A prototype KPOPS-Climate development

Sub-project: Development of a prototype of KPOPS automated management system for quasi-real time climate prediction model

Main-project: Development and Application of the Korea Polar Prediction System (KPOPS) for Climate Change and Weather Disaster

Dongwook Shin and Steve Cocke

Center for Ocean-Atmospheric Prediction Studies, Florida State University

Tallahassee, FL, USA

Submission

To : Chief of Korea Polar Research Institute

This report is submitted as the final report (Report title: "a prototype KPOPS-Climate development") of entrusted research "Development of a prototype of KPOPS automated management system for quasi-real time climate prediction model" project of "Development and Application of the Korea Polar Prediction System (KPOPS) for Climate Change and Weather Disaster" project.

2020. 1. 31

Person in charge of Entire Research   : 김 주 홍

Name of Entrusted Organization   : FSU/COAPS

Entrusted Researcher in charge   : Dongwook Shin

Participating Entrusted Researchers   : Steven Cocke

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Summary

I. Title

A prototype KPOPS-Climate development

II. Purpose and Necessity of R&D

The main purpose of this R&D is to develop a prototype quasi-operational sub-seasonal to seasonal climate modeling system in the KOPRI computer cluster. The KOPRI and the FSU/COAPS scientists work closely together to initiate, improve and optimize the first version of the KPOPS-Climate in order to make a reliable sub-seasonal to seasonal climate prediction system which necessarily provides a better weather/climate guidance to the Korean policy decision makers, environmental risk protection managers and/or the public.

III. Contents and Extent of R&D

An initial version of the prototype KPOPS-Climate was developed and installed in the KOPRI computer cluster. We have attempted to improve, revise, and/or optimize the prototype KPOPS-Climate system. The successful revisions, tune-ups, ensemble configuration, experimental designs, and evaluation system expedited the main project goal. The prototype KPOPS-Climate model should be comprehensively and systematically evaluated before issuing the quasi-operational forecasting. We re-designed the model experiments to evaluate the KPOPS-Climate in an improved way. Common and advanced sub-seasonal and seasonal forecast evaluation methods were reviewed and adopted. The KPOPS-Climate model performance was inter-compared with other state-of the art climate models' performance using adopted evaluation

methods, which could provide the current skill level and/or rank of the prototype KPOPS-Climate model.

IV. R&D Results

Year 1

- The FSU/COAPS initialization scripts and codes were referenced to develop a prototype script appropriate for the CAM5 configuration
- Several scripts were developed to generate spectral (T126, T255, et al.) and Finite Volume (~1 degree) initial conditions
- Initial understanding of the CAM dynamical processes was achieved by comparing spectral and finite volume codes and/or methods
- Physical processes options were studied by scrutinizing the code and related papers
- The basic CAM5 FV configuration was configured as a benchmark version including CLM4.0 version
- The FSU/COAPS web-based visualization system was ported to initiate a rough web-page at KOPRI
- Utilizing the FSU/COAPS global/regional climate model scripts and codes, a prototype of an automated management system was created in the KOPRI cluster (so-called elsa)
- A preliminary quasi-real time interface was developed to oversee the overall processes and performances of KPOPS-Climate

Year 2

- A new set of initialization scripts was developed to generate the Spectral Element (SE) dynamic core for the atmospheric initial condition for different resolutions using the JRA reanalysis data
- Existing spun-up land model conditions were used and interpolated to the SE grid

- Available ensemble methods were evaluated, such as breeding vector (NCEP), physical perturbation (ECMWF), and so on. Then, a lagged ensemble approach was adopted for the KPOPS-Climate based on ensemble spread and easiness of its performance

- An intensive comparison of FV and SE dynamical cores was performed and the SE is selected due to its performance superiority but it requires high computing resources

- A comprehensive winter seasonal hindcast design was used from 2001 to 2014 and there were 5 members per each runs based on the lagged ensemble method

- The reanalyses (ERA and JRA) were processed and used to evaluate the prototype KPOPS-Climate performance

- Several models are inter-compared (KPOPS-CFS vs. KPOPS-SEOF vs. FSU/COAPS0 to improve the evaluation system

- The prototype of an automated management system was revised in the KOPRI cluster and was tested in a new cluster

Year 3

- Several possible approaches for the KPOPS-Climate model experimental designs were proposed. Based on computing resources, complexities et al., the 6hrly lagged ensemble method was adopted to use winter time experimental forecast

- In addition to JRA (and/or GFS), a real-time ECMWF initial condition analysis has been employed in the KPOPS-Climate and FSU/COAPS models

- Commonly used ensemble forecast evaluation statistics were adopted, coded, and modified [Brier (skill) score, ROC, and/or Bias score] for the KPOPS-Climate evaluation

- The FSU/COAPS web-based visual forecast/evaluation system has been used to evaluate the polar month-long forecasts (0z and 12z)

- A scientifically proper KPOPS-Climate and FSU/COAPS inter-comparison setup has been designed and performed to evaluate preliminary forecast results

- The FSU/COAPS model IC sensitivity study was performed using GFS, JRA, and ECMWF
- International collaboration projects (SubX and S2S) were carefully used to evaluate the KPOPS-Climate performance

Year 4

- The real-time FSU/COAPS forecast datasets with JRA, GFS, and ECMWF initial conditions were provided [intensive experimental period: August 5 ~ September 18 2019 (daily 10-day forecast initialization at 00 UTC); forecast variables: geopotential height, air temperature, horizontal winds and specific humidity for 850, 500 200 hPa (or all pressure levels if the size is affordable), cloud amount (tropospheric levels, only in this is available), major surface variables (e.g., MSLP, SST 2-m temperature, 10-m winds for surface, precipitation (rain/snow), cloud fraction, longwave/shortwave radiative flux (upward/downward), sensible/latent heat fluxes) et al — 12 hourly; the twice daily (0Z and 12Z) real-time one month long FSU/COAPS forecast datasets (mainly maximum and minimum temperatures and precipitation)]
- Adoption and improvement of the web-based verification and visualization system were done from the FSU/COAPS real-time java-based scripts
- Advanced ensemble forecast evaluation statistics were adopted, coded, and modified [ACC, Brier (skill) score, ROC, and/or Bias score] for the ensemble KPOPS-Climate model
- Typhoon Lingling and Typhoon Tapah forecast case studies were performed [initial time; 2019/09/04 00Z and 2019/09/18 00Z; Track and intensity comparison; in the KPOPS-Climate (JRA55 and ECMWF) and the FSU/COAPS (JRA, GFS, and ECMWF) models]

V. Application Plans of R&D Results

The KOPRI needs to scrutinize, revise, and improve the prototype KPOPS-Climate to achieve a world-recognizable version of climate model. The KOPRI should

participate in international inter-comparison studies to expose the KPOPS-Climate model by evaluating its performance with other climate models' skill levels (including the NCEP/CFS, NCAR/CESM, ECMWF, SubX participating models et al.). To capture the interesting weather/climate phenomena at regional/local scales, the KPOPS-Climate should adopt a reasonably high resolution (~25km) forecast. Then, the KPOPS-Climate products might be used in a variety of application models (e.g., hydrological, crop, ecosystem models).

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Chapter 1 Introduction

1.1 The purpose of R&D

The overall goal of this R&D is to develop a prototype quasi-operational sub-seasonal to seasonal (up to 3 months) climate modeling system in the KOPRI computer cluster. The climate modeling system is named as the **"KPOPS-Climate"** following the main project theme. During the project period (2016-2019), the FSU/COAPS and KOPRI scientists have been working diligently to initiate, improve and optimize the first version of the KPOPS-Climate in order to achieve reasonable (i.e., comparable to currently available other climate models) forecasting skill levels over the Arctic region and the east Asian region, including South Korea.

Each year's specific goals are as follows,

<u>Year 1</u>: Develop a prototype automated management system, as a quasi-real time weather/climate prediction system, for data collection, model initialization, forecast, evaluation, and visualization in a web environment.

<u>Year 2</u>: Improve, revise and/or optimize the prototype automated management system, as a quasi-real time climate prediction system, for data collection, model initialization, forecast, evaluation, and visualization in a web environment.

<u>Year 3</u>: Evaluate the prototype KPOPS-Climate performance comprehensively by improving the experimental design, by using advanced evaluation methods, and by inter-comparison with other state-or-the art climate models' performance

<u>Year 4</u>: Assess the performance of the first-phase prototype KPOPS-Climate model for winter and summer time sub-seasonal to seasonal (S2S) forecasts utilizing weather/climate analysis methods, including analyzing extreme weather events (e.g., typhoon)

1.2 The necessity of R&D

A reliable sub-seasonal to seasonal climate prediction system is necessary in order to provide a better weather/climate guidance to the Korean policy decision makers,

environmental risk protection managers and/or the public. The Korea Meteorological Administration (KMA) has adopted and been using a seasonal climate model, which is based on the Unified Model (UM) from United Kingdom Met Office, so-called GloSea. However, the "imported" KMA climate model has not been performed relatively well for the winter-time seasonal forecasts, especially cold surge et al., for the last decade. Another limitation is that the model cannot be easily modified and controlled by the local weather/climate scientists. Hence, weather/climate associated institutes (e.g., KIAPS, APCC) have tried to initiate to develop a "home-made" weather and/or climate model. In particular, in order to improve the current prediction skill levels for winter season around Korean peninsula, the KOPRI administrators and scientists decided to develop a weather/climate model for their own use, the so-called KPOPS-Weather and KPOPS-Climate.

1.3   The extent of R&D

An initial version of the prototype KPOPS-Climate was developed and installed in the KOPRI computer cluster in the first R&D year.   We have attempted to improve, revise, and/or optimize the prototype KPOPS-Climate system. The successful revisions, tune-ups, ensemble configuration, experimental designs, and evaluation system expedited the main project goal. The prototype KPOPS-Climate model should be comprehensively and systematically evaluated before issuing the quasi-operational forecasting planned in 2019. We re-designed the model experiments to evaluate the KPOPS-Climate in an improved way. Common and advanced sub-seasonal and seasonal forecast evaluation methods were reviewed and adopted. The KPOPS-Climate model performance was inter-compared with other state-of the art climate models' performance using adopted evaluation methods, which could provide the current skill level (rank) of the prototype KPOPS-Climate model.

The first-phase prototype KPOPS-Climate model performance should be properly assessed before the official (public) release of its prediction for upcoming seasons. In order to evaluate the KPOPS-climate, three different atmospheric initial conditions (JRA,

GFS, and ECMWF) were used to make three-month long forecasts for summer and winter seasons. The FSU scientists designed and performed the FSU/COAPS model experiments, similar to the KPOPS-Climate configuration. The prediction data were provided to KOPRI for inter-comparison studies and visualized in the soon-to-be available KOPRI KPOPS webpage. We evaluated the weather, sub-seasonal, and seasonal forecast skill levels for the FSU/COAPS model and compared the results with those of the KPOPS-Climate model. In addition, an analysis of extreme weather events in the models, especially for tropical storms (typhoon and/or hurricane), was performed to check the KPOPS-Climate model's capability in this interesting scientific issue.

Each year's specific contents are as follows,

Year 1

- Propose and/or develop a prototype atmospheric model initialization technique
- Perform physical parameterization inter-comparison studies using the CAM and choose an appropriate combination of physical parameterizations most suitable for the Arctic region
- Adopt an ensemble method to assess the initial condition and/or model uncertainties
- Develop a prototype integrated system to implement a quasi-real time prediction

Year 2

- Improve the KPOPS atmospheric and land model initialization method
- Devise the KPOPS ensemble configuration
- Revise the KPOPS dynamical and physical model configuration
- Setup experimental designs to evaluate the KPOPS systematically
- Revise the KPOPS model evaluation system
- Improve the KPOPS automated system

Year 3

- Re-setup experimental designs to evaluate the KPOPS-Climate systematically
- Adopt/develop advanced sub-seasonal and seasonal forecast evaluation methods
- Perform inter-comparison evaluations with other available climate models' forecasts

Year 4

- Perform the FSU/COAPS model experiments with JRA, GFS, and ECMWF initial conditions, similar to the KPOPS-Climate configuration for inter-comparison studies
- Assess summer- and winter-time weather, sub-seasonal, and seasonal forecasts in the KPOPS-Climate and FSU/COAPS models
- Evaluate extreme weather events in the KPOPS-Climate and FSU/COAPS models

Chapter 2 Current R&D Status in Korea and Other Nations

Many climate models are now available around the world. Among them, a few models (e.g., CESM, ECMWF, UM) are very well-known and have been adopted and used intensively in weather and climate communities. In KMA, the GloSea climate model based on the UM from UKMET has been imported and used to make seasonal forecasting operationally in Korea. Recently, some university professors and scientists in Korean meteorological society have been evaluating the GloSea model performance. According to them, its skill levels depend on the case-by-case and the general performance for summer- or winter-time seasonal forecasting is not so reliable. Hence, they have been trying to develop or adopt different climate models to improve their own interesting target forecasting skill (e.g., drought, season-long typhoon activity, cold and hot surges).

Many climate modeling groups in the world agreed to build a new set of coordinated climate model experiments in 2008. The CMIP5 was planned to produce a standard set of climate simulations from stat-of-the art models to assess the fidelity of the models in simulating the recent past, to provide projections of future climate change, and to promote our understanding of mechanisms responsible for model differences. Although numerous studies has been conducted to validate the credibility of the newly launched CMIP5 data globally, seasonal Arctic or regional assessments of the CMIP5 have rarely been carried out.

Meanwhile, the FSU/COAPS climate model was independently developed by the FSU scientists who include the PI and co-PI in the current project (Shin and Cocke 2013, Cocke et al. 2013, Cocke et al. 2007, Cocke et al. 2006, Shin et al. 2005, LaRow et al. 2005, Shin and Krishnamurti 2003). It was originally developed and used for studies in tropical weather. The model has since been modified for seasonal climate simulations (Cocke and LaRow 2000), and now forms a core part of the FSU/COAPS climate

modeling system. This modeling system was suggested to use as a main reference tool to build the KPOPS-Climate modeling system in the KOPRI computer cluster.

The NCAR CEMS (or CAM) has been used extensively worldwide by the climate science community to understand climate on relatively long term (decadal and longer) time scales. The model climatology has been well studied, and generally it is found that the CESM provides a very realistic simulation compared to observations (Kiehl et al. 1998, Hack et al. 1998, Hurrel et al. 1998) when examined in the mean (monthly or annual) sense. Recently there has been interest in looking at the higher-frequency characteristics of climate models, for example, daily weather, to gain a better perspective of how well the models are simulating the atmosphere and improve physical parameterizations (Phillips et al. 2004). It is now generally regarded in the scientific community that short-timescale phenomena can have an important impact on the longer-term climate. For example, the diurnal cycle of convection is believed to play a key role in the propagation of the Madden-Julian oscillation. Hence examination of the CESM on short time scales may lead to better improvement in the physical parameterizations, and hopefully better simulation of the climate, both long (decadal) and short (seasonal) term. In addition to improving climate simulations, there is increasing interest in exploring the gap between medium-range forecasting and climate prediction. There has been, for example, a strong push to explore predictive capability for the sub-seasonal (2 weeks to 2 months) time scale. Hence, it is important to climate model developers to understand and bridge this gap in the model physics to better simulate the atmosphere for these time scales.

Therefore, the KOPRI and FSU/COAPS scientists agreed to use the NCAR CESM as a benchmark model. While the overall FSU/COAPS modeling system was employed as a quasi-real time forecasting system administration tool, the KPOPS-Climate model adopted the modified CAM5 as an atmospheric component with the Finite Volume dynamical core, the CLM4 as a land component, and the NOAA CFS SST with an enhanced sea ice model as a two-tier boundary condition. Thus, the KPOPS-Climate can be viewed as one of the most advanced seasonal climate prediction systems in Korea

and the world. However, the current version of the KPOPS-Climate should be eventually upgraded as time goes on in order to keep up with other climate models' improvement.

Chapter 3 R&D Implementation Contents and Results

How to achieve our purpose? We utilized the FSU/COAPS global/regional climate model scripts and codes which were mainly developed by (co-)PIs of this project. Then, the FSU/COAPS initialization scripts and codes were modified and/or developed appropriate for the selected version of CESM (CAM) configuration. In addition, we studied the CAM dynamical/physical processes by scrutinizing the codes and related papers. We explored the pros and cons of the existing physical parameterizations through inter-comparison studies. Several possible model configurations were devised and tested. Finally, a quasi-real time web interface was created to oversee the overall processes and performances.

The followings are detailed methods used.

- Develop a prototype initialization script which includes computer language codes and performs initial condition balance tests
- Configure the CAM model in a manner most suitable for the Arctic region
- Develop a prototype web-based model evaluation system
- Develop an automated management system to unify the data collection, initialization, prediction, and evaluation

3.1 contents and results of Year 1

- Research implementation method to achieve goal

Achievement Goal	Detailed Goal	Research Implementation Method (Theoretical and Experimental Access Method)	Detailed Contents
A prototype KPOPS-Climate	A prototype atmospheric model initialization method	Modify and/or develop the FSU/COAPS initialization scripts and codes appropriate for the selected version of CAM configuration	Core scripts for atmospheric model initializations for spectral and finite volume methods

	An appropriate atmospheric model configuration	– Understand the CAM dynamical/physical processes by scrutinizing the code and related papers – Explore the pros and cons of the existing physical parameterizations through inter-comparison studies	A benchmark KPOPS-climate version based on CAM5 FV/CLM4
	A prototype evaluation system	Develop a prototype web-based model evaluation system	A preliminary KPOPS evaluation system including several codes and scripts for skill measure statistics
	A prototype automated system	Create a quasi-real time web interface to oversee the overall processes and performances	A concise interface specific to the KOPRI cluster (elsa)

Year 1 research results are (1) we referenced the FSU/COAPS initialization scripts and codes to develop a prototype script appropriate for the CAM5 configuration, (2) several scripts are developed to generate spectral (T126, T255, et al.) and finite volume (~1 degree) initial conditions, (3) initial understanding of the CAM dynamical processes was achieved by comparing spectral and finite volume codes and/or methods, (4) physical processes options were studied by scrutinizing the code and related papers, (5) the basic CAM5 FV configuration is configured as a benchmark version including CLM4.0 version, (6) the FSU/COAPS web-based visualization system is ported to initiate a rough web-page at KOPRI, (7) utilizing the FSU/COAPS global/regional climate model scripts and codes, a prototype of an automated management system was created in the KOPRI cluster (so-called elsa), and (8) a preliminary quasi-real time interface was developed to oversee the overall processes and performances of KPOPS climate.

3.2 contents and results of Year 2

 - Research implementation method to achieve goal

Achievement Goal	Detailed Goal	Research Implementation Method (Theoretical and Experimental Access Method)	Detailed Contents
An improved, revised and/or optimized KPOPS-Climate	The KPOPS-Climate atmospheric and land model initialization method	Revise and/or improve the 1st year prototype KPOPS-Climate initialization scripts using advanced SE methods	Main scripts for atmospheric model initializations for finite volume (FV) and spectral element (SE) methods
	The KPOPS-Climate ensemble configuration	Explore the pros and cons of the existing ensemble methods through inter-comparison studies	A lagged ensemble configuration
	The KPOPS-Climate dynamical and physical model configuration	Test many configuration of dynamical and physical modules in the KPOPS prototype model	An optimal combination of SE dynamical and CAM5 physical packages
	Experimental designs	Design an appropriate experiment based on the scientific interest and the computing resources	2001-2014 winter season ensemble hindcast design
	The KPOPS-Climate evaluation system	Improve the prototype web-based model evaluation system	An improved KPOPS evaluation system including several codes and scripts for skill measure statistics
	The KPOPS-Climate automated system	Revise the first year quasi-real time web-based interface system	An improved interface specific to the KOPRI cluster

Year 2 research results are (1) a new set of initialization scripts was developed to generate the Spectral Element (SE) dynamic core for the atmospheric initial condition for different resolutions using JRA reanalysis data, (2) existing spun-up land model conditions were used and interpolated to the SE grid, (3) available ensemble methods

were evaluated, such as breeding vector (NCEP), physical perturbation (ECMWF), and so on, (4) the lagged ensemble approach was adopted for the KPOPS-Climate based on ensemble spread and easiness of its performance, (5) an intensive comparison of FV and SE dynamical cores was performed, (6) the SE is selected due to its performance superiority but it requires high computing resources, (7) a comprehensive winter seasonal hindcast design was used form 2001 to 2014, (8) there are 5 members per each runs based on lagged ensemble method, (9) the reanalyses (ERA and JRA) were processed and used to evaluate the prototype KPOPS-Climate performance, (10) several models are inter-compared (KPOPS-CFS vs. KPOPS-SEOF vs. FSU/COAPS0 to improve the evaluation system, and (11) the prototype of an automated management system was revised in the KOPRI cluster and was tested in a new cluster.

3.3 contents and results of Year 3

- Research implementation method to achieve goal

Achievement Goal	Detailed Goal	Research Implementation Method (Theoretical and Experimental Access Method)	Detailed Contents
The comprehensive evaluation of prototype KPOPS-Climate	The KPOPS- Climate experimental redesign	Re-design the most appropriate KPOPS-Climate experiment setup based on the KOPRI scientific interest and the computing resources	An ensemble configuration using a six hourly lagged configuration
	Advanced evaluation methods	Adopt/setup advanced ensemble evaluation statistics and the existing web-based visual evaluation system from the FSU/COAPS in order to properly evaluate the polar climate forecast	Web-based interactive visual evaluation system and Ensemble statistics
	Model inter-comparison	Search for available climate model forecasts and reorganize the design to perform the inter-comparison under the	KPOPS-Climate vs. FSU/COAPS, S2S, SubX

			same configuration	

Year 3 research results are (1) several possible approaches for the KPOPS-Climate model experimental designs were proposed. Based on computing resources, complexities et al., the 6hrly lagged ensemble method was adopted to use winter time experimental forecast (OND, NDJ, and DJF), (2) in addition to JRA (and/or GFS), a real-time ECMWF initial condition analysis has been employed in the KPOPS-Climate and FSU/COAPS models, (3) commonly used ensemble forecast evaluation statistics were adopted, coded, and modified [Brier (skill) score, ROC, and/or Bias score] for the KPOPS-Climate evaluation, (4) the FSU/COAPS web-based visual forecast/evaluation system has been used to evaluate the polar month-long forecasts (0z and 12z) as of July 2018, (5) a scientifically proper KPOPS-Climate and FSU/COAPS inter-comparison setup has been designed and performed to evaluate preliminary forecast results, (6) the FSU/COAPS model IC sensitivity study was performed using GFS, JRA, and ECMWF, and (7) international collaboration projects (SubX and S2S) were carefully used to evaluate the KPOPS-Climate performance.

3.4 contents and results of Year 4

- Research implementation method to achieve goal

Achievement Goal	Detailed Goal	Research Implementation Method (Theoretical and Experimental Access Method)	Detailed Contents
In-depth assessment of the first-phase prototype KPOPS-climate model	The FSU/COAPS model experiments	Design and perform the FSU/COAPS model with JRA, GFS, and ECMWF initial conditions, similar to the KPOPS-Climate (and/or KPOPS-Weather) configuration for model inter-comparison assessment	An intensive comparison from the specific forecast period (1.5 month) datasets from KPOPS and FSU/COAPS model

	Weather to seasonal forecast assessment	Evaluate weather, sub-seasonal, and seasonal forecasts using a web-based visualization/ verification system from the KPOPS-Climate and FSU/COAPS model results	A web-based interactive visual evaluation system and its associated statistics
	Extreme events evaluation	Choose 2 or 3 Typhoon cases which affected South Korea and analyze these extreme weather events in the KPOPS-Climate and FSU/COAPS models	Typhoon track and intensity analysis in terms of MSLP

Year 4 research results are (1) the real-time FSU/COAPS forecast datasets with JRA, GFS, and ECMWF initial conditions [intensive experimental period: August 5 ~ September 18 2019 (daily 10-day forecast initialization at 00 UTC); provided forecast variables: Geopotential height, air temperature, horizontal winds and specific humidity for 850, 500 200 hPa (or all pressure levels if the size is affordable), cloud amount (tropospheric levels, only in this is available), major surface variables (e.g., MSLP, SST 2-m temperature, 10-m winds for surface, precipitation (rain/snow), cloud fraction, longwave/shortwave radiative flux (upward/downward), sensible/latent heat fluxes) et al - 12 hourly; the twice daily (0Z and 12Z) real-time one month long FSU/COAPS forecast datasets (mainly maximum and minimum temperatures and precipitation)], (2) adoption and improvement of the web-based verification and visualization system from the FSU/COAPS real-time java-based scripts, (3) advanced ensemble forecast evaluation statistics were adopted, coded, and modified [ACC, Brier (skill) score, ROC, and/or Bias score] for the ensemble KPOPS-Climate model, (4) Typhoon Lingling and Typhoon Tapah forecast case studies [initial time; 2019/09/04 00Z and 2019/09/18 00Z; Track and intensity comparison; in the KPOPS-Climate (JRA55 and ECMWF) and the FSU/COAPS (JRA, GFS, and ECMWF) models] and (5) a higher resolution (0.5~1 degree) KPOPS needed in the next version to resolve the extreme events.

Chapter 4 Degree of R&D Goal Achievement and Degree of Contribution to Outside Research Institute

4.1 Yearly degree of achievement

4.1.1 Year 1: A prototype KPOPS-Climate

Final goal of R&D was to develop a prototype automated management system, as a quasi-real time weather/climate prediction system, for data collection, model initialization, forecast, evaluation, and visualization in a web environment.

Degree of achievement

1-1: A prototype atmospheric model initialization method

- New scripts and codes which initialize the atmospheric condition properly for the CAM5

Products: Initialization scripts and codes, Visualization of several unique initial states

1-2: An appropriate atmospheric model configuration

- The CAM5 basic physical scheme's performance evaluation
- Testing combinations of physical and dynamical options with focus in the Arctic area

Products: Model configuration summary including associated scripts and codes, CAM code analysis

1-3: A prototype evaluation system

- Preliminary web-based visualization
- The model performance statistics compared to the NCEP CFS

Products: A web interface, Visualization scripts, Performance statistic summary table

1-4: A prototype automated system

- Automated shell scripts which control all above processes

Products: Automated shell scripts

Aiming point of evaluation of year 1

Year	Achievement Goal	Detailed Goal	Weight	Aiming Point of

				Evaluation and Criteria
Year 1 (2016)	A prototype KPOPS-Climate	A prototype atmospheric model initialization method	25%	- Initialization scripts and codes - Visualization of several unique initial states
		An appropriate atmospheric model configuration	25%	- Model configuration summary including associated scripts and codes - CAM code analysis
		A prototype evaluation system	25%	- A web interface - visualization scripts - Performance statistics summary table
		A prototype automated system	25%	- Automated shell scripts

4.1.2 Year 2: Improved, revised, and/or optimized KPOPS-Climate

Final goal of R&D was to improve, revise and/or optimize the prototype automated management system, as a quasi-real time climate prediction system, for data collection, model initialization, forecast, evaluation, and visualization in a web environment.

Degree of achievement

2-1: The KPOPS-Climate atmospheric and land model initialization method

- Revised scripts and Fortran codes which initialize the atmospheric condition
- Land spun-up condition from the existing CAM5 runs

Products: Improved initialization scripts and codes, revised method update compared to the previous version

2-2: The KPOPS-Climate ensemble configuration

- Adopting lagged ensemble methods

- An optimal combination of ensemble method (on going)

Products: Ensemble spread maps and uncertainty analysis

2-3: The KPOPS-Climate dynamical and physical model configuration

- Selecting/performing the spectral element (SE) dynamical core and physical options based on the model performance for the Arctic climate

Products: Comparison between FV and SE dynamical cores, Performance results from different model configurations

2-4: Experimental designs

- Experimental design setup appropriate for the KPOPS-Climate target prediction

Products: Different design notes

2-5: The KPOPS-Climate evaluation system

- Improved prototype evaluation system

- Ensemble spread analysis

- Warm Arctic Cold Continent analysis

Products: Evaluation statistics, figures and tables

2-6: The KPOPS-Climate automated system

- Revised the prototype automated system based on the KOPRI cluster

Products: An improved shell script

Aiming point of evaluation of year 2

Year	Achievement Goal	Detailed Goal	Weight	Aiming Point of Evaluation and Criteria
Year 2 (2017)	An improved, revised and/or optimized KPOPS-Climate	The KPOPS-Climate atmospheric and land model initialization method	20%	- Improved initialization scripts and codes - Comparison between the

				-	old and new methods
		The KPOPS-Climate ensemble configuration	20%	-	Ensemble spread maps
		The KPOPS-Climate dynamical and physical model configuration	10%	-	A research note for a new configuration
		Experimental designs	10%	-	Experimental design notes
		The KPOPS-Climate evaluation system	30%	-	Summary evaluation statistics, figures, and tables
		The KPOPS-Climate automated system	10%	-	An improved shell scripts

4.1.3 Year 3: The comprehensive evaluation of prototype KPOPS-Climate

Final goal of R&D was to evaluate the prototype KPOPS-Climate model performance comprehensively by improving the experimental design, by using advanced evaluation methods, and by inter-comparison with other state-of-the art climate models' performance.

Degree of achievement

3-1: The KPOPS-Climate experimental redesign

- 6 hourly ensemble re-configuration based on a lagged ensemble approach

- A new ECMWF IC setup for the KPOPS-Climate, in addition to JRA and GFS (revised scripts and Fortran codes which initialize the ECMWF atmospheric condition properly for the KPOPS-Climate)

Products: A note on experimental design study, ECMWF IC scripts and code

3-2: Advanced evaluation methods

- Adoption of the FSU/COAPS model web-based visual evaluation system

- Ensemble evaluation statistics (Brier skill score, ROC, and/or Bias score)

Products: Web-based visual system, Fortran codes for statistics

3-3: Model inter-comparison

- Pre-setup of comprehensive inter-comparison system (KPOPS-Climate vs. FSU/COAPS)

- Initial condition sensitivity studies with GFS, JRA, and ECMWF

- Initial analysis of month-long MME forecast dataset (SubX project)

- Involvement of S2S project

Products: A paper draft on the comparison between the KPOPS-Climate and FSU/COAPS

Aiming point of evaluation of year 3

Year	Achievement Goal	Detailed Goal	Weight	Aiming Point of Evaluation and Criteria
Year 3 (2018)	The comprehensive evaluation of prototype KPOPS-Climate	The KPOPS-Climate experimental redesign	25%	- Redesigned experimental spreadsheet and corresponding run results
		Advanced evaluation methods	25%	- Review summaries - Computer scripts/codes
		Model inter-comparison	50%	- Comparison figures and tables - The current skill level (rank) of the KPOPS-Climate

4.1.4 Year 4: In-depth assessment of the first-phase prototype KPOPS-Climate model

Final goal of R&D was to assess the performance of the first-phase prototype KPOPS-Climate model for winter and supper time sub-seasonal to seasonal (S2S) forecasts

utilizing weather/climate analysis methods, including analyzing extreme weather events (e.g., typhoon).

Degree of achievement

4-1: The FSU/COAPS model experiments

- The comprehensive FSU/COAPS real-time forecast datasets with JRA, GFS, and ECMWF initial conditions for a period of August 5 ~ September 18, 2019
- The twice daily real-time sub-seasonal FSU/COAPS forecast datasets

Products: The FSU/COAPS forecast datasets with JRA, GFS, and ECMWF

4-2: Weather to seasonal forecast assessment

- A prototype web based forecast visualization/verification system based on the FSU/COAPS java script
- Advanced statistics for probabilistic forecast evaluation (ACC, Brier Skill Score and ROC)

Products: Analysis figures and tables, Analysis scritps/codes

4-3: Extreme events evaluation

- Evaluation of two Typhoon cases (Lingling and Tapah) in the KPOPS-jra55 and KPOPS-ecmwf models, compared to the FSU/COAPS models with JRA, GFS, and ECMWF

Products: Case study reports including figures and tables

Aiming point of evaluation of year 4

Year	Achievement Goal	Detailed Goal	Weight	Aiming Point of Evaluation and Criteria
Year 4 (2019)	In-depth assessment of the first-phase prototype KPOPS-climate model	The FSU/COAPS model experiments	40%	- The FSU/COAPS forecast datasets with JRA, GFS, and ECMWF
		Weather to seasonal forecast assessment	30%	- Analysis figures and tables - Analysis scripts/codes - a web-based system
		Extreme events	30%	- Case study reports including

		evaluation		figures and/or tables

4.2 Outside Academic and Economic impact

A prototype automated quasi-real time system was a good tool for students to understand the overall modeling process system in year 1. Through this project, we provided regular opportunities for networking and the development of new partnerships, for both young and established scientists. Regular meetings with the lead PI, publication in refereed journals and presentations in professional meeting played a key role for the fast and broad dissemination of our results. The improved KPOPS-Climate automated real time system was a helpful stepping stone for scientist and/or students to understand the overall modeling process flow in year 2. In years 3 and 4, the emergence of the KPOPS-Climate model system and its evaluation methods offered a necessary guidance for scientists and/or students to understand the overall weather-to-seasonal modeling framework.

The outcomes and products from the KPOPS-Climate modeling system are potentially invaluable to weather/climate prediction societies in Korea and in the world. All Korean citizens will eventually benefit, because improved weather/climate forecasts allow stakeholders (including policy-makers) to make better decisions in the short-, medium- and possibly long-term future.

Chapter 5 Application Plans of R&D Results

The current R&D should be funded in a **continuous** way. In order to maintain a competitive climate model, we need to scrutinize, revise, and improve the prototype KPOPS-Climate to have a useful version of KPOPS-Climate model and eventually the world-recognized model. The KOPRI scientists should execute comprehensive KPOPS-Climate model evaluations compared to the other seasonal forecasts (including KMA model, the NCEP CFS et al.) in an operational environment sense. An SVN-based code control has to be secured inside the KOPRI and regular project meetings with the project leaders and scientists are needed to resolve the potential scientific and technical issues.

The KOPRI should participate in the international inter-comparison studies to expose the KPOPS-Climate model by evaluating its performance with other climate models' skill levels (including the NCEP/CFS, NCAR/CESM, ECMWF, SubX participating models et al.). The current version of KPOPS-Climate model is employing a low horizontal resolution partly due to their computer resources. In order to capture the interesting weather/climate phenomena at regional/local scales, the KPOPS-Climate should adopt a reasonably high resolution (approximately 10~25km) forecast. Then, the KPOPS-Climate products might be used in a variety of application models (e.g., hydrological, crop, ecosystem models) to help human/animal/plant societies.

Chapter 6 References

All citations are located in Chapter 2.

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