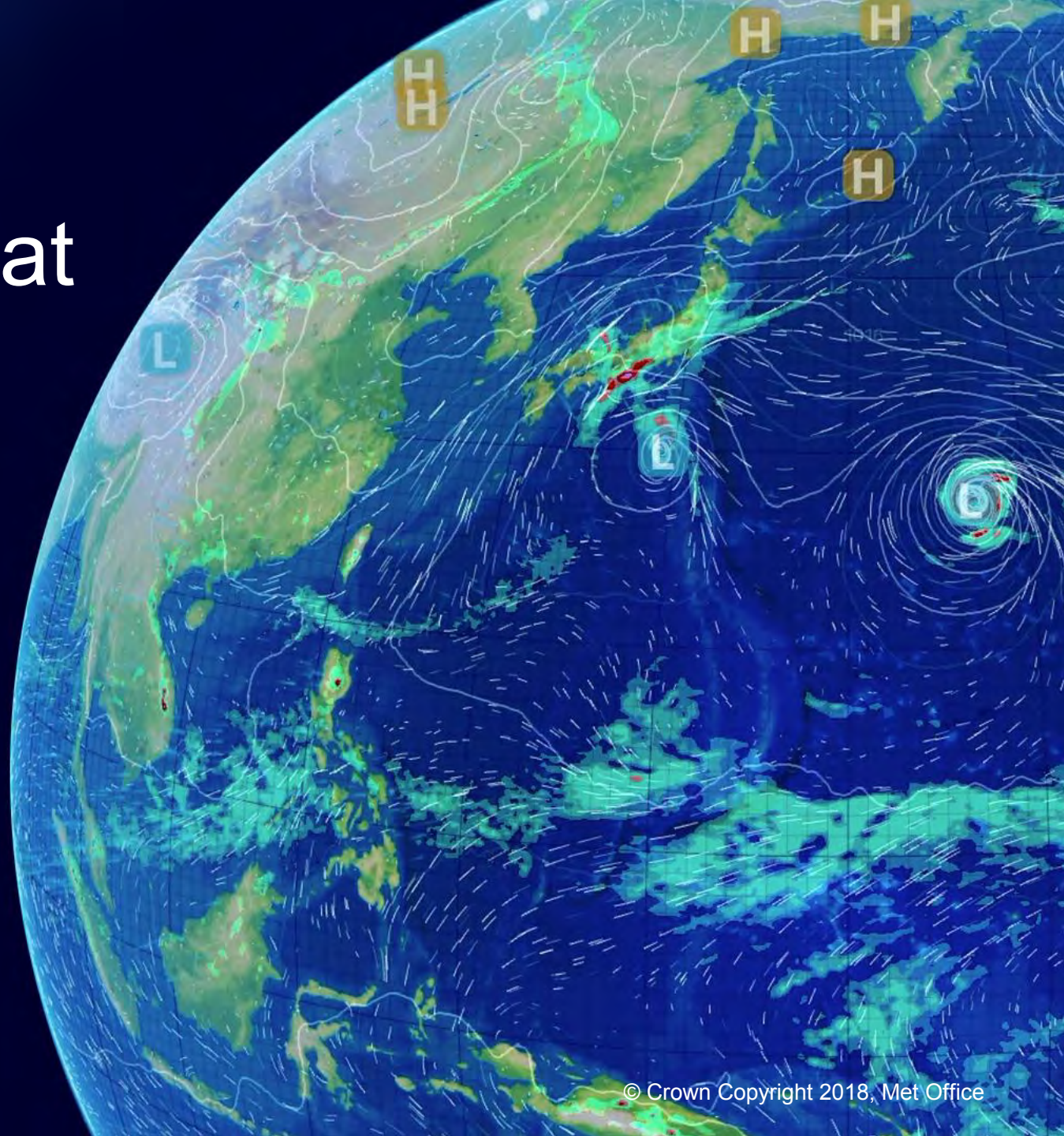
Met Office
Hadley Centre

Multi-year forecasting at the Met Office

Julia Lockwood, Nick Dunstone, Rosie Eade, Leon Hermanson, Jeff Knight, Melissa Seabrook, Adam Scaife, Doug Smith

+ *many others*

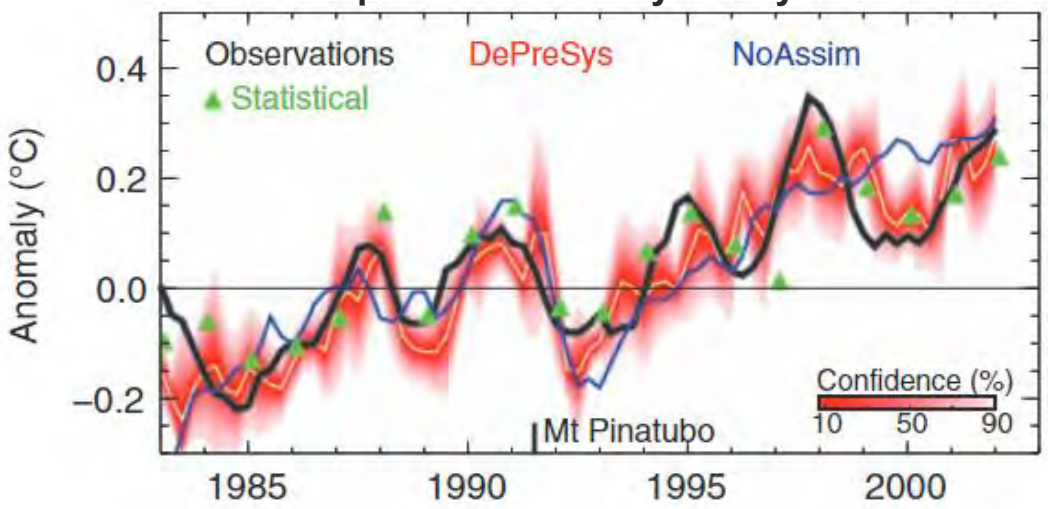
Workshop on Societally Relevant Multi-Year Predictions, 29th March 2022



The DePreSys system

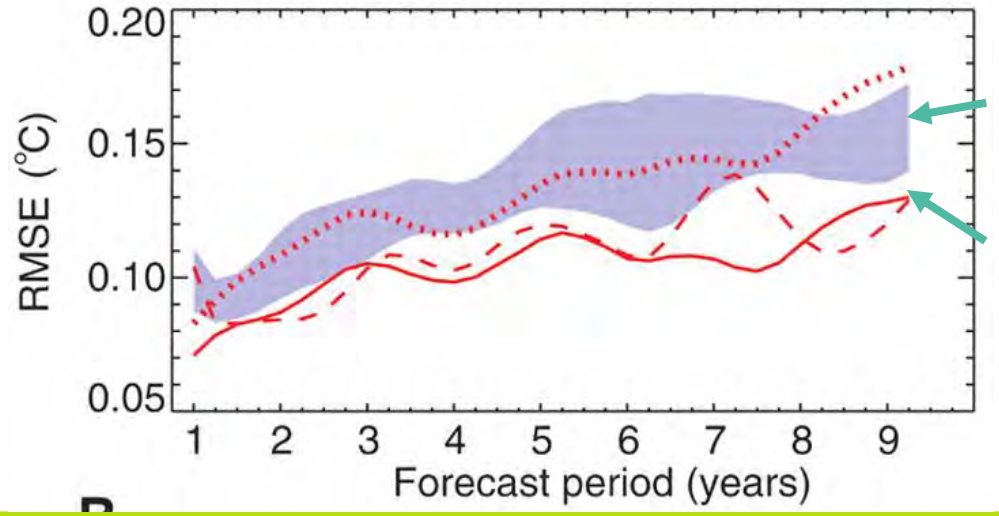
- DePreSys = Decadal prediction system
- Developed to bridge gap between seasonal forecasts and climate projections:
  - Predict internal variability and externally forced changes in near-term climate
- First developed in 2007:
  - Based on HadCM3 (2.5°x3.75° atm res)
  - 4x10 year integrations initialised 4 times per year over 1982-2001 (80 start dates) with current atmosphere and observed ICs.
  - Showed improved skill over uninitialised models for global mean temperature in first year and beyond.

Global Temperature Anomaly: first year



DePreSys (red shading): improved interannual variability in yr 1

RMSE of annual mean global tas, yr 1 to 9



NoAssim (unitialised) RMSE (blue)

DePreSys (solid red line): reduced RMSE even for yr 9

Smith et al 2007, Science
https://www.science.org/doi/10.1126/science.1139540

Since 2007…

- DePreSys used to issue global annual mean temp forecasts for coming year on Met Office website since 2008 (Folland et al 2013)
- Several upgrades: now on DePreSys4 (2021)
  - HadGEM3-GC3.1 (0.83°x0.56° atm)
  - 10 members initialised 1st Nov every year, 1960-present
- Discoveries:

Folland et al., 2013
doi:10.1002/grl.50169

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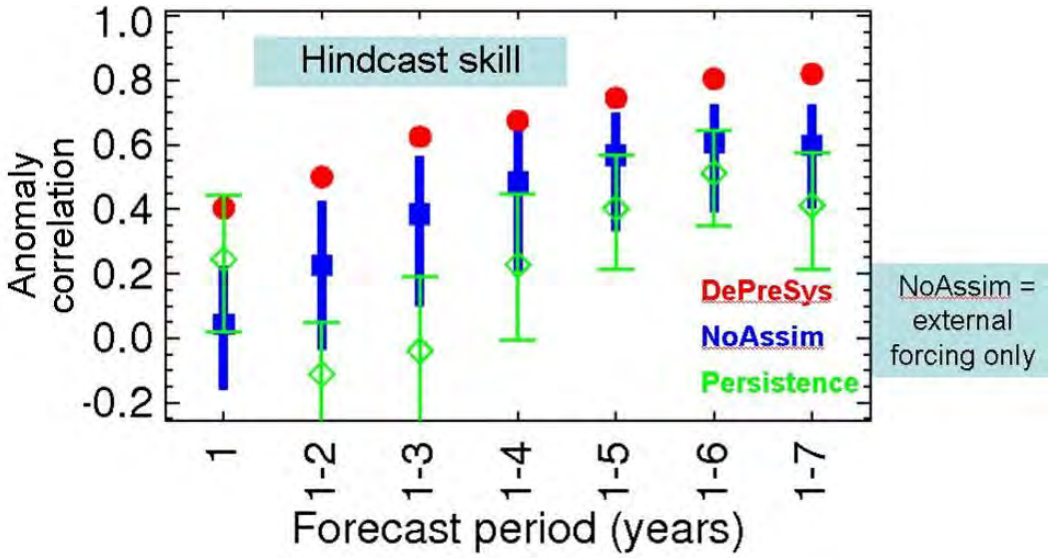
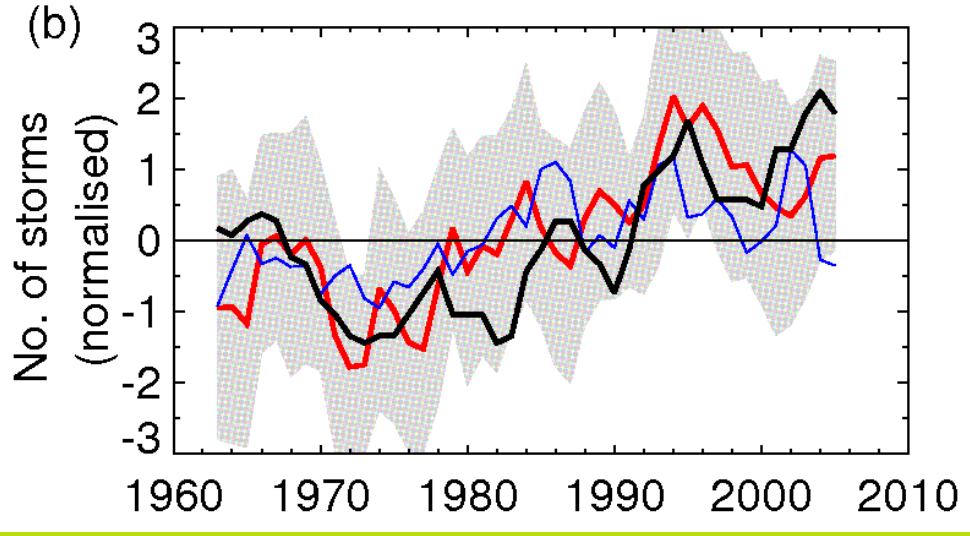
- Discoveries:
  - **North Atlantic tropical cyclone skill y1 to y1-7 (Smith et al 2010)**

Multi-year North Atlantic tropical cyclone frequency skill



5-year mean N. Atl tropical storm numbers



Smith et al., 2010
https://www.nature.com/articles/ngeo1004

Since 2007…

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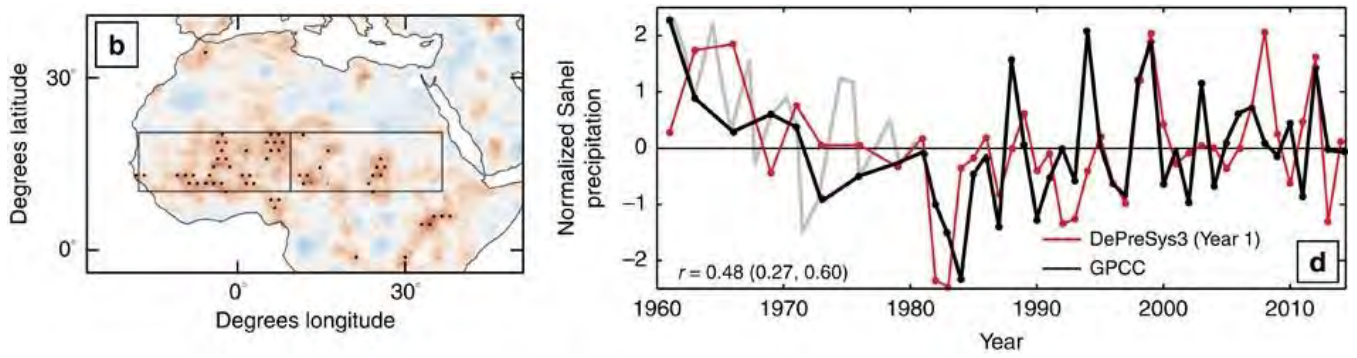
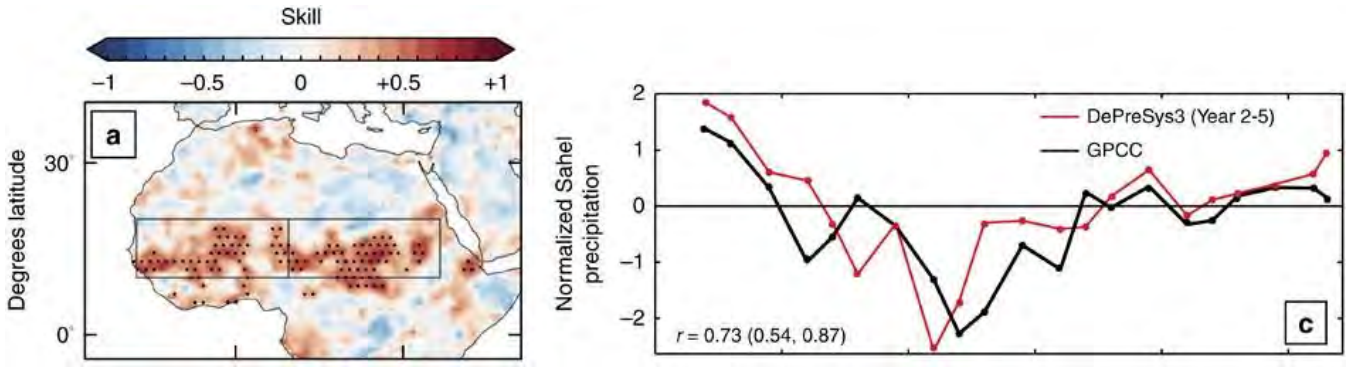
  - 10 members initialised 1st Nov every year, 1960-present
- Discoveries:
  - **Sahel summer rainfall skill for y1 (predicting summer season, 8 month lead time) and y2-5 (Sheen et al., 2017)**

Y1 summer Sahel rainfall skill (8 month lead time)



Y2-5 summer Sahel rainfall skill



Sheen et al., 2017
https://www.nature.com/articles/ncomms14966

Since 2007…

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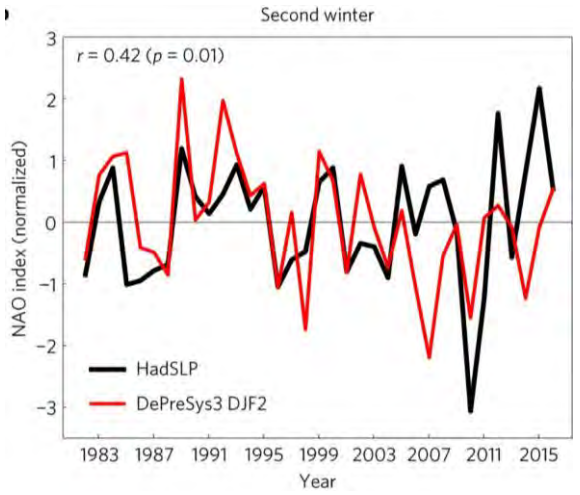
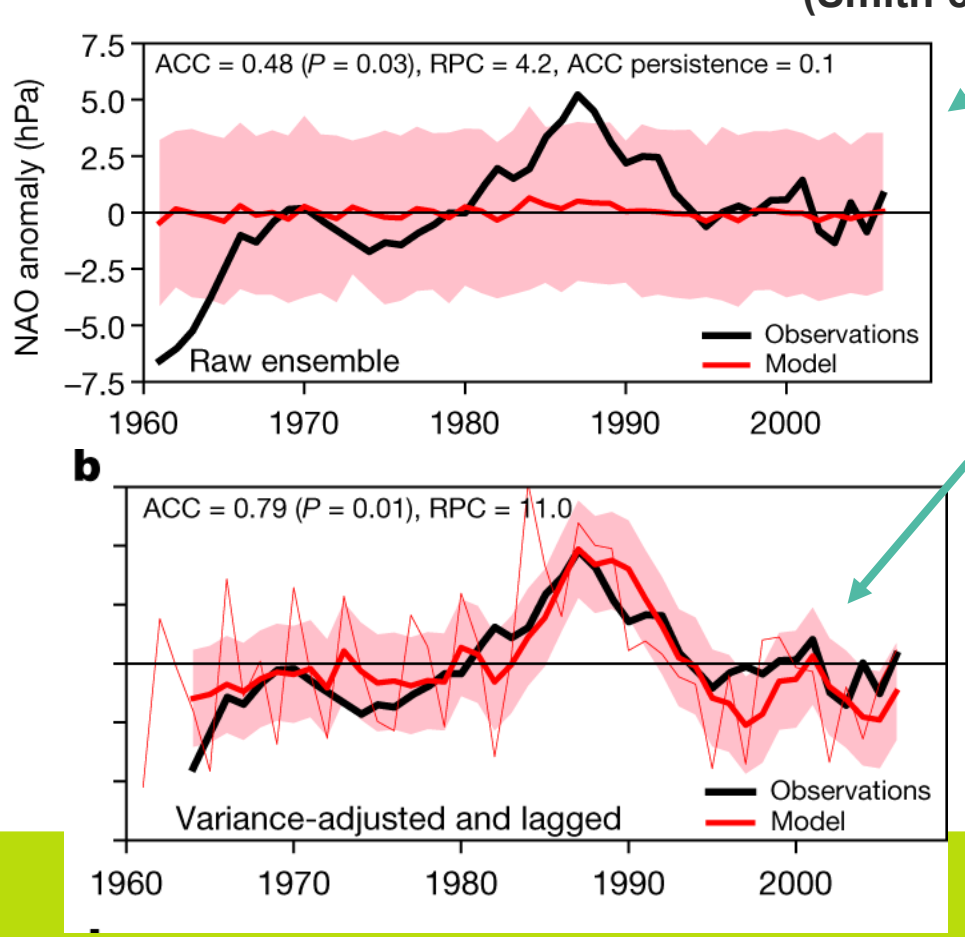
- Several upgrades: now on DePreSys4 (2021)
  - HadGEM3-GC3.1 (0.83°x0.56° atm)
  - 10 members initialised 1st Nov every year, 1960-present
- Discoveries:
  - **Extra-tropical: NAO skill in second winter (DJF y2) and y 2-9 (DJFM)**



Y2 NAO (DJF) skill (Dunstone et al 2016) Signal too weak (~x2)

Y2-8 NAO (DJFM) skill (Smith et al 2020)



Signal much too small (~x10) Need huge ensemble (676 members used here)

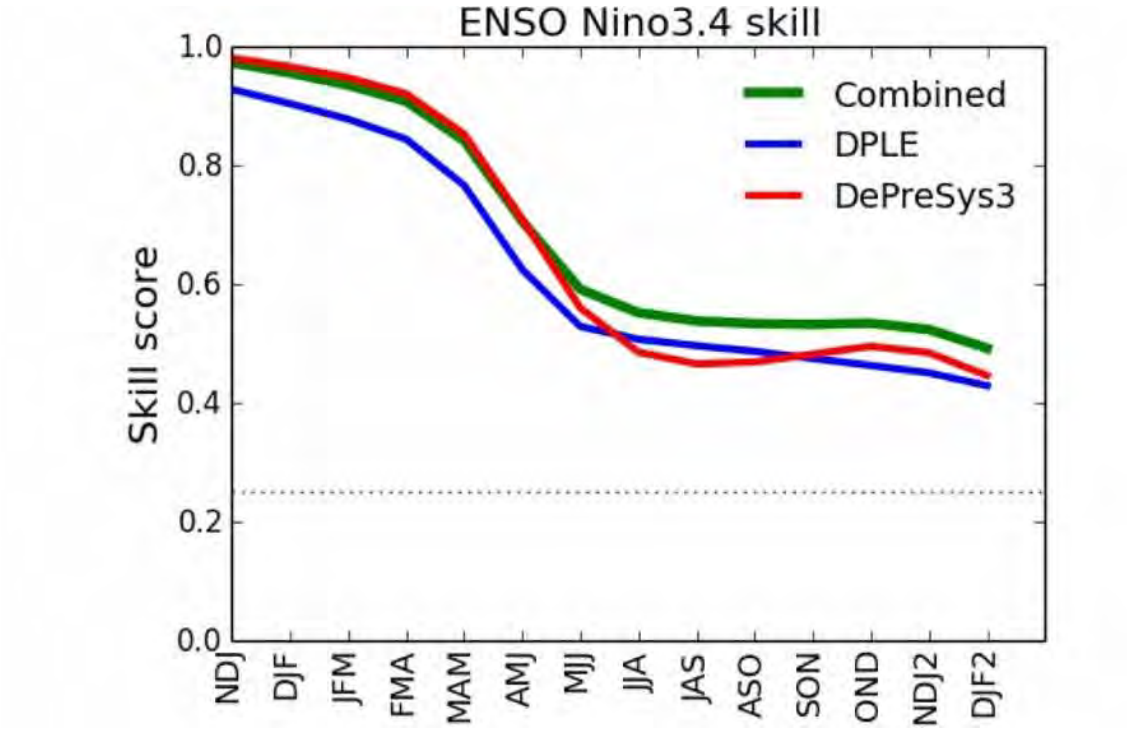
Similar result also found by Athanasiadis et al. (2020)

Dunstone et al., (2016) https://doi.org/10.1038/ngeo2824

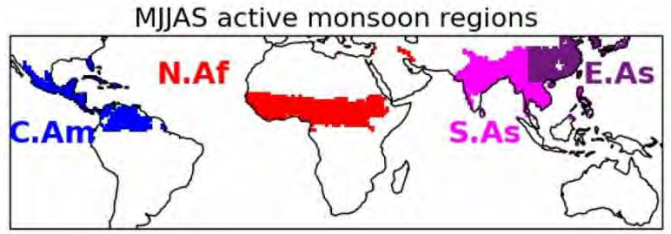
Smith et al., (2020) https://doi.org/10.1038/s41586-020-2525-0

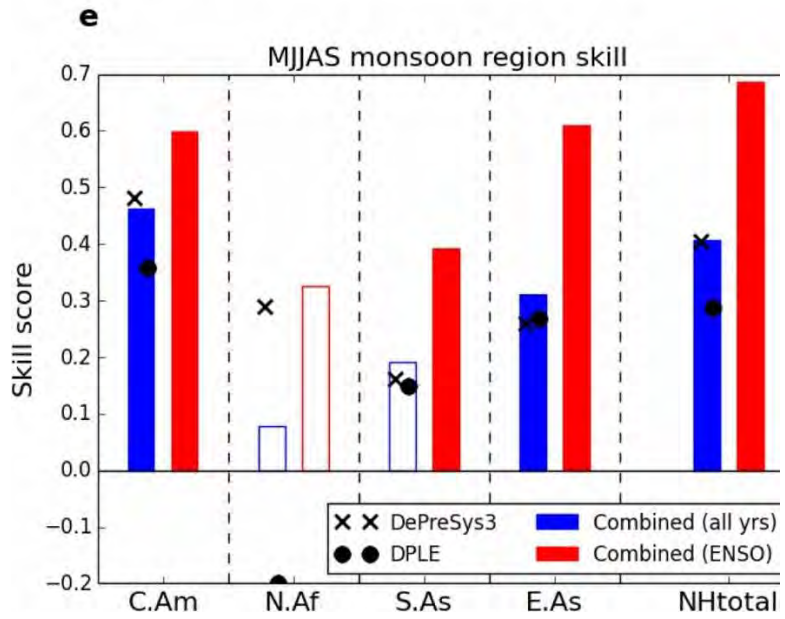
Interannual predictions

- Two 40 member ensembles (Met Office DP3 & NCAR DPLE)
- 1st November starts, 1959-2017



- Significant seasonal ENSO skill (r>0.5) out to second winter (forecast months 14-16)
- Advantage from combining systems





- Skill for boreal summer monsoon rainfall at 6 month lead time (MJJAS)
- Flow dependent – higher skill when active ENSO event is forecast (red)

Dunstone et al 2020
https://doi.org/10.1088/1748-9326/ab9f7d

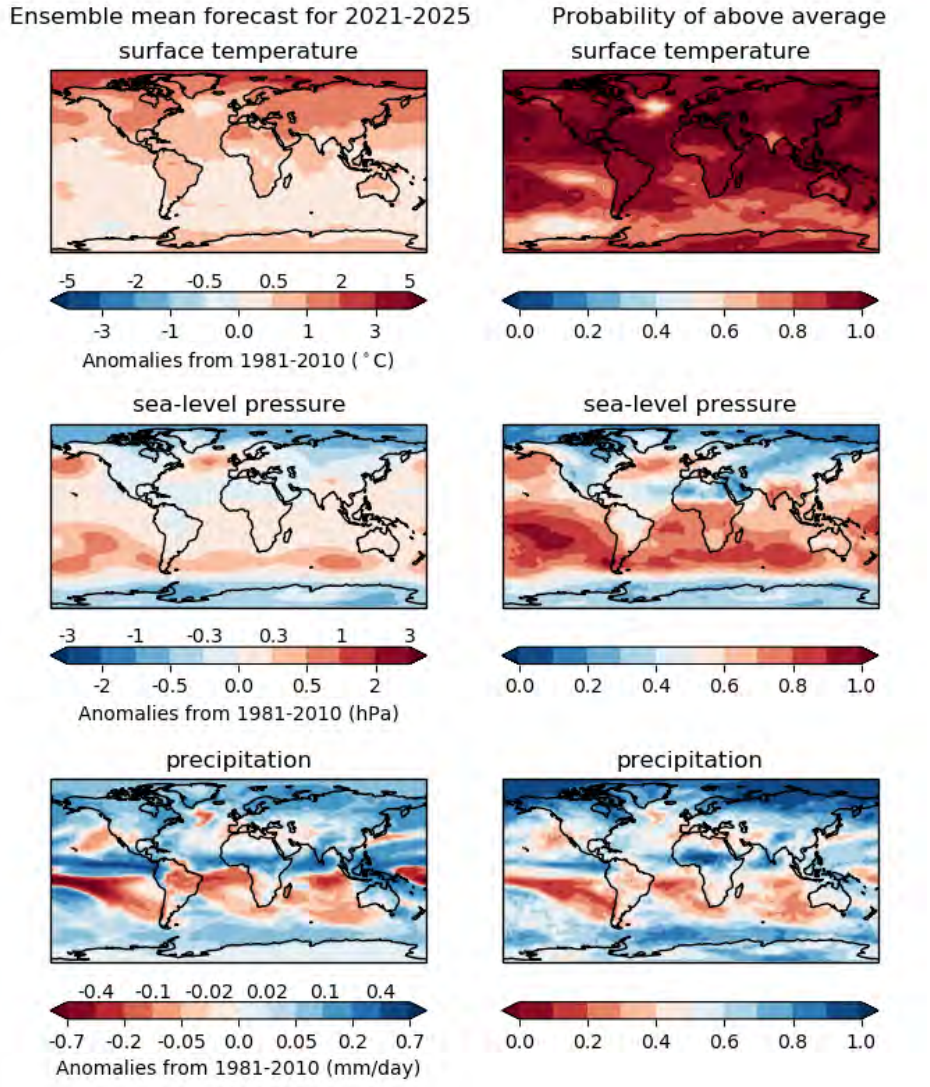
WMO Lead Centre for Annual to Decadal Climate Prediction

- Met Office was designated the Lead Centre for Annual to Decadal Climate Prediction in May 2017.
- Some of the responsibilities of the Lead Centre are:
  - Prepare forecast fields annually from the data collected
  - Create **Global Annual to Decadal Climate Update** (consensus forecast)
  - Prepare verification statistics of the multi-model and individual models
  - Make available up-to-date information on the decadal prediction systems
- This is all available at **www.wmolc-adcp.org**

Leon Hermanson, Melissa Seabrook

WMO Global Annual to Decadal Climate Update

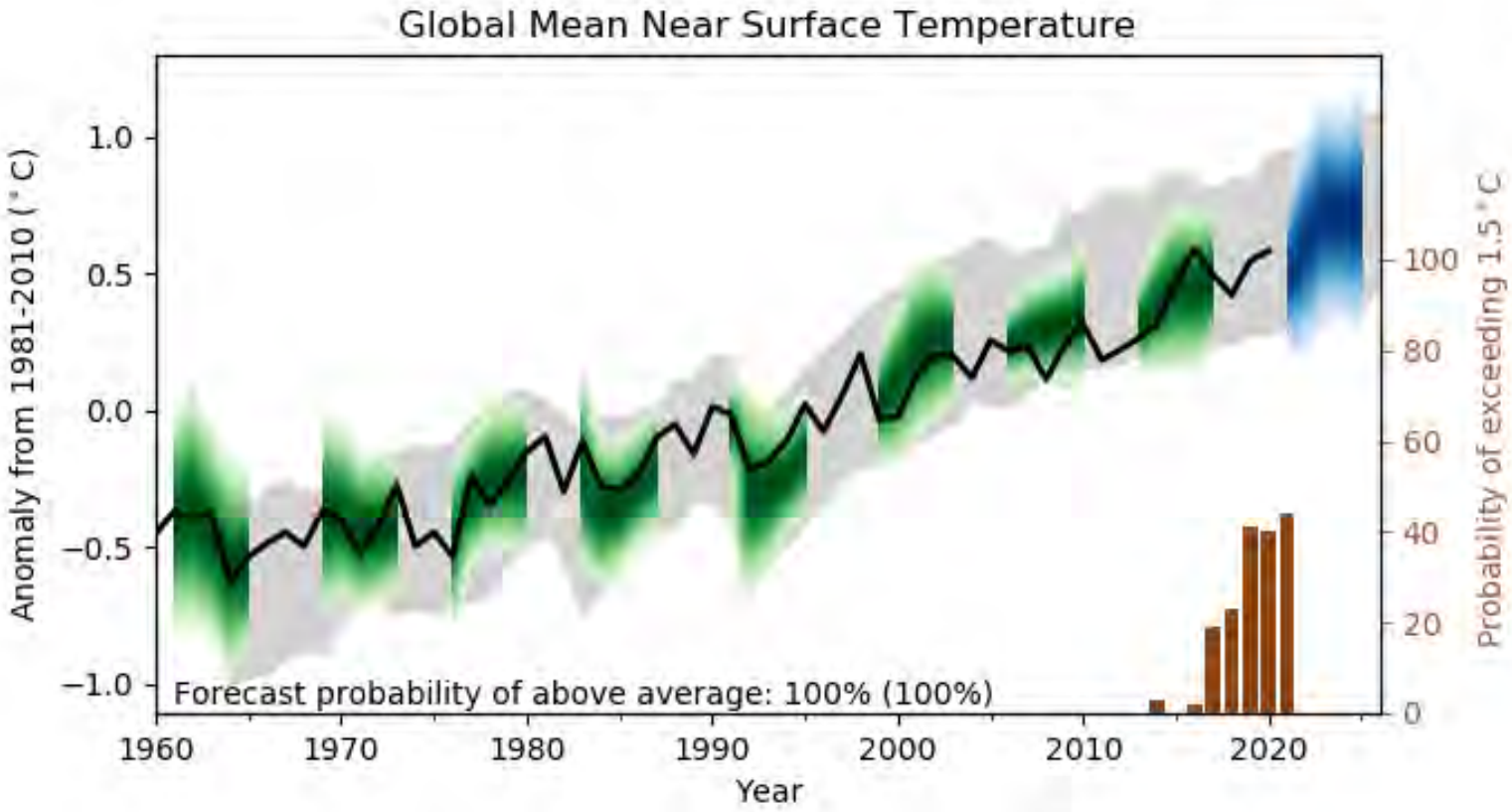
- Issued annually by WMO Lead Centre for Annual to Decadal Climate Prediction, hosted by the Met Office
- International contributions from BSC, CSIRO, CCCMA, CMCC, DWD, Met Office, GFDL, MIROC, MRI, BCCR, SMHI+DMI
- Climate *predictions* for the next year and next five years
- Now considered one of the key annual output reports of the WMO
- Press releases from WMO and Met Office had phenomenal pickup by nearly all major news outlets with millions of subscribers and in multiple languages
- www.wmolc-adcp.org

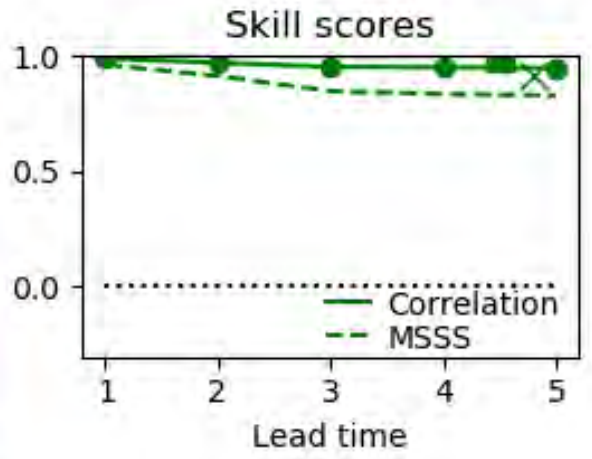


Hermanson et al., 2022, BAMS, accepted

Leon Hermanson, Melissa Seabrook

Key outputs of the Global Annual to Decadal Climate Update 2021





Observed

Forecast	Yes	No
Yes	15 (15)	0 (2)
No	1 (2)	33 (34)

Hit rate: 93% (88%)
False alarm rate: 0% (11%)

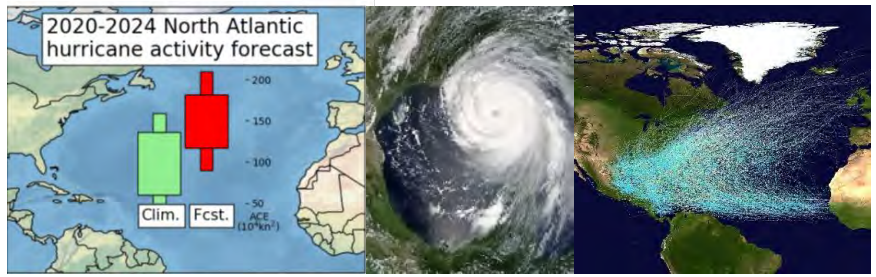
- It is about as likely as not (40% chance) that at least one of the next 5 years will be 1.5°C warmer than pre-industrial levels and the chance is increasing with time
- It is very unlikely (10% chance) that the five-year mean global near-surface temperature for 2021-2025 will be 1.5°C warmer than pre-industrial levels
- The chance of at least one year exceeding the current warmest year, 2016, in the next five years is 90%
- Next report to be released **May 2022**

Leon Hermanson, Melissa Seabrook

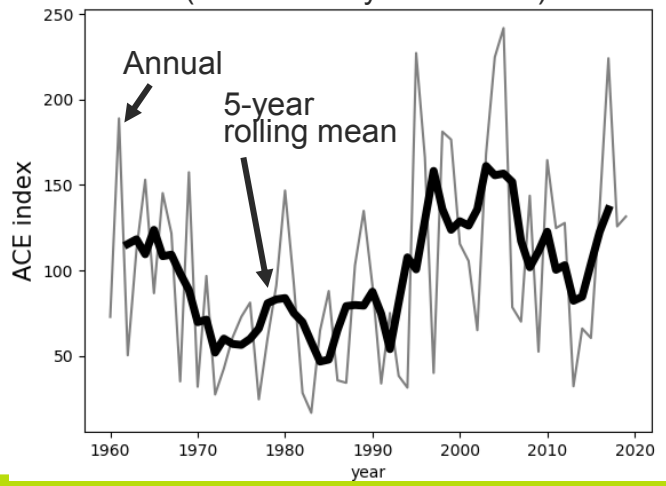
Other services: C3S Sectoral Application of Decadal Predictions

- Met Office was one of 4 centres involved in C3S Sectoral Applications of Decadal Climate Predictions (along with DWD, CMCC, BSC; for more info see Anca Brookshaw's talk, poster session)

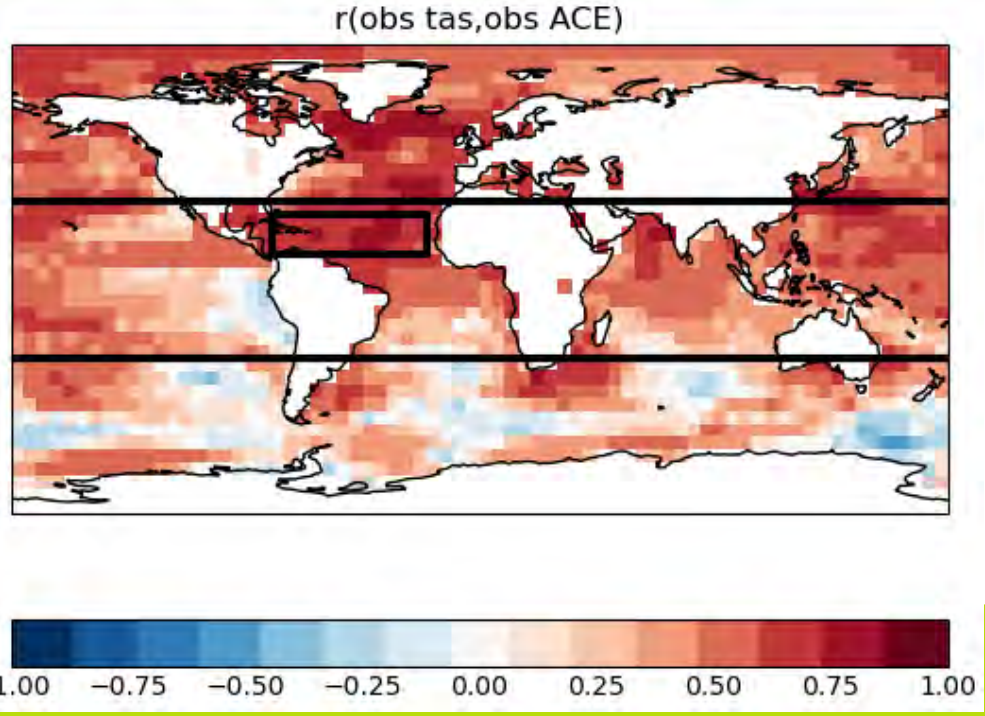
- Partnered with Willis Research Network/Willis Towers Watson to produce **y1-5** forecasts of North Atlantic hurricane activity



Observed North Atlantic hurricane activity 1960-2019
(measured by ACE index)



ACE= accumulated cyclone energy (sum of 6 hrly max windspeed^2 over track for windspeeds >35kn)



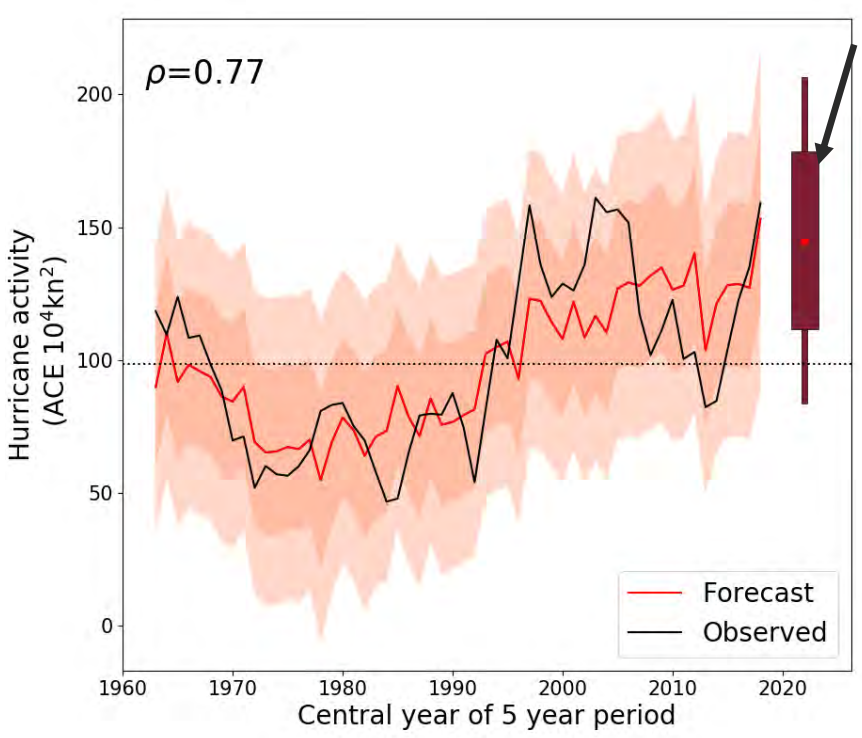
- Used relative temperature index from models to estimate hurricane activity (ACE):

$$T_{MDR}-T_{ROP}$$

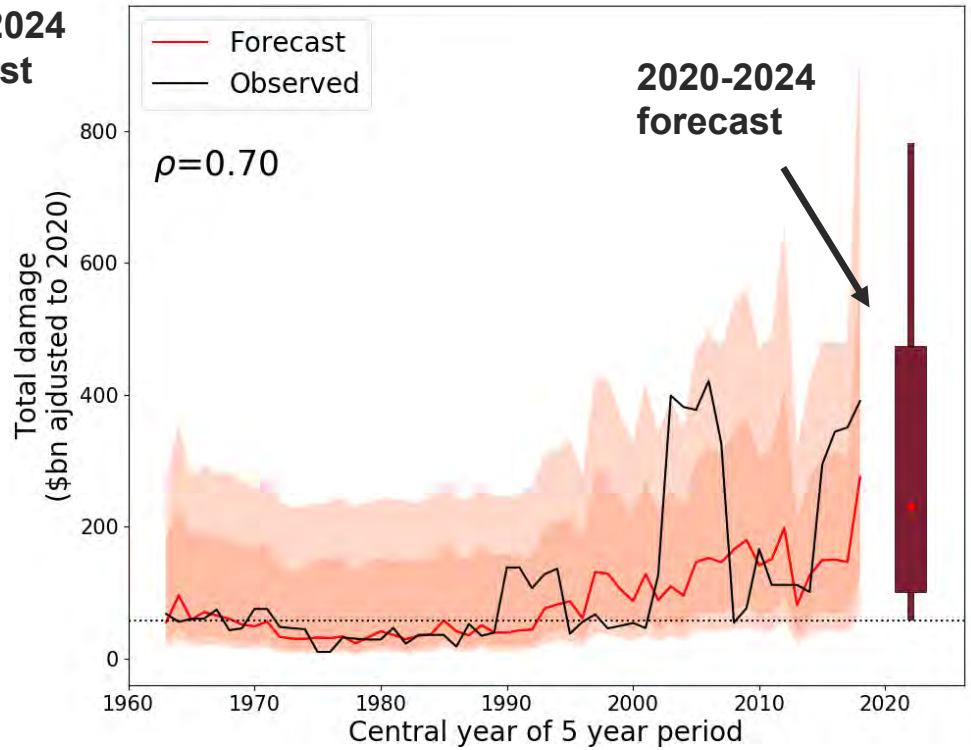
North Atlantic Tropical Cyclone Forecasts

- High skill in predicting basin wide hurricane activity (ACE)

Time series of obs and predicted ACE



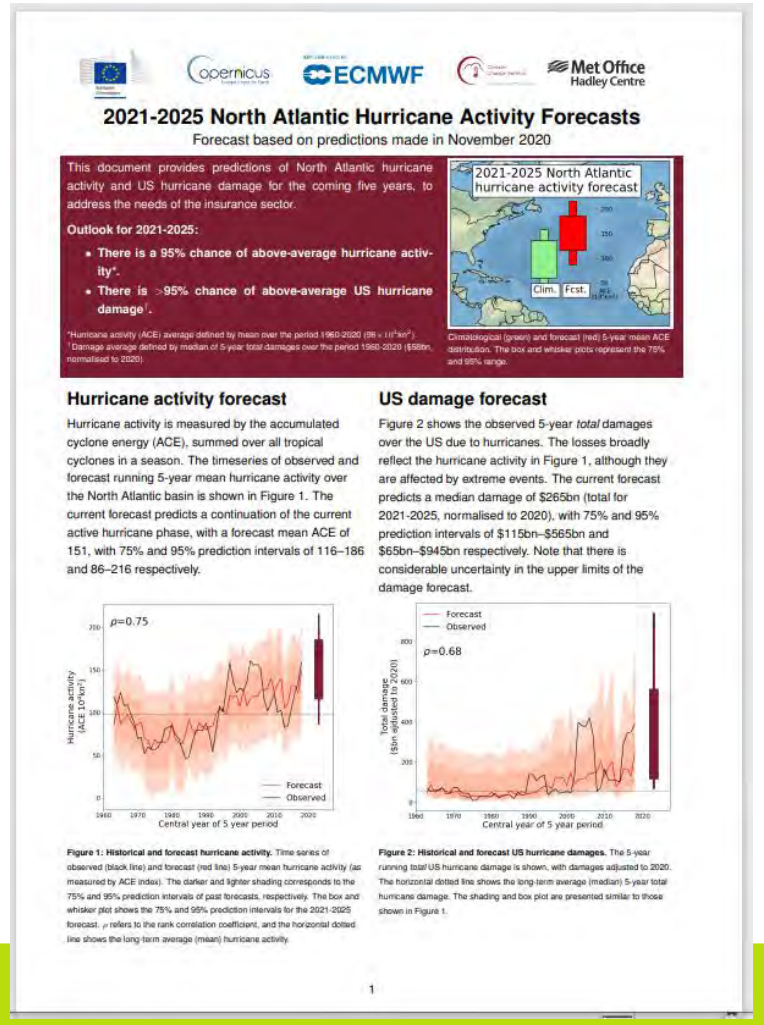
Time series of obs and predicted damages



- Also demonstrated skill in predicting 5 year **damages** (measured in USD, after adjusting for inflation, changes in wealth and population)

North Atlantic Tropical Cyclone Forecasts

Released forecasts for 2020-2024 and 2021-2025
Available on C3S website: https://climate.copernicus.eu/decadal-predictions-insurance



2021-2025 North Atlantic Hurricane Activity Forecasts

Forecast based on predictions made in November 2020

This document provides predictions of North Atlantic hurricane activity and US hurricane damage for the coming five years, to address the needs of the insurance sector.

Outlook for 2021-2025:

- **There is a 95% chance of above-average hurricane activity*.**
- **There is >95% chance of above-average US hurricane damage†.**

*Hurricane activity (ACE) average defined by mean over the period 1960-2020 (8×10^4 kn^2).
†Damage average defined by median of 5-year total damages over the period 1960-2020 ($56bn, normalised to 2020).

2021-2025 North Atlantic hurricane activity forecast

Clim. Fcst.

Climatological (green) and forecast (red) 5-year mean ACE distribution. The box and whisker plots represent the 75% and 95% range.

Hurricane activity forecast

Hurricane activity is measured by the accumulated cyclone energy (ACE), summed over all tropical cyclones in a season. The timeseries of observed and forecast running 5-year mean hurricane activity over the North Atlantic basin is shown in Figure 1. The current forecast predicts a continuation of the current active hurricane phase, with a forecast mean ACE of 151, with 75% and 95% prediction intervals of 116–186 and 86–216 respectively.

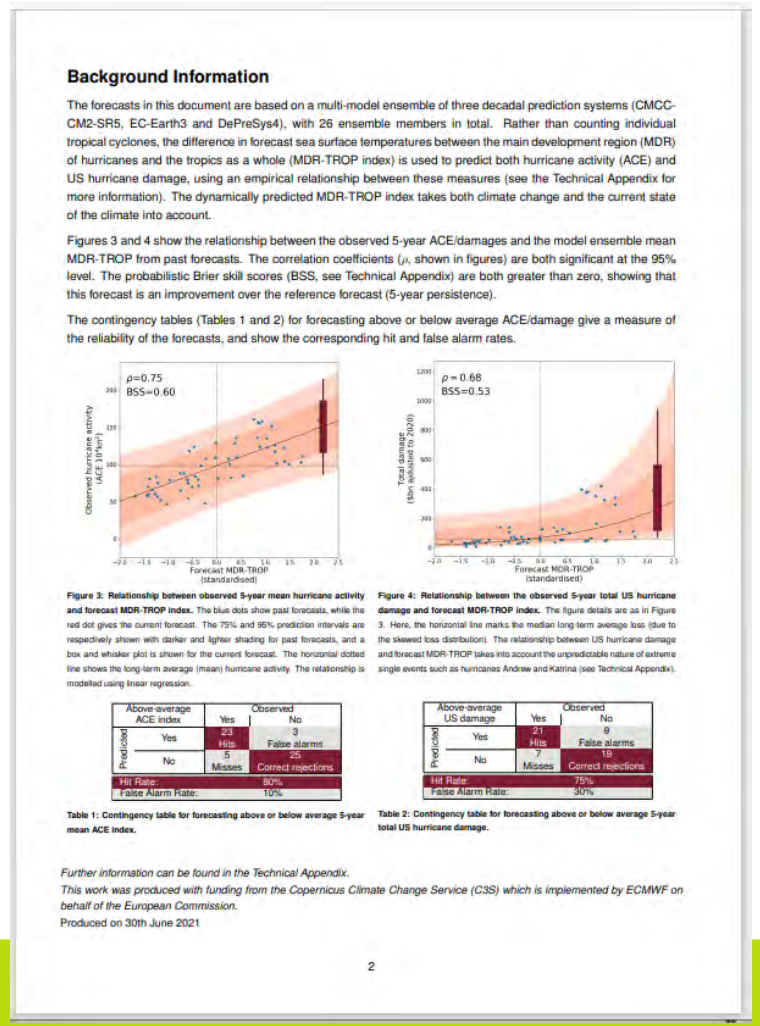
US damage forecast

Figure 2 shows the observed 5-year *total* damages over the US due to hurricanes. The losses broadly reflect the hurricane activity in Figure 1, although they are affected by extreme events. The current forecast predicts a median damage of $265bn (total for 2021-2025, normalised to 2020), with 75% and 95% prediction intervals of $115bn–$565bn and $65bn–$945bn respectively. Note that there is considerable uncertainty in the upper limits of the damage forecast.

Figure 1: Historical and forecast hurricane activity. Time series of observed (black line) and forecast (red line) 5-year mean hurricane activity (as measured by ACE index). The darker and lighter shading corresponds to the 75% and 95% prediction intervals of past forecasts, respectively. The box and whisker plot shows the 75% and 95% prediction intervals for the 2021-2025 forecast. ρ refers to the rank correlation coefficient, and the horizontal dotted line shows the long-term average (mean) hurricane activity.

Figure 2: Historical and forecast US hurricane damages. The 5-year running *total* US hurricane damage is shown, with damages adjusted to 2020. The horizontal dotted line shows the long-term average (median) 5-year total hurricane damage. The shading and box plot are presented similar to those shown in Figure 1.

1



Background Information

The forecasts in this document are based on a multi-model ensemble of three decadal prediction systems (CMCC-CM2-SR5, EC-Earth3 and DePreSys4), with 26 ensemble members in total. Rather than counting individual tropical cyclones, the difference in forecast sea surface temperatures between the main development region (MDR) of hurricanes and the tropics as a whole (MDR-TROP index) is used to predict both hurricane activity (ACE) and US hurricane damage, using an empirical relationship between these measures (see the Technical Appendix for more information). The dynamically predicted MDR-TROP index takes both climate change and the current state of the climate into account.

Figures 3 and 4 show the relationship between the observed 5-year ACE/damages and the model ensemble mean MDR-TROP from past forecasts. The correlation coefficients (ρ, shown in figures) are both significant at the 95% level. The probabilistic Brier skill scores (BSS, see Technical Appendix) are both greater than zero, showing that this forecast is an improvement over the reference forecast (5-year persistence).

The contingency tables (Tables 1 and 2) for forecasting above or below average ACE/damage give a measure of the reliability of the forecasts, and show the corresponding hit and false alarm rates.

Figure 3: Relationship between observed 5-year mean hurricane activity and forecast MDR-TROP index. The blue dots show past forecasts, while the red dot gives the current forecast. The 75% and 95% prediction intervals are respectively shown with darker and lighter shading for past forecasts, and a box and whisker plot is shown for the current forecast. The horizontal dotted line shows the long-term average (mean) hurricane activity. The relationship is modelled using linear regression.

Figure 4: Relationship between the observed 5-year total US hurricane damage and forecast MDR-TROP index. The figure details are as in Figure 3. Here, the horizontal line marks the median long-term average loss (due to the skewed loss distribution). The relationship between US hurricane damage and forecast MDR-TROP takes into account the unpredictable nature of extreme single events such as hurricanes Andrew and Katrina (see Technical Appendix).

Above-average ACE index		Observed: Yes	Observed: No
Predicted	Yes	23 Hits	3 False alarms
	No	5 Misses	25 Correct rejections
Hit Rate:		80%	
False Alarm Rate:		10%	

Table 1: Contingency table for forecasting above or below average 5-year mean ACE index.

Above-average US damage		Observed: Yes	Observed: No
Predicted	Yes	21 Hits	9 False alarms
	No	7 Misses	19 Correct rejections
Hit Rate:		75%	
False Alarm Rate:		30%	

Table 2: Contingency table for forecasting above or below average 5-year total US hurricane damage.

Further information can be found in the Technical Appendix.

This work was produced with funding from the Copernicus Climate Change Service (C3S) which is implemented by ECMWF on behalf of the European Commission.

Produced on 30th June 2021

2

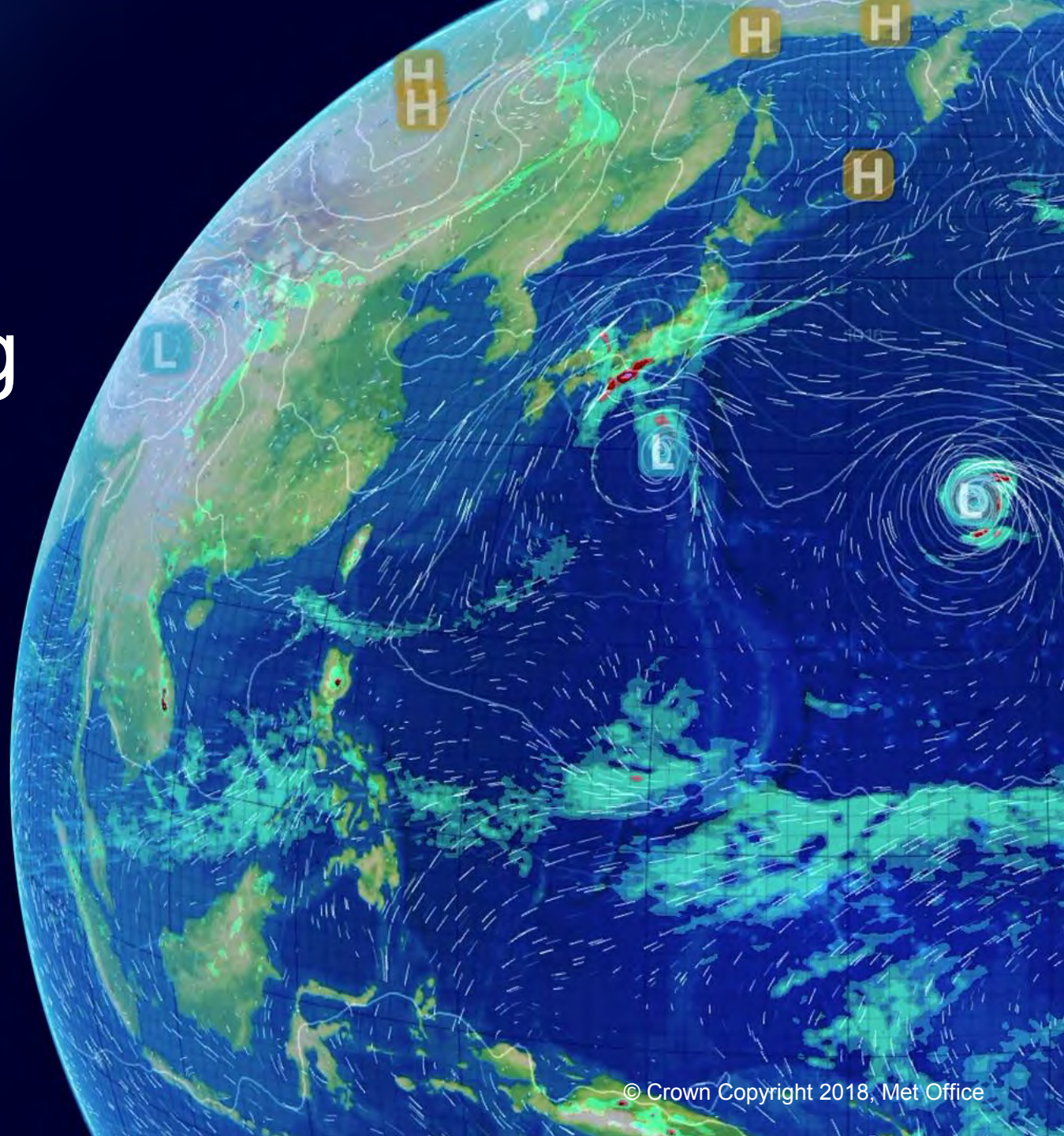
Summary

- Decadal forecasting has a long history at the Met Office, but the shorter forecast periods beyond year 1 less explored.
- Lead centre work publicises forecasts on annual to 5-year timescale.
- Sector specific services are developing (e.g. tropical cyclones, also researching product for summer rainfall in Yangtze river basin).
- Research is still needed to understand drivers on these timescales (involvement in WCRP Lighthouse Activities on Explaining and Predicting Earth System Change https://www.wcrp-climate.org/epesc)

Met Office
Hadley Centre

Thank you for listening

Any questions?



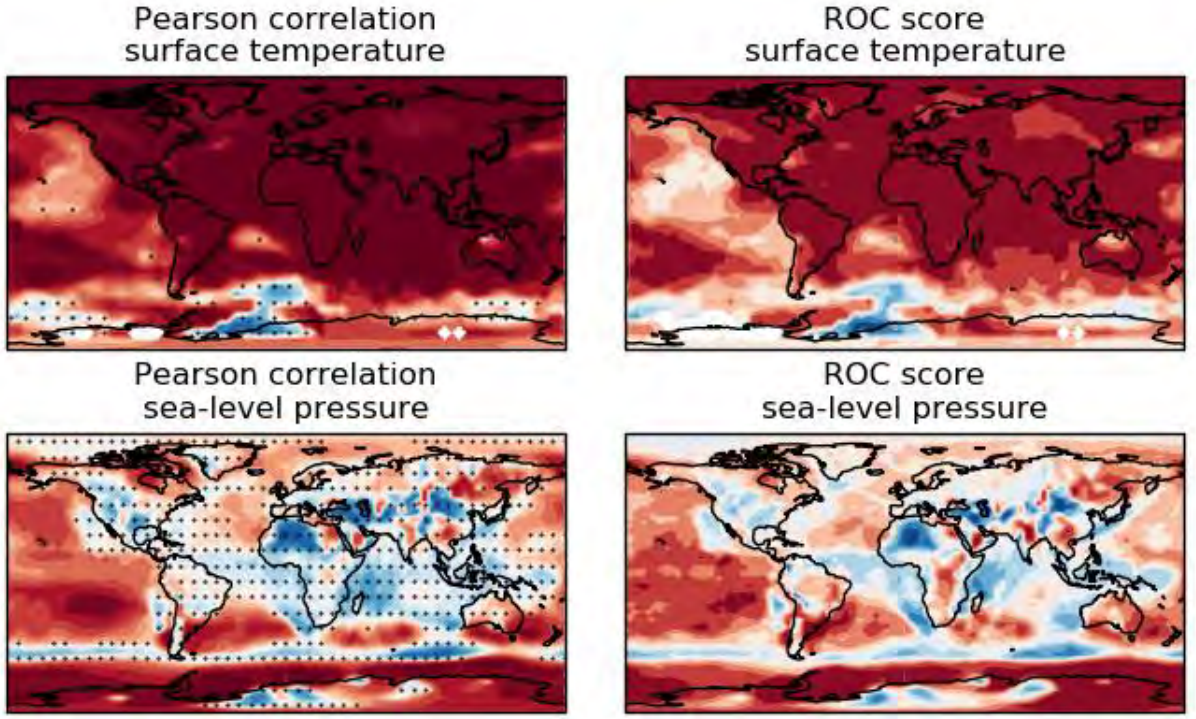
Met Office Hadley Centre

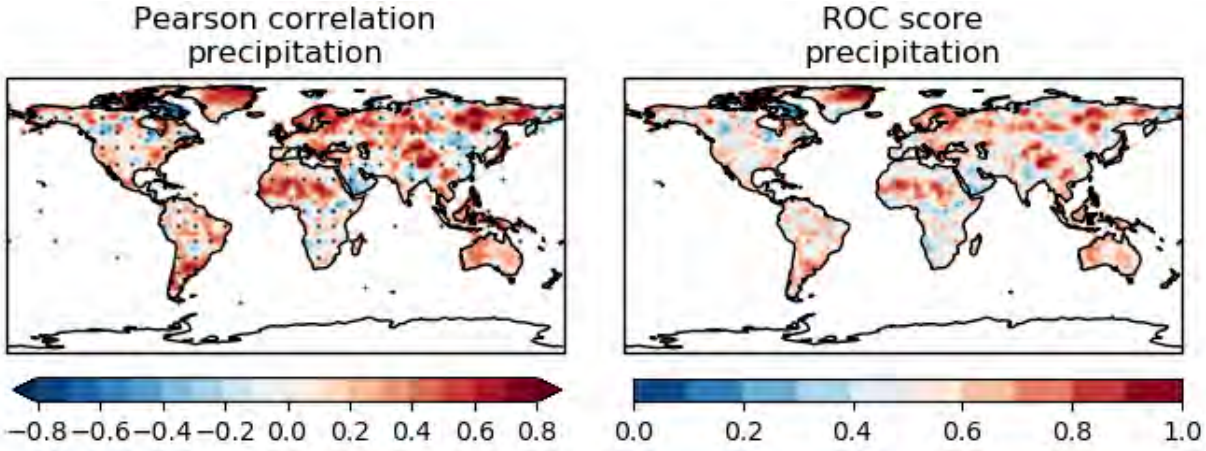
DePreSys4

	DePreSys4
Atmos. resolution	HadGEM3 GC3.1 N216 (60km) 85 levels
Atmos. reanalysis data	ERA 40/interim/5 nudged 6 hours
Ocean resolution	NEMO ¼° 75 levels
Ocean analysis data	MOSORA (10 members)
Ocean relaxation	10 days
Sea-ice conc. data	HadISST ice
Sea-ice thickness (?)	No
Sea-ice relaxation	1 day
Assimilation method	Full field
Ensemble creation	10 assimilation runs
Ensemble size	10 members

Skill maps for 1-5 years lead time

Baseline: 1981-2010





- Skill is high for temperature including for the Arctic.
- Sea-level pressure skill is moderate in the tropical Atlantic and for precipitation over land close to the ITCZ

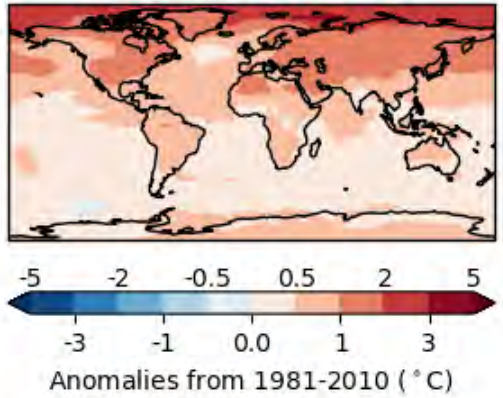
Stippling where positive correlation skill is not significant at the 5% level

Key outputs of the Global Annual to Decadal Climate Update 2021

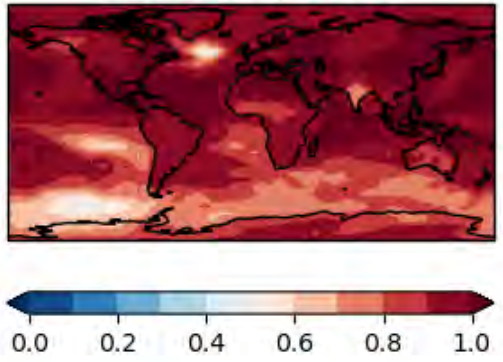
Met Office Hadley Centre

Baseline: 1981-2010

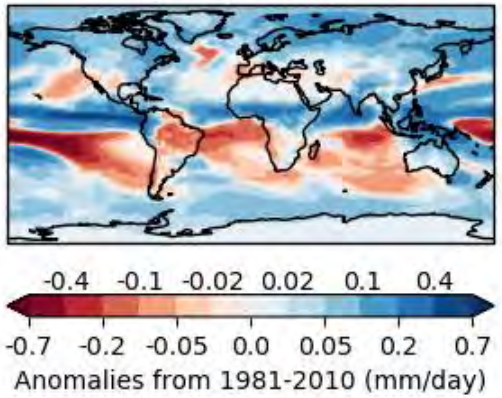
Ensemble mean forecast for 2021-2025 surface temperature



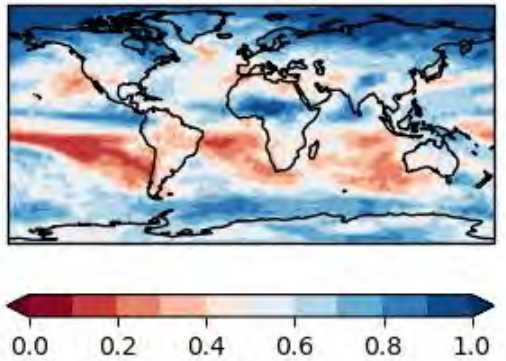
Probability of above average surface temperature



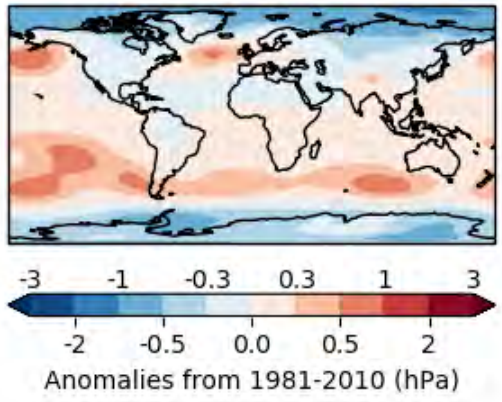
Ensemble mean forecast for 2021-2025 precipitation



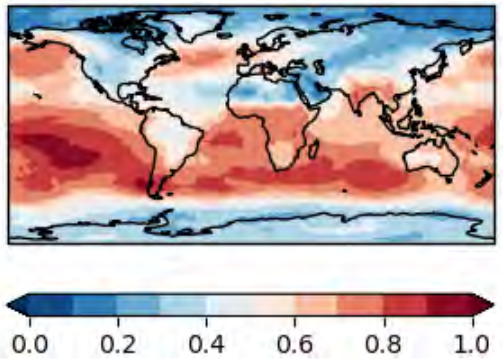
Probability of above average precipitation



sea-level pressure



sea-level pressure



- There is a high probability for above average temperatures almost everywhere, the Arctic (north of 60°N) anomaly is more than twice as large as the global mean anomaly.
- The subtropical North Atlantic, shows an increased chance of low pressure which, combined with higher temperatures and a northward displacement of the Intertropical Convergence Zone (ITCZ), suggests an increased chance of tropical cyclones in this basin.