Evidence of the El Niño/La Niña Climatic Events in New Zealand Over the Last Century

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***Abstract* — We investigate interrelations between the mean sea level, sea surface temperature, atmospheric temperature and pressure at four tide gauges in New Zealand (Auckland, Wellington, Lyttelton, and Dunedin) with records available for over a century. The least-squares linear regression analysis is applied to estimate linear (secular) trends in the seasonally-adjusted time series. The detrended annual data are then used to analyze the influence of (quasi)periodical climatic cycles on the variability of these recorded data. In particular, we assess the presence of climatic signals attributed to: (i) the inter-annual El Niño Southern Oscillation (ENSO) cycle of El Niño/La Niña events (described by the Southern Oscillation Index - SOI) and (ii) the Inter-decadal Pacific Oscillation (IPO) of the long-term climate cycle occurring over whole Pacific Ocean with a typical period of about 15-30 years. The correlation analysis reveals the presence of significant signal of the SOI and IPO in the mean sea level data in Auckland. The signature of the SOI and IPO attenuates towards higher geographical latitudes. The SOI and IPO also significantly modulate sea surface temperature and atmospheric temperature variations, while the signatures of these climatic cycles are much less pronounced in atmospheric pressure fluctuations.**

Keywords - climate; pressure; mean sea level; temperature;

I. INTRODUCTION

Because of the lack of long-term (>60 years) tide gauge records at the southern hemisphere, the sea level data from tide gauges (TGs) in New Zealand represent an important part of the global dataset for the global sea level change. These data have been collected over a century at TGs located at the ports of Auckland, Wellington, Lyttelton and Dunedin. Hannah (1988 [1]) analysed the mean sea level trends in New Zealand from historical tidal data. A first analysis of the TG records was reported in Hannah (1990 [2]) with a limited, more detailed higher-frequency analysis of TG Auckland data by Goring and Bell (1999 [3]). Revised analysis of the long-term sea level change in New Zealand can be found in Hannah (2004 [4]). He applied the University of Hawaii's data processing strategy (Caldwell, 1998 [5]) to estimate the relative sea level trends at TGs in Auckland, Wellington, Lyttelton and Dunedin. According to Hannah (2004 [4]), relative sea levels in New Zealand have been rising at an average rate of 1.6 mm/yr over the last century. He also demonstrated that there is not yet evidence of any acceleration in relative sea level rise over the record period. In the most recent study, Hannah and Bell (2012 [6]) updated the average estimate of sea level rise in New Zealand at a rate of 1.7 mm/yr. They also showed that sea level variations in New Zealand are to some extent controlled by the climatic cycles of the ENSO and IPO.

The ENSO is a (quasi)periodic climate pattern that occurs across the equatorial Pacific with on average five-year intervals. It is characterized by sea surface temperature variations throughout the tropical eastern Pacific and the atmospheric pressure variations (at sea level) in the tropical western Pacific. The warm oceanic phase, El Niño, represented by a high atmospheric pressure in the western Pacific is coupled by the cold phase, La Niña, with a low atmospheric pressure in the western Pacific (Trenberth et al., 2007 [7]). Mechanism which causes this oscillation is not yet fully understood. The Southern Oscillation is the atmospheric component of El Niño. This component is an oscillation in (lowest troposphere) atmospheric pressure between the tropical eastern and the western Pacific Ocean waters. The intensity of the Southern Oscillation is empirically described by the Southern Oscillation Index (SOI). The SOI is calculated from the monthly or seasonal fluctuations in the atmospheric pressure difference between Tahiti and Darwin (Australia). El Niño episodes are typically associated with negative values of the SOI, while positive phases of the SOI usually correspond with La Niña episodes.

The Pacific Decadal Oscillation (PDO) is a pattern of Pacific climate variability that shifts phases on at least inter-

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decadal time scale, typically between 20 to 30 years (Biondi et al., 2001 [8]). The PDO is presented by warm or cool surface waters in the Pacific Ocean, north of 20°N. During a positive (warm) phase, the west Pacific becomes cool and part of the eastern ocean warms, while during a negative (cool) phase, the opposite pattern occurs. The IPO is the Pacific-wide manifestation of the PDO (cf. Mantua et al., 1997 [9]) with as much variance in the southern hemisphere of Pacific down to at least 55°S as in the northern hemisphere. It was demonstrated that the IPO is associated with decadal climate variability over parts of the Pacific, and to modulate inter-annual ENSO-related climate variability over Australia (Salinger et al., 2001 [10]). The IPO is characterized by multi-decadal variations (with a cycle between 15 to 30 years) of sea surface temperature similar to that of ENSO, but differing in several aspects. It exhibits a marked amount of symmetry about the equator and much less variance in the eastern-most Pacific. It also shows relatively more variance in the extra-tropics and the positive tropical part of the positive IPO pattern appears to extend further towards the tropical west Pacific. The concept of the IPO was introduced by Power et al. (1999 [11]) based on work by Folland et al. (1999 [12]). They have shown that the IPO modulated ENSO climate teleconnections to Australia. Folland et al. (2002 [13]) have shown the near equivalence of the PDO and IPO and some likely independent effects of the IPO relative to ENSO on the South Pacific Convergence Zone. The concept of the IPO has recently been facilitated in paleo-climatic studies of south Pacific by Linsley et al. (2004 [14]) and was related to tropical rainfall patterns by Meinke et al. (2005 [15]). The latter also compared the IPO influences to those of sea surface temperature on purely decadal time scales.

In this study we investigate the signature of the ENSO and IPO variability in the long-term records of mean sea level (MSL), atmospheric temperature (ATT) and pressure (PRS) collected at four TGs in Auckland, Wellington, Lyttelton and Dunedin. In addition, we extend our analysis for the sea surface temperature (SST) data determined in a proximity of these TG locations.

II. Data

The monthly MSL data at four TGs in New Zealand were prepared by Hannah and Bell (2012 [6]). The periods of sea level records used for the analysis are: 1899-2008 (TG Auckland), 1891-2008 (TG Wellington), 1901-2008 (TG Lyttelton) and 1899-2008 (TG Dunedin).

The monthly ATT and PRS data were retrieved from the National Climate Database of the National Institute of Water and Atmospheric Research (NIWA).

The monthly SST data were retrieved from the Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST); see Rayner et al. (2003 [16], 2006 [17]). The data from 1870 to 1985 were adjusted from the Comprehensive Ocean-Atmosphere Data Set (COADS, now ICOADS), which were ships and harbors data, and the data from 1985 to 2010 were received through the Global Telecommunications System and in particular through AVHRR (Advanced Very High Resolution Radiometer) sensors of the National Oceanic and Atmospheric Administration (NOAA).

III. Secular trends

We applied the linear regression analysis to estimate the relative sea level change at four TGs using the seasonally-adjusted MSL data. We applied the same procedure to estimate the linear secular trends in the seasonally-adjusted SST, ATT and PRS data over the periods corresponding to the availability of TG records. The estimated linear trends and their (1-σ) uncertainties are summarized in Table 1. The time series of seasonally-adjusted MSL, STT, ATT and PRS data and respective linear trends at four TG sites in New Zealand are plotted in Fig. 1.

TABLE I. Estimated linear trends in MSL, SST, ATT, and PRS data and their (1-σ) uncertainties at 4 TGs in New Zealand.

TG	Linear trend			
	MSL [mm/yr]	SST [°C/yr]	ATT [°C/yr]	PRS [hPa/yr]
Dunedin	1.2±0.1	0.002±0.40	0.016±0.5	0.008±1.0
Lyttelton	1.9±0.1	0.007±0.42	0.006±0.5	-0.004±1.3
Wellington	2.1±0.1	0.007±0.39	0.014±0.4	0.011±1.4
Auckland	1.5±0.1	0.009±0.39	0.013±0.4	0.016±1.5

The estimated rates of relative sea level rise are between 1.2±0.1 mm/yr (TG Dunedin) and 2.1±0.1 mm/yr (TG Wellington). Based on these estimates, the average rate of relative sea level rise in New Zealand is 1.7±0.1 mm/yr. This value very closely agrees with the average estimates by Hannah (2004 [4]) and Hannah and Bell (2012 [6]). However, rates of the relative sea level can differ considerably from the absolute sea level changes due to vertical land motion. Fadil et al. (2013 [18]) have shown that the 20th century absolute sea level along the coast of New Zealand has been rising at a rate of 1.46 ± 0.10 mm/yr.

The SST rates show descending tendency towards higher geographical latitudes. The surface temperature of subtropical seawaters at the upper North Island increases faster than around the South Island attributed to temperate zone. A largest rate of 0.009°C/yr was detected in Auckland. This temperature increase over the last century is more than three times faster than that in Dunedin (0.002°C/yr). The detected rates of STT in Wellington and Lyttelton are the same (0.007°C/yr). Significant secular trends in ATT and PRS were found at TGs in Dunedin, Wellington and Auckland. The estimated ATT rates are between 0.013 and 0.016°C/yr. The PRS rates at these three TGs are between 0.008 and 0.016 hPa/yr. The ATT rate of only 0.006°C/yr was detected at TG in Lyttelton and the PRS there decreased over the investigated period at a rate of -0.004 hPa/yr.

We further inspected the correlation of the MSL with SST, ATT and PRS variations. The correlation coefficients are summarized in Table 2.

TABLE II. CORRELATION OF MSL WITH SST, ATT AND PRS.

TG	Correlation of MSL with		
	SST	ATT	PRS
Dunedin	0.36	0.74	0.19
Lyttelton	0.51	0.75	0.14
Wellington	0.61	0.49	-0.11
Auckland	0.74	0.80	0.09

The largest correlation of 0.74 between the MSL and SST was found at TG Auckland, while further south this correlation is substantially weakening to 0.36 at TG in Dunedin. A significant correlation was also found between MSL and ATT (>0.49), with the maximum correlation of 0.80 at the TG in Auckland. In contrast, the correlation between MSL and PRS is low (<0.20).

IV. CORRELATION OF MSL, SST, ATT AND PRS WITH SOI AND IPO

We used the detrended and seasonally-adjusted MSL, STT, ATT and PRS data to investigate effects of the ENSO and IPO climatic cycles. For this purpose, we compared the MSL, STT, ATT and PRS time series with the empirical models of the SOI and IPO. The monthly SOI model is made available by the National Climate Centre of the Australian Bureau of Meteorology. In our analysis we used the seasonally-adjusted SOI model. The smoothed IPO time series was compiled by Folland (2008 [19]) based on using a 11-years period low-pass Cebyshev filter. For consistency, the detrended MSL, STT, ATT and PRS data were also smoothed applying the Southern Oscillation Model based on the 11-years period low-pass Cebyshev filter. The comparison of the MSL, STT, ATT and PRS time series with the SOI and IPO empirical models is shown in Figs. 2 and 3; the corresponding correlation coefficients are provided in Tables 3 and 4. Note that we plotted opposite values of IPO in Fig. 3.

TABLE III. CORRELATION OF THE SOI WITH MSL, SST, ATT AND PRS.

TG	Correlation with the SOI			
	MSL	SST	ATT	PRS
Dunedin	0.31	0.39	0.36	0.28
Lyttelton	0.11	0.50	0.37	0.28
Wellington	0.23	0.52	0.40	0.24
Auckland	0.47	0.60	0.58	0.03

TABLE IV. CORRELATION OF THE IPO WITH MSL, SST, ATT AND PRS.

TG	Correlation with the IPO			
	MSL	SST	ATT	PRS
Dunedin	0.08	0.71	0.48	0.28
Lyttelton	0.09	0.74	0.14	-0.06
Wellington	0.41	0.54	-0.01	-0.14
Auckland	0.52	0.42	0.17	-0.03

As seen in Fig. 2, the annual fluctuations of MSL are mainly within ±10 cm, with the maxima typically during La Niña and the minima during El Niño events. It is worth mentioning that the seasonal variations in MSL (±4 cm) are about two and a half times smaller than annual fluctuations attributed to these climatic cycles.

The annual fluctuations of the SST anomalies are mainly within ±1°C, with the maxima during La Niña and the minima during El Niño events. A similar range and temporal distribution is seen in the fluctuations of ATT and SST. The annual fluctuations of PRS were mostly within ±3 hPa over the investigated period.

The ATT variations are highly correlated with the SOI (see Table 3). Their correlation increases northwards with the values between 0.36 (TG Dunedin) and 0.58 (TG Auckland). A similar correlation of PRS with the SOI was found at the TGs Dunedin, Lyttelton and Wellington (between 0.24 and 0.28), while this correlation is almost completely absent at TG Auckland (0.03). The SST variations have the highest correlation with the SOI among the investigated quantities. This correlation again increases towards subtropical seas from 0.39 (TG Dunedin) to 0.60 (TG Auckland). The largest correlation between the MSL and SOI of 0.47 was observed at TG Auckland, while this correlation at TG Lyttelton is only 0.11.

The MSL variations are systematically correlated with the IPO at TGs in Auckland and Wellington (see Table 4), while this correlation at the two TGs situated at the South Island is less than 0.1. The correlation between the SST and IPO has an opposite prevailing spatial pattern. This correlation exceeds 0.7 at TGs in Dunedin and Lyttelton (at the South Island), while reaches not more than 0.54 at TGs in Auckland and Wellington (at the North Island). A relatively high correlation between the ATT and IPO of 0.48 was detected at TG in Dunedin, while elsewhere this correlation is less than 0.17. The correlation between the PRS and IPO is slightly more pronounced at TG Dunedin (0.28) with a substantially smaller (and negative) correlations at remaining three TGs.

Interestingly, the SST variations, in overall, are correlated with the IPO more than with the SOI (compare values in Tables 3 and 4). Moreover, the surface temperature of temperature seawaters (in a proximity of TGs Lyttelton and Dunedin) has more pronounced correlation (the correlation there exceeds 0.70) than in subtropical waters (in a proximity of TGs Auckland).

V. DISCUSSION

The coast of New Zealand is characterized by the presence of two distinct upper water masses. Sub-Antarctic water mass in the south and the Subtropical South-West Pacific water mass in the north. These two water masses merge in the Subtropical Convergence Region which is often characterized by comparatively rapid fluctuations in temperature and salinity between the warmer, more saline subtropical seawater and the cooler, less saline Sub-Antarctic seawater. The Sub-Antarctic water mass extends southwards approximately between 54 and 62°S. Further south, the Antarctic Convergence separates the Sub-Antarctic water from the colder Antarctic water. The Sub-Antarctic water mass is moving mainly towards the north-east. The Sub-Antarctic Front and associated cold Antarctic Circumpolar Current flow along the deep ocean floor to the east of the Campbell Plateau and Chatham Rise. The subtropical waters move mainly westwards and after reaching the Australian coast part of this movement is deflected southwards off the east coast, forming the East Australian Current. When the subtropical water transported by this current meets the Sub-Antarctic water which moves in the north-east direction, it turns and moves eastwards across the Tasman Sea as the Tasman Front, which marks the margin between the warm water of the Coral Sea and the colder water of the Tasman Sea. Along the coast of New Zealand, the seawater circulation is dominated by the East Auckland Current, East Cape Current, Westland Current, and D'Urville Current.

The spatial pattern of the sea surface topography and temperature has a prevailing pattern associated with a typical south-north horizontal temperature gradient and regional irregularities due to the coastal configuration and the geometry of the ocean bottom relief. In contrast, their temporal variations depend mainly on a particular respond of the oceanic currents to climatic events.

We found out that the MSL variations are significantly correlated with the ATT as well as SST, while the correlation with PRS is almost completely absent. However, there is not a substantial consistency between the rates of SST and MSL to be directly attributed to steric sea level rise due to thermal expansion (salinity variations were disregarded). A rate of the SST trend at TG in Auckland (0.009°C/yr) is about 3 times larger than the SST rate detected at TG in Dunedin (0.002°C/yr). In contrast, relative differences between the corresponding MSL trends at these two TGs are only of about 25%. Rates of the SST and MSL trends at TGs in Wellington and Lyttelton are, on the other hand, more similar; with the same SST rate of 0.007°C/yr at both these TGs and the MSL rates of 1.9 (TG Lyttelton) and 2.1 mm/yr (TG Wellington).

The MSL and SST variations in New Zealand can to some extent be explained by the ENSO and IPO climatic cycles. The apparent contribution of the IPO is pronounced at TGs in Wellington and Auckland, while a signature of the IPO in MSL variations at two TGs at the South Island is almost absent. The largest effect of the ENSO on the MSL variations is seen at TG in Auckland. The SST variations in New Zealand are more correlated than MSL with the SOI and IPO. A spatial distribution of these correlations is also more regular. The correlation between the SST and SOI decreases towards subtropical seas, while the correlation between the SST and IPO decreases. The ATT variations have a relatively high and systematic correlation with the SOI at all four TGs in New Zealand. In contrast, the signature of the IPO is surprisingly seen only at the TG in Dunedin. The signature of the ENSO and IPO in the PRS time series is very low compared to other investigated quantities.

VI. CONCLUTIONS

Except for the PRS trend at TG Lyttelton, the data have shown the increasing linear trend over the study period. The MSL trend at an average rate of 1.7±0.1 mm/yr confirmed findings of published results. Over the same period, the SST increased at an average rate of 0.006±0.1°C/yr. The ATT and PRS increased at an average rate of 0.012±0.1°C/yr and 0.008±0.1°hPa/yr respectively.

Annual fluctuations in MSL did not exceed ±10 cm. The annual STT and ATT fluctuations were typically within ±1°C and the PRS fluctuations were mostly within ±3 hPa.

Results of the correlation analysis (in Tables 3 and 4) revealed that a substantial portion of the MSL and SST variations in New Zealand can be explained by the ENSO and IPO climatic events.

The ENSO signature in these data is more pronounced at subtropical waters. The IPO moderates the MSL variations especially around the North Island, while almost vanishes at TG Dunedin. In contrast, the presence of IPO increases towards higher latitudes. The MSL and SST showed a relatively good agreement with the three major IPO phases, a positive phase (1922-1944), a negative phase (1946-1977) and another positive phase (1978-1998).

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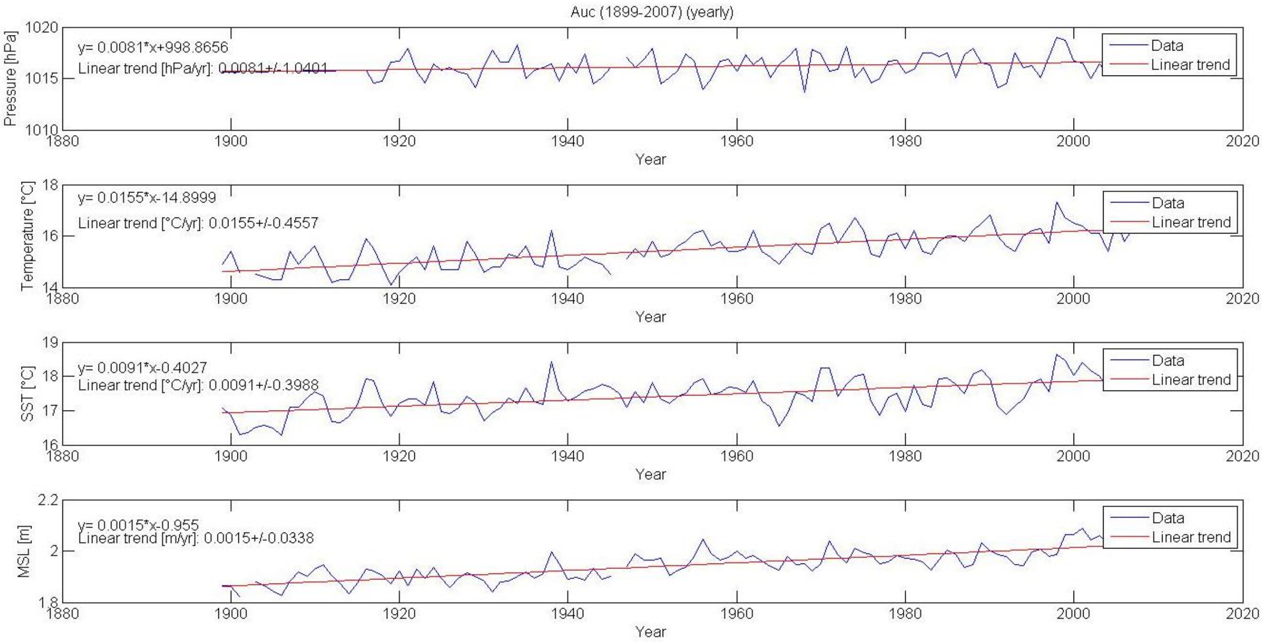
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Pressure [hPa]
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Linear trend [°C/yr]: 0.0155+/-0.4557
Temperature [°C]
y= 0.0091*x-0.4027
Linear trend [°C/yr]: 0.0091+/-0.3988
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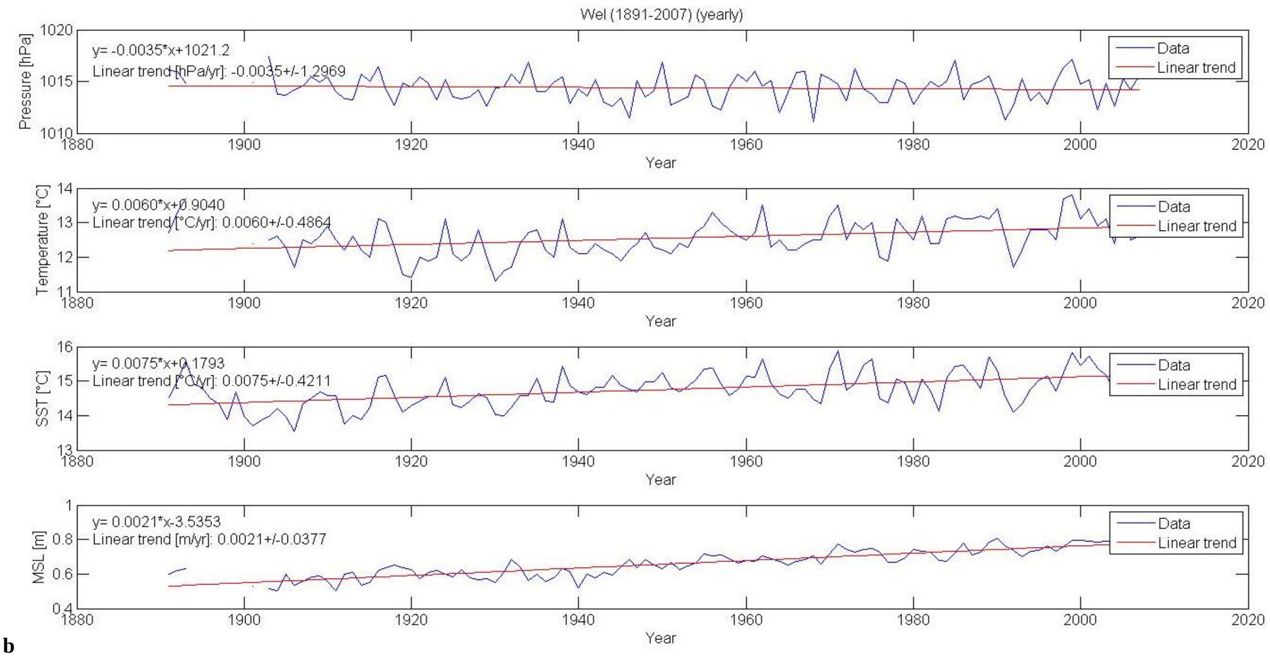
MSL [m]
Data
Linear trend
Year

a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Linear trend [°C/yr]: 0.0060+/-0.4864
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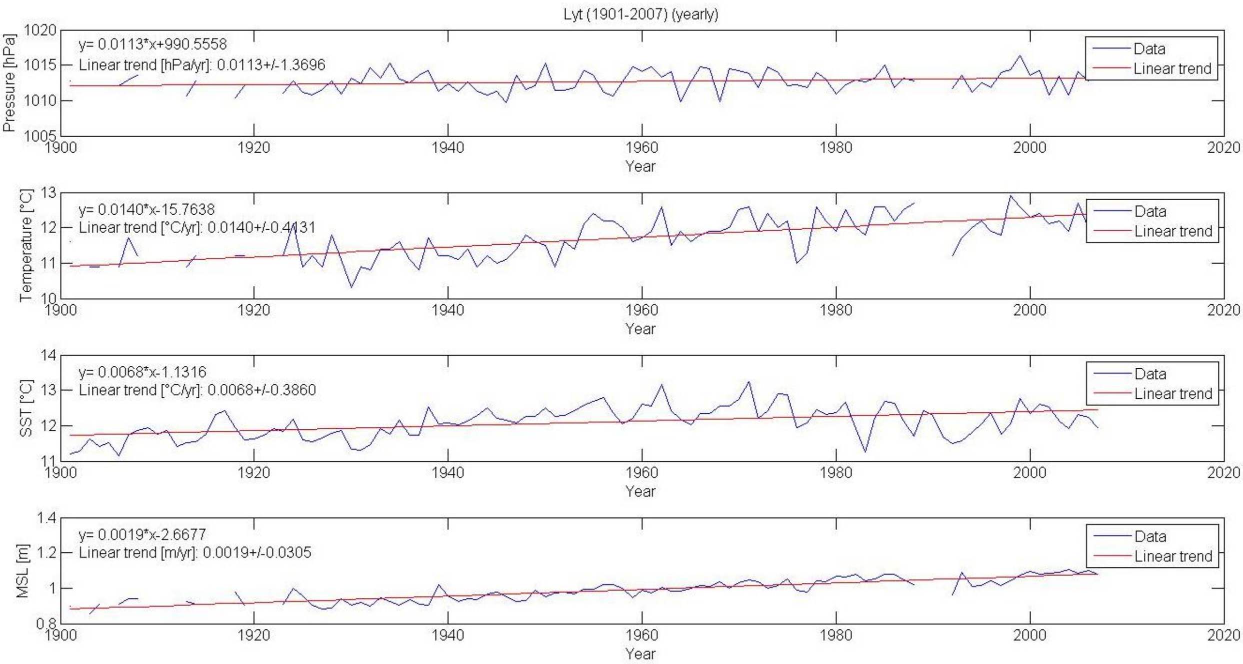
Linear trend
Year

b



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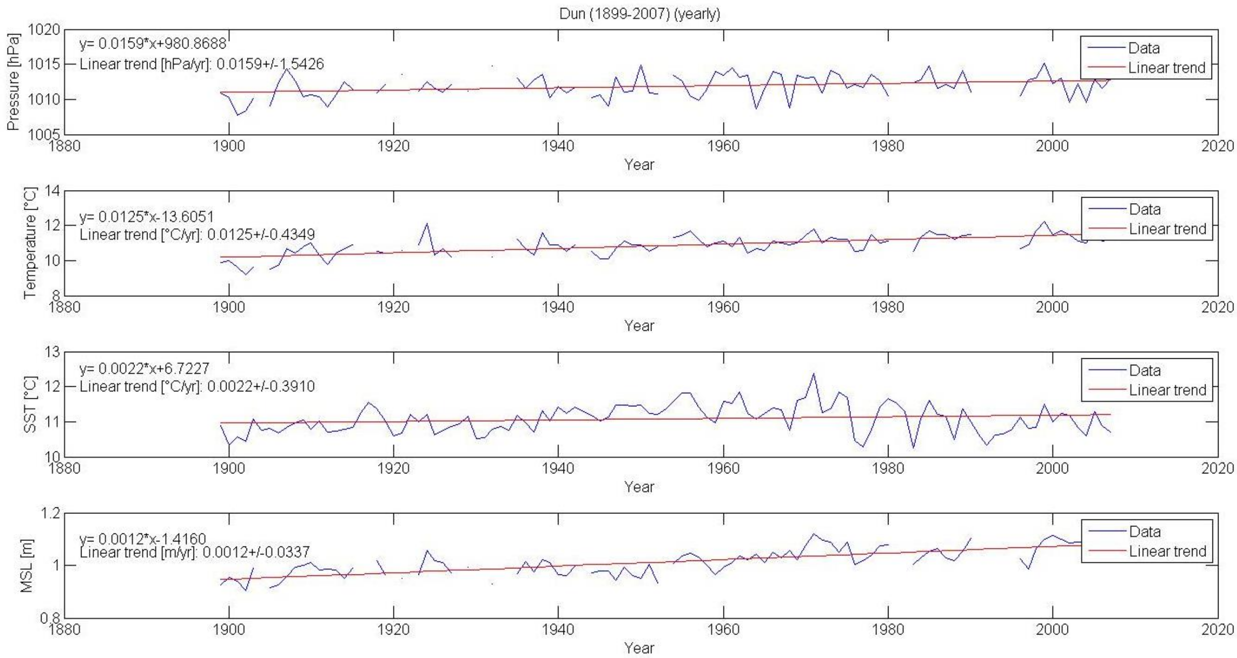

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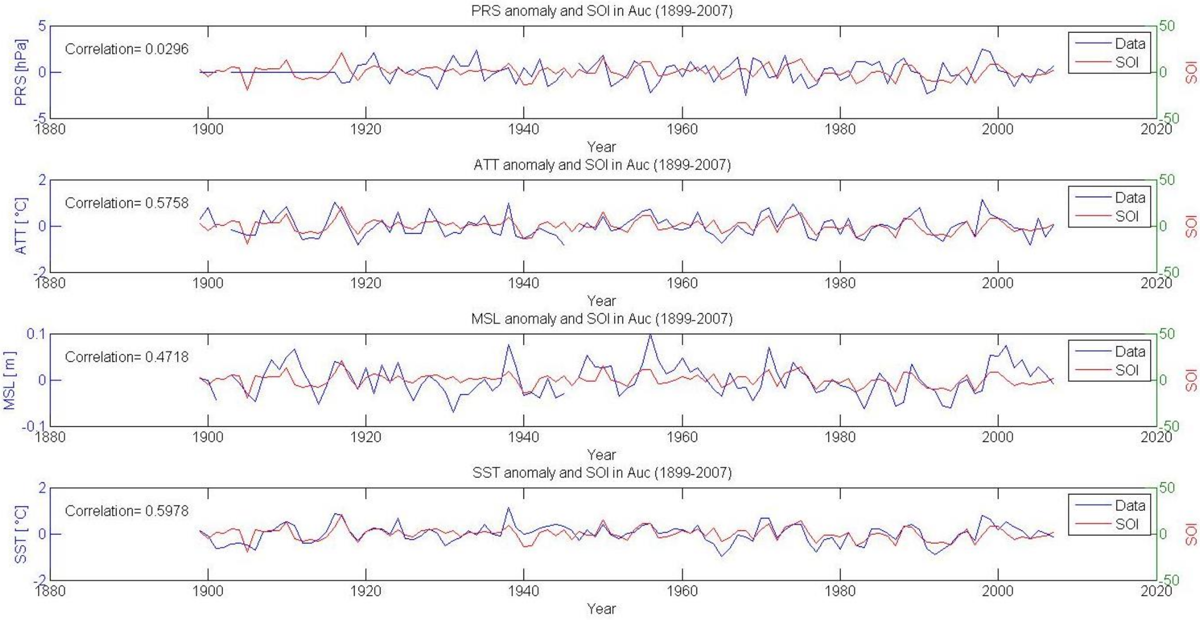
Figure 1. Linear trends in the seasonally-adjusted MSL, SST, ATT and PRS time series at TGs in: (**a**) Auckland, (**b**) Wellington, (**c**) Lyttelton, and (**d**) Dunedin.


PRS anomaly and SOI in Auc (1899-2007)
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PRS [hPa]
ATT anomaly and SOI in Auc (1899-2007)
Correlation= 0.5758
ATT [°C]
MSL anomaly and SOI in Auc (1899-2007)
Correlation= 0.4718
MSL [m]
SST anomaly and SOI in Auc (1899-2007)
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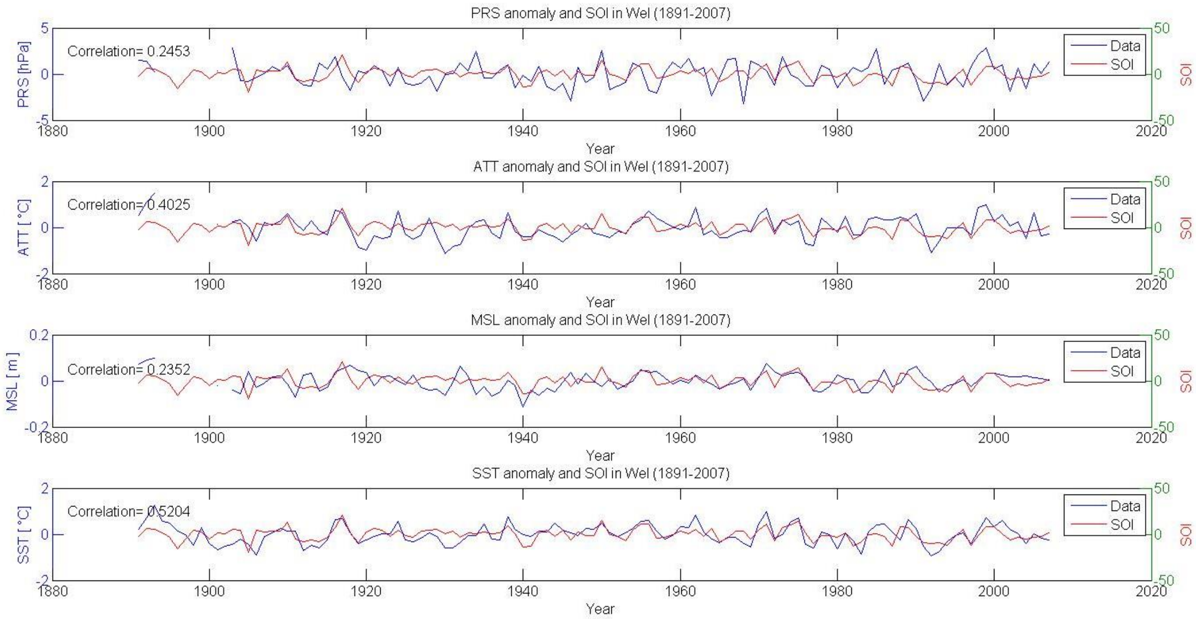
SST [°C]
Data
SOI
Year

a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ATT anomaly and SOI in Wel (1891-2007)
Correlation= 0.4025
ATT [°C]
MSL anomaly and SOI in Wel (1891-2007)
Correlation= 0.2352
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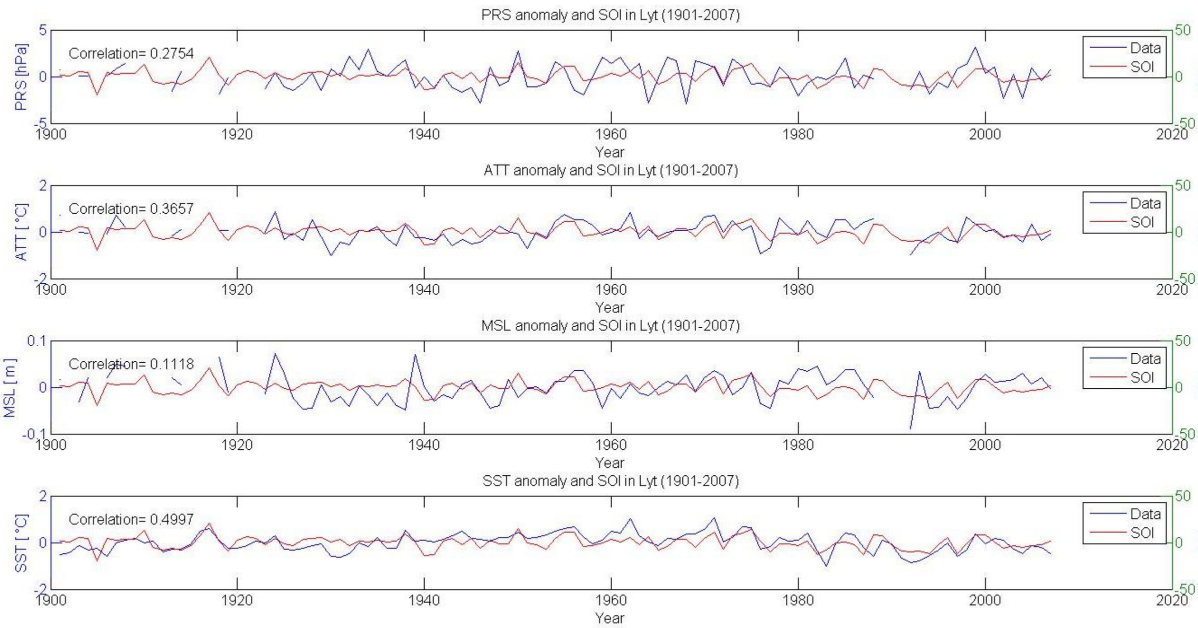
SST [°C]
Data
SOI
Year

b



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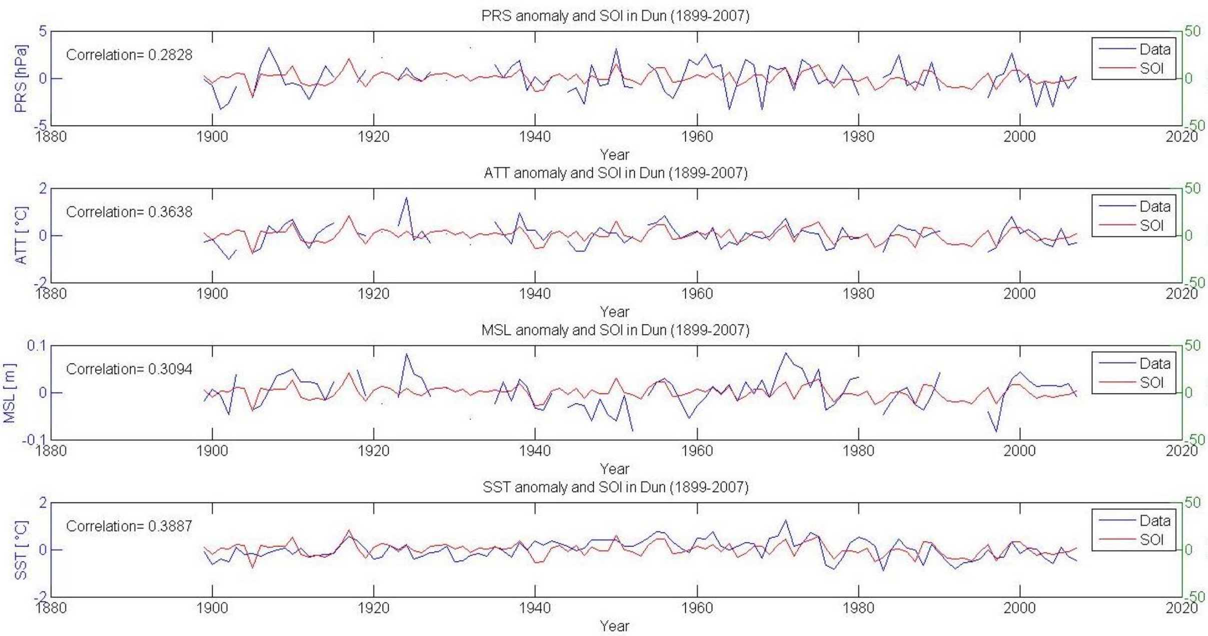

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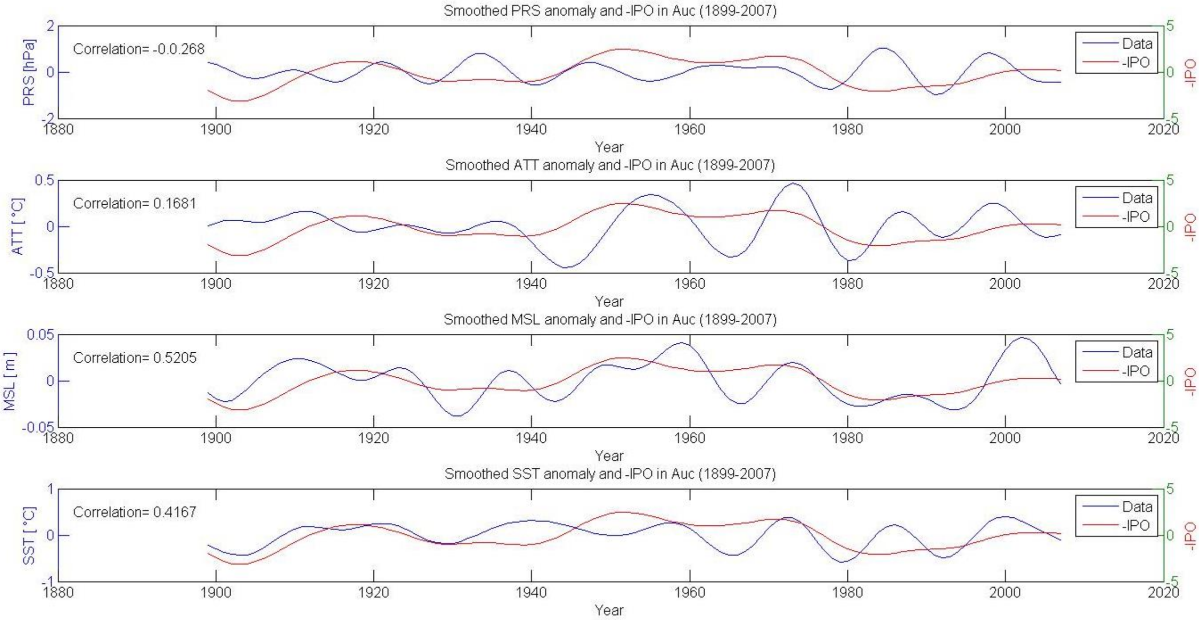
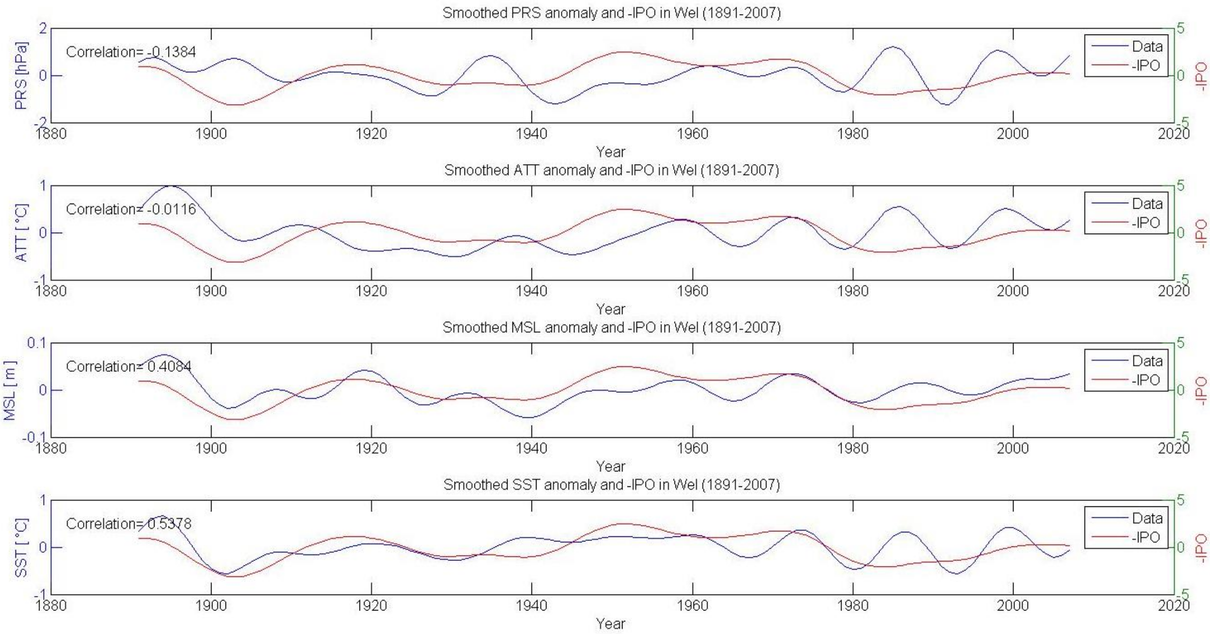
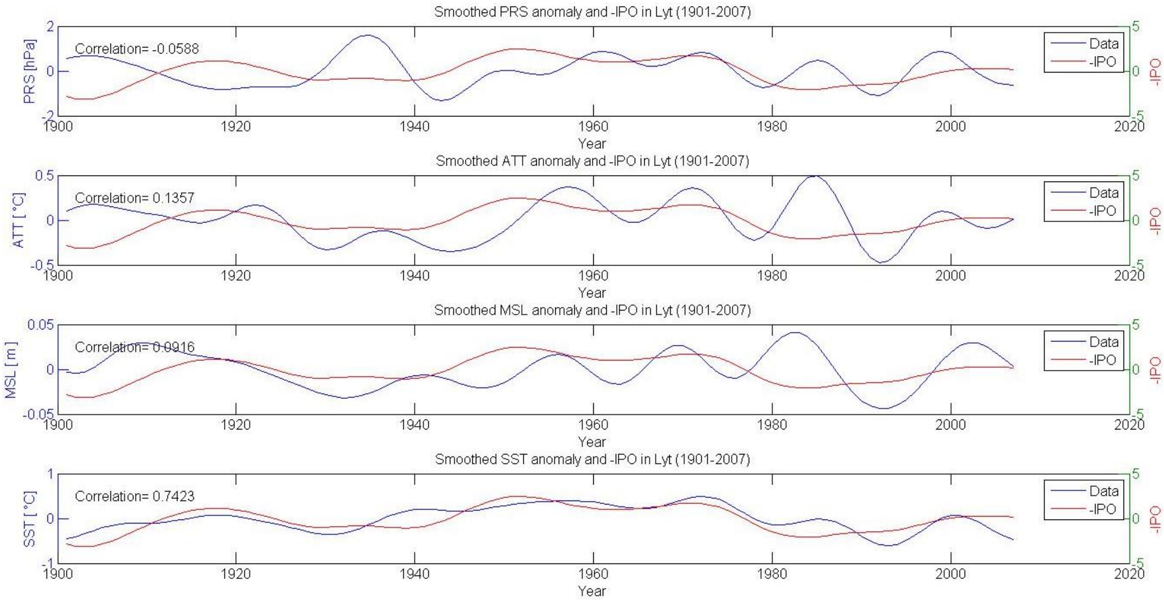
Figure 2. Correlation of the detrended MSL, SST, ATT and PRS time series with the SOI at TGs in: (**a**) Auckland, (**b**) Wellington, (**c**) Lyttelton, and (**d**) Dunedin.


Smoothed PRS anomaly and -IPO in Auc (1899-2007)
Correlation= -0.0.268
PRS [hPa]
Data
-IPO
Year
Smoothed ATT anomaly and -IPO in Auc (1899-2007)
Correlation= 0.1681
ATT [°C]
Smoothed MSL anomaly and -IPO in Auc (1899-2007)
Correlation= 0.5205
MSL [m]
Smoothed SST anomaly and -IPO in Auc (1899-2007)
Correlation= 0.4167
SST [°C]

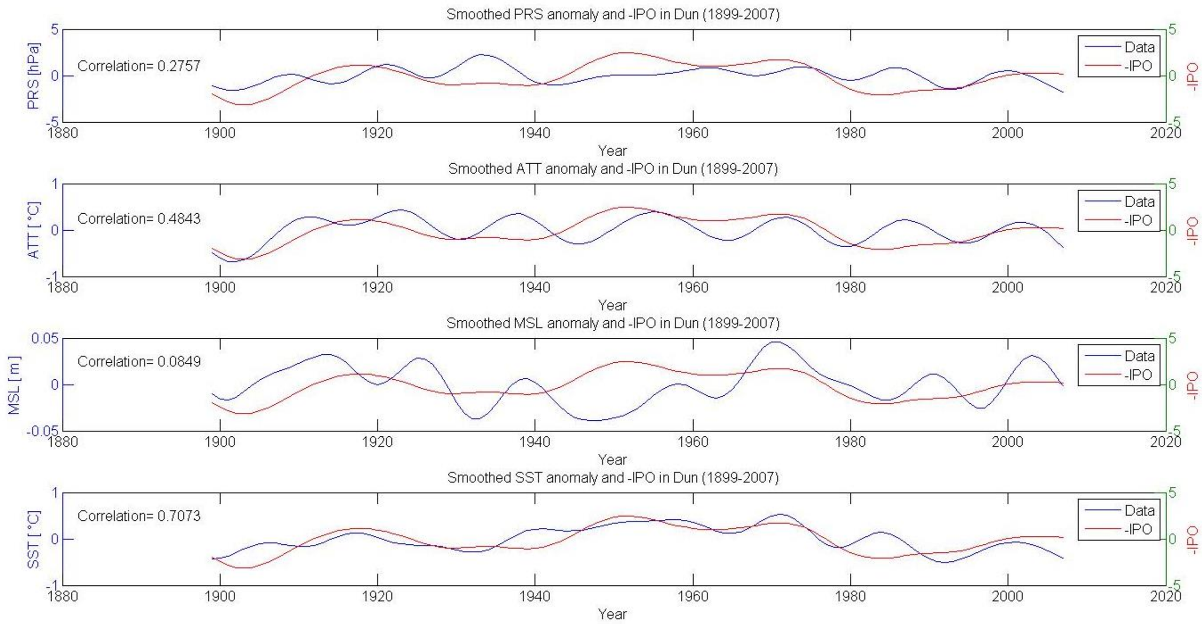
a


Smoothed PRS anomaly and -IPO in Wel (1891-2007)
Correlation= -0.1384
PRS [hPa]
Data
-IPO
Year
Smoothed ATT anomaly and -IPO in Wel (1891-2007)
Correlation= -0.0116
ATT [°C]
Smoothed MSL anomaly and -IPO in Wel (1891-2007)
Correlation= 0.4084
MSL [m]
Smoothed SST anomaly and -IPO in Wel (1891-2007)
Correlation= 0.5378
SST [°C]

b



c



d

Figure 3. Correlation of the ENSO-adjusted MSL, SST, ATT and PRS time series with the IPO at TGs in: (**a**) Auckland, (**b**) Wellington, (**c**) Lyttelton, and (**d**) Dunedin.