Abstract

The problem of formulating optimal-regulation strategies for commercial fisheries is complicated by the large interannual fluctuations often observed in the numbers and locations of various fish populations. Much of the interannual variance seen in particular cases can be attributed to the effects of environmental variability. The article reviews three examples of research showing that environmental variations can have important systematic effects on fish stocks. The three examples are all from North America and have been chosen to illustrate the biological significance of meteorological and oceanographic phenomena on a wide range of space and time scales.

1. Introduction

Many commercially important fish populations are observed to undergo large interannual variations (Cushing, 1982). An understanding of the causes of these fluctuations can make an important contribution to the formulation of management strategies for commercial fisheries. This is particularly important since in many fisheries the technical problem of actually catching the fish has been very efficiently solved—often to the point that unrestricted fishing would virtually eliminate the fish stocks. Thus the long-term value of many fisheries depends on the ability of government agencies to regulate the fishing in a rational manner.

Historically a rather simple approach to fisheries management has been taken. It has been supposed that the number of fish reaching maturity in each generation depends principally on the number of spawning fish in the parent generation. Thus declining fish stocks were taken as evidence of overfishing (i.e., allowing too-few fish to survive to spawn). Conversely, the recovery of fish stocks has been attributed to the effects of restricted fishing.

In the classic paper on the population dynamics of fish by Ricker (1954), the author supposed that at low density the number of fish in one generation that survives to maturity depends linearly on the number of parent spawning fish. As population density increases, however, the fish will have to face increasing competition and, thus, lower survival rates would be anticipated. These simple ideas have been incorporated into the “Ricker curve,” a hypothetical relation between the number of fish surviving to maturity and the number of fish that spawned them. This is illustrated schematically by the solid curve in Fig. 1. When several years of population data have been collected in a particular fishery, then a smooth Ricker curve can be drawn through the data. Once this curve is known, then it becomes a very simple matter to design the optimum regulation strategies. In order to maintain a steady-state population all one has to do is allow “fishing” down to the “replacement” line shown in Fig. 1. To optimize the exploitation of the fishery, one simply “picks” the population that “maximizes the distance” between the Ricker curve and the replacement line.

Unfortunately the real world is often much-more complicated and unpredictable than the simple model depicted in Fig. 1. For many fish stocks the Ricker model is not a truly adequate basis for regulation (Gulland, 1973). Sometimes predictions of adult–fish-stock populations based on a smooth Ricker curve will account for less than 20 percent of the variance seen in a time series of annual population values (Stocker et al. 1985).

What causes the remaining 80 percent of the interannual variance in these fish stocks? It is certainly possible to formulate simple biological models incorporating competition between a number of different species that can produce large year-to-year fluctuations in the individual populations (May, 1976). In fact the chaotic behavior of such models is often analyzed using the mathematical methods first introduced by Lorentz in his famous work on “highly truncated” atmospheric models (Lorentz, 1960, 1963).

Another potential cause of biological fluctuations is environmental variability. Within the general meteorological community, perhaps the most widely known example of environmental influence on fisheries is the devastation of the...
general oceanic warming). However, in many cases, the behavior of the fish is much-more sophisticated and rather unfathomable (at least from a human perspective!).

The next two sections discuss the evidence for environmental effects on the total populations of two different fish stocks: the capelin off eastern Canada and the anchovy off southern California. Then section 4 considers aspects of the environmental regulation of the oceanic migration of Pacific salmon. These particular examples have been chosen for their practical importance and because taken together they illustrate the biological significance of meteorological phenomena occurring over a wide range of space and time scales. (Some general conclusions are summarized in section 5.)

2. Population variations of the eastern Newfoundland and Labrador capelin

Capelin (Mallotus villosus) is a species of rather-small fish that spawns mainly in small bays and inlets along the east coast of Canada (including Newfoundland). Capelin are not particularly prized as human food (although there is a commercial fishery that harvests capelin for use as bait, fertilizer, and animal food). However, capelin are thought to be a key link in the food chain of the Northwest Atlantic Ocean (Bailey et al. 1977; Leggett et al. 1984), and may be particularly important as forage for cod (Gadus morhua).

Capelin populations are observed to undergo very large interannual variations. Fig. 2 shows the statistical areas “2J” and “3K” off the east coast of Labrador and Newfoundland as defined by the Northwest Atlantic Fisheries Organization (NAFO). The solid curve in Fig. 3 displays the estimated total population of two-year-old capelin in areas 2J and 3K for each year from 1968 through 1980. (Note that the abundance dropped 37-fold between 1975 and 1978.)

The collapse in the capelin population in the mid-1970s followed a significant development of the commercial capelin fishery, and this naturally led to speculation that overfishing was the cause of the fluctuating population. However, as Leg-
gett et al. (1984) note, the actual commercial capelin catch was always a rather-small fraction of the total population. A much more plausible scenario that explains the capelin fluctuations in terms of meteorological variability has been pieced together from detailed field studies and statistical analyses by Frank and Leggett (1981, 1982) and Leggett et al. (1984).

The capelin is a species with early life stages that are particularly amenable to detailed observation, since capelin spawn right on the beach. The eggs that are laid adhere strongly to fine gravel or small pebbles on the beach. Surface waves and tides act to distribute the eggs over the intertidal zone and to bury them several centimeters below the beach surface. The eggs hatch within the beach sediment.

At this point something rather odd happens. Most of the hatched larvae remain in the beach for periods of one to three days before they emerge from the beach into the ocean. Frank and Leggett (1981) studied this process of larval emergence on a beach at Bryants Cove in eastern Newfoundland (Fig. 2). This cove is oriented with its mouth opening towards the northeast. The top part of Fig. 4 shows the results of Frank and Leggert's surveys of larval densities in the beach sediment during the summer of 1978. The general pattern is one of increasing numbers of larvae (as more eggs hatch) punctuated by three precipitous declines sometime during the periods 30 June to 3 July, 21 to 25 July and 28 July to 2 August. Surveys of the larval density in the near-shore waters of the cove revealed increases coincident with the decreases of the beach larvae. This suggests that the larvae on the beach emerge nearly simultaneously into the ocean during a few short bursts during the summer.

The lower panel of Fig. 4 shows the number of hours each day during which the wind had an offshore component. Since the prevailing winds are from the southwest, typically one finds offshore winds during the entire day. Occasionally, however, there are some onshore-wind events. The three periods with significant onshore winds shown in Fig. 4 coincide with the times of larval emergence. Frank and Leggett (1981) observed this relationship at Bryants Cove in the summer of 1979 as well. They also made use of historical data at a number of locations along the coast of Newfoundland to demonstrate a similar connection between onshore winds and larval emergence. Presumably the larvae do not directly sense the wind direction, but rather they must detect some wind-induced change in the composition of the ocean water that covers them at high tide.

Frank and Leggett (1982) have provided a rationale for this peculiar pattern of larval emergence in the capelin. They found that under normal conditions of prevailing offshore winds, the surface waters in Bryants Cove are pushed offshore and cold water from the deep part of the open ocean is drawn up to fill the cove. When the winds change direction, relatively warm surface water is advected in from the open ocean. Frank and Leggett were able to demonstrate that the cold-water mass is much more laden with predators of the capelin larvae than is the warm surface water, and that the cold water has a lower percentage of the zooplankton population that constitutes the food for the larvae. Frank and Leggett found 3–20 fold decreases in predator density and 2–3 fold increases in available food when the warm surface waters filled the cove. Thus the capelin larvae apparently emerge into the water just when it is safest to do so!

The capelin "pay a price" for this advantage, however. As the larvae wait in the beach sediment they must live on a finite amount of nourishment provided by their yolk sacs. Thus if long periods pass without any onshore winds to trigger emergence, the condition of the larvae can seriously deteriorate. In fact Frank and Leggett (1981) showed that the fraction of their sampled beach larvae, which were judged to be in "good" condition, decreased continually in the intervals between onshore winds. Summers without reasonably frequent onshore winds (which basically amount to summers without frequent easterly winds) in the bays and inlets of Newfoundland and Labrador might thus be expected to be followed by declines in capelin population.

This idea was incorporated into a simple statistical model by Leggett et al. (1984). They regressed the logarithm of the two-year-old capelin population in NAFO areas 2J and 3K (see Figs. 2 and 3) against a measure of the maximum time between onshore winds during a period after the estimated peak of the egg hatching in the year the fish were spawned. The logarithm of the population was used in the regression in order to equally weight the fractional changes in the population between successive generations. The result of their best-fit model is shown as the dashed curve in Fig. 3 (this model actually included another environmental variable—ocean-surface temperature—as well!). The model is able to reproduce at least the most prominent features of the interannual variations in the capelin population (which are completely unexplained by the simple Ricker model of population dynamics).

The model predictions shown in Fig. 3 have some obvious deficiencies (note that the sign of the population changes in the model are incorrect in 1971–72, 1978–79, and 1979–80). How-

---

1 When the model includes only frequency of onshore winds it accounts for 38 percent of the variance in the time series of the logarithm of the capelin population. When the sea-surface temperature is added as a variable, then the linear regression accounts for 58 percent of the variance (this is the case shown in Fig. 3).
ever, Leggett et al. regard their results as encouraging, particularly given the simplicity of the statistical model and the limitations of both the fish-population data and meteorological data (the onshore-wind frequency used in constructing Fig. 3 was based on observed wind data from the single station at St. John’s).

3. Storminess and larval mortality in the northern anchovy off the southern California coast

The northern anchovy (*Engraulis mordax*) is a prominent inhabitant of the coastal waters from British Columbia to Baja, California, and serves as the basis for a valuable commercial fishery. The anchovy spawn in nearshore waters mostly from January to April (Lasker, 1975; Peterman and Bradford, 1987). The fertilized eggs hatch into larvae after three or four days. The yolk sac provides nourishment for the larvae between one and three days. After the exhaustion of the yolk sac the larvae must find an adequate source of food during the next few days or they will be subject to very high mortality (Lasker, 1975).

The larvae feed on plankton in the near-surface water. When the surface wind speeds are relatively low, the water column is usually reasonably stable and plankton can concentrate near the surface. Under stormy conditions, however, the plankton may become very dispersed. Laboratory and field studies show that anchovy larvae cannot feed as effectively on the dispersed plankton as on the concentrated plankton patches that occur under calm atmospheric conditions (Lasker, 1975). Lasker concluded that during a critical period of about 2.5 days after the exhaustion of their yolk sac the young larvae must encounter a concentrated patch of plankton or they will face greatly increased mortality. Thus one might anticipate a connection between atmospheric windiness over the spawning ground and larval mortality.

Peterman and Bradford (1987) examined this issue for the southern California population of anchovy using surveys of larval densities during 13 nonconsecutive years. The results of these surveys allowed estimates to be made of the daily mortality rate of the larvae. These values were averaged from January to April and then compared with an index of the surface wind speeds during the same period. The formulation of an appropriate wind index was guided by the biological studies of Lasker (1975) and by the study of oceanic mixed-layer dynamics by Simpson and Dickey (1981). Specifically Simpson and Dickey simulated the wind-forced mixed-layer structure using a turbulence-closure model that included realistic radiative heating in the upper ocean. For surface wind speeds of 10 m \( \cdot \) s\(^{-1} \) or greater they found that a deep well-mixed layer formed in the top 20 or 30 meters. At lower wind speeds the radiative heating in the model could produce a statically stable layer in the top few meters. In their model, radiation acts to stabilize the upper part of the water column on time scales of the order of 24 hours.

Peterman and Bradford based their approach on the view that winds calmer than 10 m \( \cdot \) s\(^{-1} \) persisting for a day or so would lead to the stable conditions required for concentrated plankton. If the calm winds last for another 2 to 3 days this would get one group of larvae through their critical “first feeding” period. Thus they chose the number of overlapping four-day periods with calm (<10 m \( \cdot \) s\(^{-1} \)) surface winds during the January to April period as their index of windiness (the surface winds were taken from summaries of ship observations). Fig. 5 shows a scatter diagram of this index (expressed as “number of calm periods per month”) versus the average daily mortality rate of the larvae during the same period for each of the 13 years considered. The results are quite striking, and indicate that increased windiness does greatly enhance the larval mortality. The linear relation with wind index accounts for 65 percent of the variance in the 13-year time series of mortality. The correlation coefficient between the wind index and the larval mortality was judged to be significant at the 99.9-percent level (Peterman and Bradford, 1987). This is a particularly nice example in which very-significant empirical results were found to support a proposed mechanism based on plausible physical and biological reasoning.

4. The return migration of the Fraser River sockeye salmon

The Pacific sockeye salmon (*Oncorhynchus nerka*) displays one of the most-remarkable examples of migratory behavior in the animal world. These fish spawn in many small streams and lakes of North America and Asia. They usually spend their first year in fresh water then migrate into the ocean where they live most of their adult life, often thousands of kilometers from the mouth of their home river. As they approach sexual maturity (typically after 2 to 4 years of ocean residence) the sockeye begin a return migration that leads them almost invariably to the very stream where they were born (Foerster, 1968). The sockeye spawn in this stream and then very quickly die. Salmon are thought to be guided by the memory of the precise odor of their natal stream during the final stage of their homeward

\[\text{Peterman and Bradford (1978) do sound a cautionary note in that the wind-induced mortality observed at the larval stage has not yet been demonstrated to affect the ultimate population of one-year-old anchovies.}\]
migration (Hasler and Wisby, 1951). However, the question of how salmon navigate in the open ocean remains very much a mystery. Tagging studies suggest that the homeward migration of the sockeye occurs along something approaching a great circle route from the oceanic feeding grounds to the vicinity of the mouth of the natal river system, and that the migration is performed at very nearly the maximum possible sustained swimming speed of the sockeye (Groot and Quinn, 1987). Therefore it appears that the sockeye must have quite-precise navigational skills in the open ocean (although they allow themselves a certain margin of error by generally “aiming” to “hit the coast” a little north of the river mouth and then turning southward).

A number of possible guidance mechanisms have been suggested to account for the navigational prowess of the sockeye. Obvious possibilities are that the fish sense their direction of movement and at least some information as to their location through observation of either the daytime or nighttime sky (Royce et al. 1968), or through sensing the earth’s magnetic field (Quinn, 1984). It is also possible that the sockeye could use environmental cues derived from ocean temperature or salinity to aid their navigation. They could conceivably even sense atmospheric wind direction through observation of the orientation of the surface gravity-wave field or by observing the motion of clouds.

If such environmental cues are important, then one might anticipate that the migration routes of the sockeye would have some interannual variability that could be related in some systematic way to the variability of atmospheric and oceanic conditions. In general it would be a very difficult and expensive proposition to study the detailed interannual variations of the salmon migrations. However, there is one population of sockeye for which a long time series of useful information concerning migration routes can be constructed, namely that which spawns in the Fraser River system of British Columbia.

The Fraser River is one of the world’s great salmon-spawning rivers. The commercial catch of Fraser River sockeye salmon is worth several tens of millions of dollars each year in both Canada and the United States (IPSFC, 1978–1984). The map of the British Columbia coast displayed in Fig. 6, shows that returning Fraser River salmon must either come around the north end of Vancouver Island through Johnstone Strait or around the southern tip of the island through Juan de Fuca Strait. Thus the homing sockeye are forced to choose between two routes that are separated by almost 500 km. Since commercial fisheries have operated in both Johnstone Strait and Juan de Fuca Strait for almost a century, it is possible to use “catch records” to estimate the fraction of fish returning by each route on a year-by-year basis. Since the majority of sockeye normally return via Juan de Fuca Strait, the fraction using Johnstone Strait in any given year is referred to as the “Johnstone Strait diversion.”

The issue of the Johnstone Strait diversion not only provides an interesting “natural experiment” on the interannual variability of salmon migration routes, it is also of considerable practical significance. Most of the returning sockeye spawning run generally arrives at the coast within a brief two-week or three-week period during the summer. Thus rapid decisions have to be made in formulating the fishing regulations each season. Such decision making is complicated if an unexpected fraction of the fish use the Johnstone Strait route. The whole situation is made even trickier by the fact that sockeye returning via Juan de Fuca Strait generally pass through United States’ territorial water in Puget Sound (and are thus available for a brief period to the American fishery), while those that return through Johnstone Strait are available only to the Canadian fishery. Since both the US and Canadian governments contribute to the maintenance of sockeye hatcheries and other facilities in the Fraser River system, one aim of regulation is to ensure some rational division of the catch between the American and Canadian fisheries. For this purpose it would be very desirable to have advance warning of the fraction of the fish likely to use the northern route.

The Johnstone Strait diversion of the sockeye has been studied recently by Hamilton (1985) using historical catch statistics and environmental data. Fig. 7 shows his estimates of the Johnstone Strait diversion each year from 1906 through 1983 (with gaps in the years 1942 and 1946–50 when the catch data

FIG. 6. Map of the British Columbia coast showing the two possible paths around Vancouver Island that are available to salmon homing to the Fraser River system.

FIG. 7. Time series of estimates of the Johnstone Strait diversion (i.e., the fraction of Fraser River sockeye returning via the northern route). The results after 1953 are official estimates supplied by the International Pacific Salmon Fisheries Commission (New Westminster, British Columbia, Canada). Prior to 1953 the results are based on the analysis described in Hamilton (1985).
was not adequate to compute the diversion). The general picture during 1906–1977 is one of typically 10-percent to 15-percent diversions punctuated by some very-large-diversion years, notably in 1906, 1915, 1922, 1926, 1936, 1944, 1958, and 1972. Since 1978 a new regime seems to have set in with much larger diversions a general rule. Particularly noteworthy is the year 1983 that had the largest Johnstone Strait diversion (85 percent) ever seen. The remarkable change in the diversion rates after 1977 has been discussed by IPSFC (1982), Roos (1982), and Groot and Quinn (1987), but has not as yet been satisfactorily explained.

The Fraser River sockeye (unlike most other Pacific sockeye stocks) have a very-regular four-year life cycle (i.e., almost all the spawning adults are in their fourth year of life). Thus any purely hereditary predilection in the choice of the return migration route ought to be manifested as a strong four-year-lagged autocorrelation in the diversion-time series. Hamilton (1985) showed that this autocorrelation is actually very small. Thus it appears that other factors must be important in determining the Johnstone Strait diversion each year.

The possibility that environmental effects may be playing a significant role in the interannual variability seen in Fig. 7 is suggested by the fact that five of the eight large-diversion years prior to 1977 (specifically 1906, 1915, 1926, 1944, and 1958), along with the exceptional diversion in 1983, all followed tropical El Niño years (Quinn et al. 1978). It is known that tropical El Niño-Southern Oscillation events are often accompanied by a strong and prolonged warming trend in the northeast Pacific Ocean (Reynolds and Rasmussen, 1982; Thomson et al. 1984; Emery and Hamilton, 1985; Hamilton and Emery, 1985; Hamilton, 1986). The warming can persist into the spring and summer of the following year. In fact the British Columbian coastal waters were warmer than normal in each of the summers of 1926 (Thomson et al. 1984), 1944 (Thomson et al. 1984), 1958 (Tully et al. 1960), and 1983 (Tabata, 1984). Unfortunately, there are no ocean-temperature observations for the years 1906 and 1915. In addition, it turns out that the British Columbian coastal waters were also anomalously warm in the summers of 1936 (Tully et al. 1960) and 1972 (Thomson et al. 1984; Emery and Hamilton, 1985).

Royal and Tully (1961) noted that large Johnstone Strait sockeye diversion was observed in the spawning run of 1958 when the waters off the British Columbia coast were anomalously warm. They pointed out that this was consistent with a rather-simple model of sockeye migration (i.e., one in which the fish effectively use ocean temperature to determine their latitude). When the surface water is anomalously warm the sockeye would tend to encounter the coast somewhat further north than normal. If the sockeye take the most-direct route to the Fraser River once they hit the coast, then the Johnstone Strait diversion represents roughly that fraction of the sockeye that first encounter the coast north of Vancouver Island. The anomalously warm coastal water might thus be expected to result in an anomalously large Johnstone Strait diversion.

Hamilton (1985) examined this possibility in more detail using the very long time series of diversion rates shown in Fig. 7. He found that there was indeed a positive correlation between the diversion and the British Columbia coastal temperature during the summer of the spawning run. In addition, however, there was an even stronger negative correlation between the diversion and the coastal temperature 18 months before the spawning run. Since the sockeye at this point in their life cycle are distributed widely throughout the northeast Pacific, this correlation cannot represent a direct effect of the coastal temperature on the fish behavior. Perhaps the solution to this dilemma is to be found in the results shown in Fig. 8. This is a scatter diagram of the Johnstone Strait diversion each year versus the surface temperature difference taken at a British Columbia coastal station between July of the year of the spawning run and January of the previous year (i.e., 18 months earlier). The results are separated into pre-1978 (circles) and post-1978 (triangles) data. The general tendency for larger diversions to follow an 18-month warming trend along the coast is quite apparent in both the pre-1978 and post-1978 data, although a single regression line could not fit the data well for both periods together.

Interpretation of this result is complicated by the fact that warming trends along the coast are themselves correlated with other environmental and biological changes. In particular, the warmings are often accompanied by intensified cyclonic atmospheric circulation over the Gulf of Alaska (Emery and Hamilton, 1985; Hamilton and Emery, 1985). This may lead to anomalous northward advection of surface waters in the eastern Gulf of Alaska. This in turn may induce a northward displacement of the principal-food sources for the sockeye (Fulton and LeBrasseur, 1985; Mysak, 1986). One might speculate that the correlation displayed in Fig. 8 represents the effect of this northward shift of the food sources (and possibly other reasonably passive tracers that the sockeye might sense) during warming events, possibly combined with a simple "temperature preference" during the final leg of the homeward migration (as originally proposed by Royal and Tully, 1961).

While much clearly remains to be learned about the detailed mechanisms connecting the environmental variation to the...
changes in Fraser River salmon-migration patterns, the empirical results displayed in Fig. 8 may serve as a useful basis for practical prediction of the Johnstone Strait diversion. In order to make such predictions significantly in advance of the arrival of the sockeye spawning run, it would be useful to have monthly or seasonal forecasts of the ocean temperature along the coast.

5. Conclusion

The investigations reviewed in this paper have provided evidence for systematic environmental impacts on fish populations and fish-migration routes. Many other examples of similar research could be cited (see Leggett, 1977; and Cushing, 1982 for additional reviews). The environmental effects can be quite spectacular and an ability to anticipate these impacts may be of considerable practical importance for the rational management of commercial fisheries.

The results concerning environmental effects on fisheries have obvious implications for the applicability of meteorological monitoring and prediction. In addition, the biological investigations in this area often raise related issues in the subject air-sea interaction that merit more detailed research. The present brief survey has shown the importance of air-sea interaction on three widely separated spatial scales: the dispersion of plankton patches in the top few meters of the ocean off the California coast, the wind-induced water-mass exchange in small bays along the Canadian east coast, and finally, the atmospheric “driving” of the large-scale, prolonged surface warming often seen in the northeast Pacific Ocean.

Acknowledgments. The author wishes to thank Dr. W. C. Leggett and Dr. R. A. Peterman for permission to reproduce figures. This work was supported by the Canadian Natural Sciences and Engineering Research Council.

References


announcements

Air Weather Association is Formed
An Air Weather Association has been formed to provide a forum for continued comradeship of those who served, or now are assigned to, the United States Air Force Air Weather Service [AWS]. The association is an all-ranks and civilian grades veterans social organization with the purpose of keeping each member in touch with other AWS alumni. The association sponsors biennial reunions, publishes a newsletter, and distributes a roster to its members. The next reunion is planned for September 1988 in Sacramento, California. Details of that reunion, plus membership information, can be obtained by contacting the Air Weather Association, 5301 Reservation Road, Placerville, CA 95667.

Competition Opens for NSF Science and Technology Research Centers
The National Science Foundation recently released the guidelines for its new program to support the establishment of a series of Science and Technology Research Centers (STC) in universities around the country.

The STC program is a major part of President Reagan’s science and technology centers initiative, announced in the 1987 State of the Union Message in which he called for the establishment of “a number of ‘science and technology centers’ based at U.S. universities...which will focus on fundamental science that has the potential to contribute to our nation’s economic competitiveness...”

In fiscal year 1988, NSF anticipates making between 10 and 20 center awards, each in the range of $500,000.00 to $5,000,000.00 per year. The actual number will depend on the availability of funds. The duration of initial awards will be five years, but successful centers will be eligible for support for up to 11 years.

Establishment of this program reflects the fact that many important research problems can no longer be studied by scientists working alone because of the need for large facilities, research support teams, or simply the need to bring together individuals with diverse experiences and expertise.

It also reflects the need to increase the transfer of knowledge from discovery to application. NSF’s new Science and Technology Research Centers will be based in universities. However, by involving students and research scientists from academia, industry, and federal laboratories, they will contribute to the more-rapid transfer of new knowledge and to the training of professionals with an awareness of the potential applications of scientific discoveries.

The STC competition is open to all fields of science and technology typically supported by the NSF. The program will make two kinds of awards in fiscal year 1988: STC awards and STC planning grants. The purpose of the latter is to assist institutions in the development of STC proposals that will be competitive for federal or other support in subsequent years.

“We believe that economic competitiveness will be fostered by closer collaboration in science and technology among governments, universities, and industry,” said NSF director Erich Bloch. “We need more integration between researchers in industry and those in academia. Through the centers’ mechanism, we hope to improve knowledge transfer, an area where as a country we are being outpaced by our competitors.”

Bloch said also, however, that “centers and cooperative activities are not a substitute for other modes of support. They are an addition, a complementary way to allow investigators to do research.”

Alan I. Leshner, director of the Office of Science and Technology Centers Development, said, “The science to be done will dictate the size, structure, and composition of each center, although all must have significant educational and knowledge transfer components.”

Leshner indicated further that “each STC will have a unifying intellectual theme. The themes may be single or multidisciplinary, but the principal focus in all cases should be advancing basic knowledge in science and technology.”

Copies of the guidelines may be obtained from the NSF Office of Science and Technology Centers Development, 1800 G Street, Washington, DC 20550.

NSSDC Offers Updated IRI and MSIS Models
The recently updated International Reference Ionosphere (IRI) and Mass Spectrometer Incoherent Scatter (MSIS) neutral atmosphere models are available from the National Space Science Data Center (NSSDC) on floppy disk for use on personal computers.

IRI is the International Union of Radio Science/Committee on Space Research (URSI/COSPAR)-sponsored empirical standard model of ionospheric plasma densities and temperatures. An international task group is in charge of updating the model, incorporating new measurements, and releasing improved editions. IRI-86 is based on the decisions made at the Louvain-la-Neuve workshop. It was released at the Toulouse COSPAR meeting.

announcements (continued on page 1565)