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ESTIMATING THE BENEFIT OF TRMM TROPICAL CYCLONE DATA IN SAVING LIVES

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1. INTRODUCTION

The Tropical Rainfall Measuring Mission (TRMM) is a joint NASA/JAXA research mission launched in late 1997 to improve our knowledge of tropical rainfall processes and climatology (Kummerow et al., 2000; Adler et al., 2003). In addition to being a highly successful research mission, its data are available in near real-time and operational weather agencies in the U.S. and internationally are using TRMM data and images to monitor and forecast hazardous weather (tropical cyclones, floods, etc.). For example, in 2004 TRMM data were used 669 times for determining tropical cyclone location "fixes" (National Research Council, 2004).

TRMM flies at a relatively low altitude, 400 km, and requires orbit adjustment maneuvers to maintain altitude against the small drag of the atmosphere. There is enough fuel used for these maneuvers remaining on TRMM for the satellite to continue flying until 2011-12. However, most of the remaining fuel may be used to perform a "controlled re-entry" of the satellite into the Pacific Ocean. The fuel threshold for this operation will be reached in the summer of 2005, although the maneuver would actually occur in late 2006 or 2007. The full science mission would end in 2005 under the controlled re-entry option. This re-entry option is related to the estimated probability of injury (1/5,000) that might occur during an uncontrolled re-entry of the satellite. If the estimated probability of injury exceeds 1/10,000 a satellite is a candidate for a possible controlled re-entry. In the TRMM case the NASA Safety Office examined the related issues and concluded that, although TRMM exceeded the formal threshold, the use of TRMM data in the monitoring and forecasting of hazardous weather gave a public safety benefit that compensated for TRMM slightly exceeding the orbital debris threshold (Martin, 2002). This conclusion was based in part on results of an independent panel during a workshop on benefits of TRMM data in operational forecasting (Pielke, 2001). However, the NASA report (and the workshop) also concluded that the benefit of TRMM data in "saving lives" through its use in operational forecasting could not be quantified.

The objective of this paper is to describe a possible technique to estimate the number of lives saved per year and apply it to the TRMM case and the use of its data in monitoring and forecasting tropical cyclones.

2. APPROACH

The approach used in this exercise is a large-scale one (i.e., one not built up from case studies). It attempts to derive a relation between increasing accuracy of tropical cyclone forecasts and decreasing loss of human life and the impact of satellite data, particularly TRMM data, on the forecast accuracy. The combination of relations can then be used to provide a framework to estimate the impact of the satellite data on the loss of life.

2.1 Relation of tropical cyclone forecast improvement to loss of life

In order to estimate the relation of tropical cyclone forecast improvement to loss of life, statistics in the U.S. are examined. Hurricane-related deaths in the U.S. have decreased from about 70/year to 25/year during the last half of the 20th century despite a population increase along the Texas to Virginia coast of 314% (Willoughby, 2000). Taking the population increase into account gives a change of 220 to 25 deaths from 1950 to 2000, a mortality decrease (MD) in the U.S., of 89%.

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Improvements in 24-hour hurricane forecasts of storm position have also been made during that period. Using information from Neumann (1981) and McAdie and Lawrence (2000) the decrease during the 1950-2000 period is from 124 nm to 90 nm, an estimated forecast error decrease (FED) of 27%.

The ratio of these two numbers (MD/FED) gives some guidance to a quantitative relation between forecast accuracy and mortality. There is obviously some cause and effect relation to increasing forecast accuracy and the decrease in lives lost over the last 50 years. However, not all of the mortality decrease is directly due to better forecasts. Improved warning dissemination, improved understanding by the public and improved evacuation planning and execution also play a role. However, improved forecasts also make storm warnings more effective. To try and take into account these other factors, a parameter, f, is created which is the fraction of mortality decrease due to forecast error decrease alone. The appropriate value of f is unclear, but it is not zero, nor is it one. Its range of assumable values is probably between 0.3 and 0.7. The combination of f(MD/FED) defines the impact of forecast error decrease on mortality decrease in the U.S.

2.2 Decrease in forecast error due to TRMM

TRMM data play a role in detecting, monitoring and forecasting tropical cyclones. A recent summary is given in an independent review of the benefits of TRMM data (NRC, 2004). TRMM data are used to identify new cyclonic circulations and are regularly used to provide location "fixes" of storms. The TRMM passive microwave data are used similarly to operational microwave data from polar orbiting satellites, but with its finer spatial resolution and better sampling in the tropics, TRMM data are playing a significant role in hurricane/typhoon monitoring. TRMM data are often available at times when overpasses of polar-orbit satellites are not available, thereby providing a finer time resolution to help understand position changes and evolution of the storms. In 2004 TRMM data were used 669 times to give location fixes of tropical cyclones (NRC, 2004) by various hurricane/typhoon forecast centers, more than any other single microwave satellite. TRMM data are also used to estimate storm intensity through examination of fine-scale structure and are frequently mentioned in forecast discussions in relation to intensity changes. These improved initial locations and intensities are important inputs into forecasts, both short-term human-based forecasts and numerical and statistical model-based forecasts. Improved location forecasts have been shown to result from the assimilation of satellite precipitation information, including TRMM-based information (Krishnamurti et al., 2001; Hou et al., 2004).

The question here is: "What is the forecast improvement due to the use of TRMM data?" This is a very difficult question to answer, unless "data out" forecast model experiments are made. Here a simple exercise involving only initial location information will be used to estimate the impact. A decrease in initial position error directly translates into forecast error decrease for tropical cyclones (Jarrell et al., 1978; DeMaria et al., 1990). We estimate that the off-time observation and finer resolution will lead conservatively to a 10% location error reduction about one-third of the time, i.e., an effective impact of about 3%. This initial position error decrease is assumed to directly result in a forecast error decrease (FED) of 3%. This decrease would mean, for example, that a 100 km forecast error would, on average, be reduced to 97 km, a very conservative impact. The value of this parameter is obviously open to question, but the 3% will serve as a starting point in sensitivity tests.

2.3 Global mortality due to tropical cyclones

In the decade 1993-2002 over 90,000 people died in floods and over 60,000 people died in "windstorms" (International Red Cross, 2003). Although not all windstorms are tropical cyclones and not all floods are caused by tropical cyclones, a majority of these 150,000 people probably died in the storm surges or floods associated with tropical cyclones. For this calculation, we will assume 100,000 people died due to tropical cyclones over the decade, an average global mortality rate (GMR) of 10,000/yr.

3. RESULTS

The final formula to calculate the TRMM impact on mortality rate (TIMR) is:

$$TIMR = f \frac{MD_{us}}{FED_{us}} FED_{TRMM}\ GMR \qquad (1)$$

Using the following nominal values of the variables based on the discussion in the previous section, f= 0.5, MD_{us} = 89%, FED_{us} = 27%, FED_{TRMM} = 3%, GMR= 10,000/yr, the

$$TIMR = (0.5)\frac{.89}{.27}(.03)(10{,}000) = 494 \text{ lives/yr.} (2)$$

The approximately 500 lives saved per year may be a reasonable estimate of the impact of TRMM. That number represents about 5% of the total annual deaths due to tropical cyclones.

The result in Eq. (2) is obviously sensitive to the value of the input parameters. A number of these values have been selected somewhat arbitrarily, based only on background knowledge and not based on specific studies or experiments. In order to test the sensitivity of the result and attempt to produce a very conservative, or minimum likely impact on lives lost, the calculation is repeated with conservative estimates of the parameters of which the least is known. The values for MD_{us} and FED_{us} are documented and because they are based on the U.S. for the last part of the 20^{th} century, that ratio is probably applicable for the present over the globe. However, the governing factor in the application of that ratio is the parameter f, which is the fraction of mortality decrease due to forecast error decrease alone. This parameter must be significantly higher than zero, otherwise advances in forecasting would not have any value. The value of 0.5 used in Eq. (2) (i.e., half of the forecast improvement has impact on humans) may be optimistic, so a lower value of 0.3 is used in this second calculation. The parameter FED_{TRMM} is the decrease in forecast error due to TRMM. The 3% value used in Eq. (2) is probably reasonable, but a 1% value is even more defensible. The number of lives lost to tropical cyclones globally (GMD) is reasonable, although it would be worthwhile to have better documentation. We will leave that number at 10,000/yr. With the modifications to f and FED_{TRMM} the new calculation is:

$$TIMR = (0.3)\frac{.89}{.27}(.01)(10{,}000) = 99 \text{ lives/yr.} (3)$$

This second estimate indicates that the result is very sensitive to the large range of reasonable values for some parameters. It also leads us to an approximate quantitative estimate of 100-500 lives saved per year globally by the use of TRMM data.

4. CONCLUSIONS

A technique has been developed to estimate the quantitative benefit of satellite data on tropical cyclone forecasting in terms of additional lives saved. The technique is applied to the case of the Tropical Rainfall Measuring Mission (TRMM), a research mission developed by NASA and the Japanese space agency, JAXA, data from which are being used operationally by weather agencies in the U.S., Japan and elsewhere for tropical cyclone monitoring and forecasting. The resulting estimates indicate 100-500 lives are saved annually through the use of TRMM data in tropical cyclone monitoring and forecasting. TRMM is currently in its eighth year of operation and has the potential for another 4-7 years of operation. The results clearly indicate that a significant public safety benefit of TRMM data exists that seems to far outweigh the estimated 1/5000 probability of injury due to debris during a natural re-entry of the satellite.

The large range of estimated values is due to the uncertainty in a number of the parameters in the estimation formula. This preliminary study indicates some of the areas which require attention if the technique is to be refined. These areas include a more exact determination of the number of deaths annually due specifically to tropical cyclones (instead of generic windstorms and floods), a better estimate of forecast error impact of TRMM (or other satellite) data through isolated analyses and/or numerical model, data denial experiments, and a better understanding of the impact of an improved forecast on warnings and resulting evacuations or other life-saving actions.

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