Climate Variability and Change in Central America

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CICESE

The Abdus Salam International Centre for Theoretical Physics (ICTP)

The Science of Climate Change: a focus on Central America and the Caribbean Islands

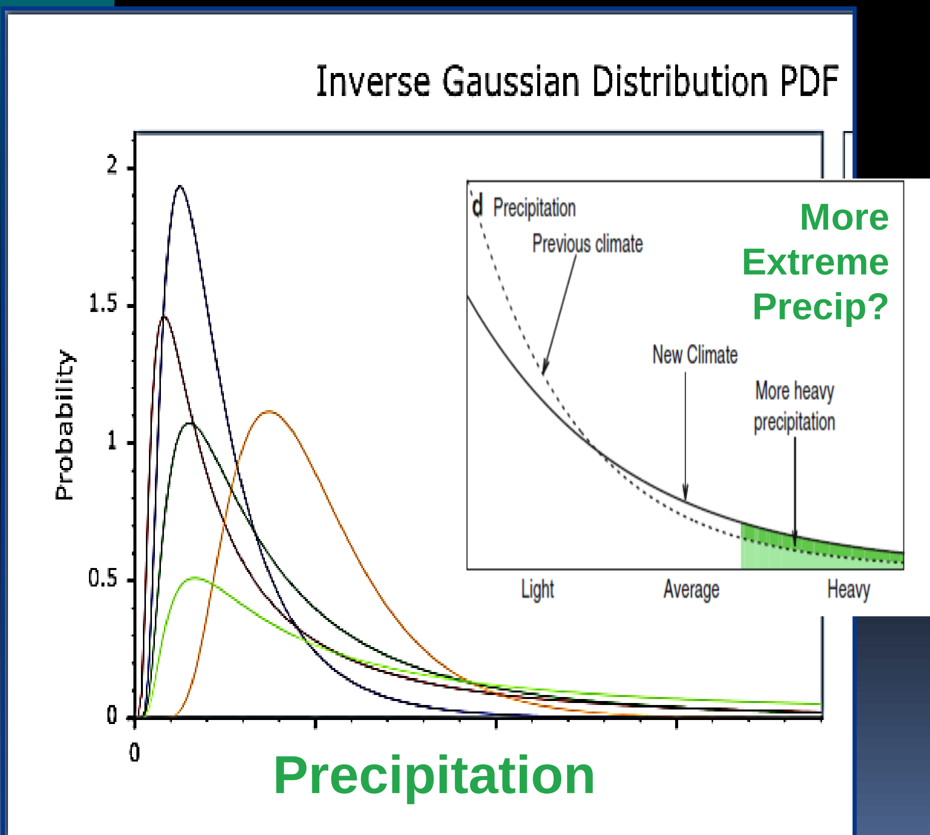
Antigua, Guatemala, 14-16 de marzo de 2017

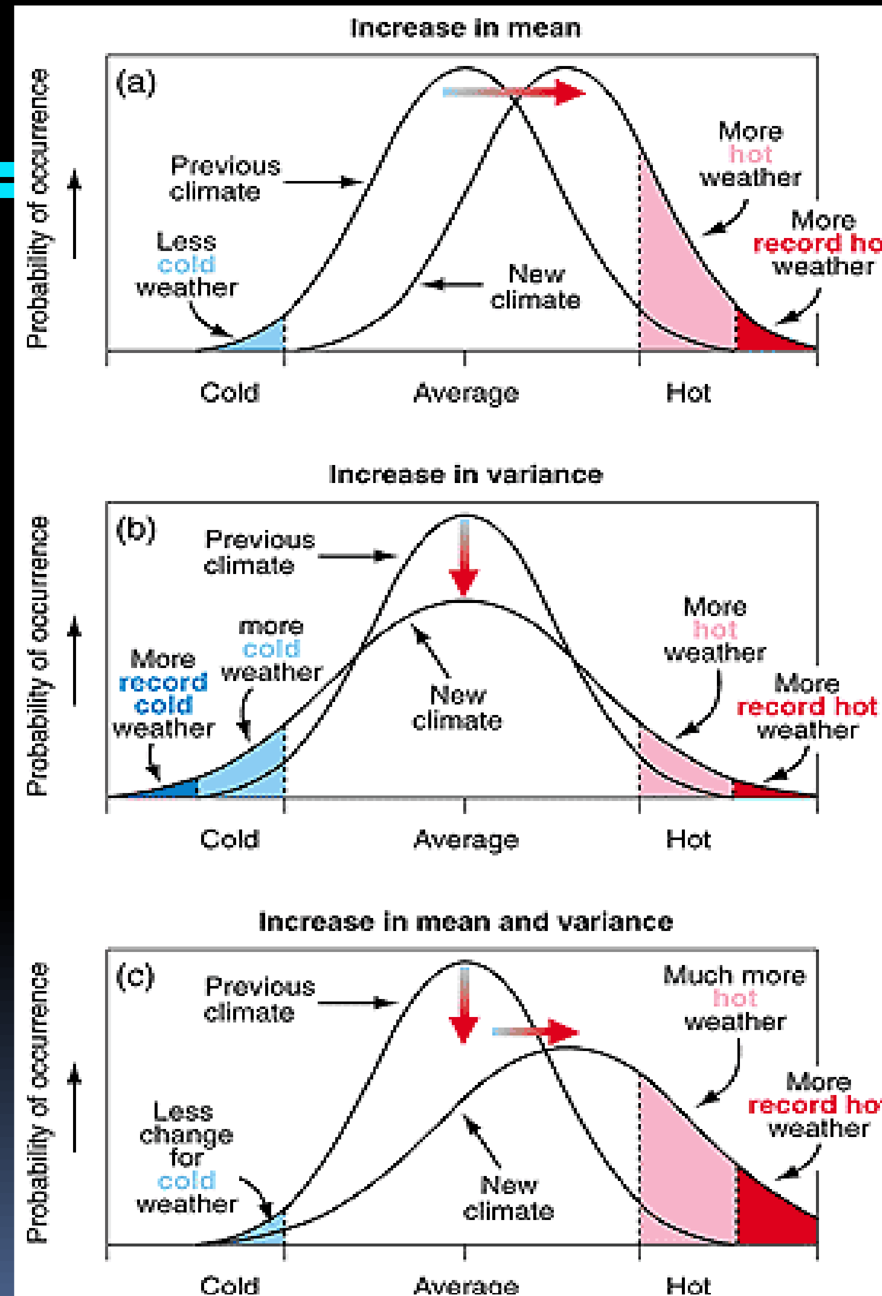
CONTENT

1. Observed Variability and Trends
2. General Circulation Models
3. Regional Climate Downscaling
4. Climate Change Scenarios
5. Regional Strategic Actions

CONTENT

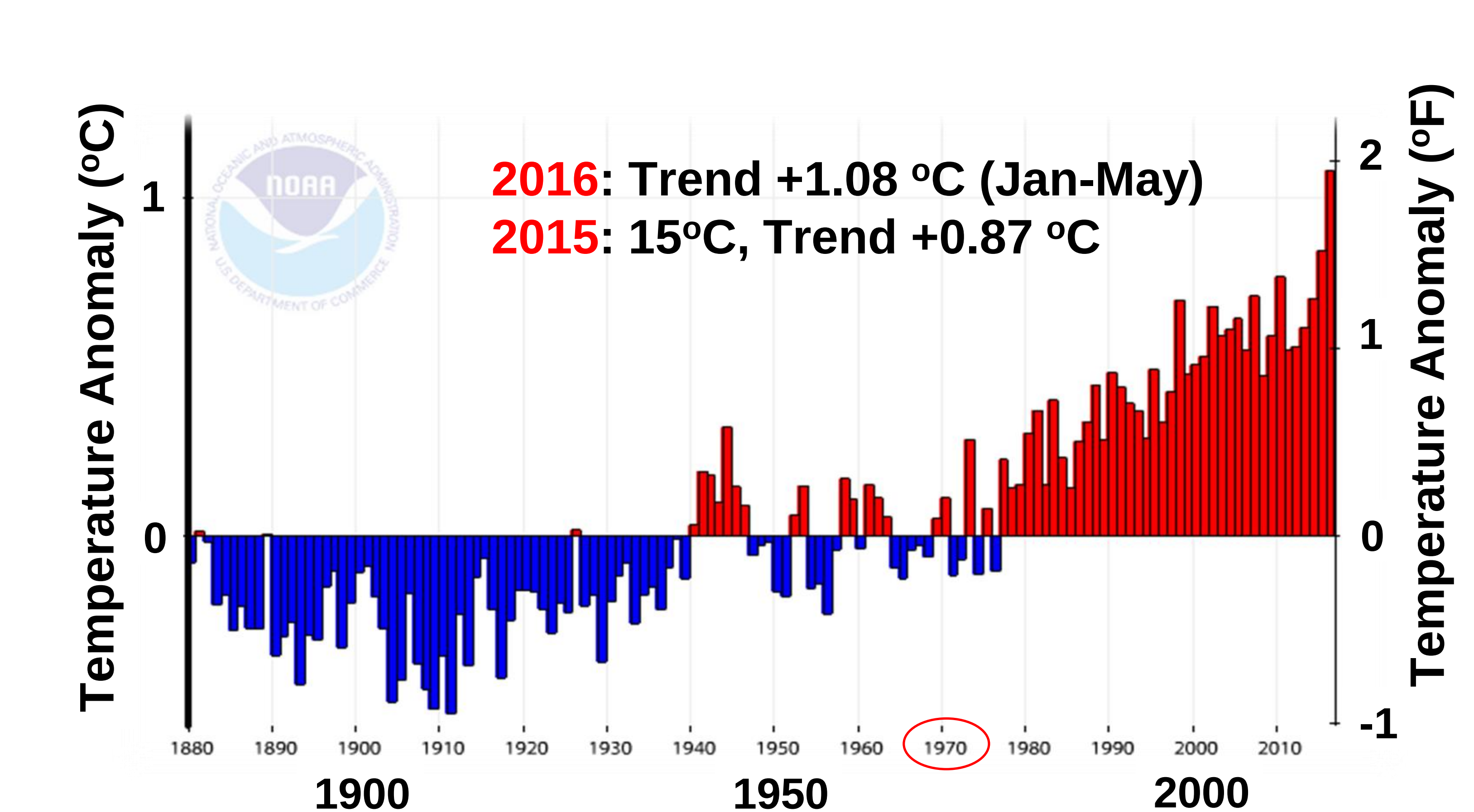
1. Observed Variability and Trends





Earth and Ocean Global Temperature Anomaly

Tmean = 14°C between 1951-1980



https://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/5/1880-2016

Jan–Dec Land & Ocean Temperature Trends

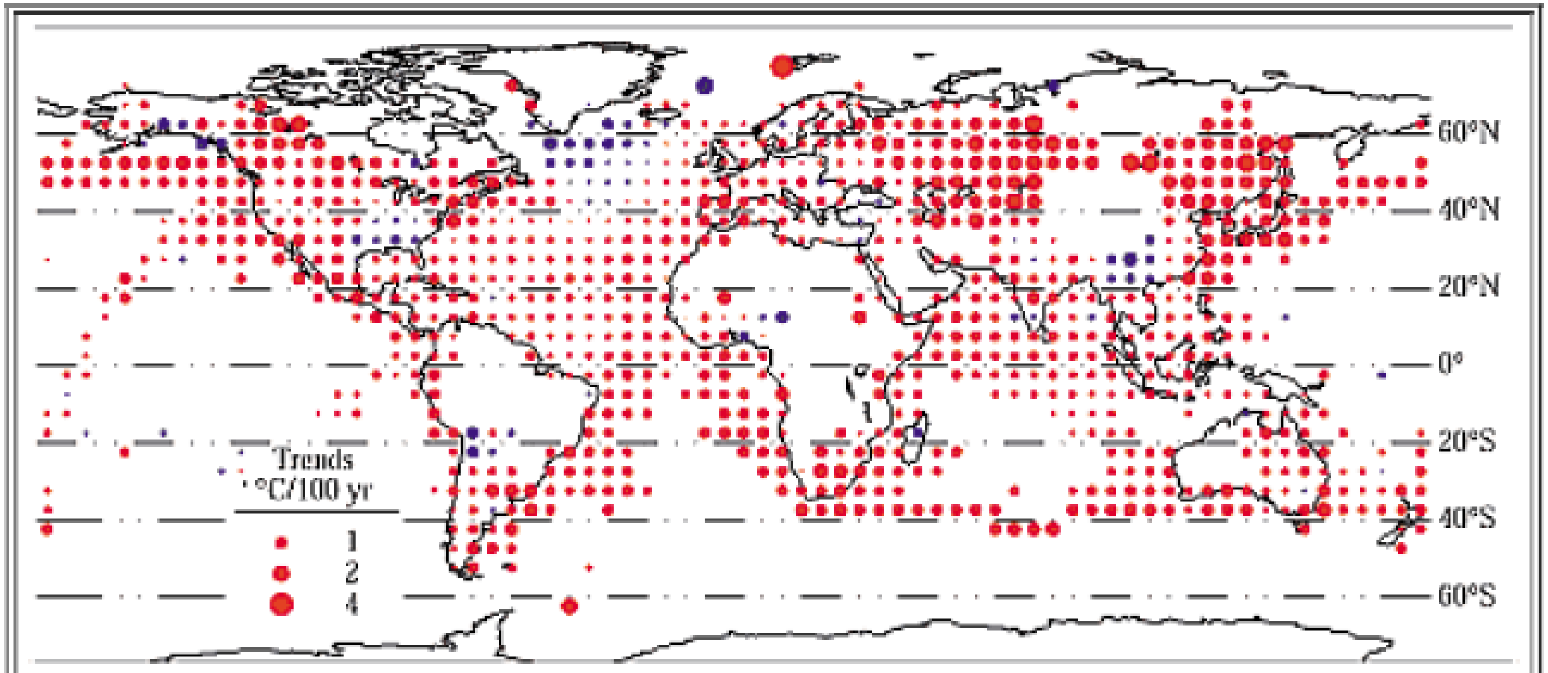


Figure A-2: Temperature-Annual 1901-1996.

http://www.ipcc.ch/ipccreports/sres/regional/305.htm#figureA-2

The Regional Impacts of Climate Change

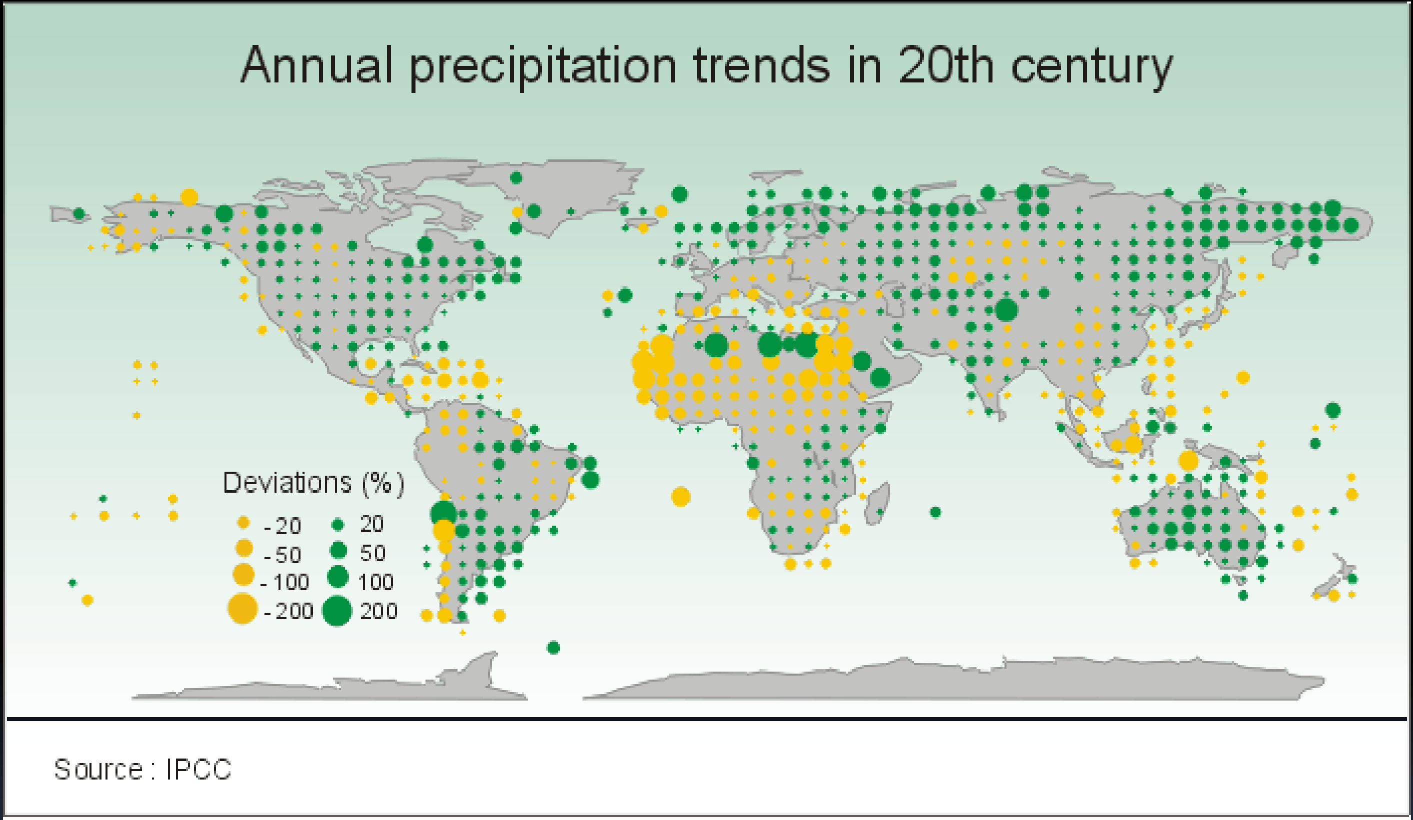
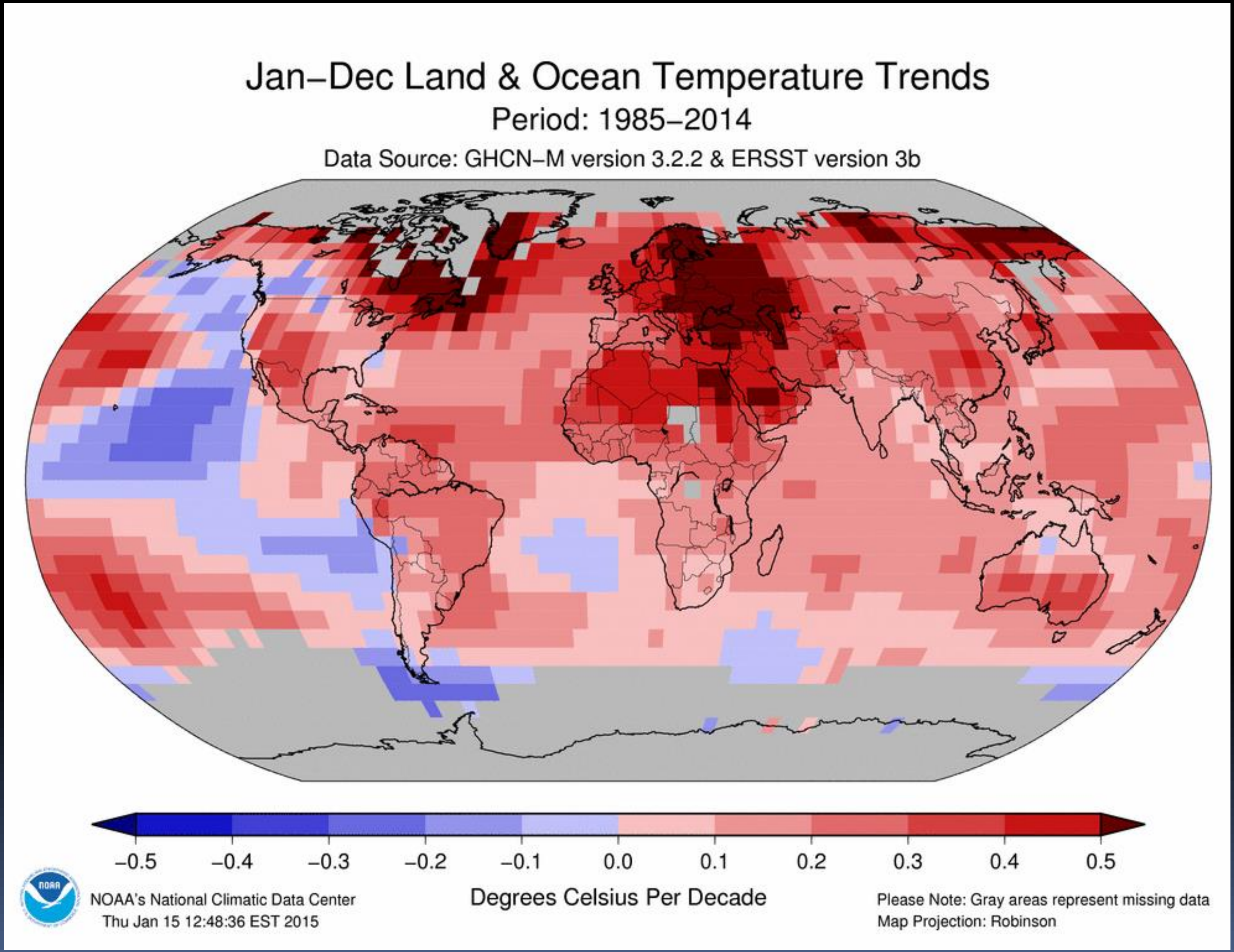
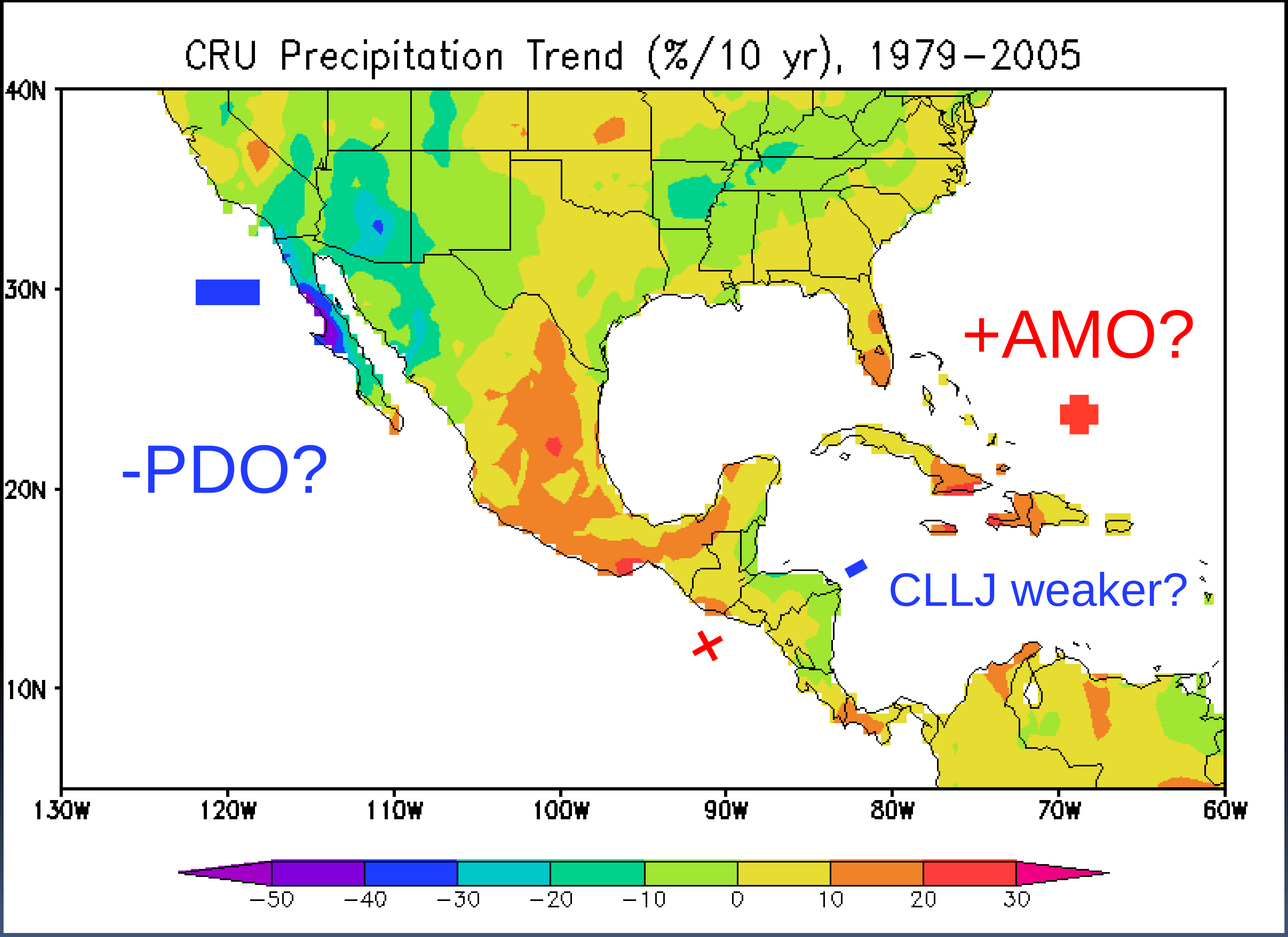


Figure A-1: Precipitation-Annual 1901-1995.

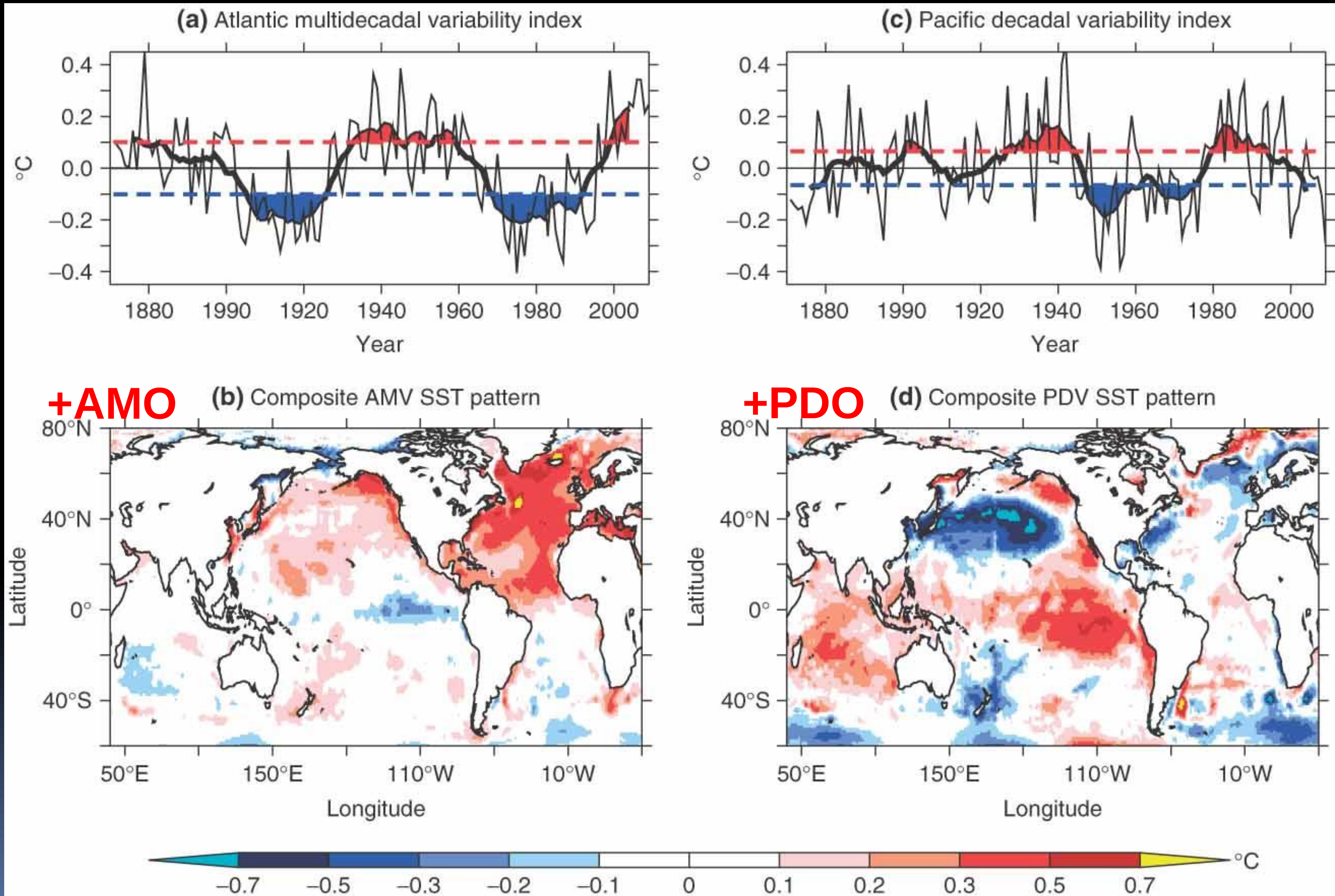
http://www.ipcc.ch/ipccreports/sres/regional/305.htm#figureA-2


Jan–Dec Land & Ocean Temperature Trends
Period: 1985–2014
Data Source: GHCN–M version 3.2.2 & ERSST version 3b
−0.5 −0.4 −0.3 −0.2 −0.1 0.0 0.1 0.2 0.3 0.4 0.5
Degrees Celsius Per Decade
NOAA's National Climatic Data Center
Thu Jan 15 12:48:36 EST 2015
Please Note: Gray areas represent missing data
Map Projection: Robinson



Cavazos 2017

Decadal Patterns of the Atlantic and Pacific



Zwiers et al. 2013

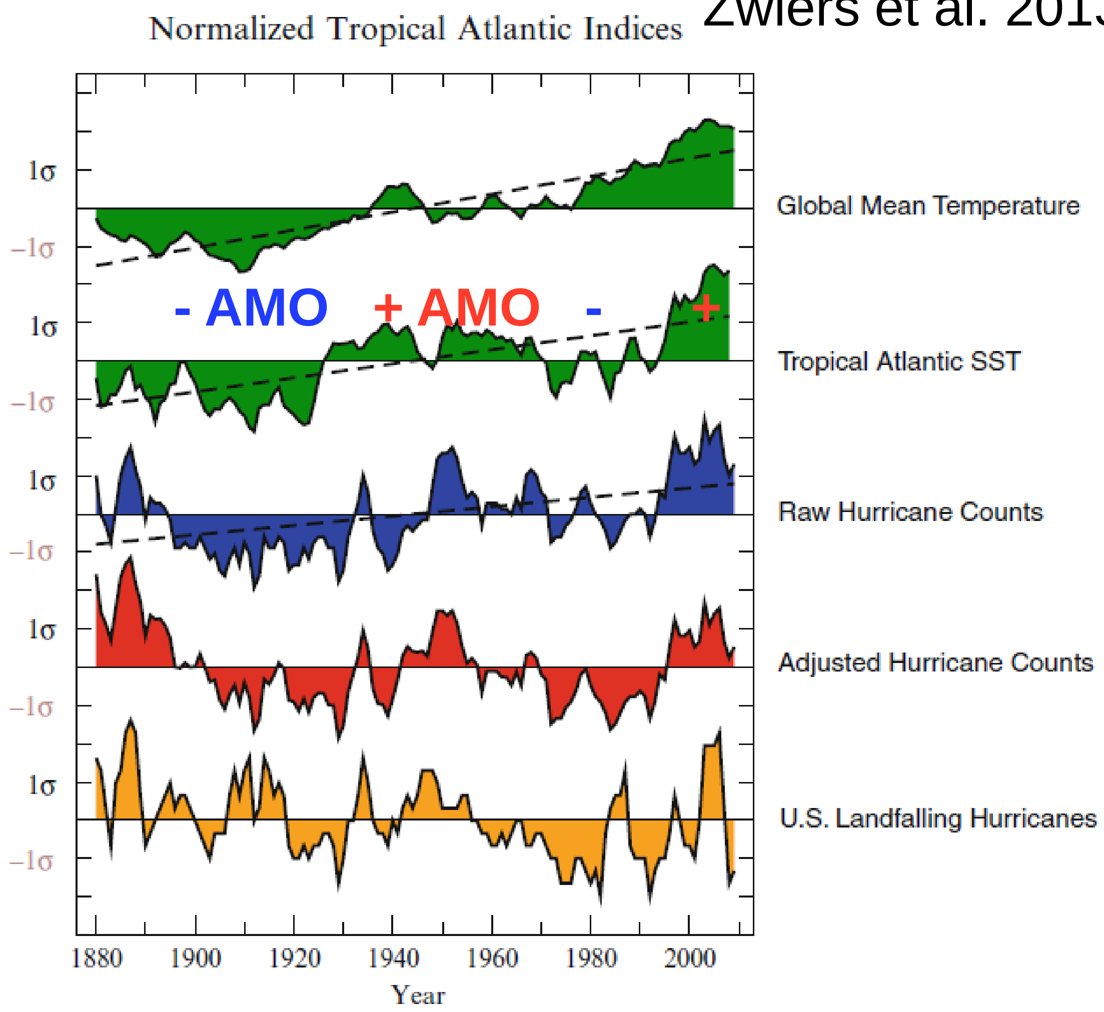
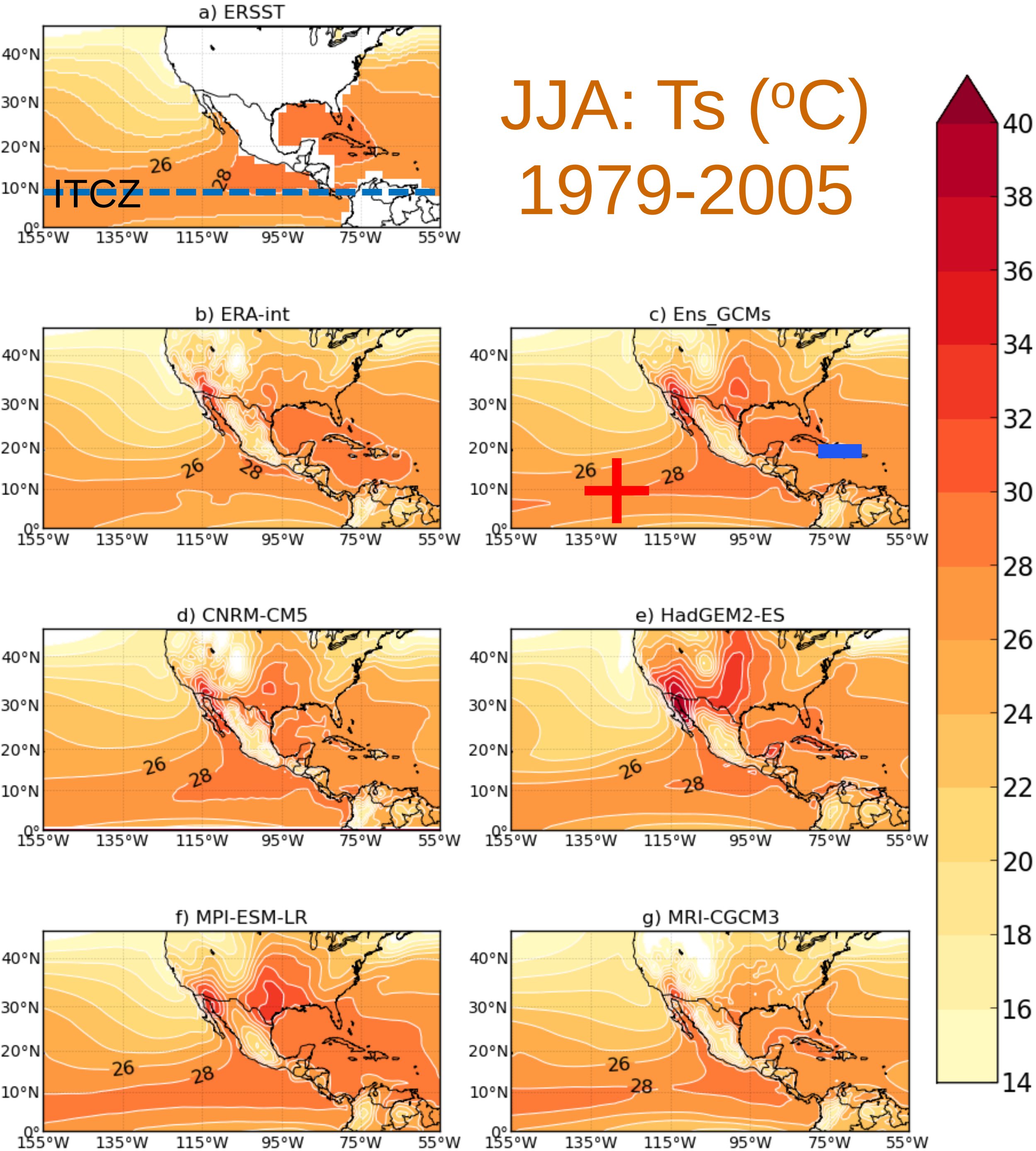


Fig. 6 Five-year running means of tropical Atlantic indices. *Green curves* depict global annual-mean temperature anomalies (*top*) and August–October Main Development Region (MDR, defined as 20–80 W, 10–20 N) SST anomalies (second from *top*). *Blue curve* shows unadjusted Atlantic hurricane counts. *Red curve* shows adjusted Atlantic hurricane counts that include an estimate of "missed" hurricanes in the pre-satellite era. *Orange curve* depicts annual U.S. landfalling hurricane counts. *Vertical axis tic marks* denote one standard deviation intervals (shown by the σ symbol). *Dashed lines* show linear trends. Only the top three curves have statistically significant trends (Source: Adapted from Vecchi and Knutson 2011)

JJA: Ts (oC) 1979-2005



Problem with the SSTs in GCMs

Inverse termal contrast

- El Niño-like
- Stronger CLLJ
- Reduced Precip

Several studies:

- Fuentes-Franco et al. 2015, 2016
- Cavazos and De Grau 2014
- Martínez-Sanchez & Cavazos 2014
- Torres-Alavez et al. 2014

Vol. 58: 221–234, 2014
doi: 10.3354/cr01192

CLIMATE RESEARCH
Clim Res

Published January 7

Eastern Tropical Pacific hurricane variability and landfalls on Mexican coasts

Julio N. Martinez-Sanchez, Tereza Cavazos*

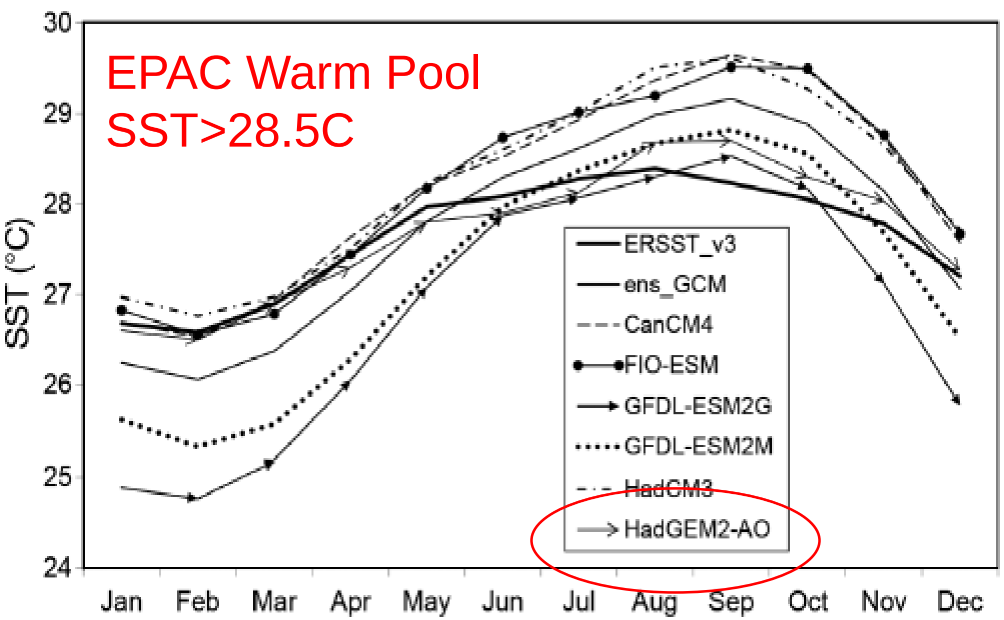


Fig. 8. Mean annual cycle of sea surface temperature (SST) averaged over the main development region of the Eastern Tropical Pacific during 1961–2000 for the observed NOAA Extended Reconstructed SST v3b (ERSST_v3) and the historical simulations of 6 general circulation models (GCMs; see Table 1) and their mean ensemble (ens_GCM)

Size of EPAC and NATL Warm Pools

Table 7. Same as Table 6, but for the average size ($\times 10^6$ km^2) of the Western Hemisphere Warm Pool in the Eastern Tropical Pacific (EPAC) and North Atlantic (NATL) basins according to observed NOAA Extended Reconstructed SST v3b (ERSST_v3) and the mean ensemble (ens_GCM) of the 6 general circulation models (GCMs) in Table 1 for the historical period 1961–2000. SST: sea surface temperature

SST	EPAC	NATL	Total
ERSST_v3	2.1	4.2	6.3
ens_GCM	3.4	2	5.4

Obs 1970-2010:

Event	EPAC	NATL	Total
La Niña	1.4	6.3	7.7
Neutral	1.8	5.4	7.2
El Niño	2.4	4.6	7.0
Average	1.9	5.4	7.3

R1XD Trends: Intense 1d Precipitation

Zwiers et al. 2013

CMIP5 GCMs: Antrop Forcing

GCMs: Nat + Ant Understimate Observations

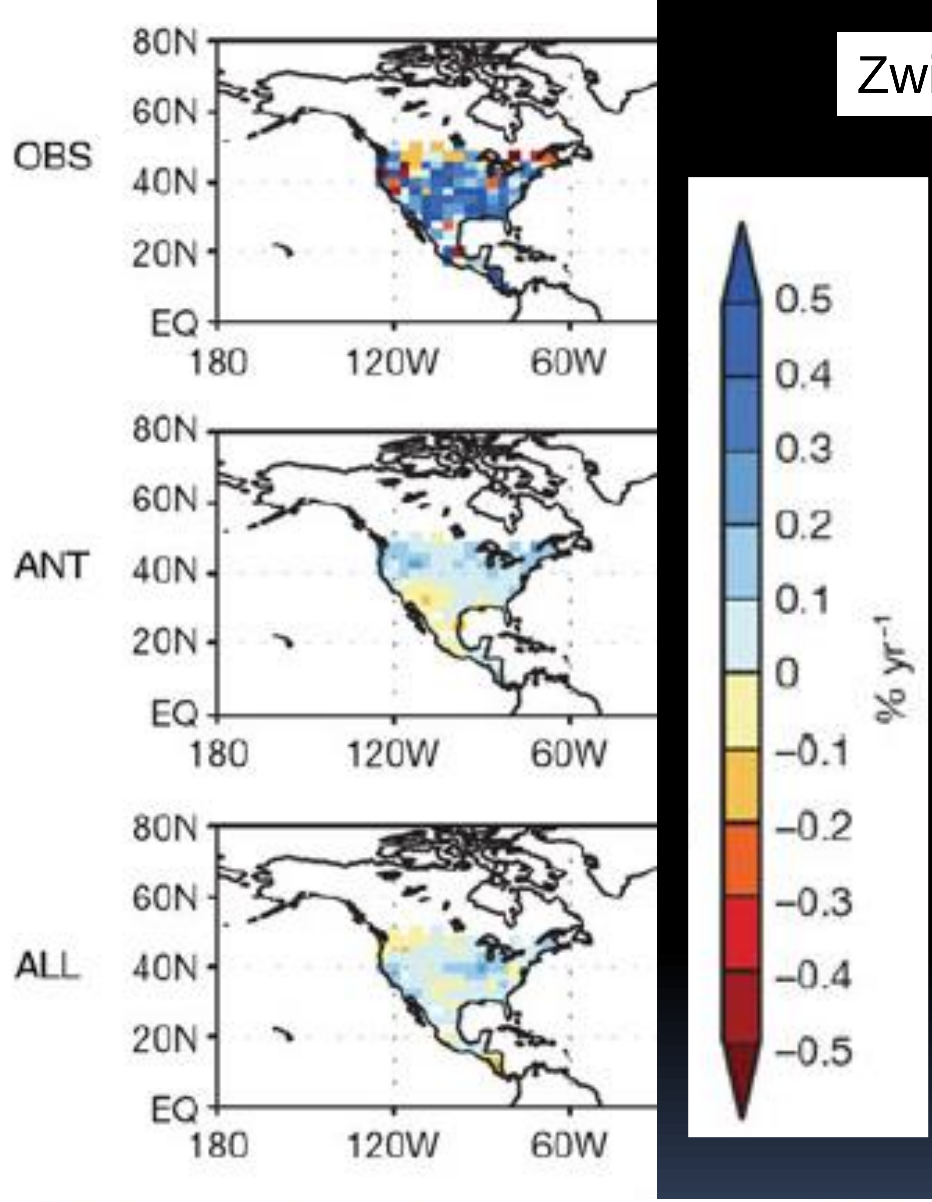
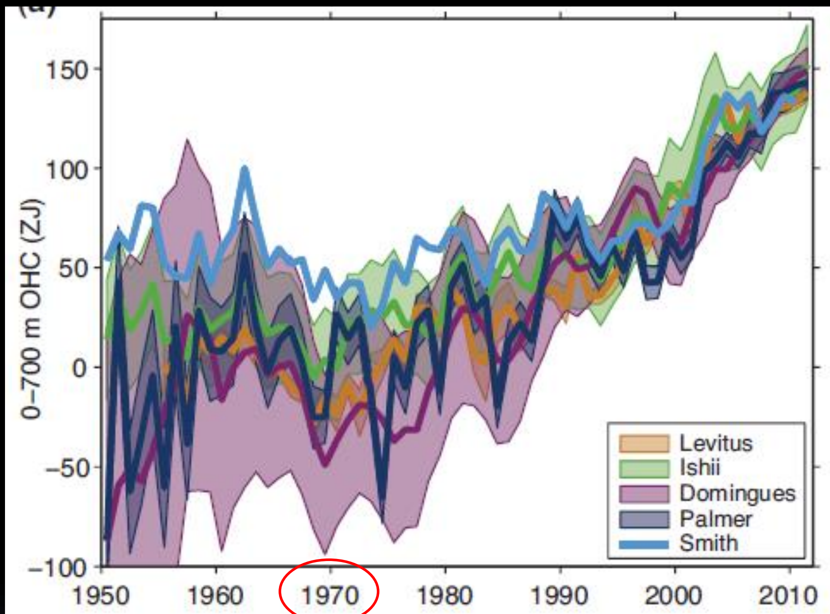


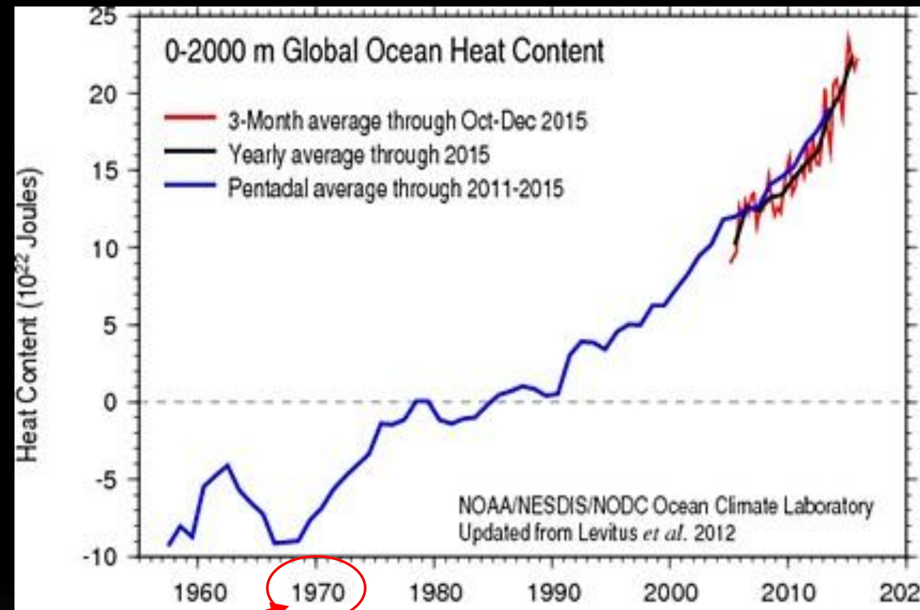
Fig. 4 Geographical distribution of trends of extreme precipitation indices (*PI*) for annual maximum daily precipitation amounts (*RX1D*) during 1951–1999. Observations (*OBS*); model simulations with anthropogenic (*ANT*) forcing; model simulations with anthropogenic plus natural (*ALL*) forcing. For models, ensemble means of trends from individual simulations are displayed. Units: per cent probability per year (From Min et al. (2011; see paper for details))

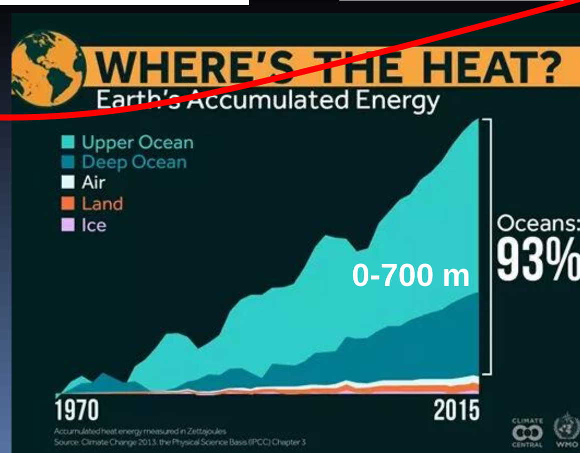
Observed Global Ocean Heat Content (Joules)

0 – 700 m (Anomaly)

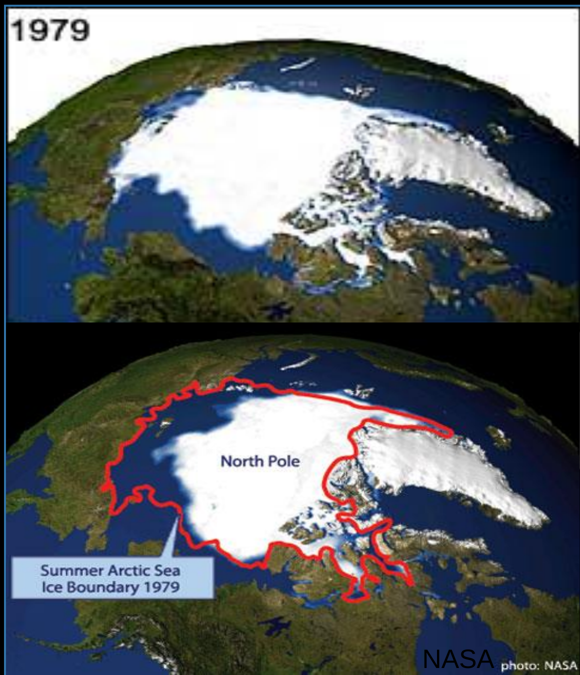


0 – 2000 m

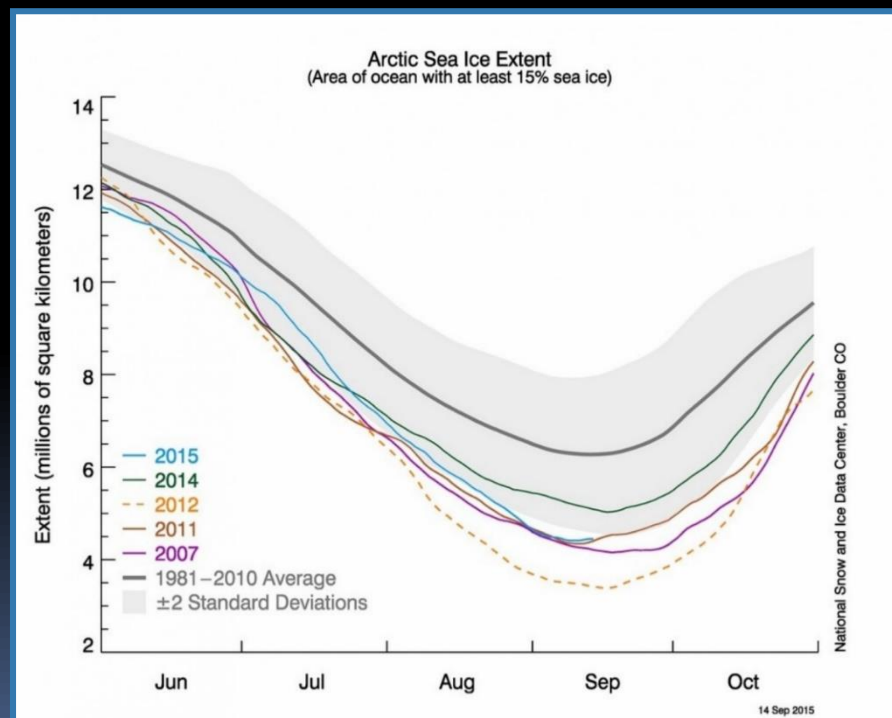




Arctic Ice Melting

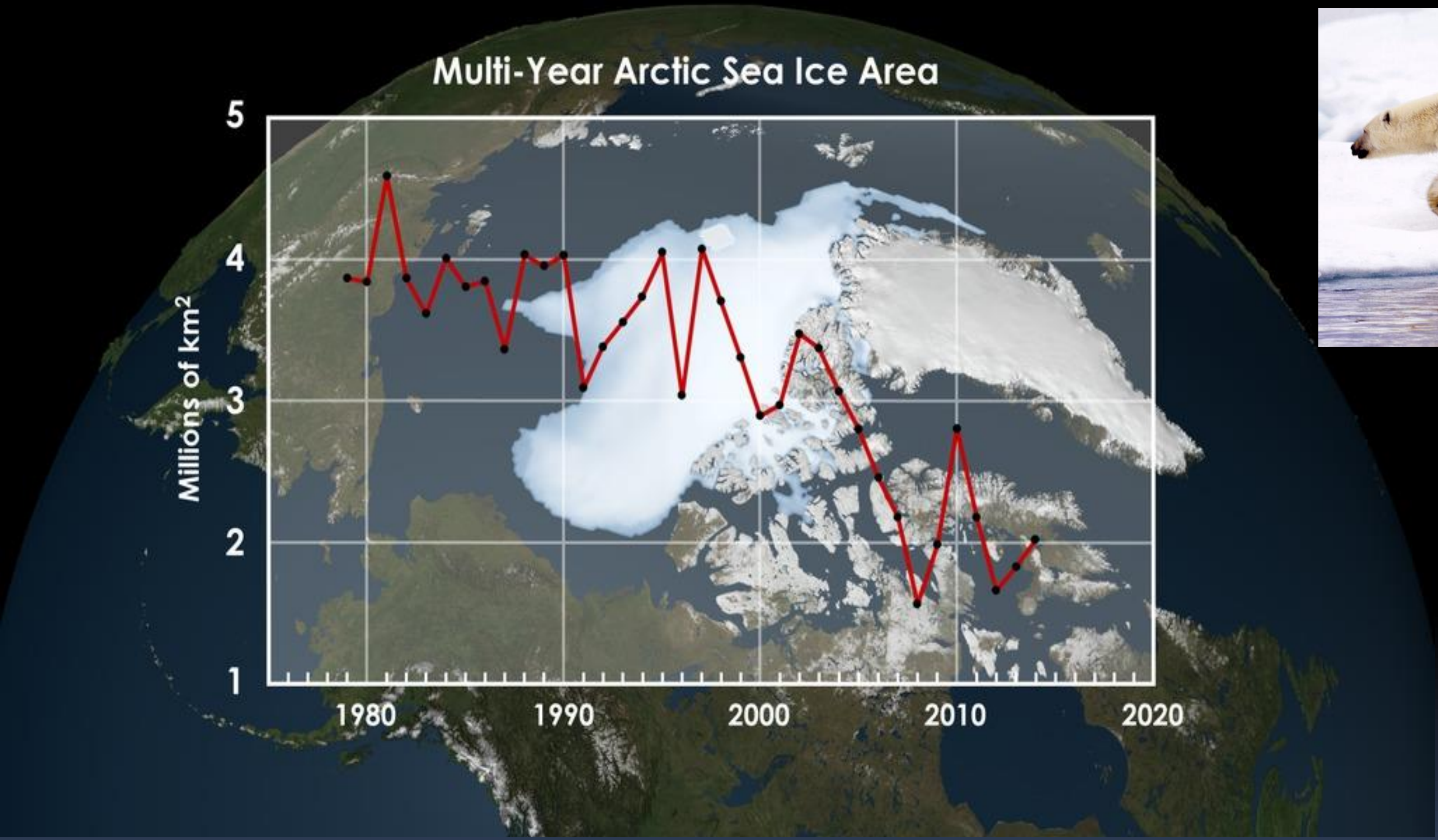


Sep 2015



https://www.washingtonpost.com/news/energy-environment/wp/2015/09/15/arctic-sea-ice-just-hit-its-annual-low-and-it-was-the-fourth-lowest-on-record/

Changes in the Arctic Sea Ice



Faster warming in the Arctic because sulfate aerosols have been reduced after actions to improve air quality in Europe? (Aerosls tend to cool the atmosphere). (Acosta Navarro *et al.* 2016, NGEO)

http://www.wired.com/2015/01/science-graphic-week-perrenial-arctic-sea-ice-continues-shrink/

Trends in extreme Sea Level (P99) (1970-2010)

Extremes 371

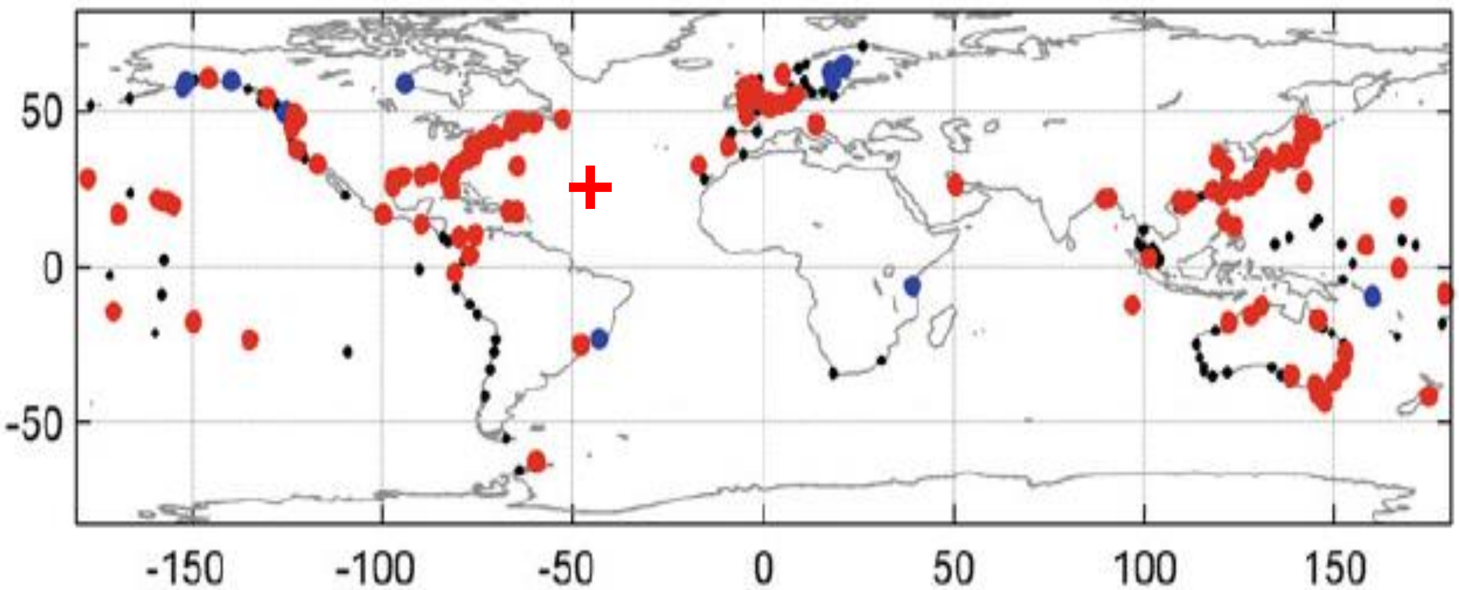
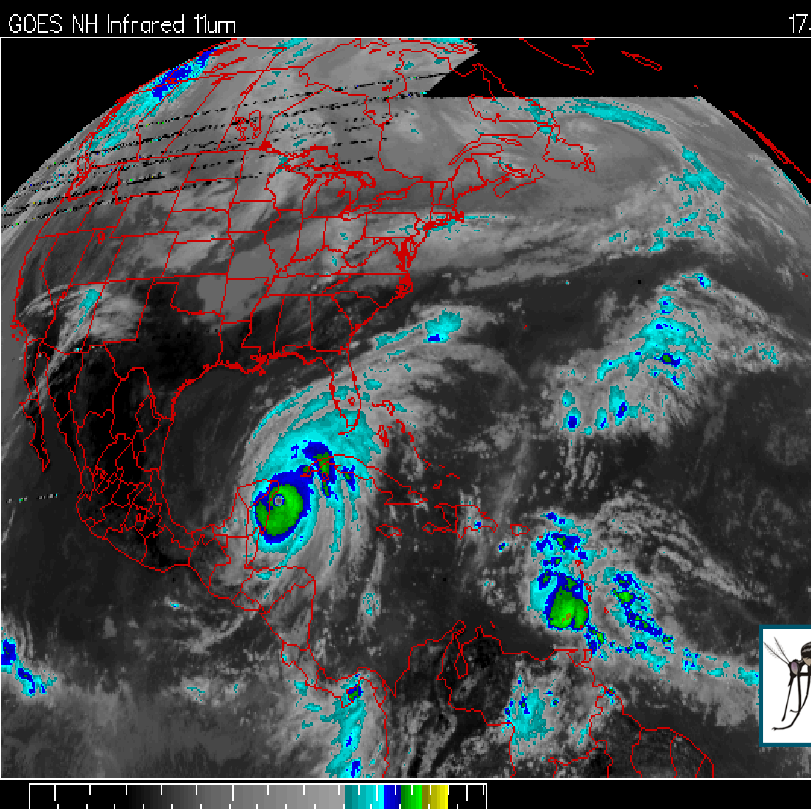


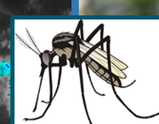
Fig. 8 Estimated trends in (*upper*) annual 99th percentile of sea level based on monthly maxima of hourly tide gauge readings from 1970 onwards, and (*lower*) 99th percentile after removal of the annual medians of hourly readings. Only trends significant at the 5 % level are shown in color: *red* for positive trends and *blue* for negative trends. Linear trends were estimated via least-squares regression taking the interannual perigean tidal influence into account (From Menéndez and Woodworth 2010). The figure shows that extreme sea levels have risen broadly, and that the dominate influence on that rise is from the increase in mean sea level

Zwiers et al. 2013

Ocean acidification

Coral bleaching



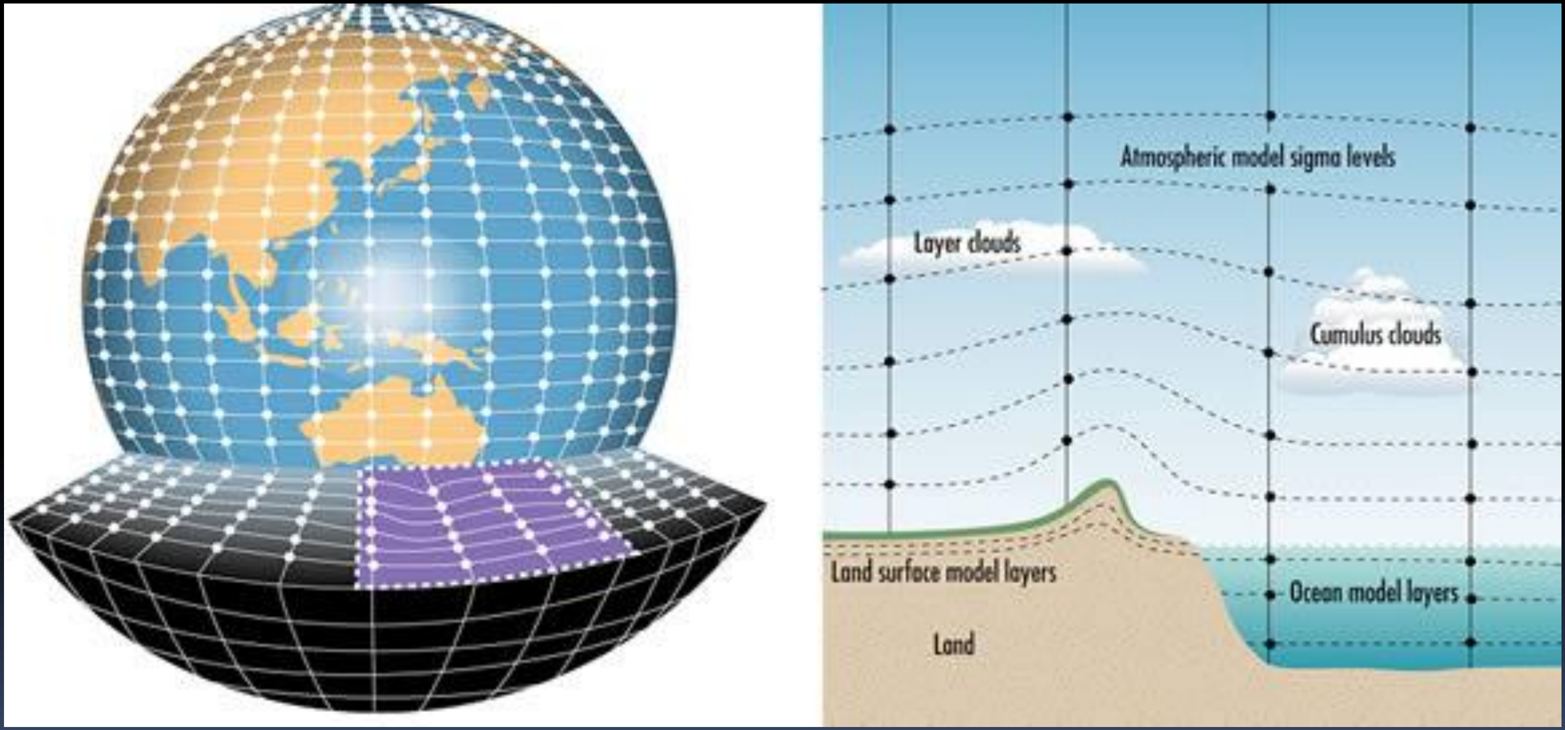


More intense tropical cyclones,
Floods, mosquitoes

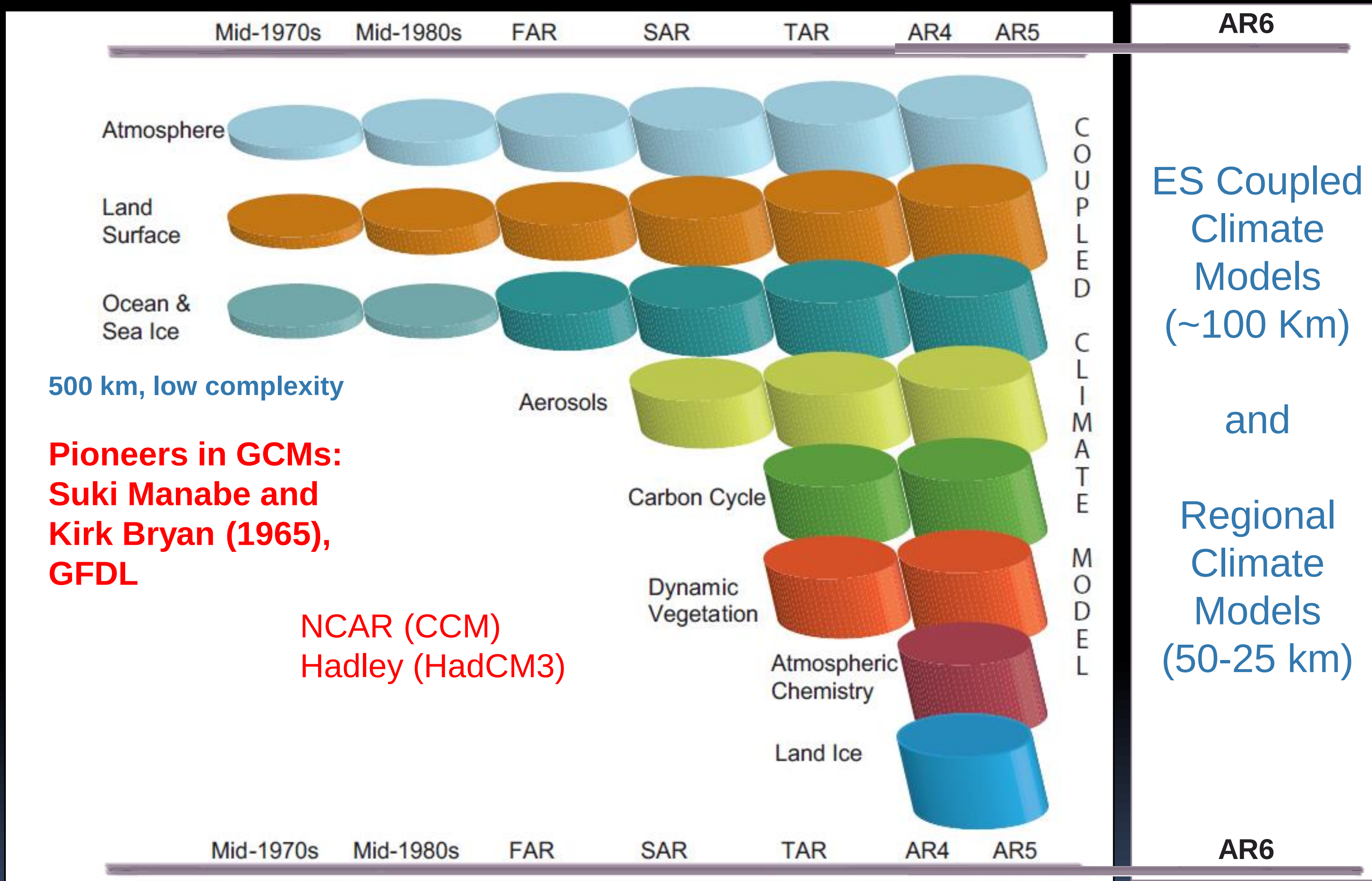
Droughts and
heat waves

CONTENT

2. General Circulation Models (GCMs)



50 yrs Evolution of Climate Modeling and IPCC



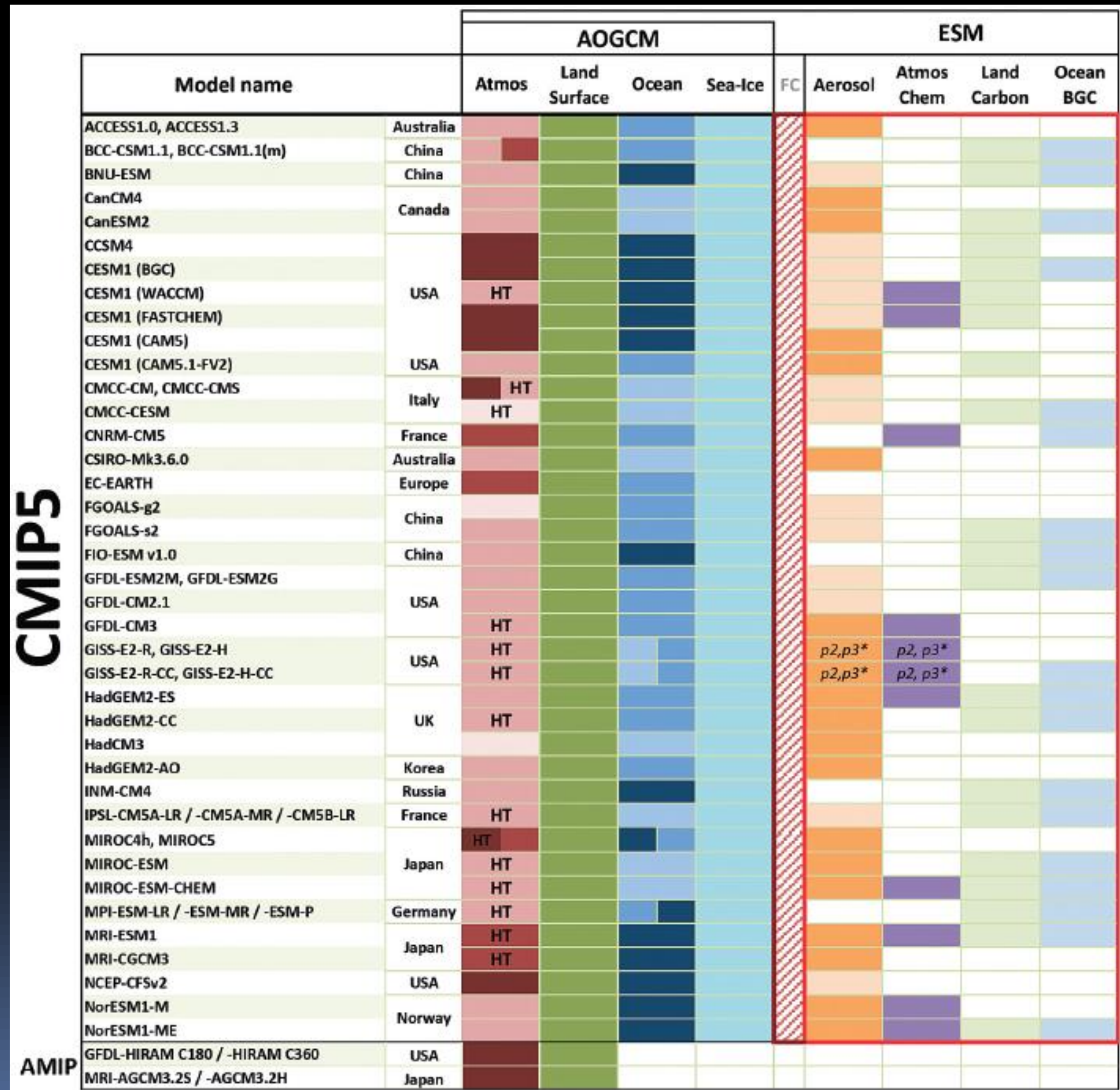
IPCC Reports 1990 1995 2001 2007 2013 2020

Figure 1.13 | The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models over time. In each aspect (e.g., the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated by growing cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizontal resolution and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three independent experiments can be considered as standard.

CMIP5 GCMs used in AR5 of the IPCC

27
AO-GCMs

12 Regional Climate Centers



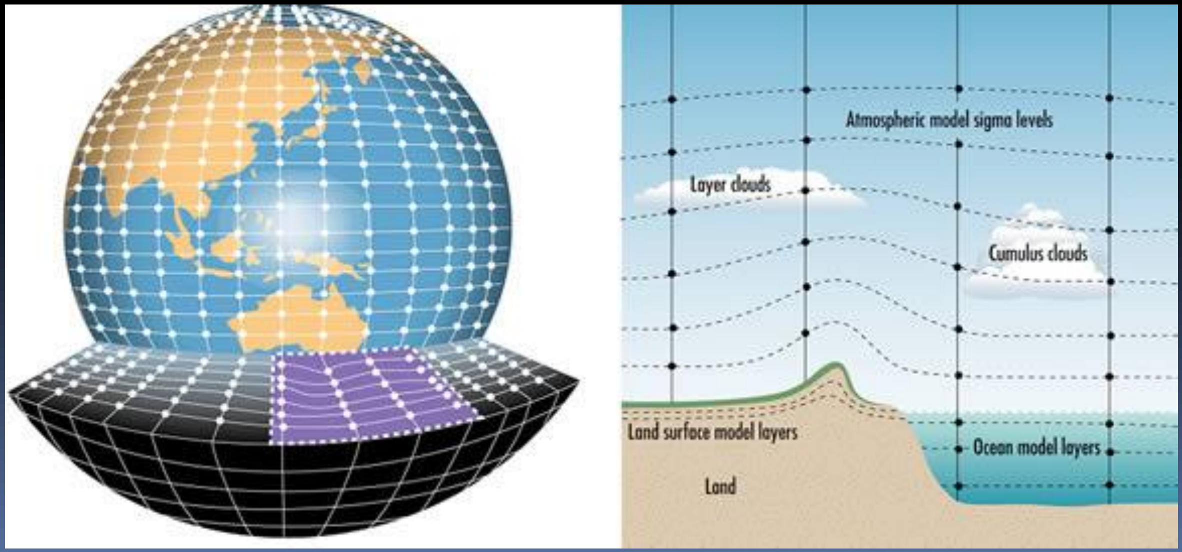
	Model name		AOGCM: Atmos	AOGCM: Land Surface	AOGCM: Ocean	AOGCM: Sea-Ice	FC	ESM: Aerosol	ESM: Atmos Chem	ESM: Land Carbon	ESM: Ocean BGC
CMIP5	ACCESS1.0, ACCESS1.3	Australia									
	BCC-CSM1.1, BCC-CSM1.1(m)	China									
	BNU-ESM	China									
	CanCM4	Canada									
	CanESM2										
	CCSM4	USA									
	CESM1 (BGC)										
	CESM1 (WACCM)		HT								
	CESM1 (FASTCHEM)										
	CESM1 (CAM5)										
	CESM1 (CAM5.1-FV2)	USA									
	CMCC-CM, CMCC-CMS	Italy	HT								
	CMCC-CESM		HT								
	CNRM-CM5	France									
	CSIRO-Mk3.6.0	Australia									
	EC-EARTH	Europe									
	FGOALS-g2	China									
	FGOALS-s2										
	FIO-ESM v1.0	China									
	GFDL-ESM2M, GFDL-ESM2G	USA									
	GFDL-CM2.1										
	GFDL-CM3		HT								
	GISS-E2-R, GISS-E2-H	USA	HT					p2,p3*	p2, p3*		
	GISS-E2-R-CC, GISS-E2-H-CC		HT					p2,p3*	p2, p3*		
	HadGEM2-ES	UK									
	HadGEM2-CC		HT								
	HadCM3										
	HadGEM2-AO	Korea									
	INM-CM4	Russia									
	IPSL-CM5A-LR / -CM5A-MR / -CM5B-LR	France	HT								
	MIROC4h, MIROC5	Japan	HT								
	MIROC-ESM		HT								
	MIROC-ESM-CHEM		HT								
	MPI-ESM-LR / -ESM-MR / -ESM-P	Germany	HT								
	MRI-ESM1	Japan	HT								
	MRI-CGCM3		HT								
	NCEP-CFSv2	USA									
	NorESM1-M	Norway									
	NorESM1-ME										
AMIP	GFDL-HIRAM C180 / -HIRAM C360	USA									
	MRI-AGCM3.2S / -AGCM3.2H	Japan									

3-Dimensional Coupled Modeling

7 Primitive equations:

1 Equation of State ➔ $p = \rho R T$
1 Hydrostatic Eq. ➔ $-1/\rho \, \partial p/\partial z = g = PGF$
1 Thermodynamic Eq. ➔ $dQ = dU + dW = c_p dT - \alpha dP$
3 Momentum Eqs. (u, v, w): Newton´s 2nd Law ➔ $dV/dt = \partial V/\partial t + V.\nabla V$
1 Continuity Eq. (DIV) ➔ $(\nabla . V)_H = - \partial w/\partial z$

Solution in each gripoint



Clouds not resolved by AO-GCMs ➔ Physical parameterizations

Difference between AOGCMs and RCMs

Governing Equations

Local change	Horiz. Advection	Vert. Advection	Coriolis	PGF	Other forcings

Momentum Eqs.

$$\frac{\partial \mathbf{V}}{\partial t} = -\mathbf{V}\cdot\nabla\mathbf{V} - \omega\frac{\partial \mathbf{V}}{\partial p} - f\mathbf{k}\times\mathbf{V} - \nabla\Phi - Fricción$$

Thermodynamic Eq.

$$\frac{\partial T}{\partial t} = -\mathbf{V}\cdot\nabla T + \omega\left(\frac{\kappa T}{p} - \frac{\partial T}{\partial p}\right) + \overline{\frac{Q_{rad}}{c_p}} + \overline{\frac{Q_{con}}{c_p}} + D_H$$

Conserv. of water vapor

$$\frac{\partial q}{\partial t} = -\mathbf{V}\cdot\nabla q - \omega\frac{\partial q}{\partial p} + E - C + D_q$$

Continuity Eq. (Div)

$$\frac{\partial \omega}{\partial p} = -\nabla\cdot\mathbf{V}$$

Hydrostatic Eq.

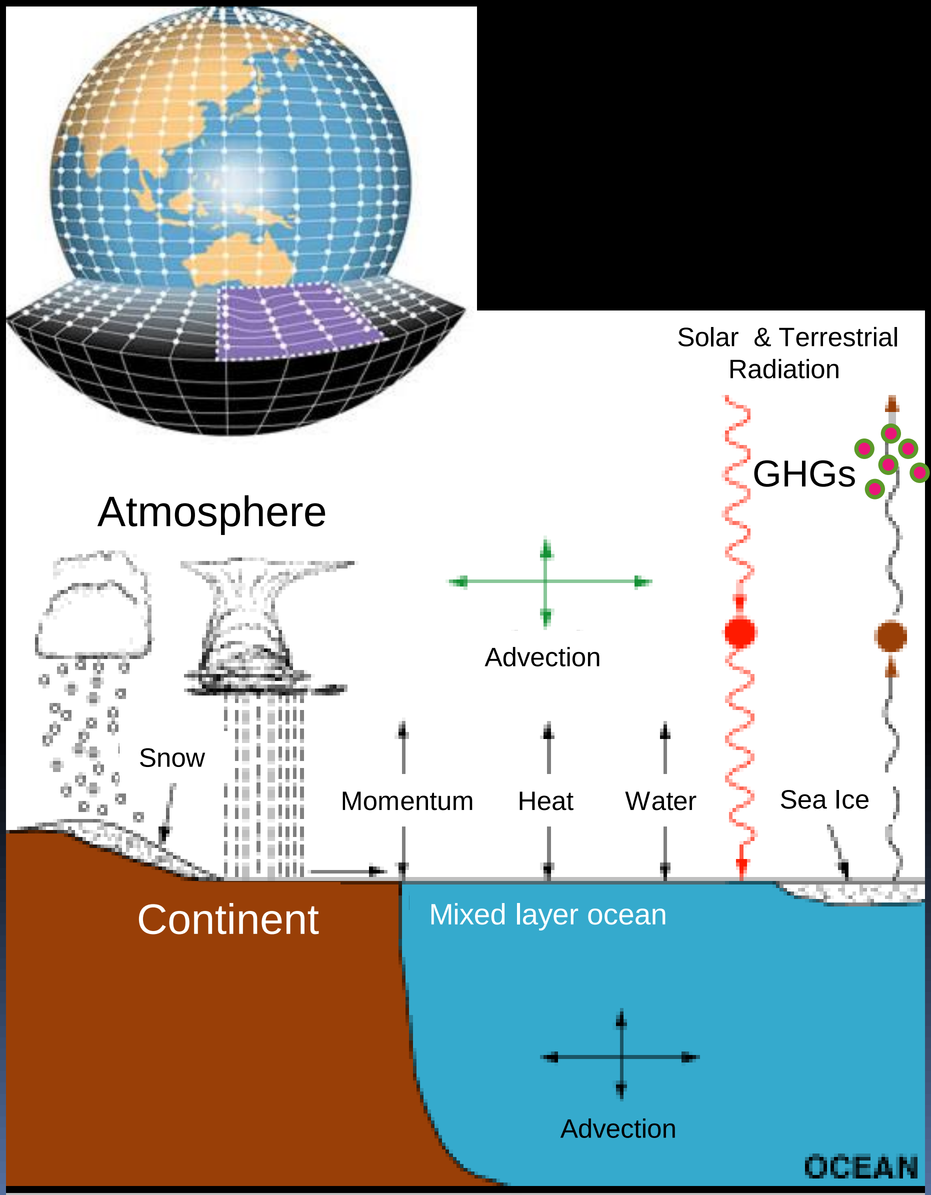
$$\frac{\partial \Phi}{\partial p} = -\frac{RT}{p}$$

$(\Phi = gZ)$

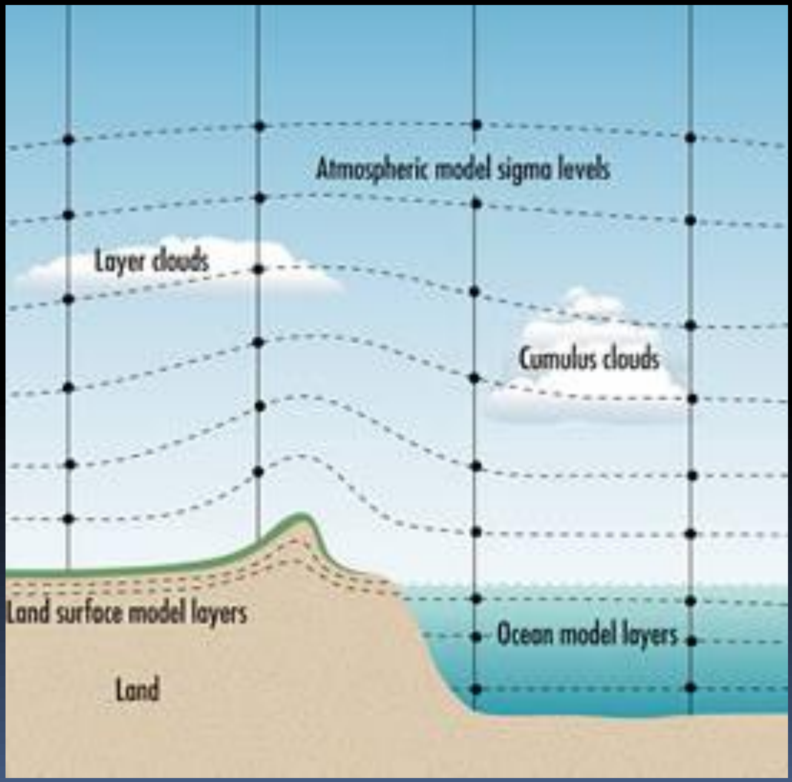
Non-hydrostatic

These terms involve scales not solved by GCMs

Physical Processes in a Model

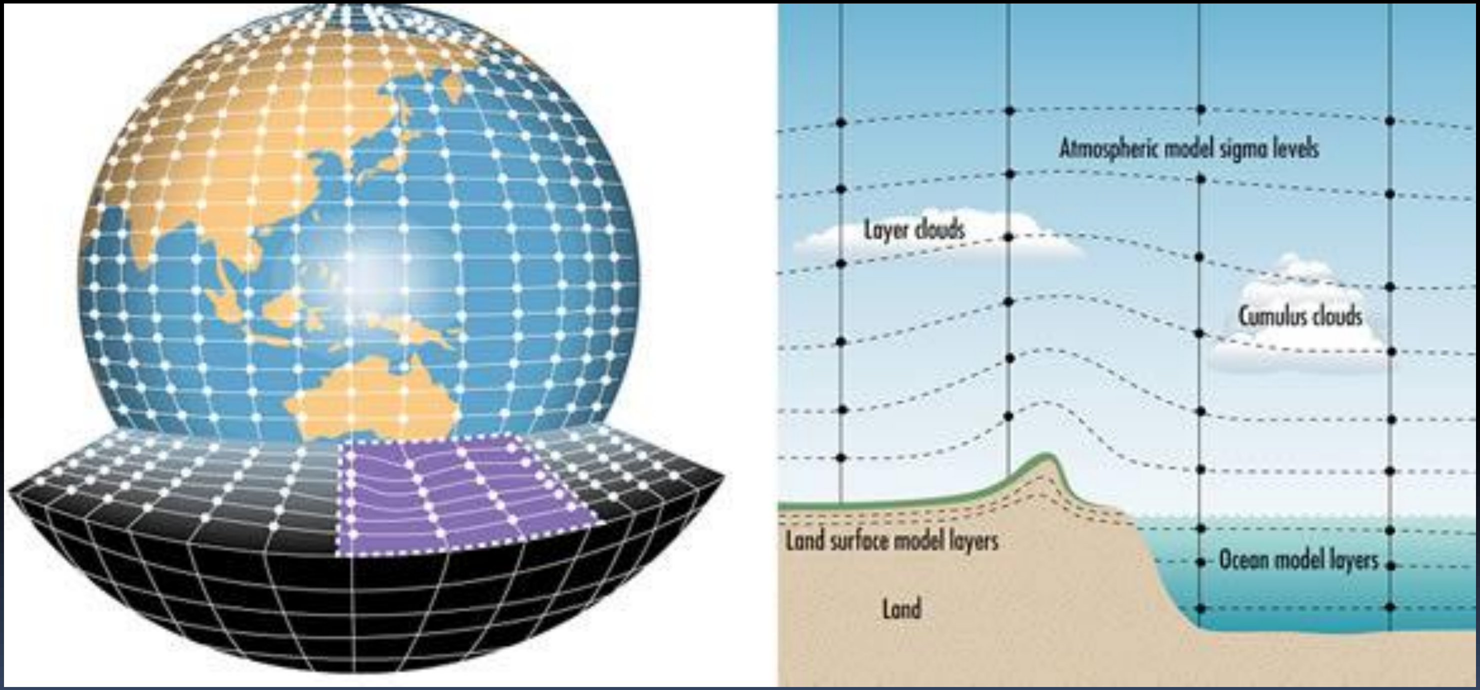


PARAMETERIZATIONS
Microphysics
Cumulus
Radiation
PBL
Surface (soil, veget, ice, albedo. etc)

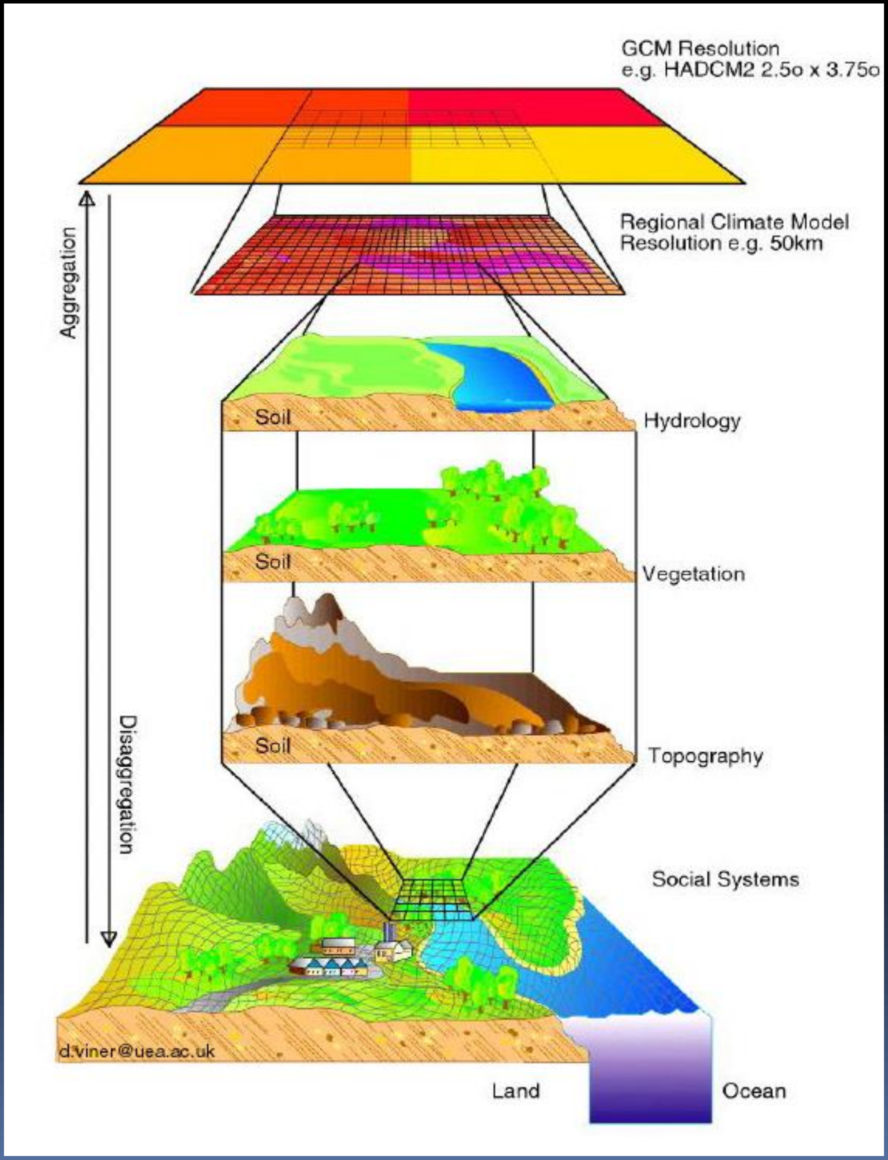


CONTENT

3. Regional Climate Downscaling



Climate Downscaling



Types of Downscaling

- **Statistical** (**SDSM**, Neural Nets, Bias Correction)
- **Hybrid** (Dynamic & Stat)
- **Dynamic** (**CORDEX**: RegCM, WRF, RCA, REMO, RCanM, PRECIS)

Utililty

- Study physical processes at meso-local scale
- Validation and sensitivity studies
- Climate change scenarios relevant for integrated **VIA** assessment (Vulnerability, Impacts and Adaptation**)**
- **Decision support tools for local climate change impacts**

Regional Climate Downscaling: Decision Support Tools

SDSM Statistical Downscaling Model
http://co-public.lboro.ac.uk/cocwd/SDSM/sdsmmain.html

CORDEX: COordinated Regional climate Downscaling Experiment
http://www.meteo.unican.es/es/projects/CORDEX

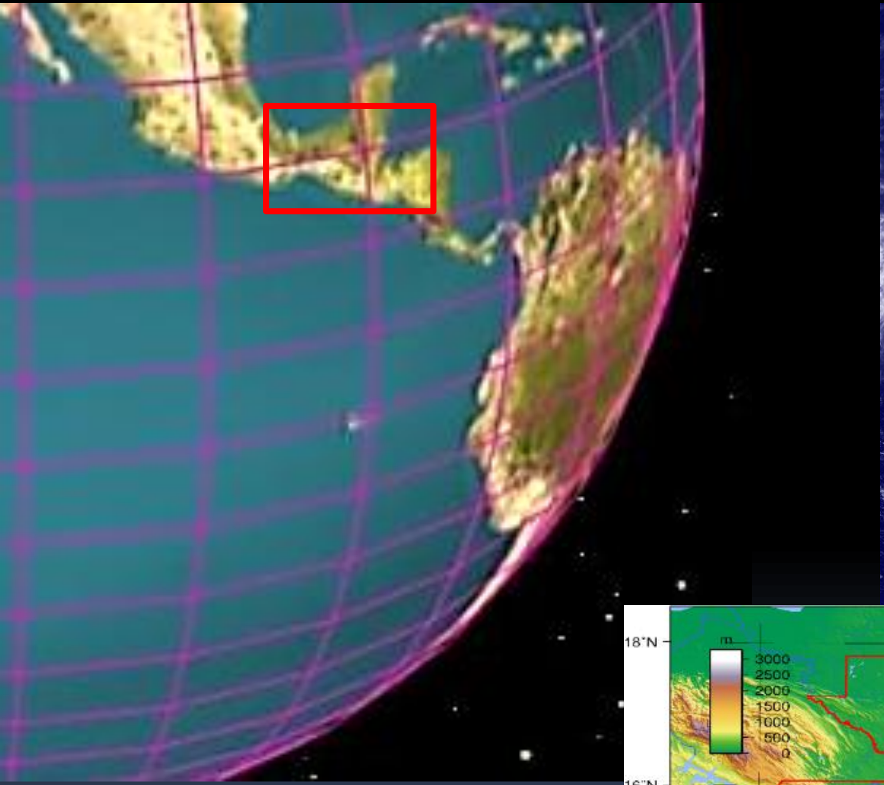
CORDEX Output
http://esg-dn1.nsc.liu.se/search/cordex/

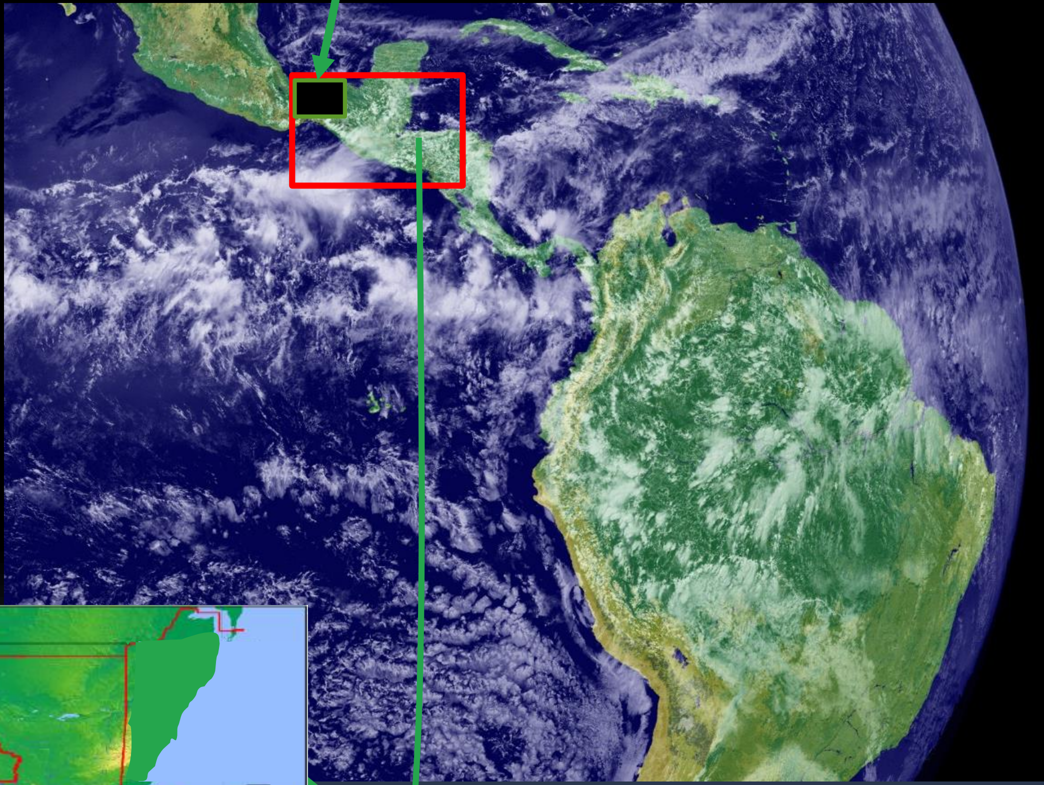
Platform for evaluation- RCMES
Regional Climate Model Evaluation System, Kyo Lee, JPL
https://rcmes.jpl.nasa.gov/content/software-support

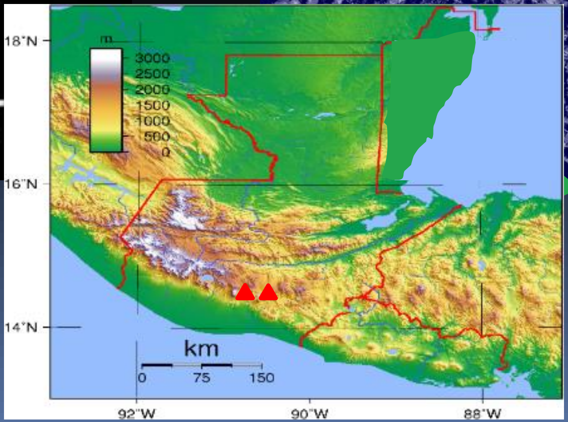
Regional Climate Downscaling

GCMs > 150 Km vs RCMs < 50 km

GCM







Added Value of Increasing the Spatial Resolution: CORDEX Alpes: Sep-Nov Precipitación

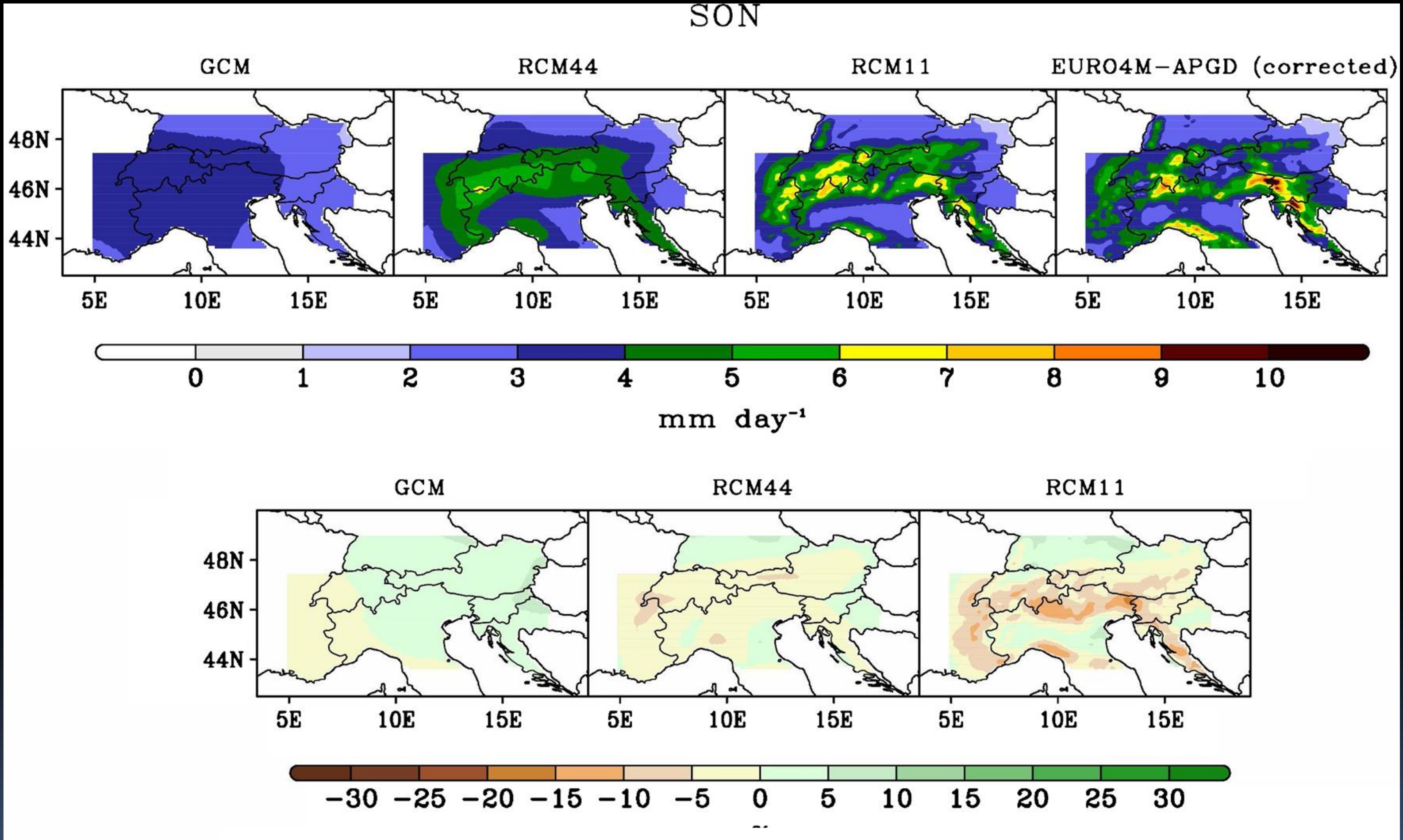


Fig. 2 Fall (September–October–November or *SON*) precipitation in an ensemble of four driving GCMs and six nested RCMs run at resolutions of 0.11° and 0.44° (RCM44 and RCM11, respectively) over the Alpine region in the EURO-CORDEX and MED-CORDEX initiatives. The *top panels* show the mean precipitation (mm/day) for the present day period (1975–2004) and compare the model data with a high-resolution observation dataset [87] (in the *last panel to the right*, observations include a gauge undercatch correction as described in [28]). The *bottom panels* show the corresponding mean precipitation change (units of % of present day values) for the period 2070–2099 with respect to 1975–2004 under the RCP8.5 greenhouse gas concentration scenario [86]. The figure is adapted from [28]

(Giorgi y Gutowski 2016)

Sources of uncertainty in regional climate change projections

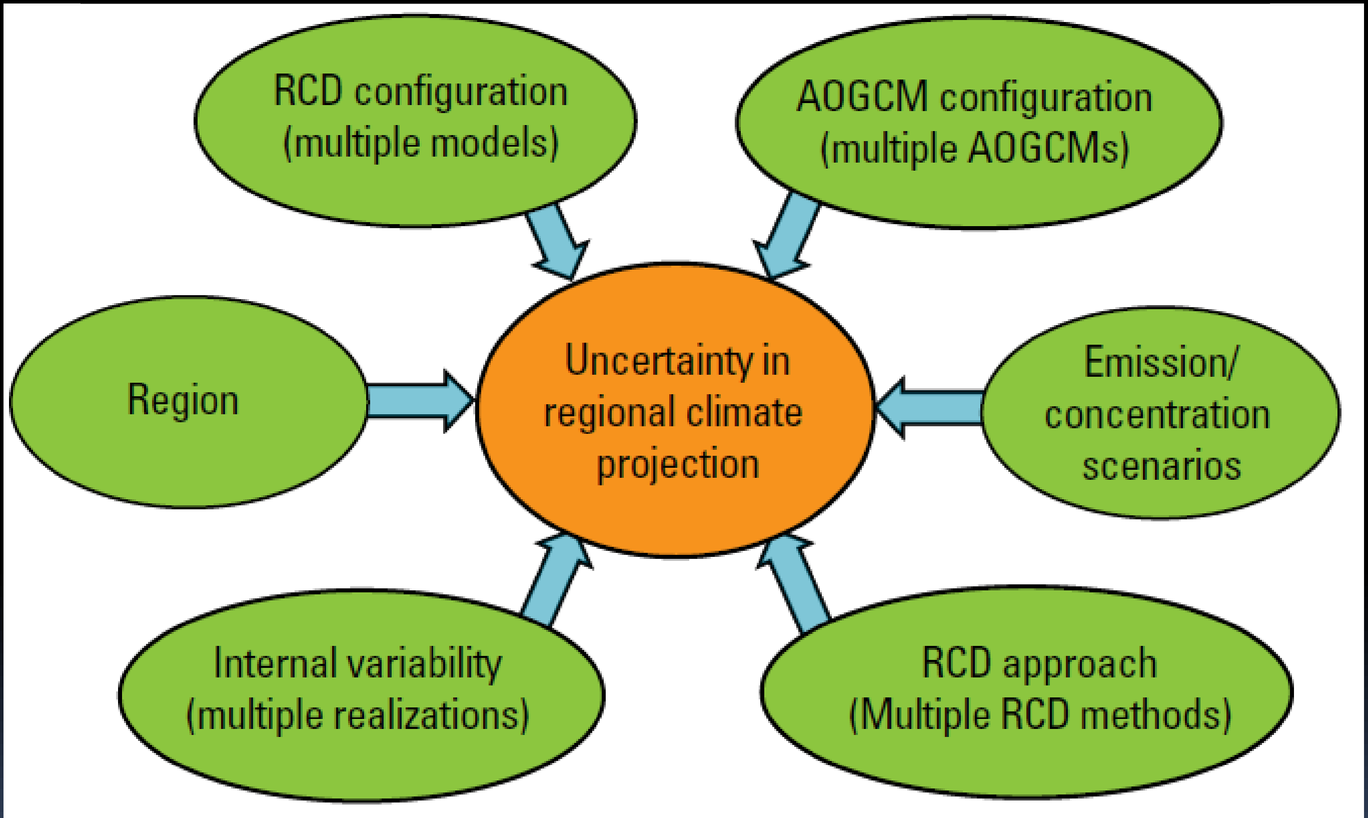
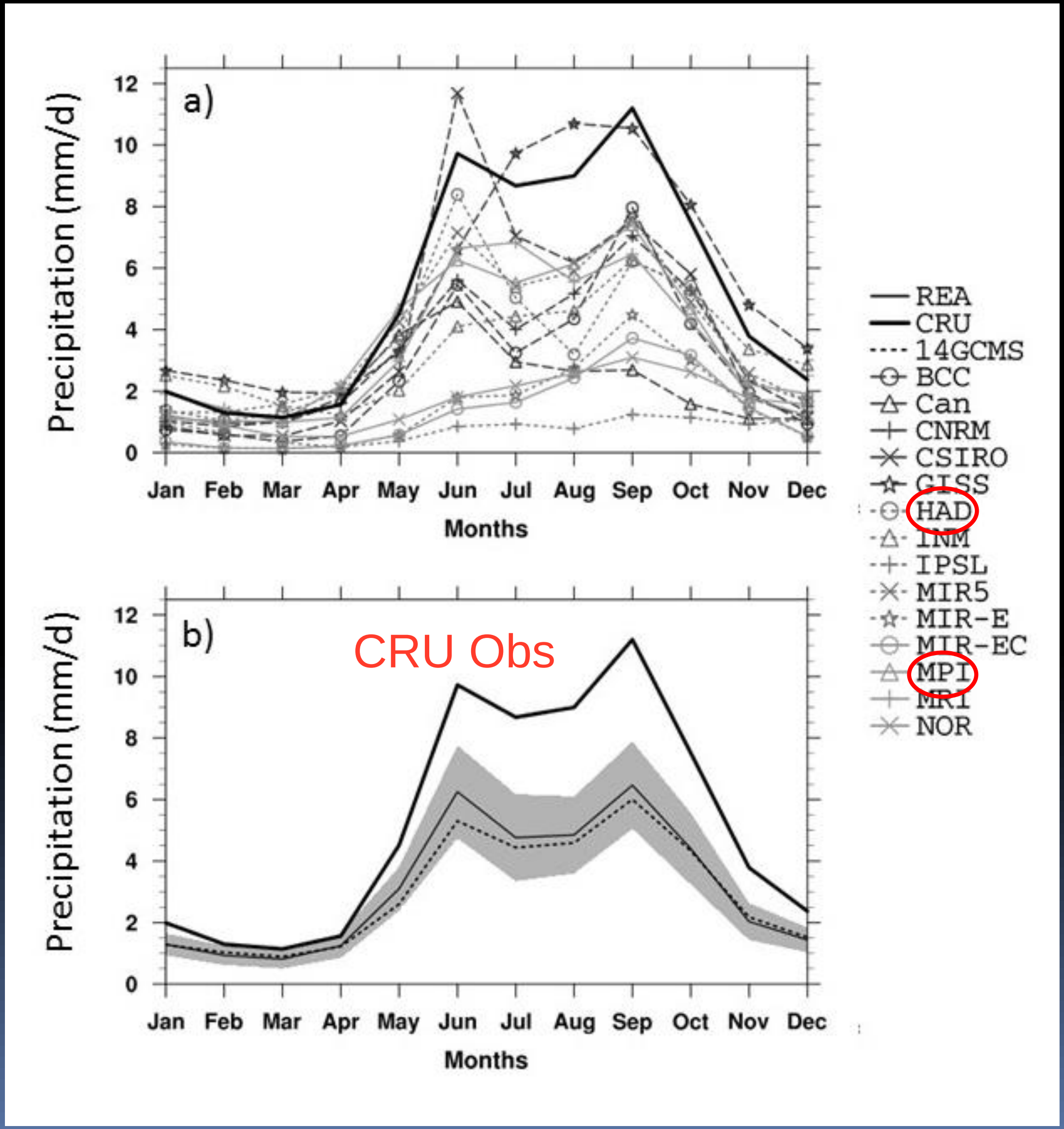


Figure 1 — Schematic depiction of the primary uncertainties in regional climate change projection

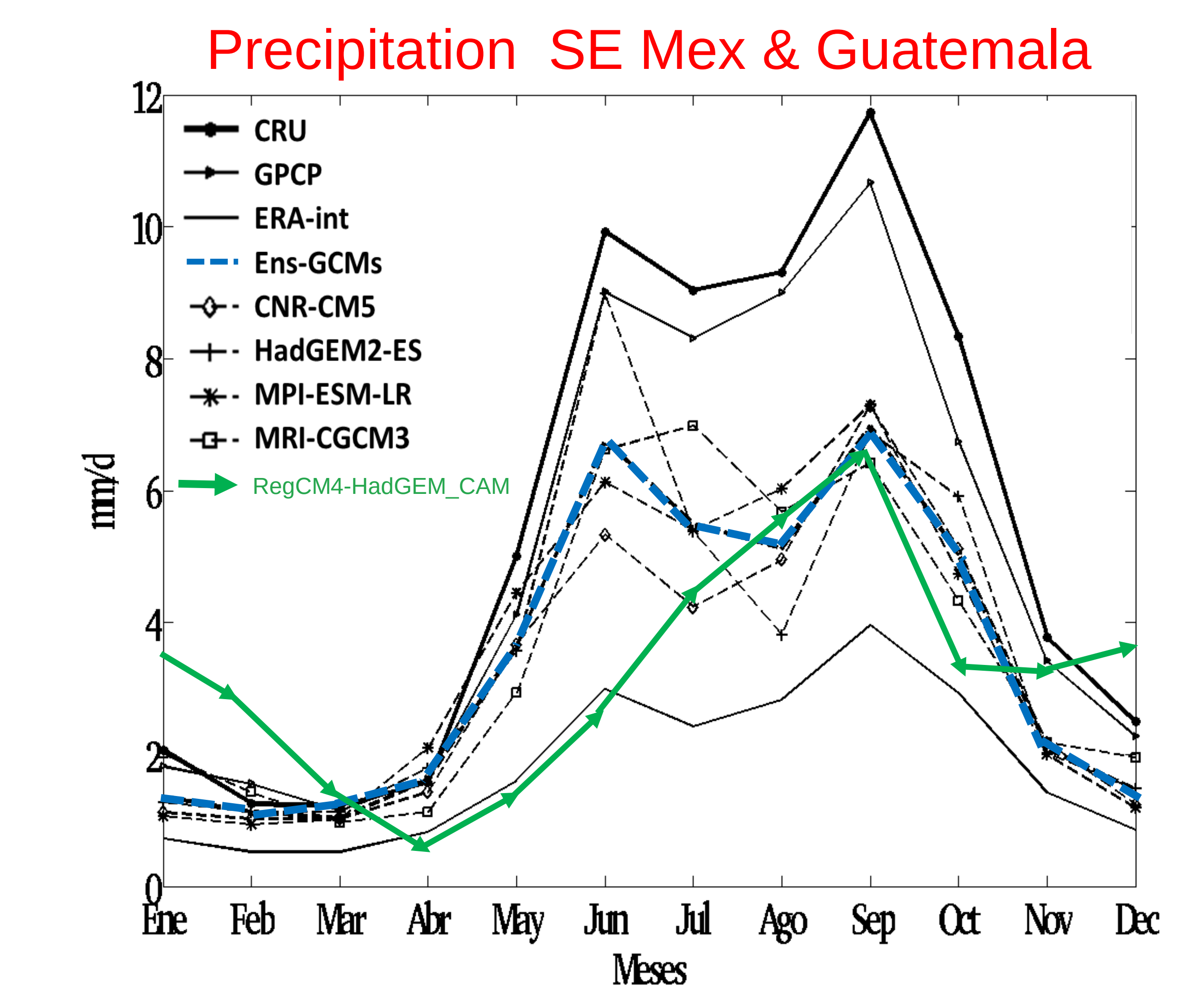
(Giorgi and Gutowski 2016)

Intercomparison of 15 GCMs 1979-2005: Mid-Summer Drought (Canícula) Region



(Cavazos et al. 2017)

Intercomparison of 4 GCMs and REgCM 1979-2005. Relevant Process: the MSD

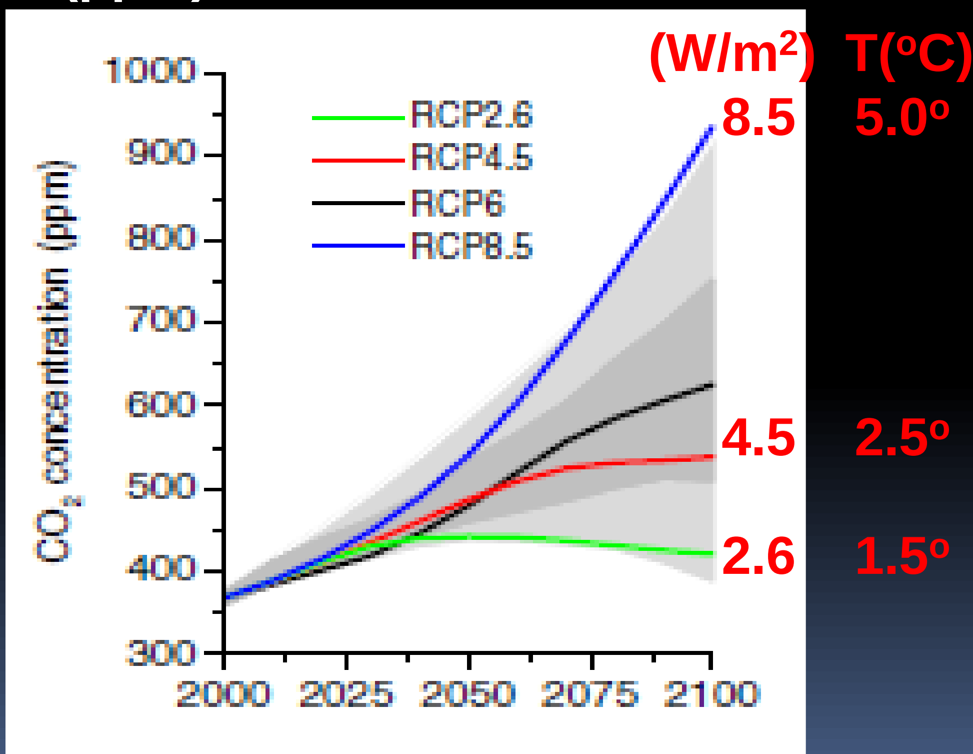


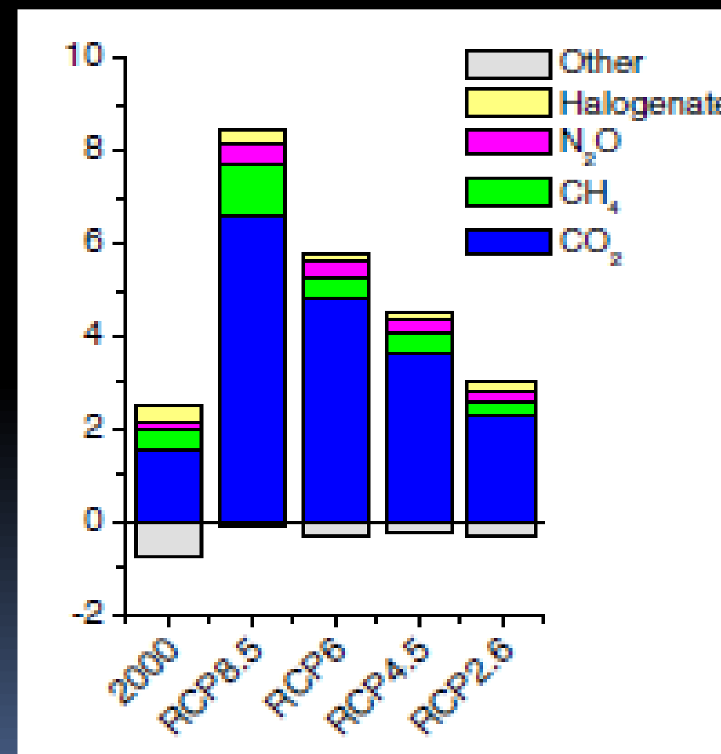
Cavazos and de Grau, 2014

CONTENT

4. Climate Change Scenarios using GCMs

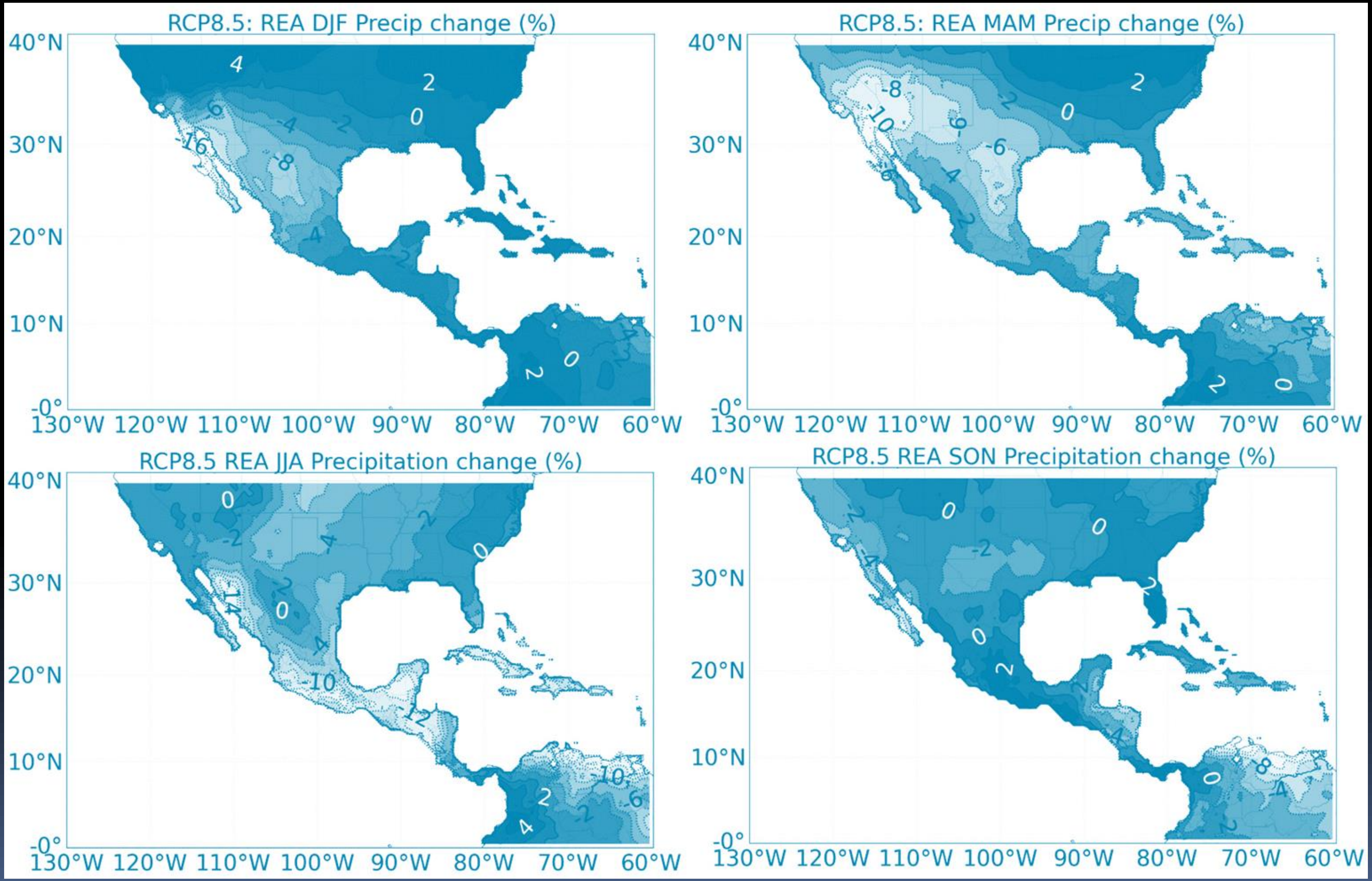
(ppm)





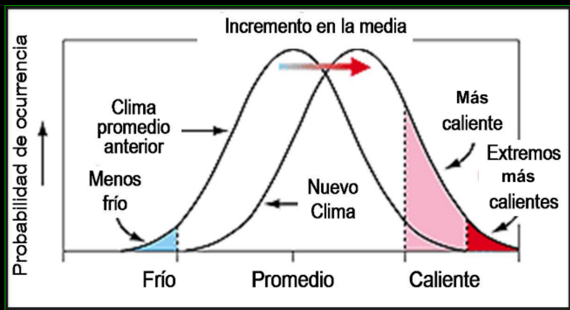
(Figs. 9 y 10, van Vuuren et al. 2011)

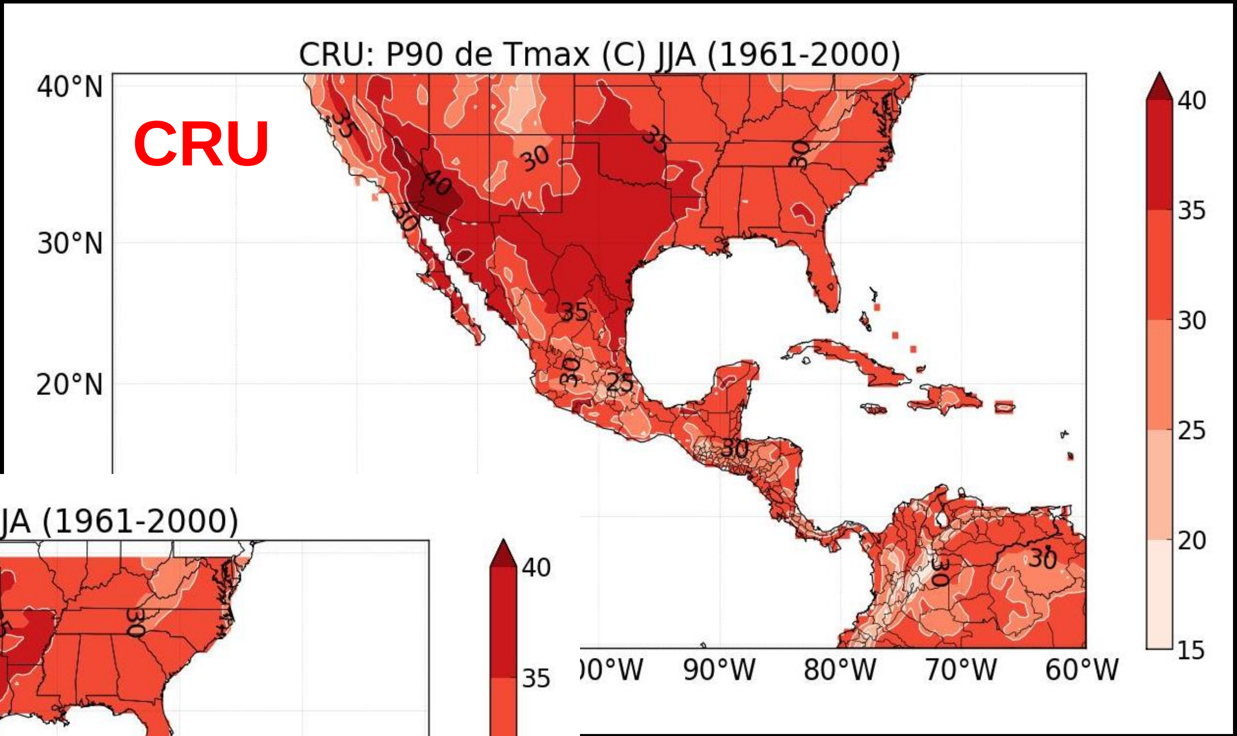
Seasonal Change of Precipitation (%)
2075-2099 minus 1961-2000 under RCP8.5

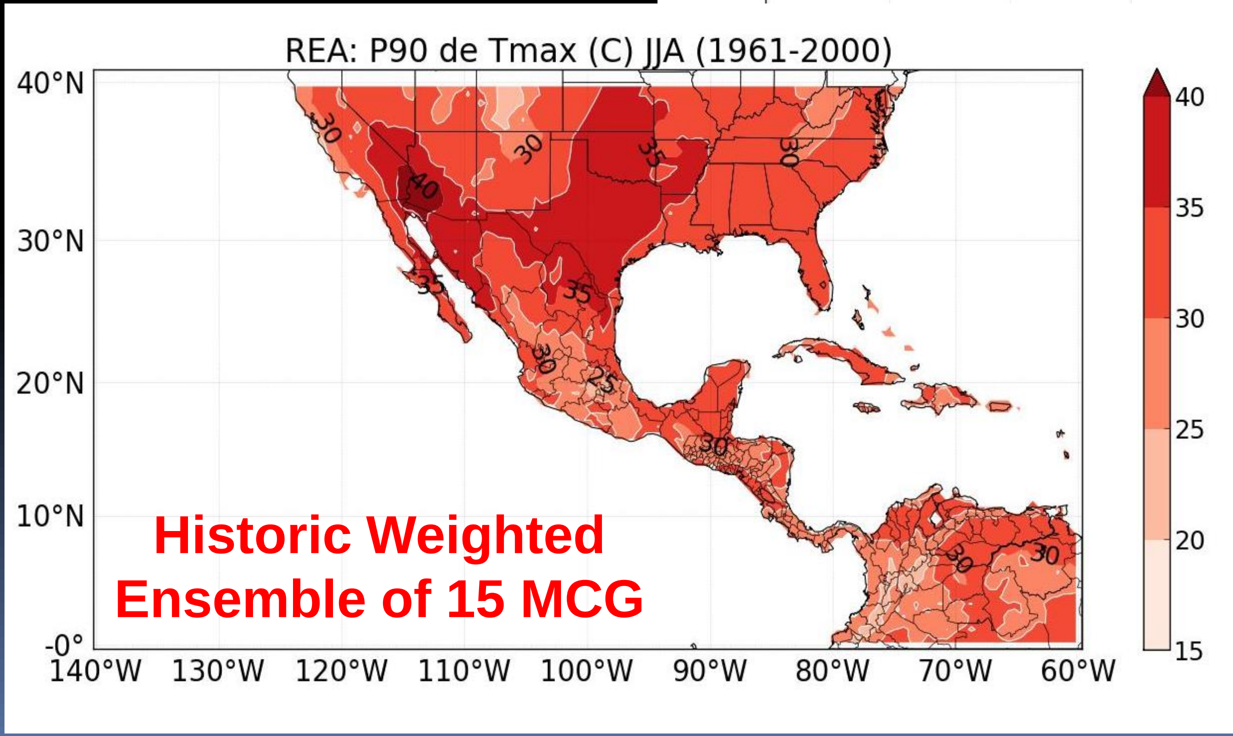


(Cavazos et al. 2017)

1961-2000: JJA P90 Threshold of Tmax (ºC)



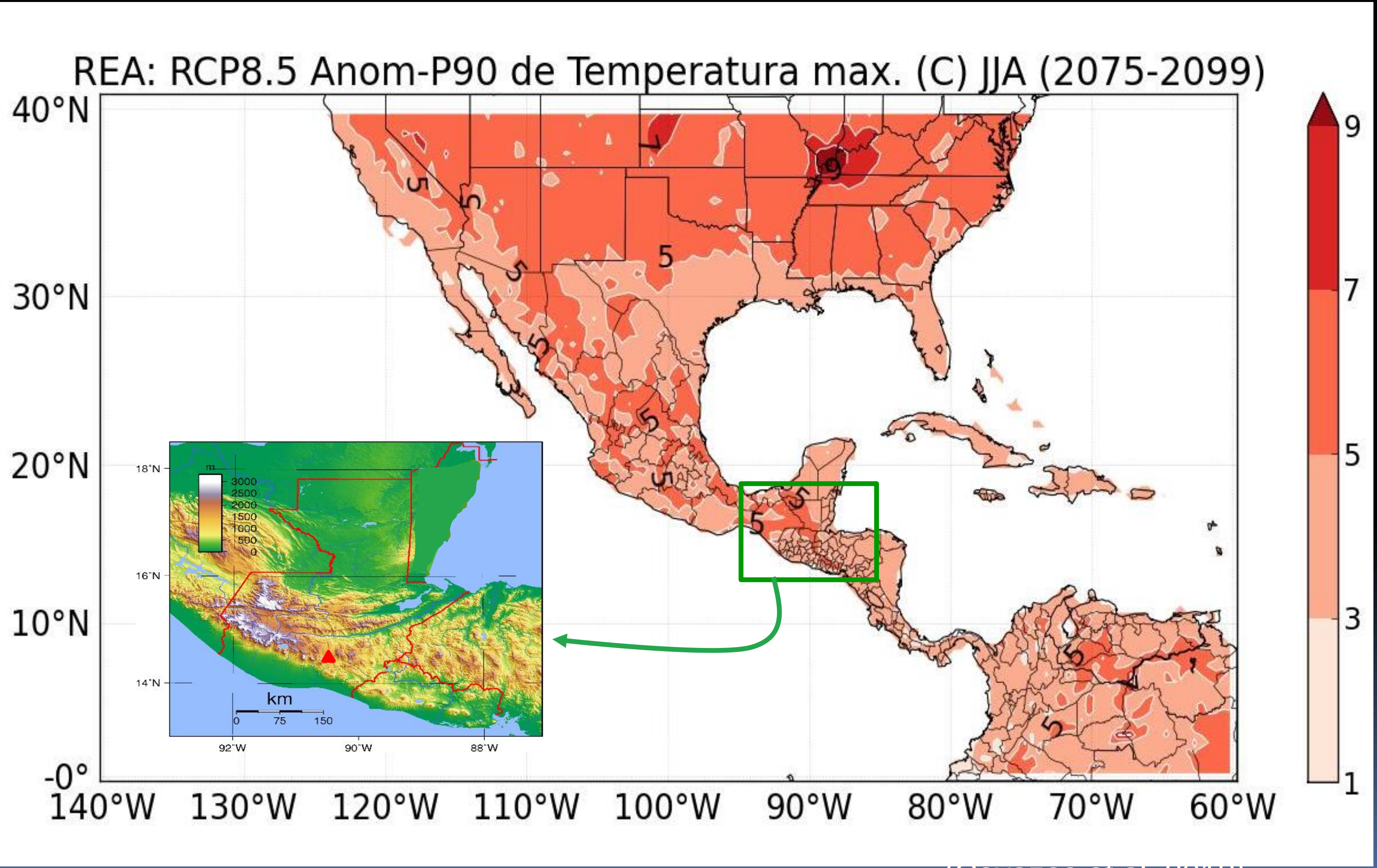




← Good approx

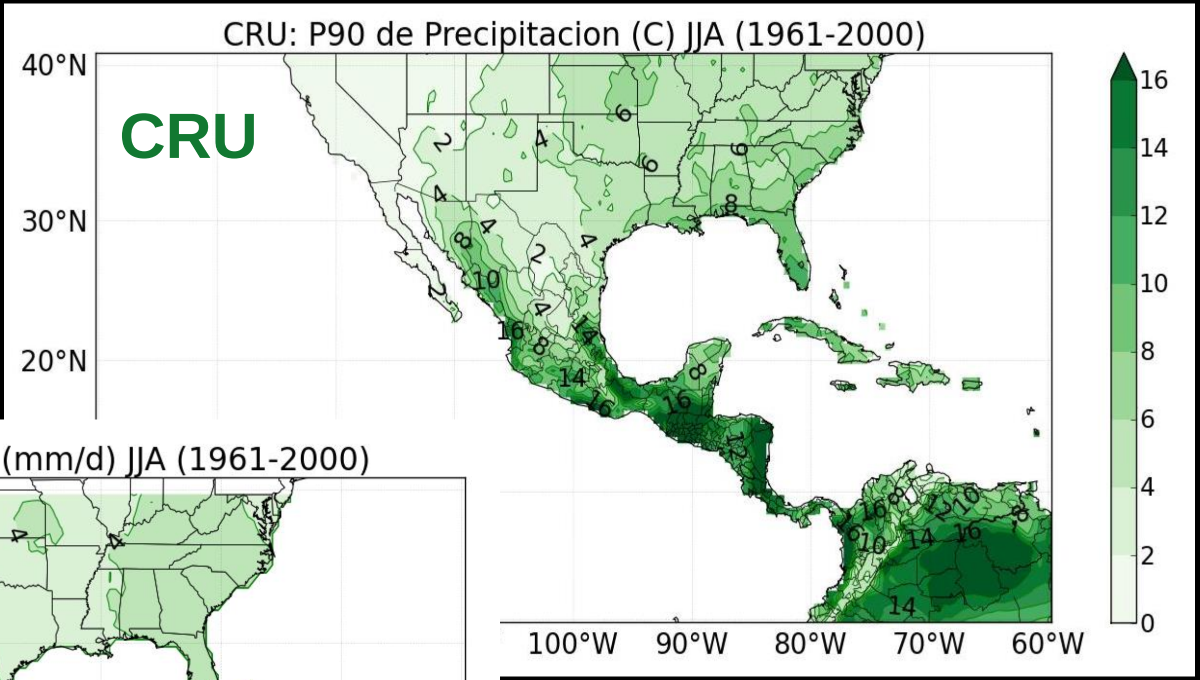
Cavazos et al. 2013

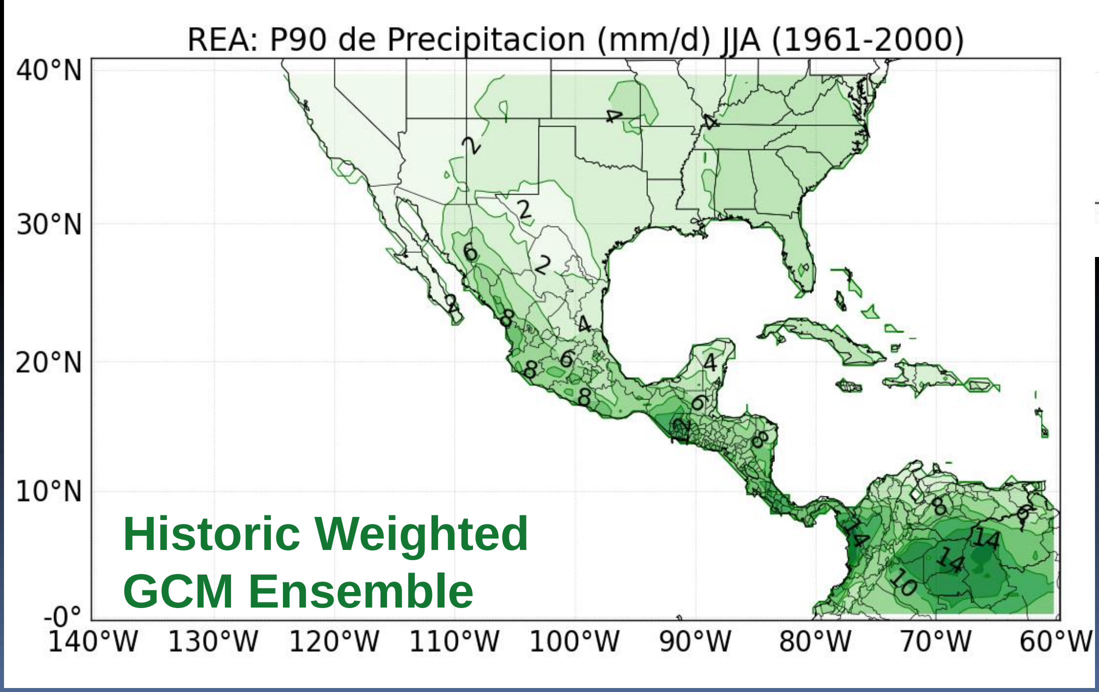
Change in the JJA P90 Threshold of Tmax, 2075-2099 minus 1961-2000 under RCP8.5



(Cavazos et al. 2013)

JJA P90 Threshold of Precip, 1961-2000

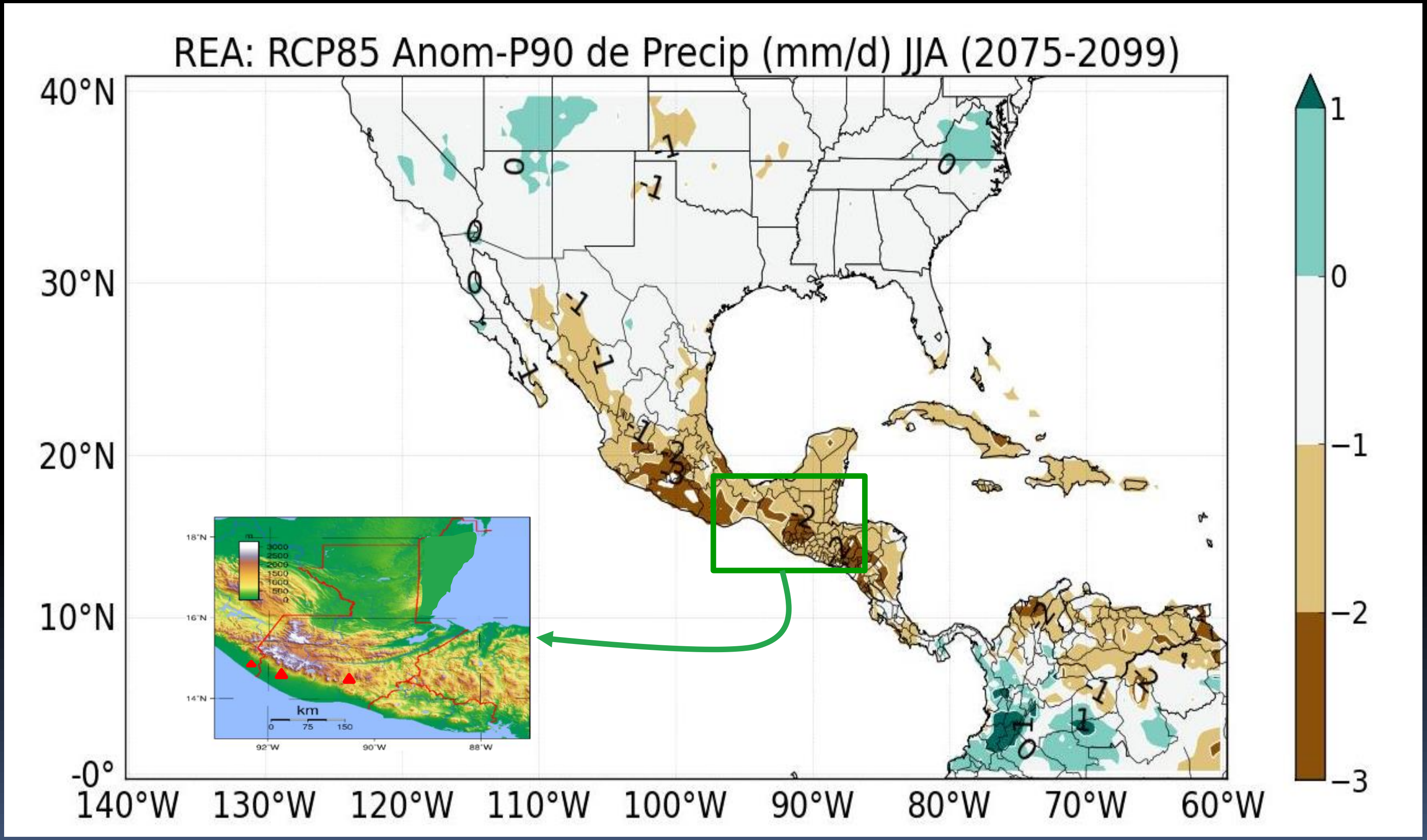




🡐 Understimation

(Cavazos et al. 2013)

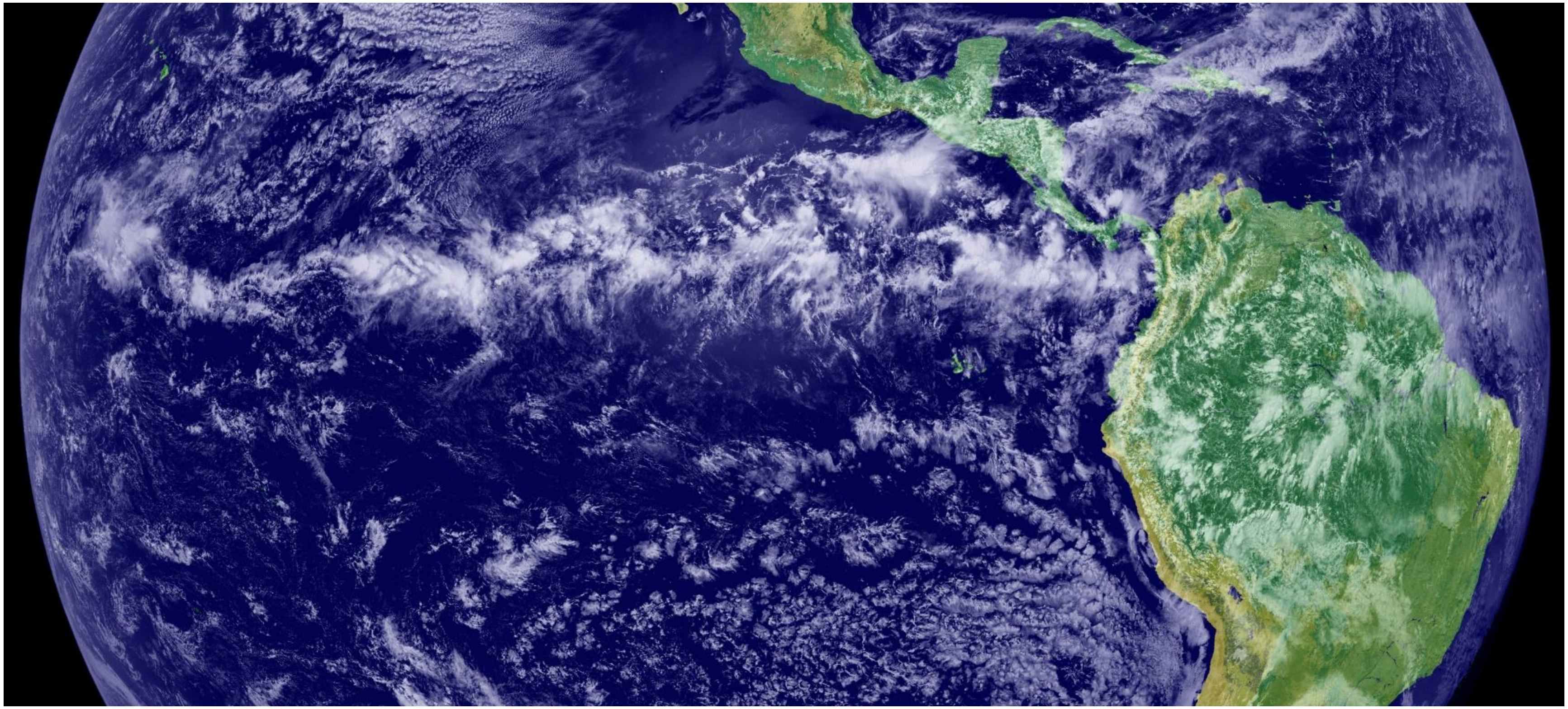
Change in the JJA P90 Threshold of Precip, 2075-2099 minus 1961-2000 under RCP8.5



(Cavazos et al. 2013)

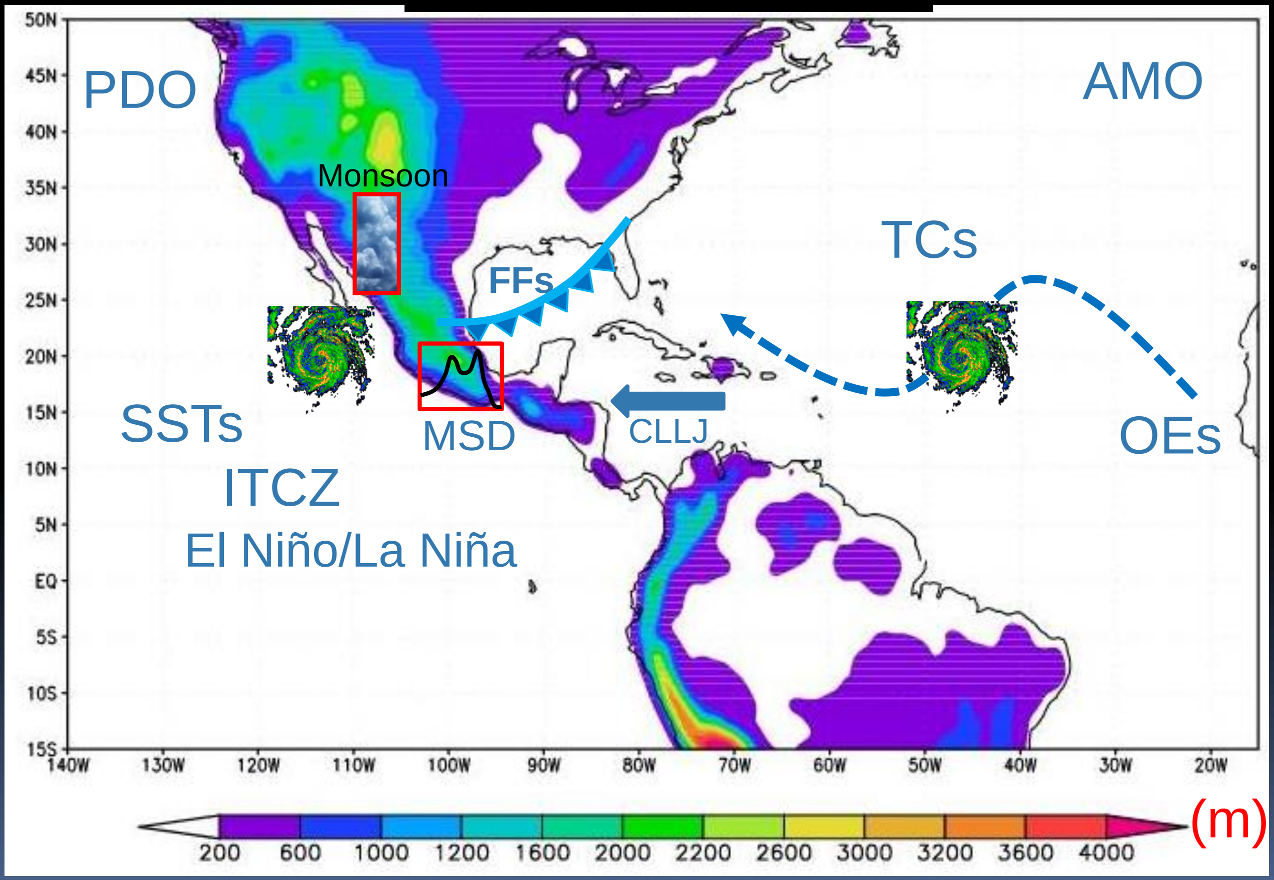
CONTENIDO

2.2 Acciones estratégicas: Estudios de procesos y Modelación regional del clima



CONTENT

5. Regional Strategic Actions



Modelación Regional

- Hacer múltipes pruebas para seleccionar el mejor GCM que va a forzar a un modelo regional
- Hacer multiples pruebas para seleccionar la mejor configuración del modelo regional
- Desarrollar de capacidades a escala regional a través de talleres de modelación, visitas académicas
- Fortalecer la colaboración científica regional para estudiar procesos y desarrollar escenarios climáticos a escala regional y local
- Promover proyectos regionales de modelación y de evaluación integrada VIA para diferentes sectores

Estrategias de investigación

Aumentar la investigación del clima, el agua y la energía

- Formación de recursos humanos y colaboraciones regionales
- Investigación básica y aplicada para comprender y predecir los fenómenos
- Desarrollos tecnológicos que resuelvan problemas de infraestructura (adaptación) y de mitigación (verdes)
- Estudios interdisciplinarios para entender los impactos
- Desarrollar mecanismos de adaptación para diferentes sectores
- Desarrollar mejores escenarios y a escalas más finas