Representation of northeast winter monsoon cold surges in global NWP and the role of coupling

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1. Abstract:

Synoptic cold surges during the boreal winter northeast monsoon bring sustained strong winds across the South China Sea associated with enhanced convergence, heavy rainfall and flood events across Southeast Asia. This study analyses for the first time the skill of a global high resolution NWP model (Met Office Unified Model) in representing cold surges and associated rainfall for the winter seasons of 2016/2017 and 2017/2018. The model skilfully predicts occurrences of cold surges and associated increased precipitation over the region up to 10 days in advance, with potential to provide useful information for extended range forecasts. Some of the errors in the model are associated with a too easterly circulation of the northeast monsoon flow to the south, and the lack of interaction between the atmosphere and evolving SSTs during cold surges. Analyses of the representation of cold surges in an experimental coupled ocean-atmosphere NWP system show that air-sea interactions over the South China Sea are important to limit predictions of excessive precipitation, especially off the coast of Malaysia Peninsula.

2. NWP experiments:

Met Office Unified Model NWP Forecasting system based on GA6 configuration (Walters et al. 2017)
Extended to 15 days

Coupled NWP system in research mode, based on GC2.1 (Shelly et al. 2014, Williams et al. 2015)

2 winter seasons NDJF, for 2016/2017 and 2017/2018

Experiment	Configu-ration	Horizontal resolution	Vertical resolution	Lead time	Dates (validity time)
Atmosphere-only winter 16/17	GA6.1	N768 (17km)	L70	15 days forecast daily from 00Z	01/11/16-28/02/17
Coupled winter 16/17	GC2.1	N768	L85	15 days forecast daily from 00Z	01/11/16-28/02/17
Atmosphere-only 17/18	GA6.1	N768	L70	15 days forecast daily from 00Z	01/11/17-28/02/18
Coupled 17/18	GC2.1	N1280 (10km)	L85	15 days forecast daily from 00Z	01/11/17-28/02/18

3. Cold surge definition and statistics:

- **CS Index criteria** (daily ERAINTERIM reanalysis), Lim et al. 2017:

1. Normalised NE 850hPa wind speed > 0.75 (region from *Chang et al. 2005*)

- 2016/2017 peculiar year with high variability and easterly circulation

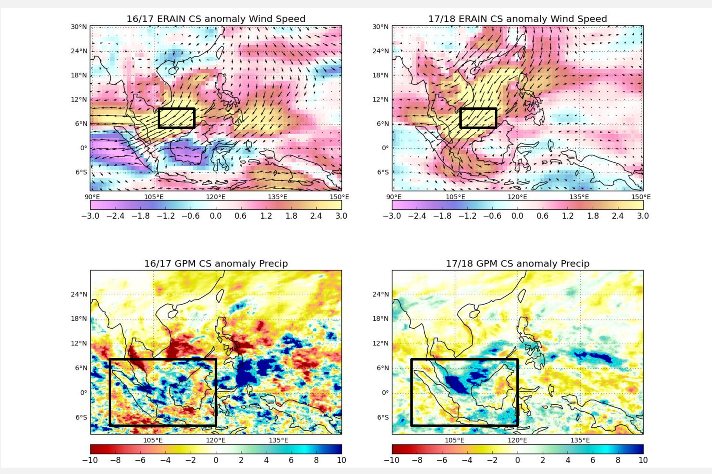

Figure 1: Anomaly composites of 850hPa wind (top row, vectors and speed in m/s) and precipitation (bottom row in mm/day) for cold surge days against November to February seasonal mean for winter 2016/2017 to the left and 2017/2018 to the right. Thick black contours represent areas used for averaging in figures 2, 3 and 4.

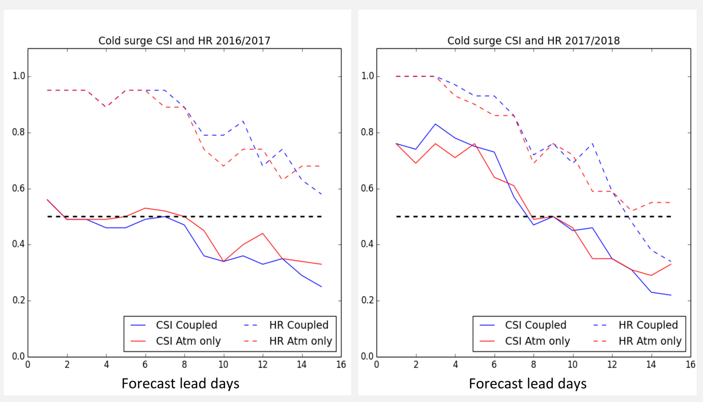

Figure 2: Verification of cold surge index days, Critical Success Indicator (CSI, plain) and Hit Rate (HR, dashed) for winter 2016/2017 (left) and winter 2017/2018 (right)

- Seasons 16/17 and 17/18 different, 16/17 presents unusual easterly flow and noisy rainfall anomaly composite, 17/18 more typical of a climatological cold surge pattern (Lim et al. 2017)
- Both models have high hit rates (observed events forecasted) for cold surge days up to 8 days lead time, for both seasons
- However, lower CSI indicates false alarms, with deterministic limit (CSI>0.5) at about 7-8 days

4. Cold surge wind and precipitation predictability

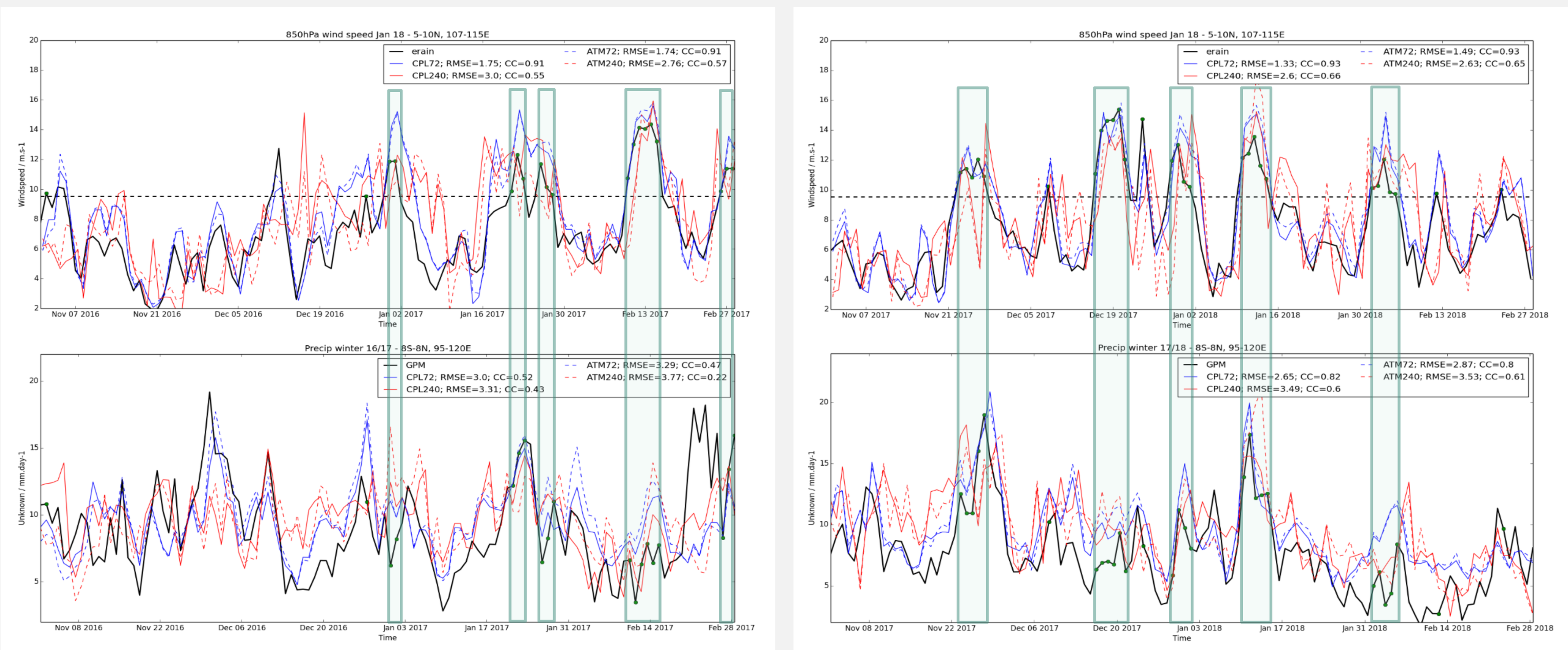

Figure 3: Winter 2016/2017 and 2017/2018 timeseries of regional means of 850hPa wind speed over the definition area for cold surges (5-10°N, 107-115°E, see Figure 1) (top) and of precipitation over the central Maritime Continent (8°S-8°N, 90-120°E, see Figure 1). Black is for reanalysis (winds) and GPM observations (precipitation), blue (red) is for the 3 (10) days lead time forecast, full lines are for the coupled mode forecast and dashed lines for the atmosphere-only. The green dots highlight cold surge days while the green shading highlights episodes of cold surge days of more than a day. Root Mean Square error and correlation are indicated in the boxed legend.

- Both atmosphere-only and coupled models capture main cold surge events and associated peaks in rainfall, including flood cases in Jan 2017, early and mid Jan 2018 over Malaysia, Feb 2018 over Indonesia. Most extreme rainfall events occur when cold surge and MJO over the region coincide (Lim et al. 2017, Xavier et al. accepted)
- Model tends to forecast longer cold surge episodes, and overestimate precipitation over the region
- 16/17 unusual with events shorter-lived and later in the season (highly variable winter monsoon, Fakaruddin et al. 2017)

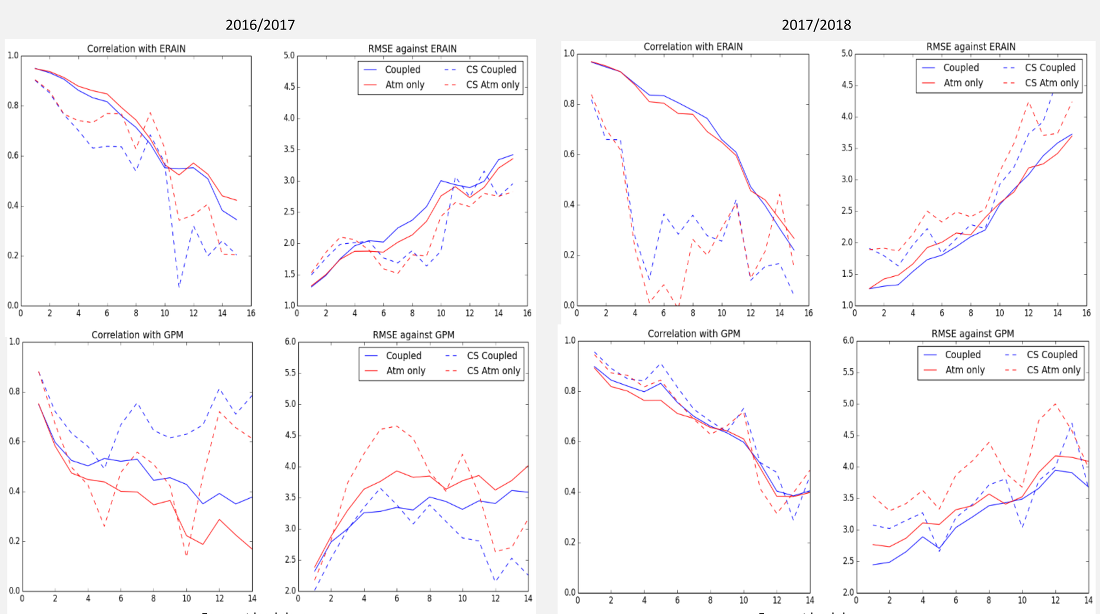

Figure 4: Correlation and root mean square error (RMSE) between forecasts at different lead times and observations from November to end of February for winds (top, against ERAINTERIM reanalysis) and for precipitation (bottom, against GPM) for all days, averaged over regions as defined in Figures 2, 3 and 4. Winter season 2016/2017 on the left, 2017/2018 on the right, blue for the coupled model, and red for the atmosphere-only. Dashed lines are for cold surge days only. Correlations are significant at the 0.05 level for the full season (120 days) above 0.25, whereas for cold surge days, they are significant above 0.6 for 2016/2017 (19 days) and above 0.5 for 2017/2018.

- Predictability up to 10-12 days
- 17/18 better skill than 16/17 for lead times up to 10 days
- Similar skill for cold surge winds for atmosphere-only and coupled models
- Better skill for precipitation averaged over central Maritime continent in the coupled model for both seasons

6. Representation of cold surge circulation

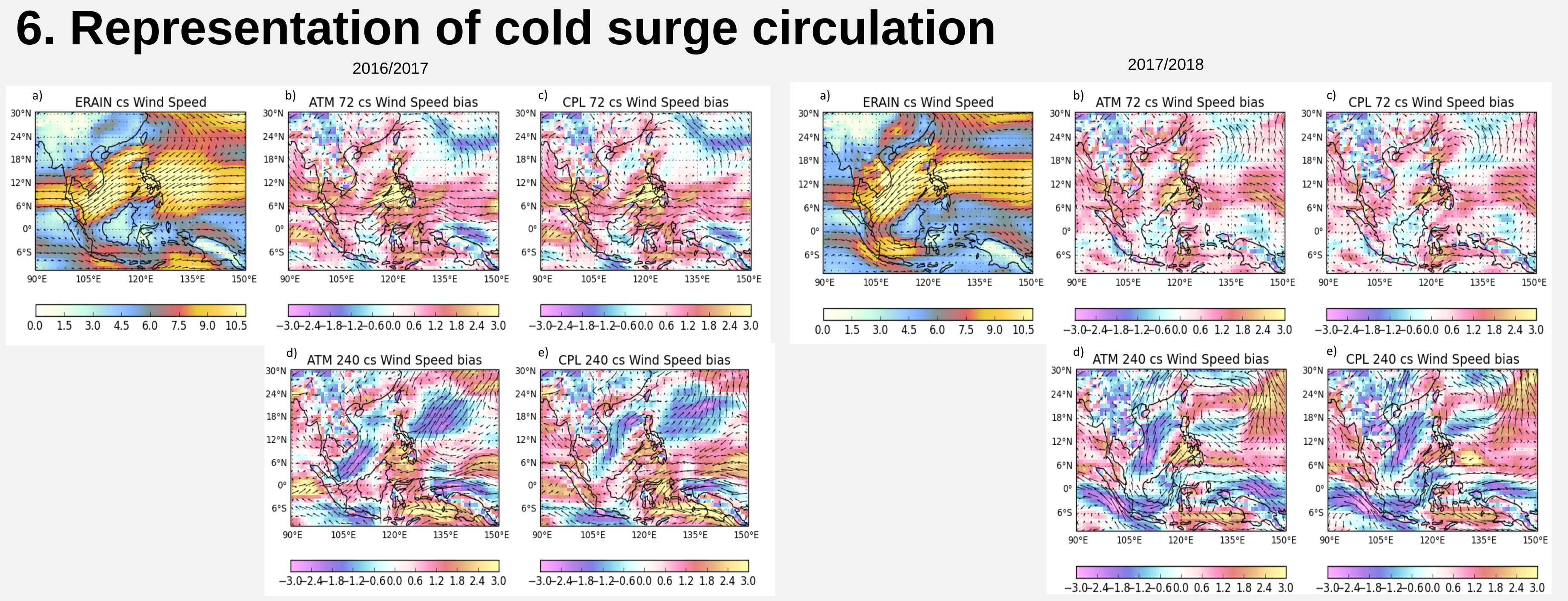

Figure 5: Winter 2016/2017 and 2017/2018 composites of cold surge days (from ERAINTERIM indices) for a) ERAINTERIM 850hPa wind and wind speed (m/s), and b) and c) for mean error of the 3 day forecast against ERAINTERIM, and d) and e) for the 10 day forecast error, for the atmosphere-only model in the middle, coupled on the right.

- Cold surge circulation well represented at +3 days for 16/17, but too easterly and strong south of Philippines, over the Gulf of Thailand and the central Pacific for both seasons. Biases are worse for 16/17
- At +10 days, the wind errors reverse sign over the South China Sea, weakening the north-easterly flow, and to the west of the Philippines. In 17/18, the strong cross-equatorial flow over the Java Sea is weakened in the coupled model
- The representation of cold surge circulation is similar in both atmosphere-only and coupled models

7. Representation of cold surge precipitation

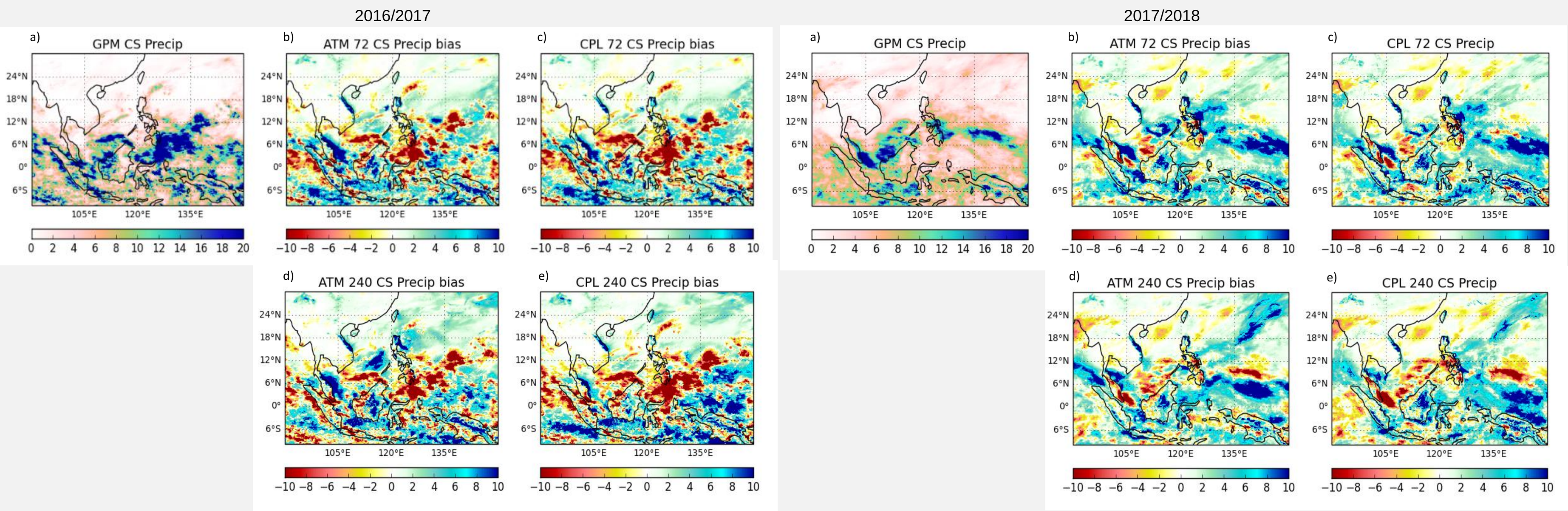

Figure 6: Same as Figure 5 but for precipitation (mm/day) against GPM observations

- Both models present a wet bias off the coast of Malaysia Peninsula associated with a dry bias over land to the south, which is typical of the convection parametrisation in this configuration (Walters et al. 2017). The coupled model significantly improves the wet bias off the coast of Malaysia and north of Borneo at all lead times and both seasons, except for +10 days in 17/18 where the drying effect is excessive
- There are other systematic biases which are present from +3 days: dry to the south of the Philippines and northeast of Borneo, and wet over central Borneo and west Java Sea
- The noisy pattern for 16/17 is indicative of the variability for this year, and smaller cold surge days sample
- A large wet bias develops to the north of New Guinea in the coupled model

8. The impact of SST changes

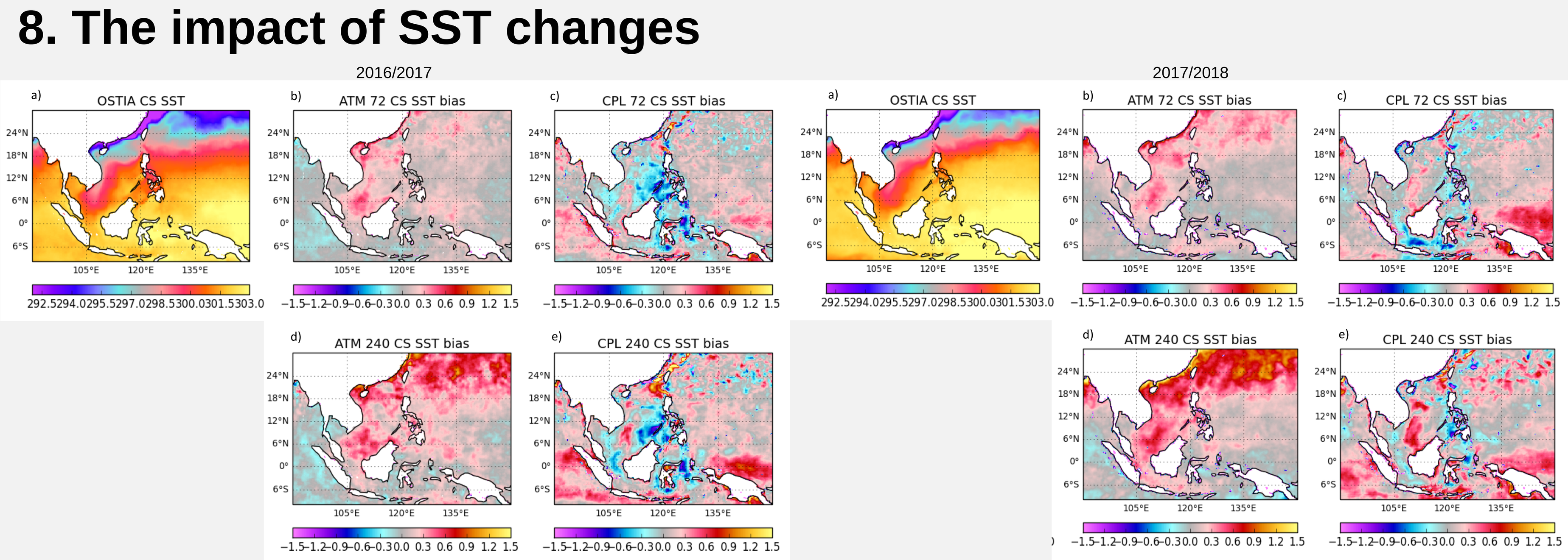

Figure 7: Same as Figure 5 but for SSTs (K) against OSTIA observations

- Distinct enhanced cold tongue across the South China Sea during cold surges in both seasons
- Persisted SSTs in the atmosphere-only forecasting system does not represent this cooling, hence warm biases against OSTIA
- The coupled model is able to represent cooler SSTs across the South China Sea (and cooler SSTs east of China due to the seasonal cycle), but cools a bit too much to the west and too little to the east. This has a thermodynamical impact to reduce excessive precipitation off the coast of Malaysia peninsula
- Cold SST biases introduced south of Philippines associated with the strong wing biases over these regions

9. Discussion

- The global NWP model is able to forecast cold surges 10-12 days in advance with promising scope to improve preparedness for associated extreme rainfall events, especially when coinciding with MJO events
- The coupled model is able to improve some of the precipitation biases and RMSEs over the region, additional analyses of the air-sea interaction processes are required
- Ensemble simulations and more seasons would be required to analyse different types of cold surges (easterly, meridional, cross-equatorial and their respective impact over different countries of Southeast Asia)

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