Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region (DOTSTAR)

An Overview

BY CHUN-CHIEH WU, PO-HSIUNG LIN, SIM ABERSON, TIEN-CHIANG YEH, WEI-PENG HUANG, KUN-HSUAN CHOU, JING-SHAN HONG, GUO-CHEN LU, CHIN-TZU FONG, KUAN-CHIEN HSU, I-I LIN, PAY-LIAM LIN, AND CHING-HWANG LIU

Typhoons are the most catastrophic weather phenomenon in Taiwan. In 2001 alone, typhoons in Taiwan caused 583 deaths and tremendous damage, including more than US$400 million in agricultural losses, and nearly paralyzed the Taipei Rapid Transit System. Ironically, typhoon rainfall is also a crucial water resource in Taiwan. An unfortunate lack of observations—other than those from satellites—in and around tropical cyclones in the region limits the accuracy of forecasts. As pointed out in the January 1999 *Bulletin* in an article by Wu and Kuo, current data are inadequate for accurate initial and boundary conditions for numerical tropical cyclone forecast models. This deficiency constrains tropical cyclone forecast accuracy, as well as general understanding of tropical cyclones in the Northwest Pacific region.

Prompted by three years of funding from the National Science Council (NSC) of Taiwan, the National Priority Typhoon Research Project was formed in July 2002. The interagency project involves a field experiment, Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region (DOTSTAR), with collaboration between researchers from the National Taiwan University and the Central Weather Bureau of Taiwan (CWB), along with scientists from the NOAA Hurricane Research Division and NCEP. The goal is to build upon previous successful work to improve tropical cyclone track forecasts with additional observations. This marks the first time in 16 years that aircraft have been used to routinely observe typhoons.

FIG. 1. The Astra SPX jet releasing a dropwindsonde (circled) during a test flight in March 2003.

The Astra SPX jet used for surveillance in the field experiment (see Fig. 1) cruises at about 750 km h^{-1} at up to about 14 km with a maximum flight range of 6 h (see Fig. 2 on the area of interest). Dropwindsondes are released every 150–200 km, about the traditional rawinsonde network resolution. The flight routes enable observation of the most sensitive region around the tropical cyclone (TC), the area with the largest deep-layer-mean wind bred vectors from the NCEP Global Forecasting System ensemble (Aberson 2003), modified to meet aircraft and air traffic control requirements. The data from the flights are assimilated in real time into the operational models at

AFFILIATIONS: WU, P-H LIN, HUANG, CHOU, HSU, AND I-I LIN—Department of Atmospheric Sciences, National Taiwan University, Taipai, Taiwan; ABERSON—Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, Florida; YEH, HONG, LU, AND FONG—Central Weather Bureau, Taipei, Taiwan; P-L LIN—Department of Atmospheric Sciences, National Central University, Chung-Li, Taiwan; LIU—Department of Atmospheric Sciences, Chinese Culture University, Taipei, Taiwan
CORRESPONDING AUTHOR: Dr. Chun-Chieh Wu, Department of Atmospheric Sciences, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei 106, Taiwan
E-mail: cwu@typhoon.as.ntu.edu.tw
DOI: 10.1175/BAMS-86-6-787

©2005 American Meteorological Society

CWB Global Forecasting System (C-GFS), NCEP Global Forecasting System, and the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) (i.e., the global model, NOGAPS; the regional model, COAMPS; and the Navy version of the GFDL hurricane model). The Japanese Meteorological Agency (JMA) and the United Kingdom Meteorological Office (UKMO) will receive the data beginning in 2004.

DOTSTAR investigators gather and process data with the Airborne Vertical Atmosphere Profiling System, and perform some onboard debugging/analysis and coding. Constrained by a requirement to submit flight plans to air traffic control two days in advance, DOTSTAR flew only two missions in the first season (2003). (With more experience in coordinating with the international air traffic control agencies, we expect 8–10 per year in 2004 and 2005.)

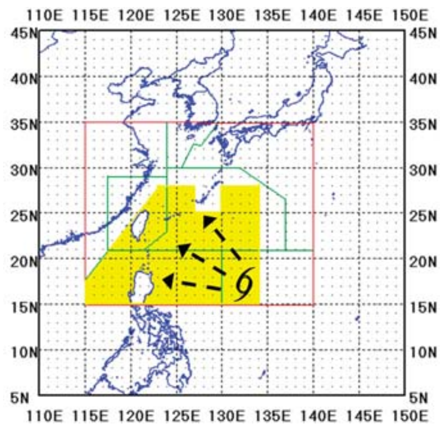

Fig. 2. The area (shaded) for proposed typhoon surveillance in DOTSTAR.

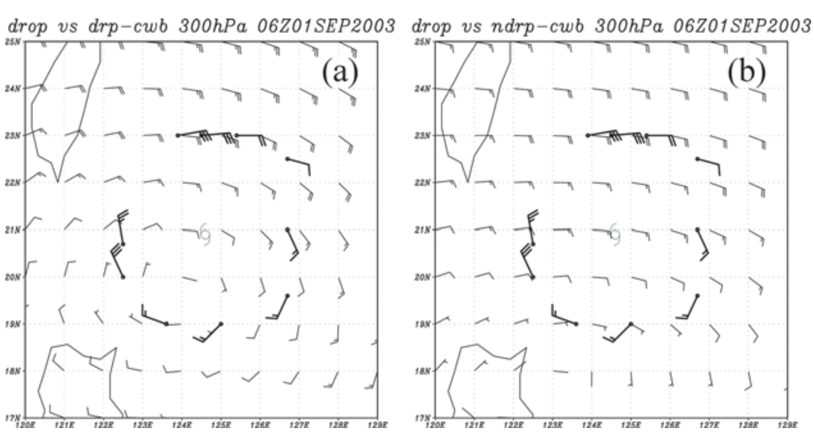

Fig. 3. The initial 300-hPa wind fields (one full wind barb represents 10 m s^{-1}) from the C-GFS (a) with assimilation of the dropwindsonde data and (b) without assimilation of the dropwindsonde data. The 300-hPa winds from the dropwindsonde observations are in bold.

The first mission, on 1 September 2003, released 11 dropwindsondes around Typhoon Dujuan. The second, on 2 November 2003, around Typhoon Melor, released 15 dropwindsondes. The flight track around the periphery of Dujuan was symmetric, whereas in Melor, the aircraft passed over the tropical cyclone center and then sampled only the western half of the circulation due to flight control restrictions.

The data were successful in improving tropical cyclone diagnosis, analyses, and forecasts. Analysis of the cyclonic circulation of Dujuan, which extended from the surface to above 200 hPa, was stronger and more coherent vertically with the data than without (cf. Fig. 3a, b). In particular, C-GFS does not analyze the closed circulation at high levels without the data (Fig. 3b). The circulation center in the C-GFS (Fig. 3a) is about 110 km south of the actual location with the assimilation of the data, likely due to both the poor first guess (the C-GFS does not perform vortex relocation as in NCEP GFS) and insufficient model resolution. The data led to a better diagnosis of the radius of gale-force winds, placing it at 250 km—30 km larger than that diagnosed from satellite data. Although Dujuan did not make landfall on Taiwan, strong winds and heavy rain caused extensive damage in southern Taiwan, testifying to the great extent of the wind field.

Due to temporary technical problems, only 3 of 11 dropwindsondes in Dujuan were assimilated into the NCEP GFS in real time. Despite this, the NCEP GFS forecasts improve by 32% to 81% between 6 and 30 h (Fig. 4a) and by nearly 10% beyond 36 h. The model initialized 6 h later improves by about 25% (not shown) between 6 and 24 h.

The ASTRA flew over the center of Melor at 41,000 ft, and five dropwindsondes were released during the traverse. A warm core is apparent in the center, with the saturated equivalent potential temperature higher than that of the surroundings by about 5°–10° (Fig. 5). The area of maximum winds tilts outward from the center with height, with a maximum measured wind speed of 24 m s^{-1} at 900 hPa.

The Melor track forecast was a great challenge for the numerical models. Most predicted that Melor would head into the South China Sea after passing Luzon. However, Melor turned northward toward

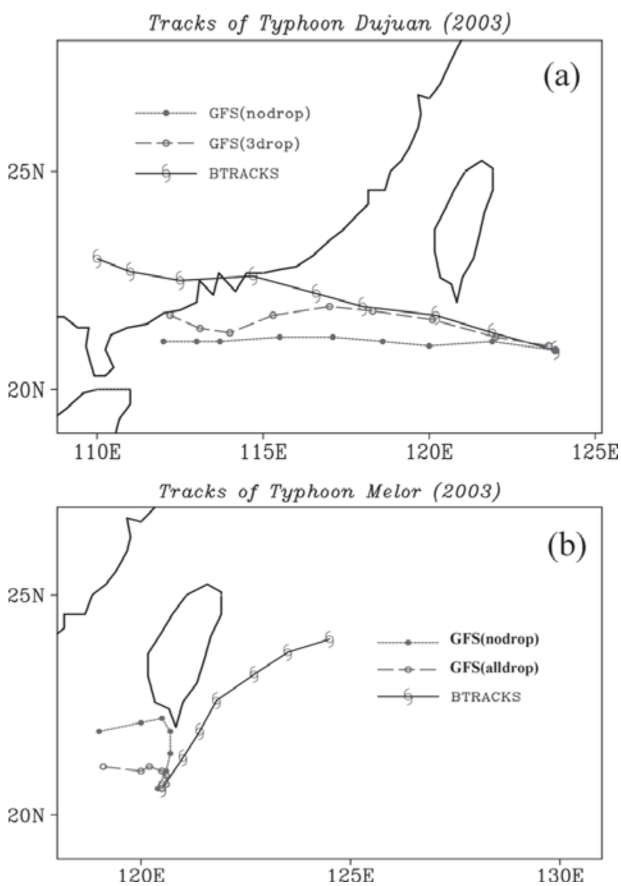

Fig. 4. The best track (BTRACKS) and corresponding 48-h [36-h for (b)] model track forecast every 6 h for (a) Typhoon Dujuan from the NCEP GFS initialized at 0600 UTC 1 September, and (b) Typhoon Melor initialized at 0600 UTC 2 November, with the assimilation of the dropwindsonde data [GFS(3drop) for Dujuan in (a) and GFS(alldrop) for Melor in (b), circles], and without assimilation of the dropwindsonde data [GFS(nodrop), dots].

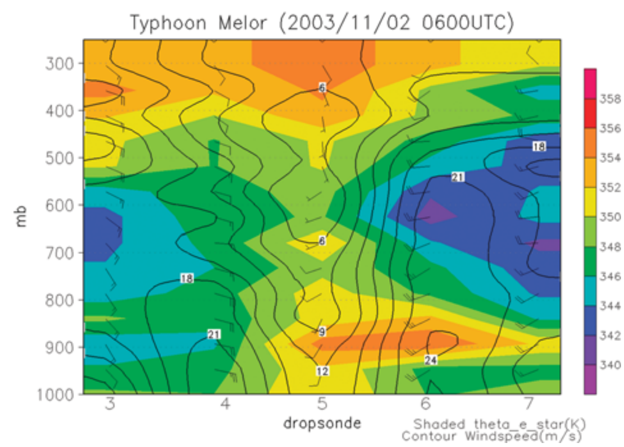

Fig. 5. The wind speed (m s^{-1}; in contour), wind vector (one full wind barb represents 10 m s^{-1}), and saturated equivalent potential temperature (shaded) cross-sections from north to south through the center of Typhoon Melor at 0600 UTC 2 Nov.

Taiwan (Fig. 4b). The NCEP GFS track forecasts are degraded by the data due to the asymmetric sampling, in agreement with Aberson (in the August 2003 *Monthly Weather Review*), who showed that sampling the entire feature is important for improved forecasts.

Besides being used to conduct research on the impact of targeted observations (mentioned to us this year, for instance, by Carolyn Reynolds and Melinda Peng of the Naval Research Laboratory), the DOTSTAR tropospheric soundings may prove to be a unique dataset for the validation and calibration of remotely sensed data for tropical cyclones in the Northwest Pacific region. Because the Northwest Pacific is the most active tropical cyclone basin, DOTSTAR is also an opportunity to obtain detailed boundary layer wind measurements important to the calculation of air–sea exchange coefficients in high wind conditions, which in turn are a critical element for understanding tropical cyclone intensity change. It is hoped that DOTSTAR will shed light on tropical cyclone dynamics, enhance track forecasting accuracy, and place Taiwan at the forefront of international research on this topic. The initial results suggest a golden opportunity for improving the tropical cyclone track forecasts near Taiwan. More data will be obtained in the peripheries of tropical cyclones near Taiwan during the subsequent two years and possibly into 2008. Already, seven missions have been conducted around Typhoons Nida, Conson, Mindulle, Magi, and Aere during 2004. As the number of missions increases, a statistically significant data impact evaluation will be possible.

Further information on DOTSTAR can be found at http://typhoon.as.ntu.edu.tw/DOTSTAR/English/home2_english.htm.

ACKNOWLEDGMENTS. The authors gratefully acknowledge Hung-Duen Yang, Director of the Division of Natural Sciences of National Science Council of Taiwan, for his strong support of DOTSTAR. Special thanks go to Ching-Yen Tsay, Shaw Liu, Hsinn-Liang Shieh (and CWB), and Frank Marks (and the Hurricane Research Division) for their help and advice. Helpful discussions with Hugh Willoughby, Kerry Emanuel, Yoshio Kurihara, Russ Elsberry, T. N. Krishnamurti, Greg Holland, Kuo-Nan Liou, Michael Montgomery, Simon Chang, C-P Chang, Bill

Kuo, Wen-Chau Lee, Chris Landsea, Yuqing Wang, Lou Lee, George Chen, Gen-Rong Liu, Ben Jou, Chung-Hsin Sui, and Hung-Chi Kuo are appreciated. We particularly appreciate the contribution from all the DOTSTAR team members, especially Chia-Hsiang Tsao, Li-Shyong Yin, and Ying-Hau Chen, who were aboard both surveillance flights in 2003. Important help from the Japanese Civil Aviation Bureau and the Meteorological Research Institute (MRI)/JMA (Tetsuo Nakazawa), Air Transportation Office of Philippines, NCEP (Hua-Lu Pan and Naomi Surgi), GFDL (Morris Bender) and FNMOC (Mary Alice Rennick and Brain Strahl) is also appreciated. Special thanks also to Dennis Keyser of NCEP/Environmental Modeling Center (EMC) for enabling the GFS rerun of the Melor case and for help in debugging communications. Thanks also goes to Russ Treadon and Mark Iredell of NCEP/EMC and Timothy Marchok of GFDL for help in running the NCEP models, and to Stephen Lord and the NCEP Central Computing Facility staff who enabled the runs to proceed in real time. The research is supported by Grant NSC 91-2119-M-002-032 and NSC 92-2119-M-002-009-AP1.

FOR FURTHER READING

Aberson, S. D., 2003: Targeted observations to improve operational tropical cyclone track forecast guidance. *Mon. Wea. Rev.*, **131,** 1613–1628.

Burpee, R. W., J. L. Franklin, S. J. Lord, R. E. Tuleya, and S. D. Aberson, 1996: The impact of Omega dropwindsondes on operational hurricane and track forecast models. *Bull. Amer. Meteor. Soc.*, **77,** 925–933.

Emanuel, K. A., 1999: Thermodynamic control of hurricane intensity. *Nature*, **401,** 665–669.

Majumdar, S. J., C. H. Bishop, B. J. Etherton, and Z. Toth, 2002: Adaptive sampling with the Ensemble Transform Kalman Filter. Part II: Field program implementation. *Mon. Wea. Rev.,* **130**, 1356–1369.

Powell, M. D., P. J. Vickery, and T. A. Reinhold, 2003: Reduced drag coefficient for high wind speeds in tropical cyclones. *Nature,* **422,** 279–283.

Wang, Y., and C.-C. Wu, 2004: Current understanding of tropical cyclone structure and intensity changes—A review. *Meteor. Atmos. Phys.,* **87,** 257–278, doi:10.1007/s00703-003-0055-6.

Wu, C.-C., and Y.-H. Kuo, 1999: Typhoons affecting Taiwan: Current understanding and future challenges. *Bull. Amer. Meteor. Soc.*, **80,** 67–80.