Megacities in China and their air quality conditions and trends: Air quality forecasting challenges for dynamic management in city

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Outline

- Air quality in China is worse than most places of the rest of the world, peaked in 2013 but improved since then due to controls and economic slow-down
  - –New air quality standards
  - –Action plan on Prevention and Control of Air Pollution
  - –National air quality **monitoring network** – trends recorded
  - –APEC blue
- Prediction using state-of-the-art models captures spatial patterns of air pollution and general trend
  - –Underestimates concentration levels to an extent that often misses observed AQI grades
  - –More accurate forecasting needed for dynamic management
- Team forecast – ensemble based human forecasting practice for dynamic management in city of Chengdu
  - –Operational 24-48hr forecast are required at provincial capital cities
  - –Human forecasting aided by model forecasts
  - –Team forecast outperforms the model forecast

$PM_{2.5}$ Pollution "Observed" Before New National Ambient Air Quality Standards Released in 2012

Beijing

Shanghai

Hong Kong

Guangzhou

China's New Ambient Air Quality Standards

(Published February 29, 2012, Effective January 1, 2016)

Primary standards

Pollutant	Averaging time	Limit		Unit
		Class 1	*Class 2*	
SO_2	annual	20	60	$\mu g/m^3$
	24 hours	50	150	
	hourly	150	500	
NO_2	annual	40	40	
	24 hours	80	80	
	hourly	200	200	
CO	24 hours	4	4	mg/m^3
	hourly	10	10	
O_3	daily, 8-hour maximum	100	160	$\mu g/m^3$
	hourly	160	200	
PM10	annual	40	70	
	24 hours	50	150	
PM2.5	annual	15	35	
	24 hours	35	75	

Additional standards

Pollutant	Averaging time	Limit		Unit
		Class 1	*Class 2*	
Total Suspended Particles (TSP)	annual	80	200	$\mu g/m^3$
	24 hours	120	300	
NO_x	annual	50	50	
	24 hours	100	100	
	hourly	250	250	
Lead (Pb)	annual	0.5	0.5	
	seasonal	1	1	
Benzopyrene (BaP)	annual	0.001	0.001	
	24 hours	0.0025	0.0025	

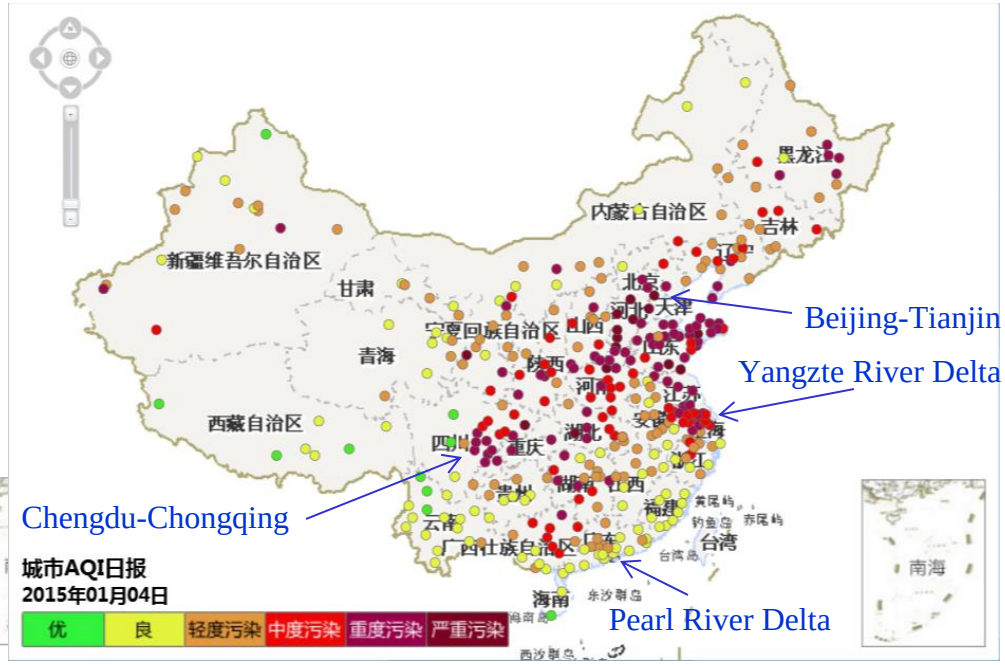
- $PM_{2.5}$ and O_3 were recently added as criteria pollutants
  - –Started pilot **monitoring networks for all six pollutants** since 2012 in key cities
  - –Daily $PM_{2.5}$ concentration of over 700ug/m3 was measured in January, 2013 in Beijing
- Nationwide monitoring network reports real-time readings to the public online
  - –Stage I with 74 key cities since January 2013
  - –Stage II with 169 cities since January 2014
  - –Stage III with 338 cities since January 2015 (fully established to cover all urban areas)

National Air Quality Monitoring Network: Public Release of Real-time Measurements

(http://113.108.142.147:20035/emcpublish/)

City Average Daily AQI
Feb.23, 2014, 169 Cities

City Average Daily AQI
Jan.04, 2015, 338 Cities



Beijing-Tianjin, Yangzte River Delta, Pearl River Delta and Chengdu-Chongqing are the four largest city clusters (Megacities) in China

Compare the PM standards between China and US

AQI Score	Description	PM10 (US) µg/m3 24 hr	PM10 (CHINA) µg/m3 24 hr	PM2.5 (US) µg/m3 24 hr	PM2.5 (CHINA) µg/m3 24 hr
0-50	Excellent	0	0	0	0
51-100	Good	50	50	15	35
101-150	Slightly Polluted	150	150	40	75
151-200	Lightly Polluted	250	250	65	115
201-300	Moderately Polluted	350	350	150	150
>300	Heavily Polluted	420	420	250	250

AQI Range	EPA Color Scale	EPA Descriptor
0 to 50	Green	Good
51 to 100	Yellow	Moderate
101 to 150	Orange	Unhealthy for Sensitive Groups
151 to 200	Red	Unhealthy
201 to 300	Purple	Very Unhealthy
Over 300	Black	Hazardous

Note the Chinese standards relaxed the ranges at the lower grades

The State Council Issued Action Plan on Prevention and Control of Air Pollution Introducing Ten Measures to Improve Air Quality (September 12, 2013 – 5 year Objective)

- Rectify small coal-firing boilers, accelerate desulphurization, denitration and dust removal. Enforce vehicle emissions inspection, promote public transport, electric vehicles and high quality of gasoline.
- Adjust industrial structure, limit the growth of high energy consumption and high emission industries.
- Develop circular economy, foster environmental industry.
- Adjust energy structure, promote clean energy. Cut coal consumption to below 65% of total energy use and boost the non-fossil fuel energy share to 13%.
- Improve policies on pricing and taxation and encourage private funds to participate in air pollution control.
- Strengthen environmental requirements to investment projects, raise the threshold, optimize industrial pattern in ecological fragile areas or sensitive areas.
- Improve environmental supervision capability and enhance environmental law enforcement.
- Establish regional coordination mechanism for air pollution controls. Set environmental responsibilities for provincial governments, conduct annual examination and strictly enforce accountability system.
- Establish monitoring, early warning and emergency response system, emergency response planning for heavy air pollution.
- Encourage public participation to improve air quality.

Monitored AQI trends in Chinese Cities: January 2014 to date

•Dominant pollutant (with the highest AQI among criteria pollutants): $PM_{2.5}$ in fall and winter, O_3 in late spring/summer/early fall, PM_{10}/NO_2 in Spring.

•There is a decreasing trend in $PM_{2.5}$ pollution from 2014 to 2015, but O_3 pollution becoming worse.

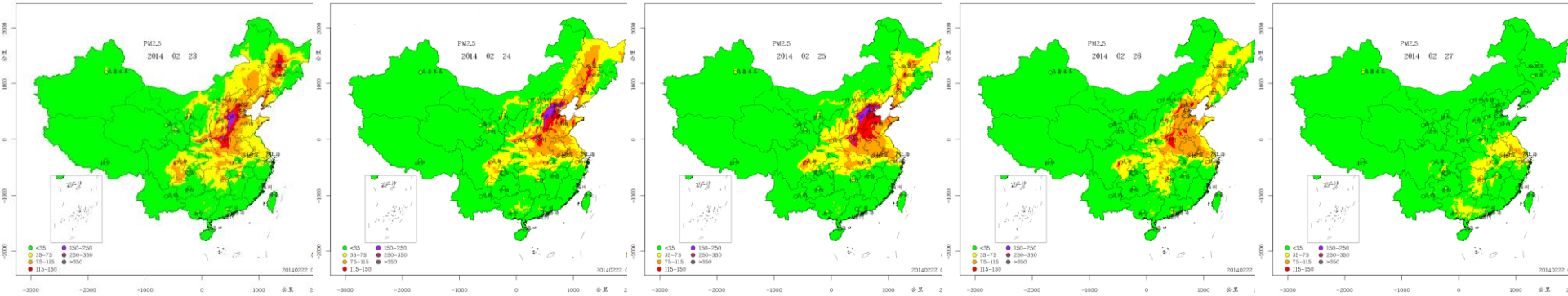
–More days of O_3 pollution , appears earlier in spring

–Both SO_2 and NO_2 see significant decreasing trends

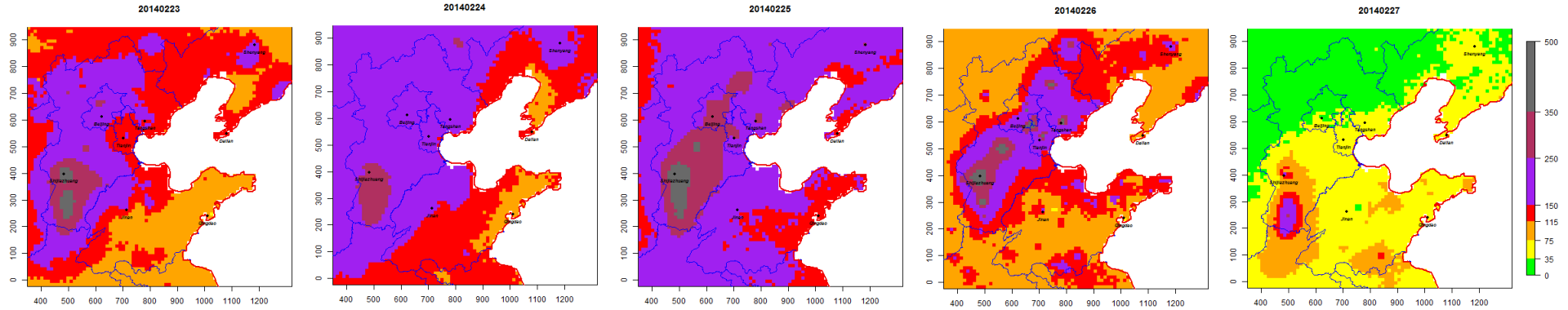
APEC Blue: A Demonstration of Temporary Air Quality Management Success

- During the Asia-Pacific Economic Cooperation China 2014, November 1-12, an emission reduction campaign was directed by the central government.
- Controls:
  - –10,000 factories suspended production
  - –Additional 39,000 ran on reduced schedules
  - –60,100 industrial plants and 123,000 other ventures including construction sites and petrol stations were closely inspected
  - –Around 11.7 million vehicles were kept off the roads
  - –6-days mandatory holidays were brought to state-owned enterprises, local government offices and educational institutions
- Results:
  - –The concentrations of $PM_{2.5}$, PM_{10}, SO_2 and NO_2 were 43, 62, 8 and 46 ug/m^3 respectively, decreasing by 55%, 44%, 57% and 31% from the same period last year
  - –This was the lowest level over the same period in the past 5 years
    - Favorable meteorological conditions might played a role
- APEC blue was achieved by ~30-50% emissions reduction in the region but with large economic costs.
- Air quality forecasting was carried out during the period.
- More sustainable approach desired: long-term determined air quality management along with short-term dynamic air quality management.

$PM_{2.5}$ Forecasting Effort for February 23-27, 2014: 120-hr forecast Using WRF-CMAQ (ug/m3)



Compare against MODIS AOD derived $PM_{2.5}$ maps for the Beijing-Tianjin city cluster area (*Lyu et al, 2015*)



The episodic regional pollution **trends are well captured but AQI grades are missed** at city level

Dynamic air quality management in city needs accurate air quality forecasting, especially accurate forecasting of AQI grades, which is challenging

- Local city governments are now required by the central government to alert the public for potential severe air pollution and to act correspondingly with **pre-planned** temporary emissions controls
- Recommended alerting grades:
  - –Class III Warning: Forecasted 200<AQI<300 for **3 days** in a row
  - –Class II Warning: Forecasted 300<AQI<500 for 3 days in a row
  - –Class I Warning: Forecasted AQI>500 (highest grade of warning)
- City level temporary management controls will be enforced according to the grade of the warning issued, e.g.:
  - –Different level of traffic controls
  - –Industry production reduction/shutdown
  - –Construction sites shutdown
  - –Schools shutdown
  - –Government shutdown (non-essential portion)

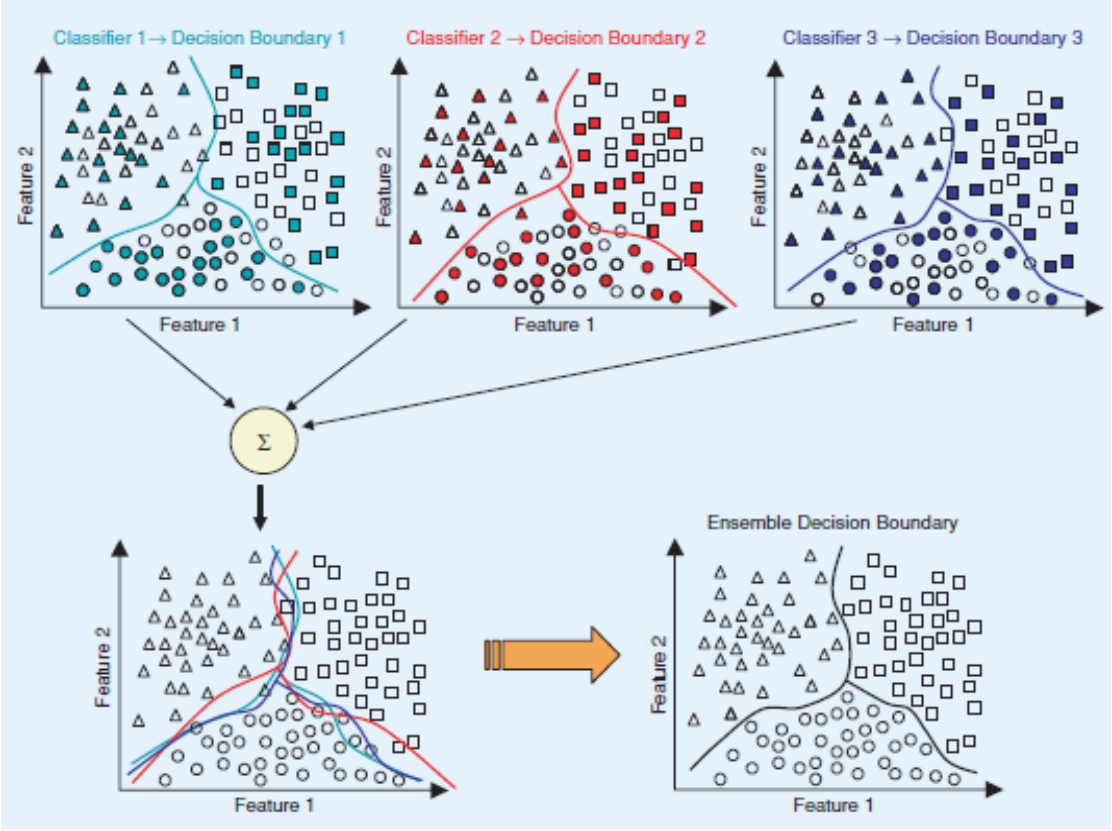
Air quality forecasting capabilities are being established in **province level and capital cities** for official forecasts starting October, 2015 required by the central government

Province/ Capitol	Forecast personnel	Tools
Beijing	14 (20)	Statistical model + CMAQ+CAMx+NAQPMS + statistical corrections
Shanghai	10	Numerical models (NAQPMS, WRF-CMAQ, WRF-Chem) + statistical corrections
Jiangsu	7 (45)	Numerical models (NAQPMS, CMAQ, CAMx, WRF-Chem) + statistical corrections
Zhejiang	5	Numerical models (MM5-CMAQ, MM5-CAMx, WRF-CMAQ, WRF-Chem) + statistical corrections
Guangdong	16	Numerical models (NASPMS) + Weather Forecast + + statistical corrections
Sichuan	8	WRF-CMAQ + statistical corrections + team forecast
Nanjing	3(5)	WRF-Chem + WRF-CMAQ + + statistical corrections
Hangzhou	5	WRF-Chem + statistical corrections
Guangzhou	5	Numerical models (NAQPMS, CMAQ, CAMx) + Statistical model + statistical corrections
……	…	……

Source: China National Environmental Monitoring Center, March 2015

Ensemble Human Forecast – Team Forecast Practice in Sichuan Basin: Chengdu City as an example

Team forecast : an ensemble based decision making system, aided by various resources/tools plus model forecasts (with statistical corrections)

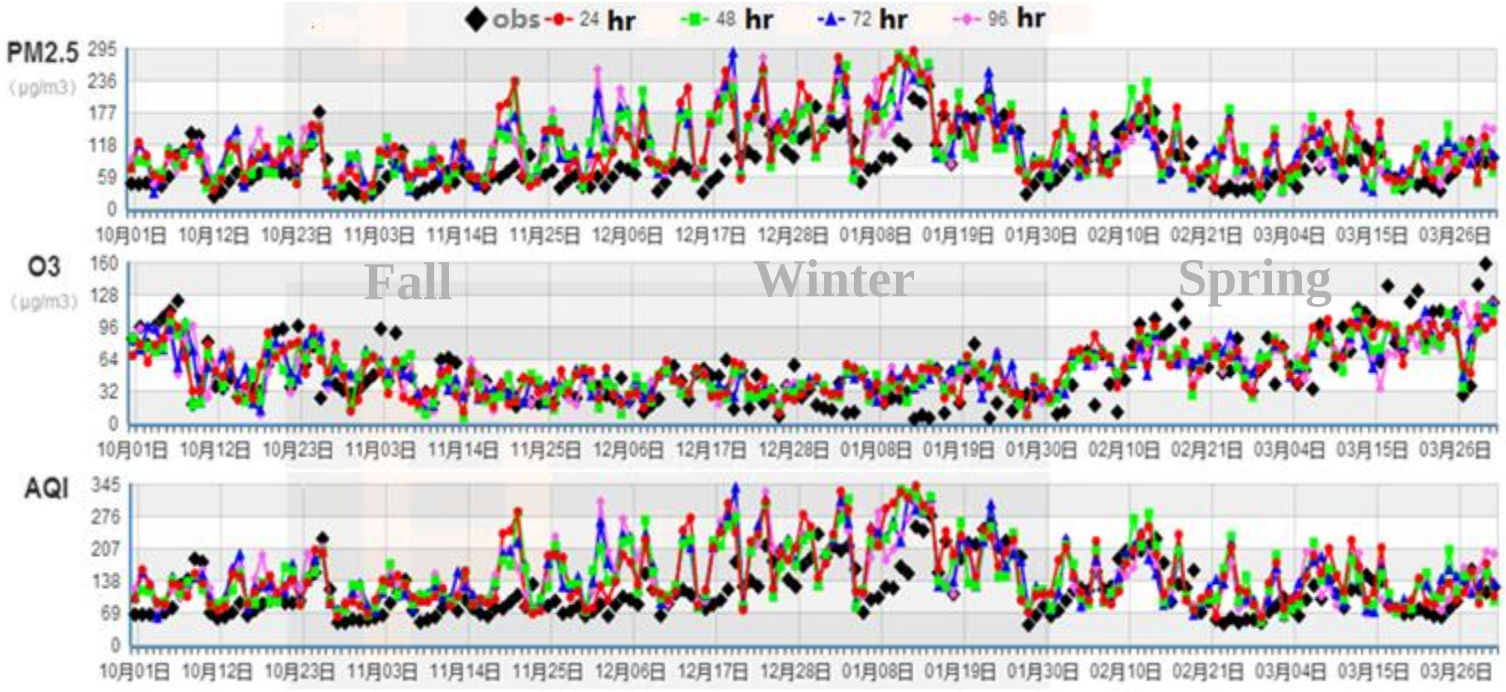


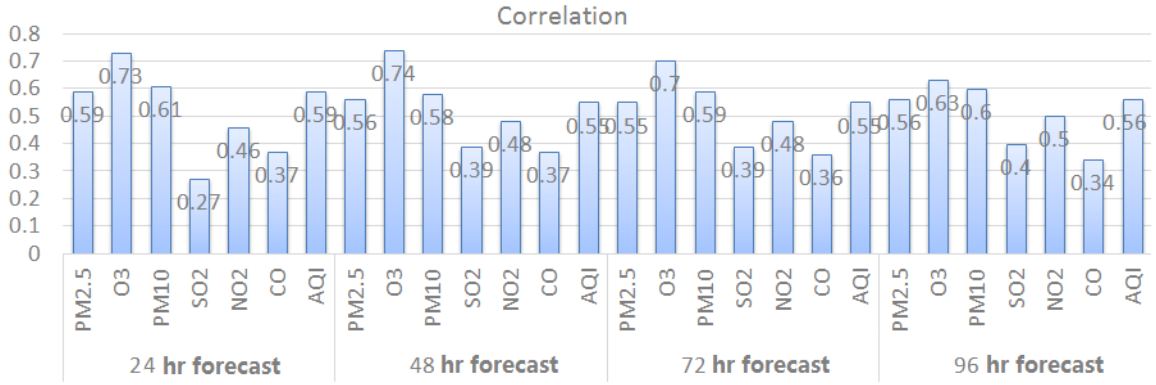
(Polikar 2006)

There are many ways to carry out team forecast. An easier way is to obtain ensemble forecast (F) through averaging individual forecaster's forecast (f) **weighted by his historical performance** (σ).

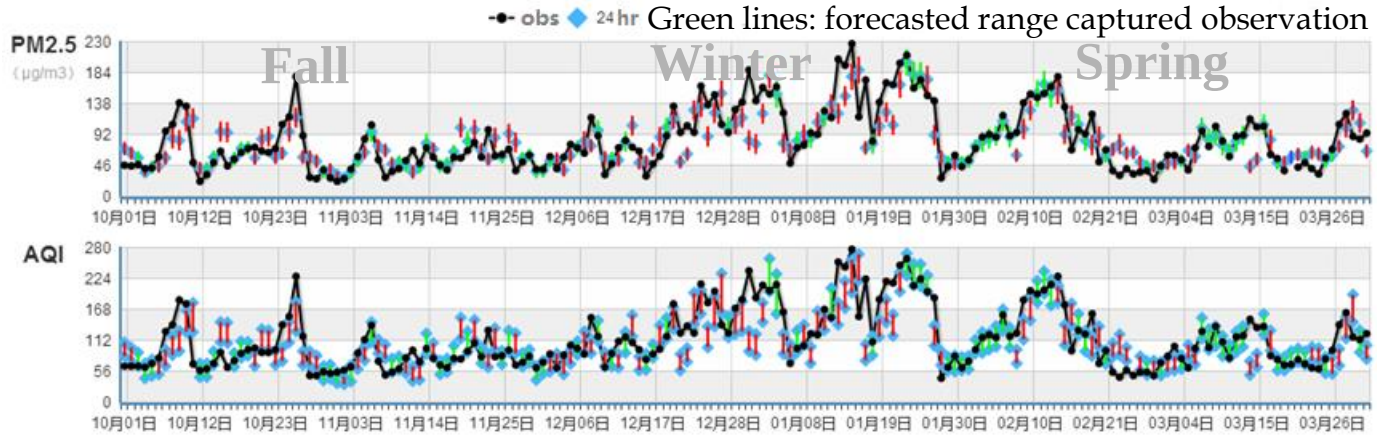
$$F = \sum_{i=1}^{N} \left[\frac{f_i}{N\sigma_i^{\,2} / \sum_{j=1}^{N} \sigma_j^{\,2}} \right]$$

Chengdu City Model Forecasts: October 1, 2014 -March 31, 2015

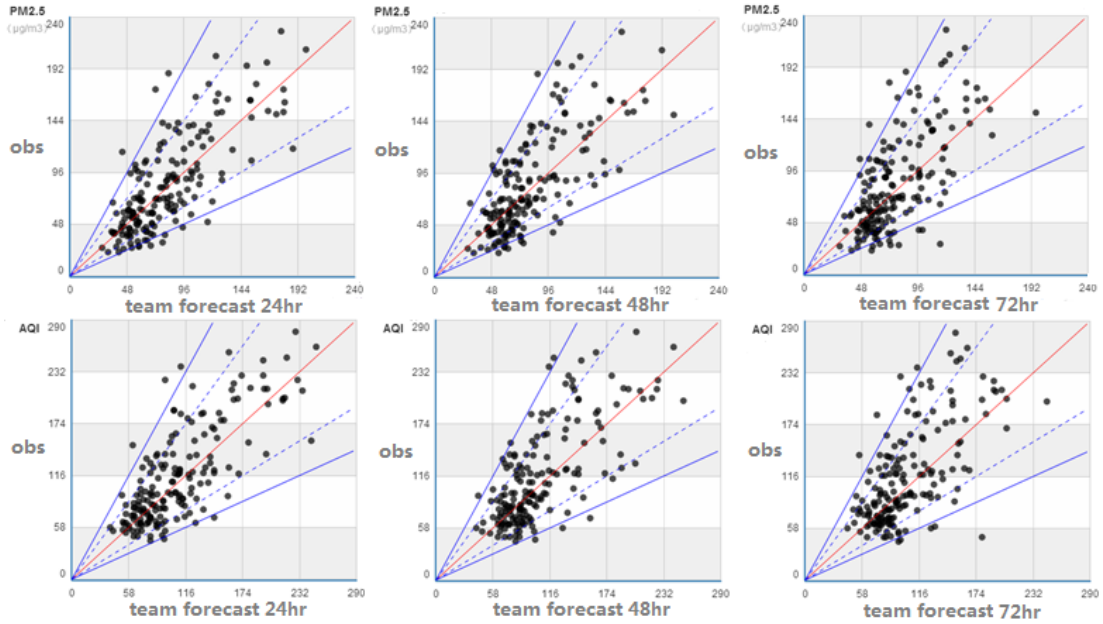




Chengdu City Human Forecasts : October 1, 2014 -March 31, 2015



Chengdu City Team Forecasts, October 1, 2014 -March 31, 2015



Forecasting accuracy (24-hr) for Dominant Pollutant and AQI grades: Model forecast (above) vs. Team forecast (below)

October 01, 2014

March 31, 2015

October 01, 2014

March 31, 2015

	Team Forecasts			Model Forecasts			
Accuracy	24-hr	48-hr	72-hr	24-hr	48-hr	72-hr	96-hr
Dominant Pollutant	71%	72%	65%	67%	64%	66%	67%
AQI grades	51%	48%	49%	35%	32%	33%	34%
Forecast Times	180	180	180	182	182	182	182

Concluding Remarks

- Air quality forecasting in China is challenging:
  - Model forecasts can **capture the air pollution trends well but usually underestimate the AQI grades** especially when $PM_{2.5}$ is the driving pollutant.
  - **Trans-province impacts** are significant and complex
  - Missing AQI grades will confound dynamic management enforcements
- Team forecasting is effective at the city level
  - Ensemble based decision making system aided by model forecasts
  - Better performance needs experienced forecasters
  - Post-correction on model forecasts can be very effective
  - Dynamic management at city cluster level – beyond city's capability– **needs regionally-coordinated efforts**