

Decadal Variability in North Atlantic Weather Regimes

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The concept of persistent and recurrent large-scale atmospheric flow regimes, or "weather regimes", is used to investigate the response of an atmospheric general circulation model (GCM) to a prescribed decade-long anomaly in sea-surface temperature (SST) over the North Atlantic during winter. We define firstly intraseasonal atmospheric variability in terms of persistent and recurrent, large-scale atmospheric flow regimes with fixed spatial patterns (Dole and Gordon, 1983; Cheng and Wallace, 1993; Kimoto and Ghil, 1993; Michelangeli et al., 1995).

Within this framework, interdecadal variability can manifest itself either as a change in the classifiable number of regimes, or as a change of the spatial patterns and frequency of occurrence of the same identifiable regimes, or as some combination of these possibilities. We test these ideas by (1) estimating weather regimes robustly from a 100-year control run of the Max-Planck Institute's atmospheric GCM (ECHAM3) at T42 horizontal resolution; (2) testing the extent to which changes of regime pattern and frequency occur when a broad-scale observed SST anomaly pattern is prescribed over the North Atlantic in a 10-year response experiment; and (3) reconstructing the GCM's response in terms of weather-regime changes.

Six weather regimes were obtained for boreal winter (DJF) over the North-Atlantic/European sector in the 100-year control run (Figure 1). Ninety-day winters of daily 700-mb heights over the North Atlantic sector (20° - 60° N, 90° W- 40° E) were used, starting on 1 December and low-pass filtered at 10 days. The mean seasonal cycle of the control run was subtracted at the outset from both the control and the SST-anomaly experiment. Two methods of constructing weather regimes for the centennial control run-PDF bump-hunting (Kimoto and Ghil, 1993; KG hereafter) and the K-means method Michelangeli et al., 1995; MVL hereafter)-yield similar results, with pattern correlations between matching regime composites exceeding 0.8 and, in most cases, 0.9, when choosing $K = 6$ clusters in the latter method.

The control regimes in Figure 1 are encouragingly realistic, with Regimes 1 and 3 corresponding approximately to the two phases of the North Atlantic Oscillation (NAO), characterized by a cyclone or anticyclone over Greenland respectively (cf. Cheng and Wallace, 1993). Pattern correlations with the five regimes derived from an identical bump-hunting analysis of 44 winters (1951-95) of NCEP observed daily 700-mb heights are 0.72, 0.89, 0.91, 0.77, 0.75, and 0.37 for each regime in Figure 1 respectively. Since SSTs in the control experiment are prescribed to follow a seasonally varying climatology, this is circumstantial evidence that regime patterns are insensitive to SST variations, both local and remote.

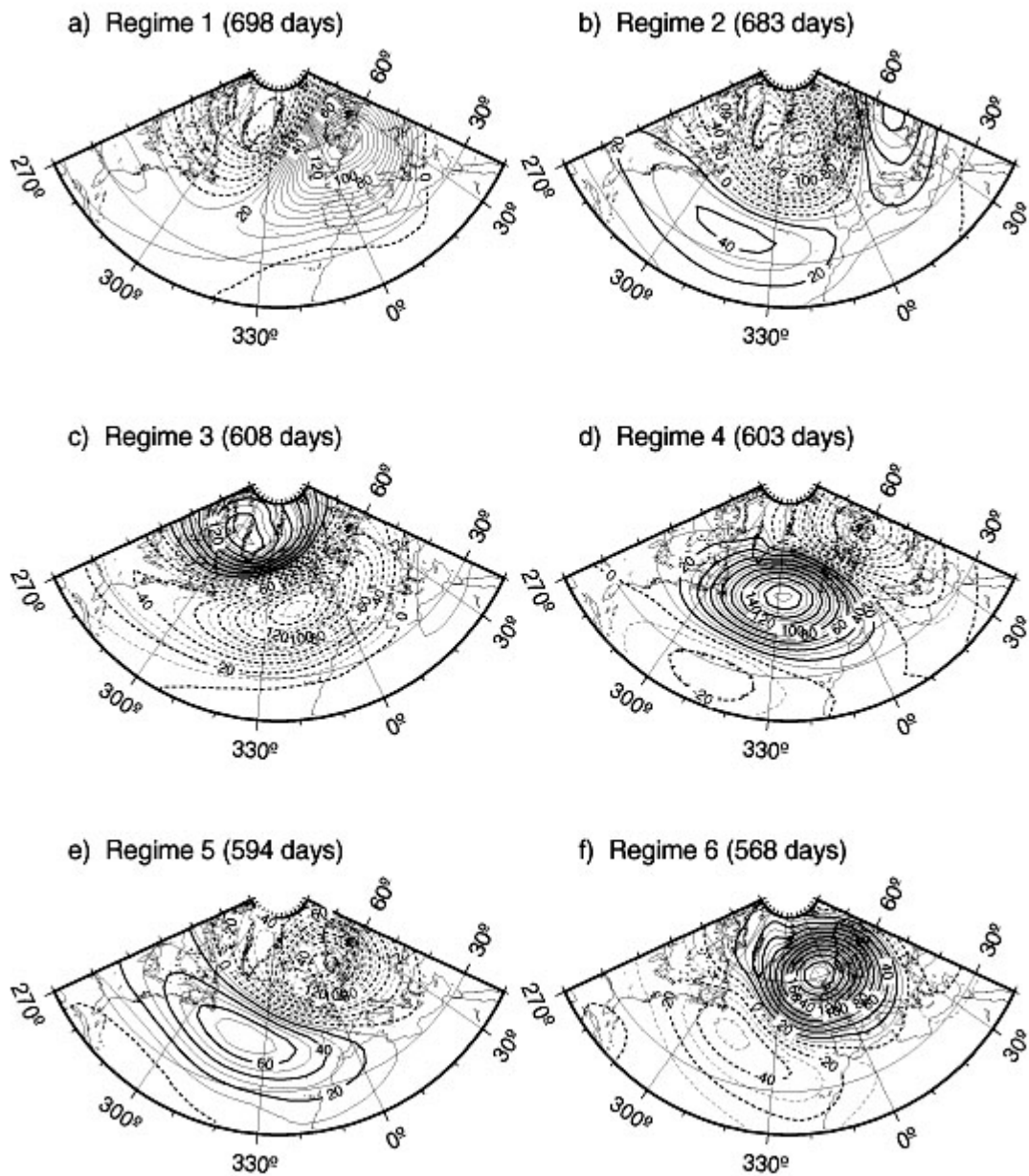


Figure 1. Weather regimes of the control experiment, derived using KG's bump-hunting method. Each map is a composite of low-pass filtered 700-mb height anomalies (gpm) on days belonging to that regime; contour interval is 10 gpm. The regimes are ranked according to the number of days belonging to each regime, given in brackets. Pattern correlations with regimes derived using K-means method are 0.82, 0.89, 0.99, 0.95, 0.91, and 0.93 respectively.

The regime's spatial patterns in the 10-year anomaly experiment in which a broad warm SST anomaly with maximum amplitude of about 2°C is prescribed over the North Atlantic are found not to differ significantly from those of the control run. The similarity in terms of pattern correlation between the least-similar clusters in the two integrations is about 0.55, which is quite close to the

mean "distance" between individual decadal samples from the control run. It appears that the decade-to-decade variability in the spatial patterns of the GCM's weather regimes is limited, and that SST anomalies do not increase it noticeably. This inference, of course, may be model-, as well as sample-dependent and longer runs with the same GCM and with additional ones should help confirm or invalidate it.

The frequencies of occurrence of the six regimes in the control run are similar, on average, so that there are no strongly preferred regimes. Decade-to-decade fluctuations of regime frequency, however, are found to be substantial in the control run, with interdecadal standard deviations of up to one-third of the centennial mean. We projected the 882 low-pass filtered daily maps from the anomaly experiment onto the four leading EOFs of the control experiment, and counted the number of days falling into each of the control regimes of Figure 1. These counts are plotted in Figure 2 (diamonds); the analogous counts for each of the 10 control decades are plotted in terms of their mean (open circles) and standard deviation (shown as a two-sided error bar).

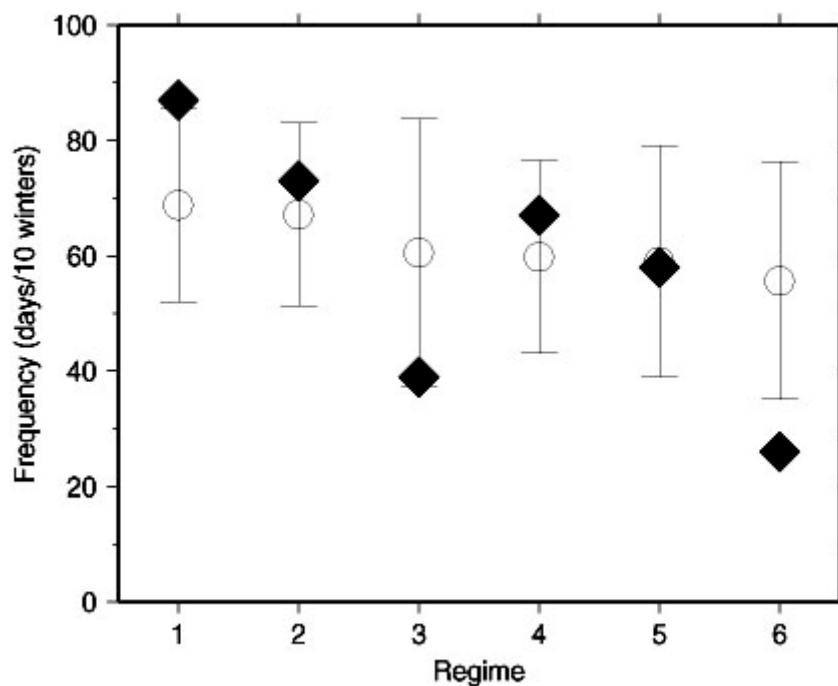


Figure 2. Frequency of occurrence of a daily map within each of the six control clusters in the SST anomaly experiment (solid diamonds). Open circles and error bars show the mean frequency of occurrence and one standard deviation on either side for the six regimes in the ten non-overlapping 882 day control decades.

Three of the six regimes show excursions in frequency for the SST anomaly experiment of about one standard deviation. The frequency anomalies of these three regimes tend to produce negative height anomalies north of 60°N and positive ones to the south, resembling the positive phase of the NAO. Our results

reveal, however, that the NAO is made up of two or three distinct weather regimes, rather than behaving like a linear mode that is preferentially excited in the presence of a warm SST anomaly over the North Atlantic. The frequency of occurrence of certain weather regimes is thus modulated by the presence of the North Atlantic SST anomaly. A longer anomaly experiment will be required to obtain greater statistical confidence, given the high interdecadal variability exhibited by the control run.

The GCM's response to the prescribed SST anomaly is reconstructed in Figure 3a as a weighted average of the six weather regimes identified in the control experiment (Figure 1). The weights are proportional to the changes in regime frequency in the decade-long anomaly experiment, each scaled by the corresponding frequency in the century-long control experiment (Figure 2). The NAO is much more pronounced in this regime-average response than in the simple difference between time means of the anomaly and control integrations; the latter is shown in Figure 3b. The signal-to-noise ratio in climate-change experiments may thus be enhanced by concentrating attention on those regions of the model's phase space that are associated with more regular, recurrent and persistent behavior.

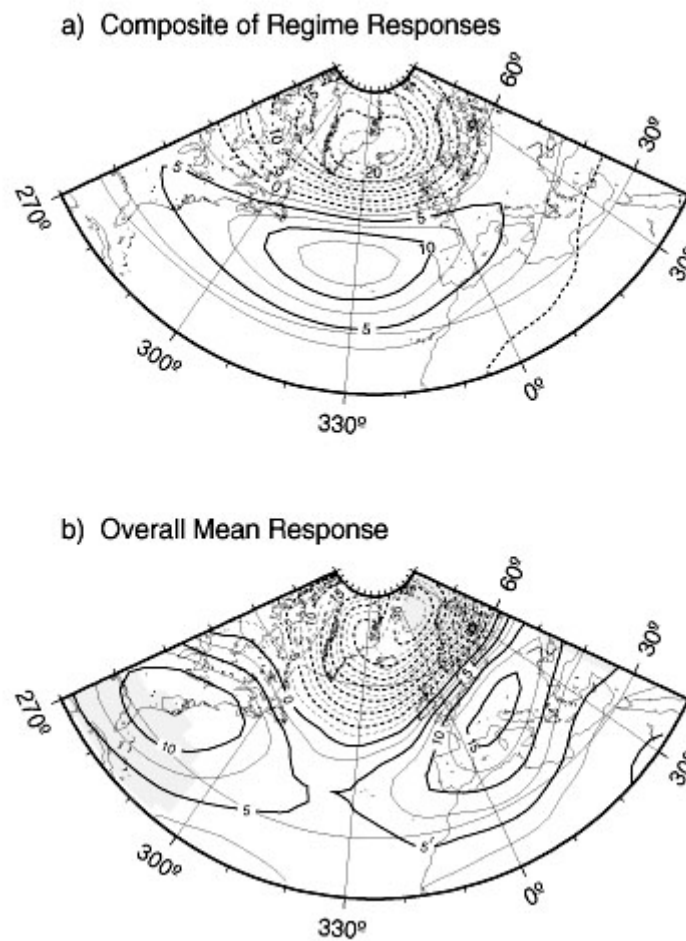


Figure 3. (a) Weather-regime response to SST anomaly, constructed by weighting the six maps in Figure 1 by the frequency ratios between anomaly and control experiment (diamonds and circles in Figure 2, respectively). (b) 700-mb DJF mean response (mean of 10-winter SST anomaly experiment, minus the mean of the 99-winter control experiment). Contour interval is 2.5 gpm. Stippled region in (b) indicates areas significant at 90% level using a two-tailed Student t-test.

[Return to beginning of page](#)

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[Return to beginning](#)

[Return to index](#)

