EVALUATION OF REGIONAL CLIMATE DOWNSCALING OVER THE MARITIME CONTINENT

Ricardo FONSECA[1], Tengfei ZHANG[2], Tieh-Yong KOH[3]

[1]Division of Space Technology, Luleå University of Technology, Kiruna, Sweden
[2]Earth Observatory of Singapore, Nanyang Technological University, Singapore
[3]UniSIM College, SIM University, Singapore

1. Introduction

- The Maritime Continent, that consists of New Guinea, the Malay Peninsula and the Greater and Lesser Sunda Islands, comprises small land masses with elevated terrain and shallow seas with the warmest surface temperatures in the world. Coarse resolution GCMs do not capture the geographic variation within the region and so regional climate models are needed to investigate local and regional circulations.
- Given that a large fraction of the world's population lives in the Maritime Continent, and its role on the global climate (Ramage, 1968), an understanding of its current regional climate is crucial to fully comprehend global changes in temperature and precipitation in Southeast Asia under climate change.

2. Regional Atmospheric Climate Model

In this study the Weather Research and Forecast model version 3.3.1 (WRF; Skamarok et al., 2008) is used to dynamically downscale the 0.5° × 0.5° NCEP's Climate Forecast System Reanalysis (NCEP CFSR) (Saha et al., 2010) for the tropics.

The spatial domain is a tropical belt extending from about 42°S to 45°N with a horizontal resolution of 30 km. In all model runs 37 vertical levels are considered, more closely spaced in the Planetary Boundary Layer (PBL) and in the tropopause region, with the model top at 30 hPa and the highest un-damped layer at about 70 hPa. Analysis nudging is applied to the horizontal winds (u, v), potential temperature perturbation (θ') and water vapour mixing ratio (q_v). These fields are relaxed towards NCEP CFSR above 800 hPa, and excluding the PBL, on a time-scale of 1 h. The time-step used is 1 minute and the output frequency 1 h.

The physics parameterization schemes used are shown in the table below:

Physics Options	Parameterization Scheme
Microphysics	WRF Double-Moment 5-class
Radiation	Rapid Radiative Transfer Model for GCM Applications (RRTMG)
Surface Layer	MM5 Monin-Obukhov Scheme
Land Surface	Noah Land Surface Model
Planetary Boundary Layer	Yonsei University (YSU) PBL Scheme
Cumulus	Betts-Miller-Janjić (BMJ) Scheme
Sea Surface Temperature	CFSR SST + simple skin temperature scheme (Zeng et al., 2005)

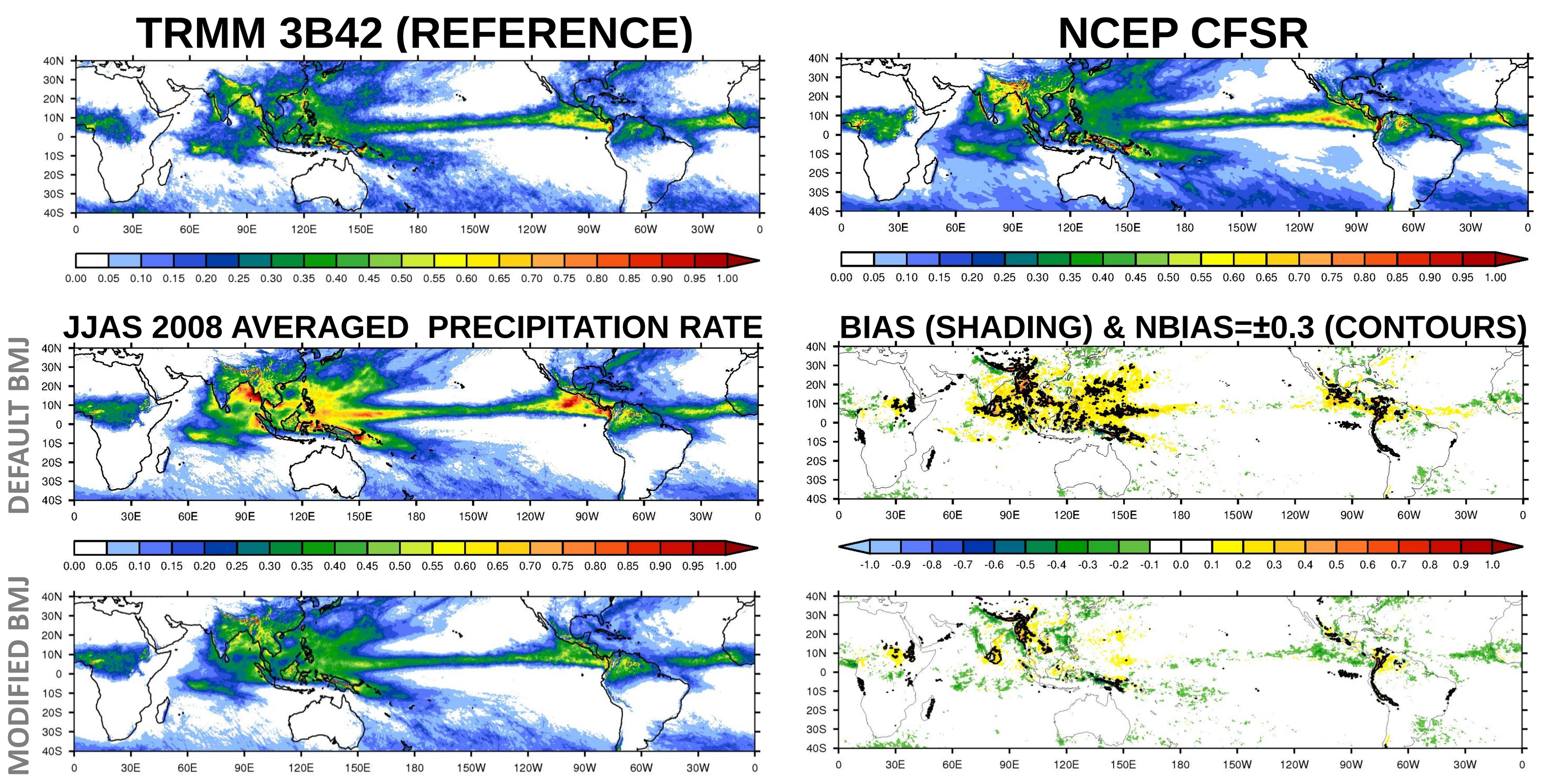
3. Modified Betts-Miller-Janjić (BMJ) Scheme

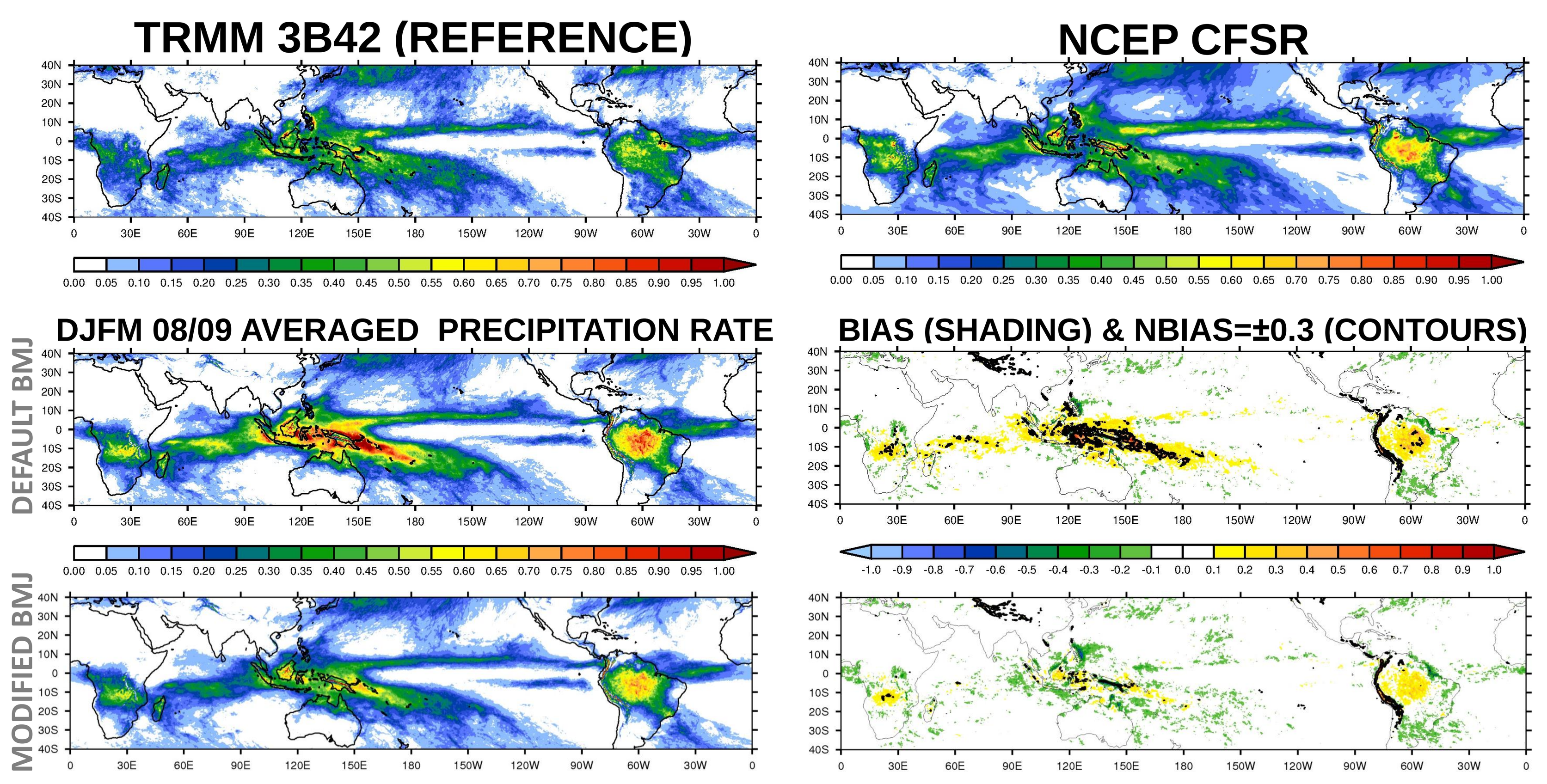
- When used to downscale CFSR data over South-east Asia, WRF is found to overestimate the observed precipitation, as given by he Tropical Rainfall Measuring Mission (TRMM) 3B42 version 6 (Huffman et al., 2007), with this excessive rainfall generated mainly by the cumulus scheme, BMJ, originally developed for North America where the environmental conditions are very different from those in the tropics.
- The BMJ scheme is modified by making the reference humidity profile more moist (Fonseca et al., 2015). In this scheme the first-guess humidity reference profile at each pressure level p_L is prescribed by the lifting condensation level, $p_L + \wp(p_L)$ where $\wp(p_L) < 0$, of an air parcel with $\theta^{f}_{REF}(p_L)$ and $q^{f}_{REF}(p_L)$. The more negative $\wp(p_L)$ is the drier the reference humidity profile will be as the air parcel has to be lifted further up to reach condensation. $\wp(p_L)$ is piecewise linearly interpolated between the values at the cloud bottom, $\wp_B$, freezing level, $\wp_M$, and cloud top, $\wp_T$, which are in turn parameterized as linear functions of the cloud efficiency E:

$$\wp_B = (-3875\,Pa)\,g(E) \qquad g(E) = \left[F_S + (F_R - F_S)\left(\frac{E' - E_1}{E_2 - E_1}\right)\right]$$
$$\wp_M = (-5875\,Pa)\,g(E)$$
$$\wp_T = (-1875\,Pa)\,g(E) \qquad F_R = 1;\ E_1 = 0.2;\ E_2 = 1.0;\ E_1 \le E' \le E_2$$

In the default WRF implementation $F_S = 0.85$, an empirically determined value over continental USA, but in Janjić (1994) $F_S = 0.6$. A smaller value of F_S will lead to a more moist humidity reference profile and hence a decrease in the BMJ precipitation. The value of F_S is decreased from 0.85 to 0.6 and the performance of this "modified BMJ scheme" is assessed with WRF being run from 1st May 2008 to 1st April 2009 with the first month regarded as spin-up.

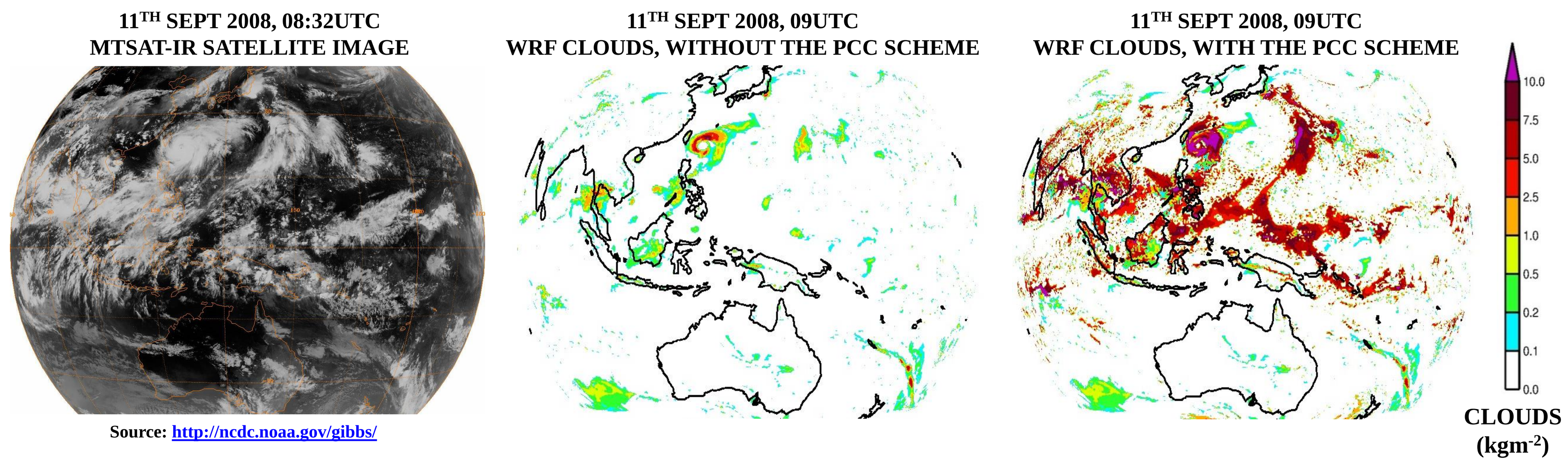
- Below the precipitation rate (in units of mm hr^{-1}) averaged over June to September (JJAS) 2008 and December to March (DJFM) 2008/2009 for the WRF experiments is shown together with the rainfall rate from TRMM and NCEP CFSR for the two seasons. Also shown is the bias (shading) and the normalized bias contours of ±0.3 (when the absolute value of the normalized bias is ≤0.3 the contribution of the bias to the RMS error is less than ~5% and the biases will not be considered significant, see Koh et al. (2012) for more details) with respect to TRMM for each WRF experiment.
- It is found that for the whole tropics, and both monsoon seasons, with the modified BMJ scheme most of the rainfall biases are corrected and in some regions the model even gives a better estimate of the observed rainfall than NCEP CFSR.





4. Precipitating Convective Cloud (PCC) Scheme

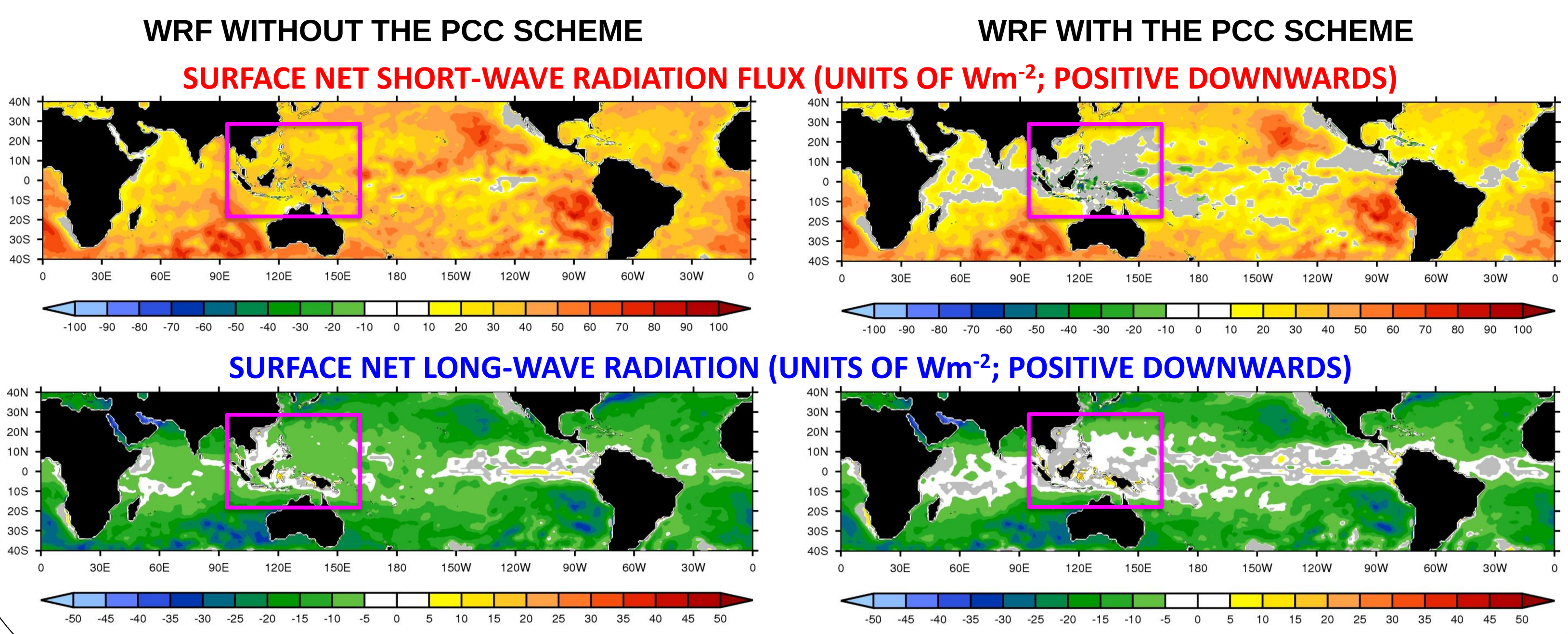
- In WRF subgrid-scale cumulus clouds are radiatively transparent so that the surface temperature remains too warm during rainfall. Recent studies showed cumulus cloud-radiation feedbacks to be important at regional weather and climate scales (Alapaty et al., 2012) in particular in regions with strong land-sea contrasts such as the Maritime Continent where many of the processes that drive regional/local climate variability ultimately depend on the accurate simulation of the radiative fields.
- A Precipitating Convective Cloud (PCC) scheme, based on the BMJ rainfall, is developed and implemented in the WRF model (Koh et al., 2015). The scheme can be described as follows:
  - following Slingo (1987), the maximum cloud fraction in a column is proportional to the logarithm of the convective precipitation rate at every time-step. The vertical cloud profile is assumed to follow a "top-heavy" Poisson distribution, similar to observed profiles;
  - the cloud condensates are defined based on the assumption that the mass of convective cloud per unit mass of water vapour in cloudy air is constant in the column.
- The 1-year experiment (April 2008 – March 2009) is repeated with the PCC scheme. In order to assess the realism of the clouds produced by the model, the WRF clouds are compared to satellite imagery for different regions/seasons. As an example the images below show the clouds for Asia and the West Pacific for a given day in the summer monsoon season. As can be seen, WRF gives a much better representation of the observed cloudiness when the PCC scheme is employed.



- The figures below show WRF's surface net short-wave and long-wave radiation bias (units of Wm^{-2}) with respect to that observed as given by the National Oceanography Centre Southampton Version 2.0 surface flux dataset (NOCSv2; Berry and Kent, 2009) with and without the PCC scheme.
- WRF overestimates the surface net short-wave radiation and underestimates the surface net long-wave radiation suggesting a lack of cloud cover, in particular the absence of shallow cumulus and stratocumulus clouds as the radiation biases are larger in the eastern side of subtropical oceans where these clouds are more predominant (Klein and Hartmann, 1993).

  This is a known problem in WRF: Huang et al. (2013) tested a combination of different physics scheme and found that the model does not properly simulate these clouds.
- In the deep tropics, where convective clouds are more prevalent, most of the radiation biases are corrected when the PCC scheme is employed. In fact, over South-east Asia, our region of interest (pink rectangles), the biases in the surface radiation fluxes are very small.

WRF BIASES FOR SURFACE NET RADIATION FLUXES WITH RESPECT TO NOCSv2



BIASES FOR WHICH |NBIAS|<0.5 ARE SHADED IN GREY

References

Alapaty, K. and Coauthors, 2012: Introducing subgrid-scale cloud feedbacks to radiation for regional meteorological and climate modeling. *Geophys. Res. Lett.*, **39**, 24809.
Berry, D.I. and E.C. Kent, 2009: A new air-sea interaction gridded dataset from ICOADS with uncertainty estimates. *Bull. Amer. Soc.*, **89**, 1111–1125.
Fonseca, R.M., Zhang, T. and T.-Y. Koh, 2015: Improved Simulation of Precipitation in the Tropics using a Modified BMJ Scheme in WRF Model. *Geosci. Model Dev.*, **8**, 2915-2928.
Huang, H.-S., Hall, A. and J. Teixeira, 2013: Evaluation of the WRF PBL Parameterizations for Marine Boundary Layer Clouds: Cumulus and Stratocumulus. *Mon. Wea. Rev.*, **141**, 2265-2271.
Huffman, G.J. and Coauthors, 2007: The TRMM multisatellite precipitation analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation at fine scales. *J. Hydrometeor.*, **8**, 38–55.
Slingo, J.M., 1987: The development and verification of a cloud prediction scheme for the ECMWF model. *Q. J. Meteorol. Soc.*, **113**, 899–927.
Klein, S.A. and D.L. Hartmann, 1993 : The seasonal cycle of low stratiform clouds. *J. Climate*, **6**, 1587-1606.
Koh, T.Y., Wang, S. and B.C. Bhatt, 2012 : A diagnostic suite to assess NWP performance. *J. Geophys. Res.*, **117**, D13109, doi:10.1029/2011JD017103.
Koh, T.Y. and R.M. Fonseca, 2016: Subgrid-scale Cloud-Radiation Feedback For the Betts-Miller-Janjić Convection Scheme. *Q. J. R. Meteorol. Soc.*, **142**, 989-1006.
Ramage, C.S., 1968: The role of a tropical "maritime continent" in the atmospheric circulation. *Mon. Wea. Rev.*, **96**, 365–370.
Saha, S. and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015–1057.
Skamarock, W. C and Coauthors, 2008: A description of the Advanced Research WRF version 3. NCAR tech. Note TN-4175_STR, 113pp.
Zeng, X. and Beljaars, A., 2005: A prognostic scheme of sea surface skin temperature for modeling and data assimilation. *Geophys. Res. Lett.*., 32:L14605, doi:10.1029/2005GL023030.