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Implementation of Kain-Fritsch convective mixing scheme into CMAQ subgrid cloud modeling

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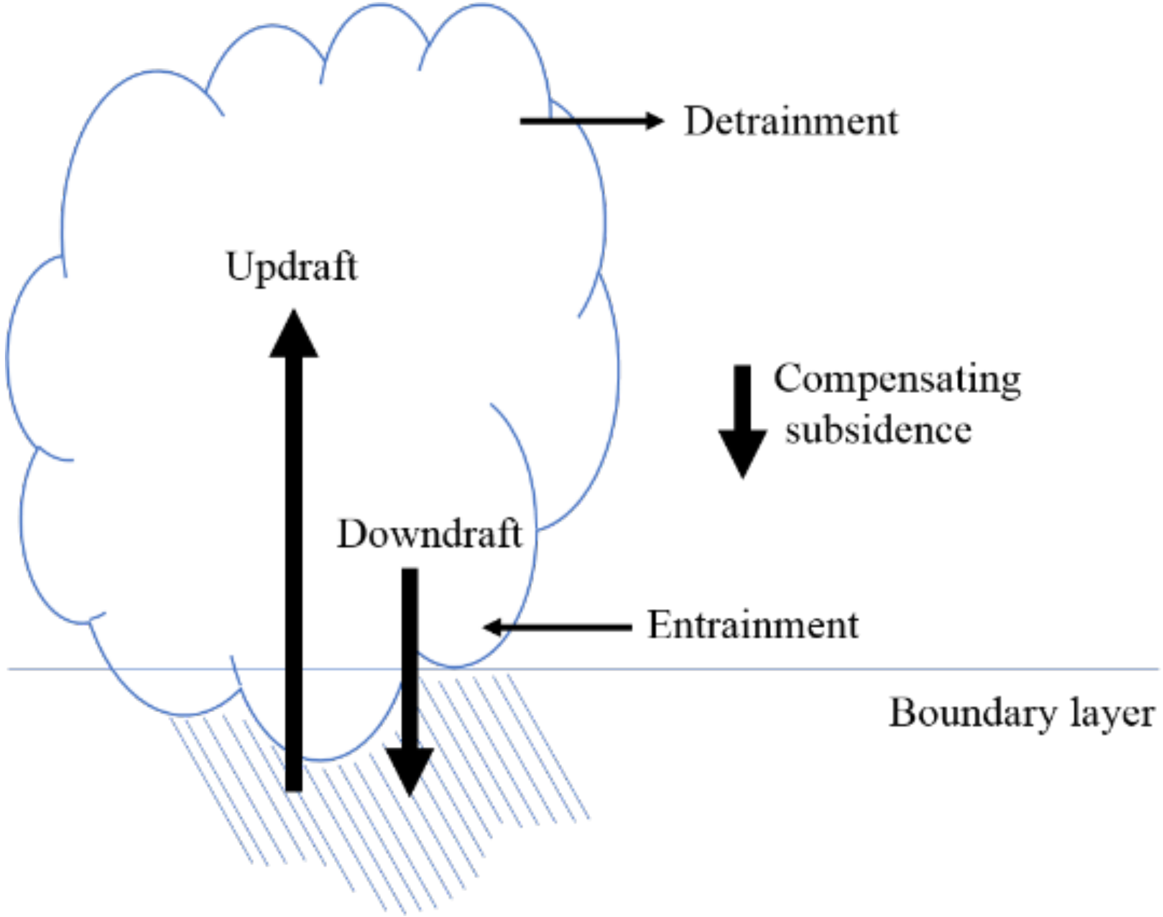
Introduction:

- CMAQ model resolves the full-grid clouds that occupy the entire grid cell by the meteorological models and parametrizes sub-grid clouds.
- The issue of nonlocal structures
- Physical efficacy in convective mixing
- Consistency of cloud parametrization with meteorological model



Objectives:

(1) To develop a more physically accurate scheme of sub-grid cloud parameterization and

(2) To enhance the capabilities of the CMAQ model to simulate the vertical distributions of chemical species in the layers of the atmosphere where convection has occurred.

KF-convection modeling → Idealized-case → Real-case → Comprehensive discussion

Standard CMAQ:

- Cloud modeling:

$$\left.\frac{\partial \overline{m_i}}{\partial t}\right|_{cld} = \left.\frac{\partial \overline{m_i}}{\partial t}\right|_{subcld} + \left.\frac{\partial \overline{m_i}}{\partial t}\right|_{rescld}$$

- Cloud mixing:

$$\overline{m}_i^{cld}(z) = f_{ent}\left[(1 - f_{ent})\overline{m}_i^{down} + f_{side}\overline{m}_i(z)\right] + (1 - f_{ent})\overline{m}_i^{up}$$

- Average pollutant concentration:

$$\overline{m}_i^{cld} = \frac{\int_{z_{cbase}}^{z_{ctop}} \overline{m}_i^{cld}(z) W_c(z) dz}{\int_{z_{cbase}}^{z_{ctop}} W_c(z) dz}$$

KF-convection:

- Dynamic description of cloud
- Mass flux variables from WRF
- WRF-CMAQ two-way system

	Standard-CMAQ Sub-grid scheme	KF-convection Cloud modeling
Temporal resolution	1 hour	Synchronization time (~6 minutes)
Cloud geometry (definition of the cloud layers and characteristics)	CMAQ parameterization	Utilizes the dynamic model (WRF)
Vertical mixing (air transporting by updraft and downdraft)	CMAQ parameterization	Develops model consistent with the dynamic meteorological model (WRF)
Convection classification	General cloud	Deep and shallow convection

Algorithm: CONV_KF

Define Cumulus convection variables

Get KF-scheme variables from WRF

for i: 1 to NROWS

for j: 1 to NCOLS

if Deep convection is happening:

Compute the updraft effect.

Compute the entrainment-detrainment effect.

Compute the effect of compensating due to updraft.

Compute the downdraft effect.

Compute the entrainment-detrainment effect.

Compute the effect of compensating due to downdraft.

else if Shallow convection is happening:

Compute the updraft effect.

Compute the entrainment-detrainment effect.

Compute the effect of compensating due to updraft.

End

End

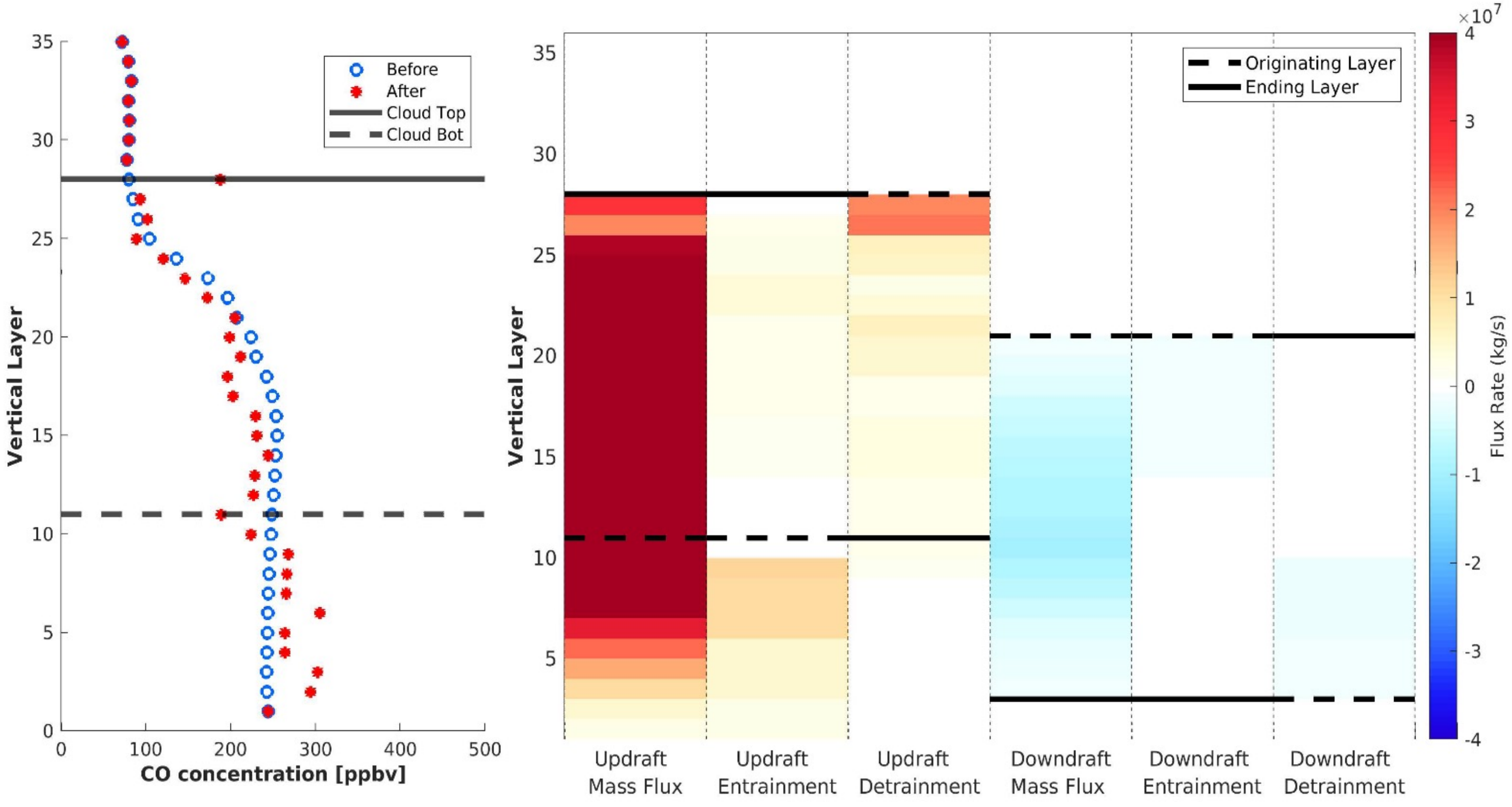
End

Update the concentrations matrix

Continue to sub-grid cloud scheme

Idealized case:

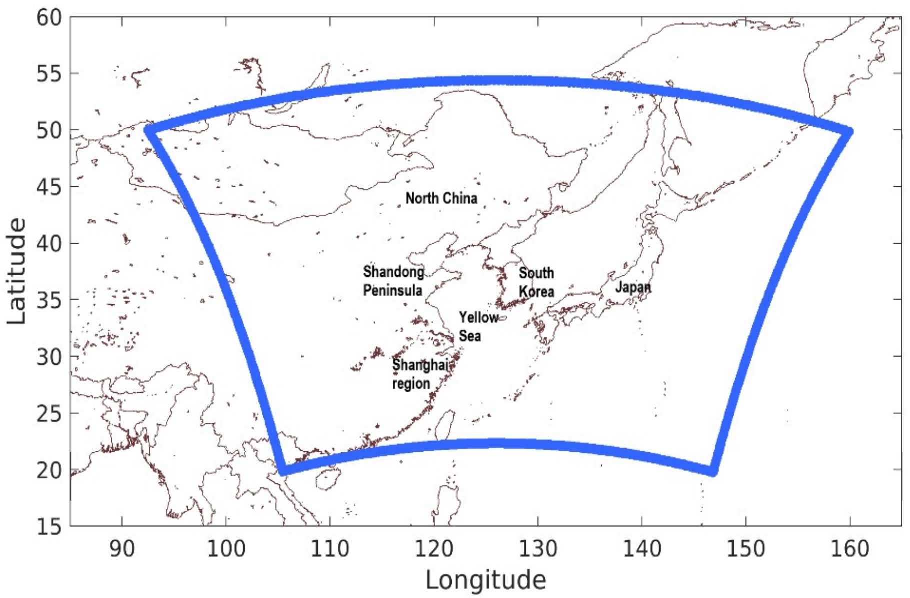
- $10 \times$ sync time-steps = 60 min
- Tested for several different cases
- Presented case: deep convection with both updraft and downdraft fluxes + effects of entrainment, detrainment and subsidence



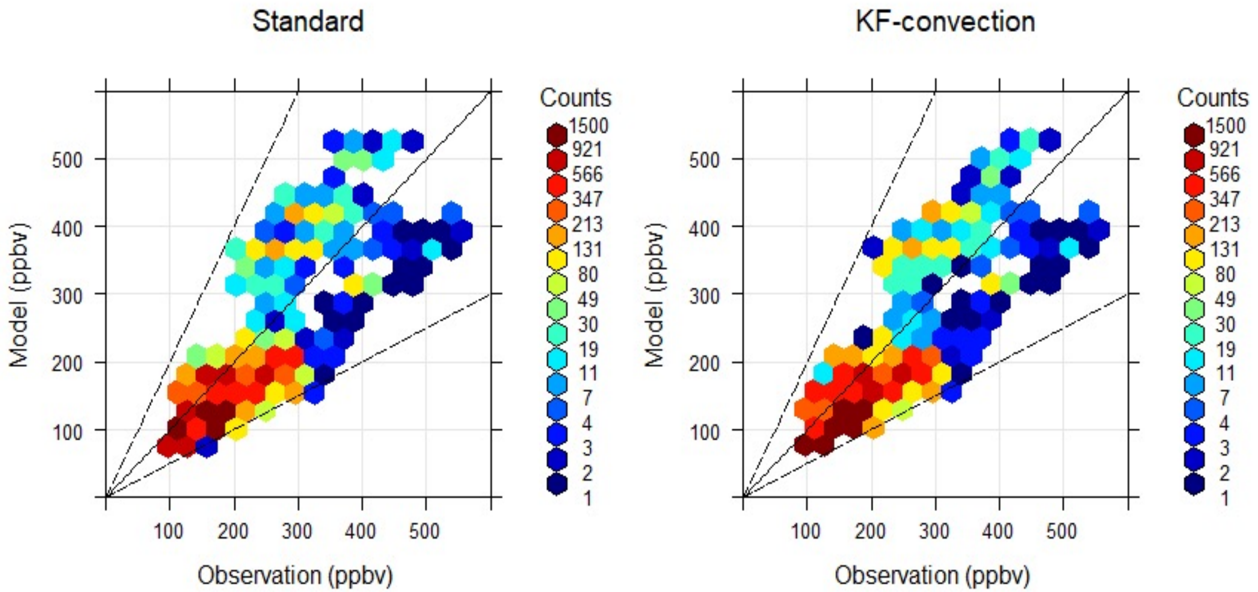
Difference in concentration profiles caused by KF-convection

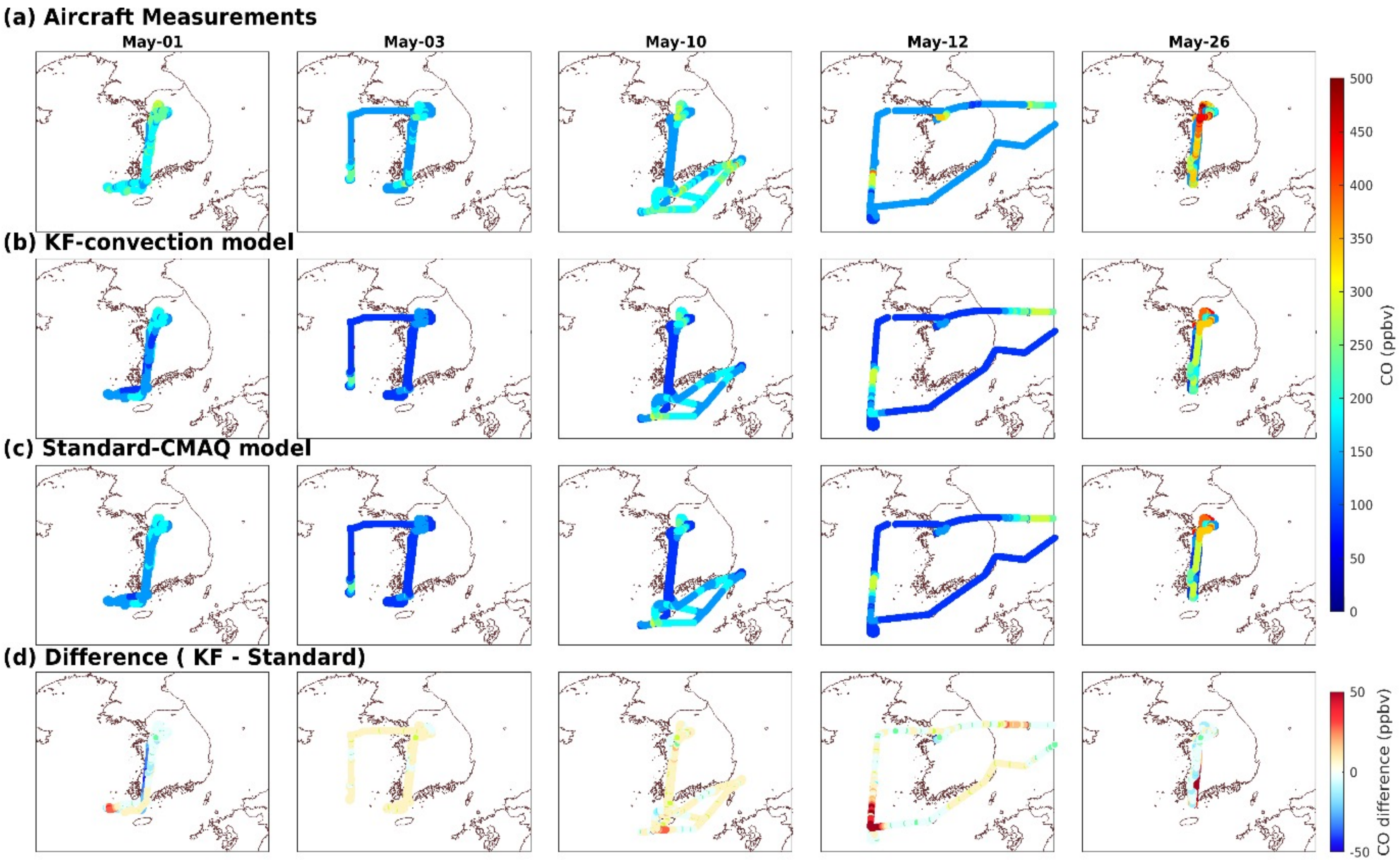
Real case:

- East Asia domain
- WRF-CMAQ Two-way framework

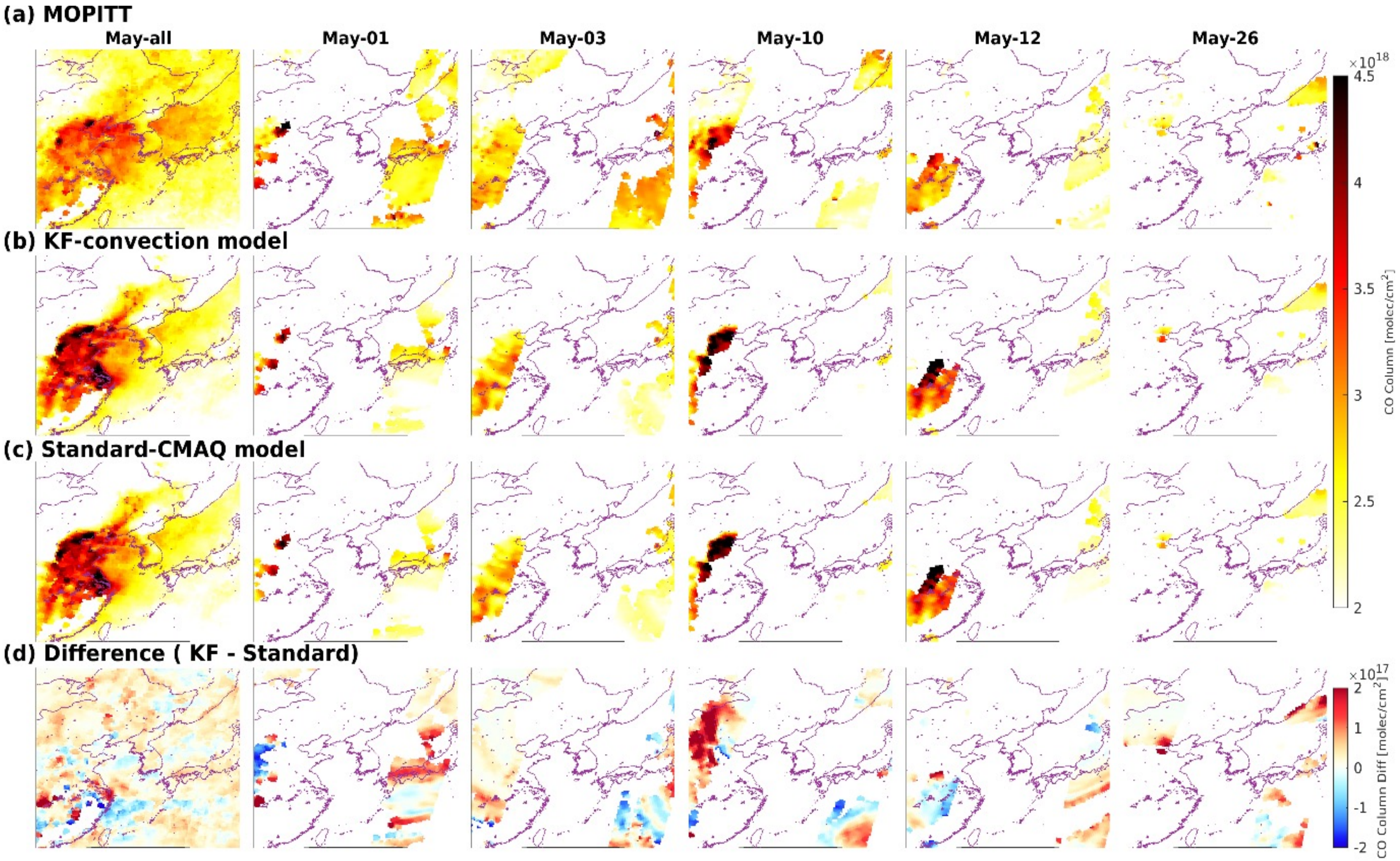


Configuration of the WRF-CMAQ Two-way model	
Domain	27x27 East Asia
Microphysics	Morrison double-moment scheme
Shortwave/Longwave radiation	RRTM
PBL model	ACM2
Surface model	Pleim-Xiu land surface
Cumulus scheme	Kain-Fritsch
Chemical mechanism	SaPRC-07 and AERO6
CMAQ Advection	YAMO and WRF omega
CMAQ diffusion	Multiscale and ACM2

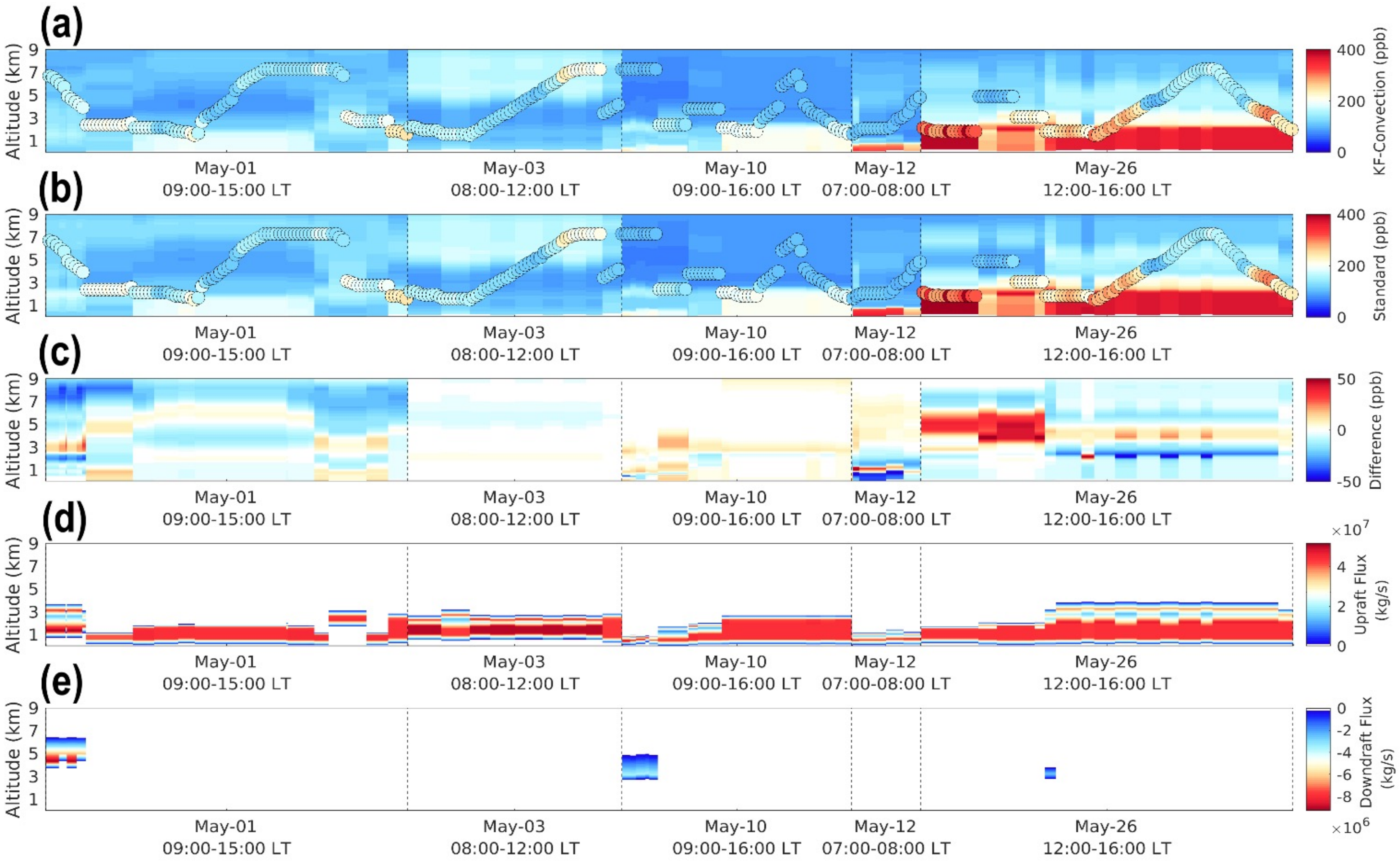




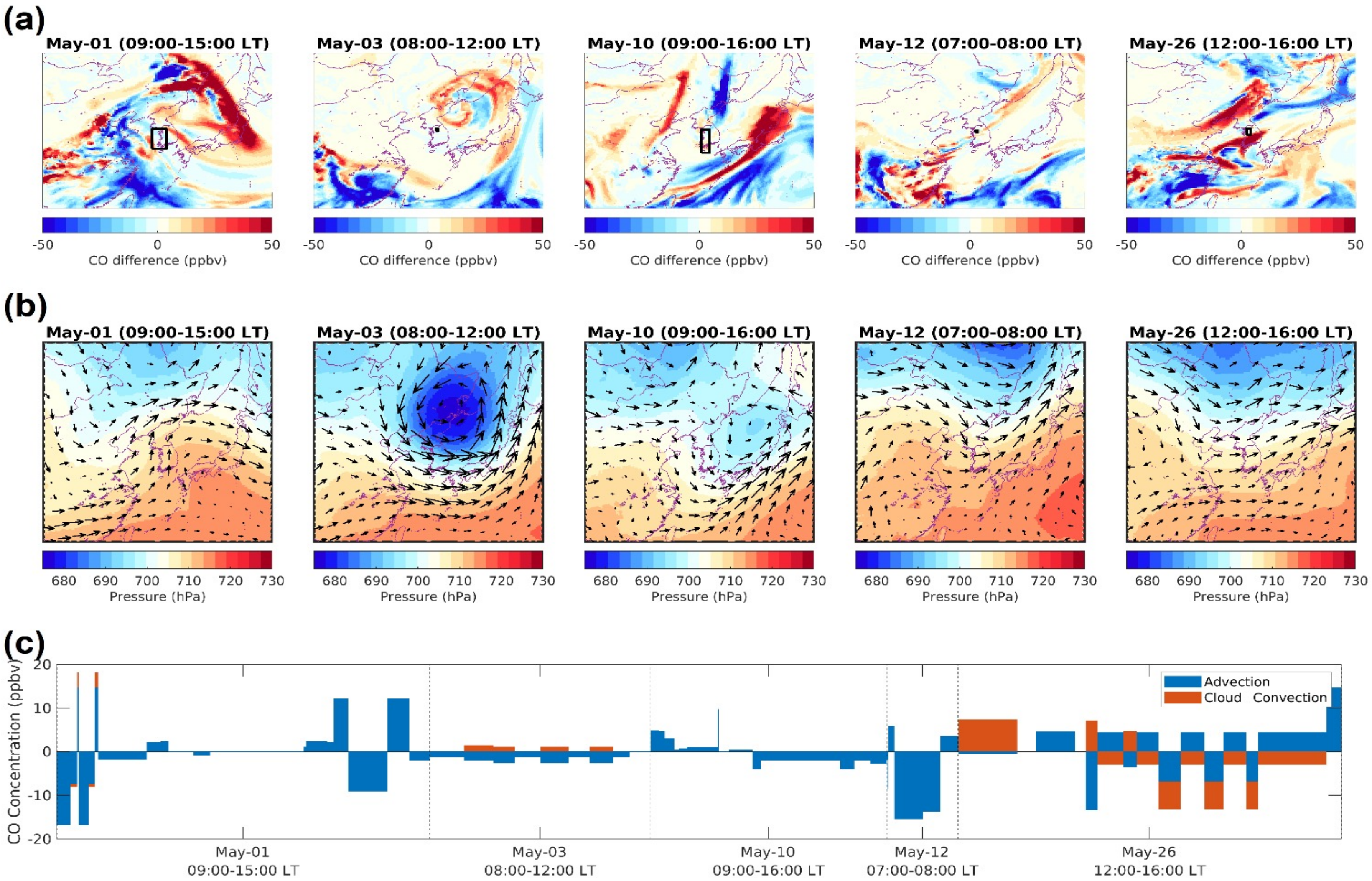
Spatial analysis of CO concentrations in aircraft tracks over South Korea on convection days



Spatial comparison of the total CO columns for the convection days in May 2016 (May-01, May-03, May-10, May-12, and May-26), averaged over the entire month (May-all)



Analysis of the direct impact of KF-convection on days with convection: (a) KF-convection model versus CO measurements of DC8 aircraft (points); (b) Standard-CMAQ model versus CO measurements of DC8 aircraft (points); (c) CO differences; (d) the updraft flux rate; and (e) the downdraft flux.



Analysis of the indirect impact of KF-convection on days with convection at 3 km altitude, (a) CO differences between models, (b) the averaged wind pattern and pressure field, (c) Process Analysis results.

Summary:

- KF-Convection model:
  - More physically accurate convective mixing
  - Consistent with meteorology model
  - Improved vertical profiles of concentrations
  - Improved long-range transport of pollutants

- The developed model can be employed in large domains (i.e., East Asia, Europe, North America, and Northern Hemisphere) with sub-grid scale cloud modeling to include the impacts of convection.

Code availability:

- Detailed description of the model:

https://doi.org/10.1029/2021MS002475

- The developed model source code:

https://doi.org/10.5281/zenodo.4724239

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Development and Implementation of a Physics-Based Convective Mixing Scheme in the Community Multiscale Air Quality Modeling Framework

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Thank you for your attention!

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