How does Arctic sea-ice loss affect the global climate ?

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Instituto Dom Luiz

IDL-RG1, Seminar, July 14th, 2021

Photographer Zoé Koenig, North of Svalbard

My Background

(2009-2013) **Engineer School (Master 2), INSA, Normandy, France**
(6 months stay North of Sweden)
→ Fluid dynamics, Thermodynamics, Energy system

Mont-Saint Michel

Port racine, smallest port in France

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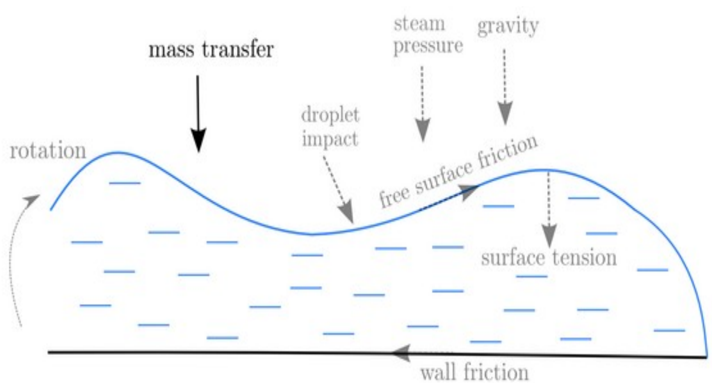
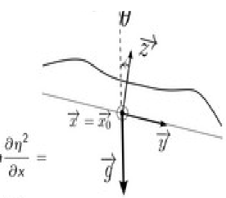
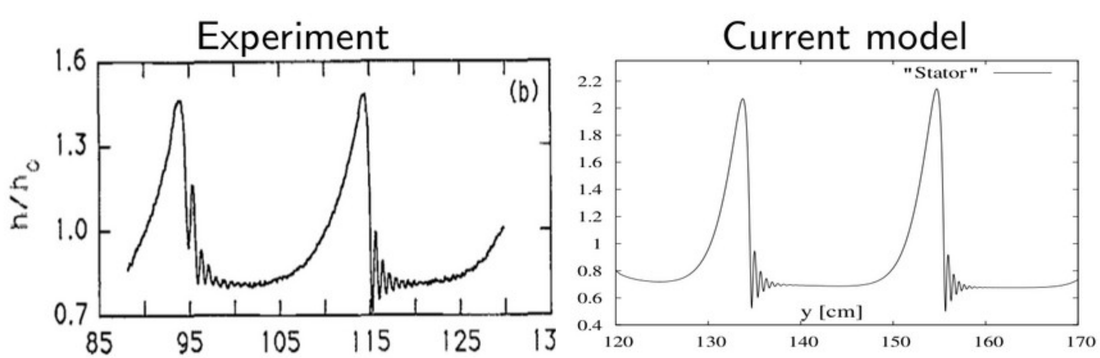


$$\frac{\partial h}{\partial t} + \frac{\partial h\bar{u}}{\partial x} + \frac{\partial h\bar{v}}{\partial y} = S_h$$



$$\frac{\partial h\bar{u}}{\partial t} + \frac{\partial}{\partial x}\left(\Gamma h\bar{u}^2 + \frac{g\cos\theta h^2}{2}\right) + \frac{\partial \Gamma h\bar{u}\ \bar{v}}{\partial y} + 2\omega_0\left(\bar{v}h\frac{\partial \eta}{\partial x} + \frac{h^2}{2}\frac{\partial \bar{v}}{\partial x}\right) - \frac{\omega_0{}^2}{2}h\frac{\partial \eta^2}{\partial x} =$$
$$-\frac{h}{\rho}\frac{\partial \mathscr{P}_g}{\partial x} - \frac{\sigma h}{\rho}\frac{\partial \mathscr{R}^{-1}}{\partial x} - hg\cos\theta\frac{\partial z_b}{\partial x} + \frac{1}{\rho}\left(\tau_{xz-r|\eta} - \tau_{xz-r|z_b}\right) + \left(\frac{\bar{u}+u_g}{2}\right)S_h$$

$$\frac{\partial h\bar{v}}{\partial t} + \frac{\partial \Gamma h\bar{u}\ \bar{v}}{\partial x} + \frac{\partial}{\partial y}\left(\Gamma h\bar{v}^2 + \frac{g\cos\theta h^2}{2}\right) + 2\omega_0\left(\bar{v}h\frac{\partial \eta}{\partial y} + \frac{h^2}{2}\frac{\partial \bar{v}}{\partial y}\right) - \frac{\omega_0{}^2}{2}h\frac{\partial \eta^2}{\partial y} + \omega_0 h^2\left(\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y}\right) =$$
$$g\sin\theta h - \frac{h}{\rho}\frac{\partial \mathscr{P}_g}{\partial y} - \frac{\sigma h}{\rho}\frac{\partial \mathscr{R}^{-1}}{\partial y} - hg\cos\theta\frac{\partial z_b}{\partial y} + h\omega_0{}^2(r+y) + 2\omega_0 h\left(\bar{u}\frac{\partial z_b}{\partial x} + \bar{v}\frac{\partial z_b}{\partial y}\right) + \frac{1}{\rho}\left(\tau_{yz-r|\eta} - \tau_{yz-r|z_b}\right)$$
$$+\left(\frac{\bar{v}+v_g}{2}\right)S_h$$



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(WP1 and WP4)
→ Marine and atmospheric heat-waves and its influence on ocean depth characteristics

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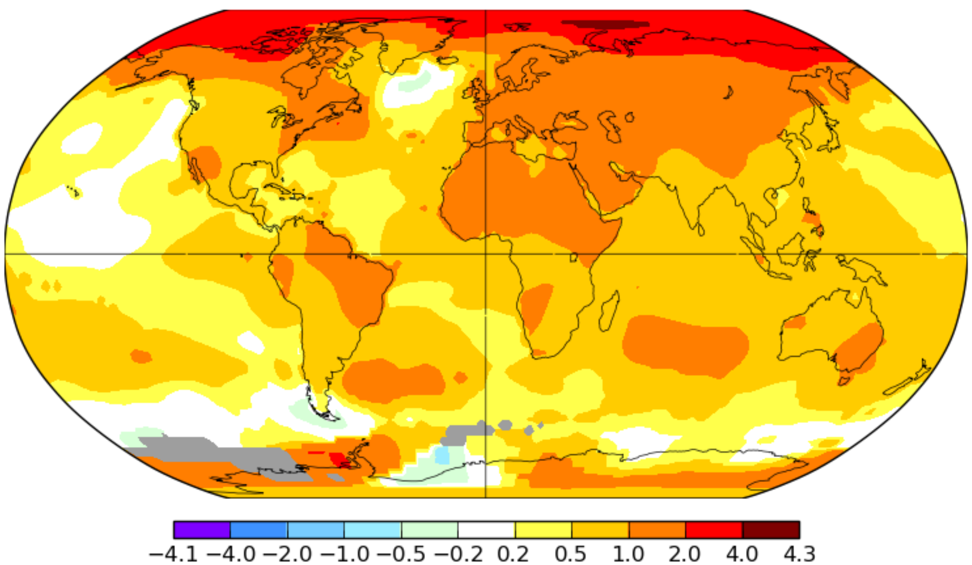
Introduction

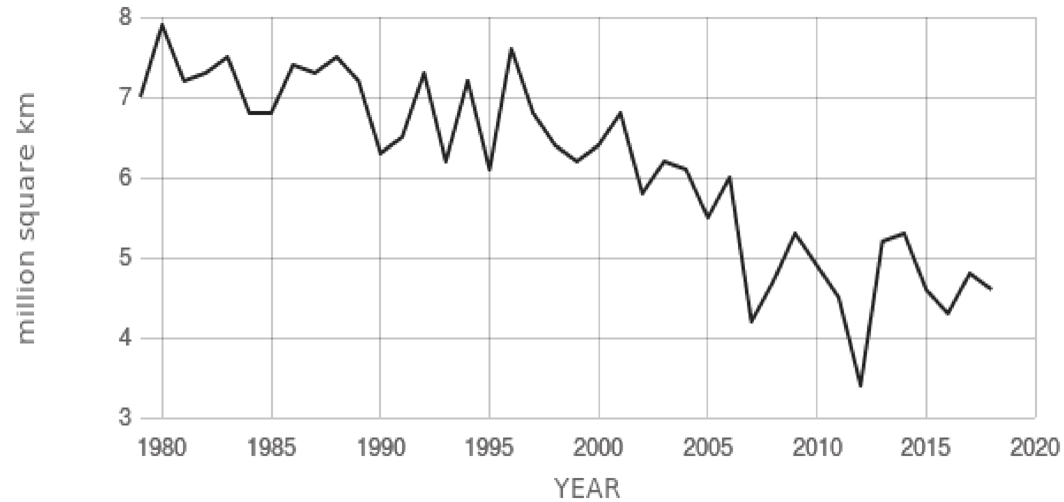
The Arctic is a region of pronounced climate changes...

Surface Temperature anomalies
between 2018-2008 and 1968-1958



Data from GISS/NASA GHCNv4_ERSSTv5__1200km

Arctic sea-ice average September extent



Data source: Satellite observations. Credit: NSIDC/NASA

... with potential impacts on lower latitudes
but it remains under debate (Cohen et al., 2019)

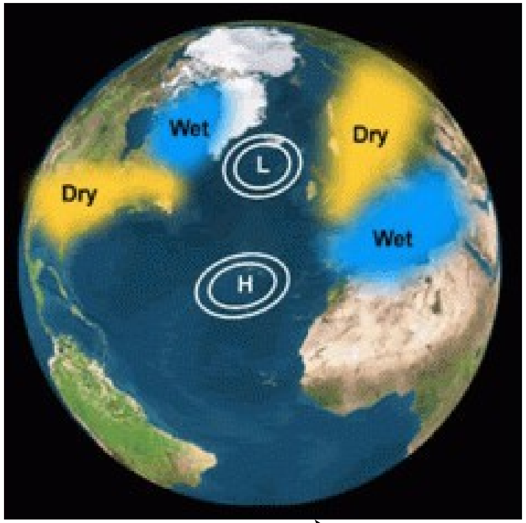
Potential impacts due to Arctic sea-ice melting on ...

North Atlantic Oscillation (NAO)

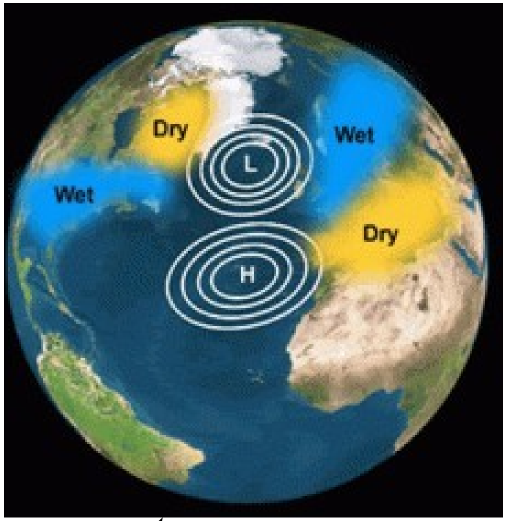
Observation →
(NAO-):
King et al., 2015
Garcia-Serrano et al., 2015
Simon et al., 2020 ...

Coupled model →
(NAO-) :
Deser et al., 2015
Screen et al., 2018
Simon et al., 2021 ...

NAO-



NAO+



Courtesy of UCAR

Atmospheric model
(NAO-/NAO+/no NAO): *Magnusdottir et al. 2004 ; Screen et al. 2014 ; Seierstad et al. 2009*

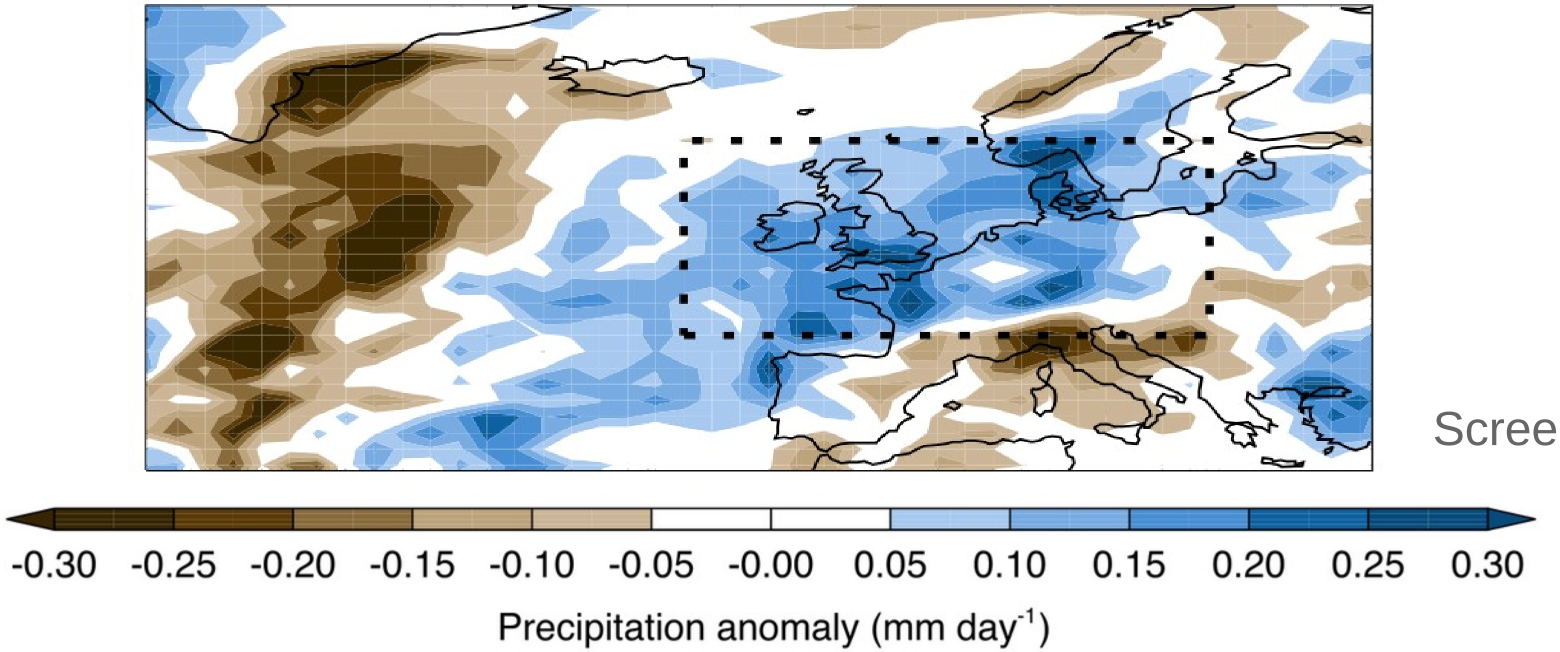
To understand the full story, it is important to investigate the interaction between Arctic sea-ice loss and persistent cofounding factor (snow cover, Sea-surface temperature, persistent atmospheric variability)

Potential impacts due to Arctic sea-ice melting on ...

North Atlantic Oscillation

Extreme Events

Francis and Vavrus, 2012;
Grassi et al., 2013
Screen et al., 2013
Cvijanovic et al., 2017
Coumou et al., 2018



Screen et al., 2013

Figure : Simulated May–June in the low Arctic ice run relative to the high Arctic ice run.

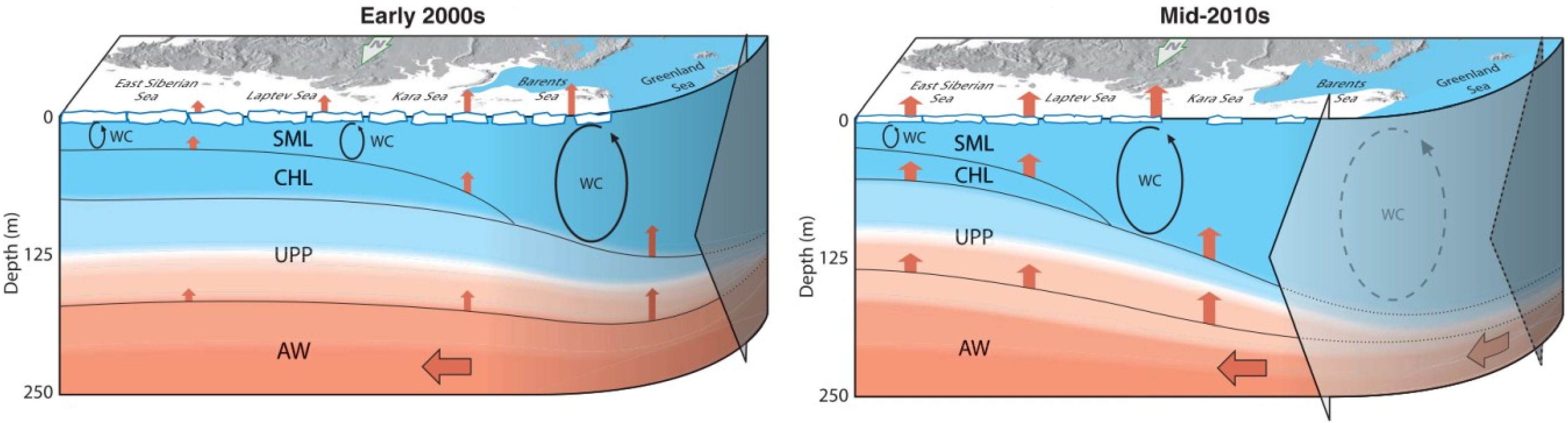
Potential impacts due to Arctic sea-ice melting on ...

North Atlantic Oscillation

Extreme Events

Arthun et al., 2012
Polyakov et al. 2017
Lind et al., 2018
Barton et al., 2018

Atlantification



Potential impacts due to Arctic sea-ice melting on …

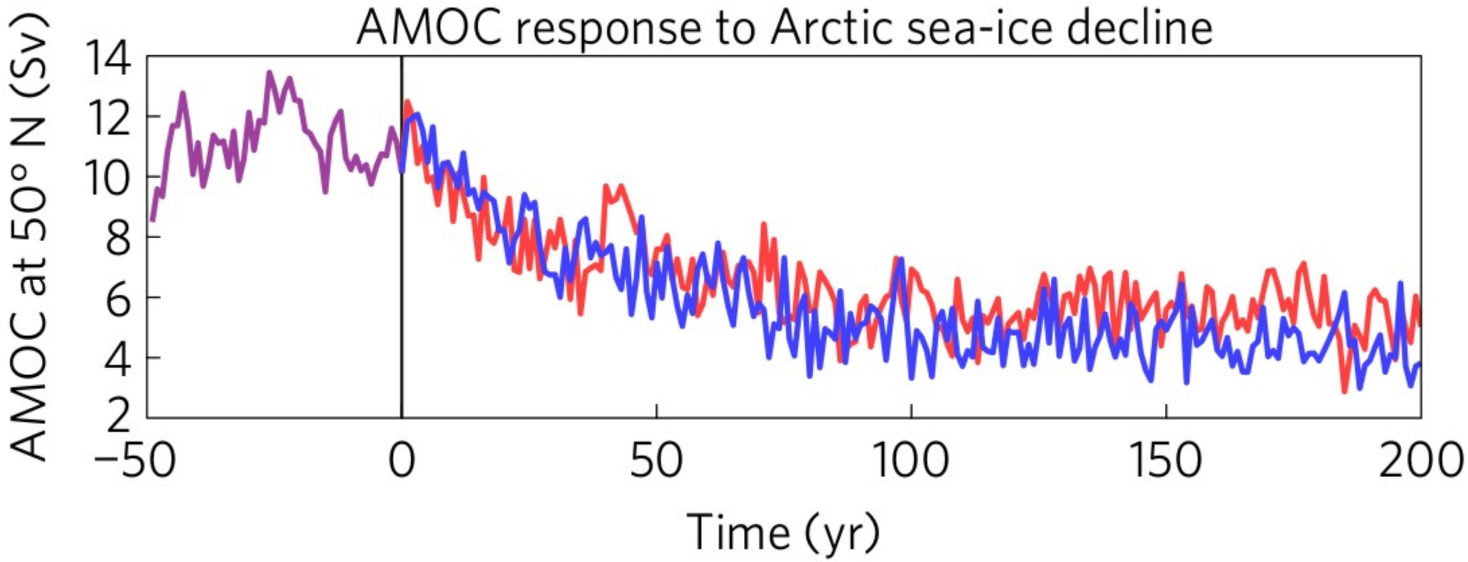
North Atlantic Oscillation

Sévellec et al., 2017,
Suo et al., 2017
Liu and Fedorov, 2019
And many others

Extreme Events

Atlantification

Atlantic Meridional Overturning Circulation (AMOC)



Sévellec et al, 2017

Potential impacts due to Arctic sea-ice melting on ...

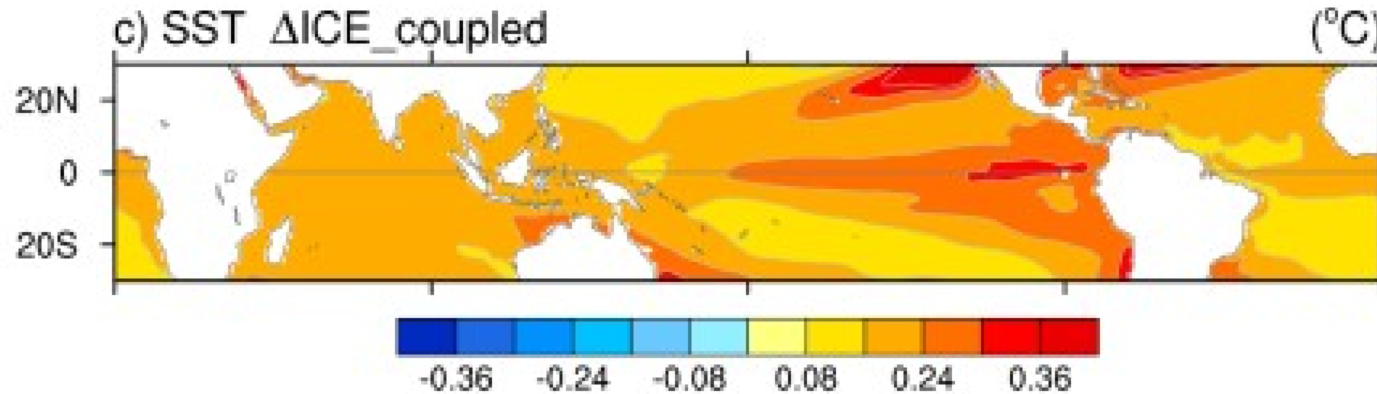
North Atlantic Oscillation

Extreme Events

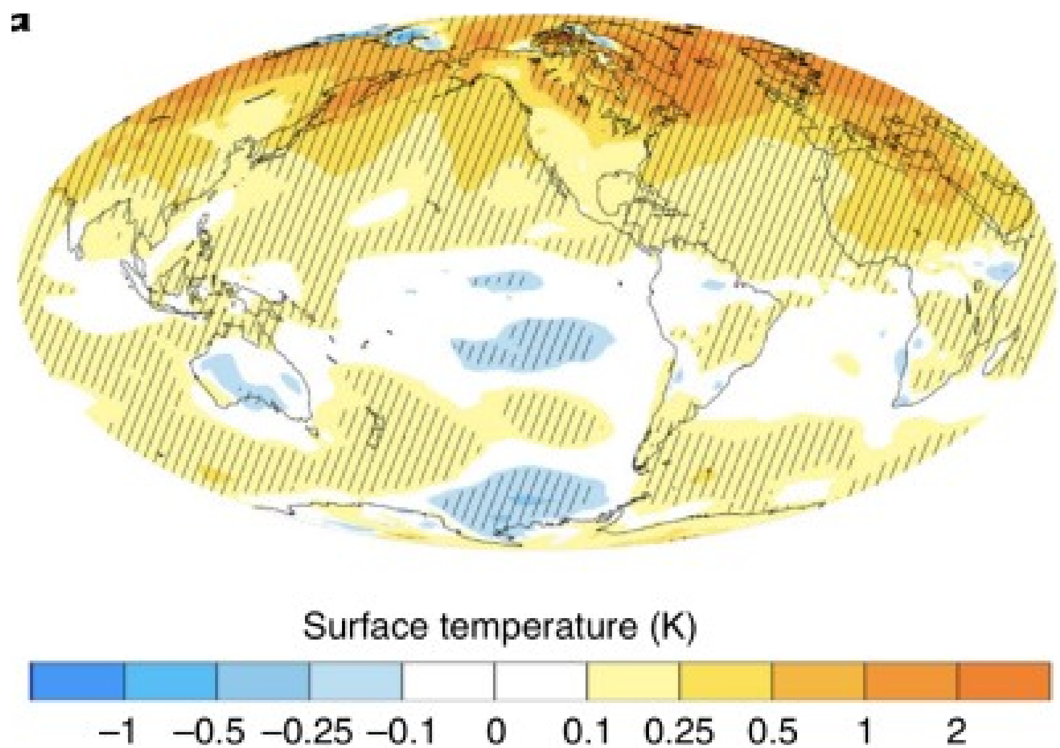
Atlantification

Atlantic Meridional Overturning Circulation (AMOC)

Tropical Pacific



Deser et al, 2015



Cvijanovic, 2017

Overview of studies

Observation

a) Direct Arctic sea-ice loss impact in winter

Simon, A., Frankignoul, C., Gastineau, G., & Kwon, Y. O. (2020). An observational estimate of the direct response of the cold-season atmospheric circulation to the Arctic sea ice loss. *Journal of Climate*, 33(9), 3863-3882.

<u>In the continuity of this work:</u>

b) Arctic sea-ice loss impact in summer

c) Antarctic sea-ice loss impact in winter

Modelling

d) Arctic sea-ice loss impact in winter at decadal timescale (CMIP5)

Simon, A., Gastineau, G., Frankignoul, C., Rousset, C., & Codron, F. (2021). Transient climate response to Arctic sea ice loss with two ice-constraining methods. *Journal of Climate*, 34(9), 3295-3310.

<u>In the continuity of this work:</u>

e) Multi-model study focusing on Mediterranean precipitation

f) Extension of the simulation for equilibrium response

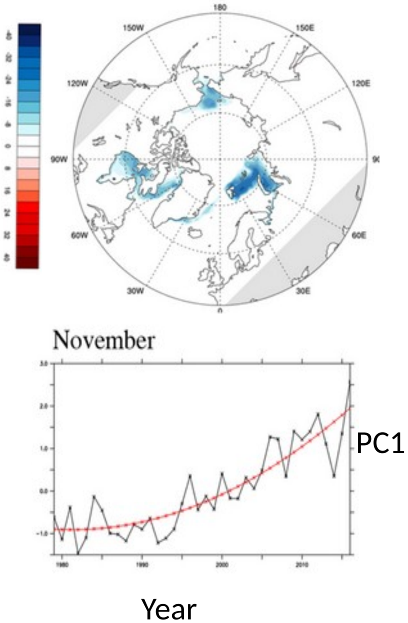
g) (CMIP6) Direct impact and the Interdecadal Pacific Variability (IPV)

h) (CMIP6) Direct impact and the Quasi-biennal Oscillation (QBO)

Observation

a) Direct Arctic sea-ice loss impact in winter

EOF of Arctic SIC



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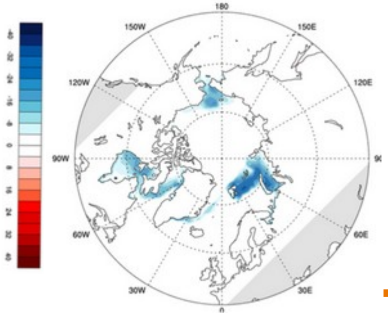
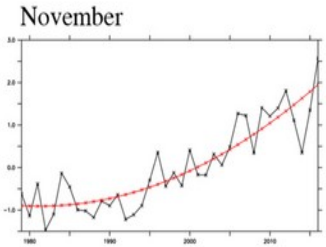
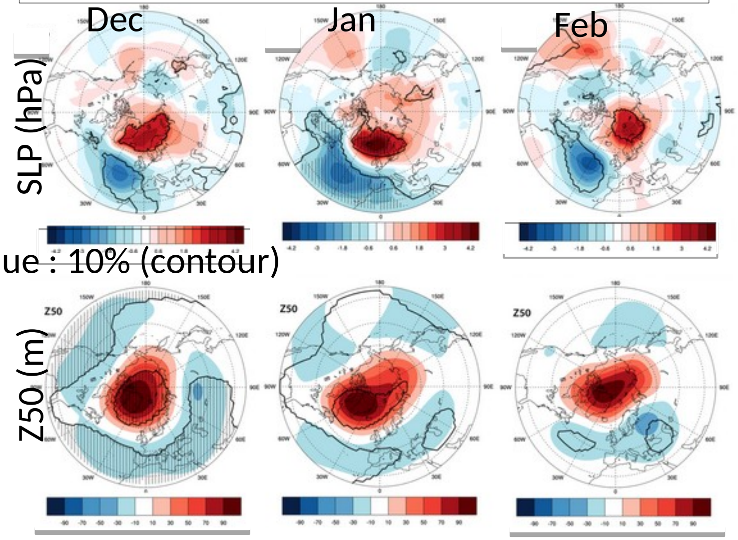




Regression on dPC1 in Nov with..



P-value : 10% (contour)

FDR : 10% (hatching)

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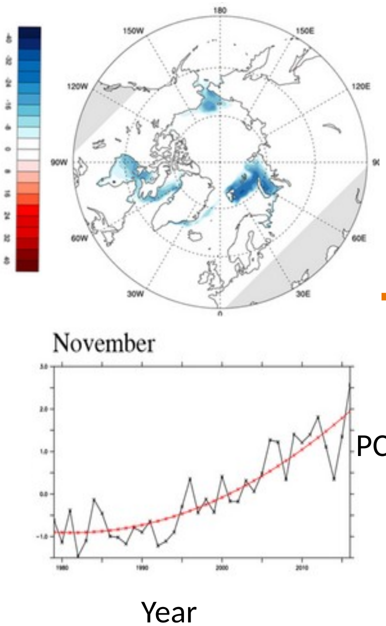

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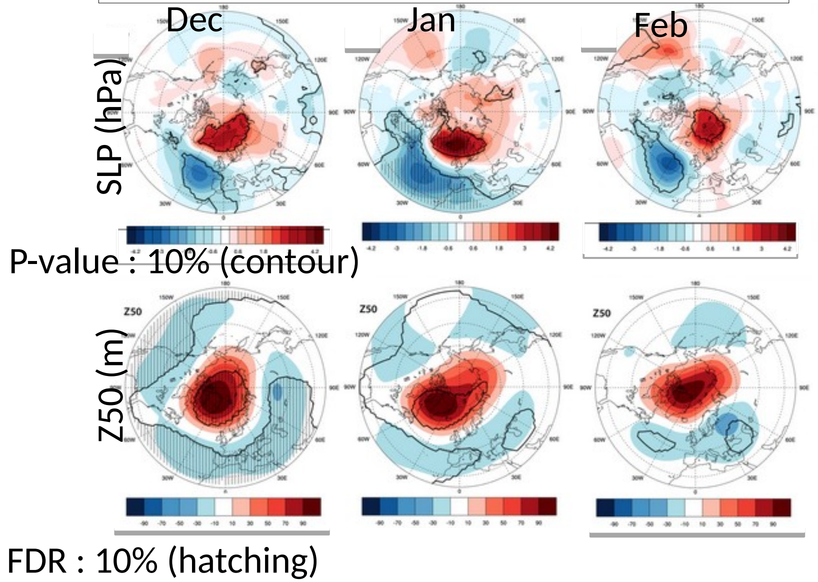
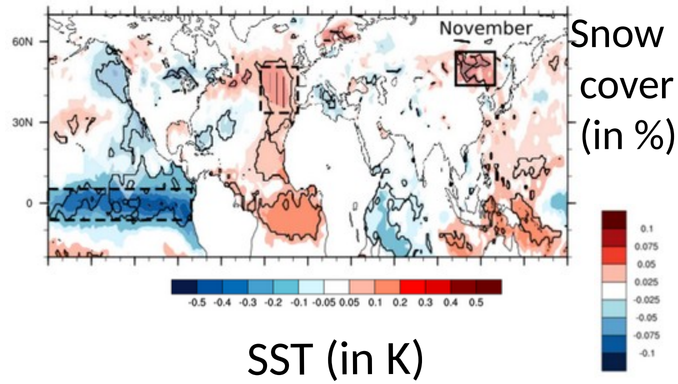


In-phase regression with SST and Snow



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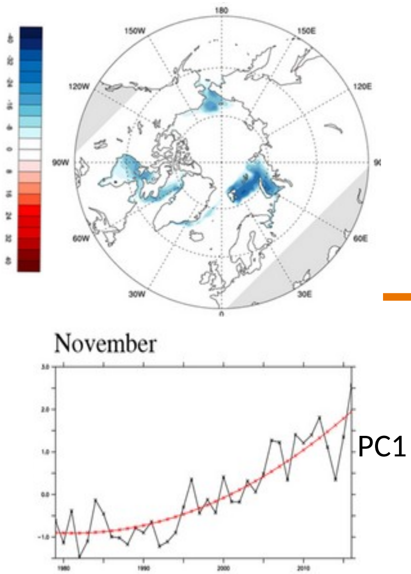

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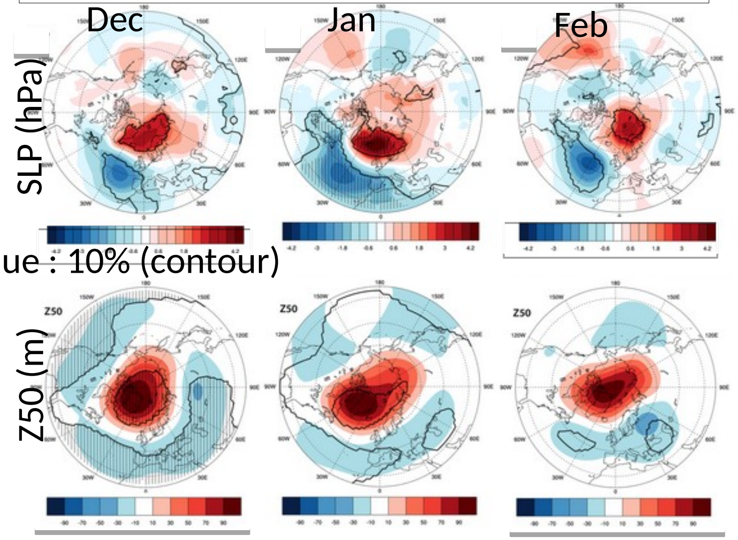

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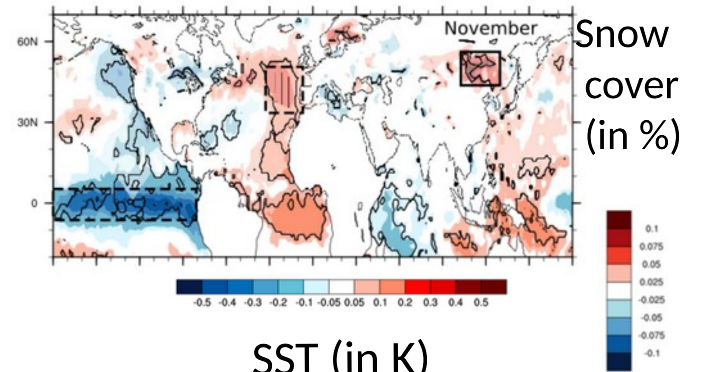
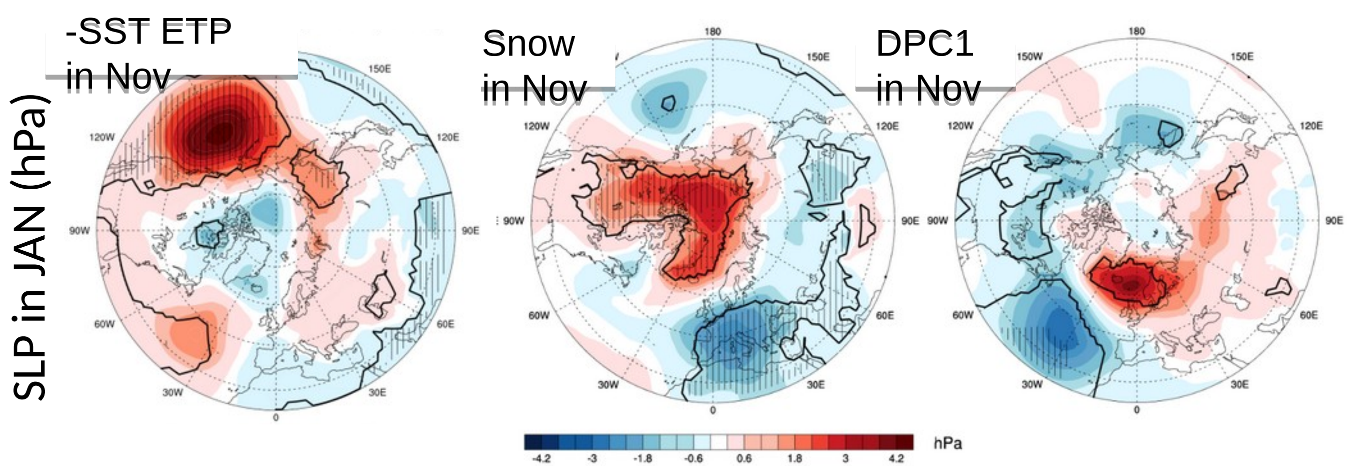


* Observations show that years with low Arctic sea ice extension have a negative NAO-like pattern in late winter



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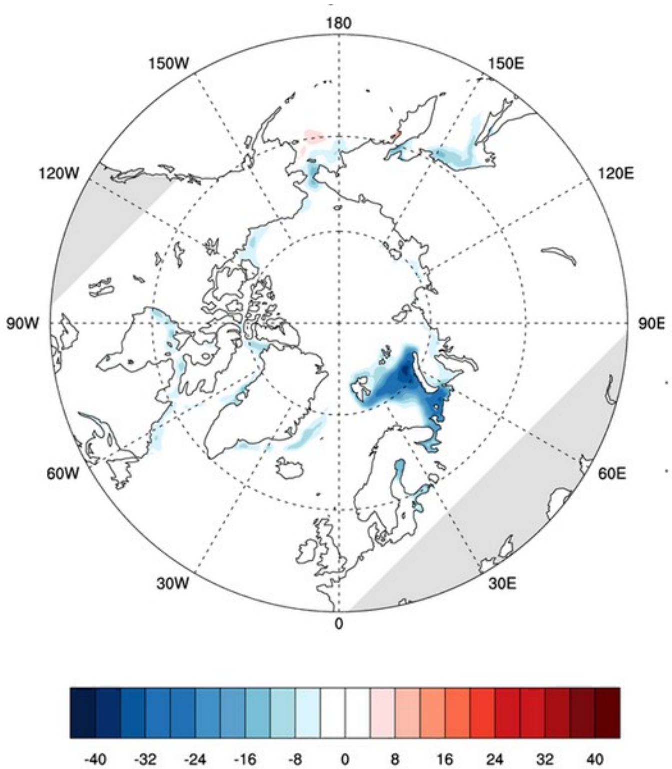
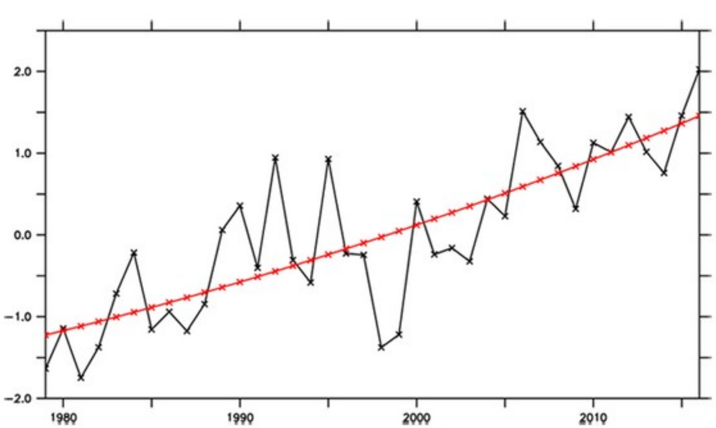
Observation

b) Arctic sea-ice loss impact in summer

Methodology based on Simon et al, 2020 but for summer

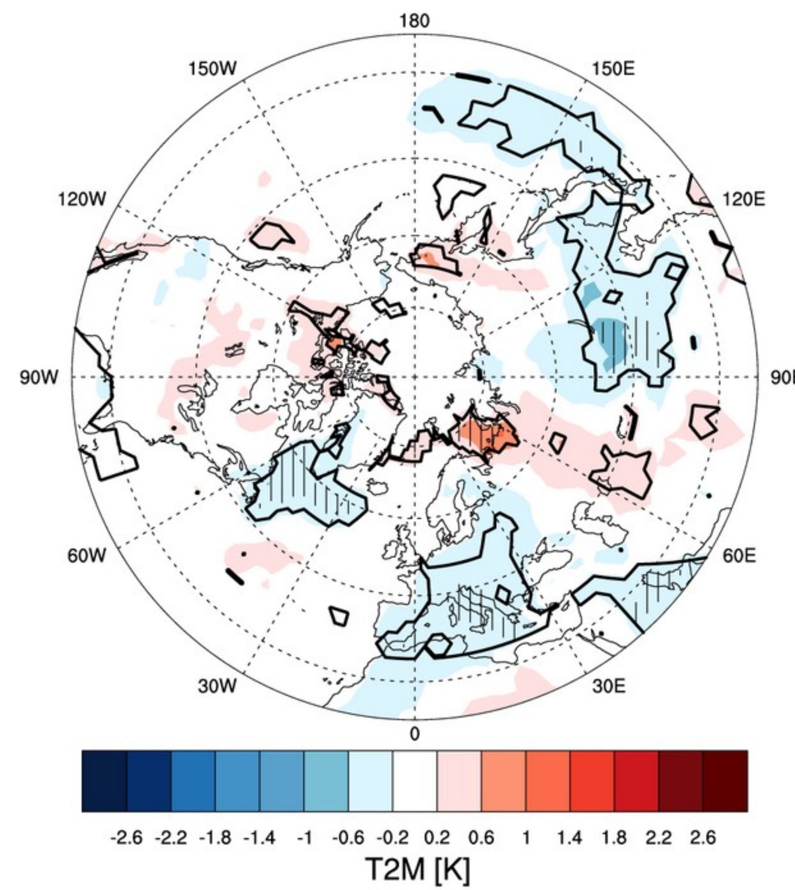


EOF1 (in %) of Arctic sea-ice concentration in April



PC1

Regression of surface temperature anomalies in May onto April dPC1.
The contours indicate 10% significance and hatching FDR significance at the 10% level.

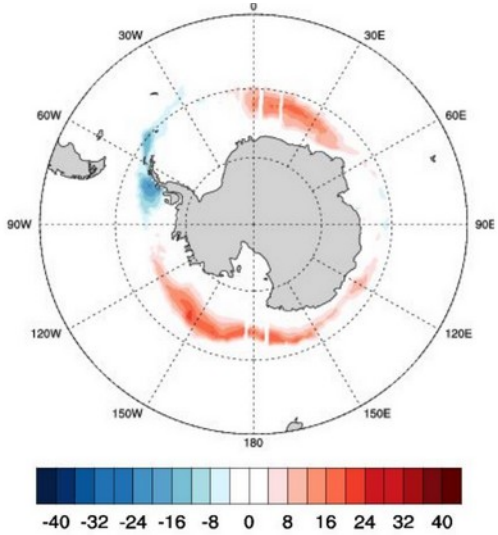


Observation

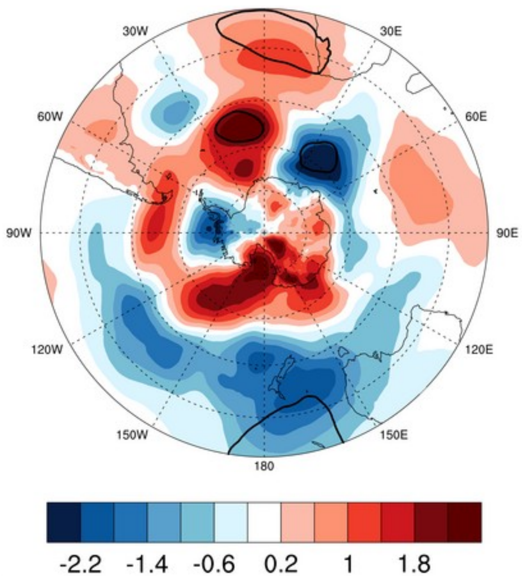
c) Antarctic sea-ice loss impact in winter

Methodology based on Simon et al, 2020
but for Antarctic sea-ice

LFP1
(Low frequency
pattern)
in June



Regression of
Detrended LFC1
in June and
detrended SLP
in July, (hPa)



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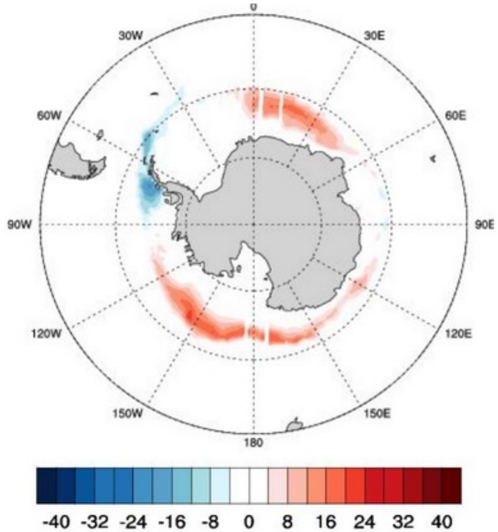
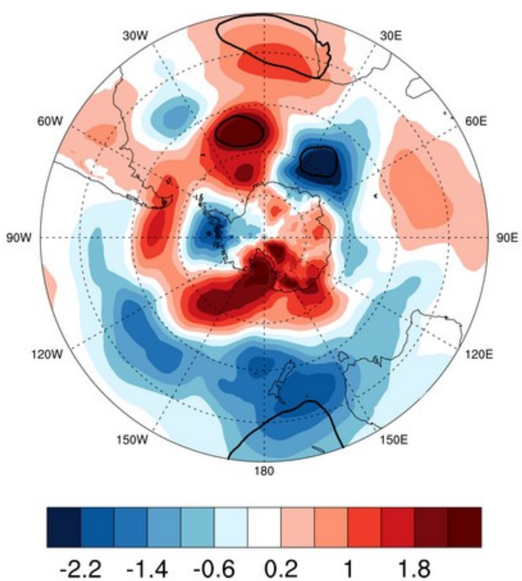
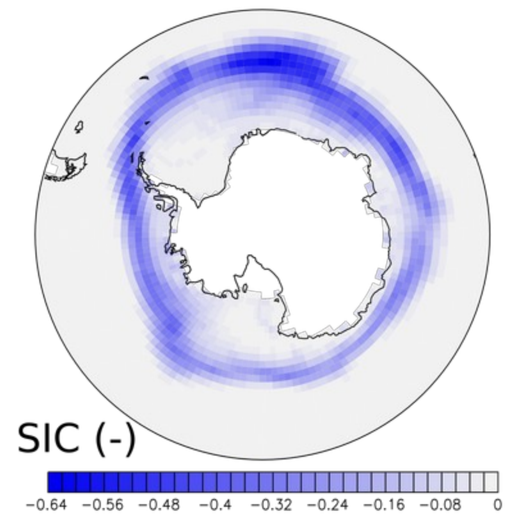
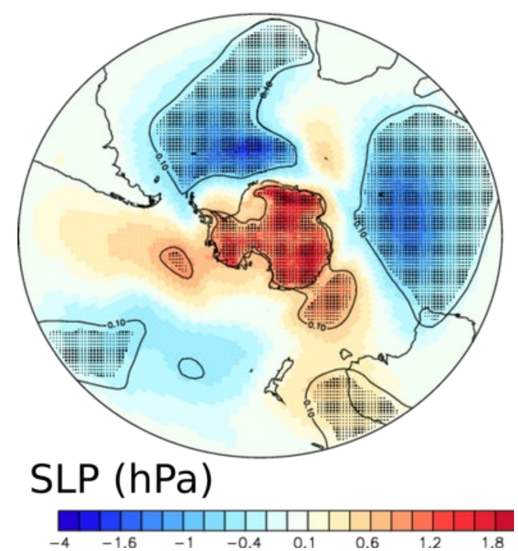


Regression of Detrended LFC1 in June and detrended SLP in July, (hPa)



Modelling analysis (LMDZ model with PAMIP) - 200 members of 14 months of future and pre-industrial Antarctic sea-ice in JAS





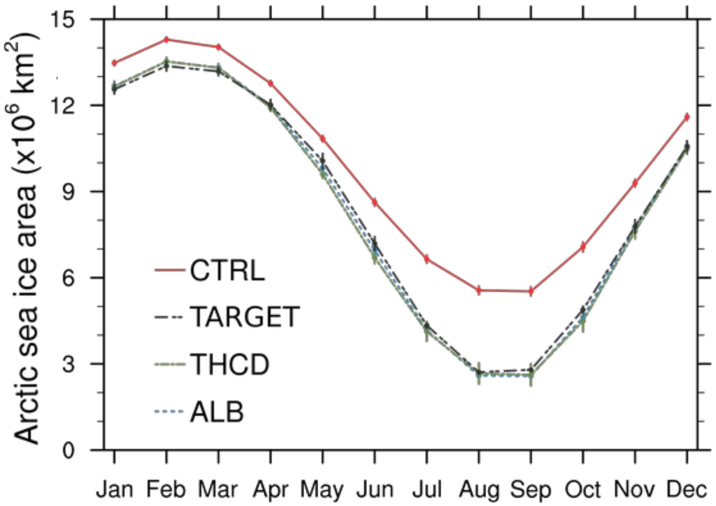
→ Antarctic sea-ice loss (gain) induces a negative (positive) Southern Annular mode like

Modelling

d) Arctic sea-ice loss impact in winter at decadal timescale

Methodology

- Coupled model IPSLCM5A2 (CMIP5)
- Arctic sea-ice constrain by reducing (i) albedo *(ALB)* (ii) thermal conductivity *(THCD)*
- Ensembles of 10 members
- Transient response: 10-30 years



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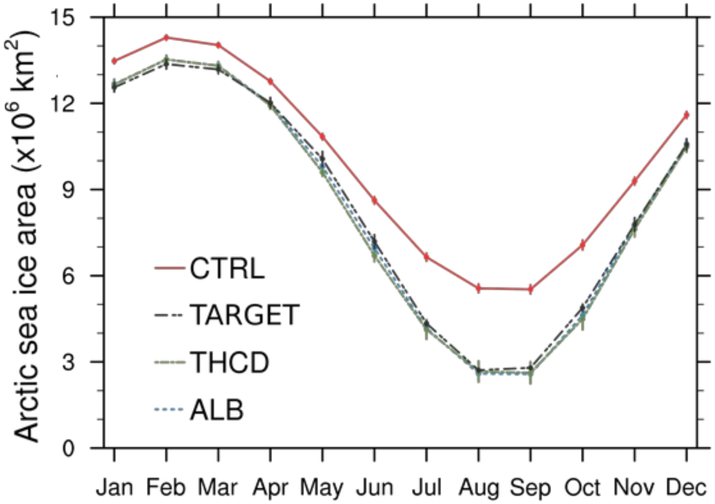

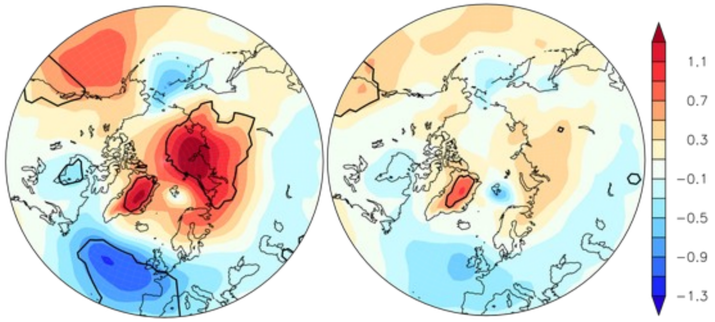

SLP anomaly in DJF (hPa)

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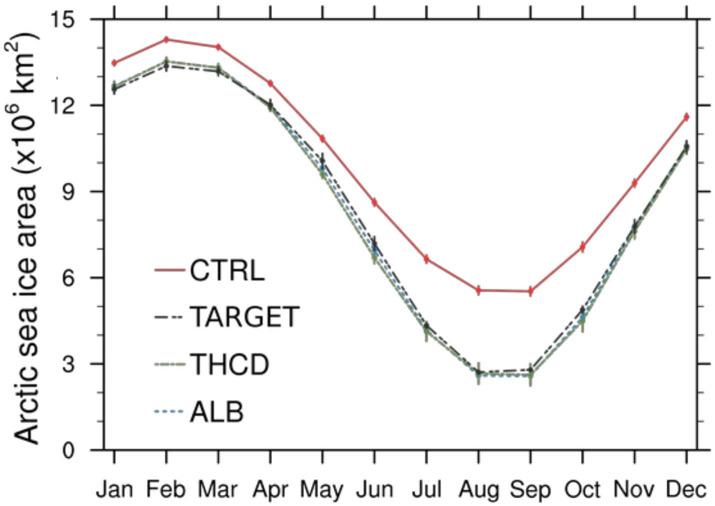
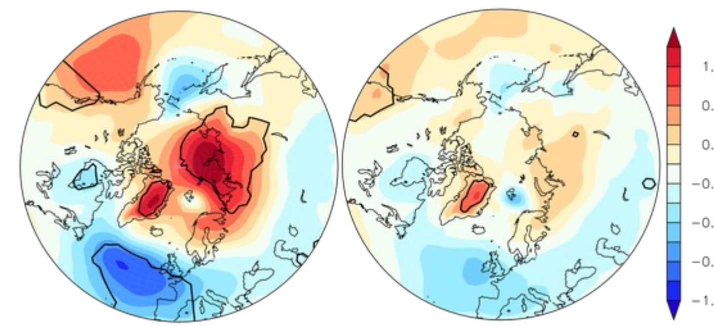


ALB - CTRL **THCD - CTRL**



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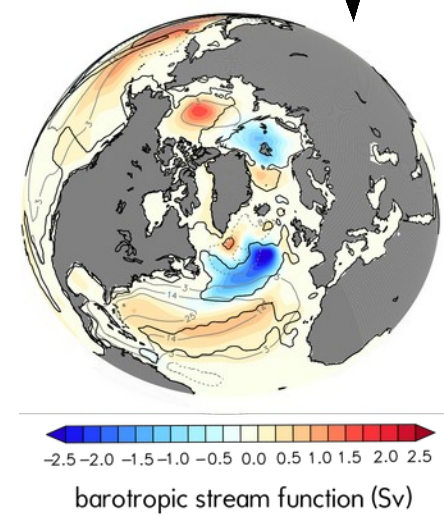

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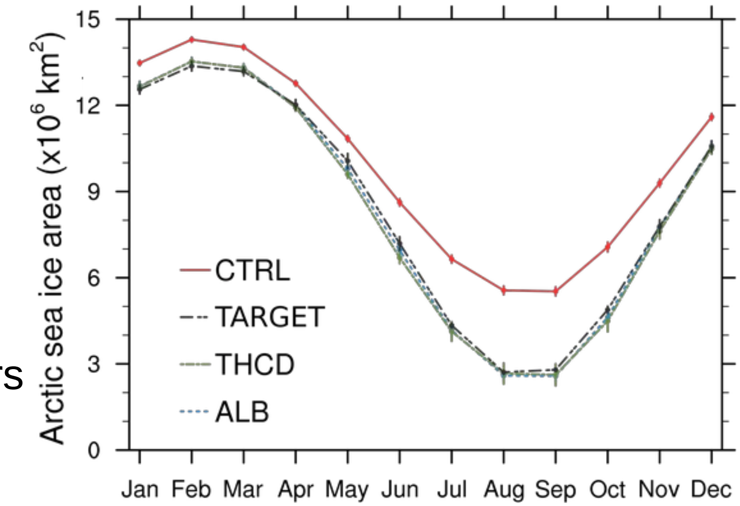
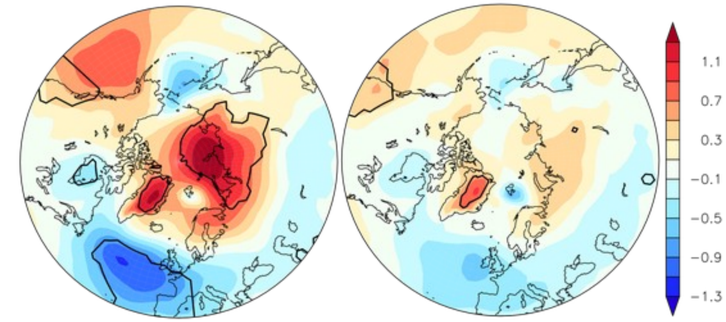
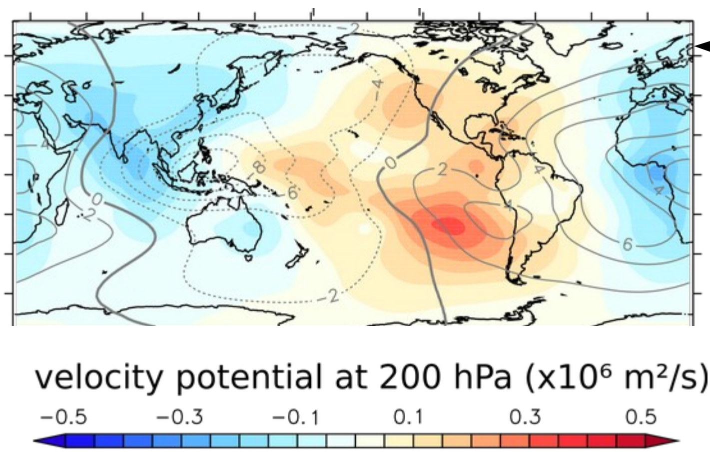


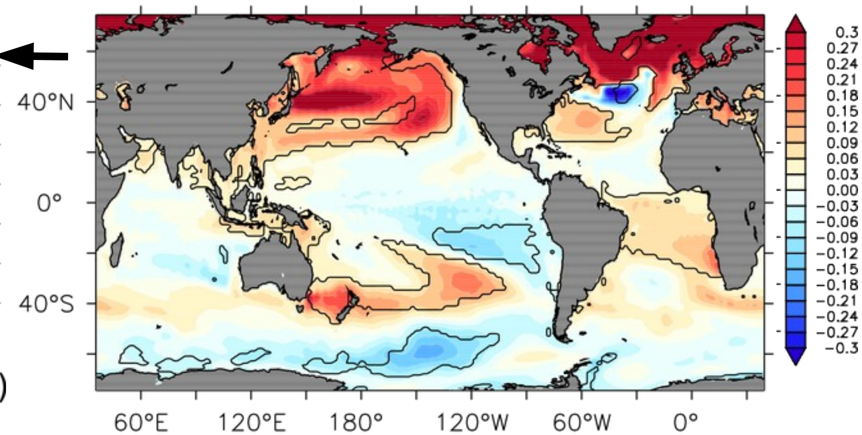
ALB - CTRL **THCD - CTRL**



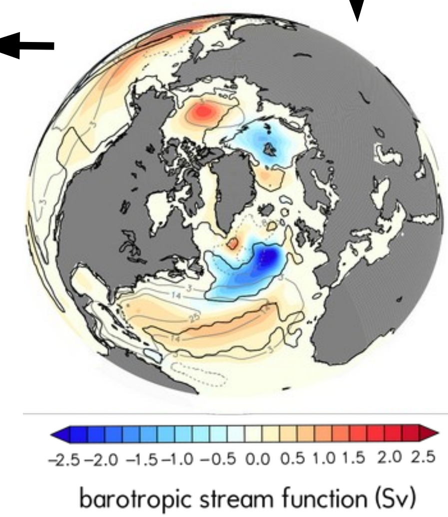
SLP anomaly in DJF (hPa)

ALB - CTRL





Sea surface temperature anomaly (°C)



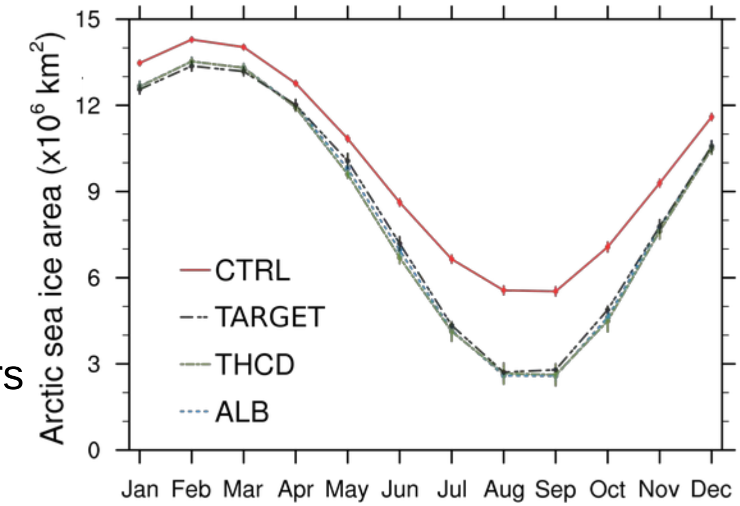
Simon, A., Gastineau, G., Frankignoul, C., Rousset, C., & Codron, F. (2021). Transient climate response to Arctic sea ice loss with two ice-constraining methods. Journal of Climate, 34(9), 3295-3310.

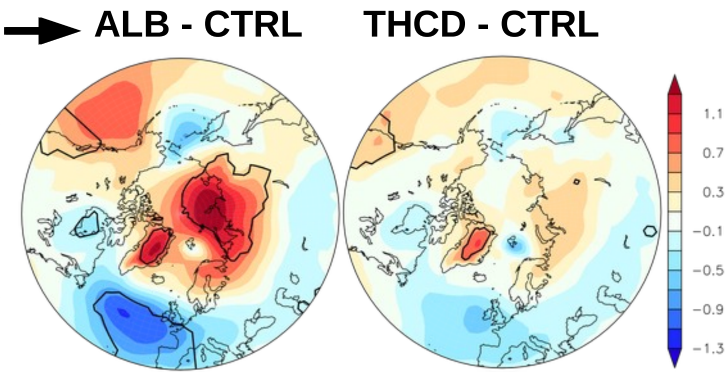
Modelling

d) Arctic sea-ice loss impact in winter at decadal timescale

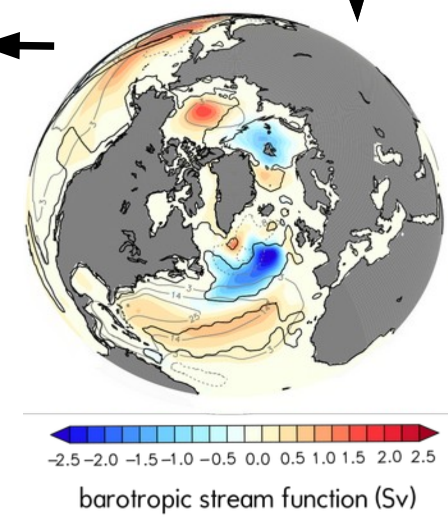
<u>Methodology</u>

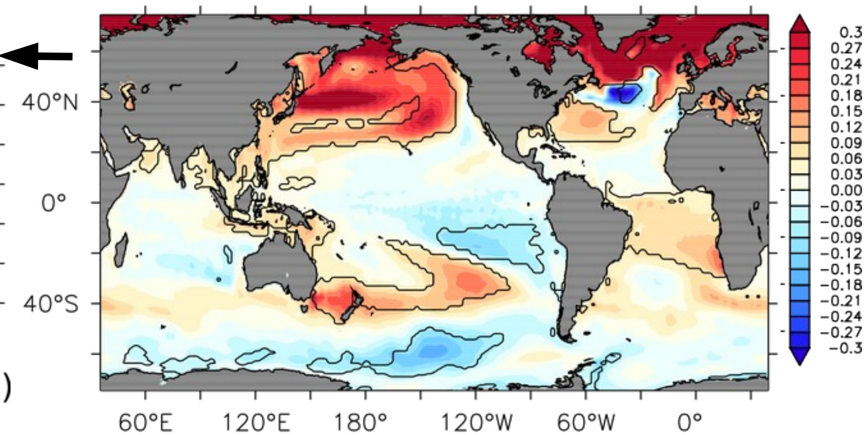
- Coupled model IPSLCM5A2 (CMIP5)
- Arctic sea-ice constrain by reducing (i) albedo *(ALB)* (ii) thermal conductivity *(THC)*
- Ensembles of 10 members
- Transient response: 10-30 years





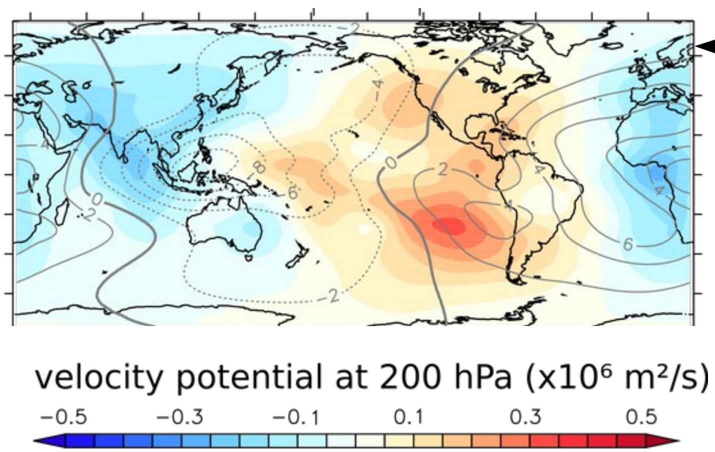
SLP anomaly in DJF (hPa)





Sea surface temperature anomaly (°C)

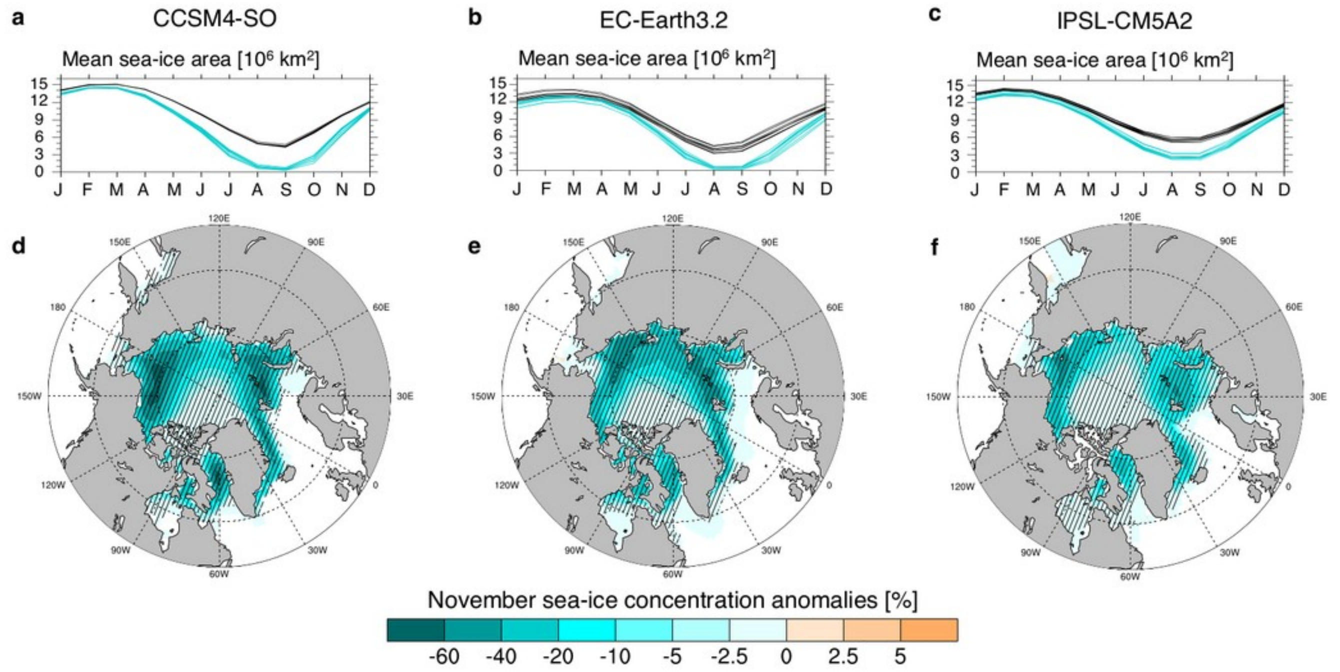
ALB - CTRL



The protocol to melt sea-ice with a coupled model lead to same pattern but different amplitude
Some robust responses (AMOC weakening, NAO-(like), Tropical Atlantic Warming) but Pacific's are not.

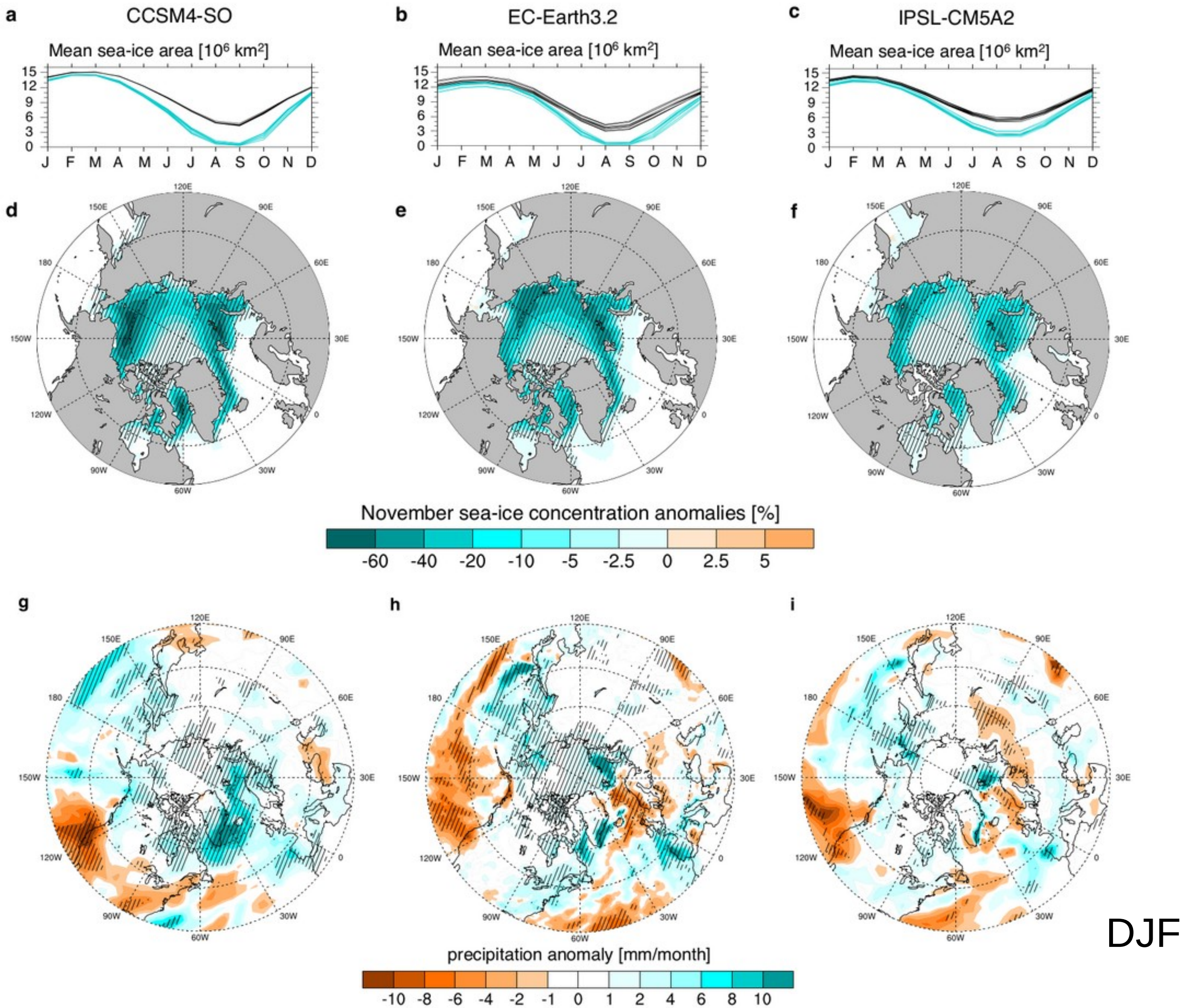
Simon, A., Gastineau, G., Frankignoul, C., Rousset, C., & Codron, F. (2021). Transient climate response to Arctic sea ice loss with two ice-constraining methods. Journal of Climate, 34(9), 3295-3310.

Modelling e) Multi-model study focusing on Mediterranean precipitation



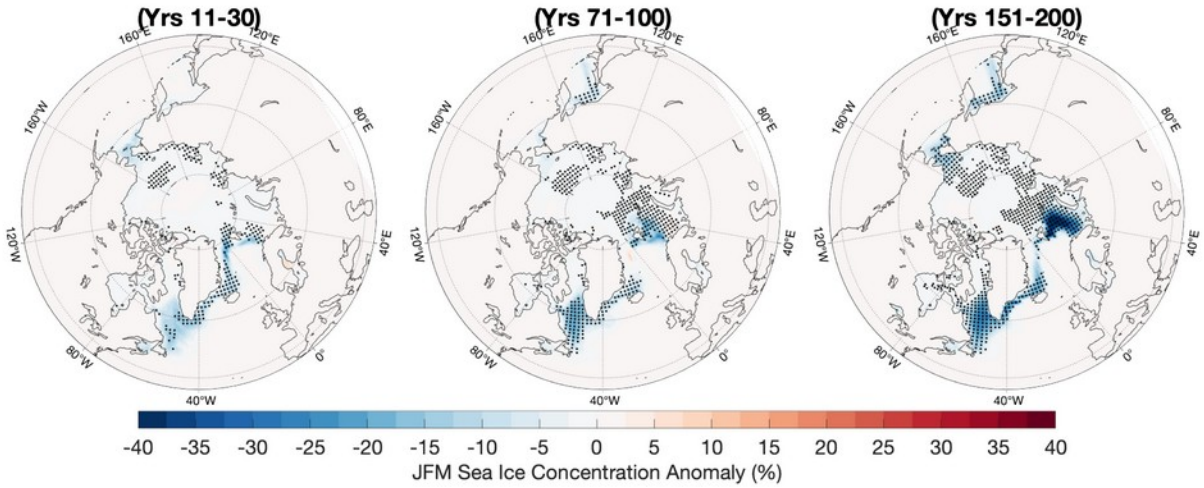
I. Cvijanovic, X. Levine, A. Simon, R. White, P. Ortega, M. Donat, D. D. Lucas, J.C.H. Chiang, A. Seidenglanz, D. Bojovic, A. R. Amaral, V. Lapin and Francisco Doblas-Reyes "Near-term impacts of Arctic sea-ice loss", *under review*

Modelling e) Multi-model study focusing on Mediterranean precipitation

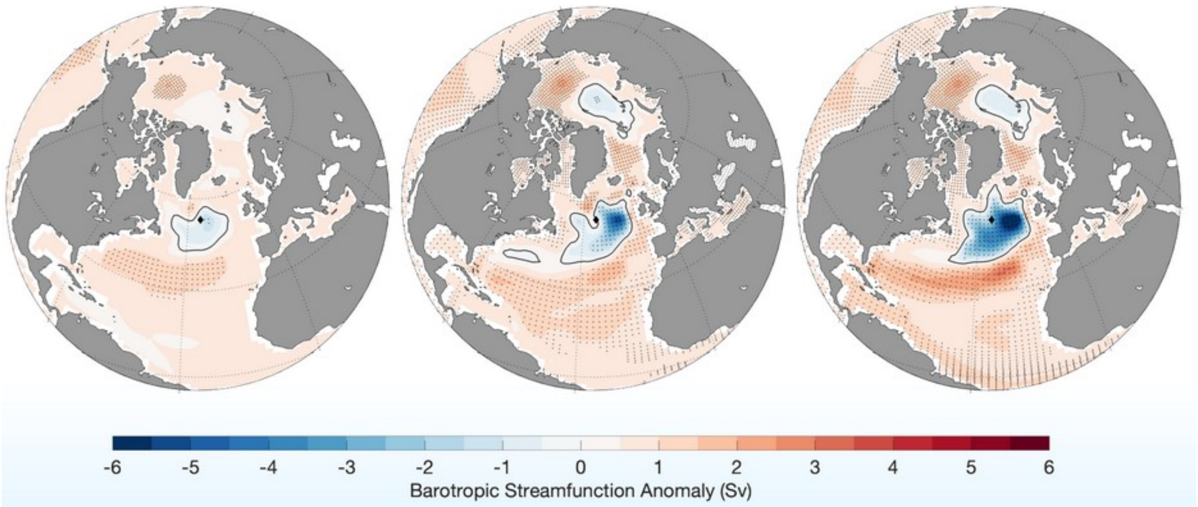


I. Cvijanovic, X. Levine, A. Simon, R. White, P. Ortega, M. Donat, D. D. Lucas, J.C.H. Chiang, A. Seidenglanz, D. Bojovic, A. R. Amaral, V. Lapin and Francisco Doblas-Reyes “Near-term impacts of Arctic sea-ice loss”, *under review*

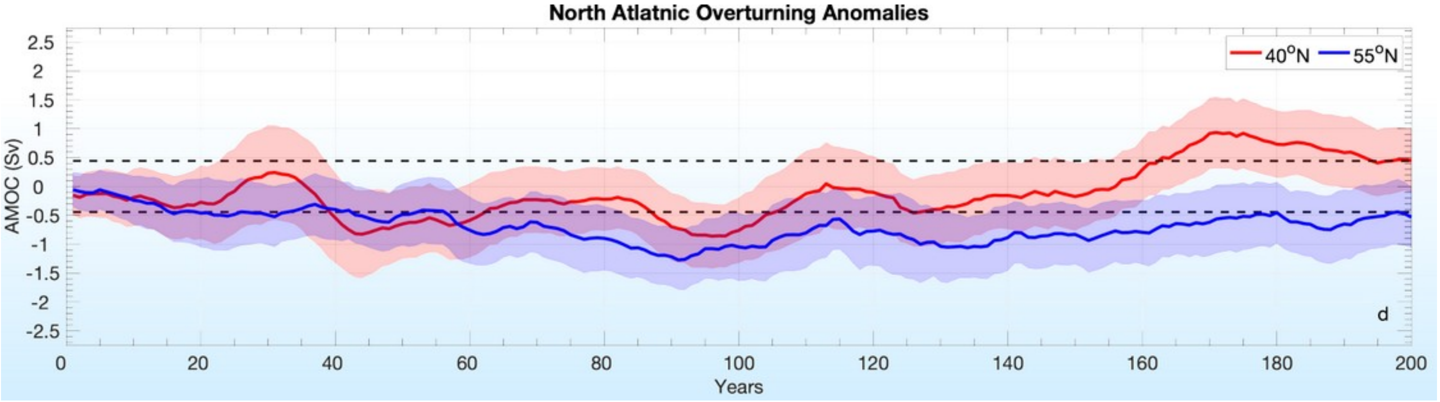
Modelling f) Arctic sea-ice impact for equilibrium response (B. Ferster)



Extension of the ALB simulation (IPSLCM5A) to 200 years.
(8 members)



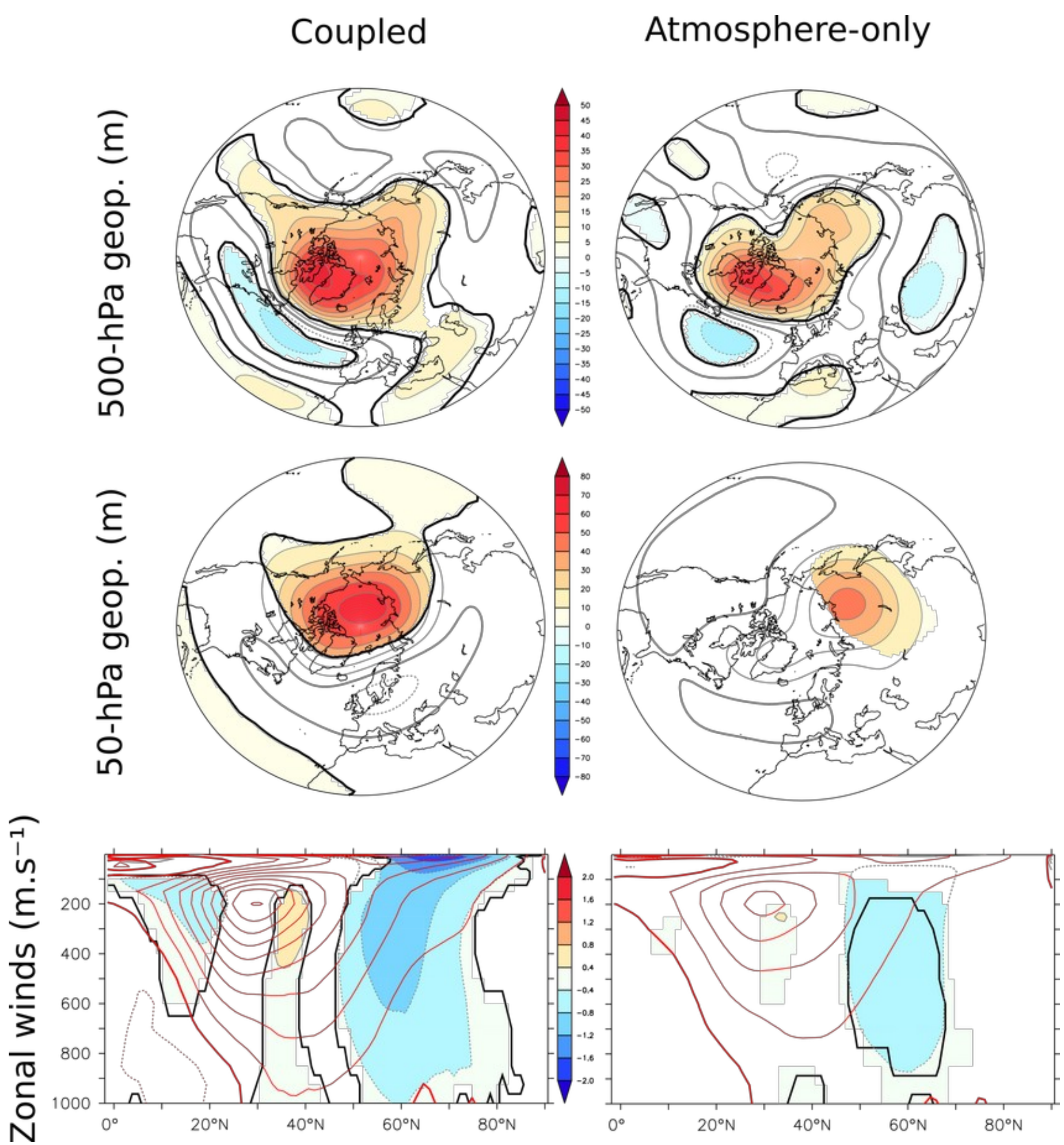
Southward shift of the subpolar gyre



An initial weakening of AMOC is followed by a recovery of AMOC

Modelling g) Direct Arctic sea-ice loss response and modulation by the Interdecadal Pacific variability (IPV) with IPSLCM6A (CMIP6)

Ensemble of 200 members of 14 months with nudged Arctic sea-ice loss



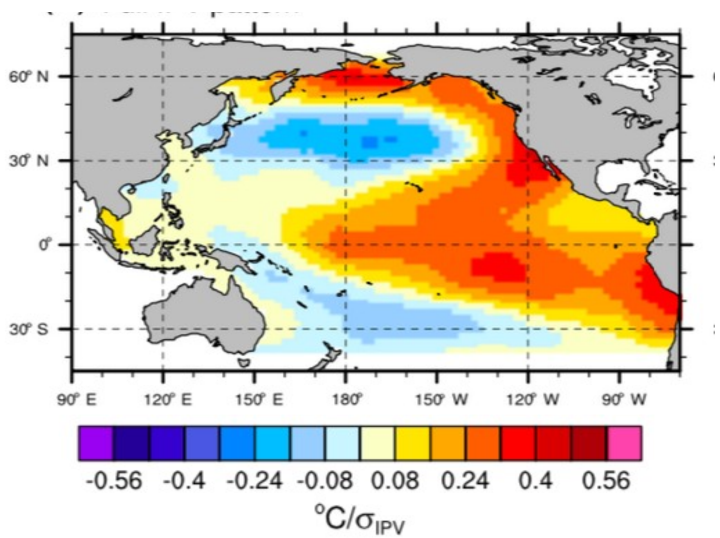
Low – High Arctic sea-ice (grey contour)
90 % confidence level based on Student t-test (colors)
90 % confidence level based on False discovery rate (black contours)
High in DJF (red contours)

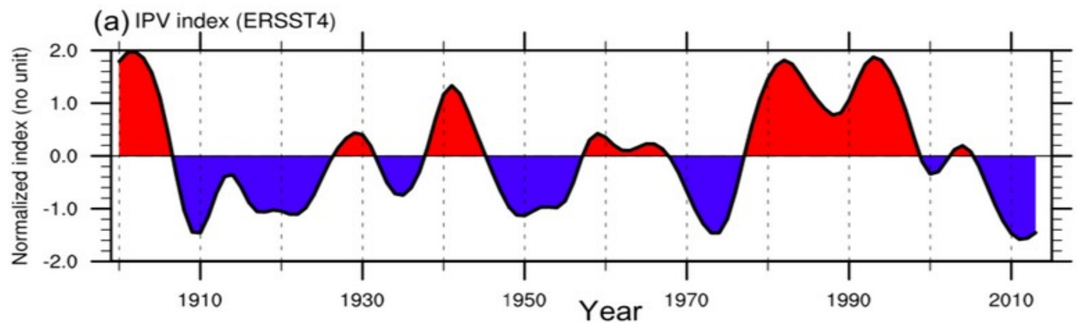
Arctic sea-ice loss is associated with a :
- * negative NAO
- * increase of z50
- * weakening of the polar vortex

The stratospheric responses are significant for the coupled model only

Modelling

g) Direct Arctic sea-ice loss response and modulation by the IPV by the Interdecadal Pacific variability (IPV) with IPSLCM6A (CMIP6)





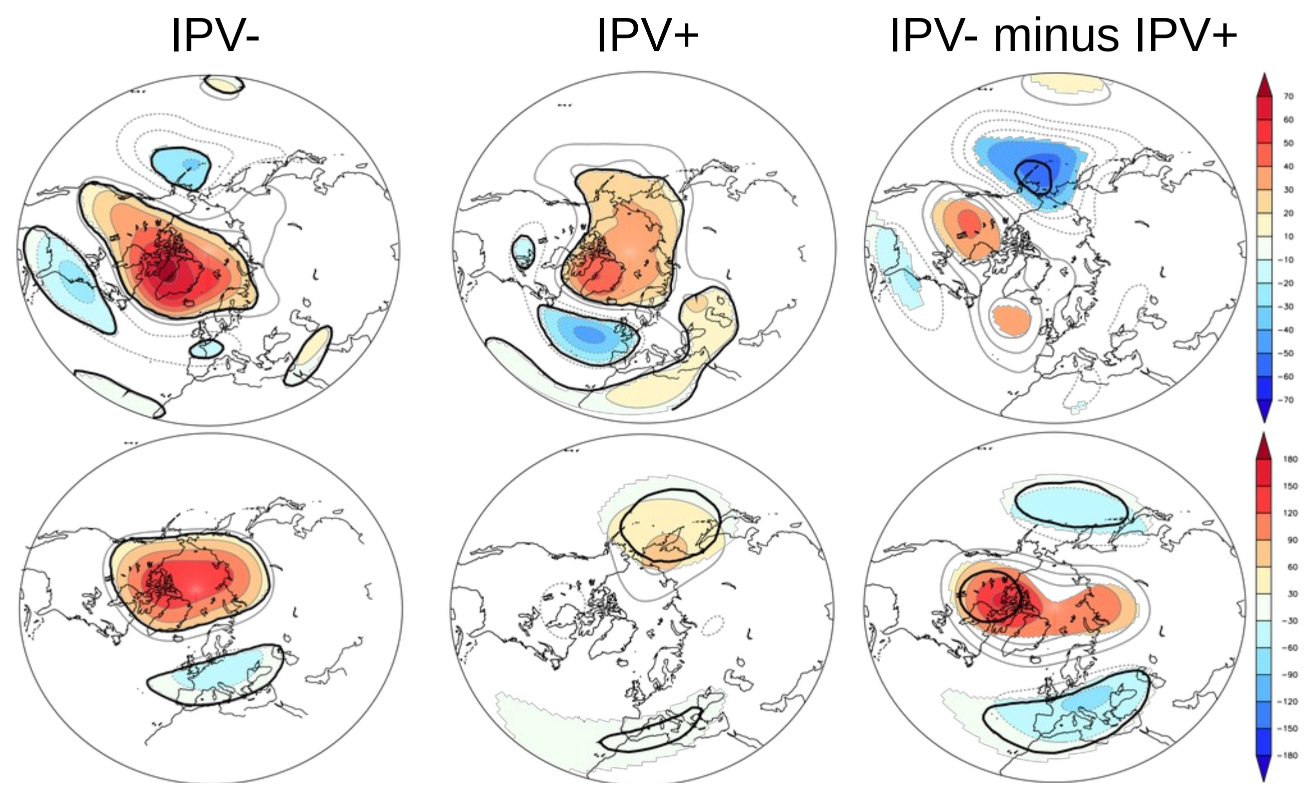
IPV index(DCPP-C; Boer et al., 2016)

Composites of IPV- and IPV+ for *Low - High Arctic sea-ice* (67 members;14 months)

Low - High Arctic sea-ice for different phase of IPV

Z500 (m)

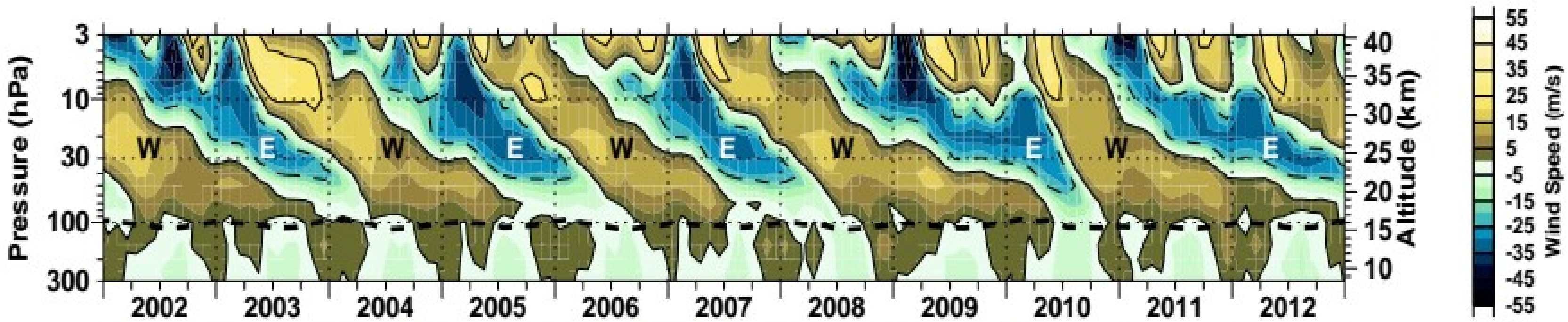
Z50 (m)



Modelling

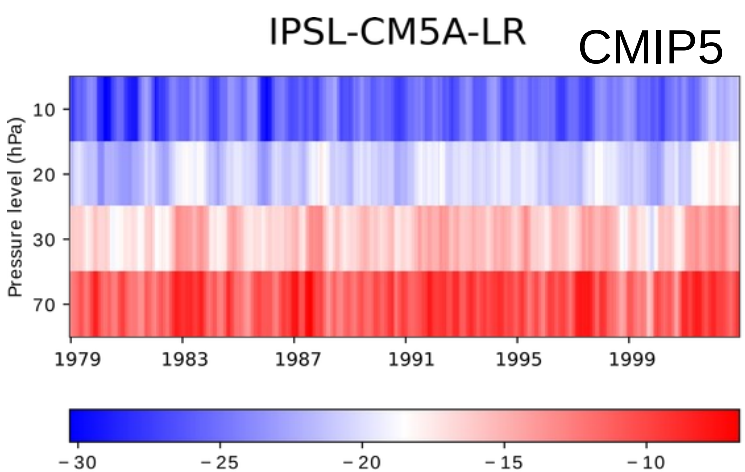
g) Direct Arctic sea-ice loss response and modulation by the QBO (Quasi-biennal Oscillation) with IPSLCM6A (CMIP6)

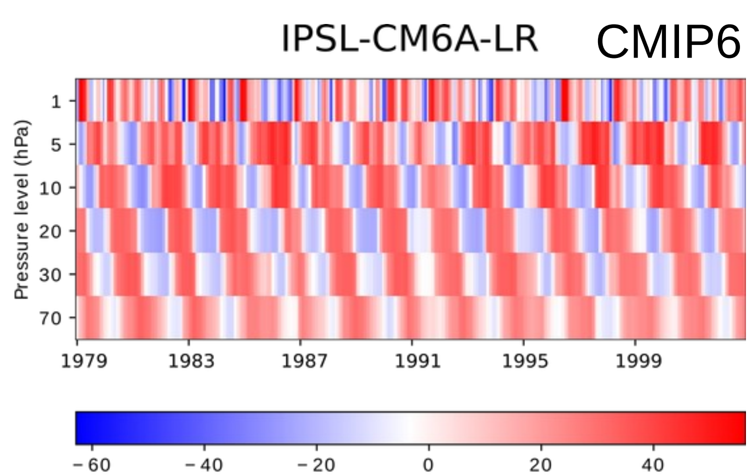
* The **quasi-biennial oscillation** (QBO) is a quasi-periodic oscillation of the equatorial zonal wind in the stratosphere between easterlies (QBO-E) and westerlies (QBO-W) with a period of 28 months (Baldwin et al., 2001).



Courtesy of NASA/GSFC (MERRA-2 reanalysis)

* QBO in models



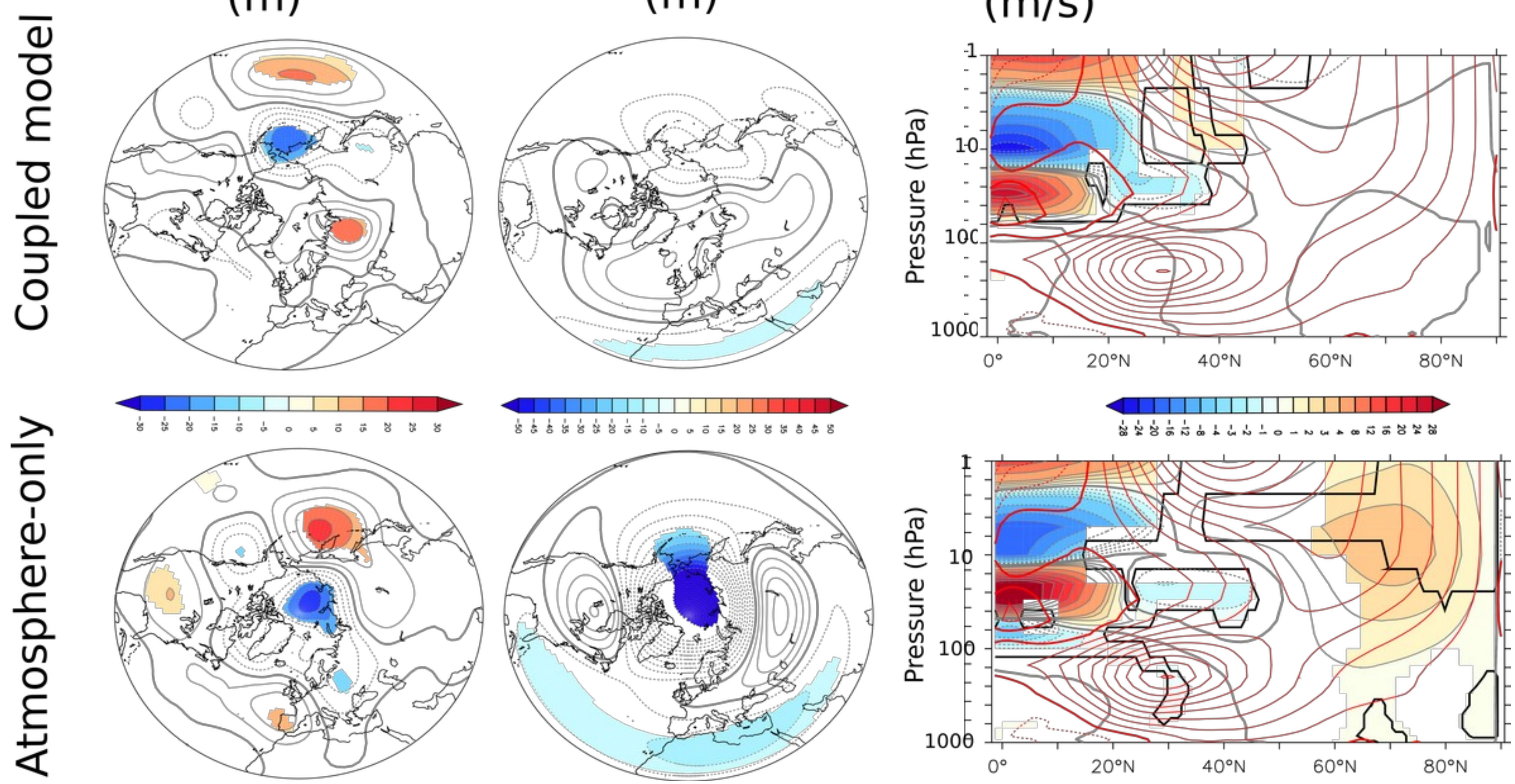


Equatorial zonal mean zonal winds (m/s) (AMIP simulations)

Modelling g) Direct Arctic sea-ice loss response and modulation by the QBO (Quasi-biennal Oscillation) with IPSLCM6A (CMIP6)

Composites of QBO-E and QBO-W
for *Low Arctic sea-ice*
(67 members;14 months)

Z500 (m) | Z50 (m) | Zonal mean zonal winds (m/s)



QBO-W minus QBO-E *(grey contour)*
90 % confidence level (colors)
90 % FDR significance (black contours)
High in DJF (red contours)

Coupled model no significant impact on mid-latitude
Atmosphere-only model: QBO-W leads to stronger polar vortex and weak positive Arctic Oscillation

Similar results for High Arctic sea-ice

Overview of studies

Observation

a) Direct Arctic sea-ice loss impact in winter

Simon, A., Frankignoul, C., Gastineau, G., & Kwon, Y. O. (2020). An observational estimate of the direct response of the cold-season atmospheric circulation to the Arctic sea ice loss. *Journal of Climate*, 33(9), 3863-3882.

In the continuity of this work:

b) Arctic sea-ice loss impact in summer

c) Antarctic sea-ice loss impact in winter

Modelling

d) Arctic sea-ice loss impact in winter at decadal timescale (CMIP5)

Simon, A., Gastineau, G., Frankignoul, C., Rousset, C., & Codron, F. (2021). Transient climate response to Arctic sea ice loss with two ice-constraining methods. *Journal of Climate*, 34(9), 3295-3310.

In the continuity of this work:

e) Multi-model study focusing on Mediterranean precipitation

f) Extension of the simulation for equilibrium response

g) (CMIP6) Direct impact and the Interdecadal Pacific Variability (IPV)

h) (CMIP6) Direct impact and the Quasi-biennal Oscillation (QBO)

Thank you for your attention

ajsimon@fc.ul.pt