On North Pacific Climate Variability

M. Latif

Max-Planck-Institut für Meteorologie

Bundesstraße 55, D-20146 Hamburg, Germany

email: latif@dkrz.de

submitted to J. Climate

23 February 2001

Abstract

The climate variability in the North Pacific is re-investigated by using the latest Hadley Centre SST analysis covering the period 1870-1998 and other observational datasets. The main result of this study is that the North Pacific decadal and multi-decadal variability on time scales from 10-50 years evolves independently of the variations in the tropical Pacific, so that this kind of variability must be regarded as internal to the North Pacific.

1. Introduction

The origin of the decadal and interdecadal variability observed in the North Pacific region is still a matter of intense scientific debate. On the one hand, Trenberth and Hurrell 1994, Graham 1994, Zhang et al. 1997 and Gu and Philander 1997, for instance, argue that the North Pacific decadal variability is forced by variations in the tropical Pacific through atmospheric teleconnections. On the other hand, Latif and Barnett 1994 and Barnett et al. 1999 claim by analysing mostly model simulations that its origin is in the North Pacific itself and that air-sea interactions within the North Pacific climate system are important. Here I investigate the origin of the North Pacific low-frequency variability at timescales longer than 10 years by analysing the new Hadley Centre sea surface temperature (SST) analysis which covers the last 130 years. The analysis of the SSTs is corroborated by the analysis of other observational datasets. The paper is organised as follows. The data and statistical method are described in section 2. The main results are summarised in section 3. The paper is concluded with a discussion of the main findings in section 4.

2. Data and statistical techniques

The datasets used in this study are the latest Hadley Centre SST dataset covering the period 1870-1998 (Folland et al. 1999), the North Pacific sea level pressure (SLP) index as defined by Trenberth and Hurrell 1994 covering the period 1900-2000, and the zonal wind stresses from the COADS dataset covering the period 1945-1994 (da Silva et al. 1994). Annual mean values were computed for the SSTs and zonal wind stresses. The North Pacific SLP index is defined for the winter season (NDJFM) only.

The analysis of the North Pacific decadal variability is based on the Principal Oscillation Pattern (POP) analysis (Hasselmann 1988, Storch et al. 1995) which is designed to extract the dominant modes of variability from a multi-variate dataset by fitting a simple linear dynamical model (AR-1 process) to the data. The POP method has been chosen as opposed to the EOF technique because it does not suffer from the orthogonality constraint and does not maximise the variance. The POP analysis was applied to the annual mean SSTs. The considered domain includes all three ocean basins and extends from 30^{o}S to 60^{o}N. No further manipulation was applied to the SSTs prior to the POP analysis.

3. Results

The North Pacific sea level pressure (SLP) index (averaged over the region 30^{o}N-65^{o}N, 160^{o}E-140^{o}W) as defined by Trenberth and Hurrell 1994 is shown in Fig. 1. Several features in this index (hereafter NP SLP index) can be noted. There is a strong trend towards lower values during the twentieth century. Superimposed on this trend, one can observe strong decadal (~20 years) and even multi-decadal (~50 years) variabilities. Interannual variability is also apparent which is known to be related, at least partly, to the El Niño/Southern Oscillation (ENSO) phenomenon.

The POP analysis yields several modes that are of importance here. The leading mode explaining about 26% of the total variance is closely associated with the ENSO phenomenon (not shown). This mode is complex (oscillatory) in nature and has a rotation period of about 5 years.

The real part time series of this POP mode, for instance, has a correlation of about -0.9 with the traditional Niño-3 SST anomaly index (5^oN-5^oS, 150^oW-90^oW) , which demonstrates its close connection to the ENSO phenomenon. The next energetic POP mode explaining about 17% of the total variance has strong loadings in the North Atlantic. This mode appears not to be relevant within the context of this paper, since it is very similar to the one described by Deser and Blackmon 1993 and is probably related to changes in the measurement techniques, as hypothesised by Deser and Blackmon 1993.

The next energetic POP mode which I refer to as the “North Pacific mode” is a real (standing) mode and exhibits highest explained variances in the North Pacific, with values exceeding 50% near the dateline (Fig. 2). This mode is clearly confined in its extent to the North Pacific, since it does not explain much variance elsewhere. In particular, the North Pacific mode does not have any significant relationship to the tropical Pacific. The pattern of the North Pacific mode is characterised by a tongue of SST anomalies originating in the subtropics in the west and extending in a northeastward direction across the Pacific basin. This anomaly is surrounded by anomalies of opposite sign.

The time evolution of the North Pacific mode is closely related to that of the (detrended) NP SLP index of Trenberth and Hurrell 1994 (Fig. 3). The correlation of the two time series amounts to about -0.6, which is significant at the 99% level. Thus, the two indices are apparently describing the same phenomenon. The phase relationship between the North Pacific SST (as described by the North Pacific mode) and the SLP (as described by the NP SLP index) is such that anomalously low (high) SLP overlays anomalously cold (warm) SST, which is consistent with the modeling study of Latif and Barnett 1994 and indicating a Palmer and Sun 1985 -type behavior. One additional feature that deserves attention is the fact that there is almost no trend in the POP time series of the North Pacific mode. Thus, it is reasonable to assume that the trend in the SLP index is not forced by variations in the North Pacific. This point is further addressed below.

The regression pattern of the zonal wind stress component associated with the POP time series of the North Pacific mode confirms that the North Pacific mode is mainly originating in the North Pacific itself. Strong loadings in the associated zonal wind stress pattern and relatively high explained variances are found only in the North Pacific region (Fig. 4). Anomalously strong westerlies are observed over the anomalously cold SST. This is consistent with the anomalously low values in the NP index that go along with anomalously cold SSTs and indicates an intensified Aleutian low. The anomalously strong westerlies cool the ocean due to increased heat loss to the atmosphere and enhanced mixing in the ocean, as shown by Miller et al. 1994. Furthermore, Latif and Barnett 1994 have shown that anomalously cold North Pacific SSTs lead to stronger westerlies over the North Pacific, so that the ocean and atmosphere may reinforce each other on decadal timescales.

In the next step, a cross spectral analysis has been performed between the time series of the North Pacific POP mode and that of North Pacific SLP. It should be noted, however, that both the index of the North Pacific mode and the NP SLP index are relatively short, considering the decadal timescales. A Bartlett procedure to compute the spectra has been used with a window of 32 years. The cross spectral analysis of the two time series yields the result that the two spectra are very similar. In particular, both spectra exhibit enhanced variance at the 20-30 year timescale (Fig. 5), and they are highly coherent at these decadal timescales (not shown). Similar results are obtained when the window width is varied, so that the results appear to be stable. However, if the window width is increased the decadal peak seen in Fig. 5 is split into one multi-decadal (~50 years) and one decadal (~20 years) peak, as described below. Although the significance of these results can be questioned given the short record lengths, they nevertheless support the hypothesis of Latif and Barnett 1994 that there exists a mode with a decadal timescale that originates in the North Pacific.

This hypothesis is supported further by a second cross spectral analysis between the North Pacific mode and the real part of the ENSO POP mode which is used as an ENSO index. The spectrum of the ENSO index does not show any peak at the 20-30 year timescale (not shown) and the ENSO index does not exhibit any significant coherence with the North Pacific mode at these timescales (Fig. 6). These results are also obtained when using the Niño-3 SSTA index instead of the time series of the real part of the ENSO POP mode. Thus, the decadal variations in the North Pacific cannot be explained by decadal changes in the ENSO statistics. This is also supported by the low correlation of the low-pass filtered (smoothed by a 5-year running mean) Niño-3 SSTA and NP SLP indices which amounts to only about -0.35. There is, of course, highly significant coherence between the indices of the North Pacific and ENSO modes at interannual timescales (Fig. 6), but this connection does not extend to decadal timescales. Thus, both the POP analysis itself and the spectral and cross spectral analyses support the picture that North Pacific decadal and multi-decadal variability originates in the North Pacific itself and is not remotely forced by the tropical Pacific.

This conclusion is also supported by a Singular Spectrum Analysis (SSA), which is a principal component analysis in the time domain, of the North Pacific POP mode time series (Fig. 3). The three leading temporal (oscillatory) modes are: A multi-decadal mode with a period of about 50 years, the ENSO mode with a period of about 5 years, and a decadal mode with a period of about 20 years. Next, the SST anomaly correlation patterns were computed for each of the three SSA modes separately. The results (not shown) confirm the conclusion derived from the cross spectral analysis shown in Fig. 6 that no significant correlations exist between the North Pacific variability associated with the decadal (~20 year) and multi-decadal (~50 year) SSA modes and the SST anomalies in the tropical Pacific. Only SSA mode 2, the interannual (5-yr) ENSO mode, exhibits highly significant correlations with the tropical Pacific SST anomaly field. This suggests that the tropics may force the *interannual* variability over the North Pacific, but not the decadal and longer timescale variability.

4. Discussion

This short investigation indicates that the decadal and multi-decadal variability in the North Pacific is generated within the North Pacific itself. Connections to the tropics are weak and not statistically significant on timescales longer than 10 years. The results of all the different statistical analyses performed point towards this conclusion. A plausible explanation for these results is the “gyre mode” hypothesis of Latif and Barnett 1994. According to this hypothesis, the decadal variability over the North Pacific should exhibit three main characteristics: First, there should be a spectral peak at decadal timescales. Second, ocean and atmosphere reinforce each other, so that the SST and SLP anomalies should vary (temporally) in phase. Finally, anomalously cold SSTs should coexist with anomalously low SLP. The analysed observations indeed show these characteristics. This is, however, certainly not proof, since Latif and Barnett 1994 assign an important role to the subsurface memory of the North Pacific (see also Münnich et al. 1998 who addressed this question with a simple coupled model). Unfortunately, long observational records of ocean heat content do not exist, so that the hypothesis can only be verified by long coupled model simulations and not by observations. Some evidence from observations, however, does exist, as described by Zhang and Levitus 1997 and Venzke et al. 2000.

What determines the slow trend in the North Pacific SLP field, as seen in the NP index shown in Fig. 1? It has been shown that this trend can be simulated by an atmospheric general circulation model (AGCM) when only tropical SSTs are used to drive the AGCM (Hoerling et al. 2001), which indicates that the secular trend in the North Pacific SLP anomaly field is forced by the tropics. As shown above, this is consistent with the findings here, since the North Pacific mode itself does not exhibit any significant trend (Fig. 3). Thus, it is reasonable to assume that the North Pacific Ocean does not force the trend in the North Pacific SLP field. The eastern and central tropical Pacific SST, however, did warm by about $0.4^{o}C$ during the last 130 years, as witnessed by the trend in the Niño-3 SST anomaly index. A similar trend is seen in the time series of the ENSO POP mode. Thus, it is plausible that this warming trend in the tropical Pacific SST forced the downward trend in the North Pacific SLP field, in a similar way to El Niño events forcing a strengthening of the Aleutian low. It should be noted, however, that not only the tropical Pacific but also the tropical Indian and Atlantic Oceans warmed considerably during the analysed period. It is unclear if and how these other two tropical oceans affect the North Pacific Ocean. More detailed modeling studies are necessary to address this question in greater detail.

The existence of a decadal mode in the North Pacific may be of large importance to the predictability of decadal changes over the North Pacific and its adjacent land masses. One caveat in this study is that the observational records are rather short, so that the analyses presented here remain inconclusive to some extent. Reliable proxy records which can be used to address the timescale issue may help in the identification of such a decadal mode in the North Pacific.

Acknowledgements

The author would like to thank Drs. Scot Johnson and Reiner Schnur for their comments on an earlier version of the paper. This work was supported by the European Union's PREDICATE programme.

References

Barnett, T. P., D. W. Pierce, R. Saravanan, N. Schneider, D. Dommenget, and M. Latif, 1999: Origins of the midlatitude Pacific decadal variability. Geophys. Res. Lett., 26, 1453-1456.

da Silva et al., A. M., C. C. Young, and S. Levitus, 1994: Atlas of surface marine data. Available from NODS, NOAA/NESDIS E/OC21, Waschington DC 20335, USA.

Deser, C. and M. L. Blackmon, 1993: Surface climate variations over the North Atlantic Ocean during winter: 1900-1989. J. Climate, 6, 1743-1753.

Folland, C. K., D. E. Parker, and A. W. Colman, 1999: Large scale modes of ocean surface temperature since the late nineteenth century. In "Beyond El Niño", A. Navarra (Ed.), Springer-Verlag, Berlin Heidelberg New York, 73-102.

Graham, N. E., 1994: Decadal-scale climate variability in the tropical and North Pacific during the 1970s and 1980s: observations and model results. Climate Dynamics, 10, 135-162.

Gu, D. and S. G. H. Philander, 1997: Interdecadal climate fluctuations that depend on exchanges between the tropics and the extra-tropics. Science, 275, 805-807.

Hasselmann, K., 1988: PIPa and POPs - The reduction of complex dynamical systems using principal interaction and oscillation patterns. J. Geophys. Res., 93, 11015-11021.

Hoerling, M. P., J. W. Hurrell, and T. Xu, 2001: Tropical origins for recent North Atlantic climate change. Science, submitted.

Latif, M. and T. P. Barnett, 1994: Causes of decadal climate variability over the North Pacific and North America. Science, 266, 634-637.

Miller, A. J., D. R. Cayan, T. P. Barnett, N. E. Graham, J. M. Oberhuber, 1994: Interdecadal variability of the Pacific Ocean: model response to observed heat flux and wind stress anomalies. Climate Dynamics, 9, 287-302.

Münnich, M., M. Latif, S. Venzke, and E. Maier-Reimer, 1998: Decadal oscillations in a simple coupled model. J. Climate, 3309-3319.

Palmer, T. N. and Z. Sun, 1985: A modeling and observational study of the relationship between sea surface temperature in the northwest Atlantic and the atmospheric general circulation. Quart. J. Roy. Meteor. Soc., 111, 947-975.

Storch, H., G. Bürger, R. Schnur, and J.-S. von Storch, 1995: Principal Oscillations Patterns: A review. J. Climate, 8, 377-400.

Trenberth, K. E. and J. W. Hurrell, 1994: Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics, 9, 303-319.

Venzke, S., M. Münnich, and M. Latif, 2000: On the predictability of decadal changes in the North Pacific. Climate Dynamics, 16, 379-392.

Zhang, R.-H. and S. Levitus, 1997: Structure and cycle of decadal variability of upper ocean temperatures in the North Pacific. J. Climate, 10, 710-727.

Zhang, Y., J. M. Wallace, and D. S. Battisti, 1997: ENSO-like interdecadal variability: 1900-93. J. Climate, 10, 1004-1020.

Figure Captions

Figure 1: North Pacific SLP index (averaged over the region 30^{o}N-65^{o}N, 160^{o}E-140^{o}W) as defined by Trenberth and Hurrell 1994.

Figure 2: Pattern (contours) and explained variances (color) of the North Pacific POP mode.

Figure 3: Time series of the North Pacific POP mode (black curve). Shown is also for reference the (detrended) North Pacific SLP index (red curve). Both time series were normalised with their respective standard deviations.

Figure 4: Accociated regression pattern of the zonal wind stress anomaly field to the POP time series shown in Fig. 3. The pattern (N/m^2) is given by the countours and the explained variances by the color.

Figure 5: Spectra of the North Pacific POP time series (black curve) and the North Pacific SLP index (red curve). A Bartlett procedure was used with a window of 32 years, yielding 8 degrees of freedom.

Figure 6: Coherence squared spectrum of the time series of the real part of the ENSO POP mode and that of the North Pacific POP mode. A Bartlett procedure was used with a window of 32 years, yielding 8 degrees of freedom.

Figure 1

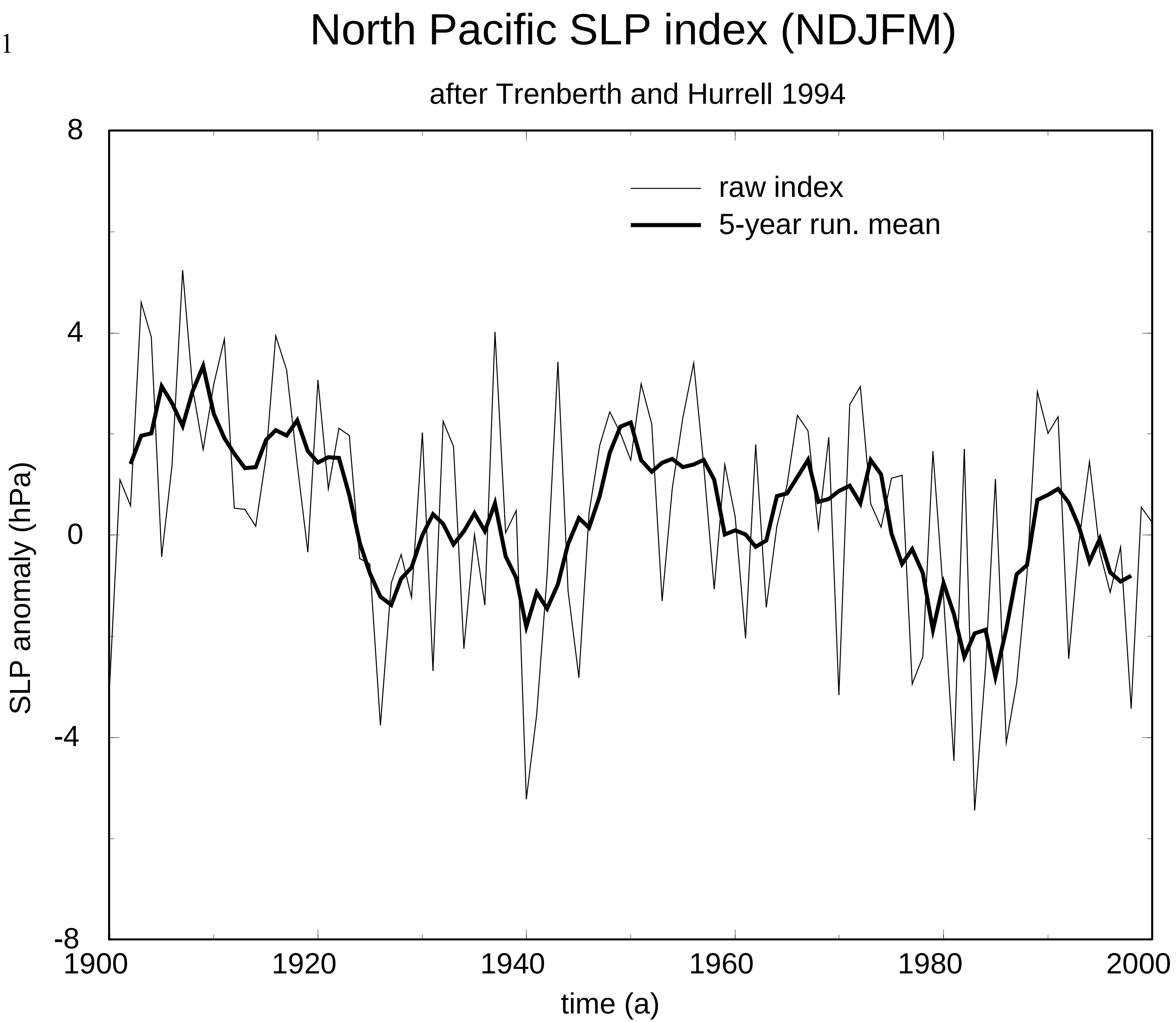

North Pacific SLP index (NDJFM)
after Trenberth and Hurrell 1994
raw index
5-year run. mean
SLP anomaly (hPa)
8
4
0
-4
-8
1900
1920
1940
1960
1980
2000
time (a)

Figure 2

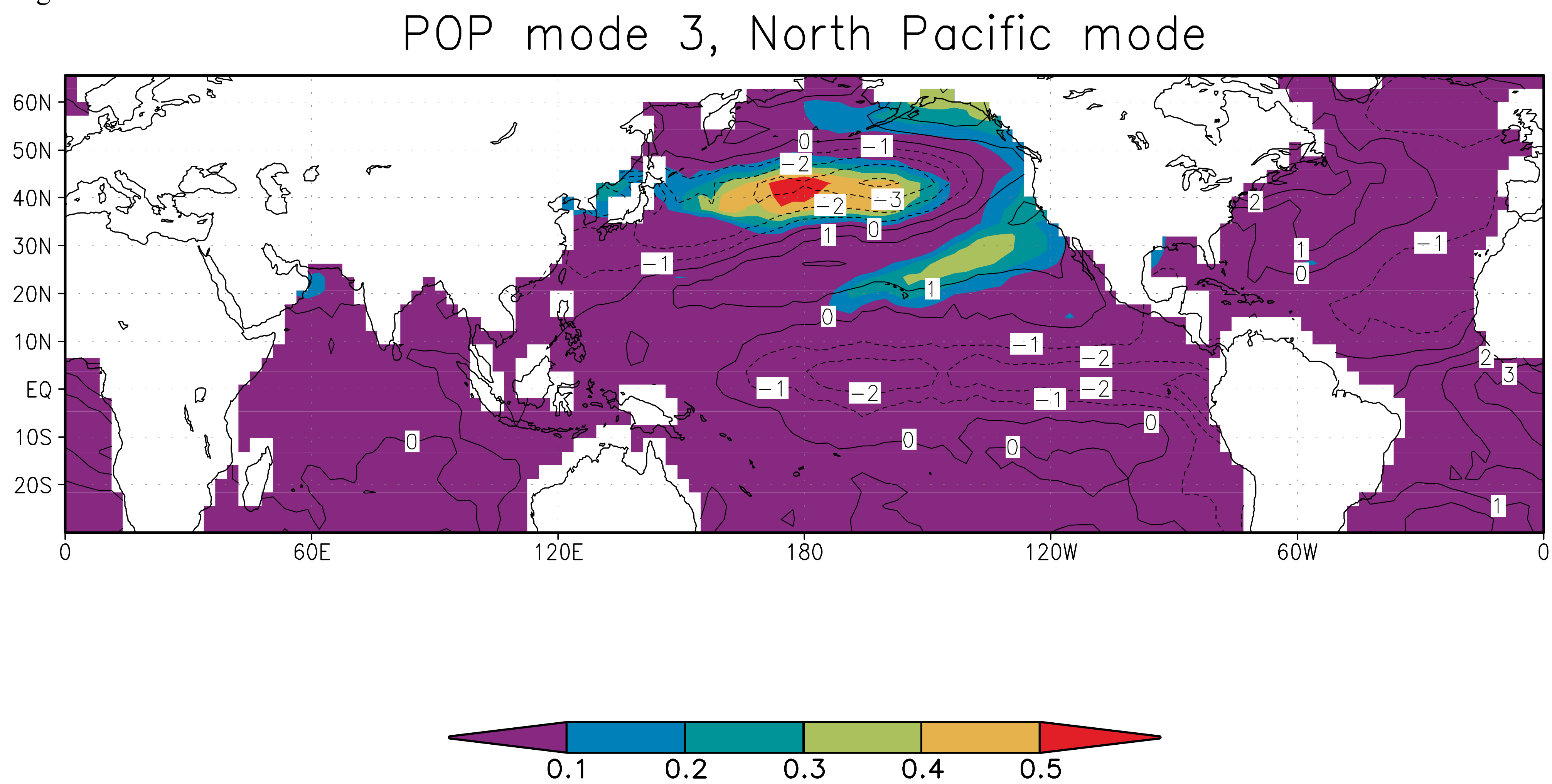

POP mode 3, North Pacific mode
60N
50N
40N
30N
20N
10N
EQ
10S
20S
0
60E
120E
180
120W
60W
0
0.1
0.2
0.3
0.4
0.5

Figure 3

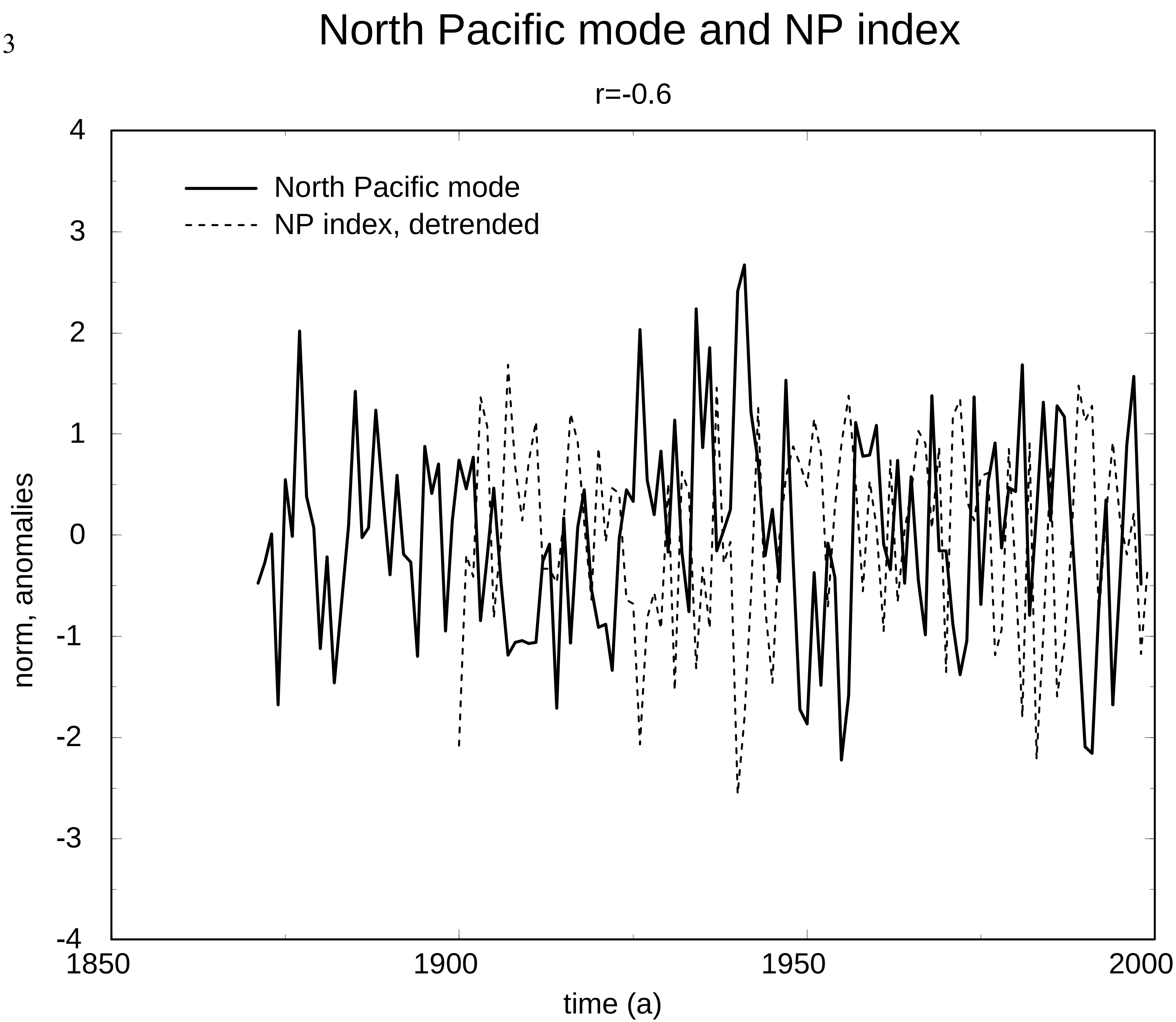

North Pacific mode and NP index
r=-0.6
North Pacific mode
NP index, detrended
norm, anomalies
4
3
2
1
0
-1
-2
-3
-4
1850
1900
1950
2000
time (a)

Figure 4

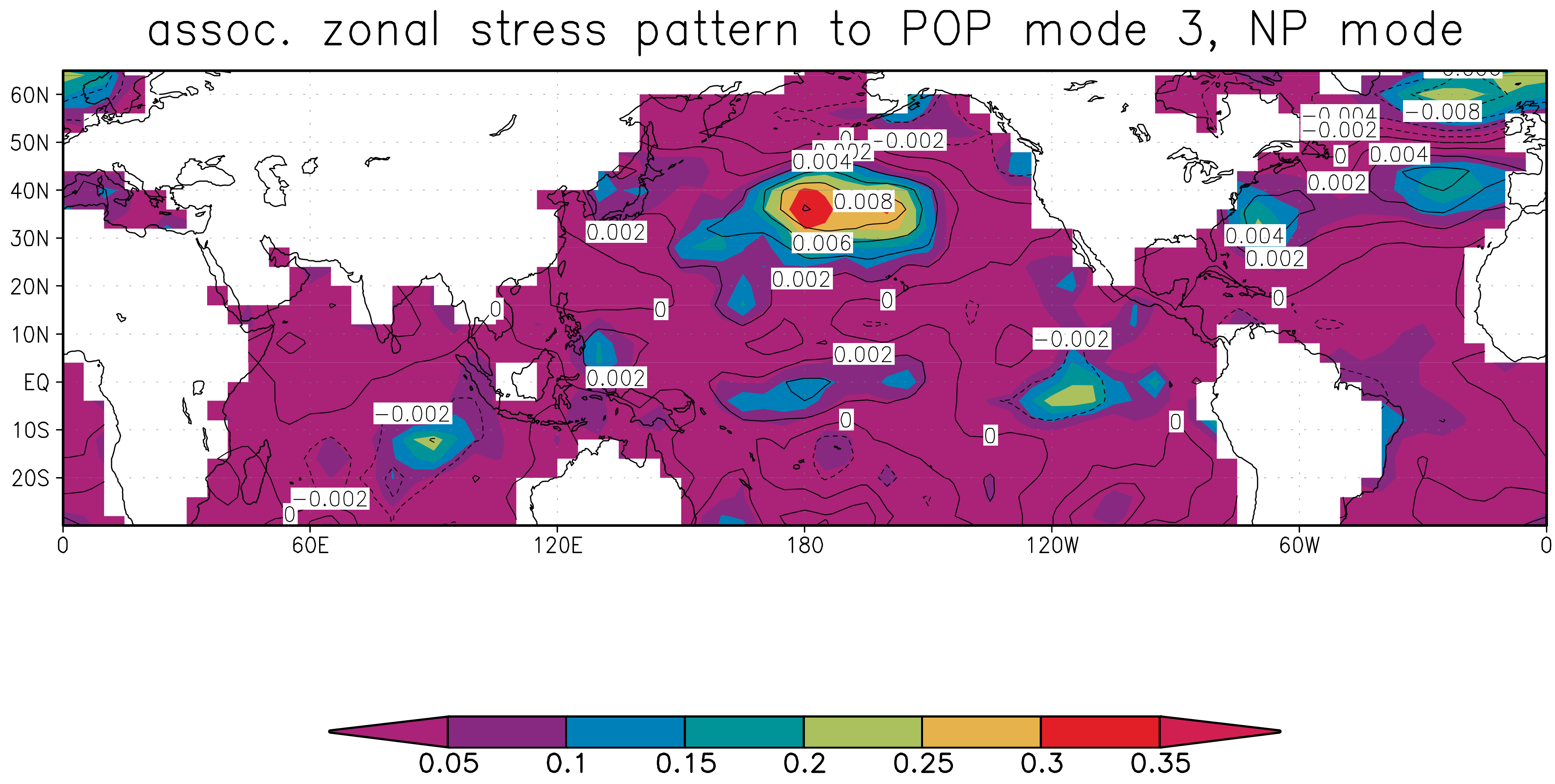

assoc. zonal stress pattern to POP mode 3, NP mode
60N
50N
40N
30N
20N
10N
EQ
10S
20S
0
60E
120E
180
120W
60W
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35

Figure 5

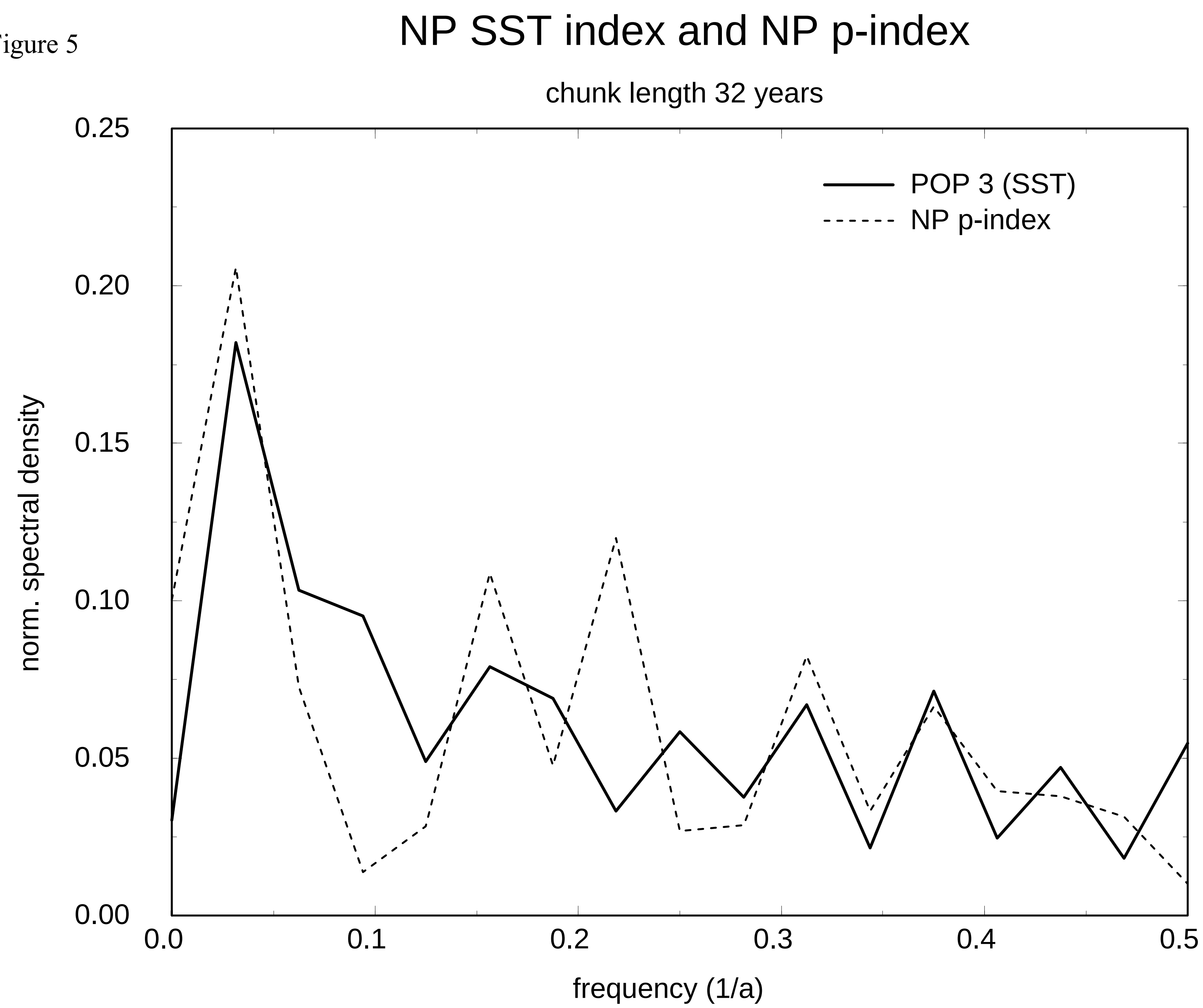
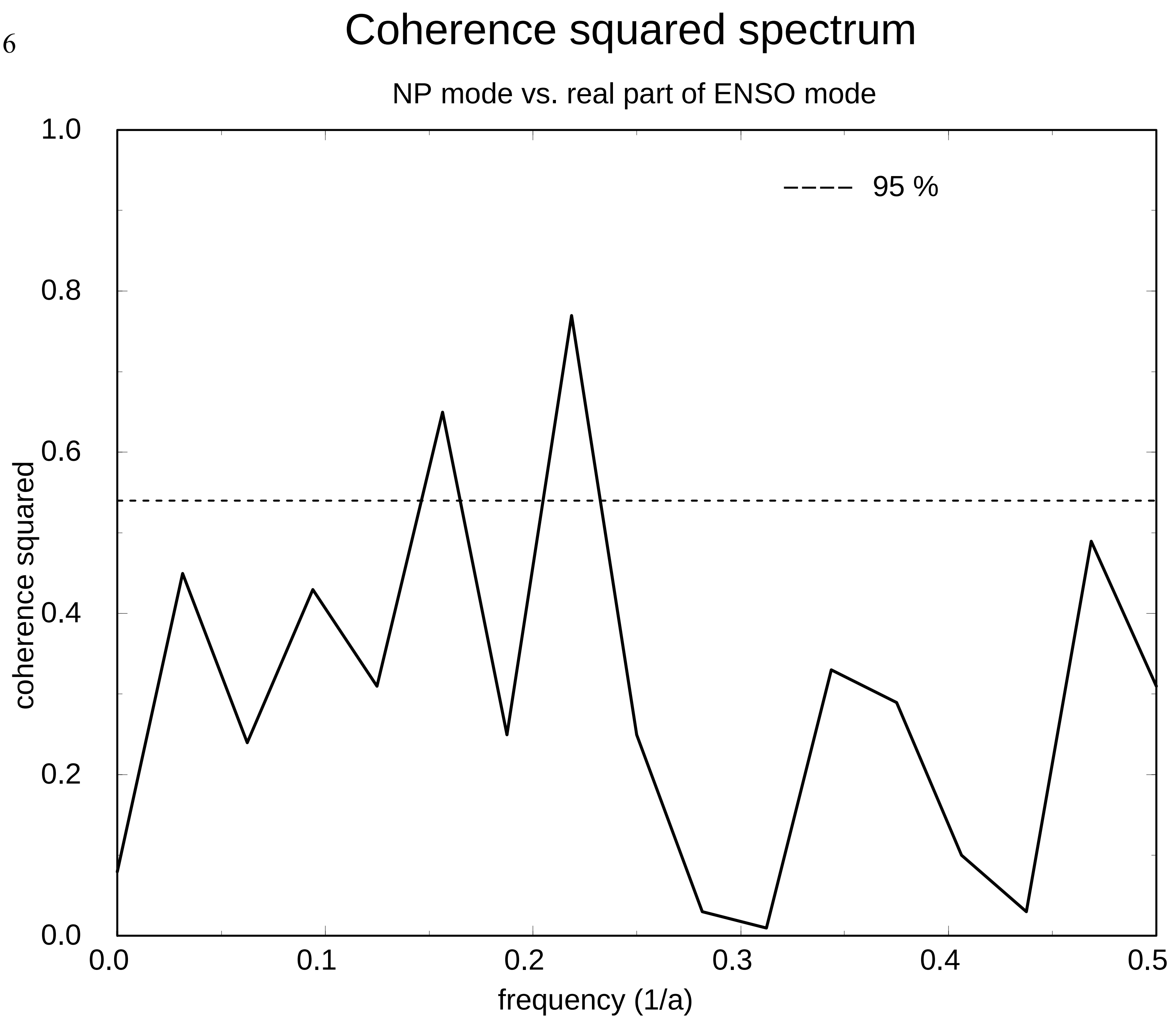

NP SST index and NP p-index
chunk length 32 years
POP 3 (SST)
NP p-index
norm. spectral density
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
0.3
0.4
0.5
frequency (1/a)

Figure 6



Coherence squared spectrum
NP mode vs. real part of ENSO mode
95 %
coherence squared
frequency (1/a)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5