The Sub-seasonal to Seasonal Prediction Project (S2S) and the prediction of extreme events

Frédéric Vitart, ECMWF

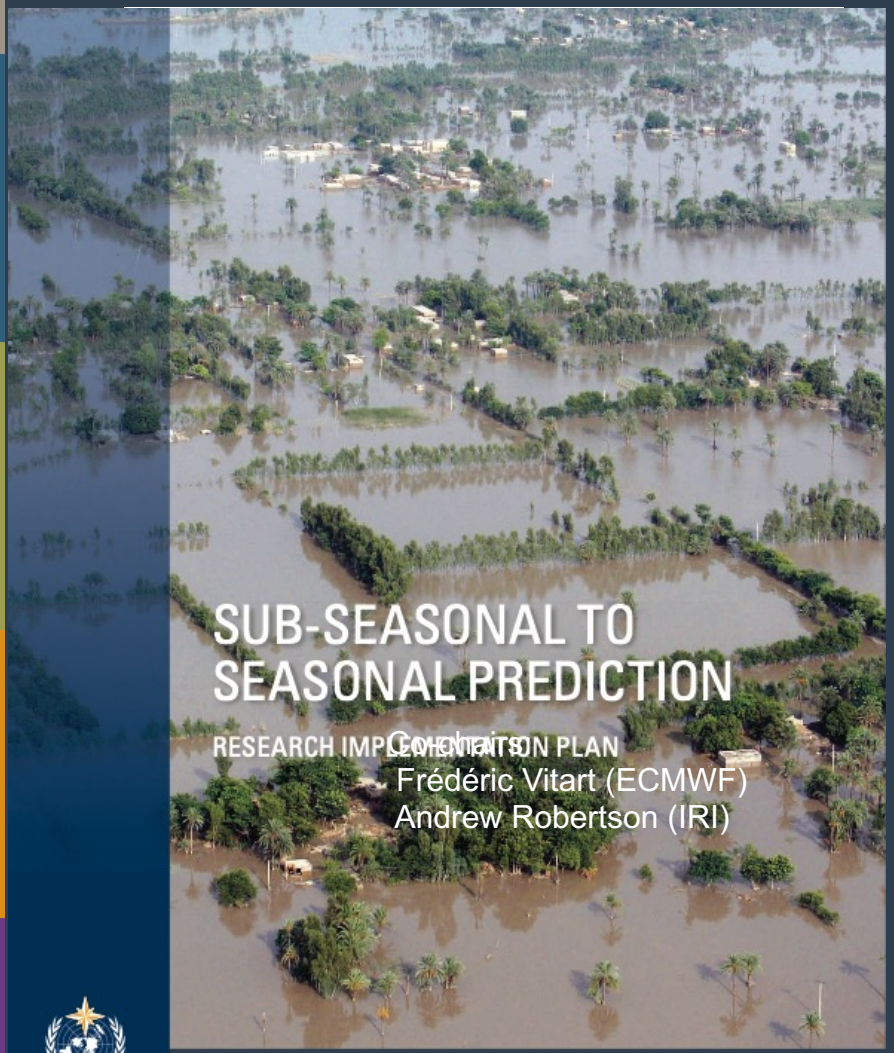
WWRP WORLD WEATHER RESEARCH PROGRAMME

WCRP World Climate Research Programme

Index

The WWRP/WCRP S2S project

The WWRP/WCRP S2S project 2013-2023



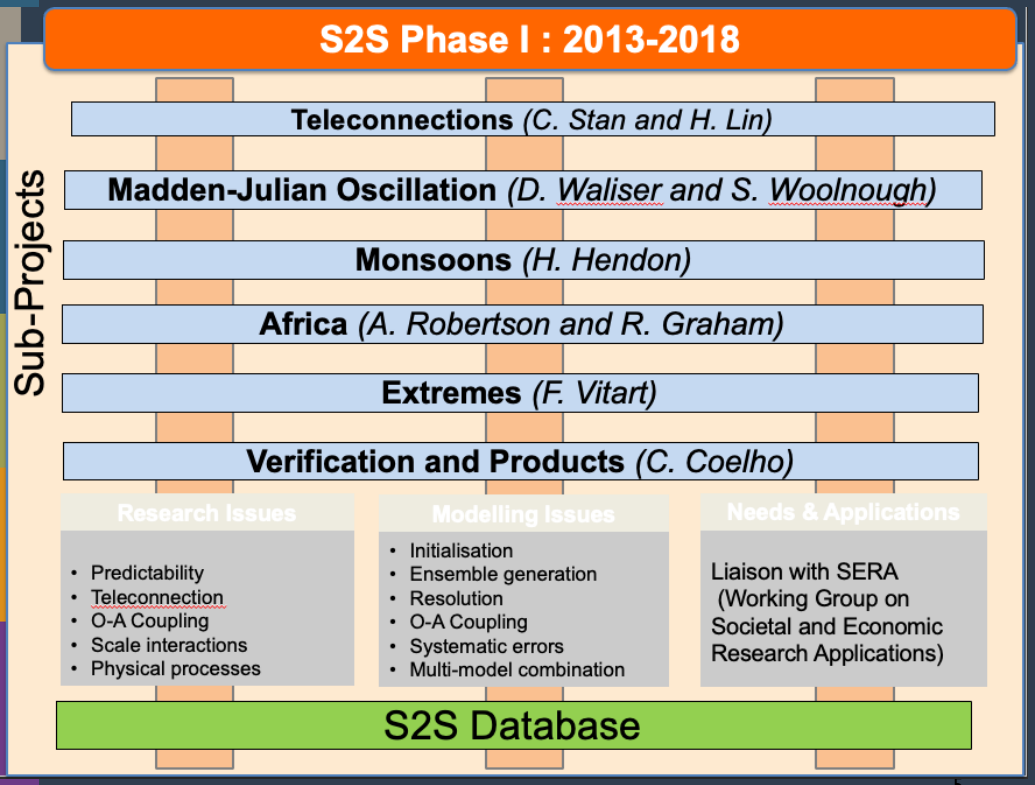
- Improve forecast skill and understanding on the sub-seasonal to seasonal timescale with special emphasis on high-impact weather events
- Promote the initiative's uptake by operational centres and exploitation by the applications community
- Capitalize on the expertise of the weather and climate research communities to address issues of importance to the Global Frame- work for Climate Services

- *The S2S project started 2013 and is now in its second phase (2019-2023)*
- *International Coordination Office hosted by APCC.*
- *Contribution to S2S trust fund from Australia, Canada, UK and Germany.*

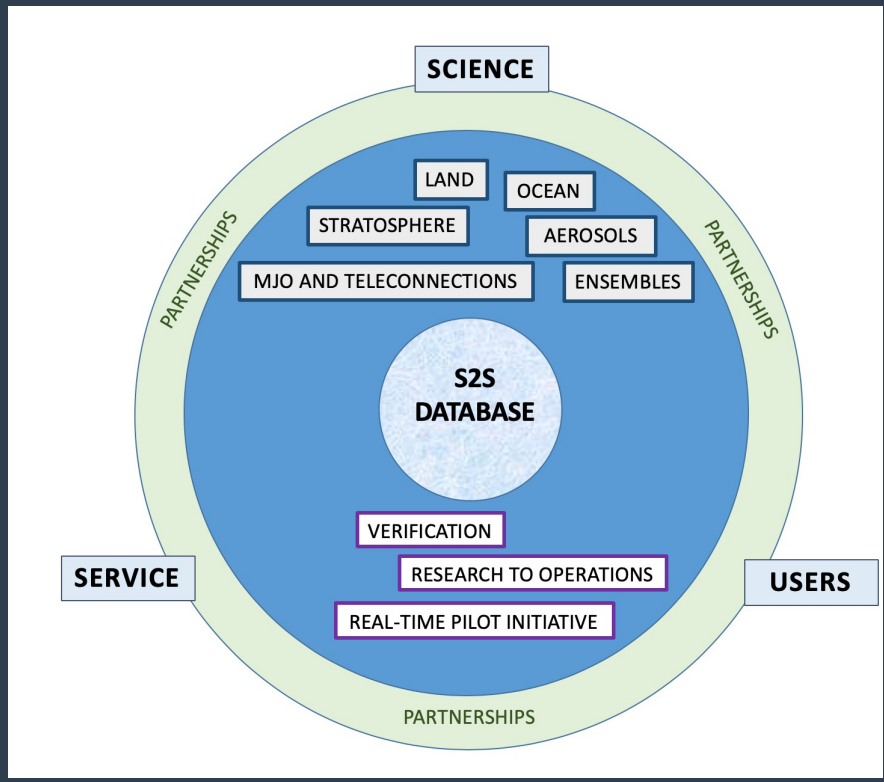
The project focuses on the forecast range between 2 weeks and a season.

The WWRP/WCRP S2S project

S2S Phase I: 2013-2018

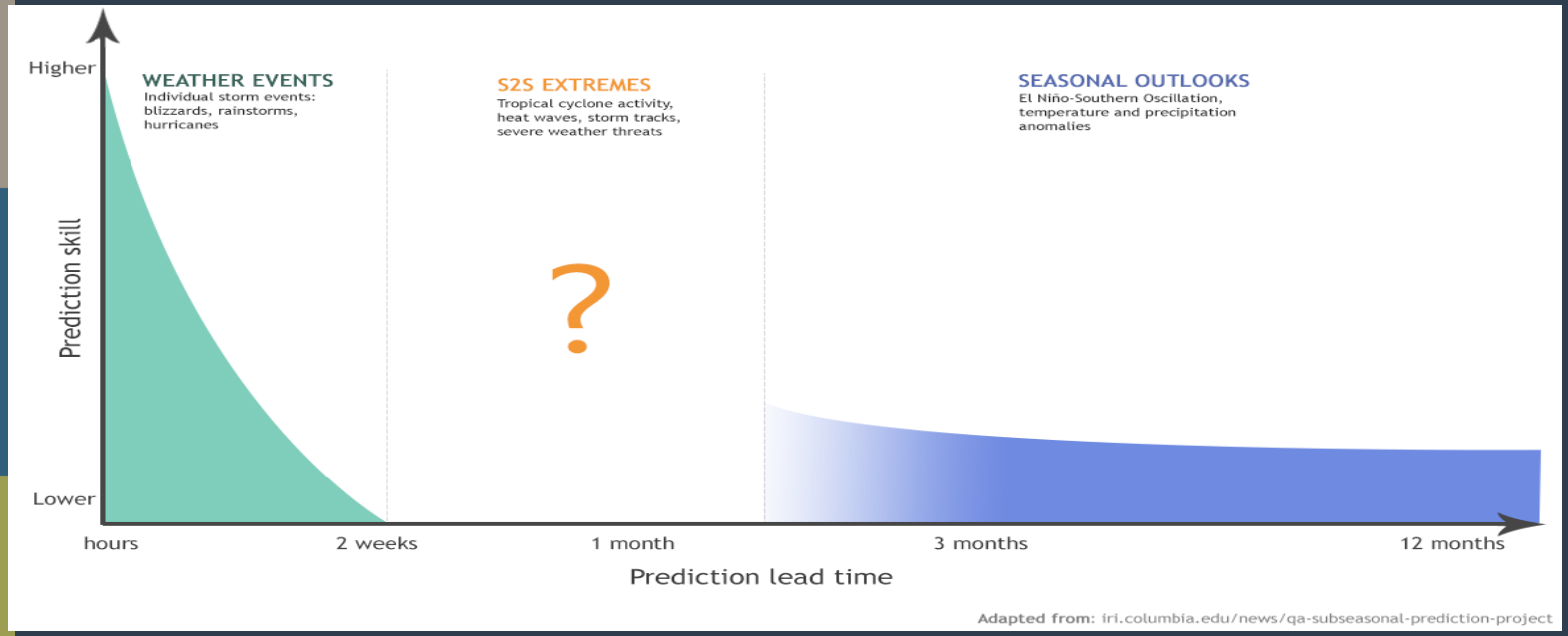


S2S Phase II: 2019–2023



Sub-seasonal to seasonal predictability

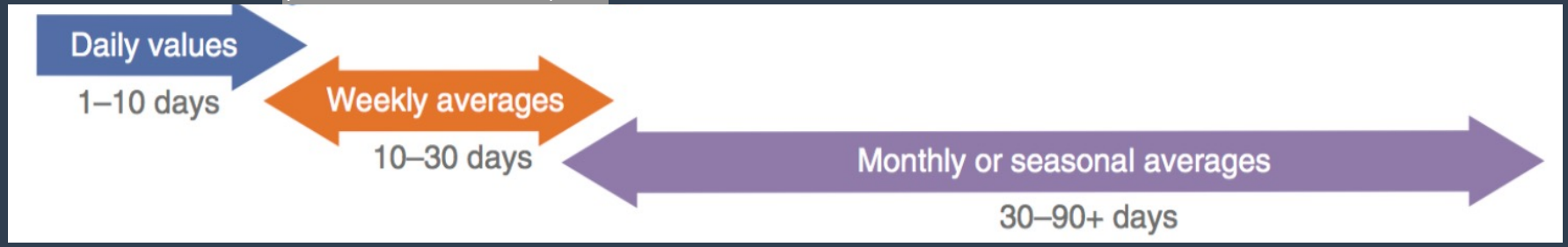
Atmospheric Predictability



Weather: Initial Value Problem (e.g., baroclinic waves)

S2S: Mixed Initial Value (e.g. MJO) and Boundary Value Problem (e.g. Soil moisture, snow cover/snow pack, sea ice, SST)

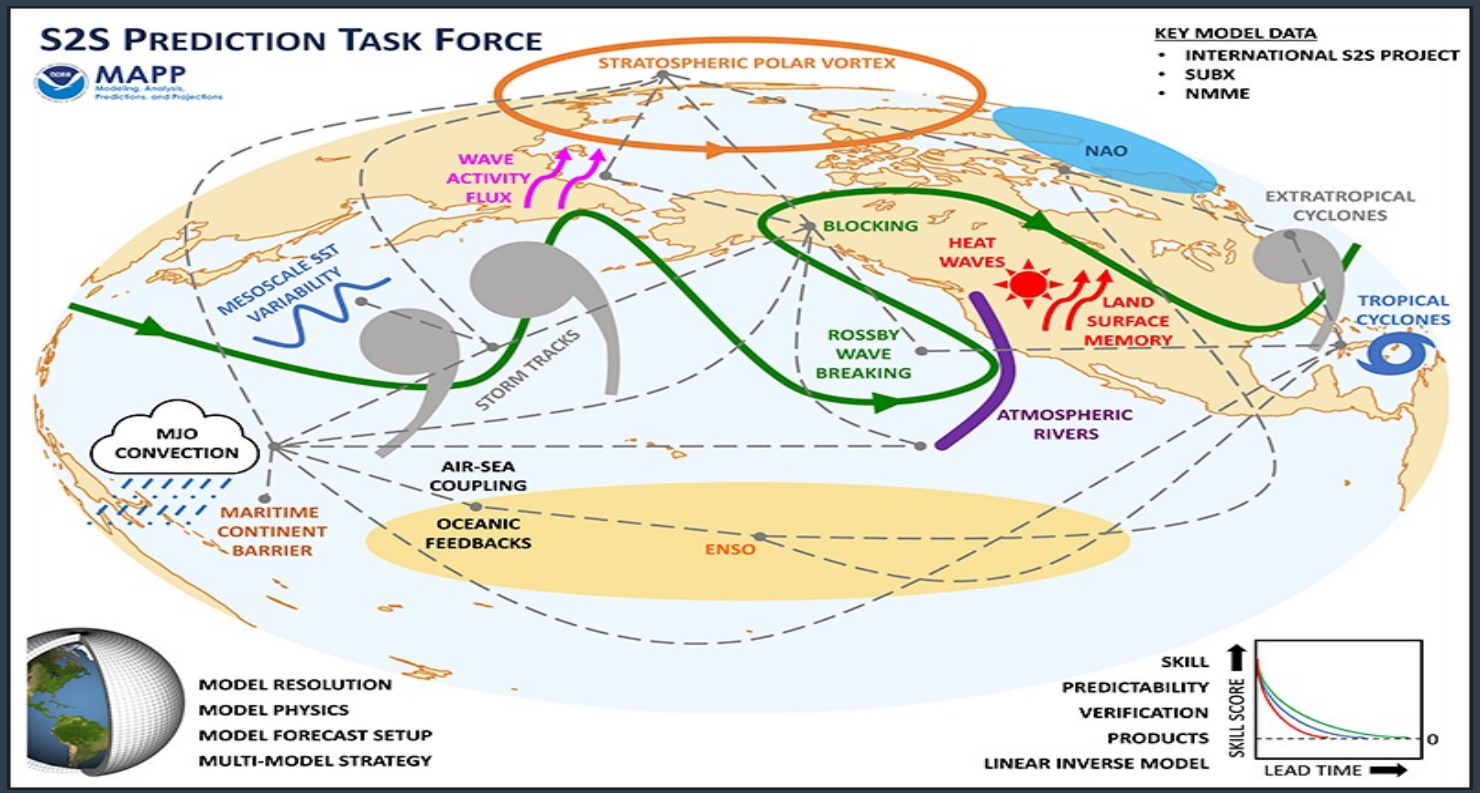
Seasonal Climate: Boundary Value Problem (e.g. ENSO SST anomalies)



TIME AVERAGING

Predictability of the Second Kind (Lorenz, 1975)

S2S sources of predictability



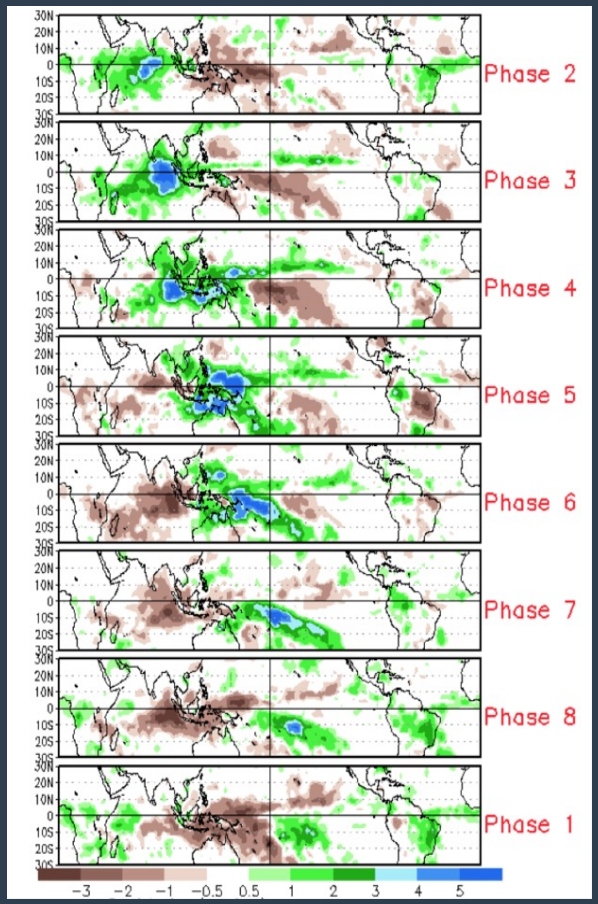
Mariotti et al., 2019

S2S main sources of predictability include:

- Madden Julian Oscillation
- Soil Moisture
- Stratospheric Initial conditions
- Rossby waves
- SSTs/Sea-ice
- Aerosols? …

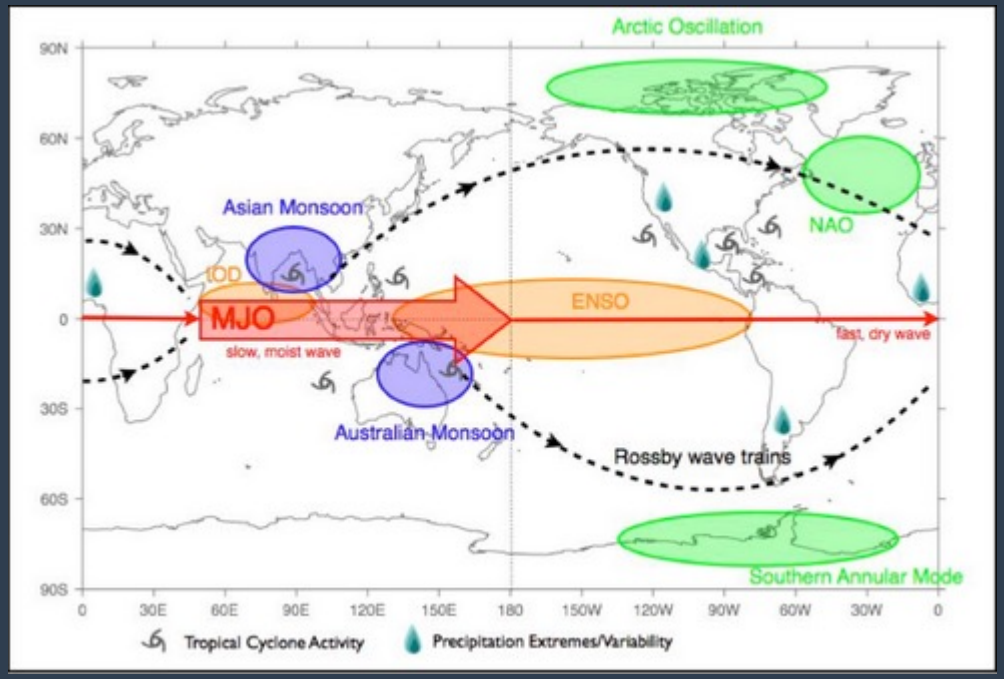
The Madden Julian Oscillation

MJO 8 phases

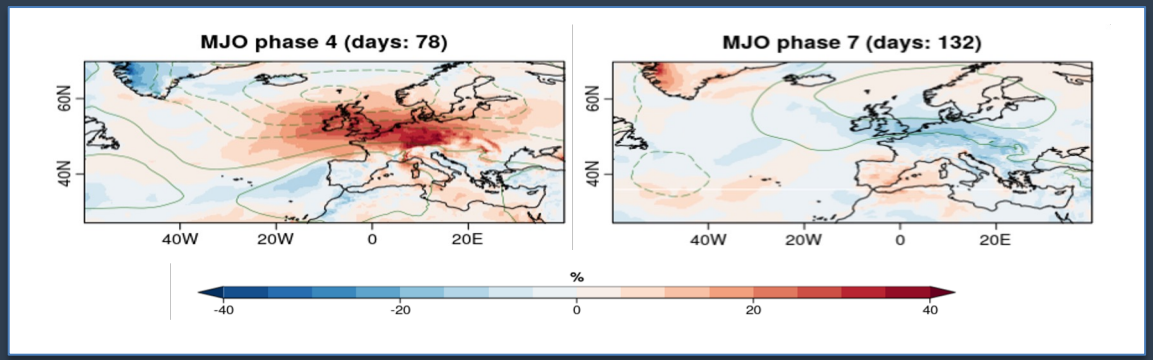


Gottschalk, 2014

MJO Impacts



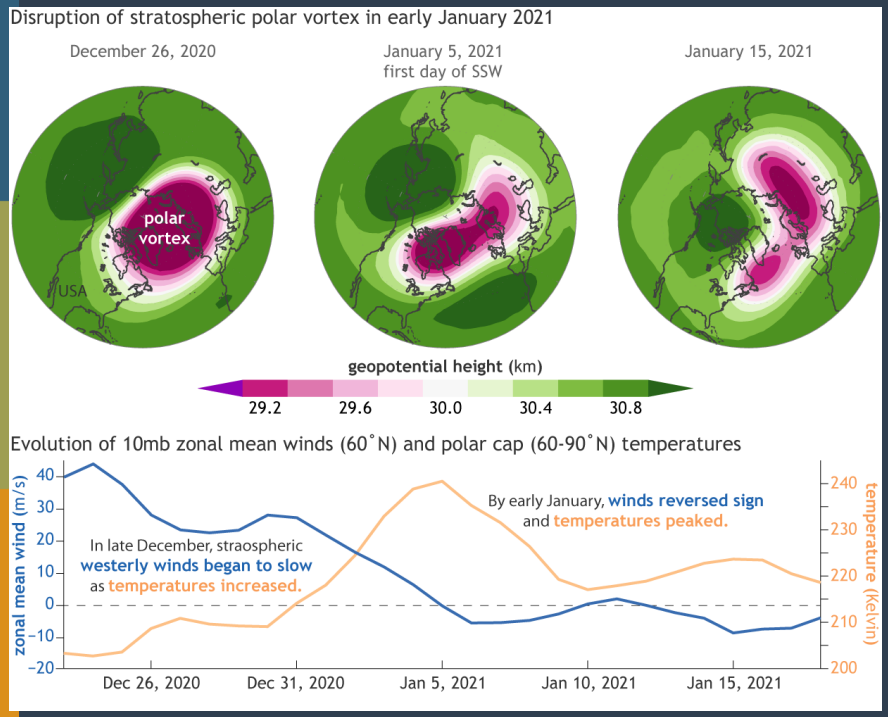
JFM surface wind anomalies over Europe

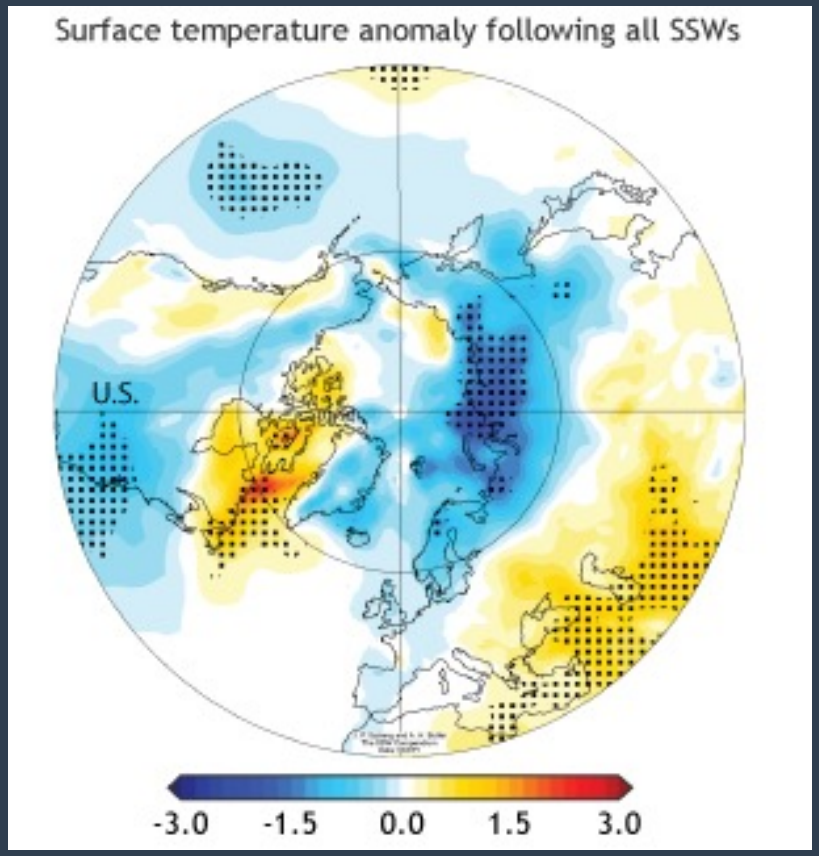


From L. Lledo

Weak stratospheric vortex events

Jan 2021 weak vortex event





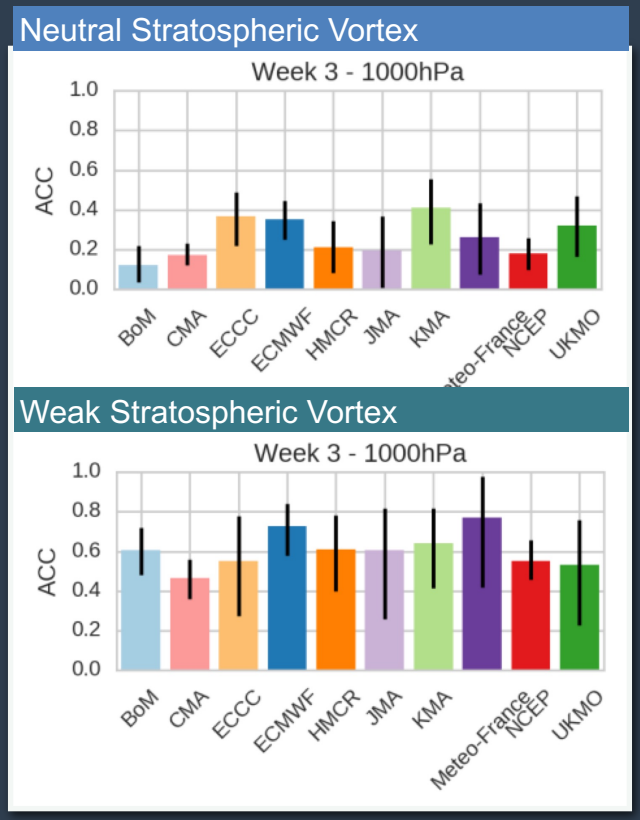
L'Heureux 2021

Surface temperature anomalies in degrees Celsius for (left) the 30 days following all identified SSWs in the NCEP-NCAR reanalysis record from 1958-2013. From Butler et al. 2017

S2S prediction is challenging

Forecast skill is not constant in time. It depends strongly on the occurrence of sources of predictability: "**windows of opportunity for forecast skill**" (e.g. strong MJO, weak vortex event…)

Prediction skill of the 1000 hPa Northern Annular Mode for week 3 in the S2S models



- For most models, skill is higher following weak vortex conditions.
- Similar results are found following strong vortex conditions.

Domeisen et al. (2019)

Interactions between sources of predictability

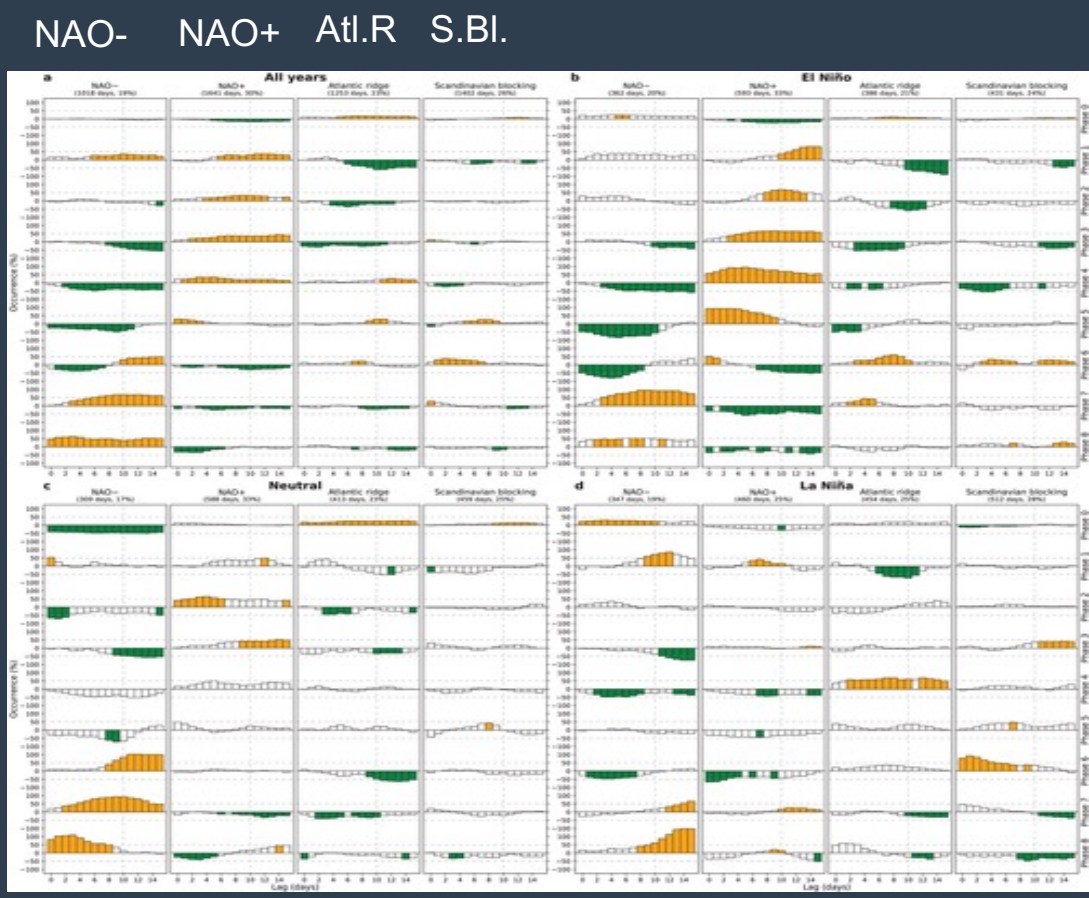
- QBO - MJO
- MJO – SSW
- MJO-NAO
- MJO - ENSO
- ENSO– MJO Teleconnection
- Decadal variability

(PDO, AMO?)

- Global Warming

How do S2S models represent these sources of predictability and their interactions?

ENSO Modulation of MJO teleconnections

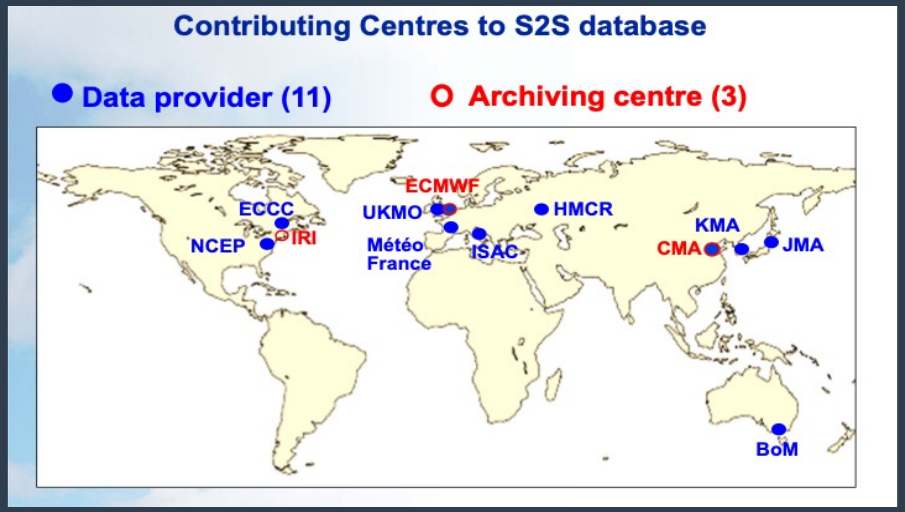


Lee et al. 2019

The WWRP/WCRP S2S Database

The WWRP/WCRP S2S database

- Daily *3-week behind real-time* forecasts since January 2015 + re-forecasts
- 12 models currently available (2 new models soon: IMD/NASA)
- Same grid (1.5 degree) / GRIB2 format (netcdf converter available)
- About 80 variables available, including 3D variables on 10 pressure levels and a few ocean sub-surface variables have been recently added.
- Hosted at ECMWF, CMA and IRI



Links to data portals available at www.s2sprediction.net

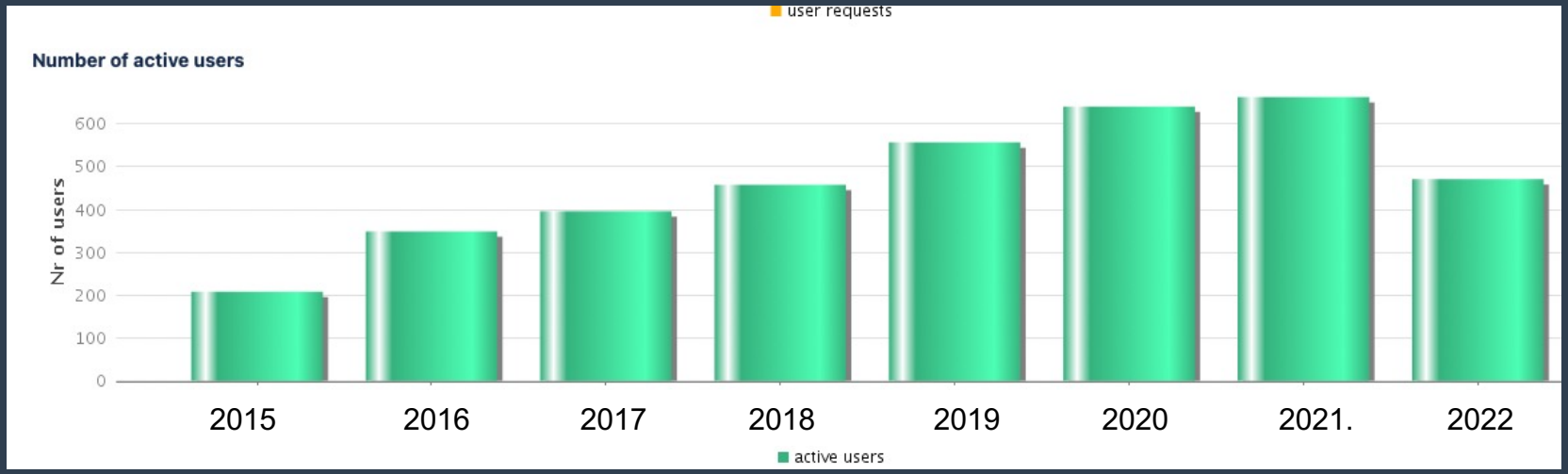
S2S database models

	Forecasts				Hindcasts			
	Time-range	Resol.	Ens. Size	Freq.	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	D 0-46	Tco639/319L91	51	2/week	On the fly	Past 20y	2/weekly	11
UKMO	D 0-60	N216L85	4	daily	On the fly	1993-2015	4/month	7
NCEP	D 0-44	N126L64	4	4/daily	Fix	1999-2010	4/daily	1
ECCC	D 0-32	~39 km 85 levels	21	weekly	On the fly	2001-2020	weekly	4
BoM	D 0-60	T47L17	33	2/weekly	Fix	1981-2013	6/month	33
JMA	D 0-34	40/55km 128 levels	50	weekly	Fix	1991-2020	2/month	13
KMA	D 0-60	N216L85	4	daily	On the fly	1996-2009	4/month	3
CMA	D 0-60	T266L56	4	2/week	On the fly	Past 15y	2/week	4
CNRM	D 0-47	T359L91	25	weekly	Fix	1993-2017	weekly	10
CNR-ISAC	D 0-32	0.75x0.56 L54	40	weekly	Fix	1981-2010	6/month	5
HMCR	D 0-63	1.1x1.4 L28	20	weekly	Fix	1990-2015	weekly	10
IAP-CAS	D0-65	C96L32	16	daily	Fix	1999-2018	daily	4

S2S database models

Models	Ocean Coupling	Active Sea Ice
ECMWF	YES	YES
UKMO	YES	YES
NCEP	YES	YES
ECCC	YES	YES
BoM	YES	YES
JMA	NO	NO
KMA	YES	YES
CMA	YES	YES
Met.Fr	YES	YES
ISAC-CNR	NO	NO
HMCR	NO	NO

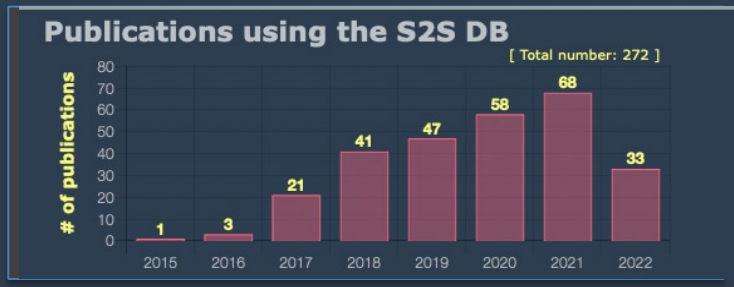
The WWRP/WCRP S2S Database



ECMWF server

Archive size 200 TBs
Number of active users 1776 (ECMWF)
Delivered volume: 1.3 PBs
Publications: > 270

At least one active user



S2S prediction of Extreme Events

S2S prediction of extreme events

1. Prediction of large-scale, long lasting events (> 1 week):
    1. Heat/cold waves
    2. Droughts
    3. Large Flooding

    Initial condition problem

2. Prediction of statistics of small scale events, for example:
    1. Tropical cyclones
    2. Flash floods
    3. Tornadoes

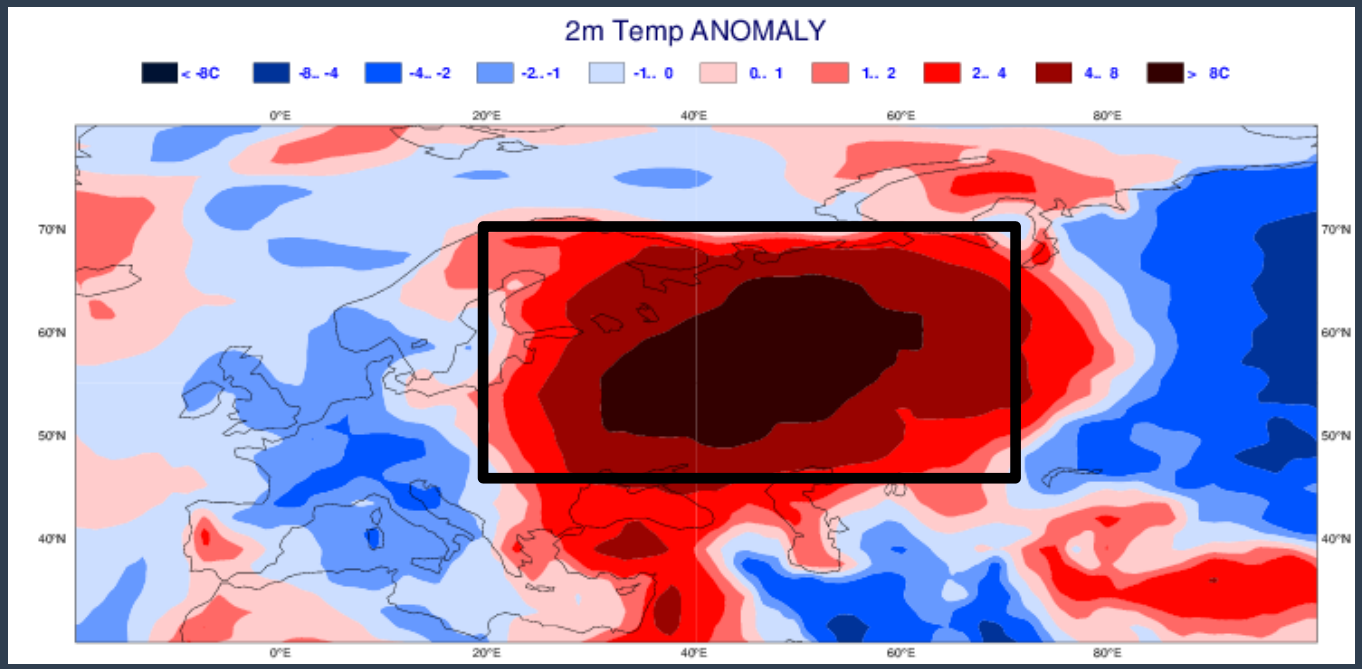
    Predictability comes from large-scale conditions (MJO/ENSO/SSW/SSTs…..)

Predicting extreme events:
Heat Wave S2S prediction

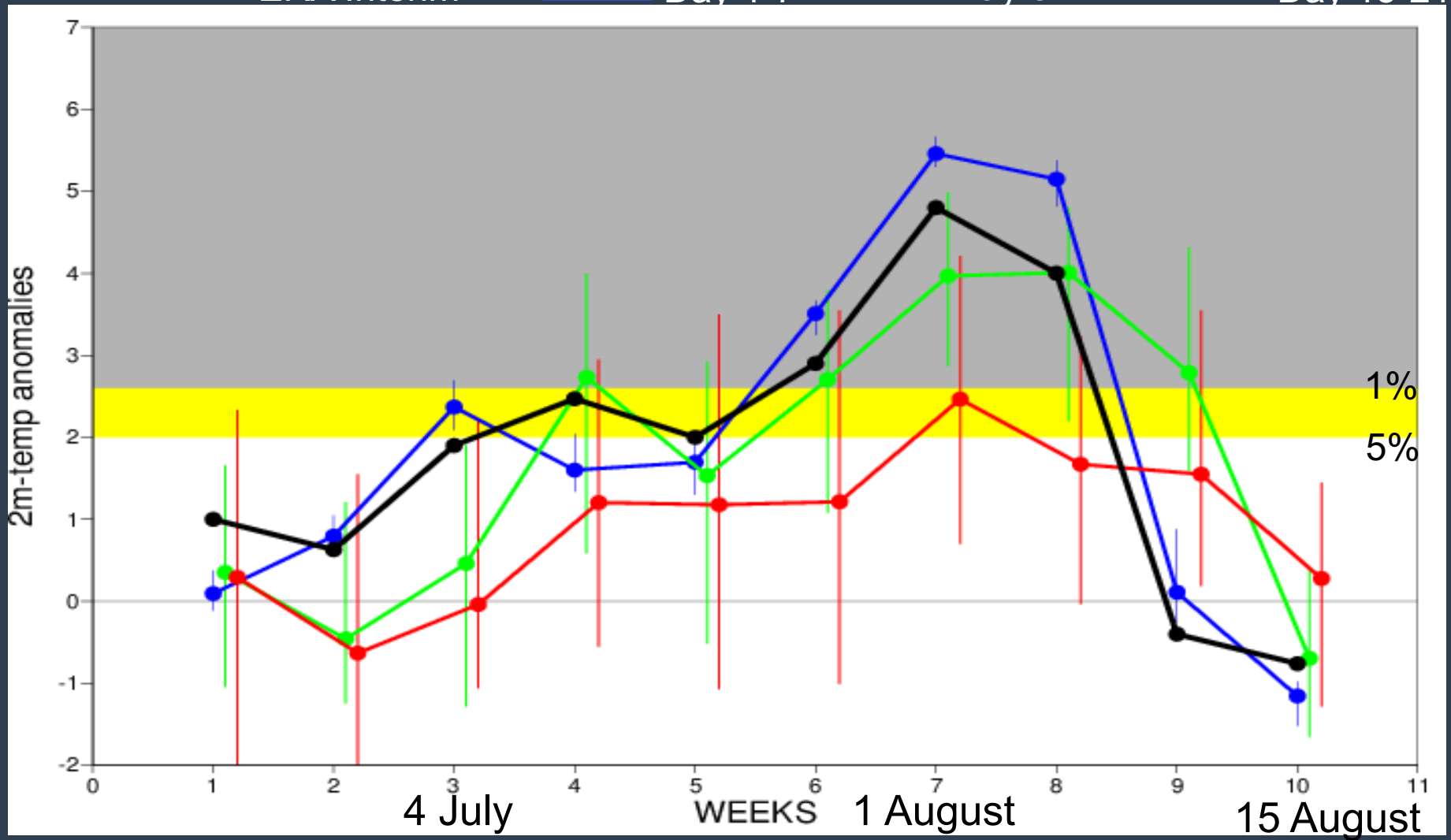
Russian Heat Wave July-August 2010

- Worst heat wave on record over the past 33 years (Hoag, Nature 2014)
- Estimated 55,000 deaths
- Wildfires, smoke

ERA interim 2mtm anomalies 1-7 August 2010



Russian Heat Wave July-August 2010

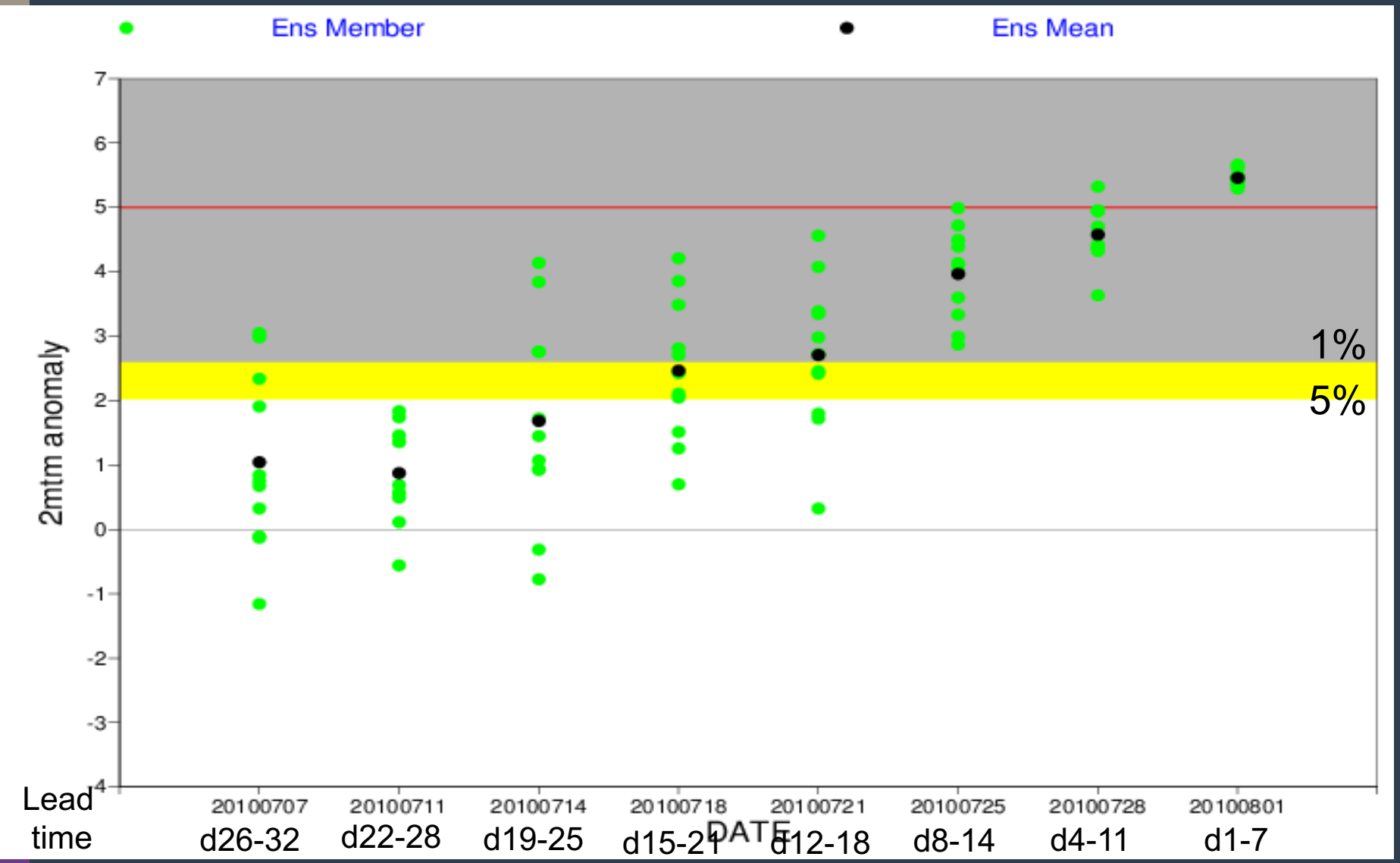


WEEK1: time evolution of heat wave well predicted

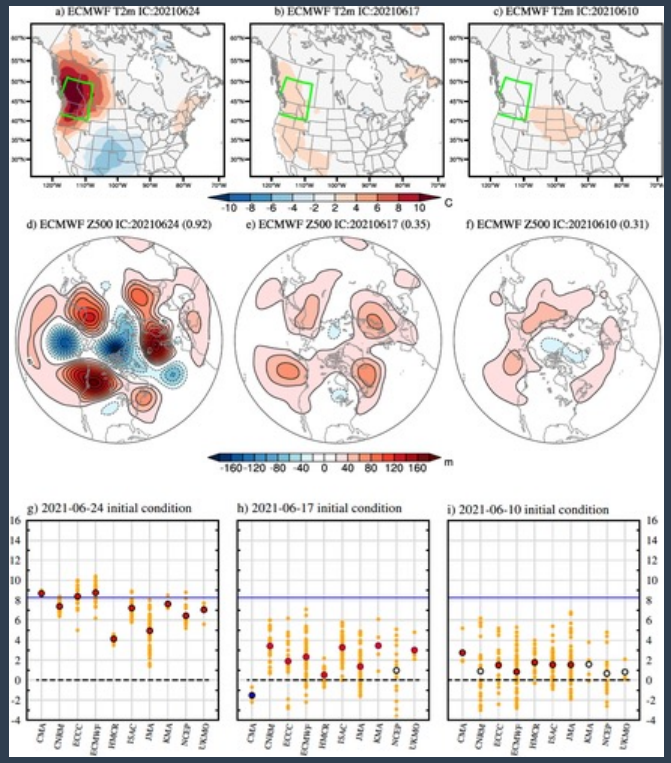
WEEK2 and 3: Onset and decay predicted one week too late

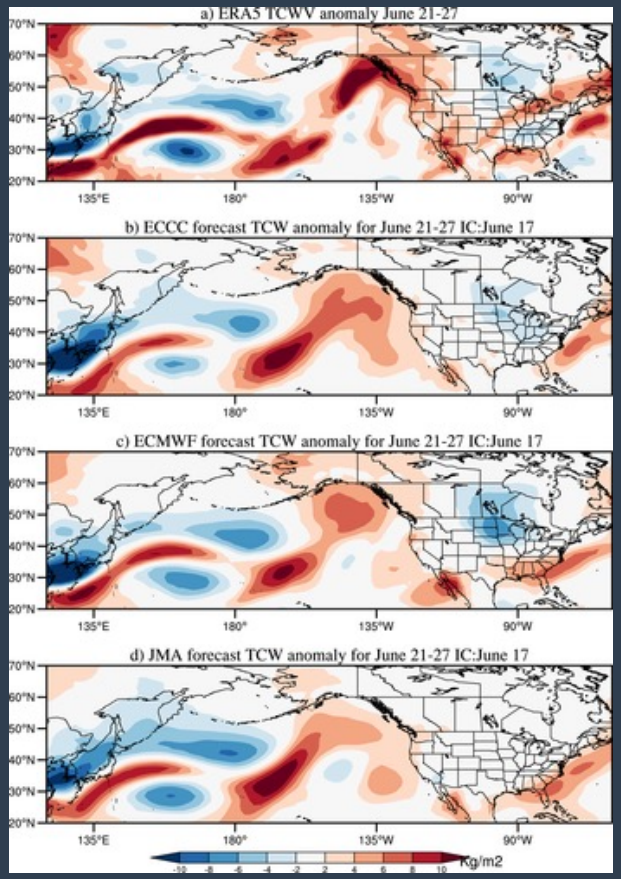
Timing of maximum well predicted

2mtm anomalies over Russia – ECMWF reforecasts
1-7 August 2010



Investigating N. American Heat wave of June 2021



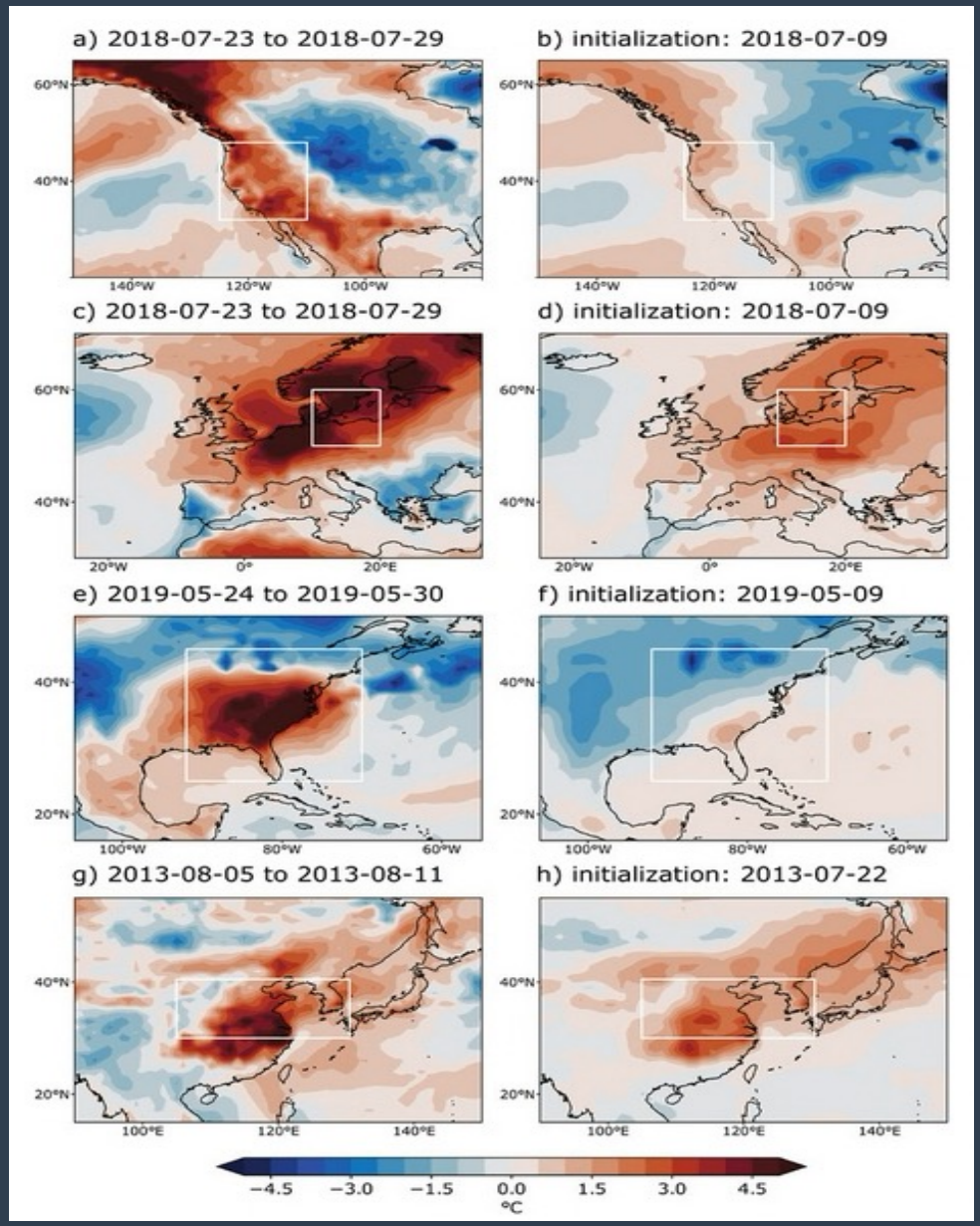


Two processes for the predictability of this heat wave:

- an upper tropospheric wave train associated with the boreal summer intraseasonal oscillation in Southeast Asia
- an anomalous North Pacific atmospheric river leading to high moisture conditions.

Lin, et al, GRL 2021; Mo et al, Nature comm. 2022

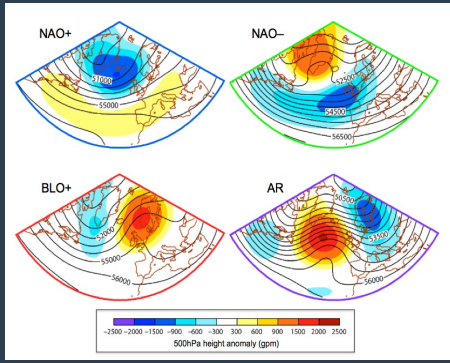
Advances in the subseasonal prediction of extreme events: Relevant case studies across the globe (Domeisen et al. 2022, BAMS)



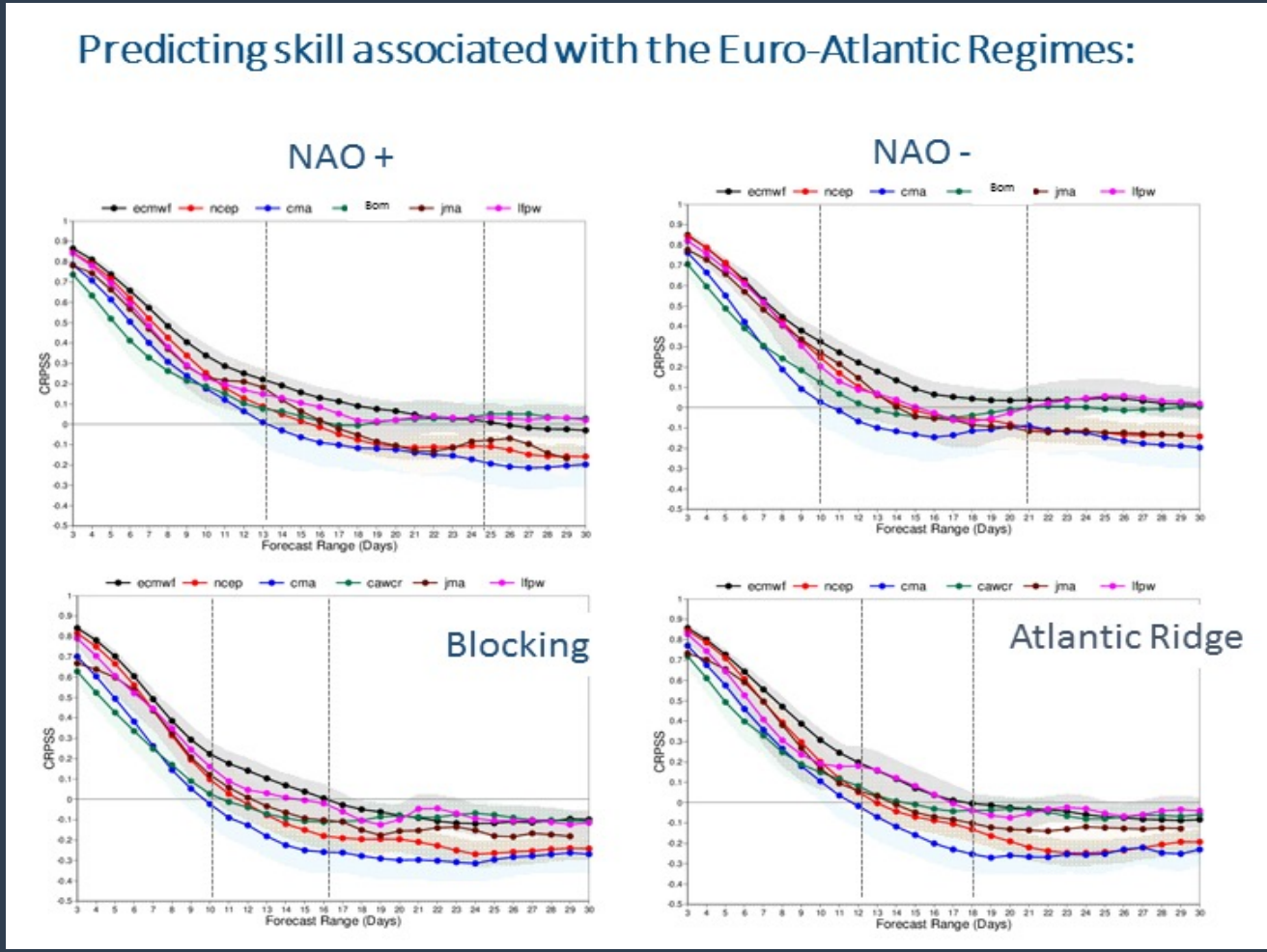
Heat wave prediction

Week 3

Predicting skill associated with the Euro-Atlantic Regimes



- NAO+ and NAO- are more predictable than Blockings and Atlantic Ridge.
- The predictability of NAO is about 3 weeks
- Predictability of Blockings and Atlantic Ridge is about 2 weeks.



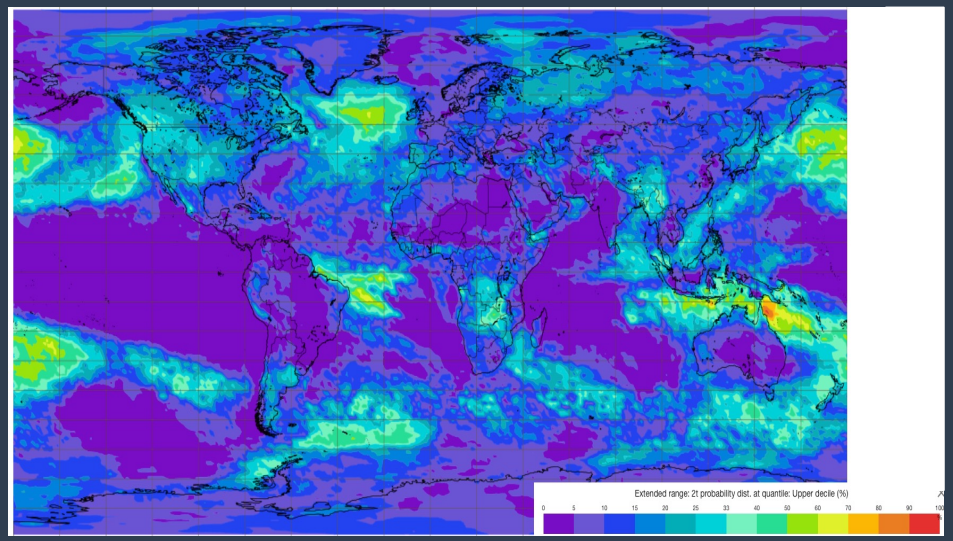
Ferranti et al, 2018

Relative Operating Characteristics (ROC) score

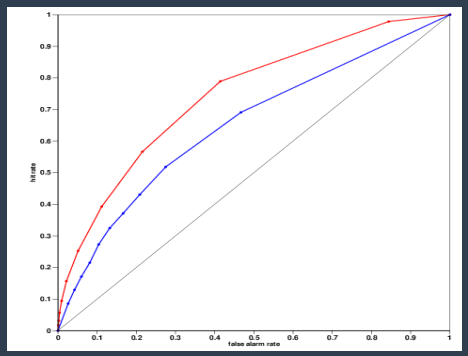
Decile Probabilities – 19 September 2022

ECMWF real-time forecasts **Day 12-18**

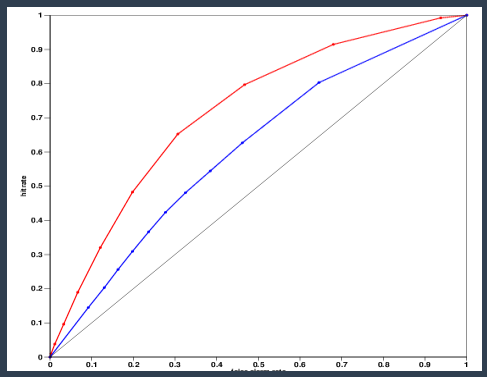
Probability of 2mtm in upper decile



ROC score for upper decile



ROC score for lower decile



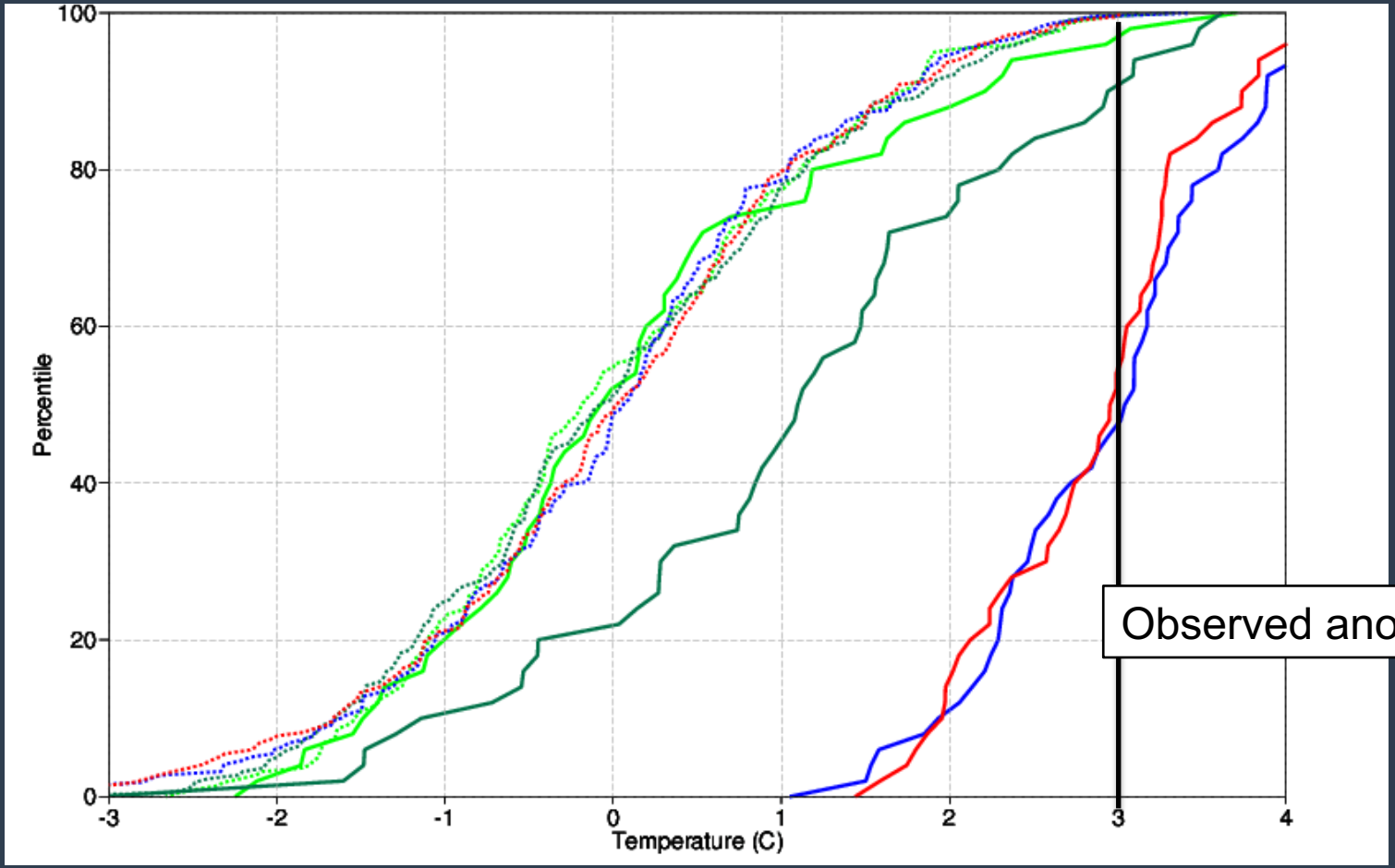
Forecast

Persistence of previous week

Extreme Forecast Index

2m temp CDF: ensemble predictions for 29 June - 5 July 2015

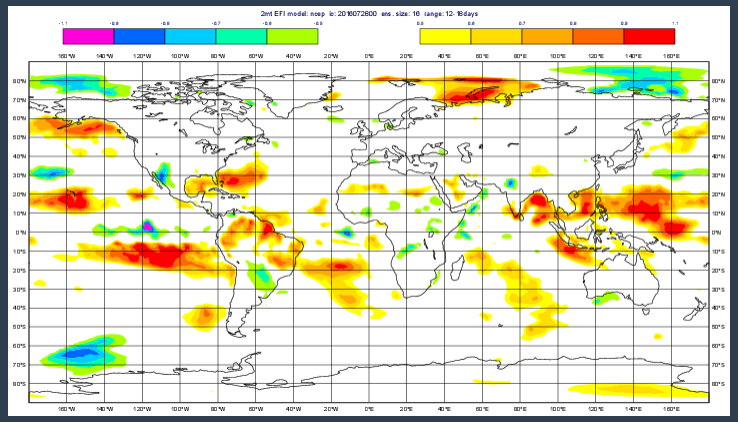
Climate | 15 June 2015 (15-21d) | 18 June 2015 (12-18d) | 22 June 2015 (8-14d) | 25 June 2015 (5-11d)



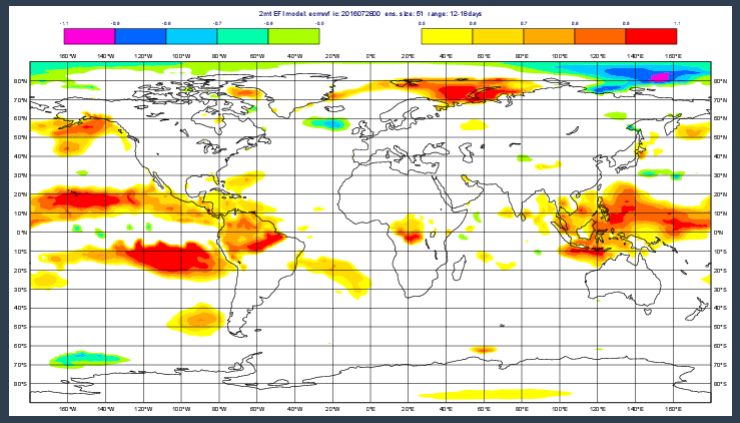
2m temp Extreme Forecast Index

Forecast range:12-18days verifying 8-14 August 2016

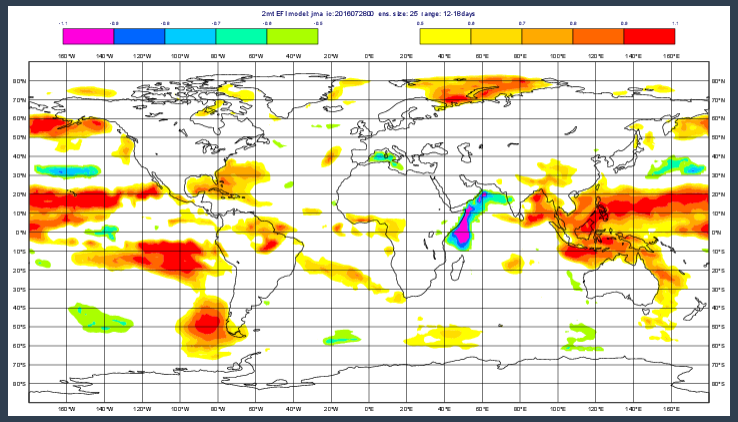
NCEP



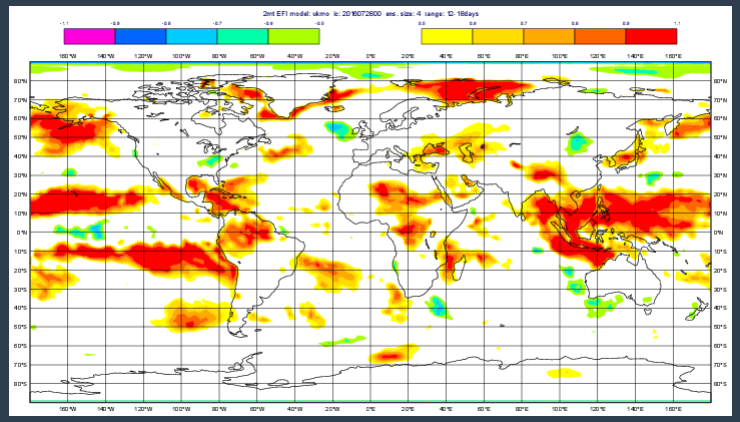
ECMWF



JMA



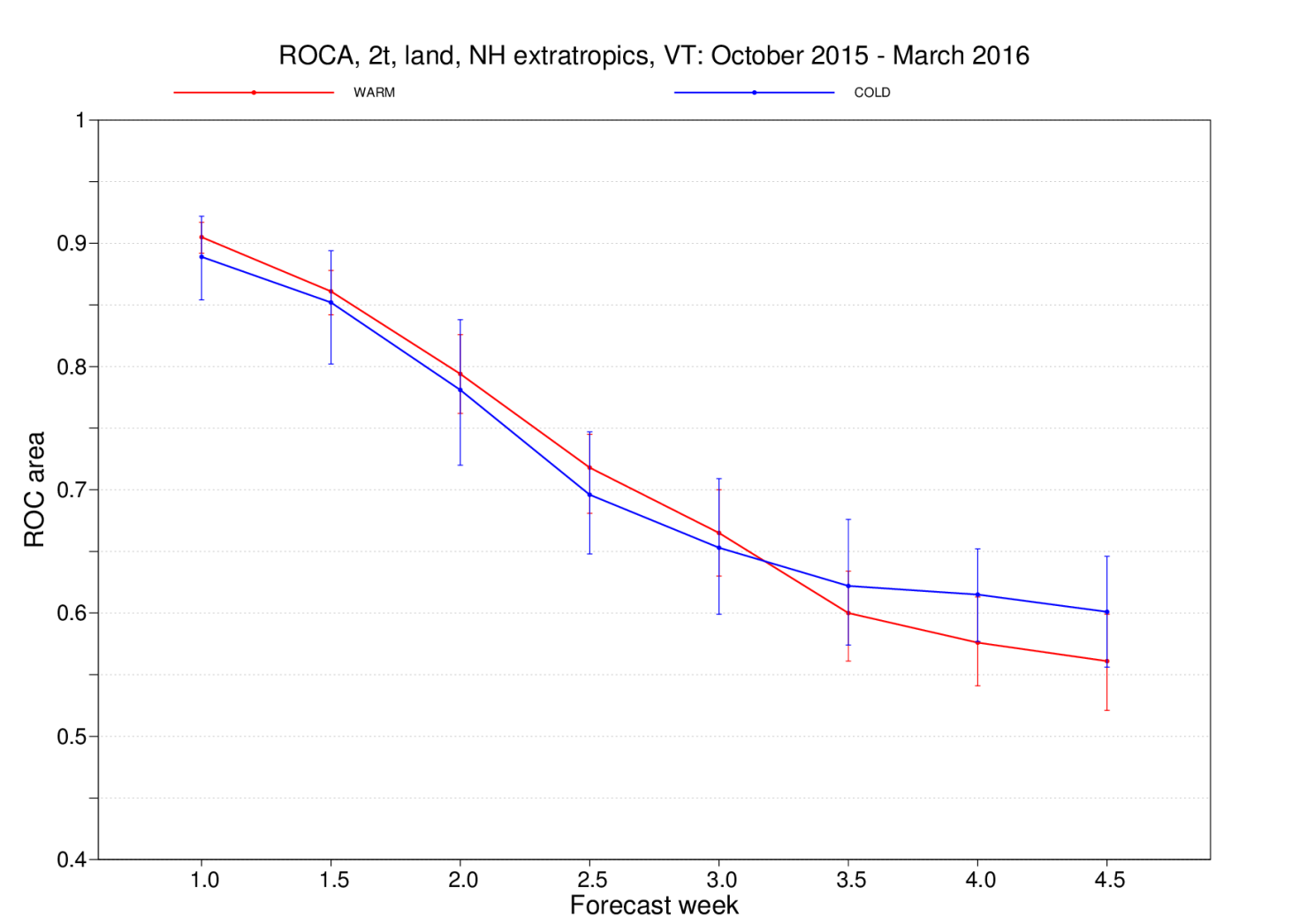
UKMO



http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/

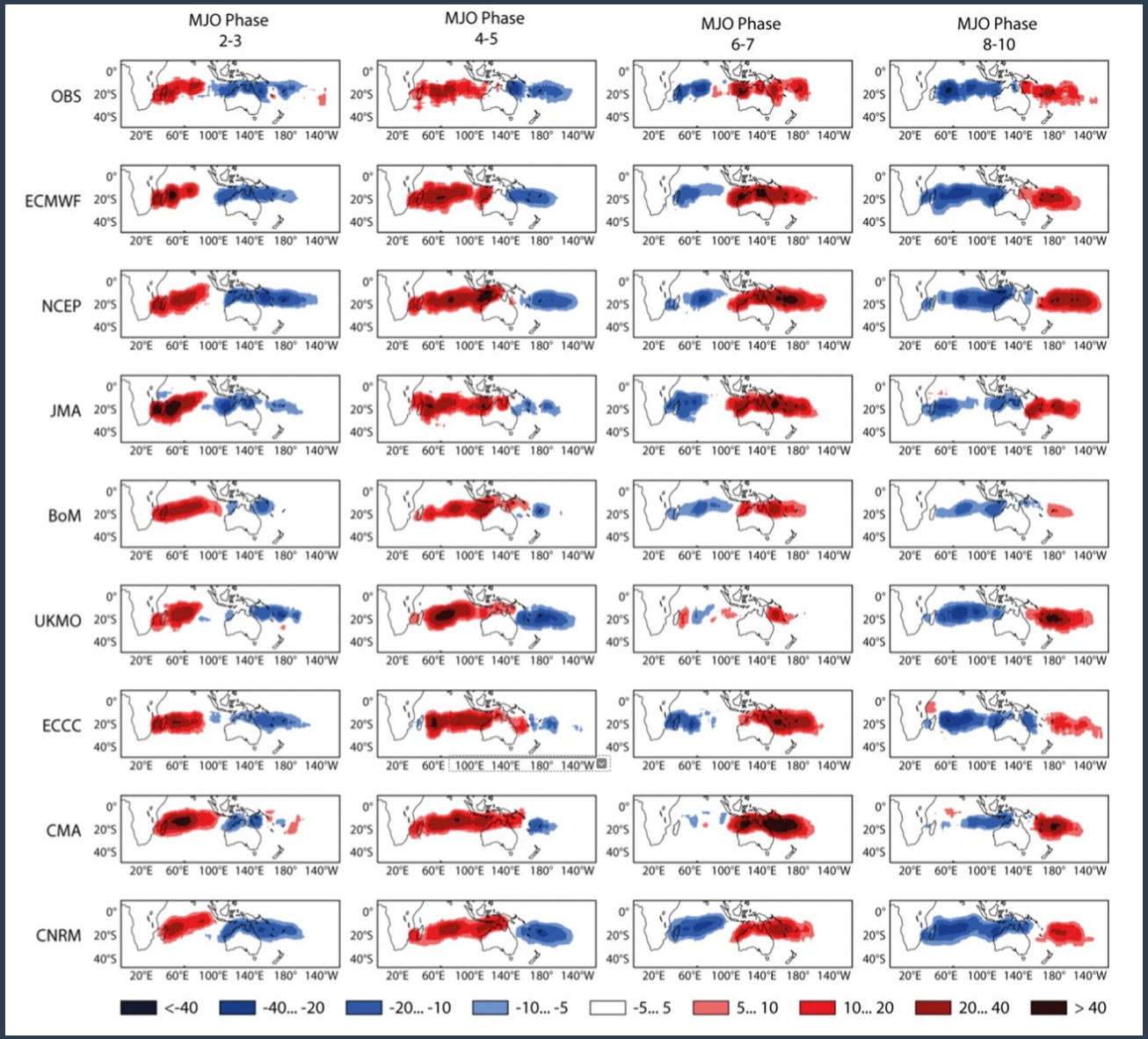
EFI skill assessment

Preliminary results based on ECMWF system:



Predicting statistics of extreme events: Tropical cyclone S2S prediction

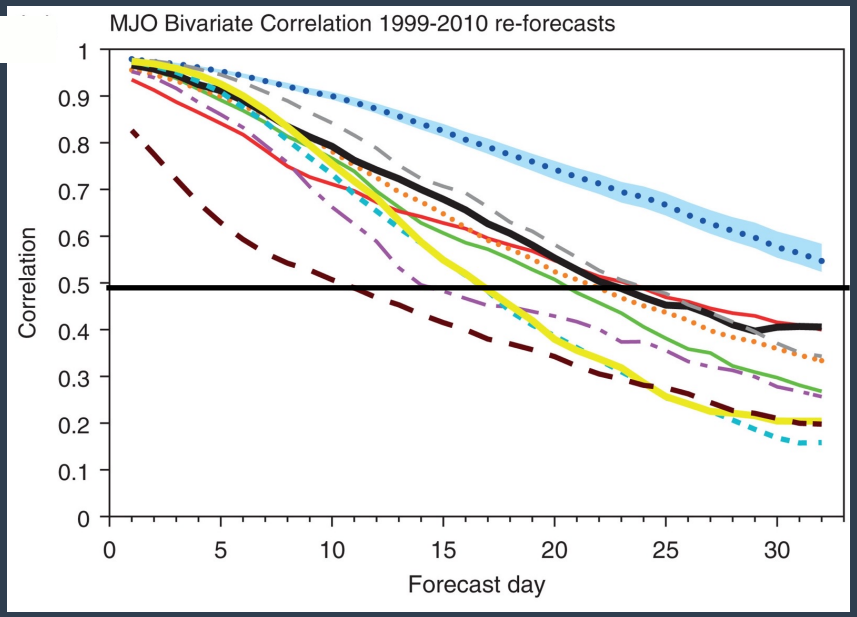
Modulation of tropical cyclone density anomaly by MJO



Vitart and Robertson, 2018

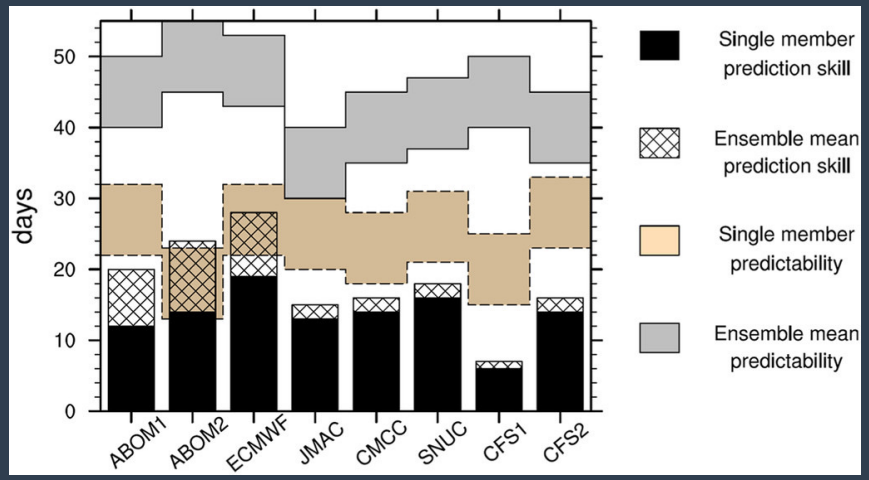
MJO prediction Skill

MJO Skill in S2S database



Vitart, 2017

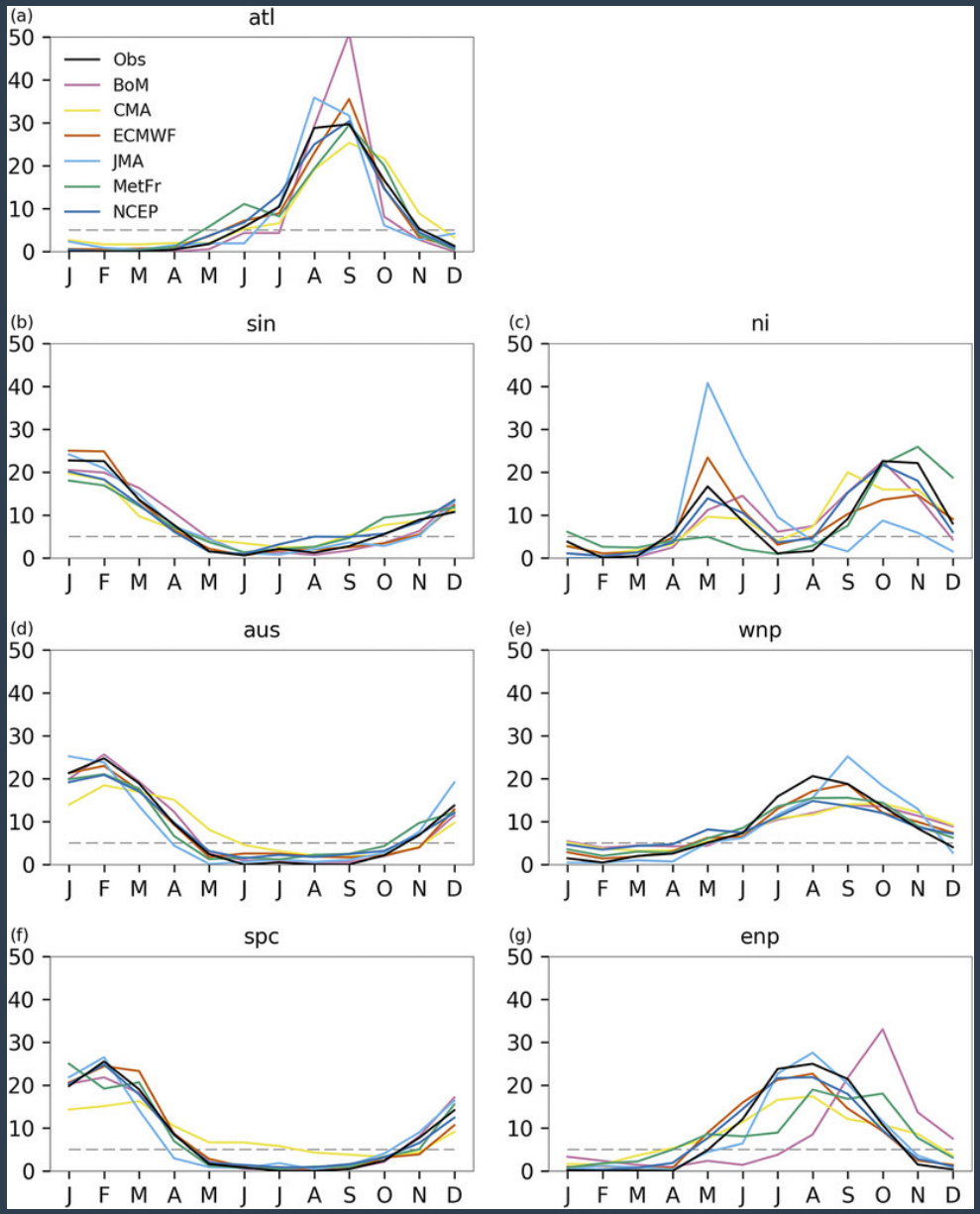
MJO Intrinsic predictability



Neena et al., 2014

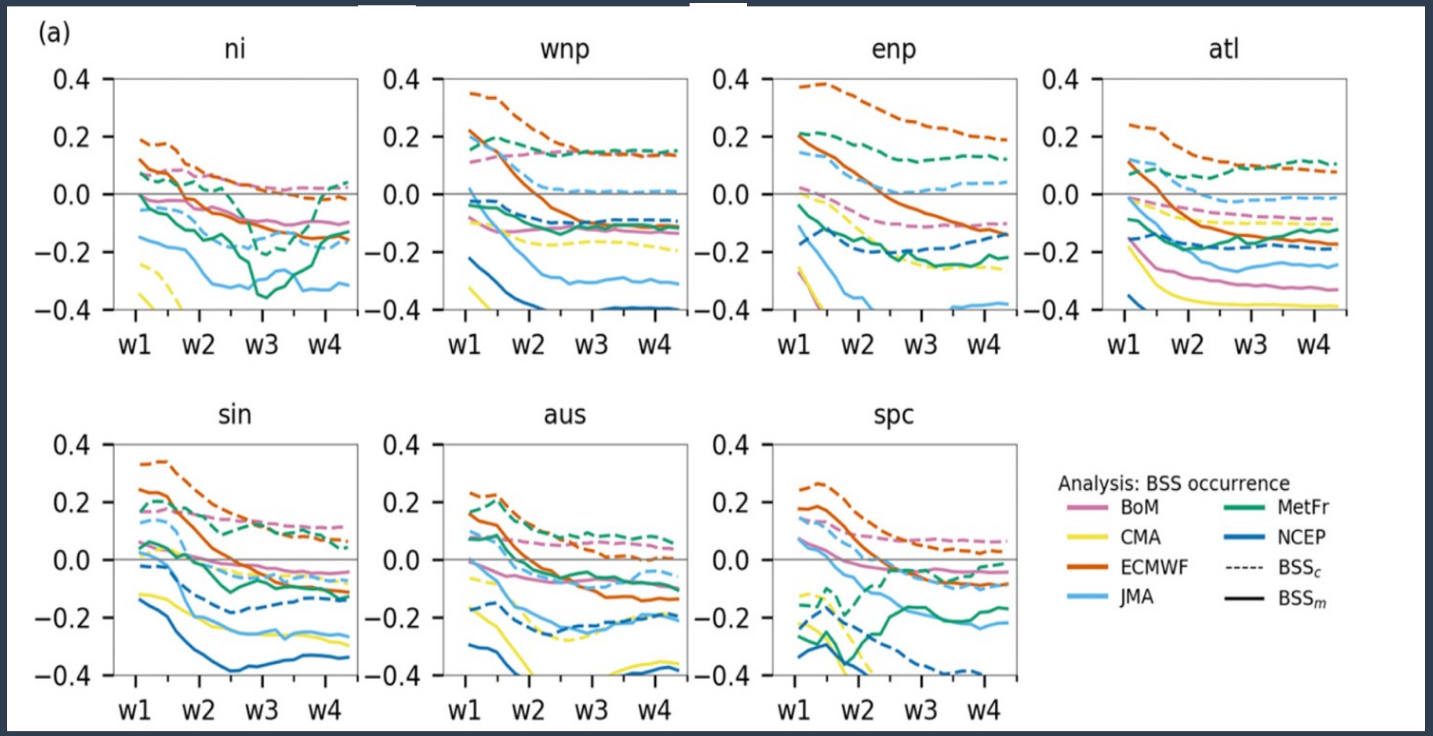
S2S models have skill to predict the evolution of the MJO up to 4 weeks in advance, but prediction skill still far from intrinsic predictablity

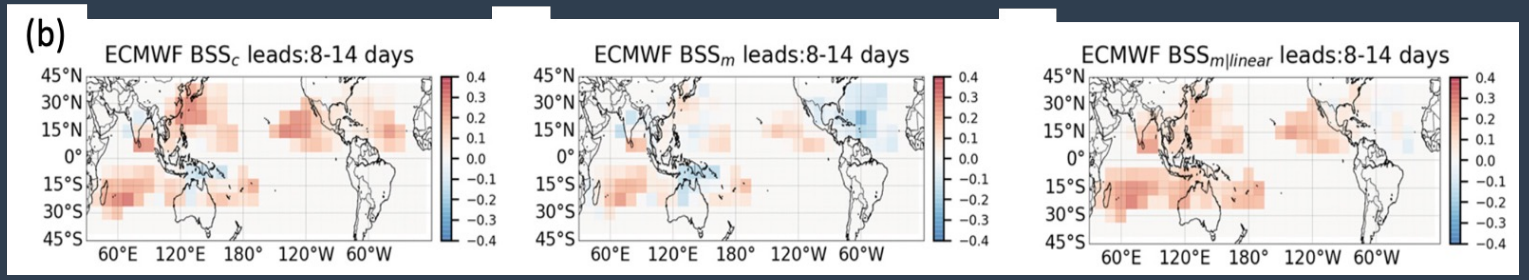
Tropical cyclones seasonal cycle



Lee et al, 2021

Tropical cyclones forecast skill

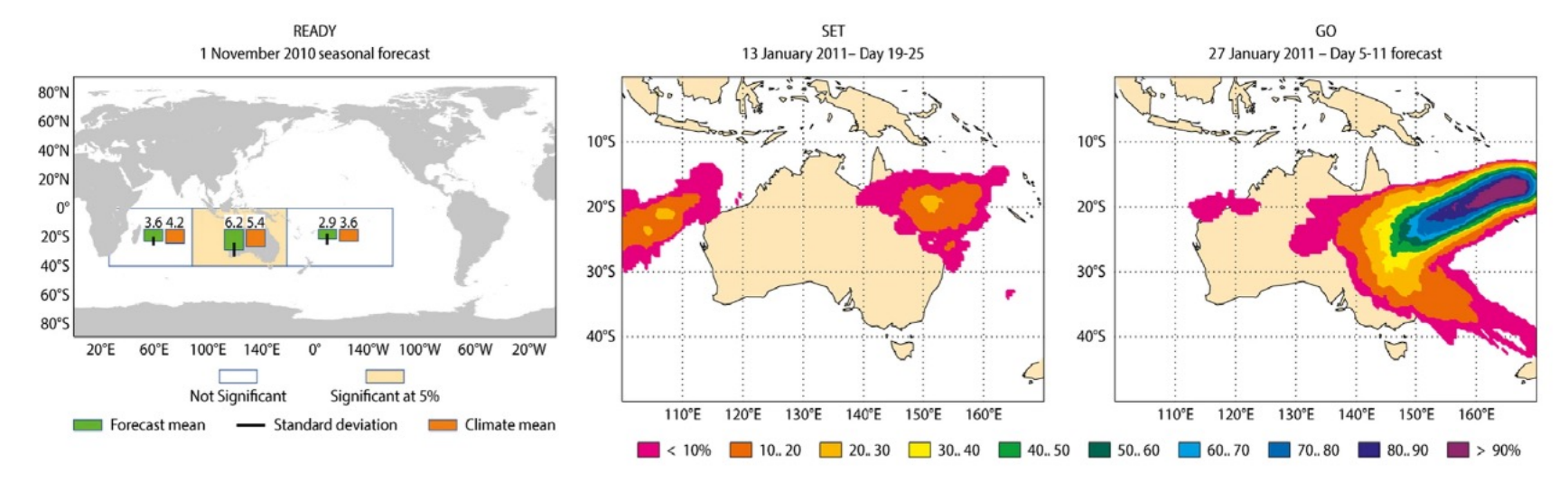




Lee et al, 2020

Tropical cyclone S2S prediction

Tropical cyclone YASI (26 January–4 February 2011)

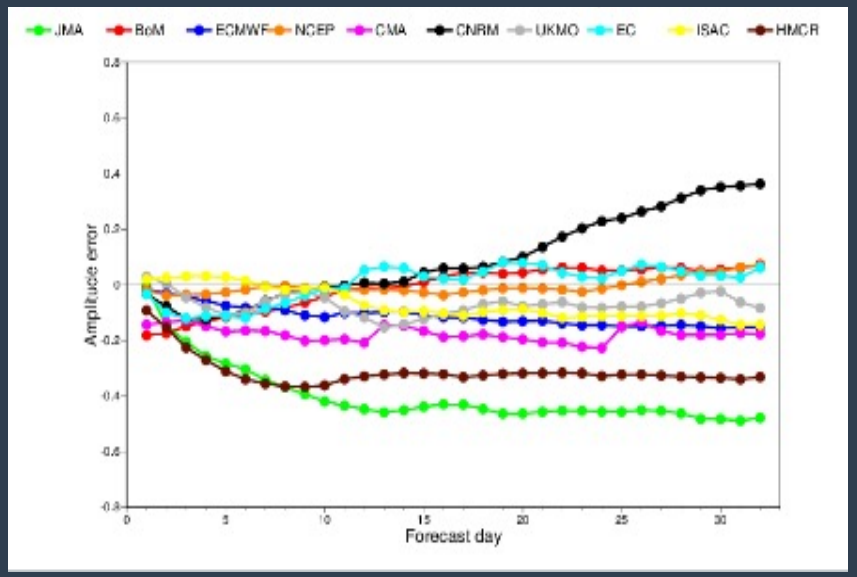


Prediction of tropical cyclones at different time ranges from ECMWF seasonal and ensemble forecasting systems.

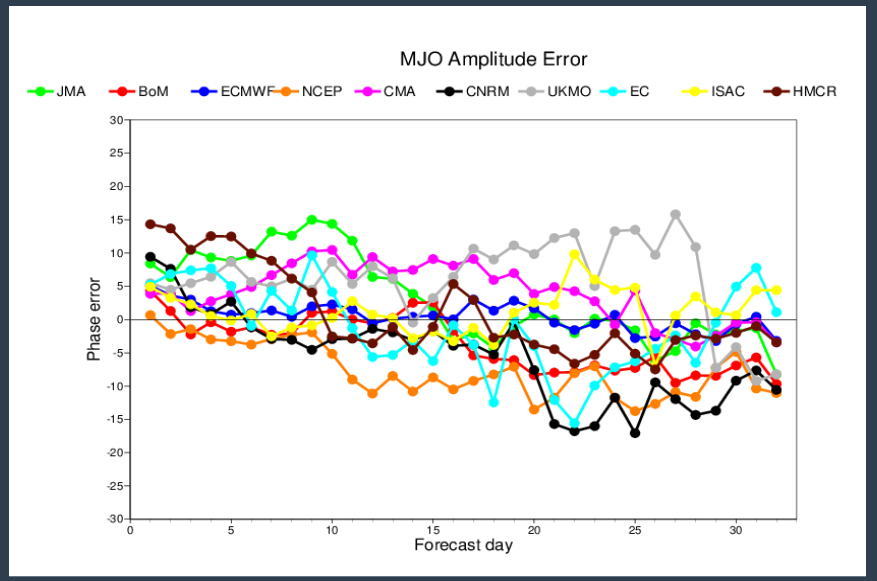
Current limitations in S2S prediction

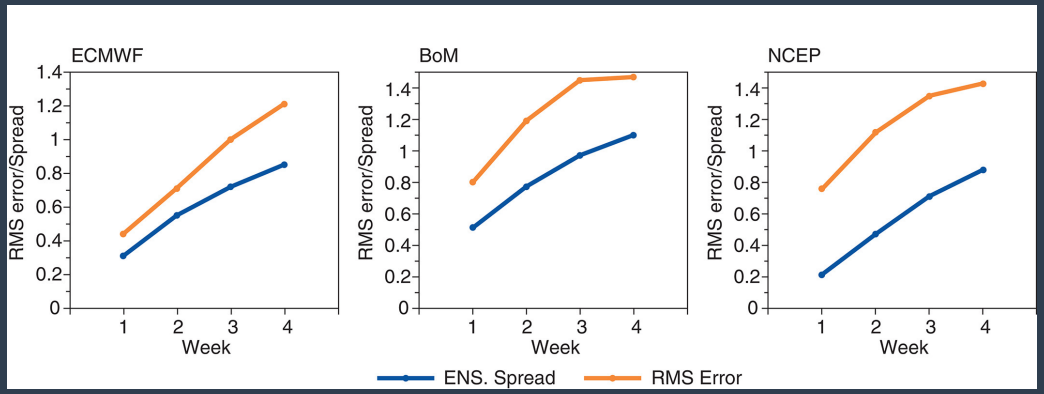
Errors in the Representation of the MJO in S2S models

MJO Amplitude error relative to ERA Interim



MJO Phase error relative to ERA Interim

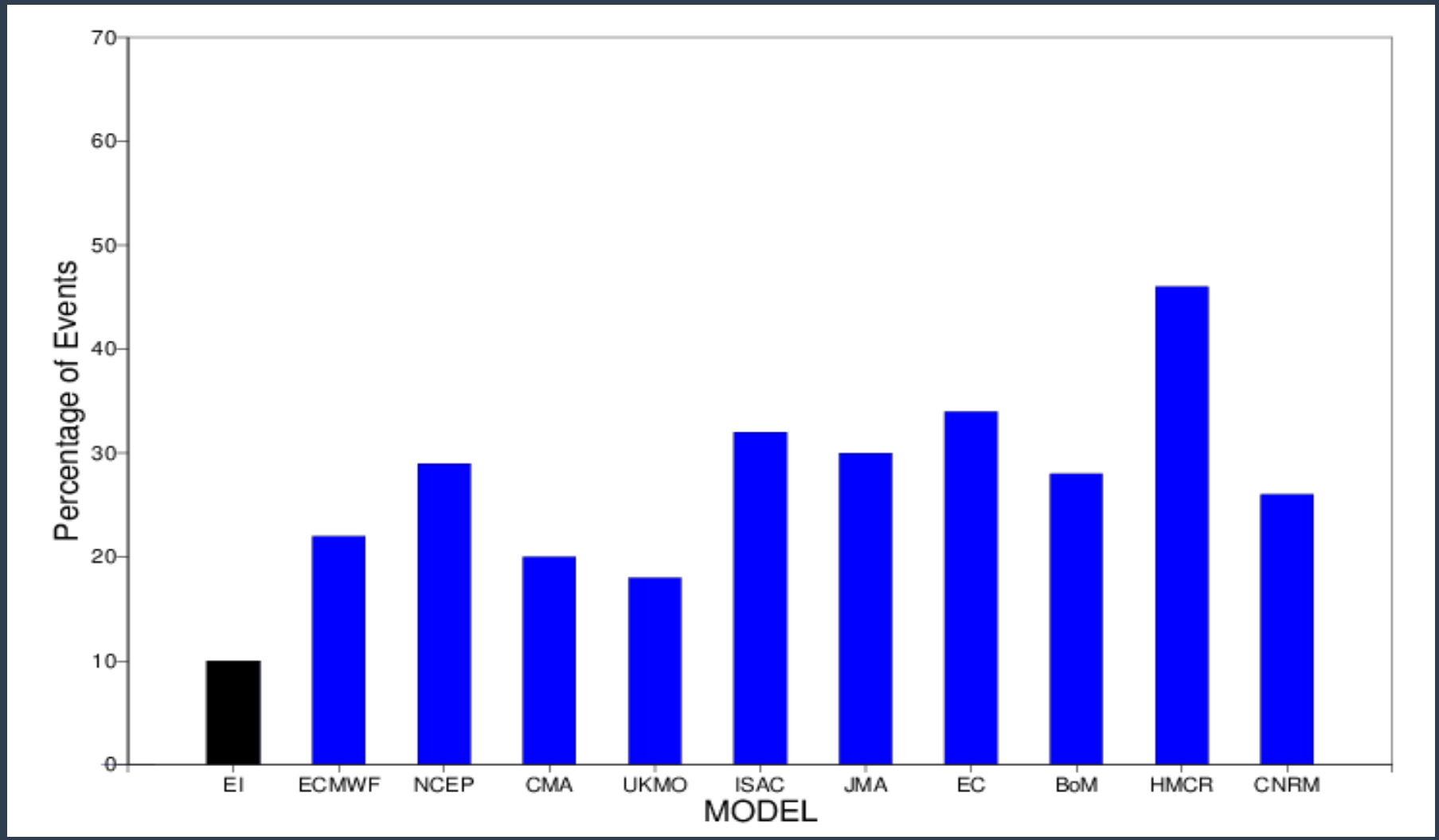




MJO in models is generally too slow and too weak. Ensemble forecasts are overconfident

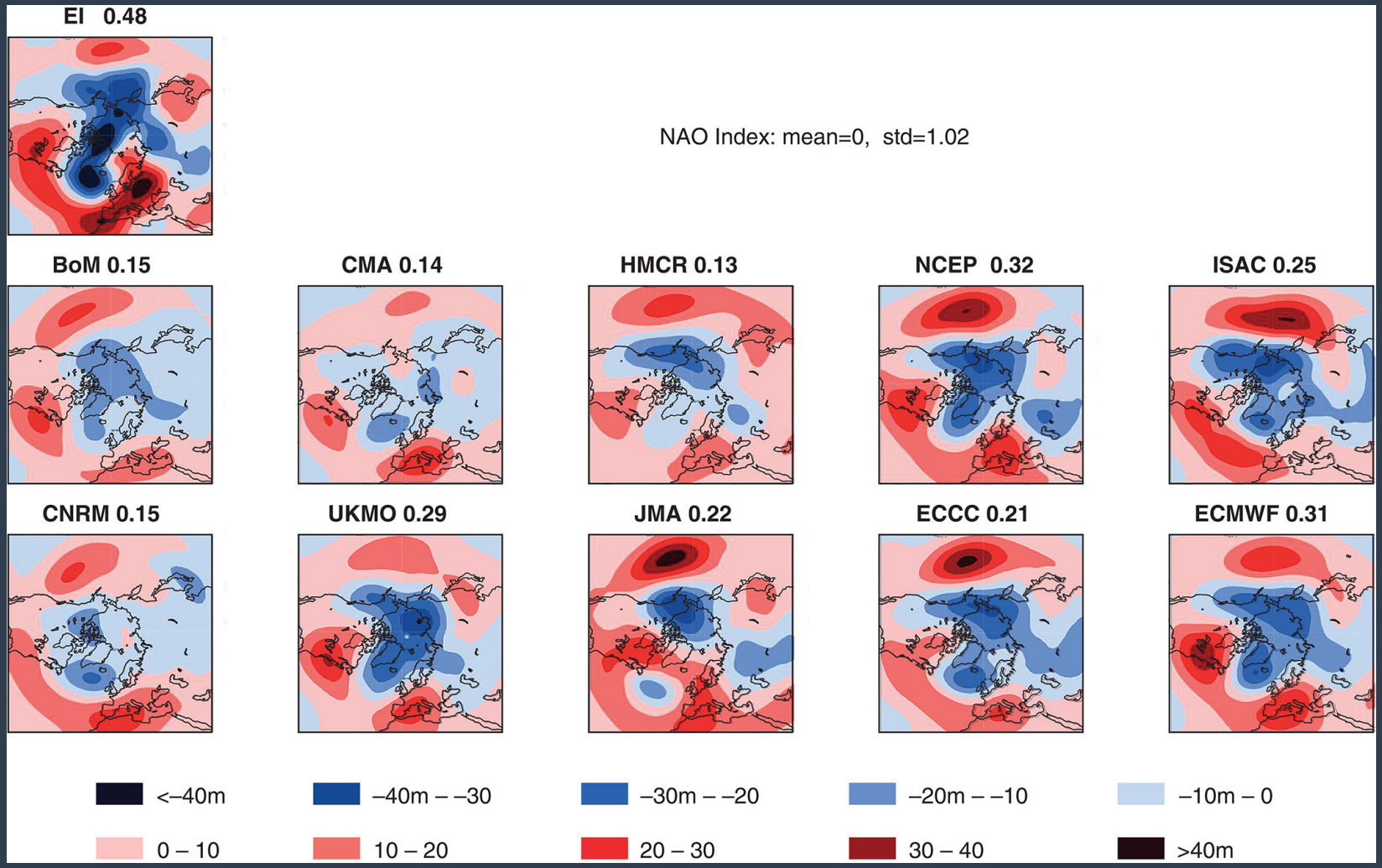
Maritime Continent Barrier

Percentage of MJO events dying while crossing the MC



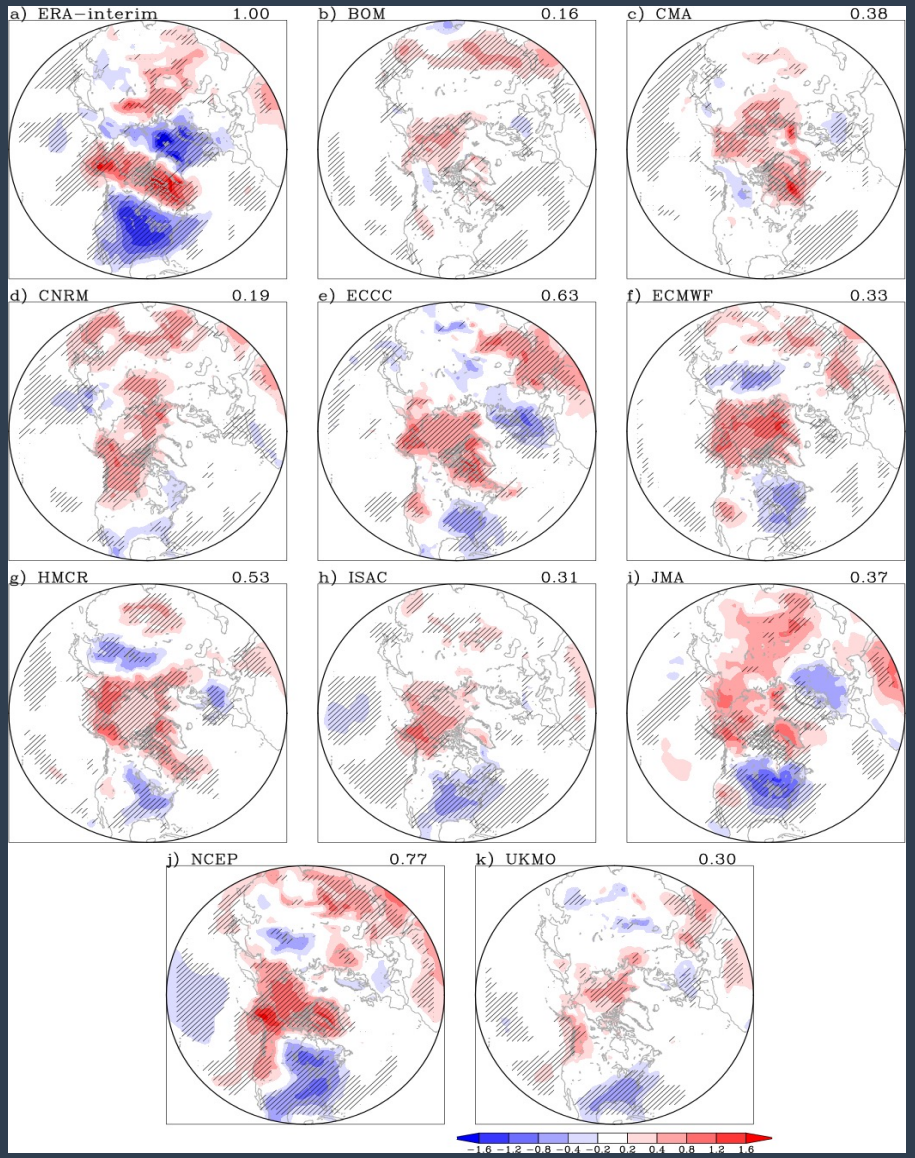
Impact of the MJO on the N. Extratropics

3 pentads after MJO in phase 3



S2S models simulate well the MJO teleconnection patterns but underestimate the amplitude of the MJO teleconnections.

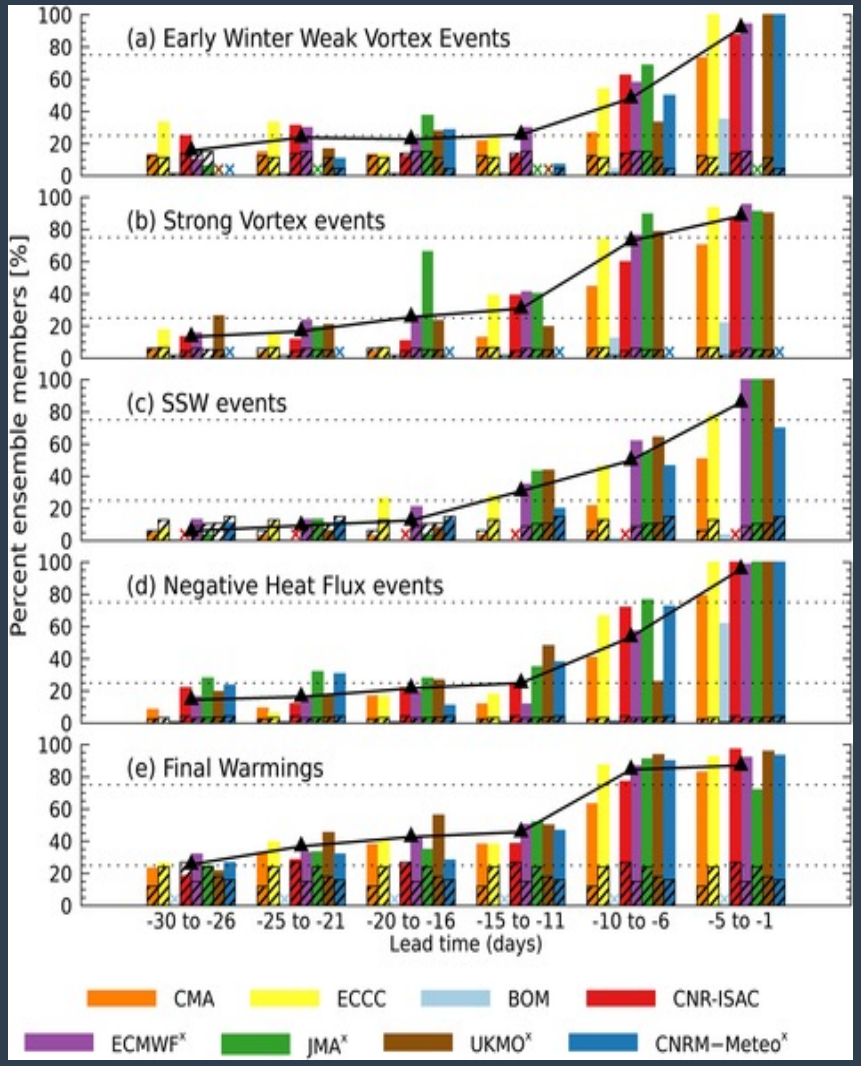
Composites of T2m anomaly 11-15 days after the MJO in phase 7



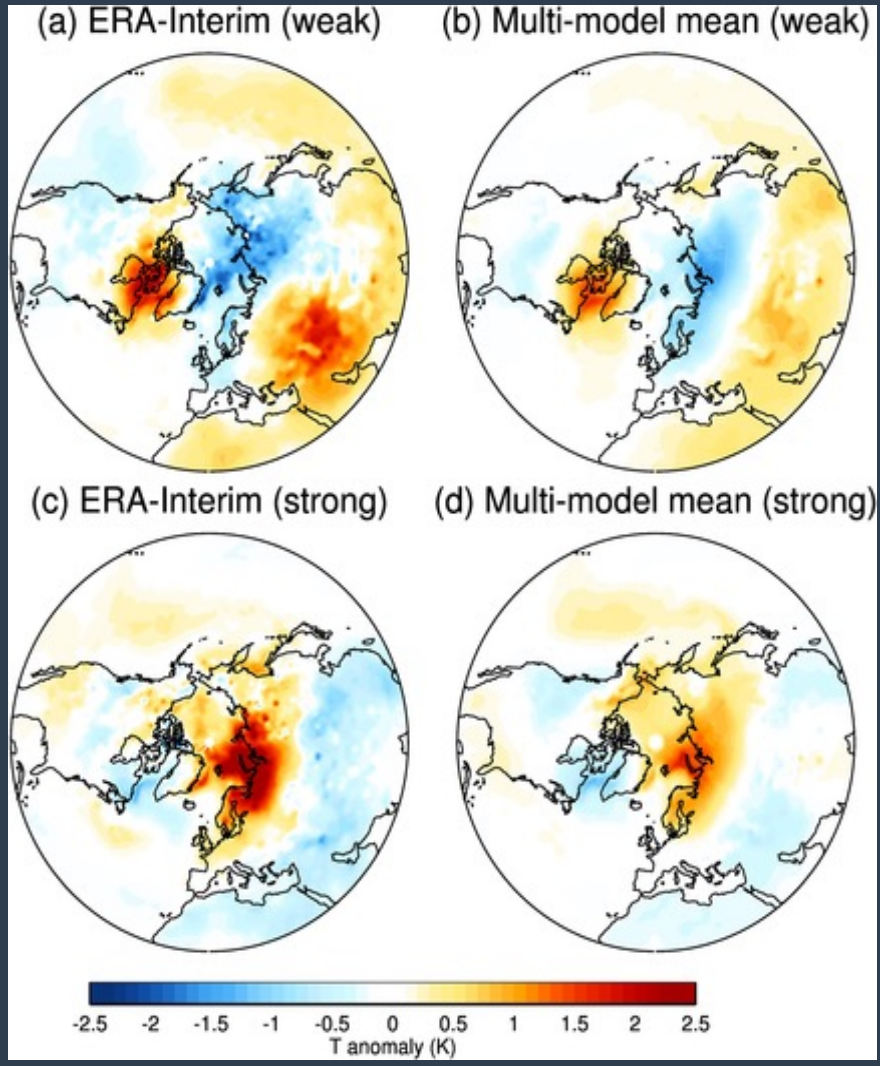
Stan et al. (2021, BAMS)

SSW predictability

Prediction of SSW events



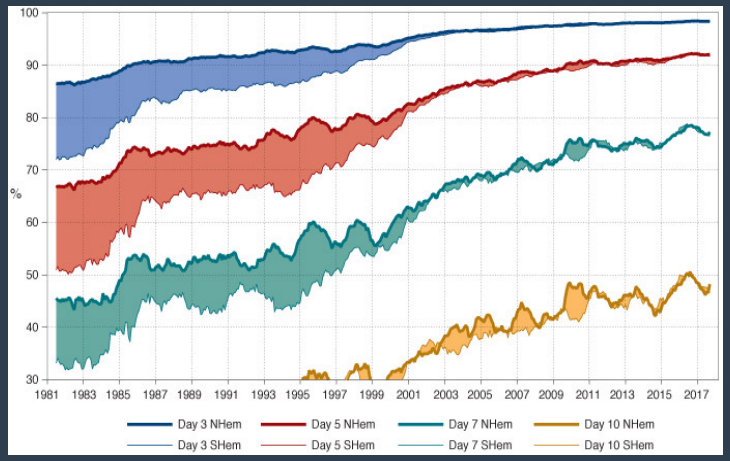
SSW teleconnections



Domeisen et al, 2019

Forecast skill. Are we filling the gap?

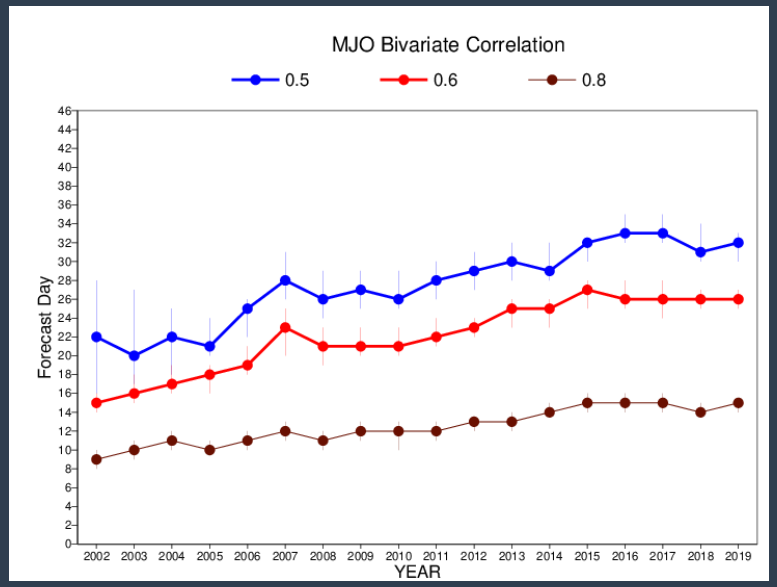
Weather forecasting



Toth and Buizza, 2018

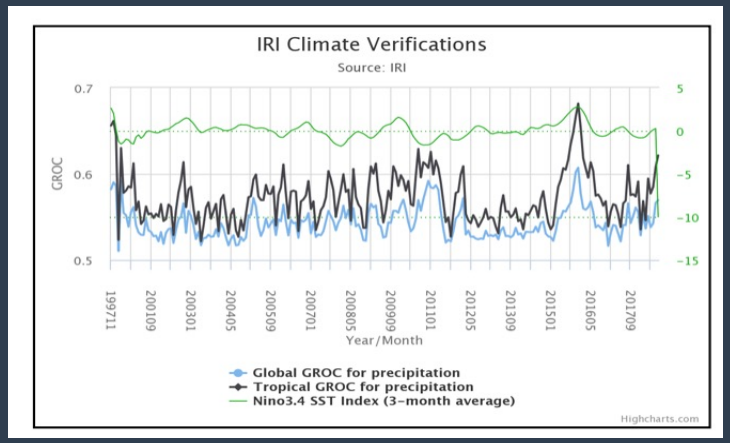
Incremental Improvement => “quite revolution”

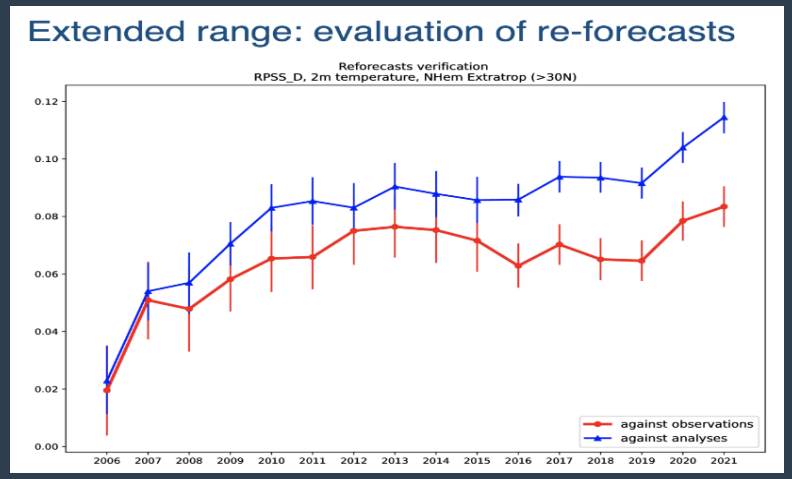
Sub-seasonal forecasting



Week 3 2m temp over N. Extratropics

Seasonal forecasting





No Clear improvement over past 20 years

Rapid progress!

S2S AI/ML Competition

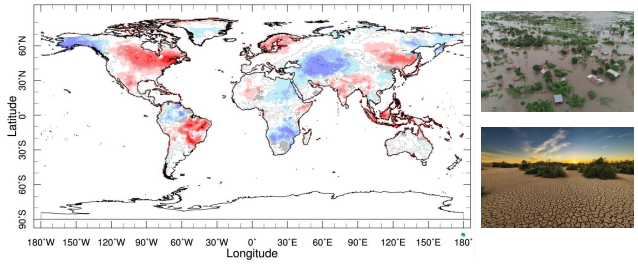
WORLD METEOROLOGICAL ORGANIZATION

WWRP WCRP S2S Prediction Project

Prize Challenge to improve Sub-seasonal to Seasonal Predictions using Artificial Intelligence

01 June – 31 October 2021

Improved sub-seasonal to seasonal (S2S) forecasts could enhance food security, sustainable energy and water, and reduce disaster risks through early warnings.



The World Meteorological Organization (WMO) is launching a prize challenge to improve current forecasts of precipitation and temperature **3 to 6 weeks into the future** from today's best computational fluid dynamical models using Artificial Intelligence and/or Machine Learning techniques.

The challenge is organized by the World Weather Research Programme (WWRP)/World Climate Research Programme (WCRP) Subseasonal-to-Seasonal Prediction Project (S2S Project), in collaboration with the Swiss Data Science Center (SDSC) and the European Centre for Medium-Range Weather Forecasts (ECMWF).

How will it work? Renkulab will host all the codes and scripts, with training and verification data easily accessible from the European Weather Cloud and data access scripts provided. All the codes and results will be made open access after the competition.

Timeline

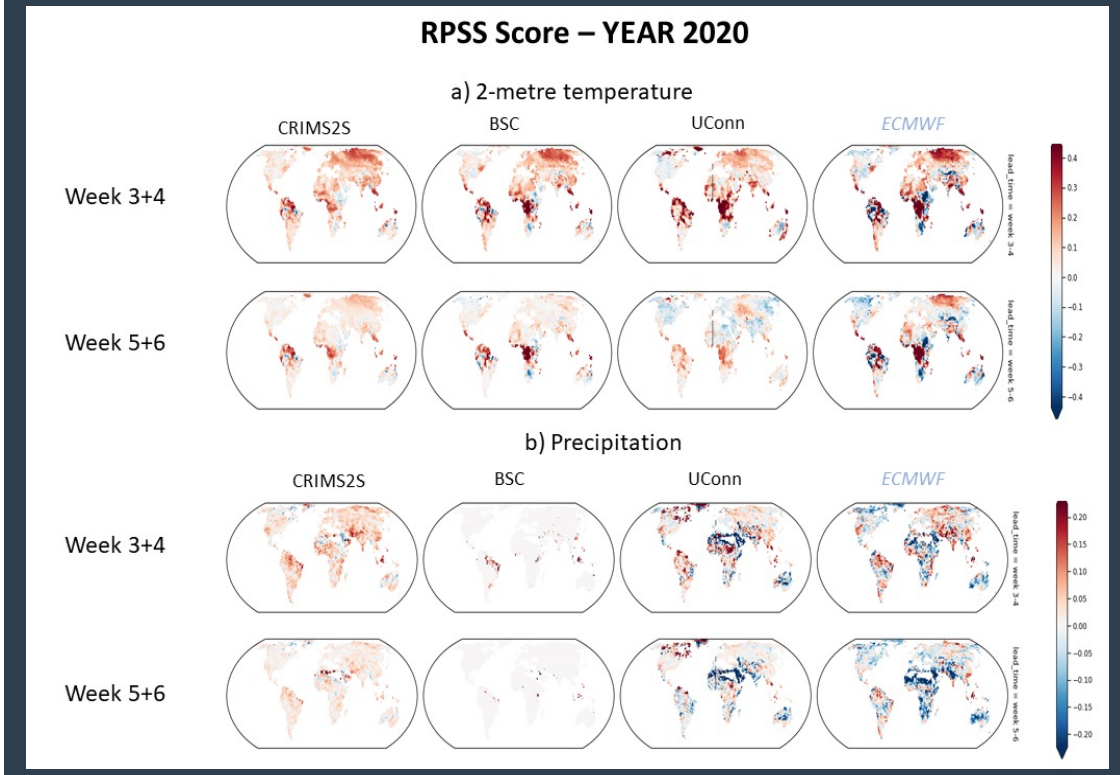
- Announcement: 4th May 2021
- Start of the competition: 1st June 2021
- End of the competition: 31st October 2021
- Announcement of winners: 15th December 2021

Prizes

Prizes for the top three submissions:

- Winning team: CHF 15 000
- 2nd team: CHF 10 000
- 3rd team: CHF 5 000

Competition website: https://s2s-ai-challenge.github.io/



Subseasonal-to-Seasonal S2S Prediction Project

S2S Real-Time Pilot Project

Real-time S2S data access for climate services co-development projects

The S2S Real Time Pilot Initiative

- Started November 2019 & will continue until end October 2022 *(includes 1-year extension recently approved)*
- Goals:
  - Identify what is needed to make S2S forecasts usable, how this varies by sector/ organisation/experience
  - Understand how projects engage with users, how this relates to pull-through/ demand
  - Develop understanding of the S2S forecast value chain & the needs for end-to-end user applications
  - Development of best practice guidelines and/or recommendations to enhance pull-through & sustainability

- Approach
  - 16 co-development projects
  - 3 sets of questionnaires: April/May 2020, Winter 2020/2021, Autumn 2021

Sectors:
- Water
- Energy
- Health
- Agriculture/ food security
- Disaster risk reduction

Countries/regions:
- Senegal
- Ethiopia
- Bangladesh
- Guatemala
- Columbia
- Ghana
- Kenya
- Nigeria
- Singapore
- USA
- Europe
- Asia & Pacific
- Global

WMO OMM

Approach
- 16 co-development projects
- 3 sets of questionnaires:
- Planned RTP virtual workshop 14-18 Nov 2022

S2S Real-Time Pilot Project

Real-time S2S data access for climate services co-development projects

Disaster risk reduction in Southeast Asia

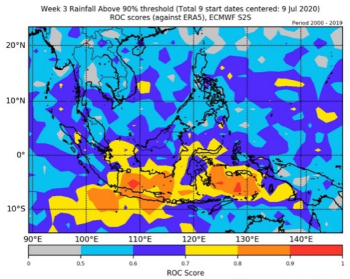
S2S Real Time Pilot

Thea Turkington[1], Raizan Rahmat[1], Ryan Kang[1], Wee Leng Tan[1], Keith Paolo Landicho[2], Lawrence Anthony Dimailig[2], G. Srinivasan[3], Laura Hendy[4]

1: **ASMC** (ASEAN Specialised Meteorological Centre), 2. The AHA Centre, 3. **RIMES** (Regional Integrated Multi-Hazard Early Warning System for Africa and Asia), 4. **UN ESCAP** (United Nations Economic and Social Commission for Asia and the Pacific).

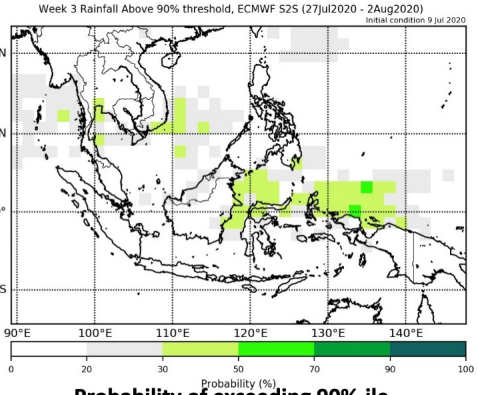
S2S Forecasts tailored to ASEAN Centre for Humanitarian Action needs:
Exceedance of weekly rainfall above 90%-ile, 3 weeks ahead

Week 3 (Day 19 -25) Skill
ROC Score for 90th Percentile

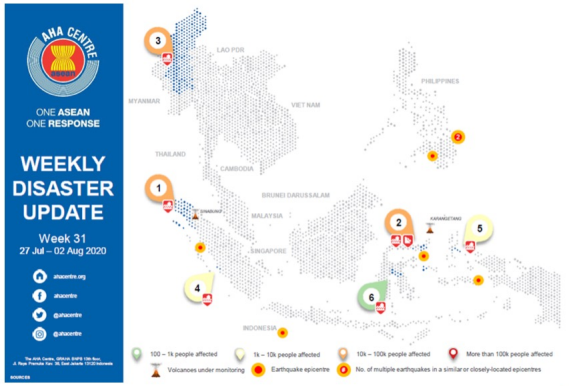


Good skill

Week 3 Rainfall Extremes Forecast
from 13 July for 27Jul–2Aug, 2020

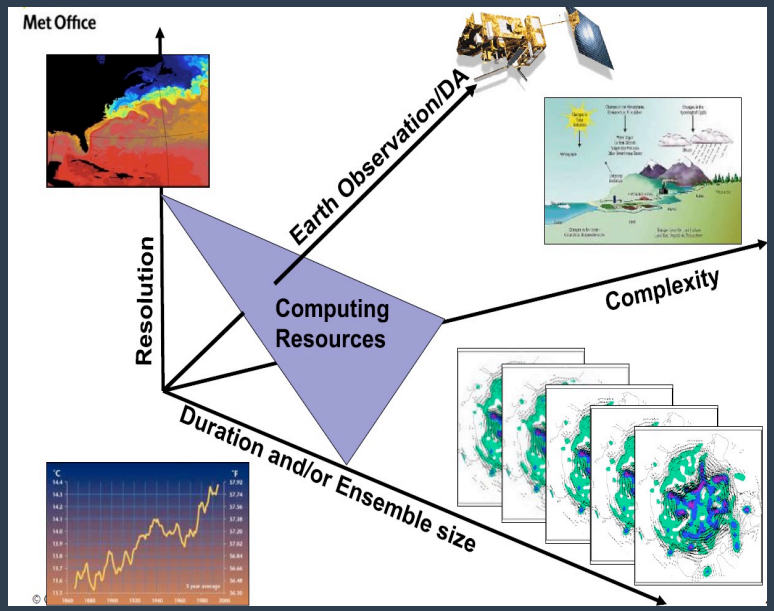


Probability of exceeding 90%-ile

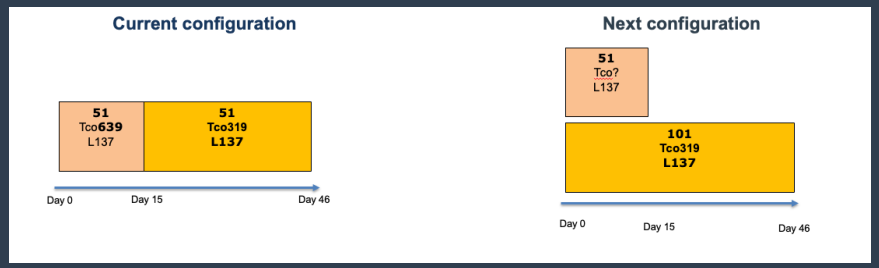


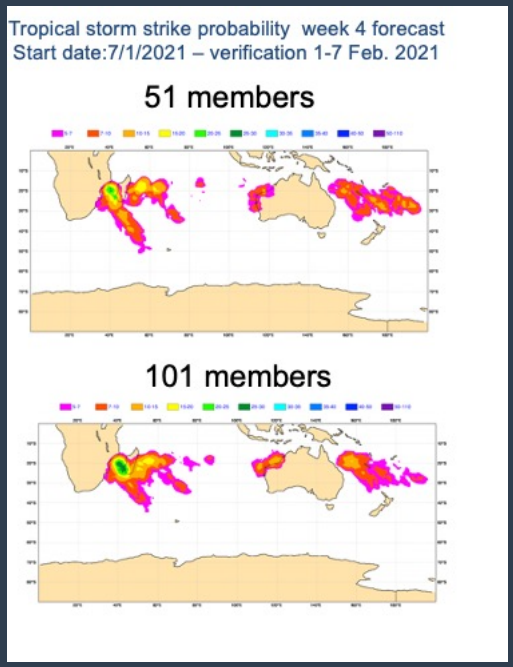
Subseasonal-to-Seasonal S2S Prediction Project

Future directions



New extended-range configuration at ECMWF (CY48R1)





- Same horizontal resolution as now
- **Daily real-time instead of twice weekly**
- **101 members instead of 51**
- Start at step 0 separately from 15-day higher-resolution ensemble

Conclusions

- The S2S database is a useful resource for assessing the skill of current operational S2S models to predict extreme weather events.
- Skill of S2S models to predict MJO has significantly improved over the past 10 years, and S2S models show skill up to 3-4 weeks.
- Russian heat wave 2010: S2S model forecasts provided indications of the possibility of an exceptional warm anomaly more than 10 days in advance.
- Tropical cyclones: S2S models display skill in predicting TC activity and simulate the strong modulation of TC activity by the MJO.
- Preliminary verification of ECMWF S2S forecasts suggests some useful skill for decile and EFI prediction
- Errors in the representation of teleconnections is a key limitation for skillful S2S prediction.

WCRP/WWRP S2S Summit:
Advancing Sub-seasonal to Seasonal Predictions and their Applications

University of Reading, UK

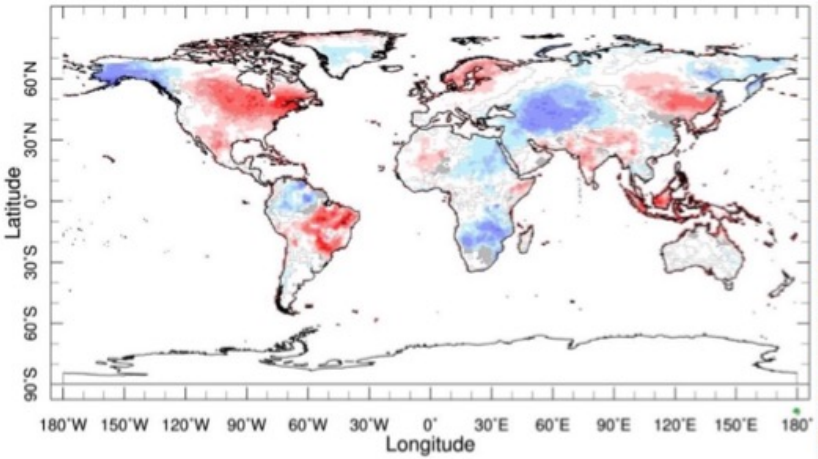
3rd -7th July 2023

Celebrating 10 years of the Sub-Seasonal to Seasonal Prediction Project and looking to the future

Abstract Submission Opens
15th November 2022

Abstract Submission Deadline
15th January 2023

Abstract Acceptance Notification
28th March 2023



www.s2sprediction.net

Subseasonal-to-Seasonal S2S Prediction Project

WORLD METEOROLOGICAL ORGANIZATION

WCRP World Climate Research Programme

WWRP WORLD WEATHER RESEARCH PROGRAMME