Hemispheric impact of Gulf Stream errors in subseasonal forecasts

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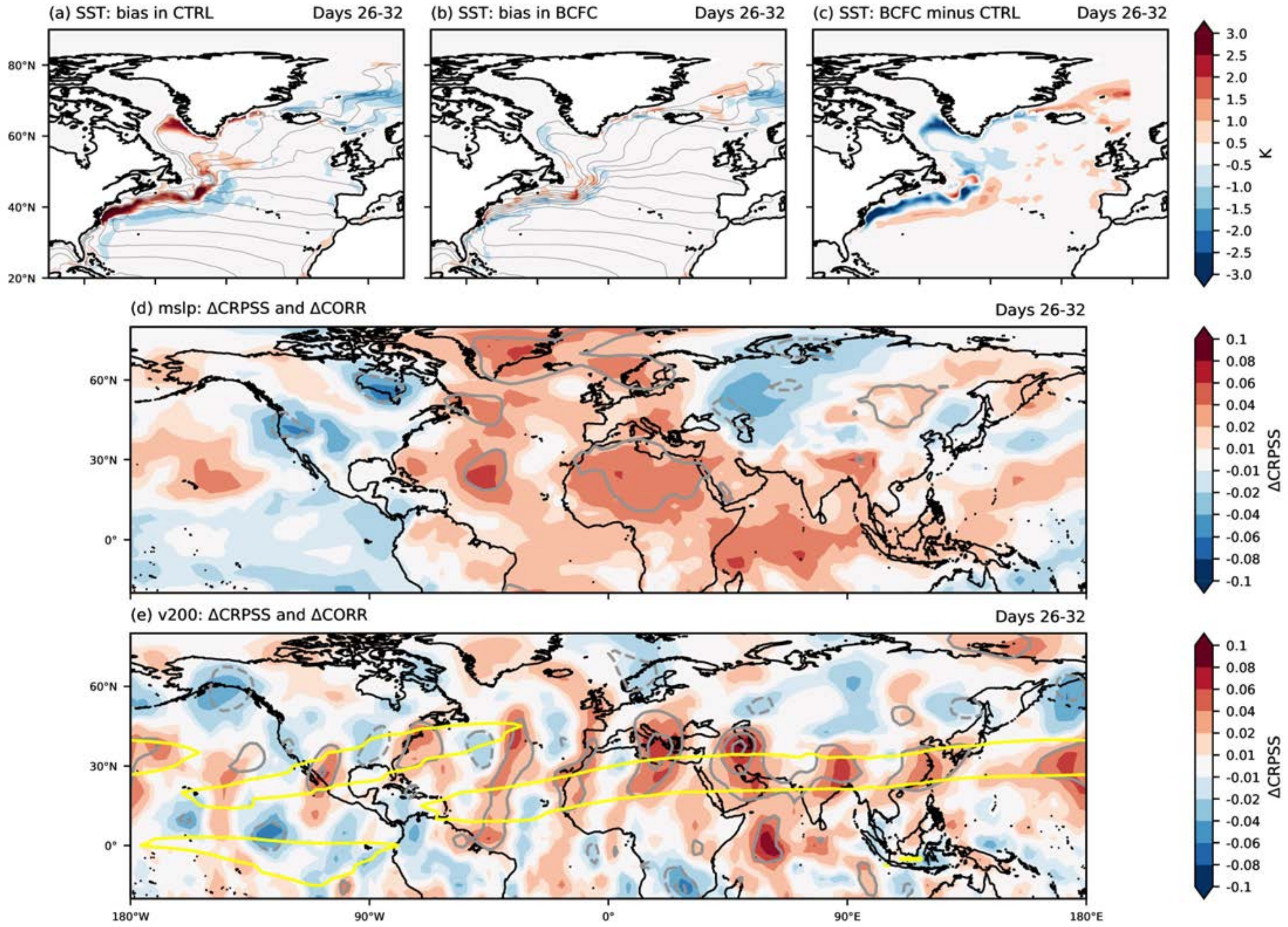
ECMWF S2S forecasts have errors in the position of the Gulf Stream.

Correcting these errors improves the atmospheric mean state and simulation of circulation anomalies.

Forecast skill is improved in the Atlantic and beyond, with impacts following the subtropical waveguide.

These results demonstrate the potential benefits of higher-resolution ocean models that can better resolve the position of the Gulf Stream.



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Motivation

- Ocean-atmosphere coupling can improve forecast skill at S2S lead times.
- However, coupling also introduces the potential for systematic errors in sea-surface temperatures (SST), which can have a negative impact on forecast quality.
- In particular, models that do not adequately resolve mesoscale ocean eddies in the midlatitudes cannot accurately simulate the separation of the Gulf Stream from the North American continent.
- It has been suggested that increases to ocean model resolution sufficient to resolve the ocean mesoscale at midlatitudes will benefit weather and climate predictions
- Previous studies have focused on the impact of fully developed SST errors from multidecadal climate integrations.
- Here, we show that North Atlantic SST biases and errors in the position of the Gulf Stream can also have a significant negative impact on atmospheric forecasts at subseasonal lead times.

Methods

- We perform coupled reforecasts with the ECMWF Integrated Forecasting System (IFS), which includes dynamic representations of the atmosphere, sea ice, ocean, land surface, and ocean waves.

- CTRL is a reference reforecast experiment, which is used to evaluate SST biases as a function of location, start date, and lead-time.

- BCFC is a second reforecast experiment in which the ocean receives atmospheric fluxes as normal, but North Atlantic SSTs seen by the atmosphere are adjusted using the model SST bias derived from CTRL.

Experiment	CTRL	BCFC
Description	Reference coupled reforecasts.	Coupled reforecasts with online bias-correction of SSTs in the North Atlantic domain.
Atm. config.	IFS cycle 43r1, Tco399 L91 (~25 km)	
Ocn/ice config.	NEMO v3.4/LIM2, ORCA025 Z75 (~25 km)	
Initial conditions	ERA interim (atmosphere, land, waves) and ORAS5 (ocean/ice).	
Reforecast config.	15-members initialized on the first and fifteenth of each month of an extended winter period (November-March) from 1989 to 2015 (i.e., 270 start dates).	

Results: impact on the mean state

- North Atlantic SST errors are effectively reduced in BCFC.
- There are also significant improvements to 2m temperatures and surface heat fluxes over the North Atlantic region, particularly over the Gulf Stream.
- Furthermore, the atmospheric circulation responds to the southward shift of the Gulf Stream with increased convective precipitation and upward motion over areas of increased SSTs, and vice versa.

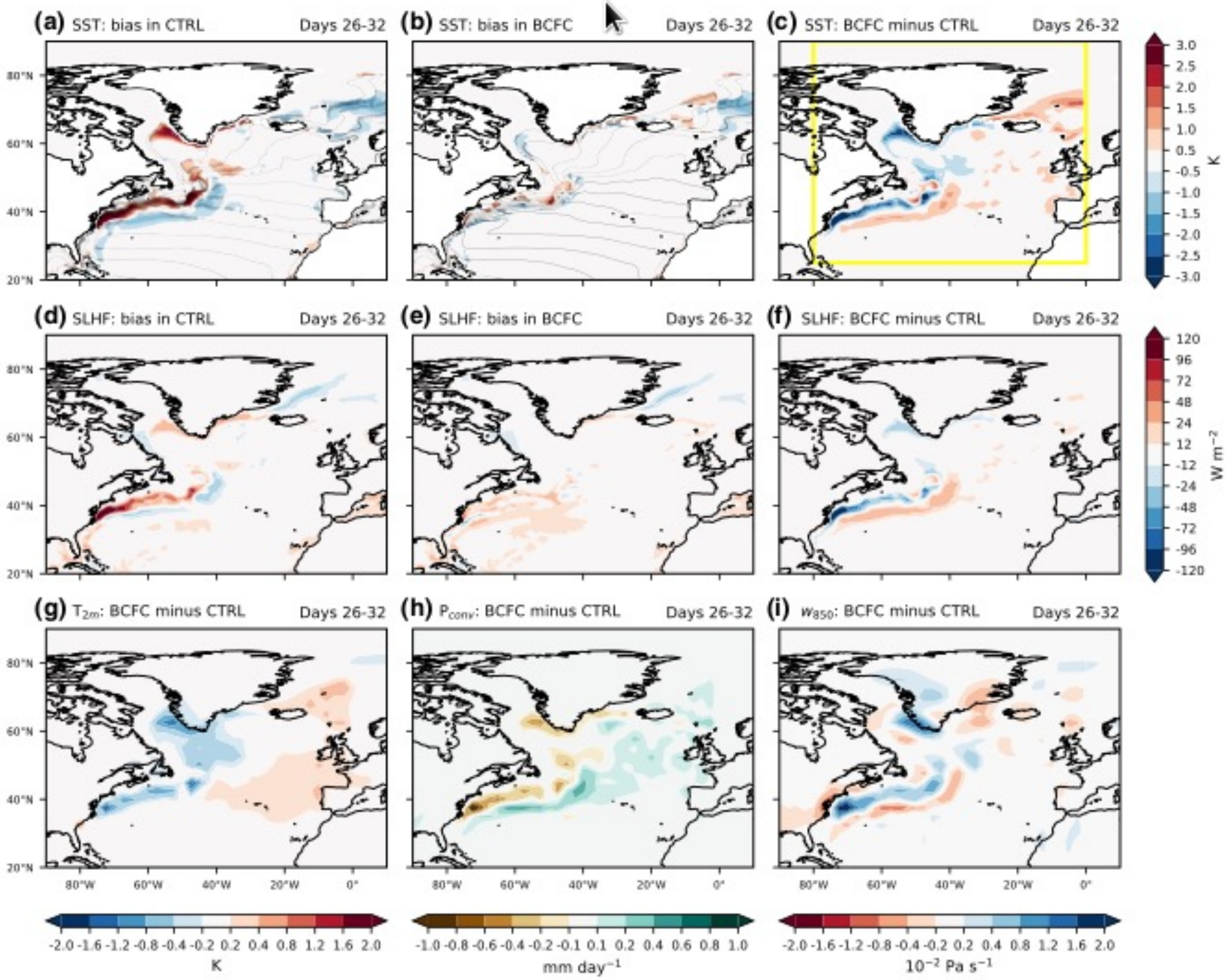

Figure 1. (a) and (b) Climatological SSTs seen by the atmosphere (contour spacing 2 K) and biases relative to ESA CCI observations (shading; Merchant et al., 2019). (c) Difference between BCFC and CTRL SST climatologies (shading) and region of SST bias correction (yellow box). (d–f) As (a–c), but for surface latent heat fluxes (SLHF) with biases relative to the ERA5 reanalysis (Hersbach et al., 2020). Positive values indicate a heat flux out of the ocean. (g–i) Differences between BCFC and CTRL climatologies of 2 m temperature (T_{2m}), parameterized convective precipitation (P_{conv}), and vertical velocities at 850 hPa (w_{850}). Negative values of w_{850} indicate ascent. All differences are computed using climatologies constructed from days 26 to 32 of forecasts initialized on the first and fifteenth of each month in the extended winter season (November-March) for the period 1989–2015.

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Results: impact on the mean state

- This figure summarizes the impact of reduced North Atlantic SST biases on the mean state for a range of variables and regions in terms of a bias score (see paper for details).
- The improvements to near-surface fields are clear at all forecast lead times, particularly in the Gulf Stream region.
- However, other than the changes to vertical velocities and convection over the Gulf Stream, we detect very few significant improvements to the upper atmospheric mean state.

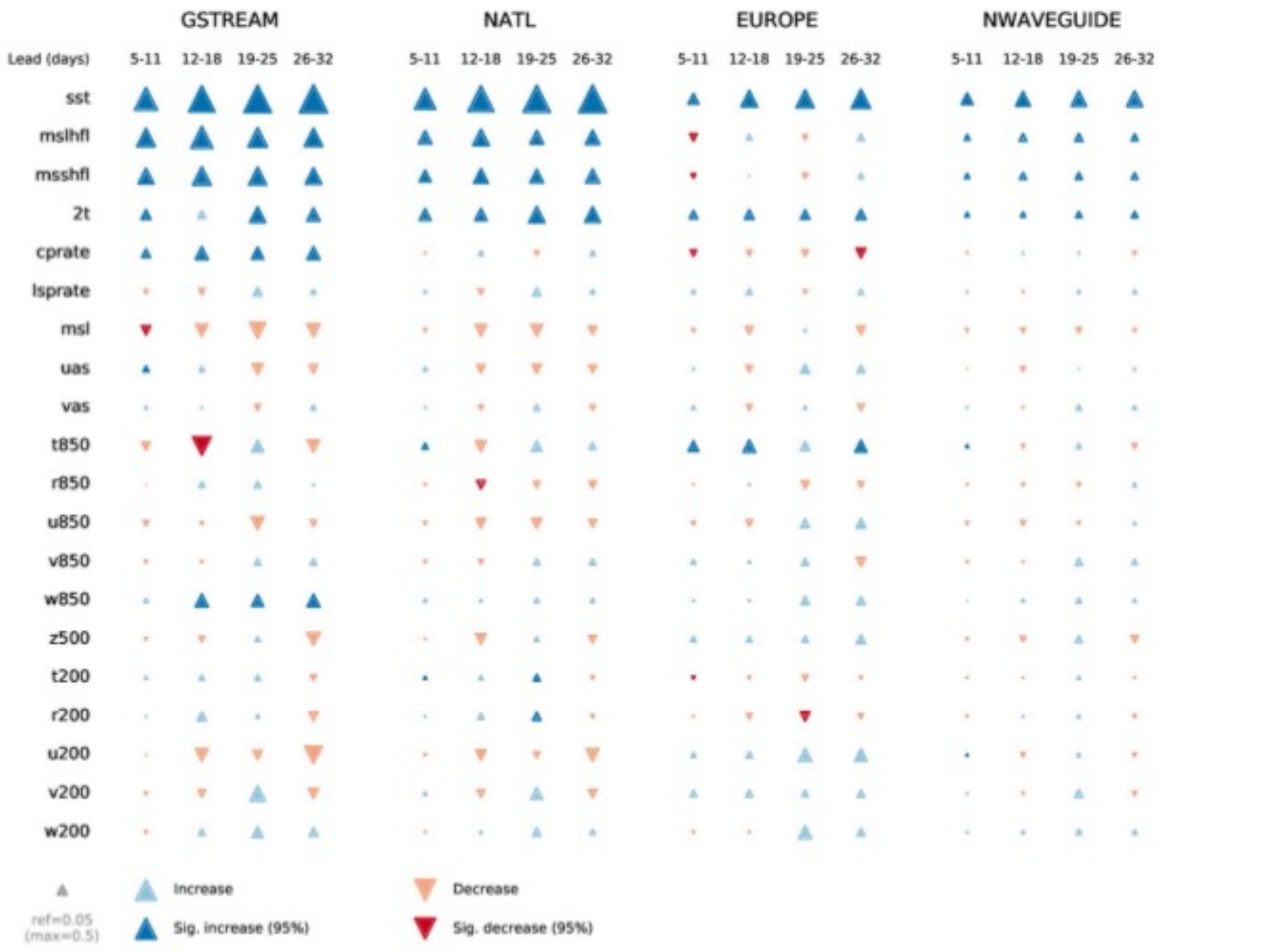

Figure 2. Score card summarizing the impact of North Atlantic SST bias correction on the mean state as diagnosed using the bias score described in Section 2. Positive (blue) values indicate an improvement in the mean state relative to ESA CCI observations (SSTs; Merchant et al., 2019) or the ERA5 reanalysis (all other variables; Hersbach et al., 2020). Note that the bias score is defined as a fractional change, and thus large signals in the bias score are not necessarily indicative of large changes in the underlying data if the bias was small to begin with. Symbol areas are proportional to the magnitude of the score and significance is determined using a bootstrap resampling procedure. The regions corresponding to GSTREAM, NATL, EUROPE, and NWAVEGUIDE are shown as yellow boxes in Figures 3a–3c. The variables shown are sea-surface temperature (SST), surface latent heat flux (mslhfl), surface sensible heat flux (msshfl), 2 m temperature (2t), convective precipitation rate (cprate), large-scale precipitation rate (lsprate), mean sea level pressure (msl), zonal/meridional wind at 10 m (uas/vas), temperature (*t*), relative humidity (*r*), zonal/meridional/vertical wind (*u*/*v*/*w*), and geopotential height (*z*). Numbers in variable names correspond to a specific pressure level in hPa.

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Results: impact on forecast skill

- Despite limited impacts on the mean state of the upper atmosphere, the reduction of SST biases in BCFC significantly improves forecasts of weekly mean atmospheric circulation anomalies at a lead time of 26–32 days (i.e., “week 4”).
- We also increased skill for the North Atlantic Oscillation (NAO) index at lead times of 15–32 days (see paper).
- Importantly, the atmospheric response to reduced SST biases is not limited to the North Atlantic and its immediate surroundings
- Impacts extend out of the North Atlantic and circumnavigate the globe along the northern hemisphere subtropical stationary wave guide.

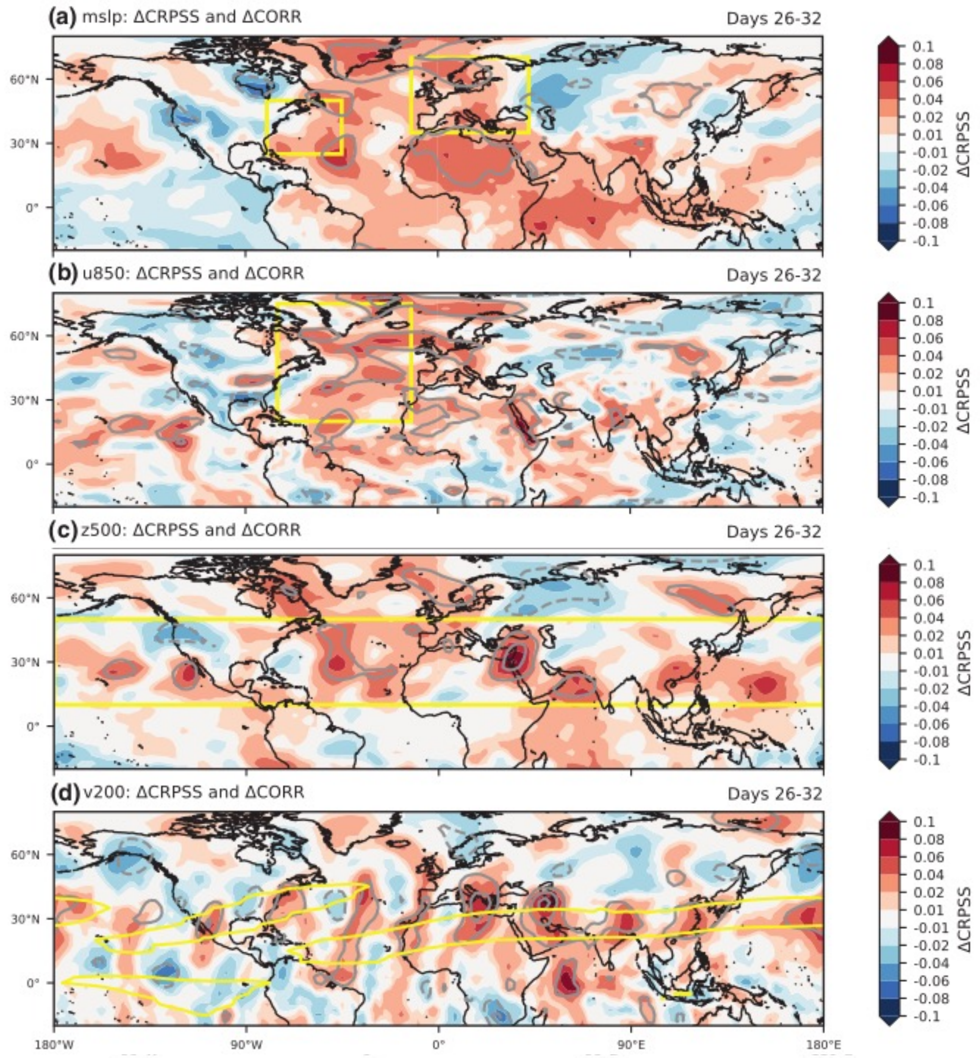

Figure 3. Impact of North Atlantic SST bias correction on the forecast skill of weekly mean anomalies at a lead time of 26–32 days (verified against ERA5; Hersbach et al., 2020). (a) Difference in CRPSS (shading) and anomaly correlation (gray contour spacing of 0.1) for mean sea level pressure (mslp). Yellow boxes indicate the GSTREAM and EUROPE regions used in Figures 2 and 4. (b) As (a), but for zonal wind at 850 hPa (u_{850}). The yellow box indicates the NATL region used in Figures 2 and 4. (c) As (a), but for geopotential height at 500 hPa. The yellow box indicates the NWAVEGUIDE region used in Figures 2 and 4, and is intended to envelope the northern hemisphere waveguide that is identified in the panel below. (d) As (a), but for meridional wind at 200 hPa. The yellow contours highlight the position of the northern hemisphere waveguide diagnosed as the 3×10^{-11} $m^{-1} s^{-1}$ contour of the meridional gradient of absolute vorticity computed from the November-March climatology of zonal wind at 200 hPa.

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Results: impact on forecast skill

- This summary score card shows that improvements to North Atlantic SSTs can have a positive and significant impact on the remote atmosphere at subseasonal lead times.
- Although the CRPSS differences may seem small, they are considerable when compared to the implementation of a new IFS cycle and thus non-negligible when considering how to improve a forecast system.
- The limited impact on forecast skill at lead times earlier than 25 days is likely a consequence of the partial coupling that mitigates the influence of SST biases in both CTRL and BCFC during days 1–10 (see paper for details) combined with the time taken for SST errors to establish and impact the atmosphere.

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Figure 4. Score card summarizing the impact of North Atlantic SST bias correction on forecast skill of weekly mean anomalies as a function of lead time and region. Variables are as described in Figure 2. Positive (blue) values indicate increased CRPSS when verified against ESA CCI observations (SSTs; Merchant et al., 2019) or the ERA5 reanalysis (all other variables; Hersbach et al., 2020). The regions corresponding to GSTREAM, NATL, EUROPE, and NWAVEGUIDE are shown as yellow boxes in Figures 3a–c. The impacts over Europe are also shown for start dates with and without an active MJO in the forecast initial conditions.

Summary

Subseasonal forecasts with the ECMWF model suffer from North Atlantic SST biases associated with errors in the location and structure of the Gulf Stream.

Correcting these errors with an online SST bias-correction scheme improves the mean state of near-surface atmospheric fields in the North Atlantic region.

Furthermore, the resulting southward shift of the Gulf Stream drives changes in convective precipitation and vertical motion, which reflect changes in the location, magnitude, and timing of air-sea interaction associated with extratropical storms.

These impacts on the mean state are associated with significant improvements to forecasts of weekly mean atmospheric circulation anomalies at a lead time of 26–32 days.

Though modest in magnitude, this increased skill extends beyond the North Atlantic into Europe and northern Africa and circumnavigates the globe with a spatial structure characteristic of stationary wave activity propagating along the northern hemisphere subtropical waveguide.

These impacts provide important evidence for the potential benefits of higher-resolution ocean models in initialized coupled forecast systems.