slower. Internal ice near the terminus of the rock glacier, where velocities are slower still (Figure 2, Profile C), may approach 3000–4000 years in age.

It is possible that decreased accumulation and consequent thinning of the rock glacier since the end of the Little Ice Age has caused velocities to decrease somewhat in the past century [*Potter*, 1972]. The bench at the mouth of the cirque and the slightly raised lateral moraines near the headwall suggest some thinning has occurred at the upper end of the rock glacier; however, the decrease in ice-thickness, and thus surface gradient and velocity, indicated by these possible changes appears to be small (probably <10 m decrease in thickness).

Looking to the Future

These results, and those of previous rock glacier coring studies [*Haeberli et al.*, 1988], show that some, and perhaps many, rock glaciers have massive ice cores, and that these cores can be drilled successfully. Models of ice flow paths and ice ages using standard glacier flow laws will be crucial to establish precise ages of ice within various sections of a rock glacier during future ice core studies. The original sedimentary structure, primary depositional isotopic information, and exceptionally old ice preserved within rock glaciers are untapped resources that may lead to new insights into the evolution of polar and alpine settings.

Rock glaciers may eventually provide records of climate change through the Holocene. In exceptionally cold, dry regions, such as the Dry Valleys of Antarctica, they might preserve intact ice records that reach much further back in time, potentially spanning the entire Pleistocene. The morphologic similarity of the Galena Creek rock glacier to many other rock glaciers in the Absaroka Mountains, and to those in other alpine regions, indicates that these findings are broadly applicable.

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Researchers Chart Course for Updating Radiation Belt Models

PAGES 217–218

Exciting new results from the Combined Release and Radiation Effects Satellite (CRRES) and Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) missions reveal that some of the energetic electrons and ions trapped in the Van Allen belts come from unexpected sources. This new development and other changing perceptions clearly show that the empirical models of the radiation belts produced by NASA and Russia about 10–15 years ago have been outdated for some time and need to be revised.

At the Radiation Belts: Models and Standards workshop held in Brussels from October 17 to 20, 1995, members of the community reviewed the most recent models of the trapped radiation belts, identified the lesser-known aspects of the radiation environment, and outlined a strategy for updating models and developing new models.

New approaches to modeling made possible by networking and the increased power of computers offer many possibilities. In one approach, data owners could form globally distributed databases simply by allowing Internet access to their local computers. Models can also be produced from the raw database at the time of use. While this does not fulfill the goal of producing a single standard model, it does allow for the evolution of models as better data become available and lets users customize models for their particular needs.

Participants agreed that a new standard model would best be produced under the supervision of a respected competent international body, such as the International Standards Organization or the Committee for Space Research. Empirical data from around the world would provide input to the models, and coordinate systems in which to organize the data would have to be agreed upon. The model would best be produced by one supervised group using a common database.

The workshop was organized into four separate but related topics: physical models, empirical models, coordinates and indices, and missions and data acquisition.

Physical Radiation Belt Models

The physical radiation belt model group was formed to answer the essential question: What do we want from physical radiation belt models? Subsidiary questions included: Which kind of models can be used? Are these models accurate? What are the principal sources of the radiation belts? And, what data are necessary to build good models?

Physical models are designed to understand the processes that create, support, and modify the structure and dynamics of the radiation belts. For experiments, physical models also must be able to allow extrapolation beyond existing measurements in all dimensions of the problem (in space, energy, pitch angle, etc.). Temporal extension into the future in order to make predictions is also crucial. This forecast capability demands simple scaling laws and requires determination of the best variables to use for describing radiation belt behavior. Obviously, well-conceived physical models can be useful for organizing large data sets.

Current radiation belt models are not adequate for space science needs, the group concluded. In particular, existing models at low altitude (for protons) must be reviewed, and a new model for electrons (especially in the outer zone, in light of the CRRES and SAMPEX results) must be devised. But before models can be reviewed or devised, more data are needed. In particular, low-altitude data (especially in the slot region) will be useful. More magnetic and electric field measurements (particularly for waves) are also necessary.

Empirical Radiation Belt Models

The empirical radiation belt model group looked at whether the existing models fulfill users' needs, and if not, the kind of new models that could be designed. The group also

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discussed guidelines for producing new models.

There is a pressing need for an easy-to-use global standard model that could be accessed by engineers, the group agreed. Models for scientific simulation need not be uniform and probably can be created in accordance with each scientist's particular interest. Users of this latter type of model expect to set up a complicated description of the magnetospheric state and exercise caution as to where the model is valid. Spacecraft engineers do not have the time to investigate the detailed properties of a model and need results that are compatible with those of their colleagues and competitors throughout the world. For engineering purposes, the state of the magnetosphere is generally unknown, except in a statistical sense.

The group identified a number of properties they would like to see in the new model that are incompatible with a single structure like the B-L grid used by the NASA models. Hence the new model needs to be a composite of submodels covering different areas of space. For instance, the low-altitude region could be described in terms of a function related to atmospheric density, while geostationary orbit could include detailed flux probabilities that would be hard to calculate throughout the magnetosphere. This scenario lends itself to a modular design of software that is an integral part of the model itself. This allows the model to be easily updated with the replacement or addition of subroutines. Updates should be developed as often as significant discrepancies occur. A top-level module would determine which subroutine to call and would present users with a very simple interface.

Coordinates and Indices

The coordinates and indices group began with a discussion of the use of canonical coordinates with empirical radiation belt models. Even canonical coordinates do not solve all problems. At low altitudes, the Earth's atmosphere acts as a moving boundary, depending on solar activity. At high altitudes, the magnetic field models cannot reconstruct the field lines on which trapped particles travel. One way out of these difficulties is to order empirical particle data in terms of geocentric coordinates (as is done in the recent Russian low-altitude electron model). However, to cover the whole region of the trapped particle belts, huge model arrays are necessary.

It is vitally important that model builders and users specify in detail how they constructed or used trapped particle models. That is, they should specify which magnetic field models they used (including epochs), which coordinates (and how they calculate them), the binning procedures, etc. Consistent and clear definitions of the coordinates and parameters used (compare, the confusion on the definition and use of L) are also important. There should be a consensus on how to treat omnidirectional data: they should not simply be binned in terms of pitch angle independent (B,L) values; deconvolution in terms of pitch angle seems to be unavoidable.

Missions and Data Acquisition

Sufficient data are already coming in to do a good job of near real-time monitoring, the missions and data acquisition group agreed. There is a pressing need for near real-time data representations. A pilot project was suggested that would assemble flux maps of the radiation belts based on current data (with a maximum 1 week delay). This should be provided as an on-line service (perhaps via the World Wide Web). The group also agreed that instruments with increased pitch angle information are needed aboard new missions.

There is a need for more accurate radiation belt data, the group concluded. This need increases substantially as new satellite systems begin operating in different regions of space. Moreover, with greater complexity and reduced active volumes, satellites are often increasingly susceptible to radiation damage. Users need statistical surveys of the radiation belts to assess the risks to their spacecraft and up-to-date reports to diagnose the causes of any anomalies experienced. Many data sets covering the vital regions of space are already being collected regularly, but their potential for monitoring radiation are not being fully exploited.

The group recommended that a global radiation belt database be compiled from current data collections using modern computing and networking technology to achieve a near real-time response and that spacecraft operators be encouraged to place standard radiation monitoring equipment on all spacecraft. Such equipment should cover hot plasma and energetic electrons. Data included in the database should provide more comprehensive spatial coverage; and the quality of the data would be enhanced by the deployment of four spacecraft in geostationary transfer orbit, equally spaced in local time, carrying instruments, capable of detailed pitch angle resolution. Such spacecraft could be microsatellites (~50 kg).

As first steps in this strategy the group suggested that, in the interests of global coverage, the major agencies be requested to make data sets freely available to all, and that an international working group be formed. The working group would pursue these objectives and seek the support necessary for an initial pilot study to collect and correlate the current data sets.

The four panel reports, this article, and the abstracts of all 60 papers or posters presented at the workshop are displayed in the WWW URL pages at magnet.oma.be/wrb.html. Most of these papers, including an additional early (1966) unpublished manuscript by C.E. McIlwain, will be published in the proceedings.

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Methane Gas Hydrate Drilled at Blake Ridge

PAGE 219

Gas hydrate is a solid phase of water and low-molecular-weight gases, mostly methane, that forms in marine sediments when gas concentrations are adequate, temperature is low, and pressure is high. Although gas hydrate may be a common phase in the shallow geobiosphere, little is known about it because it is unstable under normal surface conditions.

Leg 164 of the Ocean Drilling Program (ODP) studied natural gas hydrate in marine sediment at the Blake Ridge on the continental margin off southeastern North America and found that it occupies more than 1% of the sedimentary section from 200 to 450 m below seafloor (mbsf). At the Blake Ridge, free gas is dispersed throughout a region a few hundred meters thick beneath the gas hydrate-bearing zone. Coupled with geophysical data indicating that gas hydrate occurs throughout a laterally extensive portion of the Blake Ridge, the drilling confirmed that these sediments contain enormous amounts of methane.

Gas hydrate-bearing sediment sequences are usually indicated by bottom-simulating reflectors (BSRs) in seismic reflection profiles. BSRs are associated with the base of the gas hydrate stability field and may represent the interface between hydrate-bearing sediments above and gas-charged sediments below. However, the detailed origin of BSRs and their relationship to gas hydrate abundance are poorly understood. Sites 994, 995,