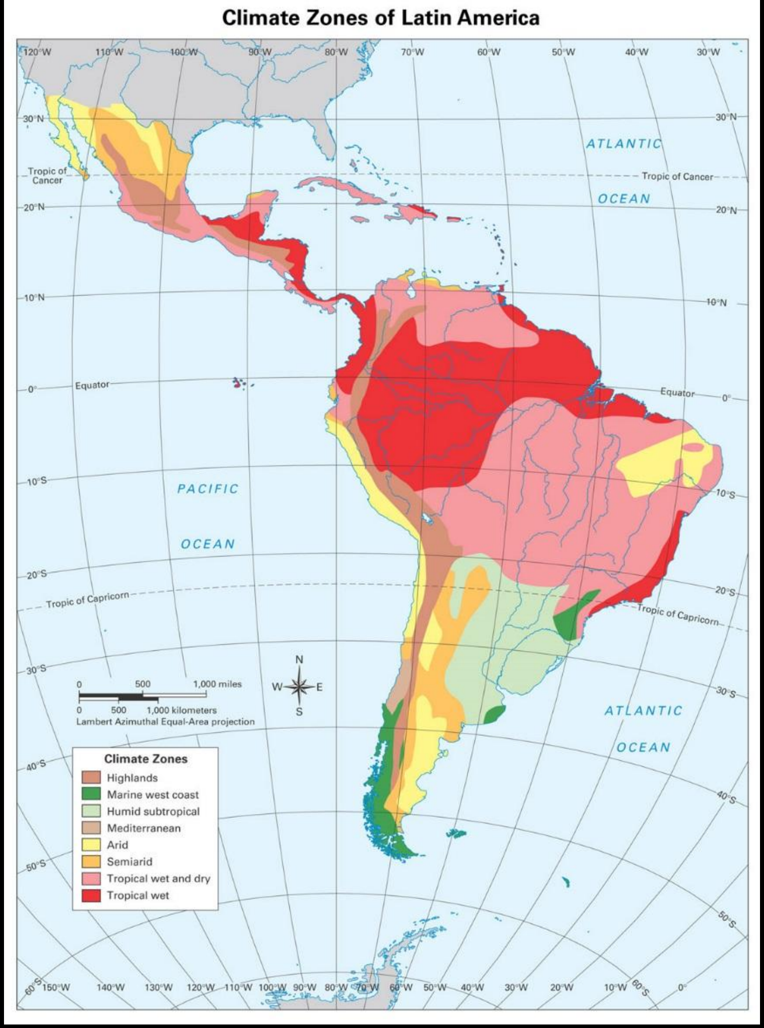


Numerical Climate Modeling:

State-of-the-art, Challenges, and a Program for Latin American and the Caribbean

C. Roberto Mechoso UCLA

Numerical modeling is a mainstay of any modern activity in climate prediction and research.

WCRP LACC 2014

A prediction made with numerical climate models (IPCC) Precipitation Change for 2090-2099 relative to 1980-1999

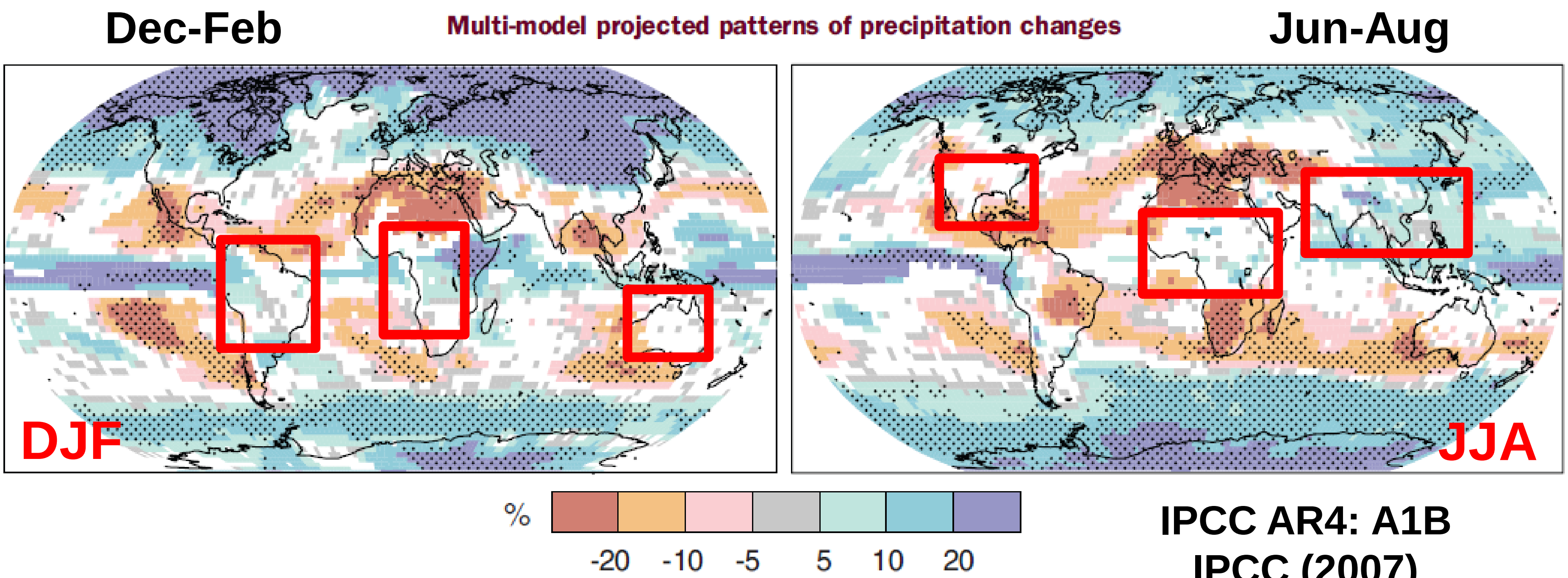


Figure 3.3. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {WGI Figure 10.9, SPM}

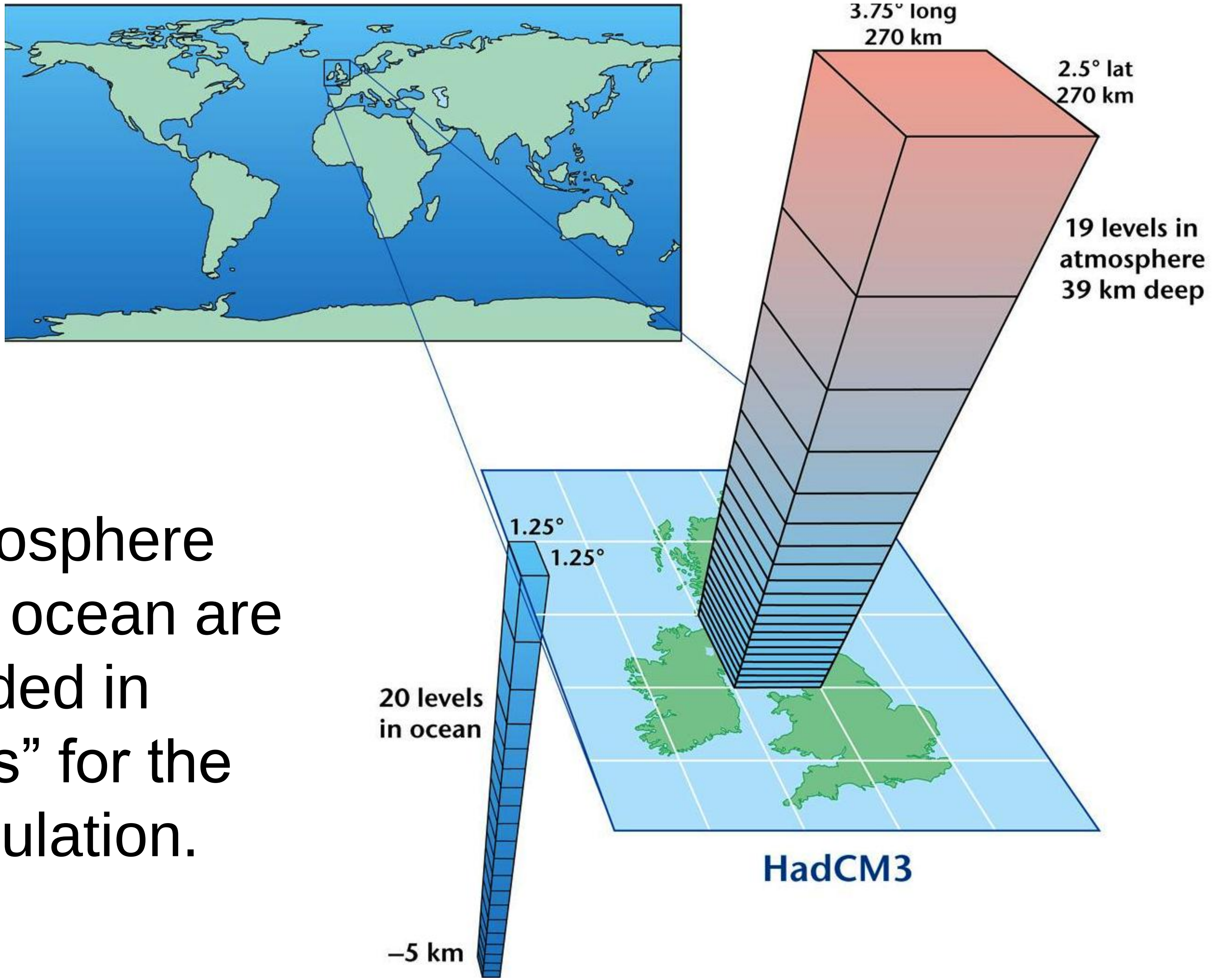
Uncertainty of future projection of precipitation change

Note how there are many areas (in white) where at least one-third of the models do not agree in the sign of the precipitation change from 1980-1999 to 2090-2099.

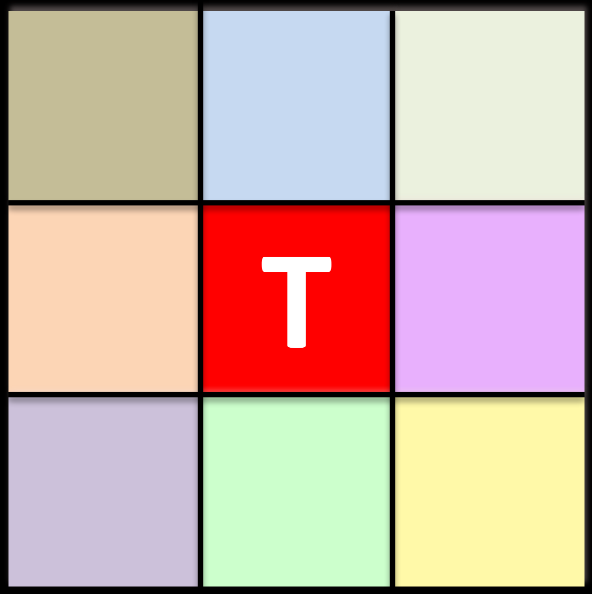
Numerical Climate Models

- Importance
- Basic concepts
- Physical processes/parameterizations

The atmosphere and ocean are divided in “tiles” for the calculation.



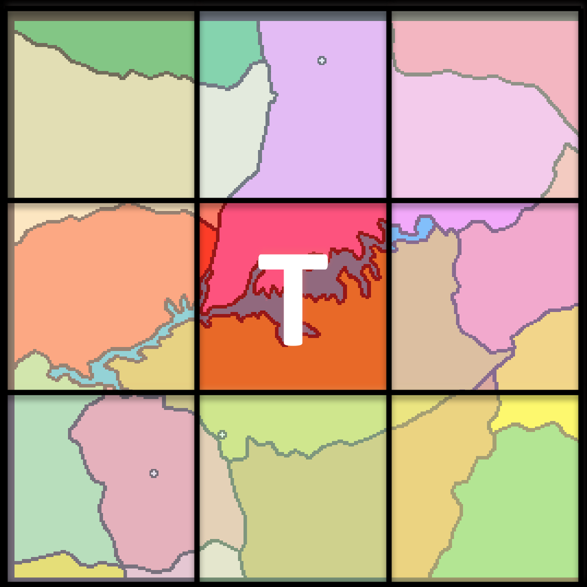
Example of Model Equation: Temperature



Once the atmosphere is “tiled”, there will be one temperature for each tile regardless how big this is.

The temperature for each tile will depend on that in the tile and the other tiles around it.

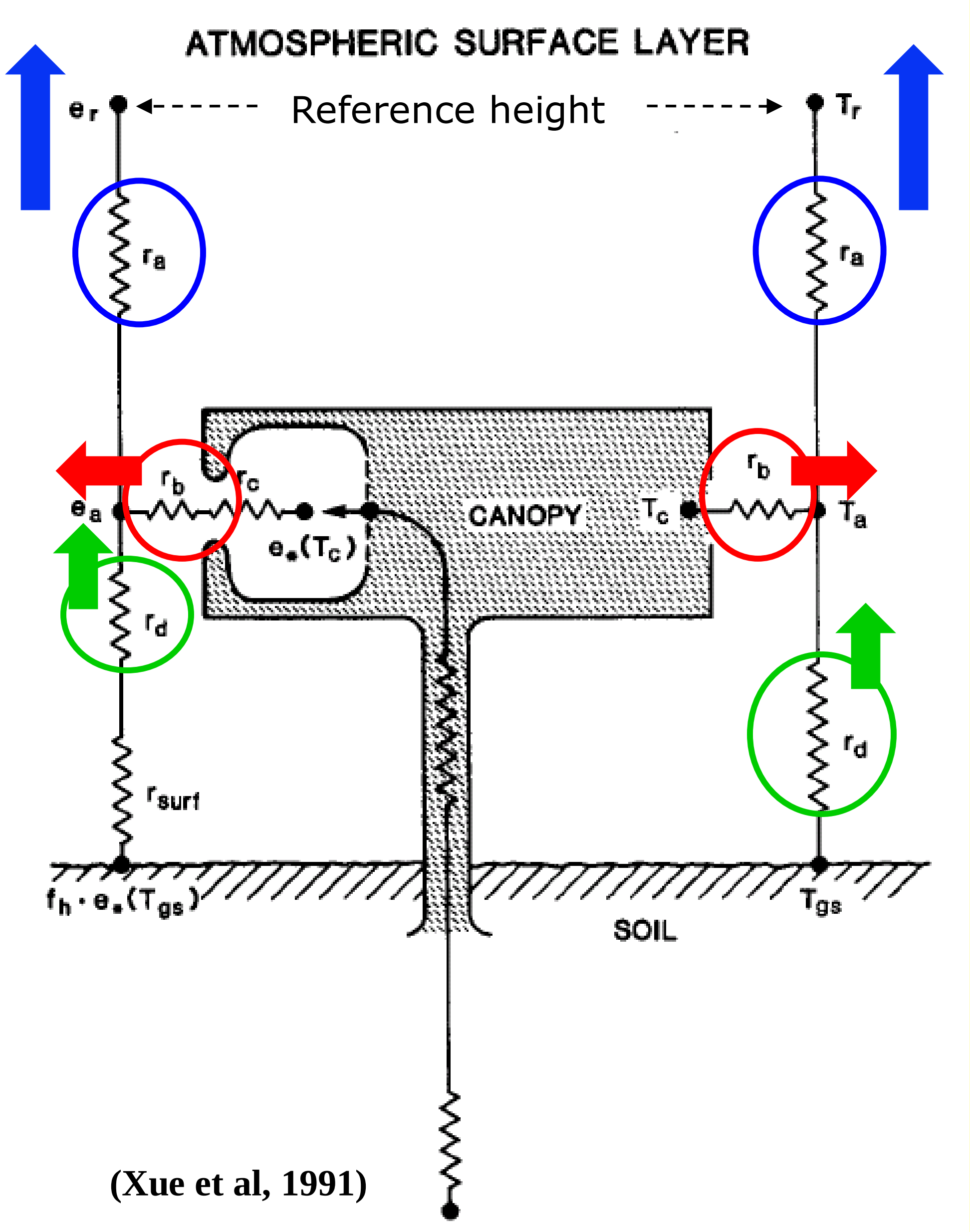
Example of Model Equation: Temperature



However, tiles may include many smaller (sub-grid) scale features such as clouds, terrain differences, etc.

The temperature of the tile (T) should also depend on these sub-grid scale features. How can one express such a dependence on the tile information *only*? This is the “parameterization” problem.

Example of parameterization: Heat (and other) fluxes from the surface to the atmosphere depend on vegetation

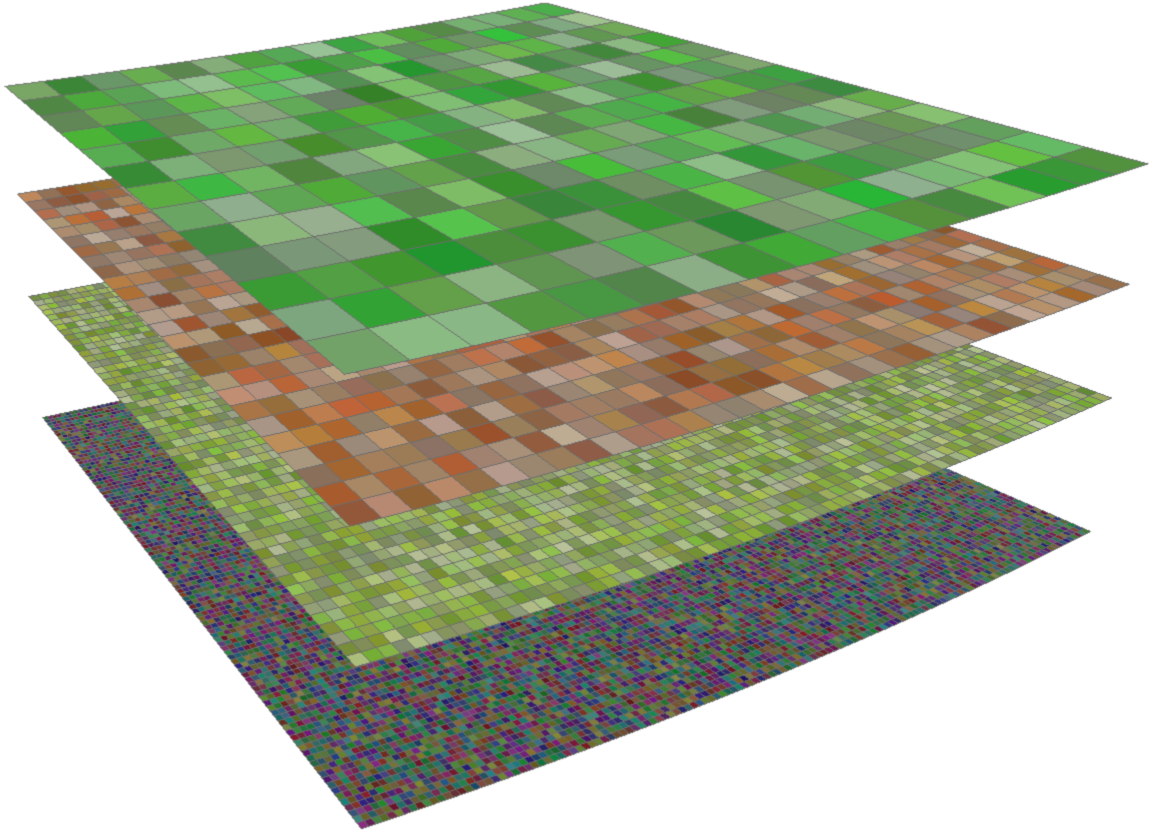


Three aerodynamic resistances:

- r_d → soil surface and canopy air space
- r_b → canopy leaves and canopy air space
- r_a → canopy air space and the reference height

The parameterization gives expressions to estimate the heat and water vapor fluxes indicated by the colored arrows from storage in the ground through the resistances.

Advances in computer power are allowing for smaller "tiles". This requires revisions of the parameterizations.



1°

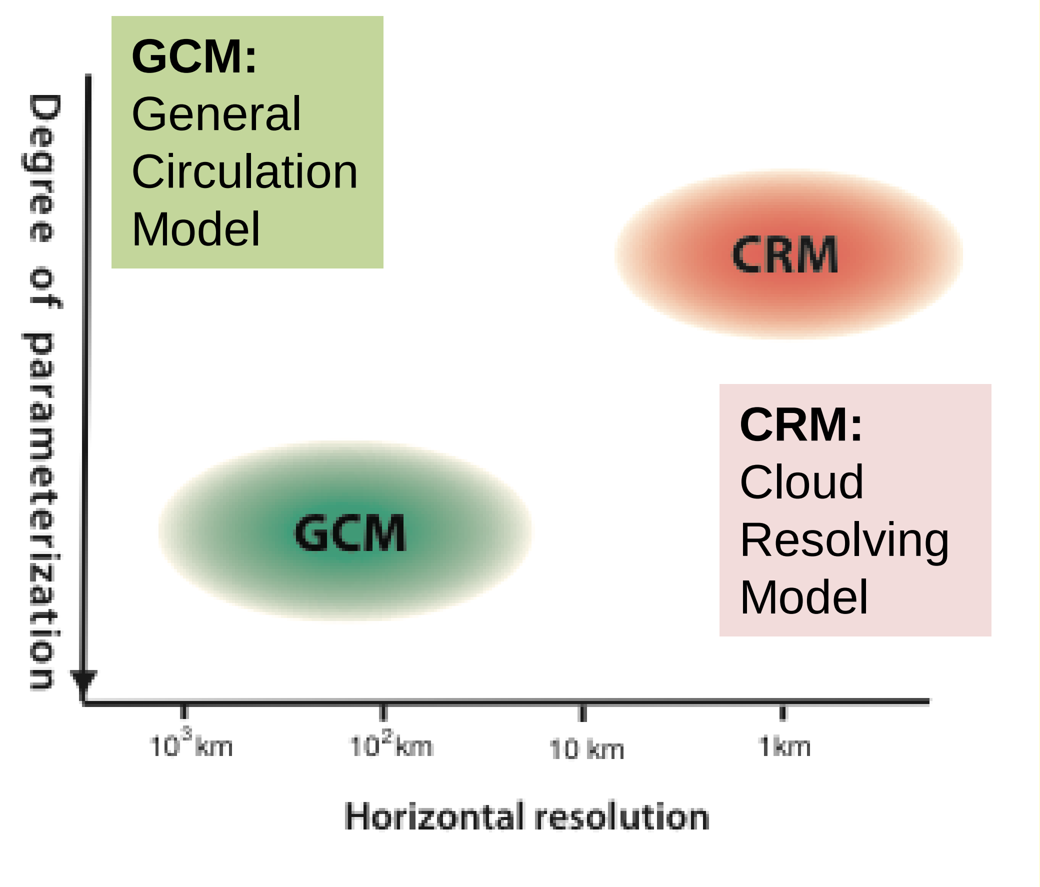
0.5°

0.25°

0.125°

Adapted from R. Leung (2013)

The degree of parameterization increases with the tile size

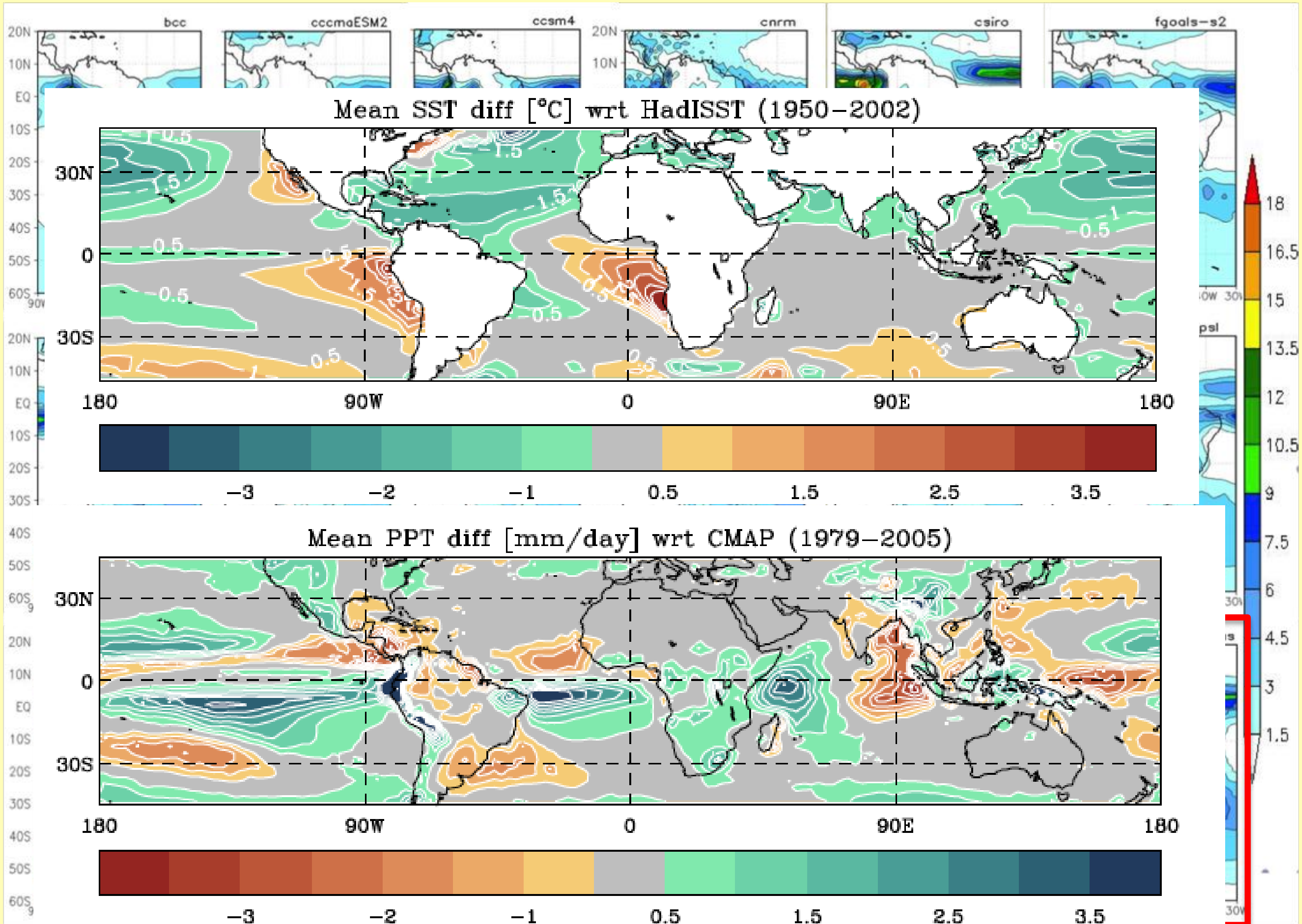


CRMs have a grid spacing low enough to explicitly simulate individual clouds, a domain large enough to contain cloud systems, and are able to run long enough to cover several cloud life cycles.

Challenges: A selection

- Poor simulation of the South American Monsoon System
- Systematic errors over the oceans
- Regional models may not solve problems despite increased resolution

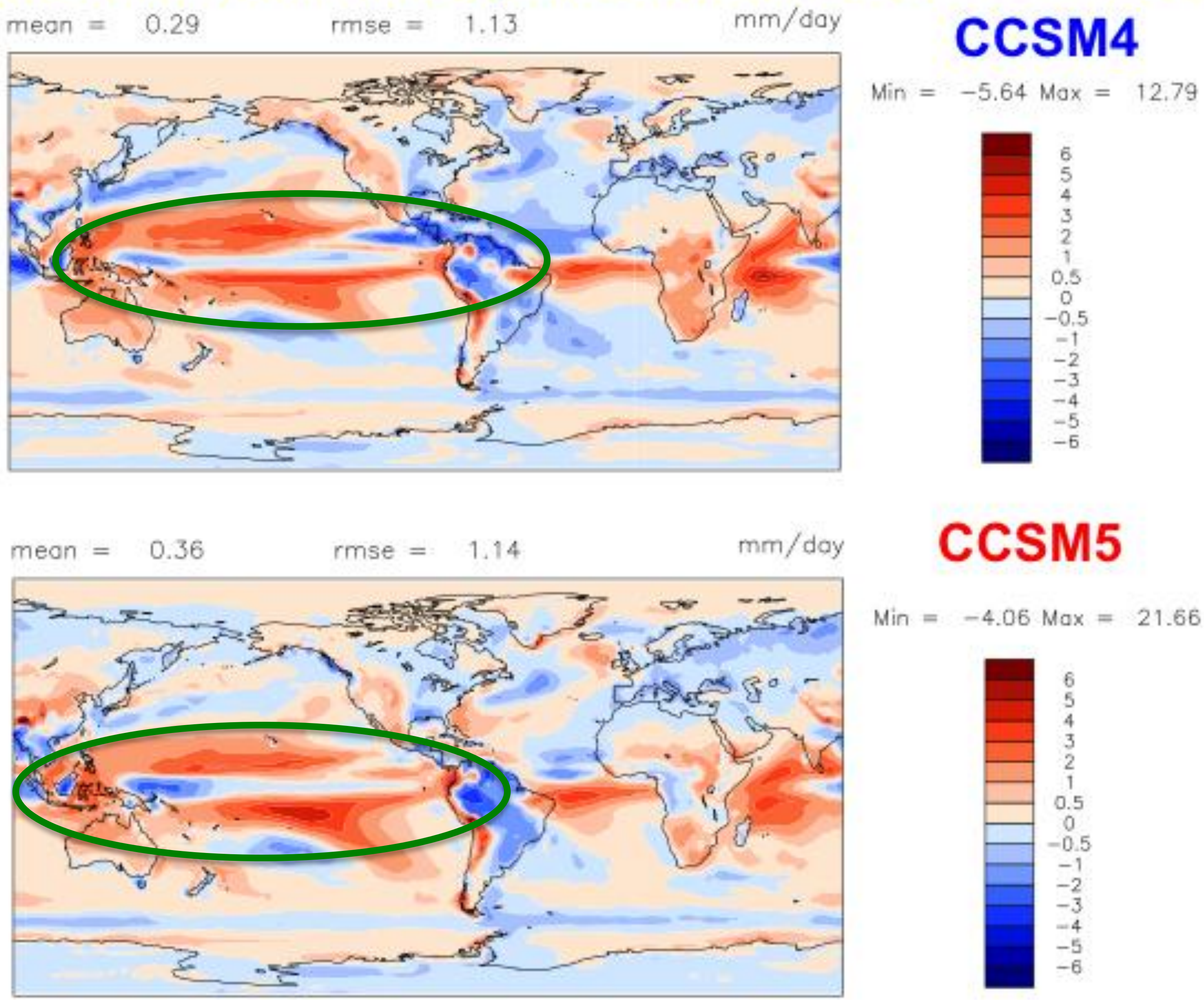
Poor simulation of the SAMS by CMIP5 models

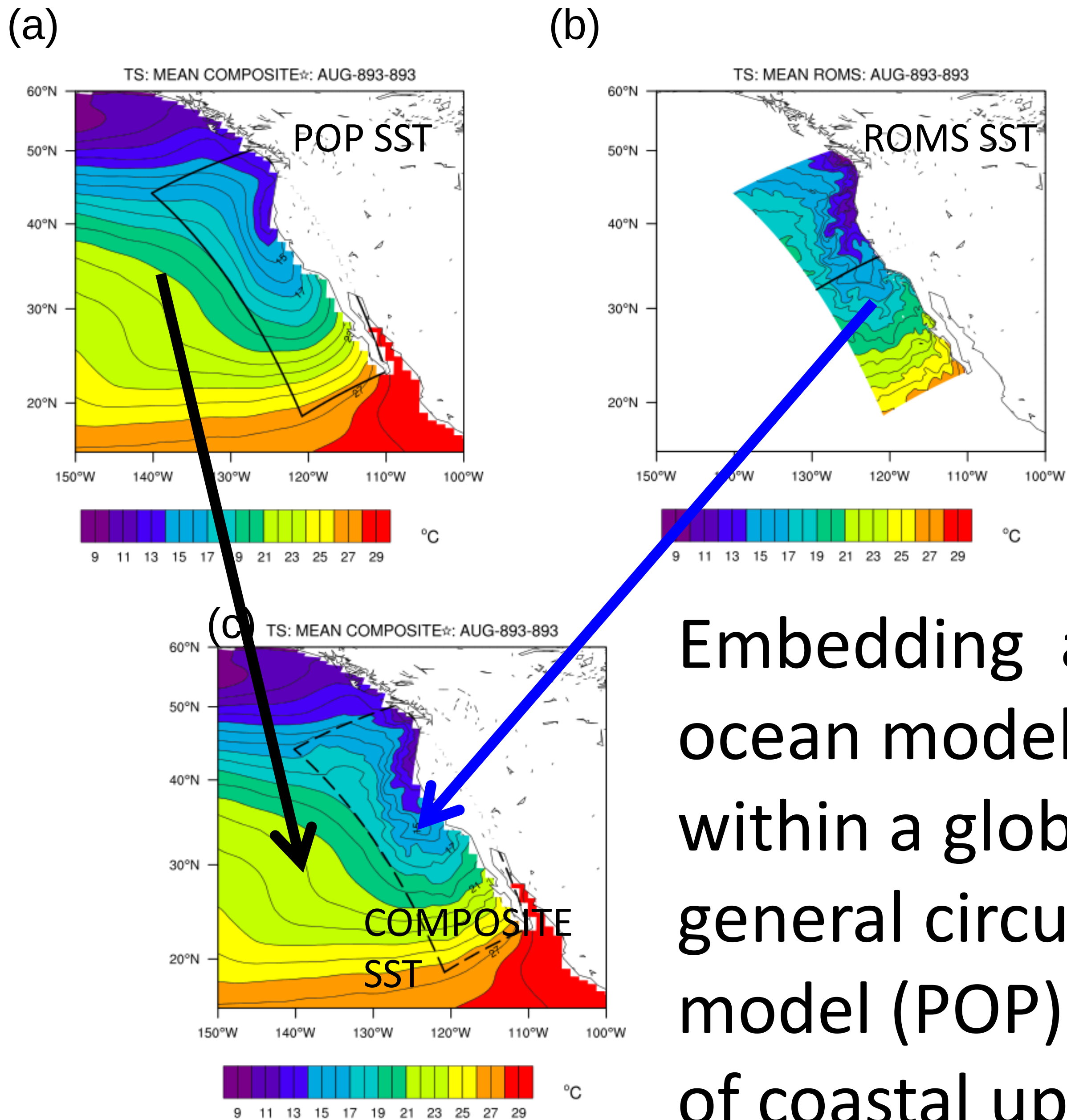


#228B

Courtesy T. Toniazzo

Annual Mean Precipitation Errors: Two ITCZs

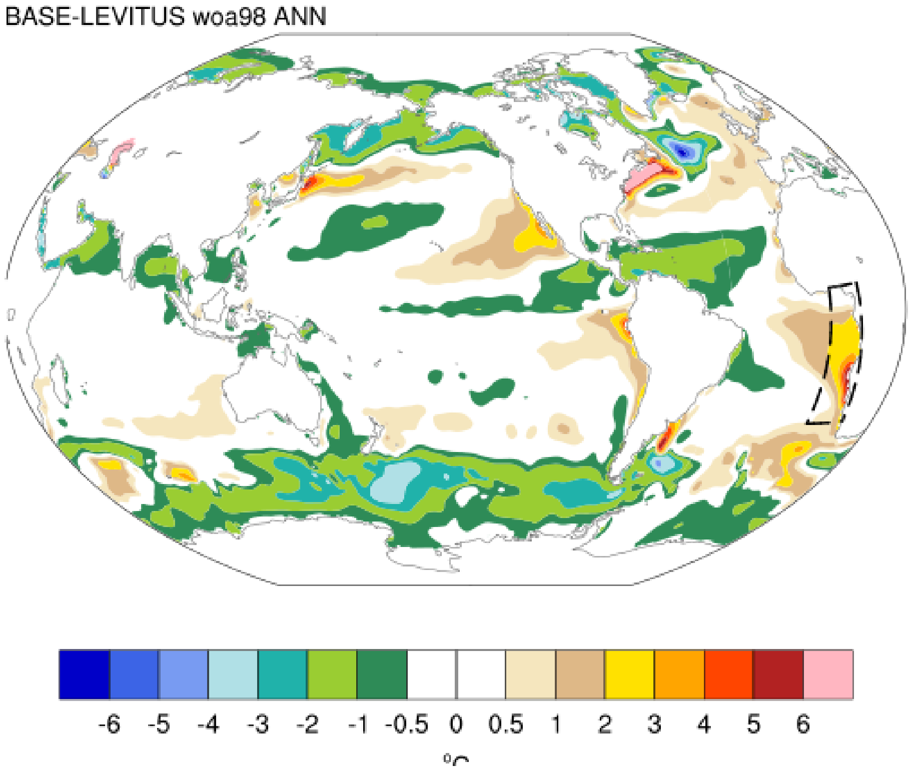


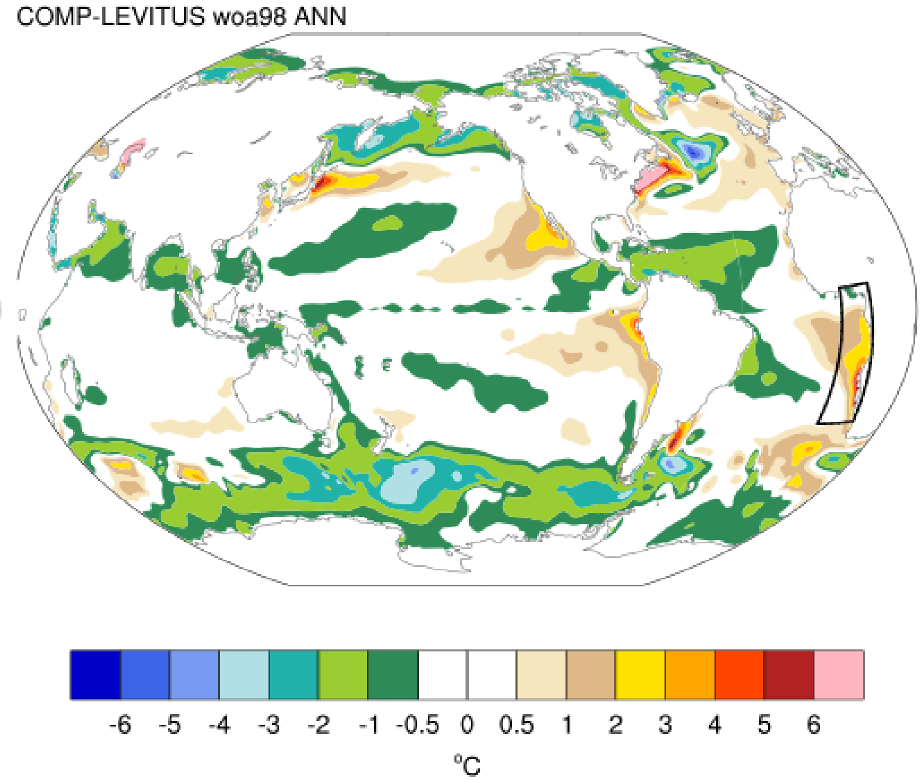


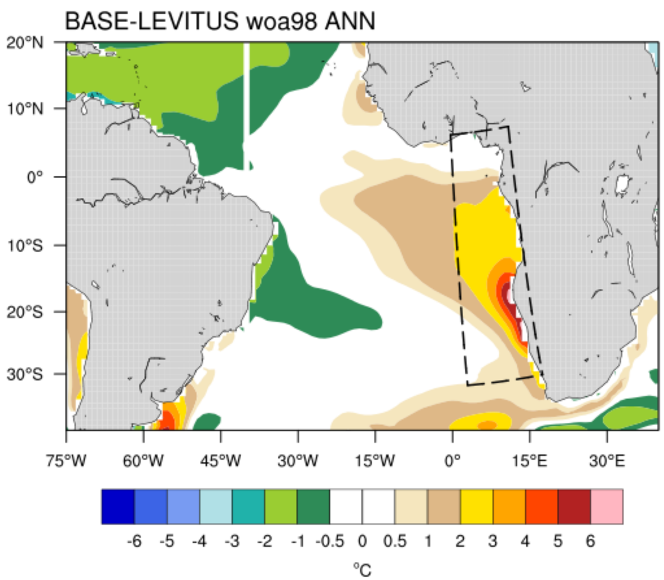
POP: 1^0
ROMS: 10 km

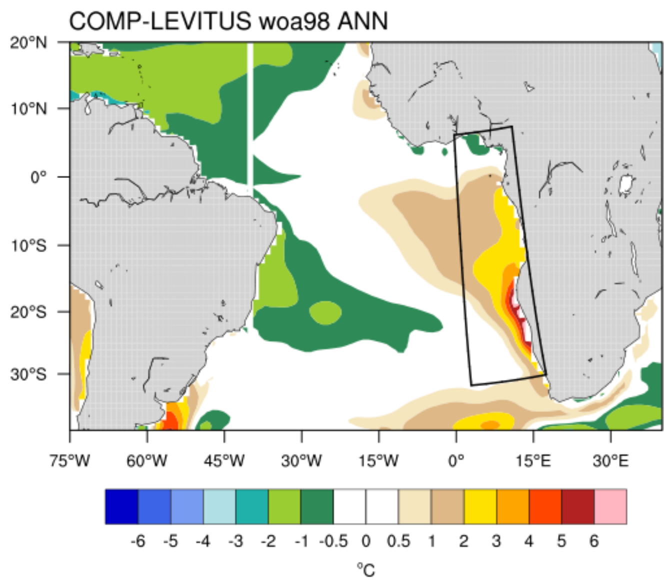
Embedding a regional ocean model (ROMS) within a global ocean general circulation model (POP) in regions of coastal upwelling.

J. Small, E. Curtchitser, B. Kauffman, B. Large, K. Hedstrom (2013)









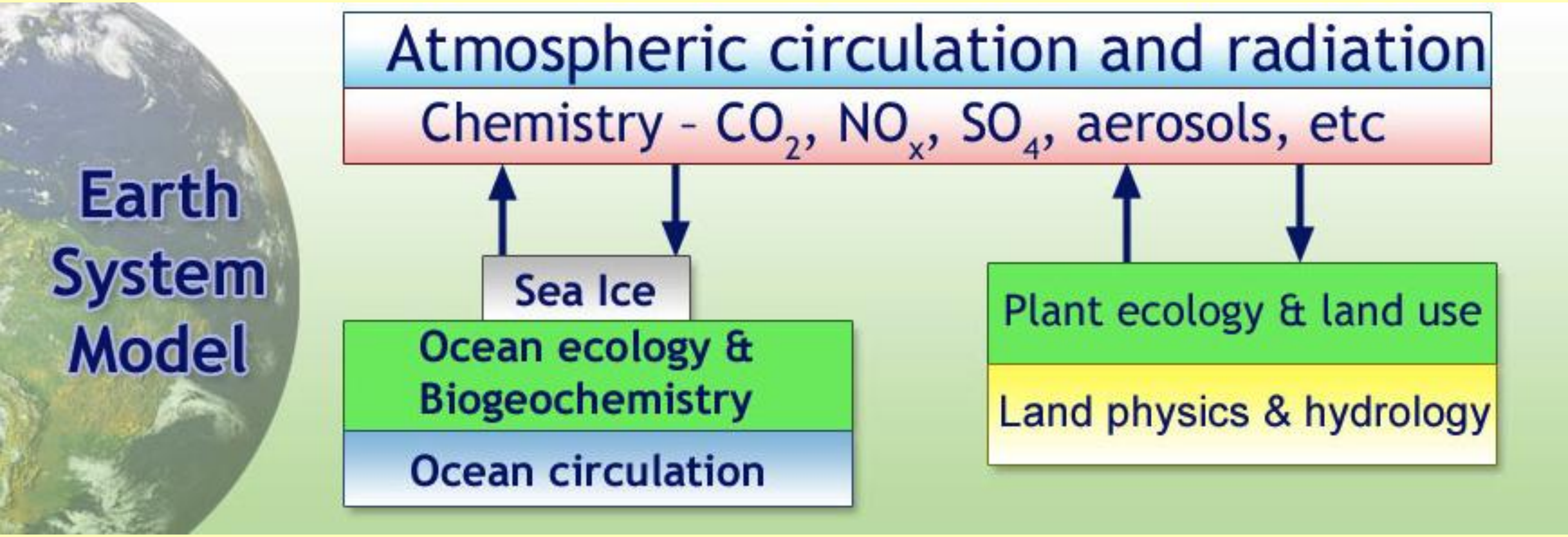
Annual mean SST errors in south-eastern Atlantic are just slightly reduced by nested model

CCSM4: 1^0; POP: 1^0; ROMS: 10 km

J. Small et al. (2013)

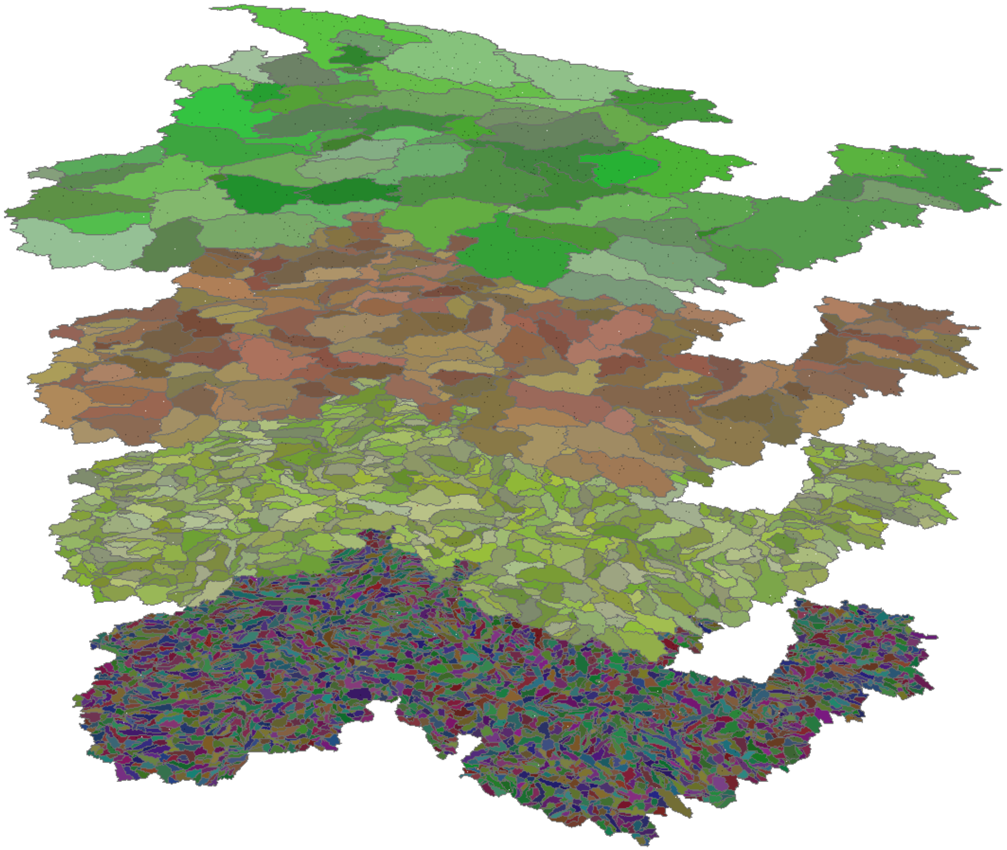
New Approaches

- Earth System Models
- Coupling climate and hydrology at the basin scales
- Global Cloud Resolving Models (CRMs)



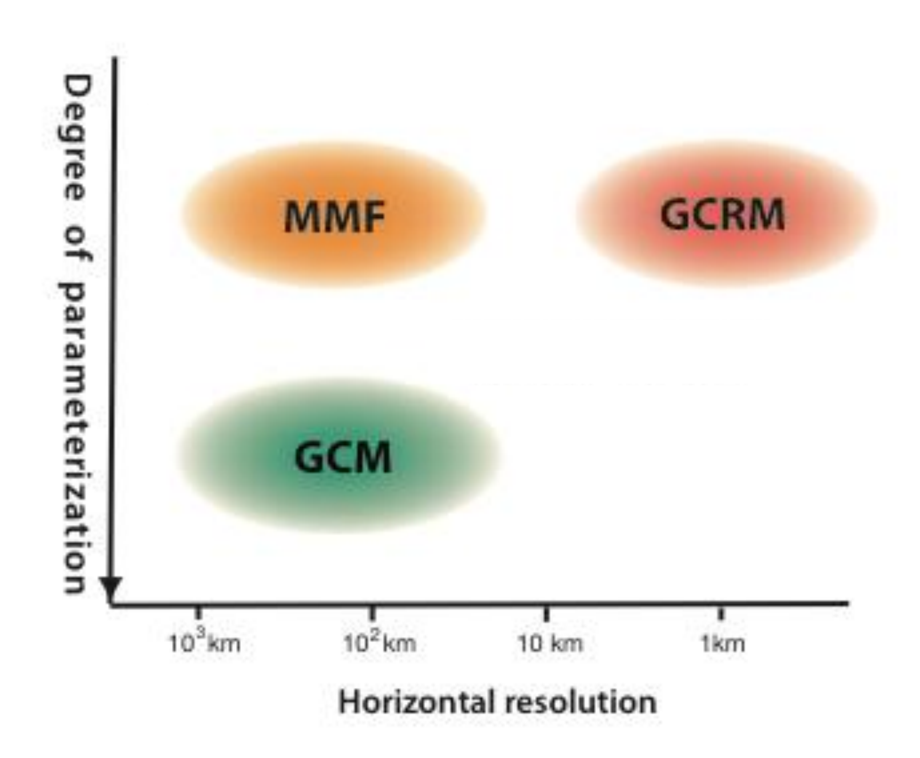
Earth System Models incorporate chemistry, biogeochemistry and plant ecology.

Hydrologic models are generally based on a subbasin tiling



Adapted from R. Leung (2013)

Multi-scale Modeling Framework (MMF)



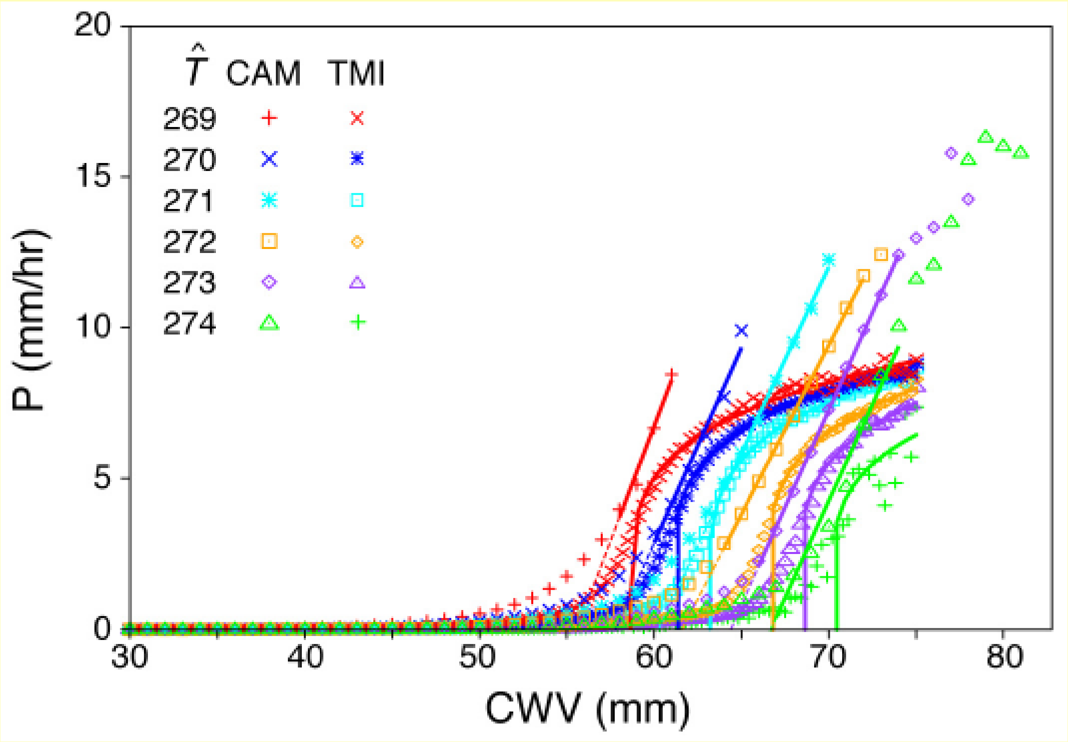
In the MMF, cumulus parameterization in conventional GCMs is replaced with the mean effects of cloud-scale processes simulated by a 2D CRM embedded in each GCM grid cell. Thus, the CRM physics is used while staying with the standard coarse resolution for the GCM.

Because of the recent advancement of computer technology, straightforward applications of 3D nonhydrostatic models with explicit cloud microphysics have begun to be feasible even for studying the global climate. When a sufficiently high horizontal resolution is used, these models become global CRMs (GCRMs)

A science agenda for LAC

- Improving prediction models by better process representation
- Researching climate-hydrology interactions in large river basins
- Examining regional climate change and climate change predictions

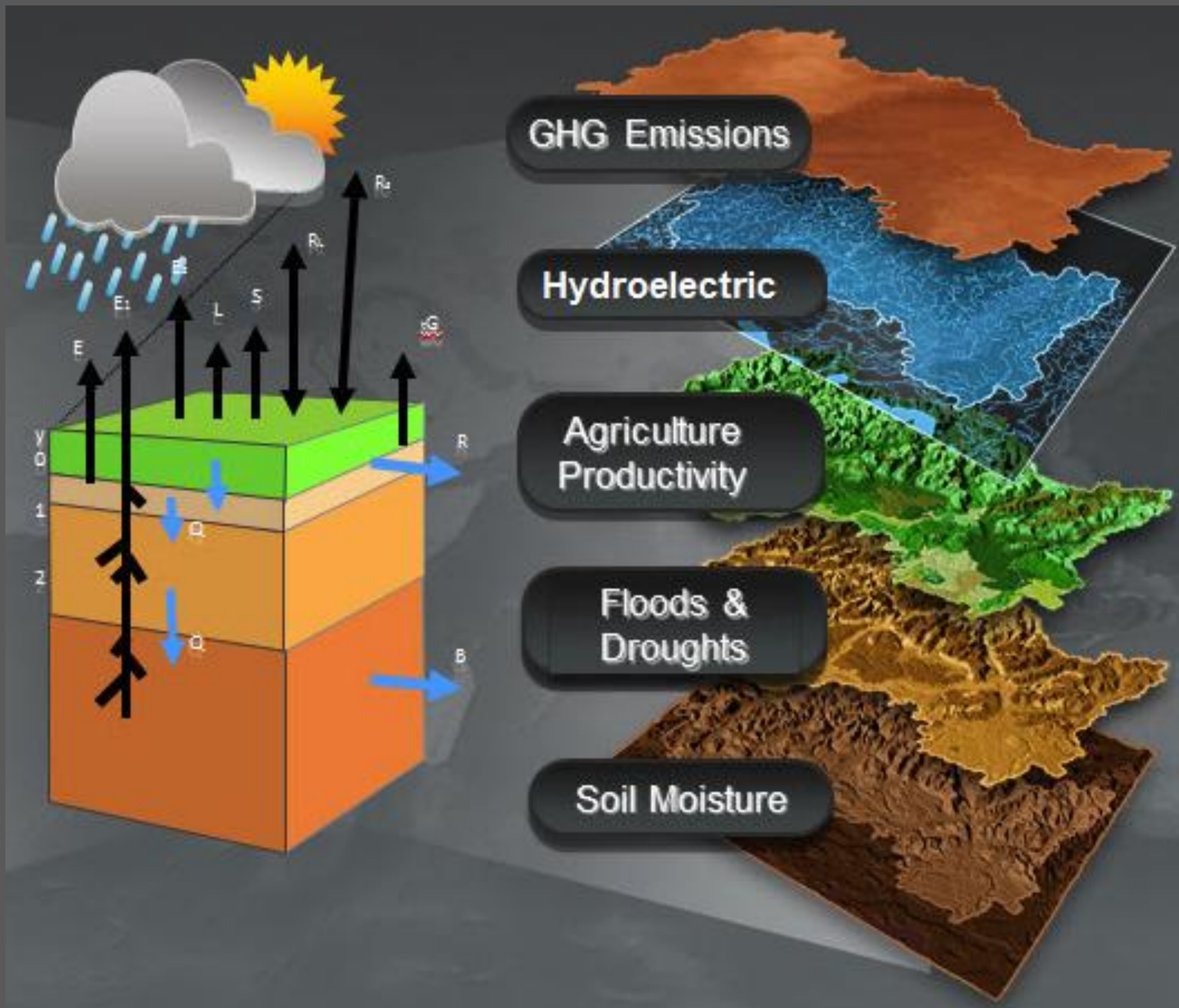
Effect of free-tropospheric humidity on deep convective onset



Precipitation binned according to mean tropospheric temperature *over the tropical eastern Pacific* shows a sharp increase beyond a threshold in column water vapor (CWV) in both observation and simulations. This is an example of constraints on parameterizations. Are there other such constraints?

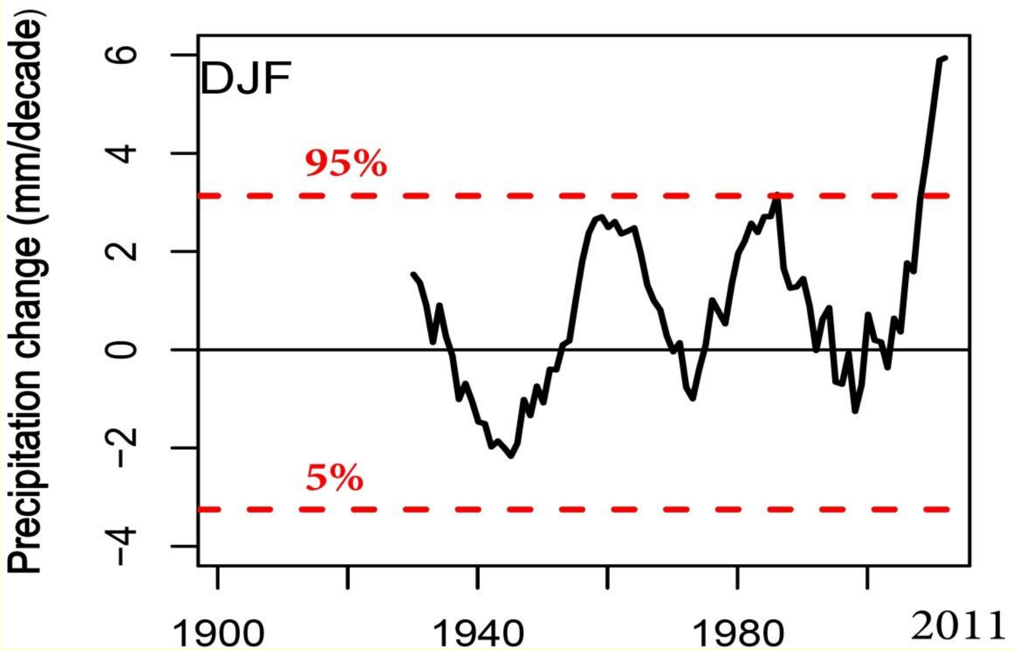
Sahany, S., J. D. Neelin, K. Hales and R. B. Neale, JAS 2012:

Hydrology in an ESM framework

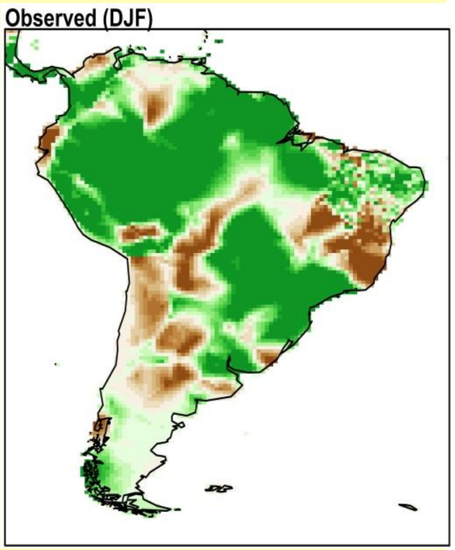


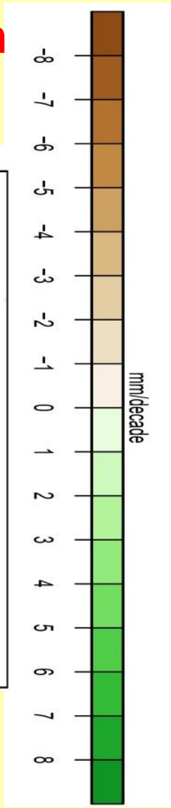
Observed summertime (DJF) precipitation trends in South America

Observed Moving 30-year Trends (1900-2011)



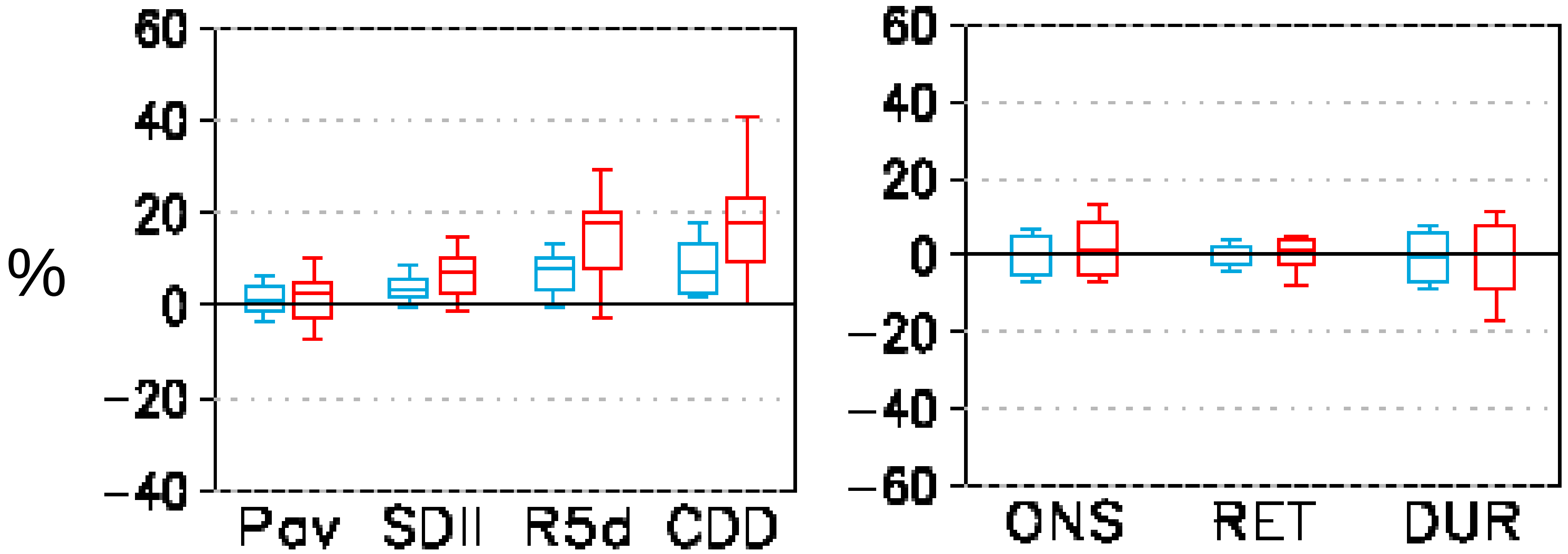
Observed trend pattern (1982-2011)





- Dashed horizontal lines: 5-95%-tile distribution of 300 unforced trends , derived from long control simulations, CMIP3.
- The trends become significant for 30-year trends ending in 2005 and later.
- The positive trends in precipitation ending in 2005 and later, cannot be explained by natural internal variability alone. Externally forced changes are detectable.

Future Projections SAMS in CMIP5 Models



Pav: Aver Precip
SDII: Daily Intensity Index
R5D: Max 5-day Precip Total
CDD: Max Consec Dry Days

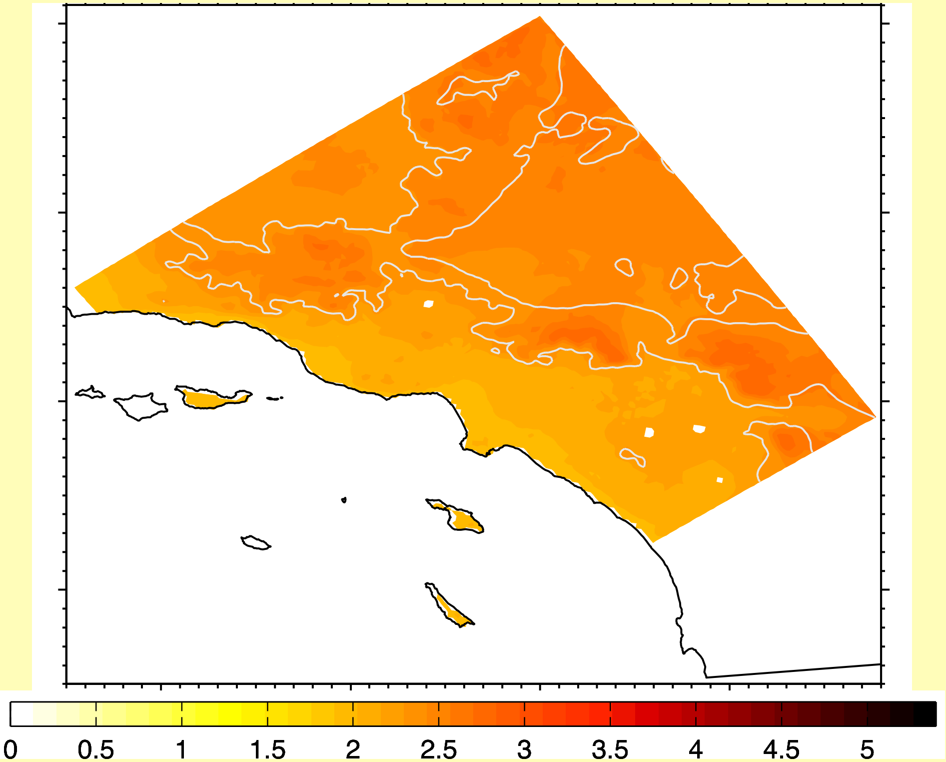
ONS: Onset Date
RET: Retreat Date
DUR: Duration

Adapted from Figs. 7 and 8 in Kitoh et al. (2013)

Blue: RCP 4.5
Red: RCP 8.5

"Climate Change in the Los Angeles Region"
Alex Hall, UCLA

- Used hybrid dynamical–statistical technique to downscale all CMIP5 GCMs to 2-km resolution, simulating baseline period of 1981–2100 and projecting climate for 2041–2060 and 2081–2100 under RCP8.5 and RCP 2.6
- Assessed changes in temperature, snowfall, precipitation, surface hydrology, Santa Ana winds, and fire*

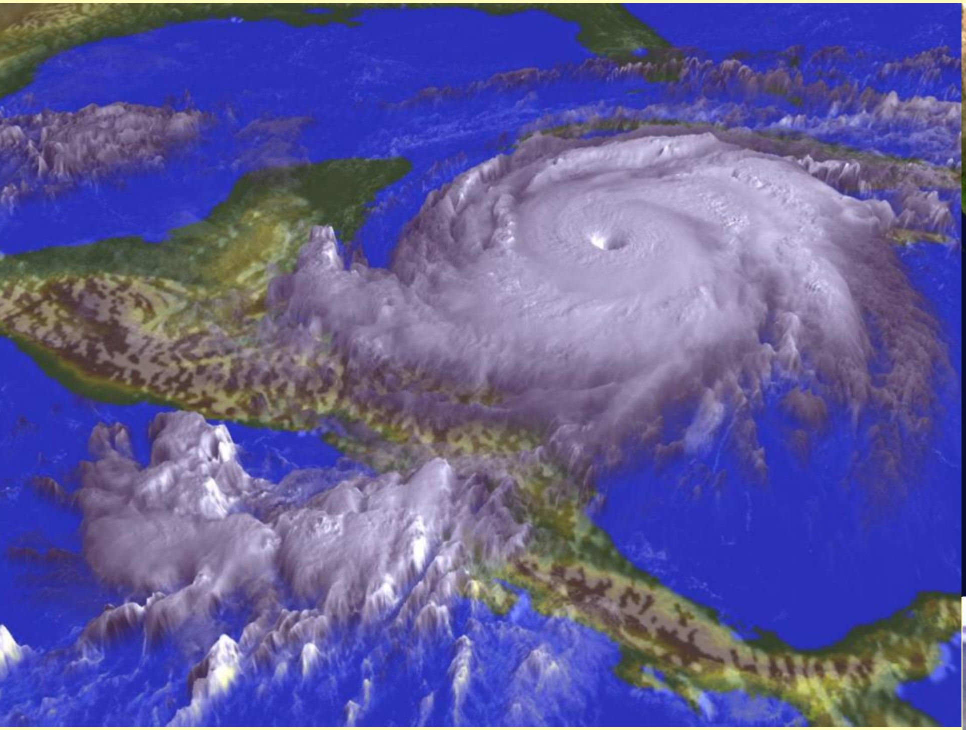


Ensemble-mean of statistically downscaled annual-mean surface warming (^{0}C) for mid-century (2041–2060) under RCP8.5. White contours are plotted at 1000m elevation.

Sun FP, DB Walton, A Hall, 2014: A Hybrid Dynamical-Statistical Downscaling Technique, Part II: End-of-Century Warming Projections Predict a New Climate State in the Los Angeles Region, submitted to *J. Clim.*

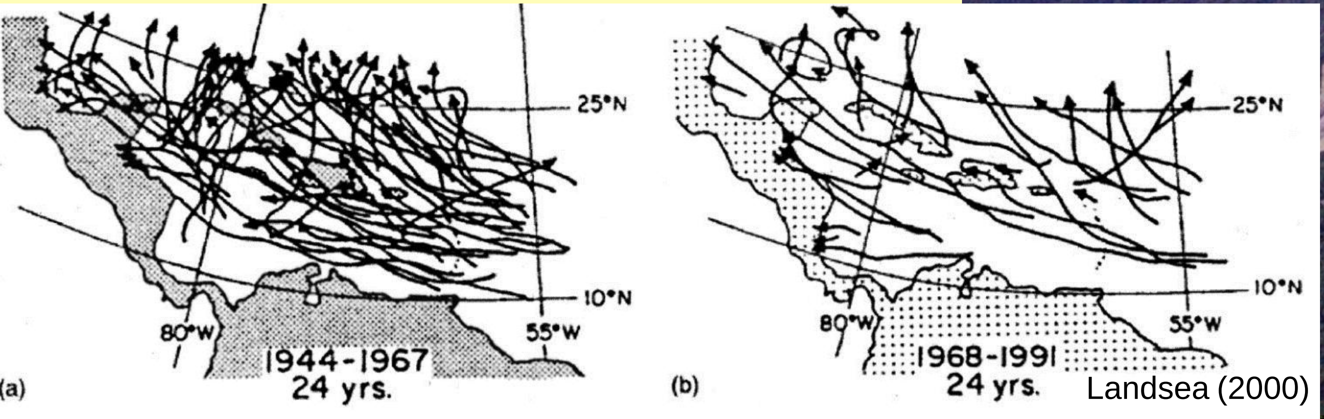
*In collaboration with UC Irvine

Huracán Mitch (1998)

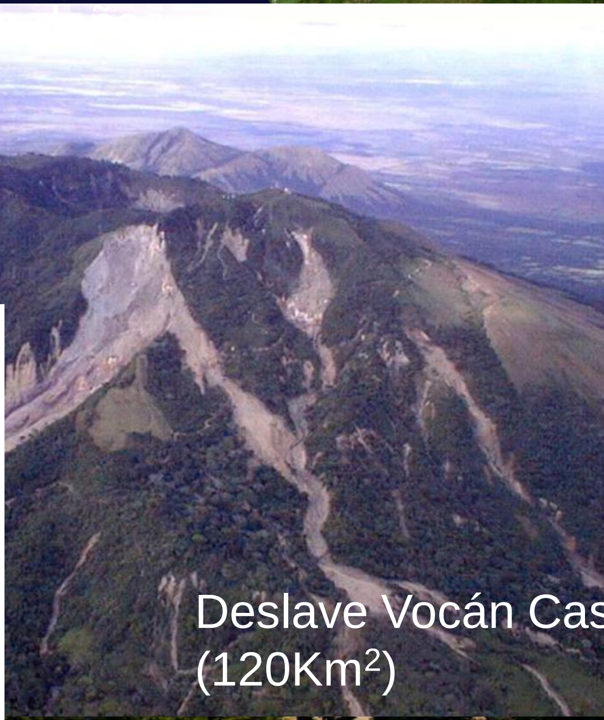


- Movimiento lento sobre Honduras y Nicaragua
- 10,000 muertos

Variabilidad inderdecadal



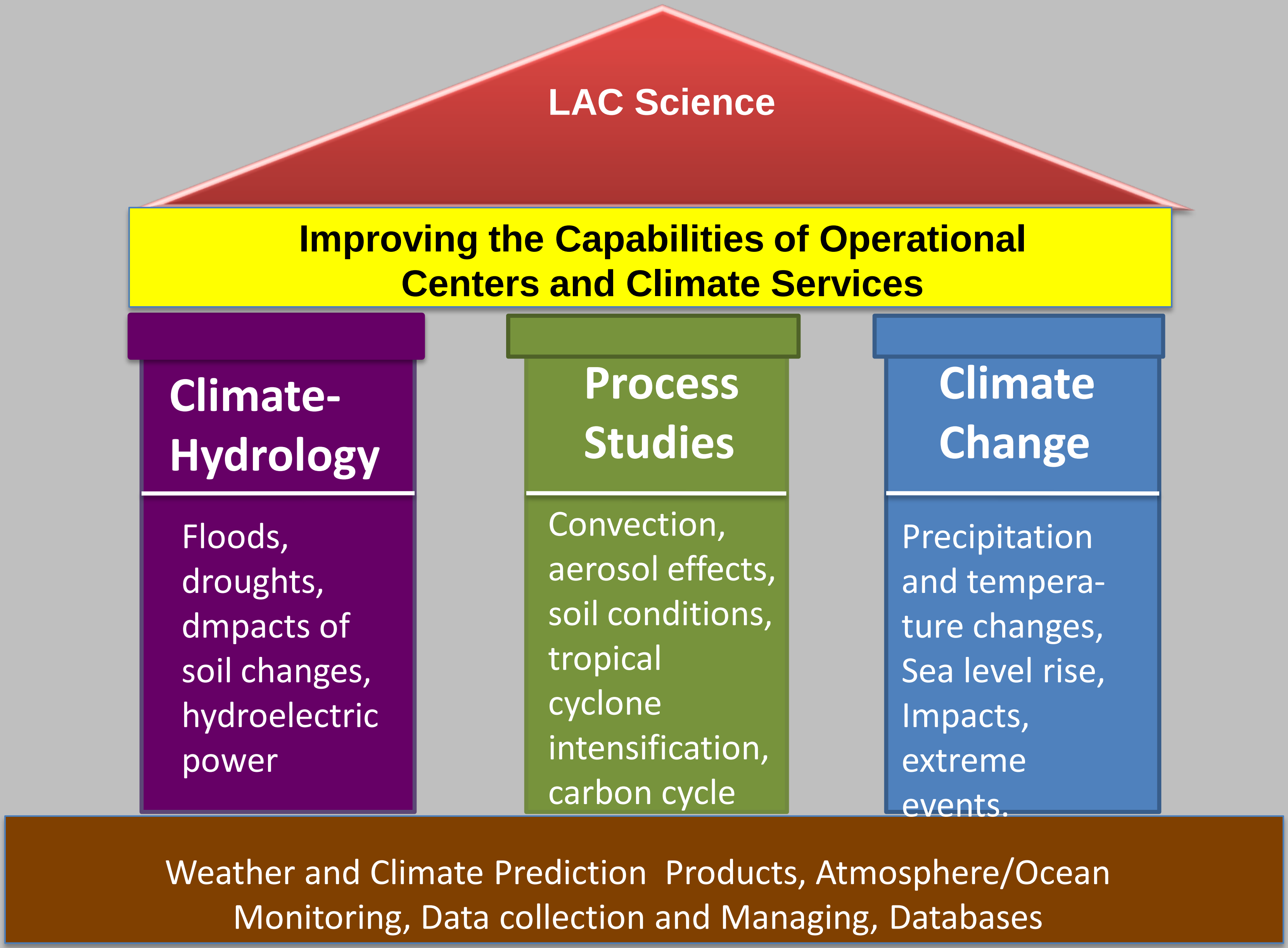
Landsea (2000)

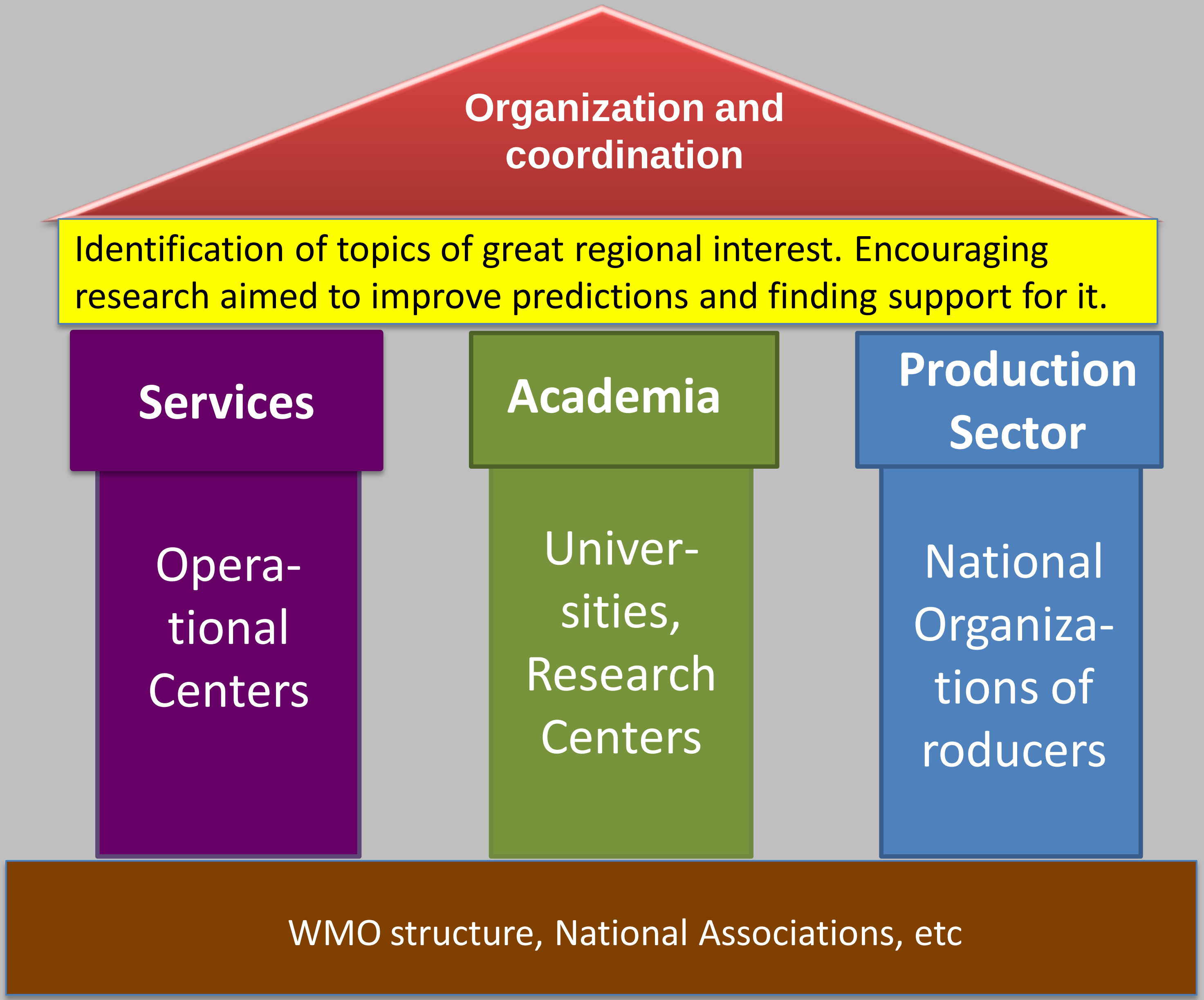


Deslave Vocán Cas
(120Km^2)

A research framework for LAC

- Improving the Capabilities of Operational Centers and Climate Services
- Establishing a coordinating structure for multi-national projects


LAC Science
Improving the Capabilities of Operational Centers and Climate Services
Climate-Hydrology
Floods, droughts, dmpacts of soil changes, hydroelectric power
Process Studies
Convection, aerosol effects, soil conditions, tropical cyclone intensification, carbon cycle
Climate Change
Precipitation and tempera-ture changes, Sea level rise, Impacts, extreme events.
Weather and Climate Prediction Products, Atmosphere/Ocean Monitoring, Data collection and Managing, Databases


Organization and coordination
Identification of topics of great regional interest. Encouraging research aimed to improve predictions and finding support for it.
Services
Opera-tional Centers
Academia
Univer-sities, Research Centers
Production Sector
National Organiza-tions of roducers
WMO structure, National Associations, etc

Highlights (1)

- **The LAC covers a wide range of latitudes and several climate regimes.**
- **This means that LAC is rich on key physical processes, from deep convection and microphysics in Amazonia and Plata Basin, to factors influencing the deepening of tropical cyclones in the Caribbean.**
- **There are many opportunities for research on the parameterization of such processes in climate models.**
- **There are also several large rivers, and hydrology-climate interactions should be very active in the region.**

Highlights (2)

- The regional climate is affected by remote variability (ENSO, MJO, etc). This make the region an ideal testbed for assessing successes and limitations of regional models in which forcing is prescribed.
- A significant impact of climate change is expected, and might be already visible in the region. Assessing climate change in sub-regions would be of great interest to policymakers.

FOR DISCUSSION

- **The richness of research possibilities in LAC means that a coordinating body will accelerate science by bringing together the different participants in a broad international framework.**

Future Projections SAMS in CMIP5 Models

- Small precipitation increases for SAMS core region in CMIP3 and CMIP5 models
  - Most related to intensification of heavy rainfall, rather than increases in duration or frequency of consecutive wet days (Skansi et al. 2013)
- Median of 5-day seasonal maximum in precipitation increases by 17.8% by 2100 in RCP8.5 (Kitoh et al. 2013)
- Median number consecutive dry days increases by 30% by 2100 in RCP8.5 (Kitoh et al. 2013)
- Inconsistent results regarding changes associated with monsoon length (Jones and Carvalho 2013; Kitoh et al. 2013)