An experiment using NSCAT winds in the numerical prediction of tropical mesoscale rainfall systems under the influence of terrain

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Abstract.

The rich mesoscale information in NSCAT wind over tropical coastal regions is used in numerical simulations of two June 1997 monsoonal cases occurring over Taiwan. It is shown that transient NSCAT mesoscale information over a localized area as small as 120 km x 240 km can result in significant improvement in the 24 h heavy rainfall forecast due to its effect on monsoonal convection and terrain effects.

1. Introduction

Several authors have shown improvements in the numerical simulation of midlatitude large-scale systems by employing SEASAT (e.g., Yu and McPherson, 1984; Duffy et al., 1984; Baker et al., 1984; Duffy and Atlas, 1986; Ingleby and Bromley, 1991) and ERS-1 (e.g., Yu et al., 1996, Andrew and Bell, 1998) scatterometer winds. However, the improvements occurred mainly over open oceanic regions where the results were not easily verifiable. The impact of scatterometer winds in tropical mesoscale cases is known even less.

An important feature of NASA's scatterometer (NSCAT) winds during the period September 1996-June 1997 data was the rich information that they provided about the surface mesoscale structure in coastal and tropical regions (Liu et al., 1998). Here we suggest its possible use in tropical and coastal mesoscale forecasting of severe weather. Because these winds exist only at the surface, without any space and time continuity provided by a 4-D assimilation, they are less effective in determining the normal modes of mesoscale systems and are quickly overcome by the model dynamics once the numerical integration begins. For tropical mesoscale systems, initializing the sea-level pressure from surface winds is also problematic because of the decreased validity of the geostrophic or gradient wind relationship.

In view of these difficulties, we conducted experiments to test the impact of NSCAT data in the numerical simulation of mesoscale heavy precipitation over terrain during the tropical monsoon. In these situations differences in the low-level winds may lead to significant differences in low-level convergence and vertical motion. These effects may be amplified by moist convection and terrain. We also tested whether the projection of NSCAT information to 925 hPa and 850 hPa is useful, as Duffy and Atlas (1986) found improvement in the simulation of the Queen Elizabeth II storm after projecting the SEASAT data on several levels above the surface. We chose the periods 4-5 June 1997 and 13-14 June 1997 over Taiwan, because heavy rainfall occurred and NSCAT winds were available.

2. Model and data input

The model used is the Navy Operational Regional Atmospheric Prediction System (Langland and Liou 1996), which includes a surface-layer (Louis, 1979), 1.5-order vertical eddy mixing (Langland and Liou, 1996), short- and long-wave radiation (Harshvardhan et al., 1987), and a Kuo (1974) type cumulus parameterization. Here the model is configured with 36 sigma levels and a 151 x 121 horizontal grid with a 30 km resolution over East Asia and the western Pacific with Taiwan near the domain's center.

In our study we found small areas of conspicuous differences between the operational analysis and NSCAT winds. The NSCAT winds were first interpolated to the model grid using a Cressman (1959) scheme and then blended into the initial surface analysis with a 75% weighting. (The simulation results changed only slightly for weightings greater than 70%). For those experiments where we extended NSCAT information to higher levels, the entire difference field between the NSCAT-modified and original surface analyses was added to the 925 hPa and 850 hPa wind analyses. No effort was made to adjust the vertical weighting to optimize the results. To assess whether the forecast differences are due to the systematic effects of the NSCAT winds, experiments were also conducted where the difference is not projected vertically, and projected only to 925 hPa. These experiments determine whether changes in the forecast skill are consistent with the increased vertical projection; thereby demonstrating that the difference is not due to random effects. We use the following terms to describe the different runs: control, no modification of initial analysis by NSCAT data; *n1*, only the surface analysis is modified; *n2*, surface and 925 hPa are modified; *n3*, surface, 925 hPa and 850 hPa are modified; and *nt*, same as *n3* except that only data in the NSCAT swath covering or upstream of Taiwan were used.

3. The case of 4-5 June 1997

Figure 1 shows the NSCAT data along with the original and NSCAT-modified initial surface wind analyses at 00 UTC 4 June. The vectors are plotted at every other grid point. The main influence of NSCAT winds is an intensification of the southwesterlies to the south and southwest of Taiwan. The 12-h accumulated rainfall between the 12 h and 24 h model times is compared with the observed rainfall. This rainfall was computed by dividing the surface area of Taiwan equally into northern and southern sectors and averaging all station reports and model forecasts within each sector. In Figure 2 the upper panel shows the accumulated rainfall while the lower panel gives the forecast errors. In all cases the rainfall is practically all convective, with large-scale rainfall accounting for about 1% or less. In the southern sector, where the observed rainfall is about 43 mm per 12 h, the NSCAT data cause a significant reduction in the forecast error, with the control error of -9 mm per 12 h reduced to -8 mm for *n1*, -4 mm for *n2* and -2 mm for *n3*. The *nt* error is almost negligible. There is no significant improvement in the NSCAT forecasts in the northern sector. (The error is nevertheless reduced by about 10-15% from the control forecast.)

The improvement of the rainfall forecast can be related to an improvement of the 12 h sea-level pressure forecast (Figure 3). At 12 UTC 4 June a mesoscale low center is observed off the northeastern coast of Taiwan. This is a common feature of the summer monsoon related to terrain and sea-surface temperature and is a dominant factor for producing rainfall over Taiwan (Chen et al., 1992). The control run completely misses this feature, while the NSCAT runs improve it systematically, with *n3* and *nt* both

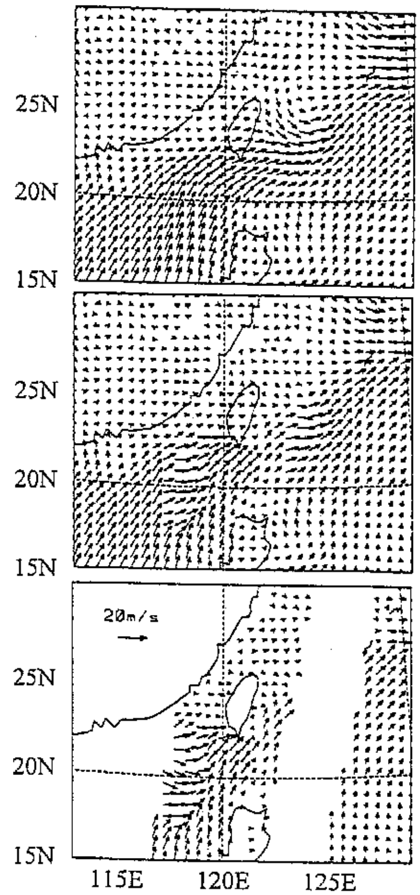

Figure 1. Initial surface wind analysis without (top) and with (middle) NSCAT winds for the 4 June 1997 case. The actual NSCAT winds are presented in the bottom frame.

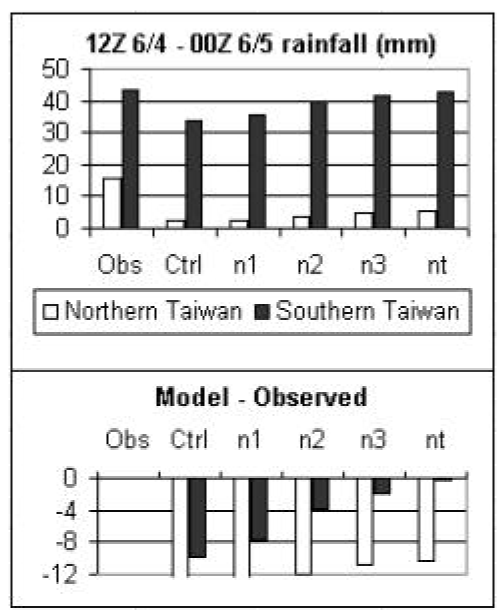

Figure 2. Comparison of observed and forecast accumulated 12 h rainfall from 12 UTC 4 June to 00 UTC 5 June. See text for definition of experiments.

predicting a mesoscale trough on the eastern coast of Taiwan. This lee trough is apparently a result of stronger onshore southwesterlies in the NSCAT data; this is sufficient to produce a major improvement in the southern rainfall. The lack of improvement of the northern rainfall is probably due to the underforecast of the low center situated over northern Taiwan.

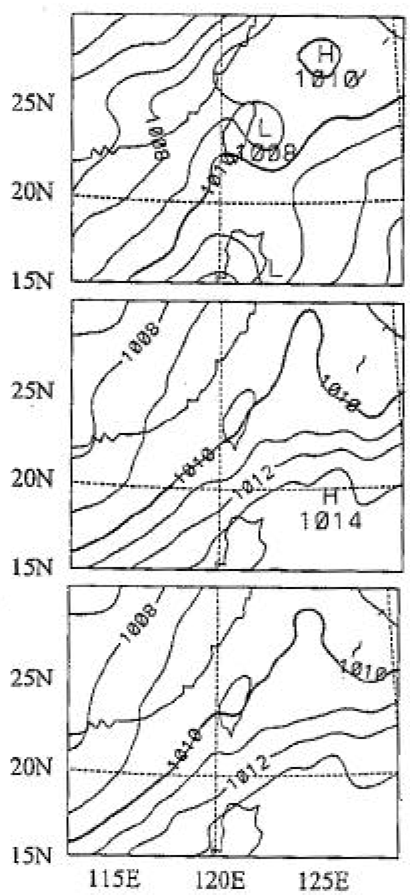

Figure 3. Verification (top) and forecasts (control, middle; *n3*, bottom) of 12 h sea-level pressure for the 4 June 1997 case.

4. The case of 13-14 June 1997

The initial surface wind analysis and the NSCAT winds for the case at 00 UTC 13 June is shown in Figure 4. Here the NSCAT swath west of Taiwan is the one used for the *nt* run. The main difference provided by the NSCAT winds consists of approximately four east-west and two north-south vectors in a small sector southwest of Taiwan, where the NSCAT winds show a seemingly anomalous westerly component. Figure 5 shows the rainfall comparison between the NSCAT forecast and observations. Again, 99% of the rainfall is convective. In this case, both northern and southern Taiwan show observed rainfall rates of approximately 15 mm

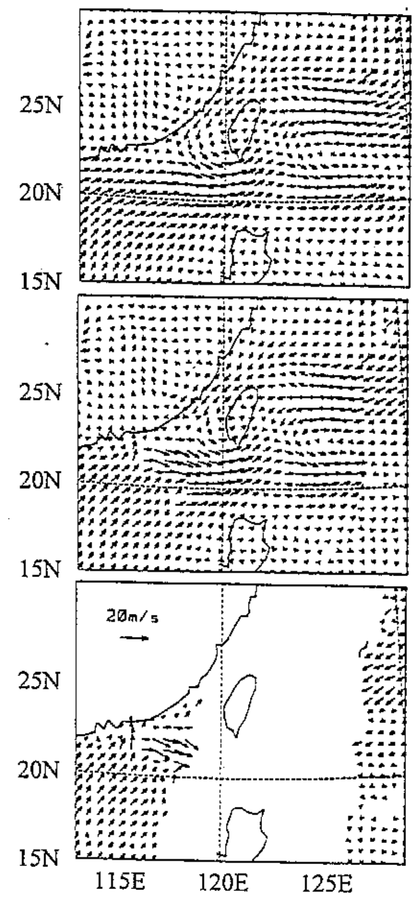

Figure 4. Initial surface wind analysis without (top) and with (middle) NSCAT winds for the 13 June 1997 case. The actual NSCAT winds are presented in the bottom frame.

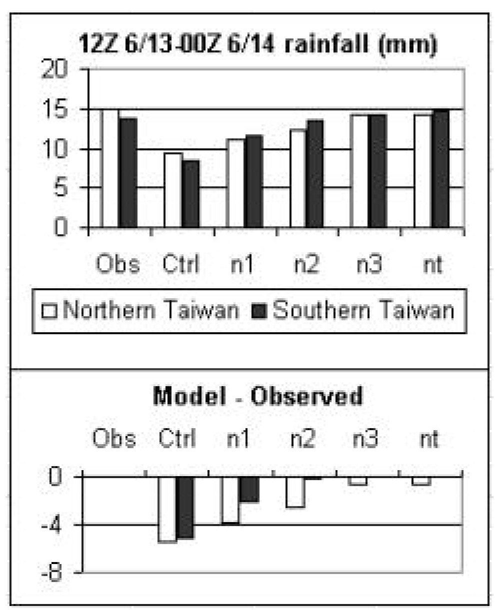

Figure 5. Comparison of observed and forecast accumulated 12 h rainfall from 12 UTC 13 June to 00 UTC 14 June.

per 12 h, and errors of -5 mm by the control forecast. NSCAT data again improved the control forecast. The northern Taiwan error is reduced to -4 mm for *n1*, -3 mm for *n2*, and very small for *n3* and *nt*. The southern Taiwan error is reduced to -2 mm for *n1*, and very small for *n2*, *n3* and *nt*. The systematic change again suggests that the improvement is not random.

The improvement may again be understood by the sea-level pressure forecasts (Figure 6). In the present case the rainfall is also significantly affected by a mesoscale monsoon low to the east of Taiwan. Verification shows an inner isobar of 1008 hPa, while the control forecast contains a weak low of 1010 hPa. The NSCAT forecasts systematically expands the area enclosed by the 1010 hPa isobar and for *n3* the central pressure drops to 1009 hPa. Again, the improvement appears to be a direct result of the stronger surface westerly component southwest of Taiwan provided by the NSCAT data, which allows a realistic lee-side meso-low to develop.

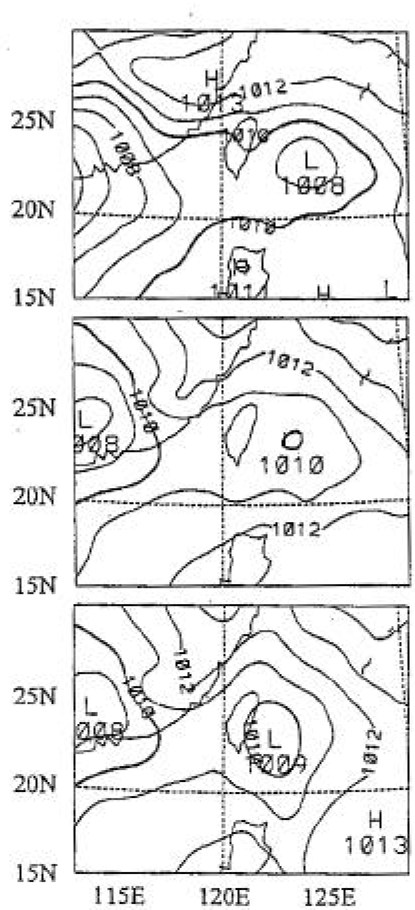

Figure 6. Verification (top) and forecasts (control, middle; *n3*, bottom) of 12 h sea-level pressure for the 13 June 1997 case.

5. No terrain experiments

The important role of the terrain in the rainfall forecast was verified by additional experiments in which the terrain height over Taiwan was set to zero. The results for both cases (Figure 7) show a very poor precipitation forecast, highlighting the crucial role topography plays in these heavy rain events. NSCAT data produce very little improvement in the severe underforecast of rainfall.

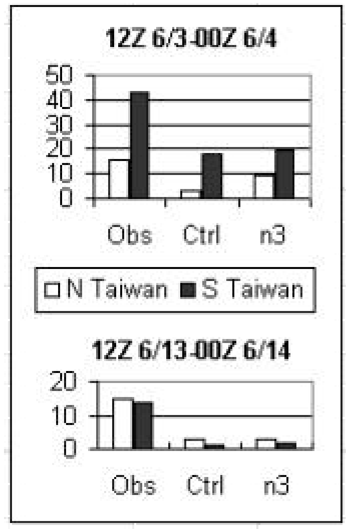

Figure 7. Comparison of observed and forecast accumulated 12 h rainfall amount for the no-terrain experiment.

6. Concluding remarks

The present study shows that the NSCAT mesoscale structure in tropical coastal regions contain useful information that may be used in certain situations to improve short-range mesoscale forecasts. In the present experiment the improvements in heavy rainfall forecasts were obtained because of the importance of the monsoon convection and terrain effects. NSCAT winds produced only localized differences from the operational surface wind analysis. Although these transient differences were contained over a localized area as small as 125 km x 250 km, positive impacts were realized because they enhanced monsoonal convection and the effects of terrain.

Acknowledgments. We wish to thank an anonymous reviewer for valuable suggestions and Prof. R. Haney for reading the manuscript. This work was supported by the NASA Scatterometer Project at JPL and by the Office of Naval Research, Marine Meteorology Program.

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(Received August 25, 1998; revised October 12, 1998; accepted December 3, 1998)

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