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THE ATMOSPHERIC MODEL INTERCOMPARISON PROJECT AT THE NATIONAL METEOROLOGICAL CENTER

Wesley Ebisuzaki
Research and Data System Corporation

Huug M. van den Dool
Climate Analysis Center
National Meteorological Center

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Wesley Ebisuzaki,
H. M. van den Dool

Climate Analysis Center
National Meteorological Center
Washington, DC

1 Introduction: AMIP

AMIP is an acronym for "Atmospheric Model Intercomparison Project." The major objective of this international project is to make a comprehensive comparison of the abilities of current general circulation models (GCMs) to simulate the atmospheric circulation when forced by prescribed boundary conditions. It is expected that the results of this study will lead to a better understanding of the strengths and weaknesses of various climate models and their parameterizations. The results will also help determine the uncertainty of climate forecasts, and help guide future research in climate modeling.

AMIP is sponsored by WGNE (Working Group on Numerical Experimentation) which is a part of the World Climate Research Programme of the World Meteorological Organization (WMO). AMIP is organized by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Laboratory (LLNL) in the United States. PCMDI, through the support of the Department of Energy (DOE), has provided technical and computational resources for a number of modeling efforts.

The modeling groups involved with this intercomparison include operational forecast centers (ECMWF, UK, NMC, etc), national laboratories

(GFDL, GLA, NCAR, etc), and university groups. Horizontal resolution of the models ranges from T21 to R40, and vertical resolution ranges from 2 to 30 vertical levels. As of October 1992, there were 29 groups participating in AMIP. For more details, see Gates (1992).

In order to make a valid comparison between the models, all the models were required to make similar integrations. All models were started from either a January 1, 1979 analysis or a reasonable winter initial state. The models were then run for 10 years of simulated time. Initial conditions were not supplied as it was assumed that the effects of reasonable initial conditions would be unimportant after the first month. Of more importance to these long integrations, all the models used the same observed sea surface temperatures (SST) and sea ice data as supplied by PCMDI. In addition, all models used common CO_2 concentrations (345 ppm) and solar constants (1365 w/m^2).

The organizers specified that all the simulations produce a set of required diagnostic fields (see Appendix A). The primary set consisted of monthly means and variances of various meteorological fields that the organizers felt would be of most importance to researchers. The NMC AMIP run has likely produced more diagnostic fields available for analysis than any previous long integration of the Medium-Range Forecast Model (MRF). In addition to the previously mentioned fields, the participants were requested to produce a history of the model's prognostic variables and surface conditions. These history files were to be made every 6 hours for models having a diurnal cycle. These 6-hour history tapes can be used to make model climatologies of the diurnal cycle and to study high-frequency phenomena such as atmospheric tides. Deficiencies in the model-simulated diurnal cycle could suggest areas where the model's parameterizations of subgrid-scale physical processes need improvement. At NMC, these 6-hour history tapes have a higher temporal resolution than from any previous long MRF integration.

AMIP, besides providing a useful benchmark for future climate models, was designed to examine cloud parameterizations and radiative processes in detail. This is important as clouds and their effect on radiative process are perhaps the greatest uncertainty in current climate models. In addition, the AMIP runs cover a period during which two El Niño-Southern Oscillation (ENSO) events were observed. This provides a chance to examine the low frequency behavior of the model to realistic changes in the 'external' boundary conditions.

For those interested in coupled atmosphere-ocean models, the AMIP simulations can be viewed as the coupling of a "perfect" ocean and an imperfect atmospheric model. From these simulations, we may be able to estimate the upper limit of predictability for a coupled model. One can even determine if a particular atmospheric model is a suitable candidate for a coupled model from these integrations. For example, if the atmospheric model has a very weak response to the SST anomalies during ENSO years, a coupled model using that atmospheric model would have difficulty simulating an ENSO event since ENSO is a coupled atmosphere-ocean phenomenon.

In summary, AMIP could be viewed simply as an intercomparison between atmospheric models. However, its value to the meteorological community is much larger. Previously researchers often used the National Center for Atmospheric Research's Community Climate Model (the NCAR CCM) because that model and its history tapes were readily available to the outside community. With AMIP, the data from many different GCMs are freely available. Studying a dozen models could be as simple as running an analysis program twelve times. In addition, the design of AMIP allows studies of both high frequency (6-hour history files) and low frequency (ENSO) phenomena. The intercomparison aspect of AMIP should benefit the modelers, and the comparison to observations should help us evaluate the value of individual and consensus climate forecasts.

2 NMC's AMIP Run

The National Meteorological Center's AMIP run was carried out with an 18 sigma level T40 spectral model which was was based on the NMC's 1992 operational medium-range forecast model (MRF, Kanamitsu et al. 1991, Kanamitsu 1989, NMC Development Division 1988, Sela 1988). The model initial conditions were NMC's FGGE analysis for January 1, 1979 00Z, observed SST, and observed sea-ice. (The latter two fields were AMIP specified.) Other fields were set to the "Model Launcher" climatological fields. (The "Model Launcher" is an NMC system for running the MRF model.) The model was then integrated for 10 years using AMIP SST and sea-ice analyses. The NMC's AMIP simulation (i.e., Run 3.1) was carried out on NMC's CRAY Y-MP between December 1992 and February 1993. Earlier model runs were used for testing and model changes.

Besides the lower resolution (T40 vs. T126), the AMIP model had several other changes relative to the 1992 operational MRF. First, the model had "water-mass" forcing (Van den Dool and Saha 1993, Qiu et al. 1991, Geleyn et al. 1991). The theory behind water-mass forcing is that precipitation reduces the mass in the atmosphere and evaporation adds to it. The method used, and implemented by Mark Iredell of NMC, changes the local surface pressure at the end of each time step depending on local 'evaporation minus precipitation.' We refer to this scheme as "water-mass forcing 1.0" as more consistent ways are being studied.

In addition, the model used the AMIP specified 345 ppm CO_2 concentration as compared with 330 ppm used by the operational MRF. The new CO_2 concentration affected the short-wave and long-wave parameterizations (Campana 1990).

Earlier extended simulations showed that the MRF tended to gain atmospheric mass (the T40 MRF gained 3 mb in 10 years, Van den Dool et al. 1991). To eliminate this entirely spurious drift, the dry atmospheric mass (total mass minus water content) was adjusted each month to its initial value of 982.3 mb. This procedure was accomplished by transforming the surface pressure and specific humidity fields from a T40 spectral representation to a 2.5 x 2.5 degree latitude-longitude grid. The total mass and water content were then calculated on all grid points and weighted by the cosine of the latitude. The ratio of the initial global dry mass to the current dry mass was then calculated. The surface pressure was then transformed to the model's Gaussian grid (128 longitudes by 64 latitudes), and all points were multiplied by this ratio in order to restore the original dry mass. Finally, the surface pressure was then transformed back into its original spectral representation.

The orographic fields and land-sea mask were generated from the US Navy's $\frac{1}{6}$ x $\frac{1}{6}$ degree orography dataset. The AMIP model used the mean orographic heights like the 1992 operational MRF. The land-sea mask determines whether the points on the model's Gaussian grid are land or water. For AMIP Run 3.1, the land-sea mask was modified to eliminate the two 'water' points in the interior of Canada (Lake Superior and Great Bear Lake) for the following reason. Since the AMIP SST/Sea-Ice dataset did not have sea ice in the interior of continents, the two Canadian lakes were keep ice free by the model, and at temperatures determined by the SST 'analysis.' As a result of being ice free, the winter latent and sensible heat fluxes were much too large over these lakes. To avoid this problem, the two water points in Canada were changed to land points.

The analyzed SST and sea-ice were linearly interpolated to daily values by assuming the monthly fields corresponded to the 15th day of the month. Since the sea-ice mask has only zeros and ones, the interpolated values were rounded to the nearest integer after interpolation. The first 15 days of the integration used the values for January 1979 as December 1978 fields were not provided. Similarly the last 15 days of the integration used the December 1988 fields.

Like the operational MRF, the model updated the atmospheric long-wave heating rates every three hours, and the short-wave heating rate and surface radiative fluxes every time step. However, it must be noted short-wave and surface radiative flux calculations used predicted cloud, albedo, and humidity fields (above the PBL) that were only updated every third hour.

The soil wetness, surface temperature and snow depth were predicted at every time step, and surface climatological fields were updated every 24 hours by a linear interpolation from the monthly climatology. The dry atmospheric mass was re-adjusted to its initial value at the beginning of each month.

Some changes did not affect the model's predicted fields such as the addition of Cloud Forcing II (Coakley and Baldwin 1984, Ramanathan 1987), and a performance modification to the MRF. Cloud Forcing II, a required AMIP diagnostic, was implemented and installed by Ken Campana of NMC, and the performance modification was developed by Ming Ji and Mark Iredell of NMC. They found that the model would run more efficiently if a scratch file was kept in memory rather on disk.

NMC's AMIP model has several differences from an earlier 10 year simulation (NMC10, Van den Dool et al. 1991). Both models had the same vertical and horizontal resolution but NMC10 was based on an earlier version of the MRF. By experimental design, NMC10 used climatological SST, sea ice, snow depth, and soil moisture. The AMIP run, on the other hand, used observed SST and sea ice, and interactive surface conditions. Other major differences include using silhouette orography, and 330 ppm CO_2 concentration in NMC10.

3 Model Specifications

3.1 1992 Operational Model Specifications

- T126 resolution, 18 levels, sigma vertical coordinates
- 330 ppm CO_2 concentration

- Short-wave radiation based on Lacis and Hansen (1974)
- Long-wave radiation based on Fels and Schwarzkoph (1975) (Campana 1990)
- Long wave heating rates were updated every 3 hours, surface radiative and short-wave fluxes were calculated every timestep (Campana 1990)
- Kuo convection
- Stratiform cloud coverage (Slingo 1987, Campana et al. 1989)
- Shallow convection (Tiedtke 1983)
- Marine status cloud parameterization (Kanamitsu et al. 1991)
- 1365 w/m^2 solar constant (modified by earth's orbital eccentricity)
- Evaporation over land based on Penman-Monteith potential evapotranspiration (Pan 1990).
- Land surface conditions (wetness, temperature, snow) were predicted by the model.
- Used 'SiB' (Simple Biosphere Model) surface climatologies for albedo, etc. (Dorman and Sellers 1989)..
- Horizontal diffusion based on Leith (1971) (Kanamitsu et al. 1991).
- Mean orography
- Gravity wave drag (Alpert et al. 1988)

3.2 AMIP Model Differences

- T40 resolution
- 345 ppm CO_2 concentration
- AMIP specified SST and sea-ice were used. The monthly analyses were assumed to be valid for the 15th of the month and the analyses were linearly interpolated for other days. The Jan. 1979 analysis was used for Jan. 1 - Jan. 15, 1979 and the Dec. 1988 analysis was used for Dec. 15 - Dec. 31, 1988.
- Water-mass forcing 1.0
- Global dry atmospheric mass restored to its original value at the beginning of each month.
- Cloud forcing II calculated
- Land-sea mask modified to eliminate two water points in Canada.

4 Data Processing

Every 6 hours, the AMIP run created three raw data files, the SIGMA, S2D, and H2D files. The SIGMA file contains the T40 spectral coefficients of the log of the surface pressure, and 18 sigma levels of virtual temperature, specific humidity, vorticity and divergence. The data in the S2D file are stored on a Gaussian grid in GRIB format. The data includes radiative fluxes at the top and bottom of the atmosphere, the cloud distribution and surface parameters such as soil moisture, precipitation, skin temperature and evaporation. Finally the H2D file contains the cloud forcing and various radiative fluxes. A fourth file, the PRS file, was derived from post-processing the SIGMA file. This data file includes the virtual temperature, vorticity, divergence, vertical velocity, relative humidity, and geopotential heights for 15 standard pressure levels. This data are stored as T21 spectral coefficients.

Some of the AMIP-required fields are not normally generated by the MRF. For example, Ken Campana added the Cloud Forcing type II. Precipitable water was calculated from the SIGMA file using a program that converted the SIGMA spectral file to a 128 longitude by 64 latitude Gaussian grid and calculated the vertical integral of the water content. The standard program to convert from sigma levels to pressure levels (POST) was modified so that data on 15 standard pressure levels were generated. In addition, the program POST only calculated the virtual temperature and relative humidity on pressure surfaces. The temperature and specific humidity were calculated by an iterative method from the virtual temperature and the relative humidity using the model's equation of state. The sea-level pressure was generated using the formula: SLP = (1000 mb height in meters)/8.57 + 1000. The total cloudiness was calculated assuming a random overlap between the low, medium and high clouds. The meridional streamfunction was calculated using the method suggested by Lisa Corsetti of LLNL (personal communication).

For various conversions, a constant density of water ($1.0\text{x}10^3$ kg/m^3) and constant latent heat of vaporization ($2.5\text{x}10^6$ J/kg) were used in order to be consistent with the model.

5 Data Being Archived

1. Monthly averages and variances (AMIP required and a few extra)
2. SIGMA files every 6 hours (humidity, virtual temperature, vorticity, divergence, log of surface pressure)
3. Surface conditions (temperature, snow, soil moisture) every 6 hours.

4. GRIB S2D files every 6 hours (surface conditions, precipitation, clouds, fluxes)
5. T21, 15 pressure levels, PRS files every 24 hours (height, virtual temperature, vorticity, divergence, vertical velocity)
6. Some fields from the H2D files every 6 hours (some radiation fluxes, all cloud forcing fields)
7. Initial conditions required to restart the model (each month)

6 Additional Runs

Variability in the AMIP run is the result of external forcing (changing SST, sea-ice) and internal dynamics. With a single run, it is difficult to determine which factor is more important; more runs are necessary. While we don't have an ensemble of runs, we do have a perturbed run which overlaps the last three years of the AMIP run (1986-1988). Three months before the overlap period started, the perturbation run was started using the model state from the AMIP run. To perturb the run, the SST was set to zero Celcius for 24 hours. This perturbation is large enough to alter the evolution of the model run but has the advantage of starting near an actual model state. Allowing three months for the perturbed run to lose its memory of the forcing, the last three years of this integration can be considered to be the result of the AMIP model running from slightly different initial conditions.

Beside the perturbation run, The 10-year AMIP run has also been extended four years to the end of 1992. As a result, the 14-year run covers a period where 3 warm ENSO events were observed, whereas only two warm events were observed during the AMIP period. The data for the extended and perturbed run are available from NMC.

7 Lessons

AMIP Run 3.1 consumed large amounts of computer resources (the model used approximately 240 Cray CPU hours), and generated more than 15 gigabytes of output. This output was managed by writing small, general purpose programs which were easy to test, debug and use. These same programs can be used for future projects by simply recompiling them with the new model resolution.

We found that a comprehensive analysis of shorter runs was very helpful in producing the official AMIP run. These shorter runs not only helped check the various components of the run but also revealed some model problems. For example, large sensible heat fluxes at some locations in Canada led to changing the land-sea mask as described in Section 2. Problems were also found in the climatological soil moisture used in the initial conditions. To generate this field, the model interpolated from a higher resolution soil moisture climatology ('Launcher' climatology) to the Gaussian grid of the model. Since the 'Launcher' climatology had no soil moisture over the oceans and 15 cm soil moisture over lakes, problems arose when interpolating near bodies of water. For example, the initial interpolated soil moisture was zero in Japan and nearly 15 cm in the Great Lakes region. Although both values are unrealistic, no changes were made in the interpolated soil moisture since no 'real' climatology exists (aside from a few locations).

Constant monitoring of the integration was also essential. When some programs fail, they only give a single line warning in a 10000 line output. Initially the AMIP run was monitored by plotting several monthly fields. This monitoring, while informative, could not detect some problems. We found that the daily time series of the globally averaged 500 mb height was a better diagnostic. This diagnostic uncovered a problem that was not detected in the monthly fields. A temporary file disappeared which caused an obvious change in the global 500 mb heights, even though the monthly means remained within their natural range of variability.

8 Early Results

Although the analysis of the AMIP Run 3.1 is in its initial stages, some interesting results can already be noted. Fig. 1, shows the model and observed values of the globally averaged $U \cdot \cos(lat)$ at 200 mb (proportional to the angular momentum at 200 mb). The simulated value is less than the observed primarily to the easterly bias in the tropical winds. Removing the the 9-year climatologies (1980-1988) from both curves (Fig. 2), we see that the model captures the low-frequency variability quite well.

One standard measure of ENSO is the Southern Oscillation Index (SOI). A simple SOI is the difference in standardized sea level pressure (SLP) between Tahiti and Darwin. To standardize the SLP, we removed the 9 year climatologies and standardized by using the monthly variance. In Fig. 3, we show an SOI for both the model and observations. For clarity and following common practice, the indices were filtered by a five-month running mean. The curves show a strong similarity, the 9 year correlation was 0.77, showing that the model successful reproduced one aspect of ENSO. However, if we plot the difference in anomalous SLP (unstandardized; i.e., in mb), we see that the model has much less variability than observed (Fig. 4). This result has implications for using this version of the MRF in a coupled atmosphere-ocean model. Such a model would have difficulty in simulating an ENSO event because some important atmosphere-ocean feedbacks would be too small.

9 Data Availability

Data generated by NMC's AMIP run are available to the general scientific community. Most of the fields can be obtained and used quite easily. The full 6-hour history tapes require special arrangements because of their size (9 gigabytes). The available fields are,

- monthly averages and variances on a Gaussian grid (see Appendix A)
- daily T21 heights, vorticity, divergence, and virtual temperature at standard pressure levels 1000–50 mb
- daily T21 vertical velocity at standard pressure levels 1000–100 mb
- daily T21 relative humidity at standard pressure levels 1000–300 mb
- 6 hour Gaussian grid outgoing long-wave radiation (OLR), snow depth, precipitation, ground temperature, soil moisture, latent heat flux, sensible heat flux, and land/sea/sea-ice mask
- 6 hour history files

Except for the last two items, the files are in IEEE format which is compatible with most workstations. The last two items will require special conversion for other systems besides the Cray. The files will be converted upon request.

10 Acknowledgments

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11 Appendix A: Archived Monthly Fields

The monthly means and variance fields were calculated using a six hour sampling frequency. Note that in addition to the required AMIP fields, there are several extra fields.

- cross-sections of cloud fraction, relative humidity, specific humidity, temperature, zonal winds, meridional winds
- meridional streamfunction
- zonal winds (mean, variances) at 200 mb, 850 mb
- meridional winds (mean, variances) at 200 mb, 850 mb
- velocity potential (mean, variances) at 200 mb, 850 mb
- stream function (mean, variances) at 200 mb, 500 mb, 850 mb
- geopotential height (mean, variances) at 200 mb, 500 mb, 850 mb
- temperature (mean, variances) at 200 mb, 850 mb
- specific humidity (mean, variances) at 200 mb, 850 mb
- sea-level pressure (mean, variance)
- total and convective precipitation
- precipitable water
- zonal and meridional surface wind stress
- snow depth
- surface sensible heat flux

- surface evaporation
- soil water content
- surface ground temperature (mean, variance)
- surface air temperature (mean, variance)
- cloud fraction (random overlap)
- short and long wave Cloud Forcing II of the atmosphere
- short and long wave Cloud Forcing II at the surface
- short and long wave Cloud Forcing II at the top of the atmosphere
- atmospheric Cloud Forcing II
- outgoing short and long wave flux at the surface
- net short and long wave flux at the surface
- outgoing short and long wave flux at the top of the atmosphere
- net short and long wave flux at the top of the atmosphere

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Fig. 1. Globally averaged U·cos(lat) at 200 mb for AMIP 3.1 (solid line) and observations (dashed line).

Fig. 2. Similar to Fig. 1 except the 1980-1988 climatologies were removed from both curves.

Fig. 3. Southern Oscillation Index for both AMIP 3.1 (solid line) and observations (dashed line). Shown are the 5-month running mean of the difference in the standardized sea-level pressure between Tahiti and Darwin. Data from 1980-1988 were used to calculate the means and variances.

Fig. 4. As in Fig. 3 except the data were not standardized.

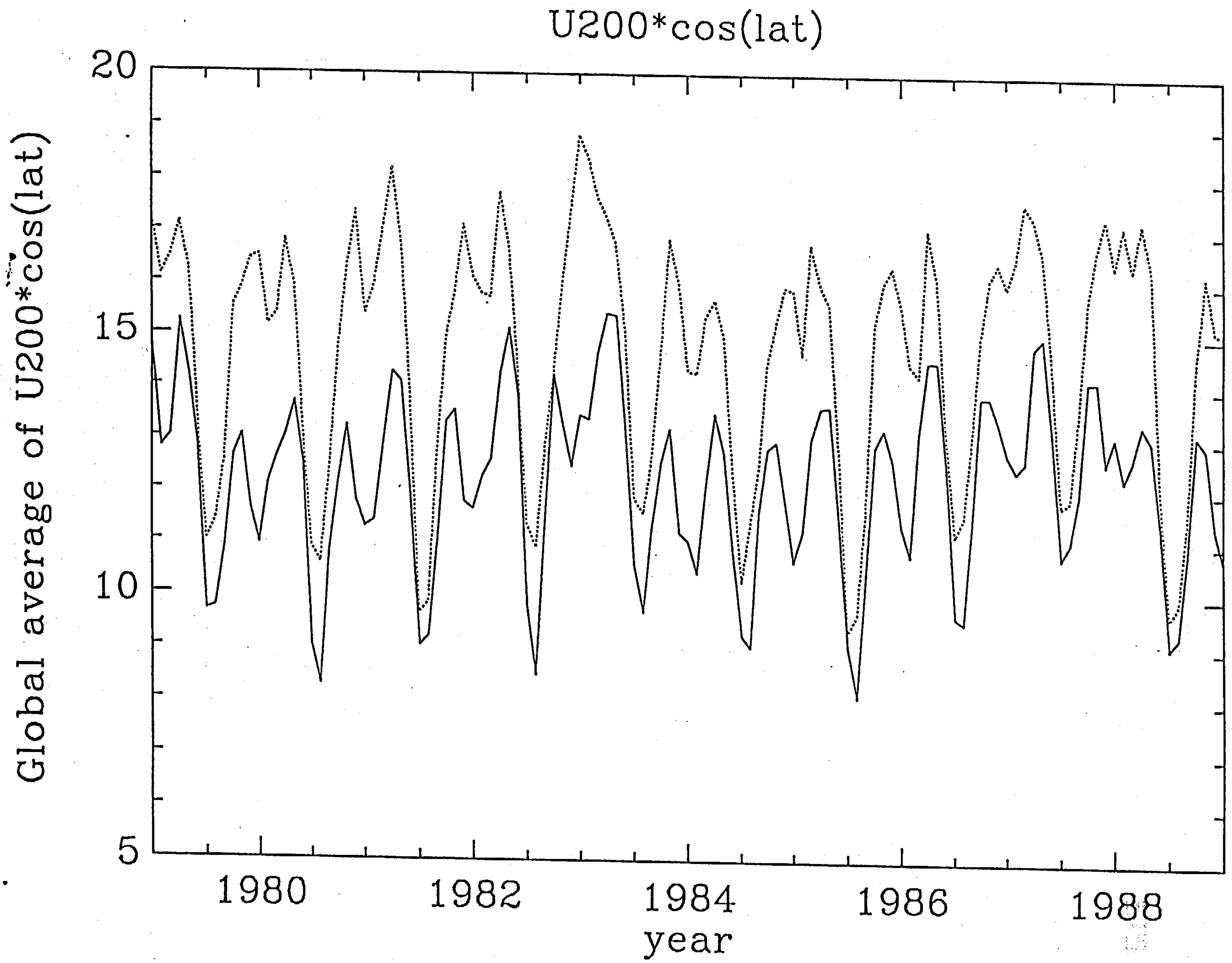
U200*cos(lat)
Global average of U200*cos(lat)
20
15
10
5
1980
1982
1984
1986
1988
year

Fig. 1

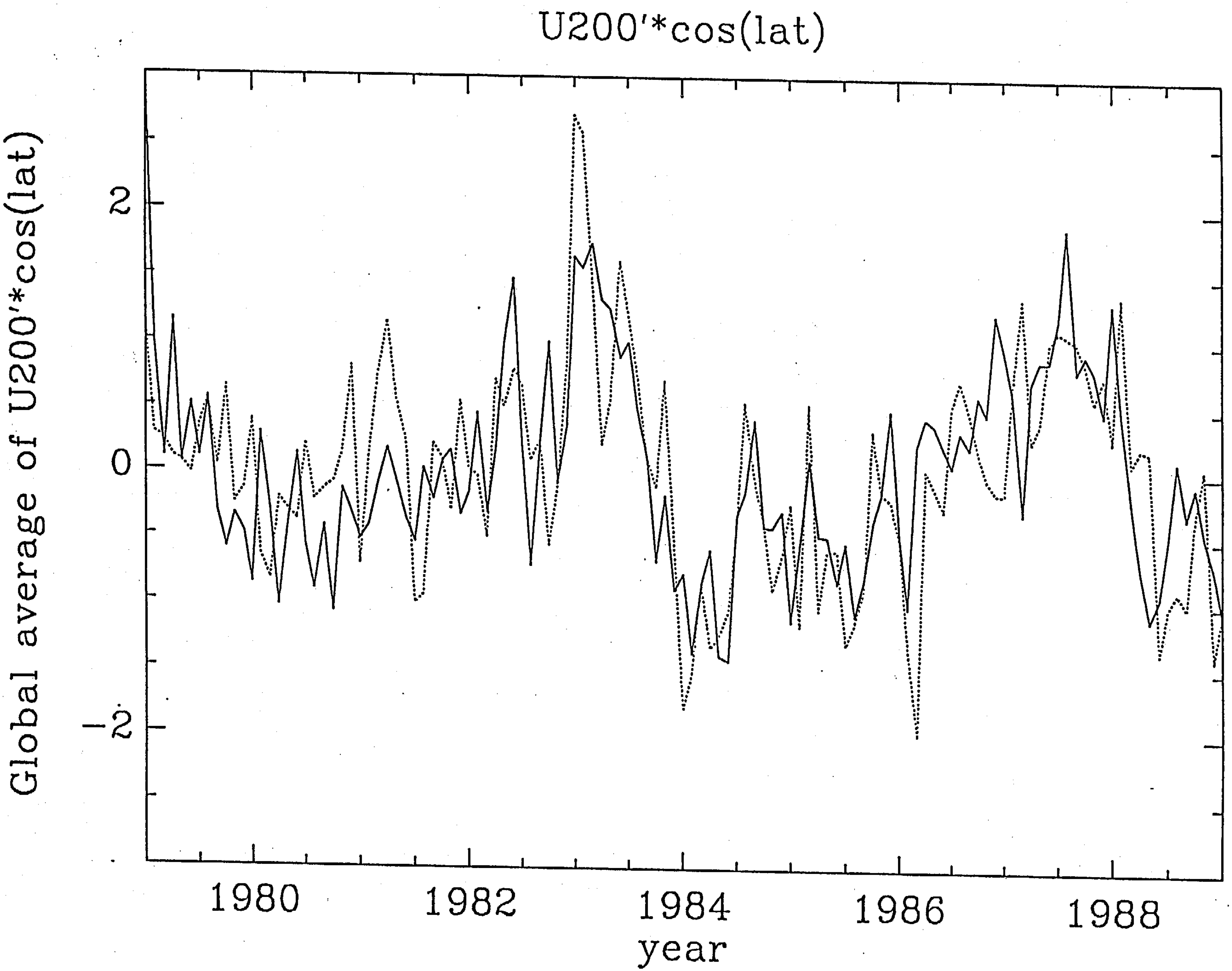
U200'*cos(lat)
Global average of U200'*cos(lat)
2
0
−2
1980
1982
1984
1986
1988
year

Fig. 2

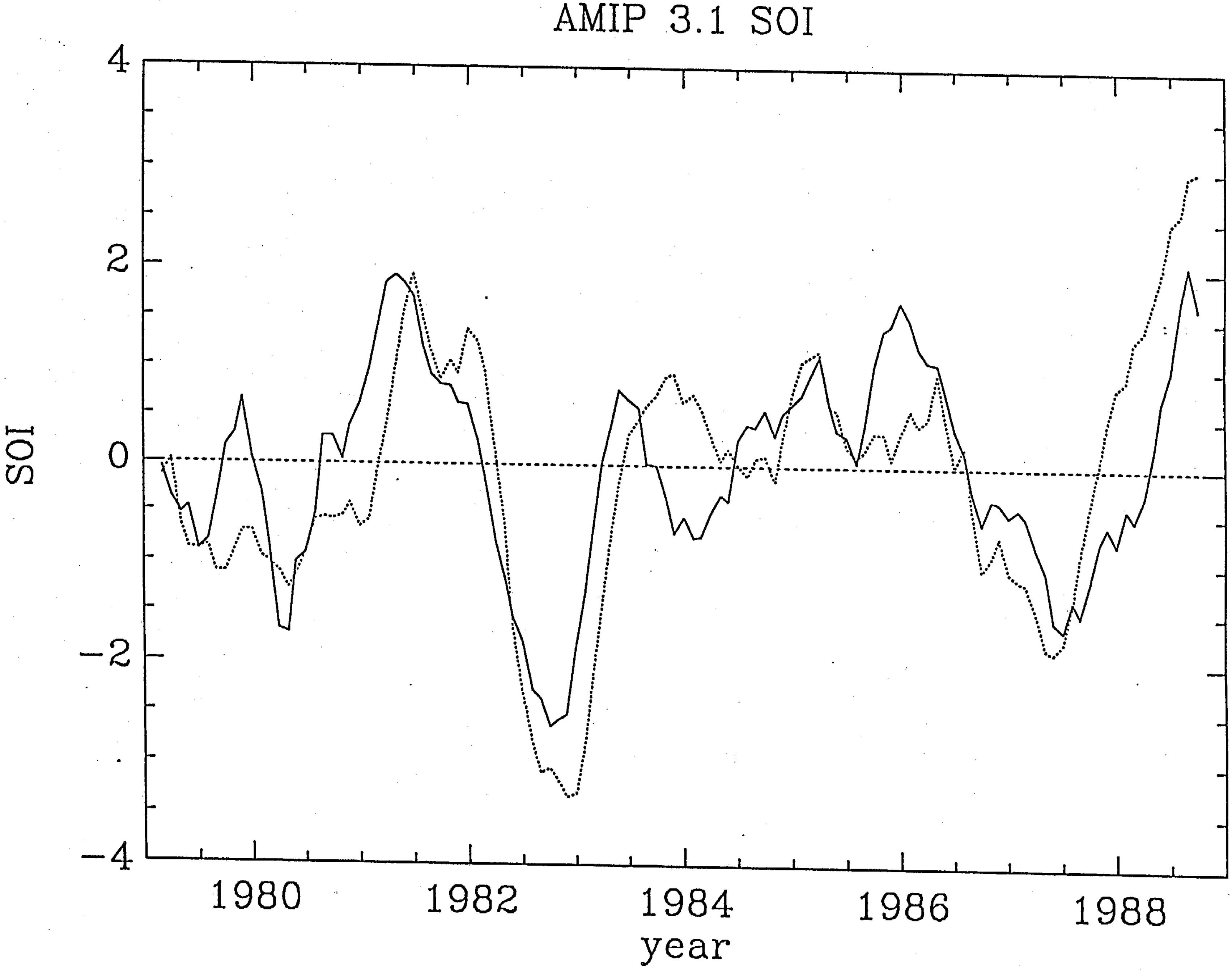

Fig. 3

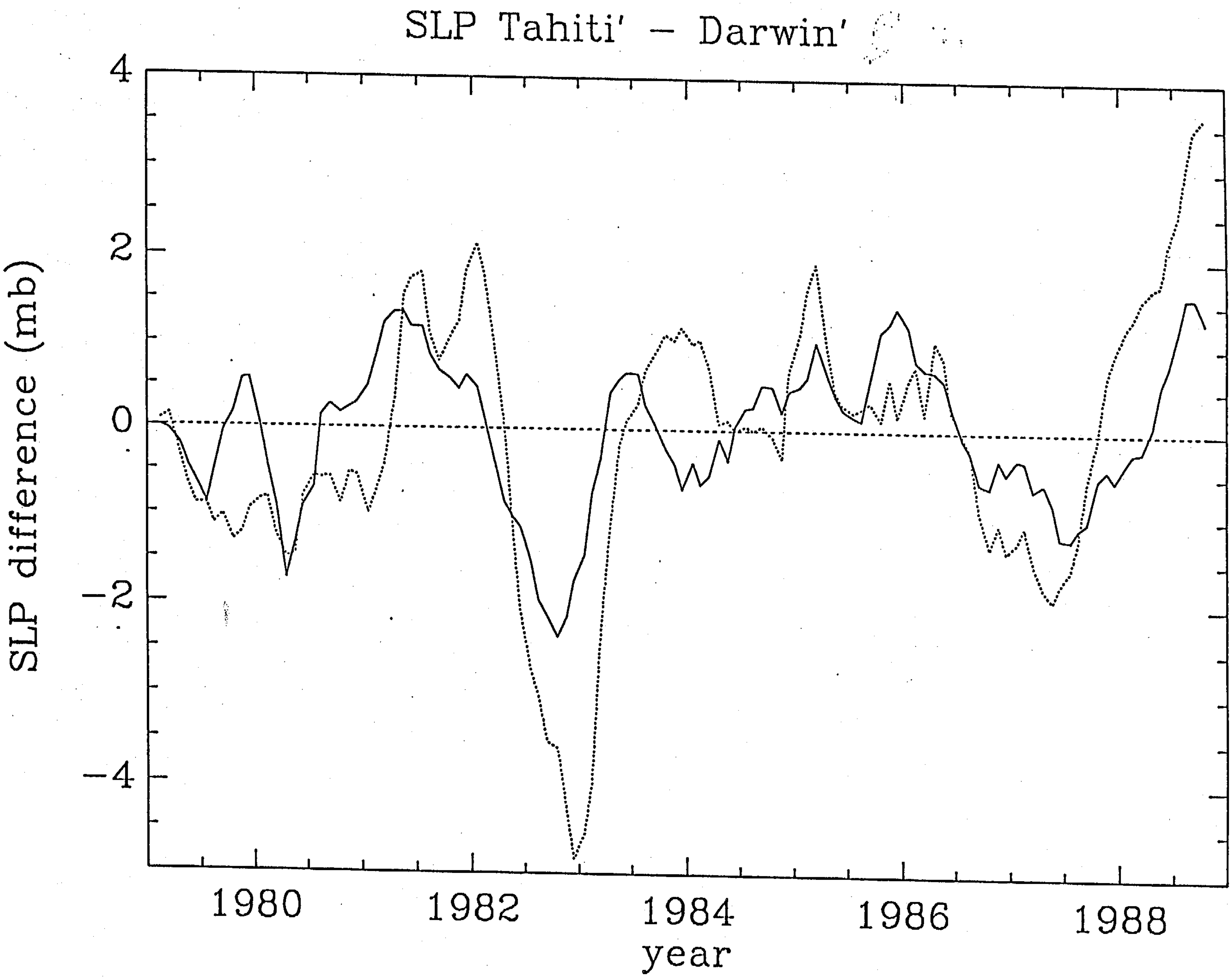
SLP Tahiti' – Darwin'
SLP difference (mb)
4
2
0
−2
−4
1980
1982
1984
1986
1988
year

Fig. 4