13. Panel Discussion

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Dr. Manabe discussed a comprehensive strategy for the validation of a climate model. It includes the monitoring of the factors that force climate, the prediction of climate change by a state-of-the-art model and the validation of the model based upon the comparable assessment of predicted and observed climate changes (Fig. 13.1). He emphasized that the long-term monitoring of climate is an indispensable part of this strategy. In order to distinguish the anthropogenic change from the natural variation of climate, he also stressed the importance of studying the latter by use of a coupled ocean-atmosphere model.

With regard to the monitoring of the energy cycle, he suggested focussing our attention on the monitoring of those variables which we can measure with sufficient accuracy. Dr. Manabe noted specifically that, in the GFDL climate model calculation for doubled CO_2, the CO_2-induced changes of globally averaged, net radiative fluxes at the top of the atmosphere and horizontal transport of heat in the atmosphere and oceans are very small and probably beyond current measurement capabilities. Instead, it may be easier to monitor the long-term change in the thermal structure of the atmosphere and oceans. He suggested that radiation budget measurements are more appropriate as part of process studies, as opposed to continuous monitoring of the detection of long-term change. He noted, however, that it is essential for the validation of a climate model to monitor the long-term changes of key variables such as solar irradiances, cloud, snow cover, sea ice, aerosols and their radiative effect. *[Monitoring the radiation budget is still considered crucial, but since plans are well in hand for spacecraft missions for this purpose, we do not consider this as "missing" - Ed.]*

In conclusion, Dr. Manabe believes that Climsat is a prudent proposal that fills critical gaps in climate monitoring.

Dr. Wigley concurred with Dr. Manabe and emphasized that interpretation of the present climate record requires knowing also about the lag in realized climate warming due to the oceans. Thus complementary programs for frequent and regular monitoring of the 3-D structure of the ocean, such as proposed as part of the Global Climate Observing System (GCOS), can contribute. *[Earlier discussions mentioned also the potential contributions of acoustic tomography, such as proposed by Munk and Forbes (1989), for analysis of the ocean thermal lag problem. Climsat would also represent an important contribution to GCOS plans by providing better calibrated, though less detailed measurements to which the operational weather measurements could be anchored - Ed.]*

Dr. McElroy reviewed scientific questions about tropospheric ozone. He pointed out that in the past decade many of the surprising changes in ozone profiles in the lower stratosphere have been revealed by SAGE measurements. There are two issues concerning ozone profiles: (1) continued monitoring of the 3-D distribution of ozone changes and (2) understanding the mechanisms for the change. He agreed that proposed SAGE measurements on Climsat would be adequate for monitoring ozone changes in the lower stratosphere and upper troposphere. It would be better still if the monitoring could be extended down to 6-8 km in the troposphere. The monitoring must be done with an overview of stratospheric chemistry. Measurements of ozone concentrations need to be good to 3 ppm; CH_4 changes need to be measured as well. A strategy to understand the processes governing the ozone changes needs to be developed; it will most likely involve aircraft measurements in conjunction with the satellite measurements. *[Improvements of SAGE III over its predecessors will increase its depth of penetration into the troposphere (Section 8), but sampling questions remain and require study - Ed.]*

Dr. Charlson endorsed Climsat for monitoring aerosols to quantify their direct effects on the radiative balance of the planet. The science for the indirect effects of aerosols on clouds is relatively

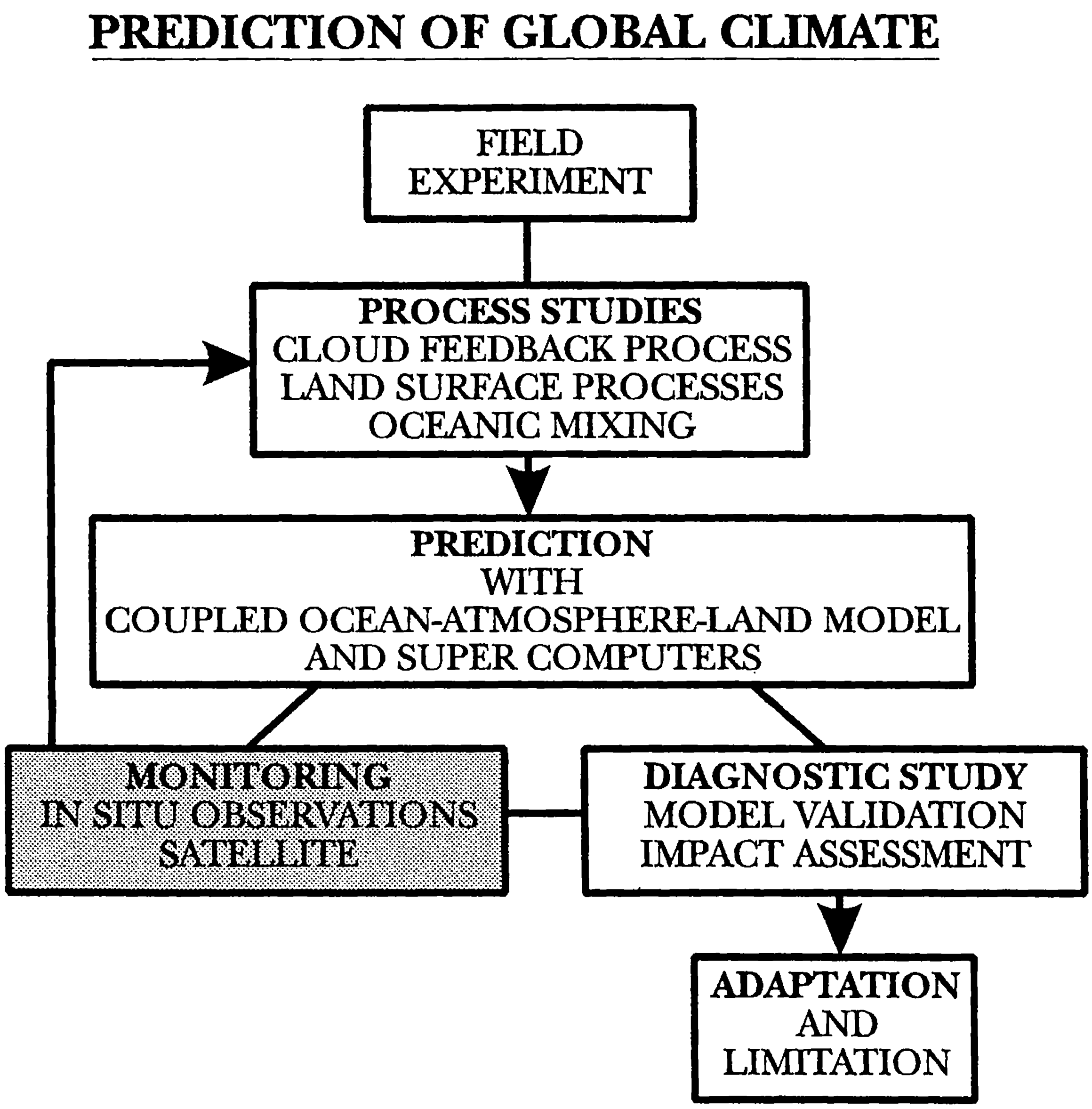

Fig. 13.1 Overall strategy for understanding and predicting climate change, as presented by S. Manabe.

young and it is premature to specify monitoring requirements to address that problem. Dr. Charlson also pointed out that there is a beautiful match between Climsat and ground-based programs, such as those of CMDL and AEROCE, in terms of geographic coverage and the sensitivity in optical thickness measured. However, the ground-based programs are not adequately funded at present. If adequately funded, they could provide the crucial ground-based supplement to Climsat. Echoing Dr. Manabe, he emphasized that understanding the role of aerosols in the changing climate comes only from the integration of ground-based and satellite datasets, process studies, documentation of aerosol composition and source fields in atmospheric chemistry models and climate models.

Dr. Hofmann reviewed the discussion on stratospheric aerosols and stressed the need for continued long-term monitoring of background aerosols in the lower stratosphere/upper troposphere. The monitoring is necessary because changes in background (without volcanic eruption) stratospheric aerosol can result directly from jet aircraft emissions or indirectly via changing stratospheric temperature and circulation. He also pointed out that increases in the mass of aerosols in the lower stratosphere have resulted from an increase in the number of large particles, even though the total number density has remained constant, so measurements of aerosol size are also needed. The relationship between changes in lower stratosphere ozone and large particle density is unclear and needs to be investigated.

Dr. Betts summarized the discussion on water vapor. He argued that the lack of a sufficiently accurate validation dataset of water vapor has been an important limitation on the improvement of climate models. Specifically, ground-based measurements of specific humidity remain poor above 6 km or below -40°C; the quality of humidity measurements from operational satellite instruments such as AMSU and HIRS in this region has not yet been established. Furthermore, products of data assimilation, such as the analyzed fields from ECMWF, are model dependent, and cannot be used as true tests of the performance of any climate model. It was only two years ago that variability in relative humidity at 300 mb in the tropics in the ECMWF GCM was validated by SAGE data, even though the SAGE data are biased towards clear sky.

Dr. Betts suggested that retrievals of humidity profiles need to resolve, at minimum, from the planetary boundary layer to the freezing level, from the freezing level to ~300 mb, and above 300 mb. In other words, vertical resolution of a couple of kilometers is acceptable. *[Such resolution is readily achievable by the MINT instrument on Climsat, especially with cross-comparison to SAGE in the upper troposphere - Ed.]*

Dr. Betts concluded that Climsat can make an important contribution to a <u>coupled</u> dataset on thermodynamics and cloud structure. Because time scales are different at different heights in the atmosphere, this dataset will be crucial for understanding coupling on longer time scales in the tropics.

Dr. Wielicki presented his views on clouds. Monitoring requires instruments that are accurate enough to measure very small changes. He is doubtful that present instruments are capable of the level of accuracy needed for detecting changes in cloud properties. Process studies, on the other hand, will contribute to improving physics in models, which can then be used to extrapolate future changes. Dr. Wielicki believes that EOS has taken a visionary step towards obtaining measurements for understanding cloud processes. Nevertheless, lidar and radar measurements are not included and should be added in the future.

In the discussion opened to all workshop participants, there was a general consensus that decadal monitoring is crucial for understanding climate change and that the monitoring needs to be low cost so that it can be continued for decades. No expensive program will be maintained on decadal time scales. The monitoring should include both ground-based and satellite measurements. Calibration is a central issue. The urgent plea for a reference sonde network highlighted the limitations of uncalibrated data for climate change studies. The discussions further emphasized Dr. Manabe's summary chart (Fig. 13.1) that the monitoring has to be carried out in the broader context of a program that also includes process studies and integrative modeling.

The discussions also generated many comments about EOS and about the relationship of Climsat to EOS.

Dr. Manabe asked whether the scientific objectives of EOS and other satellite programs have undergone the same careful scrutiny as Climsat has. He cautioned that if programs aim for more than what is absolutely needed, then inevitably scientific research will suffer during a budget crunch. He wanted to know: what are the scientific questions EOS is asking? what are the instruments needed to provide answers to the questions? and are those instruments included in EOS?

Dr. Wielicki replied that the evolution of EOS was different from that of Climsat. The Earth system is so intimately linked that it is not effective for each scientific discipline to separately address its measurement needs. The EOS strategy is to "combine and conquer" rather than to "divide and conquer." MODIS was mentioned as an example of an EOS instrument that serves the needs of several scientific disciplines.

Dr. Wielicki reiterated that EOS has recently undergone an engineering review. He also noted that the Payload and other EOS panels, comprising representatives from the science community, have spent innumerable days setting priorities for EOS.

Dr. Charlson emphasized that such reviews do not imply endorsement by the entire community, and he specifically pointed out that aerosol measurements had not been considered a priority by EOS until the recent Arizona meeting *[the EOS Tropospheric Anthropogenic Aerosol Workshop, December 16-17, 1991, chaired by R. Dickinson - Ed.]*. Dr. Hofmann commented that while ground-based measurements are acknowledged to be an integral part of EOS, and while members of that community were asked to assist in the justification of the program, there is as yet no follow-through (funding) to integrate ground-based measurements into EOS.

Dr. Manabe's sentiments were echoed several times throughout the discussion. It was suggested that the EOS program is too large for any scientist to fully grasp in its entirety, and that packaging global change observations on such a large scale effectively prohibits careful scrutiny, and thus there may indeed be gaps as well as unnecessary redundancy. Dr. McElroy suggested that there is room for programs intermediate between the regional detailed focus of ARM and the global all-encompassing ambitions of EOS.

It was pointed out that Climsat and EOS are synergistic as well as in competition. It is important to make clear how much duplication there is of Climsat on EOS. Climsat is clearly designed to be a monitoring mission. It was mentioned that the concept of monitoring may be somewhat different in the EOS program. A representative from NASA Headquarters (Dr. Ming-Ying Wei) said that while EOS has never been explicitly labelled as a monitoring program, it attempts to collect long-term datasets as best it can, but acknowledged that there may be data gaps.

Dr. Hansen explained that EOS can provide climate process data but does not fulfill the requirements of climate monitoring, showing a table listing reasons which are contained here in Table 7.5. First, EOS does not include an inclined precessing orbit, so that EOS is not able to monitor change of diurnal cycles. Second, EOS puts "many eggs in a large basket" which cannot be replaced easily, so that the failure of a single instrument or spacecraft will lead to a data gap. Third, monitoring for long-term change requires data continuity and instrument longevity for decades, which is a realistic possibility with Climsat. Fourth, Climsat is comprised of two satellites; the overlap allows cross-calibration of instruments on replacement satellites. EOS, by contrast, has back-to-back missions with no "hot spares" (satellites to launch immediately after a failure). Fifth, small instruments on small satellites are inherently cheaper and easier to replace. Furthermore, EOS does not include all the instruments in the Climsat proposal, in particular, the infrared interferometer, whose single detector gives the needed high wavelength-to-wavelength precision in the thermal region, and which has a proven long life. The conclusion is that Climsat is needed as a complement to EOS.

Dr. Wielicki argued that EOS duplicates much of the capabilities of Climsat, since both SAGE and EOSP are EOS selected instruments, and both AIRS on EOS and MINT proposed for Climsat are spectrometers that cover the thermal region. *[Table 7.5 in Section 7 of this report explains why this apparent duplication of instrumentation does not mean duplication of climate monitoring capability. Neither SAGE nor EOSP is scheduled to fly until the 21st century, and then only on a single spacecraft and orbit. Additionally, the AIRS (infrared spectrometer) has been descoped and now measures only separate portions of the spectrum. If the Climsat mission proceeds, SAGE and EOSP could be excluded from the EOS platforms, thus eliminating the potential duplication and reducing EOS costs - Ed.]* Dr. Rossow noted that instrument design should respond to the scientific questions posed. For example, even though several instruments claim to "do aerosols", most of them do not have the needed sensitivity to detect a change in optical thickness of even 0.1, not to mention the required 0.01.

The costs of EOS and Climsat were also discussed. Dr. Mahlman compared the EOS budget of $750M/yr to that of the US Global Change Research Program (USGCRP) at $1.1B/yr. If we were starting over, the scientific community would "certainly not necessarily" spend the budget in the same way. It was pointed out that the USGCRP must address a large number of questions besides those addressed by EOS. Dr. Mahlman further observed that the wisdom of Climsat is that it is designed specifically for monitoring and that its objectives and budget are consistent with the commitments of the USGCRP, whereas none of the EOS moneys is designated specifically for monitoring in support of the USGCRP.

Dr. Manabe cautioned that with a budget crunch, hardware is delayed while scientific research invariably is decimated. Dr. McElroy reminded the audience that budget crunches reduced the amount of effective science carried out in both the Apollo and Viking programs even though both programs had long-term interests in science.

Further conversation focused on the costs of Climsat. Dr. Hansen stated that Climsat instruments have well-proven predecessors and are not technological challenges, though they incorporate the latest technology where appropriate. With known weight and characteristics (e.g. the number of channels) of the instruments, cost estimates for each instrument should be fairly accurate. It was commented that the number of carbon copies of each instrument needs to be specified at the outset, so that exorbitant restart costs can be avoided, should the manufacturing plant be shut down, as in the case of SSM/I. How many copies are sufficient for two satellites to maintain data continuity should an instrument fail? Dr. Hansen said three for the initial 5-10 year period, but the number is dependent on actual lifetimes. *[Such a scenario presumes a common design target of 5-year instrument/spacecraft lifetime and one hot spare. Previous flight experience suggests that this is a reasonable estimate - Ed.]*

Dr. Hansen proposed that Climsat data would be archived with EOSDIS, which has a protected budget. However, budgets for the essential complementary measurements and for scientific investigations using the data would depend on the scientific scope of and the number of scientists in the Climsat program. Dr. Wielicki said that ERBE's science budget is $5M/yr, which includes costs for data processing and quality checking. If ERBE is used as the model, then, with three instruments, the Climsat science budget would amount to $150M for a decade, comparable to the order of magnitude of the hardware costs. This, it was remarked, would be unprecedentedly heavy weighting towards science. Dr. Hansen cautioned against an expansion of Climsat objectives, quoting Dr. V.

Suomi, who warned that "the worst enemy of a good experiment is a better experiment." The science and supplemental measurements of Climsat should be as tightly focused as possible.

There were comments that it is important to recognize that no satellite program is stand-alone. For example, the Dobson network is crucial to the calibration of TOMS data. Dr. Hofmann stressed that Climsat needs to lock in as much supplemental measurements in advance as possible. Several in-situ monitoring programs, such as those of CMDL and NDSC, all offer opportunities for comparison with and validation of Climsat data. Small programs, such as the balloon soundings of stratospheric water vapor using cross-wind hygrometers, should not be ignored. Sonde data, if calibrated, are crucial for all investigations of the hydrologic cycle, not just for validating water vapor retrievals by Climsat. Dr. Hansen suggested that perhaps some measurements could be funded as part of the Climsat program, while others could be leveraged into ongoing programs, as TRMM has led to increased funding for the Coupled Ocean-Atmosphere Research Experiment (COARE) of the Tropical Ocean/Global Atmosphere (TOGA) Program. Dr. Rind emphasized that satellite measurements should not used as an excuse to "de-select" in-situ measurements.

The discussions adjourned at 3 p.m. Dr. Hansen thanked the participants for their valuable time and candid discussion. He stated that, because of their encouragement, he and his colleagues would continue to push for the Climsat concept.