

A Report of the Field Operations and Early Results of the South China Sea Monsoon Experiment (SCSMEX)



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ABSTRACT

The South China Sea Monsoon Experiment (SCSMEX) is an international field experiment with the objective to better understand the key physical processes for the onset and evolution of the summer monsoon over Southeast Asia and southern China aiming at improving monsoon predictions. In this article, a description of the major meteorological observation platforms during the intensive observing periods of SCSMEX is presented. In addition, highlights of early results and discussions of the role of SCSMEX in providing valuable in situ data for calibration of satellite rainfall estimates from the Tropical Rainfall Measuring Mission are provided. Preliminary results indicate that there are distinctive stages in the onset of the South China Sea monsoon including possibly strong influences from extratropical systems as well as from convection over the Indian Ocean and the Bay of Bengal. There is some tantalizing evidence of complex interactions between the supercloud cluster development over the Indian Ocean, advancing southwest monsoon flow over the South China Sea, midlatitude disturbances, and the western Pacific subtropical high, possibly contributing to the disastrous flood of the Yangtze River Basin in China during June 1998.

1. Introduction

During the field phase (1 May–30 June 1998) of the South China Sea Monsoon Experiment (SCSMEX), a network of extensive meteorological and oceanographic instruments were deployed in an intensive flux array (IFA) in the northern portion of the South China Sea (SCS). These included a radar network comprising a dual-Doppler radar pair and conventional radar in adjacent coastal regions, surface radiation observations, an integrated sounding system (ISS), shipboard Global Positioning System (GPS) sounding system, aerosondes, and surface meteorological and rainfall observations from islands and from Autonomous Temperature Line Acquisition System (ATLAS) moorings. During the field phase, a team of over 100 international scientists worked at the various regional centers and staging areas in the vicinity of the SCS, carrying out synergistic atmospheric and oceanic observations. The aim of this article is to provide a description of the operations of major meteorological observing platforms during SCSMEX, to disseminate early results, and provide data access information to the general scientific community and to interested readers. Only the meteorological observations will be reported in this article. The oceanographic observing platforms and results will be reported separately.

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2. Major meteorological observing platforms during SCSMEX

a. Dual-Doppler radar

The Tropical Ocean Global Atmosphere (TOGA) C-band Doppler radar (United States) and the Bureau of Meteorological Research Center (BMRC) C-POL polarimetric C-band Doppler radar (Australia) were deployed as a dual-Doppler network, which provided detailed views of the precipitation structure and the three-dimensional wind field of mesoscale convective systems associated with the SCS monsoon. The TOGA radar was deployed on the research vessel *Shiyan#3* (China) for two 20-day cruises during two intensive observing periods (IOPs; 5–25 May and 4–23 June 1998). The C-POL radar was installed at Dongsha Island (20°N, 116°E) and operated almost continuously for the two IOPs (see Fig. 1). Rain gauges and disdrometers were located at or near each radar site. Soundings were launched four times daily and hourly surface observations were taken at both sites. The dual-Doppler observations offered the opportunity for studying mesoscale precipitation systems in a unique monsoon oceanic environment.

During the two IOPs, a variety of convective systems ranging from frontal stratiform deck and tropical deep convection were observed. Other types of convection observed included shear-type parallel bands and “popcorn” shallow convection. At least four waterspouts and a few persistent slow-moving “fine

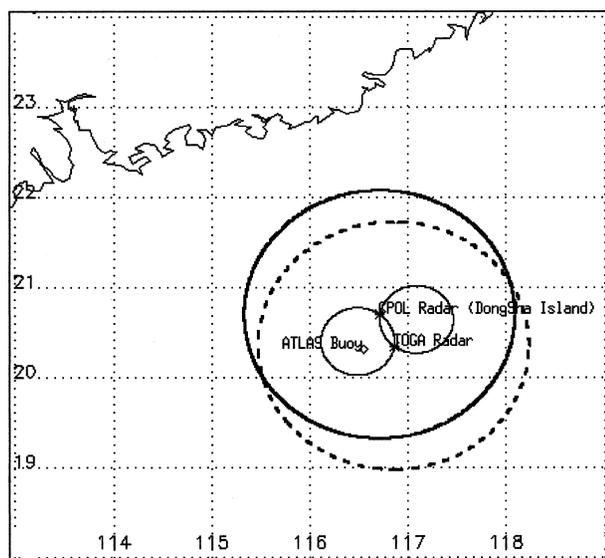


FIG. 1. Spatial distribution of the dual-Doppler and ATLAS mooring network over the northern South China Sea during SCSMEX.

lines” were also observed often with a wavelike appearance, especially when associated with decaying cold pools (Keenan et al 1998). An example illustrating the complexity and rapid propagation of the convective system over the dual-Doppler site is shown in Fig. 2. It shows a heavy rain spell (> 40 dBZ) associated with the southward intrusion of an extratropical frontal system into the Dongsha region from the east Asian continent. During 4 June at 0315 UTC (upper panel of Fig. 2), most of the heavy precipitation was located on an east–west band 50–100 km north of the island. Development of mesoscale complexes including convective cores and squall lines can be seen. Approximately 6 h later, at 0908 UTC (lower panel of Fig. 2), the frontal system swept through Dongsha Island with the heavy rainband advancing to a position southeast of the island, leaving behind light precipitation (< 20 dBZ) over the island.

A preliminary plan has been established for the quality control, processing, and analysis of the radar data. Corrections to the data incorporating calibration results and anomalous echo removal are being undertaken by the National Aeronautics and Space Administration Tropical Rainfall Measuring Mission (NASA TRMM) (T. Rickenbach and R. Cifelli), BMRC (Tom Keenan), and the University of Iowa (P. Kucera). The goal is to produce a complete, quality controlled reflectivity and velocity dataset from both radars. Rain gauge and distrometer data from both sites and from the ATLAS buoys will be used to derive relationship between reflectivity and rainfall rate, which will be used as the basis for constructing quantitative rain maps from both radars. A cross calibration of the dual-radar echo with the spaceborne TRMM Precipitation Radar (PR) will also be carried out. Figure 3 shows the PR near-surface reflectivity (top panel) from a TRMM overpass on 19 May 1998 and a corresponding radar echo from the TOGA radar on board the *Shiyan#3* (bottom panel). Some similarities of the radar features can be seen between the TRMM PR and the TOGA radar. Analysis is now under way to cross-validate the ground-based radar with the space-based observations. Quick-look data and many more illustrative examples of SCSMEX convective systems and related TRMM data can be viewed and downloaded from various SCSMEX-related Web sites listed in section 5.

b. Sounding network

During SCSMEX, a sounding network was established in the SCS and surrounding regions, in conjunc-

tion with the larger domain of the Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment. During the IOPs, 6-hourly soundings were obtained from two research vessels, *Kexue #1* and *Shiyan#3*, and several islands and coastal stations surrounding the SCS. Most of the sounding data were transmitted onto the Global Telecommunications System, and other SCSMEX sounding data were ingested and processed in real time (Ciesielski and Johnson 1999). Preliminary results showed low-level southwesterlies over the northern SCS and southern China were established around 10–20 May, associated with strong frontal activities that originated from the midlatitudes. Figure 4 shows a time–height cross section of the radiosonde wind and relative humidity over the central SCS, near Nansha Island (11°N, 113°E) for May through June 1998. From 10 to 15 May, easterlies (westerlies) prevailed in the lower (upper) troposphere over the central SCS (see Fig. 4). A marked transition occurred on 15–20 May, with the winds in the lower and upper troposphere completely reversing. From 22 to 30 May low-level westerlies prevailed. The development of westerly wind and the deepened moist layer in the lower troposphere, signaling the onset of the monsoon from 20 to 22 May, was very pronounced (Johnson and Ciesielski 1998).

A preliminary gridded dataset of wind, temperature, and humidity as well as a high-resolution sounding dataset from the two ships are now available (see data access information in section 4). An example of the wind analysis is shown in Fig. 5, which depicts the 850-hPa streamline pattern for the period 18–23 May superimposed on the daily rain rates derived from the TRMM PR Microwave

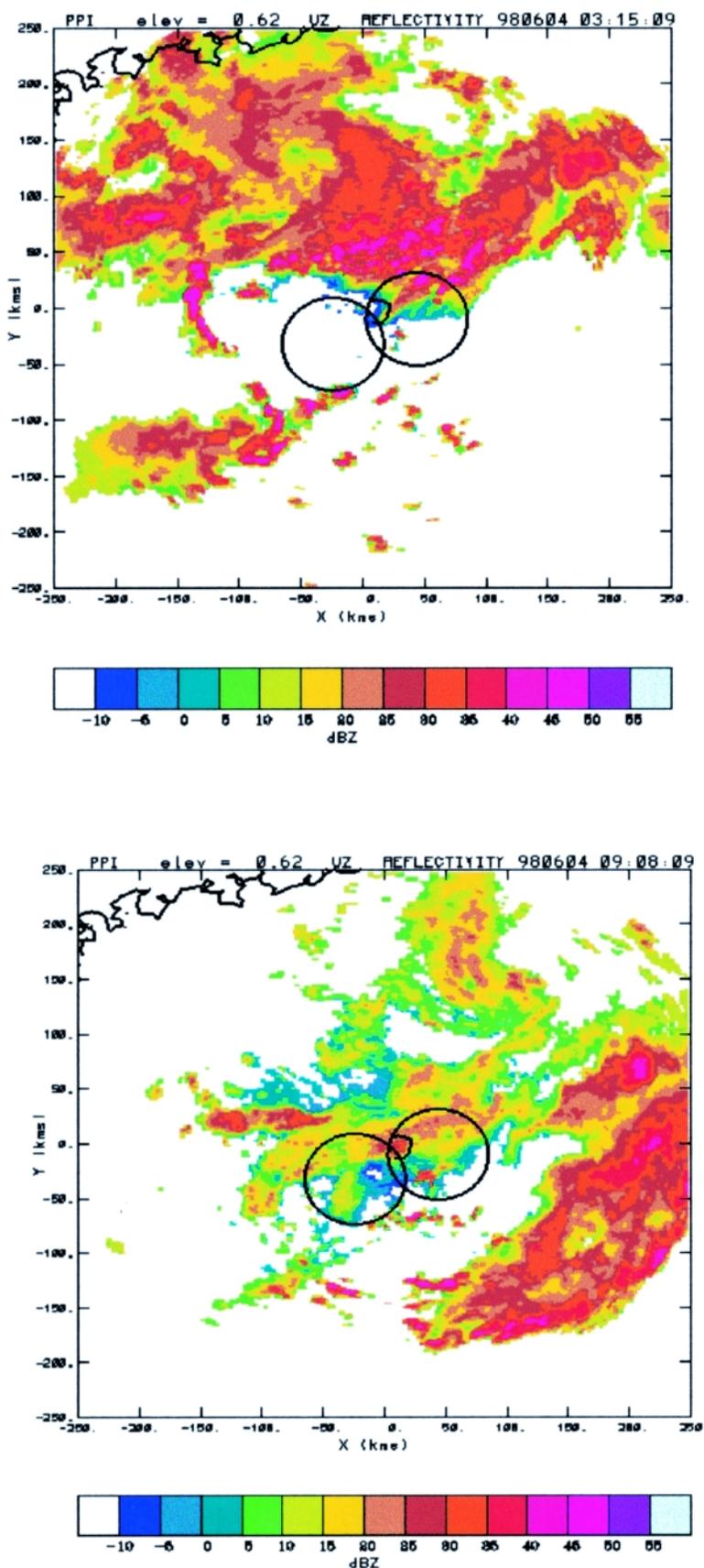


FIG. 2. Radar reflectivity from the BMRC C-Pol radar, showing complex structure in convective systems traversing Dongsha Island at (top) 0315 UTC and (bottom) 0908 UTC 4 Jun 1998.

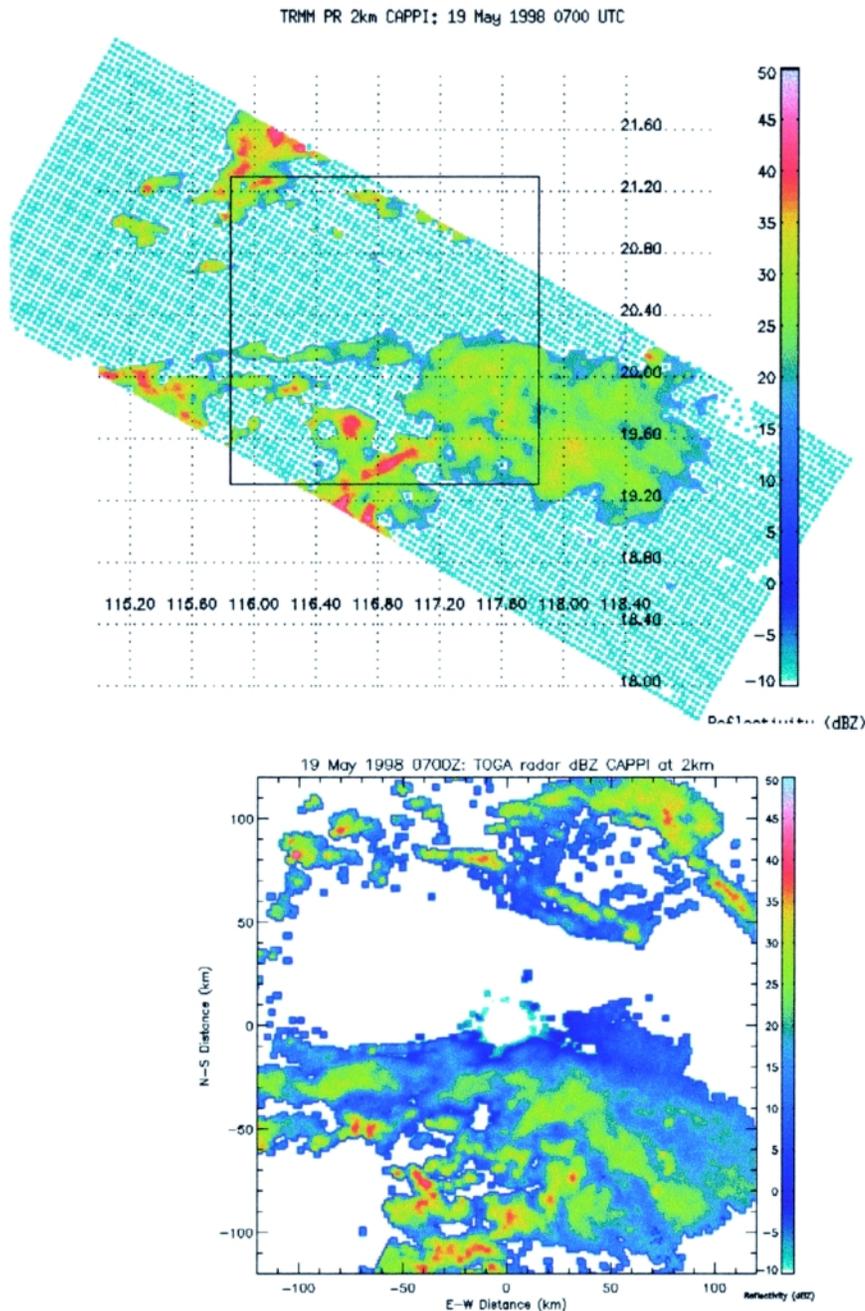


FIG. 3. (top) Satellite PR near-surface echoes from TRMM overpass at 0700 UTC 19 May showing several MCSs occurring over the SCSMEX region. (bottom) The radar reflectivity (dBZ) from the TOGA radar on board the *Shiyun#3* during the same period. The radar coverage is indicated in the square box in the TRMM overpass.

Imager (TMI). Prior to the onset of the SCS monsoon, a strong monsoon depression with heavy precipitation was established over the Bay of Bengal (18 May in Fig. 5). The Bay of Bengal cyclone induced strong surface southwesterlies across Indochina, bringing abundant moisture to southern China from the South China Sea. Just prior to the SCS monsoon onset (18–19 May), the prevailing low-level flow over the south-

ern SCS (0° – 10° N) was easterly. The northern SCS was under the influence of large-scale sinking motion. Both of these features can be attributed to the strong influence of the western Pacific subtropical high. Within the next two days, the wind shifted abruptly to northerly (20 May) and then westerly (21 May), while the Bay of Bengal depression diminished and deep convection was initiated northwest of the Philippines, in the vicinity of the location of the dual-Doppler radar. From 21 May on, the low-level wind over central and southern SCS was a prevailing westerly, in association with the eastward retreat of the subtropical high. These shifts in large-scale circulation signaled the full onset of the SCS monsoon.

c. ISS and aerosonde operations

The ISS deployed in Dongsha Island consisted of a 915-MHz profiler, a Radio Acoustic Sounding System temperature sounding system, a GPS-based NAVAID rawinsonde, and a surface meteorological station. The 915-MHz profiler was used for wind measurement during nonprecipitating periods and for rainfall estimation during rainy periods. The ISS revealed clearly the changes in wind and moisture in the atmosphere during the various transition phases of the SCS monsoon (Lin et al. 1998).

The aerosonde is a small, autonomous aircraft designed for automatic measurements of wind, temperature, and humidity over a range of up to 10 000 km with an in-flight duration of 4–5 days. An experimental version with an operating range of 1000 km, a ceiling of 4 km, and a 36-h duration was deployed during SCSMEX. Altogether, 19 aerosonde flights were carried out to examine the diurnal evolution of the PBL

structure, primarily over the ocean, and monitoring the meso-scale structure/thermodynamic evolution of convergent zones. Regression analysis between aerosonde, ISS, and GPS sounding of temperature, humidity, and wind indicated good consistency between the two datasets. Results showed large diurnal variation of the planetary boundary layer over the ocean ranging from 1400 m during afternoon to 400 m at night.

d. Satellite component

During SCSMEX IOPs, the TRMM and the TMI data over the IFA provided valuable data sources for cross calibration with the dual-Doppler radar. Satellite data from various sources have been processed for SCSMEX. The Goddard Distributed Active Archive Center in conjunction with the TRMM Science Data and Information System will provide coincident TRMM data subsets for SCSMEX. This includes level II 6-hourly data with $0.5^\circ \times 0.5^\circ$, latitude–longitude grid spacing, for surface rain rate and vertical profiles of cloud liquid water in the SCSMEX region. Other TRMM satellite datasets that are useful for SCSMEX studies include the Global Precipitation Climatology Project satellite–gauge combined products, latent heating profiles, and information on convective and stratiform rain separation.

In addition, gridded data for columnar moisture and surface wind have been derived from the Special Sensor Microwave/Imager for SCSMEX (Atlas et al. 1996). The global satellite data revealed a number of interesting features associated with the onset of the SCS monsoon. One of these pertains to the role of the intraseasonal oscillations in foreshadowing the SCS monsoon onset. Amazingly, SCSMEX-98 was almost a repeat of similar daily satellite observations during 1997 (Lau et al. 1998). Prior to the synoptic sequence during onset of the monsoon over SCS described in Fig. 5, there was enhanced organized convective activity over the Indian Ocean in the form of eastward propagating supercloud clusters and twin cyclones straddling the equator (Fig. 6). These features are tentatively identified with the convective complex associated with the Madden–Julian oscillation. A few days before the onset of the SCS monsoon (around 18 May),

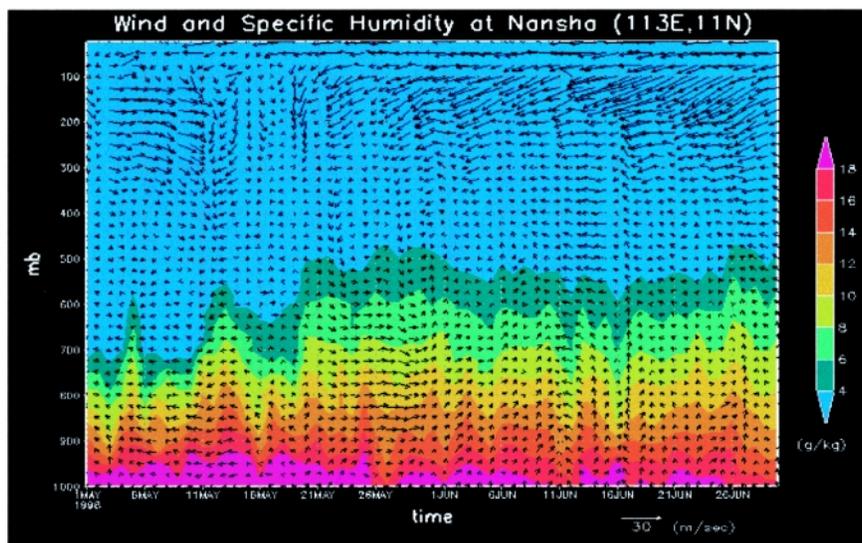


FIG. 4. Time–height cross section of wind and moisture observation at Nansha Island (11°N , 113°E) from 1 May to 30 Jun.

the twin cyclones underwent a bifurcation with the Southern Hemisphere cyclone dissipating and the Northern Hemisphere system moving northward while deepening into a monsoon depression over the Bay of Bengal. After 20 May, convection over the SCS became active and fluctuated with a timescale of 20–30 days. Rainfall estimates from TMI (not shown) indicated that there is an inverse relationship between convection over the SCS and rainfall over northern China, with heavy rainfall over southern China and the Yangtze River basin (15–30 June) coinciding with a break in the SCS monsoon.

e. Surface radiation

During the SCSMEX IOPs, surface remote sensing and radiation instruments were successfully deployed and operated at the Dongsha Island site. The scientific objectives of this observing platform were twofold: 1) to measure broadband shortwave and longwave irradiance at the surface, together with collocated satellite measurements, for studying the radiative energy budget at the IOP area, and 2) to acquire narrowband visible, near-infrared, and microwave radiance measurements at the surface for retrieving atmospheric parameters (e.g., column water vapor amount, ozone abundance, aerosol loading, and size distribution, etc.). A brief summary of the instrumental specifications, data acquisition, and processing status is given in Table 1. In addition, shortwave (PSP) and a longwave (PIR) radiometer measurements were collected on board *Shiyan #3*.

South China Sea Monsoon Onset

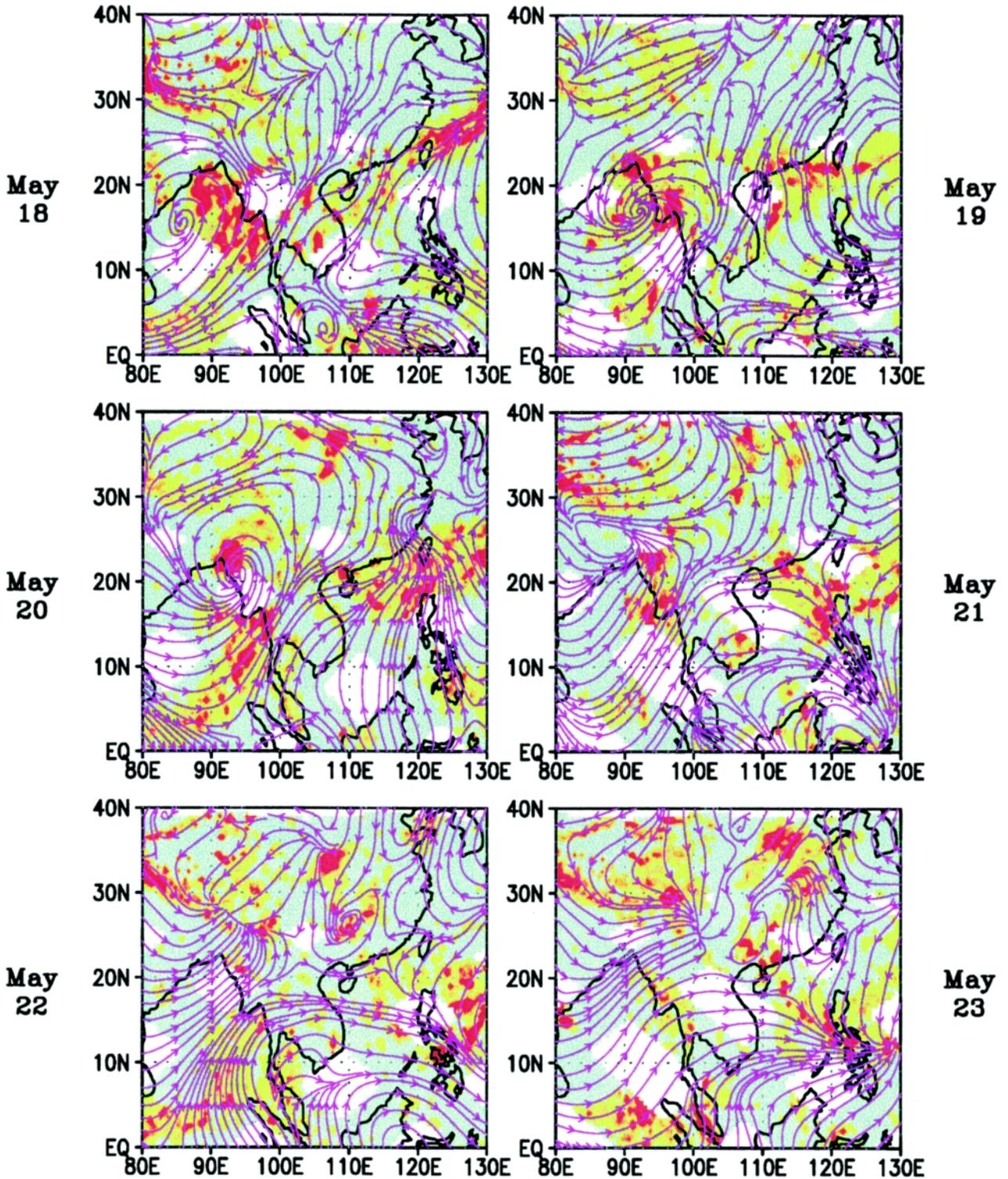


TABLE 1. Summary of surface remote sensing and radiation measurements.

Instrument	Specifications	Dates acquired	Processing status
PSP shortwave radiometers	(a) 0.3–2.8 μm (b) 0.4–2.8 μm (c) 0.7–2.8 μm	1–31 May, 1–9 Jun 12–19, 24–30 Jun	Calibrated (dark offset corrected)
TSP shortwave radiometer	0.3–2.8 μm	Same as above	Temperature (calibrated)
PIR longwave radiometer	4.0–50 μm	Same as above	Calibrated (dome factor corrected)
MFR/7 shadow-band radiometer	0.4–1.0 μm ; 416, 502, 616, 674, 869, and 938 nm	Same as above	Calibrated (preliminary)
Sun photometer screen	340, 380, 440, 670, 870, 940, and 1020 nm	1–3, 6–17, 22–31, May; 7, 12–19, 21–30 Jun	Calibrated, without thin-cloud screen
Microwave radiometers	(a) 19 GHz (b) 22 GHz	7 May–7 July	Calibrated

The monsoon onset and passage through the Dongsha Island were clearly revealed from the measurements of downwelling longwave radiation. Figure 6 shows the diurnal variation of downwelling longwave radiation at the surface for three periods of preonset, onset, and break. During the monsoon onset period (red band), heavy cloud cover, acting as a warm blanket for the surface, largely suppressed the diurnal variation of downwelling longwave radiation. However, during the break period (blue band) the mostly clear sky conditions caused a large diurnal cycle in mean value but with small variations. These radiation data currently can be obtained from Dr. S. C. Tsay (tsay@climate.gsfc.nasa.gov) and eventually will be distributed by the SCSMEX Data Center.

f. Acoustic rain gauges

Two acoustic rain gauges (ARGs) were deployed on an ATLAS mooring at 20°N, 116°E during SCSMEX. The ARGs were mounted on the mooring line 20 m below the surface. They recorded sound fields identi-

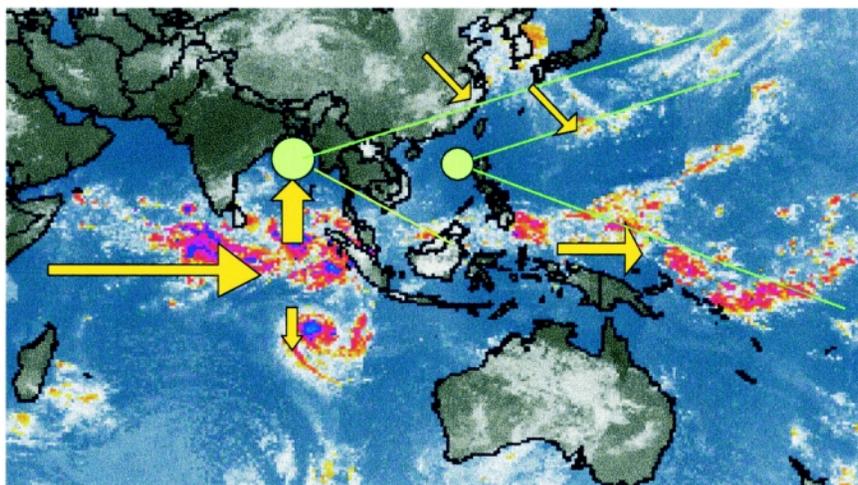


FIG. 6. Schematic showing the propagation of the twin cyclones and their bifurcation (yellow arrows), leading to the development of the Bay of Bengal depression (large green circle) and subsequently the convective outburst over the SCS (smaller green circle). The impacts of extratropical systems from the east Asian continent on the SCS monsoon, and the continued propagation of equatorial disturbances into the western Pacific, are indicated by thin yellow arrows over these regions. The thin green lines stretching from the disturbance centers indicate directions of associated cloud bands.

FIG. 5 (previous page). Daily averaged rainfall from TMI and streamline from SCSMEX wind analyses showing synoptic-scale evolutions from 18 to 23 May 1998.

fying ocean surface weather conditions from heavy rain, drizzle, wind only, and “noise.” The ARGs clearly identified the onset of the SCSMEX in terms of the occurrence of heavy rain. When heavy rain is detected, the sound field can be further analyzed to measure the drop size distribution of the rain and delineation of convective and stratiform rainfall. The acoustic rain gauge data should be available via the TRMM Web site in the near future. For further details, contact Dr. J. Nystuen (nystuen@apl.washington.edu).

3. Preliminary scientific highlights

In this section, we provide highlights of scientific results obtained so far from SCSMEX and related data. The highlights were selected from results presented at the IX Pacific Science Inter-Congress, Asian Pacific Monsoon and Typhoon Meteorology Symposium, which was held on 16–19 November 1998, in Taipei, Taiwan; the SCSMEX Organizing Committee Meeting in Macau, held 28–30 March 1999; and the SCSMEX Special Session at the Spring Meeting of the American Geophysical Union, held in Boston, Massachusetts, 1–4 June 1999. As such, these are only tentative and mostly unpublished results and are included here as teasers to stimulate further research.

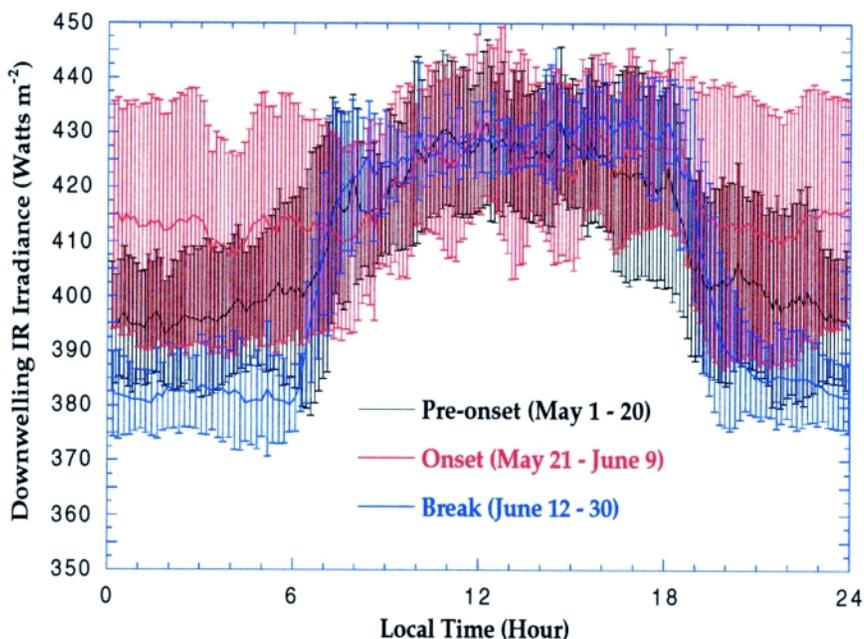


FIG. 7. Measurements of downwelling longwave irradiance ($4.0\text{--}50\ \mu\text{m}$) at the surface, data presented at 10-min mean values, and average (mean and standard deviation) for three observational periods.

- During 1998, the earliest stage of the Asian monsoon onset occurred over the northern SCS (defined by development of steady low-level southwestlies and heavy precipitation) around 15–17 May. The SCS monsoon developed over the entire SCS region around 20–25 May, signaled by a shift in the large-scale monsoon circulation pattern. The SCS monsoon onset is moderately delayed by about a week, compared to the climatological mean onset date (Ciesielski and Johnson 1999).
- The South China Sea monsoon in 1998 evolved in multiple stages. In the preonset stage, we found strong supercloud cluster activities associated with the development of quasi-symmetric twin cyclones, one in the Northern and one in the Southern Hemisphere. The former subsequently developed into a monsoon depression over the Bay of Bengal. The onset of the South China Sea monsoon was associated with a sudden shift of convection from the Bay of Bengal to the northern South China Sea and the eastward withdrawal of the western subtropical high. Similar sequences of events were observed during the same period in 1997 (Lau et al. 1998) and during the Joint Air–Sea Interaction Experiment in May 1999 (P. Webster 1999, personal communication).
- The SCSMEX IOPs witnessed a wide variety of convective systems over the IFA, from frontal bands to shear-banded structure, deep convection, popcorn-type shallow convection, and slow-moving fine lines to water spouts. Characteristics of the convection changed markedly before and after the monsoon onset (Keenan et al. 1998; Rickenbacker et al. 1998).
- Midlatitude disturbances strongly impacted the northern SCS, with an active frontal convective system that developed over the northern SCS, especially during the preonset stage (10–20 May). These disturbances continued to be active in the subsequent stages of monsoon development and might have played a crucial role in the initiation of heavy rain over

east Asia during the summer of 1998 (Ding and Li 1999).

- Shortwave cloud forcing associated with frontal clouds was considerably less (by 200 W m^{-2} during daytime) for frontal clouds than monsoonal deep clouds. Diurnal signals in surface radiation were strongest during the break period (Lin et al. 1998).
- Convective activities over the northern South China Sea and rainfall fluctuation appear to be inversely related. Strong monsoonal low-level southerly flow from the SCS as well as midlatitude disturbances from the mainland of east Asia may have been instrumental in triggering the excessive precipitation over the Yangtze River Basin in June 1999 (Ding and Li 1999).

4. Relevant SCSMEX Web sites

The SCSMEX Data Center in Beijing is the central data archive for SCSMEX data. At present, all SCSMEX data are being processed by principal investigator and/or investigator groups for different platforms. Level I data for most platforms have been sent to the SCSMEX Data Center at the project office in Beijing. In the meantime, Web sites have been set up where users can download or ftp data and/or images. The following are Web site addresses and contact information for each data type:

- <http://climate.gsfc.nasa.gov/kim/relacs/campaign/index.html>—A central Web site that contains the original science documents for SCSMEX, quick-look data, satellite images, movie loops, as well as links to all the other SCSMEX-relevant Web sites listed below. Contact: W. K. M. Lau, NASA Goddard Space Flight Center (GSFC), e-mail: lau@climate.gsfc.nasa.gov.
- http://trmm.gsfc.nasa.gov/trmm_office/field_campaigns/scsmex/scsmex_radar.html—This Web site contains descriptions of the TOGA radar operation during SCSMEX, including a photo gallery of sky conditions and radar instruments deployed during SCSMEX, radar images, and data information. Contact: Dr. T. Rickenback, NASA GSFC, e-mail: ricken@trmm.gsfc.nasa.gov, or Dr. R. Cifelli, NASA GSFC, e-mail: rob@olympic.atmos.colostate.edu.
- <http://www.bom.gov.au/bmrc/meso/New/scsmexhme.html>—This Web site for the C-Pol BMRC radar contains much interesting infor-

mation and many radar images and nice pictures of the SCSMEX Dongsha Island operation. Contact: T. Keenan, BMRC, Australia, e-mail: t.keenan@bom.gov.au.

- <ftp://updraft.atmos.colostate.edu/pub/scsmex/gridv1/>—This is the ftp site for the SCSMEX gridded sounding data. Contact: Prof. R. Johnson or P. Ciesleski, Colorado State University, e-mail: rhj@vortex.atmos.colostate.edu.
- <http://pblap.atm.ncu.edu.tw>—Web site for Dongsha rainfall and ISS operations. Contact: Prof. P.-L. Liam, National Central University, Taiwan, e-mail: tliam@storm.atm.ncu.edu.tw.
- <http://ram.as.ntu.edu.tw/aerosonde>—This Web site contains data and data access information for aerosonde data for SCSMEX. Contact: Prof. P.-H. Lin, National Taiwan University, Taiwan, e-mail: linpo@atmos.as.ntu.edu.tw.
- <http://www.pmel.noaa.gov/toga-tao/scsmex/realtime.html>—This Web site contains oceanographic and surface meteorological data from the ATLAS buoys over the South China Sea deployed during SCSMEX.
- <http://trmm.gsfc.nasa.gov/>—This is the official Web site for NASA–National Space Development Agency of Japan TRMM, containing everything you want to know about TRMM.
- <http://daac.gsfc.nasa.gov/>—This Web site contains current information on data information for TRMM, related field campaigns, and other environmental datasets.
- <http://www.ssmi.com>—This Web site has near-real-time daily updates of SSM/I global water vapor, rainfall, and SST data from the TMI.

Acknowledgments. The NASA/TRMM project provided support for U.S. participation in SCSMEX including the dual-Doppler radar in the IFA, sounding operations on ships, and SCSMEX-related modeling/diagnostic pilot activities. The NOAA Office of Global Programs and the Office of Naval Research also provided partial support for the field phase of SCSMEX.

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