Potential impacts of aerosol and dust pollution acting as cloud nucleating aerosol on water resources in the Colorado River Basin

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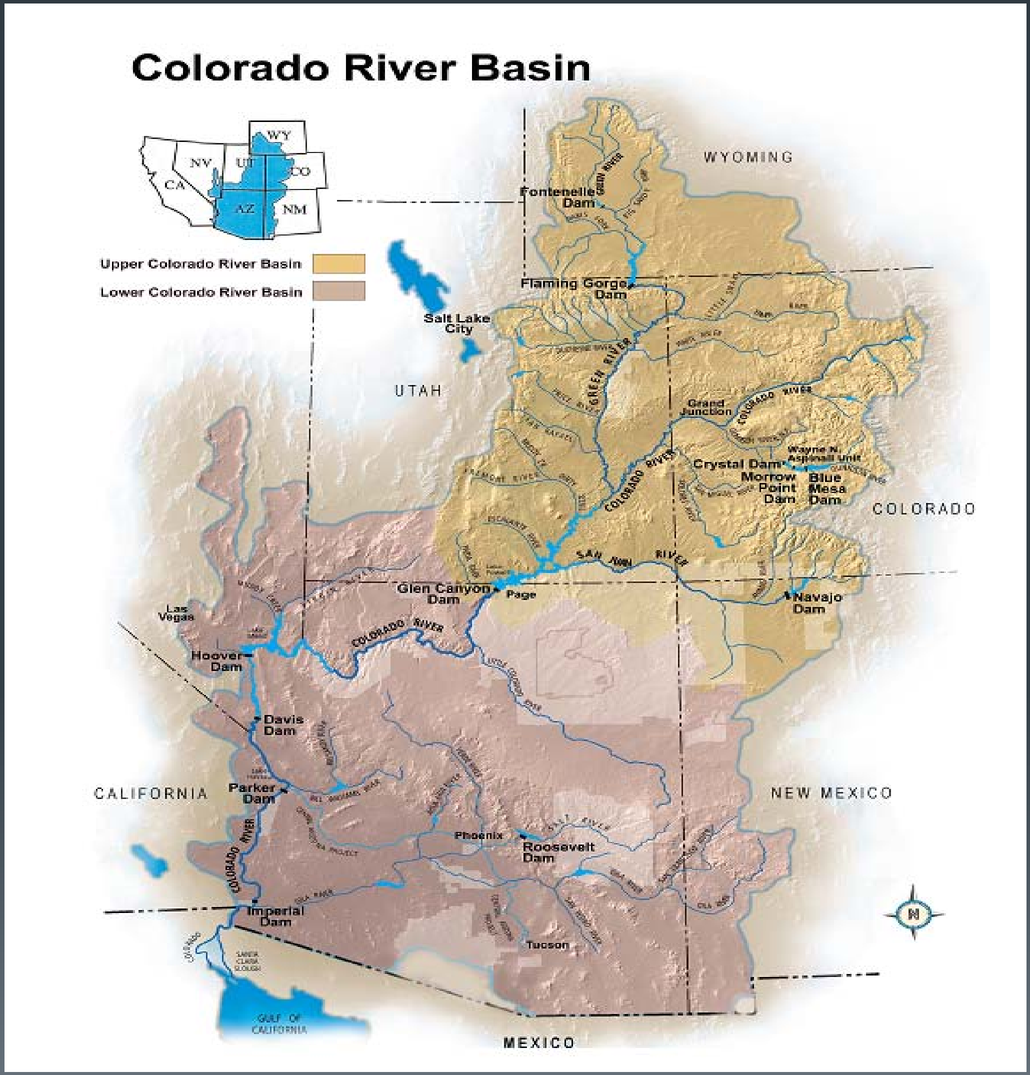
Outline

- Motivation
- Background
- Model description
- Results
- Conclusion and Future work

Motivation of Research

- The Colorado River Basin (CRB) covers the seven states of the U.S and Mexico.
- About 70% of the Colorado's water flow originates from the snowmelt.
- The water resources in the CRB are potentially impacted by aerosol pollution and dust acting as cloud nucleating aerosol as well as dust affecting the albedo of the snowpack.
- Climate models project runoff losses of 7–20% from the basin in this century due to human-induced climate change.



Desert dust impacts on snow cover and precipitation

- There has been concern that desert dust accumulating on snowpack can decrease snow albedo and shorten the duration of snow cover by several weeks (Painter et al. 2007, 2010, 2012).

- Painter et al. (2010) estimated that heavy dust loading in the San Juan Mountains of Colorado results in earlier peak runoff by 3 weeks, and increases evapotranspiration from earlier exposure of vegetation and soils, leading to decreases in annual runoff by more than 1.0 Billion Cubic Meters (BCM).

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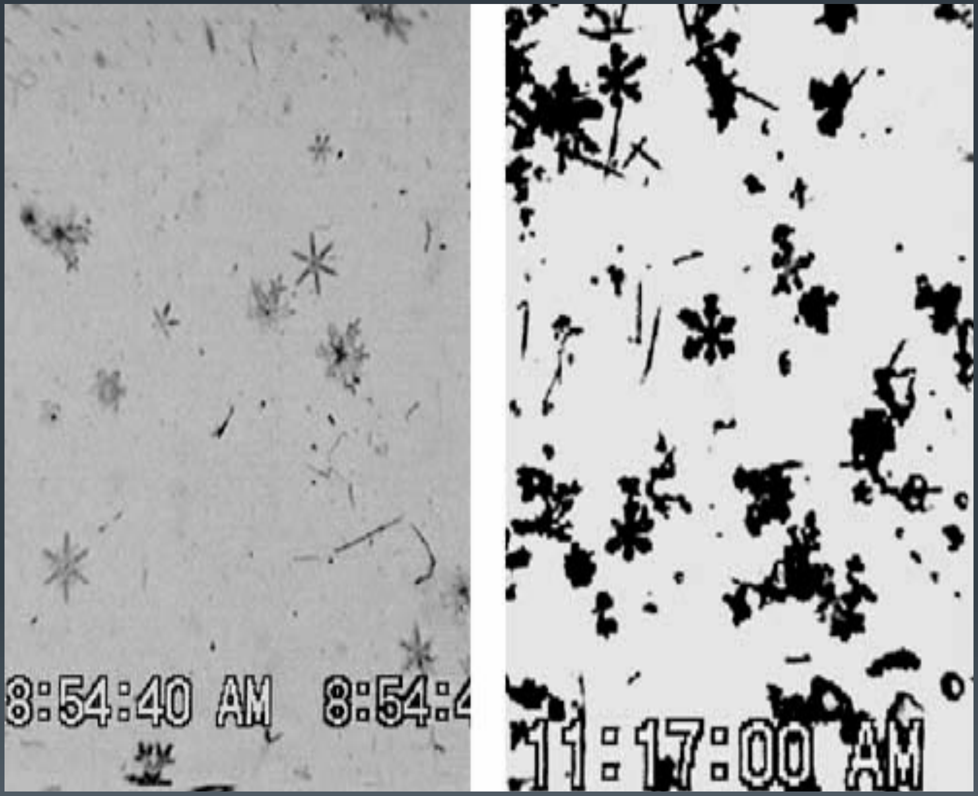
Borys et al.

- Pollution can delay precipitation in winter orographic clouds in the Rocky Mountains (Borys et al. 2000, 2003).
- Pollution increases the number concentration of CCN and therefore cloud drops, leading to the formation of smaller cloud drops and less efficient riming.
- A reduction in riming results in smaller, more pristine ice crystals with smaller fall velocities, and less surface precipitation accumulation.



Light riming polluted (left), Heavier riming clean (right)

Figure: Borys et al. 2003

Saleeby et al.

- Saleeby et al. (2009) examined the Borys hypothesis by performing 3D simulations varying concentrations of CCN over the Park Range of Colorado.
- Higher CCN concentrations lead to the formation of smaller, more numerous droplets and reduced riming.
- Reduced riming lowered snow water equivalent precipitation amounts on the windward side of the mountain barrier and increased it on the lee slopes.
- Overall total precipitation was reduced only a small amount but in the case of the Park Range, the "*spillover effect*" led to a downstream shift of precipitation from the CRB to the Atlantic watershed.
- They also showed that this effect was only important for relatively wet storms where riming is important. Low supercooled liquid water content storms are less influenced by aerosol pollution.

Spillover Effect

- A suppression of precipitation on the windward side of the orographic barrier and possibly an enhancement of precipitation on the drier lee side is termed as the spillover effect of precipitation.

- An increase in aerosol number concentration resulted in a shift in the SWE from the windward slope to the leeward slope of the major CO mountain ranges due to “spill-over effect” .

Where did the dust come from?

- Dust from Asia has been known to transport to the US, and even across the globe (Uno, et al. 2009).

- Few studies have shown transport from Africa (McKendry, et al. **2007)**.

- Modeling studies (Ginoux et al. 2004) indicate that North America is the only continent (Antarctica excluded) for which annual dust deposition exceeds emissions (by threefold). Hence long-range transport from other continents is the dominant factor controlling the magnitude and inter-annual variability of dust loading.

- The dust deposited in the San Juan Mountains migrate from the Colorado plateau deserts and from the neighboring states (NE Arizona, NW New Mexico, and SE Utah)

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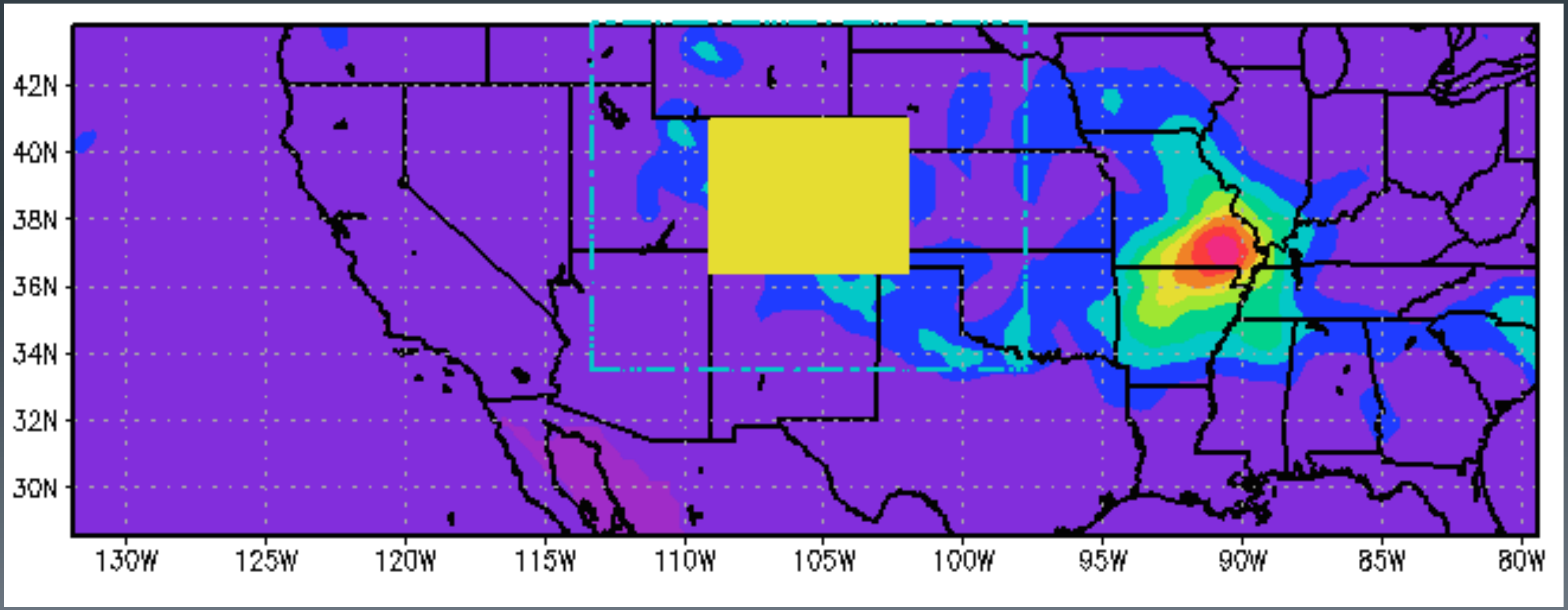
Domain of Study

- The Rocky Mountain area with latitude 37 N and longitude -109 W.
- In the 3-grid configuration, the outer grid, grid 1, uses 36-km grid spacing and encompasses the full figure panel.
- Grid 2 is displayed in dotted green color and has a grid spacing of 12 km.
- Grid 3 is shaded in yellow color and has a grid spacing of 3 km.

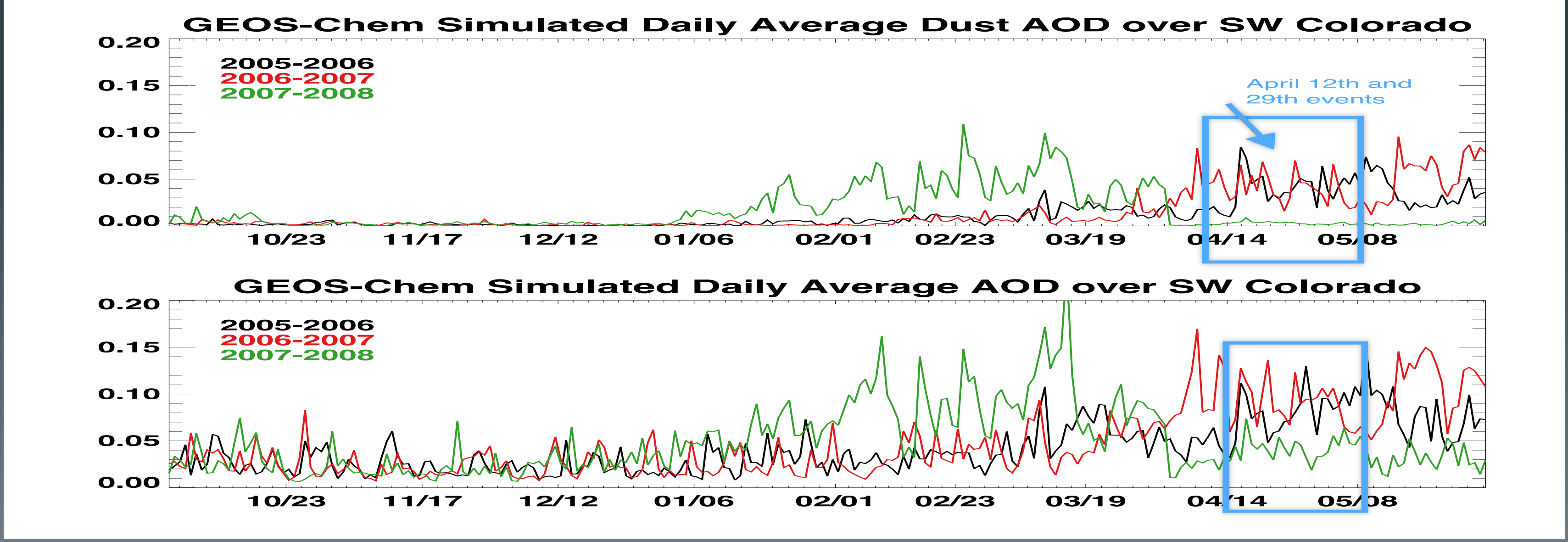


RAMS configuration

Model aspect	Settings
Grid	Arakawa C grid (Cotton et al., 2003); Horizontal grid: Grid 1: $\Delta x=\Delta y=36$ km; 150×64 points Grid 2: $\Delta x=\Delta y=12$ km; 122×101 points Grid 3: $\Delta x=\Delta y=3$ km; 210×170 points Vertical grid: Δz variable (75 m at the surface; maximum of 800 m) 35 vertical levels Model top: ~20 km; 10 levels below 1 km
Initialization	1°GFS data; Soil data initialized with ~32 km NARR analyses (Mesinger et al. 2006)
Time step	30 seconds
Simulation duration	10 day long periods for 3 months for both dirty and clean case
Aerosol and Dust Sources	GEOS-Chem plus regional dust sources in RAMS
Microphysics scheme	Two-moment bin-emulating microphysics (Saleeby and Cotton 2004, 2008, 2009) DeMott et al. 2010, heterogeneous ice nucleation

GEOS-Chem

- The aerosol and dust pollution input is obtained from the GEOS-Chem model (Courtesy: Dr. Jeff Pierce).
- Prediction of pollution aerosol sources and long-range transport of aerosols.
- Non-dust aerosols in RAMS will be simulated using 3 lumped species: inorganic species, hydrophilic organics and hydrophobic organics.



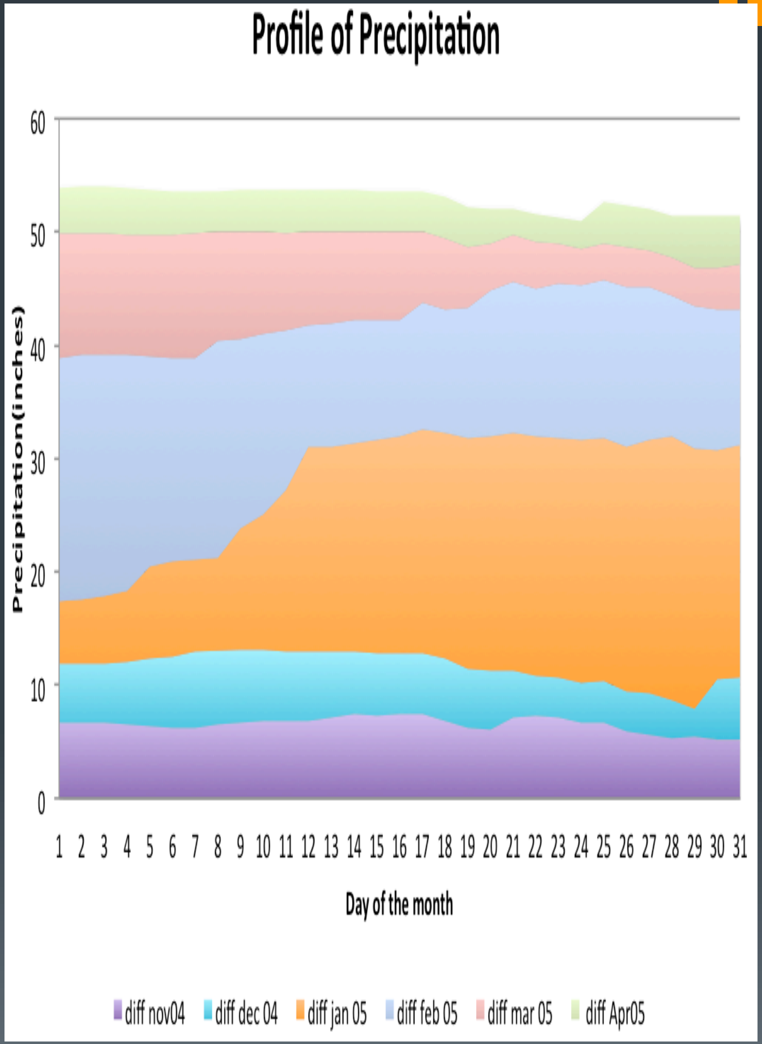
SNOTEL

- SNOTEL (SNOwpack TELemetry) provides useful high elevation climate information data about real-time precipitation, air temperature, snowpack depth and snow water content. It makes multiple measurements to provide hourly data per day.

- SNOTEL uses meteor burst communications technology to collect and communicate data in near-real-time.

- VHF radio signals are reflected at a steep angle off the ever present band of ionized meteorites existing from about 50 to 75 miles above the earth.

- Locations of over 730 SNOTEL sites in 11 western states including Alaska.



Dust as Ice Nuclei in RAMS

- Ice formation processes occurring in orographic clouds along the Park Range are dominated by heterogeneous ice nucleation.
- Homogeneous ice nucleation of cloud and haze droplets are parameterized using the DeMott et al. (1994) scheme.
- Heterogeneous ice nucleation is parameterized using the IN-based scheme of DeMott et al. (2010), which accounts for possible dust sources for ice nucleation that may impact Colorado from southwest dust sources as well as long range transport of Asian dust.
- The scheme relies on the total number concentration of aerosol particles greater than 0.5 μm in diameter and temperature.

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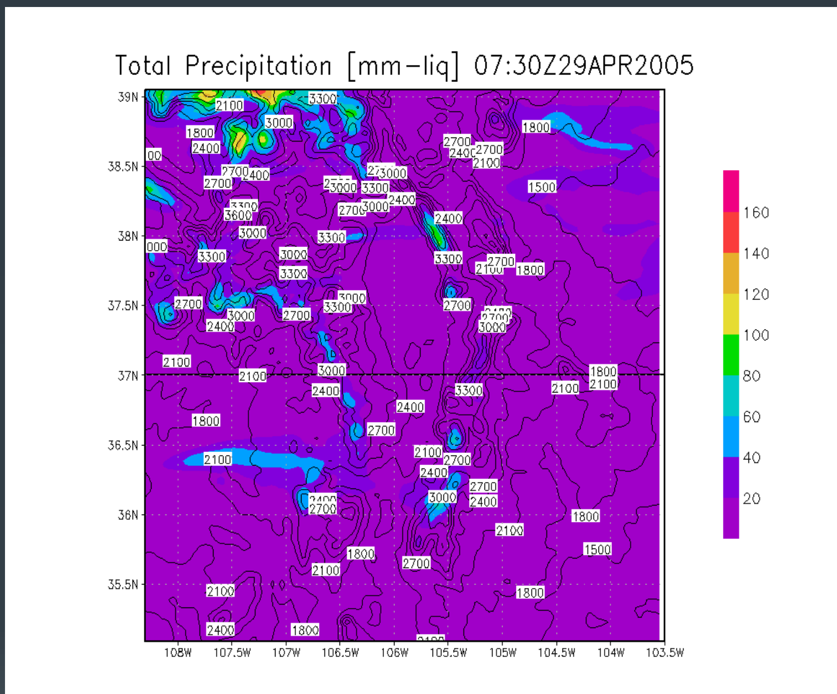
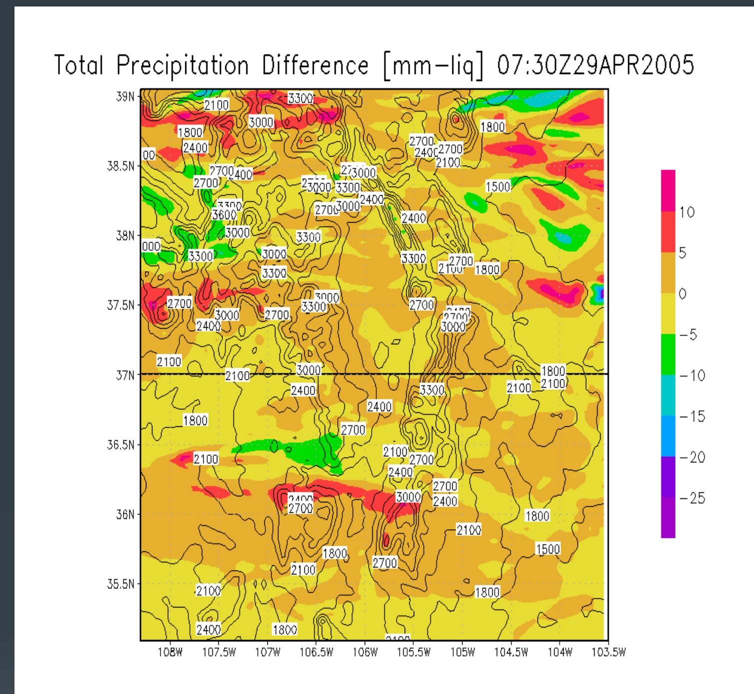
Sensitivity Studies



Total Surface Precipitation with three times dust and aerosol (a=1, d=3) (April 28th 2005)



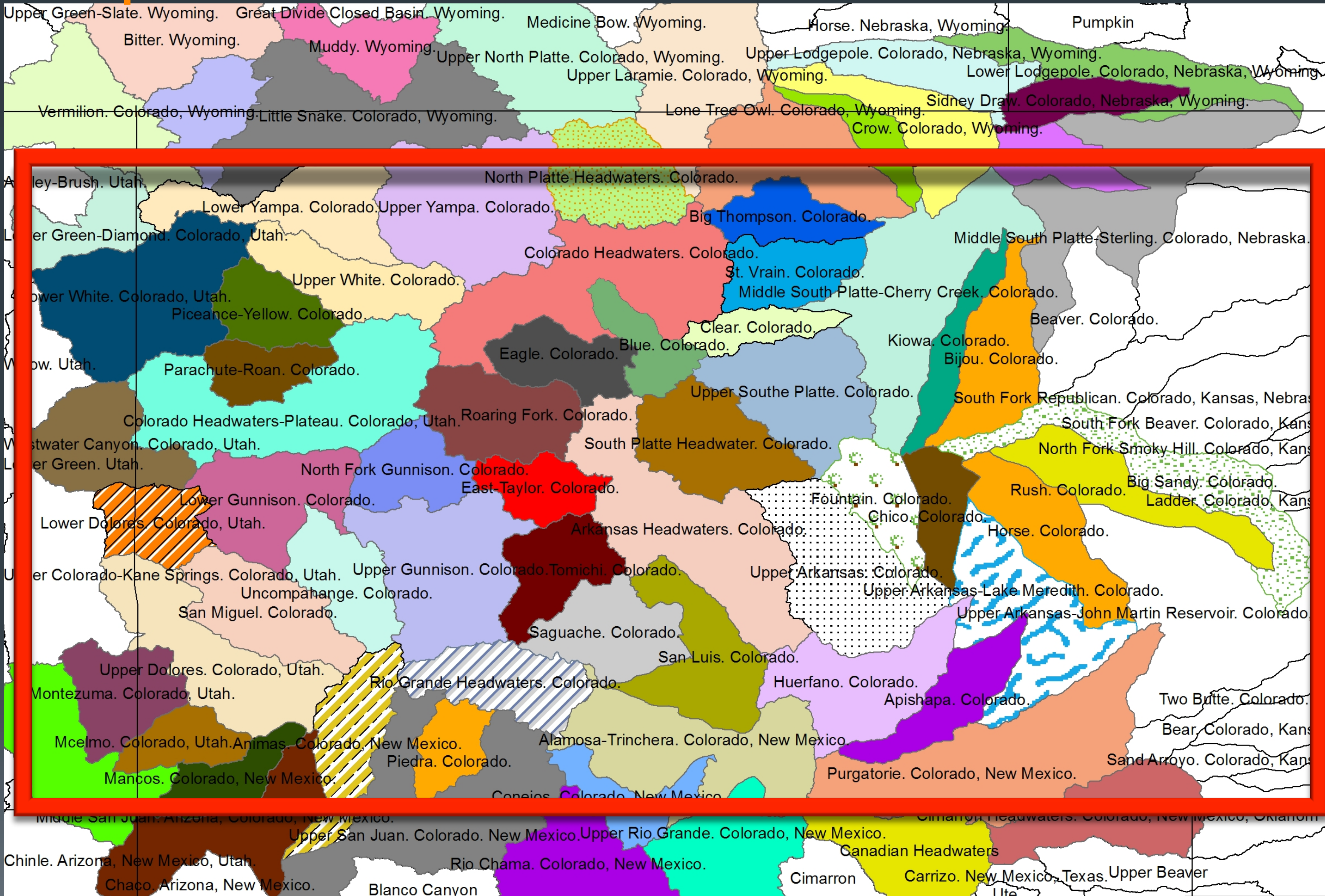
Total Precipitation Difference b/w (a=1, d=1) and (a=1, d=3) (April 28th 2005)

Preliminary Results

- Dust acts to slightly enhance wintertime orographic precipitation in the Colorado Mountains (~3%).

- The effects of aerosols are case dependent, probably linked with different environmental conditions (e.g. cloud base temperature)

Map of the Basins



Courtesy: Steve Saleeby

Comparisons

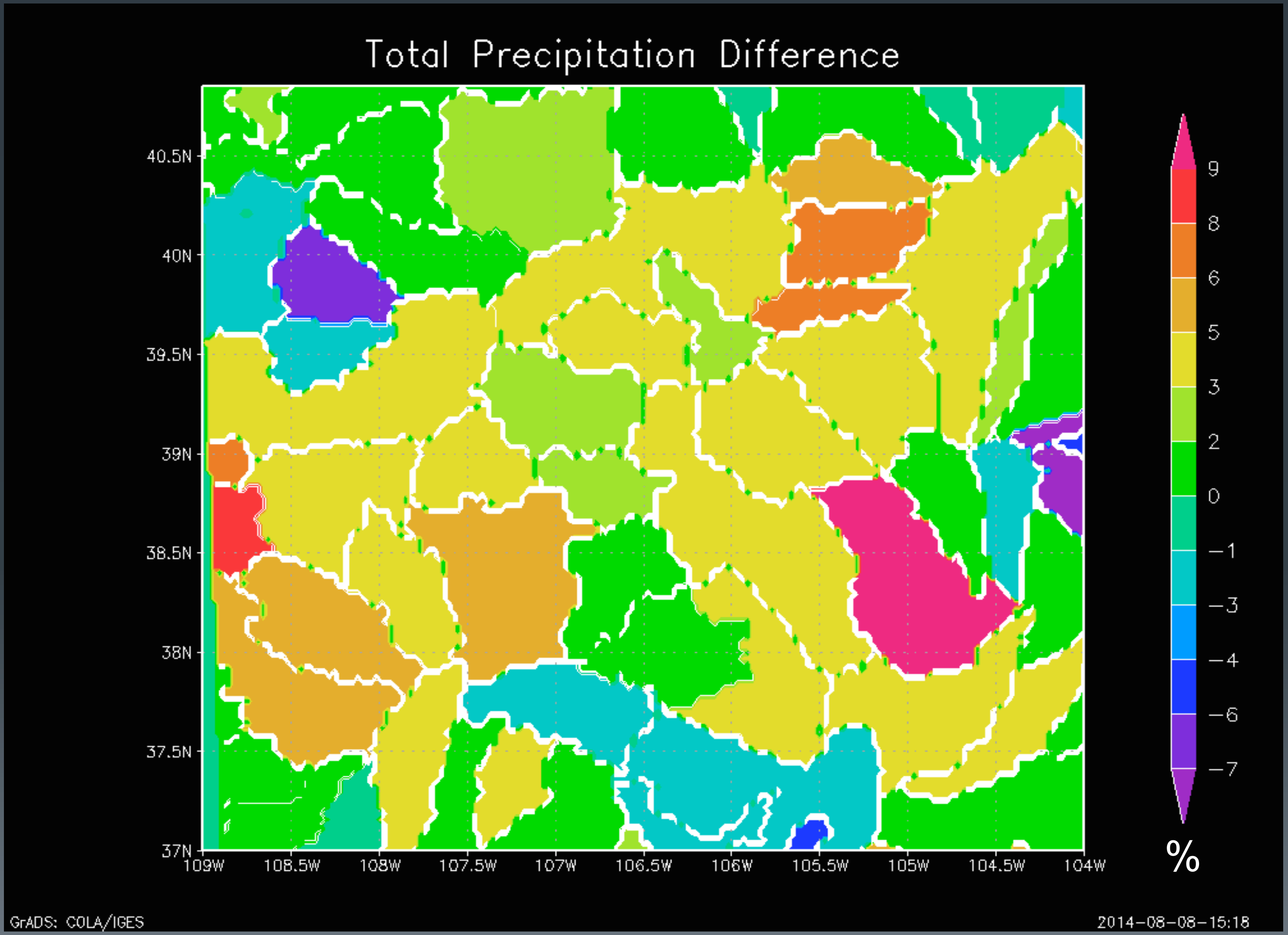
Comparison of integral precipitation per period

	CLEAN	DIRTY	DIFFERENCE	
1	3.6594736E+13	3.9821750E+13	8.818245	%
2	2.0761150E+13	2.0655513E+13	-0.5088241	%
3	2.6694210E+13	2.9320081E+13	9.836857	%
4	1.3028393E+13	1.3093737E+13	0.5015516	%
5	3.3479364E+13	3.3940214E+13	1.376517	%
6	2.3646762E+13	2.3536027E+13	-0.4682921	%
7	1.2240027E+13	1.2182320E+13	-0.4714555	%
8	7.3235652E+12	7.2217558E+12	-1.390162	%
9	1.5472108E+13	1.5500560E+13	0.1838926	%
10	3.1384079E+13	3.1406260E+13	7.0677802E-02	%
11	1.7084300E+13	1.6921843E+13	-0.9509136	%

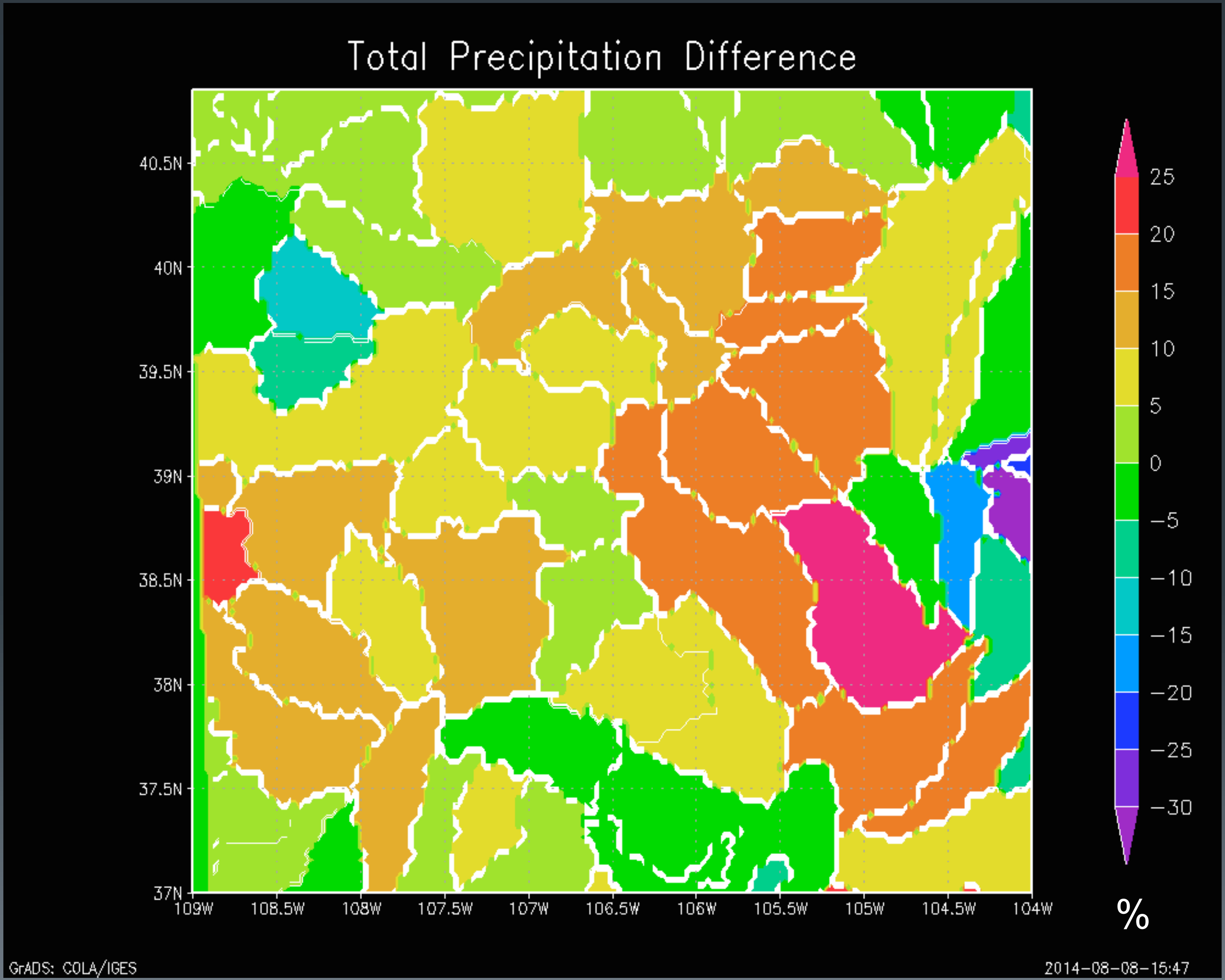
Comparison of integral precipitation over the finest grid

2.3770871E+14   2.4360006E+14   2.478392   %

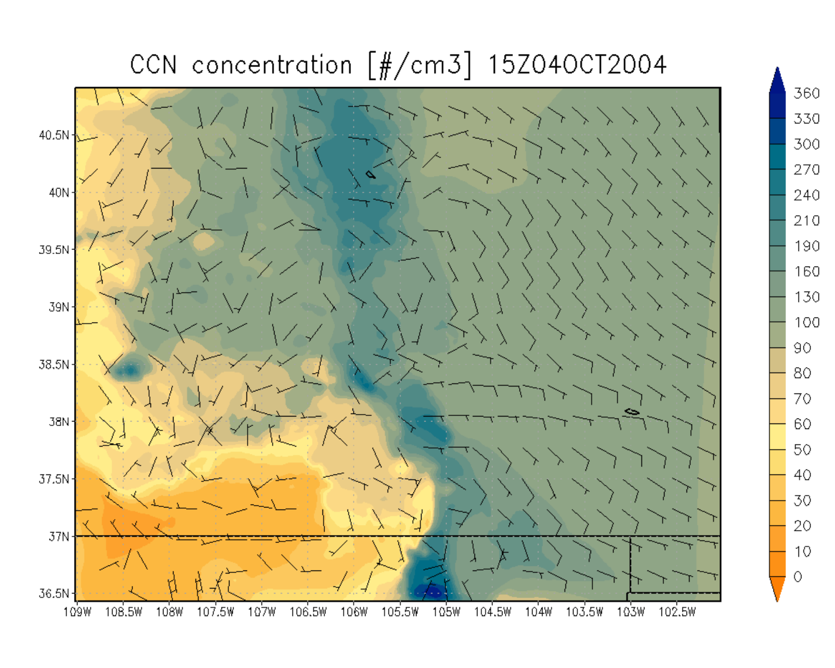
Precipitation difference for 3 months

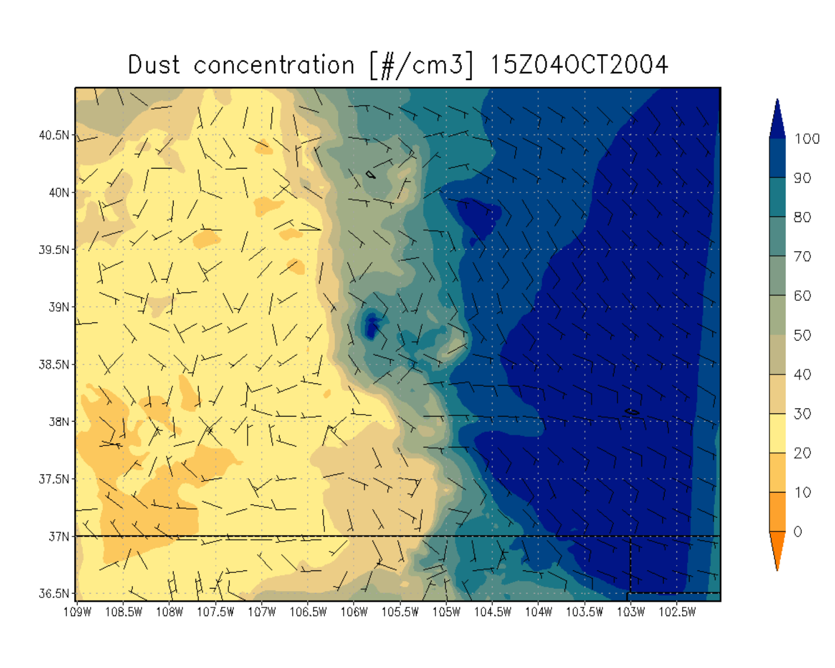


Precipitation difference for October

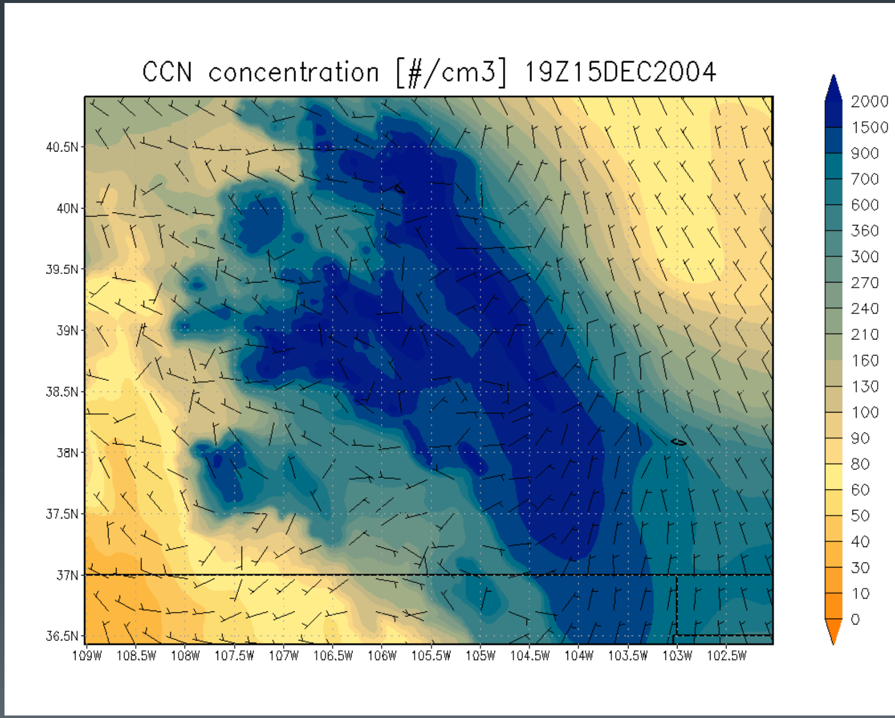


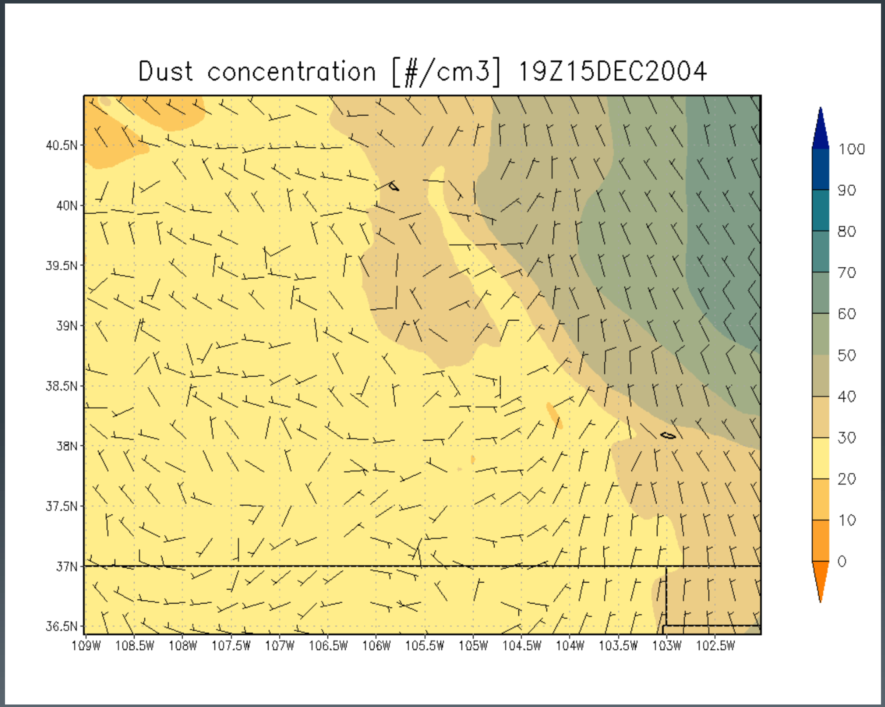
Period 1


CCN concentration [#/cm3] 15Z04OCT2004
40.5N
40N
39.5N
39N
38.5N
38N
37.5N
37N
36.5N
109W 108.5W 108W 107.5W 107W 106.5W 106W 105.5W 105W 104.5W 104W 103.5W 103W 102.5W
360 330 300 270 240 210 190 160 130 100 90 80 70 60 50 40 30 20 10 0

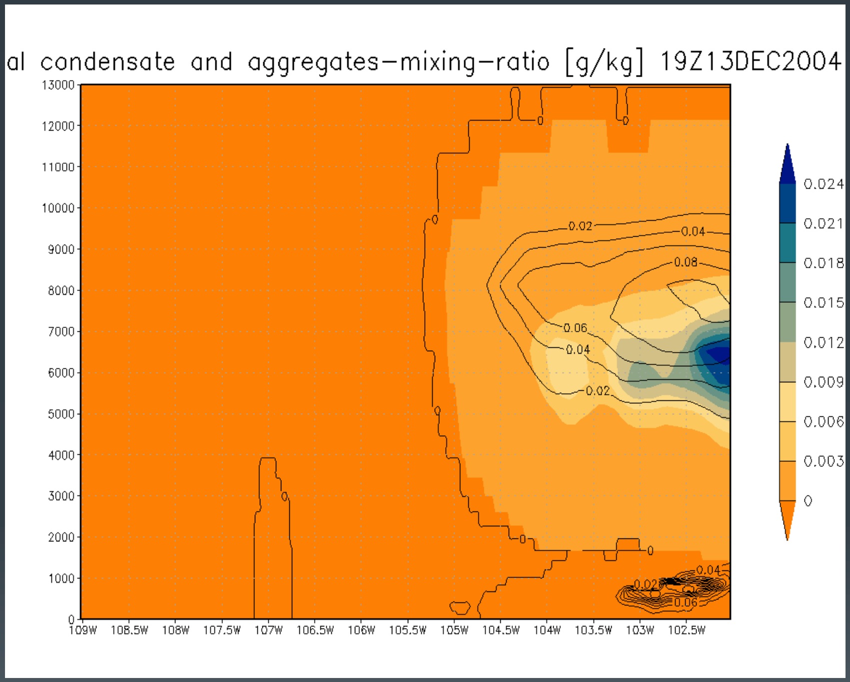

Dust concentration [#/cm3] 15Z04OCT2004
40.5N
40N
39.5N
39N
38.5N
38N
37.5N
37N
36.5N
109W 108.5W 108W 107.5W 107W 106.5W 106W 105.5W 105W 104.5W 104W 103.5W 103W 102.5W
100 90 80 70 60 50 40 30 20 10 0

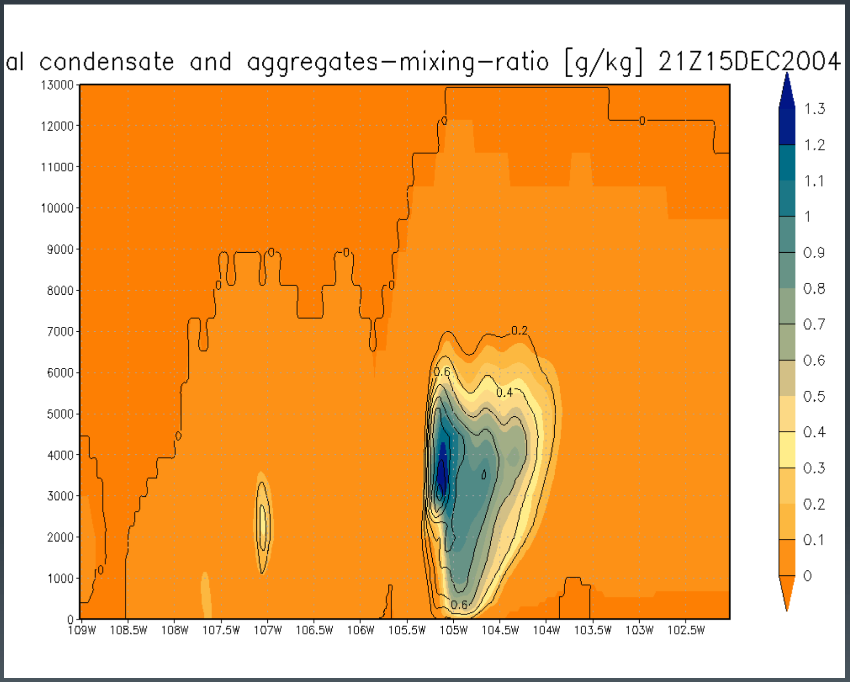
Period 8


CCN concentration [#/cm3] 19Z15DEC2004
2000
1500
900
700
600
360
300
270
240
210
160
130
100
90
80
60
50
40
30
10
0
40.5N
40N
39.5N
39N
38.5N
38N
37.5N
37N
36.5N
109W
108.5W
108W
107.5W
107W
106.5W
106W
105.5W
105W
104.5W
104W
103.5W
103W
102.5W

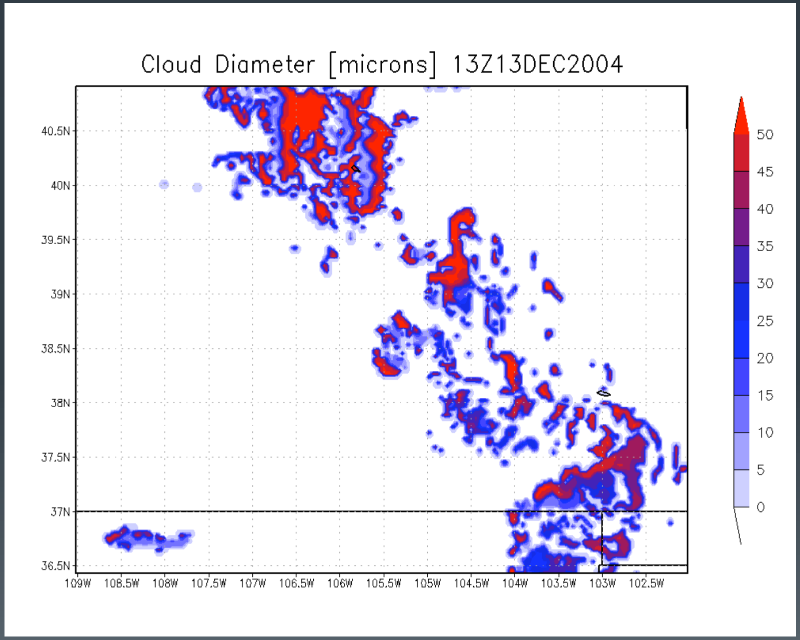

Dust concentration [#/cm3] 19Z15DEC2004
100
90
80
70
60
50
40
30
20
10
0
40.5N
40N
39.5N
39N
38.5N
38N
37.5N
37N
36.5N
109W
108.5W
108W
107.5W
107W
106.5W
106W
105.5W
105W
104.5W
104W
103.5W
103W
102.5W

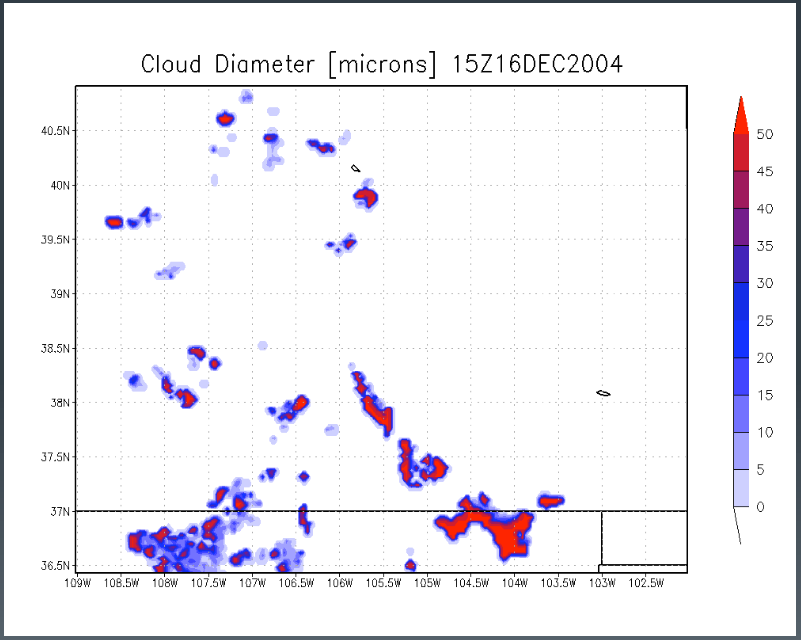
Total condensate and aggregate mixing ratios



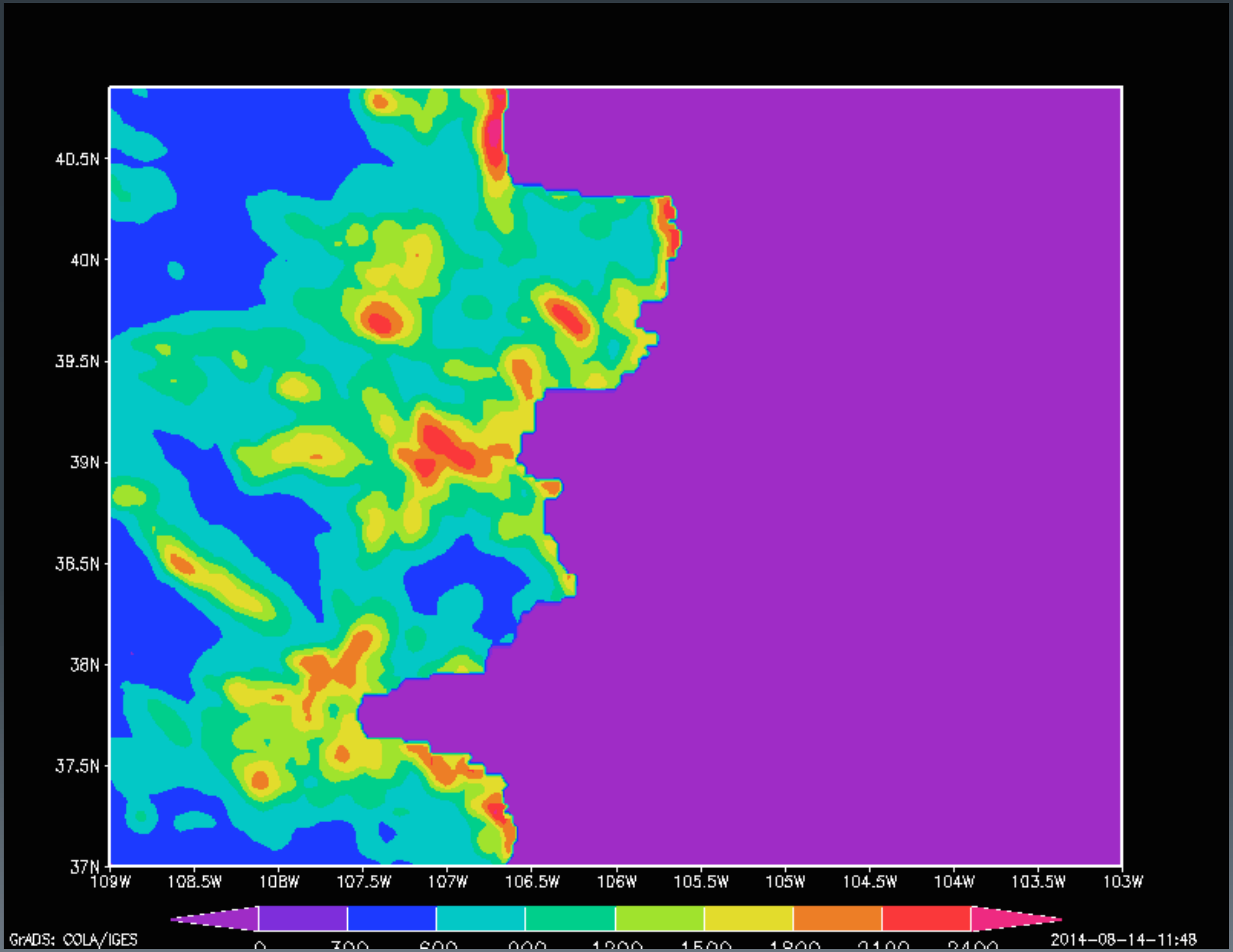


Cloud diameter

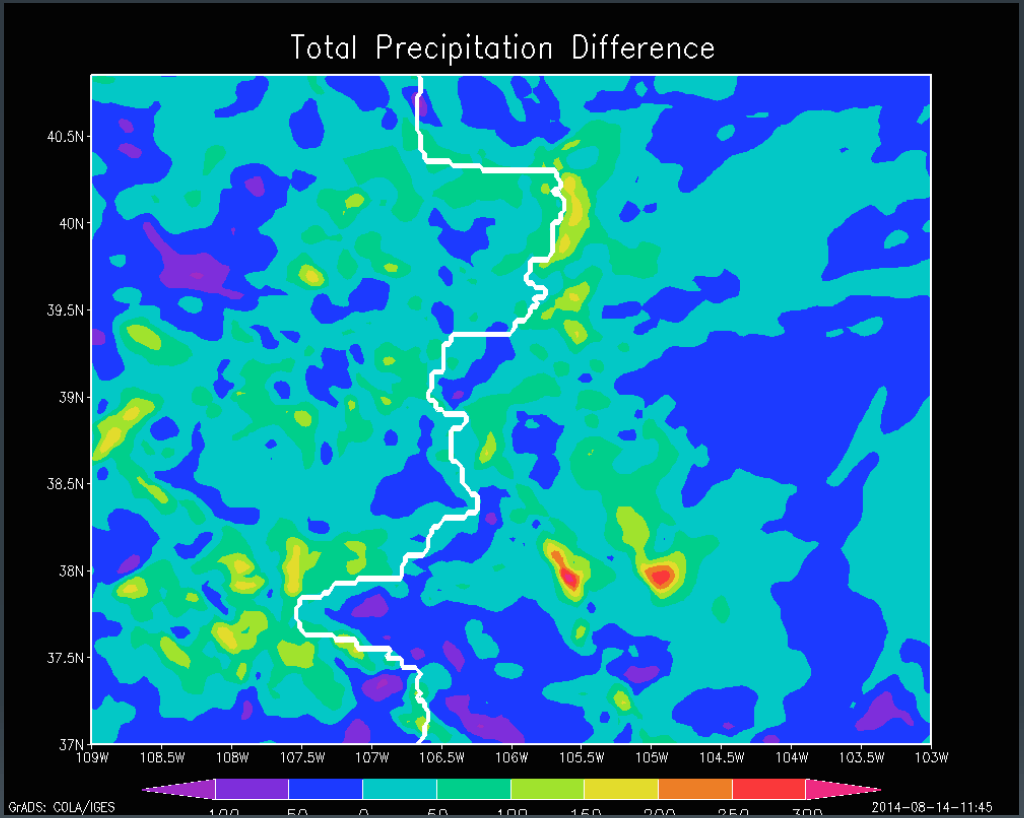




Precipitation in CRB



Precipitation difference in both regions



Differences in integral mass of precipitation:

A small decrease of ~ 0.1% for the CRB.

An increase of ~ 0.28 % in the leeward side.

Conclusions

- The simulations show a small decrease of ~ 0.1% for the CRB in the windward side.
- An increase of ~ 0.28 % in the leeward side by the ‘spillover effect’.
- The combined effect of dust and pollution aerosol is a decrease in the precipitation but the amount is moderated by dust.
- Dust can influence precipitation in the Colorado River Basin but acts in opposition to aerosol pollution.
- Applications to other basins depends on the relative importance of dust vs aerosol pollution.

Future Work

- More simulations for the entire winter seasons of 2005, 2006 and 2007 need to be done.
- Longer runs can provide a statistical image of the impact.
- Plan to cluster periods with similar behavior to understand the physics behind the differential response although it appears to be the ratio between the dust and aerosols.

Acknowledgements

- Advisor : Dr. William Cotton
- Thanks to Dr. Gustavo Carrió; Research Scientist at CSU for significant contributions.
- Dr. Jeff Pierce for the GEOS-Chem data.
- Thanks to NSF for funding the project.

- Thank you for listening!