Earth Sciences Department
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

On causality, sources of predictability, and bridging predictions across timescales

Ángel G. Muñoz
Head, Climate Services Team (CST)
Ramón y Cajal Fellow
Earth System Services (ESS) Group

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Outline

1. Liang-Kleeman causality framework (brief)

1. Identifying sources of predictability at intraseasonal to seasonal timescales

1. Bridging predictions across timescales

1. Further work on the topics

Quick Intro to Liang-Kleeman Causality

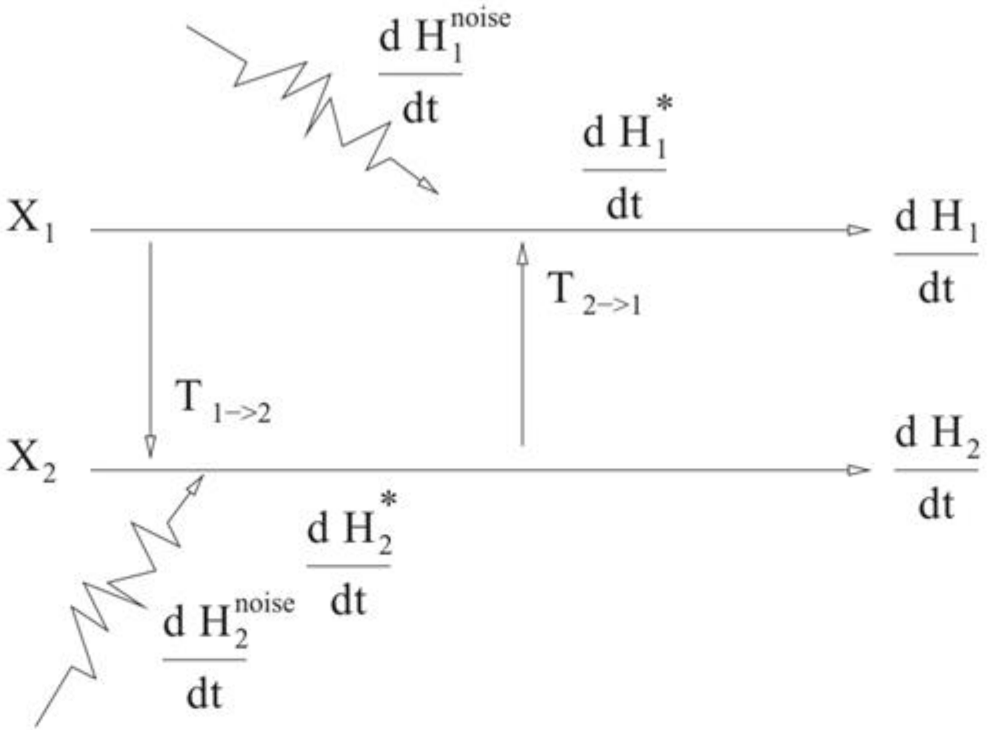

FIG. 1. Schematic of the marginal entropy evolutions and information flows in the system of (X_1, X_2).

The temporal evolution of the total marginal entropy of X_1 can be disjointly decomposed in terms of the change rate of the marginal entropy without any influence from X_2 and a term involving the influence of X_2 :

San Liang, 2015, 2016

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What is the rate information flow from, say, X_1 to X_2?

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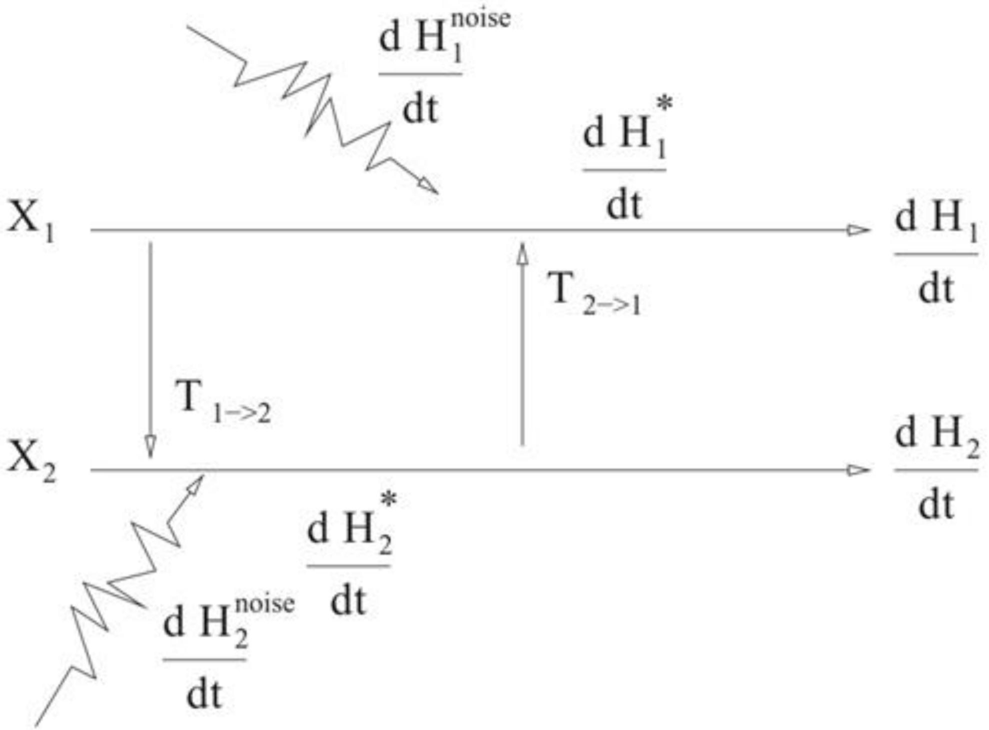

FIG. 1. Schematic of the marginal entropy evolutions and information flows in the system of (X_1, X_2).

San Liang, 2015, 2016

$$T_{2\to1} = \frac{C_{12}}{C_{11}}\hat{a}_{12}$$

$$\hat{a}_{12} = \frac{C_{11}C_{2i} - C_{12}C_{1i}}{\det C}$$

$(C)_{ij}$ are the elements of the sample covariance-crosscovariance matrix

C_{ij} is the sample crosscovariance of X_i and $\dot{X}_j$.

$$T_{2\to1} = \frac{r}{1-r^2}(r'_{2,d1} - rr'_{1,d1}).$$

Obviously, two uncorrelated events ($r = 0$) must be noncausal ($T_{2\to1} = 0$); in other words, causation implies correlation. The converse, however, does not hold; i.e., correlation does not imply causation.

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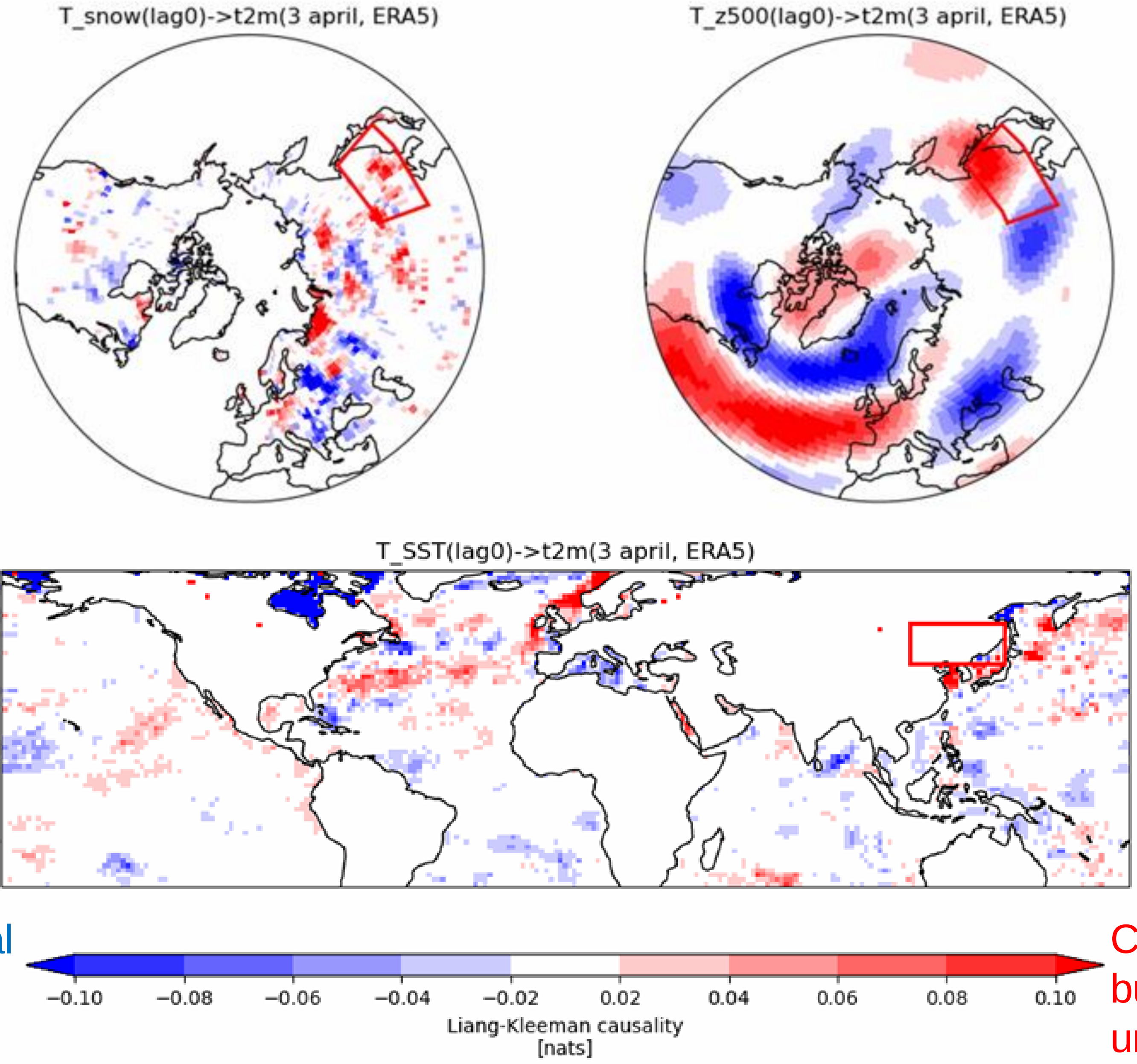
Causal ID of Sources of Predictability

LK causality between (snow, z500 and SST), and t2m over the China box, using **ERA5 data.**

(colors indicate statistically significant values, p<0.05)

Ardilouze, Materia and Muñoz (2024);
Ardilouze, Muñoz, Materia (in prep)



Causal and stable

Causal but unstable

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Using Causality in Model Diagnostics

- Work driven by our previous research (e.g., Materia et al., 2019)
- Multi-model ensemble approach, but analysis also for each independent model (and members!)
- 4 models: ECMWF, CNRM, BoM (Australia) and HMCR (Russia)
- 10 members each = 40-member ensemble
- Model selection driven by ensemble size, common reforecast period and the availability of snow cover data (not provided by the UK model, for example)

Ardilouze, Materia and Muñoz (2024);
Ardilouze, Muñoz, Materia (in prep)

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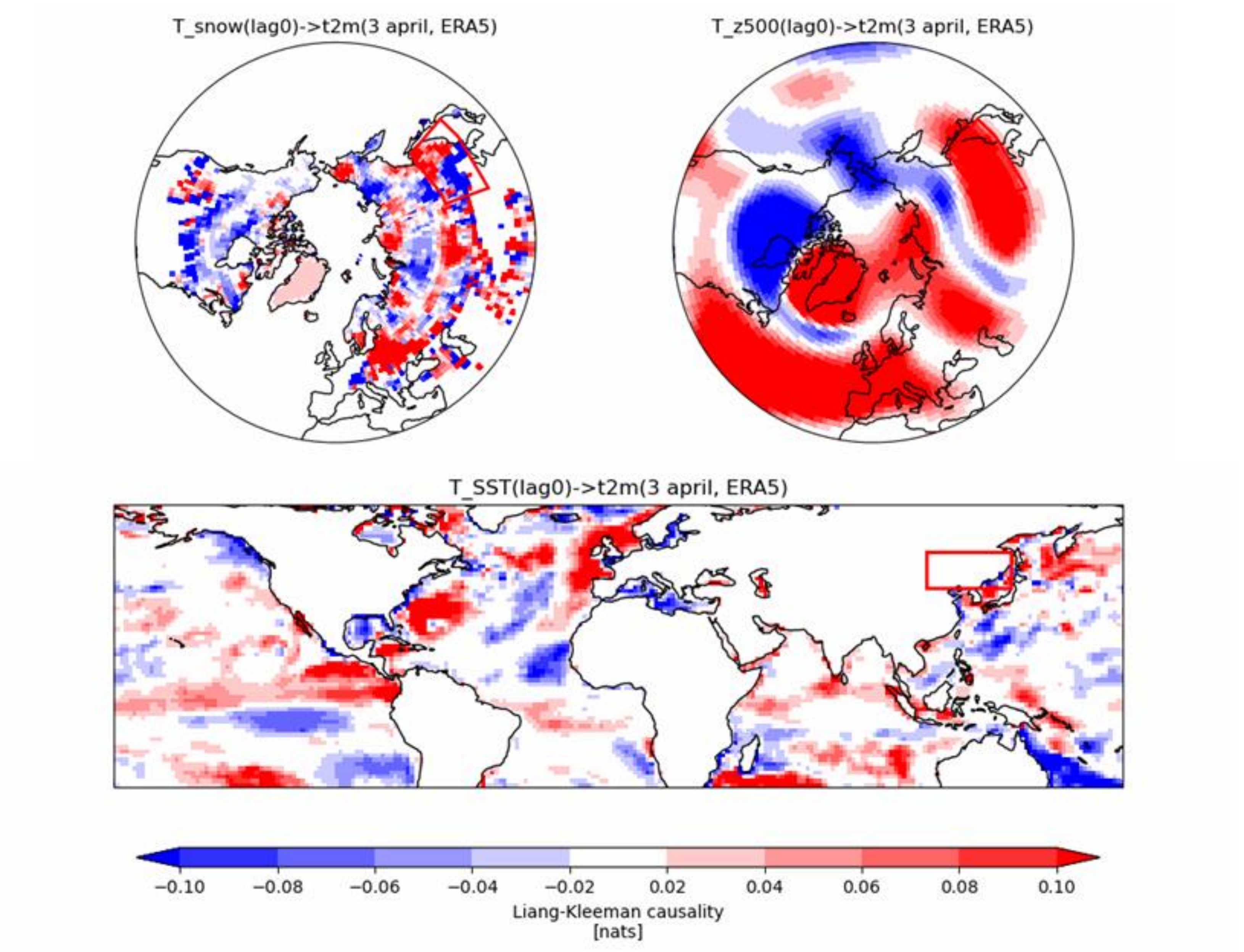
Materia, S., Muñoz, Á. G., Álvarez-Castro, M. C., Mason, S. J., Vitart, F., & Gualdi, S. (2019). Multi-model subseasonal forecasts of spring cold spells: potential value for the hazelnut agribusiness. Weather and Forecasting. https://doi.org/10.1175/waf-d-19-0086.1

Using Causality in Model Diagnostics

LK causality between (snow, z500 and SST), and t2m over the China box, for the **multi-model ensemble and ERA5**

(colors indicate statistically significant values, $p<0.05$)

Ardilouze, Materia and Muñoz (2024);
Ardilouze, Muñoz, Materia (in prep)



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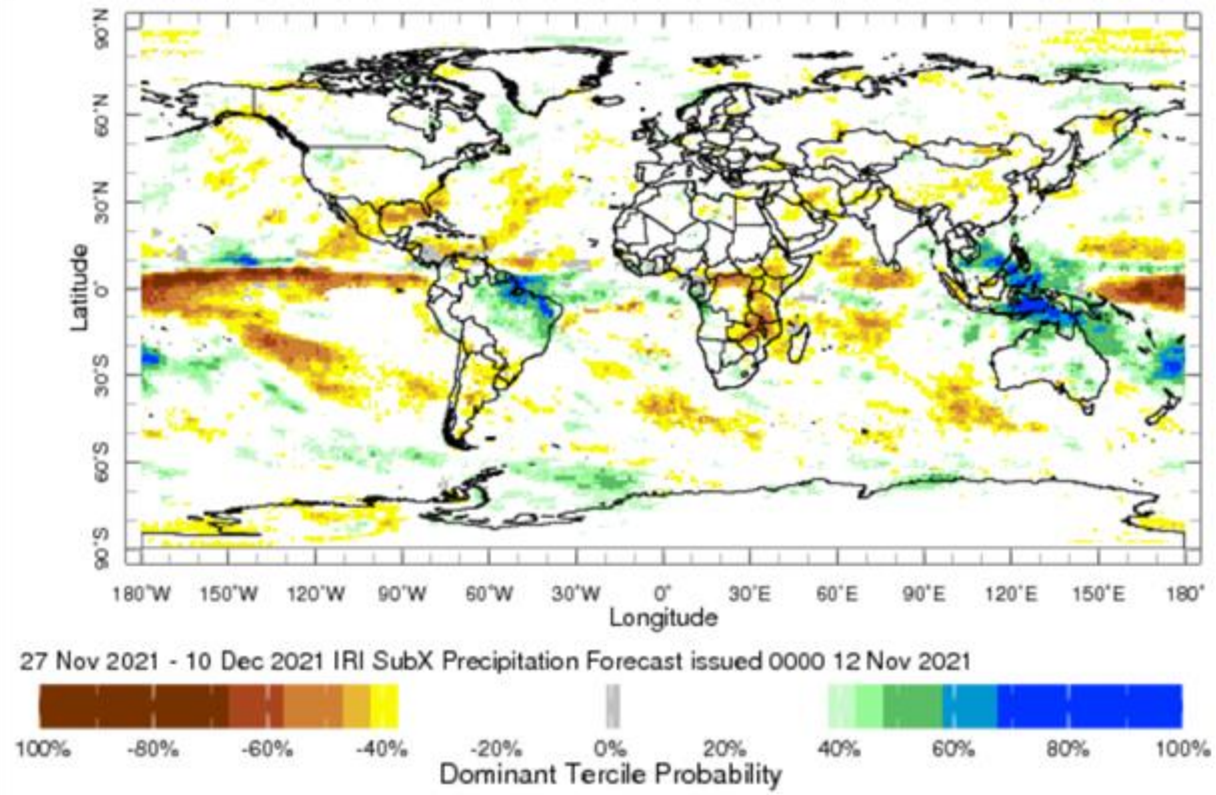
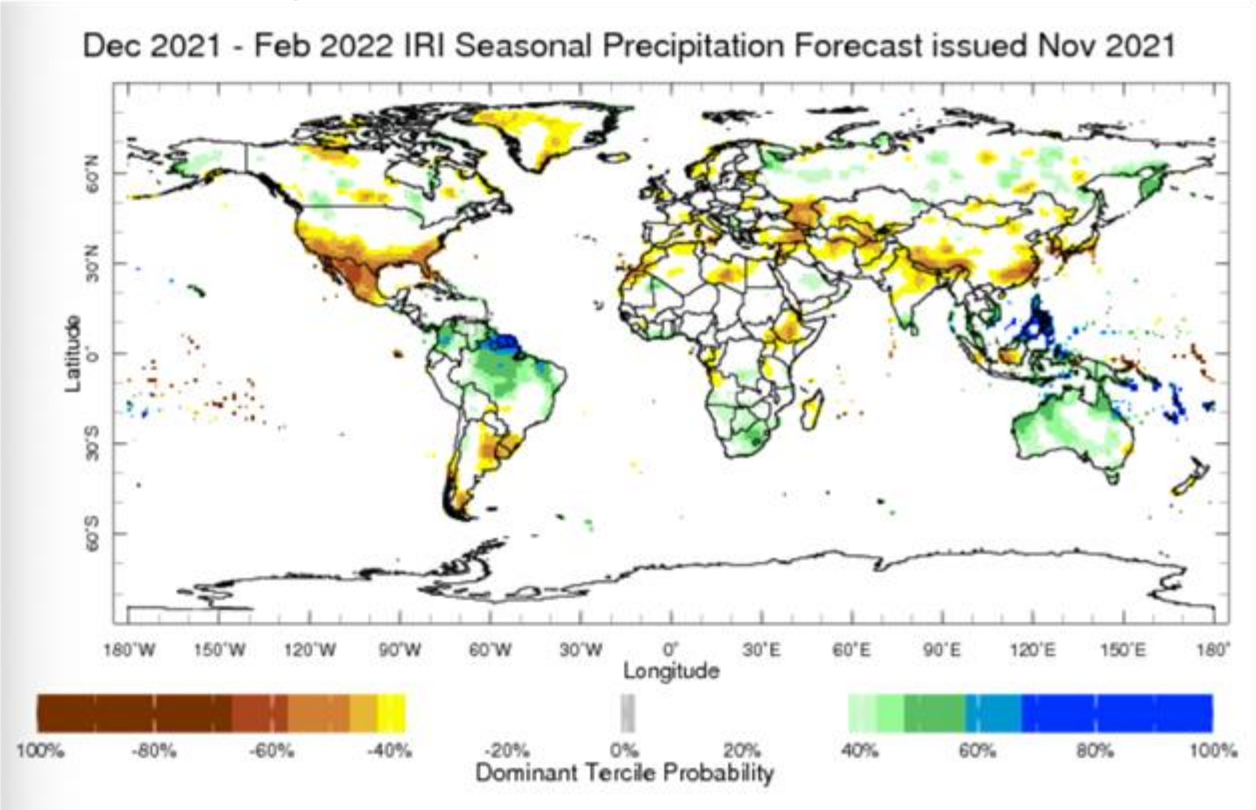
Merging Prediction Systems: The Problem

a) SubX calibrated subseasonal rainfall forecast



b) NMME calibrated seasonal rainfall forecast



Muñoz et al, 2023

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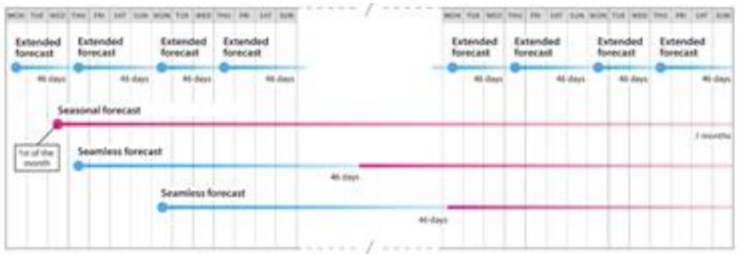
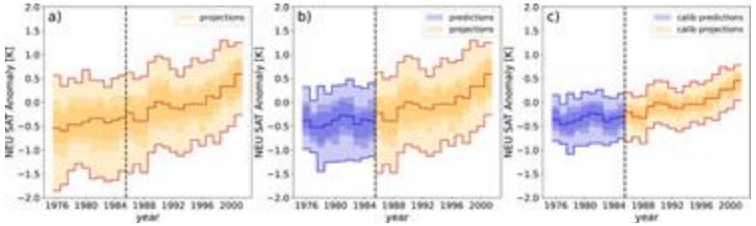
(a) SubX multi-model, calibrated subseasonal rainfall forecast system, targeting Nov 27, 2021 to Dec 10, 2021 (weeks 3-4). b) NMME calibrated seasonal rainfall forecast system, targeting Dec 2021 to Feb 2022. There are clear similarities in the regions of above-normal (green) and below-normal (brown) dominant tercile probabilities of rainfall at the two scales, both impacted by La Niña conditions, highlighting physical bridging

How can we bridge predictions?



- Stitching

  e.g. Wetterhall and DiGiuseppe (2018); Beford et al (2020)

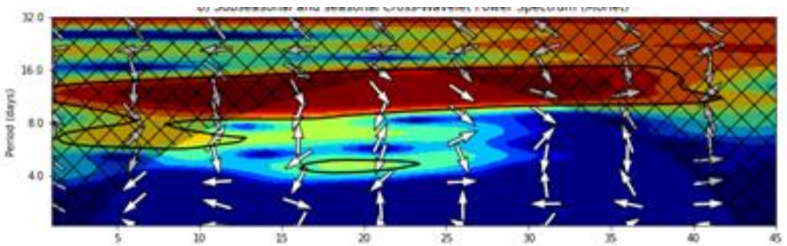


- Constraining

  e.g. Beford et al (2020, 2022); Mahmood et al (2021)

- Weighting

  e.g. Ford et al. (2018); Dirmeyer et al (2018, 2020)



- **Causal-flowing (X_{it}/Cross-it)**

  e.g. this work (Muñoz et al., 2023, 2024; in prep.)

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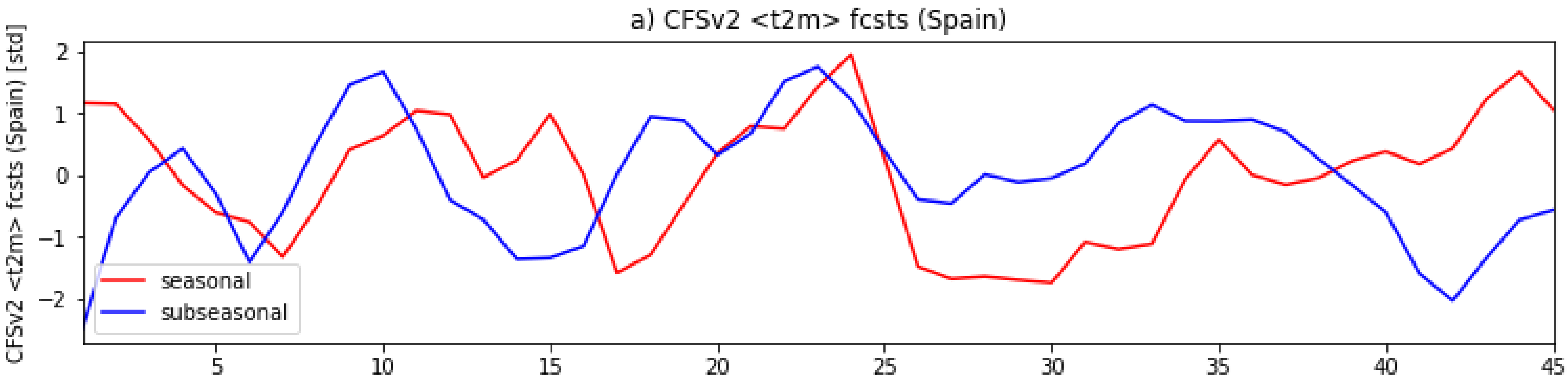

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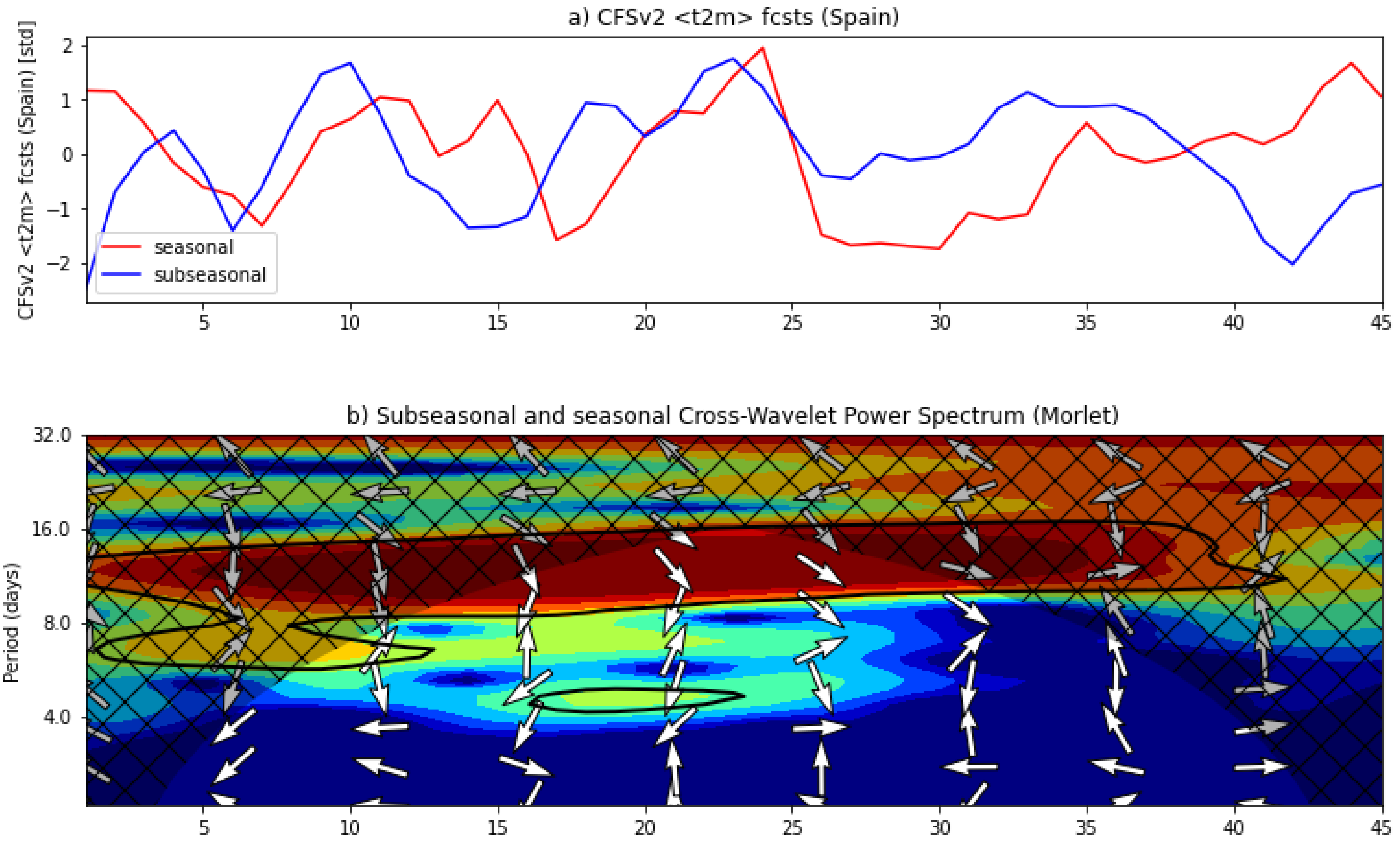
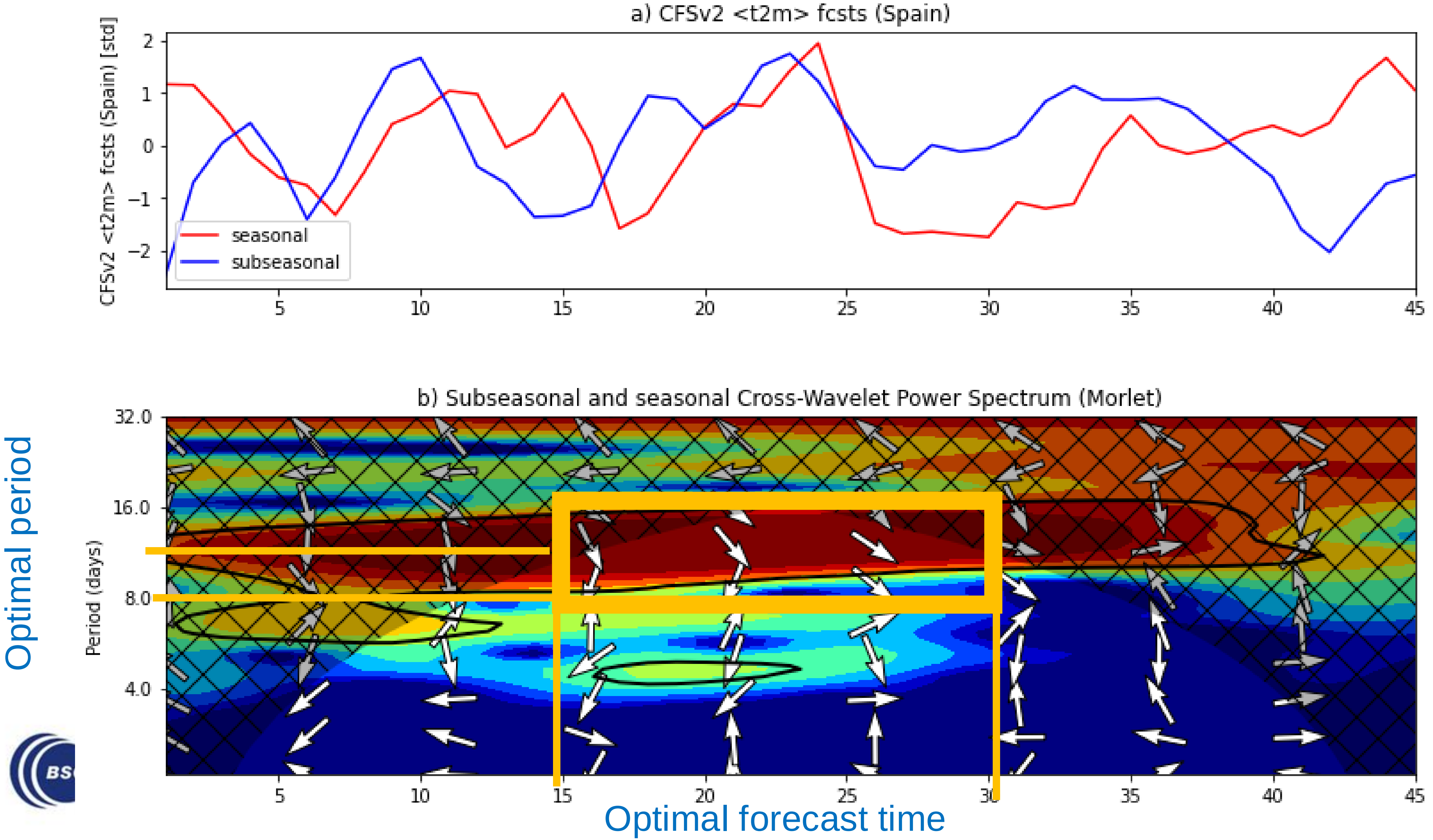


a) CFSv2 <t2m> fcsts (Spain)
CFSv2 <t2m> fcsts (Spain) [std]
seasonal
subseasonal
b) Subseasonal and seasonal Cross-Wavelet Power Spectrum (Morlet)
Period (days)



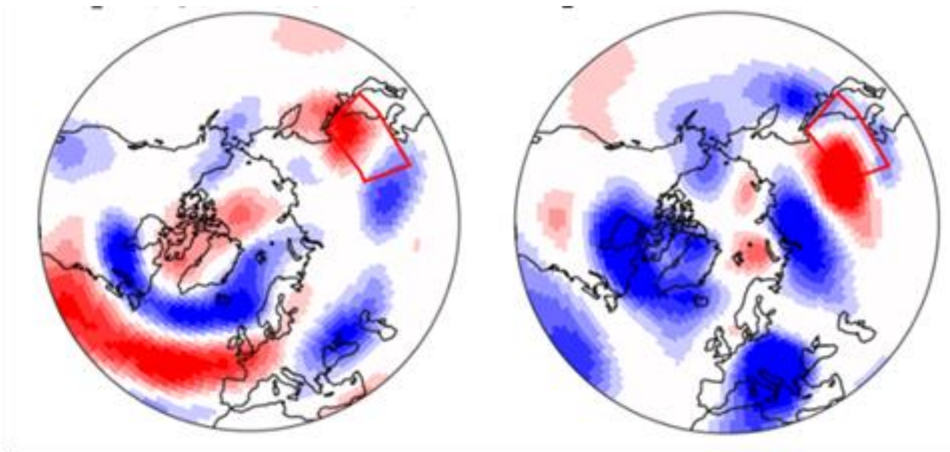
a) CFSv2 <t2m> fcsts (Spain)
CFSv2 <t2m> fcsts (Spain) [std]
seasonal
subseasonal
b) Subseasonal and seasonal Cross-Wavelet Power Spectrum (Morlet)
Period (days)
32.0
16.0
8.0
4.0
5
10
15
20
25
30
35
40
45
Optimal period
Optimal forecast time

Ongoing research
(ask us more later about it)

1. Causal patterns (linear vs non-linear)

1. Causal pattern regression

1. Causality and predictive skill



Pattern 1 Pattern 2

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