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FINAL REPORT
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X. TOVS PATHFINDER PRODUCT VALIDATION AND INTERCOMPARISON

A.. Overview

Validation and intercomparison is an essential part of the Pathfinder program. Since its organization within the International TOVS Working Group, the TOVS community has continuously emphasized this aspect of the product retrieval problem. In the previous sections of this report, the TOVS Pathfinder SWG has recommended a careful and coherent reorganization and archiving of TOVS radiance data, and three distinct pathways for deriving product variables from this TOVS radiance archive. The importance in taking this multiple path approach to creating climate datasets rests in our firm belief that there is no global "absolute truth" data for any of the derived physical parameters. Each of the selected methods is based upon a different set of assumptions. Paths A and B make the attempt to account as much as possible for the physical processes in the atmosphere and surface that create the observed radiances. Path C strives to detect earth system changes as directly from the upwelling radiance data as possible. The challenge in interpreting Pathfinder data is to determine what alterations in the physical attributes of the environment contribute to evidence of global change extracted from observed or derived Pathfinder datasets. A great deal of what we are likely to learn about climate change will come by comparing the parameters derived by these methods, and understanding their similarities and differences under a range of environmental conditions. The Pathfinder validation and intercomparison activity must include validation of the *forward problem*, by

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which one calculates an estimate of upwelling radiance information from given earth and atmospheric data, and validation of the *inverse problem*, by which one calculates estimates of earth and atmospheric information from given upwelling satellite spectral radiance data.

The challenge in interpreting Pathfinder data is to identify changes in atmospheric, oceanic, or land processes which are responsible for any observed long–term changes in either the radiances or derived products. The validation of the forward problem involves a careful comparison between calculated and measured radiances. This may be achieved by archiving a diverse set of measured radiances and colocated independent measurements of profile parameters. In practice, this means radiosondes (although rocketsondes, lidar profiles and other measurements are potentially useful). In order to properly specify errors in the forward problem, insofar as they relate to errors in radiosonde measurements of atmospheric state, there is a need to analyze forward radiative transfer model errors as a function of: air mass type; presence of clouds; land/sea flag; viewing and solar zenith angles; and radiosonde type.

It was primarily in response to the forward problem of radiance validation that previous meetings of the International TOVS Scientific Working Group stressed the importance of a *Baseline Upper Air Network* (*BUAN*) (See WMO (1988)). At this time, a few databases containing colocated observations are available: the NESDIS operational *Data Staging Disk 5* (DSD5), the *BUAN* archive (January 15 to July 15, 1988) with about 7000 radiosonde reports, L. McMillin's long term data set, and perhaps other colocated sets unknown to the TOVS Pathfinder SWG.

Also related to validation of the forward problem, the ITRA (Intercomparison of Transmittances and Radiance Algorithms) program has been encouraged to continue its efforts towards the validation of radiative transfer codes, in particular, against high quality observations like the HIS (High resolution Interferometer Spectrometer, Smith, Rivercomb, Howell, and Woolf (1983)) spectra or ground based microwave radiometric instruments (Westwater and Grody (1980)) associated with good coincident *in situ* measurements of the atmospheric state.

The inverse problem of derived product derivation must also be subjected to careful validation and intercomparison. As part of the validation/comparison exercise, both first guess information and product retrievals should be verified against a well distributed group of colocated *in situ* and *satellite* data. In order to assist in retrieval validation studies and to illustrate the existent maturity and quality of retrieval schemes, an intercomparison of retrieved data derived from common sets of satellite radiance observations should be undertaken, following what has already been done by the International TOVS Working Group. Techniques should be tested for differing conditions of cloudiness, different geophysical domains, and differing meteorological regimes.

Specific to validation and intercomparison of Path C derived products, the candidates for intercomparisons are similar products derived from radiosondes, Path A and B products, and of course the established Spencer et al. data sets. Layer averaging of radiosondes or higher vertical resolution TOVS derived products is all that is required to make the comparisons. The temporal and spatial resolutions for intercomparison with radiance data and Path A and B products are dictated by the definition of the recommended common format data archive and, additionally, by considerations discussed in Section X. Very likely nothing can be done for the radiosondes to obtain appropriate spatial averaging. In the case of the Spencer et al. data, box–car and bell–shaped weighted averages can be compared directly, provided the weighting curves overlap and have essentially the same area under them. As a general procedure, if one of the products being compared has higher spatial or temporal resolution than the other one, averaging to the lower resolution will take care of the problem. In regions where a parameter has large gradients relative to the data sampling density, or where data sampling is very variable, an alternative approach to averaging or compressing would be used.

For climate and global change purposes, it would be useful to evaluate interannual differences of coarse layer-mean temperatures, coarse layer precipitable water, effective cloud amounts, and if available, surface skin temperatures and cloud-top temperature. Layer-mean temperatures produced among the different methodologies can be compared to rawinsonde reports, or, if not in the vicinity of rawinsonde sites, to analyzed fields from NMC or ECMWF. Use of analysis for validation allows for the examination of spatial as well as temporal variability. Interannual differences of other parameters are more difficult to validate but can be compared to each other. Because the ability to account for satellite drift and intersatellite differences is important, comparisons should include time periods measured by the same satellite (e.g., May–June 1980 and May – June 1981, both measured by NOAA 6) and by different satellites (May–June 1988, measured by NOAA 10 and 11).

Developing, to the degree possible, a quantitative understanding of the physical meaning of derived parameters, over a range of environmental conditions, is the objective of the validation effort. At least one study of this type, for sea surface temperature parameters, has been performed (Njoku et al., (1985)). A key function of a TOVS Pathfinder initiative is to ensure that data sets developed therein are as easy as possible to transport, intercompare, and validate. In general terms, there should be carefully conducted design efforts such that:

- *Certain steps be taken in preparing each TOVS Pathfinder data set, in anticipation of validation and intercomparison of results,*
- *Certain preliminary work be done in developing techniques for statistically characterizing and comparing data sets, in anticipation of validation and intercomparison of results, and*
- *A set of validation and intercomparison activities be selected and included as part of the plan to prepare the TOVS Pathfinder datasets for the larger community.*

The sub-sections to follow provide specifications for a validation and intercomparison study group.

B. Scientific Aspects of Validation and Intercomparison

1. *Characterizing the Assumptions Associated with Each Parameter*

Data users need to know about assumptions that could affect the interpretation of the results without becoming expert in all aspects of the instrument and analysis code. Charting techniques, based on ideas from the system design community (e.g., Yourdon and Constantine, (1979)), have been developed to summarize assumptions (See Kahn et al. (1991)). Many assumptions made in the data reduction process have the potential to affect the scientific meaning of the data. These include assumptions made in: adopting and calibrating the instrument radiances; deriving the data production algorithm (the equations); and building the data production computer code.

A deep understanding of the subtleties of the data analysis is required to identify and describe these assumptions. Therefore, a chart of all assumptions for each TOVS Pathfinder dataset needs to be produced by scientists with a deep understanding of the data.

2. *Content of Data Sets*

In addition to the physical parameter values that are reported in the data set, quantities which characterize the retrieval, such as error flags, residuals, characteristics of rejected values, and intermediate results may be critical for the validation effort. The validation effort, including members with intimate knowledge of each of the datasets, should agree on a reasonable selection of diagnostic quantities to be stored with each data product.

3. *Selecting Spatial and Temporal Regions for Comparison*

By carefully selecting spatial and temporal regions for the validation and intercomparison effort, a validation team can control to some extent the data quality, sample density, and environmental conditions in the study. The validation team should pick a reasonable number of space–time windows for validation, covering the full range of environmental conditions and surface types that are likely to occur.

4. *Finding Statistics That Characterize Key Attributes of Individual Data Sets*

Whereas arithmetic means and standard deviations are routinely used to describe data sets, other attributes, such as those that characterize sample spacing, spacing vs. gradient of the parameter value (which could be a vector quantity), measures of heterogeneity, variance surfaces, etc., also contain important information about the meaning and utility of the data for climate change studies. Providing such information for validation and intercomparison datasets would be a key contribution of the validation. Further research needs to be done, in collaboration with the statistical community, to explore these possibilities.

5. *Defining Ways to Characterize The Comparisons Among Data Sets*

The usual way of reporting comparisons between two–dimensional surfaces is by presenting difference or ratio images. Each of these methods has serious limitations, and there are no standard ways of characterizing the movement of boundaries and changes in density and density gradient for two or higher dimensions. Such comparisons are of major importance to validation and other studies of geophysical parameter fields. Research needs to be done, in collaboration with the statistical community, to explore these possibilities.

C. Technical Aspects of Validation and Intercomparison

From the available experience with intercomparing large data sets, several technical issues regarding ease of handling and exchanging data have been recognized, and at least partial solutions have been developed. This subsection lists a few of these issues and approaches.

1. *Transportable Data File Formats*

Much work has been done to develop software that will create and read data files on a wide range of computers without additional translation steps. The HDF (Hierarchical Data Format) from NCSA (National Center for Supercomputer Applications, U. Illinois) and netCDF (netCommon Data Format), are two of the leading examples. Both packages are distributed free of cost. Given the tremendous advantages of using such formats for a distributed effort like the Pathfinder, strong consideration should be given to adopting a transportable format for the standard distribution of TOVS Pathfinder data, including both radiance datasets and derived product datasets.

2. *Labeling Data Files*

The software for transportable file formatting generally requires that "data objects" be defined (for example, each parameter in a dataset can be designated as a separate data object), and allows for descriptions of the overall data set and each data object within it. There should be an agreement to some minimum information to be included with each data file and data object description, such as definitions of parameters, units, space and time constraints, allowed values, and references.