Interactions between Asian air pollution and monsoon system: South Asia (ROSES-2014 ACMAP)

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1. INTRODUCTION

Asia's rapid economic growth over the past several decades has brought a remarkable increase in air pollution levels in South Asia. High concentrations of aerosols (also known as particulate matter or PM) from pollution sources pose major health hazards to this highly populated region.

How do pollution and dust aerosols interact with the monsoon circulation and rainfall via scattering and absorbing solar radiation, changing the atmospheric heating rates, and modifying the cloud properties? This study investigates the worsening air quality problem in South Asia by focusing on the interactions between pollution and South Asian monsoon, not merely focusing on the increase of pollutant emissions.

2. OBJECTIVES

Specifically, this work assessed the impact of aerosol-cloud-radiation (ACR) interactions on Indian regional $PM_{2.5}$ using the NASA Unified Weather Research and Forecasting modeling system (NU-WRF).

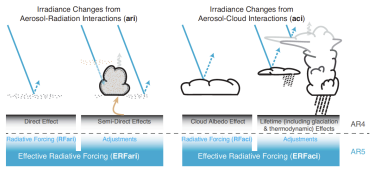

Figure 1: Schematic of aerosol–radiation (AR) and aerosol–cloud interactions (AC) (Courtesy of *Boucher et al*, 2013).

❑**AR:** Aerosol absorbs and scatters radiation to perturb the atmospheric energy balance. Absorbing aerosol heats the local atmosphere and cools the surface simultaneously, leading to a change in atmospheric stability and cloud formation.

❑**AC:** Aerosol also serves as cloud condensation nuclei (CCN) and ice nuclei (IN) to modify cloud properties (e.g., albedo, life time, thickness…) and precipitation processes.

3. METHODS

❖ We conducted a series of regional model experiments using NU-WRF regional model with coupled aerosol-chemistry-radiation-microphysics processes over South Asia (5km) for winter (January), pre-monsoon (April), and monsoon seasons (July) in 2010.

Experiment	Aerosol-radiation interaction	Aerosol-cloud interaction
f_{Ref}	off	No explicit aerosol treatment in cloud process
f_{AC}	off	Explicit aerosol-cloud interaction
f_{AR}	on	No explicit aerosol treatment in cloud process
f_{ACR}	on	Explicit Aerosol-cloud interactions

- In f_{Ref}, cloud formation is based on air temperature and water saturation, and IN is calculated as a function of ice super saturation, without explicitly considering aerosols (detailed in *Tao et al*. 2015).
- In f_{ACR}, the CNN and IN are estimated using the aerosol mass concentration calculated with the Goddard Chemistry Aerosol Radiation and Transport (GOCART) aerosol scheme, combining with the information of air temperature/super-saturation for CNN and cloud temperature for IN.
- In f_{ACR}, the Goddard microphysics and radiation schemes are applied.

❖ The factor separation method was applied in order to isolate the contributions to the total ACR interaction from aerosol-radiation (AR) and aerosol-cloud (AC) interaction.

Effect		Method
AC	Aerosol-cloud interaction	f_{AC} - f_{Ref}
AR	Aerosol-radiation interaction	f_{AR} - f_{Ref}
ACR	Aerosol-cloud-radiation interactions	f_{ACR} - f_{Ref}

4. RESULTS

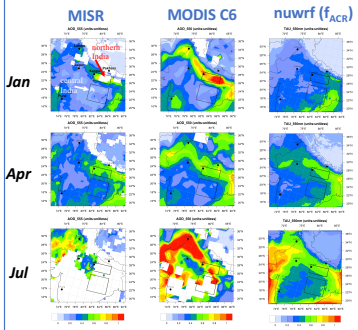

Figure 2: Evaluation of the monthly modeled NU-WRF (f_{ACR}) aerosol optical depth (**AOD**) with those observed from MISR and MODIS C6.

AOD_{550nm}	MISR@	MODIS	f_{ACR}
Jan	0.59*	1.02	0.38
	0.19#	0.22	0.38
Apr	0.52	0.60	0.50
	0.37	0.31	0.41
Jul	-	0.79	0.55
	-	0.87	0.45

@ wavelength is 555nm
* The area averaged value over northern India (80-85°E;25-27°N) is listed in upper cell
# The same as the above but for central India (80-85°E;20-24°N).

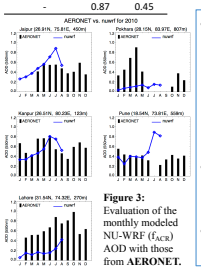

Figure 3: Evaluation of the monthly modeled NU-WRF (f_{ACR}) AOD with those from **AERONET.**

- Overall, NU-WRF can capture the spatial distribution in all seasons except for in January, high in northern India and low in other region.
- Kanpur: low bias in Jan and Apr. and high bias in July.
- Lahore and Pokhara: low bias in all months

RESULT (cont.)

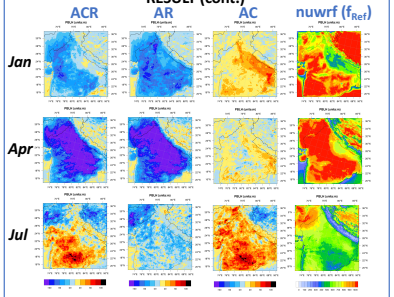

Figure 4: PBLH change (m) due to the effect of ACR, AR, and AC relative to f_{Ref}

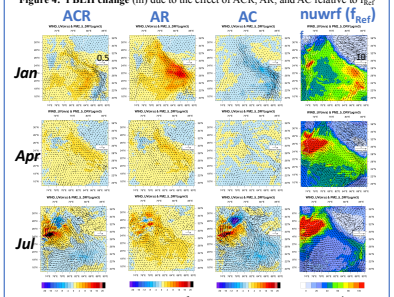

Figure 5: PM2.5_dry change (ug m^{-3}, in contour) and wind change (m s^{-1}, in vector) due to the effect of ACR, AR, and AC relative to f_{Ref}

Change of PBLH (m)	ACR	AR	AC	f_{Ref}
Jan	-9.5 (-3%)	-53.6 (-19%)	40.4 (14%)	280.6
	-48.9 (-10%)	-64.3 (-14%)	15.7 (3%)	468.5
Apr	-111.3 (-13%)	-125 (-15%)	13.4 (2%)	847.9
	-113.6 (-10%)	-115 (-10%)	1.6 (0%)	1108.0
Jul	0.9 (0%)	-27.1 (-5%)	19.2 (3%)	599.3
	43.1 (9%)	-12.2 (-2%)	55.2 (11%)	490.9

Change of $PM_{2.5\_DRY}$ (ug m^{-3})	ACR	AR	AC	f_{Ref}
Jan	3.3 (4%)*	10.7 (14%)	-3.9 (-5%)	75.6
	3.2 (5%) *	4.9 (8%)	-1.6 (-2.5)	62.7
Apr	2.5 (4%)	2.6 (4%)	-0.2 (0%)	62.6
	1.4 (3%)	1.6 (3%)	-0.1 (0%)	50.2
Jul	-0.6 (-2%)	2.7 (8%)	-3.2 (-10%)	33.2
	-2.3 (-8%)	2.0 (7%)	-3.3 (-12%)	27.3

5. CONCLUSIONS

❖ In northern India where heavy pollutions are found, the ACR interaction profoundly reduces planetary boundary layer (PBLH) in Jan. and Apr. (up to -111.3 m, -13% of reference run), while slightly enhances PBLH (0.9m; 0%) in July.

❖ The result of PM2_5_DRY are consistent with that of PBLH. In northern India, the PM2_5_DRY is enhanced in Jan. and Apr. (about 3 ug m^{-3}, 4% of the reference run), but slightly reduced in Jul. (about 0.6 ug m^{-3}, 2%).

❖ The effect of AR is to reduce PBLH and enhance $PM_{2.5}$ in northern India, opposite to those of AC. AR is the dominant factor of the overall ACR in Jan. and Apr., while AC dominates in Jul.. The similar results are found in central India but in different degree.

❖ Altogether through the ACR interaction, aerosol can affect the PBLH structure and the local/regional weather pattern including wind, which can subsequently impact $PM_{2.5}$ and thus air quality.

REFERNCES

❖ Boucher, O., et al., (2013), Clouds and Aerosols. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the AR5 IPCC report.

❖ Tao. Z. et al., 2015. "The Role of Aerosol-Cloud-Radiation Interactions in Regional Air Quality—A NU-WRF Study over the United States." Atmosphere, 6 (8): 1045-1068

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