

NASA-CR-193445

IN-47-CR
180084
P40

EOS Laser Atmosphere Wind Sounder
(LAWS) Investigation

NASA Contract: NAS5-30751

Final Report
Covering the Period
24 January 1990 to 14 December 1990

Submitted by

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11 March 1991

(NASA-CR-193445) EOS LASER
ATMOSPHERE WIND SOUNDER (LAWS)
INVESTIGATION Final Report, 24 Jan.
- 14 Dec. 1990 (Simpson Weather
Associates) 40 p

N94-17525

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A. Performance

The primary purpose of this "Definition Phase" contract is to begin the preparation of a detailed Execution/Operations Plan that is consistent with the schedule of LAWS milestones and the updated data product definitions. This process has involved attending meetings, presenting papers, conducting preliminary studies and providing a draft of the Execution Phase Plan for the LAWS Science Team Leader. Our contract outlines several ongoing responsibilities to be met over the next 10-15 years of the EOS program. A review of those responsibilities and our related activities follows:

1. Attend Team Member meetings

This team member attended the August Science Team meeting in Boulder, CO and made the following presentations:

- Report from the LAWS Simulation Committee
- Optimal Scanning Patterns in Partly Cloudy Regions
- Call for an Airborne LAWS Research Facility

2. Support EOS Project with science related activities

Given that LAWS has no space-based heritage, simulation studies are required to guide the system design, deployment and operation. The following activities have been partially funded by this contract:

- co-organized (with R. Atlas, GSFC) a LAWS workshop on OSSEs and other simulation studies supporting LAWS design and data assimilation. The workshop was held 27-28 March 1990 at GSFC.
- conducted a series of LAWS performance trades involving scan angle, platform orbit and system baseline parameters (see 8 May 1990 Quarterly Report).
- modified the LAWS Simulation Model to create simulated data bases suited to assimilation by GSFC and FSU global circulation models (see 17 July 1990 and 1 November 1990 Quarterly Reports).
- provided simulated LAWS observations to GSFC (Atlas) and FSU (Krishnamurti) and contributed to two papers for presentation at the Annual AMS meeting in New Orleans, LA (see 1 November 1990 Quarterly Report).

3. Prepare an Execution Phase Plan

Drafts of updated team member study, management and cost plans were written and provided to the LAWS Team Leaders for planning and coordination of team member activities. In addition

to the team member plans, a general proposal for a LAWS Algorithm Development and Evaluation Laboratory was developed and submitted for Science Team approval. These documents were delivered to the LAWS Science Team Leader, Wayman Baker. Copies of the Team Member Plan and the LADEL Appendix to the Team Leader's proposal accompany this final report.

4. Support LAWS and EOSDIS Related Work

From time-to-time there are needs to interact with programs related to LAWS. These include GLOBE, EOSDIS, FIRE, GEWEX and ESA related activities. By necessity, team member involvement is limited by available resources and usually limited to attending meetings. Examples of these interactions, by this team member, on behalf of the LAWS Science Team follow:

- EOSDIS Phase A review meeting, 12-16 February 1990, GSFC.
- GLOBE meeting, 7-8 March 1990, Huntsville, AL.
- EOSDIS Data Panel meeting, 21 March 1990, GSFC.
- EOSDIS prototyping planning meeting, 9-11 May 1990.
- ECMWF meeting to discuss future LAWS OSSEs, 3-5 September 1990, Reading, U.K.
- EOS IWG meeting at LaRC, 8 November 1990.

These activities have exhausted the team member funds provided. In several instances, additional support has been found within other contracts. In other cases, labor and travel costs have been underwritten by the contractor.

APPENDIX A

LAWS ALGORITHM DEVELOPMENT AND EVALUATION LABORATORY
(LADEL)

Wayman Baker
Team Leader

1.0 Introduction

Each Facility Team is required to deliver 3 sequential versions of science data processing software to the Ground System and Operations Project (GS&O) prior to the launch of the Facility instrument(s) and to maintain and update that software for a period of 15 years. The LAWS Facility Team is required to establish a Science Data Processing Software Team that will be responsible for the design, coding, testing, delivery, documentation and maintenance of such software. While science algorithms will be developed by individual Team Members (TMs) for their own research, the team as a whole is required to deliver to the EOSDIS project operational code to produce standard data products for use by the broader community of researchers.

The LAWS Team Leader (TL) has the ultimate responsibility for the LAWS data processing software. Given that LAWS will be the first space-based laser wind sounder ever launched, much of the algorithm development and evaluation will be conducted in a simulated environment. NASA has already developed a simulation capability that is currently being used to evaluate LAWS configurations, orbit selection and impacts on global climate diagnostics and numerical weather forecasts.

It is proposed that the data processing software be the final responsibility of the Team Leader through the implementation of a facility to be referred to as LADEL (LAWS Algorithm Development and Evaluation Laboratory, Fig. 1). LADEL will not only serve EOSDIS directly but will also serve the TMs in their individual research projects. LADEL would serve as a single point of contact for the GS&O project. The overall performance of LADEL would be controlled by the TL and the LAWS Science Data Processing Software Team.

LADEL is composed of two primary segments (Fig. 2) which represent its responsibilities to the design and evaluation of optimum LAWS configurations and sampling as well as to the delivery of fully functioning and tested algorithms to EOSDIS for the production of standard data products. Segment 1 includes all team functions related to the design, coding, listing and documentation of LAWS EOSDIS Science Data Processing Software (SDPS). Segment 2 provides support to the science team members, the EOS project (GSFC) and LAWS Instrument Facility project (MSFC) in developing optimal LAWS configurations, sampling strategies and algorithms. A more detailed description of these two segments is provided in Section 4.0.

2.0 Rationale

The EOS project is committed to a Data Information System (DIS) that will provide the science community with processed science data products on a near-real time schedule immediately after launch of EOS A. Enhanced access to both EOS and non-EOS

data is a primary goal of the EOSDIS design. While wanting to assure sufficient common abilities to achieve functionality, the EOSDIS project also recognizes the need to remain flexible and to accommodate the varied types of data formats and analysis requirements that are represented by a broad spectrum of EOS investigators.

To achieve an acceptable level of functionality the EOS project has established policies and guidelines to promote a common approach to software development by the more than 500 EOS investigators in order to develop portable code and provide similar documentation for all of the Science Data Processing Software. They are also intended to contribute to a higher level of overall software quality, to assure that the software can be easily integrated into the EOS Data and Information System (EOSDIS), and to assure that the software can be maintained for the life of EOS.

Policies are requirements levied by the EOS Ground System and Operations (GS&O) Project on the Science Data Processing Software development process. It is recognized that policies can not be applied blindly and that unique situations will exist that warrant a deviation from or waiver of the policy.

Guidelines are recommendations and suggestions that have proven to be beneficial on software development projects in the past.

Development of standard products, and special products with the potential to become a standard product, are subject to these standards and guidelines. The Facility Instrument (FI)

investigation teams that develop the Science Data Processing Software are referred to as "software teams".

Software for producing a specific data product from an instrument's measurements will be developed by individual team members (TMs) and co-investigators (Co-Is). This software will be integrated on an instrument and discipline basis by the responsible team leader (TL). It is the responsibility of the TLs to develop approaches and schedules that will assure the software meets quality standards and GS&O schedules.

Science Data Processing Software is developed by many of the more than 500 EOS investigators. The software from this diverse and widely distributed population must be integrated and must work together in a standard data production environment. In addition, the software must be maintained for the planned lifetime of the EOS mission of more than 15 years.

The intent of these policies and guidelines is to assure that Science Data Processing Software is developed in a consistent manner so it can be smoothly integrated, operated, and maintained. Software is required to be readable, portable, and reliable. The standard therefore specifies a flexible development methodology with (minimal) required documentation and periodic reviews to provide project-level visibility into the software development activity. It also specifies the use of relevant public standards to assure that the software is portable.

Adhering to these policies and guidelines benefits the EOS program in many ways:

- Facilitates the Peer Review process for algorithms and code;
- Facilitates algorithm and code sharing among scientists;
- Facilitates the integration of the Science Data Processing Software into the EOSDIS environment;
- Facilitates transitions in Science Data Processing Software maintenance responsibilities in later years when the original developers may no longer be available;
- Helps data users understand the processes by which science data are derived;
- Helps EOSDIS operations staff quickly determine whether Science Data Processing Software or support software is responsible for production problems;
- Facilitates algorithm software changes over time as science requirements change during the course of research; and
- Facilitates any software conversions required when EOSDIS computers are replaced.

3.0 LAWS Team Responsibilities

3.1 Investigation and Data Product Definition

The science mission of the EOS will be conducted by three types of investigator teams:

- Facility instrument teams such as LAWS conduct investigations that use one of the facility instruments being developed by the EOS Project. Each facility instrument team consists of a TL, TMs, and Co-Is.
- Instrument teams develop and conduct investigations

on their own instruments. Each such instrument is the responsibility of a PI supported by a number of CO-Is.

- Interdisciplinary teams conduct investigations based on products and data from multiple EOS instruments and other sources. Each interdisciplinary team consists of a single PI and a number of CO-Is.

Data products will be generated by the Data Products Software within and outside the EOSDIS production environment. These data products are characterized as standard or special products, metadata, and browse data.

Standard products are identified as normal project deliverables and are produced at a DAAC for spatially and/or temporally extensive sets of data. Special products are science data products considered part of a specific research investigation and produced at a Science Computing Facility (SCF) for a limited region or time period, or data products not accepted by the project as standard items.

Metadata is descriptive information about a standard or special product. It defines characteristics of the data, and includes other information such as a description of the process used to create the data product, how the product was validated, etc. A browse data set is a reduced-volume version of a standard or special product that maintains the statistical properties of the original.

3.2 Overview of the Software Development Process

Each investigation team is responsible for developing the

software that generates the data products associated with their investigations. To this end, each investigation team shall have an associated FI software team.

3.3 Parallel Software Development

Science Data Processing Software developed by an individual investigator is ultimately integrated into a production environment with Science Data Processing Software developed by other investigators. This integrated production environment has to generate all of the data products required to support the EOS scientific investigations.

Science Data Processing Software comprise two distinct segments. The first segment, the "science algorithm", is the set of routines responsible for performing the mathematical manipulations of the input data to produce the desired output. The second segment, referred to hereafter as the "shell", is the set of routines that controls execution of the science algorithm and provides the interaction with the EOSDIS processing environment (e.g., Input/Output and operator interface). The shell is the infrastructure of the Science Data Processing Software, i.e., everything except the actual science algorithm code.

The development of these two segments is done in parallel. The shell is defined by EOSDIS interface requirements and system design. It also derives its requirements from the interface requirements of the science algorithms. Both segments are designed and implemented to complement each other and EOSDIS to meet the data production performance requirements.

Development of the shell segment follows the development methodology described in the next section. The science algorithm code may be developed according to the individual investigators methodology. However, science algorithm code must satisfy quality standards and the delivery schedules for version 1 through 3.

3.4 Integration and Test Phase

Upon completion of software unit testing, the units are integrated together and then integrated into the target system. Integration of Science Data Processing Software will be conducted in three steps: TM local integration and test, TL software system integration and test, and EOSDIS DAAC central integration and test.

3.4.1 TM Local Integration and Test

As shell and science algorithm code become available from the implementation effort, they are integrated and tested to verify compatibility and to achieve functional interaction forming the subsystem. The subsystem is integrated locally to verify that it satisfies the requirements allocated to it.

To facilitate the integration of the software, the developers produce test data characteristic of the instrument data stream. EOSDIS provides, at the developer's request, simulated platform ancillary data that can be merged with the instrument test data set.

3.4.2 TL Software System Integration and Test

Upon completion of the subsystem integration and test, each TM delivers the shell and science algorithm code to the

responsible TL. The TL integrates the subsystems to form one or more Science Data Processing Software programs. The TL tests the programs using the test data sets provided by the TMs. The integration and test occurs at the TL's home institution or at the TL/PI's designated test site.

3.4.3 EOSDIS DAAC Central Integration and Test

Upon completion of testing at the TL's home institution or designated test site, the team's Science Data Processing Software "system" is ported to the associated DAAC within EOSDIS. The software teams repeat their development tests to assure that their software operates within the EOSDIS environment.

3.5 Sustaining Engineering and Operations

In the Sustaining Engineering and Operations Phase the operational capabilities of the software are sustained, and repairs and upgrades are made within the context of the original concept of the software. In the event that the hardware must be upgraded or modified, testing of the software must be performed to revalidate the integrated software. Sustaining engineering activities are conducted by the software developers.

3.6 Software Management

Each EOS FI team shall have a designated person responsible for the Science Data Processing Software development efforts. This person is referred to as the Data Processing Software Manager (DPSM).

The DPSM shall be responsible for software planning and sizing, resource estimation, monitoring and control, reporting, product assurance, configuration management, software product

deliveries, and for presentations to the GS&O Configuration Control Board (CCB) for software product acceptance and baselining.

Each DSPM shall coordinate all communications concerning the Science Data Processing Software development efforts through the responsible GS&O Software Manager.

Each FI software team shall prepare, maintain, and adhere to a Software Management Plan (SMP).

The SMP shall address the following topics, at a minimum:

- Engineering and integration planning (including planned development methodology and development adaptations);
- Documentation to be produced during each phase;
- Required resources, budgets, and schedules;
- Risk Management planning (identification of development problems);
- Configuration Management planning;
- Quality Assurance planning;
- Software sizing estimates; and
- Approved deviations and waivers.

The DSPM shall submit to the responsible GS&O Software Manager via electronic mail a monthly status report. The monthly status report shall present, at a minimum:

- Significant accomplishments since last report,
- Deliverable items status,
- Schedule performance and status,
- Cost performance and status,
- Product performance,

- Summary of results from internal reviews, if any,
- List of problems with description of causes, overall effect, and recommendations for corrective action,
- List of issues and concerns,
- Summary of open action items,
- Disposition of action items closed during the reporting period,
- Latest estimates of software size, CPU usage, and end-to-end processing time on a specified computer,
- List of planned internal or formal reviews,
- List of actions requested of GSFC management.

Each FI software team shall develop and deliver the following minimum set of documentation during (or at the conclusion of) the specified phase:

<u>Document</u>	<u>Phase</u>
Software Management Plan	Concept Definition
Data Users Guide	Implementation (each delivery)
System Description Document	Implementation (each delivery)
Algorithm Description Document	Implementation (each delivery)
Operator's Guide	Implementation (each delivery)
Version Description	Implementation (each delivery)

Regular peer reviews should be utilized to improve the quality and accuracy of the requirements, design, code and testing performed during the development.

The DPSM shall establish a mechanism for peer review and certification.

4.0 Description of LADEL

As mentioned earlier, LADEL is a LAWS Team facility established by the team leader to support and enhance the development of an optimal LAWS and its related algorithms and to meet the EOS requirements for delivered standard data product software. LADEL is to be the focal point for integrating the contribution of individual team members, the EOS project (GSFC) and the LAWS project (MSFC) into the process of developing, testing, and evaluation of "operational" software that is to be executed in the EOSDIS environment(s). In its relationship to the interests and responsibilities of individual team members, LADEL is designed to:

- provide simulated data sets to TMs,
- communicate EOSDIS software requirements as they relate to LAWS,
- provide access to global simulation test beds for evaluating TM science algorithms,
- convert TM "science or research code" into EOSDIS operational code,
- accept responsibility for the EOS required software management, reviews, documentation, etc.

4.1 Components

LADEL is a computer facility staffed with personnel trained in data/software management, computer systems engineering, numerical modeling, and meteorological data analyses. Initially LADEL will be built around three current capabilities:

- 1) Global OSSE simulation software
- 2) Regional/Engineering simulation software
- 3) EOSDIS prototyping heritage.

4.1.1 Global OSSEs

4.1.2 RLSM

4.1.3 EOSDIS Prototyping at University of Virginia

4.2 Management Plan

LADEL provides the LAWS Science Team with an end-to-end data system test capability to satisfy EOS project requirements.

LADEL and its management is the direct responsibility of the TL.

The TL proposes to delegate the day-to-day management of LADEL to team member already involved with LAWS simulations and EOSDIS design and prototyping. The management structure is shown in Fig. 3.

[EXPAND]

4.3 Facility Requirements

In general, LADEL will share many of the hardware/software and human resources that will already be in place for the designated team members SCF. The budget in Section 5, however, assumes no overlap. The degree of overlap is discussed in Section 5.3.2. In this section, facility requirements are listed.

4.3.1 Computational Requirements

A minimum of 3 workstations on a LAN will be required. The necessary computational capacity is TBD. The system must be able to handle those components of EOSDIS that are needed to develop and test SDPS. Level 1 to Level 4 algorithms will have to be

executable on this system as well.

[EXPAND]

4.3.2 Communications

It is assumed that all communication links will be provided as GFE.

4.3.3 Personnel

At a minimum the following personnel will be required to staff LADEL:

- Manager
(responsibilities)
- 3 staff programmers
- secretary
- numerical modeler
- science data analyst

4.3.4 Travel, Training, Meetings, Reviews

Given the interactive nature of LADEL with the LAWS Science Team, the LAWS Instrument Facility (MSFC) and the EOSDIS project (GSFC), there will be considerable travel and other costs associated with meetings, reviews, and training.

5.0 **Budget**

See attached table.

Figure 1

L A D E L

LAWS ALGORITHM DEVELOPMENT AND
EVALUATION LABORATORY

PURPOSE

- Provide an end-to-end data system test capability for the development and evaluation of LAWS team member algorithms for Level 1a-Level 4 products.
- Provide the capability and the support personnel for insuring EOSDIS functionality of the algorithms prior to integration.
- Provide a laboratory for performing hardware trade studies including instrument configuration, shot management, etc.
- Provide a set of models and simulation software for developing interpretive skills through OSSE's and general circulation simulations.
- Generate simulated LAWS data sets (Levels 0-4) for pre-launch testing for EOSDIS - platform to data archives to science work stations.

Figure 2

LAWS ALGORITHM DEVELOPMENT AND
EVALUATION LABORATORY
(LADEL)

SEGMENT 1

EOSDIS Science Data
Processing Software

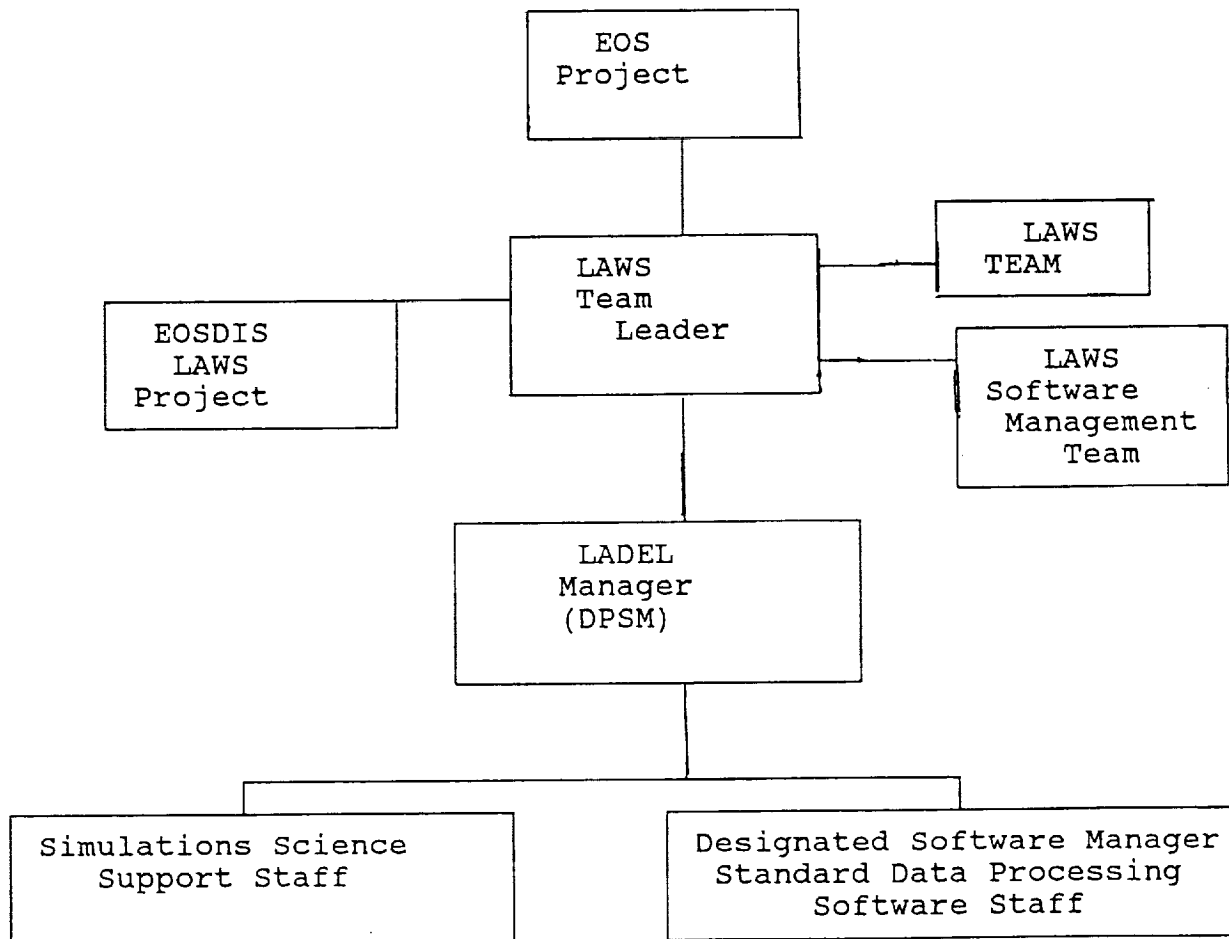
- LAWS Standard Products
- EOSDIS Requirements
- Software Management
- Data User's Guide
- Operator's Guides
- Software Acceptance Tests
- Code Optimization
- Support of Special Product Development

SEGMENT 2

Simulations and Science
Algorithm Evaluation

- Global OSSEs
- Regional OSSEs
- Data Product Definition
- LAWS Performance Evaluation
- Pre-launch Sampling Management Simulation
- Post-launch Sampling Reprogramming
- Simulated Level 1 - 4 products
- GLOBE Data Incorporation

Figure 3
LADEL
Management Structure



Facility Team Member

A Proposal to
The National Aeronautics and Space Administration
Earth Observing System

for

LAWS Sampling Strategies and Wind Computation
Algorithms - Storm-Top Divergence Studies

VOLUME I

Investigation and Technical Plan
Data Plan
Computer Facilities Plan
Management Plan

for

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Submittal Date: 30 April 1991

Starting Date: 1 October 1992

Funding for Team Member: Initial Annual:
11 Year Total*:

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I. PREFACE

1. Abstract

The proposed Lidar Atmospheric Wind Sounder (LAWS) will provide the geophysical research and operations communities with the first space-based set of directly measured clear-line-of-sight winds on a global scale. These LAWS winds combined with other EOS instrument measurements of moisture and temperature will allow the advection and divergence of moisture, mass and momentum to be computed over regions of the globe currently unobserved with regards to tropospheric winds. The impacts of such an observation on basic understanding of the biosphere and the subsequent forecasting of global atmospheric and oceanic phenomena will undoubtedly be greater than any impact that can be assessed through simulations today.

LAWS will measure the winds in a manner that is unique among all current wind sensing technologies. Although similar to Doppler radar in its principles of wind detection, the lidar's sample frequency, volumes and spatial distribution require unique approaches to sampling strategies and wind computation algorithms. This team member proposal addresses both of the sampling and wind computation issues and outlines a work plan that builds upon current efforts by the PI to develop algorithms that could be used to generate Level 1 and Level 2 data sets for EOS.

Atmospheric aerosols, very thin cirrus, and cloud tops will provide the backscatter for Doppler lidar wind measurements. The global distribution of backscatter is currently assessed by the GLOBE so that the facility team will have a rational basis for instrument design specifications. This proposer has participated in the backscatter survey studies and will use the results in simulating LAWS performance as well as in conducting additional studies to demonstrate the synergisms between several remote wind sensing techniques -- e.g., cloud tracked, water vapor tracked and scatterometer (STICKSCAT) winds and temperature sounders (AIRS).

During the pre-launch period, emphasis will be placed upon the following issues which are critical to the final configuration/operation modes for LAWS and to the algorithm for producing Level 1 and 2 data products:

- 1) shot management objectives and shot control requirements;
- 2) line-of-sight local context processing for a Level 1 product (includes data extraction in the PBL, cloud tops and in partly cloudy scenes);

- 3) model independent Level 2, horizontal wind vector product.

After LAWS is launched, the sampling and wind computation (Level 2B) algorithms will be evaluated using ground-based wind measuring facilities as well as numerical models. LAWS data will be combined with other remote wind sensing data sets in addition to data from ground-based networks to study the relationship of upper tropospheric divergence/vorticity fields with storm dynamics and precipitation.

II. INVESTIGATION AND TECHNICAL PLAN

1.0 Introduction

In Section II the proposed objectives are spelled out and the background for the proposed contribution to the LAWS facility team is presented along with the technical plan for achieving the objectives. Most of the planning detail is focused upon the Definition Phase since, in the case of LAWS, the evaluation strategies and data application will depend upon how the instrument concept matures over the next few years.

The application of LAWS data to relating the upper tropospheric divergence near convective storms to other storm attributes will occur in the post-launch phase of the Execution/Operations (E/O) Phase. Pre-launch efforts will be directed mainly towards selecting the appropriate models to be used in that study and using limited data sets collected with ground-based and perhaps airborne Doppler lidar systems.

2.0 Execution Phase Objectives

2.1 Pre-launch Objectives

As a member of the LAWS Facility Team the PI proposes to coordinate and participate in instrument design/application activities associated with:

- a) development of adaptive and non-adaptive space-based lidar sampling strategies to optimize the operation of a "shot-limited lifetime" facility;
- b) development and evaluation of horizontal wind computation algorithms for Level 2 ungridded data products;
- c) definition of potential formats for the general archiving of Levels 1, 2 and 3 LAWS data in the EOS Data and Information System (EOSDIS);
- d) development of a Cloud/Aerosol Wind System (CLAWS) that will capitalize on the synergistic relationships

between cloud (and water vapor) tracked winds and LAWS; and

- e) investigation of the combining of scatterometer (SCATT) derived winds over the oceans with the more directly measured LAWS winds [work with R. Brown].

2.2 Post-launch Instrument and Science Objectives

After the launch of LAWS, the primary objectives will be:

- a) evaluation of the LAWS wind computation algorithms by use of ground-based calibration facilities and numerical models;
- b) providing user data to the EOSDIS and meeting the obligations of facility team members as outlined in Part 1 of the EOS BIP;
- c) use of the LAWS and other remotely sensed wind data (cloud tracked and scatterometer) to study the observable relationships between lower tropospheric convergence, rainfall, and upper tropospheric divergence in the presence of meso- β and larger scale convective storm systems -- in particular tropical cyclones [work with J. Molinaro and T. Miller].

3.1 Background

Unlike other designated NASA research facility instruments such as MODIS, HIRIS and SAR, LAWS has no heritage of space-based operations. Never before has a laser been flown in space to measure aerosol backscatter and the clear-line-of-sight (CLOS) component of the winds. Expectations of success are based upon ground-based (DiMarzio et al., 1979; Post et al., 1978; Emmitt, 1984; Rothermel et al., 1985) and airborne (Bilbro et al., 1984, 1986; Emmitt, 1985; Schweissow et al., 1976; Vaughan and Woodfield, 1983) demonstrations of lidar wind detection capabilities as well as computer simulations (Arnold et al., 1985; Atlas et al., 1985; Emmitt and Houston, 1986; Huffaker, 1978; Menzies, 1986) of the likely performance of a space-based system (Fig. 1). There is, therefore, a particularly strong charge to the LAWS facility team to evaluate, in depth, all aspects of a space-based wind sensor prior to the final design and construction of the instrument.

LAWS, like its predecessor concept WINDSAT, has been generally driven by the meteorological community's desire to get wind profiles over the entire globe at "radiosonde" resolutions (i.e., ≈ 300 km spacing). While synoptic scale flow features are targeted for resolution, phenomena with length scales less than a few hundred kilometers will not only influence the wind computation for the larger scales but may also be resolvable with proper algorithms for combining clear-line-of-sight (CLOS)

components to compute horizontal winds (Emmitt, 1984, 1985, 1986, 1987, 1988). Much of the following proposed effort builds on this earlier and current work on LAWS simulations and algorithm development.

It is not appropriate for this proposal to go into any detail on the principles of lidar operation. Much of that detail is contained in the LAWS Instrument Panel Report to which the proposer made several contributions. However, several considerations of the LAWS concept need to be reviewed to provide background for the proposed facility team effort. These considerations are stated as follows:

- LAWS will obtain direct measurements of the line-of-sight (LOS) component of the mean size-weighted motion vector of the aerosols within the sample volume (length $\approx$ 500 m; diameter $\approx$ 10 m).
- Correct height assignment of the LOS component depends upon the homogeneity of the concentrations and size distributions of the distributed targets -- incorrect height assignment can lead to considerable wind velocity computation errors when LOS measurements are combined to compute a horizontal wind vector (e.g., in the marine boundary layer or near convoluted Planetary Boundary Layer (PBL) inversions).
- While the accuracy of the LOS measurement may be primarily a function of the Signal-to-Noise Ratio (SNR) in the backscattered information, the representativeness (or lack thereof) of each LOS provides a source of "error" in the horizontal wind computation -- the magnitude of this error is directly related to the spatial distribution of the lidar shots.
- The lifetime of a pulsed CO₂ lidar is a major issue in the LAWS program. Lifetime is expressed in terms of numbers ($\approx 10^8$ - 10^9) of pulses or shots. Shot management can both minimize sampling errors as well as extend the service lifetime of a LAWS instrument.
- Overall impact of LAWS on science will depend directly upon the availability of aerosols and CLOSs. Thus cloud and aerosol climatologies are needed for LAWS pre-launch performance studies.

Several of the considerations listed above have already been given preliminary attention by the proposer through a series of NASA funded studies regarding the influence of mesoscale coherent features on the computation of LAWS wind profiles. These studies have produced two preliminary versions of a Shot Management Algorithm (SMA) and a Multi-Pair Algorithm (MPA).

3.1.1 Shot Management Algorithm (SMA)

The development of the SMA was begun to optimize the distribution of shots to 1) achieve better wind estimates and 2) to extend laser lifetimes (Emmitt, 1985). Initial versions of the SMA optimize lidar shot distributions by choosing optimum combinations of lidar scan rate and pulse repetition frequency. It is proposed to improve on this first order optimization by looking at asynchronous pulse control.

The second task of the SMA is to suppress shots in regions of the globe where the information potential is low (e.g., over the poles every 90 minutes) and obtain higher than normal shot density in areas of greater interest (e.g., tropical cyclone). Preliminary computations suggest that, using the criteria of constant temporal/spatial wind information density, an extension of laser lifetime by a factor of 1.5-2.0 could be realized. Further evaluation of this level of shot management will be conducted during the Execution Phase.

3.1.2 Multi-Pair Algorithm

In early feasibility studies performed by NOAA (Huffaker et al., 1978), all the forward and aft shots into 300 km x 300 km x 1 km volumes were combined using a least squares approach which assumed that variations in the LOS measurements within that volume were spatially independent and that the vertical velocity could be assumed to be zero or very small compared to the horizontal wind components. In areas with significant wind structure both in the vertical and horizontal planes these assumptions do not hold. Emmitt (1985) proposed a more general approach that presumed no a priori averaging volume and would work better than the least squares approach in regions of coherent wind features having length scales $\approx$ 100 km. This approach is referred to as the Multi-Pair Algorithm (MPA). More detail on the MPA and its comparison with the LS approach are in NASA progress reports (Emmitt, 1985, 1986, 1987).

The application of the MPA to a global wind data set is illustrated in Figs. 3, 4 and 5. The regions of largest errors (Fig. 5) are along the outer edge of the scan domain as well as in the area of the subsatellite ground track. However, most of the scan domain exhibits small speed errors with some spatially coherent biases in the cross and along track component errors.

Although the MPA has reduced the wind measurement errors, there remain several areas that need investigation and perhaps improvement. First, since the spatial separations between members of a shot pair may be commensurate with spatial variation in backscatter structures, there could be another source of error unaccounted for in the current wind computation algorithm

evaluation. Second, the value of using the LOS measurements without pairing should be considered. That is, the LOS data could be used to regress against a model wind field based upon other inputs such as ground-based observation, cloud tracked winds, computed geostrophic winds, etc. In fact, the LOS data in the error prone regions of the lidar scan domain could be used to regress against wind vectors interpolated from the areas with good MPA horizontal wind estimates.

3.1.3 LAWS System Models and OSSEs

The SMA and MPA described above are currently being used in SWA's LAWS System Model (LSM) and in Observing System Simulation Experiments (OSSEs) conducted at GSFC. The purpose of the OSSE's is to assess the impact that LAWS might have on global scale forecasts. Earlier OSSEs (Atlas et al., 1985), which did not consider the cloud limited sampling of LAWS nor the wind speed estimate biases, showed substantial improvement in forecast skill on the average for the southern hemisphere and occasionally in the northern hemisphere. OSSE's currently being conducted include both the cloud and speed bias features of LAWS profiles. Emmitt and Wood (1988) have recently begun looking at how to include the contributions of subvisible cirrus to the LAWS detectable wind fields. The PI will continue to work closely with both the LAWS facility team as well as researchers in the International Satellite Cloud Climatology Programs (ISCCP) to document the global coverage of thin cirrus.

3.1.4 Storm-top Circulations

Much of what we know about the circulations associated with significant storms is based upon surface networks of anemometers, aircraft mounted probes, Doppler radars and special rawinsonde releases. The surface networks provide us with quantifiable evidence of downwind vertical mass transports. The strengths of these surface flows have been related to convective storm attributes such as precipitation (Ulanski and Garstang, 1978; Watson and Blanchard, 1984).

Aircraft have given us detailed information on the turbulence and vertical velocity features inside and outside of storms. The aircraft measurements have provided links between surface measurements below the clouds and Doppler radar wind measurements within clouds and the winds external to clouds in the middle troposphere where no other observational techniques (except for recently developed microwave sounders) work.

EOS instruments will provide an on-top perspective of storms. Considerable advances have been made in relating storm-top radiative properties to the dynamics and precipitation of the convective system (Barrett and Martin, 1981; Wilheit et al., 1982; Adler, 1988; Spencer et al., 1983). Another approach to inferring storm-dynamic/precipitation physics is to use satellite observed anvil growth rates (need ref.). LAWS will provide an

additional measure of storm-top dynamics with the direct measurement of winds. With present LAWS design criteria the minimum spacing between wind observations will be ≈ 50 km. This resolution will limit the study to meso- β systems unless the instrument is modified to permit a higher resolution mode of sampling. It is proposed that in the post-launch phase the LAWS data will be combined with other remotely sensed data for several case studies to look for useful relationships between the upper tropospheric divergence and vorticity fields and other convective storm parameters (e.g., vertical velocities, mass transport, water conversion rates, etc.).

4.0 Technical Plan

In achieving the stated objectives, frequent interactions and cooperative activities with other facility team members are anticipated. Close coordination between the hardware engineering studies and the data acquisition and processing algorithm development will be critical to the evolution of an optimum final LAWS design. The following outline of the proposed technical plan takes such interaction as a given and does not deal in detail with any anticipated parallel studies.

4.1 General Design

The proposed work for the execution phase is partitioned into two phases:

- 1) Execution/Operational Phase -- Pre-launch. During this period, the Level 1 and Level 2 data algorithms will be finalized and implemented in the EOSDIS; scanner/pulse design and control algorithms will be firmed; and back-scatter data will be used in detailed simulation studies to assess potential impacts on instrument design as well as geophysical research.
- 2) Execution/Operations Phase -- Post-launch. LAWS performance will be evaluated using ground-based wind measuring facilities and the numerical models used during the pre-launch simulations. LAWS data will also be used to conduct the proposed scientific research which involves the incorporation of several wind sensing systems.

Below, each objective listed in Section 2.1 is expanded and a plan for reaching that objective is presented.

4.2 Optimum Sampling Patterns

The current LAWS design calls for a fixed scale angle (value TBD), fixed scan rate (value TBD) and asynchronous triggering of the laser pulse. With this configuration, shot management is limited to the scheduling of the pulses.

The selection of shot management strategies for evaluation will be based upon discussions within the facility team and with other EOS teams involved with scanning instruments.

The selected management options will be programmed into existing SWA LAWS simulation models. The models will then be run on control wind data to produce:

- a) shot distribution maps
- b) velocity vector maps
- c) error vector maps
- d) an overall performance index (global coverage).

Sampling pattern evaluation will be carried into the pre-launch portion of the E/O Phase for further evaluation in OSSE's and refinement.

4.3 Shot Management

During the Definition Phase, the facility team has been provided with detailed information regarding the potential advantages of shot suppression and "bursting" -- i.e., providing higher than average shot density in regions of special interest. The primary advantages to shot management are increased lidar lifetime and increased information where it is needed. The primary disadvantage, initial cost, may be offset by the increased "time-in-service".

Several shot management options will be identified and preliminary evaluation performed during the Execution Phase using currently available LAWS simulation models. This work will be done in parallel with the optimum pattern and completed in the same time frame.

In the pre-launch phase, the selected shot management option will be further evaluated and operational software developed.

4.4. Wind Computation Algorithm

Most of the Execution Phase effort will focus upon operational shot management strategies. However, since the accuracy of the LAWS wind measurements will be a major consideration in that selection, a means of computing the horizontal wind from the LOS components must be defined for use in the simulations. It is proposed that several algorithms be selected and used during the Execution Phase with more advanced development scheduled for the post-launch portion of the E/O Phase. The selection of standard wind computation algorithms for the Execution Phase will be made by the facility team.

Refinement of the current MPA or development of new wind computation algorithms will be done during the pre-launch portion of the E/O Phase. Technical papers and conference presentations will result from this effort.

4.5 Definition of Level 1, 2, and 3 Data for EOSDIS

It is expected that the details of those products will undergo revisions as the instrument concept matures. The current product definitions are summarized in a document entitled "LAWS Data System Preliminary Requirements".

4.6 Development of CLAWS

The development of a hybrid cloud/aerosol wind system (CLAWS) consists of cloud tracked winds from GOES E/W and LAWS is scheduled for the pre-launch period of the E/O Phase. The application of CLAWS to the science objectives of studying the storm-top circulation will be a post-launch task.

Cloud imagery from GOES E/W archives will be processed on the McIDAS system at MSFC by SWA personnel or on a PC-McIDAS located in Charlottesville, VA. Cloud tracked winds will be obtained using standard techniques. These winds would then be combined with simulated LAWS winds using the LAWS Simulation Model (LSM) in residence at MSFC and/or at SWA.

Critical issues to be addressed will be:

- 1) height assignment of cloud track winds using LAWS based information;
- 2) reconciliation of differences at boundaries of cloud track wind zones and aerosol wind (LAWS) zones; and
- 3) availability of semi-transparent cirrus for middle to upper tropospheric wind data.

4.7 Scatterometer and LAWS Winds

A scatterometer (STICKSCAT) similar to the one on SEASAT is scheduled to fly as part of EOS. The scatterometer provides a measure of the winds near the ocean surface by inferring wind stress from the backscatter off the capillary waves on the wave surface. LAWS may not obtain reliable wind speed data in the lowest few 10's of meters near the ocean surface because of uncertainties in large sea salt concentrations and distributions. Consideration of combining LAWS and SCATT data may lead to special LAWS signal processing algorithms that will capitalize on SCATT's good near surface wind speeds and LAWS winds down to the top of the marine salt boundary layer. Use of an airborne downward scanning Doppler lidar will contribute significantly to our ability to interpret winds in this region.

The potential of a SCATT/LAWS approach to winds over the ocean will be assessed by the proposer and R. Brown of the LAWS team. Scatterometer data from the 99 days of SEASAT operations

in 1978 will be used with simulated LAWS winds over a limited study area. The SEASAT data will be obtained from the NOAA archives and/or researchers who can provide processed data sets.

4.8 Post-launch Tasks

The three post-launch tasks identified as objectives in Section 2.2 are:

- 1) evaluation of the LAWS wind computation algorithm using ground-based facilities and numerical models;
- 2) providing user data and services through EOSDIS; and
- 3) using LAWS and other remotely sensed winds to study upper-tropospheric circulations as they relate to storm dynamics.

The methodologies and resource requirements for post-launch evaluation of LAWS will need to be defined during the Definition Phase. It is expected that both ground-based facilities (e.g., surface networks, microwave sounders, rawinsondes, lidars, etc.) and numerical models (e.g., general circulation and regional scale models) will be employed. This proposal covers the participation in all phases of this evaluation but does not cover the costs of the ground-based facilities.

A primary responsibility of the PI will be in providing users of the LAWS data with information on data quality, updates on algorithm modifications, and other obligations outlined in Part I of the EOS AO. This effort is not part of this proposal but is included in the Team Leader proposed for a team facility.

The study of upper tropospheric circulations will be dependent upon the successful development of a LAWS wind computation algorithm that will resolve circulations with scales on the order of 100-500 km.

Assuming that such capability will be available, LAWS data will be used to develop relationships between the magnitude of upper tropospheric divergence and other detectable attributes of the storm systems such as anvil growth rate (GOES), cloud top vertical velocity (GOES + LAWS), precipitation stage (GOES, AMSR, AMSU, TRMM), and subcloud layer circulations (NEXRAD). These data sets will be combined in case studies which may include Mesoscale Convection Complexes (MCC), tropical cyclones, and extratropical cyclones.

III. DATA PLAN

1.0 General Overview for LAWS

The Level 0 data from LAWS is a digitized time series of the line-of-sight signal intensity from the heterodyned detector.

This time series must then be processed (Level 1) to produce an estimate of the LOS component of the wind. It is anticipated that the down-linked data will be the Level 0 digitized signal and that all further processing will be ground based. The exception to this may be some on-board signal processing necessary for managing the lidar shot budget - i.e., shot suppression and timing.

After the LOS components (Level 1) of the wind speed are determined, they can either be used directly to regress against modeled wind fields or be combined through algorithms to produce model independent estimates (Level 2) of the horizontal wind field. This proposal is directed primarily at the task of such wind computation algorithm development and evaluation.

2.0 Data Set Products, Validation and Updating

In the following subsections of this data plan, three data products are considered:

- i) LOS wind components with their associated shot geometries, global locations and signal qualities (Level 1);
- ii) Horizontal wind components (u and v) for TBD areas of averaging (Level 2); and
- iii) LAWS winds and GOES cloud winds (or scatterometer winds) combined to produce hybrid wind data sets (Level 3).

2.1 Input Data Requirements

During the execution and pre-launch phases the LAWS facility team will need access to GOES imagery for input to CLOS and cloud tracking studies, GLOBE backscatter data for use in ongoing Observing System Simulation Experiments, and any current satellite data sets (e.g., AVHRR, TOVS, GOES/VAS) that may provide global and/or mesoscale distribution of thin cirrus clouds. The NOAA series of polar orbiters are expected to provide the most appropriate set of CLOS and cirrus data since those instruments have nearly the same perspective in time and space as will the LAWS (assuming LAWS is launched on a polar platform).

It is proposed that the PI will access the data sets mentioned above through a PC version of the McIDAS system. Such a version is currently operational and would be used with either SPAN or SURANET. It is also possible that some of the Pathfinder data sets could be used for these pre-launch studies.

In the pre-launch portion of the E/O phase there will be a need for some ground-based or other form of "truth" for demonstrations of lidar system performance and algorithm

validity. Although lidar comparisons have already been done using tower anemometers, rawinsondes, radars and aircraft, it will be desirable to have the facility to evaluate various versions of LAWS as it goes through its design and pre-launch testing. The form of this facility has been addressed by the facility team during the definition phase. Presently, it is anticipated that an airborne Doppler lidar system will be available in the 1993-94 time frame.

After LAWS is launched, ground-truthing will be carried out using the facilities developed for LAWS pre-launch testing as well as all other wind data available from conventional observation systems such as rawinsondes, surface networks and sounders (microwave, lidar, etc.).

2.2 Algorithms

A primary activity by the PI during the execution phase will be the development of algorithms for scheduling lidar samples (shot management), processing the digitized LOS Doppler information and combining the LOS's to obtain estimates of the horizontal components of the wind. Current and new algorithms will be evaluated using computer models of the LAWS system and atmospheric models such as GCMs and regional scale models.

Pre-launch algorithm validation will be accomplished primarily through computer simulation and ground-based lidar scanning simulation. Priority would be given to those algorithms necessary to programming the LAWS scanning and pulse control systems. The level of control, addressed during the definition phase, may range from fixed to real-time controllable based upon on-board data processing or up-linked commands.

Computer requirements will be significant for the OSSE's owing to their use of GCM and global data sets. Currently the OSSE's are being run on the GSFC CRAY YMP. NASA/MSFC's CRAY XMP would also be adequate for any future algorithm evaluation.

Algorithm evaluation will be a primary task of the facility team after LAWS is launched. Depending upon what the team decides will be the Level 2 product, it is likely that there will be several processing options to meet user's needs. For example, there may be a first order set of soundings that would provide the highest spatial resolution for research purposes and a second order set of soundings involving lower FARs for operational needs.

2.3 Output Products

All LAWS algorithms and data outputs will conform to the standardized scientific formats to be specified by IWG and be submitted to EOSDIS as required.

2.4 Distribution Plan

While the distribution of LAWS data would be through EOSDIS and its DAACs, the data processing, validation and user servicing may be done under contract. Distribution would be done both in real-time to the operational users and also from the data archives for other users.

2.5 Definitions of User Requirements

During the definition phase, the LAWS facility solicited potential user requirements regarding wind (and backscatter) data averaging, accuracy, and format. It is expected that the LAWS team will continue to interact with critical user groups and make changes to the data definition and distribution formats.

It is further expected that there will be significant interaction between the LAWS team and other teams with instruments that measure quantities that are transported by the winds (e.g., water vapor, ozone, CO₂, etc.). This interaction should be initiated as soon as possible since sampling overlays from different instruments presents a major input to both instrument hardware design and operations.

2.6 EOSDIS Support

During the Executive Phase, the algorithm development will require significant EOSDIS support. That support must be in the form of training, data manipulation tools, programming standards, simulation environments and the necessary hardware and communication networks.

IV. MANAGEMENT PLAN

1.0 Team Member Responsibilities

G.D. Emmitt proposes to have a primary responsibility on the LAWS facility team for the Levels 1 and 2 (especially Level 2) processing algorithm development, evaluation and implementation. Contributions to the team would build upon his experience already gained from membership on the LAWS Instrument Panel, EOSDIS Science Advisory Panel and research on lidar shot management and wind computation algorithms over the last 8 years. Furthermore, the PI would direct and participate in the proposed scientific study of upper tropospheric cloud related circulations and would publish the results in refereed journals.

2.0 SWA General Management Structure

Within SWA, the management structure to support the proposed work is illustrated in Fig. 6. Each position's responsibilities

are outlined as follows:

PROJECT DIRECTOR - Overall responsibility for the execution of the proposed work including attending facility team meetings throughout the year.

ASSISTANT DIRECTOR - Day-to-day management of the project components in a manner that will assure the meeting of the work schedules. This is a full time position with the responsible person also serving as Data Quality Control Manager.

ATMOSPHERIC MODELING - Responsible for all in-house modeling - e.g., lidar system, radiative transfer, turbulence, mesoscale, etc. This person is also responsible for interfacing with LAWS modeling efforts being conducted elsewhere (e.g., OSSEs at GSFC or MSFC).

ALGORITHM DEVELOPMENT/EVALUATION - Responsible for the development and evaluation of algorithms for shot management, LOS signal processing and horizontal wind computation. Evaluation tasks include both modeled performance and ground-truthing.

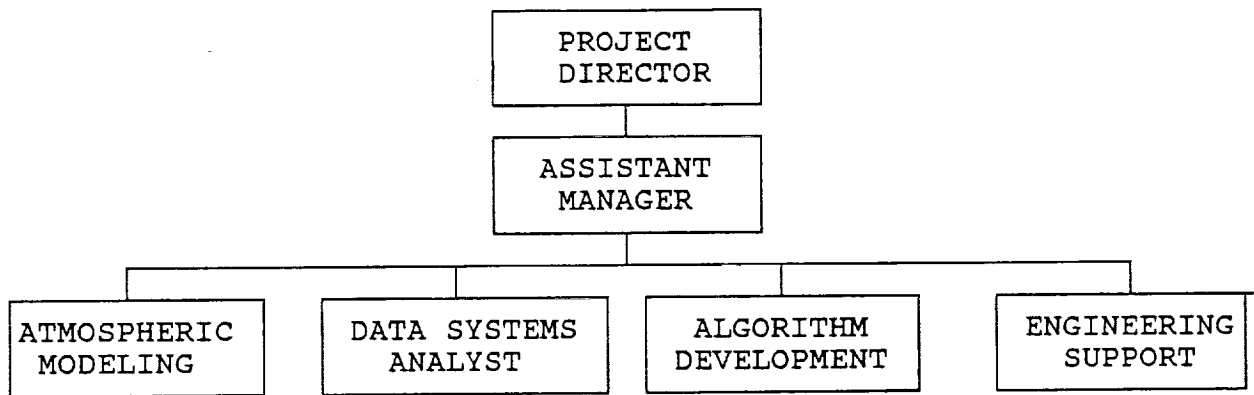
ENGINEER SUPPORT - This category of tasks covers all support obtained via consultants. It is expected that several consultants will be used in the area of optimizing data processing algorithm.

3.0 The Science Management Plan

The management of the science will follow the same lines of responsibility as is shown for the general management structure with the exception of engineering support.

4.0 The Milestone Matrix, Execution Phase

The proposed Execution Phase effort will be managed in a manner so as to adhere to the milestone matrix presented in the EOS AO documents and reproduced below with some additions.



IV. COMPUTER FACILITIES PLAN

1.0 General Computing Requirements

To define our computational requirements we break our execution phase activities into four types:

- 1) global scale OSSEs;
- 2) regional scale modeling and data assimilation;
- 3) Level 1 and 2 algorithm development for use in proposed post-launch studies - includes interfacing with EOSDIS;
- 4) Processing and manipulating large data files (satellite images, radar scans, NOAA/ECMWF analyses, etc.) in support of 2 and 3 above.

Given our current access to both GSFC's IBM and CDC and CRAY computer and MSFC's Cray XMP, we are assuming that all global simulations can be performed on those systems. The research interests of Bob Atlas, Tim Miller and T. Krishnamurti make the use of these common facilities even more imperative. The remaining three types of computing activities should be conducted using the team members on-site SCF.

2.0 Hardware Requirements

The use of regional scale models such as LAMPS, MESO, or _____, is going to be limited to non-real time simulations in support of algorithm development and LAWS based research. A workstation would be adequate for this activity.

Development of Level 1 and 2 algorithm can be accomplished with desktop PC-286s. However, to assure compatibility and operability of those algorithms in the EOSDIS environment, the operating system should be unix or posix. Again, a workstation is more than adequate for this activity.

Given that LAWS will be providing one of several wind measurements, we will be spending much effort in combining the LAWS data with radar data, cloud tracked winds, scatterometer winds, conventional winds, SWIRLS, etc. This will be the most demanding computational activity. This activity is the essence of the interdisciplinary research encouraged by the EOS program and around which the EOSDIS is being designed.

Prior to the TM receiving the hardware, and software required for EOSDIS interfacing, much of the type 4 activities will be carried out using the McIDAS software. For this we will need a PC-486 with the OS/2 operational system plus peripherals listed in the cost proposal. However, when the EOSDIS system is ready for interfacing (1994?), we intend to slowly transfer many

of these data display and analyses activities over to an EOSDIS workstation environment.

In summary, team member's proposed EOS program and scientific activities can be supported with:

- 1) access to GSFC and MSFC's mainframe computers;
- 2) a PC-486/OS/2 computer and peripherals; and
- 3) workstations equipped for optimal interfacing with EOSDIS.

2.1 Peripherals

In addition to the computational requirements above, we will need the following related hardware capabilities:

- 1) 10 Gbyte storage medium;
- 2) 6250 magnetic tape drive;
- 3) upgrade on our Tektronix color printer;
- 4) 9600 baud modem; and
- 5) several utility laser printers.

3.0 Software

At this point in time it is very difficult to be specific on our CAS or EOSDIS provided software needs. In addition to the generally available software packages such as windows, graphics, etc., the proposed research demands highly interactive image and gridded data processing, display and recording. It is anticipated that initially this demand will be met by NASA provided McIDAS capability and eventually be provided by EOSDIS.

4.0 Communications

Currently we are linked to GSFC and MSFC via 2400 baud dial-up modems. This is a major limitation to our abilities to develop optimal data product algorithm for use in global OSSEs. Also, the transmission of images and large gridded data sets over the EOSDIS network will require at least 128M baud capability within the next 3-5 years. Until that capability is provided, we can operate with a 9600 baud dial-up without any dedicated communication line.



Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle EOS Laser Atmosphere Wind Sounder (LAWS) Investigation		5. Report Date 3/11/91	
		6. Performing Organization Code	
7. Author(s) George D. Emmitt		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address Simpson Weather Associates, Inc. 809 E. Jefferson Street Charlottesville, VA 22902		11. Contract or Grant No. NAS5-30751	
		13. Type of Report and Period Covered Final Rpt. 1st year's effort (1/24-12/14/90)	
12. Sponsoring Agency Name and Address NASA/GSFC Greenbelt Road Greenbelt, MD		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract Final report covering 1st year's effort.			
17. Key Words (Suggested by Author(s))		18. Distribution Statement UNCLASSIFIED - UNLIMITED	
19. Security Classif. (of this report) N/A	20. Security Classif. (of this page) N/A	21. No. of pages 40	22. Price N/A