Storm Transfer and Response Experiment[1]

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Abstract

An air-sea interaction research program (STREX) has been carried out in the Gulf of Alaska to investigate characteristics of the boundary layers of the atmosphere and ocean in middle-latitude storms. Observations were made by ships, aircraft, satellites, and buoys in 10 storms. This paper summarizes the objectives and the observations obtained in STREX, and identifies some of the research problems being studied by meteorologists and oceanographers who participated in the program.

1. Introduction

The field phase of an air-sea interaction research program, Storm Transfer and Response Experiment, (STREX), was carried out in November and December 1980 in the Gulf of Alaska by meteorologists and oceanographers from the United States and Canada; the research phase is in progress. The program was undertaken to take advantage of observational capabilities developed over the past few years which make possible the examination of air-sea interaction processes in mature Pacific Ocean storms. The objectives of STREX are to extend our understanding of the following aspects of Pacific storms:

1) the characteristic spatial distributions of the vertical fluxes of momentum, heat, and water vapor in the atmospheric boundary layer;
2) the scales on which transfer occurs from the boundary layer to the lower troposphere;
3) the characteristic spatial distribution of latent heat release in these storms;
4) the effects of storms on the upper mixed layer of the ocean.

Results are expected to contribute to improved methods for representing boundary layer processes and the coupling of the atmosphere and ocean in numerical models.

STREX has been organized as a federation of essentially independent efforts by principal investigators responsible for their own projects, who have agreed to plan cooperatively and to collaborate in data analysis.

Major responsibilities for STREX planning and management were carried by scientists representing the Canadian Atmospheric Environment Service (AES) and Institute of Ocean Sciences, Pacific Marine Environmental Laboratories (NOAA), and the University of Washington. Other institutions represented by principal investigators include: the Jet Propulsion Laboratory; Langley Research Center; National Center for Atmospheric Research; Naval Postgraduate School; Office of Weather Research and Modification; and Research Flight Facility of NOAA; Oregon State University; University of Toronto; and University of Wisconsin. Members of the STREX Executive Committee are: J. R. Apel, PMEL–NOAA; R. G. Fleagle, University of Washington; G. A. McBean, Canadian AES; R. W. Stewart, Provincial Government, B.C.; J. Smagorinsky (corresponding member), GFDL–NOAA; and M. Miyake, Executive Scientist (ex officio).

STREX has provided the opportunity for testing of several observational techniques that may be used in research and for operational services in the future. These techniques include the NAVAID sounding system, used with ascending balloons from ships and dropsondes deployed from aircraft; a new system for balloon release in high winds; the use of thermistor chains with drifting buoys; a remote sensing microwave system of ocean surface observations; and a system for measuring ocean currents near the surface. STREX also provided an opportunity to test the Visible and Infrared Spin Scan Radiometer (VISSR) system of radiometric soundings from geostationary satellites. The STREX Operations Plan[5] describes the observational program and summarizes the scientific program.

2. Shipboard meteorological program

The Canadian weathership CCGS *Vancouver* and the NOAA ship USS *Oceanographer* were the primary observing platforms for extensive meteorological and oceanographic observational programs during STREX. The *Vancouver* was stationed at its normal position OWS P (150°N, 145°W) while the *Oceanographer* was positioned near 50°N, 141°W. Both ships made standard surface meteorological observations and upper-air soundings. Throughout the STREX period, radiosondes were launched at six-hour intervals, and during selected intensive periods, the frequency was

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0003–0007/82/010006–09$06.25

[5]Operations Plan, Storm Transfer and Response Experiment (STREX) International STREX Office, 27 October 1980.

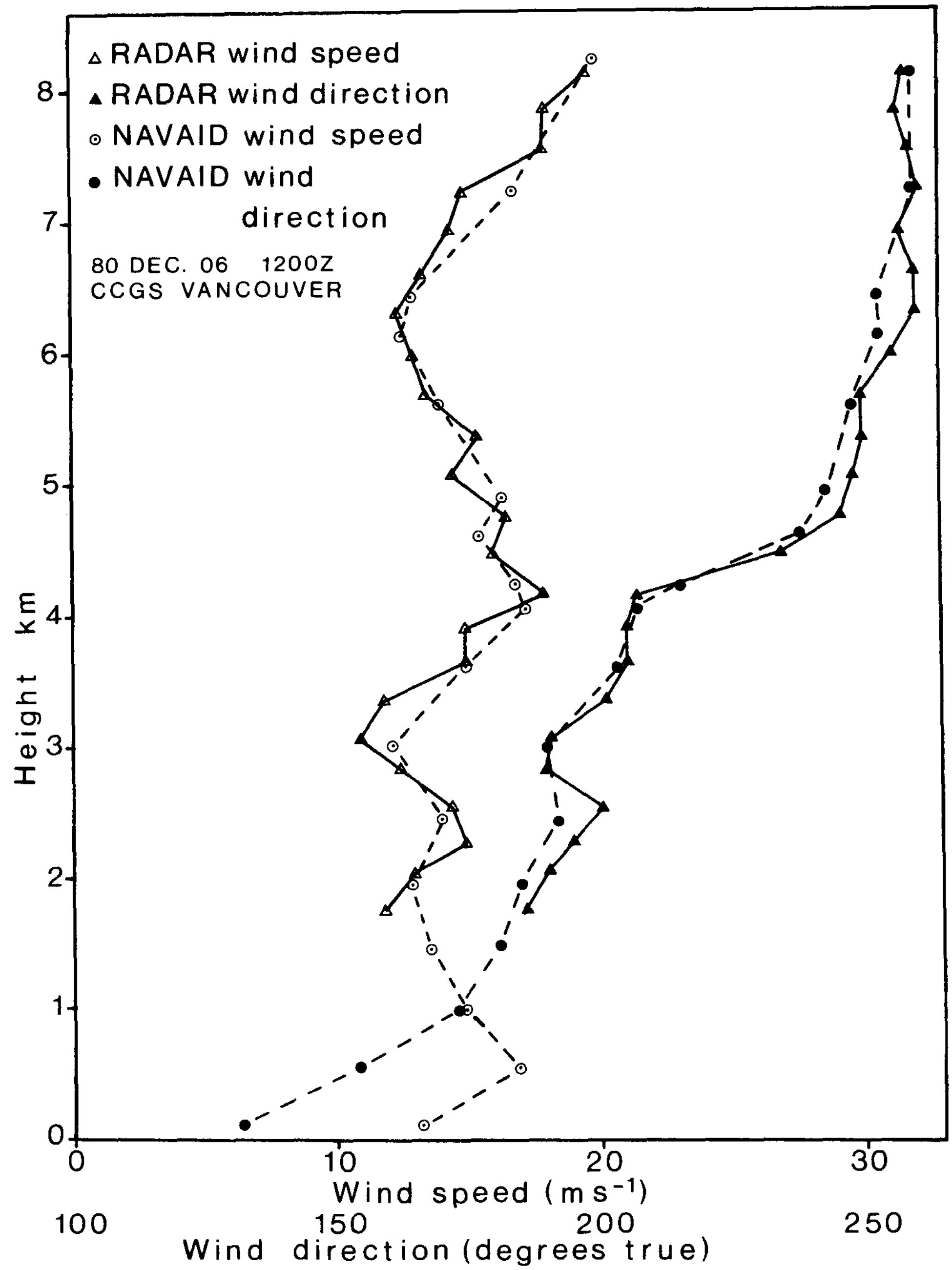

FIG. 1. Comparison of radar-tracked and NAVAID-tracked wind profiles for 1200 GMT, 6 December 1980, from CCGS *Vancouver*. The solid lines are radar; dashed lines are NAVAID. The radar data below 1.7 km are omitted to allow time for radar to lock on and track the balloon.

increased to every three hours. Approximately 200 sondes were launched from each ship.

A special NAVAID-satellite communications–real-time processing system was implemented by NOAA and AES. A FGGE-type NAVAID system was installed on both ships to track the balloons using omega navigation signals. In order to acquire and process the data in real-time, satellite uplinks were used through GOES–West to the Colorado State University ground station. These data were transmitted to NCAR for processing, and the standard coded messages were transmitted through the Global Telecommunications System (GTS). The system worked quite well, with over 81% of the *Vancouver*'s ascents (which were given priority) processed and sent on the GTS.

About once a day, the NAVAID sonde and balloon also were tracked with the *Vancouver*'s radar (the normal tracking procedure at OWS P). A comparison of two wind profiles is shown in Fig. 1. Generally, the average difference between the two systems was less than 8% of the measured wind components, excluding occasional large spurious wind speeds produced by the NAVAID. Post reprocessing has eliminated many of these spurious data. A detailed comparison to

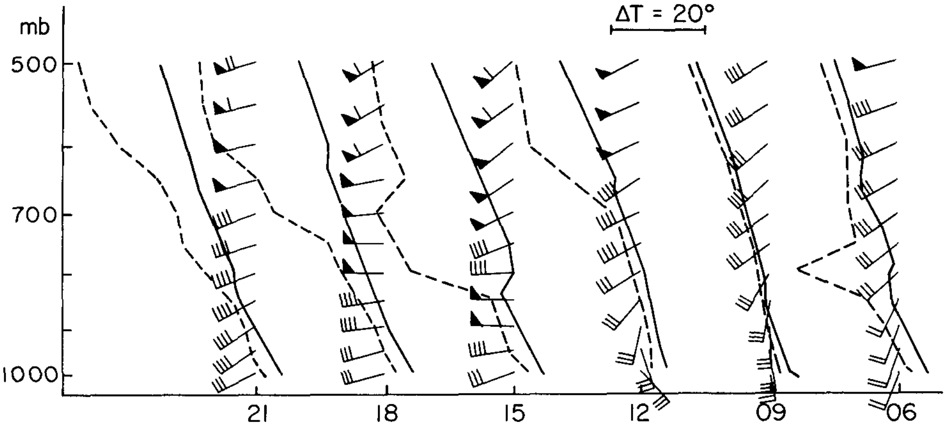

FIG. 2. Time sequence of rawinsonde observations at the CCGS *Vancouver* from 0600 GMT to 2100 GMT, 17 November 1980. Solid lines indicate temperature, and dashed lines, dew point temperatures. Full barbs indicate 5 m s^{-1} and pennants 25 m s^{-1}. Time runs from right to left; times shown are official observation times, balloons were launched about 1 h 40 min earlier.

quantify the radar-NAVAID differences by height and wind characteristics is under way; this study will include an investigation of possible differences arising from vertical smoothing.

Use of the NAVAID system for sounding permitted use of the radar to observe the distribution and characteristics of precipitation. The radar on board the *Vancouver* was a 1° beam width, (5.7 cm type) and had an effective range of 200 km. Careful calibrations of the radar were carried out. From the digital radar data, three-dimensional radar echo maps are being produced for the STREX period. These will provide the first radar mappings of storms before they reach and are influenced by the topography of the West Coast of North America.

To supplement the radiosonde observations in the lower troposphere, pressure-temperature-humidity sondes were launched from the *Vancouver* at hourly intervals during selected storm periods. These sondes yielded detailed information on boundary layer stability and structure for three cases.

Other observational programs were conducted from the two ships to measure radiation, turbulent fluxes, and aerosol and trace gas distributions. Bulk aerodynamic calculations of fluxes will be made at the two ships at three-hour intervals throughout the period of observation.

During the six weeks from 1 November to 15 December 1980, a total of 18 closed low pressure centers moved through the Gulf of Alaska, each storm resulting in substantial air-sea interaction in the region of the two ships. Ten of these storms were chosen for intensive observations. During the first half of STREX (4–22 November), five intensive periods were selected, and on each occasion the front passed both ships. During the second half of STREX (30 November–14 December) three periods were selected; in these cases the fronts were slow moving and not as well defined as those of the first half. Two cases of strong cold advection in the STREX area also were selected. The shipboard meteorological data can be illustrated by the frontal passage of 17 November. In this case, a slowly deepening low pressure center moved to 160°W, 55°N, while the occluding frontal system moved easterly at about 25 m s^{-1}. The frontal passage at the surface occurred at about 1030 GMT at the *Vancouver*, and about four hours later at the *Oceanographer*. Figure 2 shows the time sequence of rawinsonde observations through the frontal system at the *Vancouver*. The basic structure of the front was the same at both ships, but, as will be discussed, there were some differences in detail. The cold front can be identified with the inversion near 800 mb on the 1500 GMT ascent, and at 625 mb on the 1800 GMT ascent. For a translation speed of 25 m s^{-1}, this corresponds to an east-west cold frontal slope of about 1:170. The potential temperature increased by 10 K over 50 mb up through the cold front at 1500 GMT. The warm frontal surface is quite diffuse, but can be associated with the inversions at 825 mb at 0900 GMT and at 775 mb at 0600 GMT. The air above the frontal surface is moist relative to the air behind the front.

The frontal passage at the surface was marked by a wind shift and pressure change, but little temperature change. The average wind direction below the frontal surfaces was southerly in advance of the passage, swinging to almost westerly behind it. In the cold sector, a well-mixed convective boundary layer developed, leading to cumulus clouds and some showers. Flights were made with the P-3 aircraft into this region to investigate boundary-layer structure during cold-air advection.

A detailed comparison of the soundings at the *Vancouver* and the *Oceanographer* shows that the frontal system was evolving during its passage between the ships. The temperature difference across the cold front became smaller, while the moisture content in the warm sector was enhanced. Particularly noticeable was the increasing temperature and decreasing humidity in the region between 500 mb and 800 mb behind the cold front. This probably is associated with descending air behind the cold front and low-level divergence. These are some of the features of the frontal structure and its evolution that will be examined carefully.

Figure 3 shows the distribution of precipitation near the

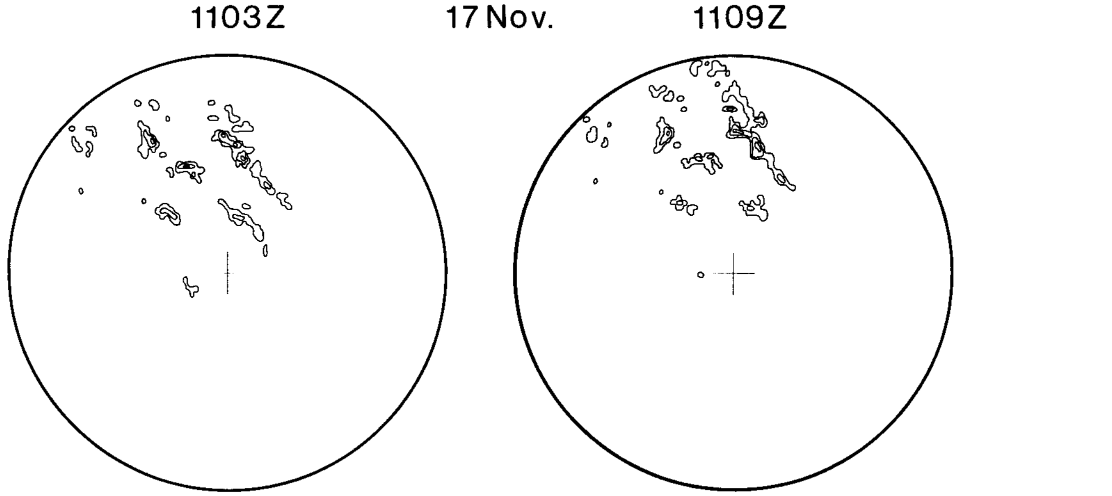

FIG. 3. Examples of PPI radar echoes from the *Vancouver* near frontal passage on 17 November. The range shown is 100 km. The normal colored output of echo return at 2 dB(Z) intervals above 15 dB(Z) have been hand-contoured here for presentation purposes. More detailed information is being used in scientific studies.

front as determined by *Vancouver*'s radar. The front appears to consist of high reflectivity bands about 40 km apart, with a narrow region of lower reflectivity in between. The area of these precipitation bands is much less extensive than the extensive cloud regions associated with the front, as seen on satellite pictures. Detailed analysis of precipitation in all storms that passed the *Vancouver* is underway.

3. The aircraft program

For the 10 cases chosen for intensive observations, research aircraft carried out a variety of observations. In 9 of these 10 cases, an Air Force Reserve C–130 (920 Weather Recon Group) flew a prescribed track to provide soundings spaced at intervals of about 300 km. On each flight, approximately nine dropsondes were deployed from a height of 300 mb. Two of the nine dropsondes were scheduled to coincide in time with the soundings taken from the two ships at three-h intervals.

In each of the nine storms, a NOAA P–3 flew a prescribed mission that included dropsondes deployed from 500 mb; multiple penetrations of clouds and fronts; and boundary layer flights to measure vertical fluxes, ocean surface properties, and other quantities. The NOAA P–3 also deployed airborne expendable bathythermographs (AXBT).

In four cases, the NCAR Electra was used to make boundary-layer measurements and to observe ocean surface properties. The NASA C–130 flew at 850 mb in four storms, making microwave and radar observations of the sea surface. The Electra flew comparison flights with the P–3 and the NASA C–130. Flight plans of all aircraft were coordinated carefully.

Cases were chosen to provide observations covering various sectors of the storms. On two occasions, occluded fronts were located to the west of the ships during the period of aircraft observation; on four occasions, the fronts were located to the east of the ships; and on two occasions, fronts were located between the ships. On two occasions of cold air

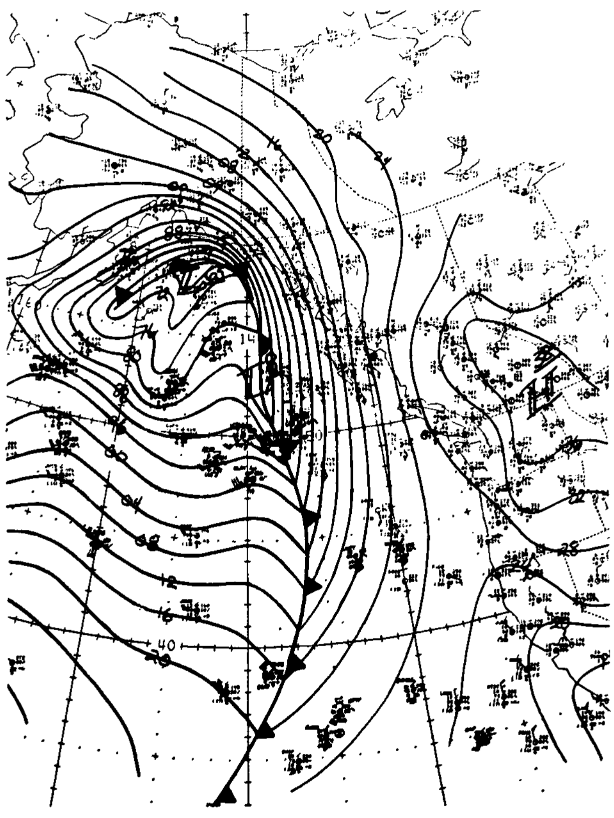

FIG. 4. Sea level synoptic map, 0000 GMT, 16 November 1980.

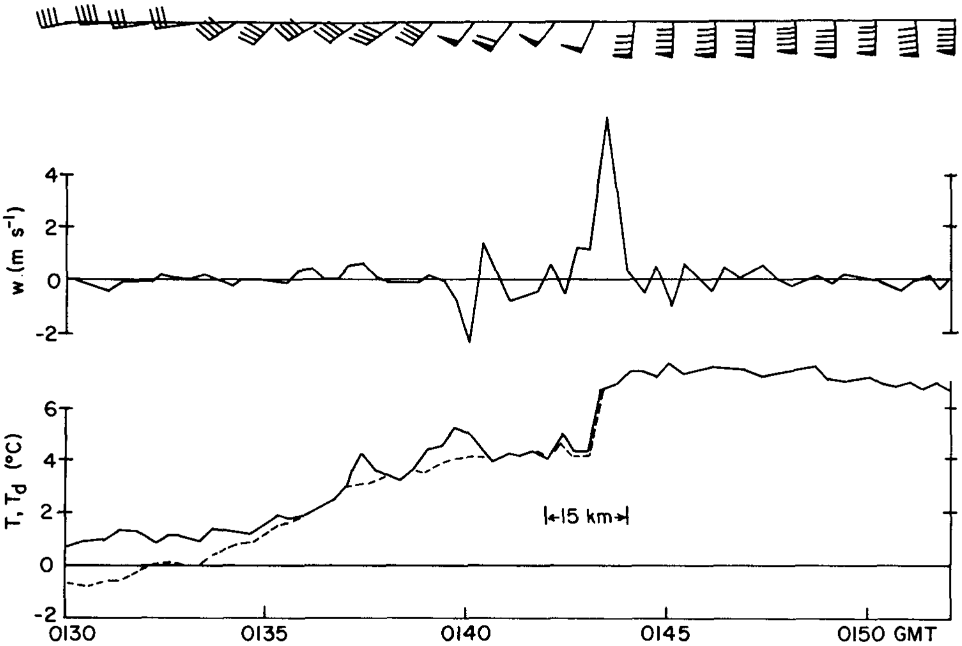

FIG. 5. Data recorded on board the NOAA P–3 in flying through the front 0130 to 0152 GMT, 16 November 1980, at a height of 950 m. The end points of the flight segment were 49.0°N, 136.4°W and 49.0°N, 134.2°W. Data are averaged in 20 s blocks. Wind directions are indicated by flags; each barb represents 5 m s^{-1}. Air temperature (T) is indicated by a solid line and dew point (T_d) by a dotted line.

flow from the continent, the aircraft probed the regions of cold advection between the ships and the continent.

The storm of 15 and 16 November is used to illustrate the aircraft data obtained in STREX. Figure 4 shows the sea level synoptic map for this storm, and the GOES–West satellite picture at 2345 GMT is shown on the cover of this issue. The Air Force WC–130 flew a prescribed pattern at 300 mb which crossed the sea level front four times. Eleven dropsondes were deployed at designated points, five west of the front and six east of the front. The NOAA P–3 deployed four dropsondes from 500 mb along an east-west line at 49°N; it also made two penetrations of the front at heights of 300 and 950 m, and measured turbulent fluxes in the boundary-layer on both sides of the front. The NCAR Electra also made two frontal penetrations and measured turbulent fluxes in the boundary layer. Dropsonde data will be used, along with soundings from the two ships, to define the storm structure and calculate mean vertical transports in sectors of the storm. The large absolute values of divergence occurring in these storms justifies some confidence in these calculations, even though errors due to limited spatial sampling, nonsimultaneity of soundings, and sensor error will be substantial.

Figure 5 shows some of the in-flight data from the P–3 block-averaged for 20 s periods. Wind directions, speeds, and temperatures observed at a height of 950 m indicate clearly that the plane penetrated the front at about 0143 GMT. Winds shifted from southwest in the region west of the front to south in the region east of the front, and the recorded upward vertical velocity at the front exceeded 6 m s^{-1}. Figure 6 shows the same frontal penetration in more detail. Here, 2 s values of vertical velocity and temperature are shown. In crossing the front, the temperature increased by about 3 K in 3 s (~300 m). The strong upward vertical velocity extended from the front eastward about 3 km into the warm air. Other frontal crossings in the boundary layer show similar features.

In regions away from fronts, aircraft measurements were carried out to provide measurements of surface layer fluxes by turbulence; vertical velocities and vertical water vapor transport in the upper part of the boundary layer; liquid and ice content of clouds; and other properties and processes. Especially important are the observations of the dominant spatial scales associated with these processes. Data of this type will be used to study both the distribution of vertical transfer from the boundary layer to the cloud layer, and the scales at which transfer occurs.

4. Satellite program

Photographic data from the polar orbiting NOAA–6/TIROS–N and the GOES–West satellites were provided to the STREX Operating Center in near real-time, and were vital for mission selection and forecasting. GOES-West also was used to relay the ship NAVAID sounding data to the Colorado State University ground station for processing at NCAR, and the NOAA 6/TIROS–N Data Collection and Platform Location System was used to relay drifting buoy data to Edmonton for processing.

Full-resolution visible and infrared geostationary photo-

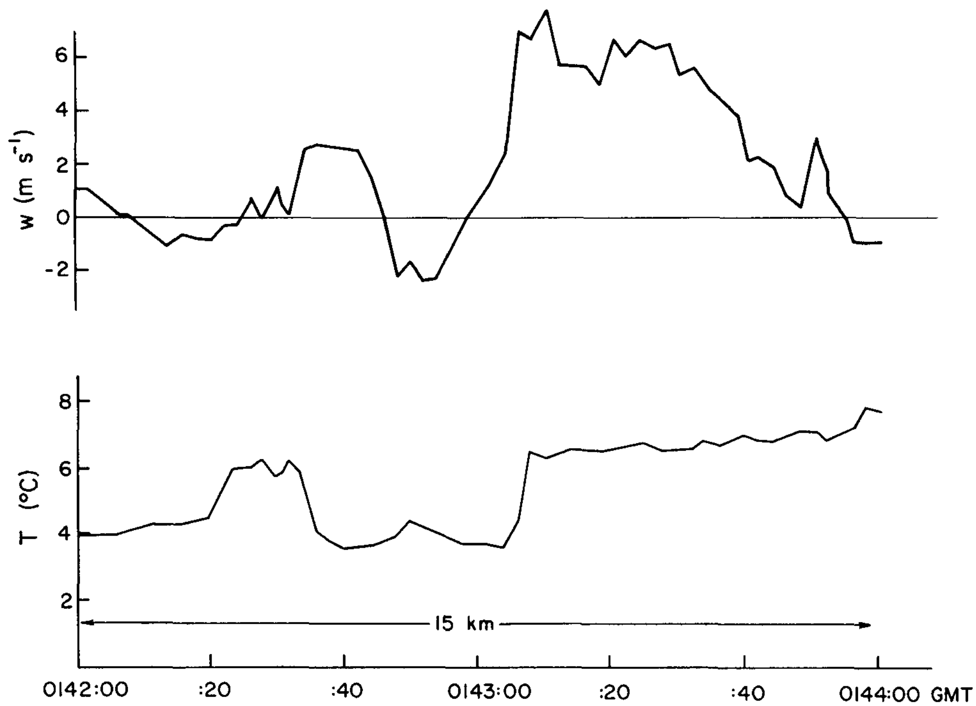

FIG. 6. Two-second average values of vertical velocity (w) and temperature (T) recorded on board the NOAA P-3 for the two-minute period crossing the front shown in Fig. 5.

graphs of the STREX region have been archived by the Space Science and Engineering Center at the University of Wisconsin, while full-resolution advanced very high resolution radiometer (AVHRR) and TIROS Operational Vertical Sounder (TOVS) data from the polar orbiting satellite have been archived by NOAA-EDIS Satellite Services Division in Washington, D.C. Those data will be vital to many of the STREX research programs.

5. Oceanography

The STREX oceanographic observations were designed to identify and examine the physical processes occurring in the upper 200 m of the ocean. More specifically, the observations should help to determine the roles played by mixing processes,,Ekman pumping, and advection in the changes of the upper ocean in the eastern North Pacific during the fall season.

Oceanographic observations were carried out from three ships: the *Vancouver, Oceanographer,* and *Parizeau.* The most important task was to obtain temperature and salinity profiles to depths of about 300 m as time series. Figure 7 shows that the upper ocean mixed layer evolved during November from an isothermal layer of 9.81°C of 60 m depth to a layer of 7.90°C of 90 m depth. The cooling shown represents the net effect of heat flux, including radiation at the ocean surface, advection in the mixed layer, and entrainment at the thermocline. The upper ocean temperature structure also was determined by three moored thermistor chains on a 20 km grid near the *Oceanographer.* Expendable temperature velocity probes (XTVP) were deployed from the *Oceanographer* to delineate the inertial current.

In order to establish spatial variability, the *Oceanographer* made three grid surveys with 50 km spacing during the six-week period. The *Vancouver* also made four grid surveys with 50 km spacing.

Horizontal variations of the upper ocean temperature structure also were observed using AXBTs in the 3° by 3° area centered midway between the two ships. Observations were made at intervals of ½° to 1°. Flights carried out by Canadian Forces planes on 10 November, 10 December, and 15 December indicate a distinct temperature gradient of about 0.5°C km^{-1} below the mixed layer.

6. Drifting buoy program

A total of 23 satellite-tracked drifting buoys were used in STREX. The buoys were basically of the two types deployed by the United States and Canada during the First GARP Global Experiment; however, several new sensors and modifications were introduced. Seven of the buoys were air dropped by the U.S. Coast Guard, while the rest were deployed from the Canadian research vessel CSS *Parizeau.*

The objectives of the program were a) to evaluate the usefulness of satellite-tracked expendable drifting buoys; b) to provide additional surface pressure and sea surface temperature observations to permit a more detailed description of the weather systems encountered during STREX than

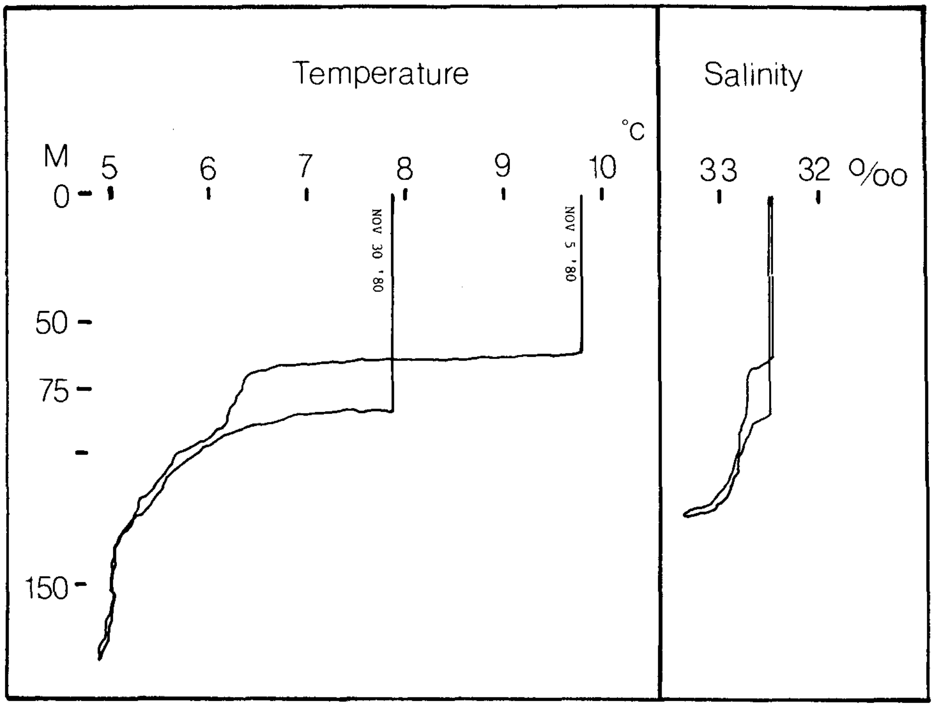

FIG. 7. Vertical profiles of temperature and salinity of upper ocean at OWS P for 30 November 1980.

would be possible from the normal ship and moored buoy reports; c) to provide some information on ocean currents and their response to the passage of storms; and d) to test and evaluate new anemometers, thermistor chains, and variations on drogues and drogue attachments.

The satellite data collection system, as well as the two different ground processing and distribution systems, functioned perfectly during the STREX period, so that an appraisal of their relative merits for such applications will be possible. Such studies are currently underway both in NOAA and in the Canadian AES.

Figure 8 shows a comparison between the pressure data reported by one of the buoys and those obtained from the weathership at OWS "P." The buoy tracks during the STREX period are shown in Fig. 9, from which it can be seen that there are significant differences in the behavior of the undrogued buoys and those with drogues or tethers. This partly reflects a difference in the behavior of the uppermost

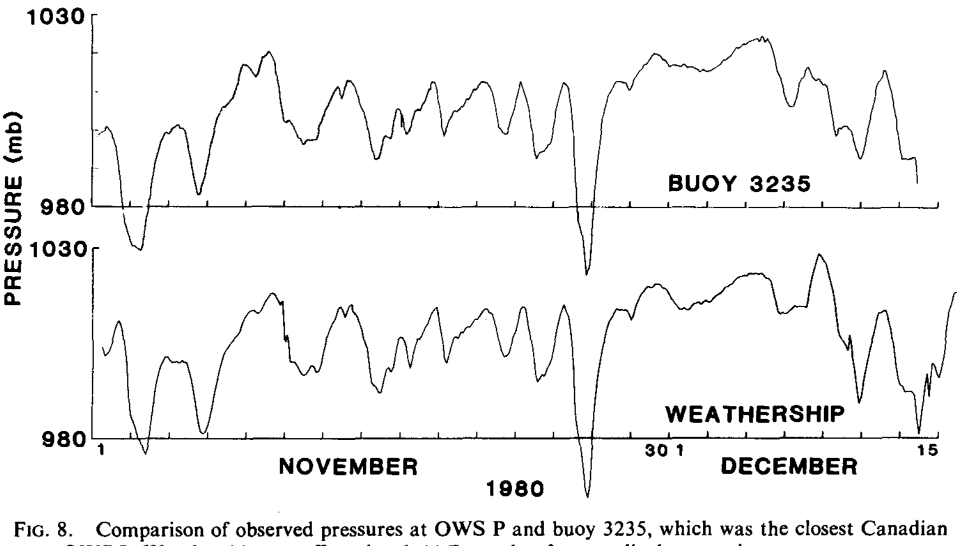

FIG. 8. Comparison of observed pressures at OWS P and buoy 3235, which was the closest Canadian buoy to OWS P. Weathership was off-station 6–11 December for a medical evacuation.

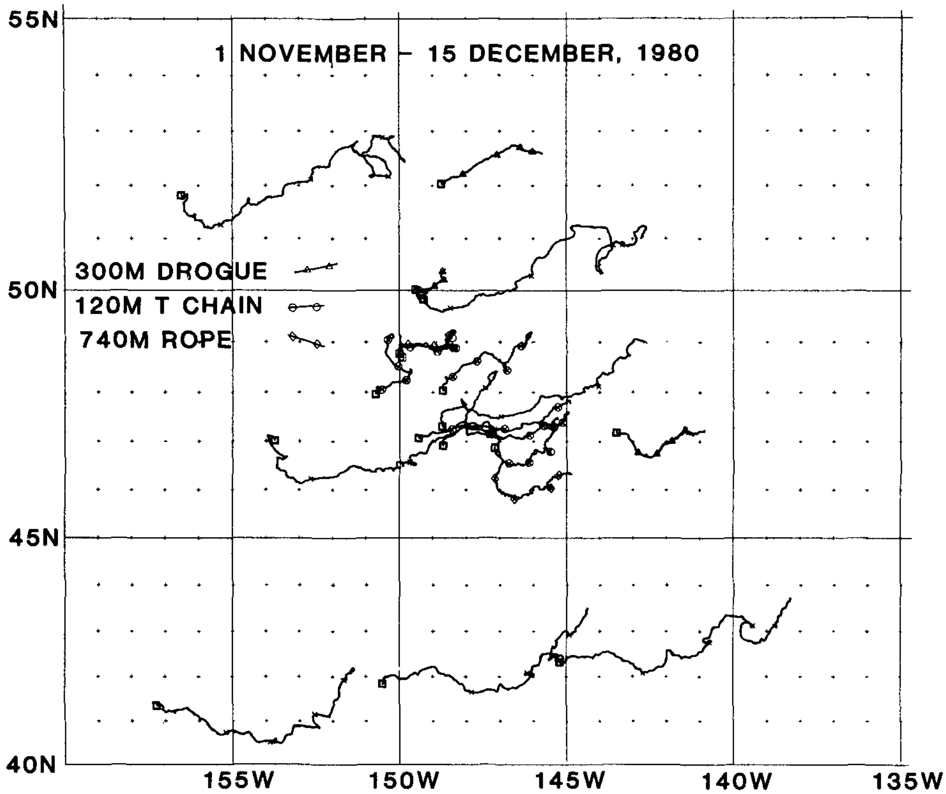

FIG. 9. Drifting-buoy tracks during STREX period. Different types of drogues and their depths are indicated by different symbols.

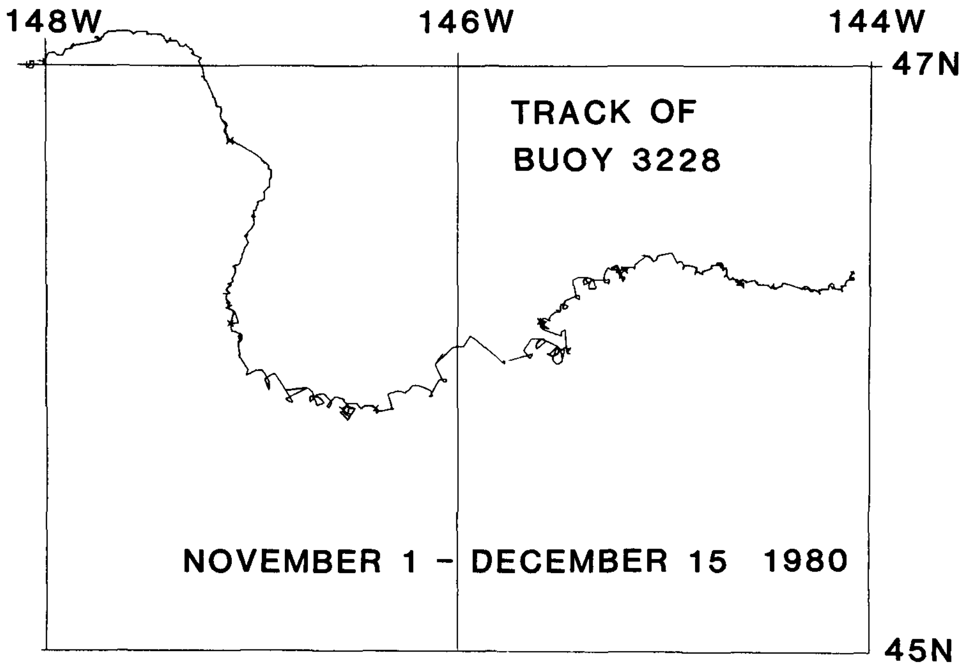

FIG. 10. Track of Canadian buoy 3228 with maximum sampling of positions displayed. Although they are aliased, inertial oscillations are clearly visible.

few meters of the water column. One interesting feature of the tracks of some of the drogued buoys is that inertial oscillations are clearly visible, as shown in Fig. 10.

Buoy data will be used to assess the use of drifting buoys for operational forecasting. The U.S. and Canadian pressure sensor systems were identical to those which earlier had performed well during the FGGE; both use the same sensor, but with different venting arrangements. However, the pressure data reported by 11 out of the 17 U.S. buoys became erratic or obviously wrong within a few weeks of their launch. In this case, the Canadian buoys all seemed to be reporting good data, but a group of Canadian buoys launched in the same area the year before also had experienced a high rate of failure in pressure data. Failures were attributed to the additional vibration, due to the addition of a droguing system to the previously undrogued Canadian FGGE buoys. A study is underway of the effects of including buoy data on the accuracy of forecasts. This study, together with the study on the timeliness of data obtained through the satellite link, should permit a reasonable evaluation of the effectiveness of this type of buoy for operational forecasting.

Evaluation of the performance of the new sensors and drogue systems is being conducted by the agencies concerned. Conclusive determination of failure modes will be possible, due to the recovery of a number of buoys after several months at sea. This was accomplished by the weathership CCGS *Vancouver*, using a radio direction finder to home in on the buoy transmissions. It is believed to be the first time that drifting buoys have been deliberately retrieved at sea.

7. Research activities

The data presented earlier in this paper should be considered as examples from the total STREX data set. Early research results on these and other aspects of STREX have been presented at a Workshop on First Scientific Results held on 28–30 July 1981[6] at the University of Washington. Twenty-eight papers were presented. Research will continue for the next several years.

Data archiving and communication among participants are facilitated by the STREX Data Center located at the University of Washington. Guidance in data transmission, processing, and archiving, as well as substantial logistic and research support, have been provided by the NOAA Special Projects Office. A Field Phase Report[7] describing the available data and summarizing operational aspects, and a STREX Meteorological Atlas[8] have been issued by the Data Center.

Acknowledgments. The authors are glad to acknowledge the help of the scientists, observers, and technicians, too many to name, who participated in the STREX field program. Support has been provided to the University of Washington by the NOAA Special Projects Office and the Environmental Research Laboratories. •

[6]Workshop Summary on First Scientific Results, STREX Data Center, September 1981.

[7]Field Phase Report, Storm Transfer and Response Experiment (STREX), STREX Data Center, May 1981.

[8]Meteorological Atlas, Storm Transfer and Response Experiment (STREX), STREX Data Center, 30 June 1981.

announcements[1]

FGGE and MONEX data sets available

The main level II-b data set for FGGE (the First GARP (Global Amospheric Research Program) Global Experiment) is now available through the World Meteorological Organization's World Data Center in Asheville, N.C. (WDC-A). A final FGGE level II-b data set is being prepared in Sweden and should be available at WDC-A in February 1983. This data set contains supplemental level II-b data, including regional data sets for the international Monsoon Experiment (MONEX), conducted in the South China Sea and the Indian Ocean during 1978–79.

The Winter MONEX level II-b data set is now at WDC-A, and should be available in the near future. The Summer MONEX level II-b data set, prepared at the International MONEX Management Center (IMMC) in Delhi, India, is now ready. Both Winter and Summer MONEX level II-b data sets contain merged FGGE level II-b data from the main II-b set.

Nonmerged data tapes (containing precipitation and agrometeorology data, etc.) from Winter MONEX are also available; nonmerged tapes for Summer MONEX are being processed by the IMMC and should be available from WDC-A by March 1982.

The WDC-A FGGE Data Catalogue and its supplements describe the contents of the various FGGE and MONEX data sets. As additional special data sets become available, they will be listed in subsequent supplements. Supplement No. 7, describing some of the Winter and Summer MONEX data sets, and Supplement No. 8, describing several special MONEX data sets, are currently available. The catalogue and its supplements may be obtained by contacting Robert Williams, WDC-A, Federal Building, Asheville, North Carolina (tel: 704-258-2850, ext. 381; FIS 672-0381).

(*continued on page 22*)

[1]Notice of registration deadlines for meetings, workshops, and seminars, deadlines for submittal of abstracts or papers to be presented at meetings, and deadlines for grants, proposals, awards, nominations, and fellowships must be received at least three months before deadline dates.—*News Ed.*