Better Understanding Late-20th Century Cloudiness Changes Over China

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Abstract: Surface-observed cloud amount data have shown evidence of significant, decreasing total cloud amount trends over China, particularly north of about 30°N latitude, over roughly the last half of the 20th century [e.g., Kaiser (2000); Qian et al. (2006); Warren et al. (2007)]. Trends have generally been thought to be "real" in the sense that it is likely that individual observers over much of China have indeed seen smaller amounts of cloud covering their local skies over recent decades. But, additional study of the surface-observed cloud amount ("cloud amount") record is warranted, due to the seemingly incongruous nature of a number of other cloud-related parameters in China's climate record (e.g., decreases in surface solar radiation), coupled with a growing body of research on the atmospheric effects of large amounts of anthropogenic aerosol emissions over recent decades, mainly over eastern China.

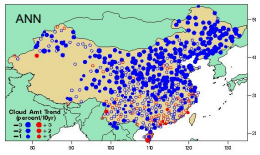
Data and Methods: Via a long-standing bilateral research agreement between DOE and the China Meteorological Administration (CMA), CDIAC (housed at Oak Ridge National Laboratory) has obtained and analyzed basic meteorological variables (including cloud amount) for China. Daily mean cloud amount records from over 500 stations have been used to compute national and regional-scale trends over 1954-2001. 6-hourly observations, available for 1954-1998 from about 200 stations, allow more detailed analysis of the frequency of occurrence of cloud amount, reported in tenths of sky cover; '0' meaning completely clear sky, and '10' indicating complete overcast.

Results: We first show a few key results from a series of our earlier papers to set the stage for our most recent results.

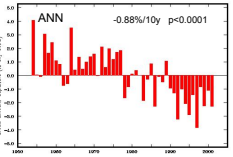
Cloud Amount Trends

Cloud amount trends from 537 stations and averaged over all of China
(Solid blue dots indicate decreasing trends significant at the 95% level)

Station trends in cloud amount

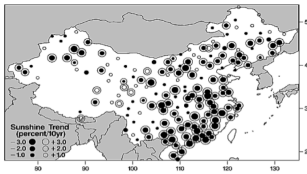


All-China cloud amount trend



- Significant decreases in annual and seasonal (not shown) cloud amount over much of China, about 1–2% sky cover per decade north of 30°.
- Decreases strongest to the north of 30°N in winter and spring, but also found in summer in the south.
- Annual and seasonal (not shown) time series show dramatic shift to mainly below average in the mid- to late-1970s.

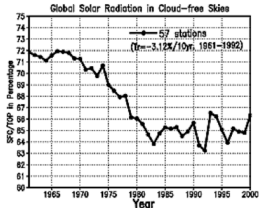
Decreasing cloud amount observed at the same time sunshine duration and direct/global solar radiation have been decreasing?

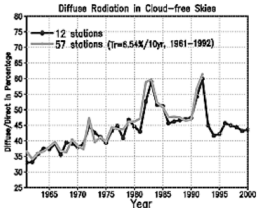


Decreases in percent of possible sunshine, 1954-1998.

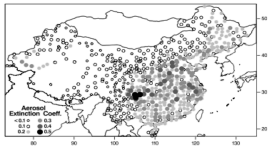
(Kaiser and Qian, GRL, 2002)

Qian et al., GRL, 2007 -

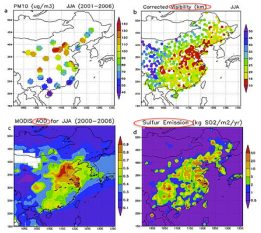




Several studies illustrate a key driver of decreasing solar radiation: increased aerosol optical depth.



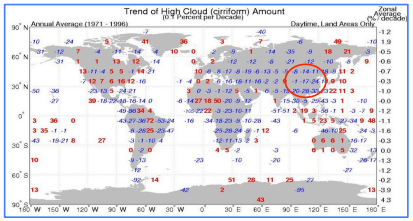
Aerosol extinction coefficient (per km) over China, 1981-1998 (Kaiser and Qian, 2002)



Clockwise from upper left: PM10 (2001-2006), Visibility (JJA), MODIS AOD (2000-2006), sulfur emissions. (Qian et al., 2009)

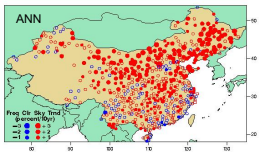
However…

- Considerably less confidence in our understanding of what has driven decreasing cloud amount and how accurate our trend estimates might be.
- Thickening aerosol haze can make it difficult for observers to see all clouds present, especially optically thin clouds such as cirrus (Warren et al. 2007, below), and could result in an artificial or exaggerated decreasing cloud amount trend.

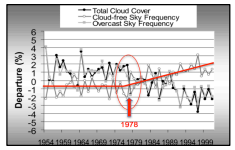


Decreasing ci trend over China, while not unique, could relate to visibility.

Can the increase in tropospheric haze and the attendant decrease in visibility (Kaiser and Qian, 2002) affect human observers' ability to detect various types of clouds and estimate the portion of the sky they cover?



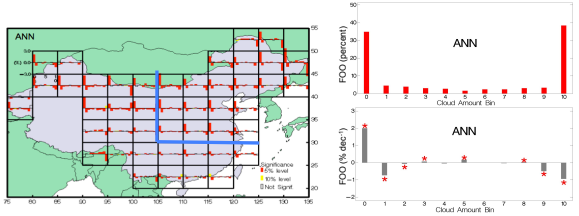
Trends in annual mean frequency of clear sky (FCLR: <10%). From Qian et al. (2006).



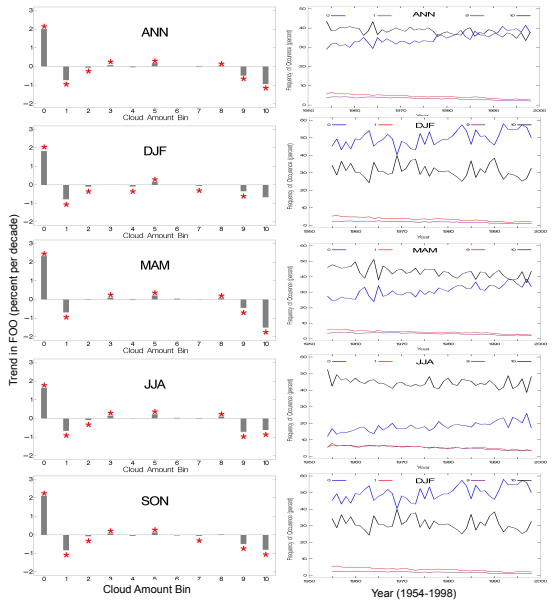
Trends in FCLR, FOVC (>90%), and total cloud amount. From Qian et al. (2006).

Above findings lent further support to the conclusion that cloud amount has indeed been decreasing over China. However, the data were *daily* means, not 6-hourly observations.

Latest work uses 6-h data and examines all 11 cloud amount classes, from 0 (0%) to 10 (100%), and all intermediate 10% classes (1-9). "FOO" is used for "frequency of occurrence."



Above: (Left) 5x5° grid box trends in annual mean FOO (% dec^{-1}) for cloud amount classes 0 to 10, 1954-1998 (red bars signif at 95% level). Blue line sets off NE China. (Right) NE China annual mean FOO (%) and corresponding trends in FOO (% dec^{-1}) for cloud amount classes (★ signif at 95% level). ***Note increasing trends in '0' but decreasing tends in '1'.***



Above: (Left) China trends in annual mean FOO (% dec^{-1}) for cloud amount classes (★ signif at 95% level). (Right) Time series of FOO for cloud amount classes 0 (blue), 1 (red) , 9, and 10. ***Note increasing trends in '0' but decreasing tends in '1'.***

	DJF				MAM				JJA				SON				ANN			
Hr/FOO Bin	0	1	9	10	0	1	9	10	0	1	9	10	0	1	9	10	0	1	9	10
02	2.19	-0.70	-0.28	-0.56	2.96	-0.85	-0.37	-1.28	2.44	-1.23	-0.62	-0.06	2.54	-0.85	-0.40	-0.37	2.55	-0.90	-0.41	-0.68
08	1.23	-0.79	-.037	-0.54	2.05	-0.61	-0.43	-1.58	1.42	-0.67	-0.59	-0.50	1.78	-0.75	-0.51	-0.63	1.64	-0.70	-0.48	-0.88
14	1.64	-0.73	-0.42	-0.92	1.04	-0.39	-0.35	-1.69	0.85	-0.22	-0.62	-1.10	1.55	-0.70	-0.53	-0.91	1.30	-0.58	-0.48	-1.20
20	2.27	-0.84	-0.29	-0.61	3.25	-0.95	-0.64	-1.88	1.83	-0.58	-1.00	-0.76	2.57	-1.00	-0.49	-0.76	2.52	-0.84	-0.61	-1.00
All Hours	1.83	-0.77	-0.34	-0.66	2.32	-0.69	-0.45	-1.58	1.63	-0.66	-0.71	-0.61	2.10	-0.83	-0.48	-0.80	2.00	-0.73	-0.49	-0.94

Table shows trends in FOO for cloud amount classes 0, 1, 2, 9, and 10 by season, averaged over all observing hours and for each observing time (02,08,14,20h Beijing Time). All shaded trends are significant; darker shading denotes time of day in each season when the '0' and '1' FOO disparity is greatest. Yellow shading indicates that daytime observations (1400h) show the smallest disparity.

Conclusions:

- Previously reported decreasing trends in cloud amount over China may be overdone because of clear sky being reported when skies are not completely clear.
- Clear-sky increases generally accompanied by decreases in scattered cloud amount (i.e., "1"), mainly, but not exclusively, in the east where aerosol haze is thickest. *Why?*

Working Hypotheses:

- May be driven by observers not being able to detect optically thin clouds (*ci*; or even some mid-level cloud types, e.g., *As*) as easily through increased aerosol haze.
- Possible changes in observing practices around the late 1970s that researchers are not aware of. (More inquiry needs to take place.)
- Highly unlikely that there is a physical basis for more clear-sky days but fewer '1' days.
- Several modeling studies (e.g., Menon et al. 2002) point to more likely *increases* in cloud amount over China in the last decades of the 20th century.

Future Work:

- Use 3-hourly ISCCP data (1984 onward) to independently examine FOO of cloud amount classes.
- Examine trends in use of present wx codes that relate to visibility (e.g, haze, mist).
- Talk w/China colleagues re: possible changes in observing practice.

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