# Role of sea fog over the Yellow Sea on air quality with the direct effect of aerosols

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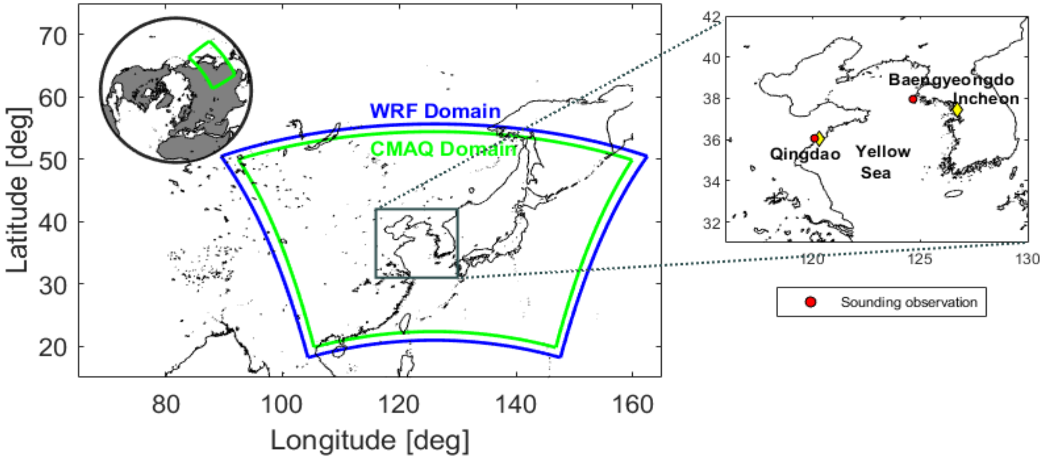
# Seasonal sea fog over the Yellow Sea

- The Yellow Sea, located between East China and the Korean Peninsula, has frequent episodes of sea fog.
- Researchers have typically categorized sea fog in this region as **advection fog** (Yang et al., 2018; Yang and Gao 2019; Zhang et al., 2009), which mainly occurs from April to July.
- Owing to the contrast between the thermal inertia of land and the ocean, quickly warmed continental air flows over the relatively colder sea surface, resulting in the formation of a temperature inversion.



# Sea fog and cloud(fog) chemistry

- Sea fog is a hazardous phenomenon
  - ✓ Myriad saturated microscopic water droplets lowers **visibility** within the marine atmospheric boundary layer (Fu et al., 2006; Gao et al., 2007; Gultepe et al., 2007; Yang et al., 2009)
  - ✓ As a pathway of long-range transport of air pollutants, the Yellow Sea, with sufficient supply of moisture, provides a medium for the **various chemical and physical processes of gaseous and aerosol pollutants** (Jeon et al., 2018; H. Lee et al., 2019; S. Lee et al., 2019). → aqueous-phase chemistry, wet deposition, in-cloud scavenging

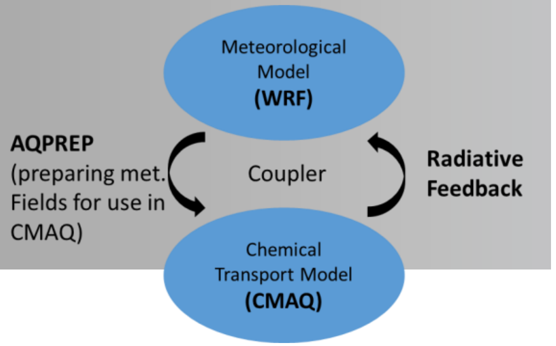
# Object of this study & experiments

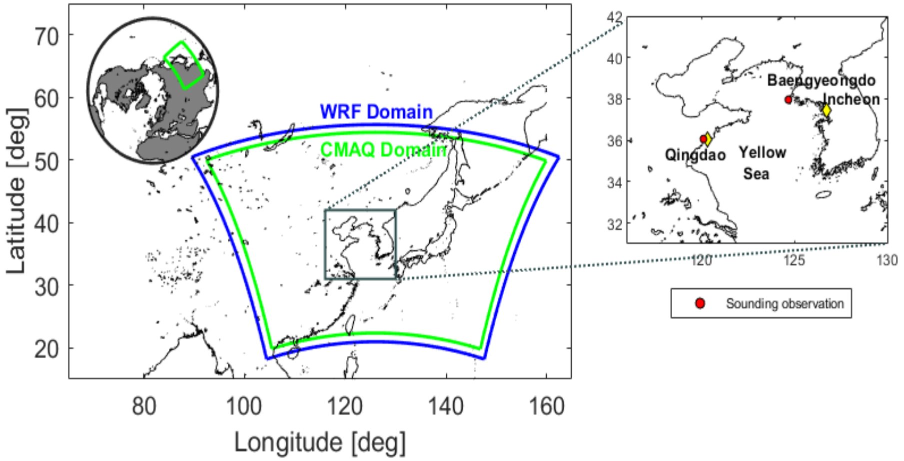
- The addition of aerosols directly affects the solar radiation budget by scattering and absorption. Meteorological changes (e.g. solar radiation, air temperature, PBLH, wind speed, precipitation, and cloud coverage) may also affect air quality.
- Using the **WRF-CMAQ two-way coupled model over East Asia for the entire year of 2016**, we conducted four model simulations to study **the impact of the direct effect of aerosols on the formation of sea fog** and its impact on **chemical and physical processes of gaseous and inorganic aerosol pollutants**.

| Experiments | Aerosol feedback | cloud chemistry in layers with temperature inversion over the ocean |
|---|---|---|
| NF | No | Yes |
| YF | Yes | Yes |
| NFAQ | No | No |
| YFAQ | Yes | No |

dT/dz > -4K/km (moist-adiabatic lapse rate)

# Modeling setup




- We used the **WRF-CMAQ two-way coupled model**, which has two-sub models, WRF model v3.8 and CMAQ model v5.2, developed and released by the US EPA (Wong et al., 2012).

- SAPRC07 and AERO6 mechanism
- Emission data: the KORUS-AQ emission inventory v5.0 (anthropogenic) and MEGAN 3.0 output (biogenic)
- Initial and boundary condition: CMAQ model with in-line dust module covering the entire Northern Hemisphere (HCMAQ) with seasonal scaling for gaseous species

**Table 1.** Configuration of the WRF-CMAQ two-way model

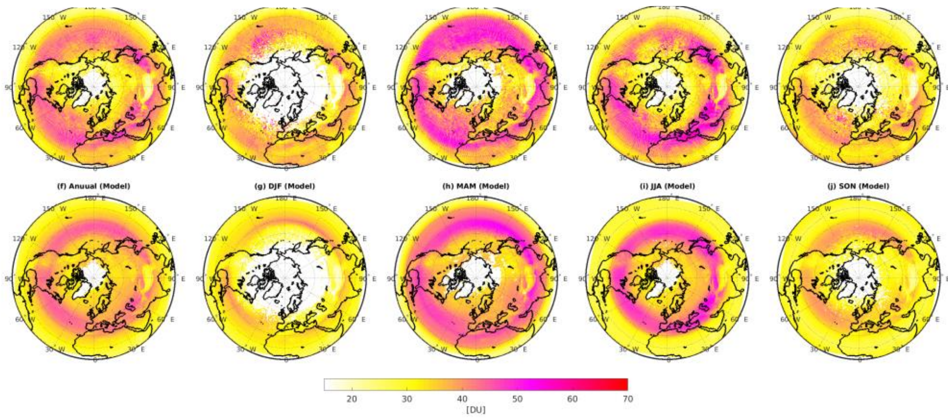
| | |
|---|---|
| Version | WRF version 3.8 and CMAQ version 5.2 |
| Microphysics | Morrison double-moment scheme |
| Longwave and shortwave radiation | RRTMG scheme |
| Land Surface | The Pleim-Xiu land surface model (Pleim and Xiu, 1995; Xiu and Pleim, 2001) |
| Surface layer | Pleim-Xiu surface layer (Pleim, 2006) |
| Planetary boundary layer | The ACM2 planetary boundary layer model (Pleim, 2007a, 2007b) |
| Cumulus parameterization | Kain-Fritsch (KF2) scheme with sub-grid cloud fraction interaction with radiation (Alapaty et al., 2012; Herwehe et al., 2014) |
| Four-Dimensional Data Assimilation (FDDA) | · Indirect soil moisture and temperature nudging technique (Pleim and Gilliam, 2009; Pleim and Xiu, 2003)<br>· A FDDA option every 6 hours above the PBL for the temperature, the water vapor mixing ratio, and wind components (magnitude of $10^{-5}$) (Hogrefe et al., 2015) |
| Initial and boundary conditions for meteorology | National Centers for Environmental Prediction FNL (final) operational global analysis data |
| Chemical mechanism | SAPRC-07 and AERO6 |
| Horizontal advection | YAMO |
| Vertical advection | WRF omega formula |
| Horizontal diffusion | Multiscale |
| Vertical diffusion | ACM2 |
| Initial and boundary conditions for chemistry | The CMAQ model version 5.3 with the in-line dust module covering the entire Northern Hemisphere |
| Call frequency between the WRF and the CMAQ | 3:1 (We set the timestep for the WRF at 120 seconds. The WRF and the CMAQ exchange meteorological data and aerosol information every 360 seconds) |

# Modeling setup

Annual DJF MAM JJA SON

OBS

MOD

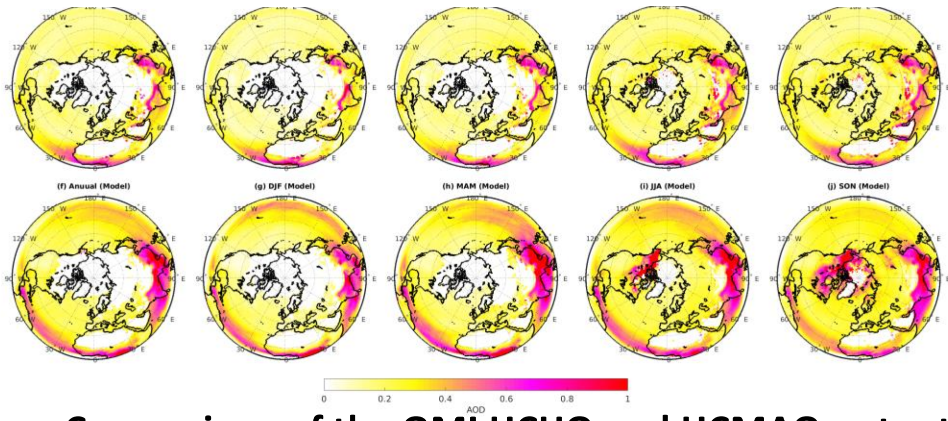



< Comparison of the OMI $O_3$ and HCMAQ output>

Annual DJF MAM JJA SON

OBS

MOD

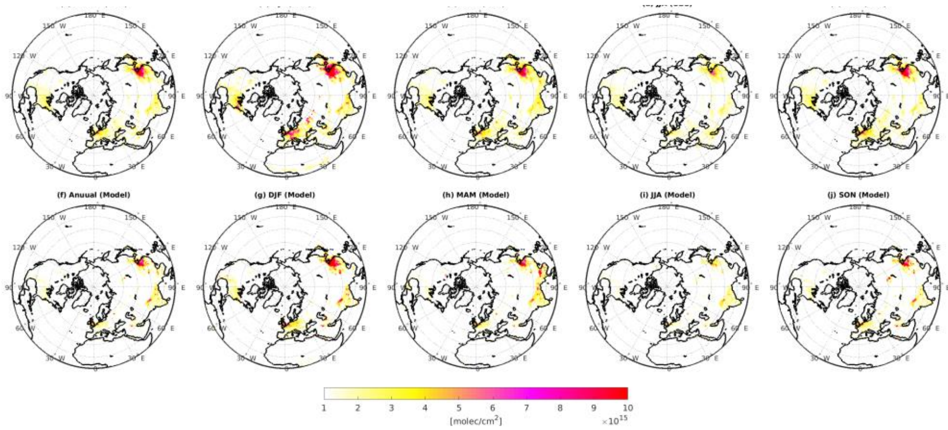



< Comparison of the OMI HCHO and HCMAQ output>

Annual DJF MAM JJA SON

OBS

MOD

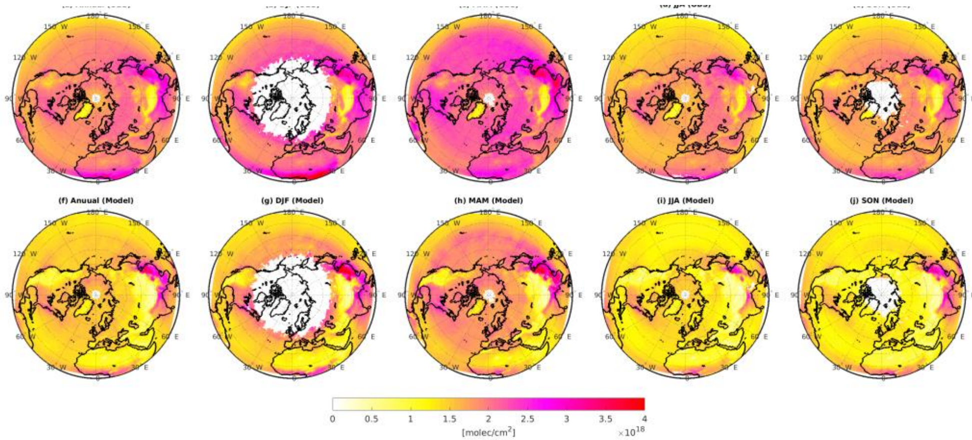



< Comparison of the OMI $NO_2$ and HCMAQ output>

Annual DJF MAM JJA SON

OBS

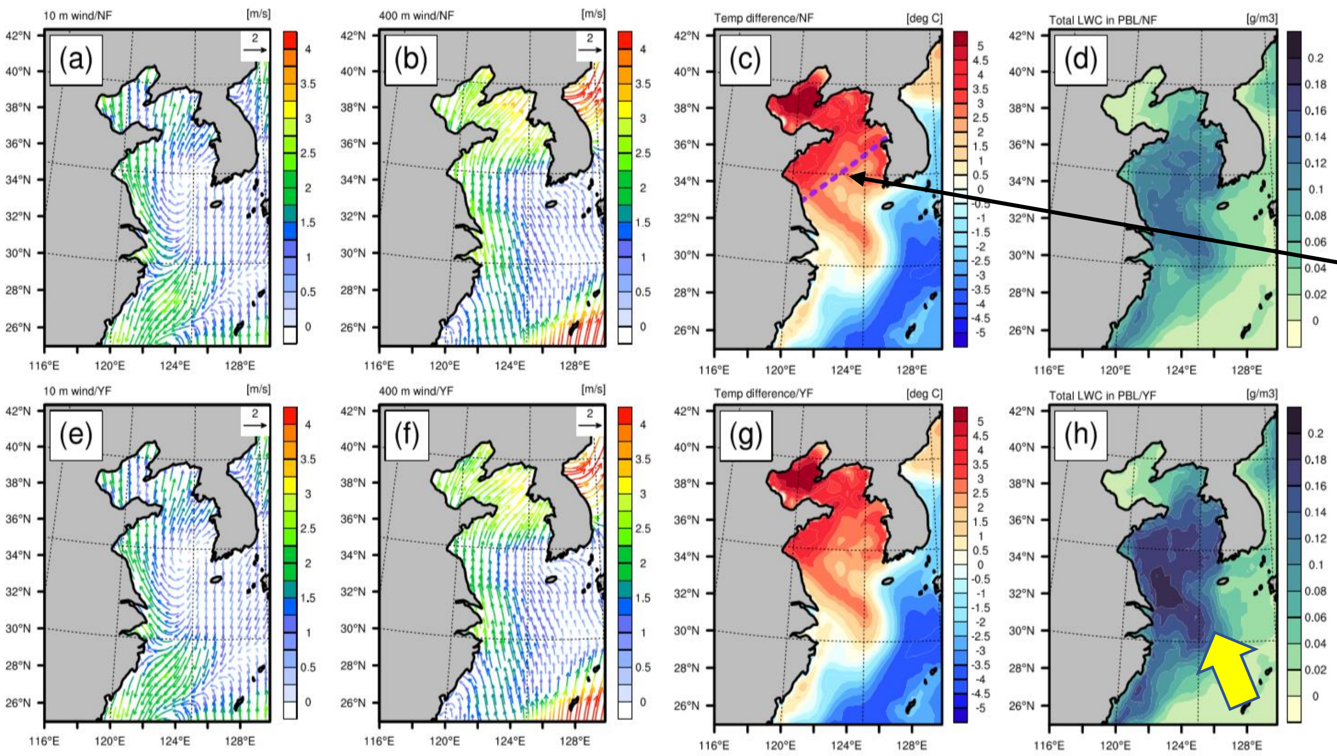
MOD

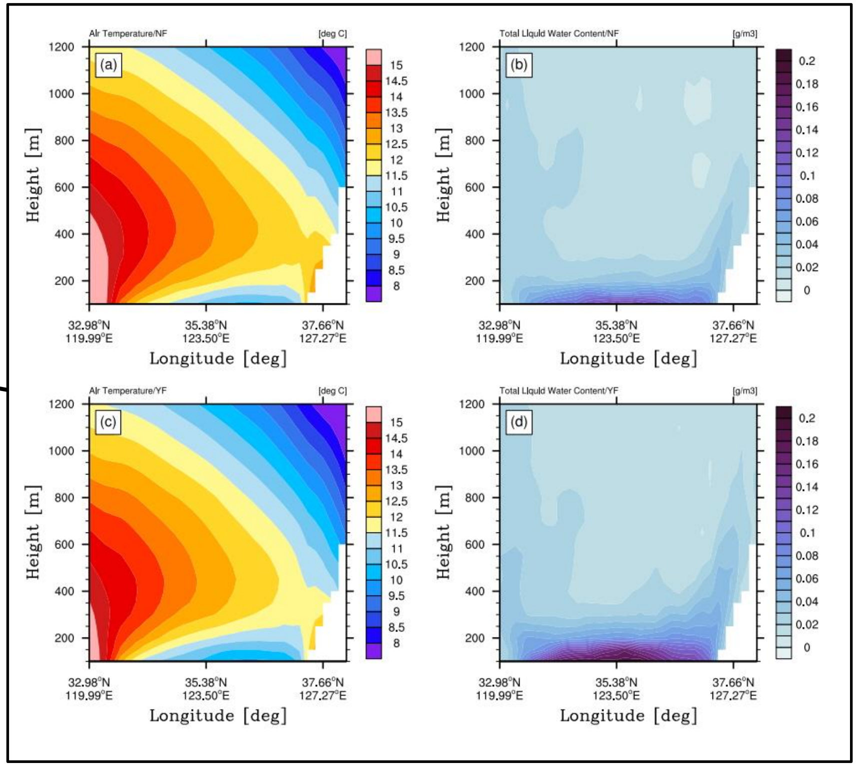



< Comparison of the MOPITT CO and HCMAQ output>

# The response of fog formation over the Yellow Sea to the direct effect of aerosols

| | 10 m wind fields | 400 m wind fields | temperature difference | Liquid water content in PBL |
|---|---|---|---|---|
| NF | | | | |
| YF | | | | |



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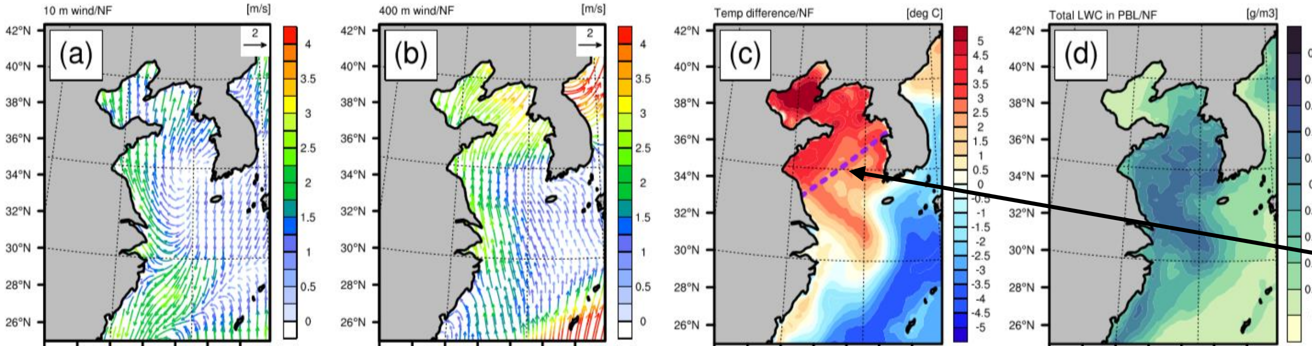


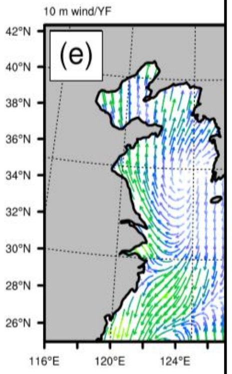


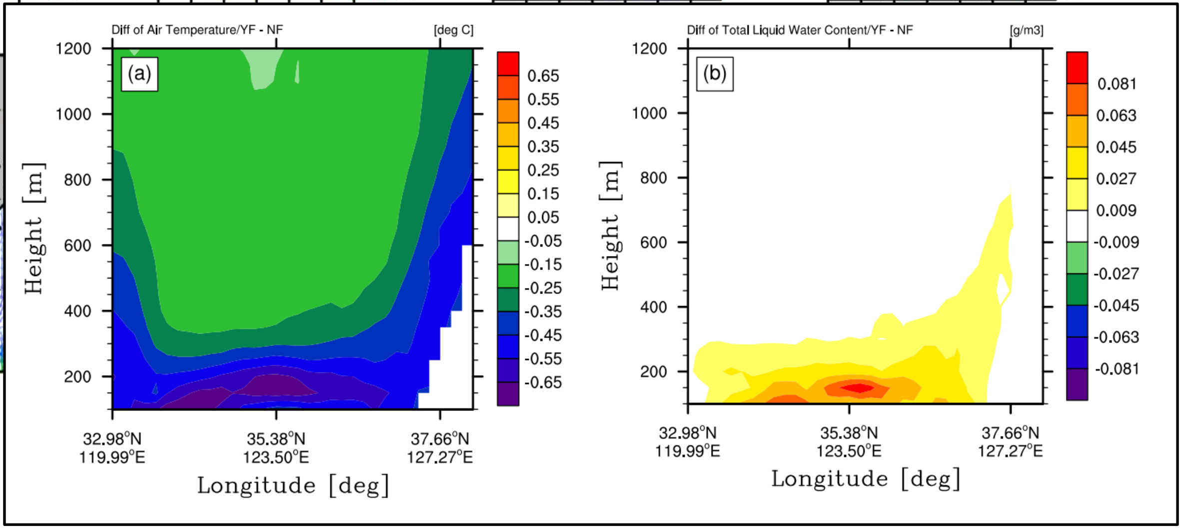


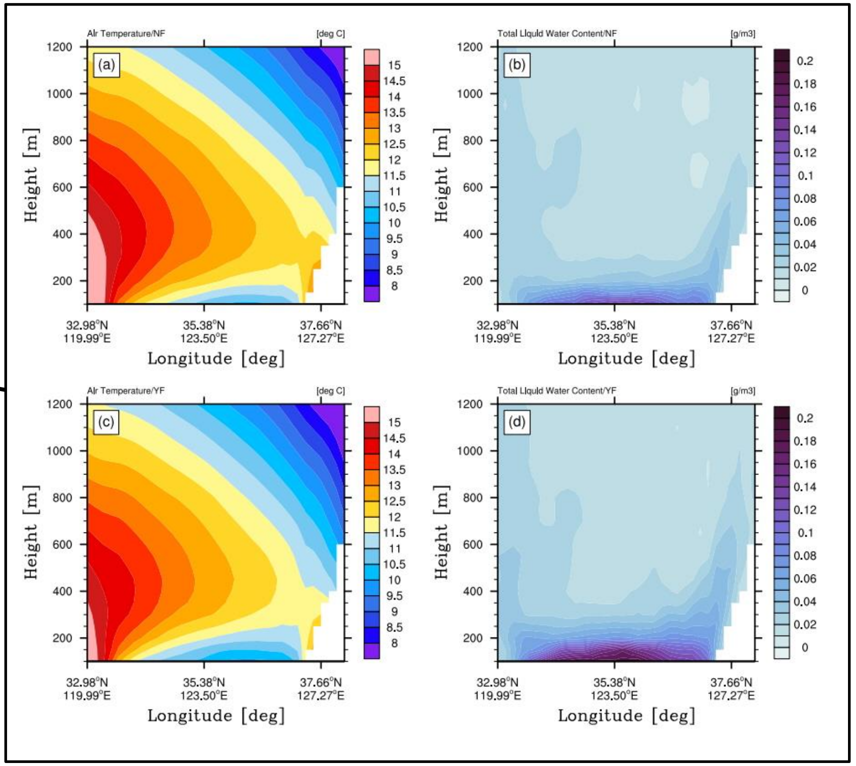

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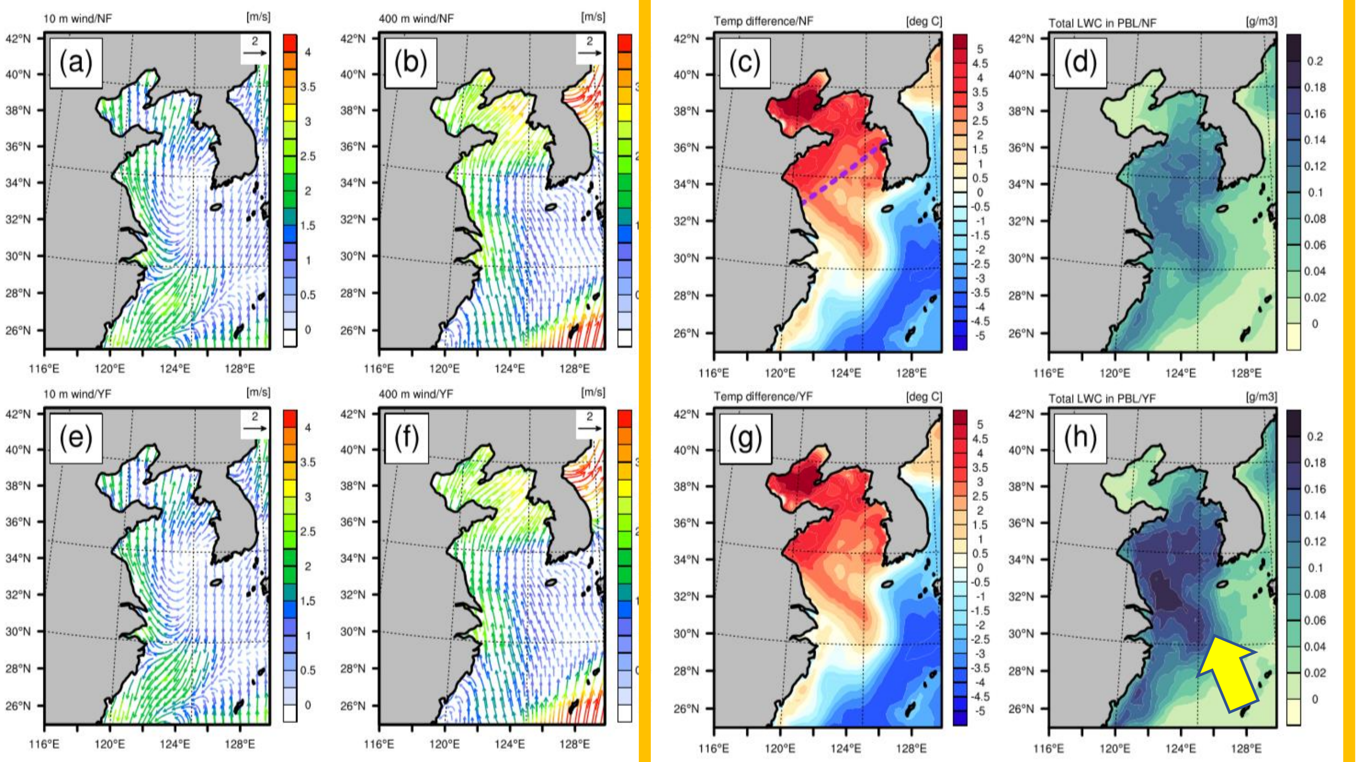
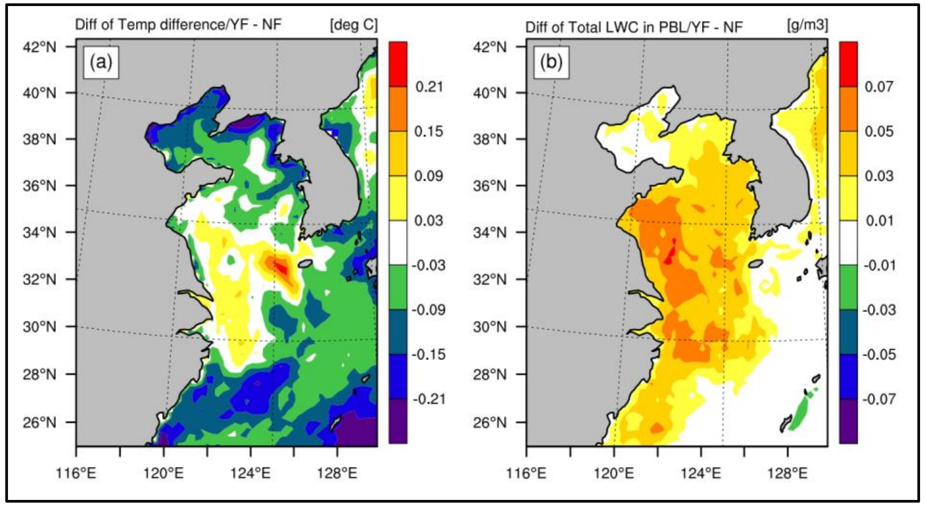



(g) – (c) (h) – (f)



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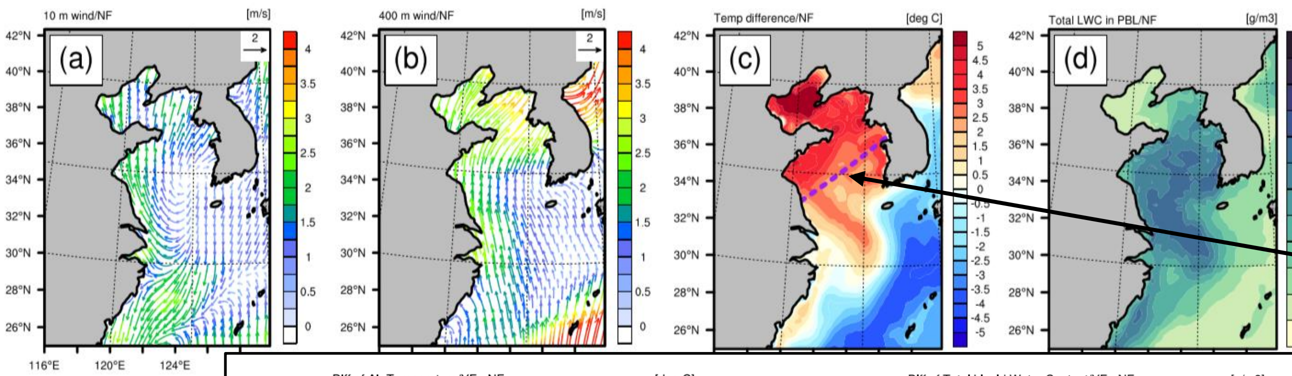


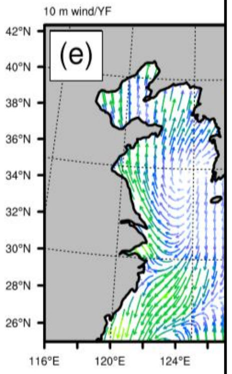


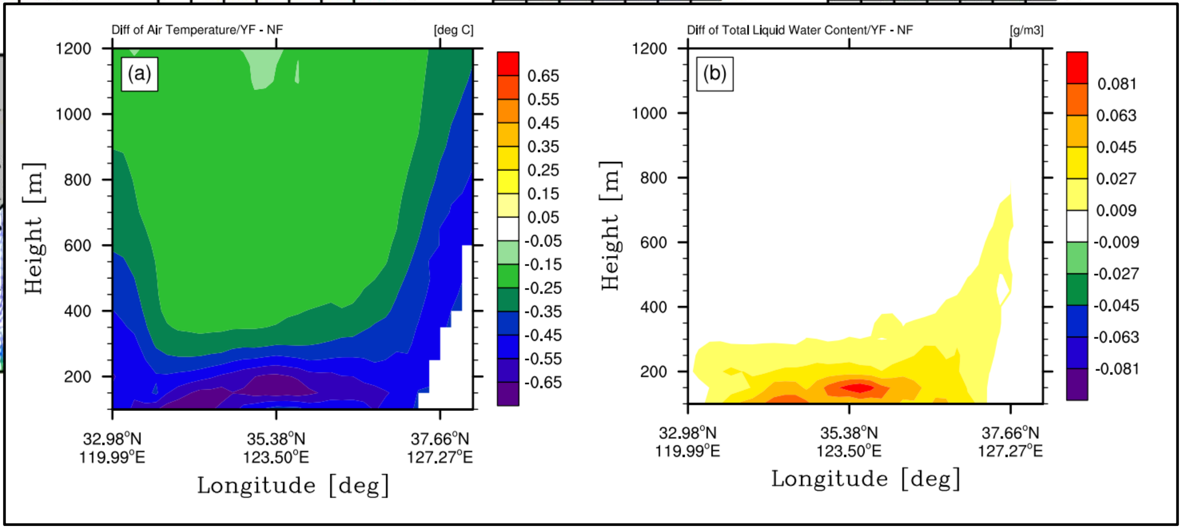


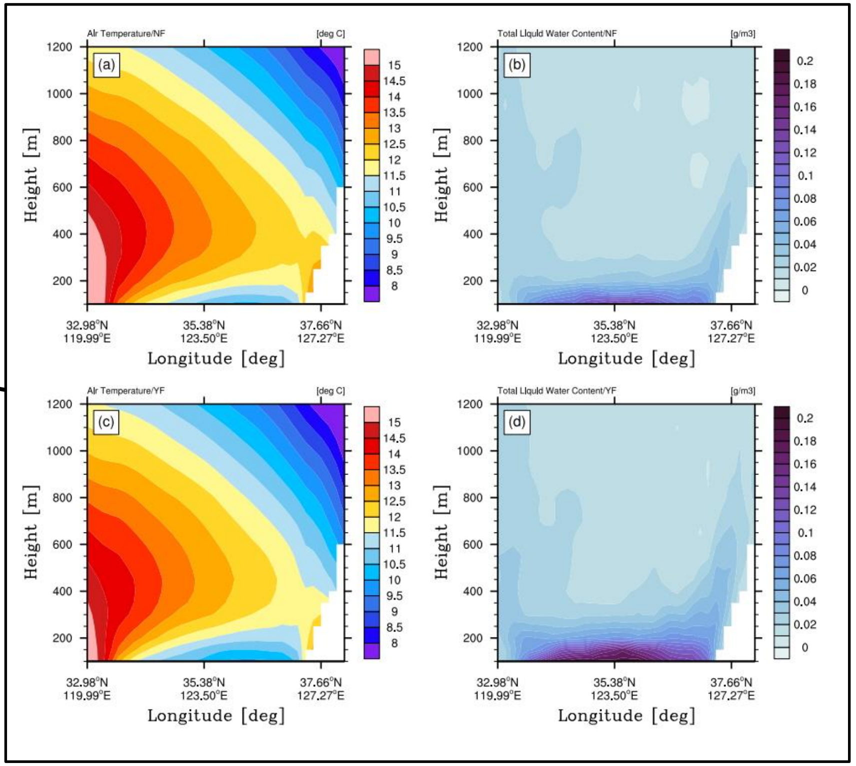

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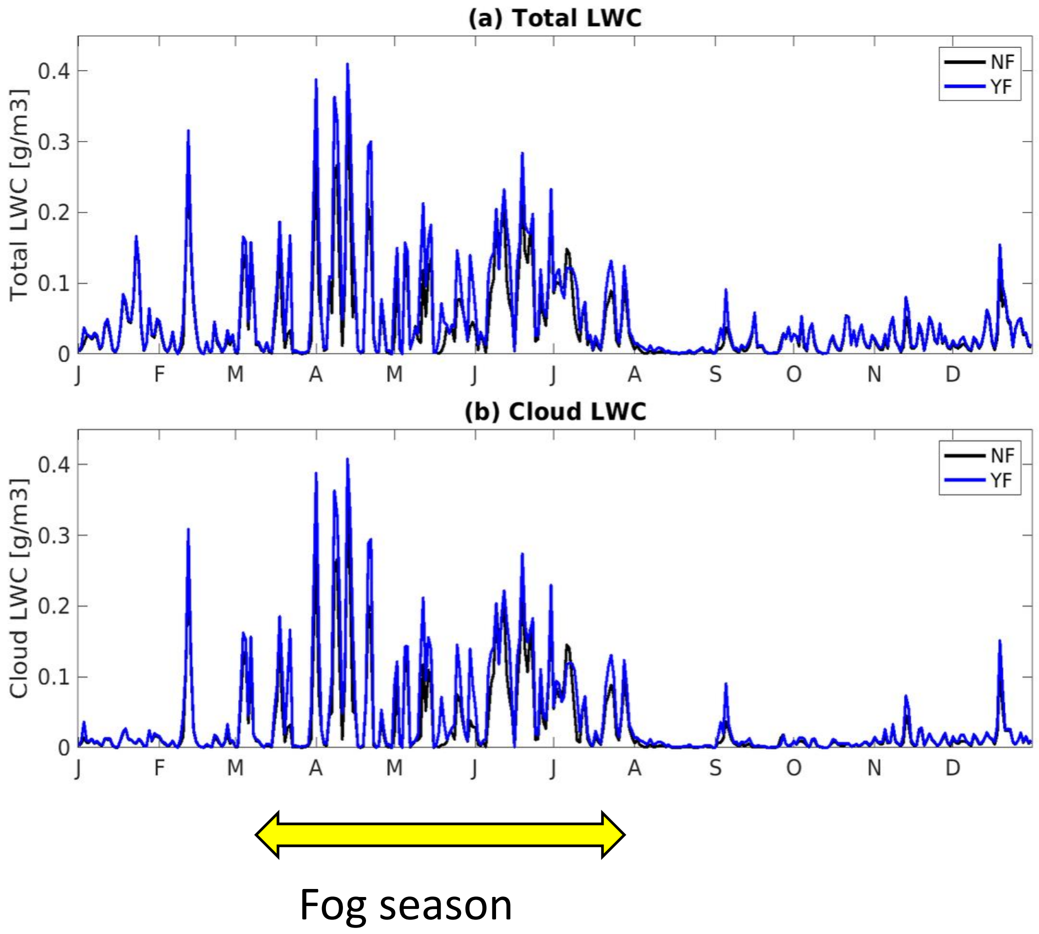
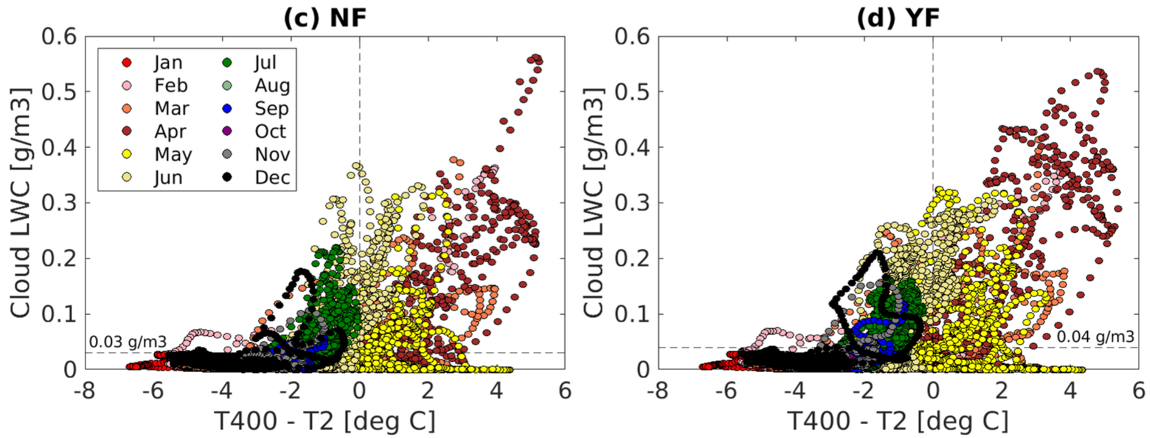



- The impact of sea fog on air quality via aqueous chemistry is determined by not only adequate concentration of precursors but also abundant cloud LWC in area.
- Therefore, we defined cases of sea fog as those in which the **cloud LWC exceeded 0.15 $g/m^3$ with a positive temperature difference** between 400 m and 2 m.

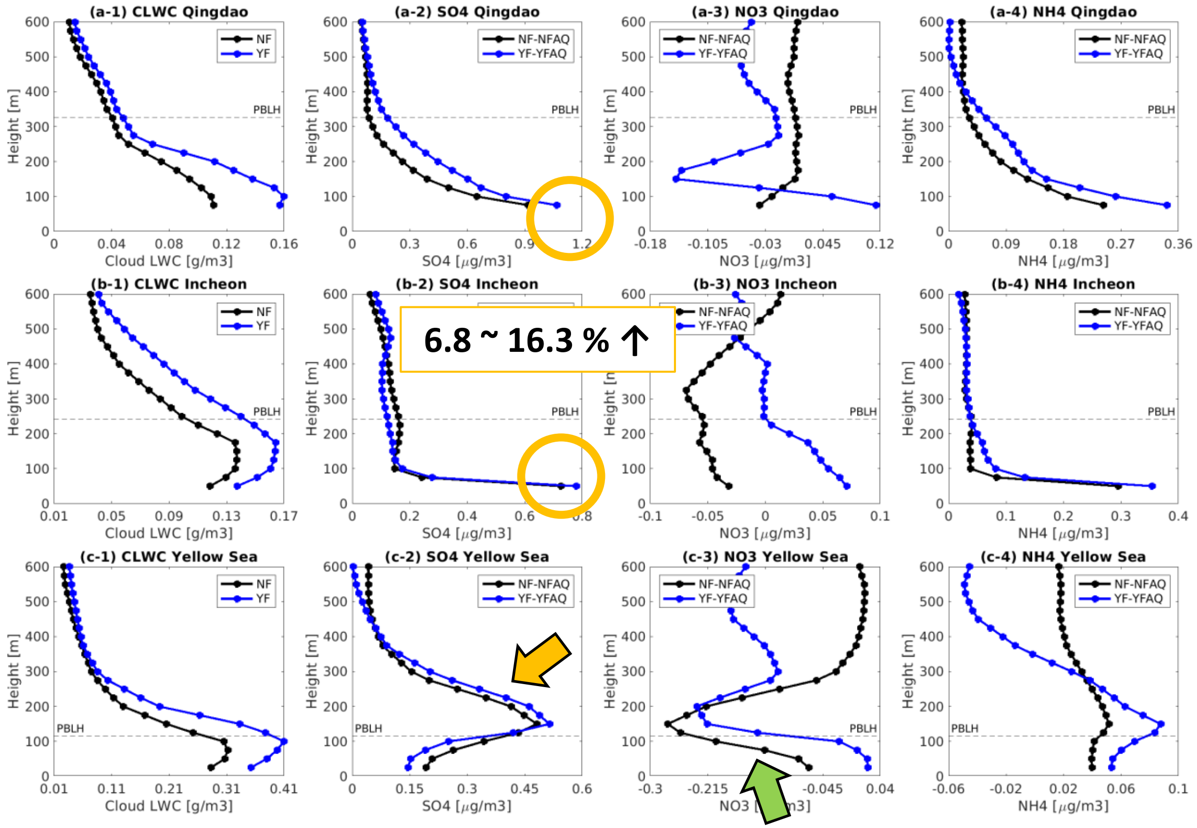
# The response of air quality to the direct effect of aerosols and sea fog over the Yellow Sea

Cloud LWC | sulfate | nitrate | ammonium

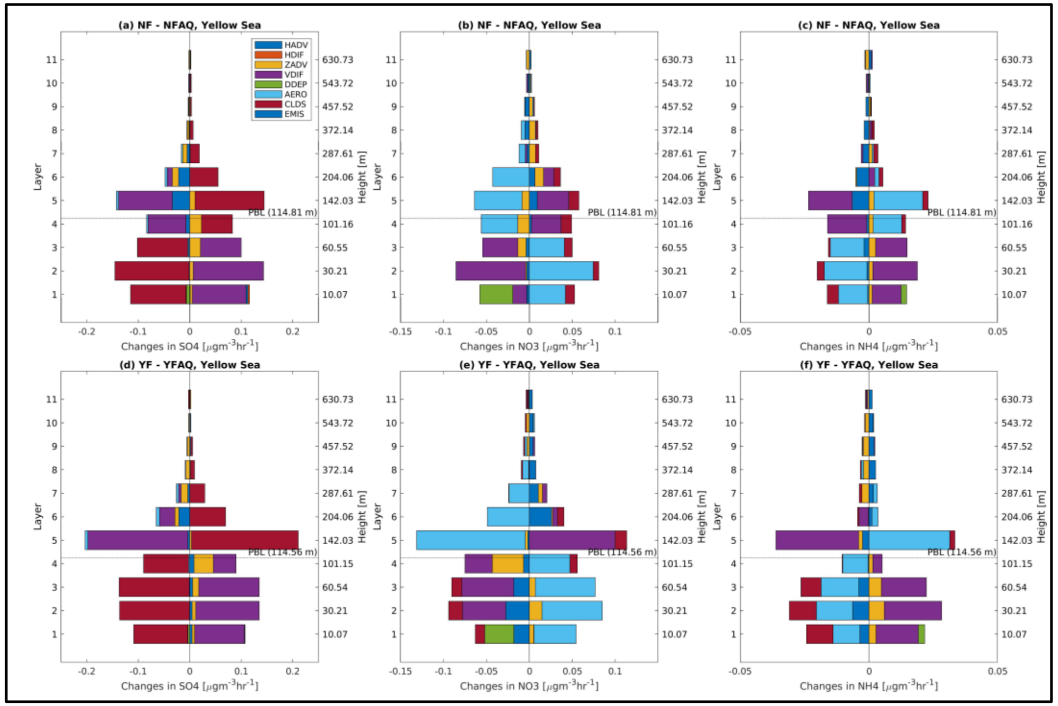
Qingdao

Incheon

Yellow Sea




sulfate | nitrate | ammonium




**<Results of the integrated process rates (IPRs) over the Yellow Sea>**

- HADV: horizontal diffusion
- HDIF: horizontal diffusion
- ZADV: vertical advection
- VDIF: vertical diffusion
- DDEP: dry deposition
- AERO: aerosol chemistry
- CLDS: cloud chemistry
- EMIS: emission

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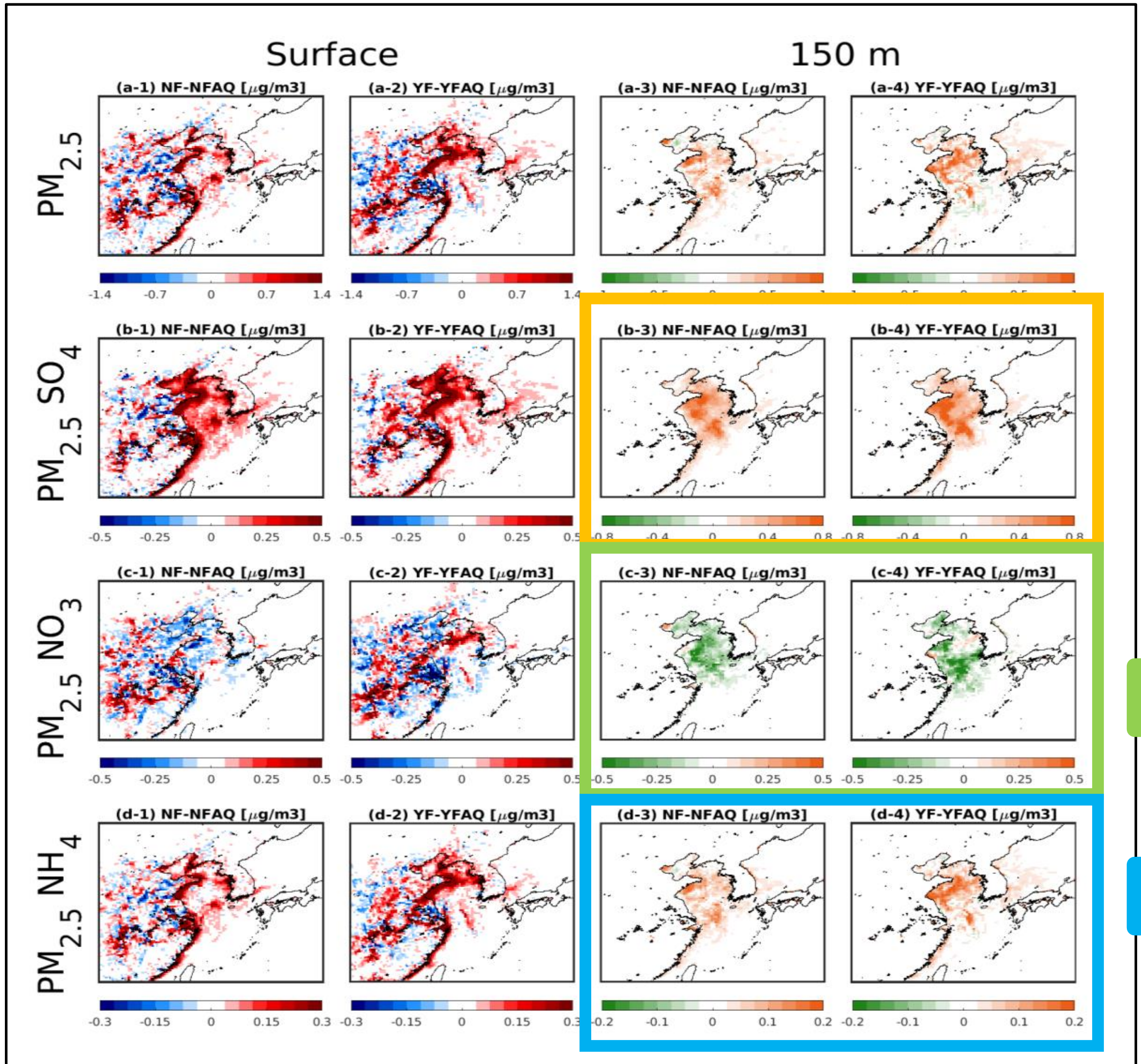


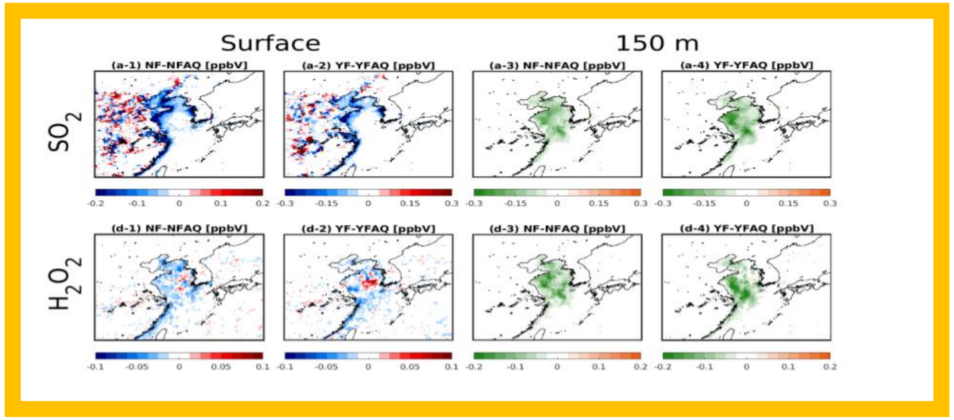


**Sulfate:**

- **NF-NFAQ → 11.73 % ↑**
- **YF-YFAQ → 12.36 % ↑**

**~ -3.79 %**

**~ 3.08 %**

# Conclusion

- This study examined the effect of sea fog over the Yellow Sea with the direct effect of aerosols on air quality over East Asia in 2016.
- This study found that the direct effect of aerosols could enhance temperature inversions over the Yellow Sea, and it modulates the impact of sea fog on air quality as a source or sink of gaseous and aerosol concentrations.
- As the frequency and intensity of sea fog over the Yellow Sea can be affected by not only aerosol concentrations related to emission control policies but also climatological changes that enhance or reduce differences between the temperature of the land and the ocean, further studies could examine such variability in the impact of sea fog over the Yellow Sea.

Thank you! ☺