Water Cycle Challenges:
Controls on Precipitation and Clouds

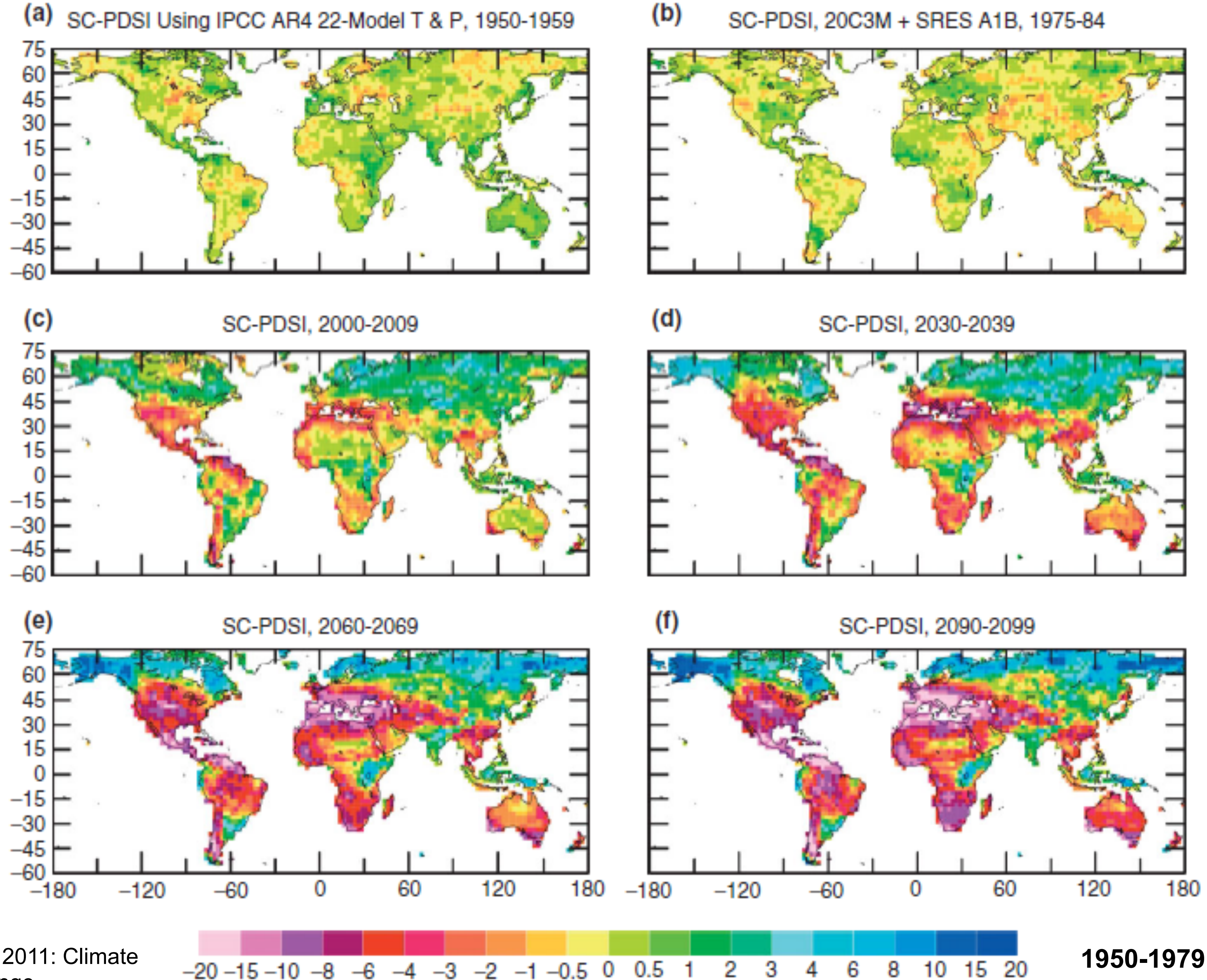
NOAA Water Cycle Challenge Workshop

Aug. 30-Sep. 1, 2011

Boulder, CO

D. Gochis

National Center for Atmospheric Research



Dai, 2011: Climate Change

1950-1979 base

Motivation:

- Opinion piece published Aug. 27, 2011 (Iain Murray and David Bier – “Do we really need a National Weather Service?”): http://www.foxnews.com/opinion/2011/08/27/do-really-need-national-weather-service/#ixzz1WSWe3M6o

- “the truth is that the National Hurricane Center and its parent agency, the National Weather Service, are relics from America’s past that have actually outlived their usefulness.”

- “Last year the Service failed to predict major flooding in Nashville because it miscalculated the rate at which water was releasing from dams there. The NWS continued to rely on bad information, even after forecasters knew the data were inaccurate. The flooding resulted in 22 deaths.”

Overarching Questions: *(atmospheric branch…)*

Water Cycle Science Mandate: To make the ‘best’ (in terms of quantifiable skill and reliability) weather, climate and streamflow predictions in the world while *dramatically reducing uncertainty in* and *increasing the credibility of* future climate projections of the principal hydrologic variables (precip., ET, runoff).

1. What are the key source, transport and discharge mechanisms for atmospheric water vapor?

2. How do/how will anthropogenic activities including land use change, water management and atmospheric composition change impact the structure and evolution of clouds and precipitation?

Issues for Water Vapor Cycling:

1. What are the key *source*, transport and discharge mechanisms for atmospheric water vapor?

- Oceanic sources…. Fundamental biases in coupled SST predictions and gaps in understanding and ‘modeling’ of oceans and ocean-atmospheric coupling as related to moisture source regions

- Land sources…How will timescales of land fluxes and ‘memory’ (soil moisture residence times) change/accelerate?

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Issues for Water Vapor Cycling:

1. What are the key source, *transport* and discharge mechanisms for atmospheric water vapor?

'Low Level Jets' :

- Principal, 'stationary' (i.e. time-mean vs. transient) pathways for moisture transport
- Exit regions are tied to persistent convection (and flooding) regimes

Issues for Water Vapor Cycling:

1. What are the key source, *transport* and discharge mechanisms for atmospheric water vapor?

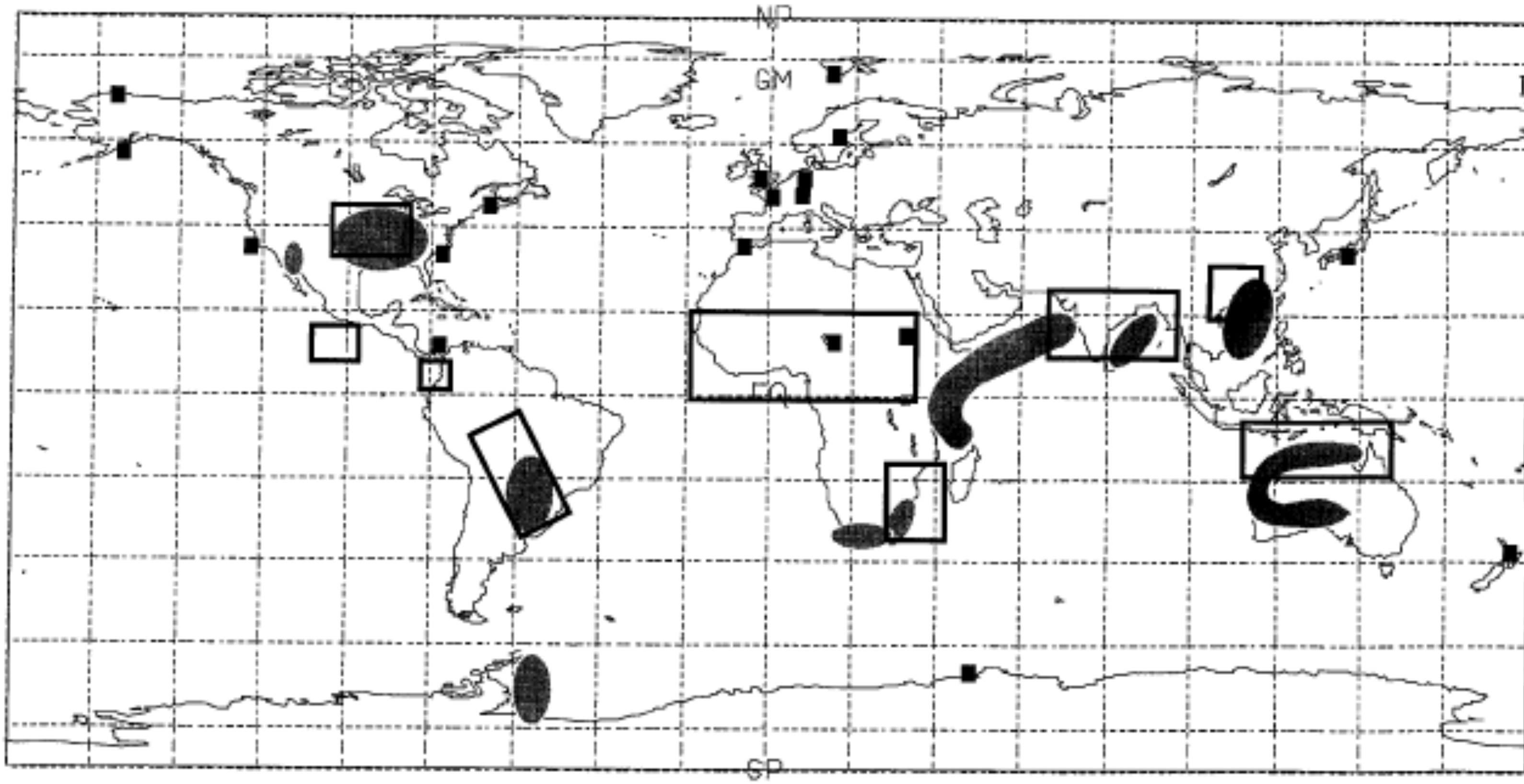


FIG. 1. Regions where low-level jets are known or suspected to occur with some regularity (shaded) and where mesoscale convective complexes are known to occur frequently during the summer (open boxes). Squares denote locations where low-level jets have been observed.

Stensrud, J. Climate, 1996

Issues for Water Vapor Cycling:

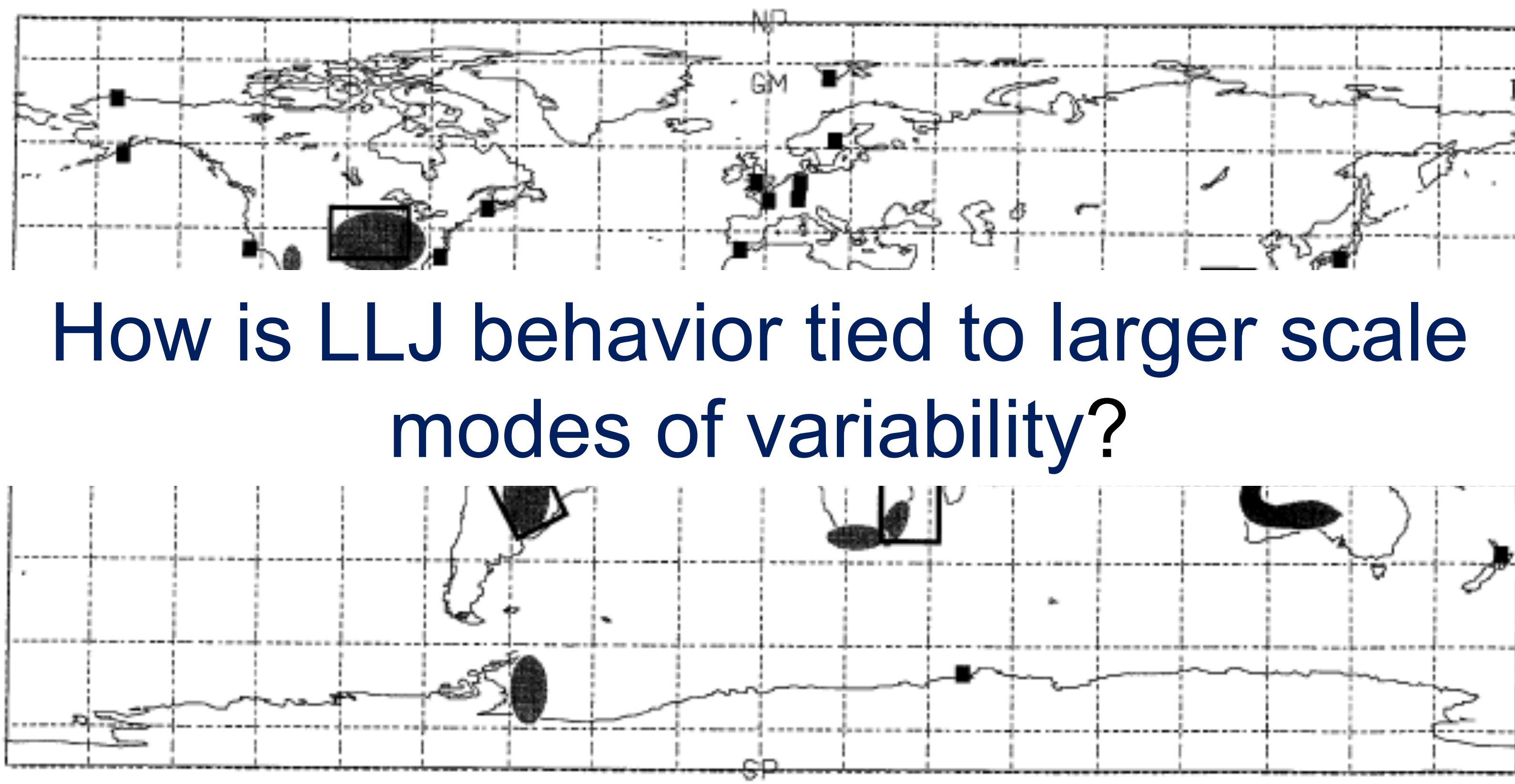
1. What are the key source, *transport* and discharge mechanisms for atmospheric water vapor?

'Low Level Jets' :

- Principal, 'stationary' (i.e. time-mean vs. transient) pathways for moisture transport
- Exit regions are tied to persistent convection regimes
- Often most evident during warm season and on westward (poleward) branch of sub-tropical circulations
- Quasi-stationarity in behavior offers significant potential predictability of precipitation if controlling mechanisms of jets can be properly depicted

Issues for Water Vapor Cycling:

1. What are the key source, *transport* and discharge mechanisms for atmospheric water vapor?



How is LLJ behavior tied to larger scale modes of variability?

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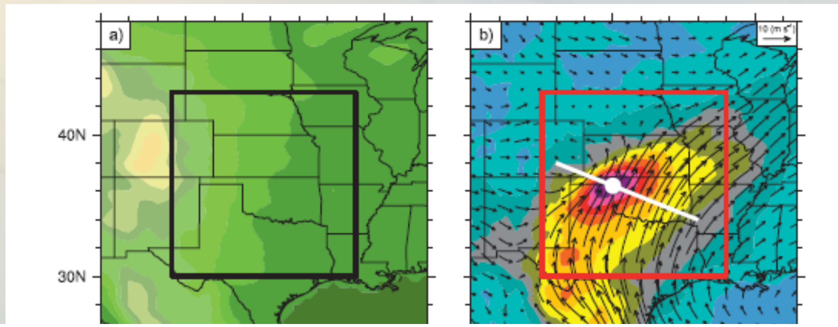

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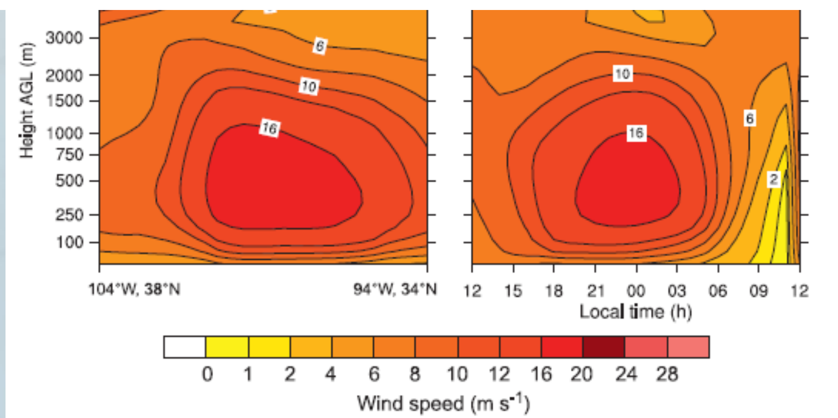

Rife et al., J. Clim., 2010

Issues for Water Vapor Cycling:

1. What are the key source, *transport* and discharge mechanisms for atmospheric water vapor?

'Low Level Jets'

'Atmospheric Rivers': (Ralph and Dettinger, Eos, 2011)

- Key 'transient' mode of synoptic moisture flux variability
- Exit regions often tied to precipitation extremes
- Observability offers significant potential for improved predictions depending on assimilation
- Frequency of occurrence as tied to larger-scale, longer-lived climate modes may offer additional potential predictability

Issues for Water Vapor Cycling:

1. What are the key source, transport and *discharge* mechanisms for atmospheric water vapor?

- Discharge = Precipitation
- Atmospheric ‘convergence’ zones: (e.g. S. Atlantic convergence zone, U.S. Great Plains, Mei-Yu front as well as monsoons)
    - Quasi-stationary jet exit regimes

Issues for Water Vapor Cycling:

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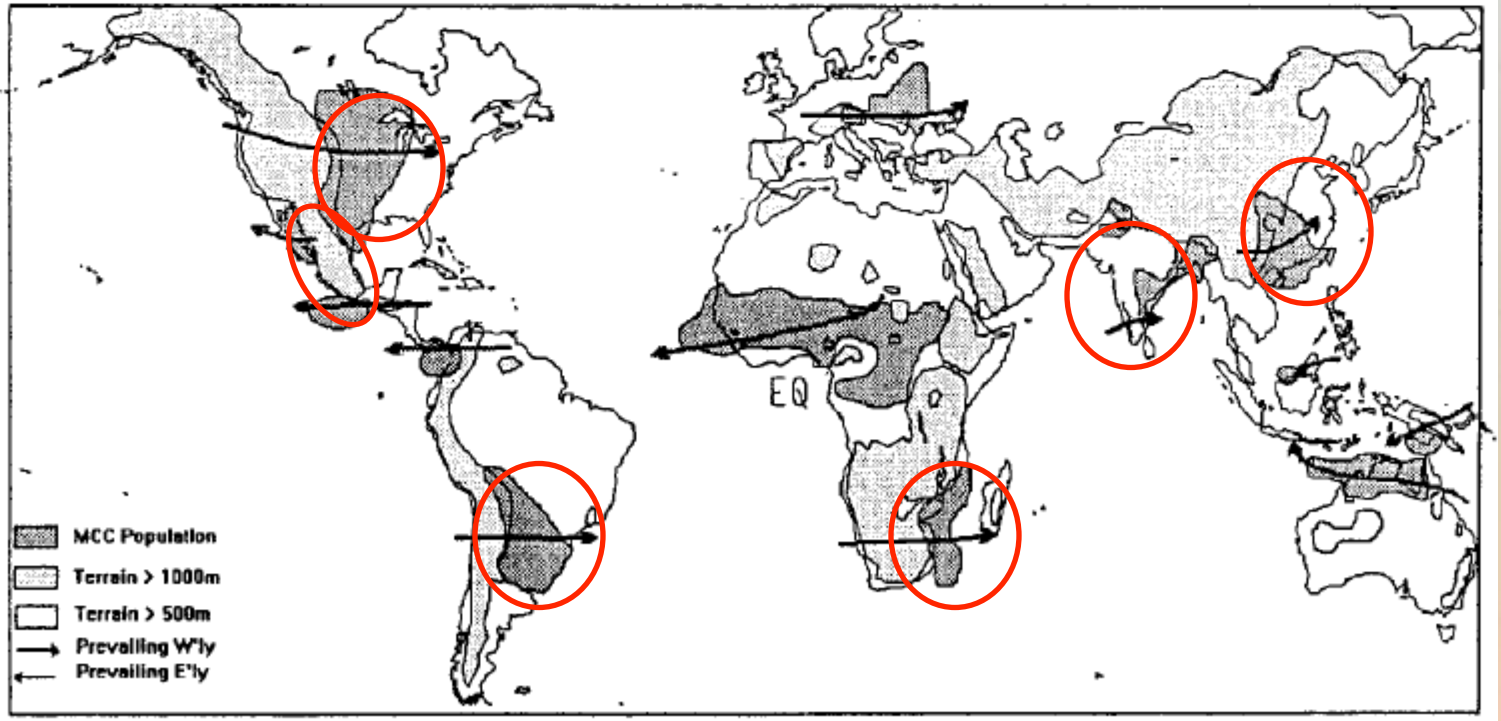


Figure 4. Relationship among mesoscale convective complex (MCC) population centres, elevated terrain, and prevailing mid-level flow.

Laing and Fritsch, 1997 QJRMS

Issues for Water Vapor Cycling:

1. What are the key source, transport and *discharge* mechanisms for atmospheric water vapor?

- Discharge = Precipitation
- Atmospheric 'convergence' zones: (e.g. S. Atlantic convergence zone, U.S. Great Plains, Mei-Yu front)
    - Quasi-stationary jet exit regimes
    - Stationarity of regime often results in substantial flooding
    - Source regions for persistent and/or long-lived deep convection (Carbone et al., 2001)
    - Dynamics are complicated (multi-scale convective initiation-feedback mechanisms) and quite difficult to predict on longer timescales
    - Climate variability/change controls often unclear

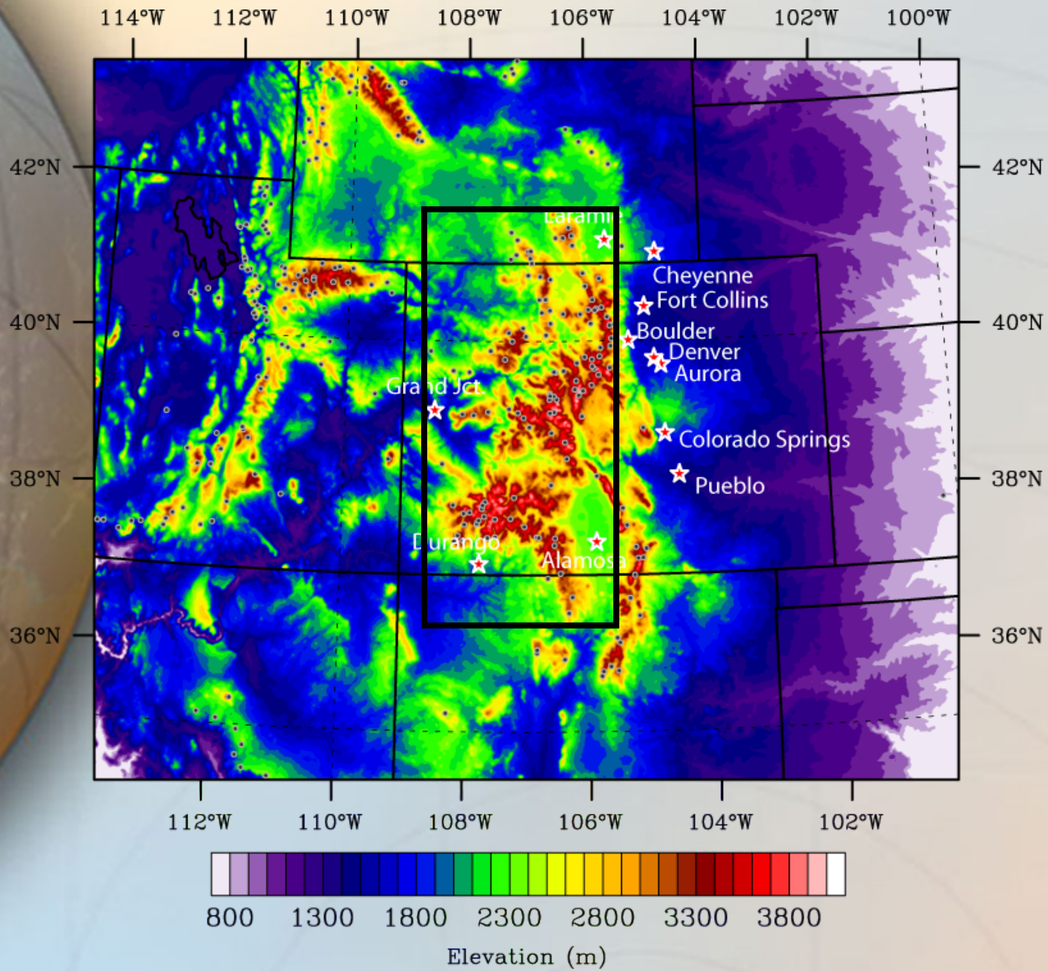
Issues for Water Vapor Cycling:

1. What are the key source, transport and *discharge* mechanisms for atmospheric water vapor?

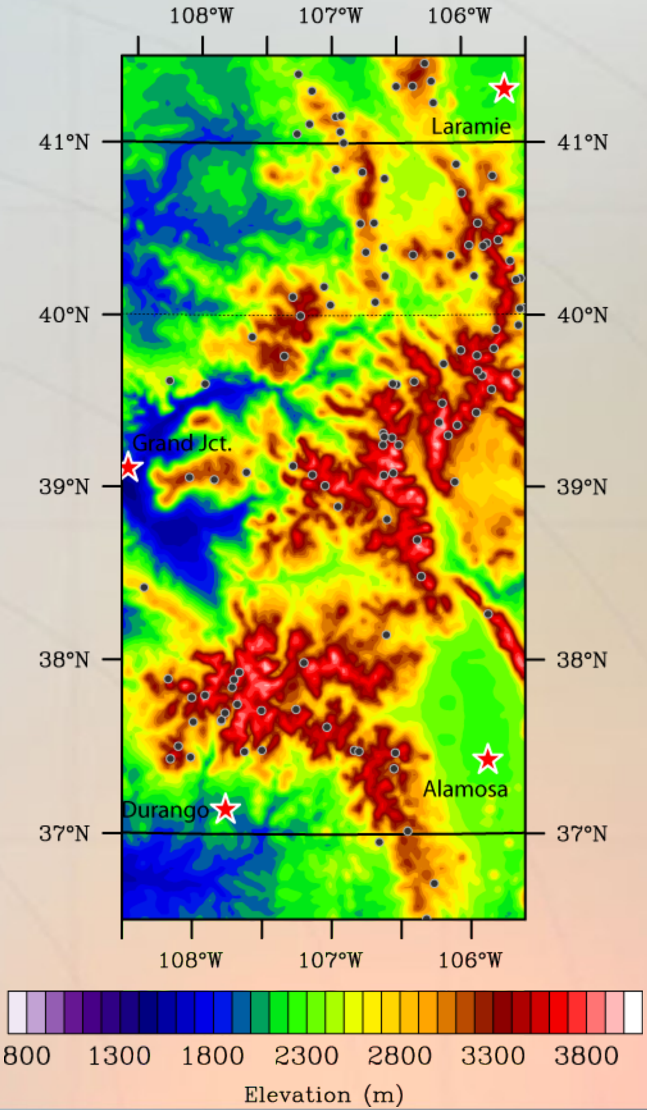
- Orographic barriers:
  - Important 'stationary' forcing mechanism for clouds and precipitation
  - Source regions for terrestrial hydrology
  - Sharp ecosystem gradients that are potentially vulnerable to small scale climatic change (e.g. changing freezing levels, snowpack)
  - How will orographic precipitation regimes evolve in a changing climate? (dynamics and surface coupling)

Advances in High Resolution Simulation of Wintertime Orographic Precipitation

Full Domain



Sub-domain



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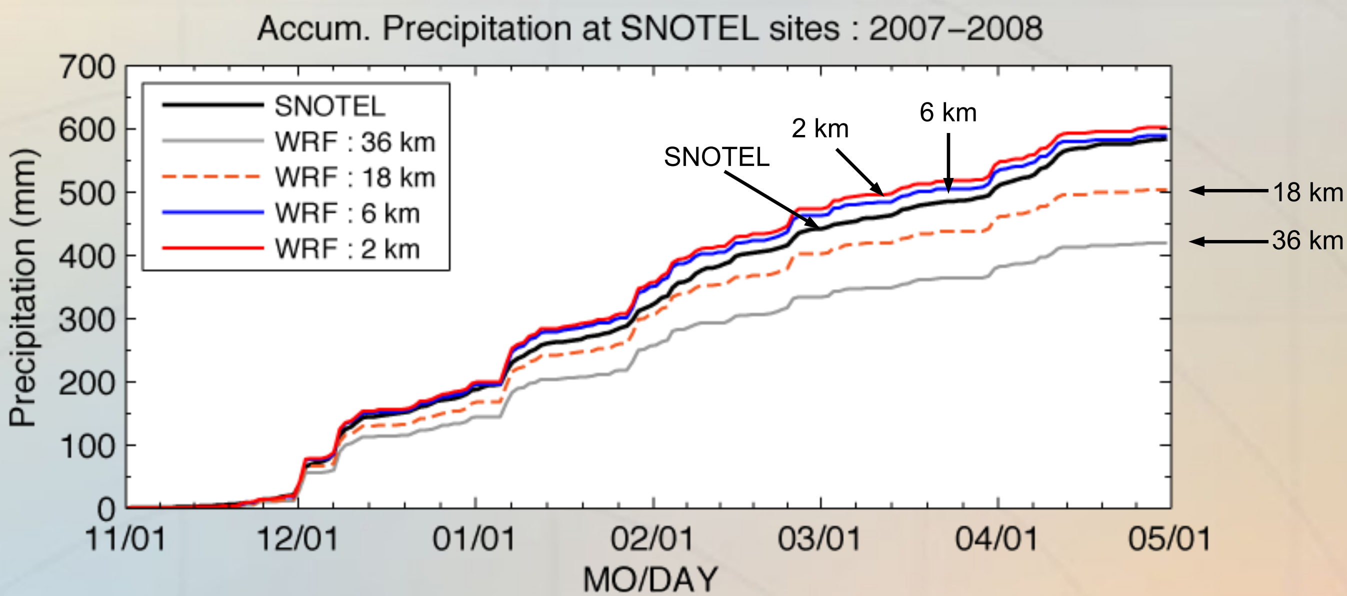
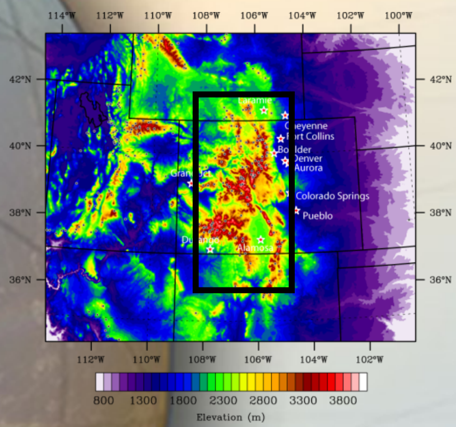
Ikeda et al., 2010 Atmo. Res.; Rasmussen et al., J. of Climate, 2011

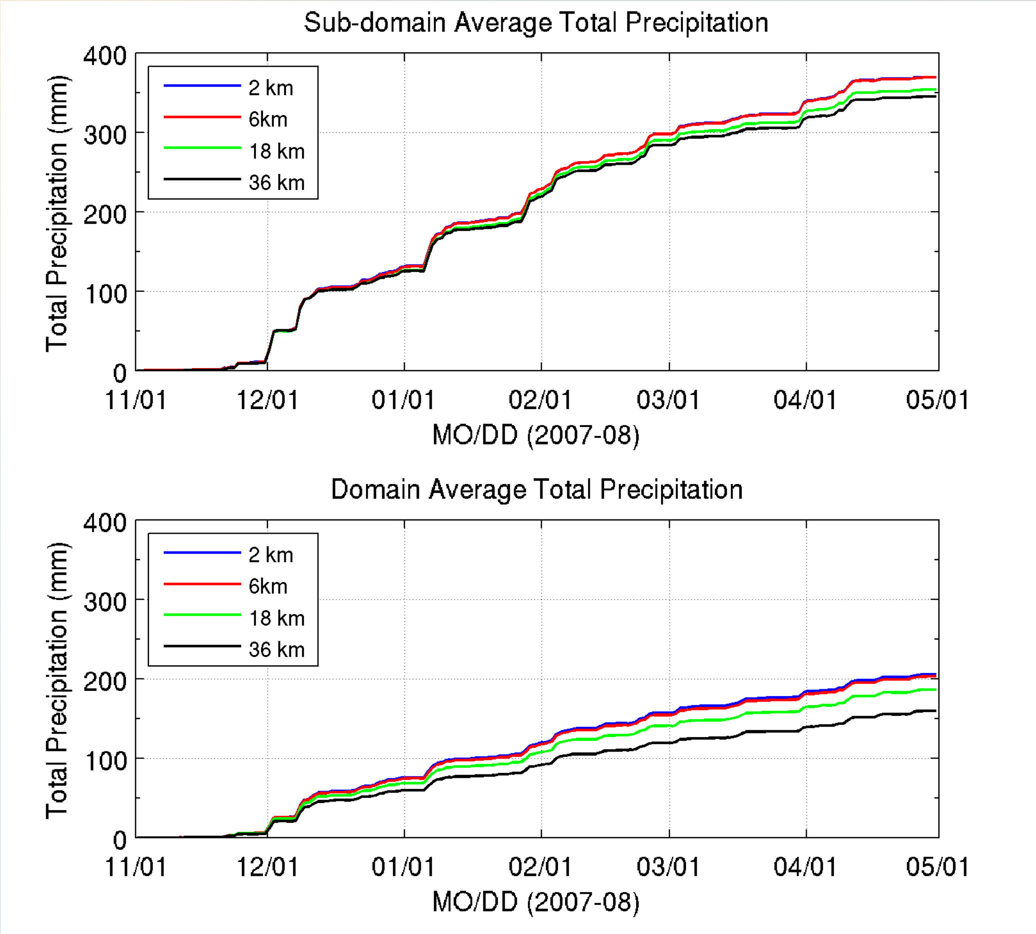
Model resolution impact on *wintertime* precipitation: Comparisons at SNOTEL sites



Ikeda et al., 2010 Atmo. Res.; Rasmussen et al., J. of Climate, 2011

Sub-domain and domain average precipitation accumulation





2km run has ~10-15% increase over 36km run

2km run has ~25% increase over 36km run

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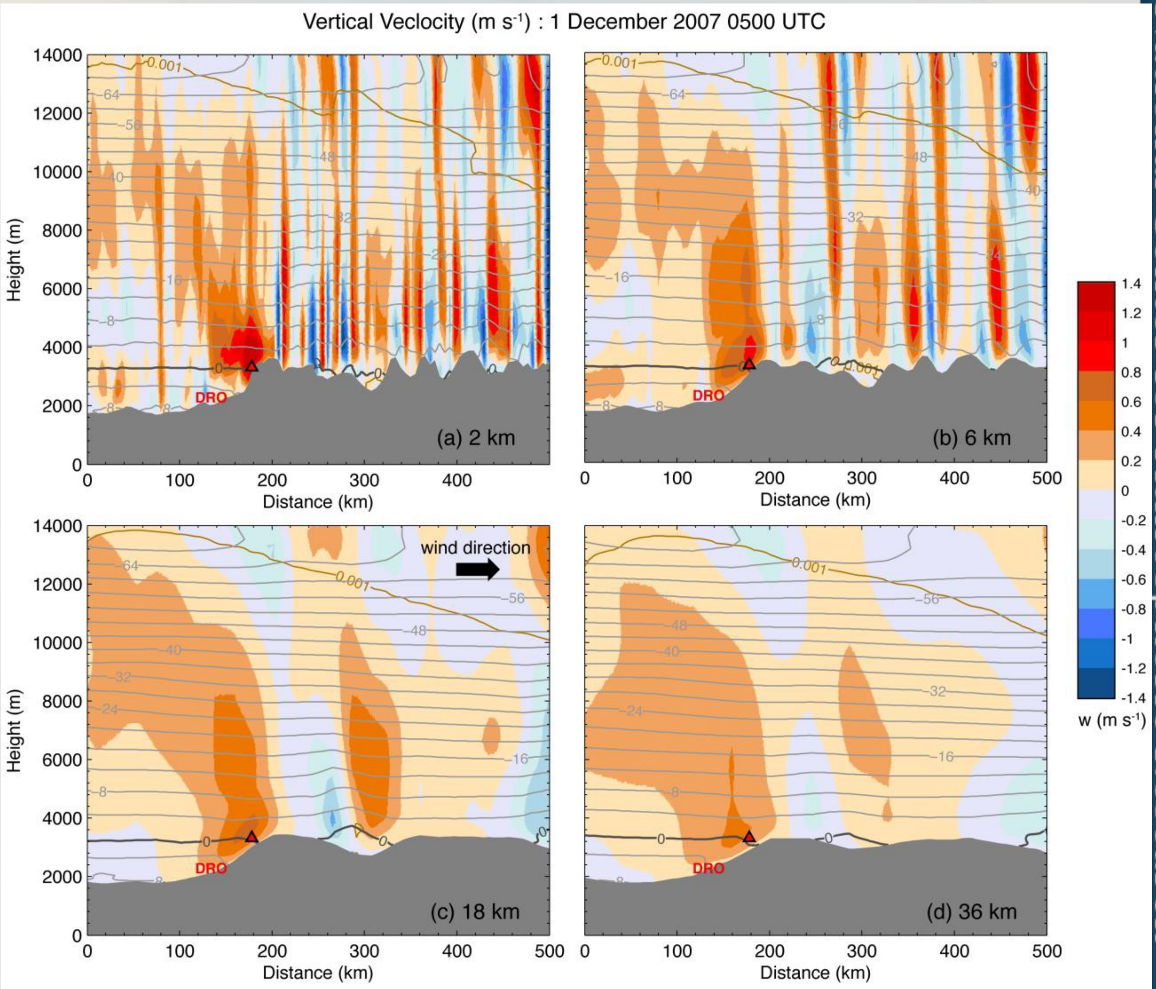
Ikeda et al., 2010 Atmo. Res.; Rasmussen et al., J. of Climate, 2011

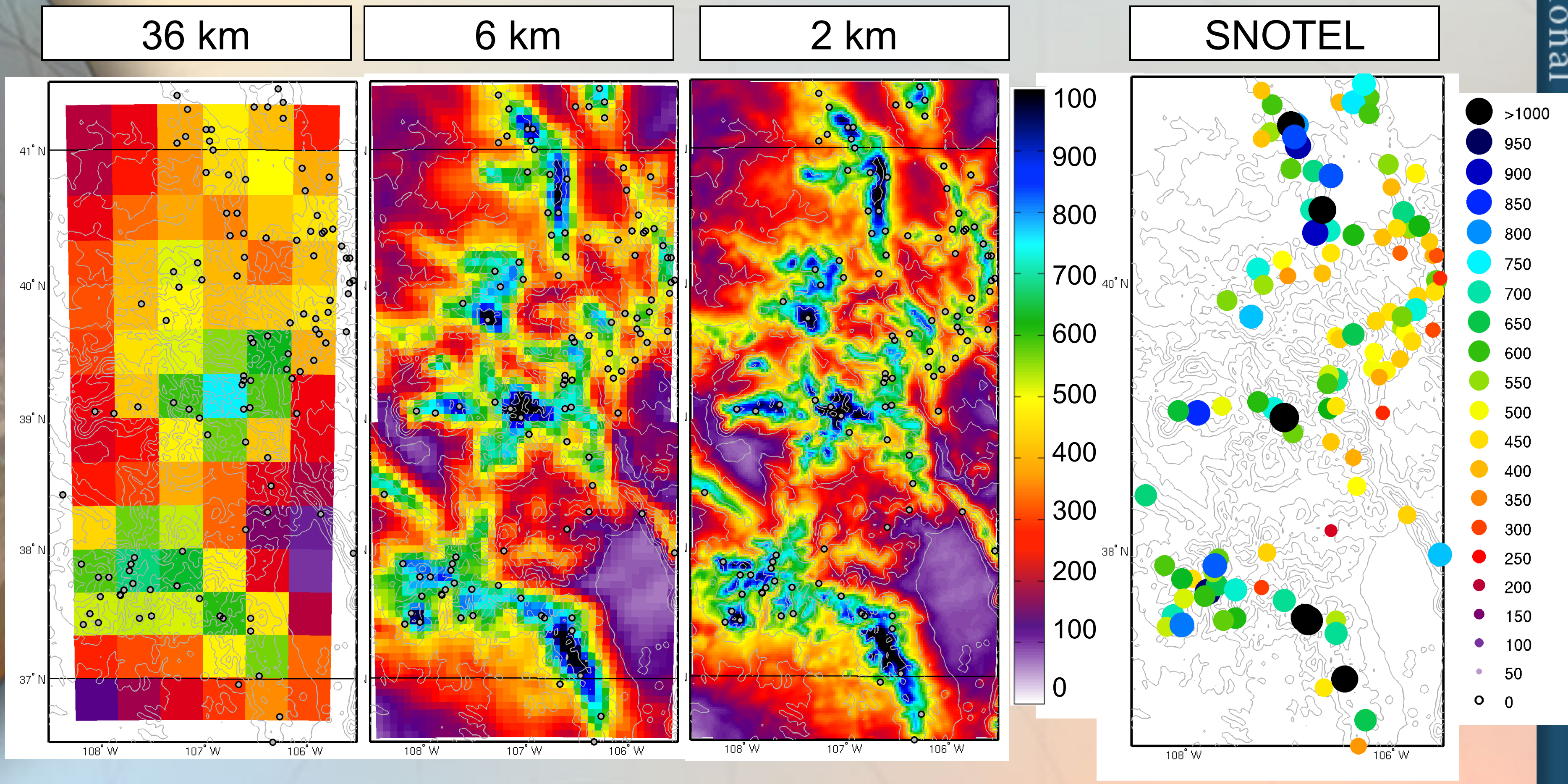
Scale Impacts:

- Crux of 'stable' orographic precipitation is the nexus of moisture and vertical motion
- Vertical motions are extremely sensitive to model terrain resolution varying by ~ 1 order of magnitude
- However, stability regime (Fr) is also critical in defining blocking and vertical motion distribution and intensity
- Variations in static stability and areas (H and V) of latent heating with height drive non-linear responses in vertical velocities and release of potential instability



Why statistical downscaling methods are limited (see Gutmann et al., J. Climate, In Press)

6-mo. Total Precipitation (mm) Comparison
1 Nov. 2007-1 May 2008



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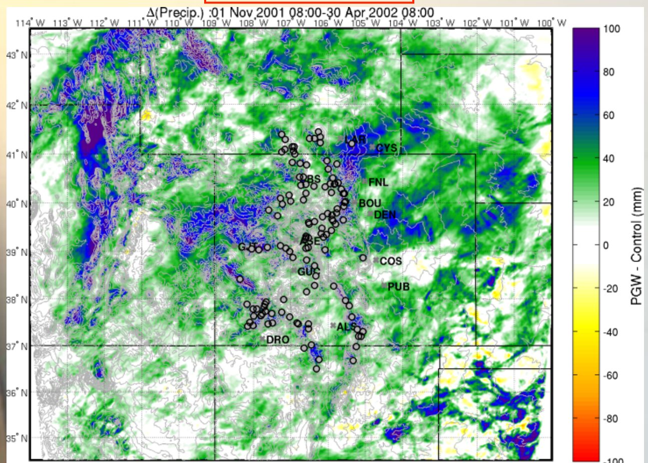
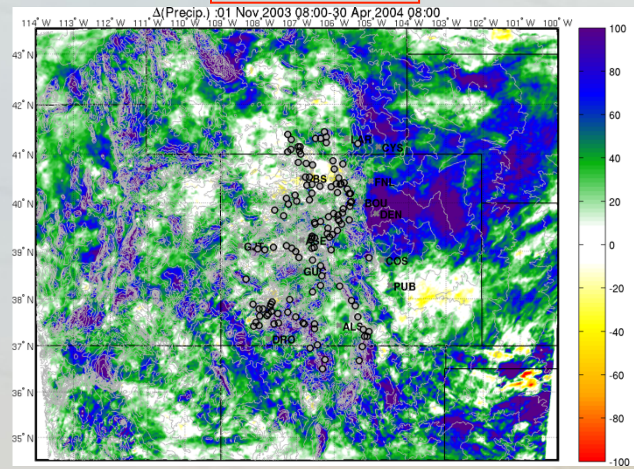
Rasmussen et al., In Press, J. of Climate.

Difference in total precipitation : 6 month period

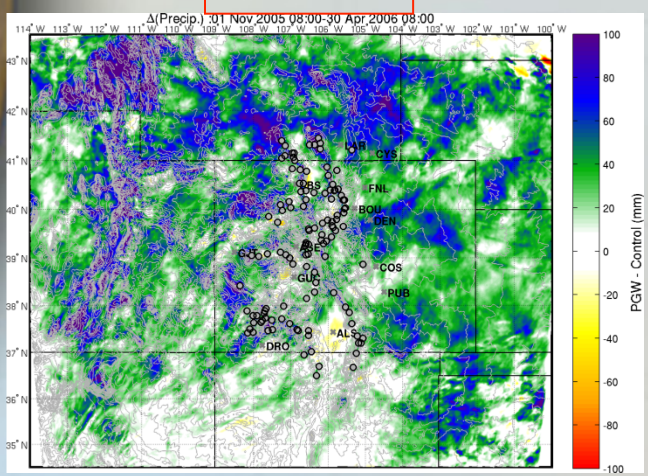
2001-2002



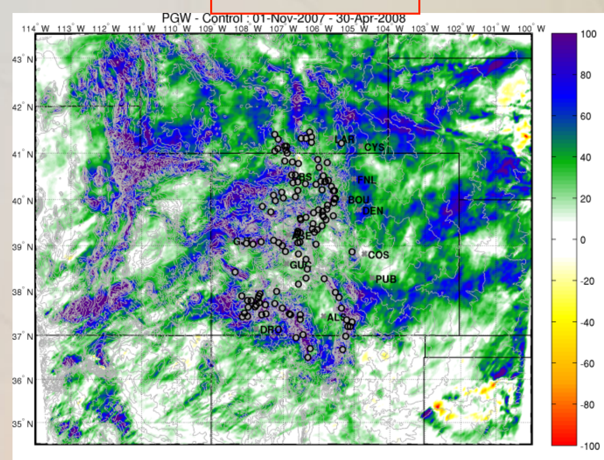
2003-2004



2005-2006



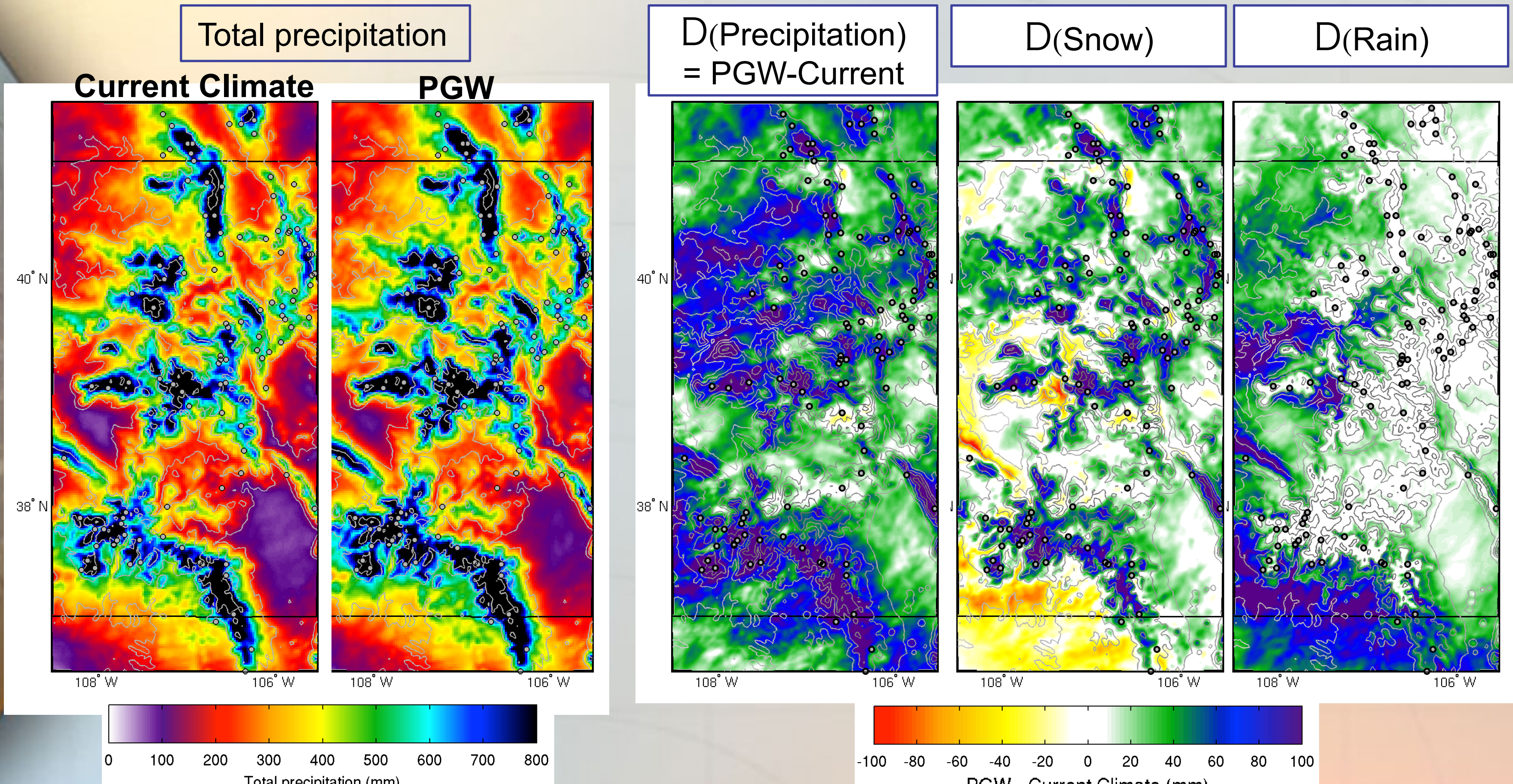
2007-2008



- Precipitation increases by 13.7 % consistent with the average increase of water vapor mixing ratio by ~10 % in the sub-domain.
- Significant inter-annual variability in the distribution of the changes between current and PGW simulations. ***Suggests that precipitation response to warming is non-linear.***

6-mo. total precipitation map from PGW and Current Climate simulations and differences

1Nov. 2007 - 1 May 2008



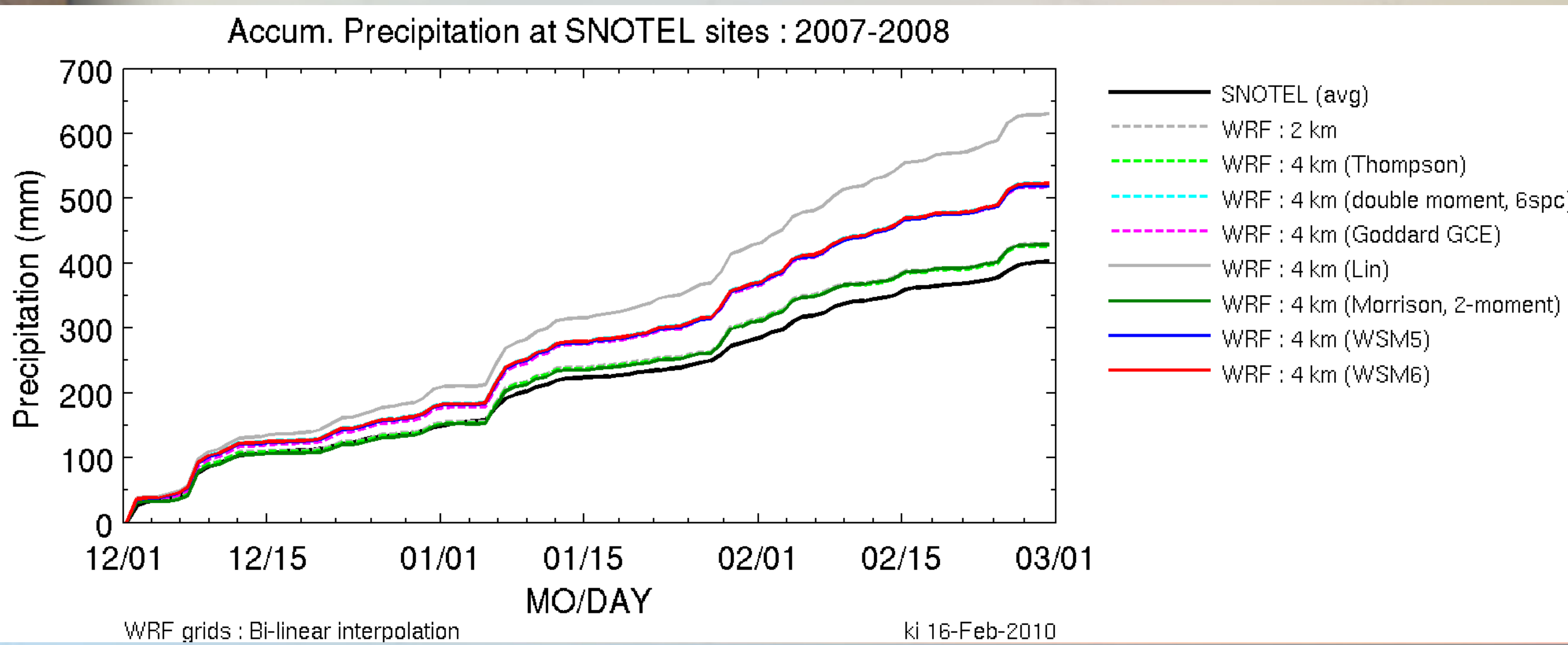
- Freezing level height increased by ~173 m, leading to a decrease of the area covered by snow by ~10%.
- Fraction of snow decreased by ~10% of the total grid cell precip. Fraction of rain increased by a similar amount.
- The PGW run indicates higher snowfall intensity at the mountain peaks.

Ikeda et al., 2010 Atmo. Res.; Rasmussen et al., J. of Climate, 2011

Issues for Water Vapor Cycling:

1. What are the key source, transport and *discharge* mechanisms for atmospheric water vapor?

   - Cloud processes have significant impact on simulation fidelity:



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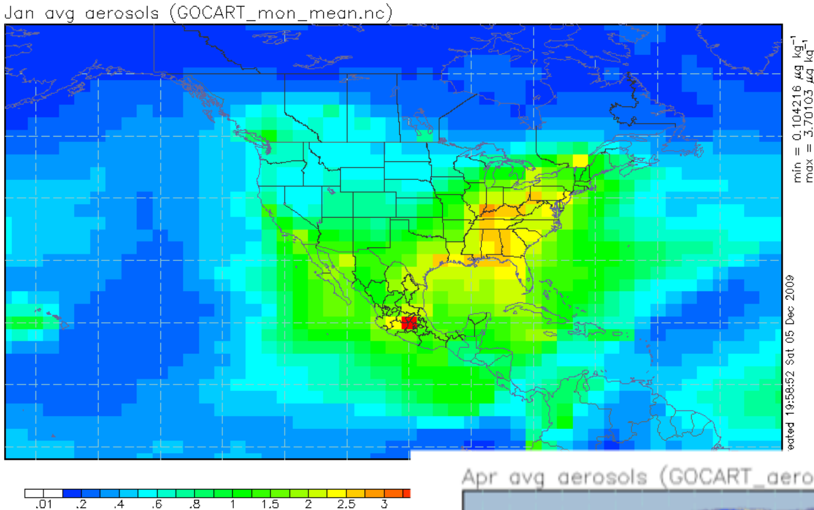
Thompson et al., 2011 NWP Physics Presentation at NCEP

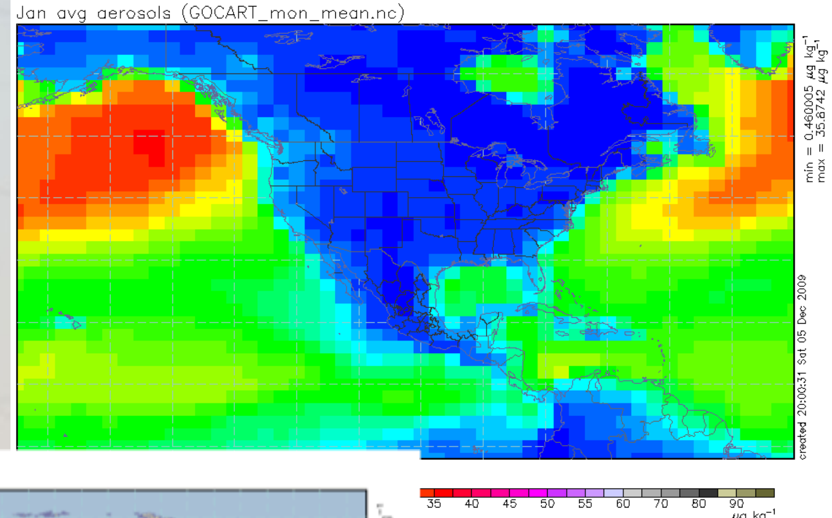
Input aerosols: sulfates, sea salts and dust

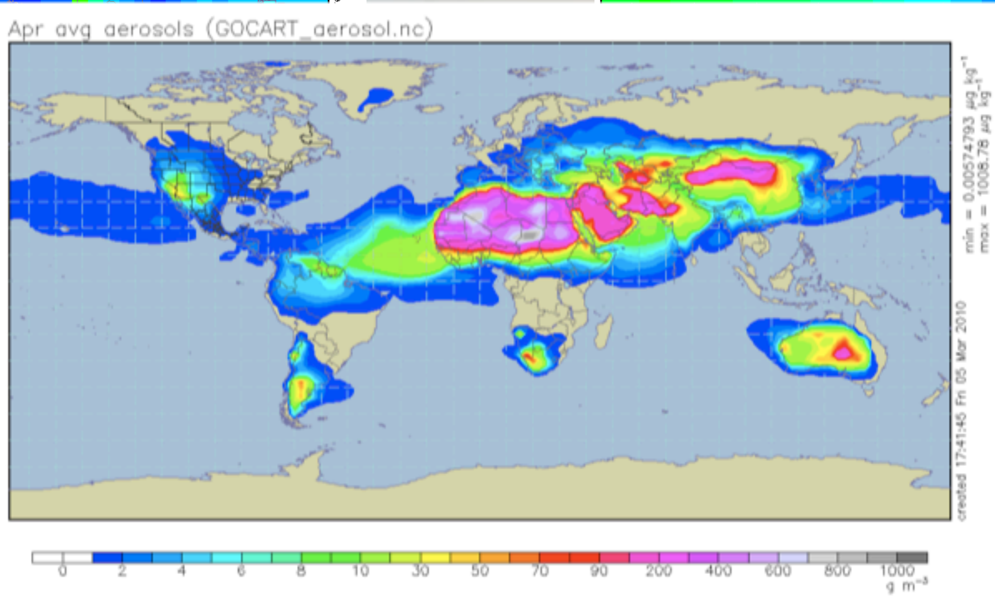
GOCART 2.5° (lon) x 2.0° (lat) global monthly avg data, 20 sigma levels

Sulfates (all bins) at k = 0

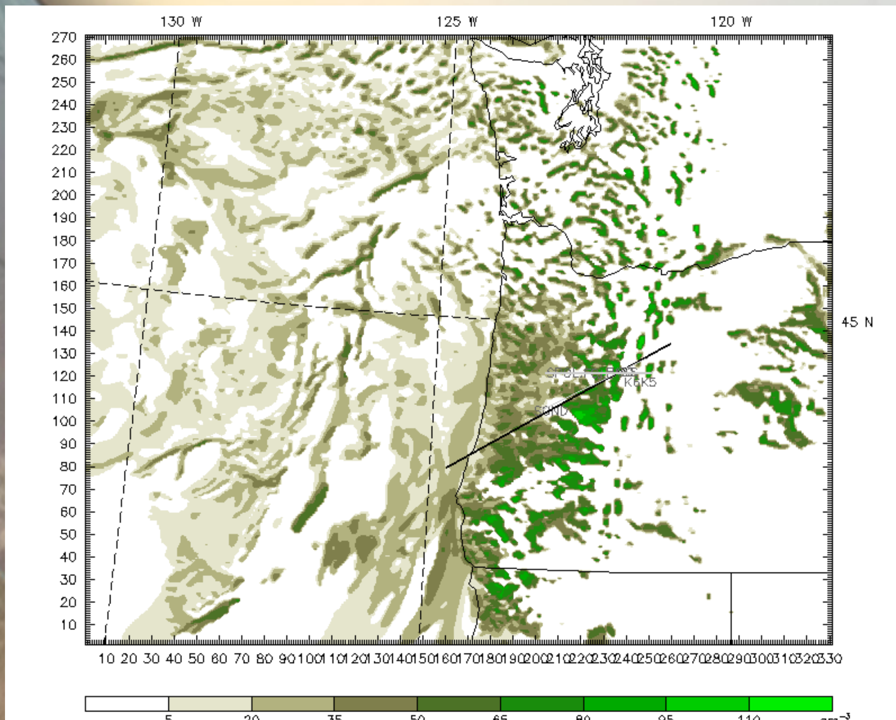


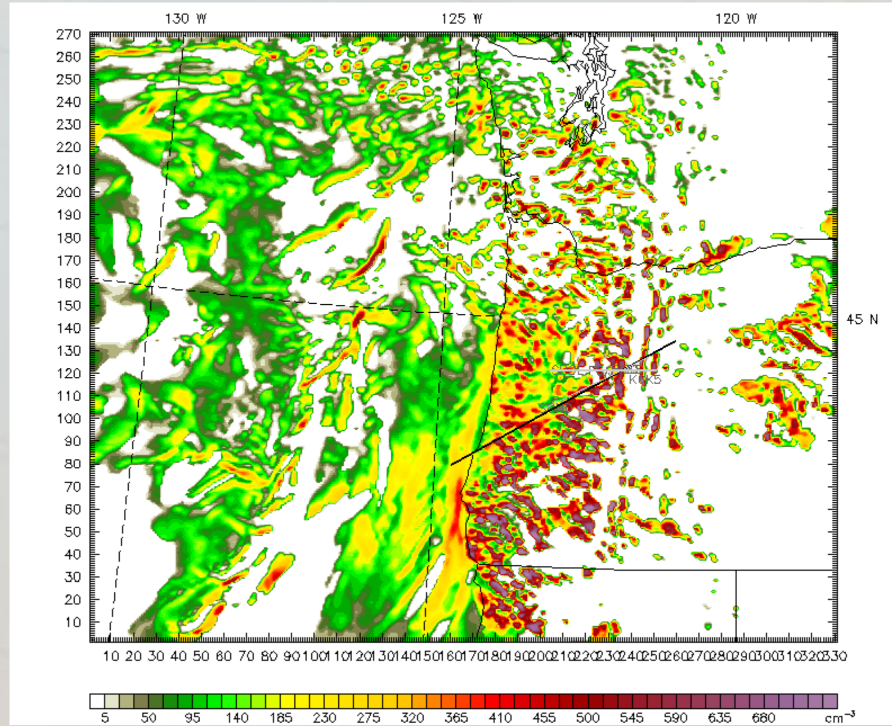
Sea salt (all bins) at k = 0





Aerosol test: clean vs. polluted airmasses

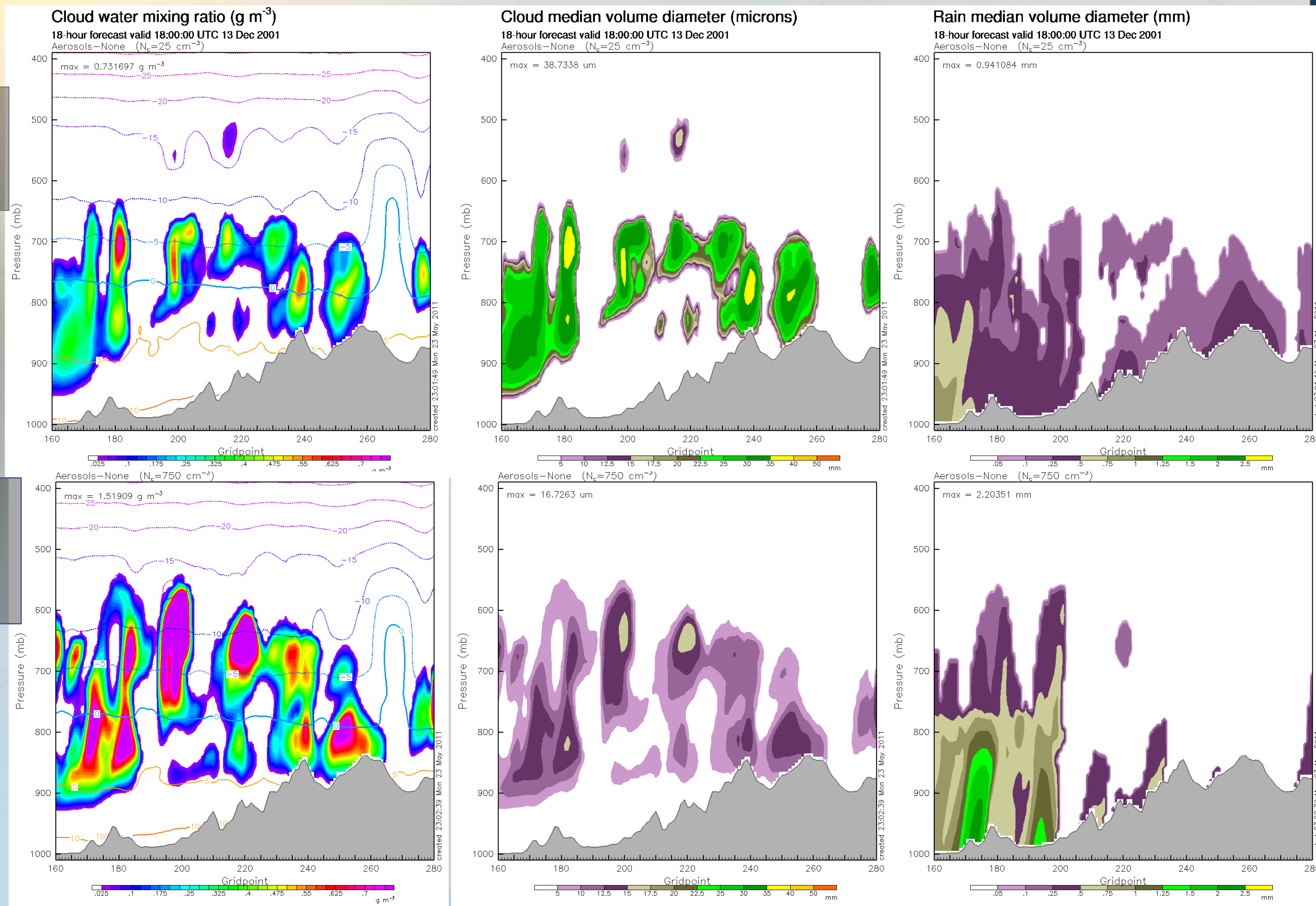




Aerosol test: clean vs. polluted airmasses

Maritime
fewer drops
much larger mean size
less liquid water content
more drizzle/light rain

Continental
more drops
much smaller mean size
more liquid water
delayed drizzle/rain
alters upper cloud



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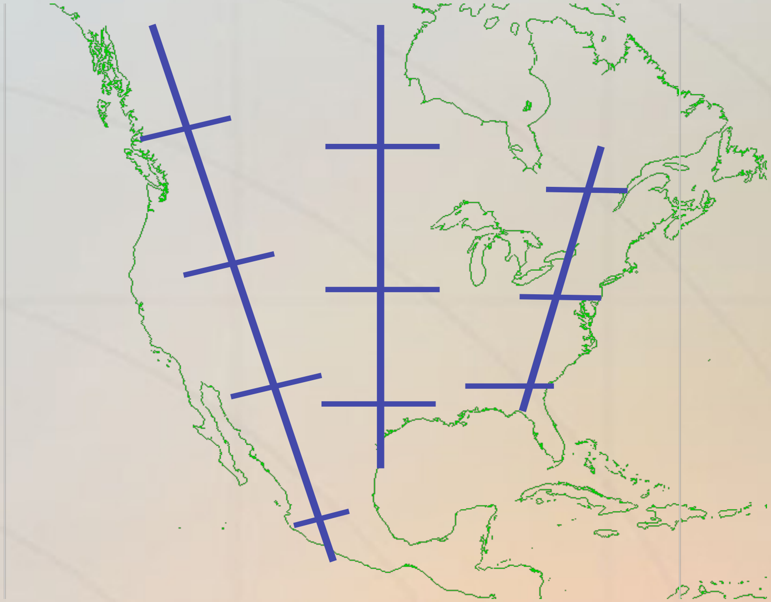
Conclusions: *(atmospheric emphasis…)*

Mandate:

1. Improving the fidelity of weather and climate predictions and future climate projections…
   a. Enhance the observational foundation of the water cycle (precipitation and clouds, transport mechanisms, land surface storage, surface-atmosphere fluxes)
   b. Rapidly advance the development and implementation of multi-scale modeling tools for prediction of *source, transport and discharge* mechanisms…
   c. Capitalize on quasi-stationary hydroclimatic regimes (i.e. LLJ/AR exit regions) for more targeted studies on precipitation processes at the weather-climate interface
   d. Improve understanding and modeling of convective-feedback processes
   e. Address observational modeling uncertainties in cloud-aerosol interactions

TRACE Mtg: 1-order activity

- Science Goal:
  - Improve understanding of internal feedbacks for *improving understanding of climate variability at intra-seasonal to inter-decadal timescales*:
    - Land forcing of climate anomalies
    - Land responses to extreme events
    - Manifestations of SST forcing
    - 'Change' as a mode of climate variability
      - Variability is where billions are lost each year, RIGHT NOW



- Design of a long-term (5-10yr) integrated observation, analysis, modeling program
  - Focusing on diagnosis and attribution of *long-term* hydrologic sensitivities
  - Improvement of land surface model parameterizations
  - Coupled model prediction systems
  - With application to water management groups…
  - Quantification and representation of coupling
  - Deliverable: A new climate system reanalysis…
  - A new R2O paradigm…
  - A new set of diagnostics for operational and climate system models…expanded concept of benchmarking.