

## The Impact of TRMM Data on Mesoscale Numerical Simulation of Super Typhoon Paka

Zhao-Xia Pu<sup>1,2,\*</sup>, Wei-Kuo Tao<sup>2</sup>, Yiqin Jia<sup>2,3</sup>, Joanne Simpson<sup>2</sup>,  
Scott A. Braun<sup>2</sup>, Jeffrey Halverson<sup>2,4</sup>, Arthur Hou<sup>2</sup>, and William Olson<sup>2,4</sup>

<sup>1</sup>Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County

<sup>2</sup>Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, Maryland

<sup>3</sup>Science System and Applications Inc., Lanham, Maryland

<sup>4</sup>Joint Center of Earth System Technology, University of Maryland, Baltimore County

### 1. Introduction

Accurate measurement of the spatial and temporal variations of tropical rainfall around the globe had remained as a critical problem in meteorology until the recent launch of the Tropical Rainfall Measuring Mission (TRMM). TRMM offers a unique opportunity to improve understanding of tropical meteorology and also offers a great opportunity to evaluate the impact of rainfall data on tropical weather forecasts. This study assesses the impact of TRMM Microwave Imager (TMI) derived surface rainfall data on the numerical simulation of Super Typhoon Paka (1997).

### 2. Super Typhoon Paka

Super Typhoon Paka was an event that was frequently sampled by TRMM in 1997. Paka formed during the first week of December 1997 and underwent three periods of rapid intensification over the following two weeks. Beginning early on December 10, Paka's maximum wind speed increased from 23 to 58 m s<sup>-1</sup> over a 48-hr period with Paka becoming a mature category 3 typhoon on December 11. Paka continued to intensify during the following days, and by December 18, at the end of the last rapid deepening period, Paka became a super typhoon with a maximum wind speed of about 80 m s<sup>-1</sup>. The detailed structural features of Paka during its lifetime were described in Rodgers et al. (2000). In order to test the impact of the TMI rainfall data on the forecast of Paka during its mature stage, 0000 UTC 12 December 1997 is taken as the initial time for the numerical simulations in this study.

### 3. Surface rainfall data and GEOS rainfall assimilation

The surface rainfall information is retrieved from the TMI microwave radiances (see details in Kummerow et al. 1996 and Olson et al. 1996,

1999). The 6-h averaged surface rainfall estimates are assimilated into the global analysis using a version of the Goddard Earth Observing System (GEOS) data assimilation system (see Hou et al. 2000). A unique feature of the GEOS data assimilation system is that it uses the incremental analysis update (IAU) procedure of Bloom et al. (1996) to assimilate the rainfall and other observed data. The GEOS assimilation is a time-continuous model integration with a gradual insertion of IAU tendencies into prognostic variables updated from rainfall and other observations every 6 h. The system eliminates the general spinup problem in rainfall data assimilation. For rainfall data assimilation, Hou et al. (2000) used a general procedure that minimizes the least-squared differences between the time-averaged TMI observations and rain rates generated by a column model averaged over a 6-h analysis window. The column model is a column version of the GEOS GCM with full model physics, with advection terms as "model forcing" along with the conventional IAU tendencies from a preliminary 6-h assimilation. The control variables are tendency corrections of moisture and temperature.

In this study, a set of mesoscale numerical simulations is performed for Paka with the initial conditions generated by two different global analyses from the GEOS: one with and one without TRMM rainfall data.

### 4. Numerical Model

The PSU/NCAR MM5 model is used to conduct numerical simulations of Paka. Physics options used for this study include the Betts-Miller cumulus parameterization, the Goddard cloud microphysics scheme (Tao and Simpson, 1993), the Blackadar high-resolution planetary boundary layer parameterization scheme (Zhang and Anthes 1982), and the cloud atmospheric radiation scheme (Dudhia 1993). A two-way interactive, four-level nested grid technique is employed to achieve the multi-scale simulation. The outer

domains A and B (135 km and 45 km horizontal grid spacings) are fixed and are designed to simulate the synoptic-scale and mesoscale environment in which the system evolves. The finer domains C and D (15 km and 5 km grid spacings) are used to simulate the detailed hurricane-scale flows. The finest domain D is started at 24 h into the simulation and is frequently moved with the storm center during the next 36 h of simulation. The model vertical structure is comprised of 27  $\sigma$  levels with the top of the model set at a pressure of 50 hPa. The  $\sigma$  levels are placed at values of 1.0, 0.99, 0.98, 0.96, 0.93, 0.89, and then decrease to 0.01 at an interval of 0.04. For the simulations, the model physics are the same for each domain except that no cumulus parameterization scheme is included for the 5-km domain.

For the experiments, the initial conditions for domains A and B are derived from 12-h GEOS analyses. The 15-km domain (domain C) is initialized by interpolation of all prognostic variables from the 45-km domain. Domain D is started at 24 h into the forecast and is initialized by interpolation of all variables from the 15-km domain. All figures in this paper present results from the 15-km and 5-km grids.

## 5. Experiments

In order to examine the impact of TMI data on the storm forecast, two experiments (see Table 1) are conducted with initial conditions generated by two different sets of large-scale analyses from the GEOS:

- 1) A control GEOS analysis data set that does not include TMI rainfall data (GEOS0) and
- 2) a second analysis data set that does (GEOSTRMM) include TMI rainfall data.

At the initial time, Paka was a mature category 3 typhoon, but there are no vortices information contained in the MM5 initial conditions for both of GEOS0 and GEOSTRMM. Since bogus vortices are often necessary for improving forecasts of mature tropical cyclones, as part of this evaluation, two additional numerical experiments (Table 1) are also performed by introducing bogus vortices generated by four-dimensional variational data assimilation (4-D VAR) using the MM5 adjoint system (Zou et al. 1998). The details of an effective bogus vortex technique used for this study were described in Pu and Braun (2001) and Pu et al. (2001). In one of the experiments, the bogus vortex is incorporated into the mesoscale initial conditions with the TMI data.

## 6. Summary of Results

- Assimilation of TMI rainfall data into the

GEOS global analysis without the bogus vortex results in stronger low-level convergence and upper-level divergence, a reduced initial SLP of the storm, and increased moisture in the upper troposphere. Rainfall assimilation thus modifies the environment of the storm such that conditions are more favorable for development. As consequently, the forecast of typhoon structure and intensity is improved significantly (Fig.1). The track forecast is also improved (Table 2). Since the GEOS large-scale analysis does not contain any mesoscale vortex information, the experiment with TMI data produces a storm of typhoon intensity after 36 h, while without TMI data; the simulation requires 60 h to generate a typhoon (Fig.1).

- Further forecast improvements are obtained by combining the TMI rainfall data with a bogus vortex in the initial conditions. Inclusion of a bogus vortex in the numerical simulation produces the most accurate forecast of typhoon track and intensity (Table 2, Fig.1), and a fairly accurate precipitation structure (Fig.2c).

- The bogus vortex can play a dominant role in forecasts of the intensity of mature typhoon Paka (Fig.1). However, even with a bogus vortex, assimilation of rainfall data into the model contributes beneficial impacts. For instance, in this study, it produces further improvements in the track forecast and a more realistic short-term precipitation forecast (Fig.2).

More detailed evaluation of TRMM data impacts performed by direct assimilation of the TMI rainfall data into the mesoscale model using 4-D VAR techniques is in progress. Results will be reported in conference.

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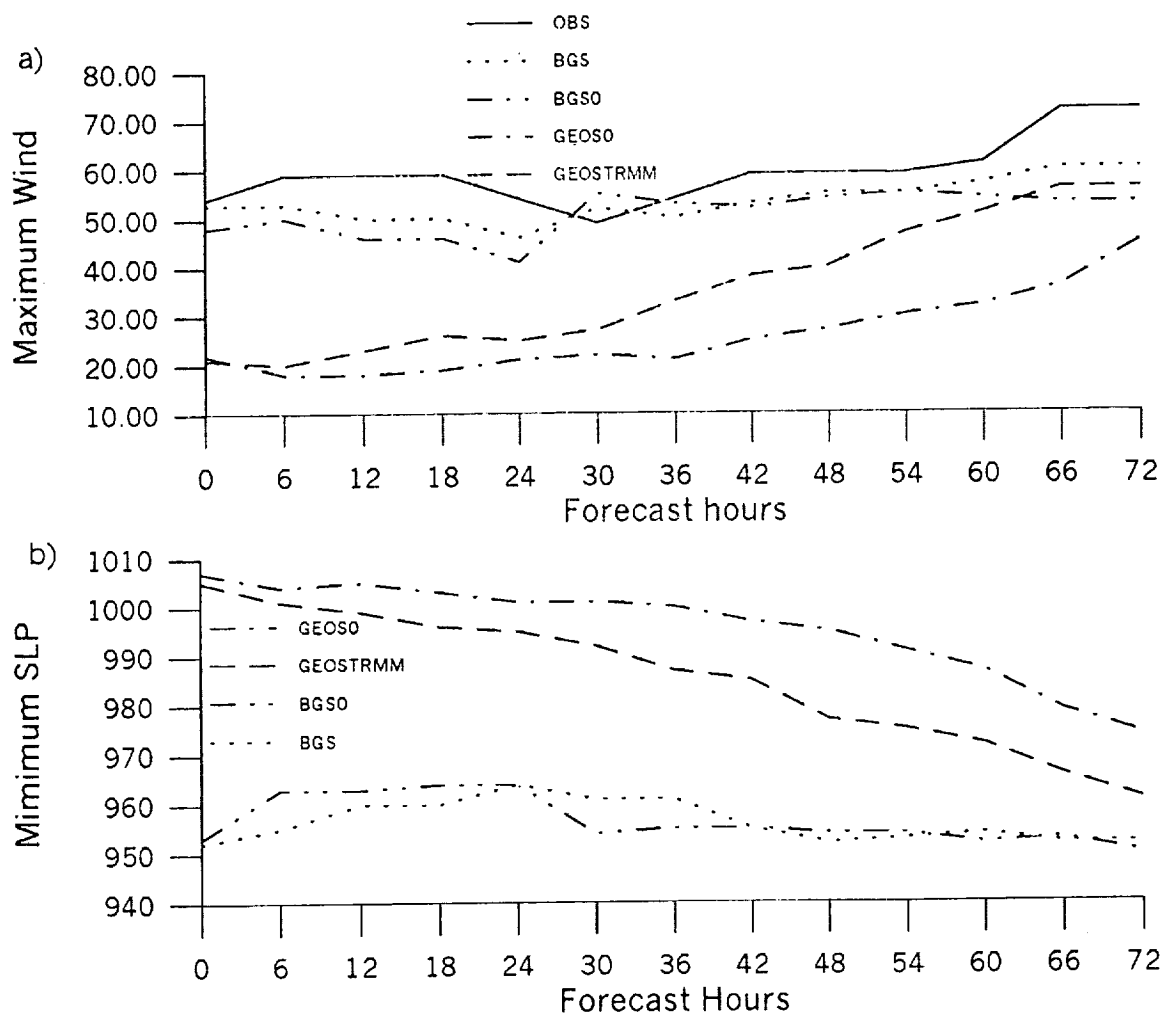
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**Table 1. Experimental design**

Numerical Experiments	Model Initial Condition	Bogus	Vortex
GEOS0	GEOS analysis without TMI rainfall		No
GEOSTRMM	GEOS analysis with TMI rainfall		No
BGS	GEOS analysis with TMI and bogus vortex	Yes	Yes
BGS0	GEOS analysis without TMI rainfall but with bogus vortex	Yes	Yes

**Table 2. Time series of the forecasted track error (km)**

Forecast Time (h)	00	06	12	18	24	30	36	42	48	54	60	66	72
GEOS0	53	288	307	231	247	284	280	309	264	320	336	352	325
GEOSTRMM	41	156	210	218	211	211	227	215	160	185	174	192	170
BGS	0	14	57	73	67	45	51	30	81	98	85	60	55
BGS0	0	45	50	67	60	90	70	80	95	112	95	115	120



**Figure 1.** series (at 6-h intervals) of a) maximum winds ( $\text{m s}^{-1}$ ) at the lowest model level ( $\sigma=0.995$ , approximately 50 m) and b) minimum sea-level pressure (hPa). Results during the period 24-60 h are from the 5-km grid forecast, while results at other times are from the 15-km grid.

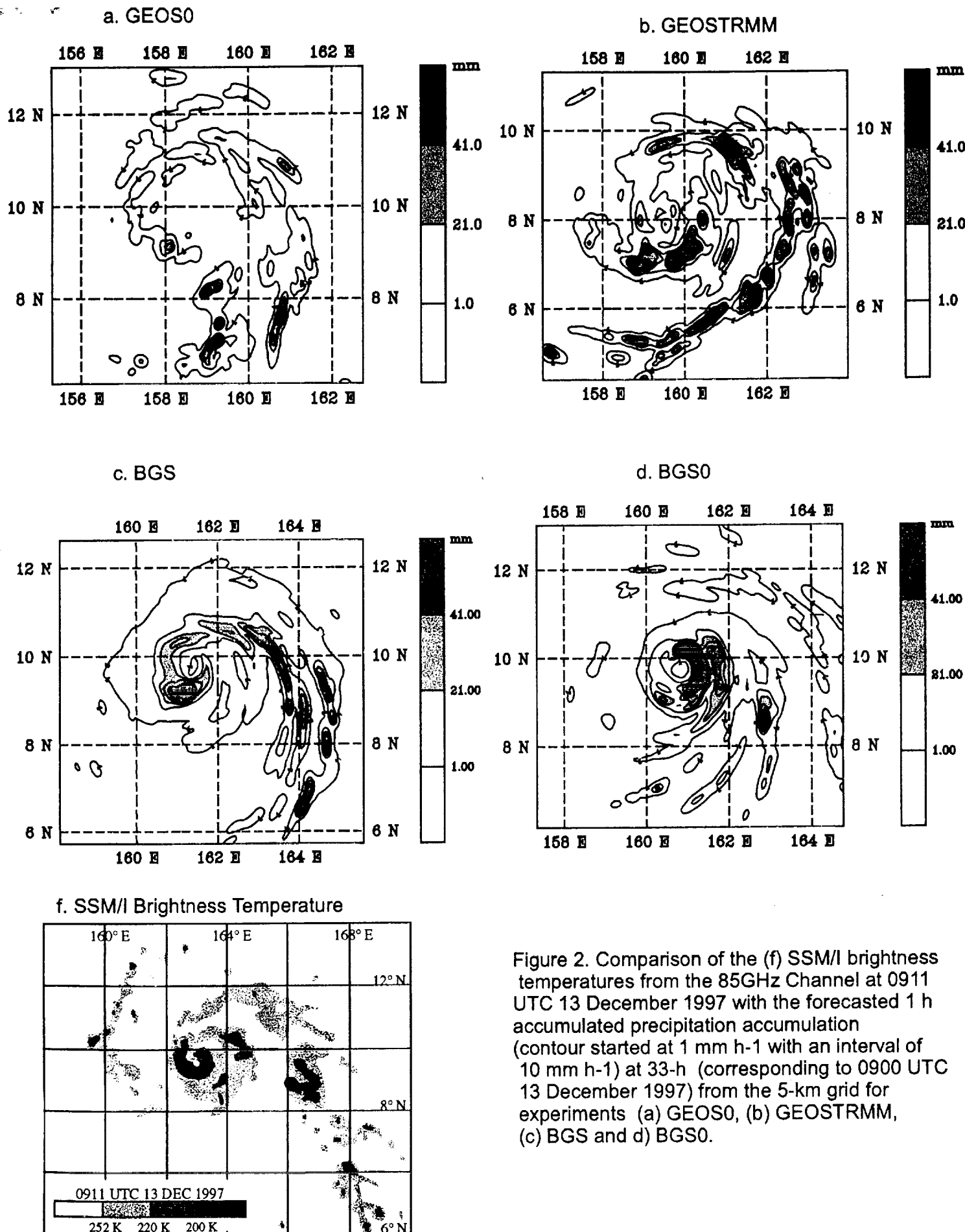


Figure 2. Comparison of the (f) SSM/I brightness temperatures from the 85GHz Channel at 0911 UTC 13 December 1997 with the forecasted 1 h accumulated precipitation accumulation (contour started at 1 mm h<sup>-1</sup> with an interval of 10 mm h<sup>-1</sup>) at 33-h (corresponding to 0900 UTC 13 December 1997) from the 5-km grid for experiments (a) GEOS0, (b) GEOSTRMM, (c) BGS and d) BGS0.