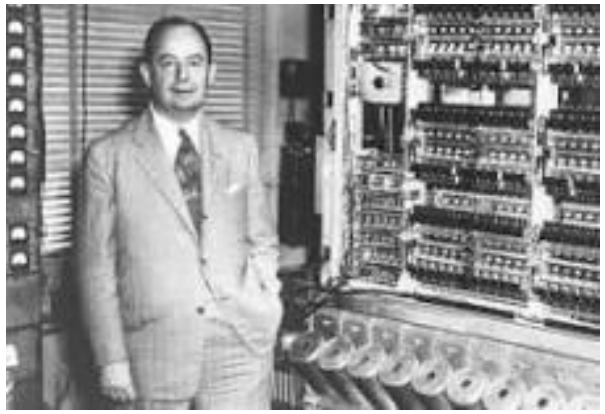
Sub-seasonal forecasting at ECMWF

Frédéric Vitart

ECMWF

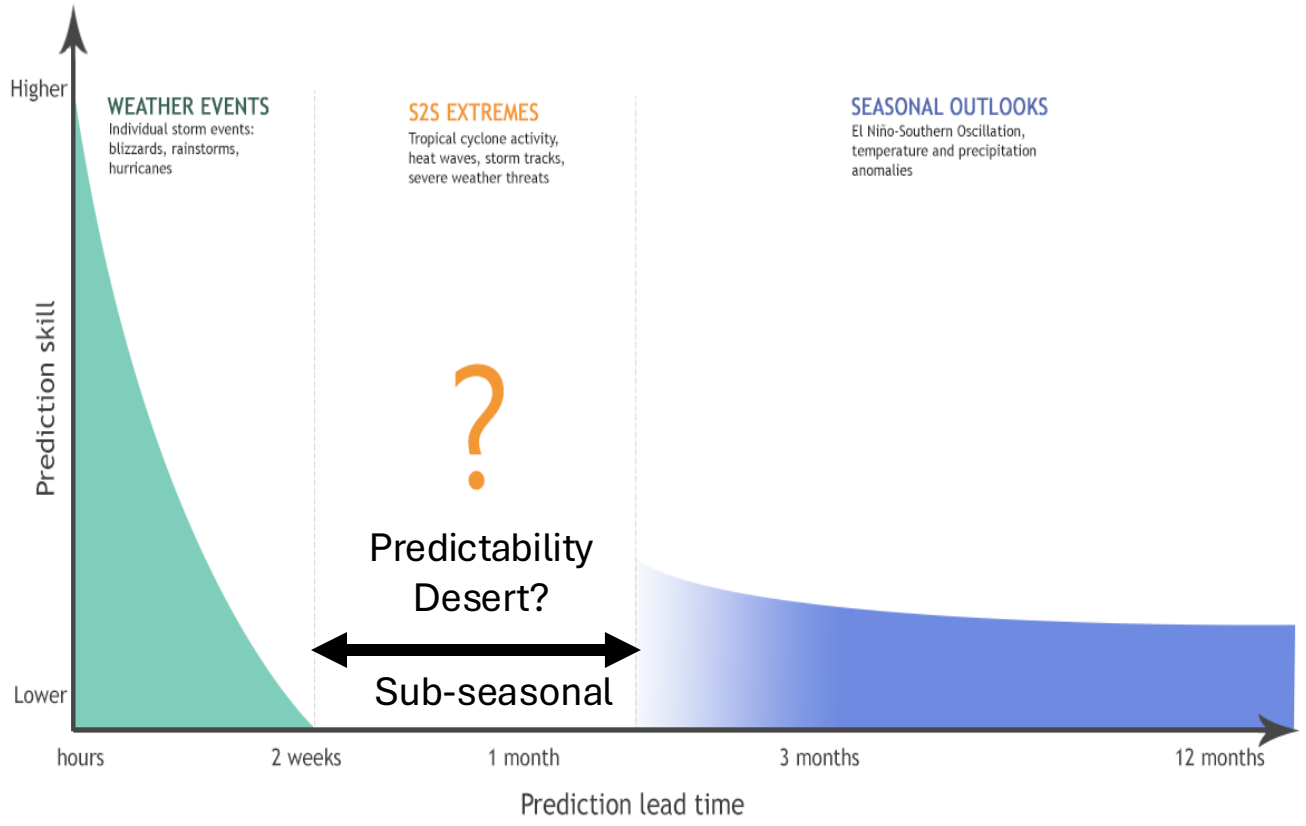
Sub-seasonal prediction

- ✓ Weather prediction **beyond two weeks but less than a season** = the "gap" between weather and climate forecasts.
- ✓ Important time scale for many applications (e.g. plan reservoir levels for flood control, irrigate and apply nutrients for agriculture, anticipating demand and production of energy).

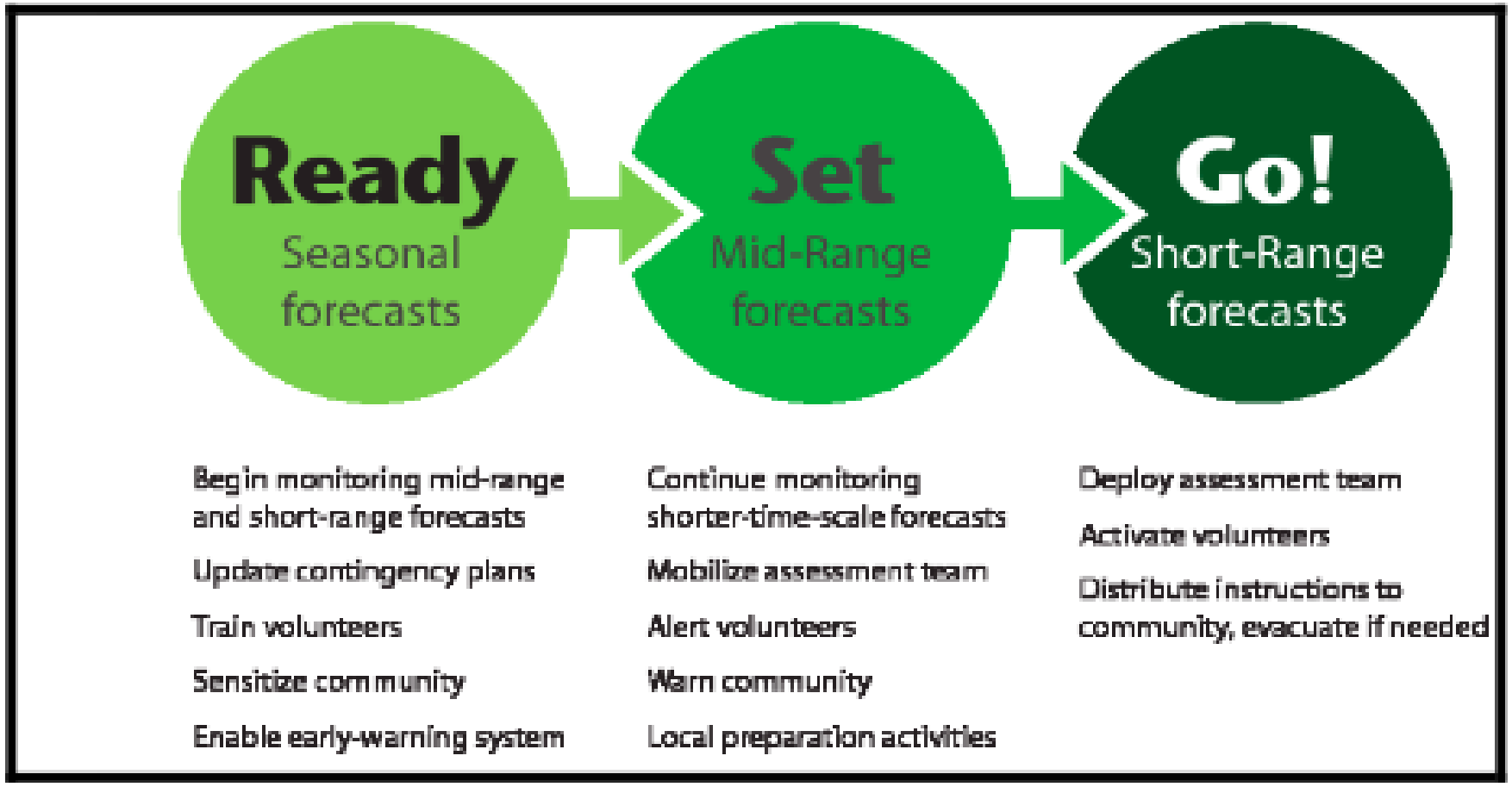


Short-term numerical weather prediction (NWP) is the easiest *— i.e., it is a pure initial-value problem;* ***long-term climate prediction is next easiest*** *— it corresponds to studying the system's asymptotic behavior;* ***intermediate-term prediction is hardest*** *— both initial & boundary values are important.*

John Von Neuman, 1955

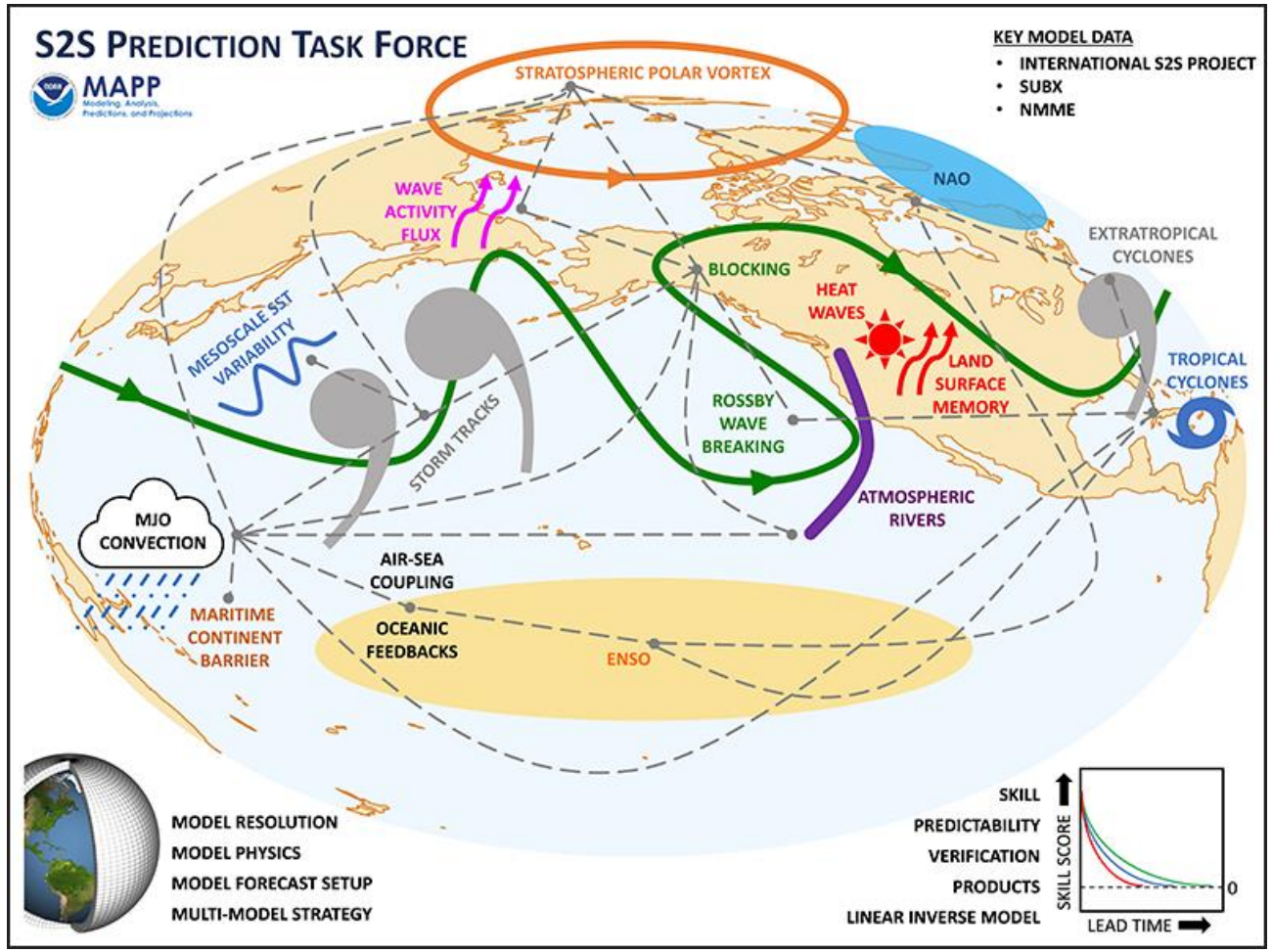


Opportunity to use information on *multiple* time scales



Red Cross - IRI example

Sources of sub-seasonal predictability



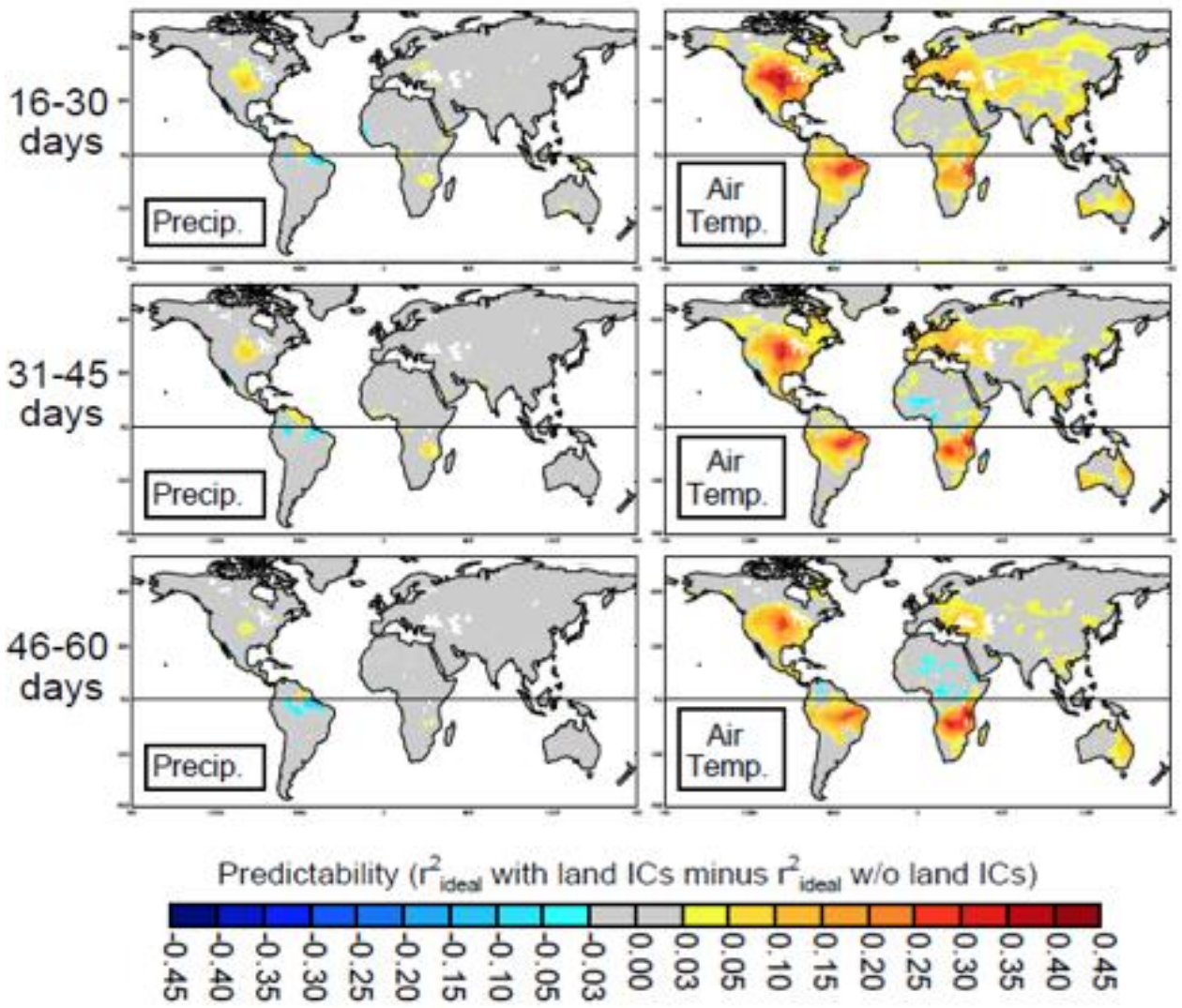
Mariotti et al., 2019

Main sources of predictability include:

- The Madden Julian Oscillation
- Stratospheric variability
- Land surface
- Rossby waves
- ENSO
- Indian Ocean Dipole (IOD)
- SSTs/Sea-ice
- Others?

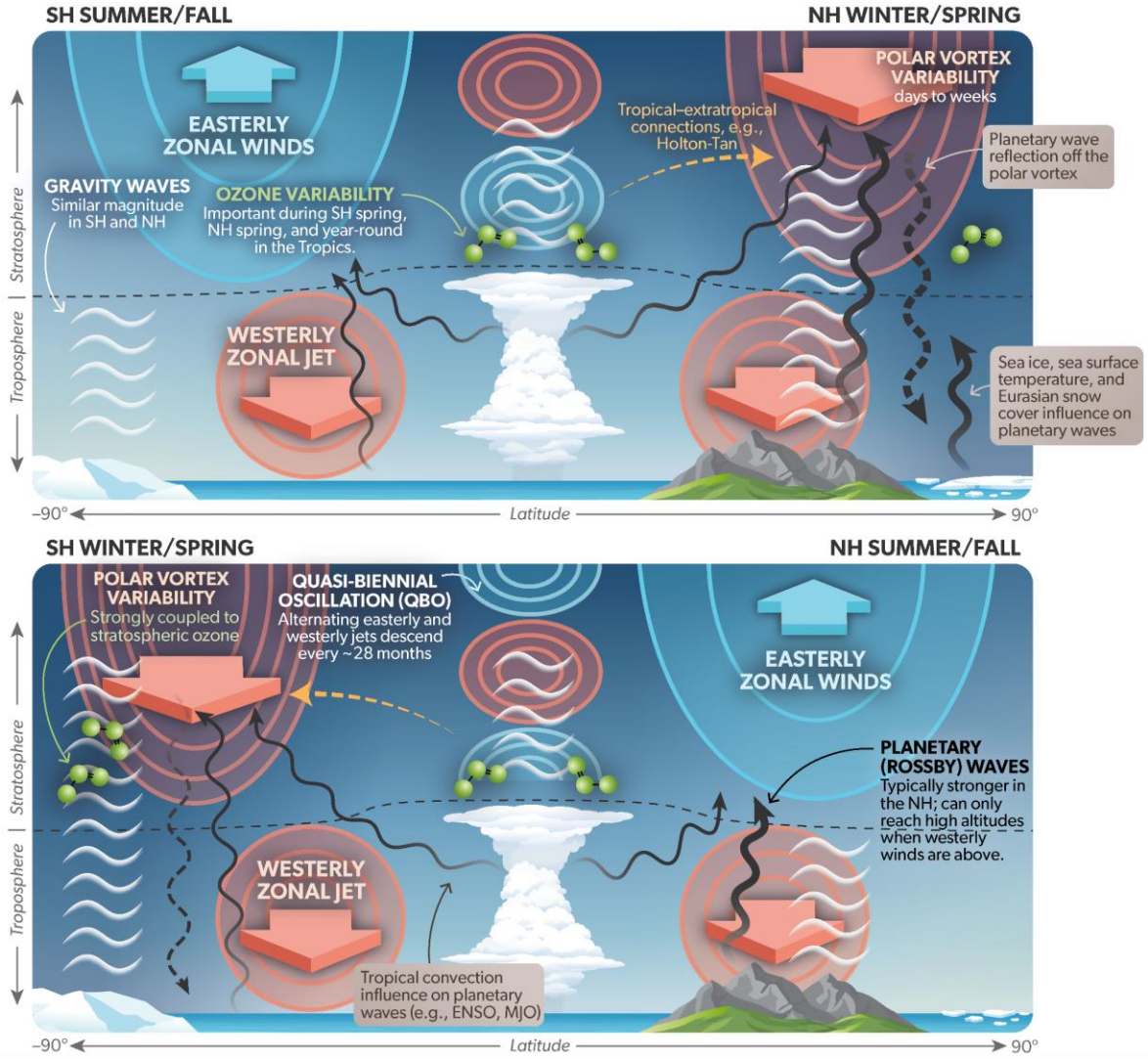
Sources of predictability such as the MJO create windows of opportunity for skillful sub-seasonal forecasts.

Impact of soil moisture



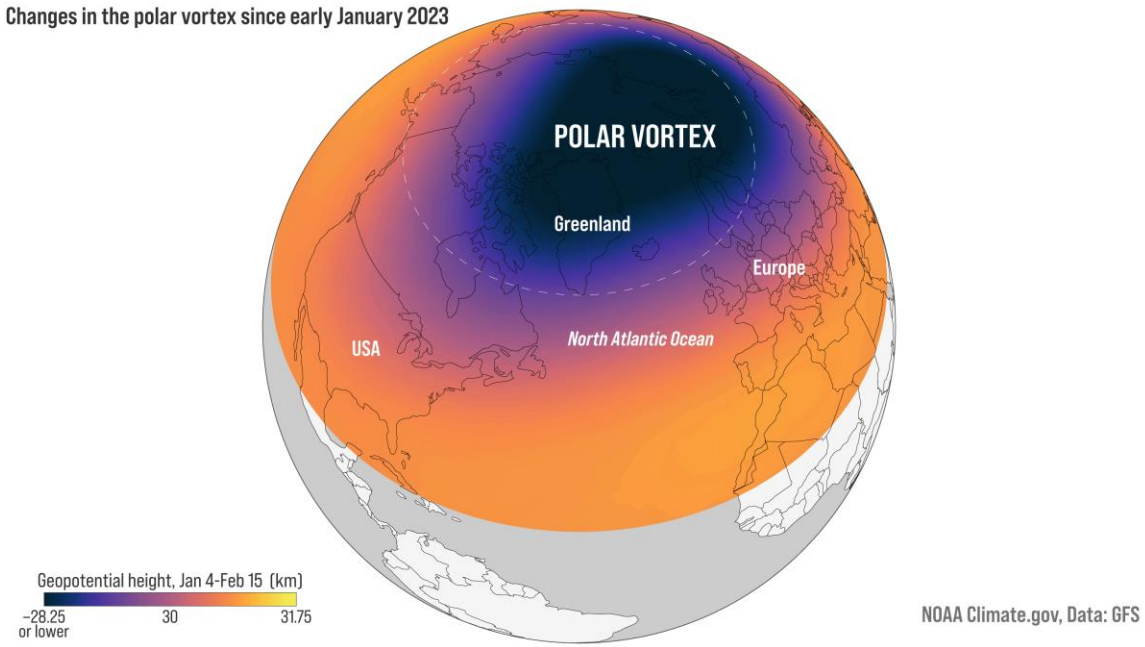
Koster et al, GRL 2011

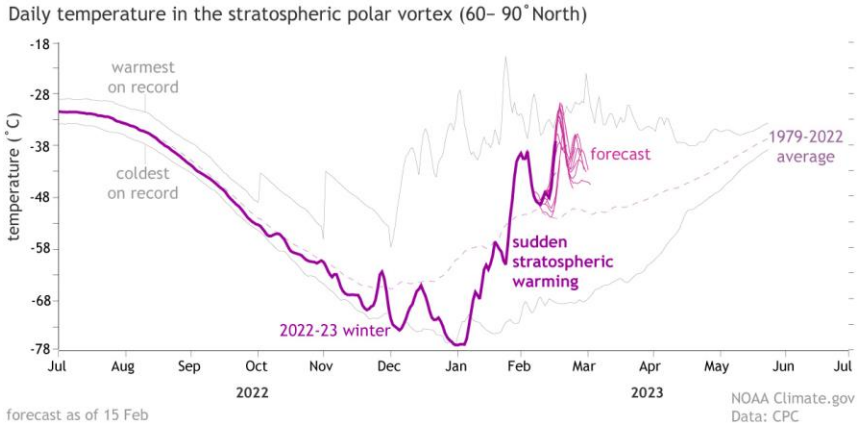
Stratospheric Variability



From Butler et al. 2024

Sudden Stratospheric Warming events (Weak Vortex events)





https://www.climate.gov/media/15082

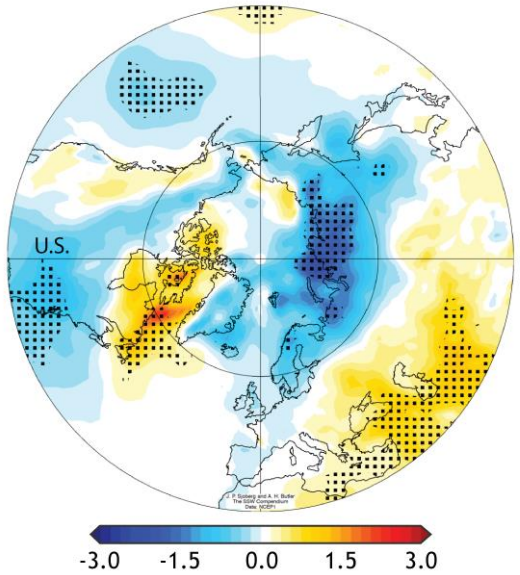
- Temperature in polar stratosphere rises by up to 50°C in a few days
- 2 types: Split events or displacement events
- About 1 SSW event every 2 years
- Happens during extended boreal winter
- Mostly in NH, but can happen in SH as well, although rarely (e.g. 2002/2019/2024)

SSW impacts

Average temperature anomalies 30 days after SSWs

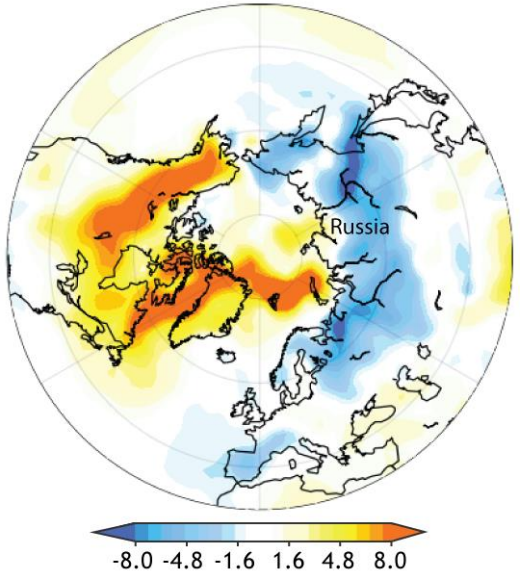
1958-2013

Surface temperature anomaly following all SSWs

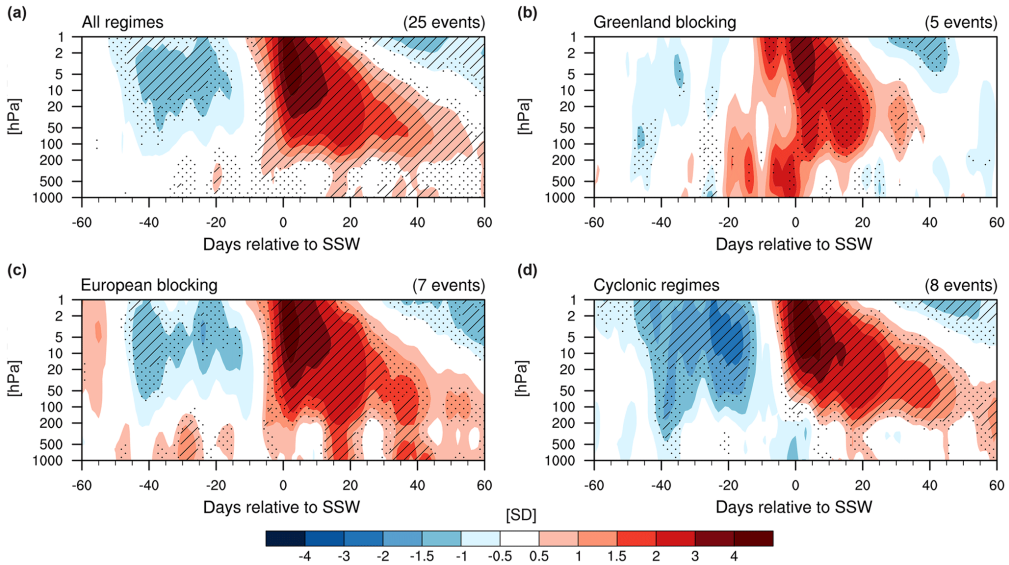


Jan 2021

Averaged surface temperature anomaly, Jan 5-23, 2021



Butler et al. 2017

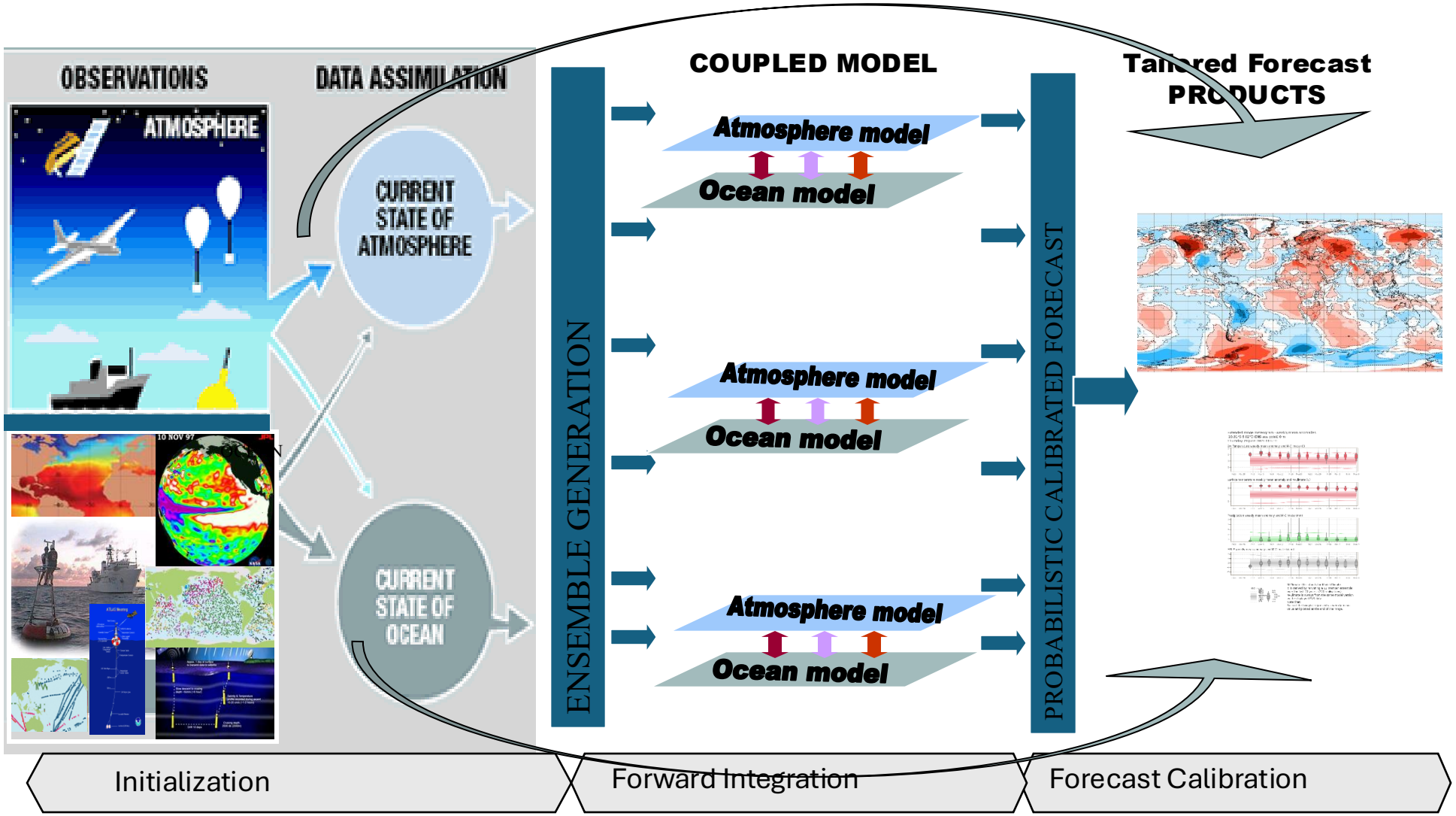


Domeisen et al. et al. 2020

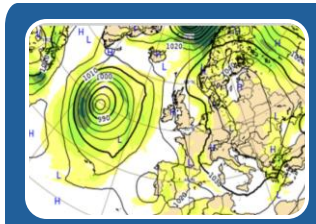
SSW impact depends on weather regimes

How are sub-seasonal forecasts produced?

End-To-End forecasting System

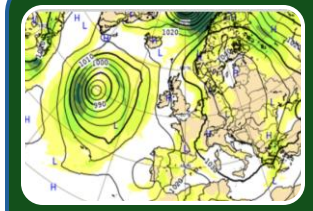


Operational ensemble forecasting systems at ECMWF



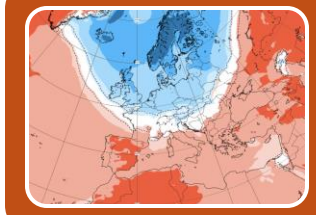
Medium range

- 0-15 days
- 9 km resolution, 137 levels
- 51 ensemble members, run twice daily
- Upgraded approximately once a year



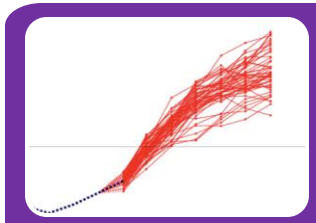
AIFS-ENS.V2: Medium range

- 0-15 days
- ~0.25 degree resolution
- 51 ensemble members running twice daily
- Upgraded as developments are ready



Sub-seasonal

- 0-46 days
- 36 km, 137 levels
- 101 ensemble members, run once daily
- Upgraded approximately once a year, with medium range



Long range: SEAS5

- 0-7 months
- 36 km, 137 levels
- 51 ensemble members, run once a month
- Four times a year, the forecast is run out to 13 months
- Last upgraded in 2017 (Cy43r1), next upgrade SEAS6

Sub-seasonal Prediction at ECMWF

- A 101-member ensemble is integrated for 46 days every day at 00Z
- Atmospheric component: IFS with the latest operational cycle and with a resolution TCo319L137
- Ocean-atmosphere coupling from day 0 to NEMO (about 1/4 degree) every hour.

Initial conditions:

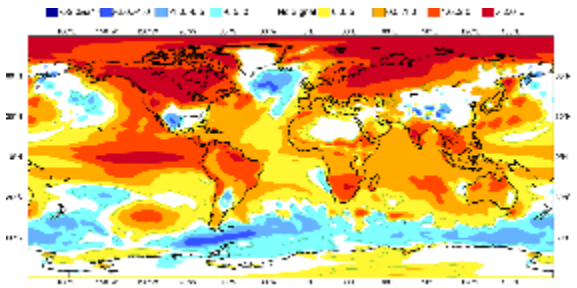
- Atmosphere: Operational 4-D var analysis + SVs+ EDA perturbations
- Ocean: 3D-Var analysis (NEMOVAR) + wind stress perturbations

Products

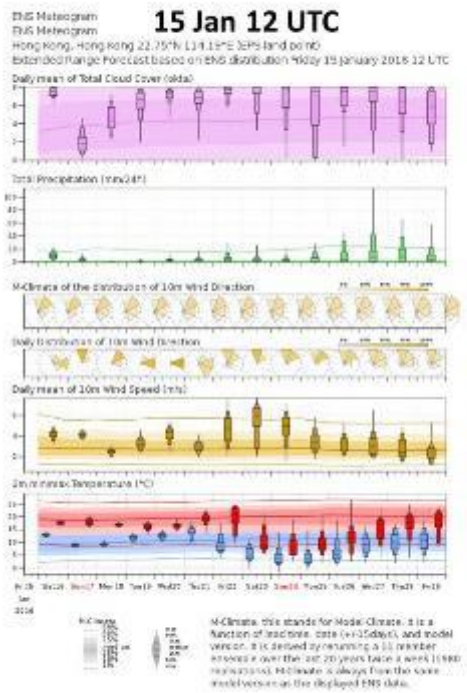
From medium-range to seasonal to extended range

Seasonal Forecast

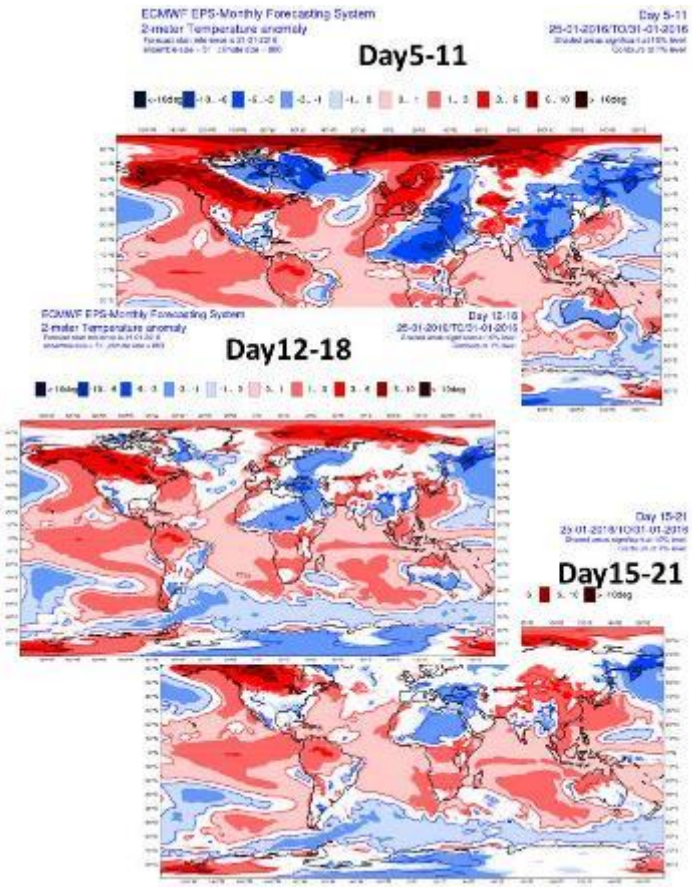
DJF 2015/16



Medium-range



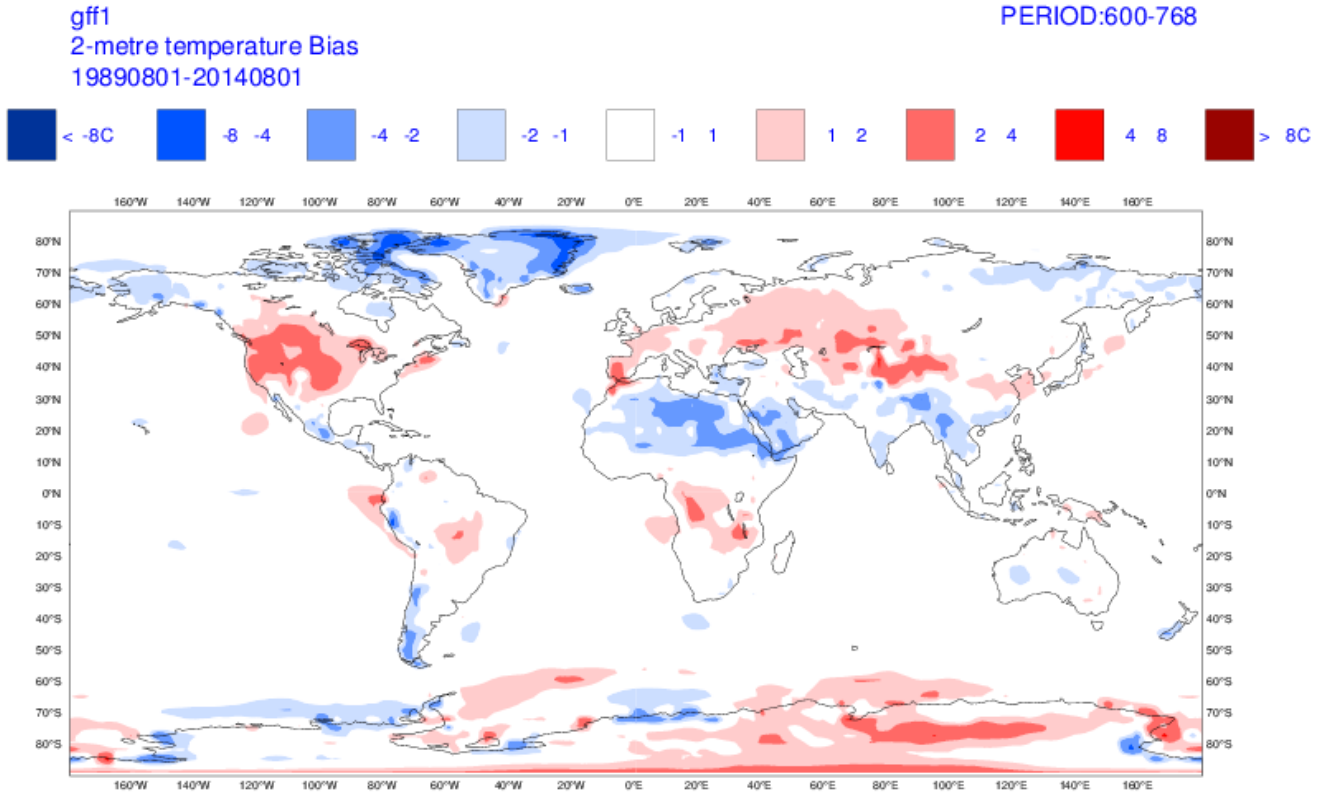
Extended-range



Weekly mean products

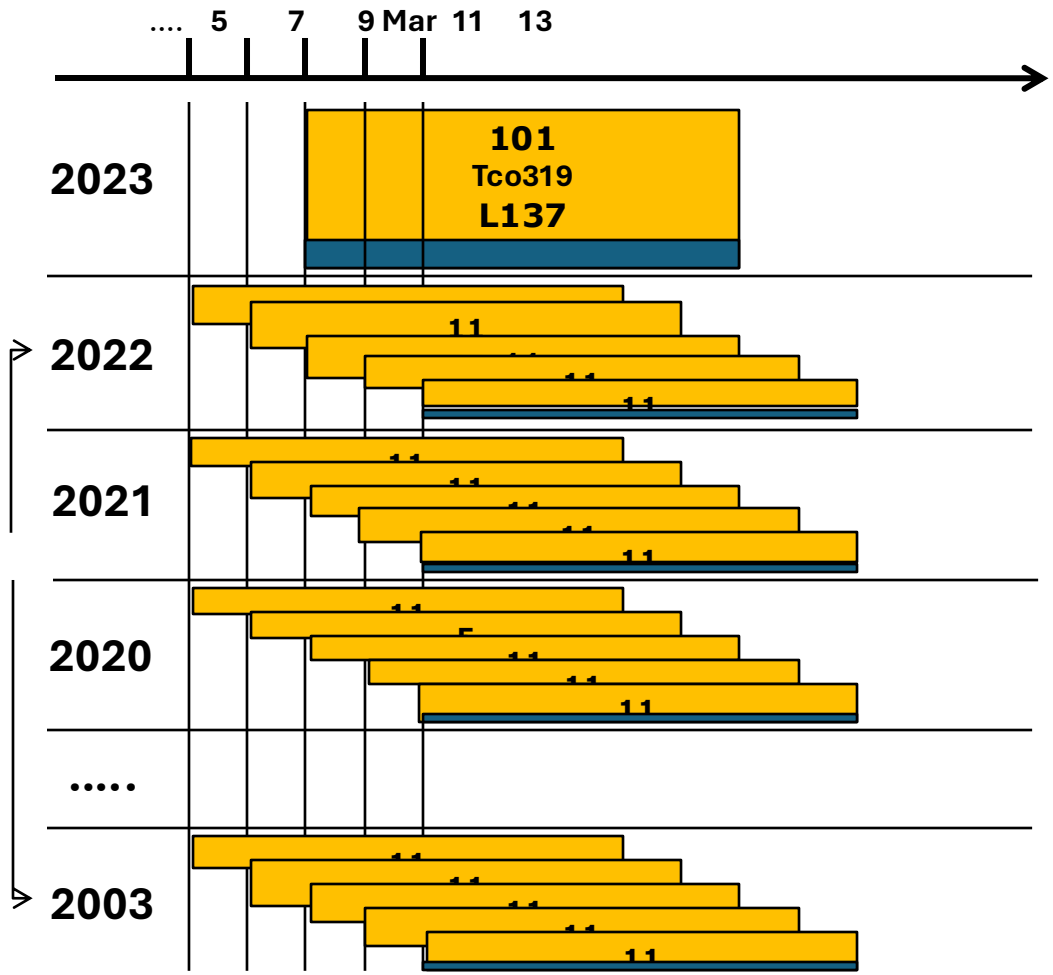
Biases

Biases (eg 2mT as shown here) are often comparable in magnitude to the anomalies which we try to predict



Re-forecasts

The SUBS re-forecast suite to estimate the M-climate
Used for calibration and forecast skill assessment



10 perturbed + 1 control fc on fixed days of the month, **every odd days,** over past 20 year

Initial conditions:

- ERA5
- ORAS5 ocean Ics
- Offline land DA

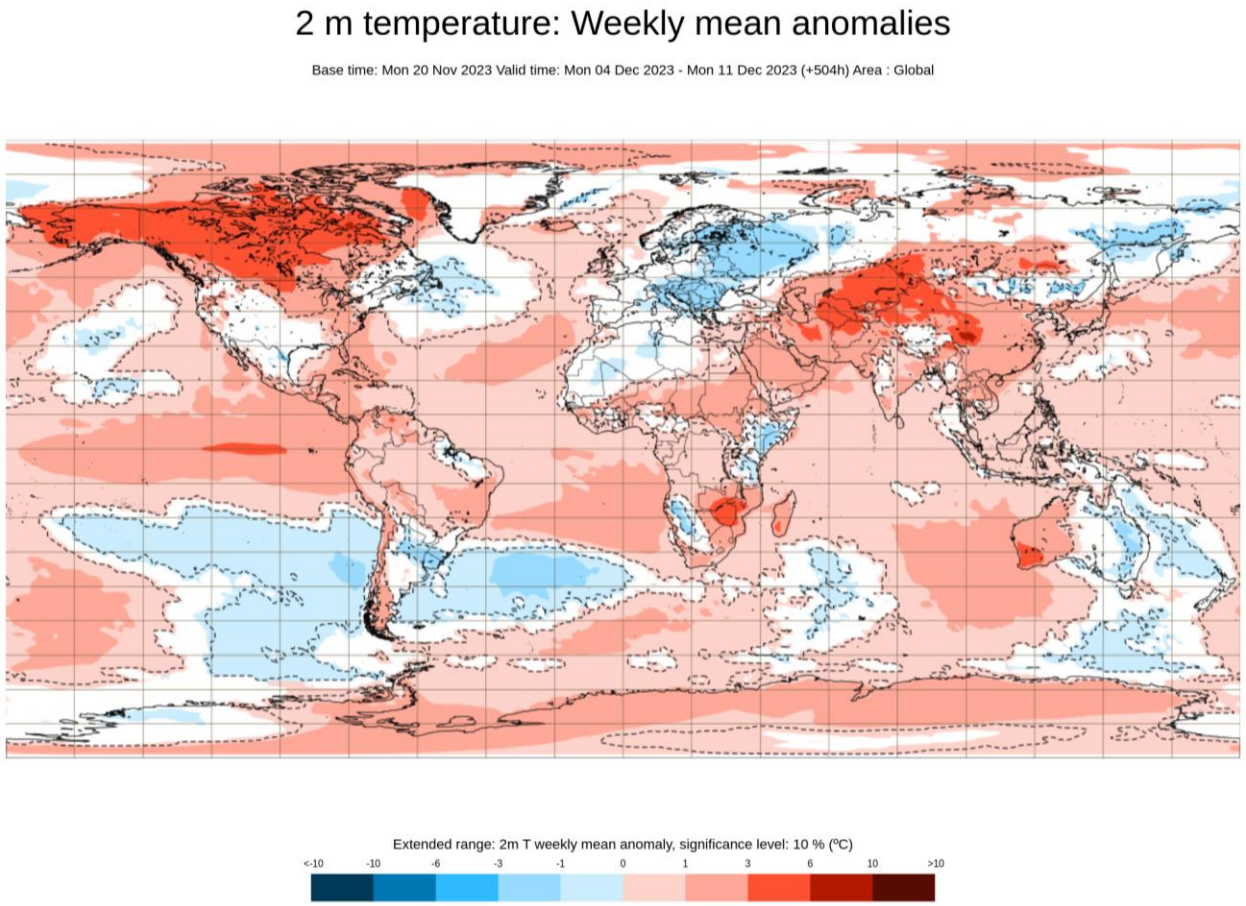
Perturbations:

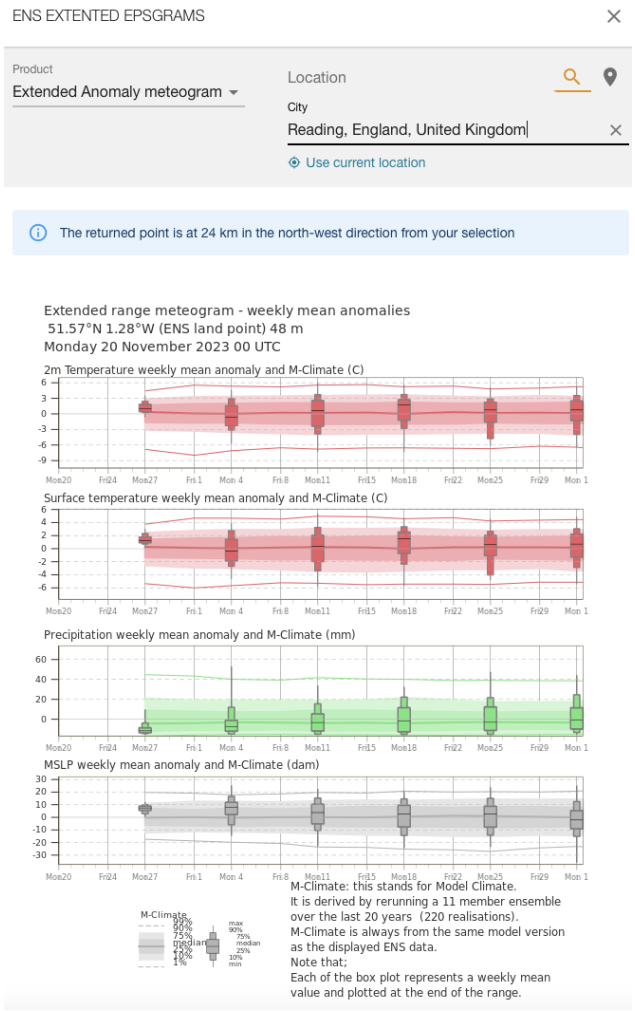
SVs+EDA(ERA5)+SPP

1-week window = 5 consecutives sets of re-forecasts= 5*11 members * 20 years=1100-member model climate

Sub-seasonal forecast charts

Anomalies (temperature, precipitation..)

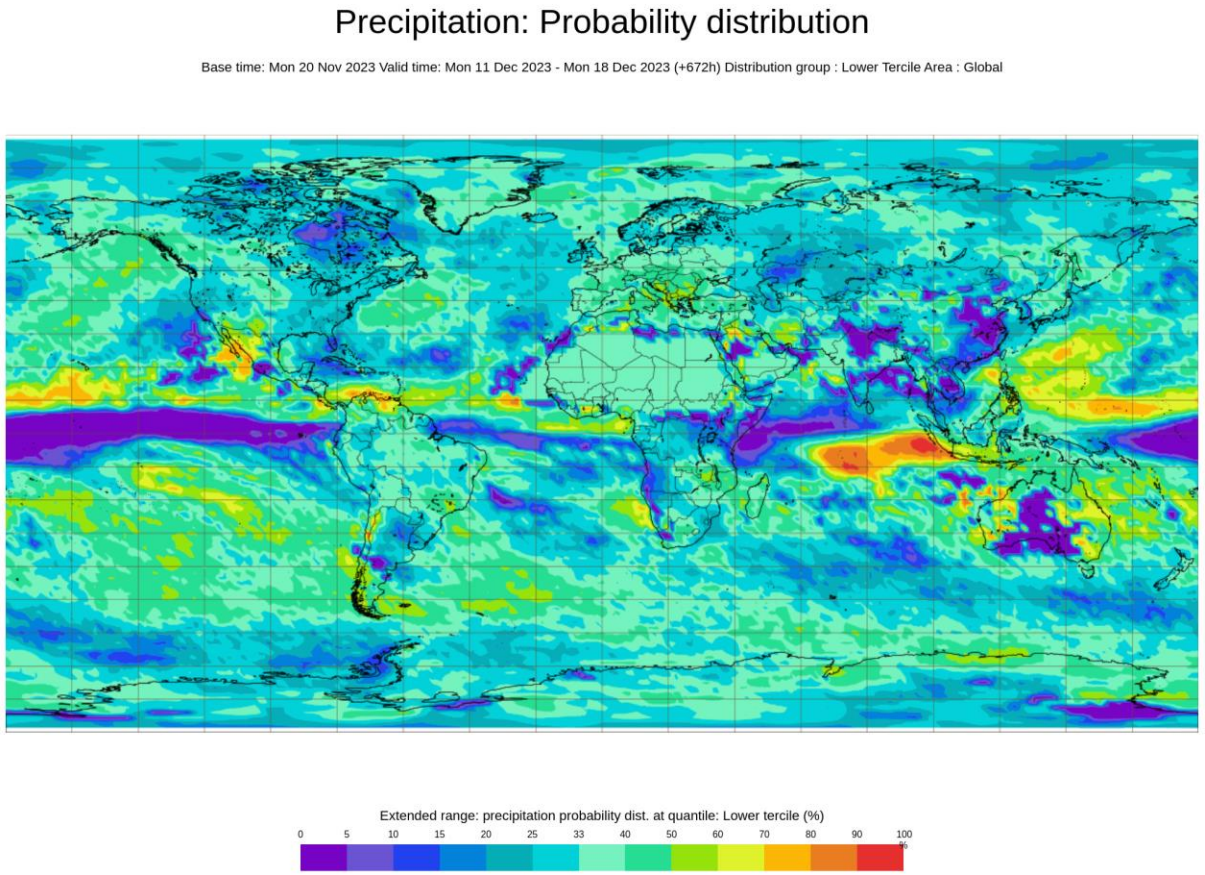




Sub-seasonal forecast charts

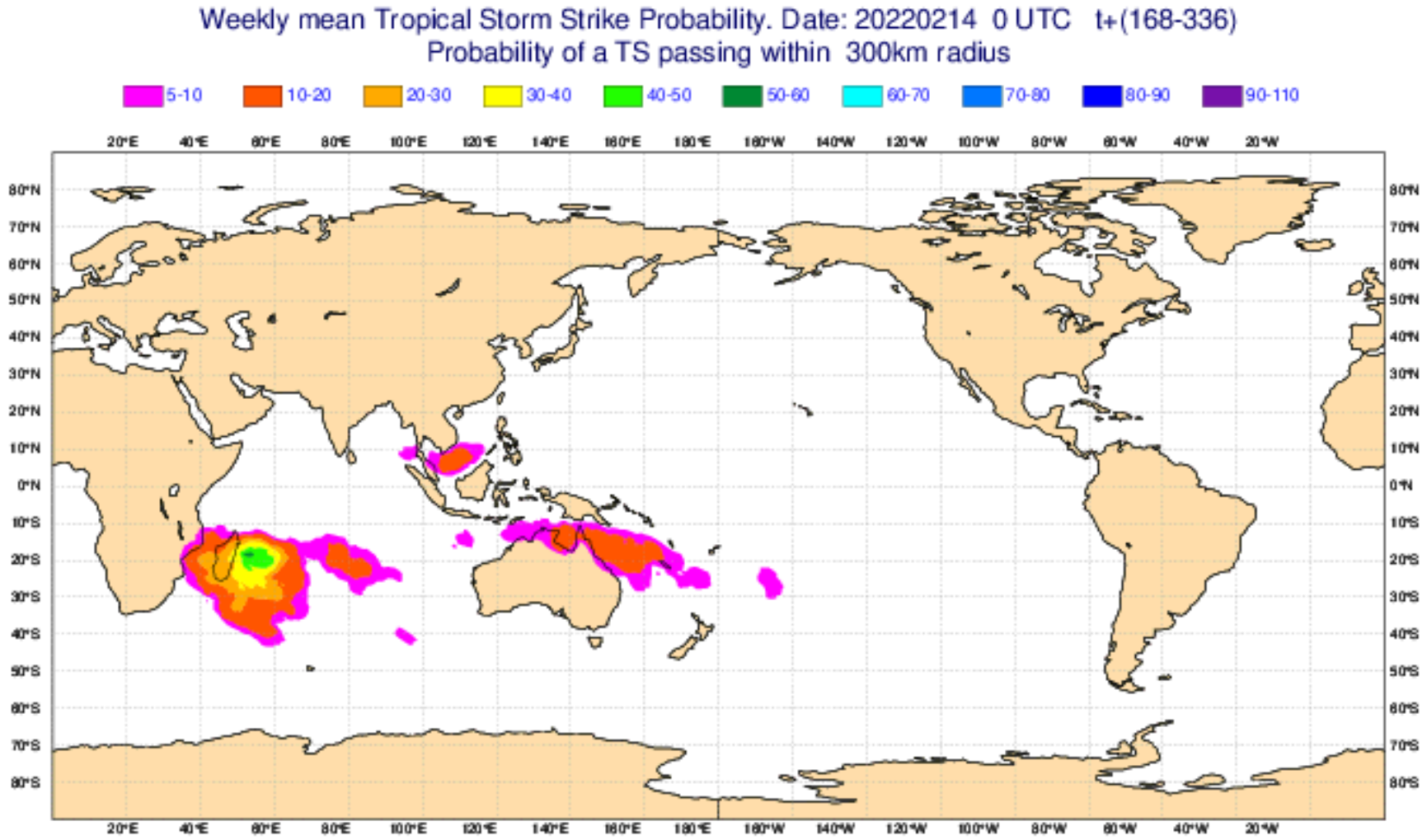
Probabilities (temperature, precipitation..)

Probability of total precipitation in upper tercile
20 Nov 2023 - Week 4



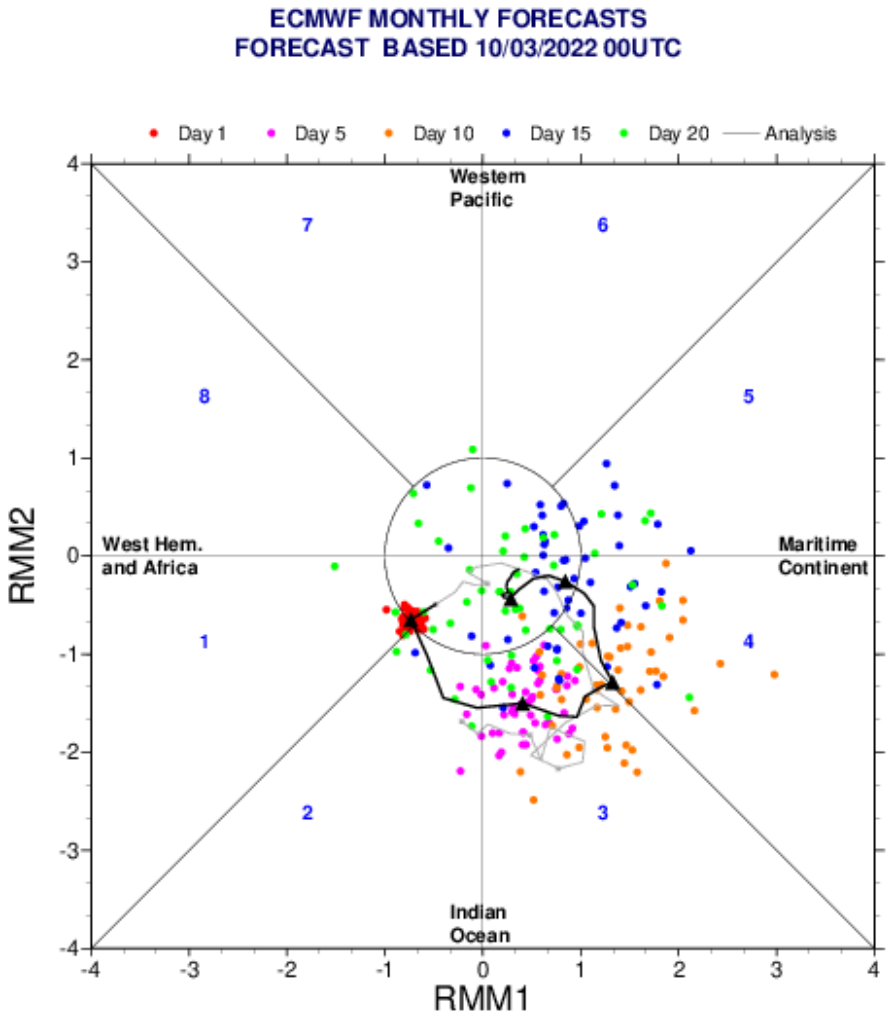
Sub-seasonal forecast charts

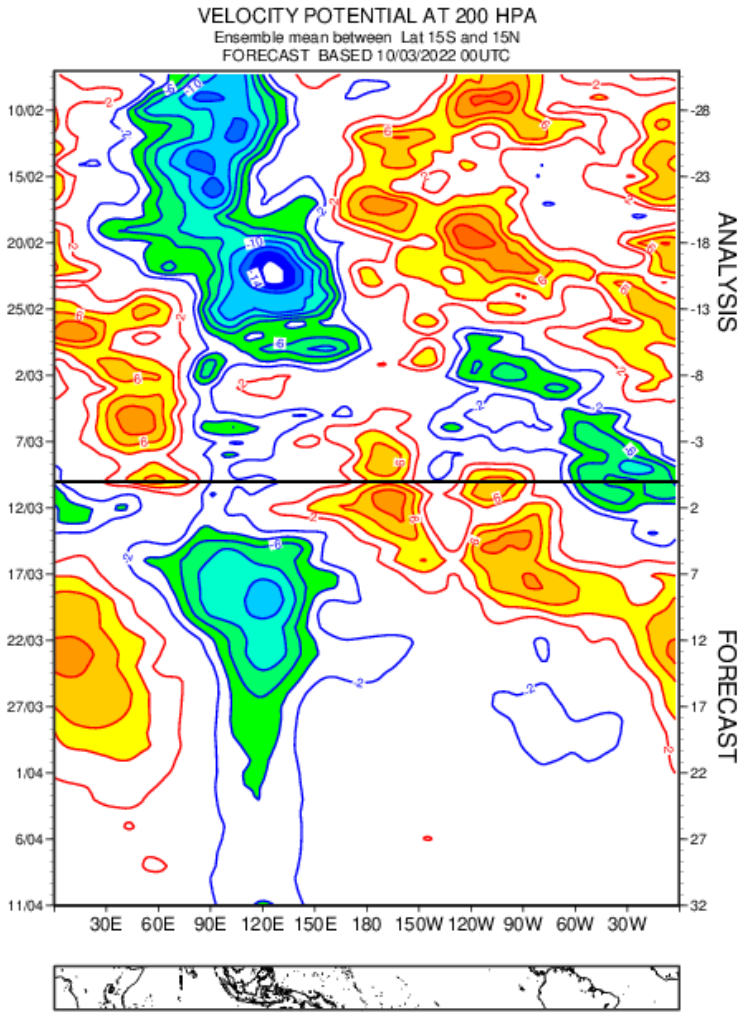
Tropical Cyclone Activity



Sub-seasonal forecast charts

MJO forecasts

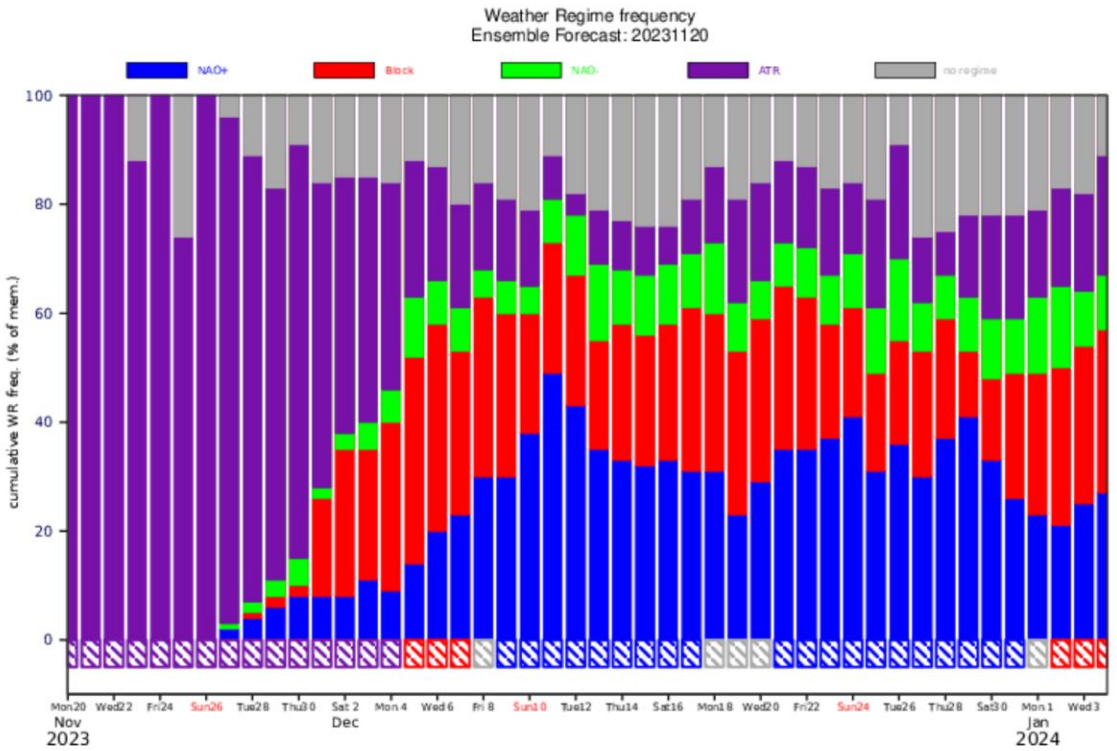




Sub-seasonal forecast charts

Euro-Atlantic weather regimes

Weather regimes probabilities - Extended range forecast



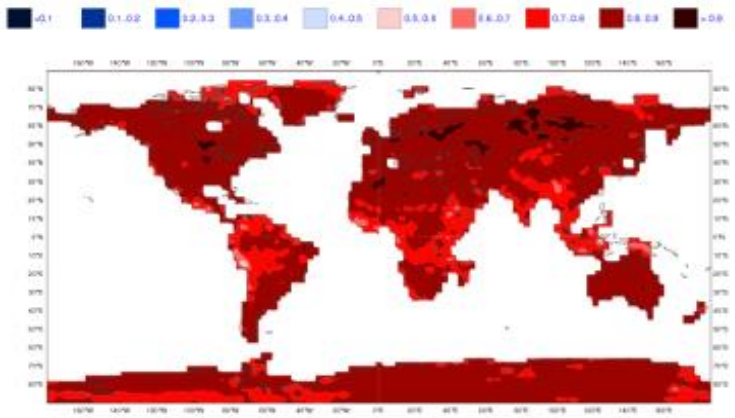
© 2023 European Centre for Medium-Range Weather Forecasts (ECMWF)
Source: www.ecmwf.int
Licence: CC BY 4.0 and ECMWF Terms of Use (https://apps.ecmwf.int/datasets/licences/general/)
Created at 2023-11-21T15:01:01.866Z

ECMWF

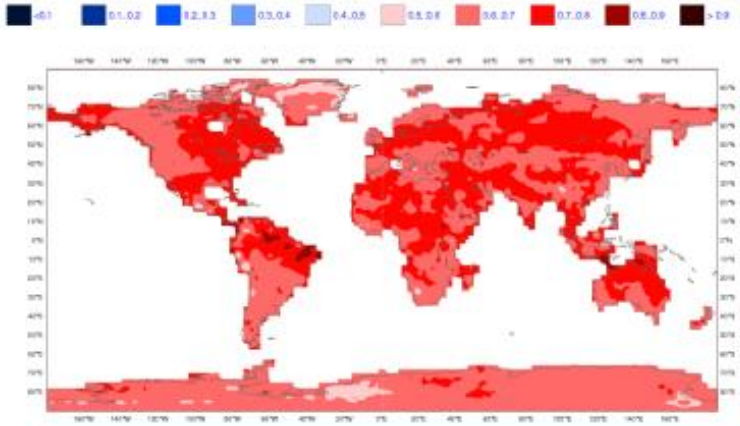
Sub-seasonal forecast Skill

ROC score: 2-meter temperature in the upper tercile

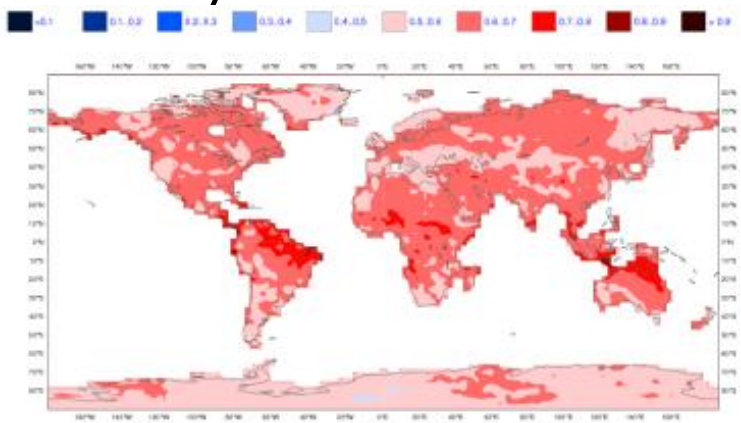
Day 5-11



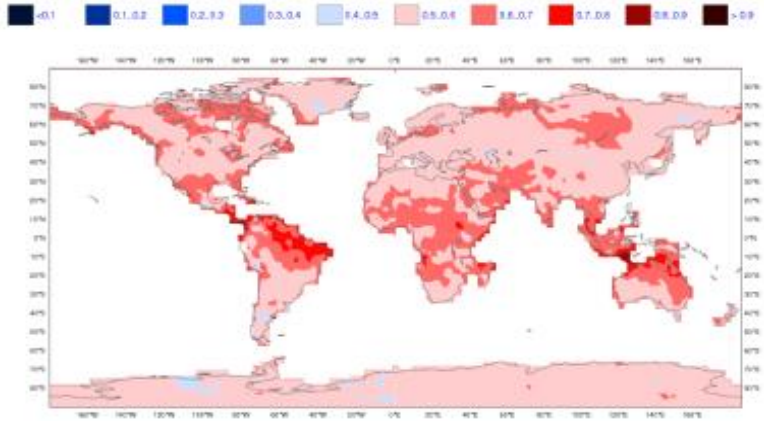
Day 12-18



Day 19-25



Day 26-32



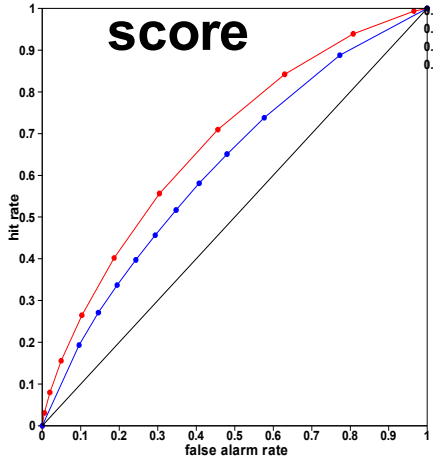
Sub-seasonal forecast Skill

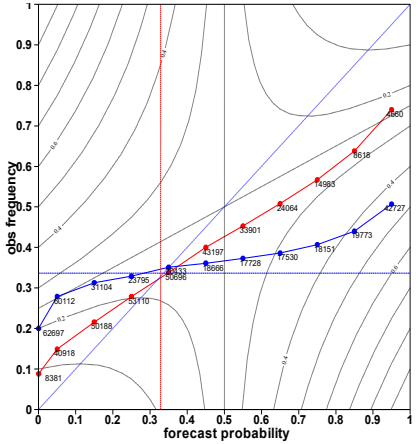
2-meter temperature in upper tercile - Day 12-18

ROC score

Reliability diagram

Day 12-18

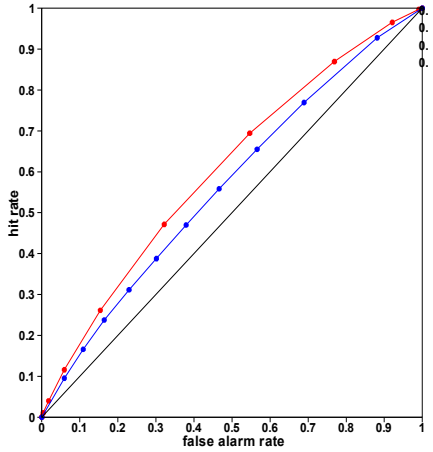


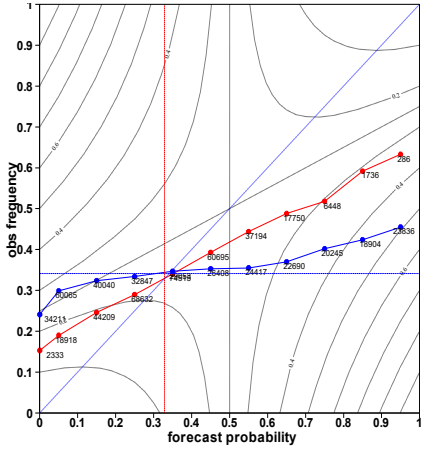


Persistence of day 5-11

day 12-18

Day 19-25





Persistence of day 5-18

day 19-32

Sub-seasonal Prediction at ECMWF

2004 version

Real-time:

- TL159 (~110km)
- 42 vertical levels
- 1º Ocean
- Persisted sea-ice
- Model Version: CY28R1
- 32- days integrations
- Once a week
- 51 ensemble members

Reforecasts:

- 12 years
- 5 ensemble members
- Once a week
- Initialized from ERA40
- ~270 years/year



- Increased resolutions
- Improved Initialization
- > 20 changes to model physics
- Increased model complexity

2026 version

Real-time:

- Tco319 (~36km)
- 137 vertical levels
- 1/4º Ocean
- Active sea-ice
- Model Version: CY50R1
- 46-days integrations
- Daily
- 101 ensemble members

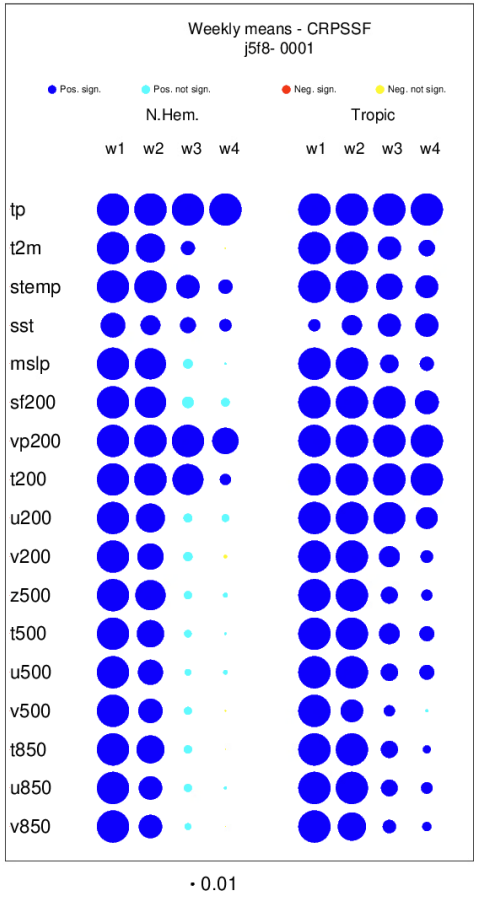
Reforecasts:

- 20 years
- 11 ensemble members
- Every odd day
- Initialized from ERA5
- ~5060 years/year

Have sub-seasonal forecasts improved since 2004?

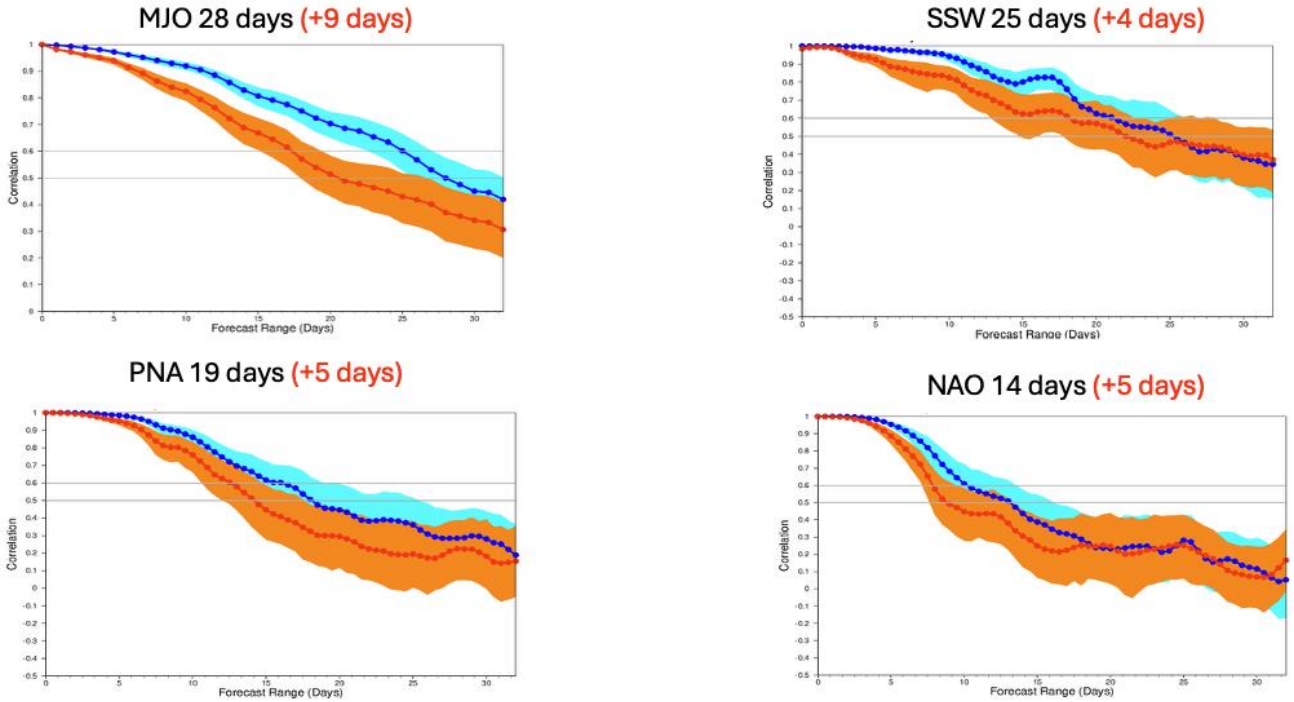
Re-forecast Experiment: 5-member ensemble, NDJFM 1992-2003, Once a week.

Scorecard: 2026 vs 2004 version



Sources of sub-seasonal predictability

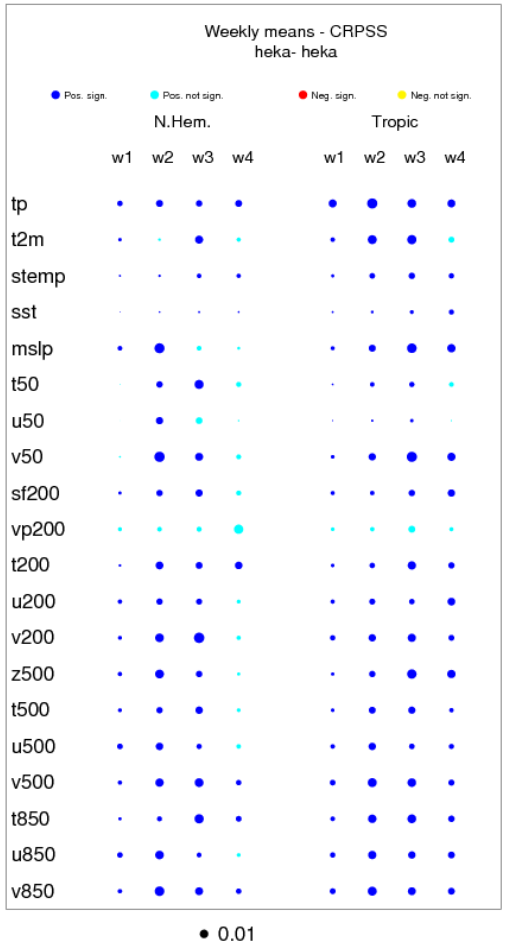
Temporal correlation with re-analysis



- Significant progress in the Tropics
- Limited progress in week 3 in the Extratropics
- Week 4 in the Extratropics is particularly challenging!

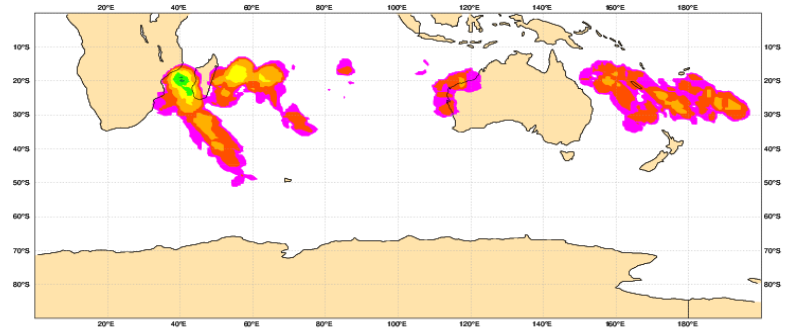
101 vs 51 ensemble members

CRPSS scorecard: 101 vs 51 members
20-year re-forecasts

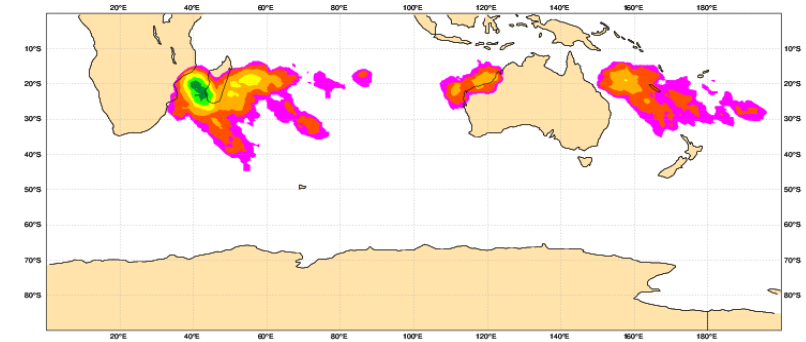


TC strike probability for week 3
Sub-seasonal forecast starting on 7 January 2021

51 members

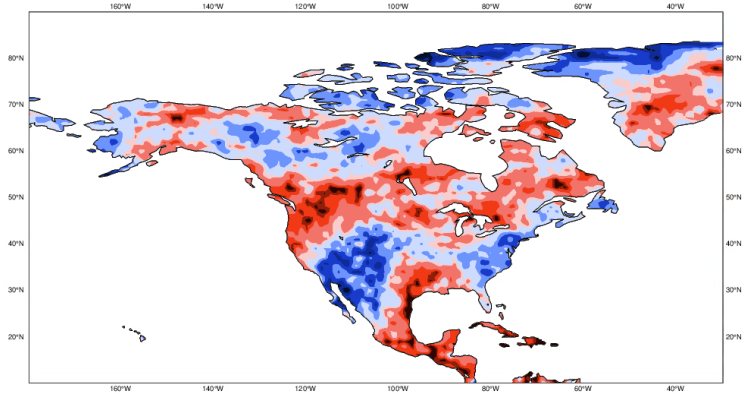


101 members

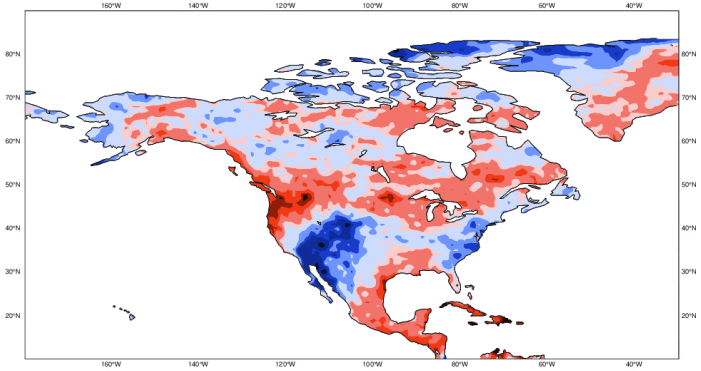


Top Decile probability: Total precip.
Start date: 5 June 2026 - Day 19-25.

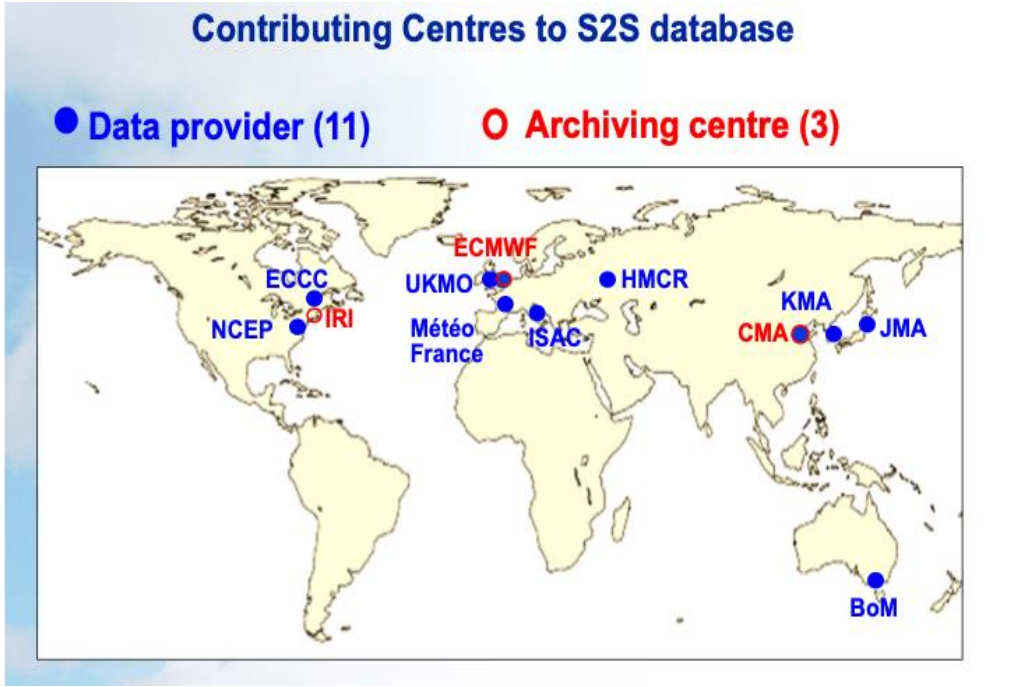
51 members



101 members



WWRP/WCRP Sub-seasonal to Seasonal (S2S) Database



- 13 S2S models
- Real-time + re-forecasts
- Atmospheric + ocean fields
- Same grid (1.5°), same format
- Opened in **2015**
- 48-hour behind real-time
- Archived at ECMWF/CMA/IRI
- > 600 publications

S2S Models

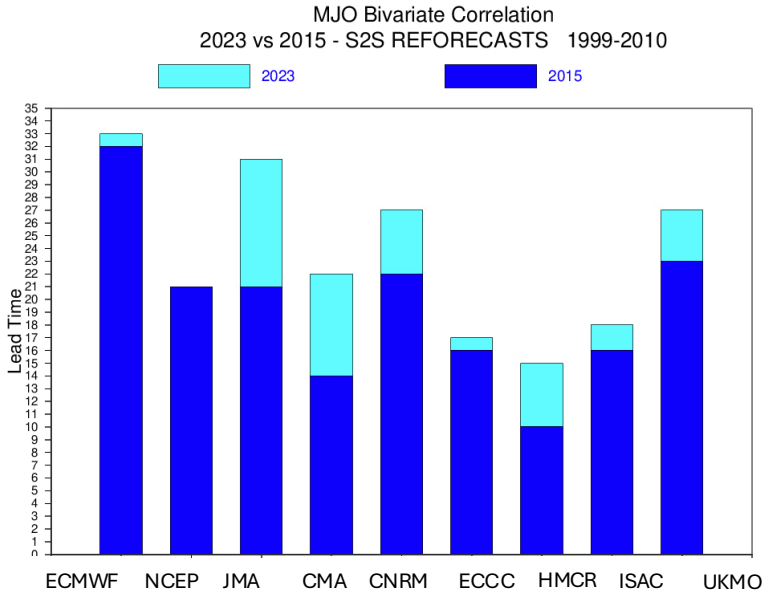
	Time-range	Resol.	Ens. Size	Freq.	Hcsts	Hcst length	Hcst Freq	Hcst Size
ECMWF	D 0-46	TCo319L137	101	daily	On the fly	Past 20y	Odd days	11
UKMO	D 0-60	N216L85	4	daily	On the fly	1993-2015	4/month	7
NCEP	D 0-44	N126L64	4	4/daily	Fix	1999-2010	4/daily	1
ECCC	D 0-39	0.25°L85	21	weekly	On the fly	2001-2021	weekly	11
BoM	D 0-60	T47L17	33	weekly	Fix	1981-2013	6/month	33
JMA	D 0-34	T319L128	5	daily	Fix	1991-2020	2/month	13
KMA	D 0-60	N216L85	8	daily	On the fly	1993-2022	4/month	7
CMA	D 0-60	T266L56	4	daily	On the fly	Past 15y	weekly	4
CNRM	D 0-46	T359L137	25	Weekly	Fix	1999-2024	4/month	11
CNR-ISAC	D 0-35	0.75x0.56 L70	41	weekly	Fix	1999-2024	Every 5 days	8
HMCR	D 0-46	0.9x0.72 L96	41	weekly	On the fly	1991-2020	weekly	11
CPTEC	D0-35	TQ126 L42	11	weekly	Fix	1999-2018	weekly	11
IAP-CAS	D0-45	C96L32	5	daily	Fix	1999-2018	daily	4

Sub-seasonal sources of predictability skill

WWRP/WCRP S2S database

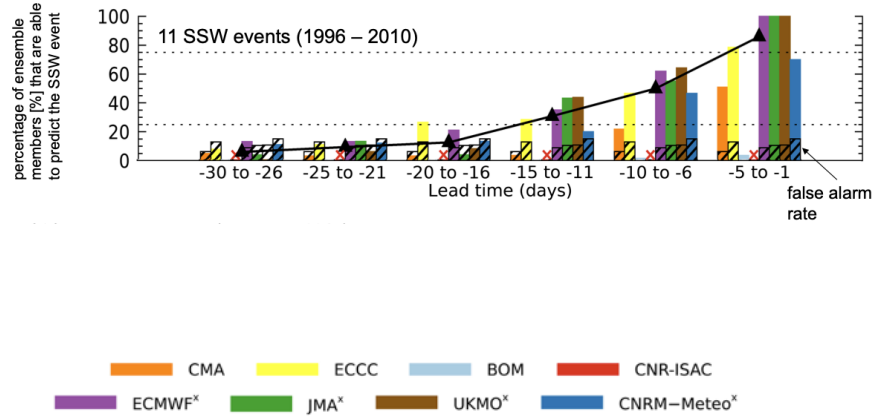
- 13 S2S models
- Real-time + re-forecasts
- Atmospheric + ocean fields
- Same grid (1.5°), same format
- Opened in **2015**
- > 400 publications

MJO forecast Skill



Vitart et al. 2025

SSW Forecast Skill



Domeisen et al., 2020

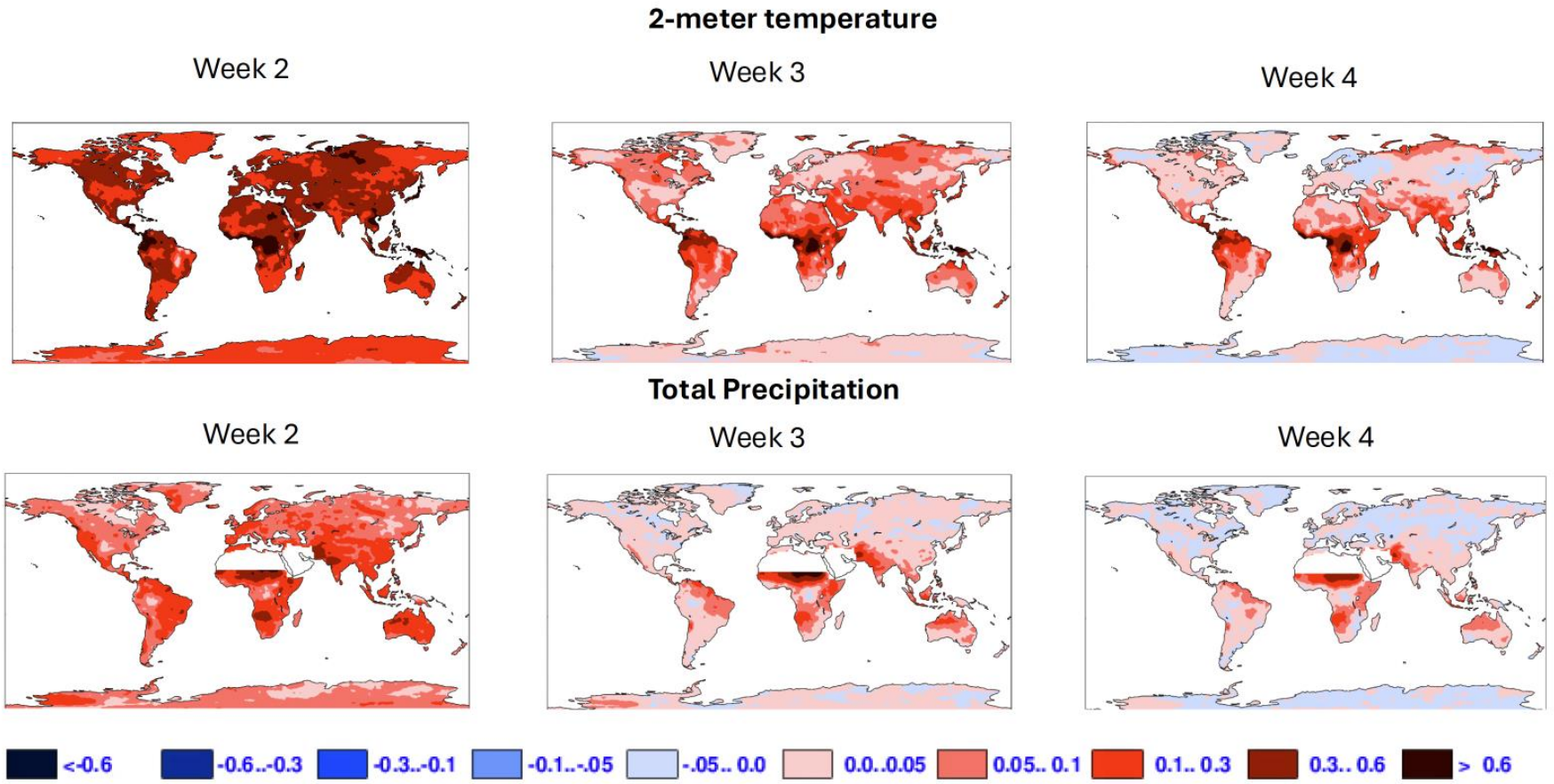
- MJO predictive skill limit of about 3 weeks on average, and up to 4 weeks for some models
- SSW predictive skill limit of about 2 weeks

ECMWF

Vitart et al. 2025

Sub-seasonal forecast Skill Scores in S2S database

RPSS S2S Multi-model 2018-2023

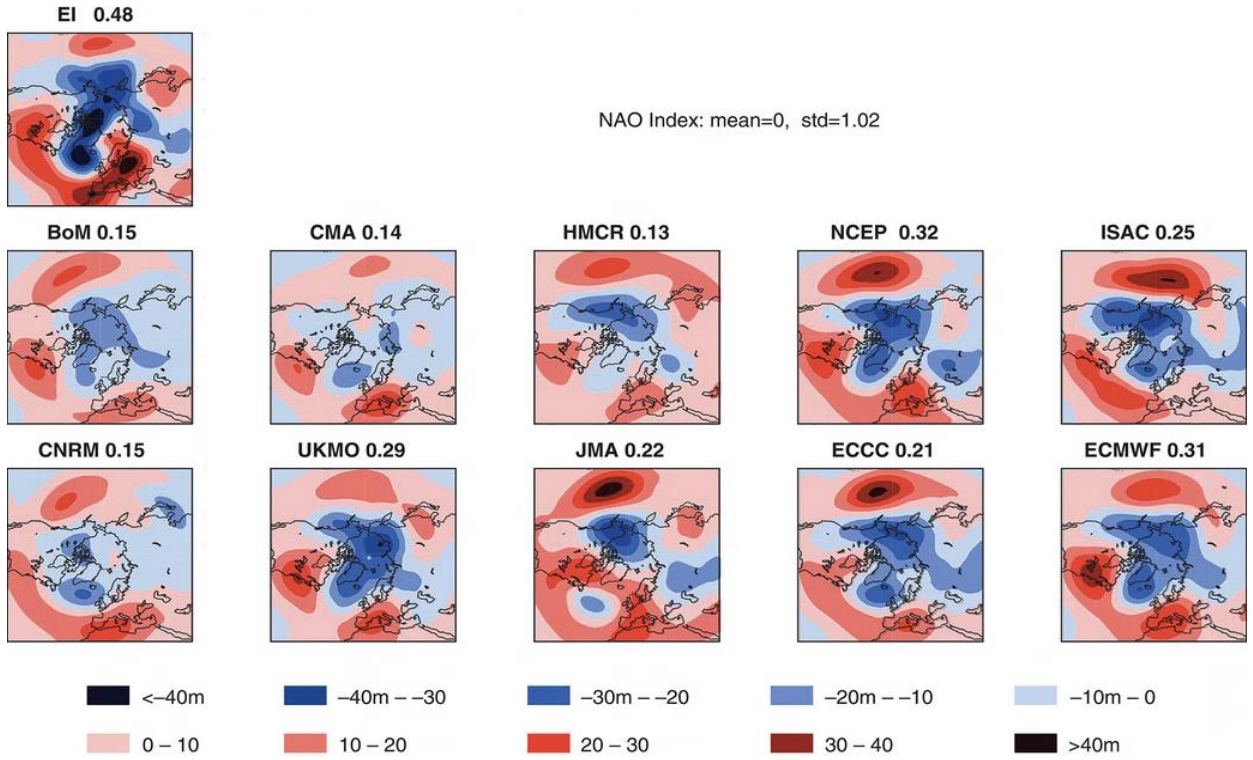


- Stronger Skill in the Tropics at weeks 3 and 4
- Low skill in the Extratropics at week 4 on average
- Higher skill scores when initialized from MJO (Vitart and Molteni , 2014) and SSW (Tripathi et al. 2014)

Vitart et al., 2025

Representation of teleconnections in sub-seasonal forecasts

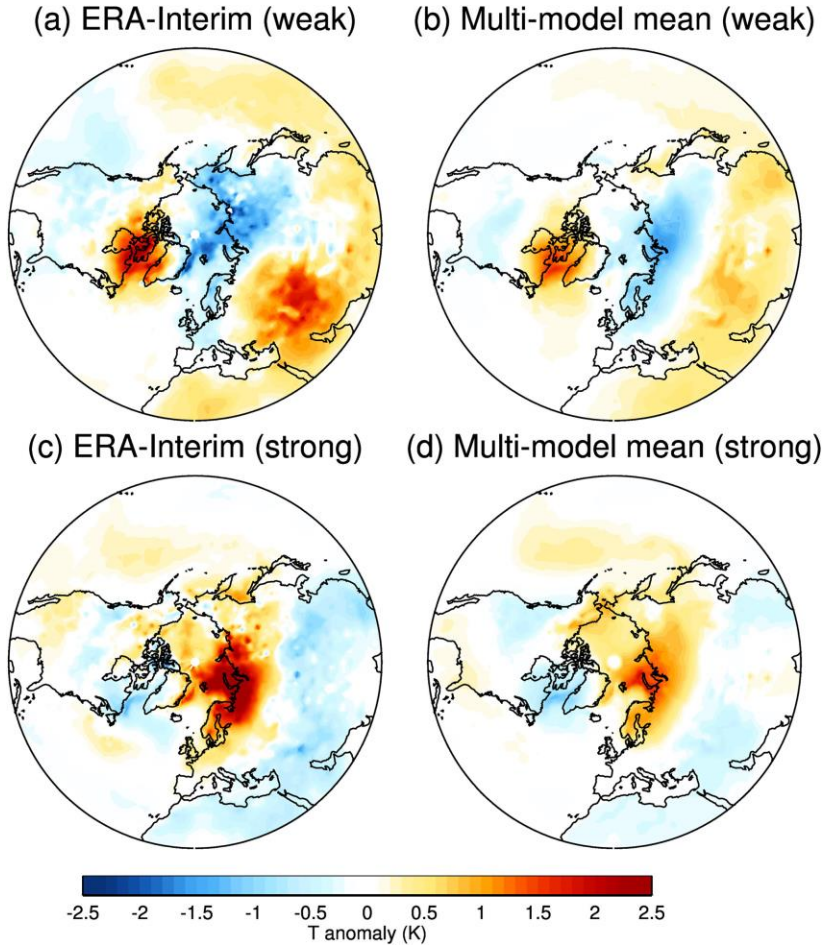
Z500 Composite 10 days after MJO in Phase 2-3



Vitart, 2017

- MJO and SSW teleconnections are underestimated in S2S models
- Modulation of MJO teleconnections by ENSO not represented in IFS (Roberts et al., 2023)

SSW impact on surface temperature



Domeisen et al., 2020

Understanding sources of MJO teleconnection errors

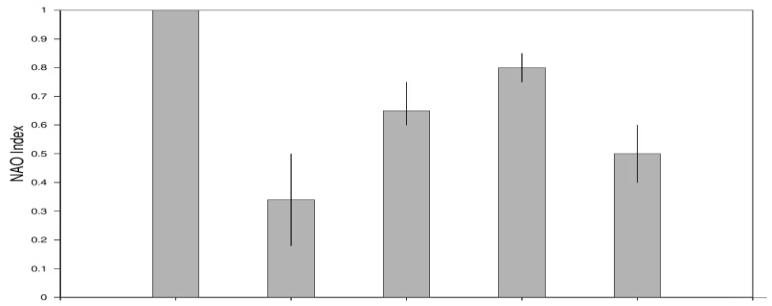
Nudging Experiment

$$\frac{\partial a}{\partial t} = -\mathbf{v} \cdot \nabla a + Q_a^p - \underbrace{\frac{a - a_{obs}}{\tau}},$$

a = {T,u,v}
τ = 12 hours
a_{obs} = ERA5

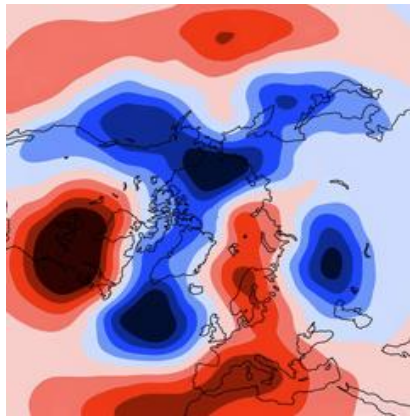
See also:
- Jung et al, 2010
- Dias et al, 2021

Amplitude of MJO teleconnections

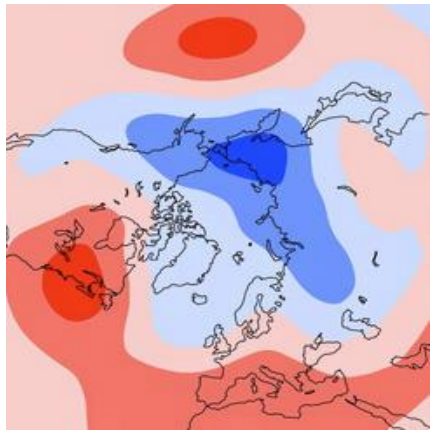


Z500 composites 3 pentads after an MJO in phase 2-3

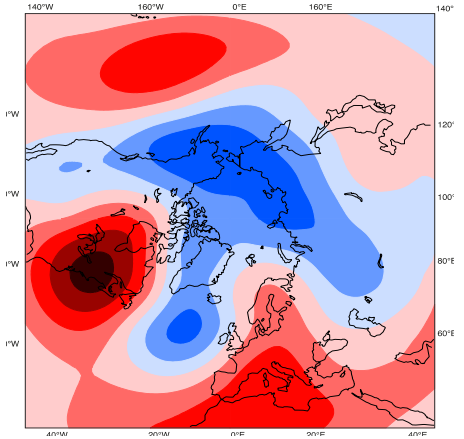
ERA5



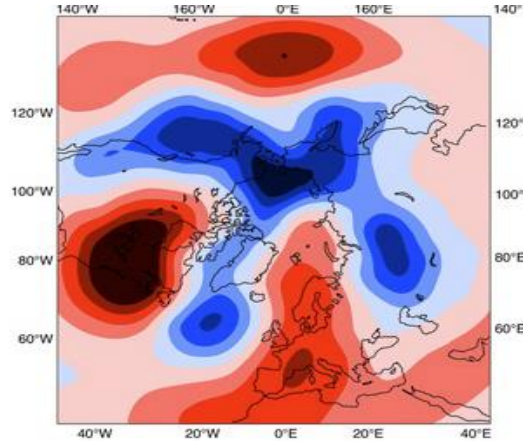
Control (CY48R1)



TROPICS RLX (10N-10S)



NO_ATL RLX



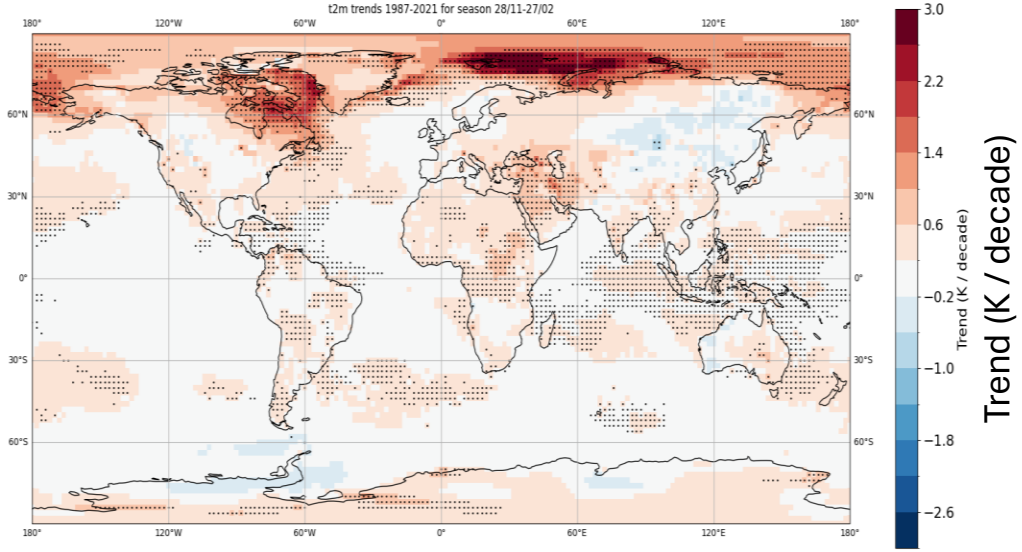
MJO teleconnections errors have multiple sources: remote (e.g. Tropics) but also local

ECMWF

Vitart and Balmaseda, 2024

Trends in Sub-seasonal Forecasts

2mtm Trends in ERA5

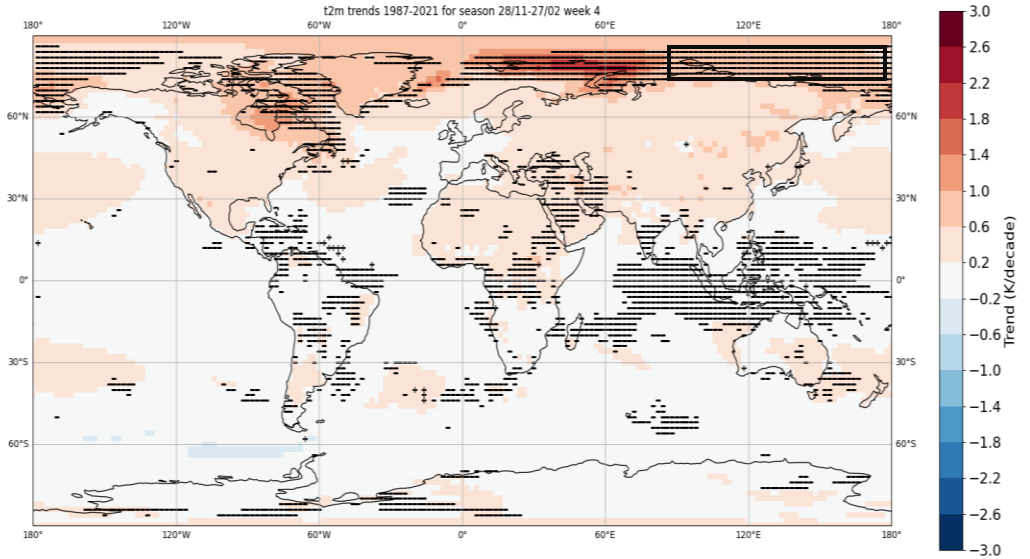


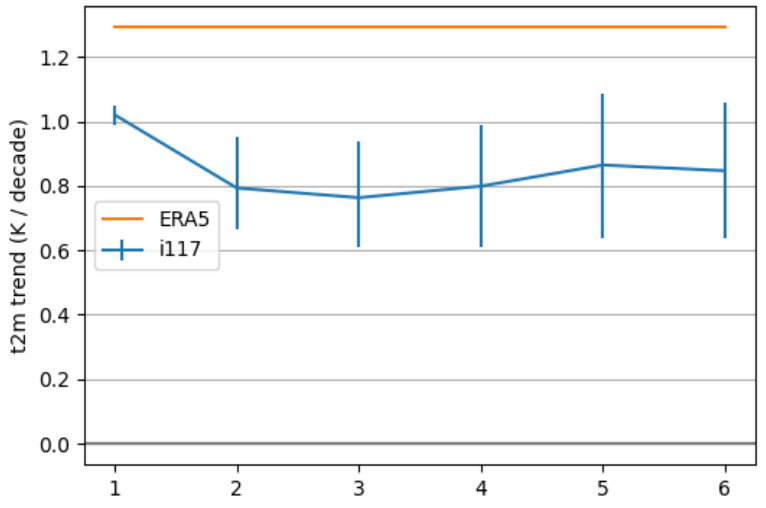
Trend of DJF 2m temperature in ERA5 from 1987 to 2021

Important trend should pass 3 criteria (stippling otherwise)

1. Robustness I: non-zero trend (Wilcoxon signed-rank test on weekly trends)
2. Robustness II: sensitivity to leaving out single years < 10%
3. Importance: total variance explained by trend > 10%

Trends in ECMWF re-forecasts – WEEK 4





Weekly reforecasts in DJF 1978-2021 (35 years) with IFS Cycle 48r1:

Severe under-estimation of ERA5 trend in some Arctic regions: e.g. 0.8 K per decade instead of 1.3 K per decade in the Eastern Arctic Ocean

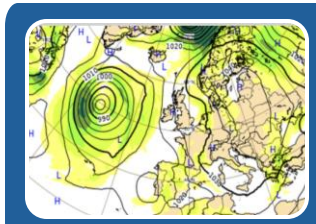
Hetsche et al, 2025

Improving sub-seasonal predictions

- Increased resolution: *Km-scale resolution?*
- Increased Earth System model complexity (e.g. interactive aerosols)
- Improved initialization/observing systems
- Online or offline model corrections
- Machine learning methods

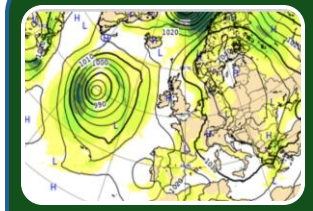
ECMWF

Operational ensemble forecasting systems at ECMWF



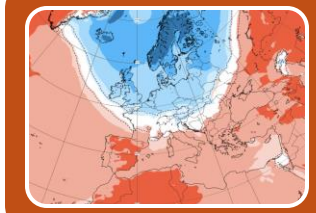
Medium range

- 0-15 days
- 9 km resolution, 137 levels
- 51 ensemble members, run twice daily
- Upgraded approximately once a year



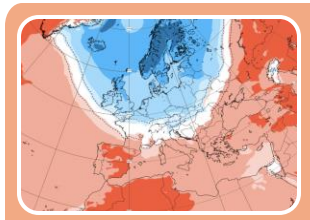
AIFS-ENS.V2: Medium range

- 0-15 days
- ~0.25 degree resolution
- 51 ensemble members running twice daily
- Upgraded as developments are ready



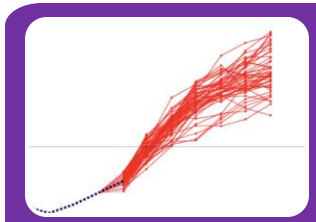
Sub-seasonal

- 0-46 days
- 36 km, 137 levels
- 101 ensemble members, run once daily
- Upgraded approximately once a year, with medium range



AIFS-SUBS

- 0-46 days
- 36 km, 137 levels
- 101 ensemble members, run once daily
- Upgraded approximately once a year, with medium range



Long range: SEAS5

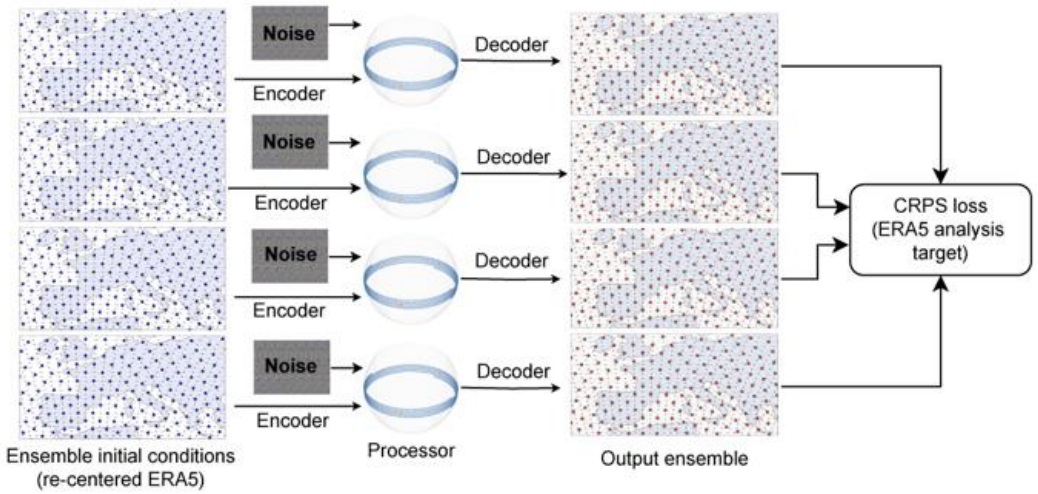
- 0-7 months
- 36 km, 137 levels
- 51 ensemble members, run once a month
- Four times a year, the forecast is run out to 13 months
- Last upgraded in 2017 (Cy43r1), next upgrade SEAS6

AIFS-SUBS

- Adapting AIFS-CPRS for sub-seasonal forecasting

Operational (experimental):
- 46-days forecast
- Real-time forecasts:
  - 101 member
  - every day
- Reforecasts:
  - 20-year reforecasts every odd day
  - 11 members

Training period: 1979-2006 + 2012-2024.
Out-of training period: 2007-2011 for forecast skill assessment.



AIFS-CRPS - Lang et al. 2024

arXiv:2607.05100 (physics)

[Submitted on 6 Jul 2026]

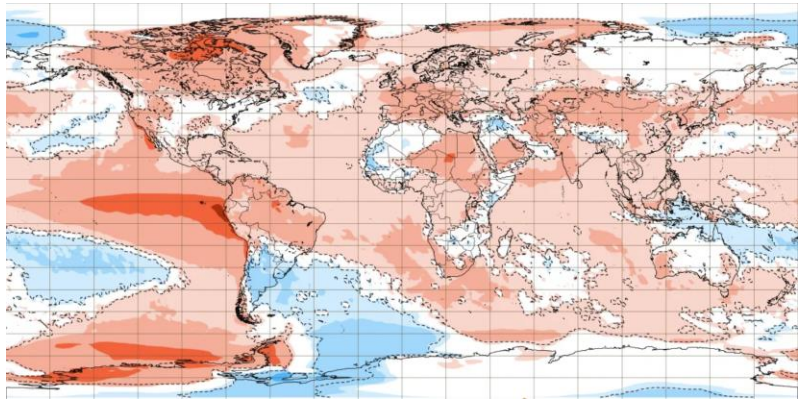
AIFS-SUBS: Extending Data-Driven Forecasting to Sub-Seasonal Timescales

Jakob Schloer, Steffen Tietsche, Christopher D. Roberts, Lorenzo Zampieri, Simon Lang, Gert Mertes, Gareth Jones, Matthew Chantry, Frederic Vitart

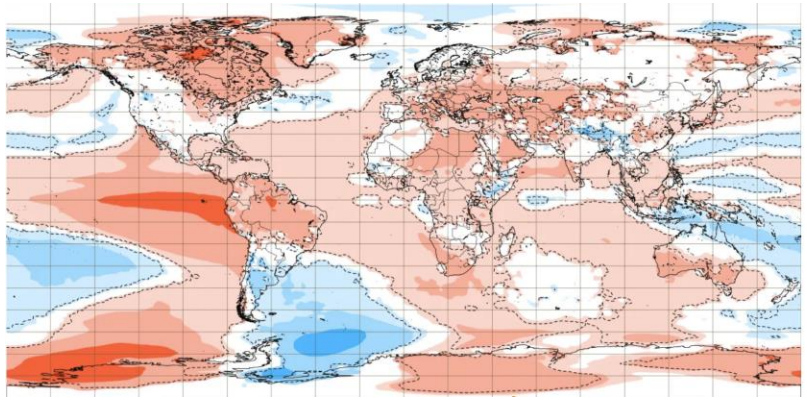
AIFS-SUBS Forecast Chart

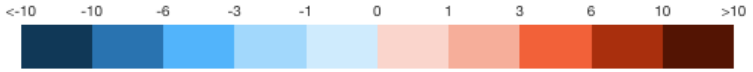
2mtm – 21/09/2026 Week 4

IFS-SUBS



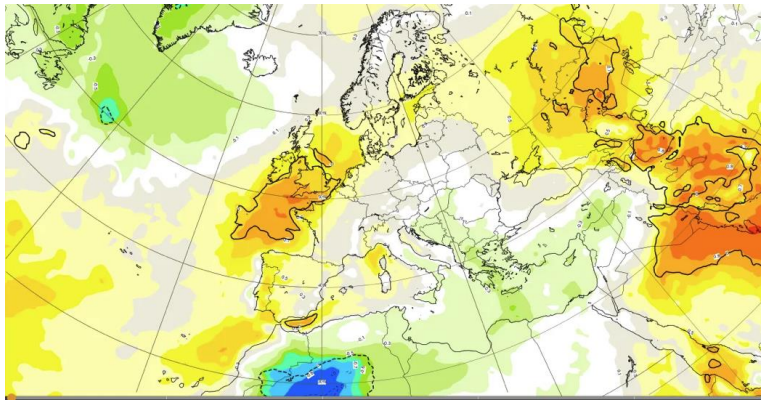
AIFS-SUBS



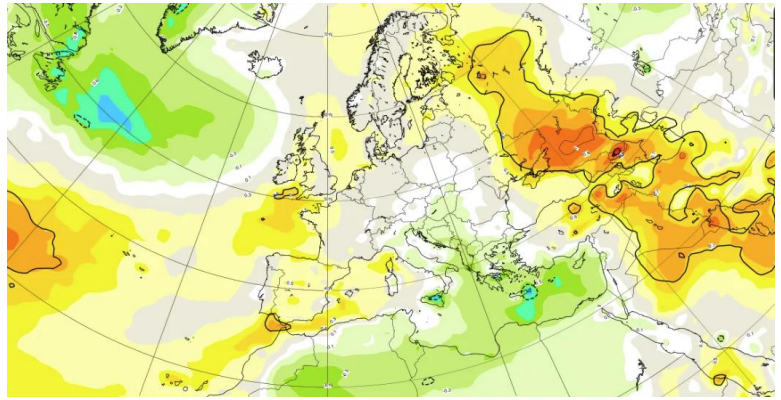


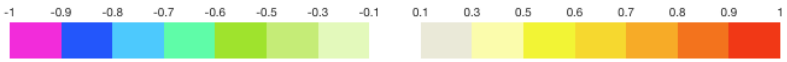
Extreme Forecast Index 2mtm 8/10/2026 Week 1

IFS-SUBS

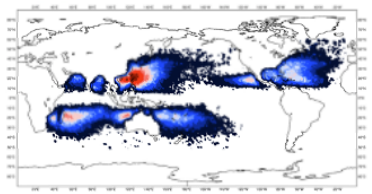


AIFS-SUBS



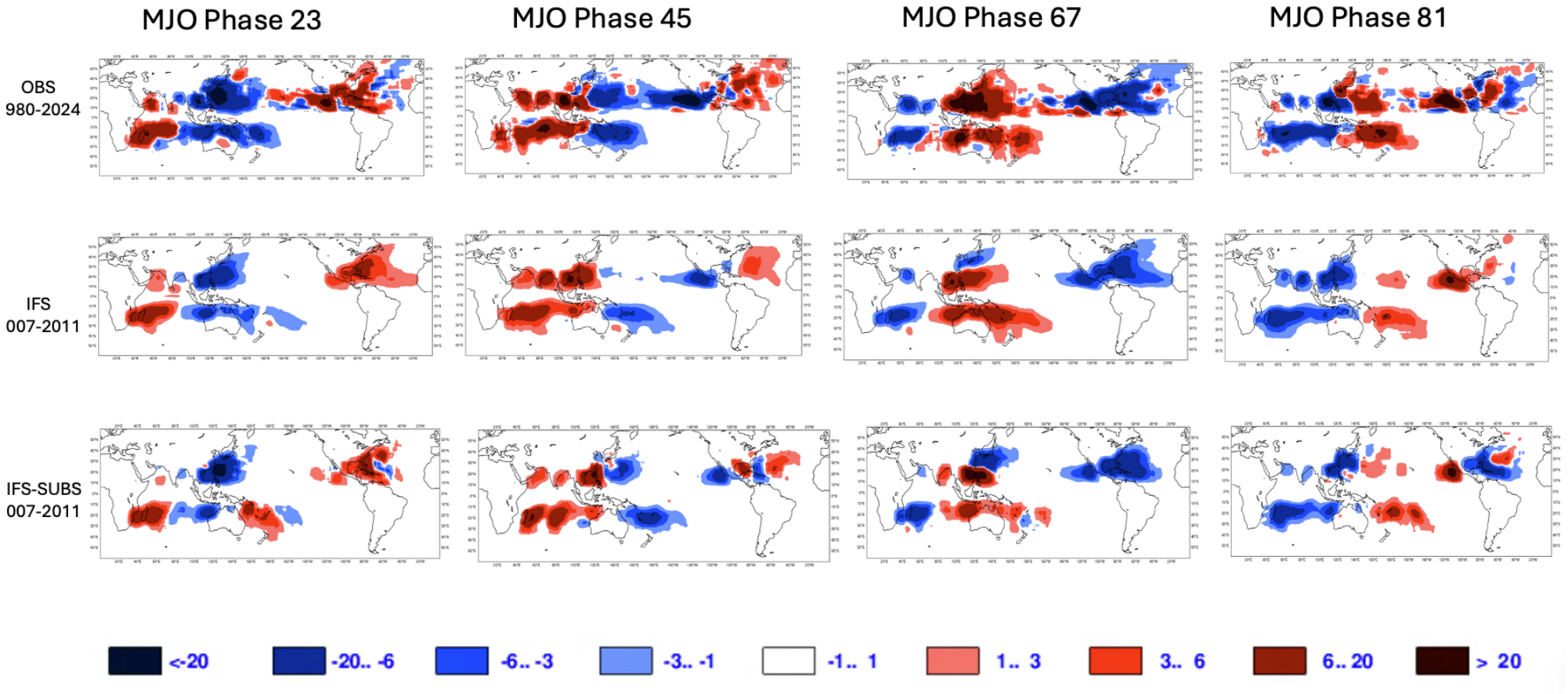


Modulation of TCs by the MJO in AIFS

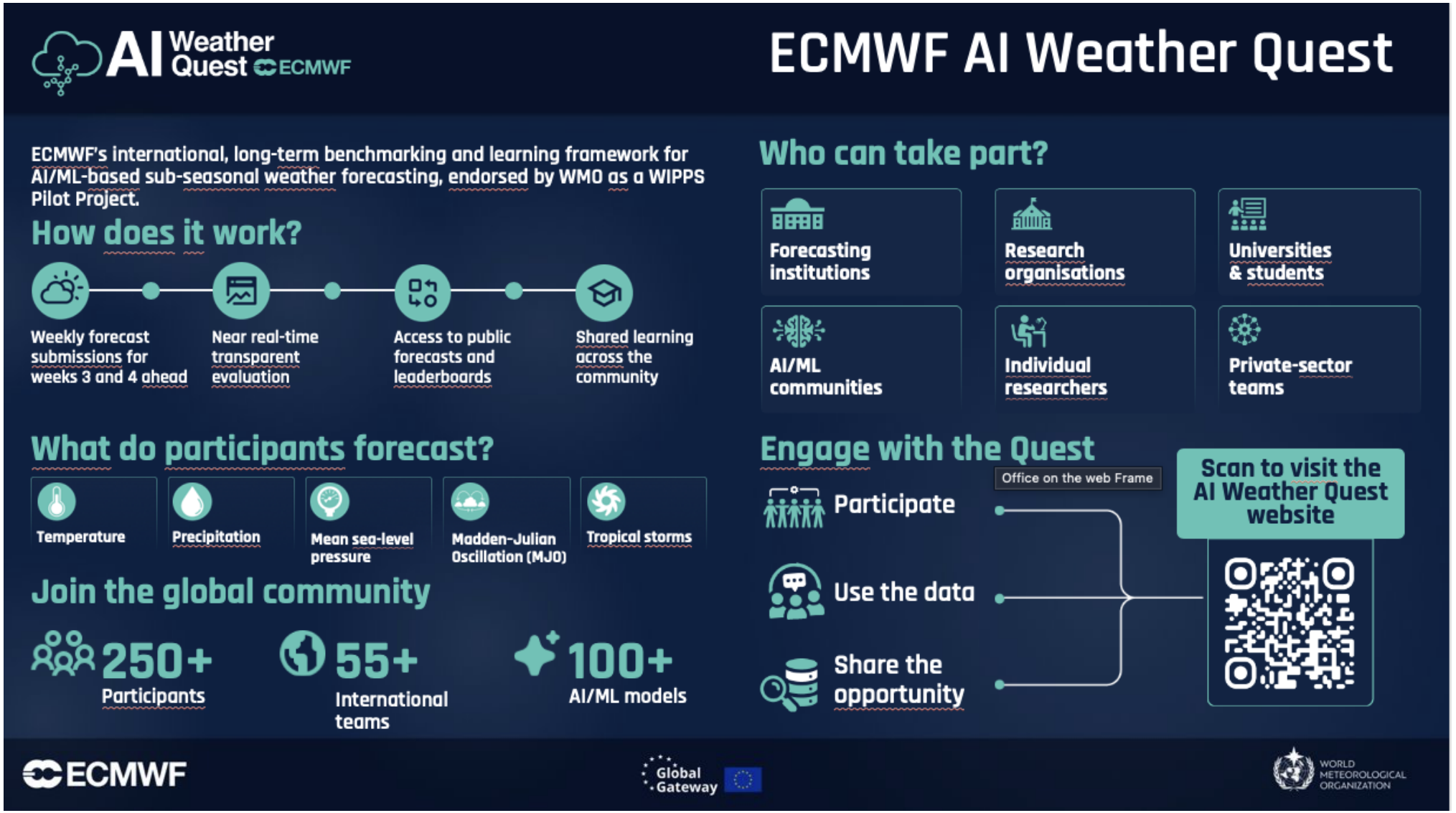


AIFS-SUBS: Modulation of TC by MJO - JJASON

Anomaly of number of tropical storm days within 300 km
Out of training period (2007-2011)– Day 10-46 lead time



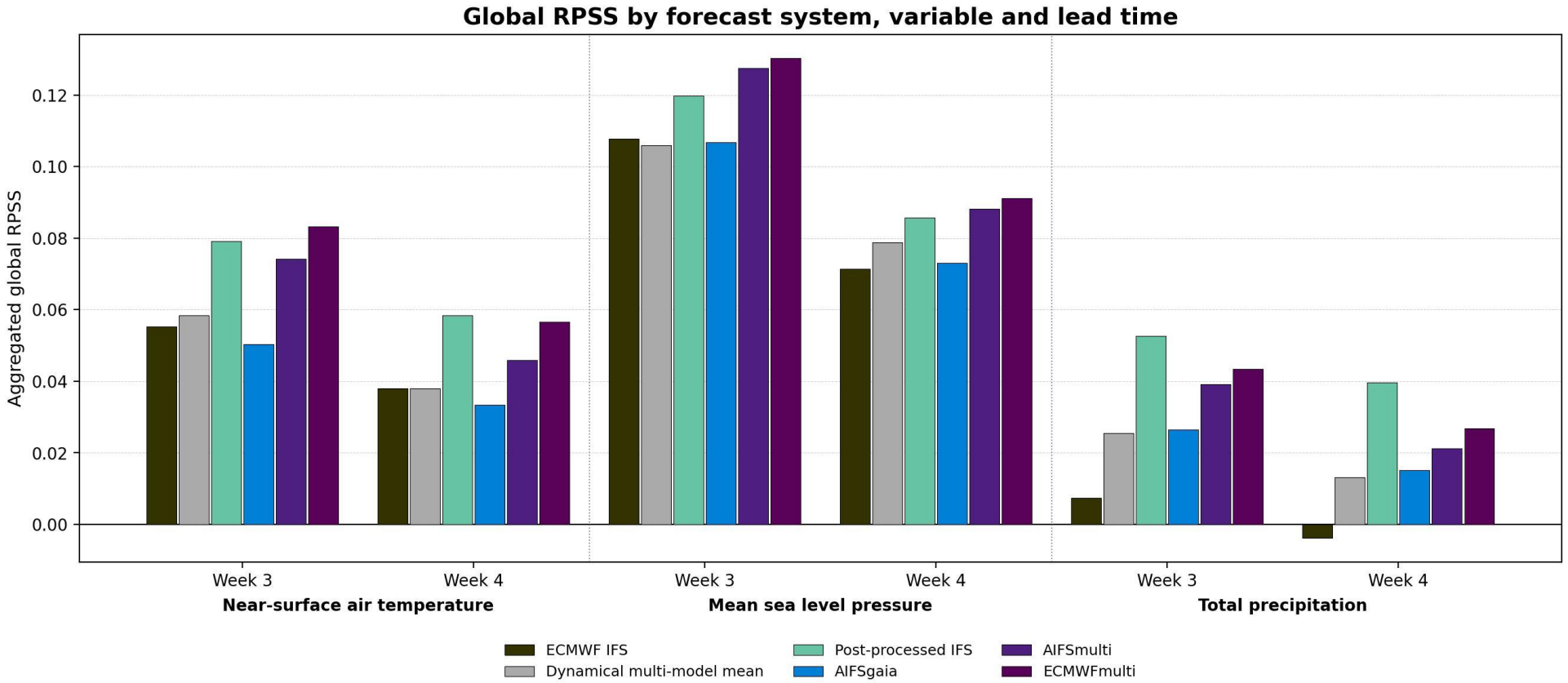
AI Weather Quest



Performances of ML sub-seasonal system

AI Weather Quest ECMWF

Sept '25 to Aug '26.



Post-processed IFS = MicroDuet
AIFSmulti = average prediction of AIFSgaia, AIFShera and AIFSthalassa
ECMWFmulti = average prediction of IFS, AIFSgaia, AIFShera and AIFSthalassa

Conclusions

- SSTs, sea ice , Soil moisture, stratospheric initial conditions and MJO are sources of predictability at the intra-seasonal time scale.
- The sub-seasonal forecasting system produces forecasts for days 12-18 that are generally more skilful than climatology and persistence of day 5-11. Beyond day 20, the monthly forecast is marginally skilful. For some applications and some regions, these forecasts could however be of some interest.
- Sub-seasonal forecasts are improving!
- AIFS-SUBS is now running routinely experimentally: forecast skill is similar to IFS-SUBS, except for precipitation where AIFS-SUBS outperforms IFS-SUBS.
- AI Weather Quest: best performing models use post-processing AI of dynamical models or multi-model combinations oof AI and dynamical models.


www.ecmwf.int