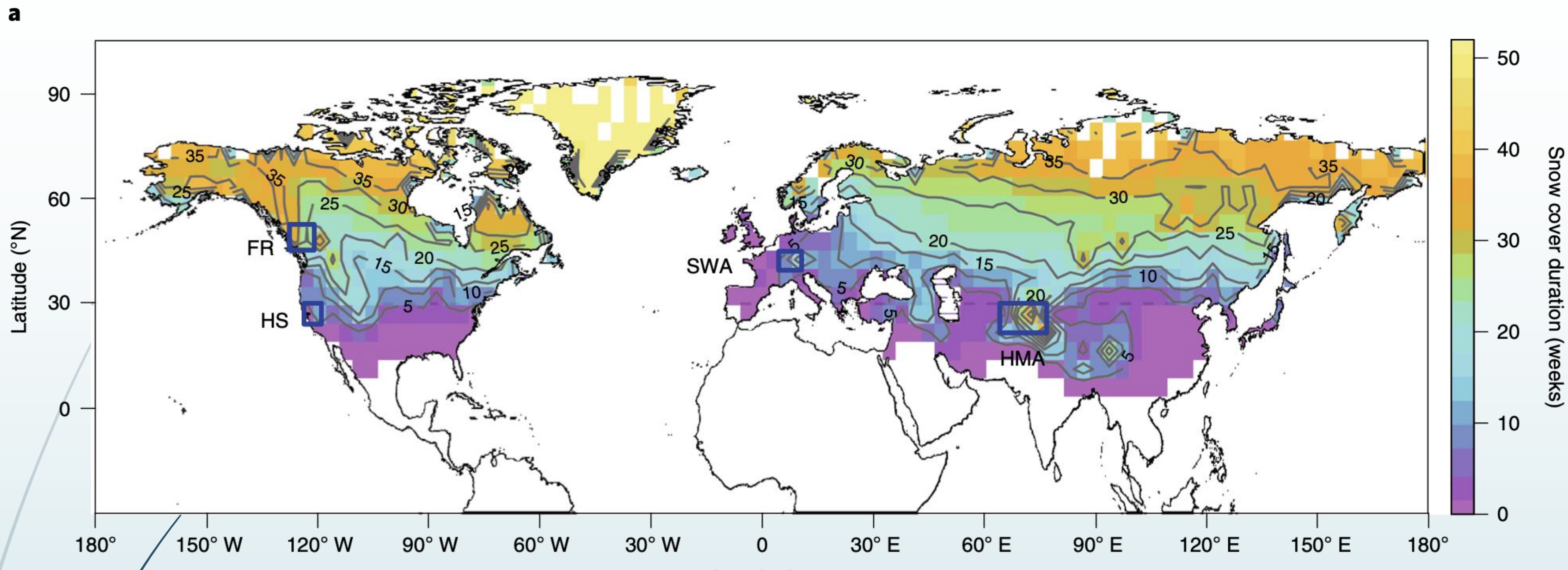
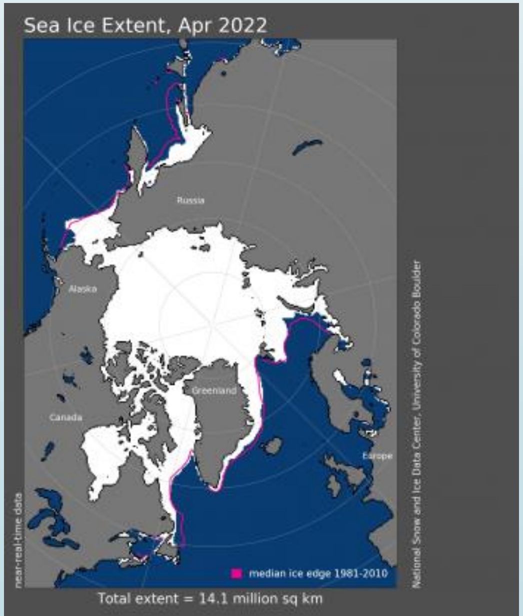
Predictability from Siberian snow cover and Arctic sea ice

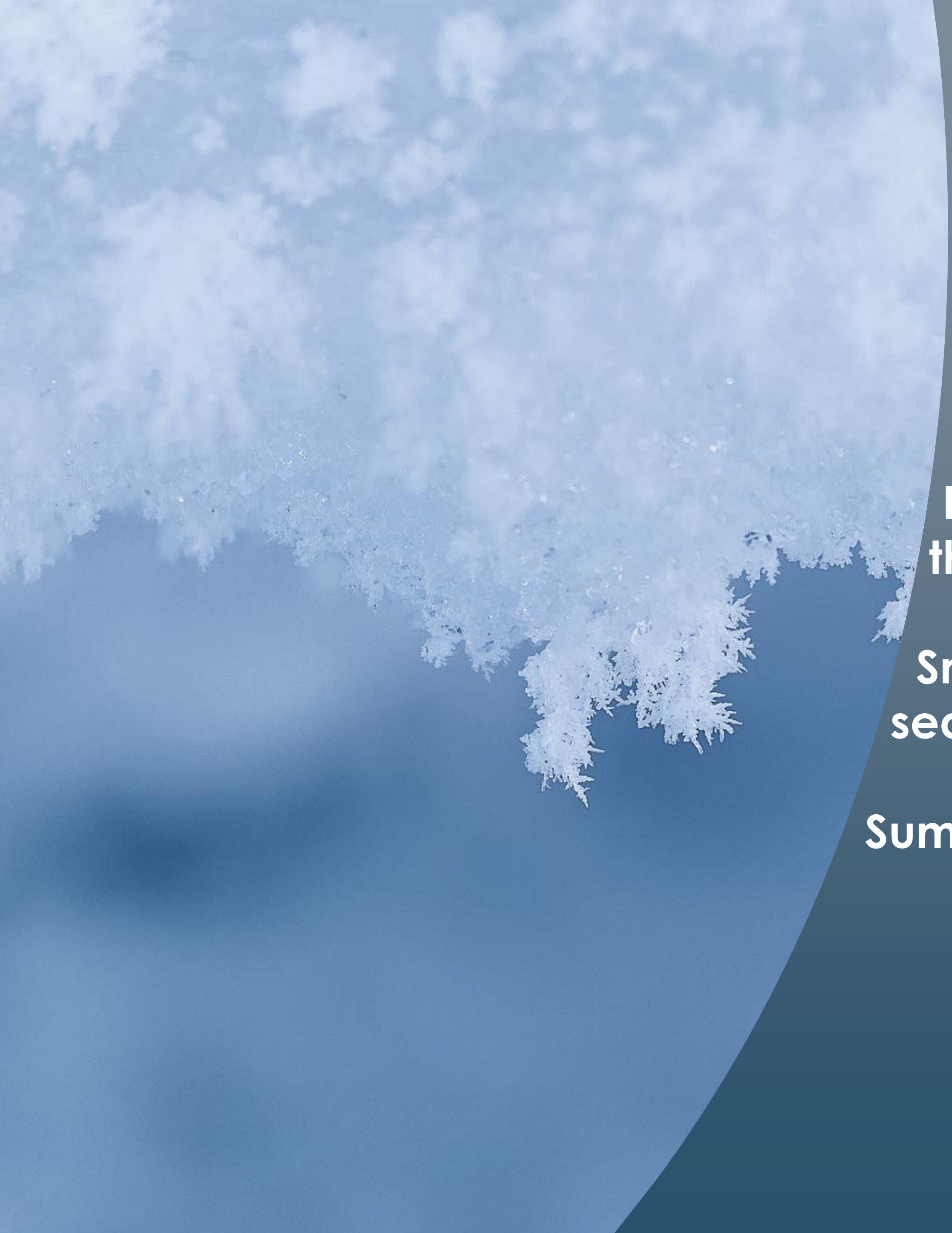
Training workshop on:
Elements for the production of Objective Seasonal Forecasts:
MedCOF sub-region

Paolo Ruggieri (UNIBO) May 31st 2022

Snow and ice cover in the Northern Hemisphere







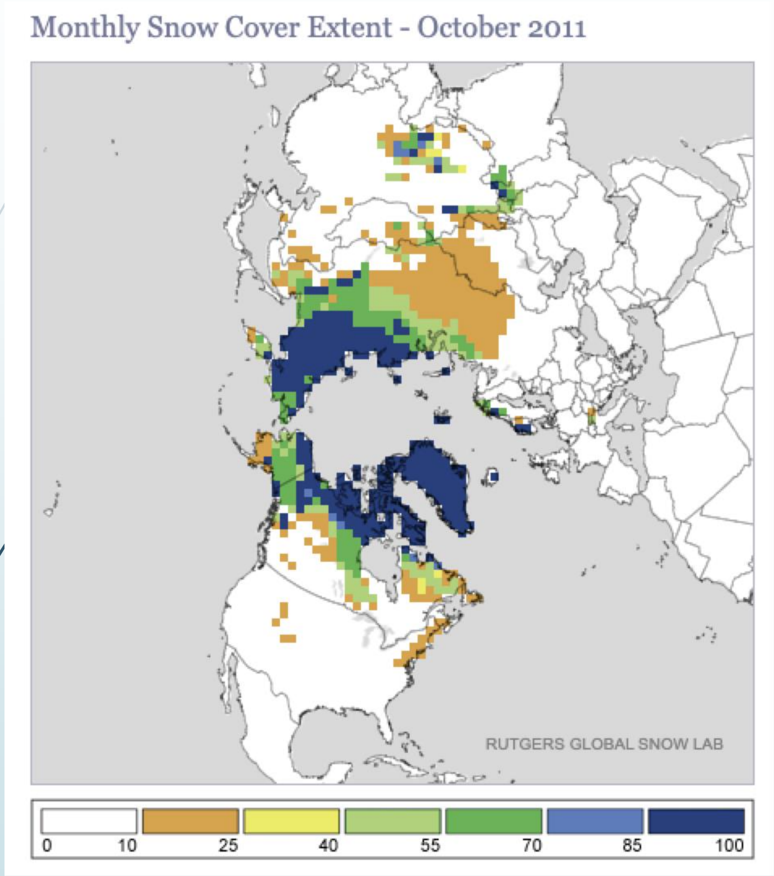
Snow and ice cover variability and its influence on climate

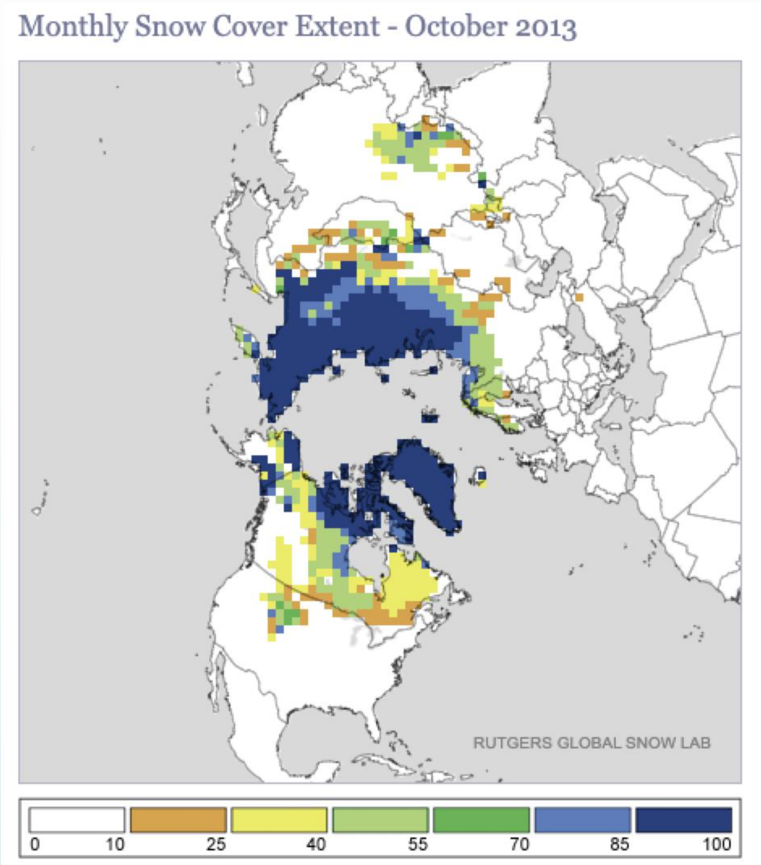
Remote response of the atmosphere

Snow cover and sea ice in seasonal predictions

Summary

Snow cover Variability





Rutgers University Global snow lab

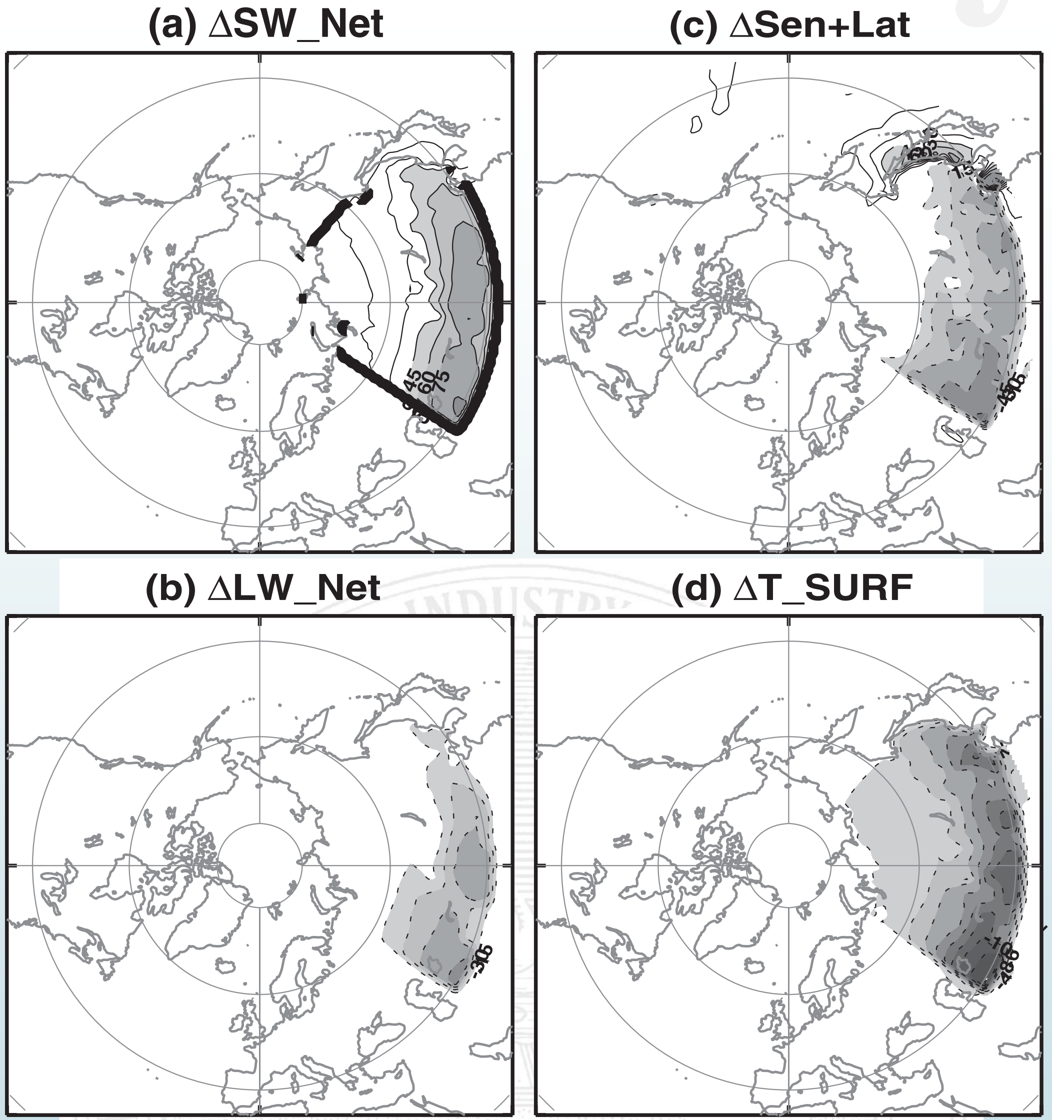
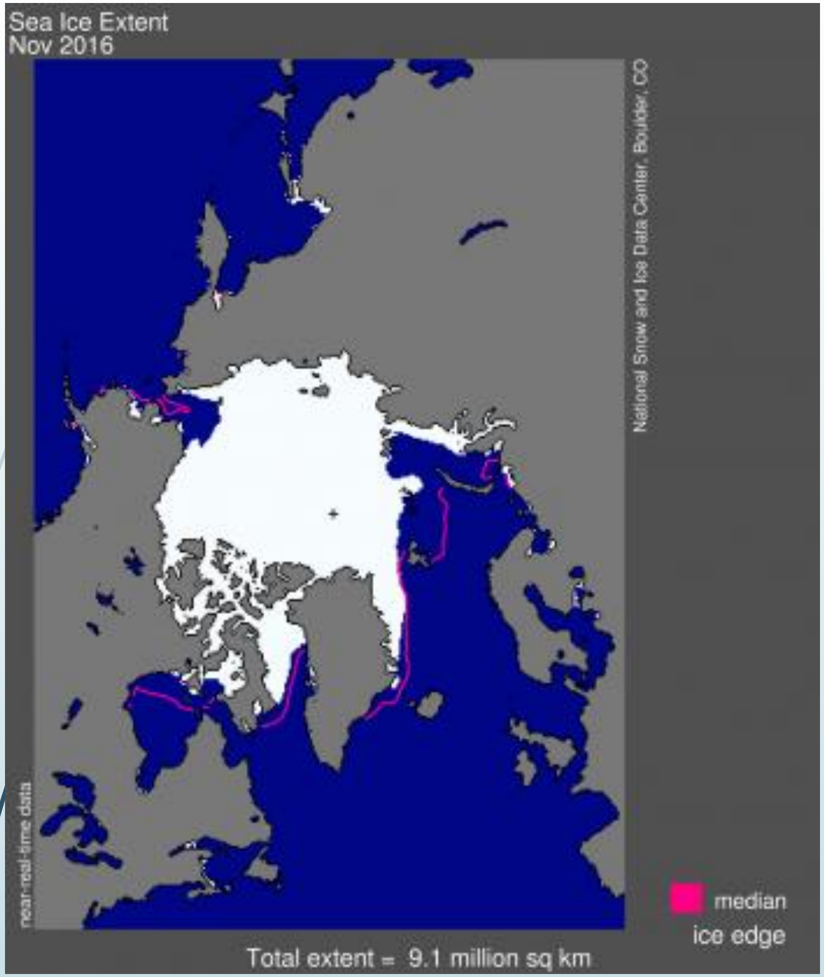
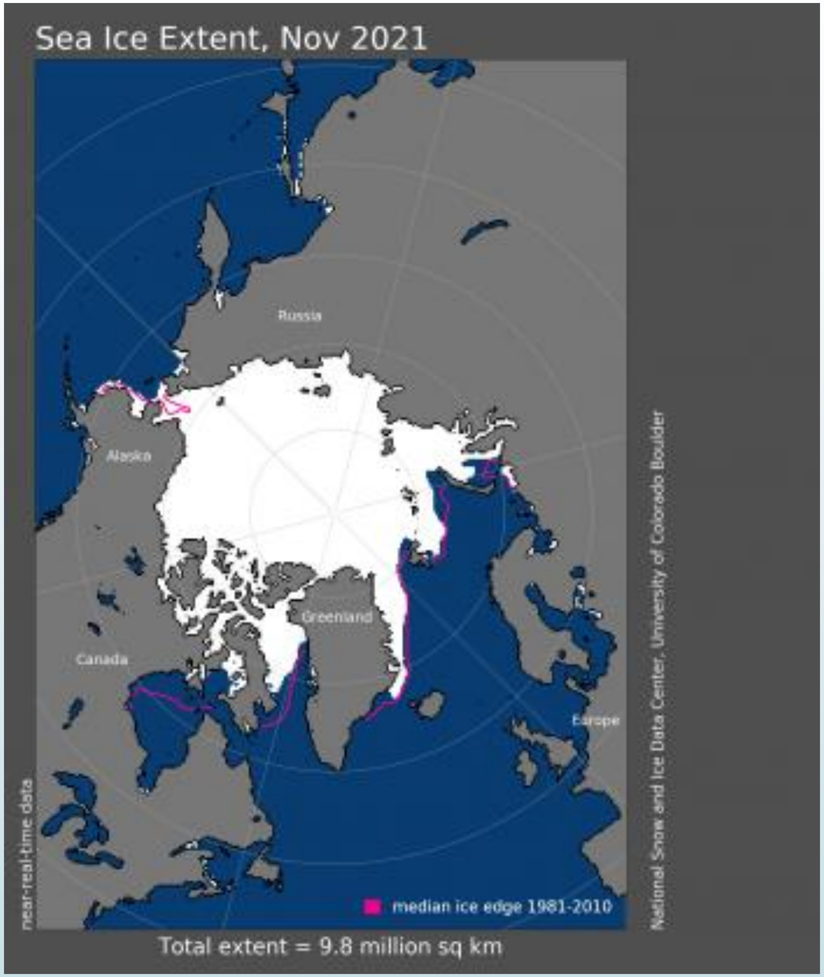


FIG. 1. Time-averaged ensemble mean surface response to snow forcing for days 1–15 in (a) net shortwave radiation (W m^{-2}), (b) net longwave radiation (W m^{-2}), (c) sensible plus latent turbulent heat fluxes (W m^{-2}), and (d) surface temperature (K). Contour interval and shading (a)–(c) is 15 W m^{-2} and in (d) is 2 K, and negative contours are dashed. All contours shown are statistically significant (see section 2b for details). Positive values (a)–(c) indicate upward fluxes. Thick black line in (a) indicates the boundary of the snow perturbation.

Fletcher et al. (2007) JClim

Ice cover Variability





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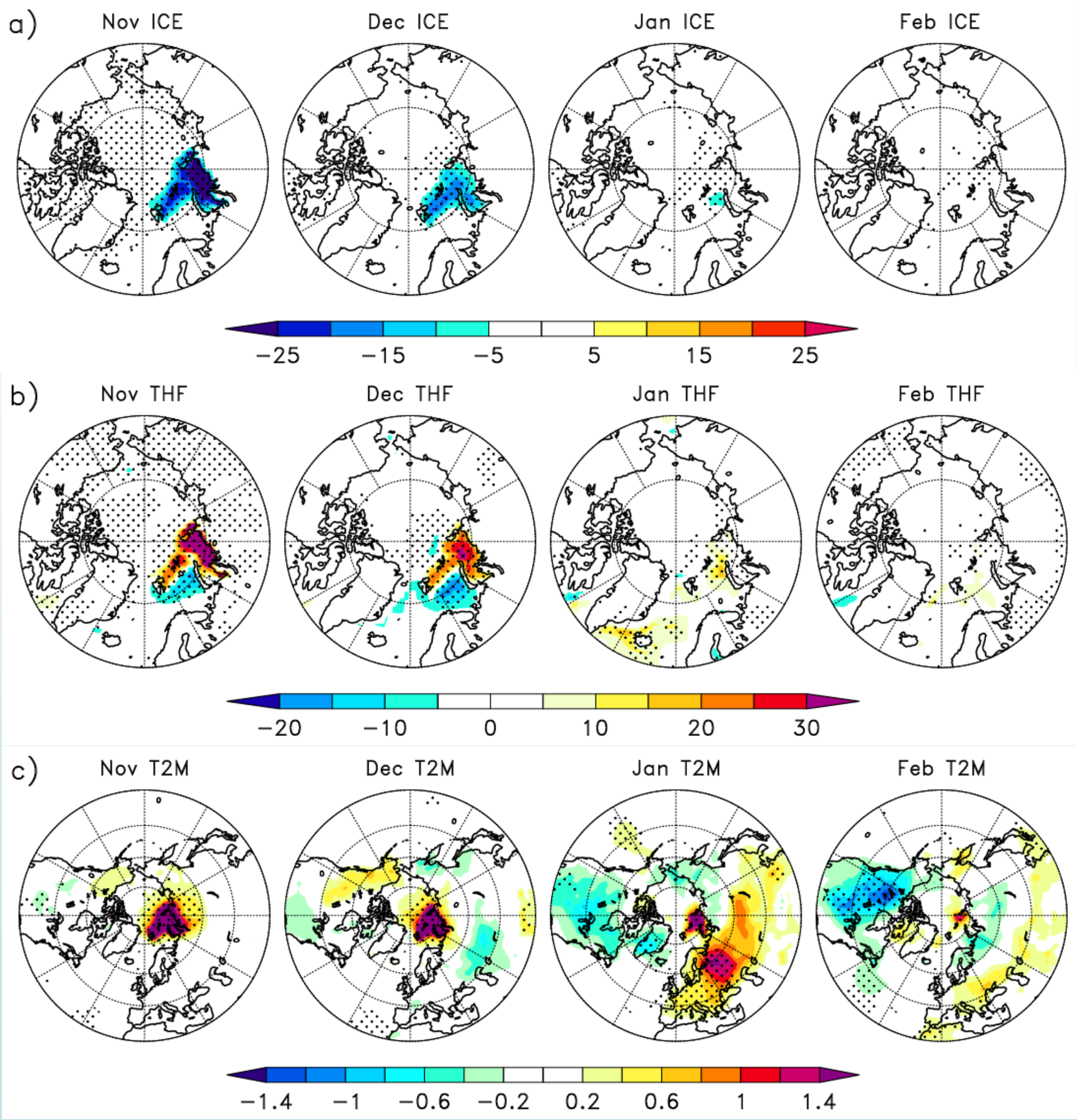

Seidenglanz et al. (2021) Climate Dynamics

Impact of SC variability on climate

At its peak in winter, snow covers about 40% of the land surface in the Northern Hemisphere. That's about 3 times the maximum extent of Arctic sea ice (Thackeray et al 2019)

Highest albedo of any natural surface and reflects solar radiation that would otherwise be absorbed at the surface.

Drives changes in the energy budget of the surface and lower atmosphere.

Drives changes in surface temperature.

Impact of Ice cover variability on climate

Arctic sea ice keeps the polar regions cool and helps moderate global climate. Ice covers up to 15 km squared at its maximum

High albedo, reflects solar radiation that would otherwise be absorbed at the surface.

Drives changes in the energy budget of the surface and lower atmosphere.

Drives changes in surface temperature.

Snow and ice cover variability and its influence on climate

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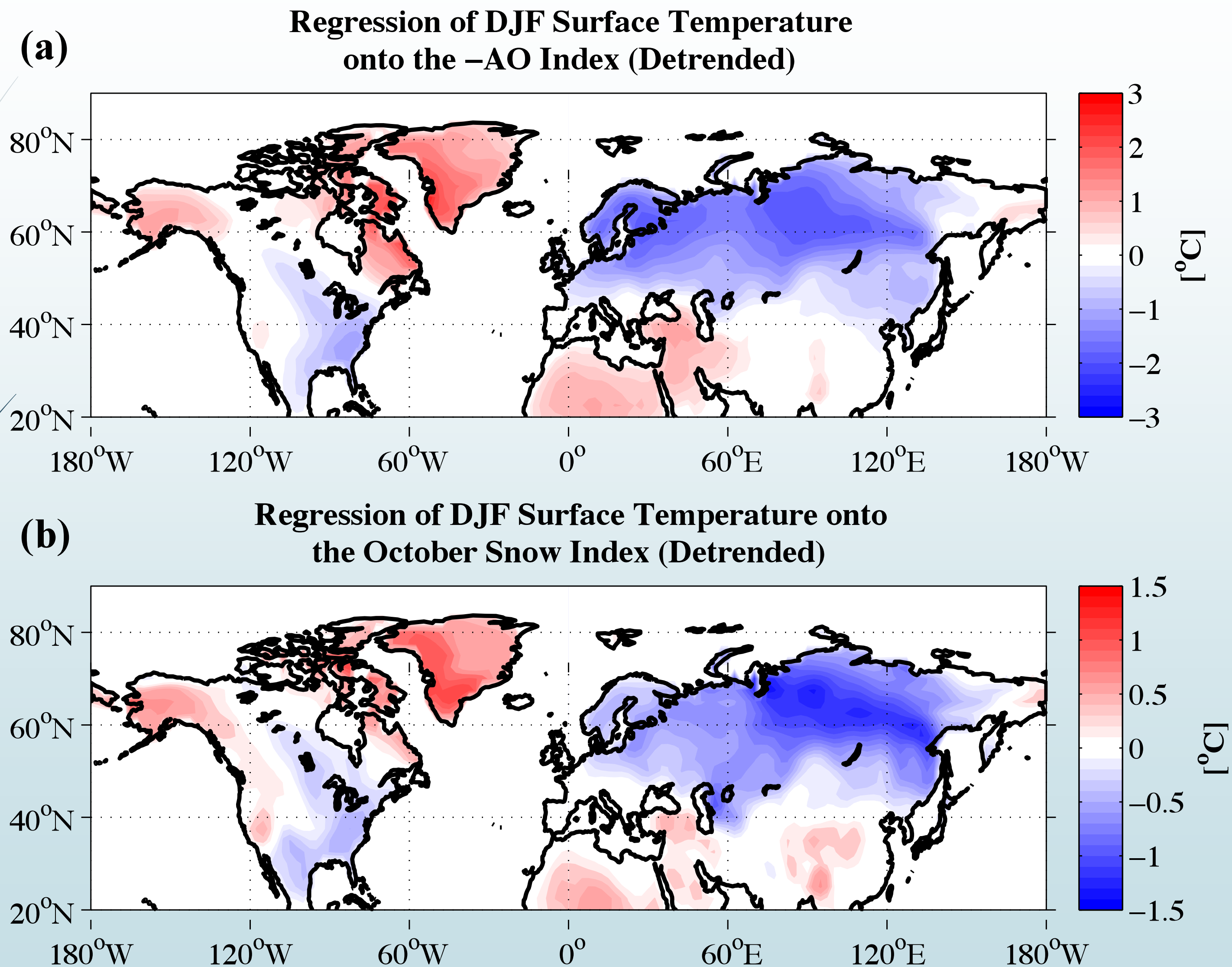
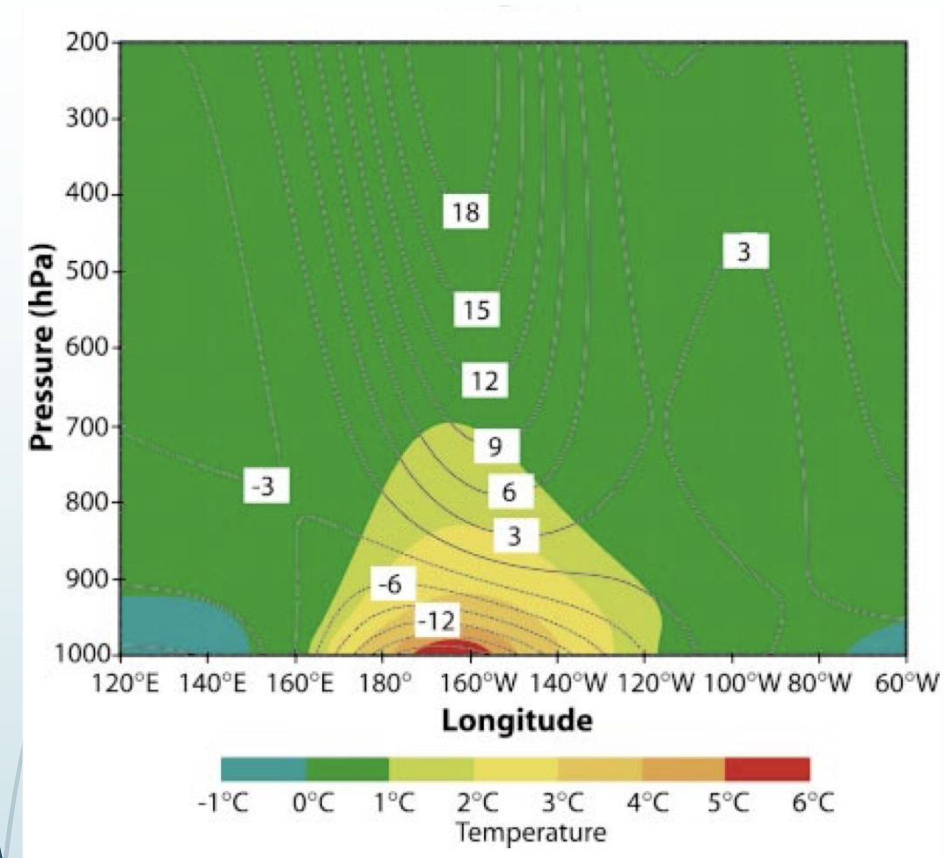
Summary

Observed relationship with the AO index



Linear response to thermal forcing



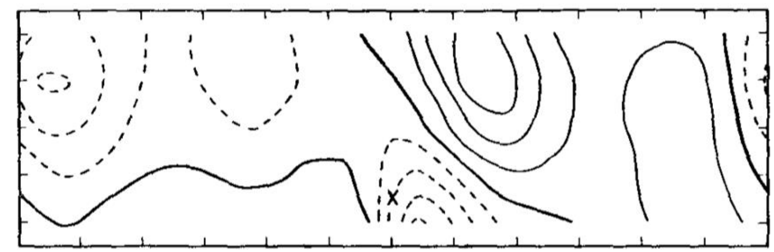


FIG. 5. Height field in a longitude-height section at 46.0°N for a shallow circular heat source at 45° with the NH winter flow. The contour interval is 2 dam.

Hoskins and Karoly

$$z'_{500} \approx \bar{z}_{500}\left(\frac{T'_o}{\overline{T}_a} + \frac{1}{\ln 2}\frac{p'_{\text{surface}}}{1000}\right).$$

Kushnir et al. (2002) JClim

Common to atmospheric response to Arctic sea ice and snow cover changes

Non-Linear response and the annular mode

Atmospheric response to sea-ice reduction in the Barents sea in a simple GCM

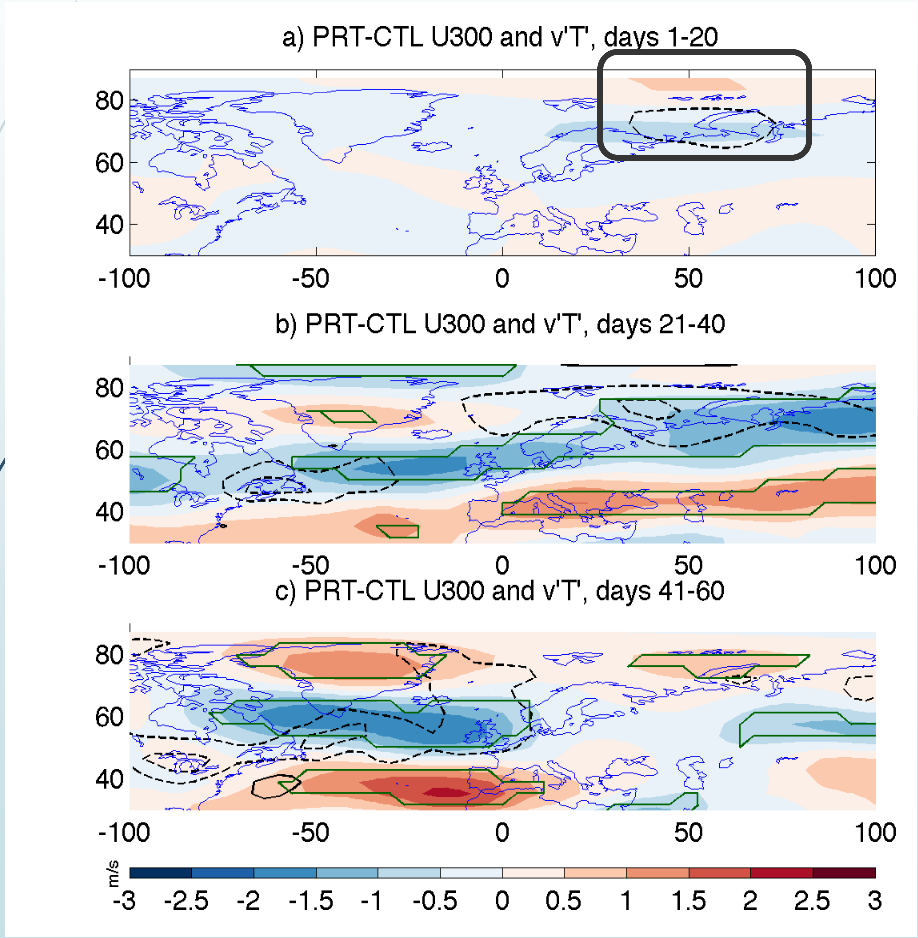


Figure 5. Projections of U at 300 hPa (shading, m/s) and transient eddy heat flux at 850 hPa (contours, Km/s, drawn every 1), for a) day 1-20, b) day 21-30, c) day 41-60. Fields are differences between PRT and CTL. The green solid line encompasses statistically significant values at 99% confidence level according to a ranksum Wilcoxon test.

Initial linear regime

Transition to a NAO-like response

Lagged NAO-response

Ruggieri et al. (2017) QJRMS

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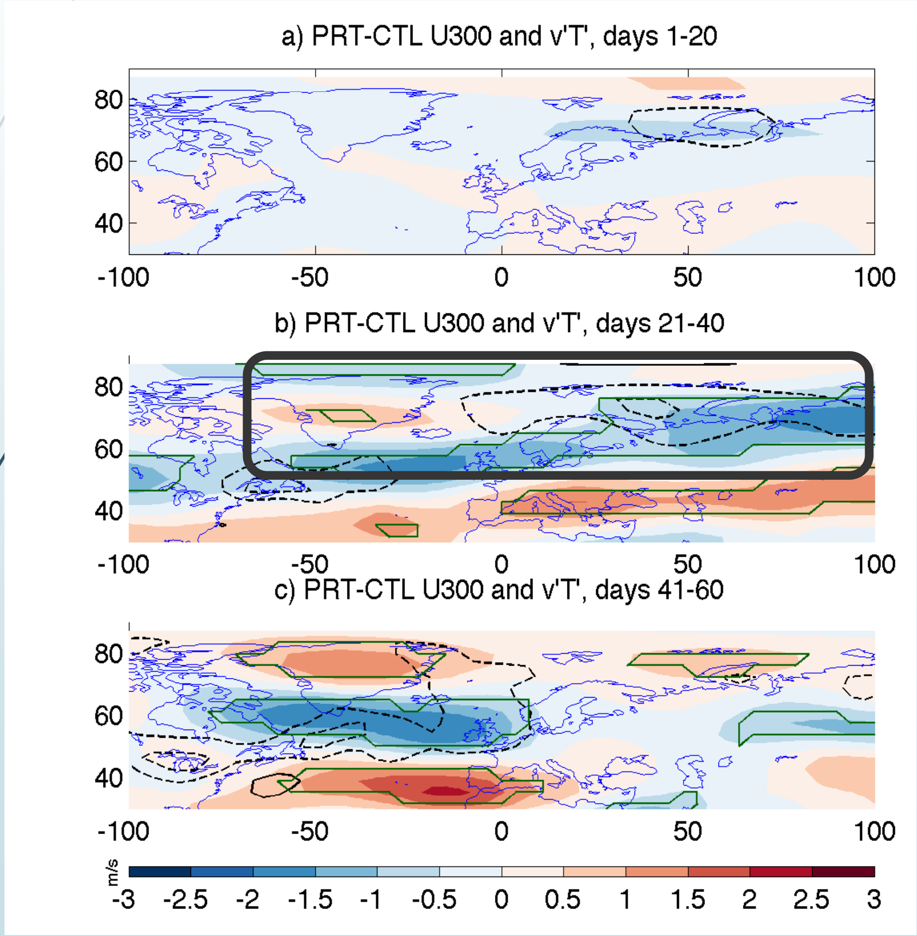

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Ruggieri et al. (2017) QJRMS

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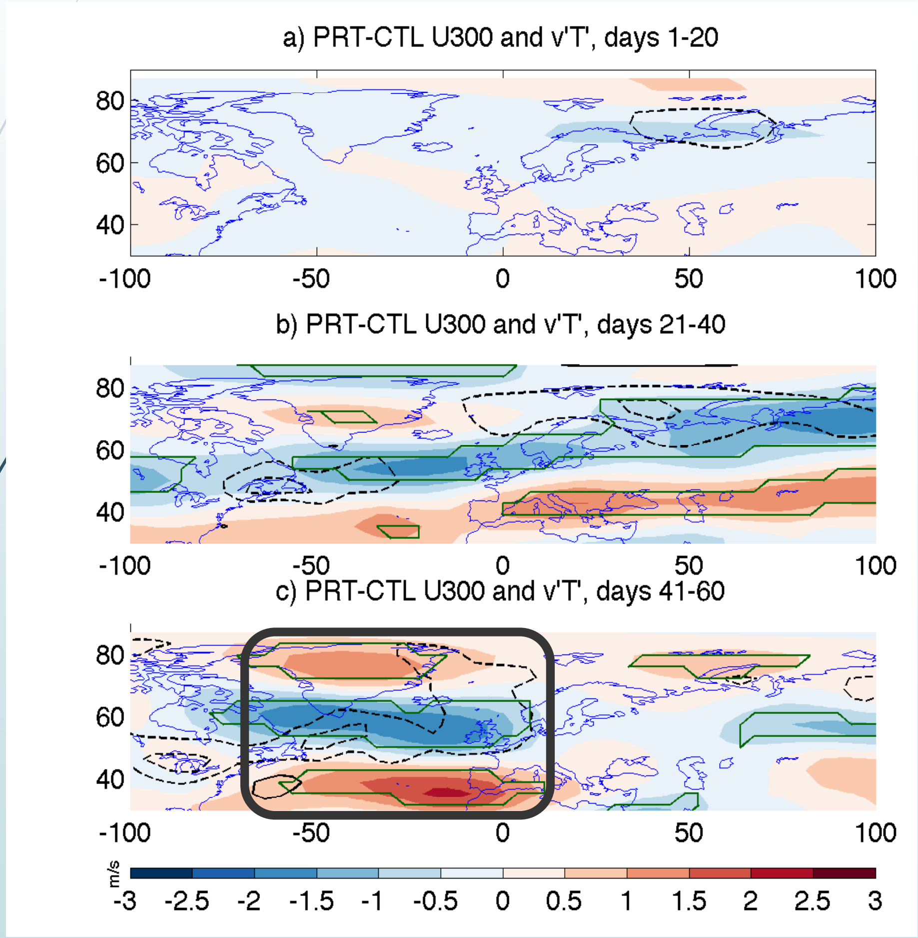

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Ruggieri et al. (2017) QJRMS

The Coupled Stratosphere–Troposphere Response to Impulsive Forcing from the Troposphere

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LORENZO M. POLVANI

Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York

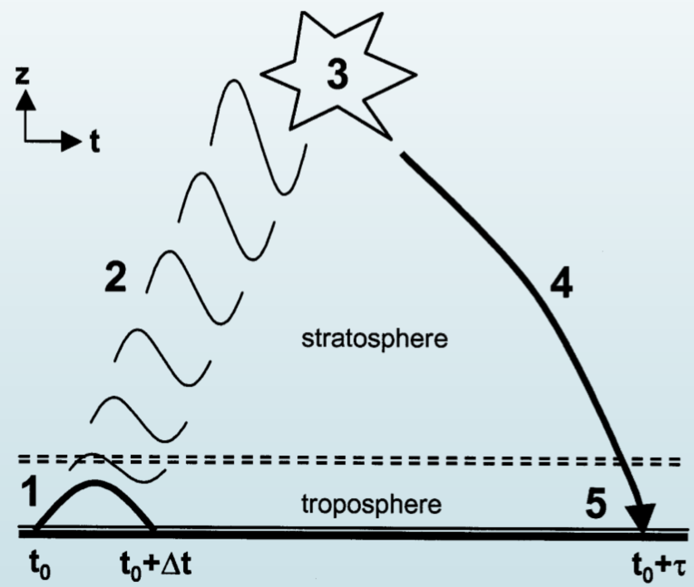
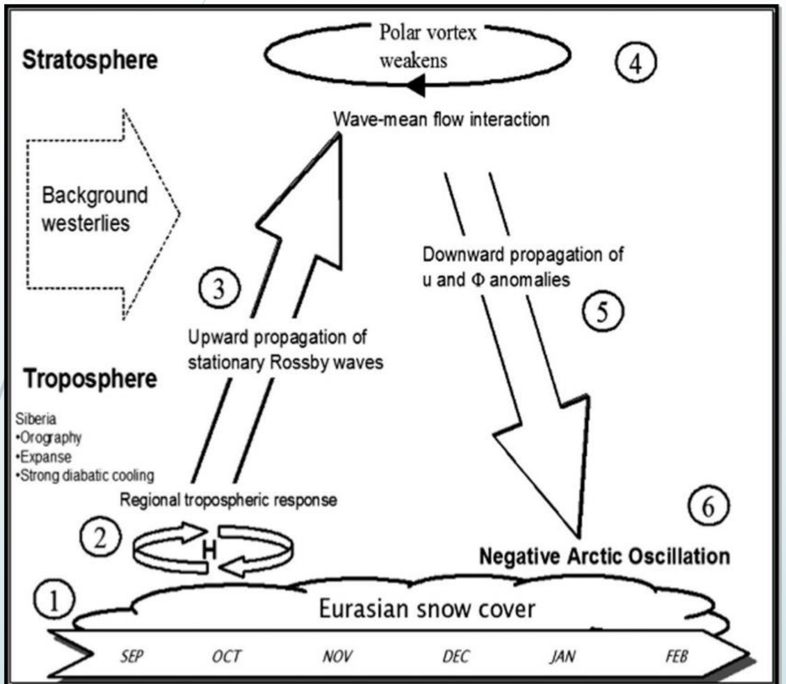
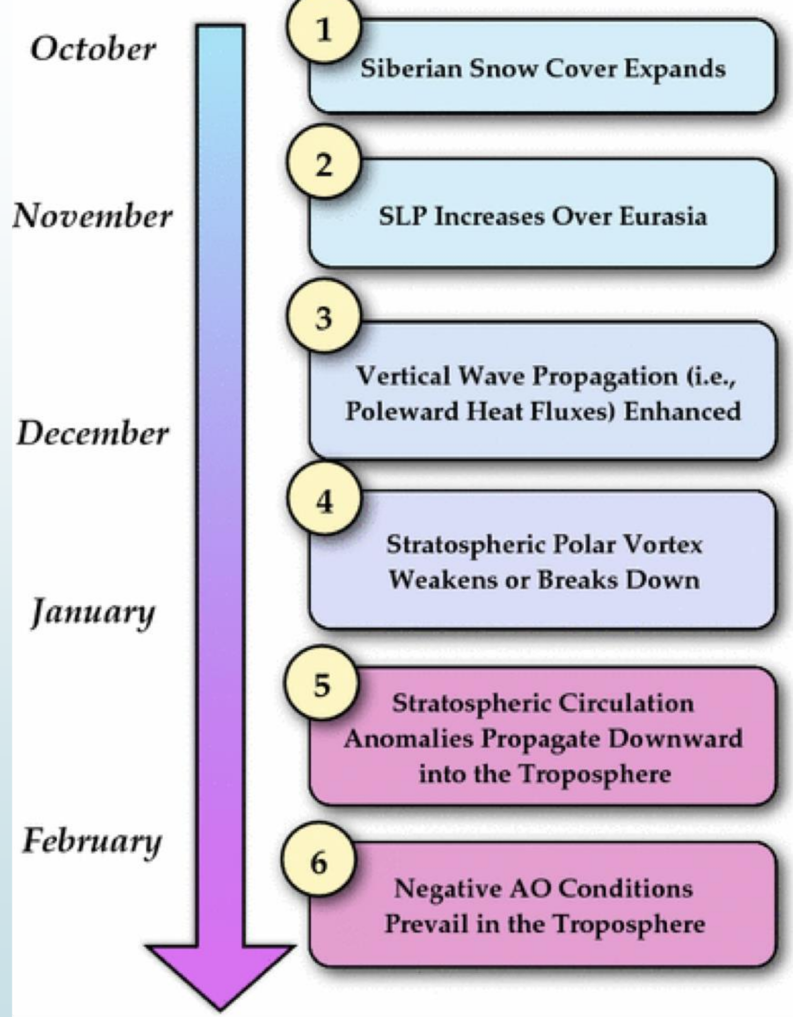


FIG. 1. Schematic illustration of the TST events simulated in this study. (1) Forced pulse of planetary waves occurring over time Δt; (2) upward-propagating waves; (3) dissipation and breaking of waves; (4) induced downward-propagating anomalies; and (5) tropospheric response at time lag $\tau > \Delta t$.

A proposed dynamical mechanism

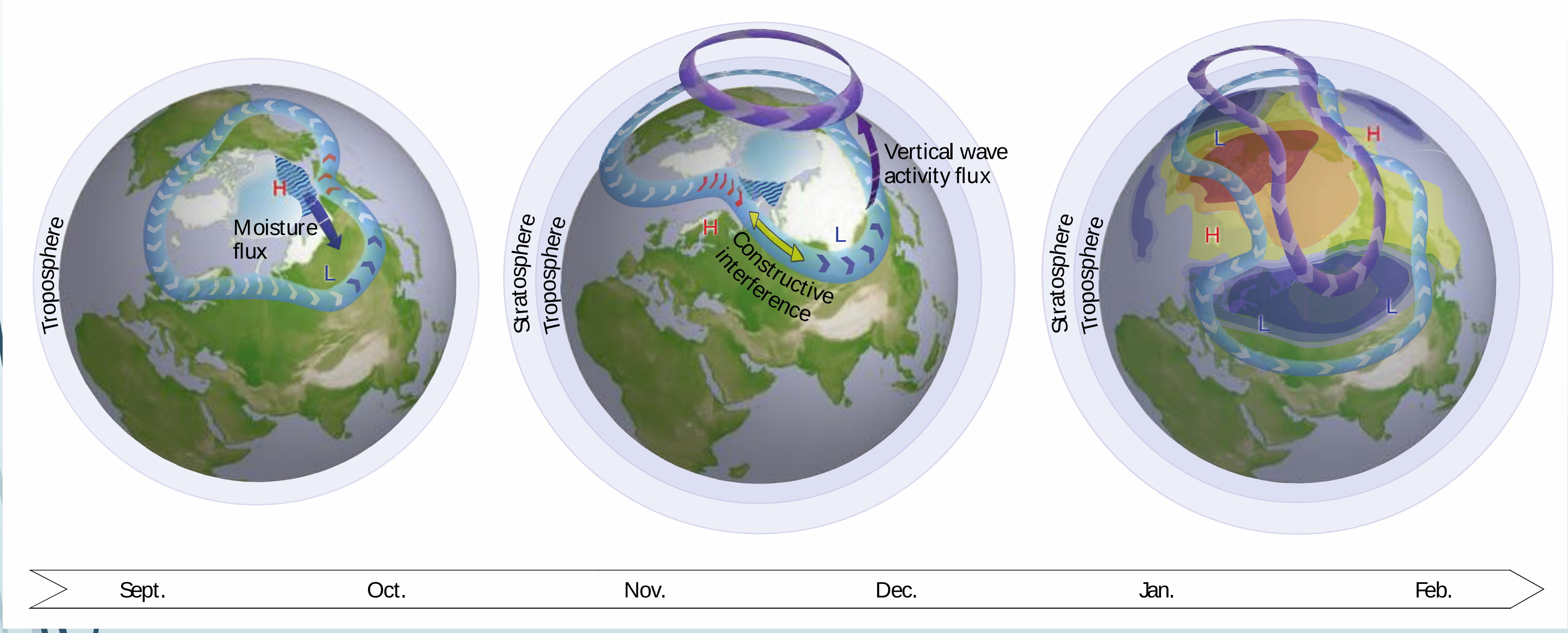


Cohen et al. 2007



Furtado et al. 2015

A proposed dynamical mechanism: snow and ice synergy



Cohen et al. (2014) NatGeoScience

Generatios of ,odels underestimated snow cover variability

CMIP 3

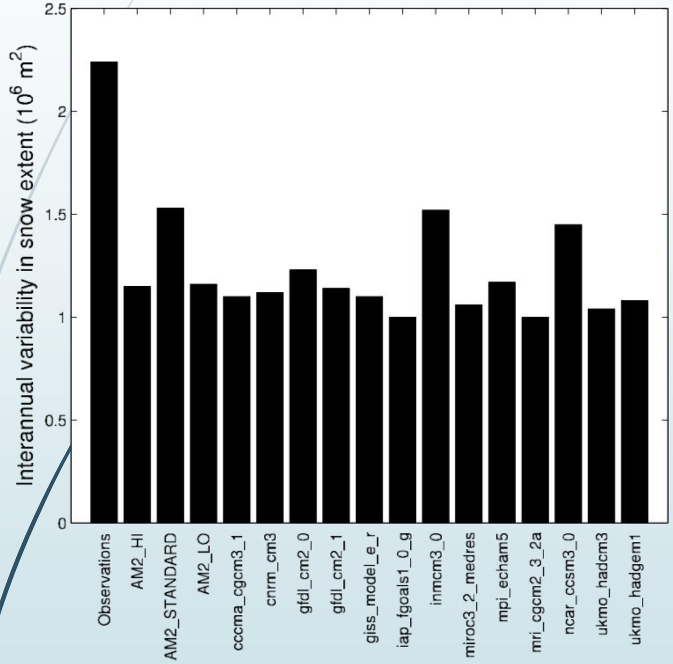
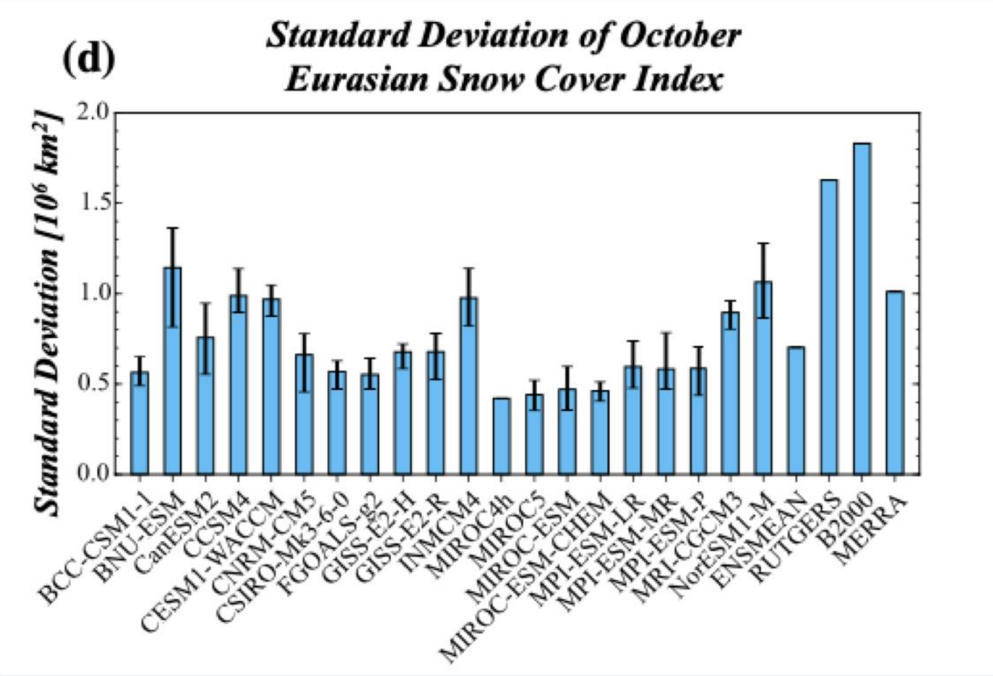


Figure 4. Standard deviation of interannual variability in the Eurasian October snow extent (10^6 m^2) for observations, AM2 models, and CMIP3 models.

CMIP 5



Furtado et al 2014 Climate Dynamics

Models still 'struggle'

Table 1 | Scientific understanding and current model capability for the snow–(N)AO/NAM linkage, for the steps shown above and in Fig. 1

Step	Description	Level of scientific understanding	Model capability
1	Expansion of snow-cover and cooling	**Moderate to high** Snow cover anomalies enhance surface cooling in fall, but how sensitive surface temperature is to autumn snow cover is uncertain.	**Moderate** Models underestimate variability in boreal fall continental snow-cover expansion, especially over Eurasia[18,42,76](Fig. 4). Circulation anomalies are better captured when realistic snow cover is initialized or prescribed.[10–12]
2–4	Planetary wave generation, propagation and breaking in the stratosphere	**Poor to moderate** What controls stationary waves and the response to surface cooling are only moderately understood. Why specific tropospheric circulation patterns (i.e., precursors to stratospheric circulation changes[44,77–79] and anomalous snow cover need to exist for robust statistical predictions of wintertime circulation[80] remains poorly understood. Persistence of the Rossby wave signal into the early winter is poorly understood.	**Poor to moderate** Models poorly simulate the background stationary wave, as well as the phasing of the circulation anomalies and cooling response to Eurasian snow[18,40,81]. Model atmospheres may be too insensitive to boundary forcing[70].
5–6	Stratosphere–troposphere propagation of zonal-mean anomaly	**Moderate to high** How increased upward Rossby wave-activity flux anomalies into the stratosphere drive negative stratospheric NAM is well understood[77,82,83], and downward coupling of NAM circulation anomalies is well-characterized (regardless of snow-cover anomalies[18,84,85]). However, stratosphere–troposphere dynamical coupling (lower stratospheric dynamical heating, wave reflection and tropospheric wave-mean-flow interactions[86–88]) is only moderately understood.	**Poor to moderate** Models simulate observed amplitude of tropospheric (N)AO/NAM reasonably well. Realistic stratospheric representation[89,90], tropospheric jet stream structure and synoptic wave variability are required to simulate observed downward coupling as well as the tropospheric (N) AO/NAM state and its variability. GCMs are challenged in these areas, especially as stratospheric NAM anomalies descend into and influence the NAO/NAM in the troposphere[18,91].

Handerson et al. (2018) Nature CC

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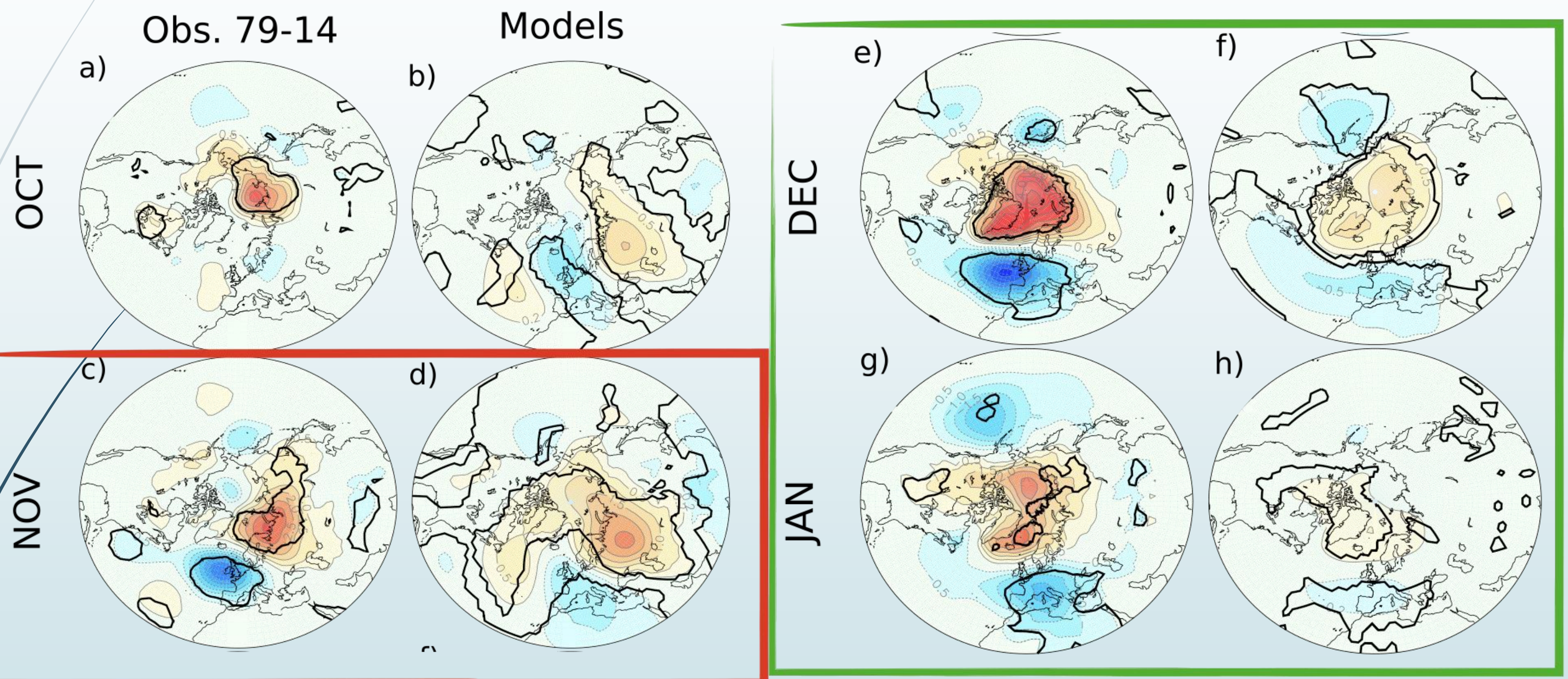
'Multiple generations of climate models have been unable to spontaneously reproduce snow-AO connections in their internal variability'

'Observed snow-(N)AO relationship non-stationary (perhaps mediated by QBO and PDO) and state-dependent'

1-2 month lagged covariance in PI control



Gastineau et al 2017 Journal of Climate

FIG. 10. Regression of the SLP (in hPa; contour interval 0.5 hPa), onto the MCA-snow index for (left) ERA-Interim and (right) models, in (a),(b) October, (c),(d) November, (e),(f) December, and (g),(h) January. The thick black line indicates 5% significance for observations or anomalies of the same sign among the four models. The contour interval at −0.2 and 0.2 hPa was added for models.

nature climate change
FOCUS | REVIEW ARTICLE
https://doi.org/10.1038/s41558-018-0295-6

Snow–atmosphere coupling in the Northern Hemisphere

Gina R. Henderson[1*], Yannick Peings[2], Jason C. Furtado[3] and Paul J. Kushner[4]

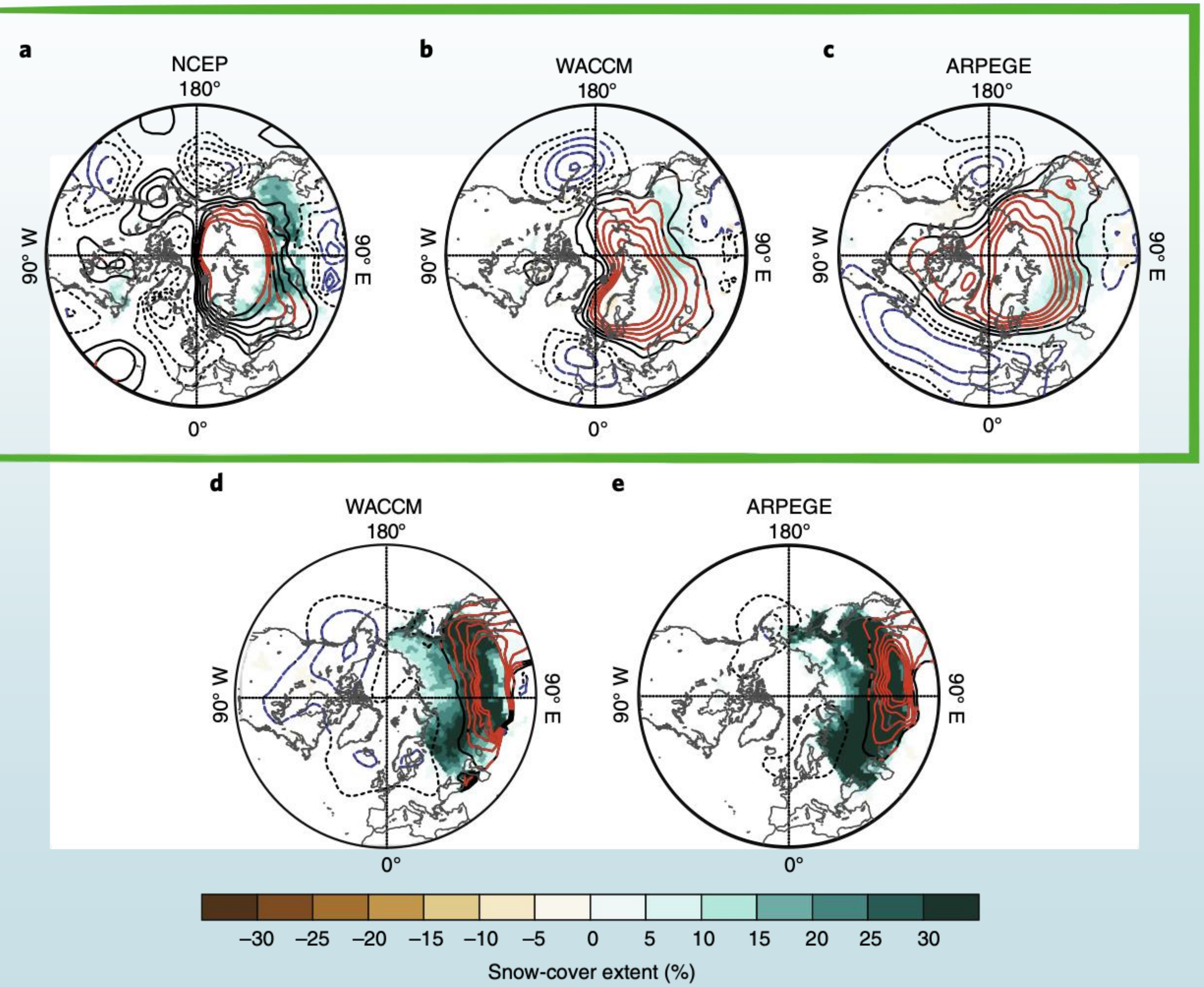


Fig. 4 | Causality between the atmosphere and snow-cover anomalies over Siberia. a, Composite of sea-level pressure (contours, 0.5 hPa) and snow-cover extent colour scale) based on high minus low extent of October–November Siberian snow cover for the period 1972–2016 in NCEP. **b**, Same composite in a 200-year control simulation of WACCM. **c**, Same composite in a 200-year control simulation of ARPEGE-Climat. **d**, Response of the October–November sea-level pressure (contours, 0.5 hPa) to increased October–November Siberian snow in WACCM (200-year average). **e**, Same as **d**

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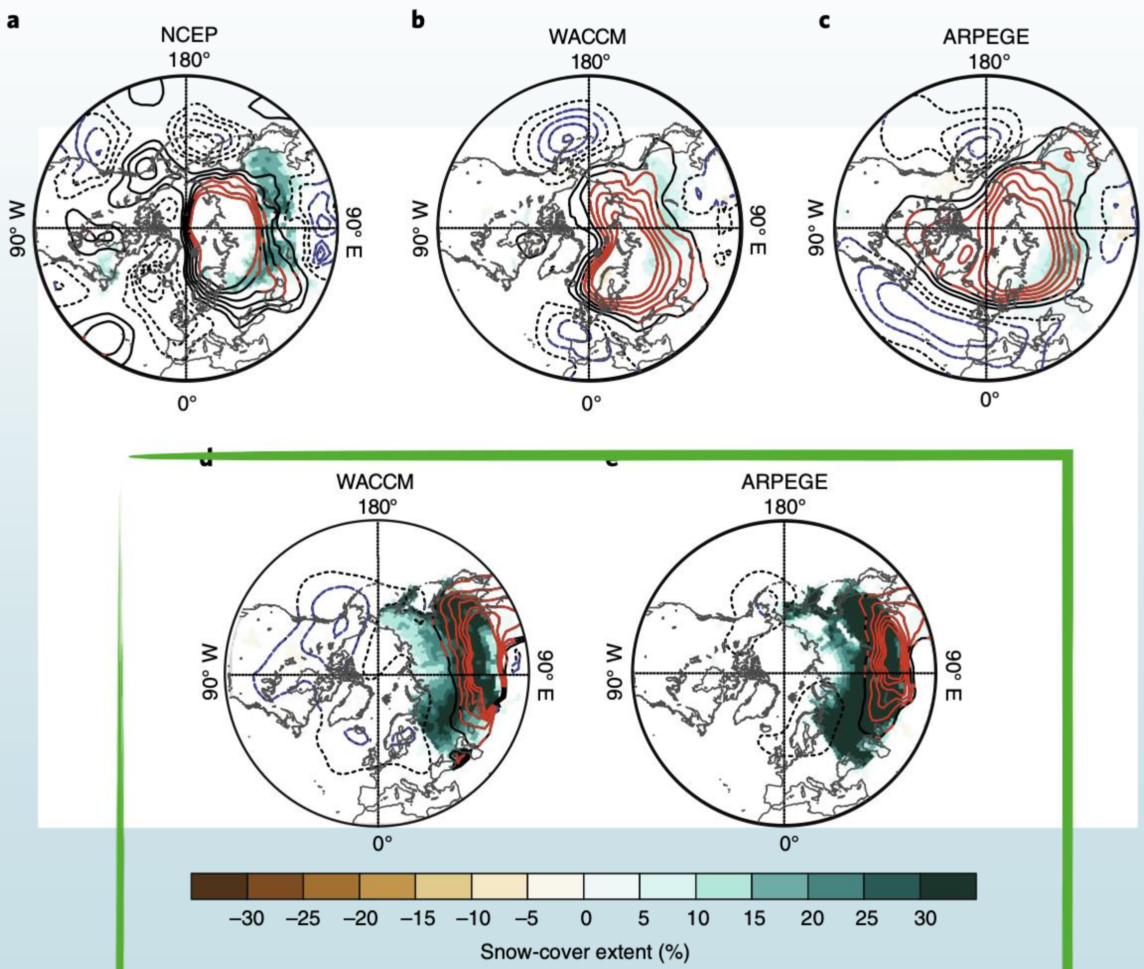

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Snow cover and sea-ice in seasonal predictions

Summary

II. "On the Connexion of the Himalaya Snowfall with Dry Winds and Seasons of Drought in India." By HENRY F. BLANFORD, F.R.S. Received April 14, 1884.

The present paper, as regards its subject-matter though not in form, is part of a general investigation of the rainfall of India, which has occupied much of my spare time for some years past, and the results of which are already partly embodied in a memoir which I hope, in the course of a few months, to issue as an official publication of the Indian Meteorological Office. The idea that the snowfall of the Himalaya exercises a direct and important influence on the dry land winds of North-Western India is not now put forward for the first time. It has been the subject of frequent reference in the annual reports on the meteorology of India since 1876, as well as elsewhere; and in a report on the administration of the India Meteorological Department lately issued, I summarised very briefly those points in the experience of the previous five years which have seemed to justify its provisional adoption as a basis for forecasting the probable character of the monsoon rains.

Relying on this experience, in the month of June last, I put forward in the Government Gazette, a note giving warning of the probability of a prolonged period of drought in the approaching monsoon season, and the result, if not in exact accordance with the terms of the forecast, has been so far confirmatory of the general idea, as to induce me to put the facts of past experience formally on record, and thereby challenge attention to the subject. If I am right in the inference that the varying extent and thickness of the Himalayan snows exercise a great and prolonged influence on the climatic conditions and weather of the plains of North-Western India,

Empirical predictions based on snow-cover and sea-ice

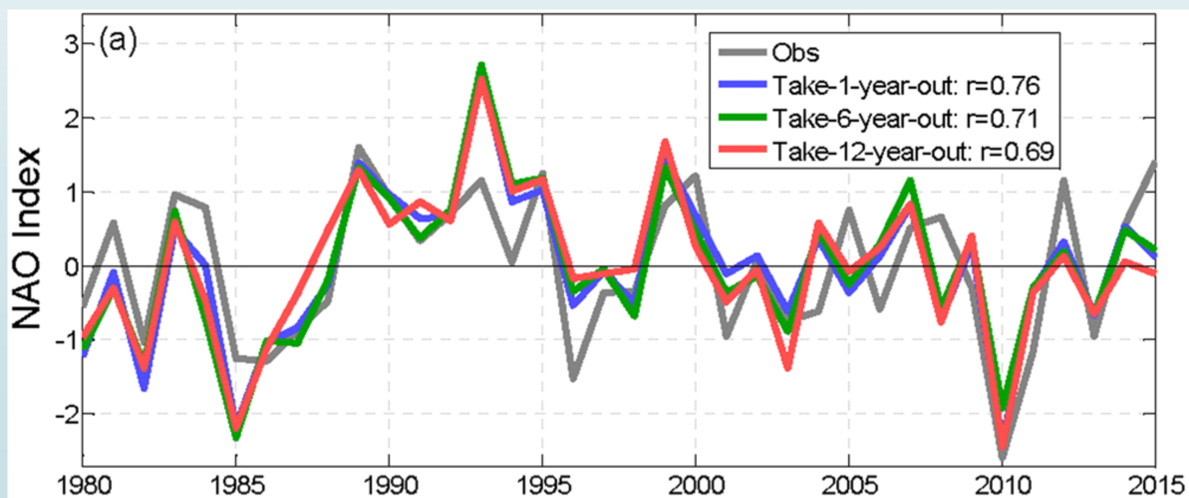
SCIENTIFIC REPORTS

OPEN

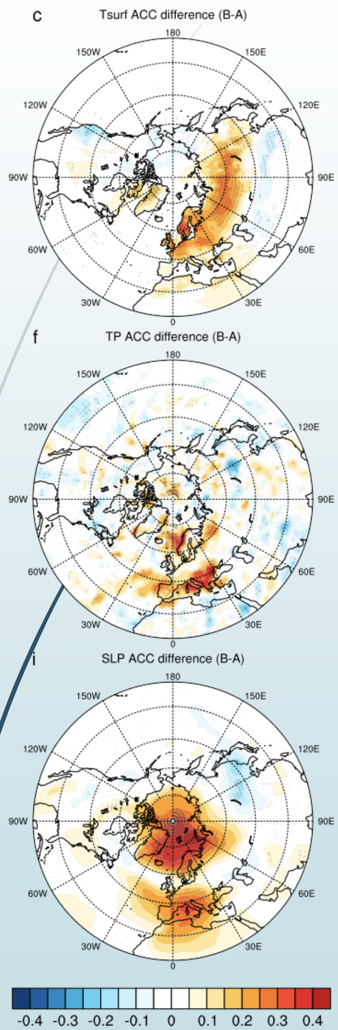
A robust empirical seasonal prediction of winter NAO and surface climate

Received: 13 October 2016

L. Wang[1], M. Ting[1] & P. J. Kushner[2]



Hybrid predictions based on snow-cover and sea-ice



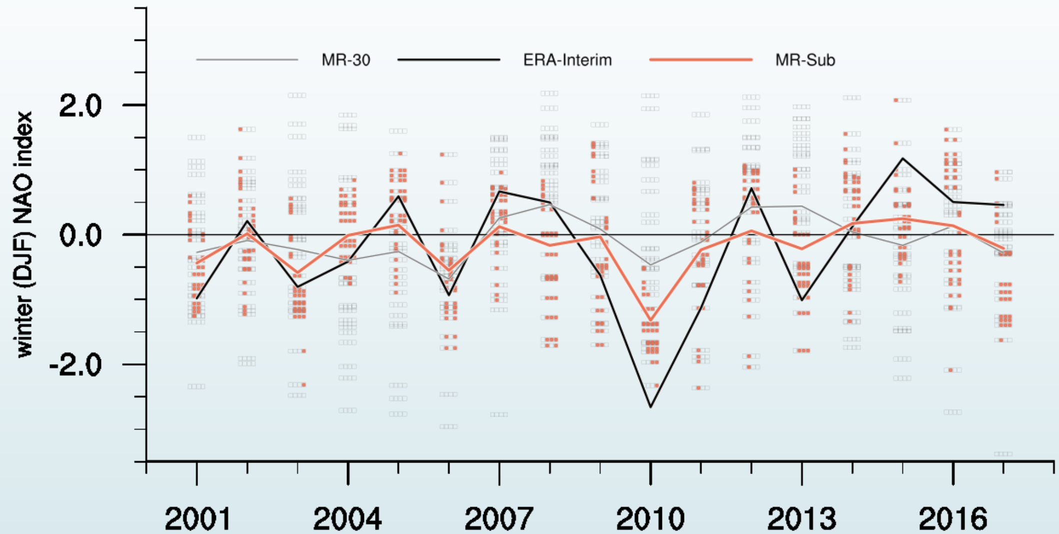


Figure 4. "Real" forecast test of the winter North Atlantic Oscillation (NAO) for the period from 2001 to 2017. The forecasted winter NAO values are calculated separately for each year and then merged into a single time series. The correlations between the MR-30 (gray line), the MR-Sub ensemble mean NAO (red line), and the ERA-Interim NAO (black line) are 0.42 and 0.86, respectively (significant at the 99% confidence level). Similar to Figure 2 each cell in gray four-cell blocks represents one of the four predictors. Ten ensemble members for each predictor are used in subsampling. DJF = December, January, and February.

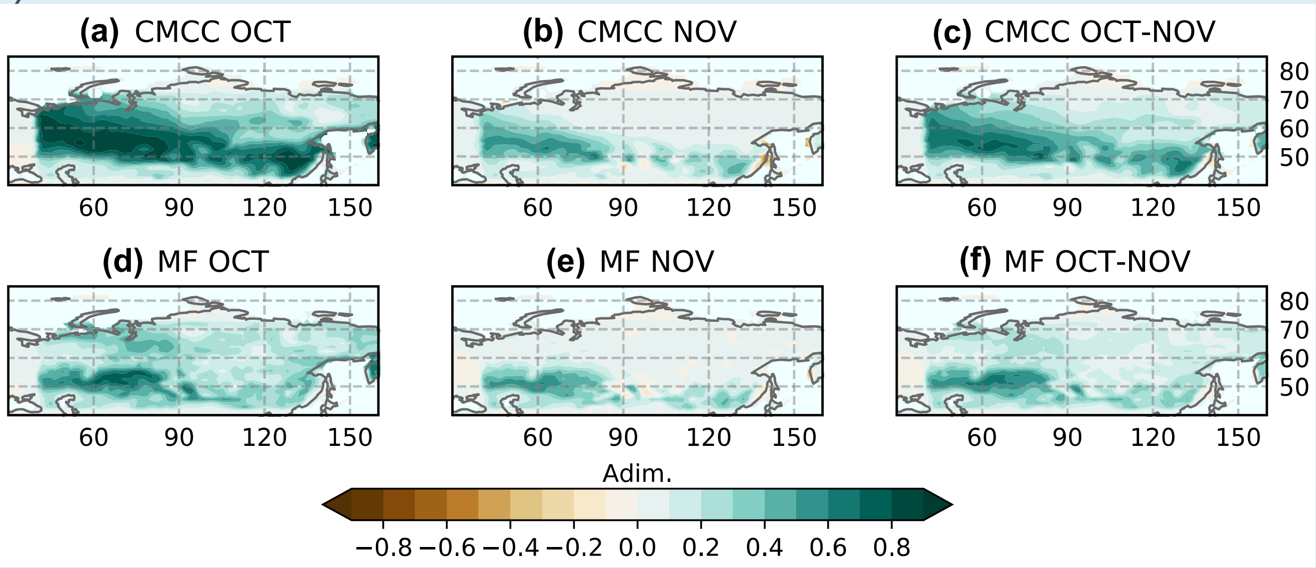
Dobrynin et al. (2018) GRL

The C3S multi-model ensemble and MEDSCOPE experiments

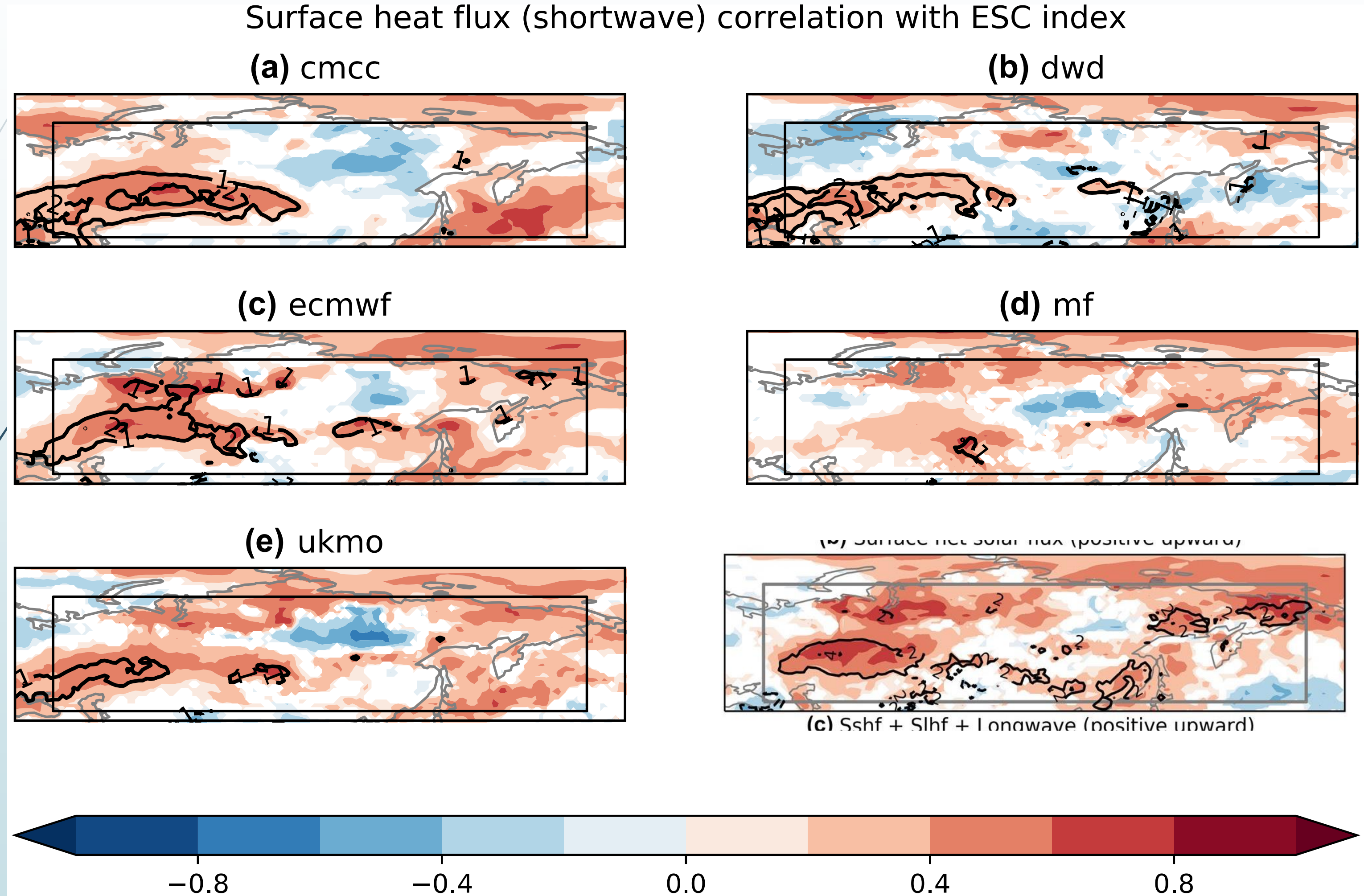
System	Resolution	Ens. size	Snow I.C.	Land model	Ref.
CMCC 3	1×1 L46	40	Forced run	CLM4.5	Oleson et al. (2013)
MF 6	TL359 L91	25	ERA-I	SURFEX v8.1	Le Moigne et al. (2009)
ECMWF 5	T_{CO}319 L91	25	Forced run	IFS 43r1	Johnson et al. (2019)
DWD 2	T127 L95	30	Indirect	JSBACH	Brovkin et al. (2009)
UKMO 13	N216 L95	21	JRA55	JULES GL 6	Walters et al. (2017)

High resolution, large ensemble, multi-model

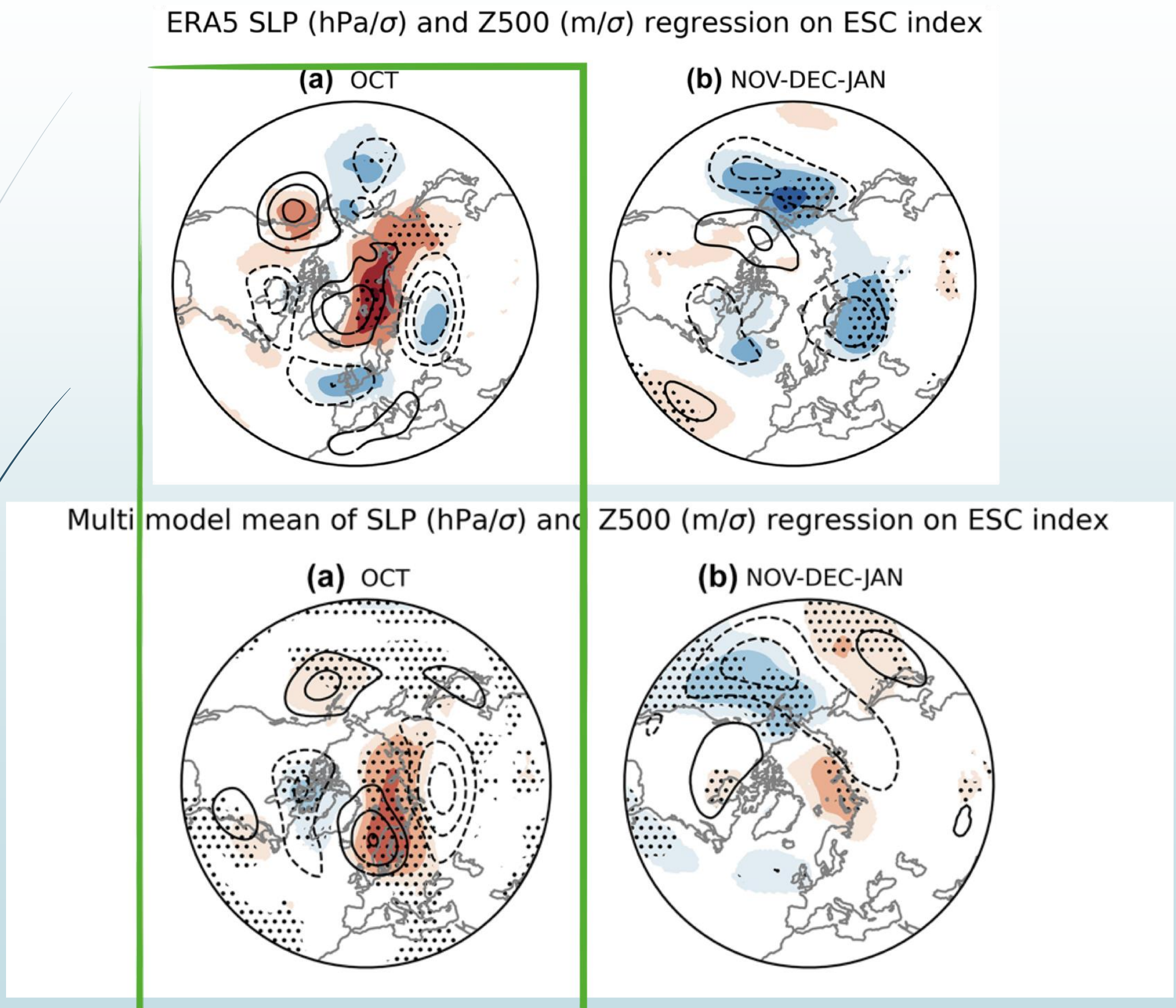
Idealised simulations with two AGCMs



Seasonal forecasts reproduce the impact on the surface energy budget



Observed and modelled relationship with the circulation



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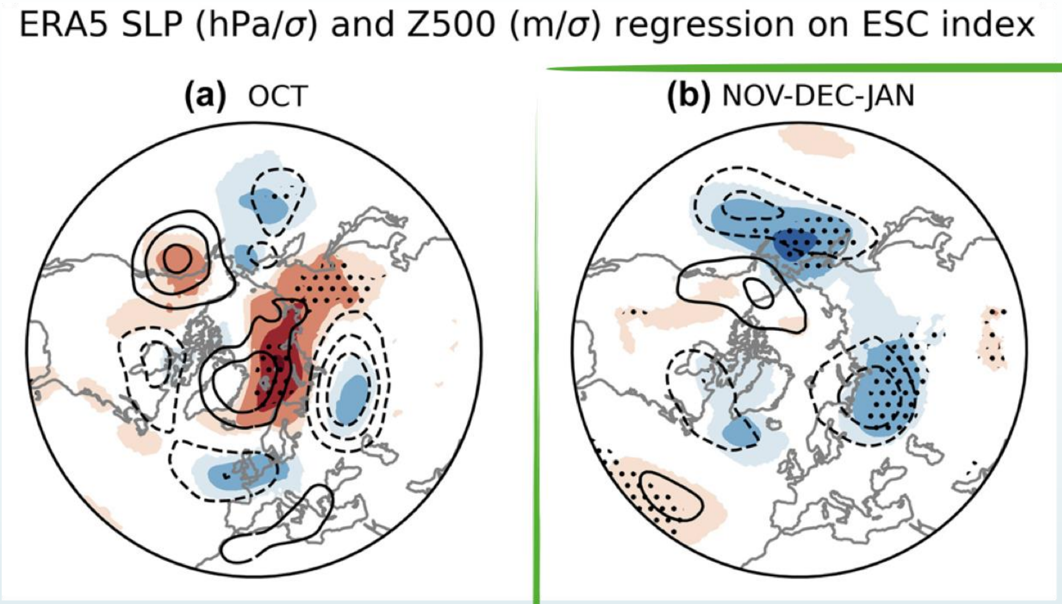
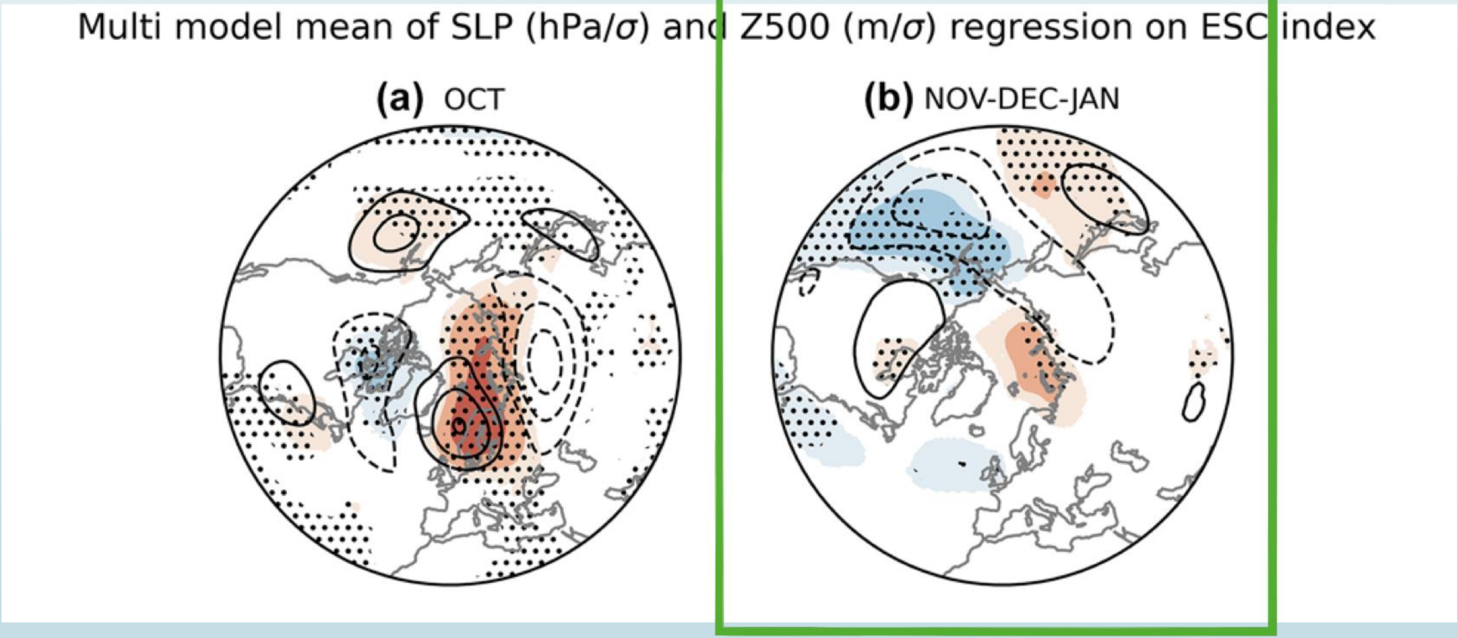
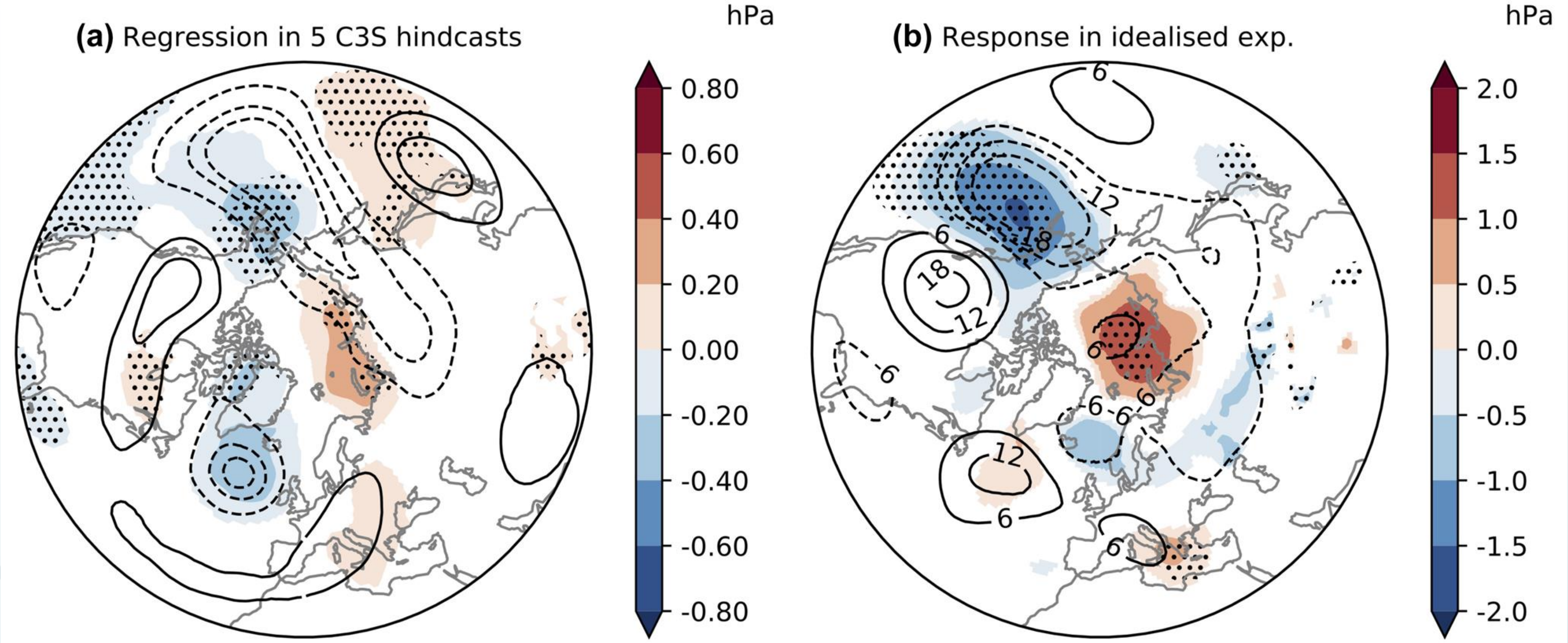


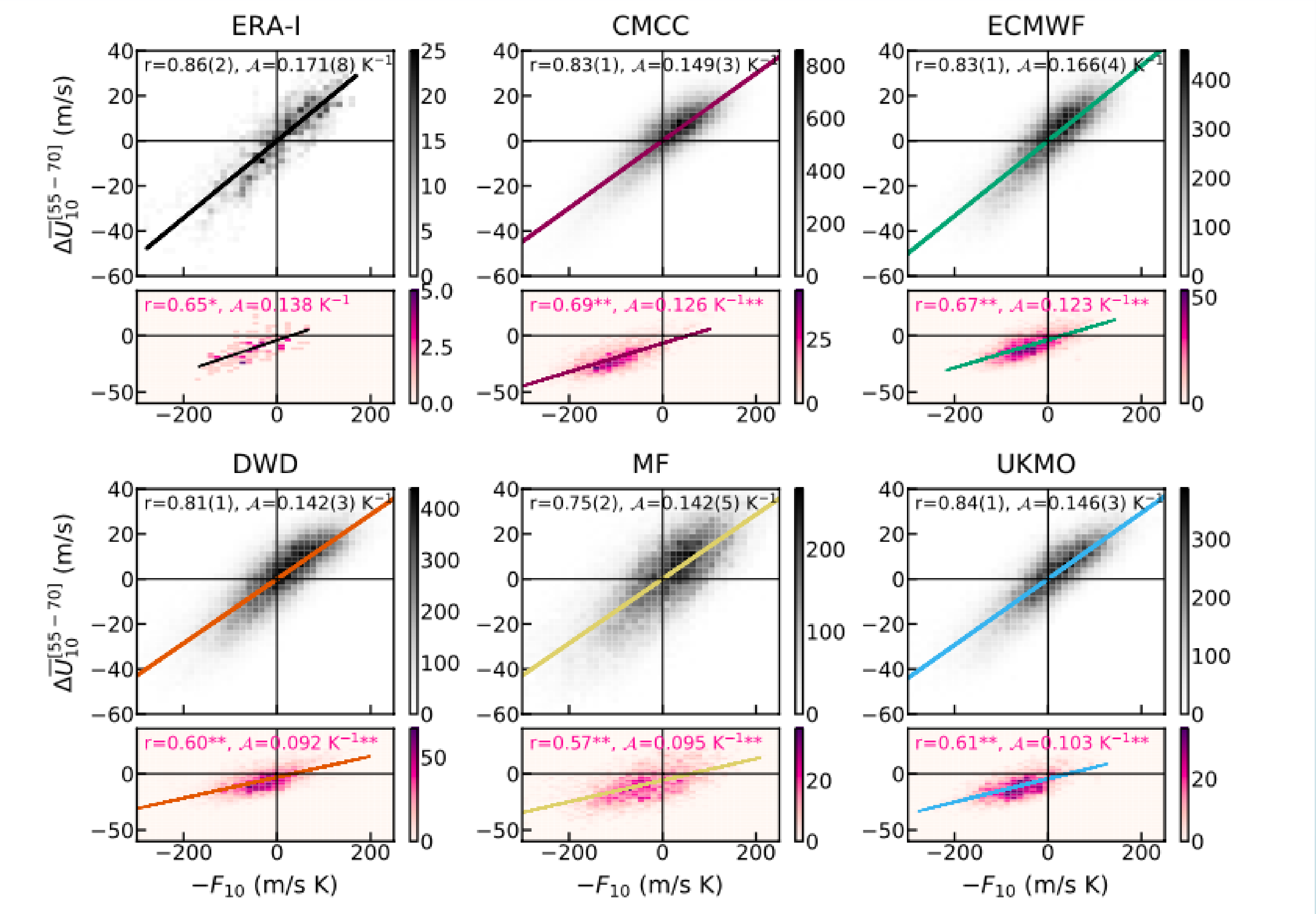


NOV-DEC response to OCT snow cover increase



Barotropic low in the Pacific
Shallow high in the Arctic
No multi-model agreement in the Atlantic
and lack of a stratospheric signal
for the October start date.

Seasonal prediction in the Boreal Winter stratosphere



Portal et al. (2021) Climate Dynamics

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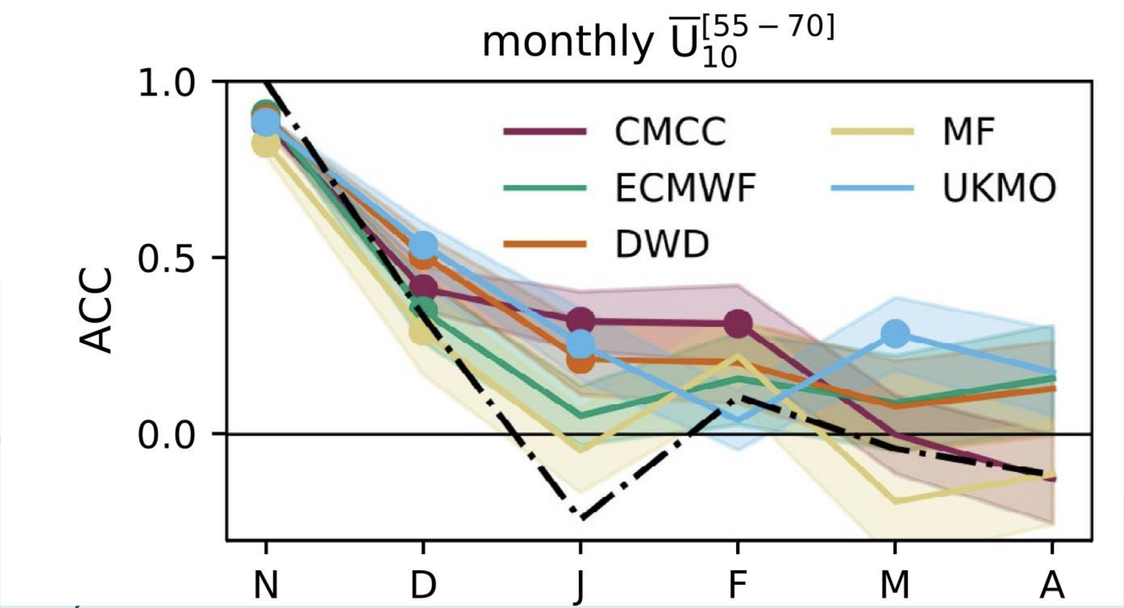
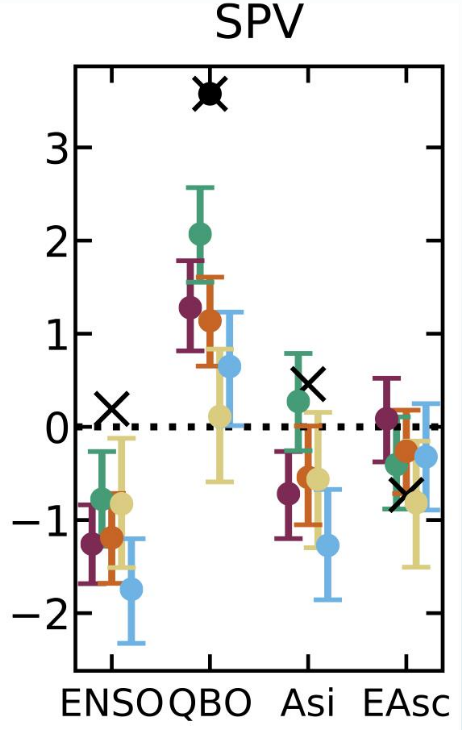


Portal et al. (2021) Climate Dynamics



Models adequately troposphere-stratosphere coupling.

Weak impact of Eurasian snow cover on the polar vortex in the Nov start date.

Snow and ice cover variability and its influence on climate

Remote response of the atmosphere

Snow cover and sea-ice in seasonal predictions

Summary

Summary

Snow cover and sea-ice variability affect the surface energy balance and surface temperature. The link is robust in observations and models.

The atmospheric response to ice and snow variability examined in GCM simulations reveals a linear and a non-linear stage.
The latter projects onto the AO/NAO and potentially involves a role for the stratosphere

Models typically underestimate snow cover variability and do not reproduce univocally the atmospheric response.

Summary

Autumn snow cover and sea-ice variability are successfully exploited in empirical and hybrid forecast of the winter NAO.

Current high-res, large ensemble dynamical seasonal forecast reproduce realistically snow cover variability and its impact on the surface energy budget.

They also feature a weak AO- lagged response, with a deep low over the Pacific and a shallow high over the Arctic.

Seasonal forecast models reproduce realistically stratospheric variability and identify a predictable component but they do not show a strong impact of snow and ice on the stratosphere.

Thank You

The linear stage of the response

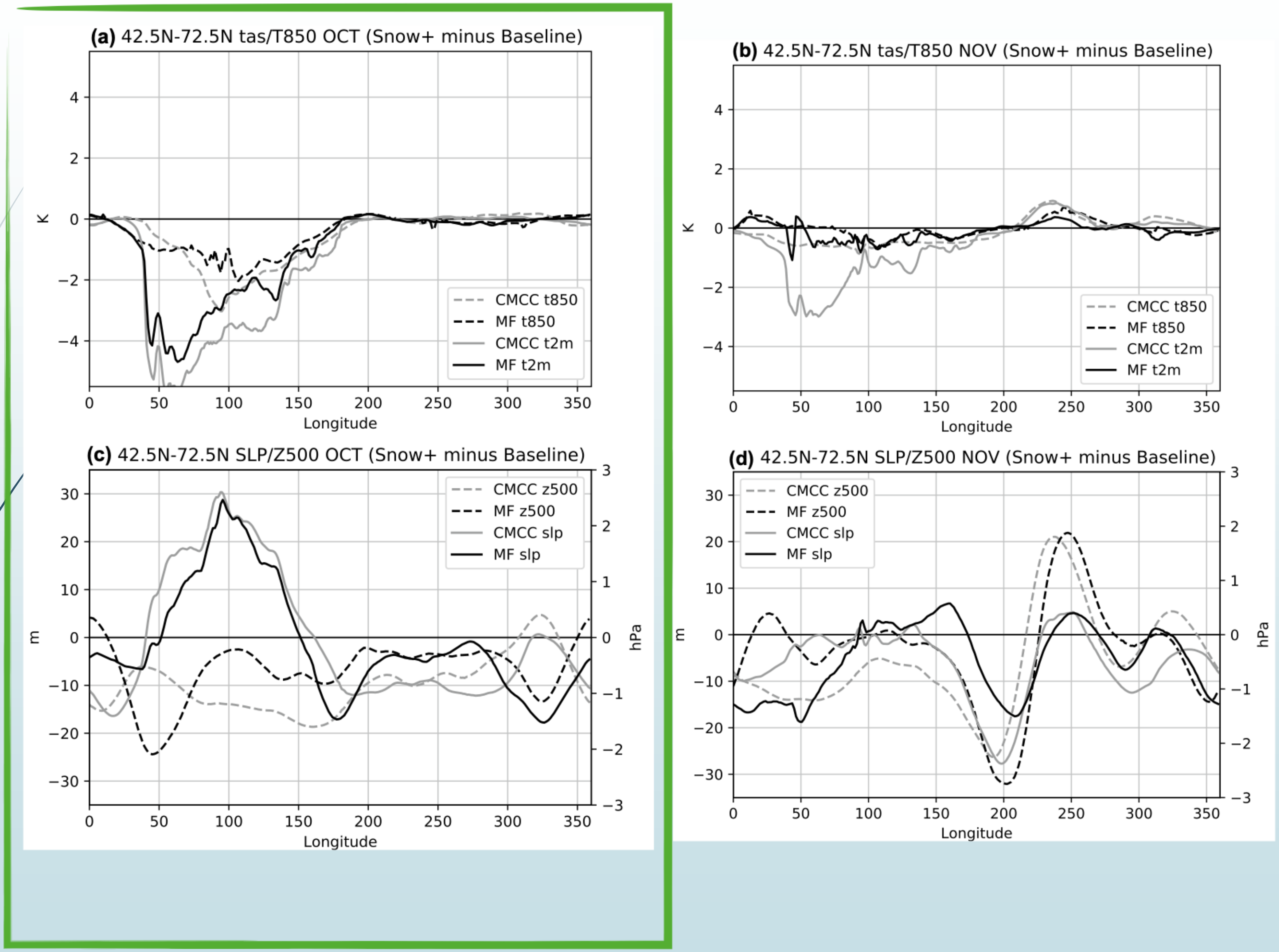
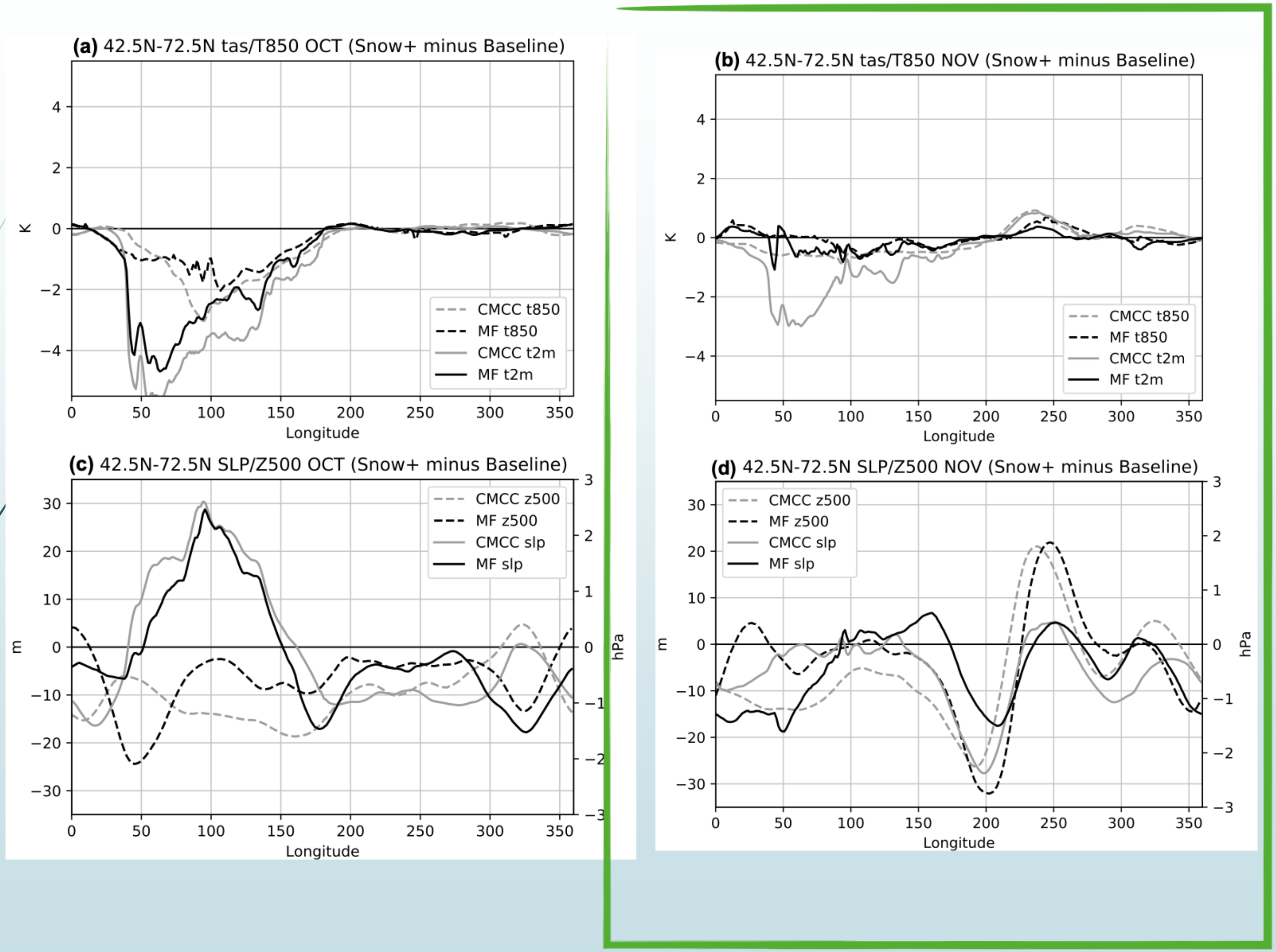


Fig. 10 Meridional mean (area-weighted) between 42.5N and 72.5N of T2m (solid lines, K) and T850 (dashed lines, K) in **a** OCT and **b** NOV for the idealized AGCM experiments with the CMCC-AGCM model (grey lines) and the MF-AGCM (black lines) model. **c** and **d** As in **a** and **b** but for SLP (solid lines, hPa) and Z500 (dashed lines, m)

The non-linear lagged response



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