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EVAPOTRANSPIRATION IN SOUTH PACIFIC TROPICAL ISLANDS : HOW IMPORTANT ?

by

J.P. Brunel

UNESCO

International Hydrological Programme

ABSTRACT

Evaporation is probably the most important element in the hydrological cycle.

Over the oceans it is a basic element of energy exchange between the surface and the air,it determines the amount of moisture released into the atmosphere as well as the sea surface temperature,two major imputs in the determinism of many climatological processes.

Over the islands ,evapotranspiration is a important component of the water balance equation.

Nonetheless,in each case, evaporation has rarely been measured in Tropical Pacific.The only data available are some few calculated mean monthly values of Penman potential evaporation (PET).

Because in a large part of tropical south Pacific,PET can be much greater than precipitation , it is not always necessarily the most relevant input to solve the water balance equation . Practical reasons for which evaporation studies have been undertaken in New-Caledonia in relation with hydro-electric,agricultural or tourism industry project development are developed . It is pointed out that PET measurements are not sufficient in many circumstances and suggestions are given ,taking into account the scales of space and time,for future investigations on this very important climatic parameter.

EVAPOTRANSPIRATION IN SOUTH PACIFIC TROPICAL ISLANDS : HOW IMPORTANT ?

J.P.BRUNEL
Departement Terre,Ocean,Atmosphere
ORSTOM PARIS

Introduction : tropical Pacific regions,almost nothing known.
1-How important it is to know more about evaporation.
2-Some practical reasons to undertake evaporation studies in Pacific tropical islands:New-Caledonia example.
3-Some results.
4-Which evaporation ? Which scales ?
Conclusion : needs for the future.

Introduction : tropical Pacific regions,almost nothing known.

Very few studies have been made in tropical pacific regions . Most of our knowledge of evaporation,in the best cases,come from mean monthly Penman potential evaporation calculations,and even these data are rarely available . Nevertheless humid tropics have also dry seasons and fluctuations in the availability of water.In many circumstances,calculated Penman evaporation might not be necessarily the relevant information to solve the water balance equation.

Energy budget measurements are almost non-existent,but still as more frequent than measurements of actual evaporation.There is a real need for more studies.

1-Why it is important to know more about evaporation

Pacific Ocean is probably one of the most important elements in the determination of world global climate.

Studies of climatological processes which occur over the inter-tropical zones of this ocean are of primary interest . But Pacific Ocean is also the Planet largest marine area,and in that respect,scientific investigations at the ocean-atmosphere interface are neither an easy nor a cheap deal.

One of the main interests in studying evaporation is the fact that it is a basic element of energy exchange between the earth surface and the atmosphere .These exchanges are particularly important over the oceans of the inter-tropical zones . Convection over the tropical oceans represents the major way by which solar energy is transferred to the atmosphere.It determined the amount of moisture and heat released into the atmosphere as well as the surface temperature of the sea,two major inputs in the determination of rainfall regimes and the mechanism of generation of tropical cyclones.

HALPERN (1988),reviewing the TOGA Program pointed out that very little progress has occurred in the determination of vertical atmospheric models is very complex;the mutual feed backs are not well understood and so tend to be poorly modelled,which is a principal cause why coupled oceanic-atmospheric models drift away from observed climatology during long time integrations.

These researches are of primary interest because the whole world has to face somewhere,permanently,the consequences of dryness,deluges or cyclone effects,as well as the consequences of possible global climatic changes in a near future.

The Pacific Region is also thousands of islands spread out all over the ocean from the east coast of Australia and asian continent to the west coast of America . Could some of them be regarded as natural laboratories in an approach for studying global climatological processes ?

Might climatological studies in tropical islands bring some relevant contribution to a better understanding of these processes ? This is something which is left to the discussion.

Even if measurements made on islands cannot be extrapolated easily to the ocean situation,measurements of evaporation are often linked to measurements of other components of the energy balance or other parameters which could provide very useful information on energy and mass exchanges between the surface and the atmosphere,as well as on the climate itself.

However tropical islands have to face their own practical problems at a local scale,and though lack of water is not usually the major problem faced by humid tropical islands,the erratic distribution of rainfalls might sometimes lead to situations where knowledge on evapotranspiration is necessary for water balance prediction for agricultural,hydro-electricity or tourism industry purposes (BRUNEL,1975,1080a,b).

2 Some practical reasons to undertake evaporation studies in tropical islands ,New-Caledonia example.

In the early seventies,the huge increase in the price of fuel had the consequence that one started to think about using other sources of energy.Mountainous tropical islands ,as New-Caledonia,often have interesting hydraulic capabilities . However ,erratic distribution of rainfall makes it very difficult to accurately predict runoff based only on statistical analysis of some mean monthly runoff chronological series,when these series exist ,which rarely happens for small size catchments.Example of rainfall extreme irregularity is given below (BRUNEL,1981).

Noumea (west coast)	February	15mm $<P<$ 586mm
	November	0mm $<P<$ 392mm
Yate (east coast)	July	5mm $<P<$ 659mm
	November	1.5mm $<P<$ 1338mm

In Noumea monthly variation coefficient are in the range of 60% (august) to more than 100% (November)

Fall in mining activities in the early eighties had the consequence of starting new agricultural development project on the west coast and because New-caledonia is normally affected by dry months and sometimes by persistent dryness,complementary irrigation is necessary.

What were the needs of water for the crops ? Which amount of complementary irrigation water was necessary ? Were the surface water resources sufficient ?

Another typical aspect of Pacific tropical island are the low level coral islands . Some of them can be of reasonable size such as the Loyalty Islands (600 to 1200 km2),situated at a hundred miles from the east coast of New-Caledonia.

One characteristic feature of those islands is the total absence of runoff,there is no river or gutter.Providing fresh water on tap to all the villages could only be done from ground water pumping . But everybody knows how fragile is the equilibrium of a fresh water lens lying above salt sea water,and accurate estimation of the water balance element was required to determine adequate pumping flow rates.

3-Some results

Some studies have been done in New-Caledonia during 4 years by the hydrological division of ORSTOM.

It was assumed that in such tropical conditions,PET should be close to ET all the year round,and so the main aim was to study PET and climatic parameter which have an effect upon it:available energy,vapour pressure deficit and wind speed.

Measurements were made in two different sites,over pasture on the west coast of the island.One of those (Noumea) was fully exposed to prevailing winds (S-E trade winds),the other,150 km further north was not concerned by this influence.Measurements of evapotranspiration were made by direct method using drainage lysimeters . Indirect estimations of evapotranspiration were made from Penman-Monteith equation using measured values of net radiations,wind velocities at 2m and vapour pressure deficit.Bowen ratio method has also been used for a few day periods each month during one year.

Some of the interesting points to come out of these studies are developed here below.

- Relative high level of Potential evapotranspiration and local variability.

Measured potential evapotranspiration values up to more than 7 mm per day have been recorded in Noumea (22°16 S),(average of 7.3 mm per day during 10 days in february 1978) . Mean annual value was 1622 mm,ranging from 1723 mm to 1452 mm. This number could be compared with mean annual PET calculated for Mackay(1608 mm) ,Cape Capricorn(1588 mm),Heron Island(1716 mm) or Bundaberg(1663 mm) ,between 21°06 S and 24°52 S on the east Australian coast.

For the same period, mean annual value was only 1263 mm at our the second site,Nessadiou.

- Major wind effect on PET. level

The comparison between the two studied sites has clearly pointed out the importance of wind effect on evaporation level.For the same average values of net radiation , relationships between actual evaporation from evaporative tanks and air vapour pressure deficit (VPD) for different wind speed intervals were significantly different. ("f"function in graph is the simple ratio of measured actual evaporation / VPD ,plotted against average wind velocity.) . Average wind velocities per decades were in the range of 2.3 and 8.8 m/s in Noumea,but between 1.5 and 2.6 m/s at Nessadiou site.

- *Radiative energy balance*

* *short waves*

Evaporation study cannot be separated from available energy study . Table 1 gives mean monthly measured values of incoming short wave solar radiation . One can easily see on clear days,fairly high values of atmospheric transmissivity (ratio of measured solar global radiation to calculated extra-terrestrial radiation) . These are in the range of 0.71 and 0.77.But diffuse radiations represent as well a high percentage of the global daily solar radiation (between 0.3 and 0.51).Minimum value of transmissivity is found in May and June ,at the same time when maximum of diffuse radiation occurs . The inverse take place in November.

* *all waves*

Table 2 gives mean monthly values of all-wave radiation energy balance with their seasonal fluctuations.On one year time basis,the lost of radiative energy from the surface is 50% of the solar global incident radiation,fluctuating from 45% in january to 59% in June . This is due to the fact that there is a drop of more than 45% in the global incident radiation between January and June,but only 31% in the daylight long-wave radiation energy budget . In addition there is a reverse trend in the night long-wave radiation energy budget with a minimum in January and an increase of 43% in June.

- *Actual evaporation*

Actual evapotranspiration (ET) has been measured at the Noumea site using the Bowen ratio technique.The results, for a selection of 29 days distributed over a whole year have shown that the ratio of actual to potential evapotranspiration varies in between 0.5 and 1.0,the averaged value for the year being 0.73.This lead to an estimation of annual actual evapotranspiration of 1180 mm . Mean annual rainfall for the same period is 1070 mm to which we must add an averaged rate of irrigation of 520 mm.

According to the fact that soils around the site were very shallow (40-60 cm),lying immediately above a quite impermeable bed-rock,and that there was no ground water,it can be assumed that all the precipitations and the irrigation would be distributed between runoff and evapotranspiration ,and therefore the water balance could be written as follow:

$$P+I = R+ET$$

Annual runoff calculated from this relation is 410 mm or 1270 l/s/km2 . Measured values of runoff in similar area during the same time were in the range of 900 and 1500 l/s/km2.

4-Which evaporation ? Which scale ?

These results were very interesting,at first because for the first time they brought some relevant information on climatic parameters which were totally unknown in this region,and secondly because they have been helpful in solving water balance problems.However they were not sufficient.

One characteristic we found in examining climatological data from the east coast of Australia and PNG to French Polynesia,along the south tropic is that mean annual rainfall are closed to mean annual potential evapotranspiration . One can say that 1000mm <P< 2000mm and 1500mm <PET<1700mm in every region which is not affected by micro climatic influences . That means that on a mean monthly basis PET could be much greater than P as showed in table 3 . For this reason PET is probably not the best input in the water balance equati on particularly if soil capabilities to retain water are unknown.

TABLE 3: *Mean monthly values of P-PET*

	J	F	M	A	M	J	J	A	S	O	N	D
Noumea	-53	-70	-75	+23	-18	+17	+23	-55	-113	-107	-136	-126
Nadi	+255	+144	+71	+55	-40	-23	-62	-53	-47	-58	-54	-108
Mururoa	-89	+32	+46	-15	-56	-45	+17	-77	-77	+11	-36	-47

Actual evapotranspiration is therefore the most appropriate information. This is obvious in the examples we have already mentioned.

Knowledge of actual need of water for crops should have really been the only information which could help to manage accurate irrigation schemes.

In the case of the coral island,outflow of underground water from the aquifer to the sea was impossible to measure.The natural forest covers more than 50% of the surface and the water table is between 40 and 80 m deep . Only measurements of ET would allowed one to solve the water balance equation.

Measurements of ET is not easy,and difficulties vary with the required accuracy as well as with time and space scale, and these three factors are linked together.

Our purpose here is not to give a critical review of methods used to measure ET but rather to suggest what could be done in Pacific tropical islands to obtain some relevant information at the lowest cost possible.

- *Scale of space*

Tropical islands in the Pacific can be divided in two groups,flat islands from coral origin and volcanic mountainous islands.

Measurements of ET from the natural vegetation (usually rain forests) in mountainous countries is quite impossible and also irrelevant because in such climatic conditions,PET should always be much lower than rainfall and then PET = ET. Here PET can be obtained using the Penman or the Penman-Monteith equation (see appendix) in which climatic data such as net radiation, air vapour pressure deficit will preferably be measured . As those two parameters would not change much at the regional scale one must only take care of the wind regime which will affect the "wind function" ($f(u)$) in the original Penman formula, or the aerodynamic resistance (ra) in the Penman-Monteith equation,surface resistance (rs) in this later will be assumed equal to 0.

Measurements of ET from the natural vegetation or crops in low altitude islands or flat regions far away enough from relief influences in mountainous islands join the cases of usual ET measurements by any classical method ,Bowen ratio method,aerodynamic method,energy budget or eddy correlation method which are well known.

The regions of interest to us have usually small dimensions ,hence the spatial scale problem of extrapolating the results from one measurement site could be sometimes simpler than in large continental areas.

But unfortunately sometimes,the usual aspect is more likely a sort of mosaic created by a juxtaposition of different crops ,coco nut trees planting, degraded bush lands with some spots of original forest.In such heterogeneous environment the use of micro-meteorological methods is simply impossible.

In the situation where we have a uniform surface (like the natural dense forest in Loyalty Islands or large dry plains like in the north-west part of New-Caledonia), where classical micro-meteorological methods can be used,it is unrealistic to think using these methods permanently in the field to measure ET for a long period of time.

These methods could be used to answer specific question or to determine parameters such as aerodynamic resistance,surface roughness,zero plane displacement height and establish relationships between surface parameters and climatic parameters over a representative range of conditions.This would improve the Penman-Monteith type model in non saturated conditions.This method being obviously of a much simple use since it eliminates the need for measurements either at the surface or at several heights above the surface.

We must also pointed out that the use of infra-red temperature measurement technique offers some great possibilities in determining ET over a large range of spatial scales.

- Scale of time

In tropical islands,daily changes in runoff as well as in underground water storage can be frequently observed,knowledge of ET on a daily basis could be therefore a relevant information.

Micro-meteorological techniques usually measure ET on a very short scale of time (seconds,minutes);values can then be added up to create hourly values or daily values, but these never or very rarely constitute extended series . The purpose of using such methods is more often to understand the processes governing the transfer of energy and matter between the surface and the atmosphere,generally in close relations with specific agricultural problems.These requiring obviously to be investigated at a short scale of time ,but for a short period.

Measuring ET by these methods in the aim to obtain long term series of ET from different natural vegetated surfaces to solve the water balance equation is unrealistic,so already mentioned .

On another side using mean monthly usual climatic data recorded in some meteorological stations are totally irrelevant.

We think that a permanent daily measurement of some relevant climatic parameters such as net radiation,wind velocity and air vapour pressure deficit or probably better just radiative surface temperature and global solar radiation combined to previous measurements of surface parameters could lead to a fairly good estimation of ET at a suitable scale of time.

Conclusion : needs for the future

" Water resource managements"," climatic changes ",these are probably for the present the two most common topics found in any specialized literature review.There is absolutely no doubt that the needs in knowledge about the elements of the hydrological cycle would increase sharply during the next decade.

Among those elements evaporation is certainly the most important because of the importance of the processes in which it is involved,which concern the whole Planet at various scales of space and time.

Components of evaporation have been well studied and quantified for different types of vegetation in temperate climates.For tropical climates there is very little information, even about relative magnitudes of evaporation components.

Research have also demonstrated that the influence of surface parameter on evaporation were much more important than previously thought,which implies that different types of vegetation can have different evaporation in the same climate.(SHUTTLEWORTH and CALDER 1979).

Keeping close to our main subject, the pacific tropical islands,one could suggest first to set up a list of some typical soil/vegetation/sub-climate associations at the whole tropical pacific scale. The second requirement would be to make measurements of ET on the selected sites with a special attention in determining surface. parameters and looking to relations with soil or climate condition . These would provide a very useful data base to develop suitable models or improve other like the Penman-Monteith for example.

France Australia and USA which have large scientific communities and facilities in tropical pacific regions could initiate a international joint program in association with local scientific organization.It is certainly worthwhile !

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APPENDIX

Penman-Monteith equation (Monteith, 1973):

$$\lambda E = \frac{\Delta\,(Rn-G) + \rho C_p\,[e_w(T)-e]/ra}{\Delta + \gamma(1+ rs/ra)}$$

Δ : slope of the saturation water vapour pressure curve at the air temp.
γ : psychrometric constant
$e_w(T)$: saturated vapour pressure of the air
e : air vapour pressure
ra : aerodynamic resitance
rs : surface resitance
λE : actual evaporation in mm
Rn : net radiation
G : ground heat flux
T : air temperature

Penman equation (Penman,1948):

$$E = \frac{\Delta}{\Delta + \gamma} Qn + \frac{\gamma}{\Delta + \gamma} E_A$$

E : potential evaporation
Qn : net radiation usually expressed as a function of global radiation using a BRUNT type equation :

$$Qn = Rg_o(1+a)(0.18+0.62\ S/S_o) - \varepsilon\sigma T^4 (0.56-0.08\ e^{0.5})(0.10+0.90\ S/S_o)$$

a : albedo
ε : emissivity of the atmosphere
σ : Stefan-Boltzman constant
Rg_o: extraterrestrial incoming short wave radiation
S_o : maximum sunshine duration
S : measured sunshine duration

EA : drying power of the air defined by

$EA = f(u)\ (e_w(T)-e)$ Where the originally proposed function is

$f(u) = 0.26(1+0.54\ u)$,u being the mean wind speed at 2m.

TABLE 1

MEAN MONTHLY VALUES FOR INCOMING SHORT WAVE RADIATIONS ($J.cm^{-2}.d^{-1}$)

	J	F	M	A	M	J	J	A	S	O	N	D	MOY.
Rg	2251	2386	1962	1732	1318	1219	1276	1617	2017	2216	2591	2461	1917
Rg / Rg MAX	0.73	0.81	0.74	0.79	0.72	0.75	0.74	0.80	0.83	0.80	0.83	0.77	0.78
Rg MAX	3086	2959	2640	2206	1823	1636	1734	2028	2421	2784	3133	3186	2467
Rgo	4189	3989	3596	3056	2560	2301	2382	2772	3303	3784	4092	4221	3354
Rg MAX / Rgo	0.74	0.74	0.73	0.72	0.71	0.71	0.73	0.73	0.73	0.74	0.77	0.75	0.73
Rg / Rgo	0.54	0.60	0.55	0.57	0.51	0.53	0.54	0.58	0.61	0.59	0.63	0.58	0.57
Rd (n.c.)	843	692	729	587	587	550	508	545	599	719	687	746	649
Rd (c) / Rg	0.43	0.33	0.42	0.39	0.51	0.51	0.45	0.38	0.34	0.37	0.30	0.35	0.39

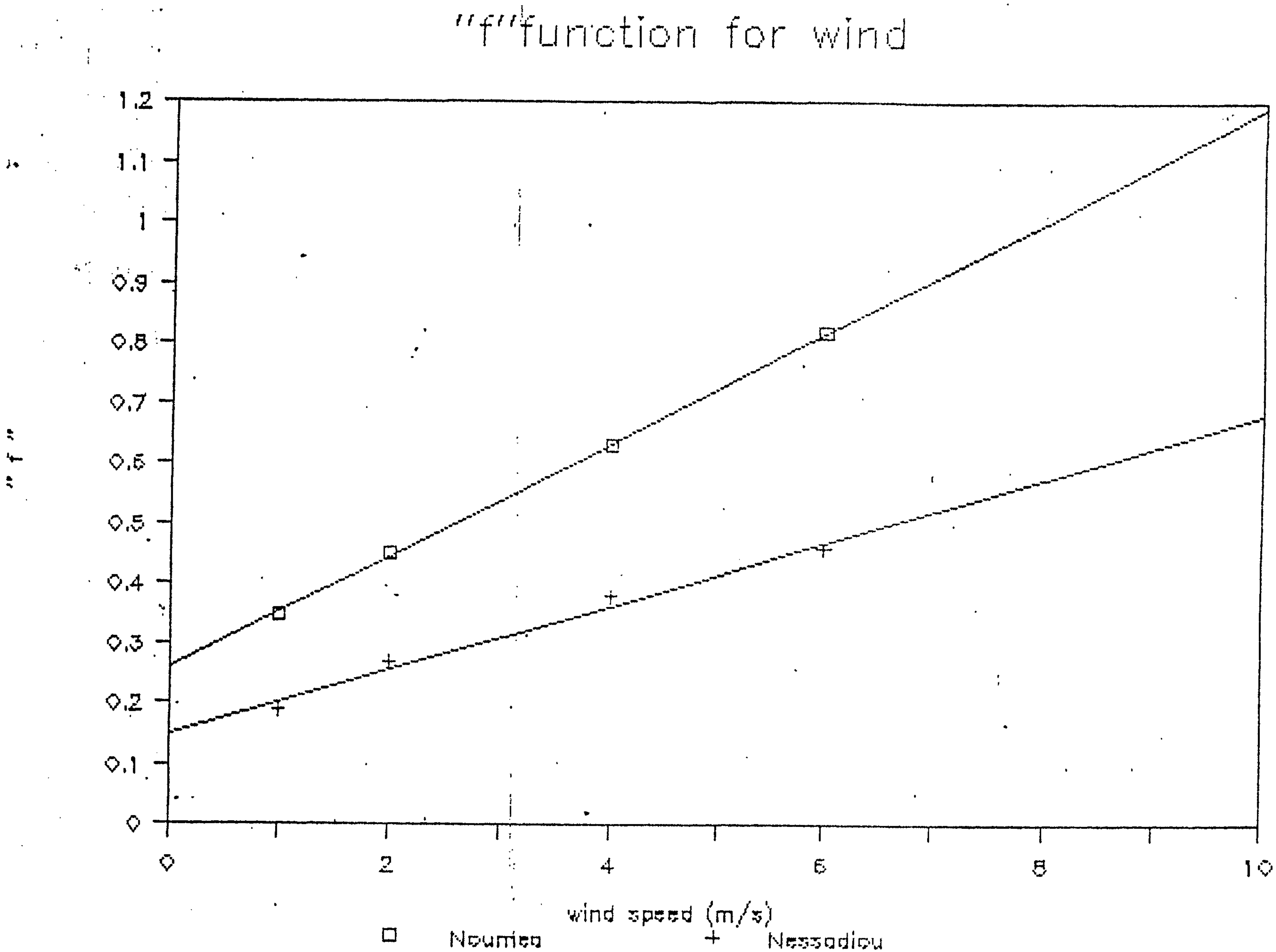
TABLE 2

MEAN DAILY RADIATIVE ENERGY BUDGET OVER PASTURE FOR EACH MONTH ($J.cm^{-2}.d^{-1}$)

	J	F	M	A	M	J	J	A	S	O	N	D	MOY.
Rn	1230	1299	1037	831	572	501	539	703	958	1139	1321	1299	950
Rn+	1357	1438	1177	1000	747	681	727	916	1174	1312	1510	1458	1122
Rn-	-127	-139	-140	-169	-175	-181	-188	-213	-216	-174	-189	-159	-173
(Ra - Rt)*	-376	-399	-334	-336	-268	-258	-256	-329	-379	-394	-485	-437	-354
(1 - a) Rg	1733	1837	1511	1336	1015	939	983	1245	1553	1706	1995	1895	1476
Rn-/Rn+	0.09	0.10	0.12	0.17	0.23	0.27	0.26	0.23	0.18	0.13	0.13	0.11	0.15
(Ra - Rt)* / Rn	0.28	0.28	0.28	0.34	0.36	0.38	0.35	0.36	0.32	0.30	0.32	0.30	0.32
Qr	0.45	0.46	0.47	0.52	0.57	0.59	0.58	0.57	0.53	0.49	0.49	0.47	0.50

(Ra – Rt)* = daylight long wave radiation balance

$$Qr = \frac{aRg + (Ra - Rt)^{*} + Rn^{-}}{Rg}$$


"f"function for wind
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
"f"
0
2
4
6
8
10
wind speed (m/s)
Noumea
Nessadiou

HYDROLOGY AND WATER MANAGEMENTS STRATEGIES IN THE HUMID TROPICS

NEEDS STATEMENTS

Primary consideration Scientific research

Major issue or problem

Very important lack of knowledge on evaporation to solve the water table equation at a suitable scale of space and time

Though lack of water is not usually the major problem faced by humid tropical islands,the erratic distribution of rainfall might sometimes lead to situations where knowledge on evapotranspiration is necessary for water balance prediction for agricultural,hydro-electricity or tourism industry purposes

Geographical area of primary interest Inter-tropical Pacific islands

Objectives

To set up a list of some typical soil/vegetation/sub-climate associations.

To measure actual evapotranspiration by appropriate techniques on sites selected from this list, for different typical climatic conditions.

To determine surface parameters and to establish relationships between these and other climatic parameters to improve existing models like Penman-Monteith or develop new models.

Level of responsibilities Regional and international

Background

Very few efforts have been done in this area .One can mention studies on energy budget and Potential evapotranspiration made in New-Caledonia by ORSTOM,and some studies made by the University of Hawaii from pan measurements and Priestley-Taylor calculations.

Prepared by

J.P.BRUNEL ,ORSTOM,FRANCE,Present address:CSIRO,Division of Water Resources,Private bag 2,Glen Osmond ,SOUTH-AUSTRALIA 5064.Tel (08)274.93.83.Fax.(08)3382144.Tlx.AA82406.

HYDROLOGY AND WATER MANAGEMENTS STRATEGIES IN THE HUMID TROPICS

NEEDS STATEMENTS

Primary consideration Scientific research

Major issue or problem Lack of knowledge on evaporation over tropical oceans.

Evaporation is a basic element of energy exchange between the earth surface and the atmosphere.These exchanges are particularly important over the oceans of the inter-tropical zones.Convection over the tropical oceans represents the major way by which solar energy is transferred to the atmosphere.It determine the amount of moisture and heat released into the atmosphere as well as the surface temperature of the sea,two major inputs in the determination of rainfall regimes and mechanism of generation of cyclones.A better understanding of these processes would lead to an improvement of dryness or deluge predictions.

Objectives

A better understanding of energy exchange processes over the oceans would help to improve the coupled oceanic-atmospheric models and therefore improve prediction of dryness and abnormal rainfall.

These researches have already been undertaken through oceanographic and meteorologic research program like TOGA,for example.Such programs need to be intensified.

The Pacific region is also thousands of islands spread out all over the ocean.Some of them could be regarded as natural laboratories in an approach for studying global climatological processes and bring a relevant contribution to understand these processes.

Level of responsibilities Regional and international

Background

A review of some previous or on-going efforts in this area can be found from two recent conferences:

-Second conference on Air-Sea Interaction,14th-17th February 1988.Merimbula ,NSW,Australia

-International Conference on Tropical Meteorology,4-8 July 1988.Brisbane,Australia.

Prepared by

J.P.BRUNEL ,ORSTOM,FRANCE,Present address:CSIRO,Division of Water Resources,Private bag 2,Glen Osmond ,SOUTH-AUSTRALIA 5064.Tel (08)274.93.83.Fax.(08)3382144.Tlx.AA82406.