EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

EOS

VOLUME 78 NUMBER 23

JUNE 10, 1997

PAGES 237–244

Scatterometer Observes Extratropical Transition of Pacific Typhoons

W. Timothy Liu, Wenqing Tang, and R. Scott Dunbar

PAGES 237, 240

From September 15 to 25, 1996, NASA's scatterometer (NSCAT) monitored the evolution of twin typhoons—Violet and Tom—as they moved north from the western tropical Pacific, acquiring features of mid-latitude storms. The typhoons developed frontal structures, increased asymmetry, and dry air was introduced into their cores. Violet hit Japan, causing death and destruction (Figure 1), and Tom merged with a mid-latitude trough and evolved into a large extratropical storm with gale-force winds (Figure 2).

We understand relatively little about the extratropical transition of tropical cyclones because of the complex thermodynamics involved [e.g., *Sinclair*, 1993], but we do know that the mid-latitude storms resulting from tropical cyclones usually generate strong winds and heavy precipitation. Since the transition usually occurs over the ocean, few measurements have been made. The transition is a fascinating science problem, but it also has important economic consequences. The transition occurs over the busiest trans-ocean shipping lanes, and when the resulting storms hit land, they usually devastate populated areas.

NSCAT was successfully launched into a near-polar, sun-synchronous orbit on the Japanese Advanced Earth Observing Satellite (ADEOS) in August 1996 from Tanegashima Space Center in Japan. NSCAT's six antennas send microwave pulses at a frequency of 14 GHz to the Earth's surface and measure the backscatter. The antennas scan two 600-km bands of the ocean, which are separated by a 330-km data gap. From NSCAT observations, surface wind vectors can be derived at 25-km spatial resolution, covering 77% of the ice-free ocean in one day and 97% of the ocean in two days, under both clear and cloudy conditions.

Jet Propulsion Laboratory 300-323, California Institute of Technology, Pasadena, CA 91109

Together with the precipitable water (vertically integrated water vapor) derived from the Special Sensor Microwave / Imager (SSM/I) onboard the Defense Meteorological Space Program's (DMSP) operational spacecraft, the wind observations provide a good opportunity to monitor and understand the evolution of Violet and Tom. The precipitable water from SSM/I has been evaluated by *Liu et al.* [1992] and others. The detailed structure of the wind-field in Figure 1 illustrates the high spatial resolution of NSCAT. The abrupt change in wind direction to the northeast was likely caused by the development of the frontal structure. The overlay of wind on precipitable water dramatically visualizes not only the structure of this evolving system, but

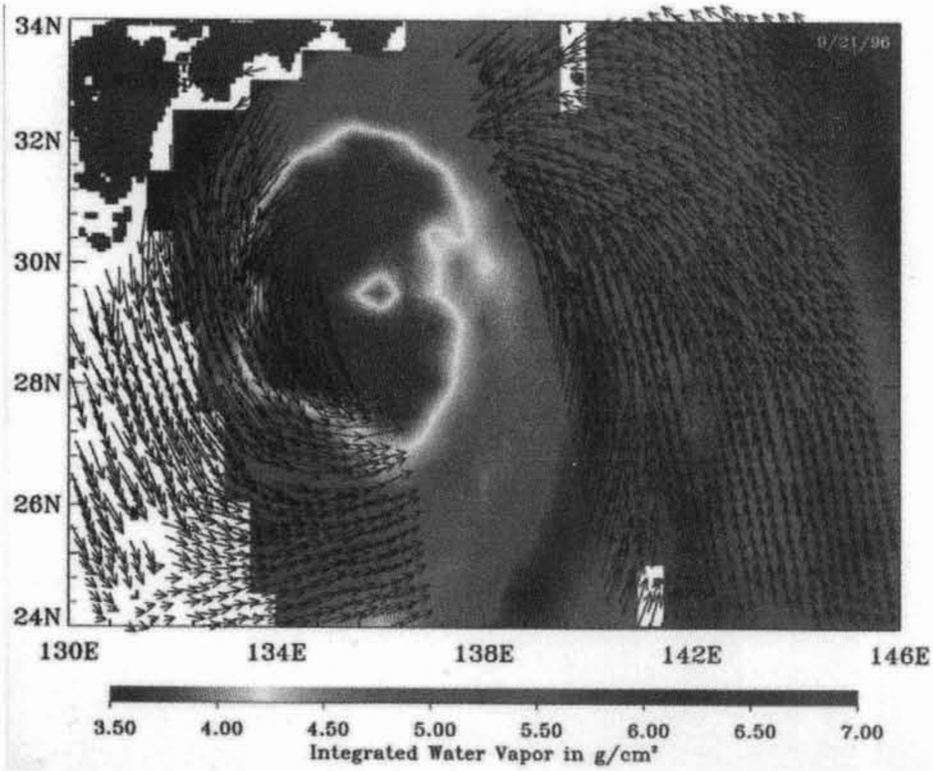

Fig. 1. Typhoon Violet is revealed by the wind vectors (dark arrows) and the integrated water vapor (color image) on September 21, 1996, just before it hit Japan, causing damage and fatalities. The wind and water vapor are derived from the observations by NSCAT on ADEOS and SSM/I on DMSP F-13, along their respective ascending orbits, which are roughly 5 hours apart. Original color image appears at the back of this volume.

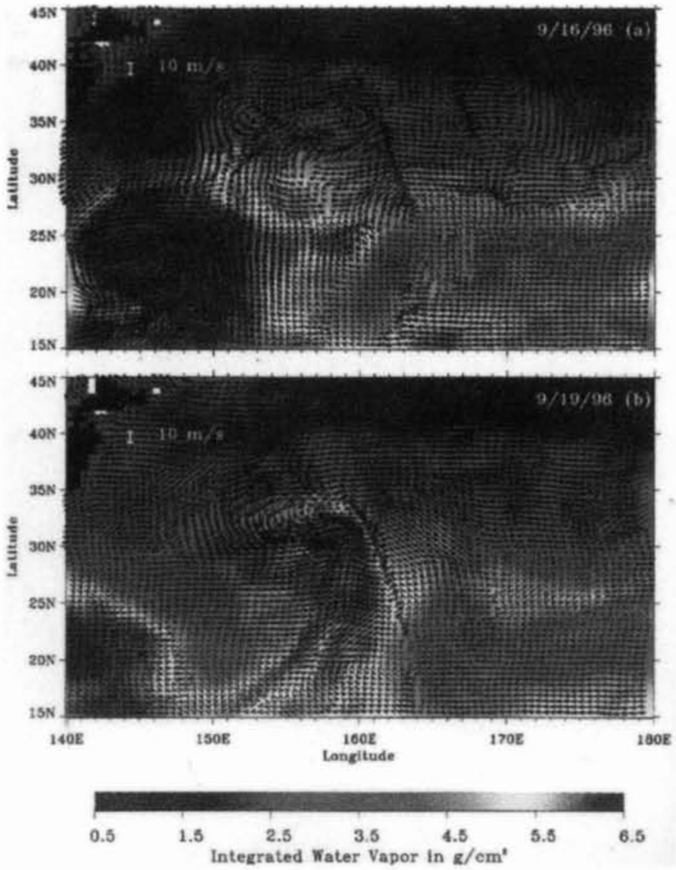

Fig. 2. Evolution of Typhoon Tom revealed by surface wind (dark arrows) and integrated water vapor (color image) fields at 0 UTC on a) September 16 and b) September 19, derived from NSCAT and SSM/I observations by using an objective interpolation scheme described by Tang and Liu *[1996], but without using any other data for initialization. Original color image appears at the back of this volume.*

also the relationship between the dynamics and the hydrologic balance in the mesoscale.

The best-track analyses from typhoon centers and the surface weather maps put out by the National Weather Service (NWS) indicate that Tom and Violet developed approximately on September 11 in the western tropical Pacific at 8°N, with Violet at 130°E and Tom at 150°E, before NSCAT data were available. In the observations for September 16, the two spaceborne sensors clearly identify Tom (at the lower left corner of Figure 2a) with high cyclonic surface wind.

A family of mid-latitude cyclones is revealed at 35°N by winds detected by the NSCAT. There are two centers of wind speed minima and cyclonic relative vorticity, at 152°E and 158°E. The former is an old occluded system that evolved from a cyclone on the previous day, while the latter is an incipient system with clear warm and cold fronts. On the 17th, NSCAT observed the development of a third cyclone centered at 167°E and the occlusion of the cyclone at 158°E. For these three days, September 15–17, the surface weather maps from NWS and the numerical weather prediction (NWP) data of the National Center for Environmental Prediction (NCEP) allow only the identification of a single low-pressure center at 35°N, moving from 148°E on the 15th, to 156°E on the 16th, and on to 166°E on the 17th. The advantage of NSCAT observation is clearly evident in comparison. While there were no NSCAT data during an ADEOS checkout period between the 17th and 18th, the surface weather maps indicate that the low-level trough remained around 35°N, with its center moving east to near 180°E. On the 19th, Typhoon Tom moved in and merged with the extratropical system.

During the three days of active cyclogenesis at 35°N, Typhoon Tom moved very slowly, with slight development of a frontal structure in the east. In Figure 2a, Tom can be distinguished from the extratropical cyclones by the high water vapor (and diabatic heating generated by latent heat release) concentrated in the core. There is much less water vapor in the extratropical cyclones, in which there is a slightly higher value in the warm sector between the fronts, but not at the core.

Tom speeded up on the 18th and moved toward the northeast, retaining a high amount of water vapor in the core. On September 19, Typhoon Tom moved into the trough at 35°N. In doing so, Tom lost much of the water vapor, but still maintained an unusually high water vapor content at the front, compared with previous extratropical cyclones (Figure 2b). This high water vapor was clearly observed by SSM/I in the next few days as the system resulting from Tom moved east. Both NCEP and NSCAT data indicate that the resulting extratropical system produced strong winds above 25 m/s, but the maximum winds from NSCAT were located to the west, while the maximum winds from NCEP are located to the east of the cyclone.

The atmosphere and clouds are much more transparent to radiation at microwave frequencies than at visible or infrared frequencies. The combination of an active (NSCAT) and a passive (SSM/I) microwave sensor provides good observations of weather systems accompanied by cloud cover. In this case, the two sensors revealed the evolution of tropical cyclones from a warm core system into more baroclinic midlatitude storms with unusually strong wind and high precipitation. However, even microwave sensors are contaminated by rain, and the accuracy of scatterometer winds above 25 m/s has not been sufficiently validated.

The NSCAT data used in this study are the interim products retrieved using a prelaunch model function developed by *Wentz et al.* [1984]. Vigorous validation efforts are under way and an improved model function is being developed. *McMurdie et al.* [1987] used a combination of microwave scatterometer and radiometer data to study midlatitude cyclones. *Hsu and Liu* [1996] used scatterometer winds to derive their surface pressure field and to provide an improved description of the location and intensity of tropical cyclones. *Hsu et al.* [1997] demonstrated that scatterometer winds can be used to significantly improve the surface divergence, vertical velocity profile, and, therefore, the heat and hydrologic budgets of convective systems. These methodologies can be used to further our understanding of the thermodynamics of the extratropical transition of tropical cyclones.

Acknowledgments

This study was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. It was jointly supported by the NSCAT Project, the Earth Observing System (EOS) Interdisciplinary Science Program, and the Physical Oceanography Branch of the Mission to Planet Earth. Some of the SSMI data were obtained from the EOS Distributed Active Archive Center at Marshall Space Flight Center; others were kindly provided by Frank Wentz. We are grateful to Johnny C. L. Chan for information on past studies of typhoon transition.

References

Hsu, C. S., and W. T. Liu, Wind and pressure fields near Tropical Cyclone Oliver derived from scatterometer observations, *J. Geophys. Res., 101*, 17,021–17,027, 1996.

Hsu, C. S., W. T. Liu, and M. G. Wurtele, Impact of scatterometer winds on hydrologic

forcing and convective heating through surface divergence, *Mon. Weather Rev., 125(7)*, in press, 1997.
Liu, W. T., W. Tang and F. J. Wentz, Precipitable water and surface humidity over global oceans from Special Sensor Microwave Imager and European Center for Medium Range Weather forecasts, *J. Geophys. Res., 97*, 2251–2264, 1992.
McMurdie, L., G. Levy, and K.B. Katsaros, On the relationship between scatterometer-derived convergence and atmospheric moisture, *Mon. Weather Rev., 115*, 1281–1294, 1987.
Tang, W., and W. T. Liu, Objective interpolation of scatterometer winds, *JPL Publ. 96-19*, Jet Propulsion Laboratory, Pasadena, 20 pp., 1996.
Sinclair, M. R., Synoptic-scale diagnosis of the extratropical transition of a southwest Pacific tropical cyclone, *Mon. Weather Rev., 121*, 941–960, 1993.
Wentz, F. J., S. Peteherych, and L. A. Thomas, A model function for ocean radar cross sections at 14.6 GHz, *J. Geophys. Res., 89*, 3689–3704, 1984.

Exotic Fluids in the Exosphere: When Hades Meets Apollo

PAGES 237–238

The interaction of magmatic volatiles with lakes and shallow groundwater systems results in some of the most exotic fluids found at the Earth's surface. Geologic environments where such fluids occur and the chemical and physical processes responsible for their formation were the subject of a multidisciplinary Chapman Conference titled "Crater Lakes, Terrestrial Degassing and Hyperacid Fluids in the Environment," held from September 4 to 9, 1996, at Crater Lake, Ore.

Sixty-eight scientists with backgrounds in geochemistry, hydrology, limnology, microbiology, economic geology, and volcanology attended the conference. Their presentations covered the physical and chemical characteristics of volcanic lakes, the geochemistry and microbiology of hyper-acidic (pH<1) fluids found in crater lakes, geothermal and acid-mine drainage environments, the rates and mechanisms of magmatic degassing in near-surface environments, and acid fluid-rock reactions and their role in alteration and mineralization associated with epithermal ore deposits.

Presentations at this Chapman Conference illustrated the wide compositional spectrum of volcanic lakes, from extremely diluted lakes like Crater Lake, Oregon, to acidic brine lakes that receive inputs of heat and volatiles primarily from underlying magma bodies, and thus are subject to full-scale eruptions, such as Ruapehu in New Zealand (see *Eos*, May 14, 1996, p. 189). Volcanic lakes can be dominated by meteoric waters ("Apollan lakes") or by volcanic and hydrothermal inputs ("Hadean lakes"). Energy budget analysis of volcanic lakes was presented as a way of creating a quantitative classification system to replace such mythological analogs.

The meeting marked the 10th anniversary of the Lake Nyos disaster, in which over 1700 people were killed when a cloud of cold CO_2 gas was ejected from a stratified lake in Cameroon. Few disagree that the CO_2 in the Nyos lake water has a deep magmatic origin, but what actually triggered the 1986 catastrophic gas burst remains poorly understood. The CO_2 may be introduced into the lake by advection—for example, by discharging CO_2-rich waters at depth—or alternatively, by diffusing CO_2 through bottom sediments. Depth / CO_2 profiles presented at the meeting indicate that Lake Nyos is again stratified and that CO_2 is accumulating in the lake's bottom waters. Calculated CO_2 accumulation rates at Lake Nyos indicate that CO_2 oversaturation could occur there in less than 30 years.

A gas-lift system to extract CO_2 from the depths of such lakes has been successfully demonstrated, but the logistics of large-scale applications are quite complex. Cold, magmatic CO_2 releases also occur in volcanic and geothermal areas not covered by lakes, such as Dieng, Indonesia, and Mammoth Mountain, California. Results of recent research at Mammoth Mountain, California, indicate that diffuse degassing of large amounts of CO_2 followed the intrusion of a shallow dike in 1989. Tree rings document the apparent ages and the stable carbon isotopic composition of past CO_2 releases at Mammoth Mountain.

The placid surfaces of Nyos-type volcanic lakes contrast starkly with turbulent, sulfur-rich, acid-brine crater lakes (Figure 1). Long-term monitoring of such lakes has shown that chemical and physical properties of these lakes change in response to changing volcanic activity. Exciting efforts are now underway to develop reliable real-time surveillance techniques, including monitoring of acoustic noise levels and in situ determinations of polythionate ($S_xO_6^{=}$) concentrations in lake water. Seepage and discharge of toxic and hyper-acidic fluids from high-level crater lakes into flank watersheds may result in strongly contaminated surface waters, an environmental hazard that deserves closer scrutiny. Circulation of such hyper-acidic fluids in volcanic flank aquifers also may affect the long-term stability of the volcanic edifice.

Studying hyper-acidic fluids with several weight percent total dissolved solids poses problems. How can we measure and interpret pH when hydronium ion concentrations exceed 1 molal, and how can we model chemical speciation, mineral solubilities, and water-rock reactions involving such fluids? A method was presented at the meeting for calibrating and accurately measuring negative pH fluids that employs the specific-ion interaction approach developed by Pitzer. Thermodynamic models that use the Pitzer approach can be used to evaluate the speciation and saturation state of such brines, whether it is from acidic mine drainage or warm crater-lake brines. Microbial populations in hyper-acidic mine waters,

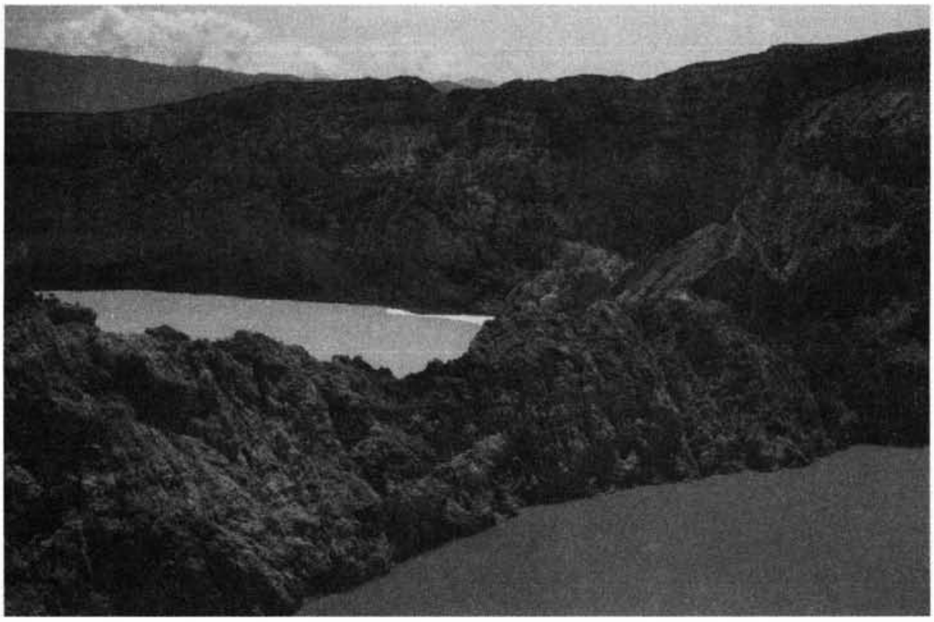

Fig. 1. The turquoise crater lakes of Keli Mutu, Flores, Indonesia. The lake with the floating sulfur slick (at left) has a pH of about 0.3.

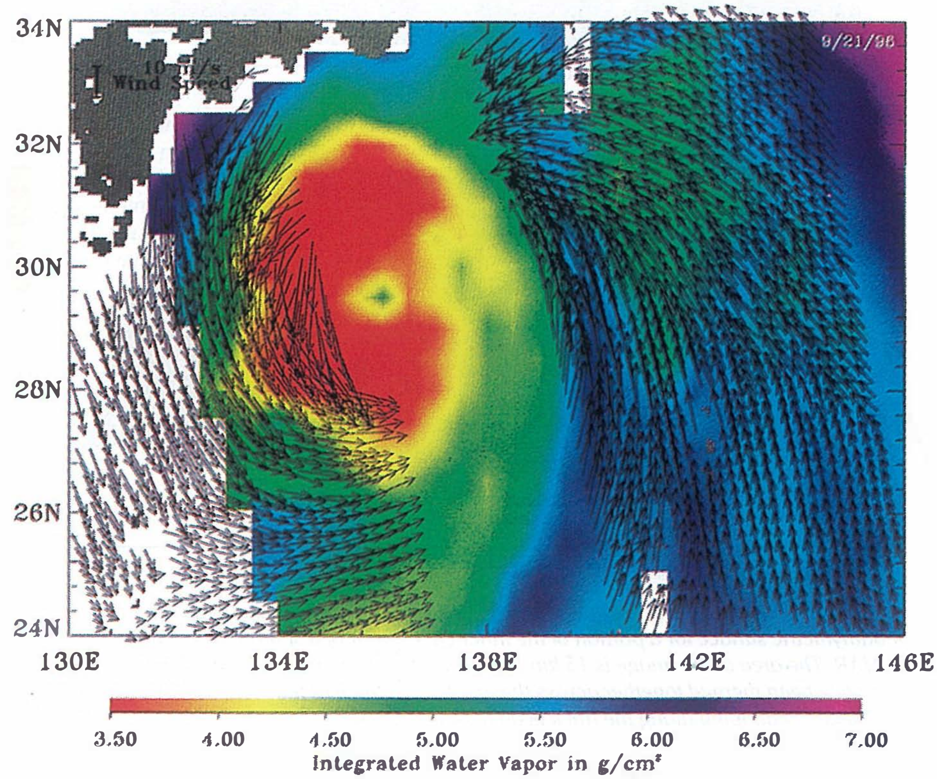

Fig. 1. Typhoon Violet is revealed by the wind vectors (dark arrows) and the integrated water vapor (color image) on September 21, 1996, just before it hit Japan, causing damage and fatalities. The wind and water vapor are derived from the observations by NSCAT on ADEOS and SSM/I on DMSP F-13, along their respective ascending orbits, which are roughly 5 hours apart.

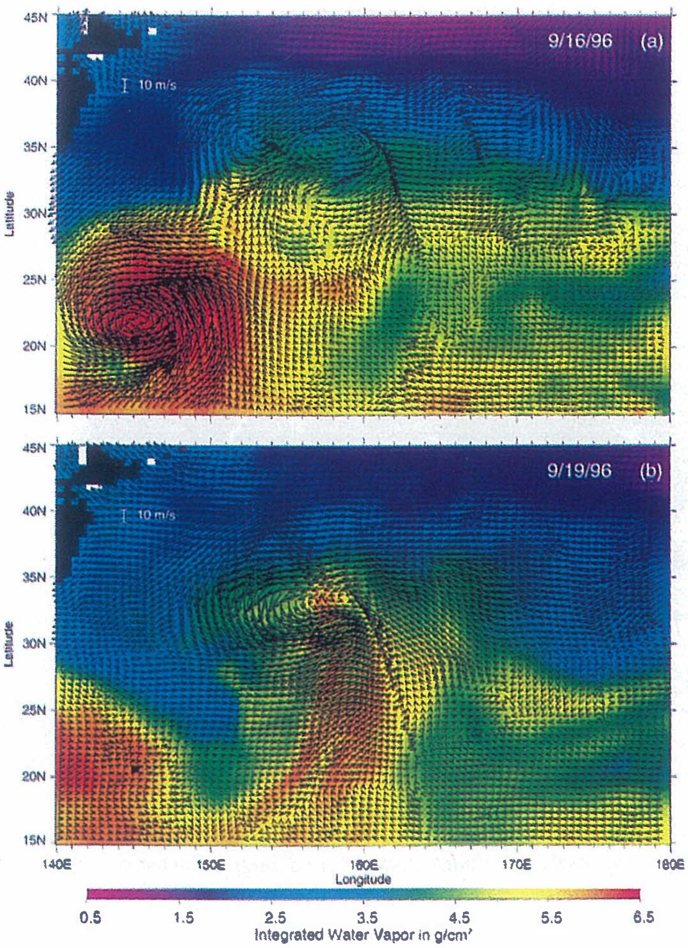

Fig. 2. Evolution of Typhoon Tom revealed by surface wind (dark arrows) and integrated water vapor (color image) fields at 0 UTC on a) September 16 and b) September 19, derived from NSCAT and SSM/I observations by using an objective interpolation scheme described by Tang and Liu *[1996], but without using any other data for initialization.*