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EARTH AND OCEAN DYNAMICS SATELLITES AND SYSTEMS

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

EARTH AND OCEAN DYNAMICS
SATELLITES AND SYSTEMS — AN OVERVIEW

F. O. Vonbun

ABSTRACT

The purpose of this introductory overview is to provide a possible guide for future IAF session activities in the general area of Earth and Ocean Dynamics, application satellites, ground systems, their necessary analytical tools and software. Some of these topics have been discussed in two previous IAF papers, but this is the first time that a serious and concentrated effort in this rather new area of space applications is to be made.

The major potentials of these earth oriented Earth and Ocean Satellite and Systems objectives is in the area of "utilization" of space science and technology. This is to help and further geophysical exploration, earthquake hazard assessment, synoptic monitoring of the dynamics of the earth and oceans, the exploration of the polar ice regions and the refinements of the earth's gravitational and magnetic fields. These objectives have practical usage in such applications disciplines as protection of life and property, protection and prevention of disasters, exploration of mineral and energy resources, the shipping and fishing industry, coastal zone construction and off-shore drillings. It is evident that rather large economical benefits will result by achieving the above objectives. It is, however, very difficult at this time to determine a real monetary value for the benefits expected. Fortunately, some work has already been performed in the past years. Methods have developed, ground and flight systems have been constructed, operated and launched to satisfy at least some of the elements mentioned before.

Geomagnetic spacecraft launched by the U.S. (OGOs) and the USSR (COSMOSs) have contributed to the construction of world magnetic field maps important for geologic studies. Other spacecraft, together with precision ground tracking systems (range and range rate, Doppler, LASER, Very Long Baseline Interferometer), have been used to develop rather sophisticated earth gravity models and geoids important to such applications as tectonic motion and earthquake studies, future global geophysical explorations and sea current studies. The Skylab and Nimbus missions contributed to the development of ocean surface wave and wind field models, sea surface temperature fields, ice fields and details of the ocean topography, to quote a few specific examples. The real intent of this paper is, as mentioned, to show one hand of some typical examples of how these applications objectives can be achieved. It is hoped that it will provide and act as a catalyst and driver for future IAF sessions to come in this area of space applications.

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ILLUSTRATIONS

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ILLUSTRATIONS (continued)

TABLES

EARTH AND OCEAN DYNAMICS SATELLITES AND SYSTEMS

I. INTRODUCTION

The purpose of this paper is to present to you an overview of the present state of satellite and ground systems making observations of the Dynamics of the solid earth and the oceans. It is necessarily confined to spacecraft and ground systems with which I am somewhat familiar, that is, NASA spacecraft and systems. Many results will not be presented because I may not be sufficiently informed about them and partly because there are too many to include in this paper.

The central theme of this application program is to provide a platform for a rather broad effort for the development of practical tools — predictive models and observational spaceborne and ground systems to further the social and economic benefit of mankind. Its primary goals are to develop, identify, demonstrate and utilize relevant space science-applications, techniques and methods for practical usage. In essence, "APPLY AND USE" to the benefit of all we have learned in the past two decades of space exploration in these particular areas. The objectives of this program fall almost naturally into two major categories — Earth Dynamics Application and Ocean Dynamics Application.

The discipline of Earth Dynamics includes the study and observation of such phenomena as tectonic plate motion, fault motion, earth rotation and polar motion, solid earth tides, as well as the motion of the earth in space. It further includes the exact determination of location of tracking stations on the earth surface, the determination and improvements of the earth gravitational and magnetic fields and in particular the study of their anomalies. The latter ones are important for practical applications in the area of mineral and energy resources, to quote an example.

The discipline of Ocean Dynamics encompasses studies and observations such as currents, circulation, waves, surface wind temperature fields, sea ice, polar ice and its structure, age and dynamics. It is understandable that all these phenomena are closely related and are of great interest to the shipping and fishing industries, the coastal zones as well as for the general area of weather forecasting. The vast ocean areas covering about 70% of the globe's surface play a large role in interacting with the atmosphere, thus influencing the world's weather and climate. It should be emphasized here that this paper is more or less result-oriented and does not particularly stress any specific planning activities. Few future systems and spacecraft are only briefly mentioned.

Geomagnetic spacecraft launched by the U.S. (OGOs) and the USSR (COSMOSs) have contributed to the construction of a world geomagnetic scalar field map important for future geologic studies. Other spacecraft, together with precision ground tracking systems (range and range rate, Doppler, LASER and Very Long Baseline Interferometer (VLBI)) have been used to develop rather sophisticated earth gravity models and geoids important to such applications as tectonic motion and earthquake studies, future global geophysical explorations and sea current studies. The Skylab and Nimbus missions contributed to the development of ocean surface wave and wind field models, sea surface temperature fields, ice fields and details of the ocean topography, to quote a few specific examples.

Tables I and II show a listing of the present state of the art and possible future requirements in the Earth and Ocean Dynamics disciplines. The numbers shown are approximate ones and in no way fixed, nor should they be. On the contrary, it is hoped that in future sessions these tables will be modified and extended so that they can be used as a guide for future national and international efforts in these disciplines.

II. OBJECTIVES AND REQUIREMENTS

As indicated, the major potential earth-oriented Earth and Ocean Dynamics Satellite Systems objectives are to "utilize" space science and technology to further and help develop and validate methods and models:

(a) to support our continuous and ever growing needs and thus search for mineral and energy resources by studying the anomalies and possible correlation of the earth gravity and magnetic fields, the geologic composition and structure of the earth surface;

(b) to study plate tectonic, fault and polar motions, solid earth tides and earth rotation leading together with ground observations to better predict probable time, location and intensity of major earthquakes;

(c) to refine our knowledge of the earth's gravitational and magnetic fields, particularly its globally distributed anomalies, to support studies mentioned under (a) above and to refine the earth geoid (sea surface topography) to support and further our knowledge on ocean currents, circulation, storm surges, and other surface phenomena;

(d) to synoptic monitor the world's oceans, transient phenomena including the magnitudes and geographical distribution of sea state, surface salinity, eddies, tides, surface winds, storm surges, swells with emphasis of identifying potential hazards for the shipping and fishing industries as well as the coastal zone areas to provide needed ocean surface (air/sea interaction) information for weather and climate forecasting; and

Table I

PRACTICAL USES OF OUTER SPACE OCEAN DYNAMICS REQUIREMENTS

PHENOMENA	STATE OF THE ART	POSSIBLE FUTURE NEEDS
WAVE HEIGHT	$\pm$30% ACCURACY , LIMITED OCEAN COVERAGE	0.5 m OR $\pm$ 10% GLOBAL
WAVE DIRECTIONAL SPECTRUM	LIMITED IN VERY LOCALIZED AREAS	DIRECTION +5°, 10% MAGNITUDE λ = 50 TO 1000 METERS
SURFACE TEMPERATURE FIELD	$\pm$1 TO 2°C, 5 km RESOLUTION IR RADIOMETER, 0 TO 35°C	+0.3°C GLOBALLY, RESOLUTION 10 km, -2 TO 40°C
SURFACE WINDS	SPEEDS DETERMINED 3 TO 15 m/s FROM MICROWAVE RADIANCE (NIMBUS)	DETERMINE SPEED TO $\pm$ 10% AND DIRECTION TO $\pm$15°
CURRENTS, CIRCULATION	BOUNDARIES DETERMINED BY TEMPERATURE MAPPING (SKYLAB, NIMBUS)	VELOCITY DETERMINATION TO $\pm$1 cm/s, (GEOSTROPHY)

Table I (continued)

PRACTICAL USES OF OUTER SPACE OCEAN DYNAMICS REQUIREMENTS (CONT'D)

PHENOMENA	STATE OF THE ART	POSSIBLE FUTURE NEEDS
TIDES	TIDAL MODEL PREDICTIONS: 1.5 m AMPLITUDE IN OPEN OCEAN, 5° TO 15° IN PHASE (MANY METERS NEAR SHORE)	GLOBAL TO 2 TO 10 cm IN AMPLITUDE & 0.3° IN PHASE
ICE, POLYNYAS	ICE AREAS MAPPED, AGE DETERMINED, OPEN AREAS GROSSLY MAPPED RESOLUTION ~ 30 km (NIMBUS)	ICE STRUCTURE, & DRIFTS, POLAR ICE CAPS VARIATION, cm/yr, DEPTH, AGE, OPEN WATER WITH HIGH RESOLUTION 10 to 20 m
SURFACE SALINITY	SPARSE DATA, L-BAND, SKYLAB, 12% ACCURACY AT $30^{\circ}C$ ONLY	WORLDWIDE, 1% ACCURACY OVER LARGER TEMPERATURE RANGE
OCEANIC EDDIES	ONLY SPARSE INFORMATION AVAILABLE FROM TEMPERATURE MAPS	SCALE 100 TO 300 km 2 TO 10 cm TOPOGRAPHY, POSITION TO 1 TO 3 km

Table II

PRACTICAL USES OF OUTER SPACE EARTH DYNAMICS REQUIREMENTS

PHENOMENA	STATE OF THE ART	POSSIBLE FUTURE NEEDS
FAULT MOTION	KNOWN NEAR THE FAULT LINE ($\pm$20 km)	0.5 TO $\pm$1 cm/yr ACCURACY NEAR & FAR FROM THE FAULT
TECTONIC MOTION	NO REAL GEODETIC MEASUREMENTS, AVERAGE OVER MILLIONS OF YRS TO $\pm$0.5 cm/yr	0.5 cm/yr OVER 300 TO 500 DAYS
POLAR MOTION	$\pm$80 cm OVER 6 TO 12 HRS. n-s COMPONENT, LASER OR CORNER CUBE SPACECRAFT, VLBI	$\pm$2 TO $\pm$5 cm TOTAL
EARTH ROTATION	1 msec OR 50 cm	LESS THAN 0.05 TO 0.1 msec OR $\sim$2 TO 5 cm
VERTICAL MOTION	INSUFFICIENT DATA OVER LARGE DISTANCES (500 km)	0.5 cm/yr OVER FEW HUNDRED KM REGIONS
SOLID EARTH TIDE	$\pm$10 cm AMPLITUDE PHASE ERROR LARGE (OCEAN LOADING)	$\pm$1 cm AMPLITUDE & $\sim$10 IN PHASE, GLOBALLY
GRAVITY FIELD	25 x 25 ORDER & DEGREE	1 TO 3 mgals, ($1^o \times 1^o$) GLOBALLY

Table II (continued)

PRACTICAL USES OF OUTER SPACE EARTH DYNAMICS REQUIREMENTS (CONT'D)

PHENOMENA	STATE OF THE ART	POSSIBLE FUTURE NEEDS
SURFACE GEOLOGY	DETECTED LINEARS, SKYLAB, LANDSAT	ACCURATE LINEAR STRUCTURE IDENTIFICATIONS
GEOID	ACCURACY 3 TO 5 m FOR 1500 km, 5 to 25 m FOR UP TO 1500 km	ACCURACY 2 TO 10 cm, λ = 200 km, GLOBAL MEAN OCEAN < 1 cm
SURVEYS (LAND) MAPPING	$\pm$10m USING TRANSIT AND OTHER POSITIONING SYSTEM	dm RANGE NEEDED IN 1980s
SURVEYS (OCEANS)	$\pm$10 m USING TRANSIT	LESS THAN 5 m
MAGNETIC FIELD	$\pm 20\gamma$ SCALAR, GLOBAL	$\pm 3\gamma$ SCALAR $\pm 6\gamma$ INVECTOR COMPONENT GLOBAL AT 300km HEIGHT

(e) to assess the general ocean circulations, currents and their transport of mass, heat, nutrients, polar ice, ice structure, drift and age, and open water areas important for the fishing industry, weather and climate forecasting.

In order to accomplish these main objectives listed above, it is obvious that proper methods, instruments, ground and flight systems have to be developed, built, launched and operated. Fortunately, an appreciable amount of work has been done over the past years in this respect.

III. SATELLITE MISSIONS AND RESULTS

Ever since the first artificial satellite was launched almost two decades ago, real progress has been made through earth viewing and sensing spacecraft in the understanding of the environment of our own planet. Here lies the great contribution of present and future applications satellites in general.

a. Earth Dynamics

In this discipline, such spacecraft as Vanguard 1, launched in 1958, together with the NASA Minitrack System (Mengel, J. T., et al., 1959), have contributed to the analyses of our earth's gravity field. The pear-shape of the earth was computed based upon orbital perturbations (O'Keefe, J. et al., 1959), to quote an example. In the following years, great strides have been made by many workers to steadily improve our knowledge in the earth gravity field (References 3 through 16). The latest model, the Goddard Earth Model (GEM 8) was developed using 400,000 optical and electronic space tracking data from 27 spacecraft (Lerch, F., 1974). These data were taken by space tracking systems such as Minitrack, Radars, Doppler, Range and Range Rate, Cameras, and over the last few years, high precision LASERS. In addition, about 1,600 ground gravity data ($5° \times 5°$ average) from the Air Force Chart and Information Service in St. Louis have been used in constructing this 25 degree and order model having an accuracy of about ±8 mgals over $4° \times 4°$ segment of the earth surface.

Polar motions and earth tides have further been detected and analyzed using precision laser tracking of Beacon Explorer-C (Smith, D. E. et al., 1972, Kolenkiewicz, R. et al., 1973). Two laser stations, one located near Seneca, New York, and one located at Goddard, have been used for this experiment. The N-S component of the pole motion was determined to within an accuracy of ±80 cm over a half a day's time interval. Figure 1 depicts the result of this first laser N-S polar motion experiment superimposed on the BIH values. As can be seen, a fairly good agreement was obtained for this first test. Interesting enough, it turned out that only one station was sufficient to perform this experiment. In addition, another result was obtained, namely, the distance between these two stations separated about 400km could be established. The ability to repeat this distance determination from separate satellite laser rangings turned out to be in the dm-range as shown in Figure 2. This result gave the actual impetus to a further new experiment, namely, the San Andreas Fault Experiment (SAFE) (Smith, D. E., Vonbun, F. O., 1973).

Improvements in the past have not only been made in the determination of the earth's gravity field as mentioned but also in the development of the earth magnetic field. Particularly instrumental were the Orbiting Geophysical Observatories launched in 1965, 1967, and 1969 (Cain, J. C. et al., 1966). From POGO data a field in terms of spherical harmonics to the order and degree of 11 was developed (Cain, J. C., Langel, R. A., 1971). This field, computed for an average height of 550km was constructed with 390,000 improved OGO observations and has an overall accuracy of about ±(6 to 8) gammas.

More important than the magnetic survey maps as such are maps of magnetic anomalies. These are more closely related to the crust, that is, to mineral and earth resources. A recent global anomaly map has been published (Regan, et al., 1975). In this map, POGO satellite magnetometer data are used as a basis for the determination of crustal magnetic anomalies. Verification of very distant anomalies was obtained by examining individual satellite profiles as well as data collected during the Project MAGNET (Stockard, H. P., 1971). The persistence of anomalies of all satellite data independent of local time indicate that these anomalies are real and not the result of any magnetospheric or ionospheric disturbance. These results demonstrate the real utility of satellite magnetometer data as a geological and geophysical survey tool.

It is suspected that the greatest range in magnetic anomalies may turn out to be areas that had the most intense geotectonic activity such as crustal movement, faulting and volcanism. The so-called Bangui anomaly depicted in Figure 3 in Africa, for example, shows up clearly in the map and lies over the tectonic uplift zone between Chad to the north and the Congo Basin to the south. It should also be noted that in the same area rather large gravity anomalies have recently been detected using the latest Goddard gravity fields. Thus, it seems that there exists a correlation between the gravity and magnetic field anomalies in this region of geography. Work will continue to study these correlations in more detail.

During the last few years, a new tracking/sensing method, namely, satellite-to-satellite tracking has been developed to specifically detect and determine global gravity anomalies of the earth's field (Vonbun, F. O., 1975).

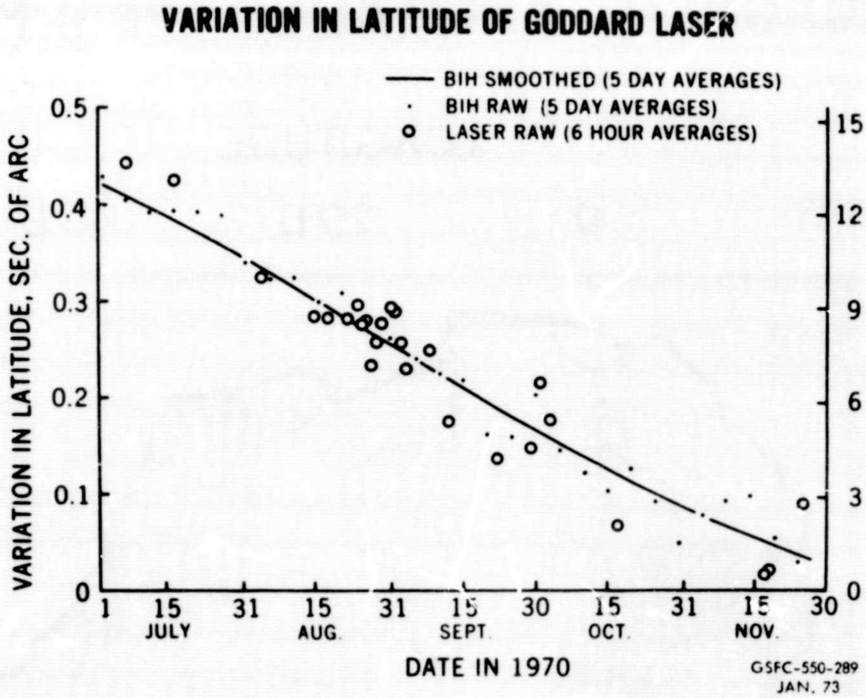


Figure 1

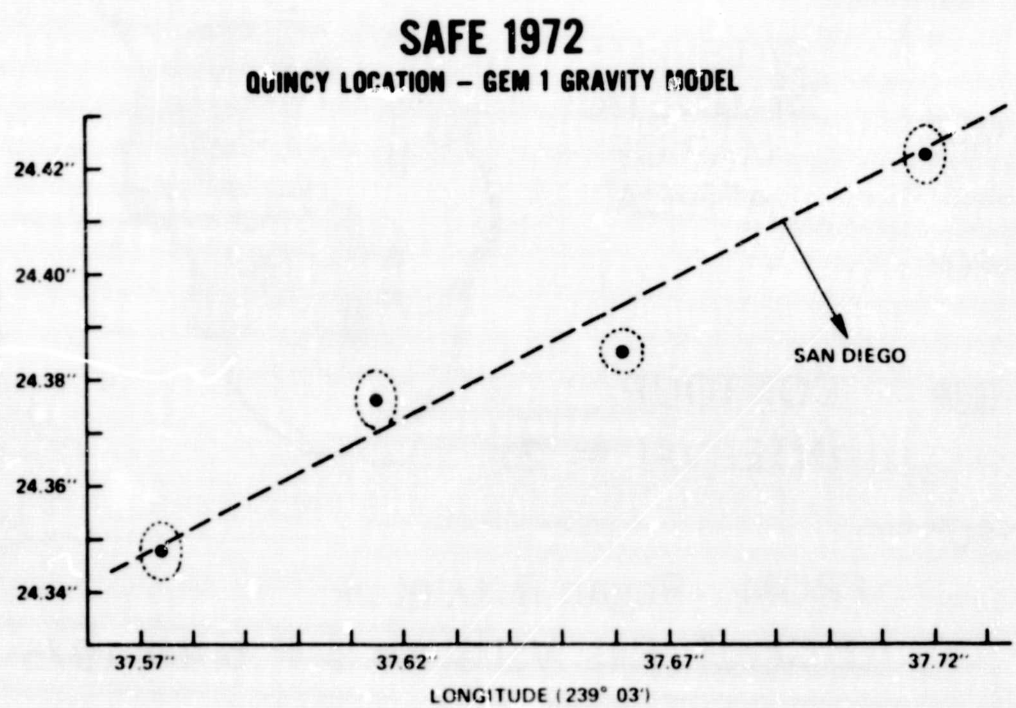
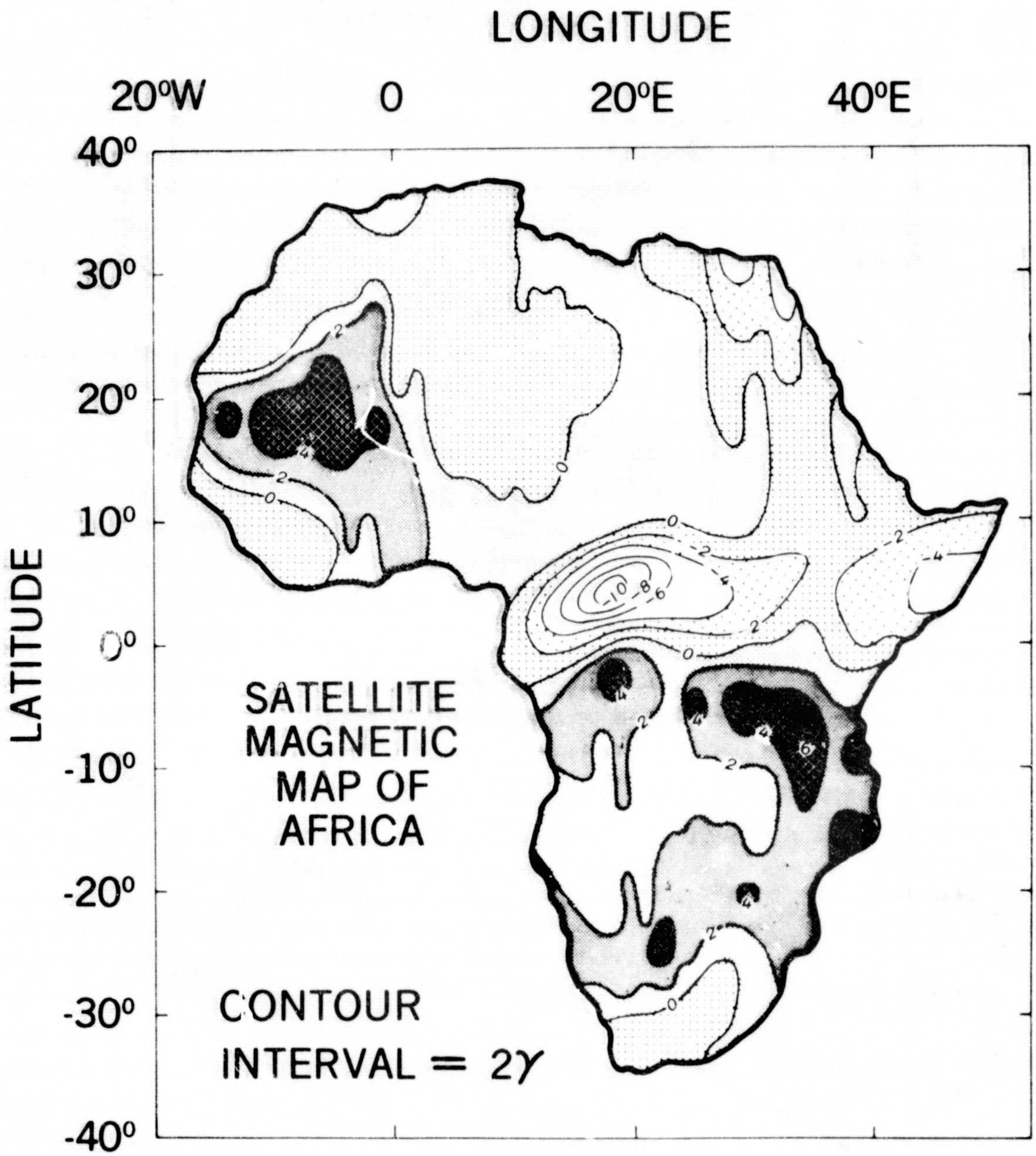


Figure 2

MAGNETIC ANOMALIES FROM POGO



FROM: Regan R. D. et al

J. Geoph, Res. Vol 8, No. 5, Feb. 10, 1975

Figure 3

Spacecraft such as GEOS-3, Nimbus-6 and recently the Apollo-Soyuz have been tracked via ATS-6. Gravity anomalies, which could not be sensed in the past by normal ground tracking systems have been "seen" by this method during the Apollo-Soyuz mission. Figure 4 shows a ground track together with an anomaly in the Himalayas. It is the anomalies as mentioned in both the earth's gravitational field, as well as magnetic field, that are of particular and practical interest for the applications disciplines. These are possible indicators of mineral and earth resources as well as crustal structures in general.

We have recently developed a new satellite geoid at Goddard as shown in Figure 5, together with the Skylab 4 ground track (Marsh, J. and Vincent S., 1974) based upon the Lerch-field. During the last Skylab mission we had the first opportunity to make an actual partial accuracy test of this geoid (Vonbun, et al., 1975). The on-board radar altimeter "measured" the "computed" sea surface which is shown in Figure 6. As can be seen, a very good agreement between these two surfaces to say within ±4 to ±8 m was obtained. It should, however, be pointed out here that we did "adjust" the Skylab orbital height which in this case is nothing else than a small height bias error as far as the sea surface variation is concerned and thus is not important in this special case.

This latter investigation brings us already into the area of Ocean Dynamics and demonstrates clearly that these earth observation disciplines are related to each other. The study of the deviation of the real ocean surface from the geoid does reveal such information as geostrophic currents, wind pile ups, eddies, storm surges, etc. providing, of course, that the sea surface is accurately known.

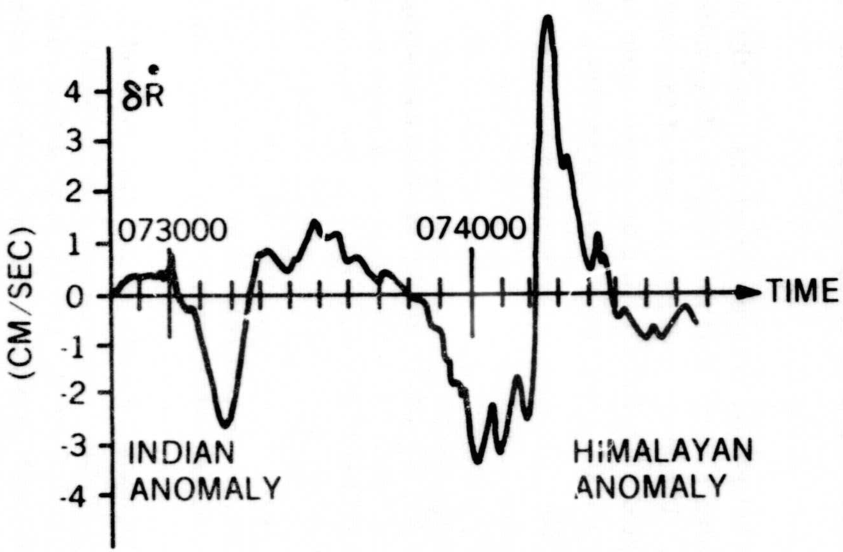
b. Ocean Dynamics

As mentioned, Skylab radar altimeter data are bridging the Earth and Ocean Dynamics disciplines. The altimeter data show such features as water "grabens" and "mountains." Figure 7 depicts the Puerto Rican Trench and Figure 8 shows a rather distinct local elevation of the ocean surface near the Cape Verde Islands from Skylab III, Pass 13, on September 3, 1973 (McGoogan, 1975 and Vonbun, et al., 1975). This clearly indicates the extreme usefulness of radar altimetry for detailed topographic studies of the oceans.

Radar altimeter data from Skylab not only refined the sea surface topography as shown but gave new information on wave height determination, rain cell and surface wind detection. Ocean wave height data is obtained by studying the shape of the leading edge of the return pulse from the sea surface. The slope of the leading edge is an indicator of the sea surface roughness

ATS-6 APOLLO-SOYUZ

INDIAN AND HIMALAYAN GRAVITY ANOMALIES



RANGE RATE RESIDUAL

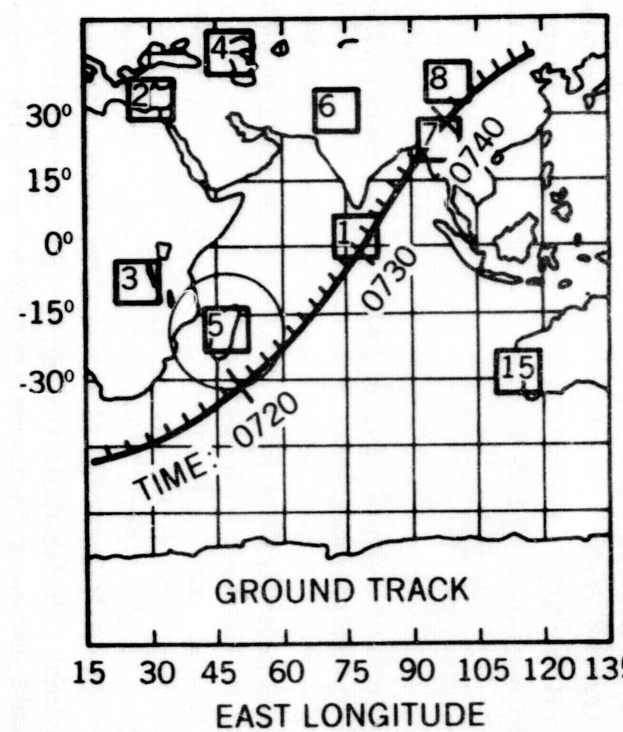
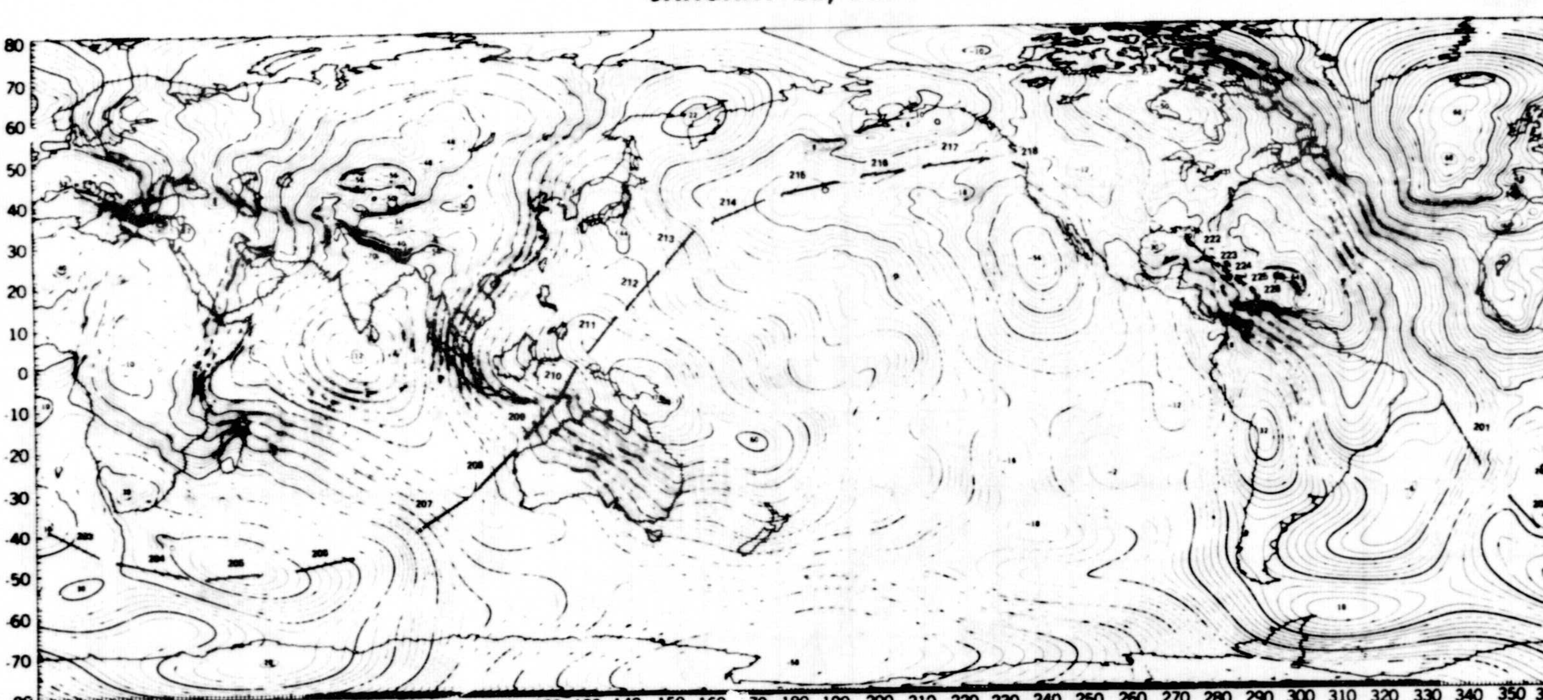


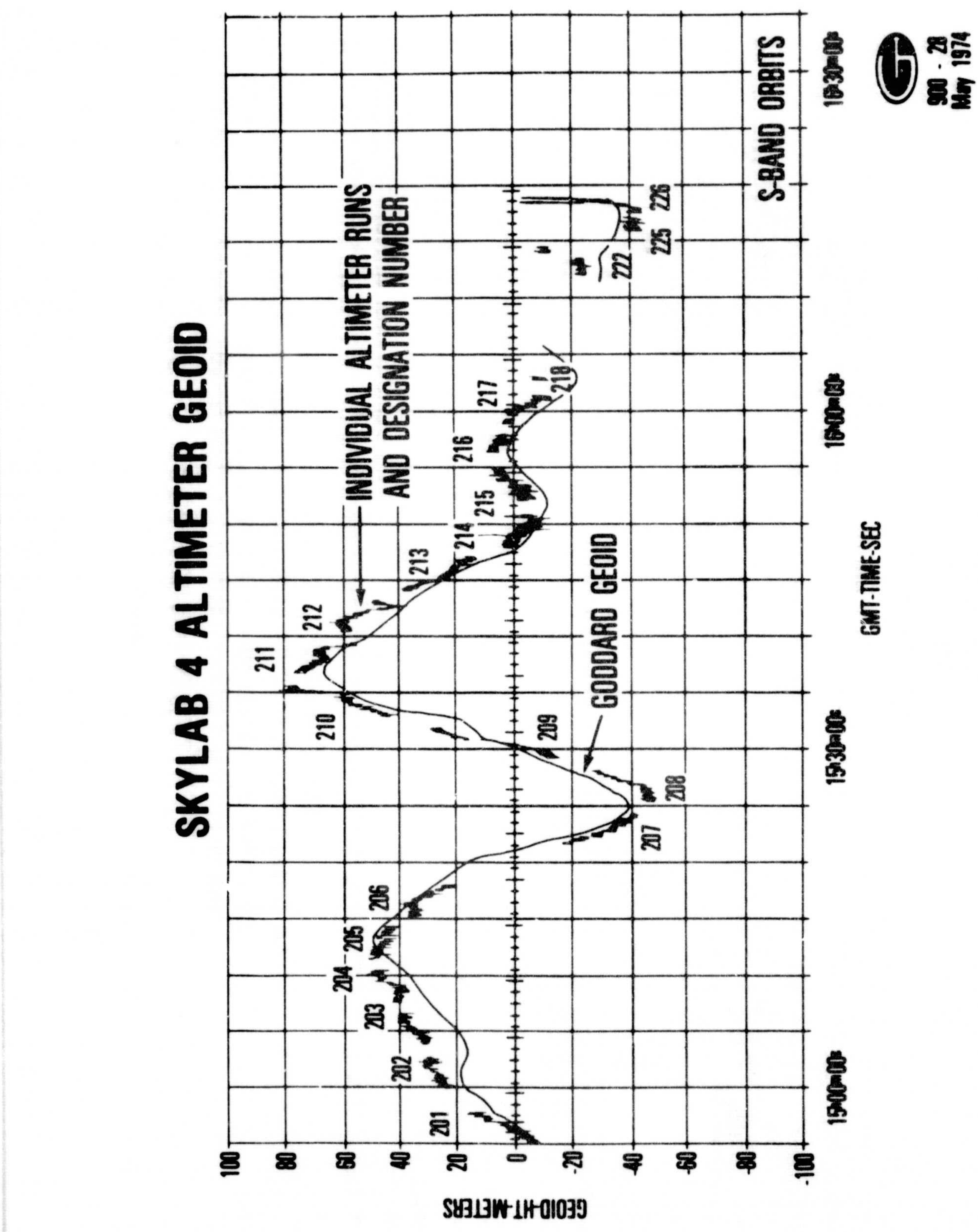
Figure 4

SKYLAB IV ALTIMETER
"ROUND-THE-WORLD
DATA TAKE"
JANUARY 31, 1974



NASA/GODDARD SPACE FLIGHT CENTER
GLOBAL DETAILED GRAVIMETRIC GEOID BASED UPON A COMBINATION OF THE
GSFC GEM-6 EARTH MODEL AND $1^\circ \times 1^\circ$ SURFACE GRAVITY DATA
CONTOUR INTERVAL 2 METERS, EARTH RADIUS : 6378.142 KM.
$1/F = 298.255, GM = 398600.9\ KM^3/SEC^2$

Figure 5


SKYLAB 4 ALTIMETER GEOID
INDIVIDUAL ALTIMETER RUNS AND DESIGNATION NUMBER
GODDARD GEOID
S-BAND ORBITS
GEOID-HT-METERS
GMT-TIME-SEC
100
80
60
40
20
0
-20
-40
-60
-80
-100
15h00m00s
15h30m00s
16h00m00s
16h30m00s
201
202
203
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217
218
222
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226
900 - 28
May 1974

Figure 6

SEASURFACE SKYLAB ALTIMETER MEASUREMENTS

(PUERTO RICAN TRENCH, SL–2 MISSION)

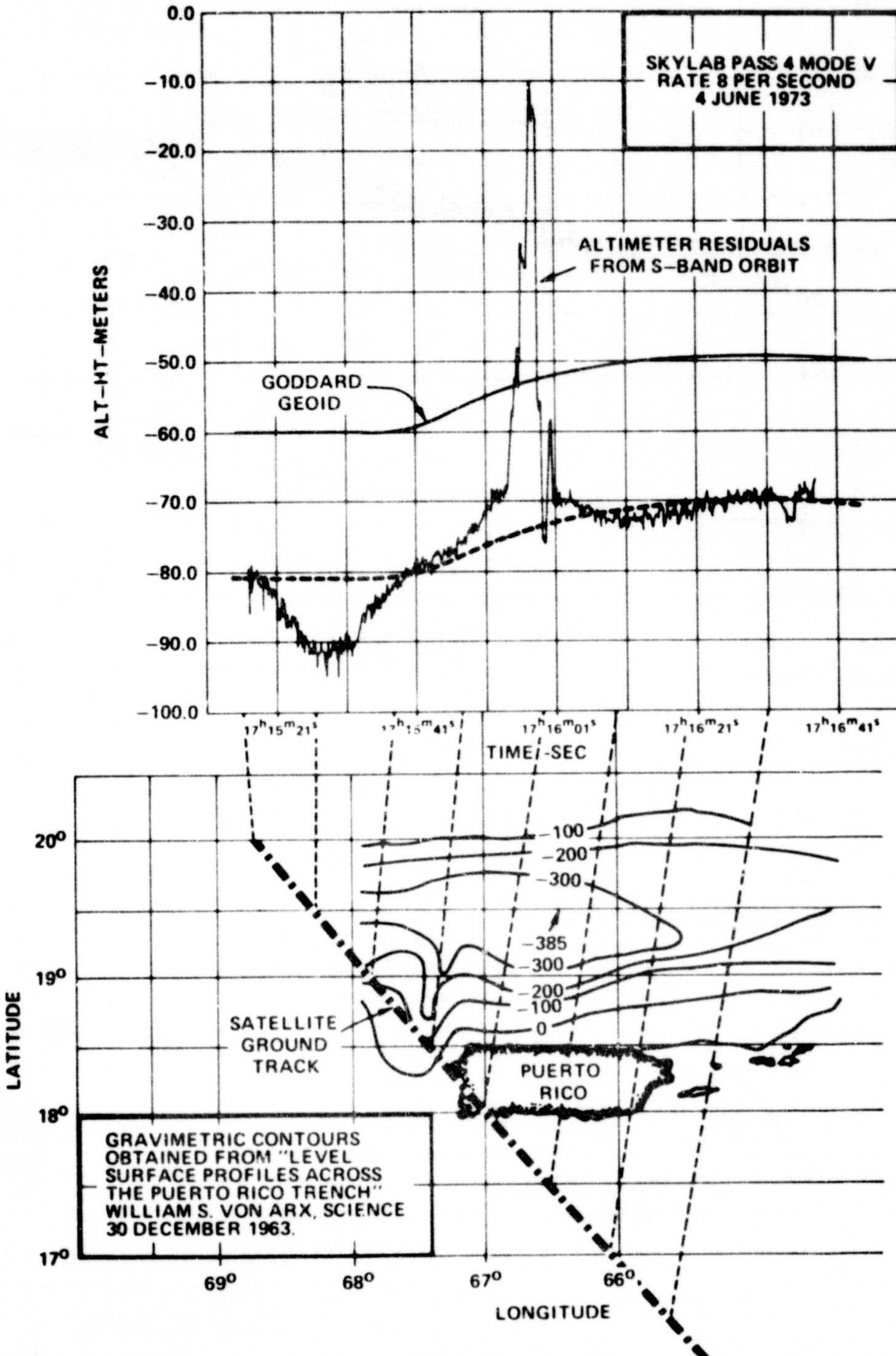


Figure 7

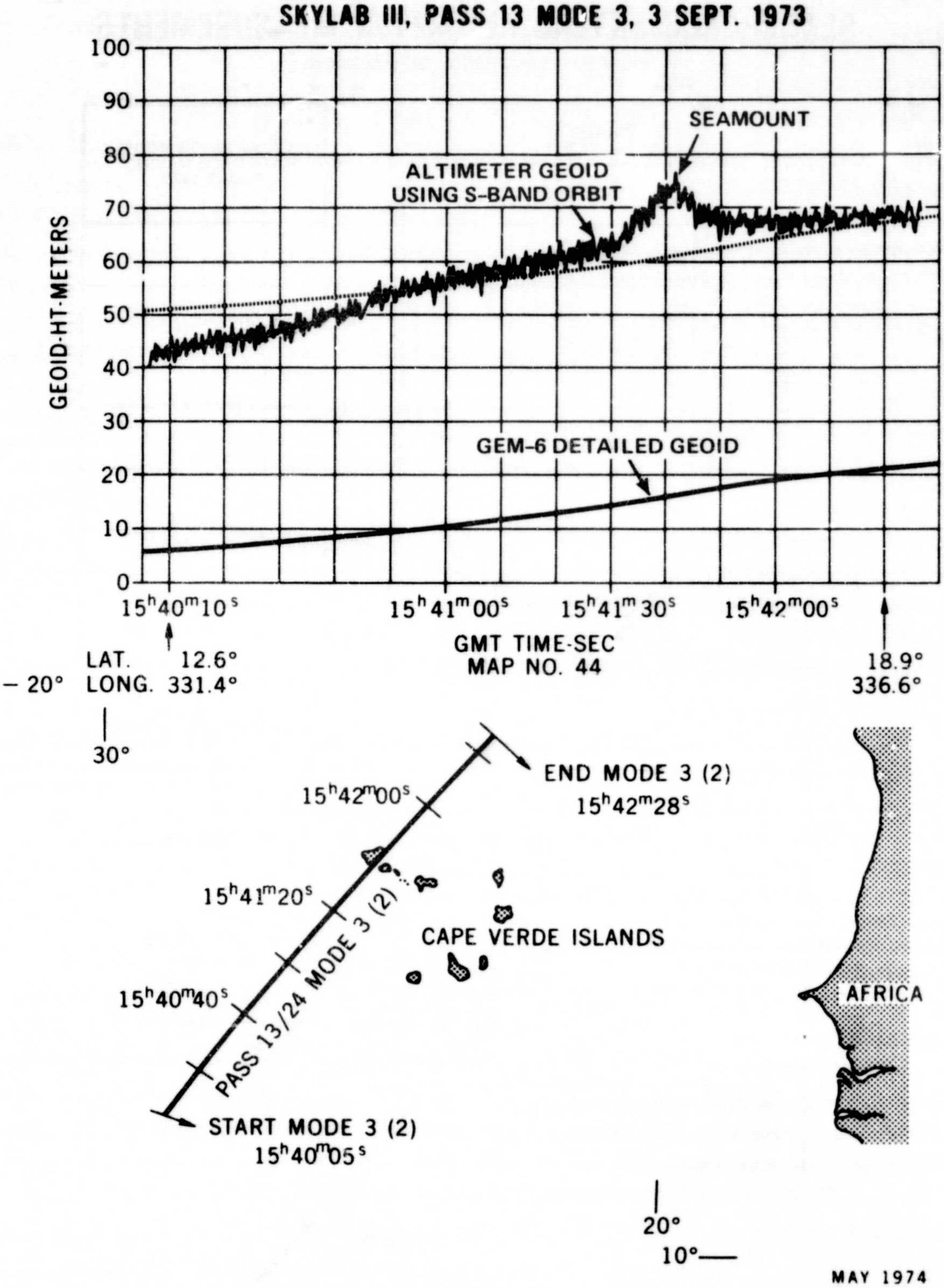

SKYLAB III, PASS 13 MODE 3, 3 SEPT. 1973
GEOID-HT-METERS
100
90
80
70
60
50
40
30
20
10
0
SEAMOUNT
ALTIMETER GEOID
USING S-BAND ORBIT
GEM-6 DETAILED GEOID
15h40m10s
15h41m00s
15h41m30s
15h42m00s
GMT TIME-SEC
MAP NO. 44
LAT. 12.6°
LONG. 331.4°
18.9°
336.6°
– 20°
30°
END MODE 3 (2)
15h42m28s
15h42m00s
15h41m20s
15h40m40s
PASS 13/24 MODE 3 (2)
CAPE VERDE ISLANDS
AFRICA
START MODE 3 (2)
15h40m05s
20°
10°
MAY 1974

Figure 8

(McGoogan, 1974 and Miller, et al., 1972). Similar, rain cells have also been detected using the Skylab altimeter as shown in Figure 9. W. Pierson further was successful in determining the surface wind from the S-193 Skylab scatterometer as shown in Figure 10. (Pierson, W., 1975).

Figure 11(a) shows the variation of the emissivity e with ocean windspeed for vertical polarization and 45° nadir angle, the variation of e with frequency for nadir observations of smooth and rough seas and the variation of e with surface temperature from nadir observations. The variation of e with wind speed has been measured over a wide range of frequencies. For wind speeds above 7 m/s, the contributions of white water becomes dominant over the contribution of waves (Nordberg, Conaway, Ross and Wilheit, 1971). The variation of e with frequency is also dominated by the white water for rough seas. The white water, streaks and foam combined, acts as a thin matching layer and raises the brightness temperature to nearly the thermodynamic temperature for wavelengths shorter than the electrical depth of the layer. As the wavelength becomes longer, the matching becomes less effective and the brightness temperature approaches the smooth water values (Webster, Gloersen and Wilheit, 1974). The variation of e with surface temperature has a maximum near 5 GHz. At this frequency, a change in the thermodynamic temperature of 2° K results in about 1° K change in the brightness temperature.

Figure 11(b) shows the variation of e with ice age for observations at vertical polarization and 45° zenith angle and the variation of e with frequency and age for nadir observation. The appearance of scattering centers within the ice and the lowering of the loss tangent as the brine pockets in the ice drain is responsible for the lowering of e at the high frequency and end of the spectrum.

This demonstrates that both active and passive microwave systems play, and will even more so in the future, an important role in the applications disciplines discussed.

It should, however, be mentioned that the only active systems flown in orbit (Skylab) was rather new and was operated on a limited schedule. GEOS-3 is the first unmanned spacecraft carrying an active radar which is intended to operate at least one full year in orbit but unfortunately has no scatterometer capability for wind determination. Thus, the output for the ocean dynamics area using this spacecraft is also somewhat restricted.

SEASAT-A, to be launched in 1978, will however be the first dedicated spacecraft for both the Earth and Ocean Dynamics disciplines. The phenomena to be observed by this spacecraft are shown in Figure 12.

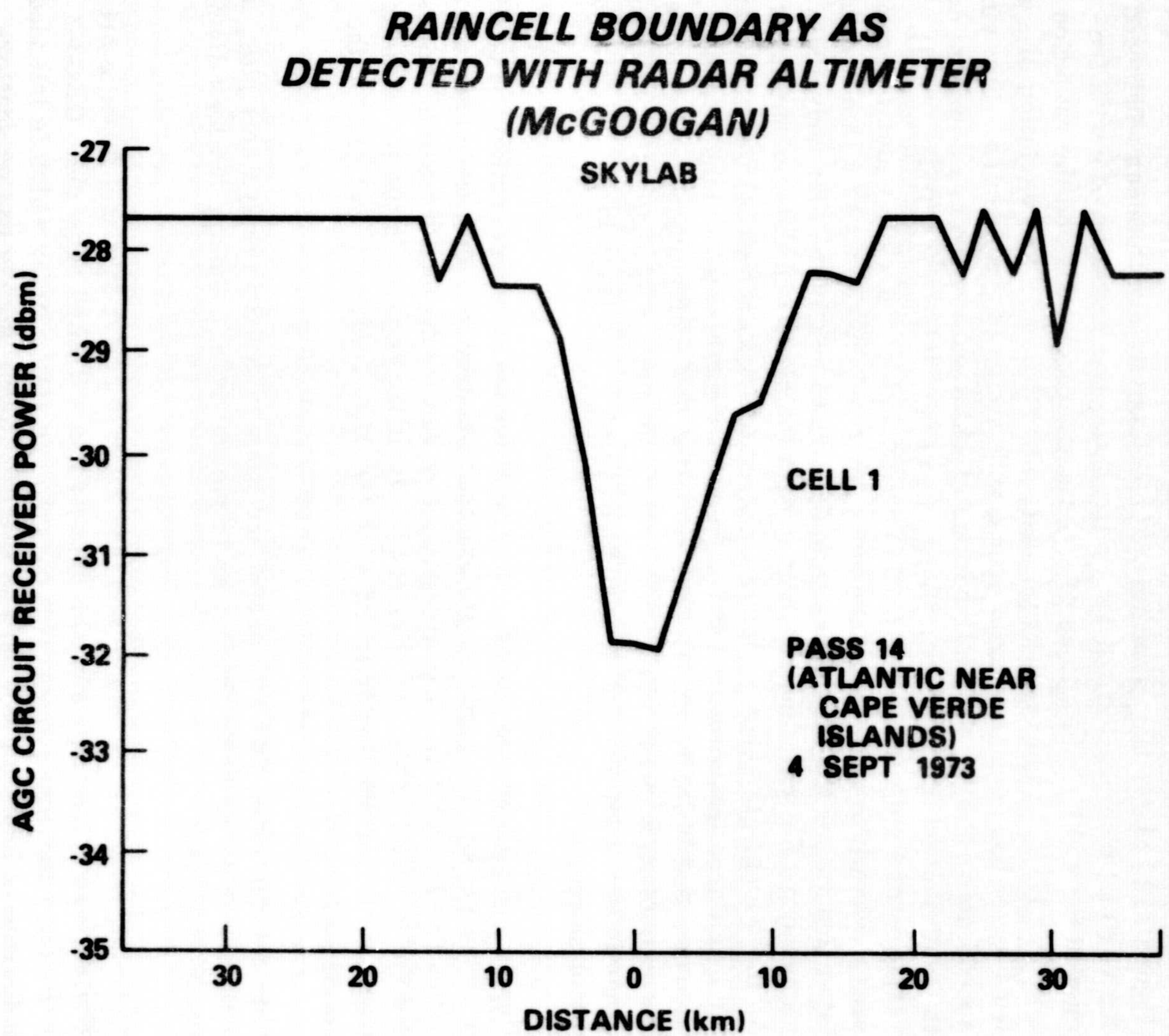

RAINCELL BOUNDARY AS
DETECTED WITH RADAR ALTIMETER
(McGOOGAN)
SKYLAB
AGC CIRCUIT RECEIVED POWER (dbm)
-27
-28
-29
-30
-31
-32
-33
-34
-35
CELL 1
PASS 14
(ATLANTIC NEAR
CAPE VERDE
ISLANDS)
4 SEPT 1973
30
20
10
0
10
20
30
DISTANCE (km)

Figure 9

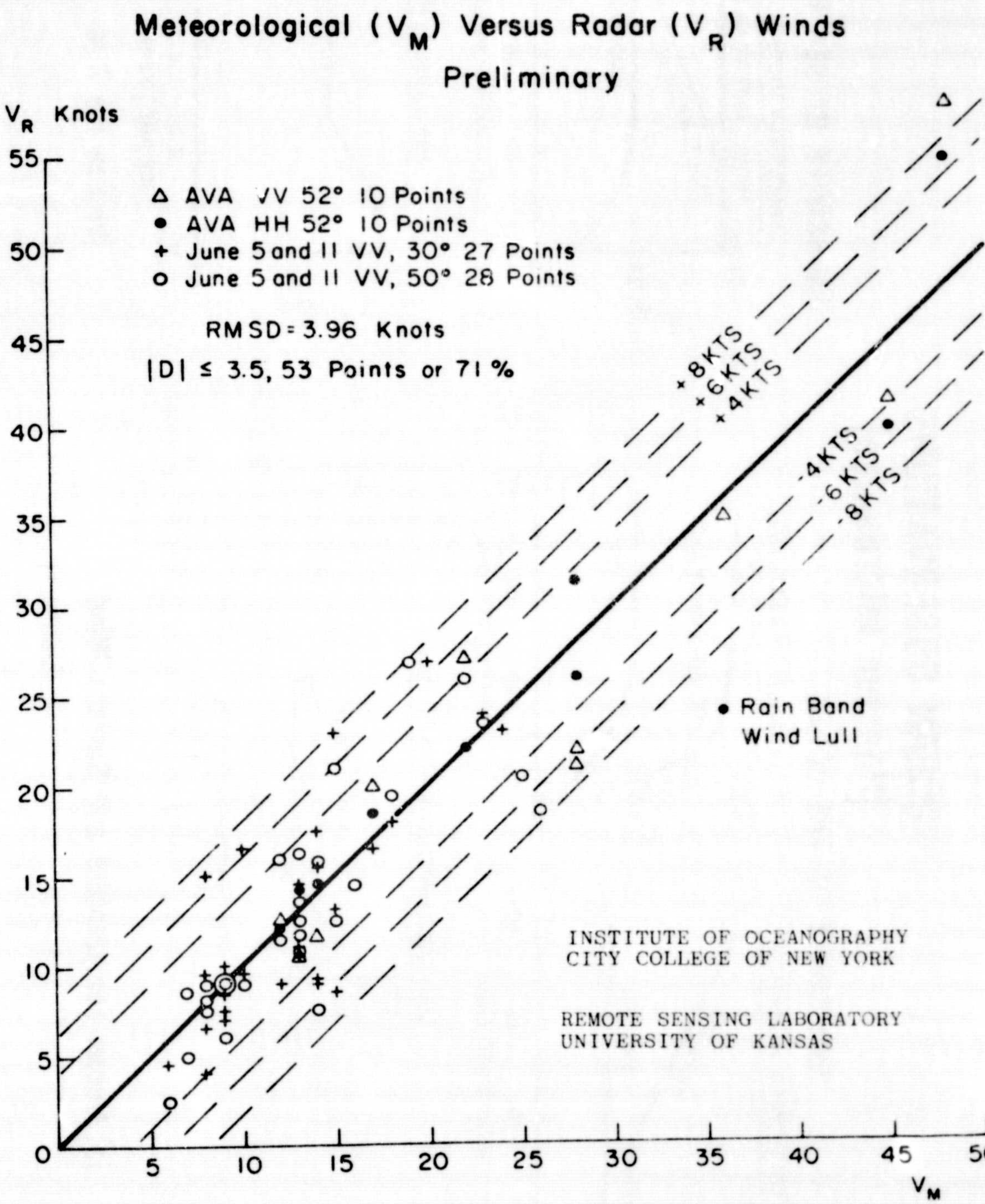
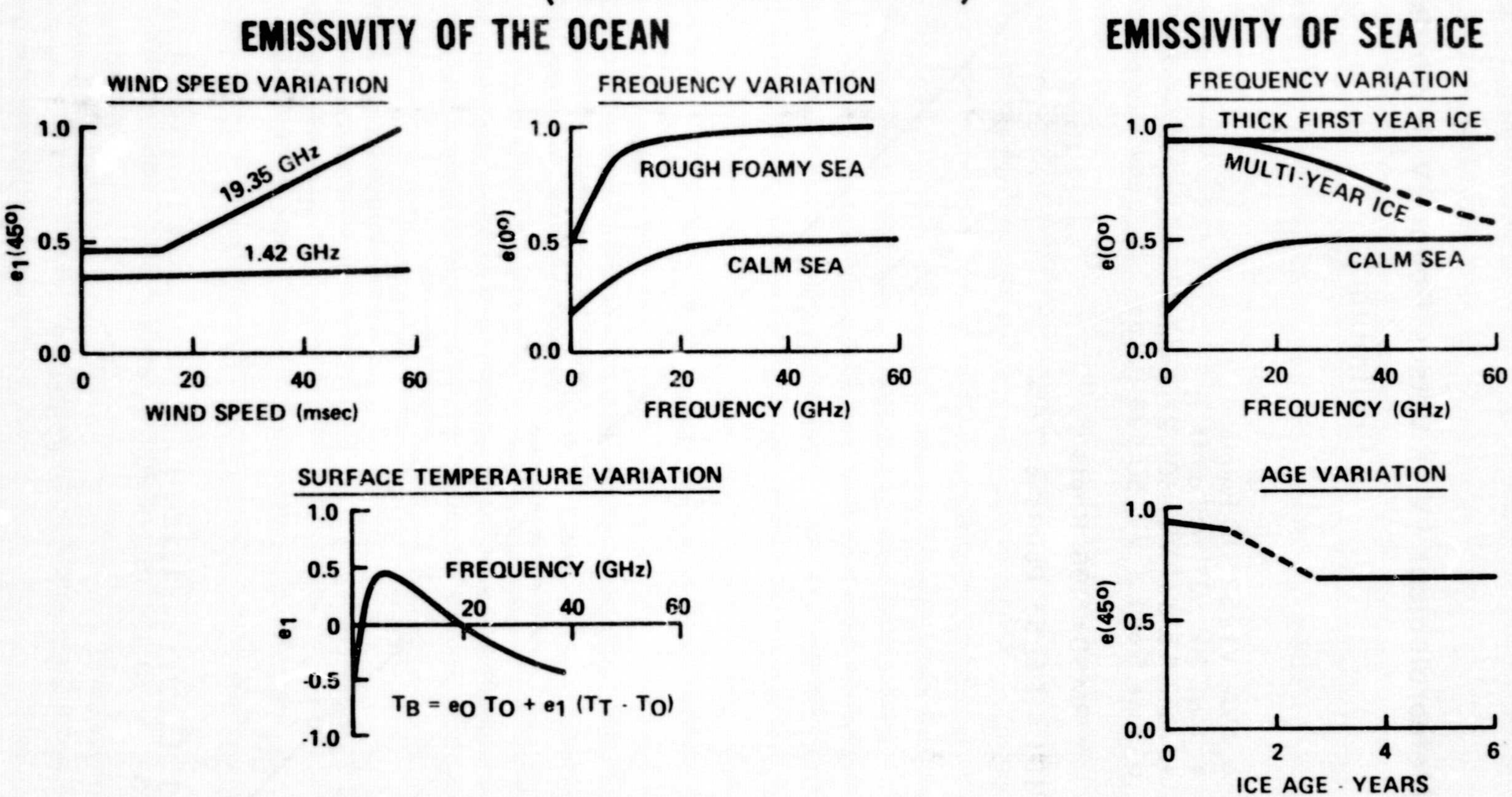

Meteorological (V_M) Versus Radar (V_R) Winds
Preliminary
V_R Knots
Δ AVA VV 52° 10 Points
● AVA HH 52° 10 Points
+ June 5 and 11 VV, 30° 27 Points
o June 5 and 11 VV, 50° 28 Points
RMSD = 3.96 Knots
|D| ≤ 3.5, 53 Points or 71 %
+8 KTS
+6 KTS
+4 KTS
-4 KTS
-6 KTS
-8 KTS
● Rain Band
Wind Lull
INSTITUTE OF OCEANOGRAPHY
CITY COLLEGE OF NEW YORK
REMOTE SENSING LABORATORY
UNIVERSITY OF KANSAS
0
5
10
15
20
25
30
35
40
45
50
55
V_M

Figure 10

OCEAN CBSERVATIONS
(Passive Microwave)



(a) Ocean Temperature and Surface Wind

(b) Sea Ice Age

Figure 11

USER REQUIREMENTS FOR SEA SURFACE PARAMETERS

PHYSICAL PARAMETER	INSTRUMENTS	RANGE	PRECISION	RESOLUTION OR IFOV	TOTAL FOV	COMMENTS
WAVE HEIGHT, $H_{1/3}(x,y)$	PULSE ALTIMETER / COHERENT ALT.	1.0 - 20m	$\pm$0.5 m or $\pm$10%	2x7 km SPOT	2 km SWATH	ALONG SUBSATELLITE TRACK ONLY
DIRECTIONAL WAVE SPECTRUM $S(\lambda, \theta, x, y)$	IMAGING RADAR (2-D TRANSFORM)	S: UNKNOWN λ: 50-1000 m θ: 0-360°	S: - - - λ: $\pm$ 10% θ: $\pm$ 10°	50 m RESOLUTION	20x20 km SQUARES	GLOBAL SAMPLES AT 250 km INTERVALS
	2 f WAVE SPECTROMETER	S: UNKNOWN λ: 6-500 m θ: 90° SECTOR	S: - - - λ: $\pm$ 10% θ: $\pm$ 90°	8 x 25 km SPOT	300 km SWATH ABOUT NADIR	GLOBAL SAMPLES AT 150 km INTERVALS
SURFACE WIND FIELD, $\vec{U}(x,y)$	SCATTEROMETER	U: 3-25 m/s θ: 0-360°	$\pm$ 2 m/s, $\pm$ 10% $\pm$ 20°	$\leq$ 50 km SPOT	TWO 450 km SWATHS	GLOBAL, 36 HRS (LOW SPEEDS)
	μW RADIOMETER	U: 10-50 m/s θ: UNKNOWN	$\pm$ 2 m/s, $\pm$ 10% - - -	$\leq$ 100 km SPOT	900 km SWATH ABOUT NADIR	GLOBAL, 36 HRS (HIGH SPEEDS)
SURFACE TEMPERATURE FIELD, $T(x,y)$	IR RADIOMETER	2° TO + 35°C	$\pm$½° - 1°C	1.7 km IFOV	1500 km SWATH ABOUT NADIR	GLOBAL, 36 HRS (CLEAR AIR ONLY)
	μW RADIOMETER	0° TO 35°C	$\pm$ 1.5°C	100 km SPOT	900 km SWATH ABOUT NADIR	GLOBAL, 36 HRS (CLOUDS & LT. RAIN)
GEOIDAL HEIGHTS, $h(x,y)$ (ABOVE REFERENCE ELLIPSOID)	PULSE ALTIMETER / COHERENT ALT.	7 cm - 200 m	$\pm$7 cm	2x7 km SPOT	18 km SPACING ALONG EQUATOR	SAMPLED THROUGHOUT ONE YEAR
SEA SURFACE TOPOGRAPHY, $j(x,y)$ (departures from geoid)	PULSE ALTIMETER / COHERENT ALT.	7 cm - 10 m	$\pm$ 7 cm	2x7 km SPOT	2 km SWATH	ALONG SUBSATELLITE TRACK ONLY
OCEANIC, COASTAL, & ATMOSPHERIC FEATURES (PATTERNS OF WAVES, TEMP., CURRENTS, ICE, OIL, LAND CLOUDS, ATMOSPHERIC WATER CONTENT)	IMAGING RADAR	HIGH RESOLUTION	ALL WEATHER	25 OR 100m	100 OR 200 km	SAMPLED DIRECT OR STORED IMAGES
	IR RADIOMETER	HIGH RESOLUTION	CLEAR AIR	1.7 km	1500 km SWATH	BROADLY SAMPLED IMAGES
	μW RADIOMETER	LOW RESOLUTION	ALL WEATHER	15-100 km	900 km SWATH	GLOBAL IMAGES

Figure 12

IV. GROUND SYSTEMS

High precision laser ranging systems have been developed at Goddard as mentioned over the past decade which enables us to determine satellite orbits accurately in the m-range and intersite distances in the cm-range, as shown in Figure 13, important for geodynamics. Today's laser systems have bias and noise errors in the order of 5 to 8 cm as can be seen from Figure 14 (noise in this case). On-going development of laser ranging system at the Goddard Space Flight Center and elsewhere will hopefully bring these errors down to the 2 cm level. It is further planned to expand the Goddard laser operations to a global basis for tectonic plate motion determination. Using properly distributed laser stations over the globe (Goddard, SAO and possible stations of other nations) will be used to measure intercontinental distances in the cm-range, together with the Lageos spacecraft as shown in Figure 15 to be launched next year, that is, in 1976. This will enable us to actually determine the relative motions with great accuracies over these distances. Verifications of computed tectonic motions will then be possible for the first time. At present, all plate motions are computed average values over millions of years.

In addition to the LASER effort, real progress has been made over the last 8 years in the area of Very Long Baseline Interferometry (VLBI). Since 1963, a rather intensive cooperative effort between MIT and Goddard Space Flight Center has been under way to develop and improve Very Long Baseline Interferometer techniques and systems. These systems are used for geodynamic observations such as polar motion, earth rotation, and the determination of intercontinental distances. The NASA worldwide tracking network with its large dishes is being utilized for this purpose. Distances between Haystack, Massachusetts and Goldstone, California have been determined with a precision in the 10 to 20 cm range as shown in Figure 16. Again, this shows a relative measure, that is, LASERS and VLBI, are being pursued at present and will be in the future for precision geodynamics work. This dual approach is essential since there is at this time no other way in checking either one of these extremely accurate systems alone.

V. CONCLUSIONS

In summary, it can be stated that very good progress has been made in the area of Earth and Ocean Dynamics since this program was initiated in the 1969 to 1971 time frame (Vonbun, F. O., 1972).

EODAP missions such as GEOS-3 have been launched; Lageos is almost finished and will be launched next year; SEASAT has just been started and is planned for a 1978 launch; and, finally, Magsat is our latest effort and is to be launched in 1980. Experiments such as SAFE, together with polar motion and earth rotation are under way.

BASE LINES DETERMINED
LASER AND SATELLITES

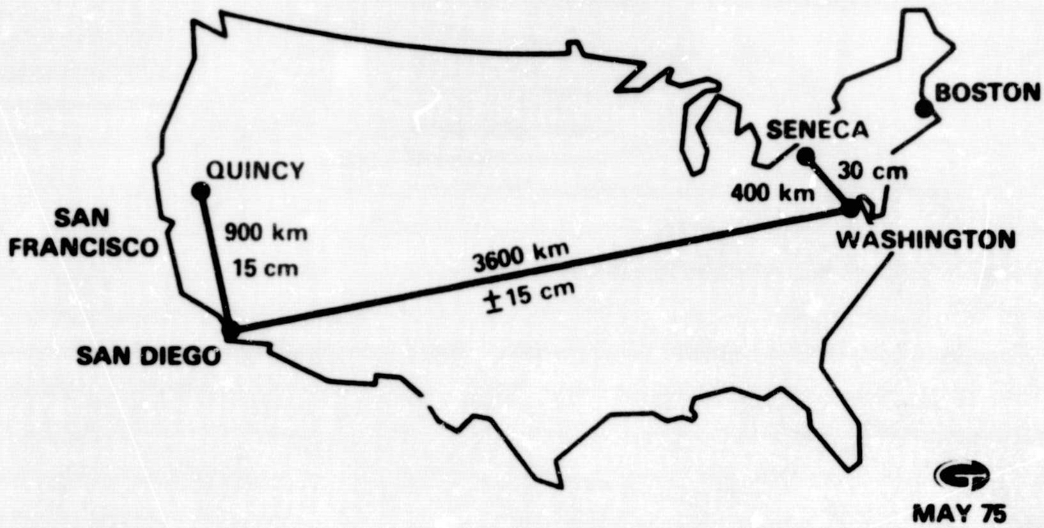


Figure 13

LASER RANGE RESIDUALS
(15TH DEGR. POLYN.)
GEOS-3
22 APR. 75

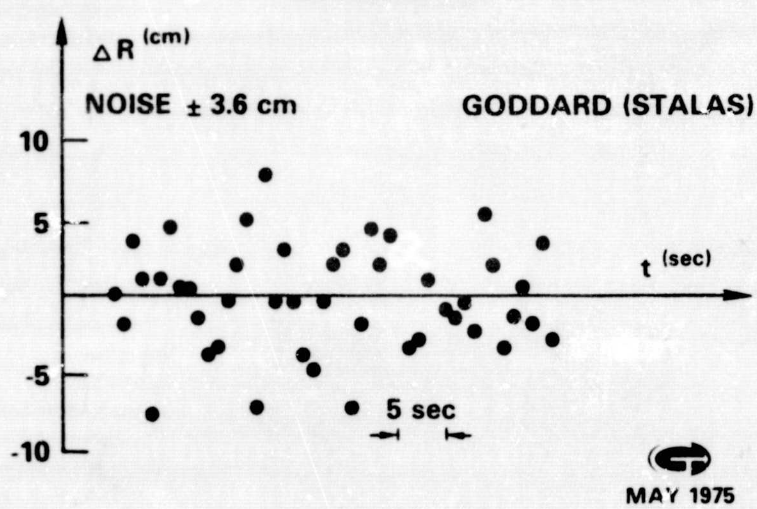


Figure 14

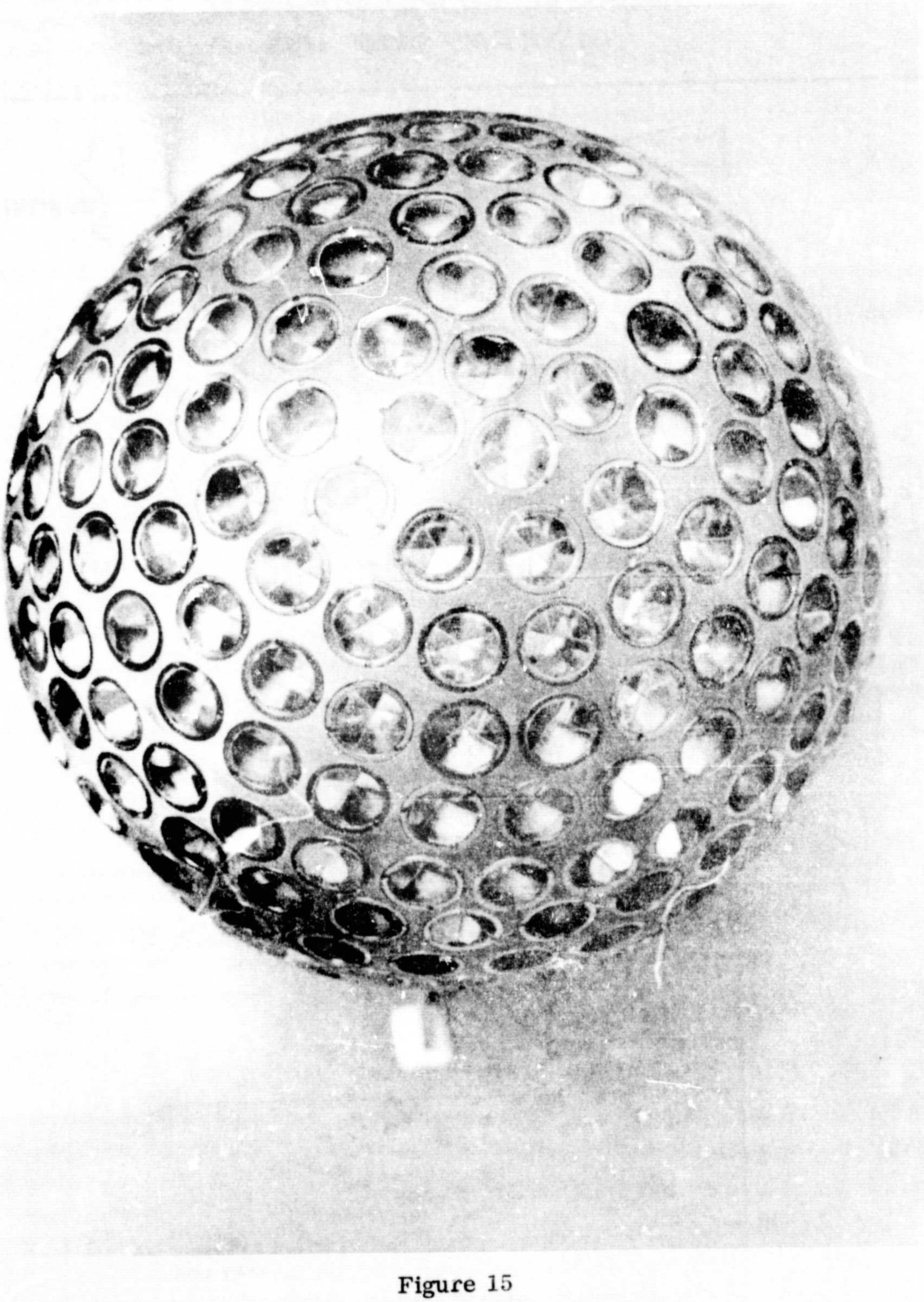


Figure 15

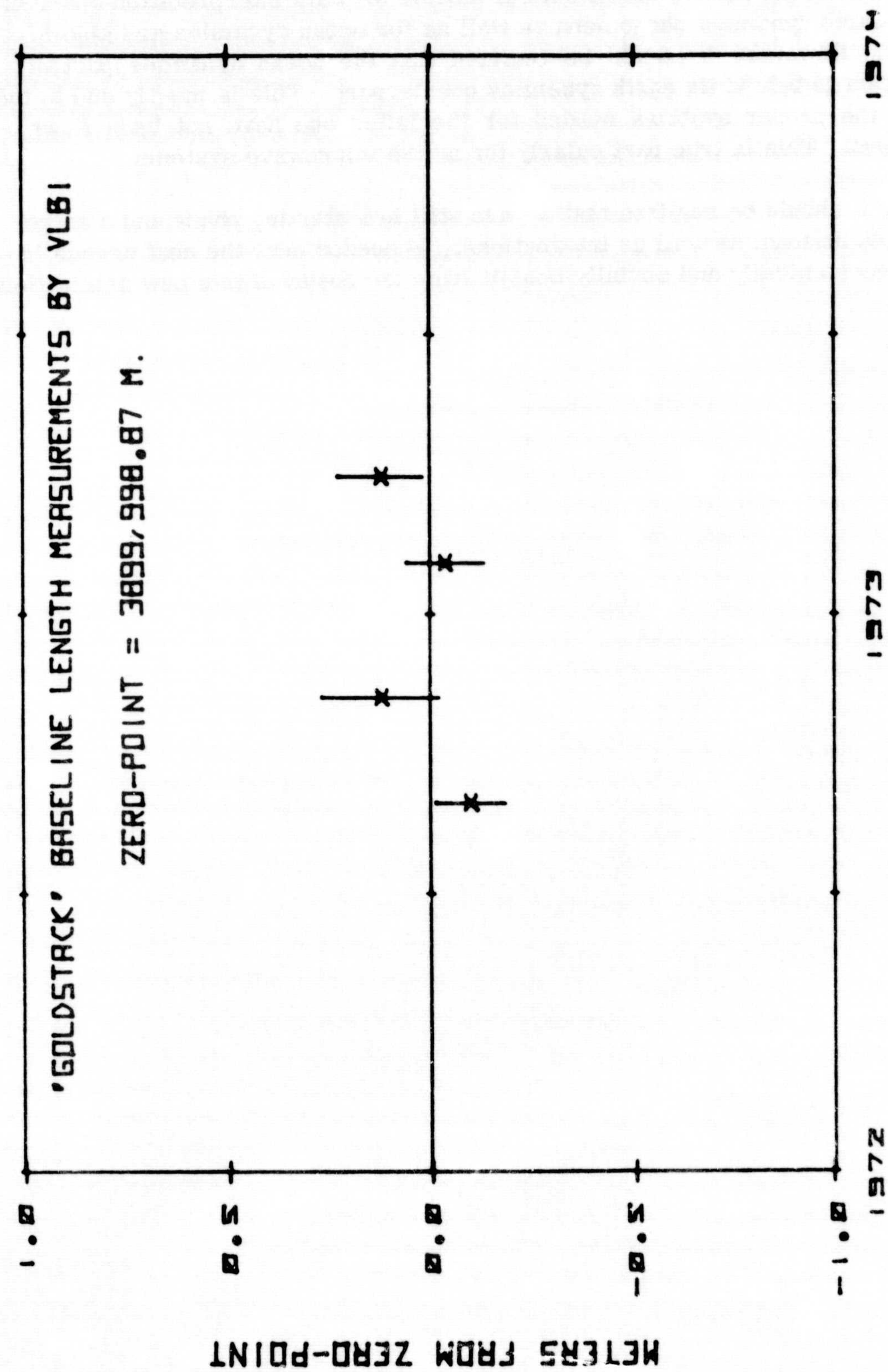

'GOLDSTACK' BASELINE LENGTH MEASUREMENTS BY VLBI
ZERO-POINT = 3899,998.87 M.
1.0
0.5
0.0
-0.5
-1.0
METERS FROM ZERO-POINT
1972
1973
1974

Figure 16

Construction of the needed mathematical models for data interpretation and analyses for earth dynamics phenomena as well as for ocean dynamics are also in progress. However, it should be realized that the ocean dynamics part of the program is behind its earth dynamics counterpart. This is mostly due to the fact that the proper systems needed for the latter one have not been flown in space yet. This is true particularly for active microwave systems.

However, it should be realized that we are still in a starting phase and a large effort, both national as well as international, is needed over the next decade in order to economically and socially benefit from the result of this new application program.

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