SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2017
Project Title:	Attributing predictable signals at subseasonal timescales to tropical forcing and surface boundary conditions
Computer Project Account:	spgbnort
Principal Investigator(s):	Warwick Norton, Dan Rowlands, Jason Beech-Brandt, Ann Shelly
Affiliation:	CFIC
Name of ECMWF scientist(s) collaborating to the project (if applicable)	…………………………………………………………………… ……………………………………………………………………
Start date of the project:	1 January 2015
Expected end date:	31 December 2017

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	11000000	11581816	11000000	6911305
Data storage capacity	(Gbytes)				

Summary of project objectives
(10 lines max)

Primary Project Objective

- Routine attribution of potentially predictable signals on subseasonal timescales (weeks 3-6).

Secondary Project Objectives

- Establishing case studies that could be used for testing model improvements.
- Suggesting areas where model improvements might increase predictive skill.

Summary of problems encountered

We had some run failures that wasted resources and so requested an extra 500,000 SBU (which was granted) to complete our runs for the 2015/16 winter.

The late arrival of ERA-interim in MARS means we have only just finished the runs for the 2016/17 winter. Ideally we would obtain the results much closer to real time (hopefully this will be available with ERA5).

Summary of results of the current year

We performed 3 sets of experiments over the 2015/16 (23 weekly start dates from 20151012 to 20160314) and 2016/17 (16 weekly start dates from 20161031 to 20170213) winters with 51 member ensembles:

1. T255L60 control initialised from ERA-interim with observed SSTs.
2. As in 1 except fields between 15N-15S are relaxed to ERA-interim fields.
3. As in 2 except initial conditions are sampled over the previous 20 years.

For each set of experiments we also ran an 11 member hindcast over 20 years (1995-2014) for each start date.

These are two very contrasting winters, 2015/16 had very strong El Nino conditions, while 2016/17 was weak La Nina and generally had weak mean atmospheric signals. For example the mean winter NAO in 2016/17 was closest to zero since 2002.

A summary of the skill in the two winters is shown in Figure 1 as the anomaly correlation as a function of lead time for the NAO (Figure 1a&c) and PNA (Figure 1b&d). Also included on these figures (in red) is the anomaly correlation from the operational monthly (which has the same Monday start dates) and average skill estimated from the 20 year hindcasts (dashed). In 2015/16 the NAO skill (Figure 1a) of both the control and the operational monthly was close to average, the tropical relaxation experiments were more skilful but again close to the average of the tropical relaxation hindcast. As is normal in El Nino years, the skill of the PNA (Figure 1b) was above average for all models against their respective average.

In contrast, in 2016/17 the skill of the NAO (Figure 1c) was very low for day 10+. By day 15 the anomaly correlation of the control was close to zero while apparently the skill of the operational monthly was negative in week 4. In the tropical relaxation experiments the skill remained positive but significantly lower than average. For the PNA both control and operational monthly had low skill (though the control somewhat higher skill than the monthly in week 4). The tropical relaxation experiments had average PNA skill.

Figure 2 shows the weekly mean NAO (Figure 2a&b) and PNA (Figures 2c&d) indices for 2015/16 (grey) and the ensemble mean week 2 (blue), week 4 (red) and week 6 (black) forecasts for the control (Figures 2a&c) and tropical relaxation (Figure 2b&d) experiments. The skill in predicting the weekly variability in the NAO was low for weeks 4 & 6 in the control run (Figure 2a) though it did know about the overall positive

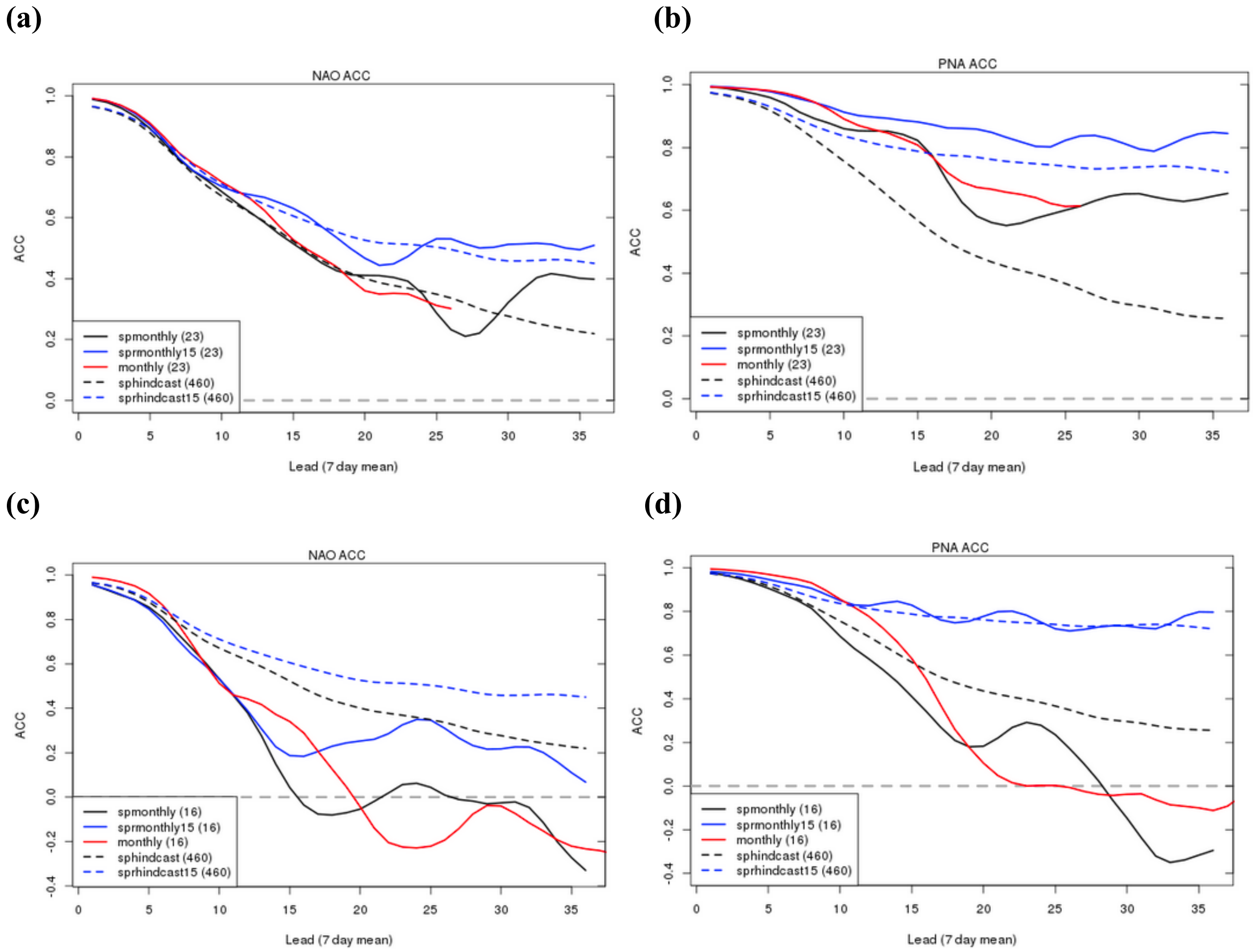


Figure 1. Anomaly correlation as a function of lead time for the NAO (a&c) and PNA (b&d) for the winters 2015/16 (a&b) and 2016/17 (c&d). Operational monthly (red), control experiment (black), tropical relaxation experiment (blue), dashed line are average from the respective 20 year hindcasts.

NAO signal (the anomaly correlation skill mainly came from the seasonal signal). In the tropical relaxation experiments (Figure 2b) some of the weekly variability of the NAO was captured at week 4 and 6, and positive NAO signal was stronger. Notable in the control and tropical relaxation experiments is the lack of skill at week 4 in capturing the –ve NAO spike in early December and the +ve NAO spike in late January. For the PNA again the seasonal signal of +ve PNA is well captured in both models at week 4, with the tropical relaxation experiments capturing more of the weekly variability.

Note in the tropical relaxation runs the poorly forecast -ve PNA spike in December and the +ve PNA spike in early January. These two events are the precursors to the –ve and +ve NAO events in January. Examination of the weekly maps shows that the –ve PNA event produced a very wavy pattern which resulted in a Scandinavian block in early January which then transitioned to –ve NAO. The tendency for poor Euro-Atlantic forecast skill in –ve PNA via underestimation of blocking over Europe has been discussed by Ferranti et al (2014). The +ve PNA event was under forecast by all the models (including the tropical relaxation model) and the associated low pressure over eastern Canada. This low pressure subsequently moved east to give the strong +ve NAO event in late January.

Figure 3 shows the corresponding plots for 2016/17. Generally both the control and tropical relaxation experiments had no idea on the weekly variability of the NAO at weeks 4 and 6, particularly notable is the large forecast miss on the NAO in December where both models at week 4 and 6 were predicting –ve NAO yet what realised was strongly positive. The relaxed model had the idea that the NAO would increase from early to late winter (which is a typical pattern in La Nina winters). The control model also had no idea about the PNA, the week 6 mean was slightly positive yet there were several large –ve PNA events, consequently

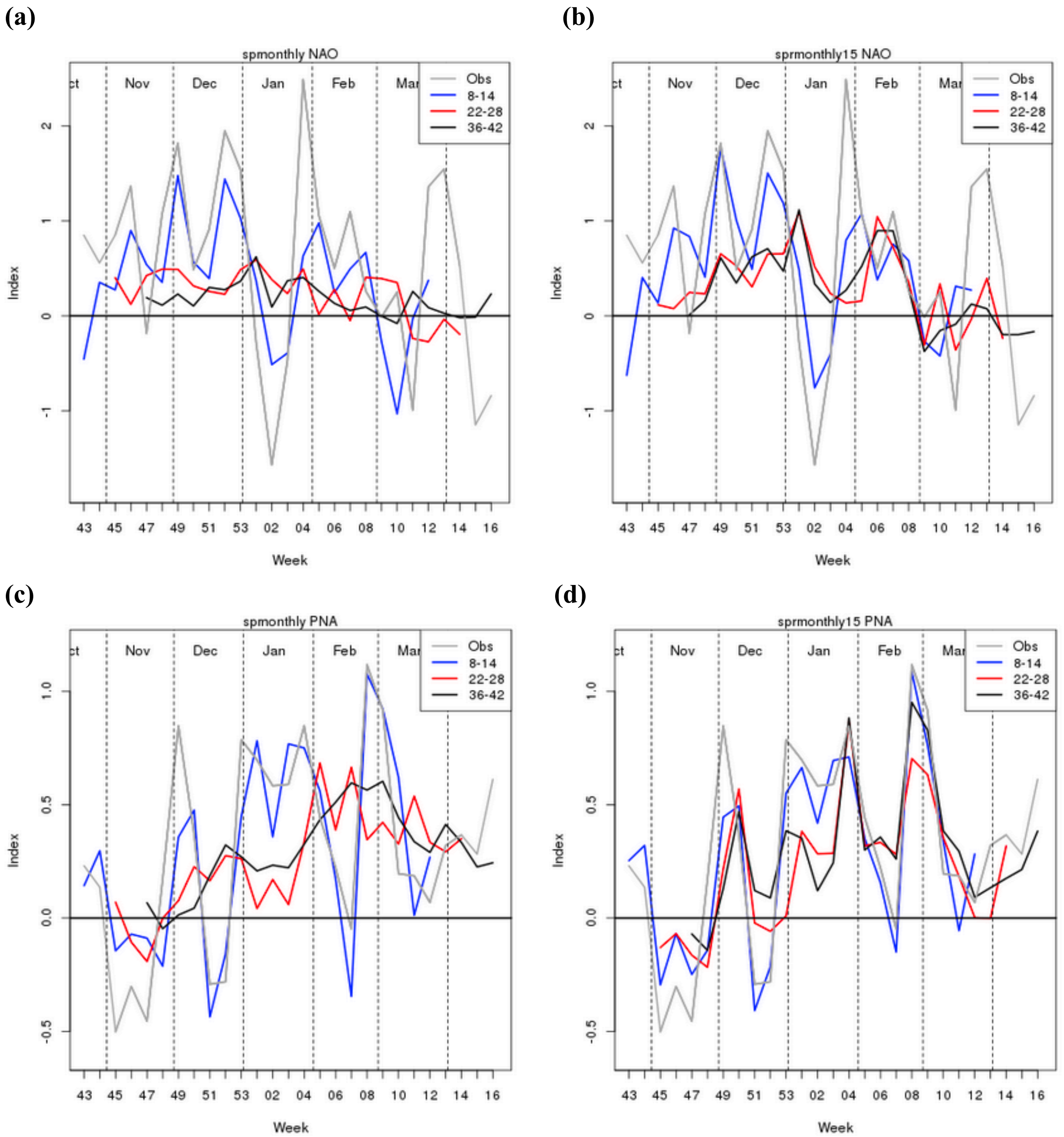


Figure 2. 2015/16 weekly mean NAO (a&b) and PNA (c&d) indices, observed (grey), ensemble mean forecast week 2 (blue), week 4 (red) and week 6 (black) for the control (a&c) and tropical relaxation (b&d) experiments.

California had a record breaking wet winter! Particularly poorly forecast by the control was the –ve PNA period in December. In contrast the tropical relaxation experiment fixed the PNA! Other diagnostics (e.g. of the RMM1 index) showed the control (and operational monthly) had particularly poor skill in predicting tropical variability in the 2016/17 winter. This is part of the reason why the control (and operational monthly) had poor skill in predicting the PNA.

We will now give two examples of individual forecasts (out of many interesting examples we have) highlighting amazing subseasonal predictability (if you can get the tropics right) but also outstanding issues (in the case of December 2016).

Figure 4 shows week 5 forecasts (500 hPa geopotential anomalies relative to respective hindcasts) initialised on 11 January 2016 (validation period 8-14 February 2016). Figure 4a shows the operational monthly and is very similar to the control (Figure 4b), both showing a typical El Nino pattern across North America and the Atlantic (weak +ve NAO). What occurred is shown in Figure 4d, there is a very strong +PNA pattern across the US which resulted in very cold temperatures in the NE US (New York got close to record cold

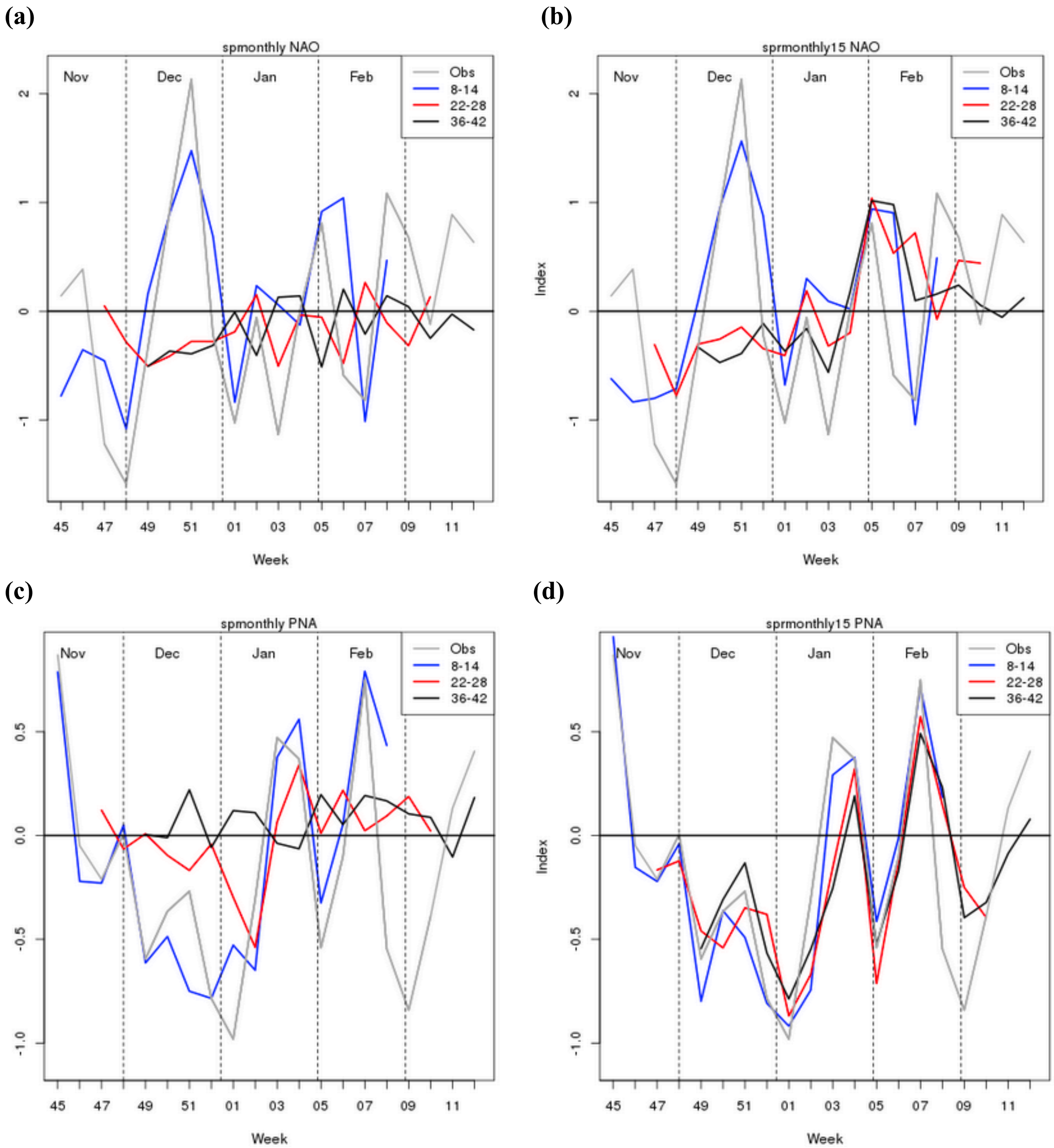


Figure 3. 2016/17 weekly mean NAO (a&b) and PNA (c&d) indices, observed (grey), ensemble mean forecast week 2 (blue), week 4 (red) and week 6 (black) for the control (a&c) and tropical relaxation (b&d) experiments.

temperatures at -18C). Across Europe there is a very deep low pressure near the UK. Figure 4c shows the tropical relaxation experiment can reproduce all the features of the observed anomalies (though with slightly reduced amplitude). In fact our experiments with mixed up extra-tropical initial conditions (not shown) are very similar to Figure 4d indicating all the observed anomalies are driven from the tropics.

Figure 5 shows week 4 forecasts initialised on 21 November 2016 (validation period 12-18 December 2016). This is the poorly forecast period in December 2016 commented on previously. Both the monthly and control (Figures 5a&b) show –ve NAO across the Atlantic (and cold for Europe). In fact what happened was a very deep low pressure across northern Canada and a ridge in the North Sea (which was moderately mild for Europe). The relaxed run (Figure 5c) had some elements of the pattern across the US but it had the pattern too far west across Europe. In the following week (19-26 December) the observed pattern transitioned to very strong +ve NAO by moving the low over Canada east. This evolution was not captured by any of the

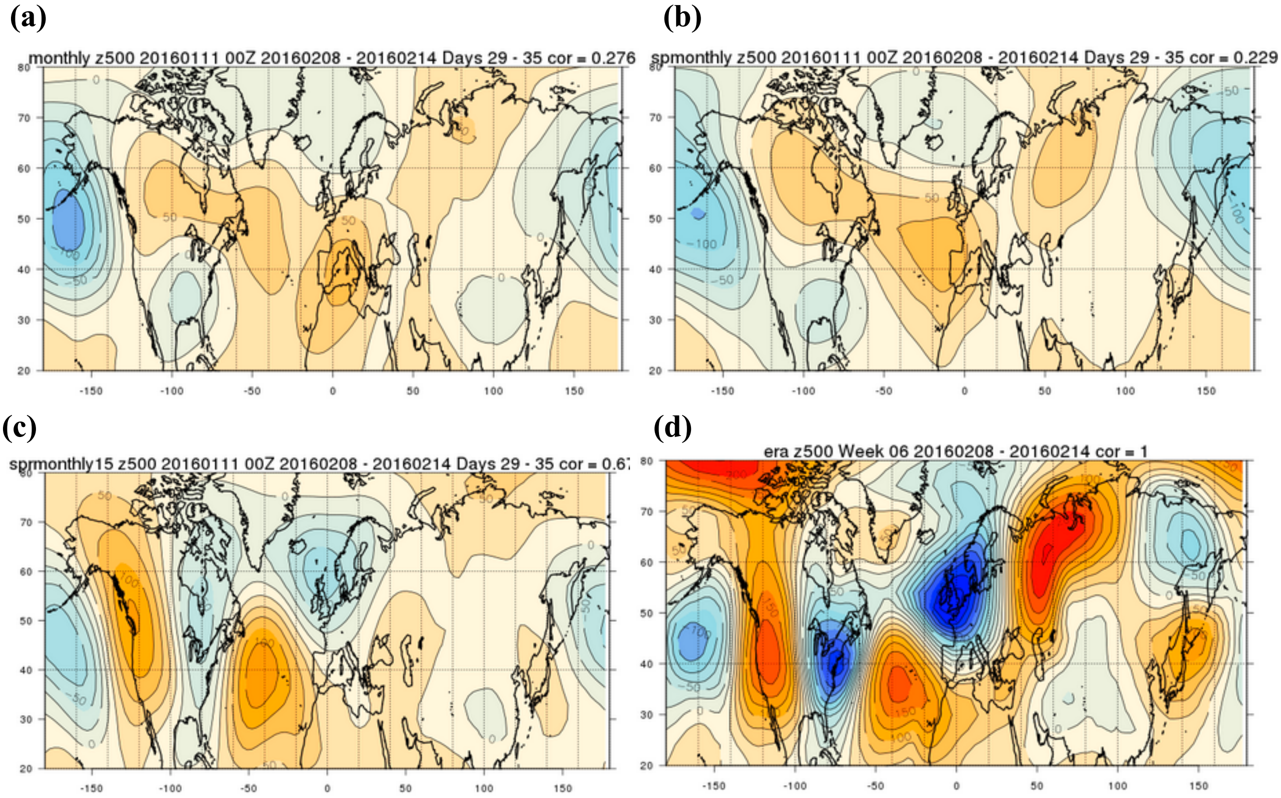


Figure 4. Ensemble mean 500 hPa geopotential anomalies from week 5 forecasts initialised on 11 January 2016, (a) operational monthly, (b) control experiment, (c) tropical relaxation experiment, (d) ERA-interim with validation period 8-14 February 2016.

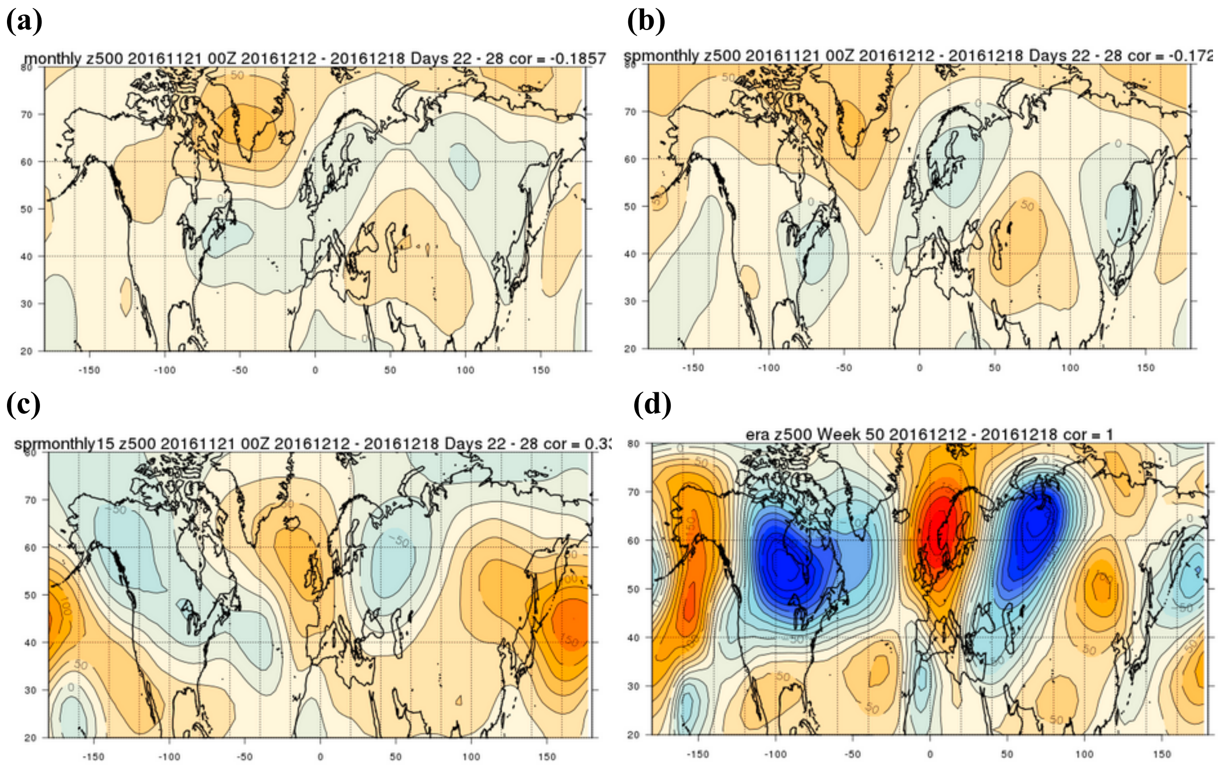
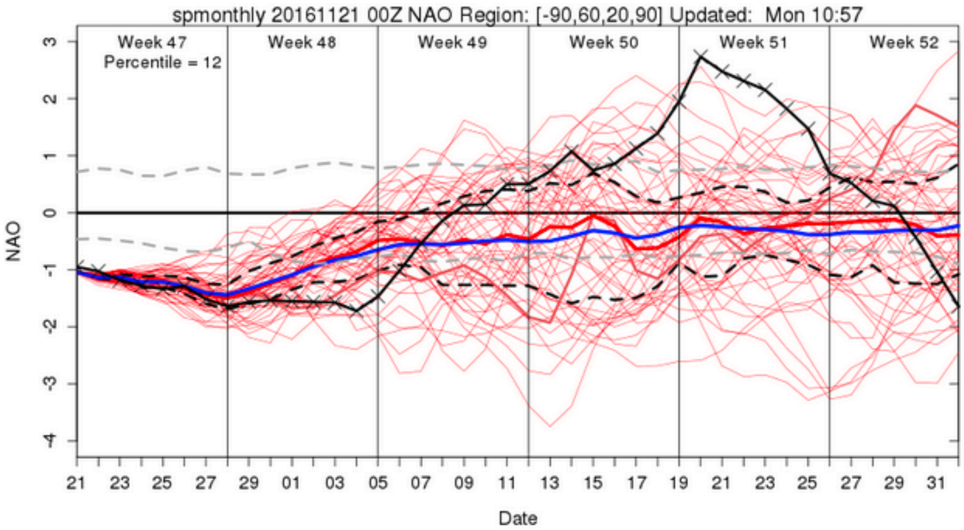


Figure 5. Ensemble mean 500 hPa geopotential anomalies from week 5 forecasts initialised on 21 November 2016, (a) operational monthly, (b) control experiment, (c) tropical relaxation experiment, (d) ERA-interim with validation period 12-18 December 2016.

models initialised on 21 November 2016. Figure 6 shows plume plots of NAO evolution (ERA-interim is black) from the control and relaxed runs. These plots show the overall –ve NAO bias of the models and that the observed NAO evolution was outside the ensemble range (the relaxed run did slightly better in weeks 49 and 50 having more ensemble members transiting to +ve NAO).

(a)



(b)

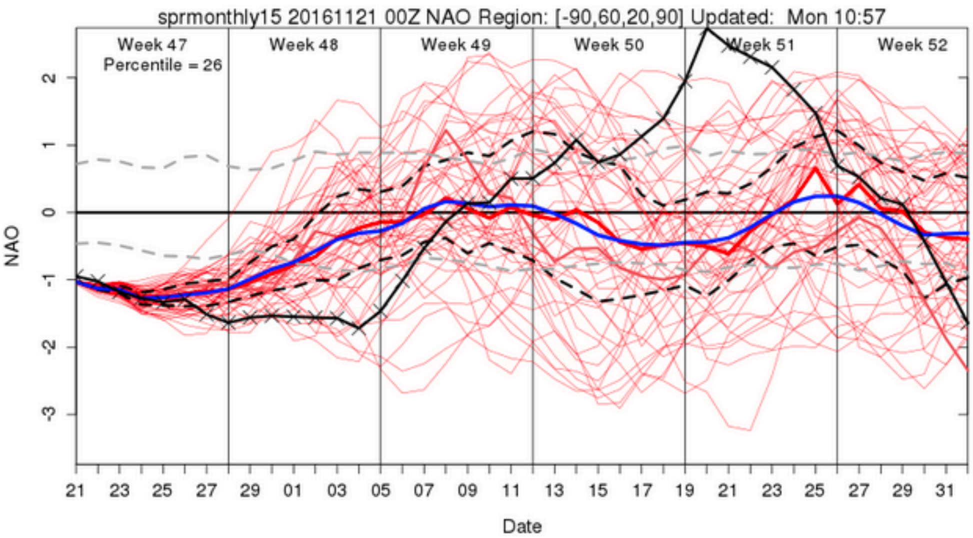


Figure 6. Ensemble forecasts of the NAO from 21 November 2016, (a) control experiment, (b) tropical relaxation experiment with ensemble mean (blue) and ERA-interim (black).

These results raise the question of why the model skill in predicting the NAO in 2016/17 was so poor even with the correct tropics and variability of the PNA? There are possibly a number of contributing factors here. First it should be pointed that much of the regime behaviour in the 2016/17 winter did not directly project onto the NAO, e.g. Figure 5d is more a Scandinavian block rather than +ve NAO, Figure 5c is an Atlantic ridge pattern. As commented previously, the skill in predicting the major modes of variability in the tropics was very low in the 2016/17 winter. There was no MJO activity from early November to mid-February but there was significant Kelvin wave activity (which is much less predictable). The lack of MJO activity could have been associated with the strong westerly phase of the QBO (Yoo and Sun, 2016) or possibly the strong –ve Indian Ocean dipole.

However the base states of the models (under weak La Nina SSTs) are also relevant. Figure 7 shows the mean winter 500 hPa height anomalies from the operational monthly at week 3&4 (Figure 7a), the control experiment at week 3&4 (Figure 7b), the relaxed experiment at week 5&6 (Figure 7c), and from ERA-interim (Figure 7d). It is apparent that both the operational monthly and the relaxed experiment underestimated the –ve PNA base state though this is somewhat worse in the operational monthly suggesting

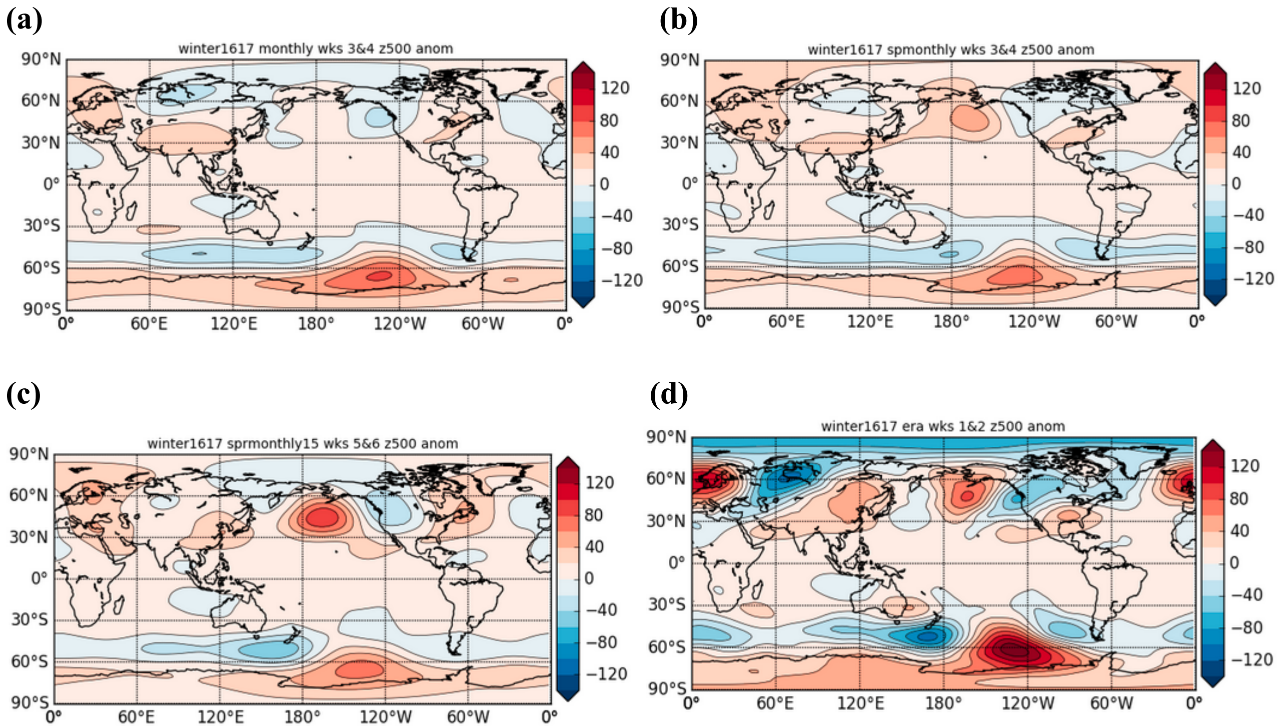


Figure 7. Winter mean 500 hPa geopotential anomalies for 2016/17 (a) week 3&4 from operational monthly forecast, (b) week 3&4 from control experiment, (c) week 5&6 from tropical relaxation experiment, (d) ERA-interim.

that the coupled ocean has degraded the forecast. With the "correct" tropics the relaxed run in Figure 7c has obtained a good simulation of the PNA over the Pacific however over the eastern US, the PNA pattern has become too north-south while the analysis shows it to be more of a great circle route leading to more low pressure over eastern Canada (compare also with Figures 5c&d). So it could be the PNA teleconnection in the tropical relaxation model is either too weak or does not propagate correctly into the western Atlantic?

It is interesting to compare the operational monthly tropical rainfall for January-March 2017 with measurements from GPM (Figure 8). Two features are evident (if you can believe GPM), the monthly forecasts significantly underestimate rainfall over the maritime continent and South America, and slightly over estimate rainfall over the central Pacific. Underestimating rainfall in the maritime continent west of 120E is particularly significant as 120E is approximately the dividing line to force –ve PNA & +ve NAO compared to +ve PNA & -ve NAO (which tends to occur with convection east of 120E) based on studies of MJO teleconnections (e.g. Riddle 2012). The other notable feature of Figure 8 is how the maritime convection (and South American) rainfall drifts lower further into the forecast. We have analysed the SSTs around the maritime continent in the monthly forecast and they also trend slightly cooler with time and this might cause the drift of the rainfall. It should also be noted that ERA-interim underestimates maritime continent convection relative to the operational analysis so our tropical relaxation experiments could underestimate forcing from the tropics.

An intriguing question is whether 2016/17 is similar to years in the 1950s-70s with poor seasonal mean NAO skill as discussed by Weisheimer et al (2017) and O'Reilly et al (2017)? They identify these poor skill years to be associated with –ve PNA when perhaps the SSTs don't have strong control over the tropical convection? We would like to address this question in an additional proposal for a 2-year special project.

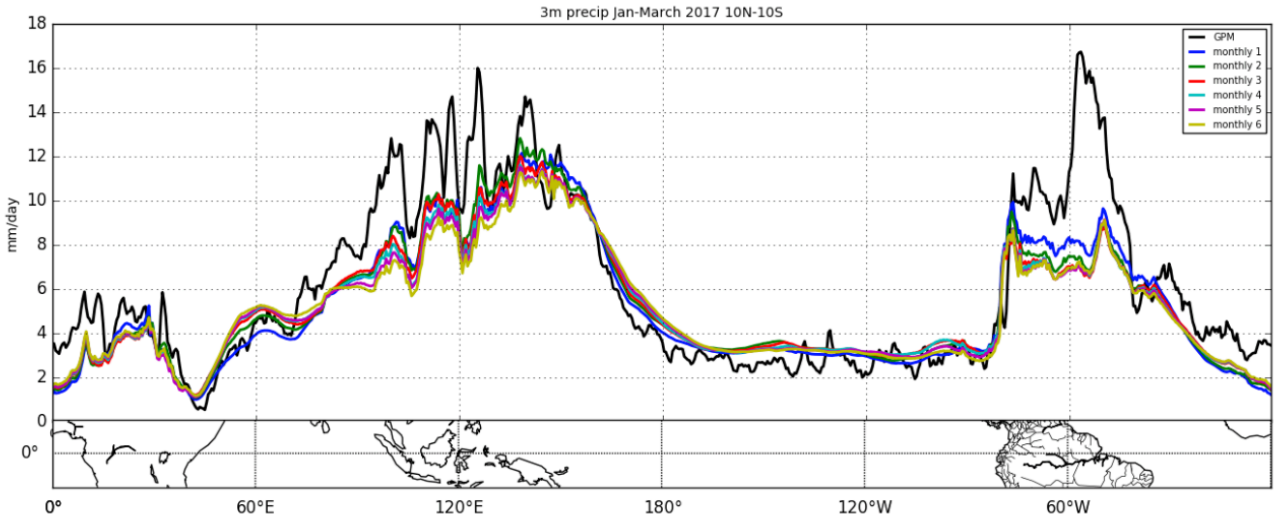


Figure 8. January-March 2017 mean tropical (10N-10S) rainfall from GPM (black) and operational monthly forecast, week 1 (blue), week 2 (green), week 3 (orange), week 4 (cyan), week 5 (purple), week 6 (yellow).

List of publications/reports/presentations from the project

November 2016, Poster at ECMWF/ESA Workshop: Tropical modelling, observations and assimilation (Ann Shelly)

December 2016, Oral presentation at S2S extremes workshop (Warwick Norton)

December 2016, Oral presentation at AGU (Ann Shelly)

January 2017, Oral presentation at AMS (Warwick Norton)

February 2017, Seminar at ECMWF (Warwick Norton)

Summary of plans for the continuation of the project

- Finish analysis of model runs particularly the mixed initial conditions experiments to establish whether the result for the 2015/16 winter that skill at week 4+ is the same whether or not extra-tropical initial conditions are used holds for the 2016/17 winter.
- Examine issues around how predictability of the PNA influences predictability of the NAO, for example understanding whether the state of the PNA influences the size of possible NAO errors.
- Examine if the control & relaxed models have a systematic error in the propagation of the PNA into the Atlantic sector. Preliminary results suggest the models have detectable drifts in the correlation structure of many fields, which then changes the teleconnections between different regions.
- Further analysis on whether the models have too weak tropical extra-tropical teleconnections. One intriguing result of initial analysis of the hindcast runs is that the PNA forecasts in the relaxed runs with “corrected tropics” appear to be under confident (like the NAO) whilst the control runs are not; to our knowledge this result has not been highlighted in the literature and suggests the control run PNA forecasts offset overconfident tropical convection forecasts with under confident teleconnections. Establishing the mechanism(s) giving rise to weak teleconnections will highlight ways to address these issues either in post-processing or improvement of model physics. For example, Figure 9 shows the 200 hPa zonal wind errors at week 4 from the operational monthly, control experiment, and tropical relaxation experiment hindcasts. All the models have a common error of not extending the Pacific jet far enough eastward. Rossby wave source (RWS) diagnostics (not shown) suggest this is the reason why RWS variability is too low across the central Pacific.
- Consider writing an ECMWF Technical Memo to give a full report of results along with suggestions

for additional diagnostics that ECMWF should routinely produce in evaluating teleconnections for new model cycles. Also suggesting case studies that could be used for testing model improvements.

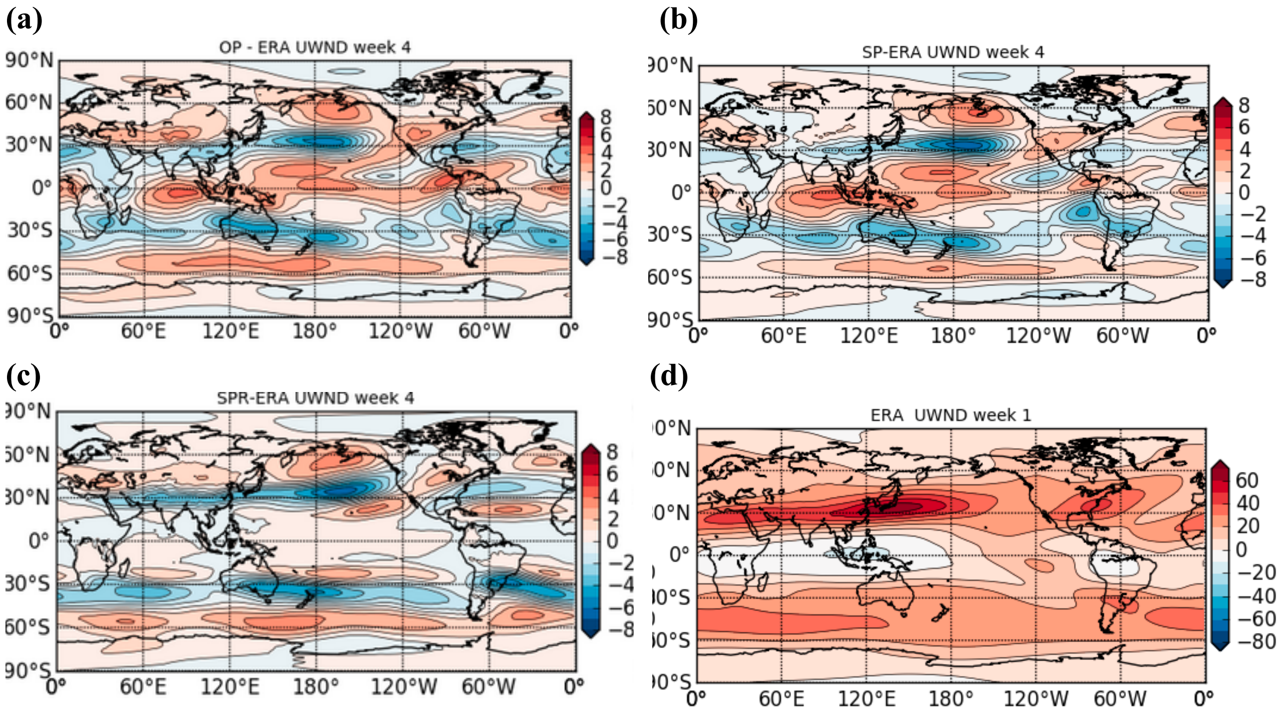


Figure 9. Winter mean 200 hPa zonal winds (a) week 4 from operational monthly hindcasts minus ERA-interim, (b) week 4 from control experiment hindcasts minus ERA-interim, (c) week 4 from tropical relaxation experiment hindcasts minus ERA-interim, (d) ERA-interim.

References

O'Reilly, C., *et al* (2017), Variability in seasonal forecast skill of Northern Hemisphere winters over the 20th century, *Geophys. Res. Letts,* 44, 5729-5738.

Ferranti, L., *et al* (2014) Flow-dependent verification of the ECMWF ensemble over the Euro-Atlantic sector, *Q. J. R. Meteorol. Soc.* DOI:10.1002/qj.2411.

Riddle, E., *et al* (2012) The impact of the MJO on clusters of wintertime circulation anomalies over the North American region, *Clim Dyn* DOI 10.1007/s00382-012-1493-y

Weisheimer, A., *et al* (2017), Atmospheric seasonal forecasts of the twentieth century: multi-decadal variability in predictive skill of the winter North Atlantic Oscillation (NAO) and their potential value for extreme event attribution, *Q. J. R. Meteorol. Soc.,* 143, 917-926.

Yoo and Sun (2016), Modulation of the boreal wintertime Madden-Julian oscillation by the stratospheric quasi-biennial oscillation, *Geophys. Res. Letts,* 43, 1392-1398.