

Report of the NASA Workshop on Risk-Benefit Assessment of Observing System Decision Alternatives

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Executive Summary of Findings and Recommendations

Workshop Goal 1: Estimate the benefits associated with TRMM data in the context of operational forecasting (particularly associated with tropical cyclones), and the associated loss of benefits in the absence of TRMM data. Such estimates will include consideration of uncertainty.

Finding 1.1. All workshop participants agreed that the TRMM data are now being, and will continue through the remaining lifetime of the mission to be, used by agencies in the US and abroad to aid operational marine forecasting, especially in the data-sparse Pacific and Indian oceans.

Finding 1.2. Participants agreed unanimously that the risk to human life of not having TRMM data available for operational uses cannot presently be accurately quantified.

Finding 1.3. Most, but not all, workshop participants subjectively estimated that the risk to human life of an uncontrolled reentry would be exceeded by the risk to human life of not having TRMM data for operational uses.

Recommendation 1.1: If NASA wishes to use risk assessments as a basis for deorbiting assessments, the agency must consider such risks and benefits more comprehensively than it presently does.

Recommendation 1.2: Given the material presented at the workshop, we recommend that NASA should not base its decision to extend the TRMM mission primarily on quantitative comparisons between "lives potentially saved" through operational exploitation of TRMM data and "potential hazard" associated with uncontrolled reentry.

Workshop Goal #2: Place the risk and benefit information into the context of the various decision alternatives that NASA is faced with for the future of the TRMM satellite.

Finding 2.1. The present and projected health and performance of TRMM are excellent in the context of experience with research satellites.

Finding 2.2. Workshop participants unanimously endorse boosting the TRMM orbit as soon as possible from 350 km to 400 km, so long as the scientific community also endorses this alternative.

Recommendation 2.1. During the approximately 3 years of additional on-orbit operations that would be provided by boosting TRMM NASA should (a) reevaluate its deorbiting decision guidelines, (b) conduct that research necessary to more comprehensively and better understand risks and benefits associated with deorbiting decision alternatives, and (c) with the reevaluated decision criteria and

results of research related to risks and benefits, revisit the TRMM deorbiting decision in late 2004.

Workshop Goal #3: Review engineering studies of risks associated with alternative TRMM reentry strategies, including consideration of the accuracy and estimates of the uncertainty associated with such studies.

Finding 3.1: As presented at the Workshop, uncertainties in potential risks of uncontrolled reentry are so large as to diminish substantially the usefulness of this calculation as a decision threshold.

Recommendation 3.1: NASA should consider (a) making its reentry risk calculation more transparent, rigorous, and meaningful, (b) placing its reentry risk calculations into a more comprehensive framework.

Workshop Goal #4: Consider a longer-term strategy for “technology assessment of observing systems” to provide decision makers with reliable and scientifically robust knowledge of risks and benefits associated with similar future situations.

Finding 4.1. To primarily, or even jointly, serve direct operational functions, the TRMM program would likely be designed, managed, and implemented in a very different manner than it has been as a research program.

Finding 4.2. If advances in engineering design and launch vehicle success rates allow for the potential extension of research missions beyond original plans, then this creates a new set of decisions for the remote sensing science community.

Finding 4.3. Decision makers lack knowledge necessary to prioritize observational programs and plans according to their contributions to science and society.

Recommendation 4.1. Decision makers would benefit from an ongoing effort devoted to the “technology assessment of observing systems” that would seek to evaluate the broad costs and benefits of alternative observing strategies for both science and society.

Recommendation 4.2. NASA and its operational partners would benefit from a more systematic approach to the “transition of research to operations.”

Introduction

In the near future NASA faces an important decision about the termination of the Tropical Rainfall Measurement Mission (TRMM). There are at least two alternatives, each with potentially significant consequences for science and society. One alternative is for NASA to de-orbit TRMM in a controlled fashion, virtually eliminating any risks to human life and property associated with an uncontrolled reentry. However, this would reduce TRMM's potential scientific data-gathering lifetime, which would reduce the benefits of that data to meteorological research and operations, particularly related to tropical cyclone forecasts. Another alternative is for NASA to extend TRMM's orbital lifetime, preserving the availability of the unique data collected by TRMM for research and operational meteorological forecasting, but increasing to an unknown extent the risks associated with TRMM's eventual reentry into the Earth's atmosphere. There are possibly other alternatives that involve similar trade-offs.

What course of action should NASA take?

As input to NASA's decision making process, a NASA sponsored a workshop, held in Boulder, CO on June 18-19, 2001, to provide a comprehensive perspective on the risks and benefits associated with the decision alternatives NASA faces with respect to TRMM. The workshop was organized by the National Center for Atmospheric Research and included the participation of a number of NASA (and NASA-supported) scientists and managers. The workshop also included participants independent of TRMM and independent of NASA. This workshop report is authored by those participants who at the time of the workshop did not receive funding from the TRMM project.

The workshop focused on the following tasks:

- Estimate the benefits associated with TRMM data in the context of operational forecasting (particularly associated with tropical cyclones), and the associated loss of benefits in the absence of TRMM data. Such estimates will include consideration of uncertainty;
- Place the risk and benefit information into the context of the various decision alternatives that NASA is faced with for the future of the TRMM satellite;
- Review engineering studies of risks associated with alternative TRMM reentry strategies, including consideration of the accuracy and estimates of the uncertainty associated with such studies;
- Consider a longer-term strategy for "technology assessment of observing systems" to provide decision makers with reliable and scientifically robust knowledge of risks and benefits associated with similar future situations.

Report findings and recommendations

Workshop Goal 1: Estimate the benefits associated with TRMM data in the context of operational forecasting (particularly associated with tropical cyclones), and the associated loss of benefits in the absence of TRMM data. Such estimates will include consideration of uncertainty.

NASA estimates that 157 kg of fuel is required to perform a controlled reentry of the satellite. At the present operational altitude of 350 km, this threshold will be reached in March 2003. With an uncontrolled reentry, i.e., letting fuel simply run out, TRMM would end its mission in October 2004. Workshop participants used the 350 km baseline orbit scenarios as the primary definition for TRMM mission milestones in the consideration of risk and benefit tradeoffs; as discussed in the next section (Workshop Goal 2), an alternate mission involving an immediate boost to 400 km and substantial delay in 157 kg and 0 kg fuel thresholds was also considered.

Finding 1.1. All workshop participants agreed that the TRMM data are now being, and will continue through the remaining lifetime of the mission to be, used by agencies in the US and abroad to aid operational marine forecasting, especially in the data-sparse Pacific and Indian oceans.

At the workshop several speakers presented evidence that use of TRMM observations has improved certain operational analyses of tropical cyclone locations. Near-real-time TRMM data are being used routinely by NOAA (TPC) and DoD (JTWC) in their tropical cyclone prediction, and analysis systems. The TRMM measurements thus contribute to these agencies' life- and property-saving missions. International use of the TMI data for tropical cyclone prediction is well documented via the interactions NRL-MRY has with the following organizations:

- NHC Miami, FL
- JTWC Pearl Harbor, Hawaii
- Fiji Meteorology Service, WMO forecast center
- Japan Meteorological Agency, Tokyo, Japan
- Bureau of Meteorology, Australia
- Meteo France, La Reunion Island, Indian Ocean

These organizations use the data via the NRL-MRY and FNMOC web page whenever there is a storm or suspect meteorological conditions in their areas of responsibility.

Statistics from JTWC showed that cyclone center location estimates based on TRMM measurements were more accurate than those from other satellite observations (SSM/I, Scatterometer, Geostationary) for a class of difficult to locate (relatively weak and disorganized) storms. The improved locations were shown in one case to have been used by the U.S. Navy as a consideration in ordering the movement of ships. In another case forecasters used TRMM data directly to modify the predicted intensity of a storm as it approached landfall in Taiwan. (However, the significance of such modifications for

emergency management and the storm's eventual impacts was not presented.) Improved cyclone initial locations have been related in the literature to improved storm location and evolution forecasts.

These rather simple, but important, uses of TRMM observations make it plausible that there is a direct link between the TRMM observations, improved forecasts of hazardous weather, and economic value of the data. However, neither estimates of these values, nor a direct link to a saved life or an injury averted from the use of TRMM data have been documented through rigorous research.

Finding 1.2. Participants agreed unanimously that the risk to human life of not having TRMM data available for operational uses cannot presently be accurately quantified.

Research has not been conducted that would allow for the quantification of the use and value of observational data in the context of decision making. Thus, decision makers lack knowledge necessary to prioritize observational program decision alternatives on the basis of quantitative risk assessment according to the actual and potential contributions to science and society. Absent such information, it is likely that decisions on issues such as TRMM deorbiting will continue to be made on an ad hoc basis.

It would be relatively simple to construct a “back-of-the-envelope” calculation of potential lives saved related to TRMM data availability based on a set of simplifying assumptions. However, participants agreed that because of the unverified nature of the cascade of assumptions on which such a calculation would be based, it would have little connection with reality. One reason for the lack of unanimity in the Workshop participants' estimation of relative risk is the lack of analysis and data on the direct and indirect roles of TRMM data in weather forecast operations. Anecdotes, back-of-the-envelope calculations, and incomplete case studies are not a substitute for reasoned conclusions based on rigorous, scientific analyses.

Finding 1.3. Most, but not all, workshop participants subjectively estimated that the risk to human life of an uncontrolled reentry would be exceeded by the risk to human life of not having TRMM data for operational uses.

This conclusion was reached primarily because the threshold of risk for an uncontrolled reentry provided by NASA is extremely small in an absolute sense – a risk of injury that NASA estimates to be 1 in 5,000 – but comparable, and in fact larger, than many decision thresholds based on risk used in NASA and other government agencies. To place this in context, if the use of TRMM data in forecast operations has only a 1% chance of contributing to avoiding a human casualty, this would be a 50 in 5,000 risk on a comparable basis. Most workshop participants considered the risk of loss of operational availability of TRMM data to be higher than this; however, several participants thought it reasonable that the risk might actually be lower.

Recommendation 1.1: If NASA wishes to use risk assessments as a basis for deorbiting assessments, the agency must consider such risks and benefits more comprehensively than it presently does.

Although the panel considered that the uncontrolled re-entry risks were likely smaller than the risks resulting from not having TRMM data available for forecast operations, the panel found that NASA was largely unprepared to quantify and evaluate the risks associated with the loss of TRMM data. NASA should support, or partner with those who support, rigorous research into the use and value of observational technologies in the context of research and operations. An example of a methodology that might be used for such quantitative risk assessments appears in Section 4.

Recommendation 1.2: Given the material presented at the workshop, we recommend that NASA should not base its decision to extend the TRMM mission primarily on quantitative comparisons between "lives potentially saved" through operational exploitation of TRMM data and "potential hazard" associated with uncontrolled reentry.

Extensions of research missions should be justifiable for several reasons distinct from immediate benefits to operational agencies, including:

- Important scientific discoveries that were unanticipated in the original mission plans and that can be exploited using additional mission data;
- Ensuring the continuity of critical climate data sets having little direct, immediate operational utility (this situation is particularly prevalent in the present period of transition from NASA-sponsored research missions to an operational climate observing system); and
- Allowing time for operational partners to evaluate and capitalize on new technologies and measurements being demonstrated in space by the NASA research mission.

The material and analyses examined by the workshop showed compellingly that TRMM makes critical contributions to scientific research. Numerical modeling results presented showed unforeseen potential for improving forecasts, especially of precipitation, and probably of cyclone movement and intensity, through research leading to improved models and assimilation of TRMM measurements. TRMM is establishing a unique time series of accurate, high resolution tropical precipitation measurements that can be added to the suite of multi-decadal measurements from other ongoing NASA missions; a substantial gap in the precipitation measurements will diminish the scientific impact and value of the entire measurement suite. Operational partners in the US and abroad are developing and testing focused data distribution systems and tailored TRMM analysis products. The TRMM mission therefore should be considered positively for extension for these reasons, independent of its contributions to immediate forecast operations.

A narrow risk-benefit evaluation would set a poor precedent for future NASA research missions that might be considered for extension. Many critical missions could (and should) qualify for extension based on the scientific and partnering criteria listed above, yet they may provide no immediate benefits to operational agencies. While contributions

to operations are important, NASA should not set the precedent that positive life-saving risk-benefit analyses are necessary to extend research missions.

NASA may desire to expand its ability to evaluate such decisions along the lines suggested in Recommendation 1.1 above.

Workshop Goal #2: Place the risk and benefit information into the context of the various decision alternatives that NASA is faced with for the future of the TRMM satellite.

Workshop attendees heard extensive presentations on the present hardware status of TRMM, and operational scenarios that are being considered to conserve onboard resources with only negligible impact on the scientific and operational quality of the data.

Finding 2.1. The present and projected health and performance of TRMM are excellent in the context of experience with research satellites.

The superb health of the combined TRMM Microwave Imager (TMI) and Precipitation Radar (PR) should be considered when any discussion is made concerning de-orbiting. These two instruments are creating a unique dataset of value to the research community. TRMM provides the first successful precipitation radar in space working along with a passive microwave sensor that increases its value to science and operations.

Fully successful research missions represent substantial engineering feats, and full or partial failures are frequent. The satellite community has recently seen the last 2 H2 rockets fail, including the demise of the MTSAT geostationary satellite that held great promise for the Asian/Western Pacific Region. SSM/IS (an operational instrument) and WindSat are both 6 months behind schedule, while EUMETSAT is almost 2 years late with MSG.

Finding 2.2. Workshop participants unanimously endorse boosting the TRMM orbit as soon as possible from 350 km to 400 km, so long as the scientific community also endorses this alternative.

In light of the excellent health of the spacecraft and its scientific payload, NASA has examined mission modifications that could conserve on-board resources with negligible impact to the TRMM data or spacecraft operation risk. In particular, NASA is evaluating raising the orbit of TRMM from 350 km to 400 km. A 400 km orbit has been identified which yields nearly identical sampling to the present orbit; the orbit raising can be accomplished using multiple applications of the identical thruster firings used to maintain the 350 km orbit at present. If boosted in August 2001, TRMM would reach the 157 kg fuel threshold (discussed in section 1 above) in November 2005. Uncontrolled re-entry from 400 km altitude following fuel exhaustion would occur in September 2009.

Workshop participants together compiled a list of potential benefits and risks associated with TRMM deorbiting decision alternatives. These are illustrative, and may not cover all potential risks and benefits. However, it is clear that the list that follows is

considerably broader than the comparison of “risk” that is apparently used currently by NASA. The list appears below the following Recommendation.

Recommendation 2.1. During the approximately 3 years of additional on-orbit operations that would be provided by boosting TRMM NASA should (a) reevaluate its deorbiting decision guidelines, (b) conduct that research necessary to more comprehensively and better understand risks and benefits associated with deorbiting decision alternatives, and (c) with the reevaluated decision criteria and results of research related to risks and benefits, revisit the TRMM deorbiting decision in late 2004.

TRMM Re-entry Dates

	157 kg	0 kg
350 km orbit	March 2003	October 2004
400 km Orbit Aug. '01 boost [Jan '02 boost]	November 2005 [Sep. 2004]	September 2009 [Nov. 2008]

Benefits of Controlled Reentry

- 1) With controlled reentry, there is a vanishingly small probability of casualty. In the single example presented, the GRO satellite reentry was controlled successfully.
- 2) By controlling TRMM reentry, the U.S. would demonstrate leadership in managing space debris. In either scenario, even though TRMM would not contribute to long-term space debris, controlled reentry sets a precedent for stewardship of space.
- 3) Controlling TRMM reentry avoids the cost of extending the mission, and thus frees up money and other resources so that NASA can move ahead with the next generation of satellites. This is beneficial to NASA, because NASA prefers to develop and introduce new technology rather than to use old technology operationally. It may also benefit society, since the data from the next generation of satellites may be even more useful than the TRMM data.
- 4) Related to this, controlling TRMM reentry "saves money" in the sense that extending the mission would cost approximately \$X million for operations and \$Y million for research (assuming an extension of the current research budget), whereas controlled reentry costs only approx \$1 million. Of course, there will almost certainly be no real money saved in the sense of being returned to taxpayers or being reallocated to non-NASA projects. Thus, to the extent that NASA has an approximately fixed amount of money that can be allocated in different ways, saving money on TRMM means freeing up money for the next generation of satellites or for research on past or future satellite data. Uncertainties include: how does extending TRMM affect the NASA budget? How much does extending TRMM delay future missions?

5) Extending the mission incurs the risk of TRMM spacecraft failure and loss of ability to perform a controlled reentry at a later time. Uncertainties include: what is the risk of something going wrong despite all of the redundancies? How does the risk change as the satellite gets older? How much does it cost if TRMM is left up beyond the controlled entry threshold, then loses all science data and is no longer useful anyway?

6) If NASA management would prefer, in general, not to extend missions, perhaps because doing so confuses the budgeting or because they'd rather just launch new technology, controlling TRMM reentry provides a precedent to help management justify not extending future missions. Similarly, bringing TRMM down on schedule helps NASA keep to its current schedule and budget, so that it won't have to consider delaying other missions to pay for extending TRMM. This can benefit not only NASA, but also the scientific community, since it could lead to fewer (shorter) delays in resource allocations and launches for other missions.

Risks of Controlled Reentry

A) By controlling reentry, scientists lose considerable data potential. The data are useful to scientists and society in the short term (e.g., for weather research and for operational weather prediction). The mission was also originally designed as a climate mission, and without more data, the data set has a biased climatology (e.g., it has been primarily been taken during La Nina events). Furthermore, TRMM is proven to work, and there is a risk that the next satellite with data that could replace TRMM data may not work, or will be delayed -- if this occurs, the data loss will be an even greater problem than anticipated. Uncertainties in this include: how useful are the data? How important is the science that the data are helping produce? What data are we really losing (i.e., what is/will be obtained from other instruments)?

B) Connected with this, by controlling reentry scientists lose some potential for overlap with other instruments collecting similar data (e.g., CloudSat, scheduled to launch in 2004?). Uncertainties include: how important is data overlap in producing a useful climatological data set, in other words, to what extent is overlap needed to calibrate the data from new instruments to the data from TRMM?

C) If NASA is viewed by policy makers as reentering a satellite that's currently working, is already paid for, is beneficial, is a poster child of success, is providing lots of "bang for the buck," etc., this could have a negative political impact on NASA. NASA could be seen as wasting a healthy asset, or as being overzealous in reducing a risk that's already very small -- particularly since NASA is an agency that's supposed to take technological risks with its own resources. On the other hand, the damage and casualty risks of an uncontrolled reentry would not be borne by NASA, but would be imposed upon others involuntarily, and such risks are of a different type than typically associated with NASA activities.

D) By controlling reentry, scientists lose the opportunity to move towards more operational uses of the data. The data may have much potential benefit that has not yet

been realized because forecasters need time to learn how to use it, or because developers of models and data assimilation systems need time to learn how use the data in numerical forecasting -- by controlling reentry, we will not realize this potential. Also, data are less likely to be used operationally if forecasters expect that it will not be continuously available; thus, if forecasters know that TRMM will have a controlled reentry in the next few years, they are less likely to use the data. Scientists at operational centers (such as those developing data assimilation systems) are also less likely to learn how to use data if they don't have it currently available or believe that it will not be available in the near future. Uncertainties include: how potentially useful are the data, and on what time scale? To what extent will this potential be realized if we do have more data?

E) A hurricane or flood will cause a loss, and someone will blame it on the loss of TRMM data. To the extent that the lack of data did result in the loss, this is a risk to anyone who might be harmed, including people living in hurricane-prone areas in the Pacific (this is not an issue in the U.S./Atlantic because of the reconnaissance aircraft data), military operations, etc. To the extent that the lack of TRMM data is perceived to be responsible (whether it is or not), this is a political or publicity risk for NASA, the meteorological community, etc.

F) Controlling reentry could also set a bad precedent for NASA management, policy-makers, etc. For example, controlling reentry may mean that NASA's "guidelines" are considered an acceptable or good framework for making future related decisions, or that missions with the capability for controlled reentry should not be extended even if there is clear and convincing evidence that the benefit from the satellite outweighs the risk from the debris.

Other questions raised by workshop participants related to risks and benefits of TRMM deorbiting decision alternatives included:

- What is the risk of TRMM debris causing a casualty compared to other risks (e.g., the risk of launch debris causing a casualty)?
- To what extent do people distinguish voluntary from involuntary risks, and what does that mean for comparing risks of different events? What responsibility does NASA have to weigh the voluntary versus involuntary risks, particularly since many of those subject to the involuntary risk would not benefit directly or indirectly from TRMM data?
- Similarly, can we compare the risk of getting hurt by a weather system to that of getting hurt by TRMM debris if people perceive the risks very differently because one is more voluntary than the other?
- What do we really lose by having a gap in the climatological data set?
- What is NASA's role in providing operational data?
- If the data is so useful, why aren't users (e.g., NOAA, DOD, Australia) of the TRMM data helping pay for it?
- One might believe that the U.S. has an obligation to help countries that can't afford to launch their own satellites, but should NASA be providing operationally

useful data to the defense department or developed countries like Australia, when they could afford to pay for some or all of the cost?

- Could NASA engage in cost sharing to help transfer research data into operations?
- The results presented showed only a small improvement in the average numerical forecast (in research mode) due to the TRMM data. Is this small improvement beneficial? Is there a direct relationship between numerical model forecast accuracy and subjective marine forecast/warning skill for severe weather systems?
- What is the real operational value of TRMM data?
- What does the learning curve for using TRMM data in operations (directly by forecasters, or by data assimilation systems and numerical models) look like?
- Will the data be more beneficial for operational forecasts in a few years (if the mission were to be extended), or will the benefit always be "just over the horizon"?
- To what extent can the potential benefits from TRMM data be realized by mining the existing TRMM data to develop algorithms, then implementing the algorithms when the replacement data sets come along?
- We know that we have had substantial investment in forecasts and substantial improvement in forecasts -- but what is the connection between the two?
- If the money saved by not extending the TRMM mission (\$X mill) was invested in scientific research, would you get more benefit from research on the existing data set than from having an extended data set?

Workshop Goal #3: Review engineering studies of risks associated with alternative TRMM reentry strategies, including consideration of the accuracy and estimates of the uncertainty associated with such studies.

Finding 3.1: As presented at the Workshop, uncertainties in potential risks of uncontrolled reentry are so large as to diminish substantially the usefulness of this calculation as a decision threshold.

The panel found NASA engineering studies on the risks of re-entry to be deficient in several respects. First, although it is relatively straightforward to develop quantitative metrics for uncontrolled reentry risk, the material presented in the workshop showed that threshold risk values were extremely sensitive to a large number of arbitrary assumptions. Second, no credible analyses of the statistics of historical uncontrolled reentries were presented to demonstrate the accuracy or meaningfulness of the derived thresholds/guidelines even if the arbitrary assumptions were correct. Third, the estimates of risk were incommensurate with other dimensions of risks and benefits associated with the TRMM deorbiting decision, making it impossible to consider the decision in a comprehensive manner.

Recommendation 3.1: NASA should consider (a) making its reentry risk calculation more transparent, rigorous, and meaningful, (b) placing its reentry risk calculations into a more comprehensive framework.

Workshop Goal #4: Consider a longer-term strategy for “technology assessment of observing systems” to provide decision makers with reliable and scientifically robust knowledge of risks and benefits associated with similar future situations.

TRMM has no official operational requirements; however, the operational use has steadily evolved over the past few years and has gained the strong support of the operational community. Even so, the panel questions the degree to which TRMM’s future should be based upon its expected role in operational forecasting. TRMM was designed as a research program with a finite mission.

Finding 4.1. To primarily, or even jointly, serve direct operational functions, the TRMM program would likely be designed, managed, and implemented in a very different manner than it has been as a research program.

The growing number of satellite missions that reach the end of their planned mission life is a planning nightmare for NASA, for other federal agencies with remote sensing operations and interests, and for the emerging commercial remote sensing industry. Two current examples are the TRMM and Landsat 5 missions that continue to provide high quality information at the end of their planned lifetimes on orbit. Both of these satellites provide scientific data for both fundamental earth science and applications that serve societal needs. In both cases the incremental funds necessary to continue on-orbit operations and a modest scientific research and applications program are very small relative to the investment in the development and launch of the hardware and in data management systems to refine, distribute, and archive the satellite data products. A number of previous NASA satellites have presented the same dilemma – a healthy satellite without a budget for extended operations (e.g., the Earth Radiation Budget Experiment, Satellite Aerosol and Gas Experiment).

There are a number of factors that influence the planning and forecast of a satellite mission lifetime including anticipated scientific benefits, financial and human resource planning, and design and engineering considerations in the satellite, data management, and operations systems. It would appear that scientists often think of three-year mission cycles, as that is the typical federal funding cycle for scientific research programs. It is also problematic to anticipate scientific benefits for most first-generation satellite sensors due to a lack of prior experience with similar data. NASA resource planning for most earth observation missions has also focused on a relatively short-term, high payoff approach due to its fundamental scientific and engineering mandate. This has caused considerable dissatisfaction in the climate science community where long-term observations are essential to fundamental research needs.

Finding 4.2. If advances in engineering design and launch vehicle success rates allow for the potential extension of research missions beyond original plans, then this creates a new set of decisions for the remote sensing science community.

NASA urgently needs to learn how to plan for success. Many future missions are likely to survive the crucial “infant mortality” period (i.e., launch failures and early on-orbit hardware failures). A nominal three-year mission will typically be capable of extending its mission for a number of additional years. The scientific community will almost always discover exciting, unanticipated information that leads to a call for an extended mission. In some cases, like TRMM, the potential for transitioning a new observational system or technology from a research mode to an operational mission will be a consideration.

Planning for success involves a number of programmatic considerations like trade-offs with opportunities for testing and evaluation of new technologies and scientific hypotheses. The transition to operational status for an extended mission poses a challenge to the need for maintaining continuity and calibration of observational systems. There are always many innovative ideas and technologies on the NASA and NOAA priority lists that would be delayed or otherwise threatened by extending the life of on-orbit satellites in the current era of fixed or declining budget resources.

More generally, given the significant resources devoted to observations and the constant demands for more resources, a number of questions naturally arise.

- Is the current mix of observational platforms effective? With respect to what criteria should “effectiveness” even be measured?
- Given the demands of scientists for ever more data, how much additional resources should be devoted to observations?
- Should these demands for new information be traded off with present capabilities?
- What new areas hold the greatest promise for benefits to environmental decision making?

The scientific and policy communities currently have no mechanism to answer such questions, meaning that “observations policy” frequently is determined on an ad hoc, and even political basis.

Finding 4.3. Decision makers lack knowledge necessary to prioritize observational programs and plans according to their contributions to science and society.

In the absence of such information observational decisions are often made on an ad hoc or even political basis. One result is that unhealthy competition for scarce resources develops: scientists compete with other scientists (e.g., weather versus climate), research vies with operations (e.g., NASA versus NOAA), and various platform advocates coalesce into warring “tribes” (e.g., satellite versus *in situ*). An example of a methodology that might be used to model the benefits and risks of observing system decision alternatives appears in the text box on the following page.

Modeling the Benefits and Risks of Observing System Decision Alternatives

Future research for technology assessment of observing satellites would significantly benefit from a framework that explicitly parameterizes the uncertainty of benefits (the value of the information) and of risks. Just as with any attempt to structure a framework for assessment, this uncertainty-based approach requires some information in the form of expert opinion or (if available) information based on previous research in order to characterize statistical probability distributions (for example, their mean and standard deviation). However, the approach does not require certainty with respect to these parameters. In this regard, the approach is perhaps more “honest” in modeling decision variables. In fact, the value of the approach is that it explicitly allows for uncertainty, hypothesis testing, and sensitivity diagnostics. These attributes can help inform decisions by (a) illustrating a more realistic range of estimates rather than a point estimate; (b) identifying priorities for which information requires further refinement from experts or other sources in order to reduce the most important of the uncertainties to facilitate a decision; and (c) more fairly representing the uncertainty that characterizes many science and technology decisions.

Example for TRMM:

Compare the expected value of information from the data (VOI) with expected future costs of mission continuation.

VOI includes the indirect benefits of science research and direct operational value of the observational data. This information can be inferred from the approximate cost of next-best alternatives for obtaining data in the absence of TRMM; probability distributions on lives saved (in the absence of more detailed research on the link between mortality, forecasts, and data, this distribution can range from 0 to more and be parameterized with different likelihood weights) and operations (ship fleet deployment, utility company load management, etc).

Future costs include operations and reentry risk under controlled and uncontrolled scenarios. For value of life estimates for both VOI and reentry risk, the approach can either use value of life estimates used by the federal government in regulating space launch third party risk (\$3 million per statistical life) or OMB guidelines for other federal health and safety regulation. This parameter, too, can be varied for sensitivity tests.

The model results would not lead to a single point value for the extent to which VOI dominates or is smaller than costs, but it does identify key ranges of values over which decisions can take place. The results would not necessarily define outcomes by decision makers but the approach would much more fairly depict benefits, risk, and uncertainties than single point estimates. In research undertaken for NASA’s new millennium program, this model has been accepted by NASA as a basis for allocating mission funding.

Recommendation 4.1. Decision makers would benefit from an ongoing effort devoted to the “technology assessment of observing systems” that would seek to evaluate the broad costs and benefits of alternative observing strategies for both science and society.

A framework for such an effort was developed by the US Weather Research Program for weather observations (<http://box.mmm.ucar.edu/uswrp/PDT/PDT7.html>), but could easily be extended to other observational contexts.

Recommendation 4.2. NASA and its operational partners would benefit from a more systematic approach to the “transition of research to operations.”

In 1980 the National Academy of Sciences concluded in a report on atmospheric observations that there was a need for new observing systems, improved computer systems, and better communication systems. But the report also noted that "the rate of progress toward better services is not limited by technology" — and, by extension, not by resources. Instead, the constraint was an "inadequate mechanism for transferring weather and hydrological information and knowledge of applications to specific users." In 2000, the Academy delivered a similar message in a report titled “Crossing the Valley of Death.”

The TRMM deorbiting decision presents a quandary for NASA in part because the observational community of scientists, administrators, and policy makers in the public and private sectors lack a comprehensive means for evaluating decision alternatives related to observational systems. A more comprehensive perspective would allow for decision making that is based, at least to some degree, on the policy tradeoffs involved with alternative courses of action.

Workshops participants agreed that the delineation of a more comprehensive perspective went well beyond the time and expertise available to this workshop, but emphasized its importance to research and operations related to environmental observations.

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Appendix B: Agenda

Agenda for Monday June 18, 2001

- 8:00 – 8:30 Introductions and Goals of the Workshop
Roger Pielke
- 8:30 – 10:00 **NASA Overview of TRMM Contributions to Science and Operations**
R. Adler, NASA/Goddard
 TRMM Background and science overview
Jeff Hawkins, NRL Monterey
 Global TRMM Near-real Time Utilization for Tropical Cyclone and Precipitation Monitoring
Frank Marks HRD (HRD, representing NHC)
 Use of TRMM DATA at NHC and HRD
Capt. Steve Barlow, JTWC
 JTWC's Use of TRMM in Typhoon Forecast Operations
Arthur Hou, NASA/Goddard
 Further Developments for Improving Weather Forecasting and Analysis Using TRMM data
Yoshi Tahara, JMA (now at NCEP)
 Operational NWP Research Using TRMM at NCEP and JMA
T.N. Krishnamurti, FSU
 Impacts of Assimilation of TRMM Information on Forecastsof Tropical Cyclones and Precipitation
- 10:00 – 10:30 Break**
- 10:30 – 12:30 NASA Overview, con't.
- 12:30 – 1:30 Working Lunch
- 1:30 – 3:00 **NASA Overview of TRMM De-orbiting Alternatives**
Thomas Magner
Vickie Moran
Brent Robertson
- 3:00 – 3:30 Break**
- 3:30 –4:30 NASA Overview, con't.
- 4:30 – 5:00 Setting Boundaries in a Risk-Benefit Assessment of Observing System Decision Alternatives
Bob Harriss
- 5:00 – 6:00 Instructions for Tuesday and Open Discussion
Roger Pielke
End of Day – Dinner on Own

Agenda for Tuesday June 19, 2001

8:00 - 9:00 Discussion

9:00 - 11:00 Breakout Groups by Decision Alternative

Break

11:00 - 12:00 Breakout Group reports

12:00 - 1:00 Working Lunch - Discussion

1:00 - 3:00 Apples to Apples Session: Integrating the Working Groups

Break

3:00 - 5:00 Writing Teams

Adjourn