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Detection of past and future atmospheric circulation changes over the North Atlantic region with the help of an automatic circulation type classification

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Abstract

Future projections of the atmospheric circulation over the Northern Hemisphere high latitudes, especially the North Atlantic, have high uncertainties and some of the projected changes are opposed to circulation changes that have been observed since the 2000s. In this thesis, we focus on three particular aspects of the past and projected future summertime atmospheric circulation over the broader North Atlantic region. First, we analyse whether the 2007–2012 summertime anticyclonic anomaly over the Beaufort Sea, the Canadian Arctic Archipelago, and Greenland might rather be due to global warming or to the internal variability of the atmospheric circulation by putting it in perspective with the circulation variability over the last 150 years given by five reanalysis datasets. Then, this analysis is extended for the future circulation projected towards 2100 by CMIP3 and CMIP5 General Circulation Models (GCMs) over Greenland. Finally, we evaluate the impact of the uncertainties of the future atmospheric circulation projections on the mitigating or enhancing influence of the summertime circulation changes on temperature and precipitation over Europe.

We use an automatic circulation type classification to analyse in detail the atmospheric circulation changes by grouping similar daily SLP (mean sea level pressure) or Z500 (500 hPa geopotential height) fields into homogeneous circulation types. It appears that the choice of the index, on the basis of which the days are grouped together, strongly influences the characteristics of the circulation types and the kinds of circulation changes that can be detected. In comparison with Euclidean distance and pressure gradient-based indices, correlation-based indices, especially the Spearman rank correlation, are the most suitable indices when focusing on the circulation pattern.

Over the Arctic region, four periods with circulation anomalies similar to that of 2007–2012 (i.e. a summertime anticyclonic anomaly over the western Arctic region) have been detected over the last 150 years, despite a higher uncertainty of

the circulation given by the reanalyses due to the scarcity of observational data before 1940. Nevertheless, the 2007–2012 anomaly appears to be exceptional and several connexions with other variables, such as the North Atlantic Oscillation index and sea ice loss, suggest that it could be part of a major climatic anomaly extending beyond the Arctic region. However, the occurrence of similar periods in the past and the influence of several external and internal forcings do not allow us to attribute it to global warming.

The future summertime atmospheric circulation projected by GCMs over Greenland confirms this conclusion. In fact, no significant circulation pattern changes are simulated towards 2100, besides a generalised Z500 increase caused by the projected warming. Since GCMs are able to simulate atmospheric circulation changes over other regions and since the atmospheric circulation itself is influenced by other variables, such as sea ice or snow extent, which are already impacted by long-term changes, we conclude that the 2007–2012 anomaly could rather be attributed to the internal variability of the climatic system.

Finally, we evidence that projected future atmospheric circulation changes impact on the SLP and precipitation changes simulated over Europe towards 2100 for summer. Over north-western Europe, these circulation changes could mitigate the SLP decrease by around 50 % and cancel out the precipitation increase. Nevertheless, high uncertainties among the GCMs on the magnitude and even on the sign of these changes cast doubt on the reliability of these projections. On the other hand, future atmospheric circulation changes are not projected to affect significantly the warming and drying simulated for the next decades over the Mediterranean region and eastern Europe.

Résumé

Les projections futures de la circulation atmosphérique pour les hautes latitudes de l'hémisphère nord, en particulier l'Atlantique Nord, sont entachées d'une grande incertitude. Certains changements projetés sont opposés aux changements de circulation observés depuis les années 2000. Dans cette thèse, nous nous focalisons sur trois aspects de la circulation estivale, à la fois passée et projetée dans le futur, pour l'Atlantique Nord. D'abord, nous tentons de déterminer si l'anomalie anticyclonique estivale de 2007–2012 au-dessus de la mer de Beaufort, de l'archipel arctique canadien et du Groenland pourrait être attribuée au réchauffement climatique ou plutôt à la variabilité interne de la circulation atmosphérique. Pour celà, nous la comparons à la variabilité de la circulation des 150 dernières années donnée par cinq réanalyses. Ensuite, cette analyse est étendue à la circulation future simulée d'ici 2100 par les Modèles de Circulation Générale (GCM) pour le Groenland. Enfin, nous évaluons l'impact des incertitudes des projections futures de la circulation atmosphérique sur l'effet atténuateur ou amplificateur des changements de circulation sur la température et les précipitations en été en Europe.

Nous utilisons une classification de types de circulations automatique pour analyser en détail les changements de circulation atmosphérique en groupant les champs journaliers de SLP (pression réduite au niveau de la mer) ou de Z500 (hauteur géopotentielle à 500 hPa) semblables en types de circulations homogènes. Il apparait que le choix de l'indice, sur base duquel les jours sont regroupés, influence fortement les caractéristiques des types de circulations, ainsi que les différents changements de circulation qui peuvent être détectés. Les indices basés sur la corrélation, en particulier la corrélation des rangs de Spearman, sont les plus appropriés pour étudier la localisation des centres de pression, par rapport aux indices basés sur la distance euclidienne ou sur le gradient de pression.

Pour l'Arctique, nous avons détecté, sur les 150 dernières années, quatre

périodes présentant des anomalies de circulation semblables à celle de 2007–2012 (à savoir une anomalie anticyclonique sur l'ouest de l'Arctique en été), alors que la circulation représentée par les réanalyses est entachée d'une plus grande incertitude due à la rareté des données d'observations avant 1940. Toutefois, l'anomalie de 2007–2012 se révèle être exceptionnelle. En outre, plusieurs connexions avec d'autres variables, comme l'oscillation nord-atlantique et la diminution de la banquise, permettent de supposer que cette anomalie fait partie d'une anomalie climatique majeure s'étendant au-delà de l'Arctique. Cependant, l'existence de périodes similaires dans le passé et l'influence de nombreux forçages internes et externes ne nous permettent pas d'attribuer l'anomalie de 2007–2012 au réchauffement climatique.

Cette conclusion est confirmée par la circulation atmosphérique future projetée par les GCM pour le Groenland en été. En effet, aucun changement significatif de types de circulations n'est simulé d'ici 2100, excepté une hausse généralisée de Z500 due au réchauffement projeté. Vu que les GCM sont capables de simuler des changements de circulation pour d'autres régions et que la circulation atmosphérique est elle-même influencée par des variables qui subissent déjà des changements à long terme, telles que l'étendue de la banquise et de la couverture neigeuse, nous concluons que l'anomalie de 2007–2012 en Arctique pourrait être attribuée à la variabilité interne du système climatique.

Finalement, nous montrons que les changements de circulation atmosphérique projetés pour le futur influencent les changements de SLP et de précipitations simulés pour l'Europe en été, d'ici 2100. Au nord-ouest de l'Europe, ces changements de circulation pourraient atténuer la diminution de SLP de 50 % et annuler l'augmentation des précipitations. Néanmoins, de grandes incertitudes entre les GCM sur l'ampleur et même sur le signe de ces changements jettent le doute sur la fiabilité de ces projections. Par ailleurs, les changements de circulation atmosphérique projetés pour le futur ne devraient pas affecter significativement le réchauffement et la diminution des précipitations simulés pour les prochaines décennies pour la région méditerranéenne et l'est de l'Europe.

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