Impacts of Black Carbon on Clouds, Precipitation and Hydrological Cycle

Source:

Black carbon (or soot) is a hydrocarbon product of incomplete combustion. The main source for black carbon is combustion of fossil fuel and biomass burning. The burning product is often a mixture of insoluble (BC, etc) and soluble (organic carbon, inorganic salt, etc) components.

With similar size distribution, organic and black carbon have different properties. Some OC is hydrophilic and reflective except for some absorption in the ultra violet and visible regions. BC is hydrophobic, but the particle can become hydrophilic as it gets coated with other soluble species. BC is a strong absorber of sun light.

Distribution:

Black carbon has complex spatiotemporal distribution. Given that fossil fuel combustion and biomass burning are the main sources, the BC concentration is the highest in the tropics and mid-latitudes, and in the lower troposphere. Regional hotspots include Western Europe, Northern America, tropics and Southeast Asia. At the high latitudes, BC mainly resides in the middle and upper troposphere due to horizontal transport of the aerosol from tropics and mid-latitudes. During this long-range transport, BC can mix with other types of aerosols (sulfates, organics, etc).

Both the horizontal and vertical distributions of BC are important to determine its effect on the atmospheric thermodynamics and precipitation.

Existing BC-cloud-precipitation mechanisms:

Category	***Mechanism***		***Details***	***Spatiotemporal scales***
Radiative Effects	BC in the atmosphere	Positive TOA Forcing	BC absorbs strongly solar radiation and thus less solar radiation is scattered back to space reducing planetary albedo.	Global annual mean (as appeared in the IPCC report)
		Atmospheric Heating	BC absorption cause additional heating, and thus alter the thermodynamic structure of the atmosphere, which further affect the boundary layer growth, and cloud and precipitation formation.	Regional effect Short lifetime
		Surface Cooling	Less solar radiation reaches the ground, thus reducing the available energy for sensible and latent heat fluxes, which drive the boundary layer growth and cloud formation.	

	Ice-albedo Feedback [positive feedback]	BC deposition on snow and sea ice enhances surface absorption and decrease snow/ice cover, further decreasing surface albedo and increasing absorption, particularly important in the Arctic. Feedback loop: Warming→more BC→snow/sea ice melting increases→albedo decreases→less reflection→warming	**Regional** effects on the seasonal scale: 1. Surface heating in high latitudes warms the permafrost layer, enhancing water drainage, organic decomposition and thus land productivity, which releases large amount of soil carbon into the atmosphere, and also drives the migration of ecosystem northward. 2. Reduced snow/ice cover and thinning of glacier and sea ice increases the energy received by high latitudes. **Global** effects on a multi-year scale: 1. Through feedbacks the latitudinal temperature gradient and general circulation (moisture transport, etc) change, and thus global weather pattern changes. 2. Freshing (addition of fresh water) of global oceans changes salinity and currents.
Dynamic Effects [radiative-convective coupling]	Atmospheric Stabilization [semi-direct effect; reduced surface sensible heat]	BC at high altitude (by advective or convective transport) absorbs sunlight, changing the atmospheric temperature profile (e.g., temperature inversion) and reduces surface sensible heat, inhibiting buoyant convection and **decreasing** cloud fraction and rainfall.	Individual cloud systems and precipitation events; Regional and decadal scale (e.g., Indian monsoon)
	Reduced Surface Latent Heat (or evapotranspiration)	Latent heat associated with evaportranspiration provides moisture for the atmosphere, and also affects the atmospheric temperature profile (e.g., level of free convection), thus reduction of latent heat due to surface cooling can **decrease** atmospheric humidity and influence the boundary layer convection.	
	Atmospheric Destabilization	BC in the lower tropospheric layer causes atmospheric heating and destabilization, which **enhances** convective boundary layer growth and cloud formation.	**Regional** effect: The heated lower tropospheric air rises and is converged in one area, accompanied with air subsidizing (drying) in the other area. This perturbed circulation results in rainfall distribution extremes (e.g., floods in Southern China vs. drought in Northern China)
	Atmospheric and Oceanic Circulation	Differential spatial distribution of BC causes perturbations of regional heating and temperature gradient, which **alter** the	Regional (e.g., Indian monsoon) or even global scale

		atmosphere and ocean circulation patterns	
Microphysical Effects [BC as CCN and/or IN]	First and Second Indirect Effects (BC as CCN)	1st indirect effect: With constant liquid water content, increased cloud droplet number concentration and reduced droplet size **decrease** the precipitation efficiency. 2nd indirect effect: precipitation suppression increases cloud liquid water path and lifetime. Note: the 1st and 2nd indirect effects are case-specific, not applicable for all situations, as was suggested in previous studies.	Early suppression of precipitation may allow the moisture to transport to high altitude and form extreme rainfall (thunderstorm, squall, etc). It may also allow the moisture to advect to other regions, causing perturbation in spatial distribution. Thus it may cause changes in temporal and spatial distribution of rainfall
	BC as IN	Insoluble BC particle is efficient IN. Ice crystal number concentration increases from contact nucleation, **enhancing** precipitation.	
	Droplet Heating	BC residing in the cloud droplet absorbs solar radiation and enhances droplet evaporation, **reducing** cloud fraction and liquid water content (LWC).	Regional scale