Uncertainty Transfer in Modeling Layers: From GCM to downscaling to hydrologic surface-groundwater modeling

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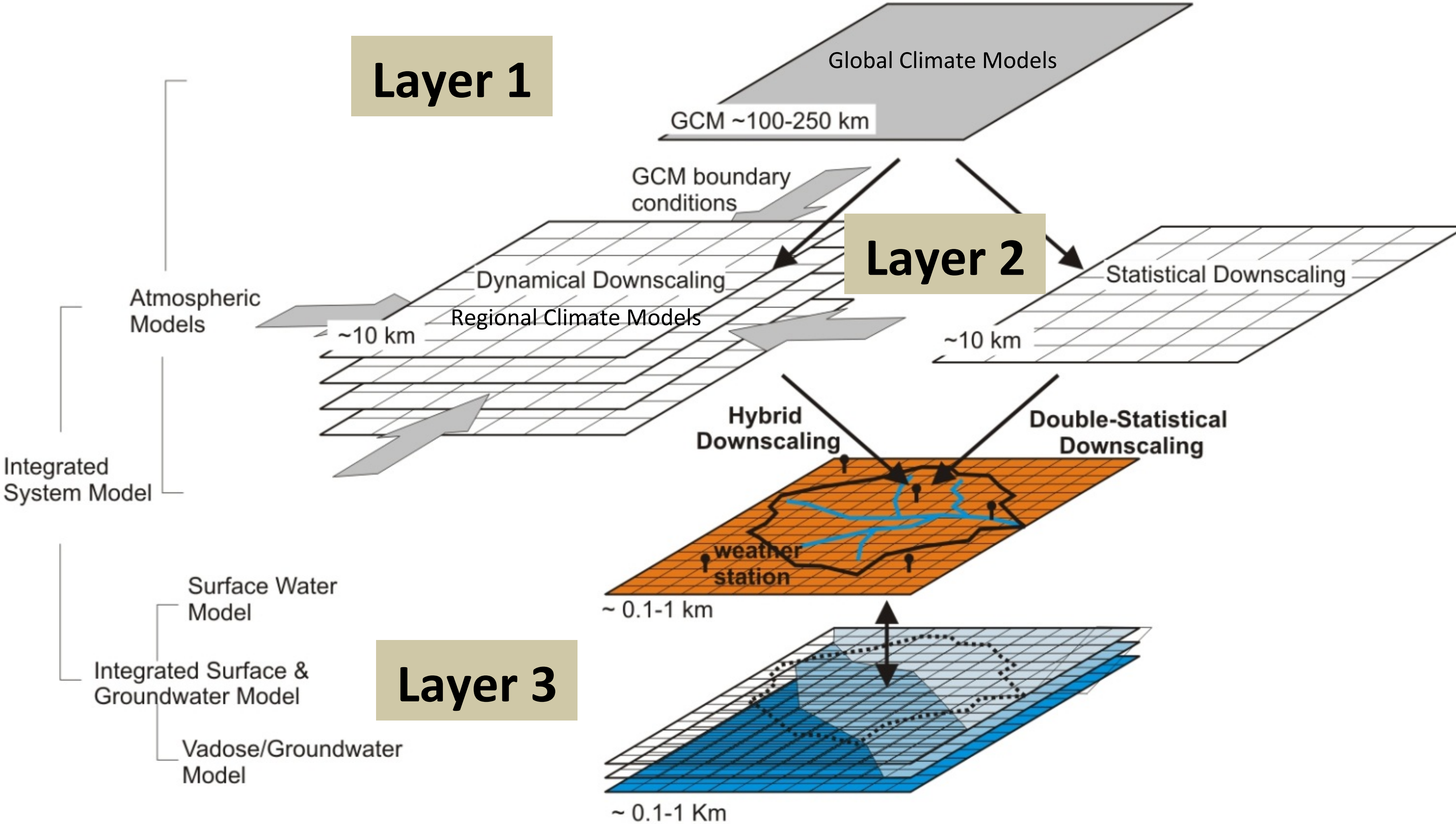
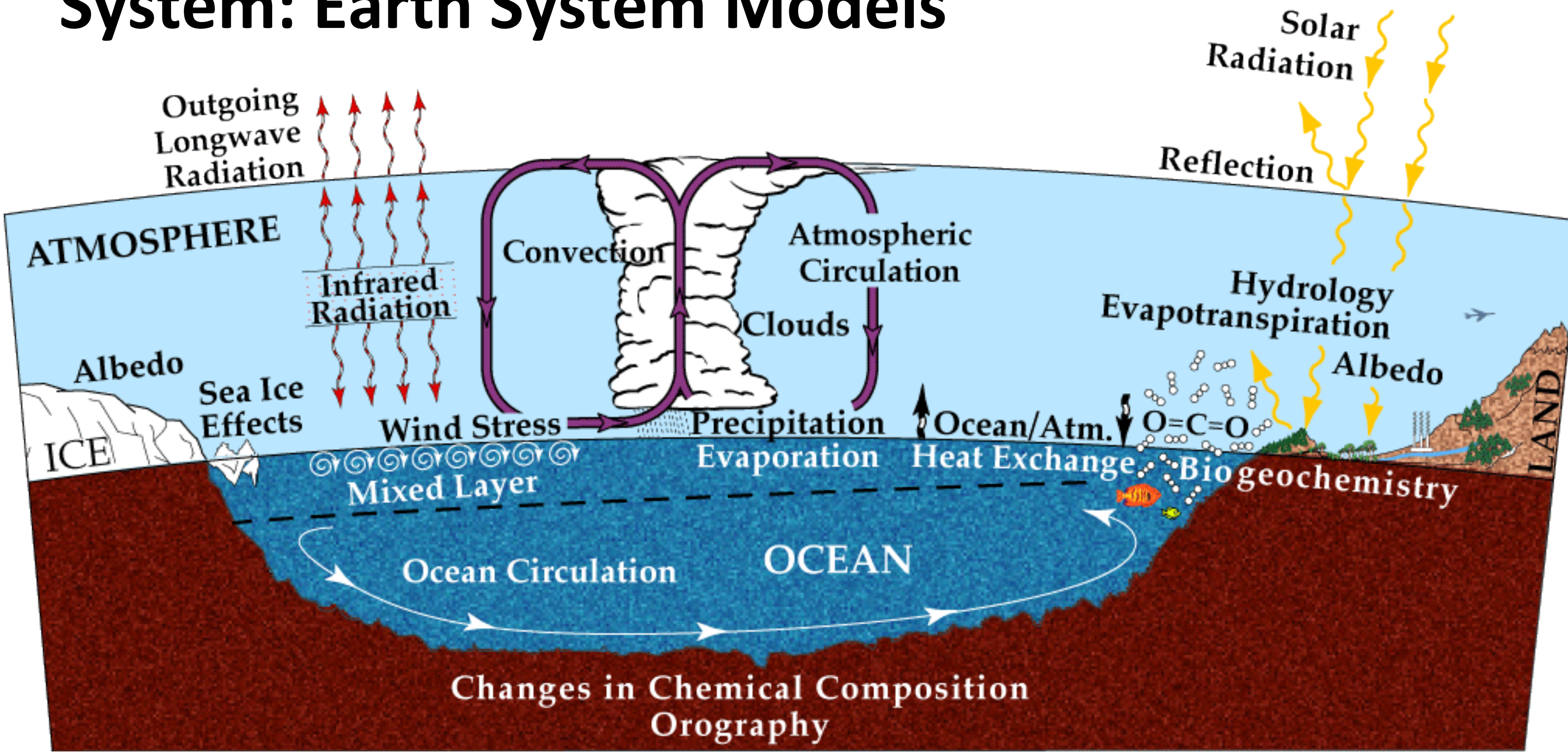
Presentation Goals

- How model uncertainty is transferred from GCMs to hydrologic model results for different downscaling strategies?
- Use historical and future assessment using:
  - GCM: coarse global climate projections (CMIP3 and CMIP5 datasets; 100 km grid size).
  - Downscale GCM using dynamical or statistical methods (~10 km grid size).
  - To drive/force/run a hydrologic surface-groundwater systems (60 m grid size).
- When possible, I would highlight ideas of Metadata, Model interoperability and Portability.

A Hydroclimate Modeling Framework

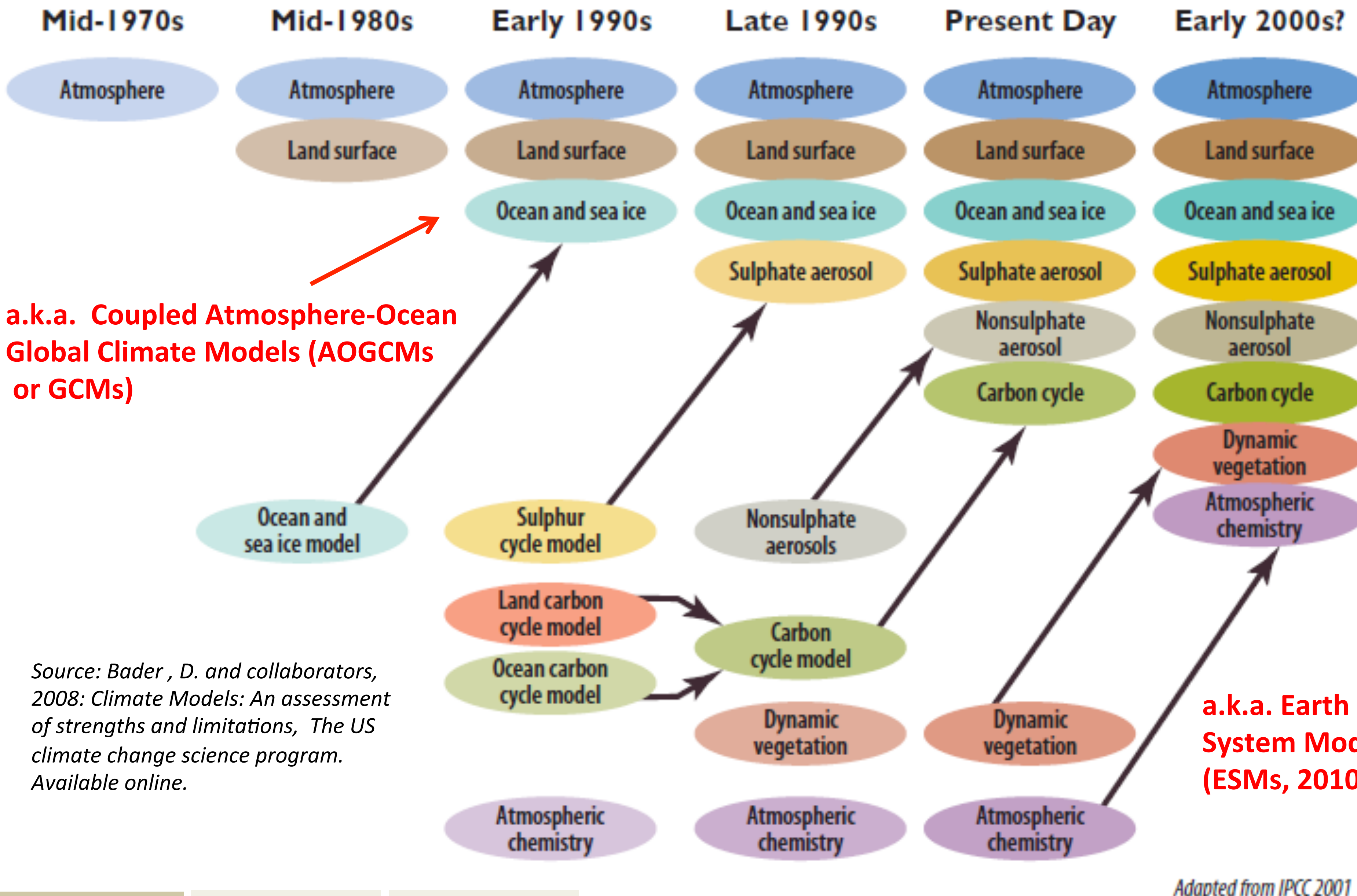


Schematic of GCM Components of the Climate System: Earth System Models



Source: Neelin, 2011. Climate Change and Climate Modeling, Cambridge University Press.

Development of Climate Models: Past, Present, and Future



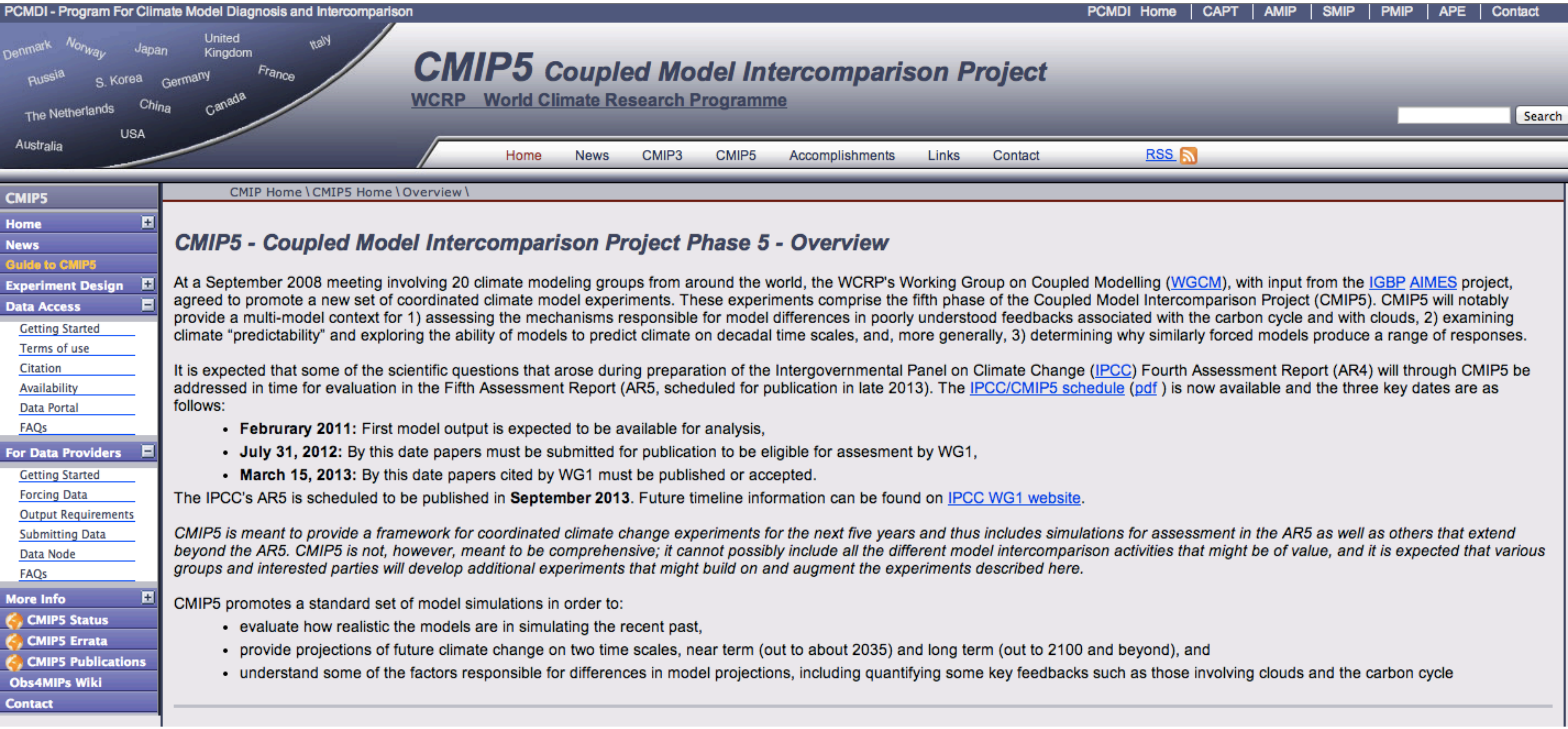
a.k.a. Coupled Atmosphere-Ocean Global Climate Models (AOGCMs or GCMs)

a.k.a. Earth System Models (ESMs, 2010s)

Source: Bader , D. and collaborators, 2008: Climate Models: An assessment of strengths and limitations, The US climate change science program. Available online.

Layer 1 Layer 2 Layer 3

http://cmip-pcmdi.llnl.gov/cmip5/


PCMDI - Program For Climate Model Diagnosis and Intercomparison

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Denmark Norway Japan United Kingdom Italy Russia S. Korea Germany France The Netherlands China Canada USA Australia

CMIP5 Coupled Model Intercomparison Project

WCRP World Climate Research Programme

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CMIP5 - Coupled Model Intercomparison Project Phase 5 - Overview

At a September 2008 meeting involving 20 climate modeling groups from around the world, the WCRP's Working Group on Coupled Modelling (WGCM), with input from the IGBP AIMES project, agreed to promote a new set of coordinated climate model experiments. These experiments comprise the fifth phase of the Coupled Model Intercomparison Project (CMIP5). CMIP5 will notably provide a multi-model context for 1) assessing the mechanisms responsible for model differences in poorly understood feedbacks associated with the carbon cycle and with clouds, 2) examining climate "predictability" and exploring the ability of models to predict climate on decadal time scales, and, more generally, 3) determining why similarly forced models produce a range of responses.

It is expected that some of the scientific questions that arose during preparation of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) will through CMIP5 be addressed in time for evaluation in the Fifth Assessment Report (AR5, scheduled for publication in late 2013). The IPCC/CMIP5 schedule (pdf) is now available and the three key dates are as follows:

- **Februrary 2011:** First model output is expected to be available for analysis,
- **July 31, 2012:** By this date papers must be submitted for publication to be eligible for assesment by WG1,
- **March 15, 2013:** By this date papers cited by WG1 must be published or accepted.

The IPCC's AR5 is scheduled to be published in **September 2013**. Future timeline information can be found on IPCC WG1 website.

CMIP5 is meant to provide a framework for coordinated climate change experiments for the next five years and thus includes simulations for assessment in the AR5 as well as others that extend beyond the AR5. CMIP5 is not, however, meant to be comprehensive; it cannot possibly include all the different model intercomparison activities that might be of value, and it is expected that various groups and interested parties will develop additional experiments that might build on and augment the experiments described here.

CMIP5 promotes a standard set of model simulations in order to:

- evaluate how realistic the models are in simulating the recent past,
- provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond), and
- understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle

- *100s TB of GCM output from a couple dozen research institutions around the world*
- *Controlled experiments; Metadata standards*
- *Data format standards using NETCDF protocols*

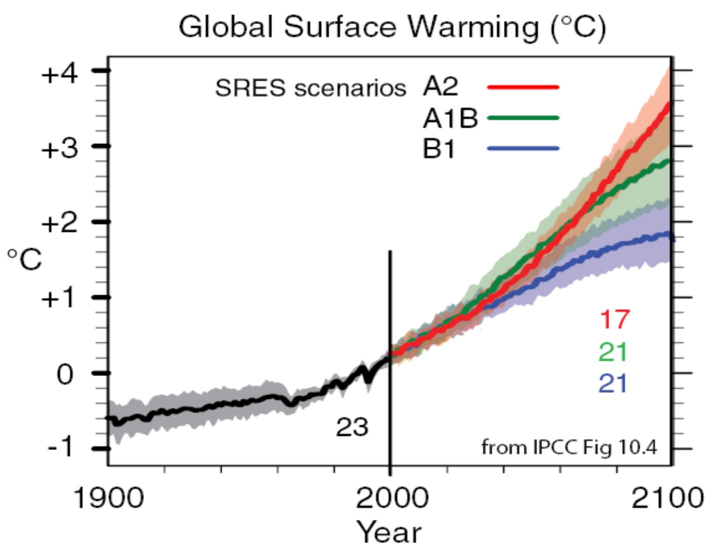
Layer 1 Layer 2 Layer 3

The Intergovernmental Panel on Climate Change (IPCC)
Attribution/Detection based on Observations and GCMs

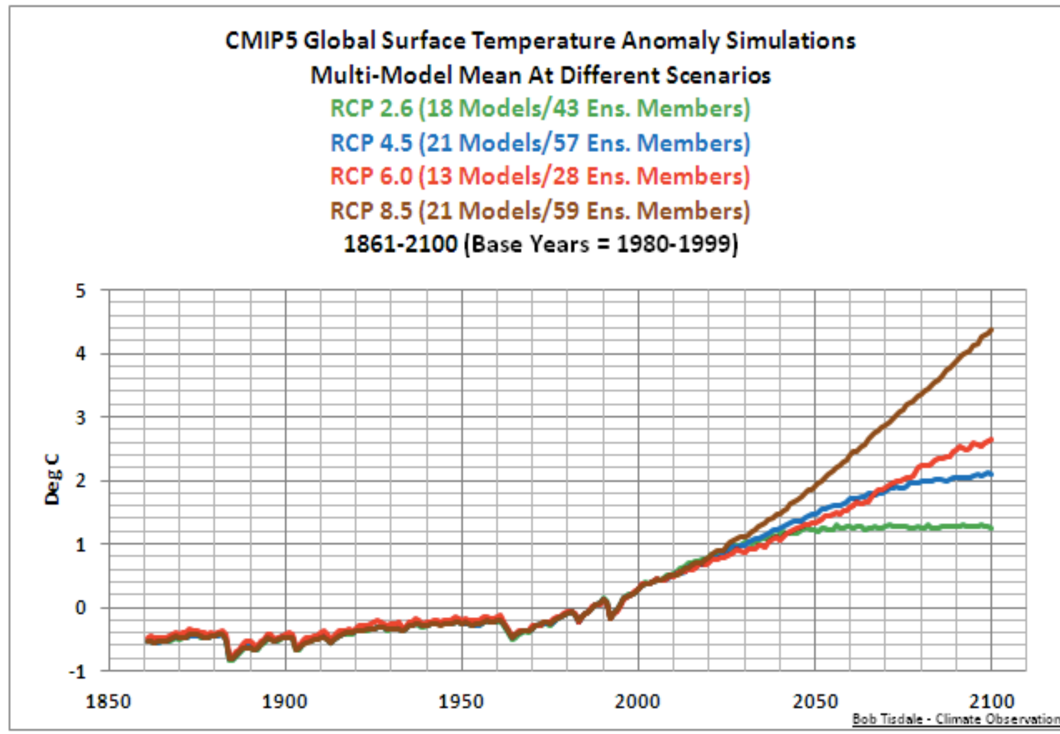
Year	Assessment Report	Attribution Statement	GCM Experiment
1990	FAR	“The size of the *warming over the last century* is broadly consistent w… …lels, but is also of the *same magnit…* … […] Thus the observed inc… …natural variability”	5 GCMs/1xC02, 2xC02 ~5° (~500km) grid size
1995	SAR	“The balance… …*le* human influence on global clir… …certainties. [...]”.	10 GCMs/CERA-CMIP/ IS92a to f; ~3° (~300km) aerosols and GHGs
1997	Kyoto Protocol sets targets		
2001	TAR	“Th… …s …tivities.”	7 GCMs/CMIP2/ SRES; < 3° grid size
2007	AR4	“Most of… …temperatures since the mi… …o the observed increase in anth… …concentrations.”	25 GCM/CMIP3/ SRES A1Fi, A1, A2, A1B, B1, B2; ~1.0-4° grid size
2013/ 2014?	AR5	“Is is extremely likely (… …nthropogenic change has been detected in surface tempe… …e with very high significance levels (less than 1% error probability).” “The long-term climate model simulations show a trend in global-mean surface temperature from 1951 to 2012 that agrees with the observed trend (very high confidence)..”	24 GCM/CMIP5/RCPs ensembles and Earth System Models; ~0.5-2° (~50-200km) grid size; decadal variations

Increasing attention to reporting uncertainty

CMIP3 (IPCC-AR4, 2007)



CMIP5 (IPCC-AR5, 2014)

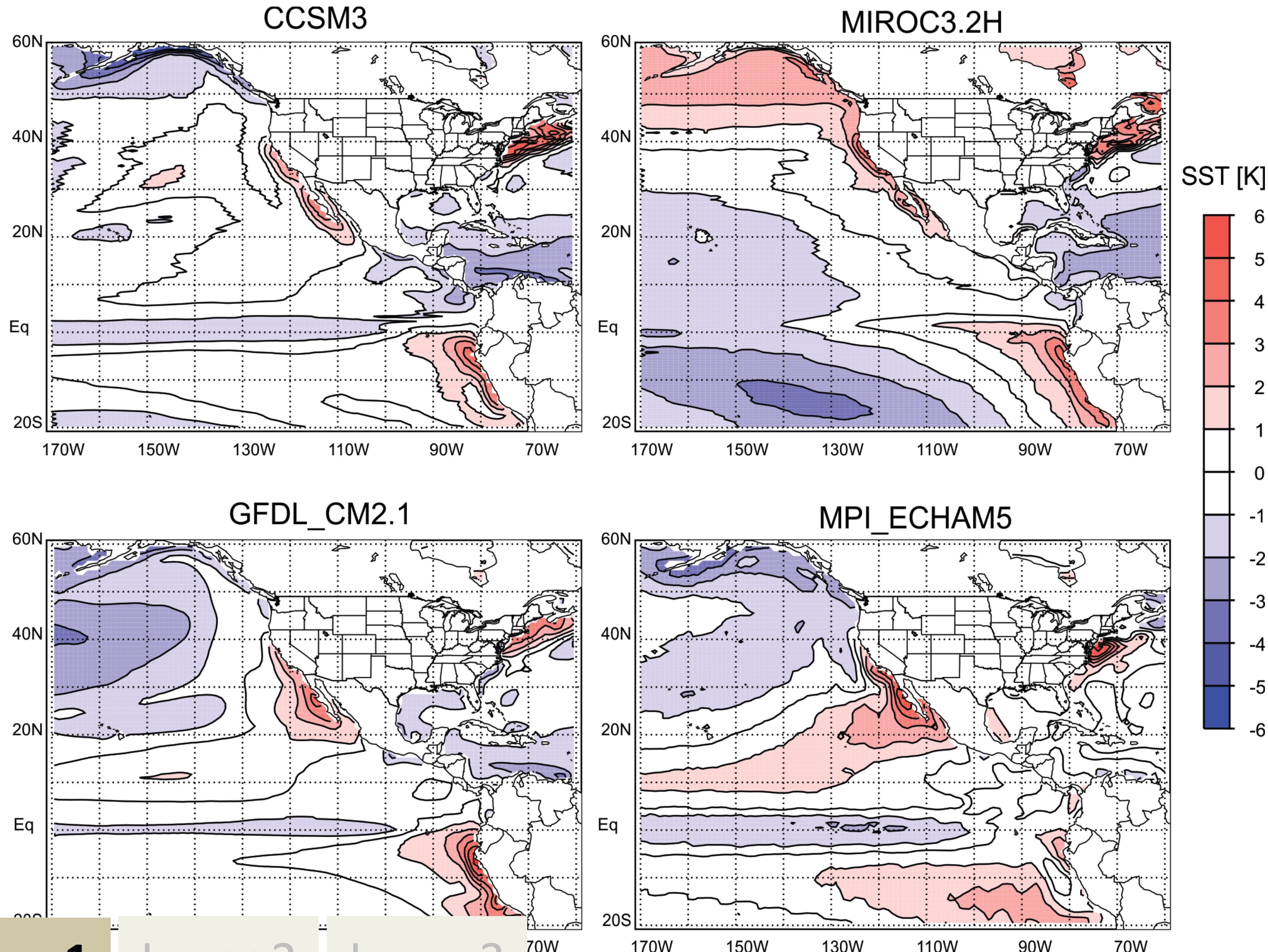


"The long-term climate model simulations show a trend in global-mean surface temperature from 1951 to 2012 that agrees with the observed trend "

Layer 1 Layer 2 Layer 3

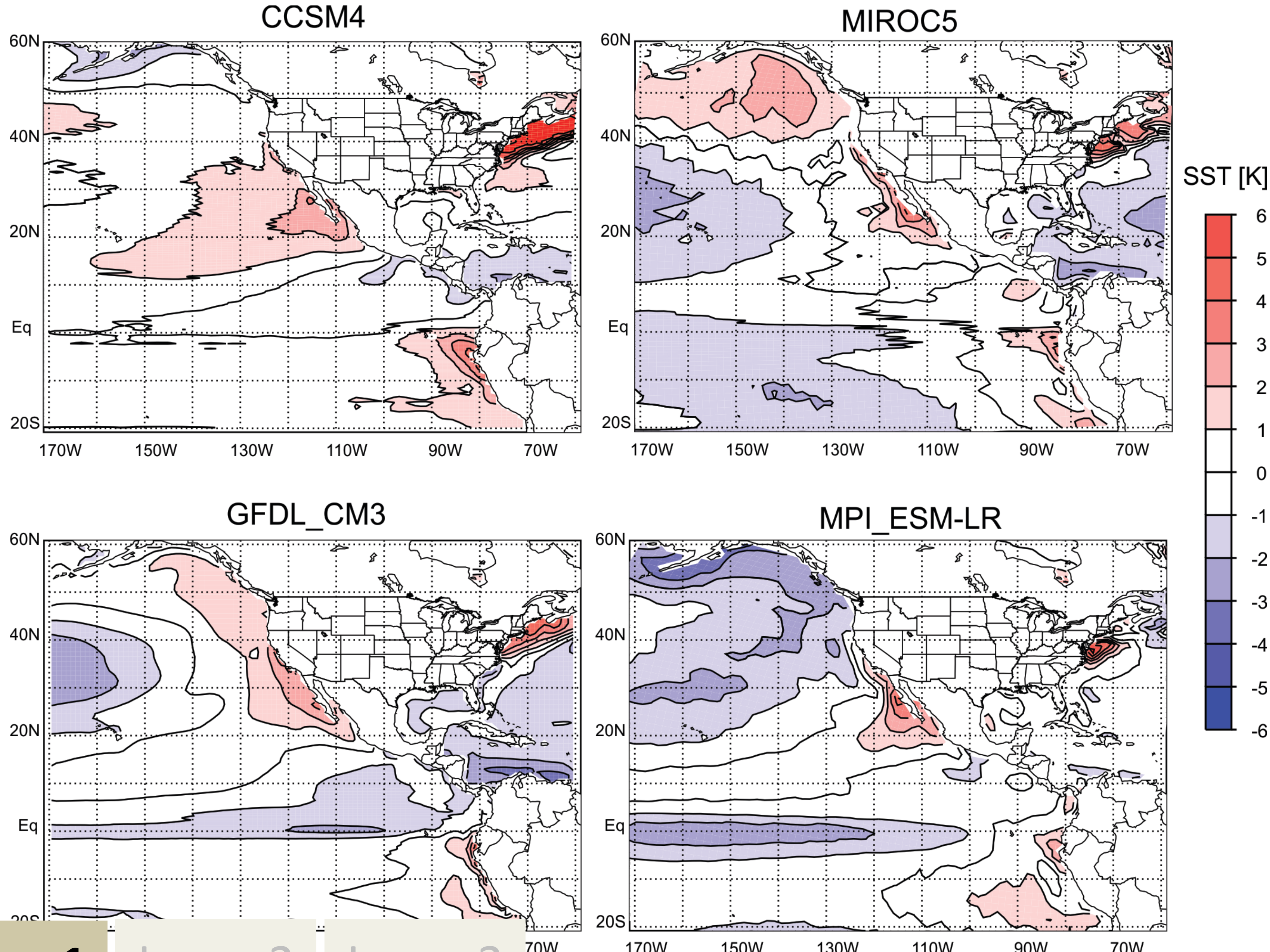
Source http://www.ipcc.ch/index.htm

CMIP3: Observed minus GCM (historical)



Layer 1 Layer 2 Layer 3

CMIP5: Observed minus GCM (historical)

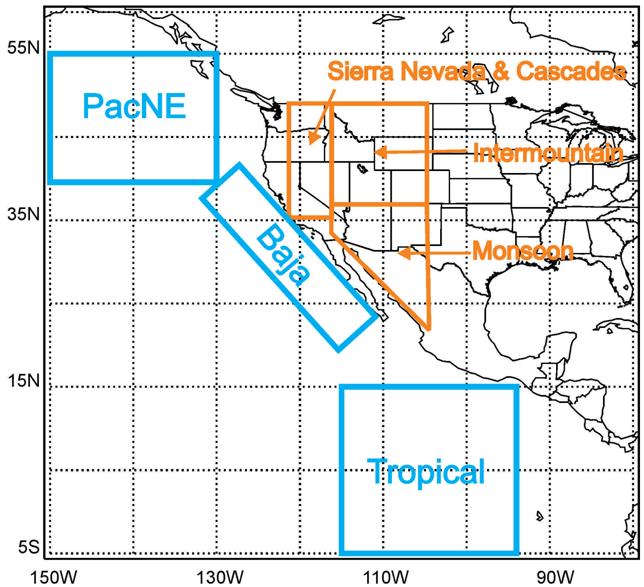


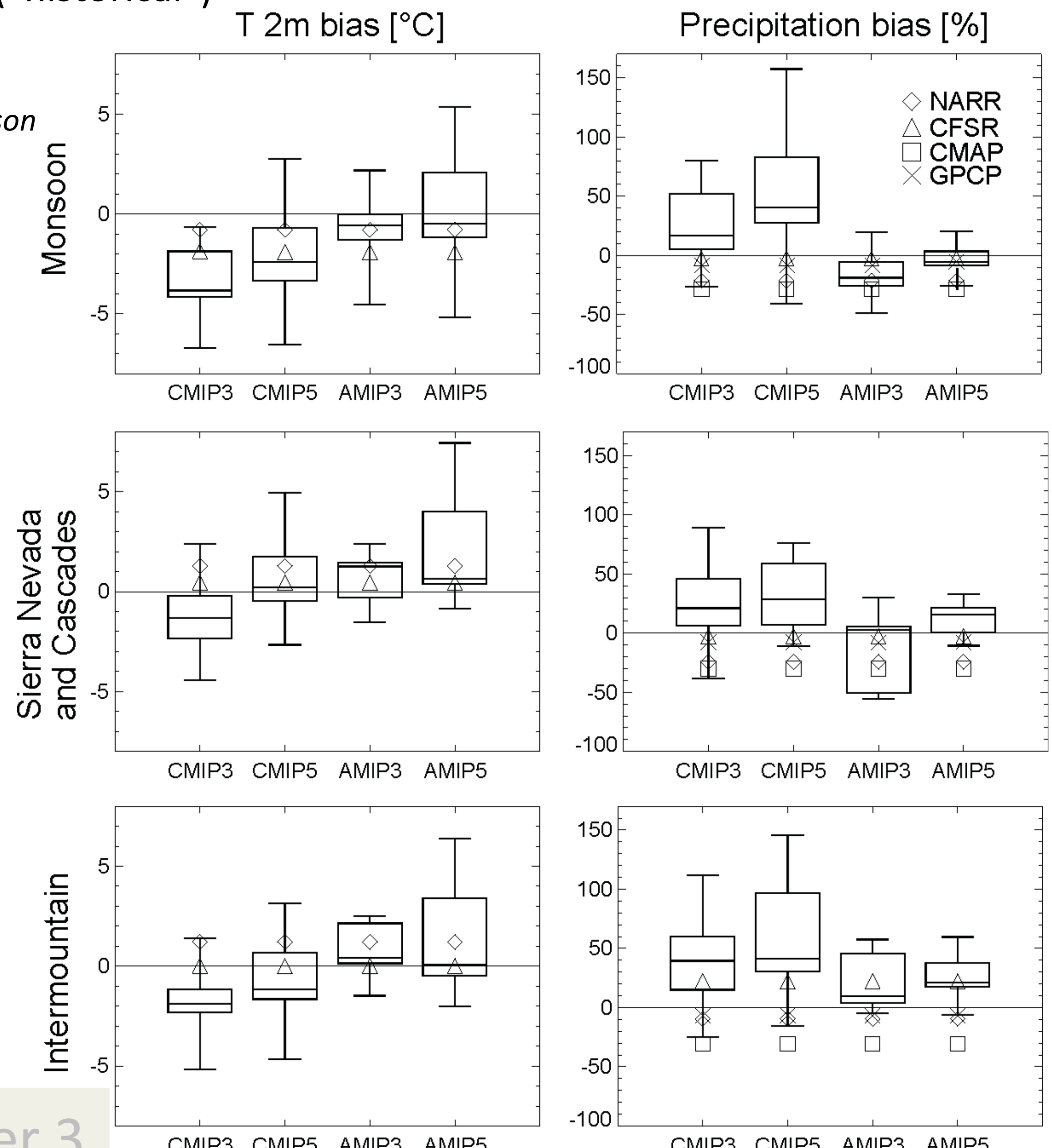
Layer 1 Layer 2 Layer 3

How do CMIP3 and CMIP5 participant GCMs compare to reproduce present ("historical") climate?

CMIP: Couple Model Intercomparison

AMIP: Atmospheric Model Intercomparison





In a way, isolating the effect of the ocean, shows that some of the uncertainty arises from remote areas.

Mejia, J.F., Koračin1, D, and E.M. Wilcox, 2014: Effect of Coupled GCM SST Biases on Simulated Climate of the Western U.S., Submitted J. of Climate.

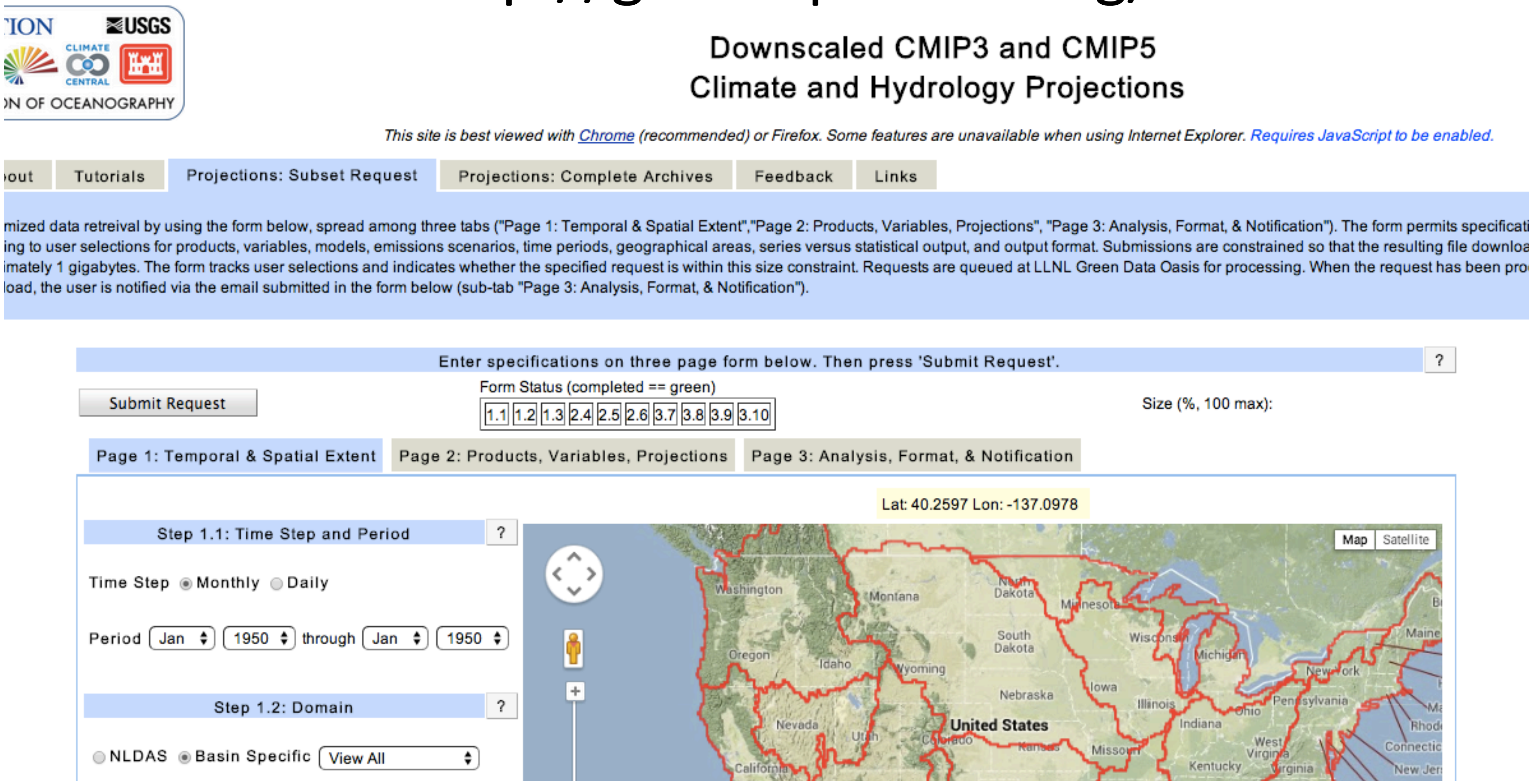
Layer 1 Layer 2 Layer 3

LAYER 2: Downscaled Products Statistical and Dynamical Downscaling

- The need to adapt GCM output (~100-250 Km) to assess their impact on Regional and Local scales (~10-50 Km)
- The idea is that finer scales are more meaningful in the context of local and regional impacts.
- Two general approaches are used in downscaling:
  - ***Dynamical***: performed by a Regional Climate Model (RCM) with a finer representation of local terrain, in theory with better simulation of weather systems improving climate processes over the region of interest – GCMs provide boundary conditions-.
  - ***Statistical:*** Computationally efficient; large scale climate features are *statistically related* –form observations- region and local conditions, examples:
    - Bias-correction and spatial disaggregation approaches (BCSD)
    - Bias-correction and constructed analogues (BCCA)

Statistical Downscaling Data Portal

http://gdo-dcp.ucllnl.org/



- ~10s TB of GCM output from a couple dozen research institutions around the world
- Controlled experiments
- Metadata standards
- Data format standards using NETCDF protocol (& ASCII and CSV).

NETCDF- Network Common Data Form (www.unidata.ucar.edu/software/netcdf)

- **All model layers in this modeling framework are run offline but use NETCDF format as output/input format to ease model connectivity.**
- Design to pack and store scientific data
- It is a flexible, machine independent, self-describing format: bundles metadata + data.
- Standard protocols : 5-Dimension grids, names of physical quantities, inclusion of units, and so on (Climate and Forecast (CF) convention).
- Widely used within the scientific community & supported many analysis and visualization packages: Fortran, C, R, MatLab, IDL, Python, NCAR Common Language (NCL; http://www.ncl.ucar.edu/Applications/wrf.shtml).

Dynamical Downscaling

CORDEX - 50km

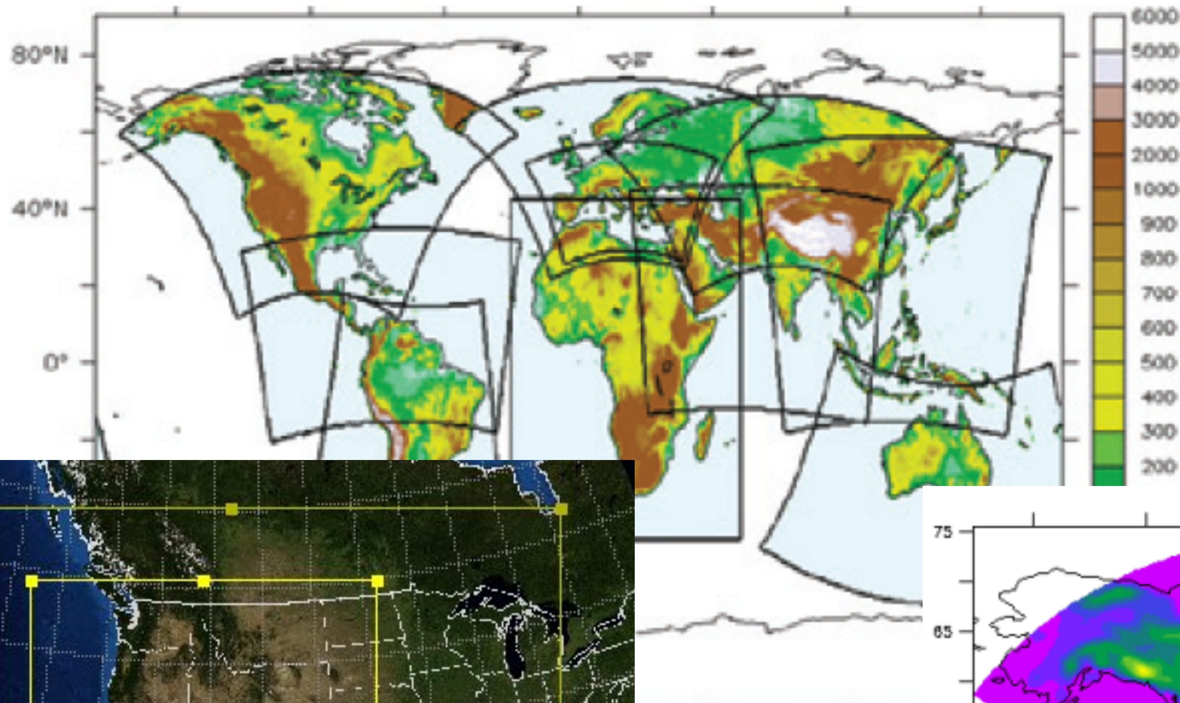
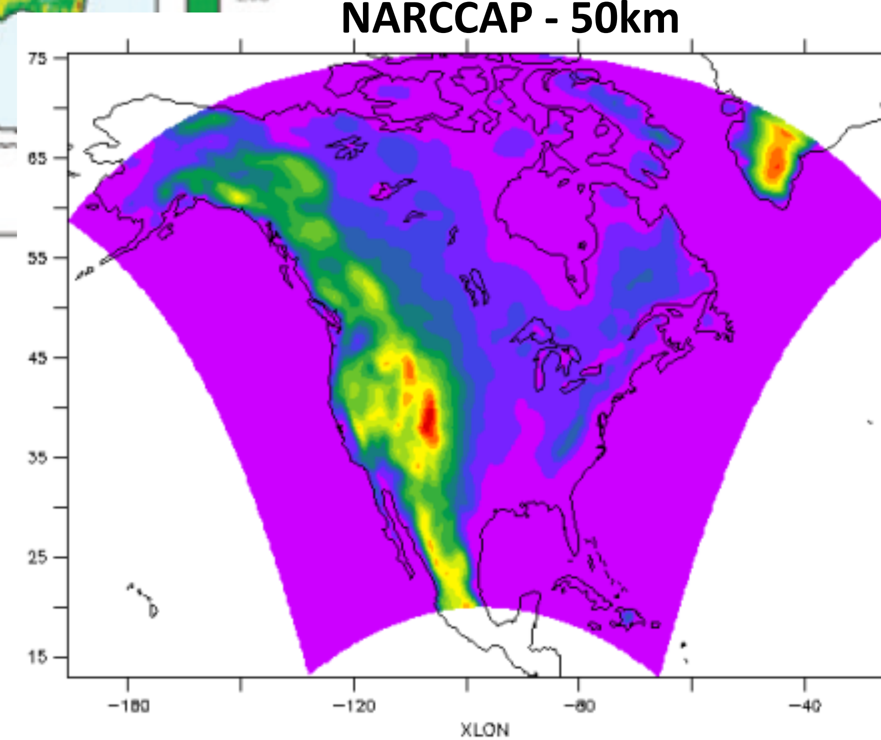


Figure 1 shows a schematic of the CORDEX RCM domains where these should be interpreted as interior analysis domains (i.e. not including the RCM boundary relaxation zone).

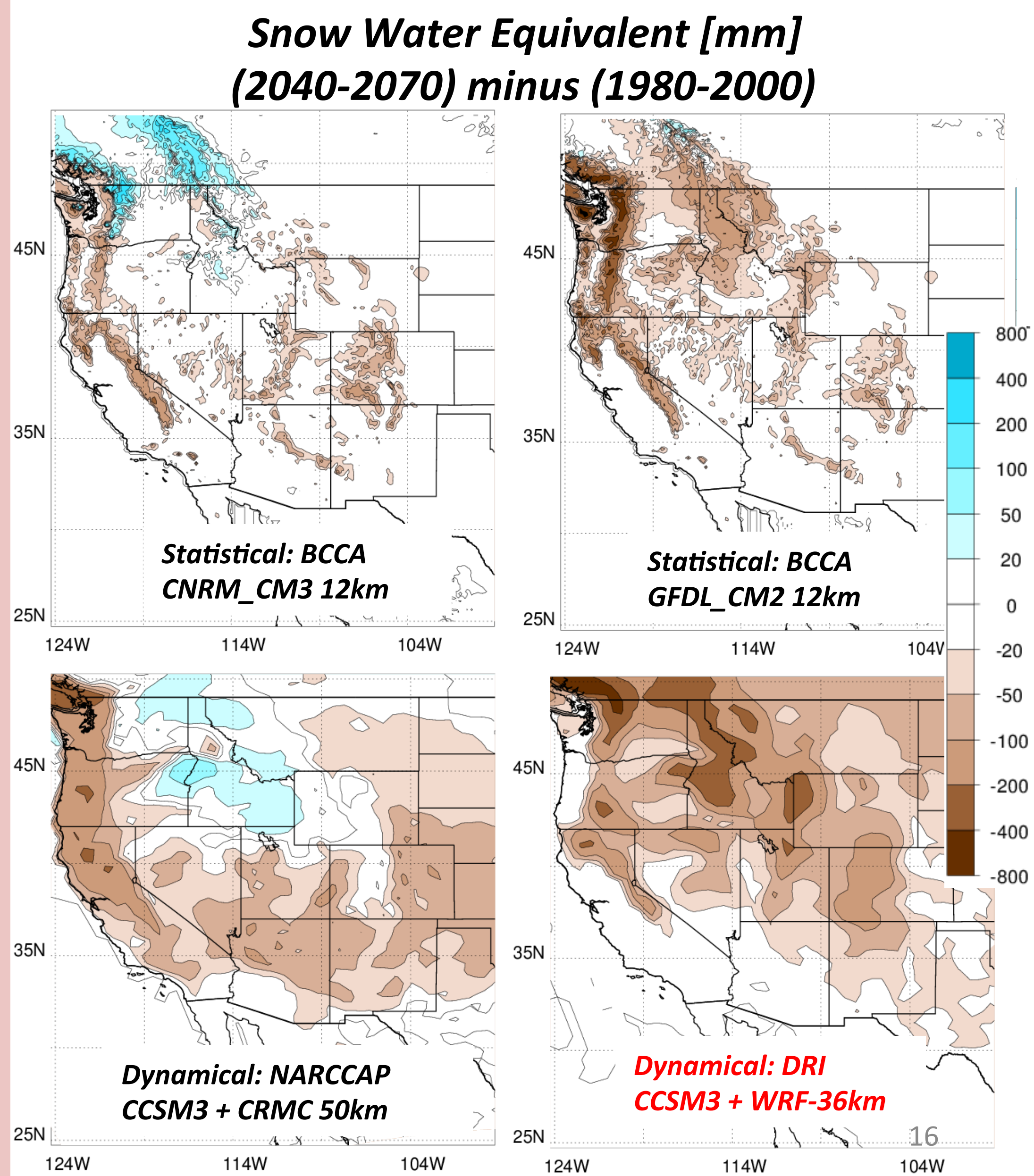
DRI-RCM
(1) 36-km
(2) 12-km
Hourly.

NARCCAP - 50km



Statistical and Dynamical Downscaling

- Snow Water Equivalent change
  - *Snow Water Equivalent: f(Tmean, Precip)*
- Large spatial differences between:
  - GCMs
  - Downscaling approach
  - Downscaling scales
- Ensemble approach?



Layer 1 | **Layer 2** | Layer 3

From GCMs to Regional Downscaling to Impact Studies

- How to understand and reason about GCMs uncertainty?
- Climate change *downscaling* and *impacts* community need to understand and assess uncertainty.
  - *"..instances of fit* [e.g., bias correction approaches] *between the model output and observational data do not confirm the models themselves.." Curry and Webster, BAMS, 2011.*

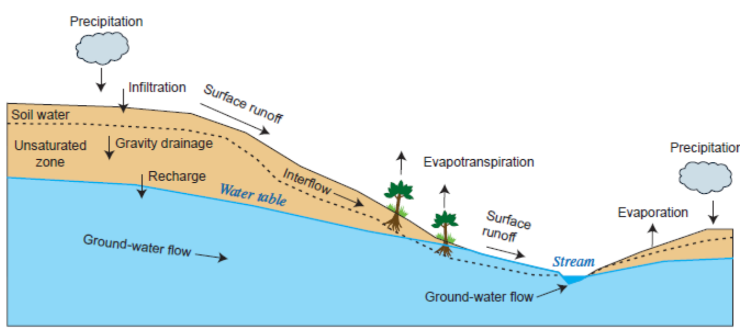
Layer 1 **Layer 2** Layer 3

LAYER 3: Hydrology Approach

USGS
science for a changing world

GSFLOW—Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005)

Chapter 1 of
Section D, Ground-Water/Surface-Water
Book 6, Modeling Techniques

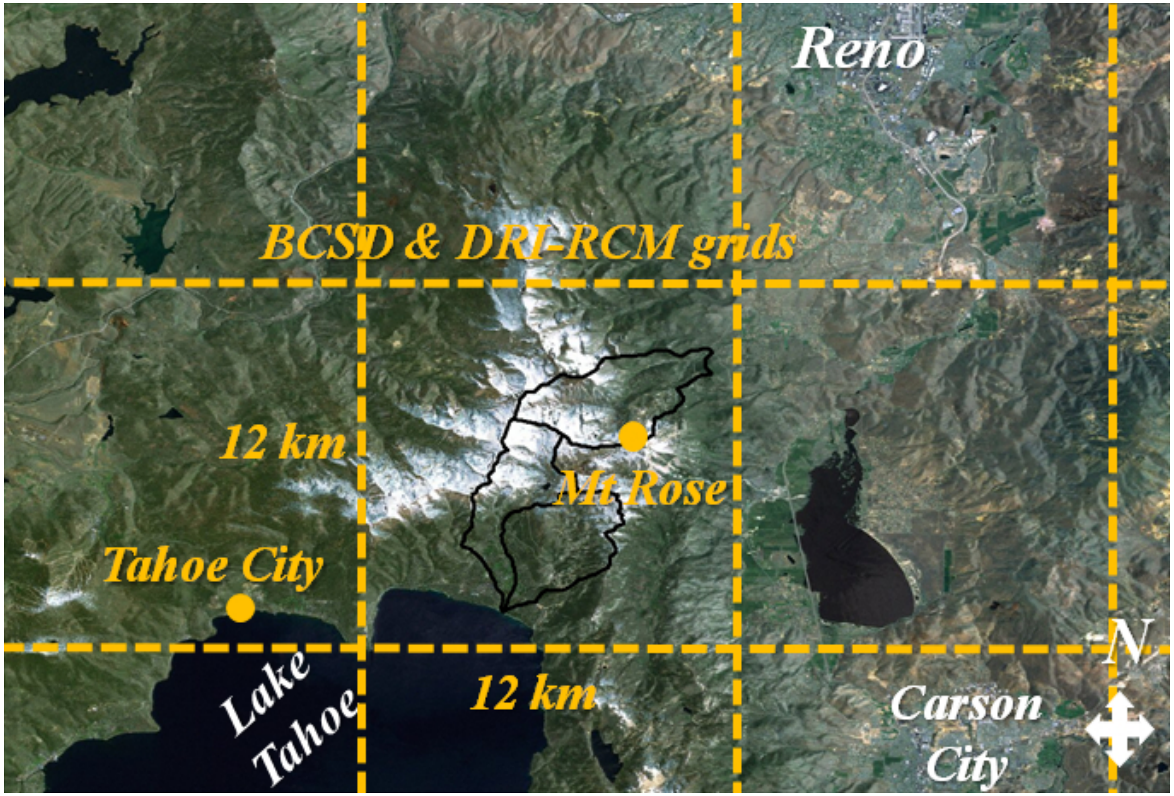


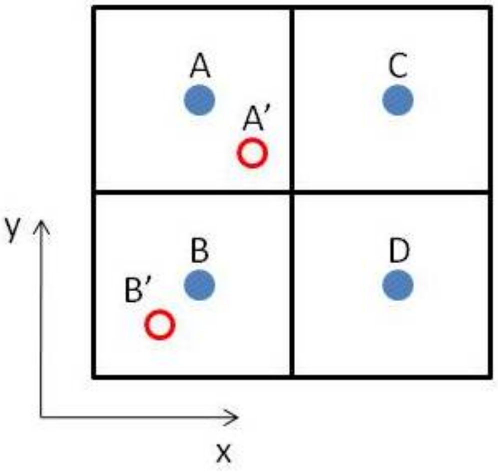
Techniques and Methods 6–D1

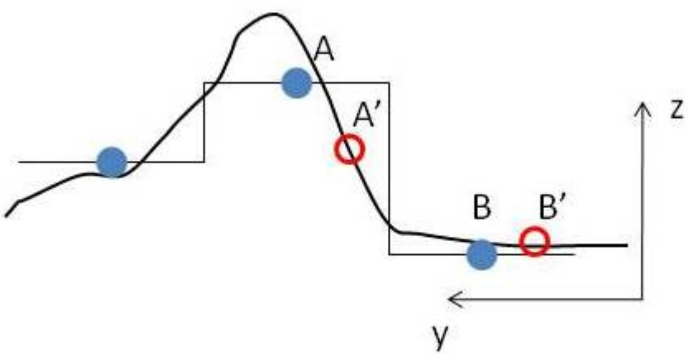
U.S. Department of the Interior
U.S. Geological Survey

- We apply atmospheric modeling output to force an integrated hydrologic model GSFLOW constructed for three watersheds in the Carson Range of the eastern Sierra.
- GSFLOW is the integration of surface-PRMS and groundwater-MODFLOW and most of the capabilities of these individual models.

Downscale data (Layer 2) mesh relative to basin of interest

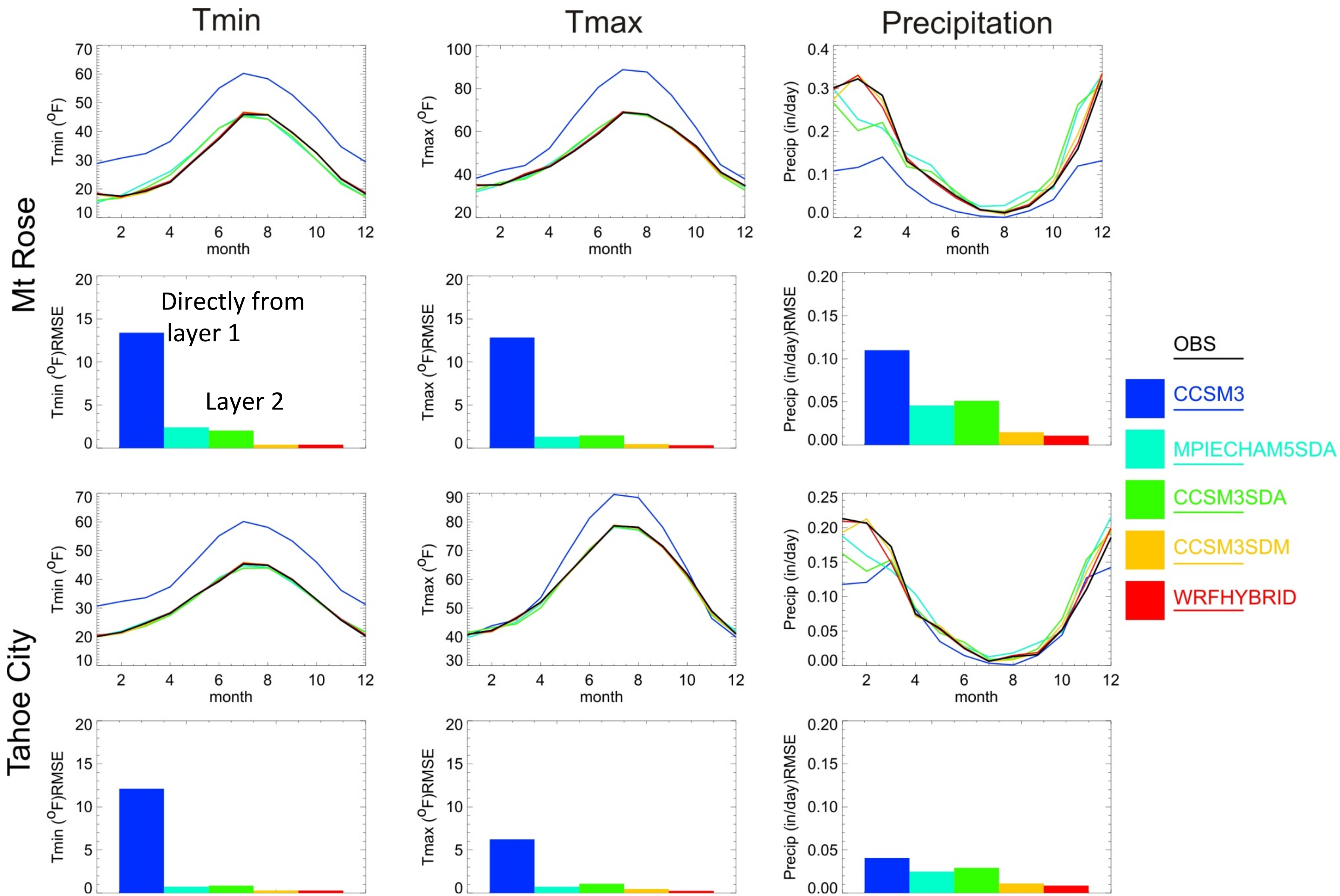






Layer 1 Layer 2 **Layer 3**

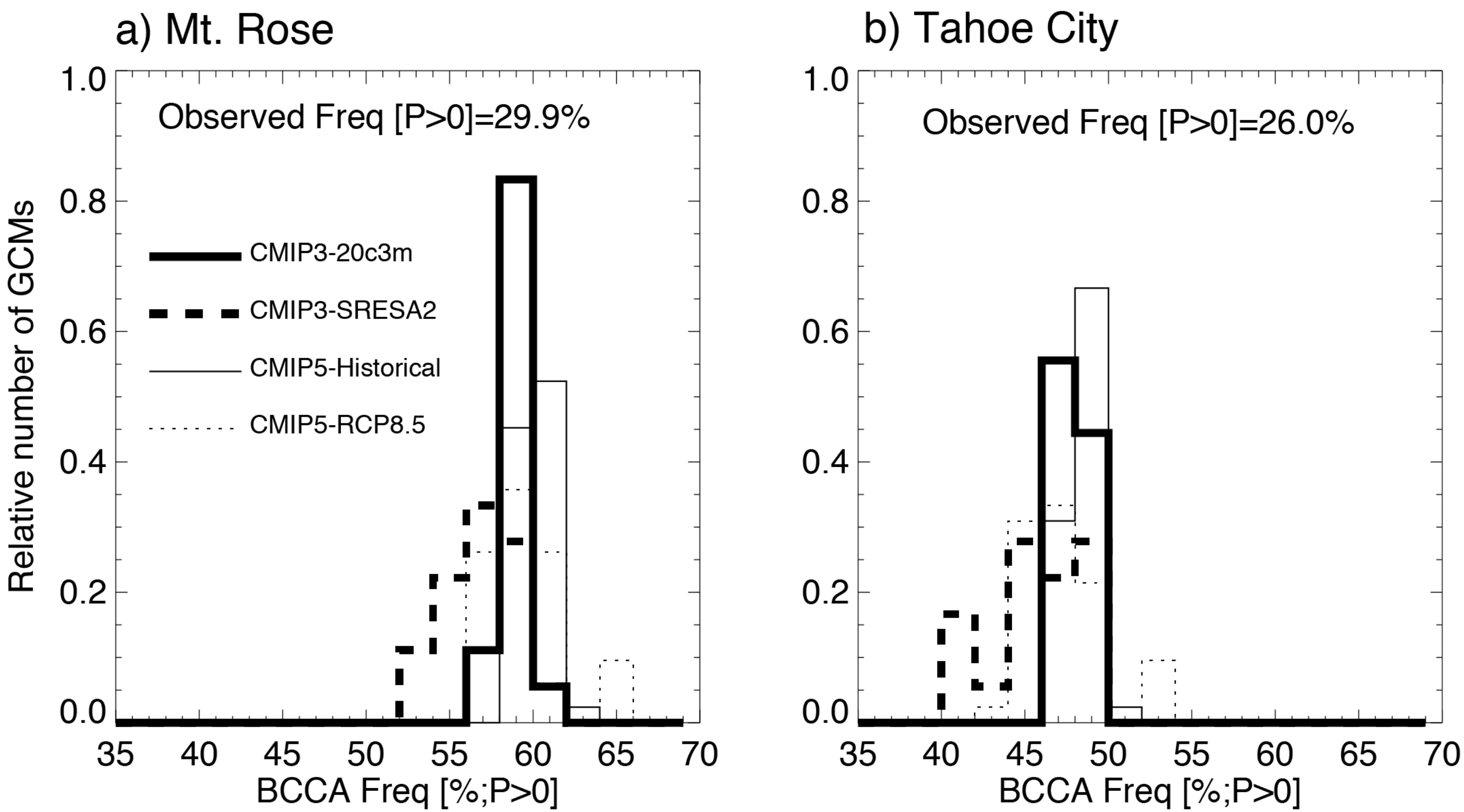
Evaluation period: 1982-2007



Layer 1 Layer 2 **Layer 3**

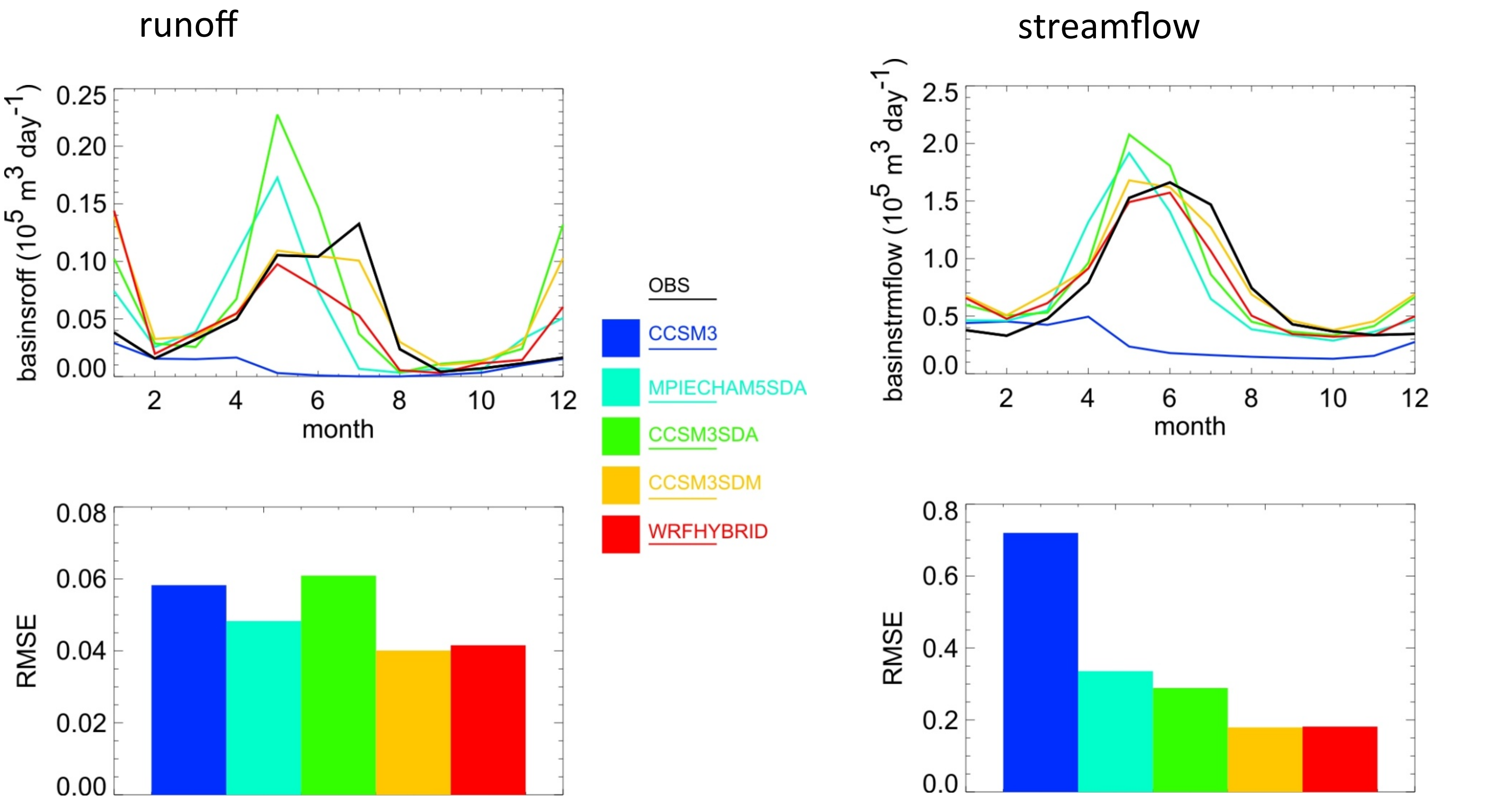
Mejia, J. F., Huntington, J., Hatchett, B., Koracin, D. and Niswonger, R. G., 2012: Linking Global Climate Models to an Integrated Hydrologic Model: Using an Individual Station Downscaling Approach. Journal of Contemporary Water Research & Education, 147: 17–27. doi: 10.1111/j.1936-704X.2012.03100.x

Other high-order statistics



Layer 1 Layer 2 **Layer 3**

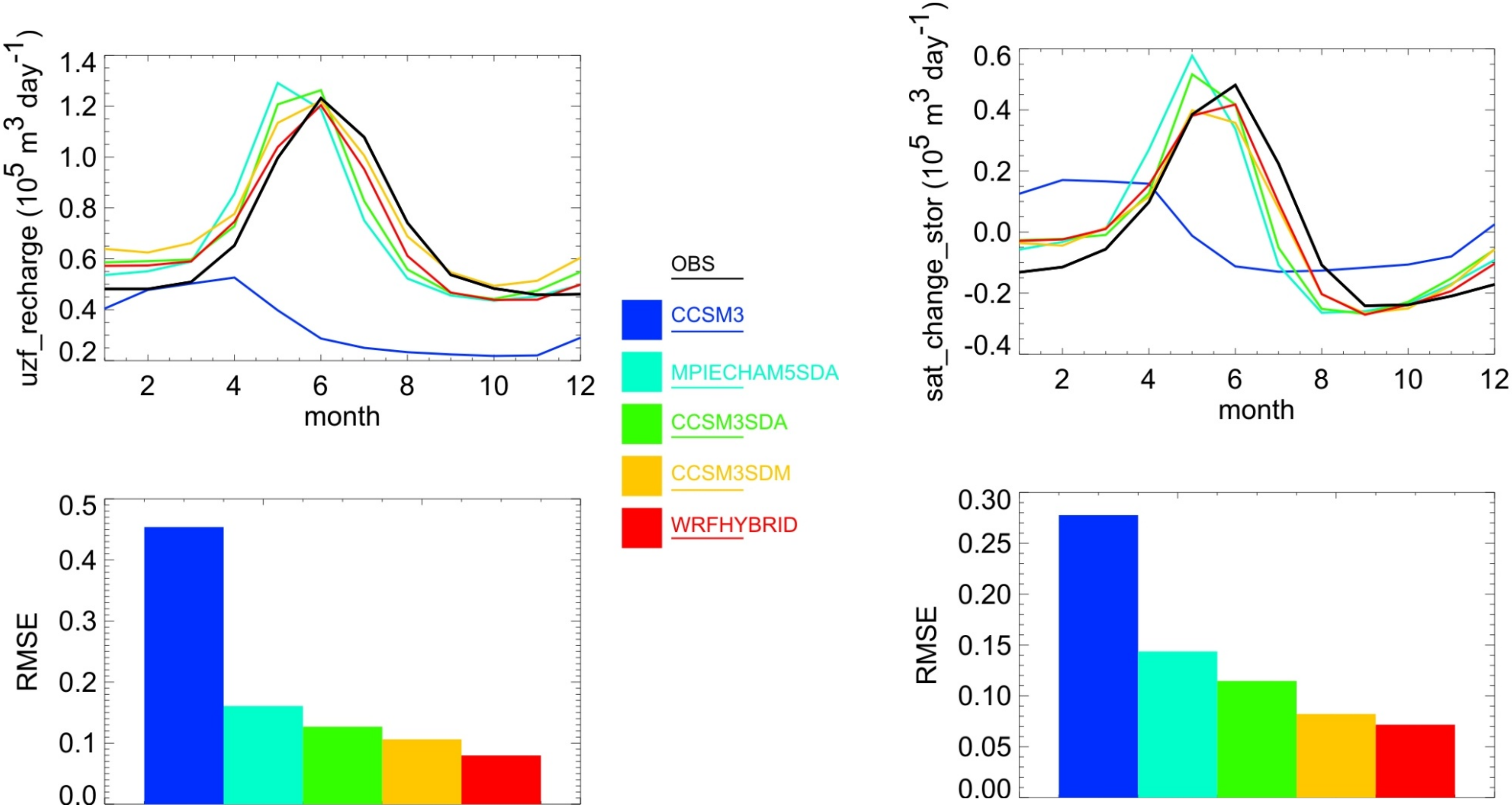
Evaluation Runs: 1982-2007



Layer 1 Layer 2 **Layer 3**

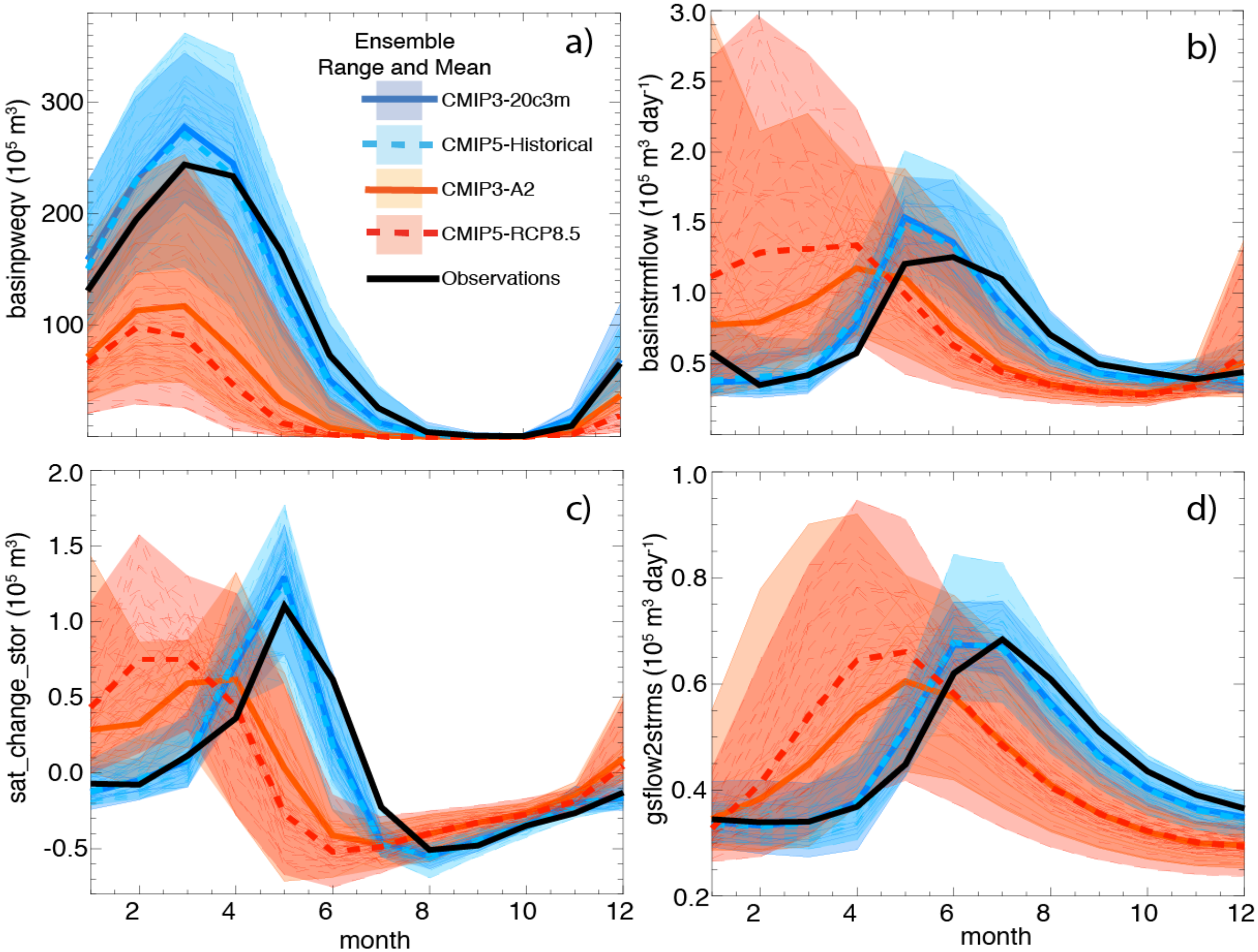
Recharge

Change in Storage



Layer 1 Layer 2 **Layer 3**

GSFLOW with Double-Statistical Downscaling Ensemble



CMIP3 and CMIP5
Historical (Blue; 1981-2000)
Future (Red; 2081-2100)

BASIN AVERAGE

(a) Volume of water in snow pack,
(b) Streamflow
(c) Change in saturated zone storage
(d) Groundwater to stream discharge.

Layer 1 Layer 2 **Layer 3**

Conclusions

- Upon the large number of degrees of freedom in the each model layer and model layer, a probabilistic (e.g., ENSEMBLE) approach is necessary.
- The MULTI-SCALE modeling framework and the large variety of modeling options LIMITS THE GENERALIZATION of the workflow/transferability.
- Model connectivity needs to be tailored to each model applications.
- A combination of Dynamical and Statistical downscaling "Hybrid Approach" offers the best meteorological input and impacts hydrological results positively.
- At least, Common formats (NETCDF) facilitates workflow structure.

Acknowledgements

- This material is based upon work supported by the USBR WaterSmart program (#R11Ap81455) and the Desert Research Institute (DRI).
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- PCMDI & WCRP CMIP3 for distributing the GCM multi-model dataset.

Questions?

- Contact John.Mejia@dri.edu for guidance and further information on GCM applications, and their strengths and limitations.