NOAA Technical Memorandum ERL PMEL-25

COMPARISON OF OCEAN AND ISLAND RAINFALL IN THE TROPICAL SOUTH PACIFIC, ATLANTIC, AND INDIAN OCEANS

Cathleen Wright
R. K. Reed

Pacific Marine Environmental Laboratory
Seattle, Washington
April 1981

UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige,
Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
James P. Walsh,
Acting Administrator

Environmental Research
Laboratories
Joseph O. Fletcher,
Acting Director

TABLE OF CONTENTS

COMPARISON OF OCEAN AND ISLAND RAINFALL IN THE TROPICAL SOUTH PACIFIC, ATLANTIC, AND INDIAN OCEANS

Cathleen Wright
R. K. Reed

Abstract

Mean annual rainfall and maximum elevation were compiled from a variety of sources for islands in the tropical South Pacific, Atlantic, and Indian oceans. Estimated annual ocean rainfall in the vicinity of each island was taken from a map of annual precipitation over the world ocean recently prepared by Reed and Elliott. Island rainfall was compared with ocean rainfall, and these island/ocean rainfall ratios were examined in terms of location and island elevation. No reliable correlation between island and ocean precipitation was revealed, although low islands near the intertropical convergence zone seem most likely to have island rainfall representative of ocean rainfall.

1. INTRODUCTION

Reed and Elliott (1979) mapped mean annual precipitation over the North Pacific from ship-of-opportunity frequency data using direct measurements of ocean rainfall to verify precipitation intensity, and Reed (1980) consequently compared these values with those obtained from tropical island rain gauges. He concluded that island data are not reliable indices of oceanic rainfall.

Reed and Elliott (1981) have now mapped annual and seasonal precipitation over the world ocean making it possible to extend island-ocean rainfall comparison to the tropical South Pacific, Atlantic, and Indian oceans. This memorandum presents compiled island and ocean rainfall data, sources, and some calculations useful in such a comparison and briefly discusses the results.

2. DATA

Tables 1, 2, and 3 list the annual mean measured rainfall for selected tropical islands in the South Pacific, Atlantic, and Indian oceans. Weather records (Table 4) were consulted to determine which islands had sufficient

Table 1. List of measured island and nearby estimated oceanic rainfall (annual amounts) in the tropical South Pacific Ocean. Elevation is the maximum island elevation where low is less than 35 m, intermediate is 60-115m, and high is greater than 140m.

Number	Name	Latitude (°S)	Longitude (°W,°E)	Elevation	Measured Island Rainfall (cm)	Estimated Ocean Rainfall (cm)	Ratio (Island/ Ocean)
1	San Cristobal	0.9	90.0°W	high	85	80	1.1
2	Easter	27.2	109.4°W	high	124	50	2.5
3	Atuona	9.8	139.0°W	high	121	45	2.7
4	Pitcairn	25.0	130.1°W	high	180	50	3.6
5	Rikitea	23.1	135.0°W	high	192	50	3.8
6	Taiohae	8.9	140.1°W	high	111	45	2.5
7	Hikueru	17.6	142.7°W	low	149	50	3.0
8	Takaroa	14.5	145.0°W	low	153	50	3.1
9	Makatea	15.8	148.2°W	intermediate	168	50	3.4
10	Tahiti(Papeete)	17.6	149.6°W	high	184	50	3.7
11	Rapa	27.6	144.3°W	high	286	60	4.8
12	Tubuai	23.4	149.5°W	high	204	55	3.7
13	Malden	4.0	155.0°W	low	69	50	1.4
14	Penrhyn	9.0	158.0°W	low	189	60	3.2
15	Bora Bora	16.5	151.7°W	high	203	50	4.1
16	Mopelia	16.9	154.0°W	low	180	50	3.6
17	Aitutaki	18.8	159.8°W	high	187	50	3.7
18	Rurutu	22.4	151.3°W	high	203	50	4.1
19	Mangaia	21.9	158.0°W	high	191	50	3.8
20	Rarotonga	21.2	159.8°W	high	206	50	4.1
21	Manihiki	10.4	161.0°W	low	232	80	2.9
22	Rakahanga	10.0	161.1°W	low	239	85	2.8
23	Palmerston	18.1	163.2°W	low	207	55	3.8
24	Puka Puka	10.9	165.8°W	low	285	110	2.6
25	Niue	19.0	169.9°W	intermediate	205	55	3.7
26	Sydney	4.4	171.2°W	low	99	95	1.0
27	Canton	2.8	171.7°W	low	70	80	0.9
28	Hull	4.5	172.2°W	low	117	100	1.2
29	Atafu	8.5	172.5°W	low	287	150	1.9
30	Gardner	4.7	174.6°W	low	132	110	1.2
31	Tutuila (Pago Pago)	14.3	170.7°W	high	352	60	5.9

Number	Name	Latitude (°S)	Longitude (°W,°E)	Elevation	Measured Island Rainfall (cm)	Estimated Ocean Rainfall (cm)	Ratio (Island/ Ocean)
32	Swain's	11.0	171.1°W	low	322	140	2.3
33	Upolu (Apia)	13.8	171.8°W	high	287	60	4.8
34	Keppel	16.0	173.8°W	intermediate	232	60	3.9
35	Vavau	18.7	174.0°W	high	218	55	4.0
36	Wallis	13.3	176.1°W	high	341	80	4.3
37	Futuna(Leava)	14.4	178.3°W	high	326	60	5.4
38	Lakemba	18.2	178.8°W	high	190	50	3.8
39	Onoilau	20.7	178.7°W	intermediate	171	50	3.4
40	Raoul	29.2	177.9°W	high	150	50	3.0
41	Funafuti	8.5	179.2°E	low	364	175	2.1
42	Vaitupu	7.5	178.7°E	low	313	160	2.0
43	Niutao	6.1	177.3°E	low	280	160	1.8
44	Arorae	2.7	176.9°E	low	143	125	1.1
45	Nui	7.3	176.2°E	low	313	175	1.8
46	Nanumea	5.6	176.1°E	low	278	155	1.8
47	Beru	1.4	176.0°E	low	122	120	1.0
48	Tamana	2.5	176.0°E	low	114	130	0.9
49	Tabiteuea	1.2	174.8°E	low	111	120	0.9
50	Matuku	19.1	179.7°E	high	178	50	3.6
51	Nurakita	10.8	179.5°E	low	351	170	2.1
52	VitiLevu(Suva)	18.1	178.4°E	high	303	50	6.1
53	Rotuma	12.5	177.0°E	high	365	120	3.0
54	Erromanga (Dillon's Bay)	18.8	169.0°E	high	178	45	4.0
55	Tongoa	16.9	168.6°E	high	282	50	5.6
56	Nguna	17.5	168.4°E	high	222	45	4.9
57	Malekula (Lamap)	16.4	167.8°E	high	210	50	4.2
58	Vanualava(Sola)	13.9	167.6°E	high	403	60	6.7
59	Vanikoro	11.7	167.0°E	high	566	160	3.5
60	Aneityum	20.2	169.8°E	high	231	45	5.1
61	Norfolk	29.0	167.9°E	high	133	40	3.3
62	Lord Howe	31.5	159.1°E	high	173	45	3.8
63	Willis	16.3	150.0°E	low	110	50	2.2

Table 2. List of measured island and nearby estimated oceanic rainfall (annual amounts) in the tropical Atlantic Ocean. Elevation is the maximum island elevation where low is less than 35m, intermediate is 60-115m and high is greater than 140m.

Number	Name	Latitude (°N,°S)	Longitude (°W,°E)	Elevation	Measured Island Rainfall (cm)	Estimated Ocean Rainfall (cm)	Ratio (Island/ Ocean)
1	Sao Tome	0.4°N	6.7°E	high	87	130	0.7
2	St. Helena	16.0°S	5.7°W	high	82	25	3.3
3	Porto Santo	33.0°N	16.3°W	high	36	25	1.4
4	Madeira(Funchal)	32.6°N	16.9°W	high	57	25	2.3
5	Fuerteventura	28.5°N	13.9°W	high	12	10	1.2
6	Gran Canaria (Las Palmas)	27.9°N	15.4°W	high	20	15	1.3
7	Tenerife (Santa Cruz)	28.4°N	16.2°W	high	33	15	2.2
8	Ascension	7.9°S	14.4°W	high	11	35	0.3
9	Sao Tiago	14.9°N	23.5°W	high	26	45	0.6
10	Sao Vincente	16.9°N	25.0°W	high	15	40	0.4
11	Bermuda	32.3°N	64.8°W	intermediate	133	55	2.4
12	St. Maarten	18.0°N	63.1°W	high	114	80	1.4
13	St. Croix	17.7°N	64.8°W	high	108	80	1.4
14	Curacao	12.2°N	69.0°W	high	52	70	0.7
15	Mayaguana	22.4°N	75.5°W	low	95	80	1.2
16	New Providence (Nassau)	25.0°N	77.5°W	low	118	80	1.5
17	Grand Cayman	19.3°N	81.4°W	low	130	80	1.6
18	Swan	17.4°N	83.9°W	low	133	80	1.7

Table 3. List of measured island and nearby estimated oceanic rainfall (annual amounts) in the tropical Indian Ocean. Elevation is the maximum island elevation where low is less than 35m, and high is greater than 140m.

Number	Name	Latitude (°N,°S)	Longitude (°E)	Elevation	Measured Island Rainfall (cm)	Estimated Ocean Rainfall (cm)	Ratio (Island/ Ocean)
1	S. Andaman (Port Blair)	11.7°N	92.7	high	314	115	2.7
2	Direction	12.1°S	96.9	low	204	80	2.6
3	Amini Divi	11.1°N	72.7	low	145	75	1.9
4	Minikoi	8.3°N	73.0	low	161	85	1.9
5	Diego Garcia	7.2°S	72.4	low	246	90	2.7
6	Rodrigues	19.7°S	63.4	high	120	55	2.2
7	Mahe	4.6°S	55.4	high	212	90	2.4
8	Raphael	16.4°S	59.6	low	105	55	1.9
9	S. Agalega	10.6°S	56.8	low	184	60	3.1
10	Tromelin	15.9°S	54.5	low	95	45	2.1
11	Mauritius†	20.3°S	57.6	high	143	45	3.2
12	Reunion†	21.4°S	55.5	high	137	45	3.0
13	Mayotte	12.8°S	45.3	high	120	40	3.0

† Mean of two stations.

Table 4. References used to compile measured rainfall data presented in Tables 1, 2, and 3.

Reference	Station Locations
U.S. Department of Commerce, Weather Bureau, Washington, D.C., 1959: World Weather Records 1941-50. 1362 pp.	Atlantic and Indian Ocean
U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Services, Washington, D.C., 1966: World Weather Records 1951-60. Vol. 3, 356 pp.	Atlantic Ocean
U.S. Department of Commerce, Environmental Science Services Administration, Environmental Data Services, Washington, D.C., 1968: World Weather Records 1951-60. Vol. 6, 605 pp.	Atlantic and Indian Ocean
Taylor, R.C., 1973: An Atlas of Pacific Islands Rainfall. Hawaii Institute of Geophysics Data Rep. No. 25, 192 pp.	Pacific Ocean

rainfall data to provide reliable annual means for comparison with mean annual ocean rainfall estimates. Taylor's atlas (Table 4) was used to select tropical South Pacific islands where records of rainfall were available for periods of at least ten years. Also selected were Swain's Island with records for six years and Easter Island and Malekula Island each with nine-year records. This same criterion (record length) was used in choosing Indian Ocean islands, and again three islands with shorter records were also accepted: Tromelin Island (six years), Reunion Island (eight years), and Direction Island (nine years). In the tropical Atlantic Ocean, several islands (including Cuba, Jamaica, and Hispaniola,) are very large compared to other Atlantic islands as well as most of those in the Pacific and Indian oceans. Data on "large" islands, an admittedly subjective criterion, were not used, and stations at high elevations and at sites sheltered from the wind were also eliminated in a few instances. Fuerteventura, Bermuda, and Grand Cayman were used even though their rainfall records cover only a nine-year period.

Of the many physical factors that may affect island rainfall, maximum island elevation is the most easily obtained and was also used by Reed (1980) in his comparison in the North Pacific. Tables 1, 2, and 3 accordingly classify stations by maximum island elevation: low is under 35 m; intermediate ranges from 60 to 115 m; and high is over 140 m. Elevations were found in the references listed in Table 5. Insufficient information about island terrain was used as the basis for rejection of some stations.

Figure 1 shows station positions numbered to correspond with the tabulated data. Figure 2 shows mean annual oceanic precipitation from Reed and Elliott (1981). Annual ocean rainfall estimates at the locations of the

Table 5. References used to determine island elevations for Tables 1, 2, and 3.

Pacific Ocean Stations

U.S. Hydrographic Office, 1929: Sailing Directions, New Zealand Pilot including the Kermadec Islands, Chatham Islands and the off-lying Islands to the Eastward and Southward of New Zealand. H.O. No. 171, 527 pp.

U.S. Hydrographic Office, 1930: Sailing Directions, Australia Pilot, Vol. II, East Coast of Australia from Port Jackson to Cape York including the Islands in the Coral Sea, Torres Strait, and the Inner Route. H.O. No. 169, 628 pp.

U.S. Navy Hydrographic Office, 1952: Sailing Directions for the Pacific Islands, Vol. II, Eastern Groups. H.O. Publ. No. 166, 420 pp.

U.S. Navy Hydrographic Office, 1952: Sailing Directions for the Pacific Islands, Vol. II, the Santa Cruz Group, the New Hebrides, New Caledonia, and Adjacent Islands. H.O. Publ. No. 165B, 238 pp.

Atlantic Ocean Stations

Defense Mapping Agency Hydrographic Center, 1976: Sailing Directions (Enroute) for the West Coast of Europe and Northwest Africa. Publ. 143, 519 pp.

Defense Mapping Agency Hydrographic/Topographic Center, 1976: Sailing Directions (Enroute) for the Caribbean Sea. Publ. 144, 467 pp.

Encyclopaedia Britannica, Inc., 1951: Encyclopaedia Britannica, Vol. 19, 1003 pp.

Times Books, New York City, 1980. The Times Atlas of the World, Comprehensive Edition. 123 plates, 227 pp.

(Table 5, cont.)

Indian Ocean Stations

Defense Mapping Agency Hydrographic Center, 1978: Sailing Directions (Enroute) for the West Coasts of Australia. Publ. 175, 304 pp.

Defense Mapping Agency Hydrographic Center, 1978: Sailing Directions (Planning Guide) for the Indian Ocean. Publ. 170, 515 pp.

Defense Mapping Agency Hydrographic/Topographic Center, 1978: Sailing Directions (Enroute) for East Africa and the South Indian Ocean. Publ. 171, 531 pp.

U.S. Government Printing Office, Washington, 1942: Sailing Directions for the West Coast of India from Point Calimere to Cape Monze including the Island of Ceylon and the Maldive and Laccadive Islands. H.O. No. 159, 452 pp.

U.S. Government Printing Office, Washington, 1951: Sailing Directions for the Bay of Bengal, the Coasts of India, Pakistan, Burma and Thailand from Calimere Point to Salang Island -- The Andaman Islands, Nicobar Islands, and the Mergui Archipelago. H.O. Publ. No. 160, 276 pp.

U.S. Government Printing Office, Washington, 1952: Sailing Directions for the South Indian Ocean including Madagascar and the Islands West of Longitude 90° East. H.O. Publ. No. 161, 454 pp.

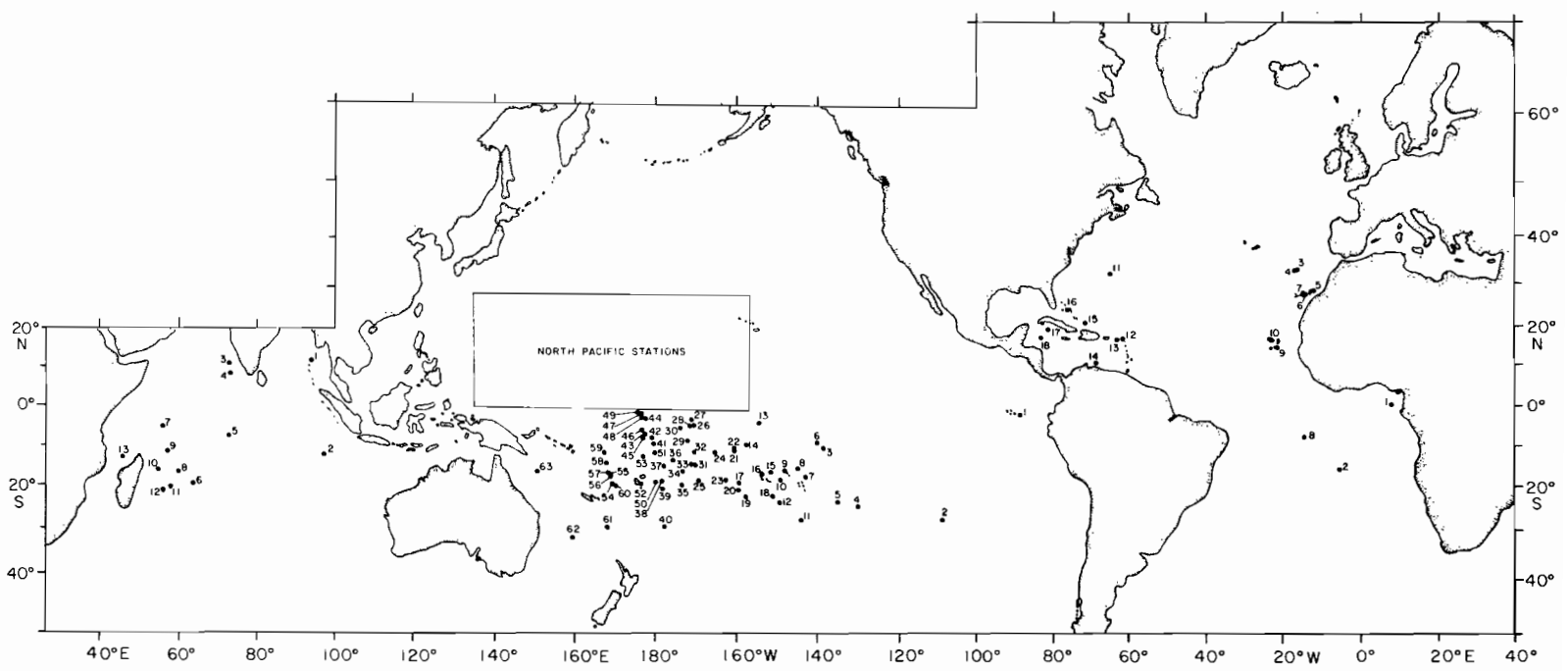

Figure 1. Locations of island rainfall stations listed in Tables 1, 2, and 3. The block labeled "North Pacific Stations" refers to a study by Reed (1980).

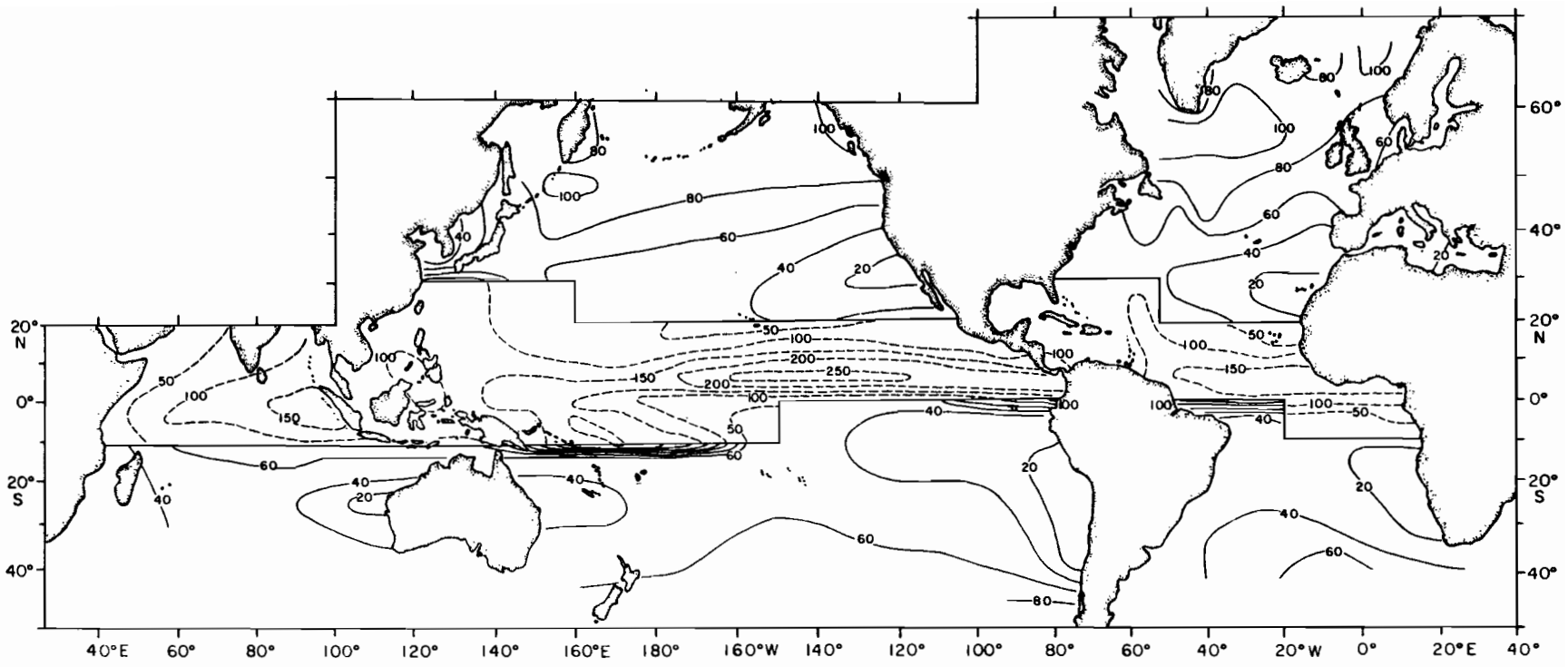

Figure 2. Distribution of mean annual ocean precipitation (cm) from Reed and Elliot (1981). The thick lines are borders of the tropical region.

islands were taken from this map and are given in Tables 1, 2, and 3. The measured island rainfall was divided by the estimated ocean rainfall to obtain the ratio printed in the last column of these tables.

Table 6 separates the islands into physical subgroups within geographical regions and tabulates mean island/ocean rainfall ratios and standard deviations.

3. ISLAND/OCEAN RAINFALL RATIOS

The best areal island distribution is in the tropical South Pacific where there are large numbers of both low and high islands. As shown in Table 6, most of the low islands form two groups: islands 13, 26-28, 30, 44, and 47-49 have a mean rainfall ratio of 1.1 and lie between 1 and 5°S; islands 14, 21, 22, 24, 29, 32, 41-43, 45, 46, and 51 have a mean ratio of 2.3 and lie between 6 and 11°S. Of all the low islands listed in Table 1, 65% have rainfall ratios greater than 1.8.

Most of the high islands (91%) have rainfall ratios of 3.0 or larger and, as a group, have a mean ratio of 4.1. In contrast, Reed (1980) listed a ratio of 3.0 ± 0.7 for high islands in the North Pacific. San Cristobal, with a ratio of 1.1, is not included statistically with the other high islands since the meteorological station seems to be exposed to the prevailing trade winds and is not generally influenced by the mountains. The high islands can be loosely grouped by position east or west of 165°W. Stations in the Tuamoto Archipelago, Society Islands, and Austral Seamount Chain (4, 5, 10-12, 15, 17-20) are east of 165°W and have a mean ratio of 3.9 ± 0.4. Stations in the Fiji, Tonga, Samoa, and New Hebrides islands (31, 33, 35-38, 50, 52, 54-60)

Table 6. Mean rainfall ratios (island/ocean) for various island groups in the South Pacific, Atlantic, and Indian Oceans.

Group	Stations	No.	Mean Ratio	Standard Deviation from Mean
South Pacific				
Low Islands (1-5°S)	13,26-28,30, 44,47-49	9	1.1	0.2
Low Islands (6-11°S)	14,21,22,24, 29,32,41-43, 45,46,51	12	2.3	0.5
High Islands	2-6,10-12,15, 17-20,31,33, 35-38,40,50, 52-62	32	4.1	1.0
Atlantic				
Low Islands	15-18	4	1.5	0.2
High Islands	1-10,12-14	13	1.3	0.9
Indian				
Low Islands	2-5,8-10	7	2.3	0.5
High Islands	1,6-7,11-13	6	2.8	0.5

are west of 165°W and have a mean ratio of 4.8 ± 1.0. While the western group has a higher mean ratio, it also has a larger standard deviation.

The tropical Atlantic Ocean islands are mostly high. The four low islands have a mean island/ocean rainfall ratio of 1.5 with a standard deviation of 0.2 and are situated west of the high islands used. While the high islands as a group have a mean rainfall ratio of 1.3, less than that for the low islands, the range is from 0.3 to 3.3. The three lowest values (stations 8-10) are for Ascension Island and the Cape Verde Islands.

The Indian Ocean stations are mostly clustered near India and Madagascar; six of the islands are high and seven are low. The mean rainfall ratio for all of the islands is 2.5 with a standard deviation of 0.5. The low-island ratio is slightly lower than this, and the high-island ratio is slightly higher.

4. DISCUSSION

The results presented here are compatible with tropical North Pacific data (Reed, 1980). In the tropical South Pacific, low islands between 1 and 5°S (Table 6) received rainfall that was in best agreement with estimated annual ocean rainfall (mean ratio = 1.1). Island rainfall increases to two to six times the estimated ocean amount for islands located farther south of this group or for sites with greater elevation.

The stations from 1 to 5°S are on the south side of the intertropical convergence zone which occurs over the entire Pacific just north of the equator. The low island stations between 6 and 11°S, which have a higher mean ratio than the 1 to 5°S group, are in a second, southern branch of the intertropical convergence zone which stretches from New Guinea to about 160°W (Hubert et al., 1969; Reed and Elliott, 1981). Reed (1980) found that

rainfall ratios for North Pacific islands nearest the northern convergence were lower than for those farther away and suggested that this resulted from a change from convective to more frontal rainfall as distance from the convergence zone increases. It is unclear, however, why the stations from 6 to 11°S have relatively high ratios unless rainfall in this southern branch of the intertropical convergence zone is different in character from that near the northern zone.

Since the mean ratio for the South Pacific high islands is greater than that for the low-island groups (Table 6), it was thought that there might be a relationship between a high island's maximum elevation and its corresponding rainfall ratio. However, calculations yielded a correlation coefficient of only 0.16. Thus, factors besides maximum island elevation (station elevation and exposure, cross-sectional area of island, island relief in relation to prevailing winds, etc.) appear to have important effects on rainfall.

Ratios for tropical Atlantic Ocean islands are unusual in that the high islands have ratios much lower there than in the other oceans (Table 6). Five of the high islands have less rainfall than the ocean estimates; however, ratios for Ascension Island and the Cape Verde Islands (Sao Tiago and Sao Vincente) may be low because they are near the "tropical boundary" (Reed and Elliott, 1981), which could not be precisely located and may have been placed too far poleward at these sites. It should also be kept in mind that ocean rainfall estimates for the western islands are subjective since Reed and Elliott's isohyets are not clearly established in this particular region.

All the Indian Ocean islands receive two to three times as much rain as occurs over the open ocean regardless of latitude or elevation. However, some of these islands are located near the tropical boundary, and the values may be suspect as noted above. Also, few of the islands are near the intertropical

convergence zone, and the rainfall may be mainly frontal in nature resulting in relatively high ratios (Reed, 1980).

5. CONCLUSIONS

High islands in the Pacific and Indian oceans generally had larger island/ocean rainfall ratios than low islands, but this was not true in the Atlantic. Calculation of a correlation coefficient for maximum island elevation versus island/ocean rainfall ratio revealed that the variations in these variables were not well correlated.

Low islands between latitudes 1 and 5°S in the Pacific have rainfall comparable to ocean estimates, but other low islands have as much as two to three times the estimated amount. Rainfall type due to island location with respect to the intertropical convergence zone may have a strong influence on island precipitation.

The main implication is that island rainfall generally does not reflect ocean rainfall and cannot be used as a predictor. In addition, it seems likely that many factors, such as cross-sectional area of island relief, type of terrain, and geographic location, all affect actual island precipitation. No matter how important orographic effects may be, maximum island elevation alone can provide only a very crude estimate of the increase in island rainfall compared with ocean rainfall.

7. REFERENCES

Hubert, L.F., A.F. Krueger, and J.S. Winston (1969): The double intertropical convergence zone--fact or fiction? J. Atmos. Sci., 26:771-73.

Reed, R.K. (1980): Comparison of ocean and island rainfall in the tropical North Pacific. J. Appl. Meteor., 19:877-80.

Reed, R.K., and W.P. Elliott (1979): New precipitation maps for the North Atlantic and North Pacific oceans. J. Geophys. Res., 84:7839-46.

Reed, R.K., and W. P. Elliott (1981): New precipitation maps for the world ocean. Unpublished manuscript.