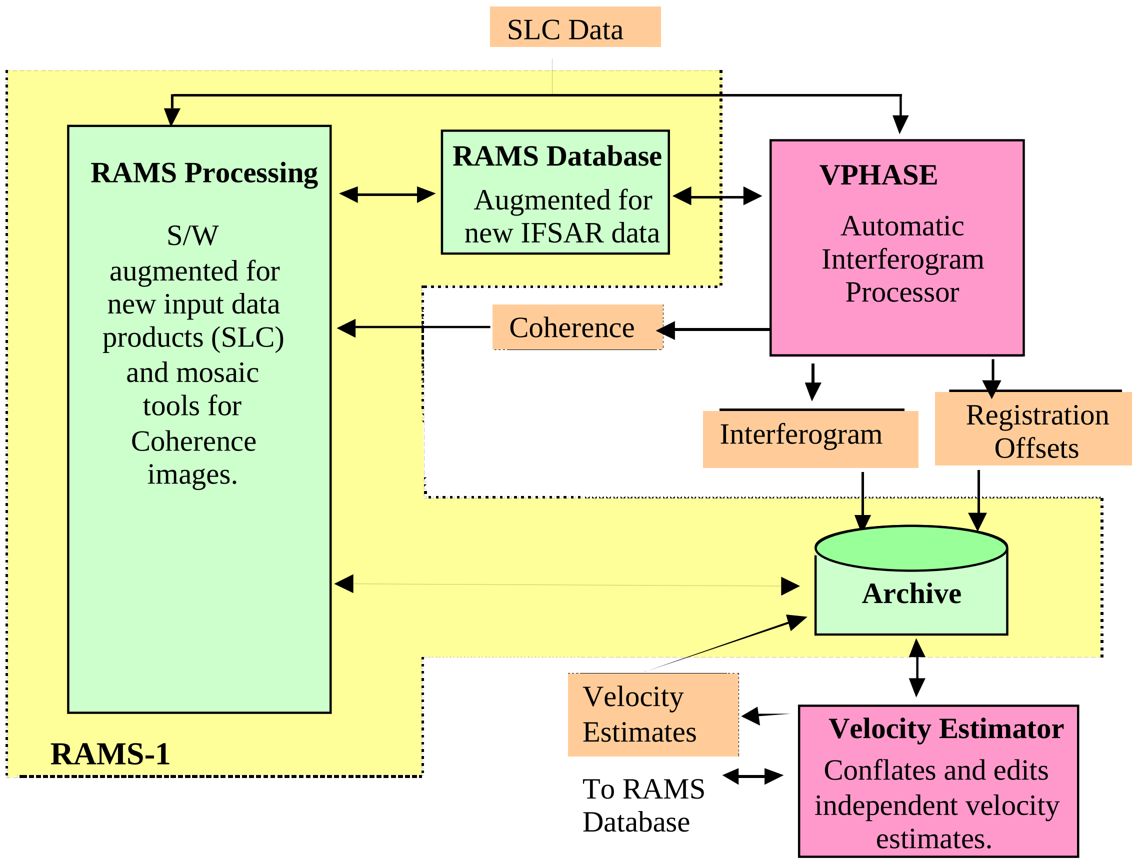

Figure 2 High-level functional diagram of the RAMS-2 mission. VPhase and Velocity Estimator are new modules. VPhase will be developed during Phase 1 and the Velocity Estimator during phase 2.

The interferometric processing will take place in two stages. The first stage is part of Phase 1 and will take place in parallel with the processing of the RAMS image data. In this first phase, VPhase will be used in a fully automated mode to calculate the interferogram and coherence image for each pair. The interferogram and fine registration offsets, used directly in the velocity estimator (Gray and others, 1998), will be archived for further processing. In the second stage of the processing, Phase 2, the archived interferogram and the registration offsets along with ancillary data will be used to create the final flow velocity product.

2.4 Upgrade to RAMS and RAMS database

The changes to the original RAMS system are outlined in detail in the statement of work. They involve modifications and additions to the software as summarized below:

2.4.1 Augment GCP database to include additional GCPs as well as Velocity Control Points (VCPs).

2.4.1.1 GCP Database TBD details: It is assumed that multi-looked detected images will be supplied to ERIM, who will return line-pixel-xyz GCP values, as in RAMS-1.

2.4.1.2 VCP Database TBD. VCP will be a GCP plus velocity vector plus uncertainty in velocity.

2.4.2 Modify I/O routines to include capability for new SLC input data.

2.4.3 Add "IFSAR Pair" database structures including parameters and graphical presentation of orbit swaths.

2.4.4 Add tools for coherence mosaic processing and balancing

2.4.5 New capability to allow transforms used for RAMS image mosaic to be used for coherence mosaic.

2.4.6 Update documentation.

2.4.7 New capability to ingest and incorporate EL1 and F1 RADARSAT data.

2.5 VPhase Processor

2.5.1 Modifications

The VPhase module will be based on an augmentation to the existing Vexcel software product, Phase™. Major modifications to be made to this software include:

2.5.1.1 Development and implementation of fine registration processing for ice speckle correlation tool.

2.5.1.2 Automated operations.

2.5.1.3 Interface to RAMS database and archive.

2.5.1.4 Additional parallelization to exploit multiple CPUs.

2.5.1.5 Manual baseline refinement tool.

2.5.2 VPhase Processing Overview

VPhase reads in a pair of single-look complex images and produces:

- coherence image for mosaicking by RAMS,
- local fine registration offsets, and
- interferograms

The generation of these products will be fully automated by default. For problematical image pairs, Vexcel will also define a well-defined operator intervention procedure.

2.5.3 Velocity Estimator

The Velocity Estimator will ingest all of the pertinent interferometric results from archive and produce velocity estimations. The precise techniques to be used are TBD at this time, but we expect to combine direct phase measurements (after unwrapping) as well as the offset fields. Since there may be several observations of a single location, we will develop conflation algorithms that will reduce the possibly ambiguous measurements in a "best manner." A special working group of AMM scientists acquainted with these techniques will be consulted regarding these processes.

2.5.4 Upgrade to LZP and FOCUS

It is anticipated that the Vexcel FOCUS processor will receive an upgrade to a RAMS-suitable batch processing capability. The details of this upgrade are currently TBD.

The LZP does not need to be modified to accept restituted state vectors from CSA, provided these files will be in the standard M00123456.orb format. As such, they supersede NORAD subdirectory state vector predicts.

The LZP will be modified to correctly indicate the L1 SLC swath width, which is slightly narrower than the raw data swath width due to range compression. Azimuth data loss will be compensated in the RAMS-2 orbit-plotting tool.

The FOCUS processor will be able to process F1 and EL1 RADARSAT data.

3 Input Data Requirements

The MAMM-2 data will be processed to complex imagery suitable for interferometry applications by the Alaska SAR Facility in Fairbanks Alaska. This data, and ancillary information, will be supplied to the RAMS-2 system at the Byrd Polar Research Center (BPRC) at Ohio State University. The RAMS-2 system will process this data to generate the scientific products outlined in the MAMM-2 Project Requirements Document (PRD)

The following requirements are placed on the SAR image formation processing of this data.

3.1 Documentation

3.1.1ASF shall supply complete documentation of all required products delivered to BPRC. This will be provided in the document "ASF MAMM-2 Products Description Document (PDD)"

3.1.2The Product Description Document (Draft form) must be provided to Vexcel and BPRC 6 months prior to start of RAMS-2 operations.

3.2 Phase 1 Test Data

3.2.1 Phase 1 Test Data objectives

1. Ensure the FOCUS processor correctly processes all modes, including contingency modes, of RADARSAT Antarctica data.
2. Verify the operation of the VPhase interferometric processor on SLC image data.
3. Verify that RADARSAT images are calibrated.

3.2.2 ASF shall supply Vexcel and BPRC with suitable Phase 1 test data that meets the specifications described in this document and the ASF MAMM-2 PDD.
This data will consist of both Level 0 Raw data and corresponding Level 1 SLC image data.

3.2.3 Test data shall include RSAT data in all modes to be used during MAMM-2.
Priority is to be given to IFSAR pairs, to primary MAMM mission modes, and to data covering Antarctica. This data will be supplied, as available and on a flexible basis, through a combination of the resources listed below. Data types are to be, in order of preference, either STF L0 data or Vexcel-Formatted CEOS L0 data. L1 SLC test data is addressed in the next section, 3.2.4.

Delivered: F1 IFSAR pair from Antarctica (ASF).
Delivered: Standard mode swath pair from Antarctica (JPL).
Delivered: Standard mode 1997 Antarctica IFSAR pair (OSU).
Pending: Delta Junction calibration data from ASF. (7/00-2/01 time frame)
Pending: Additional 1997 Standard mode, Antarctica, Left-looking (JPL, 7/00-8/00 time frame).
Pending: 6 STF requests, Antarctica (JPL, 7/00-9/00 time frame).

Pending: Post-Eclipse 2000 Antarctica prior to mission start, as available (ASF, 8/00-9/00 time frame).
Pending: Mission data (ASF, mission real-time 9/3-11/15, sites in Antarctica TBD).

3.2.4 ASF-Produced SLC images will be delivered to Vexcel for the purpose of testing the RAMS-2 development effort.
This data delivery will be coordinated by Vexcel and ASF personnel in the 7/00 – 2/01 time frame. Additional details are TBD.

3.2.5 Vexcel shall provide a feedback report on product quality one month after delivery of test datasets identifying problems to be fixed prior to operations.
This will include, but is not limited to:

1. Verifying that image specification using Time Past Ascending Node results in adequate frame overlap (95%+).
2. Data integrity (no dropouts, shifts).
3. Interferogram coherence evaluation.

3.3 Image and Data Quality

3.3.1The images produced for input into the RAMS-2 shall be single-look complex (SLC) imagery that meets the RSI specifications [7, 9] for SLC data quality.

The theoretical range resolution of the required RADARSAT beam modes are:

Beam	Bandwidth	Resolution (slant)
ST1, 2, EL1	17.28 MHz	8.7 m
ST5, 6	11.58 MHz	12.9 m
F1	30.00 MHz	5.0 m

In all beam modes, the azimuth resolution obtainable from processing 900 Hz of Doppler bandwidth is 8.0 meters [10].

For MAMM-2 processing, we require a Kaiser (or equivalent) weighting (in range and azimuth) of 2.4 (beta) in the frequency domain. This induces the following effect on the ideal impulse response function:

Main Lobe Broadening:	16.6%
PSLR	-20.5 dB
ISLR (1-D)	-18.6 dB

Processor shall therefore be capable (designed) to produce the following Impulse Response (IR):

IR Parameter	ST1, 2	ST6	EL1	F1
3.3.1.1 Range resolution m, slant	**10.5**	**15.7**	**10.5**	**6.0**

3.3.1.2	**Azimuth resolution, m**	**8.9**	**8.9**	**8.9**	**8.9**
3.3.1.3	**PSLR, dB**	**-20**	**-20**	**-20**	**-20**
3.3.1.4	**2-D ISLR, dB**	**-11**	**-11**	**-11**	**-11**

3.3.1.5 SAR imagery processed by the SAR processor must be radiometrically calibrated to +/-1dB relative and +/-2dB absolute.

3.3.1.6 Image degradation introduced by SAR processing must meet the requirements in the following table:

Image Quality Metric	SLC
Range 3dB IRW broadening	17%
Azimuth 3dB IRW broadening	17%
PSLR degradation	2.5 dB
ISLR degradation	2.8%
Radiometric Error*	0.1 dB
Radiometric Linearity*	0.97
Absolute Location Accuracy*	40 m
Geometric Distortion*	30 m
Phase Error (relative)	10 deg.

(*) Excluding ephemeris and terrain effects

The above broadening and sidelobe degradation specified values describe the permitted degradation over the specified impulse response values. These values are *compounded on top of* the Kaiser weighting degradation described above.

The phase error in the SLC product is a critical parameter for the MAMM-2. Relative phase error is the error (introduced by the SAR processor) in the phase difference formed between any two SLCs of the same area, and relates directly to an error in the ice velocity determined by this interferometric phase difference. For instance, if there are two identical SAR passes (zero baseline) acquired at different times of the same area, and there is no motion or change in the surface, the phase difference should be zero. The phase error specified above is the allowable error in this measurement. Note this does not include errors due to sources outside the image formation processor such as temporal decorrelation, atmospheric phase modulation or ionospheric effects.

There is a science requirement to be able to measure the velocity of slow ice flow to 1 m/year. A relative phase error of 10 degrees between consecutive cycles corresponds to an error of 0.0155 meters in a 24-day cycle, or 0.023 m/year. Since the interferometric techniques only measure the velocity component that is in the radial (toward or away from the SAR) direction, we must consider the angular effect which will reduce this accuracy when projected into the direction of ice flow. If we assume successful double coverage (ascending and descending), one of the views will have a reasonably small angle between the ice velocity flow direction and one of the range look vector directions (ascending or descending). Therefore, the SLC product specification of 10 degree relative phase error is acceptable for meeting the 1m/year requirement.

3.3.1.7 The SLC products shall be processed with a Doppler bandwidth of 1000 Hz. The standard RSI specification for processor bandwidth a 900 Hz. This is a conservative value compared to the "80 % of the PRF" rule of thumb, which produces a value of 1040 Hz based on the RADARSAT nominal PRF of 1300. This 1000 Hz requirement is placed on the processing to accommodate expected Doppler misalignment caused by spacecraft attitude differences between interferometric pairs.

3.3.2 The SLC products shall be in a CEOS format and include a data file and a leader file. The complex data within the CEOS file structure shall not be flipped in range or azimuth, but be organized in the natural SAR order of increasing fast time (range) and slow time (azimuth).

3.3.3The data shall be suitable for interferometric processing as described below. During the Antarctic mapping mission 2, data will be collected from a large number of orbits. During each orbit, data will be collected in one or more modes (e.g. Standard Beam 2, extend low and fine beam modes) as shown in Figure 3.

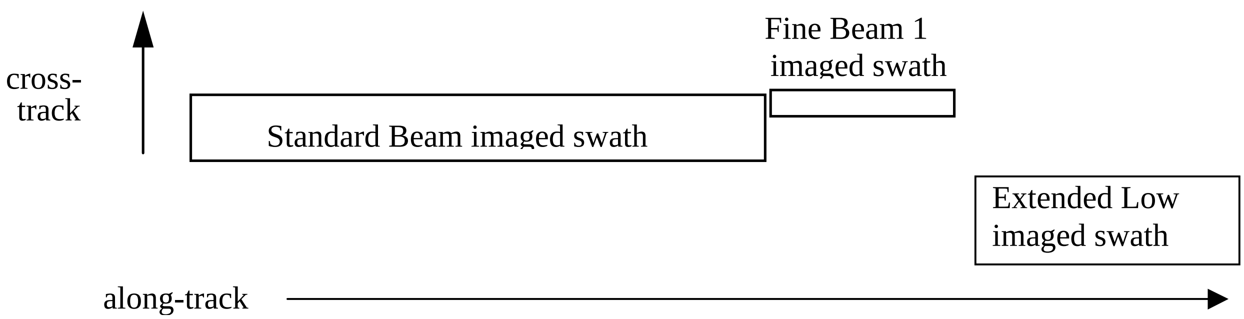

Figure 3 Imaged swaths for one orbit

3.3.4The data collected from one orbit and beam mode shall be processed into image frames with overlap:

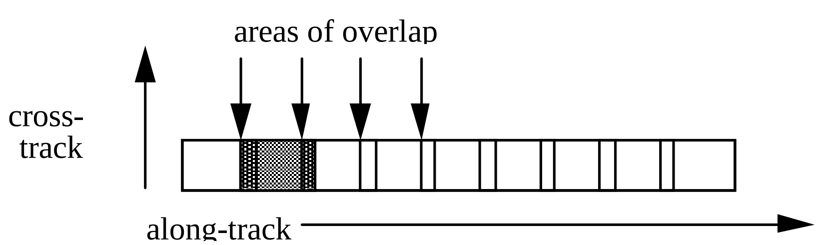

Figure 4 Imaged swaths divided into image frames

The frames will be defined by RAMS-2 Operators and in general will be between 100 and 300 km in along-track distance. The nominal frame definition will consist of four parameters:

1. Orbit number
2. Data start time as Time Past Ascending Node
3. Frame length as either elapsed time or distance in km (TBD).
4. Scene elevation value to use in antenna pattern compensation.

The overlap between the frames shall not be specified directly; it will be the responsibility of RAMS to generate processing requests that produce frames of the appropriate overlap.

The raw SAR data shall be processed with the following characteristics:

3.3.5 The SAR processor shall be able to process the following RADARSAT modes: EL1, ST1, ST2, ST5, ST6 and F1. As a contingency, the SAR processor must also be capable of processing modes ST3, 4, and 7.

3.3.6 The processed image frame will be specified by the RAMS-2 Operator in terms of Orbit number, Time Past Ascending Node, Frame Length, and Scene Elevation as described in 3.3.4.

3.3.7 The resulting processed data shall meet the image resolution and radiometric requirements specified in 3.3.1.

3.3.8 The data shall be deskewed to zero Doppler.
Since one of the primary goals for MAMM-2 is to perform IFSAR processing, it is desirable to have pairs of IFSAR SLCs that are in as similar geometry as possible. Most relative skew between SLCs due to slightly differing pointing can be removed by deskewing to a common reference, such as zero Doppler.

3.3.9 The data shall be in a deskewed slant range projection.
The slant range spacing shall be the natural slant range bin size (as determined by the ADC), projected into the zero Doppler geometry.

3.3.10 The phase of the SLC imagery shall be the zero Doppler phase.
The phase of the SLC imagery should be adjusted for non-zero Doppler processing by producing a phase correction such that the phase of the SLC corresponds to the image phase at zero Doppler. This can be accomplished by correcting the phase at the aperture center (as determined by the Doppler center frequency) by the following term:

$$\varphi_0 = \frac{4\pi}{\lambda}\left(R_s - R_0\right)$$

Where R_s is the slant range at the Doppler center frequency, and R_0 is the range at zero Doppler.

3.3.11 The time associated with each range line shall be the zero Doppler time.
The time associated with the deskewed imagery should be the time that the targets were in the zero Doppler geometry. This time is not the time at which the targets were illuminated, nor is it the time at which the targets were strictly at geometric side-looking (due to earth's rotation).

3.3.12 The processor shall be able to accept a "scene elevation" value.
This will adjust the antenna gain pattern so as to compensate for the input elevation. Only one elevation parameter per scene shall be supplied. A TBD mechanism will be established such that BPRC will pre-construct a look-up table consisting of requested scene elevation values for each frame prior to processing. The elevation value will also be used to calculate geometric parameters associated with the scene such as look angles, swath size and ground pixel size.

3.3.13 The processed image data shall consist of complex pixels.

3.3.14The complex pixels shall be represented by two 16-bit signed values corresponding to in-phase and quadrature components of the complex numbers (I and Q).

3.3.15 Processor gain shall be such that there be no saturation of natural targets. Active transponders may saturate the 16I/16Q dynamic range of the output image. It may be necessary to process calibration scenes independent of this RAMS-2 data flow so as to avoid all high-end saturation so as to be able to perform verification and calibration measurements using calibration targets.

3.3.16 The scaling shall be such that the noise equivalent sigma zero of the data shall correspond to a dn value of 32 or greater.
At the lower end of the dynamic range, we must guarantee that there is significant phase resolution for signals at or above the noise level of the data. A dn value of 32 (5 bits) provides about 1.8 degrees precision for the complex phasor.

3.3.17 The data from one orbit will be processed as a sequence of image frames determined by RAMS-2 Operators.

3.3.18 The frames will typically be between 100 and 300 km long in the along-track (orbit) direction.

3.3.19 The Doppler center frequency shall be within 150 Hz of the actual Doppler center frequency throughout the SAR frame.

3.3.20 The frames shall be processed using a single Doppler polynomial (i.e. a function of range bin) that is not updated in the along-track direction.
Frame sizes will be limited by the rate at which the Doppler parameters vary along track such that the Doppler polynomial remains valid as defined by the following requirement. Frames may be greater than 100 km along-track so long as the Doppler polynomial selected is within 150 Hz of the actual Doppler values at all ranges.

3.3.21 Adjacent image frames from the same orbit should overlap a sufficient amount that is greater than the frame alignment process accuracy expected.
It is anticipated that approximately 10 km overlap in the output SLC data will be sufficient to meet this requirement. The frame overlap size must be larger than any errors produced in the framing process for subsequent orbit cycles to guarantee sufficient interferometric frame

alignment. Exact frame overlap will be determined by the processing requests received at ASF by the RAMS operations team.

In addition to the complex imagery, each CEOS SLC product shall have a corresponding metadata (leader) file containing the following information:

3.3.22 Every image frame will be assigned a unique processing run number.
ASF shall maintain a database indexing each processing run number to the corresponding image frame and processing characteristics.

3.3.23 An estimate for the noise level as a function of range shall be provided for every image frame.
It is understood that the noise level may be an estimated value for that scene based on measurements or calibration information obtained outside the scene.

3.3.24 The SAR processor shall use an earth-centered ellipsoidal model of the earth's surface.
This model shall be parameterized by two values: the polar radius and the equatorial radius, or equivalently, the equatorial radius and a flattening factor.

3.3.25 number of range lines (integer).

3.3.26 number of range samples (integer).

3.3.27 slant range pixel spacing (floating point).

3.3.28 azimuth pixel spacing (floating point).

3.3.29 image start time (seconds, same reference system as that used for ephemeris data).

3.3.30 image end time or image duration (seconds).

3.3.31 orbit number (integer).

3.3.32 mode or beam (string).

3.3.33 near slant range (double precision, meters, if constant for entire image frame).
In the event that the near slant range might change, adequate additional data fields will be included to precisely describe the nature of these changes.

3.3.34 Doppler center frequency polynomial used to process data.

3.3.35 Full 2-D Doppler polynomial for use by VPhase.
The LZP will generate a two-dimensional (azimuth and range) polynomial for the Doppler processing parameters. The actual processing of an image frame will be done using only a 1-D polynomial (parameters allowed to vary in range, but not azimuth). However, the interferometric

processor will make use of the full two-dimensional Doppler polynomial. Therefore it must be retained in the metadata file.

3.3.36 "Deskew" indicator to provide positive indication that data is deskewed.

3.3.37 geolocation of image corners at specified scene elevation (double precision, Earth fixed coordinates (m) or geodetic lat, lon (deg)), where image corners *do* include any zero-fill pixels required to fill the file.
Note that these image corners are derived using the scene elevation value specified by the RAMS-2 Operator in the processing request. The scene is imagined to be flat; it floats above the earth-centered ellipsoidal model (described above) at this specified constant elevation.

3.3.38 Look-up table or equation to convert detected amplitude *A* to backscatter (σ^0).
The SLC complex pixel values have an associated amplitude *A* given by:

$$A = \sqrt{I^2 + Q^2}$$

where *I* and *Q* are the real and imaginary (in-phase and quadrature) components of the pixel. An equation or lookup table will be provided to convert *A* to a backscatter σ^0.

3.3.39 relative and absolute calibration quality parameters.

3.3.40 average scene elevation used to process the scene.
This parameter will be supplied in TBD fashion based on the scene location in reference to the Antarctica DEM.

3.3.41 Ephemeris Data Per Orbit: **For each frame, the spacecraft position and velocity shall be provided for the image start, center, and end.**
This information is provided in the SAR Leader file and consists of the following:

- time (floating point)
- spacecraft position (double precision, Earth Centered Inertial coordinates, meters)
- spacecraft velocity (double precision, Earth Centered Inertial coordinates, meters/sec)

3.4 Image Framing

The RAMS Operations Team will determine image framing. The RAMS-2 system will have the capability to plot imaged swaths and permit the operators to select image frame starting and ending positions for processing by ASF. This plotting procedure will make use of STF files provided by ASF. There are two scene reduction issues, presented with their nominal solutions, as follows:

1. Range swath reduction due to range reference function loss (far range) will be accounted for by the LZP.
2. The RAMS-2 image swath plotter will account for azimuth reduction due to azimuth reference function loss.

RAMS requests to ASF should take into account uncertainty in the framing position accuracy by including sufficient overlap to account for any error (see Figure 5). This accuracy will be achieved by specifying the frame in terms of four parameters as described above in 3.3.4: Orbit number, Start time as Time Past Ascending Node, Frame length (seconds or kilometers, TBD), and Scene elevation. In summary the central processing cycle will proceed as follows:

1. ASF acquires telemetry data, processes to Level 0, sends STF files to RAMS Ops.
2. RAMS Ops receives STF files, generates Processing Requests, sends to ASF.
3. ASF receives Processing Requests, processes Level 0 data to SLC products, sends to RAMS Ops.
4. RAMS Ops ingests SLC products that are subsequently queued into the VPhase processor.

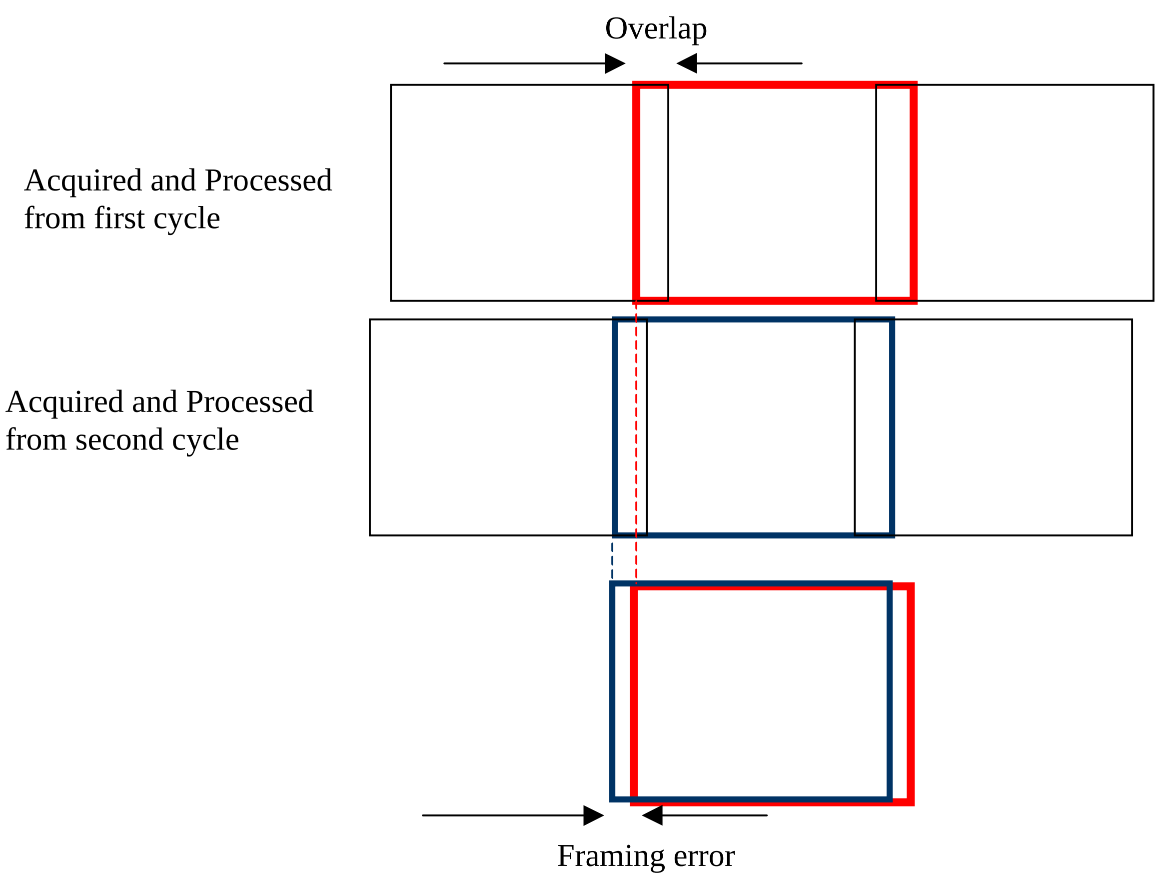

Figure 5 Framing error must be considerably less than overlap between frames

3.5 Input Data and Documents Schedule Requirements

Due to the necessarily compressed schedule of the MAMM-2, it is critical that a schedule be developed showing appropriate test data being made available in a timely fashion. In addition, final product deliveries must be made to OSU so that they may complete the project requirements on schedule as outlined in the MAMM-2 Project Requirements Document.

Milestones for the project are laid out in the PRD. Some of the milestones that effect SAR data processing include:

Calibration and Validation Plan	June 2000
MAMM-2 acquisitions begin	September 2000
Test Products	November 2000
RAMS Phase 1 delivery to OSU	February 2001
ASF begins product delivery to OSU	March 2001
MAMM-2 image and coherence products complete	Feb 2002

This leads to the following requirements on RAMS-2 input data and documentation. Dates assume the above schedule (from PRD). If MAMM-2 mission is significantly delayed, these dates may be correspondingly slipped.

3.5.1 Product Description Documents (draft from) to be delivered to OSU/Vexcel by August 15, 2000.
Redundant with requirement 3.1.2

3.5.2 Final Product Description Documents to be delivered to OSU/Vexcel by October 15, 2000.

3.5.3 Delivery of test data shall begin by May 1, 2000 and be complete by August 15, 2000.
Test data described in requirement 3.2.2 above.

3.5.4 ASF begins STF delivery to OSU by February 1, 2001.

3.5.5 ASF begins L1 SLC delivery to OSU by March 1, 2001.

3.6 System Testing

Various system tests will be devised and executed on a TBD basis. This will occur during the August 2000 – March 2001 time frame. An example of such a test will be a two-day processing dry run to verify that the ASF L1 SLC products can be produced at the mission throughput rate.

4 SAR Processor -- RAMS Interface Requirements

4.1 Overview

This section describes the ASF / RAMS interface requirements. This includes the delivery of data to OSU, requests from RAMS for reprocessing of data, and delivery and format of STF parameter files.

4.2 Data Delivery

4.2.1 Data will be delivered to OSU approximately on a weekly basis.
Note that OSU will be processing images in blocks. The number of orbits contained within one block may be greater than the average weekly rate of processing at OSU (5-8 orbits per week). The maximum efficiency will result if ASF concentrates processing to produce a complete block for each tape shipped. Data shall be provided on DLT tapes in TBD format. The use of 8mm tapes in a 5 GB format will be used as a backup.

4.3 Processing Queue

4.3.1 The processing queue will be supplied by BPRC to ASF by a method TBD.
The queue will be divided into processing blocks. The order in which data must be processed will be communicated to ASF by BPRC. For MAMM-2, processing requests will include a scene elevation parameter to be used during SAR processing for determining the proper antenna gain characteristics throughout the scene. BPRC will be responsible for creating a mapping of this scene elevation to a corresponding antenna pattern correction algorithm.

4.3.2 Periodically, the RAMS operators may decide that reprocessing of SAR data is required.
To do so, they will either enter the request via the EOSDIS IMS v0 interface or by using the API provided for submitting processing requests.

4.3.3 A new processing run number should be assigned to any reprocessed data.

4.4 ASF Processing Throughput Implications

The rate at which ASF must process data is provisionally estimated as follows:
Estimate 5,000 frames (SLC images), not including reprocessing requests.
Start processing March 1 (first processing request delivered by BPRC).
Finish processing August 1. (9 months after data collection ends)
Time period = 150 days.
Implicit processing rate is 34 frames per day, 300-km frames.
It is recommended that a 10% pad be added, to reach a throughput rate of 37 frames per day.

ASF will perform a minimum two-day dry run prior to February 1, 2001, to verify that this throughput rate is achievable.

4.5 SKY Telemetry Format (STF) Parameter Files and SCAN files

4.4.1 ASF will scan all data acquired during each MAMM prior to processing.
The result is a set of Scan Results Files describing the actual imaged swaths. The format of the Scan Results Files must be described in an ASF-provided document. It must contain either the preliminary SAR image frame corner coordinates or a description of the actual swath imaged. Format of Scan Results File will be the same as for RAMS-1. The Scan Results Files will be use for real-time (during mission) monitoring of coverage.

4.4.2 ASF will produce SKY Telemetry Format (STF) parameter files of all data acquired during MAMM2/3.
RADARSAT data will be processed using the Vexcel Level 0 Processor (LZP) at ASF. This processor produces a byte aligned raw telemetry file. The STF file may be used to generate level 0 or higher level products. In generating the STF file, the Vexcel LZP also generates a STF parameter file that contains useful information including the Doppler characteristics of the entire data take as well as geolocation of the imaged swath boundaries. The exact format of the STF parameter file is given in reference [11]. The STF parameter files for all AMM-2 (or 3) data will be provided to OSU from ASF prior to Level 1 processing. OSU will use this data to plan RAMS processing blocks and to determine processing requests back to ASF.

Note that the frame-planning utility will take into account the standard data loss (range and azimuth reference functions) in production of the L1 SLC from the L0 data.

5 RAMS-2 Processing Requirements

5.0 Phase 1 and Phase 2 Requirements

5.0.1 Phase 1 Requirements

5.0.1.1 Ingesting ASF-Produced STF files and generating Processing Requests for ASF.
RAMS-2 must be able to display MAMM coverage based on STF parameter files. Coverage must be displayed over a SAR image background formed by the AMM-1 SAR Mosaic.

5.0.1.2 RAMS-2 must be able to display coverage (from STF data) in cycle pairs/triplets to permit simultaneous order generation of interferometric pairs/triplets

5.0.1.3 Ingest GCPs and VCPs into a database.
The nominal procedure is to include the ERIM GCP feedback loop in the RAMS-2 operations beginning March 1, 2001. Further details, particularly with regard to VCPs, are TBD.

5.0.1.4 Ingesting the interferometric SLC data as indicated in requirements in section 3.3 above.

5.0.1.5 Convert SLC data to multilooked detected amplitude data.
The implementation of a local mosaic capability using 3-look F1 RSAT fine beam data will be investigated in the 7/00 – 8/00 time frame.

5.0.1.6 Block processing new multilooked amplitude data using the RAMS-1 workflow and modified RAMS-1 software.

5.0.1.7 VPhase processing to generate coherence images, interferograms, and offsets.

5.0.1.8 Grand adjustment of the amplitude data following the current RAMS-1 workflow.

5.0.1.9 Parallel dataflow paradigm
The database structure will accommodate coherence data, amplitude data, and interferometric data. These different data types will flow through the RAMS-2 processor using the same mapping transformation to map projection, i.e. to the final mosaic product. This parallel dataflow will include appropriate modifications suitable to each data type. For example, the antenna pattern compensation is not to be applied to coherence data in creating the coherence mosaic.

5.0.1.10 Block processing coherence data using previous block adjustment.

5.0.1.11 Tile processing amplitude mosaic.

5.0.1.12 Tile processing coherence mosaic using previous grand geometric adjustment.

5.0.2 Phase 2 Requirements

5.0.2.1 Phase 2 Requirements will be further elaborated at a later point.

5.0.2.2 Velocity estimation based on interferometric results (unwrapped phase and precise registration results).

5.0.2.3 Use of "Velocity Estimator" to conflate velocities.

5.0.2.4 Produce ice velocity products.

5.1 RAMS-2 Operations, Throughput and Speed

For the second Antarctic Mapping Mission (September 2000), RAMS-2 will meet the following operations schedule:

RAMS-2 Phase 1 Readiness Review at Vexcel:	January 15, 2001
RAMS-2 Phase 1 delivery complete at OSU:	February 15, 2001
ASF begins delivery of SLC products to OSU:	March, 2001
AIC-2 Image and Coherence mosaics compete:	February 2002
RAMS-2 Phase 2 Readiness Review at Vexcel	January 2002
RAMS-2 Phase 2 delivery complete at OSU	February 2002
AIC-2 velocity products complete	June 2003

A similar schedule will be in-place for the AIC-3 mission. Tentative AIC-3 mission date is currently September 2001. The RAMS-2 system must meet the following requirements regarding operations, throughput and speed:

5.1.1 RAMS-2 system must be ready for Phase 1 operations and installed at BPRC by approximately five months after start of MAMM-2 mission (February 2001).

5.1.2 RAMS-2 system must be capable of processing image mosaic products from the MAMM-2 mission within 12 months of start of weekly reception of data (September 2001).

5.1.3 RAMS-2 system must be ready for Phase 2 operations and installed at BPRC by approximately 17 months after start of MAMM-2 mission. (Phase 2)

5.1.4 RAMS-2 system must be capable of producing Phase 2 products within 16 months from start of phase 2 operations. (Phase 2)

5.1.5 The design of RAMS-2 must take into account a 50% operations margin.

5.1.6 Formation of raw interferometric products must be capable of running concurrently with mosaic processing.
This implies independent computers networked together. Furthermore, it is a goal to have the interferometric software threaded for operations on a multi-CPU platform.

5.1.7 Interferometric processor (VPhase) must include tools for automation, batch processing and quality assurance.
It is anticipated that for complicated datasets (e.g. ice streams) the usual automated processing will necessarily be superseded by operator intervention. Preparations for Phase 2 will include standardizing this intervention by providing a clear procedural plan for the operator.

6 RAMS-2 Output Requirements

6.1 Products

6.1.0 Standard RAMS-1 Products
Standard RAMS-1 image products are organized according to British Antarctic Survey (BAS) map standards (regions of bounding latitude and longitude, centered with respect to the South Pole). Each map tile consists of sub-tiles, which are headerless raster images 51.2 km square. The tile-based organization of output products was designed to yield a reasonable set of data to fit on a CD-ROM. Thus, the entire map could be distributed as a library of Antarctic tiles. The map is in a polar stereographic projection with respect to WGS84.

Unlike AMM-1, the MAMM-2 mission will be in the standard, right-looking mode of RADARSAT. In this “north-looking” mode, there will be a restricted field of view for the SAR instrument, and it will not be possible to image the entire continent. The following products are therefore only applicable and required corresponding to the area accessible to the SAR imaging instrument, which is planned to be areas north of –80 degrees latitude.

6.1.1 RAMS-2 shall construct a High-Resolution (25 m) Amplitude Mosaic Tiles
This product consists of sub-tiles (2048 by 2048 pixels square) organized into BAS map tiles. Each pixel is a 16-bit representation of scaled amplitude from a single input SAR image (i.e., it is not an averaged or composite value). Using the index tiles and their associated keys, each output pixel can be traced back to an estimated input backscatter value.

6.1.2 RAMS-2 shall construct database DEM tiles
This product also consists of sub-tiles 51.2 km square, which are organized into BAS tiles. It is of lower resolution than the amplitude mosaic, e.g., 100-m postings. Each pixel is a signed short integer (16-bits) representing elevation in meters. The database constructed during RAMS-1 operations fulfills this requirement.

6.1.3 RAMS-2 shall construct index tiles and keys
This product also consists of sub-tiles 51.2 km square, which are organized into BAS tiles. It is of lower resolution than the amplitude mosaic, e.g., 100-m postings. Each pixel is an 8-bit encoding of a thread of processing history (i.e., which frame and which block contributed the bulk of the data at the given spot). The associated key files specify the actual transformations and coefficients associated with each processing thread: the per frame radiometric transform used in block processing, the per block geometric transform of the grand geometric adjustment, and the per block radiometric transform of the grand radiometric adjustment. Given the value of a pixel in the final amplitude image, the corresponding backscatter can be estimated by inverting the transformations.

6.1.4 RAMS-2 shall construct overview products
Once tile processing is complete, overview images (at less than full 25 m resolution) can be generated at any tier of the image pyramid (50, 100, 200, 400, 800, … m/pixel). The image is a simple, headerless raster image and there must be space for it in the mission file system.

6.1.5 RAMS-2 shall construct coherence mosaic products
Coherence products will be produced similar to amplitude products. All of the aforementioned RAMS products will be available for coherence calculations and can be provided on a tile-by-tile basis at full (25 m) resolution. The coherence posting will be 200 meters.

6.1.6 RAMS-2 shall construct Velocity Products (Phase 2)
Velocity products will be headerless raster, binary GIS data layers in the map projection of the entire continent. They will be of lower resolution than the amplitude mosaic. 500 m postings will be the highest velocity posting required. Other postings to be supported include 1 km and 5 km posts.

6.1.7 RAMS-2 shall construct a Velocity Mosaic (Phase 2)
Each pixel will consist of composite (x, y) velocity components in the map projection in meters per year. Each velocity component will occupy a 32-bit single-precision floating-point value. Therefore the image will have 2 bands (a total of 64-bits) per pixel. The pixel spacing of the velocity mosaic shall be the same as the products defined in 6.1.6.

6.1.8 RAMS-2 shall construct a surface slope mosaic (Phase 2)

Each pixel will consist of surface slope in the (x, y) directions. Each slope will occupy a 32-bit single-precision, floating point value. Therefore, the image will have two bands (a total of 64-bits) per pixel.

6.1.9 RAMS-2 shall construct a velocity estimation error mosaic (Phase 2)

Each pixel will consist of the estimated error for the velocity at the given grid location. This will be an (x, y) vector of single-precision floating point values. The precise techniques to be used for quantifying this error are TBD.

Appendix A SUMMARY OF RAMS-2 FUNCTIONAL REQUIREMENTS

Listed in descending order from document:

#	FRD Requirement Number	Requirement:
1	3.1.1	ASF shall supply complete documentation of all required products delivered to BPRC. This will be provided in the document "ASF MAMM-2 Products Description Document (PDD)".
2	3.1.2	The Product Description Document (Draft form) must be provided to Vexcel and BPRC 6 months prior to start of RAMS-2 operations.
3	3.2.2	ASF shall supply Vexcel and BPRC with suitable test data that meets the specifications described in this document and the ASF MAMM-2 PDD.
4	3.2.3	Test data shall include interferometric pairs of all SAR modes to be used during MAMM-2.
5	3.2.4	One Level 1 SLC image will be produced for each RADARSAT contingency beam mode.
6	3.2.5	Images will cover the maximum frame along-track dimension (300 km).
7	3.2.6	The above data shall be acquired over ice covered regions of the Antarctic continent.
8	3.2.7	Sufficient Test data shall be acquired over a calibration site (e.g. Delta Junction) to calibrate all required MAMM-2 beam modes.
9	3.2.8	Vexcel shall provide feedback regarding product quality one (1) month after delivery identifying problems to be fixed prior to operations.
10	3.3.1	The images produced for input into the RAMS-2 shall be single-look complex (SLC) imagery that meets the RSI specifications [7, 9] for SLC data quality.
11	3.3.1.1	Range resolution m, slant.
12	3.3.1.2	Azimuth resolution, m.
13	3.3.1.3	PSLR, dB.
14	3.3.1.4	2-D ISLR, dB.
15	3.3.1.5	SAR imagery processed by the SAR processor must be radiometrically calibrated to +/-1dB relative and +/-2dB absolute.
16	3.3.1.6	Image degradation introduced by SAR processing must meet the requirements in the following table…
17	3.3.1.7	The SLC products shall be processed with a Doppler bandwidth of 1000 Hz.
18	3.3.2	The SLC products shall be in a CEOS format and include a data file and a leader file.
19	3.3.3	The data shall be suitable for interferometric processing.
20	3.3.4	The data collected from one orbit and beam mode shall be processed into image frames with overlap.
21	3.3.5	The SAR processor shall be able to process the following RADARSAT modes: EL1, ST1, ST2, ST6 and F1. As a contingency, the SAR processor must also be capable of processing modes ST3, 4, 5, and 7.
22	3.3.6	The processed image frame will be specified by the RAMS-2 Operator in terms of Orbit Number, Time Past Ascending Node, Frame Length, and Scene Elevation as described in 3.3.4.
23	3.3.7	The resulting processed data shall meet the image radiometric requirements specified in 3.3.1.
24	3.3.8	The data shall be deskewed to zero Doppler.
25	3.3.9	The data shall be in a deskewed slant range projection.
26	3.3.10	The phase of the SLC imagery shall be the zero Doppler phase.
27	3.3.11	The time associated with each range line shall be the zero Doppler time.
28	3.3.12	The processor shall be able to accept a "scene elevation" value.
29	3.3.13	The processed image data shall consist of complex pixels.
30	3.3.14	The complex pixels shall be represented by two 16 bit signed values corresponding to in-phase and quadrature components of the complex numbers (I and Q).

31	3.3.15	Processor gain shall be such that there be no saturation of natural targets.
32	3.3.16	The scaling shall be such that the noise equivalent sigma zero of the data shall correspond to a dn value of 32 or greater.
33	3.3.17	The data from one orbit will be processed as a sequence of image frames determined by RAMS-2 Operators.
34	3.3.18	The frames will typically be between 100 and 300 km long in the along-track (orbit) direction.
35	3.3.19	The Doppler center frequency shall be within 150 Hz of the actual Doppler center frequency throughout the SAR frame.
36	3.3.20	The frames shall be processed using a single Doppler polynomial that is not updated in the along-track direction.
37	3.3.21	Adjacent image frames from the same orbit should overlap a sufficient amount that is greater than the frame alignment process accuracy expected.
38	3.3.22	Every image frame will be assigned a unique processing run number
39	3.3.23	An estimate for the noise level as a function of range shall be provided for every image frame.
40	3.3.24	The SAR processor shall use an earth-centered ellipsoidal model of the earth's surface.
41	3.3.25	number of range lines (integer)
42	3.3.26	number of range samples (integer)
43	3.3.27	slant range pixel spacing (floating point)
44	3.3.28	azimuth pixel spacing (floating point)
45	3.3.29	image start time (seconds, same reference system as that used for ephemeris data)
46	3.3.30	image end time or image duration (seconds).
47	3.3.31	orbit number (integer).
48	3.3.32	mode or beam (string).
49	3.3.33	near slant range (double precision, meters, if constant for entire image frame)
50	3.3.34	Doppler center frequency polynomial used to process data
51	3.3.35	Full 2-D Doppler polynomial for use by VPhase.
52	3.3.36	Deskew indicator to provide positive indication that data is deskewed
53	3.3.37	Geolocation of image corners at specified scene elevation (double precision, Earth fixed coordinates (m) or geodetic latté, lon (deg)), where image corners *do* include any zero-fill pixels required to fill the file.
54	3.3.38	Look-up table or equation to convert detected amplitude *A* to backscatter ($\square^0$).
55	3.3.39	Relative and absolute calibration quality parameters.
56	3.3.40	Average scene elevation used to process the scene.
57	3.3.41	Ephemeris Data Per Orbit: For each frame, the spacecraft position and velocity shall be provided for the image start, center, and end.
58	3.5.1	Product Description Documents (draft from) to be delivered to OSU/Vexcel by August 15, 2000.
59	3.5.2	Final Product Description Documents to be delivered to OSU/Vexcel by October 15, 2000.
60	3.5.3	Delivery of test data shall begin by May 1, 2000 and be complete by August 15, 2000.
61	3.5.4	ASF begins STF delivery to OSU by February 1, 2001.
62	3.5.5	ASF begins L1 SLC delivery to OSU by March 1, 2001.
63	3.6	System Testing (TBD basis)
64	4.2.1.	Data will be delivered to OSU approximately on a weekly basis
65	4.3.1	The processing queue will be supplied by BPRC to ASF through the NASA EOSDIS IMS v0 interface
66	4.3.2	Periodically, the RAMS operators may decide that reprocessing of SAR data is required.
67	4.3.3	A new processing run number should be assigned to any reprocessed data.
68	4.4.1	ASF will scan all data acquired during each MAMM prior to processing.
69	4.4.2	ASF will produce SKY Telemetry Format (STF) parameter files of all data acquired during MAMM2/3.
70	5.0.1.1	Ingesting ASF-Produced STF files and generating Processing Requests for ASF.
71	5.0.1.2	RAMS-2 must be able to display coverage (from STF data) in cycle pairs/triplets to permit simultaneous order generation of interferometric pairs/triplets

72	5.0.1.3	Ingest GCPs and VCPs into a database.
73	5.0.1.4	Ingesting the interferometric SLC data as indicated in requirements in section 3.3 above.
74	5.0.1.5	Convert SLC data to 4-look detected amplitude data.
75	5.0.1.6	Block processing new 4-look amplitude data using the RAMS-1 workflow and modified RAMS-1 software.
76	5.0.1.7	VPhase processing to generate coherence images, interferograms, and offsets.
77	5.0.1.8	Grand adjustment of the amplitude data following the current RAMS-1 workflow.
78	5.0.1.9	Cloning the mission, producing a parallel mission with coherence data substituted for amplitude data to produce a coherence mosaic.
79	5.0.1.10	Block processing coherence data using previous block adjustment.
80	5.0.1.11	Tile processing amplitude mosaic.
81	5.0.1.12	Tile processing coherence mosaic using previous grand geometric adjustment.
82	5.0.2.2	Velocity estimation based on interferometric results (unwrapped phase and precise registration results).
83	5.0.2.3	Use of “Velocity Estimator” to conflate velocities.
84	5.0.2.4	Produce ice velocity products.
85	5.1.1	RAMS-2 system must be ready for Phase 1 operations and installed at BPRC by approximately five months after start of MAMM-2 mission.
86	5.1.2	RAMS-2 system must be capable of processing image mosaic products from the MAMM-2 mission within 12 months of start of weekly reception of data (September 2001).
87	5.1.3	RAMS-2 system must be ready for Phase 2 operations and installed at BPRC by approximately 17 months after start of MAMM-2 mission. (Phase 2)
88	5.1.4	RAMS-2 system must be capable of producing Phase 2 products within 16 months from start of phase 2 operations. (Phase 2)
89	5.1.5	The design of RAMS-2 must take into account a 50% operations margin
90	5.1.6	Formation of raw interferometric products must be capable of running concurrently with mosaic processing.
91	5.1.7	Interferometric processor (VPhase) must include tools for automation, batch processing and quality assurance.
92	6.1.1	RAMS-2 shall construct a High-Resolution (25 m) Amplitude Mosaic Tiles
93	6.1.2	RAMS-2 shall construct database DEM tiles
94	6.1.3	RAMS-2 shall construct index tiles and keys
95	6.1.4	RAMS-2 shall construct overview products
96	6.1.5	RAMS-2 shall construct coherence mosaic products
97	6.1.6	RAMS-2 shall construct a Velocity Products (Phase 2)
98	6.1.7	RAMS-2 shall construct a Velocity Mosaic (Phase 2)
99	6.1.8	RAMS-2 shall construct a surface slope mosaic (Phase 2)
100	6.1.9	RAMS-2 shall construct a velocity estimation error mosaic (Phase 2)