Regional Climate Modeling: Research Needs and Direction

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Why Regional Climate Modeling?

- *Downscaling* of climate variability and change at the regional scale (e.g., climate change effects on water resources, ecosystem, extreme weather; hurricane frequency; storm track; distribution of MCS and warm season precipitation; use of seasonal forecasts for water management)
- *Process studies* (e.g., Amazon biomass burning and aerosol effects; orographic effects; land-atmosphere interactions; ocean-atmosphere interactions; sea ice; cloud-radiation feedbacks)
- *Upscaling* of regional phenomena with global consequences (e.g., subtropical and tropical eastern boundary upwelling regimes; subgrid-scale clouds; organized convection; gravity wave drag)

RCM Development Using WRF

- Since 2003, NCAR has supported a project to develop regional climate modeling capability with WRF
- Same source for all applications: weather and forecasting research, process studies, upscaling, and downscaling
- Compatible physics with CCSM: implemented CAM3 radiation and the Community Land Model (CLM3)
- Model tested for simulating cold season orographic precipitation in the western U.S. for 6 months at 6 km and 30 km resolution
- Warm season precipitation in the U.S. at 30 km resolution for 6 months (the 1993 flood case)
- Cloud resolving simulation at 4 km resolution for 2 months in the Southern Great Plains (IHOP 2002)
- Performed a U.S. simulation driven by the NCAR PCM

WRF Development Teams

RCM WG: Ruby Leung (Chair, PNNL), Bill Collins (NCAR), Jimy Dudhia (NCAR), Alex Hall (UCLA), Filippo Giorgi (ICTP), Bill Gutowski (ISU), Xin-Zhong Liang (UI), Ken Mitchell (NOAA/NCEP)

Numerics and Software (J. Klemp)	Data Assimilation (C. Bishop)	Analysis and Validation (K. Droegemeier)	Community Involvement (W. Kuo)	Operational Implementation (G. DiMego)
Dynamic Model Numerics (W. Skamarock)	Standard Initialization (W. Wang)	Analysis and Visualization (M. Stoelinga)	Workshops, Distribution, and Support (J. Dudhia)	Data Handling and Archive (G. DiMego)
Software Architecture, Standards, and Implementation (J. Michalakes)	3-D Var (J. Derber)	Model Testing and Verification (C. Davis)	Model Physics (J. Brown)	Operational Requirements (G. DiMego)
	Advanced Techniques (D. Barker)	Ensemble Forecasting (D. Stensrud)	Atmospheric Chemistry (G. Grell)	Operational Forecaster Training (T. Spangler)
			Land Surface Models (J. Wegiel)	
			Regional Climate Modeling (R. Leung)	

Workshop on Research Needs and Directions of Regional Climate Modeling Using WRF and CCSM (March 22-23, 2005)

- Organizing committee: L. Ruby Leung, Bill Kuo, Joe Tribbia, Phil Merilees
- 60 US and international participants
- Define research needs for the development of a next generation community regional climate model based on WRF and CCSM
- Define upscaling and downscaling research that can be addressed by regional climate models
- Develop a plan of actions that would meet the research needs

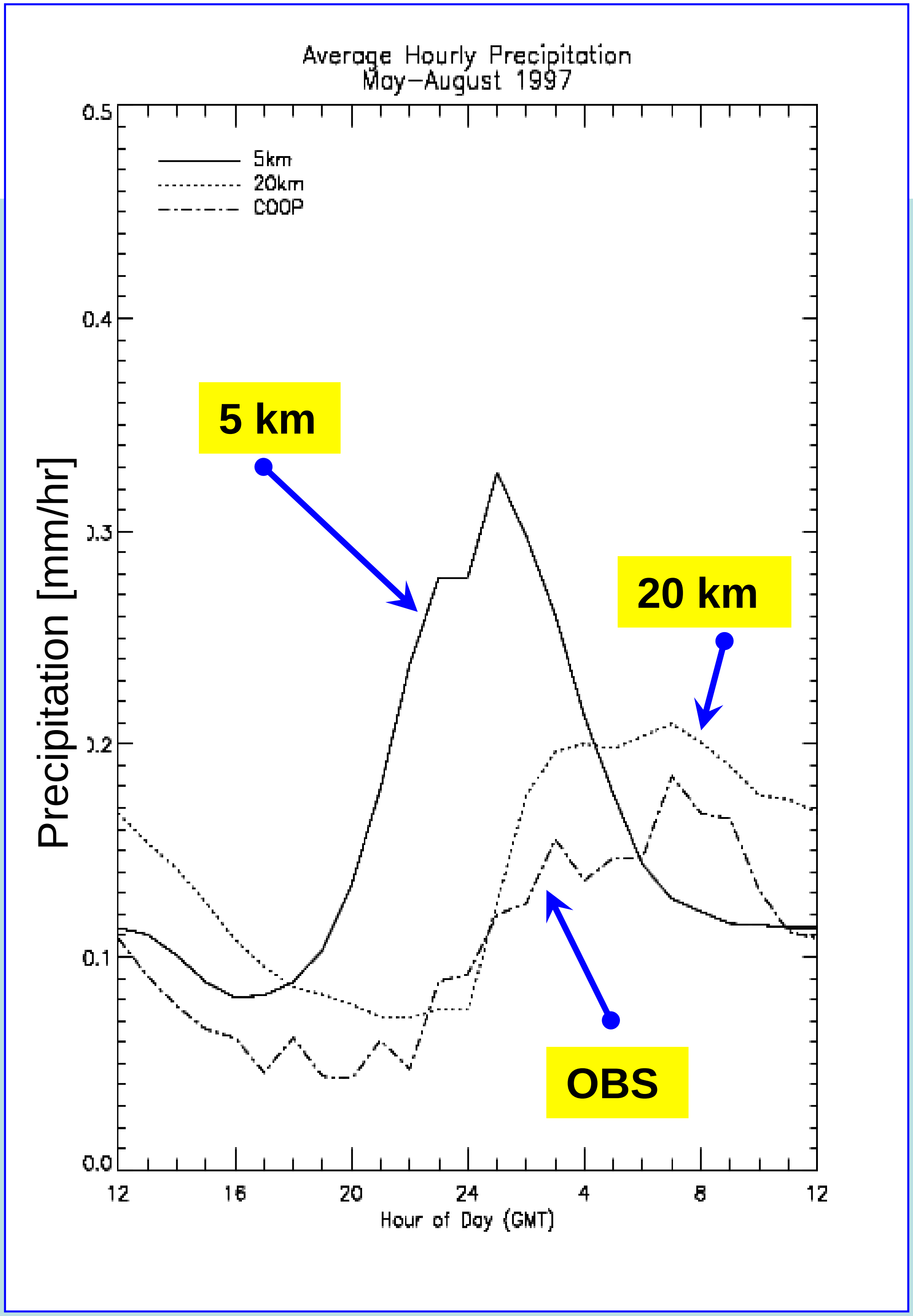
Recommendations: (1) Regional Earth System Modeling Rationale

- The role of the ocean and cryosphere in regional climate is not well understood because most RCMs are atmospheric models.
- Air-sea interactions play an important role in the initiation and propagation of the Madden-Julian Oscillation, which influences mesoscale processes such as convection and tropical cyclone activities.
- GCMs lack the spatial resolution to represent regional scale processes and feedbacks.
- Workshop participants strongly recommended the development of WRF towards a regional earth system model to address a wide range of science questions specific to regional scale processes and forcing and response.

Recommendations: (1) Regional Earth System Modeling

- Develop interactive coupling with sea ice and ocean models to represent air-sea interactions.
- Develop interactive coupling with chemistry and aerosol models, including dust, to represent chemistry-aerosols-clouds-radiation feedbacks.
- Develop more comprehensive treatments of land surface and hydrological processes including river routing, sub-surface flow, lake, land use, fires, and land ice.
- Develop interactive coupling with marine and terrestrial ecosystem models.
- Develop data assimilation capabilities for the coupled model that can be used to develop regional analysis of the earth system. Examples are ocean and land data assimilation system.
- Accelerate the transition of WRF to the Earth System Modeling Framework (ESMF) to facilitate model coupling.

Does higher resolution help?



Flory (2003)

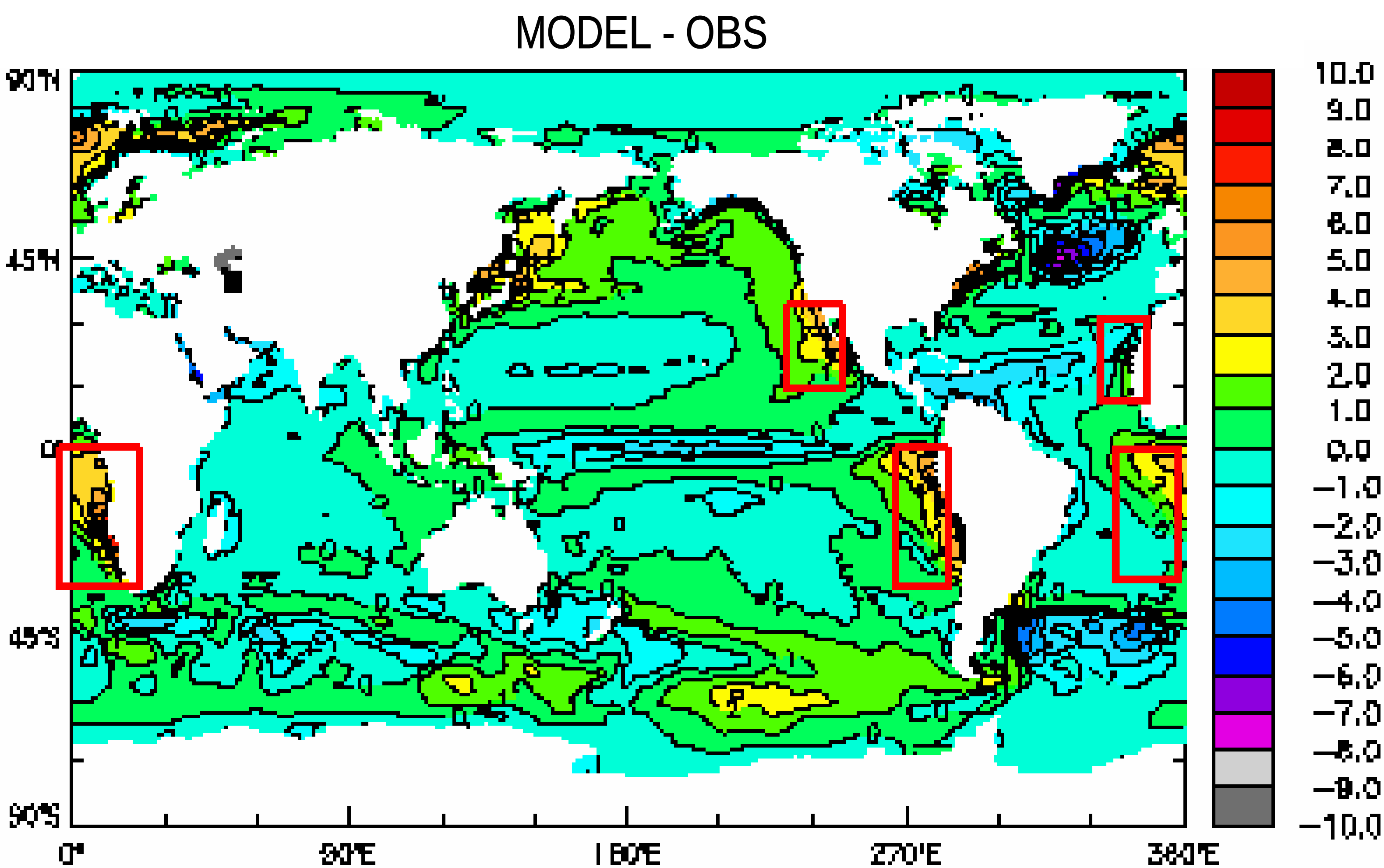
Recommendations: (2) High Resolution Modeling Rationale

- With non-hydrostatic dynamics cores and high-order, conserving numerical techniques, WRF is designed for use at any scale from large-eddy simulations to hemispheric applications.
- High resolution modeling (1-20 km resolution) may improve the fidelity of climate simulations and provide climate information at the scales needed for resource management and impact assessment. However, more research is needed to assess and improve the skill of the model at high resolution.

Recommendations: (2) High Resolution Modeling

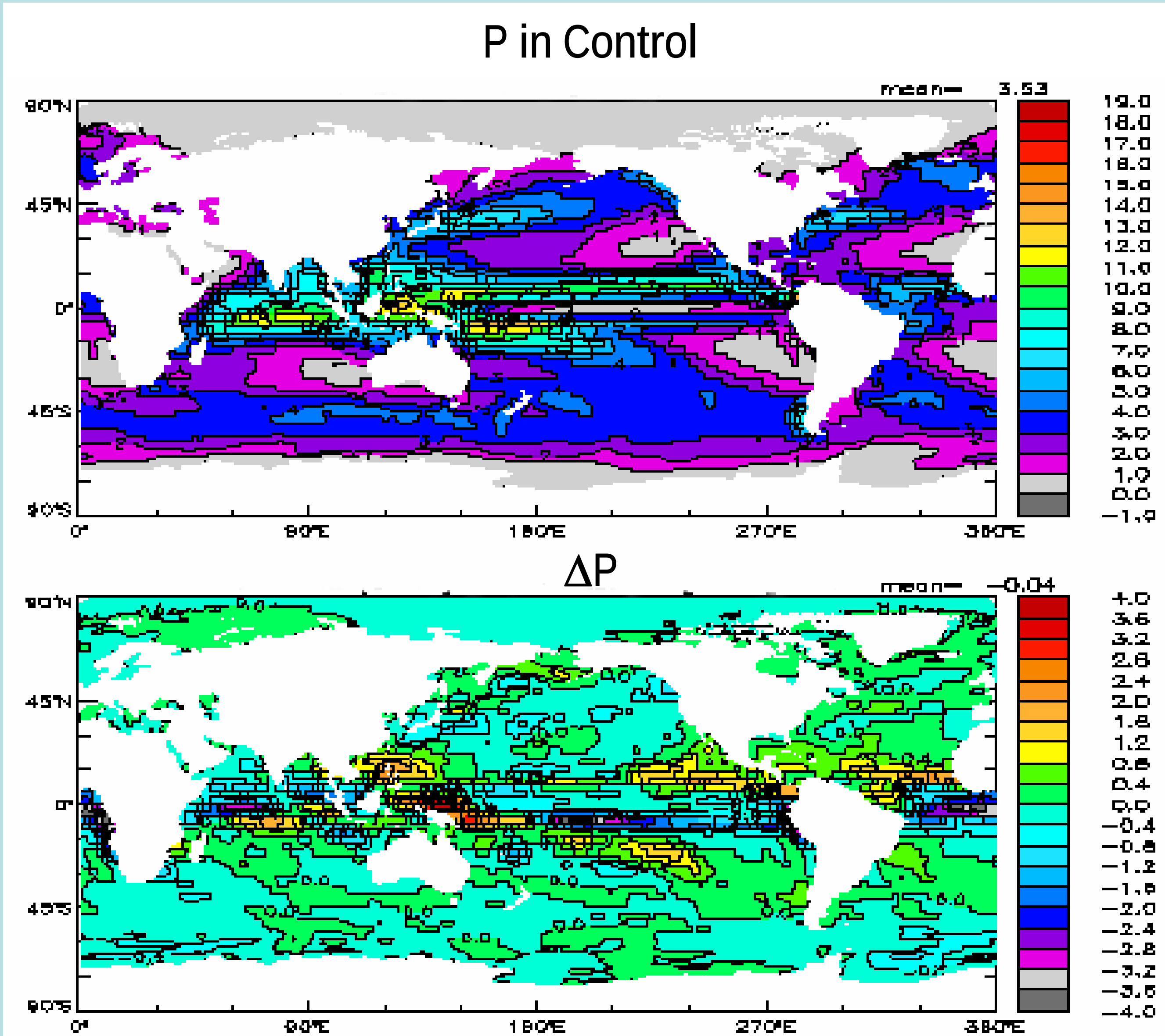
- Develop and test physics parameterizations suitable for high resolution applications. Examples include processes such as cloud microphysics, turbulence, and shallow convection.
- Develop and implement representations of processes important at the high resolution. Examples are terrain sloping effects on the planetary boundary layer and radiation and urban effects.
- Develop more options for mesh refinement such as multiple nesting, stretch grid, and adaptive mesh refinement for high resolution modeling, and evaluate their performance.
- Systematically investigate the value of high resolution modeling in regional climate modeling.
- Apply WRF as a cloud resolving model to explore its usefulness and limitations. Such research is timely as the climate modeling community is investigating approaches to global cloud resolving modeling. A limited-area cloud resolving model capable of ingesting real data is a useful framework for model evaluation and scientific investigations.

CCSM2 SST Bias



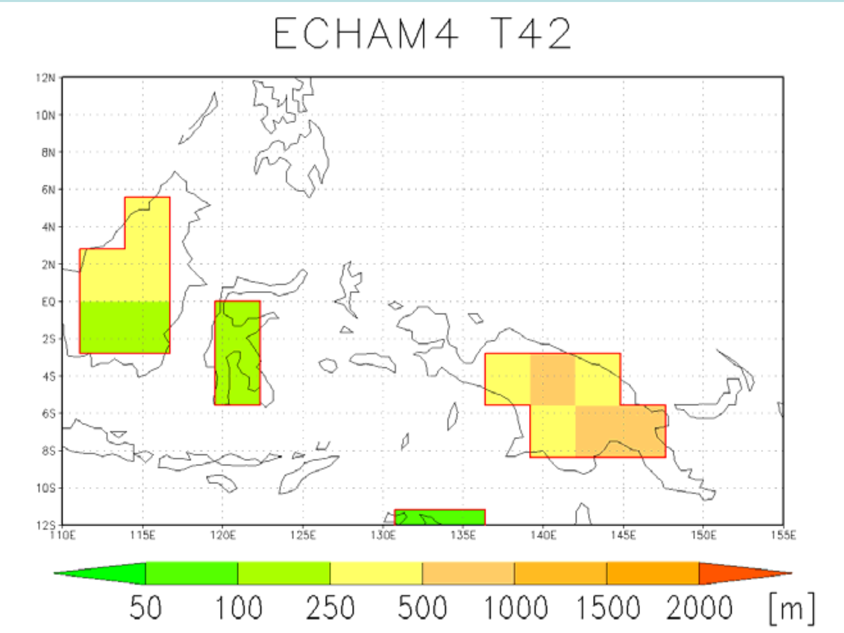
Large and Danabasoglu 2005

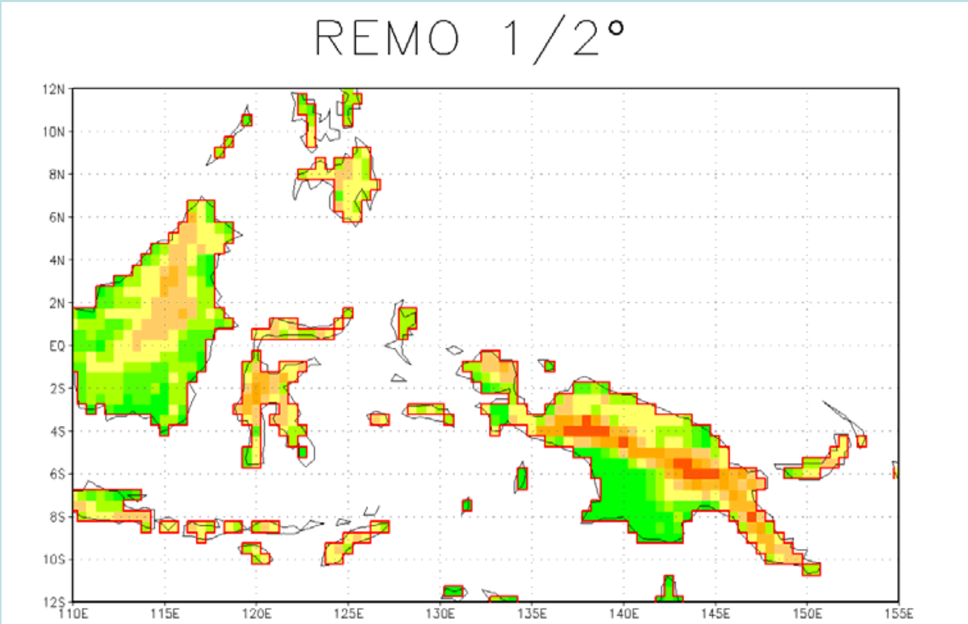
Large-Scale Effects of ΔSST < 0 off South America and South Africa



Two-Way Nested Domains

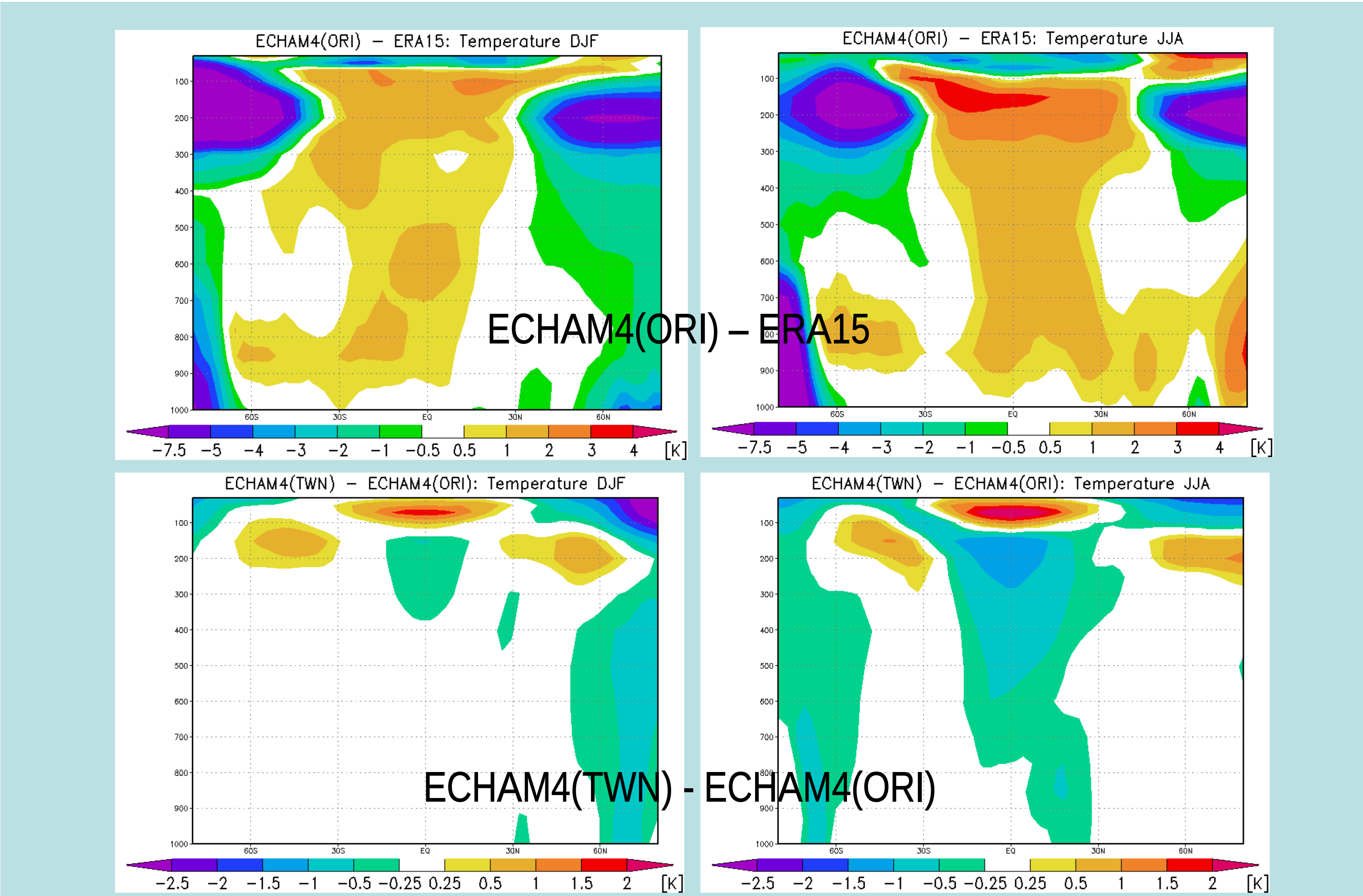
A 10-year simulation with two-way nesting over the Western Pacific regional “Warm Pool”





Lorenz and Jacob (2005)

Zonal Mean Temperature Difference



Recommendations: (3) Upscaling Research Rationale

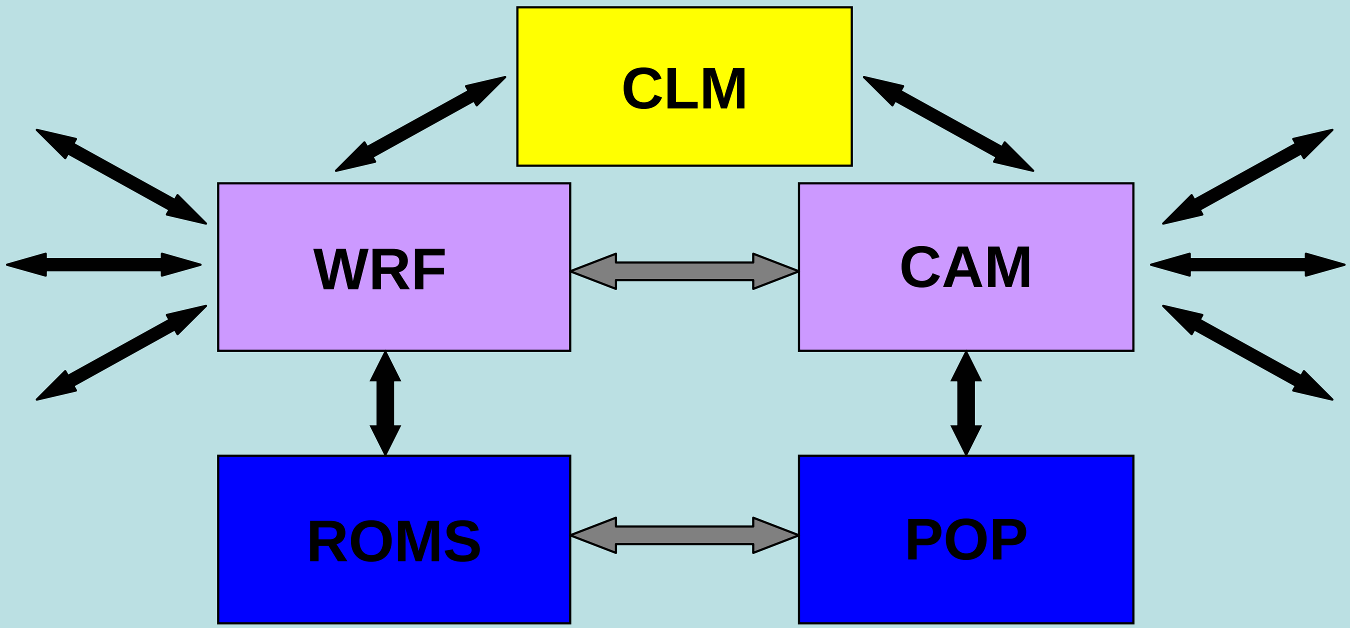
- The significance of representing scale interactions must be more fully addressed using non-hydrostatic models capable of resolving dynamical processes at the 5 – 30 km spatial scale.
- Currently, this is not achievable with GCMs for long term simulation because of computational constraints and/or limitations of the hydrostatic formulation.
- The coupling of regional and global models to represent upscaled effects is considered by the workshop participants as the most expeditious path to addressing this science question because significant investments have already been made to develop models such as WRF and CCSM.

Recommendations: (3) Upscaling Research

- Develop more general coupling capabilities in WRF for coupling with CCSM as well as other earth system components. Most of the intriguing scale interaction issues involve feedbacks between different earth system components.
- Identify and analyze the importance of model compatibility issues between WRF and CCSM. These include matching of model top and modeling of the upper atmosphere such as gravity wave drag and stratospheric physics in WRF.
- Develop and test different methodologies for coupling WRF and CCSM. These include testing different approaches and frequencies for applying feedback from WRF to CCSM (e.g., data assimilation versus direct updating of CCSM variables with the WRF variables).
- Develop pilot projects on two-way coupling of regional and global climate models over “hot spots” (e.g., Maritime Continent, Monsoon regions, and Subtropical Eastern Boundaries).

Proposed Modeling Framework

- WRF/ROMS (regional ocean modeling system) nested within CCSM with WRF interacting with ROMS and CAM, and ROMS interacting with WRF and POP (global ocean model)



Summary

- RCM has demonstrated skill in simulating regional water cycle and its variability
- RCM provides a framework for parameterization development and testbed for high resolution and cloud resolving modeling
- Transition to regional earth system model opens opportunities to investigate a wide range of climate questions (including air-sea interactions) and interdisciplinary studies
- Two-way GCM-RCM coupling facilitates research on scale interactions and teleconnections