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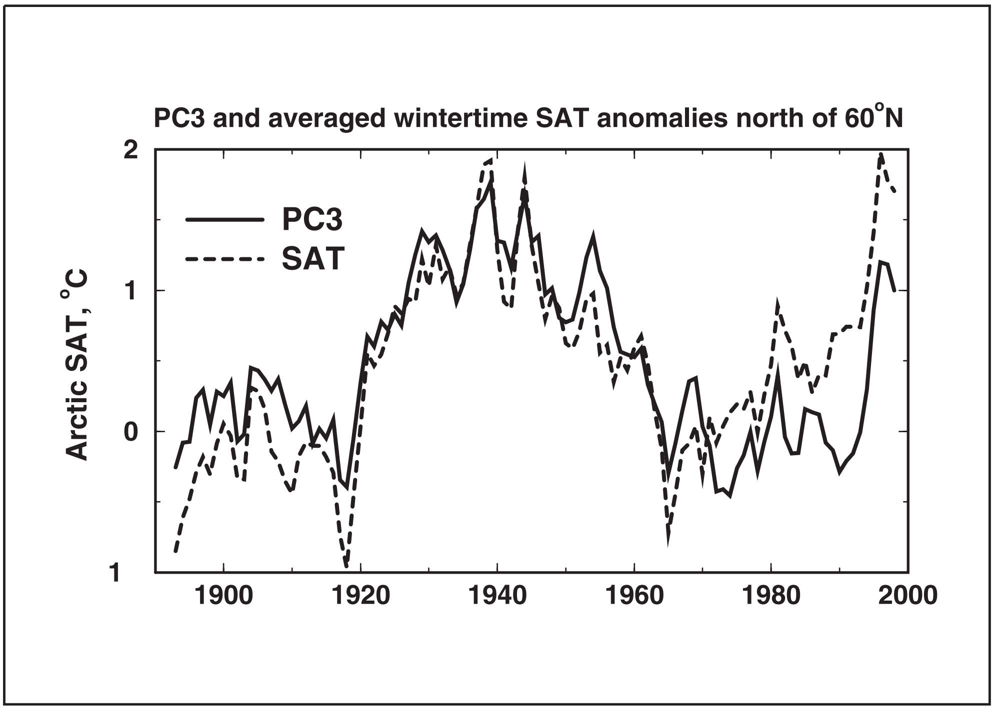

Modes of the wintertime Arctic temperature variability

by

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Modes of the wintertime Arctic temperature variability

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Abstract

It is shown that the Arctic averaged wintertime temperature variability during the 20th century can be essentially described by two orthogonal modes. These modes were identified by an EOF decomposition of the 1892-1999 surface wintertime air temperature anomalies (40°N-80°N) using a gridded dataset covering high Arctic. The first mode (also the first leading EOF) is related to the NAO and has a major contribution to Arctic warming during the last 30 years. The second one (the third leading EOF) dominates the SAT variability prior to 1970 including the early century warming anomaly. A correlation between the corresponding principal component timeseries PC3 and the averaged SAT anomalies north of 60°N is 0.79. This mode has the largest amplitudes in the Kara-Barents Seas and Baffin Bay and exhibits no direct link to the large-scale atmospheric circulation teleconnection patterns, in contrast to the other leading EOFs. We suggest that the existence of this mode is caused by long-term sea ice variability in the Kara-Barents Seas and Baffin Bay presumably due to the Atlantic inflow variability.

1. Introduction

The ongoing global warming during the last three decades exhibits highest trends in the Arctic [Hansen et al., 1999; Jones et al., 1999]. The surface air temperature, SAT, increase is accompanied by significant changes of the Arctic sea ice cover [Johannessen et al, 1999] and of the northern extratropical atmospheric circulation [Walsh et al., 1996]. The higher warming rate in the Arctic as well as its seasonality (most pronounced wintertime SAT increase) is in agreement with anthropogenic climate change scenarios simulated by climate models [Räisänen, 2002]. At the same time, the very strong early century warming anomaly in the Arctic, which has only recently been exceeded by the ongoing warming (or even have not been exceeded yet, according to some data [Polyakov et al., 2002]), does not support the polar amplification concept when century-long time periods are considered [Polyakov et al., 2002]. The northern high latitudes are characterized by high natural variability most pronounced during winter. It has been shown that a substantial part of the wintertime SAT variability in the northern hemisphere extratropics, including interdecadal fluctuations, is related to atmospheric circulation regimes, in particular, to the North Atlantic Oscillation, NAO, and Southern Oscillation, SO [Hurrell, 1996; Wallace et al., 1996]. A shift to the positive phase of the NAO was proposed as a reason for the recent Arctic warming [Moritz et al., 2002]. A mechanism for the early century warming is presently under debate. Although external forcing, such as volcanoes or solar irradiation variations, cannot be fully dismissed as a contributor to the early century warming (and the present warming either), there are strong indications that this anomaly was a manifestation of internal variability [Bengtsson et al., 2003]. Global climate models are capable to simulate similar anomalies in the scenario and control integrations [Delworth and Knutson, 2000; Johannessen et al., submitted]. It has also been suggested that the early century warming may be a part of a low frequency oscillation

[Polyakov and Johnson, 2000], associated with variability in the thermohaline circulation and the related North Atlantic SST anomalies [Delworth and Mann, 2000]. However, no coupling mechanism has been proposed to link North Atlantic SST and Arctic SAT variations, nor do the length of the temperature records allow us to identify a particular multidecadal oscillation in the Arctic. Knowledge of spatial SAT variability patterns is important for attributing the variation to a particular physical mechanism. The SAT patterns related to the atmospheric circulation have been analyzed in several studies [Hurrell, 1996; Wallace et al., 1996]. The analysis is usually restricted to the last 50 years, when reliable data and good spatial coverage exist (e.g. NCEP reanalysis). This time period does not include the early century warming anomaly. Kelly et al. (1982) have described the Arctic SAT variability patterns for the period 1881-1980 using principal component analysis with qualitative consideration of the variability mechanisms.

In this study, we describe spatial patterns of the wintertime SAT variability between 40°N and 80°N during 1892-1999 using a gridded SAT dataset covering the high Arctic. A link between the main SAT patterns and atmospheric circulation is analyzed. The length and spatial coverage of the data allowed us to clearly identify a multidecadal variability mode, and to assess a time-dependent contribution of different modes to the averaged Arctic SAT variability.

2. Data

Temperature observations in the Arctic and adjacent regions include a number of records from land-based weather stations, several of them extending back to the 19th century [Przybylak, 2000, for a review]. Since the 1950s, data for the interior Arctic have been collected primarily by manned drifting polar stations, buoys and dropsondes [Martin et al., 1997; Kahl et al., 1993; Rigor et al., 2000]. Due to different temporal-spatial coverage and measurements techniques, the analyses of these data usually embrace only recent decades, which can sometimes lead to contradictory conclusions about the magnitude and direction of the Arctic temperature trends [Serreze et al., 2000; Kahl et al., 1993].

Global SAT datasets [Jones et al., 1999; 2001; Hansen et al., 1999], which have been widely used for climate research, have major gaps over the highest northern latitudes, in particular over ice covered ocean areas in the Arctic as well as for some surrounding land areas. This complicates an adequate analysis of the SAT spatial-temporal variability in the Arctic during the 20th century, especially for the first half of the 20th century.

Here, we analyze a century-long gridded SAT dataset, which focuses on the high latitudes of the Northern hemisphere [Alekseev et al., 1999]. The dataset consists of monthly mean values on 5ºx10º latitude/longitude resolution and comprises, in particular, land- and drifting station meteorological observations. The data cover the extratropical part of the northern hemisphere (generally north of 20ºN) for 1892-1999. A comparison of these data with independent observations and other datasets reveal a good agreement (O. Johannessen, personal communications).

The principal component analysis has been performed on the SAT anomalies averaged for the winter half of a year (November through April) between 40°N-80°N. The EOFs presented are computed for the period 1892-1999. The analysis was also performed for different subperiods.

A statistical method described by Kelly et al. (1999) indicates that the first 4 EOFs bear meaningful information. These patterns are also found to be independent on the time period and have physically explainable structures.

In order to investigate relations between temperature variability and atmospheric circulation, principal component (PC) timeseries have been correlated with different northern hemisphere atmospheric teleconnection indices, representing the main modes of the atmospheric circulation variability [Barnston and Livezey, 1987]. These indices are available from 1950 onwards from the NOAA/NCEP Climate Prediction Center (http://www.cpc.noaa.gov/data/teledoc/telecontents.html). The correlations were also computed with the PCs of the wintertime (November-April) SLP, referred below as SLP PC# (where # spans from 1 to 6), using a century-long dataset [Trenberth and Paolino, 1980] as well as the NAO and SOI indices [Hurrel, 1995; Ropelewski and Jones, 1987].

3. Results

Figure 1 shows the 4 leading EOFs of wintertime (November through April) SAT variability for 1892-1998 between 40°N-80°N. These modes explain 54% of the SAT variance during this period. The variances explained by each mode and the correlation with the atmospheric circulation indices are summarized in Table 1.

Table 1: Variance explained by the SAT PCs and their correlations with atmospheric teleconnection indices (TI, 1950-1999) and PCs of wintertime (NDJFMA) SLP anomalies between 25°N-80°N (1900-1999). Only the highest correlations are listed.

	Explained Variance	Highest correlations, TI (1950-99)	Highest correlations, SLP EOFs (1900-99)
EOF 1	21.2%	PE, 0.58; NAO, 0.51	PC1, 0.77; PC2 –0.32
EOF 2	12.3%	PNA, -0.49; WP,-0.44	PC2, -0.57; PC1 0.34
EOF 3	11.7%	Arctic SAT, 0.79 (1892-1999)	
EOF 4	9.1%	SCA, 0.33;	PC5, -0.45

The first EOF, which represents 21.2% of the variability, (Fig. 1a) is related to NAO variability and has large positive temperature anomalies over northern Europe, eastern and central Eurasia, and negative anomalies over Baffin Bay. This mode looks very similar to the well known SAT-NAO regression pattern, which is related to the enhanced advection of warm Atlantic air masses over northern Eurasia and cold Arctic air masses west of Greenland during the positive phase of the NAO [Fig. 3a, Hurrell, 1996]. The correlation between SAT PC1 and the NAO index is 0.60 for 1892-1999. For the 1951-98 period the highest correlation (0.58) is found with the Polar/Eurasia Pattern index (PE), which characterizes the Polar vortex strength. Correlation with the NAO index for the same time period is 0.51. The highest correlation (0.77) is found with the SLP PC1, related to the Arctic Oscillation [Thompson and Wallace, 1998].

The second mode is a dipole with a large positive anomaly over northern Eurasia and a negative anomaly over northern Canada and Greenland (Fig. 1b). This mode is connected to circulation variability over the North Pacific, which is indicated by relatively strong correlations with the Pacific/North American (PNA) and West Pacific (WP) patterns (see the Table). A significant correlation (0.34) for the whole 1892-1999 period has been found with the SOI index. This mode is highly correlated with SLP PC2, which has the largest anomaly over the North Pacific. A statistically significant correlation with the SLP PC2 (and the NAO) reflects some similarity between the SAT EOF2 and the NAO-related temperature anomalies.

The third mode, responsible for 11.7% of the variability, exhibits no significant connection to any atmospheric circulation indices. The highest correlations with TI or SLP PCs do not exceed 0.25. This third mode is highly correlated (0.79) with the averaged SAT anomalies over the Arctic, perfectly describing the early century warming episode (Figure 2). The mode has its strongest positive SAT anomalies over the Kara and Barents Seas, the northern part of the Greenland Sea, and Baffin Bay (Fig. 1c). This mode is very similar to the first leading mode described by Kelly et al. (1982) for annual mean Arctic SAT anomalies. In their study, the NAO-related mode stood out as the second one. This was also the case with our data when the 1892-1950 period was considered. As the third PC does not show any significant link to the large-scale atmospheric circulation and the strongest anomalies of the EOF3 are located in (or close to) the regions of the highest interannual to interdecadal variability of the sea ice concentrations, SIC (Venegas and Mysak, 2000; Deser, 2000), it is suggested that this mode is related to the interdecadal variability of the wintertime sea ice concentrations. A relatively short duration of reliable wintertime sea ice observations (basically starting from 1953 [Walsh and Johnson, 1979]) does not allow one to identify such a long fluctuation in the SIC data for the Arctic Ocean. However, regional sea ice records or reconstructed data show a similar long-term variation in the Barents and Kara Seas [Zakharov, 1997; Polyakov et al., 2002].

The EOF4 pattern (Fig. 4c) consists of a positive anomaly over the eastern part of the Arctic Ocean and Greenland, and a very strong negative anomaly over central Eurasia. The timeseries of the corresponding PC is correlated (0.33 for NDJFMA, and 0.51 for the DJF means) with the Scandinavia pattern (SCA) index, which represents pressure variability over the Barents Sea. This PC is significantly correlated with the SLP PC5, which is associated with a corresponding SLP increase over central Eurasia and a decrease over the Atlantic sector of the Arctic.

In order to demonstrate a contribution of the EOF patterns to the Arctic averaged SAT variability, the anomalies associated with EOF1, EOF3, and EOF1 combined with EOF3 (EOF1+3), respectively were subtracted from the SAT variability. The residual timeseries are shown in Figure 3 in comparison with the original data. These two EOFs were found to explain 94% of the Arctic SAT variability. EOF2, due to its symmetrical west-east dipole structure, does not contribute significantly to the zonally averaged SAT, despite its substantial impact on the SAT over Eurasia and North America. EOF4 makes a small contribution to the Arctic SAT (about 5%). No noticeable contribution of EOF1 (or the NAO related anomalies) is found prior to 1970, while afterwards the SAT upward trend is significantly reduced (Figure 3a). The residual trend is 0.31°C/decade against 0.58°C/decade observed for 1971-1999. These trends become 0.14°C/decade against 0.45°C/decade respectively for the 1971-1995 period, which excludes the NAO downward trend during 1995-1999 (coinciding with the rapid increase in the PC3, Figure 2). As could be expected, the residual Arctic temperature after the EOF3 subtraction exhibits no early century warming, and leaves the recent warming trend almost unchanged (Figure 3b). Subtraction of the combined patterns (EOF1+3) results in a total disappearance of the interdecadal variability, leaving only minor residual fluctuations without any trend (Figure 3c). This analysis also indicates that the most rapid Arctic warming in the second half of the 1990s is related to the fast increase of PC3 despite the decrease in PC1 (or the NAO index).

4. Discussion

The fact that two, presumably internal, modes of SAT variability describe the Arctic SAT variations in the 20th century, emphasizes the potential difficulties involved in detecting and attributing anthropogenic climate changes in the Arctic. This does not mean that greenhouse warming has not effected the recent Arctic SAT increase. Greenhouse warming can either manifest itself through intensification of an existing pattern or by generating a new pattern, which is similar to an internal mode. The first is likely the case for NAO-related variability, as many climate models simulate increased NAO with warmer climate [Gillett et al., 2002 and ref. therein] and there is some evidence that NAO increase is related to global warming, in particular in the tropical oceans [Hoerling et al., 2001; Schneider et al., 2003]. The second may happen because of the melting of arctic sea ice due to the greenhouse warming effect, and increased heat transport by warmer Atlantic waters. This melting during the wintertime takes place in the marginal arctic sea ice zone, which may result in SAT anomalies similar to the EOF3 pattern. Weather this was the case during the recent warming 1995-1999 or part of an upward phase of a natural multidecadal oscillation is an open question.

Although the multidecadal SAT variability mode (EOF3) was found to be uncorrelated with any large-scale atmospheric circulation indices, it may be linked to local atmospheric variability. It was shown [Bengtsson et al., MPI] that a multidecadal variability of the wintertime pressure gradient between Spitzbergen and northern Norway could produce the observed warming by enhanced wind-driven Atlantic inflow into the Barents Sea with a subsequent sea ice retreat. Long-term variability in the ocean circulation [Delworth and Mann, 2000] could also be a cause of multidecadal changes in the Arctic as well as variability of the Arctic fresh water balance [Zakharov, 1997].

Acknowledgements

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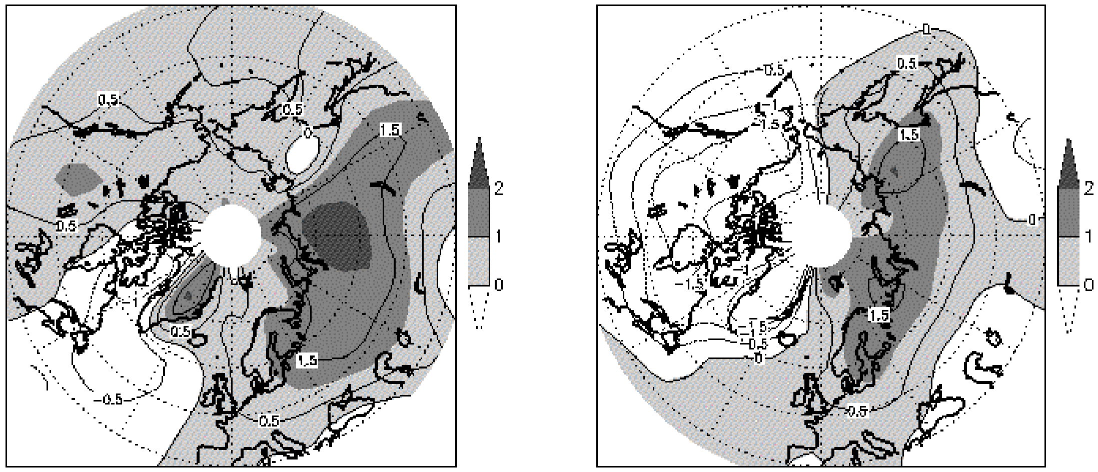
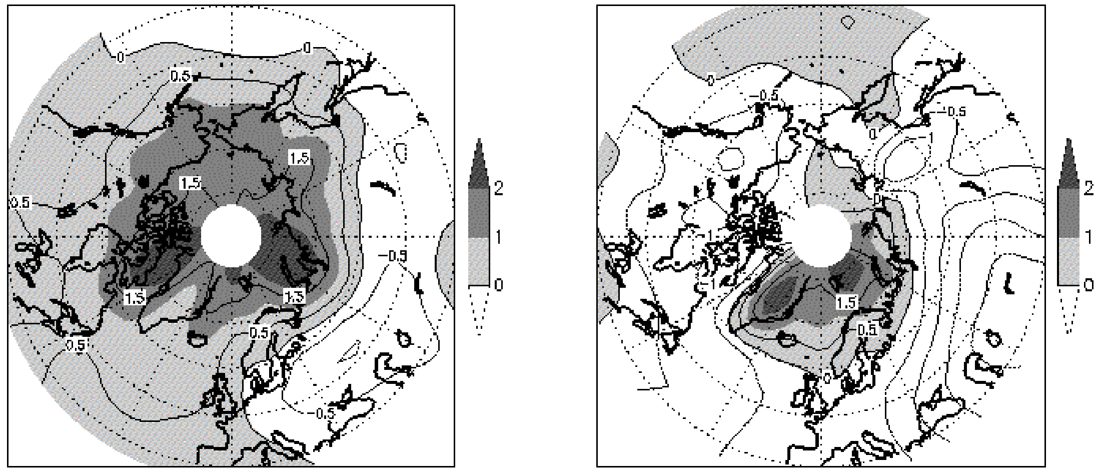
Figure 1



(a) EOF 1 (21.2%)

(b) EOF 2 (12.3%)



(c) EOF 3 (11.7%)

(d) EOF 4 (9.1%)

Figure 1. The four leading EOFs of the wintertime (NDJFMA) SAT variability (40°N-80°N) for 1892-1998. Values greater than 0,1 and 2 are shaded at different densities. Contours are at –2, -1.5, -1, -0.5, 0, 0.5, 1.5.

Figure 2

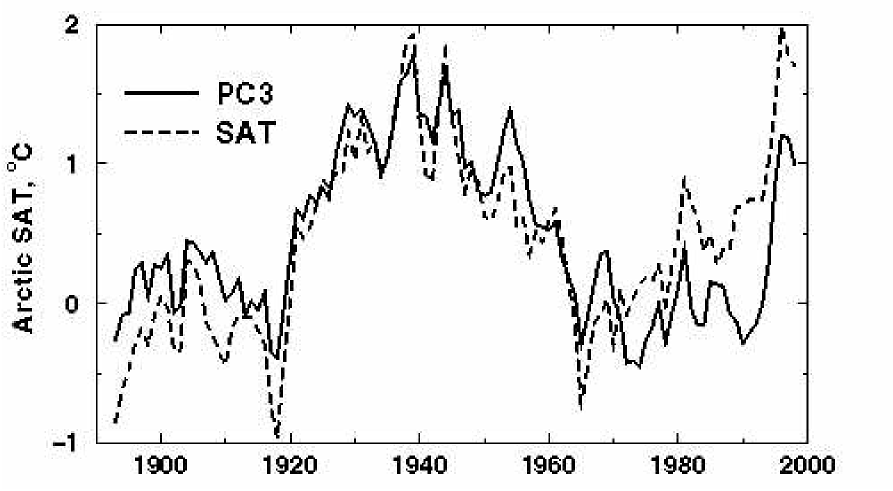


Figure 2. PC3 (solid) and averaged wintertime SAT anomalies north of 60°N (dashed, ºC), 5 years running means.

Figure 3

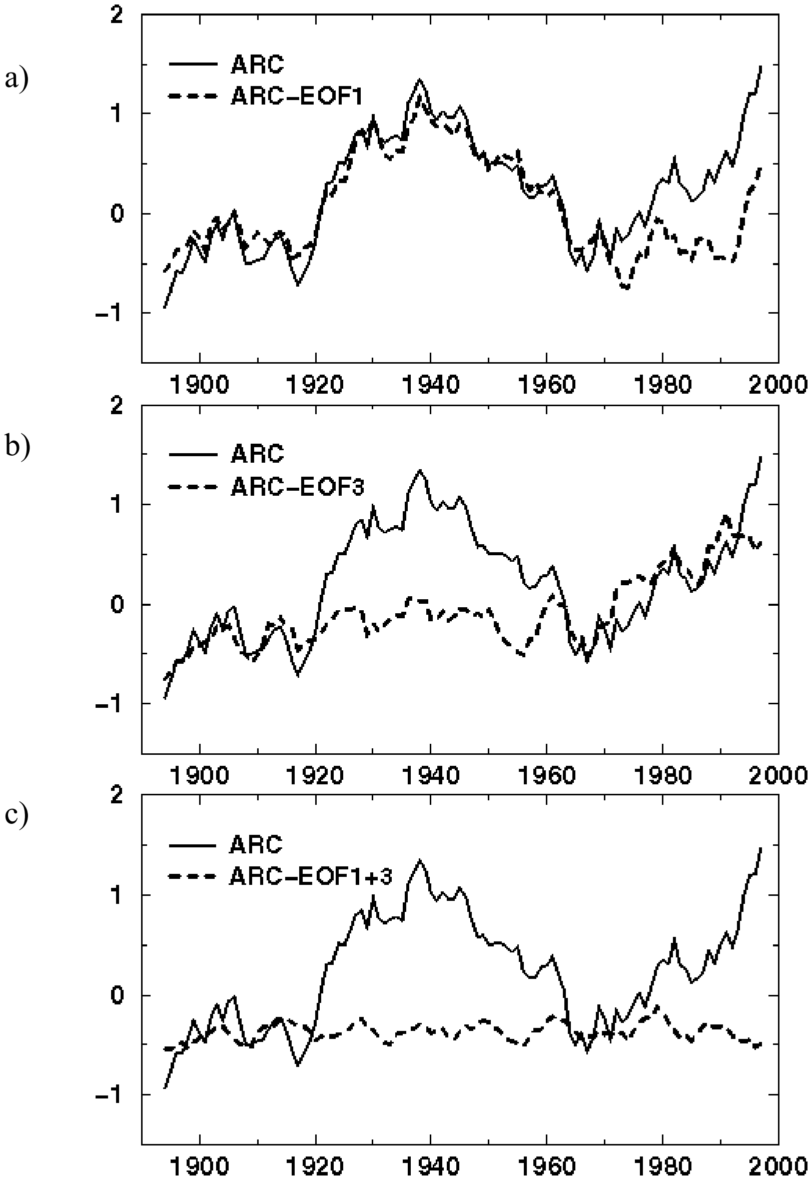


Figure 3. Arctic SAT (60°N-80°N, NDJFMA) anomalies with subtracted variability (dashed lines) related to the EOF1 (a), EOF3 (b) and EOF1+3 (c) and without subtraction (solid lines). 5 years running means.

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