COLUMBIA GLACIER METEOROLOGIC AND HYDROLOGIC DATA: MAY THROUGH OCTOBER, 1984

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INTRODUCTION

Columbia Glacier is a large tidewater glacier located about 38 kilometers west of Valdez, Alaska. The glacier flows approximately 65 kilometers from the crest of the Chugach Mountains to Columbia Bay in east-central Prince William Sound (figure 1). Presently the glacier is undergoing an historically unprecedented retreat and is the last of the tidewater glaciers in Prince William Sound, Alaska to do so. During retreat, the increased production of iceburgs near vital shipping lanes has caused considerable interest in the glacier's behavior.

Between 1899 and 1978, Columbia Glacier remained relatively stable while perched upon Heather Island and a submarine moraine. Post (1975) concluded that if Columbia Glacier would retreat from its stable position it would commence a retreat that would last until the terminus is once again near sea level. The retreat would occur primarily because of the high calving rates when the glacier terminates in deep water. In a dynamic response to increased calving in the deeper water and because of decreased backpressure from the terminus, these glaciers thin and their velocity increases. Columbia Glacier may retreat upvalley to expose a fiord about 40 km in length from the terminal moraine. In another study Sikonia and Post (1979) noted the tendency of embayments to form and enlarge where subglacial water discharges. These studies and related ones are reported in some of the following publications: Post (1975)--hydrography; Mayo et.al. (1979)--mass balance; Meier et.al.(1980) --retreat prediction; Brown et.al.(1982) calving relations; Sikonia (1982) --finite element model of drastic retreat; and Rasmussen and Meier (1982) --continuity equation model of drastic retreat.

Several hydrologic projects were initiated in an effort to understand the role of subglacial discharge in the glacier's calving behavior as well as the glacier's dynamics in general. During 1982 and 1983 measurements were made in front of the terminus in an effort to determine sub-glacial discharge (Walters, Josberger, and Driedger, 1988). Because continuous measurements were difficult to obtain, the nearby Number One River was gaged in an attempt to find a continuous analog of the subglacial flow. Meteorologic measurements collected near the terminus and upglacier in conjunction with this study. This report contains hydrologic and meteorologic data gathered during 1984 in the vicinity of Columbia Glacier.

In addition to these measurements, another study utilized electronic distance meters (EDM) to measure distance from a point on Heather Island to reflectors on the glacier surface approximately 1.6 kilometers from the terminus (Vaughn et al, 1985). These data subsequently have been analyzed with respect to diurnal speed variations in response to variations in weather and sea tides at the terminus (Walters and Dunlap, 1987).

DATA COLLECTION

Between April and October of 1984, hydrologic, meteorologic, ablation and tidal variables were measured at seven locations in the vicinity of Columbia Glacier, Alaska for use in the analysis of ice calving, and in a hydrologic model. These 1984 measurements were gathered in conjunction with other glaciological measurements including mass balance (Mayo and Trabant, personal communication), surface elevation, and ice velocities (Vaughn et. al., 1985). Data types presented in the report are as follows: wind speed and direction, air temperature, relative humidity, precipitation, barometric pressure,insolation, ice surface ablation, river discharge and tidal height. The 1984 data is published in this report for use with related projects. Data collected during 1982, 1983, and 1985 is available from the authors.

The measurement stations listed below were occupied during 1984. The environment and duration of study for each station is described in the sections following. Figure one indicates the location of the measurement stations. The appendix lists instrument specifications at each station. Figure two through twelve display the data collected after processing to hourly values.

HYDROLOGIC, METEOROLOGIC, AND TIDAL STATIONS

Number One River originated as a subglacial river flowing from a small distributary ice lobe on the east side of Columbia Glacier. It originated at a distributary terminus on the east side of Columbia Glacier. The river flowed .5 km over a glacial outwash plain then narrowed before descending a 20 m high cataract informally known as The Gate, to a floodplain below. Only one major tributary stream flows into Number One River between the Gate and the ocean and it originates from the margin of the glacier. After flowing over a broad floodplain the river is ponded in two sinuous unnamed lakes bordered on the west side by ice. The amount of water entering the lakes subglacially from the ice margin is unknown. For this reason Number One River was gaged below the lakes about one kilometer from the river mouth and at The Gate near the glacier terminus. Direct measurements of discharge were unsafe at The Gate because of swiftly flowing water. In the tracer-dilution method of measuring discharge, Rhodomene dye of a known concentration was injected into the stream 10 meters upstream of The Gate. The discharge of the river was computed using a comparison of this initial concentration with that of water samples collected one kilometer downstream.

Measurements of temperature and precipitation were collected approximately 50 meters northwest of The Gate.

Number One River

A meteorologic station and a gaging station were established on August 10, 1982. Recorded at twenty minute intervals were temperature, barometric pressure and the gage height of Number One River. The station is located in an Alder thicket about .7 km due East of the east flank of Columbia Glacier, and about 1.2 km upstream of Number One River. The resulting rating curve was useful for determinations of discharge through 1986. During 1987 changes in the margin of the glacier allowed Number One River to change course toward the west leaving the gage site region as a stagnating backwater.

The Gate

Station Gate was established for the purpose of obtaining a rating curve for water solely of glacial origin. Precipitation, temperature, and gage height data were collected at twenty minute intervals between August 14th and October 16th, 1984 (figure 3). A pressure transducer measured stream gage height at the Gate.

Waterfall Creek

Meteorologic and gaging stations operated on Waterfall Creek between August 7th and 31st, 1984. This unofficially named creek carries no glacial runoff water and thus was useful for examining local precipitation and snowmelt. The measurement site was located about 2.5 km southeast of the glacier terminus at the edge of a meadow near a stand of trees. Due to complications in the operation of the pressure transducer, the stream stage record was not recoverable. However, a Campbell CR-21 data logger recorded measurements of precipitation and temperature at fifteen minute intervals (table 2).

Dalli Bay Tide Gage

Dalli Bay is a small inlet of Heather Bay located about 2 km south of the northern tip of Heather Island. It was chosen as a site to measure tidal variation because of the absence of ice burgs, the convenience of a nearby bluff and the relatively small amount of wave activity in the area. The tide gage was weighted with rocks and secured to the bluff with a buried cable (figure 6).

METEOROLOGICAL STATIONS

Heather Island Meteorological Station

The Heather Island met station was established during August, 1982 and was removed in September, 1987. It was situated on the Northwest corner of Heather Island due south and about 2.5 km from the center of the glacier terminus. It is located upon a terminal moraine vacated by the glacier as late as 1977 and now sparcely vegetated with dwarfed fireweed. Collected is data describing wind speed and direction, temperature, barometric pressure, and insolation. The data were collected at 20 minute intervals and stored on magnetic tape in an Aanderaa data logger (Table 1, figure 4). The magnetic tapes were collected approximately every three months for translation and reformatting.

Fantastic Island Meteorological Station

The Fantastic meteorological station was occupied between August 2nd and 27th, 1984. It was located at an elevation of 880 meters on the southeast shoulder of a nunatak about 34 kilometers upglacier of the terminus (see figure 1). The surface rocks were frost shattered and vegetated only with lichens and some dwarfed flowering plants. A Campbell CR-21 data logger was used to record measurements of wind speed, temperature, relative humidity, barometric pressure, precipitation, and insolation (Table 2, figure 5).

Joy

Joy was located at elevation 915 meters on a sparcely vegetated ridge ___kilometers upvalley of the terminus and above the west margin of Columbia Glacier. It was established to obtain a record of air temperature that would be useful for future calculations of lapse rate (Table 2, figure 5).

Mojave and West Ice Station

Surface lowering was measured at two stations that were established on the west margin of the glacier at WESTSIDE ICE STATION (WIS), and on the eastern margin at the MOJAVE ICE STATION (MIS). The ablatographs consisted of digital gage height recorders that had been modified to measure distance to the ice surface. A wooden cross was suspended from a cord and wound upon the recorder wheel. The instrument recorded hourly values of surface lowering between August 8th and August 29th at the Mohave Station and between August 16th and August 21st at West Side Station (Table 3).

DATA PROCESSING

The raw data files were of two types. In the first, the file contained 10 bit integers with values from 0 to 1023 as is typical for Aanderaa data loggers. In the second, the file contained real numbers representing voltages, scaled values, and pulse counts.

In the first processing step, all data was converted to MKS units. For the integer data, the calibration constants for the sensors were used to convert wind speed and direction, barometric pressure, air temperature, and voltages into MKS units. Using the calibration for the solarimeter, the output voltage was converted to insolation in W/m2. Using the calibration to the tipping bucket rain gage, the counts were converted to mm of water per measurement interval. At the stream gage at Gate, the voltage measurements of the output from the pressure transducer were converted to meters of water using the calibration constants for the transducer.

For the real numbered data, wind speed and air temperature were already scaled quantities. The pulse counts for the rain gages were converted to mm of water during the measurement interval as noted earlier. Similarly, the voltage for the pressure transducer was converted to meters of water using the factory transducer calibration. Unfortunately, the oil used to isolate the pressure transducer at Waterfall Creek had a large variation in density as a function of temperature. The signal is, in fact, dominated by this temperature dependence. Thus, water levels cannot be recovered without further data processing.

The time interval between measurements at a particular station was determined by the data capacity of the station, and by the need to sample at a higher frequency than that of significant variations in the data so as to prevent aliasing. The processed data required hourly time intervals to adequately resolve diurnal and longer period variations. Measurement intervals of from 10 to 30 minutes were adequate to satisfy the data storage criterion above, while providing a margin for signal processing.

In general, all discretized analog data were low pass filtered with a filter cutoff of one hour using a variation of the Godin filter (Godin, 1982). The wind speed and direction were converted to orthogonal vector components and then each filtered, which is equivalent to vector averaging. This step removed high frequency variations (considered noise) from the data and allowed subsampling at one hour intervals. All pulse data was totalized for the one hour interval; ie precipitation. The resultant data set is the hourly values shown in figures 2 to 5.

The processing steps to arrive at daily values depends upon the type of data. For the precipitation data, the values were totalized for the day. For insolation, the data were integrated in time by Simpson's rule. Integration from midnight to midnight on the following day, and the result divided by 24 to reflect a daily average. The remaining signals were processed with a low pass filter of the Godin type (Walters anmd Heston, 1982) with a cutoff of 25 hours and the time series subsampled at noon on each day. The wind speed and direction were processed in a vector sense as before. The maximum wind speed was selected from the daily maximum in the data for the original measurement interval. The daily maximum and minimum temperatures were selected from the hourly data set. The daily summaries of the data are contained in Tables 1 to 3.

DEVELOPMENT OF RATING CURVES

Rating curves were developed for gaging sites at two locations on Number One River-- at The Gate, located approximately one kilometer downvalley from the terminus of the east eastern lobe of Columbia Glacier, and at a site called Number One River further downstream and near the mouth of the river. The two stations are separated by ponds and braided channels which filter the effect of hydrologic events occurring in the upper drainage basin. Thus, gaging began in 1982 at the Number One River gaging site but was superseded in 1984 by a new site at The Gate.

The rating curves were established using standard procedures applied to water heights as read from staff gages, and from point measurements of discharge made using current meters or dye.

Because of The Gate's location near the top of a waterfall and the river's rapid flow direct measurements were not feasible. For the indirect measurements of discharge a slug of rhodomine dye of known concentration was injected into the water; fluorometric analysis of samples collected .5 km downstream indicated the amount of dilution by river water and its discharge. The rating curve at Number One River is known to within 10 percent. It is expressed as

$$Q = 16.78 * (ght)^{1.97} \qquad (1)$$

where y is river discharge; a is the slope of the line; b is the y-intercept and x is gage height. Above this height the river floods over its banks on to a low-lying plain whereby the flow characteristics are modified. A series of rapids about three meters in height separate Number One River site from tidal fluctuations. However, at low flow during winter the record indicates that tidal fluctuations exist at the site. These variations have been filtered from the record. The gage-height-discharge relation at The Gate is expressed as

$$Q = 69.85 * (ght - .4968)^{1.28} \qquad (2)$$

where Q is discharge; a is the slope of the line; b is the y-intercept and x is any gage height. The maximum gage height for this is not well known although it is suspected that ponding occurs at the gorge at higher gage heights perhaps above two meters. The error is estimated to be ten percent.

APPENDIX I
INSTRUMENT SPECIFICATIONS

HEATHER ISLAND MET STATION

		Model	S/N
Timer interval 30 minutes			
Data logger:	Aanderaa DL-1	DL-1	614
	Block enumerator	2614	78
Sensors:	Anemometer	2593	275
	Wind vane	2053	583
	Air thermister	1289	1662
	Barograph	2056	133
	Rain gage (MRI)	----	--
	Precipitation pulse counter	2217	73
	Radiometer	----	--
	Solarimeter (Kipp and Zonen)	2537	43
	Millivolt integrator	2217	256

FANTASTIC

		Model	S/N
Timer interval 15 minutes			
Data logger:	Campbell Scientific	CR-21	---
Sensors:	Anomometer	Met-1 #104	418
	Wind vane	----	---
	Wind thermister	----	---
	Hygrograph	----	---
	Barograph	----	---
	Radiometer	Li-cor	3580

WATERFALL CREEK

		Model	S/N
Timer interval 15 minutes			
Data logger:	Campbell Scientific	CR-21	---
Sensors:	Thermister	----	---
	Rain Gage	----	---
	Pressure transducer	----	---

NUMBER ONE RIVER

		Model	S/N
Timer interval 15 minutes			
Data logger:	Aanderaa	DL-1	569
	Block enumerator	2614	61
Sensors:	Barograph	2056	132
	Thermister	1289	1663
	Pressure transducer	EA015	----
	Millivolt integrator	2240B	240

ATE

		Model	S/N
Timer interval 15 minutes		Model	S/N
Data logger:	Aanderaa	DL-1	786
	Block enumerator	2614	60
Sensors:	Air temperature	1289	---
	Rain Gage pulse counter	----	---
	Precipitation	2217	138
	Pressure transducer (Enviro-Labs)	PT-105V	---
	Millivolt integrator	2240B	248

DALLI BAY TIDE GAGE

Timer interval 15 minutes		Model	S/N
Data logger:	Aanderaa	TG2A	118
Sensor:	Tide gage	--	--

OY

Timer interval 15 minutes

Data logger and sensor: MRI weather station

MOJAVE ICE STATION

Timer interval hourly minutes

Data logger: Fisher-Porter recorder
Sensors: wooden crosses on wires

EST ICE STATION

Timer interval 60 minutes

Data logger: Fisher-Porter recorder

Sensor: wooden crosses on wires

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CAPTIONS

Figure 1-- Map of Columbia Glacier showing the location of meteorological stations as indicated by the symbol ^ and stations where hydrologic or tidal variables were measured in addition as indicated by . The index map illustrates the location of Columbia Glacier, Alaska.

Figure 2a,b,c,-- The three graphs indicate hourly values of Number One River (a) gage height in meters; (b) air temperature in degrees Celsius; and (c) precipitation in millimeters per hour as measured from julian day 221 through 288, 1984.

Figure 3a,b,c-- These graphs indicate hourly values at The Gate (a) river gage height in meters; (b) air temperature in degrees Celsius; and (c) precipitation in millimeters per hour as measured from julian day 227 through 288, 1984.

Figure 4a,b,c,d,e,f,g-- The graphs indicate hourly values of meteorological variables measured at Heather Island meteorological station (MET) whereby (a) indicates solar insolation in watts per square meter; (b) indicates air temperature in degrees Celsius; (c) indicates barometric pressure in millibars; (d) indicates precipitation in millimeters per hour; (e)indicates average wind speed in meters per second; (f) indicates maximum wind speed in meters per second; and (g) indicates wind direction where true north is 180.

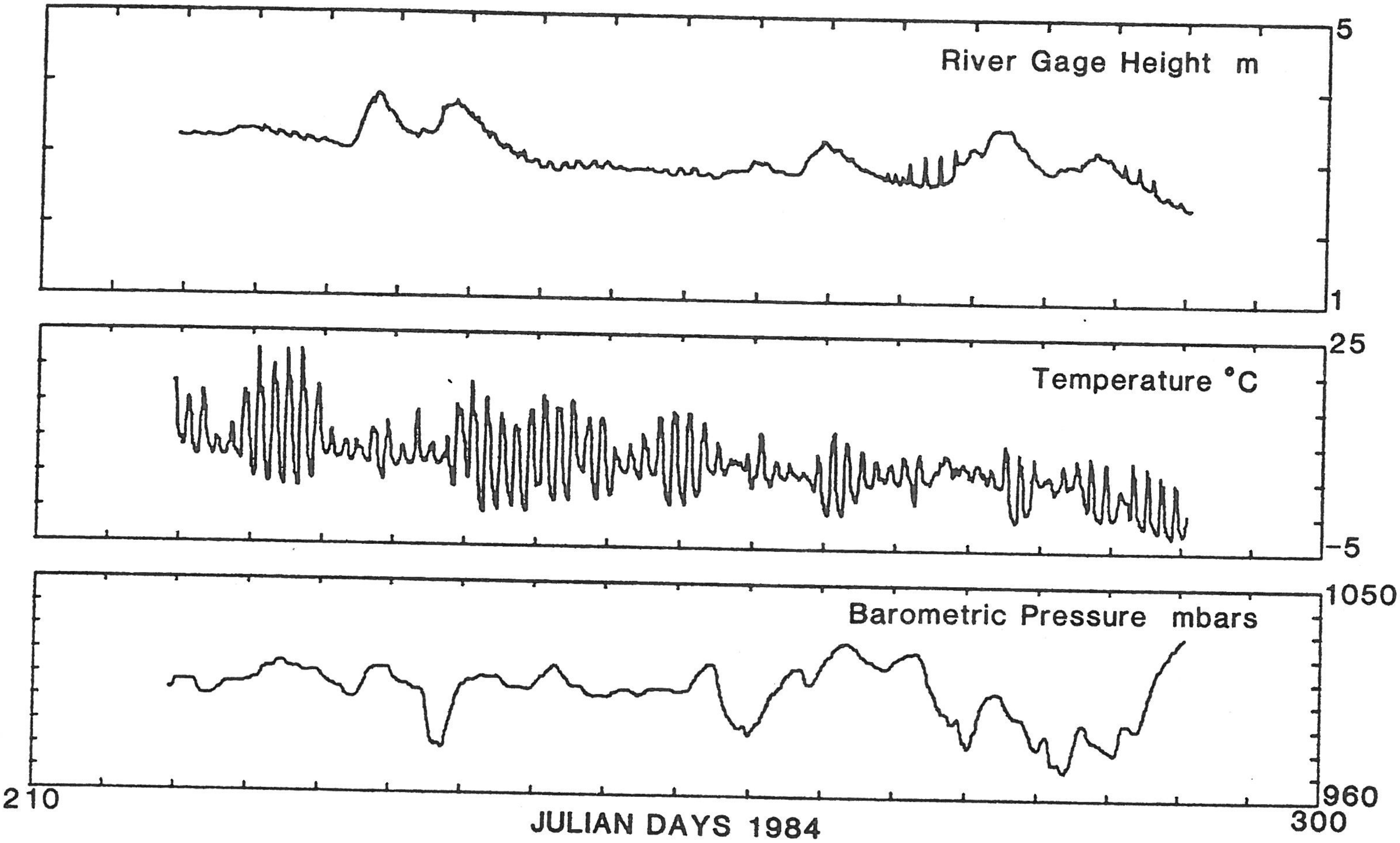
Figure 5a,b,c,d,e,f-- Figure 5a-e illustrate hourly values of meteorological variables at station Fantastic between julian days 218 and 239, 1984. The graphs illustrate (a) solar radiation in watts per meter squared; (b) temperature in degrees Celsius; (c) relative humidity in percent; (d) average wind speed in meters per second; (e) precipitation in millimeters per hour. Figure 5f indicates hourly temperature values in degrees Celsius at station Joy between julian day 217 and 238.

Figure 6-- Dalli Bay tides are shown in meters between julian day 210 and 300.

Table 1a,b,c-- Daily values of data were collected at (a)Heather Island meteorological station between julian days 223 and 289; (b) Number One River gaging station between julian day 221 and 288; (c)The Gate between julian day 227 and 288, 1984. Average and maximum wind speeds were measured in meters per second; wind direction is indicated in degrees from true north; temperature was measured in degrees Celsius; barometric pressure is in millibars; solar insolation is in watts per square meter; precipitation is in millimeters per hour; and gage height is in meters.

Table 2a,b-- Daily data collected at (a) station Fantastic between julian day 218 and 239; (b) Waterfall between julian days 222 and 243. Relative humidity was measured in percent; temperature was measured in degrees Celsius; average wind speed was measured in meters per second; solar insolation was measured in watts per square meter; precipitation was measured in millimeters per day; and gage height was measured in meters.

Table 3-- This table lists ice surface lowering in centimeters measured at noon for West Ice station (Wis) and Mohave Ice Station (MIS) between julian days 227 and 232 (MIS), and between 219 and 240 (WIS).



STATION NUMBER ONE RIVER

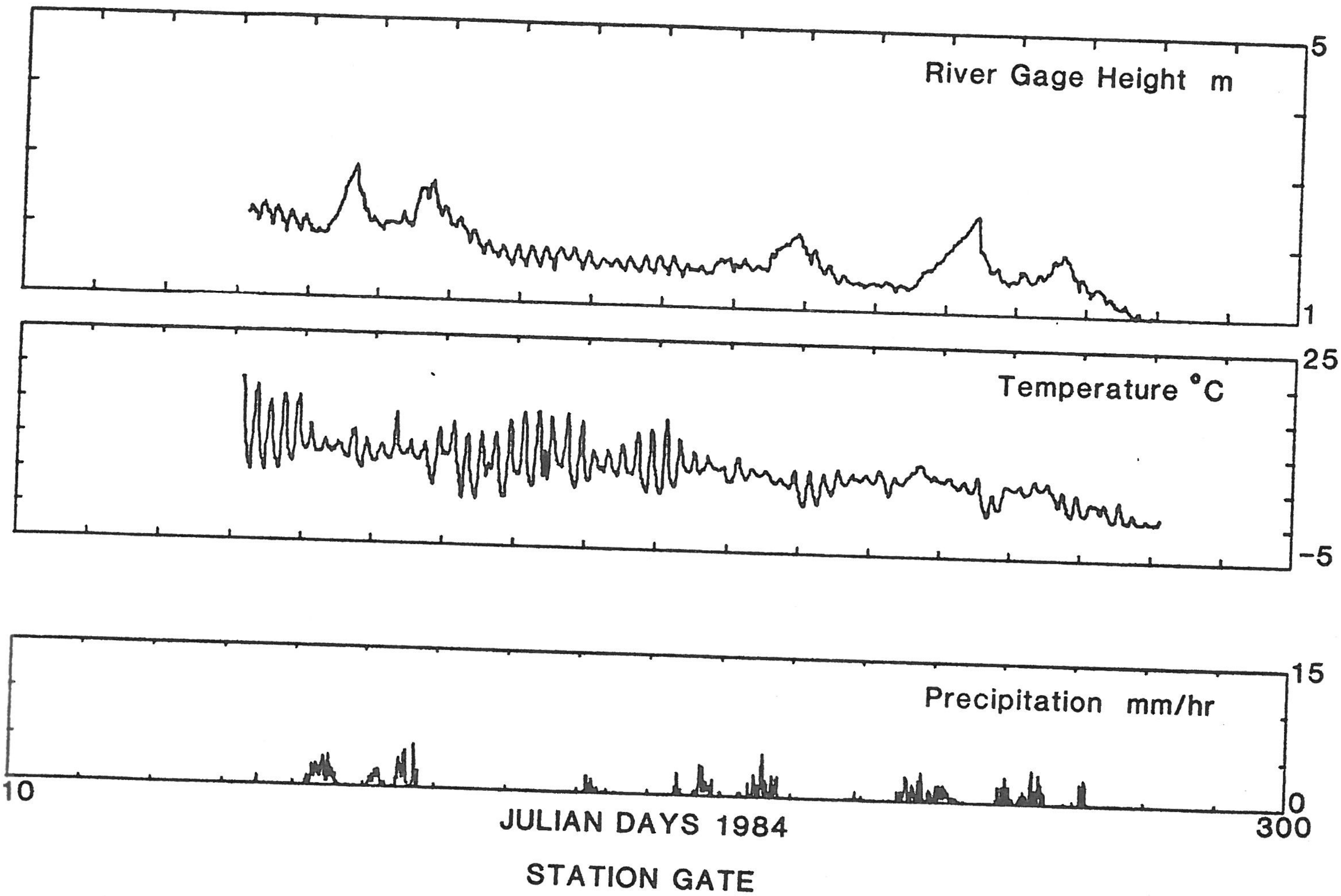

5
River Gage Height m
1
25
Temperature °C
-5
15
Precipitation mm/hr
10
0
300
JULIAN DAYS 1984
STATION GATE

fig 3

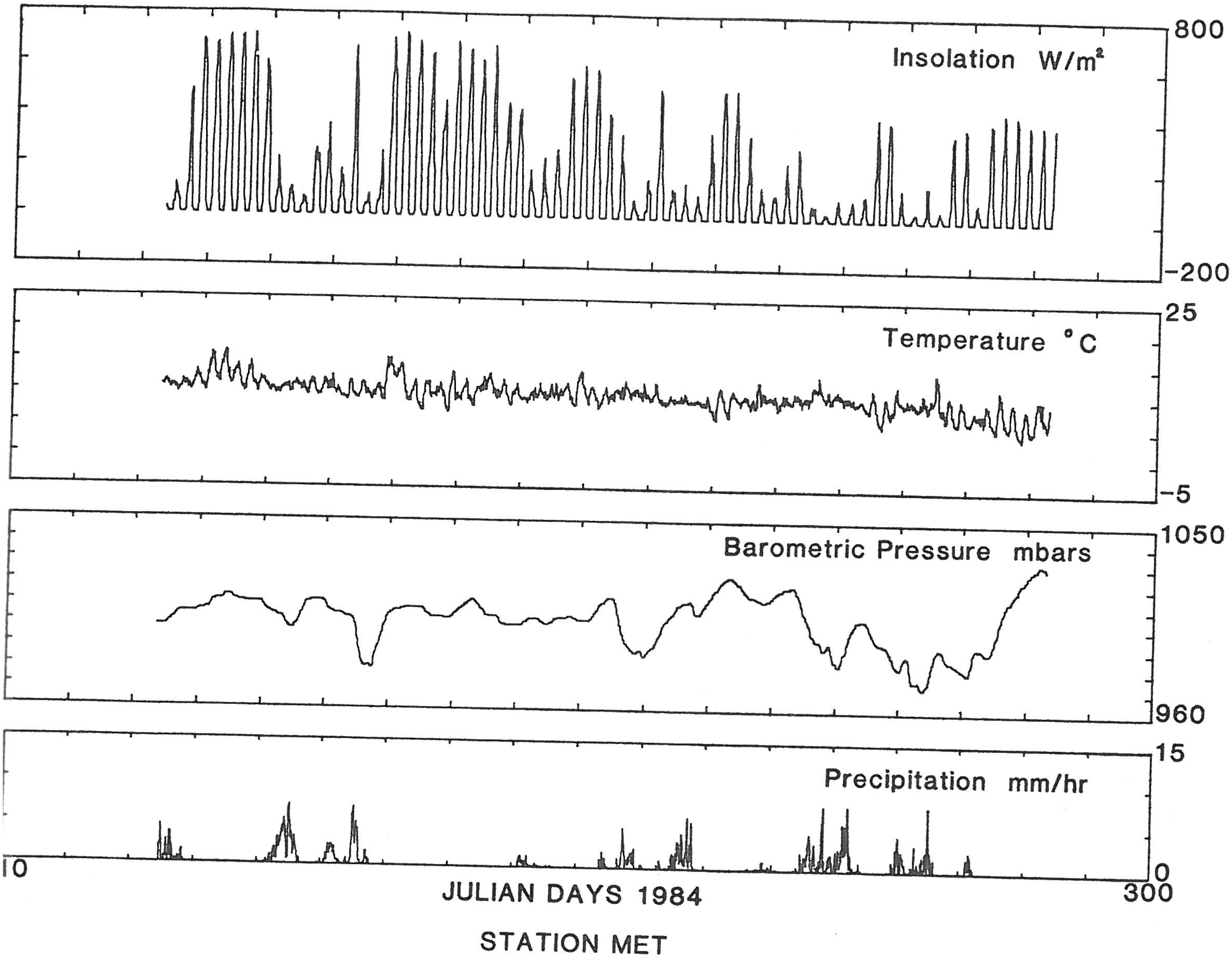
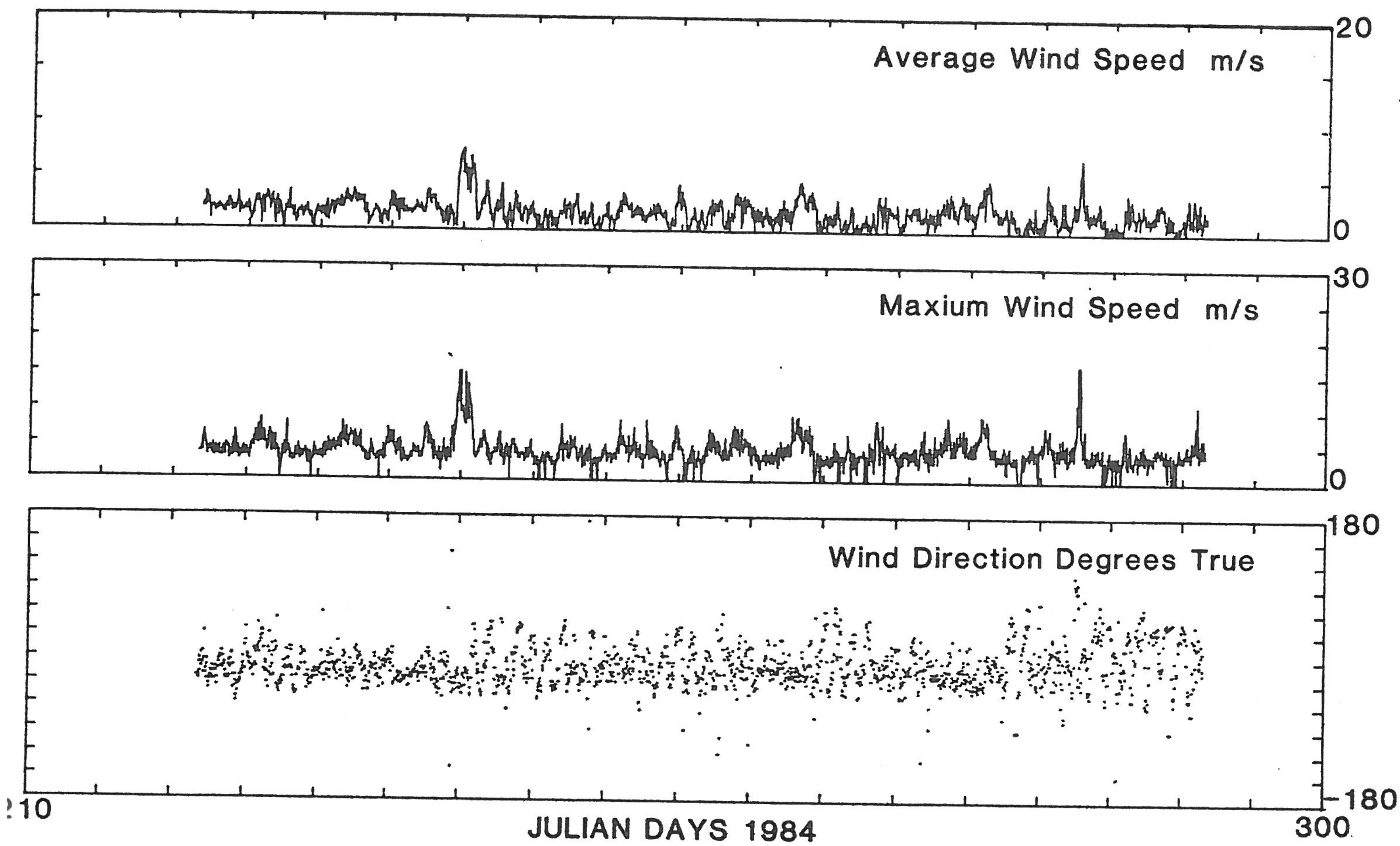
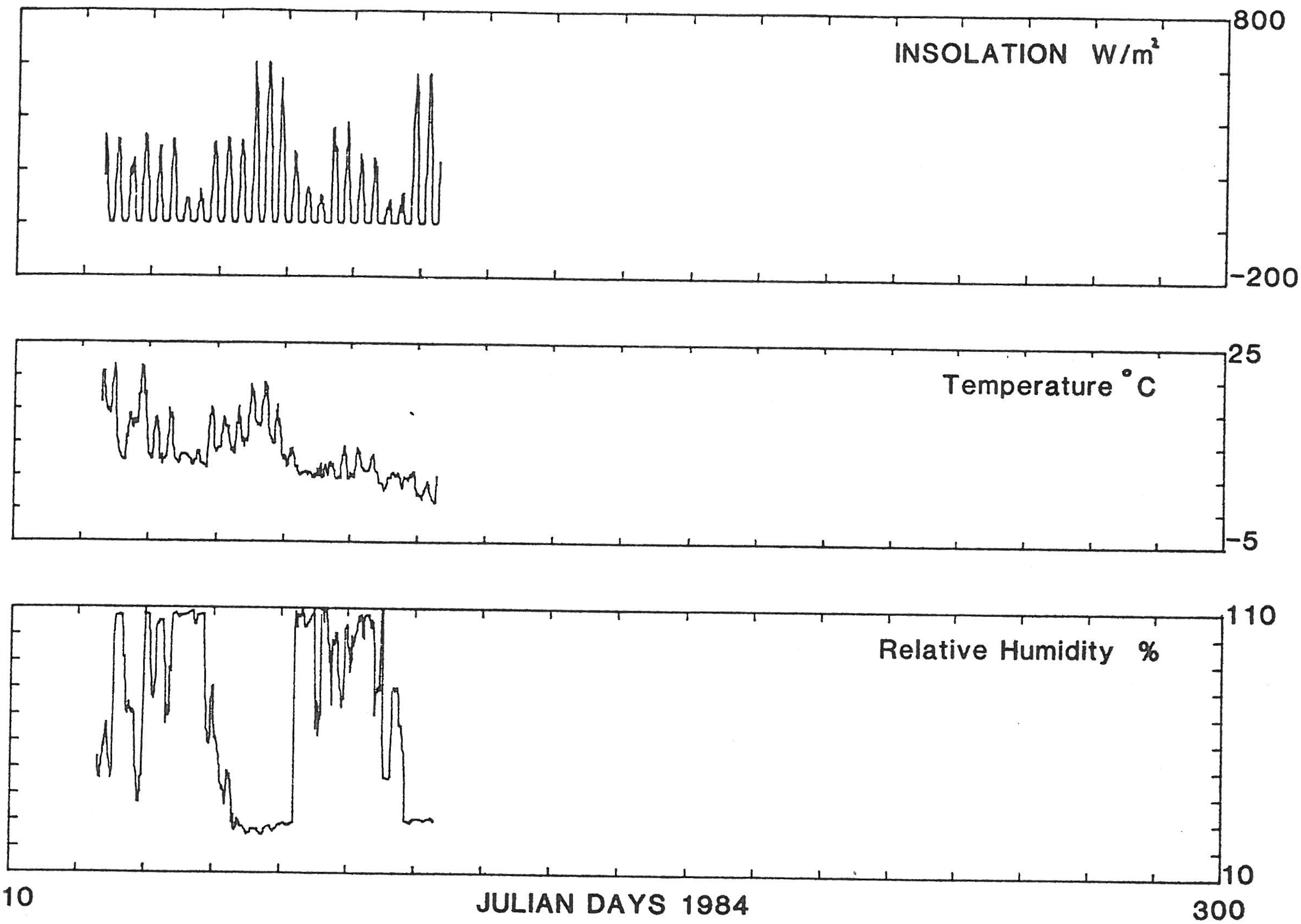

Insolation W/m²
800
-200
Temperature °C
25
-5
Barometric Pressure mbars
1050
960
Precipitation mm/hr
15
0
10
300
JULIAN DAYS 1984
STATION MET

fig. 4a-d



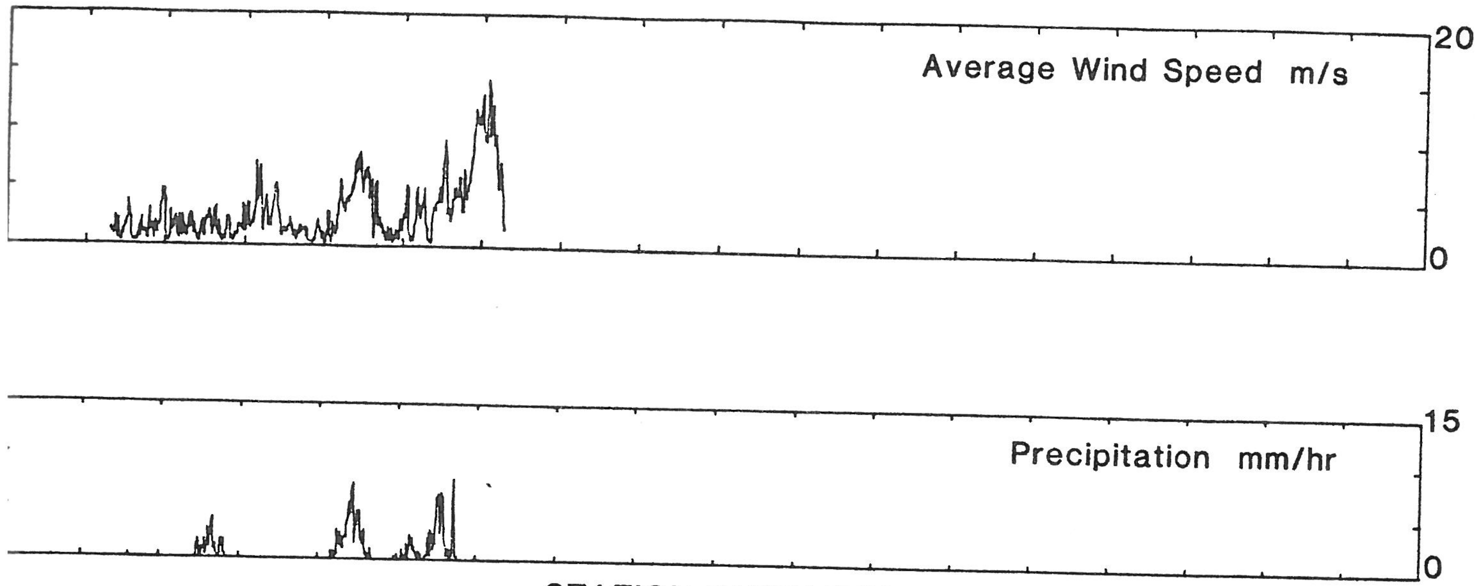
STATION MET

Fig 4

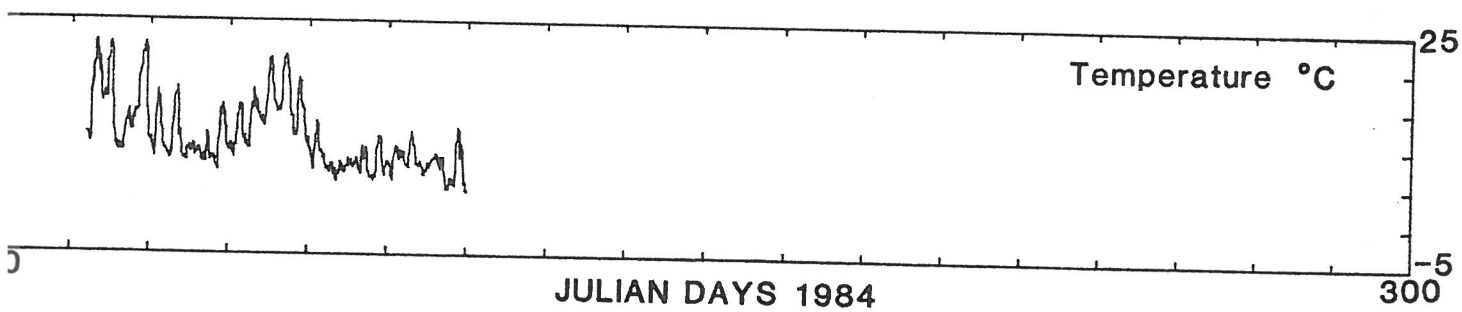


STATION FANTASTIC

fig 5a-c

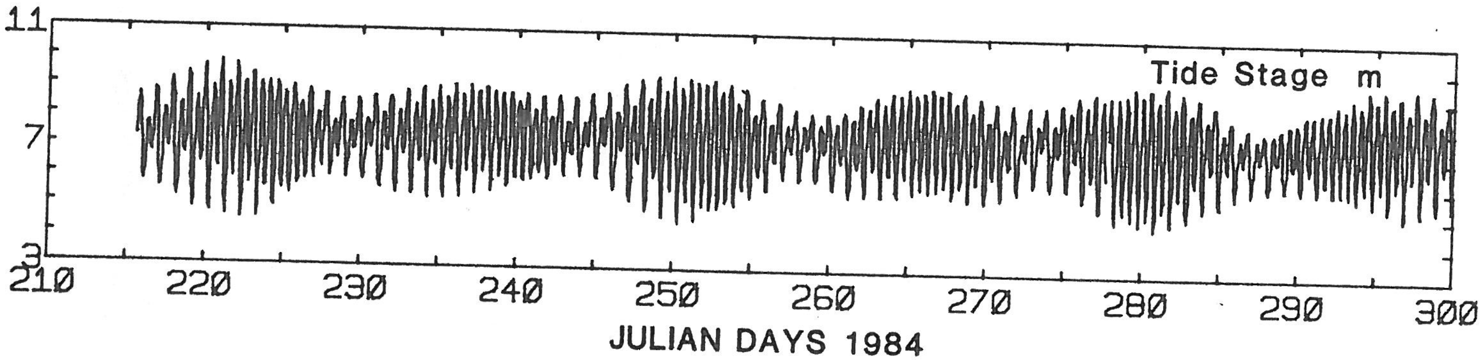


STATION FANTASTIC



STATION JOY

fig.5d-f



STATION DALLI BAY TIDE GAGE

fig 6

TABLE Ia

HEATHER ISLAND MET STATION

TIME day	h	min	AVG SPD m/s	MAX SPD m/s	DIR TRUE	TEMP C	BP mbar	INSOL W/m	PREC mm/d
223	12	0	1.98	4.78	-16.03	5.72	1003.71	101.02	20.30
224	12	0	1.89	6.57	-20.53	6.40	1005.21	248.75	6.71
225	12	0	2.05	5.37	-5.68	7.77	1007.17	266.41	0.00
226	12	0	2.08	8.36	-1.82	8.40	1010.73	258.46	0.00
227	12	0	1.60	6.87	-18.50	7.47	1011.78	270.60	0.00
228	12	0	1.47	8.06	-19.54	6.81	1010.25	273.79	0.00
229	12	0	1.38	4.78	-18.89	6.26	1009.27	214.04	0.00
230	12	0	1.79	4.78	-16.34	5.44	1006.10	53.41	0.00
231	12	0	2.53	5.97	-14.86	5.53	1002.05	36.22	0.00
232	12	0	2.57	8.06	-16.06	5.78	1000.81	23.72	14.41
233	12	0	1.64	6.57	-15.26	5.57	1007.96	100.47	81.91
234	12	0	1.70	5.37	-13.41	5.66	1010.30	94.65	41.65
235	12	0	2.06	7.16	-16.59	5.30	1006.62	51.54	0.00
236	12	0	1.99	5.67	-23.42	4.91	1003.53	160.12	4.14
237	12	0	2.42	7.16	-14.14	5.06	993.03	22.18	29.61
238	12	0	1.78	7.76	-16.55	5.10	983.79	46.18	11.26
239	12	0	3.21	7.46	-28.01	7.24	995.90	241.32	50.93
240	12	0	4.26	15.22	-26.44	7.45	1005.84	248.22	5.33
241	12	0	2.33	12.54	-19.05	5.02	1007.61	234.52	0.00
242	12	0	1.61	6.87	-15.56	4.88	1006.80	193.89	0.00
243	12	0	1.52	6.57	-18.68	4.98	1004.31	148.09	0.00
244	12	0	1.34	5.67	-2.56	5.02	1003.97	224.53	0.00
245	12	0	0.98	5.67	-14.87	5.04	1007.51	224.42	0.00
246	12	0	1.31	3.88	-9.04	5.27	1010.13	212.54	0.00
247	12	0	1.72	7.76	-6.66	6.16	1006.44	182.70	0.00
248	12	0	1.25	6.27	-15.86	5.33	1002.82	145.33	0.00
249	12	0	1.06	5.07	-9.70	4.81	1000.61	146.11	0.00
250	12	0	1.74	5.07	-8.97	4.59	1001.47	50.66	0.00
251	12	0	2.03	8.36	-8.19	5.01	1002.46	56.85	0.00
252	12	0	1.63	7.46	-8.63	5.21	1001.98	80.64	12.22
253	12	0	1.56	8.36	-18.21	5.29	1003.53	166.35	1.39
254	12	0	1.59	4.18	-3.79	5.74	1003.43	190.08	0.60
255	12	0	1.31	7.76	3.35	5.12	1003.73	182.71	0.00
256	12	0	1.30	5.07	-13.59	4.61	1009.23	118.30	0.00
257	12	0	1.74	7.16	-15.22	5.21	1008.68	72.23	0.00
258	12	0	1.80	5.97	-9.04	5.51	994.77	20.76	5.34
259	12	0	2.15	7.76	-7.10	5.16	988.23	40.55	3.36
260	12	0	1.48	5.97	-13.53	4.73	990.47	131.76	36.29
261	12	0	1.37	4.48	-10.48	4.14	999.78	37.34	1.38
262	12	0	2.12	5.67	-14.39	4.31	1008.03	27.94	1.79
263	12	0	2.91	9.25	-15.90	4.08	1010.02	24.45	6.30
264	12	0	1.45	8.06	-8.77	3.57	1009.53	83.11	30.38

HEATHER ISLAND MET STATION (cont.)

TIME			AVG SPD	MAX SPD	DIR TRUE	TEMP	BP	INSOL	PREC
day	h	min	m/s	m/s		C	mbar	W/m	mm/d
265	12	0	0.98	4.18	-2.23	3.64	1016.62	160.65	0.00
266	12	0	0.79	5.67	-8.87	4.14	1021.89	127.23	0.00
267	12	0	0.69	6.57	-8.86	4.34	1019.40	69.84	0.00
268	12	0	1.34	5.67	-5.78	4.57	1014.57	30.97	0.40
269	12	0	1.61	8.66	-10.46	4.55	1013.43	31.26	0.80
270	12	0	1.45	5.67	-14.87	4.27	1016.72	54.81	3.56
271	12	0	1.47	4.78	-5.47	4.51	1017.22	62.18	0.20
272	12	0	1.53	7.46	-14.65	5.02	1006.74	19.39	0.99
273	12	0	2.21	7.76	-19.27	5.63	994.88	9.24	32.35
274	12	0	2.17	8.95	-19.47	5.01	988.69	19.81	36.71
275	12	0	2.57	7.46	-23.37	4.58	989.03	17.10	19.51
276	12	0	2.51	9.25	-17.15	3.96	1000.01	26.98	57.44
277	12	0	1.34	5.07	-8.31	3.42	999.92	94.43	3.37
278	12	0	0.66	4.78	9.49	2.85	992.89	120.06	0.00
279	12	0	0.88	5.67	-3.35	3.97	986.26	26.33	0.00
280	12	0	1.56	7.76	-10.88	3.97	982.10	9.95	25.65
281	12	0	1.24	7.46	-2.68	4.05	975.72	22.76	12.82
282	12	0	1.53	9.25	25.03	4.61	981.01	11.02	14.01
283	12	0	1.43	16.42	14.82	3.21	986.83	84.53	21.50
284	12	0	0.69	4.78	23.22	2.38	982.86	88.15	0.00
285	12	0	0.92	4.48	-1.56	2.05	983.68	18.54	0.00
286	12	0	1.47	7.16	10.83	2.22	989.50	109.33	12.23
287	12	0	1.39	5.37	22.37	2.36	996.67	110.58	0.00
288	12	0	1.50	5.07	26.11	1.61	1011.26	103.68	0.00
289	12	0	0.85	5.07	22.72	0.85	1021.12	92.50	0.00

TABLE I b

NO. 1 RIVER GAGING STATION

TIME day h min	TEMP C	BP mbar	GAGE HEIGHT m	TIME day h min	TEMP C	BP mbar	GAGE HEIGHT m
221 12 0	10.67	1004.04	3.23	255 12 0	7.11	1005.16	2.80
222 12 0	8.93	1001.92	3.23	256 12 0	7.26	1010.97	2.77
223 12 0	8.87	1004.83	3.30	257 12 0	7.11	1010.72	2.78
224 12 0	10.58	1006.29	3.33	258 12 0	6.91	996.51	2.84
225 12 0	11.02	1008.38	3.30	259 12 0	6.55	989.26	2.90
226 12 0	10.76	1012.50	3.26	260 12 0	6.64	991.59	2.91
227 12 0	11.12	1013.95	3.23	261 12 0	5.83	1001.25	2.84
228 12 0	10.99	1012.32	3.19	262 12 0	5.68	1009.59	2.82
229 12 0	10.45	1011.05	3.16	263 12 0	5.29	1011.92	3.00
230 12 0	8.90	1007.59	3.12	264 12 0	4.60	1011.25	3.18
231 12 0	8.06	1003.53	3.15	265 12 0	4.38	1018.77	3.13
232 12 0	7.98	1002.43	3.50	266 12 0	4.67	1023.87	3.00
233 12 0	8.08	1009.42	3.73	267 12 0	5.10	1021.87	2.88
234 12 0	7.75	1012.08	3.55	268 12 0	5.49	1017.46	2.79
235 12 0	7.40	1008.13	3.34	269 12 0	5.58	1015.99	2.74
236 12 0	8.22	1004.59	3.29	270 12 0	5.62	1019.09	2.73
237 12 0	7.81	994.01	3.40	271 12 0	5.29	1019.57	2.72
238 12 0	7.28	984.20	3.64	272 12 0	5.85	1008.72	2.74
239 12 0	9.18	996.89	3.63	273 12 0	7.01	996.81	2.87
240 12 0	9.33	1006.98	3.45	274 12 0	6.49	989.72	3.07
241 12 0	6.92	1009.02	3.26	275 12 0	6.12	989.43	3.20
242 12 0	6.43	1008.21	3.11	276 12 0	5.50	1001.02	3.39
243 12 0	6.17	1005.54	3.00	277 12 0	4.64	1001.20	3.38
244 12 0	7.14	1005.14	2.92	278 12 0	2.92	994.50	3.17
245 12 0	8.35	1008.91	2.86	279 12 0	4.11	986.97	2.96
246 12 0	7.69	1011.98	2.85	280 12 0	4.78	982.23	2.88
247 12 0	8.29	1008.00	2.88	281 12 0	4.77	975.75	2.93
248 12 0	8.05	1004.16	2.88	282 12 0	5.03	981.29	2.99
249 12 0	7.10	1002.12	2.88	283 12 0	3.51	987.37	3.09
250 12 0	6.35	1002.83	2.85	284 12 0	2.19	982.93	3.02
251 12 0	6.69	1003.76	2.83	285 12 0	1.98	984.05	2.87
252 12 0	7.24	1003.34	2.83	286 12 0	2.19	990.42	2.77
253 12 0	7.56	1004.59	2.81	287 12 0	1.18	997.93	2.65
254 12 0	7.13	1004.64	2.80	288 12 0	0.33	1013.09	2.51

Table Ic.

GATE GAGING STATION

TIME day h min	GAGE HEIGHT m	PREC mm/d	TEMP C
227 12 0	2.16	0.89	9.60
228 12 0	2.09	0.00	9.69
229 12 0	2.04	0.00	10.30
230 12 0	1.96	0.00	9.37
231 12 0	2.07	15.60	8.52
232 12 0	2.47	42.88	8.40
233 12 0	2.53	16.68	8.27
234 12 0	2.15	0.22	7.68
235 12 0	2.07	4.20	7.86
236 12 0	2.11	22.47	8.69
237 12 0	2.28	10.26	8.23
238 12 0	2.49	32.57	7.32
239 12 0	2.29	12.26	7.57
240 12 0	2.09	0.00	8.29
241 12 0	1.94	0.00	6.18
242 12 0	1.78	0.00	6.22
243 12 0	1.70	0.00	6.83
244 12 0	1.66	0.00	6.93
245 12 0	1.67	0.00	8.07
246 12 0	1.66	0.00	8.19
247 12 0	1.67	0.00	8.59
248 12 0	1.68	0.00	8.27
249 12 0	1.63	0.00	7.43
250 12 0	1.60	0.22	7.18
251 12 0	1.59	10.67	7.12
252 12 0	1.58	0.88	7.23
253 12 0	1.58	0.22	7.26
254 12 0	1.59	0.00	6.90
255 12 0	1.59	0.00	7.03
256 12 0	1.55	0.00	7.18
257 12 0	1.54	6.47	7.29

TIME day h min	GAGE HEIGHT m	PREC mm/d	TEMP C
258 12 0	1.57	2.44	7.24
259 12 0	1.65	28.26	6.63
260 12 0	1.62	0.66	6.43
261 12 0	1.59	1.76	6.38
262 12 0	1.69	8.01	6.15
263 12 0	1.90	25.14	5.39
264 12 0	1.97	15.34	4.85
265 12 0	1.78	0.00	4.02
266 12 0	1.60	0.00	4.33
267 12 0	1.47	0.00	5.23
268 12 0	1.41	0.22	5.77
269 12 0	1.39	1.32	5.94
270 12 0	1.40	2.45	5.92
271 12 0	1.37	0.22	5.39
272 12 0	1.39	0.44	6.14
273 12 0	1.56	20.47	7.17
274 12 0	1.74	18.26	6.39
275 12 0	1.97	12.68	5.84
276 12 0	2.18	20.04	5.33
277 12 0	2.00	1.99	4.56
278 12 0	1.63	0.00	2.85
279 12 0	1.50	0.00	3.98
280 12 0	1.53	18.92	4.93
281 12 0	1.54	6.85	5.09
282 12 0	1.68	14.45	5.05
283 12 0	1.74	14.05	3.58
284 12 0	1.53	0.22	2.58
285 12 0	1.39	0.00	2.48
286 12 0	1.27	13.16	2.28
287 12 0	1.14	0.00	1.60
288 12 0	1.04	0.22	1.01

Table IIa

MET STATION FANTASTIC

TIME day h min	RH %	TEMP C	AVG SPD m/s	INSOL W/m	PREC mm/d
218 12 0	78.58	11.64	1.29	88.23	0.26
219 12 0	47.83	14.36	1.95	124.92	0.00
220 12 0	85.19	10.48	1.85	76.38	0.00
221 12 0	80.28	9.58	1.54	104.05	0.00
222 12 0	97.03	8.04	1.72	32.57	5.20
223 12 0	96.91	7.54	1.45	37.19	35.36
224 12 0	72.75	9.68	1.59	104.77	11.18
225 12 0	39.86	10.86	3.16	121.76	0.00
226 12 0	24.97	11.26	3.32	109.92	0.00
227 12 0	16.18	13.58	2.00	186.69	0.00
228 12 0	15.93	14.12	1.19	226.90	0.00
229 12 0	17.21	11.06	1.05	175.33	0.00
230 12 0	18.85	7.56	2.06	85.10	0.00
231 12 0	94.81	5.60	4.60	49.17	19.50
232 12 0	81.01	5.36	5.51	36.84	89.44
233 12 0	89.87	5.69	2.66	122.58	31.98
234 12 0	79.80	6.04	1.53	107.47	0.00
235 12 0	89.01	6.46	2.41	83.23	3.12
236 12 0	94.20	6.05	2.76	75.57	22.10
237 12 0	60.58	4.52	4.32	26.27	34.06
238 12 0	58.02	4.60	4.95	28.62	67.60
239 12 0	27.01	4.04	8.76	185.07	20.28

TABLE IIb.

WATERFALL GAGING STATION

TIME day h min	GAGE HEIGHT m	PREC mm/d
222 12 6	2.09	
223 12 6	2.05	
224 12 6	2.01	
225 12 6	2.04	
226 12 6	2.09	
227 12 6	2.13	
228 12 6	2.16	
229 12 6	2.19	
230 12 6	2.23	
231 12 6	2.23	13.26
232 1211	2.02	72.54
233 1211	1.97	45.50
234 1211	2.15	0.00
235 1211	2.22	5.46
236 1211	2.17	31.20
237 1211	2.06	9.10
238 1211	1.95	65.06
239 1211	2.11	6.82
240 1211	2.21	0.00
241 1211	2.29	0.00
242 1211	2.34	0.00
243 1211	2.35	0.00

TABLE III.

SURFACE LOWERING FOR MOHAVE (MIS) AND WEST (WIS) ICE STATIONS

TIME	MIS	WIS
day h min	cm	cm
219 12 0	0.00	
220 12 0	-6.73	
221 12 0	-11.69	
222 12 0	-17.12	
223 12 0	-21.84	
224 12 0	-27.26	
225 12 0	-33.51	
226 12 0	-40.66	
227 12 0	-47.33	-8.94
228 12 0	-53.43	-19.72
229 12 0	-59.86	-29.17
230 12 0	-65.66	-35.37
231 12 0	-70.85	-39.26
232 12 0	-77.15	-44.37
233 12 0	-82.41	
234 12 0	-86.10	
235 12 0	-90.11	
236 12 0	-94.33	
237 12 0	-100.02	
238 12 0	-104.55	
239 12 0	-108.20	
240 12 0	-113.82	