Observations of Relative Humidity Effects on Aerosol Light Scattering in the Yangtze River Delta of China

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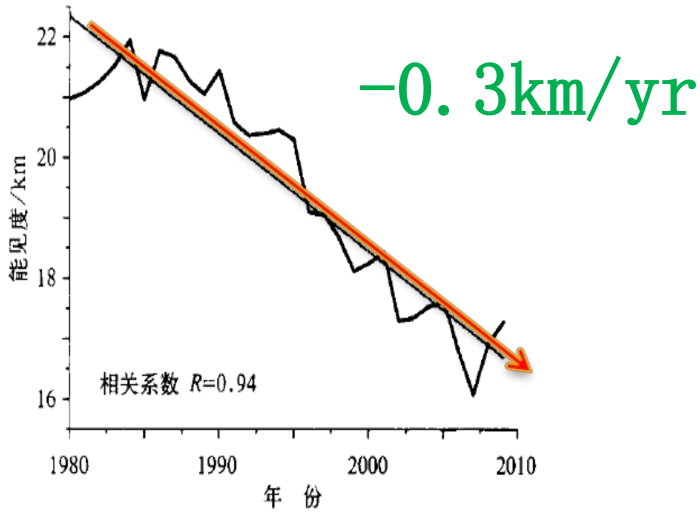
Questions

1. **What are the hygroscopic enhancement factors for scattering properties "f(RH)" in Yangtze River Delta?**
2. **Which chemical species are the main factors that determine f(RH)?**
3. **What is the influence of f(RH) on aerosol direct radiative forcing?**

Visibility

Haze-fog



The visibility decrease of the Yangtze River Delta during 1980-2009.
-0.3±0.013km/yr
(Zhang et al., 2012)

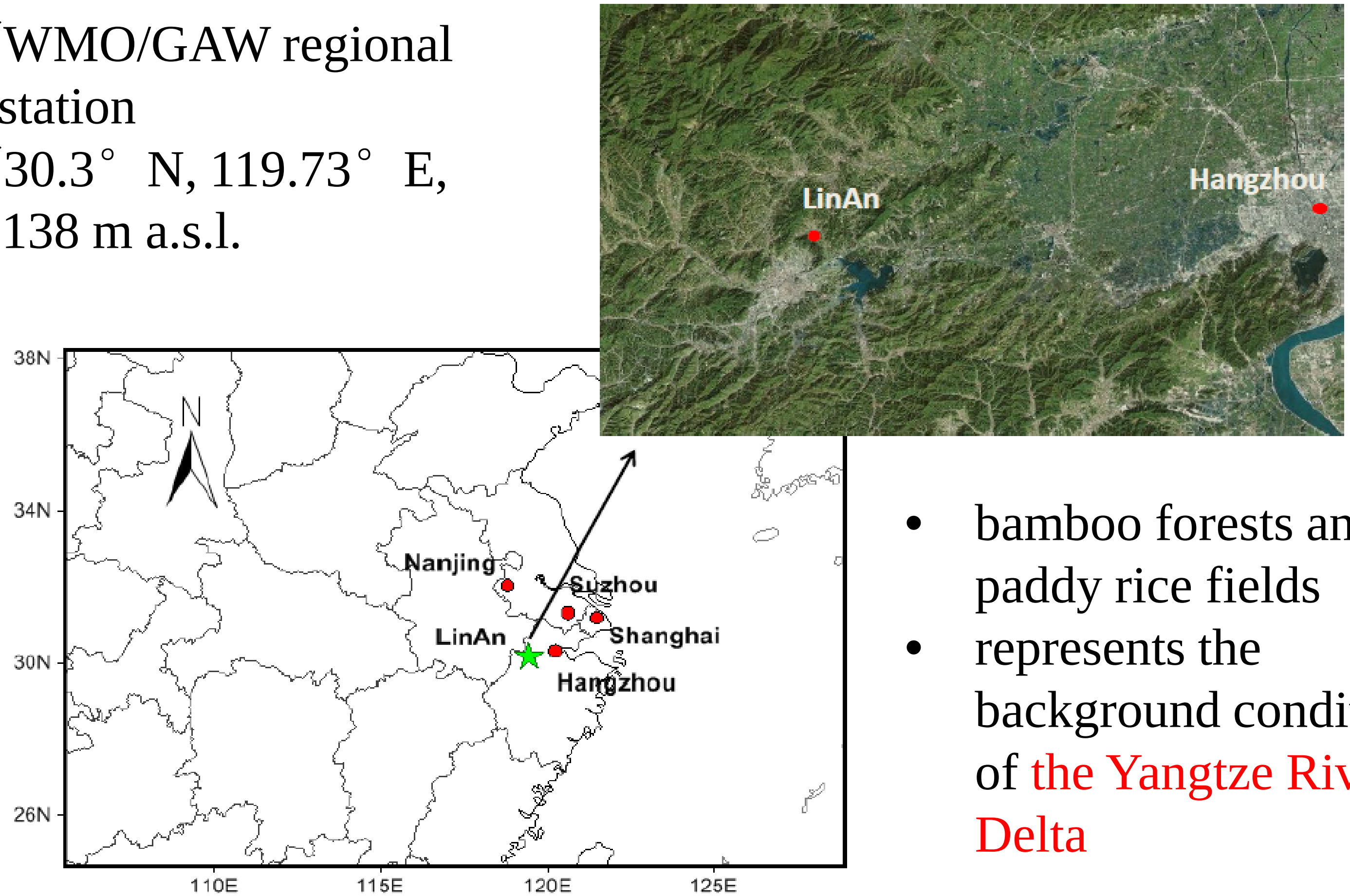
Yangtze River Delta:

Economy
Population
Vehicles
Emissions of NO_x, SO_2, VOC…

LinAn Regional Atmosphere background station

✓WMO/GAW regional station

✓30.3° N, 119.73° E, 138 m a.s.l.



- bamboo forests and paddy rice fields
- represents the background conditions of the Yangtze River Delta

Sulfate Nitrate Ammonium

Chloride Organics

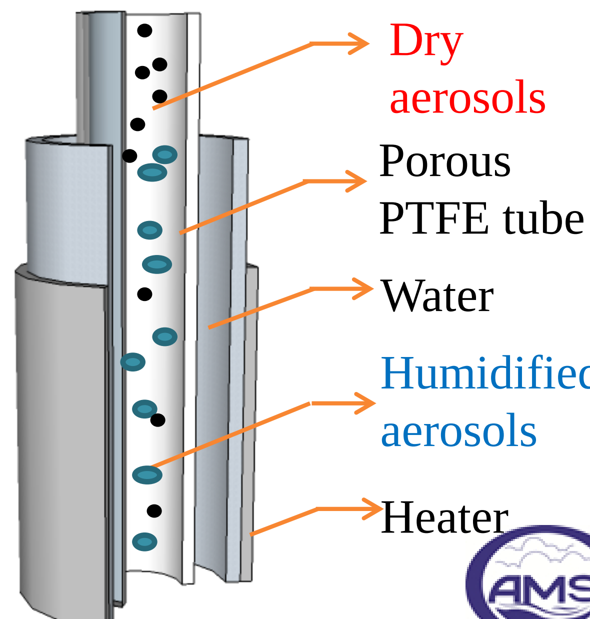
(D<1μm)

Q-AMS

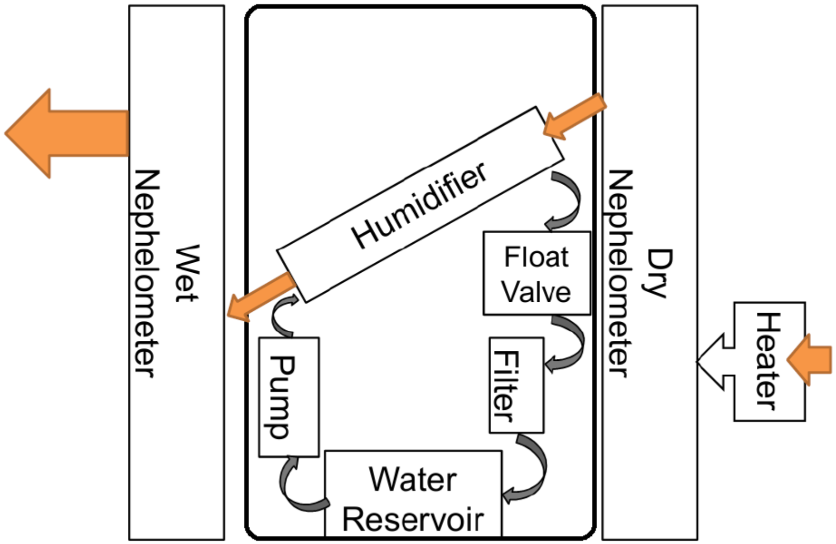
PM_{10} → Dryer → Splitter → Size distribution

Splitter → Q-AMS

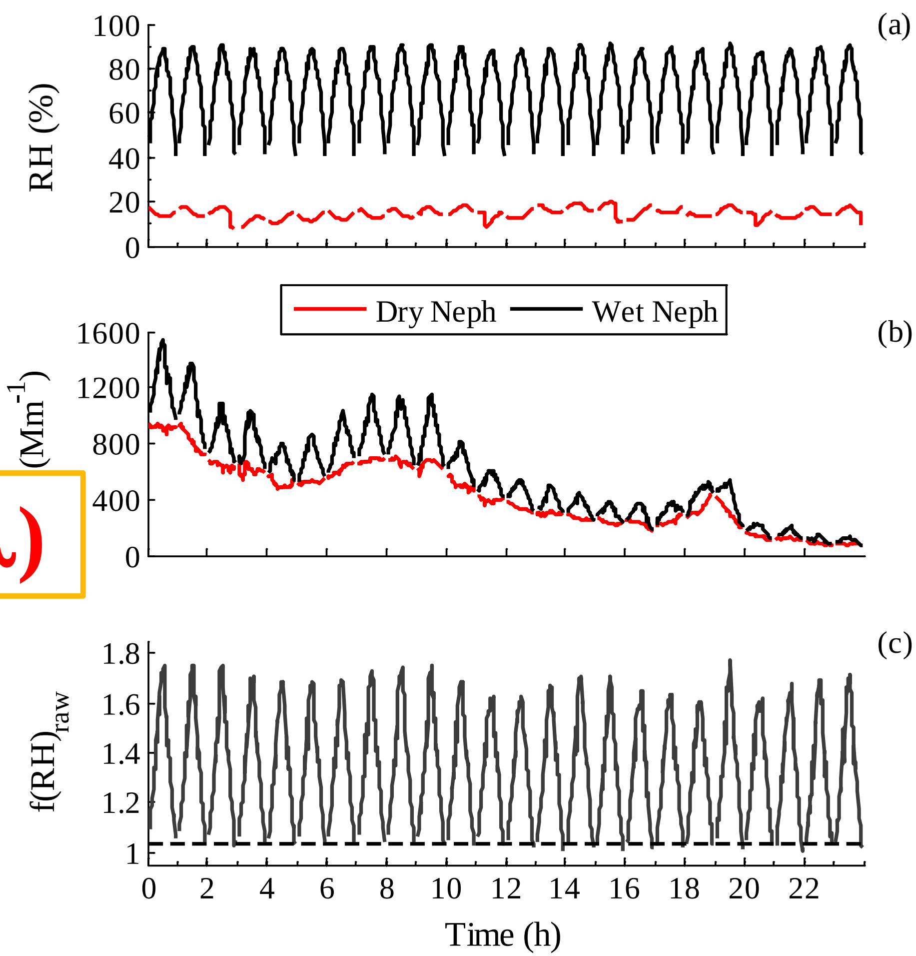
Splitter → Humidification system → Light scattering as f(RH)



The humidification system

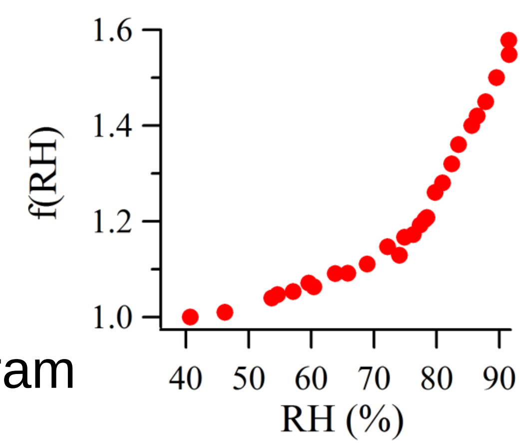


Example of recorded data on 17 March 2013

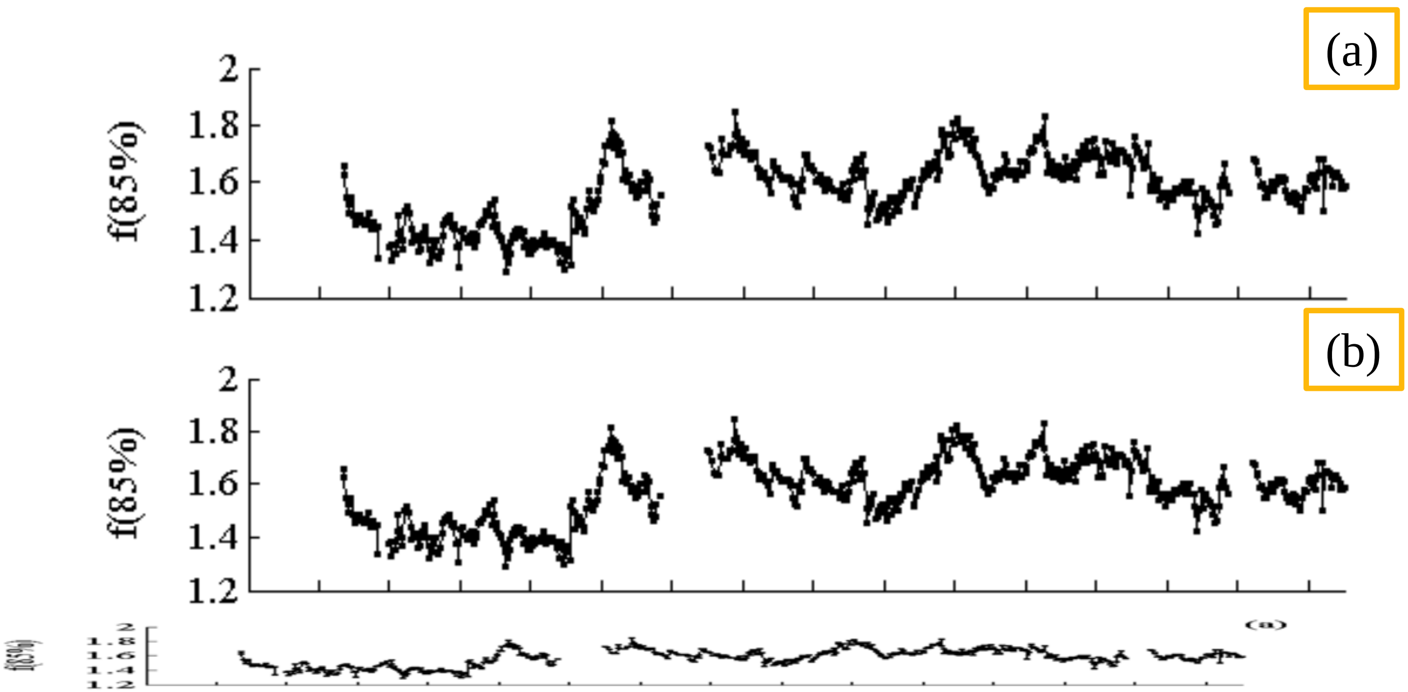


$$f(RH)=\sigma_{sp}(RH, \lambda)/\sigma(dry, \lambda)$$

Sample humidogram

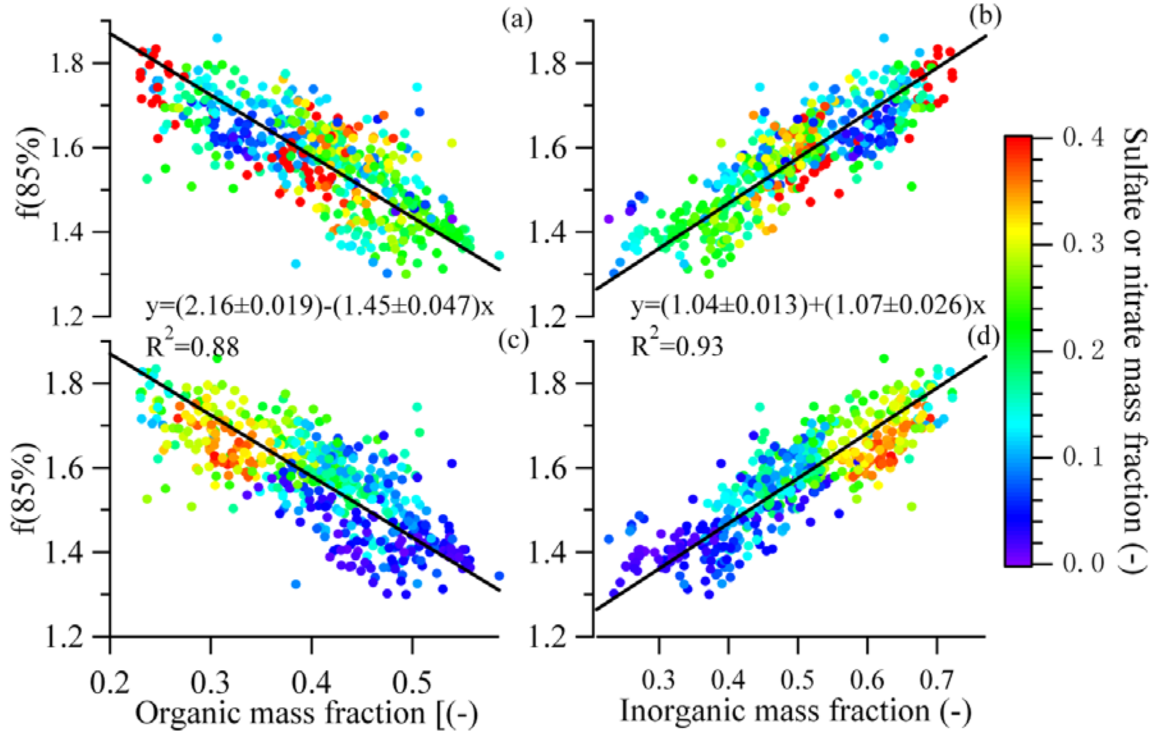


Time series and average hygroscopic enhancement factor



RH(%)	50	60	70	80	85
f(RH)	1.07	1.14	1.24	1.43	1.58

The Relationship of f(RH) and Chemical Composition



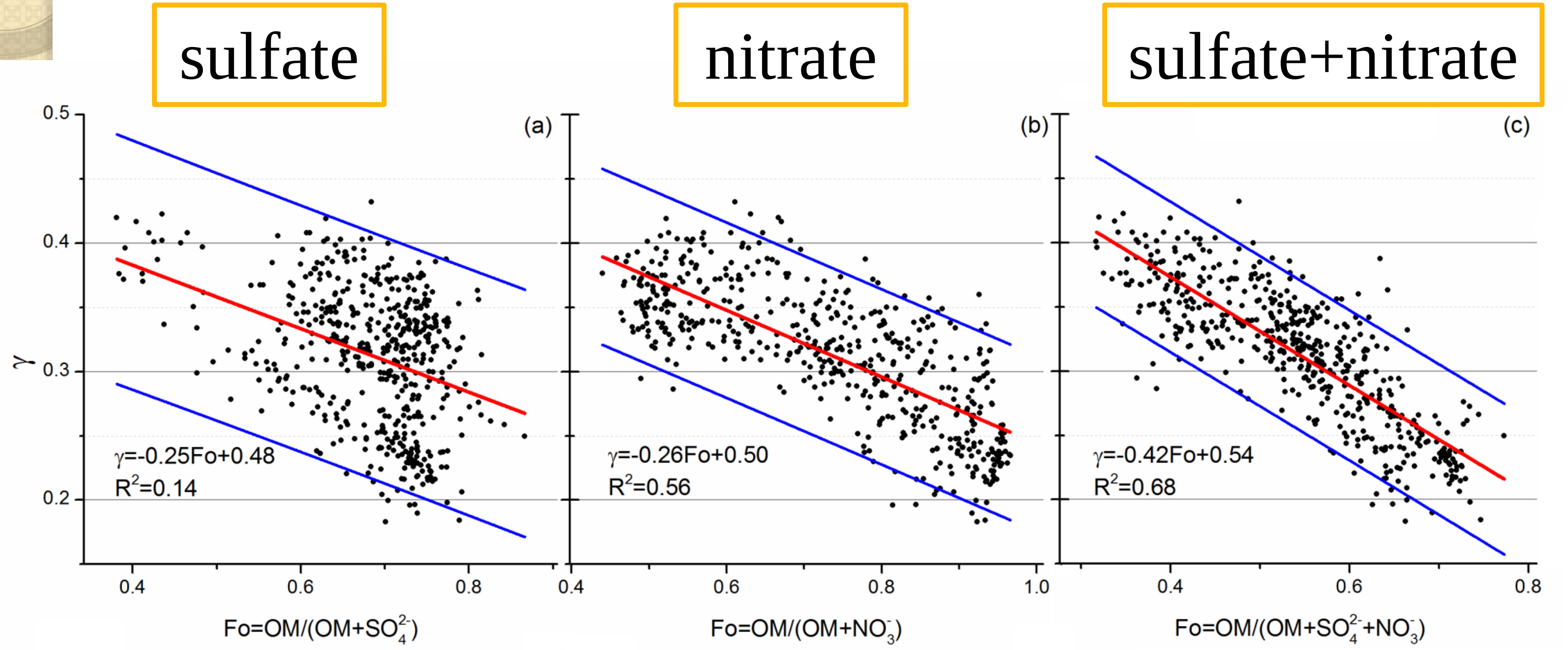
(a) and (b) colored by sulfate

(c) and (d) colored by nitrate

- ✓ **f(RH) increases with inorganic mass fraction, but decreases with organic mass fraction**
- ✓ **f(RH) shows clearer relation with Nitrate fraction than sulfate fraction**

Importance of Nitrate

$\gamma = \ln f(85\%)/\ln((100-40)/(100-85))$

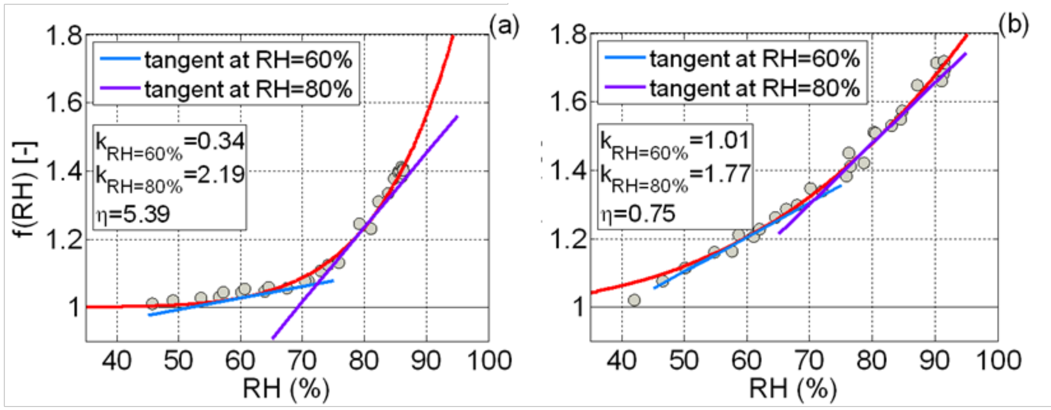


Nitrate plays a more important role than sulfate in the determination of the magnitude of f(85%) at LinAn.

Compared with Quinn et al. (2005)

Steepness index η

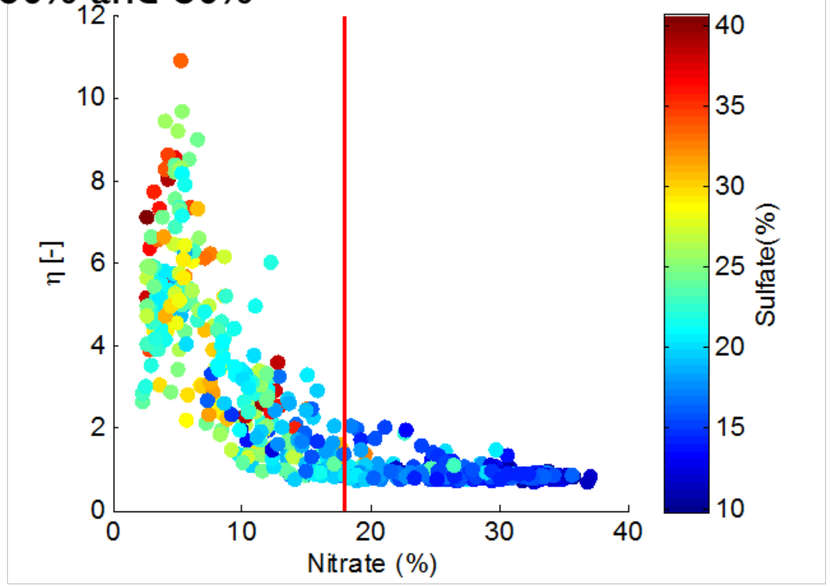
$$\eta = \frac{f'(80\%)}{f'(60\%)} - 1$$



The Red lines represent the regression line, the fitting equation was **$f(RH)=1+a\cdot RH^b$**
The Blue lines represent the tangent line at RH 60% and 80%

- ✓ $\eta = (4/3)^{b-1} - 1$
- ✓ η only matters with b, **$f(RH)=1+a\cdot RH^b$**
- ✓ An indicator of the steepness of humidograms
- ✓ η decreases with the increase of NO_3^-;

Nitrate also plays an important role in the steepness of humidograms in our study at LinAn.



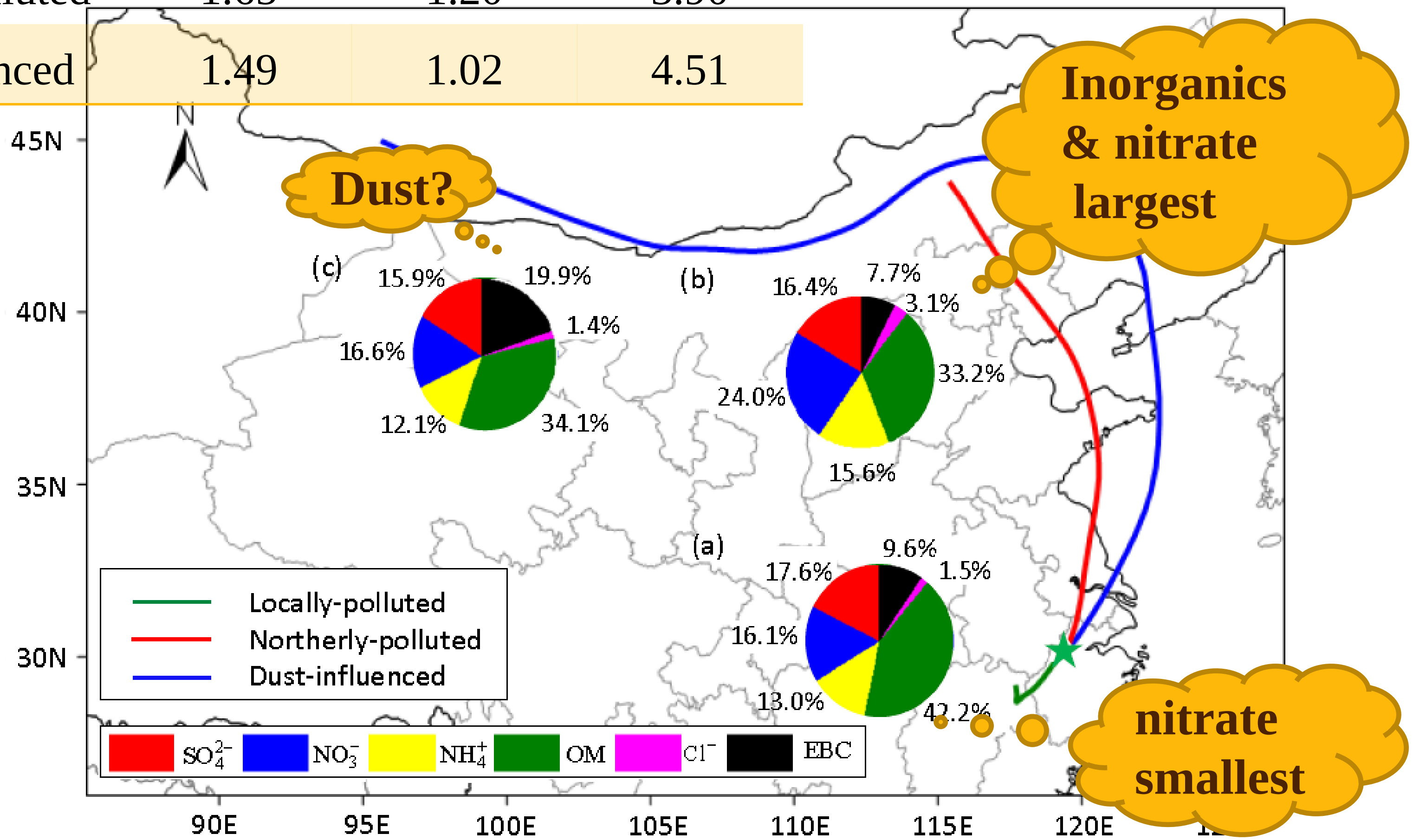
The scattering plot of the mass fraction of NO_3^- and η

Classified by trajectory

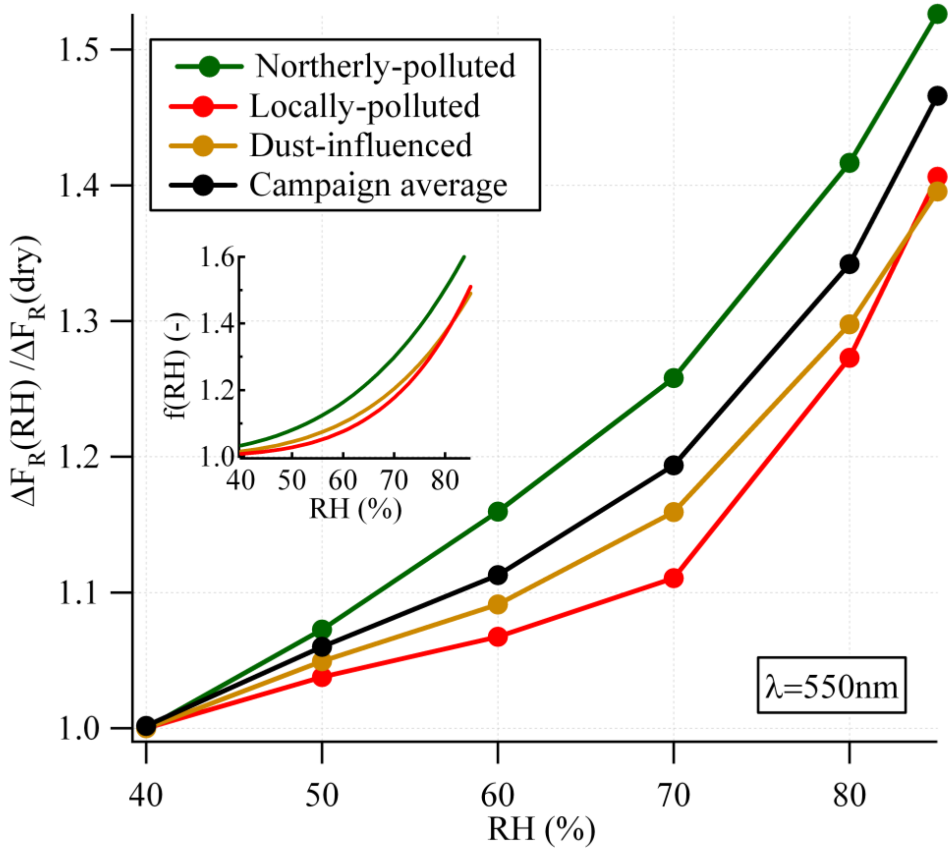
	f(85%)	a	b
Locally-polluted[a]	1.53	1.24	5.46
Northerly-polluted[b]	1.65	1.20	3.90
Dust-influenced	1.49	1.02	4.51

Fitting equation:

$$f(RH)=1+a\cdot RH^{b}$$



Sensitivity of the direct radiative forcing of different aerosols to f(RH)



The dependence of TOA radiative forcing on relative humidity for various periods.

- ✓ The increasing pattern of the dependence of TOA radiative forcing on relative humidity basically follow the increase of f(RH)
- ✓ At 85% RH, the TOA radiative forcing increased by 47% compared to that at dry conditions；

Summary

1. On average, aerosol light scattering in March in LinAn was 58% higher at 85% RH.
2. Aerosol uptake of water decreased with increasing organic mass fraction.
3. Nitrate played an important part in both the magnitude and shape of f(RH) during our study.
4. At 85% RH, the direct radiative forcing increased by as much as 47% due to the aerosol hygroscopicity.

Acknowledgments

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In order to estimate the sensitivity of the forcing to different RHs for various aerosol types (locally-polluted, northerly-polluted and dust-influenced aerosols), the ratio of direct aerosol radiative forcing ΔF_R at a defined RH to that at dry condition was calculated:

$$\frac{\Delta F_R(RH)}{\Delta F_R(dry)} = \frac{(1-R_s)^2\bar{\beta}(RH)\alpha_s f(RH) - 2R_s\alpha_\alpha}{(1-R_s)^2\bar{\beta}(dry)\alpha_s f(dry) - 2R_s\alpha_\alpha} \quad (8)$$

Parameters used in Eq. (8) were R_s=0.15, and α_a=0.3 $m^2 \cdot g^{-1}$ (Wang et al., 2012;Hand and Malm, 2007). The mass scattering efficiency α_s is 2.76 $m^2 \cdot g^{-1}$, which is derived from the slope of a linear regression of the measured scattering coefficients and the calculated PM_{10} mass concentrations based on TDMPS and APS measurement (see Fig. 13); the high mass scattering efficiency is explained by the high ratio of PM_1 to PM_{10} mass at this site (average 0.81). The average upscatter fraction $\bar{\beta}$ was calculated as $\bar{\beta}$=0.0817+1.8495b-2.9682b^2 (Delene and Ogren, 2002). The sensitivity of direct radiative forcing to RH for various aerosol types were shown in Fig. 14. As is shown in the figure, the variation of $\Delta F_R(RH)/\Delta F_R(dry)$ with RH was in accordance with the variation of humidograms. The f(RH) was the largest during the northerly-polluted period, correspondingly, the effects of RH on aerosol radiative forcing during this period was the largest. The same was true for the locally-polluted period and the dust-influenced period. Since b decreases with increasing RH, this correspondence also demonstrated the vital role f(RH) played in direct forcing enhancement. At 85% RH, the average ratio was 1.47, i.e. the direct radiative forcing