Introduction to Regional Climate Modeling

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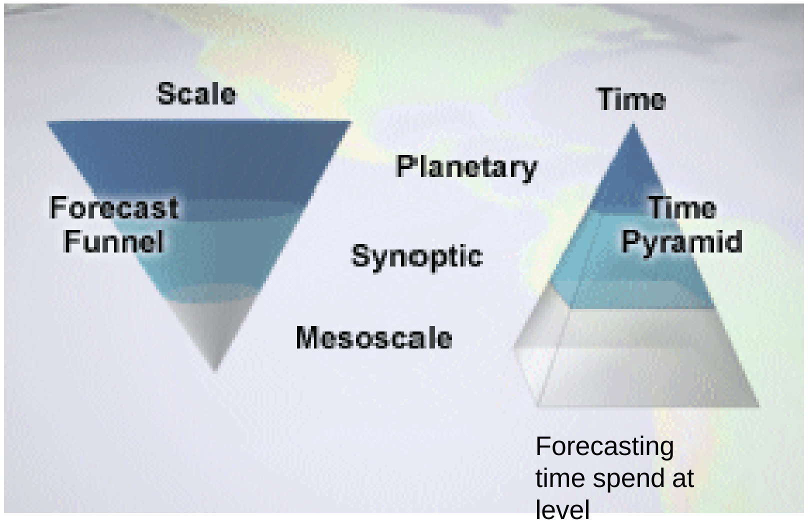
Outline

1. Regional Climate Modeling for Non-atmospheric Scientist
   - The scale problem
   - Regional Climate Model components
   - Boundary Conditions
   - Examples
2. Where to get climate modeling data
3. Exercise: Model Intercomparison

Definitions

- Regional Climate Modeling: a.k.a.
  - – Dynamical downscaling
  - – “Nested” Regional Climate Model (RCMs)
  - – Limited-Area Model (LAM)
- Nested: telescoping the domain grid size from an outermost coarse grid size to a inner domain at finer grid size.

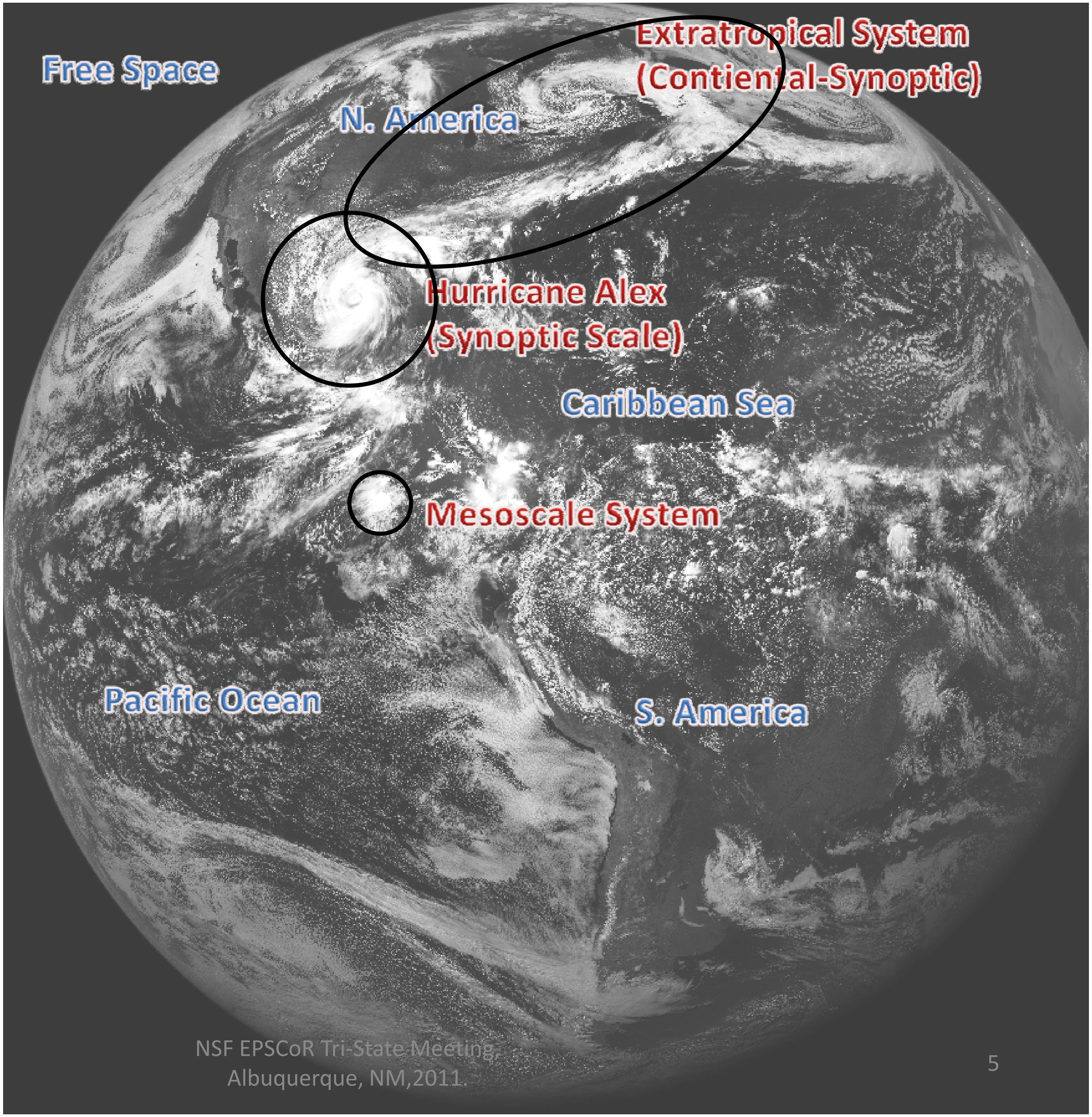
The multiscale problem



Forecasting time spend at level

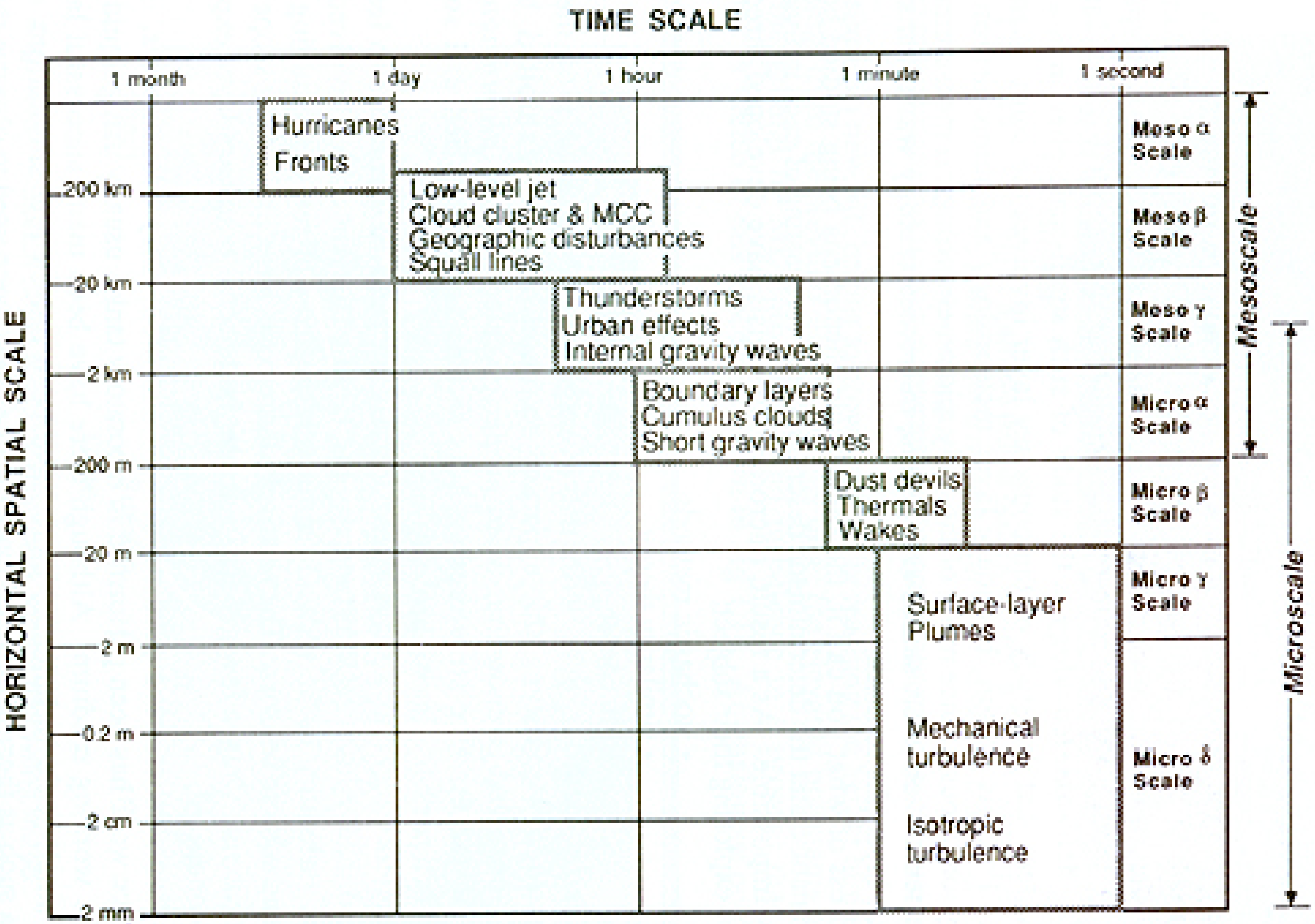
Definitions:

- Microscale (10m-1km).
- Mesoscale (~1-100km).
- Synoptic (~1000km).
- Large-scale (continental-hemispheric).
- Combinations… Cold front (mesoscale across; synoptic-scale along).



GOES Satellite visible imagery. Whites indicate clouds. Source: http://goes.gsfc.nasa.gov

…The multiscale problem..



from Stull 1988

Fig. 1.15 Typical time and space orders-of-magnitude for micro and mesoscales. (After Orlanski, 1975.)

Energy dissipation: Large Scale to Fine Scales

- Climate varies across a wide range of temporal and spatial scales.
- “Large-scale climate determines the environment for mesoscale and microscale processes that govern the weather and local climate, but, likewise, processes that occur at the regional scale may have significant impacts on the large-scale circulation.” http://www.mmm.ucar.edu/facilities/nrcm/nrcm.php

The atmospheric model: Numerical Solution of the Primitive Equations

- Navier-Stokes ***Equations of Motion*** of the atmosphere: some terms may be negligible ("Characteristic scales") depending of the simulated phenomena.
- Plus ***Conservation of Mass, and Thermal Energy Balance equations*** .
- 6 by 6 system of partial differential equations: u, v, w, P, T, Q.

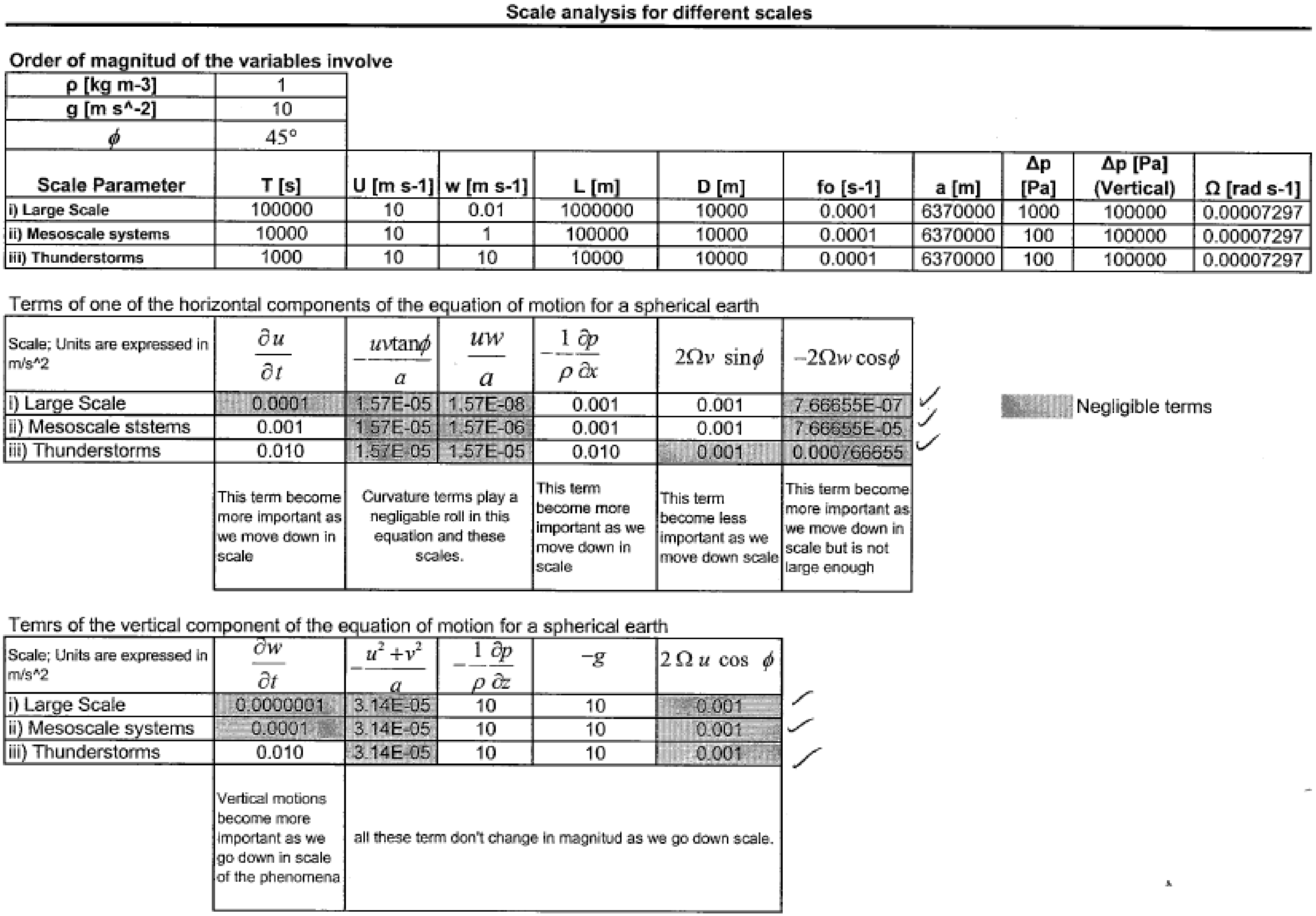
$$\frac{Du}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + fv + \nu\nabla^2 u$$

$$\frac{Dv}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial y} - fu + \nu\nabla^2 v$$

$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + \nu\nabla^2 w$$

Total derivative:

$$\frac{Da}{Dt} = u\frac{\partial a}{\partial x} + v\frac{\partial a}{\partial y} + w\frac{\partial a}{\partial z} + \frac{\partial a}{\partial t}$$



Scale analysis for different scales

Order of magnitud of the variables involve

ρ [kg m-3]	1
g [m s^-2]	10
ϕ	45°

Scale Parameter	T [s]	U [m s-1]	w [m s-1]	L [m]	D [m]	fo [s-1]	a [m]	Δp [Pa]	Δp [Pa] (Vertical)	Ω [rad s-1]
i) Large Scale	100000	10	0.01	1000000	10000	0.0001	6370000	1000	100000	0.00007297
ii) Mesoscale systems	10000	10	1	100000	10000	0.0001	6370000	100	100000	0.00007297
iii) Thunderstorms	1000	10	10	10000	10000	0.0001	6370000	100	100000	0.00007297

Terms of one of the horizontal components of the equation of motion for a spherical earth

Scale; Units are expressed in m/s^2	$\frac{\partial u}{\partial t}$	$-\frac{uv\tan\phi}{a}$	$\frac{uw}{a}$	$-\frac{1}{\rho}\frac{\partial p}{\partial x}$	$2\Omega v\ \sin\phi$	$-2\Omega w\cos\phi$	
I) Large Scale	0.0001	1.57E-05	1.57E-08	0.001	0.001	7.66655E-07	✓
ii) Mesoscale ststems	0.001	1.57E-05	1.57E-06	0.001	0.001	7.66655E-05	✓
iii) Thunderstorms	0.010	1.57E-05	1.57E-05	0.010	0.001	0.000766655	✓
	This term become more important as we move down in scale	Curvature terms play a negligable roll in this equation and these scales.		This term become more important as we move down in scale	This term become less important as we move down scale	This term become more important as we move down in scale but is not large enough	

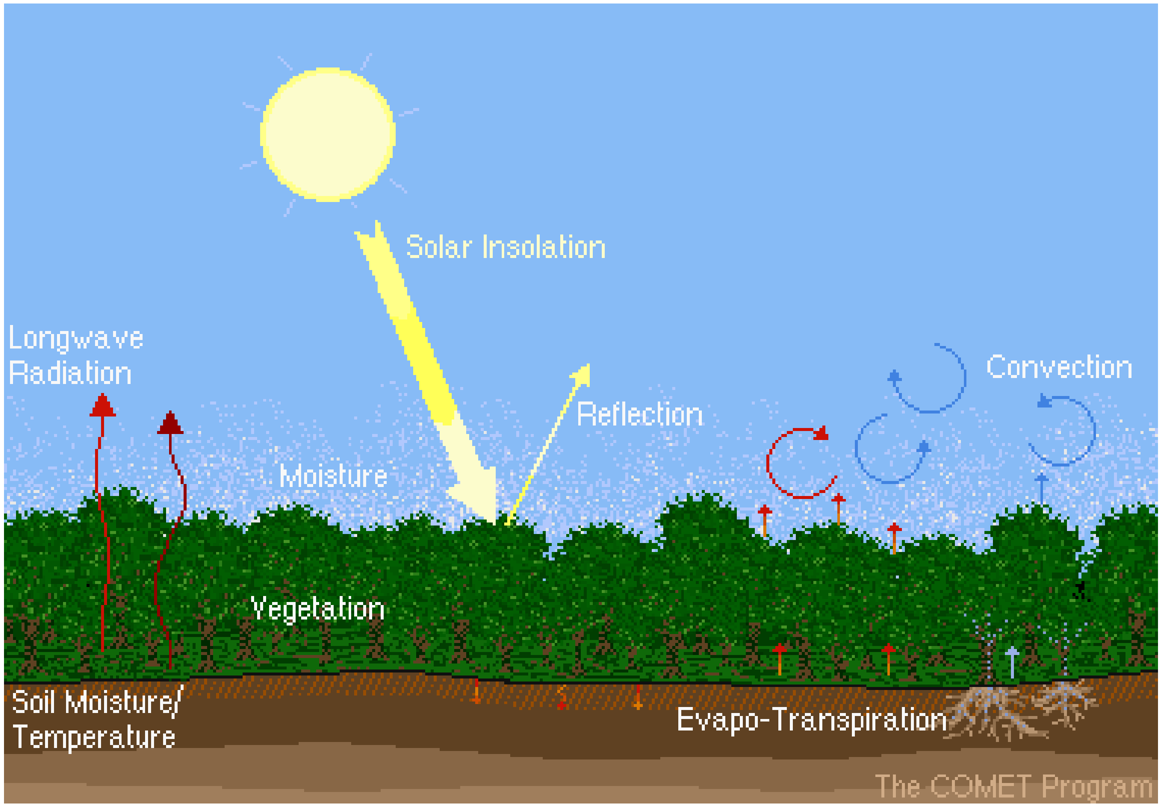
▨ Negligible terms

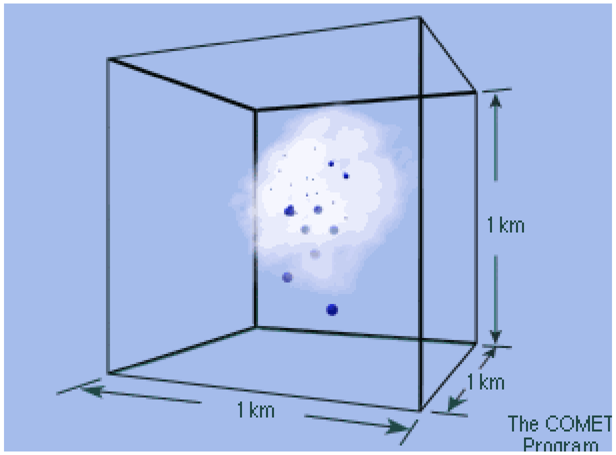
Temrs of the vertical component of the equation of motion for a spherical earth

Scale; Units are expressed in m/s^2	$\frac{\partial w}{\partial t}$	$-\frac{u^2+v^2}{a}$	$-\frac{1}{\rho}\frac{\partial p}{\partial z}$	$-g$	$2\,\Omega\,u\ \cos\ \phi$	
i) Large Scale	0.0000001	3.14E-05	10	10	0.001	✓
ii) Mesoscale systems	0.0001	3.14E-05	10	10	0.001	✓
iii) Thunderstorms	0.010	3.14E-05	10	10	0.001	✓
	Vertical motions become more important as we go down in scale of the phenomena	all these term don't change in magnitud as we go down scale.				

From Mejia, 2005, Mesoscale simulations…

The need of physical parameterization



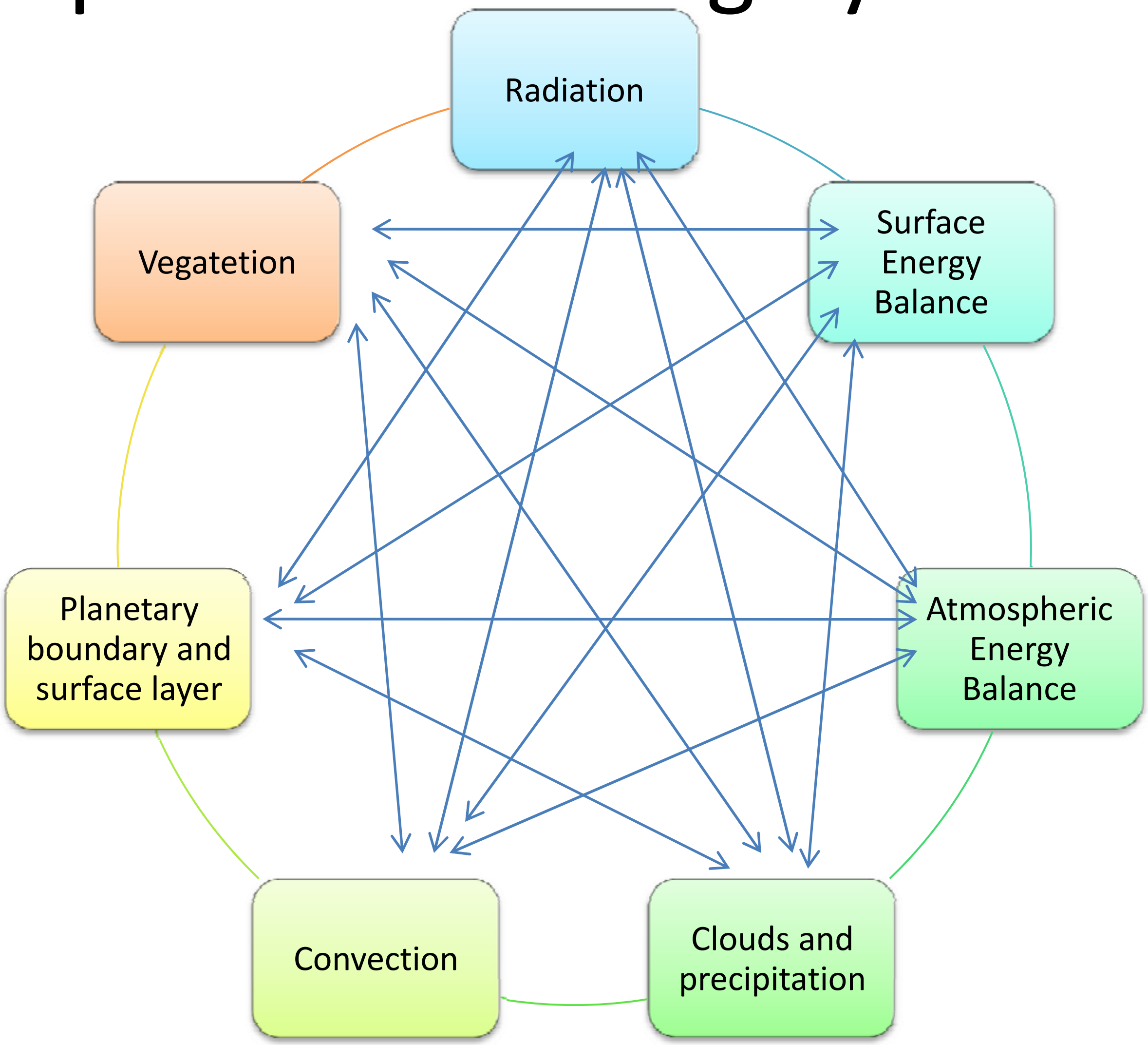


-Sub-grid scale processes solved as a spatially implicit models.

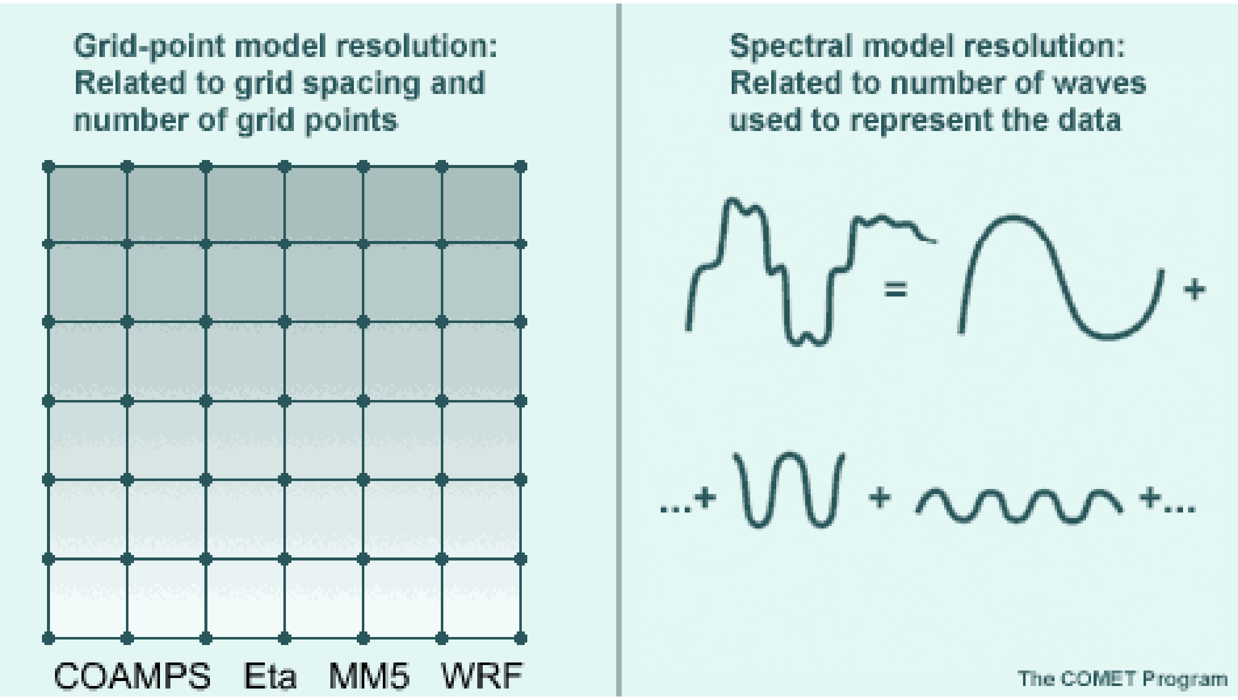
-Suffer of the scaling problem.

-Larger scale evolution of the system controls the sub-grid processes processes

However: The physics representations are scale dependent and highly inter-related



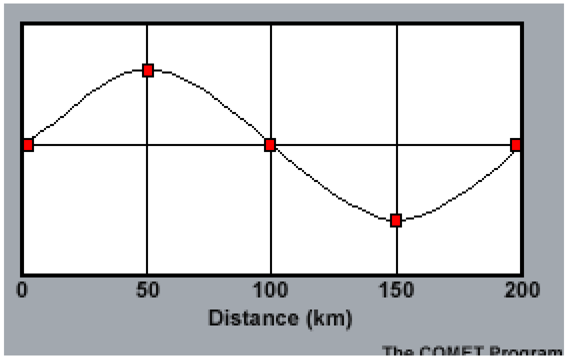
Horizontal Resolution



Grid-point model resolution: Related to grid spacing and number of grid points

Spectral model resolution: Related to number of waves used to represent the data

At least 5 points to define a wave…



Vertical Resolution

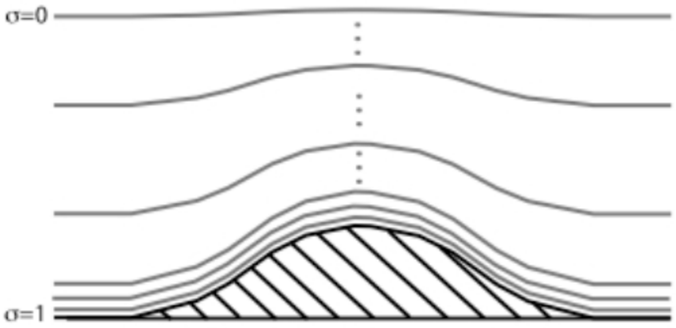


Figure 1.4. Idealized vertical cross-section showing the orientation of the sigma levels in a NWP model vertical grid over a bell-shaped ground surface. The ground is indicated by the diagonal hatching. Note how the sigma levels follow the terrain.

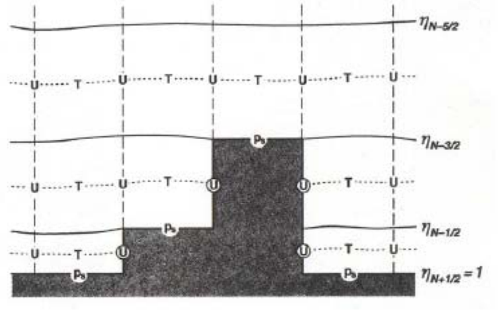


Figure 1.6. An idealized vertical cross-section of the step topography used by the Eta coordinate. Each T indicates a mass variable within the grid box, while each U represents both horizontal wind components. The quantity p_s is the surface pressure. The circled U's on the sides of the steps indicate wind points that are defined as zero at all times of the model integration. From Black (1994).

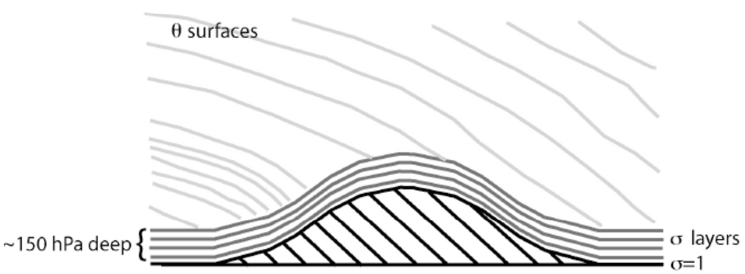
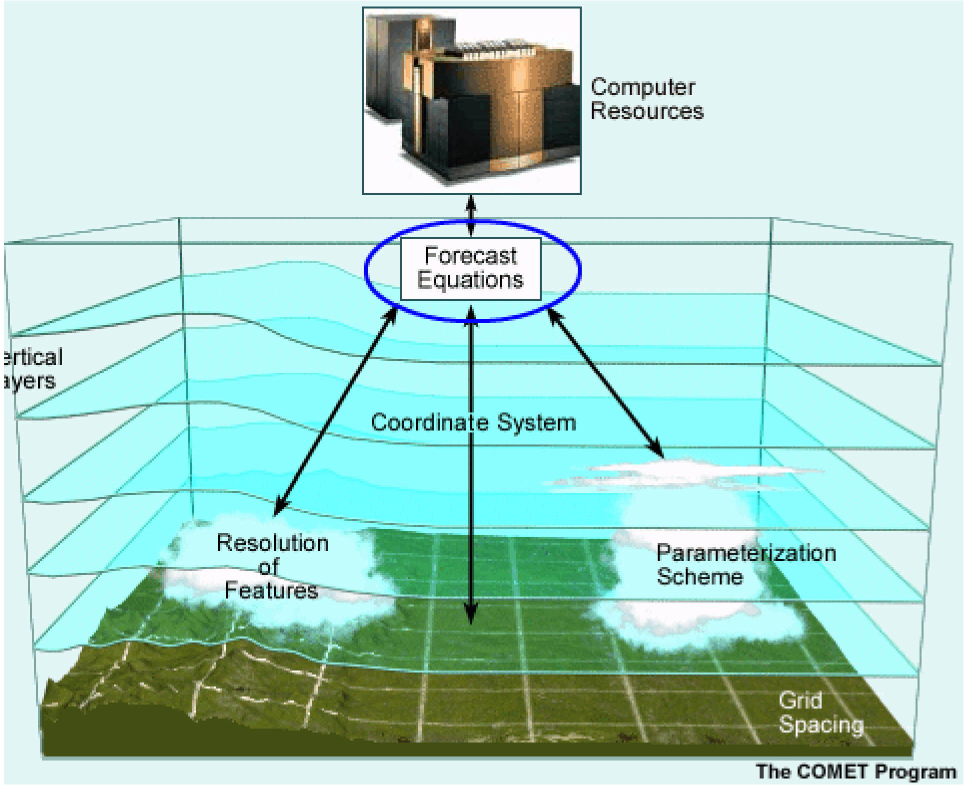


Figure 1.8. Schematic of the vertical structure of a hybrid sigma-theta coordinate system over a bell-shaped mountain. The sigma surfaces are used next to the ground surface and throughout the planetary boundary layer, while the theta surfaces are used for the free atmosphere. This provides for very good resolution of features in the boundary layer and in frontal zones.

Atmospheric Models: Numerical weather prediction and Regional Climate Model

- NWP models and RCMs require huge computational resources.
- The spatial scale we resolve such models:
  - Physical parameterizations designs for limited scales….
  - Computer resources...
  - Relevant questions…

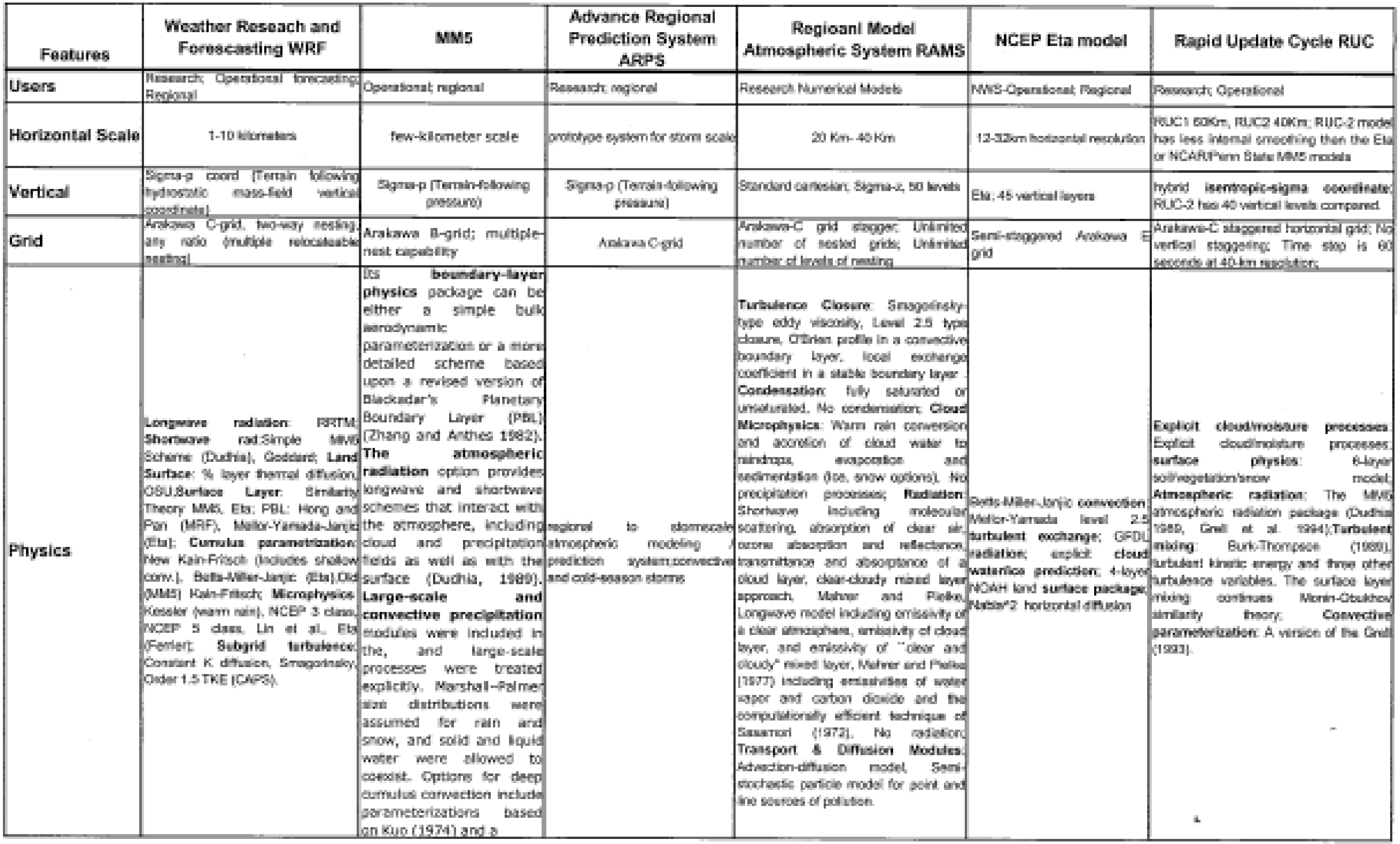


Weather vs Climate Mode

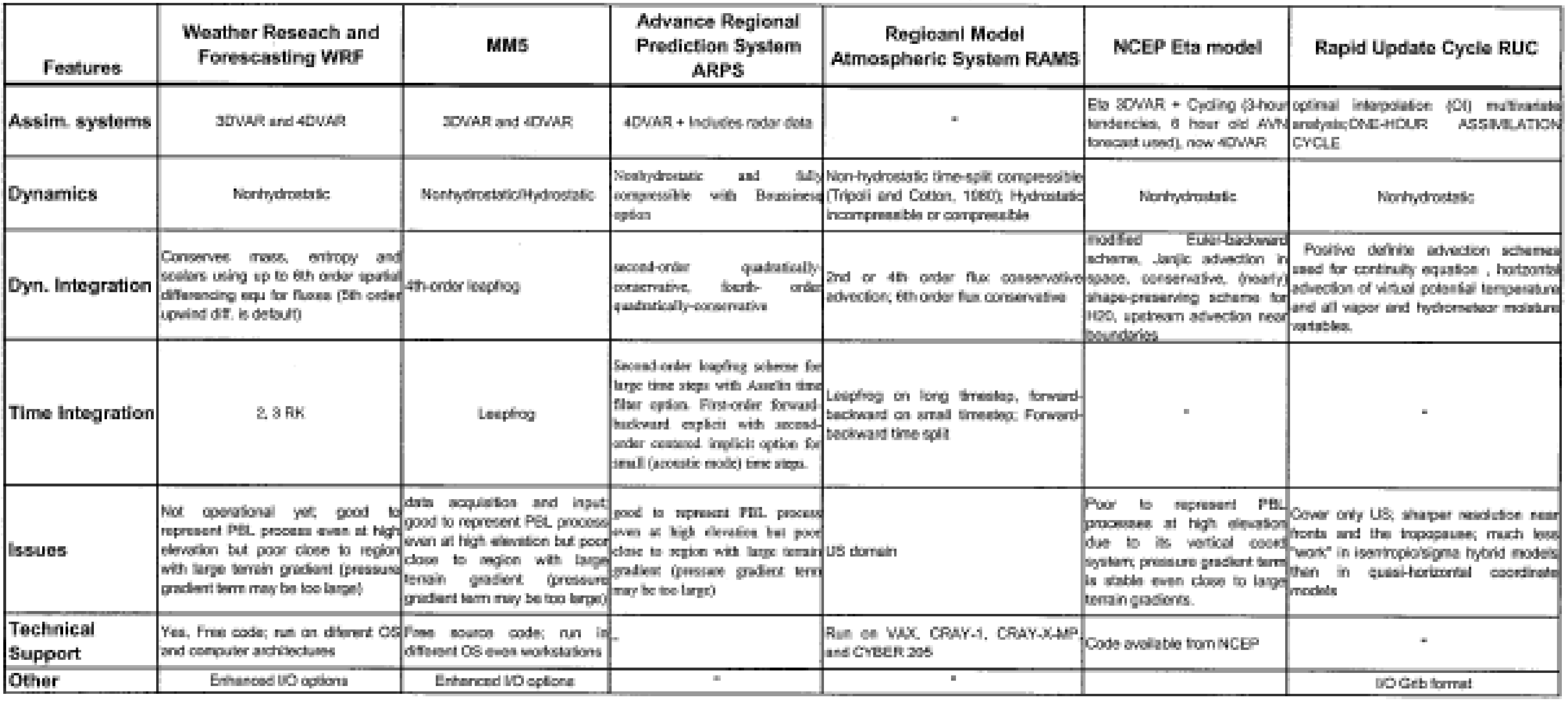
Parameter	Weather	Climate
Sea Surface Temperatures (SSTs)	Kept constant as observed during initial time integration of the model	Prescribed and updated regularly, e.g., 6-hourly or daily…From observed or simulated SSTs
Albedo and Vegetation	constant	Prescribed fields: e.g., based on long-term monthly means
Green house gases, ozone, and aerosol concentrations	constant	Prescribed observed or predicted trends
Bottom soil layer	constant	Updated fields

Regional Climate Models (Mesoscale Models)

- The Weather Research and Forecasting (WRF) Model http://www.wrf-model.org/index.php: NCAR, NOAA/NCEP, FSL, FWA, NRL, Univ. of Oklahoma, FAA.
- CRCM – Canadian Regional Model http://cccsn.ca/?page=download-crcm
- ECPC RSM – Scripps Regional Spectral Model
- MM5 – NCAR/PSU model
- HadRM3 - Hadley Center regional model v. 3
- Regional Climate Model (RegCM): The International Centre for Theoretical Physics http://users.ictp.it/~pubregcm/RegCM3/



Features	Weather Reseach and Forescasting WRF	MM5	Advance Regional Prediction System ARPS	Regioani Model Atmospheric System RAMS	NCEP Eta model	Rapid Update Cycle RUC
Users	Research; Operational forecasting; Regional	Operational; regional	Research; regional	Research Numerical Models	NWS-Operational; Regional	Research; Operational
Horizontal Scale	1-10 kilometers	few-kilometer scale	prototype system for storm scale	20 Km- 40 Km	12-32km horizontal resolution	RUC1 60Km, RUC2 40Km; RUC-2 model has less internal smoothing than the Eta or NCAR/Penn State MM5 models
Vertical	Sigma-p coord (Terrain following hydrostatic mass-field vertical coordinate)	Sigma-p (Terrain-following pressure)	Sigma-p (Terrain-following pressure)	Standard cartesian; Sigma-z, 50 levels	Eta; 45 vertical layers	hybrid **isentropic-sigma coordinate**; RUC-2 has 40 vertical levels compared.
Grid	Arakawa C-grid, two-way nesting, any ratio (multiple relocateable nesting)	Arakawa B-grid; multiple-nest capability	Arakawa C-grid	Arakawa-C grid stagger; Unlimited number of nested grids; Unlimited number of levels of nesting	Semi-staggered Arakawa E grid	Arakawa-C staggered horizontal grid; No vertical staggering; Time step is 60 seconds at 40-km resolution;
Physics	**Longwave radiation**: RRTM; **Shortwave** rad:Simple MM5 Scheme (Dudhia), Goddard; **Land Surface**: % layer thermal diffusion, OSU,**Surface Layer**: Similarity Theory MM5, Eta; PBL: Hong and Pan (MRF), Mellor-Yamada-Janjic (Eta); **Cumulus parametrization**: New Kain-Fritsch (includes shallow conv.), Betts-Miller-Janjic (Eta),Old (MM5) Kain-Fritsch; **Microphysics**: Kessler (warm rain), NCEP 3 class, NCEP 5 class, Lin et al., Eta (Ferrier); **Subgrid turbulence**: Constant K diffusion, Smagorinsky, Order 1.5 TKE (CAPS).	Its **boundary-layer physics** package can be either a simple bulk aerodynamic parameterization or a more detailed scheme based upon a revised version of Blackadar's Planetary Boundary Layer (PBL) (Zhang and Anthes 1982). **The atmospheric radiation** option provides longwave and shortwave schemes that interact with the atmosphere, including cloud and precipitation fields as well as with the surface (Dudhia, 1989). **Large-scale and convective precipitation** modules were included in the, and large-scale processes were treated explicitly. Marshall–Palmer size distributions were assumed for rain and snow, and solid and liquid water were allowed to coexist. Options for deep cumulus convection include parameterizations based on Kuo (1974) and a	regional to stormscale atmospheric modeling / prediction system;convective and cold-season storms	**Turbulence Closure**: Smagorinsky-type eddy viscosity, Level 2.5 type closure, O'Brien profile in a convective boundary layer, local exchange coefficient in a stable boundary layer . **Condensation**: fully saturated or unsaturated. No condensation; **Cloud Microphysics**: Warm rain conversion and accretion of cloud water to raindrops, evaporation and sedimentation (Ice, snow options). No precipitation processes; **Radiation**: Shortwave including molecular scattering, absorption of clear air, ozone absorption and reflectance, transmittance and absorptance of a cloud layer, clear-cloudy mixed layer approach, Mahrer and Pielke, Longwave model including emissivity of a clear atmosphere, emissivity of cloud layer, and emissivity of ``clear and cloudy" mixed layer, Mahrer and Pielke (1977) including emissivities of water vapor and carbon dioxide and the computationally efficient technique of Sasamori (1972). No radiation; **Transport & Diffusion Modules**: Advection-diffusion model, Semi-stochastic particle model for point and line sources of pollution.	Betts-Miller-Janjic **convection**; Mellor-Yamada level 2.5 **turbulent exchange**; GFDL **radiation**; explicit **cloud water/ice prediction**; 4-layer NOAH land **surface package**; Nabla*2 horizontal diffusion	**Explicit cloud/moisture processes**: Explicit cloud/moisture processes; **surface physics**: 6-layer soil/vegetation/snow model; **Atmospheric radiation**: The MM5 atmospheric radiation package (Dudhia 1989, Grell et al. 1994);**Turbulent mixing**: Burk-Thompson (1989), turbulent kinetic energy and three other turbulence variables. The surface layer mixing continues Monin-Obukhov similarity theory; **Convective parameterization**: A version of the Grell (1993).



Features	Weather Reseach and Forescasting WRF	MM5	Advance Regional Prediction System ARPS	Regioani Model Atmospheric System RAMS	NCEP Eta model	Rapid Update Cycle RUC
Assim. systems	3DVAR and 4DVAR	3DVAR and 4DVAR	4DVAR + Includes radar data	*	Eta 3DVAR + Cycling (3-hour tendencies, 6 hour old AVN forecast used), now 4DVAR	optimal interpolation (OI) multivariate analysis;ONE-HOUR ASSIMILATION CYCLE
Dynamics	Nonhydrostatic	Nonhydrostatic/Hydrostatic	Nonhydrostatic and fully compressible with Boussinesq option	Non-hydrostatic time-split compressible (Tripoli and Cotton, 1980); Hydrostatic incompressible or compressible	Nonhydrostatic	Nonhydrostatic
Dyn. Integration	Conserves mass, entropy and scalars using up to 6th order spatial differencing equ for fluxes (5th order upwind diff. is default)	4th-order leapfrog	second-order quadratically-conservative, fourth- order quadratically-conservative	2nd or 4th order flux conservative advection; 6th order flux conservative	modified Euler-backward scheme, Janjic advection in space, conservative, (nearly) shape-preserving scheme for H2O, upstream advection near boundaries	Positive definite advection schemes used for continuity equation , horizontal advection of virtual potential temperature and all vapor and hydrometeor moisture variables.
Time Integration	2, 3 RK	Leapfrog	Second-order leapfrog scheme for large time steps with Asselin time filter option. First-order forward-backward explicit with second-order centered implicit option for small (acoustic mode) time steps.	Leapfrog on long timestep, forward-backward on small timestep; Forward-backward time split	*	*
Issues	Not operational yet; good to represent PBL process even at high elevation but poor close to region with large terrain gradient (pressure gradient term may be too large)	data acquisition and input; good to represent PBL process even at high elevation but poor close to region with large terrain gradient (pressure gradient term may be too large)	good to represent PBL process even at high elevation but poor close to region with large terrain gradient (pressure gradient term may be too large)	US domain	Poor to represent PBL processes at high elevation due to its vertical coord system; pressure gradient term is stable even close to large terrain gradients.	Cover only US; sharper resolution near fronts and the tropopause; much less "work" in isentropic/sigma hybrid models than in quasi-horizontal coordinate models
Technical Support	Yes, Free code; run on different OS and computer architectures	Free source code; run in different OS even workstations	-	Run on VAX, CRAY-1, CRAY-X-MP, and CYBER 205	Code available from NCEP	*
Other	Enhanced I/O options	Enhanced I/O options	*	*		I/O Grib format

Appropriate Spatial-Temporal scales

- Large-scale climate determines the environment for mesoscale and microscale processes that govern the weather and local climate.
- The finer the scales the better the model solutions?

  Well, we know that topography, lakes and land-sea contrast, vegetation and land use are better represented…….
- but, are the physical schemes scale-invariant?

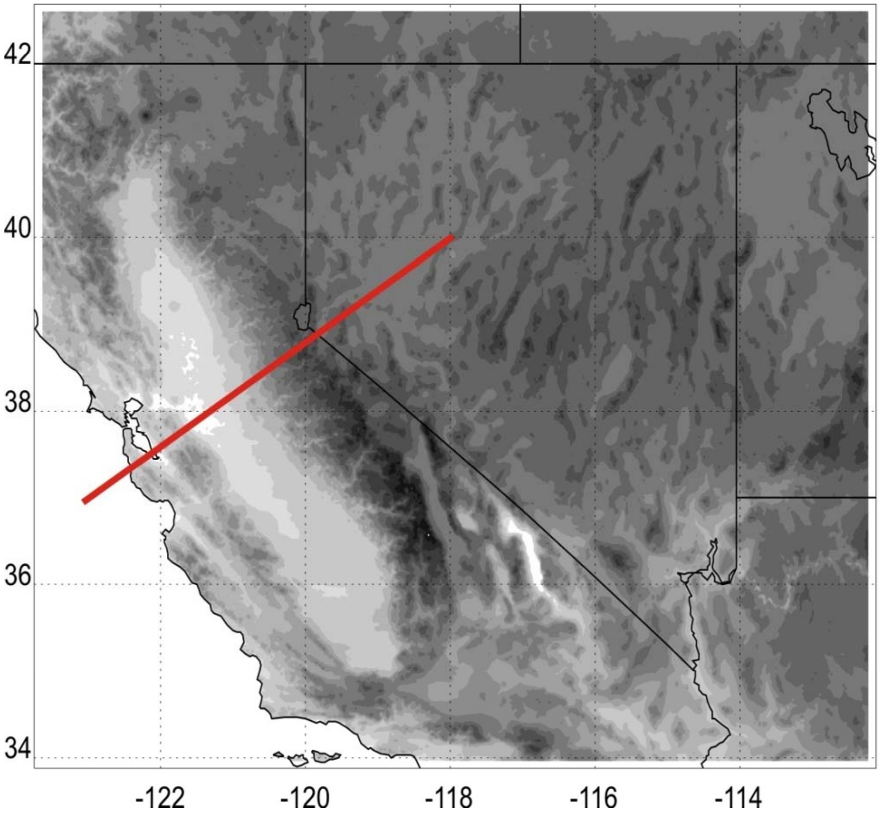
…Appropriate Spatial-Temporal scales

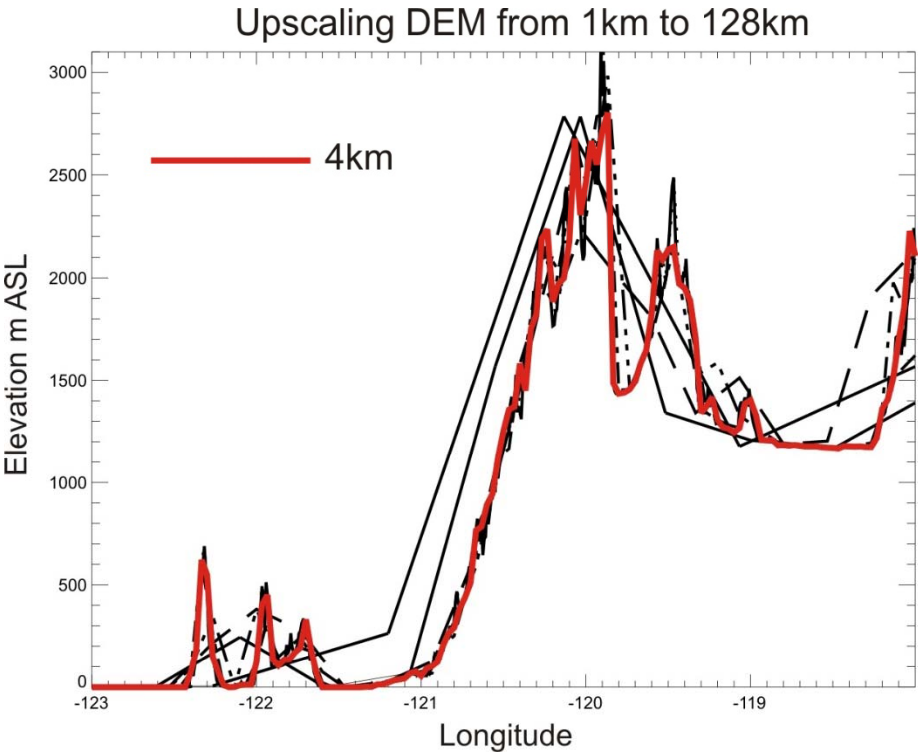
- Consequently, the model can better resolve the effects of underlying topography/surface forcing and mesoscale circulations. Examples of these are processes strongly forced by topography:
  - orographic precipitation
  - monsoon circulations.

However,

- *The sensitivity* of physics parameterizations to model grid-spacing may overwhelm any benefits of higher resolution simulation.

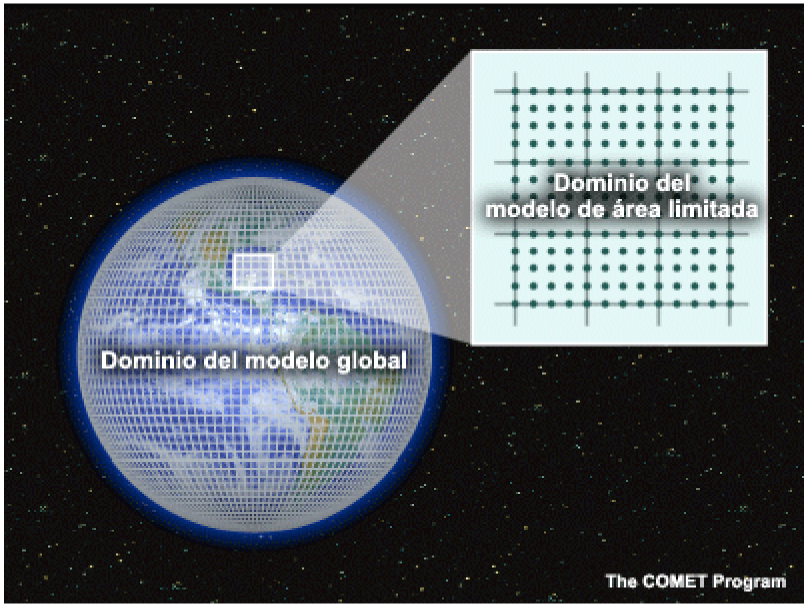
topography comparison





RCM domain

Global Climate Model (GCM) provides the lateral boundary conditions (LBC) for the RCM

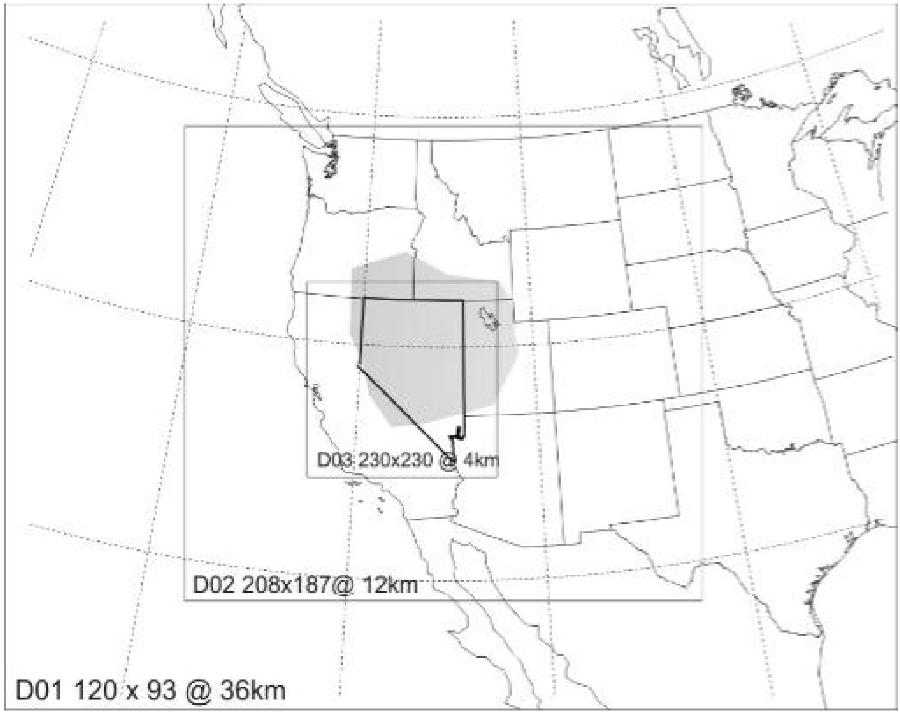


It is impractical to run a Atmospheric and Oceanic **GCMs** (AGCM and OGCM) at scales ~ 10km

GCM

GCM

GCM



GCM

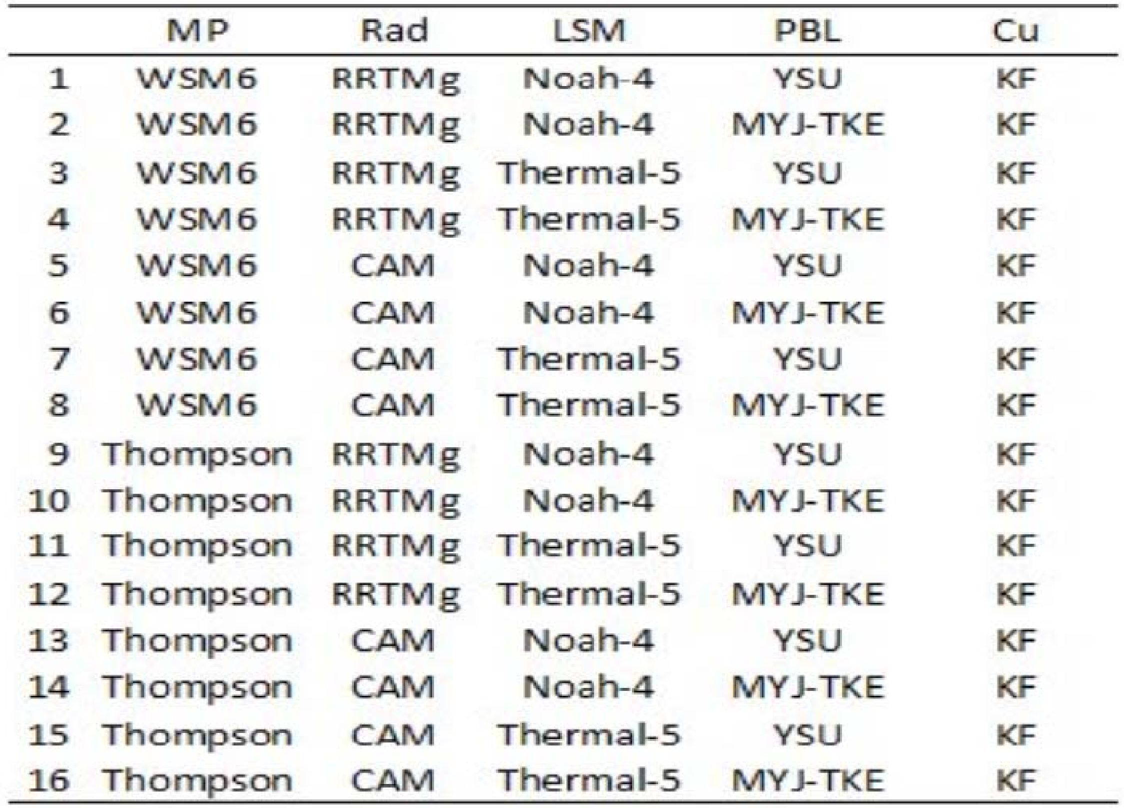
Nested RCM for dynamical downscaling over the SW North America (at 36 km grid size), the Great Basin (at 12km grid size) & Tri-State, and Nevada (at 4km grid size). Gray shadings represent approximate location of the Great Basin region.

The importance of the Lateral Boundary Conditions (LBCs)

- RCM solution vary with:
  - Size of the computational domain,
  - Location
  - Season
- LBCs provided with high temporal resolution to capture the temporal variations of large-scale flow.
- Some RCMs also use “nudging” or relaxation of large scales in the interior of the domain; minimizes distortion of the large scales inside the RCMs domain, although it can also ***<u>HIDE</u>*** model biases.

Regional Climate Model:
Weather and Research Forecasting (WRF) model
Maintained by NCAR http://www.wrf-model.org/

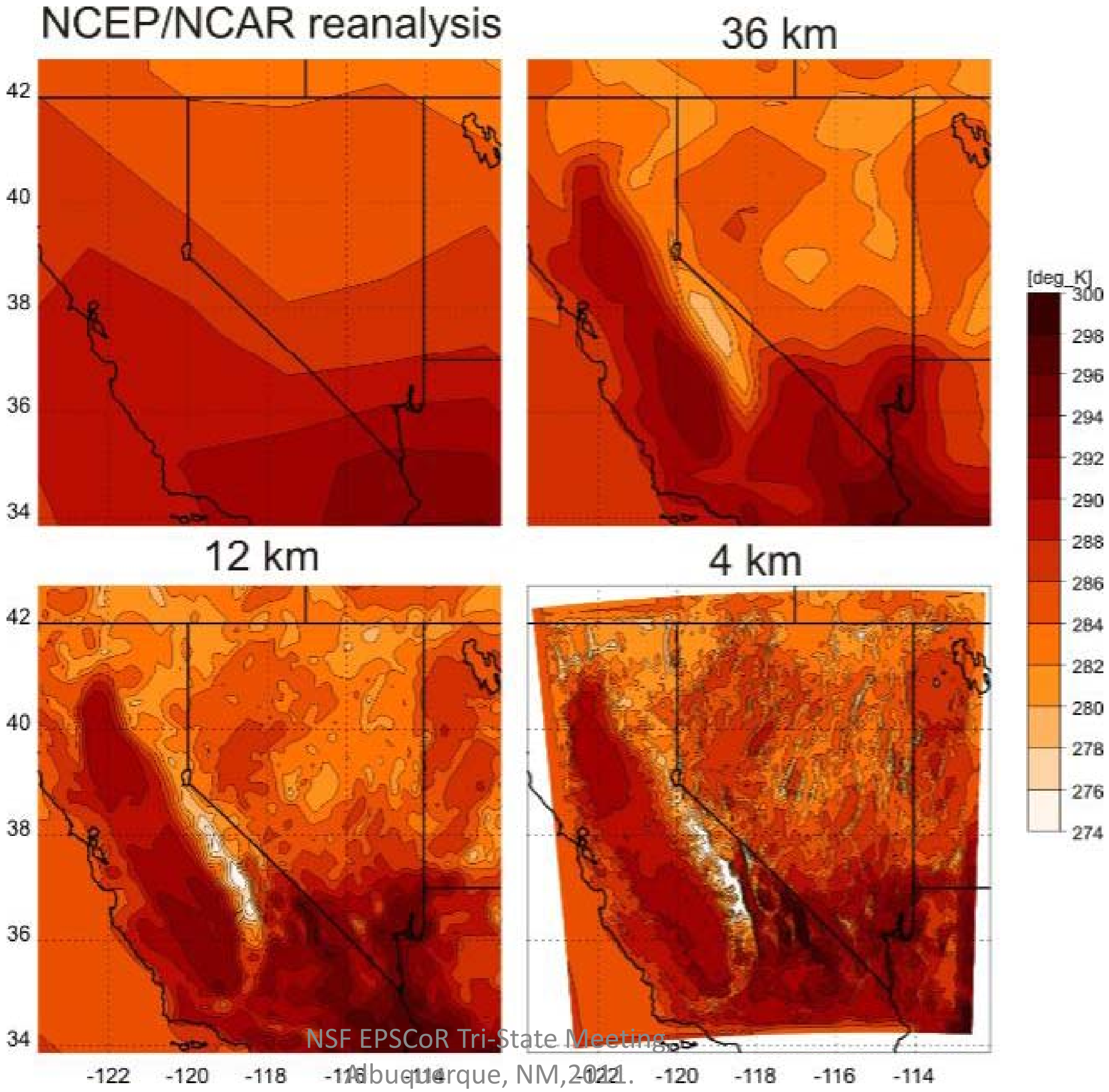
Does physic schemes selection affect the predictions?



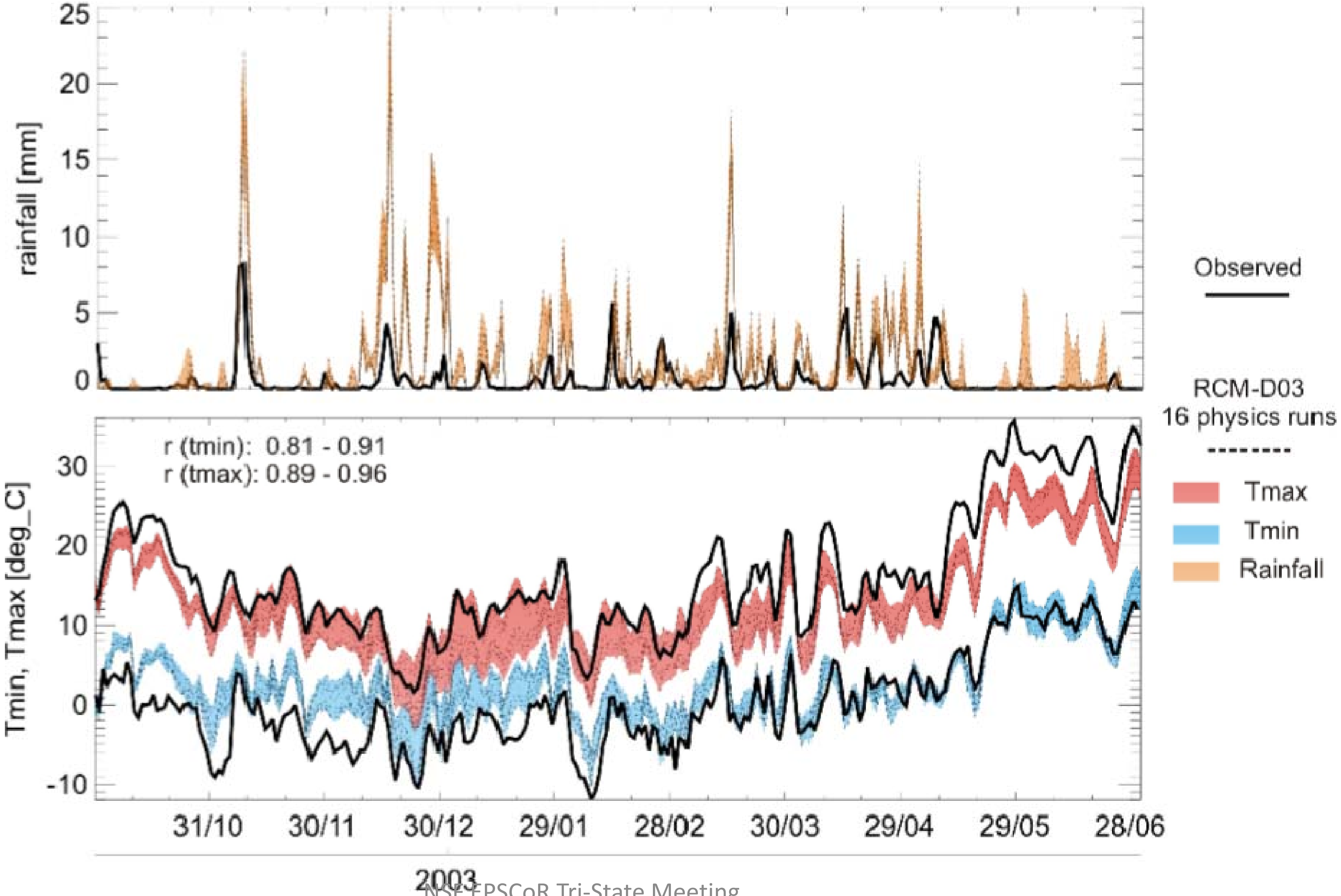
	MP	Rad	LSM	PBL	Cu
1	WSM6	RRTMg	Noah-4	YSU	KF
2	WSM6	RRTMg	Noah-4	MYJ-TKE	KF
3	WSM6	RRTMg	Thermal-5	YSU	KF
4	WSM6	RRTMg	Thermal-5	MYJ-TKE	KF
5	WSM6	CAM	Noah-4	YSU	KF
6	WSM6	CAM	Noah-4	MYJ-TKE	KF
7	WSM6	CAM	Thermal-5	YSU	KF
8	WSM6	CAM	Thermal-5	MYJ-TKE	KF
9	Thompson	RRTMg	Noah-4	YSU	KF
10	Thompson	RRTMg	Noah-4	MYJ-TKE	KF
11	Thompson	RRTMg	Thermal-5	YSU	KF
12	Thompson	RRTMg	Thermal-5	MYJ-TKE	KF
13	Thompson	CAM	Noah-4	YSU	KF
14	Thompson	CAM	Noah-4	MYJ-TKE	KF
15	Thompson	CAM	Thermal-5	YSU	KF
16	Thompson	CAM	Thermal-5	MYJ-TKE	KF

Microphysics (MP); short- and long-wave radiation (Rad); Land Surface Model (LSM); Planetary Boundary Layer (PBL); Cumulus physics (Cu)

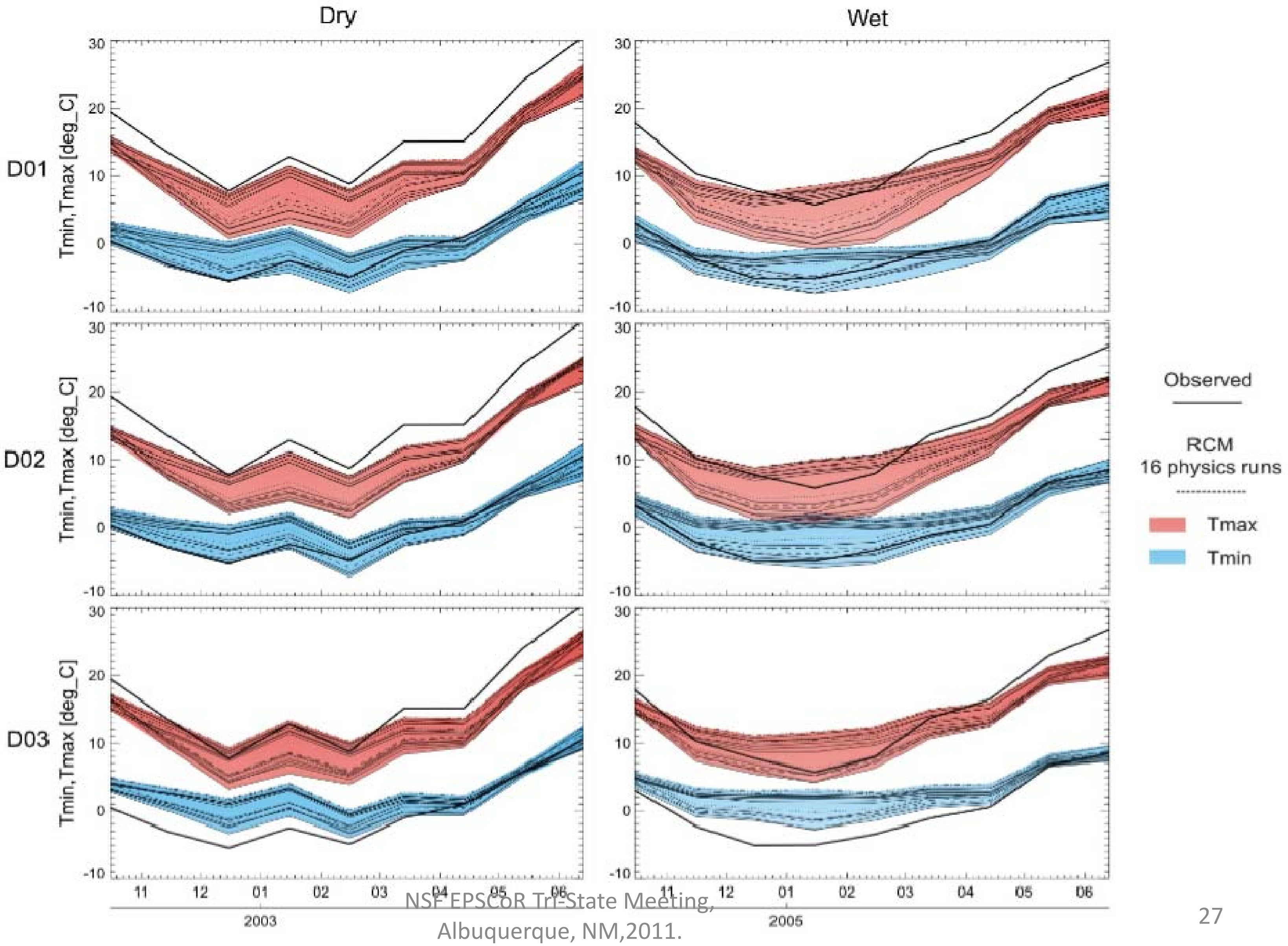
From GCM ~250km to 4km Mean Temperature



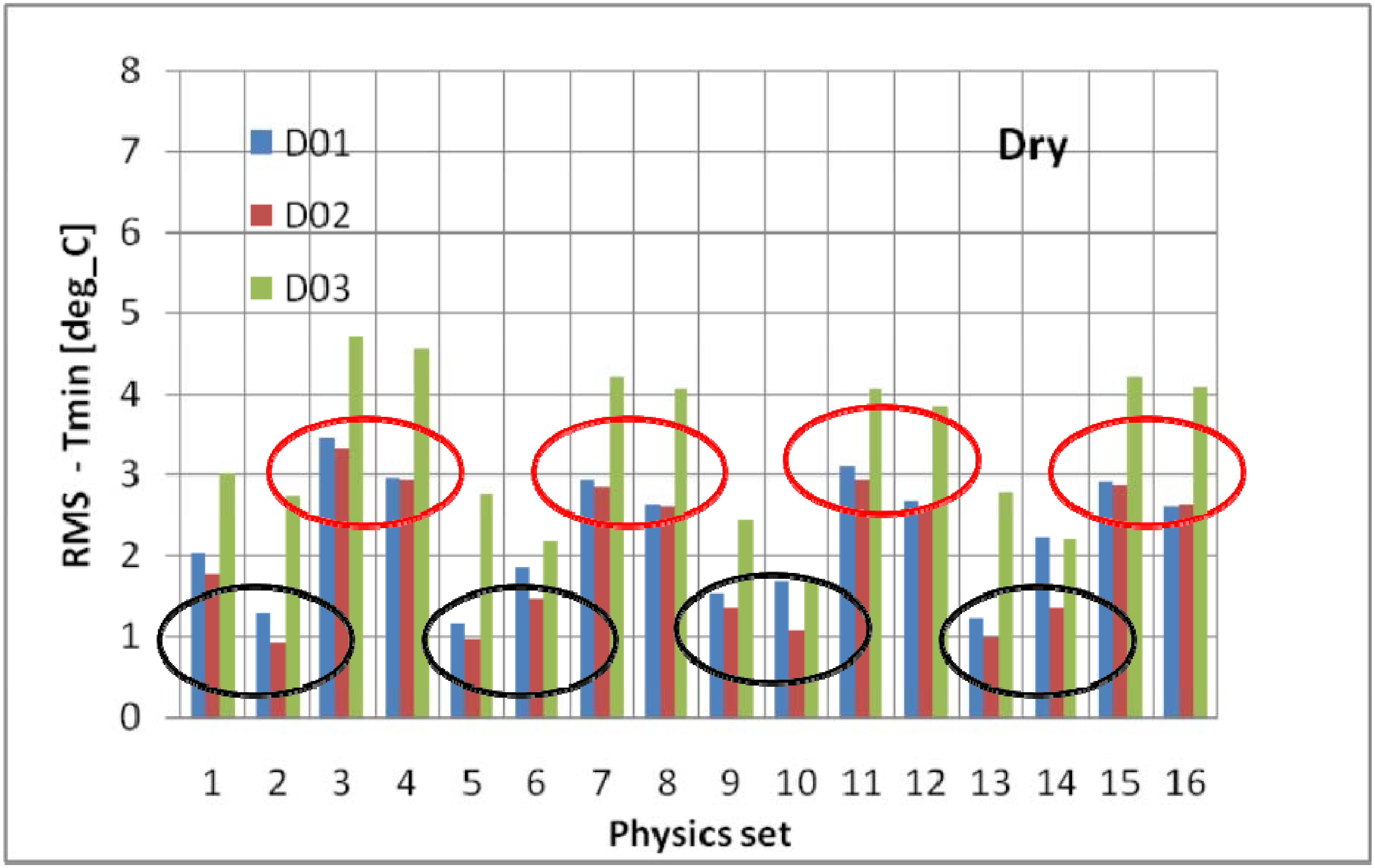
Day-to-day Variability



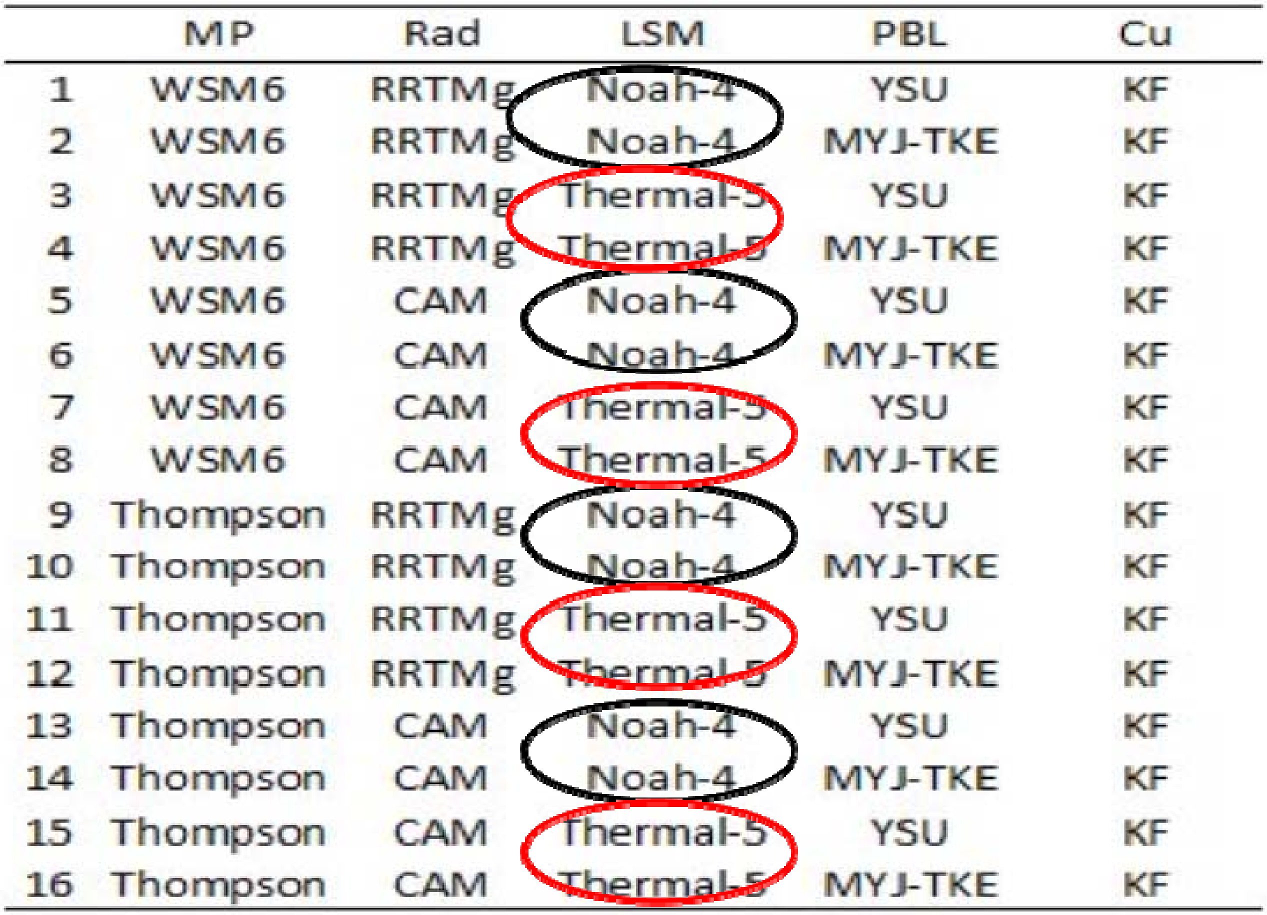
Monthly Means



RMS Error: Minimum Temperature



Regional Climate Modeling:
Weather and Research Forecasting (WRF) model



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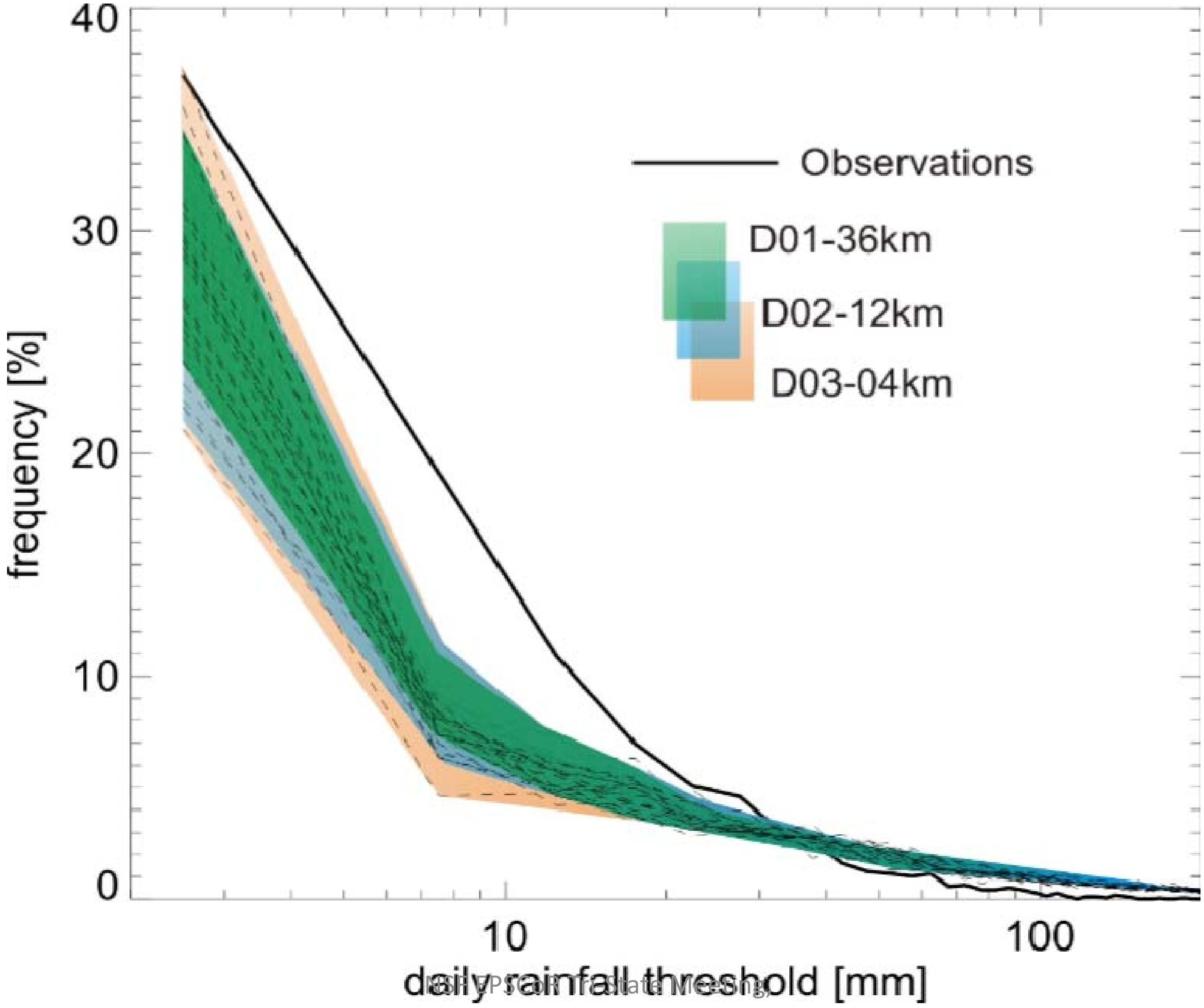
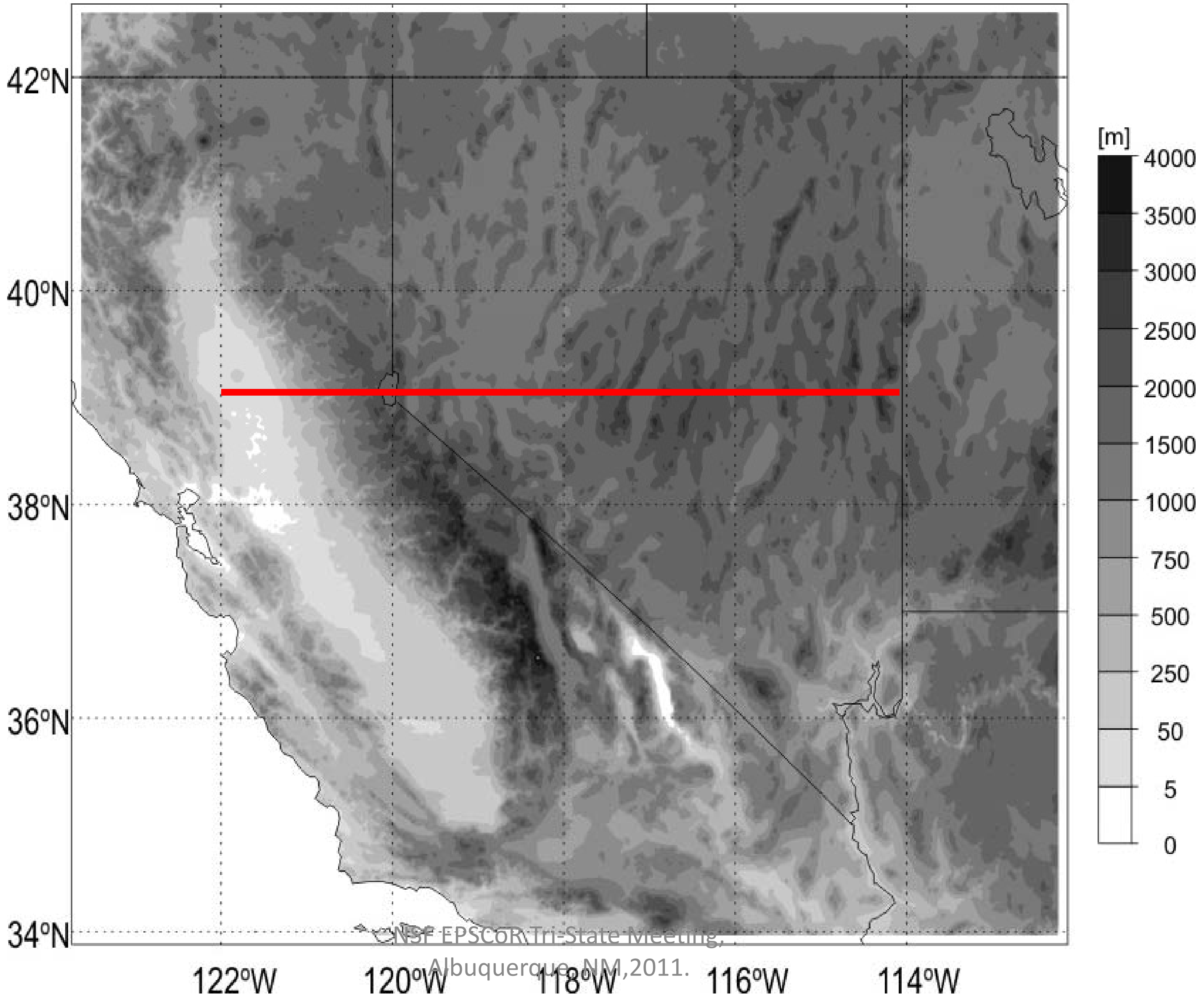
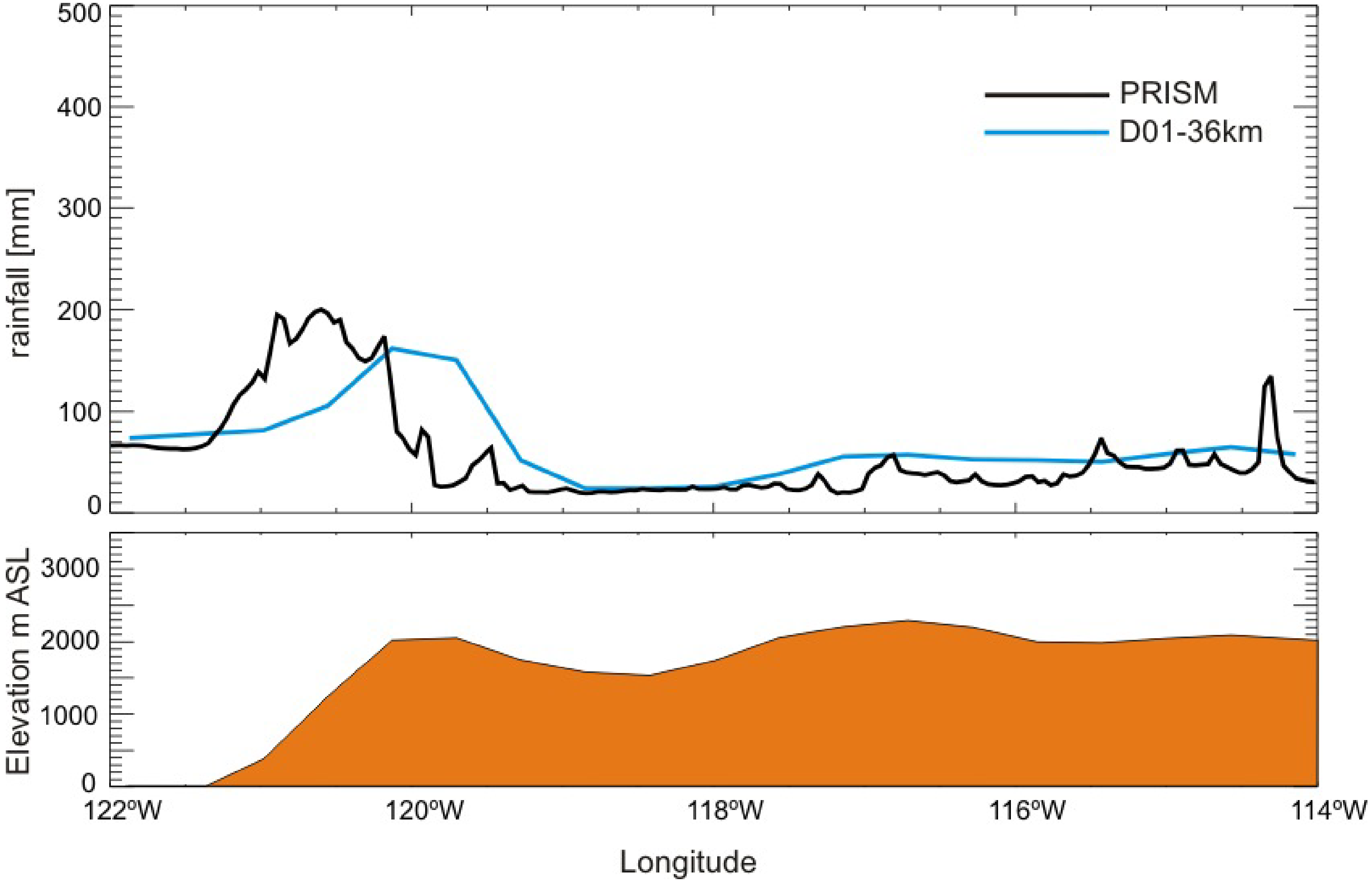
15	Thompson	CAM	Thermal-5	YSU	KF
16	Thompson	CAM	Thermal-5	MYJ-TKE	KF

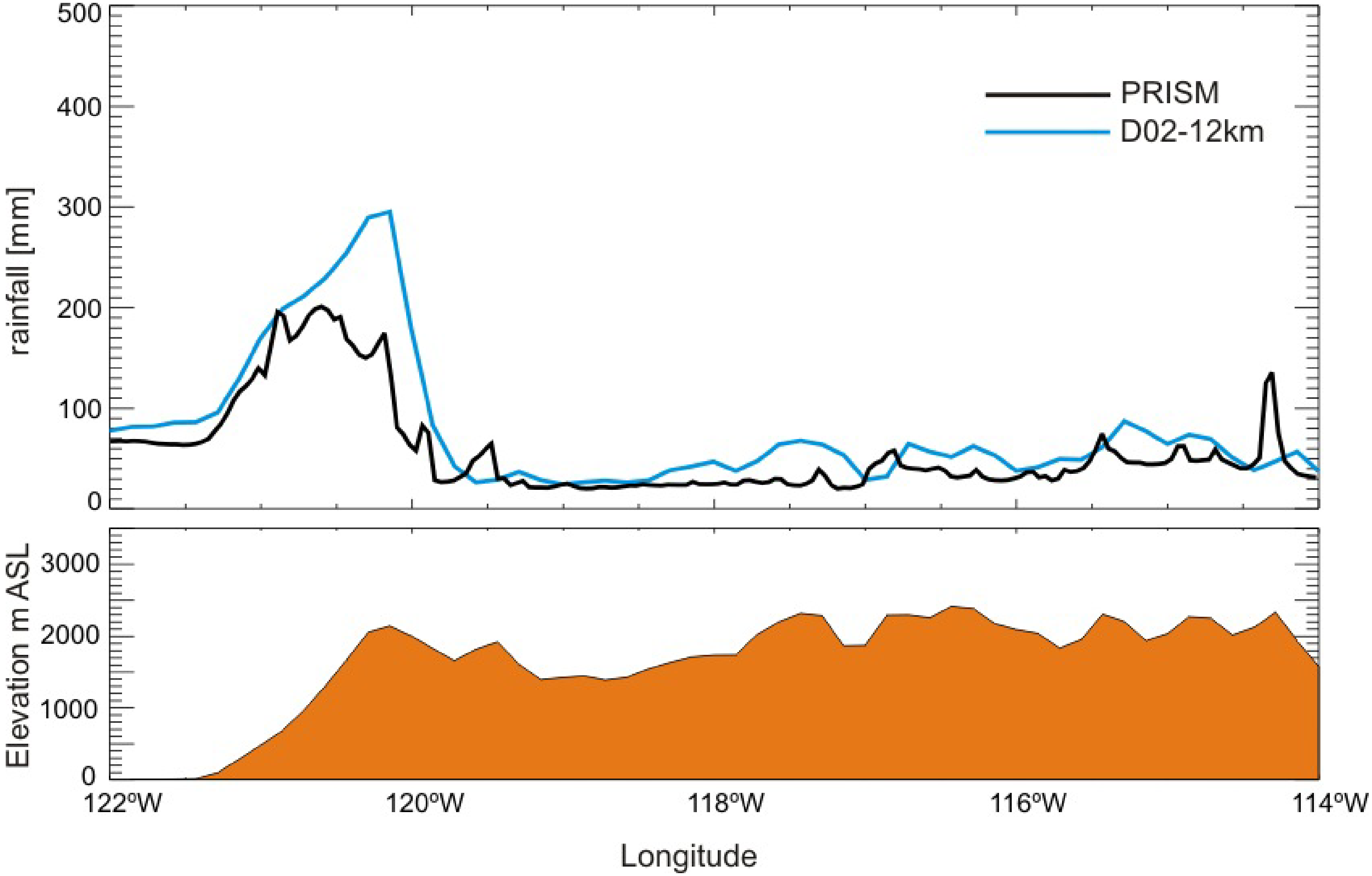
Daily Rainfall Thresholds

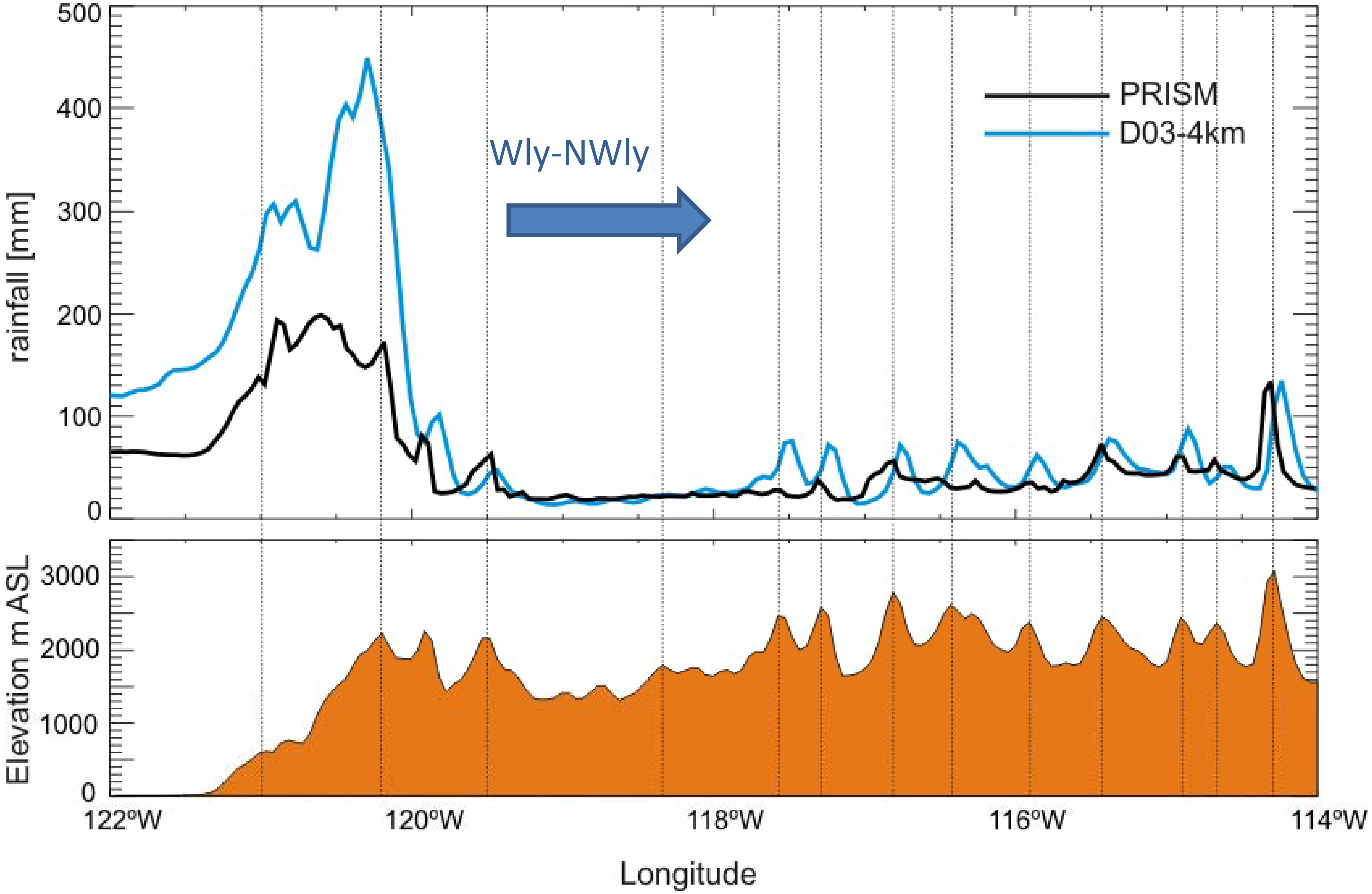


Cross section details of precipitation: 36, 12, and 4 km grid size



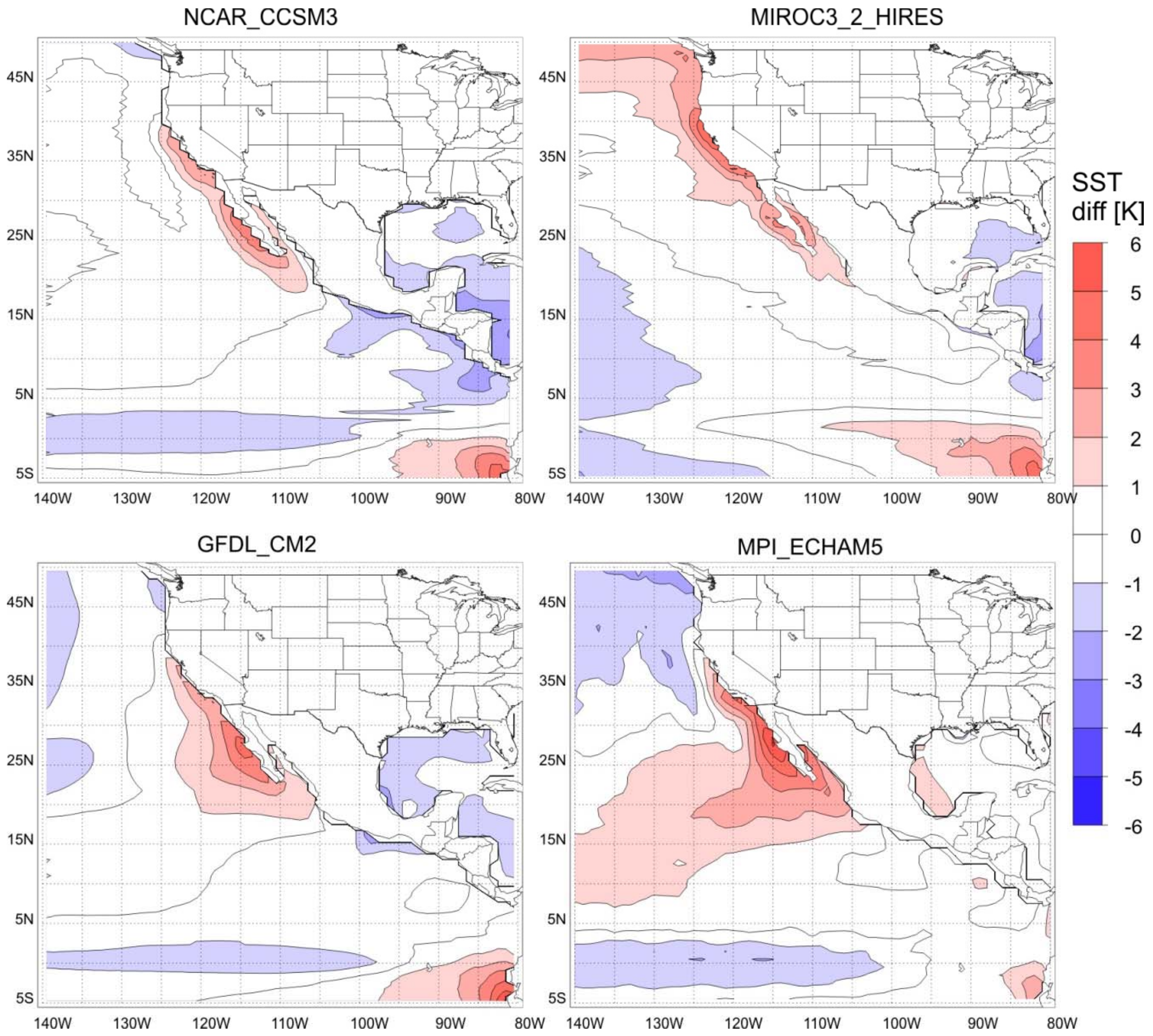

500
400
300
200
100
0
rainfall [mm]
PRISM
D01-36km
3000
2000
1000
0
Elevation m ASL
122ºW
120ºW
118ºW
116ºW
114ºW
Longitude


500
400
300
200
100
0
rainfall [mm]
PRISM
D02-12km
3000
2000
1000
0
Elevation m ASL
122ºW
120ºW
118ºW
116ºW
114ºW
Longitude


500
400
300
200
100
0
rainfall [mm]
PRISM
D03-4km
Wly-NWly
3000
2000
1000
0
Elevation m ASL
122°W
120°W
118°W
116°W
114°W
Longitude

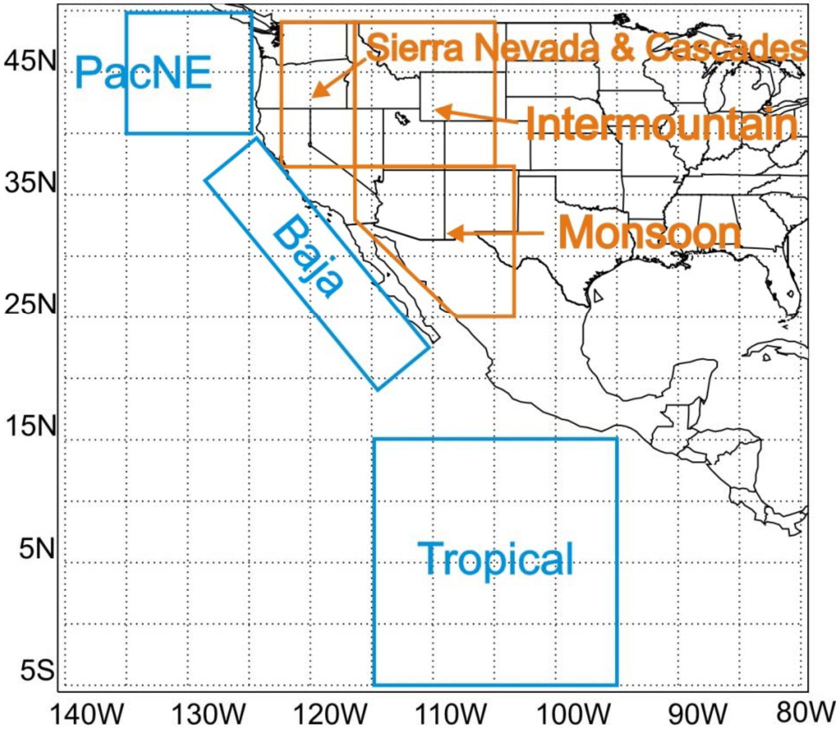
Problematic boundary conditions

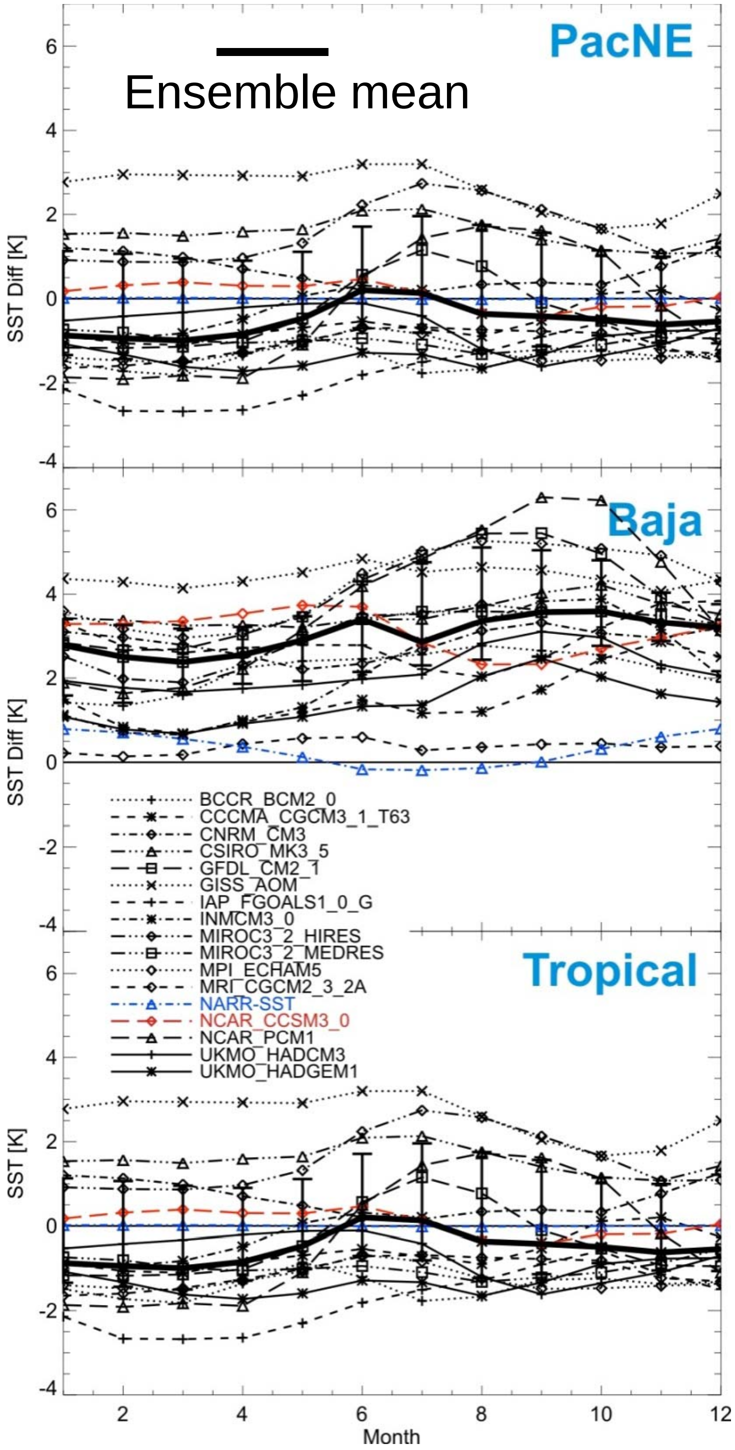
Third Coupled Model Inter-comparison Project (CMIP3) IPCC-**AR4**

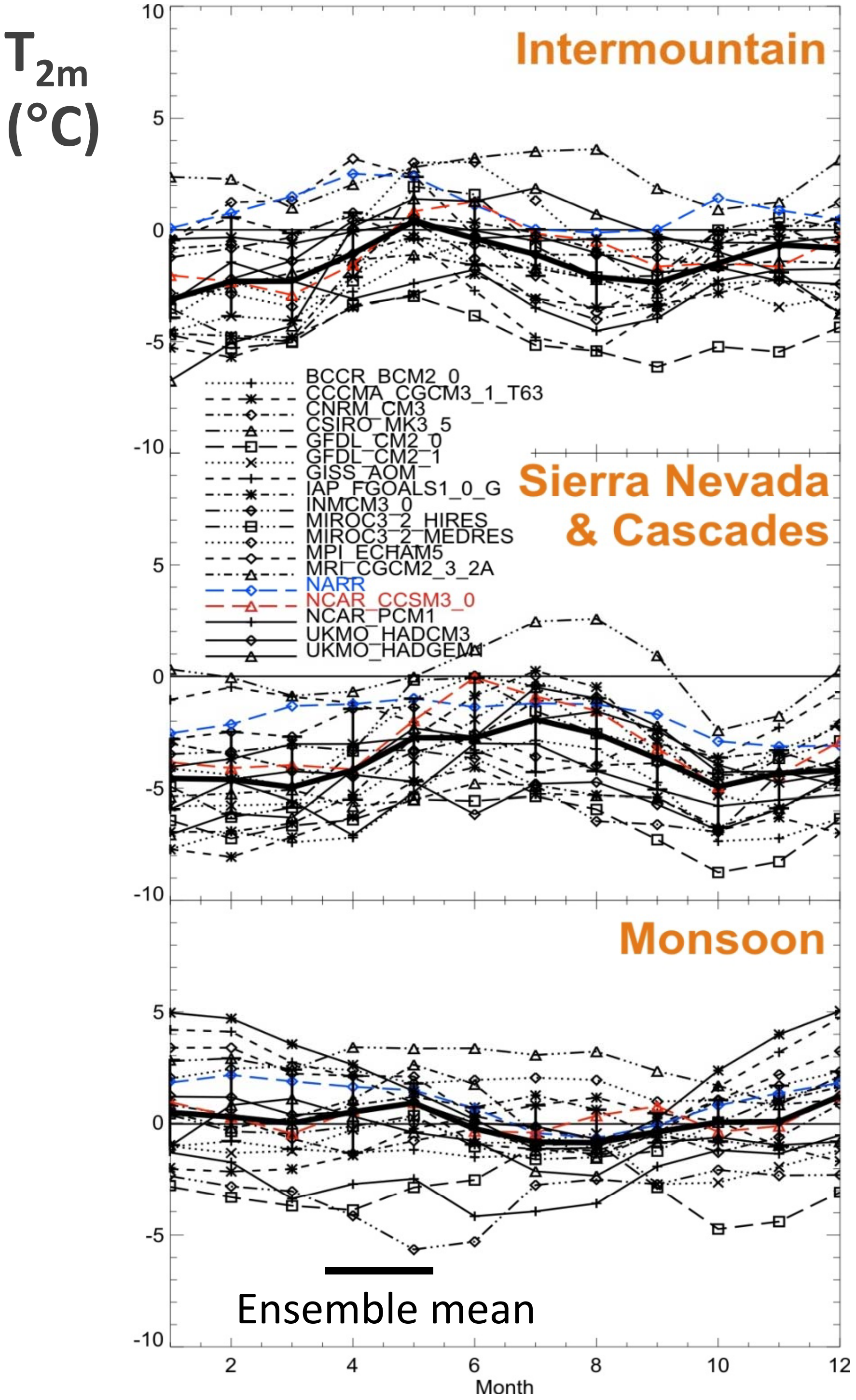


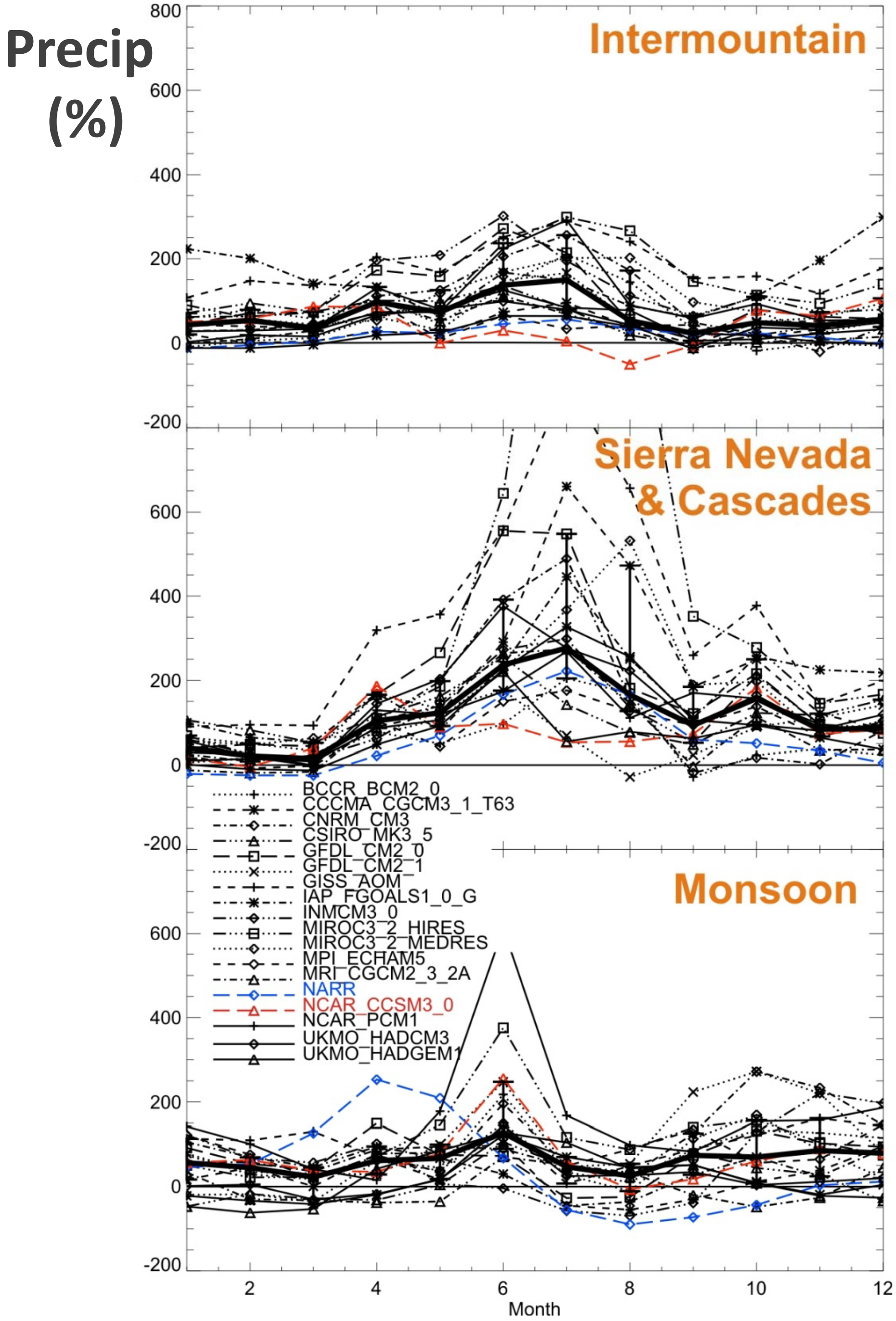
GCM Sea Surface Temperature biases (1982-2000)
When comparing against NOAA Optimum Interpolation SST Analysis V2.0 (OISST)

- SST biases for 17 different GCMs (CMIP3) and NARR w.r.t. NCEP/NCAR reanalysis.
- Period 1982-2000.
- Ideally, ensemble average has better skill than a single model.
- But in this case, the models in the ensemble have systematic errors
- The ensemble itself is out of the solution domain with seasonal dependence.



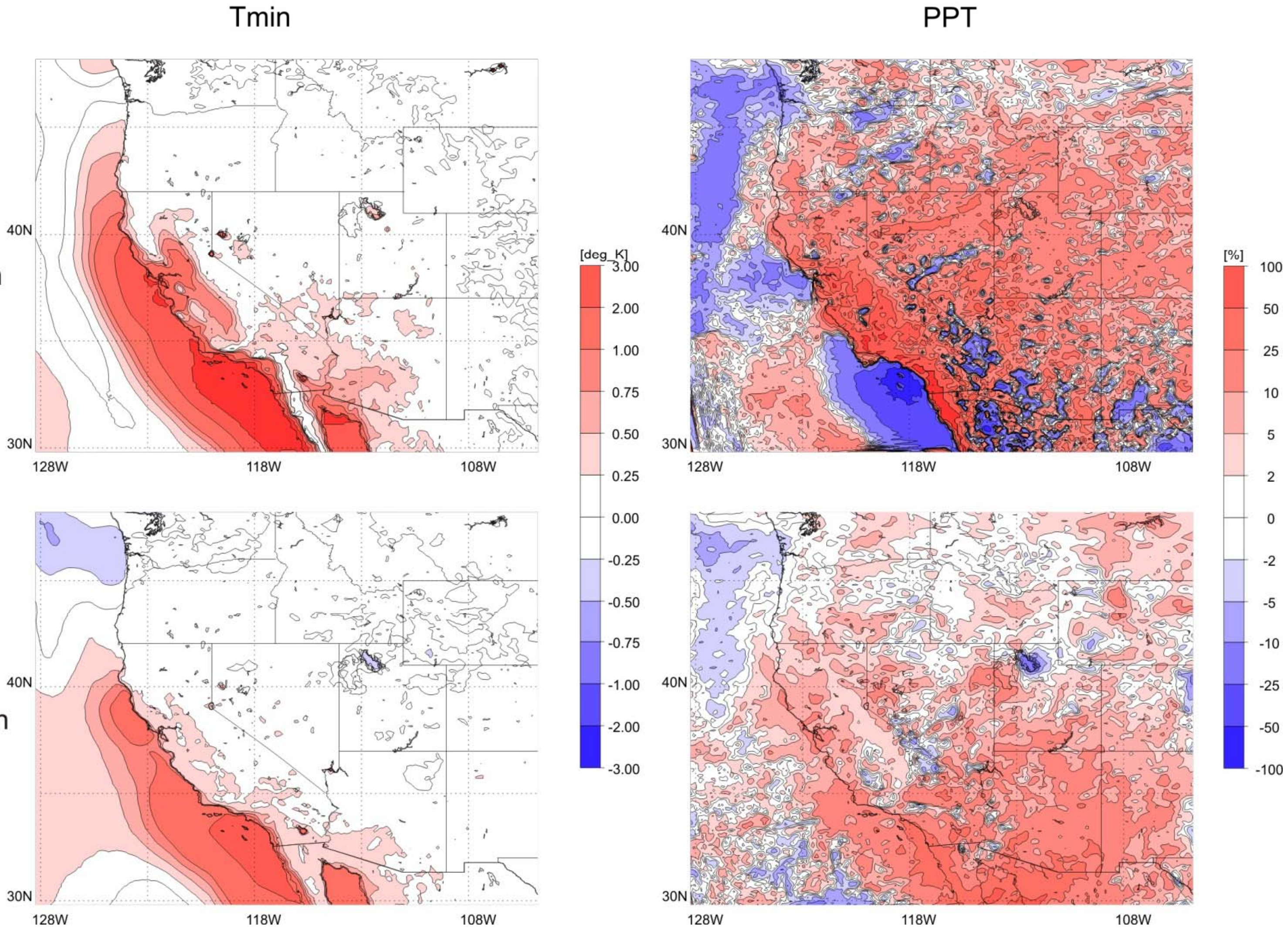



T$_{2m}$ (°C)
Intermountain
Sierra Nevada & Cascades
Monsoon
10
5
0
-5
-10
BCCR_BCM2_0
CCCMA_CGCM3_1_T63
CNRM_CM3
CSIRO_MK3_5
GFDL_CM2_0
GFDL_CM2_1
GISS_AOM
IAP_FGOALS1_0_G
INMCM3_0
MIROC3_2_HIRES
MIROC3_2_MEDRES
MPI_ECHAM5
MRI_CGCM2_3_2A
NARR
NCAR_CCSM3_0
NCAR_PCM1
UKMO_HADCM3
UKMO_HADGEM1
Ensemble mean
2
4
6
8
10
12
Month


Precip (%)
Intermountain
Sierra Nevada & Cascades
Monsoon
800
600
400
200
0
-200
BCCR_BCM2_0
CCCMA_CGCM3_1_T63
CNRM_CM3
CSIRO_MK3_5
GFDL_CM2_0
GFDL_CM2_1
GISS_AOM
IAP_FGOALS1_0_G
INMCM3_0
MIROC3_2_HIRES
MIROC3_2_MEDRES
MPI_ECHAM5
MRI_CGCM2_3_2A
NARR
NCAR_CCSM3_0
NCAR_PCM1
UKMO_HADCM3
UKMO_HADGEM1
2
4
6
8
10
12
Month

D02 (12km)

CCSM minus CCSM*OISST*



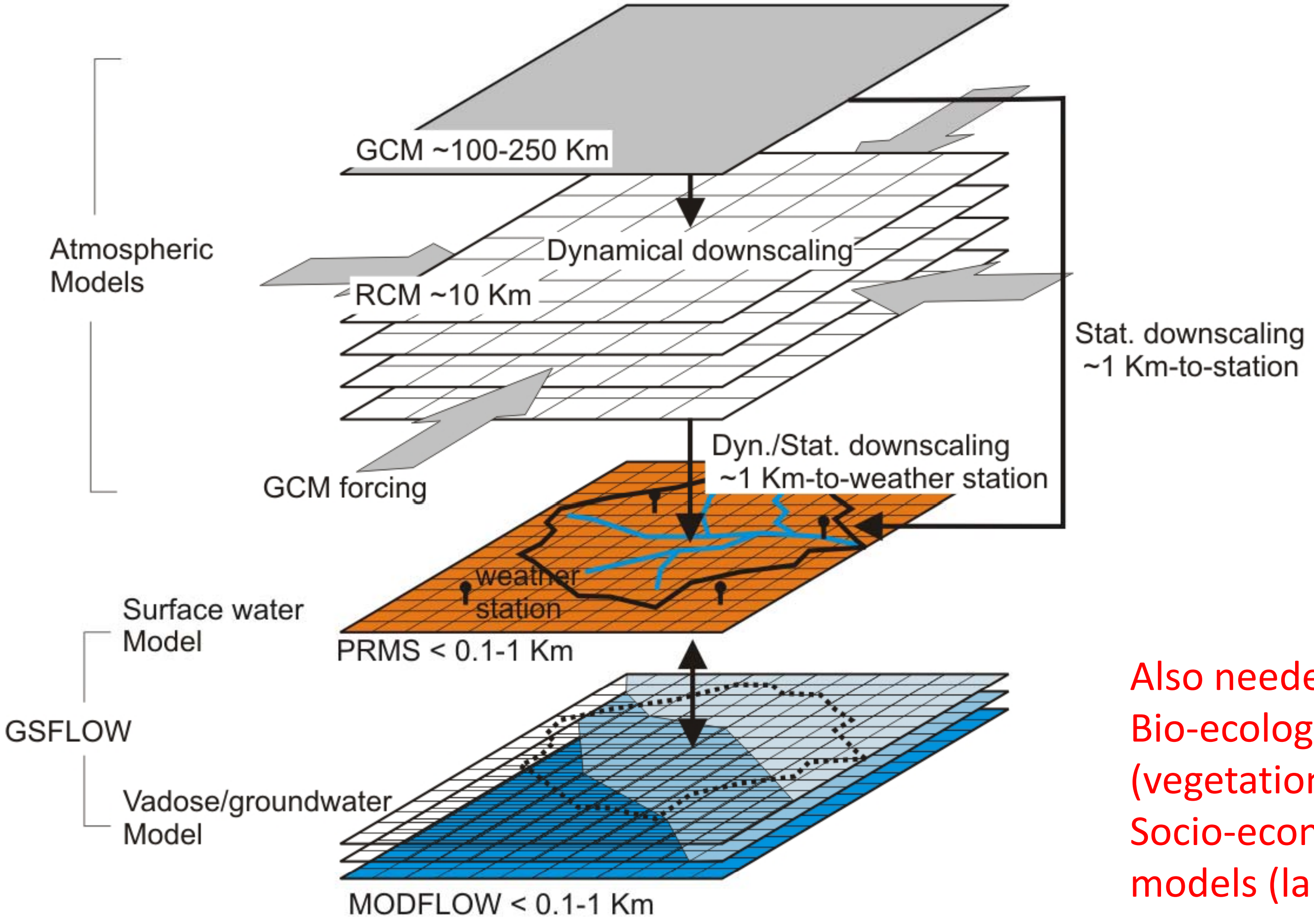
Warm Season

(May-Sept)

Cold Season

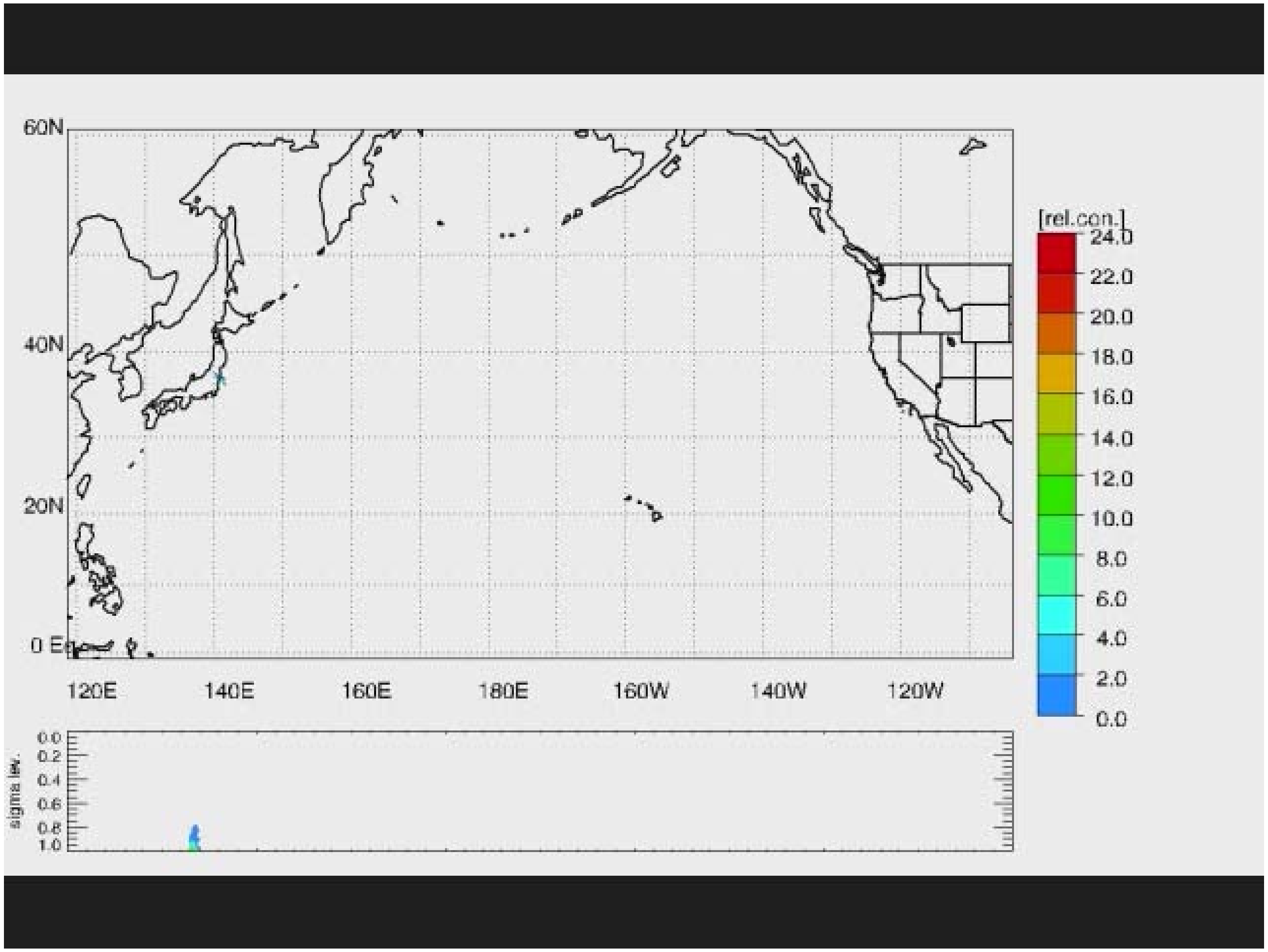
(Nov-Mar)

Integration with Hydrological and Groundwater Model



Also needed…
Bio-ecology
(vegetation dynamics),
Socio-economical
models (landscape)

Integration with Air Pollution Models



Japan Radiation Plume: 03/12 – 03/18; Meteorology from WRF-30km + Dispersion Model

Summary

Grid size and regime dependence. However, finner-resolution does not translate into overall better simulations.

In our example, 36 km runs does provide better error statistics, while 4 km runs improve spatial distribution. (non-linear interactions, dynamics).

Sensitivity to physics schemes selection reveals some potential for regional optimization.

Summary

Daily rainfall:

model overestimates rainfall amounts with large scale dependency.

model underestimates frequency of small events and overestimates frequency of large event.

Daily Tmin and Tmax:

Tmin warmer than observed

Tmax colder than observed

While colder months display larger differences.

Simulated biases MUST be corrected!

- We can either create better physical parameterization tools (very expensive!!!)
- Use bias correction methods (affordable!!).

Remarks

Appropriate implementation of the RCM for present and future climate dynamical downscaling tool requires an immense amount of work/computer resources.

While, statistical downscaling is computationally efficient it does not take care of non-stationarity (e.g. trends in the mean and variance).

Remarks

- “The ability of RCMs to simulate the regional climate depends strongly on the realism of the large-scale circulation that is provided by the LBCs”
- Further reading: IPCC Fourth Assessment Report: Climate Change 2007; Working Group I: The Physical Science Basis; Assessment of Regional Climate Projection Methods http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch11s11-10.html

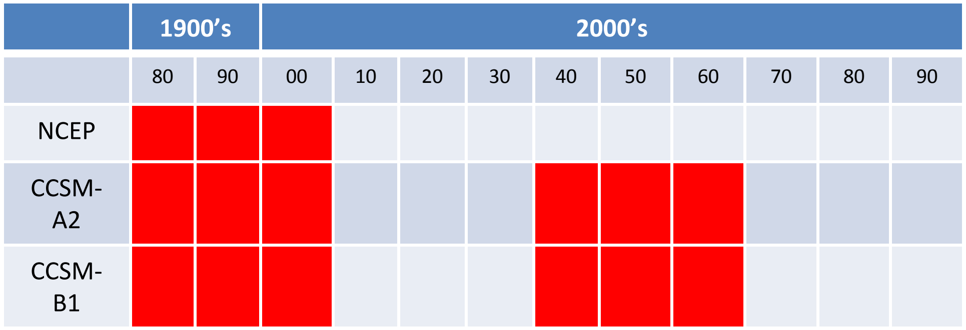
Simulated Hydro-Climate Variability and Change Data

John Mejia

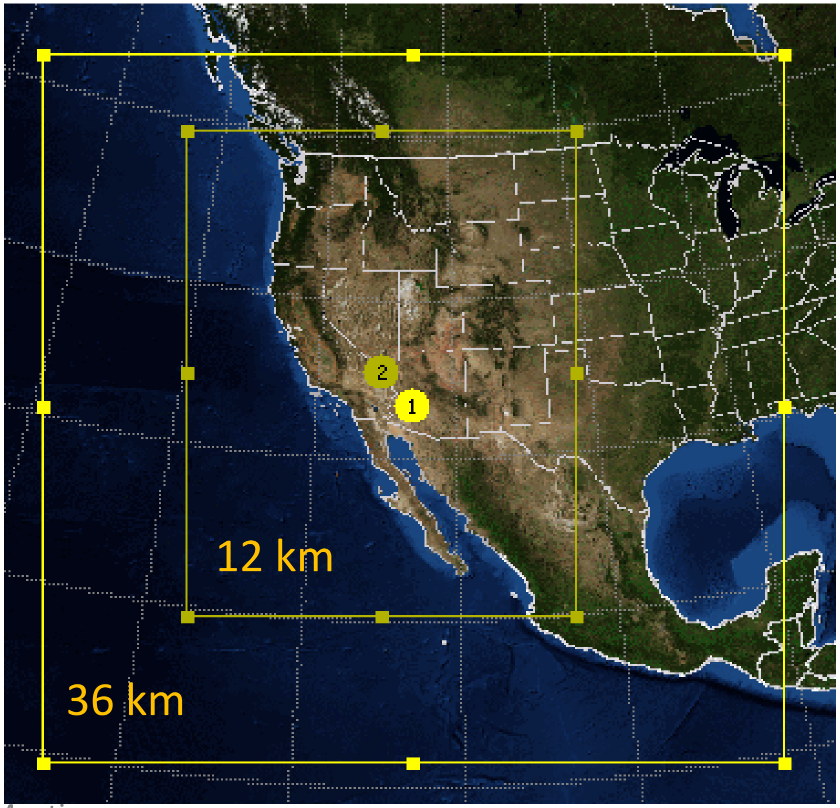
Desert Research Institute
Department of Atmospheric Sciences
John.Mejia@dri.edu

Got RCM data? (1)

- DRI-RCM
- Lead by the DRI-Climate Modeling Group(contact: John.Mejia@dri.edu)
- *Sponsored by NSF-EPSCoR, NV*
- Based on WRF-Climate Mode.
- 36 and 12km domains
- NCEP/NCAR, CCSM3 (SRES-A2, A1Fi, B1)
- Up to Hourly



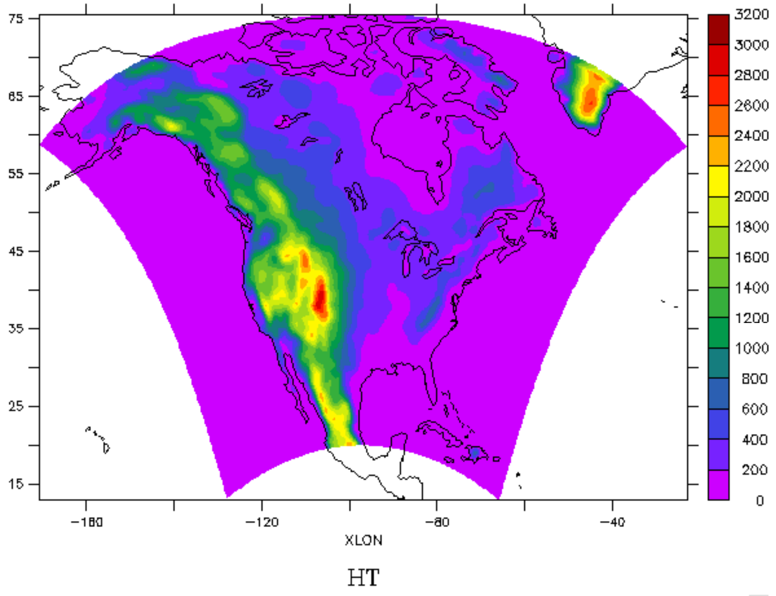
	1900's		2000's									
	80	90	00	10	20	30	40	50	60	70	80	90
NCEP	🟥	🟥	🟥									
CCSM-A2	🟥	🟥	🟥				🟥	🟥	🟥			
CCSM-B1	🟥	🟥	🟥				🟥	🟥	🟥			



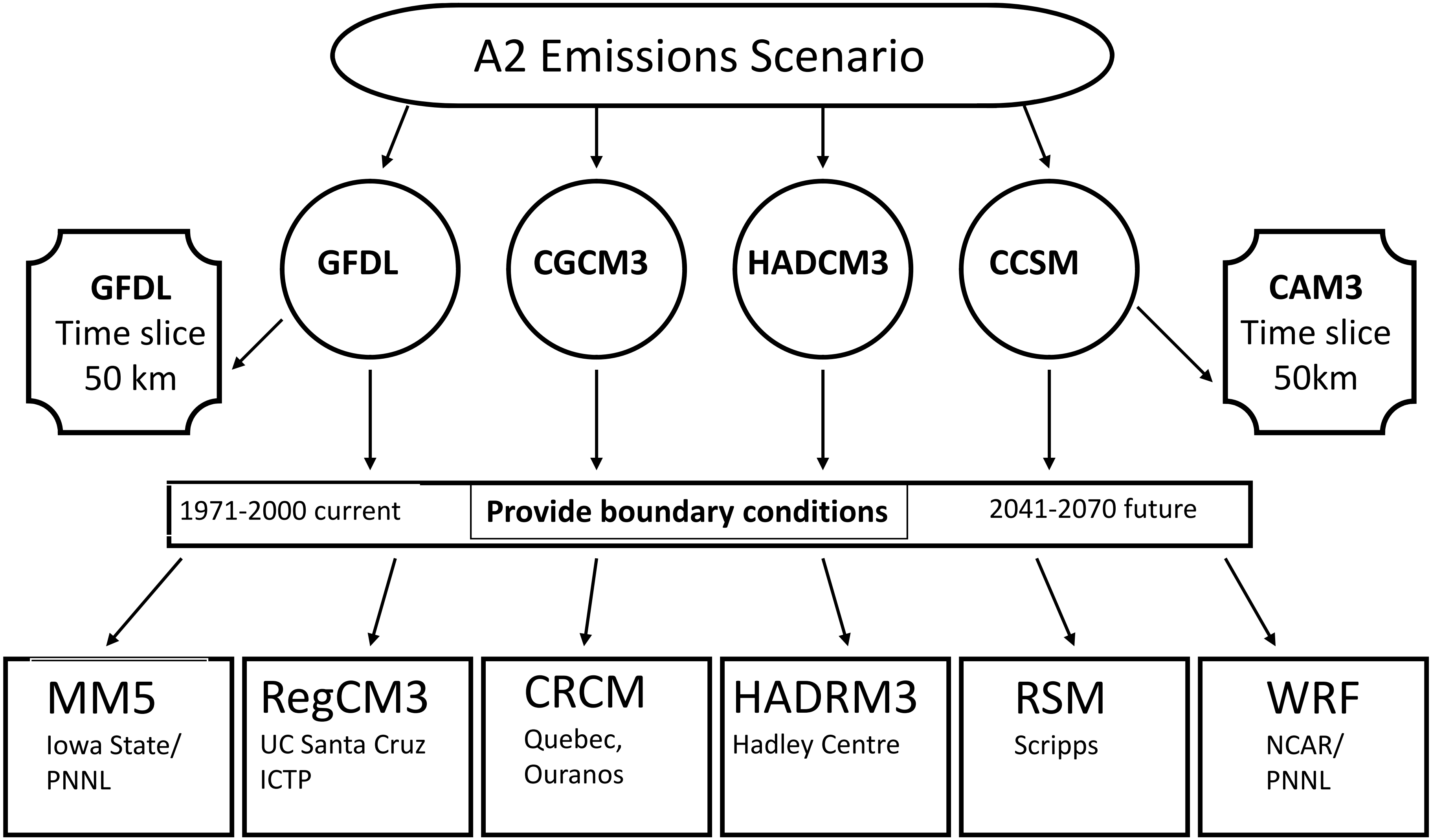
Got RCM output? (2)

- The North American Regional Climate Change Assessment Program (NARCCAP): http://www.narccap.ucar.edu/

- *Lead by NCAR (***Mearns & collaborators***)*
- *Sponsored by NSF, DoE, NOAA, EPA*



NARCCAP PLAN



A2 Emissions Scenario

GFDL

CGCM3

HADCM3

CCSM

GFDL
Time slice
50 km

CAM3
Time slice
50km

1971-2000 current

Provide boundary conditions

2041-2070 future

MM5
Iowa State/
PNNL

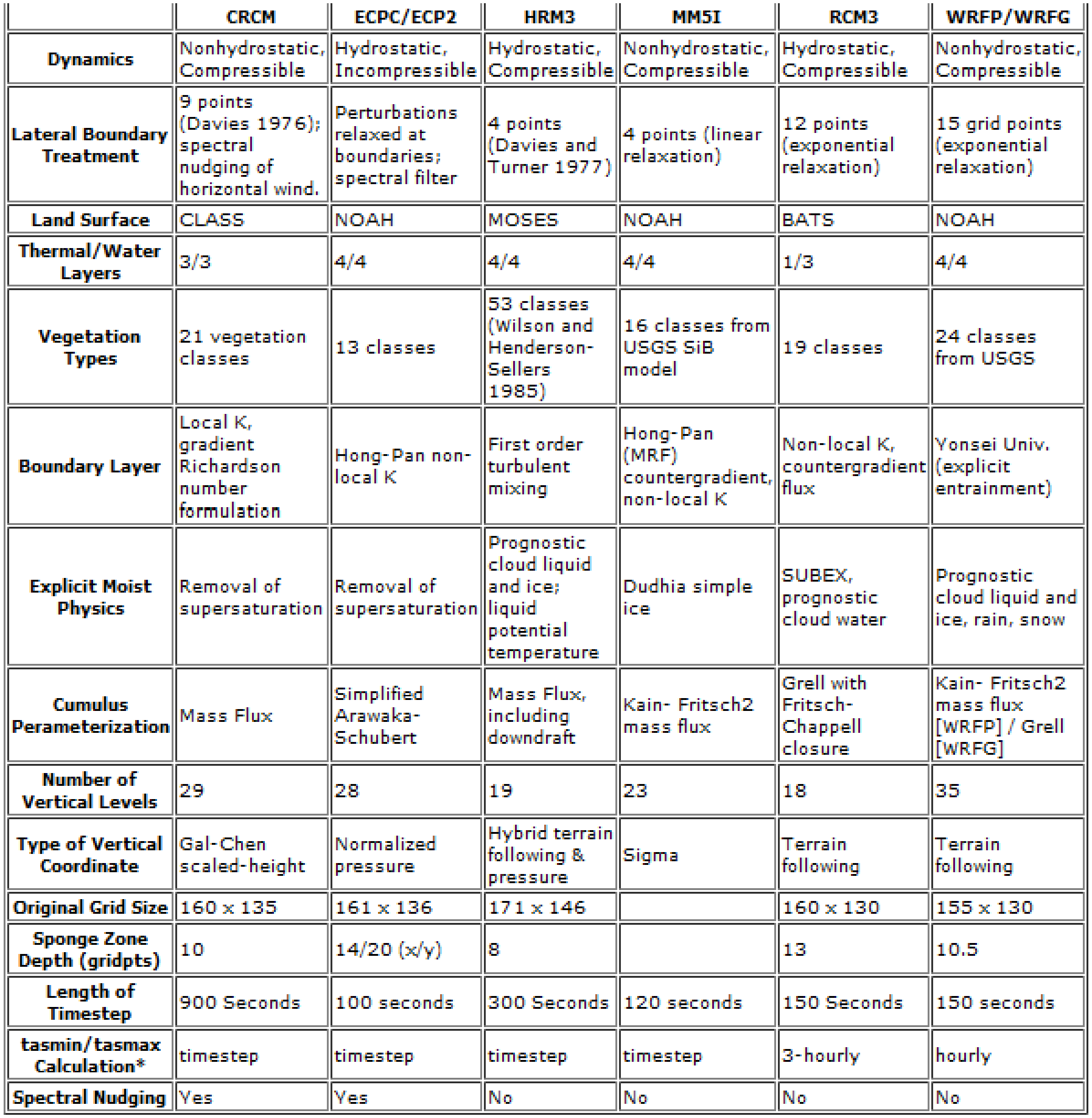
RegCM3
UC Santa Cruz
ICTP

CRCM
Quebec,
Ouranos

HADRM3
Hadley Centre

RSM
Scripps

WRF
NCAR/
PNNL



	CRCM	ECPC/ECP2	HRM3	MM5I	RCM3	WRFP/WRFG
Dynamics	Nonhydrostatic, Compressible	Hydrostatic, Incompressible	Hydrostatic, Compressible	Nonhydrostatic, Compressible	Hydrostatic, Compressible	Nonhydrostatic, Compressible
Lateral Boundary Treatment	9 points (Davies 1976); spectral nudging of horizontal wind.	Perturbations relaxed at boundaries; spectral filter	4 points (Davies and Turner 1977)	4 points (linear relaxation)	12 points (exponential relaxation)	15 grid points (exponential relaxation)
Land Surface	CLASS	NOAH	MOSES	NOAH	BATS	NOAH
Thermal/Water Layers	3/3	4/4	4/4	4/4	1/3	4/4
Vegetation Types	21 vegetation classes	13 classes	53 classes (Wilson and Henderson-Sellers 1985)	16 classes from USGS SiB model	19 classes	24 classes from USGS
Boundary Layer	Local K, gradient Richardson number formulation	Hong-Pan non-local K	First order turbulent mixing	Hong-Pan (MRF) countergradient, non-local K	Non-local K, countergradient flux	Yonsei Univ. (explicit entrainment)
Explicit Moist Physics	Removal of supersaturation	Removal of supersaturation	Prognostic cloud liquid and ice; liquid potential temperature	Dudhia simple ice	SUBEX, prognostic cloud water	Prognostic cloud liquid and ice, rain, snow
Cumulus Perameterization	Mass Flux	Simplified Arawaka-Schubert	Mass Flux, including downdraft	Kain- Fritsch2 mass flux	Grell with Fritsch-Chappell closure	Kain- Fritsch2 mass flux [WRFP] / Grell [WRFG]
Number of Vertical Levels	29	28	19	23	18	35
Type of Vertical Coordinate	Gal-Chen scaled-height	Normalized pressure	Hybrid terrain following & pressure	Sigma	Terrain following	Terrain following
Original Grid Size	160 x 135	161 x 136	171 x 146		160 x 130	155 x 130
Sponge Zone Depth (gridpts)	10	14/20 (x/y)	8		13	10.5
Length of Timestep	900 Seconds	100 seconds	300 Seconds	120 seconds	150 Seconds	150 seconds
tasmin/tasmax Calculation*	timestep	timestep	timestep	timestep	3-hourly	hourly
Spectral Nudging	Yes	Yes	No	No	No	No

http://narccap.ucar.edu/data/rcm-characteristics.html

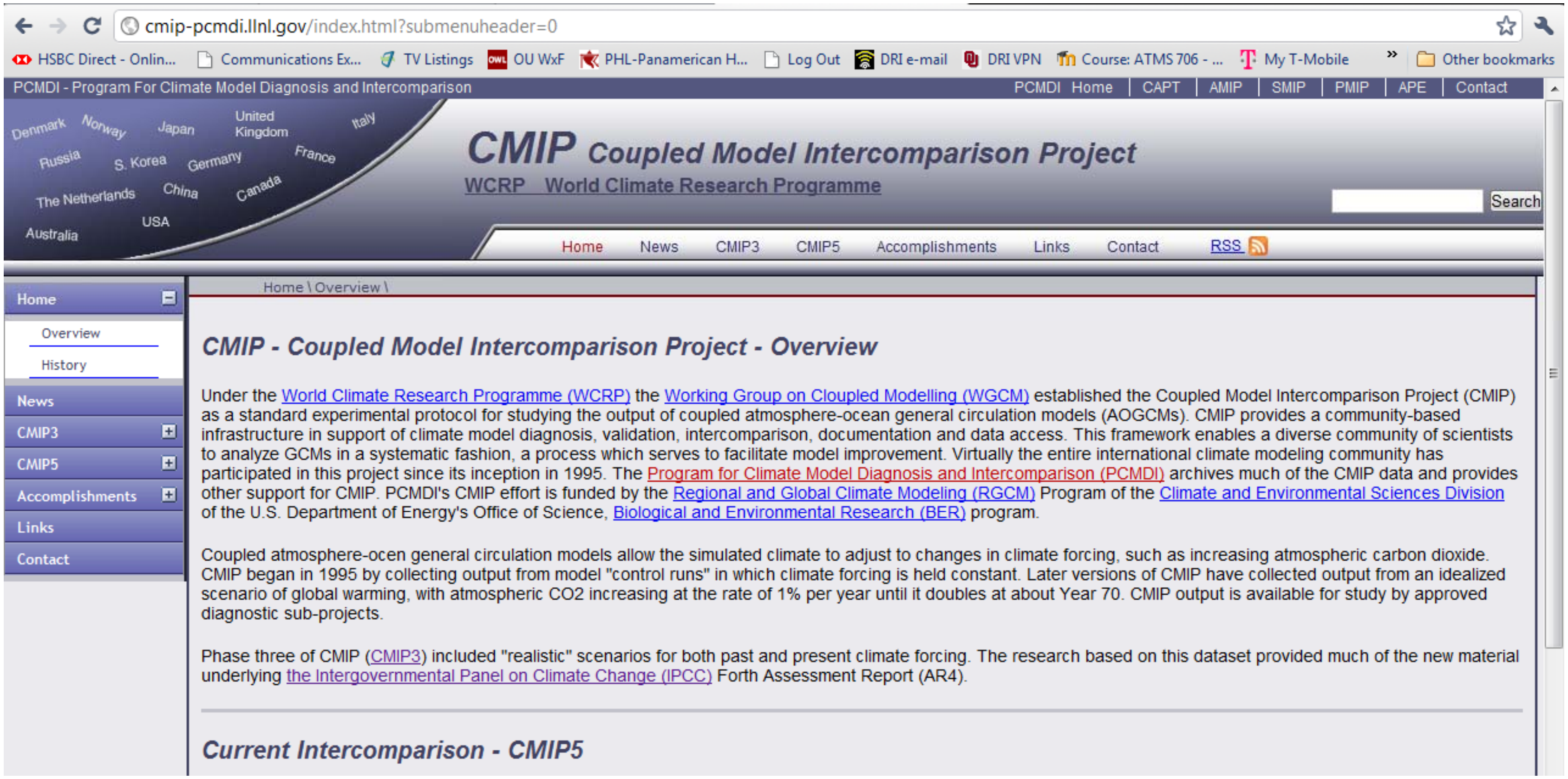
Got GCM Variability and Change data?

- World Meteorological Organization/World Climate Research Programme's (WCRP's)
- Intergovernmental Panel on Climate Change (IPCC). Fourth Assessment Report (AR4-2007), Fifth AR coming on 2013-14?.
- Coupled Model Intercomparison Project (CMIP3 used for AR4; CMIP5 for AR5)
- Where can you download these data?

WCRP CMIP3 multi-model dataset

The Program for Climate Model Diagnostics and Intercomparison (PCMDI) - Lawrence Livermore National Laboratory DATA PORTAL

http://www-pcmdi.llnl.gov/



CMIP - Coupled Model Intercomparison Project - Overview

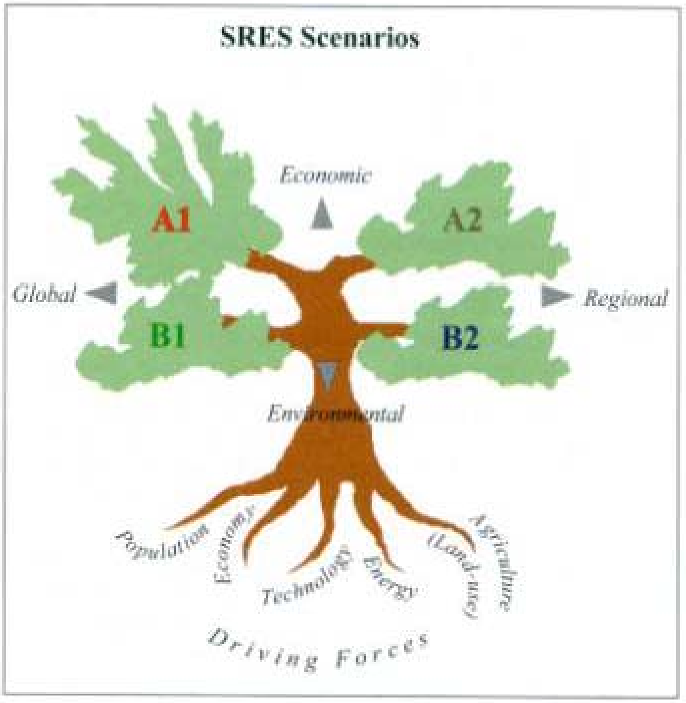
Under the World Climate Research Programme (WCRP) the Working Group on Cloupled Modelling (WGCM) established the Coupled Model Intercomparison Project (CMIP) as a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs). CMIP provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyze GCMs in a systematic fashion, a process which serves to facilitate model improvement. Virtually the entire international climate modeling community has participated in this project since its inception in 1995. The Program for Climate Model Diagnosis and Intercomparison (PCMDI) archives much of the CMIP data and provides other support for CMIP. PCMDI's CMIP effort is funded by the Regional and Global Climate Modeling (RGCM) Program of the Climate and Environmental Sciences Division of the U.S. Department of Energy's Office of Science, Biological and Environmental Research (BER) program.

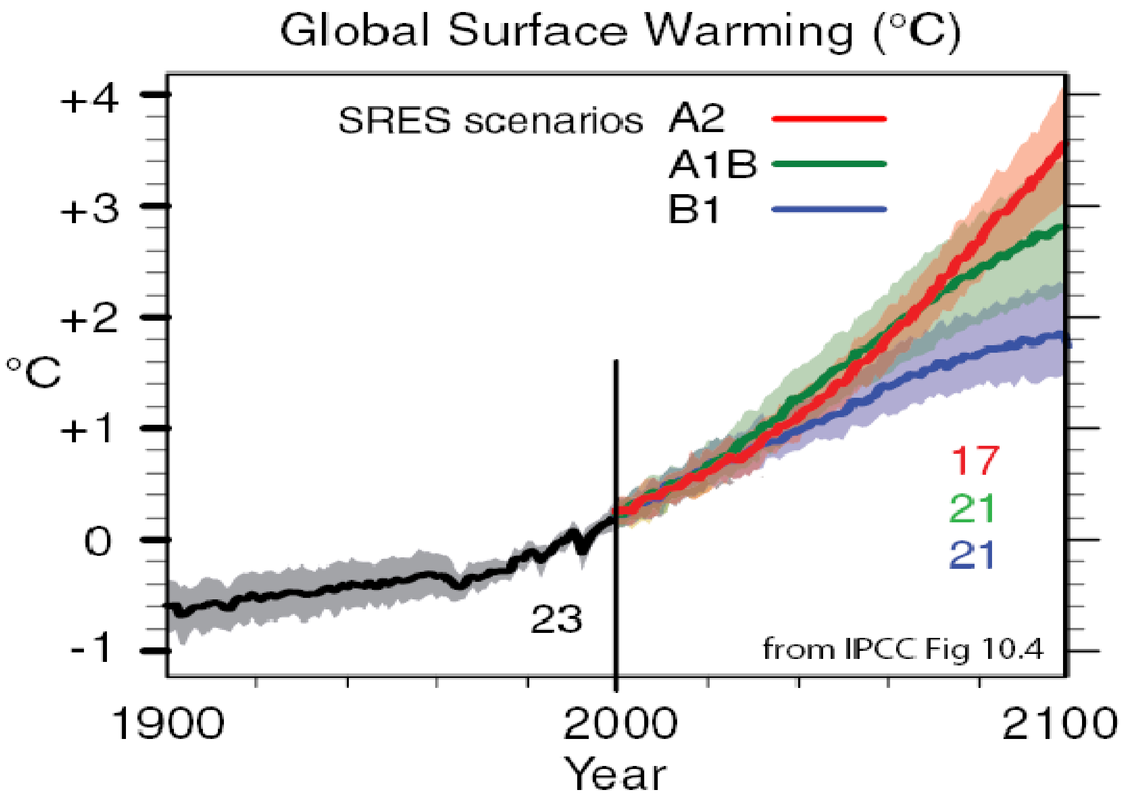
Coupled atmosphere-ocen general circulation models allow the simulated climate to adjust to changes in climate forcing, such as increasing atmospheric carbon dioxide. CMIP began in 1995 by collecting output from model "control runs" in which climate forcing is held constant. Later versions of CMIP have collected output from an idealized scenario of global warming, with atmospheric CO2 increasing at the rate of 1% per year until it doubles at about Year 70. CMIP output is available for study by approved diagnostic sub-projects.

Phase three of CMIP (CMIP3) included "realistic" scenarios for both past and present climate forcing. The research based on this dataset provided much of the new material underlying the Intergovernmental Panel on Climate Change (IPCC) Forth Assessment Report (AR4).

Current Intercomparison - CMIP5

Special Report on Emissions Scenarios - SRES





Figures adapted from http://www.ipcc.ch/index.htm

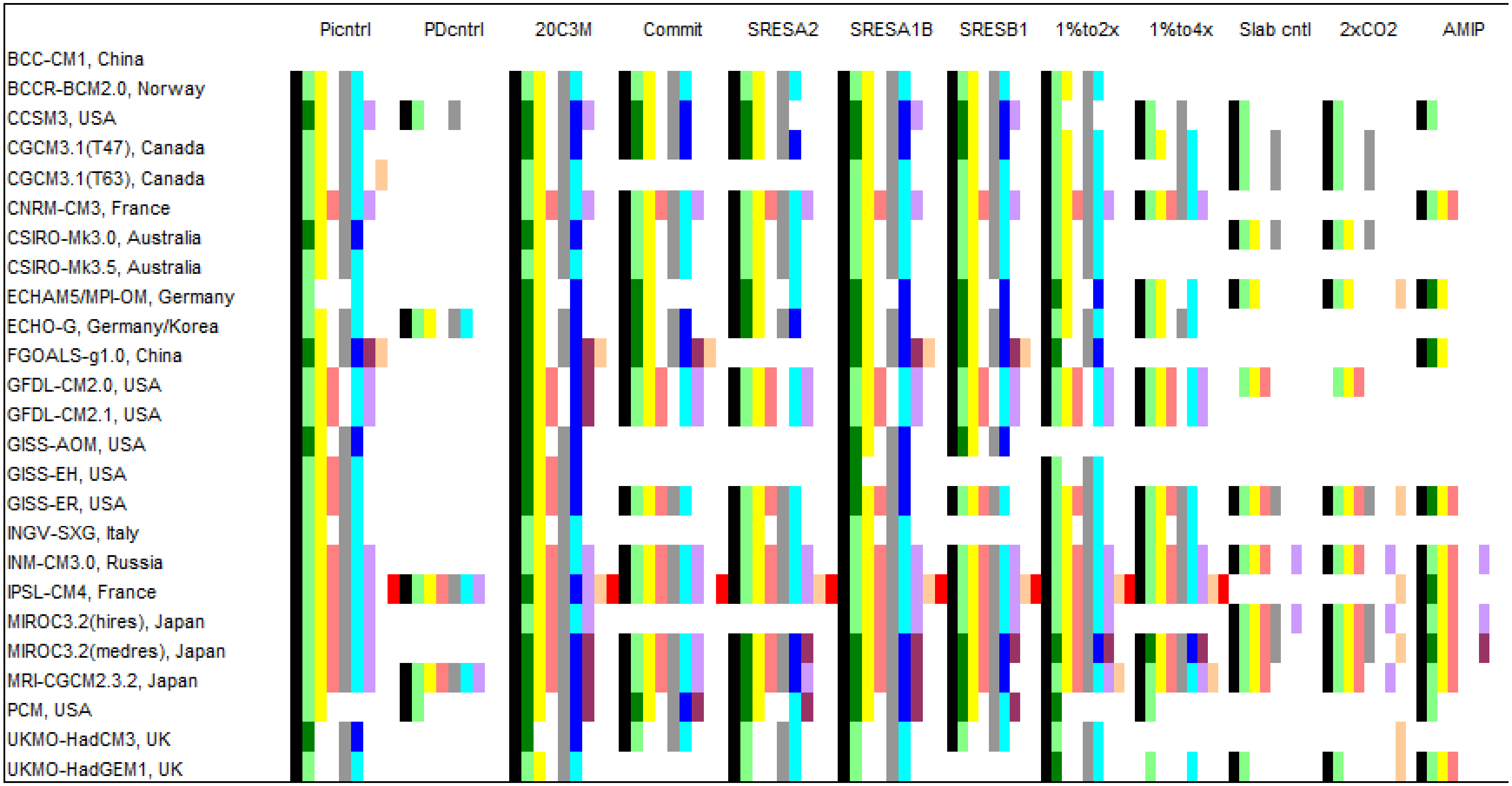
- Scenarios of socio-economical and environmental translated into the GCM driving forces: greenhouse gas and aerosol emissions.

Couple Atmosphere-Ocean GCMs

Data Availability Summary (as of 27 February 2008)

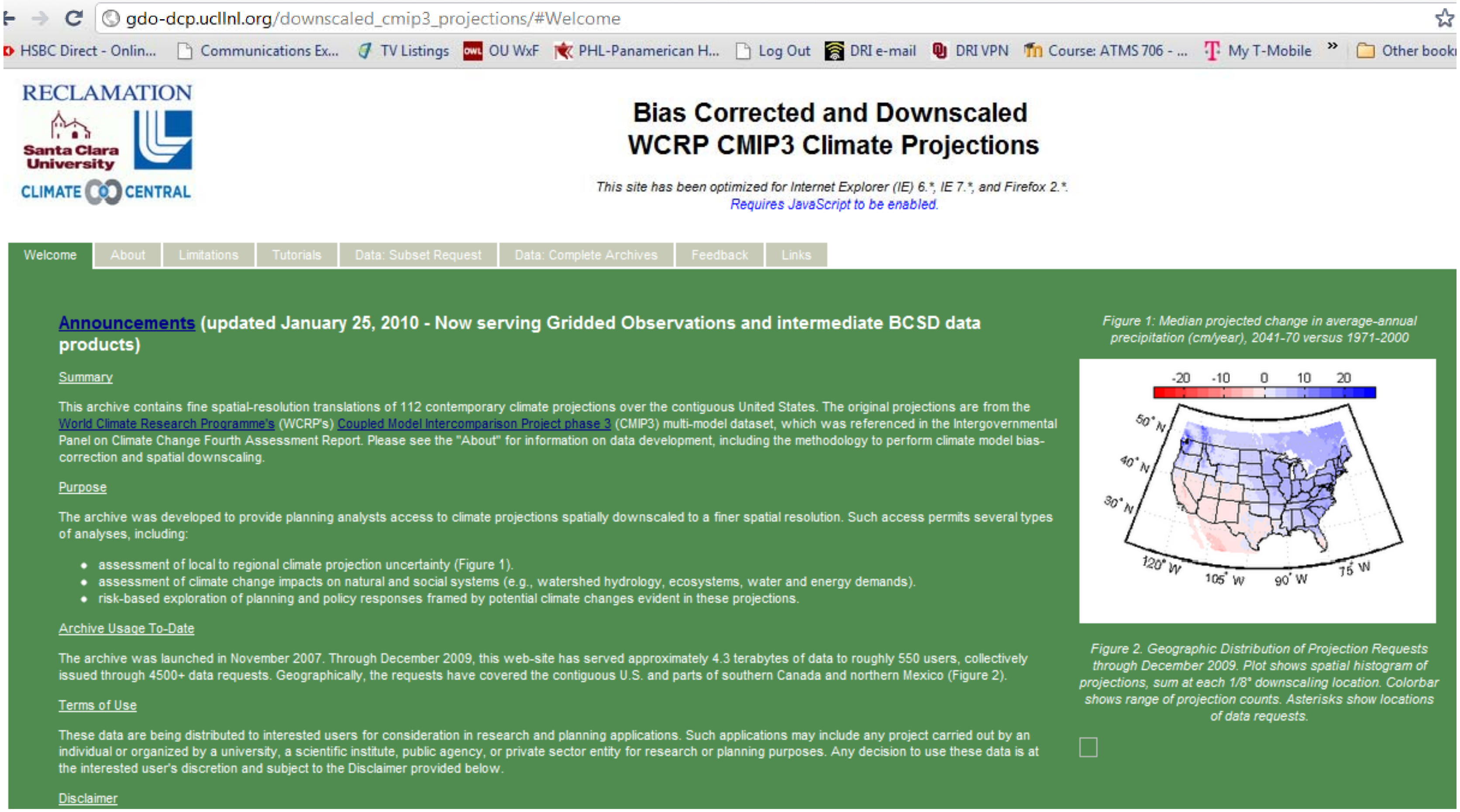
shaded area indicates that at least some but not necessarily all fields are available for data type indicated

- ■ time-independent land surface
- >1 1 monthly-mean atmosphere
- 🟨 daily-mean atmosphere
- ■ 3-hourly atmosphere
- ■ time-independent ocean
- >1 1 monthly-mean ocean
- >1 1 Extreme Indices
- ■ Forcing
- 🟥 ISCCP Simulator



Bias-Correction and Spatial Disaggregation (BCSD) Statistical Downscaling Approach:

http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/#Welcome



Bias Corrected and Downscaled WCRP CMIP3 Climate Projections

This site has been optimized for Internet Explorer (IE) 6., IE 7.*, and Firefox 2.*.*
Requires JavaScript to be enabled.

[Announcements](#) (updated January 25, 2010 - Now serving Gridded Observations and intermediate BCSD data products)

Summary

This archive contains fine spatial-resolution translations of 112 contemporary climate projections over the contiguous United States. The original projections are from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Report. Please see the "About" for information on data development, including the methodology to perform climate model bias-correction and spatial downscaling.

Purpose

The archive was developed to provide planning analysts access to climate projections spatially downscaled to a finer spatial resolution. Such access permits several types of analyses, including:

- assessment of local to regional climate projection uncertainty (Figure 1).
- assessment of climate change impacts on natural and social systems (e.g., watershed hydrology, ecosystems, water and energy demands).
- risk-based exploration of planning and policy responses framed by potential climate changes evident in these projections.

Archive Usage To-Date

The archive was launched in November 2007. Through December 2009, this web-site has served approximately 4.3 terabytes of data to roughly 550 users, collectively issued through 4500+ data requests. Geographically, the requests have covered the contiguous U.S. and parts of southern Canada and northern Mexico (Figure 2).

Terms of Use

These data are being distributed to interested users for consideration in research and planning applications. Such applications may include any project carried out by an individual or organized by a university, a scientific institute, public agency, or private sector entity for research or planning purposes. Any decision to use these data is at the interested user's discretion and subject to the Disclaimer provided below.

Disclaimer

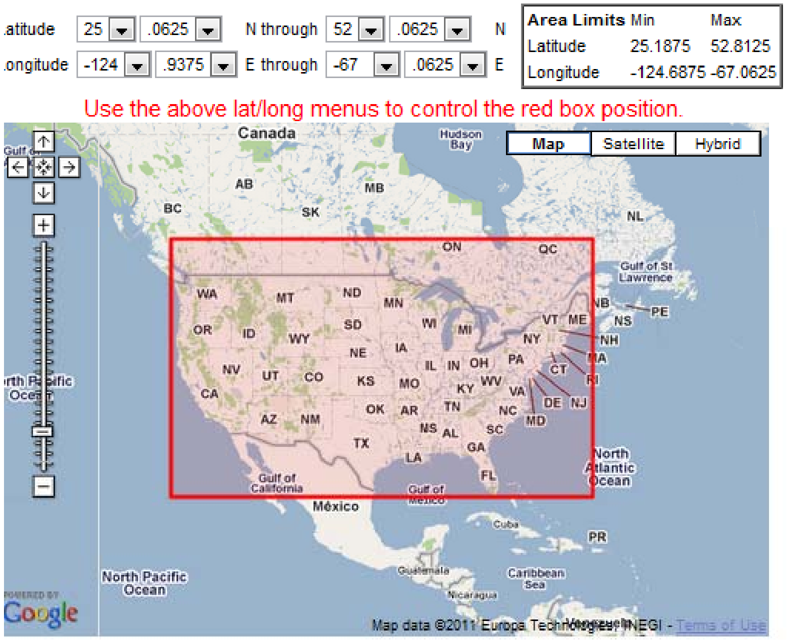
Figure 1: Median projected change in average-annual precipitation (cm/year), 2041-70 versus 1971-2000

Figure 2. Geographic Distribution of Projection Requests through December 2009. Plot shows spatial histogram of projections, sum at each 1/8° downscaling location. Colorbar shows range of projection counts. Asterisks show locations of data requests.

NSF EPSCoR Tri-State Meeting,
Albuquerque, NM,2011.

BCSD

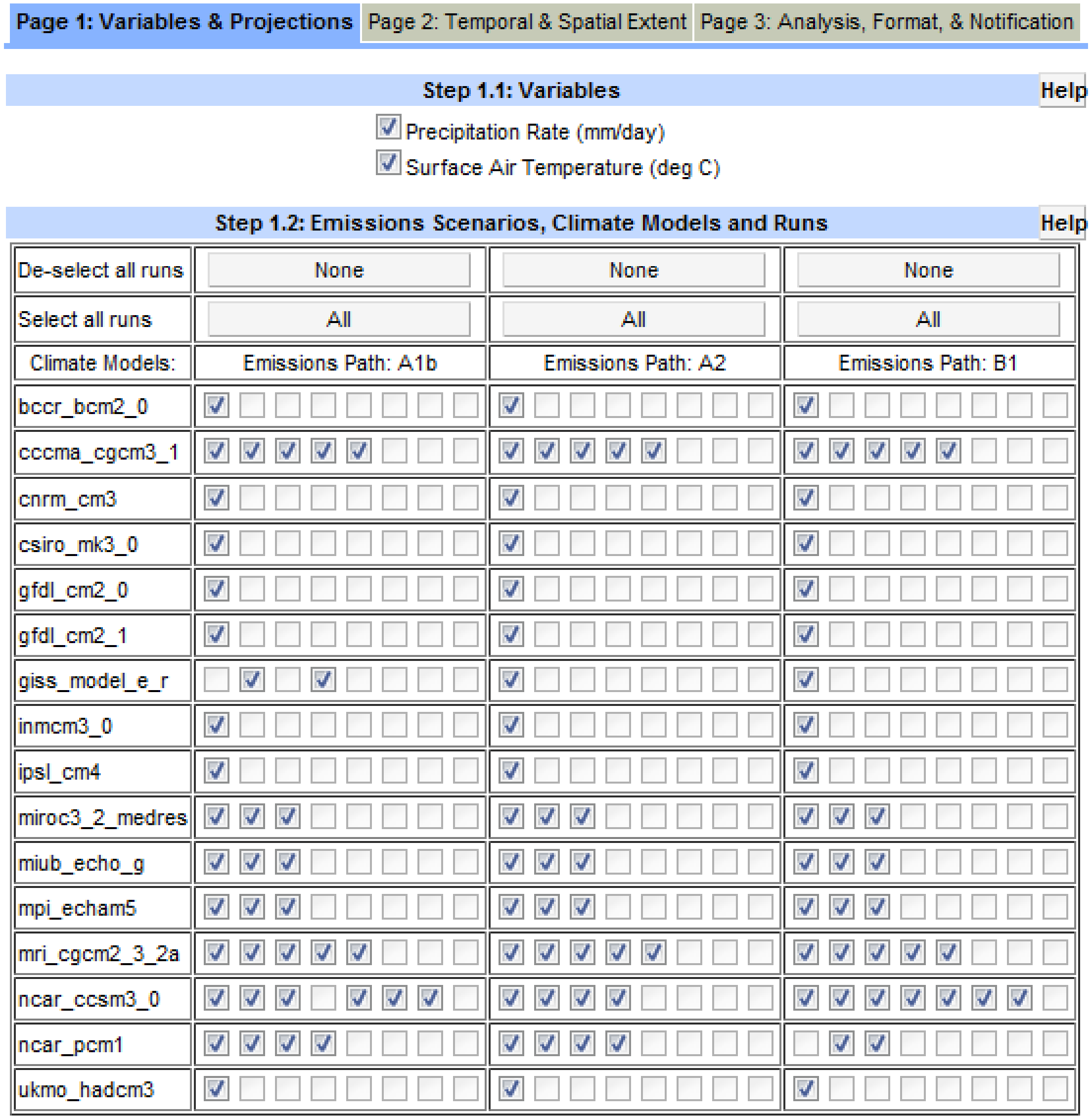
- $1/8^{th}$ degree (~12km) resolution gridded Precipitation and Surface Air Temperature
- Monthly time increments
- 1950-2100
- SRES A1b, A2, B1



atitude 25 .0625 N through 52 .0625 N
ongitude -124 .9375 E through -67 .0625 E

Area Limits	Min	Max
Latitude	25.1875	52.8125
Longitude	-124.6875	-67.0625

Use the above lat/long menus to control the red box position.



Step 1.1: Variables Help

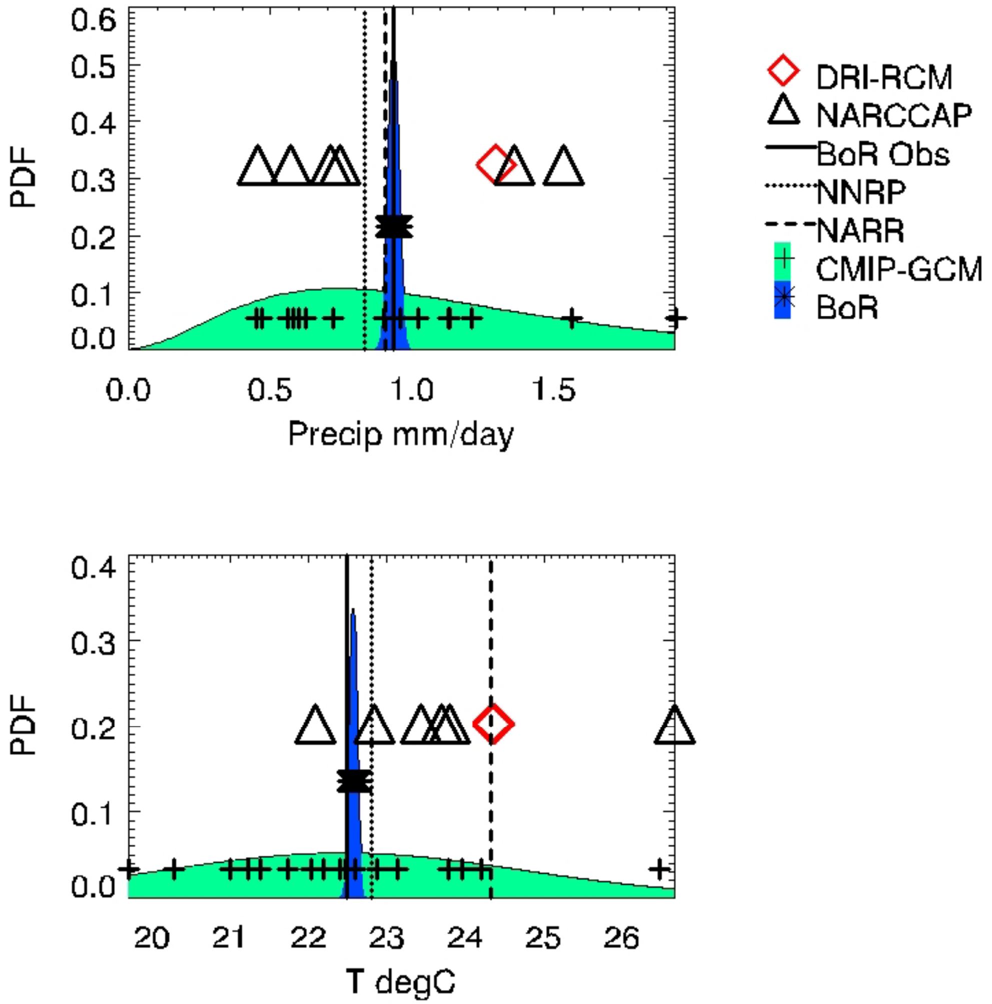
☑ Precipitation Rate (mm/day)
☑ Surface Air Temperature (deg C)

Step 1.2: Emissions Scenarios, Climate Models and Runs Help

De-select all runs	None	None	None
Select all runs	All	All	All
Climate Models:	Emissions Path: A1b	Emissions Path: A2	Emissions Path: B1
bccr_bcm2_0	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
cccma_cgcm3_1	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐
cnrm_cm3	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
csiro_mk3_0	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
gfdl_cm2_0	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
gfdl_cm2_1	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
giss_model_e_r	☐ ☑ ☐ ☑ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
inmcm3_0	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
ipsl_cm4	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐
miroc3_2_medres	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐
miub_echo_g	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐
mpi_echam5	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☐ ☐ ☐ ☐ ☐
mri_cgcm2_3_2a	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☑ ☐ ☐ ☐
ncar_ccsm3_0	☑ ☑ ☑ ☐ ☑ ☑ ☑ ☐	☑ ☑ ☑ ☑ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☑ ☑ ☑ ☐
ncar_pcm1	☑ ☑ ☑ ☑ ☐ ☐ ☐ ☐	☑ ☑ ☑ ☑ ☐ ☐ ☐ ☐	☐ ☑ ☑ ☐ ☐ ☐ ☐ ☐
ukmo_hadcm3	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐	☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐

F2: Use of Climate Records:

- Downscaled Products Intercomparison
- King et al. : Regional Climate Modeling activities over intermountain West.
- Thursday 8 April, 3:45pm….
- Room: Bear A&B..



More on Future Climate Projections

- Dynamical Downscaling
  - Chris Castro and F. Dominguez: University of Arizona
  - UW, UT, LLNL, PNNL, Iowa State Univ.
- Statistical Downscaling
  - Walden Von, Brandon Moore: Univ. of Idaho

Station-based model intercomparison exercise

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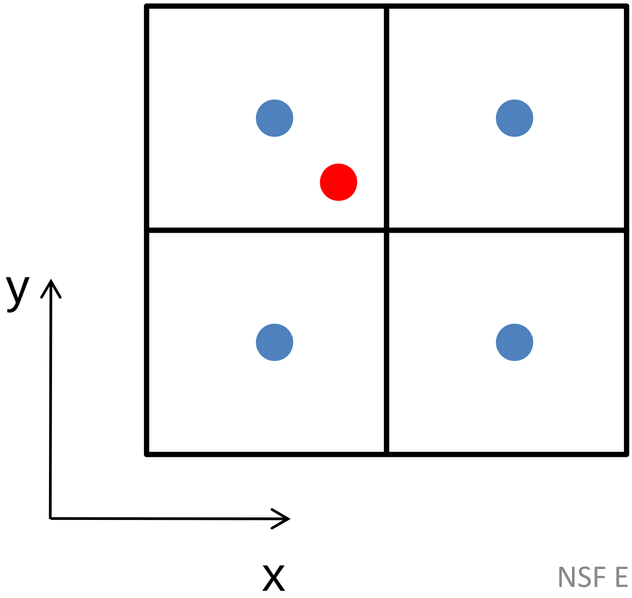
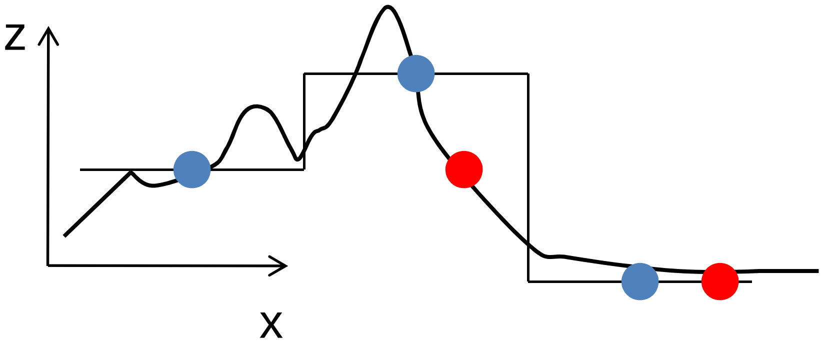
Evaluating the downscaling techniques (lab exercise):

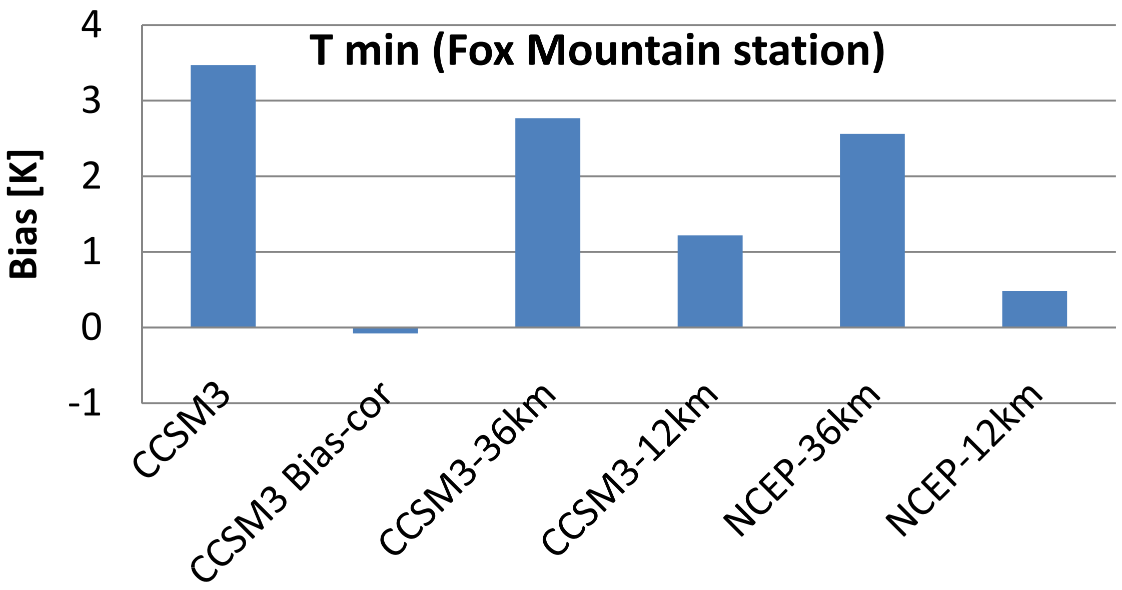
- Monthly means time increments 1997-2008.
- Observation from 3 different surface stations.
- Minimum and Maximum temperature.
- Two GCMS forcing (CCSM3 and NCEP/NCAR reanalysis)
- Statistical and Dynamical (RCM 36km and 12km grid sizes) downscaled data.
- Error definitions…. Root Mean Square Error, Mean Bias, Skill Score.
- Stratification of results: cold season (Dec-April), warm season (Jun-Sept), all year.....

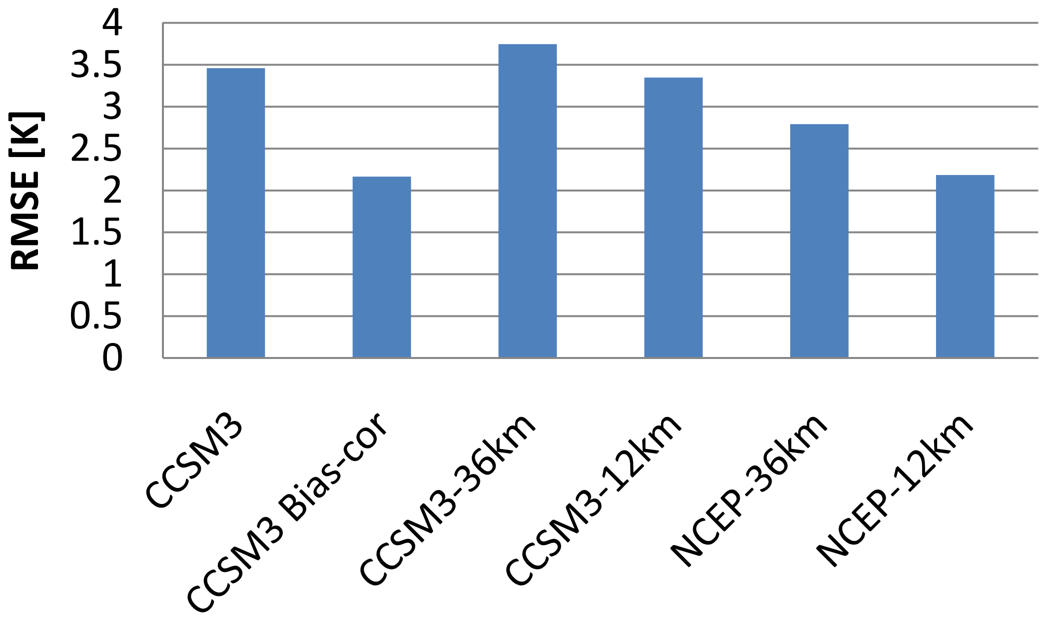
From gridded data to station-based data

- Interpolation scheme:
  - Nearest neighborhood?
  - Bilinear interpolation?






T min (Fox Mountain station)
Bias [K]
4
3
2
1
0
-1
CCSM3
CCSM3 Bias-cor
CCSM3-36km
CCSM3-12km
NCEP-36km
NCEP-12km


RMSE [K]
4
3.5
3
2.5
2
1.5
1
0.5
0
CCSM3
CCSM3 Bias-cor
CCSM3-36km
CCSM3-12km
NCEP-36km
NCEP-12km

Evaluating the downscaling techniques (lab exercise):

1. Which downscaling technique works better using the CCSM3, the statistical or RCM methods?
2. Which GCM works better using the RCM, CCSM3 or NCEP/NCAR reanalysis?
3. Which RCM grid size works better, the 36 km or the 12 km grid size?
4. Do your answers change if considering i) all year ii) only warm seasons, or iii) only cold seasons?