Study on sensitivity of CCAM model to the sea surface temperature boundary conditions

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Abstract:

The ability of simulation on large-scale global circulation, as well as temperature and rainfall over Vietnam area with different sea surface temperature (SST) boundary conditions by the Conformal-Cubic Atmospheric Model (CCAM) is presented in this paper. CCAM is a global circulation model, which may be used in the variable resolution mode to function as a regional climate model. That is, the model may be integrated with high horizontal resolution over the area of interest, with the resolution gradually decreasing as one moved away from the area of interest. The results show that model has well predicted large global circulation all over the global compared to Climate Forecast System (CFS) analysis data, two experiment of CCAM model were not too different with CFS model. For detailed forecasts in Vietnam region, the CCAM model will capture surface temperature compared to observed data with correlation coefficient above 0.85. Forecast temperature of CCAM tends to be lower than observed data, but the magnitude of error is not so much. Comparing the two experiments, forecast skill of CCAM_IRI is slightly better than CCAM_CFS. For rainfall, CCAM generally tends to forecast rainfall higher than observation data in summer and lower in winter. The predictive skill of rainfall in short lead times is better than others and skill of CCAM_CFS is significantly better than CCAM_IRI.

Keywords: ***CCAM, forecast SST, global model, region Vietnam, seasonal forecasting.***

Classification number: ***6.2***

Introduction

Seasonal climate prediction is currently one of the top concerns because of its benefits and has been applied widely in many sectors like agriculture, construction and socio-economic activities. Seasonal prediction information plays an important role in making plans and decisions for upcoming activities like, crop production and disaster response. Seasonal prediction usually provides information on seasonal statistical features, with lead times from 1 to 9 months. The two main approaches used in seasonal forecasting are statistical and dynamical methods [1]. The dynamical method has been shown to have more advantages, as it can capture the nonlinearity of the climate variables. Along with the development of science and technology, especially in computing and storage capabilities, dynamical models have been used more commonly, with dynamic processes described in more detail on both global and regional scales. In Vietnam, there have been many studies on regional models such as RegCM and clWRF [2-4]; the results are positive in forecasting temperature, but still have significant error in rainfall prediction. However, the initial boundary conditions for these regional models are mainly collected from forecast products of meteorological agencies in the world. To be more active in data sources for operational forecast system, the study of constructing global model for Vietnam is very necessary. In this study, we firstly apply a global model to simulate climate for Vietnam. The main purpose of this paper is to investigate sensitivity of CCAM model to SST boundary conditions, both on global scale and downscaling for Vietnam area. The paper is organised as follows: Section 2 outlines the model description and experimental configuration. In Section 3, the ability of CCAM to simulate large-scale global circulation, as well as temperature and rainfall over Vietnam area is presented and discussed. Summary and conclusions can be found in Section 4.

Methodology and data

The conformal-cubic atmospheric model and experimental configuration

CCAM is a variable-resolution global atmospheric model, developed at the Commonwealth Scientific and Industrial

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Research Organisation (CSIRO). This model uses the conformal cubic grid. The application of conformal cubic grid in CCAM derives from Sadourny's idea [5]. Then, through much research, experimentation, and development of Rancic, et al. [6] and McGregor [7-10] in construction and incorporation of primitive equations into the grid, it was basically completed and is being applied so far. The remarkable advantage of this grid is that it can solve problems in the polar and sub-polar regions, where the resolution of grid is uneven and narrowed down; this may lead to serious limitations on integration time steps or require special filtering techniques. Although CCAM is a global model, it also can simulate or predict with high resolution for specific areas. The concept of "stretched grid" was introduced to do this [11]. In "stretched" state, the grid system is shaped like a square frustum, with a small face corresponding to higher resolution region, and the remaining faces in other regions have coarser resolution. Due to this feature, even when downscaling for a given region, simulations or predictions of CCAM are always global, allowing CCAM to avoid some complicated processes when calculating in a domain's boundaries, different from other regional models.

CCAM can either be used as a global model, or be downscaled for a specific area such as other regional models. On the other hand, beside initial conditions, CCAM just requires boundary condition of monthly average SST. This is an important advantage of CCAM, making it easier to add different inputs than other models. Additionally, CCAM is a global model, so output from CCAM can be used as input for other regional models.

In this study, CCAM includes GFDL SEA/ESF radiation scheme (Fels and Schwarzkopf [12]; Schwarzkopf and Fels [13] vertical mixing scheme of Holtslag and Boville [14] CABLE biosphere-atmosphere exchange model consisting of 6 layers for soil temperature, 6 layers for soil moisture and 3 layers for snow [15], cumulus convection scheme described by McGregor [16] and some schemes developed specifically for this model, see more detail in McGregor's description [17].

To evaluate effects of SST boundary condition on CCAM's seasonal prediction for the global and Vietnam region, CCAM will be run with two different SST data. One is from the output of CFS and another is from the SST forecast of International Research Institute for Climate and Society (IRI). Experiments began from January 2008 until September 2014. The CCAM configuration used in the experiment was as follows:

1) Global forecast: Use C96 grid with 96 x 96 grid points (horizontal resolution of about 100 km) and 27 vertical levels.

2) Regional forecast: CCAM itself is also a regional model, so in this experiment, CCAM was used to downscale for Vietnam area, the domain centre was 108°E and 17°N, horizontal resolution of 25 km, and vertical levels same as the global. The terrain elevation and the domain size are shown in Fig. 1 (left).

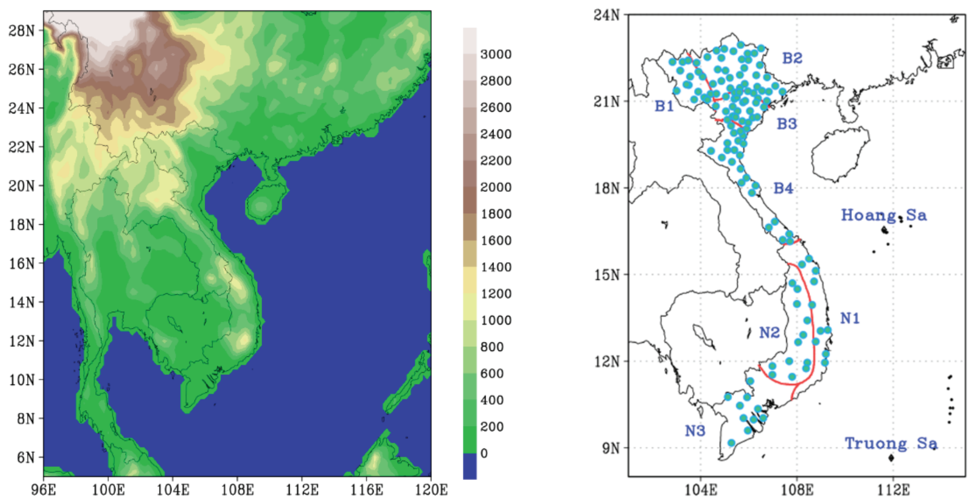

Fig. 1. Topography and domain of Vietnam (left); location of observed station (right).

Data

Initial condition data for the model included atmospheric (0.5 degree horizontal resolution) and surface variables (0.3 degree resolution) from CFS analysis data (CFSnl). The boundary condition data is monthly SST, with 6-month forecasts from CFS and IRI. In which, CFS is operational forecasting data of the National Oceanic and Atmospheric Administration (NOAA), with 1 x 1 degree resolution, and lead time up to 9 months. IRI is forecast data of anomaly of SST, 2.5x 2.5 degree resolution, with a 7-month forecast. When using IRI data, it is necessary to add to average climate period of IRI, combined from Raynolds' SST data from 1961 to 1981 and the NOAA optimum interpolation SST V2 from 1982 to 1990 [18, 19]. For convenience, CCAM_CFS is represented for CCAM run with CFS SST and CCAM_IRI is for CCAM with SST input from IRI.

As CFSnl is assimilation data from observations, so in this study, CFSnl data is also used to evaluate forecast results of global circulation from CCAM. The regional prediction of CCAM for temperature and rainfall will be compared to observed data at 128 stations all over Vietnam (The location of the stations is shown in Fig. 1, right). Statistical indicators used in the paper included mean error (ME), mean absolute error (MAE), and correlation coefficient.

Results and discussions

Evaluating global forecasts

Firstly, the results of CCAM's global prediction at 850 mb from CCAM_CFS and CCAM_IRI will be compared with the CFS model and CFSnl data for January and July of 2008-2014 period, according to 1, 3 and 5 month lead times.

In January, overall, CCAM_CFS and CCAM_IRI both predicted geopotential height and winds at 850 mb, quite similar to CFS and CFSnl with all of lead times (1, 3 and 5 months). For more detail, CCAM predicts geopotential height higher than CFS and CFSnl in most of the tropical and subtropical regions, especially in Atlantic region. However, geopotential height of CCAM tends to be lower than CFSnl in northeastern Russia. For wind at 850 mb level, CCAM can capture very well the main wind direction in January in most parts of the globe, the predicted wind speed of the model also is not too different from CFSnl. Comparison of two CCAM experiments shows that there is not significant difference, but CCAM_CFS result tends to be better than CCAM_IRI in the Pacific region.

In July, similar to January, CCAM in both experiments also forecasts relatively well, the spatial distribution of geopotential height, as well as wind at 850 mb level compared to CFSnl. CCAM still predicts geopotential height higher than CFSnl in tropical and subtropical regions, but the difference is clearer than in January. In the Northern Hemisphere's high latitude region, the geopotential height predicted by CCAM tends to be significantly lower than CFSnl. Wind at 850 mb in July of CCAM is still well suited to CFS and CFSnl in most parts of the globe. However, the predicted wind speed tends to be stronger than CFSnl. Comparing two CCAM model experiments, there is not much difference between CCAM_CFS and CCAM_IRI (Figs. 2-4).

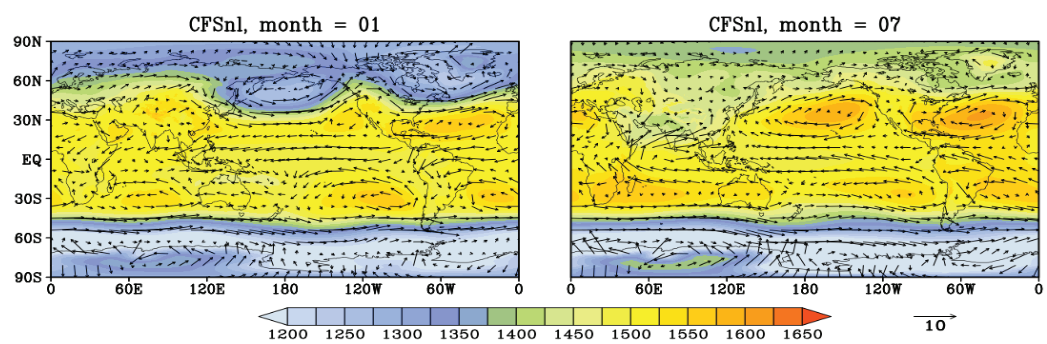

Fig. 2. Geopotential height (m) and wind (m/s) at 850 mb level, for January (left) and July (right), average of 2008-2014 period, from CFSnl analysis data.

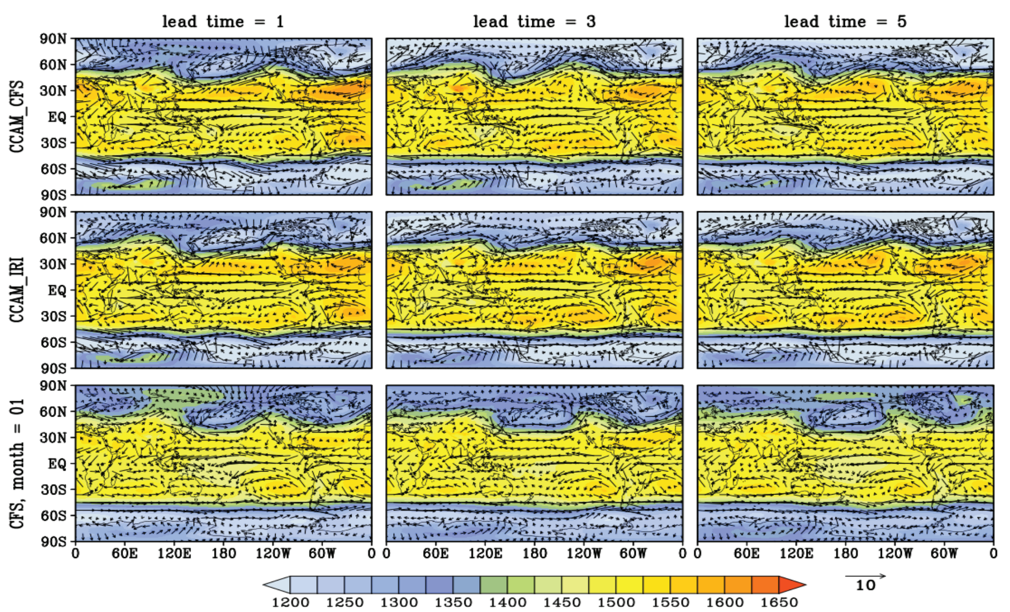

Fig. 3. Prediction of geopotential height (m) and wind (m/s) at 850 mb level, for January with lead times of 1, 3 and 5 months (from left to right), average of 2008-2014 period. CCAM_CFS (top), CCAM_IRI (middle) and CFS (bottom).

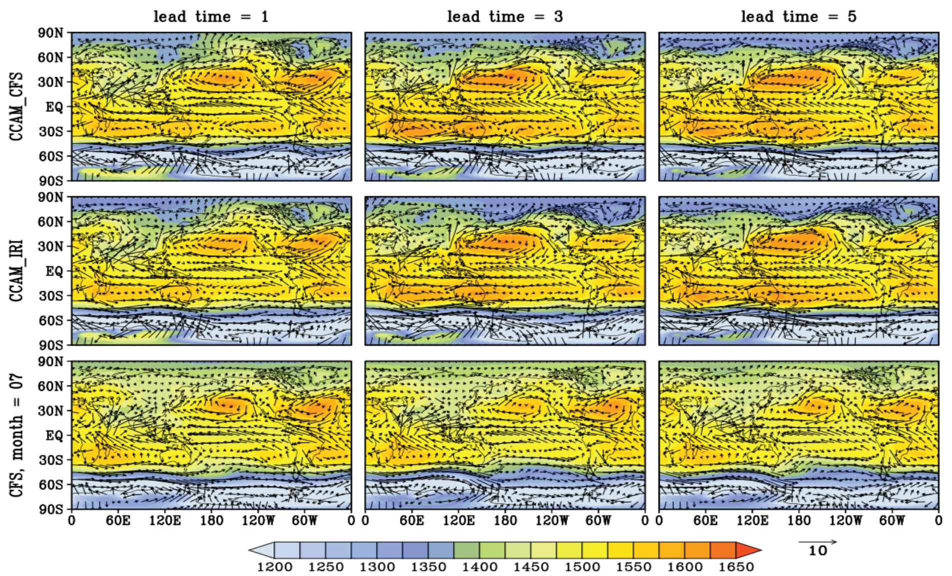

Fig. 4. Prediction of geopotential height (m) and wind (m/s) at 850 mb level, for July with lead times of 1, 3 and 5 months (from left to right), average of 2008-2014 period. CCAM_CFS (top), CCAM_IRI (middle) and CFS (bottom).

Evaluating regional forecasts

Next, regional forecast of CCAM will be assessed through temperature and rainfall at 128 stations in the Vietnam area.

Figure 5 shows errors (ME and MAE) of temperature from CCAM_CFS and CCAM_IRI with observation data for 1-month, 3-month and 5-month lead times. In general, ME value is negative, indicating that forecast temperature of CCAM tends to be lower than observed data in most climatic regions across the country with three lead times. Forecasting temperature is higher than observed data in spring in Northern Delta and Northern Central areas, especially with 3-month and 5-month lead times. With MAE error, CCAM's results are quite good with magnitude of error not exceeding 2-3^{o}C; October, November and December have maximum error value, which may be up to 5^{o}C in Northern regions. Error for 1-month lead time is greater than 3-month and 5-month lead times. Comparing two experimental options, CCAM_CFS could be found to have a larger error than CCAM_IRI in October, November and December with 5-month lead time.

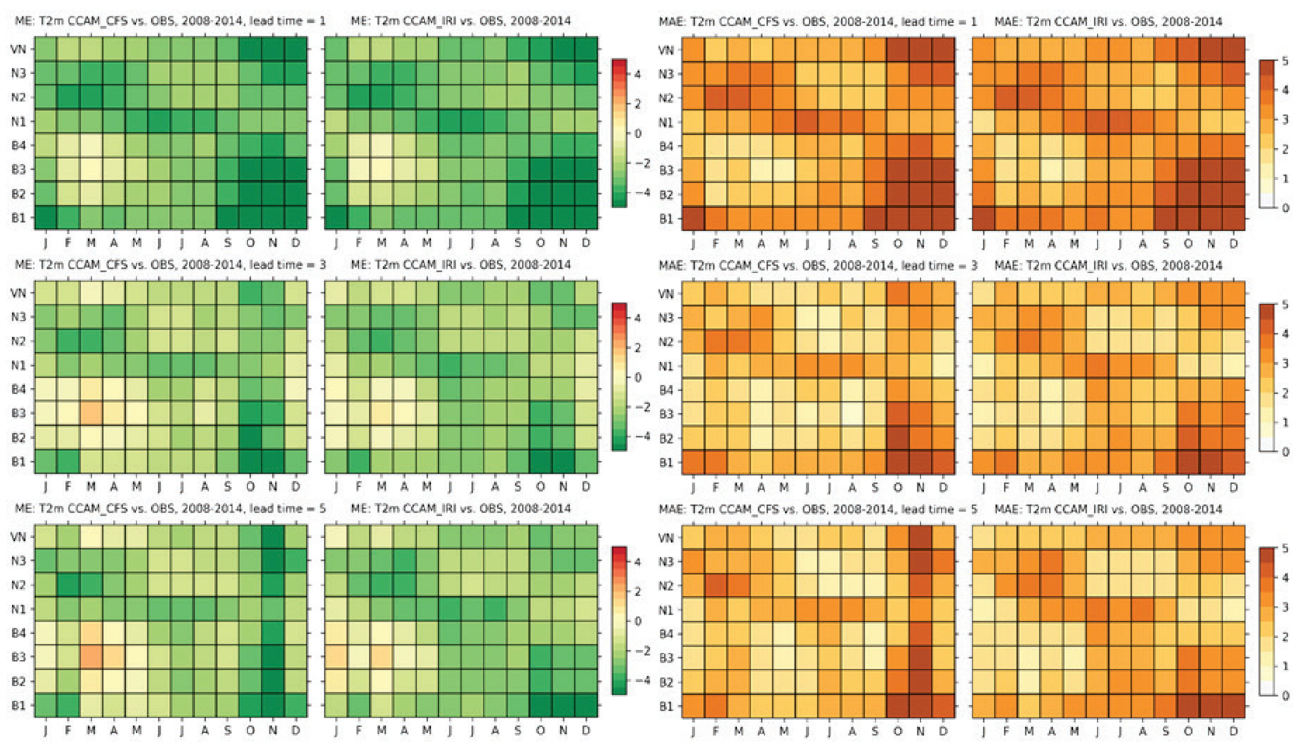

Fig. 5. The monthly ME error (^{o}C, left) and the MAE error (^{o}C, right) of temperature from CCAM_CFS and CCAM_IRI compared to observed data, average for 7 climatic regions and Vietnam, with lead times of 1, 3 and 5 months (order from top to bottom), period of 2008-2014.

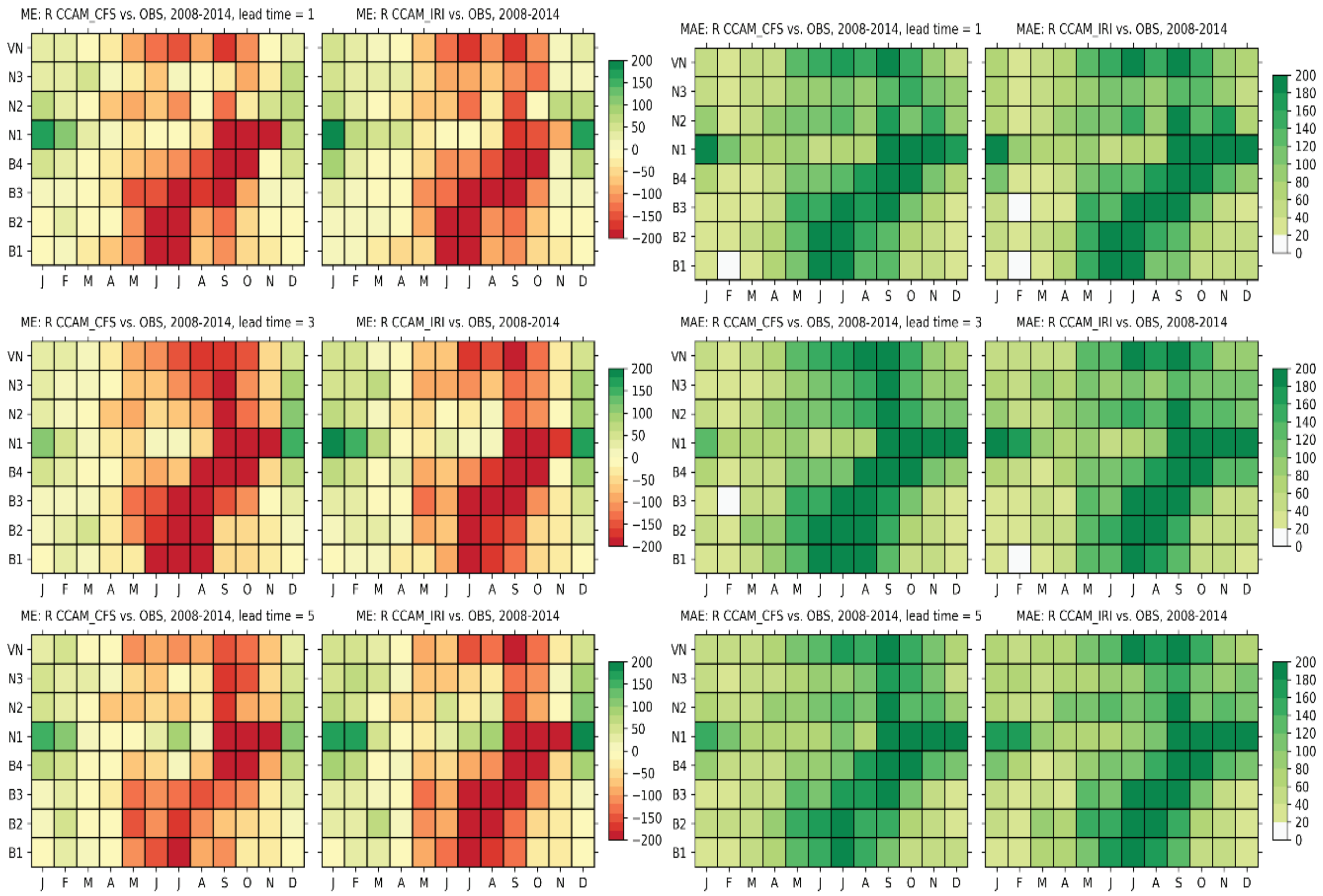

Fig. 6. The monthly ME error (mm, left) and the MAE error (mm, right) of rainfall from CCAM_CFS and CCAM_IRI compared to observed data, average for 7 climatic regions and Vietnam, with lead times of 1, 3 and 5 months (order from top to bottom), period of 2008-2014.

For rainfall, CCAM generally tends to forecast rainfall higher than observation data in summer and lower in winter. In the summer months, the error of rainfall is about 80 to more than 200 mm/month, southern regions have smaller errors than northern ones, results of 1-month lead time is better than 3-month and 5-month lead times in southern part of Vietnam with two cases. For the winter months, error of rainfall varies 20-80 mm/month, South Central region has larger errors than the rest of Vietnam. There is not significant differences in two experimentations, however, with the 5-month lead time, error of CCAM_CFS is smaller than CCAM_IRI in summer months (Fig. 6).

Figures 7-8 show the scatter graph of temperature and precipitation from two experimental options of CCAM compared to observed data at the stations across Vietnam, and for 1-month, 3-month and 5-month lead times. With temperature, the correlation coefficient between CCAM and observation is very high, above 0.85 for all lead times. For rainfall, CCAM_CFS with 1-month lead time has best correlation (0.497); the correlation coefficient for 3-month lead time is lower than others. In general, the correlation coefficient of rainfall from CCAM_CFS is higher than CCAM_IRI.

In order to evaluate the predictive skills of CCAM with two input data and be able to give a conclusion on which one is better, this study applied model assessment method based on the Taylor diagram [20]. The model's skill is evaluated based on the combination of correlation coefficient and standard deviation; the skill measure is the distance from model point to observation point on the diagram. The Taylor diagram of forecast temperature and rainfall from two CCAM cases, with lead times ranging from 1 to 5 months compared to observed stations across Vietnam, was shown in Fig. 9. The results show that with temperature, the model's forecasting skill in lead times is not much different. However, it can be pointed out that skills of short and long lead times are lower than the medium, and CCAM_IRI skills are slightly better than CCAM_CFS. For rainfall, it is easy and better seeing predictive skill in short lead times and skill of CCAM_CFS is significantly better than CCAM_IRI.

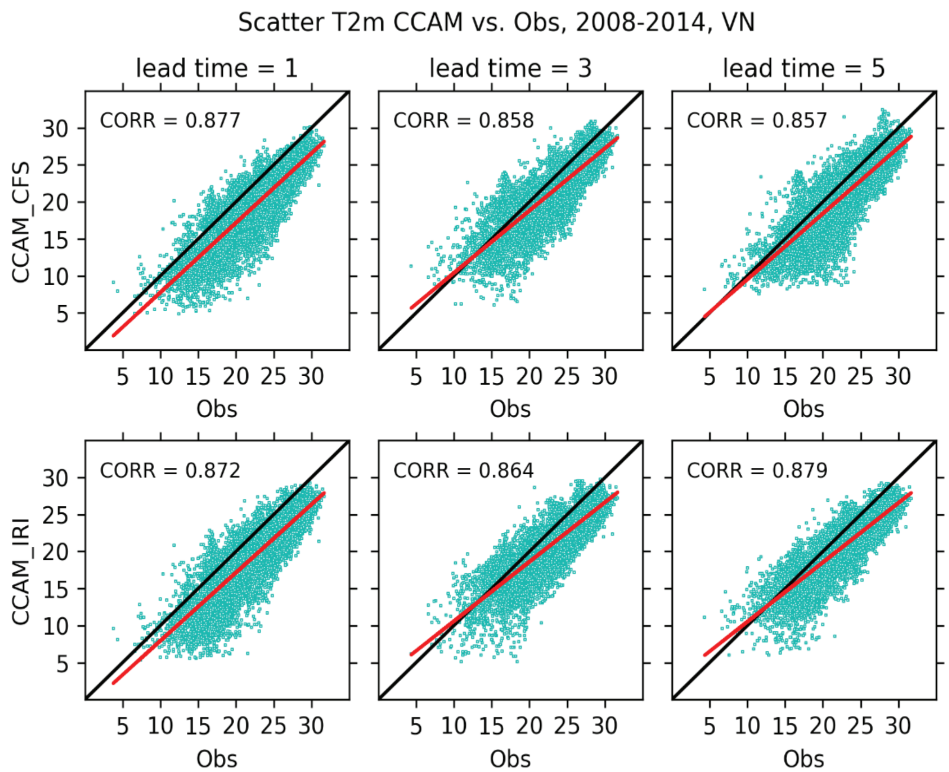

Fig. 7. Scatter graph of the temperature (°C) predicted by CCAM_CFS (top) and CCAM_IRI (bottom) compared to observations, with lead times of 1, 3 and 5 months (from left to right), for the period of 2008-2014, throughout-Vietnam.

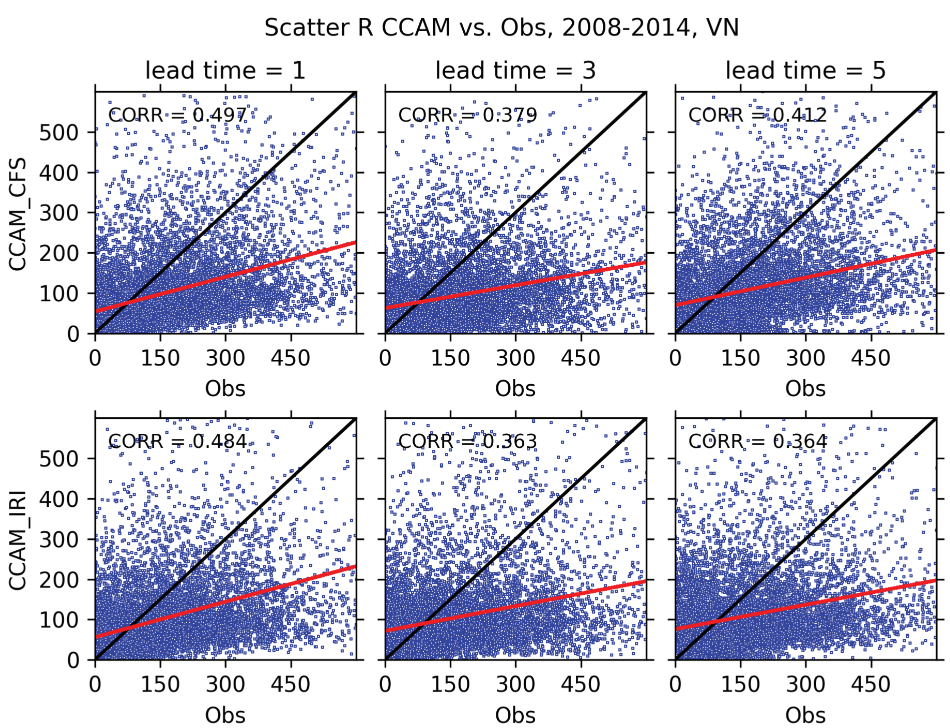

Fig. 8. Scatter graph of the rainfall (mm) predicted by CCAM_CFS (top) and CCAM_IRI (bottom) compared to observations, with lead times of 1, 3 and 5 months (from left to right), for the period of 2008-2014, throughout Vietnam.

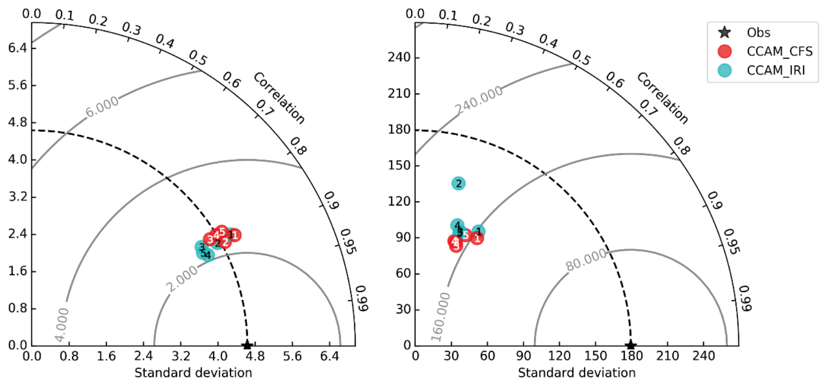

Fig. 9. The Taylor diagram of CCAM_CFS and CCAM_IRI with observation of monthly temperature (^{0}C, left) and rainfall (mm, right), with 5 lead times from 1 to 5 months, for the period of 2008-2014.

Summary and conclusions

This research has illustrated the applicability and development of a global model for seasonal climate prediction in Vietnam. CCAM has modern advantages on conformal cubic grid and "stretched grid" technique, which makes it possible to run for both global and regional forecasts with boundary conditions from monthly SST. The study ran CCAM with two SST sources, for global and regional prediction in Vietnam, with lead time up to 5 months, for the period of 2008-2014. The purpose of this study is to show the sensitivity of CCAM with SST on seasonal prediction, as well as to evaluate which CCAM option is better to construct climate period from the model, and initially orientating the use of SST sources for future studies with CCAM. From above results, the following conclusions can be made:

CCAM can capture quite well large-scale circulation including geopotential height and wind at 850 mb level compared to CFS and CFSnl. In which, the geopotential height of CCAM tends to be higher than the CFS and CFSnl in the tropics and subtropics, but lower in the Northern Hemisphere, although the difference is not significant. The January forecast for CCAM is better than in July. The two experiments of CCAM_CFS and CCAM_IRI were not much different.

The prediction of temperature and rainfall of CCAM were evaluated with observed data at 128 stations all over Vietnam. The results show that forecast temperature of CCAM tends to be lower than observed data in most climatic regions across the country, but the magnitude of error is not so much. The correlation coefficient between CCAM and observation is very high, above 0.85 for all lead times. Comparing the two experiments, forecast skill of temperature of CCAM_IRI is slightly better than CCAM_CFS. CCAM generally tends to forecast rainfall higher than observation data in summer and lower in winter; southern regions have smaller errors than northern ones. The predictive skill of rainfall in short lead times is better than others and skill of CCAM_CFS is significantly better than CCAM_IRI.

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REFERENCES

[1] T.N. Stockdale (2000), "An overview of techniques for seasonal forecasting", *Stochastic Environmental Research and Risk Assessment*, **14**, pp.305-318.

[2] Van Tan Phan, Thi Minh Ha Ho, Manh Thang Luong, Quang Duc Tran (2009), "Applicability of Regional Climate Model (RegCM) for seasonal scale prediction of surface climate fields in Vietnam", *VNU Journal of Science: Earth and Environmental Sciences*, **25**, pp.241-251.

[3] Thanh Hang Vu, Thi Hanh Nguyen (2014), "Monthly Temperature and Precipitation Seasonal Forecast over Vietnam using clWRF model", *VNU Journal of Science: Earth and Environmental Sciences*, **30**, pp.31-40.

[4] Thi Hanh Nguyen, Thanh Hang Vu, Van Tan Phan (2016), "Seasonal Rainfall Forecast Using clWRF Model: The Sensitivity of the Convective Parameterization Schemes", *VNU Journal of Science: Earth and Environmental Sciences*, **32**, pp.25-33.

[5] R. Sadourny (1972), "Conservative finite-difference approximations of the primitive equations on quasi-uniform spherical grids", *Monthly Weather Review*, **100**, pp.136-144.

[6] M. Rančić, R.J. Purser and F. Mesinger (1996), "A global shallow water model using an expanded spherical cube: Gnomonic versus conformal coordinates", *Quarterly Journal of the Royal Meteorological Society*, **122**, pp.959-982.

[7] J.L. McGregor (1993), "Economical determination of departure points for semi-Lagrangian models", *Monthly Weather Review*, **121**, pp.221-230.

[8] J.L. McGregor (1996), "Semi-Lagrangian advection on conformal-cubic grids", *Monthly Weather Review*, **124**, pp.1311-1322.

[9] J.L. McGregor (2005a), "C-CAM: Geometric aspects and dynamical formulation [electronic publication]", *CSIRO Atmospheric Research Tech. Paper*, **70,** 43 pp.

[10] J.L. McGregor (2005b), "Geostrophic adjustment for reversibly staggered grids", *Monthly Weather Review,* **133**, pp.1119-1128.

[11] F. Schmidt (1977), "Variable fine mesh in spectral global model", *Beitrage Physical Atmosphere*, **50**, pp.211-217.

[12] S. Fels and M. Daniel Schwarzkopf (1975), "The simplified exchange approximation: a new method for radiative transfer calculations", *Journal of the Atmospheric Sciences*, **32(7)**, pp.1475-1488.

[13] M.D. Schwarzkopf and S. Fels (1991), "The simplified exchange method revisited: An accurate, rapid method for computation of infrared cooling rates and fluxes", *Journal of Geophysical Research,* **96(D5)**, pp.9075-9096.

[14] A.A.M. Holtslag and B.A. Boville (1993), "Local versus Nonlocal Boundary-Layer Diffusion in a Global Climate Model", *J. Climate,* **6**, pp.1825-1842.

[15] E.A. Kowalczyk, J.R. Garratt and P.B. Krummel (1994), "Implementation of a soil-canopy scheme into the CSIRO GCM - regional aspects of the model response", *CSIRO Atmospheric Research Technical Paper,* 32 pp.

[16] J.L. McGregor (2003), "A new convection scheme using a simple closure. In 'Current issues in the parameterization of convection", *BMRC Research Report*, **93**, pp.33-36.

[17] J.L. McGregor and M.R. Dix (2008), "An Updated Description of the Conformal-Cubic Atmospheric Model, High resolution simulation of the atmosphere and ocean", *Springer New York,* pp.51-75.

[18] R.W. Reynolds (1988), "A real-time global sea surface temperature analysis", *Journal of Climate,* **1**, pp.75-87.

[19] R.W. Reynolds, N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang (2002), "An improved in situ and satellite SST analysis for climate", *Journal of Climate*, **15**, pp.1609-1625.

[20] K.E. Taylor (2001), "Summarizing multiple aspects of model performance in a single diagram", *Journal of Geophysical Research: Atmospheres*, **106**, pp.7183-7192.