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Approach to Sounding on the VAS Processor

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ABSTRACT

This document outlines the key features of the "sounding software laboratory" being installed on the VAS Processor at NASA/GSFC. It emphasizes the support data and personal guidance that a meteorological researcher will have to provide to attune a physically-modeled VAS sounding to his experiment. The fundamental aim of the sounding-support effort is to provide a research-and-development system which makes use of: radiation transfer models based upon laboratory data, analytic inversion schemes, human guidance for quality control, statistically conditioned retrieval methods, and current ancillary data.

APPROACH TO SOUNDING ON THE VAS PROCESSOR

Chapter 1

INTRODUCTION

1.1 OVERVIEW

This document is a non-mathematical description of the design features being used for satellite-sounding estimates on the VAS (VISSR Atmospheric Sounder) Processor at NASA/GSFC. It acquaints the user with the "software sounding laboratory" viewpoint that he must adopt to make the best possible VAS soundings from the observed radiances. In particular, the meteorological user is urged to supply the VAS Processor with case study data before an experiment (to precondition the retrievals) and local meteorological data during the experiment (to initialize the retrievals). The paragraphs follow a rough project design – they state the user requirements, the general approach, and the technical methods for that approach:

- The user's view
  - Key features (utilities and science functions)
  - Overview (input/output)
- Software laboratory approach
  - General scientific support
  - Estimation theory
  - Experimental soundings
  - Contrast to operational soundings
- Techniques for modeled sounding (algorithms and datasets)
  - Radiances and retrievals
  - Conditioning procedures
  - Ancillary data
  - Human interaction.

Details of the science algorithms can be found in the detailed planning[1] and operational[2] documentation for the VAS Processor.

1.2 KEY USER FEATURES

As a research and development tool for satellite sounding, the VAS Processor interacts with the user every step of the way from raw radiances to finished profiles. The key features of this interactive system are:

- Quick-service data/image utility support, which helps to control the flow of processing and review the quality of the results.
- Menu-driven, modularized science functions, which control the information content of the results, using radiation transfer models and ancillary meteorological data to remove the unnecessary uncertainties from the VAS soundings.

In order to estimate temperature and moisture profiles from the VAS infrared radiances, it is necessary for the user to work within the functional step-by-step approach that has been adopted on the VAS Processor:

- The choice and ordering of the steps is entirely the user's responsibility.
- Many of the existing steps require the user to supply ancillary data, such as a first guess and/or statistical expectations.
- Many of the existing steps allow the user to pick and/or tune special options.
- All of the steps expect the user to keep track of the names of his own datasets with the aid of the VAS catalog.
- Many steps allow the user to review the data, so he can be responsible for his own quality control.
- User-specific algorithms can be programmed into the menus rather easily.

The interested reader may consult several documents describing the broader scope of the VAS Demonstration[3] and the specific details of the VAS Processor, such as: algorithms on the science function menus,[4] operational usage,[5] supporting datasets,[6] potential data products,[7] software[8] development,[9] image usage,[10] resident case studies,[11] the preparation of meteorological data,[12] software project organization,[13] and use of[14] the system software.[15]

1.2.1 Data/Image Utilities

The user can pause at any time to review data on the VAS Processor. Science processing is suspended (keeping one's place), and data/image management functions are called to:

- Catalog and/or archive/retrieve datasets by name, type or group.
- Convert slices of multi-dimensional datasets into grey-level images for color coding, contouring, hardcopy, and/or overlay.
- XY-plot lists of values from VAS science datasets.
- Review and/or edit any value on a dataset for quality control.

These automatic utilities make experimentation, quality control and personalized dataset control/documentation a manageable task.[16]

1.2.2 Science Functions (Computer Tasks)

Each scientific process can be thought of as an algebraic function (computer task) in the form:

$$z, \ldots = F(x,y, \ldots ; a,b, \ldots ; \text{options}),$$

which calculates the dependent variables (output datasets) from the independent variables (input datasets), using some coefficients (conditioning data) and/or user options (yes or no decisions).

Each function has a name on a menu of similar functions, which are in turn grouped into categories on a higher menu called the Principal Science Functions.[17]

Processing VAS data then consists of stepping through a chain of such science functions as the user's needs and the data quality allow. Each selected step prompts the user to name the inputs, the options/coefficients, and the outputs. The entire chain of interactive functions becomes "The VAS Sounding Method" for that particular case. The VAS Processor could provide a "captain's log" of the science menus executed by the user as he goes, making a written record of the sequence of steps and the supporting data he used to get his sounding.

There is no "best VAS sounding method," because each chain of steps is attuned by the human decisions, by the available datasets, by the order of processing, and by the algorithms used. In addition, there is an analytic indeterminacy to any remote sounding due to the instrumental limitations, inherent ambiguity of passive remote sensing, and simplifications of the radiative models. The "best" VAS soundings reduce the unnecessary uncertainties for each case by using the best current information one can get, the best previous experience one can codify, and the best guidance one can provide.

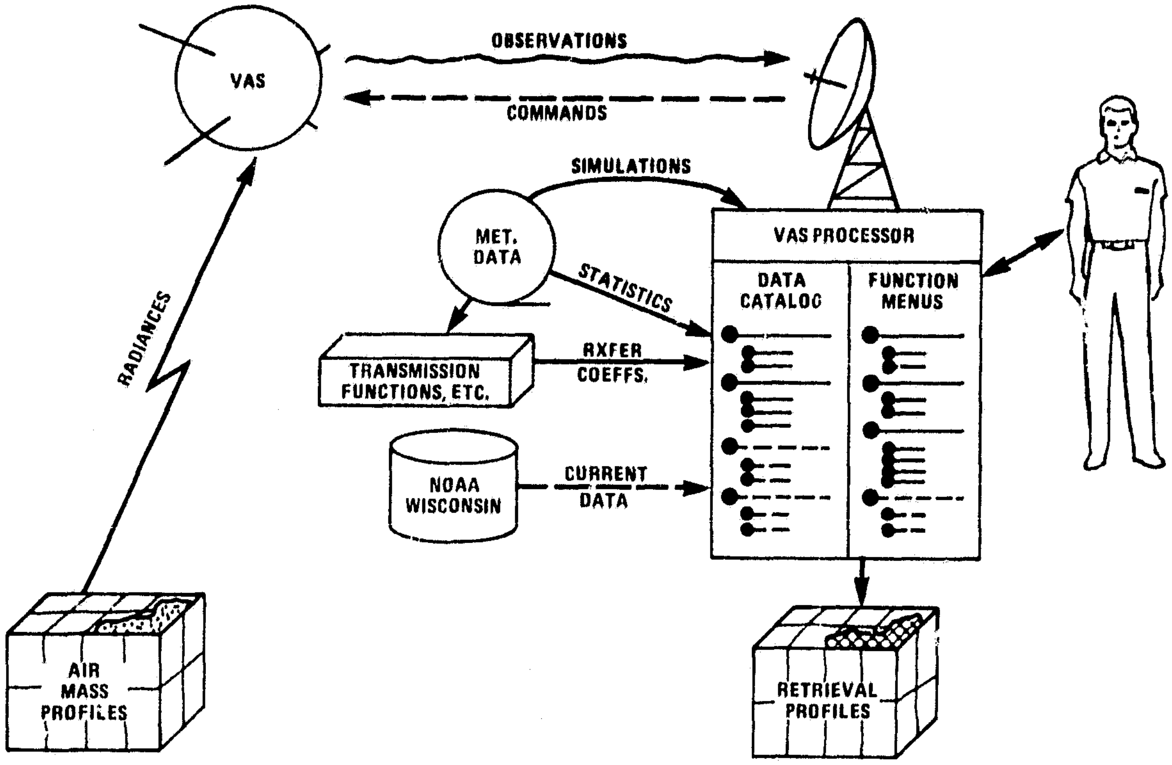

Figure 1. Overview of the VAS Processor

1.3 VAS PROCESSOR OVERVIEW (INPUT/OUTPUT)

Figure 1 shows the VAS Processor as a man-interacting "black box," which converts VAS radiance data into tropospheric temperature/moisture profile estimates at selected sites, using algorithms chosen from the science menus and support datasets chosen from the catalog. It also indicates some of the other input/output roles that are quite important to the user:

- Real-time data transfer in order to:
  - Command the VAS Instrument
  - Copy, collate and reinterleave the raw VAS radiances from the VAS preprocessor.

- Pass Visible and Infrared Spin Scan Radiometer (VISSR) and MultiSpectral Image (MSI) radiances to the Atmospheric and Oceanographic Image Processing System (AOIPS).
- Forecast navigation coefficients of the image locations for inclusion with the VAS radiances.
- Get ancillary meteorological and radiance data from VAS at NOAA/Wisconsin.
- Provide human-compatible hardcopy.

- Off-line data transfer of:
  - Radiation transfer coefficients.
  - Meteorological case study profiles and statistics.
  - Radiosonde sounding data.
  - Surface-condition data at sites of interest.
  - Replays of the raw VAS radiances from the VAS pre-Processor.
  - Archived VAS science datasets on tape or disk pack.
  - VAS-sounding profiles for use on other computers.

The approach to carrying out the science functions of the VAS Processor are discussed in the following chapters.

Chapter 2

THE SOFTWARE LABORATORY APPROACH

2.1 MODULARIZED FUNCTION APPROACH

The guiding principles for design of complex systems are:

- Form follows function
- Functions are modular.

Since the research and development effort is a piecemeal activity, a functionally modularized "software laboratory" approach was taken for the VAS Processor. Each function becomes a computer task with well-defined user options and input/outputs – standard-format VAS science datasets. This allows the functions to exchange data easily and to be custom-designed to the user's needs. It should be possible to chain the individual functions together into "sounding sequences" that can operate as automatically or as interactively as the user requires.

The need to analyze any part of the retrieval process requires a processing system which allows the sounding scientist to control every significant aspect of every algorithm, to run them in any order, and to examine all of the intermediate results. This must seem like too much freedom and responsibility to the meteorological user, but it is necessary if the VAS Processor is to be an analytical sounding laboratory. If the VAS Processor is used for VAS meteorological work after the VAS Demonstration Experiment, it will be possible to create chains of algorithms to serve as automatic sounding sequences. Until then, soundings will be produced step-by-step by experienced operators of the VAS Processor.

2.2 GENERAL SUPPORT FUNCTIONS

The VAS Processor is expected to serve as the research and development tool for VAS sounding study experiments. It is also expected to produce VAS sounding datasets for meteorological research into severe storms, calculating temperature/moisture profiles from VAS radiances in "real-time" – putting out profiles before the next radiances are put in. The two requirements are not very compatible in one system. Experience with satellite soundings indicates a need for human guidance to maintain quality control. Consequently, the research and development requirements have been given first consideration in the general design of the sounding system on the VAS Processor. Consideration is given to potential operational needs by allowing the user to pre-define personalized chains of science functions from the menus. These could be used as automated sounding sequences, while still leaving responsibility for quality control in the user's hands. General computational support is provided for:

- Error detection and correction in the VAS radiances.
- Fast-but-accurate radiation transfer algorithms.
- Several flexible, physically modeled retrieval algorithms.
- Human-interactive guidance and control of processing.
- Resident datasets for standard atmospheric conditions and for some climatological and stormy conditions.
- Recent ancillary datasets via communications with VAS at NOAA/Wisconsin.
- Standardized datasets for use/exchange/archive purposes.
- Software and dataset flexibility for experimentation.

2.3 ESTIMATION THEORY

All atmospheric soundings are estimates of the mean properties in each slab of air forming the stack we call a "profile." Radiosonde soundings merely have different error and resolution properties than satellite soundings. No type is a "true" or "unique" or "complete" list. Satellite soundings are generally less accurate and resolved in the lower troposphere, but have better space/time sampling. It is the dependence of the quality of the satellite soundings upon the algorithms, support data, and human guidance, as well as the instrument location and characteristics, that make the VAS Demonstration an experiment, not just an application.

Satellite soundings are indeed poorly determined vertically compared to the standard radiosonde levels. The broad vertical extent of the radiation-transfer weighting functions convolve the details within the absorption scale-height of each channel ($dP/P = d\ln P = 1$, which corresponds to about

5 kilometers in the troposphere). Profile details on a finer scale are calculated by intercomparison of the radiances among channels. Obviously, one trades increasing vertical resolution for decreasing accuracy by trying to extract information from small differences among noisy channels. Even more fundamentally, there is a basic uncertainty in assigning a profile variation to this or that thin slice of the atmosphere when looking through all of them. This uncertainty gives passive remote soundings their reputation for non-uniqueness.

Fortunately, there are two reasons why the lack of vertical resolution is not a critical problem for satellite soundings in meteorological research:

- Numerical models of the atmosphere are formulated to use average atmospheric values within a few relatively thick layers.
- The atmosphere itself only occasionally has a vertical fine structure that is not correlated with grosser, more detectable features.

On the other hand, when compared to radiosondes, the VAS instrument has a relatively high spatial resolution (30 kilometers instead of 300 kilometers) and a very high temporal resolution (15 minutes instead of 12 hours). This is what makes it such a promising observational tool for frequent synoptic analyses of mesoscale events.

2.4 VAS SOUNDING EXPERIMENTATION

Meteorologists are unsure both of the kind and quality of the atmospheric parameters that they need to understand severe weather development. Without a list of well-defined stability indicators to retrieve, the VAS-sounding parameters have been chosen to be temperature and moisture profiles, with error bounds similar to those claimed for polar-orbiting sounders – ±2°C for temperature and ±25 percent for moisture. Of course, the error and resolution limits are really controlled by the engineering design of the VAS instrument, the accuracy of the algorithms, the data, and the human guidance and experience.

The VAS radiances are limited by the instrumental design and by the convolutions of passive remote sensing. The information in the VAS radiances is used to estimate the most probable variation in the atmospheric profile as conditioned by the user's experience. If first-order atmospheric data is not provided, the information in the VAS radiances is wasted in re-determining it. A similar point of view has been expressed for operational satellite soundings, which are treated as interpolation aids in the space-time gaps between the radiosonde soundings.

To summarize for the meteorological user:

- One must model all of the radiative factors that significantly affect the radiation, including the factors one wants to ignore (e.g., reflected sunlight, broken clouds, albedo variations).
- One must supply case studies of the meteorological conditions to be observed, both for modeling/retrieval practice and for statistical conditioning.
- One must provide recent ancillary data (nearby "spot" measurements of good quality) on the meteorological conditions being observed to be used as a "first guess" to the updating and retrieval algorithms.
- One should get some experience with the VAS radiances at the observing site before doing a serious experiment for familiarization with the VAS Processor and to establish the local surface conditions.

2.5 CONTRAST TO THE OPERATIONAL APPROACH

An operational system aims to make the best product using as many sources of data as possible and treating the VAS radiances as interpolation information. The VAS Processor at NASA/GSFC aims to find the best process, using as much physical modeling as possible, treating the VAS radiances as the crucial information.

An operational approach relies on recent radiance/radiosonde correlations for profile prediction, which is a method that can produce large quantities of uniform data. The research and development approach relies on detailed physical radiance/profile models for radiance prediction and variance interpretation, which is a method that can trace the information-extraction process.

There are many advantages and disadvantages to each approach, but a more detailed comparison is beyond the scope of this document. The approaches are different because the aims are different; in fact, the "success" of each cannot be measured with the same criteria, since one aims at dataset production while the other aims at procedural analysis.

Chapter 3

MODELED SOUNDING

3.1 RETRIEVAL ALGORITHMS

The retrieval algorithms on the VAS Processor are based upon physical models for radiation transfer, since detailed analytical algorithms are the best way to do research and development. The retrieval algorithms are based also upon statistical and ancillary meteorological data, modeling the results with the most probable conditions within the atmosphere. Of course, this approach depends upon good formulation and supporting coefficients for its success. The study of these models is as much a part of the VAS Demonstration as is the study of the retrieved profiles.

Mathematical formulation of each science function on the VAS Processor is described elsewhere.[18] The radiative models and supporting datasets make an eclectic list, as would be expected in a research and development system. The guiding principles for the radiative models are described in the following section.

3.2 RADIANCE/RETRIEVAL MODELS

Many of the physical factors affecting the VAS radiances are large, complicated, nonlinear effects (such as transmission functions and cloud effects). Because of the limited capacities of the VAS Processor, these factors are first analyzed off-line, and then modeled with fast-but-accurate algorithms on-line. The radiance algorithms keep their nonlinear character by modeling the burdensome effects with coefficients that can be quickly updated by some parametric scheme. The retrieval algorithms are mostly based upon linearized radiation transfer models, which were selected for their flexible analytic powers. Empirical regression algorithms are also available in many functional categories to provide data processing support while physically modeled algorithm development is underway. The main categories requiring radiative modeling are:

- Radiation studies
  - Radiance Corrections – Adjustments for the quirks of the instrument. Ancillary data for verification is usually required.
  - Estimated Radiances – Physical formulations requiring estimated atmospheric conditions (clouds, temperatures, etc.), adjustable radiation transfer coefficients, surface conditions, geometrical corrections, etc. Recent ancillary data is usually required.
- Retrieval studies
  - Nonlinear algorithms – Physical formulations using the VAS radiances to estimate large factors (e.g., clouds). Human interaction is often required.
  - Linear algorithms – Flexible physical formulations using VAS radiance variations to estimate atmospheric variations (e.g., temperature profiles). Ancillary and statistical data is often required.

"VAS Processor studies" consist of testing the effect of different models, model parameters, and information-budget controls upon the VAS soundings.

3.2.1 Radiation Transfer Algorithms

Each model is suited to the user's intent for the function being executed with the following guidelines:

- Use adjustable physical coefficients based upon fast-but-accurate parameterizations where necessary.
- Include corrections for VAS instrumental effects, such as viewing geometry and channel selection.
- Include adjustments for ancillary meteorological data, such as temperature/moisture/ozone profiles.
- Model surface effects separately using specifications of temperature, emissivity, and height.
- Model clouds with sheets of fractionally absorbing layers.

- Model the atmosphere as a stack of thin slabs with layer-average temperature and moisture profiles.
- Provide simple, reasonable standard default values for all datasets.

3.2.2 Radiation Transfer Datasets

Supporting radiative coefficients (and their adustment parameterization) are computed off-line for the VAS Processor as they are needed. Standard values are provided for:

- Line-by-line transmission functions.[19]
- Sensitivity functions.
- Adjustment parameterizations for fast-but-accurate updates from the standard values to a "first guess" profile.

Some coefficients, such as continuum absorption by water vapor, can be calculated within the VAS Processor itself. In addition to coefficients for the U.S. Standard Atmosphere, a modest set of coefficients, based upon global climatology, is available.

3.3 CONDITIONING PROCEDURES

It is obviously a waste of information to use the VAS radiances to determine the first-order conditions of the atmosphere. The earth is not an unknown planet – both the geographical and seasonal behavior are quantitatively available in statistical form. Nor are the air-masses unknown – the locale and developmental behavior are qualitatively understood, although the quantitative statistical data is sparse.

When available, the meteorological expectations of the user can be introduced to condition the VAS retrieval algorithms to resolve the ambiguities in the radiances in favor of the most probable state. The expectations must be in the form of covariances between the temperature and moisture profiles for a type of air-mass. Statistical functions for covariance and regression calculations are provided on the VAS Processor. These are used in a statistically conditioned inverse that minimizes the profile deviations for the "training set," modeling the sensitivity of the channels to the profile variations. The sensitivity remodeling is done by adjusting the sensitivity functions from the U.S. Standard profile to a "first guess" profile with some fast-but-accurate coefficient-adjustment scheme.

3.3.1 Radiance Corrections

The VAS radiances themselves may not be as independent, unbiased, and generally error-free as the design specifies. Ad hoc algorithms to test and correct these quirks will be developed after launch, using internal consistency and agreement with the more familiar polar-orbiting satellites as conditioning criteria.

Likewise, the laboratory measurements of spectral line parameters may be incorrect, biasing the coefficients in the radiation transfer models. Ad hoc algorithms also will have to be developed to detect and correct systematic discrepancies between observed and calculated radiances at well-understood sites.

3.3.2 Meteorological Statistics

In the absence of good air-mass statistics, the available global climatological statistics can be used to condition retrieval techniques. It is the user's responsibility to provide the best statistics he can to condition the VAS retrievals for his own experiments. Developed statistical datasets will be resident on the VAS Processor for all to use. The usual sounding statistics are the mean and cross-correlations among temperature and moisture profiles of a common class of data (e.g., pre-thunderstorm conditions in Texas). Ideally, the statistics are partitioned according to the significant structure and stage of the air-mass development. At worst, VAS may have to "bootstrap" the statistical datasets from its own poorly conditioned initial soundings.

Profile statistics are being developed on the VAS Processor from NSSL data for severe thunderstorms in Oklahoma. These are the best data available to use to prepare for the planned VAS Verification Experiment in May 1981, which will compare special radiosonde soundings to simultaneous VAS soundings.

3.3.3 Simulated Cases

A meteorologist can prepare not only his conditioning datasets but also himself and his special algorithms by using case study soundings of the air-mass of interest to simulate the VAS radiances that might be seen. Science utilities exist to fill fields with profiles interpolated from the available soundings. "VAS scenes" can be used to practice retrieval techniques with considerable sophistication if the user can provide cloud and surface detail estimates.

More importantly, early walkthroughs of the sounding processes will uncover the need for the specialized functions and datasets that one may need.

3.3.4 Locale Familiarization

The user can expect the VAS Processor to make good lower tropospheric soundings only if he provides data on the surface conditions – temperature, emissivity, and height, at least. Fortunately, these are relatively fixed/measurable conditions, so that the VAS window-channels can then be used to determine the variable low-cloud conditions. Note that the infrared "surface temperature" is not the same "surface temperature" reported by the meteorological ground stations. VAS may be able to "bootstrap" such data for itself at remote locations by using a long series of observations at the site as a baseline.

3.4 ANCILLARY DATA

During a VAS experiment, one can usually get a few "spot" measurements of the local meteorological conditions. The modeled sounding techniques use these as a "first guess" estimate of the soundings and of the VAS radiances. The radiance variations are then used to infer the meteorological variations from some statistically conditioned model of the radiance sensitivity.

The ancillary data will be provided to the VAS Processor by access to the recent data files at VAS/NOAA/Wisconsin via a menu-driven communications link with their database. Data availability is determined by VAS/NOAA/Wisconsin.

3.4.1 Other Radiances

Verification of the VAS radiances can be done by comparison to similar channels on the HIRS2 instruments carried by the TIROS-N and NOAA-A polar-orbiting satellites. The comparison will be necessary to verify calibration whenever the stability of the VAS instrument is in question, such as after eclipse. Radiance-stability experiments will require a baseline of "normal" intercomparisons by each satellite for similar scenes and viewing conditions.

3.4.2 Other Satellite Soundings

It may be more useful to compare VAS soundings to TIROS/HIRS2 soundings than to compare them to isolated radiosonde soundings (e.g., in mid-ocean hurricane development). Such other satellite evaluation can be done with objective figure-of-merit parameters, such as RMS statistics. However, a human being must exercise judgment upon the unexpected features in the observations. A number of display and manipulation utilities are provided on the VAS Processor to support quality control of the detailed data values.

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