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Research Note

The POLYMODE Program

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Abstract *This article summarizes our perspective of U.S. and Soviet interactions during a joint physical oceanography experiment. One author (RHH) was involved in early instrumentation and logistic work with the Soviets beginning in 1970, and was U.S. executive manager for the program from 1976–84. One author (CAC) was the National Science Foundation program manager responsible for administering the program. The experiment began with a preliminary meeting of Soviet and American oceanographers in 1973 and activities concluded with the publication of an atlas (see n. 9) in 1986. The intervening years included a variety of joint scientific activities which spanned a broad spectrum from theory and numerical modeling to at-sea experiments. The total cost of U.S. activities as part of this program was about $25 million.*

Introduction

Physical oceanography is concerned with describing and understanding the movement, properties, and mixing of waters in the oceans. Historically, physical oceanography was a broad-based observational science with theoretical ideas playing an important role in guiding the collection of data and interpretation of results. Although the recent development of large-scale computers offers the possibility of realistically simulating ocean circulation, our understanding of ocean circulation is limited by our lack of a detailed time sequence of charts of the interior circulation. The observational resources necessary to obtain these data involve ships, current meters, floats, and profilers (to determine the variation of temperature and salinity with depth) as well as seamen and oceanographers.

In the 1960s physical oceanographers reached a fairly good understanding of the mean circulation of the ocean: the mean wind stress over the ocean, coupled with rotation of the earth, resulted in a strong western boundary current and a rather quiescent ocean interior. However, new technology, capable of collecting accurate time series of six months to one-year duration, revealed the ocean interior to be unexpectedly energetic.

Both Soviet and American oceanographers organized experiments to study this phenomena. From February through September 1970, the Soviets carried out surveys[1] in a region 200 km square centered at 16.5N, 33.5W. Here, the ocean bottom lies at a depth

between 5,000 and 5,500 m. Seventeen moorings were maintained in an array (the Soviet word for array is *polygon*, and this experiment was called Polygon 70), each with 12 current meters spanning the depth interval 25 to 1,500 m. Each current meter mooring was replaced monthly. Density surveys of the entire region were conducted twice. Density surveys of the central half of the region were conducted four times. Seven Soviet research ships participated in the project.

Within the United States, mechanisms did not exist for focusing the resources of a number of different academic institutions in a single experiment of the type conducted by the Soviets. The International Decade of Ocean Exploration provided a framework for this.[2] The National Science Foundation was assigned funding and responsibility for sponsoring large-scale, coordinated research projects.

From March to July 1973 American and British oceanographers conducted a concentrated study[3] in a circular region 400 km in diameter in the midocean southwest of Bermuda at 69.7W, 28N where bottom depth is about 5,400 m. The study, known as the Mid-Ocean Dynamics Experiment (MODE), involved six ships and two aircraft. Biweekly surveys of the density structure in the region were conducted by research vessels from April through June. Twenty-one current meter moorings were set in this region, each instrumented with four current meters at depths between 500 and 3,000 m; because moorings with surface floats were found to introduce large errors in measured current speeds,[4] all but one mooring was set using subsurface flotation. (This issue was to eventually influence U.S. views on the value of Soviet data as described below.) A variety of other instrumentation was used in this experiment, including subsurface floats and bottom pressure gauges.

As a result of the MODE and POLYGON studies, the existence of mesoscale eddies was clearly documented. These eddies are the oceanic analog of the atmospheric high and low pressure systems that determine our weather. At this point, there was a great deal of excitement and speculation in the physical oceanography community regarding mesoscale eddies and their role in determining the general circulation of the ocean. Would these provide the "missing link" in a theory that unifies small-scale turbulent motions and the general circulation? Given the opportunity to cooperate (see below), Soviet and American physical oceanographers proposed to combine resources in a single project, hence POLYMODE (taking POLY from "polygon") began.

The Bilateral Agreement

As part of detente, an agreement between the Soviet Union and the United States on "Cooperation in Studies of the World Ocean" was signed on June 19, 1973 by Secretary Brezhnev and President Nixon. The agreement was an outgrowth of 1972 exchange visits between oceanographers of the two countries. The agreement specified six initial areas of cooperation including "Ocean currents of planetary scale and other questions of ocean dynamics," and it was in this area that mesoscale eddy studies were conducted. The agreement also included a provision to facilitate the use of port facilities for ships' services and supplies for vessels engaged in cooperative activities.

Implementation of the agreement was the responsibility of a U.S.-USSR Joint Committee on cooperation in World Ocean Studies. In addition, each country had an executive agent responsible for maintaining contact with the other side and supervising the development and implementation of cooperative activities. In the United States, the executive agent was the National Oceanic and Atmospheric Agency (NOAA); in the Soviet

Union, the State Committee for Science and Technology provided executive secretariat support. The Joint Committee was to meet every 12 to 18 months.[5]

The U.S. side of the Joint Committee on Cooperation in World Ocean Studies was chaired by the administrator of NOAA and included representation from the Navy Department (vice chairman), the State Department, the National Science Foundation, the National Advisory Committee for the Oceans and Atmosphere, and the National Academies of Science and Engineering. The U.S. committee functioned with a secretariat from NOAA, NSF, and the Office of Naval Research—agencies that were expected to sponsor oceanographic research under the agreement. Working groups of practicing oceanographers were established for each of the areas of cooperation; the working groups included a federal area coordinator who acted in the capacity of executive secretary and coordinated all activities. The coordinator was from the federal agency that sponsored the research.

Recommendations and activities were to be developed at the working group level, and reviewed and approved by the Joint Committee. Each side independently considered proposals from working groups and assessed the results of cooperative activity. In addition to approving projects, the Joint Committee was to try to correct problems that developed in executing these projects.

In our experience, the U.S. side of this bilateral structure worked well. It provided representation by both scientists and federal program officials at all levels so that only projects with the requisite support would be considered. In developing projects, not only were the usual review questions asked about creativity, capability, and importance, but related issues regarding export of equipment, ship visits, etc. were addressed. Finally, at the Joint Committee level, policy review could take into account more general agency views and perhaps resolve specific questions that had arisen. This "one-stop shopping" meant that, once approved, there would be only relatively minor bureaucratic obstacles from federal agencies in the execution of U.S. plans for POLYMODE.

Even now, our knowledge of the workings of the Soviet side of this agreement are vague. Various institutes of the Academy of Sciences (Oceanology, Acoustics, Geology), the Hydro-Meteorological Service (the Institute for Arctic and Antarctic Research in Leningrad), Fisheries Institutes, the Soviet Naval Oceanography Office, and the Ukranian Academy of Sciences were active in various programs. It was not clear how well the various institutes communicated with each other and the State Committee. The working groups were not active on a continuing basis (the Working Group for "Ocean Currents . . ." met only once). After a few years, regular meetings of the Joint Committee stopped.

The POLYMODE Program

Why work with Soviet oceanographers? Strengths of Soviet physical oceanography include: (1) a tradition of excellence in theoretical topics including turbulence, (2) a modern fleet of very large vessels, which are typically gone from their home port for four or five months and, unlike American practice, it is unusual for the scientific crew to be rotated in a foreign port; the ships are relatively comfortable in rough weather, but are poorly equipped in terms of modern scientific equipment and, because of the high freeboard, it is difficult to handle equipment over the side; (3) it appeared in 1973 that the Soviets would have equipment similar to that of American oceanographers (see below); and (4) the idea of meeting Soviet scientists on an oceanographer-to-oceanographer level

and hence to gain some understanding and help to bridge east-west differences, appeals to the idealistic instinct of most academics—the oceans are global and we are working on common problems.

The main scientific objective of the POLYMODE project was broad and diverse: to understand the role of eddies in determining the mean circulation of the ocean.[6] It was felt that to achieve this goal a broad spectrum of activities was necessary. This included theoretical and numerical studies as well as a variety of field experiments. One type of experiment required long time series at single but diverse locations to determine the number and intensity of eddies; this was called an incoherent array and formed the basis of statistical geographical experiments. Another type of experiment required repeated mapping of a region of the ocean to see how eddies would interact with one another; this required more closely spaced current meter moorings and repeated shipboard surveys of the region. These were called "Synoptic-Dynamic Experiments." The final type of experiment involved even more closely spaced moorings and ship surveys and was called a "Local Dynamics Experiment."

Activities in the United States were mainly focused on statistical-geographic and local dynamics experiments.[7] Soviet efforts were concentrated in a Synoptic Dynamics Experiment, with the United States possibly supplying some instrumentation. Other activities that were considered by the United States to complement POLYMODE included: Canadian moorings in the region of the Gulf Stream; French, German, and British moorings in the northeastern Atlantic; and French drifting buoy experiments in the Bay of Biscay. However, the Soviets never agreed to consider these "third-country" activities a part of the program.

U.S. Assumptions and Expectations

Planning of the joint POLYMODE program on the U.S. side was shaped by two premises. One was overt and public and was, in fact, used to justify the program to funding agencies, Congress, and the press and public. The rationale was that a joint program in mesoscale ocean science was necessary because the temporal and spatial scales of the next obvious step in mesoscale studies dictated field observational programs that were so large that they could not be accomplished with the resources of either country alone.

The second premise was discussed privately among U.S. participants and funding agencies. It reflected nervousness about the difficulties of working with the Soviets and doubts about the effectiveness of the Soviet oceanographic technology. The participants attempted to plan and carry out the U.S. program in such a way that it could stand alone as a scientific program.

By the beginning of POLYMODE planning in 1973, U.S. oceanographers already had considerable information on the instrumentation and techniques used by their Soviet colleagues. The intercomparisons of U.S. and Soviet current meters had been underway under the auspices of an international working group since at least 1967.[8] In the course of the fieldwork for these intercomparisons, U.S. engineers also gained a great deal of data on the state of Soviet deep-sea mooring technology.

In general, Soviet technology in each of these areas was a decade or more behind the United States and Western Europe. The attraction to U.S. oceanographers of a joint program was greatly enhanced at a meeting in April 1974 when Soviet oceanographers

outlined what amounted to a plan to modernize and broaden their deep-sea physical oceanographic technical capabilities.

At that meeting, the Soviets projected deployment of 500 tape-recording, temperature-sensing current meters on modern moorings. Both the current meters and the necessary mooring technology were said to be under development and test at that time. There was also reference to a new generation of profiling instruments to be available for POLYMODE.

It is clear that, had this new technology materialized, combined with the quantity of ship time available to the Soviet side, the Soviet contribution to POLYMODE would have been at least potentially equal to that of the United States. At least in the early planning stages, U.S. scientists expected that these resources would be available and the early scientific discussions were based on this expectation.

There was, on the other hand, a definite concern on the U.S. side about logistical and management issues. Early logistical delays and difficulties were sometimes written off as startup pains. "Once we learn how to do it, it will go easier." However, there was a real awareness of the potential problems of working together, which is reflected, for instance, in the initiatives from the U.S. side to get up a liaison personnel exchange and a dedicated communications network, as described below.

What Actually Happened?

We present here discussions of some areas of activity within the joint program. In each case, we try to give a brief background, describe what was expected or intended, and outline what actually happened. Of course, "why it happened" is a matter of interpretation.

Joint Meetings

The organization of and preparation for joint meetings with POLYMODE presented very different problems from those to which U.S. oceanographers had been accustomed in their dealing with scientists from Western countries. Oceanography, by its very nature, has long been an internationally oriented science. Formal international meetings are a common feature of this community, and meetings between small groups of scientists in various countries are frequent and casual.

Meetings involving Soviet scientists, however, whether in the United States or the USSR, involved very long lead times and frequent visa problems. It is clear that these problems greatly inhibited a free flow of scientific ideas and discussion. The difficulties certainly contributed greatly to the fact, that, by the end of the program, many U.S. scientists were reluctant to be involved in joint POLYMODE meetings.

Visa applications for meetings in the USSR had to be submitted as long as four months in advance. (Dr. William Simmons was POLYMODE executive scientist from 1974 to 1976. In his notes from the first joint POLYMODE meeting in Moscow in 1975 is a comment to the effect that it had taken four months to set up the meeting. Dr. Simmons stated that if this was to be the norm, it did not bode well for the scientific effort. Four months and more did, indeed, become the norm.) The principal effect was to drastically reduce the flexibility on the U.S. side in terms of participants and travel arrangements. In every case, visas were not available from the Soviet Embassy in Wash-

ington until the last working day before the delegation was to leave, no matter how far ahead of time the applications had been submitted. With participants coming from both coasts, we thus spent a lot of time and energy getting the visas to the travelers.

In one case a delegation of four was reduced unexpectedly to two when only two visas were issued. All four travelers proceeded to London when we were assured that the two additional visas would be issued by the Soviet Embassy in London. When the visas were not issued in London, two of the delegation returned home. No explanation was ever given.

Once in the Soviet Union, U.S. scientists rarely had occasion to request itinerary changes. Those few were mostly changes of departure dates and were handled by the Soviet POLYMODE executive officer, as were all hotel arrangements and local travel.

For meetings in the United States, a list of all Soviet participants was sent to the U.S. POLYMODE office, which in turned passed it on to the State Department. The visas were issued by the U.S. Embassy in Moscow, picked up by someone from the Soviet Foreign Ministry, and distributed to the Soviet scientists along with their passports on the day before they were to leave. No Soviet scientist was ever denied a visa. However, there were instances when, although a visa had been issued, a scientist did not attend. We were given reasons in only a few instances.

Changes of itinerary within the United States after a Soviet delegation had arrived were easily arranged on short notice by the POLYMODE officer with a phone call to the State Department, followed by a letter of confirmation. All hotel and travel arrangements within the United States were handled by the U.S. POLYMODE office.

Soviet delegations could legally enter the United States only through Washington and New York. The preparations for the last joint meeting, which was held in Cambridge, Massachusetts, were particularly difficult due to a last-minute Soviet request to delay the meetings by two weeks. This request could not be granted since schedules for meeting rooms, travel, etc., had been set months before. When the four-day meeting started, there was uncertainty as to whether the Soviet delegation would attend at all. On the second day of the meeting, the Soviet delegation turned up in Montreal, holding tickets to Boston. Since U.S. Immigration would not let them enter Boston, considerable expense and delay was encountered getting them to Cambridge by way of Washington, D.C. We never knew why they had expected to come directly to Boston, since the entry restrictions were by this time well known to the Soviet scientists and authorities.

Travel and housing arrangements within the USSR were in general in line with the usual standards for tourist travel in the Soviet Union. However, the low quality of Soviet hotel accommodations by U.S. standards, difficulties of meeting preparation, visa problems, and general level of difficulty of travel to the USSR, combined with declining scientific expectations for the program, caused many U.S. scientists to be reluctant to participate in joint meetings in the USSR by the later stages of the program. During meeting preparations, there was always pressure from U.S. scientists to shorten the duration, and reluctance or outright refusal of many U.S. scientists to go at all.

The result was that, by the end of the program, there was a large imbalance in the number of man-days spent in the United States and the Soviet Union. In fact, Soviet scientists spent three times as many man-days in the United States as U.S. scientists spent in the USSR. This was a violation of the spirit, if not the letter, of the bilateral agreement. However, to deny admittance to Soviet scientists would have been to "punish" them for a situation that was really caused primarily by the reluctance of the U.S. scientists to go to the USSR.

To our knowledge, language was never a problem at meetings. Most discussions were

carried out in English. From the very first meetings in the United States, the Soviet side provided their own interpreters. At meetings in the Soviet Union, where a larger number of non-English-speaking Soviet scientists attended, again Soviet interpreters were provided. Information documents were generally exchanged in English. The proceedings for joint meetings were assembled and confirmed in English. We do know that such documents were later translated into Russian for circulation in the Soviet Union.

Early in the cooperative effort, the United States obtained a Soviet translation into Russian of the English version of a joint document, and had it re-translated back into English. There were no discrepancies, apart from an interesting and amusing treatment of several acronyms.

Liaison

In 1974 it was agreed that the Soviet and American POLYMODE groups would begin a continuing program of liaison exchange in 1975, with one scientist from each side on extended visit to the other country. It was intended that this arrangement would be continuous and permanent until the end of the program. Individual "tours of duty" were to be of the order of six months, and liaison scientists were to be accompanied by their wives.

As part of the preparations for the 1975 joint meeting, arrangements were made for the first U.S. liaison to go for a six-month period to the USSR. This scientist was to go with the joint delegation and stay when they left, and he accordingly made arrangements for an extended absence, and for the later arrival of his wife. However, all visas, including that of the liaison scientist, were issued for only the five-day period of the meetings. The U.S. POLYMODE office was assured by cable that the liaison scientist's visa would be adjusted when the delegation arrived.

After a few days in the Soviet Union, the U.S. delegation was informed that the visa could not be changed, and the scientist returned with the rest of the delegation. No reason was given. However, the joint protocol for that meeting reaffirmed the plans for a liaison exchange.

The liaison exchange continued to be the subject of (sometimes spirited) discussions for the next three years, at meetings and by letter, cable, and telex. Eventually, there were three liaison visits to the United States by Soviet scientists. One Soviet scientist came for 10 weeks, a second for 11 weeks, and finally there was a 9-week-visit by two scientists. There were two short visits to the USSR by U.S. scientists. Two U.S. scientists went for a week and a half. Later one of the same scientists, but with a different partner, went on a two-day trip that was labeled a liaison visit.

The problem seemed to be that the Soviet side wanted the United States to send a high-level scientist with authority to make decisions regarding the joint program on the spot. The U.S. side, with its consensus approach, was unwilling or unable to do this.

Communications

In the 1975 joint meeting protocol, both sides agreed to a U.S. suggestion for a dedicated teletype line between the Soviet and U.S. POLYMODE offices. This was envisioned by the U.S. side as a full-time dedicated teletypewriter link, with extensions within the United States to several major U.S. sites of POLYMODE research activity, on which

scientists and administrators could send messages and "converse" in real time if they wished.

The United States proposed and obtained funding for their share of this system, but for almost two years the USSR POLYMODE office said they could not get permission for it. Then, in December 1976, a commercial telex was received at the U.S. POLYMODE office saying that the Institute of Oceanology had installed a telex machine and was ready to receive communications. After some debate, the U.S. organization decided to accept this as adequate and installed a telex machine. (Some telexes and cables had been sent and received before this point via the regular telex desk at M.I.T., where the U.S. POLYMODE office was located.)

Telex communications between the U.S. POLYMODE office and the Soviet POLYMODE office and Soviet vessels (via cablegrams) became the primary mode of communication. The telex machine was removed from the U.S. POLYMODE office in the fall of 1980, after which the regular M.I.T. telex desk was again used. From November 4, 1976 to June 26, 1981, there were 768 telexes sent by the U.S. office to the Soviet office or to Soviet vessels. During the same period, 631 telexes were received from the Soviet POLYMODE office and from Soviet ships. The numbers are roughly comparable, but time delays of up to two weeks in receiving answers to even routine U.S. telexes were typical.

Joint XBT Program

A basic, and ubiquitous, instrument in modern physical oceanography in the West is the Expendable Bathythermograph, or XBT. This is a system composed of a ship-mounted launcher and data recorder, which drops expendable probes that send back a profile of the temperature in the upper several hundred meters of the water. At the time of the program, the data was recorded on strip charts for digital processing. The XBT allows the collection of such measurements quickly and cheaply, with the vessel traveling at full cruising speed. An array of such profiles, collected in areas of interest over a period of time, is a valuable data set, used in determining basic statistics of the water volume under investigation.

Early in the program, the possibility of the U.S. supplying XBT shipboard units and probes for use on USSR research vessels was discussed. The Soviets had no such instrument, being forced to rely on the older, mechanical bathythermograph, which is cumbersome and supplies data in a form difficult to process. They indicated that they were not able to purchase the equipment and probes with U.S. dollars. (Depending on quantity and model, probes at that time cost approximately $30 apiece. A shipboard support unit cost about $5,000.)

Discussions continued on this proposal for some time. It should be noted that such discussions included, at least as observers, program officers from the National Science Foundation and the Office of Naval Research. Whereas agreement in principle was achieved, a major point of disagreement developed over whether U.S. technicians would be allowed to routinely ride Soviet vessels to train USSR personnel and oversee the data collection. The Soviet scientists felt that this was not necessary and that the bureaucratic arrangements to do this would be formidable. The U.S. side felt, just as strongly, that this would be necessary to insure the quality of the data. In the later stages of the debate, it became apparent that the Soviets had taken offense at what they considered U.S. disparagement of their technical competence.

In the end, U.S. technicians visited Soviet ships in port and installed and tested the equipment. One technician went on a single three-day cruise on a Soviet ship to train personnel. But, in general, all data were collected by Soviet personnel. Approximately 7,000 XBT probes were supplied to the Soviet vessels. The failure rate on these was not significantly greater than that experienced on our own ships.

Problems with the XBT program, however, did surface from an unexpected source. In order to be of maximum value, the data set must be properly distributed in time and space. Before the start of the field program, a plan for the XBT array was jointly agreed upon. This plan allowed for the expected number of probes to last for the 12 months of the field program, while providing an optimum time and space array.

This plan, however, fell apart, seriously degrading the usefulness of the XBT data set. There were three reasons for this. First, the Soviet ship schedule became quite erratic at times, apparently due to extended repair and maintenance periods. As a result, for instance, when the schedule called for two Soviet ships in an area, only one was there. The single vessel thus collected only half the expected data, with the other half being collected perhaps a month later.

The second reason involved a failure by the United States to fulfill a part of the plan. During the early planning stages, the Soviets indicated that there would be a gap in their ship time, and asked that U.S. ships be used to fill it. The United States agreed. However, by the time the ships actually sailed, U.S. scientists had decided to send them to a somewhat different area than where the USSR ships had been working (see section on Location). Thus there is a time/space gap in the data set.

Third, the Soviet chief scientists at sea showed a tendency to divert from the planned surveys to examine closely certain oceanic features they came across. This is known to U.S. oceanographers as "feature-chasing." It was done in spite of the fact that the features in question (so-called Gulf Stream rings) had been explicitly declared (at least by the United States) as not of interest to the program. The effect was twofold: valuable shiptime was lost from the XBT surveys, and a large number of XBT probes were expended in the features. As a result, the stock of probes had run low only 8 months into the 12-month program, and a special request had to be made for funds for more.

Arrangements had been made for the Soviet vessels to radio all or most of the XBT data to U.S. Coast Guard stations on a daily basis, where it was put on a Weather Service teletype line and received at the U.S. POLYMODE office.[10] The original purpose of this was to provide pseudo-real-time data for scientific planning. However, since the data included the location of the observations, the U.S. executive manager was able, in effect, to track the ships. On several occasions, the U.S. office cabled Moscow and individual Soviet chief scientists at sea inquiring or complaining about diversions from the planned data collection pattern and consequent waste of probes, generally to no avail.

The final result was a data set that is of undeniable scientific value, but that could have been greatly improved if the original plan had been followed. Complete sets were eventually distributed to scientists in both countries.

Politics

Superpower politics did not seem to have an appreciable impact on the program or any joint activities. During the six years of the most intensive joint work, U.S.-Soviet relations had a number of ups and downs. The authors can recall no instance of any apparent impact on the scientific program, positively or negatively.

On one occasion, the U.S. delegation arrived in Moscow for a meeting a few days after the United States had announced that it had dredged up from the bottom of the Pacific Ocean a sunken Soviet submarine. We were quite concerned about the effect of the Soviet reaction on our reception or the meetings. Not only was there no mention at all of the incident, but none of our Soviet colleagues had heard of it since it was not in the Soviet press at all!

Similarly, issues involving Soviet dissidents had no visible affect on the program. At one time, there were informal memos circulated among some participants regarding the status of Soviet dissidents, such as Shcheranski, but no one ever explicitly refused to participate on those grounds. Nor, as far as we know, did the 1979 Soviet invasion of Afghanistan affect the participation of any U.S. POLYMODE scientist.

We do not know whether there were U.S. scientists who quietly decided not to participate in POLYMODE for reasons connected with politics. We can say that there were no explicit withdrawals or refusals on these grounds.

National Security and Technology Transfer Concerns

In mid-1977, after the XBT program was underway, the U.S. Navy expressed concern over what they felt was a technology transfer issue. The XBT is a crucial tool in underwater acoustics and in Anti-Submarine Warfare operations. However, the United States was merely supplying expendable probes for which there would be an accounting, and only loaning the shipboard equipment. There were no secrets in the design of the XBT, but the probes were beyond the manufacturing capabilities of the USSR. In any case, personnel from the Office of Naval Research had been present at all of the negotiations with Soviet scientists.

These issues were eventually resolved by a meeting in late 1977 between representatives of the Navy, the Department of Commerce, the Department of State, and the National Science Foundation.

Meanwhile, the U.S. POLYMODE office had been actively keeping a number of Navy facilities and offices informed, at some inconvenience. Finally, the Navy designated one office (the Office of the Oceanographer of the Navy) as POLYMODE liaison, and the POLYMODE office funneled all information through that office for the duration of the program.

The Navy raised another issue when Magnavox satellite navigation units were delivered to the first two Soviet POLYMODE ships to touch port in the United States. They assumed that the units were part of the POLYMODE program, which was not the case. The objections were withdrawn when it was shown that the units had been purchased by the Soviets on a commercial purchase order and that the export order had been approved by the appropriate Navy office.

In general, the organizational structure of the U.S. side of the bilateral agreement worked effectively to quickly resolve such problems.

Deep-sea Mooring Technology

The technology of placing instruments in the deep ocean on recoverable moorings was another basic and well-developed technique in the Western physical oceanographer's repertoire. In the early negotiations over the scientific plan, several aspects of the Soviet capabilities in this area were disturbing to the U.S. participants. Put simply, they were of

primitive design. This degraded the data and forced the Soviets to replace them at sea too frequently. (Soviet moorings were replaced every month. At that time, U.S. moorings are frequently left in place for 12 to 18 months.) The data degradation problem is discussed below under Current Meters. The necessity to frequently replace moorings meant a large amount of valuable shiptime was being expended in this way.

Early in the discussions, the U.S. side offered to supply to the Soviet program a quantity of high-grade mooring wire for use on their moorings. It was expected that this would allow the Soviets to leave their moorings in for much longer periods of time, thus freeing Soviet shiptime for important activities, such as XBT and density surveys.

After much communication and discussion on technical issues and measurements, several thousand meters of mooring wire were procured and delivered to a Soviet vessel. This wire was purchased on an NSF grant, the title of which was "Re-allocation of Soviet Ship-time for POLYMODE."

A few months later, however, in the course of routine visits to Soviet ships in port, it became apparent that the wire was not being used. The Soviet personnel complained that they did not have equipment for handling the wire. Handling procedures were then worked out to the satisfaction of U.S. technical people. In fact, the U.S. POLYMODE office purchased and delivered to a Soviet ship handling equipment for this purpose, which the Soviets said they could not obtain themselves. However, as far as we were able to determine, the wire was never used on moorings, and in any case the Soviet ships continued to replace their moorings every month.

CTD Intercalibration Facilities

In the fall of 1976, an intercomparison of Conductivity/Temperature/Depth (CTD) profiling instruments was carried out on a Soviet ship. As a result of that work, a Joint Technical Working Group report was issued that recommended that facilities be supplied by the U.S. for use on three Soviet vessels. This would make it possible to intercompare the calibrations of the Soviet and U.S. CTDs.

The United States obtained estimates of between $10,000 and $15,000 apiece for the units and found that they would take several months to procure. At the June 1977 joint meeting in Moscow, it was explicitly agreed that the United States would supply two units for Soviet ships.

In July 1977 two cables were received from Soviet ships at sea, referring to the units and requesting delivery to two Soviet vessels in port at Boston at the end of July. The cables were forwarded to a U.S. scientist who was involved, but no action was taken. On August 1, a third cable was received urging that we get the units in place.

When two U.S. participats visited the lead Soviet vessel in Curacao on August 5–6 to attempt to present the case for moving the Soviet work 150 miles north, the intercalibration issue was not discussed at any length. The Soviets were simply told that the units were not available. The issue was never raised again.

Given the eventual problems with the quality of the Soviet CTD data, the calibration units might have been of great value to the program if they had been delivered. They were not because:

- No participant on the U.S. side cared enough to propose and obtain funds, specify the equipment, and procure, install, and maintain the units.
- The location of the experiment quickly overshadowed all other joint

issues, and dominated discussions on the U.S. side, as well as between the U.S. and Soviet scientists.

Current Meters

Perhaps the most serious technical issue, and one that spilled over inevitably into the scientific discussions, was that of the performance of the Soviet current meters. Disagreement on this point eventually became central to many U.S. scientists' dissatisfaction with the Soviet part of the program.

Current meters are instrument packages that are placed on mooring wires to measure the horizontal flow of the ocean past a point in space. In actuality, the meter measures the flow of water relative to the meter, which is not the same if the meter is itself moving in space. Since the mooring line to which the meter is attached inevitably moves somewhat, there is an unavoidable bias in the measurements. It had been shown by several studies by U.S. and European scientists that this effect could be minimized by using moorings that were totally submerged, with no flotation on the surface. Since most of the forcing of the mooring motion is by surface waves, any current meters then in general use when put on surface moorings would produce badly biased readings.

This effect was well documented in studies dating back to 1967 and that specifically included tests on Soviet current meters.[8] Soviet oceanographers had participated in some of these tests. The general effect was that current meters in such circumstances overestimate the speed of the water flow. As a result, by 1973 Western oceanographers had begun using current meters only on subsurface moorings. The subsurface mooring has no part of its structure on the surface of the ocean. Thus it requires using a device, known as an acoustic release, to release the anchor upon receipt of a coded acoustic command, which allows the instruments to be retrieved and the data collected.

At the start of the planning of the POLYMODE program, Soviet oceanographers were using only surface moorings, since they did not have a reliable acoustically actuated anchor release. In 1974 the U.S. planners were informed that by the start of the field program, the USSR side would have a workable acoustic release and that all moorings would be subsurface. In addition, the Soviet side said they had under development a more modern current meter, which would further improve the data collected.

In 1976 it was revealed that the Soviet engineering development program for the releases had not been successful and that all Soviet POLYMODE moorings would be surface. Similarly, the current meter development program had been scrapped and they would be using mostly their old current meters. This was seen by U.S. oceanographers as a serious blow to the integrity of the Soviet data set.

Subsequently, a large amount of effort on the U.S. side was spent on an attempt, in collaboration with Soviet oceanographers, to quantify the error and provide for some degree of calibration and correction of the data. These efforts were largely stymied by Soviet refusal to formally admit that a problem even existed. At least one joint paper never reached publication because the American author insisted on a simple statement that the data indicated overestimation of speeds by the Soviet meters and the Soviet author refused to allow the statement to be made in the paper. The problem appeared to be exacerbated by the fact that research efforts are more compartmentalized in the Soviet Union so that many oceanographers are unaware of (and unconcerned with) engineering and data processing issues.

This issue was never resolved, and eventually caused several U.S. scientists to quietly withdraw from active participation in the joint program.

Computers

The general lack of modern computers in the Soviet oceanography community had impacts in several areas, including ocean modeling, data reduction, and at-sea data collection.

At the time that POLYMODE was planned, the Soviet oceanographers had no suitable mini-computers for use at sea. On one of their first POLYMODE expeditions, they arrived in Bermuda with an HP-2100 computer on board, essentially the same as that in use at that time by U.S. oceanographers at sea. As would be expected, it was some time before they acquired the peripherals, software, and experience for this machine to have any impact on their shipboard activities. On the other hand, it does not appear that the poor state of the art in Soviet shipboard computing power had any significant effect on POLYMODE.

In the area of shore-based data reduction, however, the lack of computing resources caused a general slow-down in the processing of POLYMODE data. U.S. scientists visiting the USSR to work jointly on intercomparisons and data analysis reported completely unacceptable response time (or no computer time available at all) at the Institute in Moscow.

Toward the later stages of the program, when the data exchange was one of the final formal activities to be finished, the U.S. side was told for over a year that data processing was causing delays.

Last, the Soviet numerical modeling efforts were severely hampered by lack of any adequate computers. This was acknowledged by the Soviets early on. In fact, they specifically requested that provision be made for Soviet modelers to work on the Cray I at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, so that the Soviet side would not be at a disadvantage in the planning.

However, arrangements for this were not straightforward. Access to the Cray at NCAR could be obtained only by submitting a proposal for internal (NCAR) review and approval. The first Soviet proposals for Cray time were unrealistic, perhaps reflecting their general lack of experience with supercomputers. In addition, some individuals at NCAR were reluctant to grant precious time to Soviet modelers whose work was felt to be not up to U.S. standards. Eventually, two Soviet modelers did spend some time at NCAR.

Joint Publications

The precise number of U.S. publications resulting from the POLYMODE program is not certain, because so many publications overlapped with the earlier MODE program, and the contribution lists for the two programs were merged. We do not know if the Soviet side kept a contribution list or the number of Soviet POLYMODE papers in Soviet journals.

However, at least 50 U.S. scientific papers can be identified as being primarily concerned with the POLYMODE program. Four of these had joint U.S.-U.S.S.R. authorship. As noted above under Current Meters, at least one potential joint paper was never

published when the Soviet collaborator refused to allow inclusion of data and conclusions on the performance of Soviet current meters.

A final "joint" publication was *The POLYMODE Atlas*.[9] The Soviets supplied 200 pages of material; the United States supplied a similar amount and bore all costs associated with Atlas publication.

Another form of publication that was very popular with U.S. and "third-country" scientists was the *POLYMODE News*. This newsletter, published in the United States, was an effective way to communicate recent results and plans without the delays involved in publishing in referreed journals.

POLYMODE News was used reasonably effectively by Soviet scientists. An informal count of the cumulative index shows 19 Soviet and two joint U.S.-Soviet articles out of a total of approximately 200 articles during the lifetime of the newsletter from January 1976 to August 1980.

At first, several copies of *POLYMODE News* were sent to the Institute of Oceanology for circulation. When it was discovered that Soviet scientists were not seeing the newsletter, the editor began sending copies directly to individual Soviet participants.

Experiment Location

Perhaps no issue so polarized the program, nor had such an impact on the scientific results, than that of the selection of the geographical location of the field program. The scientific and logistic issues involved are quite complex and are not dealt with in detail here. However, we believe the chronology of events is illustrative and educational.

At meetings during 1974 and 1975, a preliminary plan was developed that included an extensive scientific rationale for locating the experiment in an area to the south and east of Bermuda. This is well documented in the joint protocols for these meetings. These plans were discussed extensively in the United States between meetings and fit well with the interests of U.S. scientists. The primary area was centered in the vicinity of latitude 29N.

Upon arrival in Moscow for the April 1976 joint meetings, the U.S. delegation was presented with a working paper that stated an intention by the Soviet side to work over 1,000 miles to the north and west of the previously agreed-upon site.

This was seen by the U.S. side as a serious blow to the joint field program. The region chosen by the Soviets was:

- Of less scientific interest to the U.S. scientists.
- Characterized by currents of such high velocity as to jeopardize the security of the Soviet moorings.
- Too far north to permit the use of a key U.S. instrument type (SOFAR floats).

Considerable discussion ensued, some of it quite heated. It was apparent that many of the Soviet scientists were not happy with the decision, but were unable to influence it. The basis for the decision (or who made it) is still unknown to us today.

This decision by the USSR side effectively decoupled the location and timing of the U.S. field operations from that of the Soviet fieldwork. Much effort went into tying together the scientific goals, in spite of the geographical separation. Subsequently, the United States went ahead in its planning activities as if there was no direct linkage between the time and place for the U.S. and Soviet field observations.

During the remainder of 1976, some joint work was planned and carried out in the northern region, having to do with mooring survival in the higher currents. Some of the test moorings did, indeed, come adrift, confirming the fears of U.S. engineers concerning the longevity of Soviet moorings in the area.

The U.S. side continued in meetings, telexes, and phone conversations to push very hard during all of 1976 for the Soviets to move their fieldwork back to the south. Meanwhile, however, a split had developed in the U.S. scientific planning between a contingent that continued to want to work at 29N and a group that wanted to move to 32N, about 150 miles north.

On January 12, 1977 the U.S. POLYMODE office received a telex saying that the Soviet side had decided to move south, and asked that the United States specify the exact location.

This sudden shift caused major problems for the United States. The U.S. schedule for a final decision on the detailed location of the observational work was not geared to the need of the Soviet ships to go to sea in July 1977. Instead the U.S. planners had worked under the assumption that they had more time to decide. The U.S. side, committed as always to a consensus approach, was unable to make a decision by the spring of 1977. The Soviets strongly preferred the southern site, at 29N, (as originally agreed upon in the early planning) and the first Soviet POLYMODE cruises began in July at that latitude.

In August 1977 the United States made a decision to work at 32N. It was decided to ask the USSR to move their work (already underway) to the more northern location. While the initial response from some key Soviet scientists at sea (briefed in Curacao during a port stop) was cautiously positive, the eventual response from Moscow was quite negative.

This issue was never resolved. The U.S. team performed its fieldwork at 32N, whereas the Soviet year-long survey was centered at 29N. This continued to be a source of friction until the last days of the program.

Leadership

From a U.S. perspective, POLYMODE would not have been possible without the leadership provided by Professor Allan Robinson of Harvard University. We are reasonably certain that the same is true from the Soviet perspective for Professor Andre Monin of the Institute of Oceanology.

Differences in their positions are notable. Prof. Monin was the director of the world's largest oceanographic institution. As a Harvard professor, Professor Robinson had managerial control of only a small executive office and his own research staff; he depended upon colleagues to write proposals for resources needed for POLYMODE and for their support in his role has chairman of U.S. efforts. Both Robinson and Monin's research interests can be characterized as theoretical.

They never developed a good relationship. Monin appeared to often delegate the mechanics of dealing with the United States (and Robinson) to Professor Kort (of his own institute) or Professor Nelepo (of the Marine Hydrophysical Institute in Sevastapol) without delegating any responsibility. Differences, primarily due to the location issue, worsened.

At one point during the dispute over the location, Monin sent telegrams to all key U.S. scientists, asking them, in effect, to overrule Robinson on the issue. Apart from ignoring the delicacies of protocol, this tactic ignored (or demonstrated ignorance of) the U.S. process of consensus decision making.

At the end of the program, Robinson and Monin were effectively not speaking to one another.

Summary and Conclusions

The goals and objectives of the POLYMODE program were too broad and diffuse for joint U.S.-U.S.S.R. implementation. This was accentuated by a basic difference in the approach to the planning process by the two sides.

The U.S. side assumed that any "decisions" arrived at in joint meetings that had any programmatic implications or impact on scientists not present needed to be discussed back in the United States. Further, any decision that required funding for implementation would need to be passed through the NSF proposal and peer review process, which implied a sort of consensus decision even beyond the immediate POLYMODE community (via the peer review process).

The Soviet decision-making process similarly appeared to involve many individuals or agencies (not necessarily scientists) in planning decisions. We were often told that decisions had to be confirmed or modified later back in the Soviet Union. One problem from the point of view of the United States was that we were never sure on a given issue who would decide.

The result was that both sides took considerable time to make and ratify decisions. (One of the authors [RRH] in his final report to the NSF on the management activity, stated ". . . even the U.S. funding process was generally faster than the Soviet bureaucracy.")

On the other hand, once a position was taken on the U.S. side, it tended to be stable, since a position arrived at by hard-earned consensus was not casually modified. Decisions on the USSR side, on the other hand, appeared sometimes to have been modified without regard to the scientific issues. At times such changes seemed either arbitrary or politically motivated (in the broad sense of the word "politically"—as noted above, conventional superpower politics did not seem to have any affect on the program).

Whereas differences in the planning process made a joint decision process difficult, our inability to communicate easily and freely with the Soviets made planning impossible. U.S. initiatives to correct this situation—liaison scientist exchanges, teletypewriter links—were unsatisfactory. Long delays in issuance of visas became intolerable. Animosity developed between the leaders of the project. Bilateral mechanisms to resolve differences failed.

We take free, open, and convenient communication for granted. When dealing with the Soviets, one must plan on the basis of a very limited information exchange rate. The state of facilities such as instrumentation laboratories and computers in the Soviet Union means that only theoreticians (who need only paper and pencil) can take advantage of extended visits. Joint cruises on Soviet vessels seem the most profitable type of exchange; Soviets would benefit from advanced American instrumentation and U.S. scientists would benefit from shiptime, especially in waters that are closed to U.S. ships or are so remote that they are rarely visited by American vessels. Data exchange in this case should be completed by the end of the cruise so further communication is not needed. This type of shipboard exchange could be facilitated if the Soviets posted advance notice of their ship schedules on electronic bulletin boards.

The general inferiority of Soviet technology became an issue in POLYMODE for all

the wrong reasons. It began when the Soviets projected an unrealistic development rate for new equipment. It was accentuated when they failed to keep us informed of the failure of those same development initiatives. It was compounded by the unfamiliarity of Soviet scientists with equipment and data quality issues. American attempts to address these issues were successful in some cases (XBT equipment) and could have been successful in others (wire rope for moorings, calibrations for CTD accuracy) if we had recognized these deficiencies earlier. The unwillingness of the Soviets to admit the limitations of their data, especially current meter results, remains bewildering.

The U.S. experience in POLYMODE demonstrated that substantial time and effort are needed for planning. In the academic sense, this effort is unproductive because it does not lead to refereed publications. Young, not-yet-established (untenured) researchers must be leery of involvement in such programs and must ask themselves whether participation promises them better scientific results than they could get by other means. This is unfortunate for it implies that such programs will be planned and carried out primarily by senior scientists. This would lead to a generally more conservative approach while depriving the younger scientists of an experience that would allow them to build professional relationships over the course of their careers.

The direct financial cost (travel, joint meeting arrangements, etc.) to the U.S. of collaboration with the Soviet Union in POLYMODE was about $1 million. Did the United States derive scientific benefits from the Soviet program to this extent? We would answer this question with a firm no. That sum represents the costs, for instance, of the data collected by two mooring clusters, and we believe that oceanographic science would have been further advanced with two additional clusters.

In the POLYMODE program, many of the problems that one might have feared beforehand either did not come up or were easily solved. These included superpower politics, interference by the military or by intelligence agencies, and Soviet dissident considerations. Actual problem areas might be divided into three classes:

Fundamental differences in the way of doing things on each side.
Logistical and bureaucratic bottlenecks.
The general inferiority of Soviet oceanographic technology.

Unfortunately, none of these kinds of problems is easily resolvable by an application of good will or "elbow grease." All are, in some sense, inherent in the two cultural and political systems. We would not argue that these difficulties cannot be overcome. We would however, contend that nothing is to be gained by denying they exist or by not attempting to provide mechanisms to deal with them.

The authors suspect that the Soviet participants were (and are) as mystified by what they perceived as strange American behavior as we were amazed (and sometimes outraged) by what we saw as the unpredictability and irrationality of Soviet behavior.

Last, we note that there was never a joint "postmortem" of POLYMODE. That is, participants from both sides never discussed, even informally, what happened or why. As a result, participants from the U.S. side, including the present authors, still do not know, a decade later, why certain key decisions were made on the USSR side. We must assume that the Soviet participants are equally in the dark about what they perceived as strange U.S. decisions and reactions.

That no one on the U.S. side ever suggested or initiated such an information exchange may be attributed to "burnout" and the momentum of other activities. By the end

of POLYMODE, most participants were actively engaged in other projects and were, in any case, not inclined to hash over what they felt had been a great drain on their time and energy.

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