RGC Ref.: A-PolyU502/16

The Research Grants Council of Hong Kong
ANR/RGC Joint Research Scheme
Completion Report

(Please attach a copy of the completion report submitted to the ANR by the French researcher)

Part A: The Project and Investigator(s)

1. Project Title (ANR Acronym)

Impact of Air-Sea Exchanges on Air Quality in Coastal Megacities (SEA-M)

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	French Team
Name of Principal Investigator *(with title)*	Professor WANG Tao	Dr GEORGE Christian
Post	Chair Professor	Senior Research Scientist/ CNRS-DR1; Deputy-Director of CNRS-IRCELYON
Unit / Department / Institution	Environmental Engineering/ Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University	Research Institute for Catalysis and Environment Lyon (IRCELYON / The National Centre for Scientific Research (CNRS)
Contact Information	Prof WANG Tao Email: tao.wang@polyu.edu.hk	Dr GEORGE Christian Email: christian.george@ircelyon.univ-lyon1.fr
Co-investigator(s) *(with title and institution)*	Dr WANG Zhe / The Hong Kong University of Science and Technology	Dr Abdelwahid MELLOUKI / The National Centre for Scientific Research (CNRS)

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 March 2017	N/A	N/A
Project Completion date	28 February 2021	31 August 2021	3 February 2021
Duration *(in month)*	48 months	54 months	3 February 2021
Deadline for Submission of Completion Report	28 February 2022	31 August 2022	3 February 2021

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

The specific scientific topics to be addressed will be focused on 4 work packages (WP)

WP1. Sea-surface chemistry under polluted conditions – here the photochemical production of unsaturated carbonyls, possibly halogenated products, will be investigated in a multiphase simulation chamber. This family of reactive VOC has been recently identified under pristine conditions by the group at Lyon as arising from abiotic processes at the air/water interface. They act as sources of organic aerosols. WP1 will measure for the first time the boosting effect of air pollution on such emissions. (PI: C. George from IRCELYON in France)

WP2. Gas-phase chemistry of functionalized/halogenated and reactive VOCs formed at the air-sea interface and of BVOCs – here the gas phase chemistry of the VOCs identified in WP1 will be investigated in a large outdoor chamber under various simulated environmental conditions and natural sunlight. This chemistry may lead to some HOx recycling, production of further reactive molecules, SOA precursors (such as glyoxal) and SOA. WP2 will aim at characterizing all of these secondary species. (PI: A. Mellouki from ICARE in France)

WP3. Field study of atmospheric chemistry in coastal megacity and adjacent marine areas using Hong Kong as the case study - here the outcomes of the above objectives will be tested, identified and quantified in the field. (PI: Zhe Wang and Tao Wang from PolyU in HK)

WP4. Model assessment of the impacts of sea-surface interactions on regional air quality under continental outflow and sea-land breeze circulations – here these data will be implemented into a model for impact assessments. (PI: Tao Wang from PolyU in HK)

5.2 Revised Objectives

N.A.

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

Below we report the major findings and research outcome from the Hong Kong Team related to WP3 and WP4.

(1) Discovery of daytime Cl_2 and its impact on the oxidative power of the coastal atmosphere.

Chlorine atoms (Cl) are highly reactive and can strongly influence the abundances of climate and air quality-relevant trace gases. Cl_2 is a precursor of Cl atoms. During a comprehensive field campaign conducted by a multi-institution team in a coastal area of Hong Kong, we found the daytime Cl_2 concentrations of up to 1 ppbv, which is the highest level reported to date. Field and laboratory experiments indicate that photodissociation of particulate nitrate by sunlight under acidic conditions (pH <3.0) can activate chloride from sea-salt aerosols and account for the observed daytime Cl_2 production. Model calculations show that the high Cl_2 concentrations significantly increased atmospheric oxidation. This so far unaccounted for source of chlorine can have substantial impacts on atmospheric chemistry. In view of the ubiquitous existence of chloride, nitrate, and acidic aerosols, we propose that nitrate photolysis is a significant daytime chlorine source globally. This work was published in *Nature Communications* (Peng et al., 2022), in collaboration of researchers from France, US, Spain, Germany, Sweden, Hong Kong and mainland China.

(2) New knowledge on the sources of HONO and its impact on air quality

HONO is a source of OH radical which is the most important oxidant in the atmosphere, but its sources and impact are not well understood. Based on the field observations, the project investigated the sources and sinks of HONO in coastal Hong Kong and found important contribution of ship emissions to HONO (Gu et al., 2022) and a potential source from photolysis

of nitro-phenols (Chen et al., 2021). Lab experiments were conducted to measure the production rates of HONO from NO_2 uptake on surface of particles, sea water, and urban grime, and the results show that NO_2 interaction with seawater is not a source of HONO and particles deposited on urban surface is (Yu et al., 2021). Chemical transport models incorporating the HONO sources proposed by researchers demonstrate that HONO can aggravate photochemical (ozone) pollution and haze in Hong Kong and other regions of China (Fu et al., 2019, 2020).

(3) Impact of improved emissions on air quality in the coastal and inland regions
With our improved chloride emissions, we used a WRF-Chem model to simulate the production of $ClNO_2$ (produced from N_2O_5 uptake on Cl-containing aerosol) and its impact on ozone under sea-land circulations in Hong Kong and adjacent coastal waters and found contribution to surface ozone of up to 6% (Dai et al., 2020). We collaborated with researchers from the US and Spain, who conducted simulations of halogens impact on the atmospheric oxidation capacity (Li et al., 2020, 2021) and PM2.5 (X. Wang et al., 2021). The results confirm the important contributions of halogen to secondary pollutants in China. We also evaluated the effect of drought on ozone and aerosol in southern China (P. Wang et al, 2021). We collaborated with US and European scientists and investigated the impact on ozone of reductions in human activities by community lockdown to contain the Covid-19. The results provided valuable insights into the complex response of ozone to meteorology and emission changes in China and the world (Liu et al., 2021; Stavarakou et al., 2021; Gaubert et al., 2021; Bouarar et al., 2021; Doumbia et a., 2021). The result demonstrates that ozone concentration can increase despite large reductions in anthropogenic pollutants emission as the result of non-linear relationship of O_3 to precursors (NOx and VOCs).

(4) Other findings
With the support of this project, we developed an I-CIMS technique to concurrently measure HONO and reactive halogen gases, improved a widely used MCM model by including additional chlorine and bromine chemistry (Peng et al., 2021), and enriched knowledge on $ClNO_2$, N_2O_5, Cl_2, isoprene oxidation and sulfate formation from analysis of field observations (Chao et al., 2019; X. Wang et al., 2020; Xia et al., 2021; Li et al., 2020; Tsiligiannis et al., 2022).

Potential for further development of the research and the proposed course of action *(maximum half a page)*

A major finding of this project is the unexpected high concentrations of Cl_2 produced from liberation of inert chloride in sea salt aerosols. However, an important chlorine reservoir (gas-phase HCl) was not measured in the field study, limiting understanding of total chlorine source. We have proposed a new research to modify our CIMS technique to measure HCl, and the proposal tilted “Hydrochloric acid in the polluted coastal atmosphere of South China: abundances, sources, and impacts” has been supported by the RGC GRF 2021-2022 scheme. In addition, it is desirable to measure Cl_2 on other regions to confirm its presence and impact in other geographical areas. We will propose additional research to address such need.

7. The Layman's Summary

(describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

This project aims to understand the interactions of man-made pollutants with sea sprays and their impacts on air quality in coastal cities. The project developed advanced techniques to measure radical precursors and improved air quality models for better simulations of radical chemistry (OH and halogen atoms) which plays key roles in the chemical production of air pollutants. The project conducted a comprehensive field campaign, lab experiments, and computer simulations. The project found unexpected high concentrations of Cl_2, unraveled its source and impact on ozone - a persistent air pollutant in Hong Kong. This is an important discovery that points out a new direction for atmospheric chemistry research and air quality management. The project has also advanced knowledge on other halogen and nitrogen compounds. The improved instruments and models have been used in other studies, and our findings have been disseminated to the Hong Kong Environmental Protection Department. The project has strengthened/established collaborations with international and mainland scientists.

Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of each publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2019			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Xiao Fu, Tao Wang*, Li Zhang, Qinyi Li, Zhe Wang, Men Xia, Hui Yun, Weihao Wang, Chuan Yu, Dingli Yue, Yan Zhou, Junyun Zheng, and Rui Han.			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang	0000-0002-4765-9377	tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	The significant contribution of HONO to secondary pollutants during a severe winter pollution event in southern China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Atmospheric Chemistry and Physics			
vii. **Volume**	19			
viii. **Issue number**	1			
ix. **Pages**	1–14			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2019			
xiii. **Original language of the publication**	English			

xiv. **Publisher or equivalent**	EGU
xv. **Digital object identifier (DOI)**	https://doi.org/10.5194/acp-19-1-2019
xvi. **Abstract (as set out in the journal article)**	Nitrous acid (HONO) can strongly affect atmospheric photochemistry in polluted regions through the production of hydroxyl radicals (OHs). In January 2017, a severe pollution episode occurred in the Pearl River Delta (PRD) of China, with maximum hourly PM2.5, ozone, and HONO levels reaching 400 µg m−3, 150 ppb, and 8 ppb, respectively, at a suburban site. The present study investigated the sources and processes generating such high HONO concentrations and the role of HONO chemistry in this severe winter episode. Four recently reported HONO sources were added to the Community Multiscale Air Quality (CMAQ) model, including RH-dependent (relative humidity) and light-enhancing effects on heterogeneous reactions, photolysis of particulate nitrate in the atmosphere, and photolysis of HNO3 and nitrate on surfaces. The revised model reproduced the observed HONO and significantly improved its performance for O3 and PM2.5. The model simulations showed that the heterogeneous generation on surfaces (with RH and light effects) was the largest contributor (72 %) to the predicted HONO concentrations, with the RH-enhancing effects more significant at nighttime and the light-enhancing effects more important in the daytime. The photolysis of total nitrate in the atmosphere and deposited on surfaces was the dominant HONO source during noon and afternoon, contributing above 50 % of the simulated HONO. The HONO photolysis was the dominant contributor to HOx production in this episode. With all HONO sources, the daytime average O3 at the Heshan site was increased by 24 ppb (or 70 %), compared to the simulation results without any HONO sources. Moreover, the simulated mean concentrations of TNO3 (HNO3+ fine particle) at the Heshan site, which was the key species for this haze formation, increased by about 17 µg m−3 (67 %) due to the HONO chemistry, and the peak enhancement reached 55 µg m−3. This study highlights the key role of HONO chemistry in the formation of winter haze in a subtropical environment.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	

xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	2019
xxviii. **Attached to this report** *(Yes or No)*	No
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2019			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Chao Yan, Yee Jun Tham, Qiaozhi Zha, Xinfeng Wang, Likun Xue, Jianing Dai, Zhe Wang, Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang	0000-0002-4765-9377	tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Fast heterogeneous loss of N2O5 leads to significant nighttime NOx removal and nitrate aerosol formation at a coastal background environment of southern China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Science of The Total Environment			
vii. **Volume**	677			
viii. **Issue number**				
ix. **Pages**	637-647			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2019			
xiii. **Original language of the publication**	English			

xiv. **Publisher or equivalent**	Elsevier
xv. **Digital object identifier (DOI)**	https://doi.org/10.1016/j.scitotenv.2019.04.389
xvi. **Abstract (as set out in the journal article)**	Nitrate radical (NO3) and dinitrogen pentoxide (N2O5) play crucial roles in the nocturnal atmosphere. To quantify their impacts, we deployed a thermal-dissociation chemical ionization mass spectrometry (TD-CIMS), to measure their concentration, as well as ClNO2 at a coastal background site in the southern of China during the late autumn of 2012. Moderate levels of NO3, N2O5 and high concentration of ClNO2 were observed during the study period, indicating active NOx-O3 chemistry in the region. Distinct features of NO3, N2O5 and ClNO2 mixing ratios were observed in different airmasses. Further analysis revealed that the N2O5 heterogeneous reaction was the dominant loss of N2O5 and NO3, which showed higher loss rate compared to that in other coastal sites. Especially, the N2O5 loss rates could reach up to 0.0139 s−1 when airmasses went across the sea. The fast heterogeneous loss of N2O5 led to rapid NOx loss which could be comparable to the daytime process through NO2 oxidization by OH, and on the other hand, to rapid nitrate aerosol formation. In summary, our results revealed that the N2O5 hydrolysis could play significant roles in regulating the air quality by reducing NOx but forming nitrate aerosols.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No

xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	2019
xxviii. **Attached to this report** *(Yes or No)*	No
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2020			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Yuanyuan Li, Wei Nie*, Yuliang Liu, Dandan Huang, Zheng Xu, Xiang Peng, Christian George, Chao Yan, Yee Jun Tham, Chuan Yu, Men Xia, Xiao Fu, Xinfeng Wang, Likun Xue, Zhe Wang, Zhengning Xu, Xuguang Chi, Tao Wang, and Aijun Ding			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Wei Nie	0000-0002-6048-0515	niewei@nju.edu.cn	
iv. **Title (in published language)**	Photoinduced Production of Chlorine Molecules from Titanium Dioxide Surfaces Containing Chloride			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	7			
viii. **Issue number**	2			
ix. **Pages**	70–75			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.estlett.9b00704			

xvi. **Abstract (as set out in the journal article)**	Titanium dioxide (TiO2) is extensively used with the process of urbanization and potentially influences atmospheric chemistry, which is yet unclear. In this work, we demonstrated strong production of Cl2 from illuminated KCl-coated TiO2 membranes and suggested an important daytime source of chlorine radicals. We found that water and oxygen were required for the reactions to proceed, and Cl2 production increased linearly with the amount of coated KCl, humidity of the carrier gas, and light intensity. These results suggested that water promotes the reactivity of coated KCl via interaction with the crystal lattice to release free chloride ions (Cl–). The free Cl– transfer charges to O2 via photoactivated TiO2 to form Cl2 and probably the O2– radical. In addition to Cl2, ClO and HOCl were also observed via the complex reactions between Cl/Cl2 and HOx. An intensive campaign was conducted in Shanghai, during which evident daytime peaks of Cl2 were observed. Estimated Cl2 production from TiO2 photocatalysis can be up to 0.2 ppb/h when the TiO2-containing surface reaches 20% of the urban surface, and highly correlated to the observed Cl2. Our results suggest a non-negligible role of TiO2 in atmospheric photochemistry via altering the radical budget.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.estlett.9b00704
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	

xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2020			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Xinke Wang, Rachel Gemayel, Nathalie Hayeck, Sebastien Perrier, Nicolas Charbonnel, Caihong Xu, Hui Chen, Chao Zhu, Liwu Zhang, Lin Wang, Sergey A. Nizkorodov, Xinming Wang, Zhe Wang, Tao Wang, Abdelwahid Mellouki, Matthieu Riva, Jianmin Chen*, and Christian George*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	Atmospheric Photosensitization: A New Pathway for Sulfate Formation			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	54			
viii. **Issue number**	6			
ix. **Pages**	3114–3120			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.est.9b06347			

xvi. **Abstract (as set out in the journal article)**	Northern China is regularly subjected to intense wintertime “haze events”, with high levels of fine particles that threaten millions of inhabitants. While sulfate is a known major component of these fine haze particles, its formation mechanism remains unclear especially under highly polluted conditions, with state-of-the-art air quality models unable to reproduce or predict field observations. These haze conditions are generally characterized by simultaneous high emissions of SO2 and photosensitizing materials. In this study, we find that the excited triplet states of photosensitizers could induce a direct photosensitized oxidation of hydrated SO2 and bisulfite into sulfate S(VI) through energy transfer, electron transfer, or hydrogen atom abstraction. This photosensitized pathway appears to be a new and ubiquitous chemical route for atmospheric sulfate production. Compared to other aqueous-phase sulfate formation pathways with ozone, hydrogen peroxide, nitrogen dioxide, or transition-metal ions, the results also show that this photosensitized oxidation of S(IV) could make an important contribution to aerosol sulfate formation in Asian countries, particularly in China.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.est.9b06347
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	

xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2020			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Xiao Fu, Tao Wang*, Jian Gao, Peng Wang, Yiming Liu, Shuxiao Wang, Bin Zhao, and Likun Xue			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang	0000-0002-4765-9377	tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Persistent Heavy Winter Nitrate Pollution Driven by Increased Photochemical Oxidants in Northern China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	54			
viii. **Issue number**	7			
ix. **Pages**	3881-3889			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.est.9b07248			

xvi. **Abstract (as set out in the journal article)**	Nitrate is an increasingly important component of fine particulate matter (PM2.5) during winter in northern China. Past emission control has been ineffective in reducing winter nitrate. Here, we use extensive observations and a model with state-of-the-art nitrogen chemistry to identify the key factors that control the nitrate formation in the heavily polluted North China Plain (NCP). In contrast to the previous view of weak winter photochemistry, we show that the O3 and OH productions are sufficiently high in winter to facilitate fast gas-phase and heterogeneous conversion of NOX to nitrate over the NCP. Increasing O3 and OH productions from higher precursor levels and fast ROX cycling accelerate the nitrate generation during heavy pollution. We find that the 31.8% reduction of NOX emissions from 2010 to 2017 in the NCP lowers surface nitrate by only 0.2% and even increases nitrate in some polluted areas. This is mainly due to the increase of O3 and OH (by ~30%), which has subsequently increased the conversion efficiency of NOX to HNO3 (by 38.7%). Future control strategies for the winter haze should also aim to lower photochemical oxidants, via larger and synchronized NOX and VOCs emissions reduction, to overcome the effects of nonlinear photochemistry and aerosol chemical feedback.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.est.9b07248
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	

xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2020			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Qinyi Li, Alba Badia, Tao Wang, Golam Sarwar, Xiao Fu, Li Zhang, Qiang Zhang, Jimmy Fung, Carlos A. Cuevas, Shanshan Wang, Bin Zhou, Alfonso Saiz-Lopez*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Alfonso Saiz-Lopez	0000-0002-0060-1581	a.saiz@csic.es	
iv. **Title (in published language)**	Potential Effect of Halogens on Atmospheric Oxidation and Air Quality in China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Journal of Geophysical Research			
vii. **Volume**	125			
viii. **Issue number**	9			
ix. **Pages**	e2019JD032058			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	AGU			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1029/2019JD032058			

xvi. **Abstract (as set out in the journal article)**	Air pollution has been a hazard in China over recent decades threatening the health of half a billion people. Much effort has been devoted to mitigating air pollution in China leading to a significant reduction in primary pollutants emissions from 2013 to 2017, while a continuously worsening trend of surface ozone (O3, a secondary pollutant and greenhouse gas) was observed over the same period. Atmospheric oxidation, dominated by daytime reactions involving hydroxyl radicals (OH), is the critical process to convert freshly-emitted compounds into secondary pollutants, and is underestimated in current models of China's air pollution. Halogens (chlorine, bromine, and iodine) are known to profoundly influence oxidation chemistry in the marine environment; however, their impact on atmospheric oxidation and air pollution in China is unknown. In the present study, we report for the first time that halogens substantially enhance the total atmospheric oxidation capacity in polluted areas of China, typically 10% to 20% (up to 87% in winter) and mainly by significantly increasing OH level. The enhanced oxidation along the coast is driven by oceanic emissions, and that over the inland areas by anthropogenic emission. The extent and seasonality of halogen impact are largely explained by the dynamics of Asian monsoon, location and intensity of halogen emissions, and O3 formation regime. The omission of halogen emissions and chemistry may lead to significant errors in historical re-assessments and future projections of the evolution of atmospheric oxidation in polluted regions.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019JD032058
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	

xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2020			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Xuan Wang*, Daniel J. Jacob, Xiao Fu, Tao Wang, Michael Le Breton, Mattias Hallquist, Zirui Liu, Erin E. McDuffie, and Hong Liao			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Xuan Wang		xuanwang@cityu.edu.hk	
iv. **Title (in published language)**	Effects of Anthropogenic Chlorine on PM2.5 and Ozone Air Quality in China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	54			
viii. **Issue number**	16			
ix. **Pages**	9908–9916			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.est.0c02296			

xvi. **Abstract (as set out in the journal article)**	China has large anthropogenic chlorine emissions from agricultural fires, residential biofuel, waste incineration, coal combustion, and industrial processes. Here we quantify the effects of chlorine on fine particulate matter (PM2.5) and ozone air quality across China by using the GEOS-Chem chemical transport model with comprehensive anthropogenic emissions and detailed representation of gas-phase and heterogeneous chlorine chemistry. Comparison of the model to observed ClNO2, HCl, and particulate Cl– concentrations shows that reactive chlorine in China is mainly anthropogenic, unlike in other continental regions where it is mostly of marine origin. The model is successful in reproducing observed concentrations and their distributions, lending confidence in the anthropogenic chlorine emission estimates and the resulting chemistry. We find that anthropogenic chlorine emissions increase total inorganic PM2.5 by as much as 3.2 μg m–3 on an annual mean basis through the formation of ammonium chloride, partly compensated by a decrease of nitrate because ClNO2 formation competes with N2O5 hydrolysis. Annual mean MDA8 surface ozone increases by up to 1.9 ppb, mainly from ClNO2 chemistry, while reactivities of volatile organic compounds increase (by up to 48% for ethane). We find that a sufficient representation of chlorine chemistry in air quality models can be obtained from consideration of HCl/Cl– thermodynamics and ClNO2 chemistry, because other more complicated aspects of chlorine chemistry have a relatively minor effect.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.est.0c02296
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	

xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
			2020	
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Wei Pu, Zhouxing Zou, Weihao Wang, David Tanner, Zhe Wang, and Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	Development of a chemical ionization mass spectrometry system for measurement of atmospheric OH radical			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Atmospheric Measurement Techniques Discussions			
vii. **Volume**				
viii. **Issue number**				
ix. **Pages**				
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**				
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	EGU			
xv. **Digital object identifier (DOI)**	https://doi.org/10.5194/amt-2020-252			

xvi. **Abstract (as set out in the journal article)**	The hydroxyl radical (OH) is the most important oxidant in the atmosphere and plays a central role in tropospheric chemistry. Ambient OH is extremely difficult to measure because of its low concentration and high reactivity. We have developed and optimized a chemical ionization mass spectrometry (CIMS) system to measure OH based on ion-assisted mass spectrometry. A calibration unit was developed based on chemical actinometry to convert detected signals to OH concentration. Different types of ion sources (210Po and corona source) and scavenger gases (propane, C3F6, and NO2) were compared. Radioactive ion source (210Po foils) was chosen for lower detection limits, and propane was selected for high elimination efficiency and the negligible influence on the signal stability. The sensitivity of the CIMS instrument to OH radicals is influenced by the efficiencies of titration reaction, ion conversion, and ion transmission. Through adjusting their efficiencies by changing the flow rates and voltages, optimal sensitivity was determined. The background noise from OH interferences was reduced by adjusting the flow rate of scavenger gas. The CIMS system achieved a detection limit of ~ 0.15×106 molecules cm−3 (signal/noise = 2). The CIMS was then taken out to measure ambient OH radicals at an urban site in Hong Kong in April 2019. An obvious diurnal pattern of OH radicals was observed, with the highest concentration of ~ 6×106 molecules cm−3 at midday and the lowest concentration of ~ 0.25×106 molecules cm−3 at night, with an overall accuracy of about ±51 %. The results demonstrated the capability of our CIMS for OH measurements on clear days. The tests and results from our study provide a useful reference to other researchers who wish to develop and apply the CIMS technique to measure OH and other chemicals.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://amt.copernicus.org/preprints/amt-2020-252/

xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
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xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

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ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Jianing Dai, Yiming Liu, Peng Wang, Xiao Fu, Men Xia, Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	The impact of sea-salt chloride on ozone through heterogeneous reaction with N2O5 in a coastal region of south China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Atmospheric Environment			
vii. **Volume**	236			
viii. **Issue number**				
ix. **Pages**	117604			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2020			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	Elsevier			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1016/j.atmosenv.2020.117604			

xvi. **Abstract (as set out in the journal article)**	In coastal regions, particulate chloride (Cl−) in sea-salt can react with gaseous dinitrogen pentoxide (N2O5) and produces nitryl chloride (ClNO2) after the heterogeneous uptake of N2O5. Photolysis of ClNO2 by sunlight enhances atmospheric oxidation capacity and contributes to the formation of ozone (O3). Using a regional chemical model (WRF-Chem), we evaluated the emission of particulate Cl− from the South China Sea, the chlorine loss in sea-salt aerosols, and the impact of sea-salt chloride on O3 formation over the Hong Kong-Pearl River Delta (HK-PRD) and surrounding maritime regions. Two typical O3 episodes in early autumn (September 2017 and 2018) were analyzed. The modeled results of particulate Cl− agreed well with the observations at a coastal site in both two cases, but the model underestimated ClNO2 by a factor of 2 in the 2018 case when N2O5 and ClNO2 were measured. The temporal and spatial distributions of chloride loss and ClNO2 production were simulated for the 2017 case which contained maritime inflow and continental outflow. During maritime winds, the oceanic fine particulate Cl− penetrated deep inland and was depleted by up to 40% by N2O5 heterogeneous reaction which lead to elevated ClNO2 mixing ratios (up to 0.6 ppb) produced at night. During the phase of continental outflow, the heterogeneous reaction of N2O5 contributed 18–33% to the depletion of particulate sea-salt Cl− in the coastal areas, leading to an increase in ClNO2 mixing ratio up to 0.8 ppb in the residual layer (~300 m). The ClNO2 from sea-salt chloride increased the O3 mixing ratios by up to 2.0 ppb (4%) over the inland areas during marine winds and up to 3.8 ppb (5.5%) and 6.5 ppb (7.6%) over the South China Sea. This study highlights the considerable impact of the heterogeneous reaction of reactive nitrogen on chlorine loss of sea-salt and O3 formation in coastal regions.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.sciencedirect.com/science/article/pii/S1352231020303381#!

xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

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^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Benjamin Gaubert, Idir Bouarar, Thierno Doumbia, Yiming Liu, Trissevgeni Stavrakou, Adrien Deroubaix, Sabine Darras, Nellie Elguindi, Claire Granier, Forrest Lacey, Jean-François Müller, Xiaoqin Shi, Simone Tilmes, Tao Wang, Guy P. Brasseur*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	Global Changes in Secondary Atmospheric Pollutants During the 2020 COVID-19 Pandemic			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**				
vii. **Volume**	126			
viii. **Issue number**	8			
ix. **Pages**	e2020JD034213			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	AGU			
xv. **Digital object identifier (DOI)**				

xvi. **Abstract (as set out in the journal article)**	We use the global Community Earth System Model to investigate the response of secondary pollutants (ozone O3, secondary organic aerosols SOA) in different parts of the world in response to modified emissions of primary pollutants during the COVID-19 pandemic. We quantify the respective effects of the reductions in NOx and in volatile organic carbon (VOC) emissions, which, in most cases, affect oxidants in opposite ways. Using model simulations, we show that the level of NOx has been reduced by typically 40% in China during February 2020 and by similar amounts in many areas of Europe and North America in mid-March to mid-April 2020, in good agreement with space and surface observations. We show that, relative to a situation in which the emission reductions are ignored and despite the calculated increase in hydroxyl and peroxy radicals, the ozone concentration increased only in a few NOx-saturated regions (northern China, northern Europe, and the US) during the winter months of the pandemic when the titration of this molecule by NOx was reduced. In other regions, where ozone is NOx-controlled, the concentration of ozone decreased. SOA concentrations decrease in response to the concurrent reduction in the NOx and VOC emissions. The model also shows that atmospheric meteorological anomalies produced substantial variations in the concentrations of chemical species during the pandemic. In Europe, for example, a large fraction of the ozone increase in February 2020 was associated with meteorological anomalies, while in the North China Plain, enhanced ozone concentrations resulted primarily from reduced emissions of primary pollutants.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020JD034213
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	

xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

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ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Trissevgeni Stavrakou*, Jean-François Müller, Maite Bauwens, Thierno Doumbia, Nellie Elguindi, Sabine Darras, Claire Granier, Isabelle De Smedt, Christophe Lerot, Michel Van Roozendael, Bruno Franco, Lieven Clarisse, Cathy Clerbaux, Pierre-François Coheur, Yiming Liu, Tao Wang, Xiaoqin Shi, Benjamin Gaubert, Simone Tilmes and Guy Brasseur			
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iv. **Title (in published language)**	Atmospheric Impacts of COVID-19 on NOx and VOC Levels over China Based on TROPOMI and IASI Satellite Data and Modeling			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Atmosphere			
vii. **Volume**	12			
viii. **Issue number**	8			
ix. **Pages**	946			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	MDPI			
xv. **Digital object identifier (DOI)**	https://doi.org/10.3390/atmos12080946			

xvi. **Abstract (as set out in the journal article)**	China was the first country to undergo large-scale lockdowns in response to the pandemic in early 2020 and a progressive return to normalization after April 2020. Spaceborne observations of atmospheric nitrogen dioxide (NO2) and oxygenated volatile organic compounds (OVOCs), including formaldehyde (HCHO), glyoxal (CHOCHO), and peroxyacetyl nitrate (PAN), reveal important changes over China in 2020, relative to 2019, in response to the pandemic-induced shutdown and the subsequent drop in pollutant emissions. In February, at the peak of the shutdown, the observed declines in OVOC levels were generally weaker (less than 20%) compared to the observed NO2 reductions (−40%). In May 2020, the observations reveal moderate decreases in NO2 (−15%) and PAN (−21%), small changes in CHOCHO (−3%) and HCHO (6%). Model simulations using the regional model MAGRITTEv1.1 with anthropogenic emissions accounting for the reductions due to the pandemic explain to a large extent the observed changes in lockdown-affected regions. The model results suggest that meteorological variability accounts for a minor but non-negligible part (∼−5%) of the observed changes for NO2, whereas it is negligible for CHOCHO but plays a more substantial role for HCHO and PAN, especially in May. The interannual variability of biogenic and biomass burning emissions also contribute to the observed variations, explaining e.g., the important column increases of NO2 and OVOCs in February 2020, relative to 2019. These changes are well captured by the model simulations.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.mdpi.com/2073-4433/12/8/946
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	

xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
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ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Thierno Doumbia*, Claire Granier*, Nellie Elguindi, Idir Bouarar, Sabine Darras, Guy Brasseur, Benjamin Gaubert, Yiming Liu, Xiaoqin Shi, Trissevgeni Stavrakou, Simone Tilmes, Forrest Lacey, Adrien Deroubaix, and Tao Wang			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	Changes in global air pollutant emissions during the COVID-19 pandemic: a dataset for atmospheric modeling			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Earth System Science Data			
vii. **Volume**	13			
viii. **Issue number**	8			
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x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	Copernicus Publications			
xv. **Digital object identifier (DOI)**	https://doi.org/10.5194/essd-13-4191-2021			

xvi. **Abstract (as set out in the journal article)**	In order to fight the spread of the global COVID-19 pandemic, most of the world's countries have taken control measures such as lockdowns during a few weeks to a few months. These lockdowns had significant impacts on economic and personal activities in many countries. Several studies using satellite and surface observations have reported important changes in the spatial and temporal distributions of atmospheric pollutants and greenhouse gases. Global and regional chemistry-transport model studies are being performed in order to analyze the impact of these lockdowns on the distribution of atmospheric compounds. These modeling studies aim at evaluating the impact of the regional lockdowns at the global scale. In order to provide input for the global and regional model simulations, a dataset providing adjustment factors (AFs) that can easily be applied to current global and regional emission inventories has been developed. This dataset provides, for the January–August 2020 period, gridded AFs at a 0.1×0.1 latitude–longitude degree resolution on a daily or monthly basis for the transportation (road, air and ship traffic), power generation, industry and residential sectors. The quantification of AFs is based on activity data collected from different databases and previously published studies. A range of AFs are provided at each grid point for model sensitivity studies. The emission AFs developed in this study are applied to the CAMS global inventory (CAMS-GLOB-ANT_v4.2_R1.1), and the changes in emissions of the main pollutants are discussed for different regions of the world and the first 6 months of 2020. Maximum decreases in the total emissions are found in February in eastern China, with an average reduction of 20 %–30 % in NOx, NMVOCs (non-methane volatile organic compounds) and SO2 relative to the reference emissions. In the other regions, the maximum changes occur in April, with average reductions of 20 %–30 % for NOx, NMVOCs and CO in Europe and North America and larger decreases (30 %–50 %) in South America. In India and African regions, NOx and NMVOC emissions are reduced on average by 15 %–30 %. For the other species, the maximum reductions are generally less than 15 %, except in South America, where large decreases in CO and BC (black carbon) are estimated. As discussed in the paper, reductions vary highly across regions and sectors due to the differences in the duration of the lockdowns before partial or complete recovery.

xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://essd.copernicus.org/articles/13/4191/2021/
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
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xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

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ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Idir Bouarar, Benjamin Gaubert, Guy P. Brasseur*, Wolfgang Steinbrecht, Thierno Doumbia, Simone Tilmes, Yiming Liu, Trissevgeni Stavrakou, Adrien Deroubaix, Sabine Darras, Claire Granier, Forrest Lacey, Jean-François Müller, Xiaoqin Shi, Nellie Elguindi, Tao Wang			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
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iv. **Title (in published language)**	Ozone Anomalies in the Free Troposphere During the COVID-19 Pandemic			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Geophysical Research Letters			
vii. **Volume**	48			
viii. **Issue number**	16			

ix. **Pages**	
x. **Article Number**	
xi. **Other necessary publishing details (if any)**	
xii. **Year of publication / Year of acceptance**	2021
xiii. **Original language of the publication**	English
xiv. **Publisher or equivalent**	AGU
xv. **Digital object identifier (DOI)**	https://doi.org/10.1029/2021GL094204
xvi. **Abstract (as set out in the journal article)**	Using the CAM-chem Model, we simulate the response of chemical species in the free troposphere to scenarios of primary pollutant emission reductions during the COVID-19 pandemic. Zonally averaged ozone in the free troposphere during Northern Hemisphere spring and summer is found to be 5%–15% lower than 19-yr climatological values, in good agreement with observations. About one third of this anomaly is attributed to the reduction scenario of air traffic during the pandemic, another third to the reduction scenario of surface emissions, the remainder to 2020 meteorological conditions, including the exceptional springtime Arctic stratospheric ozone depletion. For the combined emission reductions, the overall COVID-19 reduction in northern hemisphere tropospheric ozone in June is less than 5 ppb below 400 hPa, but reaches 8 ppb at 250 hPa. In the Southern Hemisphere, COVID-19 related ozone reductions by 4%–6% were masked by comparable ozone increases due to other changes in 2020.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021GL094204
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No

xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
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^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Yiming Liu*, Tao Wang*, Trissevgeni Stavrakou, Nellie Elguindi, Thierno Doumbia, Claire Granier, Idir Bouarar, Benjamin Gaubert, Guy P.Brasseur			
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	Yiming Liu and Tao Wang		liuym88@mail.sysss.edu.cn; tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Diverse response of surface ozone to COVID-19 lockdown in China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Science of The Total Environment			
vii. **Volume**	789			
viii. **Issue number**				
ix. **Pages**	147739			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ELSEVIER			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1016/j.scitotenv.2021.147739			

xvi. **Abstract (as set out in the journal article)**	Ozone (O3) is a key oxidant and pollutant in the lower atmosphere. Significant increases in surface O3 have been reported in many cities during the COVID-19 lockdown. Here we conduct comprehensive observation and modeling analyses of surface O3 across China for periods before and during the lockdown. We find that daytime O3 decreased in the subtropical south, in contrast to increases in most other regions. Meteorological changes and emission reductions both contributed to the O3 changes, with a larger impact from the former especially in central China. The plunge in nitrogen oxide (NOx) emission contributed to O3 increases in populated regions, whereas the reduction in volatile organic compounds (VOC) contributed to O3 decreases across the country. Due to a decreasing level of NOx saturation from north to south, the emission reduction in NOx (46%) and VOC (32%) contributed to net O3 increases in north China; the opposite effects of NOx decrease (49%) and VOC decrease (24%) balanced out in central China, whereas the comparable decreases (45–55%) in these two precursors contributed to net O3 declines in south China. Our study highlights the complex dependence of O3 on its precursors and the importance of meteorology in the short-term O3 variability.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.sciencedirect.com/science/article/pii/S0048969721028102#!
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	

xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2021			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Men Xia, Xiang Peng, Weihao Wang, Chuan Yu, Zhe Wang, Yee Jun Tham, Jianmin Chen, Hui Chen, Yujing Mu, Chenglong Zhang, Pengfei Liu, Likun Xue, Xinfeng Wang, Jian Gao, Hong Li, and Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang	orcid.org/0000-0002-4765-9377	tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Winter ClNO2 formation in the region of fresh anthropogenic emissions: seasonal variability and insights into daytime peaks in northern China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Atmospheric Chemistry and Physics			
vii. **Volume**	21			
viii. **Issue number**	20			
ix. **Pages**	15985-16000			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	EGU			
xv. **Digital object identifier (DOI)**	https://doi.org/10.5194/acp-21-15985-2021			

xvi. **Abstract (as set out in the journal article)**	Nitryl chloride (ClNO2) is an important chlorine reservoir in the atmosphere that affects the oxidation of volatile organic compounds (VOCs) and the production of ROx radicals and ozone (O3). This study presents measurements of ClNO2 and related compounds at urban, polluted rural, and polluted lower tropospheric (mountaintop) sites in the winter of 2017–2018 over the North China Plain (NCP). The nocturnal concentrations of ClNO2 were lower at the urban and polluted rural sites but higher at the polluted lower tropospheric site. The winter concentrations of ClNO2 were generally lower than the summer concentrations that were previously observed at these sites, which was due to the lower nitrate radical (NO3) production rate (P (NO3)) and the smaller N2O5 uptake coefficients (γ (N2O5)) in winter, despite the higher ratios of dinitrogen pentoxide (N2O5) to NO3 in winter. Significant daytime peaks of ClNO2 were observed at all the sites during the winter campaigns, with ClNO2 mixing ratios of up to 1.3 ppbv. Vertical transport of ClNO2 from the residual layers and prolonged photochemical lifetime of ClNO2 in winter may explain the elevated daytime concentrations. The daytime-averaged chlorine radical (Cl) production rates (P(Cl)) from the daytime ClNO2 were 0.17, 0.11, and 0.12 ppbv h−1 at the polluted rural, urban, and polluted lower tropospheric sites, respectively, which were approximately 3–4 times higher than the campaign-averaged conditions. Box model calculations showed that the Cl atoms liberated during the daytime peaks of ClNO2 increased the ROx levels by up to 27 %–37 % and increased the daily O3 productions by up to 13 %–18 %. Our results provide new insights into the ClNO2 processes in the lower troposphere impacted by fresh and intense anthropogenic emissions and reveal that ClNO2 can be an important daytime source of Cl radicals under certain conditions in winter.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://acp.copernicus.org/articles/21/15985/2021/acp-21-15985-2021.pdf

xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
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^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Peng Wang*, Yiming Liu, Jianing Dai, Xiao Fu, Xuemei Wang, Alex Guenther, Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Peng Wang and Tao Wang		peng.ce.wang@polyu.edu.hk; tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Isoprene Emissions Response to Drought and the Impacts on Ozone and SOA in China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Journal of Geophysical Research			
vii. **Volume**	126			
viii. **Issue number**	10			
ix. **Pages**				
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	AGU			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1029/2020JD033263			

xvi. **Abstract (as set out in the journal article)**	Among the various environmental factors that affect isoprene emissions, drought has only been given limited attention. Four different drought response (DR) schemes were implemented in the Model of Emissions of Gases and Aerosols from Nature (MEGAN, version 2.1), and the Community Multiscale Air Quality (CMAQ) model was applied to investigate the drought impacts on air quality during both drought and normal years in China. Generally, all DR schemes decrease isoprene emissions except for mild drought conditions. The significant decrease and even termination of isoprene emissions are predicted in South China under severe drought conditions. During the drought period, the DR scheme considering both mild and severe drought (SMD) improves the model performance especially in severe drought-hit regions when compared with the Ozone Monitoring Instrument (OMI) averaged formaldehyde vertical column density (HCHO VCD). The results show that most of the DR schemes decrease simulated ozone (O_3) and secondary organic aerosols (SOA) levels. For both O_3 and SOA, noticeable changes are predicted in the Sichuan Basin (5 ppb and 4 μg m^{-3} for O_3 and SOA, respectively). This investigation is the first modeling study to investigate the impacts of isoprene drought response on air quality in China.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020JD033263
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	

xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
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^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Xiang Peng, Weihao Wang, Men Xia, Hui Chen, A R Ravishankara, Qinyi Li, Alfonso Saiz-Lopez, Pengfei Liu, Fei Zhang, Chenglong Zhang, Likun Xue, Xinfeng Wang, Christian George, Jinhe Wang, Yujing Mu, Jianmin Chen, Tao Wang*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang	orcid.org/0000-0002-4765-9377	tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	An unexpected large continental source of reactive bromine and chlorine with significant impact on wintertime air quality			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	National Science Review			
vii. **Volume**	8			
viii. **Issue number**	7			
ix. **Pages**	nwaa304			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**				
xv. **Digital object identifier (DOI)**	https://doi.org/10.1093/nsr/nwaa304			

xvi. **Abstract (as set out in the journal article)**	Halogen atoms affect the budget of ozone and the fate of pollutants such as hydrocarbons and mercury. Yet their sources and significances in polluted continental regions are poorly understood. Here we report the observation of unprecedented levels (averaging at 60 parts per trillion) of bromine chloride (BrCl) at a mid-latitude site in North China during winter. Widespread coal burning in rural households and a photo-assisted process were the primary source of BrCl and other bromine gases. BrCl contributed about 55% of both bromine and chlorine atoms. The halogen atoms increased the abundance of 'conventional' tropospheric oxidants (OH, HO_2 and RO_2) by 26%–73%, and enhanced oxidation of hydrocarbon by nearly a factor of two and the net ozone production by 55%. Our study reveals the significant role of reactive halogen in winter atmospheric chemistry and the deterioration of air quality in continental regions where uncontrolled coal combustion is prevalent.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://academic.oup.com/nsr/article/8/7/nwaa304/6054541?login=true
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

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ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	ChuanYu, ZheWang*, Qingxin Ma, Likun Xue, Christian George, TaoWang*			
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iv. **Title (in published language)**	Measurement of heterogeneous uptake of NO_2 on inorganic particles, sea water and urban grime			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Journal of Environmental Sciences			
vii. **Volume**	106			
viii. **Issue number**				
ix. **Pages**	124-135			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ELSEVIER			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1016/j.jes.2021.01.018			

xvi. **Abstract (as set out in the journal article)**	Heterogeneous reactions of NO_2 on different surfaces play an important role in atmospheric NO_x removal and HONO formation, having profound impacts on photochemistry in polluted urban areas. Previous studies have suggested that the NO_2 uptake on the ground or aerosol surfaces could be a dominant source for elevated HONO during the daytime. However, the uptake behavior of NO_2 varies with different surfaces, and different uptake coefficients were used or derived in different studies. To obtain a more holistic picture of heterogeneous NO_2 uptake on different surfaces, a series of laboratory experiments using different flow tube reactors was conducted, and the NO_2 uptake coefficients (γ) were determined on inorganic particles, sea water and urban grime. The results showed that heterogeneous reactions on those surfaces were generally weak in dark conditions, with the measured γ varied from $<10^{-8}$ to 3.2×10^{-7} under different humidity. A photo-enhanced uptake of NO_2 on urban grime was observed, with the obvious formation of HONO and NO from the heterogeneous reaction. The photo-enhanced γ was measured to be 1.9×10^{-6} at 5% relative humidity (RH) and 5.8×10^{-6} at 70% RH on urban grime, showing a positive RH dependence for both NO_2 uptake and HONO formation. The results demonstrate an important role of urban grime in the daytime NO_2-to-HONO conversion, and could be helpful to explain the unknown daytime HONO source in the polluted urban area.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.sciencedirect.com/science/article/pii/S100107422100022X
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	

xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2021			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Qinyi Li, Xiao Fu, Xiang Peng, Weihao Wang, Alba Badia, Rafael P. Fernandez, Carlos A. Cuevas, Yujing Mu, Jianmin Chen, Jose L. Jimenez, Tao Wang*, and Alfonso Saiz-Lopez*			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Tao Wang, and Alfonso Saiz-Lopez	orcid.org/0000-0002-4765-9377; orcid.org/0000-0002-0060-1581	tao.wang@polyu.edu.hk; a.saiz@csic.es	
iv. **Title (in published language)**	Halogens Enhance Haze Pollution in China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	55			
viii. **Issue number**	20			
ix. **Pages**	13625-13637			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.est.1c01949			

xvi. **Abstract (as set out in the journal article)**	Severe and persistent haze events in northern China, characterized by high loading of fine aerosol especially of secondary origin, negatively impact human health and the welfare of ecosystems. However, current knowledge cannot fully explain the formation of this haze pollution. Despite field observations of elevated levels of reactive halogen species (e.g., BrCl, $ClNO_2$, Cl_2, HBr) at several sites in China, the influence of halogens (particularly bromine) on haze pollution is largely unknown. Here, for the first time, we compile an emission inventory of anthropogenic bromine and quantify the collective impact of halogens on haze pollution in northern China. We utilize a regional model (WRF-Chem), revised to incorporate updated halogen chemistry and anthropogenic chlorine and bromine emissions and validated by measurements of atmospheric pollutants and halogens, to show that halogens enhance the loading of fine aerosol in northern China (on average by 21%) and especially its secondary components (~130% for secondary organic aerosol and ~20% for sulfate, nitrate, and ammonium aerosols). Such a significant increase is attributed to the enhancement of atmospheric oxidants (OH, HO_2, O_3, NO_3, Cl, and Br) by halogen chemistry, with a significant contribution from previously unconsidered bromine. These results show that higher recognition of the impact of anthropogenic halogens shall be given in haze pollution research and air quality regulation.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.est.1c01949
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	

xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2021			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Chen, Y., Zheng, P., Wang, Z.*, Pu, W., Tan, Y., Yu, C., Xia, M., Wang, W., Guo, J., Huang, D., Yan, C., Nie, W., Ling, Z., Chen, Q., Lee, S., Wang, T.			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Wang Zhe	orcid.org/0000-0002-5627-6562	z.wang@ust.hk	
iv. **Title (in published language)**	Secondary Formation and Impacts of Gaseous Nitro-Phenolic Compounds in the Continental Outflow Observed at a Background Site in South China			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Environmental Science & Technology			
vii. **Volume**	56			
viii. **Issue number**	11			
ix. **Pages**	6933-6943			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2021			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ACS			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1021/acs.est.1c04596			

xvi. **Abstract (as set out in the journal article)**	Nitro-phenolic compounds (NPs) have attracted increasing attention because of their health risks and impacts on visibility, climate, and atmospheric chemistry. Despite many measurements of particulate NPs, the knowledge of their gaseous abundances, sources, atmospheric fates, and impacts remains incomplete. Here, 18 gaseous NPs were continuously measured with a time-of-flight chemical ionization mass spectrometer at a background site in South China in autumn and winter. Abundant NPs were observed in the continental outflows from East Asia, with a total concentration up to 122.1 pptv. Secondary formation from the transported aromatics dominated the observed NPs, with mono-NPs exhibiting photochemical daytime peaks and nighttime enrichments of di-NPs and Cl-substituted NPs. The budget analysis indicates that besides the •OH oxidation of aromatics, the NO3• oxidation also contributed significantly to the daytime mono-NPs, while the further oxidation of mono-NPs by NO3• dominated the nocturnal formation of di-NPs. Photolysis was the main daytime sink of NPs and produced substantial HONO, which would influence atmospheric oxidation capacity in downwind and background regions. This study provides quantitative insights on the formation and impacts of gaseous NPs in the continental outflow and highlights the role of NO3• chemistry in the secondary nitro-aromatics production that may facilitate regional pollution.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	(Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://pubs.acs.org/doi/full/10.1021/acs.est.1c04596
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	

xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2022			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Peng, X., Wang, T.*, Wang, W., Ravishankara, A. R., George, C., Xia, M., Cai, M., Li, Q., Salvador,, C. M., Lau, C., Lyu, X., Poon, C. N., Mellouki, A., Mu, Y., Hallquist, M., Saiz-Lopez, A., Guo, H., Herrmann, H., Yu, C., Dai, J., Wang, Y., Wang, X., Yu, A., Leung, K., Lee, S., Chen, J.			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Wang Tao		tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Photodissociation of particulate nitrate as a source of daytime tropospheric Cl_2			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Nature Communications			
vii. **Volume**	13			
viii. **Issue number**	1			
ix. **Pages**	939			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2022			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	Nature			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1038/s41467-022-28383-9			

xvi. **Abstract (as set out in the journal article)**	Chlorine atoms (Cl) are highly reactive and can strongly influence the abundances of climate and air quality-relevant trace gases. Despite extensive research on molecular chlorine (Cl_2), a Cl precursor, in the polar atmosphere, its sources in other regions are still poorly understood. Here we report the daytime Cl_2 concentrations of up to 1 ppbv observed in a coastal area of Hong Kong, revealing a large daytime source of Cl_2 (2.7 pptv s^{-1} at noon). Field and laboratory experiments indicate that photodissociation of particulate nitrate by sunlight under acidic conditions (pH < 3.0) can activate chloride and account for the observed daytime Cl_2 production. The high Cl_2 concentrations significantly increased atmospheric oxidation. Given the ubiquitous existence of chloride, nitrate, and acidic aerosols, we propose that nitrate photolysis is a significant daytime chlorine source globally. This so far unaccounted for source of chlorine can have substantial impacts on atmospheric chemistry.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.nature.com/articles/s41467-022-28383-9
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	2022
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2022			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Gu, R., Wang, W., Peng, X., Xia, M., Zhao, M., Zhang, Y., Wang, Y., Liu, Y., Shen, H., Xue, L*., Wang, T*., Wang, W.			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	Xue Likun and Wang Tao		xuelikun@sdu.edu.cn; tao.wang@polyu.edu.hk	
iv. **Title (in published language)**	Nitrous acid in the polluted coastal atmosphere of the South China Sea: Ship emissions, budgets, and impacts			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Science of the Total Environment			
vii. **Volume**	826			
viii. **Issue number**				
ix. **Pages**	153692			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2022			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	ELSEVIER			
xv. **Digital object identifier (DOI)**	http://dx.doi.org/10.1016/j.scitotenv.2022.153692			

xvi. **Abstract (as set out in the journal article)**	Nitrous acid (HONO) can significantly contribute to hydroxyl radicals (OH) and thus regulate atmospheric oxidation chemistry; however, ambient HONO sources are not well quantified and vary in different environments. In this study, we conducted comprehensive field observations at a coastal site in the South China Sea and performed chemical box modelling to demonstrate contrasting budgets and impacts of diurnal atmospheric HONO derived from the sea, coastline and continent. The ship emission ratio of HONO/nitrogen oxides (NOx) (1.21 ± 0.99%) was calculated from hundreds of night-time fresh plume measurements. Offshore marine air was frequently influenced by ship exhausts, and the sea acted as an HONO sink. Heterogeneous conversions of nitrogen dioxide (NO2) on underlying surfaces and photolysis of adsorbed nitric acid (HNO3(ads)) were the major HONO sources in coastal air, when heterogeneous NO2 conversions on the ground surface and the homogeneous NO + OH dominated HONO formation in continental air. HONO photolysis was a significant source of reactive radicals (ROx = OH + HO2 + RO2) in these air masses. Atmospheric box model including only homogeneous HONO source of the NO + OH reactions significantly underpredicted the OH concentration and atmospheric oxidising capacity in coastal and continental air. This study provides new insights into the complex sources and significant impacts of HONO in the polluted coastal boundary layer.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://www.sciencedirect.com/science/article/pii/S0048969722007847
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	

xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	2022
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

i. **The Latest Status of Publication**	**Published**	**Accepted but not yet published^**	**Under Review^**	**Under Preparation^** (optional)
	2022			
^ For not-yet-published publication, items (vi) to (xxvi) can be left blank if information is not yet available.				
ii. **Author(s)** *(denote the corresponding author with an asterisk*)*	Tsiligiannis, E., Wu, R., Lee, B. H., Salvador, C. M., Priestley, M., Carlsson, P. T. M., Kang, S. Novelli, A., Vereecken, L., Fuchs, H., Mayhew, A. W., Hamilton, J. F., Edwards, P. M., Fry, J. L., Brownwood, B., Brown, S. S., Wild, R. J., Bannan, T. J., Coe, H., Allan, J., Surratt, J. D., Bacak, A., Artaxo, P., Percival, C., Guo, S., Hu, M., Wang, T., Mentel, T. F., Thornton, J. A. *, Hallquist, M*.			
iii. **Contact information of the corresponding author(s)**	Name	ORCID (if any)	Email	
	M. Hallquist and J. A. Thornto		hallq@chem.gu.se; thornton@atmos.washington.edu	
iv. **Title (in published language)**	A Four Carbon Organonitrate as a Significant Product of Secondary Isoprene Chemistry			
v. **Title in other language (if any)**				
vi. **Full name of journal/book**	Geophysical Research Letters			
vii. **Volume**	49			
viii. **Issue number**	11			
ix. **Pages**	1-12			
x. **Article Number**				
xi. **Other necessary publishing details (if any)**				
xii. **Year of publication / Year of acceptance**	2022			
xiii. **Original language of the publication**	English			
xiv. **Publisher or equivalent**	AGU			
xv. **Digital object identifier (DOI)**	https://doi.org/10.1029/2021GL097366			

xvi. **Abstract (as set out in the journal article)**	Oxidation of isoprene by nitrate radicals (NO_3) or by hydroxyl radicals (OH) under high NOx conditions forms a substantial amount of organonitrates (ONs). ONs impact NO_x concentrations and consequently ozone formation while also contributing to secondary organic aerosol. Here we show that the ONs with the chemical formula $C_4H_7NO_5$ are a significant fraction of isoprene-derived ONs, based on chamber experiments and ambient measurements from different sites around the globe. From chamber experiments we found that $C_4H_7NO_5$ isomers contribute 5%–17% of all measured ONs formed during nighttime and constitute more than 40% of the measured ONs after further daytime oxidation. In ambient measurements $C_4H_7NO_5$ isomers usually dominate both nighttime and daytime, implying a long residence time compared to C_5ONs which are removed more rapidly. We propose potential nighttime sources and secondary formation pathways, and test them using a box model with an updated isoprene oxidation schemes.
xvii. **Open access status** *(Immediate open access / Embargoed open access / Non-open access)*	Immediate open access
xviii. **Embargo end date (month, year) (if any)**	
xix. **Accessible from the institutional repository** *(Yes or No)*	Yes
xx. **Hyperlink to the publication (the link to institutional repository if preferred) (if any)**	https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021GL097366
xxi. **Other affordable means for access (if any)** *(Individual article purchase offered by the publisher / Access through the university libraries (on membership) / Contacting the corresponding author(s))*	
xxii. **Article Processing Charge (APC) for publishing the article in an open access journal*** *(Required / Not required / Not applicable)*	
xxiii. **Total amount of associated APC* (in Hong Kong dollars, if any)**	
xxiv. **Amount of associated APC paid by university* (or universities, in case it is borne by more than one university) (in Hong Kong dollars, if any)**	
xxv. **Copyright retained by author(s)** *(Yes or No)*	No
xxvi. **Number(s) and jurisdiction(s) of the granted patents associated with the article (if any)**	
xxvii. **Submitted to RGC (indicate the year ending of the relevant progress report)**	2022
xxviii. **Attached to this report** *(Yes or No)*	Yes
xxix. **Acknowledged the support of RGC** *(Yes or No)*	Yes

* *This information will be for the Secretariat's reference only and not be disclosed to the public.*

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
April/2018/ Maroc	Improving urban air quality: Lessons learned from Hong Kong	Colloque Francophone "COMBUSTION ET POLLUTION ATMOSPHERIQUE" COMPOLA@2018	2019	No	Yes	Yes
September/ 2018/France	Nitrate formation from heterogeneous reactions of dinitrogen pentoxide during a severe winter haze in southern China	Sino-French Joint Workshop on Atmospheric Environment	2019	No	Yes	Yes
November/ 2018/China	The significant contribution of HONO to secondary pollutants during a severe winter pollution event in southern China	24th Annual Conference on Atmospheric Environment of China	2019	No	Yes	Yes

10. Student(s) trained *(Please attach a copy of the title page of the thesis.)*

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
WANG Weihao	PhD	October 2014	Thesis submitted July 2020, Degree awarded March 2021

11. Other impact *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

The project has strengthened/established collaborations with international and mainland scientists.

12. Statistics on Research Outputs *(Please ensure the summary statistics below are consistent with the information presented in other parts of this report.)*

	Peer-reviewed journal publications	Conference papers	Scholarly books, monographs and chapters	Patents awarded	Other research outputs (Please specify)
No. of outputs arising directly from this research project	23	3	nil	nil	nil