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On the use of Intermediate Infrared and Microwave Infrared in Weather Satellites

by

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INTRODUCTION

This Third Annual Report is the final report on our original Contract NASA NsG-632. However, we have been granted an extension of the Contract (NsG-632) for the year 1967-68 to continue our work. The microwave work conducted by William Kreiss will soon be presented as a Ph.D. thesis at the University of Washington; it will then be published as a separate scientific report early in 1968. The microwave study will continue with analysis of data obtained on a NASA Convair flight.

SUGGESTED SATELLITE EXPERIMENTS

by

Konrad J. K. Buettner

Ever since the first weather map, meteorologists have had but one wish: More of the same. This means huge expenditure for horizontal and vertical coverage of the globe. It has also meant a corresponding increase in understanding of large scale features of dynamic fluid motions of our atmosphere. The best net we have still has a space grid width of hundreds of kilometers horizontally, of 50 or more mb vertically, and a time grid width of half a day or so. In between these data we interpolate or "smooth." The original discovery of the jet stream, as well as the thin stable Danielsen layers, were delayed because they were initially "smoothed" away. The fine art of cloud watching, highly developed at the Potsdam Observatory in the twenties, the weather observer flying daily in a tiny open airplane observing details of the lower troposphere are matters of the past. The word surface temperature means "eye level values" to synoptic meteorologists, and "real" or "true" surface temperature to the despairing radiation, or micro-meteorologist. In my fourteen years of residence in Seattle, the local 12 to 24 hour forecast has not become significantly better in spite of all superior maps transmitted from Headquarters. Dr. F. Möller assures me that the same holds for Germany, ten years after Sputnik, and six years after Tiros. The cry "more of same", of course, persists as seen in the constant pressure level balloons. We are like astronomers using only Schmidt telescopes and not the Hale telescope or the spectrograph.

The present wide angle satellite instruments show large areas in every bit of information. All but the best photographs taken by astronauts permit only the statement that there is cloudiness, not the vertical and horizontal extent of each individual cloud. If a 50% solar albedo is actually observed, it could mean a stratus of that specific albedo or a mixture of brighter, small clouds with dark background.

Cloud and surface details could be detected with greater resolution by the implimentation of nadir oriented, orbiting telescopes. Longer focal length mirror optics than have previously been used would obtain a smaller bulk of information per satellite orbit, but perhaps more information helpful in solving smaller scale cloud and surface problems throughout the .4μ - 15μ range.

The Rayleigh criterion for the resolving power of a telescope shows that an aperture as small as two inches allows a surface element of 10 m size to come under scrutiny by visible light. A seven inch aperture in an intermediate infrared telescope (8μ - 14μ) permits the separation of images of surface objects about 100 m apart. Infrared detector arrays are available with element size and spacing of 0.0005 inches. When these are employed, the telescope focal length required is about ten inches. Detector element response time necessary for resolution of 100 m wide areas is only about ten milliseconds. The following proposal is aimed at creating an observational system having the smallest possible area coverage, but the largest possible discovery of pertinent data.

Parallel to this telescope could be mounted a microwave receiver of as small a field of view as feasible. The following could be investigated:

(a) Lower troposphere ozone. Reflected solar light will be equally affected by cloud or surface reflection and by scattering losses for three selected wavelengths, λ = 0.47, 0.57, 0.67μ. However, λ 0.57 will additionally be subdued by absorption as it passes twice through the ozone layer. With proper arrangements the readout could be made to mean directly the total O_3 in a vertical column below the spacecraft. If the reflector is alternatingly the snowy ground and one or two adjacent cloud decks the differences in O_3 readout would indicate the O_3 between said levels. Since lower tropospheric ozone is a conservative element, except for surface contact, and is highly variable with the air mass origin, we would have a potent new means of frontal analysis. The method fails in cloudless areas, e.g., clear air in anticyclones. But here O_3 distribution would be of little interest. As shown below, clouds cannot well be discovered, from their albedo, over snow, e.g., via vidicon. Method (a) would yield reflector altitude data if the O_3 distribution has been determined by another method.

(b) For method (a) height and quality of the reflector are to be known or surmised. Reflector quality follows our knowledge of visible albedo; reflected signals come, as a rule, from a shallow top layer in the cloud. A special survey for Antarctic clouds might be needed. Height measurements, specifically differences of cloud decks vs. each other or vs. ground might be evaluated using absorption of the red O_2 line. Measuring cloud top temperatures at 4 or 11μ might be another indirect way of cloud height determination.

(c) A combination of visible and infrared signals can give fine details of reflection characteristics and shape of clouds specifically cumulo-nimbus. Additional data will be received simultaneously in the 15 GH_z band in order to spot heavy rain.

(d) Looking for lightning could be an enormous waste of recorder tape. However, a special filter for the orange line (Hα 6563 Å) or for another lightning emitted line could be temporarily inserted by a mechanism triggered by a spheric, i.e., arriving in the cone of meter wave transmission through the ionosphere. Sperics emission antedates light emission long enough to permit this triggering. In this way lightning signals could be received any time using the same equipment used for other continuous programs.

(e) Over snow fields, clouds are hard to recognize from above. The same holds for clouds over green forests at 0.84μ. Also, of course, visible albedo data do not yield much information on open water leads covered by summer arctic stratus.

Quantitatively, the combined effect of a scattering cloud above a snowfield may be described as follows:

We assume that our cloud does not absorb. Let $\underline{c}$ and $\underline{c'}$ be albedo and transmissivity of a cloud; $c + c' = 1$. Let also $\underline{s}$ be the albedo of the surface, e.g., the snow below. Then the reflected radiant flux density for an incoming flux of unity is

$$A = c + c'sc' + c'cs^2c' + \ldots + s(c')^2s^nc^n = c + \frac{(1 - c)^2 \cdot s}{1 - sc} \qquad (1.1)$$

and the flux arriving at the surface and intercepted by a flat totally absorbing upward looking radiometer is

$$B = c' + c'sc + c's^2c^2 + \ldots\ldots + c's^nc^n = \frac{1 - c}{1 - sc} \qquad (1.2)$$

For a black surface of $s = 0$ we have, as expected

$$A = c \text{ and } B = c' = 1 - c$$

i.e., true cloud albedo for an observer above and true cloud transmission for one below. For an ideal diffuse reflector or $s = 1$ we find

$$A = 1 \text{ and } B = 1$$

i.e., clouds seem "non-existing" for the observer in an aircraft or spacecraft as well as for one on the ground looking up.

For a cloud of saturation thickness or $c = 1$ we have

$$A = c = 1 \text{ and } B = 0$$

For the case of no cloud or $c = 0$ we have

$$A = s \text{ and } B = 1$$

One might ask, can a cloud deck increase the albedo of the earth measured from a satellite, even when the ground surface is more reflective than the cloud?

That is: $A > s$

$$c + \frac{(1 - c)^2 \cdot s}{1 - sc} > s$$

which can be reduced to $c(1 - s)^2 > 0$, which is true for all s providing $c \neq 0$.

Thus a non-absorbing cloud always increases the albedo. In Table I we see how the relative values of c and s influence A.

TABLE I

Cloud Reflectivity	Surface Reflectivity	Combined Reflectivity
c	s	A
0	s	s
1	s	1
c	0	c
c	1	1
0.20	0.20	0.35
0.20	0.80	0.81
0.50	0.20	0.55
0.50	0.50	0.67
0.50	0.80	0.83
0.80	0.20	0.81
0.80	0.80	0.89

From Table I, it can be concluded that for thin clouds the total albedo is influenced mainly by the ground reflectivity, as expected, and over a ground surface of low reflectivity 0.20 used here, the cloud reflectivity dominates strongly. It would be difficult to attempt to deduce any parameters of a cloud such as its thickness, water content or dropsize distribution quantitatively from an albedo measurement. However, for the case of a cirrus anvil having been blown away from the main cumulonimbus over the sea or over land of low s, the albedo change should be easily detectable. This should yield not only data of the cloud build-up, but also of the wind direction near its top.

Over highly reflective ground such as snow, a change in cloud reflectivity from 0.2 → 0.8 shows up only as a 8% change in A. With a thick cloud deck, c = 0.8, over the Arctic Ocean, the effect of a change in ground reflectivity from 0 for an open lead to 0.8 for the ice pack, would also give a 8% change in A. The percentage change would vary with c. However, an ambiguity obviously enters here. An additional method for determining the cloud amount and type would be needed, for instance infrared or total ozone. Once it had been established that a stratus cloud deck existed over the Arctic Ocean, the effect of open water would show up strongly, and should be worth testing.

(f) The system using 4μ infrared detectors of quick response such as PbSe also will detect the following indicative infrared signals.

(g) Multispectral photography in the visible and near infrared gives intriguing prospects for observation of salinity changes in the surface waters of the ocean from a remote platform. (See further Section III below.)

(i) A warm or cold rain persists for a short while on the ocean surface. A temperature deviation of ocean surface signals in cloudless areas may indicate the rain that fell recently. This finding would give cloud direction and intensity of rain.

(ii) Over land isolated cumulus rain will leave cool areas behind.

(iii) Cloud top temperatures which are obviously quite important.

INFRARED EMISSIVITY EXPERIMENT

by

Robert Dana

Instrumentation for the "cold box" emissivity experiment has been improved by the acquisition of a more modern infrared thermometer and a faster response stripchart recorder. The infrared thermometer is a Barnes Model PRT-5 on loan from the United States Geological Survey. It should provide a sensitivity of 0.1 degree centrigrade and a response time (time constant) as fast as 5 milliseconds. It also has a field of view (cone angle) of about 2 degrees, which promises emissivity measurements at greater angles from the normal than the old Barnes IT-2 (3^{o} F.O.V.) would allow for a given sample size.

The recorder has a response time of 40 milliseconds for full scale deflection and chart speeds up to 5 inches per second.

Some preliminary results are given on the following page in Table 2.1. The sand sample was a light gray, small grained sand. The wet sand measurement used the same sand saturated with water. The farm soil was brown, fertile soil from a southern Minnesota corn field. It was somewhat of a clay soil and contained a few bits of stalks or other vegetation. The clod size was less than 5 millimeters.

Table (2.1) Angular distribution of emissivity averaged over the 8 - 14 micron band width

Target sample	Angle of view from surface normal (degrees)					
	0	20	30	40	50	60
dry sand	.911	.903	.887	.884	.880	-
wet sand	.934	.920	.915	.910	.883	.872
dry farm soil	.936	.933	.931	.930	.907	.866

A curve of effective radiance for the Barnes PRT-5 versus blackbody temperature gives a measure of the expected accuracy of these results. The effective radiance is the integral over wave length of the product of the Planck function for blackbody radiance and the normalized spectral response of the radiometer. Taking the uncertainties in the surface temperature as measured by the radiometer and the real surface temperature measured by a bead thermister as being $\pm$ 0.2°C, we get an uncertainty in emissivity of 0.0044. The uncertainty in the correction factor due to the small amount of radiation reflecting off the sample from the cold box walls is 0.0033. The root mean square of these errors is 0.006. For most measurements deviations from the average fall within the limit $\pm$ 0.006.

The data shows a trend to lower emissivity at large angles from the normal as exhibited by the Fresnel equations and by the experimental results of Eckert (1959). The results shown here, however, may be effected somewhat by the cooling of the outer edges of the sample. As the radiometer swings to greater angles, it views a larger amount of the periphery of the target, which may be slightly cooler. This point will be carefully checked very soon.

The emissivity values normal to the surface compare favorably to Buettner and Kern's (1965) values of 0.914 and 0.936 for large grain quartz sand in the dry and wet states respectively. Lyon and Burns (1964) averaged the specral emissivity of "beach" sand over the bandwidth 7.8 to 13 microns getting a value of 0.80. The sand is assumed to have been dry. No other work on soils was available to compare with the farm soil result.

HIGH RESOLUTION INFRARED RADIOMETER ADAPTATION

by

Robert Dana

A Nimbus HRIR Radiometer was acquired on loan from NASA, Goddard Space Flight Center in April, 1967. It was decided to adapt this radiometer to our needs rather than follow the line of development of a 3.5 - 4.1 micron detector from basic components as outlined in the fifth semi-annual report of this contract. To facilitate the use of this instrument as a portable infrared detector in the field and for low level flying to measure detailed ocean surface temperature and emissivity (the former use being the more urgent), two important additional components must be developed. The radiometer needs to be operated in dry air, inert gas, or vacuum atmosphere to protect its optical system from corrosive moisture. Therefore, a window must be developed for transmission of 3.5 - 4.1 micron radiation. Also a cooling system must be designed to keep the detector cell at a steady low temperature below -70°C.

A literature search for infrared transmission properties of plastic materials showed that teflon, mylar, nylon, and polyethylene might be economical window materials. Transmission measurements on the Beckman IR-8 infrared spectrophotometer revealed that teflon and mylar had the best possibilities. Teflon had to be ruled out as a window for a vacuum chamber due to its weakness to rupturing and tendency to stretch. The transmission curve of teflon also places an emphasis on the short wave length portion of the 3.56 - 4.13

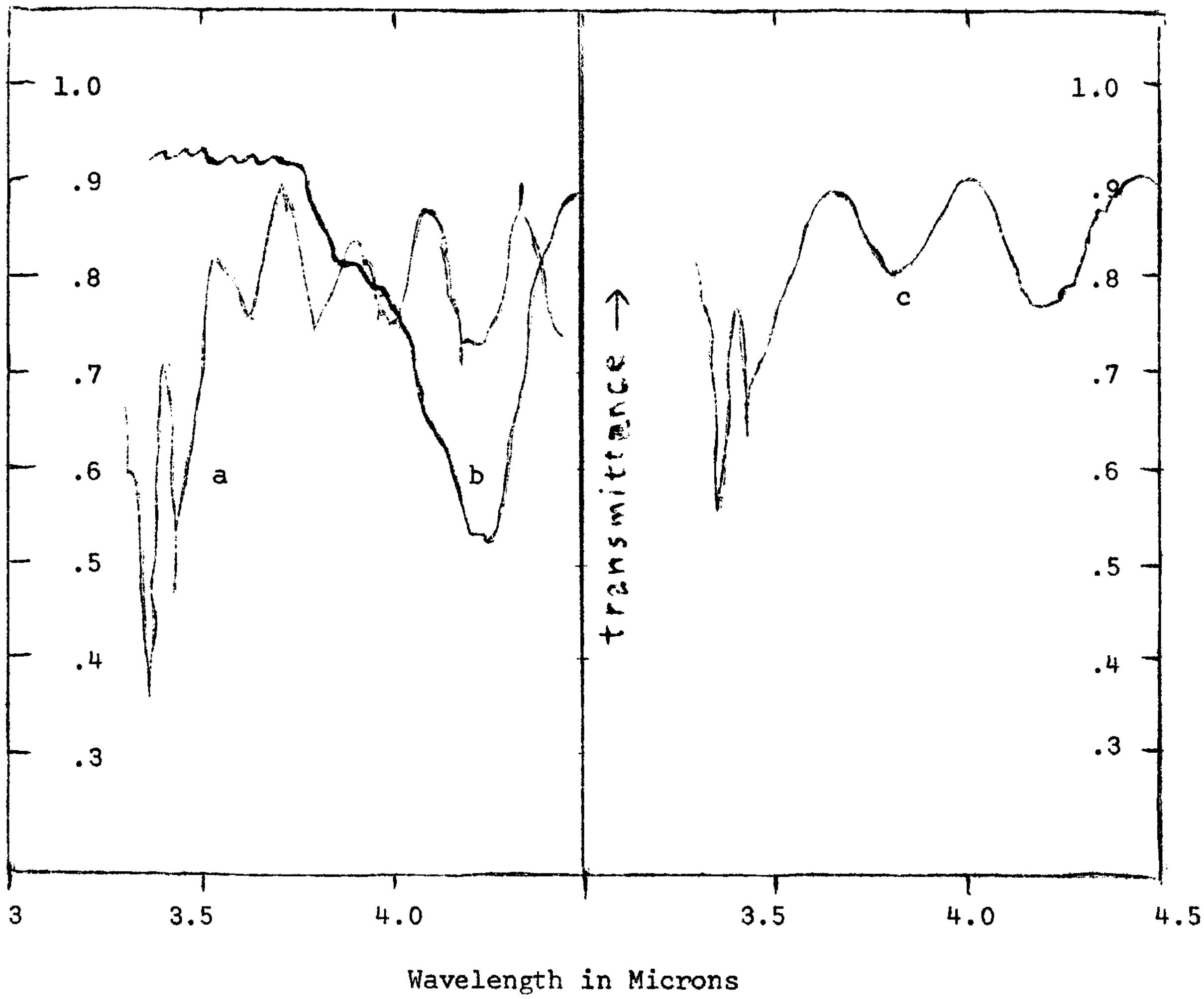

Fig. (3.1) External transmittance normal to plastic film surfaces as measured by a Beckman IR-8 Infrared Spectrophotometer

(a) Mylar 25 microns thick

(b) Teflon 76 microns

(c) Mylar 13 microns

micron band received by the HRIR radiometer, as seen in Fig. (3.1).

Mylar with a thickness of 25 microns (1 mil) transmits an average of 81% in this wave length band; 13 micron thick mylar transmits 85%. The thicker mylar will withstand one atmosphere pressure over an area equal to the aperture of the radiometer and can be used on a vacuum chamber. A non-evacuated chamber could employ the 13 micron mylar for a window.

Developmental work on the problem of cooling the PbSe detector has led to two plans of attack differentiated by the time required to build the apparatus and the use to which the radiometer will be put. The ultimate use of the HRIR is to be a co-operative effort with the Energy Transfer Research Group at this Department to obtain apparent sea surface temperatures from the air. High resolution measurements of the effects of sea state, nadir angle and the presence of foam and oil on emissivity and surface temperature are required. Since water surface emissivity in the microwave region is a strong function of temperature, accurate measurement of surface temperature would be an aid of the microwave infrared efforts of this contract as well.

The earliest use of the HRIR is for field measurements of the emissivity and temperature distribution of various terrestrial surfaces. This calls for tripod mounting of the radiometer, facilitated by portable detector cooling and a portable power supply.

Ultimately the radiometer should be housed in a vacuum chamber and cooled by radiation as it is on board the satellite. This would be done by having the cooling patch radiate longwave radiation out to a vessel of liquid nitrogen or a block cooled by stacked thermoelectric coolers. Operation in this configuration requires that the drive of the scan mirror be disconnected from the motor which rotates the chopper and scanner, allowing the telescope to be aimed and held in one direction. This is essential to allow for the window in the chamber to be of minimum area and thickness. Efficient data taking for strictly vertical measurements from a low flying plane requires that the scanning mechanism be deactivated.

For the present, it is proposed to cool the detector cooling patch and the cylindrical chamber in which it is housed by a flow of cold nitrogen gas boiled off a dewar of liquid nitrogen. The boiling will be controlled by a resistive heating element in the liquid, activated by a proportional temperature controller, which will employ as its sensor a thermistor mounted on the cooling patch. A test model of the radiometer housing and cooling patch requires about 7 watts of power to the heater to produce the boiling rate needed for keeping the cooling patch below -70°C. From this boiling rate the calculated liquid nitrogen loss rate was about 0.16 liters per hour.

The nitrogen gas can pass out past the detector and through the telescope to purge the radiometer of moist air. Hopefully, a simple housing or hood can be employed to produce a "dead air" condition in the telescope and no window will be needed.

The results of the NASA Convair 990 flights as discussed by Hovis and Tobin (1967) have discouraged the use of the 3.4μ to 4.2μ for remote emissivity measurements and identification of surface constituents. In keeping with the de-emphasis of the 3.4 - 4.2μ window most of the work with the HRIR will be done outside the scope of this contract (having the status of a student project) until such time as its use will directly apply to meteorological satellites.

The authors wish to thank those people at NASA Goddard Space Flight Center who have allowed us to use the HRIR and have aided us in its adaptation to our operating requirements.

INFLUENCE OF RAINFALL ON SURFACE TEMPERATURE AND SALINITY OF THE OCEAN

by

Kristina Katsaros

Calculations and theoretical work

A computer program has been developed, which uses a numerical method spanning two time steps for integration of the equations of heat and salt diffusion in the top ocean layers. This method, according to Saul'ev, is unconditionally stable, which means that short vertical increments, and relatively long time steps may be used.

The diffusion of heat and salt are interrelated in that they both affect the density gradients which in turn influence the mixing in free or forced convection regimes. In this sense the two systems are coupled in the calculations. The so-called Soret effect, which links molecular diffusion of salt to the temperature gradient would be a secondary effect, and has been disregarded so far. Turner (1964) at Woods Hole gives a discussion of heat and salt diffusion for a two-layer system in stable stratification, where convection occurs nonetheless. The lower layer is of higher salt content and is being heated from the bottom. Because of the molecular coefficient of diffusion of heat being two orders of magnitude larger than that of salt, convection currents are set up in the upper layer. This type of mixing may occur in the situation of cold rain on the ocean.

The boundary conditions at the surface include, for the temperature calculation: long wave radiation, latent heat exchange and sensible heat flow, short wave radiation being disregarded for the moment, and for salt diffusion mass exchange due to evaporation or condensation. After extensive literature survey, relatively simple equations for the heat and mass transfer between sea surface and atmosphere have been adopted from Malkus (1962).

Some assumptions have to be made about the diffusion coefficients of salt and heat in the top layers. It has been established by several workers that even under conditions of strong mechanical mixing one expects a molecular boundary layer. The thickness of this layer has been discussed recently by Saunders (1967), and he finds that this thickness should differ for momentum, heat and salt transport.

If we assume a molecular layer then we would expect a transition zone, and at greater depth fully turbulent flow, where the gradients are much weaker. The character of the transition zone is really our concern in this study. When there is wave action on the water the orbital motions of the particles under the wave lead to a mean horizontal mass transport in the direction of wave motion, which decreases as a function of depth. (See, for instance, Phillips 1966). This should give rise to a certain velocity shear below the surface and as a consequence turbulence. In addition to wave production, there is a stress exerted on the ocean surface by the wind, and this stress sets up the "wind driven" current in the water, with an accompanying velocity shear. As a first attempt on the stress induced turbulence, it will be assumed that the eddy diffusion coefficients of heat and salt equal the eddy viscosity, and similarly to the development for the atmospheric boundary layer we will assume that the eddy coefficient is proportional to a mixing length, which in turn is a function of z, the distance from the boundary. Near the boundary we assume that the stress τ remains constant, and that the mixing length is directly proportional to distance from the boundary. We can then write the eddy viscosity $K_m = C \cdot z$ where C is a constant, and the equation for the stress becomes:

$$\tau = \rho C \cdot z \frac{\partial \bar{u}}{\partial z}$$

ρ = density, and $\bar{u}$ = the mean horizontal velocity of the current. Integrating we get

$$\bar{u}_s - \bar{u} = \frac{\tau}{sC} \ln \frac{z}{z_o}$$

where z_o is the so called roughness length and u_s is the surface current.

A recent paper by Bye (Bye 1967) discusses the velocity profile for irrotational wave motion. He starts from a wave spectrum and finds theoretically that the velocity profile is approximately logarithmetic in a region 1 cm - 10 m depth. He also compares this result with data on the surface current obtained by him, and again finds a logarithmic profile in fairly good agreement. From ~~agreement~~ knowledge of the current profile one would like to be able to determine the state of turbulence under the surface specifically the eddy diffusion coefficients. However, this profile information does not seem to be sufficient, since there is an ambiguity as to what the cause is for one particular structure. At least intuitively there seems to be no reason why an irrotational wave should have the same state of turbulence as boundary flow in a fluid subjected to a surface stress. One only needs to consider the case when there are waves on the water, but no wind blowing to realize that the two types of current flow are independent. These questions are most interesting and will be probed further.

The effect of stability on the forced convection regime can probably best be included in the form of a Richardson number dependency. For the stable case we would have:

$$K_m = K_{mo} (1 + \beta \, Ri)^n$$

where K_{mo} is the eddy viscosity under conditions of neutral stratification, and β and n are constants, and Ri is the Richardson number defined through $Ri = \dfrac{\frac{g}{\theta} \frac{\partial \theta}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2}$ where g = acceleration of gravity, and θ = potential temperature. The value of n, in a study of the thermocline by Munk and Anderson (1948) was given as n = - 1/2 for eddy viscosity, and - 3/2 for the eddy diffusion coefficient for heat, both from the fitting of empirical data. The value n = - 1/4 has been derived theoretically and is thus better justified. According to Kolesnikov (1960) data on surface turbulence in the sea and in lakes show a large effect of stability on the ratio K_m/K_H. For neutral conditions the ratio is approximately 1, but in very stable cases can be on the order 50, and both K_m and K_H decrease uniformly for an increase in stability.

When no wind action to cause mechanical mixing is present, some criterion for the onset and effectiveness of free convection would have to be established. This situation is very unusual on the open ocean. We will not concern ourselves much with either free convection or turbulence due to causes other than wind and waves in this study. However, after the rain has stopped, and we have a very stable density distribution near the surface, it may be that convection produced by evaporative surface cooling plays an important role in destroying the density gradient.

During the rain fall the splashing of the drops at the surface with the ensuing Rayleigh jet, and the vertical velocity of the sub-surface vortex ring should give rise to an increase in the near surface eddy diffusion coefficients of heat, salt, and momentum. It is also often observed that the wave motion on the surface subsides during the rain. This could be due to the mechanical action of the drops or to a change in the wind pattern around a raining cloud.

When a steady state temperature and salinity structure for a certain meteorological condition has been established for the computer experiment, rain will be added to the top grid points. We then have to assume something about the effect of the mechanical action of the rain in increasing the diffusion coefficients. Something also has to be assumed about the effective depth of penetration of the rain. Raindrops have fall velocities from 4 to 8 m/sec. They splash at the surface, penetrate as vortex rings to some distance in the water but being buoyant then rise toward the surface mixing in along the way. Here again the different rate of heat and salt diffusion on the molecular level may be important. Perhaps an exponential decrease with depth of rain absorption should be expected. The program uses a linear model at present, but the experimental work should give a better idea of the analytic form to be used. When the rain has been absorbed, a shift in the grid positions has to take place due to added mass because the Saul'ev method requires equal grid intervals.

The computer program is now in a working condition. It has been attempted to keep it flexible enough so that insight into the interaction and relationships gained from the literature and experiments can be incorporated.

The lateral variations of turbulence in the ocean due to coupling with the atmospheric eddy motions have been disregarded. The approach has been to try to express the average structure and not necessarily explain the detail mechanisms of the individual air-sea interactions.

Experimental Work

The laboratory model sea and rain apparatus has been tested on a few runs. The rain drops fall from hypodermic needle points extended from arms at the outlet of a tank, suspended under the ceiling. The problem has been to keep all the rain at a uniform temperature, and to measure its temperature. Collecting the drops near the surface of the salt water tank into a syringe with a fine built-in thermocouple and continually letting some of the water escape through the narrow hole, seems to be a solution. The rain water tank is now well insulated and can be flushed thoroughly before the start of an experiment.

The surface temperature is measured with a Barnes PRT5 infrared radiometer of 0.1°C accuracy. This instrument is lent to us this fall by the U. S. Geologic Survey in Tacoma. The Barnes IT2 proved much too crude.

A thermocouple array to measure the temperature gradient in the water has been completed. Several materials were tested for insulation against the electric conduction through sea-water and a neoprene paint[1] was found, which seems to do the job and also has the advantage that it can be applied to fine metallic wire without extensive beading. An attempt is being made to construct a 5 micron differential thermocouple to measure the gradient in the top millimeter, at least in the laboratory.

The first few experimental rains indicate that the temperature and salinity anomaly at the surface is directly proportional to the temperature difference between the rainwater and the saltwater, rate of rainfall and the duration of rainfall. The effect of stability is very plainly seen, when one compares a cold rain on a warm fresh water tank to rains on a salt water tank with a density of approximately 1.023 g/cm^3. The change in the radiative temperature normalized with respect to the above mentioned parameters: rain to tank temperature difference rain rate and duration, is about 4 times larger in the stable case. Below the surface one finds in the stable

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[1]Manufacturer--Gaco Western, Seattle, Washington

case a well mixed region 2 - 4 cm thick and below that steep temperature and salinity gradients. In the case of cold rain on a fresh water tank, the temperature difference is contained in a cool surface film.

Climatology and field data

A climatological survey of the possible differences of the rain temperature from that of the underlying ocean, and the accompanying heat and vapor transfers has been started.

Raindrops have been found to attain the wet bulb temperature of the air while descending through it with a time constant of 3 - 4 seconds, in laboratory studies. (See Kinzer and Gunn 1951). Fletcher (1962) refers to temperature measurements of natural rain by Byers et al, and Maulaud and although the temperature of the rain commonly approaches the wet-bulb temperature of the air, it can be either warmer or colder. What this implies in terms of expected ocean-rain temperature differences at various places on the earth will be established.

A report by Boudreau (1965) on the radiative temperature of the ocean surface in the Caribbean, employing Eppleys, showed on two occasions after rain showers a surface to interior temperature difference approximately $1^{o}C$ larger than was otherwise found.

If the salinity depression is large enough and persists at the surface for a substantial length of time the effects on the flora and fauna can prove disastrous. A drastic case is described in the article titled "Mass mortality of a marine fauna following tropical rains." (Goodbody, 1961). In this case, we have a sheltered lagoon and river runoff to amplify the effect.

In a recent article in LIFE magazine (Stolley, 1967) there are some very interesting color photographs of the Miami Beach Gold Coast, the result of multispectral photography employing panchromatic, black and white film and several filters in the visible and near infrared. One picture shows a distinct difference between fresh water at the surface after a rain shower and the neighboring unaffected salt water. This technique developed for Fairchild Space and Defense Systems, (Yost and Wenderoth, 1967) could prove a very useful way to study the rain fall effect on surface salinity, and perhaps indirectly turbulence, by remote sensing, if a quantitative correlation between color and salt content could be established.

Immediate Plans

In the next few months, many laboratory experiments will be carried out so that the effect of the various parameters can be separated. In addition, the tank should be put out-of-doors during a natural rainfall to observe possible differences. The laboratory rains are limited in that they have monodisperse dropsize distributions; (all drops turn out to be approximately 3 mm in diameter), and the height of fall is insufficient for the drops to attain terminal velocity. However, rain amount and number of drops per unit area and unit time can be adjusted with the hydraulic pressure in the rain container, the size of the hypodermic needles and the number of needles used.

MICROWAVE STUDY

by

W. T. Kreiss

Most of the work conducted on passive microwave techniques under this grant will be presented in a separate report to follow shortly. This work has included the construction of a radiometer operating at a wavelength of 1.6 cm and subsequent ground-based zenith-viewing observations. Concurrent theoretical efforts have centered around model computations of "brightness" temperatures in the spectral region 15-30 GHz for upward viewing observations from mean sea level and downward viewing observations from above the atmosphere. Many cases for several kinetic temperature and humidity profiles, with and without clouds, have been computed. Comparisons with available observations generally show good agreement providing an encouraging outlook for further studies. The need for complete meteorological support data for correct interpretation of observations has become evident from analyses of data from both ground-based and aircraft observational programs. Therefore, it is strongly recommended that future studies be as fully co-ordinated with meteorological observations as possible, if the potential of passive microwave systems is to be determined. From computations it appears that multi-frequency observations can provide much more valuable information than can be obtained with a single frequency. For example, a better measure of precipitable centimeters of water vapor in the atmosphere, a measure of liquid water content of clouds and much better estimates of cloud thicknesses may be possible. Single frequency observations are frequently ambiguous but do provide much qualitative information.

For studies of the structure of individual cumulus cells from satellites high spatial resolution is required. This can easily be achieved with optical systems but leads to very large microwave structures. However, since microwaves penetrate much further into such clouds than do infrared and visible radiation the combination of sensors might provide a powerful tool. To estimate the dimensions of a suitable microwave antenna assume that a circle of coverage of 1 km diameter at the earth's surface is required. Then, for a satellite in circular orbit at 250 km a half-power antenna beamwidth of about 0.5 degrees is necessary and leads to aperture dimensions of about two meters for an operating wavelength of 1.5 cm. If the orbit is at 1000 km then the corresponding beamwidth and aperture are of the order of 0.1 degree and 10 m respectively for the same operating wavelength. Relaxing the coverage circle to 5 km would yield less information but acceptable antenna dimensions.

High resolution studies of specific cloud types would fit best into a manned spacecraft program and then probably only in the large craft such as the saturn launch vehicles presently under study. On such a craft, reasonably large antenna structures could be tolerated from the standpoints of size, weight, shape and compatability with other experiments. Such antennas could be mechanically deployed from an aerodynamic housing, be of inflatable design or even assembled by astronauts. Currently, design studies of large antennas for space vehicles are being performed which should be directly applicable to meteorological uses. However, even when suitable antenna designs and space platforms are available the task will be to justify installation of these large antennas for meteorological purposes. It will take careful and thoroughly organized experimental programs to prove the value of passive microwave systems and to achieve this goal.

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