
High Resolution Climate Simulation and Regional Water Supplies

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High-Performance Computing for Climate Modeling as a Planning Tool

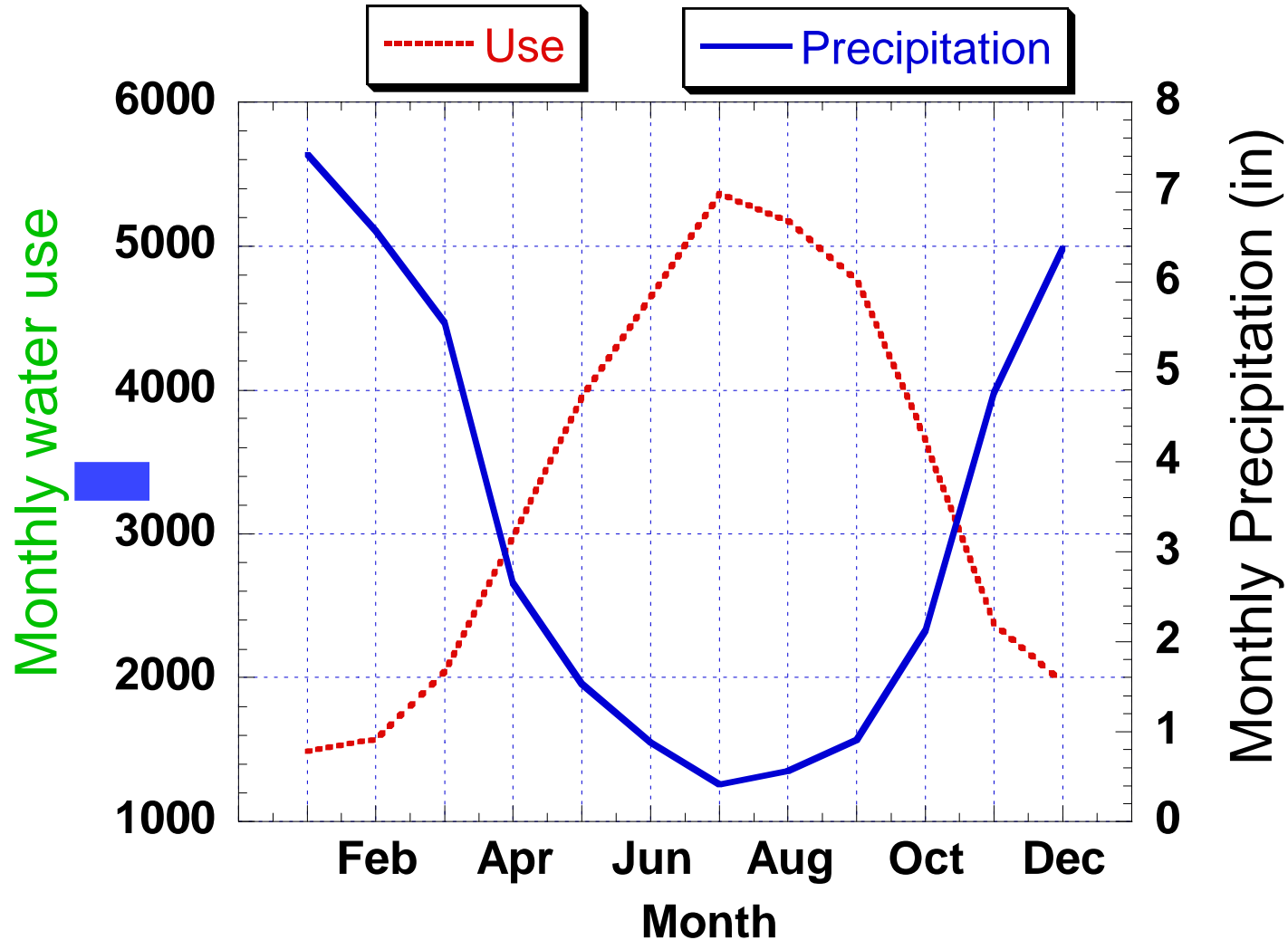
- **GLOBAL WARMING IS HERE!! ... so now what?**
- **How will climate change really affect societies?**
- **Effects of global climate change are local**
- **Some effects of climate change can be mitigated**
- **Requires accurate information**

Climate simulation can be used as a planning
and policy tool

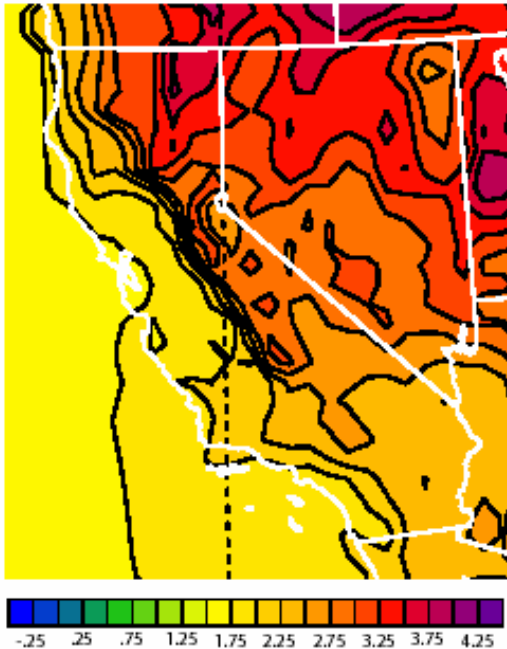
California Water Supply: Critical to California Economy

- **Central valley: the nation's vegetable garden;**
- **Fifth largest economy on earth;**
- **Population continues to grow**
- **Plenty of water – distribution in time and space is the issue**

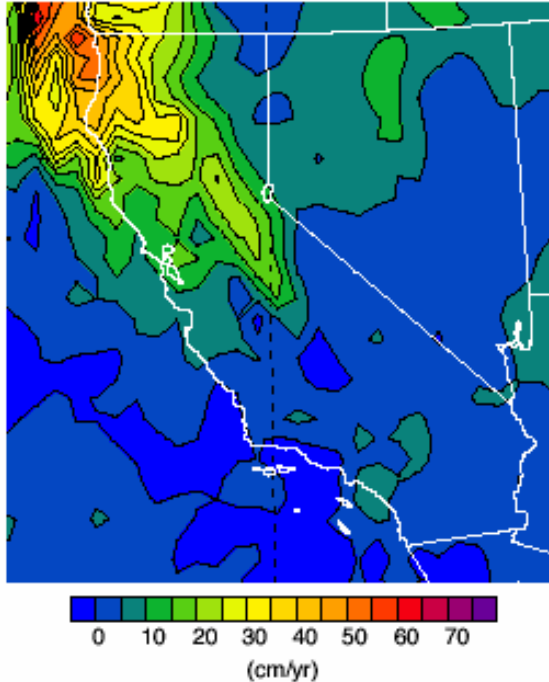
Global Climate Change and Water Supply



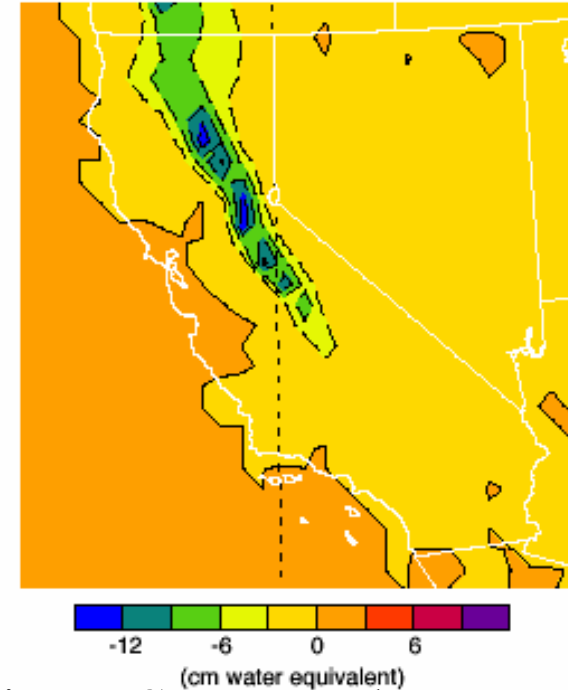
Global Climate Change: California



Higher Temp



More precip



Sierra Snowpack
smaller by factor of 2-3

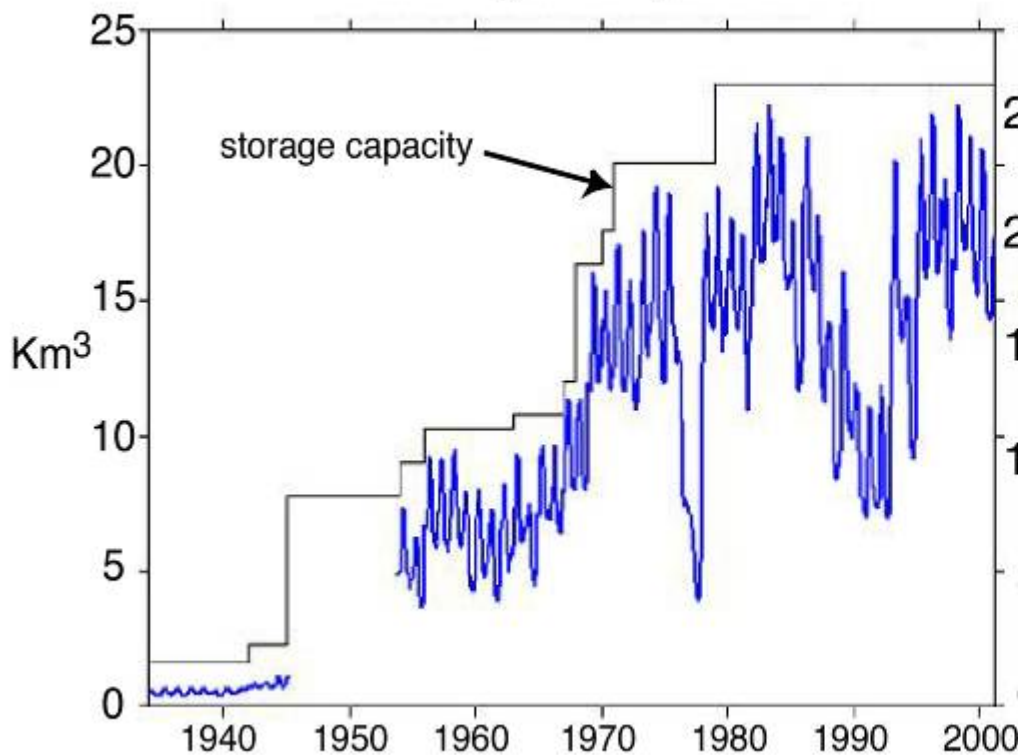
Figures show projected changes in California region ($2\times\text{CO}_2$ - $1\times\text{CO}_2$) from a joint UCSC/LLNL study.

California Water Supply: Snowpack is a Huge Reservoir

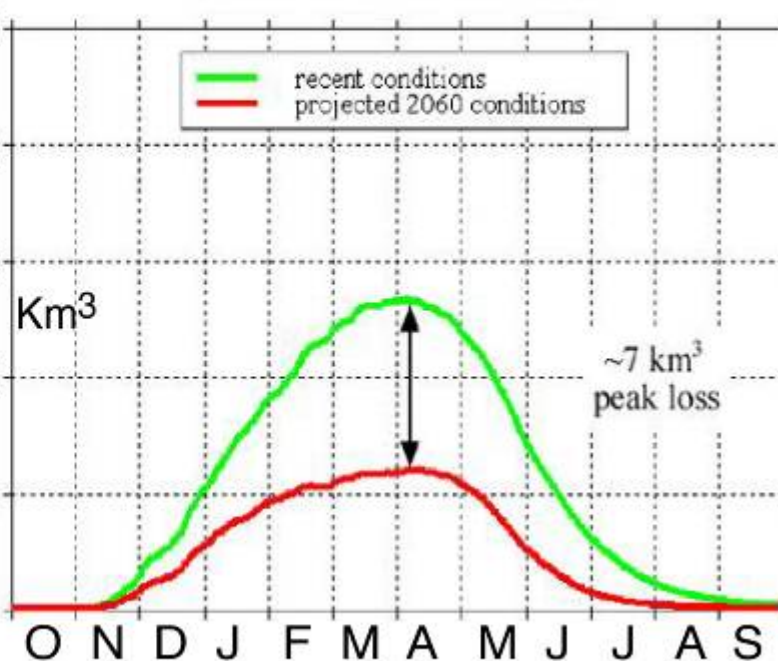


CA will need >25% new reservoir capacity

Historic storage in major reservoirs



Storage in the snowpack



What specific questions will we address?

- Amounts and spatial pattern of precipitation;
- The partitioning of precipitation between rain and snow;
- The water content of the Sierra snowpack;
- Rates and timing of river flows

We will predict changes in peak values as well as in time-averages

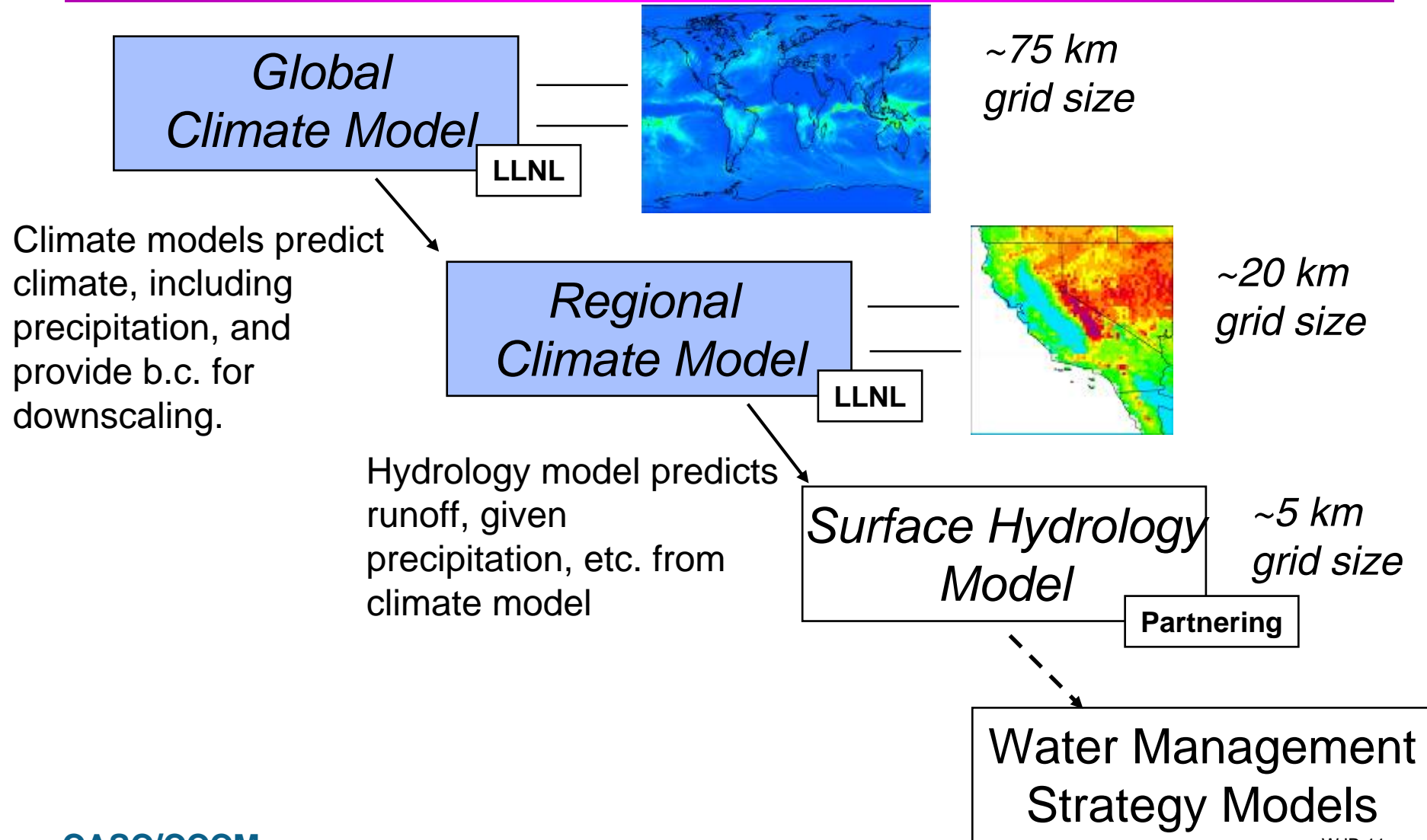
New Univ of California Institute at LLNL

- **Institute for Research on Climate change and its Societal Impacts (IRCCSI) will**
 - **Address problems of societal impacts of climate change (on agriculture, human health, water, etc.);**
 - **Combine high-power climate modeling at UC labs with impacts expertise at UC campuses;**
 - **Increase flow of UC students, postdocs, and faculty through LLNL;**
- **Recently approved by the UC President's Office.**

We will pursue 3 “streams” of activity:

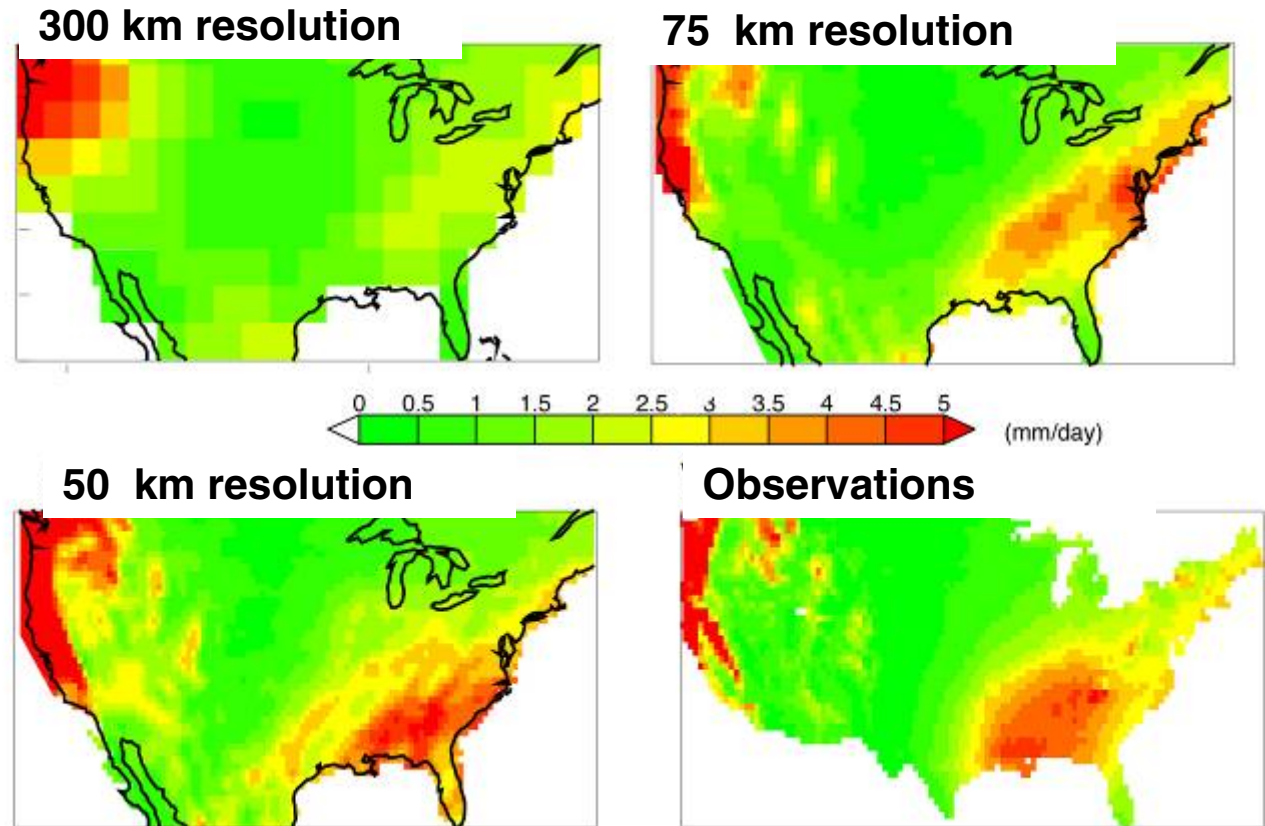
1. ***Apply models*** to improve understanding of impacts of climate change/variability on hydrological cycle
 - Use California as the regional area of interest
 - Develop/Use quantitative metrics to evaluate skill
2. ***Advance the science*** by improving our models
 - improve subgrid scale physics (clouds, convection, precipitation)
 - Increase spatial resolution
 - Improve computational efficiency
3. ***Make our results useful*** to policymakers and water managers

Methodology: High-Res Nested Models



LLNL leads in high-res modeling

Higher resolution leads to improved simulated regional climate and hydrology



Simulated winter precipitation converges towards observations as model resolution becomes finer.

NASA / GSFC fvgcm climate code

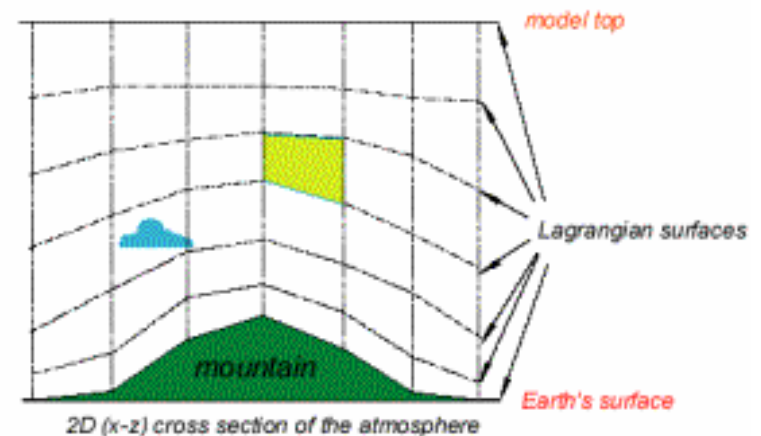
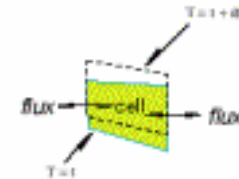
- Finite-vol dynamical core
- Lagrangian vertical coord system
- Fast numerical algorithm
- Adaptable to massively parallel architectures
- “Highly scalable”

Terrain-following Lagrangian Control-Volume Coordinate system of the DAO "Dynamical Core"

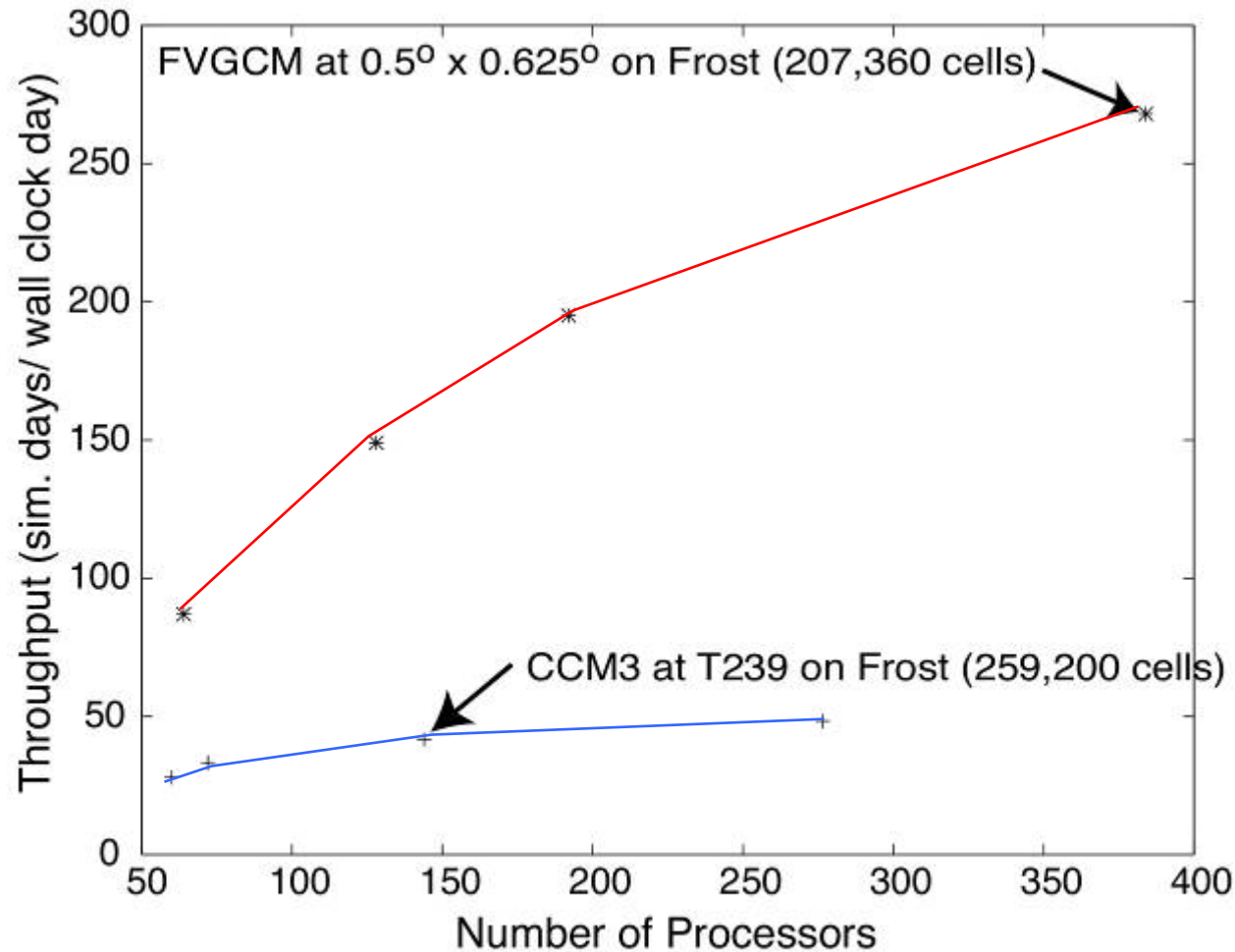
*Example: more than 6.6 million "cells" at 55 km resolution
with 32 vertical layers*

Basic physical laws for each "cell":

1. mass conservation
2. momentum conservation
3. energy conservation



Climate Simulation Codes



CCM3 = model used for previous high-resolution simulations
FVGCM = model we propose to use here

Computational Requirements

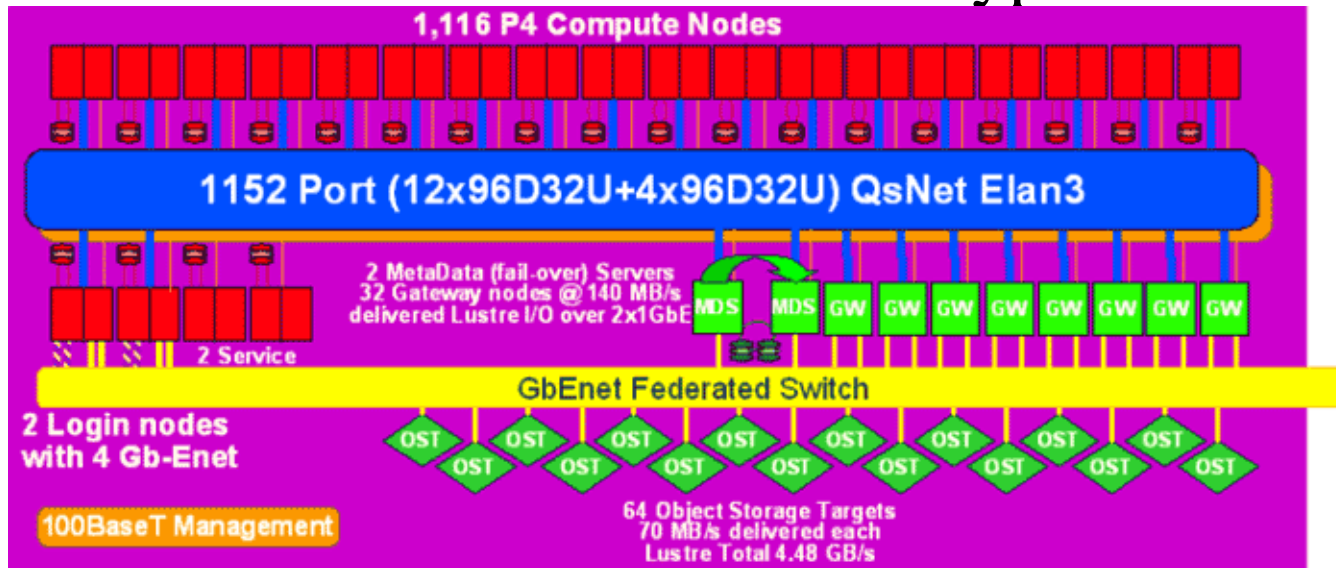
- **50 year climate simulations at ~ 60 km resolution**
 - ~ 4 months wall time with 3 latitude stripes / node and 2 processors per node on MCR machine
 - 10 Terabytes data
- **50 years regional simulation @ 5 km resolution**
- **Surface hydrology simulation**

Livermore MCR linux cluster

- 11.06 Tflops (1116 x 2 Intel 2.4 GHz processors)
- 4.6 TB memory
- 135 TB local disk
- 110 TB global disk (13 B:F)
- 320 MB/s MPI bandwidth and $<5 \mu\text{s}$ latency over QsNet
- 120 MB/s transfers to Archive over dual Jumbo Frame Gb-Enet from each Login node
- 25 MB/s POSIX serial I/O to any file system
- Lustre file system with 4.48 GB/s delivered parallel I/O performance

Livermore MCR: Processing power

- Achieved 7.6 TFLOP/s (Linpack) on 12/3
- Dual 2.4Ghz Intel “Prestonia” with hyperthreading

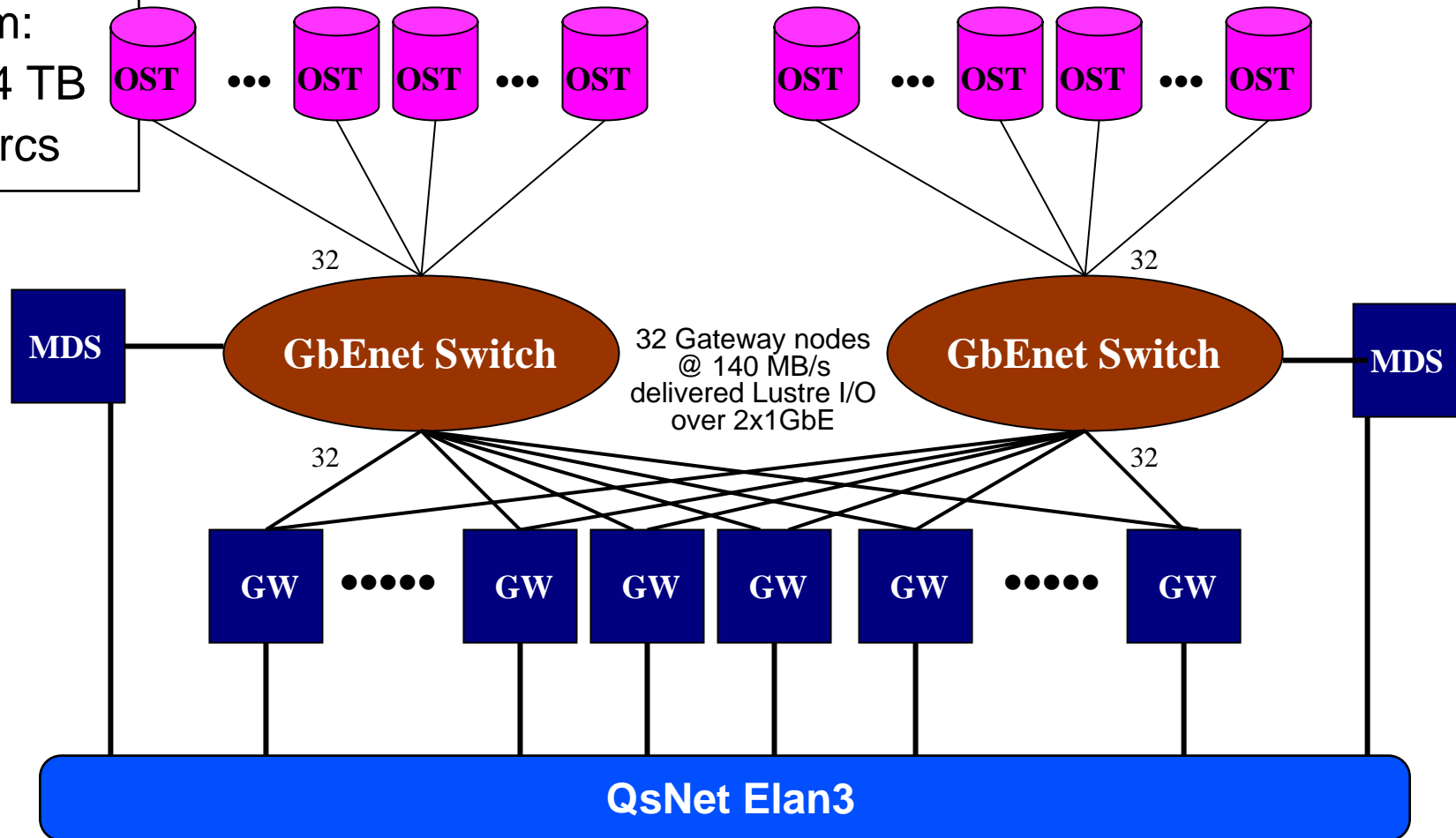


- Memory: 4GB PC-200 DDR SDRAM
- Local disk: 120GB ATA100 EIDE hard drive
- Quadrics QsNet Elan3 PCI adapter

Livermore MCR: I/O and Storage

Interim file
system:
32x1.4 TB
BlueArcs

64 BlueArc Object Storage Targets
1.7GB fiberchannel RAID5 each
70 MB/s delivered I/O each



Fvgcm on MCR: General Observations

- **The Good:**

- MCR processors fast
- fast fluid dynamics in Fvgcm code
- tested at GSFC (SP, SGI, linux cluster) and LLNL (SP)
- ~60 km resolution: 1 sim year / 3 days wall time w/ 120 proc
- MPI2 (1-sided comm) appears to run ~ 20% faster than MPI1

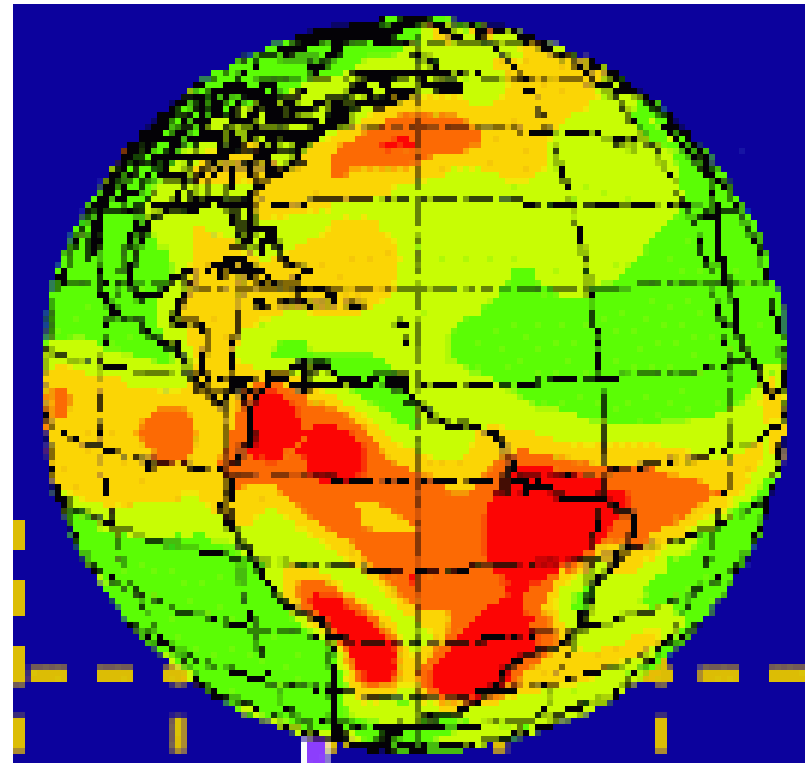
- **The Bad:**

- Porting took longer than expected (weeks, not hours)
- Problems with MPI1 (2-sided comm) on mpi_gather
- OpenMP thread problems: 1 cpu per node utilization
- Fvgcm 1-d domain decomposition severely limits machine utilization

Fvgcm climate code mapped to MCR

- **Domain decomposition:**
Mpi bands in latitude
Example: “60 km” resolution
576 lon x 360 lat x 32 vert
(6,635,520 cells)
120 shared mem nodes max

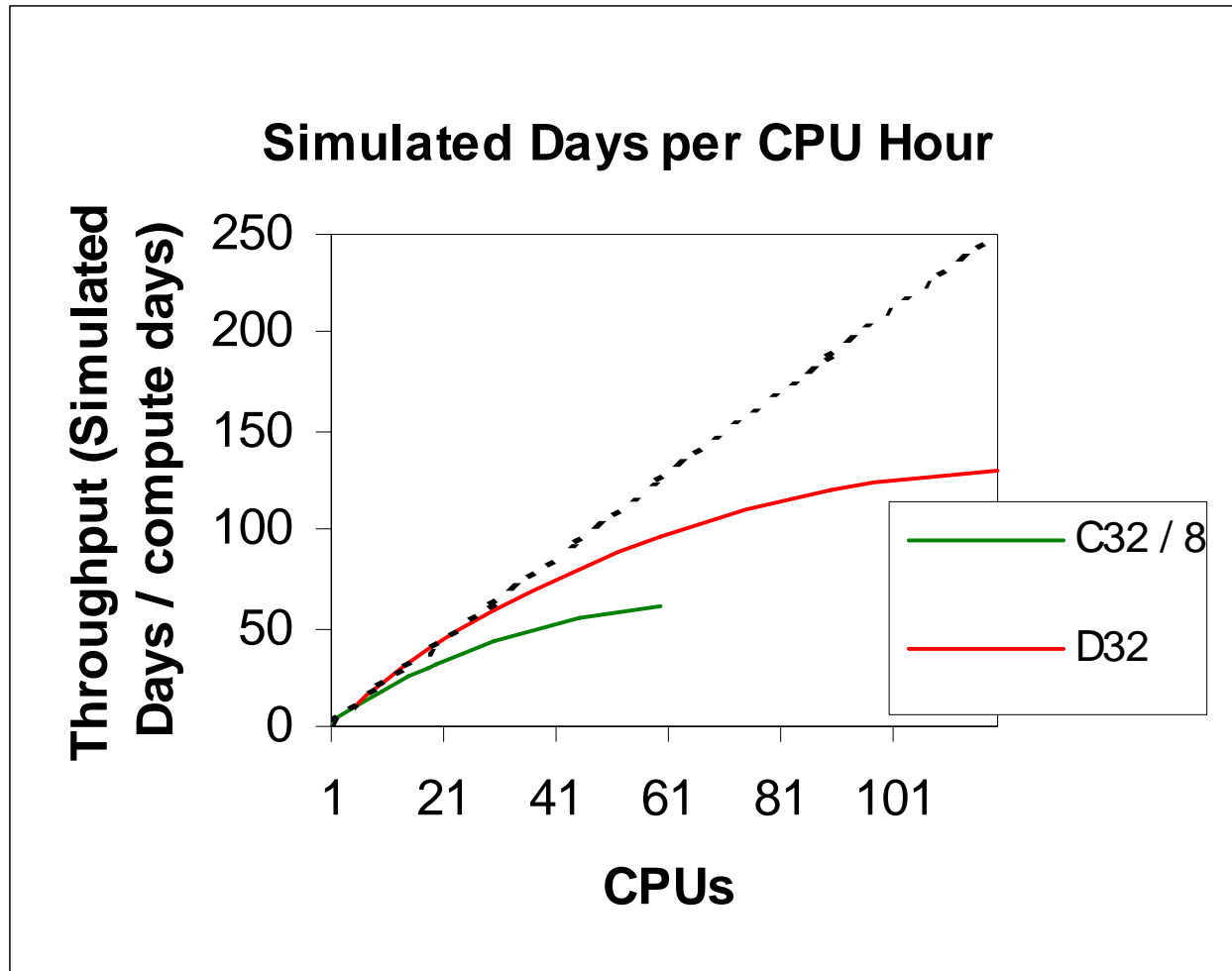
OpenMP threads
Mainly vertical
2 proc / node on mcr cluster
240 proc => 27648 cells/proc
- **Single processor output :**
global gather to master
processor



Fvgcm on MCR

- **Output through master only after global gather =>**
 - **buffer problems with mpi1**
 - **potentially slow output ?**
- **OpenMP threads fail (seg fault) with > 1 cpu / node**
 - **problem not yet solved**
 - **only observed on MCR machine**

Scale-up Results



CPU and Storage Requirements

~ 60 km resolution: 576 x 361 x 32 (d32)

Simulated Climate Period	Wall Time	Data Storage Requirements (Terabytes)
1 month	5 hours	0.17
1 year	~ 3 days	2
50 years	~ 4 months	10

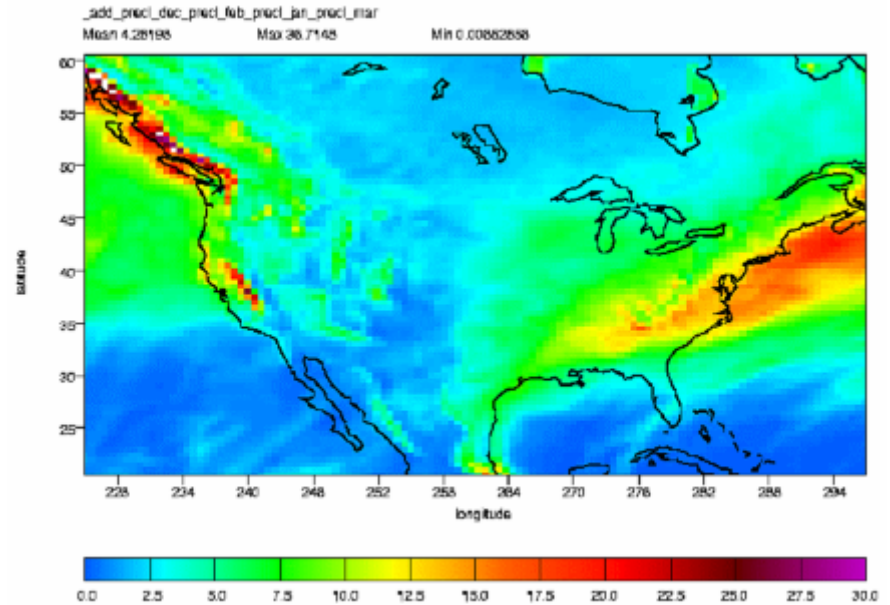
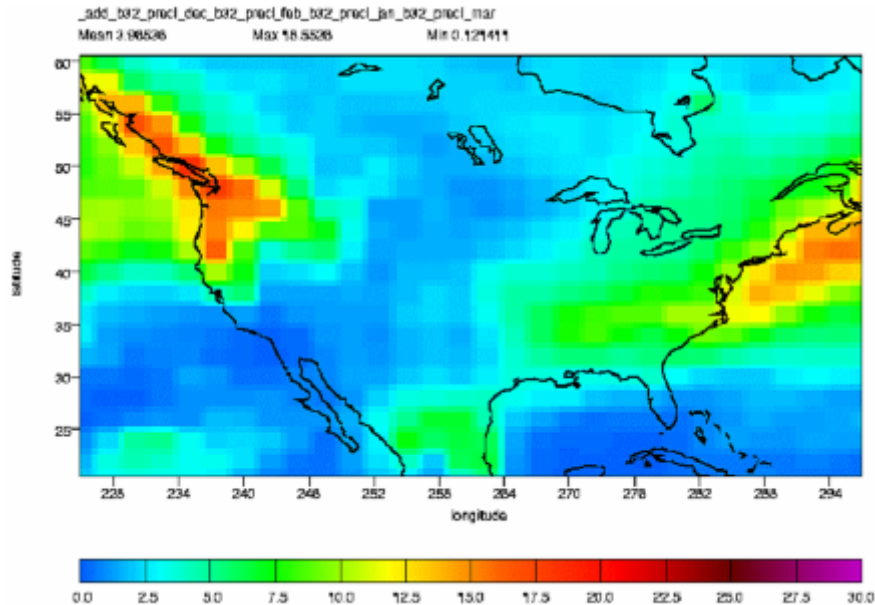
- ~2x Speedup with OpenMP ?

Initial Simulations: 60 km resolution (d32)

Mean large-scale winter precip rate (mm/day)

B32 resolution: ~ 240 km

D32 resolution: ~ 60 km



Summary

- **Significant climate impact study: effects of increased CO2 on California water supply**
- **Livermore MCR linux cluster has fast processors – good candidate for climate code**
- **Machine utilization limited by code domain decomp**
- **Unique MCR “features” cause problems with MPI and OpenMP; not seen on NASA/GSFC linux cluster**
- **Initial indications: total compute time quite good**

Future Work

- **California Water Project**
 - Climate simulation for planning
 - May have high impact on agriculture and other industries in California
 - High-resolution simulation essential
- **Long-term Climate Modeling**
 - Better domain decomposition to take advantage of large node availability
 - Multi-resolution grids: regional impacts
 - I/O is important!
 - Move to commodity clusters a “good thing”: porting is still a major issue

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