METEOROLOGICAL APPLICATION OF APOLLO PHOTOGRAPHY

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Final Report
Contract
NAS 9-10305

DEPARTMENT OF ATMOSPHERIC SCIENCE
COLORADO STATE UNIVERSITY
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ABSTRACT

This final scientific report on Contract NAS 9-10305 summarizes past meteorological research using Apollo IX photographs. In addition, it contains a discussion of opportunities for additional research in connection with future manned spacecraft missions. These include: (a) an extension of sub-synoptic scale atmospheric wave investigations begun under the present contract, (b) a plan to obtain high accuracy measurements of the energy exchange between earth and space (the "radiation budget" of our planet), and (c) the opportunity to provide vital support to ongoing large-scale weather modification efforts in the western mountains.

These new opportunities address significant environmental problems of the 1970's--the kind presently planned for study within the international Global Atmospheric Research Program (GARP), by scientists concerned with worldwide effects of pollution and global climatic change, and by our national effort to productively modify certain aspects of regional weather related to hydrology.

I. Summary of Past Work

1. Apollo XI Photographs of Cloud Features

Cloud photographs acquired during the course of the Apollo IX mission provided meteorological information which justified making computations on a scale well below the conventional rawinsonde data network scale. Numerous cirrus cloud streaks and cumulus streets, oriented with the airflow at the cloud levels (Kuettner, 1959), yielded detailed wind direction patterns in the high, middle, and low troposphere.

Gravity waves, evident from the characteristic ribbed patterns imposed on middle and high clouds, occurred over large areas of the southwestern United States. The wave structure was clearly visible in the Apollo IX photographs, even in thin cirrus which could not be detected in the operational weather satellite pictures taken at about the same time.

The high-resolution Apollo IX photographs clearly exhibited "billows," or short breaking waves a few hundred meters in length, superimposed on the lee waves over western Texas. Cap clouds visible over mountain ranges in New Mexico and Colorado verified the substantial vertical motions which occurred when the airflow was perturbed by the high mountains.

2. Data Utilization

The interpolated rawinsonde and pilot balloon data were added to the wind direction information deduced from the cirrus streaks and cumulus streets observed in the gridded Apollo IX photographs. The total data population was objectively fitted at seven standard levels from 100 mb to 700 mb to a computational grid beginning at 30 N and about 95 W and extending to 38 N and about 114 W. The grid mesh interval was about 111 km and the area covered by the calculations of vertical fluxes of horizontal zonal momentum and of kinetic energy approximated 10^6 km^2.

3. Vertical Momentum Fluxes

The mountainous region of the western United States constitutes an area of particular importance to the atmospheric circulation. Broad currents of eastward-moving air have often been observed to undergo a significant change in vertical structure when passing over the rugged terrain. The curvature of the vertical profile of the zonal wind component often changes, with a sharp maximum developing near tropopause levels (Rossby, 1951). This development of a jet maximum over the mountains occurs most frequently over the Rocky Mountains of the southwestern United States (Lester, 1969).

The research performed under this contract measured the contribution of subgrid-scale fluxes of zonal momentum to the concentration of momentum at tropopause levels. The computations utilized the component momentum equations including the pressure gradient force, Coriolis, and inertial terms plus a residual term which contained the vertical divergence of subgrid-scale momentum transport. The residual term is frequently referred to as the shearing, or Reynolds', stress term where the stress is proportional to the correlation between the zonal perturbation velocity u' and the vertical perturbation velocity w':

$$\tau_{xz} = -\overline{\rho u' w'} \quad . \qquad (1)$$

ρ is the atmospheric density.

The inertial term dominated the momentum flux computations for most of the Apollo IX mission period in the free atmosphere over the grid area. The horizontal acceleration at upper levels measured 20 m sec^{-1} to 40 m sec^{-1} from the western to the eastern boundaries of the study region during the transit of the airflow; the residual term, representing the subgrid-scale vertical momentum flux, was determined largely by the inertial term.

Vertical flux divergence of zonal momentum occurred at the level of maximum wind (LMW) at 1800 GMT March 8, 1969, over the region of study. Very limited wave activity and cap cloud formation were observed in the Apollo IX photographs taken at that time. By 1800 GMT March 9, the vertical flux of momentum converged into tropopause levels and the vertical profile of zonal wind velocity exhibited a sharp maximum at the tropopause with increased jet stream velocity.

The vertical profile changed from convex curvature at 1800 GMT March 8 to concave below the LMW by 1800 GMT March 9. The concave structure persisted through March 12, 1969, the end of the Apollo IX photography mission. By 1800 GMT March 10 the zonal wind velocity at the LMW attained a mean value of about 65 m sec^{-1} over the southwestern United States, with an average downstream acceleration across the grid area to 76 m sec^{-1} at the eastern boundary from 44 m sec^{-1} at the western boundary. The mean zonal wind diminished after 1800 GMT March 10 until the end of the mission period.

Contours of zonal shearing stress at standard atmospheric levels displayed a maximum downward flux of zonal momentum to the lee of the mountains of central New Mexico at 1800 GMT March 8, 1969. By 1800 GMT March 9 a maximum upward flux of approximately 10^2 dynes cm^{-2} (10 kgm m^{-1} sec^{-2}) occurred at 700 mb over the mountains of New Mexico.

The vertical flux of horizontal zonal momentum, according to (1), depends upon the correlation between the zonal perturbation velocity and the vertical perturbation velocity. The vertical perturbation velocity approximates the vertical velocity when averaged over large regions. Figure 1 demonstrates the direction of the vertical flux of momentum in a gravity wave with the vertical axis tilting downstream with height.

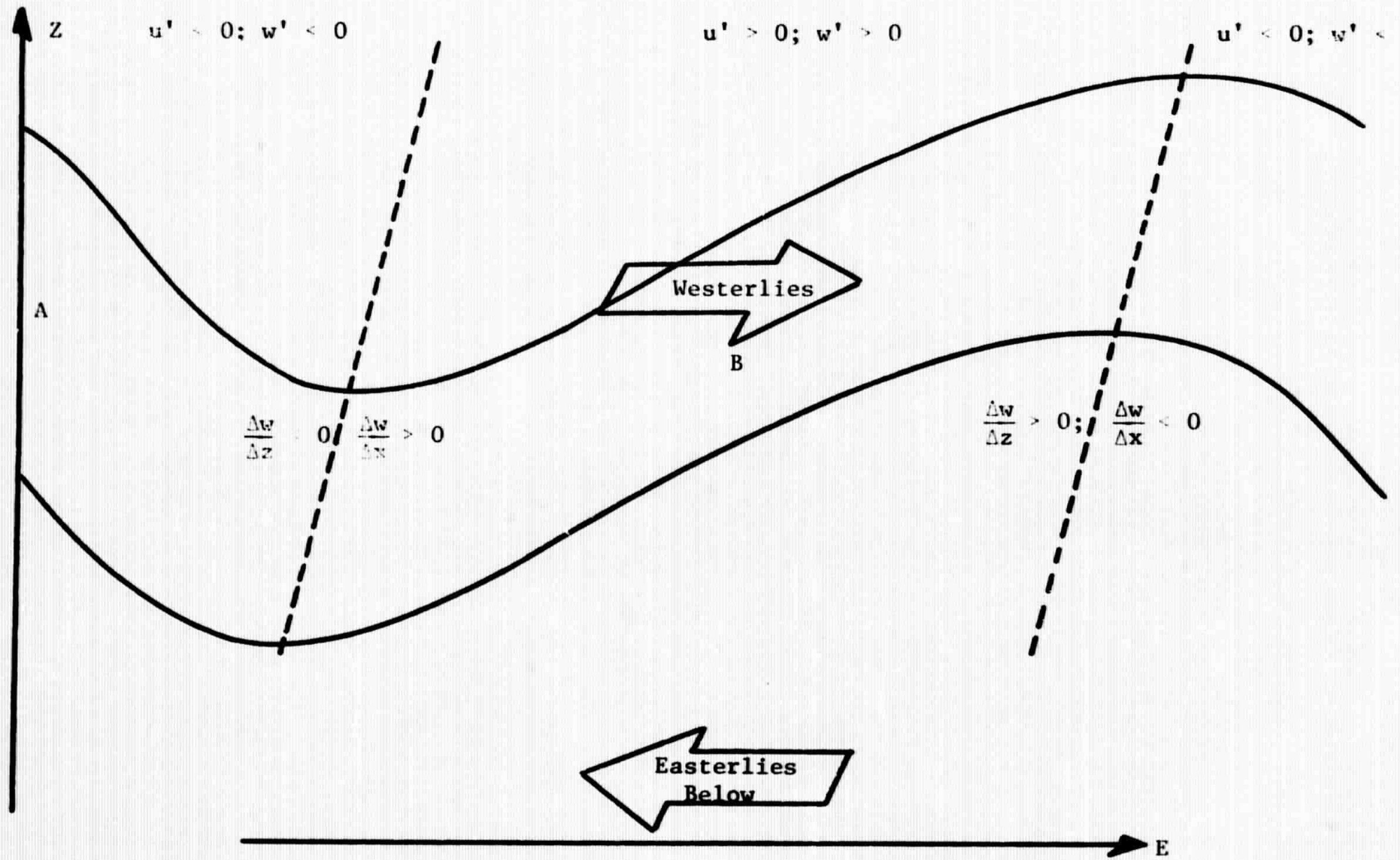

Figure 1. Schematic of gravity wave with downstream tilt of axis with height. Perturbation velocities indicated at top; vertical and horizontal gradients of vertical velocity indicated at center.

The waves photographed from Apollo IX over New Mexico on March 9, 1969, had an average wavelength of about 4 km.

Downstream from the crest of the wave (see Figure 1) the perturbation zonal velocity u' is negative; in the same region the vertical velocity w' is also negative. Consequently, the vertical flux of momentum u'w' is positive since the density ρ is always positive. Downstream from the wave trough u' and w' are positive; the vertical flux is again positive. Thus the net upward flux does not depend upon the difference between an upward and a downward flux, but is everywhere positive; the gravity wave becomes an efficient mechanism for vertical transport of horizontal momentum when the vertical axis tilts as shown in Figure 1. Conversely, it can be shown that the perturbation velocity correlation is negative when the wave axis tilts upstream with height, and momentum is transported downward.

Representative values of u' and w' illustrate the magnitude of the vertical momentum flux possible in gravity waves. If u' is 3 m sec^{-1}, w' is 3 m sec^{-1}, values not uncommon in lee waves (Vergeiner and Lilly, 1969), and the density ρ is 1.1 kgm m^{-3}, the vertical flux is about 10 kgm m^{-1} sec^{-2}, equal to the flux calculated for 1800 GMT March 9, 1969, over New Mexico.

4. Vertical Flux of Kinetic Energy

The kinetic energy budgets calculated for the five-day period March 8 through 12, 1969, indicated a "negative viscosity" in the 200-500 mb levels. This phenomenon has also been found by Kung (1967) over the North American continent at levels at and just below the tropopause. The apparent subgrid-scale generation of energy can be viewed as vertical subgrid-scale flux of kinetic energy from lower or higher levels in the atmosphere. The gravity waves suggested as a mechanism for vertical transport of zonal momentum may be considered for the vertical transport of energy.

Eliassen and Palm (1960) have shown that, for cases of non-resonating gravity waves in the x-z plane, the vertical flux of kinetic energy can be computed from:

$$\overline{pw} = \frac{U\rho_o}{k^2} \overline{\frac{\partial w}{\partial x} \frac{\partial w}{\partial z}} \tag{2}$$

in which U is the mean zonal velocity, ρ_o is the atmospheric density at the reference level, p is pressure, and k is the wave number. $\overline{pw}$ represents the vertical transport of energy through a unit horizontal surface.

In Figure 1, downstream from the inflection point A to the next inflection point B, $\Delta w/\Delta z < 0$ and $\Delta w/\Delta x > 0$; the correlation between these gradients of vertical velocity is negative in the distance interval, and energy is transported vertically downward. Downstream from B to the next inflection point, $\Delta w/\Delta z > 0$ and $\Delta w/\Delta x < 0$; again the correlation is negative, and energy is transported downward. The contra-directional vertical fluxes of momentum and kinetic energy are in agreement with the theory presented by Eliassen and Palm (1960) for gravity waves and with the flux calculations for the Apollo IX mission period.

For representative values for 1800 GMT March 9 of $U = 50 \text{ m sec}^{-1}$, $\rho_o = 0.6 \text{ kgm m}^{-3}$, $\Delta w/\Delta z = 10^{-4} \text{ sec}^{-1}$, $\Delta w/\Delta x = 10^{-3} \text{ sec}^{-1}$, $k = 0.25 \times 10^{-3} \text{ m}^{-1}$, and a 20% areal coverage by waves with a downstream axis tilt, the vertical flux of kinetic energy measured 9.6 watts m^{-2}. If a comparable flux downward from the LMW is added to the kinetic energy computations, the "negative" viscosity in the upper troposphere becomes positive.

5. Energy Storage in Gravity Waves

The potential energy in gravity waves due to buoyant forces acting on density perturbations can be estimated from (Bolgiano, 1962):

$$\Phi = -\frac{1}{2}\frac{g}{\rho_o}\frac{(\rho')^2}{d\bar{\rho}/dz} , \qquad (3)$$

where $d\bar{\rho}/dz$ represents the vertical gradient of mean potential density, ρ' is the perturbation density, ρ_o is the equilibrium potential density, and g is the gravitational acceleration. Computations using (3) and the sounding for Albuquerque, New Mexico at 1800 GMT March 9, 1969, show a potential energy in the gravity waves of about 9.3×10^5 joules m^{-2}; this energy suggests a storage rate of over 10 watts m^{-2} over a time period of one day at that point.

6. Gravity Wave Mechanisms

The preceding calculations indicate that the vertical fluxes of angular momentum and kinetic energy on the mesoscale required to balance the zonal momentum and kinetic energy budgets during the Apollo IX photographic mission period could have been accomplished through the areal coverage of gravity waves displayed in the pictures.

Further, a large portion of the kinetic energy generated on the synoptic scale early in the mission period could have been accounted for by the potential energy stored in the density perturbations in the gravity wave population.

II. Possible Application of Results

From the studies described in the foregoing chapter it becomes obvious that gravity waves in the atmosphere may fulfill a vital function at the subgrid scale in maintaining or modifying large-scale atmospheric flow patterns. They may transport appreciable amounts of momentum and kinetic energy vertically through the atmosphere, against or along the gradient of these quantities, depending on the tilt of the waves with height. Such momentum and energy transports are different from those achieved in turbulent flow. Under turbulent conditions a mass exchange between the different layers of the atmosphere takes place, together with an exchange of momentum and kinetic energy between individual (turbulent) air parcels. An exchange of air mass characteristics, such as chemical composition, heat contents, etc., occurs together with the mass exchange (see Table 1).

The action of gravity waves, on the other hand, may be visualized even under laminar flow conditions. This means that momentum and kinetic energy may be transferred <u>without</u> an accompanying net transport of mass or of other quasi-conservative air-mass properties. Thus, countergradient fluxes of momentum or kinetic energy may be envisioned that do not reflect themselves in an equivalent flux of atmospheric constituents, etc.

It has also been pointed out in the foregoing chapter that a considerable amount of energy may be stored in gravity waves in the form of potential energy. This stored energy may benefit the atmospheric energy budget at relatively large distances from the source regions of the gravity waves under consideration.

The transport and energy storage processes occur at scales of atmospheric flow that elude the present standard upper-air observational network. Hence, the effect of such waves on large-scale flow-patterns has been largely ignored in the past. This may be permissible for the

TABLE 1:

Transport Processes by Various Scales of Atmospheric Motion

Scale		Transport of		
		Mass characteristics (heat and chemical constituents)	Momentum	Kinetic energy
Synoptic		against/ with gradient	against/ with gradient	against/ with gradient
Meso	Cumulus convection	against/ with gradient	with gradient	with gradient
	Gravity waves	0	against/ with gradient	against/ with gradient
Microscale turbulence		with gradient	with gradient	with gradient

solution of short-range forecasting problems, where the initial conditions of the large-scale atmospheric flow patterns dominate the development of these patterns. In long-range forecasting, however, the boundary conditions by which energy is fed into, and extracted from, the atmosphere become the dominant factors that control the evolution of the atmospheric general circulation.

It has been well recognized in the past that subgrid-scale processes play a dominant role in atmospheric energy fluxes (for a summary see Reiter, 1969). The main concern of the Line Island Experiment (Zipser, 1970), BOMEX (Kuettner and Holland, 1969), and of many future efforts of GARP (Joint Organizing Committee, 1970) rested, and will rest, with the exploration of convective systems in low latitudes. These systems, also of subgrid scale, manage to transport heat energy (in the form of sensible and latent heat) against the vertical gradient of temperature in the atmosphere. Thus they become the main "fuel" that drives the atmospheric general circulation.

The convective systems of tropical and extratropical latitudes have different effects on vertical transports than those of gravity waves described before. Convective cells may effect a countergradient vertical heat flux (Palmén, 1966), whereas gravity waves, as long as they are in a quasi-laminar state, will not transport heat. The transport of momentum by convective cells will be in the direction of the vertical gradient of momentum and kinetic energy and thus differs greatly from the action of gravity waves described in the foregoing chapter. With respect to the momentum distribution convective cells act more like large turbulent eddies, a fact that may have some importance in the reformulation of the Ekman flow in the planetary boundary layer (Griesseier and Jacobsen, 1970).

Present efforts in numerical modeling of the atmospheric general circulation and in long-range numerical weather forecasting try to allow for the subgrid-scale convective motions by devising convenient parameterization schemes. Even if such schemes were found eventually, we have to question their universal applicability in the light of the findings reported in the foregoing chapter. Because gravity waves are an almost ubiquitous phenomenon in the atmosphere, and because they have transport characteristics which are essentially different from other sub-synoptic grid scale processes, recognition of convective processes alone in the atmosphere will not provide a full balance of momentum and energy fluxes.

The importance of gravity waves in the dynamics of the upper atmosphere has been stressed by Hines (1960) and by others (for a summary see Reiter, 1971). The "trapping" of momentum transported vertically by relatively long Kelvin waves has even been held responsible for the quasi-biennial wind oscillation in the tropics (Wallace and Kousky, 1968; Maruyama, 1968a, 1968b). Detailed measurements of vertical wind profiles in the troposphere, stratosphere, and mesosphere (see e.g. Weinstein et al., 1966; Kochanski, 1964; Reiter, 1971) indicate the omnipresence of wave motions--probably of the gravity inertia type--in the atmosphere. It is surprising, therefore, that their effect on energy and momentum transport has largely been ignored.

Especially over rough terrain features, such as mountains, hills, coast lines, etc., in the presence of vertical wind shears and of a suitable thermal stability structure, gravity waves with a wave length of the order of 10 km may reach considerable amplitudes, hence may contain large amounts of perturbation energy. Lenticular cloud formations, such as observed from Apollo IX photographs, give a visual indication of the presence of such waves. Obstacles to tropospheric flow, other than mountains, such as strong convective activity in thunderstorm clouds, may also excite the formation of gravity waves. "Lenticular clouds" have been observed in the vicinity of thunderstorms and squall lines.

In the previous chapter it has been demonstrated that these waves, especially over mountainous terrain, are highly effective in transporting momentum and kinetic energy vertically through the atmosphere. Under laminar flow conditions there could be an exchange of energy between different wave numbers by non-linear interaction (Saltzman and Fleisher, 1960; Saltzman and Teweles, 1964; Reiter, 1969) but there could be no loss from, or transport out of, a particular atmospheric layer due to turbulent exchange. In the real atmosphere truly laminar flow can hardly ever be expected to exist. Therefore a certain amount of energy will pass from the eddy sizes characteristic of the wave motion into small-scale turbulence. Especially large-amplitude lee-waves have a tendency to break down readily into random turbulent motion. This is evident from the correlation between clear-air turbulence (CAT), orographic barriers (Clodman et al., 1960), and lee-wave formation (Reiter and Foltz, 1967).

From this it appears that gravity waves especially over mountainous terrain, not only transport energy and momentum by wave action, but also by turbulence, the latter being generated by local shearing stresses developed in the wave pattern (Lester, 1970). The transports by wave action and by turbulence action do not necessarily have the same direction but may oppose each other.

As has been demonstrated in Chapter I, but also in many studies by a number of authors, jet streams overflowing large mountain barriers, such as the Rocky Mountains, are especially conducive for lee-wave formation as well as for unusually large energy levels in the high-frequency end of the atmospheric turbulence spectrum. The great regularity with which strong jet streams are found over the Rocky Mountains, mainly during winter and spring (Lester, 1969), suggests that this geographic region may play a localized, but nevertheless important role in vertical energy and momentum exchange on the meso-scale. Squall-lines over the midwestern United States may also provide large transfers of these quantities. Even hills and coast lines may, under favorable conditions, generate gravity waves with vertical transport characteristics.

From the foregoing discussion it appears to be obvious that in future efforts of the exploration of the earth's atmosphere on a global basis the mesoscale structure and the effects of gravity waves should not be overlooked. Chapter I, and a more detailed report by Wooldridge (1970), contain a detailed description of but one synoptic case study of possible momentum and energy transports by gravity waves. In order to be able to assess the effects of such waves upon large-scale circulation features more fully, additional case studies under a variety of conditions will have to be conducted. Every possible attempt should be made to measure the energy budget of, and the energy and momentum fluxes within, gravity waves directly. This will entail detailed measurements of the wind field, the amplitudes, and the vertical structure of such waves. Since mountainous regions usually abound in gravity wave formation, mostly in the form of quasi-stationary lee-waves, future investigations should focus their attention on large orographic barriers. Gravity-wave activity associated with squall lines may serve as a secondary target for investigation.

Well-instrumented aircraft have been used successfully to explore the structure of lee-waves over confined regions (Lilly and Toutenhoofd, 1969; Lovill, 1969; Lester, 1970). The degree of space-resolution available from such measurements extends from the mesoscale of wave formation to the microscale of turbulence (mostly felt as CAT). For a large-scale assessment of the wave activity and its possible effects upon synoptic-scale circulation systems aircraft measurements usually will not suffice. Attempts should be made, therefore, to combine detailed photographic satellite missions with aircraft measurements. The choice of target areas and the required detail in the resolution of measurements calls for a very close coordination between satellite and aircraft observations. Such coordination could easily be established with photographic missions flown on future manned spacecraft. Especially the decision-making procedures involved in selecting suitable target regions for aircraft and drop-sonde measurements will be enhanced by the direct overview available from a manned spacecraft. Inversely, high-resolution data-gathering techniques may be employed by a manned spacecraft to the confined regions in which air-borne measurement operations are in progress. Lower-resolution spacecraft measurements may be taken over wide areas adjacent to the region of flight operations.

In the following chapter, we present the outline of a manned spacecraft experiment designed to complement and enlarge upon the initial results of the present contract.

III. Opportunity for Expanded Meteorological Experiments from Manned Spacecraft--SKYLAB

Throughout the sections above it is apparent that the use of special measurements from manned spacecraft can be of vital importance to meteorological research on topics unable to be studied using more conventional surface or satellite data. Properly planned experiments from the SKYLAB will allow detailed study of problems heretofore only amenable to theoretical treatment; they can also take advantage of special aspects of the manned program to obtain data of very high absolute accuracy from a space platform; in addition, they can provide specialized support to optimize ground-based meteorological activities.

The following discussion outlines the scientific potential and implementation of three special meteorological experiments that have been nurtured through the conceptual phase under this contract.

1. Sub-synoptic Scale Wave Investigations Over Selected Test Sites

The demonstrated value of high resolution photos from Apollo together with the results of the present contract (Wooldridge, 1970) and the enhanced experiment payload planned and possible from future manned spacecraft missions combine to offer the very exciting possibility of special sub-synoptic scale studies of atmospheric motion over special test sites. Specifically, a combination of manned spacecraft, aircraft, and ground-based measurements should provide information on the three-dimensional space and time distribution of gravity waves (approximately 10^2 m to 10^2 km). Such data should yield estimates of

wave amplitude wave tilt with height phase velocity area coverage of wave activity.	} as functions of wave length and location

Manned spacecraft photography should have high resolution to approximately 10^2 m, and stereo capabilities of approximately 70% overlap in area coverage. Remote sensing of infrared and microwave spectra to derive vertical temperature and moisture profiles should be considered strongly to provide data on atmospheric structure with greater area resolution than presently available from the standard radiosonde network.

Ground-based support data may be gained from an array of all-sky cameras with time-lapse capabilities. The non-stationary aspects of lee-wave clouds may be monitored with such cameras.

A network of microbarographs or sensitive microphones will help in estimating phase velocities and propagation direction of traveling gravity waves. Hopefully, some of these disturbances may also be identified from airborne and satellite measurements.

Additional radiosonde ascents (4 times daily) should be considered for a better-than-average space and time resolution of the vertical structure of the atmosphere. These measurements will support remote sensing efforts from manned spacecraft missions.

Constant-density balloons tracked by radar and/or aircraft may provide additional information on the wave length of orographically generated lee waves. Under ideal circumstances such balloons may be tracked over great distances by the FAA radar network. Wave modes measured from such balloon flights may be compared with satellite and aircraft data.

Last, but not least, airborne data collection should include high-resolution records of the u, v, and w wind components. To obtain lee-wave modes reliably the use of inertial platforms is advocated. Potential temperature distributions should be available from detailed records of temperature and pressure altitude. Sensitive humidity instruments should be available.

Two test sites are suggested to study distinct but related classes of atmospheric gravity waves, namely, those associated with mountainous terrain and those which are found under severe weather conditions. For example, one site would be set in and to the lee of some western mountain ranges, the other over the National Severe Storms Research Network in Kansas City. Once proper conditions develop near a site the astronauts on the manned spacecraft would activate the experiment as often as orbital sampling will allow during a sequence of days.

2. High Accuracy Measurements of the Earth's Radiation Budget

The first successful meteorological experiment on a spacecraft (Explorer VII, 1959) measured the earth's radiation budget. This was not surprising since the space and time variation of the earth's exchange of solar and infrared radiation with space is the fundamental forcing function that drives the overall motion of our atmosphere and oceans. Vonder Haar (1968) and Vonder Haar and Suomi (1969, 1971) discuss the results of several years of measurements from the first generation of meteorological satellites. Raschke and Bandeen (1970) present results from the first of the NIMBUS satellite data.

These spacecraft experiments have shown a consistent picture of more energy gained by the tropical regions than was previously thought, indicating a more vigorous circulation of atmosphere and oceans than was anticipated. Early results also indicated that year-to-year variations in the equator-to-pole gradient of energy exchange do exist with magnitudes that must definitely affect the resulting circulation, although the exact feedback relations are not yet well understood. While we have gained a great deal from the unmanned satellite experiments and even though the sophistication and improvement of the sensors has progressed, better precision and absolute accuracy of the energy flux measurements is still needed to meet present meteorological requirements. For example, the longterm (climatological) problem of earth warming or cooling due to inadvertent or natural modification (i. e. pollution) of our environment has not yet been attacked, certainly not because of lack of interest, but because of lack of data with high enough accuracy (Chapter 5 of the First Annual Report of the Council on Environmental Quality, August 1970, pp. 93-104).

We propose a radiation budget experiment for future manned spacecraft missions that will allow intercomparison of simultaneous measurements of very high accuracy from the manned platform with the global and long-lasting data to be returned from the operational meteorological satellite program. Figure 2 shows this experiment schematically. Actually, matched sensors measuring

the solar constant,

the reflected solar radiation,

and the emitted infrared radiation

will be built, calibrated against laboratory standards, and flown (one on the unmanned spacecraft, the other on the manned spacecraft). The experiment shall last for the duration of the manned flight, after which the manned craft's sensor package will be returned to earth for laboratory calibration. Space-proven, simple sensors (of the type already used to make 80% of our radiation budget measurements) can be used; the key is proper calibration, deployment, inflight checks, and recovery.

Of course, close collaboration with NOAA, responsible agency for the operational program, will be required as well as liaison with radiation budget experiment opportunities on NASA's NIMBUS and ATS spacecraft. However, it is the high accuracy data from the manned application that will advance the state of our knowledge about the absolute energy exchange between earth and space on global, hemispheric, and zonal scales.

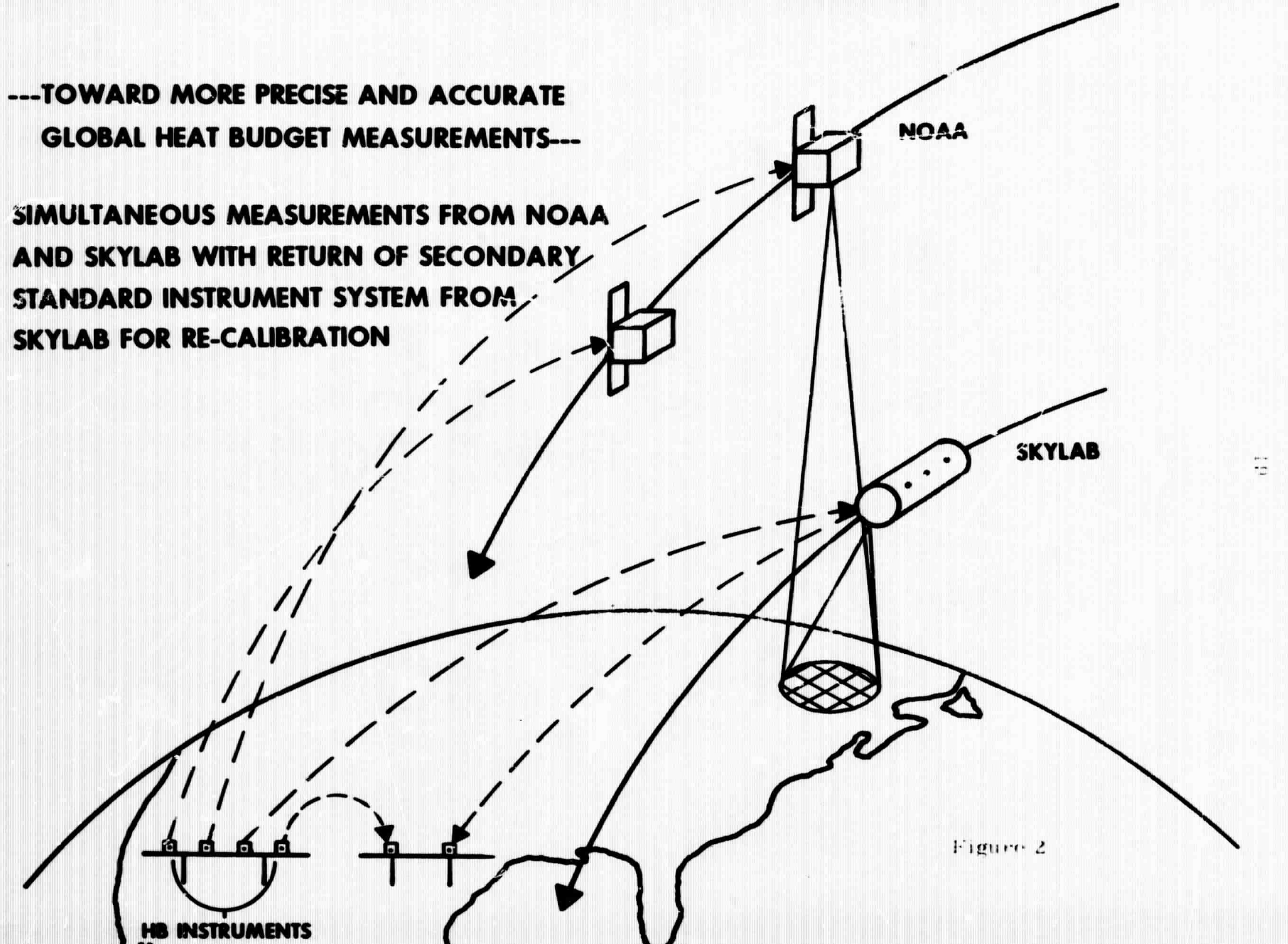
---TOWARD MORE PRECISE AND ACCURATE
GLOBAL HEAT BUDGET MEASUREMENTS---
SIMULTANEOUS MEASUREMENTS FROM NOAA
AND SKYLAB WITH RETURN OF SECONDARY
STANDARD INSTRUMENT SYSTEM FROM
SKYLAB FOR RE-CALIBRATION
NOAA
SKYLAB
HB INSTRUMENTS

Figure 2

3. Special Measurements in Support of Weather Modification Experiments

Presently "pilot" projects designed to increase the water resources of the arid southwest United States are actively being developed (e.g. Bureau of Reclamation project in the San Juan Mountains of Colorado). These pilot projects will lead to full-scale operational programs by 1975. Research on orographically induced clouds at which these projects are aimed has shown that the effect of the cloud seeding process is dependent upon the physical characteristics of the cloud. Depending primarily on the cloud-top temperature, the seeding may increase or decrease the precipitation. The frequency of cloud forms is such that a selective program for seeding is necessary and depends upon sufficient and accurate observational material.

We propose to design a manned spacecraft mission experiment to support this economically vital weather modification effort. Three applications are proposed.

a. Use trained astronauts, in real-time communication with the ground project manager, to give heretofore unavailable data concerning the temperature and other characteristics of the clouds to be seeded. The instrumentation would be centered around a very high accuracy infrared "window" radiometer. Resulting radiance measurements, converted to effective cloud-top temperature, would be compared with selected "in situ" measurements from an aircraft, then used over a wider range of space and time to guide real-time decisions. Improved snowpack (precipitation) results should accrue.

b. Study the down-wind effects of highly localized weather modification programs. Recent evidence of significant precipitation increase responses over distances of 100's of kilometers from cloud seeding experiments has been reported. The time and distance scales (1-2 days, 100's kilometers) is such that conventional observation networks are inadequate to study the mechanisms producing these effects. The manned spacecraft observational program through the use of infrared photography would be able to observe the changes in down-wind conditions, specifically the height of the cloud tops and their behavior in time and space. This, coupled with the conventional data in the lower atmosphere, would lead to a solution of the problem and this solution would be used in the design of seeding programs.

c. The photographic monitoring of the snow cover for use in the forecast of river flows. The ultimate purpose of the orographic cloud modification studies is to increase river flow from increased snowpack. Of fundamental importance to this water resource management is the knowledge of the expected river flow. Stereo photography of the snow surface on cloudless days is a technique that would yield the snow depth as a function of space and time and could be evaluated as one variable in the forecast of river flow during spring runoff. Snow depth is inferred from the stereo photography and known ground-truth check points.

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