Model Types and Existing Modeling Systems for AQF

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Outline

- Introduction
- Types of CW-AQF Models
  - Model Types
  - Lagrangian vs. Eulerian Models
  - 3-D Models
  - Offline vs. Online-Coupled Air Quality Models
- Global and Regional CW-AQF Models
  - Global
  - Regional
- Demonstration Cases for CW-AQF Model
  - Global
  - Regional
- Summary

Sources: Zhang et al. (2012a, b), Zhang and Baklanov (2019), and Zhang (2008, 2020)

Spatial and Temporal Scales of Atmospheric Processes

(Seinfeld and Pandis, 2016)

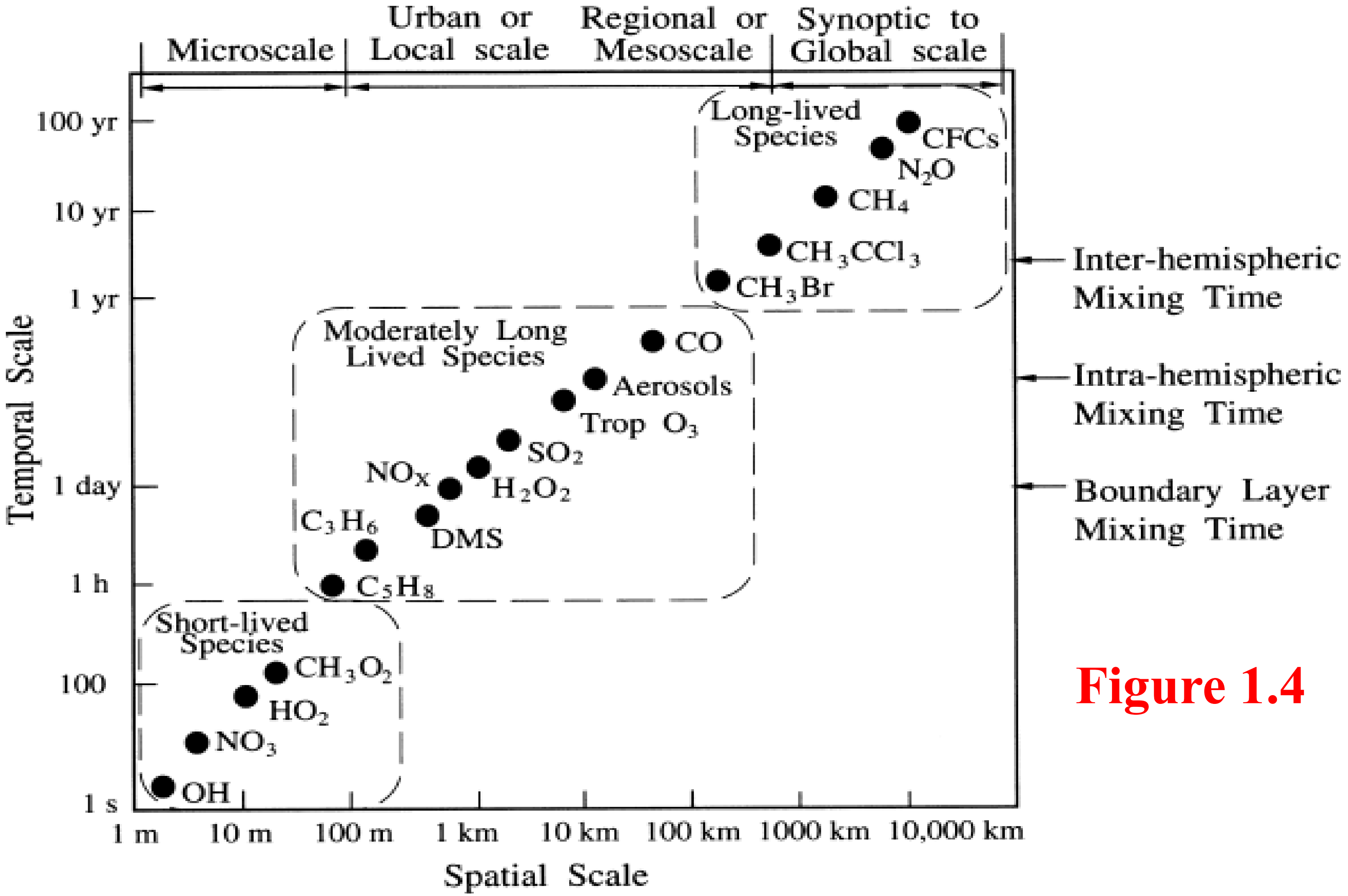

Figure 1.4

Lifetime: the average time that a molecule of a species resides in the atmosphere before removals

Spatial Scales of Atmospheric Processes

(Seinfeld and Pandis, 2016)

TABLE 1.1 Spatial Scales of Atmospheric Chemical Phenomena

Phenomenon	Length scale, km
Urban air pollution	1–100
Regional air pollution	10–1000
Acid rain/deposition	100–2000
Toxic air pollutants	0.1–100
Stratospheric ozone depletion	1000–40,000
Greenhouse gas increases	1000–40,000
Aerosol–climate interactions	100–40,000
Tropospheric transport and oxidation processes	1–40,000
Stratospheric–tropospheric exchange	0.1–100
Stratospheric transport and oxidation processes	1–40,000

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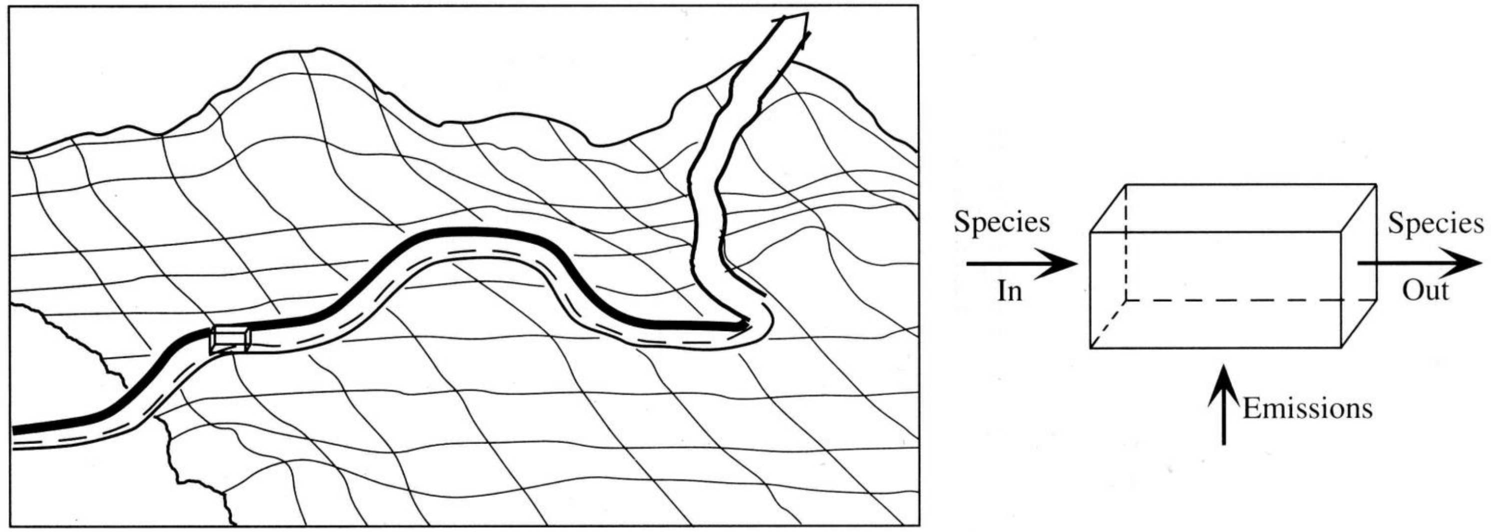
Types of Chemical Weather-Air Quality Forecasting Models

- **Framework**
  - » Source-based models
    - » Eulerian (e.g., the EPA Models-3/CMAQ)
    - » Lagrangian (e.g., NAME, DERMA)
    - » Hybrid Lagrangian/Eulerian (e.g., SILAM)
  - » Statistical (e.g., regression models, Bayesian models, data fashion, RSM)
- **Temporal Scale**
  - » Episodic (days to months, e.g., WRF/Chem-MADRID, CMAQ)
  - » Long-term/climatological (> 1 year, e.g., CMAQ, WRF/Chem (3 modes))

Lagrangian vs. Eulerian Models
(Seinfeld and Pandis, 2016)

Lagrangian **Eulerian**



(a) (b)

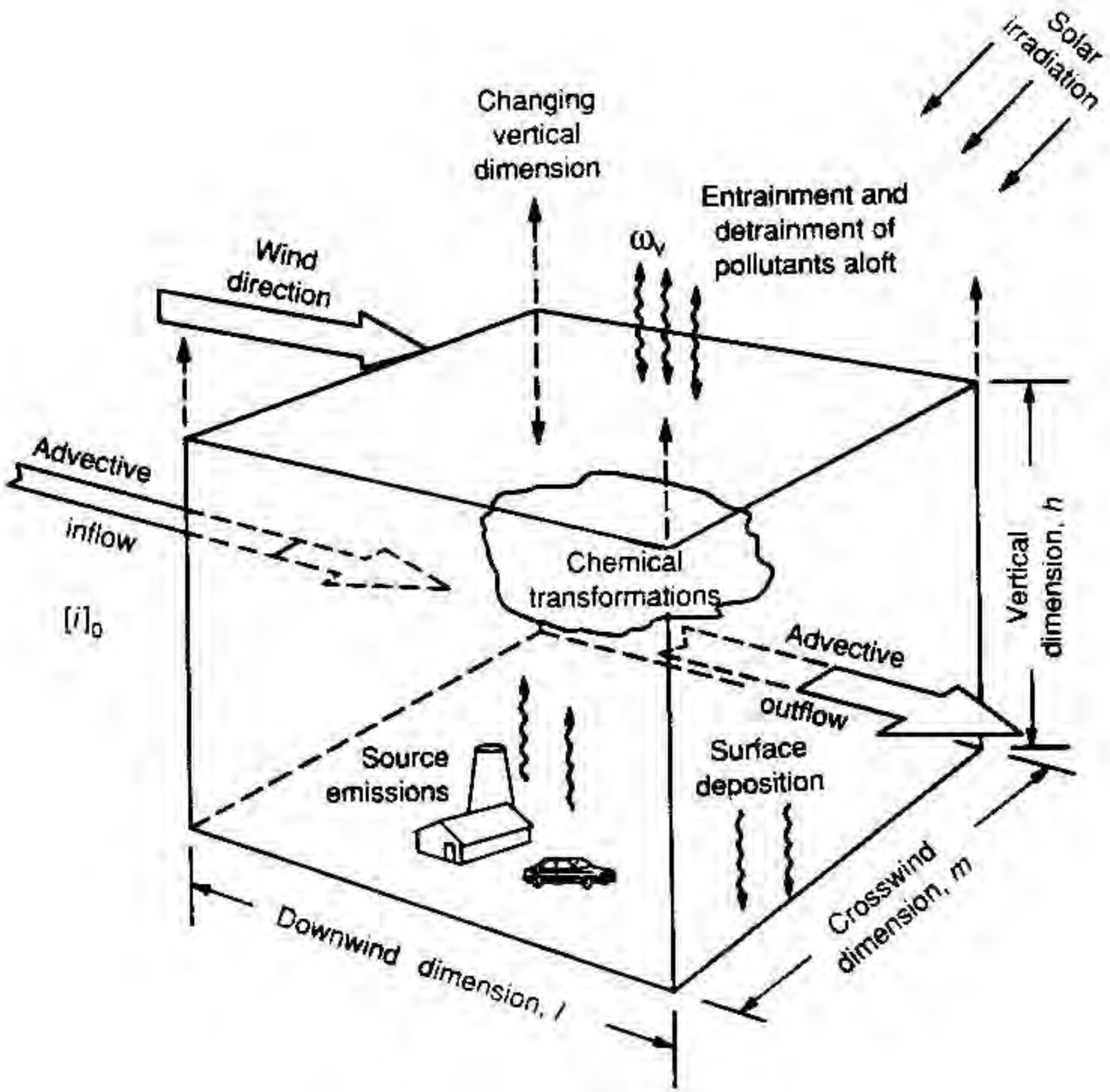
25.2

FIGURE ~~**23.2**~~ — Schematic depiction of (a) a Lagrangian model and (b) an Eulerian model.

Lagrangian model — a mathematical model that tracks the movement of a large number of pollution plume parcels as they move from their initial location by following pollution plume parcels as the parcels move in the atmosphere. A Lagrangian model uses a moving frame of reference as the parcels move from their initial location. An observer of a Lagrangian model follows along with the plume.

Eulerian model — Similar to a Lagrangian model but it uses a fixed 3-D Cartesian grid as a frame of reference rather than a moving frame of reference. An observer of an Eulerian model watches the plume go by.

3-D Models



$\partial c_i/\partial t$

$= u_j(\partial c_i/\partial j)+$ Advection

$+ \partial(K_j\, \partial Ci/\partial j)/\partial j+$ Turbulent transport

$+ Q_i\,(x, y, z, t)$ Source

$- S_i(x, y, z, t)$ Removal

$+ R_i\,(c_1, c_2, \ldots c_n)$ Reaction

Advantage: spatial distribution of concentrations; accurate representation of atmosphere

Disadvantages: numerical diffusion, computationally expensive (large memory requirement, data storage); complex model system, high level of skills

Types of Chemical Weather-Air Quality Forecasting Models

- Spatial Scale
  - Local (<1 km) (SinG, UAQIFS, OPANA)
  - Urban (1 km – 12 km) (WRF/Chem-Urban)
  - Regional/Continental (i.e., Mesoscale) (12 -1,000 km) (CMAQ, WRF/Chem)
  - Synoptic to Global (1,000-20,000 km) (e.g., CAMS/ECMWF)
  - Multiscale (e.g., SILAM)
- Generation of Meteorology
  - Online-coupled (e.g., WRF/Chem)
  - Offline-coupled (e.g., WRF-CMAQ)
- Community Involvement
  - community-based model (e.g., CMAQ, WRF/Chem, and Polyphemus)
  - non-community based model (e.g., GRAPES – CUACE)

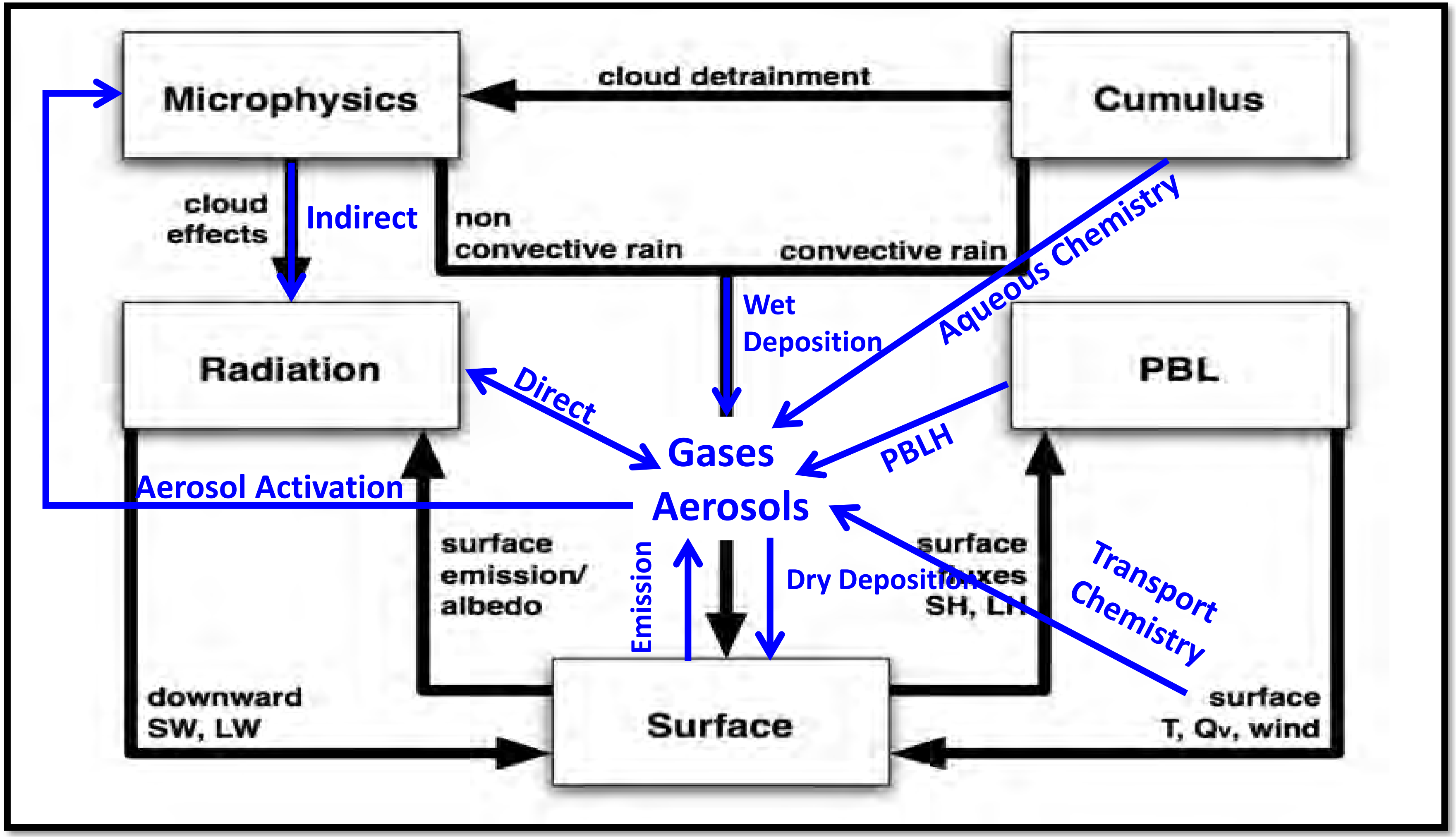
Definitions of Online-Coupled Models

(Zhang, 2008; Baklanov et al., 2014)

- **Offline-Coupled Models**
  - **The meteorological model is run before the CTM is run. Meteorological information is used to drive the CTM but no data exchange between the two models. There is no feedback from chemistry to meteorology.**
- **Online-Coupled Models**
  - **The CTM and meteorological models are run at the same time, and exchange information at every time step; they consider chemistry feedbacks to meteorology to various degrees**
  - **Types of Framework**
  - **Separate online coupling:** **couples a meteorology model with an air quality model in which the two systems operate separately but exchange information every time step through an interface (also referred to as online access models).**
  - **Unified online coupling:** **integrates an air quality model into a meteorology model as a unified model system in which meteorology and air quality variables are simulated together in one time step without an interface between the two models (also referred to as online integrated models or inline coupling).**

The Online-Coupled Weather Research and Forecasting Model with Chemistry (WRF/Chem)

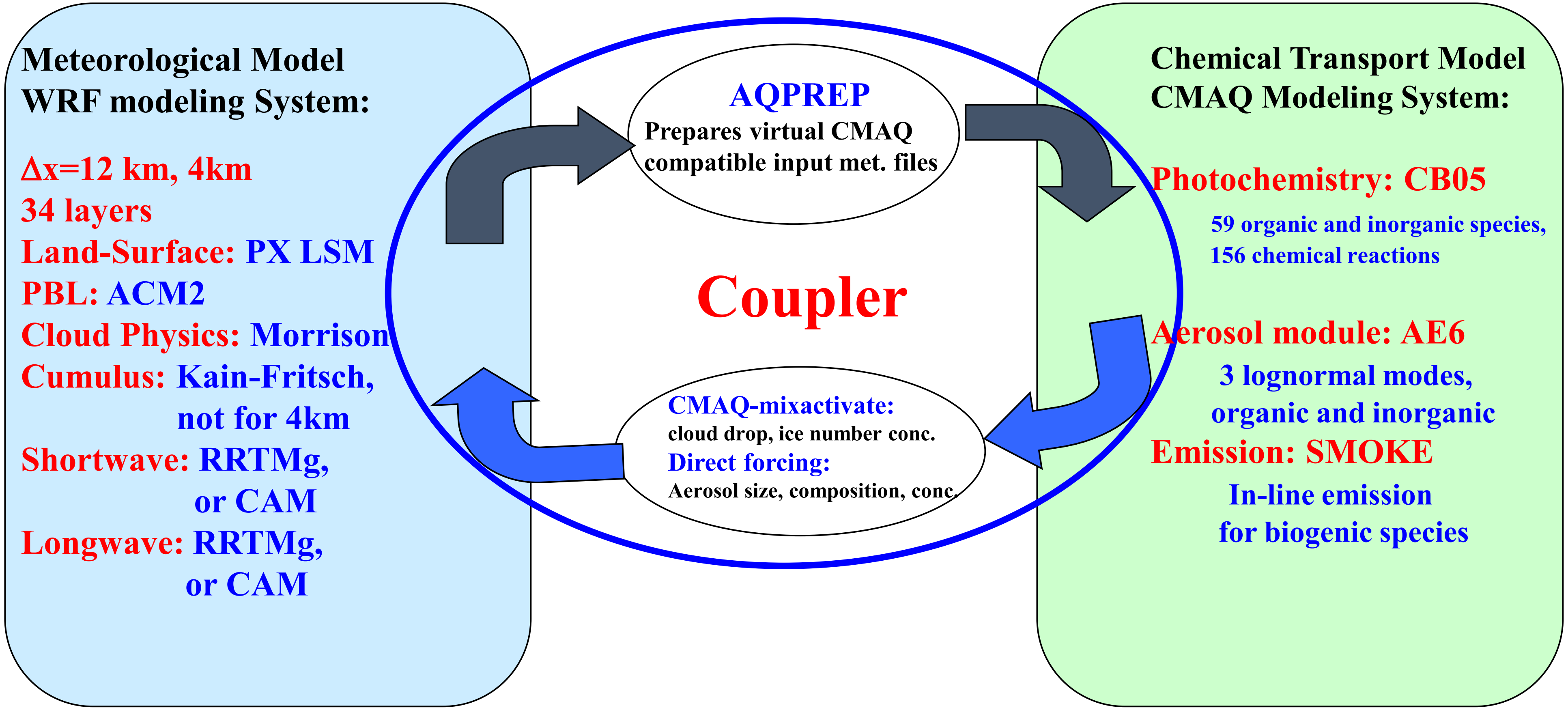
(Zhang, 2020)



Flow chart in black from Dudhia (2012), coupling with chemistry is reflected in Blue

Separate Online Coupling

Two-way coupled WRF-CMAQ modeling System (Yu et al., 2015)



Types of Air Quality (AQ) Models: Offline vs. Online

	Offline	Online
Advantages	1. Easy to develop and use 2. Independent schemes 3. Simple model framework 4. Low computational costs	1. AQ-meteorology (met) feedbacks 2. Consistent treatments for met and AQ 3. No time and space interpolation 4. No met. pre- or post-processor 5. Realistic atmospheric representation 6. Coupled earth system modeling
Limitations	1. Info. loss (e.g., precipitation, cloud formation, turbulence) 2. Time/space interpolation 2. No AQ-Met feedbacks 3. High data storage and flow	1. Challenges in development and use 2. Sophisticated model framework 3. Difficulties in result interpretation 4. Higher computational costs
Applications	1. Ensemble operational AQF 2. Long-term simulations 3. Sensitivity simulations 4. Inverse & adjoint modeling 5. Air quality management	1. Episodes with important feedbacks 2. Fast changes in wind/circulation 3. Real-time operational forecasting 4. Impact of future climate change on AQ

Examples of Important Feedbacks

- **Effects of Meteorology and Climate on Gases and Aerosols**
  - Changes in temperature, humidity, and precipitation directly affect species conc.
  - The cooling of the stratosphere due to the accumulation of GHGs affects lifetimes
  - Changes in tropospheric vertical temperature structure affect transport of species
  - Changes in vegetation alter dry deposition and emission rates of biogenic species
  - Climate changes alter biological sources and sinks of radiatively active species
- **Effects of Gases and Aerosols on Meteorology and Climate**
  - Decrease net downward solar radiation and photolysis (direct effect)
  - Affect PBL meteorology (decrease near-surface air temperature, wind speed, and cloud cover and increase atmospheric humidity and stability) (semi-direct effect)
  - Aerosols serve as CCN, reduce drop size and increase drop number, reflectivity, and optical depth of low level clouds (LLC) (the Twomey or first indirect effect or cloud albedo effect)
  - Aerosols increase liquid water content, fractional cloudiness, and lifetime of LLC but enhance or suppress precipitation via affecting formation of various types of clouds (the second indirect effect or cloud lifetime effect)

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17 Global CW-AQF Models

Country/ Organization	Model System	Meteorological Model (MetM)	Air Quality Model (AQM)	Microscale Models	Scale	MetM -AQM coupling
Canada/EC	GEM-MACH	GEM	GEM-MACH15	None	Global/ Regional	Unified Online
Canada/ York Univ.	GEM-AQ	GEM	AQ	None	Global/ Regional	Unified Online
China/MCA and CAMS	GRAPES - CUACE	GRAPES	CUACE	None	Global/ Regional	Unified Online
Finland/FMI	SILAM	ECMWF/IFS; WRF; HIRLAM; AROME; COSMO HARMONIE	SILAM	None	Global/ Regional	Offline
France/LMD	LMDzt -INCA	ECMWF/IFS; LMDzt v4.0 with nudged with NCEP	INCA v3	None	Global	Separate Online
France/MF-CNRM	MOCAGE	ARPEGE (global) ALADIN (regional) ECWMF	MOCAGE	None	Global/ Regional	offline
Germany/MPIM	ECHAM5	ECHAM5	ECHAM5	None	Global	Unified Online
Norway NIAR/ FLEXPART	FLEXPART	ECMWF NCEP	FLEXPART	None	Global	offline
Japan-FRCGC	GR-RT-AQF	CCSR/NIES/FRCGC atmospheric GCM (global) WRF (regional)	CHASER (global) WRF/Chem (regional)	None	Global/ Regional	Offline for global/regional Unified online for regional
Japan/JMA	MASINGAR	AGCM	MASINGAR	None	Global	Online
Spain, BSC-CNS	NMMB/BSC-CTM	NMMB	BSC-CTM (dust module)	None	Global/ regional	Separate Online
UK/ECMWF, MACC	ECMWF-IFS CTMs; ECMWF/CAMS	IFS	MOZART-3, TM5, or MOCAGE; C-IFS	None	Global/ Regional	Separate online
UK/Met Office	MetUM	MetUM	Dust module	None	Global/ Regional	Unified Online
US/FNMOC/NRL	NAAPS	NOGAPS	NAAPS	None	Global	Offline
US/NASA	GEOS-5 ESM	GEOS DAS	GEOS-Chem GOCART	None	Global	Unified Online
US/NCAR, Germany/MPIC	MATCH-NCAR	NCEP/NCAR	MATCH-NCAR	None	Global	offline
US/NOAA-NCEP	NEMS GFS-NGAC	NEMS GFS	NGAC (dust only)	None	Global	Unified Online

51 Regional/Urban CW-AQF Models

Country/ Organization	Model System	Meteorological Model (MetM)	Air Quality Model (AQM)	Microscale Models	Scale	MetM -AQM coupling
Australia/CSIRO	AAQFS Or AQFx	LAPS, UM, CCAM; ACCESS	CSIRO's CTM, C-CTM	None	Regional	offline
Austria/ZAMG	ALADIN- CAMx	ALADIN-Austria	CAMx	None	Regional	offline
Brazil/CPTEC	CCATT-BRAMS	BRAMS	CCATT	None	Regional	Unified Online
Canada/EC	GEM-AURAMS	regional GEM	AURAMS	None	Regional	offline
Canada/EC	GEM-CHRONOS	regional GEM	CHRONOS	None	Regional	offline
Canada/EC	GEM-MACH15	GEM	chemistry from AURAMS	None	Regional	Unified Online
China/IAP-CAS	EMS-Beijing	MM5	NAQPMS, CMAQ, CAMx	None	Regional	offline
China/Zhejiang Univ.	Two-way coupled WRF-CMAQ	WRF (ARW)	CMAQ	None	Regional	Separate Online
Denmark/DMU-ATMI	THOR	The US NCEP, Eta	DEOM DEHM (UPM, OSPM)	BUM OSPM DREAM	Regional	offline
Denmark/DMI	DACFOS	HIRLAM	MOON, CAMx, Enviro-HIRLAM	M2UE	Hemispheric/ Continental/ regional	offline/ Separate Online
Denmark, Finland, Norway, Spain, Italy/FUMAPEX UAQIFS[3]	1. UAQIFS-Norway 2. UAQIFS-Finland 3. UAQIFS-Spain 4. UAQIFS-Italy1 5. UAQIFS-Italy2 6. UAQIFS-Denmark	1. HIRLAM 2. HIRLAM 3. RAMS 4. RAMS 5. LAMI 6. HIRLAM	1. AirQUIS (dispersion) 2. CAR-FMI (dispersion) 3. CAMx (O_3 only) 4. FARM 5. NINFA-OPPIO/ADAM 6. DERMA-ARGOS	Some include population exposure models, some include urban dispersion/statistical models	Regional /local	offline
Egypt/EMA; South Africa/SAWS	RegCM-CHEM	RegCM4.6	RegCM-CHEM4.6	None	Regional	Unified Online

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Country/ Organization	Model System	Meteorological Model (MetM)	Air Quality Model (AQM)	Microscale Models	Scale	MetM -AQM coupling
France/AIRPARIF[2]	ESMERALDA	MM5	CHIMERE	None	Regional	offline
France/INERIS	Prev'air	MM5, WRF, ECWMF/IFS	CHIMERE, MOCAGE, Polair3D	None	Regional	offline
France/CEREA	POLYPHEMUS	ECMWF, MM5, WRF	Polair3D	MUNICH	Regional/urban	offline
France/CNRS, Météo-France	Meso-NH-C	Meso-NH-C	Meso-NH-C	None	Continental/ regional/urban/local	Unified online
Germany/FRIUUK, RIU, Cologne	EURAD-RIU	MM5	EURAD-IM	None	Regional	offline
Germany/FU-Berlin, Institute for Meteorology	RCG	GME	REM- CALGRID	None	Regional	offline
Germany/KIT	COSMO- ART	COSMO	ART	None	Continental/regional	Unified Online
Germany/LITR	COSMO-MUSCAT	COSMO	MUSCAT	None	Continental/regional	Separate Online
Germany/Uni. of Hamburg	M-SYS	METRAS	MECTM	MITRAS- MICTM	Regional/urban/local	Unified Online
Germany/IMK-IFU	MCCM (MM5-Chem)	MM5	Chem	None	Continental/regional/urban	Unified Online
Greece/Aristotle University	MEMO/MARS	MEMO	MARS-aero	None	Regional/urban	Separate Online
Greece/ NKUA	CAMx- AMWFG	SKIRON/Dust	CAMx	None	Regional	offline
Greece/NKUA, AUT	MM5-CAMx	MM5	CAMx	None	Regional	offline
Greece/UA	SKIRON/TAPM	SKIRON/dust;Eta	CAMx v4.31	None	Regional	Offline
Italy/CETEMPS	ForeChem	MM5	CHIMERE	None	Regional	offline
Italy/ARIANET s.r.l.	FARM	RAMS	FARM	None	Regional	offline
Italy/CNR-ISAC	BOLCHEM	BOLAM	CHEMistry modules	None	Continental/regional	Separate Online
Italy/ITCP	RegCM-Chem	RegCM4	RegCM-Chem4	None	Continental/regional	Unified Online
Japan/Kyushu University	CFORS	RAMS	Parameterized chemical tracers in RAMS	None	Regional	Unified Online
Morocco/Maroc Météo	ADMS URBAN 3.1	ALADIN	GRS Chemical Model	Urban canopy	Regional/local	Separate online?
Netherlands/KNMI, TNO, RIVM, PBL/KN	LOTOS-EUROS	Archived analyses, ECMWF, RACMO2	LOTOS-EUROS	None	Regional	Offline/ Separate Online

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Country/ Organization	Model System	Meteorological Model (MetM)	Air Quality Model (AQM)	Microscale Models	Scale	MetM -AQM coupling
Norway/ MET-NO	EMEP-Unified	ECMWF/IFS	Unified EMEP-CWF	None	Regional	offline
Singapore/MSS	ATLAS-NAME	UM	NAME	None	Regional	Offline
Spain/BSC-CNS	CALIOPE	WRF, MM5	CMAQ, DREAM, CHIMERE,	None	Regional	offline
Spain/TUM, LHTEE, AUT, NCAR/Pen	OPANA v4.0	MM5 MEMO	CMAQ	MICROSYS	Regional /local	offline
Sweden/SMHI	MATCH	ECMWF/IFS HIRLAM	MATCH	None	Regional	offline
UK/Uni. Of Hertfordshire	WRF-CMAQ	WRF(ARW)	CMAQ v5.02	None	Regional/ national	Offline
UK/AEA	WRF/CMAQ	WRF	CMAQ	None	Regional	offline
UK Met Office	AQUM	MetUM	UKCA	None	Sub-regional/ national	Unified Online
UK/Met Office	NAME-III	ECMWF, Met Office Unified Model	NAME-III	None	Regional /local	offline
US/BAMS	MAQSIP-RT CMAQ	BAMS-MM5, WRF	MAQSIP CMAQ	None	Regional	offline
US/WSU	AIRPACT3	MM5	CALGRID, CMAQ	None	Regional	offline
US/SUNY-Albany	AQFMS	SKIRON/Eta; WRF (NMM and ARW)	CAMx, CMAQ	None	Regional	offline
US/UI	STEM-2K3	MM5, WRF	STEM	None	Regional	offline
US/NOAA, ARL	NAQFC (NAM-CMAQ)	Eta, WRF (NMM), NAM	CMAQ	None	Regional/ national	Offline
US/NCAR, Greece	MM5-CHIMERE	MM5	CHIMERE	None	Regional	offline
US, Greece	RAMS/ICLAMS	RAMS	ICLAMS	None	Continental/ urban	Separate Online
US/NOAA, EMSL	WRF/Chem	WRF (ARW)	WRF/Chem	None	Regional/urban	Unified Online
US/NCSU	WRF/Chem-MADRID	WRF (ARW)	WRF/Chem	None	Regional/urban	Unified Online

Characteristics of the Global CW-AQF Models (1)

- Meteorological fields are produced by reanalysis data such as National Centers for Environmental Prediction (NCEP) or general circulation models such as GEM, ECMWF/IFS, LMDzt, ECHAM5, and GEOS-5.
- In online-integrated models such as GEM-AQ, ECHAM5, and GEOS-5 ESM, a chemistry module is incorporated into a GCM. In offline or online-access models, an AQM is driven by data from meteorological reanalysis (e.g., BSC-CTM) or used in conjunction with a GCM (e.g., MOCAGE, MOZART-3, TM5), respectively.
- 9 global models are multiscale models and have been applied to regional domains for RT CW-AQF. They use two methods for downscaling. While some models (e.g., GEM-AQ, GEM-MATH, MOCAGE, NMMB/BSC-CTM, and SILAM) were directly downscaled to a regional domain at a finer horizontal grid resolution, the global-regional RT CW-AQF model system was used to provide ICONs and BCONs to drive a regional online-integrated model, WRF/Chem.
- Among the 17 global RT CW-AQF models, two of them offer an integrated flexible, advanced global forecasting modeling tool with data assimilation of satellite observations: ECMWF/IFS-CTMs developed by ECMWF and GEOS-5 ESM developed by U.S. NASA.

Characteristics of the Global CW-AQF Models (2)

- The selection of multiple CTMs and their ensemble results provides a range and an indication of the robustness of the forecasts. In ECMWF/CAMS, the coupled system can directly utilize the IFS 4D-Var algorithm to assimilate atmospheric observations (Flemming et al., 2009). In GEOS-5 ESM, two chemical model configurations have been implemented: the chemistry-climate model (CCM) that simulates the feedbacks between circulation and chemical composition and the chemistry-transport model (CTM) that simulates air quality without considering such feedbacks.
- The most recent ICAP multi model ensemble (ICAP MME) consists of seven global models including four comprehensive global aerosol models (NASA GEOS-5, FNMOC/NRL NAAPS, ECMWF MACC, JMA MASINGAR), and three dust-only global models (NOAA NGAC, BSC NMMB/BSC-CTM, UKMO Unified Model) (Sessions et al., 2015). The ICAP-MME is run daily at 0Z for 6 hourly forecasts at one degree resolution out to 120 hrs.

Characteristics of the Regional CW-AQF Models (1)

- Most popular met models: MM5, WRF, and ECMWF/IFS. Other NWP models: Eta, SKIRON, UM, RAMS, GEM, GME, ALADIN, RegCM, HIRLAM, HARMONIE, COSMO, and BRAMS. Many AQMs (e.g., CHIMERE and Polyphemus/Polair3D) can be driven by several met models. The most commonly-used regional AQMs include CMAQ, CAMx, WRF/Chem, and CHIMERE.
- Offline-coupled models: CMAQ, CAMx, and CHIMERE. CMAQ has been used in U.S., Spain, U.K., and China. CAMx has been used in U.S., Spain, Greece, Austria, and China. CHIMERE has been used in France, Italy, Spain, Greece, and U.S. AAQFS is one of the earliest offline CW-AQF models developed by the BM, CSIRO, and Australian EPA in late 1990s. The U.S. NOAA/EPA's National Air Quality Forecasting Capability (NAQFC) is one of the first offline CW-AQF models in the U.S.
- Online-coupled regional CW-AQF models: WRF/Chem and WRF/Chem-MADRID include the most coupled met, microphys, chem, and radiative processes and allow the simulation of aerosol direct, semi-direct, and indirect effects, thus representing the state-of-the-science. Since its first release in 2002, WRF/Chem has been further developed and improved by community users and increasingly applied to many regions of the world. WRF/Chem and its variants have been used for CW-AQF worldwide. CCATT-BRAMS is a new online model developed by the CPTEC for RT CW-AQF in South America. The online Regional integrated coupled RegCM-CHEM is being used for CW-AQF in Italy, Egypt, and South Africa.

Characteristics of the Regional CW-AQF Models (2)

- Regional ensemble air quality forecasting: CAMS is based on ensemble of seven state-of-the-art numerical air quality models developed in Europe: CHIMERE from INERIS (France), EMEP from MET Norway (Norway), EURAD-IM from University of Cologne (Germany), LOTOS-EUROS from KNMI and TNO (Netherlands), MATCH from SMHI (Sweden), MOCAGE from METEO-FRANCE (France) and SILAM from FMI (Finland). Other ensemble air quality forecasting programs include the MarcoPolo – Panda, EU FP7 Programme for China
- Among 56 regional models, eight are suitable for urban/local scale applications at a spatial resolution of 1 km or less (THOR, DACFOS, M-SYS, ADMS URBAN 3.1, OPANA, and four UAQIFS models, and the Polyphemus. The Polyphemus has been extended to include a street network model, the Model of Urban Network of Intersecting Canyons and Highways (MUNICH), which is online-coupled with a 3D Eulerian chemical-transport model (Polair3D) within Polyphemus. The resulting model system is referred to as Street-in-Grid (SinG) model.

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List of Demonstration Cases for Real-Time CW-AQF and Case Providers

Domain	Case #	Case Title	Case Providers	Affiliation
Global	a1	Long-range transport of Sahara dust and smoke from Portuguese Wildfire emissions to North-West Europe forecast by the global CAMS forecasting system for atmospheric composition	Johannes Flemming	ECMWF, United Kingdom
	a2	A study of the 2016 post-monsoon air pollution event over India using the GEOS forecasting system	Christoph A. Keller and Anton Darmenov	NASA Goddard Space Flight Center, U.S.A.
	a3	Impact of wild-land fires on atmospheric aerosols in Northern Hemisphere in 2012	Mikhail Sofiev	Finnish Meteorological Institute, Helsinki,Finland

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North America	b1	National Air Quality Forecasting Capability for the U.S.A.	Pius Lee	NOAA Air Resources Laboratory (ARL) and George Mason University, U.S.A.
	b2	Application of WRF/Chem-MADRID over Southeastern U.S.	Yang Zhang	North Carolina State University, North Carolina, U.S.A.
	b3	Wildland fire smoke forecasting capability in the U.S.A.	Mariusz Pagowski and Stuart McKeen	NOAA Earth Research Laboratory, U.S.A.

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Africa	g1.1-1.2	Application of RegCM-CHEM4.5 for dust storm and air quality forecast over southern Africa	Melaku Tesfaye Yigiletu	South African Weather Service, Pretoria, South Africa
	g2	Performance of WRF-CHEM Model to simulate North African Aerosols: preliminary results	A. Abdallah and Magdy M. Abdel Wahab	Al-Azhar University, Cairo, Egypt Cairo University, Giza, Egypt
	g3	Application of ADMS Urban over the Grand Casablanca area, Morocco	Kenza Khomsi	National Climate Center, Air Quality Department, Morocco

Case Highlight 1: National Air Quality Forecasting Capability for the U.S.A.

Pius Lee, Air Resources Laboratory (ARL), NOAA

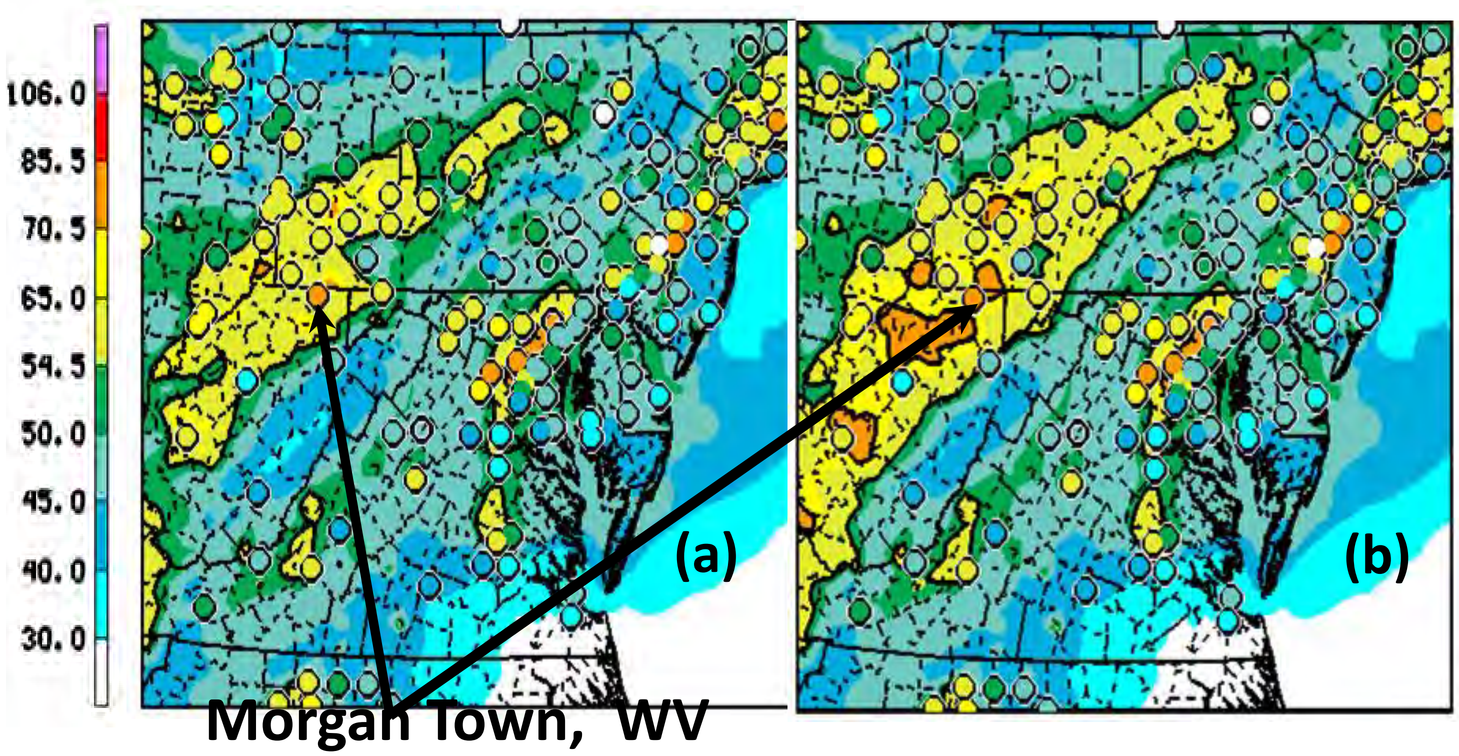
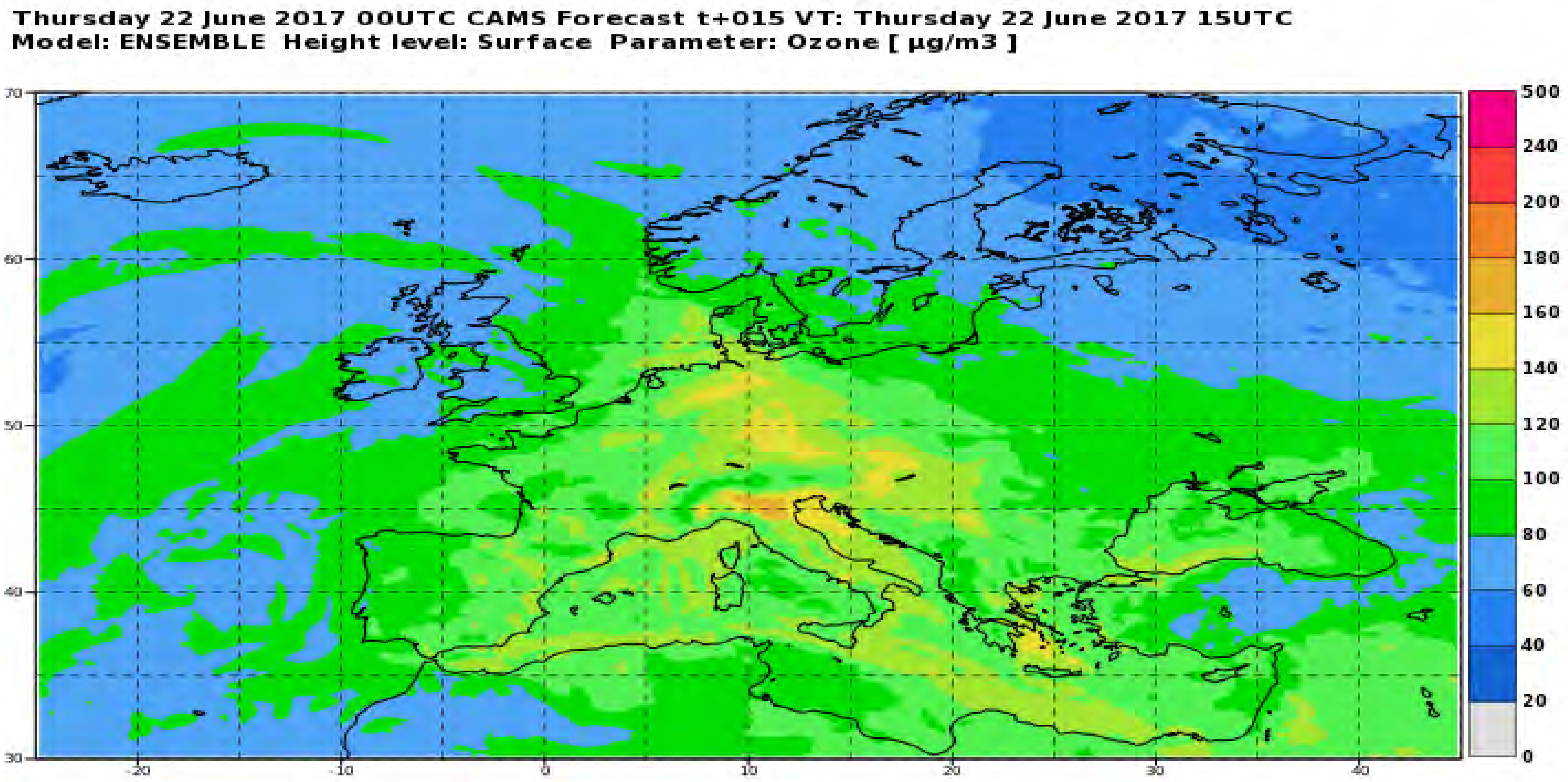


Figure 12.12. NAQFC 2nd day forecast (color shading) versus near real-time US EPA AIRNow measurements (filled solid circles) for July 18, 2017, 18:00 UTC by (a) Case_Base, and (b) Case_Oil_n_Gas.

- In (a), NAQFC had difficulty to predict exceedances in the Northeastern US. It happened on July 18 2017 over Western PA and its neighboring Northeastern WV using 2011 EPA NEI
- In (b), the oil and gas sector NO_x and VOC emissions were adjusted to the US Energy Information Agency 2016 actual energy production data to account for impacts of shale field oil and gas exploration and production since 2010 in the Marcellus and Utica Shales in Western PA, WV and the State of Ohio. O_3 underprediction downwind of the shale around the state border between PA and WV was largely reduced

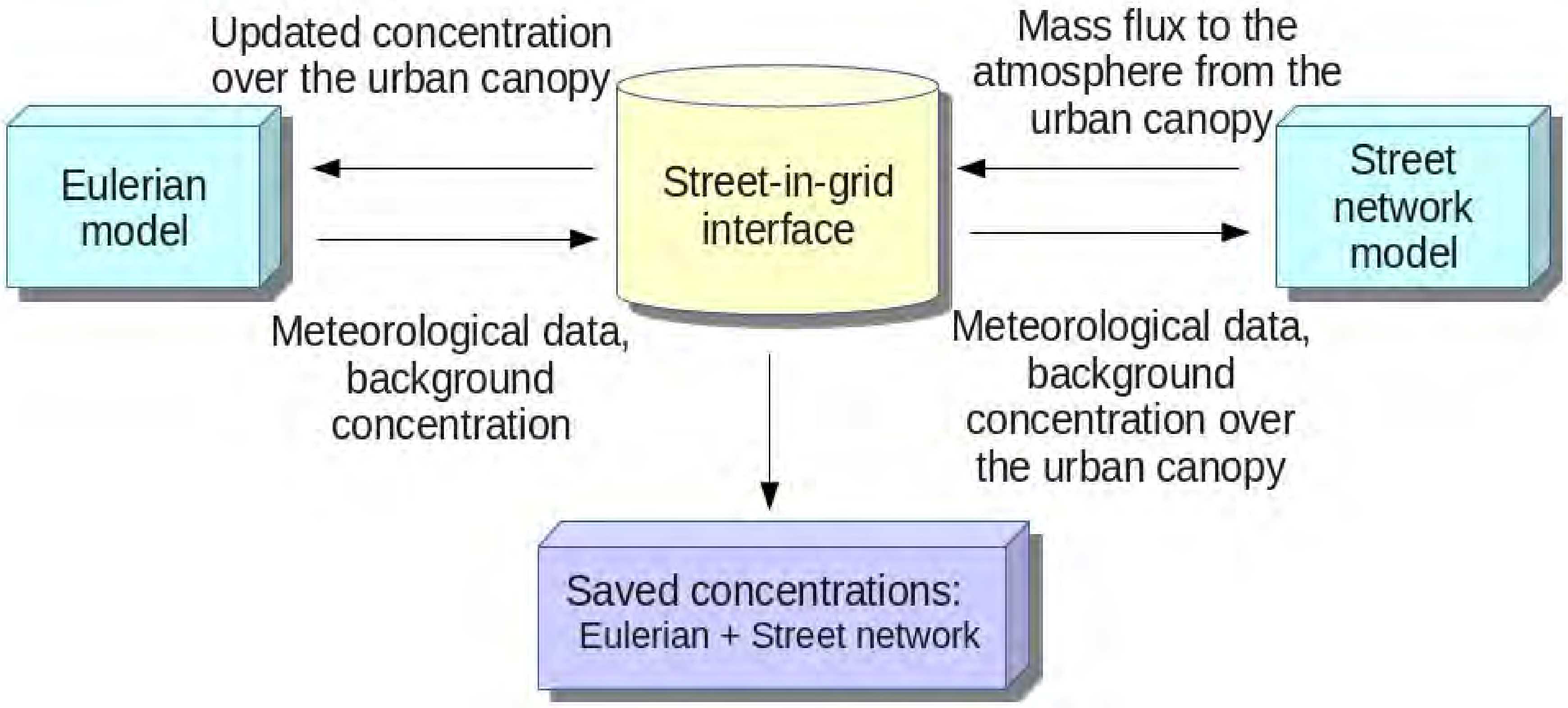
Case Highlight 2: Regional CAMS Ensemble Forecasting of High O_3 Event

Matthieu Plu, Meteo-France, France



- **The ozone concentration values reached and overpassed the 180 µg m^{-3} threshold during 21-22 June 2017**
- **Sunny anticyclonic conditions, with high temperatures and light winds were favourable to high ozone in Italy, Germany, France, and Hungary. Photochemistry contributed to high production of ozone**

Case Highlight 3: Framework of a Street-in-Grid (SinG) Model Youngseob Kim and Karine Sartelet CEREA, France

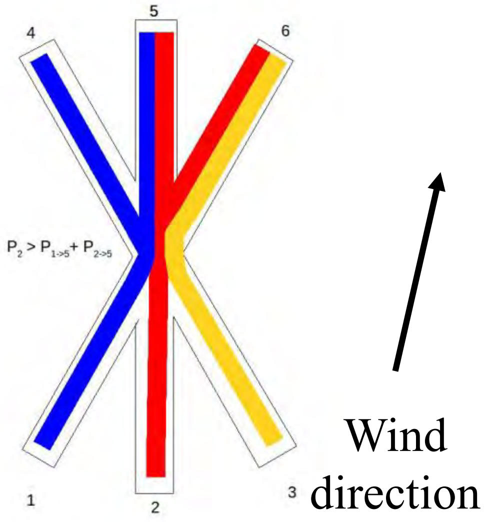


- Simultaneous simulation of the urban background pollution (spatial scale > 1 km) and the traffic pollution (spatial scale ~ 10 to 100 m)
- A 3-D CTM provides urban background pollution; a street network model combining traffic, emissions, and dispersion simulates pollution near traffic

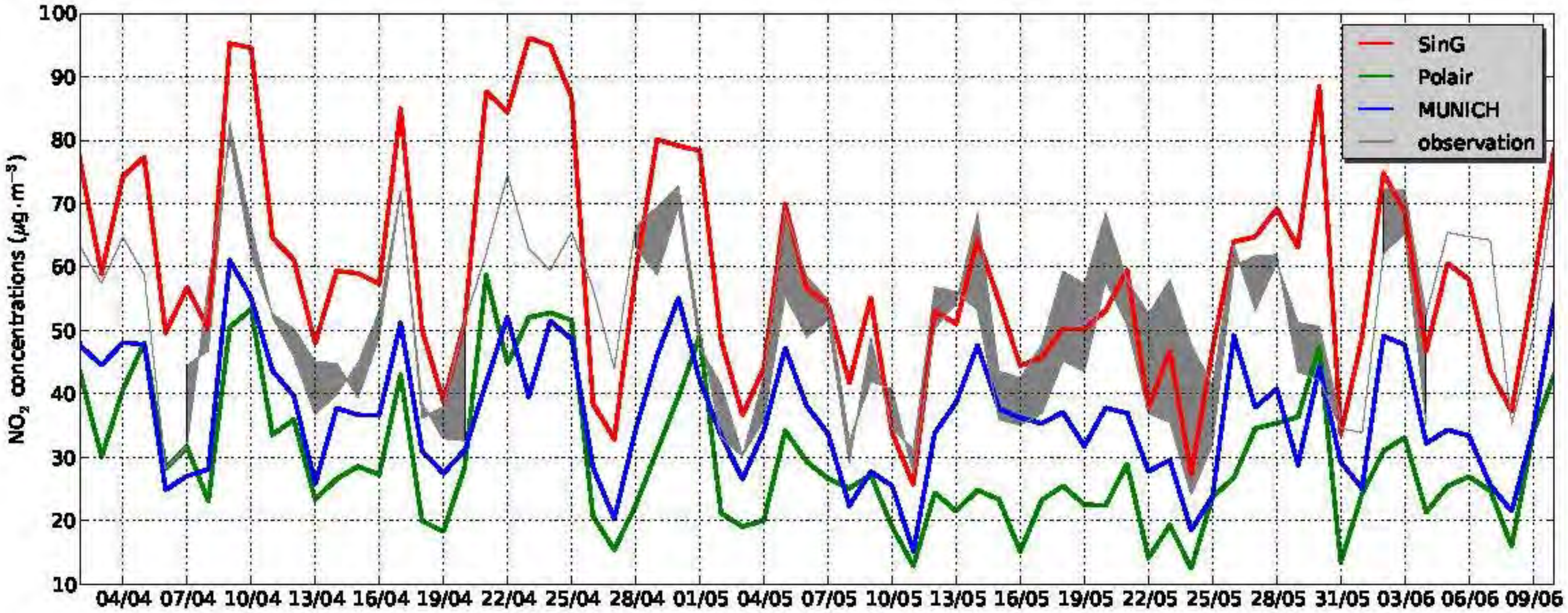
Description of Model of Urban Network of Intersecting Canyons and Highways" (MUNICH)

(Soulhac et al., 2008; Kim et al., 2016)

- **Street-canyon component**
  - Concentrations are uniform in each segment of the street-canyon
  - Building heights and street widths are uniform in the street-canyon
  - Wind direction follows the direction of the street and the average wind speed is calculated using an exponential vertical profile
  - Mass flux occur at intersections and at roof level
- **Street-intersection component**
  - Flow lines do not intersect
  - Account for fluctuations in wind direction
  - Mass balance is calculated across the intersection
- **Calculation of concentrations**
  - The CB05 chemical kinetic mechanism
  - Assumption of the steady state for each street network in a mesh



Temporal Evolution of NO_2 Daily-Averaged Concentrations Nearby Traffic
(Kim et al., 2018)



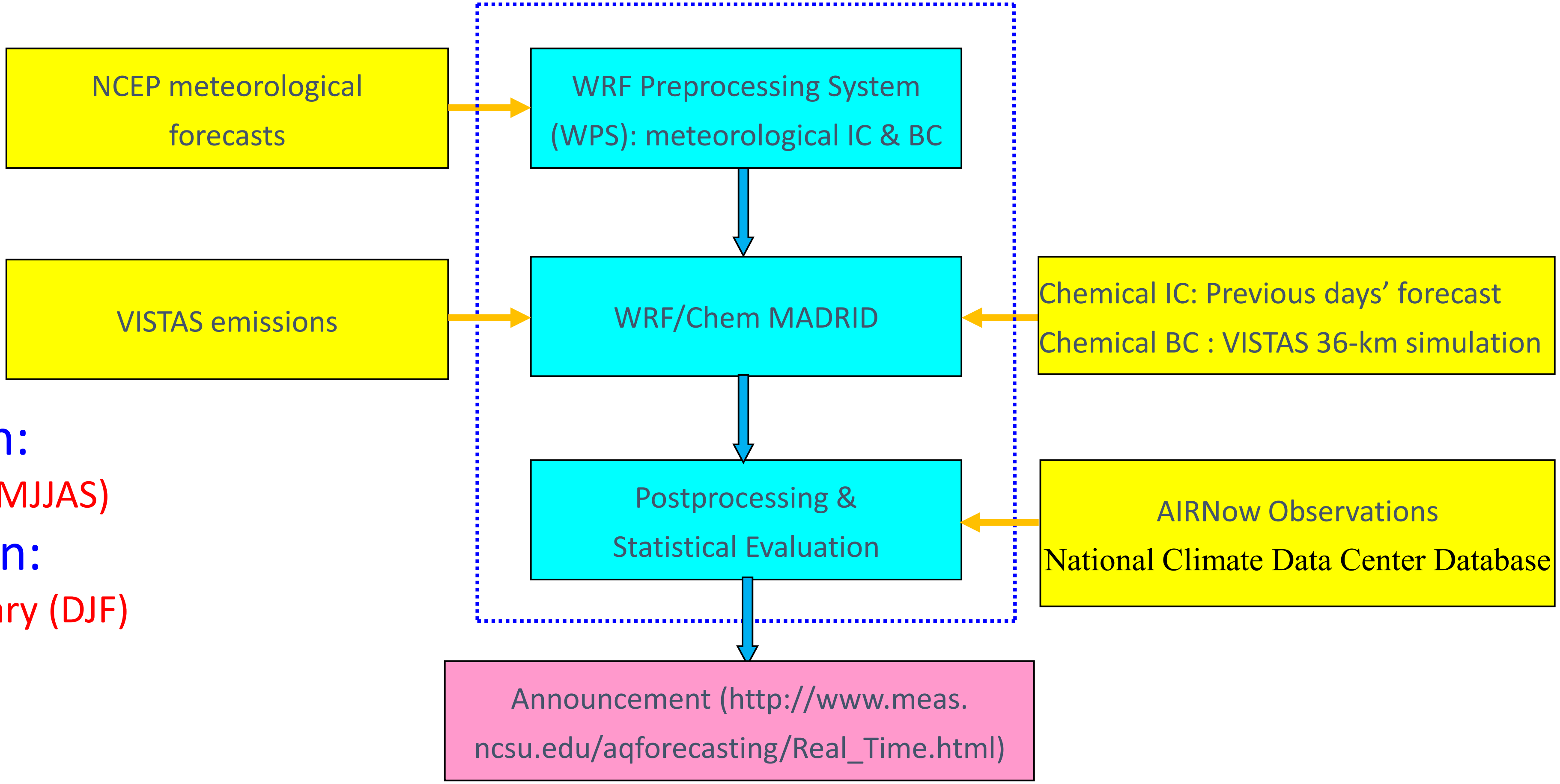
NO2	Polair	MUNICH	SinG
FB	-0.52	-0.32	0.13
R	0.51	0.67	0.64

NOx	Polair	MUNICH	SinG
FB	-1.19	-0.99	-0.64
R	0.54	0.64	0.64

- MUNICH outperforms Polair3D; SinG performs the best in terms of both FB and R
- All models underpredict NO_x, due in part to uncertainties in NOx emissions or an overestimation of NOx transport at roof top

Case Highlight 4: NCSU's RT-AQF System

(Chuang et al., 2011; Zhang et al., 2016)



Ozone Season:
May-September (MJJAS)

Winter Season:
December-February (DJF)

Lead Time:
60-hr cycle with
2-day forecast

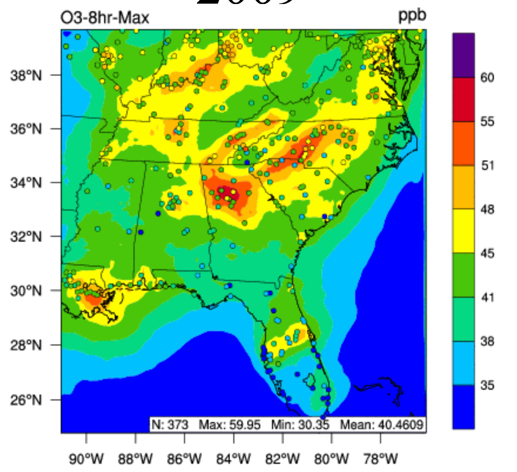
Grid Resolution:
12-km

WRF/Chem-MADRID – Weather Research and Forecasting Model with Chemistry and the Aerosol Dynamics, Reaction, Ionization, and Dissolution

Spatial Evaluation-O_3 Season (MJJAS)

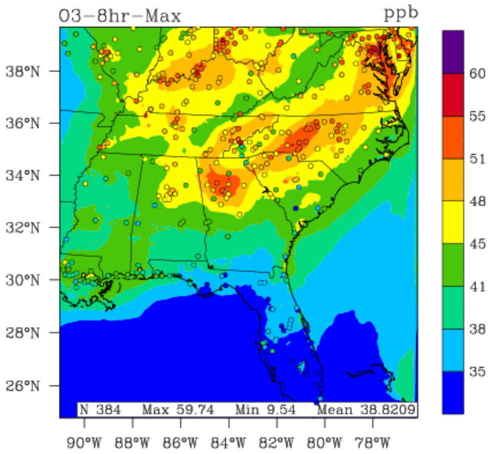
Mean Max 8-hr O_3 against AIRNow (2009-2014)

2009



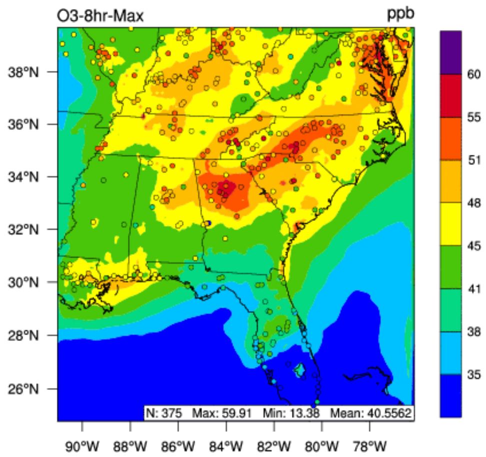
NMB=8.5%

2010



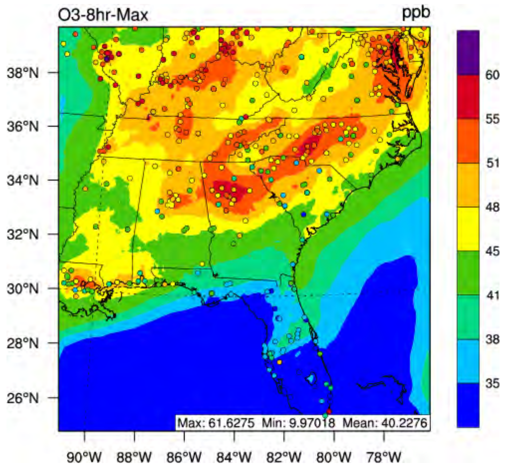
NMB=-3.7%

2011



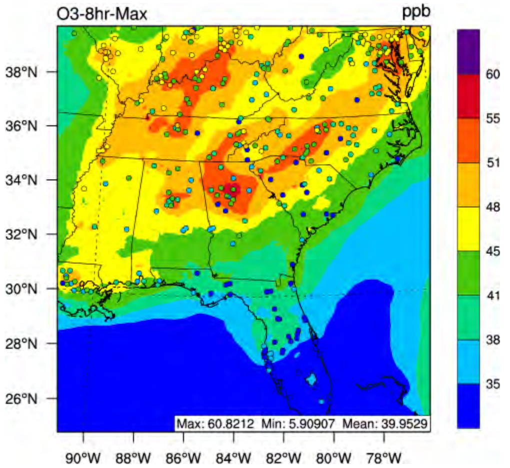
NMB=-3.7%

2012



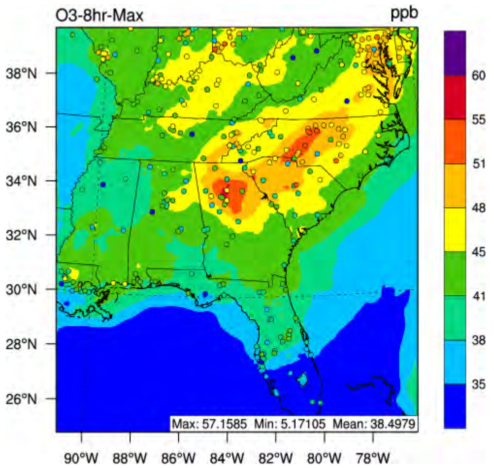
NMB=0.4%

2013



NMB=16.9%

2014 (MJJ only)



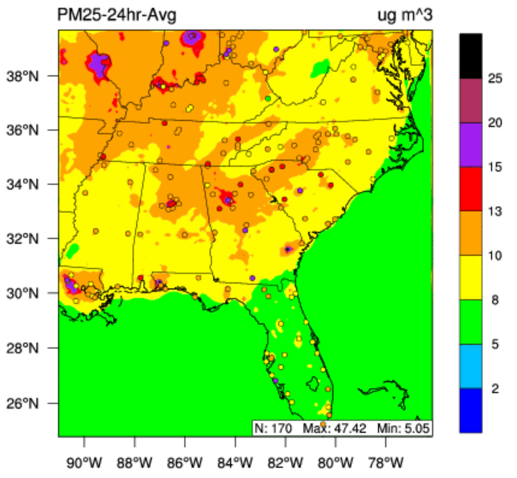
NMB=1.0%

- The model generally captures well hotspots and spatial variation with NMBs of -3.7 to 16.9%

Spatial Evaluation-O_3 Season (MJJAS)

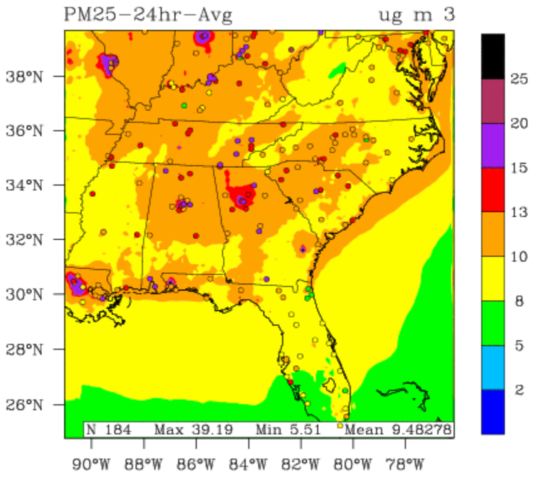
Mean 24-h $PM_{2.5}$ against AIRNow (2009-2014)

2009



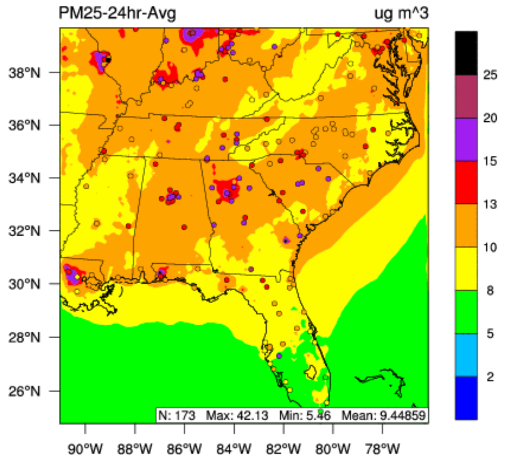
NMB=-5.2%

2010



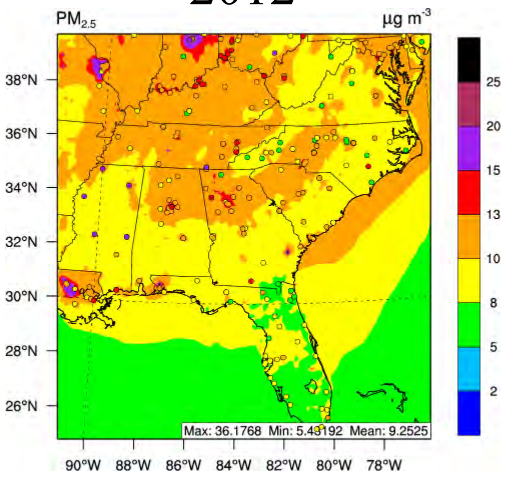
NMB=-9.0%

2011



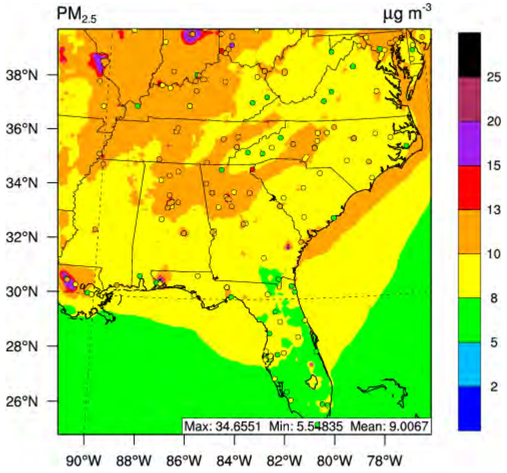
NMB=-10.1%

2012



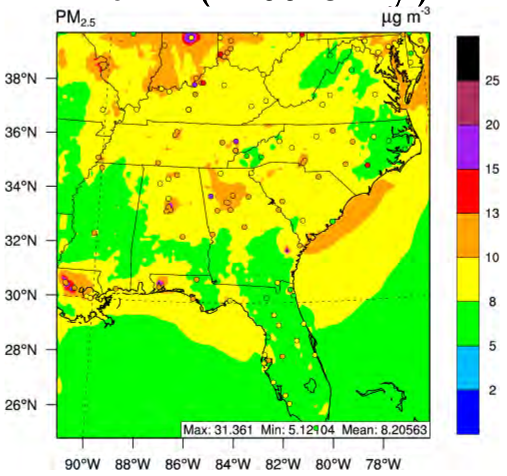
NMB=2.0%

2013



NMB=14.7%

2014 (MJJ only)

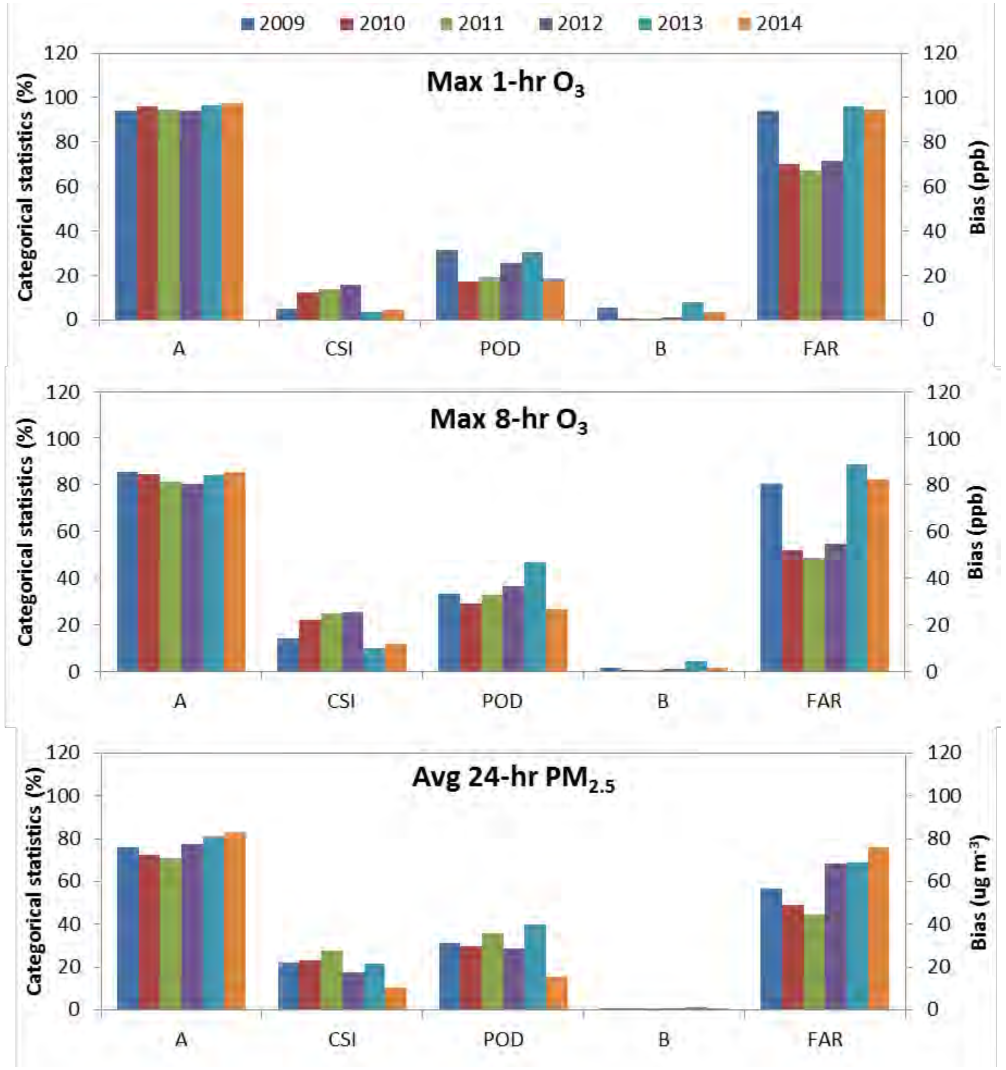


NMB=-4.5%

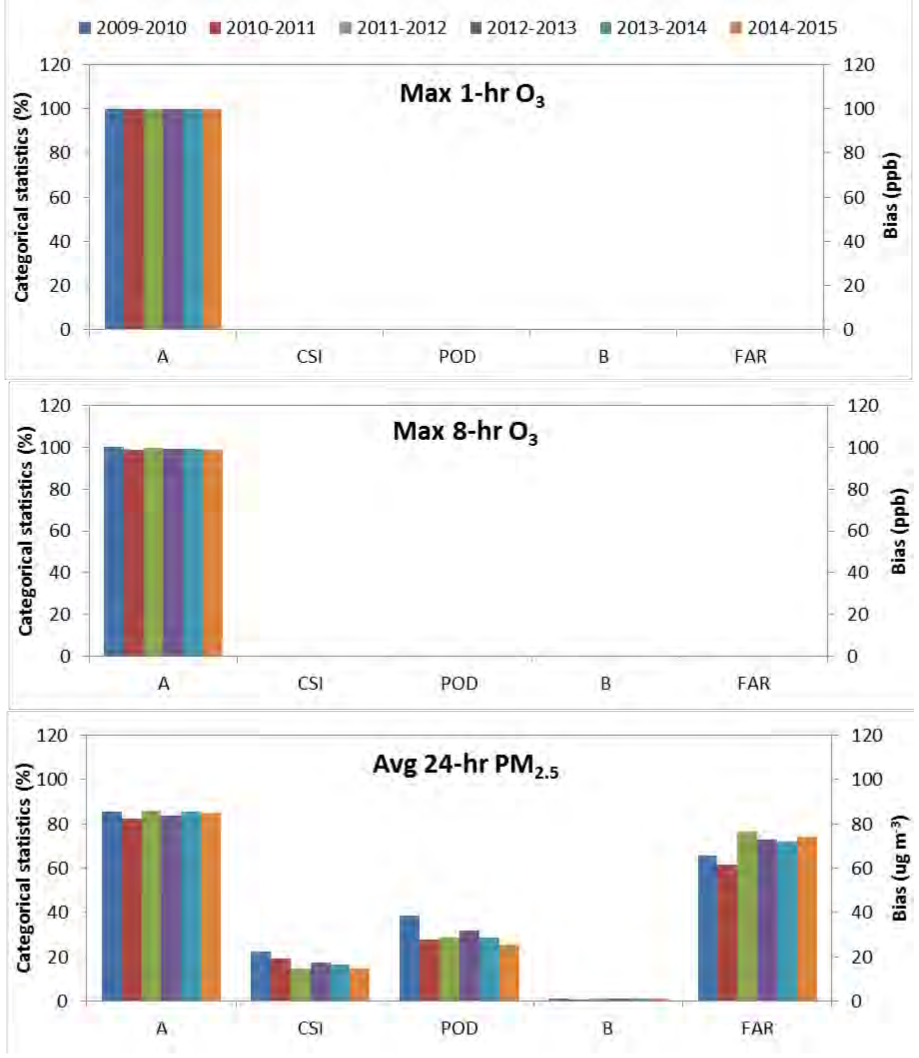
- The model generally captures well hotspots and spatial variations with NMBs of -10.1 to 14.7%

Categorical Evaluation Against AIRNow (2009-2014)

O_3 Season



Winter Season

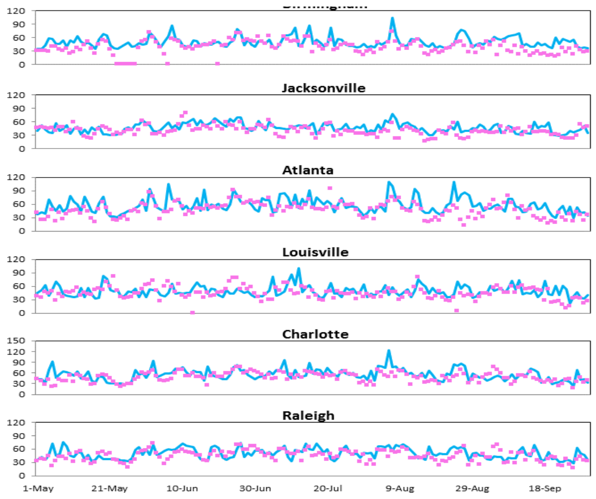


- Overall good performance in terms of A and B, but with relatively low CSI and POD and high FAR

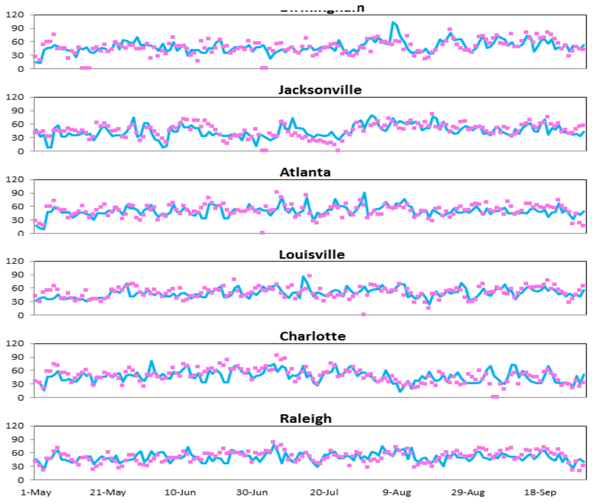
Temporal Max 8-h O_3 Variation at Urban Cities

(May-Sept., 2009-2014)

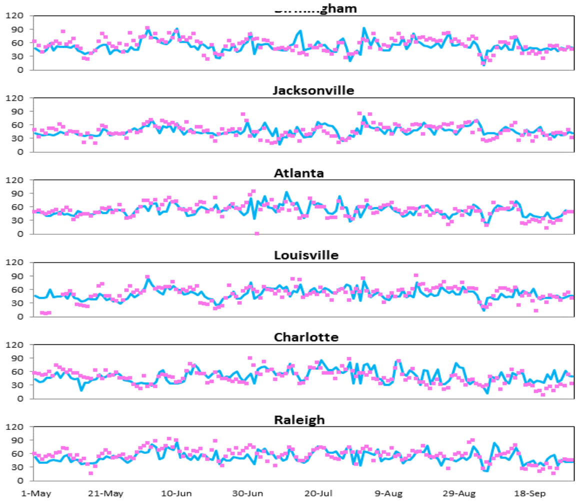
2009



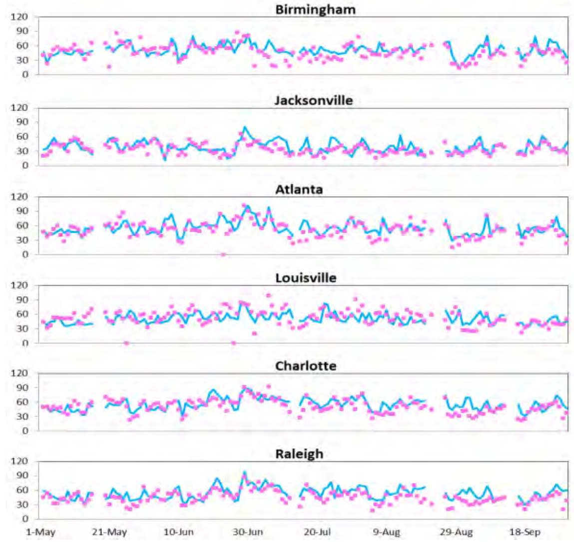
2010



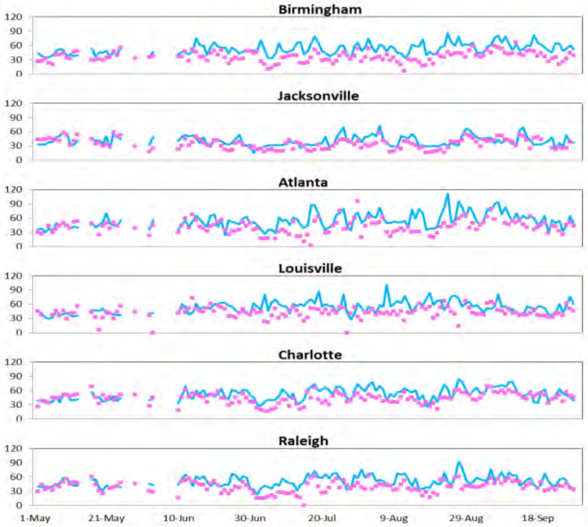
2011



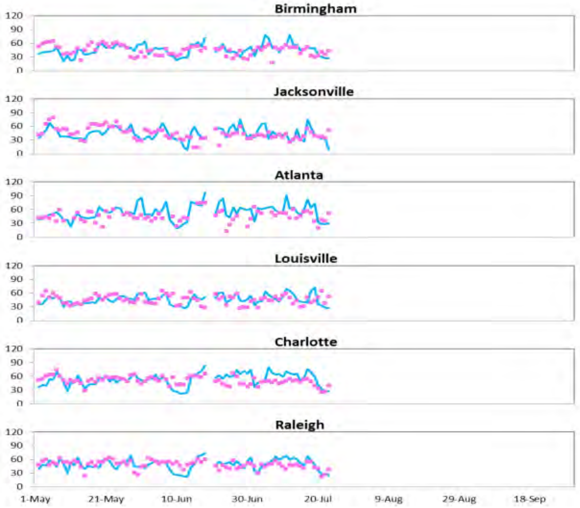
2012



2013

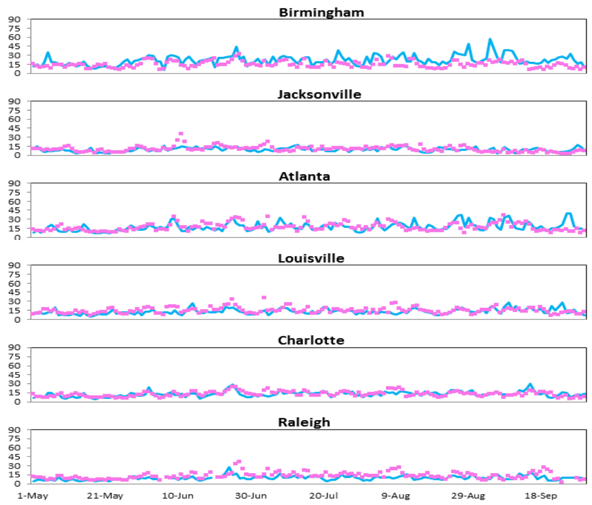


2014

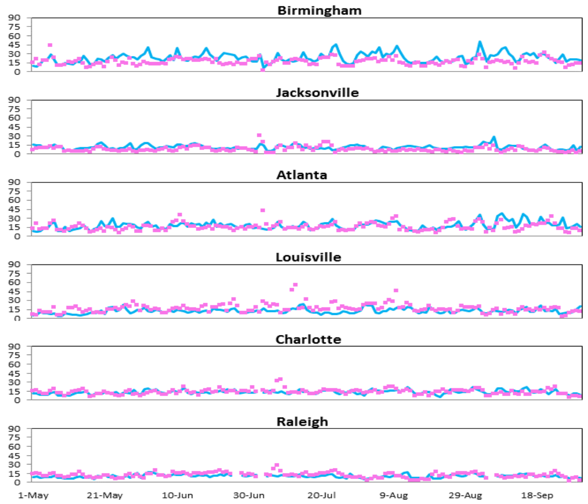


Temporal 24-h Avg. $PM_{2.5}$ Variation at Urban Cities
(May-Sept., 2009-2014)

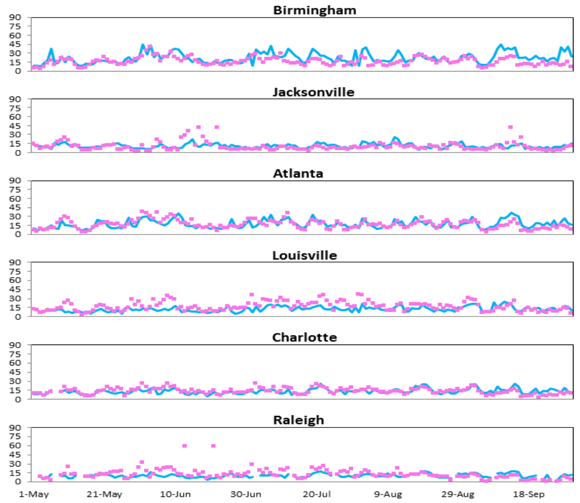
2009



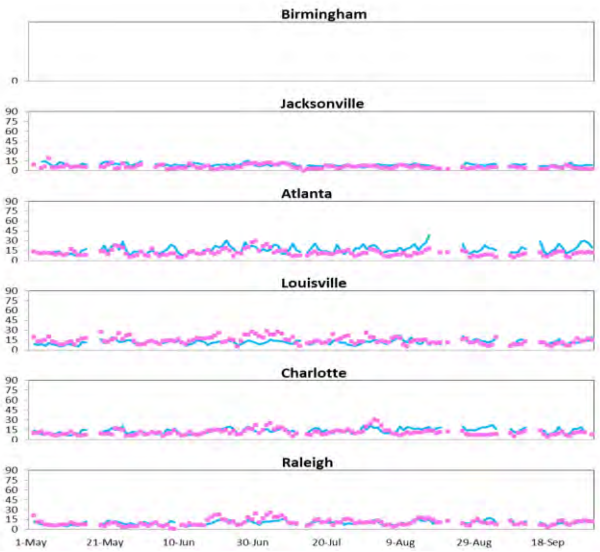
2010



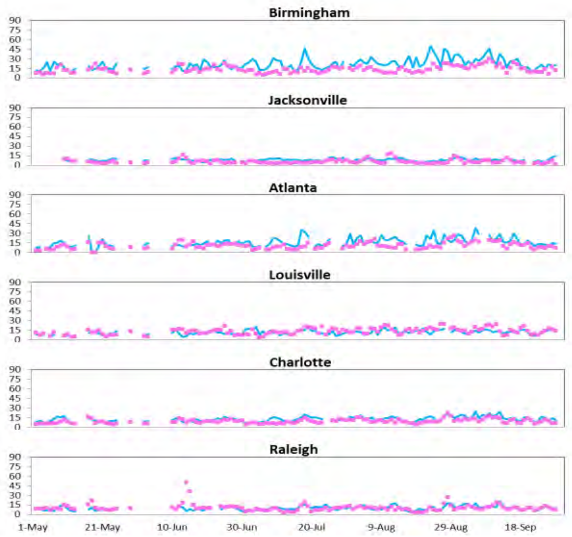
2011



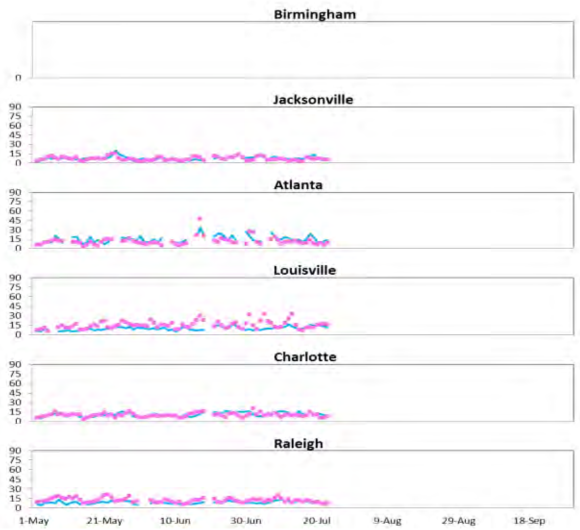
2012



2013



2014



Outline

- Introduction
- Types of CW-AQF Models
  - Model Types
  - Lagrangian vs. Eulerian Models
  - 3-D Models
  - Offline vs. Online-Coupled Air Quality Models
- Global and Regional CW-AQF Models
  - Global
  - Regional
- Demonstration Cases for CW-AQF Model
  - Global
  - Regional
- **Summary**

Sources: Zhang et al. (2012a, b), Zhang and Baklanov (2019), and Zhang (2020)

Summary

- CW-AQF models can be grouped into three types (Eulerian, Lagrangian, and hybrid models) based on model framework, four types (local, urban, mesoscale, and global) based on horizontal grid resolution, two types (short- and long-term) based on temporal scale, two types (online- and offline-coupled) based on the chemistry coupling with the meteorology, and two types (community- and non-community) based on community involvement.
- Current CW-AQF models differ in many aspects including their component models (i.e., meteorological models, air quality models, microscale models), spatial scale, and coupling between meteorology and chemistry.
- Among 17 global and 56 regional/urban real-time CW-AQF models reviewed in this section, 9 global models and 23 regional models are suitable for multi-scale applications and 8 regional models can be applied on urban/local scale at a spatial resolution of 1 km or less. 11 global models and 21 regional models are online-coupled models.
- Regional ensemble air quality forecasting has been increasingly applied. Examples include the Copernicus Atmosphere Monitoring Service (CAMS) for Europe and the MarcoPolo – Panda, EU FP7 Programme for China.

References

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- Zhang, Y., C. Seigneur, M. Bocquet, V. Mallet, and A. Baklanov, 2012, Real-Time Air Quality Forecasting, Part I: History, Techniques, and Current Status, *Atmospheric Environment*, 60, 632-655, doi:10.1016/j.atmosenv.2012.06.031.
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