**The GEWEX Global Water Vapor Project (GVaP)--U.S. Opportunities**

Global Energy and Water Cycle Experiment (GEWEX) Panel, National Research Council

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# The GEWEX Global Water Vapor Project (GVaP)— U.S. Opportunities

*A brief report from the*

Global Energy and Water Cycle Experiment (GEWEX) Panel
Climate Research Committee
Board on Atmospheric Sciences and Climate
Commission on Geosciences, Environment, and Resources
National Research Council

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# Preface

In 1998, the National Research Council's (NRC) Global Energy and Water Cycle Experiment (GEWEX) Panel was asked by the agencies of the U.S. Global Change Research Program to review the draft GEWEX Global Water Vapor Project (GVaP) Science and Implementation Plans and to advise on U.S. involvement in GVaP. The NRC GEWEX Panel held meetings on October 8–9, 1998 and March 19, 1999 to hear presentations on GVaP and related topics. The panel is grateful for presentations from John Bates, Moustafa Chahine, Ted Cress, Rex Fleming, John Gaynor, David Randel, Robert Schiffer, Pamela Stephens, and Thomas Vonder Haar. At each of these meetings, closed sessions were also held to discuss GVaP and arrive at the consensus findings presented in this brief report. Throughout this study, the panel and staff benefited considerably from consultations with Dian Gaffen and Paul Try.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible, and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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While the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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# Summary

Water vapor plays a vital role in shaping weather and climate on Earth. Hence, monitoring water vapor is critical if we are to explain and predict the behavior of the climate system. Unfortunately, measuring and analyzing water vapor on the time and space scales needed for this purpose have proven elusive. Therefore, it is appropriate and timely for the international climate research community, through the Global Energy and Water Cycle Experiment (GEWEX), to focus a project around water vapor. To this end, a GEWEX Global Water Vapor Project (GVaP) has been proposed, and draft Science and Implementation Plans have been developed. As requested by the U.S. Global Change Research Program (USGCRP), the National Research Council's (NRC) GEWEX Panel has reviewed these plans with an eye toward U.S. priorities. The panel commends GVaP for attempting to bring together the diverse water vapor measurement and research communities. The ultimate objectives of GVaP are laudable and should be vigorously pursued, both for their own scientific merit and especially for their potential contributions to the breadth of hydrometeorological research.

To achieve its potential, the project should give particular attention to the following activities (described more fully in the body of the report), many of which are already integral elements of the draft GVaP plans:

- *Gather, assess, and distribute existing water vapor data sets and products.*
- *Coordinate data set intercalibration and comparison with results from validation experiments.*
- *Highlight upper tropospheric water vapor.*
- *Create new water vapor products, including a merged global water vapor product.*

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- *Foster broad community involvement.*

In particular, strong interaction with the operational weather community and the broader hydrometeorological research community will also help to ensure that the promise of GVaP is fulfilled.

Because water vapor data are needed by the U.S. climate research community, the United States should participate in the international GVaP to better leverage the nation's resources. Contributions that the United States should make—in addition to its current activities such as remote sensing—include the following: (a) improve instruments and analysis techniques, with special emphasis on efforts to increase vertical and temporal resolution and to improve measurements of water vapor in the upper troposphere-lower stratosphere; (b) implement use of reference radiosondes; (c) provide critical, high quality data sets to validate satellite remote sensing results; (d) lead the effort to compare and evaluate available and new data sets; and (e) undertake a new synthesis of existing and new sources of information about water vapor to produce a global water vapor data set. In addition, the panel recommends that U.S. agencies consider targeting support for one or more of the individual GVaP Data Centers and/or the Central Facility, as appropriate.

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# Background

In 1988 the World Climate Research Programme (WCRP) initiated GEWEX to observe, understand, and model the hydrological cycle and energy fluxes in the atmosphere, at the land surface, and in the upper oceans. GEWEX is an integrated program of research, observations, and science activities with the ultimate objective of substantially enhancing the ability to predict global and regional hydrologic processes and water resources and their response to environmental change.

In 1990 the GEWEX Science Steering Group (an international advisory body) held a workshop in Easton, Maryland, titled "The Role of Water Vapor in Climate Processes." The discussions and papers presented at that workshop highlighted several key deficiencies in the understanding of water vapor's spatiotemporal characteristics. It was recognized that improvements in this understanding would be necessary to realistically characterize fundamental aspects of the atmospheric system, including radiative heating, precipitation, cloud formation, and horizontal and vertical moisture transport and convergence. Without improved understanding of these critical aspects of the atmospheric system, the ability of models to accurately predict weather and climate at all time scales will be significantly hampered.

To address this need, a GEWEX Global Water Vapor Project (GVaP) was initiated, and in May 1991 a strategic research plan was prepared and published by the National Aeronautics and Space Administration (NASA), describing an approach for providing the data to answer some of these critical questions. This initial plan was designed to: (1) improve the accuracy and availability of global water vapor data through the development of a global water vapor data set, (2) establish reference observation stations, and (3) conduct intercomparison studies among the existing water vapor data sets.

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In November 1991, a meeting was held in Columbia, Maryland, to discuss the implementation of this initial plan. The results of these discussions are described in a document titled "Implementation Plan for the Pilot Phase of the GEWEX Water Vapor Project." This plan included the addition of a fourth element, namely, the improvement and standardization of radiosonde humidity sensors and data processing procedures for worldwide use.

The cornerstone of this initial phase has been the production of the NASA Water Vapor Project (NVAP) data set (Randel et al., 1996). This is a global, 9-year (1988–1996), 1×1 degree resolution product that quantifies both atmospheric water vapor and liquid water, with daily, pentad (5-day), and monthly temporal resolutions for three layers (1000–700, 700–500, and 500–300 mb), as well as the entire atmospheric column. The NVAP data set, which is available on CD-ROM, was constructed through a blending of radiosonde, Special Sensor Microwave/Imager (SSM/I), and TIROS (Television and Infrared Observation Satellite) Operational Vertical Sounder (TOVS) water vapor soundings.

In August 1993, a GVaP workshop was held in Breckenridge, Colorado, to discuss the current state of the art in satellite retrievals, radiosonde climatologies, the GVaP pilot phase, and the NVAP data set. In October 1994, an American Geophysical Union Chapman Conference on Water Vapor was held on Jekyll Island, Georgia, to review theoretical and observational aspects of water vapor and to identify areas of future research.

The development of the NVAP data set and the advancement of validation processes during the initial phase of GVaP led the GEWEX Science Steering Group to conclude that the success of the pilot period, coupled with recognition of the potential importance of upper tropospheric and lower stratospheric water vapor for GEWEX, had set the stage for GVaP to make major contributions to GEWEX. An international planning workshop for GVaP was held in November 1996 in Geneva, Switzerland, at which representatives from WCRP, the National Oceanic and Atmospheric Administration (NOAA), and NASA endorsed the development of plans for the main phase of GVaP. In 1997, the GEWEX Joint Steering Committee recommended a new, 7-year phase of GVaP with the participation of all WCRP programs, including the Arctic Climate Systems Study (ACSYS), the Climate

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Variability and Predictability (CLIVAR) Program, GEWEX, and the Stratospheric Processes and their Role in Climate (SPARC) Program.

Thomas Vonder Haar, assisted by Paul Try and David Randel, was tasked with organizing the Science and Implementation Plans for this new phase. An International Working Group on Science and Data for GVaP was convened in Silver Spring, Maryland, in June 1997. The goals of this meeting were to formalize the international commitments to GVaP, prioritize the main science and data management tasks, and establish a framework and timeline for their implementation. Input from this meeting was used in the development of the latest drafts of the GVaP Science Plan (IGPO, 1998a) and Implementation Plan (IGPO, 1998b), which are the subject of this report.

Drawing upon the progress made in the pilot phase of the project, these documents outline the plans for the main phase. These plans articulate the goal, approach, and research objectives as follows:

## OVERARCHING SCIENCE GOAL OF GVAP

*Quantify and understand the role of water vapor in the meteorological, hydrological, and climatological processes by improving our knowledge of its variability, radiative effects, feedbacks, and change due to human activities.*

## GVAP APPROACH

- *Understand those mechanisms and processes responsible for the observed variability, at all time scales, in the global water vapor distribution.*
- *Document the climatology of water vapor with respect to both the natural and anthropogenic forced variability.*

## GVAP RESEARCH OBJECTIVES

- *Determine the horizontal and vertical transport and the surface fluxes of water vapor on regional and global scales.*
- *Study the interannual and interseasonal variability of regional systems with emphasis on water vapor recycling through the monsoons.*

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- *Investigate how the hydrologic cycle will change during periods of global warming.*
- *Characterize the role of clouds and other processes that maintain the vertical distribution of water vapor.*
- *Examine the direct and indirect water vapor feedbacks on the climate system, including the relationship of water vapor to other climate variables such as sea surface temperature, cloudiness, and precipitation.*
- *Document the three-dimensional distribution of water vapor at time scales ranging from interannual down to short-term daily variability.*

Implementation of the main phase of GVaP will be organized around four major thrusts, discussed in both the Science Plan (IGPO, 1998a) and the Implementation Plan (IGPO, 1998b):

1. *Develop and deploy the tools for verification, validation, and calibration of observations for in situ and satellite retrievals of water vapor.*
2. *Document the climatology of water vapor.*
3. *Address the GVaP research areas.*
4. *Develop and test new water vapor observing systems and instruments.*

GVaP will combine existing data, collected in NVAP, with a number of new data collection systems, including retrievals from satellite systems such as the Global Positioning System (GPS), the Advanced Microwave Sounding Unit (AMSU-B), the Advanced Infrared Sounder (AIRS), and the Microwave Humidity Sensor (MHS). In addition, GVaP will take advantage of data from the Water Vapor Sensing System (WVSS), an aircraft-based component of the Meteorological Data Collection and Reporting System (MDCRS).

The main phase of GVaP is being initiated with a series of workshops and research meetings to advance knowledge of water vapor data set calibration/ validation issues, including algorithm development and data intercomparison. The first of these was the GVaP upper tropospheric humidity (UTH) Intercomparison Workshop held in June 1998 in Darmstadt, Germany, with the objective of quantifying existing differences in top-of-the-atmosphere radiances in the 6.3μm water

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vapor absorption band as simulated by different radiative transfer codes. Other workshops are planned to steer activities in the following areas: lower tropospheric algorithm intercomparison, instrument validation and intercomparison, GVaP data set development, verification of satellite water vapor, and water vapor science and applications.

Validation and calibration capabilities will be enhanced by the development and testing of new instruments and systems such as Differential Absorption Lidar (DIAL) and Raman Lidar, ground-based microwave and infrared radiometers, GPS measurements, improved radiosonde technologies, very long baseline interferometry (VLBI), and aircraft reporting systems. The Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) program will incorporate, within the ARM structure, responsibility for coordination of the calibration/validation activities and data collection and will undertake fully instrumented calibration/validation measurements at 4–5 locations around the world for verification of satellite retrievals and algorithm development.

One of the key foci of GVaP will be documenting the climatology of water vapor. Issues at stake include defining the appropriate spatial and temporal resolutions for improving the understanding of various atmospheric phenomena, such as greenhouse warming and large-scale water vapor transport. In addition, the results of calibration/validation work will be assessed and drawn upon to characterize the accuracy of the data and to assist in developing data merging algorithms. This work will lead to defining the inputs and processing of a second GVaP data set (the follow-on to NVAP), which is proposed to include a minimum of 4–5 vertical levels. It will also lead to the development of an improved suite of water vapor products that include separate satellite-only, ground-only, and blended data sets. Such a hierarchical approach will allow independent comparison amongst the various data sources and merged products. GVaP will also assess the use of new observational sources, such as those mentioned above, as they become available.

The Implementation Plan (IGPO, 1998b) calls for these data sets to be used as part of GVaP investigations into the GVaP research objectives. The timeline given in the Implementation Plan indicates that these investigations, as well as the final development of the GVaP data sets, will be completed in 2005.

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## The Need for GVaP

Few would argue about the importance of water vapor to the weather and climate on Earth. By modulating the transfer of radiation in and through the atmosphere, water vapor strongly influences the overall energy balance of the planet. The release of latent heat, which accompanies the condensation of water vapor, provides much of the energy driving storms and the atmosphere's general circulation. The presence of water vapor in the atmosphere influences evaporation from the surface, thereby affecting land temperatures and groundwater storage. Moreover, because of its great mobility and brief residence time, water vapor is a central component of the global hydrological cycle. How this cycle may change globally and regionally in the future is a major issue for climate science and society.

Because water vapor is vital for Earth's energy and water cycles, it must be monitored in time and space if we are to explain and predict behavior of the climate system. In particular, to properly appraise the response of the climate system to external forcing, the atmospheric transport and cycling/recycling of water vapor must be well understood and modeled. If water vapor transport is to be accurately estimated, then water vapor concentrations and wind velocities are required at sufficient accuracy and resolution to account for the atmosphere's often-distinct vertical gradients of water vapor and wind. Furthermore, in regions like the upper troposphere and stratosphere, where water vapor concentrations can be less than tens of parts per million, water vapor has significant radiative and chemical effects that need to be properly quantified and modeled to address questions about anthropogenic and natural global change, including the feedback of water vapor on changes in radiative forcing.

Unfortunately, measuring water vapor sufficiently well to properly understand the processes responsible for its variability has proven disappointingly elusive. This situation results in part because water vapor is not dynamically constrained, and its high spatial variability makes adequate sampling difficult. Problems associated with the various water vapor measurement technologies also have hindered

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progress. Standard humidity sensors carried by radiosondes have complex error characteristics up through the mid-troposphere, and their performance is severely diminished at higher levels. Furthermore, the network of radiosonde stations is strongly biased to locations on land, and the number of radiosonde stations has declined in the past few decades. Satellite measurements provide global coverage, but their vertical resolution in the lower troposphere, where water vapor is most abundant, is poor compared with that of radiosondes or other ground-based systems. Long-term water vapor monitoring with satellites can also be problematic due to several factors such as gradual changes in instrument sensitivity and local crossing time, abrupt changes resulting from satellite replacements, and short or intermittent system lifetimes.

As a consequence of such difficulties, the research community relies heavily on global analyses of water vapor produced by operational weather centers or similar institutions. All such analyses, however, are model- and/or methodology-dependent and therefore differ notably from each other. While these analyses produce multi-layered output, the accuracy of these data is constrained by the vertical resolution of the inputs of observational data. For instance, in the absence of reliable water vapor measurements in the upper troposphere, operational analyses of this quantity are questionable in this region. Also, in the absence of observed humidity profiles over data sparse regions (e.g., oceans), the vertical detail of model-based analyses tends to exceed the degrees of freedom allowed by satellite observations.

Given this state of affairs, the GEWEX Panel feels that it is appropriate and timely for the international climate research community, acting through GEWEX, to focus a project around water vapor. GVaP may not be able to rectify or overcome some of the important deficiencies in current water vapor measurements (e.g., low vertical resolution from space-based sensors). However, GVaP can and should contribute to developing an improved observing capability by conducting a more detailed and quantitative assessment of the limitations of the current measurements and the potential for new experimental measurement systems that have not yet been fully exploited (e.g., microwave sounders [including the Microwave Limb Sounder], radio occupation, and infrared spectrometers). Careful and coordinated analyses of all of these measurements will be needed to discover how far we can progress in obtaining the information about water vapor required to answer the main research questions. The

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international GVaP is to be commended for recognizing this need and for attempting to bring together the diverse measurement and research communities under a single project devoted to water vapor. The panel believes that one of GVaP's most enduring legacies may indeed lie in the communication it can establish among the measurement, analysis, and research communities.

## Comments on the Science and Implementation Plans

The overarching goal, approach, and research objectives listed in the draft Science Plan (IGPO, 1998a) are at once meritorious and extremely ambitious. The GEWEX Panel believes that some aspects of the proposed program, especially those positioning GVaP as an interface between data providers and users, are more tractable than others. In particular, attempts to deal with cloud-scale processes will be especially difficult given the resolution of the observing systems discussed in the GVaP Implementation Plan. Nevertheless, the microphysics of hydrometeors—for example, their re-evaporation in the tropical upper troposphere—is critical for understanding water vapor-radiation feedbacks. In this connection, however, GVaP can be especially valuable to the modeling community by synthesizing the larger-scale measurements that are an important component of developing improved parameterizations within global models.

Moving forward with its plans, GVaP should pay particular attention to the following activities:

- *Gather, assess, and distribute existing water vapor data sets and products.*

  The proposed effort to gather all relevant water vapor data sets should include careful attention to incorporating metadata so that updated versions of data sets can be properly identified and linked to previous versions. Other documentation, such as error estimates, also will be critical to future reprocessing efforts. Because of the large number of existing and planned data sets, a primary initial objective should be to assess their quality so that users are made

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aware of the strengths and limitations of each observational product, including its utility in documenting long-term trends. This will also enable the measurement community to define the performance characteristics of prospective observing systems to resolve these deficiencies.

- *Coordinate data set intercalibration and comparison with results from validation experiments.*

  The GVaP project should take specific responsibility to examine and understand the systematic differences between available water vapor data sets and those resulting from its own analyses. This effort would be the first step in developing and applying new, consistent calibrations to water vapor data. The panel recommends that the development and implementation of a reference radiosonde be a high priority. Given the crucial importance to climate research of detecting long-term trends in tropospheric water vapor and the limited lifetime of GVaP, the implementation of a reference radiosonde is important to ensure the ongoing calibration of different moisture sensors.

- *Highlight upper tropospheric water vapor.*

  Upper level water vapor feedbacks are a major source of uncertainty in global warming simulations. The proposed GVaP focus on global upper tropospheric water vapor could yield especially large benefits in addressing this issue, given the known strengths and weaknesses of the principal data sets to be assimilated. Because of the growing collection of existing, and often conflicting, measurements for this region, GVaP needs to give additional thought to how it can best contribute to this subject. Close collaboration with the work of the SPARC program should be established, in particular with SPARC's work to better understand upper troposphere-stratosphere interactions.

- *Create new water vapor products, including a merged global water vapor product.*

  The emphasis here should be on a hierarchy of products, including, for example, higher resolution regional products and global products of different space-time resolutions. The panel recognizes that for many users, however, a single merged, “final” product

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would be most useful and should be generated. The panel strongly recommends that access to the base data used to derive a merged product be maintained, in light of the diverse applications of such data for which properties of "optimal" analyses may differ substantially. The techniques to be employed for a merged product should be drawn from the mathematical tools associated with data assimilation in support of numerical weather prediction. In applying data assimilation approaches to create water vapor products, the direct input of radiances may be preferable to the input of retrievals. Quantification of uncertainties, including bias and error covariance properties, should accompany the creation of any new water vapor data products intended for broad use.

- *Foster broad community involvement and sponsor workshops.*

  End users of GVaP products must have mechanisms for providing feedback about the quality of these products. The free and open international exchange of GVaP data and products must be supported in order for the measurement, analysis, and modeling communities to be properly engaged. It is especially important for GVaP to engage those responsible for maintaining operational, global climate observing capabilities so that the advances of GVaP can extend beyond its proposed lifetime. GVaP should also involve those responsible for developing new measurement capabilities by documenting and prioritizing deficiencies in current data bases so that performance characteristics of new observing systems (including sampling strategies and optimal mixes of measurements and models) can be designed to remedy the most important problems. Furthermore, in addition to the focused workshops described in the draft Implementation Plan, GVaP ought to help sponsor more broadly based conferences organized by others interested in water vapor-related issues. Community interaction might also be facilitated through the effective use of Web-based tools.

To accomplish the goals discussed above, the Data Development activities described in sections 2.2.4 and 2.2.5 of the draft Implementation Plan provide a structure that can deliver meaningful and necessary products to users. The panel believes that the heart of this structure, the Global Processing Center envisioned in the draft

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Implementation Plan, ought to assume a broader role, as a Central Processing and Assessment Facility for Water Vapor Data and Analyses, by actively ensuring that the goals cited above are achieved.

Within the currently planned structure, GVaP should explicitly involve centers that collect and compare special, high-quality, high-resolution water vapor measurements with the measurements made by various global observing systems. Especially important, too, is the need to involve operational weather centers in GVaP, which will not only benefit the creation of a merged product, but, conversely, will also expose the operational centers to ongoing developments in the measurements. One of the more tangible benefits of the GEWEX Continental-Scale International Project (GCIP) has been the improvement of the National Centers for Environmental Prediction (NCEP) operational weather analysis system using results obtained from the measurement campaigns (NRC, 1998). The panel believes that the operational centers would accrue similar benefits were they to be linked to GVaP through the Central Facility. This goal could be accomplished by including an Operational Weather Analyses and Data Center on equal footing with the other Centers in the Implementation Plan's Data Development Procedure. The outputs from such a Center could, for instance, be effectively used to inform the process of defining the vertical structure needed for computing water vapor fluxes.

As noted in the draft Implementation Plan (IGPO, 1998b), models for structuring GVaP already exist in both the International Satellite Cloud Climatology Project and the Global Precipitation Climatology Project. There is every reason to believe that a GVaP similarly organized around a scientifically strong, active Central Facility will also be successful. Like these two projects, one of the greatest benefits of GVaP will be the creation of carefully synthesized water vapor data sets to serve the research community.

## U.S. Opportunities

To understand the role of water vapor in the climate system, a comprehensive and ambitious program is required, as recognized by the GVaP Science and Implementation Plans. GVaP could make major

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contributions to this effort by focusing on the data collection, processing, and analysis tasks, in a fashion similar to that of other GEWEX Radiation Projects. In making these contributions, GVaP must maintain close ties to the relevant research communities to ensure that its products are being developed with maximum utility. A U.S. national research program would benefit considerably from a foundation grounded thusly on quality-controlled, comprehensive data sets.

To realize the key contributions noted above, the panel recommends that U.S. agencies consider targeting support for one or more of the individual Data Centers and/or the Central Facility, as appropriate. For example, NCEP, the only civilian operational meteorological center in the nation, might be selected by the federal agencies to host a center focused on the utilization of operational products related to water vapor. Competitive proposals and bids for operating any of these organizations will help ensure that the best possible expertise is brought to bear on the challenge of measuring and analyzing water vapor. The panel wishes to emphasize, however, that in no way should such support, including that for a scientifically strong and active Central Facility, be regarded as a substitute for maintaining a vigorous, well-funded extramural research community. Agency support for research outside the GVaP data development structure needs to be part of an overall GVaP effort, and the activities of individual investigators need to be properly considered by GVaP.

The first step in advancing understanding of water vapor and its role in the climate system is to obtain an accurate quantitative description of the variations of water vapor in space and time; several global data sets already exist, but, as alluded to at the outset, their quality is less than desirable. The U.S. program can leverage its limited resources to accomplish this step most effectively by participating in the international GVaP project. Contributions that the United States should make—in addition to its current activities such as remote sensing —include the following: (a) improve instruments, analysis techniques, and sampling strategies to make better water vapor measurements, with special emphasis on efforts to increase vertical and temporal resolution and to improve accuracy in the upper troposphere-lower stratosphere region; (b) implement use of reference radiosondes to facilitate the ongoing calibration of different moisture sensors; (c) provide critical, high quality data sets from the U.S. DOE ARM

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program sites and WVSS to validate satellite remote sensing results; (d) lead the effort to compare and evaluate available and new data sets; and (e) undertake a new synthesis of existing and new sources of information about water vapor to produce a global water vapor data set with the needed improvements in accuracy.

Although the above are necessary first steps, it is essential that a U.S. GVaP effort recognize the importance of combining water vapor observations with other data to understand the complete water exchange process. For example, a close association between GVaP and the GEWEX Cloud System Study will help advance understanding of cloud-water vapor interactions. In addition, effort should be made to collect improved and more detailed water vapor measurements as part of the GEWEX America Prediction Project. A goal of U.S. hydrologic research programs should be to quantify the rates of evaporation from the land and ocean surface, the rates of water transport by large-scale atmospheric motions, and the rates of conversion of water vapor into clouds and precipitation. Thus, the products of the GVaP program must be capable of being integrated with other analyses of evaporation, clouds, precipitation, convection, and winds, over Earth's entire surface. For instance, improvements in wind observing capabilities, particularly in the lower troposphere, will be required if water vapor transport is to be accurately estimated. It is therefore necessary that the development of new data products within GVaP be undertaken with an awareness of how the data will be used (e.g., for analysis and modeling estimates of large-scale transport, radiative effects, energy cycling) to ensure that the research objectives of the scientific community are met.

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# Acronyms

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| ACSYS | Arctic Climate Systems Study |
| AIRS | Advanced Infrared Sounder |
| AMSU-B | Advanced Microwave Sounding Unit |
| ARM | Atmospheric Radiation Measurement |
| CLIVAR | Climate Variability and Predictability |
| DIAL | Differential Absorption Lidar |
| DOE | Department of Energy |
| GCIP | GEWEX Continental-Scale International Project |
| GEWEX | Global Energy and Water Cycle Experiment |
| GPS | Global Positioning System |
| GVaP | GEWEX Global Water Vapor Project |
| MDCRS | Meteorological Data Collection and Reporting System |
| MHS | Microwave Humidity Sensor |
| NASA | National Aeronautics and Space Administration |
| NCEP | National Centers for Environmental Prediction |
| NOAA | National Oceanic and Atmospheric Administration |
| NVAP | NASA Water Vapor Project |
| SPARC | Stratospheric Processes and their Role in Climate |
| SSM/I | Special Sensor Microwave/Imager |
| TIROS | Television and Infrared Observation Satellite |
| TOVS | TIROS Operational Vertical Sounder |
| UTH | upper tropospheric humidity |
| VLBI | very long baseline interferometry |
| WCRP | World Climate Research Programme |
| WVSS | Water Vapor Sensing System |

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