Analysis and Evaluation of WRF Tropical Channel Simulations

L. Ruby Leung
Pacific Northwest National Laboratory

B. Kuo, J. Tribbia, G. Holland, J. Done, J. Dudhia, W. Collins, W. Large, J. Hack, J. Caron, J. Hurrell, T. Henderson, J. Michalakes, C. Bruyere, R. Anthes, M. Moncrieff, W. Wang
National Center for Atmospheric Research

Predicting the Earth System Across Scales

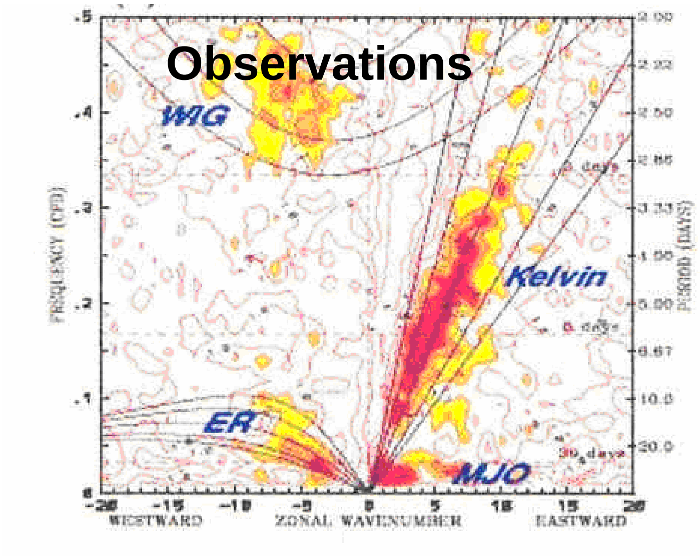
Overarching Goal:

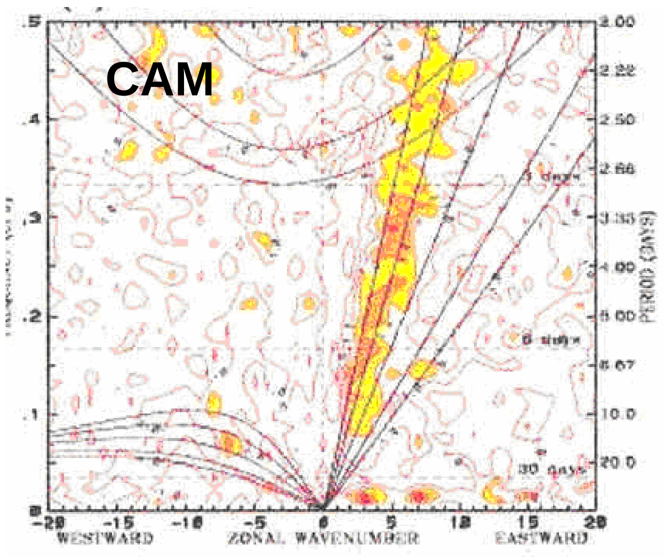
- To improve our understanding and simulation of the complex, 2-way scale interactions that are critical to climate and weather predictions

Objectives:

- To improve *downscaling* from global climate simulations for accurate regional predictions
- To improve *upscaling* of regional processes in global climate simulations;

Getting the Tropical Modes





(Lin et al. 2006)

- Currently CAM and CCSM have difficulty capturing the modes of tropical variability, from equatorial Rossby, through westward inertia gravity and MJO. Even the Kelvin modes are poorly captured.
- This program will focus on understanding and reducing such biases.
- A working hypothesis is that the upscale development from <u>organized tropical convection</u> is a critical factor.
- By <u>utilizing cloud-resolving nested models</u> in critical areas, we plan to both test this hypothesis and develop an approach to <u>improving CAM and CCSM</u> in this important characteristic.
- Taking advantage of Blue Vista during its bedding in period, we performed WRF simulations with cloud resolving nest to investigate the usefulness of the nesting approach

Nested Regional Climate Model

WRFV2.1

Physics:

- CAM radiation: radt = 30min
- WSM-6 microphysics
- Noah LSM
- YSU bounday layer
- Kain Fritsch (new Eta) convection

Code modifications:

- Periodic lateral boundary conditions in East-West.
- Updated lower boundary condition: SST and Vegetation Fraction.
- Wide buffer zone of 10 grid points using a combined linear-exponential relaxation.
- Expanded diagnostic outputs including the ISCCP simulator and accumulated fluxes

Tropical Channel Simulations

Forcing Data:

- NCEP-NCAR reanalyses at north and south boundaries (6 hourly at 2.5°)
- Periodic lateral boundary conditions East-West.
- Lower boundary conditions: AMIP SST (0.5 degree) and mean monthly vegetation fraction

Vertical Levels:

- 35 sigma levels for all domains.
- Terrain following close to surface transitioning to pressure levels at model top.

Model Outputs:

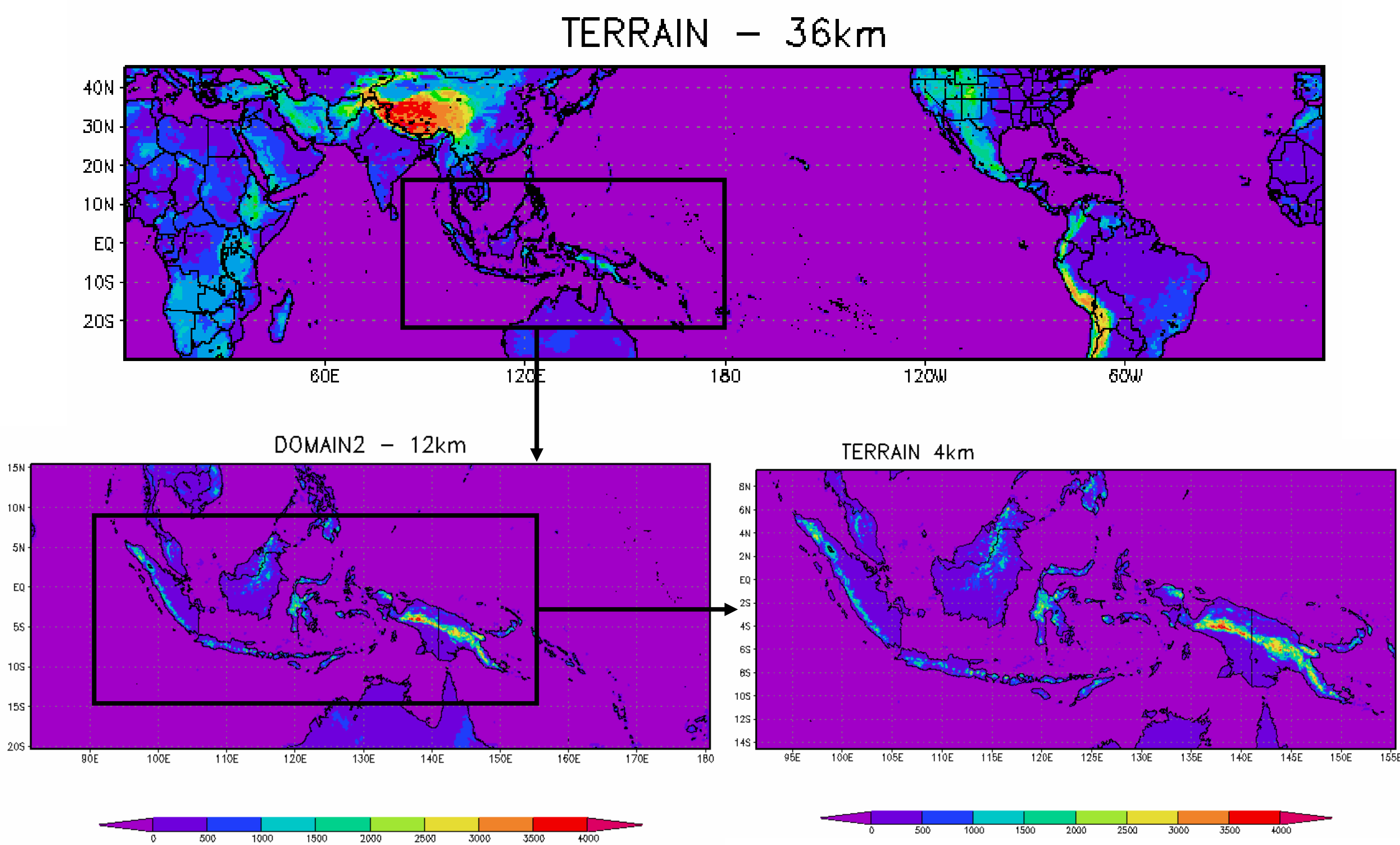
- 3-hourly instantaneous 3D fields
- Hourly surface and TOA fields and averaged fluxes

Analysis and Evaluation:

- Climate diagnostics (Julie Caron and Jim Hack)
- EUROCS transect (Ruby Leung and Roger Marchand)
- Tropical cyclone statistics (Greg Holland)

Model Setup

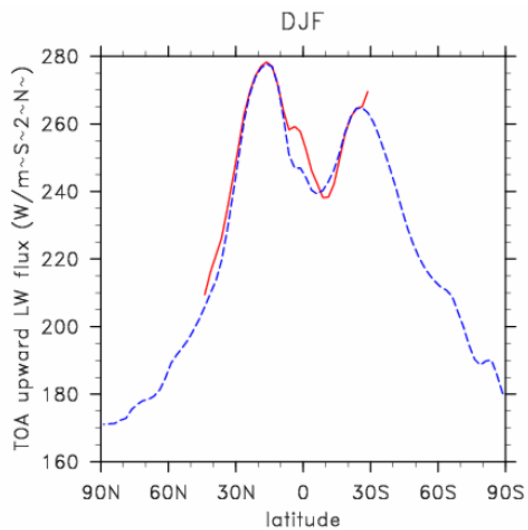
- Center latitude = 9.5 Center longitude = 180.0 Map projection = Mercator
- Domain 1: 1112 x 255 grid points at dx = 36 km (Jan 1, 1996 to Jan 1, 2001)
- Domain 2: 922 x 340 grid points at dx = 12 km (Domains 1 + 2: Jan 1, 1996 to Mar 1, 1998)
- Domain 3: 1783 x 673 grid points at dx = 4 km (Domains 1 + 2 + 3: Jan 1, 1997 to Jul 1, 1997)

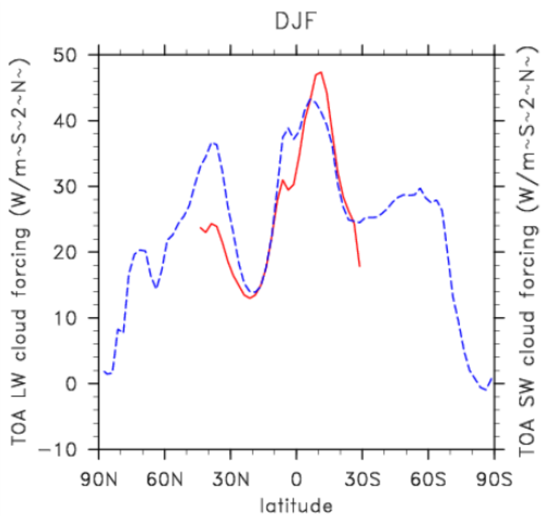


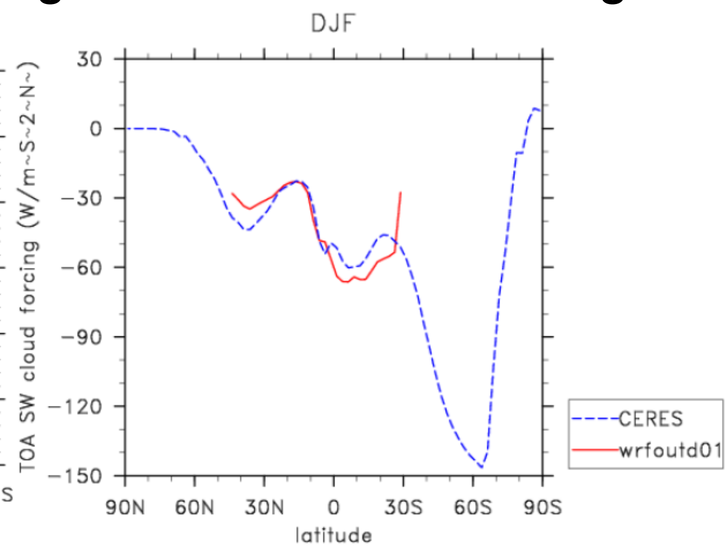
TOA Radiative Fluxes

TOA Upward LW | **TOA LW Cloud Forcing** | **TOA SW Cloud Forcing**

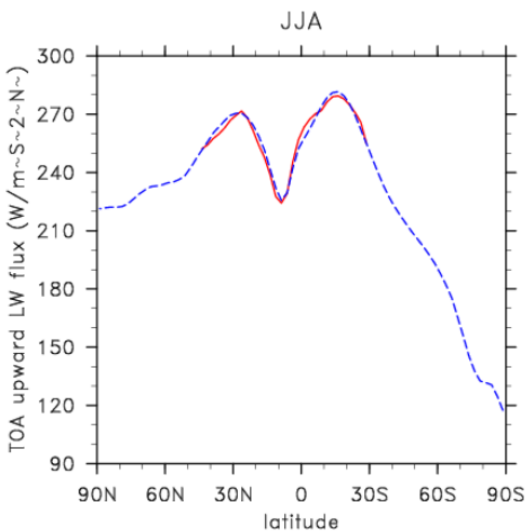
DJF

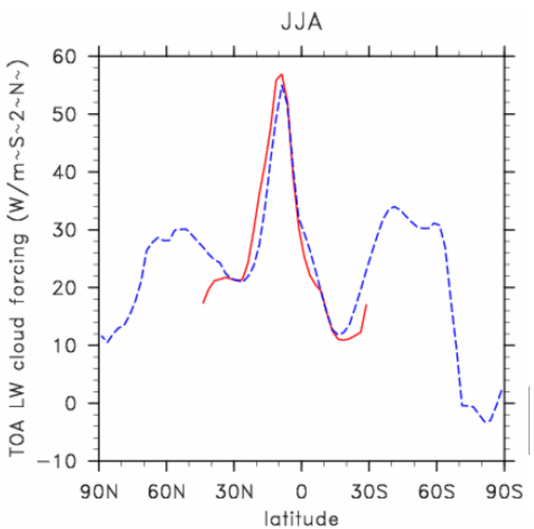


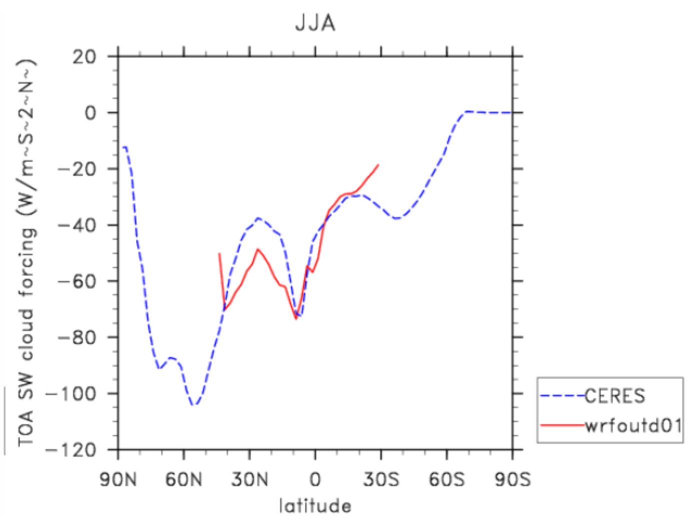




JJA





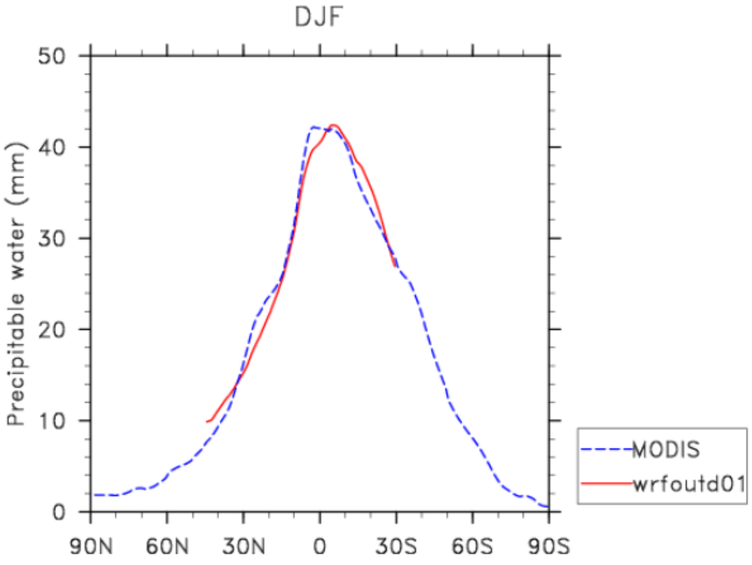


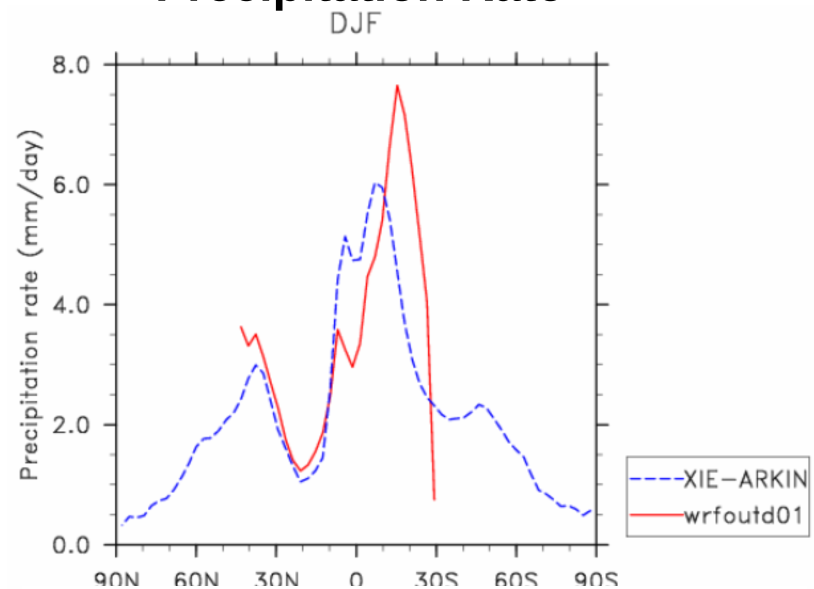
Precipitable Water/Precipitation

Precipitable Water

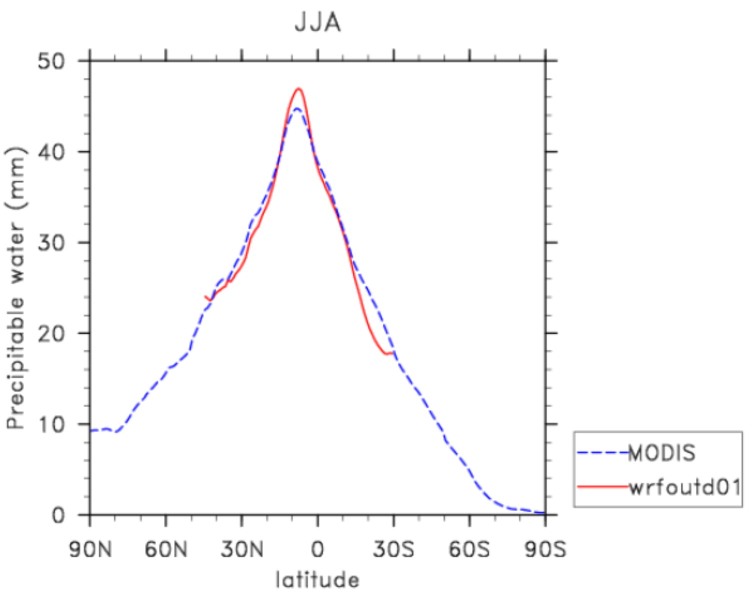
Precipitation Rate

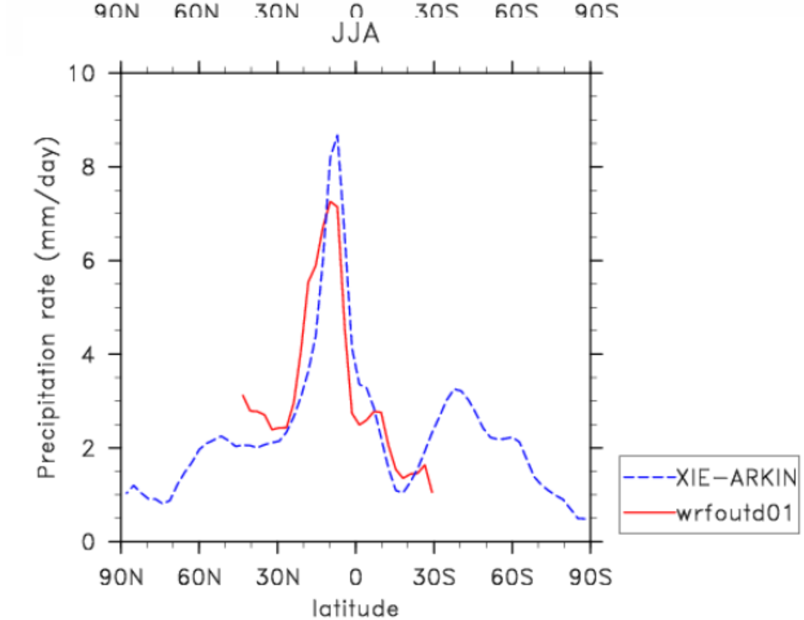
DJF





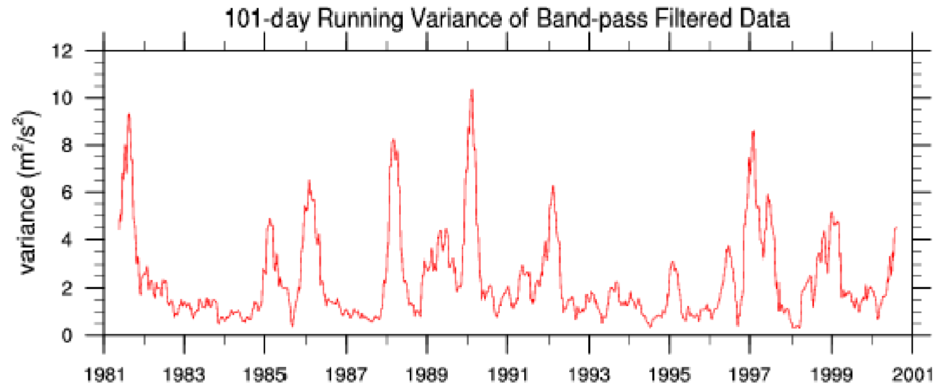
JJA



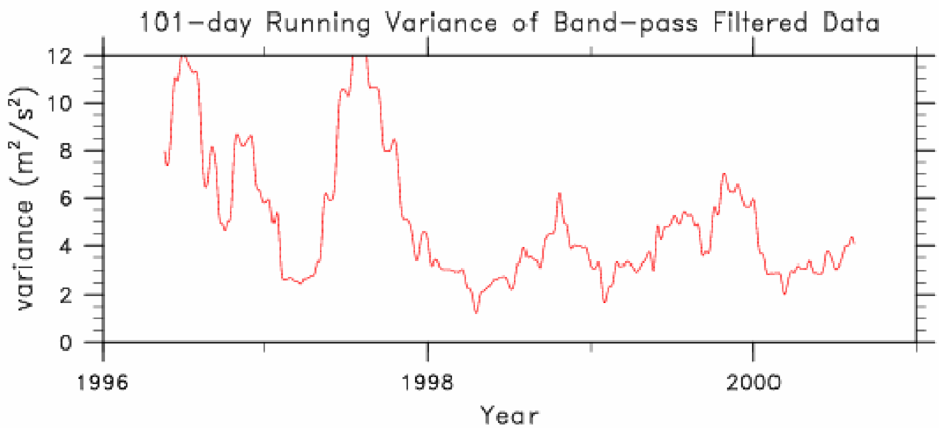


MJO Indices

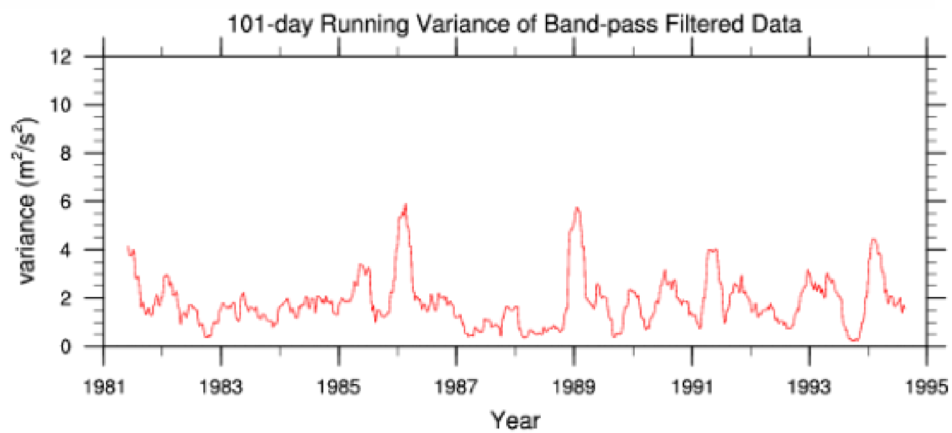
NCEP



WRF

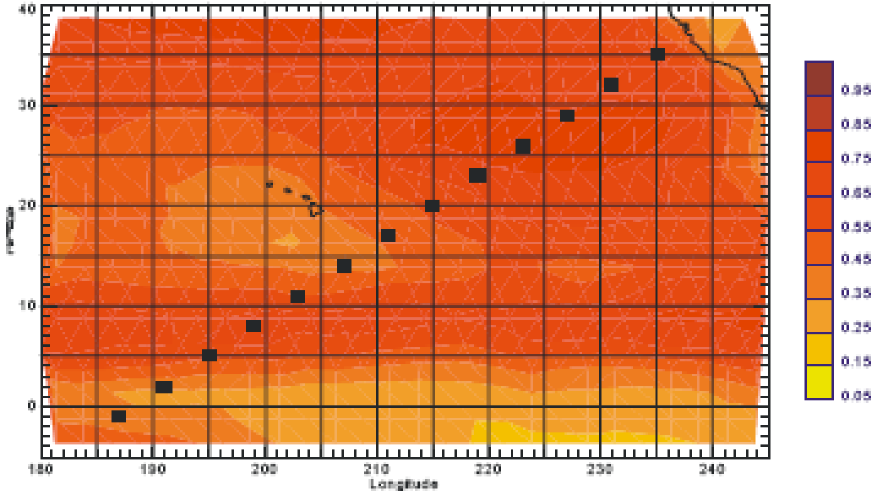


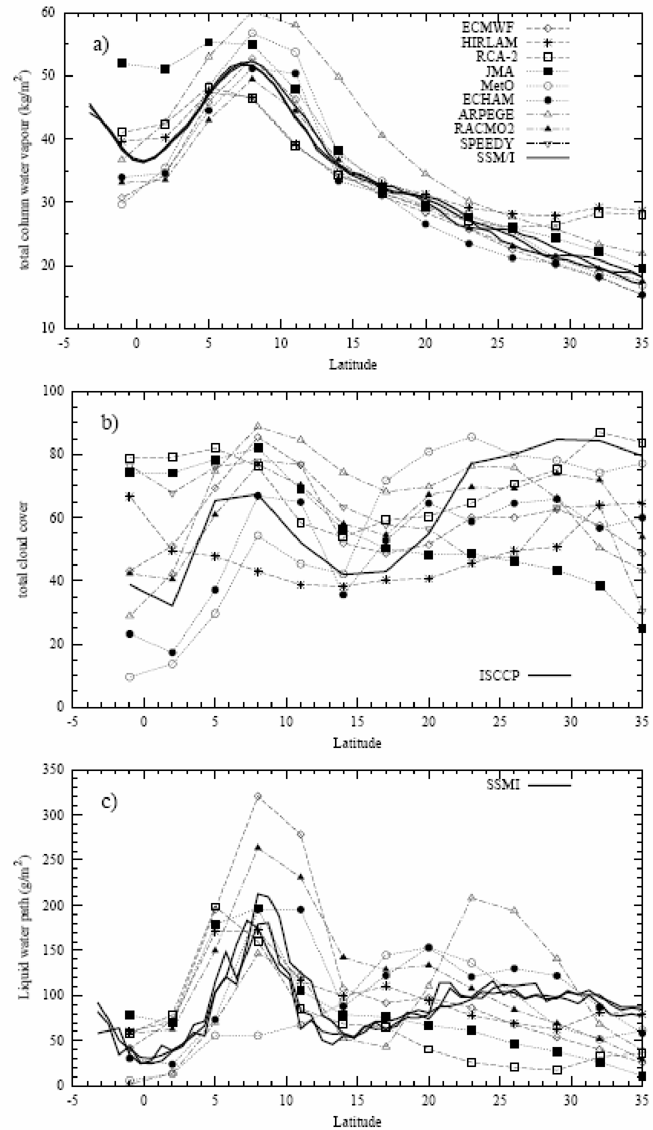
CAM
T170



EUROpean Cloud Systems Study (EUROCS)

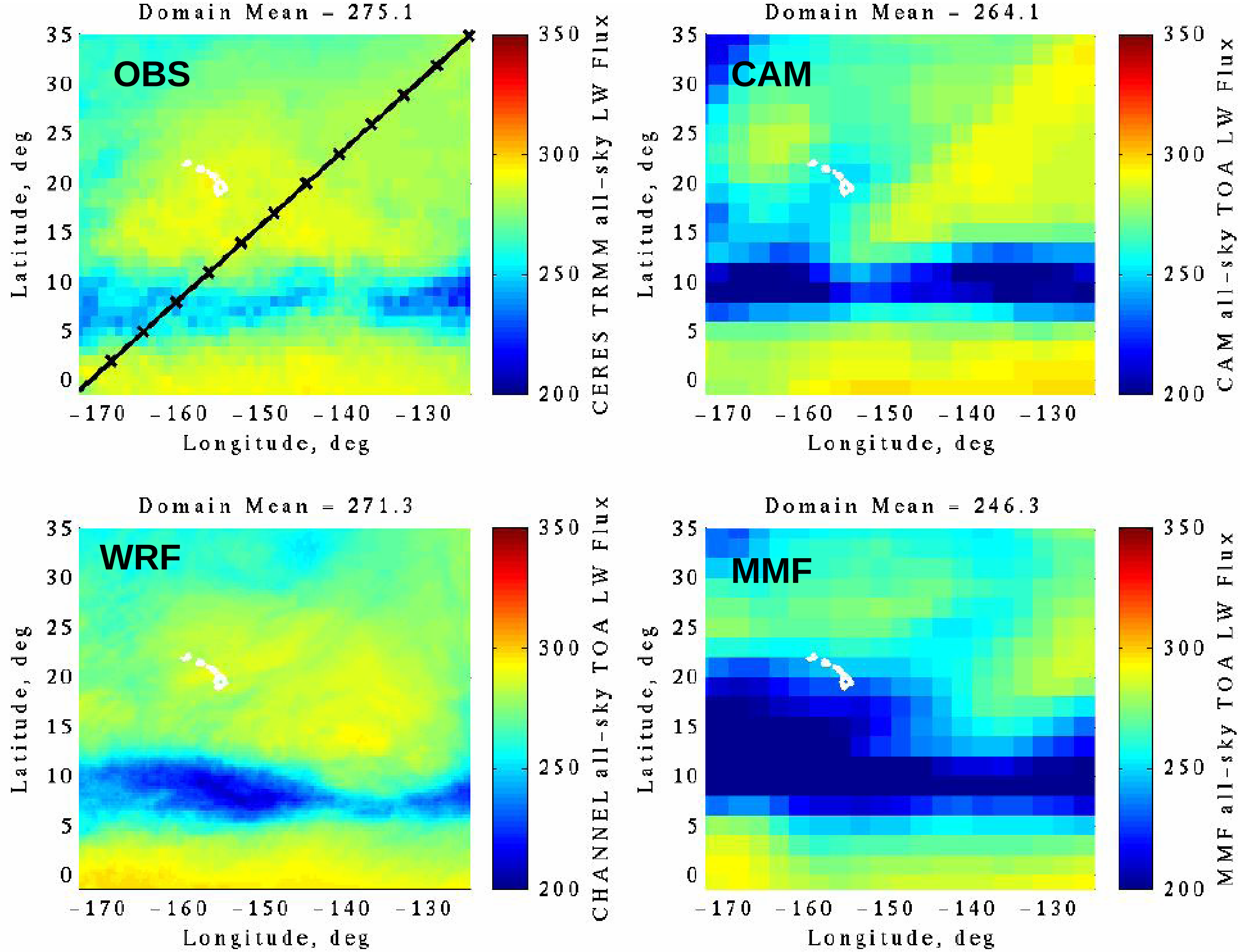
(Siebesma et al. 2002)





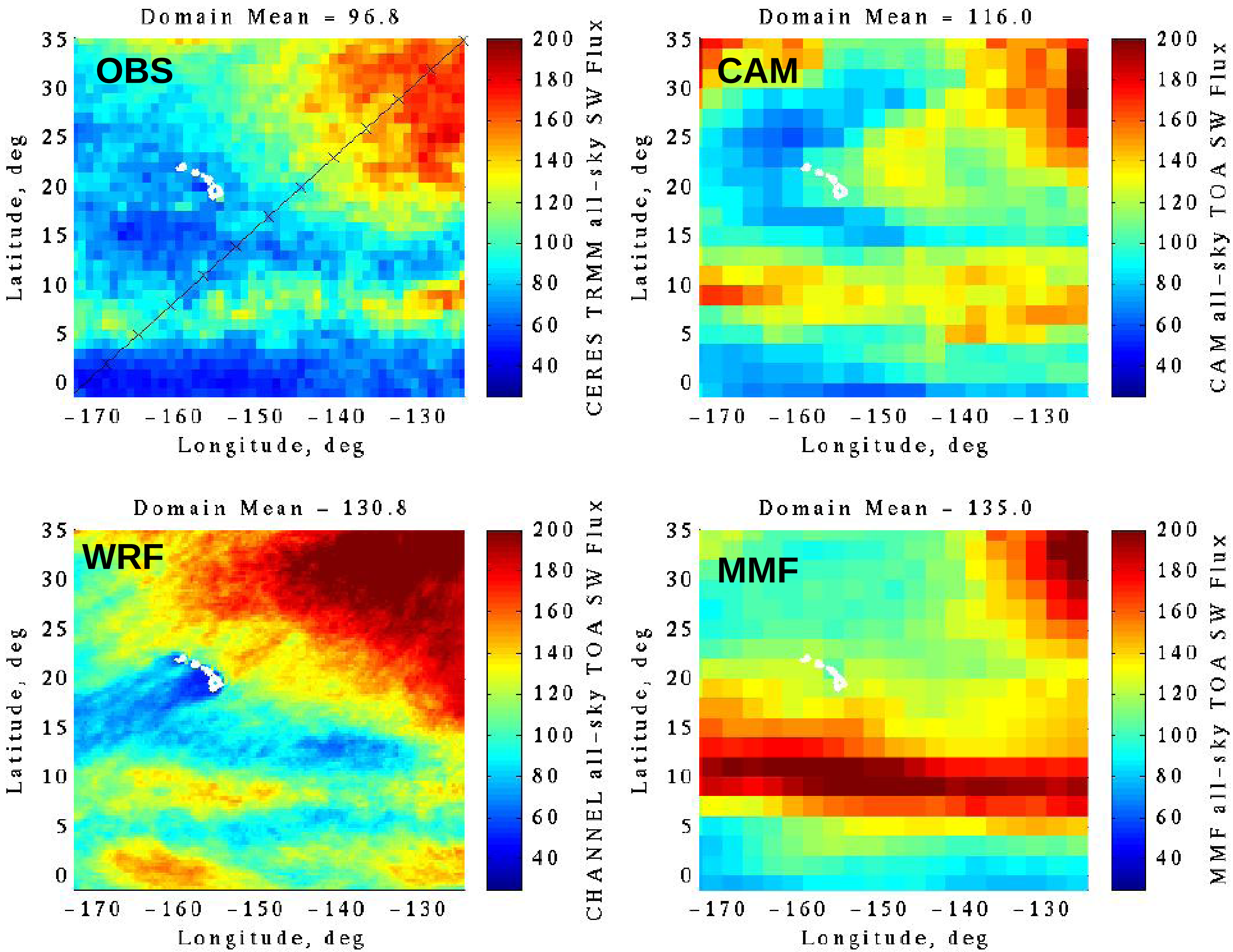
1. June – August 1998
2. Idealized transect along the eastern Pacific representing the transition from stratocumulus, shallow cumulus, and deep cumulus
3. 9 climate and weather models participated
4. Most models underpredict cloud cover in the stratocumulus regime, and vice versa in the trade wind and ITCZ region

TOA Upward LW Fluxes



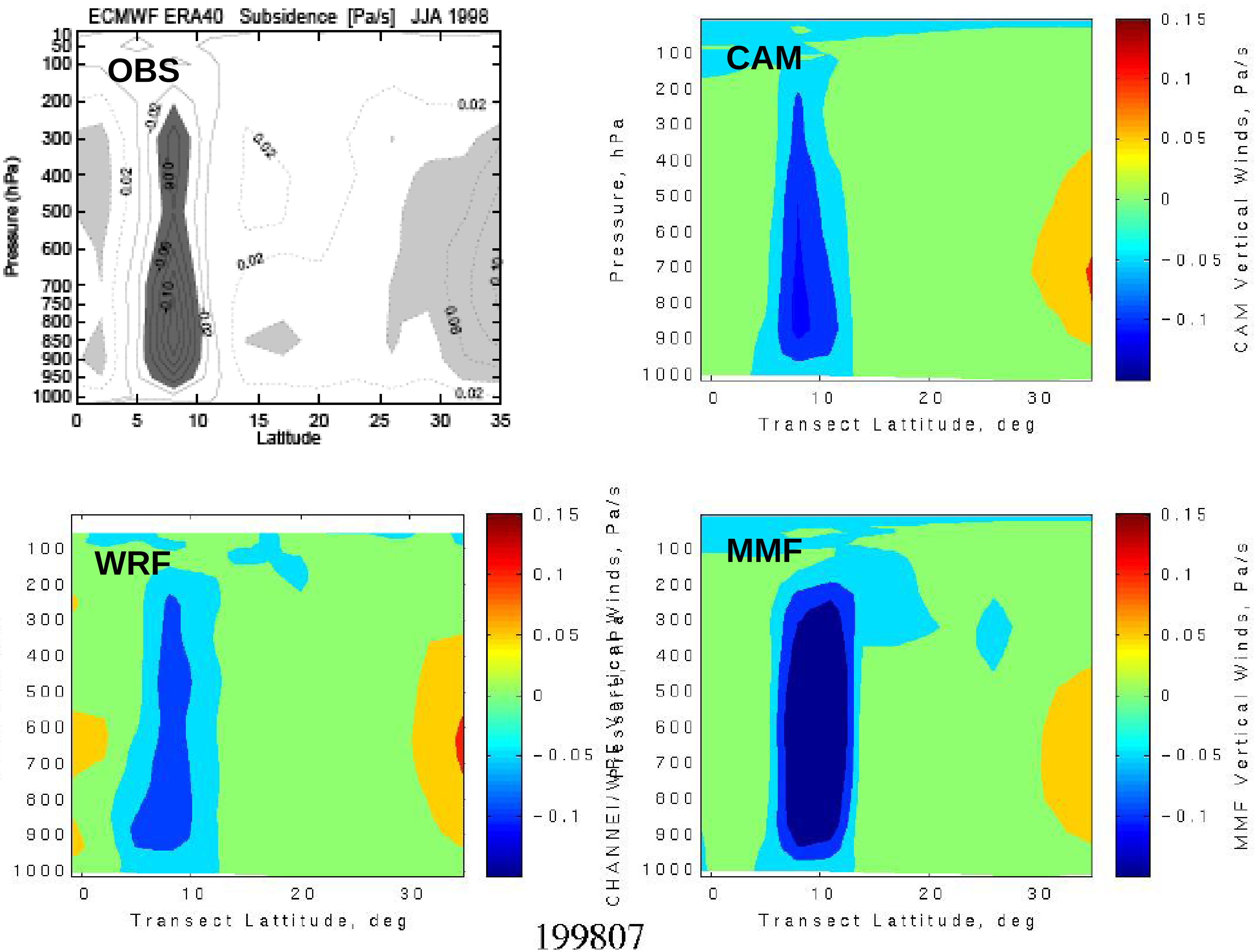
199807

TOA Upward SW Fluxes



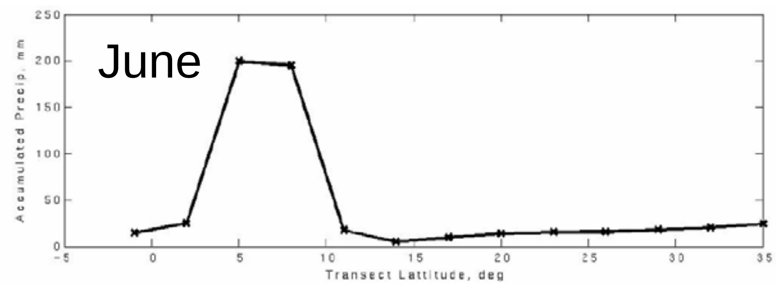
199807

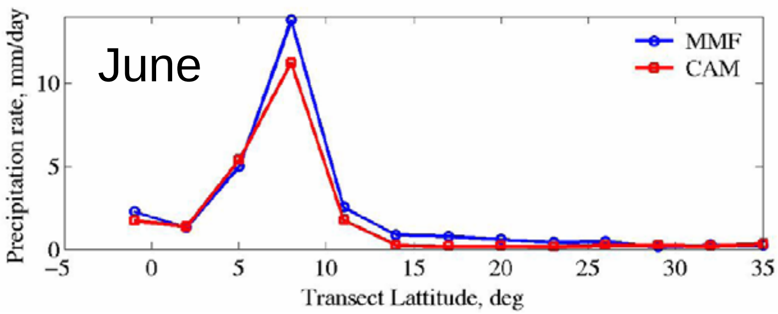
Vertical Velocity

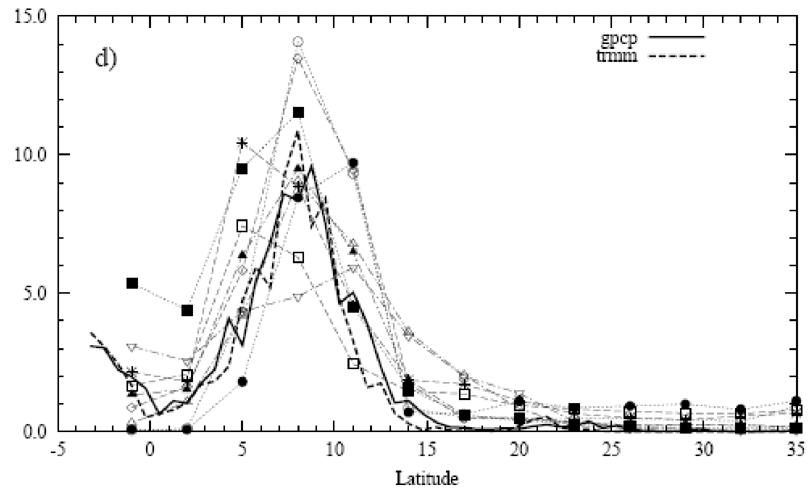


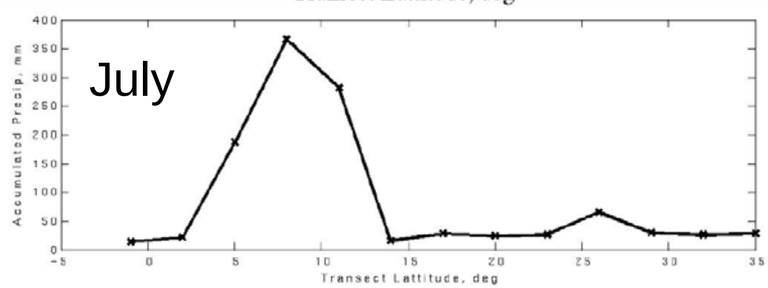
Rainfall Along Transect

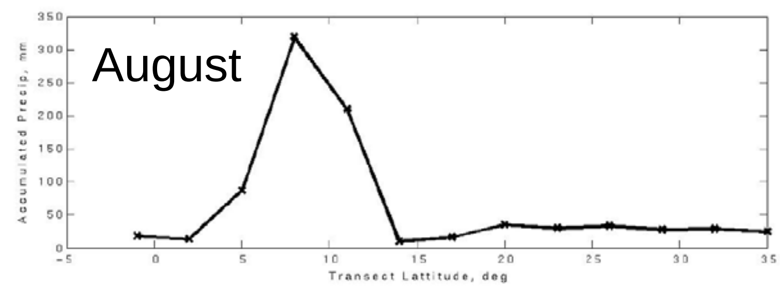
WRF: 10 mm/day   CAM: 15 mm/day
MMF: 20 mm/day   GPCP: 10 mm/day

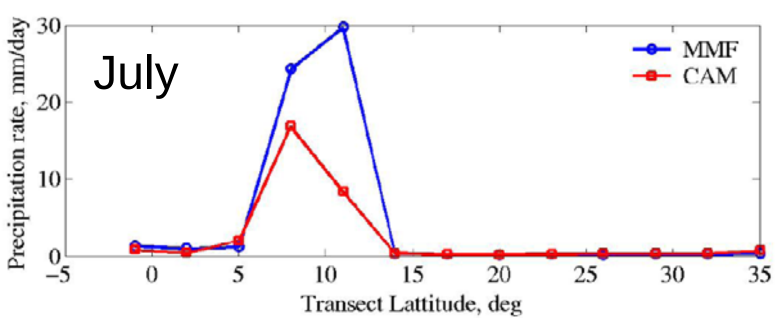


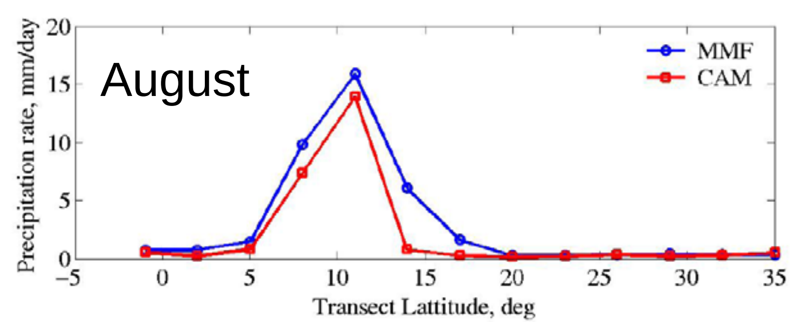




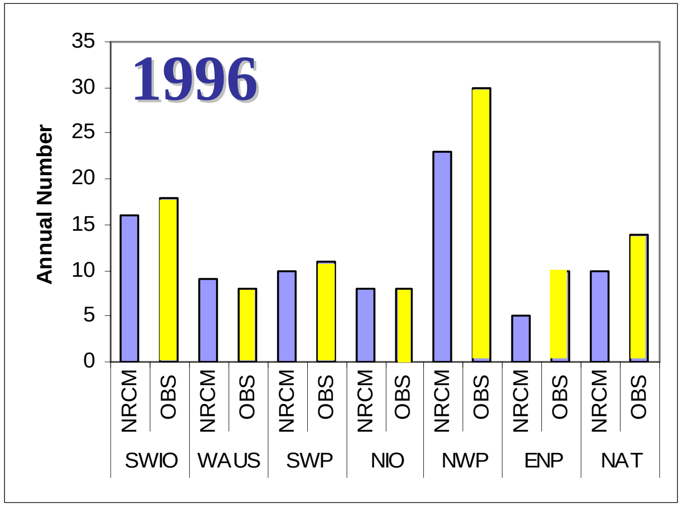


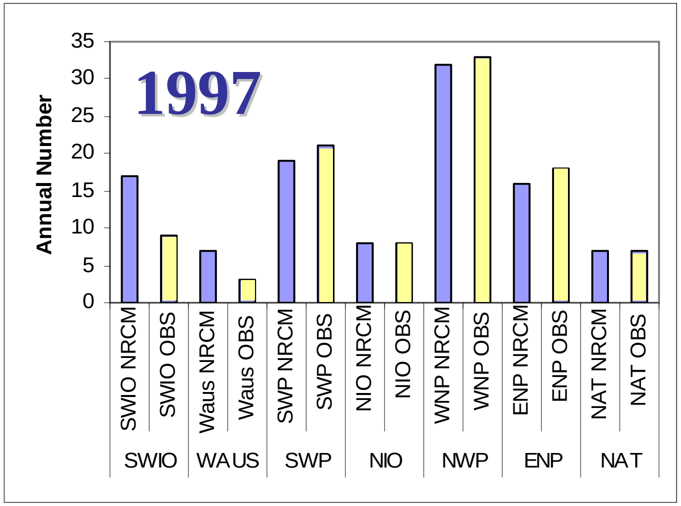


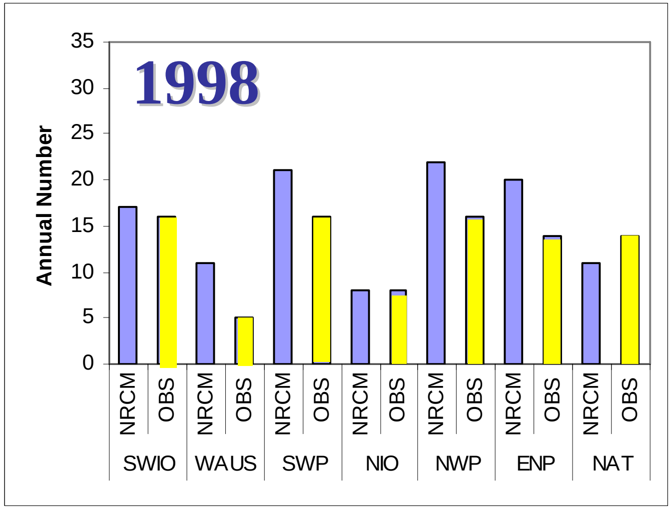




Annual Tropical Cyclone Statistics

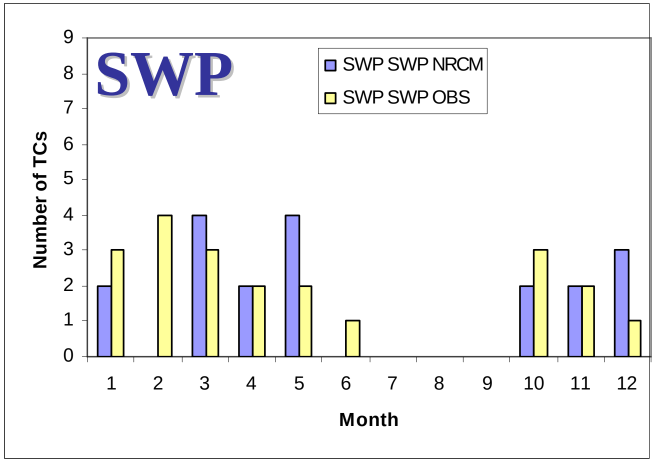


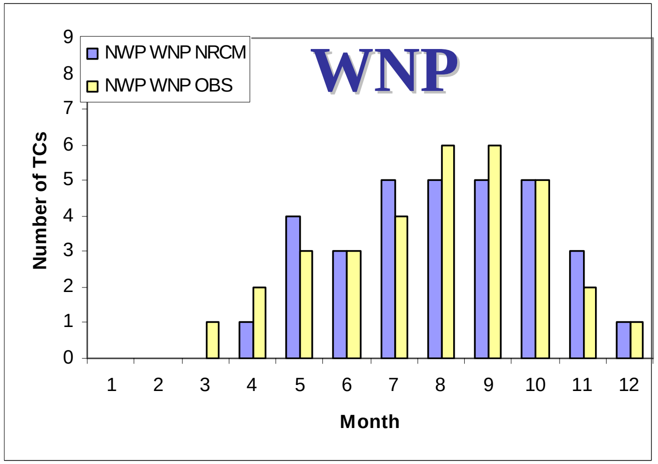


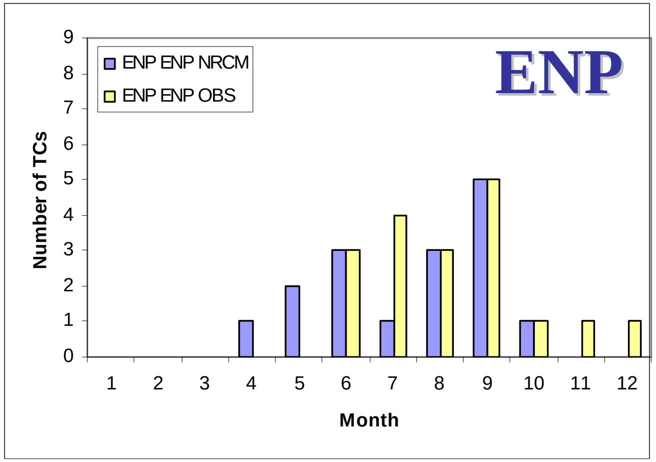


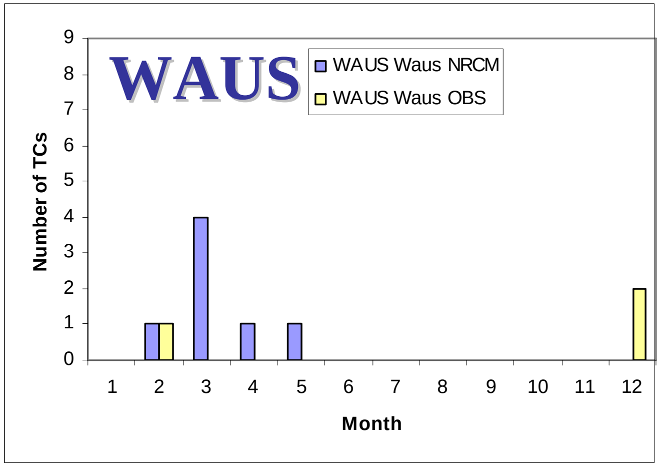
Greg Holland

1997 Tropical Cyclone Statistics





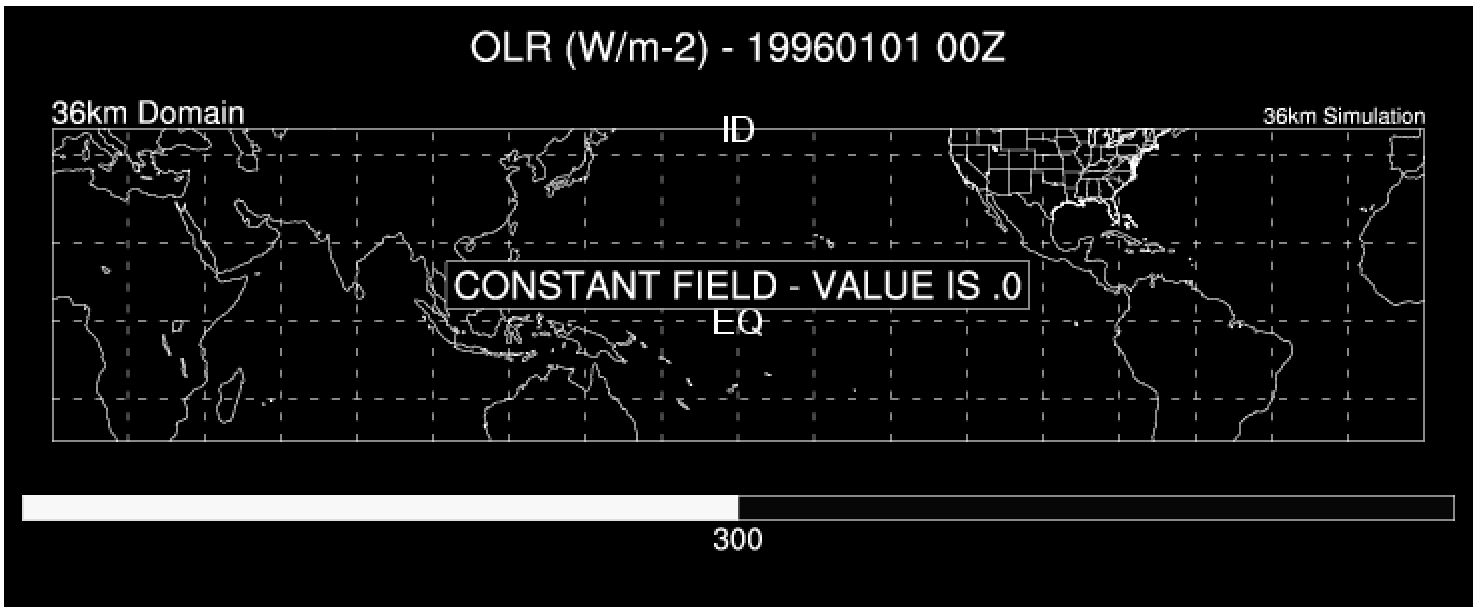




Greg Holland

Summary

- The 36-km WRF tropical channel simulation reproduces large scale climatic features reasonably well
- Comparison of WRF, CAM, and MMF simulations over the EUROCS transect shows that WRF simulates more realistic structure of the ITCZ, but more extensive stratocumulus
- The WRF tropical cyclone statistics compare well with observations; this suggests the simulation may be a useful dataset for investigating cyclogenesis and its relationship to large scale circulation
- Future studies will investigate the upscaled effects of tropical convection by comparing the 36 km runs with and without nesting, analysis of tropical modes, and climatic features including the monsoon in different continents
- These simulations will be extended using the Columbia computing resources to provide a unique dataset for studying scale-interactions, tropical modes, and their influence on large scale and regional scale climate
- A two-way coupled CAM-WRF will be developed as an approach to incorporate upscaled effects to address CAM biases


OLR (W/m-2) - 19960101 00Z
36km Domain
36km Simulation
ID
CONSTANT FIELD - VALUE IS .0
EQ
300

Key Areas for Development

- **To Include regional earth system components**

- Ocean and sea ice
- Chemistry/aerosols/clouds
- Land surface and hydrology (e.g., CLM, crop model (including carbon/nitrogen), dynamic vegetation in LSM)
- Biogeochemistry
- Address model development, evaluation, computational efficiency, model sensitivity
- Priority – one-way coupling of atmosphere, updating of sea ice
- Implement some components from CCSM to start with – test them at the regional scale – need flux coupler similar to CCSM

Key Areas for Development

- **Model numerics and physics for high-resolution applications**

- Evaluate long term cloud resolving simulations to understand limitations
- Develop physics parameterizations for cloud resolving simulations (e.g., microphysics, turbulence and shallow convection, terrain effects on PBL and radiation, urban effects)
- Balance complexity and computational efficiency
- Low resolution physics (subgrid topography, cumulus convection)

Key Areas for Development

- **Nesting RCMs within global models**
- Two-way coupling allows both downscaling and upscaling
- Basic assumption: such coupling is only important in certain regions such as the warm pool and monsoon regions
- Address model compatibility issues
- Maintain conservation in the host GCM

Key Areas for Development

- **Global WRF**

- A global WRF with nesting capability will ensure compatibility of the regional and global domains
- Include other earth system components
- Examine alternative grid structures
- Ensure global conservation (mass and momentum)
- Must be able to produce realistic TOA and surface energy budgets and large scale circulation

What are the science/application questions?

- Embed WRF in CCSM to study Arctic sea ice, etc. Need compatible components between WRF and CCSM
- Polar climate, sea ice
- Extreme events
- Reconstruction/reanalysis
- Climate change
- Seasonal climate prediction
- Agriculture and land use
- Rainfall – distribution, frequency, and feedback to landuse etc
- Model coupling (land, ocean, etc) – what software eng. Framework should be used

What do we need in the near term?

- Earth system components – one-way coupling (WRF-CAM), use of CCSM components, existing community efforts (e.g., crop model)
- Low resolution physics (e.g., cumulus convection, subgrid topography, cloud fraction)
- Systematic model evaluation
- Framework for coupling earth system components
- Framework for coupling WRF and CAM, and examine impacts of resolving clouds/mesoscale organization
- Testing of global atmospheric WRF and address physics for global WRF toward an atmospheric GCM

What do we need in the long term?

- More complete regional earth system model
- High resolution physics for nested models and global cloud resolving model
- Global WRF for high resolution climate system simulation?

Action Plan

- Establish an advisory group built on the existing WRF RCM working group to develop an action plan to prioritize and implement model development activities, and establish stronger ties to the CCSM group.
- Promote and coordinate community efforts in regional climate research using WRF, and integrate model components from community regional climate model development efforts into the WRF single-source code.
- Promote interactions between the regional and global climate modeling communities to define research needs and priorities, and identify opportunities to support collaborative model development efforts that take advantage of the expertise and experience from both communities.
- Participate in community model intercomparison projects to establish a benchmark against other regional climate models applied to different geographical regions and climate regimes.
- Coordinate with other WRF model development efforts that address model physics for high-resolution applications and coupling with other earth-system component models.